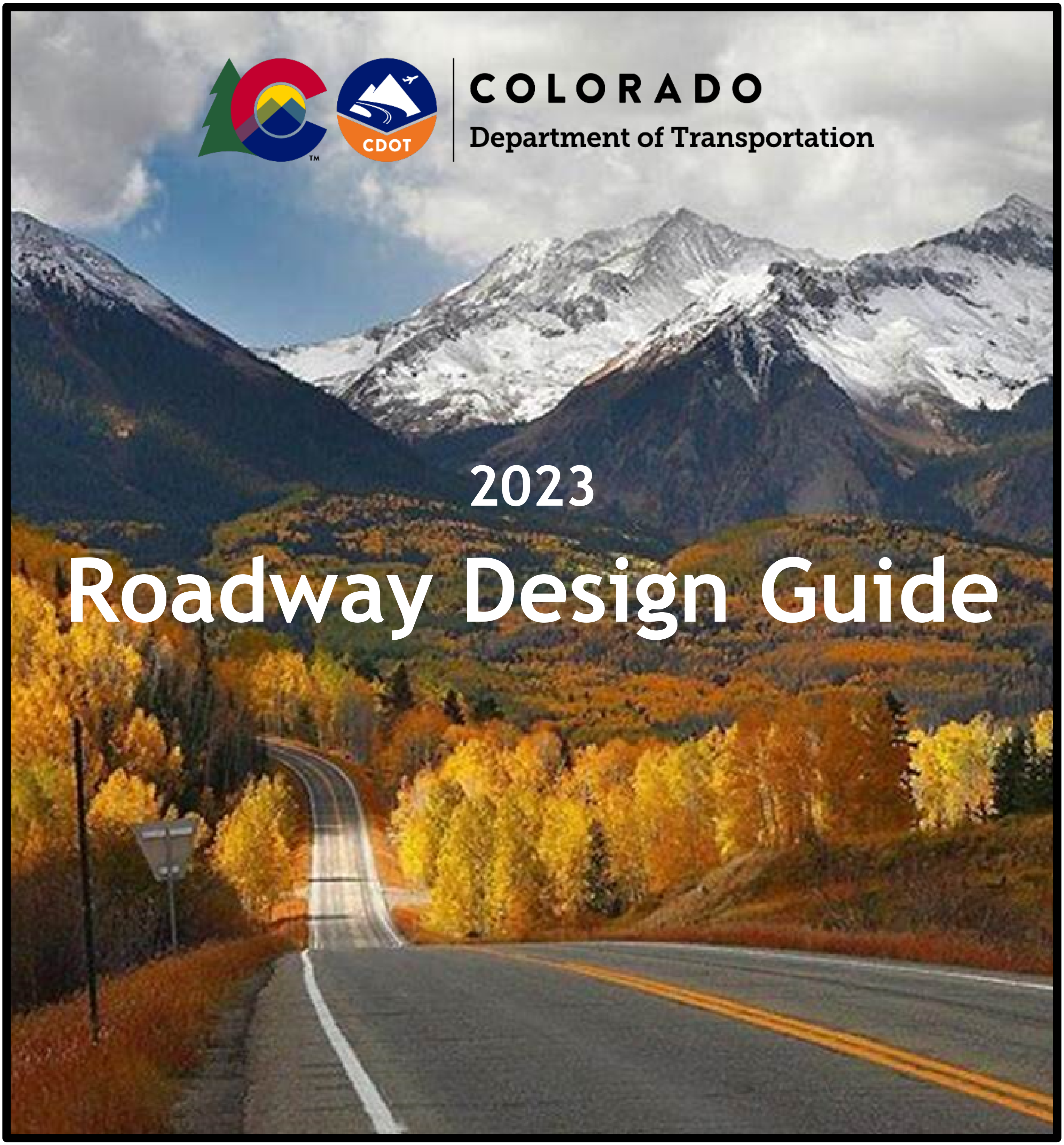
COLORADO
Department of Transportation



2023

Roadway Design Guide

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Preface

The 2023 Roadway Design Guide was authored in collaboration with each of the five Colorado Department of Transportation regions. It is a transitional/transformational guide that introduces new concepts to defining and implementing all modes of transportation, with guidance on how planners, engineers, and designers can exercise greater latitude when scoping and delivering projects throughout Colorado.

This Guide integrates practices that have been exercised for many years without a common framework. These are: multimodal design (MM), context sensitive solutions (CSS), and performance based practical design (PBPD). These processes can be applied to combine and optimize all modes of travel, while considering the contextual elements a transportation facility supports.

MM, CSS, and PBPD recognize the American Association of Highway Transportation Officials (AASHTO) roadway classifications. However, contextual analysis applying CSS, MM, and PBPD results in a simpler decision-making process for design. By defining the facility type and using MM, CSS, and PBPD, the designer can balance roadway requirements and contextual elements to better identify and suggest options that address the specific needs of local agencies, communities, and multimodal users.

How to Use This Manual

This manual provides direction to the user from scoping through final design. The overall goal is to help the designer to identify the geographic and contextual area the facility is supporting.

Chapter 1 provides the overarching guidance on how to determine a specific context classification based on traditional classification metrics, such as average daily traffic (ADT), terrain, access spacing, roadside amenities, and drainage type. These contextual considerations were developed in consideration of AASHTO's traditional classifications:

- Freeways
- Arterial Road or Street
- Collector Road or Street
- Local Road or Street

The finer aggregate of context classifications presented in Chapter 1 include:

- Rural Mountainous Environment
- Rural Places
- Suburban Places
- Traditional Neighborhoods
- Downtown Places
- Urban Cores

The AASHTO functional classifications, though broader than the context classifications, are still relevant and required for Federal Highway Administration (FHWA) oversight, documentation, and most importantly federal funding.

Chapter 2 presents the design controls and considerations for all facility types, followed by more specific guidance for Roads (Chapter 3), Streets (Chapter 4), and Freeways, Expressways, and Interstates (Chapter 5).

Any of the three main facility types—Roads; Streets; and Freeways, Expressways, and Interstates—can be found within any of the context classifications. The context classification provides the designer additional guidance in working with local communities to address specific issues and community considerations. The facility type and the contextual classification become the basis for discussion around what travel modes need to be considered or accommodated in the design.

Design elements common to all facility types are presented in Chapter 6. Chapter 7 contains cross section elements that include the contextual considerations related to multimodal implementation. The remaining chapters provide additional guidance and contain specific information about elements to be considered in design.

This Guide contains references to numerous manuals, standards, other documents, and websites that are resources for the designer. The references are current as of the date of publication. It is understood that the users of the Guide will refer to the latest documentation available, regardless of the version of the documents noted in the Guide.

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Chapter 1

1 New Framework for Geometric Design

1.0 Introduction

The Colorado Department of Transportation (CDOT) Roadway Design Guide 2023 (Guide) establishes a new framework for designing roads; streets; and freeways, expressways, and interstates that move people and goods in Colorado. It is a fresh approach to design that considers a facility's functional classification, its surrounding physical environment (context), and how it will accommodate people using various travel modes.

The Guide is consistent with current industry practice.

- The American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (the Green Book) (2018 AASHTO GDHS) (AASHTO, 2018) encourages flexibility in design, emphasizing the role of the planner and designer in determining appropriate design elements and dimensions based on project-specific conditions and existing and future roadway performance, more than on meeting specific nominal design criteria.
- The Transportation Research Board (TRB) *Highway Capacity Manual, Seventh Edition: A Guide for Multimodal Mobility Analysis* (*Highway Capacity Manual*) (TRB, 2022) includes information about assessing traffic operations for all transportation modes.
- The AASHTO *Highway Safety Manual* (AASHTO, 2010) highlights the relationship of geometric design features to crash frequency and severity.
- The National Cooperative Highway Research Program (NCHRP) Report 855, An Expanded Functional Classification System for Highways and Streets (NCHRP, 2018), describes how to incorporate a project purpose and need and how to accommodate all transportation modes, including transit and freight.

- The NCHRP Report 785, Performance-Based Analysis of Geometric Design of Highways and Streets (NCHRP, 2014) presents the trending approach to identify the desired outcomes of a project, selecting performance measures that align with the desired outcomes, and using data driven geometric decisions that will deliver those outcomes.

This Guide builds on these industry tools with information that is specific to Colorado's diverse range of environments and transportation modes. It briefly describes CDOT's Project Development Process and the relationship of project planning and budgeting to the design process. It then presents an integrated approach to design that uses a range of considerations to define the overall context of a facility, leading to the geometric design criteria necessary to meet purpose and need of a project and accommodate user needs and safety.

1.1 Project Development Process

The project development process for the new framework for geometric design follows the concepts of CDOT's Project Development Process that is described in the CDOT *Project Development Manual* (CDOT, [2013] 2022).

Use this link to access CDOT's Project Development Manual: https://www.codot.gov/business/designsupport/bulletins_manuals/2013-project-development-manual

1.1.1 Scoping, Budgeting, and Programming

The idea for a project is vetted through CDOT's statewide planning process coordinated by CDOT's Division of Transportation Development. Participants in the process include internal and external planning partners and the public across the state. The results of this process are a Statewide Transportation Plan that incorporates the Statewide Transit Plan, Regional Transportation Plans, the Strategic Transportation Safety Plan, the Colorado Freight Plan, the Statewide Bicycle and Pedestrian Plan, and a 10-Year Vision Plan. The Statewide Transportation Improvement Program (STIP) is updated and adopted by the Colorado Transportation Commission annually and includes projects that are scoped and funded for the next four years. A longer list of identified projects in a 10-Year Strategic Project Pipeline informs which projects move into the STIP as funding becomes available.

A project must be included in the STIP before design and construction can begin. Projects in the STIP are not typically defined beyond preliminary engineering and a budget estimate.

Use these links to access CDOT's planning process: https://www.codot.gov/programs/planning and https://www.codot.gov/programs/planning/planning-process

Use this link to access CDOT's Scenic & Historic Byways Corridor Management Plan: Microsoft Word - CDOTByways.CMPTemplate_FINAL.docx (codot.gov)

1.1.2 Project Development/Design

The designer may or may not be involved in a project's planning phases where the purpose and need and budget are determined. However, the role of the designer is to take the initial project definition and thoughtfully apply the process defined in Chapter 1 and Chapter 2 of this Guide to consider the relevant characteristics and facility needs. The context classification process results in defining a facility type (Road; Street; or Freeway, Expressway, Interstate) with project-specific geometric design criteria that serve a distinct set of user needs.

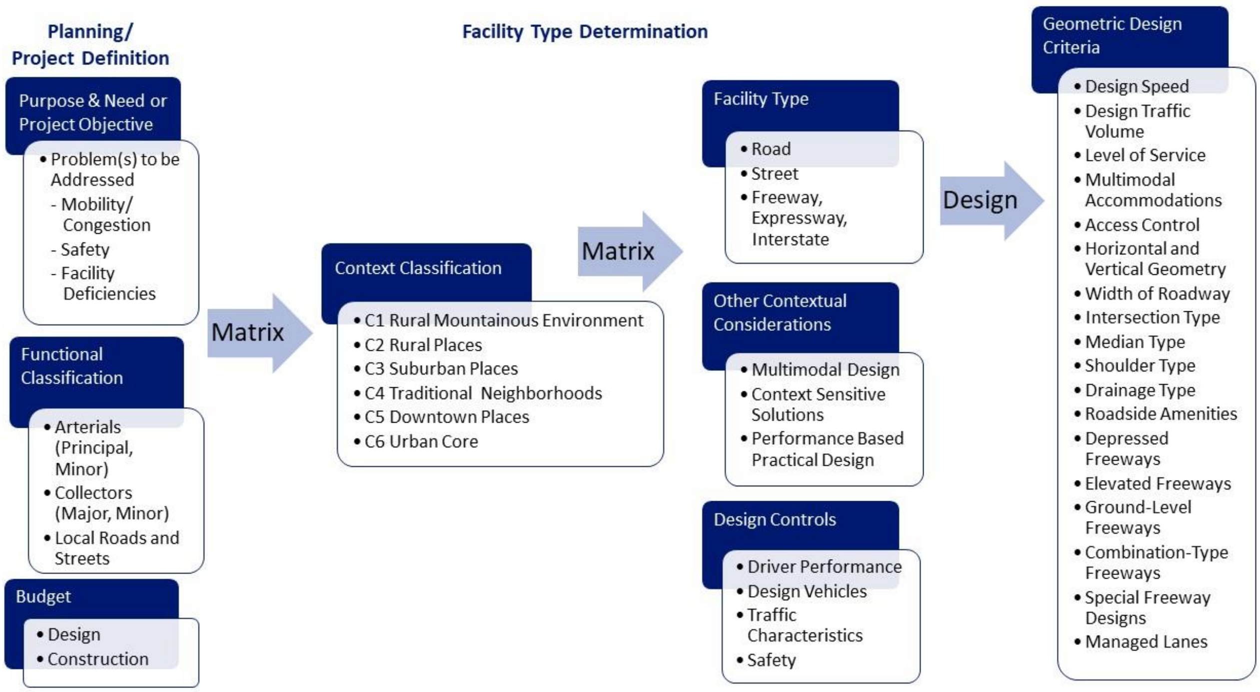
The steps in the design process are as follows and illustrated in Figure 1-1. A detailed step-by-step process with how to use this Guide is provided in Section 1.9.

- Review and update the preliminary scope, purpose and need, and budget that were determined during the planning phases.
- Identify the facility's functional classification, using CDOT's Online Transportation Information System (OTIS), that characterizes a roadway by its hierarchy in the transportation network and the type of service it provides to travelers.

Use this link to access CDOT's OTIS online tool:
https://dtdapps.coloradodot.info/otis

- Determine the context classification that characterizes a facility by its surrounding environment and how the facility fits into the community (Section 1.3 of this Chapter).
- Identify the facility type from the context classification: Road; Street; or Freeway, Expressway, Interstate that determines the project's geometric design criteria (Section 1.6 of this Chapter).
- Evaluate design controls that further describe the facility's conditions at a high level (Chapter 2 of this Guide). These may include:
  - Driver Performance
  - Design Vehicles
  - Traffic Characteristics
  - Safety Performance
- Examine additional design considerations that help to define the context for the design. These include:
  - *Multimodal Design.* Consideration of all transportation modes (motor vehicle, pedestrians, bicycles, transit, etc.).
  - *Context Sensitive Solutions.* A collaborative, interdisciplinary decision-making process and design approach to develop a transportation facility that fits its physical setting.
  - *Performance-Based Practical Design.* A decision-making approach that helps agencies better manage transportation investments and serve system-level needs using a data driven analysis and performance priorities.

Figure 1-1 Design Process Workflow



Note: "Matrix" refers to the Context Classification to Facility Type Matrix introduced in Section 1.6.

1.2 Planning/Project Definition

1.2.1 Project Purpose and Need or Objective

A project purpose and need (or objective) is developed at the beginning of the Project Development Process. This excerpt from the AASHTO 1.2 – Project Purpose and Need describes what it is and how it is used.

"The design of every road or street improvement project should begin with an explicit statement developed by the roadway agency that indicates why the project is being undertaken and what the project is intended to accomplish. This statement may be in the form of the purpose and need statement used in National Environmental Policy Act (NEPA) analyses, a formal statement of objectives for the project, or a combination of the two approaches. Either separately or collectively, these statements set out the purpose and need for the project and the objectives that the project should satisfy in fulfilling that purpose and need. In the remainder of this discussion, these two types of documents collectively will be referred to as the purpose and need statement.

The purpose and need statement informs priorities on what will, and what will not, be undertaken in the project. The designer should refer to this purpose and need statement in determining the scope of geometric design changes to include in the project and assessing whether any geometric design changes suggested by others are germane to the project purpose and need.

The purpose and need statement for a project should be built around an assessment of past performance for all transportation modes of the roads and streets within the project limits and a forecast of future performance if no project is undertaken. The purpose and need statement should address the project context and how each transportation mode should be accommodated. The purpose and need statement should also indicate what aspects of performance should be improved and, in some cases, may also set targets for how much performance should be improved. Thus, improvement needs should be based on specific performance issues that are identified by the agency as in need of improvement. Both quantitative and qualitative performance measures may be used in defining the purpose and need for projects. The roadway agency should involve other stakeholders in establishing the project purpose and need." (2018 AASHTO GDHS)

A fundamental change from the AASHTO guidance quoted above is the practice of incorporating data-driven Performance-Based Practical Design considerations into the development of a project purpose and need. NCHRP and TRB are conducting studies in support of this change to include in the next edition of the 2018 AASHTO GDHS and in other state departments of transportation guidance documents. A data-driven safety analysis (DDSA) of past and future performance of the roadway facility, including the contextual elements that it supports, will define the purpose and need for the project with goals or targets for the design. Taking the context of the project into consideration at this early stage helps establish overall project goals.

1.2.2 Budget

The initial budget is determined during the statewide planning processes described in Section 1.1.1.

1.2.3 Functional Classification

Functional classifications define the range of mobility and access of the roadway facility. The basic concepts related to the functional classification of roadway facilities and systems are discussed in the 2018 AASHTO GDHS. There are three general functional classifications:

- *Arterials* are roadways that provide a high level of mobility.
- *Collectors* provide a balance of mobility and access.
- *Local Roads and Streets* provide a high level of land accessibility.

Each functional classification can be found in both urban and rural areas. Urban and rural designations for each of the functional classifications are tied to U.S. Census data, which is taken every ten years.

Functional classification is a required overlay to align with federal guidance and requirements, for evaluation of access requirements in the State Highway Access Code, and for general reporting in CDOT's form 463 Design Data. This is used as a stepping stone to move ahead in context classifications for design.

Because there is a set percentage of roadways that can be on the National Highway System (NHS), new roadways are seldom added to the NHS. It is also rare that a roadway functional classification will change, and the request must be reviewed and accepted by the Colorado Transportation Commission and the Federal Highway Administration (FHWA).

Use this link to access FHWA's Highway Functional Classification Concepts, Criteria and Procedures (FHWA, 2013): *https://www.fhwa.dot.gov/policyinformation/hpms/hfcccp.cfm*

The functional classifications as defined in the 2018 AASHTO GDHS are:

Arterials

Principal Arterials. Principal Arterials serve a large percentage of travel between cities and activity centers. Principal Arterials are the frequent route for intercity busses and trucks. They are generally designed for higher-speed, higher-volume, and long-distance travel that may pass directly through or bypass activity centers. Principal Arterials have three classifications:

Arterials carry high traffic volumes between population and activity centers.

- *Interstates.* Interstates are the highest classification of Arterials and are designed and constructed for mobility and long-distance travel. Roadways in this category are officially designated as an "Interstate" by the U.S. Secretary of Transportation.
- *Other Freeways & Expressways.* Freeways & Expressways with full access control are similar to Interstates. By definition, Freeways are characterized by full access control with access points limited to on/off ramps and with no at-grade intersections. Expressways are more common in rural settings where at-grade intersections are permitted to varying degrees depending on context. In general, these types of roadways favor through movements over access, particularly Freeways.
- *Other Principal Arterials.* Other Principal Arterials serve activity centers and allow more access than Interstates and Freeways & Expressways. They provide additional access to parcels and have at-grade intersections. Other Principal Arterials provide similar service in both urban and rural areas; the primary difference in urban areas is the quantity of arterials serving a particular urban area. Rural areas would typically be served by one Arterial.

Minor Arterials. Minor Arterials provide service for moderate length trips, serve geographic areas that are smaller than the Principal Arterials, and have higher connectivity to the Principal Arterials. In urban settings, they interconnect and supplement the Principal Arterial system, connect communities, and may carry bus routes. In rural settings, they are typically designed to provide higher travel speeds with minimum interference to the through movement.

Collector Roads and Streets

Collectors provide the connection from Local to the Arterial systems. Collectors may be subdivided into Major and Minor Collectors in both the urban and rural areas. A large proportion of the rural roadway system consists of two-lane Collector Roads. The rural roadways generally serve short-distance, intra-county movement rather than long-distance, inter-county or statewide movement. The urban Collector Street typically offers more mobility options than an Arterial, includes facilities for pedestrians and bicycles, and often accommodates public utility facilities within the right of way.

Collector Roads and Streets are primarily used to travel shorter distances at slower travel speeds.

- *Major Collector.* Major Collectors are typically longer in length, balance through movement and access, and may have higher posted speeds and traffic volumes and more travel lanes than the Minor Collector.
- *Minor Collector.* Minor Collectors serve both land access and traffic circulation, penetrate residential neighborhoods for short distances, operate at lower posted speeds, provide service to smaller communities not served by Arterials, and link locally important traffic generators with rural surroundings.

Local Roads and Streets

Local Roads and Streets account for the largest percentage of roadways in terms of mileage and are typically designed to discourage through traffic. A local road or residential street primarily serves as access to a farm, residence, or other abutting property.
On these roadways, the through traffic is local in nature and extent rather than regional, intrastate, or interstate. Local roadways are typically classified by default; once all other roadways have been classified as Arterial or Collector, the remainder are Local roadways.

Local Roads and Streets provide access to properties and typically have traffic control measures.

1.2.3.1 Functional Classifications in Colorado

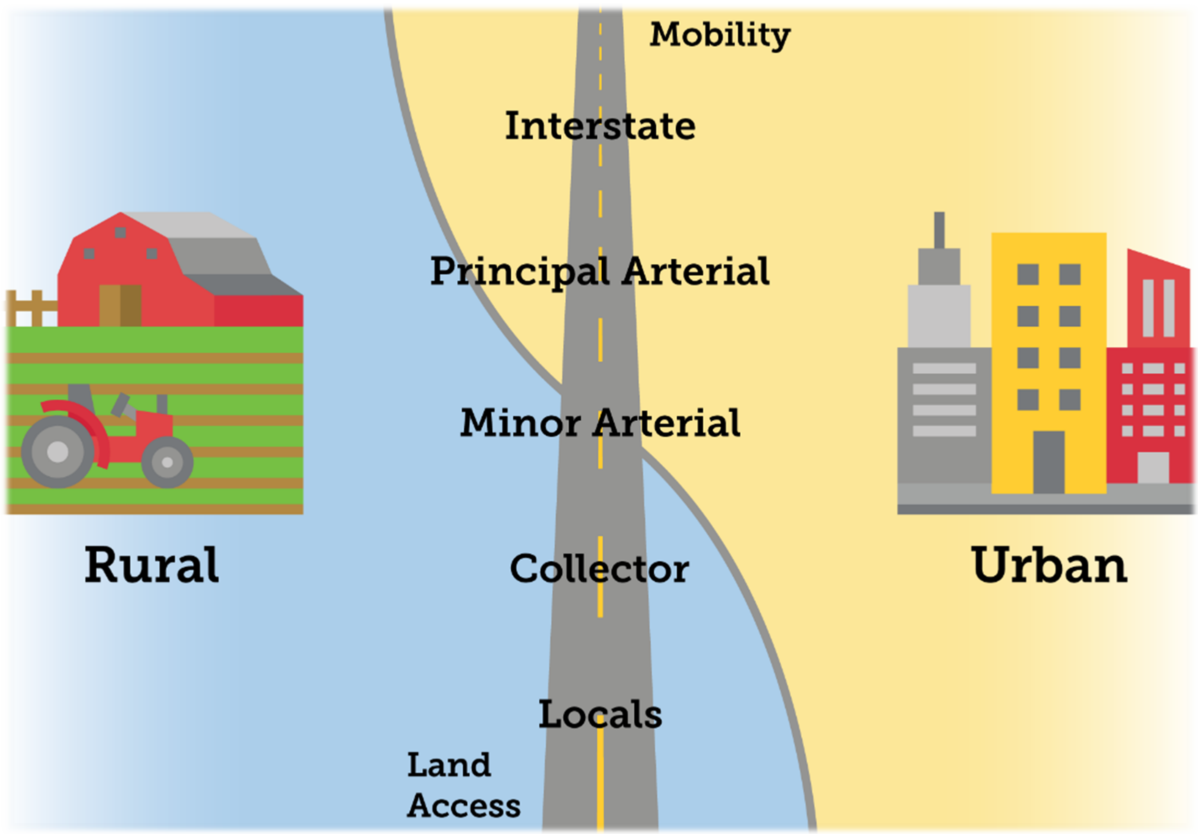
The functional classification for existing facilities in Colorado is already defined and can be found on the CDOT Online Transportation Information System (OTIS)

(CDOT, n.d.). OTIS shows the system classifications of the roadways, such as the administrative class, the functional classification, the NHS designation, and other special system classifications. Ramps and other non-mainline roadways are assigned the functional classification of the highest functional classification of the intersecting mainline that serves the ramp or other facility.

Use this link to access CDOT's OTIS data: [CDOT-OTIS Online Transportation Information System | Home (coloradodot.info)]

Figure 1-2 aids in the vision of transportation of Urban Mobility and Rural Land Access. The classifications between them help categorize the area of context that they may fit.

Figure 1-2 Mobility and Land Access



1.3 Context Classification

The context classifications defined in this Guide are related to the context classifications of Rural, Rural Town, Suburban, Urban, and Urban Core described in Chapter 1, Section 1.5, of the 2018 AASHTO GDHS.

"Context classification" is a land use term that describes a geographic location based on its population density and natural or built environment characteristics. There are six context classifications ranging from rural to urban (C1 through C6). The C1 context classification is the least populated and is characterized as a natural, unchanged landscape or a remote mountainous area. The C6 context classification is the most heavily populated in a built-out, human-made urban environment.

The context classification and the transportation modes a facility supports influence roadway design. A roadway facility can traverse one or more context classifications. For example, US 6 in Colorado moves from rural eastern plains to heavily populated urban areas, and then on to remote or small-town mountainous areas before entering the high deserts of western Colorado. Its design has very different functional characteristics in each geographic area.

1.3.1 Special Traffic Generators Within Context Classifications

There are special traffic generators within context classifications. Special traffic generators are unique land uses that may generate traffic that is not typical for the context classification. The following land uses are special traffic generators to consider within a specific context classification:

- Major Industrial
- Schools
- Hospitals
- Ski Areas
- Sport Complexes
- Major Warehouses
- Seasonal Events
- Airports
- Colleges
- Military Installations

For additional information, refer to NHCRP 855 Report, An Expanded Functional Classification System for Highways and Streets (NCHRP, 2018).

1.3.2 Context Classifications in Colorado

The classifications used to define context in Colorado are as follows:

C1 - Rural Mountainous Environment. C1 is characterized by wilderness or forested areas that may include mountains, canyons, and rivers. The challenging geographic and environmental conditions in these areas have a strong influence on the alignment, design, and performance of a highway. The roadways may have right of way and environmental constraints. They may be in more remote areas with access to outdoor recreation, such as bicycling, mountain biking, skiing, hiking, river activities, and camping. There may also be interregional transit in areas where towns and business centers tend to be interspersed across rural geographic areas. Roadways may have passenger vehicles, freight transport, recreational vehicles, and the occasional bicyclist. Examples of roadways in a C1 context classification include I-70 through Glenwood Canyon and US 550 between Durango and Ouray.

C1 – Rural Mountainous Environment

C2 - Rural Places. C2 is characterized by agricultural lands, ranches, rural towns, or farming areas. Roadways may have passenger vehicles, freight vehicles, interregional transit, and occasional bicycle and pedestrian activity. Oversized agricultural equipment may regularly use the roadway to travel to fields. Examples of roadways in a C2 context classification include US 285 in the San Luis Valley and CO 71 north and south of Brush, Colorado.

C2 - Rural Places

C3 - Suburban Places. C3 is characterized by housing areas and strip commercial development just outside of larger urban cores or small pockets of housing outside of rural town cores. In the Denver area, Highlands Ranch is considered suburban; in Grand Junction, the Redlands is considered suburban. Roadway uses in this context classification can vary depending upon the density of development the roadway supports, and the uses may evolve as the area grows and becomes more populated. Roadways may have passenger vehicles, buses, freight transport, trains, pedestrians, and bicyclists.

C3 - Suburban Places

C4 - Traditional Neighborhoods. C4 is characterized by well-connected or established streets and blocks with a range of housing types, amenities, schools, and businesses. It is often located in or adjacent to an urban area and is closer to the downtown core than a suburb. Traditional neighborhoods are found in large urban areas and rural towns. Travel between the Traditional Neighborhood and an Urban Core may occur by foot, bicycle, or transit, in addition to vehicular travel. In Denver, the Washington Park neighborhood would be considered a Traditional Neighborhood. In Greeley, the Glenmere/Cranford neighborhood would be an example of a Traditional Neighborhood.

C4 - Traditional Neighborhoods

C5 - Downtown Places. C5 is characterized by retail, office, and other business activity in both large and small towns, with main streets or civic spaces like town squares. Its roadways support a greater percentage of bus transit, pedestrian, bicycle, and passenger vehicle activity, as well as some freight and delivery traffic. The variability of this context classification is demonstrated by downtown Lamar or Alamosa, larger city centers in Grand Junction or Fort Collins, or town squares in the mountain communities of Aspen or Steamboat Springs. C5 is generally located very close to a C4.

C5 - Downtown Places

C6 - Urban Core. C6 is characterized by a primarily built environment with a mix of multiuse buildings (office, residential, retail), civic spaces, and cultural or entertainment districts in large, densely populated cities. Numerous amenities are available within walking distance to those who live or work in the Urban Core. Downtown Denver and downtown Colorado Springs are examples of this context classification. Roadways accommodate multiple uses with complex interrelationships. This context classification has the highest level of pedestrian, bicycle, bus and light rail transit, and freight and delivery activity of all the context classifications. C4 may circle a C6 or be located within walking distance to that core.

C6 - Urban Core

1.4 Facility Type

The new framework for geometric design uses three facility types, defined as:

Road

Context Classifications: C1 Rural Mountainous Environment, C2 Rural Places, C3 Suburban Places.
A facility generally characterized by shoulders and roadside ditches, mainly found in rural, low-density settings.

Street

Context Classifications: C3 Suburban Places, C4 Traditional Neighborhoods, C5 Downtown Places, C6 Urban Core.
A facility generally characterized by the inclusion of curb and gutter, sidewalks, and storm sewers in more urban contexts, which may include on street parking, bike lanes, and transit stops.

Freeway, Expressway, Interstate

Context Classifications: C1 Rural Mountainous Environment, C2 Rural Places, C3 Suburban Places, C4 Traditional Neighborhoods, C5 Downtown Places, C6 Urban Core.
A facility generally characterized by more restrictive access controls. Access is managed at specific locations that are sufficiently spaced apart to facilitate effective free flow travel.

1.5 Other Contextual Considerations

1.5.1 Multimodal

This term can be defined as a planning and design approach that results in an efficient and equitable transportation system for all facility users and modes. The designer needs to evaluate and understand the context of the facility and local multimodal plans to establish design controls and criteria that will accommodate the identified modes of transportation that will use the facility.

Use this link for FHWA multi-modal approach: https://highways.dot.gov/complete-streets

Example Multimodal Application

A highway has begun to see more traffic and needs an overlay and widening. The highway approaches a suburban area where bicyclists and pedestrians use regional trail systems, transit, and other modes of transportation for recreation and commuting. The designer needs to take all user modes into consideration, investigate local plans for multimodal development, along with purpose and need and context, to set the design controls and criteria for the project.

1.5.2 Performance-Based Practical Design (PBPD)

PBPD is a decision-making framework that helps an agency improve its management of transportation investments while fulfilling systemwide needs and performance priorities with limited resources. PBPD involves the application of a performance management framework to make decisions about how best to address purpose and need and project performance goals. In Colorado, Data Driven Safety Analysis plays a large role in PBPD.

PBPD is a process in which quantitative performance analysis guides decision-making throughout the project development process. Ideally, stakeholder consensus is achieved in the planning phase on the desired project performance outcomes (goals). Using the performance-based goals as a guide through project development, the designer focuses on optimizing system-level needs while meeting clearly defined project-level needs. For example, if meeting full design standards for a geometric element comes at significant cost to the system without adding notable performance value relevant to the project's goals, PBPD may be used to establish more project-appropriate design standards.

Use this link to access Performance Based Practical Design information on FHWA's website: https://www.fhwa.dot.gov/design/pbpd/

In the NCHRP Report 785, Performance-Based Analysis of Geometric Design of Highways and Streets (NCHRP, 2014), safety performance is a prevalent project performance goal evaluated in PBPD. The six PBPD project examples in NCHRP Report 785 demonstrate the importance of considering predicted safety performance in design alternatives development and selection. AASHTO's *Highway Safety Manual* (AASHTO, 2010) role in all NCHRP Report 785 project examples emphasizes the importance of the powerful relationship between design dimensions and predicted future safety performance.

CDOT's PBPD procedures are evolving as the prevailing PBPD methodologies and relevant technologies advance. The designer's role is to understand how data-driven analysis can benefit a project and the overall transportation system. The designer should coordinate with the Region Traffic Engineer early in project development to identify opportunities to apply a Data Driven Safety Analysis.

For example, in a scenario where safety performance is a project performance goal, the Region Traffic Engineer can provide predicted KABCO injury scale statistics (fatal crash(K), incapacitating injury crash(A), non-incapacitating injury crash(B), possible injuries(C), no apparent injuries(O)) for the various design alternatives under consideration within specified timeframes so that the forecasts can be considered in decisions regarding design alternative selection.

Use this link to access the KABCO Injury Classification Scale and Definitions table: https://safety.fhwa.dot.gov/hsip/spm/conversion_tbl/pdfs/kabco_ctable_by_state.pdf

Another application would be to conduct a safety performance analysis to understand how a proposed design modification, or a design variance request, is predicted to influence future safety performance. In addition to using safety performance forecast data, a benefit-cost analysis can be performed to evaluate the realized benefits of the proposed design modification or variance. For more information on PBPD, refer to the 2018 AASHTO GDHS.

Example PBPD Application

An existing roadway with a low volume of traffic and no crash history is proposed to be widened to improve shoulders and repaved due to age of pavement. There are currently 4-foot gravel shoulders. Using Data Driven Safety Analysis (DDSA), it could be determined that 4-foot gravel shoulders may be adequate for this type of roadway to meet the purpose and need, and shoulder widening is not necessary.

1.5.3 Context Sensitive Solutions (CSS)

The principles of Context Sensitive Solutions (CSS) apply to any transportation project aiming to bring the full range of stakeholder values to the table and actively incorporate them into the design process and results.

> "CSS is a collaborative, interdisciplinary decision-making process and design approach that involves all stakeholders to develop a transportation facility that fits its physical setting."
> *Source: FHWA https://highways.dot.gov/research/innovative-program-delivery/innovation-life-cycle/ongoing-planning-environment-realty-research*

Use this link to access FHWA's Context Sensitive Solutions and Design page: https://www.fhwa.dot.gov/planning/css/

Use this link to understand how CSS approaches can be used to establish design controls and criteria: https://www.fhwa.dot.gov/planning/css/design/controls/index.cfm

CSS is a public engagement and stakeholder engagement process that begins early and continues throughout the project development process—from project concept development; through alternative studies, design and construction; and beyond into maintenance and monitoring improvements. CSS means maintaining commitments to communities. CSS applies essentially anywhere and everywhere because every project has a context defined by terrain and topography, communities, users, and surrounding land use.

Use this link to access information on how CSS is being applied on the I-70 Mountain Corridor: https://www.codot.gov/projects/i70mountaincss/assets/docs/css

Example CSS Application

A project area is in need of a wider roadway to accommodate an increase in vehicular traffic. There are many businesses and accesses along the roadway. The agency is working with project stakeholders to develop a plan and purpose and need to accommodate the widening within the context of the area. The designer uses the project purpose and need to develop design controls and criteria that meet the intent of desired context-sensitive solutions.

1.6 Context Classification to Facility Type Matrix

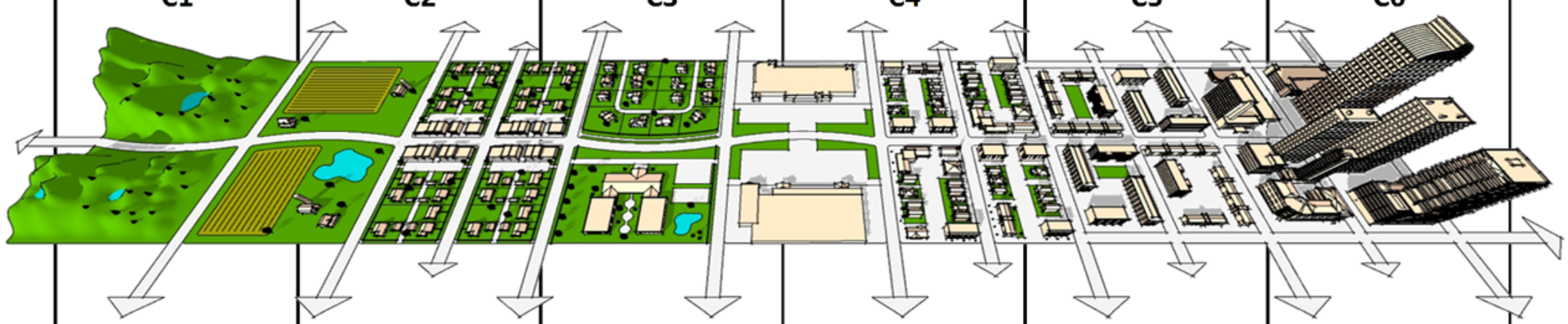
The Context Classification to Facility Type Matrix beginning on the next page uses the existing roadway data elements (typical section, average daily traffic, etc.), context of the surrounding area the facility serves, and other elements and characteristics of a facility to determine the facility type.

The designer is asked to check off elements on the matrix that apply to the facility being designed. This helps guide the designer to determine if the facility type is a Road; Street; or Freeway, Expressway, or Interstate; and in what contextual classification the facility is located. The facility type and the contextual classification are the basis for discussion around what travel modes need to be considered or accommodated in the design.

Context Classification to Facility Type Matrix

Industrial Area

	C1	C2	C3	C4	C5	C6
	Rural Mountains	Rural Places	Suburban Places	Traditional Neighborhoods	Downtown Places	Urban Core



FACILITY ELEMENTS (ROAD)

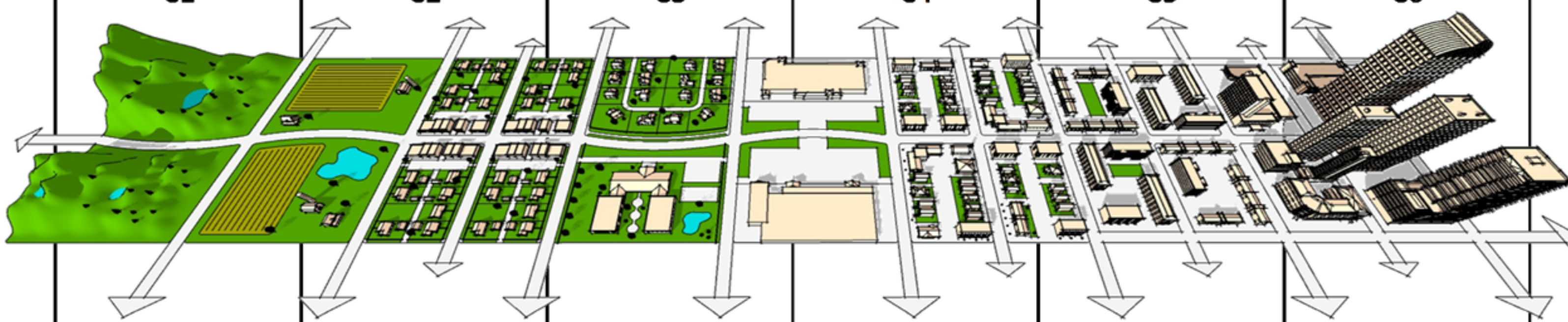
	C1	C2	C3	C4	C5	C6
Facility Location						
Urban				STREETS		
Rural		ROADS				
Annual Average Daily Traffic						
0-500						
500 - 5000						
5000 to >50,000						
Number of Access Points per Mile						
1/2-mile spacing minimum						
1 access per parcel						
Number of Lanes						
2						
2 to 4						
4 or more						
Intersection Type						
Stop Controlled Intersection						
Roundabout or Signal						
Grade-separated Interchange						
Median Type						
Painted Separator						
Painted and/or Depressed						
Raised and/or Barrier						
Shoulder Type						
Gravel						
Paved						
Curb and Gutter						
Drainage Type						
Roadside Ditch						
Storm Sewer						
Overlays						
Attached Sidewalk						
Detached Sidewalk / Trail						
Bike Lane						
Transit Stop						
On-street Parking						

FACILITY ELEMENTS (STREET)

	C1	C2	C3	C4	C5	C6
Facility Location						
Urban				STREETS		
Rural		ROADS				
Annual Average Daily Traffic						
500 - 5000						
5000 - 10,000						
10000 to >50,000						
Number of Access Points per Mile						
1 access per parcel						
>1 access per parcel						
Number of Lanes						
2 to <4						
4 or more						
Intersection Type						
Stop Controlled Intersection						
Roundabout or Signal						
Grade-separated Interchange						
Median Type						
Painted Separator						
Painted and/or Depressed						
Raised and/or Barrier						
Drainage Type						
Roadside Ditch						
Storm Sewer						
Overlays						
Attached Sidewalk						
Detached Sidewalk / Trail						
Bike Lane						
Transit Stop						
Bus Rapid Transit Lane						
On-street Parking						

Context Classification to Facility Type Matrix

Industrial Area



	C1	C2	C3	C4	C5	C6
	Rural Mountains	Rural Places	Suburban Places	Traditional Neighborhoods	Downtown Places	Urban Core

FACILITY ELEMENTS (FREEWAY, EXPRESSWAY, INTERSTATE)

	C1	C2	C3	C4	C5	C6
Facility Location						
Urban			STREETS	STREETS	STREETS	STREETS
Rural	ROADS	ROADS	ROADS			
Annual Average Daily Traffic						
0 - 5000	↕	↕	↕			
5000 - 10,000		↕	↕	↕		
10,000-50,000			↕	↕	↕	↕
>50,000				↕	↕	↕
Number of Access Points per Mile						
Minimum 1-mile spacing	↕	↕	↕	↕		
<1 mile spacing					↕	↕
Number of Lanes						
4		↕	↕			
4 or more			↕	↕	↕	↕
Intersection Type						
Stop Controlled Intersection	↕	↕				
Roundabout or Signal			↕	↕		
Grade-separated Interchange	↕	↕	↕	↕	↕	↕
Median Type						
Painted Separator						
Painted and/or Depressed	↕	↕	↕			
Raised and/or Barrier			↕	↕	↕	↕
Drainage Type						
Roadside Ditch	↕	↕	↕	↕		
Storm Sewer			↕	↕	↕	↕
Overlays						
Attached Sidewalk						
Detached Sidewalk / Trail	↕	↕	↕	↕		
Bike Lane						
Transit Stop						
Bus Rapid Transit Lane			↕	↕	↕	
On-street Parking						

1.7 Design Controls

Driver performance, design vehicles, traffic characteristics, and safety are some of the design controls to consider. Chapter 2 of this Guide covers these elements, as well as others, in more detail. Refer to the design controls and criteria described in Chapter 2 of this Guide when using the matrix.

1.8 Geometric Design Criteria

The end results of the design process are the geometric design criteria that will be used to design the project. There is general design criteria information in Chapter 2 of this Guide, and more specific design criteria information for roads; streets; and freeways, expressways, and interstates in Chapters 3, 4, and 5 of this Guide, respectively. Specific information on design criteria for other modes and facilities can be found in other chapters of this Guide.

1.9 Roadway Design Guide Step by Step Process

The following steps include details about the steps to complete to design a project.

Step 1: Identify Project Purpose and Need / Context of Project

- Team communication with Project Manager.
- What is the scope and budget of the project?
  - What is the scale of the project based on geographic size and budget?
  - What type of project is it?
    - Widening / Overlay.
    - Intersection.
    - Corridor Design.
    - Interchange.
- What is the timeframe that the project will be constructed?

Step 2: Determine Functional Classification

- Identify the facility's functional classification using CDOT's Online Transportation Information System (OTIS).
  - This is a classification assigned by CDOT and will aid in identifying the facility type through the Context Classification to Facility Type Matrix.
  - Use functional classification to help fill out CDOT form 463 (Design Data).
  - If this is a new facility, discuss the appropriate functional classification to use in the Form 463 with the Project Manager.
- Team communication with Project Manager.

Step 3: Determine Context Classification

- Use the Context Classification to Facility Type Matrix to help determine context area of project.

- Review the project area geography and future development to help identify the appropriate context classification (C1 to C6).
- Team communication with Project Manager.

Step 4: Determine Facility Type

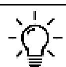
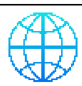
- Use the Context Classification to Facility Type Matrix to help determine facility type.
  - Use facility elements of each facility type to validate the facility type.
  - Use data for current facility to check off the elements to verify that the correct context classification and facility type are selected.
  - Identify facility type (Road; Street; Freeway, Expressway, Interstate) through the above steps.
- Refer to respective facility type chapter in the Guide once the facility type has been determined.
- Team communication with Project Manager.

Step 5: Design Process of Project

- Use the appropriate facility type chapter and references within the chapter to begin shaping the design parameters for the project.
- Evaluate additional design considerations, including multimodal design, context sensitive solutions, and performance-based practical design.
- Use Chapter 6 (Elements of Design) to aid and guide decisions for elements of design.
- Use Chapter 7 (Cross Section Elements) to aid and guide in development of project cross section.
  - Use the cross section elements based on the context determined in the previous steps.
- Team communication with Project Manager.

Chapter 2
Design Controls and Criteria for All Facility Types

Legend

	Multimodal Application Example
	Context-Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context-Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO-Specific Information

Chapter

2

2 Design Controls and Criteria for All Facility Types

2.1 Introduction

"Design flexibility is of critical importance because each project has a specific purpose and need, has specific context and constraints, serves a unique set of users, and fills a distinct position in the transportation network. No project is exactly like another; therefore, no single set of design criteria can be applicable to or meet the needs of all, or even most, projects. The range of factors to be addressed in the project development process is too diverse, the needs of individual transportation modes too varied, and the limitations on available funding too great to simply apply the same design approach to every project. Designers typically consider a range of factors when applying design criteria, making trade-offs among many possible design options to best serve the traveling public and the community at large. Design flexibility removes an additional layer of unnecessary constraints to achieving the most appropriate design.

Exercise of design flexibility may, in some cases, involve leaving some design elements unchanged, if they are performing well, even if they do not fully meet the design criteria generally used in new construction. In some cases, it may be desirable to reduce the dimensions of some design elements, so that other aspects of performance can be improved. For example, shoulder widths might be decreased in some cases to provide space for an additional through travel lane or a bicycle lane. The effects of such design changes on all aspects of performance should be assessed as part of the design process." American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (the Green Book) (2018 AASHTO GDHS) (AASHTO, 2018)

A Key Performance Indicator (KPI) is a quantifiable measure used to evaluate how effectively a facility is meeting expectations. The results of these measures inform design controls and criteria for projects.

KPIs are applied in the Performance-Based Practical Design (PBPD) are data driven decision-making framework to determine how best to address purpose and need and achieve project performance goals.

Local agencies desiring to use federal funds must design projects to meet or exceed the design standards or the minimums presented in the 2018 AASHTO GDHS and in this design guide. The use of federal funds requires that the National Environmental Policy Act (NEPA) process to be followed. Historic districts require special consideration that may require consultation with the State Historic Preservation Office (SHPO).

2.2 Driver Performance and Human Factors

The interaction between users and the roadway envelope needs to be considered when setting design controls for a project. Refer to Chapter 2, Section 2.2.1, in the 2018 AASHTO GDHS for more information.

2.2.1 Information Handling

Information handling refers to the observations a user sees or feels while traveling on a roadway facility. This is a continual process involving visual queues (sight distance, signs, markings, etc.) that indicate what to expect ahead, also detection of changes in the facility, such as curves or hills; or even indicate changes in vehicle operation. All these bits of information are continually processed by the user to help navigate the roadway safely. This applies to a vehicle driver, as well as a pedestrian or bicyclist.

Refer to Chapter 2, Section 2.2.6, of the 2018 AASHTO GDHS for more information regarding information handling.

2.2.2 Driver Error

Driver characteristics can have an impact on how designers and engineers set design controls and criteria. Although some of the factors cannot be controlled, designers and engineers need to consider driver behavior in the area and context of the project.

Refer to Chapter 2, Section 2.2.7, of the 2018 AASHTO GDHS for more information.

2.2.3 Speed and Design

Speed has a direct impact on a driver’s ability to perceive and react to data when traveling on a roadway, or a bicyclist’s ability to perceive and react to data on a roadway, a shared-use path, or path. The facility must be designed to appropriately inform the user with the spacing needed to provide sufficient time to perceive data and decide upon the appropriate reaction.

Refer to Chapter 2, Section 2.2.8, of the 2018 AASHTO GDHS for more information.

2.2.4 Cone of Vision

Vision factors that affect the design controls include:

- A driver with 20/20 vision can read a sign from a distance of 90 feet; however, many drivers do not have 20/20 vision.
- Sign placement and lettering can affect driver behavior.
- Some drivers have difficulties with peripheral vision and angle of vision.
- Night driving impacts a driver's sight distance and angle of vision.

2.3 Design Vehicles (Roadway User Design Characteristics)

2.3.1 General Characteristics

The physical characteristics and the proportions of vehicles of various sizes using the facility are key controls in geometric design. The four general classes of design vehicles are:

- *Passenger cars.* Passenger cars of all sizes, sport/utility vehicles, minivans, vans, and pickup trucks.
- *Buses.* Intercity (motor coaches), city transit, school, and articulated buses.
- *Trucks.* Single-unit trucks, truck tractor-semitrailer combinations, and truck tractors with semitrailers in combination with full trailers.
- *Recreational vehicles.* Motor homes, cars with camper trailers, cars with boat trailers, motor homes with boat trailers, and motor homes pulling cars.

The bicycle may be a second design vehicle where a bicycle facility is part of the traveled roadway or where there is a separated shared-use path adjacent to a facility. See Chapter 13 of this Guide for design considerations for bicycle and pedestrian facilities.

In the design of any facility, the designer should consider the least maneuverable vehicle that routinely uses a facility, which is often the largest vehicle, in determining the design of corner radii at intersections and radii of horizontal curves of roadways.

To determine project-specific design standards, the designer could collect traffic data that includes vehicle types, look at crash records for lane encroachment crashes, and look at surrounding land uses that might influence the design vehicle.

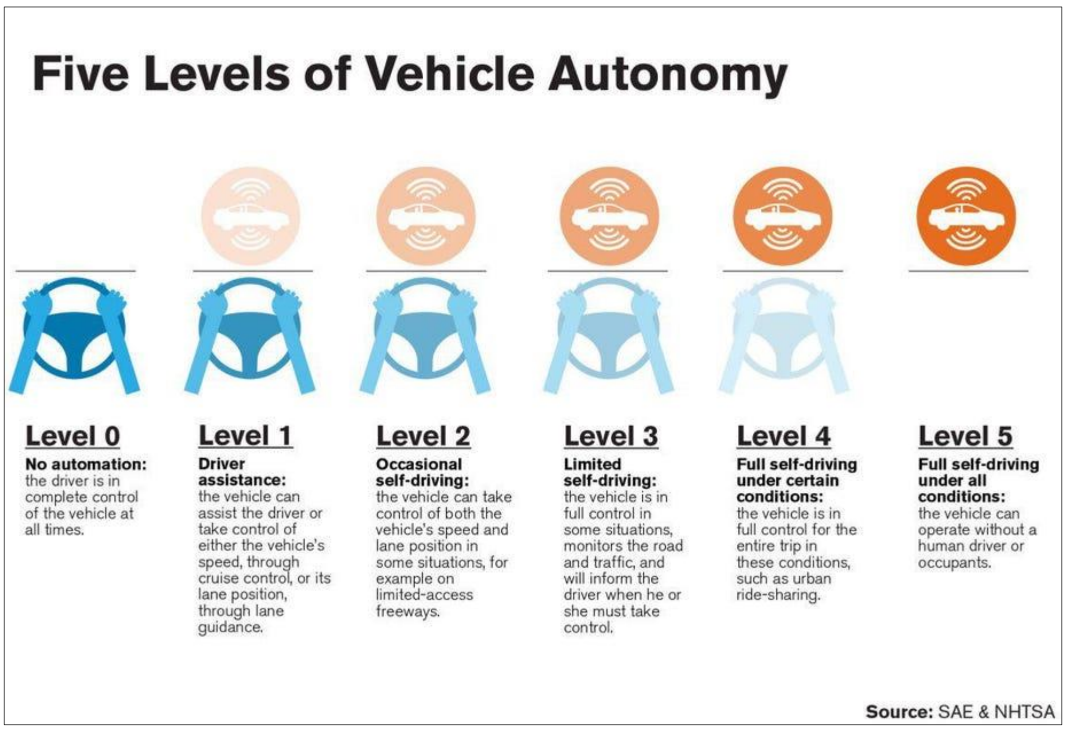
Refer to Table 8-3 in Chapter 8 of this Guide for the minimum size design vehicle considered for intersections of freeway ramp terminals with arterial crossroads and for other intersections on state highways and industrialized streets that carry high volumes of truck traffic and/or that provide local access for trucks.

Refer to Chapter 2, Section 2.8.1, of the 2018 AASHTO GDHS for additional information.

2.3.1.1 Autonomous Vehicles

Autonomous vehicles and hybrid autonomous vehicles are increasing in use. Designing roadways that these vehicles can safely and effectively interpret and navigate will be the next challenge for designers and traffic engineers. It will be important to understand how the roadway infrastructure can accommodate the multiple forms of autonomous vehicles and the levels of sophistication that each level is capable of. Figure 2-1 illustrates the differing levels of autonomy the vehicles may have that the designer needs to be prepared to accommodate.

Figure 2-1 Levels of Vehicle Autonomy



Some of the semi-autonomous and autonomous technologies used in the motor vehicle industry include:

- Realtime posted speed limit in the driver information systems.
- Lane departure warnings and steering correction.
- Adaptive Cruise Control.
- Adaptive Steering to control the vehicle for the driver.
- Collision avoidance systems.
- Roadway mapping and guidance information.

These systems use infrastructure elements, such as striping and signing, to evaluate the conditions and provide feedback to the driver in real time. The more these technologies advance the more infrastructure elements they will interface with. This could include traffic signals, pedestrian and bicycle identification and location, guardrail identification, and roadway information systems for roadway conditions, weather information, and incident awareness.

2.3.1.2 Bus Rapid Transit (BRT)

2.3.1.2.1 Concurrent-Flow Median Lanes

Concurrent-flow dedicated bus/high-occupancy vehicle (HOV)/managed lanes are dedicated lanes operating in the same direction of travel as adjacent general purpose lanes. They are not physically separated from the general purpose traffic lanes and are designated for exclusive use by eligible vehicles for all or part of the day.

Dedicated lanes often are developed by retrofitting a freeway cross section within the right of way. For example, the inside shoulder of a freeway median may be converted to an additional lane, or the freeway and right of way may be expanded to create lanes next to the median. Pavement markings normally separate the dedicated lanes from other traffic.

Specific access points placed every several miles should be provided, although in many places unrestricted access is permitted. Because there may be a high speed differential between the general purpose lanes and the concurrent-flow lane, unrestricted access may introduce a safety concern in locations where there is a high amount of traffic weaving. Conversely, designating access may inordinately congest these locations. The median (left) lane normally is preferred because it is removed from conflicts with entering and exiting traffic. However, a right-side dedicated lane designed primarily for buses may be appropriate in special circumstances, such as between successive on- and off-ramps.

2.3.1.2.2 Lane and Shoulder Widths

The desirable cross section for a concurrent-flow lane includes a full-width shoulder on the median side to accommodate vehicles pulling over for breakdowns or for HOV lane enforcement.

The 2018 AASHTO GDHS identifies a shoulder width of 10 to 14 feet as desirable next to a median barrier. Many projects use narrower widths because of design constraints. The use of narrow shoulders or limited lateral clearances next to a median barrier needs careful examination on a project-by-project basis.

Refer to Chapter 4 Section 4.3 and Section 4.4 of the 2018 AASHTO GDHS for more information.

Enforcement of HOV lanes is important to their success. Shoulders used for enforcement require additional right of way, but this investment is valuable. Enforcement shoulders may not be necessary along the entire length of a dedicated lane, but rather at key enforcement locations.

2.3.1.2.3 Concurrent-Flow Right-Side Lanes

Dedicated bus and HOV lanes sometimes are located in the outside lane or on a designated outside shoulder or lane. In those cases, conflicts may occur with freeway on- and off-ramps. They generally are limited to locations where transit only or 3+ passenger occupancy use is justified for low volumes. There are few conflicting ramps, and the conflicting volumes at ramps are relatively low.

2.3.1.2.4 Barrier-Separated Lanes

Barrier-separated bus or HOV lanes within freeway medians typically operate with one or more lane in each direction, or two-way lanes. From a bus transit operations perspective, two-way lanes are preferable because they enable buses to run in one direction at all times and to deadhead without encountering off-peak direction congestion. Both types of lanes are separated from the adjacent general purpose freeway lanes by concrete barriers. The barrier separation limits the number of direct access points to the lane. Access occurs by slip ramps or fly-over ramps to and from adjacent lanes or other intersecting roadways and transit facilities.

A barrier should separate the opposing flow traffic in a two-way operation. However, the barriers are not essential if the lanes are used only by buses driven by professional drivers. In such a case, a 1- to 2-foot painted buffer stripe may suffice.

Reversible lanes, typically located within the freeway median, should always be physically separated from the general-purpose lanes. The lanes should be gated and operated directionally—typically inbound toward a central business district in the morning and outbound in the afternoon. Daily set-up is required, which often includes opening gates to the lanes in the morning, closing the lanes to inbound traffic after peak hour traffic, reopening the lanes in the reverse direction of travel in the afternoon, and closing the lanes in the evening. Usually, a combination of manual and automated techniques is used to open and close reversible lanes, since some field intervention is needed to assure safe operation.

2.3.1.3 Bicycles

Most design criteria for roadways will not be impacted by the bicycle as a design vehicle; however, bicycle facilities may impact design criteria to accommodate the design vehicle. For example, if a design vehicle requires a 30-foot radius, the actual versus effective curb radius should be considered. The engineer may be able to use a 15-foot actual curb radius, which is better for pedestrian accessibility, because the effective curb radius is 30 feet with the presence of bike lanes.

On a shared-use path, the bicycle is likely the largest vehicle to normally use that facility, so it would be the design vehicle for design criteria for design speed, stopping sight distance, maximum degree of horizontal curvature, minimum vertical curve lengths, etc. The recommended design values for shared-use paths and other bicycle facilities are based upon those in the AASHTO *Guide for the Development of Bicycle Facilities* (AASHTO, 2012), with supplemental information provided from the Federal Highway Administration (FHWA) *Characteristics of Emerging Road and Trail Users and Their Safety* (FHWA, 2004).

Use this link to access FHWA Characteristics of Emerging Road and Trail Users and Their Safety (FHWA, 2004): [Characteristics of Emerging Road and Trail Users and their Safety - FHWA-HRT-04-104 (dot.gov)]

Refer to Chapter 13 of this Guide for additional information.

2.3.1.4 Oversize/Overweight

During the scoping phase for a project where there are oversize/overweight vehicles using the facility, the designer should contact the area freight unit for specific design vehicle loadings and dimensions to be accounted for during design.

2.3.2 Minimum Turning Paths of Design Vehicles

Chapter 2, Section 2.8.2, of the 2018 AASHTO GDHS has drawings and tables to be referenced for minimum turning paths for typical design vehicles.

It is recommended that the Tables 2-5a and 2-5b in the 2018 AASHTO GDHS be applied for the appropriate design vehicle. The designer should confirm that the chosen turning radius design will function as planned by using turning template software.

2.4 Traffic Characteristics

2.4.1 General Considerations

Information on traffic characteristics is vital in selecting the appropriate geometric features of a roadway. Obtaining this information for all transportation modes should be completed at the inception of any design project to aid in establishing design controls and criteria that support the project purpose and need.

Refer to Chapter 2, Section 2.3.1, of the 2018 AASHTO GDHS for more information.

2.4.2 Volume

Refer to the Colorado Department of Transportation (CDOT) Online Transportation Information System (OTIS) (CDOT, n.d.) for traffic volume data. Also, refer to Section 4.01 of the *CDOT Project Development Manual* (CDOT, [2013] 2022) for guidance on traffic data. Refer to Chapter 2, Section 2.3.2, of the 2018 AASHTO GDHS for more information.

If there are existing or proposed bicycle or transit facilities, bicycle and transit data should be collected.

Use this link to access CDOT's OTIS data: CDOT-OTIS Online Transportation Information System | Home (coloradodot.info)

Use this link to access CDOT's Project Development Manual: 2013 Project Development Manual — Colorado Department of Transportation (codot.gov)

2.4.3 Directional Distribution

Refer to Chapter 2, Section 2.3.3, of the 2018 AASHTO GDHS for information on directional distribution.

2.4.4 Traffic Composition

Traffic composition is the percentage of large vehicles with respect to the total number of all vehicles. Traffic composition can influence design controls and criteria, such as materials, as well as environmental considerations, such as noise.

Refer to Chapter 2, Section 2.3.4, of the 2018 AASHTO GDHS for more information.

The CSS framework can help designers develop a facility that fits its physical setting. If there is a facility with a high number of large vehicles, like a freeway through a C3 context classification with residential and warehouses in proximity, a collaborative approach involving the varied stakeholders can inform design considerations, such as a noise barrier wall, that mitigate negative impacts while meeting the purpose and need of the project.

2.4.5 Projection of Future Traffic Demands

Information for future traffic demands is usually obtained from traffic engineers that are working on the project or have been involved in a traffic study that has determined what those future traffic volumes will look like based on numerous factors included in the guidelines listed in CDOT's Traffic Analysis and Forecasting Guidelines.

Use this link to access CDOT's Traffic Analysis and Forecasting Guidelines (CDOT, 2018): Traffic Analysis Forecasting Guidelines (codot.gov)

Chapter 2, Section 2.3.5, of the 2018 AASHTO GDHS provides additional information regarding projection of future traffic demands.

2.4.6 Speed

Target speed is the desired travel speed and considers the purpose and need of a facility within its context. Design speed is a tool used to determine geometric features of the roadway.

Speed plays a large role in establishing design controls and criteria. There are many factors and equations that are used for speed to determine design for all user modes. In Colorado, major factors that affect speed are the weather and terrain in the project area. Designers and engineers should consider these factors when it comes to safety and flexible project design, incorporating speed into the design controls and criteria.

Example CSS Application

In 2020, there were 137 motorcyclist fatalities in Colorado. Motorcyclists are about 3% of the roadway traffic and accounted for about 22% of fatalities. Speed is a primary contributing factor in these crashes that can be considered in roadway design. For example, a roadway in the C1 context classification that is a designated Scenic Byway could be designed for lower target speeds, particularly on curves.

Use this link to access the selection of design speeds on FHWA's website: Speed Concepts: Informational Guide - Safety | Federal Highway Administration (dot.gov)

Refer to Chapter 2, Section 2.3.6, of the 2018 AASHTO GDHS for more information.

2.4.7 Traffic Flow Relationships

Refer to Chapter 2, Section 2.3.7, of the 2018 AASHTO GDHS regarding projection of traffic flow relationships.

2.5 Safety

Refer to Chapter 15 of this Guide for more information.

2.5.1 Key Factors Related to Traffic Crashes

Use this link to access the 2020-2023 Colorado Strategic Transportation Safety Plan (CDOT, CDPHE, CDOR, 2020): strategictransportationsafetyplan.pdf (codot.gov)

2.5.2 Bicycle and Pedestrian Safety

Bicyclists and pedestrians are the transportation system's most vulnerable users. From 2014 to 2018 in Colorado, 1% of crashes involved pedestrians, but pedestrians made up 14% of all incapacitating injuries or fatalities resulting from crashes. The potential for injury or fatality when a pedestrian or bicyclist is involved in a crash is much higher than when automobile occupants are involved in a crash. Roadway design should provide the utmost protection for bicyclists and pedestrians and limit speeds where there are conflict points between bicyclists, pedestrians, and vehicles to limit the severity of injuries in the case of a crash. A walking or bicycling route is only as safe and comfortable as its least safe or comfortable link. Designing safe and comfortable crossings or facilities at hotspots or challenging intersections should be considered a high priority to remove these safety or comfort barriers.

Refer to Chapter 2, Section 2.7, of the 2018 AASHTO GDHS for more information.

2.5.3 Roadway Geometry Considerations

Refer to Chapter 2, Section 2.9, of the 2018 AASHTO GDHS for more information.

2.5.4 Proven Safety Countermeasures

FHWA provides information on Proven Safety Countermeasures applicable to a variety of roadway or highway contexts. There are 20 Proven Safety Countermeasures that should be reviewed and considered for relevance to a design project.

Use this link to access FHWA's 20 Proven Safety Countermeasures: [*https://safety.fhwa.dot.gov/provencountermeasures/*](https://safety.fhwa.dot.gov/provencountermeasures/)

Use this link to access FHWA's Pedestrian and Bicycle Safety resources: *Pedestrian & Bicycle Safety - Safety | Federal Highway Administration (dot.gov)*

Use this link to access CDOT's Safety Resources: Safety — Colorado Department of Transportation (codot.gov)

2.6 Highway Capacity (Transportation Facility Operations)

It is essential for the designer to understand the project goals and establish the appropriate evaluation criteria to meet those goals. The type of facility designed depends on its context classification (refer to Chapter 1 of this Guide), and will accommodate different travel modes at varying levels. Refer to the *Highway Capacity Manual, Seventh Edition: A Guide for Multimodal Mobility Analysis* (*Highway Capacity Manual*) (TRB, 2022) for information on how highway capacity impacts a project design.

After the designer has collected data and information about the facility, a PBPD methodology is applied to establish the appropriate design and controls for a project.

2.6.1 General Characteristics

To determine design criteria for a project, the designer must take the following into consideration—variations in traffic volumes at different times of the day, the surrounding area, and the context of the roadway envelope, including all user modes. Refer to the *Highway Capacity Manual* (TRB, 2022) for information on evaluating lane alternative designs for projects.

Refer to Chapter 2, Section 2.4.1, of the 2018 AASHTO GDHS for more information.

2.6.2 System Performance

2.6.2.1 HCM and Level of Service

The Region Traffic Engineering Section should be consulted to obtain current and projected traffic counts and to ascertain if a highway capacity analysis is necessary. Refer to the *Highway Capacity Manual* (TRB, 2022) and associated software to determine the effect of design improvements on the Level of Service.

Table 2-1 General Definitions of Level of Service

Level of Service	General Operating Conditions
A	Free flow
B	Reasonably free flow
C	Stable flow
D	Approaching unstable flow
E	Unstable flow
F	Forced or breakdown flow

Note: Specific definitions of Level of Service A through F vary by facility type and are presented in the Highway Capacity Manual (TRB, 2022).

Level of Service is one of many measures that can be used to evaluate the operations and effectiveness of transportation networks. Level of Service is a qualitative measure describing operational conditions in a traffic system based on service measure, such as speed and travel time, freedom to maneuver, traffic interruptions, comfort, and convenience. Level of Service analysis results focus only on the throughput of vehicles and should be considered as one element of the facility's overall context.

Through the CSS process, travel priorities for a road may be defined. Depending on the priority of a road, lower Levels of Service may be acceptable to meet other project CSS goals, such as accommodating pedestrian and bicycle networks or traffic calming. Other multimodal amenities may influence the roadway context as these roads transition into urban context classifications.

2.6.2.2 Multimodal Performance Measures

In assessing the needs of each transportation mode, planners and designers need to consider the current and future demand for travel by each mode, which may not always be reflected in current travel volumes. Where facilities for a transportation mode do not currently exist or where the existing facilities are inadequate to serve the full demand volume, trips may be diverted to other facilities or not made at all. Planning studies can identify appropriate demand volumes for each transportation mode for any given facility or corridor.

Bicycle Level of Service (BLOS) is a nationally used measure of on-road bicyclist comfort level as a function of a roadway's geometry and traffic conditions. BLOS is in the Highway Capacity Manual (TRB, 2022).

2.7 Bicycle and Pedestrian Considerations

Designers need to understand the purpose and need of the project related to all modes of transportation prior to initiating project design.

Refer to Chapter 1 of this Guide for how the purpose and need of a project is used in design. Refer to Chapters 12 and 13 of this Guide for multimodal considerations for guidance and more information on integration of transportation modes.

Understanding the purpose and need of the project related to all modes of transportation helps define the typical section of the roadway facility that can accommodate multimodal uses and avoid impacts to the surrounding area. Refer to Chapter 1 of this Guide for how the purpose and need of a project is used in design.

Chapter 3
Facility Type – Road

Legend

	Multimodal Application Example
	Context-Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context-Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO-Specific Information

Chapter

3

3 Facility Type – Road

Road
Context Classifications: C1 Rural Mountainous Environment, C2 Rural Places, C3 Suburban Places.
A facility generally characterized as a two or more-lane roadway with shoulders and roadside ditches, mainly found in a rural, low-density settings.

3.1 Introduction

The guidelines in this chapter apply to facilities defined as Roads, consistent with the definitions in Chapter 1 of this Guide and Chapter 5 of the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (the Green Book) (2018 AASHTO GDHS) (AASHTO, 2018). Guidelines for Streets and Freeways, Expressways, and Interstates are described in Chapters 4 and 5, respectively.

A road facility type (Road) is typically found in low-density and rural areas, such as the Rural Mountainous Environment, Rural Places, and Suburban Places context classifications, and are characterized as a two or more-lane roadway with shoulders and roadside ditches. A Road can be any functional classification—Arterial, Collector Road and Street, or Local Road and Street. Low-volume facilities may provide access to a farm, a residence, a business, or other abutting property. Low-volume facilities include forest, recreational, and resource development roads. High-volume facilities may connect communities.

Refer to Chapter 1 of this Guide for definitions of functional classifications, facility types, and context classifications that are used in this chapter.

3.2 Highway Capacity (Transportation Facility Operations)

3.2.1 Highway Capacity Manual

When a Road is being scoped for improvements, the designer needs to know current and projected traffic volumes and level of service (LOS) for the future design year. A 20-year capacity design project for what is a Road in current year might need to be designed as a Street facility type with additional lanes in the future year if there are projected traffic volume increases and lower levels of service. If capacity improvements for future conditions can be addressed by adding a passing lane to the facility, the Road may be appropriate.

The *Highway Capacity Manual, Seventh Edition: A Guide for Multimodal Mobility Analysis* (*Highway Capacity Manual*) (TRB, 2022) has tools for the designer to quickly evaluate and compare multimodal operational effects of concepts, performance measures, and analysis techniques to determine the appropriate facility type.

Along with the operational and capacity analysis presented in the *Highway Capacity Manual*, the considerations presented in this chapter will help determine the appropriate context classification (C1 through C3) for design of a Road. Decisions regarding which context classification to apply to a Road should be discussed with the Resident Engineer and Region Traffic Engineer so that there is agreement on the appropriate project outcome and scope.

3.2.2 Factors Other Than Traffic Volume That Affect Operating Conditions

There are many factors that can affect the operating conditions of a Road. Some examples the designer should consider are:

- Design speed of the existing road.
- Weaving sections of the road.
- Intersection type or types.
- Number of side road accesses.
- Vertical and horizontal sight distances.
- Mixture of vehicle types using the road.

Refer to Chapter 2, Section 2.4.4, of the 2018 AASHTO GDHS for information on these factors.

3.2.3 Multimodal Considerations

Because a Road is often in a rural environment, design considerations for pedestrian, bicycle, and transit activity may be minimal. However, the designer needs to understand the context and potential multimodal trip generators in the area. This requires the designer to consider the facility's ability to support these multimodal elements. The guidance in the following resources can help determine how to accommodate alternative modes of transportation in Road design.

Use this link to access FHWA's Small Town and Rural Multimodal Networks publication (FHWA, 2016): Small Towns - Publications - Bicycle and Pedestrian Program - Environment - FHWA (dot.gov)

Use this link to access FHWA's Guidebook for Measuring Multimodal Network Connectivity (FHWA, 2018): *https://www.fhwa.dot.gov/environment/bicycle_pedestrian/publications/multimodal_connectivity/*

Use this link to access the National Association of City Transportation Officials (NACTO) Transit Street Design Guide (NACTO, n.d.): *https://nacto.org/publication/transit-street-design-guide/transit-system-strategies/*

3.2.4 Design Service Flow Rates

In general, the design service flow rate is defined as, the maximum hourly vehicular volume that can pass through a Road element at the selected level of service for the facility. Refer to Chapter 2, Section 2.4.3.1, of the 2018 AASHTO GDHS for information on design service flow rates.

3.3 General Design Considerations

In the rural parts of Colorado, a Road may be a State Highway. In some instances, the Road can be the "main street" as it passes through a town. In this situation, the facility can transition from a Road to a Street facility type, which means there would be two sets of design criteria for the project—one for the rural context (C1 and C2) and one for the higher-density context that may have a mix of pedestrian, bicycle, and transit uses (C3 through C6). This needs to be acknowledged and discussed during project scoping and design.

Local agencies desiring to use federal funds must design projects to meet the design standards or the minimums presented in the 2018 AASHTO GDHS and in this Guide. The use of federal funds also requires that the National Environmental Policy Act (NEPA) process be followed. Historic districts require special consideration that may require consultation with the State Historic Preservation Office (SHPO).

3.4 Design Speed

Design speeds ranging from 25 to 45 mph are typically considered for a Road, depending on available right of way, terrain, adjacent development, and other area controls. When a Road is also a highway the design speeds could be as high as 65 mph. For new and reconstructed facilities, the designer should strive to design the segment to the appropriate standards to maintain the designated design speed. Refer to Table 5-1, Minimum Design Speeds for Roads, in the 2018 AASHTO GDHS to determine appropriate design speeds while considering traffic volumes and context.

A designer needs to recognize conditions when actual operating speeds may exceed the posted speed or even the design speed and consider those nuances in the overall design of a segment. For example, a rural Road (C1) with relatively low traffic volumes may create a sense of confidence in the driver to drive faster than the posted speed. Another common example is an older Road that may have terrain or a roadway curve that requires a design and posted speed below the general operating speed. The common practice is to post an advisory speed sign in advance of the varying terrain or curve to alert drivers to adjust to a lower safe operating speed if the design cannot easily accommodate the design speed for the corridor.

For new and reconstructed facilities, the designer should strive to design the Road segment to the appropriate standards to maintain the designated design speed. Refer to Table 5-1, Minimum Design Speeds for Roads, in the 2018 AASHTO GDHS to determine appropriate design speeds taking into consideration traffic volumes and terrain.

Designing a Road to too high a design speed may inadvertently become a barrier and/or increase crash potential for non-motorized uses, such as people and bicyclists, along the corridor. See Chapter 13 of this Guide for more information on the design of bicycle facilities.

When designing a Road, the surrounding natural and built environment can directly influence the design considerations for a specific Road segment. The designer needs to recognize how the physical setting will influence the design speed and consider what measures can be used to influence driver expectations to maintain appropriate speeds. For example, a driver will operate at the posted speed or faster if the Road is designed for 45 mph as a straight, two-lane Collector with 10-foot shoulders. When that same Road transitions from a Rural Places to Mountainous Environment context and begins to curve, a driver can enter a curve at too high a speed if traffic calming features are not considered.

The designer may use the current posted speed as a logical governing design criterion, but a better practice is to use performance-based practical design (PBPD). The designer can drive the road and observe what drivers are doing. It may also be appropriate to request a traffic and safety analysis to determine the 85th percentile speed and safety performance to determine if there are crash patterns to potentially mitigate.

3.5 Design Traffic Volume

Current and future traffic volumes are important design considerations. The basis of traffic design is to calculate the anticipated Design Hour Volume (DHV) of traffic projected to a future design year. During the planning stage of a project, the Region Traffic Engineer can provide current traffic volumes, predict future traffic volumes, and determine the future design year that is appropriate for the project. Design traffic volume should be estimated for at least 10 years, and preferably 20 years, from the date of completion of construction. A simple resurfacing project may only need a future DHV of 10 years, while a major rehabilitation or reconstruction project may require a future DHV of 20 years.

In determining the design traffic volume, it is important to understand the perceptions of the local community regarding traffic growth and congestion. In rural parts of Colorado, three cars stopped at an intersection may be perceived as congestion. The designer must consider the local context of the traffic impacts and determine if something can be done differently. Understanding the perception of traffic volumes and their impacts, no matter how large or small, helps to make the design context-sensitive and appreciated by the local users.

3.6 Level of Service

Understanding level of service (LOS) and how it impacts design must take several factors into consideration. Consider that a stop-controlled intersection on a Road may target a LOS C rather than an LOS D or LOS E for a signalized intersection. Discussions with the local traffic engineer and individuals who have a good working knowledge of the conditions at the project location can determine what an acceptable LOS target should be for the design.

Generally, the side friction of the road will meter traffic progression and speed that determine LOS. Traffic activity at an intersection is what most likely impacts overall LOS for a rural Road; therefore, the intersection LOS plays a more important role in the general traffic progression of a Road. Refer to the *Highway Capacity Manual* (TRB, 2022) for further information on LOS.

3.7 Multimodal Accommodations

Road facility types are more commonly found in rural areas where bicycle, pedestrian, and transit activities are less prevalent than on Street facility types. When there are multimodal activities, it may be related to recreation and/or tourism attractions where bicyclists, transit patrons, and pedestrians may be using a Road simultaneously.

3.7.1 Transit

While transit systems most commonly operate on Street facility types in medium to large cities, such as Grand Junction, Pueblo, Boulder, and Denver, they can also operate on a Road in more rural contexts. For example, the VelociRFTA Bus Rapid Transit, serving the Roaring Fork Valley, is the first rural bus rapid transit system in the nation. While most of the VelociRFTA route operates on Roads in a Rural Places (C2) context, it passes through several Downtown Places (C5) areas with Streets. The designer needs to coordinate with the local and regional agencies, such as school districts, cities, counties, and Metropolitan Planning Organizations, to identify where transit systems exist and where they may be planned in the future. This will help determine what accommodations need to be incorporated into the Road design.

The single largest public transit service in the state is the school bus system. It is important to coordinate with the local school district to identify whether a roadway is a school bus route, to identify the location of the bus stops, and to discuss roadway design that will make school pick-up and drop-off safe.

3.7.2 Bicycles

In Colorado, bicycles are considered a vehicle. They are allowed on most roadways but generally not on interstates unless there is no alternate route available. Colorado has 26 Scenic & Historic Byways, which are also popular bicycle routes on Roads in rural areas. The designer should investigate whether there are bicycle facilities on the Road and consult with local agencies to understand policies and plans related to current and to future bicycle infrastructure and accommodations.

Use this link to access information about Colorado's Scenic & Historic Byways: https://www.codot.gov/travel/colorado-byways

Use this link to access the Colorado Bicycle & Byways Map: https://www.codot.gov/programs/bikeped/information-for-bicyclists/colorado-bicycling-maps

Use this link to access the Colorado's High Demand Bicycle Corridors Map: https://www.codot.gov/programs/bikeped/high-demand-bicycle-corridors

Bicycle facility design is largely dependent on the physical surroundings (context classification) and functional classification, namely speed and motorized traffic volume; and preferred facilities vary by local or regional agencies. Often, agencies have plans and recommendations for facility types, but, if none exist, the CSS process can help determine the appropriate facility, using Chapter 13 of this Guide as a reference.

"Sharrow" markings can be used on Roads with restricted roadway width and posted speeds of 35 mph or less. Sharrows should be only used where no other alternative is possible to accommodate the bicycle activity. The use of sharrows could be appropriate where the Road is making its final transition from a Rural Places context to more urban environment. The appropriate use of a sharrow markings should be discussed with the Region Traffic Program.

3.7.3 Pedestrians

A Road in a C1 or C2 context classification typically does not have pedestrian activity, but the designer should exercise due diligence to identify if there are pedestrian trip generators and activity. If pedestrian activity is occurring, the designer needs to consider ways to make that activity safe, particularly on Roads with a higher functional classification where vehicular speeds tend to be higher. Refer to Chapter 13 of this Guide for more information on shared-use paths.

Crash histories show that pedestrians are most vulnerable at crossings, designers should consider street design elements that reduce pedestrian exposure at these locations.

Refer to Chapter 2, Section 2.6.1, of the 2018 AASHTO GDHS for more information. Refer to Section 3.8 for information on accessible design.

3.7.4 Motorized Vehicles

Motorized vehicles that typically use a Road include passenger vehicles, freight transport, agricultural equipment, school buses, interregional transit, industrial machinery, trash trucks etc.

Knowing the type of vehicles that commonly use a Road and the land uses they access impacts design decisions regarding lane widths, shoulder widths, turning radii, and stopping sight distance. Typically, passenger vehicles and light trucks are the starting point for vehicle design considerations on a Road. Design standards for larger vehicles can be used based upon the specific project area and the local business needs and the types of vehicles that use the Road.

3.8 Accessible Design

When designing improvements to a Road, the designer should determine if existing Americans with Disabilities Act (ADA) accommodations are to standard or if they need to be added or upgraded. ADA elements are unique to each location and require a level of design detail that cannot be short-cut. CDOT follows design and construction guidance and standards found in the U.S. Department of Transportation ADA Standards for Transportation Facilities (USDOT, 2006), the U.S. Department of Justice 2020 ADA Standards for Accessible Design (U.S. Department of Justice, 2020), Americans with Disabilities Act Architectural Guidelines for Buildings and Facilities (ADAAG) (U.S. Access Board, 2002), and the *Manual on Uniform Traffic Control Devices for Streets and Highways* (FHWA, [2009] 2022). In addition, CDOT adopted the Proposed Right-of-Way Accessibility Guidelines (PROWAG) for curb ramps, which also provides design guidance for sign heights and pedestrian pushbuttons for traffic signals (U.S. Access Board, 2011). The designer should evaluate innovative ways to shorten pedestrian crossings at intersections to provide the greatest safety to the pedestrian. If the intersection is signalized, PROWAG guidance is highly recommended to provide the highest level of ADA accommodations.

Refer to Chapter 12 of this Guide for information on CDOT's design standards for ADA accessibility and PROWAG related to curb ramps.

Refer to Chapter 2, Section 2.6.7, of the 2018 AASHTO GDHS for more information.

Use this link to access CDOT's ADA resources for engineers, including CDOT's ADA Transition Plan: https://www.codot.gov/business/civilrights/ada/resources-engineers

3.9 Access Control and Access Management

Access control and management is critical to maintaining a safe facility. When access is managed and controlled, there is a safer environment for the public. Refer to Chapter 2, Section 2.5.1, of the 2018 AASHTO GDHS, the State Highway Access Code (2 CCR 601-1) (State of Colorado, 2002), and Chapter 11 of this Guide for further information on access control and management.

3.10 Horizontal and Vertical Geometry

The horizontal and vertical design elements for a Road are determined by the surrounding environment and context classification.

The designer must fully consider what horizontal and vertical design elements for a Road are required within a given context classification. A residential Road in a C3 or C4 context classification may have curb and gutter, storm sewer, sidewalks, buffer areas, bike lanes, and on road parking. A Road in a C1 or C2 context classification may have travel lanes, shoulders, and roadside ditches. A forest service road may be gravel, in steeper terrain, and may include elements to ensure proper drainage, while minimizing erosion and environmental impacts. A county road may need shoulders, z-slope, and ditches to contain surface runoff from adjacent properties. The designer must fully consider the different design requirements within a given context classification, understanding that a project may be located in more than one context classification.

Intersections on a Road may require special design considerations for safety. In more rural environments, even though crashes may be infrequent, the severity of crashes may be elevated. Minor improvements can provide major safety benefits. Design considerations should include:

- Avoid locating intersections on steep profile grades.
- Avoid locating intersections just before or after a crest vertical curve.
- Avoid locating intersections within horizontal curves.
- Design intersection approaches to be as close to perpendicular with the major roadway as possible.
- Design with adequate corner radii for the design vehicle.
- Stopping sight distances.
- Intersection sight triangles.

Refer to Chapters 6, 7, and 8 of this Guide for additional information on design calculations and considerations for Roads.

3.11 Alignments

Road alignments should fit closely with the existing topography to minimize the need for cuts or fills. The alignment should not reduce safety but may be altered to serve a special purpose if desired by the local planning officials.

Road alignments in industrial areas (in C2 and C3) should take into account the topography but should be as direct as possible. The choice of alignment, cross section, and right of way width may be based on avoiding and minimizing construction impacts to adjacent property associated with hazardous waste or petroleum product contamination.

Curvature for a Road should be designed with a radius appropriate for the design vehicle, design speed, and intended superelevation. Superelevation of a Road with a higher design speed is not uncommon. However, the designer needs to consider winter driving conditions and the effects of reduced friction factors on a superelevated roadway due to winter icing conditions.

Refer to Chapter 6 of this Guide and Chapter 3, Section 3.3.3.3, of the 2018 AASHTO PGDHS for additional information on superelevation considerations.

3.12 Grades

Maximum grades for a Road are a function of terrain and design speed. Refer to Table 5-2 in the 2018 AASHTO GDHS.

There are locations where grades cannot meet the 2018 AASHTO GDHS standards, and a PBPD analysis of the current roadway operations, crashes, etc. may reveal that the current condition is acceptable. The analysis could also indicate hot spots where a problem exists. Using PBPD may help the designer to better determine where necessary improvements are needed and to better maximize the project budget to improve those hot spots.

The grade for a residential Road in a C3 classification should be as flat and consistent with the surrounding terrain as possible. When grades are 4% or steeper, drainage design to manage water velocity may become more of a factor in design. For a Road in an industrial area with truck traffic (C2 or C3), grades should be less than 8% and desirably less than 5%. For a Road that is a state highway, the grades can be as high as 10%. Ideally, the grades should be less than 7% for long descents. Long, steep grades are problematic for heavy trucks to descend safely. The designer should carefully consider descent grades where trucks commonly use a Road. Refer to Table 6-4 in Chapter 6 of this Guide for maximum grades.

To provide for drainage, the minimum preferred grade used for a Road with curbs is 0.30% but as flat as 0.20% may be used when sufficient drainage can be provided. Where bikeways are present, there may be specific grade requirements to accommodate bicycles.

Approach grades to intersections should be reduced to less than 8% to accommodate improved stopping distances and to improve vehicle starts to efficiently cross the intersection quickly and safely. This is also beneficial in areas where winter conditions are common.

3.13 Vertical Curves

Design controls for vertical sag and crest curves are provided in Table 5-3 (stopping sight distance) and Table 5-4 (passing sight distance) of the 2018 AASHTO GDHS. Criteria for measuring stopping sight distance include an eye height of 3.5 feet and an object height of 2.0 feet. Passing sight distance criteria include an eye height of 3.5 feet and the object height of 3.5 feet.

3.14 Cross Slope and Superelevation

The cross slope for a Road is dependent on the Road’s surface type, posted speed, and whether it has curb and gutter or shoulders and ditches. Cross slope can also be affected by topographic features. Adding superelevation to a Road may be necessary as the design speed increases.

Using PBPD principles may help to determine if superelevation is appropriate, as applied in the following scenario.

Example PBPD Application

A designer is considering whether superelevating a curve is warranted. The curve is not superelevated in the existing condition. The designer contacts the Region Traffic Representative with traffic engineering expertise in the area of Data Driven Safety Analysis (DDSA). The designer provides the Region Traffic Representative the estimated cost associated with superelevating the curve. The Region Traffic Representative examines the Road for the presence of correctable crash patterns and the potential for crash reduction at this specific curve location—if the curve is not superelevated versus if the curve were superelevated. This key analysis feeds into the benefit-cost analysis of the superelevated versus non-superelevated scenarios. The designer uses this analysis to inform the decision whether to superelevate the curve in conjunction with context-sensitive solutions (CSS) considerations and other factors.

Pavement cross slope should be adequate to provide proper drainage. A typical cross slope of 1.5% to 2.0% is acceptable for most paved roads. A steeper cross slope may be necessary for gravel or unpaved roadways. An example of a Road cross slope is shown in Figure 4-1 of the 2018 AASHTO GDHS. The designer should strive to maintain the same roadway cross slope on the shoulder.

Although superelevation is advantageous for traffic operations, such factors as wide pavements, abutting properties, drainage, intersections, and access points may make it impractical in more developed environments. Therefore, superelevation is not usually provided on low-speed and secondary Roads in residential and commercial areas (C2 or C3). It may need to be considered, however, in industrial areas (C2 or C3) or on a Road with operating speeds above 40 mph. A detailed discussion of superelevation is found in Chapter 6 of this Guide.

3.15 Cross Section Elements

Cross section elements of a Road (lane, shoulder, median, topographic impacts, parking, multimodal amenities, etc.) are varied and can be quite simple or complex. PBPD plays a key role in developing cross sections. Using good data analysis helps define the cross section elements that are needed and the widths that are appropriate to accommodate all users. Refer to Chapter 7 of this Guide for cross section elements.

When bicycle facilities are included as part of the design, refer to Chapter 13 of this Guide for bicycle facilities design, and refer to Chapter 12 of this Guide for accessible pedestrian design considerations.

3.16 Median Type

Medians on a low-speed Road are either raised or painted; justification is required to provide a continuous type median. Residential Roads (C2 or C3) rarely have medians. Roads that are state highways may have medians when there are passing lanes, auxiliary turn lanes, or an increased presence of accesses creating multiple turning movements on and off the highway. Median widths can vary from 4 feet to 20 or more feet. A raised median should be wide enough to accommodate the largest required signing width so that a sign does not extend beyond the median and become a striking hazard to vehicles. Median areas of 1 to 3 feet in width are considered" separators" or "dividers" and not medians and may not accommodate required sign widths.

3.17 Drainage

Proper drainage design minimizes high runoff and flooding potential. Drainage facilities, such as bridges, culverts, channels, curbs, gutter, and storm sewer systems, carry water across the right of way and are designed so that stormwater is removed from a Road surface.

The principal objective in drainage design is to control the presence and flow of water on a Road surface such that pedestrians, bicyclists, and vehicles are not placed in an unsafe situation during storm events.

It is desirable to use a minimum crown slope of 2.0% (0.02 foot/foot), particularly where the surrounding terrain is relatively flat. This reduces ponding areas that can contribute to deterioration of pavement and create safety problems. For additional information, refer to the CDOT *Drainage Design Manual* (CDOT, 2019).

Drainage requirements for a Road vary depending upon the context classification. County Roads and Roads in a C1, C2, or C3 classification may have a shoulder and a ditch that collects sheet flow off the Road. In this instance, drainage facilities need to accommodate runoff from the Road and the water that is intercepted by the ditch from adjacent properties. If a Road intercepts runoff from a specific drainage basin, the designer needs to ensure that the runoff makes its way back to the drainage basin it originated in. Diverting drainage away from a basin should be avoided as much as possible.

3.18 Pedestrian Facilities

Pedestrian facility design is largely dependent on the physical surroundings (context) and functional classification, namely speed and motorized traffic volume, and preferred facilities vary by local agency. Often, local agencies have plans and recommendations for facility types. If none exist, the CSS process can help determine the appropriate facility, using Chapter 13 of this Guide.

Pedestrian curb ramps must be compliant with PROWAG (U.S. Access Board, 2011). Other pedestrian facilities must be compliant with Americans with Disabilities Act Architectural Guidelines for Buildings and Facilities (ADAAG) (U.S. Access Board, 2002). Refer to Chapter 12 of this Guide for accessible pedestrian design.

3.19 Bicycle Facilities

Bicycle facility design is largely dependent on the physical surroundings (context) and functional classification, namely speed and motorized traffic volume, and preferred facilities vary by local agency. Often, local agencies have plans and recommendations for facility types. If none exist, the CSS process can help determine the appropriate facility using Chapter 13 of this Guide.

When bicycle facilities are also pedestrian facilities, such as shared-use paths, they must be compliant with PROWAG (U.S. Access Board, 2011). Refer to Chapter 12 of this Guide for accessible pedestrian design.

3.20 Transit Facilities

Transit facilities are becoming more common on Roads in both rural and urban settings. If there is a transit route or a school bus route with stops within the project limits, the designer needs to determine if there is adequate space within the Road cross section at the stops to accommodate the safe loading and unloading of passengers without impeding through vehicles.

Chapter 4
Facility Type - Street

Legend

	Multimodal Application Example
	Context-Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context-Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO-Specific Information

Chapter

4

4 Facility Type – Street

Street
Context Classifications: C3 Suburban Places, C4 Traditional Neighborhoods, C5 Downtown Places, C6 Urban Cores.
A facility generally characterized by the inclusion of curb and gutter, sidewalks, and storm sewers in more urban contexts that may include on-street parking, bike lanes, and transit stops.

4.1 Introduction

The guidelines in this chapter apply to facilities defined as Streets, consistent with the definitions in Chapter 1 of this Guide and Chapter 5 of the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (the Green Book) (2018 AASHTO GDHS) (AASHTO, 2018). Guidelines for Roads and Freeways, Expressways, and Interstates are described in Chapters 3 and 5, respectively.

A Street facility type (Street) is typically found in higher-density areas, such as Suburban Places, Traditional Neighborhoods, Downtown Places, and Urban Cores context classifications. They are characterized by curb, gutter, storm sewers, bicycle and pedestrian accommodations, and transit uses; and have higher access frequency to the street. A Street can be any functional classification—Arterial, Collector Road and Street, or Local Road and Street.

Refer to Chapter 1 of this Guide for definitions of functional classifications, facility types, and context classifications that are used in this chapter.

Use this link to access CDOT's Roadway Functional Classification Guidance Manual (CDOT, 2019): *https://www.codot.gov/business/designsupport/bulletins_manuals/cdot-roadway-design-guide-2018/2018-rev-rdg/dg18-01-revs*

4.2 Highway Capacity (Transportation Facility Operations)

4.2.1 Highway Capacity Manual

When a Street is being scoped for improvements, the designer needs to know current and projected traffic volumes and level of service (LOS) for the future design year. A 20-year capacity design project for what is a Street in current year might need to be designed as a Road facility type with fewer lanes in the future year if there are projected traffic volume decreases and higher levels of service.

4.2.2 Factors Other Than Traffic Volume That Affect Operating Conditions

There are many factors that can affect the operating conditions of a Street. Some examples the designer should consider are:

- Design speed of the existing road.
- Weaving sections of the road.
- Intersection type or types.
- Number of side road accesses.
- Vertical and horizontal sight distances.
- Bicycle and pedestrian usage and crossings.
- Mixture of vehicle types using the road.

Refer to Chapter 2, Section 2.4.4, of the 2018 AASHTO GDHS for information on these factors.

4.2.3 Measures of Multimodal Connectivity

In the C3 through C6 context classifications, it is important to provide a variety of practical and efficient mobility options. In some cases, local agencies may choose to prioritize modes other than single-occupancy vehicles to achieve congestion reduction and environmental goals. Designers should consult local, regional, and state plans when working in these context classifications to understand transportation goals for an area and to include bicycle, pedestrian, and transit infrastructure where appropriate. A few references for how to include multimodal elements in a street facility are provided below.

Use this link to access the FHWA Bikeway Selection Guide:
https://safety.fhwa.dot.gov/ped_bike/tools_solve/docs/fhwasa18077.pd

Use this link to access the U.S. Access Board (Proposed) Public Rights-of-Way Accessibility Guidelines (PROWAG) for ADA and ABA accessibility:
https://www.access-board.gov/prowag

Use this link to access the NACTO design guides for pedestrian, bicycle, and transit street designs: https://nacto.org/publications/

4.2.4 Design Service Flow Rates

In general, the design service flow rate is defined as, the maximum hourly vehicular volume that can pass through a Street element at the selected level of service for the facility. Refer to Chapter 2, Section 2.4.3.1, of the 2018 AASHTO GDHS for information on design service flow rates.

4.3 General Design Considerations

Local agencies desiring to use federal funds must design projects to meet or exceed the design standards or the minimums presented in the 2018 AASHTO GDHS and in this Guide. The use of federal funds also requires that the National Environmental Policy Act (NEPA) process be followed. Historic districts also require special consideration that may require consultation with the State Historic Preservation office.

4.4 Design Speed

Design speeds ranging from 25 to 45 mph are typically considered for a Street, depending on available right of way, terrain, adjacent development, and other area controls. When a Street is also a Principal Arterial, the design speeds could be as high as 50 or 55 mph. For new and reconstructed facilities, the designer should strive to design the street segment to the appropriate standards to maintain the designated design speed. Refer to Table 5-1, Minimum Design Speeds for Roads in the 2018 AASHTO GDHS to determine appropriate design speeds while considering traffic volumes and terrain.

Designing a Street at a higher design speed may inadvertently become a barrier and/or increase crash potential for non-motorized uses, such as pedestrians and bicyclists. See Chapter 13 of this Guide for more information on pedestrian and bicycle design.

The surrounding natural and built environment can directly influence the design considerations for a specific Street segment. The designer needs to recognize how the physical setting will influence the design speed and consider what measures can be used to influence driver expectations to maintain appropriate speeds. For example, a Major Collector Street in a C3 context classification may have single family housing on one side and a small strip mall on the other side. It may have different design speed requirements than a Major Collector Street in a C5 context classification adjacent to store fronts and on-street parking.

The designer may use the current posted speed as a logical governing design criterion, but a better practice is to use performance-based practical design (PBPD). The designer can drive the street and observe driver behaviors to influence their design decisions. It may also be appropriate to request a traffic and safety analysis to determine the 85th percentile speed and safety performance to determine if there are crash patterns to potentially mitigate.

4.5 Design Traffic Volume

Current and future traffic volumes are important design considerations. The basis of traffic design is to calculate the anticipated Design Hour Volume (DHV) of traffic projected to a future design year. During the planning stage of a project, the Region Traffic Engineer can provide current traffic volumes, predict future traffic volumes, and determine the future design year that is appropriate for the project. Design traffic volume should be estimated for at least 10 years, and preferably 20 years, from the date of completion of construction. A simple resurfacing project may only need a future DHV of 10 years, while a major rehabilitation or reconstruction project may require a DHV of 20 years.

In determining the design traffic volume, it is important to understand the perceptions of the local community regarding traffic growth and congestion. In rural parts of Colorado, three cars stopped at a street intersection may be perceived as congestion, while in a more urban area, it would be expected and not questioned. The designer must consider the local context of the traffic impacts and determine if something can be done differently. Understanding the perception of traffic volumes and their impacts, no matter how large or small, helps to make the design context-sensitive and appreciated by the local users.

4.6 Level of Service

Understanding level of service (LOS) and how it impacts design must take several factors into consideration. Consider that a stop-controlled intersection on a street may target a LOS C rather than an LOS D or E for a signalized intersection. Discussions with the local traffic engineer and individuals who have a good working knowledge of the roadways and conditions at the project location can determine what an acceptable LOS target should be for the design. Refer to the *Highway Capacity Manual* (TRB, 2022) for further information on LOS.

4.7 Multimodal Accommodations

Street facility types are more commonly found in higher-density areas where alternative modes of travel are more prevalent in the transportation system and where local agencies may have bicycle, pedestrian, and/or transit plans and goals. The designer should consider these multimodal visions and how they may influence the design of a Street.

4.7.1 Transit

While transit systems most commonly operate on Street facility types in medium to large cities, such as Grand Junction, Pueblo, Boulder, and Denver, they can also operate on a Road in more rural contexts. For example, the VelociRFTA Bus Rapid Transit, serving the Roaring Fork Valley, is the first rural bus rapid transit system in the nation. While most of the VelociRFTA route operates on Roads in a Rural Places (C2) context, it passes through several Downtown Places (C5) areas with Streets. The designer needs to coordinate with the local and regional agencies, such as school districts, cities, counties, and Metropolitan Planning Organizations, to identify where transit systems exist and where they may be planned in the future. This will help determine what accommodations need to be incorporated into the Road design.

4.7.2 Bicycles

In Colorado, bicycles are considered a vehicle and are allowed on most roadways but generally not on interstates unless there is no alternate route available. The designer should investigate the level of bicycle activity and consult with local agencies to understand policies and plans related to current and proposed bicycle infrastructure and accommodations. Furthermore, bicycles may play a role in reducing greenhouse gas emissions, reducing congestion, and improving public health; and the right design can eliminate barriers making bicycling a preferred mode choice for a greater number of travelers.

Bicycle facility design is largely dependent on the physical surroundings (context classification) and functional classification, namely speed and motorized traffic volume; and preferred facilities vary by local or regional agencies. Often, agencies have plans and recommendations for facility types, but, if none exist, the CSS process can help determine the appropriate facility, using Chapter 13 of this Guide as a reference.

“Sharrow” markings can be used on Streets with restricted streetway width and posted speeds of 35mph or less. Sharrows should be only used where no other alternative is possible to accommodate the bicycle activity. The use of sharrows could be appropriate where the Street is making its final transition from a Rural Places context to more urban environment. The appropriate use of a sharrow markings should be discussed with the Region Traffic Program.

4.7.3 Pedestrians

A differentiating characteristic of a Street facility type is that it is located in areas where there is higher residential and business density, so pedestrian activity is expected. Because crash histories show that pedestrians are most vulnerable at crossings, designers should consider street design elements that reduce pedestrian exposure at these locations.

Refer to Chapter 2, Section 2.6.1, of the 2018 AASHTO GDHS for more information. Refer to Section 4.8 for information on accessible design.

4.7.4 Motorized Vehicles

Knowing the type of vehicles that commonly use a Street and the land uses they access impacts decisions regarding lane widths, shoulder widths, turning radii, and stopping sight distance. Typical land uses adjacent to a Street, such as an industrial park, maintenance facility, or waste transfer facility, indicate the type of vehicles that use the Street. Typically, passenger and transit vehicles and box trucks should be the starting point for vehicle design considerations on a Street. Larger vehicle design standards may be required based upon the local business needs and the types of vehicles that use the Street.

PBPD principles can be used to consider trade-offs in the design process. For example, a design solution might be a tighter radius to reduce pedestrian crossing distances and conflicts by allowing vehicle tracking to encroach into an adjacent lane, or it might be a wider right turn lane to allow off tracking from the curb to avoid jumping the curb. Knowing the frequency of use and size of vehicle using an intersection helps the designer to optimize the curb radius for all users.

4.8 Accessible Design

When designing improvements to a Street, the designer should determine if current Americans with Disabilities Act (ADA) accommodations are to standard or if they need to be added or upgraded. ADA elements are unique to each location and require a level of design detail that cannot be short-cut. CDOT follows design and construction guidance and standards found in the U.S. Department of Transportation ADA Standards for Transportation Facilities (USDOT, 2006), the U.S. Department of Justice 2020 ADA Standards for Accessible Design (U.S. Department of Justice, 2020), Americans with Disabilities Act Architectural Guidelines for Buildings and Facilities (ADAAG) (U.S. Access Board, 2002), and the *Manual on Uniform Traffic Control Devices for Streets and Highways* (FHWA, [2009] 2022). In addition, CDOT adopted the Proposed Right-of-Way Accessibility Guidelines (PROWAG) for curb ramps, which also provides design guidance for sign heights and pedestrian pushbuttons for traffic signals (U.S. Access Board, 2011). The designer should evaluate innovative ways to shorten pedestrian crossings at intersections to provide the greatest safety to the pedestrian. If the intersection is signalized, PROWAG guidance is highly recommended to provide the highest level of ADA accommodations.

Refer to Chapter 12 of this Guide for information on CDOT's design standards for ADA accessibility and PROWAG related to curb ramps.

Refer to Chapter 2, Section 2.6.7 of the 2018 AASHTO GDHS for more information.

Use this link to access CDOT's ADA resources for engineers:
https://www.codot.gov/business/civilrights/ada/resources-engineers

4.9 Access Control and Access Management

Access control and management is critical to maintaining a safe facility. When access is managed and controlled, there is a safer environment for the public. Refer to Chapter 2, Section 2.5.1, of the 2018 AASHTO GDHS, the State Highway Access Code (2 CCR 601-1) (State of Colorado, 2002), and Chapter 11 of this Guide for further information on access control and management.

4.10 Horizontal and Vertical Geometry

The horizontal and vertical design elements for a Street are determined by the surrounding environment and context classification. A Street in C4 context classification may have bike lanes and on street parking to consider. In a C6 context classification, there may be tall buildings that cast shadows, exacerbating roadway icing in the winter.

Intersections on a Street may need special design considerations for safety as many modes may be present, each having unique considerations. Minor improvements can provide major safety benefits. Considerations should include:

- Avoid locating intersections on steep profile grades.
- Avoid locating intersections just before or after a crest vertical curve.
- Avoid locating intersections within horizontal curves.
- Try to minimize access openings that are too close to the intersection and within any auxiliary lanes.
- Designing intersection approaches to be as close to perpendicular with the major roadway as possible.
- Design with adequate corner radii and intersection sight distance.

4.11 Alignments

Street alignments should fit closely with the existing topography to minimize the need for cuts or fills. The alignment should not reduce safety but may be altered to serve a special purpose if desired by the local planning officials.

Street alignments in commercial and industrial areas (in C3, C4, C5, and C6) should consider the topography but should be as direct as possible. The choice of alignment, cross section, and right of way width may be based on avoiding and minimizing construction impacts to adjacent properties and properties associated with hazardous waste or petroleum product contamination.

Refer to Chapter 6 of this Guide and Chapter 3, Section 3.3.4, in the 2018 AASHTO GDHS for additional information on superelevation considerations.

4.12 Grades

Maximum grades for a Street are a function of terrain and design speed. Refer to Table 5-2 in the 2018 AASHTO GDHS.

There are locations where grades cannot meet the 2018 AASHTO GDHS standards, and a PBPD analysis of the current roadway operations, crashes, etc. may reveal that the current condition is acceptable. The analysis could also indicate hot spots where a problem exists. Using PBPD may help the designer to better determine where necessary improvements are needed and to better maximize the project budget to improve those hot spots.

The grade for a residential Street should be as flat as the surrounding terrain and topography permit. When grades are 4% or steeper, drainage design may become critical. Steep grades can create elevated runoff velocities. Faster-moving runoff requires larger storm water inlets to capture the water. In curves or at curb cuts, the water can leave the curb pan and scour or flood properties adjacent to the Street. For a Street in an industrial area (with truck traffic) (C3, C4, C5, or C6), grades should be less than 8% and desirably less than 5%. The designer should carefully consider descent grades where trucks will be commonly using a Street. Refer to Table 6-4 in Chapter 6 of this Guide for maximum grades.

To provide for drainage, the minimum preferred profile grade used for a Street with curbs is generally 0.30%, but can be as flat as 0.20% when sufficient drainage can be provided. Where bikeways are present, there may be specific grade requirements to accommodate bicycles.

Approach grades to intersections should be reduced to less than 8% to accommodate improved stopping distances and to improve vehicle starts to efficiently cross the intersection quickly and safely. This is also beneficial in areas where winter conditions are common.

4.13 Vertical Curves

Design control for vertical sag and crest curves are provided in Table 5-3 (stopping sight distance) and Table 5-4 (passing sight distance) of the 2018 AASHTO GDHS. Criteria for measuring stopping sight distance include an eye height of 3.5 feet and an object height of 2.0 feet. Passing sight distance criteria include an eye height of 3.5 feet and the object height of 3.5 feet.

4.14 Cross Slope and Superelevation

The cross-slope for a Street is dependent on the Street's surface type, posted speed, and whether it has curb and gutter or shoulders and ditches. Typically, a cross-slope of 2% may be appropriate for a Street with a paved surface, but for a gravel Street, a steeper cross-slope may be necessary. Cross-slope can also be affected by topographic features. Adding superelevation to streets maybe necessary as the design speed increases. Using PDPB principles may help to determine if superelevation is necessary. Pavement cross slope should be adequate to provide proper drainage.

Although superelevation is advantageous for traffic operations, such factors as wide pavements, abutting properties, drainage, intersections, and access points may make it impractical in more developed environments. Therefore, superelevation is not usually provided on low-speed Streets in residential and commercial areas. It should be considered in industrial areas or Streets where operating speeds are above 40 mph. A maximum superelevation of 4% to 6% is commonly used. A detailed discussion of superelevation is found in Chapter 6 of this Guide.

4.15 Cross Section Elements

Cross section elements of a Street (lane, shoulder, median, topographic impacts, parking, multimodal amenities, etc.) are varied and can be quite simple or complex. PBPD plays a key role in developing cross sections. Using good data analysis for the roadway helps define the cross section elements and the widths that are appropriate to accommodate all users. Refer to Chapter 7 of this Guide for cross section elements.

When bicycle and/or pedestrian facilities are included as part of the design, refer to Chapter 13 of this Guide for bicycle facilities design, and refer to Chapter 12 of this Guide for accessible pedestrian design considerations.

4.16 Median Type

Medians on a low-speed Street are either raised or painted. Median widths can vary from 4 feet to 20 or more feet depending upon the specific Street. Raised median widths should be designed to accommodate required signing widths. On a Street, median areas of 1 to 3 feet in width are considered" separators" or "dividers" and not medians, and they may not accommodate required sign widths. A sign may extend beyond the raised median and be a striking hazard to large vehicles. Raised medians can be used for access control on a Street.

CSS Application Example

Medians of sufficient width will provide refuge at pedestrian crossings allowing the pedestrian to focus on traffic from one direction to reach the median refuge and to safely prepare for the other direction of travel before completing the crossing. An appropriately sized median can provide safe refuge for pedestrians and bicyclists on large crossings along busy corridors.

4.17 Drainage

Proper drainage design minimizes high runoff and flooding potential. Drainage facilities, such as bridges, culverts, channels, curbs, gutter, and storm sewer systems, are designed to carry water across the right of way and are designed so that stormwater is removed from a Street surface.

The principal objective in drainage design is to control the presence and flow of water on a Street surface such that pedestrians, bicyclists, and vehicles are not placed in an unsafe situation during storm events.

It is desirable to use a minimum crown slope of 2.0% (0.02 foot/foot), particularly where the surrounding terrain is relatively flat. This reduces ponding areas that can contribute to deterioration of pavements and create safety problems. For additional information, refer to the CDOT *Drainage Design Manual* (CDOT, 2019).

4.18 Pedestrian Facilities

Pedestrian facility design is largely dependent on the physical surroundings (context) and functional classification, namely speed and motorized traffic volume, and preferred facilities vary by local agency. Often, local agencies have plans and recommendations for facility types. If none exist, the CSS process can help determine the appropriate facility, using Chapter 13 of this Guide.

Pedestrian facilities must be compliant with PROWAG (U.S. Access Board, 2011). Refer to Chapter 12 of this Guide for accessible pedestrian design.

4.19 Bicycle Facilities

Bicycle facility design is largely dependent on the physical surroundings (context) and functional classification, namely speed and motorized traffic volume, and preferred facilities vary by local agency. Often, local agencies have plans and recommendations for facility types. If none exist, the CSS process can help determine the appropriate facility using Chapter 13 of this Guide.

When bicycle facilities are also pedestrian facilities, such as shared-use paths, they must be compliant with PROWAG (U.S. Access Board, 2011). Refer to Chapter 12 of this Guide for accessible pedestrian design.

4.20 Transit Facilities

Transit facilities, such as bus stops, mobility hubs (bus, parking, and train hubs), and bus rapid transit lanes are common in urban areas where Street systems are prominent. The designer should communicate early in the scoping development with the local transit agencies to identify if there are transit routes, bus stops, or multimodal hubs within or near the project limits. When present or planned, the designer should consider if improvements or additional accommodations are needed to facilitate safer pedestrian, bike, bus, and vehicle access to the facilities and incorporate them into the design.

4.21 Sidewalks

Sidewalks should be provided along both sides of a Street in commercial areas and when they are used for pedestrian access to schools, parks, shopping areas, and transit stops. In residential areas, it is desirable to have sidewalks on both sides of a Street, but can be provided on at least one side. Sidewalks may be considered as an addition to a Street in rural areas, and should be separated from the Street. The preferred cross slope for sidewalks should be 2% or less, be gentle enough to accommodate ADA accessibility, and slope toward the Street.

Where practical, the sidewalk should be separated from the edge of traveled way. The principal reasons for doing this are:

- Greater separation of pedestrians from moving traffic provides a more comfortable pedestrian experience.
- An area for placement of street hardware and traffic signs that does not interfere with pedestrian traffic.
- A location for landscaping.
- A location for placing removed snow.

Maintenance of the area between curb and sidewalk can be difficult, and some jurisdictions may desire to eliminate the area in favor of additional sidewalk width. The designer should coordinate with local agencies for maintenance outside of the back of curb.

Clear sidewalk width should be an absolute minimum of 4 feet; 5 feet is desirable. If a continuous sidewalk has a width of 4 feet, a minimum 5-foot by 5-foot passing space needs to be provided at 200-foot intervals for ADA accessibility. Sidewalk widths of 8 feet or greater may be needed in commercial areas. If roadside appurtenances are situated on the sidewalk adjacent to the curb, additional width is required to secure a minimum clear width of 4 feet.

Chapter 5
Facility Type - Freeway, Expressway, and Interstate

Legend

	Multimodal Application Example
	Context-Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context-Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO-Specific Information

Chapter

5

5 Facility Type – Freeway, Expressway, and Interstate

Freeway, Expressway, and Interstate

Context Classifications: C1 Rural Mountainous Environment, C2 Rural Places, C3 Suburban Places, C4 Traditional Neighborhoods, C5 Downtown Places, C6 Urban Core.

A facility generally described as a Major Arterial that has strict access controls. Access to a Freeway, Expressway, or Interstate is managed at specific locations that are sufficiently spaced apart to facilitate effective free-flow travel along these roadways. Freeways and Interstates only have grade-separated intersections from a Major Arterial; Expressways can have either at-grade or grade-separated intersections.

5.1 Introduction

The guidelines in this chapter apply to facilities defined as Freeways, Expressways, and Interstates, consistent with the definitions in Chapter 1 of this Guide and Chapter 8 of the American Association of State Highway and Transportation Officials (AASHTO) A Policy on Geometric Design of Highways and Streets (the Green Book) (2018 AASHTO GDHS) (AASHTO, 2018).

The use of the term "Freeway" in this chapter applies to Freeways, Expressways, or Interstates.

The functional classification for existing facilities in Colorado is already defined and can be found on the Colorado Department of Transportation (CDOT) Online Transportation Information System (OTIS) (CDOT, n.d.). Detailed information about functional classifications in the *CDOT Roadway Functional Classification Guidance Manual* (CDOT, 2019). Refer to Chapter 1 of this Guide for definitions of functional classifications, facility types, and context classifications that are used in this chapter.

Use this link to access CDOT's Roadway Functional Classification Guidance Manual (CDOT, 2019): *https://www.codot.gov/business/designsupport/bulletins_manuals/cdot-roadway-design-guide-2018/2018-rev-rdg/dg18-01-revs*

A Freeway or Interstate is a divided highway with full control of access and two or more through lanes for the exclusive use of traffic in each direction. Traffic flow on a Freeway is unhindered because there are no traffic signals, intersections, or at grade crossings with other roads, railways, or multiuse paths. A helpful concept to commit to memory is that a Freeway and Interstate is "free" of at-grade crossings or intersections that are not part of an interchange design. Full control of access is the condition where the right of owners or occupants of abutting land to access a Freeway is fully controlled by a public authority. Access connections to a Freeway are at selected public roads only. Crossings at grade or direct private driveway connections are prohibited. For more information on Freeway access, refer to the Colorado State Highway Access Code (State of Colorado, 2002).

Use this link to access the Colorado State Access Code (State of Colorado, 2012): *https://www.codot.gov/business/permits/accesspermits/references/601_1_accesscode_march2002_.pdf/view*

The guidelines in this chapter apply to Freeways in all context classifications (C1, C2, C3 C4, C5, and C6). They apply to both urban and rural Freeways, except where noted. Essential Freeway elements include medians; grade separations; ramps; and in some cases, frontage or collector roads.

5.2 Rural Freeway, Expressway, and Interstate

5.2.1 Alignment and Profile

A rural Freeway should have smooth-flowing horizontal and vertical alignments. Consistent typical sections along a Freeway enhance driver expectations, resulting in a safer Freeway. Changing median widths should be avoided where practical.

A rural Freeway can usually be constructed near ground level with a smooth and relatively flat profile. The profile of a Freeway in a rural context classification is controlled more by drainage and earthwork considerations and less by the need for frequent grade separations and interchanges. In mountainous areas, topographic elements, such as rivers and terrain, have a greater impact on Freeway design.

5.2.2 Medians

Median widths of 30 to 100 feet are common on a rural Freeway. A median should provide a minimum of 6-foot paved shoulders and 6:1 foreslopes with a recoverable median ditch that is designed to prevent saturation of the roadway substructure and can adequately manage the surface runoff from the Freeway section until the water can be conveyed away the median area. A wider median accommodates independent profiles in rolling terrain to blend a Freeway more appropriately with the environment while maintaining flat slopes for vehicle recovery. In flat terrain, a wider median is also suitable when designing for the future addition of traffic lanes.

Where the terrain is extremely rolling or mountainous, a wide variable median may be desirable. When geographic constraints prohibit use of a wide median, independent roadway alignments, both horizontally and vertically, may provide the best opportunity to blend a Freeway into the natural topography. Proper foreslopes and backslopes used within the clear zone can accommodate safe vehicle recovery. The remaining median width, outside of the clear zone, may be left in its natural state of vegetation, trees, and rock outcroppings. In areas where right of way restrictions dictate, or in extreme terrain, narrower median widths with barriers may be necessary.

In some context classifications, such as C1 and C2, large Freeway rights-of-way can provide opportunity for bicycle facilities. The designer should determine nearby facilities and potential gaps caused by the Freeway facility.

Emergency crossovers on a rural Freeway are normally provided where interchange spacing exceeds 5 miles. Between interchanges, emergency crossovers are spaced at 3- to 4-mile intervals. Maintenance crossovers may be required at one or both ends of interchange facilities for snow removal and at other locations to facilitate maintenance operations. Crossovers should not be located closer than 1,500 feet to the end of a speed-change taper of a ramp or to any structure. Crossover foreslopes shall be no steeper than 10:1. Crossovers should be located where minimum stopping sight distance can be provided in both directions and preferably should not be located within curves.

The width of the crossover should be sufficient to provide vehicle storage out of the traveled way and safe turning movements; and the crossover should have a surface capable of supporting the maintenance equipment used on it. Crossovers should not be placed in restricted-width medians unless the median width is sufficient to safely accommodate a vehicle length of 25 feet or more.

Installation of median cable rail should be considered wherever possible to prevent vehicles from crossing medians into opposing traffic lanes or to contain roadside departures.

Use this link to access the CDOT Cable Barrier Guide (CDOT, 2017): [*https://www.codot.gov/business/designsupport/bulletins_manuals/cable-barrier-guide/cable-barrier-guide*](https://www.codot.gov/business/designsupport/bulletins_manuals/cable-barrier-guide/cable-barrier-guide)

For further information on medians, refer to the AASHTO *Roadside Design Guide* (AASHTO, 2011).

5.2.3 Sideslopes

Flat or rounded sideslopes, fitting with the topography and consistent with available right of way, should be provided on a rural Freeway. Foreslopes of 6:1 or flatter are recommended in cut sections and for fills of moderate height. Where fill heights are intermediate, a combination of recoverable and traversable slopes may be used to provide the acceptable vehicle recovery area. For high fills, steeper slopes protected by guardrail may be necessary. It is preferred to have backslopes of 3:1 or flatter to accommodate better slope stability, landscaping, and erosion control practices and for ease of maintenance operations.

5.2.4 Frontage Roads

Refer to the 2018 AASHTO GDHS.

5.3 Urban Freeway, Expressway, and Interstate

5.3.1 Alignments

An appropriate balance of vertical and horizontal alignments will create an easily understood facility for the user to navigate and optimizing the construction costs to make the roadway economically feasible.

Refer to Chapter 3, Section 3.5.2, of the 2018 AASHTO GDHS for information on General Design Controls including alignments.

5.3.2 Medians

The desirable median width for a four-lane urban Freeway is 14 feet or greater. A 14-foot median accommodates two 6-foot paved shoulders and a 2-foot median barrier. Additional horizontal clearance may be required to provide minimum stopping sight distance along the inside lane on sharper curves. A desirable feature is a wider clearance area for vehicle storage in case of a vehicle break down.

A wide median width can be used for the addition of Bus Rapid Transit (BRT) lanes, High Occupancy Vehicle (HOV) lanes, or Managed Lanes. In addition to HOV lanes, Express Lanes and Peak Period Shoulder Lanes (PPSL) are examples of Managed Lanes in Colorado.

Median crossovers for emergency or maintenance purposes are generally not warranted on urban Freeways because of the close spacing of interchange facilities, extensive development of the abutting street network, and a desire to prevent vehicles from making u-turns on the Freeway.

Considering the needs of the users within an urban area and how they travel from location to location, including travel modes, is critical to determining the capacity expansion of a Freeway system. Using the principles of Context-Sensitive Solutions (CSS) to engage the public to identify their needs, identifies ways to accommodate travel modes that are most effective for all users.

BRT lanes, HOV lanes, and multimodal transit stops (mobility hubs) are often integrated with Freeway, Expressway, and Interstate operations to promote faster more consistent travel for alternative modes of transportation. Integrating these alternative transportation options increases the efficiency of the transportation system when expanding the facilities is not feasible or cost-effective.

5.4 Highway Capacity (Transportation Facility Operations)

5.4.1 Highway Capacity Manual

Freeways typically have uninterrupted traffic flows. Considerations for Freeway capacity include lane capacity for efficient vehicle passage based on average daily traffic and peak hour traffic volumes, as well as current and future traffic volumes 20 or more years into the future.

Access or cross-street activity on a Freeway is often accomplished with grade-separated interchanges. Cross section widths and lane capacity must be closely coordinated with interchange design, so the structures can adequately accommodate existing and future traffic volumes.

Adequate intersection capacity at an interchange prevents traffic queues at the intersection from backing onto a Freeway. Backups onto a through lane create safety issues, such as speed differentials and unanticipated congestion on a Freeway, which can result in primary and secondary traffic crashes.

Refer to Chapter 2, Section 2.4, of the 2018 AASHTO GDHS for information on Freeway capacity.

5.4.2 Rural Freeway Capacity

In a rural setting, a driver has different expectations about the Freeway capacity than in an urban setting. In a rural setting, a driver is typically traveling for a long period of time over longer distances, and the expectation is to travel nearly unimpeded with little or no traffic congestion, maintaining a constant travel speed at or near the design speed for the Freeway. For these reasons, rural Freeway design capacity tends to target a level of service (LOS) of C (stable flow rate) or better.

Refer to Chapter 2, Section 2.4.5, of the 2018 AASHTO GDHS for information on Levels of Service.

5.4.3 Urban Freeway Capacity

In an urban setting, a driver has a higher tolerance level for congestion if the trip is faster than on the local street system. A certain level of congestion is acceptable if a constant flow of traffic is maintained with only infrequent stop and go traffic conditions.

Depending upon the existing level of congestion, urban Freeway capacity may be designed to a future condition of LOS D or E. LOS D (approaching unstable flow) is the desired operational goal for a future design year of 20 years or more. If the cost of construction to achieve LOS D is prohibitive, designing to an LOS E may be necessary and is acceptable.

5.4.4 Factors Other Than Traffic Volume That Affect Operating Conditions

Refer to Chapter 2, Section 2.4.4, of the 2018 AASHTO GDHS for information on these factors.

5.4.5 Transit

With the increased emphasis on promoting alternative modes of travel, Freeway design should consider transit in a capacity analysis. If transit exists or is planned, Freeway access to transit and multimodal hubs must be designed for easy access. Guidance on how to accommodate transit activity is contained in the NACTO *Transit Street Design Guide* (NACTO, n.d.).

Use this link to access NACTO Transit Street Design Guide (NACTO, n.d.): https://nacto.org/publication/transit-street-design-guide/transit-system-strategies/

5.4.6 Design Service Flow Rates

In general, the design service flow rate is defined as, the maximum hourly vehicular volume that can pass through a Freeway element at the selected LOS for the facility. Refer to Chapter 2, Section 2.4.3.1 of the 2018 AASHTO GDHS for information on design service flow rates.

5.5 General Design Considerations

Local agencies desiring to use federal funds must design projects to meet or exceed the design standards or the minimums presented in the 2018 AASHTO GDHS and in this design guide. The use of federal funds requires that the National Environmental Policy Act (NEPA) process be followed. Historic districts require special consideration that may require consultation with the State Historic Preservation Office (SHPO).

5.6 Design Speed

Design speeds ranging from 55 to 75 mph are typically considered for a Freeway, depending on available right of way, terrain, adjacent development, and other area controls.

Freeway and interstate design speed is the prevailing speed a driver chooses under low-volume conditions when the interaction between vehicles and the influence of traffic control devices is minimal. Freeways must be designed so that the desired posted speed can be maintained in a free-flow condition. Access movements and congestion can interrupt the free-flow condition. These can be avoided through the design of roadway geometry, traffic operations, grade separated intersections, as well as median type, access point density, number of lanes, lane width, and segment length.

Designers need to recognize conditions where actual operating speeds may exceed the posted speed and consider those nuances in the overall design of a segment. For example, a Freeway or interstate with relatively low traffic volumes may create a sense of confidence for the driver to drive faster than the posted speed. If the design of a segment of Freeway cannot easily accommodate the prevailing or posted speed for the corridor, the common practice is to post an advisory speed sign in advance of the varying low speed curves to alert drivers to adjust to a lower safe operating speed.

For new and reconstructed facilities, the designer should strive to design the Freeway segment to the appropriate standards, in order to maintain the designated posted speed.

The nature of the surroundings in all Context Classifications can directly influence the design speed considerations for a Freeway segment. The designer needs to recognize how the context classification might influence the design speed and consider what measures can be used to influence driver expectations to maintain appropriate safe operating speeds.

5.7 Design Traffic Volume

The basis of traffic design is to calculate the anticipated Design Hour Volume (DHV) of traffic projected to a future design year. During the project's planning stage, the region traffic engineer can provide current design hour traffic volumes, predict future design hour traffic volumes, and determine the future design year that is appropriate for the project. A simple resurfacing project may only need a future DHV of 10 years, while a major rehabilitation or reconstruction project may require a DHV of 20 years. Freeway designs will typically require a 20-year design hour volume estimate at a minimum. The DHV and desired LOS for the Freeway determines the necessary lane requirements for the Freeway.

5.8 Level of Service

Understanding LOS and how it impacts the Freeway must take several factors into consideration. In Freeway design, the desired LOS will depend on the context and future needs. Refer to Table 2-3 in Chapter 2 of the 2018 AASHTO GDHS, which gives a range of LOS for Freeways depending upon the context the Freeway is operating in. Also Refer to the *Highway Capacity Manual* (TRB, 2022) for further information and considerations for Freeway LOS.

5.9 Multimodal Accommodations

Freeway design should consider multimodal operations within and adjacent to the facility. For example, a Freeway may include transit operations in the median, on a reinforced shoulder, or on a separate transit track, like high-speed passenger rail. While the high-speed travel lanes are not appropriate for bicycle and pedestrian use, the Freeway itself should not be a barrier to these modes. Designers should consider how to provide connectivity for bicycles and pedestrians, and design easy access to multimodal hubs.

5.9.1 Transit

Generally, a Freeway will not have transit stops within its right of way. However, there may be multimodal hubs off alignment where transit vehicles stop, for example intercity buses. These vehicles require easy on and off Freeway access to facilitate efficient movements.

A Freeway may have specific lanes for bus rapid transit service or tolls and managed lanes within its right of way, and provisions must be made on the Freeway for on and off access.

5.9.2 Bicycles

It is common for bicycle and pedestrian shared-use trails to run adjacent to Freeways or cross them as part of the transportation network. Considerations for accommodating bicycle and pedestrian connections in Freeway design are encouraged. These considerations should separate bicycles and pedestrians from the traffic flow with buffers and grade-separated crossings.

Refer to Chapter 2, Section 2.7, of the 2018 AASHTO GDHS for more information.

5.9.3 Pedestrians

Pedestrian facilities should be separated from high-speed traffic on a Freeway. If pedestrian activity is to be accommodated, it should be done through the local street, along a frontage road, or on a detached trail system to effectively keep the pedestrian separated at a safe distance from the high-speed traffic.

Refer to Chapter 2, Section 2.6.1, of the 2018 AASHTO GDHS for more information.

5.9.4 Motorized Vehicles

Design vehicle considerations may be different on a Freeway used by larger or even oversized vehicles for interstate or inter-regional travel. Designing a Freeway for the largest appropriate vehicle is critical to preventing bottlenecks and safety issues along the roadway. Many Freeway corridors have height restrictions due to the existing grade separated crossing elevations above the Freeway. As grade crossings are improved the Freeway vertical profile and clearances should be investigated and improved if the purpose and need can accommodate that change.

Refer to Chapter 2, Section 2.8, of the 2018 AASHTO GDHS for more information on design vehicles.

5.10 Accessible Design

When designing the separated trail or pedestrian crossings at an interchange or intersection, the designer must determine if current ADA accommodations are compliant or if they need to be improved or upgraded to meet standards. American with Disabilities Act (ADA) elements are unique to each location and require a level of design detail that cannot be short-cut. In rolling or mountainous terrain, the length, grade, and requirement for flat rest areas becomes a factor in trail design to meet ADA standards.

CDOT follows design and construction guidance and standards found in the U.S. Department of Transportation ADA Standards for Transportation Facilities (USDOT, 2006), the U.S. Department of Justice 2020 ADA Standards for Accessible Design (U.S. Department of Justice, 2020), Americans with Disabilities Act Architectural Guidelines for Buildings and Facilities (ADAAG) (U.S. Access Board, 2002), and the *Manual on Uniform Traffic Control Devices for Streets and Highways* (FHWA, [2009] 2022). In addition, CDOT adopted the Proposed Right-of-Way Accessibility Guidelines (PROWAG) for curb ramps, which also provides design guidance for sign heights and pedestrian pushbuttons for traffic signals (U.S. Access Board, 2011). The designer should evaluate innovative ways to shorten pedestrian crossings at intersections to provide the greatest safety to the pedestrian. If the intersection is signalized, PROWAG guidance is highly recommended to provide the highest level of ADA accommodations.

Refer to Chapter 12 of this Guide for information on PROWAG.

Refer to Chapter 2, Section 2.6.7, of the 2018 AASHTO GDHS for more information.

Use this link to access CDOT's ADA resources for engineers:
https://www.codot.gov/business/civilrights/ada/resources-engineers

5.11 Access Control and Access Management

- Difference between a Freeway and an expressway.
- State of Colorado State Highway Access Code (State of Colorado, 2012).
- Interchange and intersection spacing.
- Frontage roads and collector systems to maintain a level of Freeway or Interstate.

Safety and improved mobility are considerations for access control and access management. Different types of Freeways have different access requirements. An interstate Freeway is highly controlled with access only via a grade-separated interchange. On a rural expressway, access points are allowed directly to the highway and may be at grade rather than grade separated. The number of expressway accesses may be limited and spaced farther apart to improve free flow conditions. A hybrid expressway has both grade-separated and at-grade access control.

The access classification and design standards can change based on projected traffic volumes and capacity needs. The design needs to take future traffic growth into consideration so that these changes can be accommodated when needed.

If there is transit on the Freeway, Expressway, or Interstate, or is planned, priority access should be considered.

Refer to Chapter 2, Section 2.5.1, of the 2018 AASHTO GDHS and Chapter 11 of this Guide for further information.

5.12 Horizontal and Vertical Geometry

A Freeway is thought of as a "long travel" route for inter-regional or interstate travel where a driver is expecting to travel long distances. Horizontal and vertical alignments that are more gradual and predictable to the driver are appropriate for a higher design speed up to 75 or even 80 mph.

Refer to Chapter 8 of the 2018 AASHTO GDHS for further information.

5.13 Alignments

The designer should strive to meet design standards for the alignment of a Freeway segment unless there are contextual influences that limit the ability to design to the standard.

If the design standard cannot be met, PBPD principles can be leveraged to make data-driven decisions on how to modify or adjust the Freeway design to address the needs.

Refer to Chapter 6 of this design guide and Chapter 8, Section 3.3.4, of the 2018 AASHTO GDHS for additional information on Freeway alignments.

5.14 Grades

The maximum grade for a Freeway is a function of terrain or context classification (urban or rural) and design speed. Refer to Table 8-1 in the 2018 AASHTO GDHS for grades in urban and rural settings.

There are locations where grades cannot meet 2018 AASHTO GDHS standards because of the costs and the impact to adjacent uses or the environment.

A PBPD analysis of the current roadway operations, crashes, etc., may reveal that the current condition is acceptable, or may identify specific hot spots in the segment where there is a problem. PBPD may help to determine how the budget can be used most effectively to improve those specific locations.

5.15 Vertical Curves

Design controls for vertical sag and crest curves are provided in Chapter 3, Section 3.4.6.2 Crest Vertical Curves (Table 3-35, Table 3-36 and Table 3-37) of the 2018 AASHTO GDHS. Criteria for measuring stopping sight distance include an eye height of 3.5 feet and an object height of 2.0 feet. Passing sight distance criteria include an eye height of 3.5 feet and the object height of 3.5 feet.

The designer may need to introduce a gradual sag vertical curve to develop sufficient vertical clearance under a Freeway overpass. Ideally, a vertical clearance across the entire roadway should be at least 17 feet.

Refer to Chapter 8, Section 8.2.9, of the 2018 AASHTO GDHS for further information on vertical clearances for Freeways.

5.16 Cross-Slope and Superelevation

A typical cross-slope on a Freeway in Colorado is generally 2% to the outside of the roadway prism. Superelevation can vary from 2% to 8% depending upon the radius of curvature and design speed. An urban Freeway is allowed a maximum superelevation of 6%, and Colorado limits the maximum superelevation rate to 8% for rural facilities because of the frequent snow and icing conditions that occur across the state.

A detailed discussion of superelevation is found in Chapter 6 of this Guide; more information can be found in the CDOT Standard Plans - M&S Standards M-203-11 (CDOT, 2019).

Use this link to access CDOT Standard Plans - M &S Standards (CDOT, 2019): *https://www.codot.gov/business/designsupport/2019-and-2012-m-standards/2019-m-standards-plans/2019-m-standards-plan-sheets/2019-m-standards*

5.17 Cross Section Elements

Cross section elements of a Freeway include travel lanes, inside and outside shoulders, median, topographic elements, etc. These elements are typically determined through the planning process and the context classification (refer to Chapter 1 of this Guide). The designer must determine what can be implemented within a project's budget and contextual constraints. Cross section elements of a Freeway can vary across segments; the transitions between the variations should be gradual and predictable for a driver to interpret easily.

PBPD plays a key role in developing cross sections. Good data analysis will help define the cross sectional elements and the widths that are appropriate to accommodate all roadway uses. Desired widths are as follows:

- Freeway travel lanes should be a minimum of 12 feet wide. For narrower lane widths, there needs to be a clear rationale on why. Narrower lane widths may require changes in the design speed and final posted speed if implemented.
- Auxiliary lanes along a Freeway should be 12 feet wide and accommodate WB-67 truck turning movements at intersections off the Freeway.
- The width of inside and outside paved shoulders can vary and depends on the rural or urban context. Ideally, the inside shoulder should be a minimum of 6 feet wide if a barrier is present; wider is preferred. The outside shoulder width should be a minimum 8 feet wide, enough to accommodate vehicle breakdowns outside of the traveled lane. In highly constrained urban

corridors, the inside shoulder may be less than 6 feet with a barrier that separates opposing lanes of traffic.

- A median is desired on a Freeway to separate opposing directions of travel. On a rural Freeway, a vegetated depressed median is common, and the median width is directly influenced by the clear zone requirements for both directions of travel. In urban areas, a median may include paved shoulders, BRT lanes, or HOV or Express Lanes in both directions of travel separated by a median barrier. Median width on an urban Freeway depends on the design speed and whether or not there is a barrier.

A Freeway generally is not designed for pedestrian or bicycle activity because of the high speeds of traffic, the uninterrupted traffic flow, and the need to separate slower pedestrian and bicycle movements from these vehicles. Similarly, transit stops are not included on a Freeway because this interrupts traffic flow and would be unsafe.

The designer, however, needs to look at the contextual elements of the Freeway, which may require adding amenities for bicycles and pedestrians in the form of a separated pathway outside of the Freeway's roadway prism. Additionally, if a Freeway supports interregional transit services, connections to and from the Freeway to a multimodal hub may be necessary. All of this is determined in the planning stages of a project using a CSS analysis.

Refer to Chapter 6 of this Guide and to Chapter 8, Section 8.2, of the 2018 AASHTO GDHS for further information on design considerations for a Freeway.

5.18 Median Type

Refer to Chapter 8, Section 8.3.2, of the 2018 AASHTO GDHS for further information on medians for a Freeway.

5.19 Drainage

The principal objective in drainage design is to control the presence and flow of water on a Freeway surface such that users are not placed in an unsafe situation during storm events. Proper drainage design prevents ponding of water along the Freeway and prevents overtopping of the Freeway during severe storms.

Drainage facilities are designed to carry water across the right of way and to remove stormwater from the Freeway itself. These facilities can include bridges, box culverts, pipe crossings, median or edge drains, stormwater detention ponds, sediment catchments, and storm sewer systems.

To provide for proper drainage on a Freeway, it is desirable to use a minimum crown slope of 2.0% (0.02 foot/foot), particularly where the surrounding terrain is relatively flat. This reduces ponding areas that can contribute to vehicles hydroplaning, deterioration of pavements, and impacting driver visibility.

Drainage requirements for a rural Freeway can vary significantly from an urban Freeway. A rural Freeway may have a depressed median with cross drains to convey drainage under the Freeway to the outside shoulder area.

An urban Freeway may have entire storm sewer systems to capture impermeable runoff along the median area to convey it off the roadway without carrying it directly across the traveled lanes. An urban depressed Freeway may have even more complicated drainage requirements because the roadway is lower than the surrounding terrain. Many times, an urban Freeway (and occasionally a rural Freeway) fall under the designation of Municipal Separate Storm Sewer System (MS4) requirements. The designer must have discussions with the project hydraulics engineer and the environmental staff to fully understand the expectations and requirements for stormwater management on the project. This may also include discussions with the local agency that is ultimately responsible for the stormwater requirements.

For additional information, refer to the CDOT *Drainage Design Manual* (CDOT, 2019).

5.20 Types of Freeways

5.20.1 Depressed Freeways

Information for the following is found in Chapter 8 of the 2018 AASHTO GDHS:

- Slopes and walls.
- Typical cross section.
- Restricted cross section.
- Walled cross section.

5.20.2 Elevated Freeways

Information for the following is found in Chapter 8 of the 2018 AASHTO GDHS:

- Medians.
- Ramps and terminals.
- Frontage roads.
- Clearance to building lines.
- Typical cross section.
- Viaduct freeways without ramps.
- Two-way viaduct freeways with ramps.
- Freeways on earth embankments.

5.20.3 Ground-Level Freeways

Information for the following is found in Chapter 8 of the 2018 AASHTO GDHS:

- Typical cross sections.
- Restricted cross sections.

5.20.4 Combination-Type Freeways

Information for the following is found in Chapter 8 of the 2018 AASHTO GDHS:

- Profile control.
- Cross section control.

5.20.5 Special Freeway Designs

Information for the following is found in Chapter 8 of the 2018 AASHTO GDHS:

- Reverse-flow roadways.
- Dual-divided freeways.
- Freeways with collector-distributor roads.

5.20.6 Accommodation of Transit and High-Occupancy Vehicle Facilities

Information for the following is found in Chapter 8 of the 2018 AASHTO GDHS:

- Buses.
- Rail transit.

Chapter 6
Elements of Design

Legend

	Multimodal Application Example
	Context-Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context-Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO-Specific Information

Chapter

6

6 Elements of Design

6.1 Introduction

The design of Roads; Streets; and Freeways, Expressways, and Interstates in differing context classifications is treated differently. Information on these specific facility types can be found in Chapters 3, 4, and 5 of this Guide, respectively. However, common to all facility types are several principal elements of design—sight distance, cross slope, travel lane width, and horizontal and vertical alignments. These elements are discussed in this chapter, and, as appropriate, in Chapters 3, 4, and 5 pertaining to those specific facility types.

The alignment of facilities has the potential to increase or mitigate impacts on the environment, community, and roadway user. The alignment is comprised of a variety of elements joined together to create a facility that serves the roadway user in a safe and efficient manner, consistent with the facility's intended function. Each alignment element should complement the others to produce a consistent, safe, context-sensitive, efficient, and environmentally responsible design.

6.2 Sight Distance

6.2.1 General Considerations

A critical element in assuring safe and efficient operation of vehicles on a roadway is the ability of the driver to see ahead. Sight distance is the distance along a roadway throughout which an object of specified height is continuously visible to the driver. Sight distance requirements can vary depending upon the intended actions of the driver and vehicle. Sight distance will vary if the driver is departing the highway, entering the highway, or attempting to pass a vehicle. These are just a few examples of the differing actions and sight distance requirements that need to be considered by the designer. This distance is also dependent on the height of the driver's eye above the road surface; the specified object height above the road surface; and the height and lateral position of sight obstructions such as cut slopes, guardrail, and retaining walls within the driver's line of sight. Sight distance of sufficient length must be provided to allow drivers to avoid striking unexpected objects in the traveled way. Certain two-lane roadways should also provide sufficient sight distance to allow drivers to occupy the opposing lane for passing without hazard.

When designing a separated shared-use path, the design vehicle will likely be a bicycle and have different sight distance requirements for the path design. Refer to Chapter 13 of this Guide for more information on bicycle design and Chapter 12 of this Guide for accessibility guidelines.

6.2.2 Stopping Sight Distance for Roadways

Stopping sight distance along a roadway is the sum of two distances (reaction distance and braking distance). This calculation and further details regarding stopping sight distance can be found in Chapter 3, Section 3.2.2.3, of the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (the Green Book) (2018 AASHTO GDHS) (AASHTO, 2018).

- *Reaction Distance.* The distance a vehicle travels from the instant the driver sights an object necessitating a stop to the instant the brakes are applied (brake reaction distance), and
- *Braking Distance.* The distance required to stop the vehicle from the instant brake application begins.

$$SSD = 1.47Vt + 1.075\,\frac{V^2}{a}$$

SSD= stopping sight distance, ft
V = design speed, mph
t = brake reaction time, 2.5s
a = deceleration rate, ft/s^2

Stopping sight distance is measured from the passenger vehicles driver's eyes, which are assumed to be 3.5 feet above the pavement, to an object 2 feet high on the road. Distances greater than the minimum stopping sight distance provide an additional measure of safety and should be considered where practical. For locations with increased truck activity, it may be appropriate to use different operator heights to calculate sight distance depending upon the vehicle type. Refer to Chapter 3, Section 3.2.2.5, of the 2018 AASHTO GDHS for additional information.

Table 6-1 is referred to in this chapter for sight distance adjustments.

Table 6-1 Sight Distance Adjustments for Grades or Vertical Curves

Design Speed (mph)	Stopping Sight Distance (Design Values)									Passing Sight Distance (2-Lane Road)	
	No Grade Adjustment	% Down Grade			% Up Grade			Crest	Sag	Crest Vertical Curve	
	Dist. (ft)	3	6	9	3	6	9	K	K	Dist. (ft)	K
15	80	80	82	85	75	74	73	3	10	400	57
20	115	116	120	126	109	107	104	7	17		
25	155	158	165	173	147	143	140	12	26	450	72
30	200	205	215	227	200	184	179	19	37	500	89
35	250	257	271	287	237	229	222	29	49	550	108
40	305	315	333	354	289	278	269	44	64	600	129
45	360	378	400	427	344	331	320	61	79	700	175
50	425	446	474	507	405	388	375	84	96	800	229
55	495	520	553	593	469	450	433	114	115	900	289
60	570	598	638	686	538	515	495	151	136	1000	357
65	645	682	728	785	612	584	561	193	157	1100	432
70	730	771	825	891	690	658	631	247	181	1200	514
75	820	866	927	1003	772	736	704	312	206	1300	604
80	910	965	1035	1121	859	817	782	384	231	1400	700
AASHTO Tables	(3-1)	(3-2)						(3-35)	(3-37)	(3-5) (3-36)	(3-36)

Source: 2018 AASHTO GDHS.

$$K = \frac{L}{A}$$

Where:
L = Length of vertical curve (ft)
A = Algebraic difference in intersecting grades, in percent

K value is a coefficient by which the algebraic difference in grade is multiplied to determine the length in feet of the vertical curve that will provide minimum sight distance. Values of K=167 or greater should be checked for drainage.

Refer to Chapter 3, Section 3.2.2, of the 2018 AASHTO GDHS for more information.

6.2.2.1 Effect of Grade on Stopping Sight Distance

Stopping distances on upgrades are shorter than on flat terrain and conversely longer in distance on downgrades. Design speed is used in calculating downgrade corrections; average running speed is used in calculating upgrade corrections. The different criteria for descending and ascending grades are based on the effect grades have on the speed of individual vehicles, particularly trucks; the effect these vehicles have on the overall speed of the traffic stream; and the premise that many drivers, particularly those in automobiles, do not appropriately compensate for the changes in speed caused by grades.

Most facilities support two-way traffic, the roadway grade is traversed by traffic in both directions, but the sight distance at any point on the roadway generally is different for each direction, particularly on straight roads in rolling terrain. As a general rule, the sight distance available on downgrades tends to be greater than on upgrades, more or less automatically providing the necessary corrections for grade. Exceptions are one-way roadways or divided roadways with independent design profiles for the two roadways. In these locations separate grade corrections are necessary and the refinement in design is consistent with the overall standards used.

For those areas where there is a high volume of trucks, refer to Chapter 3, Section 3.2.2.5, of the 2018 AASHTO GDHS for more information on adjustments for large vehicles.

6.2.3 Decision Sight Distance

Stopping sight distance may not always be adequate when drivers are required to make complex or instantaneous decisions, when information is difficult to perceive, or when unexpected or unusual maneuvers are required. In these instances, stopping sight distances may not provide sufficient visibility distance for drivers to corroborate advance warnings and to perform the necessary maneuvers. Decision sight distance provides the greater length that drivers need in these instances.

The 2018 AASHTO GDHS provides values for appropriate decision sight distances at critical locations and for criteria in evaluating the suitability of the sight lengths at these locations. Refer to Chapter 3, Section 3.2.3, of the 2018 AASHTO GDHS for more information.

Decision sight distance is the distance required for a driver to:

- Detect an unexpected or otherwise difficult to perceive information source or hazard in a roadway environment that may be visually cluttered.
- Recognize the hazard or its threat potential.
- Select an appropriate speed and path.
- Initiate and complete the required safety maneuver safely and efficiently.

Drivers need decision sight distances whenever there is a likelihood for error in either information reception, decision making, or control actions. The following are examples of critical locations where these kinds of errors are likely to occur and where it is desirable to provide decision sight distance:

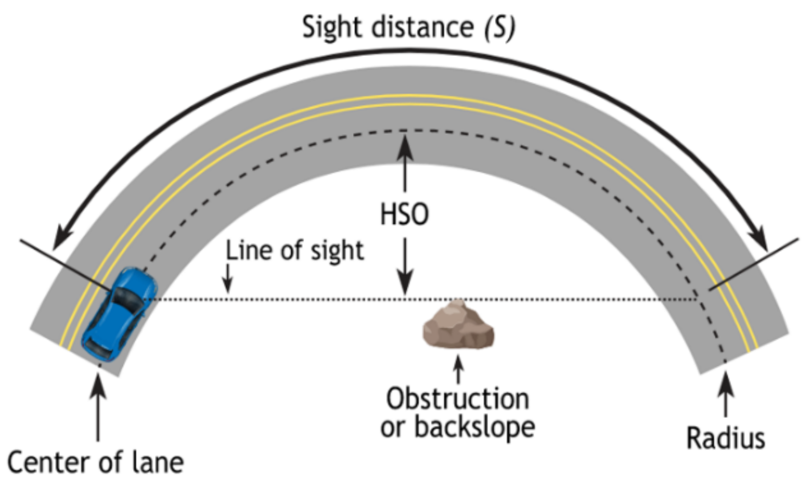
- Interchange and intersection locations where unusual or unexpected maneuvers are required.
- Changes in cross section such as tunnels and lane drops.
- Areas of concentrated demand where there is apt to be "visual noise" whenever sources of information compete, as those from roadway elements, traffic, traffic control devices, surrounding land use, pedestrian activity, and advertising signs.

6.2.4 Sight Distance on Horizonal Curves

Stopping sight distance on horizontal curves may be obtained with the aid of Figures 6-1. For passenger vehicles, it is assumed that the driver's eyes are 3.5 feet above the center of the inside lane (inside with respect to the curve) and the object is 2 feet high. The line of sight is assumed to intercept the obstruction at the midpoint of the sight line and 2 feet above the center of the inside lane. The middle horizontal sightline offset (HSO) is obtained from Figure 6-1.

Sight distance obstructions should be considered in the design; refer to Chapter 3, Section 3.3.12.1, of the 2018 AASHTO GDHS.

Figure 6-1 Horizontal Stopping Sight Distance



$$S = \frac{R_i}{28.65} arccos\left(\frac{R_i - HSO}{R_i}\right)$$

Where:

$R_i = R_{\,(Radius\ of\ curve)} \pm Offset_{\,to\ center\ of\ driving\ lane}\ (ft)$

HSO = Horizontal sightline offset distance from center of inside lane to object or obstruction (ft)

S = Available stopping distance (ft)

Example PBPD Application - Calculating Sight Distance

When calculating sight distance, the designer shall always calculate the radius to the center of the lane with the most limited sight distance. The horizontal sightline offset shall also be calculated to the center of the lane.

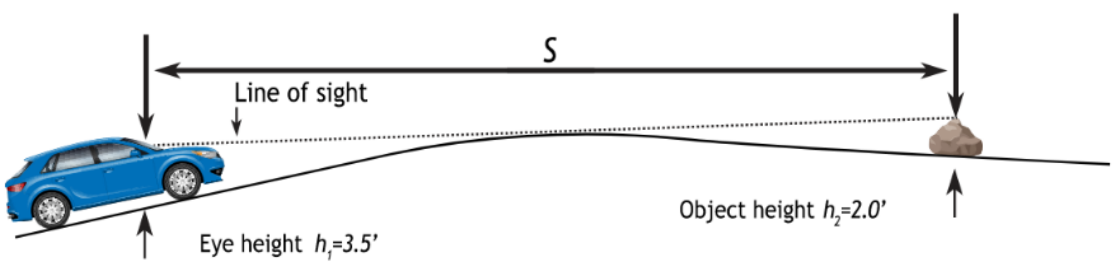
On a divided highway with a median barrier, the shortest sight distance could be the closest inside lane to the obstruction (cliff or hillside) relatively close to the lane, or it could be the inside lane closest to the median barrier. The designer should check both conditions to determine the most restrictive case to design to. There are software design tools to help the designer check sight distance, but the designer must check the settings in the software to make sure the vehicle and object heights are set appropriately.

6.2.5 Sight Distance on Vertical Curves

6.2.5.1 Crest Vertical Curves

Stopping sight distance is measured when the height of eye is 3.5 feet, and the height of object is 2 feet, as shown in Figure 6-2.

Figure 6-2 Stopping Sight Distance on a Crest Vertical Curve



When: S < L $\quad L = \frac{AS^2}{2158} \quad S = \sqrt{\frac{2158L}{A}}$

When: S > L $\quad L = 2S - \frac{2158}{A} \quad S = \frac{L}{2} + \frac{1079}{A}$

Where:
L = Length of sag vertical curve (ft)
A = Algebraic difference in grades (%)
S = Light beam distance (ft)

6.2.5.2 Sag Vertical Curves

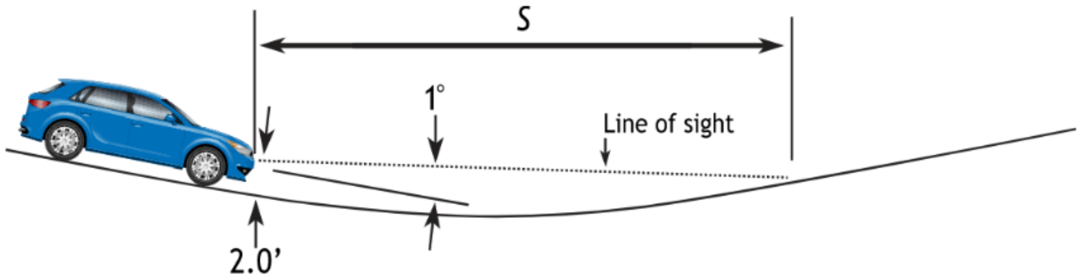
Headlight sight distance is the basis for determining the length of sight distance. Prior to calculating the following formula, review Table 3-37 of the 2018 AASHTO GDHS to ascertain if S is less than or greater than L.

When: S < L $\quad S = \frac{3.5L \pm\sqrt{12.25L^2+1600AL}}{2A}$

When: S > L $S = \frac{AL+400}{2A-3.5}$

Where:
L = Length of sag vertical curve (ft)
A = Algebraic difference in grades (%)
S = Light beam distance (ft)

Figure 6-3 Example of a Sag Vertical Curve



Given:

L = 300 feet, check if curve s adequate for a design speed of 40 MPH, and find S.

A = 2.5 - (-2.0) = 4.5

$$K = \frac{L}{A} = \frac{300}{4.5} = 66.7$$

From “Sag K” column of Table 6-1, with K(Sag) value of 64 for 40 mph. Curve is adequate for a design speed of 40 mph.

Since it is unknown whether S>L or S<L, try each equation or consult Figure 3-37 Design Controls for Sag Vertical Curves in the 2018 AASHTO GDHS.

Try:

$$\mathrm{S} < \mathrm{L} \rightarrow \mathrm{S} = \frac{3.5\mathrm{L} \pm \sqrt{12.25\mathrm{L}^2 + 1600\mathrm{AL}}}{2\mathrm{A}} = \frac{3.5\,(300) \pm \sqrt{12.25(300)^2 + 1600\,(4.5)(300)}}{2(4.5)}$$

$$\mathrm{S} = 317\ \text{ft., which is greater than L} = 300\ \text{ft.}$$

which is not good, S is not less than L

Try:

$$\mathrm{S} > \mathrm{L} \rightarrow \mathrm{S} = \frac{\mathrm{AL}+400}{2\mathrm{A}-3.5} = \frac{(4.5)(300)+400}{2(4.5)-3.5} = 318\ \text{ft.}$$

Which is okay, S is greater than L

6.2.5.3 Passing Sight Distance

Passing sight distance is the minimum sight distance required for the driver of one vehicle to pass another vehicle safely. Passing sight distance is considered only on two-lane roadways. Passing sight distance is measured between an eye height of 3.5 feet and an object height of 3.5 feet. Table 6-1 presents minimum passing sight distances for various design speeds. Refer to Section 3.4.6.2.2, of the 2018 AASHTO GDHS for more information.

Generally, it is impractical to design crest vertical curves to provide for passing sight distance because of the high cost where crest cuts are involved and the difficulty of fitting the required long vertical curves to the terrain, particularly for high-speed roads.

Passing sight distance calculations are for design purposes only to assist in providing as many passing opportunities as possible. Actual passing and no-passing zone locations for striping need to be field measured and placed in accordance with the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (FHWA, [2009] 2022).

When vehicles are passing a bicyclist, there needs to be room for the bicyclist both for comfort and safety. In accordance with Colorado State law, a driver must maintain a minimum separation of 3 feet between the vehicle and the bicyclist. The roadway design needs to include the width of the vehicular travel lane and the bicycle lane or shoulder so this distance can be maintained, given the nature of traffic volume in adjacent travel lanes.

6.2.5.4 Passing Sight Distance on Crest Vertical Curves

Design values of crest vertical curves for passing sight distance differ from those for stopping sight distance because of the different height criterion, i.e., 3.5 feet for the height of object for passing sight distance compared to 2 feet for stopping sight distance. The following formulas apply:

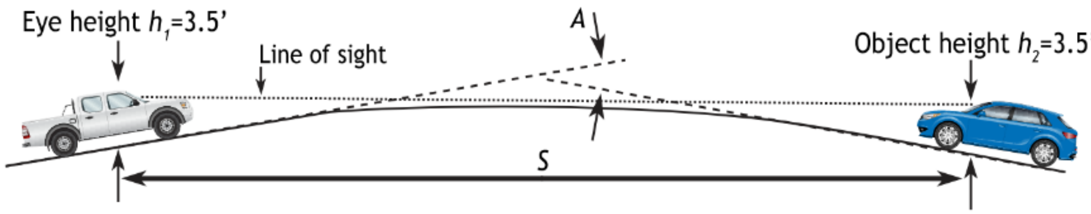
When S>L $$L = 2S - \frac{2800}{A} \qquad S = \frac{L}{2} + \frac{1400}{A}$$

When S<L $$L = \frac{AS^2}{2800} \qquad S = \sqrt{\frac{2800L}{A}}$$

Where:
L = Length of vertical curve (ft)
A = Algebraic grade difference (%)
S = Sight Distance (ft)

For minimum passing sight distances, the required lengths of crest vertical curves are substantially longer than those for stopping sight distances, as evidenced by the values in Table 6-1.

Figure 6-4 Example of Passing Sight Distance on Crest Vertical Curve



6.2.5.5 Passing and Stopping Sight Distances at Undercrossings

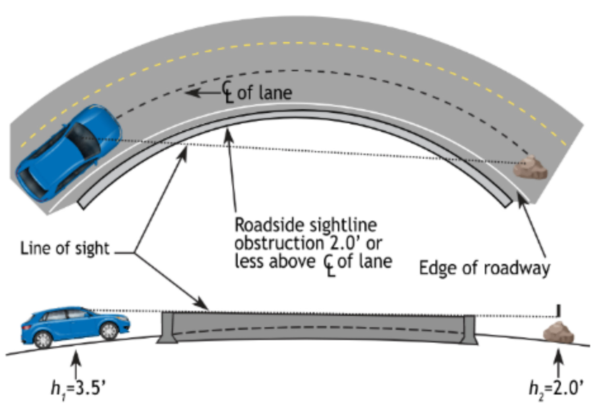
If economically feasible, passing sight distance should be maintained as the roadway passes under a structure. On occasion, topographic conditions may result in a pronounced sag curve, and the underside of the structure may limit the sight distance. Such conditions may best be checked graphically on the profile using the vertical clear dimension of the structure, the height of the eye for a truck driver as 7.6 feet and the height of object as 2 feet for the taillights of a vehicle.

Refer to Chapter 3, Section 3.2.4, of the 2018 AASHTO GDHS for more information.

6.2.5.6 Overlapping Horizontal and Vertical Curves

Vertical curves on a horizontal curve have a unique effect that the designer should consider very carefully. Crest vertical curves make roadside objects more likely to hinder the ability of the driver to see the obstruction ahead, as shown in Figure 6-5. Sag vertical curves may make roadside objects less likely to be a sight line obstruction.

Figure 6-5 Overlapping Horizontal and Vertical Curves



The designer may need to check sight lines graphically with software to determine if the roadside object is hindering the calculated passing and/or stopping sight distance requirements on a roadway with both a horizontal and vertical curve.

6.3 Horizontal Alignment

6.3.1 Theoretical Considerations

As stated in the 2018 AASHTO GDHS,

"To achieve balance in highway design, all geometric elements should, as far as economically practical, be designed to operate at a speed likely to be observed under the normal conditions for that roadway for a vast majority of motorists."

Refer to Chapter 3, Section 3.3, of the 2018 AASHTO GDHS for more information.

6.3.2 General Considerations

Horizontal alignment should provide for safe and continuous operation of vehicles at a uniform design speed for substantial lengths of roadway. The major considerations in horizontal alignment are:

- Topography.
- Type of facility.
- Design speed.
- Design vehicle.
- Traffic volumes and vehicle classification.
- Profile grade.
- Subsurface conditions.
- Existing roadway and development.
- Existing and future land use.
- Location of the roadway terminals.
- Right of way.
- Safety.
- Construction costs.
- Environmental and seasonal weather conditions.
- Ecological and geological resources.
- Drainage.

All the above considerations should be balanced to produce an alignment that is contextually appropriate for the location and functional classification of the roadway. Functional classification is explained in Chapter 1 of this Guide.

To a large extent, topography controls both curve radius and design speed. In mountainous areas or areas subject to icing, consideration should be given to locating the road so that it has a southern exposure wherever possible.

Geological features that may affect design, such as potential land and rock slide areas along with subsurface water, should be investigated by the CDOT Materials and Geotechnical Branch.

Sight distance, compatible with the selected design speed, is required for proper design.

Horizontal alignment must afford at least the minimum stopping sight distance for the design speed at all points on the roadway, as given in Table 6-1.

Every effort should be made to exceed the minimum curve radii. Minimum curve radii should be used only when the cost of realizing a higher standard is not consistent with the benefits. The final considerations for the safety of any curve should be the combination of the factors of radius, sight distance, curve length, and superelevation.

To avoid the appearance of inconsistent distribution, the horizontal alignment should be coordinated carefully with the profile design.

Refer to Chapter 3, Section 3.3, of the 2018 AASHTO GDHS for more information.

6.3.3 MM, PBPD, and CSS Considerations

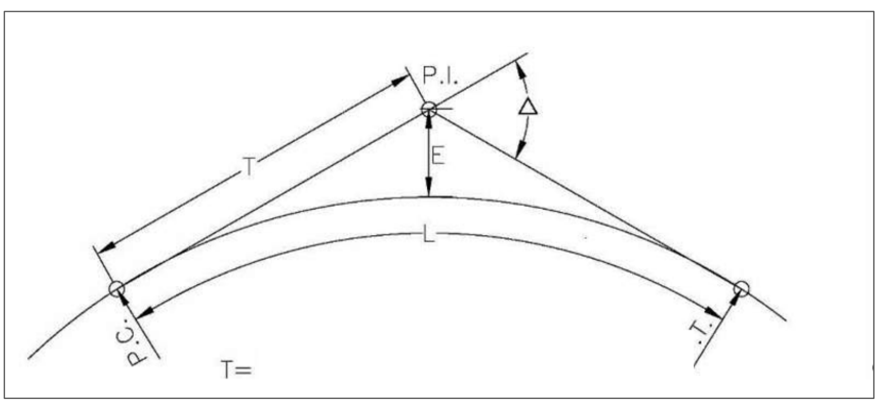
Development of horizontal alignments need to account for all modes of transportation based on the purpose and need of the project. The context of the area must be evaluated when determining the project criteria for horizontal alignment. Utilizing performance-based practical design (PBPD) tools and accounting for the aesthetics and character of the area that are important to the stakeholders can help determine the ultimate location of control for the project.

6.3.4 Types and Properties of Horizontal Alignments

6.3.4.1 Simple Curves

A simple curve is a circular arc joining two tangents, as shown in Figure 6-6.

Figure 6-6 Simple Curve



$$T = R\ \tan\frac{\Delta}{2} \qquad L = \frac{R\,\Delta}{5729.58}$$

$$E = R\left(\sec\frac{\Delta}{2}\right) - R = \frac{R}{\cos\frac{\Delta}{2}} - R$$

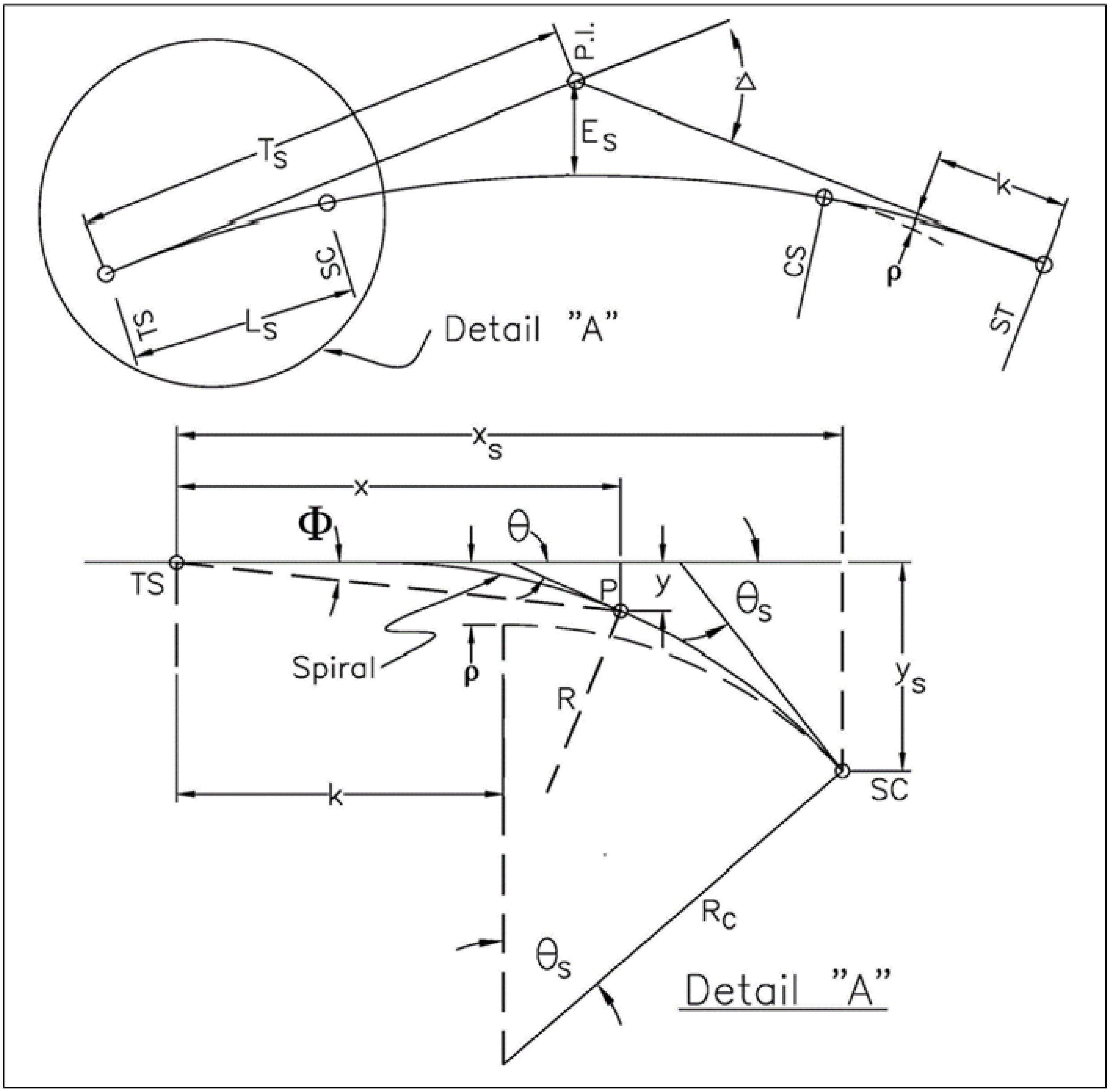
$$\textit{Calculating Number of Chords} \quad _{P.C.to\,P.T.} = \frac{R\,\Delta}{57.2958}$$

Where:
R = Radius of curve (ft)
L = Length of curve in stations
∆ = Deflection angle between the tangents, decimal degrees
T = Length of tangent (ft)
E = External distance (ft)

6.3.4.2 Spiral Curves

Spiral curves provide a gradual change in curvature from a straight to a circular path. Spiral transitions are not required but may be used on all roadways, including interchange ramps where recommended by the CDOT Standard Plans - M & S Standards on Superelevation (CDOT, 2019) and that include minimum transition lengths to be used with given curvature and speed. For further information on spiral curves, refer to *Route Location and Design* by T .F. Hickerson (Hickerson, 1967).

Figure 6-7 Spiral Curve Detail



P is any point on the spiral curve.

Equations for the spiral curve are as follows:

$$T_s = (R_c + \rho)\tan\left(\frac{\Delta}{2}\right) + k$$

$$E_S = (R_c + \rho)\left(\frac{1}{\cos\left(\frac{\Delta}{2}\right)} - 1\right) + \rho = \frac{R_c+\rho}{\cos\left(\frac{\Delta}{2}\right)} - R_c$$

$$L_s = \frac{200\theta_s}{D_c}$$

$$\theta = \left(\frac{L}{L_s}\right)^2 \theta_s$$

$$D = \left(\frac{L}{L_s}\right) D_c$$

$$y = \frac{L_s}{100}(0.5818\,\theta_s - 0.1266 \times 10^{-4}\theta_s^3)$$

$$x = \frac{L_s}{100}(100 - 0.3046 \times 10^{-2}\theta_s^3)$$

Where:
L is in feet and θ is measured in decimal degrees.

$$\rho = 0.001454\theta_s L_s$$
$$k = L_s(0.5 - 5.0770 \times 10^{-6}\theta_s^2)$$

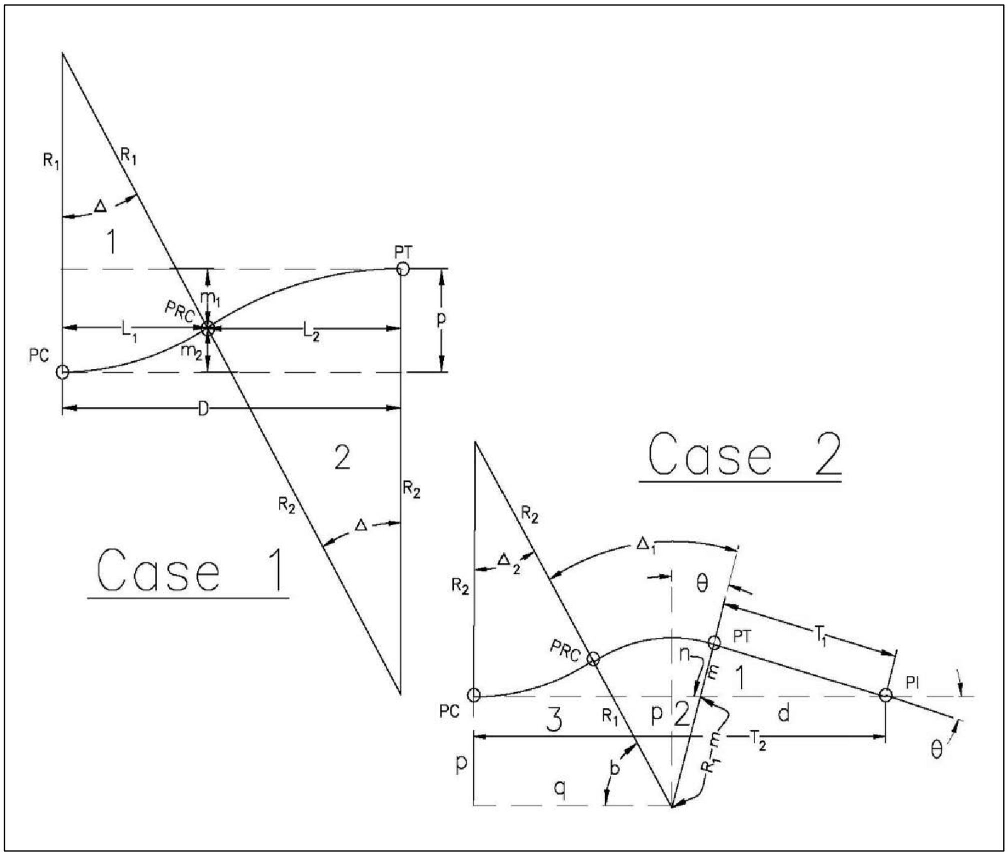
Where:
θ is measured in decimal degrees.

Where:
TS = point of change from tangent to spiral
SC = point of change from spiral to circle
CS = point of change from circle to spiral
ST = point of change from spiral to tangent
L = spiral arc from the TS to any point on spiral
L_s = total length of spiral from TS to SC
θ = central angle of spiral arc L
θ_s = central angle of spiral arc Ls, called "spiral angle"
Φ = spiral deflection angle at the TS from initial tangent to any point on spiral
D = degree of curve of the spiral at any point
R = radius
D_c = degree of curve of the shifted circle to which the spiral becomes tangent at the SC
R_c = radius of curve of the shifted circle to which the spiral becomes tangent at the SC
Δ = total central angle of the circular curve
Δ_c = central angle of circular arc of length L_c extending from SC to CS
y = tangent offset of any point on spiral with reference to TS and initial tangent
y_s = tangent offset at the SC
x = tangent offset of any point on spiral with reference to TS and initial tangent
x_s = tangent distance for the SC
ρ = offset from the initial tangent to the PC of the shifted circle
k = abscissa of the shifted PC referred to the TS
T_s = total tangent distance = distance from PI to TS, or from PI to ST
E_s = total external distance

6.3.4.3 Reverse Curves

Two consecutive circular curves constitute a reverse curve if they join at a point of tangency where their centers are on opposite sides of the common tangent. True reversing of curves should be avoided, although they may at times be used in designing detours. In cases of reversing curves, a sufficient tangent should be maintained between them to avoid overlapping of the required superelevation runoff and tangent runout.

Figure 6-8 Reverse Curve Case Examples



PRC = Point of Reversing Curvature.

In **Case 1**, the two parallel tangents are to be connected by a reversed curve (such as in a detour).

R_1, R_2, and p are given.

From triangle 1,

$$\frac{L_1}{R_1} = \sin \Delta$$

$$L_1 = R_1 \sin \Delta$$

From which,

$$P = m_2 + m_1$$

$$p = R_1(1 - \cos \Delta) + R_2(1 - \cos \Delta)$$

$$p = (R_1 + R_2)(1 - \cos \Delta)$$

And,

$$\frac{R_1 - m_2}{R_1} = \cos \Delta$$

$$\frac{p}{R_1 + R_2} = 1 - \cos \Delta$$

$$m_2 = R_1 (1 - \cos \Delta)$$

And,

$$D = L_1 + L_2$$

From triangle 2,

$$\frac{L_2}{R_2} = \sin \Delta$$

$$D = R_1 \sin \Delta + R_2 \sin \Delta$$

$$\frac{R_2 - m_1}{R_2} = \cos \Delta$$

$$D = (R_1 + R_2) \sin \Delta$$

From the preceding equations and the ordinary functions of a simple curve, all ordinary cases of reversed curves between parallel tangents can be solved.

In **Case 2**, the two tangents, intersecting with the angle θ, are to be connected by the reversed curve in which T_1, R_1, and R_2 are known, and the tangent distance T_2 and the central angles of the two branches (Δ_1 & Δ_2) are required.

In triangle 1, the base $T_1$and the angles are known, from which the sides d and m can be computed.

In triangle 2, the hypotenuse is R_1 - m, and the angles are known from which the base p and the altitude n are determined.

In triangle 3, the base is R_2 + p, and the hypotenuse is R_1 + R_2, from which the angles Δ_2 and b and the distance q can be found.

Then $\Delta_1 = \theta + \Delta_2$

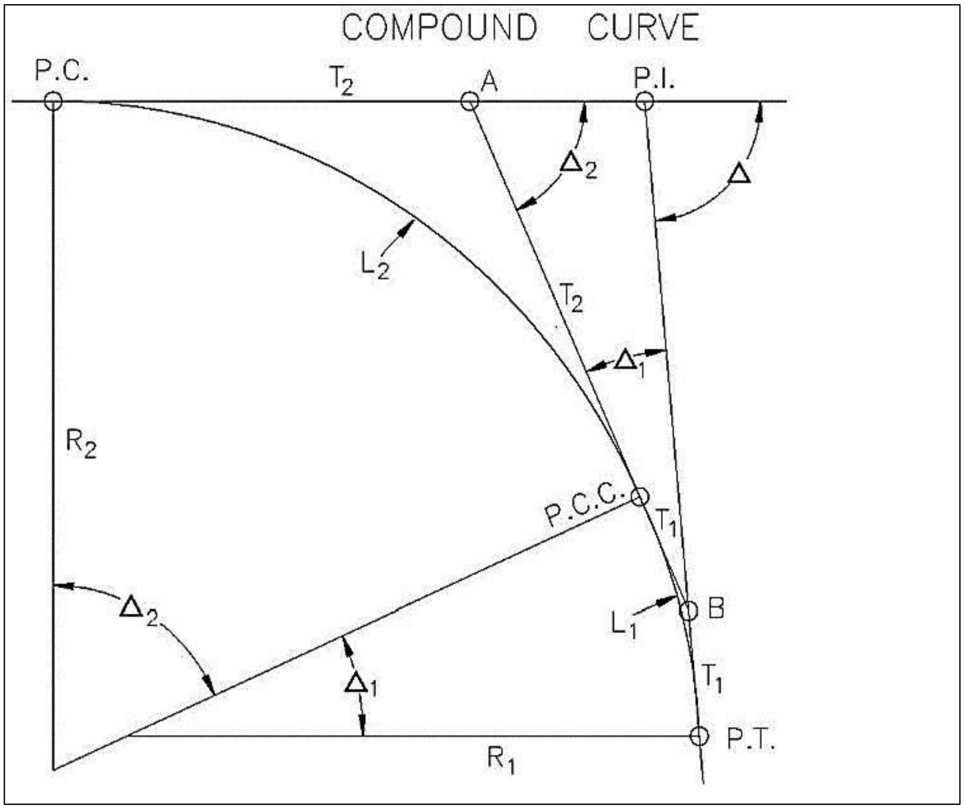
and $T_2 = d + n + q$

6.3.4.4 Compound Curves

Compound circular curves are two or more consecutive circular curves in the same direction with varying radii. Compound circular curves are joined at a point of tangency and located on the same side of the common tangent.

While simple curves are preferred, compound curves can be used to satisfy topographical constraints that cannot be as effectively balanced with simple curves. For compound curves on open roadways, it is generally accepted that the ratio of the flatter radius to the sharper radius should not exceed 1.5:1. For compound curves at intersections or on ramps, the ratio of the flatter radius to the sharper radius should not exceed 2:1. When this is not feasible, an intermediate simple curve or spiral should be used to provide the necessary transitions. Since drivers are often unable to distinguish the change in horizontal radii while navigating a compound curve, appropriate warning signs as detailed in the MUTCD should be provided. Refer to the 2018 AASHTO GDHS Chapter 3 for more discussion on compound curves at intersections and Figure 6-9.

Figure 6-9 Compound Curve



Given: $\Delta = \Delta_1 + \Delta_2$ $\quad$ $T_2 = R_2 \tan\frac{\Delta_2}{2}$ $\quad$ $T_1 = R_1 \tan\frac{\Delta_1}{2}$

Curve is laid out as two adjacent simple curves:
One having a radius "R2" with its P.I. at "A";
The other having a radius "R1" with its P.I. at "B".

On open highways, the ratio R2/R1 should not exceed 1.5:1.
On other curves (intersections and ramps), the ratio R2/R1 should not exceed 2:1.
For sharper curves, use a three-centered curve or a spiral.

6.3.4.5 Alignment on Bridges

Ending a curve on a bridge is undesirable and complicates design and construction. Likewise, curves beginning or ending near a bridge should be placed so that no part of the spiral or superelevation transitions extends onto the bridge. Compound curves on a bridge are equally undesirable. If curvature is unavoidable, every effort should be made to keep the bridge within the limits of the simple curve.

6.3.4.6 Curvature Zoning

In addition to the specific design elements for horizontal alignment discussed previously, a number of general controls are recognized in practice. These controls are not subject to theoretical derivation, but they are important for providing improving the safety and comfort of driver's navigation these highways. Excessive curvature or poor combinations of curvature have the potential to impact traffic operations and decreasing travel speeds, increasing operating and maintenance costs and reduces the overall driver comfort. To avoid such poor design practices, the general controls that follow should be used where practical.

Consistent alignment should always be sought. Sharp curves should not be introduced at the ends of long tangents. Sudden changes from areas of flat curvature to areas of sharp curvature should be avoided. Where sharp curvature is introduced, it should be approached, where practical, by a series of successively sharper curves.

- *Broken-Back Curve.* A broken-back curve consists of two curves in the same direction joined by a short tangent (under 1,500 feet). Broken-back curves are undesirable and can typically be replaced by one simple curve. If used, a simple curve, a compound curve or spiral transitions should be used to provide some degree of continuous superelevation. Lengths need to be adequate to transition superelevation correctly. The "broken-back" arrangement of curves should be avoided except where very unusual topographical or right of way conditions make other alternatives impractical.
- *Small Deflection Angles.* For small deflection angles, curves should be sufficiently long enough to avoid the appearance of a kink. Curves should be at least 500 feet long for a central angle of 5 degrees, and the minimum length should be increased 100 feet for each 1 degree decrease in the central angle. Horizontal curves should not be used when the central angle is 59 minutes or less on non-freeways. The minimum length for horizontal curves on roadways should be fifteen times the design speed (15V). On higher-speed access-controlled facilities that use flat curves for aesthetic reasons, the desired minimum length for curves should be 30 times the design speed (30V), where length of curve (L) is in feet and design speed (V) is in mph.
- *Passing Tangents.* Passing tangents are used to provide passing opportunities on two-lane roads. One-half mile is considered an adequate length. Passing tangents should be provided as frequently as possible in keeping with the terrain.

  An effort to introduce a passing tangent or to increase the length of a passing tangent is desirable if the project's budget can accommodate this addition. Nothing is gained by using large radii at the ends of a tangent if they reduce its length to less than that required for safe passing. It is better to use somewhat shorter radii and increase the intervening tangent to a more satisfactory length. At the other extreme, sharp curves at the ends of a passing tangent should be avoided as indicated above.

Example PBPD Application

A designer is considering whether increasing the radius of a curve to meet standards is warranted. The existing condition curve does not meet standards but increasing curve radius to meet standards will be challenging considering the topographic and cost realities. Data, such as speed and volume, as well as crash patterns, can help determine the optimal radius for a given curve.

The designer contacts the Region Traffic Representative to access traffic engineering expertise in the area of Data Driven Safety Analysis (DDSA). The designer provides the traffic engineer the estimated cost associated with expanding the curve to meet standards. The traffic engineer leverages DDSA software with Colorado specific crash modification factors (CMF) to quantify the predicted safety performance of this specific curve location if it is left as is versus if the curve were modified to meet full standards. This key analysis then feeds into the benefit-cost analysis of the existing condition curve versus full standard curve scenarios. The designer then uses this analysis to inform the decision whether to modify the curve in conjunction with CSS considerations and other factors. Beyond this example involving curve radius, the designer should understand what other geometric elements can be similarly analyzed to make geometric design decisions.

6.3.5 Superelevation

6.3.5.1 General

One of the most important factors to consider in roadway safety is the centripetal force generated when a vehicle traverses a curve. Centripetal force increases as the velocity of the vehicle and/or the degree of curvature increases.

To overcome the effects of centripetal force, curves must be superelevated. It is impossible to balance centripetal force by superelevation alone because for any given curve radius, a certain superelevation rate is exactly correct for only one driving speed. At all other speeds, there will be a side thrust either outward or inward, relative to the curve center, which must be offset by side friction. Refer to Chapter 3, Section 3.3 of the 2018 AASHTO GDHS for further discussions on side friction.

Refer to Section 6.5 of this Guide for superelevation of detours.

6.3.5.2 Standards for Superelevation

The CDOT Standard Plans – M & S Standards on Superelevation (CDOT, 2019) give the required rate of superelevation for the various radius lengths at different design speeds for the maximum superelevation rate. Refer to CDOT Standard Plans – M & S Standards M-203-11, and M-203-12. The tables in the M&S Standards use Method 5 and are equivalent to 2018 AASHTO GDHS Tables 3-8, 3-9, and 3-10. Method 2 may be used for superelevation distribution for facilities in urban areas.

In general, the highest superelevation rate used on roadways in climates with snow and ice should be 8%. In practice, the maximum superelevation rate chosen on Colorado highways is typically either 6% or 8% after the designer considers the four factors discussed in Chapter 3, Section 3.3.3, of the 2018 AASHTO GDHS.

While a maximum superelevation rate of 8% is generally practical elsewhere, a maximum superelevation rate of 6% is typically chosen in urban areas. The selection of 6% as the maximum superelevation rate is also common on viaducts where freezing and thawing conditions are likely because bridge decks generally freeze more rapidly than other roadway sections. Where roadways are intermittently elevated on bridges and viaducts, the lower superelevation rate should be used throughout for design consistency.

The maximum superelevation rate may be less than shown on CDOT Standard Plans – M & S Standards (CDOT, 2019) when the designer determines that the lower rate is required because of traffic congestion or extensive marginal development that act to restrict top speeds.

For divided roadways where the median width is less than 60 feet, future inside widening of bridges or providing additional lanes requires the designer to properly plan the superelevation. Things to consider are:

- Superelevation pivot point.
- Vertical clearance.
- Superelevation transitions.

6.3.5.3 Superelevation Transition

Superelevation runoff is the term denoting the length of roadway needed to accomplish the change in cross slope from a section with the adverse crown removed (one side superelevates at normal crown slope, the other side at zero slope) to the fully superelevated section, or vice versa. When a spiral is used, its length is used to accommodate the superelevation runoff.

Tangent runout is the term denoting the length of roadway needed to accomplish the change in cross slope from a normal crown section to a section with the adverse crown removed (one side superelevates at normal crown slope, the other side at zero slope), or vice versa.

The length of the tangent runout is determined by the amount of adverse crown to be removed and the rate at which it is removed. This rate of removal should be the same as the rate used to affect the superelevation runoff.

The location, with respect to the curve, and the various lengths of the superelevation transitions are shown on the CDOT Standard Plans - M & S Standards on Superelevation (CDOT, 2019).

6.3.5.4 Design for All Rural Roadways, Urban Freeways and High-Speed Urban Streets

On most roadways where speed is relatively high and relatively uniform, horizontal curves are generally superelevated and successive curves are generally balanced to provide a smooth riding transition from one curve to the next.

Refer to Chapter 3, Section 3.2.3.2, of the 2018 AASHTO GDHS, for the recommended maximum superelevation rates for all rural roadways, urban freeways, and high-speed urban streets.

6.3.5.5 Design for Low-Speed Urban Streets

Although superelevation is advantageous for traffic safety on higher speed, continuous flow roadways, various factors often combine to make its use impractical in many built-up areas. Such factors include wider pavement areas; need to match the grade of adjacent property; surface drainage considerations; pedestrian mobility challenges; and frequency of cross streets, alleys and driveways. Therefore, horizontal curves on low-speed streets in urban areas are frequently designed without superelevation, counteracting the centrifugal force solely with side friction. On these curves, traffic entering a curve to the left has an adverse or negative superelevation due to the normal crown, but with flat curves and lower speeds the resultant friction required to counteract both the centrifugal force and the negative superelevation is small.

On successively sharper curves for the same design speed, the maximum degree of curvature or sharpest curve without superelevation is reached when the side friction factor developed to counteract centripetal force and adverse crown reaches the maximum allowable value based on safety and comfort considerations. For travel on sharper curves, superelevation is needed.

The maximum superelevation rate of -2% (normal crown) in Table 6-2 on the next page establishes the minimum radius for each speed below which superelevation is not provided on local streets in residential and commercial areas but could also be considered for reverse curves at continuous flow intersections and special circumstances to accommodate proper drainage of the roadway. A maximum superelevation rate of 4% or 6% is commonly used. The cross slope of the roadway will determine the minimum radii to be used in Table 6-2. An adverse cross slope requires a larger radius. The maximum curvature for a given design speed is defined for low-speed urban streets when both the maximum superelevation rate and the maximum allowable side friction factors are utilized.

Refer to Chapter 3, Section 3.3.6, of the 2018 AASHTO GDHS for more information.

6.3.6 Widths for Turning Roadways at Intersections

Refer to Chapter 8 of this Guide for design of intersections.

Table 6-2 Minimum Radii and Superelevation for Low-Speed Urban Streets

e	R (ft) for Design Speed (mph)						
(%)	15	20	25	30	35	40	45
-2.0	50	107	198	333	510	762	1039
-1.5	49	105	194	324	495	736	1000
0	47	99	181	300	454	667	900
1.5	45	94	170	279	419	610	818
2.0	44	92	167	273	408	593	794
2.2	44	91	165	270	404	586	785
2.4	44	91	164	268	400	580	776
2.6	43	90	163	265	396	573	767
2.8	43	89	161	263	393	567	758
3.0	43	89	160	261	389	561	750
3.2	43	88	159	259	385	556	742
3.4	42	88	158	256	382	550	734
3.6	42	87	157	254	378	544	726
3.8	42	87	155	252	375	539	718
4.0	42	86	154	250	371	533	711
4.2	41	85	153	248	368	528	703
4.4	41	85	152	246	365	523	696
4.6	41	84	151	244	361	518	689
4.8	41	84	150	242	358	513	682
5.0	41	83	149	240	355	508	675
5.2	40	83	148	238	352	503	668
5.4	40	82	147	236	349	498	662
5.6	40	82	146	234	346	494	655
5.8	40	81	145	233	343	489	649
6.0	39	81	144	231	340	485	643

Source: 2018 AASHTO GDHS.

Notes:
Computed using Superelevation Distribution Method 2.
Superelevation may be optional on low-speed urban streets.

6.3.7 Traveled Way Widening on Horizontal Curves

Curve widening is used primarily on pavements of substandard width or curvature to support the off tracking of larger design vehicles as described in the following sections. This can be especially important when bicycle lanes or shoulders are located adjacent to tighter horizontal curves and would otherwise require a larger vehicle to track into the path of a cyclist. On open roadway curves, the pavement should be widened as shown in Chapter 3, Section 3.3.10, of the 2018 AASHTO GDHS, which is based on a WB-62 design vehicle.

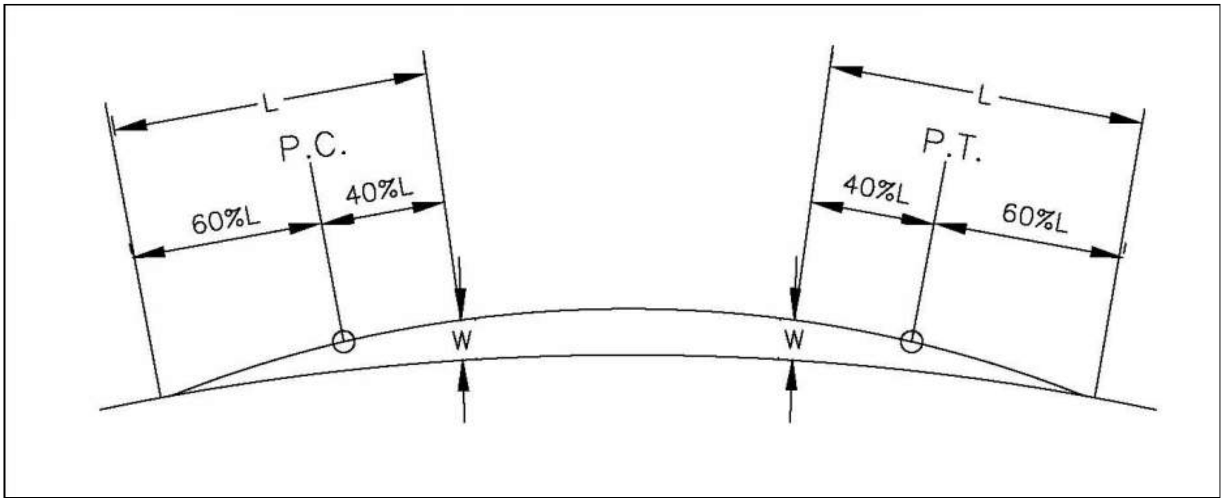
Refer to Chapter 3, Section 3.3.10, of the 2018 AASHTO GDHS for more information.

6.3.7.1 Attainment of Widening on Curves

Widening should be attained gradually on the approaches to a simple curve and spiral curve, as shown in Figure 6-10 and Figure 6-11 respectively, to ensure a reasonably smooth alignment of the edge of the pavement and to fit the paths of vehicles entering or leaving the curves.

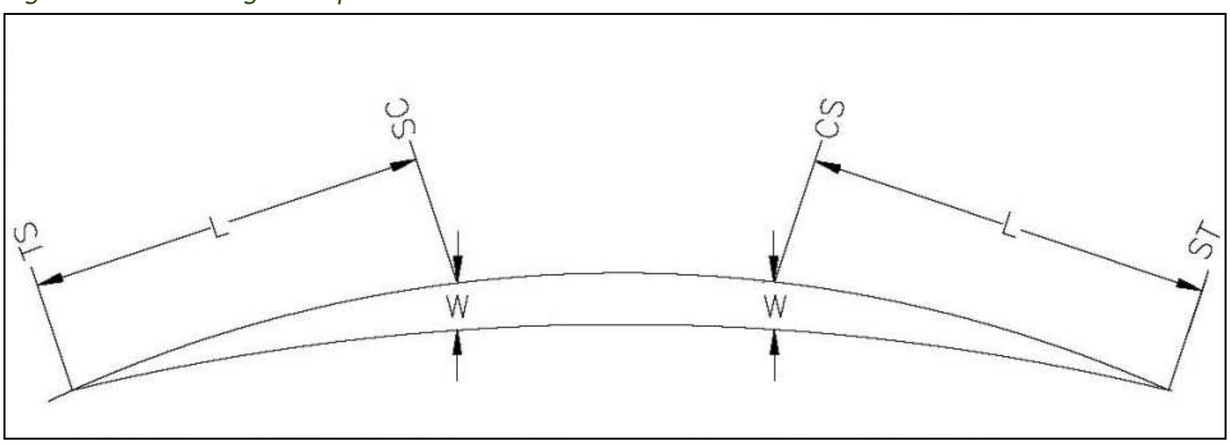
Widen (W) on the inside edge of the pavement and extend the transition over the same transition length (L) as the superelevation runoff.

Figure 6-10 Widening on a Simple Curve



Source: Section 6C.08 of the MUTCD.

Figure 6-11 Widening on a Spiral Curve



Source: Section 6C.08 of the MUTCD.

When V ≤ 40 mph $L \geq \frac{WV^2}{60}$

When V > 40 mph $L > WV$

Where:
W = Width of widening (ft)
V = Design Speed (mph)

Example:

Given:
Pavement = 22 feet
Degree of curve = 9°
Radius = 636.62 feet
Icing conditions frequently exists, crowned highway

When V=30 mph
From Table 3-26b of the GDHS **(1)**, Widening (W) = approximately 3.5 feet
From CDOT *Standard Plans – M&S Standards* **(3)**, Superelevation
Crowned Highways, L=100 feet

Since V≤40, $\frac{WV^2}{60} = \frac{3.5(30)^2}{60} = 52.5$ feet

And $L > \frac{WV^2}{60}$ OK

When V=50 mph and curve radius = 760 feet with other parameters same as above,
From Table 3-36b of the GDHS **(1)**, Widening (W) = approximately 4.3 feet
From CDOT *Standard Plans – M&S Standards* **(3)**, Superelevation
Crowned Highways, L= 240 feet
Since V>40 mph, WV=4.3(50) = 215 feet
And L>WV ……. OK

6.3.8 Transition Design Controls

Refer to Chapter 3, Section 3.3.8, of the 2018 AASHTO GDHS for more information.

6.3.9 Pavement Transitions

6.3.9.1 General

A pavement transition is the area of variable pavement width encountered when changing from one roadway width, or section, to another.

6.3.9.2 Two Lanes to Multilane Divided

This type of transition should be made only where sight distance is not restricted, such as on a tangent section or on a flat curve. On a tangent section, the transition may be accomplished on either one or both lanes. A maximum of 1 degree reversing curves and a minimum total transition length of 1,000 feet should be used. This minimum length shall also apply where the transition is accomplished on a curve.

Design standards of the two lanes should be consistent with those of the multilane facility.

6.3.9.3 Other Transitions

Other, more simplified, transitions occur at speed-change lanes, truck climbing lanes, and widening for curves. All transitions shall be consistent with the design speed for the facility.

6.3.10 Off Tracking

As stated in Chapter 3, Section 3.3.9, of the 2018 AASHTO GDHS, "Off tracking is the characteristic, common to all vehicles, although it is much more pronounced with larger vehicles, where the rear wheels do not precisely follow the same path as the front wheels when the vehicle traverses a horizontal curve or makes a turn. When a vehicle traverses a curve without superelevation at low speed, the rear wheels track inside the front wheels. When a vehicle traverses a superelevated curve, the rear wheels may track inside the front wheels more or less than they do for a curve without superelevation. This is because of the slip angle of the tires with respect to the direction of travel, which is induced by the side friction developed between the pavement and rolling tires. The relative position of the wheel tracks depends on the speed and the amount of friction developed to sustain the lateral force not offset by superelevation or, when traveling slowly, by the friction developed to counteract the effect of superelevation not compensated by lateral force. At higher speeds, the rear wheels may even track outside the front wheels."

Refer to Chapter 3, Section 3.3.9, of the 2018 AASHTO GDHS for more information.

6.3.11 General Controls for Horizontal Alignments

Refer to Chapter 3, Section 3.3.13 of the 2018 AASHTO GDHS for more information.

6.3.12 PBPD, MM, and CSS Considerations

Design options for determining a rock cut or widening the median on the I-70 Mountain Corridor included Context Sensitive Solutions (CSS) and PBPD considerations.

The walls in the median on the I-70 Mountain Express Lane have always been considered an interim solution. Clear Creek County stakeholders valued an open median area and did not want I-70 to feel like an urban corridor. However, because of the geology, widening to the rock side would have required blasting and cutting the rock back, resulting in a 20-foot widening instead of the 6-foot widening needed for the additional lane. The rock cut would be considered much more permanent than the walls in the median, which could be removed in the future.

6.4 Vertical Alignment

6.4.1 Terrain

The grade line is a reference line by which the elevation of the pavement and other features of the roadway are established. It is controlled mainly by topography and structure clearances, but the factors of horizontal alignment, safety, sight distance, design speed, construction costs, and the performance of heavy vehicles on a grade also must be considered.

In flat terrain, the elevation of the grade line is often controlled by drainage considerations.

In rolling terrain, an undulating grade line is often desirable, both from a standpoint of construction and maintenance economy. However, undulating grade lines involving substantial lengths of descending grades should be evaluated for their effect upon traffic operations and safety since they may result in undesirably high downgrade truck speeds.

In mountainous terrain, the grade line is usually closely dependent upon physical controls, although adverse grades should be avoided. On divided roadways, independent profiles with grade differential should be considered. Broken-back grade lines should always be avoided.

On long grades, it is preferable to flatten the grades near the top of the ascent particularly on low design speed roadways.

In all cases, the consideration of adequate sight distance requirements and other safety factors should take precedence over construction and maintenance costs.

6.4.2 Position with Respect to Cross Section

The grade line should generally coincide with the axis of rotation for superelevation.

- On undivided roadways, the grade line should coincide with the roadway centerline.
- On ramps and interstate-to-interstate connections, the grade line is generally positioned at the left edge of the traveled way. Either edge of traveled way or centerline may be used on multilane facilities.
- On divided roadways, the grade line should be positioned at the centerline of the median for paved medians 60 feet wide or less.

In selecting where the grade line is in relation to the axis of rotation for superelevation, the designer should consider the following:

- Future widening.
- Mountainous terrain.
- Right of way constraints.
- Topographic features.
- Earthwork.
- Matching existing typical sections (as-constructed plans).

Table 6-3 on the next page shows clearances to structures and obstructions for the various functional classifications within the right of way.

6.4.3 Standards for Grades

6.4.3.1 Minimum Grades

Flat and level grades on uncurbed pavements are acceptable when the pavement is adequately crowned to drain the surface laterally (refer to Chapter 4 of this Guide).

With curbed pavements, longitudinal grades should be sufficient to facilitate curb drainage. A minimum curb flowline grade for the usual case is 0.5%, but a grade of 0.3 % may be used where there is a high-quality pavement adequately crowned and supported on firm subgrade. With curbed sections on sag vertical curves, a grade of at least 0.30% should be retained at the curb and gutter line by increasing the crown slope or, if necessary, shortening the vertical curve length to keep the crown slope from exceeding the maximum value given in Chapter 4.

6.4.3.2 Maximum Grades

The desirable maximum grades for the various functional classifications are shown in Table 6-4. The maximum design grade should be used infrequently; in most cases, grades should be less than the maximum design grade.

The term "critical length of grade" is used to indicate the maximum length of a designated upgrade upon which a loaded truck can operate without an unreasonable reduction in speed. On grades longer than "critical," consideration of auxiliary climbing and decent lanes should be made.

Refer to Chapter 3, Section 3.4.2, of the 2018 AASHTO GDHS for more information.

6.4.4 Methods for Increasing Passing Opportunities on Two-Lane Roads

Passing lanes can reduce crash potential on two lane roads. The designers should look for opportunities to introduce passing lanes where feasible and based on the project purpose and need.

Refer to Chapter 3, Section 3.4.4, of the 2018 AASHTO GDHS for more information.

Table 6-3 Minimum Vertical Clearances Within Right of Way

	HIGHWAY UNDERPASSES		RAILWAY UNDERPASSES ***		OVERHEAD WIRES	
	HORIZONTAL	**VERTICAL***	**HORIZONTAL**	**VERTICAL* ‡**	**HORIZONTAL▲**	**VERTICAL***
Local Rural Roads					**A**	
Local Urban Streets**		15 feet			**B**	
Rural Collectors					**C**	
Urban Collectors**	**E**		**F**	**G**		**H**
Rural Arterials					**D**	
Urban Arterials**		16.5 feet#				
Freeways						

A 10 feet from edge of traveled way.

B Use A when practical, but in any event, provide a minimum of 2 feet from curb face or from shoulder edge. See *AASHTO Interim Revisions to Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (AASHTO, 2020).

C ≤40mph use **A**, ≥45mph use **D.**

D Use a clear zone according to the *AASHTO Roadside Design Guide* (AASHTO, 2011) or provide guard rail.

E Carry full approach roadway section through structure; minimum clearance from edge of through traffic lanes to walls, piers, or toes of slopes shall correspond to **D**, but, desirably, should not be less than 30 feet, unless guard rail is used. For tunnels and depressed roadways see the *AASHTO Standard Specifications for Highway Bridges* (AASHTO, 2012).

F See *CDOT Bridge Design Manual* (CDOT, 2023).

G Minimum requirements vary by railroad. BNSF requires 23.5 feet, UPRR requires 23.33 feet per UPRR-BNSF Guidelines for Grade Separation Projects-Rev 2016 (Union Pacific, 2016). PUC and federal minimum requirement is 23 feet per AREMA.

H Communication lines and power lines in accordance with Table 1 of the *State Utility Accommodation Code (CDOT, 2021)*:

Type of Conductor, Cable & Voltage	Over Roadway Template (feet)	Outside Roadway Template (feet)
Insulated communication conductors & cables; messengers; grounded or effectively insulated guys; effectively grounded neutral conductors;230C1 supply cables.	24	20
Noninsulated communication conductors; supply cables 0-750 Volts (multiplex wire)	24	20.5
Open Supply Conductors 0-750 Volts	24	21
Open Supply Conductors >750 Volts to 22 kVolts	25	23
Voltages exceeding 22 kVolts to 50 kVolts	25◆	23◆
Voltages exceeding 50 kVolts	25.5◆◆	23◆◆

◆ plus 0.4 inch per 1,000 Volts in excess of 22 kVolts

◆◆ plus [0.4 inch per 1,000 Volts in excess of 22 kVolts] X [1.0 + (.03 per 1,000 feet above 3,300 feet above sea level)] or alternate method for voltages exceeding 98 kVolts

Voltages are phase to ground for effectively grounded circuits and those other circuits where all ground faults are cleared by promptly de-energizing the faulted section, both initially and following subsequent breaker operations

Source CDOT Utility Accommodation Code (2021) (2 C.C.R. 601-18)

Table 6-4 Relation of Maximum Grades to Design Speed

Type of Terrain	Maximum Grade (%) for Design Speed (mph)										
	20	30	40	45	50	55	60	65	70	75	80
RURAL AND URBAN FREEWAYS[a] [2018 AASHTO GDHS Table 8-1]											
LEVEL					4 [c]	4 [c]	3 [c]	3	3	3	3
ROLLING					5 [c]	5 [c]	4 [c]	4	4	4	4
MOUNTAINOUS					6	6	6	5	5	--	--
RURAL ARTERIALS [2018 AASHTO GDHS Table 7-2]											
LEVEL			5 [c]	5 [c]	4 [c]	4 [c]	3	3	3	3	3
ROLLING			6 [c]	6 [c]	5	5	4	4	4	4	4
MOUNTAINOUS			8	7	7	6	6	5	5	5	5
URBAN ARTERIALS [2018 AASHTO GDHS Table 7-4]											
LEVEL		8	7	6	6	5	5				
ROLLING		9	8	7	7	6	6				
MOUNTAINOUS		11	10	9	9	8	8				
RURAL COLLECTORS [b] [2018 AASHTO GDHS Table 6-2]											
LEVEL	7 [c]	7 [c]	7	7	6	6	5				
ROLLING	10 [c]	9	8	8	7	7	6				
MOUNTAINOUS	12	10	10	10	9	9	8				
URBAN COLLECTORS [b] [2018 AASHTO GDHS Table 6-8]											
LEVEL	9 [c]	9	9	8	7	7	6				
ROLLING	12 [c]	11	10	9	8	8	7				
MOUNTAINOUS	14 [c]	12	12	11	10	10	9				
LOCAL RURAL ROADS [2018 AASHTO GDHS Table 5-2]											
LEVEL	8 [d]	7	7	7	6	6	5				
ROLLING	11	10	10	9	8	7	6				
MOUNTAINOUS	16	14	13	12	10	10	--				

a Grades 1% steeper than the value shown may be used in urban areas.

b Maximum grades shown for rural and urban collector conditions of short lengths (less than 500 feet) and on one-way downgrades may be 2% steeper.

c Design speed shown not recommended (less than minimum).

d Use only on urban streets.

6.4.5 Passing Lanes

Passing lanes on two-lane highways improve traffic operations on roadway sections of lower capacity and on lengthy sections with no passing opportunities (greater than 6 miles).

The logical location for a passing lane is where passing sight distance is restricted, but adequate sight distance should be provided at both the add and drop lane tapers. A minimum sight distance of 1,000 feet on the approach to each taper is recommended. The selection of the passing lane location should consider the location of intersections and high-volume driveways, as well as physical constraints such as bridges and culverts, that could restrict provision of a continuous shoulder.

Use the following design procedure to identify the need for passing sections on two-lane roadways:

1. Design horizontal and vertical alignment to provide as much of the roadway as practical with passing sight distance. Refer to the Passing Sight Distance column in Table 6-1.

2. Where the design volume approaches capacity, recognize the effect of lack of passing opportunities in reducing the level of service.

3. Determine the need for climbing lanes.

4. Where the extent and frequency of passing opportunities made available by application of Criteria 1 and 3 are still too few, consider the construction of passing lane sections.

Passing lane sections should be sufficiently long to permit several vehicles in a line behind a slow-moving vehicle to pass before returning to the normal cross section of two-lane roadway. The minimum length, excluding tapers, should be 1,000 feet. A lane added to improve overall traffic operations should be long enough, over 0.5 mile, to provide a substantial reduction in traffic platooning, as shown in Table 3-5. Consideration should also be given to implementing a pavement marking taper in accordance with the MUTCD that redirects all traffic into the outside travel lane as a way to encourage slower moving traffic to move to the right and allow drivers to complete their passing maneuver on the left.

Table 6-5 Optimal Passing Lane Lengths for Traffic Operations Efficiency

One-Way Flow Rate (vehicles/hour)	Passing Lane Length (miles)
100-200	0.50
201-400	0.50-0.75
401-700	0.75-1.00
701-1200	1.00-2.00

Source: Table 3-31 of the 2018 AASHTO GDHS.

The transition tapers at each end of the added lane section should be designed to encourage safe and efficient operation. The lane drop taper should be computed from the MUTCD formulas below.

For S ≥ 45 mph, $L = WS$

For S < 45 mph, $L = \frac{WS^2}{60}$

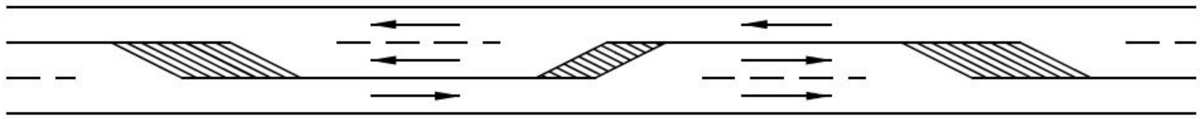
Where:
L = Length of taper (ft)
W = Width of lane (ft)
S = Posted Speed (mph)

The recommended length for the lane addition taper is half to two-thirds of the lane drop length. The transitions should be located where the change in width is in full view of the driver.

6.4.6 2+1 Roadways

The 2+1 roadway concept has been found to improve operational efficiency and reduce crashes along some two-lane highways. The 2+1 concept provides a continuous three-lane cross section with alternating passing lanes (Figure 6-12). This configuration may be suitable for corridors with traffic volumes higher than can be served with isolated passing lanes, yet not high enough to require a consistent four-lane cross section.

Figure 6-12 Schematic for 2+1 Roadways



Source: Figure 3-33 of the 2018 AASHTO GDHS.

A 2+1 roadway generally operates two levels of service higher than a conventional two-lane road with the same traffic volume. 2+1 roadways should not generally be considered where the volume exceeds 1,200 vehicles per hour in one direction. 2+1 roadways should be used on level or rolling terrain where climbing lanes should be used on mountainous terrain or steep grades as an alternative. Intersection locations should be considered when determining passing locations to minimize turning movements within passing lanes or to provide dedicated left-turn lanes at intersections.

6.4.7 Turnouts

It is not always economically feasible to provide passing lanes or continuous wide shoulders on roadways through deep rock cuts or where other conditions limit the cross section width. In such cases, consideration should be given to use of intermittent sections of shoulder or turnouts along the roadway. Such turnouts provide an area for emergency stops and allow slower-moving vehicles to pull out of the through lane so following vehicles can pass.

Turnouts should be located so that approaching drivers have a clear view of the entire turnout to determine whether the turnout is available for use. The sight distance for vehicles re-entering the road should also be reconsidered. Refer to Table 3-32 of the 2018 AASHTO GDHS for recommended lengths of turnouts, including taper.

Bicycle turnouts can be utilized where there is a lack of shoulder space. Refer to Chapter 13 of this Guide for design guidance.

6.4.8 Emergency Escape Ramps

Emergency escape ramps (runaway truck ramps) are widely used in Colorado because of the mountainous terrain and steep grades that are present throughout a large portion of the state. There are many long and descending grades that need to be accounted for with larger vehicles. For design elements, design guidelines, and more information refer to Chapter 3, Section 3.4.5, of the 2018 AASHTO GHDS.

6.4.9 Vertical Curves

Properly designed vertical curves should provide adequate sight distance, safety, comfortable driving, good drainage, and pleasing appearance.

Vertical curves are parabolic. Figure 6-13 gives the necessary mathematical relations for computing a vertical curve, at either crests or sags.

Minimum lengths of sag vertical curves are typically controlled by headlight sight distance that should be approximately the same as stopping sight distance. In areas with adequate overhead lighting where headlight sight distance is not a limitation, the driver comfort factor can be used to determine the minimum length of sag vertical curve. Sag vertical curve lengths satisfying the comfort factor are approximately 50% of that needed to satisfy headlight sight distance criterion.

Refer to Chapter 3, Section 3.4.6 of the 2018 AASHTO GDHS for more information.

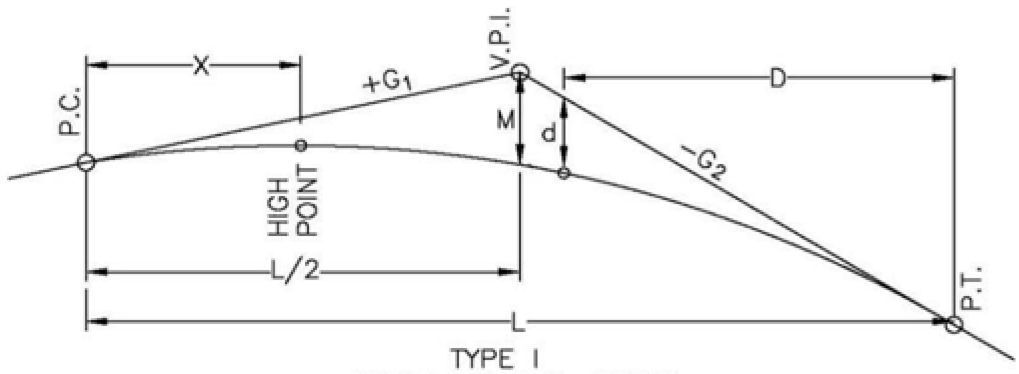
Vertical curves are not required where algebraic grade difference is less than 0.20%. In rural applications, the minimum length of vertical curves on main roadways, both crest and sag, should be 300 feet. For other applications, the minimum length should be about three times the design speed.

Vertical curves that have a level point and flat sections near their crest or sag should be evaluated for drainage where curbed pavements are used.

Values of K = 167 or greater should be checked for drainage. $(K = \frac{L}{A})$; where L is the length of curve in feet, and A is the algebraic difference in grade. K value is a coefficient by which the algebraic difference in grades (A) may be multiplied to determine the length in feet (L) of the vertical curve that will provide minimum sight distance.

Also, vertical curves that are long and flat may develop poor drainage at the level section. This difficulty may be overcome by adjusting the flow line of the ditch section.

Figure 6-13 Vertical Curves



TYPE I
CREST VERTICAL CURVE

L = LENGTH OF CURVE IN STATIONS

G_1 AND G_2 = GRADES IN FEET PER 100 FEET(%)

X = DISTANCE FROM THE P.C. OF THE CURVE IN STATIONS

d = DISTANCE IN FEET

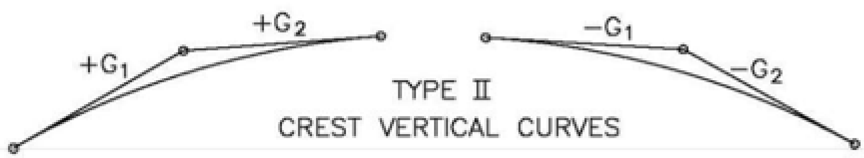
D = DISTANCE IN STATIONS

$$M = \frac{L\,(\text{ALGEBRAIC DIFFERENCE IN GRADES})}{8}$$

$$d = \frac{(\text{ALGEBRAIC DIFFERENCE IN GRADES})}{2L} \times D^2 \quad \text{OR} \quad d = 4M\left[\frac{D}{L}\right]^2$$

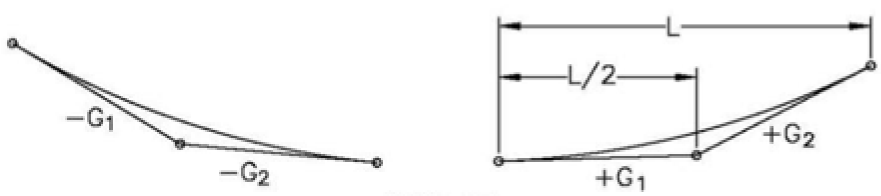
TO DETERMINE HIGH POINT
(OR LOW POINT ON SAG VERTICAL CURVES) USE THE FOLLOWING:

$$X = \frac{G_1 \times L}{(\text{ALGEBRAIC DIFFERENCE IN GRADES})}$$



TYPE II
CREST VERTICAL CURVES

TYPE III
SAG VERTICAL CURVE



TYPE IV
SAG VERTICAL CURVES

6.4.10 Climbing Lanes

On long, steep grades, a climbing lane for the slow-moving vehicles may be required. Criteria for establishing the need for such lanes are usually based on traffic volume, capacities, percent of trucks, grades, speeds, and level of service. Because of many variables, no set of conditions can be properly described as typical. A detailed analysis should be made wherever climbing lanes are being considered. A discussion of the analytical approach to be followed is presented in Chapter 3-4 of the 2018 AASHTO GDHS.

The following three criteria, reflecting economic considerations, should be satisfied to justify a climbing lane:

- Upgrade traffic flow in excess of 200 vehicles per hour.
- Upgrade truck flow rate in excess of 20 vehicles per hour.
- One of the following conditions exist:
  - A 10 mph or greater speed reduction is expected for a typical heavy truck or recreational vehicle.
  - Level of service (LOS) E or F exists on the grade.
  - A reduction of two or more LOS is experienced when moving from the approach segment to the grade.

The width of the climbing lane should be the same width as the regular traffic lanes. The beginning of the climbing lane should be preceded by a tapered section with a taper ratio of 25:1, and at least 150 feet long.

Desirably, the shoulder on the outer edge of a climbing lane should be as wide as the shoulder on the normal two-lane section. Conditions, however, may dictate otherwise, particularly when the climbing lane is added to an existing roadway. A usable shoulder of 4 feet wide or greater is acceptable.

Where there is a known bicycle route on a long ascent, bicycle climbing lanes could be considered. In mountainous areas, a 4- to 6-foot bicycle climbing lane can provide operational and safety benefit. When combined with a 4-foot shoulder, the bicycle lane + shoulder can be used in an emergency for pull-off.

The ideal design would be to extend the climbing lane to a point beyond the crest, where a typical truck could attain a speed that is within 10 mph of the speed of the other vehicles with the desirable speed being at least 40 mph, approximately at a LOS D. Even this may not be practical in many instances because of the unduly long distance required for trucks to accelerate to the desired speed. For such a condition, the climbing lane should end at a point where the truck can return to the normal lane without creating undue hazard. This would be feasible where the sight distance becomes sufficient to permit passing with safety when there is no oncoming traffic or preferably at least 200 feet beyond this point. In addition, a corresponding length of taper should be provided to permit the truck to return to the normal lane.

For example, on a roadway where the safe passing sight distance becomes available 100 feet beyond this point, the truck lane should extend 100 feet:

- Plus 200 feet or 300 feet beyond the crest,
- Plus an additional length for taper, preferably at a ratio of 50:1 but with a taper length of at least 200 feet.

Figures 3-24 and 3-25 of the 2018 AASHTO GDHS show the relationship between rate and length of grade for several reductions in speed. The 10 mph speed reduction curve is used as the design guide.

Climbing lanes can also be a bicycle facility, particularly on two-lane Roads in the C1 context classification. Refer to Chapter 13 of this Guide for design details.

The method for determining passing lane location is described in Section 3.4.3 (page 3-125) of the 2018 AASHTO GDHS.

6.5 Combination of Horizontal And Vertical Alignment

Refer to Chapter 3, Section 3.5, of the 2018 AASHTO GDHS for more information.

To avoid the possibility of introducing serious hazards, coordination is required between horizontal and vertical alignment. Particular care must be exercised to maintain proper sight distance. Where grade line and horizontal alignment will permit, it is desirable to superimpose vertical curves on horizontal curves. This reduces the number of sight distance restrictions and makes changes in the profile less apparent, particularly in rolling country. Care should be taken, however, not to introduce a sharp horizontal curve near a pronounced summit or grade sag. This is particularly hazardous at night.

Horizontal curvature and profile grade should be made as flat as possible at roadway intersections.

On divided roadways, variation in the width of median and the use of separate profiles and horizontal alignment should be considered to derive the design and operational advantages of one-way roadways.

6.6 Guidelines For Designing Detours

For the purpose of applying these guidelines, a detour is any temporary routing of traffic off its usual course, including the use of existing alternate routes or use of modified lane widths on the main roadway.

The following criteria guidelines are recommended when designing a detour. Items are those that must be addressed when requesting detour approval. This is not a design policy, and circumstances may often justify departure from these guidelines. For further reference, refer to CDOT Form 518.

6.6.1 Detour Design Speed

The design speed of a detour should be as close to the mainline operating speed as possible. Every effort should be made to keep the speed differential within 10 mph so as not to affect the safety and operation of the facility, although in some cases a maximum of 15 mph or more may be necessary. As truck traffic increases so should the emphasis on providing the lowest possible speed differential. An exception may be posted city streets. Refer to Chapter 3 of this Guide.

6.6.2 MM, PBPD, and CSS Considerations

6.6.2.1 Pedestrian Accommodations

To the extent possible, construction impacts on sidewalks and pedestrian ramps should be minimized. Where sidewalk narrowing or closure is unavoidable, pedestrians should be provided with a convenient and accessible path that replicates as nearly as practical the existing facility. If the temporary traffic control affects an accessible and detectable pedestrian facility, accessibility and detectability shall be maintained along the alternate pedestrian route (refer to MUTCD 6D). This includes providing a smooth continuous hard surface, detectable channelization or barriers, and ramps at grade changes.

When sidewalks are impacted by construction, the best solution is to accommodate pedestrians with a sidewalk diversion as opposed to a detour. A sidewalk diversion is a safe, protected, accessible route that runs parallel to the existing sidewalk, typically utilizing the adjacent parking lane, travel lane or roadway shoulder with a detectable and compliant vertical barrier. Sidewalk diversions provide a predictable, accessible route that minimizes the additional distance pedestrians must walk and eliminates pedestrians walking in active vehicle travel lanes instead of using a detour. This is especially true on high traffic volume arterials that may not have sufficient pedestrian crossings to provide a reasonably short detour route and may increase instances of pedestrians crossing mid-block at uncontrolled locations.

If unavoidable, sidewalk detours should meet the same accessibility and detectability requirements as a sidewalk diversion. Special care should be paid to advance notification of sidewalk closures (with detectable edges on all signage and barriers). Audible information devices may be used to verbally describe detour routes to pedestrians with visual disabilities.

6.6.2.2 Transit Accommodations

To the extent possible, construction impacts to transit stops should be minimized. Where possible, an ADA accessible temporary facility can be implemented in a parking lane to provide uninterrupted transit service. If no other alternative is feasible, the work zone designer should work with the transit operator to temporarily relocate the transit stop outside of the work zone within a reasonable distance of the existing stop, and accessible routes to the stop should be provided if not already in place.

6.6.2.3 Bicycle Accommodations

To the extent possible, construction impacts on linear bicycle facilities such as bicycle lanes and shared use paths should be minimized. The context of the bicycle facility is critical to designing safe and effective temporary traffic control plans, with urban and rural contexts requiring differing approaches based on traffic volumes and speeds.

For all contexts, if impacts to linear bicycle facilities are necessary for project construction, then a viable alternative should be provided immediately adjacent to the existing facility where possible. Temporary bicycle facilities should maintain a similar quality as the existing facility (width, protection, surface) which may require removal of parking lanes, underutilized traffic lanes or shoulders. Narrowing of parking lanes, traffic lanes or shoulders should also be considered. Maintaining separate temporary bicycle facilities is critical where high traffic volumes and speeds would make a shared roadway treatment unsafe. If an on-roadway separate facility is infeasible on high speed/volume roadways, an off-roadway temporary path may be provided if space is available. In situations where a shared roadway or signed bicycle route requires flaggers for an alternating one-way operation, processing bicycle and vehicle queues separately will maintain separation of users. Detour routes or vehicle shuttles should only be employed when necessary for safety reasons (especially in rural contexts where distances may be greater) and should consider detour length, grade, shoulder width, and surface condition (grates, surface type, etc.)

6.6.3 Detour Clear Zone

Criteria corresponding to the speed, geometry, and traffic of the existing roadway should be used to design the detour. Detour culverts should be included in the clear zone analysis. For more information refer to Chapter 9 of the 2011 AASHTO RSDG.

Portable barriers may often be the most cost-effective method of resolving detour clear zone problems.

6.6.4 Detour Typical Sections

Lane Width. It is desirable to maintain the width of the main roadway, but if this is not practical, the following guidelines apply:

- A minimum lane width of 10 feet may be used if all of the following conditions are satisfied:
  - The truck annual average daily traffic (AADT) is less than 50.
  - The design speed is ≤ 45 mph.
  - No curves are greater than 7 degrees.
- If one or more of the above conditions fails, 11-foot or wider lanes should be used.

- If any of the following conditions apply, 12-foot lanes should be used:
  - Design speed of 55 mph or more.
  - The truck AADT is greater than 300.
  - The road is classified as an arterial or on an arterial truck network system.
- If main roadway lanes are 11 feet, the detour may retain 11-foot width.

Shoulder Width. Desirable shoulder width is 4 feet. Two feet minimum is required.

6.6.5 Detour Barrier

A detour barrier is required when there are any hazards within the clear zone, including drop-offs or steep slopes. It may also be required for the protection of workers. Shoulder drop offs 3 inches or greater shall be mitigated within 24 hours.

When a barrier is used, it shall be installed at least 2 feet offset from edge of pavement with an appropriate distance from back of barrier to obstruction (refer to CDOT Standard Plans - M & S Standards [CDOT, 2019]). If shoulders are not provided, the barrier shall be installed 2 feet from the edge of the traveled lane. Where the situation allows, an offset of 4 feet from the travel lane should be provided.

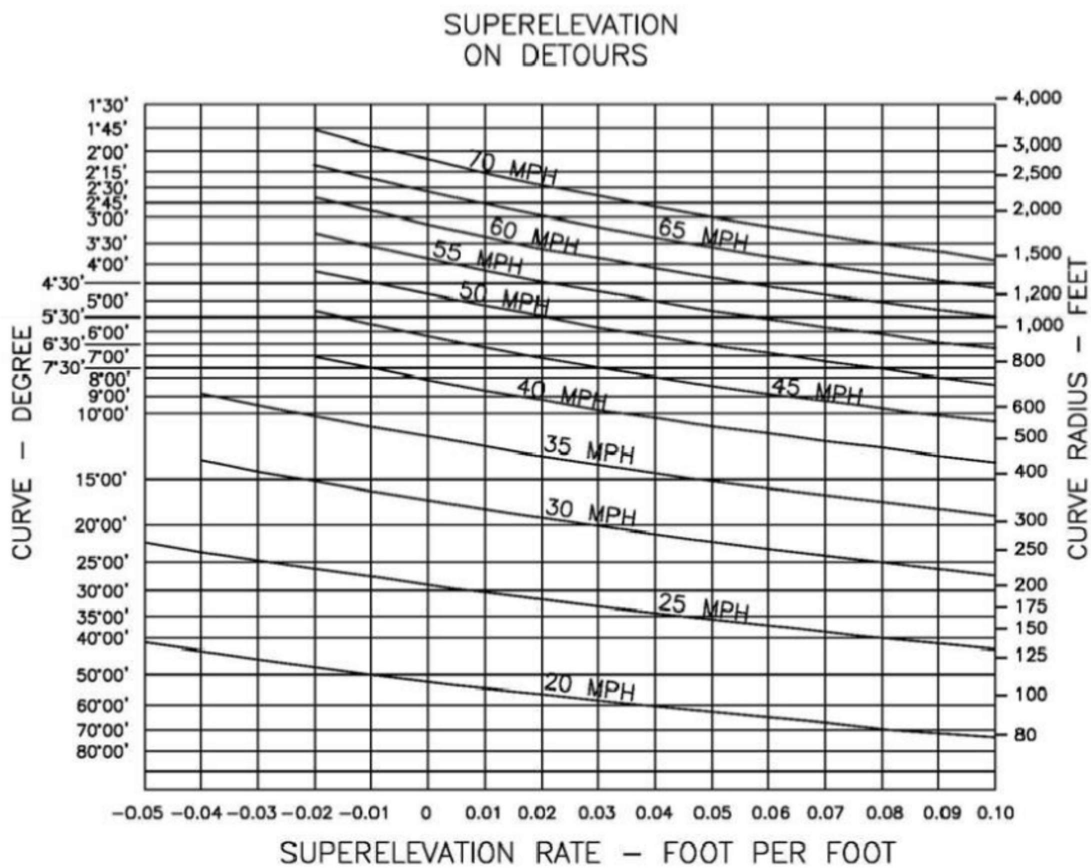
6.6.6 Detour Surfacing

An asphalt surface is usually functionally superior to gravel, although gravel may have economic and other advantages. Asphalt should be used if detour speed is over 40 mph or the detour will be used for three weeks or more. Consult Region Materials Engineer for detour pavement design. Refer to the *CDOT Project Development Manual* (CDOT, [2013] 2022) for additional information.

6.6.7 Detour Superelevation

Figure 6-14 gives the rate of superelevation to be used on detours during construction of culverts, bridge replacement or widening, or repairs when proper construction signing is in place.

Figure 6-14 Superelevation on Detours



SPEED	FRICTION FACTOR
20	0.240
25	0.208
30	0.180
35	0.162
40	0.150
45	0.145
50	0.140
55	0.135
60	0.130
65	0.127
70	0.120

e= SUPERELEVATION
f= FRICTION FACTOR
V= SPEED– MILES PER HOUR
R= RADIUS IN FEET

$$V = \sqrt{15(e+f)R}$$

The formula shown in Figure 6-14 is the same as used in CDOT Standard Plans - M & S Standards (CDOT, 2019) shows superelevation and curvature for various design speeds, except that the "e" value shown in CDOT Standard Plans - M & S Standards (CDOT, 2019) is based on maximum driving comfort and safety, combined with a widely variable friction factor due to the potential for adverse pavement surface and weather conditions during construction.

Using Figure 6-14, the designer can choose a combination of friction factor, superelevation, and curvature to meet required design speed without the necessity of building up an excessive amount of superelevation and runoff which must be removed after a short time.

Values on Figure 6-14 have been checked by the "Ball Bank Indicator" to determine the point of discomfort for safe speeds on curves.

6.6.8 Detour on Local Roads

When local roads are used in detour routing, the stabilization needs must be reviewed. If necessary, additional overlay should be placed to protect the structural integrity of the street.

All the above-listed design elements, including the information on "Detour Design Data," shall be specified in the plans.

The following should be considered:

- Intergovernmental Agreement.
- Weight limits.
- Noise.
- Vibration.
- Traffic.
- Schools.
- Land-use.
- Pedestrian and bicycle use.

6.6.9 Environmental Considerations of Detours

When designing detours, it is important to consider and mitigate any possible environmental impacts. These can include wetlands, archaeology or paleontology resources, hazardous waste, water quality, or Section 4(f) involvement. These impacts may be avoided by the proper placement of the detour. For assistance in evaluating possible impacts, contact the Region Planning/ Environmental Section.

6.6.10 Detour Transverse Underdrains

Transverse underdrains are those constructed perpendicular to roadway. Refer to the *CDOT Drainage Design Manual* (CDOT, 2019).

6.7 Other Elements Affecting Geometric Design

6.7.1 Drainage and Erosion Control

Consider the following:

- Collect water prior to transitioning superelevation to prevent sheet flow.

- Design and locate inlets to limit the spread of water on the traveled way to tolerable widths.
- Install extra inlets near low points of sag vertical curves to take any overflow from blocked inlets.
- Locate inlets just upgrade of pedestrian crossings.
- Address environmental issues such as erosion and sediments.
- Dikes in medians and on the edge of the road should comply with clear zone requirements.
- Coordinate NPDES issues with Region Planning and Environmental Manager (refer to the *CDOT Project Development Manual* (CDOT, [2013] 2022).

Also refer to the *CDOT Drainage Design Manual* (CDOT, 2019).

6.7.2 Rest Areas

For design of rest areas, coordinate with CDOT's Property Management group and the FHWA Operations Engineer. Refer to the AASHTO *Guide for Development of Rest Areas on Major Arterials and Freeways* (AASHTO, 2001).

6.7.3 Lighting

Consider the following:

- Refer to the *Lighting Design Guidelines for the Colorado Department of Transportation* (CDOT, 2019).
- Coordinate with the Region Utility Engineer and the local utility company.
- Minimize light pollution in conformance with Colorado Revised Statutes (CRS) 24-82-902.
- Safety enhancement.

6.7.4 Utilities

Consider the following:

- Coordinate with the Region Utilities Engineer early and throughout the design process.
- Pothole to locate utilities as practical.
- Plot existing utilities in plan, profile, and cross sections to identify potential conflicts with design elements.
- Utility Notification Center of Colorado will not locate CDOT-owned utilities; contact the Region Traffic Signal Supervisor.
- Utility relocation requirements should be compatible with construction phasing.
- An Intergovernmental Agreement (IGA) may be necessary.

The clear zone dimensions to be maintained for a specific functional classification are discussed in the Section 4.6.1 of the 2018 AASHTO GDHS.

Utilities that are to cross or otherwise occupy the right of way of rural or urban freeways should conform to the AASHTO *A Policy on the Accommodation of Utilities Within Freeway Right-of-Way* (AASHTO, 2005a). Those on non-controlled access roadways and streets should conform to the AASHTO *A Guide for Accommodating Utilities Within Highway Right-of-Way* (AASHTO, 2005b).

6.7.5 Traffic Control Devices

The development of traffic control plans is an essential part of the overall project design and may affect the design of the facility itself. Refer to Chapter 15 of this Guide and the MUTCD.

6.7.6 Clear Zone

Refer to the AASHTO *Roadside Design Guide* (AASHTO, 2011) for more information.

6.7.7 PBPD, MM, and CSS Considerations

Picture a scenic road in a rural context surrounded by trees. This route is enjoyed by visitors and the local community alike in its current form. This scenic route currently has two 16-foot lanes with no accommodation for bicyclists although it is a popular cycling route. The scope of improvements of this corridor project places it in the 4R category. The design team is curious whether PBPD, MM and CSS considerations can be leveraged to arrive at the optimal design solution.

From a CSS perspective, it is clear the local stakeholders want the trees to stay. Unfortunately, many of the trees are within the clear zone.

While some stakeholders are not in favor of bike lanes, there is a concerning pattern of vehicle-bicycle crashes developing.

The design team decides to coordinate with their Region Traffic Representative regarding the need for Data Driven Safety Analysis (DDSA), a subtopic of PBPD. The goal of the DDSA will be to understand the safety performance impact of choosing a reduced clear zone where the vast majority of the trees can stay or where minimal guardrail will be required. The design team is also seeking to understand the safety performance impact of providing 11-foot driving lanes with 5-foot bike lanes. They wonder if the DDSA will reveal the predicted number of crashes for the reduced clear zone scenario will be elevated compared to the full clear zone scenario. They are also curious whether the predicted number of crashes for the 11-foot driving lane scenario will be elevated compared to the 16-foot lane scenario.

Additional design considerations (e.g., adjusting posted speed limit) or safety countermeasures may need to be applied to mitigate the potential increase in expected crashes.

Chapter 7
Cross Section Elements

Legend

	Multimodal Application Example
	Context-Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context-Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO-Specific Information

Chapter

7

7 Cross Section Elements

7.1 Introduction

The development of roadway cross sections is often the building block for transportation decision-making and project development. Recognizing that Colorado's roadways serve a diverse set of travel modes and commerce needs, a balanced approach needs to be considered when developing a cross section and its elements that meets the purpose and need, project statement, local community's needs, and the Colorado Department of Transportation (CDOT) Region goal for the roadway. This often requires a high level of stakeholder outreach to understand the modal priorities on a particular corridor and how those priorities can be allocated within the limited roadway space.

7.2 General Description

The roadway cross sectional elements extend from vehicular travel lanes to include dedicated bicycle/transit lanes or shoulders, parking lanes, raised or flush medians, landscape buffers and pedestrian sidewalk and amenity zones. The allocation and design of the available space should be done with an understanding of both the cross section and the corridor. Cross sections will often vary throughout a project length to adapt to different context zones and identified constraints. Design of a cross section should also consider the longitudinal and crossing movements of all users, with the elements balanced to optimize functionality and safety within constraints and practicality.

There is no definitive minimum standard governing one or two-way roadway widths. As an example, on urban arterials, sufficient unobstructed width should be provided for oversized loads if they are known to use the facility. Determining if this is necessary should be based upon the frequency and number of oversized transports and/or the location of oversized transport generators in the area. The impacts of accommodating these transport types and anticipated volume should be weighed against the cost, speed, and safety advantages or disadvantages of a widened cross section. In general, urban and suburban roadway widths should be kept to a practical minimum necessary to accommodate the modes and volumes expected. This approach may require truck turns and oversized loads to encroach on adjacent and/or opposing lanes. If the volume of large vehicles is minimal, it may be acceptable to incur occasional encroachments.

In addition, during winter conditions, it is reasonable to assume there may be a small loss (e.g., 1 to 3 -feet) in usable width along each outside curb line to accommodate snow removal deposition and ice buildup. Designers should take this into account and understand how the facility will operate under such conditions. Alternatively, a wider landscape area between the edge of the roadway and the sidewalk could be used as a snow storage area in locations that experience more frequently higher snow accumulation totals.

General guidance and criteria include:

- For reconstruction and preservation on rural highways, begin with the existing total roadway section width as a starting point for design consideration. Reallocation of lateral space among lane and shoulder width should be investigated using the *AASHTO Highway Safety Manual* (AASHTO, 2010) to identify beneficial tradeoffs and potential performance improvement.
- Use locally calibrated *Highway Safety Manual* data, where available, when considering tradeoffs between lane and shoulder widths on rural highways.
- On urban and suburban streets, allocate lane and shoulder widths to balance the functionality and safety of all modes of travel. Wider is not necessarily safer.

7.2.1 Surface Type

The selection of pavement type is determined by the volume and composition of traffic, soil characteristics, recurring weather conditions, performance of pavements in the area, availability of materials, energy conservation, the initial cost and the overall annual maintenance and service life cost. The structural design of pavements is not included in this chapter but may be found in the CDOT *M-E Pavement Design Manual* (CDOT, 2021). Prior to the beginning of the pavement design process, it is highly recommended that the designer, at project inception, discuss the general scope of the project with the local CDOT materials engineer or pavement manager to begin the pavement design process. The materials engineer will provide guidance pavement type or pavement treatment selection.

Refer to Chapter 4, Section 4.2.1, of the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (the Green Book) (2018 AASHTO GDHS) (AASHTO, 2018) for more information.

7.2.2 Reference Documents

CDOT *Mechanistic Empirical (M-E) Pavement Design Manual*. The *M-E Pavement Design Manual* (CDOT, 2021) provides a uniform and detailed procedure for designing pavements on CDOT projects. It is highly recommended that the designer work with the CDOT Region Materials Engineer to initiate a pavement design for a project early during the project scoping phase.

Use the following link to access CDOT's M-E pavement Design Manual: CDOT M-E Pavement Design Manual.

CDOT Standard Plans – M&S Standards. The CDOT Standard Plans - M & S Standards (CDOT, 2019) is a compilation of CDOT Standard Plans for CDOT construction projects. Standard Plans that are applicable to a specific project are identified on the project plans and are not physically attached to those plans. The designer specifying any of these Standard Plans for a specific project accepts the responsibility of determining their applicability. Additional information concerning the Standards Plans are available in the *CDOT Standard Specifications for Road and Bridge Construction* (CDOT, 2022). Standard Plans adopted or revised subsequent to the adoption of this Guide shall be listed on the index of the project plans and physically included in the plans. The designer should regularly check for new or revised standards at the link below as they are frequently updated.

Use this link to access CDOT Standard Plans – M&S: CDOT Standard Plans - M&S

7.2.3 Cross Slope

Design of the roadway cross slope often requires a balance between the need for reasonably steep cross slopes for drainage purposes and relatively flat cross slopes for user comfort. Pavement superelevation on curves is determined by the speed-curvature relationships given in Chapter 3 of this Guide and CDOT Standard Plans - M & S Standards (CDOT, 2019).

Two-lane and wider undivided highways on tangents have a crown or high point at the centerline and slope downward at an even rate outward. On higher speed and intermediate type undivided roadway, crowned at the center, the desired rate of cross slope is 2%.

An overlay typically will match the existing cross slope unless the safety assessment report indicates cross slope corrections need to be made. The profile grade and pivot point are generally located at the pavement crown.

On divided highways, typically each direction of roadway has a consistent cross slope across the entire width of pavement. At intersections, interchange ramps or in unusual situations, the crown position may vary depending upon the presence of medians, islands, auxiliary lane configurations, drainage, or other site-specific controls.

To avoid excessively close inlet spacing, hydroplaning, and other drainage problems associated with flat pavement slopes and wide typical cross sections, superelevation transitions and vertical curve lengths should be minimized in wide typical cross sections to reduce flat areas that may accumulate water.

On steeper cross slopes or super elevated cross sections, bicyclists and pedestrians using mobility devices may have trouble balancing or traveling along their intended path and therefore the roadway shoulder cross slope should be kept to 2% or less. See Chapters 12 and 13 for design guidance.

7.2.4 Skid Resistance

"Pavement types and textures also affect a roadway's skid resistance. The four main causes of poor skid resistance on wet pavements are rutting, polishing, bleeding, and dirty pavements. Rutting causes water accumulation in the wheel tracks. Polishing reduces the pavement surface micro-texture and bleeding can cover it. In both cases, the rough surface features needed for penetrating the thin water film are diminished. Pavement surfaces will lose their skid resistance when contaminated by oil drippings, layers of dust, or organic matter. Measures taken to correct or improve skid resistance should result in the following characteristics: high initial skid resistance durability, the ability to retain skid resistance with time and traffic, and minimum decrease in skid resistance with increasing speed." (2018 AASHTO GDHS).

CDOT's practice for concrete pavements is to use longitudinal tining. Tining is defined as pulling a specially designed rake across the finished uncured surface to create grooves in the pavement which aids in reducing hydroplaning and skidding. Tining is required for design speeds of 40 mph and greater. Transverse tinning is typically not installed as it increases road noise significantly.

Roadway shoulders used for bicyclists and pedestrians should be paved and of a consistent material with the vehicular travel lanes. Refer to Chapters 12 and 13 for design guidance.

7.2.5 Traveled Lane Texturing (Rumble Strips)

Transverse travel lane rumble strips may be considered for locations where unexpected roadway conditions cannot be corrected through traditional geometric or traffic control measures and supplemental audible and vibratory indications are necessary to inform a driver of the approaching condition. These transverse rumble strips are typically installed by saw cutting or grinding the pavement and only done so in locations where the noise from the rumble strips will not adversely affect nearby residents where the CDOT Region Traffic Engineer approves of the installation. Examples of where transverse rumble strips may be effective include:

- Advanced warning on a high-speed rural roadway approaching a stop-controlled intersection.

- Advanced warning for the dropping of a traveled lane on a high-speed roadway.
- Advanced warning for the existence of a horizontal curve that is well below the design speed for the rest of the roadway (i.e., a 25 mph curve on a 45 mph highway).
- Other locations as determined by the CDOT Region Traffic Engineer or a safety study.

The transverse rumble strips are typically installed in conjunction with other warning and regulatory devices to help increase driver awareness and understanding of the potential hazard or unexpected condition ahead.

If rumble strips are installed on a facility that is a bicycle route, a minimum of 4 feet of clearance should be provided between the outside edge of the rumble strips and the edge of pavement (or guardrail if applicable), and they should be intermittent to provide gaps for bicyclists to move between the shoulder and outside travel lane if needed to avoid obstructions or debris. If space is limited, edge line rumble strips can be used to maintain 4 feet of clear space on the shoulder. Refer to Chapter 13 of this Guide for design guidance.

Refer to CDOT Standard Plans – M & S Standards Project Special Detail M-614-1 (CDOT, 2019) for additional details.

7.3 Lane Widths

Before identifying the proposed travel lane width of the vehicular travel lanes, the context of the roadway, intended users and surrounding land use should be considered. Depending on these factors along with others, the roadway travel lane width can generally vary between 10 and 12 feet. For lower speed roadways in more urban or downtown land use contexts with less truck traffic and greater pedestrian and bicycle activity, 10-foot lanes may be appropriate. As a roadway transitions to more rural and high-speed contexts, 12-foot lanes might be more appropriate. Cross Sections in this Guide provides a general overview of the lane widths based on various context zones.

Refer to Chapter 4, Section 4.3, of the 2018 AASHTO GDHS for more information.

7.3.1 MM, PBPD, and CSS Considerations

- *Multimodal ((MM).* In more urban contexts, pedestrian and bicycle safety and operations may be prioritized over vehicular mobility and travel speed and thus may support narrower travel lanes to reinforce lower travel speeds and opportunities for shorter pedestrian crossings and wider bicycle facilities. Many studies have confirmed that there is no reduction in vehicle capacity by using 10-foot travel lanes and have proven a positive influence on reduced vehicle crashes and overall crash severity.
- *Context Sensitive Solutions (CSS).* Designing travel lanes and shoulders as wide as possible along with providing wider unobstructed roadway clear zones has the potential to encourage

higher travel speeds and result *in* roadway becoming a barrier to pedestrians trying to cross the roadway. Serious consideration and discussion should occur with the local community stakeholders to determine the desired priorities for the roadway that reflect the community, statewide safety strategies, and mobility goals.

- *Performance-based practical design (PBPD).* Engineers should use national best practice research found in AASHTO and NACTO guides for determining the appropriate lane width that reflects the various contextual elements of the roadway location. Context considerations should include modal priorities, land use context, regional and local roadway relevance, historic safety performance and community input. Furthermore, narrowing a travel lane may reduce right of way impacts, operation and maintenance costs, capital costs, and improve operations and performance, but this must be evaluated for each project.

7.4 Shoulders

7.4.1 General Characteristics

A shoulder is the portion of the roadway that is generally located to the left and/or right of the active travel lanes depending on the roadway orientation. Shoulders serve a variety of purposes including but not limited to allowing a space for stopped vehicles or slower moving vehicles to pull off, bicycle lanes, emergency use, lateral support of subbase, base, and surface courses and a recovery area in an avoidance maneuver.

Refer to Chapter 4, Section 4.4, of the 2018 AASHTO GDHS for more information.

7.4.2 Width of Shoulders

For purposes of this Guide, the shoulder shall be the minimum continuous usable width of shoulder that provides an all-weather surface and meets the purpose and need and/or project statement. The typical width will vary from 4 to 12 feet, depending on the roadway design vehicle, constraints, safety, and funding. Shoulders should be paved full width in accordance with the functional or physical characteristic of the roadway. The shoulder width will likely vary where speed-change lanes, auxiliary lanes, turn lanes, climbing lanes, or curb and gutter are used. Refer to Chapter 14 of this Guide for additional information for designing bicycle paths using shoulders.

7.4.3 MM, PBPD, and CSS Considerations

The needs of bicyclists and pedestrians should be considered when determining the appropriate shoulder width. Shoulders can generally range in width from 4 to 16 feet and should reflect the intended context, whether it be a bicycle uphill climbing lane or a truck chain up area. From a bicycling perspective, wider shoulders are generally preferred to provide increased separation from moving traffic, allow for side-by-side riding in compliance with state law, and provide opportunity to avoid roadway debris without having to travel into the adjacent travel lane (especially important along steeper downhill sections). In mountain locations where there is insufficient shoulder width to provide an appropriate width shoulder in both directions, consideration should be given to maximizing the width of the bicycle shoulder in the uphill direction where speed differential is greatest; and to utilize a narrower shoulder the downhill direction where bicyclists are more likely to be traveling a speed closer to that of vehicular traffic.

If determined appropriate, rumble strips located between the travel lane and shoulder should be installed in accordance with Standard Plan No. M-614-1 and should only be installed where a minimum of 4-foot of clearance between the outside edge of the rumble strip and outside edge of pavement can be maintained. When necessary to maximize the width of usable shoulder for bicyclists, the rumble strips can be located on the edge of the travel lane within the white edge line stripe. In accordance with the M-614-1 standard plan, gaps in the rumble strip should be provided to allow cyclists to transition between the shoulder and adjacent travel lane to allow for the avoidance of debris or stopped vehicles along with making a left turn at a downstream intersection.

The cross slope of the roadway shoulder should also be considered when evaluating the needs of bicyclists and pedestrians. Ideally a shoulder needs to be at least 4 feet wide to provide a level of confidence for a cyclist to use on a regular basis. Shoulders narrower than 4 feet reduce the comfort of the cyclist and the motorist alike when a car is overtaking a bicycle or group of bicycles.

Shoulders can help reduce roadway departure crashes, but in a PBPD design this may not be best option based on the data, context, and purpose and need of the project. It may not be the most cost-effective decision to widen shoulders as this can increase earthwork, right of way, and pavement costs to the project. In a PBPD process, one of the first steps the engineer should take is to determine what users are frequenting the corridor. Are there bicyclists using the shoulders? Are farm and agriculture vehicles present that use the shoulder to move from field to field? Is there a bus route and stops? What is the crash history for the roadway, and is there a concentration of roadway departures at specific locations? If the recommended shoulder widths of the 2018 AASHTO GDHS are being used, why not consider providing wider shoulders where crash concentrations suggest this to be beneficial, but use a narrower shoulder to accommodate other uses where there is little or no crash history indicating the need for a widened shoulder?

Use this link to access information about CDOT's High Demand Bicycle Corridors: [*https://www.codot.gov/programs/bikeped/high-demand-bicycle-corridors*](https://www.codot.gov/programs/bikeped/high-demand-bicycle-corridors)

7.4.4 Shoulder Cross Sections

In most cases, the shoulder cross slope should be the same as the cross slope of the adjacent travel lanes. However, in sag vertical curves in tangent horizontal alignments with narrow shoulder widths or where inlet spacing becomes excessive, the shoulder cross slope should be steepened up to 1% greater than the adjacent lane cross slope to increase the hydraulic carrying capacity of the shoulders. The designer also should consider breaking the uphill shoulder in the opposite direction on fully superelevated roadways to reduce water draining across the road and preventing icing conditions. The algebraic difference between the shoulder and travel lane cross slopes shall be 5% or less. Greater algebraic differences require rounding the travel lane slope to transition to the shoulder break and maintain the maximum 5% algebraic difference.

7.4.5 Shoulder Stability

Shoulders should be paved full depth in accordance with the functional or physical characteristic of the roadway. At certain locations, erosion of topsoil or shouldering materials adjacent to the pavement edge results in hazardous conditions for the motorist and a reduction in lateral support for the pavement. The use of a pavement safety edge is required on all projects having roadway pavement. The pavement safety edge shall be included on all resurfacing or reconstruction projects. Vertical pavement edge drop-off on highways has been linked to many serious crashes when errant vehicles attempt to steer back onto the roadway. Instead of a vertical drop-off, the safety edge shapes the edge of the pavement to 30 to 35 degrees. Research has shown this is the optimal angle to allow drivers to reenter the roadway safely. Refer to the CDOT Standard Plans - M & S Standards Project Special Detail D-614-1 (CDOT, 2019) for additional information.

Use this link to access the CDOT Safety Edge details: Project Special Safety Edge Detail D-614-1

7.4.6 Shoulder Contrast

Distinguishing paved shoulders from the mainline pavement is recommended to discourage the use of the shoulder as a travel lane and provide guidance and warning to drivers. This can be accomplished by pavement markings and differences in shoulder surface texture.

Shoulder texture treatments that provide an audible or vibrational warning to errant drivers have proven effective in keeping traffic off the shoulder and reducing crashes on long tangent or highway sections with a history of roadway departure crashes. Rumble strips may also be used to differentiate a shoulder and minimize roadway departure crashes and shall comply with the current CDOT Standard Plans - M & S Standards (CDOT, 2019).

This is a viable option that should be considered based on the purpose and need and/or project statement. This option needs to fit within the context and functionality of the project.

Rumble strips should always be considered for use in rural areas where flat or rolling terrain with long tangents and relatively flat curvature is predominant. These physical elements tend to result in increased driver inattentiveness or drowsiness. Under these circumstances, the use of shoulder rumble strips is highly recommended but should be discussed with the CDOT Region Traffic Engineer before being included in the design.

If there is any doubt on the use of rumble strips, further analysis should be conducted with input from the CDOT Region Traffic Engineer. The analysis shall include taking into consideration crash history, bicycle usage, and other pertinent risk factors that will help to decide the appropriate application of rumble strips. Suggested designs to accommodate rumble strips and a bicycle facility are found in Chapter 13 of this Guide.

Other textures or methods, such as chip seals, slurry seals, or cape seals, may be used in lieu of shoulder grooving on an experimental basis. Course chip seals (1/2-inch aggregate or larger) are not recommended in areas with regular bicycle traffic.

7.4.7 Turnouts

Refer to Chapter 6 of this Guide for information on turnouts.

7.5 Cross Section Templates

This section includes typical facility type cross section templates with common overlays, such as bicycle, pedestrian, and transit facilities, for the each of the six context classifications described in Chapter 1. These templates are meant to serve as a starting point, with modifications and overlays dictated by the CSS and PBPD processes.

Design influences begin before "design" begins. In other words, knowing who the users of the roadway prism are and evaluating the data analytics for the roadway (corridor vision plans, crash data, pedestrian data, truck, bike, and transit data) may directly influence the scope development of the project. Early project scoping and alternatives identification and evaluation efforts have a major influence on design outcomes. As a project moves from preliminary to final design, it becomes much more difficult to modify design configurations to achieve overall project outcomes. Future versions of the AASHTO GDHS will emphasize a performance-based process framework and a design model for identifying project contexts and developing and evaluating roadway configurations that meet intended project outcomes. Conducting these evaluations early in the project development process increases the opportunities for design flexibility. NCHRP Report 785: *Performance-Based Analysis of Geometric Design of Highways and Streets* conceptually depicts the influence and role geometric design performance measures have from project planning to final design.

Following good investigative scoping analysis into the current roadway users and characteristics is a major step to ensure that multimodal and context sensitive needs for the corridor are being considered. This is also the foundation of performance based practical design that will establish the roadway template that will meet the needs and vision of the users.

The dimensions of a typical cross section depend on several features that vary with the type of roadway and context. The design may be adjusted for specific conditions as indicated in the appropriate chapter of this Guide or for the specific classification of roadway.

CDOT includes Z slopes in typical sections. The Z slopes, which slope gently away from the edge of the pavement, provide for safety, drainage, snow storage, sign placement, and rockfall containment and shall be included in the design. The typical section also indicates the locations of the following points:

- *Hinge Point*. The point on the subgrade directly below the edge of the pavement from which the subgrade slopes downward to the point of slope selection.

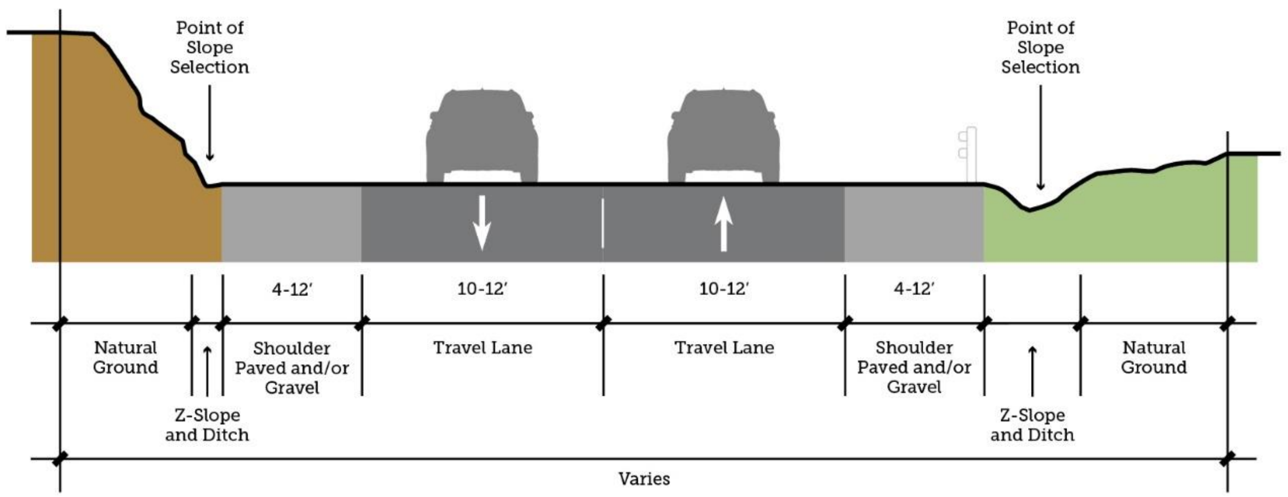
- *Point of Slope Selection.* The point at the toe of the Z slope that intersects with the subgrade. The point of slope selection is the point at which the embankment or excavation begins to slope away from the roadway prism.
- *Profile Grade.* The point on the pavement surface, defined by its location on the vertical alignment of the roadway, from which all other points and slopes on the cross section are determined.
- *Pivot Point.* The point on the pavement surface about which the cross slope of the roadway is rotated to effect superelevation. The pivot point may be at the same location as the profile grade.

Templates and renderings are provided on the following pages for:

- C1: Rural Mountainous Environment
- C2: Rural Places
- C3: Suburban Places
- C4: Traditional Neighborhood
- C5: Downtown Places
- C6: Urban Core
- Freeway

C1: RURAL MOUNTAINOUS ENVIRONMENT / CROSS SECTION EXAMPLES

TYPICAL SECTION



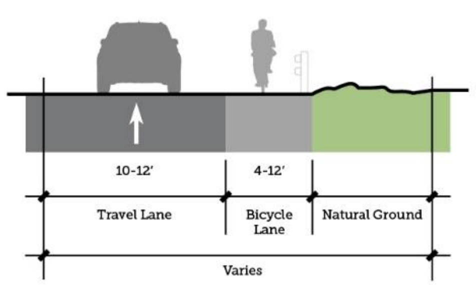

Rural Mountain Road: Ground Level


Rural Mountain Road: with Bike Shoulders

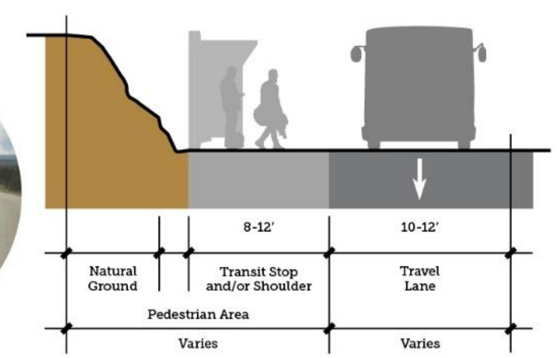

Rural Mountain Road: with Slow Vehicle Turn-outs at High Altitude

TYPICAL SECTION OVERLAYS

Bicycle Lane: Type A



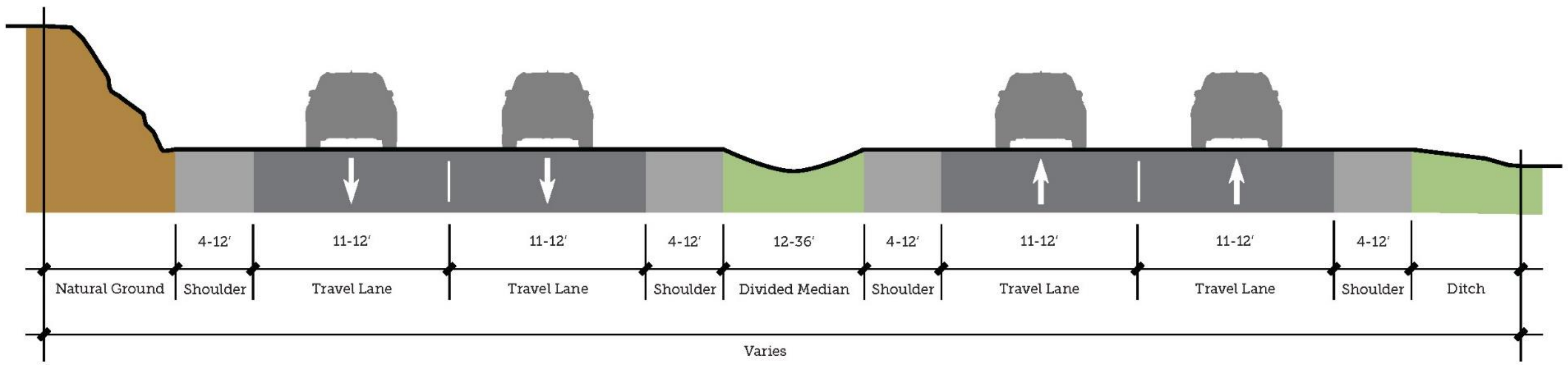
Transit Stop: Type B



C1: RURAL MOUNTAINOUS ENVIRONMENT / RENDERING EXAMPLE

C2: RURAL PLACES / CROSS SECTION EXAMPLES

TYPICAL SECTION

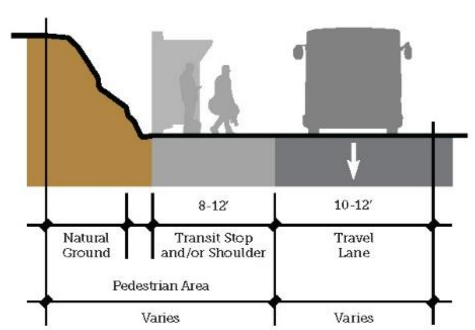



Rural Places: Ground Level

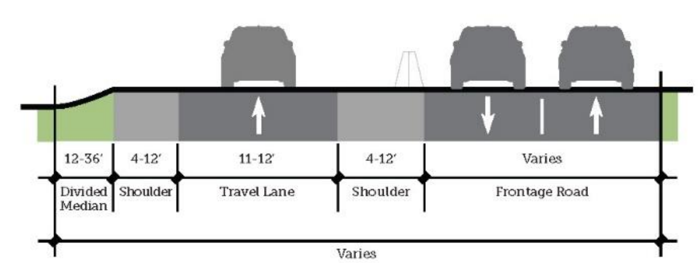

Rural Places: Aerial Level

TYPICAL SECTION OVERLAYS

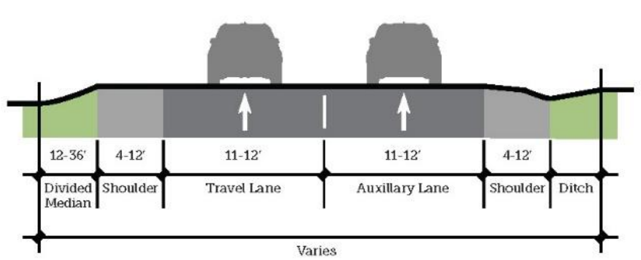
Transit Stop: Type B



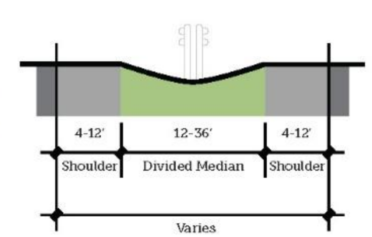
Frontage Road



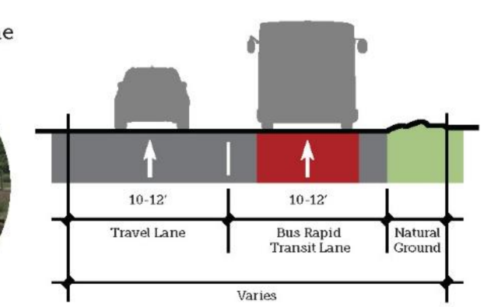
Auxiliary Lane



Median Guardrail/Barrier Divider



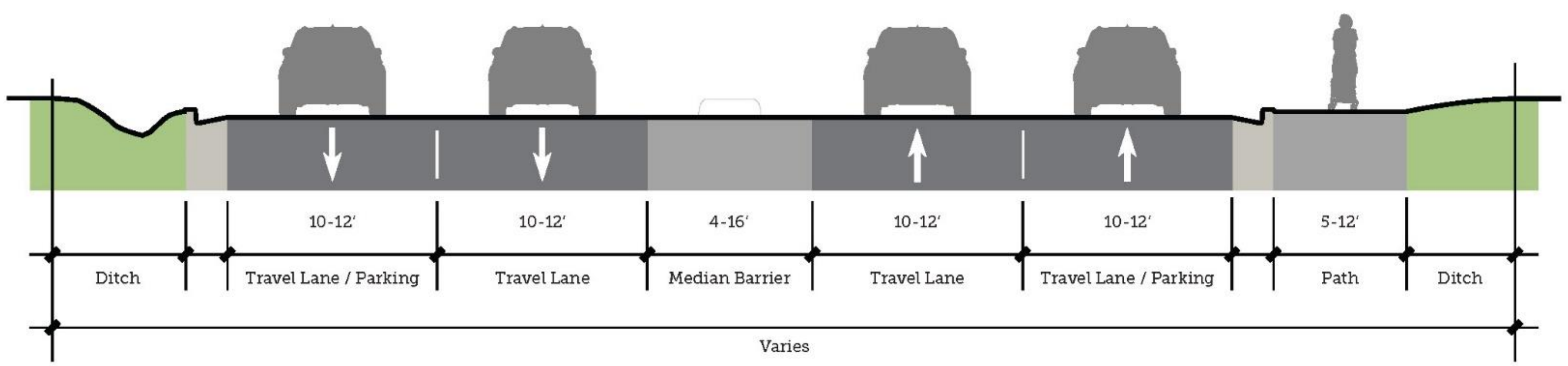
Bus Rapid Transit Lane



C2: RURAL PLACES / RENDERING EXAMPLE

C3: SUBURBAN PLACES / CROSS SECTION EXAMPLES

TYPICAL SECTION

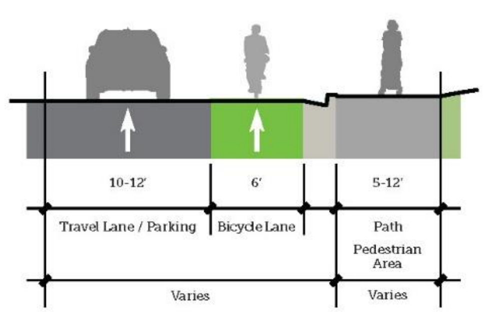


Suburban Places:
Ground Level

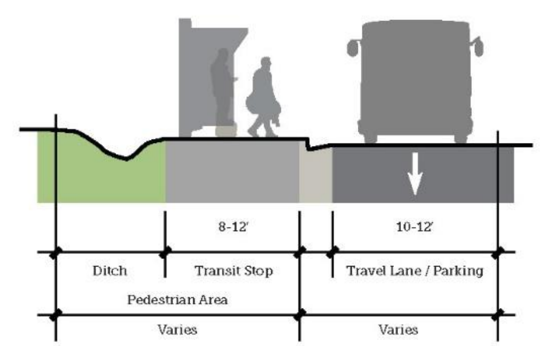
Suburban Places:
Ground Level

TYPICAL SECTION OVERLAYS

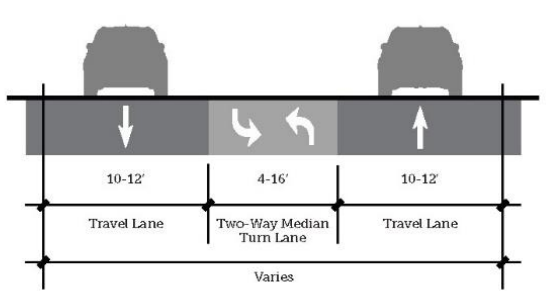
Bicycle Lane



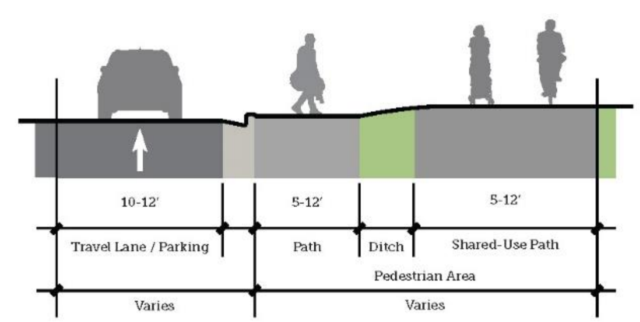
Transit Stop



Two-Way Turn Lane



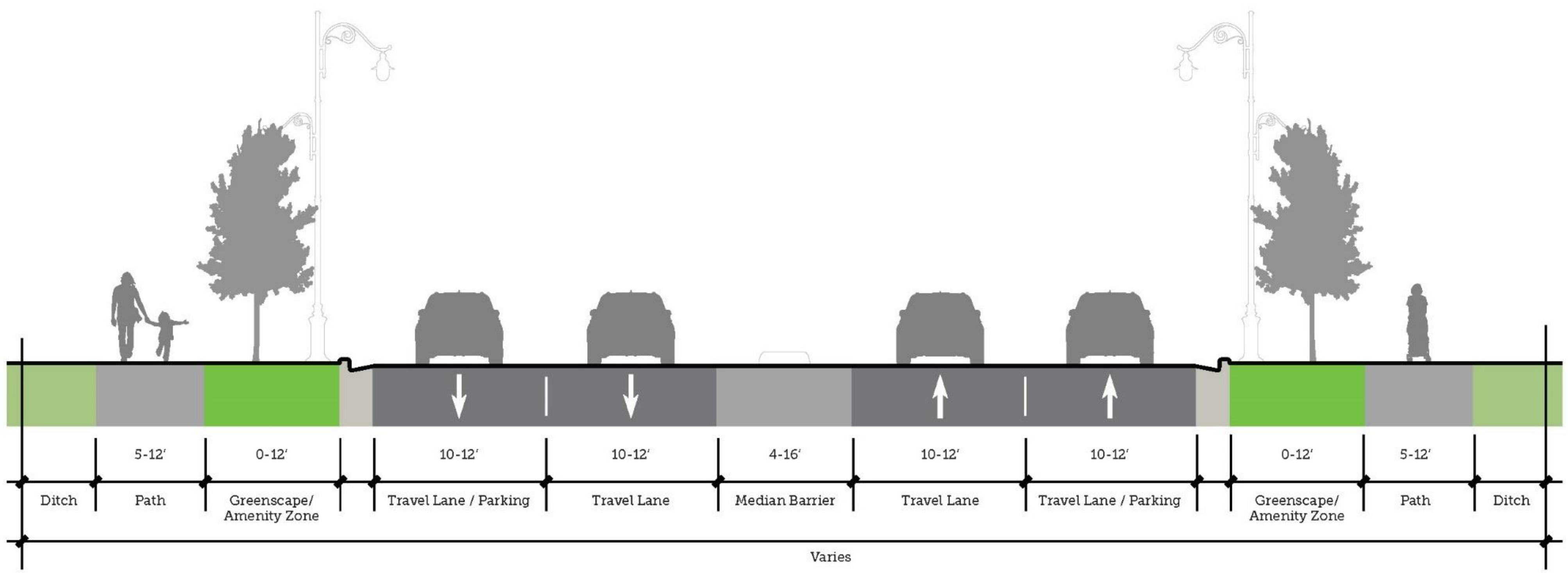
Shared-Use Path



C3: SUBURBAN PLACES / RENDERING EXAMPLE

C4: TRADITIONAL NEIGHBORHOOD / CROSS SECTION EXAMPLES

TYPICAL SECTION

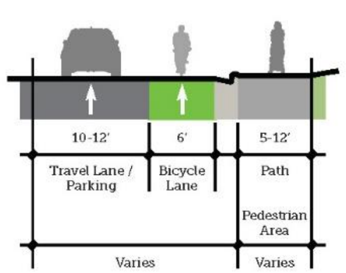


Traditional Neighborhood: Ground Level

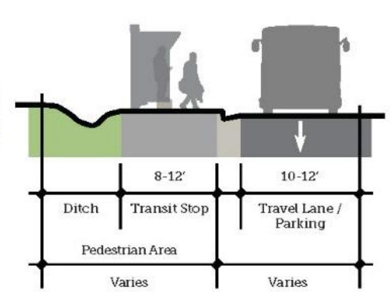
Traditional Neighborhood: with Bike Lane

TYPICAL SECTION OVERLAYS

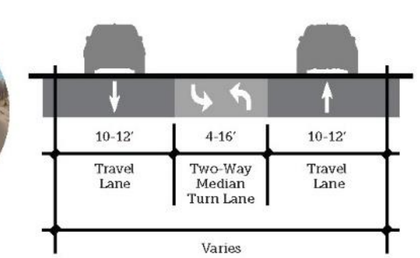
Bicycle Lane



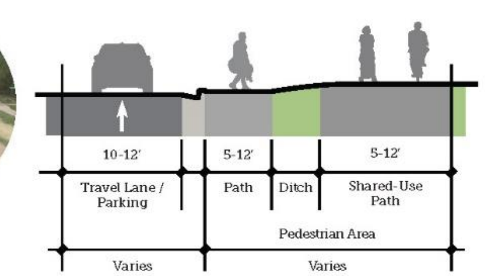
Transit Stop



Two-Way Turn Lane



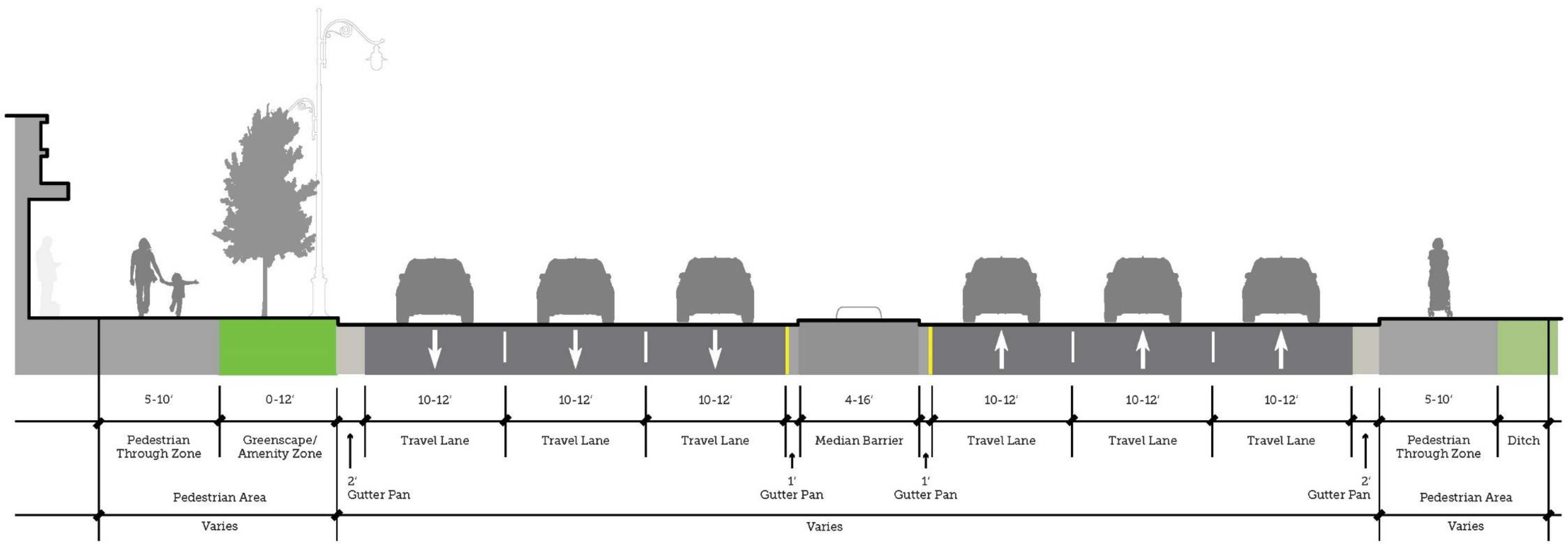
Shared-Use Path



C4: TRADITIONAL NEIGHBORHOOD / RENDERING EXAMPLE

C5: DOWNTOWN PLACES / CROSS SECTION EXAMPLES

TYPICAL SECTION

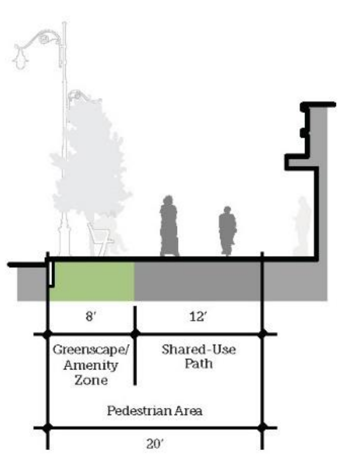


Downtown Places: Ground Level

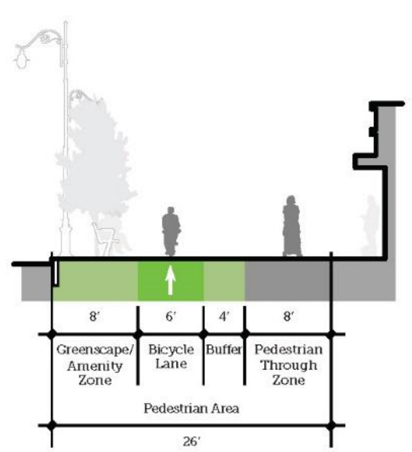
Downtown Places: Ground Level

TYPICAL SECTION OVERLAYS

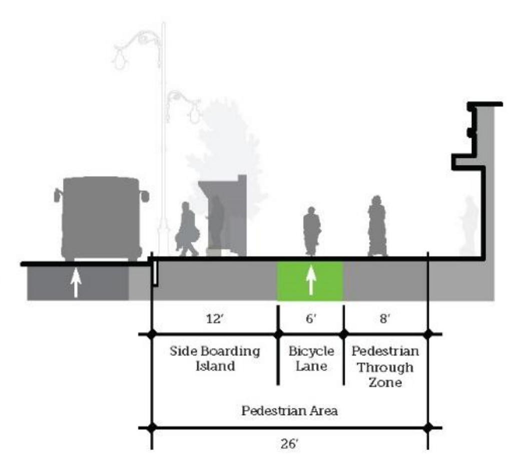
Shared-Use Path: Type A



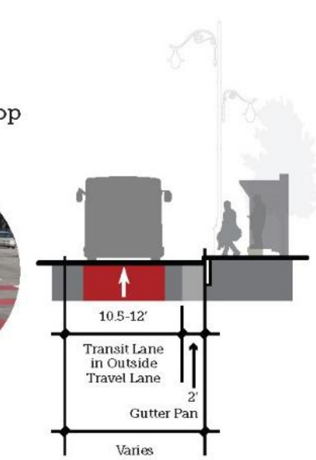
Protected Bicycle Lane: Type B



Bicycle Lane with Transit Stop



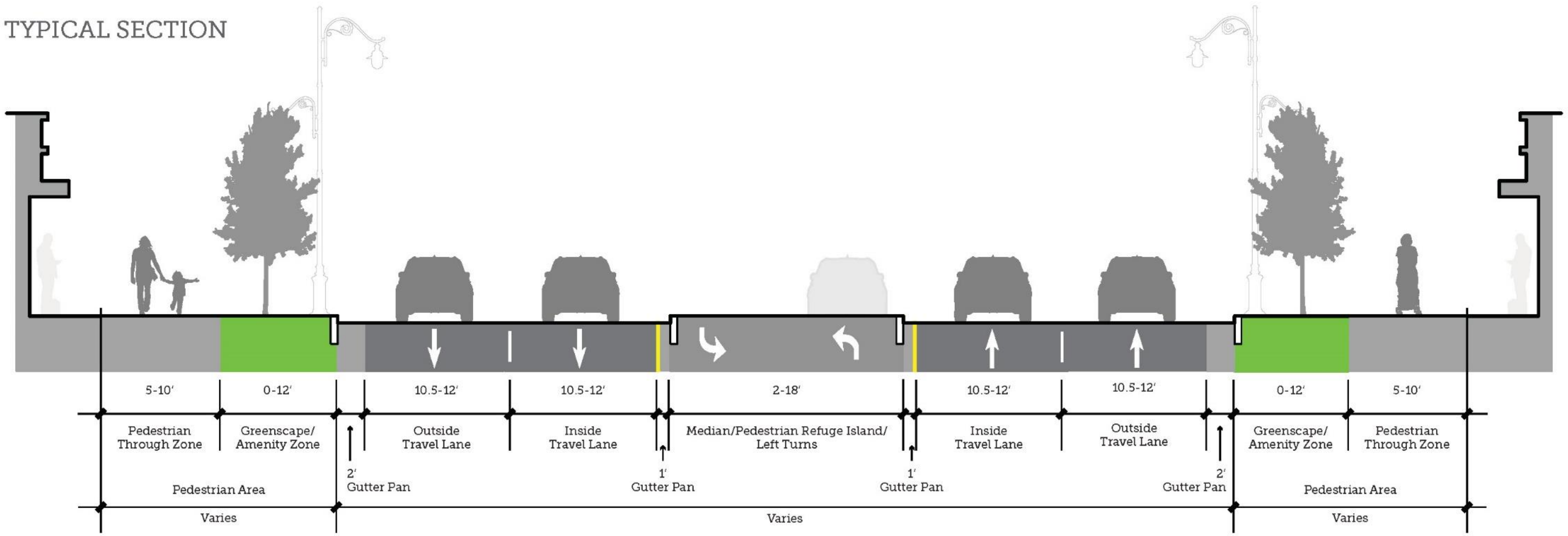
Transit Lane with In-Lane Stop



C5: DOWNTOWN PLACES / RENDERING EXAMPLE

C6: URBAN CORE / CROSS SECTION EXAMPLES

TYPICAL SECTION

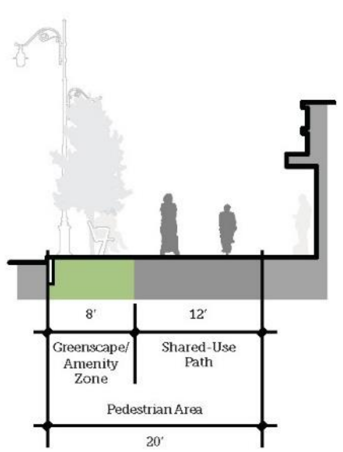


Urban Core: Ground Level

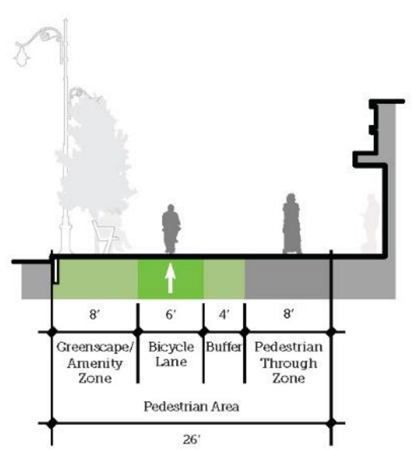
Urban Core: Ground Level

TYPICAL SECTION OVERLAYS

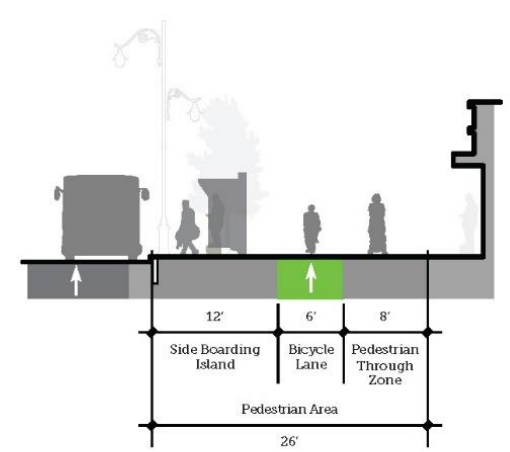
Shared-Use Path: Type A



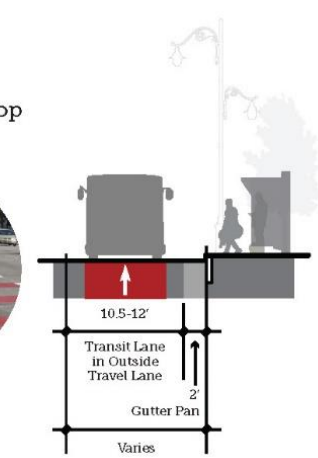
Protected Bicycle Lane: Type B



Bicycle Lane with Transit Stop



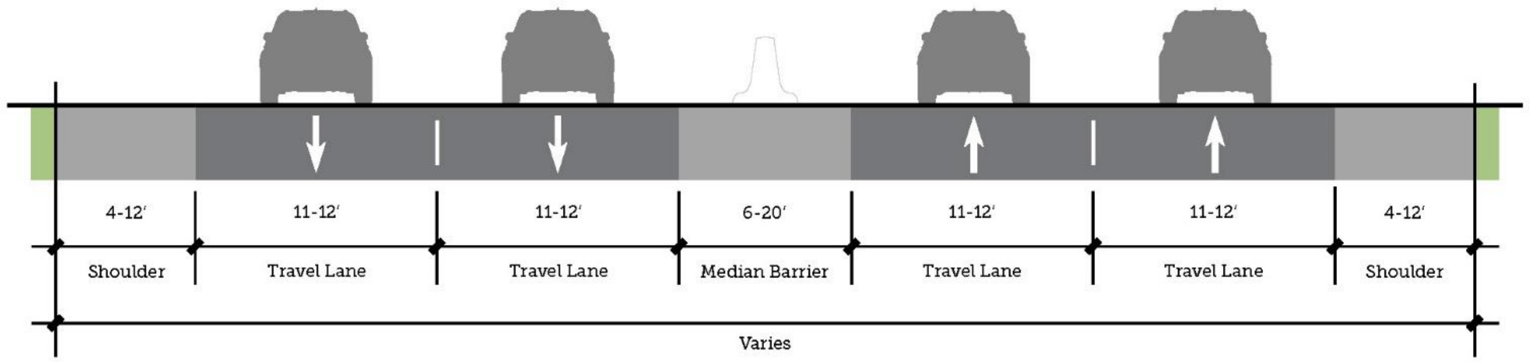
Transit Lane with In-Lane Stop



C6: URBAN CORE / RENDERING EXAMPLE

FREEWAY / CROSS SECTION EXAMPLES

TYPICAL SECTION



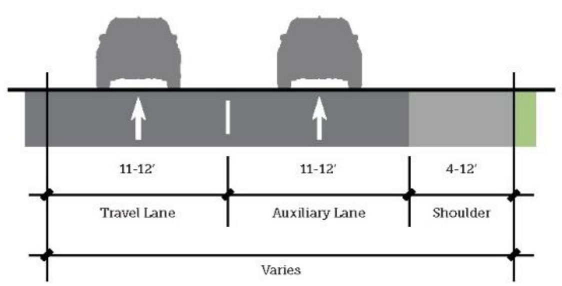
Freeway:
Ground Level

Freeway:
Overpass Level

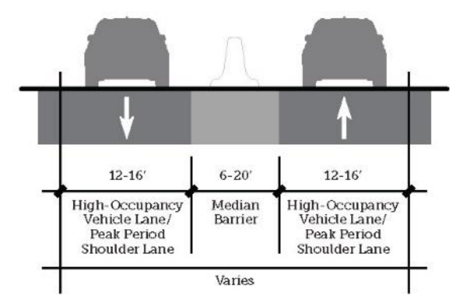
Freeway:
Aerial Level

TYPICAL SECTION OVERLAYS

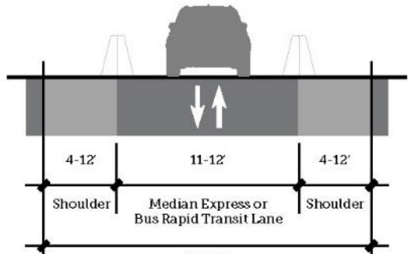
Auxiliary Lane

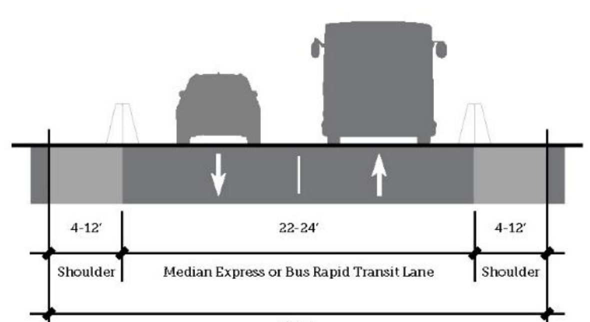


High-Occupancy Vehicle / Peak Period Shoulder Lane

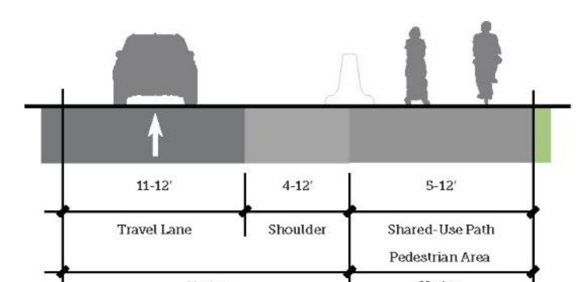


Median Express or Bus Rapid Transit Lane





Protected Shared-Use Path



FREEWAY / RENDERING EXAMPLE

7.6 Roadside Design

The term "clear zone" is used to designate the unobstructed, relatively flat area provided beyond the traveled way for the recovery of errant vehicles. The traveled way does not include shoulders.

The width of the clear zone is influenced by the traffic volume, speed, and embankment slopes as discussed in the AASHTO *Roadside Design Guide* (AASHTO, 2011). The AASHTO Guide should be used as a reference for determination of clear zone for freeways, rural arterials, and high-speed rural collectors.

For urban arterials, collectors, and local streets where curbs are utilized, space for clear zones is generally restricted. Where right of way is not restricted, a desirable clear zone area would be 4 feet behind the curb on tangent sections and 6 feet behind the curb on the outside of curve sections. In constricted right of way conditions, a minimum clear zone offset distance of 18 inches or more should be provided beyond the face of the curb to the face of the obstruction. The designer should consider large pole foundation diameters to avoid interference with back of curb. Where shoulders are provided rather than curbs, a clear zone commensurate with the AASHTO *Roadside Design Guide* (AASHTO, 2011) should be provided.

At signalized intersections, there are instances to have curbed medians with traffic signal poles located in the medians. The designer should discuss signal pole placement with the traffic engineer. Placing signal poles too close to the traveled lanes to reduce mast arm length is contrary to good safety practices. The cost of a longer mast arm to position the pole as far away from high-speed traffic should be exercised to provide the largest safety margin to avoid crashes with the poles.

Additionally, when considering pole placement in curbed median areas the designer must consider Public Rights of Way Accessibility Guidelines (PROWAG) (U.S. Access Board, 2011) requirements for accessibility-impaired pedestrians. Good thoughtful design of these elements and how they work together is critical to meet these requirements.

Use this link to access CDOT's ADA Resources for Engineers, including policy information, scoping and design resources, construction resources, measurement resources for curb ramps and push buttons, and training materials https://www.codot.gov/business/civilrights/ada/resources-engineers

7.6.1 Clear Zone Requirements with MM, PBPD, and CSS

It is important to understand the relationship that clear zone has on drivers' perceived level of safety and its influence on travel speed. Generally, as drivers perceive less risk when traveling along a roadway, they feel more comfortable traveling at higher rates of speed as is often found in more urban or mountain conditions. This should be considered when accounting for clear zones and the context of the project area. In many cases, designers and the community are looking to achieve travel speeds closer to the posted speed limit to improve safety, increase comfort of multimodal facilities, and reduce wildlife-vehicle collisions.

7.7 Curbs

"The type and location of curbs affects driver behavior and, in turn, the operation of a highway. Curbs serve any or all of the following purposes: drainage control, roadway edge delineation, right of way reduction, aesthetics, delineation of pedestrian walkways, reduction of maintenance operations, and assistance in orderly roadside development. A curb, by definition, incorporates some raised or vertical element." (2018 AASHTO GDHS)

The use of curbs on higher-speed roadways is discouraged in the interest of safety and because storm water runoff can be accommodated through natural runoff into the surrounding environment. In urban situations, curbs are more commonly used. In suburban contexts with higher travel speeds, judgment must be used, and the land uses should be considered, such as availability of closed drainage systems (storm sewers) and associated safety aspects.

Curbs can be configured in a number of ways and may be sloped to allow mounting by vehicles and bicycles or more vertical to discourage drivers from mounting the area outside of the roadway edge. Vertical curbs shall be used only on roadways where speed is 45 mph or less, with sloping curb being used where speeds are greater than 45 mph. Curbs should be avoided in front of the face of guardrail as the curb vaulting of the vehicle could affect the proper restraint the barrier is attempting to provide. Refer to CDOT Standard Plans - M & S Standards M-606-1 (CDOT, 2019) for guidance and alternatives to curb placement with guardrail systems. Vertical curbs should not be used along freeways or other high-speed arterials; but if a curb is needed, it should be of the sloping type and located as far from the active traveled way outside of the shoulder as possible. Refer to the CDOT *Drainage Design Manual* (CDOT, 2019) for minimal longitudinal slope requirements.

A 1-foot gutter is used with a curb where drainage control is not required, e.g., medians and islands. Sloping curb may be used on islands and medians where vehicle encroachment is expected based on the surrounding land use and desire lines. Sloping curb can also be used where there is a desire to limit general purpose traffic but accommodate larger design vehicles such as in the case of a truck apron of a roundabout or a mountable median cut through for emergency vehicles. Vertical curb should be used wherever a more physical deterrent to restricting access is desired.

Areas that require drainage control should have a curb with an integrated 2-foot gutter. Cross slope of gutter varies depending on whether the water is to flow toward or away from the curb. Refer to CDOT Standard Plans - M & S Standards (CDOT, 2019). Inlets and storm drains are favored over valley gutters for carrying drainage across intersections based on the potential impacts on safety and operations from navigating the depressed gutters. Radii of curbs in intersections are generally dictated by the type of roadway, intended design vehicle and the surrounding land use context. Larger radii should be used sparingly and should be kept as small as possible to control travel speeds and improve safety for all modes at the intersection.

Normally, the curb and gutter are not considered to be part of the usable travel lane width as drivers and bicyclists prefer to not operate in the gutter area based on the proximity to the curb face and the presence of a longitudinal joint. However, there may be exceptions in areas where lane width is constrained or a monolithic concrete pavement surface with consistent cross slope across the travel way and gutter are used. A 2-foot offset from the edge of travel way to the face of curb is preferred because placement of the curb may affect driver perception of the roadway, causing shying away from the curb.

Certain special circumstances occur with curb:

- Special curb types, such as curb without gutter or bituminous curbing, may be required.
- 10-foot transitions between different curb styles may be necessary.
- In high snow areas with frequent plowing operations, leading edge tapered median curb approaches are beneficial to prevent plow and curb damage.

Refer to CDOT Standard Plans - M & S Standards (CDOT, 2019) for further specific information on curbs.

7.8 Drainage Channels and Sideslopes

7.8.1 General Considerations

Current highway drainage design should incorporate safety, aesthetics, good appearance, ecology and control of pollutants, and economy in maintenance and construction. The above may be direct benefits of using flat sideslopes, broad drainage channels, and liberal warping and rounding. These features avoid obsolescence, improve appearance, and invite favorable public reaction.

The interrelationship between the drainage channel and the sideslope is important for safety because of the great influence they have on the sequence of events that can occur when a vehicle leaves the traveled way.

7.8.2 Drainage Channels

Drainage channels perform the vital function of collecting and conveying surface water from the highway right of way. Drainage channels, therefore, should have adequate capacity for the design runoff, should accommodate unusual storm water runoff conditions to minimize potential damage to the highway, and should be located and shaped to avoid creating a hazard to traffic.

Design flows and channel capacities can be determined based upon the CDOT *Drainage Design Manual* (CDOT, 2019). Side ditches should be used in all cut sections. Steep-sided channels are more desirable from a hydraulic point of view, but hydraulic performance shall be carefully evaluated if it introduces a steep slope hazard to errant vehicles within the clear zone of the highway. Channels shall be designed in accordance with the AASHTO *Roadside Design Guide* (AASHTO, 2011).

The depth of channel should be sufficient to remove the water while preventing saturation of the pavement subgrade. The depth of water that can be tolerated, particularly on flat channel slopes, depends upon the soil characteristics. In flat and low-lying areas with poor drainage and soil characteristics, a built-up roadway section or other means to move water well away from the roadway will help to prevent wicking of moisture back into the roadway subgrade prism.

Refer to Chapter 4, Section 4.8.3, of the 2018 AASHTO GDHS for more information.

7.8.3 Sideslopes

Sideslopes should be designed to ensure the stability of the roadway and to provide a reasonable opportunity for an out-of-control vehicle to regain control and return to the roadway safely. Three regions of the roadside are important when evaluating the safety aspects: the top of the slope (hinge point), the foreslope, and the toe of the slope (intersection of the foreslope with level ground or with a backslope, forming a ditch). In many situations, the toe of the slope is within the clear zone and the probability of reaching the ditch is likely, in which case safe transition between foreslope and backslope should be provided.

Rounded slopes reduce the chances of an errant vehicle becoming airborne, thereby reducing the hazard of encroachment and affording the driver more control over the vehicle. Foreslopes steeper than 4:1 are not desirable because their use severely limits the choice of backslopes. Slopes 3:1 or steeper are recommended only where site conditions do not permit use of flatter slopes. Clear runout space at the base of non-recoverable slopes is desirable. When foreslopes steeper than 3:1 must be used, consideration should be given to the installation of a roadside barrier. The designer should keep in mind that the introduction of a roadside barrier is actually adding a hazard to the roadway. Will this barrier hazard be more or less safe than the hazard protected by the barrier?

Normally, backslopes should be 3:1 or flatter to make it easier for motorized equipment to be used in maintenance. In developed areas, sufficient space may not be available to permit the use of desirable slopes. Backslopes steeper than 3:1 should be evaluated with regard to soil stability and traffic safety.

- Slopes that are 4:1 or greater are considered to be recoverable.
- Slopes that are between 3:1 and 4:1 are considered non-recoverable but traversable.
- Slopes that are steeper than 3:1 are considered to be non-traversable.

Design of a safe roadside depends upon design speed, traffic volumes, horizontal and vertical alignment of the roadway, type of highway, and other factors. For a thorough discussion of safety in design of side slopes, highway clear zones, and drainage channels, refer to the AASHTO *Roadside Design Guide* (AASHTO, 2011).

7.8.4 Cut Slope Standards

Cut slopes should not be steeper than 3:1 unless material is encountered that will stand on steeper slopes. Flatter slopes should be used in shallow cuts or in soils highly susceptible to erosion.

Geotechnical Considerations

Geotechnical strata in Colorado are highly variable and can be solid rock structure, glacial till (loose sandy rock) cobble and boulders, heavy clays, sandy soils, weak volcanic rock, or sedimentary shale deposits. Whenever a design is considering large cut or fill sections, it is advisable to make the initial investment to explore the existing geotechnical conditions. For large cut sections, identifying the angle of repose and presence of moisture in the cut slope will affect final cut slope stability and help to identify final slope grade to avoid slope stability issues later. For large fill sections, determining the load bearing capacity of the in-situ soils and water table conditions may help to avoid settlement issues and fill slope stability problems later.

7.8.5 Fill Slope Standards

Fill slopes are determined by a combination of terrain, height, and template type. The other chapters have specific information on desired fill slopes and CDOT practices for different highway types. Where 3:1 slopes or steeper are used, a comparison of costs of these slopes with any guardrail required vs. flatter slopes should be made. Refer to the AASHTO *Roadside Design Guide* (AASHTO, 2011) for guardrail guidelines.

Table 7-1 gives the standards for fill slopes to be used for different types of highways. Flatter slopes should be used in soils highly susceptible to erosion.

The minimum clearance from the right of way line to the catch point of a cut or fill slope should be 10 feet for all types of cross sections, but the desirable clearance is 20 feet. Access for maintenance activities should be considered.

Table 7-1 Fill Slopes

Highway Type	H*	Terrain: Plains Slope Ratio**	Terrain: Rolling and Mountainous Slope Ratio**
4 or more lanes (Z=12'@ 6:1)	≤4 ft	Z, then 6:1	Z, then 6:1
	>4 ft to 10 ft	Z, then 4:1	Z, then 4:1
	>10 ft to 15 ft	Z, then 4:1	Z, then 3:1
	>15 ft	Z, then 3:1	Z, then 3:1
▲ 2 lanes (Z=8'@ 6:1 or 6'@ 6:1 or 4'@ 6:1)	≤4 ft	Z, then 6:1	Z, then 4:1
	>4 ft to 10 ft	Z, then 4:1	Z, then 4:1
	>10 ft to 15 ft	Z, then 4:1	Z, then 3:1
	>15 ft	Z, then 2:1	Z, then 2:1

***** H is the vertical distance between outside edge of top layer of pavement and catch point where fill meets natural ground.

Slopes 3:1 or steeper should be reviewed for safety and guardrail warrants.

****** May be steep in special cases.

▲ In constrained situations on a 2-lane roadway, the Z slope may be constructed as steep as 4:1.

7.8.6 Clearance from Slope to Right of Way Line

It is desired to maintain a minimum of a 10-foot clearance from the slope to the existing or proposed right of way line. This provides an adequate distance that is needed for maintenance of slopes, walls, fences, etc.

7.8.7 Slope Benches

The necessity for benches, their width, and vertical spacing should be determined only after an adequate geotechnical materials investigation has been completed. The designer should contact the Materials and Geotechnical Branch.

For ease of maintenance, a 20-foot width of bench is satisfactory. Benches slope approximately 20:1 towards the roadway to prevent ponding of moisture behind the bench, thus creating additional slip plane problems. Benches should be constructed to blend with geologic strata rather than conforming to any set grade.

7.8.8 Cut Slope Treatment

The tops of all cut slopes should be rounded where the material is other than solid rock. A layer of earth overlying a rock cut also should be rounded. Refer to the Slope Rounding details on the typical sections and Subsection 203.05 of *CDOT Standard Specifications for Road and Bridge Construction* (CDOT, 2022).

Refer to Chapter 4, Section 4.8.4, of the 2018 AASHTO GDHS for more information.

7.9 Multimodal Accommodations

Developing a cross section template is not a one-size-fits-all approach. It requires an analysis of various factors including the contextual and functional classifications. These site conditions will help to determine the appropriate design elements and treatments to be considered. Many factors may be applicable in deciding the correct template needed. Those factors may include:

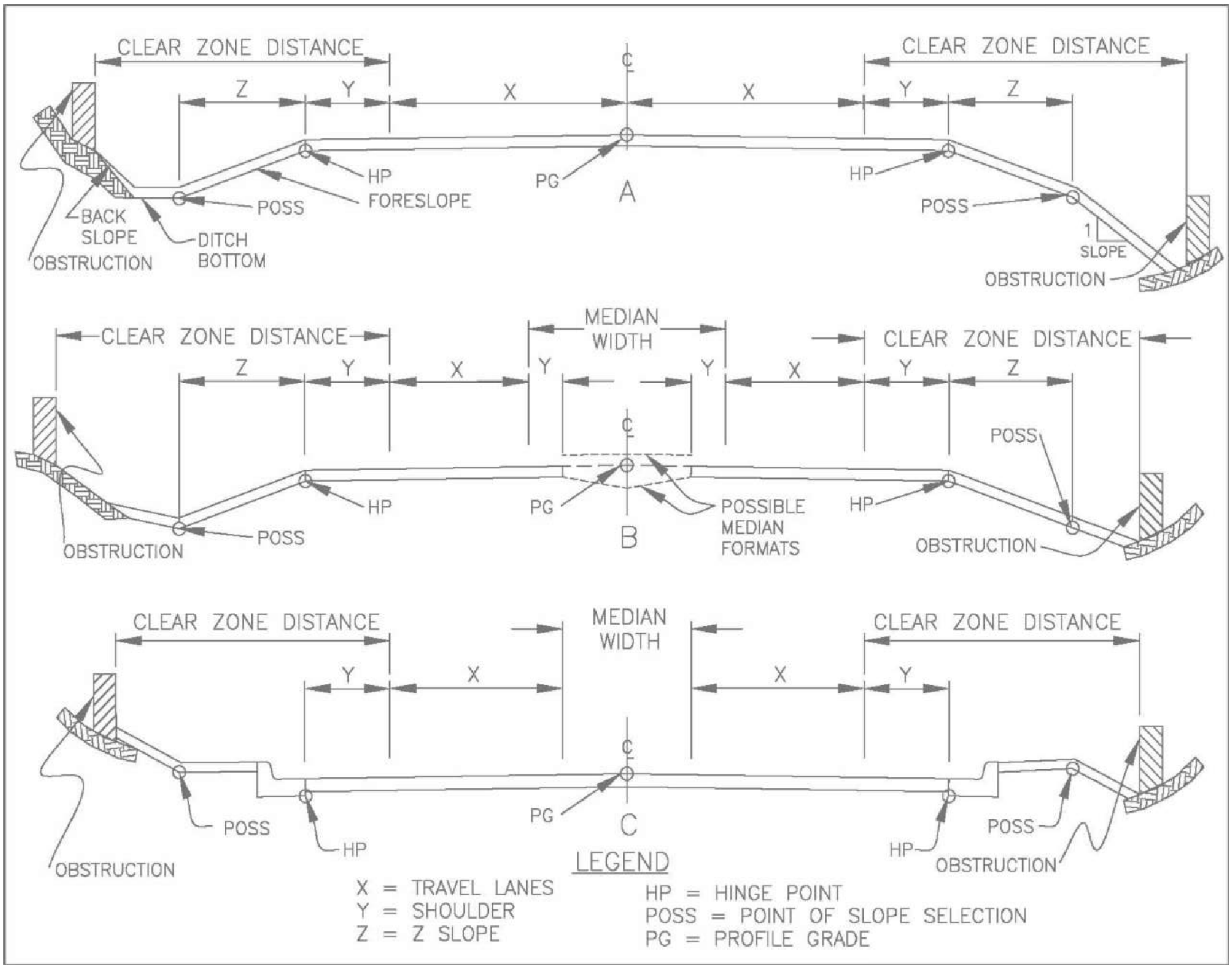
- Physical characteristics.
- Land use and roadway context classifications.
- Functional roadway classifications.
- Crash history.
- Expected pedestrian, bicycle, and motor vehicle demand.

There is not a single set of templates for a multimodal roadway. A multimodal roadway template is made of various zones (or elements) that need to be considered both independently and collectively to understand how they can best be balanced and stitched together to reflect the project goals. The appropriate accommodation for each mode of travel is dependent on a number of factors including transportation demands and conditions, traffic volume (by mode), traffic speed (by mode), and context and functional classification. The goal is to balance the needs of each mode based on these factors.

7.10 Illustrative General Cross Section

Figure 7-1 illustrates typical combinations of the highway elements: travel lanes, shoulders, side-drainage channels/landscaping areas, sidewalks, curbs, and side slopes.

Figure 7-1 General Cross Section Information



7.10.1 Normal Crown Sections

Figure 7-1 shows cross sections commonly used in CDOT highway practice, undivided and divided highways. Shoulder widths and Z slopes are included on both the fill and cut sections. The embankment or fill sections on the right side of the sections are composed of the Z slope and fill slopes.

The drainage channels shown on the left side of the sections are formed by the Z slope on the roadway side and the cut slope or backslope on the outer side. The Z slope and backslope combination should be selected to produce a cross section that can be safely traversed by an errant vehicle. Any hazardous object should be located outside of the clear zone.

What is a Z-slope?

When developing a roadway cross section, the designer starts with the centerline/profile grade (PG) and works outward by carrying a uniform cross slope for the pavement section. Typically, this cross slope for the pavement is a decreasing 2% grade, but it can be flatter or steeper depending upon superelevation or contextual constraint that require a flatter or steeper cross slope. The uniform cross slope away from the profile grade generally ends at the hinge point, which also corresponds to the outside edge of the roadway pavement.

The z-slope is the gravel area outside of the pavement edge that provides a strong traversable area. The intent of the z-slope is purely safety related as it provides an area for a driver to recover an errant vehicle, to safely traverse off the road and to recover back to the road. Generally, the z-slope has a 6:1 slope and can vary in width depending upon the terrain or right of way constraints.

The far outside edge of the z-slope is called the Point of Slope Selection (POSS). The POSS is where the designer begins developing a varying slope to connect to the existing terrain. The POSS slope can vary before it catches with the natural ground. If the POSS is still within the clear zone area, the slope may need to be maintained at 4:1 or flatter to provide a recoverable slope, or no less than 3:1 if the slope can be maintained down to the catch with natural ground for a traversable slope. If the POSS needs to be steeper than 3:1. the designer should investigate if roadside barrier installation is required. For example, if the Truck DDHV exceeds 250 veh/hr, then use 12 feet and then it can vary between 8 feet and 4 feet depending on lane and shoulder width.The designer should reach out to the Region Traffic Engineer to discuss the need for barrier installation.

For further information on traversable and recoverable slope, refer to the AASHTO *Roadside Design Guide* (AASHTO, 2011).

Z-Slope for Subgrade Drainage

Another advantage of the Z-slope is to extend it sufficiently enough away from the pavement section to allow the layers of the pavement subgrade to drain moisture away from under the pavement. By developing a Z-slope, with a grade sloping away from the roadway, this avoids the “bathtub” effect that could trap moisture under the roadway and weaken the pavement structure.

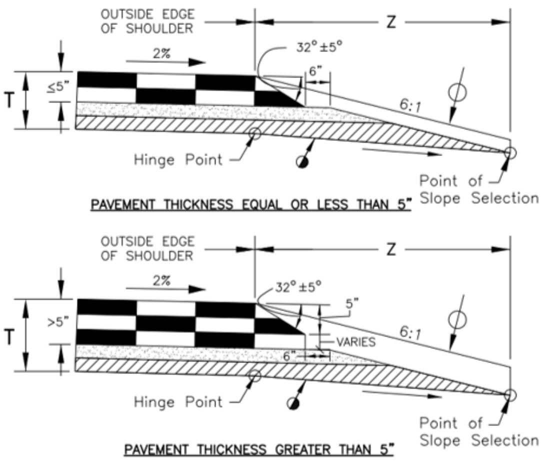
Figure 7-2 Z Slope Formula

T = TOTAL THICKNESS OF THE PAVEMENT STRUCTURE FROM TOP OF PAVEMENT TO TOP OF SUBGRADE.

Tm = MAXIMUM THICKNESS OF T WHICH WILL ALLOW A 50:1 OR STEEPER SLOPE BETWEEN THE HINGE POINT AND THE POINT OF SLOPE SELECTION.

Tm FOR 8' Z SLOPE @4:1= 25.58 inches
Tm FOR 6' Z SLOPE @4:1= 19.06 inches
Tm FOR 4' Z SLOPE @4:1= 13.54 inches
Tm FOR 8' Z SLOPE @6:1= 17.08 inches
Tm FOR 6' Z SLOPE @6:1= 13.56 inches
Tm FOR 4' Z SLOPE @6:1= 10.04 inches

FOR T GREATER THAN Tm, DIMENSION Z MUST BE INCREASED TO THE DISTANCE AT WHICH A 50:1 SLOPE FROM THE HINGE POINT INTERSECTS THE 6:1 SLOPE FROM THE SHOULDER.



FORMULA FOR SUBGRADE Z SLOPE

SUBGRADE Z SLOPE (ft/FT.) =

$$\frac{1}{\text{Z SLOPE}} + \frac{4" - T}{\text{Z WIDTH}}$$

(NOTE: ALL DIMENSIONS FOR FORMULA ARE IN INCHES)

7.10.2 Superelevated Sections

Although superelevation is advantageous for traffic operations, various factors such as wide pavements, abutting properties, drainage, intersections, and access points may make it impractical in built-up areas. Therefore, superelevation is not usually provided on low-speed urban streets in residential and commercial areas. It should be considered in industrial areas or streets where operating speeds are above 40 mph. A maximum superelevation of 4% to 6% is commonly used. A detailed discussion of superelevation is found in Chapter 3.

Refer to Chapter 4, Section 4.9.2 of the 2018 AASHTO GDHS for more information.

7.10.3 PBPD, MM, CSS Geometric Example

The development of a roadway cross section will generally follow an iterative process that involves a review and analysis of existing data sets and continuous outreach with project stakeholders to arrive at a series of options that best balance the project area constraints and context, intended users, and available budget. In many instances the cross section will not be a one size fits all and will need to vary throughout the project area. It is important to keep the main cross section consistent through the context of the project to improve safety and minimize user confusion.

Generally, as part of the project goal setting or purpose and need development, thoughtful conversations should be had with project area stakeholders to understand the priorities of the project and intended users that are looking to benefit. Realizing that CDOT has limited right of way and funding, tradeoffs will need to be discussed to develop a solution that best meets the project goals. This tradeoff discussion will likely further discussions around using design minimums to fit all the various modal needs into the project area limits.

Where practical to do so, general best practice is to focus on one or two modes and provide good quality facilities for those modes, then look for alternate corridors to accommodate some of the modes that were not catered to as much on the original project.

The use of design minimums should be avoided, especially when it comes to bicycle and pedestrian travel since they are the most vulnerable facility users. If needed, a balanced approach should be applied to reducing facility width across the roadway cross section. For example, this could involve reducing travel lane widths down to 11 feet to allow for a more useable 8-foot bicycle shoulder or more comfortable 6-foot sidewalk that allows two people to comfortably walk side by side.

7.11 Traffic Barriers

7.11.1 General Considerations

Traffic barriers are used to minimize the severity of potential crashes involving vehicles leaving the traveled way, where the consequences of errant vehicles striking a barrier are less severe than leaving the roadway. Barriers are a source of crash potential themselves, and their use should be carefully considered. For more detailed information regarding traffic barriers, refer to the CDOT *Safety Selection Guide* (CDOT, n.d.) and the AASHTO *Roadside Design Guide* (AASHTO, 2011).

The designer should request a safety analysis to determine crash patterns, including vehicle types, when discussing traffic barriers.

Use this link to access the CDOT Safety Selection Guide and resources: [CDOT Safety Selection Guide]

Performance level, or barrier capability, lateral deflection characteristics, and the space available to accommodate barrier deflection are important factors in the selection of a longitudinal barrier system. To accommodate the deflection, Guardrail Types 3 and 7 should be placed so that the back of the barrier is at least the minimum distance shown in the CDOT Standard Plans - M & S Standards (CDOT, 2019) from the obstruction.

In the C3 through C6 context classifications where there may be pedestrian and shared-use facilities adjacent to a general traffic lane warranting a Type 3 guardrail, a double block and rail median barrier or a railing should be considered to protect a bicyclists or pedestrian from injury if a collision with the guardrail occurs from the path side.

Consideration should be given to the adaptability of the system to operational transitions, end treatments, and to the initial and future maintenance cost.

Evaluation of the roadside environment entails six options in priority order:

- Remove or redesign the obstacle so it can be safely traversed.
- Relocate the obstacle to a point where it is less likely to be struck.
- Reduce impact severity by using an appropriate break-away device.
- Redirect the vehicle by shielding the obstacle with a longitudinal traffic barrier and/or crash cushion.
- Delineate the obstacle if the above alternatives are not appropriate.
- Make no change to existing. Refer to the CDOT *Project Development Manual* Section 2.09 (CDOT, [2013] 2022).

The sixth option would normally be cost effective only on low-volume and/or low-speed facilities or where engineering studies or safety evaluations show that the probability of a crash occurring is low. Clear documentation of this decision shall be completed and added to the project design file.

Site preparation is an important consideration in the use of traffic barriers. To ensure maximum barrier effectiveness, site conditions should be tailored to the performance characteristics of the particular barrier.

Roadway cross section significantly affects traffic barrier performance. Curbs, dikes, drainage inlet structures, sloped shoulders, and stepped medians can cause errant vehicles to vault or undermine a barrier or to strike a barrier so that the vehicle overturns. Optimum barrier system performance is provided by a relatively level surface in front of the barrier and, for semi-rigid and flexible barriers, beneath and behind the barrier. Where curbs and dikes are used to control drainage, they should be located directly in line with or behind the face of the barrier. Some barrier manufacturers have very specific details on the location of curbs or dikes to ensure they still meet crash test criteria in AASHTO's *Manual for Assessing Safety Hardware* (MASH) (AASHTO, 2016). The designer should investigate the proper placement of curb or dikes relative to the barrier that will be used.

7.11.2 Longitudinal Barriers

Longitudinal barriers are generally denoted as one of three types: flexible, semi-rigid, or rigid. The major difference between the types is the amount of barrier deflection that takes place when the barrier is struck.

Consider the following:

- Height of the barrier affecting driver sight distance, e.g., glare screen or offset barrier affecting sight distance on curves.
- Barrier transitions from different types of rail.

- Barrier transitions and end treatments used based on the context of the area involving multimodal applications.
- Wildlife being able to make passage under or over barriers.
- Maintenance concerns with snow drifting, ease of maintenance, immediacy of making repairs, and continuity of type and material.
- Height of the barrier in relation to a bicyclist's center of gravity in the case of barrier strike and potential overturning.
- Drainage concerns and icing (barrier shadows).
- Adequate room for entrance gating.
- Context-sensitive solutions (CSS). Refer to the Federal Highway Administration (FHWA) *Flexibility in Highway Design* document (FHWA, 1997).
- Materials selection such as wood vs. steel posts and galvanized vs. corrosion-resistant steel.
- Aesthetics and CSS considerations. Consider visual impact of selected barrier type and any memorandum of agreement that may apply to a specific corridor. Refer to the AASHTO *Roadside Design Guide* (AASHTO, 2011).

7.11.2.1 Roadside Barriers

A roadside barrier is a longitudinal system used to shield motorists from natural or manmade hazards located along either side of a roadway. It may occasionally be used to protect pedestrians, bystanders, and bicyclists from vehicular traffic. Temporary barriers are also used to protect workers in work zones.

Height and slope of the embankment are the basic factors in determining the barrier need through a fill section. Refer to the AASHTO *Roadside Design Guide* (AASHTO, 2011) for determination of barrier needs.

A clear, unobstructed, flat roadside is desirable. The objective of a barrier is to enhance safety. Therefore, a barrier should be installed only if it is clear that the barrier will have lower crash severity potential than the roadside obstacle it is shielding.

Short lengths of roadside barriers are discouraged. Where needed in two or more closely spaced locations, the barrier should be continuous. The designer should also be sure to communicate with the CDOT Region traffic staff to ensure proper calculations for length of need to adequately shield the greater hazard have been completed.

7.11.2.2 Median Barriers

"A median barrier is a longitudinal system used to minimize the possibility of an errant vehicle crossing into the path of the traffic traveling in the opposite direction."

> "Special consideration should be given to barrier needs for medians separating traveled ways at different elevations. The ability of an errant driver leaving the higher elevated roadway to return to the road or to stop diminishes as the difference in elevations increases. The potential for crossover, head-on crashes increases in these situations."
>
> "For all divided highways, regardless of median width and traffic volume, the median roadside must also be examined for clear zone hazards."
>
> "Barriers should also be considered on outer separations of 50 feet or less adjacent to frontage roads." (2018 AASHTO GDHS)

Common types of median separation barrier include:

- Cable barrier.
- Double-faced steel W-beam (blocked-out) installed on strong posts.
- Concrete barrier.

Some use is also made of a three- or four-cable barrier installed on light steel posts, a double-faced steel W-beam installed on weak posts, a double-faced steel thrie beam (blocked-out) installed on strong posts, and a cable-chain-link-fence combination. When cable barrier is considered, the designer should fully investigate the maximum deflection of the cable barrier when struck so that the deflection does not encroach oncoming traveled lanes.

Use this link to access the CDOT Cable Barrier Guide: CDOT Cable Barrier Guide — Colorado Department of Transportation (codot.gov)

During the selection and design of a median barrier, consideration should be given to the possible effect of the barrier on horizontal sight distance.

Precast concrete median barrier and other CDOT approved barriers can be used for temporary positive protection of work areas and for guiding traffic during construction.

Refer to Chapter 4, Section 4.10.2.2, of the 2018 AASHTO GDHS for more information.

7.11.3 Bridge Railings

When designing bridge rail, the designer should consider the protection of pedestrians and bicyclists. In accordance with the AASHTO *Guide for the Development of Bicycle Facilities* (AASHTO, 2012b), bridge railing heights should be a minimum of 42 inches, with a preference of 48 inches, where pedestrians and cyclists are anticipated, and a more serious injury is likely to occur if either user were to fall over the edge. In addition, a bicycle handlebar rub rail that spans a height of 36 inches to 48 inches should be provided where bicyclists are expected to be traveling adjacent to the bridge railing.

The need for traffic barriers generally does not stop at the end of the bridge. The need must be filled by extending the bridge railing with a roadside barrier, which in turn must have a crash-worthy end terminal.

At the juncture between a bridge railing and roadside barrier, there is nearly always incompatibility in the stiffness of the two barrier types. This stiffness must be transitioned over a transition length that will prevent the barrier system from pocketing or snagging an errant vehicle. Refer to the CDOT Standard Plans - M & S Standards (CDOT, 2019).

Refer to Chapter 14 of this Guide for more information on bridges.

7.11.4 Crash Cushions

"Crash cushions are protective systems that prevent errant vehicles from impacting roadside obstacles by decelerating the vehicle to a safe stop when hit head-on or redirecting it away from the obstacle. A common application of a crash cushion is at ramp gores where a bridge-rail end exists in the gore. Where site conditions permit, a crash cushion should also be considered as an alternative to a roadside barrier for shielding rigid objects, such as bridge piers, overhead sign supports, abutments, and retaining wall ends. Crash cushions may also be used to shield roadside and median barrier terminals." (2018 AASHTO GDHS)

Design of new highways should consider alternatives to a crash cushion where possible. Where a crash cushion is the best alternative, adequate level space free from curbs or other physical features should be provided. Site preparation is important in using crash cushion design. Site conditions not compatible with the cushion design can compromise cushion effectiveness.

Refer to the CDOT *Safety Selection Guide* (CDOT, n.d.) for guidance in selecting crash cushions.

7.12 Medians

Use of medians will vary according to the type of highway and future developments expected on the highway. Medians may be used to:

- Separate opposing traffic.
- Provide an area for emergency stopping and recovery of errant drivers.
- Allow for left turns and U-turns.
- Provide width for future lanes or other alternate travel modes.
- Provide an area for snow storage.
- Minimize headlight glare.
- Provide a refuge area for pedestrians or bicyclists (refer to Chapters 9 and 14 of this Guide).
- Provide area for landscaping and lighting.

Median width is measured as the distance between the edges of traveled way and includes inside shoulders. The width of median should be appropriate to its purpose. The primary determinant of required median width is the type of facility. Width may be limited by right of way limitations, economics, pedestrian crossing distance, topography, aesthetic concerns, and at-grade intersection signal operations.

Roadways with opposing directions of travel less than 4 feet should be considered separators, not medians. When designing separators, sign width and location should be considered, and placement discussed with the CDOT Region Traffic Engineer.

Medians may be flush, depressed, or raised. Advantages of depressed medians include improved drainage and opportunities for snow storage. Depressed medians should be sloped downward on a 6:1 slope to a central valley with adequate median drainage provided. Where profile grades differ, engineering judgment must be used to provide a median that will drain properly and be as safe as possible.

Raised medians have application on arterial streets where it is desirable to regulate left-turn movements and control access. Raised medians are typically used in urban settings especially if medians are to provide an area for pedestrians to stand or be planted with landscaping. Consider that plantings and other landscaping features in median areas may constitute roadside obstacles and may limit sight distance. However, these vertical features have been shown to positively influence a reduction in travel speeds as drivers tend to slow down when traveling near vertical objects that are closer to the travel way edge.

Flush (or painted) paved medians are often used where two-way left-turn lanes are desired to improve capacity and reduce rear-end crashes resulting from left turning vehicles having to stop in active through travel lanes. Dedicated left-turn lanes may also be placed in the median area. In these cases, the turn lanes are not considered to be part of the median but are designed as an auxiliary lane.

Normally, the turn lane should be the same width as the travel lanes. Conditions with high numbers of truck or bus movement or conditions with limiting geometry may warrant different widths. Slightly wider turn lane widths, when width is available, provide an offset from opposing turning traffic and can improve sight distance for the motorist for a safe turning movement.

Refer to Chapter 4, Section 4.11 of the 2018 AASHTO GDHS for more information.

7.12.1 MM, PBPD, and CSS Considerations

In urban and suburban areas, or key rural areas (such as where a shared-use path crosses the highway/roadway), medians are highly beneficial to facilitate pedestrian or bicyclist crossings. In this case, a “refuge” or cut-out in the median is provided to allow for a two-stage crossing. This provides a waiting area in between bi-directional traffic to help cross streets with wider cross sections and allow pedestrians or bicyclists to judge gaps in traffic one direction at a time rather than trying to judge both directions simultaneously. Refuge areas must meet ADA compliance requirements. Refuges can be sited at intersections or at midblock locations depending on the pedestrian desired lines and adjacent activity generators. In general, if the logical crossing occurs midblock, and the crossing can be accommodated and controlled with signage, striping, and other traffic control devices, such as pedestrian hybrid beacons, it should be considered in that logical location rather than providing the crossing at adjacent intersections and expecting pedestrians or bicyclists to travel out-of-direction to cross the street.

7.13 Frontage Roads

A frontage road is a local auxiliary road generally located adjacent to more rural and higher speed roadways. It is primarily used in conjunction with expressways and freeways, although it may be used with any roadway.

Among the functions of frontage roads are controlling access, segregating high-speed through traffic from lower-speed local traffic, and keeping traffic generated by development in the surrounding area from directly affecting the safety and operations of the higher speed regional roadway.

Frontage roads provide an opportunity to allow bicycle and pedestrian connectivity adjacent to high-speed facilities that are not suitable for these modes of travel. They also provide opportunities to encourage travel by transit with transit hubs and/or access to park-n-ride facilities.

Specific applications of frontage roads vary with the type of roadway. One disadvantage of frontage roads is that they increase the complexity of the roadway operations, possibly leading to driver confusion, particularly at night when cars on frontage roads could be perceived as driving on the wrong side of the highway. Additional complexity is also found at crossroad intersections and how two very closely spaced intersections on both sides of the roadway are signalized.

Frontage road alignment may be parallel or divergent, continuous or broken, one-way or two-way, and on one or both sides of the main roadway. The connection at the frontage road and the main roadway is one of the more important aspects of frontage road design. Its cross section is dependent on geometric constraints, traffic characteristics and often intersection operations.

Traffic operations are improved if the frontage roads are located a considerable offset distance from the main roadway at the intersecting crossroads, in order to lengthen the spacing between successive intersections along the crossroads. In urban areas, a desirable spacing is approximately 150 feet (edge of shoulder to edge of shoulder) between the main roadway and the frontage road.

At the intersection, for satisfactory operation with moderate-to-heavy traffic volumes on the frontage roads, the outer separation should be 150 feet or more in width. However, wider separations can enhance operations significantly. Outer separations of 300 feet accommodate turning movements and provide a minimal amount of vehicle storage.

When a frontage road approaches a cross street that also connects to the mainline (highway), the minimum separation should be 300 feet between intersections, but the desired separation of these intersection should be investigated through a traffic analysis to determine current and future traffic queue impacts and storage requirements for all turning operations.

Narrower separations are acceptable where frontage-road traffic is light, where the frontage road operates one-way only, or where some movements can be prohibited. In these situations, outer separations as narrow as 16 feet may operate satisfactorily with barrier separation on roadways greater than 45 mph. For narrower separations on roadways less than 45 mph a 4-foot separation for barrier and a minimum of a 6-foot shoulder area for both roadways can be prohibited

Refer to Figures 4-7 through 4-10 in the 2018 AASHTO GDHS for schematics of frontage roads.

Refer to Chapter 4, Section 4.12, of the 2018 AASHTO GDHS for more information.

7.14 Outer Separations

The area between the outside edge of the main roadway and inside edge of traveled way of any street or frontage road is designated as the outer separation (Table 7-2). The separation functions as a buffer between the highway and local traffic and may be landscaped for improved aesthetics. The width of the outer separation is dependent on the highway classification and the type of street from which it is being separated. Plantings and other landscaping features in outer separators may constitute roadside obstacles. Separations should also be designed to prevent unauthorized access between main line and frontage roads.

Outer separations must meet clear-zone criteria. Refer to the 2018 AASHTO GDHS and AASHTO *Roadside Design Guide* (AASHTO, 2011).

Refer to Chapter 4, Section 4.13, of the 2018 AASHTO GDHS for more information.

Table 7-2 Width of Separation for Frontage Roads

Type of Frontage Road	Separation Width Minimum	Separation Width Desirable*
Two-Way Frontage Roads	24 ft	≥ 40 ft
One-Way Frontage Roads	20 ft	≥ 30 ft
Arterial Streets With Frontage Roads	8 ft	

**Use on non-urban highways.*

7.15 Noise Control

7.15.1 General Considerations

Roadway noise is generally defined as unwanted sound. Motor vehicles generate traffic noise from the motor, aerodynamics, exhaust, and interaction of tires with the roadway. Efforts should be made to minimize the radiation of noise into noise-sensitive areas along the roadway. The designer should coordinate with the CDOT Region Planning/Environmental Manager to evaluate noise levels and the need for reducing highway traffic noise through location and design considerations.

The physical measurement of human reaction to sound is difficult because there is no instrument that will measure this directly. A close correlation can be obtained by using the A-scale on a standard sound-level meter. The meter yields a direct reading in A-weighted decibels (dBA).

Traffic noise produces varying human reactions. The physical factor of noise is not, in itself, a good predictor of the level of public displeasure; the reaction is usually less if the noise source is hidden from view. The type of development in an area is another factor that affects the displeasure level. Higher traffic noise levels are usually more tolerable in industrial areas than in residential areas.

Other factors that influence human reactions to sound are pitch and intermittency. The higher the pitch or the more pronounced the intermittency of the noise, the greater the degree of annoyance.

For more information, refer to Chapter 16 of this Guide.

Refer to Chapter 4, Section 4.14, of the 2018 AASHTO GDHS for more information.

Refer to *CDOT Noise Analysis and Abatement Guidelines* (CDOT, 2020).

Use this link to access the CDOT Noise Analysis and Abatement Guidelines: CDOT Noise Analysis & Abatement Guidelines

7.16 Roadside Control

7.16.1 General Considerations

The efficiency and safety of a roadway depend greatly upon the amount and nature of roadway access points to the surrounding land uses. The designer should consult the State Highway Access Code (State of Colorado, 2002) and coordinate with the CDOT Region Access Manager for questions related to property owner right of access. Increased turbulence resulting from indiscriminate roadside development and uncontrolled driveway connections results in lowered capacity, increased hazards, and early obsolescence of the highway.

Refer also to Chapter 11 of this Guide and the State Highway Access Code (State of Colorado, 2002) for further information on access.

7.16.2 Driveways

Driveway terminals are, in effect, low-volume intersections; thus, their design and location merit special consideration.

In general, driveways should be consolidated whenever possible after consulting with the Region Access Coordinator. Full movement driveways should naturally be oriented to the adjacent local roadways that are primarily meant to serve more local-access-oriented streets. Especially on more regional and arterial and higher volume collector roadways, access control should be considered where possible to limit the number of driveways and the number of movements that are allowed. On higher roadway classification, access should be limited to right-in/right-out and with left turns restricted and limited to only discrete locations that may provide proper traffic control devices. Cross access agreements between adjacent property owners should be pursued whenever possible. Another important consideration is to eliminate large graded or paved areas adjacent to the traveled way that are uncontrolled access points. Driveway width should be reduced and made as narrow as possible to accommodate the average design vehicle and limit entry or exit speeds to reduce potential conflicts with pedestrians and bicyclists that may be crossing through the driveway. The driveway cross slope shall accommodate ADA PROWAG regulations for pedestrians.

Refer also to Chapter 11 of this Guide for further information on access.

7.16.3 Mailboxes

Most vehicles stopped at a mailbox are clear of the traveled way when the mailbox is placed outside an 8-foot-wide usable shoulder or turnout.

For guidance on mailbox installations, refer to the latest edition of AASHTO *Roadside Design Guide* (AASHTO, 2011), and the CDOT Standard Plans - M & S Standards (CDOT, 2019). Local postal regulations should be consulted for additional criteria. Refer to Chapter 4, Section 4.15 of the 2018 AASHTO GDHS for more information.

7.17 Tunnels

7.17.1 General Considerations

Sections of streets or highways may be constructed in tunnels to carry them under or through a natural obstacle or to minimize the impact of the freeway on the community.

It may be necessary to engage a consultant to design the tunnel and associated lighting, fire prevention, and electrical and ventilation systems.

7.17.1.1 Shared Roadways

Depending on the nature of the roadway, width of shoulder and lighting levels within the tunnel, bicycle and pedestrian accommodations should be considered where necessary. Based on the confined nature of tunnels, any bicycle and pedestrian accommodations should be well thought out to ensure the safety and comfort of those users. If bicycle lanes or shoulders are provided, they should be wide enough to allow a bicyclist the space to maneuver around any debris or water collecting in the tunnel. Lighting levels should provide adequate illumination that is consistent with national best practice to allow a bicyclist to be seen by a driver and for a bicyclist to see any potential hazard in the roadway. Drainage grates and manhole covers should be reviewed to ensure that they are oriented to prevent any bicycle tires from becoming stuck in them and leading to a potential crash. If bicycle lanes or shoulders cannot be provided and bicyclists must share the roadway with moving traffic, passive or actuated warning devices should be considered to be installed on the approaches to the tunnel portals to alert drivers to the presence of bicyclists in the tunnel.

7.17.2 Types of Tunnels

Tunnels can be classified into two major categories: tunnels constructed by mining methods, and tunnels constructed by cut-and-cover methods. Of particular interest to the highway designer are the structural requirements of these construction methods and their relative costs.

7.17.3 General Design Considerations

The feeling of confinement in tunnels is unpleasant, and traffic noises are magnified. Because tunnels are the most expensive highway structures, they should be made as short as practicable.

Keeping as much of the tunnel length as possible on tangent will minimize the length and improve operating efficiency.

7.17.4 Tunnel Sections

From the standpoint of service to traffic, the design criteria used for tunnels should not differ materially from grade separation structures. The same standards for alignment, profile, and vertical and horizontal clearances generally apply.

Full left- and right-shoulder widths of the approach roadway should be carried through the tunnel. The need for added lateral space is greater in tunnels than under grade separated structures because of the greater likelihood of vehicles becoming disabled in the longer lengths and the natural desire to shy away from the walls of the tunnel and potential oncoming traffic.

Normally, pedestrians are not permitted in roadway tunnels; however, space should be provided for emergency walking and for access by maintenance personnel. Raised sidewalks, a minimum of 4 feet wide, are desirable beyond the shoulder areas to serve the dual purpose of a safety walk and an obstacle to prevent the overhang of the vehicles from damaging the wall finish or the tunnel lighting fixtures.

7.17.5 Examples of Tunnels

Figure 7-3 includes examples of tunnels in Colorado.

Figure 7-3 Tunnels in Colorado

Left to right: US 550 Bear Creek, I-70 Veterans Memorial Tunnels, and I-70 Eisenhower-Johnson MemorialTunnel.

7.18 Pedestrian Facilities

Consistent with CDOT Procedural Directive 1602.1, “Elevating Bicycle and Pedestrian Opportunities in Colorado” (CDOT, 2017), roadway designers shall accommodate pedestrians and bicyclists during planning, programming, design, construction, operation, and maintenance of the state highway system. Appropriate provisions must be made to provide accessible walking routes where pedestrians are expected. The type of facility can vary between a raised or separated sidewalk to a multiuse path or grade separated pedestrian bridge. Similar to the development of roadway cross sections, the context of the surrounding land use, expected pedestrian volume, vehicular traffic conditions, intersection configurations, separation between the pedestrian and vehicular facilities, and other general study area constraints play a part in determining the type of facility provided.

Based on the scale and resource implications to developing any grade-separated pedestrian structures, decisions regarding pedestrian overpasses and underpasses should be coordinated with the local agencies and the public. Care must be exercised to ensure access to persons with disabilities at pedestrian crossings. Refer to CDOT Standard Plans - M & S Standards (CDOT, 2019), and the requirements of the Public Rights of Way Accessibility Guidelines (PROWAG). For more information, contact CDOT's Civil Rights and Business Resource Center.

The project design shall also maintain ADA-compliant access during construction for the safety of pedestrian and bicyclists.

7.18.1 Sidewalks

Sidewalks are most often located where there is identified pedestrian demand such as schools, residential and commercial areas. Sidewalks should be considered in rural areas that have land use that support pedestrian activity. In project locations that presently do not have sidewalks, engineers can frequently identify historic pedestrian activity through defined “goat paths” or worn areas of grass where pedestrians have been traveling. Sidewalks should be considered for bridges especially in locations where sidewalks are provided on the approach and departure ends to the bridge.

Sidewalk width may vary due to physical limitations but generally should be a minimum of 5 to 6 feet of unobstructed width. It should be noted that two people need at least 6 feet to walk side by side comfortably. In constrained locations sidewalks can be reduced down to 4 feet but would require 5-foot-by-5-foot-wide passing zones every 200 feet to allow wheelchair users to pass one another. The width of the sidewalk generally should increase as the pedestrian volume increases up to 8 feet and often can expand to from 8 to 12 feet wide in denser commercial areas categorizing it as a shared use path. Where available the sidewalk should be separated from the moving traffic lane through a landscaping strip that varies in width from a minimum of 2 feet depending on the available right of way and type of landscaping being provided.

The designer should check with local agencies for design considerations.

For more information refer to Chapter 13 of this Guide.

7.18.2 Sidewalk Curb Ramps

In general, curb ramps within the project limits shall be brought into compliance with CDOT Standard Plan M-608-1 Curb Ramps. Most projects with curb ramps are required to upgrade ramps that do not meet the minimum requirements for functional accessibility, as defined in CDOT's *ADA Transition Plan* (CDOT, 2017). Additional guidance can be found in CDOT's *ADA Transition Plan*; Chapter 12 of this Guide; and CDOT Procedural Directive 605.1, “ADA Accessibility Requirements in CDOT Transportation Projects” (CDOT, 2017).

Questions about project-specific ramps should be directed to the CDOT ADA Regional Representative. Refer to Chapter 12 of this Guide.

Refer to Chapter 4, Section 4.17, of the 2018 AASHTO GDHS for more information.

7.19 Bicycle Facilities

Bicyclists should be expected on all state roadway facilities and should be accommodated to varying degrees unless there is an insurmountable constraint or safety reason for prohibiting bicycles from a section of roadway or highway. Generally, bicycles can share the roadway with vehicular traffic, utilizing shared lanes, paved shoulders, dedicated bike lanes, or protected bike lanes (also called separated bike lanes). Off-street trails or shared-use paths provide the highest-comfort bicycle facility for bicyclists of all ages and abilities and are ideal when there is sufficient right of way to provide them. The criteria for evaluating how best to accommodate the appropriate bicycle facility include land use context, traffic speeds, traffic volumes, the presence of on-street parking, the frequency of driveways or intersections, and the street’s importance within the larger local, regional, or statewide bicycle network.

Specific information on warrants and construction requirements for bicycle facilities can be found in Chapter 14 of this Guide.

Refer to Chapter 4, Section 4.18, of the 2018 AASHTO GDHS for more information.

7.20 Bus Turnouts

Bus travel is an increasingly important mode of public transportation. Bus turnouts are safe areas for buses outside of the traffic lanes. The location and design of turnouts should be readily accessible in the safest and most efficient manner possible. The designer should coordinate details with the local transit agency. Intergovernmental Agreements may be required.

7.20.1 Freeways

A bus turnout off of the freeway must accommodate the deceleration, standing, and acceleration of buses on pavement areas clear of and separated from the through-traffic lanes. Speed-change lanes should be long enough to enable the bus to leave and enter the traveled way at approximately the average running speed of the highway without undue discomfort to the passengers. Refer to Section 4.19 of the 2018 AASHTO GDHS.

7.20.2 Arterials

The operations between buses and other traffic on arterial roadway should be considered in the context of the frequency of the bus headway, average stop duration, number of travel lanes and overall impact on traffic operations. In some conditions an in-lane stop might be acceptable and in higher volume roadway conditions with available right of way a bus turn out might be appropriate. It should be noted that bus operators often have trouble reentering the stream of traffic resulting in additional delay to bus riders and thus generally prefer in-lane stops. The designer should coordinate details with the local transit agency.

Use this link to access the Colorado Transit Directory Map: Colorado Transit Directory Map - Colorado Association of Transit Agencies

Refer to the AASHTO *Guide for Design of High-Occupancy Vehicle and Public Transportation Facilities* (AASHTO, 2004) for more information on bus turnouts.

7.20.3 Park-and-Ride Facilities

Park-and-Ride facilities are designed to accommodate:

- Bus loading and unloading.
- Taxis and ride share companies.
- Bicycle parking.
- Parking for bus passengers including persons with disabilities.
- Drop-off facility, plus holding or short-term parking area for passenger pickup. Coordinate details with CDOT's Division of Transit and Rail and local transit agency.

Refer to the AASHTO *Guide for Design of High-Occupancy Vehicle and Public Transportation Facilities* (AASHTO, 2004).

7.21 Transit Facilities

"Public transportation provides high passenger capacities in heavily traveled corridors, and allows high employment concentrations in city centers. It permits compact urban developments that are pedestrian and bicycle friendly and provides mobility for people that are unable to drive or do not have access to motor vehicles.

Transit vehicles operate in a wide range of environments, both on-street and off-street. Commuter rail and rapid transit operate in exclusive rights-of-way that are frequently grade-separated from intersecting roadways. However, bus routes on public streets and roadways and light rail or streetcar operations often share or intersect with the street environment.

Streets and roadways often must accommodate transit vehicles as well as motor vehicles, bicyclists, and pedestrians. Transit provisions are best accomplished when incorporated into all phases of street planning, design, and operation. This is essential especially where agencies at the state, county, and municipal level are required to plan, design, or modify streets and roadways to accommodate public transportation vehicles and facilities.

Planning and design guidelines, standards, and practices for transit accommodation have evolved over the past decade. Most of this guidance, however, encompasses a specific mode, such as buses, rapid transit, and light rail transit (LRT) and are sometimes prepared in response to specific agency needs. Recognizing that situation, AASHTO has developed the *Guide for the Geometric Design of Transit Facilities on Streets and Highways* (AASHTO, 2018) to provide design practitioners with a single, comprehensive resource that documents and builds upon past and present experience in transit design in streets and roadways.

The dominant form of public transportation in most urban areas is bus transit. Most bus transit operates in mixed traffic on streets. Generally, designs that make traffic move faster and more safely will improve bus speeds and service reliability. Roadway geometry should be adequate for bus movement, and pedestrian access to stops should be convenient. There are situations where preferential treatment for transit (dedicated lanes, stations, and priority at traffic signals) may be desirable. In those cases, the benefits to transit riders should typically be balanced with the effects on roadway traffic. Treatments and priorities for bus transit can vary depending upon specific traffic, roadway, and environmental conditions. Regardless of the type of treatment, the geometric design and traffic control features should adequately and safely accommodate all vehicles, pedestrians and bicyclists that would use a street or roadway. Where a street facility will be limited to bus use only, design features can generally be modified easily from those that apply for general traffic use.

This section addresses bus transit turnouts on freeway and arterial facilities. For guidance on other elements of transit facility design, including other types of transit facilities operating in and adjacent to streets and roadways, refer to AASHTO's *Guide for the Geometric Design of Transit Facilities on Streets and Highways* (AASHTO, 2018). Guidelines for high-occupancy vehicle (HOV) facilities on arterial streets are addressed in NCHRP Report 414, *HOV Systems Manual (NCHRP, 1998)*." (2018 AASHTO GDHS)

7.22 On-Street Parking

On-street parking is generally found in locations where local commercial and residential land uses support this application. In many urban and residential areas, on-street parking can be seen as essential to support the commerce of local businesses and the community. Where there is current or future demand for its use, parking should be considered where applicable. While parking does often create additional roadway turbulence and slows through vehicles in these areas, this does present the opportunity to help calm traffic.

Parking can be provided in a variety of parking configurations. Generally, it most commonly oriented in a parallel layout. Recently, variations of these parking layouts have been introduced through the inclusion of parking protected bicycle lanes where parking is located in between active vehicular travel and bicycle lanes. As is noted previously, the surrounding land use context and corridor transportation needs should be considered when determining where parking should be provided and in what configuration.

Chapter 8
Intersections

Legend

	Multimodal Application Example
	Context-Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context-Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO-Specific Information

Chapter 8

8 Intersections

8.1 Introduction

An intersection is defined as the general area where two or more roadways join or cross, including the roadway and roadside facilities for traffic movements within it.

Intersections operate with vehicles, pedestrians, and bicycles proceeding in many directions, often at the same time, creating the potential for conflicts. Managing these conflicts are the basis for most intersection design standards, criteria, and proper operating procedures.

An intersection is an important part of a transportation system because, to a great extent, the efficiency, safety, speed, cost of operation, and capacity depend on its design. Each intersection involves through or cross-traffic movements on one or more of the facilities concerned and may involve turning movements between these facilities. These movements may be handled by roundabouts, traffic signals, signing, and channelization depending on the type of intersection.

8.2 General Design Considerations

8.2.1 Characteristics of Intersections

The main objective of intersection design is to provide convenience, ease of use, and comfort to the people traversing the intersection while facilitating the efficient movement of passenger cars, buses, trucks, bicycles, and pedestrians. The design should be fitted closely to the natural transitional paths and operating characteristics of the users.

Four basic elements enter into design considerations of intersections:

- *Human factors.* decision reaction times, sight distance, distractions to the driver, pedestrian behavior, and bicyclist behaviors.

- *Traffic considerations.* Number of conflicting movements, required storage lengths, varying travel demand, roadway capacity, design hour traffic volumes, and vehicle speeds.
- *Physical elements.* Intersection skew, approach grades, context of the surroundings, availability of right of way, transit elements, and sight distance.
- *Economic factors.* Cost of improvements, planning horizon for improvements, community needs and desires, and energy consumption.

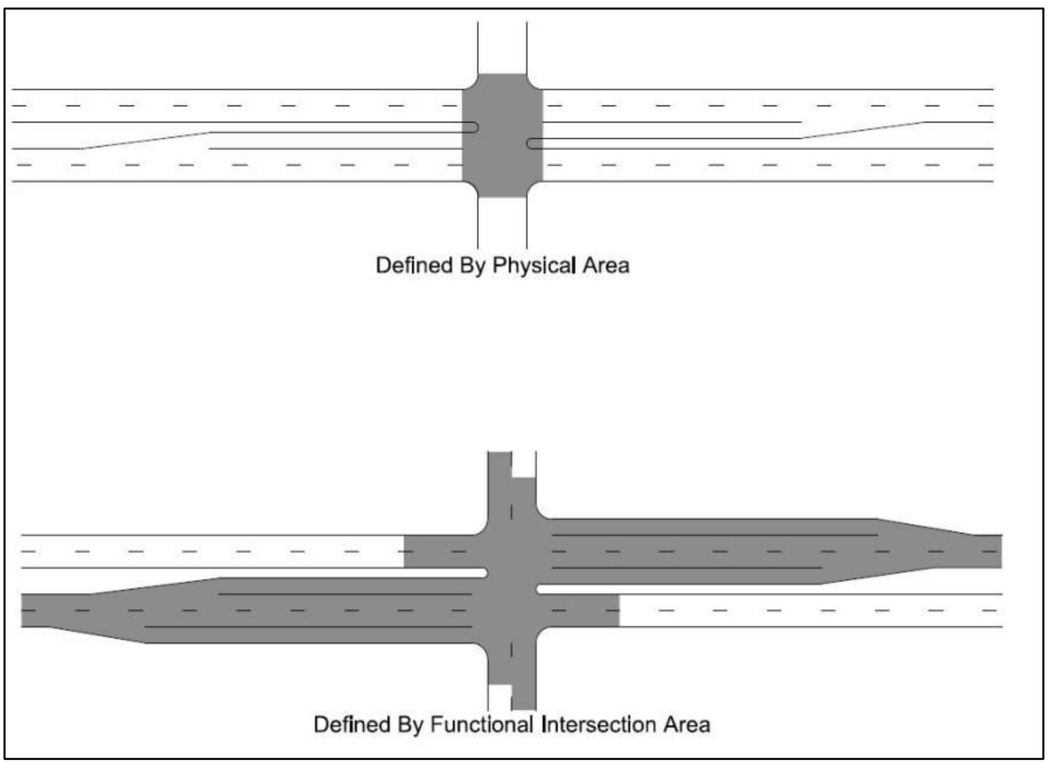
Although intersections have many common factors, each intersection is unique in regard to intersection design variables and operational characteristics.

Each facility radiating from an intersection is an intersection leg. The most common intersection has two facilities crossing each other, resulting in four legs. It is recommended that an intersection have no more than four legs.

8.2.2 Intersection Physical and Functional Areas

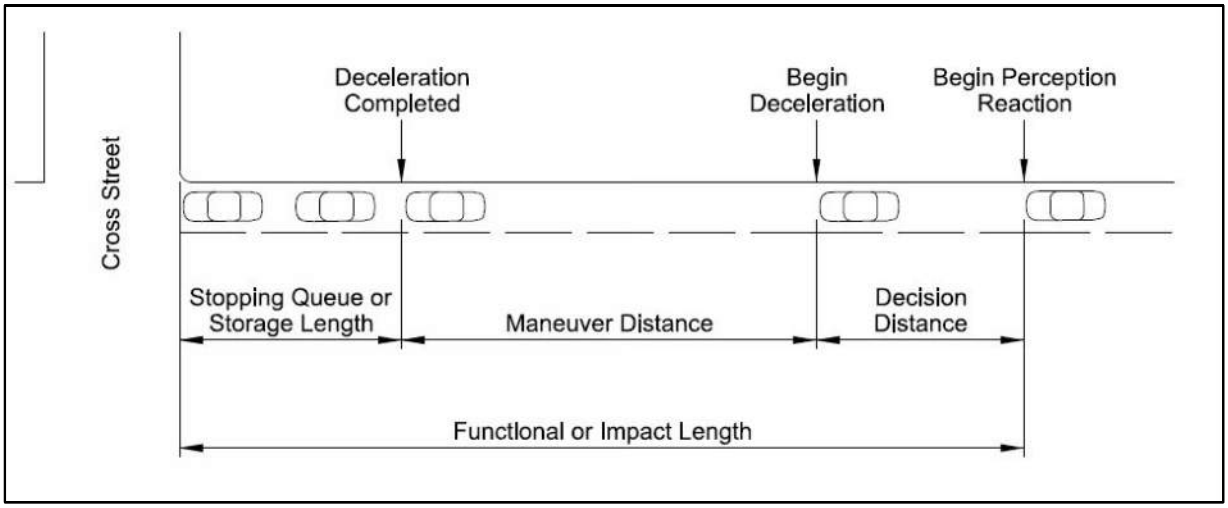
Intersections are defined by both the physical and functional areas, as shown in Figure 8-1. The physical intersection area traditionally extends from point of control perpendicular across the roadway. The functional intersection area extends both upstream and downstream of the physical intersection area and includes speed change lanes and their tapers.

Figure 8-1 Physical and Functional Intersection Area



The functional area of the approach to an intersection or access point includes the perception-reaction decision distance, deceleration distance that includes maneuvering, and storage distance. Elements of the functional area are shown in Figure 8-2.

Figure 8-2 Elements of the Functional Area of an Intersection



8.2.3 Design Objectives

When considering the intersection design and specific elements such as length of auxiliary lanes, the designer should have the intersection traffic counts completed and modeled to replicate the traffic movements through a series of intersection configurations to determine the optimal design solution and auxiliary lane lengths for the intersection. This helps to optimize the intersection and avoid over designing an intersection.

8.2.4 Design Considerations for Intersection User Groups

Information gained from the local agency or community may help the designer to understand the common uses at and around an intersection. The uses that can help define the context the intersection must support include transit stops, schools, bicycle and pedestrian movements, and complex multimodal settings in urban areas. Taking these uses into consideration will help determine the various intersection elements that can best support the context.

8.2.5 Intersection Capacity

Capacity and level of service analysis is one of the most important considerations in the design of intersections. While highway level of service is typically defined by density, delay typically defines intersection level of service. Table 9-1 in Chapter 9 of the American Association of State Highway and Transportation Officials (AASHTO) A Policy on Geometric Design of Highways and Streets (the Green Book) (2018 AASHTO GDHS) (AASHTO, 2018) describes intersection level of service.

Optimum capacities can be obtained when at-grade intersections include auxiliary lanes, proper use of channelization, and traffic control devices. For more complete coverage of capacity of intersections, including procedures for making capacity computations, refer to Chapter 16 of the *Highway Capacity Manual* (TRB, 2022).

8.2.6 Intersection Design Elements

There are many variables and elements that influence the design of an intersection. This is what makes each intersection location unique. Below is a listing of some key elements to consider. Additional information can be found in Chapter 9, Section 9.2.6, of the 2018 AASHTO GDHS.

- Alignment and profile.
- Intersection sight distance.
- Pedestrian, bicycle, and transit activity.
- Access spacing along the roadway.
- Auxiliary lanes.
- Intersection type.

8.2.7 Multimodal Integration

In all context classifications, intersection design should reduce conflicts between bicyclists, pedestrians, and motorists. This is typically achieved by increasing visibility of all roadway users and designating facilities to create awareness of all modes of travel. Designers should consider the needs of each mode and how to best accommodate those needs to achieve overall system goals. For example, when thinking about pedestrians, it is a best practice to design the shortest crossing distance, to provide lighting, and to utilize directional ramps. For bicyclists, the design should enable them to bypass vehicle queues, so the bicyclist can clear the intersection as quickly as possible. For transit, bus stops are generally preferred on the far side of an intersection and may include utilizing right-turn lanes as bypass lanes. Each intersection is unique, so designers should utilize the CSS and PBPD frameworks to understand the needs and make data-driven decisions when determining how to best integrate multimodal elements.

8.3 Types and Examples of Intersections

8.3.1 General Considerations

The type of at-grade intersections is determined primarily by the number of intersecting legs, the topography, the traffic patterns, and the desired type of operation. Intersection Control Evaluation (ICE) should be used as a method to help screen intersection types for projects. Basic intersection types are the following:

- T-intersection (with multiple variations of angular approach).
- Four-leg intersection.

- Multileg intersection.
- Roundabout (refer to Chapter 9 of this Guide).
- Grade separations and interchanges (refer to Chapter 10 of this Guide).

Each intersection type can vary greatly in scope, shape, and degree of channelization. To arrive at a suitable geometric plan for a specific intersection type, the designer applies the context described in Chapter 1, the facility type described in Chapter 3, 4, or 5, and the design controls and criteria covered in Chapter 2; and the intersection design elements described in Chapter 6, Chapter 7, and this chapter.

Use this link to access the Colorado Intersection Control Assessment Tool (ICAT): https://www.codot.gov/programs/maintenance-operations/tsmo-evaluation

Use this link to access the FHWA Intersection Control Evaluation: https://highways.dot.gov/safety/intersection-safety/ice

Each at-grade intersection type is discussed in Chapter 9 of the 2018 AASHTO GDHS, and likely variations of each are demonstrated. It is not practical to cover all possible variations, but the types demonstrated are sufficient to cover the general application of at-grade intersection design. Many other variations of types and treatment may be found in the NCHRP Report 279, Intersection Channelization Design Guide (NCHRP, 1985), which shows examples in detail that are not included in this Guide.

For roundabout design, refer to Chapter 9 of this Guide.

8.4 Alignment and Profile

8.4.1 General Considerations

Horizontal and vertical alignment and profile features affect driver behavior on the approach to and at the intersection. The horizontal and vertical alignment of the intersecting roads should permit users to readily discern and perform the maneuvers necessary to pass through the intersections safely with minimum interference with other users.

As a rule, alignment and grade are subject to greater control at or near intersecting roads than on a roadway segment. Alignment and grade at or near the intersection must produce traffic lanes that are clearly visible to the operators, plainly understandable for any desired direction of travel, free from unexpected hazards, and consistent with the portions of the roadway just traveled.

8.4.2 Alignment

Driver expectancy, vehicle operations, and vehicle conflicts are affected by the approach angle of an intersection. Approach angles of 75 to 90 degrees are generally considered desirable. Approach angles less than 75 degrees should be avoided on new construction. Existing intersections with an acute skew that is less than 75 degrees ideally should have the skew angle corrected. If improving the skew is not possible then alternative measures should be considered such as modifying the intersection to right in right out access on the skewed leg.

Angles less than 60 degrees are considered acute or skewed angles and are undesirable because they pose many safety issues, particularly an increased potential for broadside and approach turn crashes. Acute angles tend to have restricted line of sight at the corner and drivers can't see other vehicles approaching the intersection. When a truck turns on an obtuse angle, the driver has blind areas on the right of the vehicle. It can be difficult for a vehicle to make the acute turn and increase the time needed to pass through the intersection, which increases the exposure time of the vehicles crossing the main traffic flow and the potential for crashes. For these reasons, a wider turning area may also be required.

The designer should look at the intersection and surroundings to identify elements that may impact the safe operation of the skewed intersection and incorporate design and control features to mitigate them. These may include more positive traffic control (all stop, traffic signals) and/or geometric improvements, such as greater corner sight distance.

Geometric countermeasures to reduce or eliminate the skew of an intersection (such as greater corner sight distance), although expensive, are generally the best solution for skewed-angle intersections. Design for reconstruction of an intersection should take into consideration traffic patterns at the intersection, as well as constraints, such as available right of way. Chapter 9 of the 2018 AASHTO GDHS includes successful examples of how to realign roads intersecting at acute angles. Refer to Figure 9-22 in the 2018 AASHTO GDHS for an example of an acute angle intersection and how the sight distance of a vehicle maybe restricted by roadside objects or buildings to see an approaching vehicle on the cross street.

Special care should be taken in designing intersections near horizontal curves. Tracking the curve takes up much of the driver's focus, leaving less attention for avoiding potential conflicts. An effective countermeasure for signalized intersections is to provide advance "signal ahead" signing with flashing beacons to alert the driver to the upcoming curve and intersection.

8.4.3 Profile

In general, grades at intersecting roads should be as flat as possible to accommodate storage platforms and to maintain adequate sight distance. In areas prone to winter snow and icing conditions, there is a need for flat storage areas. Grades at intersections where these conditions exist should not exceed more than 2% so cars can more safely stop and accelerate from a stop.

Most drivers are unable to anticipate the increase or decrease in stopping or accelerating distances required on steep grades. It is not uncommon for the driver's decisions and reactions to be in error when judging stopping and acceleration distances on steep grades. On grades steeper than 3%, grade adjustment factors need to be applied to other design elements to produce conditions equivalent to those on level highways. Regarding approaches to intersections the designer should attempt to flatten the grades approaching the intersection to 3% or less.

The profile grade and cross sections (cross slope) on the approach legs to an intersection should be adjusted in advance of the intersection to provide a smooth transition with the cross street and to facilitate proper drainage. Generally, 20 feet or more maybe required. For highway intersections, the grade line and cross section (cross slope) of the highway is carried through the intersection, and the cross road or street is adjusted to match the highway profile and cross slope.

Changes from one cross slope to another should be gradual. Intersections where a minor road crosses a multilane divided highway with a narrow median and superelevated curve should be avoided whenever possible because of the difficulty in adjusting approach grades to match the superelevation to provide a suitable crossing.

Superelevated roadways tend to be high-speed roadways (greater than 45 mph posted speed). The decision to install or retain an intersection within a superelevated section should be carefully discussed with the Traffic Engineer. Solutions for an intersection on a superelevated section include modifying it to eliminate all left-turn movements (i.e., a right-in/right-out only intersection), raising the minor street profile grade to the same elevation of the superelevated roadway with a flat storage area for visibility and driver decision making, and lowering or removing the superelevation to improve the intersection approach profile grade lines.

8.5 Intersection Sight Distance (Sight Triangle)

8.5.1 General Considerations

Intersection sight distance (ISD) is a critical intersection design safety topic. Sufficient sight distances contribute to the safety of vehicles approaching an uncontrolled intersection. A safe sight distance is directly related to vehicle approach speeds and to the distances traversed during perception, reaction time, and braking.

A well-designed intersection will have an unobstructed sight distance along all legs of the intersection and across its corners of sufficient length that a driver has enough decision and reaction time to avoid a potential collision by accelerating, slowing down, or stopping.

Figures 8-3A and 8-3B illustrate these maneuvers, as well as the sight distances that must be provided for vehicles approaching on a major highway from either direction. Distance “b” is the length of roadway traveled by the respective vehicle on a major roadway during the time required for the stopped vehicle to depart from its stopped position and either cross the intersection or to turn onto the major roadway.

Figure 8-3A Sight Distance at Intersections, Minimum Sight Triangle

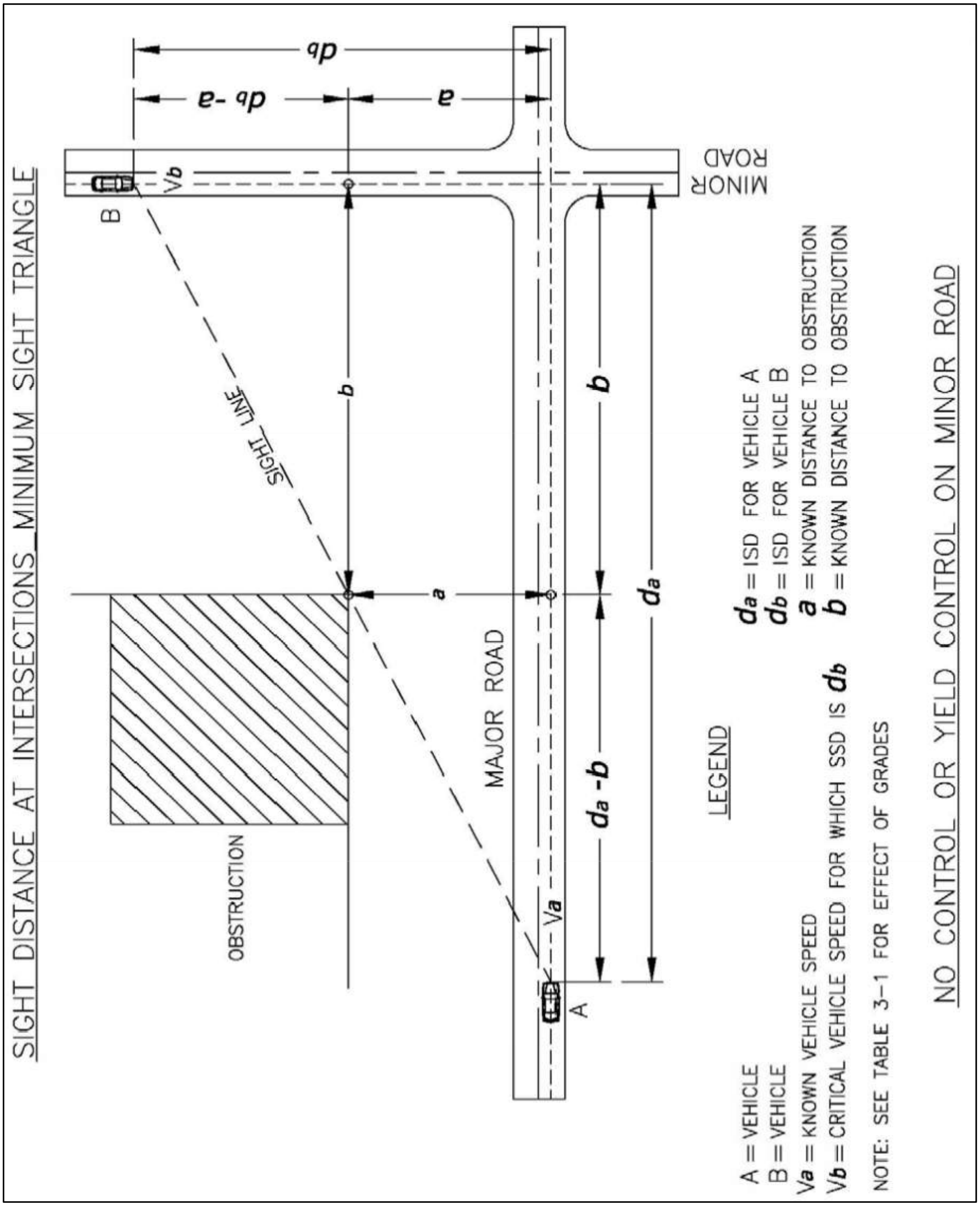
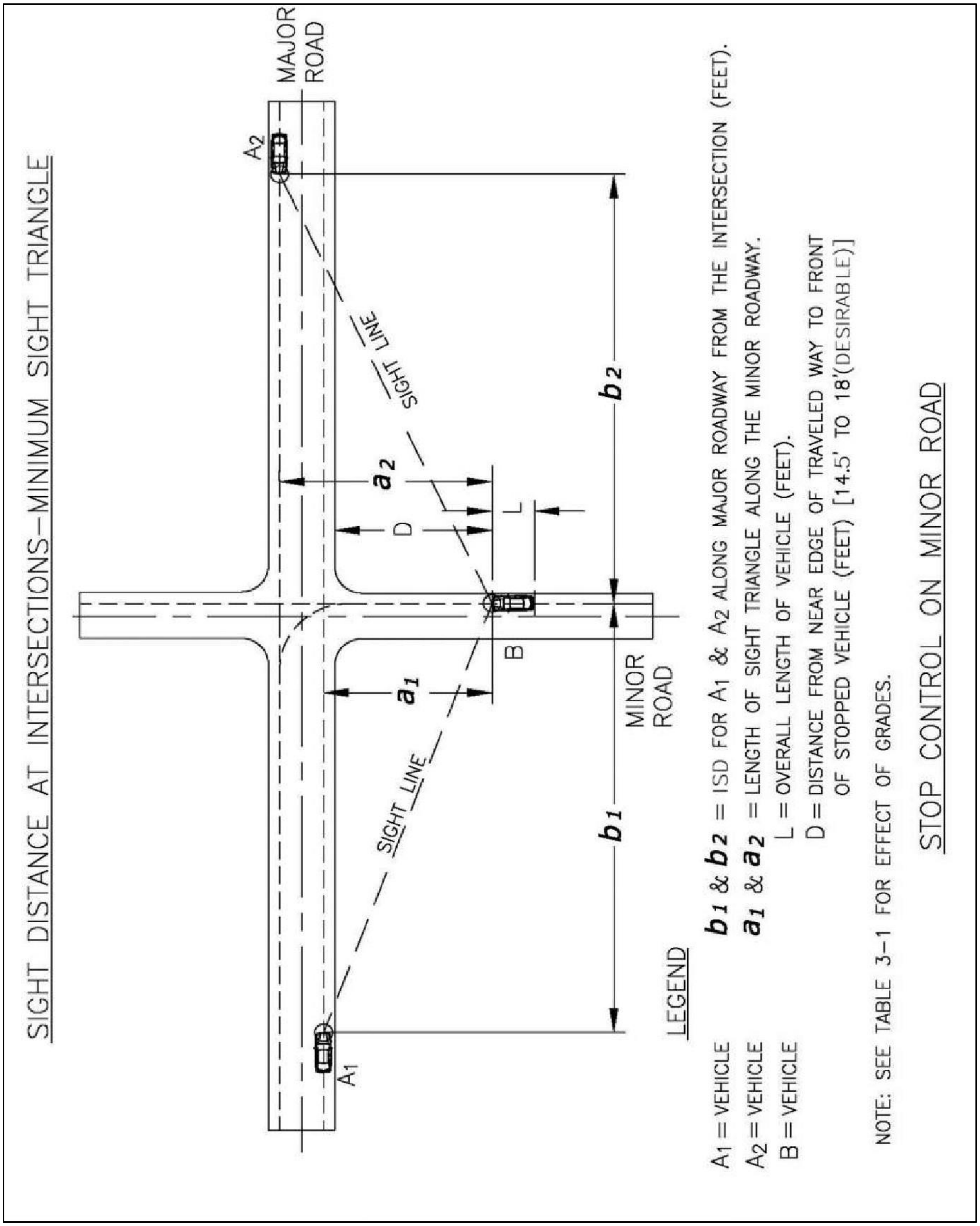


Figure 8-3B Sight Distance at Intersections, Minimum Sight Triangle



In the more urban environments in context classifications C4, C5, and C6, it is unlikely that the preferred sight distances will be unobstructed by objects, such as buildings and parked cars, so the designer can use the PBPD framework to adjust many factors, such as approach speed or lane width, to achieve an acceptable condition.

Sight triangles are potentially impeded by landscaping (trees or tall brush), roadside amenities (signs, etc.), or other objects that can block a driver's line of sight to approaching vehicles. Discussions with the local agency about roadside enhancements can identify what options are available to ensure the sight triangle line of sight is maintained. For example, low-height (3 feet or less) shrubs and plants will not impair a driver's ability to see approaching vehicles.

To improve the visibility of bicyclists at urban intersections, the designer can consider bike boxes, dashed bike lanes, and advanced/protected signal phases. Refer to Chapter 13 of this Guide and the NACTO Urban Bikeway Design Guide (NACTO, 2014) for bicycle treatments.

Directional curb ramps help motorists understand which leg of the intersection a pedestrian intends to cross. Leading pedestrian intervals in the signal phasing can improve visibility and reduce conflicts with turning vehicles.

8.5.2 Multimodal Integration

Intersections serve many users, and the designer needs to be prepared to help support all modal types that use the intersection. Below are several suggestions and examples of ways the designer can support pedestrians, bicycles, and transit in intersection design.

- Considerations for pedestrians – with and without crosswalks:
  - Adequate sight triangle line of sight.
  - Rapid rectangular flashing beacon (RRFB) at stop or uncontrolled intersections.
  - Advanced walk signal phase for pedestrians at signalized intersections.
- Considerations for bicyclists – with and without dedicated bike lanes:
  - "Bicycle ahead" signing at crossings with frequent bicycle activity.
  - Bike boxes and bike markings at signalized intersections.
  - Advanced or protected movement signal phase for bicyclists at signalized intersections.
- Considerations for transit – bus stops, dedicated bus lanes, no dedicated bus lane, rail cars:

- Locate bus stops downstream from the intersection to improve sight triangle visibility for the pedestrian and motorists at the intersection and to help the bus merge back into the travel lanes more easily.
- Pull-outs for buses to improve intersection visibility for motorists.

8.5.3 Traffic Control and Sight Distance

The recommended dimensions of a sight triangle vary with the type of traffic control used at an intersection because different types of control impose different legal constraints on drivers and, therefore, result in different driver behavior. Procedures to determine sight distances, depending on the type of traffic control, are presented in Chapter 9 of the 2018 AASHTO GDHS for each of the cases below:

- Case A – Intersections with no control (not used on State Highways).
- Case B – Intersections with stop control on the minor road.
  - Case B1 – Left turn from the minor road.
  - Case B2 – Right turn from the minor road. **Note: Case B2 applies to signalized intersections, including ramp terminals where right-turn on red is permitted.**
  - Case B3 – Crossing maneuver from the minor road.
- Case C – Intersections with yield control on the minor road.
  - Case C1 – Crossing maneuver from the minor road.
  - Case C2 – Left- and right-turn maneuvers.
- Case D – Intersections with traffic signal control.
- Case E – Intersections with all-way stop control.
- Case F – Left turns from the major road.

8.5.4 Effect of Skew

Refer to Section 9.5.4 of the 2018 AASHTO GDHS.

8.6 Intersection Curves

8.6.1 Roadway Widths for Turn Movements

Note: The terms “turning movements” and “turn movements” used in this Guide are also referred to as “turning roadways” in the 2018 AASHTO GDHS.

The desired roadway and pavement widths for turn movements at an intersection are governed by the level of turn movement traffic volumes, the types of vehicles to be accommodated, and the geometric pattern of the intersection (one-way or two-way operation). Widths determined for turn movements are also applied to the roadway widths within an intersection. In addition, the turning radii and the pavement cross slopes are functions of design speed and types of vehicles to be accommodated.

Pavement widths for turn movements are classified as shown in Table 8-1.

Table 8-1 Design Widths of Pavements for Turn Movements

--	Case I One-Lane, One-Way Operation - No Provision for Passing a Stalled Vehicle			Case II One-Lane, One-Way Operation - With Provision for Passing a Stalled Vehicle			Case III Two-Lane Operation - Either One-Way or Two-Way		
--	Pavement Width (ft) for Design Traffic Conditions								
Radius on Inner Edge of Pavement (ft)	A	B	C	A	B	C	A	B	C
50	18	18	23	20	26	30	31	36	45
75	16	17	20	19	23	27	29	33	38
100	15	16	18	18	22	25	28	31	35
150	14	15	17	18	21	23	26	29	32
200	13	15	16	17	20	22	26	28	30
300	13	15	15	17	20	22	25	28	29
400	13	15	15	17	19	21	25	27	28
500	12	15	15	17	19	21	25	27	28
Tangent	12	14	14	17	18	20	24	26	26
Width Modification Regarding Edge Treatment									
No stabilized shoulder	None			None			None		
Sloping Curb	None			None			None		
Vertical curb	Add 1 foot			None			Add 1 foot		
1 Side	Add 1 foot			None			Add 1 foot		
2 Sides	Add 2 feet			Add 1 foot			Add 2 feet		
Stabilized shoulder, one or both sides	Lane width for conditions B and C may be reduced to 12 feet where shoulder is 4 feet or wider.			Deduct shoulder width; minimum pavement width as under Case I.			Deduct 2 feet where shoulder is 4 feet or wider.		

A = Predominantly P vehicles, but some consideration for SU trucks

B = Sufficient SU vehicles to govern design, but some consideration for semi-trailer combination trucks

C = Sufficient bus and combination-trucks to govern design

8.6.1.1 Widths Outside Traveled Way

The roadway width for a turning movement, as distinct from pavement width, includes the shoulders or equivalent lateral clearance outside the edges of pavement.

Table 8-2 is a summary of the range of design values for pavements outside of the traveled way. The widths shown are for usable shoulders. On roadways without curbs or those with sloping curbs, the adjacent shoulder should be of the same type and section as that on the approach roadway. Where there are roadside barriers, the width indicated should be measured to the face of the barrier, and the graded width should be about 2 feet greater.

Wheel tracking for turn movements by large vehicles, buses, or vehicle-trailer combinations should be checked with the appropriate software.

Table 8-2 Range of Useable Shoulder Widths or Equivalent Lateral Clearances Outside Turn Movements, Not on a Structure

Turning Roadway Condition	Shoulder Width or Lateral Clearance Outside of Traveled Way Edge (ft)	
	Left	Right
Short length, usually within channelized intersection	2 to 4	2 to 4
Intermediate to long length, or in cut or on fill	4 to 10	6 to 12

Note: All dimensions should be increased where necessary for sight distance.

8.6.2 Minimum Designs for Sharpest Turns

After the lane width has been determined, site conditions, along with traffic and island requirements, govern the curve selection. Generally, a three-centered curve is used to minimize the paved area and right of way requirements. The curve should be suitable for the anticipated truck traffic; the curve design for a commercial vehicle (SU) is considered the desirable minimum.

Curbs along the edge of pavement of sharp intersection curves restrict vehicles making the turn, and a design vehicle making its minimum turn will need to be maneuvered carefully to avoid scraping or jumping the curb. For this reason, when there are curbs, it is desirable to use somewhat flatter curves than those in minimum edge-of-pavement designs.

In the design of the edge of the pavement for the minimum path of a given design vehicle (refer to Figure 9-23 through 9-30 of the 2018 AASHTO GDHS), it is assumed that the vehicle is properly positioned within the traffic lane at the beginning and end of the turn, i.e., 2 feet from the edge of pavement on the tangents approaching and leaving the intersection curve. Curve designs for edge of pavement conforming to this assumption for passenger vehicles, single-unit trucks and buses, and semitrailer combinations are shown in Chapter 9 of the 2018 AASHTO GDHS. The paths indicated, which are slightly greater than the minimum paths of nearly all design vehicles in each class, are the minimums attainable at speeds less than 10 mph. In each case, these widths must be increased to address turn movements of vehicles operating at over 10 mph. The wheel path should be 2 feet or more away from the edge of pavement throughout most of the turn, and at no point less than 1 foot.

Although not shown separately in the figures in the 2018 AASHTO GDHS, these edge-of-pavement designs also apply to left-turn layouts, such as a left turn to leave a divided highway at a very low speed. The designer should analyze the likely paths and encroachments that result when a turn is made by a large vehicle, for example a truck swinging wide into adjacent traffic lanes, and provide a design that minimizes traffic disruption.

The design should be modified where alignment conditions provide the assumed positioning, such as curvature prior to or at the end of the turn. Superimposing the appropriate design-vehicle turning template is the most expeditious way to customize a design for special conditions. However, the designer should not rely solely on a turning template for the layout. The traffic engineer and the local maintenance staff can provide insight into whether existing turning movements are difficult or track differently than the template models. This can help the designer solve a specific problem with a solution that the template may not account for.

Figures and data for three-centered curves (symmetrical and asymmetrical) are shown in Figures 8-4A, 8-4B, and 8-4C, and Table 9-16 in the 2018 AASHTO GDHS.

Figure 8-4A Three-Centered Compound Curve (Symmetrical)

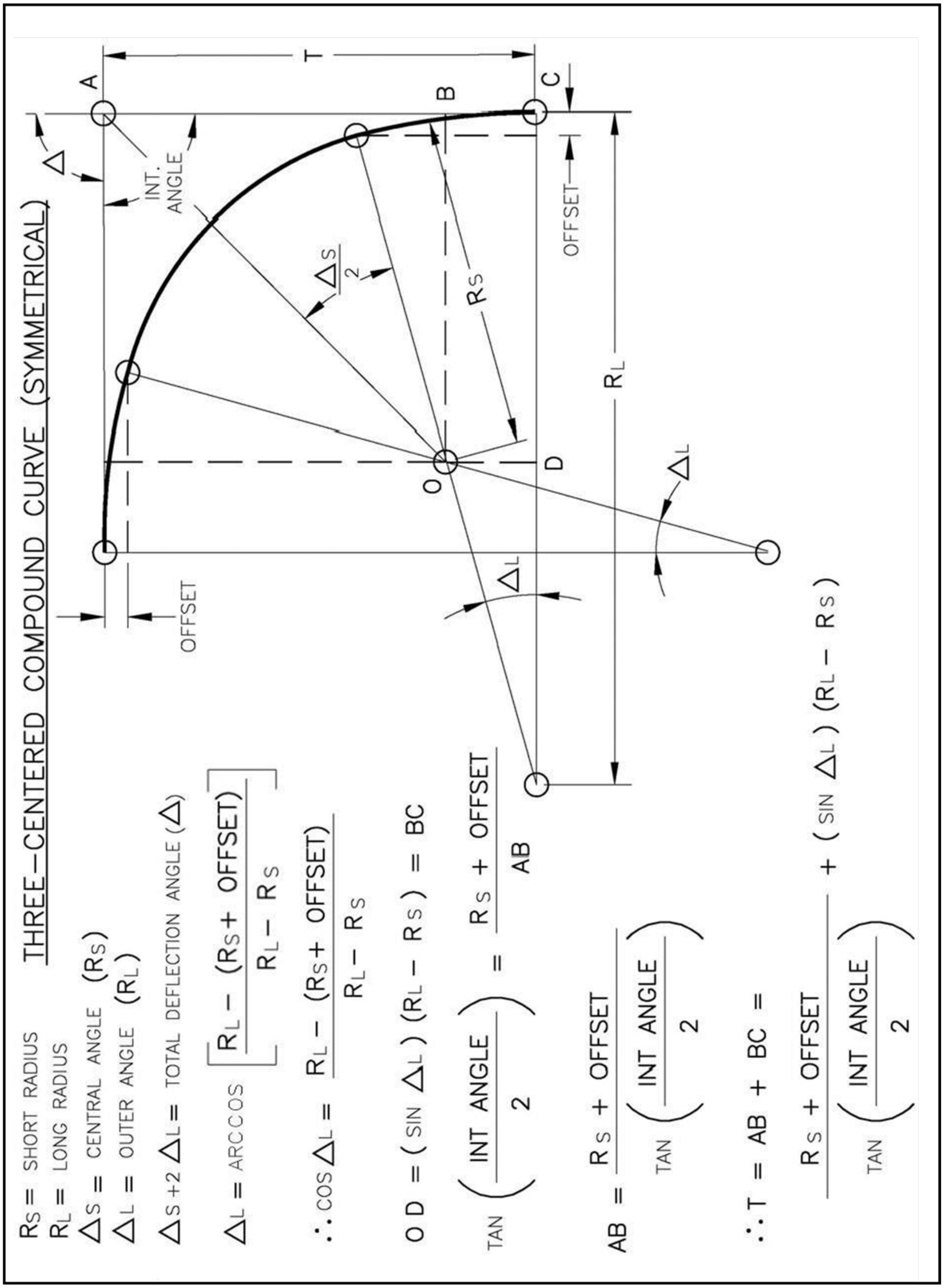


Figure 8-4B Three-Centered Compound Curve (Symmetrical)

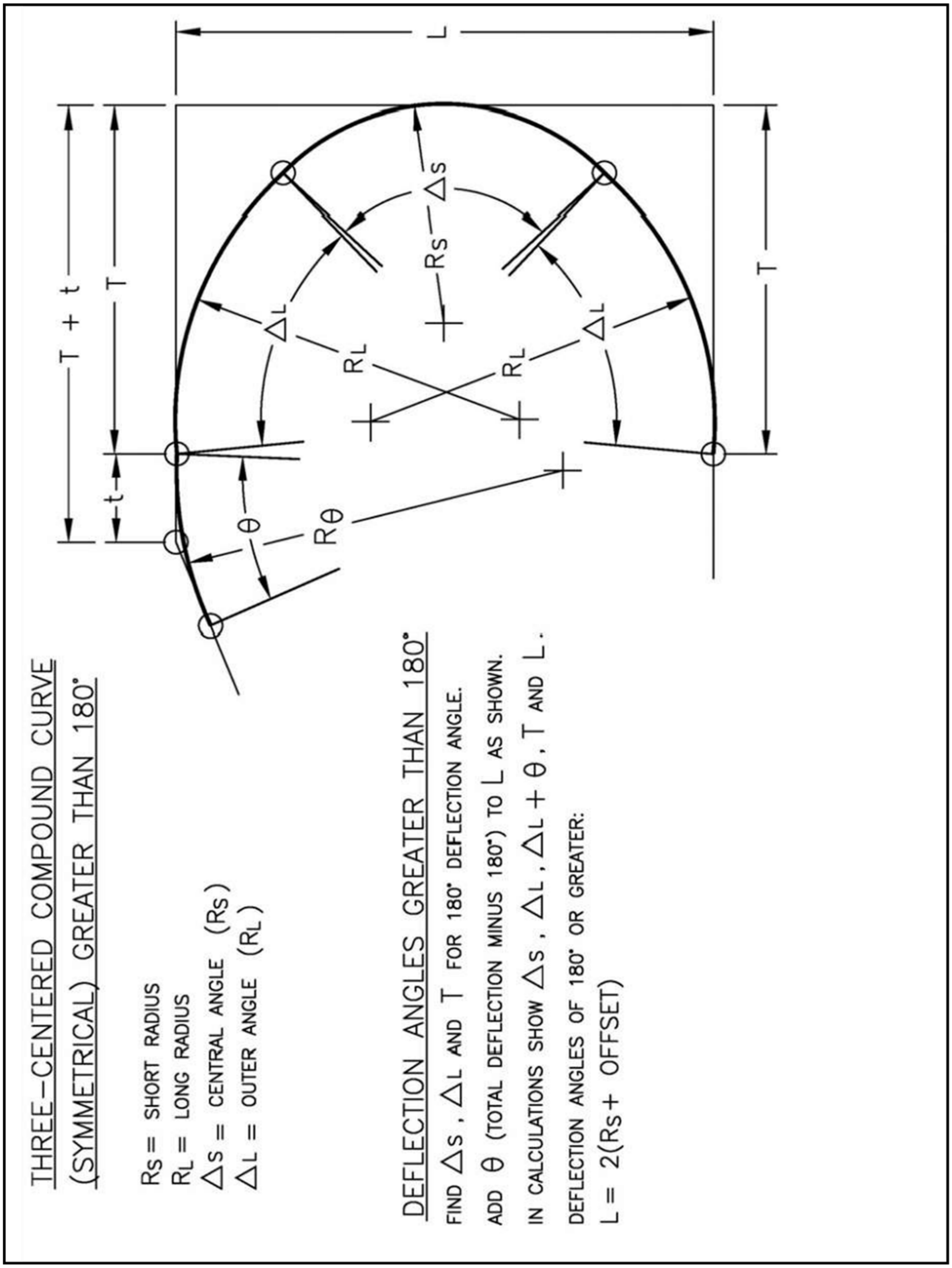
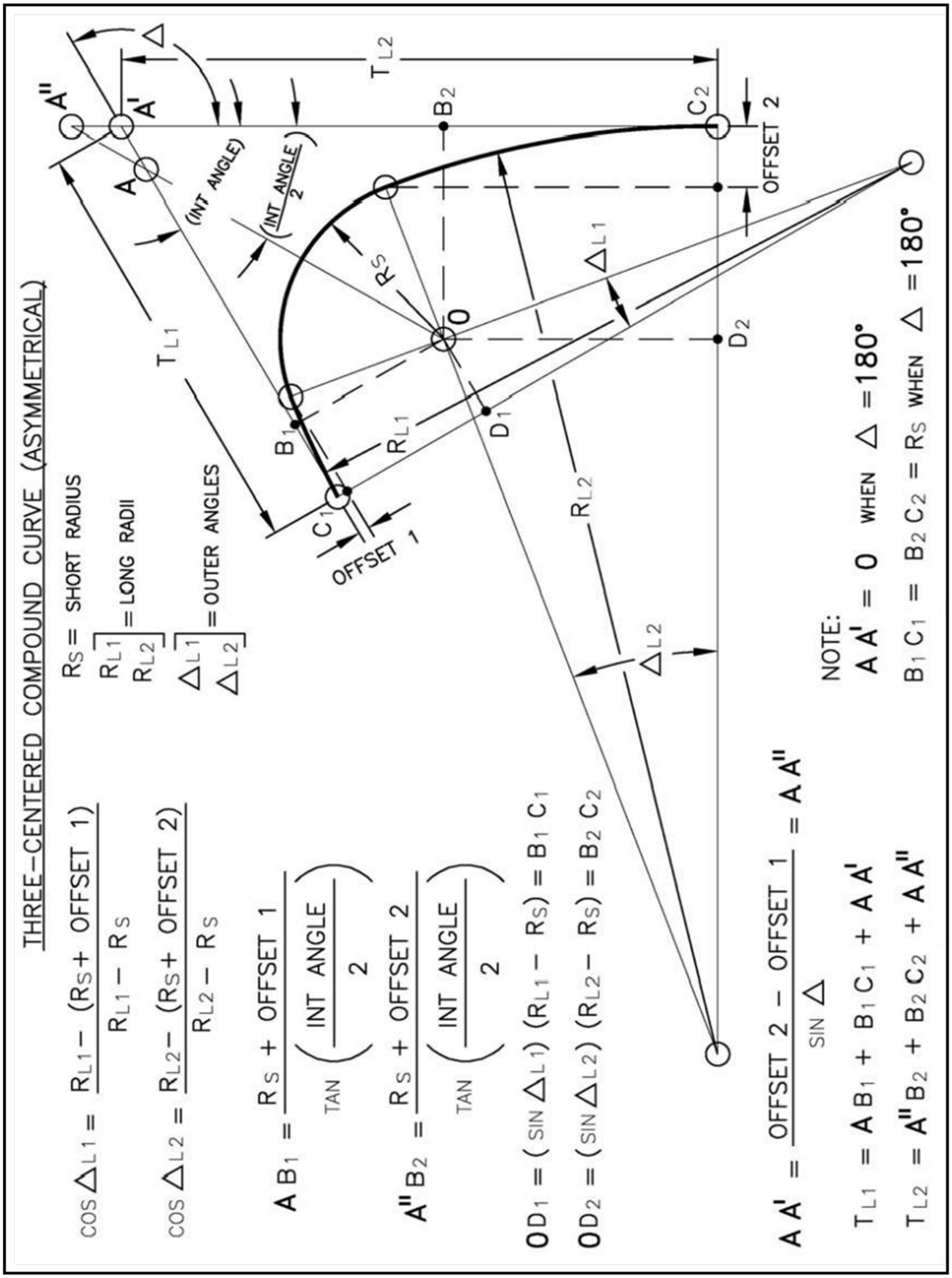


Figure 8-4C Three-Centered Compound Curve (Asymmetrical)



8.6.2.1 Design Vehicles

The classes of design vehicles and their characteristics are provided in Chapter 2 of this Guide. For a thorough discussion and dimensions of the design vehicles, refer to Chapter 2 of the 2018 AASHTO GDHS.

The primary use of the design vehicle in intersection design is to determine the turning radius requirements for each leg of the intersection. A different design vehicle can be used for each leg of the intersection. It is recommended to select a design vehicle that is the largest vehicle that normally uses the intersection or intersection leg. Table 8-3 shows the minimum design vehicle to use for different intersection types. If there are reasons to use a smaller design vehicle (such as in pedestrian priority zones or transit corridors), a traffic analysis showing that the proposed vehicle is appropriate is recommended. The traffic analysis could be as simple as a discussion and concurrence from the traffic engineer and a note to the project file on the decision made.

Table 8-3 Intersection Design Vehicle

Intersection Type	Design Vehicle
Junction of Major Truck Routes	WB-67
Junction of State Highways	WB-67
Ramp Terminals	WB-67
Other Rural	WB-67
Industrial	WB-40
Commercial	SU[1, 2]
Residential	SU[1, 2]

1. To accommodate pedestrians, the P vehicle may be used as the design vehicle if justification with a traffic analysis is documented.
2. When the intersection is on a transit or school bus route, use the BUS design vehicle as a minimum.

To minimize the disruption to other traffic, the intersection design should allow the design vehicles to make each turning movement without encroaching on curbs, opposing lanes, or same-direction lanes at the entrance leg.

Each intersection curve should be designed so the largest vehicle that is anticipated to use the intersection can make the turn without leaving the paved shoulders or encroaching on a sidewalk. At all state highway to state highway junctions, the largest design vehicle should be determined by the surrounding context that the facility supports, and purpose and need of the project.

8.6.2.2 Effect of Curb Radii on Turning Paths

The widths for various angles of intersecting streets occupied by turning vehicles are shown in Table 9-17 and Figure 9-33 of the 2018 AASHTO GDHS. When the angles increase, the streets must be very wide, or a very large curb radius must be used. For this reason, three-centered curves are preferred for this type of situation.

Corner radii at intersections on arterial streets should satisfy the requirements of the drivers using them to the extent practical. The design should consider the amount of right of way available, the approach angle of the intersection, presence of pedestrians, roadway width and number of lanes on the intersecting streets. Other considerations include the functional classifications and uses of the minor street, such as parking, transit, bicycles, pedestrians, ADA, etc.

8.7 Turning Lanes and Channelization

8.7.1 General

A safe and effective turn lane that does not hinder a driver's expectations and movement through the intersection is designed with the proper curvature, turning widths, and shoulders. Effective channelization can enhance and improve the safety of turn lanes by keeping the driver in the appropriate lane to avoid sideswipe collisions with other vehicles. The channelization can also provide refuge for pedestrians where multiple conflict points and vehicle movements are occurring.

Channelization is the separation or regulation of conflicting traffic movements into delineated paths of travel using physical traffic islands or pavement markings that facilitate the safe and orderly movements of vehicles, bicycles, and pedestrians.

8.7.2 Channelized Right-Turn Lanes

The designs given in Table 9-17 of the 2018 AASHTO GDHS relating to minimum edge-of-pavement designs for turns at intersections are those suggested to fit the sharpest turns of the different design vehicles at oblique-angle intersections. For angles of turn less than 90 degrees, trucks also can turn on an inner edge of pavement designed for passenger vehicles with even less encroachment than that for the 90-degree turns. For turning angles of more than 90 degrees, the minimum design must be adjusted to ensure that all turning trucks remain within two lanes of pavement on each roadway.

8.7.3 Superelevation at Turning Roadway Ramp Terminals

Superelevation commensurate with curvature and speed seldom is practical at ramp terminals where:

- A flat intersection curve results in little more than a widening of the through traffic pavement.
- It is desirable to retain the cross slope of the through pavement.
- There is a practical limit to the difference between the cross slope on the through pavement and that on the intersection curve.

8.7.4 Design Considerations

- Literature review of the safety and operation aspects of intersections
- Survey of design practices of state, cities, and counties
- Collection of example intersection designs
- Field studies of intersections
- Development of design guidelines for channelizing

8.8 Islands

8.8.1 General

An island is a defined area between traffic lanes that controls vehicle movements. Within an intersection, a median or an outer separation is considered an island. An island may range from an area delineated by a curb to a pavement area marked by paint. At some intersections, both curbed and painted islands may be desirable.

Multiple intersections with similar intersection needs may occur in a given project. It is desirable to have a common geometric design for each intersection within the project limits to the extent practicable to enhance driver expectancy. For the various types and shapes of islands, refer to Figure 9-36 of the 2018 AASHTO GDHS.

Islands generally are included in intersection design (channelization) for one or more of the following purposes:

- Separation of conflicts.
- Control of angle of conflict.
- Reduction in excessive pavement areas.
- Regulation of traffic and indication of proper use of intersection.
- Arrangements to favor a predominant turning movement.
- Protection of pedestrians (including ADA requirements).
- Protection and storage of turning and crossing vehicles.
- Location of traffic control devices.
- Access control.

Islands generally are either elongated or triangular in shape and are situated in areas normally unused as vehicle paths. Their sizes and shapes vary materially, and there are variations for multiple and acute-angle intersections. The dimensions depend on the particular intersection design. Islands should be located and designed to offer little hazard to vehicles, be relatively inexpensive to build and maintain, and occupy a minimum of roadway space, yet be commanding enough that motorists will not drive over them.

Painted, flush medians and islands may be preferred to curbed medians under certain conditions, including the following:

- In lightly developed areas.
- At intersections where approach speeds are relatively high.
- Where there is little pedestrian traffic.
- Where fixed-source lighting is not provided.
- Where signals, signs, or lighting standards are not needed on the median or island.

All pavement markings shall be reflectorized.

8.8.2 Channeling Islands

Raised channelizing islands are effective pedestrian accommodations to shorten the crossing distance, improve visibility, and reduce vehicular speed where pedestrians are entering the roadway. Refer to Chapters 12 and 14 of the Guide and the NACTO Urban Bikeway Design Guide (NACTO, 2014).

8.8.3 Divisional Islands

Divisional islands are generally used to separate opposing directions of travel on a roadway. These islands can be narrow or wide, but the minimum width of the island shall be at least 1 foot wider than the largest sign that will be placed in the island to avoid vehicle strikes from large vehicles passing by.

8.8.4 Refuge Islands

Refuge islands are raised medians that are wide enough to meet ADA requirements. They decrease the crossing distance for pedestrians and provide increased comfort at large intersections by delineating opposing traffic. Refer to Chapter 12 and Chapter 14 of the Guide and NACTO Urban Bikeway Design Guide (NACTO, 2014).

8.8.5 Island Size and Designation

Islands should be sufficiently large to command attention. The preferred dimension for a curbed island is 100 square feet or larger. In an urban setting, the smallest curbed island that should be considered is one that is approximately 50 square feet; the smallest curbed island in a rural setting is 75 square feet.

Elongated or divisional islands should be no less than 4 feet wide to accommodate sign installations, and no less than 20 to 25 feet long. Triangular islands should be no less than 12 feet long to a side, and preferably 15 feet or longer on a side after rounding of corners. Details of triangular curbed islands and their size designation are shown in Chapter 9, Section 9.6.3, of the 2018 AASHTO GDHS.

In general, introducing curbed divisional islands at isolated intersections on high-speed highways is undesirable unless special attention is directed to providing high visibility for the islands. Options for high visibility may include the addition of object markers at the leading edge of the curbed divisional island and the installation of vertical reflective delineation along the length of the divisional island.

Curbed divisional islands introduced at isolated intersections on high-speed highways should be at least 4 feet wide and 100 feet long and preferably several hundred feet in length.

8.8.6 Island Delineation

An island can be delineated or outlined by a variety of treatments, depending on its size, location, and function, and whether it is in an urban area or a rural area.

In a physical sense, islands can be divided into three groups:

- Raised islands outlined by curbs or barriers.
- Islands delineated by pavement markings placed on all paved areas. Buttons and raised (jiggle) bars are not used on Colorado facilities because of snow removal operations.
- Non-paved areas formed by the pavement edges, possibly supplemented by delineators on posts or other guideposts, or a mounded earth treatment beyond and adjacent to the pavement edges.

Delineation of a small, curbed island is primarily addressed by curbs. A large, curbed island may be sufficiently delineated by color and texture contrast of vegetative cover, mounded earth, shrubs, guard posts, signs, or any combination of these.

In rural areas, an island curb should nearly always be a sloping type, except where there is a definite need for a vertical curb, for example at structures or pedestrian crossings. In special cases, a vertical curb is suitable, commonly no more than 6 inches high. A vertical or sloping curb could be appropriate in urban areas, depending on the context of the roadway. A high-visibility curb is advantageous at critical locations or on islands and roadway forks approached by high-speed traffic.

A curbed island is sometimes difficult to see at night because of the glare from oncoming headlights or from distant luminaires or roadside businesses. Therefore, where a curbed island is used, the intersection should have fixed-source lighting or appropriate reflectorized delineation.

Delineation and warning devices are especially pertinent at approach ends of a median curbed island, which is usually in a direct line with approaching traffic. In rural areas, the approach should consist of a gradually widening center stripe. Although not as frequently obtainable, this approach should be strived for in urban areas also. Preferably, it should gradually change to a raised marking of color and texture contrasting with that of the traffic lanes. This section should be as long as practicable.

8.8.7 Approach Treatment

The outline of a curbed island is determined by the edge of through traffic lanes and turning roadways, with lateral clearance to the curbed island sides. The points at the intersections of the curbed island are rounded or beveled for visibility and construction simplicity. The amount that a curbed island is offset from the through traffic lane is influenced by the type of edge treatment and other factors, such as island contrast, length of taper or auxiliary pavement preceding the curbed island, and traffic speed. An island curb is introduced rather suddenly and should be offset from the edge of through traffic lanes even if it is sloping. A sloping curb at an island need not be offset from the edge of a turning roadway, except to reduce its vulnerability. A vertical curb should be offset from the edges of through and turning roadway pavements.

Snowplow-friendly curbed island approaches should be installed in areas with frequent snow removal operations. It is desirable to design a vertically tapered island approach on the leading edge of the island. A 3:1 vertical taper to establish a curbed nose allows a snowplow to ride up and over the nose without damaging the curb and plow.

Refer to Figure 9-40 in the 2018 AASHTO GDHS.

8.8.8 Corner Islands for Turning Roadways

The turning roadway pavement should be wide enough to permit the outer and the inner wheel tracks of a selected vehicle to be within the edges of the pavement by about 2 feet on each side. Generally, the turning roadway pavement width should not be less than 14 feet. For designs of turning roadways of 90 degrees with minimum corner islands, refer to Figure 9-38 of the 2018 AASHTO GDHS.

Minimum design dimensions for oblique-angle turns, determined on a basis similar to that for right-angle turns, are given in Table 8-4. Curve design for the inner edge of pavement, turning roadway pavement width, and the approximate island size are indicated for the three chosen design classifications described at the bottom of the table. For a particular intersection, the designer may choose from the designs shown in accordance with the size of vehicles, the volume of traffic anticipated, and the physical controls at the site.

In Table 8-4, design values are not given for angles of turn less than 75 degrees. Turning roadways for flat angle turns involve relatively large radii and are not considered in the minimum class. Such arrangements require a design that fits site controls and traffic conditions. For angles of turn between 75 and 120 degrees, the designs are governed by a minimum island, providing for turns on more than minimum turning radii. For angles of 120 degrees or more, the design is generally controlled by the sharpest turning paths of the selected vehicles, and arrangements of curves on the inner edge of traveled way to fit these paths. The resulting island size is greater than the minimum. The size of the island for the large turning angles in Table 8-4 is indicative of the otherwise unused and uncontrolled areas of traveled way that are eliminated by the use of an island.

Table 8-4 Typical Designs for Turning Roadways

Three-Centered Curve					
Angle of Turn (degrees)	**Design Classification**	**Radii (ft)**	**Offset (ft)**	**Width of Lane (ft)**	**Approximate Island Size (sq ft)**
75	A	150-75-150	3.5	14	60
	B	150-75-150	5.0	18	50
	C	220-135-220	5.0	22	360
90	A	150-50-150	3.0	14	50
	B	150-50-150	11.0	21	150
	C	200-70-200	11.0	25	270
105	A	120-40-120	2.0	15	70
	B	150-35-150	11.5	29	65
	C	180-60-180	9.5	32	260
120	A	100-30-100	2.5	16	120
	B	150-30-150	10.5	33	130
	C	140-55-140	7.0	45	215
135	A	100-30-100	2.5	16	460
	B	150-30-150	10.0	38	395
	C	140-45-140	7.0	52	485
150	A	100-30-100	2.5	16	1400
	B	150-30-150	9.0	42	1350
	C	160-40-160	6.0	53	1590

A Primarily passenger vehicles; permits occasional design single-unit truck to turn with restricted clearances.

B Provides adequately for SU-9 [SU-30] and SU-12 [SU-40] design vehicles; permits occasional WB-19 [WB-62] design vehicles to turn with slight encroachment on adjacent traffic lanes.

C Provides fully for WB-19 [WB-62] design vehicle.

Asymmetric three-centered compound curves and straight tapers with a simple curve can also be used without significantly altering the width of roadway or corner island size.

8.9 Design to Discourage Wrong-Way Entry

Intersections of crossroads at major highway interchanges have an inherent problem of the possibility of a wrong way driver entering one of the exit ramps from the crossroad and proceeding along a major highway in the wrong direction in spite of signing. Attention to several details of design at the intersection can discourage this hazardous maneuver.

Details of designs to discourage wrong-way entry are shown in Figures 10-58 and 10-59 of the 2018 AASHTO GDHS.

8.10 Superelevation at Intersections

8.10.1 General Design Guidelines

Poorly designed drainage can create operational issues on low-speed roadways. Cross slopes of the two roadways that are not transitioned properly as they approach the intersection can cause water ponding creating operational and safety issues for drivers. Refer to Tables 9-19 and 9-20, and Figures 9-44 to 9-47 of the 2018 AASHTO GDHS.

8.10.2 Superelevation Runoff

Superelevation runoff and intersection spacing may come into conflict at locations with tight intersection spacing. The designer needs to carefully consider if superelevation is appropriate when multiple intersections are closely spaced together. The first indication of changing or removing superelevation with intersections is if the superelevation runoff cannot be effectively completed due to limited spacing between intersections.

8.10.3 Development of Superelevation at Turning Roadway Ramp Terminals

The designer should establish a superelevation runoff from the end of the intersection ramp terminal before superelevation is fully established. Moving the superelevation too close to the ramp terminal can cause issues with drainage, stopping sight distance, and vehicle handling when starting from a stopped condition on a superelevated roadway.

8.11 Stopping Sight Distance at Intersections for Turning Roadways

8.11.1 General Design Guidelines

The values for stopping sight distance as computed in Chapter 6 for open highway conditions are applicable to roadway intersections of the same design speed.

Refer also to Table 9-21 in the 2018 AASHTO GDHS and Table 6-1 in Chapter 6 of this Guide.

8.12 Auxiliary (Speed Change) Lanes

The primary purpose of an auxiliary lane at an intersection is to provide storage for left- and right-turning vehicles. A secondary purpose is to provide space for turning vehicles to decelerate from the normal speed of traffic to a stopped position in advance of the intersection or to a safe speed for the turn in case a stop is unnecessary. Additionally, an auxiliary lane may be provided for bus stops or for loading and unloading passengers from passenger cars.

A speed change lane is an auxiliary lane with tapered areas, primarily for the acceleration or deceleration of vehicles entering or leaving the through traffic lanes. The terms “speed-change lane,” “deceleration lane,” or “acceleration lane,” as used here, apply broadly to the added pavement joining the traveled way of the highway or street with that of the turning roadway and do not necessarily imply a definite lane of uniform width.

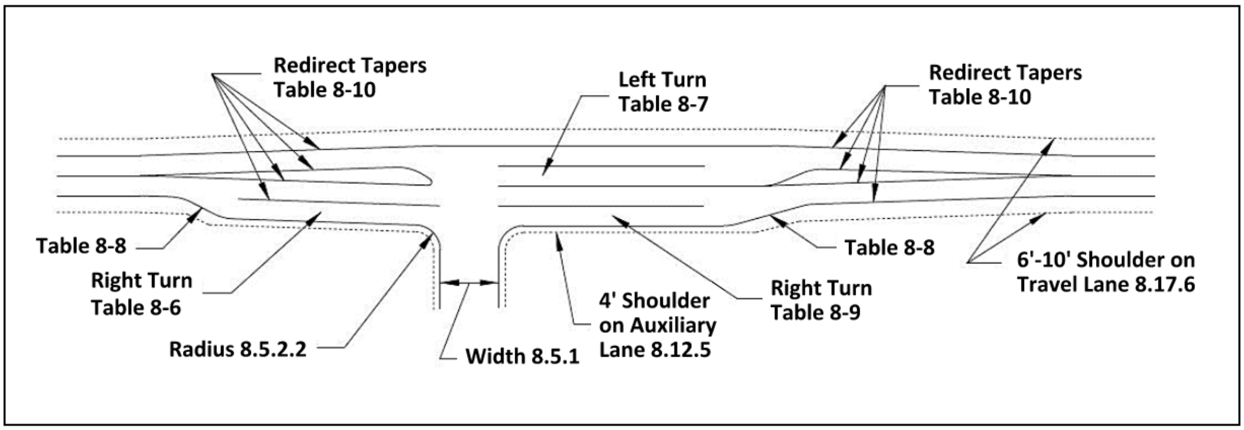
Speed-change lanes may be justified on high-speed and high-volume highways where a change in speed of 10 mph or more is necessary during acceleration and deceleration for vehicles entering or leaving the through traffic lanes.

8.12.1 General Design Considerations

Desirably, the total length of the auxiliary lane should be the sum of the length for three components (storage length, deceleration or acceleration length, and taper length). Where intersections occur as frequently as four per mile and posted speed is less than 45 mph, it is customary to forego most of the deceleration length and to provide only the storage length plus taper. On a roadway with posted speed of 45 mph or higher, the deceleration and acceleration length shall be included in the auxiliary lane length.

Each component of the auxiliary lane length is discussed in the following sections. Where geographically possible, a continuous auxiliary lane shall be established between accesses in instances where speed change lanes overlap or are separated by less than 300 feet or half their length (whichever is shorter). Figure 8-5 illustrates basic auxiliary lane elements.

Figure 8-5 Information Guide to Basic Auxiliary Lane Elements



Auxiliary lanes should be at least 10 feet wide and desirably should equal the width of the through lane. Where curbing is to be used adjacent to the auxiliary lane, an appropriate curb offset should be provided. The paved shoulder width adjacent to an auxiliary lane can be narrower than the standard shoulder for the roadway but should allow for a uniform transition to the standard shoulder when the lane transition ends. The length of the auxiliary lanes for turning vehicles consists of three components:

- Deceleration length.
- Storage length.
- Entering taper.

Warrants for the use of auxiliary lanes cannot be stated definitively. If the designer is unsure about when to apply speed change lanes, a traffic engineer can assist. Observations and considerable experience with speed change lanes have led to the following general conclusions:

- Speed-change lanes are warranted on high-speed and high-volume highways where a change in speed is necessary for vehicles entering or leaving the through traffic lanes.
- All drivers do not use speed change lanes in the same manner – some use little of the available facility. As a whole, however, these lanes are used sufficiently to improve the overall safety and operation of the highway.
- Use of speed change lanes varies with volume; the majority of drivers use the lanes during high volumes.
- The directional type of speed-change lane consisting of a long taper fits the behavior of most drivers and does not require maneuvering on a reverse curve path.
- Deceleration lanes on the approaches to intersections that also function as storage lanes for turning traffic are particularly advantageous, and experience with them generally has been favorable. Such lanes reduce hazards and increase capacity.

A deceleration lane is advantageous, particularly on high-speed roads, so a driver of a vehicle leaving the highway can use it to slow down outside of the through traffic lane. The speed differential of a vehicle slowing in the through traffic lane can result in increased potential for rear-end collisions.

Acceleration lanes are not always necessary at stop-controlled intersections where drivers entering the flow of traffic can wait for an opportunity to merge without disrupting traffic flows. Acceleration lanes are advantageous on highways without stop control and on high-volume roads even with stop sign control where openings between vehicles in the peak hour traffic streams are infrequent and short.

On urban streets with high volumes of traffic, acceleration lanes provide little benefit as there may not be sufficient gaps in traffic flow to provide a safe merging operation for the driver. Some drivers even stop in the acceleration lane waiting for an opening in traffic, which can result in rear-end crashes.

The use and design of speed change lanes differ between roadway types. Table 8-5 defines the speed change lane design components for facility types. Consultation with a traffic engineer can help determine the need for auxiliary lanes by calculating the roadway's capacity and determining if the operational capacity could be improved by the addition of acceleration and deceleration lanes.

Table 8-5 Components of Speed Change Lane Length

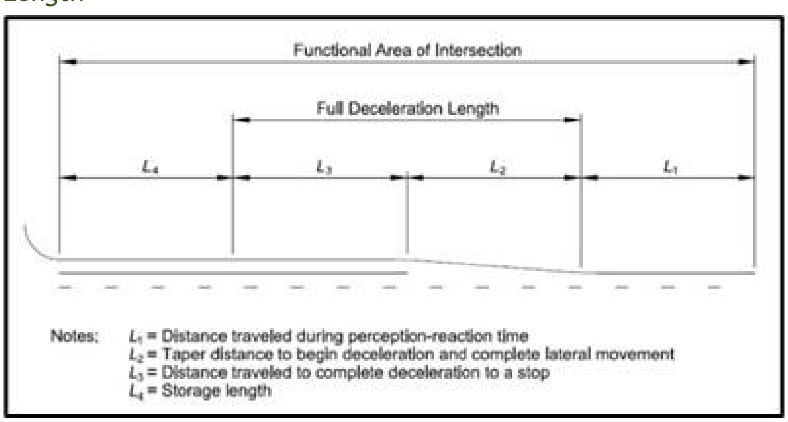
Facility Type and Context Classification	Left-Turn Deceleration Lane	Right-Turn Deceleration Lane	Acceleration Lane
Freeway C1 - C6	Design must meet federal interstate standards, and no less than expressway standards.		
Expressway C1 - C6	Taper + Decel. Length + Storage	Taper + Decel. Length	Accel. Length + Taper
Street C5 - C6	Taper + Storage	Taper + Storage	*Accel. Length
Street ≤ 40 mph C3 - C4	*Decel. Length	*Decel. Length	*Accel. Length
Street > 40 mph C3 - C4	*Decel. Length	*Decel. Length	*Accel. Length
Road ≤ 40 mph C1 - C3	*Decel. Length + Storage	*Decel. Length	*Accel. Length
Road > 40 mph C1 - C3	*Decel. Length + Storage	*Decel. Length	*Accel. Length

*Taper length is included within stated Acceleration or Deceleration Length.

8.12.2 Deceleration Lanes

The functional area of an intersection with relation to the deceleration lane length is shown in Figure 8-6. This graphic illustrates the upstream functional area of an intersection with three components: perception-reaction distance, deceleration length, and storage length. The physical length of the deceleration lane includes the taper length, the deceleration length, and the storage length.

Figure 8-6 Functional Area Upstream of an Intersection Illustrating Components of Deceleration Lane Length



Source: Figure 9-48 of the 2018 AASHTO GDHS.

Table 8-6 represents the estimated distances to maneuver from the through lane into a turn bay and brake to a stop. It is not always practical to provide the full deceleration length of the auxiliary lane for deceleration because of constrained right of way or the available distance between intersections. In these cases, the driver should begin deceleration prior to entering the auxiliary lane.

Table 8-6 Desirable Full Deceleration Length

Speed (mph)	20	30	40	50	60	70
Distance[a] (feet)	70	160	275	425	605	820

[a] Rounded to the nearest 5 feet.

8.12.2.1 Perception-Reaction Time

Perception-reaction time is the amount of time it takes for a driver to perceive and recognize the upcoming turn lane and prepare to use the turn lane. For more information on perception-reaction time refer to Chapter 9, Section 9.7.2.1, of the 2018 AASHTO GDHS.

8.12.2.2 Storage Length

The auxiliary lane should be sufficiently long:

- To store the number of vehicles likely to accumulate during a critical period.
- To avoid the possibility of left-turning vehicles stopping in the through lane waiting for a signal change or for a gap in the opposing traffic flow.

At unsignalized intersections, the storage length, exclusive of taper, may be based on the number of turning vehicles likely to arrive in an average two-minute period within the peak hour. The two-minute waiting time may need to be changed to some other interval that depends largely on the opportunities for completing the left-turn maneuver. These intervals, in turn, depend on the volume of opposing traffic. Where the volume of turning traffic is high, traffic signal warrants should be performed. It would be advisable to engage a traffic engineer to perform the signal warrant analysis.

There are several techniques to determine the necessary storage length. Desirable auxiliary lane lengths for vehicles to come to a stop at an unsignalized intersection are provided in Table 8-7.

Table 8-7 Storage Lengths for Auxiliary Lanes at Unsignalized Intersections

Turning Vehicles Per Peak Hour	Below 30	30	60	100	200	300
Required Storage Length (ft)	25	40*	50*	100	200	300

*Minimum storage length is 100 ft when trucks equal or exceed 10% of turning vehicles.

A left-turning volume of 200 vehicles per hour, or more, cannot complete the turn without difficulty unless the volume of opposing through traffic during the same hour is about 88 or less.

Turning volumes in this range usually require special design or traffic signal control. Storage lengths for signalized intersections may be determined from highway capacity nomographs in the *Highway Capacity Manual* (TRB, 2022).

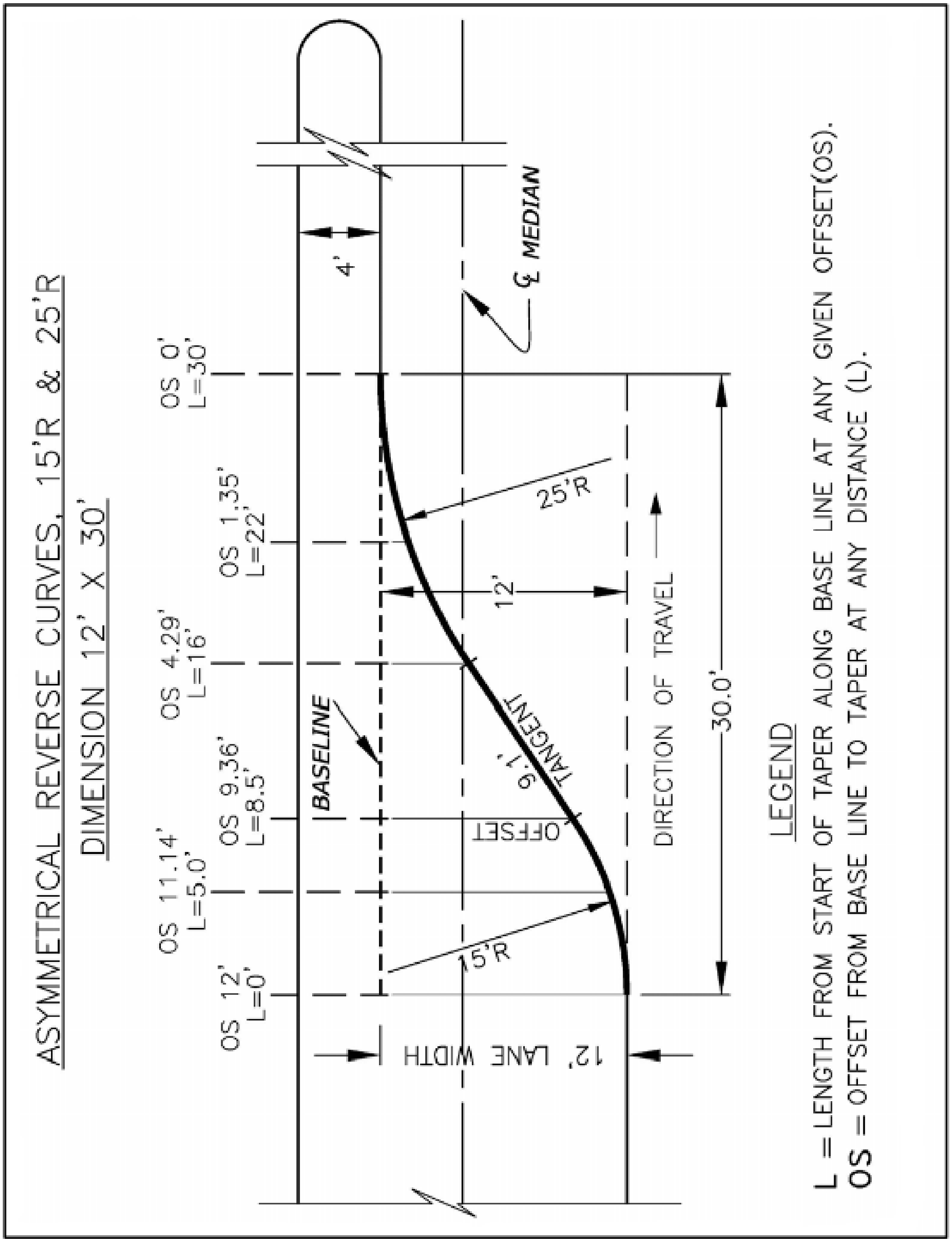
The designer should check with the local agency to ascertain their established minimum lengths for auxiliary lanes with low turn volumes for secondary roadways.

The important factors that determine the storage length needed are:

- The design year volume for the peak hour.
- An estimate for the number of cycles per hour if the location is signalized.
- The type of signal phasing and timing that will control the left-turn movement. The designer should seek guidance through coordination with the Traffic Engineer.
- To reduce the total length of queues formed in the left-turn lane, it is an allowable practice to allow “permissive” turns following “protected” turn phases. Permissive turns are made when gaps in opposing traffic occur and can increase the capacity of a turn lane from 20 to 50%.
- Another alternative is to identify if a flashing yellow arrow would be allowed by the traffic engineer for left-turning traffic movements. A flashing yellow left-turn arrow allows permissive lefts to occur and possibly clear the queue during the green phase. If the queue does not clear, the signal can provide an end of green left-turn phase to clear the remaining vehicles.

Median bay tapers (asymmetrical reverse curves) may be used for deceleration transition tapers. Use of a bay taper and auxiliary lane striping will reduce drifting of the through vehicles into the deceleration lane. Where there are horizontal or crest vertical curves, consider using a bay taper for more visible definition. Figure 8-7 illustrates asymmetrical reverse curves for a median bay taper.

Figure 8-7 (CDOT) Median Bay Taper



8.12.2.3 Elements of Left-Turn Design (Lane Drop and Redirect Tapers)

Lane drop and lane transition (redirect) tapers should be designed to encourage efficient operation and reduce crashes. The lane-drop and lane transition (redirect) taper length where the posted or statutory speed limit is 45 mph or greater should be computed with Equation 8-1, based on the MUTCD. Where the posted or statutory speed limit is less than 45 mph, the lane-drop or redirect taper length should be computed with Equation 8-2.

For speeds equal to or greater than 45 mph: L = WS

Where,
L = length of taper (ft)
S = posted or statutory speed (mph)
W = offset (ft)

For speeds less than 45 mph: $L = \frac{WS^2}{60}$

8.12.2.4 Taper Length

To develop the width needed for auxiliary lanes, a transition (or taper) must be established in advance of the auxiliary lane. This taper allows a driver to recognize that an exclusive lane is becoming available and allows some deceleration to occur prior to entering the storage lane itself.

Design configurations for straight-line and curved tapers are shown in Chapter 9 of the 2018 AASHTO GDHS. Recommended taper ratios for speed-change lanes are given in Table 8-8.

Table 8-8 Taper Length and Ratio for Parallel-Type Entrance

Posted Speed (mph)	25	30	35	40	45	50	55	60 [a]	65 [a]	70 [a]
Taper Ratio [b]	7.5:1	8:1	10:1	12:1	13.5:1	15:1	18.5:1	25:1	25:1	25:1

[a]Uniform 50:1 to 70:1 tapers are recommended where lengths of acceleration lanes exceed 1300 feet.
[b]Taper Length equals taper ratio times lane width.

8.12.3 Acceleration Length

Acceleration lanes are used when there is a free-flow right and the *Highway Capacity Manual* (TRB, 2022) dictates. For traffic signal warrants, refer to Chapter 15 of this Guide. For design, refer to Table 8-9.

Table 8-9 Desirable Acceleration Length from Stop Condition

Design Speed (mph)	30	35	40	45	50	55	60	65	70	75
Acceleration Length (feet)	180	280	360	560	720	960	1200	1410	1620	1790

*These approximate lengths are based on grades less than 3%.

Provision for acceleration clear of the through traffic lanes is a desirable objective on arterial roads and streets and should be incorporated into design whenever feasible and practicable (refer to the State Highway Access Code [State of Colorado, 2002] for guidance on warrants). The total length required is that needed to reach a safe and comfortable speed to enter the through lane. Acceleration requirements are as shown in Figure 10-69 and Tables 10-3 to 10-4 of the 2018 AASHTO GDHS.

When the roadway is operating in context classifications C4, C5, and C6, the addition of acceleration lanes may not be appropriate. Acceleration lanes are to help a vehicle reach operating speed before entering the through lane. In urban areas this is not as critical, and the acceleration lane can pose greater risks to pedestrians by lengthening the crossing distances across the roadway and creating conflict areas with bicycle activity. The designer should weigh the benefit and need for the acceleration lane versus the potential safety impacts of this on other travel modes.

8.12.4 Speed Change Lane Width

Speed change lane widths must be a minimum of 11 feet, not including the gutter pan or shoulder, whenever posted speeds are greater than 40 mph, or when truck volumes exceed 9%. Ten-foot lanes may be used in instances where the posted speed limit is less than 45 mph, and truck volumes are less than 10%, so long as the local agency design standards allow. In instances where adjacent travel lanes are 12 feet wide, the speed change lane should be designed at 12 feet wide. Figure 8-8 illustrates speed-change lane taper for continuously curbed medians.

8.12.5 Shoulder Width Along Speed Change Lanes Where Curbs Are Not Present

Shoulders must be present in all locations where there is no curb and gutter. Shoulders adjacent to through travel lanes should be six feet wide, but no less than the existing shoulder width. Shoulders along speed change lanes shall be a minimum of 4 feet wide.

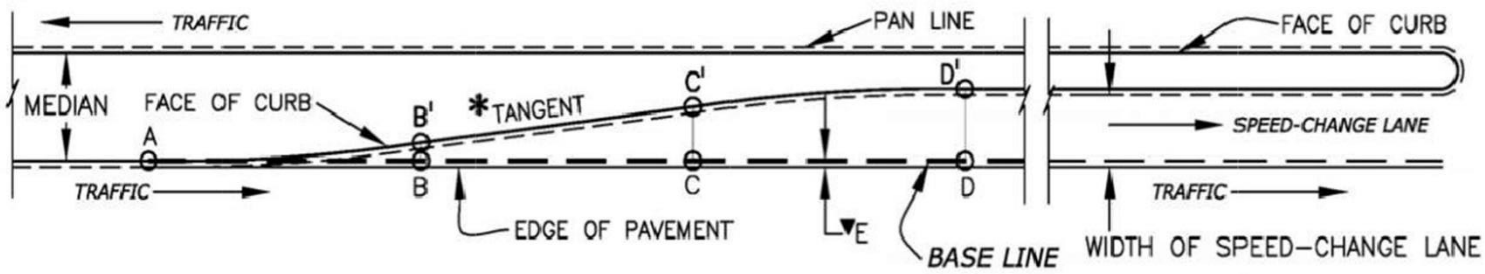
8.12.6 Design Treatments for Left-Turn Maneuvers

If there is sufficient median width, the ideal design treatment is to have the left-turn lane offset to the left of the opposing turn lane at the intersection. The offset to the left of the opposing lane increases the driver's sight distance to better see and anticipate gaps in approaching traffic. This is also a benefit where large trucks are regularly making left-turns.

8.12.6.1 Guidelines for Provision and Design of Left-Turn Bypass Lanes

A left-turn bypass lane is often associated with alternative intersection designs. One example is an advanced left lane at a continuous flow intersection (CFI) where the left-turn bypass occurs in advance of the intersection. This allows the left-turn movement on the major movement to occur simultaneously with the minor street through movement. There are other examples of this, and current modeling software should be used to help evaluate the viability and benefits of alternative intersections such as this example.

Figure 8-8 Speed-Change Lane Taper for Continuously Curbed Medians



NOTES

1. AD = TAPER LENGTH
2. AB = BC = CD = 1/3 AD
3. A B' & C' D' ARE PARABOLIC CURVES.
4. THE INCLUDED TABLE GIVES OFFSETS FROM A ***BASE LINE*** PARALLEL TO THE EDGE OF PAVEMENT TO THE FACE OF CURB AT INTERVALS MEASURED FROM POINT A.

OFFSET DISTANCE (FEET)		DESIGN SPEED (MPH)			
		30	40	50	
		LENGTH OF TAPER (FT)			
		60	90	150	
DD' = 10'	DD' = 12'	DISTANCE FROM POINT A (FEET)			
0	0	---	---	---	
0.16	0.19	5	7.5	12.5	
0.62	0.75	10	15.0	25.0	
1.41	1.69	15	22.5	37.5	
2.50	3.00	20	30.0	50.0	DATA FOR POINT B'
5.00	6.00	30	45.0	75.0	
7.50	9.00	40	60.0	100.0	DATA FOR POINT C'
8.59	10.31	45	67.5	112.5	
9.38	11.25	50	75.0	125.0	
9.84	11.81	55	82.5	137.5	
10.00	12.00	60	90.0	150.0	

5. * WHERE EDGE OF PAVEMENT IS A CURVE, NEITHER ***BASE LINE*** NOR TAPER BETWEEN **B'**&**C'** WILL BE A TANGENT. USE PROPORTIONAL OFFSETS FROM **B'** TO **C'**
6. ▼ THE ADOPTED OFFSET E IS USUALLY ONE FOOT ALONG OUTSIDE EDGE OF PAVEMENT BUT MAY VARY IN SOME CASES.
7. THE ABOVE TABLE MAY ALSO BE USED WITH A PAINTED MEDIAN TO DELINEATE THE STORAGE AREA.

8.12.6.2 Median Left-Turn Lanes

Accommodation of left-turns in many cases is the critical factor in design of intersections. Provisions for left-turn lanes greatly influence both level of service and intersection safety.

A median lane provides refuge for vehicles awaiting an opportunity to turn, and thereby keeps the highway traveled way clear for through traffic. The width, length, and general design of median lanes are similar to those of any other deceleration lane, but their design includes some additional features. Examples of median left-turn channelization are shown in Figures 8-9A and 8-9B.

Analysis of conflicts involving left turns shows why their treatment is so critical. Left-turning vehicles conflict with:

- Opposing through traffic.
- Crossing traffic.
- Through traffic in the same direction.

Median widths of 20 feet or more are desirable at intersections with single-median lanes, but widths of 16 to 18 feet permit reasonably adequate arrangements. Where two median lanes are used, a median width of at least 28 feet is desirable to permit the installation of two 12-foot lanes and a 4-foot separator. Although not equal in width to a normal traveled lane, a 10-foot lane with a 2-foot curbed separator or paint lines separating the median lane from the opposing through lane may be acceptable where speeds are low, and the intersection is controlled by traffic signals.

Figure 8-9A Minimum Median Left-Turn Channelization, Four-Leg Intersection

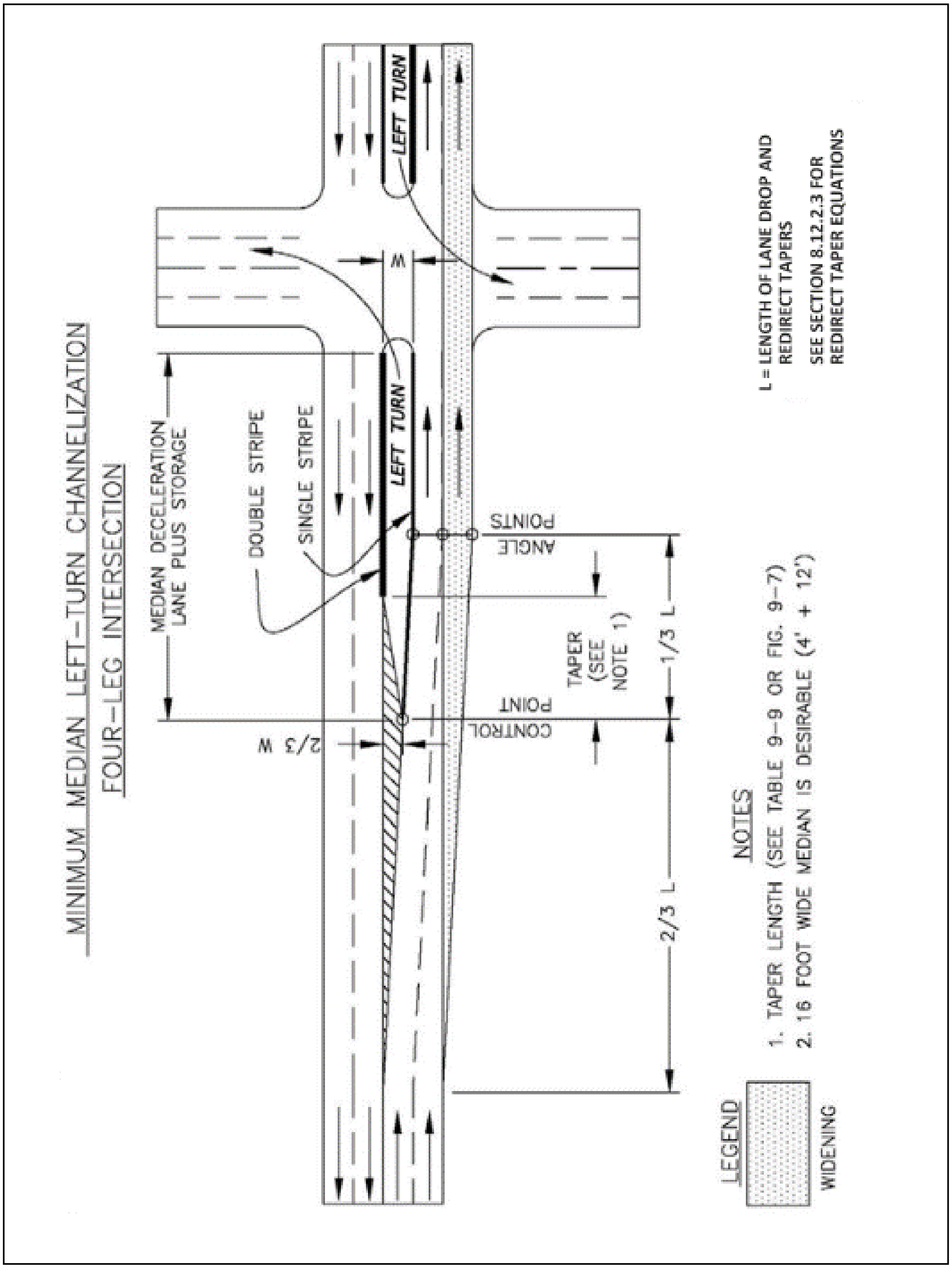
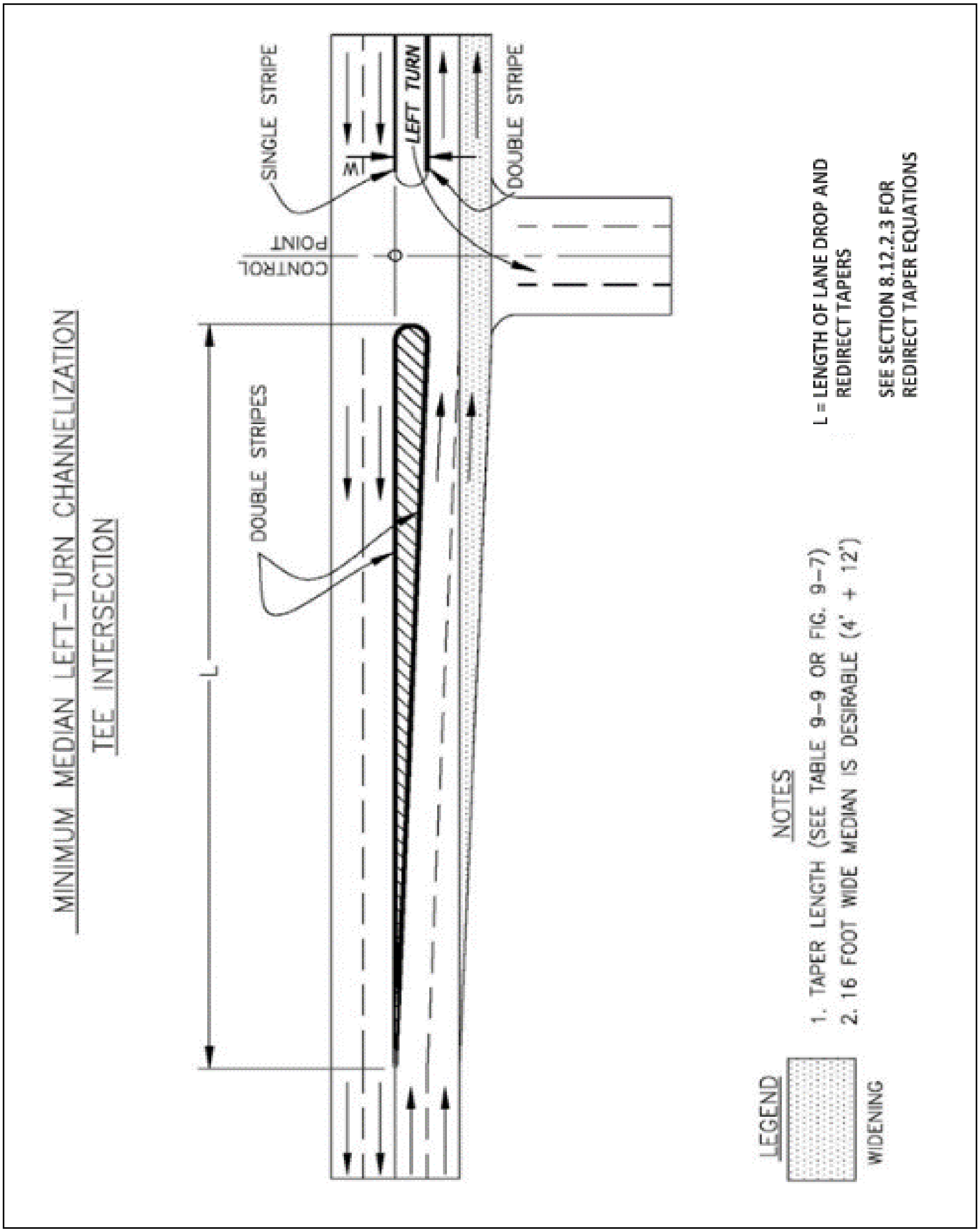


Figure 8-9B Minimum Median Left-Turn Channelization, Tee Intersection



8.12.6.3 Median Left-Turn Lane Warrants

Because of the many variables involved, it is not feasible to develop guidelines for all conditions at signalized intersections. However, the following information should be considered in evaluating left-turn needs at specific locations.

At high-speed, rural-signalized intersections, separate left-turn lanes are considered necessary for safe operations. While capacity is not generally a problem, protection of queued left-turning vehicles from through vehicles is critical. Because the availability and cost of right of way can be expensive, it is important to objectively evaluate and calculate traffic queueing for the turning movement to determine the necessity for a separate left-turn lane.

To facilitate flow where the intersection is unsignalized, the following guidelines are suggested:

- Left-turn lanes should be considered at all median crossovers on divided, high-speed highways.
- Left-turn lanes should be provided at all uncontrolled approaches of primary, high-speed rural highway intersections with other arterials and collectors.
- Left-turn lanes should be provided on stopped or secondary approaches based on analysis of the capacity and operations of the unsignalized intersection.

8.12.6.4 Median End Treatment

The form of treatment at the end of the narrowed median adjacent to lanes of opposing traffic depends largely on the available width. The narrowed median may be curbed to delineate the lane edge, to separate opposing movements, to provide space for necessary signs, markers, and lighting standards, and to protect pedestrians.

For medians wider than about 18 feet, as shown in Figure 9-10C and in Figure 9-51 in the 2018 AASHTO GDHS, it is usually preferable to align the left lane in a manner that will reduce the width of the divider to 6 to 8 feet immediately in advance of the intersection, rather than to align it exactly parallel with and adjacent to the through lane. This alignment places the vehicle waiting to make the turn as far to the left as practical and improves visibility of opposing through traffic. The advantages of offsetting the left-turn lanes are:

- Better visibility of opposing through traffic.
- Decreased possibility of conflict between opposing left-turn movements within the intersection.
- More left-turn vehicles served in a given period of time, particularly at a signalized intersection.

For curbed dividers 4 feet or more in width at the narrowest end, the curbed nose can be offset from the opposing through traffic lane 2 feet or more, with gradual taper beyond to make it less vulnerable to contact by through traffic. The shape of the nose for curbed dividers 4 feet wide usually is semicircular, but for wider widths the ends are normally shaped to a bullet nose pattern to conform better to the paths of turning vehicles.

8.12.6.5 Offset Left-Turn Lanes

Refer to Chapter 9, Section 9.7.3.4, of the 2018 AASHTO GDHS for information on offset left-turn lanes.

8.12.6.6 Simultaneous Left-Turns

Refer to Chapter 9, Section 9.7.3.5, of the 2018 AASHTO GDHS for information on simultaneous turn lanes.

8.12.6.7 Double or Triple Left-Turn Lanes

Double left-turn lanes have been applied successfully nationwide at locations with severe capacity or operational problems. Their applicability is generally greatest at high volume intersections with significant left-turning volumes in one or more direction. Double left-turn lanes should be considered at any signalized intersection with high design hour demand for left-turns. As a general rule, left-turn volumes of 300 vehicles per hour or more are appropriate for consideration for double left-turn lanes.

Left-turning vehicles leave the through pavement to enter the median lanes in single file, but once within it, store in two lanes and, on receiving the green indication, turn simultaneously from both lanes. With three-phase signal control, such an arrangement results in an increase in capacity of approximately 180% of that of a single median lane. Because of the high turning volumes, double left-turn lanes should only be used with fully protected signal phasing.

Where there are two left-turn lanes, the storage length can be reduced to approximately 0.6 of that required for single-lane operation. Ideally a traffic modeling analysis should be completed to determine the storage area that is necessary for two left-turn lanes.

The widening on the curve for the two lanes of turning traffic is an important design element. Drivers are most comfortable with extra space between the turning queues of traffic. Because of off-tracking characteristics of vehicles and the relative difficulty of two abreast turns, a 36-foot width for the two lanes on the curve is desirable. In constrained situations, a 30-foot width on the curve is an acceptable minimum. Vehicle tracking patterns from both directions need to be evaluated for turning movement conflicts. If opposing movements conflict, the intersection may need to be modified to alleviate the turning conflicts, or the opposing turning movements need to be phased separately.

A summary of the current use of triple left-turn lanes can be found in the Florida DOT report *Triple Left Turn Lanes at Signalized Intersections* (FDOT, 2002).

8.12.6.8 Median Lane Width

A median width of 20 feet or more is desirable at intersections with single-median lanes, but widths of 16 to 18 feet permit reasonably adequate arrangements. The minimum narrowed median width of no less than 4 feet is recommended, but 6 to 8 feet wide is preferred. These dimensions can be provided within a median 16 to 18 feet wide and a turning lane width of 10 to 12 feet.

Widening of the highway equally on both sides of the centerline may be required to accommodate the median area.

Figures 8-10A and 8-10B show a minimum design for a median left-turn lane within a 14- to 18-foot median. The left-turn lane is 10 to 12 feet wide with a 4-foot wide median. Figure 8-10C shows a design for a median left-turn lane with a median greater than 18 feet.

Figure 8-10A 14 to 16-Foot Median Left-Turn Design

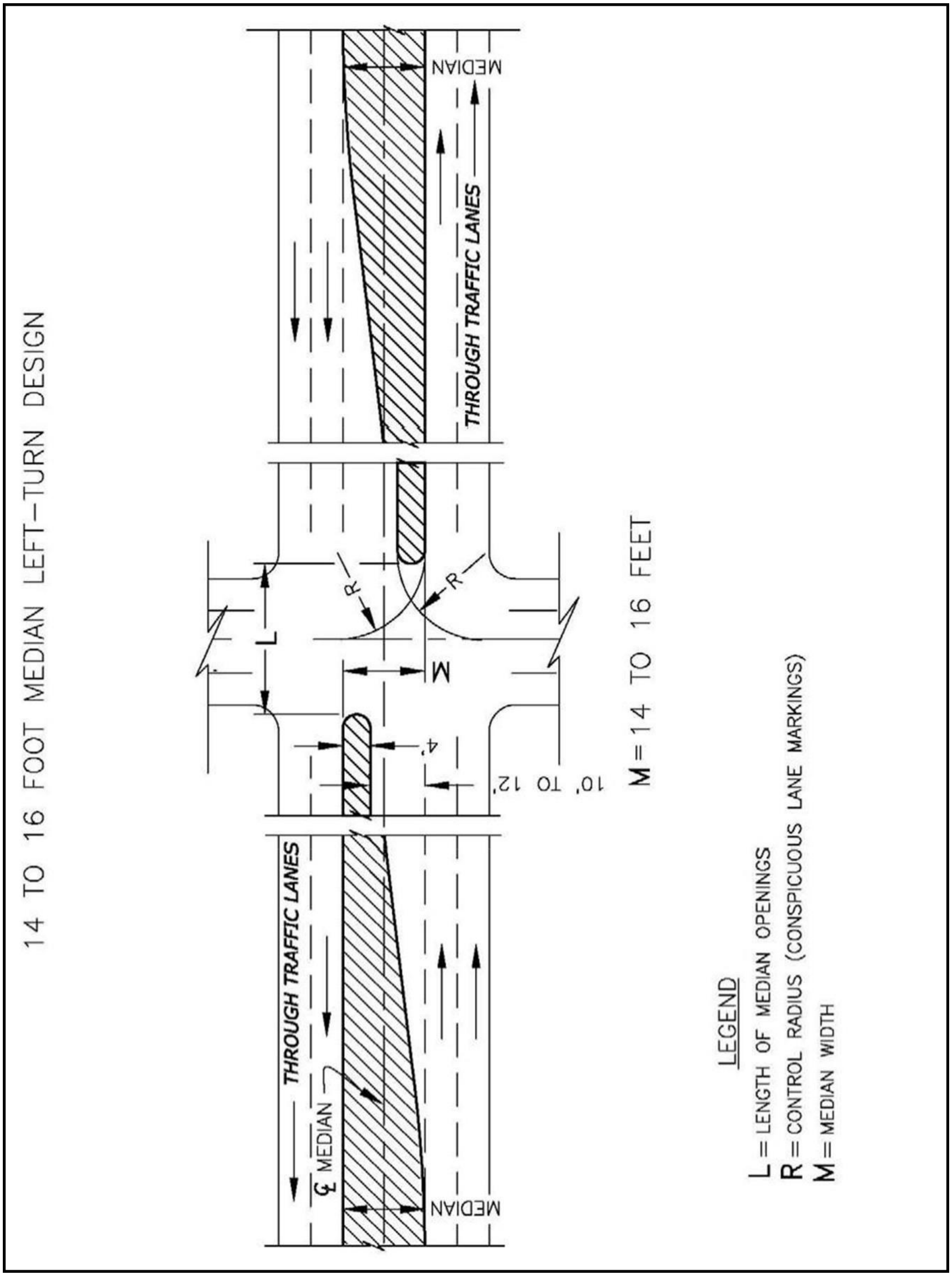


Figure 8-10B 16 to 18-Foot Median Left-Turn Design

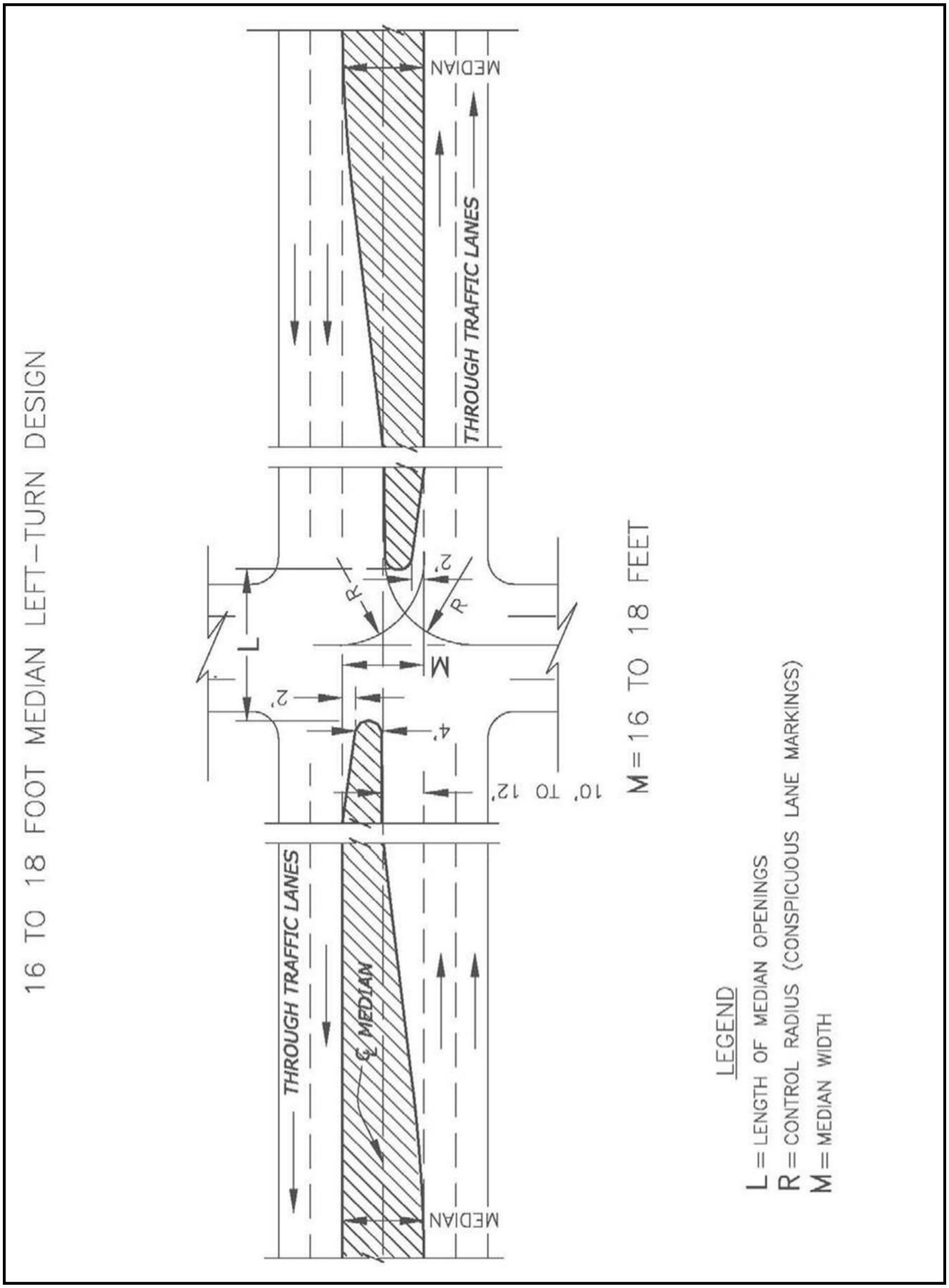
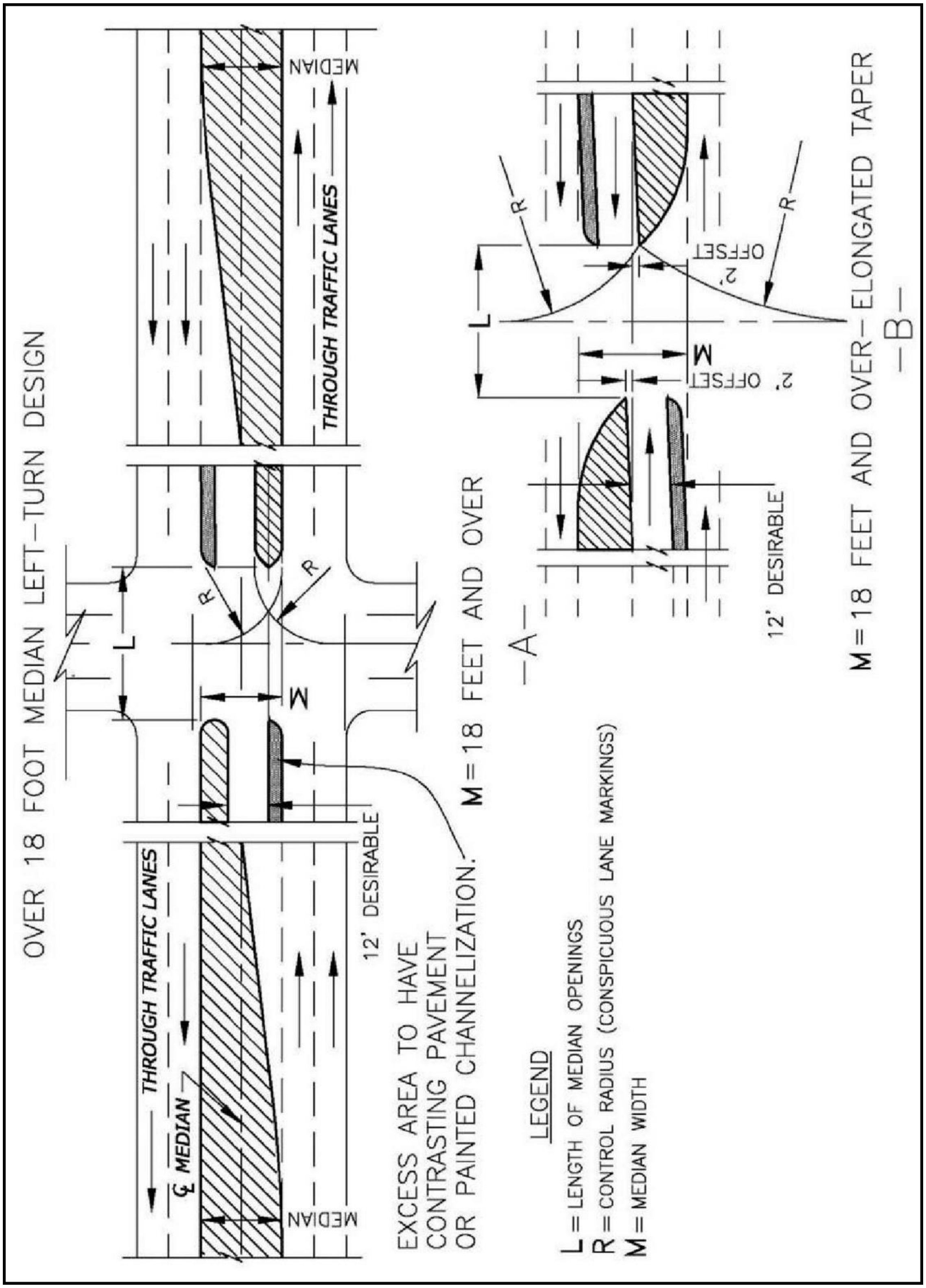


Figure 8-10C Median Left-Turn Design for Median Width Greater Than 18 Feet



8.13 Median Openings

8.13.1 General Design Considerations

Refer to Tables 9-25 through 9-27 and Figures 9-55 through 9-58 in the 2018 AASHTO GDHS.

Medians are discussed in Chapter 4 of this Guide chiefly as an element of the cross section. In Chapter 4, general ranges in width are given, and the width of the median at intersections is treated briefly.

For intersections, the median width, the length of the opening, and the design of a median opening and median ends should be based on traffic volumes and type of turning vehicles. Cross and turning traffic must operate in conjunction with the through traffic on the divided highway. This requirement makes it necessary to know the volume and composition of all movements occurring simultaneously during the design peak hours.

The design of a median opening becomes a matter of considering what traffic is to be accommodated, choosing the design vehicle to use for layout controls for each cross and turning movement, investigating whether larger vehicles can turn without undue encroachment on adjacent lanes, and finally checking the intersection for capacity. If the capacity is exceeded by the traffic load, the design must be expanded, possibly by widening or otherwise adjusting widths for certain movements.

If a median is primarily used by pedestrians, it should be raised and at minimum match the width of the continuing path. If the median is wide enough, an angled cut-through should be provided to position pedestrians and bicyclists to face oncoming traffic. If a median is primarily used by bicycles, designers should consider keeping the median crossing flat to avoid pedal strikes. Median refuge areas for pedestrians should be at least 6 feet wide to provide sufficient refuge to protect a bicyclist or a person pushing a stroller, but any refuge is better than none.

8.13.2 Control Radii for Minimum Turning Paths

An important factor in designing median openings is the path of each design vehicle making a minimum left-turn at 10 to 15 mph. Where the volumes and types of vehicles making the left-turn movements call for higher than minimum speed, the design may be made by using a radius of turn corresponding to the speed deemed appropriate. However, the minimum turning path at low speed is needed for minimum design and for testing layouts developed for one vehicle with an occasional larger vehicle.

The paths of design vehicles making right-turns are shown in Chapter 2 of the 2018 AASHTO GDHS. Any differences between the minimum turning radii for left-turns and those for right-turns are small and are insignificant in highway design. Minimum 90-degree left-turn paths for design vehicles are shown in Figure 9-54 of the 2018 AASHTO GDHS. Turning templates, whether electronic or transparent, for various design vehicles should be utilized.

By considering the range of radii for minimum right-turns and the need to accommodate more than one type of vehicle at intersections, the following control radii can be used for minimum practical design of median ends:

- A control radius of 40 feet accommodates P vehicles suitably and occasional SU-30 vehicles with some swinging wide.
- A control radius of 50 feet accommodates SU-30 vehicles and occasional WB-40 vehicles with some swinging wide.
- A control radius of 75 feet accommodates WB-40 vehicles.
- A control radius of 130 feet accommodates WB-62 and occasionally WB-67 vehicles.

Refer to Figures 9-55 to 9-58 of the 2018 AASHTO GDHS.

8.13.3 Shape of Median End

One shape of a median end at an opening is a semicircle as shown in Figure 8-11. This simple design is satisfactory for narrow medians. For medians greater than about 10 feet in width, the bullet nose is superior to the semicircular end. Consider plowable end treatments with a minimum 3:1 slope from the pan to top of curb.

Alternate minimum designs for median ends to fit the design control radii of 40, 50, 75 and 130 feet are shown in Chapter 9 of the 2018 AASHTO GDHS. Refer to Figures 9-55 to 9-58 of the 2018 AASHTO GDHS.

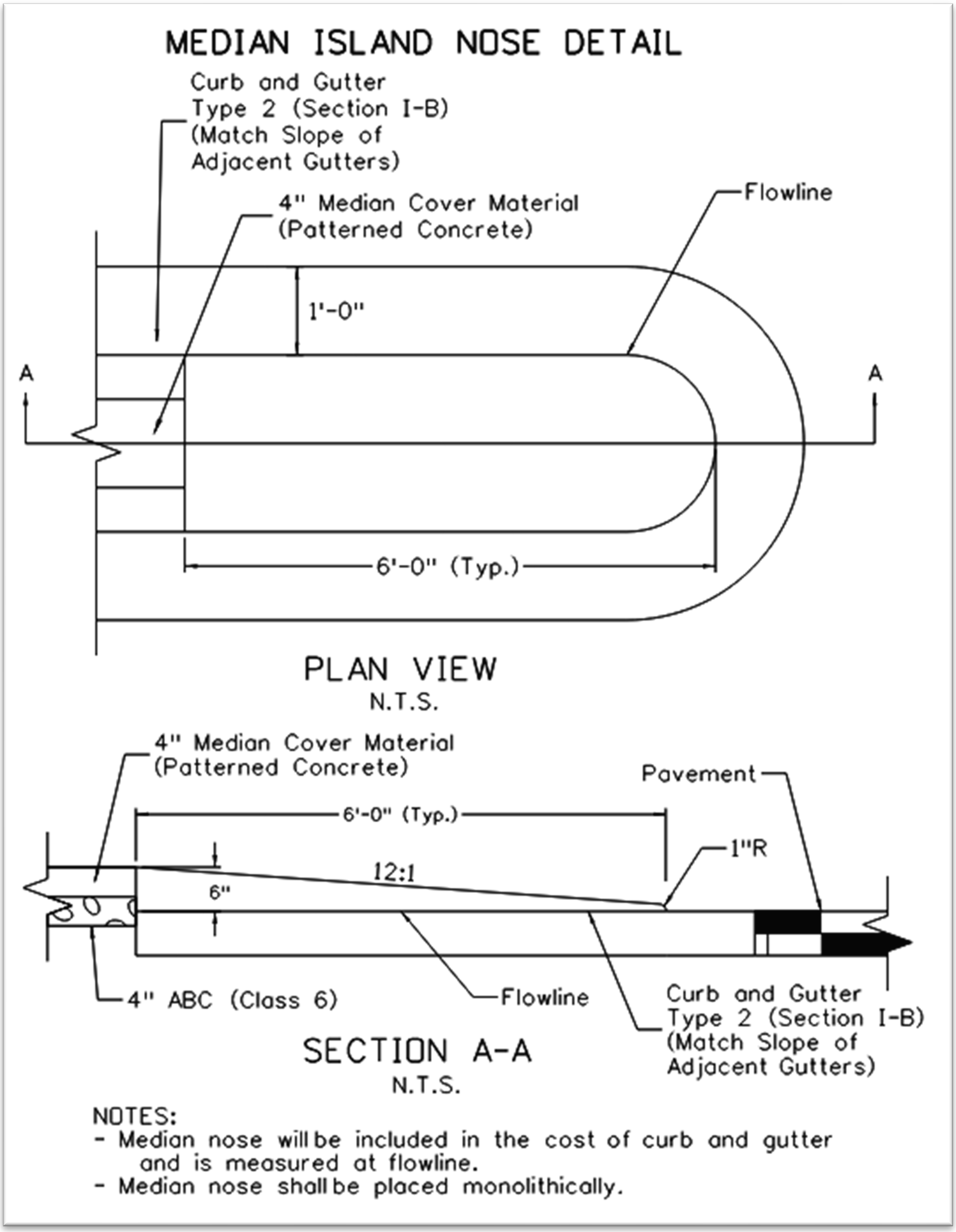
8.13.4 Effect of Skew

Using a control radius for design vehicles as the basis for minimum design of median openings results in opening lengths that increase with the skew angle of the intersection. Refer to Tables 9-28 and 9-29 of the 2018 AASHTO GDHS for details of the effect of skewed crossings on the length of median openings.

8.13.5 Design Considerations for Higher Speed Left-Turns

Refer to Figure 9-59 of the 2018 AASHTO GDHS.

Figure 8-11 Median Island Nose Detail



8.14 Flush or Traversable Medians

The discussion in Section 8.15 of this chapter on design for indirect left-turns and U-turns with raised curb medians brings into focus the difficulties involved in providing access to abutting properties, especially where such access is by commercial vehicles. These conditions are common in commercial and industrial areas where property values are high and right of way for wide medians is difficult to acquire. A flush or traversable median by design does not have any physical obstruction that would prohibit it from being crossed with ease and comfort. However, the intent of the flush or traversable median is to create a contrast in the pavement section for motorists to avoid crossing.

One method for solving this left-turn conflict problem while maintaining access to roadside activities is the use of continuous two-way left-turn lanes. Two-way left-turn lanes (TWLTL) should be considered where there is a history of midblock crashes involving left-turning vehicles, multiple driveways are closely spaced, or where there are strip development or multiple-unit residential land use along the corridor.

A number of studies have evaluated the cost-effectiveness of TWLTLs. Based on these studies, the following warrants and guidelines are suggested for their application:

- Annual Average Daily Traffic (AADT) – four lanes – between 10,000 and 20,000 vehicles, or two lanes – between 5,000 and 12,000 vehicles.
- Left-turn volumes – 70 midblock turns per 1,000 feet, or at least 20% of total volume making left-turns in the peak hour.
- Minimum length – 1,000 feet, or 2 to 3 blocks.

In general, TWLTLs can be considered when operating speeds are 50 mph or less and AADT is below 24,000 ADT for the roadway segment. TWLTL widths in use range from 10 to 16 feet. Table 8-10 provides suggested lane widths for various types of highways. Designs for new facilities should strive for median lane widths of 12 to 14 feet.

Table 8-10 Lane Widths for Continuous Two-Way Left-Turn Lanes

Lane Widths for Continuous Two-Way Left-Turn Lanes		
Prevailing Speed (mph)	**Lane Use (Vehicle Type)**	**Appropriate Width of Lane (ft)**
25 to 30	Residential, business (passenger cars)	9 ft absolute minimum, 12 ft desirable
30 to 40	Business (passenger cars, some trucks)	12 ft minimum, 14 ft desirable
	Industrial (many large trucks)	14 ft to 16 ft
40 to 50	Business	12 ft minimum, 14 ft desirable

Conversion of existing cross sections typically has more constraints. Narrow widths should be avoided except for on low-speed streets. Lane widths should not be so great, however, that shared use of the lane (i.e., side-by-side) by opposing drivers is created.

The TWLTL is generally continued through minor or unsignalized intersections. For signalized intersections or those controlled by four-way stops, it is generally advisable to restrict entry into the lane for a reasonable distance from the intersection using pavement markings.

8.15 Indirect Left-Turns and U-Turns

8.15.1 General Design Considerations

Indirect left-turns and U-turns can be used to achieve safe and efficient left-turn operations near intersections in the following situations:

- Where the median is too narrow to accommodate a lane for left-turning vehicles and the traffic volumes and/or speeds are relatively high.
- Where vehicles are using a through traffic lane to turn left and slow down or stop, increasing the potential for rear-end collisions.
- In urban or heavily developed residential or commercial areas where vehicles turn left at an uncontrolled access point.
- In residential and commercial areas where a left-turn at the desired access point is not feasible.

Chapter 9 of the 2018 AASHTO GDHS shows several options that may be considered for indirect left-turns on high-speed/high-volume highways.

A U-turn design should look closely at intersection spacing, access conflicts, and the amount of room available to accommodate the largest design vehicle expected to make the U-turn. U-turns should not be permitted from the through lanes. The width of the highway, including the median, should be sufficient to permit the design vehicle to turn from an auxiliary left-turn lane in the median into the lane next to the outside shoulder or outside curb and gutter on the opposing traffic lanes.

8.15.2 Intersections with Jug Handle or Loop Roadways

Refer to the 2018 AASHTO GDHS Chapter 9, Section 9.2.

8.15.3 Displaced Left-Turn Intersections

Refer to the 2018 AASHTO GDHS Chapter 9, Section 9.3.

8.15.4 Wide Medians with U-Turn Crossover Roadways

Refer to the 2018 AASHTO GDHS Chapter 9, Section 9.4.

8.15.5 Location and Design of U-Turn Median Openings

Refer to the 2018 AASHTO GDHS Chapter 9, Section 9.5.

8.16 Right-Turn Lanes

8.16.1 General Design Considerations

Minor intersections that are skewed and all major intersections require separate right-turn lanes. Design of right-turn lanes is similar to that of left-turn lanes.

A right-turn lane can fulfill one or more of the following functions:

- A means of safe deceleration outside the high-speed through lanes for right-turning traffic.
- A storage area for right-turning vehicles to assist in optimization of traffic signal phasing.
- A means of separating right-turning vehicles from other traffic at stop-controlled intersection approaches.

Bicycle facilities sometimes share the right-turn lane with vehicles. A common crash type results from vehicles making right-turns cutting off bicyclists. Dashed green bike markings approaching an intersection can improve driver awareness that there may be bicycles in the right-turn lane. At signalized intersections in urban areas, a “no right-turn on red” phase could help to prevent this type of bicycle crash.

Refer to Chapter 13 and the NACTO Urban Bikeway Design Guide (NACTO, 2014).

8.16.2 Tapers

Auxiliary lane tapers help to build a transition to right- and left-turn lanes at intersecting roadways. The length and type of taper is dependent upon the facility type it is serving (Road, Street, or Freeway), and if the turn lane will be a stop condition, merge condition, or free-flow condition to the adjacent facility. The designer needs to consider the traffic volumes this lane serves and provide sufficient storage length after the taper depending on the stop condition at the intersection to avoid traffic queuing back into the travel lanes.

8.16.2.1 Taper Length

Refer to the 2018 AASHTO GDHS Chapter 9, Section 7.2.3.

8.16.3 Storage

Design for storage at signalized intersections is based on arrival rates for right-turn volumes and departure conditions (i.e., available green time, cycle length). In designing for storage, the adjacent through lane volume will often control the desirable length because:

- Right-turn lanes have greater capacity due to greater signal timing flexibility.
- There is potential for right-turn on red movements.

For further information, refer to the *Highway Capacity Manual* (TRB, 2022).

8.16.4 Length

Right-turn lanes at stopped approaches should be of sufficient length to enable right-turning vehicles to bypass queued through lane or left-turning vehicles. This allows the higher capacity right-turn movement to operate independently of other stopped movements.

The required length for a right-turn lane is calculated in the same manner as described in Section 8.12.2 of this Guide. Signal timing, pedestrian activity, and vehicle arrival patterns are the most important aspects to consider when designing the length. Normally, a minimum storage length of 100 feet should be provided in addition to the taper.

8.16.5 Width

Lane width requirements for right-turn lanes are similar to those for other lanes. In general, 12-foot lanes are desirable, although widths as low as 10 feet have been used in severely constrained situations unless large trucks and buses are using the lane.

The width of a separate right-turning lane shall normally provide at least one-way one-lane operation with passing permitted. In some cases, it may be necessary to provide one-way two-lane operation; additional shoulder width for emergency parking under this condition is usually not required. When two-lane operation is required, the maximum desirable turning radius should be 200 feet.

Right-turn lanes adjacent to barrier curbs should be designed to full widths to negate the constricting effects of a curb. This is particularly important if the gutter width dimension is nominal.

It may be necessary, for example, to relocate a bus stop to midblock or to the far side if a right-turn lane is introduced.

8.16.6 Shoulders

Refer to Section 7.4.2 and Section 8.12.5 of this chapter.

8.17 Intersection Design Elements with Frontage Roads

Frontage roads are generally required contiguous to arterials or freeways where adjacent property owners are not permitted direct access to their property. Short lengths of frontage roads may be used along urban arterials to preserve the capacity and safety of the arterial through access control.

Where an arterial is flanked by two frontage roads, the roadway design and traffic control at intersections become more complex. There are actually three intersections at each cross street (two, if there is only one frontage road). A hazard is introduced with the increase in the number of conflicting movements at the intersection of the frontage road(s) and the arterial and from the confusing pattern of roadways and separations, which can lead to wrong-way entry.

For satisfactory operation with moderate-to-heavy traffic volumes on the frontage roads, the outer separation should preferably be 150 feet or more in width at the intersection. A thorough discussion of the separation of main line and frontage road is discussed in Chapter 9 of the 2018 AASHTO GDHS.

8.18 Traffic Control Devices

Determination of the type and use of traffic control devices for intersections of various types is defined by the Manual on Uniform Traffic Control Devices. This includes markings, signing, traffic signals, and delineation to name a few.

Use the following link to access FHWA's Manual on Uniform Traffic Control Devices (MUTCD): https://mutcd.fhwa.dot.gov/

8.19 Bicycles at Intersections

When on-street bicycle lanes and/or off-street bicycle paths enter an intersection, the intersection design should be modified accordingly. Further guidance in accommodating bicycles at intersections can be found in Chapter 13 of this Guide, the AASHTO *Guide for Development of Bicycle Facilities* (AASHTO, 2012), and the NACTO *Urban Bikeway Design Guide* (NACTO, 2014).

8.20 Lighting at Intersections

Lighting can enhance the safety at intersections, as well as efficiency of intersection traffic operations. Statistics indicate that the non-daylight crash rate is higher than that during daylight hours. This fact, to a large degree, may be attributed to impaired visibility.

In urban and suburban areas where there are concentrations of pedestrians and roadside and intersectional interferences, fixed-source lighting tends to reduce crashes. The need for lighting of rural at grade intersections depends on the planned geometrics and the turning volumes. Intersections that generally do not require channelization are seldom lighted. However, for the benefit of non-local highway users, lighting at rural intersections is desirable to aid the driver in ascertaining sign messages during non-daylight hours. Refer to Section 3.7 of this Guide.

Intersections with channelization, particularly multiple road geometrics, should include lighting. Large, channelized intersections especially need illumination because of the higher range of turning radii that are not within the lateral range of vehicular headlight beams. Vehicles approaching the intersection also must reduce speed. The indication of this need should be definite and visible at a distance from the intersection that may be beyond the range of headlights. Illumination of at-grade intersections with fixed-source lighting fulfills this need.

The location of intersection luminaire supports should be where it presents the least possible hazard to out-of-control vehicles. Refer to the AASHTO *Roadside Design Guide* (AASHTO, 2011) for further design guidance.

Use this link for research on luminaire recommendations for pedestrians: https://apps.ict.illinois.edu/projects/getfile.asp?id=9812

8.21 Driveways

A driveway is, in effect, an at-grade intersection and should be designed consistent with its intended use. Depending upon the traffic generation of access, auxiliary turn lanes or a TWLTL maybe needed to safely serve the traffic demand. Refer to Section 9.11.6 in the 2018 AASHTO GDHS.

The regulation and design of driveways are intimately linked with the right of way and zoning of the roadside. On new facilities, during right of way acquisition, access control can be negotiated and secured, to provide the desired degree of driveway regulation and control. Additional right of way and access control can be acquired on existing highways, or access agreements can be completed with local agencies to improve existing undesirable access conditions. Often, the desired degree of access control may be subject to the police powers for state highway purposes as stated in the State Highway Access Code (State of Colorado, 2002), to require permits for all new driveways or change in land use of properties.

A designer should coordinate with the following people: Region Right of Way Manager, Region Access Program Manager, Region Traffic Engineer or local agency traffic engineer if access changes are being considered on a project. Refer to CDOT Standard Plans - M & S Standards (CDOT, 2019) and the State Highway Access Code (State of Colorado, 2002) for design information on driveways.

8.22 Railroad-Highway Grade Crossings

A railroad-highway crossing is typically at grade. The horizontal and vertical geometrics of a highway approaching an at-grade railroad crossing should be designed so that they do not divert a driver's attention from roadway conditions. It is advisable to coordinate early and often with the CDOT Region utilities engineer, Public Utilities Commission (PUC) Chief of Rail/Transit Safety, and the railroad companies to accommodate their specific regulations.

Ideally highway rail grade crossings should be aligned as close to a 90-degree skew to improve driver visibility to see oncoming trains, to facilitate safer crossings for bicyclists, and to provide sufficient advance stopping sight distance for the driver to see rail signal crossing activations if present. For further information on railroad crossings, refer to the 2018 AASHTO GDHS.

Chapter 9
Roundabouts

Legend

	Multimodal Application Example
	Context-Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context-Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO-Specific Information

Chapter

9

9 Roundabouts

9.1 Introduction

A roundabout is a form of a circular intersection in which traffic travels counterclockwise around a central island and entering traffic must yield to circulating traffic. Roundabouts feature, among other things, a central island, a circulatory roadway, and splitter islands on each approach. Roundabouts rely upon two basic and important operating principles:

- Speed reduction at the entry and through the intersection will be achieved through geometric design.
- The yield-at-entry rule, which requires traffic entering the intersection to yield to traffic that is traveling in the circulatory roadway.

The benefits of roundabouts are:

- Over half of vehicle-to-vehicle points of conflict associated with intersections are eliminated with a roundabout. Fewer conflict points typically result in fewer collisions and collisions with less severity. Additionally, a roundabout separates the points of conflict so that users can more easily identify a conflict and prevent conflicts from becoming collisions.
- Roundabouts are designed to reduce vehicular speeds at intersections. Lower speeds lessen the severity of vehicular collisions and pedestrian and bicyclist collisions with motorized vehicles.
- Roundabouts allow continuous free-flow of vehicles and bicycles when no conflicts exist. This results in less noise and air pollution and reduces overall delays at the intersections.

Locations where a roundabout may be feasible include:

- Intersections with a high-crash rate or a higher severity of crashes.
- High-speed rural intersections.

- Freeway ramp terminals.
- Transitions between context classifications (C3 to C4) or speed reductions (rural to urban roadway transition in the same context area).
- Existing intersections that are failing operationally.
- Intersections where aesthetics is an objective.
- Four-leg intersections with entering volumes less than 5,000 vehicles per hour (vph) or approximately 50,000 average daily traffic (ADT).
- Three-leg intersections.
- Intersection of two signalized progressive corridors where turn proportions are heavy (random arrival is better than off-cycle arrival).
- Closely spaced intersections where signal progression cannot be achieved.
- Replacement of all-way stops.
- Intersections near schools.

The contents of this chapter are intended to serve as design guidance only.

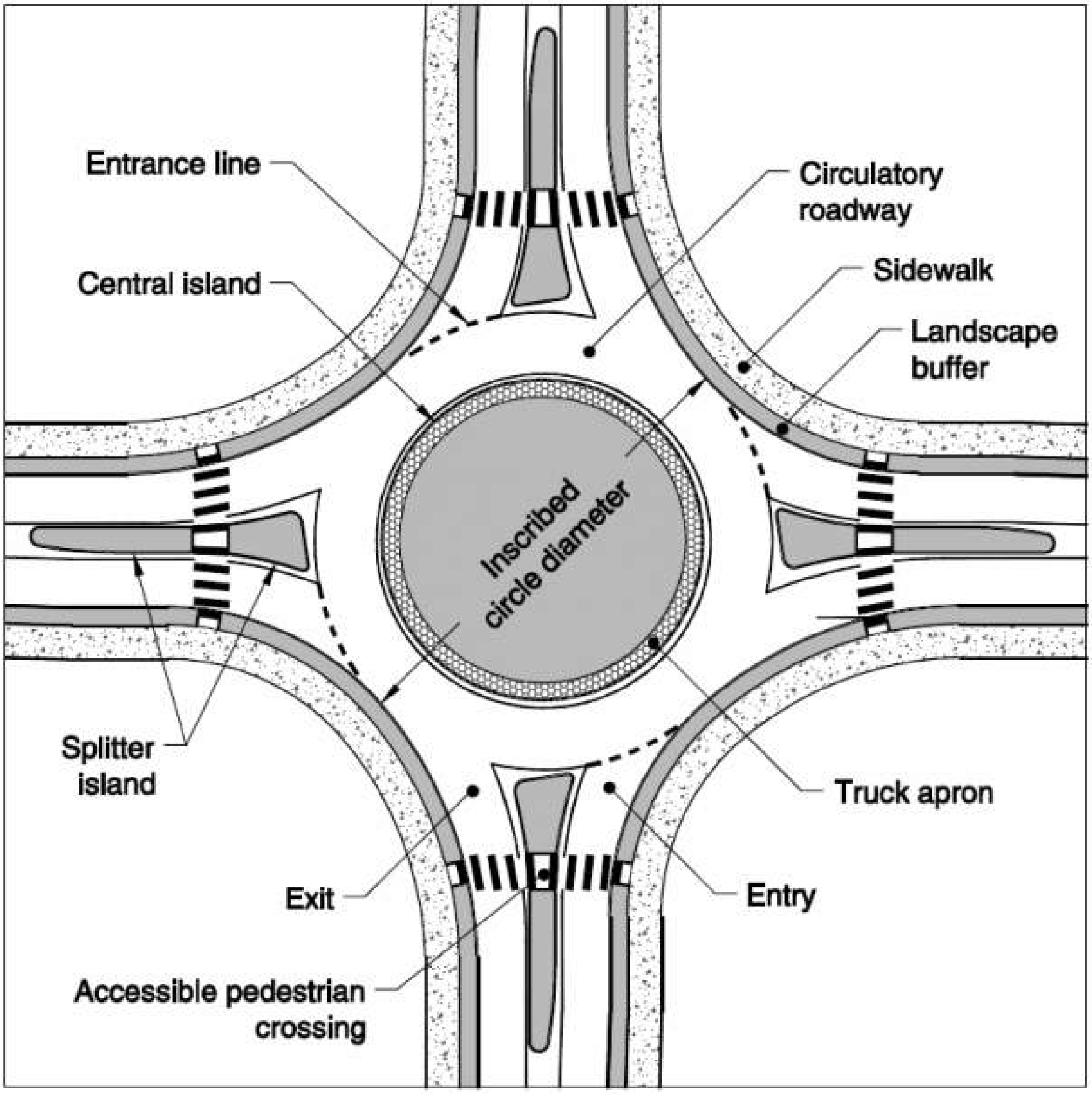
Roundabout intersections on the Colorado State Highway System must be developed and evaluated in accordance with the National Cooperative Highway Research Program (NCHRP) Report 672, Roundabouts: An Information Guide, Second Edition, dated October 2010, or the latest edition (NCHRP, 2010).

Use this link to access NCHRP Report 672, Roundabouts: An Informational Guide, Second Edition: https://nacto.org/docs/usdg/nchrprpt672.pdf

Roundabout considerations, planning, operational analysis, and safety are not covered in this chapter. Signs, striping, and markings at roundabouts must comply with the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) latest edition (FHWA, [2009] 2022).

Figure 9-1 depicts the typical nomenclature associated with roundabouts.

Figure 9-1 Roundabout Geometric Elements



Note: This figure is provided to only shown nomenclature and is not to be used for design details.

9.2 Roundabout Categories

Roundabouts are separated into three basic categories according to the size and number of lanes used at the roundabout: mini-roundabouts, single-lane roundabouts, and multilane roundabouts. Table 9-1 summarizes and compares some fundamental design and operational elements for each roundabout category.

Table 9-1 Roundabout Category Comparison

Design Element	Mini- Roundabout	Single-Lane Roundabout	Multilane Roundabout
Desirable maximum entry design speed	15 to 20 mph (25 to 30 km/h)	15 to 25 mph	25 to 30 mph
Maximum number of entering lanes per approach	1	1	2+
Typical inscribed circle diameter	45 to 90 ft	90 to 180 ft	150 to 300 ft
Central island treatment	Fully traversable	Raised (may have traversable apron)	Raised (may have traversable apron)
Typical daily service volumes on 4-leg roundabout below which may be expected to operate without requiring a detailed capacity analysis (veh/day)*	Up to approximately 15,000	Up to approximately 25,000	Up to approximately 45,000 for two-lane roundabout

*Operational analysis needed to verify upper limit for specific applications or for roundabouts with more than two lanes or four legs.

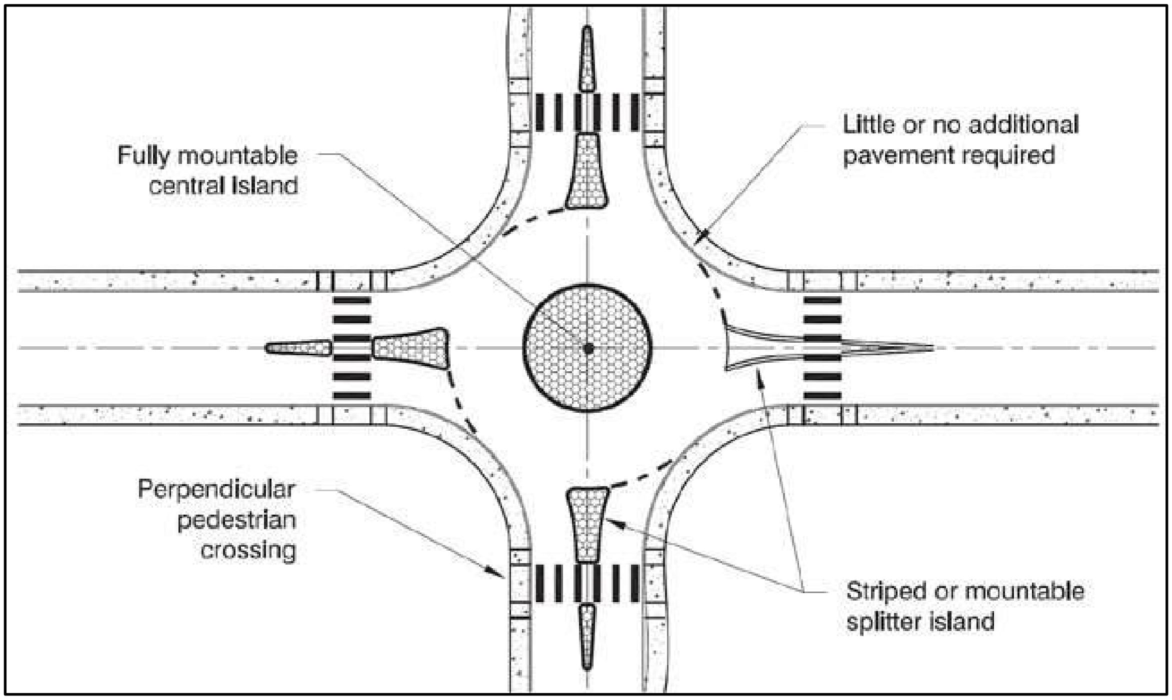
9.2.1 Mini-Roundabout

A mini-roundabout is a small single-lane roundabout with a fully traversable central island. It is most often used in low-speed urban environments with average operating speeds of 30 mph or less and where conventional roundabout design is precluded by right of way constraints. In retrofit applications, mini-roundabouts are relatively inexpensive because they typically require minimal additional pavement at the intersecting roads and minor widening at the corner curbs. They are mostly recommended when there is insufficient right of way to accommodate the design vehicle with a traditional single-lane roundabout. Because they are small, mini-roundabouts are perceived as pedestrian-friendly because of short crossing distances and very low vehicle speeds on approaches and exits.

A fully traversable central island accommodates large vehicles that may need to traverse the island to navigate the turns. The design of a mini-roundabout should align vehicles at entry to guide drivers to the intended path and minimize running over of the central island to the extent possible.

Figure 9-2 illustrates a typical mini-roundabout and its important characteristics.

Figure 9-2 Typical Mini-Roundabout

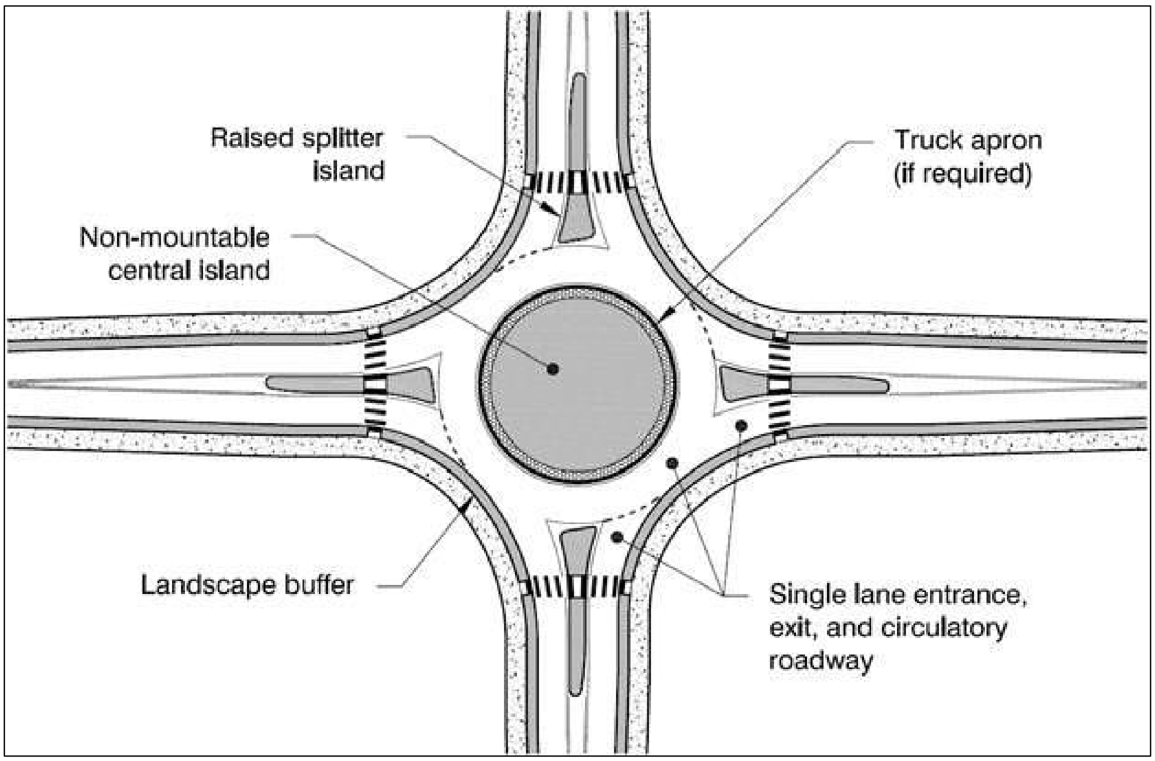


9.2.2 Single-Lane Roundabout

A single-lane roundabout has a single-lane entry at all legs and one circulatory lane. It is distinguished from a mini-roundabout by a larger inscribed circle diameter and a non-traversable central island. Their design accommodates slightly higher speeds at the entry, on the circulatory roadway, and at the exit. The size of the roundabout is largely influenced by the design vehicle and available right of way.

Figure 9-3 illustrates the features of a typical single-lane roundabout. The geometric design typically includes raised splitter islands, a non-traversable central island, crosswalks, and a truck apron.

Figure 9-3 Typical Single-Lane Roundabout

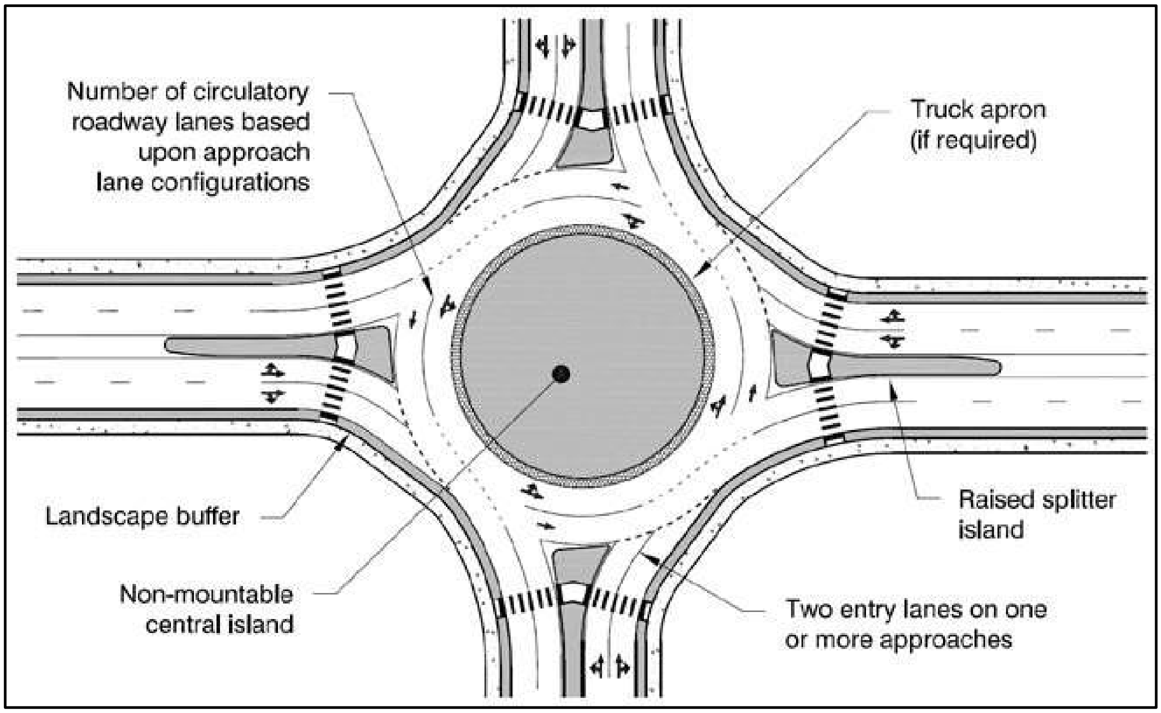


9.2.3 Multilane Roundabout

A multilane roundabout has at least one entry with two or more lanes. In some cases, it may have a different number of lanes on one or more approaches. Some multilane roundabouts have entries on one or more approaches that flare from one to two or more lanes. They require wider circulatory roadways to accommodate more than one vehicle traveling side by side. The speeds at the entry, on the circulatory roadway, and at the exit are similar or may be slightly higher than those for a single-lane roundabout.

Figure 9-4 provides an example of a typical multilane roundabout. The geometric design includes raised splitter islands, a truck apron, a non-traversable central island, and appropriate entry path deflection.

Figure 9-4 Typical Multilane Roundabout



9.3 Roundabout Design Process

9.3.1 Roundabout Design Process

Roundabout design is an iterative process where a variety of design objectives must be considered and balanced within site-specific constraints. Maximizing the operational performance and safety for a roundabout requires the designer to think through the design rather than rely upon a design template.

A general outline for the roundabout iterative design process includes the following: incorporating elements of project planning, preliminary design, and final design. Information from the operational analysis is used to determine the required number of lanes for the roundabout (single or multilane), which dictates the required size and many other design details. The basic design should be laid out based upon the principles identified in this chapter and the NCHRP Report 672, Roundabouts: An Informational Guide, Second Edition (NCHRP, 2010) to a level that allows the designer to verify that the layout meets the design objectives. The key is to conduct enough work to be able to check the design and identify whether adjustments are necessary. Once enough iteration has been performed to identify an optimum size, location, and set of approach alignments, additional detail can be added to the design.

9.3.2 General Design Considerations

Throughout this chapter and the NCHRP Report 672 (NCHRP, 2010), ranges of typical values are given for many of the different geometric elements to design individual roundabout components. The use of a design technique not explicitly included or a value that falls outside of the ranges presented does not automatically create an unsafe condition if a few basic design principles can be achieved. The following list of principles should be the objective of any roundabout design:

- Provide slow entry speeds and consistent speeds through the roundabout by using deflection.
- Provide the appropriate number of lanes and lane assignment to achieve adequate capacity, lane volume balance, and lane continuity.
- Provide smooth channelization that is intuitive to drivers and results in vehicles naturally using the intended lanes.
- Provide adequate accommodation for the design vehicles.
- Design to meet the needs of pedestrians and bicyclists.
- Provide appropriate sight distance and visibility for driver recognition of the intersection and conflicting users.
- Bike lanes approaching roundabouts – circulating with traffic; exit ramps to shared-use paths.
- Types of multimodal elements and vehicles using the roundabout.
- Pedestrian crossings at roundabout entry points.
- Location of transit stops near roundabouts.

Each of the principles affects the safety and operations of the roundabout. When developing a design, the trade-offs of safety, capacity, cost, etc., must be recognized and assessed throughout the design process. Favoring one component of design may negatively affect another. A common example of competing needs is accommodating large trucks on the roundabout approach and entry while maintaining slow design speeds. Increasing the entry width or entry radius to better accommodate a large truck may simultaneously increase the speeds that vehicles can enter the roundabout. The designer must balance these competing needs and may need to adjust the initial design parameters.

A best practice for on-street bicycle facilities is to drop the bike lane on the approach to the roundabout, which requires bicyclists to merge with traffic. It should be expected that bicyclists who stay in the travel lane will take the center of the lane. Depending on nearby land uses, such as an elementary school where there may be children using the roundabout, it could be expected that young bicyclists may choose to stay on the sidewalk.

Raised crossing tables on the approach to a roundabout can reinforce desired vehicular entry speeds.

9.4 Geometric Design

This section includes a general set of guidelines to be considered when first laying out a roundabout. These are not to be interpreted as a standard or rule, but general best practices. As described above, roundabout design is an iterative process where a variety of design objectives must be considered and balanced within site-specific constraints.

9.4.1 Initial Design Elements

- Design vehicle.
- Lane widths.
- Entry speed.
- Deflection angles.
- Sight distance.
- Entrance angle.
- Path overlap.

9.4.1.1 Roundabout Size

The inscribed circle diameter is the overall outside diameter of a roundabout, which is the distance across the circle inscribed by the outer curb (or edge) of the circulatory roadway, as illustrated in Figure 9-1. The inscribed circle diameter is determined by a number of design objectives, including accommodation of the design vehicle, project impacts, and speed control. Setting the inscribed diameter for a roundabout may take a few iterations based on the design vehicle used and the movements that vehicle will be making as it enters, circulates, and exits the roundabout.

Table 9-2 provides typical ranges of inscribed diameters for various roundabout configurations.

Table 9-2 Typical Inscribed Diameter Ranges

Roundabout Configuration	Typical Design Vehicle	Common Inscribed Circle Diameter Range*
Mini-Roundabout	SU-30	45 to 95ft
Single-Lane Roundabout	B-40	90 to 150 ft
	WB-50	105 to 150 ft
	WB-67	130 to 180 ft
Multilane Roundabout (2 lanes)	WB-50	105 to 220 ft
	WB-67	165 to 220 ft
Multilane Roundabout (3 lanes)	WB-50	200 to 250 ft
	WB-67	220 to 300 ft

* Assumes 90° angles between entries and no more than 4 legs. List of possible design vehicles is not all-inclusive.

9.4.1.2 Alignment of Approach Legs

The alignment of the approach legs affects the amount of deflection (speed control) that is achieved, the ability to accommodate the design vehicle, and the visibility angles to adjacent legs. The optimal alignment is generally governed by the size and position of the roundabout relative to its approaches. Various options for approach alignment are summarized in Figure 9-5.

A common starting point in design is to offset the centerline of the approach to the left (i.e., the centerline passes to the left of the roundabout's center point). This alignment typically increases the deflection achieved at the entry to improve speed control. This location typically allows the geometry of a roundabout to be adequately designed such that a vehicle maintains slow approach speeds through the entry.

In urban environments, it is important to have drivers maintain sufficiently low vehicular speeds at the pedestrian crossing to reduce the risk for pedestrians. The fastest-path procedure provided in Section 9.7.1 in this chapter identifies a methodology for estimating speeds for large-radius (or tangential) exits where acceleration may govern the attainable speed.

Designing the approaches at perpendicular or near-perpendicular angles generally results in relatively slow and consistent speeds for all movements. Highly skewed intersection angles can often require significantly larger inscribed circle diameters to achieve the speed objectives. Approaches that intersect at angles greater than approximately 105° can be realigned by introducing curvature in advance of the roundabout to produce a more perpendicular intersection.

Other possible geometric modifications include changes to the inscribed circle diameter or modifications to the shape of the central island to manage vehicle speeds. For roundabouts in low-speed urban environments, the alignment of the approaches may be less critical.

Figure 9-5 Approach Alignment Alternatives

Entry Alignment

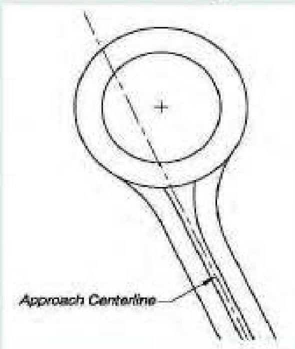
Question

Should the approach alignment run through the center of the inscribed circle? Or is it acceptable to offset the approach centerline to one side?

Design Principle

The alignment does not have to pass through the center of the roundabout; however, it has a primary effect on the entry/exit design. The optimal alignment allows for an entry design that provides adequate deflection and speed control while also providing appropriate view angles to drivers and balancing property impacts/costs.

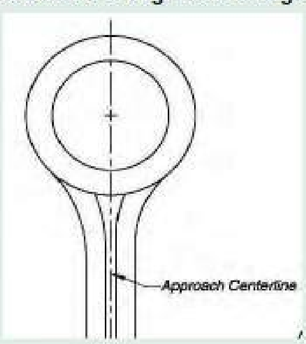
Alternative 1: Offset Alignment to the Left of Center



ADVANTAGES:
- Allows for increased deflection
- Beneficial for accommodating large trucks with small inscribed circle diameter—allows for larger entry radius while maintaining deflection and speed control
- May reduce impacts to right-side of roadway

TRADE-OFFS
- Increased exit radius or tangential exit reduces control of exit speeds and acceleration through crosswalk area
- May create greater impacts to the left side of the roadway

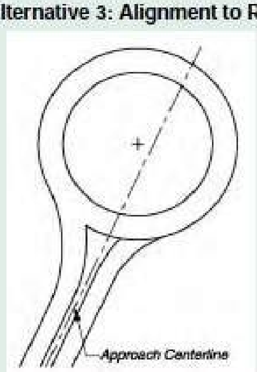
Alternative 2: Alignment through Center of Roundabout



ADVANTAGES:
- Reduces amount of alignment changes along the approach roadway to keep impacts more localized to intersection
- Allows for some exit curvature to encourage drivers to maintain slower speeds through the exit

TRADE-OFFS
- Increased exit radius reduces control of exit speeds/acceleration through crosswalk area
- May require a slightly larger inscribed circle diameter (compared to offset-left design) to provide the same level of speed control

Alternative 3: Alignment to Right of Center



ADVANTAGES:
- Could be used for large inscribed circle diameter roundabouts where speed control objectives can still be met
- Although not commonly used, this strategy may be appropriate in some instances (provided that speed objectives are met) to minimize impacts, improve view angles, etc.

TRADE-OFFS
- Often more difficult to achieve speed control objectives, particularly at small diameter roundabouts
- Increases the amount of exit curvature that must be negotiated

9.4.1.3 Design Vehicle

The design vehicle will dictate many of the roundabout's dimensions and the designer should consider the largest design vehicle to normally use that facility. The vehicle type to be considered should be based on the context of the area. Consult Chapter 2, Design Controls and Criteria, for more information regarding the appropriate design vehicle.

Large trucks and buses often dictate many of the roundabout's dimensions, particularly for single-lane roundabouts. Nearly all roundabouts feature truck aprons, which provides additional paved surface to accommodate the wide path of the trailer but keeps the actual circulatory roadway width narrow enough to maintain speed control for smaller passenger cars. The roundabout should be designed so that buses do not track over the truck apron.

The designer should also consider the ability of snowplows to be able to operate and effectively clear snow within the roundabout. The turning movements with a large plow extended beyond the front wheels of the vehicle is different from a standard box truck turning template.

9.5 Single-Lane Roundabouts

This section presents general guidelines for the design of individual geometric elements at a single-lane roundabout. Many of these same principles also apply to the design of multilane roundabouts; however, there are some additional complexities to the design of multilane roundabouts that are described in detail in Section 9.6.

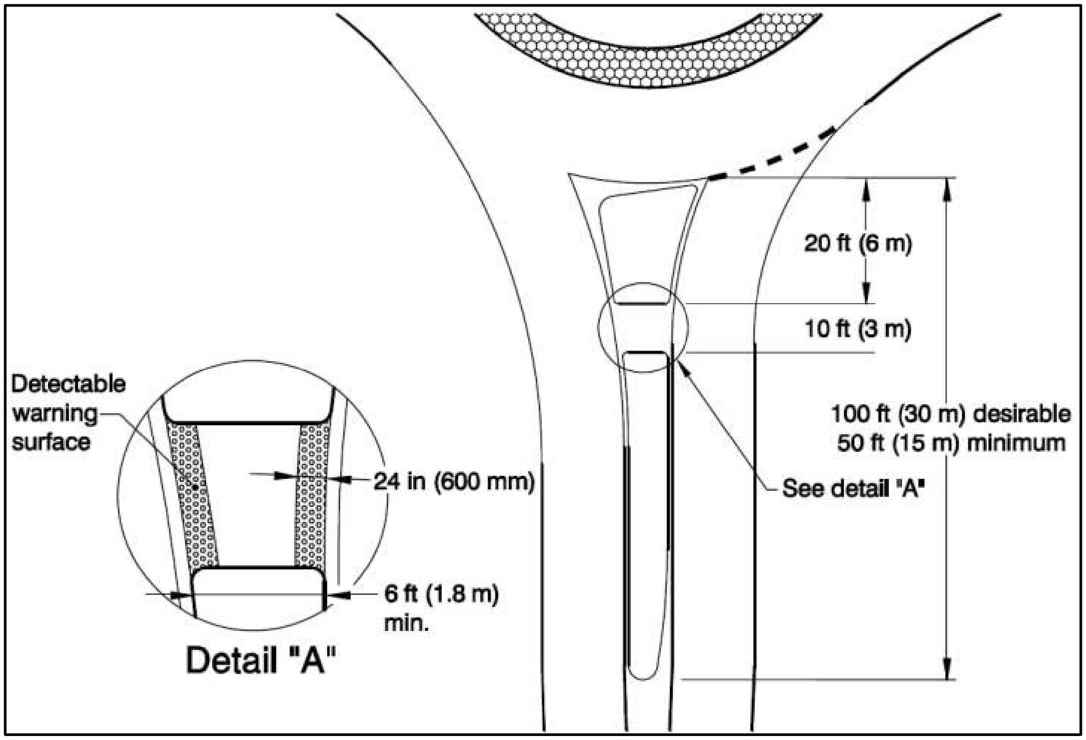
9.5.1 Splitter Islands

Splitter islands (also called separator islands or median islands) should be provided on all single-lane roundabouts. Their purpose is to provide refuge for pedestrians, assist in controlling speeds, guide traffic into the roundabout, physically separate entering and exiting traffic streams, and deterring wrong-way movements.

When performing the initial layout of a roundabout's design, a sufficiently sized splitter island envelope should be identified prior to designing the entry and exits of an approach. This will ensure that the design will eventually allow for a raised island that meets the minimum dimensions (offsets, tapers, length, widths).

The total length of the splitter island will vary based on terrain, access considerations, site-specific mainline and crossroad operational speeds, and the stepdown speeds to the final desired entry speed. However, the raised island should be at least 50 feet in length (100 feet is desirable) to provide sufficient protection for pedestrians and to alert approaching drivers to the geometry of the roundabout. On higher speed roadways, splitter island lengths of 150 feet or more are often beneficial. Additionally, the splitter island should extend beyond the end of the exit curve to prevent exiting traffic from accidentally crossing into the path of approaching traffic. The splitter island width should be a minimum of 6 feet at the crosswalk to adequately provide refuge for pedestrians. Figure 9-6 shows the minimum dimensions for a splitter island at a single-lane roundabout, including the location of the pedestrian crossing.

Figure 9-6 Minimum Splitter Island Dimensions

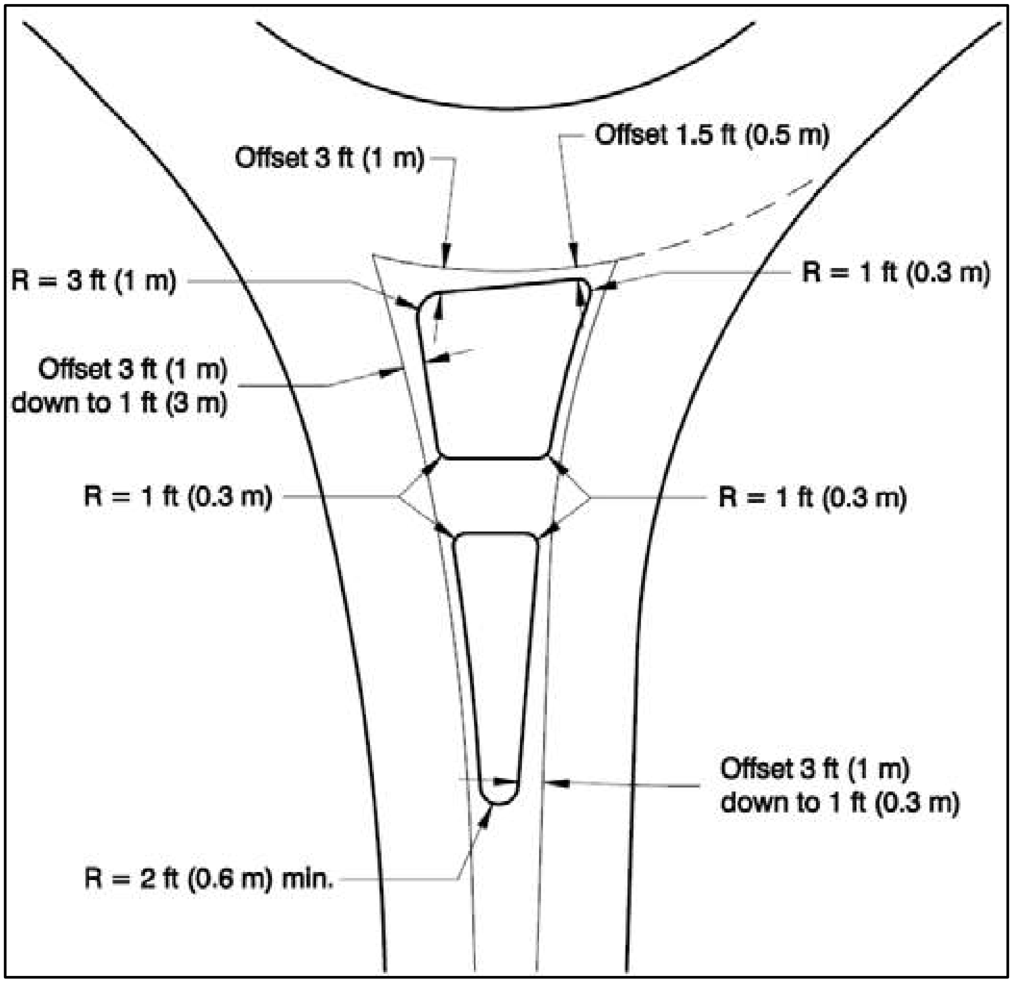


While Figure 9-7 provides minimum dimensions for splitter islands, there are benefits to providing larger islands. An increase in the splitter island width results in greater separation between the entering and exiting traffic streams of the same leg and increases the time for approaching drivers to distinguish between exiting and circulating vehicles. This results in better gap acceptance and can help reduce confusion for entering motorists. A larger splitter island width also supports better pedestrian refuge.

Standard AASHTO guidelines for island design should be followed for the splitter island. This includes using larger nose radii at approach corners to maximize island visibility and offsetting curb lines at the approach ends to create a funneling effect. The funneling treatment also aids in reducing speeds as vehicles approach the roundabout.

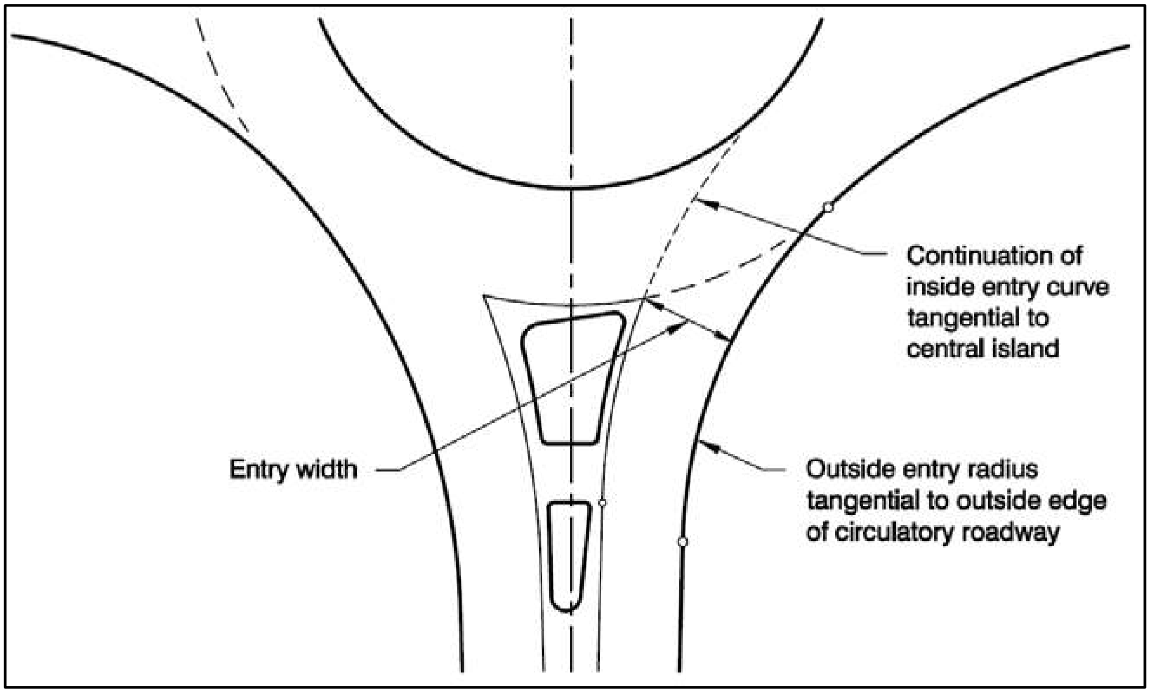
Figure 9-7 shows typical minimum splitter island nose radii and offset dimensions from the entry and exit traveled ways. The nose radii shall be tapered at the front of the nose to allow snowplow blades to ride up and over the nose without damaging the plow or the nose.

Figure 9-7 Typical Minimum Splitter Island Nose Radii and Offset Entry Width



Typical entry widths for single-lane roundabout entrances range from 14 to 18 feet. It is recommended to use 18 feet for the opening to provide enough width to maneuver around a stalled vehicle. These entries are often flared from upstream approach widths. However, values higher or lower than this range may be appropriate for site-specific design vehicle and speed requirements for critical vehicle paths. An 18-foot entry width from curb face to curb face is a common starting value for a single-lane roundabout. Care should be taken with entry widths greater than 18 feet or for those that exceed the width of the circulatory roadway, as drivers may mistakenly interpret the wide entry to be two lanes when there is only one receiving circulatory lane. Figure 9-8 shows a typical single-lane roundabout entry design.

Figure 9-8 Single-Lane Roundabout Entry Design



9.5.2 Circulatory Roadway Width

The circulating width should be at least as wide as the maximum entry width and up to 120% of the maximum entry width. For single-lane roundabouts, the circulatory roadway width usually remains constant throughout the roundabout. Typical circulatory roadway widths range from 16 to 20 feet for single-lane roundabouts. Care should be taken to avoid making the circulatory roadway width too wide within a single-lane roundabout because drivers may think that two vehicles are allowed to circulate side-by-side. The circulatory roadway width should typically be designed to accommodate the swept path of a bus design vehicle without using the truck apron to avoid jostling bus passengers by running over the truck apron.

9.5.3 Central Island and Truck Apron

The central island of a roundabout is the raised, mainly non-traversable area surrounded by the circulatory roadway. It may also include a traversable truck apron. The island is typically landscaped for aesthetic reasons and can be used for public art or gateway markers. They also enhance driver recognition of the roundabout upon approach. Raised central islands for roundabouts are preferred over depressed central islands on the Colorado State Highway system.

Truck aprons should be designed such that they are traversable by trucks but discourage passenger vehicles from using them. Truck apron width is dictated by the swept path of the design vehicle using a CAD-based vehicle turning path simulation software (Figure 9-9 and Figure 9-10). Truck aprons should generally be 3 to 15 feet wide and have a cross slope of 1% to 2% away from the central island. To discourage use by passenger vehicles, the outer edge of the apron should be raised approximately 2 to 3 inches above the circulatory roadway surface. The apron should be constructed of a different material and color than the pavement to differentiate it from the circulatory roadway. The texture and color of the truck apron should be determined as part of the CSS process through the stakeholder involvement.

Figure 9-9 Truck Apron Typical Detail

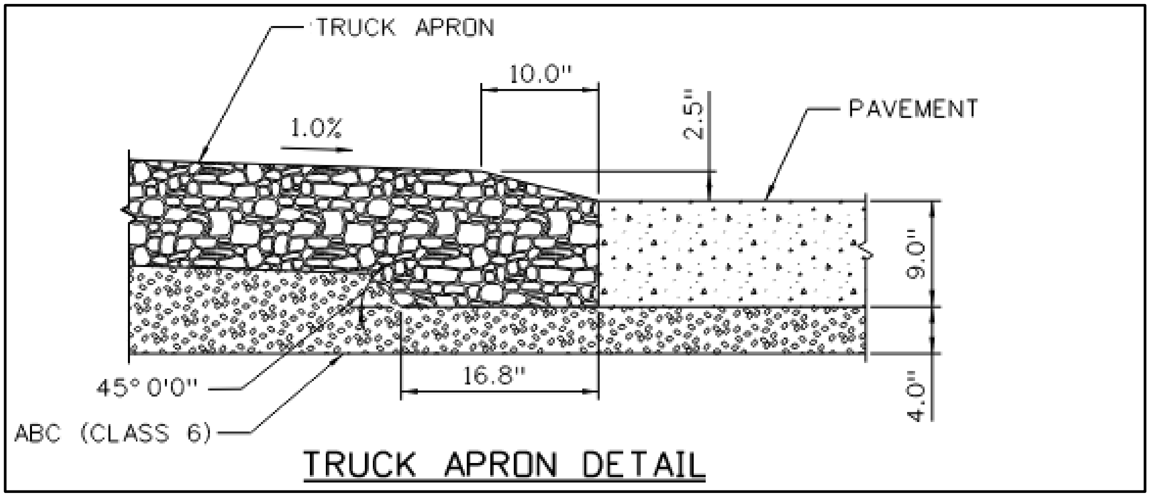
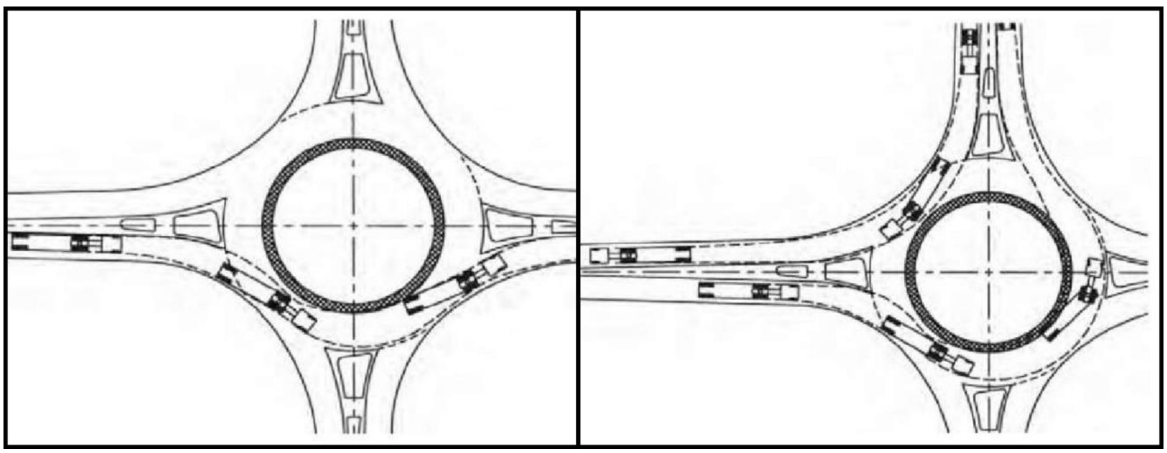


Figure 9-10 Typical Swept Path of a Large Design Vehicle through a Single-Lane Roundabout



9.5.4 Entry Design

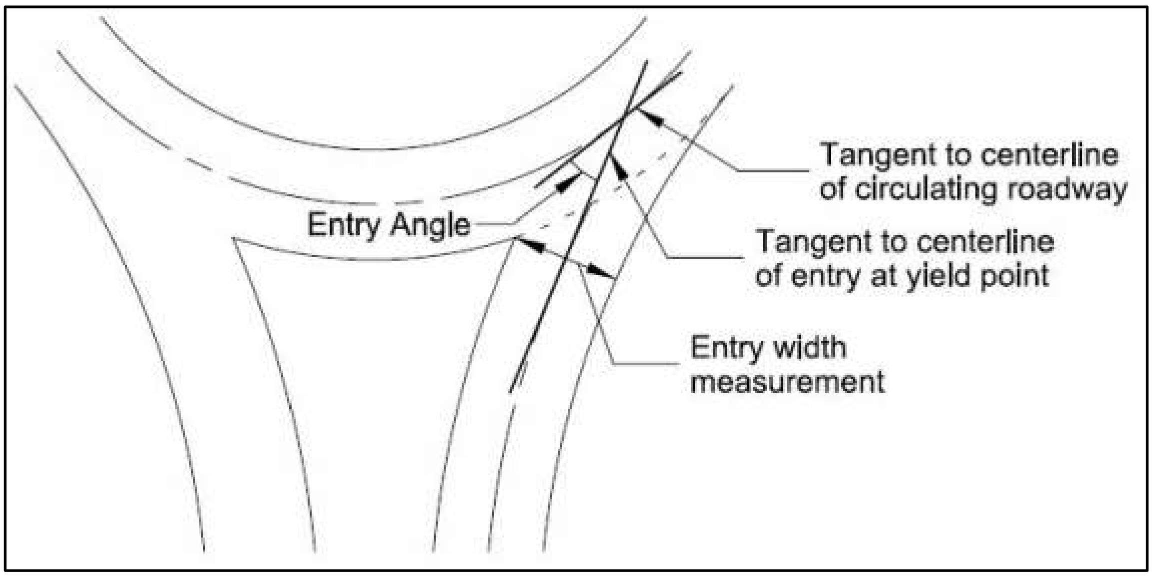
At single-lane roundabouts, a single-entry curb radius is typically adequate. For approaches on higher speed roadways, the use of compound curves may improve guidance by lengthening the entry arc.

The entry curb radius, in conjunction with the entry width, the circulatory roadway width, and the central island geometry, controls the amount of deflection imposed on a vehicle's entry path. Excessively large entry curb radii have a higher potential to produce faster entry speeds than desired.

Entry radii at urban single-lane roundabouts typically range from 50 to 100 feet. A common starting point is an entry radius in the range of 60 to 90 feet; however, a larger or smaller radius may be needed to accommodate large vehicles or serve small diameter roundabouts, respectively. Larger radii may be used, but it is important that the radii not be so large as to result in excessive entry speeds.

The entry geometry should provide adequate horizontal curvature to channelize drivers into the circulatory roadway to the right of the central island. It is also often desirable for the splitter island to have enough curvature to block a direct path to the central island for approaching vehicles. The entry angle aids in slowing the vehicle entry speed, and it prevents vehicles from hitting broadside in the event of a collision. The entry angle is one of the critical factors of design for roundabouts. The angle helps define the path that the vehicle enters the roundabout into the intended circulatory lane. Identifying the entry angle can help with path overlap on two lane roundabouts. Figure 9-11 depicts the roundabout entry angle.

Figure 9-11 Roundabout Entry Angle

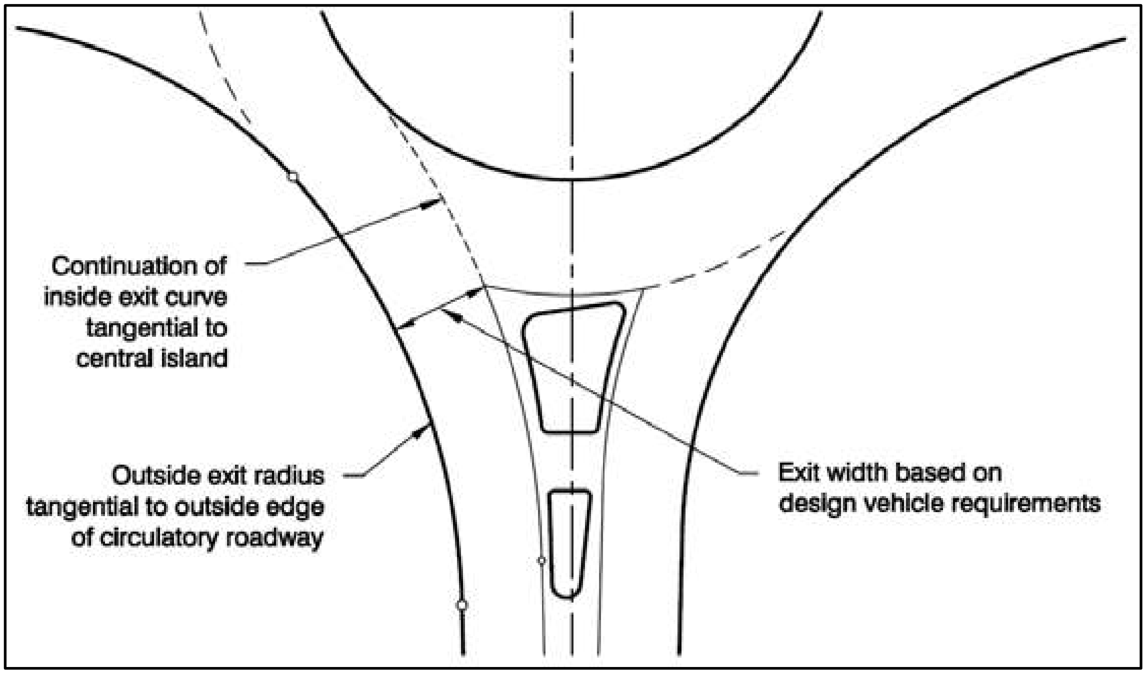


9.5.5 Exit Design

The exit curb radii are usually larger than the entry curb radii in order to minimize the likelihood of congestion and crashes at the exits. This, however, is balanced by the need to maintain slow speeds through the pedestrian crossing on exit. The exit design is also influenced by the design environment (urban versus rural), pedestrian demand, the design vehicle, and physical site constraints.

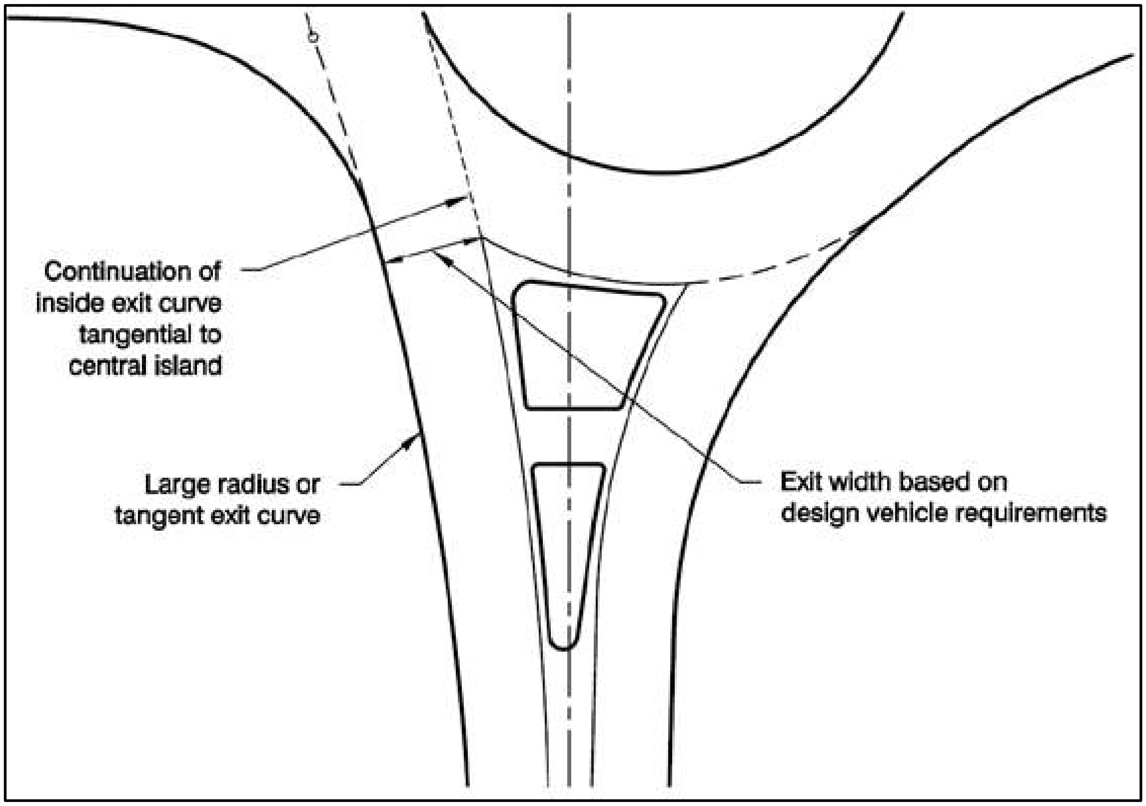
The exit curb is commonly designed to be curvilinearly tangential to the outside edge of the circulatory roadway. Likewise, the projection of the inside (left) edge of the exit roadway is commonly curvilinearly tangential to the central island. Generally, exit curb radii should be no less than 100 feet, with values of 200 to 500 feet being more common. Figure 9-12 shows a typical exit layout for a single-lane roundabout.

Figure 9-12 Single-Lane Roundabout Curvilinear Exit Design



For designs using an offset-left approach alignment, the exit design may require much larger radii, ranging from 300 to 800 feet or greater. Larger exit radii may also be desirable in areas with high truck volumes to provide ease of navigation for trucks and reduce the potential for trailers to track over the outside curb. These radii may provide acceptable speed through the pedestrian crossing area given that the acceleration characteristics of the vehicles will result in a practical limit to the speeds that can be achieved on the exit. Figure 9-13 depicts the larger radius exit design of a single-lane roundabout.

Figure 9-13 Single-Lane Roundabout Larger Radius Exit Design

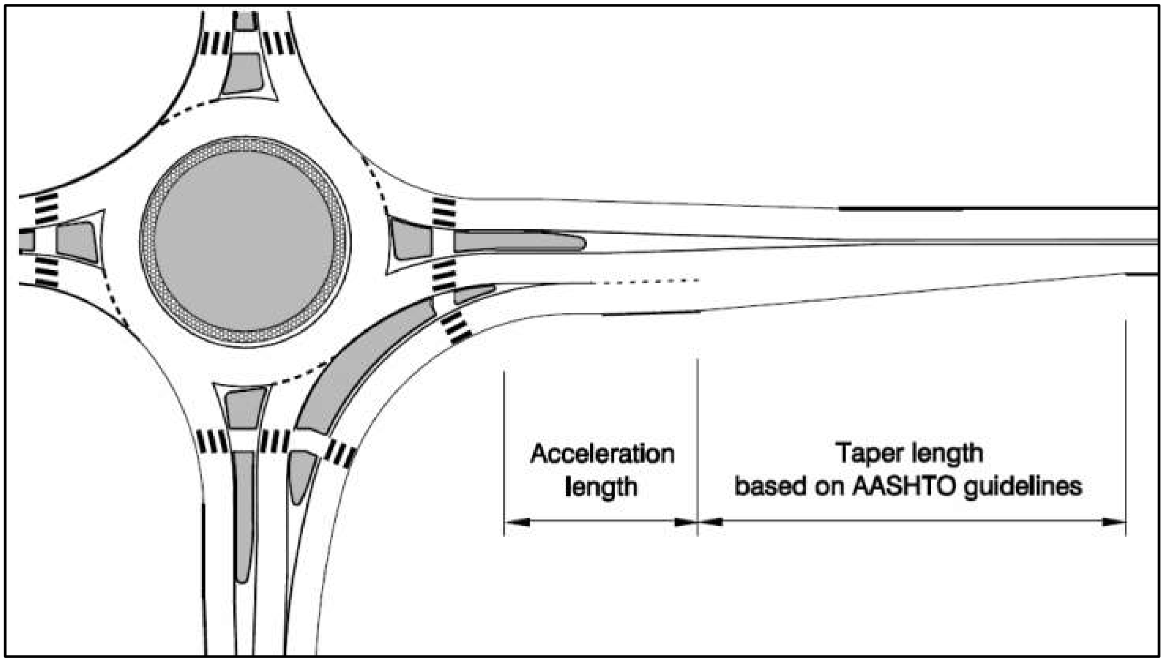


9.5.6 Right-Turn Bypass Lanes

Right-turn bypass lanes are a proven way to increase the "life" of a single-lane roundabout by removing traffic that would otherwise enter the roundabout and reduce the available capacity to other movements. Extending the life of a single-lane roundabout is desirable given the stronger safety performance in comparison to multilane roundabouts due to the smaller size and slower speeds that are achieved. To determine if a right-turn bypass lane should be used, the appropriate capacity and delay calculations should be performed.

A right-turn bypass lane should be implemented only where needed. In urban areas with heavy bicycle and pedestrian activity, a right-turn bypass lane should be used with caution. The entries and exits of the bypass lane can increase conflicts with bicyclists and with merging maneuvers on the downstream leg. The generally higher speeds of bypass lanes and the lower expectation of drivers to stop may increase the risk of collisions with pedestrians. They also introduce additional complexity for pedestrians with visual impairments who are attempting to navigate the intersection. However, in locations with minimal pedestrian and bicycle activity, or where bicycle and pedestrian concerns can be addressed through design solutions, right-turn bypass lanes can be used to improve capacity when heavy right-turning traffic exists. Figure 9-14 shows a sample layout of a right-turn bypass lane for a single-lane roundabout.

Figure 9-14 Sample Layout of Right-Turn Bypass Lane with Acceleration Lane



9.6 Multilane Roundabouts

The principles and design process described previously for single-lane roundabouts also apply to multilane roundabouts but in a more complex way. Because multiple traffic streams may enter, circulate through, and exit the roundabout side-by-side, the engineer should consider how these traffic streams interact with each other. The geometry of the roundabout should provide adequate alignment and establish appropriate lane configurations for vehicles in adjacent entry lanes to be able to negotiate the roundabout geometry without competing for the same space.

The number of lanes within the circulatory roadway may vary depending upon the number of entering and exiting lanes. The important principle is that the design requires continuity between the entering, circulating, and exiting lanes such that lane changes are not needed to navigate the roundabout. The driver should be able to select the appropriate lane upstream of the entry and stay within that lane through the roundabout to the intended exit without any lane changes.

The number of lanes provided at the roundabout should be the minimum needed for the existing and anticipated demand as determined by the operational analysis. The engineer is discouraged from providing additional lanes that are not needed for capacity purposes as these additional lanes can reduce the safety effectiveness at the intersection. If additional lanes are needed for future conditions, a phased design approach should be considered that would allow for future expansion.

When considering phased design of roundabouts, the designer should phase the addition of future lanes to the interior of the circulating lanes of the roundabout. By adding lanes to the interior of the roundabout this minimizes impacts to the entry and exit points and reconstruction of the splitter islands.

9.6.1 Entry Width

A typical entry width for a multilane roundabout varies from 24 to 30 feet for a two-lane entry and from 36 to 45 feet for a three-lane entry. Typical widths for individual lanes at entry range from 12 to 15 feet. The entry width should be primarily determined based upon the number of lanes identified in the operational analysis combined with the turning requirements for the design vehicle. Excessive entry width may not produce capacity benefits if the entry width cannot be fully used by traffic.

At locations where any of the intersection approach legs is a 2-lane roadway, but a multilane roundabout capacity is required to meet the operational needs, there are generally two options for developing the second roundabout entry lane:

- Adding a full lane upstream of the roundabout and maintaining parallel lanes through the entry geometry (Figure 9-15).
- Widening the approach by gradually flaring through the entry geometry (Figure 9-16).

Figure 9-15 Approach Widening by Adding a Full Lane

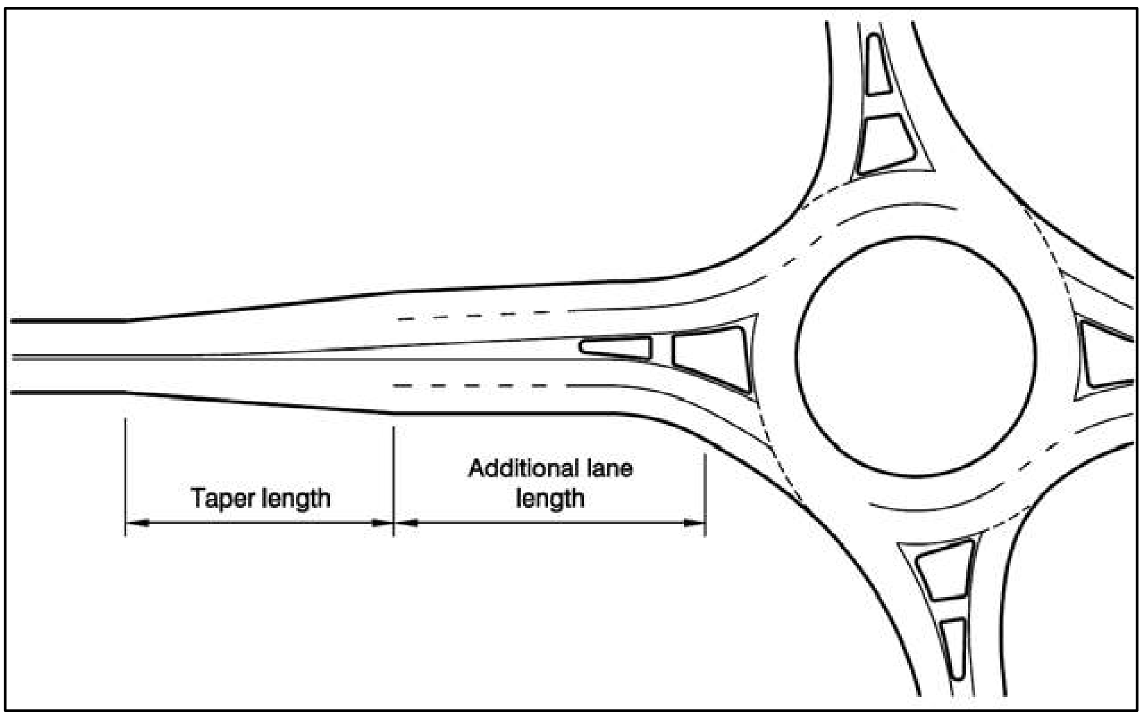
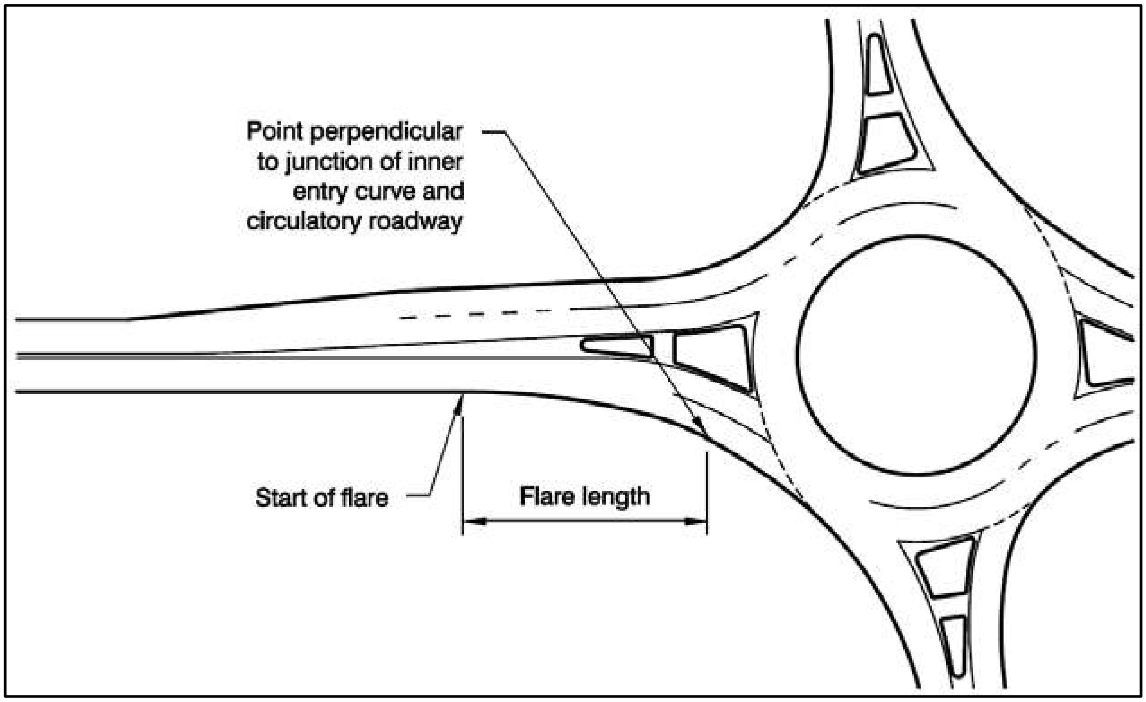


Figure 9-16 Approach Widening by Entry Flaring



9.6.2 Circulatory Roadway Widths

The circulatory roadway width for multilane roundabouts is usually governed by the design criteria relating to the types of vehicles that may need to be accommodated adjacent to one another. If the entering traffic is predominantly passenger cars and single-unit trucks (AASHTO P and SU design vehicles, respectively) and semi-trailer traffic is infrequent, it may be appropriate to design the width for two passenger vehicles or a passenger car and a single-unit truck side-by-side. If semi-trailer traffic is relatively frequent (greater than 10%), it may be necessary to provide sufficient width for the simultaneous passage of a semi-trailer in combination with a P or SU vehicle.

Multilane circulatory roadway lane widths typically range from 14 to 16 feet. Use of these values results in a total circulating width of 28 to 32 feet for a two-lane circulatory roadway and 42 to 48 feet total width for a three-lane circulatory roadway.

A constant width is not required throughout the entire circulatory roadway. It is desirable to provide only the minimum width necessary to serve the required lane configurations within that specific portion of the roundabout. A common combination is two entering and exiting lanes along the major roadway, but only single entering and exiting lanes on the minor street (Figure 9-17).

In some instances, the circulatory roadway width may need to be wider than the corresponding entrance that is feeding that portion of the roundabout. For example, in situations where two consecutive entries require exclusive left turns, a portion of the circulatory roadway will need to contain an extra lane and spiral markings to enable all vehicles to reach their intended exits without being trapped or changing lanes (Figure 9-18).

Figure 9-17 Multilane Major Street with Single-Lane Minor Street

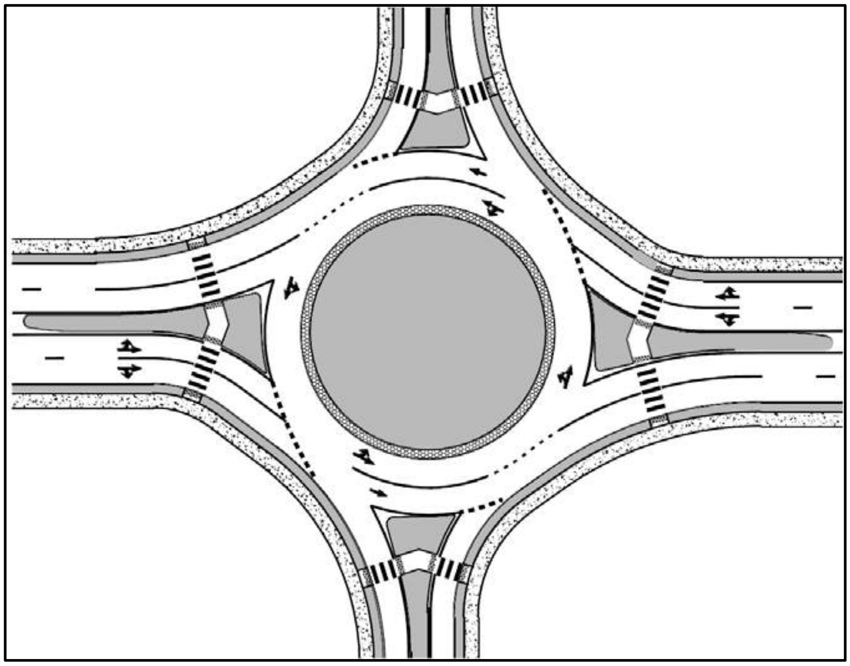
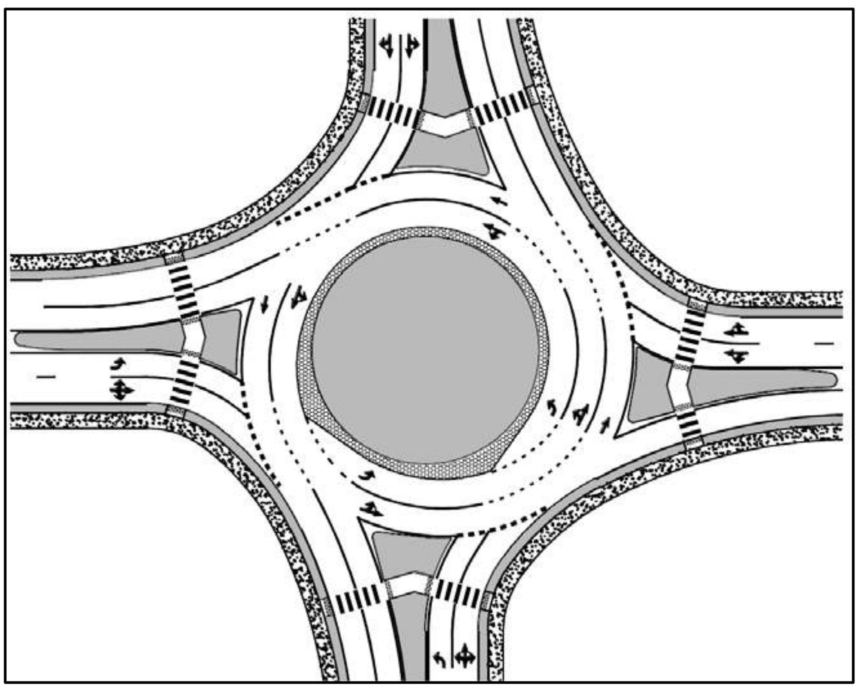


Figure 9-18 Two-Lane Roundabout with Consecutive Double-Lefts

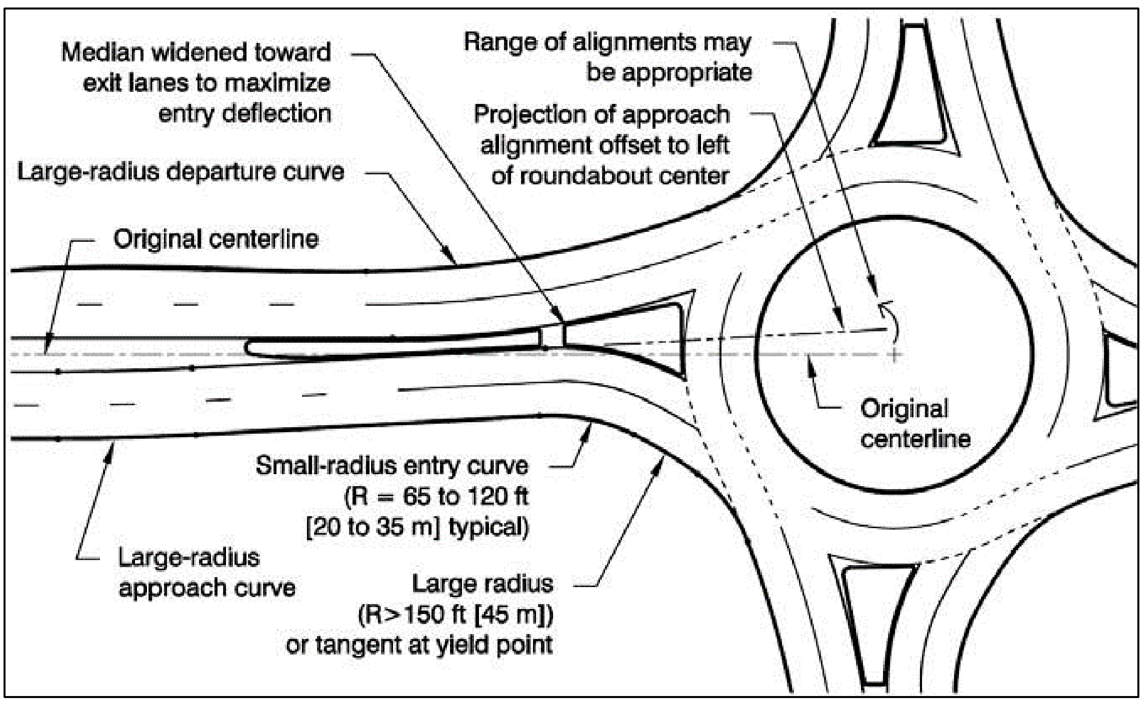


9.6.3 Entry Geometry and Approach Alignment

Entry radii for multilane roundabouts should typically exceed 65 feet to encourage adequate natural paths and avoid sideswipe collisions on entry. Engineers should avoid the use of overly tight geometrics in order to achieve the fastest-path objectives. Overly small (less than 45 feet) entry radii can result in conflicts between adjacent traffic streams, which may result in poor lane use and reduced capacity. Similarly, the R1 (entry path radius) fastest-path radius should also not be excessively small. If R1 is too small, vehicle path overlap may result, reducing the operational efficiency and increasing potential for crashes. Values for R1 in the range of 175 to 275 feet are generally preferable. This results in a design speed of 25 to 30 mph. Refer to Section 9.7.1 for more discussion on the fastest path guidelines.

One possible technique to promote good path alignment using a compound curve or tangent along the outside curb is shown in Figure 9-19. The design has an initial small-radius entry curve set back from the edge of the circulatory roadway. A short section of a large-radius curve or tangent is provided between the entry curve and the circulatory roadway to align vehicles into the proper circulatory lane at the entrance line.

Figure 9-19 Example Minor Approach Offset to Increase Entry Deflection

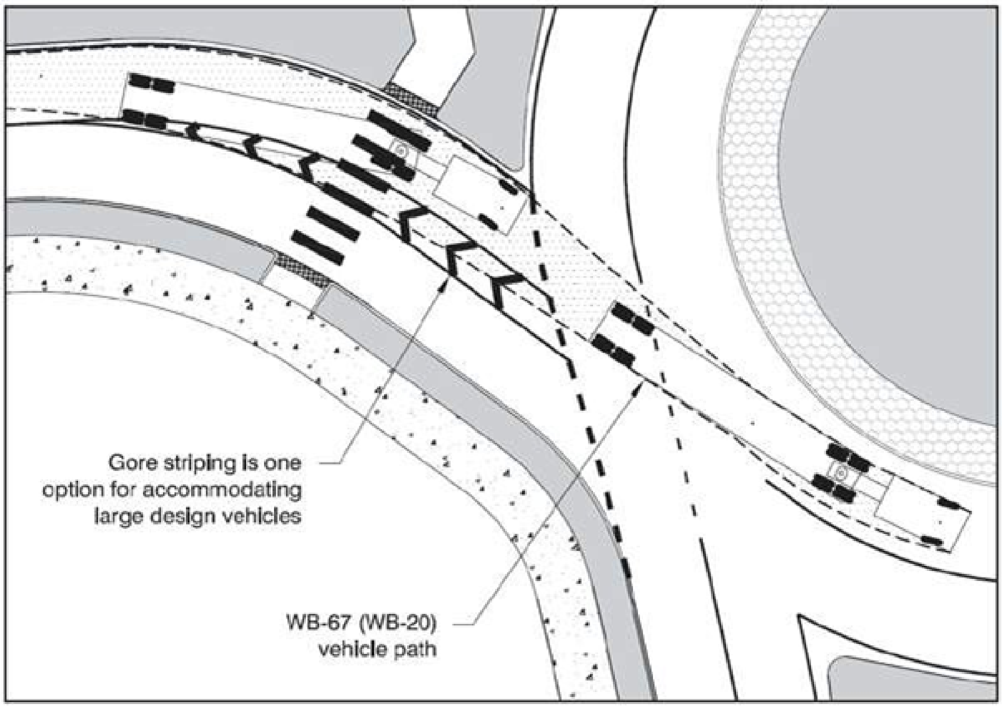


For the method illustrated in Figure 9-19, entry curve radii commonly range from approximately 65 to 120 feet and are set back at least 20 feet from the edge of the circulatory roadway. A tangent or large-radius curve (greater than 150 feet) is then fitted between the entry curve and the outside edge of the circulatory roadway.

9.6.4 Entry Geometry and Design Vehicle Considerations

Where there is a need to accommodate a large design vehicle, there are a number of design considerations. A larger inscribed circle diameter and entry/exit radii may be required to maintain speed control and accommodate the vehicle. A common technique is to provide gore striping between the two entry lanes to help center the vehicles within the lane and create a cushion for off-tracking. This technique is illustrated in Figure 9-20.

Figure 9-20 Truck Path with Gore Striping at Entry



Another technique that accommodates a larger design vehicle is to use a wider lane width for the outside lane and a narrower lane width for the inside lane of the circulatory roadway. Larger vehicles would have an extra buffer of circulating width in the outside lane. Larger vehicles in the inside lane would use the truck apron to accommodate any off tracking. Eliminating all overlap with the outside lane may not always be desirable or feasible, as this may dictate a much larger inscribed circle diameter than desired for overall safety performance for all vehicle types and the context.

9.6.5 Entry Path Alignment

In a multilane roundabout, the design should align the entering vehicle to the correct lane in the circulatory roadway to avoid path overlap shown in Figure 9-21. Figure 9-22 illustrates the desired design vehicle path alignment of a multilane roundabout.

Figure 9-21 Entry Vehicle Path Overlap

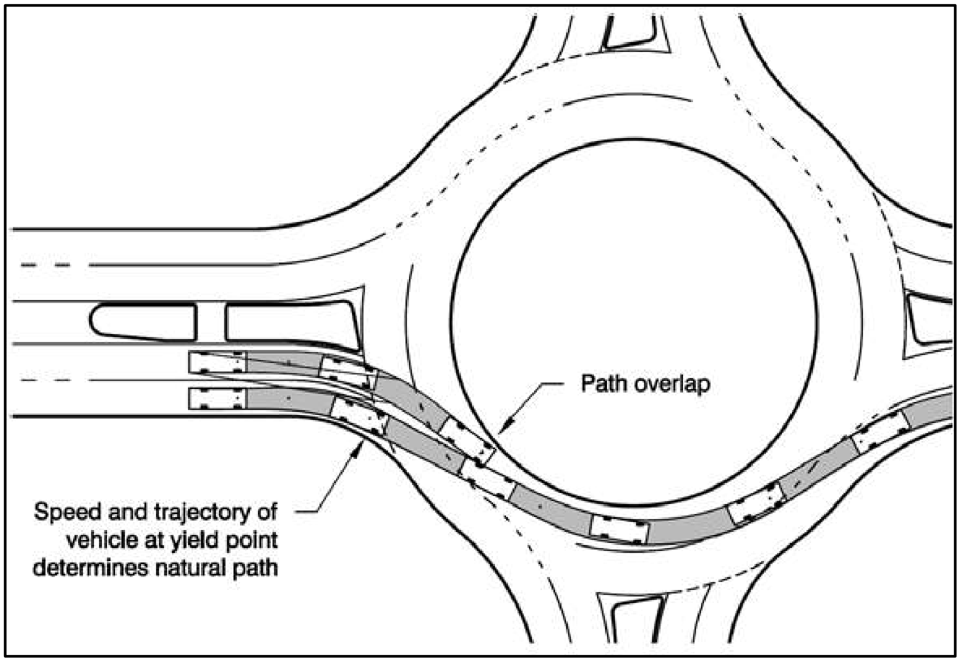
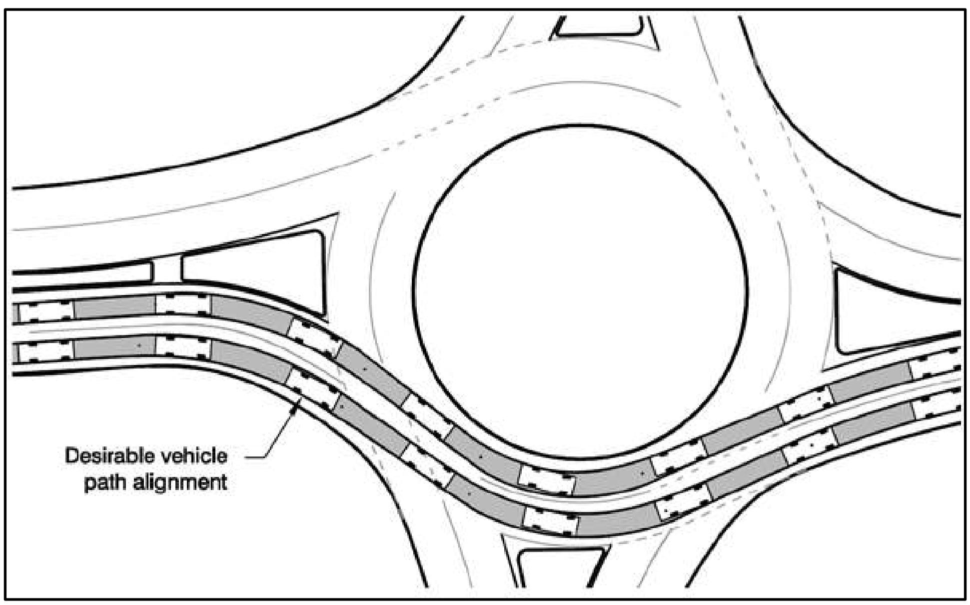


Figure 9-22 Desired Vehicle Path Alignment



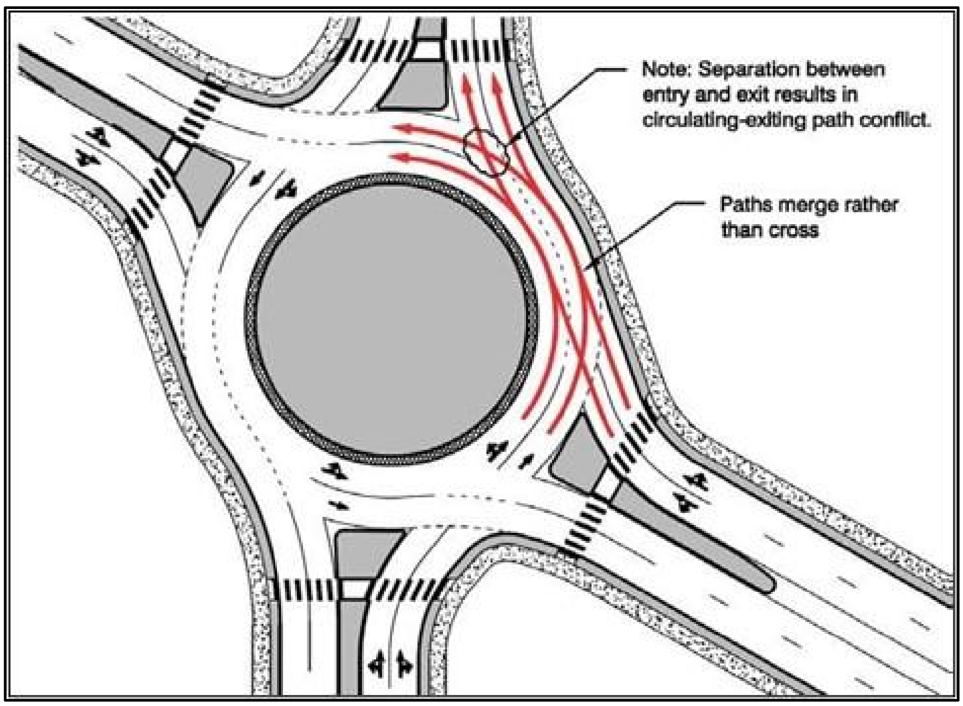
9.6.6 Exit Curve

Conflicts can occur between exiting and circulating vehicles if appropriate lane assignments are not provided. Inadequate horizontal design of the exits can result in exit vehicle path overlap, like that occurring at entries. The radii of exit curves are commonly larger than those used at the entry because of other factors (entry alignment, diameter, etc.). Larger exit curve radii are typically used to promote good vehicle path alignment. However, the design should be balanced to maintain low speeds at the pedestrian crossing at the exit.

To promote good path alignment at the exit, the exit radius at a multilane roundabout should not be too small. If the exit radius on a multilane exit is too small, traffic on the inside of the circulatory roadway tends to exit into the outside exit lane on a more comfortable turning radius. At single-lane roundabouts, it is acceptable to use a minimal exit radius to control exit speeds and maximize pedestrian safety.

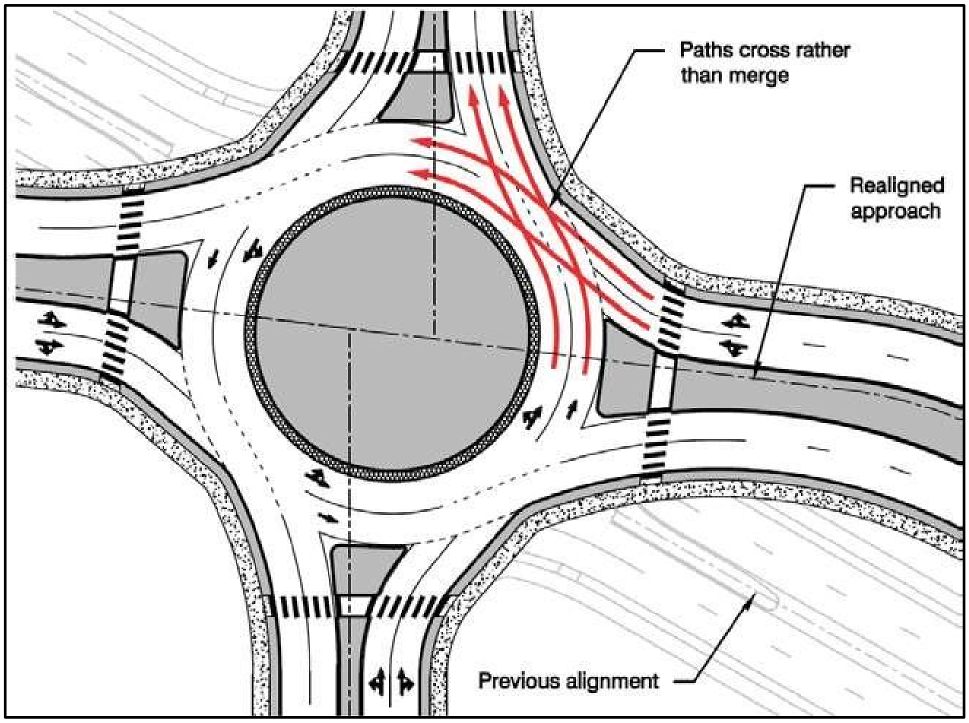
Problems can occur when the design creates too much separation between entries and exits. Large separations between approach legs cause entering vehicles to merge with circulating traffic that may be intending to exit at the next leg, rather than to cross the path of the exiting vehicles. This can create conflicts at the exit point between exiting and circulating vehicles, as shown in Figure 9-23.

Figure 9-23 Exit-Circulating Conflict Caused by Large Separation between Legs



A low-cost solution to prevent exit-circulating conflicts is to modify the lane arrangements with a combination of striping and other physical modifications. However, a better solution to eliminate the conflict is to realign the approach legs so the paths of entering vehicles cross the paths of the circulating traffic (rather than merging), as shown in Figure 9-24.

Figure 9-24 Realignment to Resolve Exit-Circulating Conflicts



9.7 Performance Checks

Performance checks help the designer determine whether the design meets its performance objectives. Critical performance checks that need to be performed prior to finalizing any roundabout design include:

- Fastest path.
- Path alignment.
- Sight distance.
- Angles of visibility.

9.7.1 Fastest Path

The fastest path through the roundabout is drawn to achieve a safe design speed. The fastest path allowed by the roundabout geometry determines the negotiation speed for that particular movement into, through, and exiting the roundabout. It is the smoothest, flattest path possible for a single vehicle, in the absence of other traffic and ignoring all lane markings. The fastest path does not represent expected vehicle speeds, but rather theoretical attainable entry speeds for design purposes.

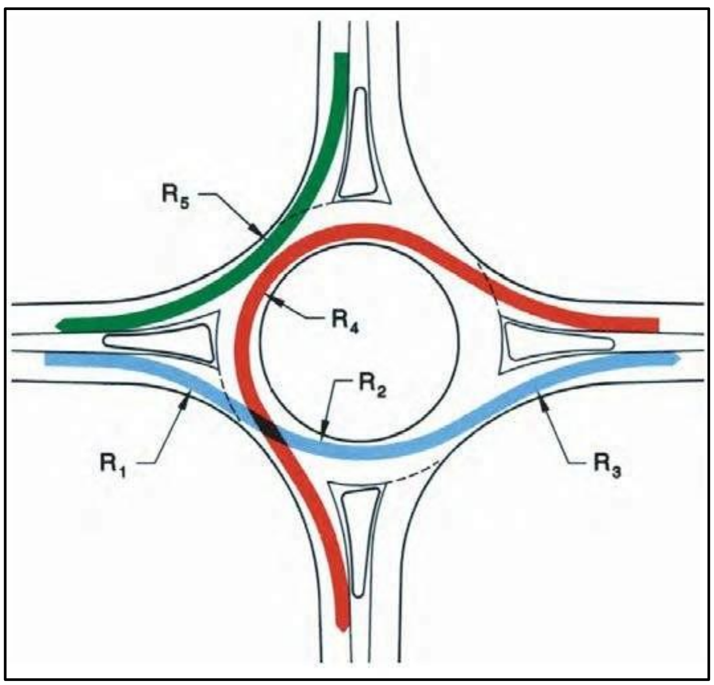
Maximum entering design speeds are based on a theoretical fastest path of 20 mph or less for mini-roundabouts; 20 to 25 mph for single-lane roundabouts. At multilane roundabouts, maximum entering design speeds of 25 to 30 mph are recommended. These speeds are influenced by a variety of factors, including the geometry of the roundabout and the operating speeds of the approach legs. Speed management is often a combination of managing speeds at the roundabout itself and managing speeds on the approach legs.

The five critical vehicular path radii that must be checked for each roundabout approach are illustrated in Figure 9-25 and include:

- R1, the entry path radius, is the minimum radius on the fastest through path prior to the entrance line.
- R2, the circulating path radius, is the minimum radius on the fastest through path around the central island.
- R3, the exit path radius, is the minimum radius on the fastest through path into the exit.
- R4, the left-turn path radius, is the minimum radius on the path of the conflicting left-turn movement.
- R5, the right-turn path radius, is the minimum radius on the fastest path of a right-turning vehicle.

It is important to note that these vehicular path radii are not the same as the curb radii. The R1 through R5 radii represent the vehicle centerline in its path through the roundabout.

Figure 9-25 Fastest Path Radii



Once a conceptual roundabout design is complete, the designer should draw out the fastest path alignment to determine the design speed of the roundabout. The design speed of the roundabout is determined from the smallest radius along the fastest allowable path. The smallest radius usually occurs on the circulatory roadway as the vehicle curves to the left around the central island.

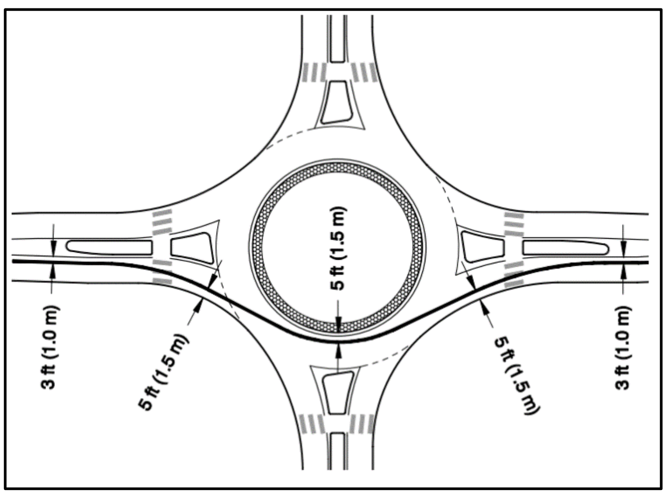
A vehicle is assumed to be 6 feet wide and maintain a minimum clearance of 2 feet from a roadway centerline or concrete curb and flush with a painted edge line. Thus, the centerline of the vehicle path is drawn with the following distances:

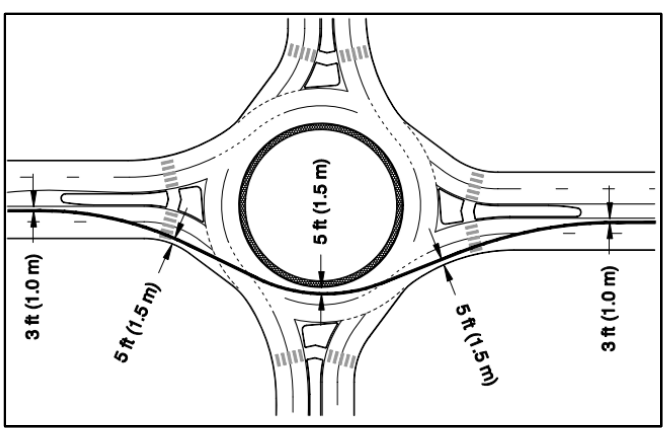
- 5 feet from the face (flowline) of a concrete curb.
- 5 feet from a roadway centerline.
- 3 feet from a painted edge line.

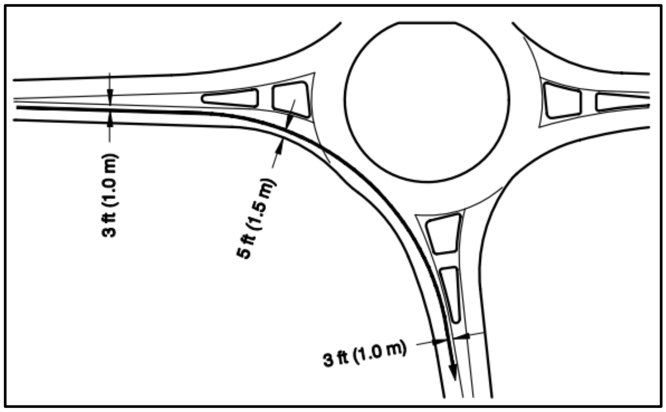
Spirals should be used for the radii curvature to develop the fastest path.

Figure 9-26 illustrates the fastest vehicle path alignment at a multilane roundabout.

Figure 9-26 Fastest Path Radii

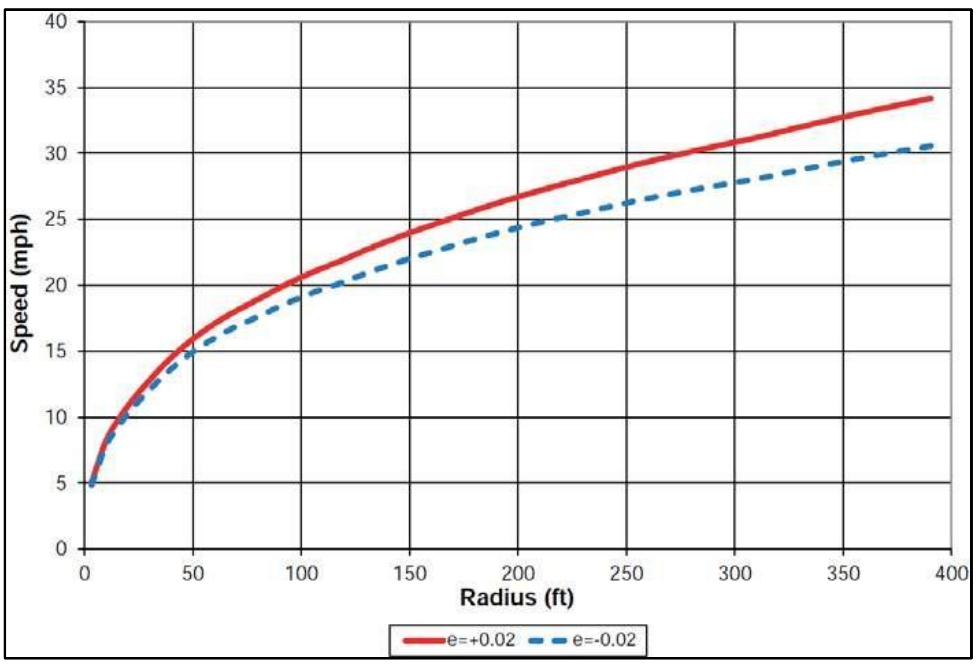






The relationship between travel speed and horizontal curvature is documented in the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (the Green Book) (2018 AASHTO GDHS) (AASHTO, 2018). Both superelevation and the side friction factor affect the speed of a vehicle. Side friction varies with vehicle speed and can be determined in accordance with AASHTO guidelines. The most common superelevation values encountered are +0.02 and −0.02, corresponding to 2% cross slope. Figure 9-27 depicts the speed-to-radius relationship.

Figure 9-27 Speed-to-Radius Relationship



The speed–radius relationship given above is generally a reasonable prediction for the left turn and through movement circulating speeds. However, this method does not consider the effects of deceleration and acceleration and therefore may overpredict entry and exit speeds in cases where the path radius is large.

Creating consistency between the speeds of various movements within the intersection can help to minimize the crash rate between conflicting traffic streams. Relative speeds between conflicting traffic streams and between consecutive geometric elements should be minimized such that the maximum speed differential between movements is no more than approximately 10 to 15 mph. These values are typically achieved by providing a low absolute maximum speed for the fastest entering movements. Creating speed consistency should be balanced with other design objectives.

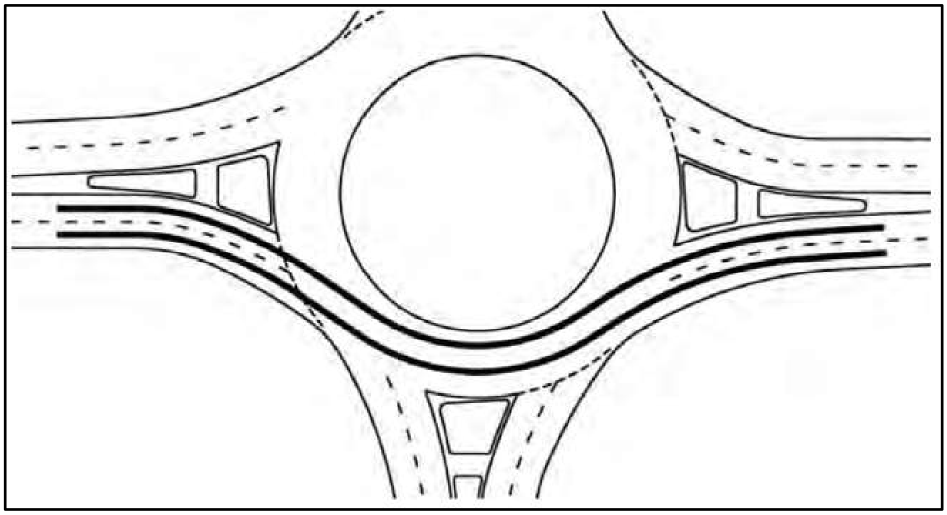
The desirable maximum R1 radius is 150 feet for single-lane roundabouts and 250 feet for multilane roundabouts. Generally, for urban roundabouts with pedestrian accommodations, a lower entry speed is desirable. Rural roundabouts typically have a slightly higher entry speed than urban roundabouts. The R1 and R2 radii should be used to control exit speed. Typically, the speed relationships between R1, R2, and R3, as well as between R1 and R4, are of primary interest. Along the through path, the desired relationship is R1> R2< R3, where R1 is also less than R3. Similarly, the relationship along the left-turning path is R1> R4. For most designs, the R1 – R4 relationship will be the most restrictive for speed differential at each entry. However, the R1 – R2 – R3 relationship should also be reviewed to be sure the exit speed is not overly restrictive. Design criteria in past years advocated relatively tight exit radii to minimize exit speed; however, recent best practice suggests a more relaxed exit radius for improved drivability.

9.7.2 Path Alignment (Natural Path) Considerations

In addition to determining the fastest path, the natural vehicle path at multilane roundabouts is a design consideration. This is the path approaching vehicles will naturally take through the roundabout geometry, assuming there is traffic in all approach legs.

The key consideration in drawing the natural path is to remember that drivers cannot change the direction or speed of their vehicle instantaneously. This means that the natural path does not have sudden changes in curvature; it has transitions between tangents and curves and between consecutive reversing curves. It also means that consecutive curves should be of similar radius. If a second curve has a significantly smaller radius than the first curve, the driver will be traveling too fast to negotiate the turn and may not be able stay within the lane. If the radius of one curve is drawn significantly smaller than the radius of the previous curve, the path needs to be adjusted. As a rule of thumb, the design should provide at least one car length of large radius or tangent to adequately align vehicles into the correct lane within the circulatory roadway. Figure 9-28 illustrates a sample sketch of the natural path through a multilane roundabout.

Figure 9-28 Vehicle Path Sketched through Roundabout



9.7.3 Sight Distance

The roundabout design needs to achieve adequate stopping sight distance and intersection sight distance. Stopping sight distance and intersection sight distance are measured using an assumed height of the driver's eye of 3.5 feet and an assumed object height of 2 feet.

9.7.3.1 Stopping Sight Distance

Stopping sight distance is needed at every point within a roundabout. NCHRP Report 400: Determination of Stopping Sight Distance recommends the following formula for determining stopping sight distance.

$$d = (1.486)(t)(V) + 1.087\frac{V^2}{a}$$

Where:

d = stopping sight distance (ft)
t = perception-brake reaction time, assumed to be 2.5 sec.
V = initial speed (mph)
a = driver deceleration, assumed to be 11.2 ft/s^2

Table 9-3 gives stopping sight distances computed from the above equation.

Table 9-3 Stopping Sight Distance

Speed (mph)	Computed Distance* (ft)
10	46.4
15	77
20	112.4
25	152.7
30	197.8
35	247.8
40	302.7
45	362.5
50	427.2
55	496.7

* Assumes 2.5 s perception-breaking time, 11.2 ft/s^2 driver deceleration.

For roundabouts, there are three additional stopping sight distances that should be checked:

- Approach sight distance (Figure 9-29).
- Sight distance on circulatory roadway (Figure 9-30).
- Sight distance to crosswalk on exit (Figure 9-31).

Figure 9-29 Stopping Sight Distance on Approach

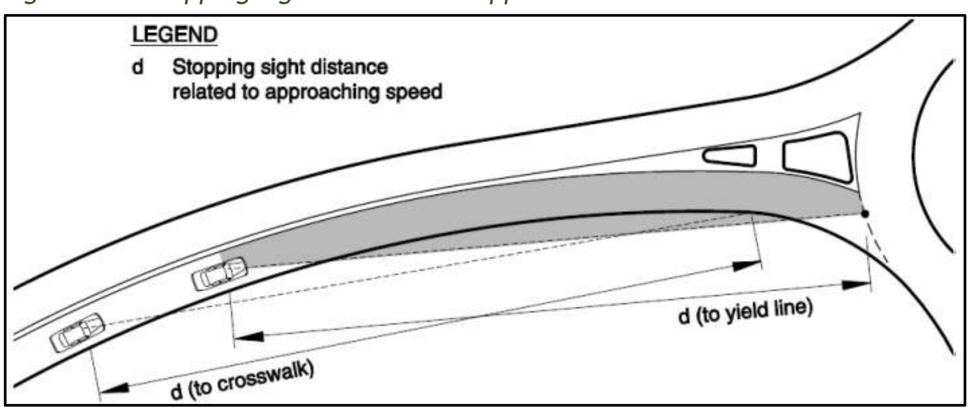


Figure 9-30 Stopping Sight Distance on Circulatory Roadway

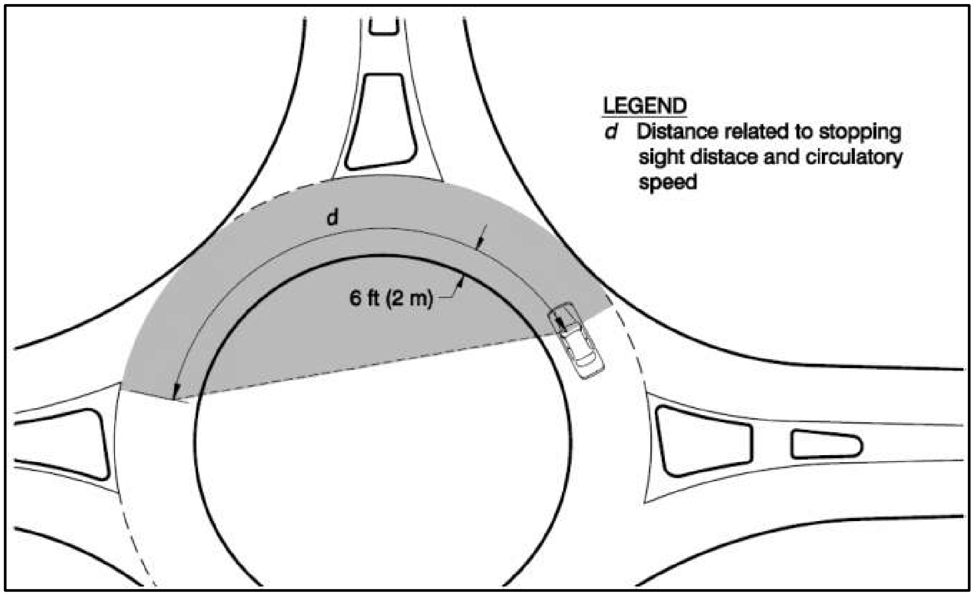
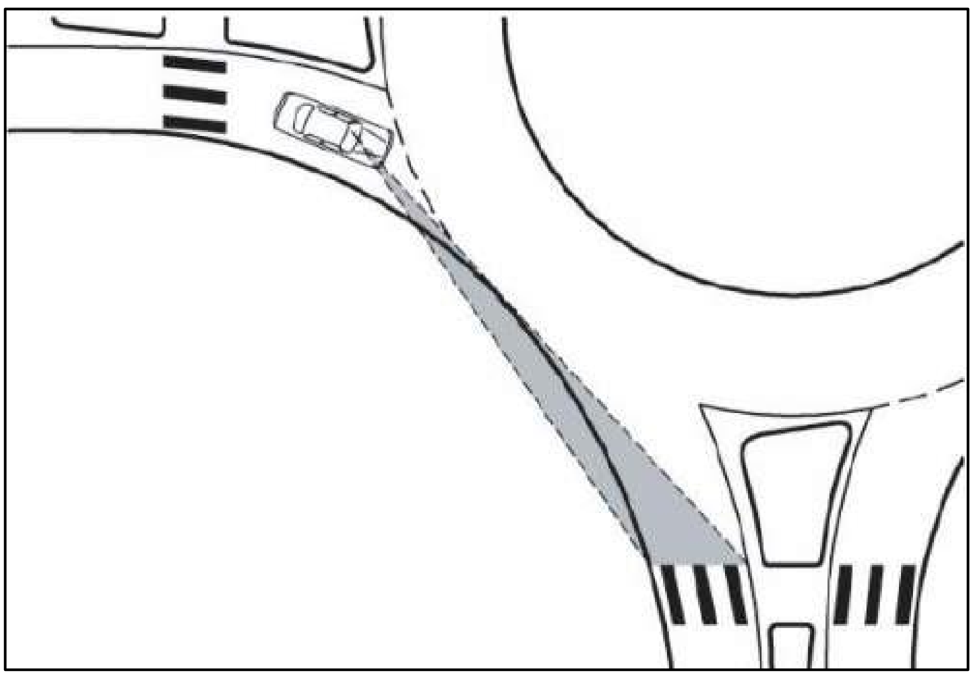


Figure 9-31 Sight Distance to Crosswalk on Exit

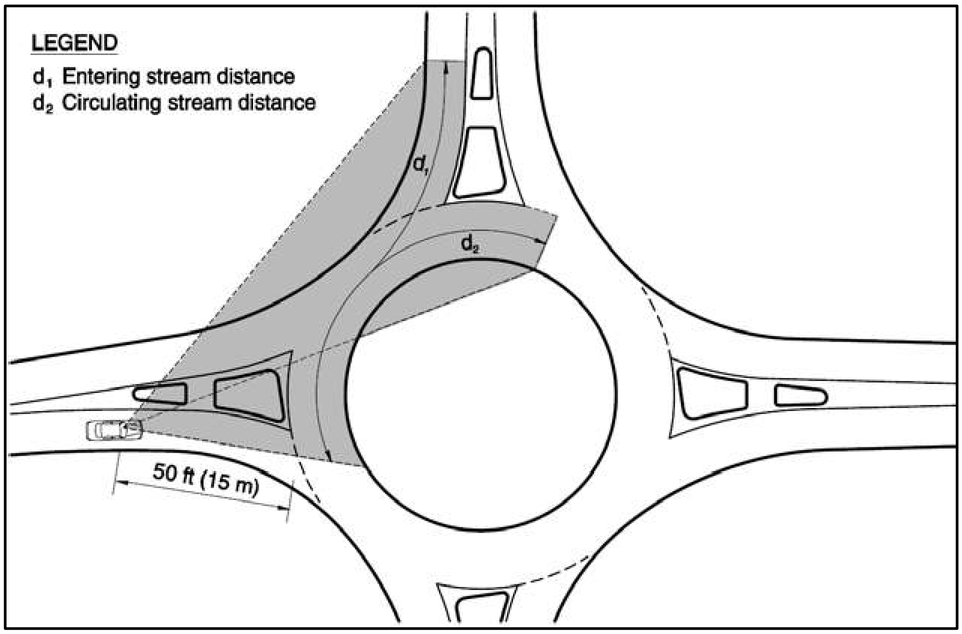


9.7.3.2 Intersection Sight Distance

Intersection sight distance is arguably the most critical intersection design safety issue. Intersection sight distance must be of sufficient distance for a driver to perceive and react to the presence of conflicting vehicles, pedestrians, and bicyclists. For roundabouts, the only location requiring evaluation of intersection sight distance is at the entry to the roundabout.

Intersection sight distance is achieved by establishing sight triangles where the triangle is bounded by a length of roadway defining a limit away from the intersection on each of the two approaches and by a line connecting those two limits. For roundabouts, these legs should be assumed to follow the curvature of the roadway, and distances should be measured not as straight lines but as distances along the vehicular path, as shown in Figure 9-32. The approach leg of the sight triangle should be no more than 50 feet.

Figure 9-32 Intersection Sight Distance



International research shows that excessive intersection sight distance can lead to higher vehicle speeds and a higher frequency of crashes. In most cases, it is best to provide no more than the minimum required intersection sight distance. Landscaping within the central island can be effective in restricting sight distance to the minimum requirements.

As shown in Figure 9-32, a vehicle approaching a roundabout entry faces two conflicting traffic streams—the entering stream of the immediate upstream entry (d1) and the circulating stream (d2). Vehicle speed for the entering stream can be approximated by taking the average of the theoretical entering (R1) speed and the circulating (R2) speed. Vehicle speed for the circulating stream can be approximated by taking the speed of the left-turning vehicles (R4). The length of the conflicting leg is calculated using the following equations.

$$d_1 = (1.468)(V_{major,entering})(t_c)$$

$$d_2 = (1.468)(V_{major,circulating})(t_c)$$

Where:

d_1 = length of entering leg of sight triangle (ft)
d_2 = length of circulating leg of sight triangle (ft)
V_{major} design speed of conflicting movement, mph, discussed below
t_c = critical headway for entering the major road, s, equal to 5.0 sec.

The critical headway for entering the major road is based on the amount of time required for a vehicle to safely enter the conflicting stream. The critical headway value of 5.0 seconds given in the equations is based upon the critical headway required for passenger cars. Table 9-4 shows computed length of the conflicting leg of an intersection sight triangle.

Table 9-4 Computed Length of Conflicting Leg of Intersection Sight Triangle

Conflicting Approach Speed (mph)	Computed Distance (ft)
10	73.4
15	110.1
20	146.8
25	183.5
30	220.2

Note: Computed distances are based on a critical headway of 5.0 s.

9.7.4 Angle of Visibility

The intersection angle between consecutive entries must not be overly acute so that drivers can comfortably turn their heads to the left to see oncoming traffic from the immediate upstream entry. The intersection angle between consecutive entries, and the angle of visibility to the left for all entries, should conform to the same design guidelines as for conventional intersections. Guidance for designing for older drivers and pedestrians recommends using 75 degrees as a minimum intersection angle.

For roundabouts, the intersection angle may be measured as the angle between a vehicle's alignment at the entrance line and the sight line required by intersection sight distance guidelines. Figure 9-33 illustrates an example of where the angle of visibility is poor, and the intersection needs to be improved. Figure 9-34 shows an example of a possible correction to improve the angle of visibility.

Figure 9-33 Roundabout Example with Poor Angle of Visibility

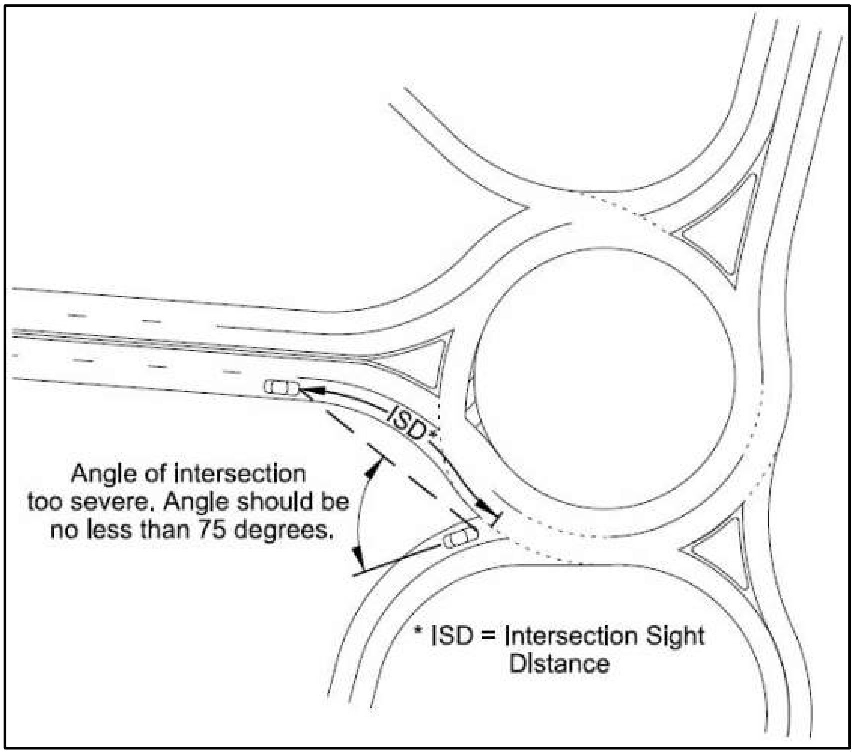
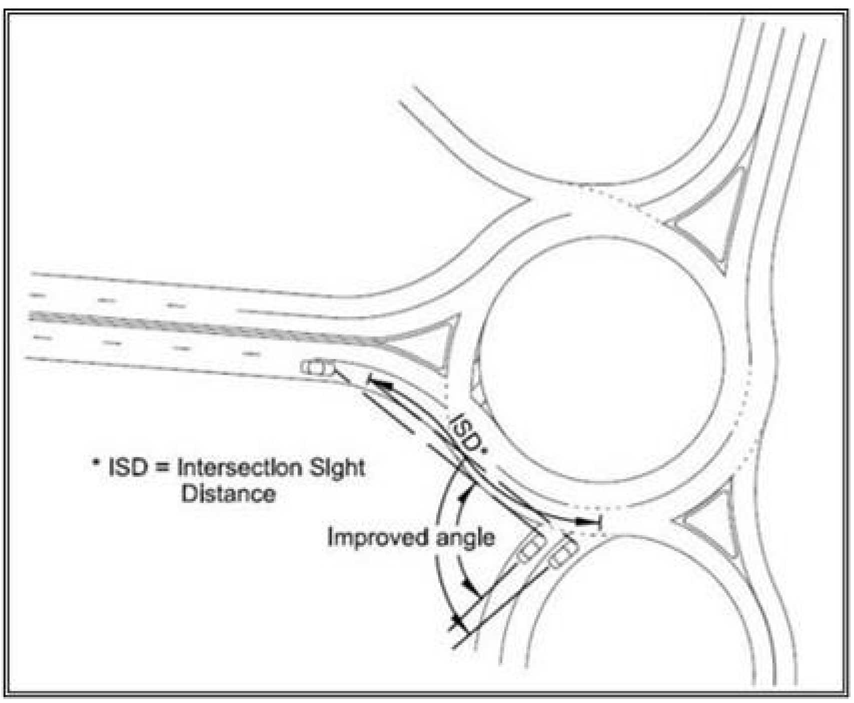


Figure 9-34 Roundabout Example with Improved Angle of Visibility



9.8 Design Details

The design considerations in this section are based on best practices for roundabout design. They are not to be interpreted as a standard or rule, or as a complete set of design detail elements.

9.8.1 Sidewalk Considerations

Wherever possible, sidewalks at roundabouts should be set back from the edge of the circulatory roadway with a landscape strip. A recommended set back distance of 5 feet should be used (2-foot minimum), and it is best to plant low shrubs or grass in the area between the sidewalk and curb.

The recommended sidewalk width at roundabouts is 6 feet (5 feet minimum). In areas with heavy pedestrian volumes, sidewalks should be as wide as necessary to accommodate the anticipated pedestrian volume. At any roundabout where ramps provide sidewalk access to bicyclists, the sidewalk should be a minimum of 10 feet wide to accommodate shared use by pedestrians and bicyclists. Examples of sidewalk setbacks are shown in Figure 9-35 and Figure 9-36.

Figure 9-35 Example Roundabout Sidewalk

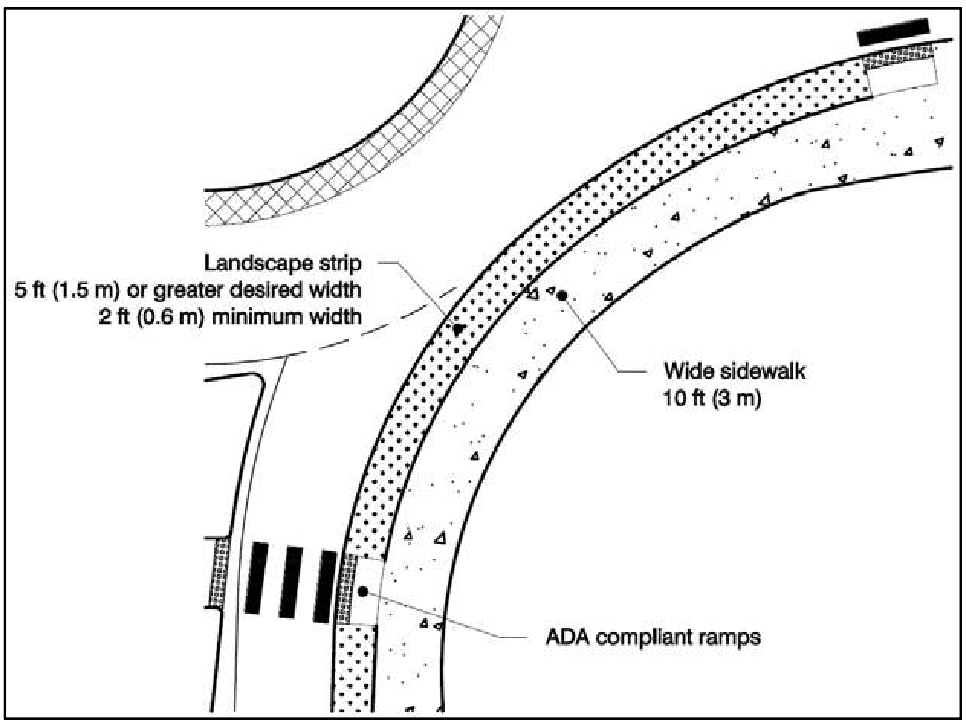
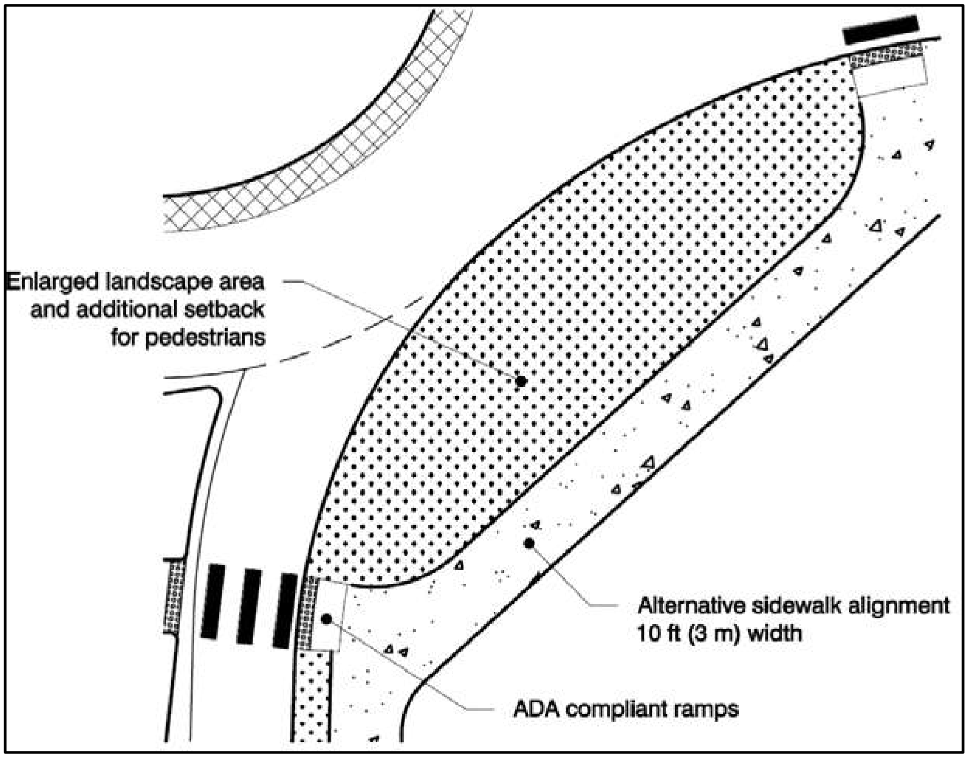


Figure 9-36 Alternative Roundabout Sidewalk Treatment



9.8.2 Crosswalk Considerations

Pedestrian crosswalk placement at roundabouts requires consistency that is based on a balance of pedestrian convenience, pedestrian safety, and roundabout operations. Considerations for pedestrian crosswalks design include:

- The raised splitter island width should be a minimum of 6 feet at the crosswalk to adequately provide pedestrian refuge.
- A typical and minimum crosswalk setback of 20 feet is recommended (refer to Figure 9-6). This is the length of one vehicle without any additional distance to account for the gap between vehicles. At some roundabouts, it may be desirable to place the crosswalk two or three car lengths (45 feet to 70 feet) back from the edge of the circulatory roadway. It is desirable to minimize pedestrian crossing distances and placement of the crossing where the vehicle speeds will be lower. Spacing too far away from the roundabout could introduce higher vehicle speeds approaching the crossing.

The walkway through the splitter island should be cut-through instead of ramped. This is less cumbersome for wheelchair users and allows the cut-through walkway to be aligned with the crosswalks, providing guidance for all pedestrians, but particularly for those who are blind or who have low vision. The cut-through walkway should be approximately the same width as the crosswalk, ideally a minimum width of 10 feet. Raised crosswalks (speed tables with pedestrian crossings on top) are another design treatment that can encourage slow vehicle speeds where pedestrians cross. Refer to Chapter 12 for additional information regarding pedestrian crossings at roundabouts.

9.8.3 Median Refuge Considerations

- Place ADA Tactile warnings across both ends of the walkway on the splitter island.
- On higher-speed and multilane roundabouts, use rectangular rapid flashing beacons at crossings to warn motorists of pedestrian activity, which can reduce vehicle-pedestrian conflicts. The RRFB should be installed downstream of the crosswalk in the direction of traffic so the pedestrian can see that is flashing before beginning to cross.
- Improved pedestrian refuge protection can be accomplished by transitioning to a low height median barrier in advance of the pedestrian crossing. The low height median barrier also helps to generate greater side friction for the driver, resulting in slower approach and exit vehicle speeds.
- Keep the crosswalk alignment straight to make traversing of the crossing easier for the visually impaired pedestrian. Imparting an angled crossing may not be easily detected and could result in the pedestrian leaving the crossing area and not making it safely across the roadway.

9.8.4 Bicycle Design Considerations

Bicyclists should have similar options to travel through roundabouts as at traditional intersections.

Where there are bicycle lanes or shoulders on approach roadways, they should be terminated at least 100 feet in advance of the circulatory roadway of the roundabout to remind bicyclists that they need to merge. Bicycle lanes should not be located within the circulatory roadway. At roundabout exits, an appropriate taper should begin after the crosswalk, with a dotted line for the bike lane through the taper. The solid bike lane line should resume as soon as the normal bicycle lane width is available.

Bicyclists can navigate a roundabout in the same lanes as motor vehicles or as pedestrians, depending on the size of the intersection, traffic volumes, their experience level, and other factors. Roundabouts can be designed to simplify this choice for bicyclists.

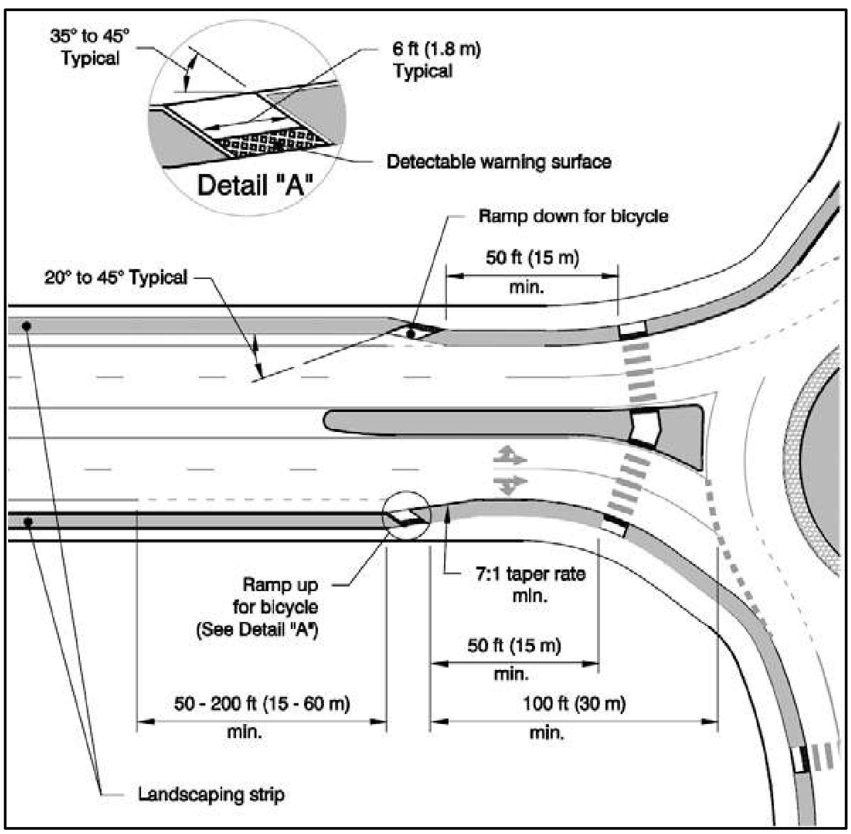
Bicyclists are often comfortable riding in the vehicle travel lane through single-lane roundabouts in low-volume environments because their speeds are comparable and potential conflicts are low. At larger or busier roundabouts, bicyclists may be more comfortable using ramps that connect to a sidewalk or shared path around the perimeter of the roundabout. In general, bicycle ramps are not recommended at urban, single-lane roundabouts; however, they may be appropriate if traffic speeds or other conditions (i.e., a right-turn bypass lane) pose a challenge to circulating in the vehicle lanes.

Bicycle ramps at roundabouts have the potential to be confused with pedestrian ramps, particularly for visually impaired pedestrians. Therefore, bicycle ramps should only be installed where the roundabout complexity or design speed may be uncomfortable for bicyclists.

Where bicycle ramps are provided, consideration should be given to how they connect to a shared-use path or a widened sidewalk at the roundabout, as described in Section 9.8.1. Bicycle ramps should be placed at the end of the full-width bicycle lane where the taper for the bicycle lane begins. Cyclists approaching the taper and bike ramp have the choice of merging left into the travel lane or moving right onto the sidewalk. Bike ramps should not be placed directly in line with the bike lane or otherwise placed in a manner that appears to bicyclists that the bike ramp and the sidewalk are the recommended path of travel through the roundabout.

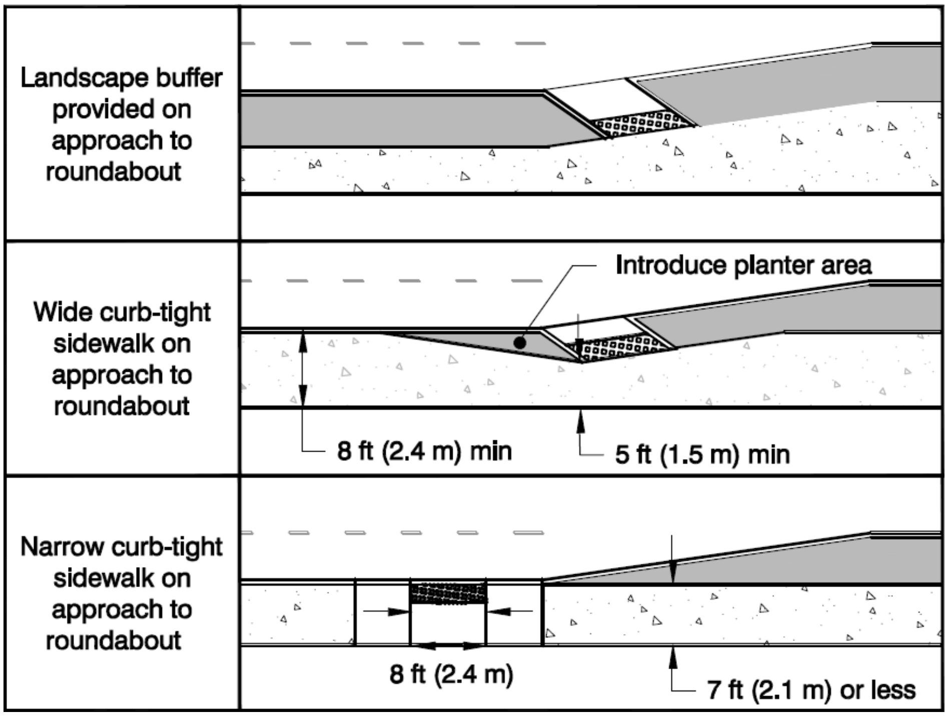
Wherever possible, bicycle ramps should be placed entirely within the planting strip between the sidewalk and the roadway, as shown in Figure 9-37. In these locations, the bicycle ramps should be placed at a 35- to 45-degree angle to the roadway and the sidewalk to enable cyclists to use the ramp even if pulling a trailer, but to discourage them from entering the sidewalk at high speed. The bike ramp can be fairly steep, with a slope potentially as high as 20%. If placed within the sidewalk area itself, the ramp slope must be built in a manner so that it is not a tripping hazard.

Figure 9-37 Possible Treatments for Bicycles at Roundabouts



Because bike ramps can be confusing for visually impaired pedestrians, detectable warnings are needed on the ramp. Where the ramp is placed in a planter strip, the detectable warning tile should be placed at the top of the ramp since the ramp itself is part of the vehicular area for which the detectable warning is used. If the ramp is in the sidewalk itself (as shown in one of the options in Figure 9-38), the detectable warning should be placed at the bottom of the ramp. Refer to Chapter 13 for additional information regarding bicycles at roundabouts.

Figure 9-38 Bicycle Ramp Design Options



9.8.5 Parking and Bus Stop Considerations

Parking areas at entries and exits should be set back far enough so as not to hinder roundabout operations or to impair the visibility of pedestrians. Curb extensions or bulb-outs are recommended to clearly mark the limit of permitted parking and reduce the width of the entries and exits. Parking in a circulatory roadway is not conducive to efficient and safe roundabout operations and is not recommended.

For safety and operational reasons, bus stops should be located sufficiently far away from entries and exits and never in the circulatory roadway.

9.8.6 High-Speed Approach Considerations

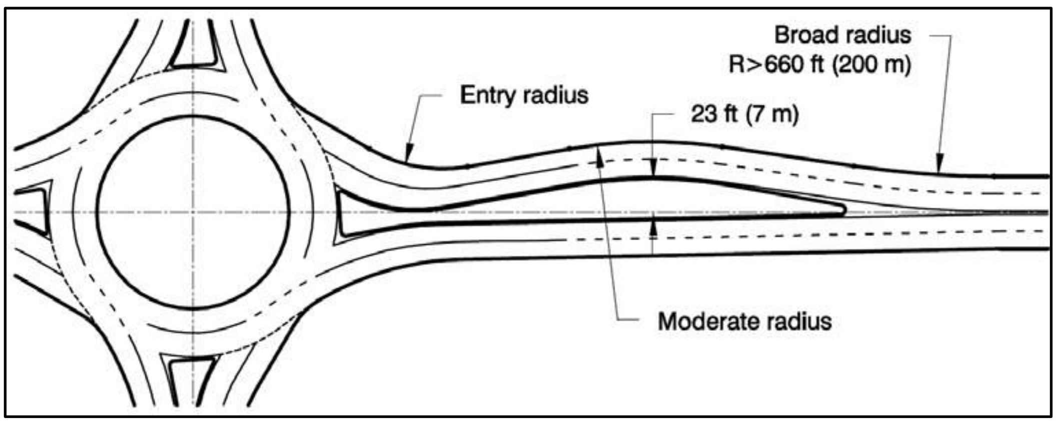
The visibility of the intersection itself is a safety consideration. Where possible, the geometric alignment of approach roadways should maximize the visibility of the central island and the shape of the roundabout. Where adequate visibility cannot be provided solely through geometric alignment, additional treatments can be considered, such as signing, pavement markings, advanced warning beacons, etc.

On open rural highways, changes in the roadway's cross section can be an effective means to help approaching drivers recognize the need to reduce speed in advance of the roundabout. Rural highways typically have no outside curbs with wide paved or gravel shoulders. Narrow shoulder widths and curbs on the outside edges of pavement, on the other hand, are a cue that the roadway is transitioning to a more controlled setting, causing a driver to naturally slow down. Therefore, it is recommended to provide curbs at the roundabout and on the approaches, and to consider reducing shoulder widths.

Longer splitter islands on the approaches can be used to reduce approach speeds. Splitter islands should generally be extended upstream of the entrance line to the point at which entering drivers are expected to begin decelerating comfortably. A minimum length of 200 feet is recommended for high-speed approaches.

Another method to achieve speed reduction and reduce the number of single-vehicle crashes at the roundabout is the use of successive curves (chicanes) on approaches, as shown in Figure 9-39. These approach curves should be successively smaller to emphasize the reduction in speed between successive curves.

Figure 9-39 Use of Successive Curves on High-Speed Approaches



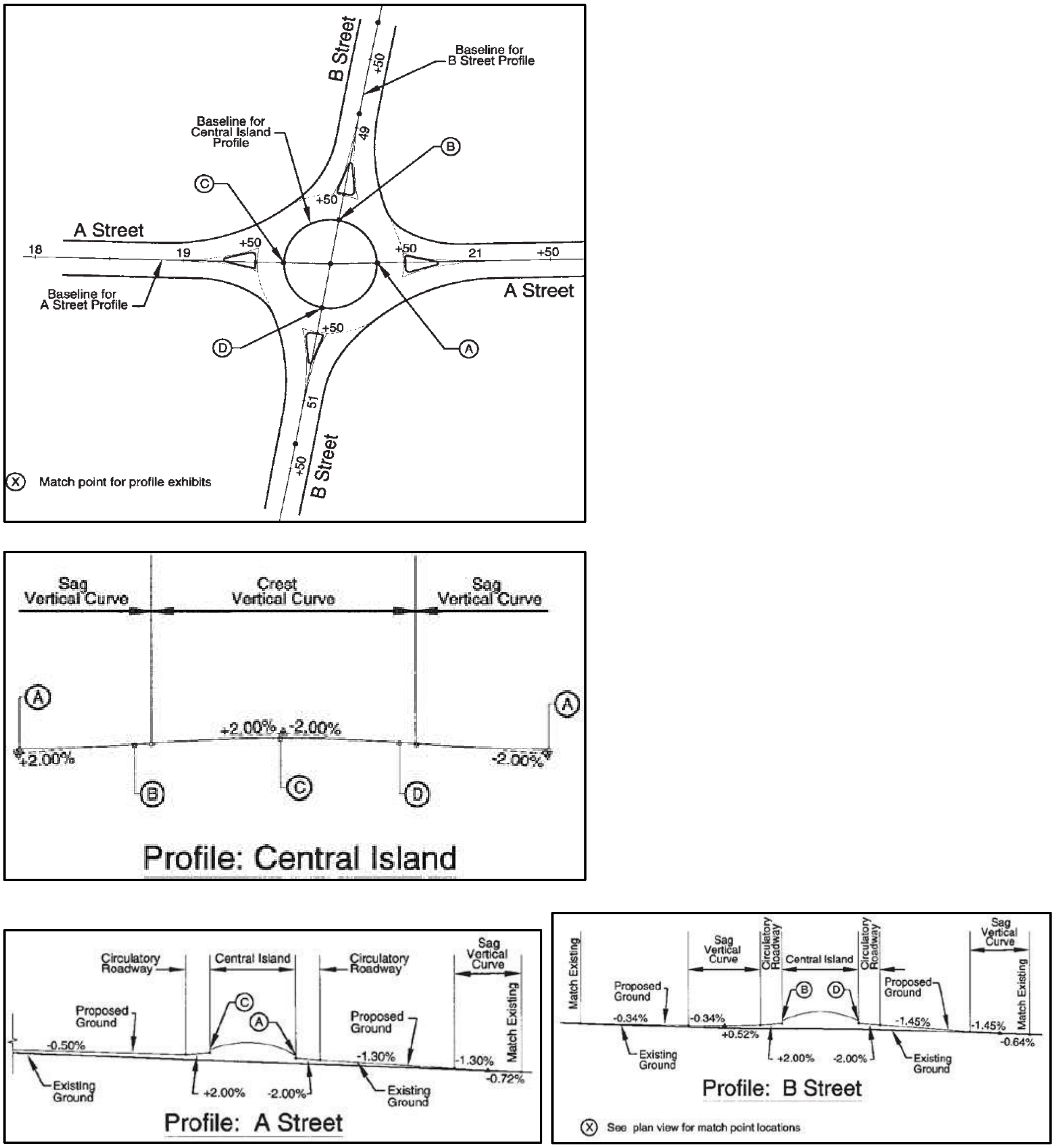
9.8.7 Vertical Considerations

The vertical design of a roundabout begins with the development of the approach roadway and central island profiles. The development of each profile is an iterative process that involves tying the elevations of the approach roadway profiles into a smooth profile around the central island.

Each approach profile should be designed to the point where the approach baseline intersects with the central island, as shown in Figure 9-40. A profile for the central island is then developed that passes through these four points (in the case of a four-legged roundabout). The approach roadway profiles are then readjusted as necessary to meet the central island profile.

It is generally not desirable to place roundabouts in locations where grades through the intersection are greater than 4%, Especially in Colorado resort towns where snow and ice are even more frequent. Roundabouts have been installed on grades of 10% or more but localized Colorado context, especially as it relates to prevailing winter conditions, must be thoroughly considered within the roundabout design process. At locations where a constant grade must be maintained through the intersection, the circulatory roadway may be constructed on a constant-slope plane. This means, for instance, that the cross slope may vary from +3% on the high side of the roundabout (sloped toward the central island) to −3% on the low side (sloped outward). On approach roadways with grades steeper than −4%, it is more difficult for entering drivers to slow or stop on the approach. At roundabouts on crest vertical curves with steep approaches, a driver's sight lines may be compromised, and the roundabout may violate driver expectancy.

Figure 9-40 Sample Central Island Profile Cross Slope



Entry grade profiles (approximately two car lengths from the outer edge of the circulatory roadway) should not exceed 3%, with 2% being the desirable maximum. It is desirable to match the exit grades and the entry grades; however, the exit grade may be steeper but should not exceed 4%. Adjustments to the circulatory roadway cross slope may be required to meet these criteria but should be balanced with the effects on the circulatory roadway.

As a general practice, on single-lane roundabouts, a cross slope of 2% away from the central island should be used for the circulatory roadway. This is most practical in relatively flat terrain; however, roundabouts in hilly terrain may require the designer to warp the profile to get the vertical design to work. An abrupt negative change in superelevation at a roundabout entry point increases the potential for single-vehicle crashes and loss-of-load incidents for trucks, particularly if speeds are too high.

One method, primarily intended for consideration at multilane roundabouts, is to crown the circulatory roadway. The circulatory roadway is crowned with approximately two-thirds of the width sloping toward the central island and one-third sloping outward. This may alternatively be reversed so that half of the circulatory roadway slopes toward the central island. The maximum recommended cross slope is 2%. Asphalt paving surfaces are recommended under this type of application to produce a smoothed crown shape.

9.8.8 Truck Apron

Where truck aprons are used, the slope of the apron should generally be no more than 2%. Greater slopes may increase the likelihood of loss-of-load incidents. It is preferred to slope truck aprons away from the central island toward the outside of the roundabout; however, some roundabouts have truck aprons that are sloped inward (toward the central island) to minimize water shedding across the roadway and to minimize load shifting in trucks.

The vertical design of the truck apron should be reviewed to confirm that there is sufficient clearance for low-boy type trailers, some of which may have only 6 to 8 inches between the roadway surface and bottom of the trailer. The vertical clearance can be reviewed by drawing a chord across the apron in the position where the trailer would sweep across. In some cases, warping of the profile along the circulatory roadway can create high spots that could cause trailers to drag or scrape along the truck apron. This should be checked during final design.

Between the truck apron and the circulatory roadway, a curb is required to accommodate a change in vertical elevation. As discussed in Section 9.5.3, the outer edge of the apron should be raised approximately 2 to 3 inches above the circulatory roadway surface. The apron should be constructed of a different material than the pavement to differentiate it from the circulatory roadway.

9.8.9 Drainage

With the circulatory roadway sloping away from the central island, inlets are generally placed on the outer curb line of the roundabout. Inlets can usually be avoided on the central island for a roundabout designed on a constant grade through an intersection. As with any intersection, it is recommended to place low points and inlets upstream of crosswalks.

9.8.10 Concrete Jointing Patterns

If concrete pavement is used, joint patterns should be concentric and radial to the circulating roadway within the roundabout. Ideally the joints should not conflict with pavement markings within the roundabout, although concrete panel sizes may control this. On multilane roundabouts, circumferential joints within the circulating roadway should follow the lane edges to the extent practical.

9.8.11 Access Management

It is preferable to avoid locating driveways where they must take direct access to a roundabout. Nonetheless, site constraints sometimes make it necessary to consider providing direct access into a roundabout.

Public and private access points near a roundabout often have restricted operations due to the channelization of the roundabout. Driveways between the crosswalk and entrance line complicate the pedestrian ramp treatments and introduce conflicts in an area critical to operations of the roundabout. Driveways blocked by the splitter island are restricted to right-in/right-out operation and are best avoided altogether unless the impact is expected to be minimal or no reasonable alternatives are available.

Queuing from nearby intersections (the roundabout or others nearby) should be checked to see if the operation of the access point will be affected.

9.8.12 Illumination

Illumination should be designed to create a break in the linear path of the approaching roadway and emphasize the circular aspect of the roundabout, which improve the users' understanding of the roundabout's operations.

Illumination is recommended for all roundabouts, including those in rural environments. However, it can be costly to provide if there is no power supply in the vicinity of the intersection. Where lighting is not provided, the intersection should be well signed and marked (including the possible use of reflective pavement markers) so that it can be correctly perceived by day or night, recognizing that signing and markings alone cannot correct for the limited view of headlights when circulating.

In areas where only the roundabout is illuminated and there is no lighting on the approach roadways, the scope of illumination needs to be carefully considered. Any raised channelization or curbing should be illuminated. A gradual illumination transition zone should be provided beyond the final trajectory changes at each exit. This helps drivers adapt their vision from the illuminated environment of the roundabout back into the dark environment of the existing roadway.

Chapter 10
Grade Separations and Interchanges

Legend

	Multimodal Application Example
	Context-Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context-Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO-Specific Information

Chapter 10

10 Grade Separations and Interchanges

10.1 Introduction

Grade separations and interchanges are most commonly associated with freeways. As defined in Chapter 5 of this Guide, a Freeway is "free" of at-grade intersections. Nevertheless, at-grade intersections are still elements of consideration within the specialty of grade separation and interchange design. For example, interchange design typically also involves at-grade intersection design at ramp termini. Furthermore, at-grade intersections are also typically an integral part of the larger transportation network.

A transportation network influenced by many factors, including the design characteristics of one interchange, with its own effects reaching far beyond one interchange often spilling into adjacent at-grade intersections. Accommodating high volumes of traffic safely and efficiently through an intersection depends largely on how the intersecting traffic lanes are configured. Grade separations of intersecting traffic lanes facilitate uninterrupted flow or traffic, resulting in the greatest efficiency, safety, and capacity for traffic and the least amount of air pollution.

An interchange is a system of two or more interconnecting roadways or highways and one or more grade separations. Interchange design is the most specialized and highly developed form of intersection design. The designer should be thoroughly familiar with the following relevant material in Chapter 8 of this Guide and apply it to interchange design:

- General factors affecting design.
- Basic data required.
- Principles of channelization.
- Design procedure.
- Design standards.

An interchange or series of interchanges on a freeway or expressway adjacent to or through a community may have a large economic effect on large contiguous areas or even the entire community. Interchanges must be located and designed to provide the most desirable overall plan of access, traffic service, and community development. For this reason, it is recommended to have an active public process to gain input for the development of context sensitive solutions.

The type and design of a grade separation and interchange are influenced by factors such as highway classification, contextual classification, character and composition of traffic, design speed, and degree of access control. The consideration of these controls, plus signing requirements, economics, terrain, environment, and right of way, result in a design with adequate capacity to safely accommodate the traffic demands. The design of an interchange must be considered in conjunction with adjacent interchanges, driver expectancy, and the at-grade intersections on the intersecting corridors.

Interchange types are characterized by the basic shapes of ramps, for example, diamond, loop, directional, "urban," and cloverleaf interchanges. Figure 10-1A, Figure 10-1B, Figure 10-1C, Figure 10-1D, and Figure 10-1E illustrate these basic interchange types. Cloverleaf interchanges usually have a larger footprint and require more right of way and easements than other interchange types. Cloverleaf interchanges are not as common anymore due to more operationally efficient interchange alternatives that do not require as large of a physical footprint.

Alternative types of intersections and interchanges, such as diverging diamond interchange (DDI), continuous flow intersection (CFI) (displaced left turn), and single point urban interchange (SPUI), have modified intersection turning movements that improve traffic operations for high travel demands. These configurations can be implemented as local street intersections or as part of freeway-to-freeway interchanges.

For further information on grade separations and interchanges, refer to Chapter 10 of the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (the Green Book) (2018 AASHTO GDHS) (AASHTO, 2018).

Figure 10-1A Interchange Types

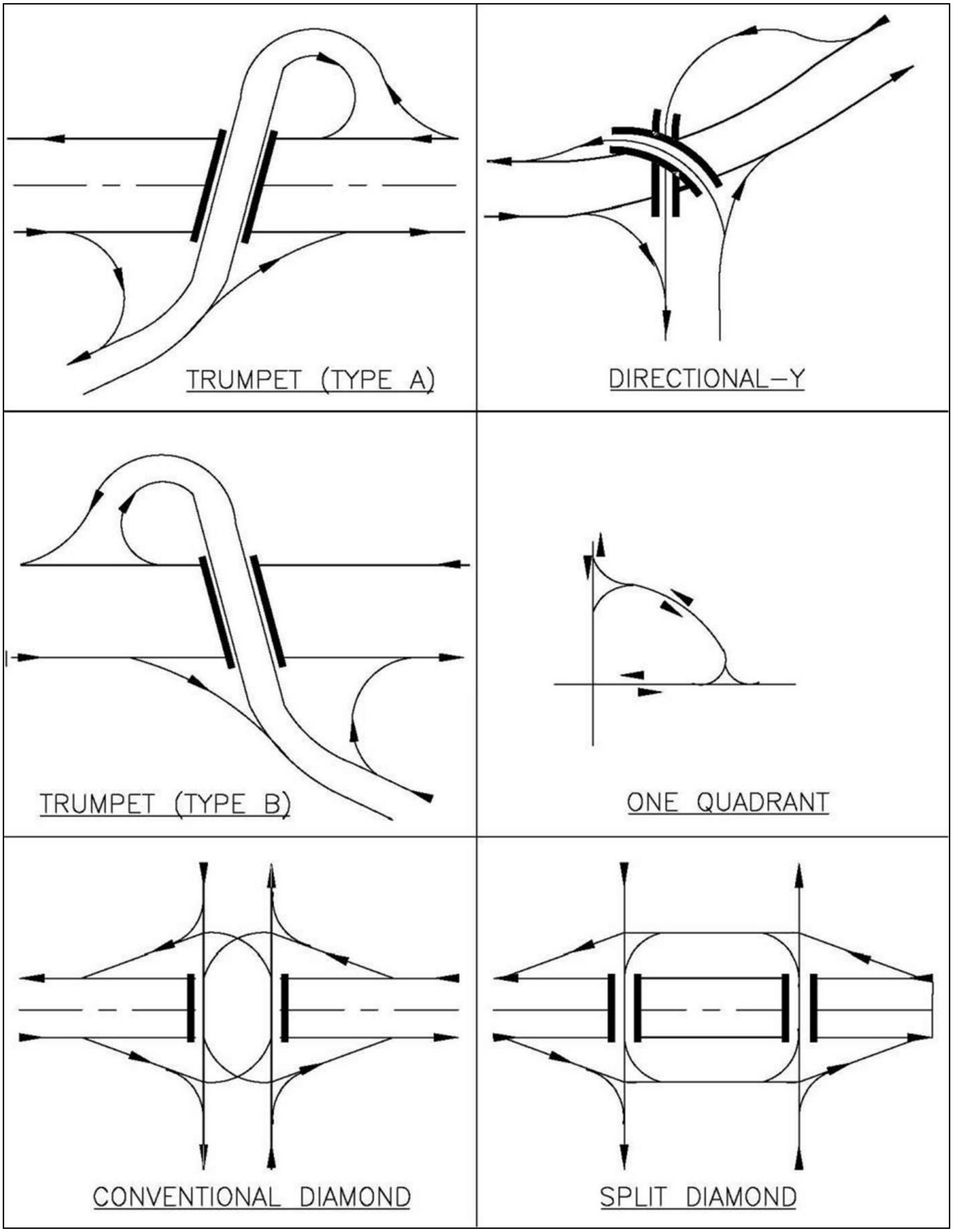


Figure 10-1B Interchange Types

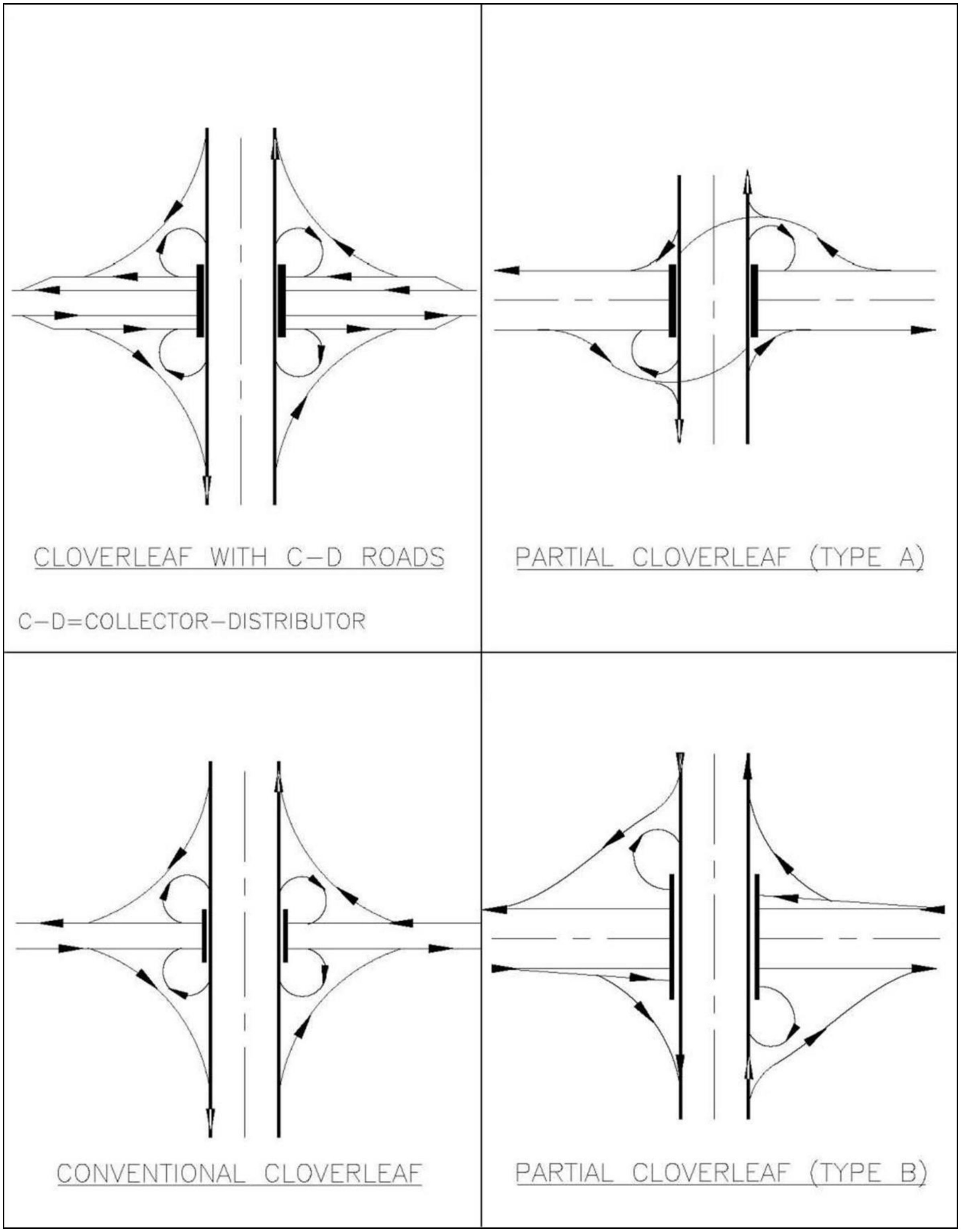


Figure 10-1C Interchange Types

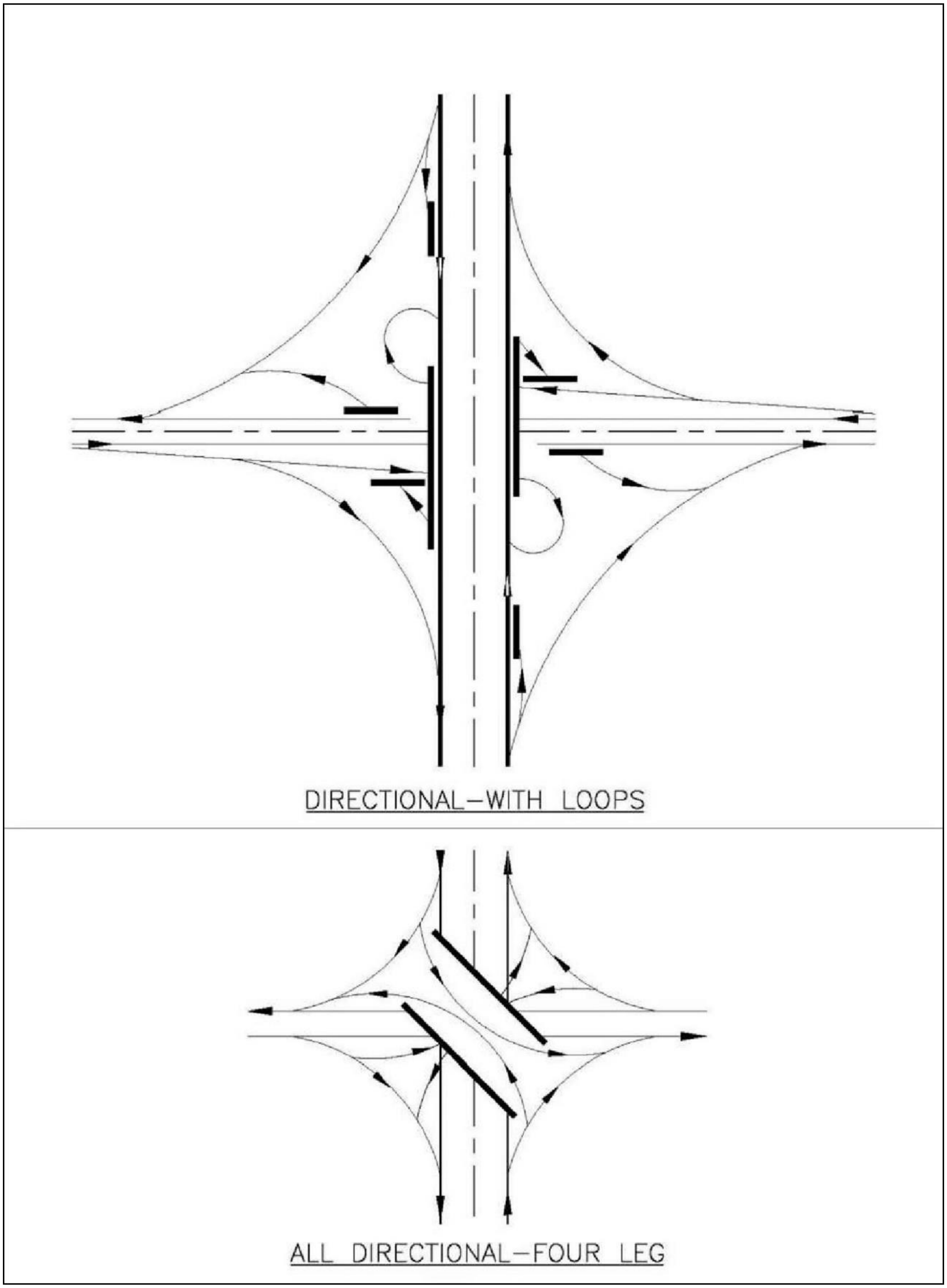


Figure 10-1D Interchange Types

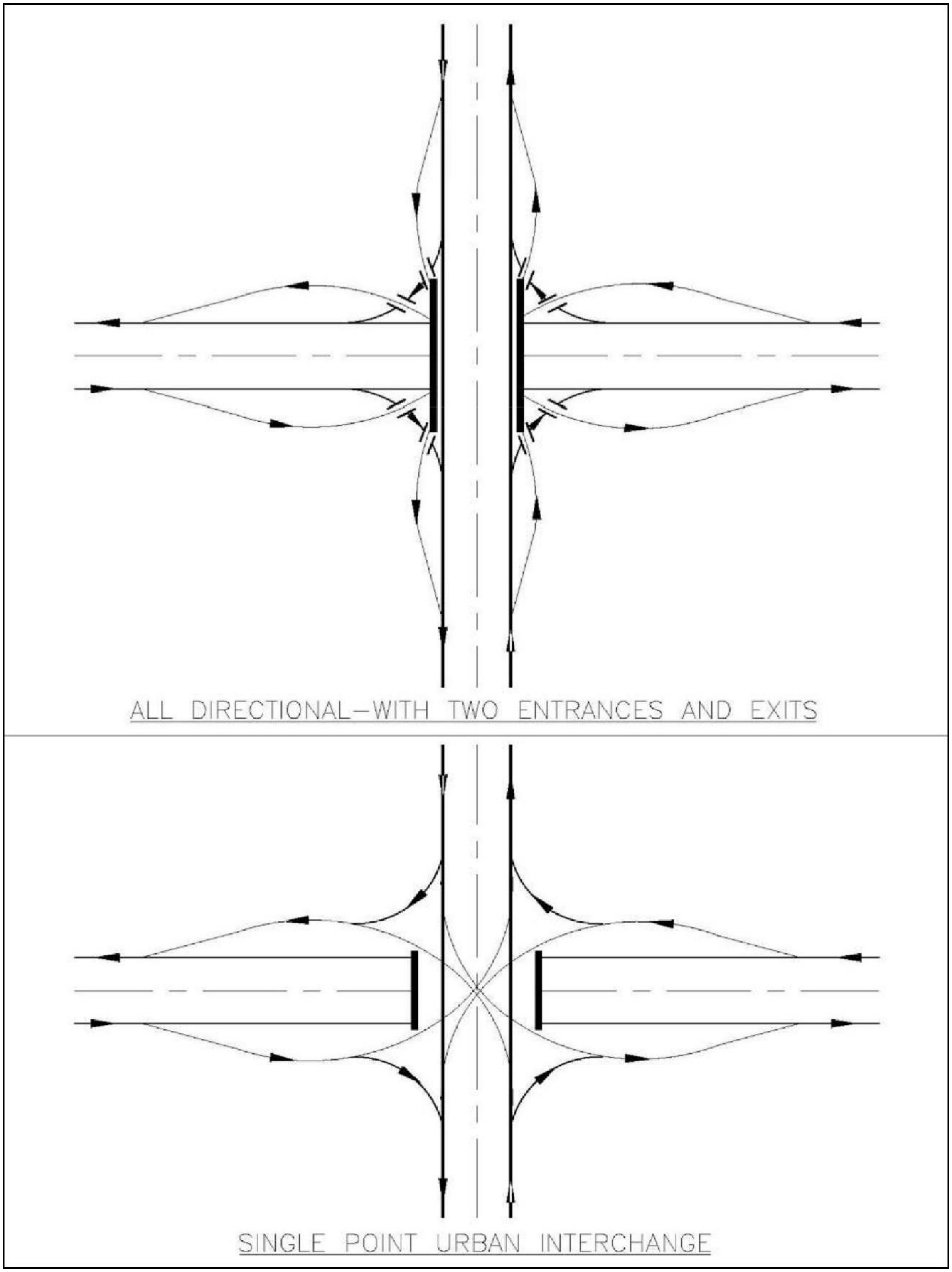
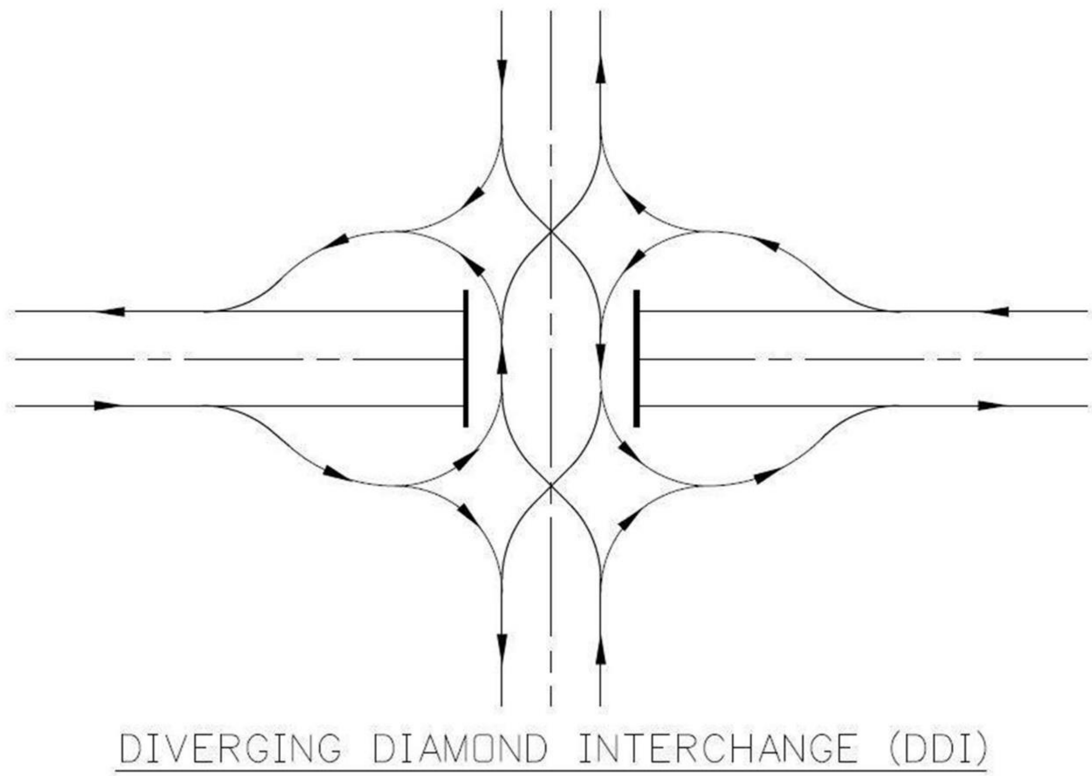


Figure 10-1E Interchange Types



10.2 Warrants for Interchanges and Grade Separations

Intersecting interstates or freeways generally warrant an interchange. A grade separation or interchange also may be warranted at intersecting rural freeways, non-interstate highways, expressways, or non-access-controlled highways. Because of the wide variety of site conditions, traffic volumes, highway types, and interchange layouts, the warrants that justify an interchange may differ at each location. Warrants, therefore, are necessarily general and must be based on engineering judgment and data driven analysis. CDOT Policy Directives 1601.0 Interchange Approval Process (CDOT, 2021) and Procedural Directive 1601.1 Requests for Interchange Access and Modifications to Existing Interchanges on the State Highway System (CDOT, 2022) must be followed.

When determining conditions that may warrant an interchange, the following should be considered:

- *Design designation.* Determining if a corridor warrants a freeway designation and improvements to interchanges along that corridor.
- *Reduction of bottlenecks or intersection congestion.*

- *Reduction of crash frequency and severity. At intersections with a disproportionate frequency or severity of crashes, a grade separation* or interchange may be warranted if inexpensive methods of crash reduction are likely to be ineffective or impractical. Higher crash frequencies can occur at intersections of comparatively lightly traveled highways in rural areas where speeds are high and at heavily traveled intersections.
- *Improved operational efficiency for all traffic movements.*
- *Site topography.* The site topography and the grades of the intersecting roadways help to determine the interchange type and location. The right of way required for an interchange is dependent largely on the type of highway, topography, and the overall type of interchange.
- *Road-user benefits.* Reduction in travel time delay and improvements in travel time reliability.
- *Traffic volume warrant.* Except on freeways, interchanges usually are provided only where crossing and turning traffic cannot readily be accommodated on a less costly at-grade intersection.
- *Transit.* Improved transit operations and transit time reliability.
- *Functional classification of the road.*
- *Transportation Demand Management (TDM) strategies.* These preserve the long-term functionality of the constructed interchange improvements and preserve the overall functionality and operability of the highway system. Updated TDM plans are also required with Type 1 and 2 interchange modifications requests under CDOT Policy Directive 1601.1 Requests for Interchange Access and Modifications to Existing Interchanges on the State Highway System (CDOT, 2022).

10.3 Adaptability of Highway Grade Separations and Interchanges

The three types of intersections are:

- At-grade intersections.
- Highway grade separations without ramps.
- Interchanges.

Factors that would determine the need for a grade separation or interchange and type include:

- *Traffic and Operations.*
- *Context Classification.*
- *Site Conditions.*
- *Design Speed.* The hazard from stopping and direct turns at an intersection increases with the design speed so that high-design-speed highways warrant interchange treatment earlier than low-design-speed roads with similar traffic volumes.

- *Intersecting Facility.* The extent or degree to which local service must be maintained or provided. Service can be provided readily on certain types of at-grade intersections, whereas considerable additional facilities may be necessary on some types of interchanges.
- *Safety.* Evaluating the current crash patterns and rates to determine if the addition of an interchange can reduce the crash rates by removing specific crash types at the intersection.
- *Stage Development.* Where the ultimate development consists of a single grade-separation structure, stage construction may not be economical unless provisions are made in the original design for a future stage of construction. Ramps, however, are well adapted to stage development.
- *Economics.* Initial cost needs to be considered. The interchange is the costliest type of intersection because of the cost of the structure, ramps, through roadways, right of way acquisition, grading and landscaping of large areas.
- *Maintenance Costs.* Interchanges have large pavement and variable slope areas, the maintenance of which, together with that of the structure, signs, and landscaping, exceeds that of an at-grade intersection.

In a complete analysis of the adaptability of interchanges, it is necessary to compare vehicular operating costs of all traffic with those for other intersections.

10.3.1 Traffic Operations

A traffic operations analysis validates the need for a grade separation or interchange. During initial project scoping, many times during the NEPA phase of a project, traffic analysis can help identify specific operations criteria that need to be met for a grade separation or an interchange to be warranted. The analysis evaluates the current conditions of the intersection to determine the operational efficiency or Level of Service (LOS) for the intersection and the individual legs of the intersection. Refer to Chapter 8 of this Guide regarding how to determine the intersection LOS.

10.3.2 Site Conditions

Site conditions may justify the need for a grade separation or interchange, for example, a grade separation over or under a rail line, access to properties or areas where no access currently exists, or a crossing to serve a high volume of pedestrian or bicycle traffic.

10.3.3 Type of Highway and Intersecting Facility

The functional type of the intersection highway or roadway dictates the required type of grade separation or interchange. An interchange at intersecting interstates or freeways must be designed to maintain an uninterrupted flow of traffic. Arterials feeding to the interchange require intersection controls at the freeway or interstate ramps. Depending on the anticipated traffic demand and the functional types of the intersecting facilities, these could be a simple stop control, signalized, roundabout, DDI, or CFI intersection.

10.3.4 Multimodal Considerations

Accommodations for transit, including buses and rail, as well as bicycles and pedestrian traffic must be considered in the design of a grade separation or interchange. It is best practice to provide bicycle and pedestrian facilities outside the general-purpose lanes of a freeway, such as a shared-use path or the adjacent local street network. It is important to consider safety, such as recovery areas for vehicles, and noise when determining placement of a bicycle or pedestrian facility. Grade separations may be appropriate for bicycle and pedestrian traffic. Although generally discouraged, under Colorado law, when no secondary routes are available, bicyclists and pedestrians may use freeways unless otherwise posted.

Use this link to access Colorado Bicycles and Byways Map: [Colorado Bicycle & Byways Map (coloradodot.info)]

10.4 Access Separations and Control on the Crossroad at Interchanges

Safely manage and minimize weaving by providing appropriate spacing between adjacent intersections and the interchange.

For further information, refer to Chapter 10, Section 4, of the 2018 AASHTO GDHS.

10.5 Safety

- Minimize crossing and turning conflicts.
- Points of access.

For further information, refer to Chapter 10, Section 5, of the 2018 AASHTO GDHS.

10.6 Stage Development

The design of a grade separation or interchange for a project that may be built in stages needs to take into consideration the desired ultimate configuration so that the earlier phases of the project do not preclude future phases.

For further information, refer to Chapter 10, Section 6, of the 2018 AASHTO GDHS.

10.7 Economic Factors

- *Initial Costs.* Most costly type of intersection. Does the need justify the cost?
- *Maintenance Costs.* Increased maintenance and operations costs. Is there adequate equipment and staffing for this or is there a plan to augment the budget for the addition of an interchange?
- *Vehicular Operating Costs.* Different interchange configurations can have a significant cumulative effect in vehicle operating costs. Which alternative minimizes the vehicle operating and overall combined costs of the interchange options.

For further information, refer to Chapter 10, Section 7, of the 2018 AASHTO GDHS.

10.8 Grade Separation Structures

It is recommended to conduct a detailed study for a proposed grade separation to determine which of the intersecting roadways should be the grade-separated structure. Often, the choice is dictated by such features as cost, environmental impacts, topography, or highway classification. It may be necessary to make several nearly complete preliminary layout plans before a decision regarding the most desirable general layout plan can be reached.

When initiating the interchange analysis there are a lot of tools to help the designer identify the right interchange solution that fits the context, traffic, and roadway features. Much of this begins with initial traffic analysis tools like FHWA's Cap-X Tool or other similar tools that can evaluate current and future traffic volumes and help to prioritize the best interchange types for the anticipated traffic conditions.

Use this link to access FHWA's Capacity Analysis for Planning of Junctions (CAP-X) Tool User Manual: http://www.cmfclearinghouse.org/collateral/FHWA-SA-18-067%20CAP-X%202018%20Tool%20User%20Guide%20(Final).pdf

Use this link to access FHWA's Capacity Analysis for Planning of Junctions (CAP-X) Tool Software: https://www.fhwa.dot.gov/software/research/operations/cap-x/

As a rule, an interchange design that best fits the existing topography is the most economical to construct and maintain, and this factor is the first consideration in design. Notwithstanding notable exceptions such as the Central 70 project in Denver, another general rule is that the facility with the lesser footprint is typically elevated above or depressed below the facility with the greater footprint. Bear in mind, all other items equal, elevated or depressed freeway area is typically more costly compared to at-grade freeway facilities with a larger footprint/acreage. Every effort should be made to design the grade separation structure so that it fits the environment and context in a pleasing and functional manner without drawing unnecessary or distracting attention.

The type of structure best suited to a grade separation is one that maintains a constant roadway width and typical section. The clear width on bridges should be as wide as the approach pavement, including shoulders, so that a driver has a secure feeling. When the full approach roadway is continued across the structure, the protective railing or parapet rail on both sides of the roadway should align with the guardrail on the approach roadway to achieve a uniform appearance.

Minimum lateral clearances at underpasses and retaining walls should include any provisions for the dynamic lateral deflection that the guardrail may require. Refer to Section 8.4 of this Guide for information on vertical clearances.

For more information on grade separation structures, refer to Chapter 10 of the 2018 AASHTO GDHS.

10.9 Interchanges

10.9.1 General Considerations

The design and selection of an interchange type are influenced by many factors, as described elsewhere in this chapter. Even though interchanges are, of necessity, designed to fit specific conditions and controls, the pattern of interchange ramps along a freeway should follow some degree of consistency from the standpoint of driver expectancy. An interchange should have one point of exit located in advance of the crossroad wherever practical. Along with the interchange design, it is desirable to reconfigure portions of the local street system to achieve an effective overall plan of traffic service and community development.

The interchange design must be tested to determine if it can be signed properly for the smooth, safe flow of traffic. The need to simplify interchange design from the standpoint of signing and driver comprehension cannot be overstated.

There are several basic interchange forms or ramp geometric patterns for turning movements at an interchange. Their application at a particular site is determined by the number of intersection legs, the expected volumes of through and turning movements, topography, culture, design controls, signing, context classification, and the designer’s judgment.

From the standpoint of safety and preventing wrong-way movements, freeway interchanges with non-access-controlled highways should have ramps to serve all basic directional movements. A specific freeway-to-freeway movement may be omitted if the turning traffic volume is minor and can be accommodated via route signing to other nearby major state highways or other freeway facilities.

The basic interchange configurations are:

- Three-leg designs.
- Four-leg designs.
- Ramps in one quadrant.
- Diamond interchanges.
- Diverging diamond interchanges (DDI).
- Single-point urban interchanges (SPUI).
- Cloverleafs.
- Partial cloverleaf ramp arrangements.
- Directional and semi directional interchanges.
- Offset interchanges.

- Combination interchanges.

CDOT and FHWA discourage the use of partial interchanges, and these should be avoided. Refer to Chapter 10 of the 2018 AASHTO GDHS.

The CSS process can help a designer determine the best interchange type for the context it is within while including stakeholders in the discussion. Understanding the stakeholders needs will lead to the design that will best accommodate the highest demands for operations and safety.

10.9.2 Three-Leg Designs

Refer to Chapter 10, Section 10.9.2, of the 2018 AASHTO GDHS.

10.9.3 Four-Leg Designs

Refer to Chapter 10, Section 10.9.3, of the 2018 AASHTO GDHS.

10.9.4 Other Interchange Configurations

Refer to Chapter 10, Section 10.9.4, of the 2018 AASHTO GDHS.

10.10 General Design Considerations for Interchanges

Except for crash data, the same basic data for intersection design considerations covered in Chapter 8 of this Guide is required for interchange design. This includes:

- Design speed.
- Design traffic volumes.
- Level of service.
- Pavement and shoulders.
- Curbs.
- Superelevation.
- Grades.
- Structures.
- Horizontal and vertical clearance sight distance.

Data that should be obtained prior to interchange design includes community service (community access needs), traffic (projected traffic volumes), physical (topographic), environmental (NEPA considerations), economic factors (potential right- of-way acquisition), and potential area development (context sensitive solutions). Specifically, this includes:

- The location and standards (types) of existing and proposed local streets and highway development, including types of traffic (access) control.

- Existing and potential traffic circulation and multimodal connectivity over the affected local roads or streets.
- Existing and proposed land use, including such developments as shopping centers, recreational facilities, housing developments, schools, churches, hospitals, and other institutions.
- A traffic flow diagram (a schematic interchange layout) showing current and future (typically 20-year) annual average daily traffic, design hourly volumes, level of service, as well as time of day (a.m. or p.m.), anticipated on the freeway ramps and any affected local roads or streets.
- The relationship with (distances to and from) adjacent interchanges and intersections.
- The location of major utilities and multimodal facilities (e.g., railroads, transit, airports).

10.10.1 Determination of Interchange Configuration

Interchanges may be implemented on all functional roadway classifications, as discussed in Section 10.2 of this chapter.

In rural areas, interchange-type selection is determined based on service demand. The common rural interchange type in use in Colorado is the diamond interchange. Interchange-type determination in an urban environment requires considerable analysis of regional conditions so that the most practical interchange configurations can be developed.

A combination of directional, semi-directional, and loop ramps may be appropriate where turning volumes are high for some movements and low for others. When loop ramps are used in combination with direct and semi-direct ramp designs, it is desirable that the loops be arranged so that weaving sections are not created.

Cloverleaf interchanges are not commonly used anymore. Proper spacing between the entry and exit points on loops are hard to achieve without creating a large interchange footprint. Also, the size of the loops needs to be large to accommodate faster vehicle travels speeds to prevent roadway departure crashes. There are many alternative interchange designs that do not require these large footprints and operate effectively to manage traffic. A simple diamond interchange is the most common type of interchange for the intersection of a major roadway with a minor facility. The capacity of a diamond interchange is limited by the capacity of the at-grade terminals of the ramps at the cross road. High through and turning volumes could preclude the use of a simple diamond unless signalization is used. It is becoming more common to see roundabouts as an intersection type with diamond interchanges in rural areas.

Another intersection alternative for diamond interchanges is the displaced left-turn also known as a continuous flow intersection (CFI) configuration. The benefit of a CFI intersection is the ability to combine movements that do not conflict with one another to reduce the number of phases required to move all the traffic. This benefits operations for the overall interchange.

A DDI is a variation of a conventional diamond interchange. The DDI uses directional crossover intersections to shift traffic on the cross street to the left-hand side between the ramp terminals within the interchange. Crossing the through movements to the opposite side replaces left-turn conflicts with same-direction merge/diverge movements and eliminates the need for exclusive left-turn signal phases to and from the ramp terminals. All connections from the ramps to and from the cross street are joined outside of the cross-over intersections, and these connections can be controlled by two-phase signals, have stop or yield control, or can be free flowing. In addition to the added safety benefits, DDIs typically have higher left-turn volume capacity and improved operations compared to conventional signalized diamond interchanges because of shorter cycle lengths, improved safety through the elimination of turning conflicts, reduced time lost per cycle phase, reduced stops and delay, and shorter queue lengths.

A SPUI is an interchange with all four turning movements controlled by a single traffic signal and the opposing left turns operate to the left of each other, so their paths do not intersect. As a result, a major source of traffic conflict is eliminated, increasing the overall intersection efficiency, and reducing the traffic signal phasing from a four-phase to a three-phase operation. Due to their large footprint, a SPUI on surface grade is preferred to a SPUI on an elevated structure.

A partial cloverleaf interchange may be appropriate where rights-of-way are not available in one or two quadrants or where one or two movements in the interchange are disproportionate to the others, especially when they require left turns across traffic. In the latter case, loop ramps may be utilized to accommodate the heavy left-turn volume.

Interchanges in rural areas are widely spaced and can be designed without any appreciable effect to or from other interchanges within the system.

The final decision on the interchange configuration may be determined by the need for route continuity, uniformity of exit patterns, single exits in advance of the separation structure, elimination of weaving on the main facility, signing potential, and available right of way.

10.10.2 Multimodal Considerations

Because interchanges are often receiving or dispersing vehicles from local roadways, arterials and collectors to the freeway system, it is necessary to consider how transit, bicycle, and pedestrian modes using the local roadways will navigate the interchange. The CSS and PBPD processes can determine modal priorities that lead to the best design.

Refer to Chapter 10 of the 2018 AASHTO GDHS.

10.10.3 Alignment, Profile, and Cross Section

Traffic passing through an interchange should be afforded the same degree of utility and safety as that given on the approaching highways. The design elements in the grade separation area, therefore, should be consistent with those on the approaching highways, even though this may be difficult to attain. Preferably, the geometric design at the highway grade separation should be better than that for the approaching highways to counterbalance any possible sense of restriction caused by the structure. When it is practical to design only one of the intersecting roadways on a tangent with flat grades, it should be the major highway. Regarding order of precedence in geometric design, it is most common to allow major highway or mainline geometrics to control interchange geometrics over the secondary roadway. Interchange designers are sometimes tempted to not follow this protocol as they struggle to establish the interchange geometrics. For example, drastically raising the mainline elevation may make flyover geometrics easier to design but this will likely be a more costly proposition for the DOT overall.

The general controls for horizontal and vertical alignment and their combination, as stated in Chapter 3 of this Guide, should be adhered to closely. Particular attention should be given to providing decision sight distance in situations where drivers must make complex or instantaneous decisions within interchanges.

The longitudinal distance needed for adequate design of a grade separation depends on the design speed, the roadway gradient, and the amount of rise or fall needed to achieve the separation. The amount of rise or fall needed depends on the amount of vertical clearance needed in addition to the structure depth. The approximate distance needed to achieve a grade separation (assuming flat terrain) can be determined using Figure 10-8 in Chapter 10 of the 2018 AASHTO GDHS. This table provides an approximate distance to achieve grade separation; however, a detailed design profile should be developed to confirm all design criteria have been met.

Typically, a minimum 20- to 22-foot difference in elevation is needed at a grade separation of two highways for essential vertical clearance and structure depth. This is also a good rule of thumb when considering the overall height of a multilevel interchange. For example, one could estimate that the upper-most driving surface of a four-level interchange is approximately between 80 to 88 feet high. The same 20- to 22-foot dimension generally applies to a single-level highway undercrossing a railroad; however, about 28 feet is needed for a highway overcrossing a railroad. However, input from bridge designers is required to determine relevant final design considerations.

10.10.3.1 Sight Distance

Sight distance on the highways through a grade separation should be at least as long as that needed for stopping, and preferably longer. Where exits are involved, decision sight distance is preferred, although not always practical. Ramp terminals at crossroads should be treated as at-grade intersections and should be designed in accordance with Chapter 8 of this Guide.

10.10.4 Interchange Spacing

In general, the desired minimum interchange spacing should be one mile in urban areas and two miles in rural areas. In urban areas, spacing of less than one mile may be allowed with the use of auxiliary lanes, grade-separated ramps, or collector-distributor roads.

10.10.5 Uniformity of Interchange Patterns

To the extent practical, all interchanges along the freeway should be reasonably uniform in geometric layout and general appearance. Except in special cases, all entrance and exit ramps should be on the right. Left entrances are undesirable because of difficulties related to merging with high-speed through traffic.

10.10.6 Route Continuity

Refer to Chapter 10 of the 2018 AASHTO GDHS.

10.10.7 Coordination of Lane Balance and Basic Number of Lanes

Fundamental to establishing the number and arrangement of lanes on a freeway is the designation of the basic number of lanes. A certain consistency should be maintained in the number of lanes provided along any route of arterial character. The basic number of lanes is defined as a minimum number of lanes designated and maintained over a significant length of a route, irrespective of changes in traffic volume and lane-balance needs. Stating it another way, the basic number of lanes is a constant number of lanes assigned to a route, exclusive of auxiliary lanes along a corridor.

Taking the extra step to evaluate upstream and downstream traffic operations and to model those operations with modeling software can avoid the potential of lane imbalance at interchange ramps and connections. This will prevent secondary crashes upstream by preventing the bottleneck condition if addressed properly during the early design analysis stage of the interchange.

10.10.8 Auxiliary Lanes

An auxiliary lane is defined as the portion of the roadway adjoining the traveled way for speed change, turning, storage for turning, weaving, truck climbing, or other purposes supplementary to through-traffic movement. The width of an auxiliary lane should be equal to the through lanes. An auxiliary lane may be provided to comply with the concept of lane balance; to comply with capacity needs; or to accommodate speed changes, weaving, and maneuvering of entering and exiting traffic. Where auxiliary lanes are provided along freeway mainlines, the adjacent shoulder width should be 8 to 12 feet in width, with a minimum 6-foot-wide shoulder in width-restricted areas.

Proper development of auxiliary lanes on the secondary road can greatly reduce weaving and queueing conflicts improving the operations on the secondary road around the interchange.

10.10.9 Lane Reduction

If a basic lane or an auxiliary lane is to be dropped between interchanges, it should be accomplished at a distance of 2,000 to 3,000 feet from the previous interchange. It is important to remember that the lane reduction should not be made so far downstream that drivers become accustomed to a certain number of lanes and are surprised by the reduction. The minimum taper rate should be 50:1, and the desirable taper rate is 70:1.

Left-side lane reductions should be avoided because of generally higher speeds and drivers' unfamiliarity with left-side merges.

10.10.10 Weaving Sections

A weaving section is a length of one-way roadway where vehicles are crossing paths, changing lanes, or merging with through traffic as they enter or exit a freeway or collector-distributor road.

Weaving sections occur frequently along freeways and expressways in urban areas. Weaving sections are inherent to some interchanges, such as the cloverleaf and those with semi-direct connections. They are also found between ramps of closely spaced, successive interchanges.

Because considerable turbulence occurs throughout weaving sections, interchange designs that eliminate weaving or remove it from the main facility are desirable. Weaving sections may be eliminated from the main facility by the selection of interchange types that do not have weaving or by the incorporation of collector-distributor roads in the design.

A simple weaving section has an entrance at the upstream end and an exit at the downstream end. A multiple weaving section has more than one point of entry followed by one or more points of exit. For the various types of weaving situations, refer to Figure 10-2A and Figure 10-2B.

Figure 10-2A Types of Weaving Sections

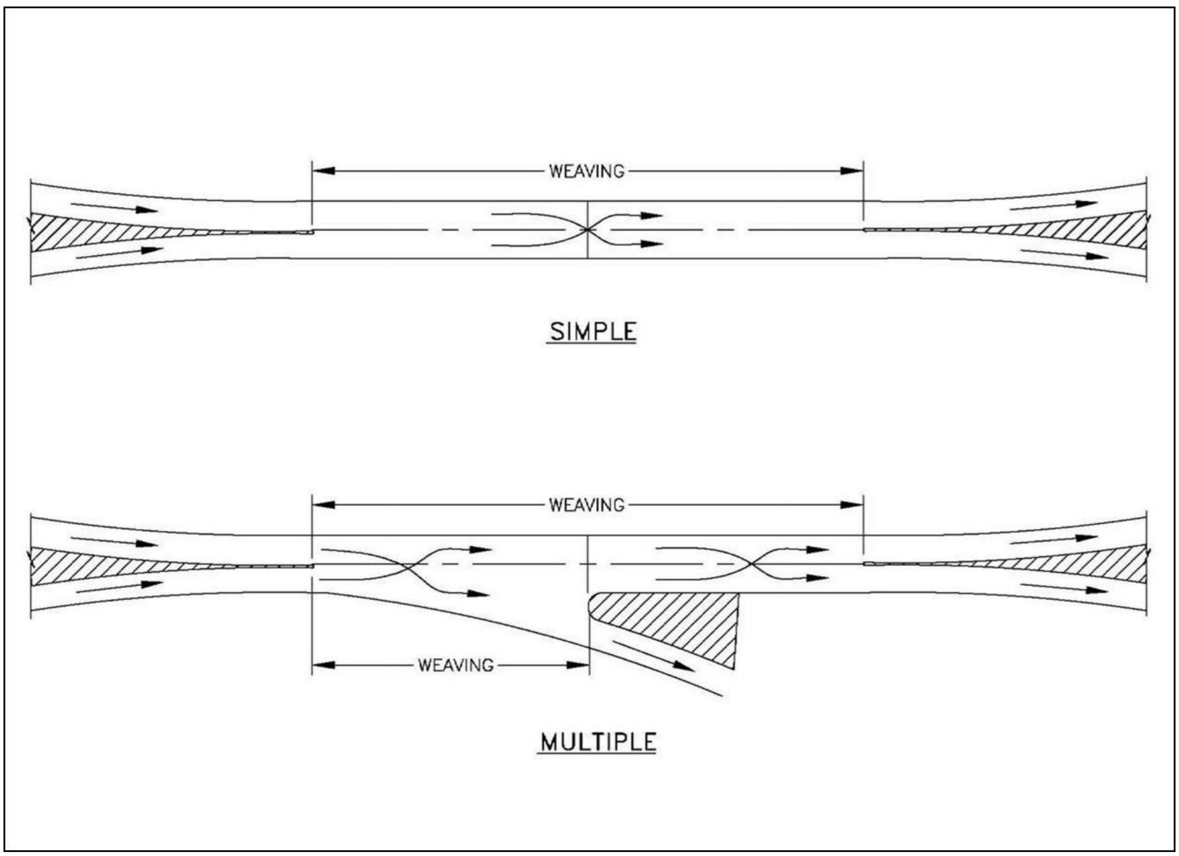
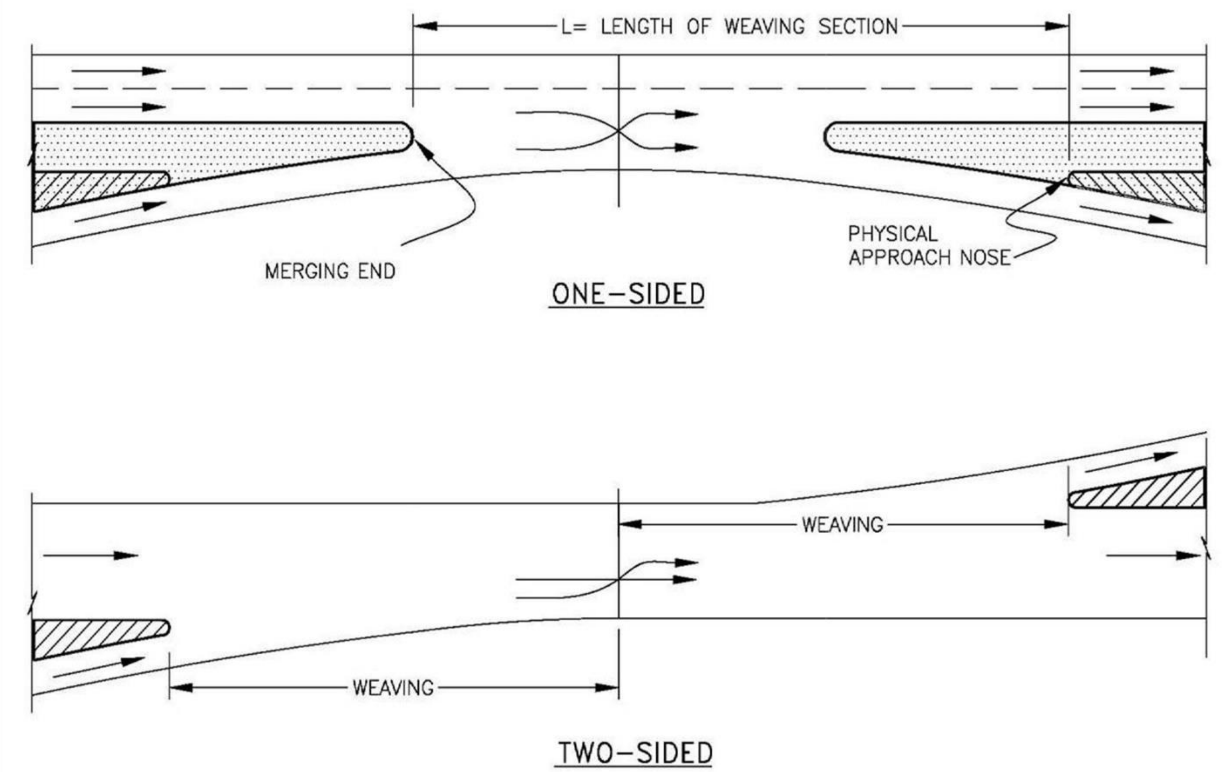


Figure 10-2B Types of Weaving Sections



Adequate length and width are required through the weaving section, along with lane balance, to maintain adequate capacity of weaving sections. Refer to Chapter 2 of the 2018 AASHTO GDHS for how to determine weaving lengths and widths.

Figure 10-2C and Figure 10-2D are examples of balanced lane conditions. The established relation of factors used in the design of weaving sections is found in Chapter 13 of the *Highway Capacity Manual* (TRB, 2016). Weaving sections in urban areas should be designed for LOS C or D where possible. Weaving sections in rural areas should be designed for LOS B or C. Volume in equivalent passenger cars per hour (PCPH) is adjusted for freeway grade and truck volumes.

The CDOT Region Traffic and Safety Engineer should be consulted for difficult weaving analysis problems.

Figure 10-2C Lane Configuration of Weaving Sections

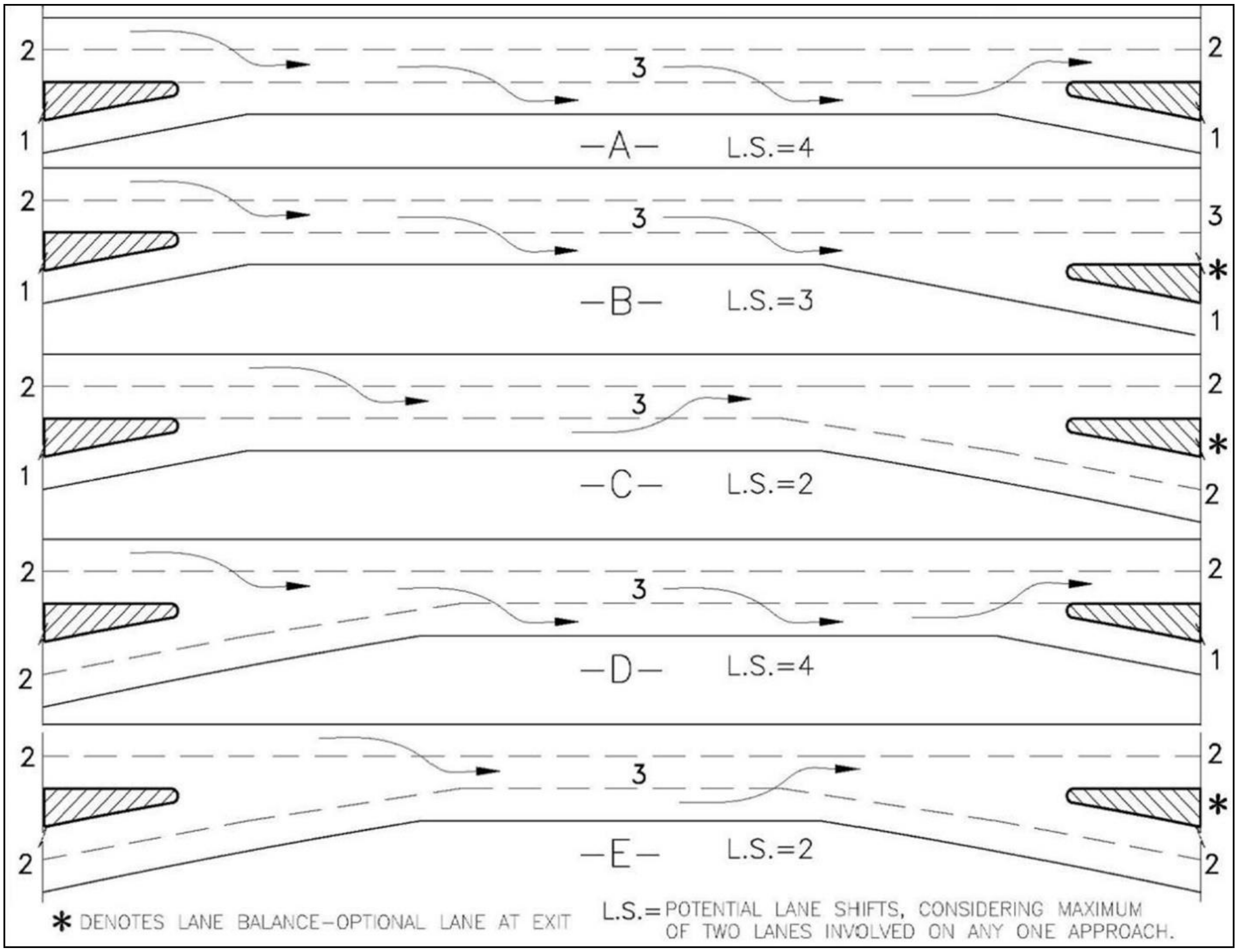
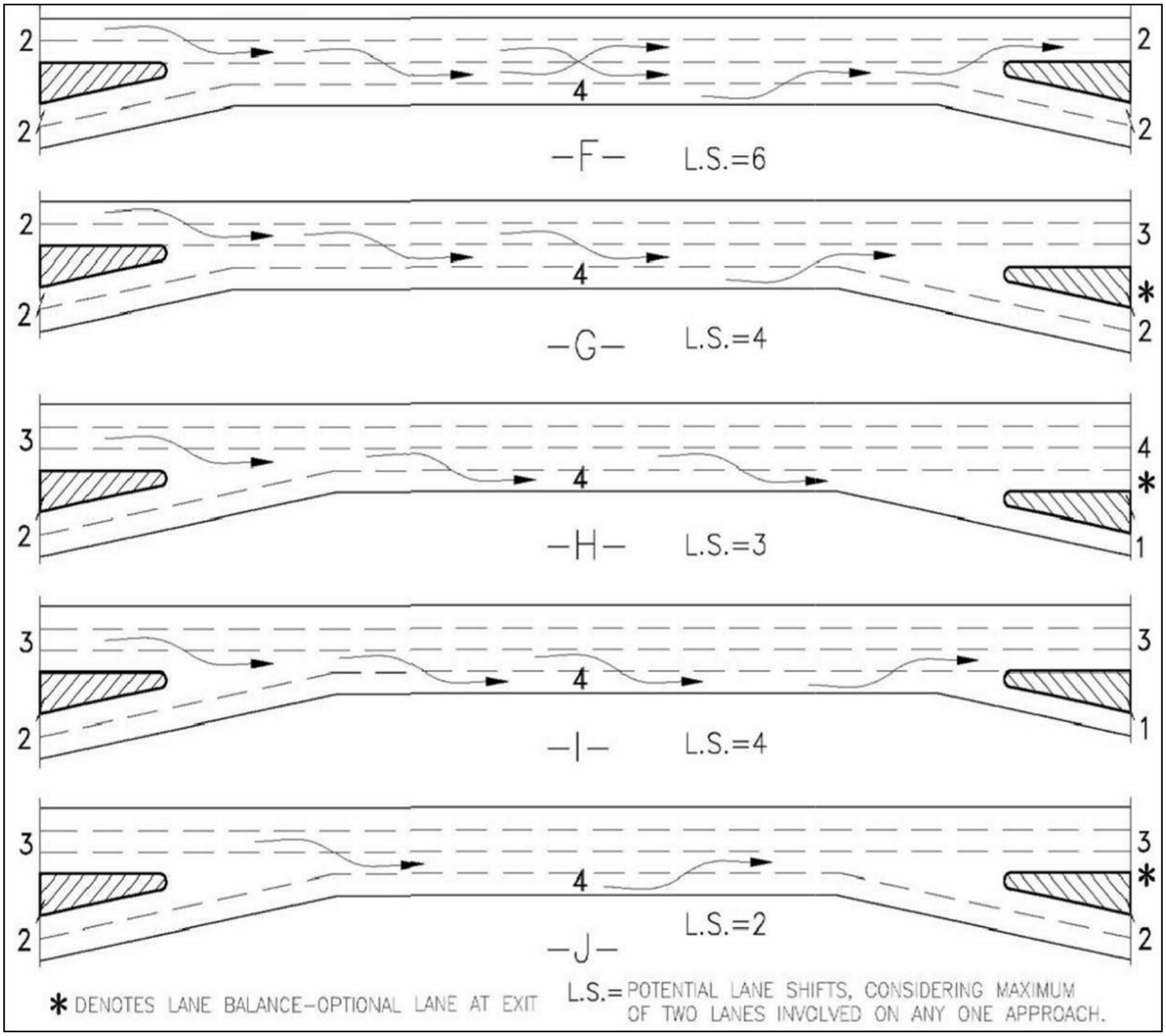


Figure 10-2D Lane Configuration of Weaving Sections



10.10.11 Collector-Distributor Roads

Collector-distributor roads between two interchanges and continuous collector-distributor roads are discussed in Chapters 8 and 10 of the 2018 AASHTO GDHS.

10.10.12 Two-Exit Versus Single-Exit Interchange Design

In general, interchanges that are designed with single exits are preferred over those with two exits, especially if one of the exits is a loop ramp or the second exit is a loop ramp preceded by a loop entrance ramp. Whether used in conjunction with a full cloverleaf or with a partial cloverleaf interchange, the single-exit design may improve operational efficiency of the entire facility.

When designing a two-lane exit, it is advantageous to develop a single drop lane (right most lane) and a "choice lane" in which the motorist in the second (left hand lane) can either exit

to the interchange or continue past the interchange along the roadway. This can help to avoid sudden lane changes at the last minute when a motorist is deciding to exit or not and will reduce the potential for high-speed side-swipe crashes due to sudden lane changes.

10.10.13 Wrong-Way Entrances

Wrong-way entrance onto freeways and arterial streets is not a frequent occurrence, but it should be regarded as a serious problem whenever the likelihood exists, because each occurrence has such a high potential for culminating in a serious crash. This problem should be given special consideration at all stages of design. Most wrong-way entrances occur at freeway off ramps, at intersections at-grade along divided arterial streets, and at transitions from undivided to divided highways.

Refer to Chapter 10 of the 2018 AASHTO GDHS for more information.

10.11 Ramps

10.11.1 Types and Examples

The term "ramp" includes all types, arrangements, and sizes of turning roadways that connect two or more legs at an interchange. The components of a ramp are a terminal at each leg and a connecting road, usually with some curvature, and on a grade. Generally, the horizontal and vertical alignment standards of ramps are below that of the intersecting highway, but in some cases it may be equal. The basic types of ramps are:

- Diagonal.
- One quadrant.
- Loop and semidirect.
- Outer connection.
- Directional.

For further information on these basic ramp types, refer to Chapter 10 of the 2018 AASHTO GDHS.

10.11.2 General Ramp Design Considerations

Desirably, ramp design speeds should approximate the low-volume running speed on the intersecting highways. This design speed is not always practical, and lower design speeds may be selected, but they should not be less than the low range presented in Table 10-1 at this end of this section. Only those values for highway design speeds of at least 50 mph apply to freeway and expressway exits.

Consider the following when applying the values in Table 10-1 to various conditions and ramp types:

- *Portion of ramp to which design speed is applicable.* Values in Table 10-1 apply to the sharpest, or controlling, ramp curve, usually on the ramp proper. These speeds do not pertain to the ramp terminals, which should be properly transitioned and provided with speed-change facilities adequate for the highway speed involved.

- *Ramps for right turns.* An upper range value of design speed is often attainable on ramps for right turns, and a value between the upper and lower range is usually practical. The diamond ramp of a diagonal interchange may also be used for right turns. For these diagonal ramps, a value in the middle range is usually practical.
- *Semi-direct connections.* Design speeds between the middle and upper ranges shown in Table 10-1 should be used. A design speed less than 30 mph should not be used. Generally, for short single-lane ramps, a design speed greater than 50 mph is not practical. For two-lane ramps, values in the middle and upper ranges are appropriate.
- *Direct connections.* Design speeds between the middle and upper ranges shown in Table 10- 1 should be used. The minimum design speed preferably should be 40 mph.
- *Different design speeds on intersecting highways.* The highway with the greater design speed should be the control in selecting the design speed for the ramp as a whole. However, the ramp design speed may vary, the portion of the ramp closer to the lower speed highway being designed for the lower speed. This variation in ramp design speed is particularly applicable where the ramp is on an upgrade from the higher speed highway to the lower speed highway.
- *At-grade terminals.* Where a ramp joins a major cross road or street, forming an intersection at grade, Table 10-1 is not applicable to that portion of the ramp near the intersection because a stop sign or signal control is normally employed. This terminal design should be predicated on near-minimum turning conditions, as given in Chapter 8 of this Guide. In urban areas, where the land adjacent to the interchange is developed commercially, provisions for pedestrian movements through the interchange area should be considered.
- *Loops.* Upper-range values of design speed generally are not attainable on loop ramps. Ramp design speeds above 30 mph for loops involve large areas, rarely available in urban areas, and long loops, which are costly and require left-turning drivers to travel a considerable extra distance. Minimum values usually control, but for highway design speeds of more than 50 mph, the loop design speed preferably should be no less than 25 mph (150-foot radius). If less restrictive conditions exist, the loop design speed and the radius may be increased.

If lower-range design speeds are used for ramps, consideration should be made for additional acceleration/deceleration length and warning signs.

Refer to Chapter 10 of the 2018 AASHTO GDHS on Curvature.

10.11.3 Bicyclist and Pedestrian Integration

Integration of pedestrians and bicyclists needs strong consideration due to the inherent nature of the high vehicle speeds on facilities with interchanges and the driver expectations that they will not encounter pedestrians or cyclists. To provide the safest environment for the pedestrian and bicyclist, it is advisable to include separated shared-use paths that run parallel to the freeway; and to provide traffic signals with pedestrian/bicycle phases in the signal timing at ramp terminal intersections with high traffic volumes so pedestrians and bicyclists can safely cross the ramp terminals.

10.11.4 Stopping Sight Distance

Stopping sight distance along a ramp should be at least as great as the design stopping sight distance. Stopping sight distance consistent with the design speed as shown in Table 6-1 should be provided on each ramp of an interchange. Sight distance for passing is not required. There should be a clear view of the entire exit terminal, including the exit nose and a section of the ramp pavement beyond the gore. Decision sight distance should be provided when drivers must make complex or instantaneous decisions within interchanges.

If the exit terminal is signalized or stop controlled, design the terminal as an at-grade intersection and refer to Chapter 8 of this Guide or the 2018 AASHTO GDHS.

10.11.5 Ramp Profiles

Ramp profiles generally consist of a section of tangent grade between the vertical curves. The tangent or controlling grade on ramps should be as flat as feasible, but may be steeper than on the through facilities. Adequate sight distance is more important than a specific gradient control and should be favored in design. Consider the following:

- It is desirable that upgrades on ramps with a design speed of 45 to 50 mph be limited to 3 to 5%.
- Upgrades on ramps having a design speed of 40 mph should be limited to 4 to 6%
- Upgrades on ramps having design speeds of 25 to 30 mph should be limited to 5 to 7%.
- Upgrades on ramps having a design speed of 15 to 25 mph should be limited to 6 to 8%.
- Downgrades preferably should be limited to 3 to 4% on ramps with sharp horizontal curvature and significant heavy truck or bus traffic. Short upgrades of as much as 5% do not unduly interfere with truck and bus operation.
- Ramps with high design speeds or those joining high-speed highways generally should have flatter grades than ramps with low design speeds or minor, light-volume ramps.

Usually ramp profiles assume the shape of the letter "S," with a sag vertical curve at the lower end and a crest vertical curve at the upper end. Additional vertical curves may be necessary, particularly on ramps that cross under or over other roadways. Where a crest or sag vertical curve extends onto a ramp terminal, the length of the curve should be determined by using a design speed intermediate between those on the ramp and the highway. Minimum lengths of crest vertical curves on ramps are based on stopping sight distance as shown in Chapter 3 of this Guide.

The design controls for sag vertical curves differ from those for crests; therefore, separate design values are needed. Minimum values of sag vertical curves are based on values of K and stopping sight distance, as shown in Chapter 3 of this Guide.

Profiles of ramp terminals should be designed in association with horizontal curves to avoid sight restrictions that adversely affect operations. At an exit onto a ramp on a descending grade, a horizontal curve ahead should not appear suddenly to a driver using the ramp. Instead, the initial crest vertical curve should be made longer and sight distance over it increased so that the beginning and the direction of the horizontal curve are obvious to the driver in time for safe operations. At an entrance terminal from a ramp on an ascending grade, the portion of the ramp and its terminal intended for acceleration should closely parallel the through lane profile to permit entering drivers to have a clear view ahead, to the side, and to the rear on the through road.

A "platform" area should be provided at the at-grade terminal, approach nose, and merging end of a ramp. This platform should be an area on which the profile and cross slope do not greatly differ from that of the through traffic lane. The length of this platform should be determined from the type of traffic control and the capacity at the terminal but is typically at least 200 feet. For further discussion, refer to Chapter 9, Figure 9-44 through 9-47 of the 2018 AASHTO GDHS.

In addition, an aesthetics analysis of each alternate preliminary plan should be conducted. A ramp design that meets all design requirements may have objectionable features that can be eliminated with small changes. Examples of objectionable features are:

- Humps or rolls in a ramp profile.
- Short reverse curvature in ramp alignment.
- Abrupt grade changes when ramp termini profile meets crossroad cross slope.

Where the main roadway in level terrain is taken over a cross road, an undesirable hump may appear in the ramp profile unless the ramp exit splits away from the main roadway before the main roadway begins to rise.

Short reverse curvature introduced in ramp alignment to obtain separation of ramp and main roadway in a short distance should be avoided because it is impossible to obtain proper superelevation of the curves without an intervening length of tangent for superelevation transitions between the reversing curves.

10.11.6 Ramp Horizontal Geometrics and Superelevation

Ramp design should be looked at as a three-dimensional system to analyze the facility to function as anticipated. For example, the ramp gores and sight distance need to be evaluated from a safety aspect and may require the designer to provide sight distances greater than the minimum stopping sight distance and using above minimum design criteria for other geometric elements. The vertical and horizontal coordination is particularly critical when horizontal curves occur at the end of a downgrade and at the top of a vertical curve. The maximum speed differential between adjacent alignment elements should not exceed 10 miles/hour. These conditions are typical of interchange ramp design. Each ramp terminal is considered its own intersection design for interchanges unless signalized and signed with no right turn on red.

10.11.7 Superelevation and Cross Slope

Consider the following for cross slope design on ramps:

- Superelevation as related to curvature and design speed on ramps is given in CDOT Standard Plans – M & S Standards (CDOT, 2019). Where drainage impacts to adjacent property or the frequency of slow-moving vehicles are important considerations, the superelevation rates and corresponding radii in Figure 6-16 of the 2018 AASHTO GDHS can be used.

- The superelevation development starts or ends along the auxiliary lane of the ramp terminal. Alternate profile lines for both edges should be studied so that all profiles match the control points and there are no unsightly bumps and dips. Spline profiles are very useful in developing smooth lanes and shoulder edges.
- Another important control in developing superelevation along the ramp terminal is the crossover crown line at the edge of the through traffic lane. The maximum algebraic difference in cross slope between the auxiliary lane and the adjacent through lane is shown in Table 10-1.
- Three segments of a ramp should be analyzed to determine superelevation rates that would be compatible with the design speed and the configuration of the ramp. The exit terminal, the ramp proper, and the entrance terminal should be studied in combination to ascertain the appropriate design speed and superelevation rates.
- Drainage and icing issues should be considered when transitioning between superelevations.

Table 10-1 Maximum Algebraic Difference in Pavement Cross Slope at Turning Roadway Terminals

Design Speed of Exit or Entrance Curve (mph)	Maximum Algebraic Difference in Cross Slope at Crossover Line (%)
20 and under	5.0 to 8.0
25 and 30	5.0 to 6.0
35 and over	4.0 to 5.0

10.12 Interchange Design Criteria

10.12.1 General

The following design criteria pertain to design elements of all grade separations and interchanges. Geometric and structure criteria for the design of the through highway within the interchange area are presented elsewhere in this Guide. Ramp design criteria are described in Section 10.11 of this chapter.

Grade separations and interchanges have a combination of channelization elements. Design criteria pertaining to intersections at grade are described in Chapter 8 of this Guide; design criteria unique to interchanges are included in this section.

10.12.2 Multimodal Considerations

Chapter 13 of this Guide provides design criteria for bicycle and pedestrian facilities.

10.12.3 Sight Distance

Sight distance on the highways through a grade separation or interchange should be at least as long as that required for stopping and preferably longer. Where exits are involved, decision sight distance is preferred, although not always practical. Design of the vertical alignment is the same as that at any other point on the highway. Ramp terminals at crossroads should be treated as at-grade intersections and should be designed in accordance with Chapter 9 of the 2018 AASHTO GDHS, with specific attention to intersection sight distance.

At underpasses, care should be taken to ensure that the vertical sight distance is not limited by the bottom of the girders of the overpassing structure. This may occur at locations where the highway is depressed for a short distance and the maximum grades and minimum sag vertical curves are used under the structure. Particular attention should be given to trucks, where the sight distance is further limited because of the higher driver's height of eye.

The horizontal sight distance limitations of piers and abutments at curves usually present a more difficult problem than that of vertical limitations. With curvature of the maximum degree for a given design speed, the normal lateral offset of piers or abutments of underpasses does not provide the minimum stopping sight distance.

Similarly, on overpasses with the sharpest curvature for the design speed, sight deficiencies result from the usual practical shoulder offset to the bridge rails. This factor emphasizes the need for use of below-maximum curvature on highways through interchanges. If sufficiently flat curvature cannot be used, the clearances to abutments, piers, or bridge rails should be increased as necessary to obtain the proper sight distance even though it is necessary to increase span lengths or structure widths.

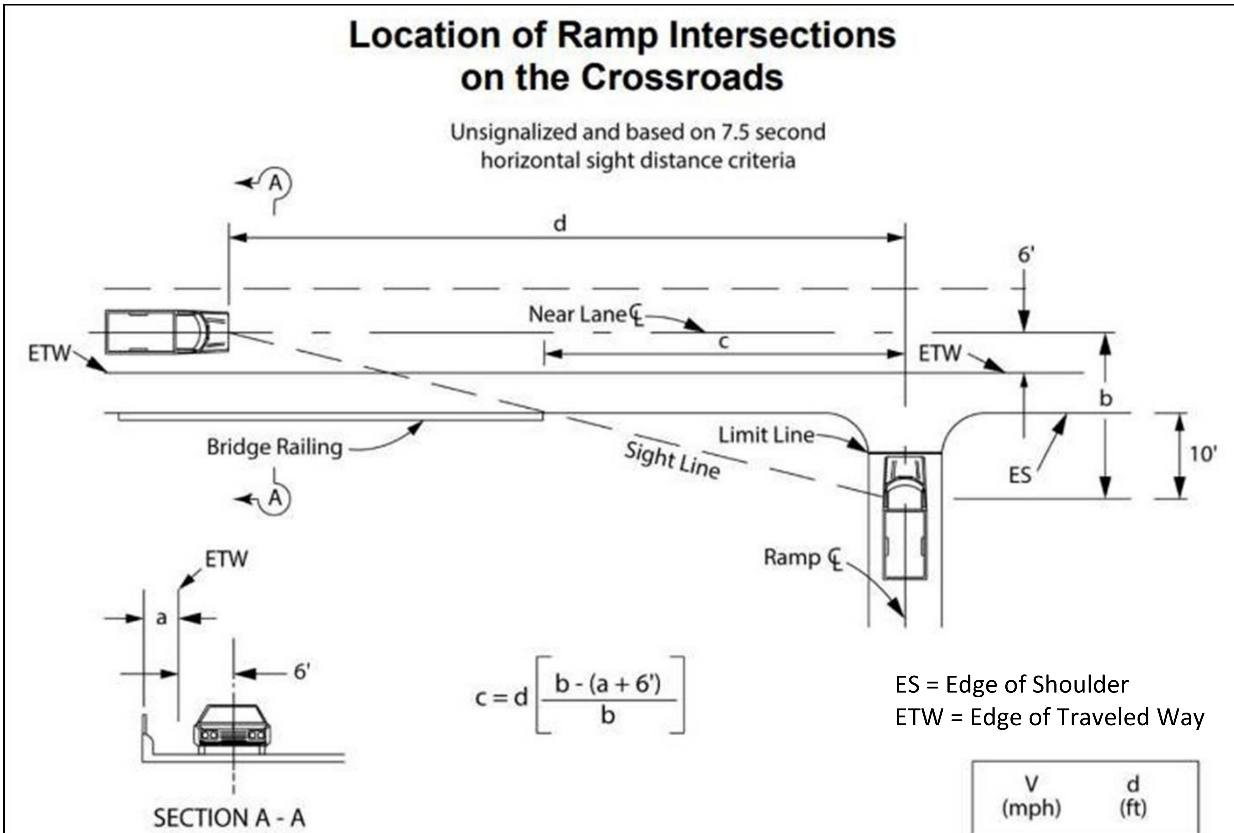
Normally, no more than 12 feet are allowed on overpass structures for the lateral offset from the lane line to the bridge rail. Exceptions can be made for future lanes or for construction phasing requirements when replacing existing structures. Refer to Section 8.3 for additional information about lateral clearances on structures.

10.12.4 Sight Distance to Exit Nose

A clear view of the entire exit ramp terminal is desired, including the exit nose and a section of the ramp pavement beyond the gore. The sight distance on a freeway preceding the approach nose of an exit ramp should exceed the minimum for the through traffic design speed, desirably by 25% or more. In addition, the minimum sight triangle shown in Figure 10-3 and Figure 10-4 should be provided between vehicles approaching the ramp intersections. For considerations of longer sight distances, refer to Chapter 3 of this Guide.

Decision sight distance given in Chapter 6 of this Guide is preferred at all freeway exits and branch connections. In all cases, sight distance is measured to the center of the ramp lane right of the nose. Refer to Chapter 8 of this Guide.

Figure 10-3 Location of Ramp Intersections on the Cross Road



$$c = d\left[\frac{b - (a + 6')}{b}\right]$$

V (mph)	d (ft)
25	275
30	330
35	385
40	440
45	495
50	550
55	605
60	660
65	715
70	770

a = Distance from edge of traveled way to bridge railing.

b = Distance from center of near lane to eye of ramp vehicle driver. Ramp driver's eye is assumed to be located 10′ from the edge of shoulder, but not less than 15′ from the ETW (therefore, b = 6′ + shoulder width + 10′). See Index 405.1.

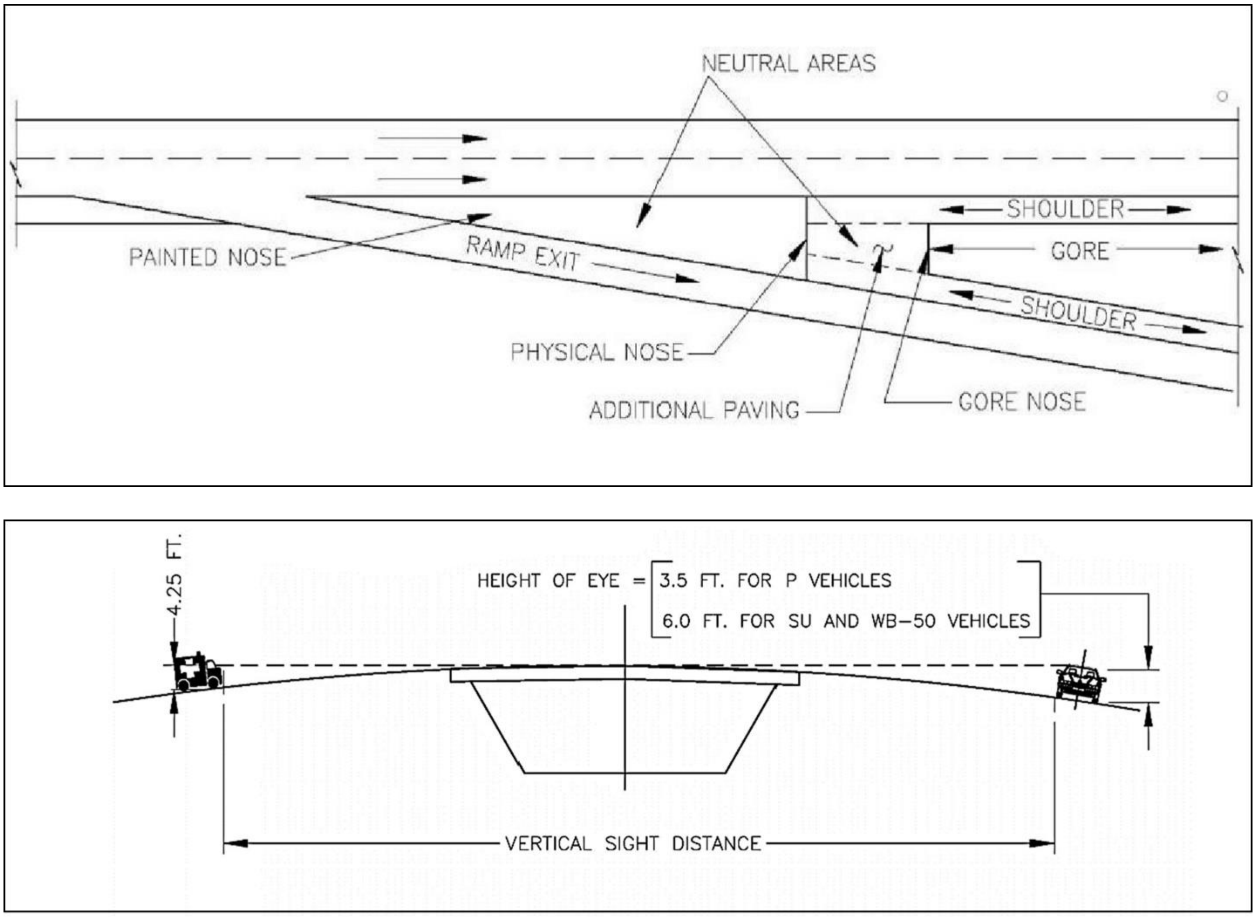
c = Ramp set back from end of bridge railling.

d = Corner Sight distance along highway from intersection. (See Table above) Sight distance is measured from a 3½′ eye height on the ramp to a 4¼′ object height on the crossroad.

V = Anticipated prevailing speed on crossroad.

ETW = Edge of Traveled Way; ES = Edge of Shoulder.

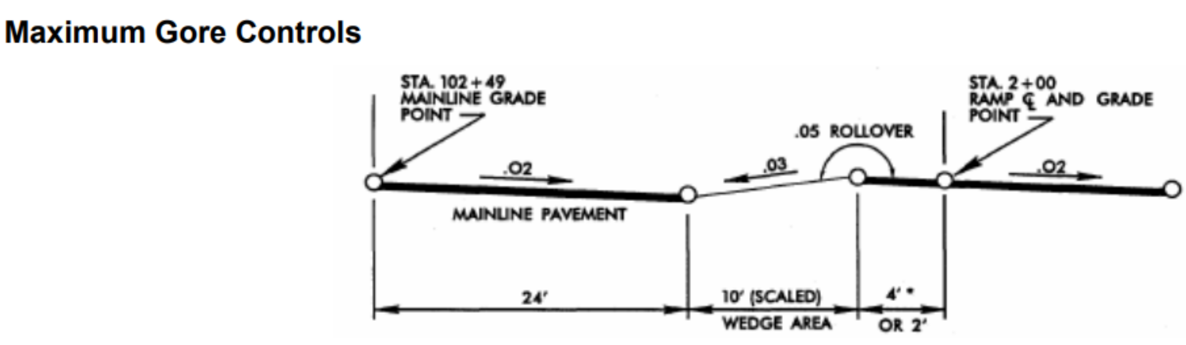
Figure 10-4 Measurement of Sight Distance at Ramp Terminals with Stop Control



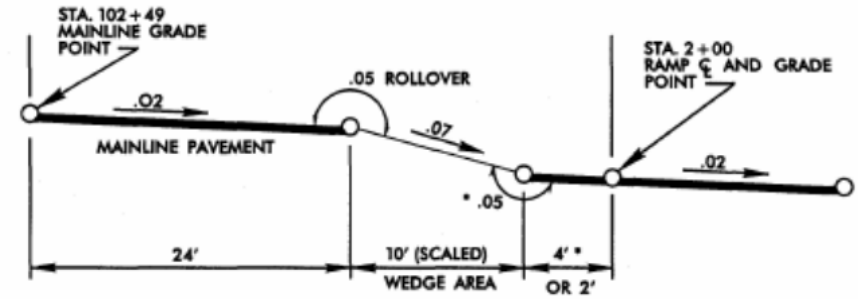
10.12.5 Gores

The term "gore" indicates an area downstream from the shoulder intersection points, as illustrated in Figure 10-5.

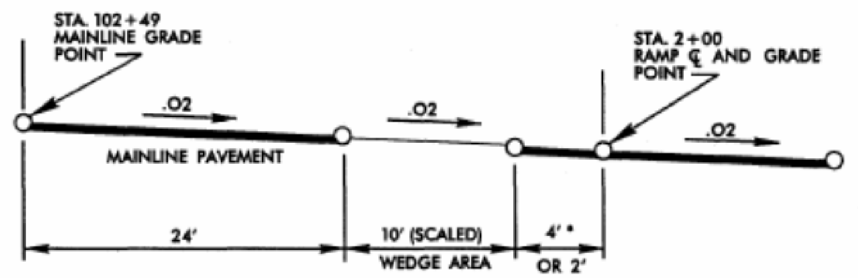
Figure 10-5 Typical Gore Area Controls



Minimum Gore Controls



Desirable Gore Controls



It is the decision point area that must be clearly seen and understood by approaching drivers. Further, the separating ramp roadway must be clearly evident and must be of geometric shape to fit the likely speeds at that point. In a series of interchanges along a freeway, the gores should be uniform and have the same general appearance.

As a general rule, the width at the gore nose is typically between 20 and 30 feet, including paved shoulders, measured between the traveled way of the main line and that of the ramp. This dimension may be increased if the ramp roadway curves away from the freeway immediately beyond the gore nose or if speeds in excess of 60 mph are expected to be common.

The entire triangular area should be striped to delineate the proper paths on each side and to assist the driver in identifying the gore area.

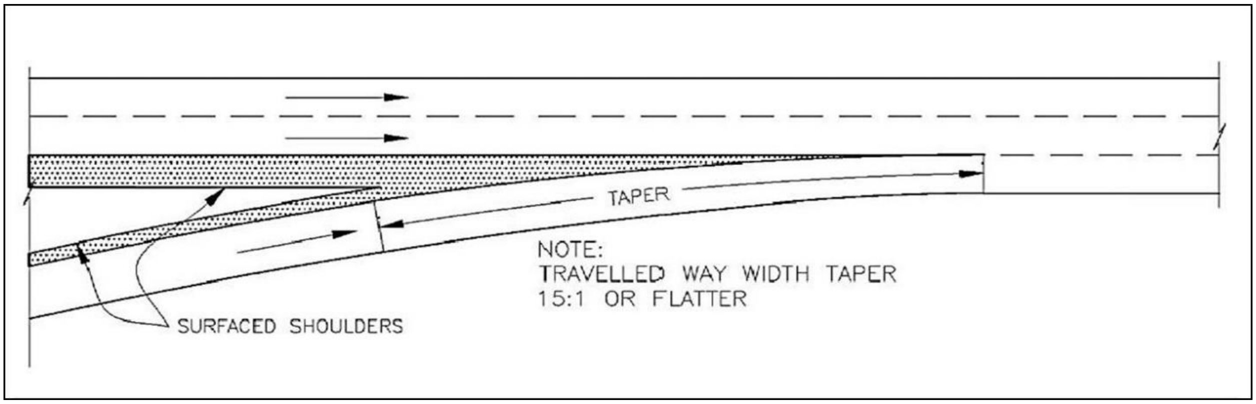
It is imperative that gore areas and the areas beyond provide clear recovery area for out-of-control-vehicles or for drivers who decide at the last second not to exit. Additional paving should be placed in the neutral area between the physical nose and the gore nose to allow drivers to recover after starting their exit maneuver.

The gore area and the unpaved area beyond should be kept as free of obstructions as possible to create a clear recovery area. The unpaved area beyond the nose should be graded as nearly level with the roadways as is practicable so that vehicles inadvertently entering are not overturned or abruptly stopped by steep slopes. Heavy sign supports, street light standards, and roadway structure supports should be kept well out of the graded gore area. Yielding or breakaway type supports should be used for the standard exit sign, and concrete footings, where used, should be kept flush with adjoining ground level. If non-yielding obstructions are unavoidable in the gore area, impact attenuators should be considered.

The term "gore" can refer to the area between a through roadway and an exit ramp or between a through roadway and a entrance ramp. At an entrance terminal, the point of convergence (beginning of all paved area) is defined as the "merging end." In shape, layout, and extent, the triangular maneuver area at an entrance terminal is much like that at an exit. However, it points downstream and separates traffic streams already in lanes, thereby being less of a decision area. The width at the base of the paved triangular area is narrower, usually limited to the sum of the shoulder widths on the ramp and freeway plus a narrow physical nose 4 to 8 feet wide.

Figure 10-6 diagrammatically details a typical gore design for an entrance ramp.

Figure 10-6 Traveled Way Narrowing on Entrance Ramps



10.12.6 Ramp Pavement Widths

10.12.6.1 Width and Cross Section

Ramp pavement widths are governed by the type of operation, curvature, volume, and type of traffic. It should be noted that the roadway width for a turning roadway, as distinct from pavement width, includes shoulders or equivalent clearance outside the edges of pavement. Refer to Chapter 3 of this Guide for additional information on the treatments at the edge of pavement. Design widths of ramp pavements for three general design traffic conditions are given in Table 8-1 (Design Widths of Pavements for Turning Movements) of this Guide.

10.12.6.2 Shoulders and Lateral Clearances

Design values for shoulders and lateral clearances on the ramps are as follows:

- Paved shoulders on ramps should have a uniform width for the full length of ramp. For one-way operation, the sum of the right and left shoulder widths should not exceed 10 to 12 feet. A paved shoulder width of 2 to 4 feet is desirable on the left, with the remaining width of 8 to 10 feet used for the paved right shoulder.

- The ramp traveled way widths from Table 3-29 of the 2018 AASHTO GDHS for Case II and Case III should be modified when there are paved shoulders on the ramp. The ramp traveled-way width for Case II should be reduced by the total width of both right and left shoulders. However, in no case should the ramp traveled way be less than needed for Case I. For example, with condition C and a 400-foot radius, the Case II ramp traveled-way width without shoulders is 22 feet. If a 2-foot left shoulder and an 8-foot right shoulder are provided, the minimum ramp traveled-way width should be 16 feet.
- Directional ramps with a design speed over 40 mph should have a paved right shoulder width of 8 to 10 feet and a paved left shoulder width of 1 to 6 feet.
- For freeway ramp terminals where the ramp shoulder is narrower than the freeway shoulder, the paved shoulder width of the through lane should be carried into the exit terminal. It should also begin with the entrance terminal, with the transition to the narrower ramp shoulder accomplished gracefully on the ramp end of the terminal. Abrupt changes should be avoided.
- Ramps should have a lateral clearance on the right outside of the edge of the traveled way of at least 6 feet, and preferably 8 to 10 feet; and a lateral clearance on the left of at least 4 feet beyond the edge of traveled way.
- Where ramps pass under structures, the total roadway width should be carried through the structure. Desirably, structural supports should be located beyond the clear zone. At a minimum, structural supports should be at least 4 feet beyond the edge of paved shoulder. The AASHTO Roadside Design Guide (AASHTO, 2011) provides guidance on the clear zone and the use of roadside barriers.
- Ramps on overpasses should have the full approach roadway width carried over the structure.
- Edge lines or some type of color or texture differentiation between the traveled way and shoulder are desirable.

10.12.7 Ramp Terminals

The terminal of the ramp is that portion adjacent to the through traveled way, including speed-change lanes, tapers, and islands. Ramp terminals may be the at-grade type as at the crossroad terminal of diamond or partial cloverleaf interchanges, or the free-flow type where ramp traffic merges with or diverges from high-speed through traffic at flat angles. Design elements for the at-grade ramp terminals are discussed in Chapter 8 of this Guide; Free-flow ramp terminals are discussed in the following sections.

Terminals are further defined according to the number of lanes on the ramp terminal, either single or multilane, and according to the configuration of the speed-change lane, either taper type or parallel type.

10.12.7.1 Right-Hand Entrances and Exits

Freeway entrances and exits typically connect to the right of through traffic. Right-hand entrances and exits operate fairly well and do not violate the concept of driver expectancy.

10.12.7.2 Left-Hand Entrances and Exits

Because left-hand entrances and exits are contrary to driver expectancy, it is recommended to avoid their use in an interchange and on high-speed, free-flow ramp terminals. Special attention should be given to the weaving movements from adjacent right-hand entrances or exits, appropriate advanced signing, and adequate decision sight distance that can alert the driver to an unusual situation.

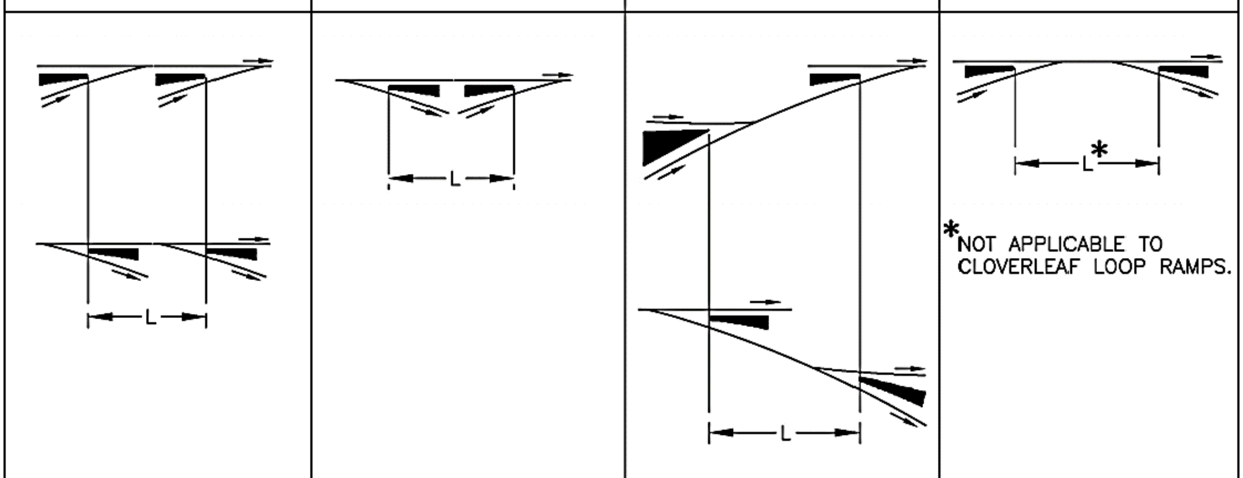
At major forks and branch connections, the less significant roadway should exit and enter on the right. Refer to the discussion on route continuity in Chapter 10 of the 2018 AASHTO GDHS.

Left-side terminals break up the uniformity of interchange patterns and, in general, result in driver hesitancy. Left-hand entrances and exits in an interchange may be considered in unusual circumstances or for collector-distributor roads.

10.12.7.3 Terminal Location and Sight Distance

Freeway ramp entrances and exits should be located on tangent sections wherever possible to provide maximum sight distance and optimum traffic operations. Entrances and exits at left-hand curves, particularly curves requiring superelevation, should be avoided whenever possible. Ramp terminal spacing should conform to Figure 10-7 wherever practical.

Figure 10-7 Recommended Minimum Ramp Terminal Spacing



EN–EN OR EX–EX		EX–EN		TURNING ROADWAYS		EN–EX (WEAVING)			
FULL FREEWAY	CDR OR FDR	FULL FREEWAY	CDR OR FDR	SYSTEM INTERCHANGE	SERVICE INTERCHANGE	SYSTEM TO SERVICE INTERCHANGE		SERVICE TO SERVICE INTERCHANGE	
						FULL FREEWAY	CDR OR FDR	FULL FREEWAY	CDR OR FDR
MINIMUM LENGTHS MEASURED BETWEEN SUCCESSIVE RAMP TERMINALS (FEET)									
1000	800	500	400	800	600	2000	1600	1600	1000

EN = Entrance, CDR = Collector/Distributor Road, FDR = Freeway Distributor

10.13 Speed-Change Lanes

There are two general types of speed-change lanes: the taper and the parallel. The taper type has a direct entry or exit at a flat angle, whereas the parallel type has an added lane for changing speed. When conditions allow, CDOT prefers the parallel type.

Speed-change lanes are provided at all ramp connections. Minimum lengths are provided in Table 10-2 for the ramp types shown in Figure 10-8 and in Figure Table 10-3 for the ramp types shown in Figure 10-9. Table 10-4 identifies corrections to be applied when the speed-change lane grades are 3% or steeper.

Table 10-2 Minimum Deceleration Lengths for Exit Terminals with Flat Grades of 2% or Less

Highway Design Speed, mph (V)	Speed Reached, mph (V_A)	L = Deceleration Length, (ft) for Design Speed of Exit Curve, mph (V')								
		Stop Condition	15	20	25	30	35	40	45	50
		For Average Running Speed on Exit Curve, mph (V'_A)								
		0	14	18	22	26	30	36	40	44
30	28	235	200	170	140	---	---	---	---	---
35	32	280	250	210	185	150	---	---	---	---
40	36	320	295	265	235	185	155	---	---	---
45	40	385	350	325	295	250	220	---	---	---
50	44	435	405	385	355	315	285	225	175	---
55	48	480	455	440	410	380	350	285	235	---
60	52	530	500	480	460	430	405	350	300	240
65	55	570	540	520	500	470	440	390	340	280
70	58	615	590	570	550	520	490	440	390	340
75	61	660	635	620	600	575	535	490	440	390

Figure 10-8 Ramp Types for Table 10-2 (Exit Terminals)

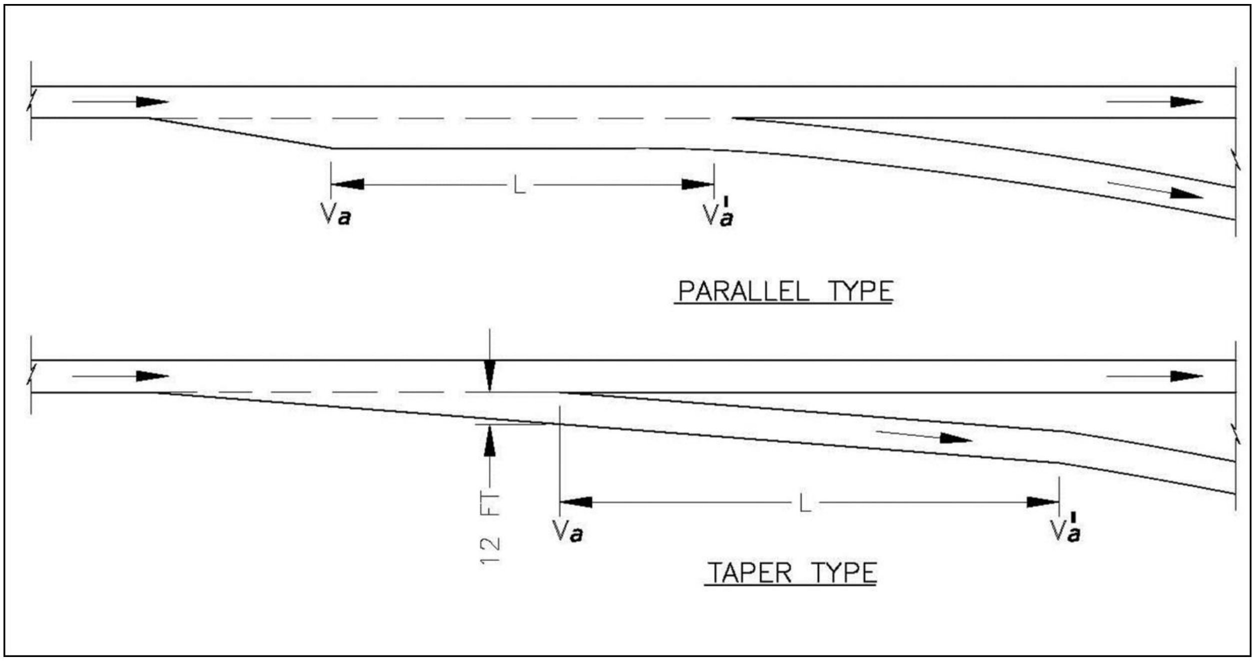


Table 10-3 Minimum Acceleration Lengths for Entrance Terminals with Flat Grades of 2% or Less

Highway Design Speed, mph (V)	Speed Reached, mph (V_A)	L = Acceleration Length, (ft) for Design Speed of Entrance Curve, mph								
		Stop Condition	15	20	25	30	35	40	45	50
		and initial speed, mph (V'_A)								
		0	14	18	22	26	30	36	40	44
30	23	180	140	---	---	---	---	---	---	---
35	27	280	220	160	---	---	---	---	---	---
40	31	360	300	270	210	120	---	---	---	---
45	35	560	490	440	380	280	160	---	---	---
50	39	720	660	610	550	450	350	130	---	---
55	43	960	900	810	780	670	550	320	150	---
60	47	1200	1140	1100	1020	910	800	550	420	180
65	50	1410	1350	1310	1220	1120	1000	770	600	370
70	53	1620	1560	1520	1420	1350	1230	1000	820	580
75	55	1790	1730	1630	1580	1510	1420	1160	1040	780

Uniform 50:1 to 70:1 tapers are recommended where lengths of acceleration lanes exceed 1,300 ft.

Figure 10-9 Ramp Types for Table 10-3 (Entrance Terminals)

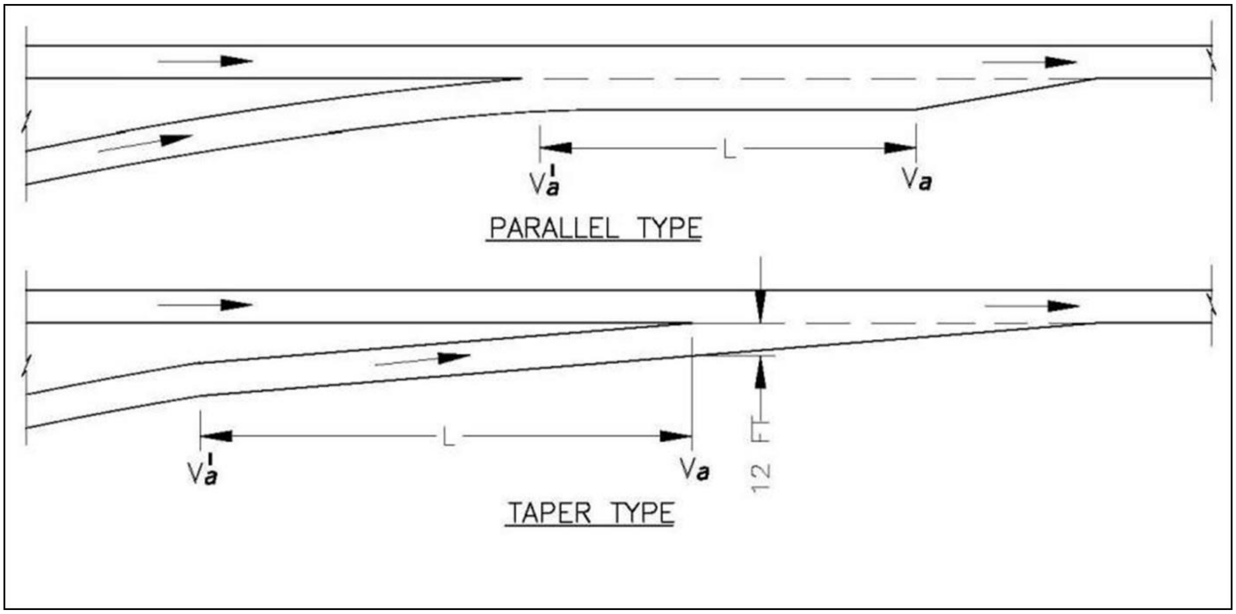


Table 10-4 Speed-Change Lane Adjustment Factors as a Function of Grade (All Terminal Types)

DESIGN SPEED OF HIGHWAY (mph)	Ratio of Length on Grade to Length on Level for Design Speed of Turning Curve (mph)[a]				
All speeds	3 to 4% UPGRADE 0.9				3 to 4% DOWNGRADE 1.2
All speeds	5 to 6% UPGRADE 0.8				5 to 6% DOWNGRADE 1.35
DESIGN SPEED OF HIGHWAY (mph)	**ACCELERATION LANES** **Ratio of Length on Grade to Length of Level for Design Speed of Turning Curve (mph)[*]**				
	DESIGN SPEED OF TURNING ROADWAY CURVE, mph				
	20	**30**	**40**	**50**	**All speeds**
	3 to 4% UPGRADE				**3 to 4% DOWNGRADE**
40	1.3	1.3	---	---	0.7
45	1.3	1.35	---	---	0.675
50	1.3	1.4	1.4	---	0.65
55	1.35	1.45	1.45	---	0.625
60	1.4	1.5	1.5	1.6	0.6
65	1.45	1.55	1.6	1.7	0.6
70	1.5	1.6	1.7	1.8	0.6
	5 to 6% UPGRADE				**5 to 6% DOWNGRADE**
40	1.5	1.5	---	---	0.6
45	1.5	1.6	---	---	0.575
50	1.5	1.7	1.9	---	0.55
55	1.6	1.8	2.05	---	0.525
60	1.7	1.9	2.2	2.5	0.5
65	1.85	2.05	2.4	2.75	0.5
70	2.0	2.2	2.6	3.0	0.5

* Ratio from this table multiplied by length in Table 10-3 or 10-4 gives length of speed-change lane on grade.

10.13.1 Single-Lane Free-Flow Terminals, Entrances

10.13.1.1 Entrance Ramp Terminals

Design of entrance ramp terminals should conform to the standard designs illustrated in Figure 10-10A, Figure 10-10B, Figure 10-11, and Figure 10-12. Single-lane ramps should be designed for a one-lane, passing-permitted operation. It is up to the designer, with the approval of the project manager, to determine the type of ramp terminal, taper type or parallel type, at each location, although there should be an effort to obtain consistency in a corridor.

Figure 10-10A Typical Single-Lane Entrance Ramps (Tapered)

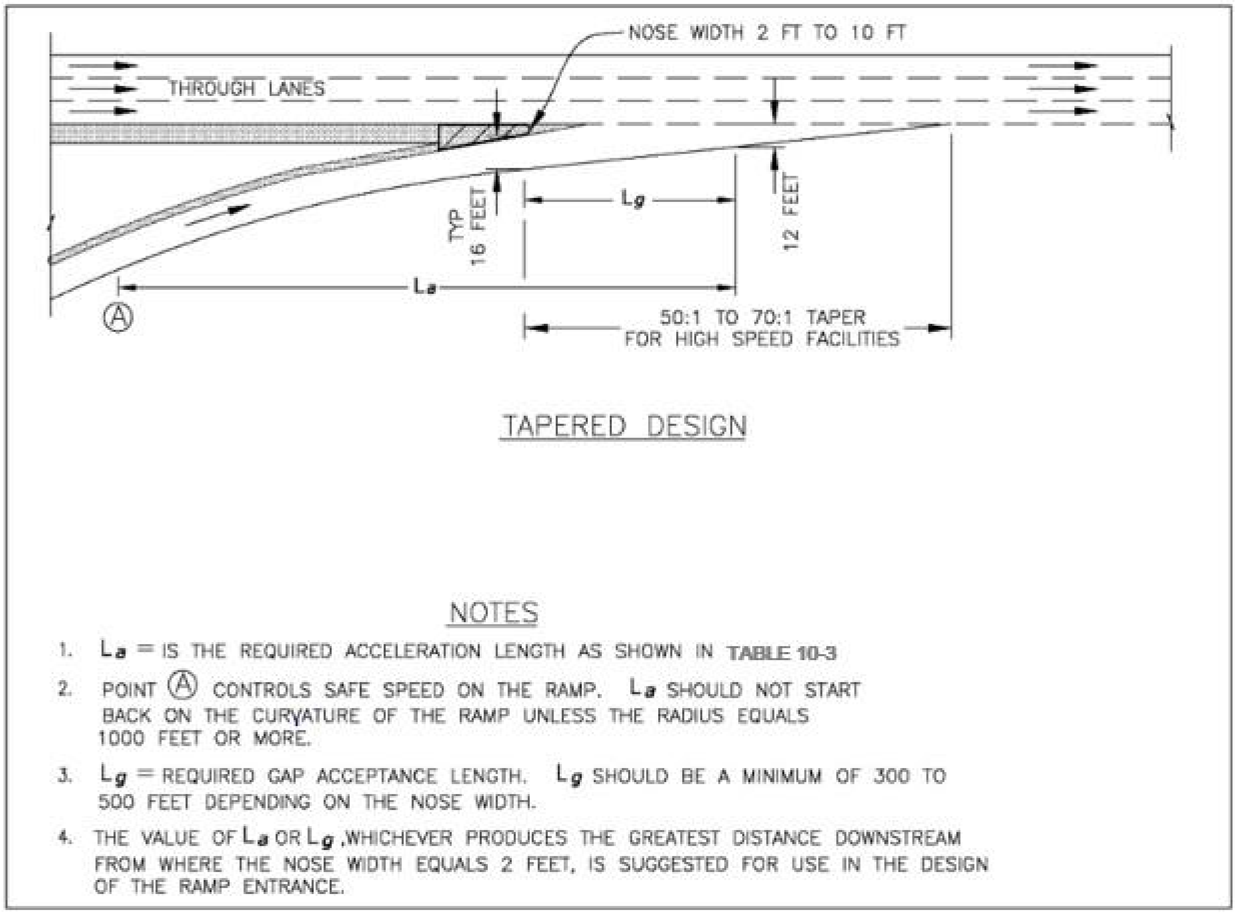
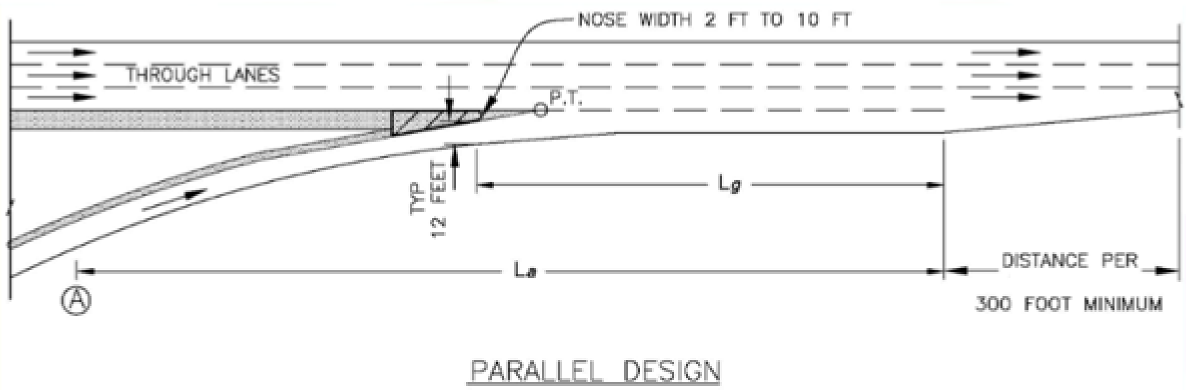


Figure 10-10B Typical Single-Lane Entrance Ramps (Parallel) (Preferred)



NOTES

1. L_a = IS THE REQUIRED ACCELERATION LENGTH AS SHOWN IN TABLE 10-3
2. POINT (A) CONTROLS SAFE SPEED ON THE RAMP. L_a SHOULD NOT START BACK ON THE CURVATURE OF THE RAMP UNLESS THE RADIUS EQUALS 1000 FEET OR MORE.
3. L_g = REQUIRED GAP ACCEPTANCE LENGTH. L_g SHOULD BE A MINIMUM OF 300 TO 500 FEET DEPENDING ON THE NOSE WIDTH.
4. THE VALUE OF L_a OR L_g, WHICHEVER PRODUCES THE GREATEST DISTANCE DOWNSTREAM FROM WHERE THE NOSE WIDTH EQUALS 2 FEET, IS SUGGESTED FOR USE IN THE DESIGN OF THE RAMP ENTRANCE.

Figure 10-11 Freeway Entrance Terminal (Taper Type)

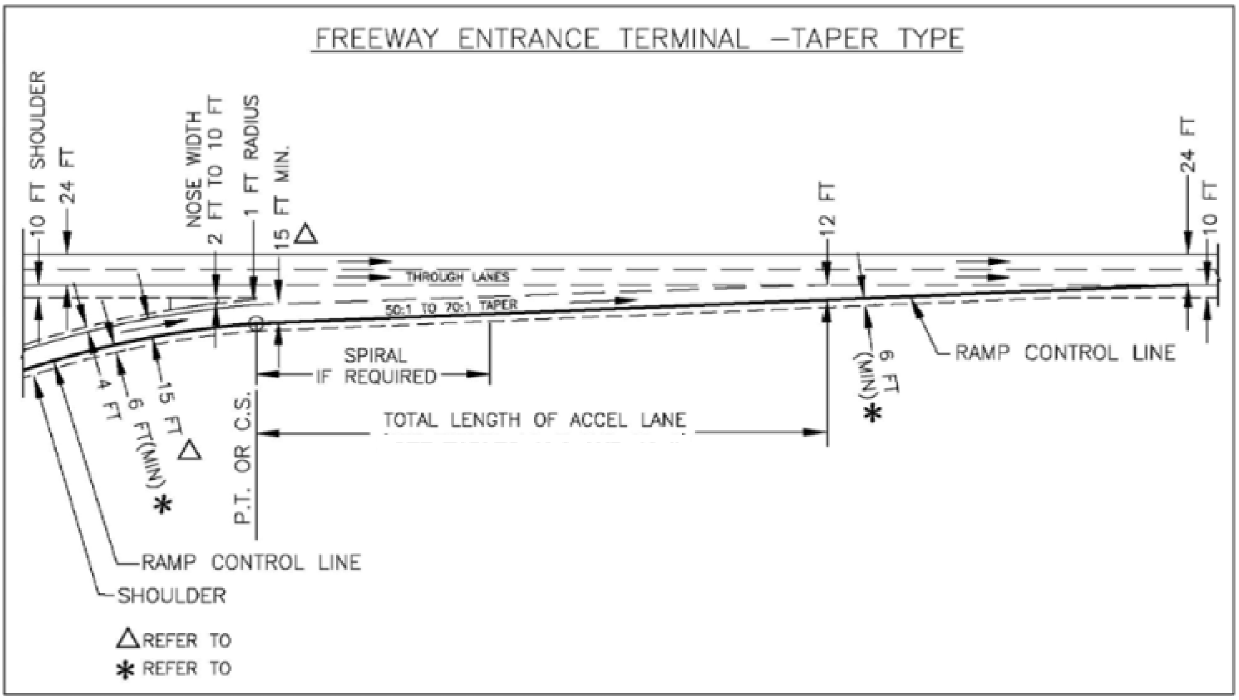
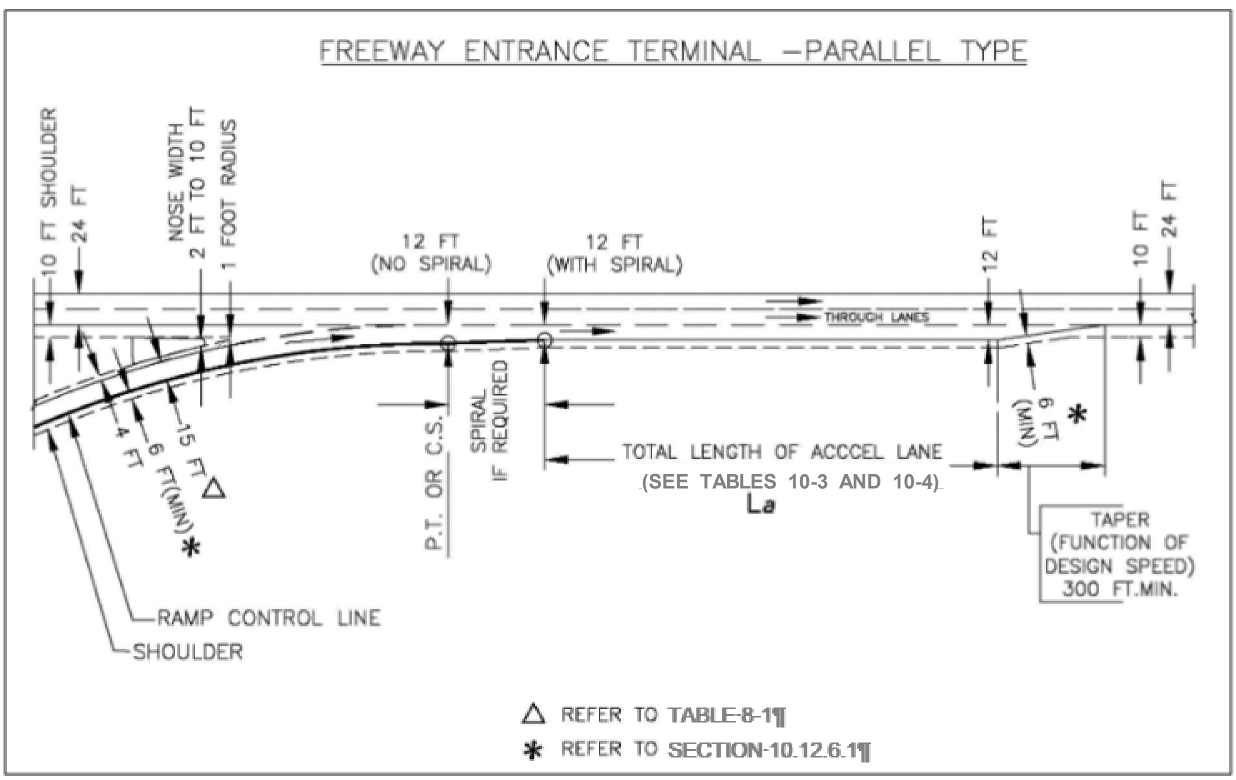


Figure 10-12 Freeway Entrance Terminal (Parallel Type) (Preferred)



10.13.2 Single-Lane Free-Flow Terminals, Exits

10.13.2.1 Exit Ramp Terminals

Design of exit ramp terminals should conform to the standard designs illustrated in Figure 10-13 and Figure 10-14. Single-lane ramps should be designed for a one-lane, passing-permitted operation. Table 10-5 details the minimum length of taper beyond an offset nose.

Figure 10-13 Freeway Exit Terminal (Taper Type)

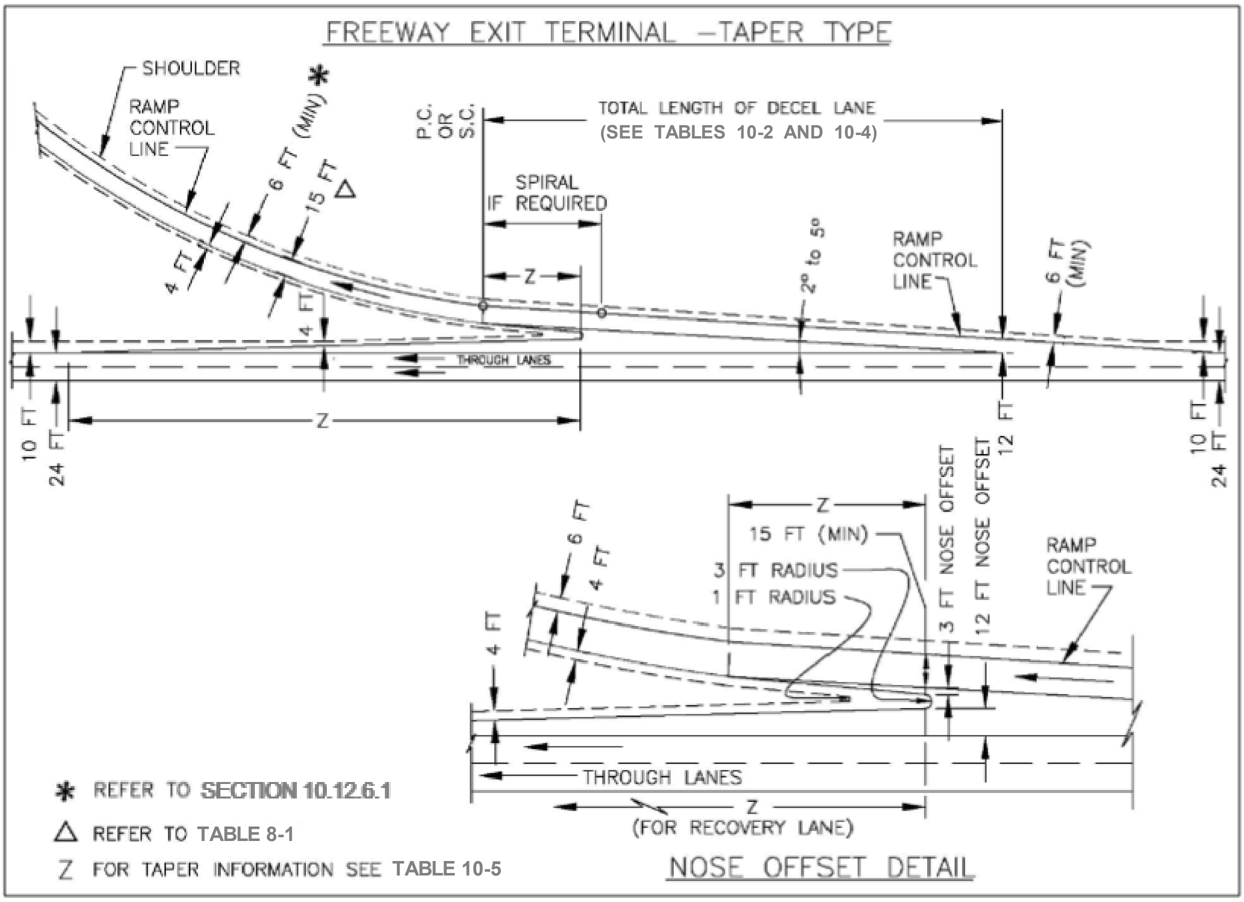


Figure 10-14 Freeway Exit Terminal (Parallel Type Z)

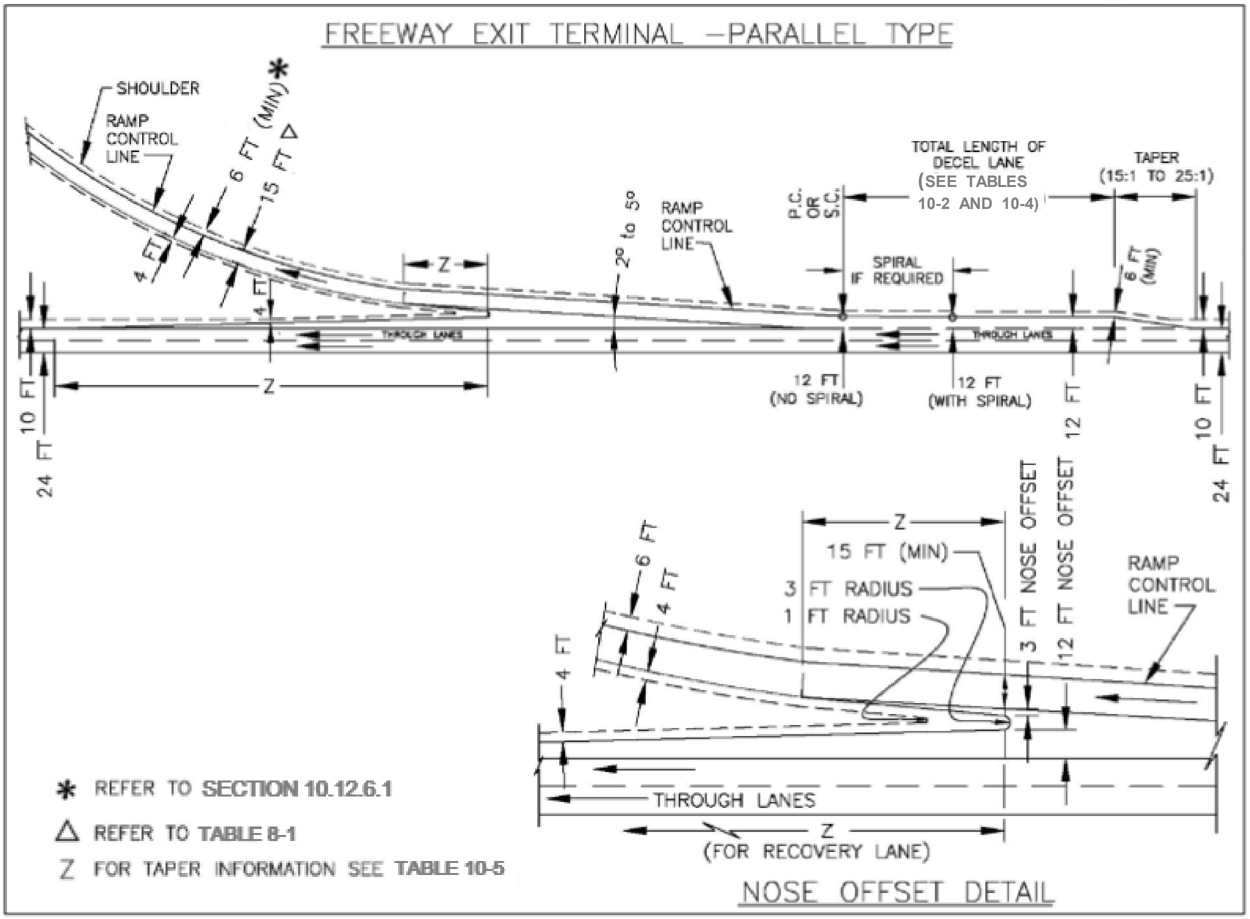


Table 10-5 Minimum Length of Taper Beyond an Offset Nose

Design Speed of Approach Highway	Length of Nose Taper (Z) Per Unit Width of Nose Offset
30	15.0
35	17.5
40	20.0
45	22.5
50	25.0
55	27.5
60	30.0
65	32.5
70	35.0
75	37.5

10.13.2.2 Taper Type Entrance

The taper type entrance of proper dimensions usually operates smoothly at all volumes up to and including the design capacity of merging areas. By relatively minor speed adjustment, the entering driver can see and use an available gap in the through-traffic lane. The taper type entrance accommodates proper superelevation transitions from the curve to the tangent section in the long, merging end area.

10.13.2.3 Parallel Type Entrance

The parallel type entrance is preferred over the taper type entrance. The parallel type has an added lane of sufficient length to enable a vehicle to accelerate to near-freeway speed prior to merging. A taper is provided at the end of the added lane. A 300-foot taper is the normal length of taper for design speeds up to 70 mph.

Desirably, a curve with a radius of 1,000 feet or more and a length of at least 200 feet should be provided in advance of the added lane. If this curve has a short radius, drivers tend to drive directly onto the freeway without using the acceleration lane, which results in an undesirable merging operation. The length of the parallel lane is generally measured from the point where the left edge of the traveled way of the ramp joins the traveled way of the freeway to the beginning of the taper. If the curve approaching the acceleration lane has a radius of 1,000 feet or more, and the driver has an unobstructed view of traffic on the freeway to the left, a part of the ramp proper may be considered part of the acceleration lane.

The operational and safety benefits of long acceleration lanes are well recognized, particularly where both the freeway and ramp carry high-traffic volumes. A long acceleration lane provides more time for the merging vehicles to find an opening in the through-traffic stream. An acceleration length of at least 1,200 feet, plus the taper, is desirable whenever it is anticipated that the ramp and freeway carry traffic volumes approximately equal to the design capacity of the merging area.

10.13.2.4 Parallel-Type Exits

A parallel-type exit terminal usually begins with a taper, followed by a derived length of added full lane that is parallel to the traveled way. This design assumes that a driver will exit near the beginning of the added lane, and slow down thereafter. It requires a reverse-curve maneuver that is somewhat unnatural. Some drivers may choose to avoid the reverse-curve exit path and turn directly off the through lane in the vicinity of the exit nose. This may result in undesirable deceleration on the through lane, in undesirable conflict on the deceleration lane, or in excessive speed in the exit-nose area.

The length of a parallel-type deceleration lane is usually measured from the point where the added lane attains a 12-foot width to the point where the alignment of the ramp roadway departs from the alignment of the freeway. Longer parallel-type deceleration lanes are more likely to be used properly.

The taper portion of the exit should be 15:1 to 25:1.

10.13.2.5 Taper Type Exits

The taper-type exit fits the direct path preferred by most drivers, permitting them to follow an easy path within the diverging area. Vehicles leave the through lane at a higher speed than on the parallel type, thereby reducing the possibilities of rear-end collisions. Deceleration is accomplished on the taper once the vehicle has left the through lane. The length for deceleration begins at the point where the deceleration lane is 12 feet wide and extends to the point controlling the safe speed for the ramp, usually the PC of the exit curve. The divergence angle is usually between 2 and 5 degrees.

The taper-type exit terminal design can be used advantageously in developing the desired long, narrow, triangular emergency maneuver area just upstream from the exit nose. The taper configuration also works well in the length-width superelevation adjustments to affect a ramp cross slope different from that of the through lane.

10.13.2.6 Free-Flow Terminals on Curves

If an exit ramp is required at a sharp left-hand curve, the change in superelevation from the main line to the ramp can be troublesome. Sometimes this change in superelevation can be transitioned smoothly using a long taper-type design.

A parallel-type design in this situation usually results in adverse superelevation on the exit curve. This can result in operational problems at the exit, particularly when snow and ice are present.

If an exit ramp is required near the beginning of a curve on the mainline, a taper-type exit may cause traffic in the right-most lane to follow the ramp. In this case, a separate and parallel ramp upstream of the PC may be required. Another option would be to move the exit taper to a point in advance of the PC of the curve thus avoiding the tendency of traffic in the right-most lane to follow the ramp. Refer to Figure 10-71 of the 2018 AASHTO GDHS for layout.

10.13.2.7 At-Grade Terminals

Ramps in metropolitan areas may require additional lanes to provide storage space for vehicles waiting to cross or enter heavy city street traffic. Refer to Figure 10-15A and Figure 10-15B for examples of a single-lane ramp exit transition to two lanes. Contact the Region Traffic Engineer for required storage lengths.

Figure 10-15A Single-Lane Ramp Exit Transition to Two Lanes (Alternate A)

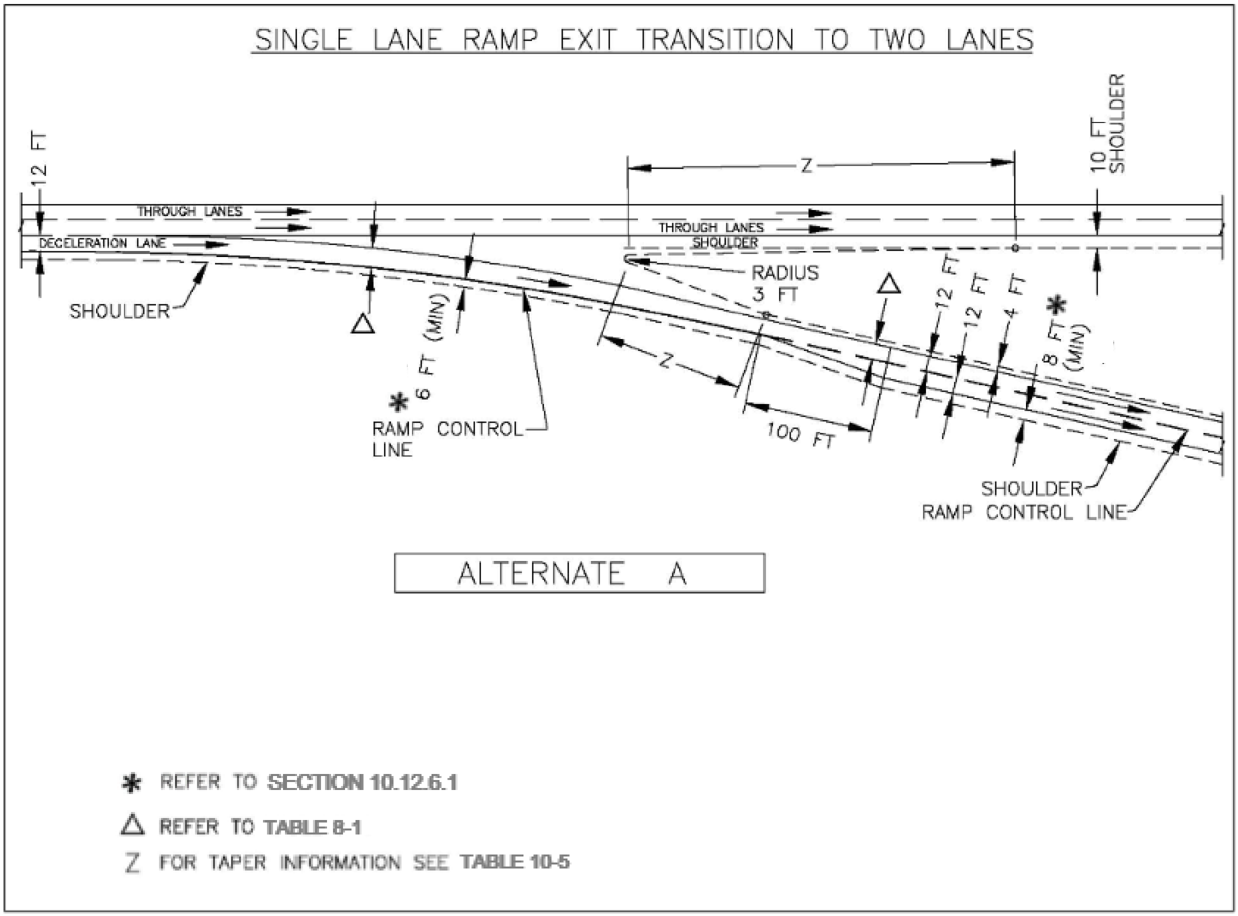
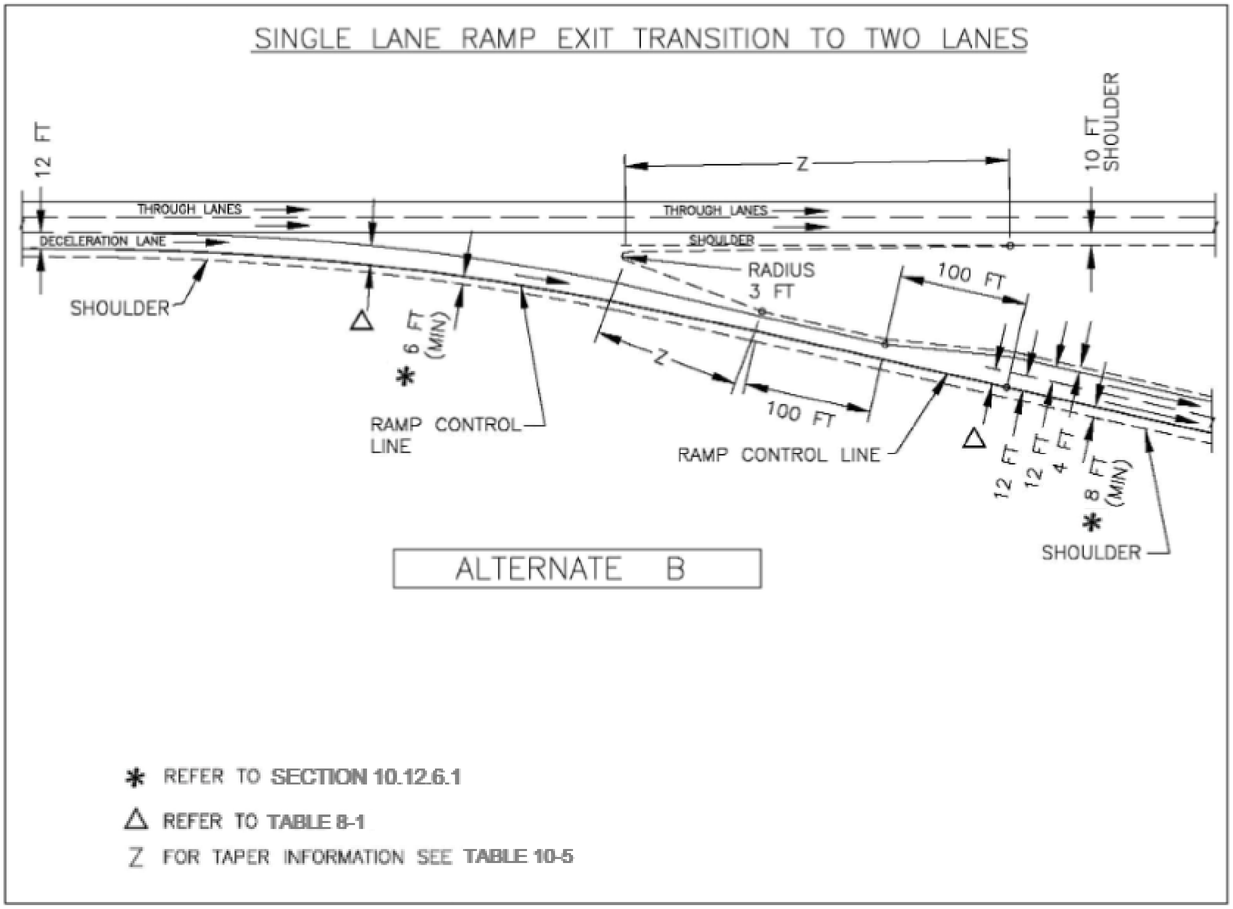


Figure 10-15B Single-Lane Ramp Exit Transition to Two Lanes (Alternate B)



10.13.3 Multilane Free-Flow Terminals

Multilane terminals are required where traffic volumes are too high for single-lane operation. The most common multilane terminals are two-lane entrances and exits at freeways. Other multilane terminals are sometimes termed "major forks" and "branch connections." The latter term denotes a separation and joining of two major routes.

10.13.3.1 Two-Lane Entrances

Two-lane entrances are warranted for either a branch connection, ramp metering, or in situations created by capacity requirements on the on-ramp. To satisfy lane-balance requirements, at least one additional lane must be provided downstream. This additional lane may be a basic lane if also required for capacity, or an auxiliary lane that may be dropped 2,500 to 3,000 feet downstream or at the next interchange. In some cases, two additional lanes may be necessary because of capacity requirements. This results in a right lane drop on the two-lane ramp, rather than a forced inside-lane merge on the classic taper-type two-lane entrance. In some cases, where volumes on the two-lane ramp are at the lower end, the outer edge of pavement may be continuously tapered, usually on a 50:1, with the striping showing a right-lane drop. In no case should a two-lane ramp be striped for an inside merge with the right lane being the continuous lane. In areas where interchanges are closely spaced, one lane may become a continuous auxiliary lane.

10.13.3.2 Two-Lane Exits

Where traffic leaving the freeway at an exit terminal exceeds the design capacity of a single lane, it is necessary to provide a two-lane exit terminal. To satisfy lane-balance requirements and not reduce the basic number of through lanes, it is usually necessary to add an auxiliary lane upstream from the exit. Refer to Figure 10-16B.

Figure 10-16A Two-Lane Entrance or Branch Connection (Taper)

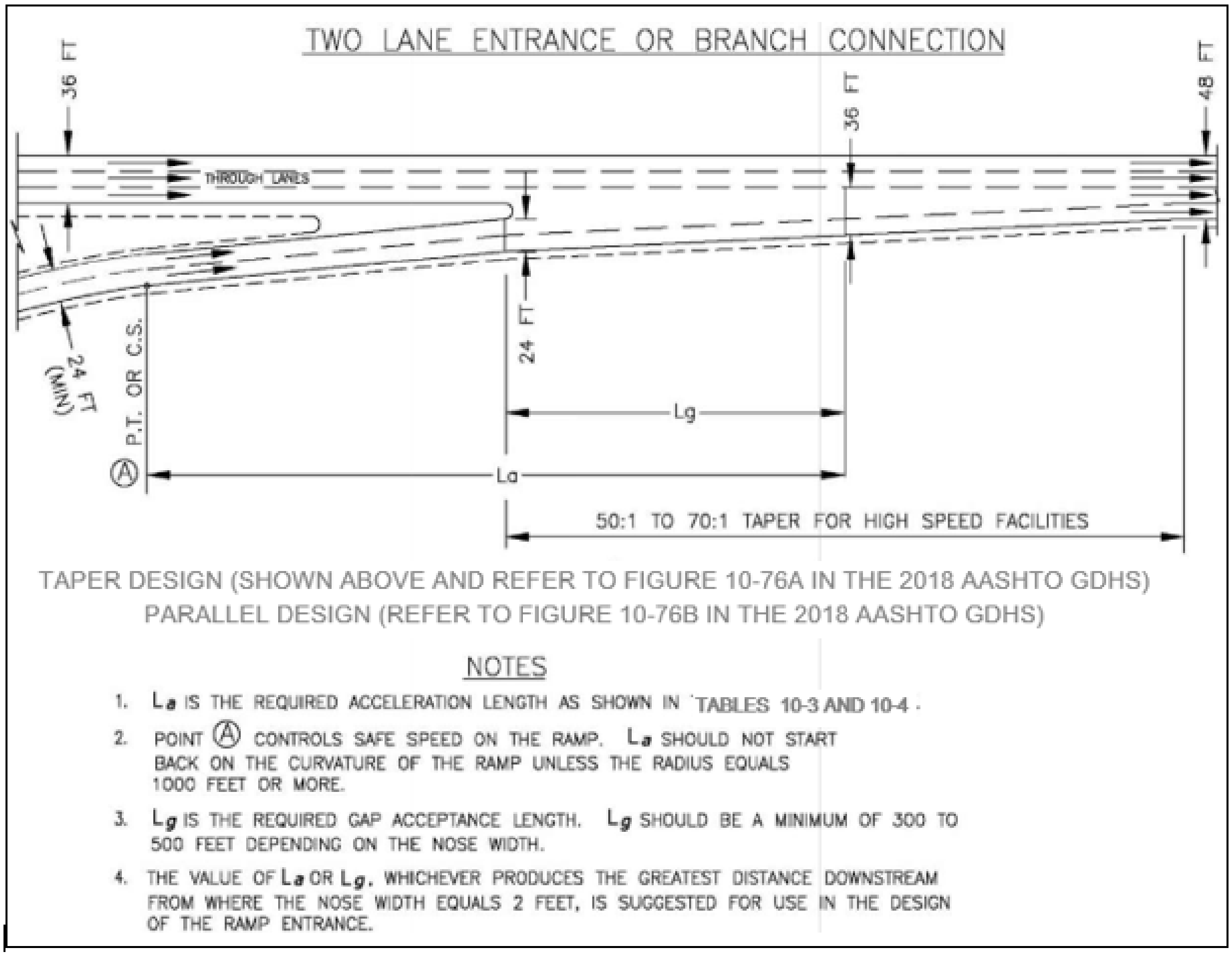
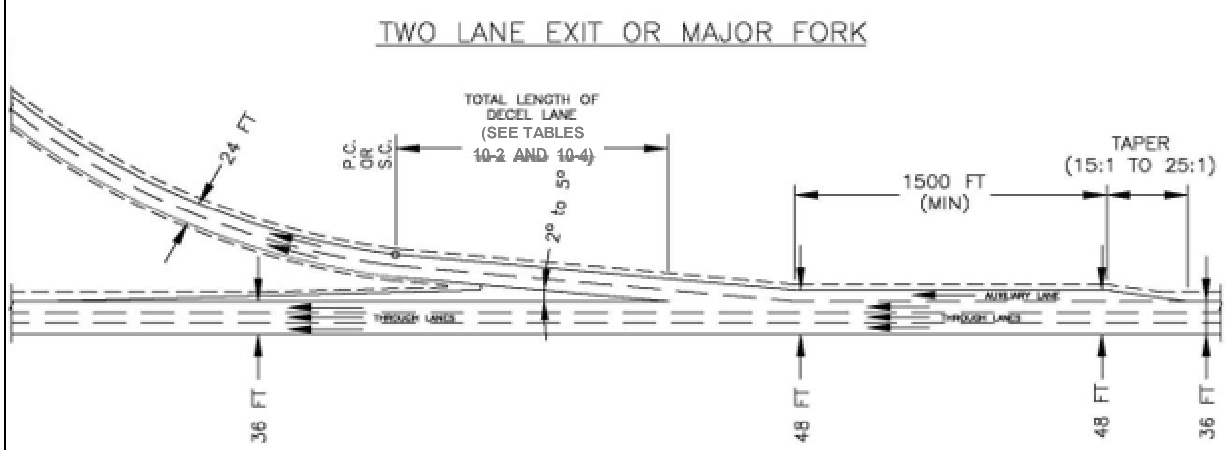


Figure 10-16B Two Lane Exit or Major Fork (Taper)



TAPER DESIGN (SHOWN ABOVE AND REFER TO FIGURE 10-77A IN THE 2018 AASHTO GDHS)
PARALLEL DESIGN (REFER TO FIGURE 10-77B IN THE 2018 AASHTO GDHS)

On two-lane parallel type exits, the total length from the beginning of the first taper to the point where the ramp traveled way departs from the right-hand through lane of the freeway should range from 2,500 feet for turning volumes of 1,500 vehicles per hour (vph) or less upward to 3,500 feet for turning volumes of 3,000 vph.

If the design year estimated volumes exceed 1,500 equivalent passenger cars per hour (PCPH), a two-lane width of ramp should be provided initially. For volumes less than 1,500 but more than 900 PCPH, a one-lane width exit ramp should be provided with provision for adding an auxiliary lane and an additional lane on the ramp. Provisions may be made for widening to three or even four lanes at the crossroad intersection, depending on the capacity of the intersection. Design of ramp terminals for two-lane exits should conform to the standard designs illustrated by Figure 10-16B.

For two-lane exits, the preferred type is the taper type for the same reasons identified in Section 10.10.12 of this chapter on the single-lane exit. For the parallel-type exit, traffic in the outer through lanes of the freeway must change lanes twice to exit on the right-hand lane of the exit ramp. This requires considerable lane changing to operate efficiently. Also, the parallel-type exit requires a longer distance from beginning of the taper to the exit nose to develop the full capacity of the ramp.

10.13.3.3 Major Forks and Branch Connections and Freeway-to-Freeway Connections

A major fork is defined as:

- The bifurcation of a directional roadway of a terminating freeway route into two directional multilane ramps that connect to another freeway, or
- The separation of a freeway route into two separate freeway routes of equal importance.

The design of a major fork is subject to the same principles of lane balance as any other diverging area. The total number of lanes in the two roadways beyond the divergence should exceed the number of lanes approaching the diverging area by at least one. Refer to Chapter 10 of the 2018 AASHTO GDHS for additional information.

A branch connection is defined as the beginning of a directional roadway of a freeway formed by the convergence of two directional multilane ramps from another freeway or by the convergence of two freeway routes to form a single freeway route. Refer to Figure 10-76 in the 2018 AASHTO GDHS.

10.14 Multimodal Accommodations

The accommodation of pedestrians and bicycles through urban interchanges should be considered early in the development of interchange configurations. High-density land use near an interchange can generate heavy bicycle and pedestrian movements, resulting in conflicts between vehicles and bicycles or vehicles and pedestrians. Refer to Chapter 13 of this Guide for additional information on considerations for bicycle and pedestrian facilities.

10.15 Other Interchange Design Features

10.15.1 Testing for Ease of Operation

Refer to 2018 AASHTO GDHS Chapter 10.9.7

10.15.2 Managed Lanes and Transit Facilities

Refer to 2018 AASHTO GDHS Chapter 10.9.7

10.15.3 Ramp Metering

The purpose of ramp metering is to reduce congestion or improve operations on urban freeways. The metering may be limited to only one ramp or integrated into a series of entrance ramps.

Ramp meters are traffic signals installed on entrance ramps in advance of the entrance terminal to control the number of vehicles entering the freeway. The traffic signals may be pre-timed or traffic-actuated to release the entering vehicles individually or in platoons.

The designer should contact the Region Traffic Engineer for design considerations.

For more information refer to 2018 AASHTO GDHS Chapter 10.9.7

10.15.4 Grading and Landscape Development

Refer to 2018 AASHTO GDHS Chapter 10.9.7

10.15.5 Models

Refer to 2018 AASHTO GDHS Chapter 10.9.7

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Access Control and Management

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Chapter

11

11 Access Control and Management

11.1 Introduction

Access management is the planned and regulated interaction between the roadway network and property access. It is an intentional strategy to reduce conflict points and to maximize network efficiency while supporting a safe and efficient transportation system that also supports a diversity of travel modes

Access management is vital to protect and maintain the public's safety and welfare, maintain the functional roadway classifications, and accommodate both the drivers using the state highway and drivers accessing the highway from adjacent developments and communities. Access management is a cost-effective approach to ensure the longevity of the public facilities, given the likelihood of increased growth in population and traffic volumes. Access management strategies must be developed with input from traffic access planners and developers because these decisions can directly impact adjacent land use and access to the road network.

The objectives of access management are accomplished by applying the following principles found in TRB's *Access Management Manual* (TRB, 2014):

- Provide a specialized roadway system.
- Promote an intersection hierarchy.
- Locate and appropriately space traffic signals to favor through movements.
- Preserve the functional area of intersections and interchanges.
- Limit the number of conflict points.
- Separate conflict areas.
- Remove turning vehicles from through traffic lanes.
- Use non-traversable medians on major roadways.
- Provide a supporting secondary street network.
- Provide unified access and circulation systems.

Colorado's State Highway Access Code (State of Colorado, 2002) defines the eight highway categories arranged in a hierarchical order, as shown in Table 11-1.

Table 11-1 Overview of the Access Category Classification Hierarchy

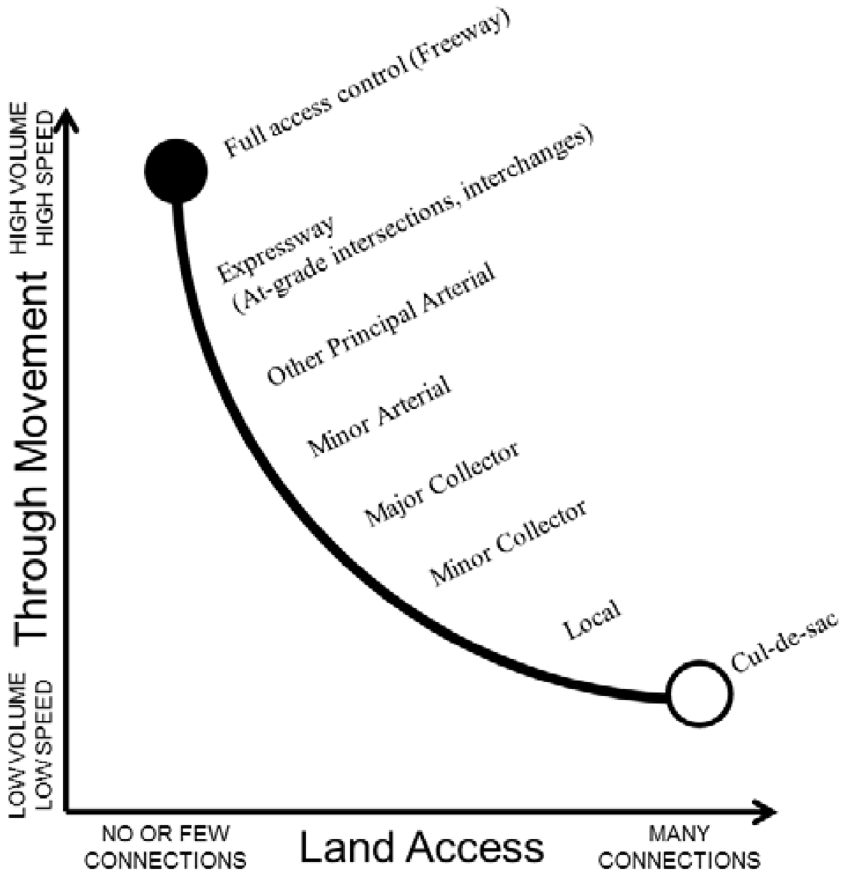
F-W Interstate System, Freeway Facilities	
E-X Expressway, Major Bypass	
Rural	**N**on-**R**ural
R-A Regional Highway	**NR-A** Regional Highway
R-B Rural Highway	**NR-B** Arterial
	NR-C Arterial
F-R Frontage Roads (both Urban and Rural)	

All segments of Colorado state highways are assigned an access category classification, which can be found in the State Highway Access Category Assignment Schedule (CDOT, 2013). Roadway classifications range from the highest classification (F-W Interstate System, Freeway Facilities) to the lowest (F-R Frontage Roads) (both urban and rural). Section Three of the State Highway Access Code (State of Colorado, 2002) contains descriptions of these functional classifications and the criteria for granting access, access spacing, auxiliary lane requirements, and traffic signal treatments.

11.2 Functional Classification and Category Assignment Criteria

The roadway network is such that roadways at the highest classification account for the smallest percentage of the network yet carry the highest percentage of traffic volumes. The highest classification roadways typically carry traffic long distances at high speeds with limited direct access to the roadway. Conversely, roadways at the lowest classification account for the highest percentage of total roadway network, carry the lowest traffic volumes (in vehicle miles traveled), have the highest number of direct access points, and operate at lower speeds. With this understanding, it is clear to see a direct correlation between roadway functions and adjacent land access. Figure 11-1 illustrates this relationship.

Figure 11-1 Conceptual Roadway Functional Hierarchy



11.3 Access Coordination

Access management is part of the traffic operations evaluation that must be conducted on each project. The Region Traffic Representative Liaison is the point of contact for operations evaluations. In addition to coordinating with the Region Traffic Representative Liaison, the operations evaluation also requires coordination and collaboration with the other CDOT project stakeholders. For more information on the operations evaluation, refer to Section 4.12 in the CDOT *Project Development Manual* (CDOT, [2013] 2022). The Region CDOT Access Program Administrator also can answer questions.

Use this link to access the CDOT 2013 Project Development Manual (CDOT, [2013] 2022): *https://www.codot.gov/business/designsupport/bulletins_manuals/2013-project-development-manual*

Use this link to access the State Highway Access Code and information on Access Permits: https://www.codot.gov/business/permits/accesspermits

11.4 Multimodal Accommodations

When an access is modified or created, the designer should consider if the existing or proposed pedestrian, bicycle, or transit facilities should be retained and included in the access design. In some cases, like emergency accesses on public rights of way, non-emergency pedestrian and bicycle access should be considered, especially if it will decrease the distance a pedestrian or a bicyclist needs to travel to access transit services.

11.5 Design Standards And Specifications

If an access permit is approved, the design standards and specifications found in Section Four of the State Highway Access Code (State of Colorado, 2002) must be followed to meet the criteria defined in Section Three of the State Highway Access Code (State of Colorado, 2002). Brief descriptions of the design standards follow.

11.5.1 Sight Distance

Access permits will only be approved at locations that maintain adequate, unobstructed sight distance in both directions for drivers entering the roadway from the access point and for users and drivers on the roadway approaching the access point. Refer to Section 8.11 of this Guide for information on intersection sight distances. Table 11-2 identifies the appropriate design vehicle to be considered for sight distance calculations. Additionally, sight distance criteria for an access permit can be found in Section 4.3 of the State Highway Access Code (State of Colorado, 2002). The context and facility type need to be identified as part of sight distance as well as the uses of vehicles in and around the project.

Table 11-2 Design Vehicle Selection

Land Use(s) Serviced by Access	Design Vehicle(s) (to be used for Sight Distance calculations)
Residential (A Non-School Bus Route)	Passenger Cars, Pickup Trucks
If Access is a Part of Any School Bus Route Regardless of Land Use	No Less Than Single Unit Trucks
Office	Single-Unit Trucks
Recreational	Single-Unit Trucks
Commercial/Retail	Multi-Unit Trucks*
Industrial	Multi-Unit Trucks*
Municipal Streets & County Roads	Multi-Unit Trucks*
Agricultural Field Approaches, < 1 Per Day	Single-Unit Trucks

*If Less Than 2 Multi-Unit Truck Trips Per Day (Average), Use Single Unit Truck

11.5.2 Access Spacing

The minimum spacing between access points is based on the calculated sight distance along the highway. In instances where there are existing or planned speed change lanes, access spacing should be a minimum of the speed change lane, including transition tapers. Access points are not permitted within a speed change lane, including transition tapers. Refer to Section 8.12 of this Guide for speed change lane requirements. Additionally, access spacing criteria for an access permit is defined by the highway access category classification and can be found in Section three of the State Highway Access Code (State of Colorado, 2002).

11.5.3 Access Width

Table 11-3 illustrates access widths for one-way and two-way access points. In instances where a public roadway access intersects a state highway, the access width should be determined by considering the long-term traffic projections and modal use.

Table 11-3 Access Width

Design		Criteria
One-Way Access	16 ft - 18 ft'	
Two-Way Access	16 ft - 30 ft'	Single-unit vehicles peak hour volume < 5
	25 ft - 40 ft	When one or more of the following apply: • Single-unit vehicles peak hour volume > 5 • Multi-Unit vehicles intended to use access • Single-unit vehicles in excess of 30 feet in length • Special vehicles using the access > 16 feet wide
Two-Way Public Access	> 36 ft	Design Hourly Volume > 10

If there are parallel pedestrian and/or bicycle facilities, such as a shared-use path, the smallest access width to accommodate the design vehicle is preferred. Shorter crossing distances reduce crash potential.

Refer to Section 4.5 of the State Highway Access Code (State of Colorado, 2002) for additional information on access width requirements.

11.5.4 Access Radii

Access radii should be a minimum of 20 feet. In instances where there are no shoulders, for example residential and field accesses, access radii should be 25 feet. If the design vehicle intended to use the access daily is a single-unit truck exceeding 30 feet, multi-unit truck, or another vehicle requiring a larger radius, the minimum turn radius accommodating this design vehicle should be used.

Access radii must allow safe maneuvers without intrusion into adjacent highway travel lanes. In instances where multiple larger vehicles are likely to oppose each other at the access, the radii should be adequate to accommodate both vehicles without conflict or undue slowing. Local design standards must be followed unless the minimums listed here are not met. Radii should be designed only to what is required to minimize pedestrian conflicts.

Refer to Section 4.6 of the State Highway Access Code (State of Colorado, 2002) for additional access radii information.

If there are parallel pedestrian and/or bicycle facilities, such as a shared-use path, the smallest access radii to accommodate the design vehicle is preferred. The larger the radii, the faster motorists driving vehicles smaller than the design vehicle can make the turn. Crash potential increases as speed and radii increases.

11.5.5 Access Surfacing

Access surface material may include gravel, asphalt, and concrete. At a minimum, accesses shall be surfaced between the roadway and the right of way line. Table 11-4 lists the hard surface (asphalt or concrete pavement) minimum limits. When a hard surface access joins existing pavement, the existing pavement edge shall be saw cut a minimum 1-foot back from the current pavement edge to provide a strong stable vertical profile edge for the tie in. Accesses must be surfaced before opening to public use. Access surfacing materials and design shall conform to the local agency design standards unless the minimums listed in Table 11-4 are not met.

Refer to Section 4.7 of the State Highway Access Code (State of Colorado, 2002) for additional access surfacing information.

Table 11-4 Hard Surface Minimum Limits

Criteria	Hard Surface Minimum Limits From Edge of Traveled Way (ft)
5 average annual daily traffic (AADT) of access	4
20 AADT of access	20
100 AADT of access	50
Turn lane present	50

11.6 Speed Change Lanes

Speed change lane considerations are discussed in Section 8.12 of this Guide. Refer to Section 4.8 of the State Highway Access Code (State of Colorado, 2002) for additional speed change lane information.

When in doubt about which design standard to follow (AASHTO or the State Highway Access Code), start a discussion with the Traffic Resident Engineer to weigh the pros and cons of each methodology based upon the known contextual and operational issues at the access. This conversation keeps everyone informed and can realize performance benefits that may be missed otherwise.

11.7 Other Design Elements

At curb cut locations, crest curves must not exceed a 4-inch hump per 10-foot chord, and sag curves must not exceed a 4- inch dip per 10-foot chord to prevent vehicle drag. At locations with curb returns and not curb cuts, the first 20 feet beyond the travel way should slope away from the highway at 2 percent. Some exceptions may be permitted on a case-by-case basis but should protect the highway from drainage flows.

Within the right of way, field and residential accesses should not exceed 10 percent grade, and all other accesses should not exceed 8 percent. Accesses within the right of way should be designed to not impede future use of the right of way. The access centerline should intersect the highway centerline at 90 degrees. If significant physical constraints require a skew angle, then the angle should be no less than 60 degrees with the approval of the Department. The access should extend from the edge of travel way in a tangent direction at least 40 feet, or to the right of way, whichever is greater.

All signing, striping, traffic signals, and other traffic control, must conform to standards presented in the *Manual on Traffic Control Devices* (FHWA, [2009] 2022).

Refer to Section 4.9 of the State Highway Access Code (State of Colorado, 2002) for additional design information.

11.8 Emergency Access

Emergency accesses may be less than 16 feet wide, so long as one-way traffic is still accommodated. The access should be unsuspecting to avoid use by the public but should be designed to accommodate emergency vehicles. Access Radii can be omitted as emergency vehicles may encroach other lanes of travel to gain access. The emergency access shall have a suitable barrier to prevent non-emergency use. Any barrier used to close off this access shall be outside of the highway right of way.

Refer to Section 4.10 of the State Highway Access Code (State of Colorado, 2002) for additional emergency access information.

11.9 Drainage

The existing highway drainage system is designed to accommodate the drainage relative to the state highway and not for development outside of the right of way (beyond historical flows). Any drainage entering the right of way from accesses should not exceed the rate of historical flow. Any drainage appurtenances, such as a detention pond, must be fully located outside of the right of way. In locations where there is curb and gutter, a storm sewer system should be the drainage option of design. In locations where there is no curb and gutter, a roadside ditch should be the drainage option of design.

Refer to Section 4.11 of the State Highway Access Code (State of Colorado, 2002) for additional drainage information.

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Chapter

12

12 Accessible Pedestrian Design

12.1 Introduction

Pedestrians may be present in all roadway environments and facility types. Pedestrian access, accommodation, and safety should be given full consideration during all project planning, scoping, and design. Accommodation can take many forms but most often appears as sidewalks or shared-use paths. In rural areas or on roadways with limited pedestrian demand, paved shoulders and sometimes no facility at all may be an acceptable level of pedestrian accommodation. Sidewalks are not a requirement on every roadway; however, if there is evidence that pedestrian demand exists or will exist in the future, suitable pedestrian facilities shall be provided.

CDOT's Civil Rights & Business Resource Center's website for CDOT's Accessibility Program has Quick Links to the Program's resources, including a page with Americans with Disabilities Act (ADA) Resources for Engineers," which illustrates how CDOT's Accessibility program implements the requirements of the ADA on its projects through CDOT's ADA standards, guidelines, and policies.

Use this link for information about CDOT's Accessibility Program: https://www.codot.gov/business/civilrights/ada

The Americans with Disabilities Act of 1990 was the nation's first comprehensive civil rights law that prohibits discrimination against people with disabilities. Under Title II of the ADA and Section 504 of the Rehabilitation Act of 1973 (504), entities that are responsible for roadway and pedestrian facilities may not discriminate on the basis of disability in any transportation program, activity, service, or benefit which is provided to the general public. In other words, entities responsible for transportation infrastructure must ensure that people with disabilities have equitable opportunities to use the infrastructure that is provided to the public. The ADA accessibility requirements apply throughout the entire transportation facility lifecycle including planning, design, construction, maintenance, and operation.

Where pedestrian facilities are provided, they must be constructed so they are accessible to all potential users. This chapter provides guidance and direction regarding the requirements for the design of accessible pedestrian facilities. There are many supplemental resources that can help with pedestrian accommodations. Links to those resources are provided throughout this chapter.

Under the ADA, the U.S. Department of Transportation (USDOT) and the U.S. Department of Justice (USDOJ) are responsible for issuing and enforcing accessibility standards. The standards are developed by the U.S. Access Board, which is an independent agency that promotes equality for people with disabilities and is the leading source of information on accessible design. The U.S. Access Board's guidelines become enforceable once they are adopted by the respective standard setting agency, which in the case of CDOT are the Americans with Disabilities Act (ADA) Standards for Transportation Facilities adopted by the USDOT (USDOT, 2006). Both USDOJ's latest ADA Standards and the USDOT's 2006 ADA Standards are very similar and are closely based on the U.S. Access Board's ADA Accessibility Guidelines (ADAAG) (U.S. Access Board, 2002). However, each contain a few unique provisions. One very important difference for CDOT is the requirement of Detectable Warnings on curb ramps.

To ensure that people with disabilities have access to the built environment, the U.S. Access Board developed design guidelines known as the ADA Accessibility Guidelines (ADAAG) (U.S. Access Board, 2002). However, pedestrian infrastructure in the public right of way can pose many challenges to accessibility, and the ADAAG was developed with a focus on providing accessible buildings and facilities.

Although the ADAAG does address some features found within the public right of way, it was determined that additional guidance was necessary to address conditions and constraints that are unique to public rights of way. The additional guidance developed was titled the Proposed Rule Public Rights of Way Accessibility Guidelines (PROWAG) (U.S. Access Board, 2011). These draft guidelines are not standards until adopted by the USDOJ and the USDOT. However, in 2006, USDOT adopted the 2004 ADAAG as accessibility standards under Section 504, but in doing so, USDOT added Section 406.8, which requires detectable warnings at curb ramps.

Use this link to read FHWA's 2006 Questions and Answers About ADA/Section 504:
hhttps://www.fhwa.dot.gov/civilrights/programs/ada/ada_sect504qa.cfm

Both the ADAAG and the PROWAG provide the means to meet the requirements of the ADA. Generally, facilities located within the public right of way shall be consistent with the requirements set forth in the PROWAG. Once the PROWAG is adopted by the USDOJ and the USDOT, it will become the enforceable standard for transportation facilities under Title II of the ADA.

Throughout this chapter, there are specific PROWAG scoping and technical references in parenthesis next to the subject/title with additional CDOT-specific language, if applicable. (i.e., PROWAG R200).

Use this link for information on the ADAAG and PROWAG: https://www.access-board.gov/ada

12.1.1 CDOT's ADA Transition Plan

CDOT's *ADA Transition Plan* describes how the various departments within CDOT are implementing ADA requirements for facilities owned by CDOT. It also describes CDOT's policies and standards related to PROWAG, including CDOT's definition of PROWAG functional accessibility related to curb ramps.

Use this link to access CDOT's ADA Transition Plan: https://www.codot.gov/business/civilrights/ada/transition-plan

12.1.2 List of Definitions

- *Accessible.* Describes a facility in the public right of way that complies with the requirements set forth in the ADAAG or the PROWAG.
- *ADA.* Americans with Disabilities Act.
- *ADA Transition Plan.* The 1991 ADA regulation (28 CFR Part 35) required all public entities to evaluate all their services, policies, and practices and to modify any that did not meet ADA requirements. Public entities with 50 or more employees were required to develop a transition plan detailing any structural changes that would be undertaken to achieve program access and specify a period for their completion.
- *ADAAG.* An acronym for ADA Accessibility Guidelines.
- *Accessible Pedestrian Signal (APS).* A traffic signal that incorporates a device to communicate information to a pedestrian in audible and vibrotactile formats.
- *Alteration.* A change to a facility in the public right of way that affects or could affect the usability of that facility. Alterations include, but are not limited to, resurfacing, rehabilitation, reconstruction, historic restoration, or changes or rearrangement of structural parts or elements of a facility.
- *Blended Transition.* A raised pedestrian street crossing, depressed corner, or similar connection between the pedestrian access route at the level of the sidewalk and the pedestrian street crossing.
- *Cross Slope.* The grade that is perpendicular to the dominant direction of pedestrian travel.

- *Curb Ramp.* A combination of a ramp and landing to accomplish a change in elevation at a curb face. This element provides street and sidewalk access to pedestrians using a mobility device, such as a wheelchair, a walker, or crutches.
- *Detectable Warning Surface (DWS).* A standardized surface feature of truncated domes that provides an indication to individuals with disabilities that they are transitioning from the pedestrian realm to the vehicular way.
- *Equivalent Facilitation.* The use of alternative designs, products, or technologies that result in substantially equivalent or greater accessibility and usability than the requirements in the PROWAG and/or ADAAG.
- *Facility.* All or any portion of buildings, structures, improvements, elements, and pedestrian or vehicular routes located in the public right of way.
- *Grade Break.* The line where two surface planes with different grades meet.
- *Landing/Landing Space.* The area of the Pedestrian Access Route at the top or bottom of a curb ramp. Refer to Turning Space definition below for requirements.
- *Maximum Extent Feasible.* Where existing physical constraints on existing facilities make it impracticable for altered elements, spaces, or facilities to fully comply with the requirements for new construction, compliance is required to the extent practicable within the scope of the project. Not applicable to new construction. Also referred to as “Maximum Extent Practicable.”
- *Mobility Device.* Any assistive technology or device that aids the movement of people with a physical impairment. Examples include lift chairs, wheelchairs, scooters, etc.
- *Operable Part.* A component of an element used to insert or withdraw objects, or to activate, deactivate, or adjust the element.
- *Other Power-Driven Mobility Device (OPMD).* Any mobility device powered by batteries, fuel, or other engines that is used by individuals with mobility disabilities for the purpose of locomotion, whether or not it was designed primarily for use by individuals with mobility disabilities. OPDMD’s may include electronic personal assistance mobility devices, such as the Segway ® Personal Transporter (PT), or any mobility device that is not a wheelchair and is designed to operate in areas without defined pedestrian routes.
- *Pedestrian.* A person afoot, using a mobility device, or using another power-driven mobility device (OPMD).
- *Pedestrian Access Route (PAR).* A continuous and unobstructed path of travel provided for pedestrians with disabilities within or coinciding with a pedestrian circulation path.
- *Pedestrian Circulation Path*. A prepared exterior or interior surface provided for pedestrian travel in the public right of way.

- *Pedestrian Ramp.*s The ramp, or ramp run, is the sloped section (minimum 48 inches wide) that individuals who use wheelchairs travel up and down when transitioning between the street and the sidewalk.
- *PROWAG.* An The acronym for the U.S. Access Board's proposed Public Rights of Way Accessibility Guidelines for the design, construction, and alteration of pedestrian facilities in the public right of way.
- *Qualified Historic Facility.* A facility that is listed in or eligible for listing in the National Register of Historic Places or designated as historic under an appropriate state or local law.
- *Running Slope.* The grade that is parallel to the dominant direction of pedestrian travel.
- *Sidewalk.* A paved pathway paralleling roadway that is intended for pedestrian travel.
- *Shared-Use Path.* A paved travel-way separated from motor vehicle traffic by an open space or barrier and either within the right of way or in an independent right of way. Refer to Chapter 13 of this Guide for more information on Shared-Use Path Design.
- *Technically Infeasible.* With respect to an alteration of a building or existing facility, something that has little likelihood of being accomplished because existing structural conditions would require removing or altering a load-bearing member that is an essential part of the structural frame; or because other existing physical or site constraints prohibit modification or addition of elements, spaces, or features that are in full and strict compliance with minimum requirements.
- *Turning Space.* A circular or T-shaped turning space that will allow a wheelchair to make a 180 degree or 360 degree turning movement at a minimum of a 60-inch diameter.
- *Vertical Surface Discontinuities.* Vertical differences in level between two adjacent surfaces.
- *Vibrotactile.* Relaying information to the user through the perception of vibration or touch.

12.2 ADA Accessibility Requirements, Standards, and Guidelines

The ADAAG and the PROWAG are not requirements of the ADA, but they serve as the standards and guidelines by which compliance of the law is measured. Generally, the ADA law requires:

- New construction to be accessible.
- Alterations to existing facilities that are within the scope of a project to provide accessibility to the maximum extent feasible.
- Existing facilities that have not been altered shall not deny access to persons with disabilities.

12.2.1 New Construction Project Requirements

All new construction projects where pedestrian demand is exhibited must incorporate appropriate pedestrian facilities that are accessible to persons with disabilities. New construction projects can mitigate constraints through good planning and design practices. Project budget or limited scopes are not an acceptable reason to fail to provide compliant accessible facilities during new construction.

12.2.2 Alteration Project Requirements PROWAG (R202 & R203)

Whenever existing facilities are altered, each altered element must meet the most current accessibility standard if it is within the scope of the alteration project. If elements are within a project's limits and scope but are not accessible, they must be made so. For example, if a project is resurfacing a roadway and curb ramps are missing at pedestrian crossings, compliant curb ramps must be incorporated into that project because that project affected the crossing served. That same project would not be required to install pedestrian push buttons if the existing signals are to remain, because that work is outside of the original resurfacing scope.

Where existing physical constraints make it impractical for facilities to comply with the current standard, improvements must be made to provide accessibility to the maximum extent practical within the scope and limits of the project

Alteration roadway projects shall not intentionally skip or "gap" pedestrian elements to avoid triggering the requirement to make ADA improvements.

Only the altered portion of a facility is required to be made compliant at the time of a project. If elements are altered or added but the pedestrian circulation path is not altered, the pedestrian circulation path is not required to be made accessible. However, it is often beneficial to improve surrounding unaltered facilities while construction forces are mobilized. When possible, consideration should be given to making nearby facilities accessible. The alteration of a facility may affect the usability of an adjoining facility and additional improvements can at times be unavoidable. An alteration project shall not decrease accessibility, or the accessibility to a connecting or adjacent building or site, below the current standards required of new construction during the time of the alteration. (PROWAG R202.3). These considerations should be taken into account during project scoping.

12.2.3 Alterations - PROWAG (R202)

All alteration projects must remove existing pedestrian access barriers. For example, projects must install curb ramps at locations where they are missing if they are within the limits of the altered area.

Examples of alteration projects include, but are not limited to:

- Addition of new layers of asphalt.
- Mill and fill / mill and overlay.
- Rehabilitation and reconstruction.
- Cape seals.
- Micro surfacing and thin lift overlays.
- Widening.
- Bridge projects.

Use these links for the USDOT's technical assistance information regarding what treatments or combinations thereof constitute alterations:
https://www.fhwa.dot.gov/civilrights/programs/doj_fhwa_ta.cfm
https://www.fhwa.dot.gov/civilrights/programs/doj_fhwa_ta_glossary.cfm
https://www.fhwa.dot.gov/civilrights/programs/ada_resurfacing_qa.cfm

The USDOT prepared the graphic shown in Figure 12-1 to help illustrate what items may be considered maintenance or alterations. If two maintenance items are performed at the same time, they may rise to the level of an alteration.

The technical assistance from the USDOT should be consulted when determining whether an item(s) is considered maintenance or an alteration.

Figure 12-1 Maintenance vs. Alteration for Surface Treatment Projects

12.2.4 Alterations to Qualified Historic Facilities – PROWAG (R202.3.4) Non-Alteration Project Requirements

Activities that are considered normal maintenance do not require simultaneous improvements for accessibility under the ADA. The USDOJ and USDOT offer the following guidance:

> "What kinds of treatments constitute maintenance rather than an alteration?
>
> Treatments that serve solely to seal and protect the road surface, improve friction, and control splash and spray are considered to be maintenance because they do

> not significantly affect the public's access to or usability of the road. Some examples of the types of treatments that would normally be considered maintenance are: painting or striping lanes, crack filling and sealing, surface sealing, chip seals, slurry seals, fog seals, scrub sealing, joint crack seals, joint repairs, dowel bar retrofit, spot high-friction treatments, diamond grinding, and pavement patching**. In some cases, the combination of several maintenance treatments occurring at or near the same time may qualify as an alteration and would trigger the obligation to provide curb ramps." (Emphasis added)**
>
> Source: Department of Justice/Department of Transportation Joint Technical Assistance1 on the Title II of the Americans with Disabilities Act Requirements to Provide Curb Ramps when Streets, Roads, or Highways are Altered through Resurfacing (USDOJ, USDOT.)

Generally, maintenance activities are considered those actions that are intended to preserve the functionality or condition of an asset without increasing its capability or structural capacity.

Emergency repairs, such as interim paving or patching, would not trigger the requirement to upgrade or install accessible pedestrian facilities.

12.2.5 Technically Infeasible

Site constraints can make it impractical to make facilities fully compliant with the standards, so improvements at those locations can be deemed "technically infeasible" when sound engineering judgement is exercised. When full compliance is deemed technically infeasible, facilities being altered should be made accessible to the maximum extent practicable. If a site cannot meet accessibility standards, the proper documentation procedures should be followed.

Use this link for CDOT's ADA Resources for Engineers:
https://www.codot.gov/business/civilrights/ada/resources-engineers

For example, should a hypothetical curb ramp be constrained by a historic property, the designer needs to prepare a Curb Ramp Variance Support Document (on CDOT's ADA Resources for Engineers webpage) to prepare documentation for the affected ramp. The Curb Ramp Variance Support Document should be initiated as early as possible so the variance review does not hinder the project schedule.

Examples of site constraints that may make it technically infeasible to make a facility fully compliant include:

- Underground structures or utilities that would have to be altered to make a facility compliant and would expand the project scope.
- Adjacent development or buildings that would need to be moved or altered to make a facility fully compliant.
- Required improvements that would alter the status of a historic property.

- Drainage that could not be maintained if an area is made fully accessible.
- Underlying terrain that would require significant expansion of the project scope to achieve full compliance. An example would be altering a roadway profile to make the cross slope of a crosswalk fully compliant.

Project scope, not cost, should determine when existing constraints make an item technically infeasible. This has been supported by decisions from the Dept. of Justice. For example, a resurfacing project that does not include the relocation of existing utilities may be justified in providing a facility that does not comply fully with the standards and is accessible to the maximum extent feasible if those utilities prohibit compliance. However, a widening project that includes right of way acquisition and utility relocations would not be able to use that same justification because those elements are within the scope of the project.

12.2.6 Unaltered Existing Facilities & the ADA Transition Plan

Facilities that are not to be addressed in any current or planned CDOT projects are to be addressed as described in CDOT's ADA Transition Plan (refer to Section 12.1.1 of this chapter).

12.3 Technical Requirements for Accessibility

12.3.1 Pedestrian Access Route Technical Requirements - PROWAG (R302)

The following section provides detailed technical criteria and guidance for the development of accessible pedestrian routes (PAR). The material in this section is derived from information found in the PROWAG and other relevant sources. It is the intent of this chapter to be consistent with all of the criteria provided in existing federal or CDOT standards. This section is intended to provide the most relevant technical requirements in one location and provide additional guidance and best practices when possible. The minimum and maximum values that are provided are taken from the PROWAG. Target values may also be provided. Designing features to values other than the allowable minimums or maximums allows for adjustments in the field and provides flexibility during construction.

A pedestrian access route (PAR) is a continuous and unobstructed path of travel intended to provide accessibility for pedestrians with disabilities. A pedestrian access route shall be provided where a prepared surface has been constructed for pedestrian travel within the right of way.

Examples of areas that may be considered a PAR include:

- Pedestrian street crossings at intersections (marked or unmarked crosswalks) and mid-block locations.
- Curb ramps.
- Pedestrian overpasses and underpasses.
- Sidewalks.
- Shared-use paths.
- Elevators.

- Doorways.
- Accessible parking space access aisles.

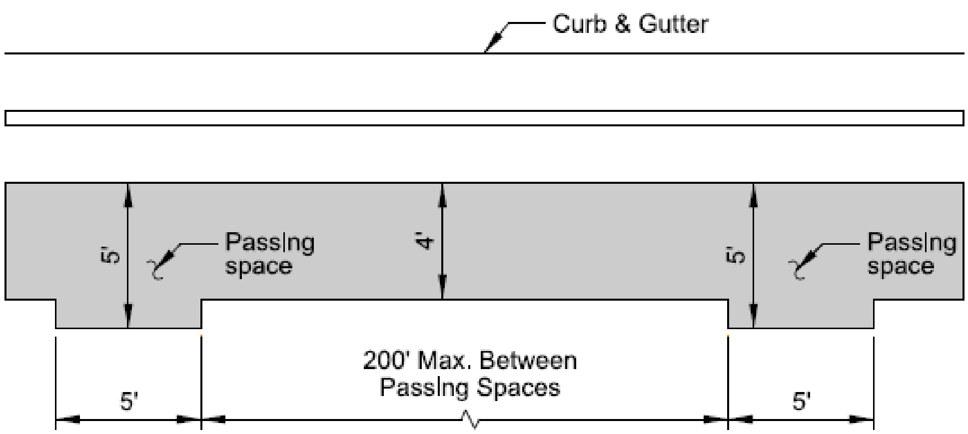
The following describes the common requirements of the PAR.

12.3.1.1 Continuous Width PROWAG (R302.3)

(R302.3) The continuous width of the PAR shall be 4 feet minimum, exclusive of the curb. For example, where a pedestrian access route makes a 90-degree turn, it should be widened to 5 feet to accommodate the continuous passage of a wheelchair (e.g., pedestrian design vehicle). CDOT projects should have minimum 5-foot sidewalks, exclusive of the curb, unless unique constraints are present. If the clear width of the PAR is less than 5 feet, passing spaces shall be provided at a maximum of 200-foot intervals. If passing spaces are provided, they shall be 5 feet by 5 feet minimum. The clear width of a pedestrian refuge island shall be 5 feet minimum.

Passing Space - Curb Ramps, Medians, Pedestrian Refuge Islands & Shared Use Paths – PROWAG (R302.3.1, R302.3.2 and R302.4). Figure 12-2 illustrates passing space requirements.

Figure 12-2 Passing Spaces

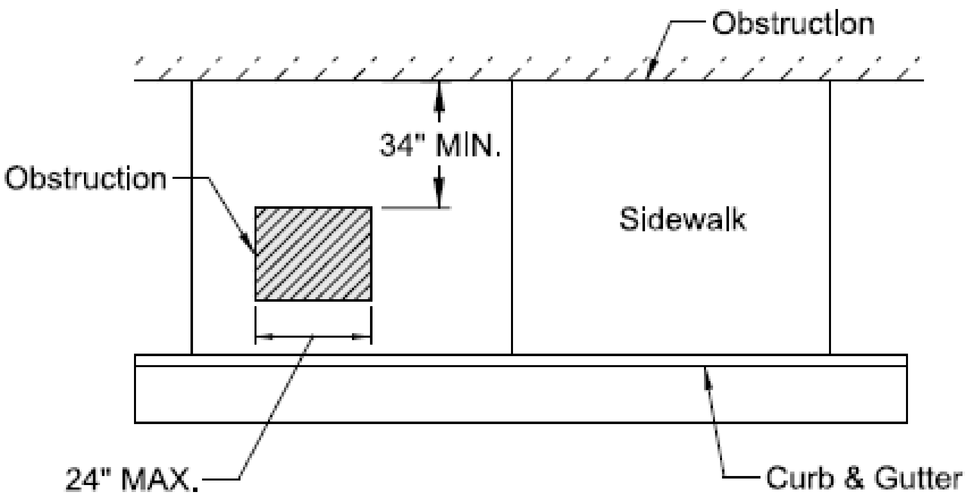


12.3.1.2 Pinch Points

Reduction in Access - PROWAG (R202.3.3)

Pinch points within the PAR shall not be less than 34 inches in width and not exceed 24 inches in the direction of pedestrian travel as shown in Figure 12-3. A study by the U.S. Access Board determined that a 34-inch width allowed 95% of the wheel mobility users to pass the obstruction in the study areas (Anthropometry of Wheel Mobility Project, US Access Board). Pinch Points are permitted in constrained areas on maintenance and alteration projects only with approval of the Project Engineer. **Pinch points are not acceptable in new construction.**

Figure 12-3 Pinch Point



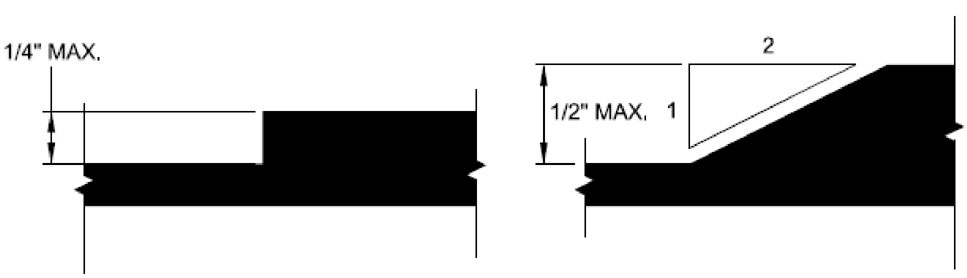
12.3.1.3 Surface – PROWAG (R302.7)

A standard test has not been defined to measure slip resistance or stability, so sound engineering judgement must be applied to ensure that users with mobility impairments can traverse the PAR. The preferred surface for pedestrian walkways and sidewalks is concrete with a broom finish. Examples of noncompliant surfaces include cobblestones, split-faced stone, loose sand, dirt, gravel, and any other similar irregular surface. Grade breaks within curb ramps shall be flush, as shown in Figure 12-4. Grade breaks in curb ramps shall be perpendicular to the path of travel. The characteristics of the surface when wet should be taken into consideration when determining if a surface is firm, stable, and slip resistant.

There exists an allowance for vertical surface discontinuities for occasional expansion joints and objects such as utility covers, vault frames, and gratings that cannot be located in another portion of the sidewalk or outside the PAR. Objects such as utility covers, vault frames, and gratings should not be located on curb ramp runs, blended transitions, turning spaces, or gutter areas within the PAR. This may not always be possible in alterations, but it should be avoided when possible. Vertical surface discontinuities between unit pavers should be minimized.

Vertical surfaced discontinuities shall be a 0.5-inch maximum. When there is a surface discontinuity between 0.25 inch and 0.5 inch, the discontinuity shall be beveled at 2:1. The bevel shall be provided for the entire length of the discontinuity

Figure 12-4 Allowable Vertical Discontinuities



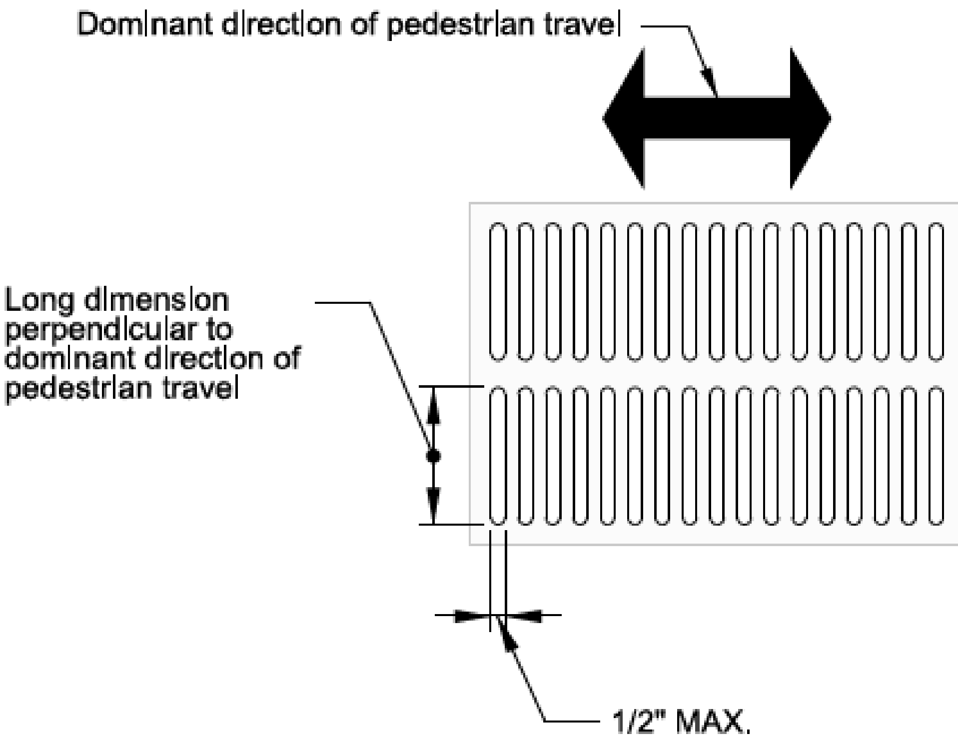
12.3.1.4 PAR Vertical Alignment – PROWAG (R302.7.1)

Where the PAR crosses a rail at grade, the pedestrian access route should be level with the top of the rail.

12.3.1.5 Openings and Horizontal Gaps – PROWAG (R302.7.3)

The use of grates, handholes, and inlets within the PAR, especially curb ramps and other pedestrian crossings, should be avoided.

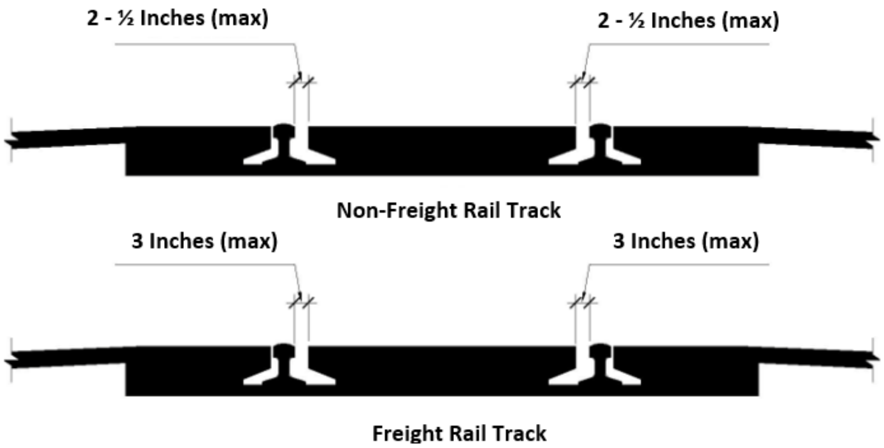
Figure 12-5 Horizontal Openings in Grates



12.3.1.6 Flangeway Gaps - PROWAG (R302.7.4)

When the PAR crosses a railway the horizontal gap between the pedestrian surface and the rail shall be no more than 2.5 inches on a non-freight railway and no more than 3 inches on a freight railway.

Figure 12-6 Flangeway Gaps at Pedestrian At-Grade Rail Crossings

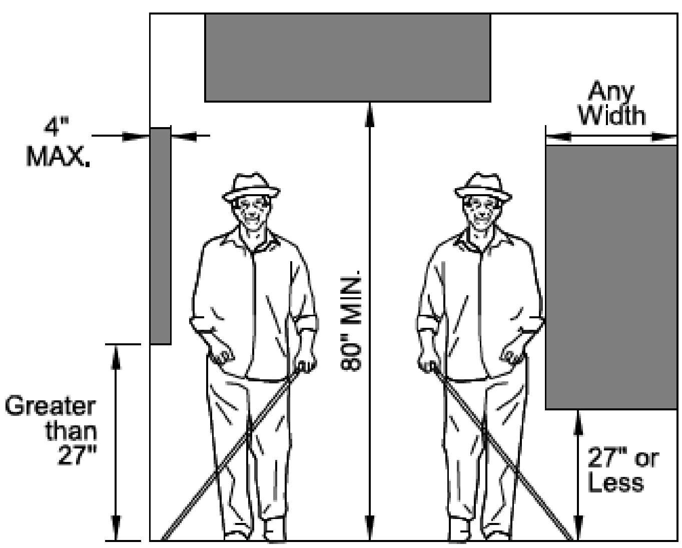


12.3.1.7 Protruding Objects - PROWAG (R402)

Objects with leading edges more than 2.25 feet and not more than 6.7 feet above the finish surface shall protrude 4 inches maximum horizontally in the pedestrian circulation paths.

12.3.1.8 Shared-Use Path Protruding Objects - PROWAG (R210.3)

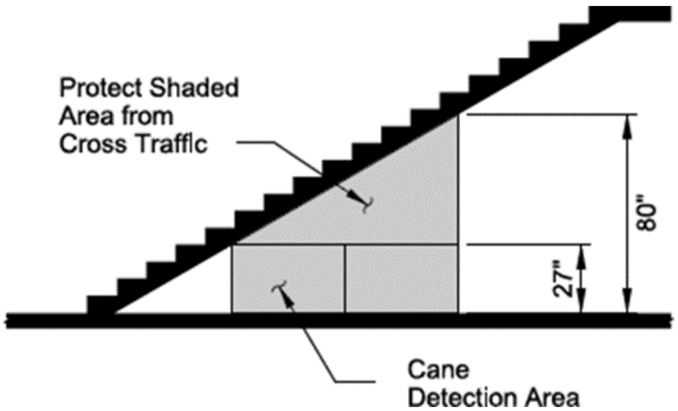
Figure 12-7 Protruding Objects



12.3.1.9 Reduced Vertical Clearance - PROWAG (R402.4)

Guardrail or other barriers to pedestrian travel shall be provided where vertical clearance is less than 6.7 feet high. The leading edge of the barrier or guardrail shall be at least 27 inches tall when measured from the finished floor surface.

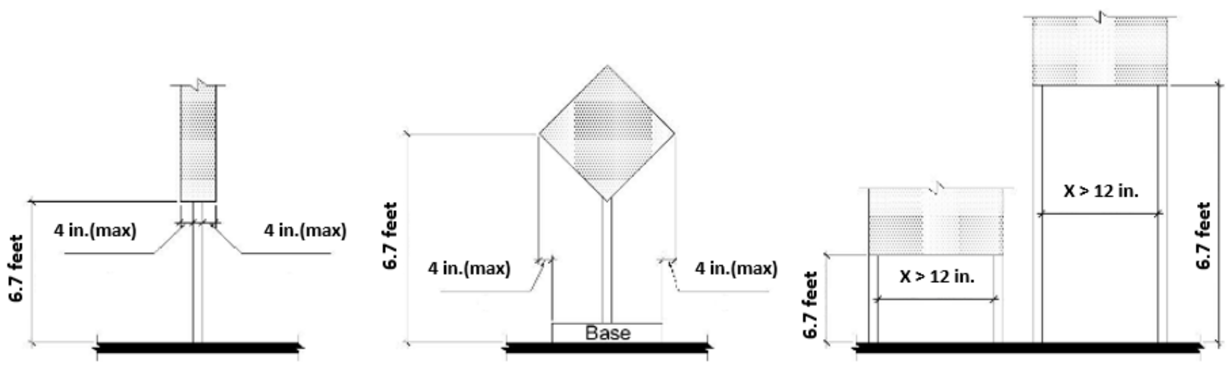
Figure 12-8 Protection from Stairways



12.3.1.10 Post Mounted Objects PROWAG (R402.3)

When objects such as signs are mounted on free-standing posts and the objects are 2.25 feet minimum and 6.7 feet maximum above the finished surface. The objects shall overhang pedestrian circulation paths by no more than 4 inches measured horizontally from the post. This may require the addition of a raised base to protect pedestrians from encroaching the hazard area.

Figure 12-9 Post-Mounted Objects



12.3.1.11 Grade – PROWAG (R302.5 through 302.5.5)

Maximum slope for grade is 5%, but designers should target grade slopes of PARs and Pedestrian Street Crossings of 4.5% to provide flexibility during construction.

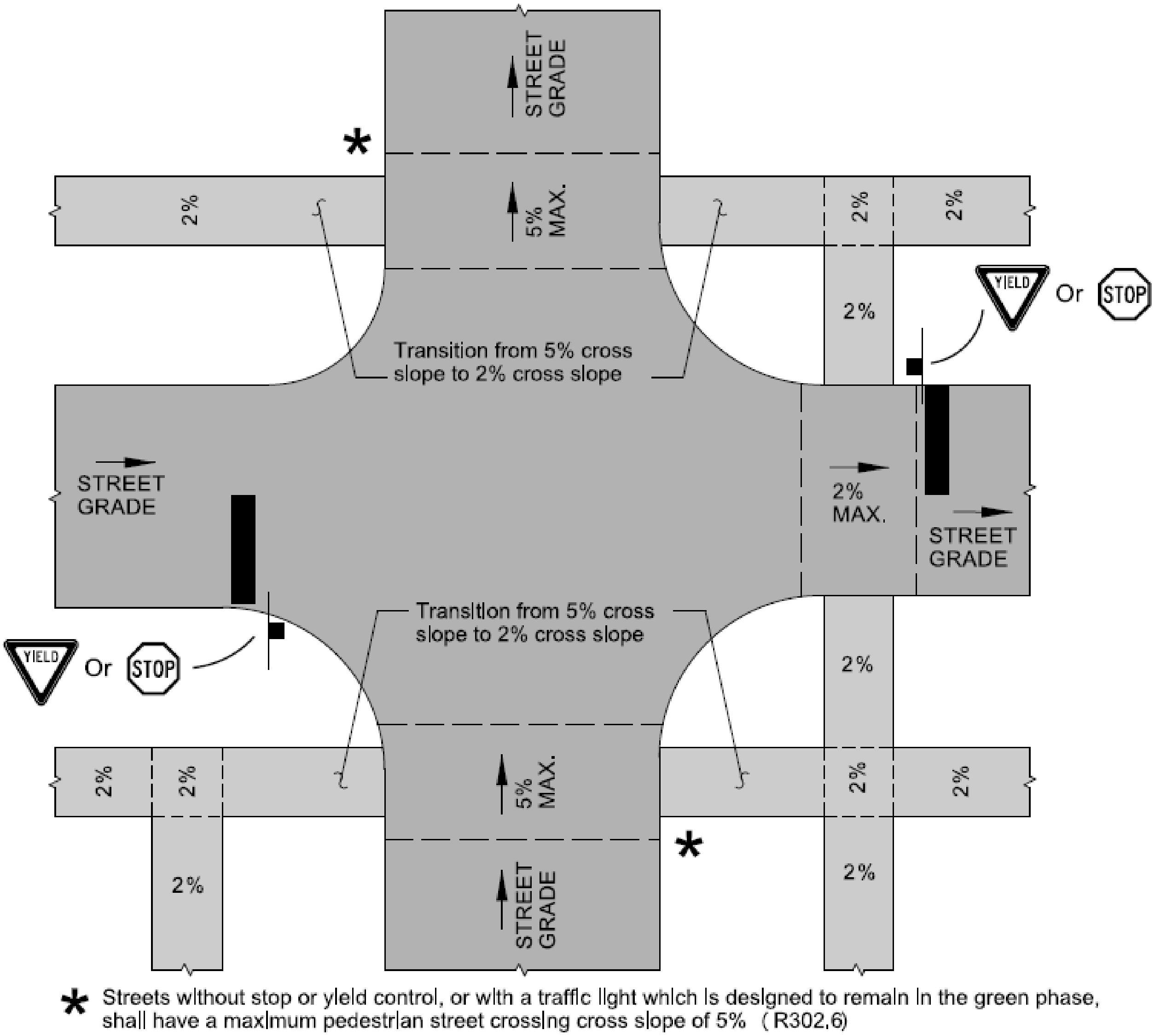
12.3.1.12 Cross Slope - PROWAG (R302.6)

The cross slope of the PAR is measured perpendicular to the direction of travel and shall not exceed 2.0%.

PROWAG has set limits for the maximum allowable cross slope at pedestrian street crossings. At these locations the roadway longitudinal grade becomes the cross slope of the pedestrian crossing. The maximum allowable cross slope for pedestrian street crossings is dependent on the type of vehicular traffic control present at the crossing. At times, these requirements limit the longitudinal grade of the roadway and require a “tabled crosswalk” at the intersection. Pedestrian crossings without yield or stop control are defined as those without a yield or stop sign, or where a traffic signal is designed to remain in the green phase. requirements for cross slope of pedestrian street crossings are found at R302.6.1.

- *Intersection leg with yield or stop control.* The pedestrian street crossing must not have a cross slope greater than 2.0%.
- *Intersection leg without yield or stop control.* The pedestrian street crossing must not have a cross slope greater than 5.0%.
- *Mid-block pedestrian crossing.* The pedestrian street crossing is allowed to have a cross slope equal to the street or highway grade.

Figure 12-10 Pedestrian Street Crossing Cross Slope



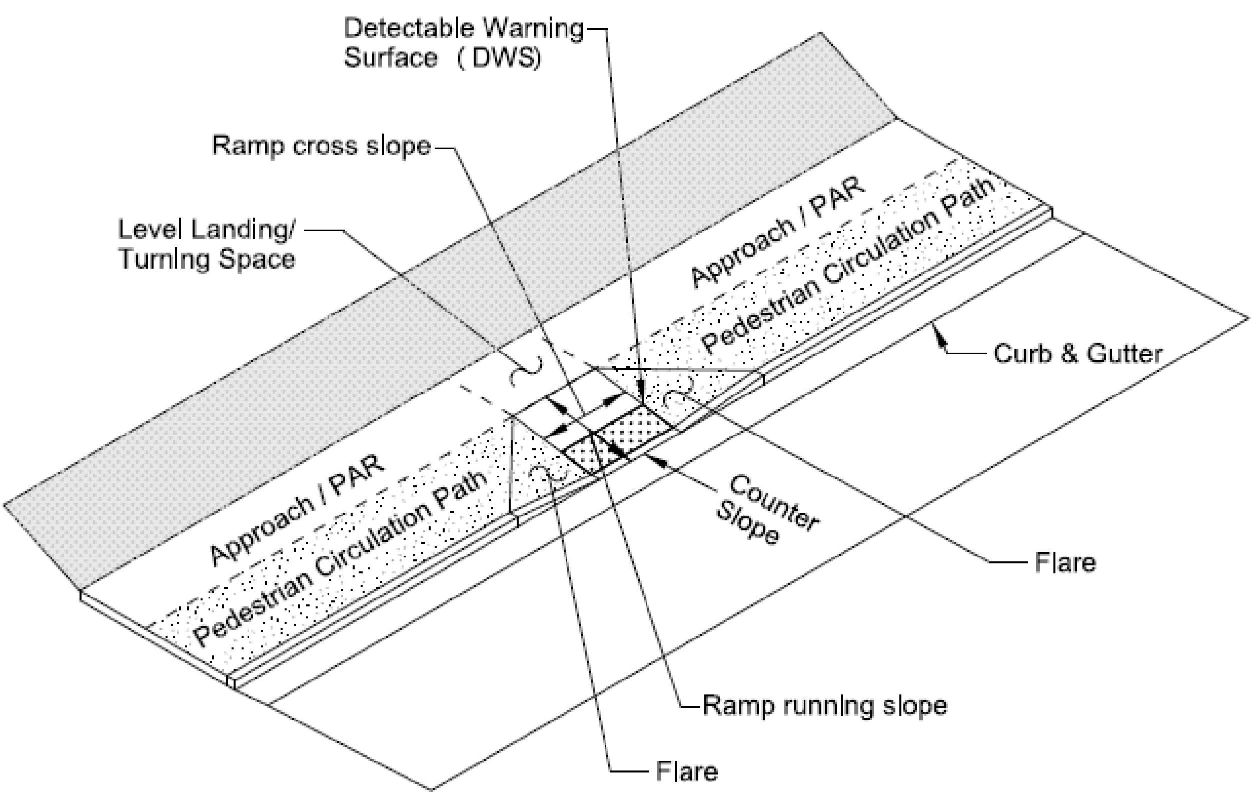
12.4 Curb Ramp General Information

Curb ramps are intended to provide pedestrians access between the sidewalk and street when a curb face or vertical change in elevation is present. For new construction or on streets being altered, curb ramps are mandated by Title II of the ADA. In addition to providing access for those with mobility impairments, curb ramps make street crossings easier for pedestrians without disabilities including people pushing strollers, riding bicycles, and making deliveries.

Most curb ramps contain a combination of the following core elements: approach, ramp runs, flares, vertical curb faces, landings or turning spaces, transition between the ramp run and gutter, and detectable warnings. These common elements can be configured in several ways to create a variety of curb ramp designs. Generally, curb ramps can be grouped into three categories: perpendicular ramps, parallel ramps, and blended transitions.

Use this link to access CDOT's ADA Resources for Engineers:
https://www.codot.gov/business/civilrights/ada/resources-engineers

Figure 12-11 Curb Ramp Elements



Curb ramps should not be placed in locations where pedestrians must cross drainage inlets or ponding water. Designers should consider the location of drainage inlets relative to any curb ramps that are being installed. Locating or moving drainage inlets upstream of curb ramps helps eliminate ponding and should be a consideration during design. Curb ramps should be located away from the low point of a curb return when possible.

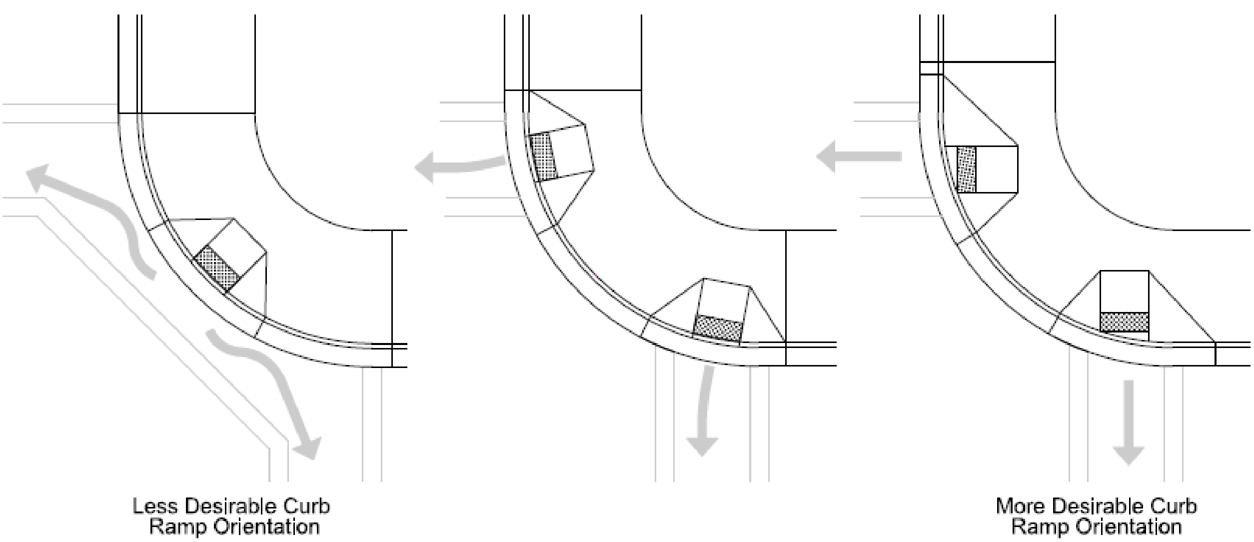
Often curb ramp locations will be determined by the existing site constraints; however, the preferred design is to have a separate curb ramp aligned with each crossing. In new construction, where existing constraints do not exist, one curb ramp for each crossing is required. On CDOT projects, a single diagonal curb ramp (on the apex) will only be permitted on reconstruction and alteration projects where physical site constraints prevent two curb ramps from being installed. Designers should make every attempt to provide one ramp per crossing.

If there is an uncontrolled or mid-block crossing in a project, a designer may request a traffic analysis to determine volumes and speed, and a crash analysis to determine any crash patterns, to understand if the location may need additional enhancements, such as pedestrian rapid flashing beacons, to improve pedestrian visibility and reduce crash potential.

Diagonal curb ramps present several challenges of which designers should be aware:

- Providing a level clear space at the bottom of a ramp is often difficult to achieve.
- Diagonal ramps present a problem for pedestrians because pedestrians are directed towards the middle of the intersection. This may be particularly troublesome for pedestrians with vision impairments who cannot determine the correct alignment of the street crossing. They create uncertainty for motorists who cannot determine which direction the pedestrian is trying to cross. As a result, motorists are less likely to yield to pedestrians trying to cross the street.

Figure 12-12 Preferred Curb Ramp Placement

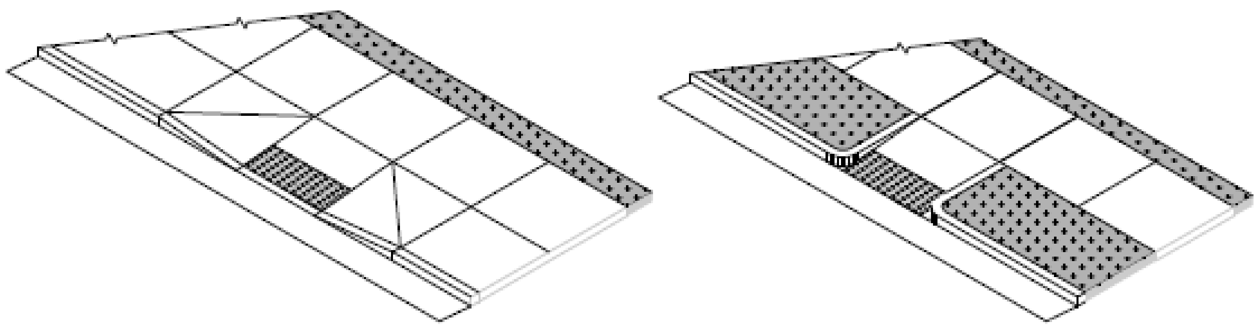


12.5 Curb Ramp Types

Perpendicular curb ramps are oriented perpendicular to the curb face or vertical elevation change they traverse. Perpendicular ramps have a turning space located at the top of the ramp to allow users to get oriented in the direction of the crossing before travelling down the ramp.

Perpendicular curb ramps are generally the preferred design to accommodate pedestrians if there is enough space for their installation. When possible, perpendicular ramps should be aligned with the pedestrian street crossing they serve. When ROW is limited for the installation of a perpendicular curb ramp, consideration could be given to the use of parallel curb ramps, particularly in retrofit scenarios.

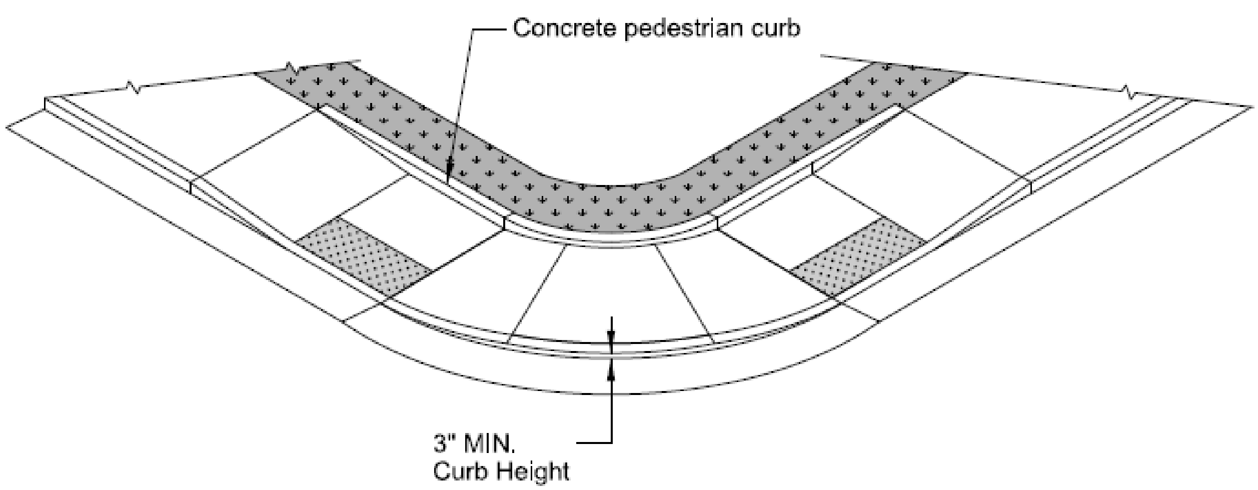
Figure 12-13 Perpendicular Curb Ramp Examples



Parallel curb ramps are oriented parallel to the curb face or elevation change which they traverse. These are often used when there is little room between the curb and the back of sidewalk for a perpendicular curb ramp and turning space. Parallel curb ramps transition down to the roadway elevation and require individuals to traverse multiple ramp surfaces when traveling along a sidewalk. To avoid this, it is preferred that perpendicular ramps be used where possible.

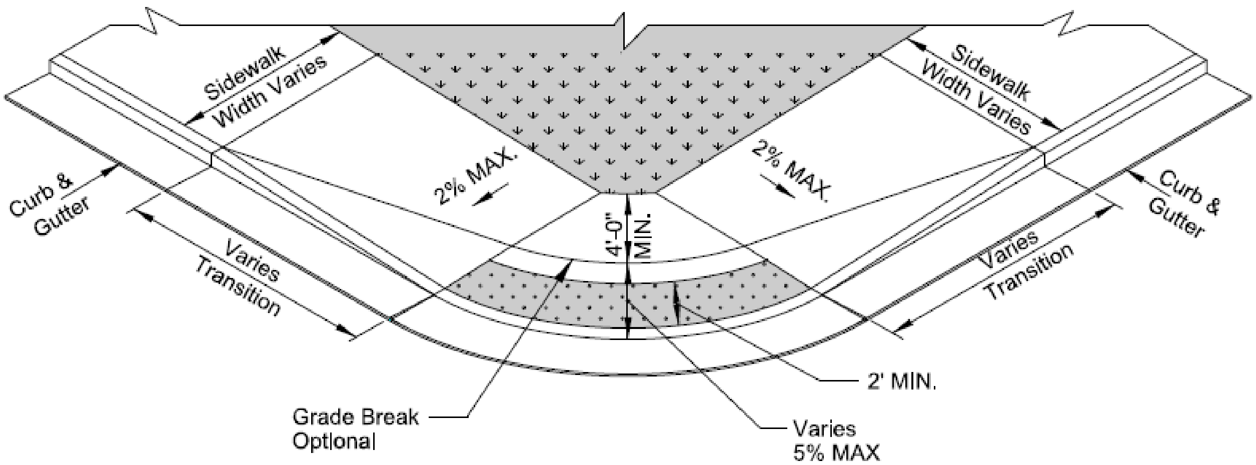
Additionally, because the turning space of a parallel ramp is at the roadway grade, sedimentation and drainage can be an issue with parallel style curb ramps.

Figure 12-14 Parallel Curb Ramp Example



In a blended transition, the elevation of the sidewalk is slowly lowered to the street level at the corner. The maximum grade of a blended transition is 5.0% and the maximum cross slope is 2.0%. Blended transitions are typically seen in dense urban areas such as central business districts, around stadiums, or in main street environments. Blended transitions present an opportunity for turning vehicular traffic to traverse the sidewalk and thereby pose a safety risk to pedestrians. Blended transitions also create challenges for the visually impaired because they provide limited directionality. Blended transitions should be used sparingly, and only where appropriate.

Figure 12-15 Blended Transition/Depressed Corner Example



12.6 Curb Ramp Technical Requirements

Although there are several types and configurations of curb ramps, including combinations of the types mentioned above, they all have the following general requirements:

12.6.1 Curb Ramp Running Slope – PROWAG (R304.2.2, R304.3.2 & R304.4.1)

Curb ramps should be designed to a maximum running slope of 7.5% to 8.0% to allow for construction tolerances. The running slope of a turning space should be design to a maximum of 1.5% to 1.8% to allow for construction tolerances. For more detailed information refer to PROWAG R304.2.2.

12.6.2 Curb Ramp Cross Slope – PROWAG (R304.5.3)

Designers should target a cross slope of 1.5% to provide for flexibility during construction. For street crossings that do not have stop or yield control, or at mid-block crossings, the cross slope is allowed to match the street or highway grade. See the PAR cross slope requirements for more information.

12.6.3 Curb Ramp Width – PROWAG (R304.5.1)

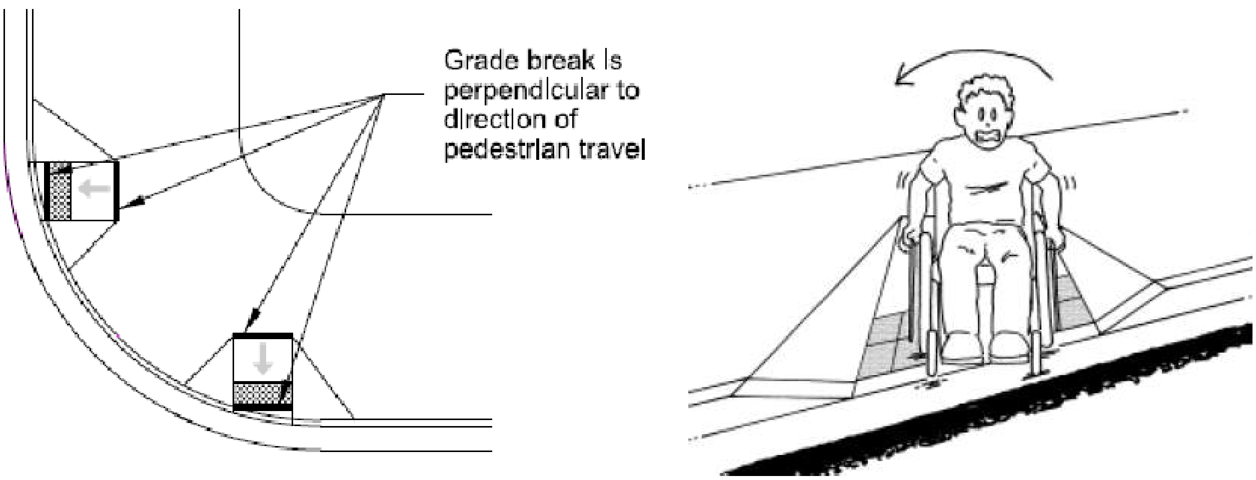
The clear width of curb ramp runs, turning spaces, and blended transitions shall be 4 feet minimum. On CDOT projects, curb ramp runs, turning spaces, and blended transitions should be 5 feet in width or greater.

If the sidewalk the curb ramp is servicing is wider than 5 feet, the ramp should match the width of the facility it is serving. Curb ramps that service shared-use paths should match the width of the path.

12.6.4 Grade Breaks - PROWAG (R304.5.2)

When grade breaks are not perpendicular to the path of travel, they pose challenges to pedestrians using a mobility device, such as wheelchairs and walkers, because one wheel may strike or leave the ramp before the other.

Figure 12-16 Curb Ramp Grade Breaks



12.6.5 Curb Ramp Turning Spaces – PROWAG (R304.2.1 & R304.3.1)

Turning spaces allow users to maneuver on and off the curb ramp and are required at the top or bottom of a curb ramp. Turning spaces are required at the top of a perpendicular curb ramp and at the bottom of a parallel curb ramp. The maximum running slope and cross slope of turning spaces shall be 2.0%. Designers should target slopes of 1.5% to provide flexibility during construction. At mid-block crossings or locations without yield or stop control, the cross slope of the turning space is allowed to equal the roadway grade. Turning spaces shall be 4 feet by 4 feet minimum. If the turning space is constrained by a vertical element, such as a raised curb or other vertical obstruction, on one or more sides, provide 5 feet of turning space in the direction of the street crossing.

Use this link to access CDOT's M-608-1 standards for turning space requirements: [*m-608-1-curb-ramps.pdf (codot.gov)*]

When the profile of the roadway being crossed has an excessive slope, the curb ramp cross slope should be transitioned slowly to the turning space. The transition shall be spread evenly over the length of the curb ramp.

Figure 12-17 Transitioning Steep Roadway Slopes

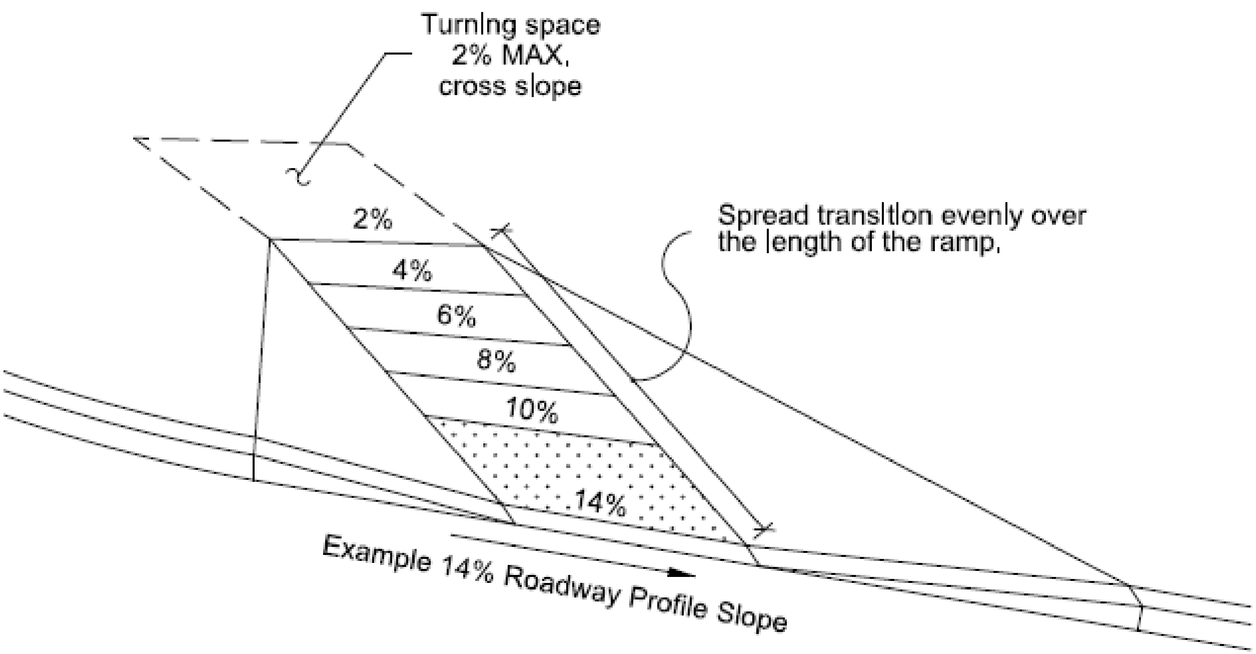
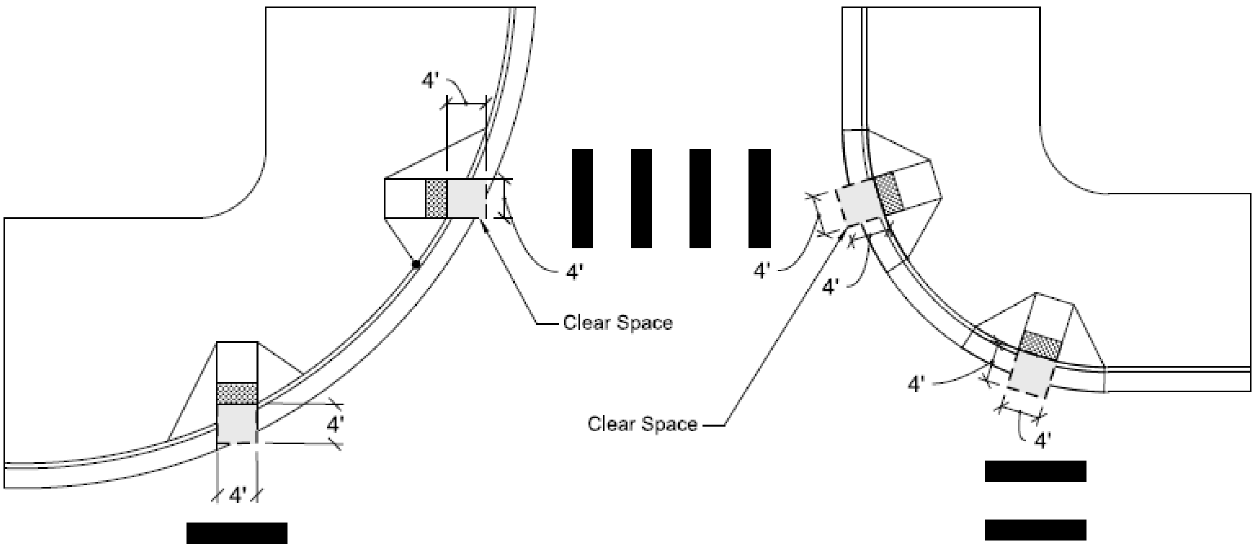


Figure 12-18 Street Grade at Curb Ramps Examples

12.6.6 Curb Ramp Clear Spaces – PROWAG (R304.5.5)

Beyond the bottom grade break of perpendicular ramps, a clear space 4-foot by 4-foot minimum shall be provided. This clear space must be within the pedestrian street crossing (crosswalk) and wholly outside of any vehicle travel lanes. Clear space should not be confused with turning space/landing space as it is a distinct concept.

Figure 12-19 Perpendicular Curb Ramp Clear Spaces

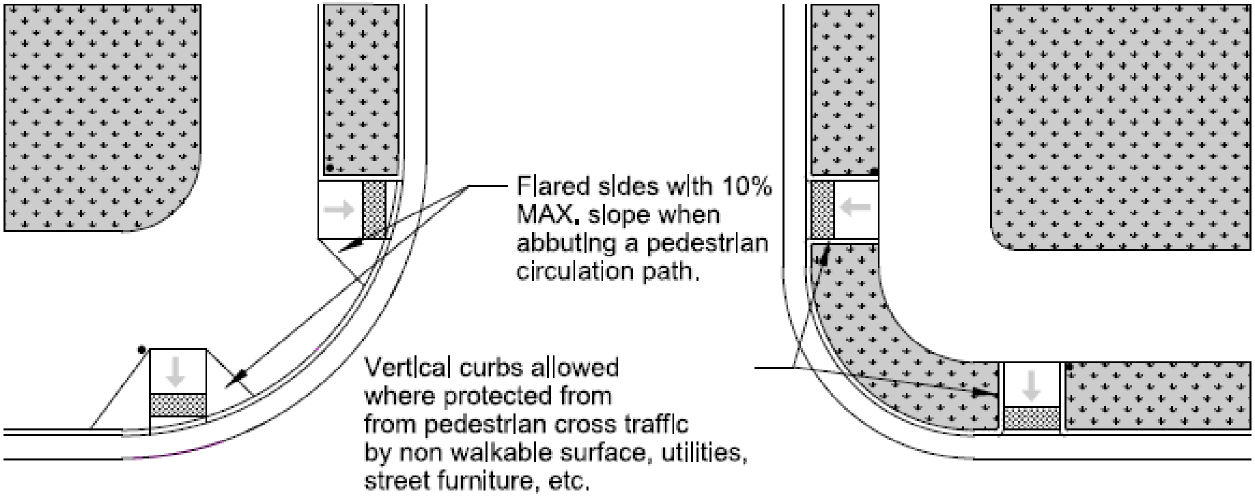


12.6.7 Flared Sides – PROWAG (R304.2.3)

Where a pedestrian can walk across a curb ramp, flared sides shall be provided to prevent a tripping hazard. Flared sides shall be sloped at 10.0% maximum and be measured parallel to the curb line. A best practice is to design flares with slopes between 8.0% and 9.0%, Flared sides are only required where the curb ramp abuts a portion of a pedestrian circulation path. If access to a ramp flare is blocked from pedestrian travel by an item such as street furniture or a utility, then consider a vertical or return curb.

A vertical curb face may be used if the ramp abuts a non-walkable surface. Vertical curb faces can be beneficial to pedestrians with visual disabilities because they align pedestrians in the direction of the street crossing. Flared sides may be used when the ramp abuts a non-walkable surface, in this situation the allowable slope of the flare is at the designer’s discretion. Using flared sides can be beneficial in protecting the ramp from vehicle strikes such as snowplows, however, they do not provide the directionality benefits of vertical faces.

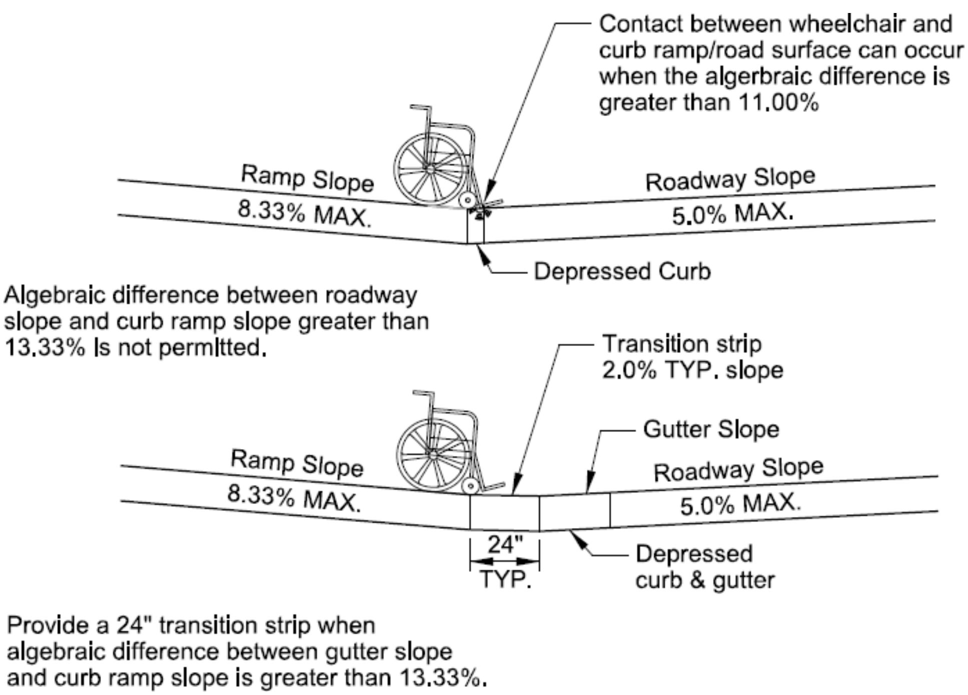
Figure 12-20 Flared Sides



12.6.8 Counter Slope – PROWAG (R304.5.4)

The transition from the curb ramp to the roadway surface must be flush. The counter slope of 5.0% or less, a best practice would be to target less. The algebraic difference of the ramp run and the street counter slope shall not exceed 13.33% (8.33% and 5% respectively). A rapid change in grade at the bottom of a ramp run can be difficult for someone using a wheelchair to traverse. This may occur in limited instances through design of counter slope.

Figure 12-21 Curb Ramp Counter Slope Requirements



12.7 Detectable Warning Surfaces – PROWAG (R305)

Detectable Warning Surfaces (DWS) provide an indication to individuals with disabilities that they are entering a potentially dangerous area. This is communicated through a distinct patterned surface consisting of truncated domes. DWS should be detectable by cane or underfoot and are intended to differentiate the boundary between the pedestrian realm and vehicular routes when a raised curb face is missing. The color of detectable warnings surfaces shall contrast visually with adjacent walking surfaces, either light-on-dark or dark-on-light.

The truncated dome pattern of the DWS should be aligned so that the rows of domes are parallel to the direction of pedestrian travel. This alignment allows people using wheelchairs to track between the domes and avoid excessive vibration, which can be uncomfortable to individuals with a spinal cord injury. The orientation of the truncated domes is not intended to provide wayfinding assistance (orient users in the direction of the crossing) for pedestrians with visual disabilities. While a best practice, this is not a requirement and cannot always be accomplished.

DWS shall extend 2 feet in the direction of pedestrian travel and are typically placed at the back of curb. DWS shall extend the full width of a curb ramp (excluding flared sides), blended transition, or turning space. DWS shall extend the full width of pedestrian rail crossings or shared-use path crossing. At boarding platforms for railways or buses, DWS shall be placed along the full length of the platform. At boarding areas at the sidewalk or street level the DWS shall extend the full length of the transit stop. When a border is required for installation, such as when pavers are used, the border shall be no more than 2 inches in width.

For the technical requirements of the truncated dome size and spacing, refer to PROWAG section R305.1 & CDOT Standard Plan M-608-1.

Of the DWS allowed on CDOT projects, pavers require the most ongoing maintenance over time. This should be considered when specifying their usage on a project.

12.7.1 Placement

12.7.1.1 Pedestrian Street Crossings – PROWAG (R208.1 & R305.2)

Detectable warning surfaces must be installed at all pedestrian street and rail crossings. PROWAG recommends that DWS not be placed at residential driveway crossings or at locations where the pedestrian right of way continues across driveway aprons. However, it does recommend that DWS be placed at commercial driveways when yield or stop control is present. This guidance is not necessarily comprehensive and may be confusing to designers. For example, small commercial centers might have less driveway traffic than large apartment complexes but require DWS. Sound engineering judgement should be applied regarding the application of DWS at driveway crossings. Conditions that make a driveway function more like a street crossing may warrant the use of DWS, regardless of the land use category. Types of driveway locations that may warrant the use of DWS include:

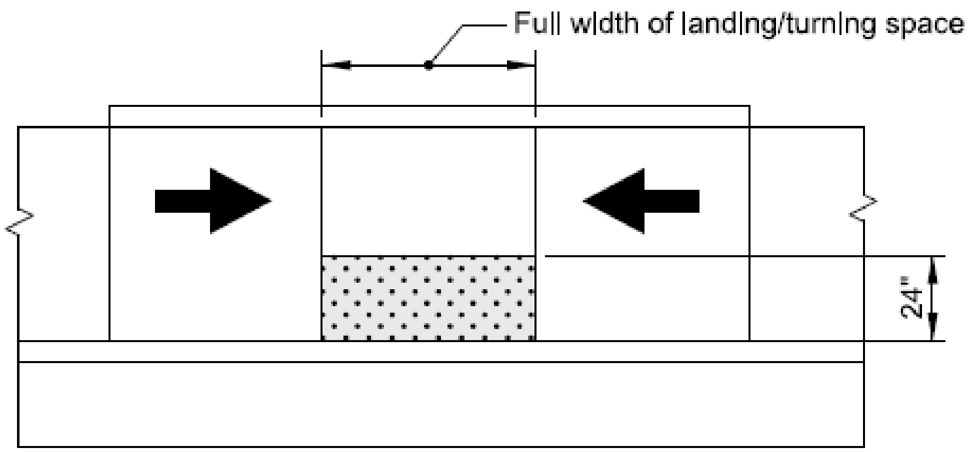
- If there is the presence of a traffic control device that indicates the driveway functions more like a street crossing than a driveway (e.g., lane or pavement markings, signals, stop signs).

- Where a sidewalk descends to meet the grade of the street at the driveway crossing.
- Where the sidewalk changes material and ceases to be clearly defined as sidewalk, for example, changing from concrete sidewalk to asphalt that looks more similar to the street at the driveway.

12.7.1.2 Parallel Curb Ramps – PROWAG (R305.2.2)

On parallel curb ramps the DWS shall be placed in the turning space at the back of curb where the curb face is missing.

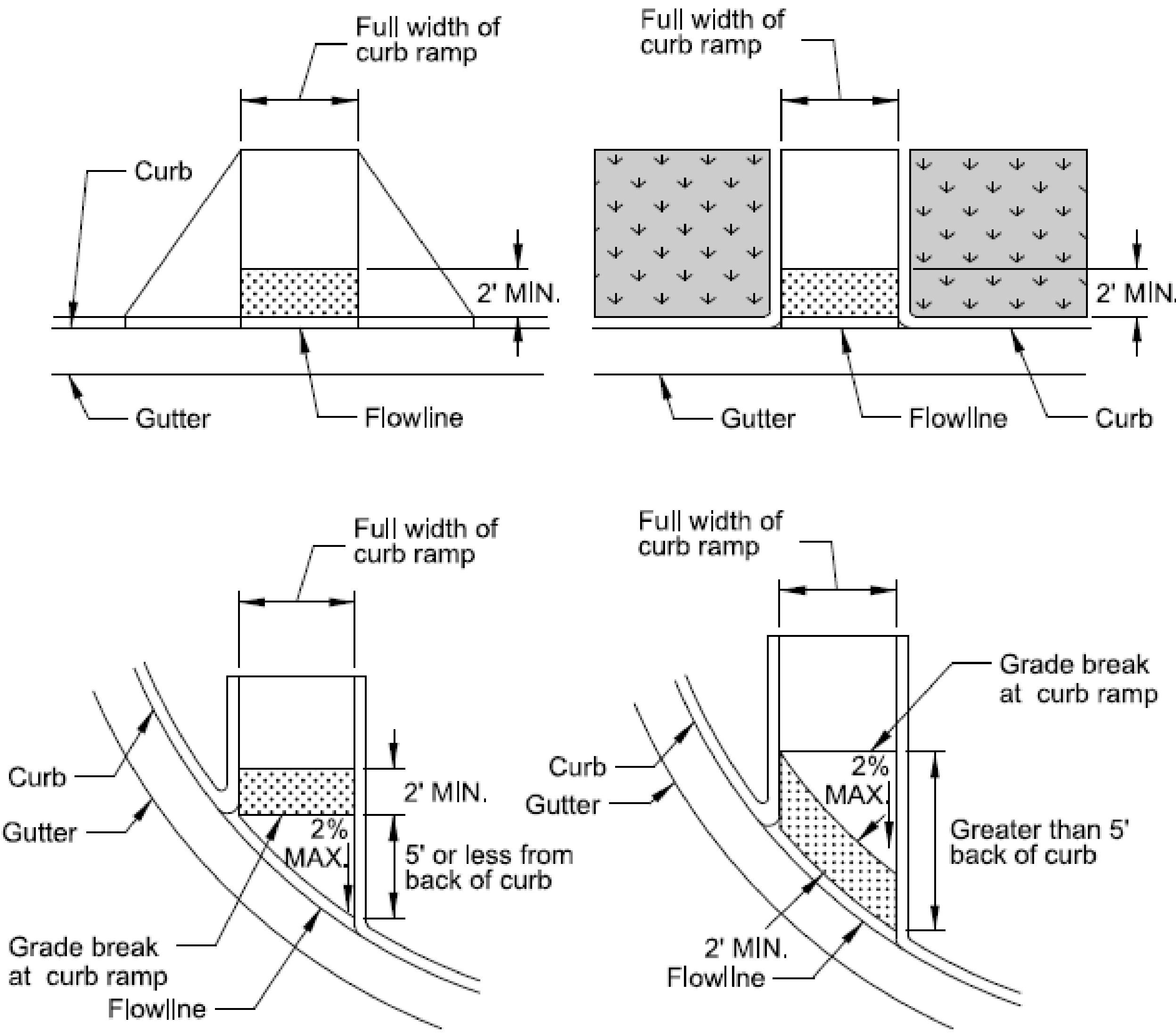
Figure 12-22 Parallel Curb Ramp DWS Placement



12.7.1.3 Perpendicular Ramps – PROWAG (R305.2.1)

The placement of the DWS on perpendicular curb ramps varies depending on the location of the grade break at the bottom of the ramp. Generally, the DWS is placed at the back of curb where the curb face is missing. In situations where the ramp is located on a radius and the grade break at the bottom of the ramp is less than 5 feet from the back of curb, the DWS is placed at the bottom of the ramp (refer to Figure 12-20 in this chapter).

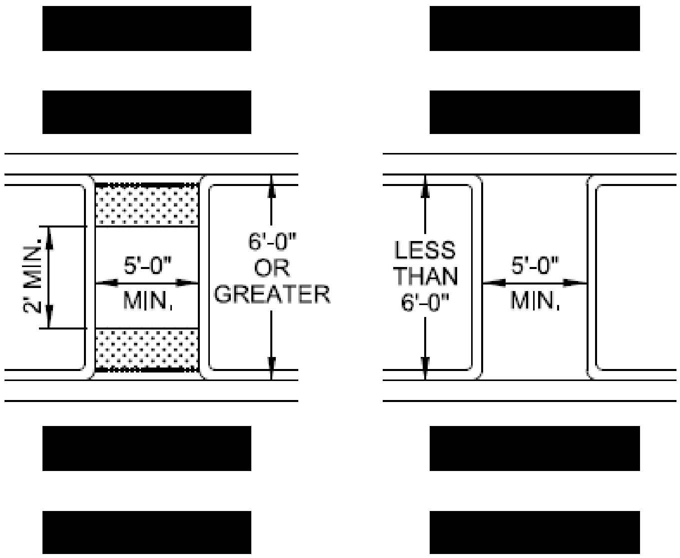
Figure 12-23 Perpendicular Curb Ramp DWS Placement



12.7.1.4 Pedestrian Refuge Islands – PROWAG (R305.2.4)

When a pedestrian refuge island is 6 feet wide or greater from the face of curb to face of curb, DWS shall be installed. When installed, the detectable warning surfaces must be separated by a surface without DWS that is a minimum of 2 feet in length (parallel to pedestrian travel). If this 2-foot space cannot be provided, DWS shall not be installed because the island is not wide enough to be considered a pedestrian refuge and timing should be evaluated to allow pedestrians to cross safely and in accordance with the MUTCD.

Figure 12-24 Pedestrian Refuge DWS Placement



12.7.1.5 Pedestrian At-Grade Rail Crossings – PROWAG (R305.2.5)

Refer to PROWAG (R305.2.5), Figure 12-6 of this chapter, and CDOT Standard Plans – M & S Standards (CDOT, 2019) for more information. The designer should very carefully read the expectations for detectable warning requirements at at-grade pedestrian crossings, platforms, and alighting areas that are not on streets or highways.

12.8 Pedestrian Push Buttons

When pedestrian activated crossing controls (Push Buttons) are provided, they must meet the requirements set forth in the MUTCD, specifically sections 4E.08 through 4E.13. An accessible pedestrian signal (APS) is a device that communicates information to pedestrians about the street crossing through audible tones and vibrotactile surfaces. Operable parts on items such as pedestrian push buttons and APS shall comply with Section R403 of the PROWAG. The required clear space of 2.5-feet by 4-feet adjacent to the push button with a max cross slope of 2%. It is recommended for designers to plan for the location of the push button and associated 2.5-foot-by-4-foot clear space when designing the curb ramp. A best practice is to locate the push button post assembly in the middle of the 4-foot clear space dimension to better facilitate side reach.

Consistency throughout the pedestrian system is critical. On CDOT signal projects, the CDOT Accessible Pedestrian Signal Protocol should be used to determine if there is a need for an APS.

Use this link to view CDOT's Accessible Pedestrian Signal Protocol:
https://www.codot.gov/business/civilrights/ada/resources-engineers

In addition to the requirements in the MUTCD and PROWAG, the following should be taken into consideration when installing pedestrian push buttons for pedestrian accessible routes:

- Pedestrian push buttons should be located as close as practical to the curb ramp they are servicing while at the same time permit operation from a clear and level space.
- The pedestrian push button location should not interfere with the use of the curb ramp or the sidewalk.
- If a push button cannot be practically located within the recommended area, consider moving it back and adjusting the pedestrian crossing time.
- Do not place the push button pole in the pedestrian access route.
- A firm, stable, slip resistant surface must be provided to allow for a forward or side reach to the pedestrian push button from a wheelchair.
- Pedestrian push buttons should not be placed adjacent to the running slope of a curb ramp.
- Pedestrian push buttons should be located on the side of the pole from which the pedestrian accesses the button. Pedestrians should not have to reach around the pole to access the button.

Use this link to view further information on CDOT's Pedestrian Crossing Guidelines: *https://www.codot.gov/safety/traffic-safety/assets/documents/cdot-pedestrian-crossing-guidelines-2021.pdf*

Figure 12-25 Pedestrian Push Button Reach Ranges

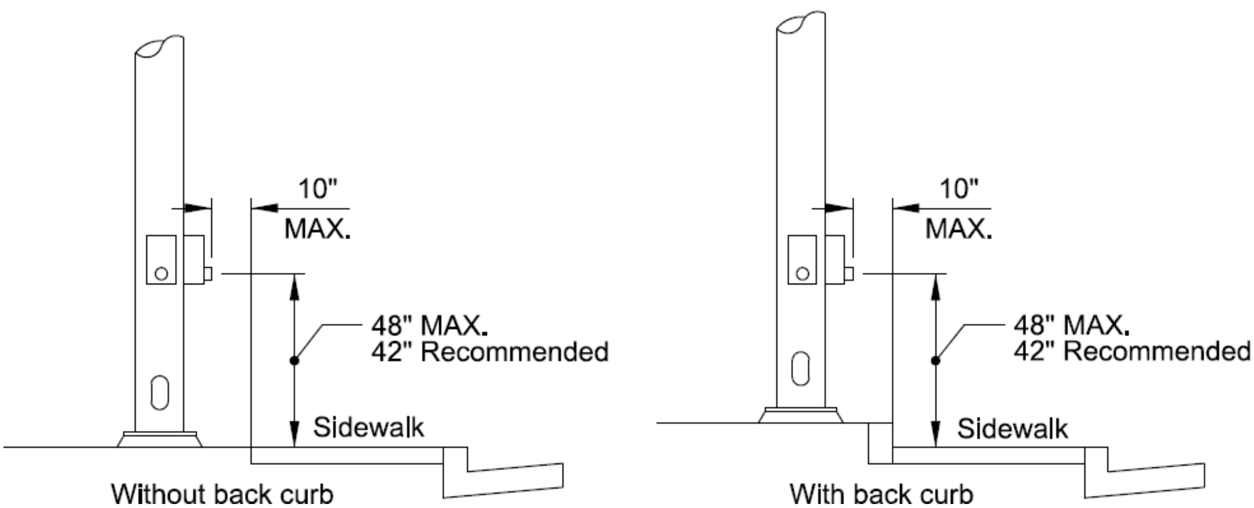
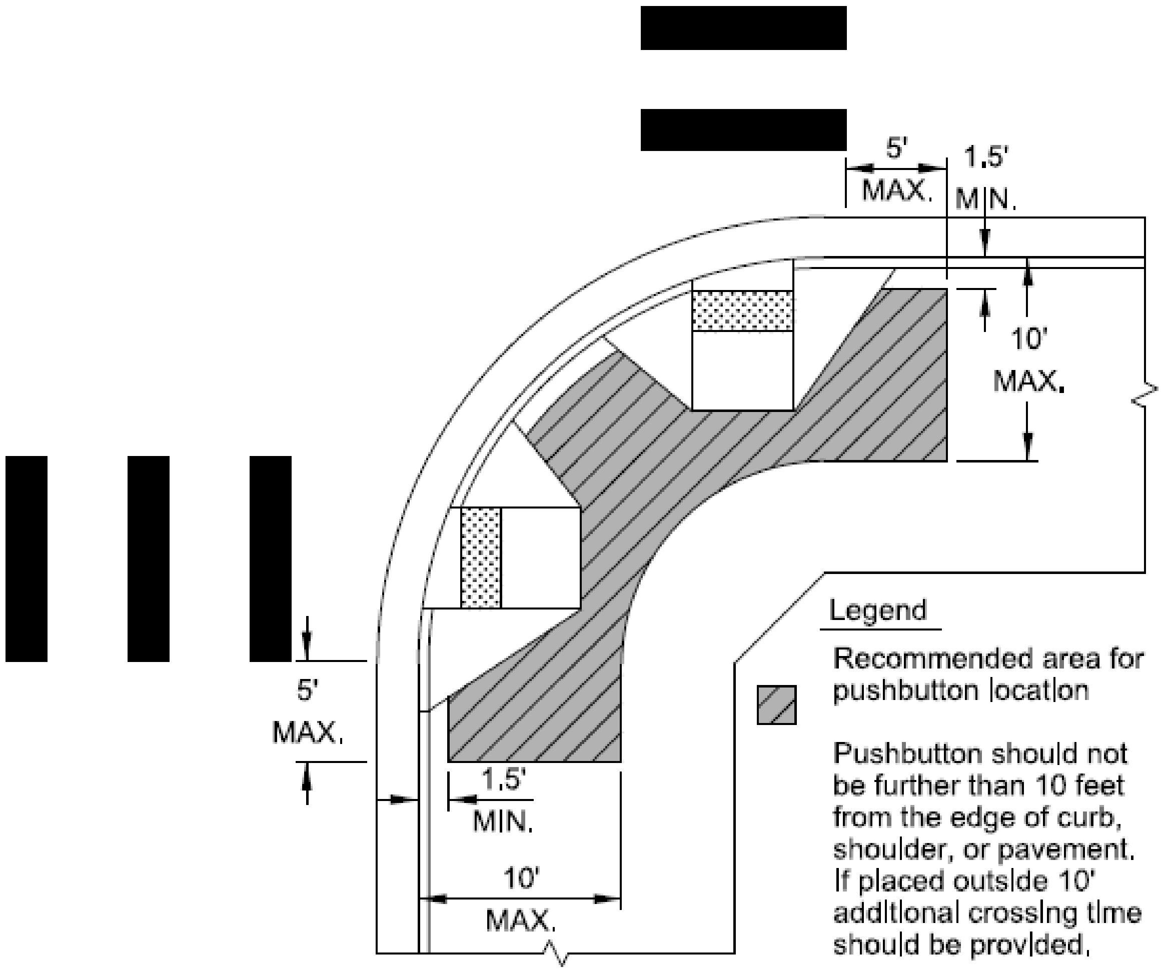


Figure 12-26 Pedestrian Push Button Placement



12.9 Pedestrian Ramp, Landings & Handrails – PROWAG (R407 "RAMPS")

Pedestrian ramps (not to be confused with curb ramps) that traverse changes of elevation should use a running slope between 5.0% and 8.33%. Where possible, the flattest running slope should be used to accommodate the widest possible range of users. Wheelchair users with disabilities affecting their arms, or individuals with low stamina, can have difficulties using pedestrian ramps. For this reason, level landing areas are provided at regular intervals on pedestrian ramps. The vertical rise of any ramp run shall not exceed 30 inches without a level landing space. Ramps shall have level landing spaces at both the top and the bottom of each ramp run. Landing spaces should be 5 feet in length and match the width of the ramp. If the landing space is located at a 90-degree turn in the ramp it should have a minimum dimension of 5 feet by 5 feet.

Any ramp with a vertical rise greater than 6 inches shall provide handrails. For requirements for pedestrian handrails refer to R409 in PROWAG.

Figure 12-27 Pedestrian Ramp Elements

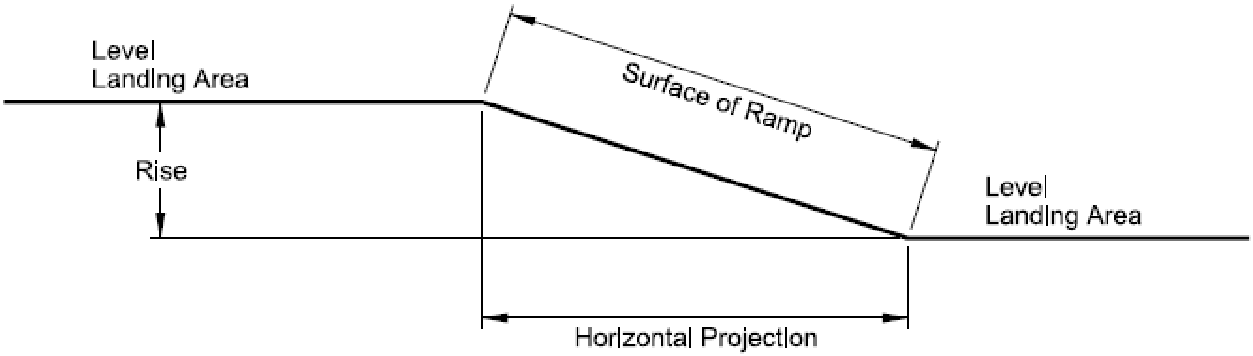
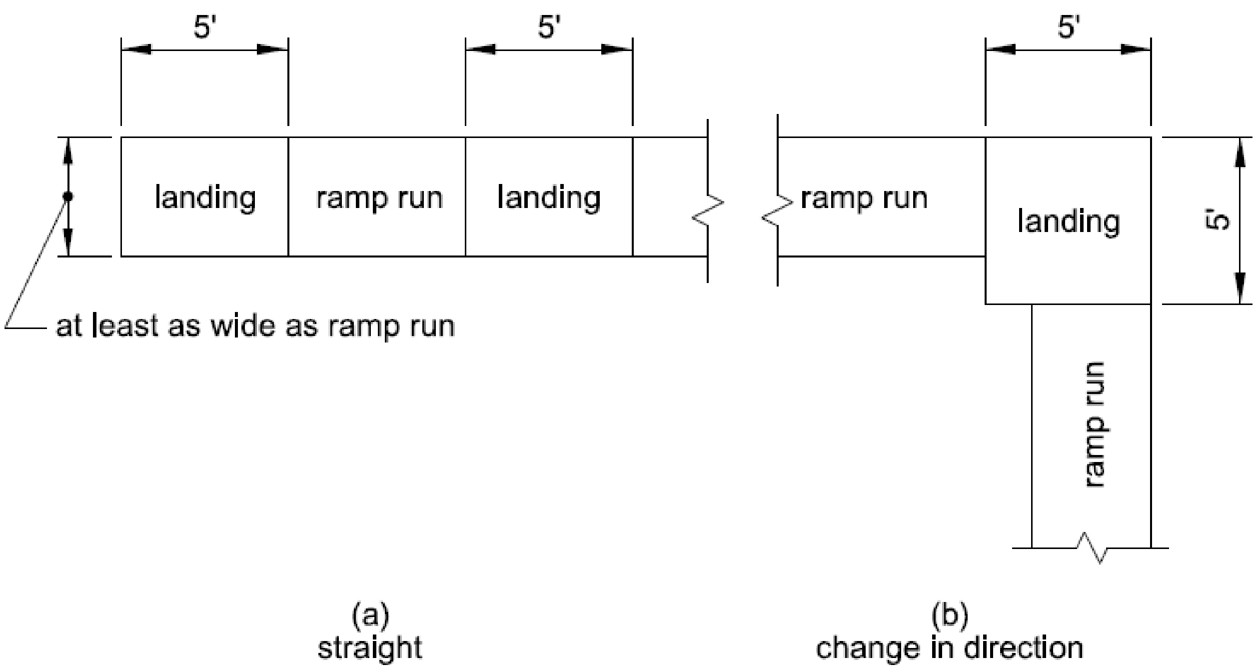


Figure 12-28 Pedestrian Ramp Turning Space Requirements



Chapter 13
Bicycle and Pedestrian Facilities

Legend

	Multimodal Application Example
	Context-Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context-Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO-Specific Information

Chapter

13

13 Bicycle and Pedestrian Facilities

13.1 Introduction

Bicycle and pedestrian modes of transportation are key elements of CDOT's mission to provide an integrated multimodal transportation system that effectively and safely moves people, goods, and information. Interconnected bicycle and pedestrian infrastructure accommodate walking and biking as viable transportation modes that contribute to the health, safety, equity, and equality of our communities. To support this mission, CDOT adopted a Policy Directive and a Procedural Directive to improve the accommodation of bicycles and pedestrians in CDOT programs. Additionally, federal surface transportation law places a strong emphasis on creating a seamless transportation system that persons of all ages and abilities can utilize for safe and convenient access to jobs, services, schools, and recreation.

This chapter provides information for planners, designers, and engineers to develop infrastructure that supports walking and bicycling for people of all ages and abilities. This chapter also discusses context-sensitive design and the need to plan and design projects such that they align with local and regional priorities. The selection of the appropriate bicycle and pedestrian facilities is imperative to provide safe, convenient, and accessible transportation options for all users. This guide does not address education, encouragement, evaluation, or enforcement programs that are required to provide a well-rounded system. This Guide does not intend to supersede the need for judgement by knowledgeable transportation or traffic engineering professionals and should serve as engineering guidance.

This chapter consolidates guidance for planners, designers, and engineers to develop the physical infrastructure needed to support people of all ages and abilities walking and bicycling. It also provides additional guidance where none exists in the current standards or guidance documents. This chapter also includes treatments that have FHWA interim approval to represent the state of the practice accurately.

National resources for multimodal design criteria and standards include:

- AASHTO Policy on the Geometric Design of Streets and Highways (2018 AASHTO GDHS) (AASHTO, 2018).
- AASHTO *Guide for the Development of Bicycle Facilities, 4th Edition* (2012).
- AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities, 2nd Edition* (2021).
- FHWA *Small Town and Rural Multimodal Networks* (2016).
- FHWA *Bikeway Selection Guide* (2019).
- FHWA *Achieving Multimodal Networks: Applying Design Flexibility and Reducing Conflicts* (2016b).
- FHWA *Guide for Improving Pedestrian Safety at Uncontrolled Crossings* (2018).
- FHWA *Accessible Shared Streets Notable Practices and Considerations for Accommodating* Pedestrians *with Vision Disabilities* (2017).
- FHWA *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (FHWA, [2009] 2022).
- National Association of City Transportation Officials (NACTO) *Urban Bikeway Design Guide* (2014).
- NACTO *Urban Street Design Guide* (2013).
- NACTO *Transit Street Design Guide* (2016).
- NCHRP *Crossing Solutions at Roundabouts and Channelized Turn Lanes for Pedestrians with Vision Disabilities: A Guidebook* (2017).
- Institute of Transportation Engineers *Implementing Context Sensitive Design on Multimodal Corridors: A Practitioner's Handbook* (2017).
- U.S. Department of Justice 2010 ADA Standards for Accessible Design (2010).
- U.S. Access Board Proposed Guidelines for Pedestrian Facilities in the Public Right-of-Way (PROWAG) (2011).

13.1.1 CDOT Bike and Pedestrian Policy Directive 1602.0

In January 2017, the Colorado Transportation Commission updated CDOT's bicycle and pedestrian Policy Directive 1602.0 (CDOT, 2017). The purpose of this policy is:

> The Transportation Commission supports the Colorado Department of Transportation ("CDOT" or "Department") in elevating the needs of bicyclists and pedestrians in the planning, design, and operation of transportation facilities as a

> necessary component of all projects. The Department will promote transportation mode choice by enhancing safety and mobility for bicyclists and pedestrians on or along the state highway system. This includes all aspects of accommodating pedestrians and bicyclists, from planning, programming, design, construction, to operation, maintenance and education."

The intent of this policy is to:

> It is the policy of the Colorado Transportation Commission to provide transportation infrastructure that accommodates bicycle and pedestrian use of the highways in a manner that is safe and reliable for all highway users. The needs of bicyclists and pedestrians shall be included in the planning, design, and operation of transportation facilities, as a matter of routine. A decision to not accommodate them shall be documented based on the exemption criteria in the procedural directive.

13.1.2 CDOT Bike and Pedestrian Procedural Directive 1602.1

CDOT Procedural Directive 1602.1 requires the incorporation of bicycle and pedestrian considerations throughout CDOT's planning, programming, design, construction and maintenance operations (as well as educational and enforcement efforts) (CDOT, 2017). Specifically with respect to design, the procedural directive states the following:

> DESIGN
>
> A wide range of options can serve to enhance bicycle and pedestrian mobility. Bicycle and pedestrian accommodation comes in many sizes and styles from signage and striping to sidewalks and shoulders. Context sensitive solution practices are encouraged to determine the appropriate solution for accommodating bicyclists and pedestrians within the project area so that they are consistent with local and regional transportation plans. Bicycle and pedestrian accommodations shall be integrated into the overall design process for state highway projects that begin the scoping process after the approval date of this procedural directive. Consideration of bicycle and pedestrian accommodations in on-going projects will be incorporated as reasonable and feasible given budget and schedule constraints.
>
> Current AASHTO, MUTCD, and CDOT standards for bicycle and pedestrian facilities shall be used in developing potential facility improvements. To provide consistent information on accommodating bicyclists and pedestrians on the state highway system, staff shall develop a chapter on bicycle and pedestrian design guidelines as part of the existing CDOT Design Manual.

It is recognized that in some limited cases, bicycle or pedestrian facilities may be impractical. Consequently, the procedural directive provides the following:

EXEMPTION

CDOT will utilize FHWA exemption guidance in situations where one or more of the following occur:

- Bicyclists and pedestrians are prohibited by law from using the roadway.
- The cost of establishing bikeways or walkways would be excessively disproportionate to the need or probable use. (Excessively disproportionate is defined as exceeding 20% of the cost of the larger transportation project.)
- Where scarcity of population or other factors indicate an absence of need.
- In a resurfacing project on a state highway, if the only means of accommodating bicycle and pedestrian needs is adding a shoulder, the project shall be automatically exempted on the grounds that under CDOT's current asset management guidelines, resurfacing money cannot be used for shoulders
- If the resurfacing project on a state highway runs through a town, consideration must be given to restriping that portion within the town to accommodate bicyclists and pedestrians. If the accommodation cannot be made, an Exemption must be documented on Form 464BP.

Requests for an exemption from the inclusion of bikeways and walkways shall be documented with supporting data that indicates the basis for the decision. Exemption requests shall be submitted on the Form 464BP to the Region Transportation Director and the headquarters Bicycle Pedestrian Coordinator. Review and response will be done within 30 days following submittal.

13.1.3 Design Exemptions

The design requirements set forth in this chapter apply to all projects. Pursuant to Chief Engineer Policy Memo 7, "it is imperative that surface treatment dollars are optimized in regard to maintaining the pavement surface. In that light, surface treatment dollars are not to be used to fund enhancements or other project related costs."

Use this link to access CDOT's Policy Directives:
https://www.codot.gov/business/designsupport/policy-memos

When bicycle and pedestrian improvements are included in resurfacing, restoration, and rehabilitation projects, the designer must adhere to the requirements of CDOT Policy Directive 548.0, Safety Considerations on 3R Projects.

When bicycle and pedestrian facilities are required, project managers should investigate additional funding sources to supplement the primary funding for the project. If funds are not available, the project manager shall document this with a letter to the design file that specifically states what improvements were considered in addition to the efforts made to obtain other sources of funding. Additionally, the project manager should determine if other pedestrian or bicycle improvement projects are planned in the same area to determine if there are opportunities to consolidate the projects. It is not the intent of this chapter to create a new process for documenting design variances and exemptions. A design letter will be used to document when any of the design criteria of this chapter cannot be met on a project. In addition to the Regional Transportation Director approval, when the exemption is for bicycle or pedestrian criteria, the headquarters Bicycle and Pedestrian Coordinator must also acknowledge being provided an opportunity to comment on the request for an exemption.

13.1.4 Federal Guidance Concerning Bicycle and Pedestrian Facilities

13.1.4.1 U.S. Department of Transportation (DOT) Policy Statement

In a policy statement dated March 11, 2010, the U.S. Secretary of Transportation stated the following:

> The DOT policy is to incorporate safe and convenient walking and bicycling facilities into transportation projects. Every transportation agency, including DOT, has the responsibility to improve conditions and opportunities for walking and bicycling and to integrate walking and bicycling into their transportation systems. Because of the numerous individual and community benefits that walking and bicycling provide — including health, safety, environmental, transportation, and quality of life — transportation agencies are encouraged to go beyond minimum standards to provide safe and convenient facilities for these modes.

Title 23 U.S.C. 217 states:

> Bicycle transportation facilities and pedestrian walkways shall be considered, where appropriate, in conjunction with all new construction and reconstruction of transportation facilities, except where bicycle and pedestrian use are not permitted.

> In any case where a highway bridge deck being replaced or rehabilitated with Federal financial participation is located on a highway on which pedestrians or bicyclists are permitted to operate at each end of such bridge, and the Secretary determines that the safe accommodation of pedestrians or bicyclists can be provided at reasonable cost as part of such replacement or rehabilitation, then such bridge shall be so replaced or rehabilitated as to provide such safe accommodations.

13.1.4.2 Restrictions on Severing Bicycle and Pedestrian Facilities

In addition to encouraging the provision of bicycle facilities, FHWA is prohibited from funding projects that would sever or have a significant adverse impact on the safety of non-motorized transportation. Title 23 of the United States Code includes the following (§109(m)):

> Protection of Non-Motorized Transportation Traffic. --The Secretary shall not approve any project or take any regulatory action under this title that will result in the severance of an existing major route or have significant adverse impact on the safety for non-motorized transportation traffic and light motorcycles, unless such project or regulatory action provides for a reasonable alternate route or such a route exists.

13.1.5 Context Sensitive Solutions

Context Sensitive Solutions (CSS) is a collaborative, interdisciplinary approach to design. It determines the engineering design features that balance the interests of various stakeholders with the needs of the transportation project to help the project fit harmoniously into its surroundings. CSS is particularly relevant for pedestrian and bicycle facilities because it balances the desired need to move motor vehicles cars with the priorities and safety of vulnerable roadway users and the neighboring communities.

13.1.6 User Counts

CDOT's Bicycle and Pedestrian Program instituted a program to collect bicycle and pedestrian volume data. Bicyclist and pedestrian counts provide data information regarding how many bicyclists and pedestrians use Colorado facilities. New or reconstruction projects, as well as facilities requiring non-motorized evaluation usage, should consider the installation of non-motorized continuous counting stations or conducting short duration counts. This information can be used in setting priorities for new facilities, making engineering decisions, and identifying potential routes. It can also measure increases in bicycling and walking as the Colorado network is improved. Additionally, counts provide a denominator for crash rates.

During the planning or design phase of a project, the project manager should consider installing non-motorized continuous counting stations or conducting short duration counts to determine the level of bicycle and pedestrian usage.

Use this link to access CDOT's bicycle and pedestrian volume data:
https://www.codot.gov/programs/bikeped/bicycle-pedestrian-counts

CDOT's Traffic Analysis Unit or the Active Transportation and Main Streets Section within the Division of Transportation Development can provide count data, provide support for selecting a new counting site, or help purchase counting equipment for a project.

13.2 Bicycle Facilities

Bicyclists should be expected on all roadways except where their use is prohibited by law. Per CDOT policies and directives, all design on CDOT facilities, except those roadways where cyclists are prohibited, shall include accommodations for bicyclists. A network of safe, comfortable, connected, and intuitive bicycle facilities supports bicycling as a viable mode of transportation for people of all ages and abilities. Communities with well-planned and designed networks typically have higher rates of bicycling.

Use this link to view Colorado's Bicycle and Byways Map and the routes where bicycles are prohibited https://www.codot.gov/business/designsupport/policy-memos

13.2.1 Bikeway Facility Selection

The selection of a preferred bikeway requires a careful balance of data analysis, engineering judgment, and management of community goals, all while working within existing project constraints. Key selection criteria include the target design user, non-motorized and motorized traffic data, existing and future land use, and other operating characteristics of the roadway.

The type of bicycle facility should be consistent to the maximum degree possible. Alternating facility types on a corridor can cause confusion for both bicyclists and motorists.

Roadway improvements for bicycles should be continued to logical termini. Advanced signage should be provided to inform bicyclists that the facility is coming to an end.

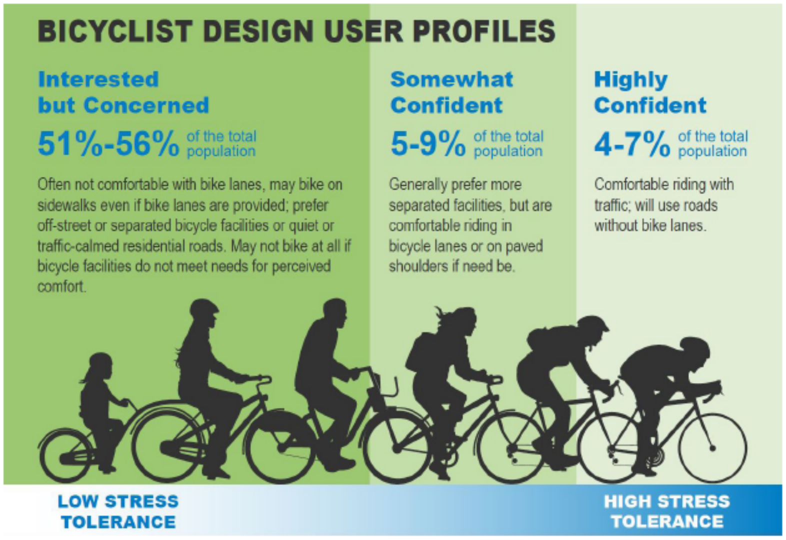
13.2.1.1 Bicyclist User Types

Bicyclists are directly impacted by their perceived comfort operating near or with motor vehicle traffic. Providing low stress, connected bicycle networks improves bicyclist safety and encourages a wider range of bicyclists to use that facility. Many people are interested in bicycling for transportation, but choose not to due to expected, stressful interactions with motorists. It has also been shown that the presence of more bicyclists and pedestrians encourages motorists to look for these street users where they are prevalent.

The FHWA Bikeway Selection Guide (FHWA, 2019), identifies the following three types of bicyclist user types based on a person's age, comfort, skill, experience, and trip purpose (Figure 13-1).

- Interested but Concerned.
- Somewhat Confident.
- Highly Confident.

Figure 13-1 Bicyclist Design User Profiles



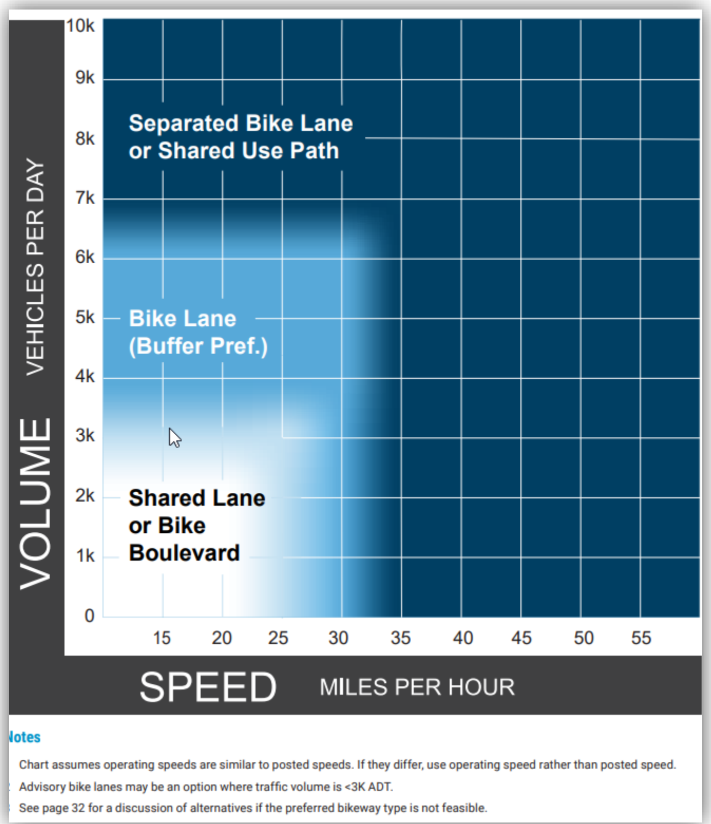
Note: the percentages above reflect only adults who have stated an interest in bicycling.
Source: FHWA Bikeway Selection Guide (FHWA, 2019).

These user types can be used to inform planning and design of bicycle facilities. Generally, the Interested but Concerned bicyclist should be the target design user. This group represents 51% to 56%of the population that would like to bicycle, but choose not to because of the lack of connected, low stress networks. Bicycle facilities designed for this user type maximizes the potential for bicycling as a viable transportation option and accommodates the Somewhat Confident and Highly Confident user types as well.

There are several factors that influence the stress and discomfort for bicyclists: motor vehicle speed, motor vehicle volume, and proximity to traffic. The crash and fatality risks rise significantly when the motor vehicle traffic speed exceeds 25 mph. Additionally, when motorized traffic volumes exceed 6,000 vehicles/day, it becomes increasingly difficult for motorists to share roadway space. For example, on a roadway with 10,000 vehicles/day a bicyclist traveling at 10 mph will be passed approximately every four seconds by a motor vehicle during the peak hour.

Figure 13-2 provides general guidance on how motor vehicle volume and speed should be considered to determine the preferred bikeway type for the Interested but Concerned Bicyclist in Rural Places (C2), Suburban Places (C3), Downtown Places (C5), and Urban Core (C6) Context Classifications (refer to Chapter 1).

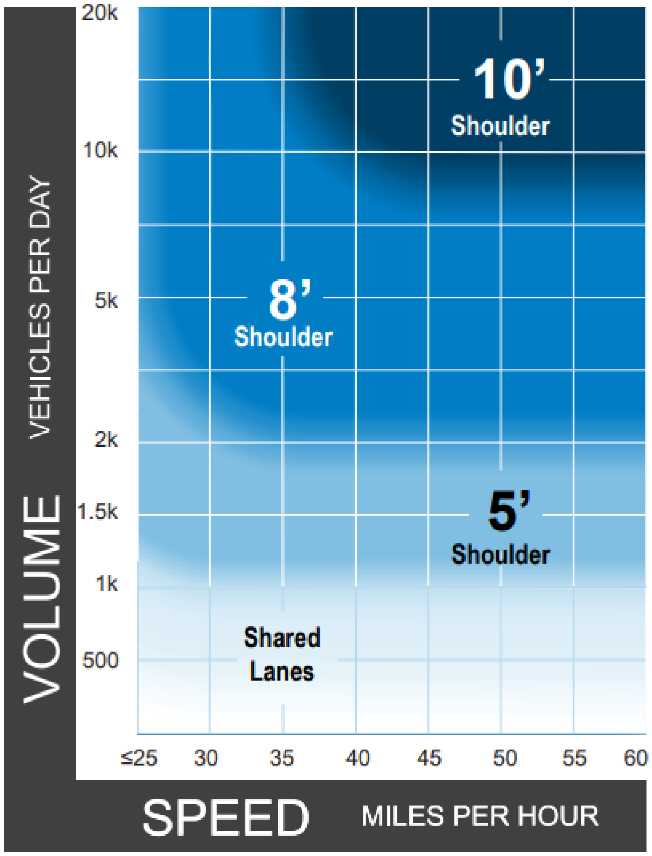
Figure 13-2 Preferred Bikeway Type for Interested but Concerned Bicyclists in Rural Places (C2), Suburban Places (C3), Downtown Places (C5), and Urban Core (C6) Context Classifications



Source: FHWA Bikeway Selection Guide (FHWA, 2019).

Rural roadways, shared lanes, bike lanes, paved shoulders, and shared-use paths are also potential bikeway types. In rural scenarios, Highly Confident or Somewhat Confident bicyclists are most likely to travel long distances on rural roadways between towns and cities and are therefore assumed as the default design user in this context. Figure 13-3 provides general guidance on how motor vehicle volume and speed should be considered to determine the preferred bikeway type for the Highly Confident Bicyclist by providing appropriate shoulder widths.

Figure 13-3 Preferred Shoulder Widths for Rural Roadways



Notes

1 This chart assumes the project involves reconstruction or retrofit in constrained conditions. For new construction, follow recommended shoulder widths in the AASHTO Green Book.

2 A separated shared use pathway is a suitable alternative to providing paved shoulders.

3 Chart assumes operating speeds are similar to posted speeds. If they differ, use operating speed rather than posted speed.

4 If the percentage of heavy vehicles is greater than 5%, consider providing a wider shoulder or a separated pathway.

Source: FHWA Bikeway Selection Guide (FHWA, 2019).

13.2.2 On-Road Bicycle Facilities

This section provides design guidance for accommodating bicycles on roadways. Bicyclists have the same rights and duties applicable to a driver of any other vehicle and generally have similar access and mobility needs. Designers of on-road facilities should understand that these facilities are also used by people on scooters, skateboards, and other micro mobility devices, all of which should be considered in the planning and design processes. Travel by these modes should be safely accommodated at bridges, viaducts, tunnels, intersections, traffic signals, interchanges, roundabouts, transit stops, and railroad crossings.

On-road bicycle facilities can take any number of forms and can be any one of the following types:

- Bike routes (Section 13.2.4)

- Shared lanes (Section 13.2.5)
- Paved shoulders (Section 13.2.6).
- Bike lanes/buffered bike lanes (Section 13.2.7).
- Separated bike lanes (cycle tracks) (Section 1313.2.10).
- Bicycle boulevards (Section 1313.2.11).

13.2.2.1 Sharing Roadway Space

Bicycles operating on Colorado roadways are considered vehicles (Colorado Revised Statutes, Section 42-1-102[10]). As such, bicyclists are subject to the same rules of the road as operators of other vehicles. The design criteria and treatment guidance provided in this chapter assume the operation of bicycles as vehicles.

On-road bicycle facilities are the most common facility type on Colorado roadways, since bicycles may operate on all roadways except where prohibited. Most commonly on CDOT projects, the on-road facility is a bike lane or paved shoulder. Other bicycle facilities may be appropriate if the project is located on a non-CDOT roadway or if a project is constrained. If a community or agency has adopted a minimum level of bicycle accommodation (level of service), bike lanes or shoulders that are wider than the minimums may be required to meet that level of accommodation. Where practical, the bicycle facility provided on CDOT roadway projects should comply with the locally adopted bicycle plan.

13.2.3 Additional Bicycle Facility Types

When the preferred on-road bicycle facility cannot be accommodated, alternative or parallel routes (Section 1313.2.12) should be considered to make sure that the project's purpose and need are met. Shared-use paths (Section 13.3) and bicycle boulevards (Section 1313.2.11) are physically separated from motorized vehicular traffic. Bicycle boulevards and may be considered where on-road facilities cannot be accommodated.

13.2.3.1 Role of Design Factors

The level of accommodation for bicyclists can be measured by a range of methods from subjective to objective. The *Highway Capacity Manual* (TRB, 2022) establishes an objective method for determining the level of bicycle accommodation (level of service) based upon the geometric and operational characteristics of the roadway being analyzed. This method is based upon numerous research projects that quantified what factors influence how bicyclists perceive a roadway's safety and comfort. The model for links (roadway segments between intersections) includes the following factors:

- Width of the outside through lane.
- Presence and width of a paved shoulder or bike lane.
- Encroachments into the bike lane.
- Presence and width of a parking lane.
- Percent of parking occupied by parked cars.

- Pavement condition.
- Operating speeds on the roadway.
- Traffic volume on the roadway.
- Percent heavy vehicles on the roadway.

The primary geometric conditions that are influenced by design are the width of the outside lane, the presence of a paved shoulder or bike lane, the width of the paved shoulder or bike lane, and encroachments into the bike lane or paved shoulder. As stated in Section 13.2.2.1, in Colorado, it is likely that paved shoulders and bike lanes are the preferred bicycle facility. However, in some cases, a shared lane may be adequate. Wide outside lanes tend to increase vehicle speeds and should be avoided.

On some projects, pavement cannot be widened or restriped for a paved shoulder or bike lane. On these roads, the project available roadway space and traffic conditions should be analyzed and strive to achieve at least the minimum adopted level of service for bicycles by narrowing motor vehicle lane widths, removing on-street parking, reducing posted speeds, or by using other methods to accommodate bicyclists to provide wide curb lanes.

Designers should consider all likely users of a bicycle facility when establishing design criteria. As with the design of roadways, the design vehicle is an important consideration for bicycle facilities. Most design criteria for roadways, beyond the addition of extra space for the bike lane or paved shoulder, are not impacted by the bicycle as a design vehicle.

On a shared-use path, the bicycle and other non-motorized modes are used as design vehicles. Their characteristics dictate numerous design values and criteria, such as design speeds, stopping sight distances, maximum degree of horizontal curvature, minimum vertical curve lengths, etc. The design values used in this chapter are based upon those in the AASHTO *Guide for the Development of Bicycle Facilities* (AASHTO, 2012), with supplemental information provided from the FHWA *Characteristics of Emerging Road and Trail Users and Their Safety* (FHWA,2004).

Design vehicle considerations can be grouped as key dimensions, operating space, and key performance criteria. These are briefly summarized in the following paragraphs. Some of those design vehicles expected are shown in Figure 13-4.

- The *key dimensions* that are associated with the various types of bicycles are listed in Table 13-1. These are not exact and represent the 85th percentile (unless otherwise noted) of distribution that encompasses most bicyclists.

- Recommended widths of bicycle facilities can be determined from the bicyclist *operating space*, as shown in Figure 13-5. Additional operating width may be required in circumstances including but not limited to steeper grades, mixed traffic (parked cars), and poorly lit areas.

- Key *performance criteria* that are associated with the various types of bicycles are listed in Table 13-2. These performance criteria vary greatly based on age, health, physical and cognitive abilities, bicycle design, traffic, environmental conditions, and terrain.

Data for e-bikes varies from the data in Table 13-1 and Table 13-2. If e-bikes will potentially be on a trail, the designer should seek guidance on the design standards for this vehicle type.

Table 13-1 Bicycle Dimensions

User Type	Feature	Dimension
Typical upright adult bicyclist	Physical width (95th percentile)	30 in.
	Physical length	70 in.
	Physical height of handlebars (typical dimension)	44 in.
	Eye height	60 in.
	Center of gravity (approximate)	33-44 in.
	Operating width (minimum)	48 in.
	Operating width (minimum)	60 in.
	Operating height (minimum)	100 in.
	Operating height (minimum)	120 in.
Recumbent bicyclist	Physical Length	82 in.
	Eye height	46 in.
Tandem bicyclist	Physical length (typical dimension)	96 in.
Bicyclist with child trailer	Physical width	30 in.
	Physical length	117 in.
Hand bicyclist	Eye height	34 in.
Inline skater	Sweep width	60 in.

Table 13-2 Key Performance Criteria

Bicyclist Type	Feature	Value
Typical upright adult bicyclist	Speed, paved level terrain	8 - 15 mph
	Speed, downhill	20 - 30 plus mph
	Speed, uphill	5 - 12 mph
	Perception reaction time	1.5 seconds* (expected stop) 2.5 seconds* (unexpected stop)
	Acceleration rate	2.5 ft/s^2 [1]
	Coefficient of friction for braking, dry level pavement	0.32*
	Coefficient of friction for braking, wet level pavement	0.16*
	Deceleration rate (dry level pavement)	10 ft/s^2 [1*]
	Deceleration rate for wet conditions (50- 80% reduction in efficiency)	5 ft/s^2 [1*]
Recumbent bicyclist	Speed, level terrain	11 - 18 mph
	Acceleration rate	3 - 6 ft/s^2
	Deceleration rate	10 - 13 ft/s^2

* 2018 AASHTO GDHS.

[1] Parkin, J. & Rotheram, J. (2010) Design speeds and acceleration characteristics of bicycle traffic for use in planning, design and appraisal. Transport Policy, 17 (5). pp. 335-341. ISSN 0967-070X. Available from: http://eprints.uwe.ac.uk/20767.

[2] Figiolizzi, M., Wheeler, N. & Monsere, C. (2013). Methodology for estimating bicyclist acceleration and speed distributions at intersections. Transportation Research Record: Journal of the Transportation Research Board, No. 2387, Transportation Research Board of the National Academies, Washington, D.C., pp. 66–75.

[3] Landis, B., Petritsch, T., Huang, H., & Do, A. (2004). Characteristics of Emerging Road and Trail Users and Their Safety. Transportation Research Record: Journal of the Transportation Research Board, (1878), 131-139.

Figure 13-4 Summary of Expected Design Vehicles and Dimensions

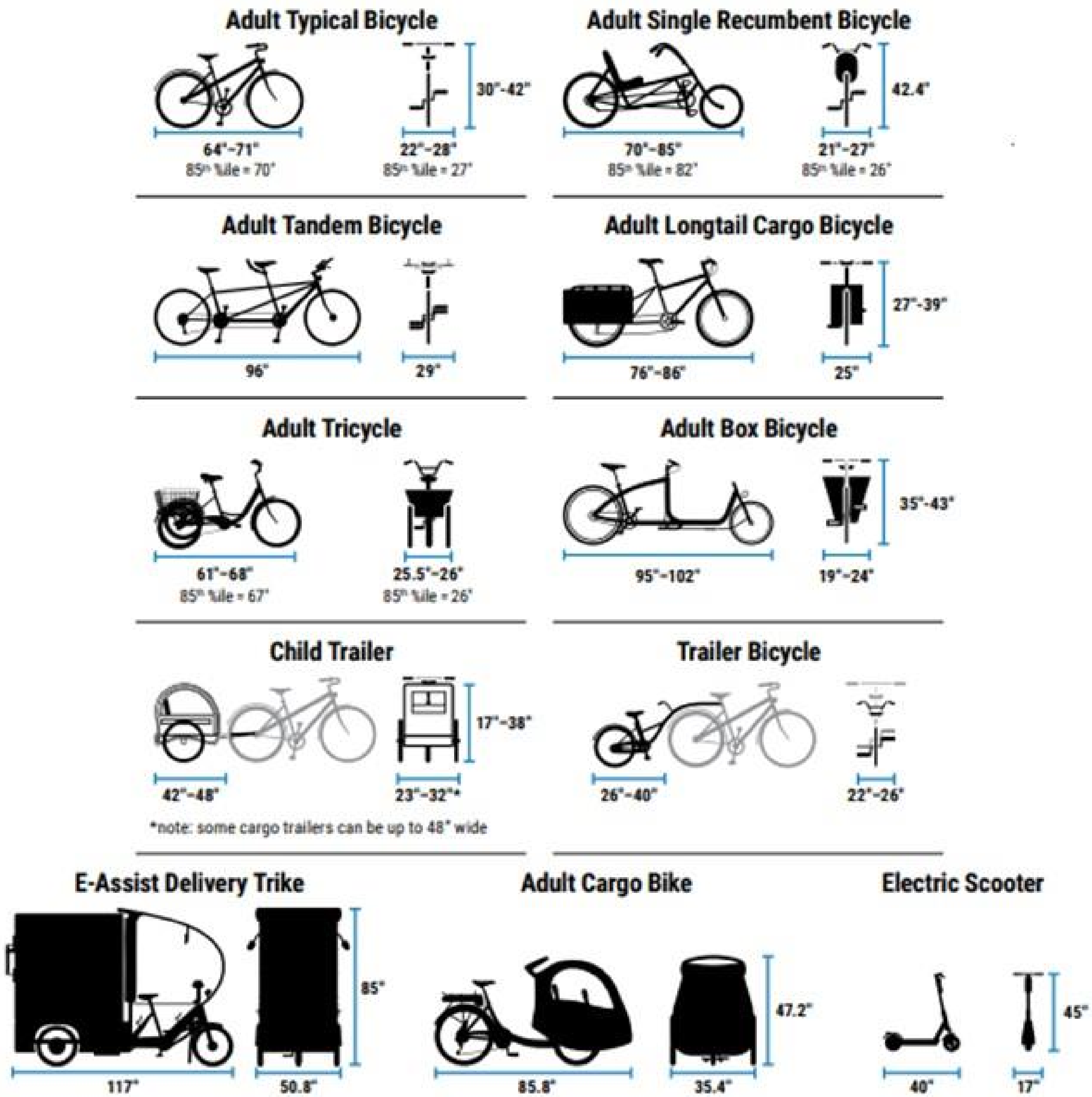
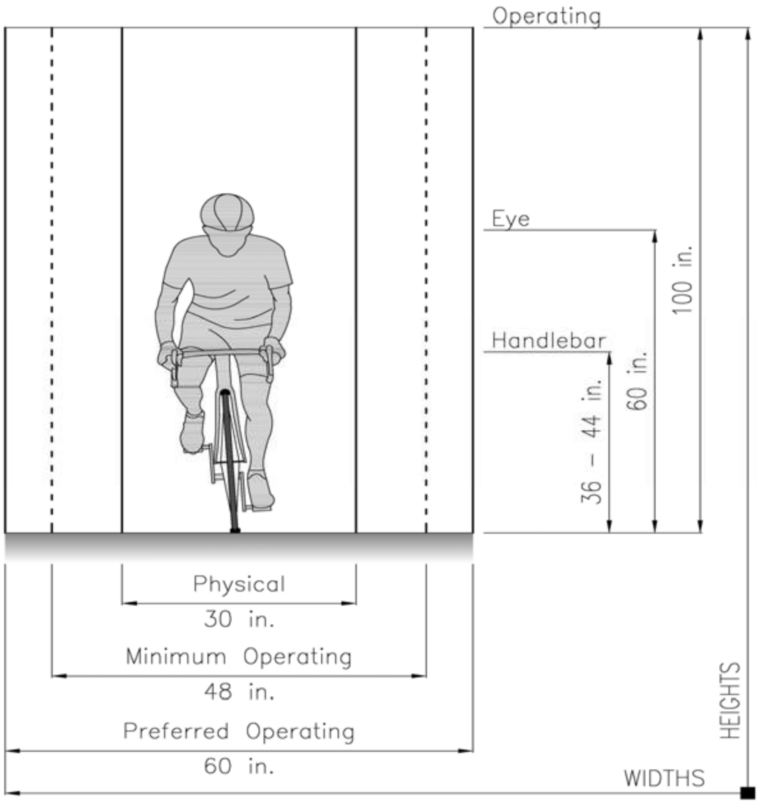


Figure 13-5 Bicycle Operating Space Requirements



With regard to calculated design values such as stopping sight distance or the minimum length of vertical curves, the equations used to calculate the design values are the same for non-motorized vehicles as they are for motorized vehicles. Appropriate assumptions and input values are provided in the section related to specific design values (Section 13.3.3.3).

13.2.4 Bike Routes

Bike routes are not a facility type, but rather a designation of a facility, or collection of facilities, that link origins and destinations that have been improved for, or are considered preferable for, bicycle travel. Bike routes include a system of wayfinding and route signs that provide at least the following basic information:

- Destination of the route.
- Distance to the route's destination.
- Direction of the route.

Bike routes can be designated in two ways: General Routes and Number Routes.

13.2.4.1 General Routes

General Routes are links with a single origin and a single destination. General Routes connect users to destinations within a community. Typical destinations include the following:

- Attraction Areas (e.g., stadiums, parks, etc.)
- Neighborhood Areas (e.g., downtown, historic neighborhoods, etc.)
- Trail Networks or trailheads (e.g., Glenwood Canyon Trail)

Bike Route Guide signs may be provided along designated bike routes to inform bicyclists of bike route direction changes and to confirm route direction, distance, and destination. Typical sign examples that convey the basic wayfinding information for general routes are shown in Figure 13-6. The MUTCD (FHWA, [2009] 2022) provides several different types of signs that can be used to provide guidance along bike routes. Some of these are shown below.

Figure 13-6 Examples of Bike Route Guide Signs

13.2.4.2 Number Routes

Number Routes form a network of bike routes that connect several origins to several destinations. Some communities may implement a numerical system to designate bike routes. These routes should be designated using Bike Route Signs like those in Figure 13-7. Bike Route Signs can be customized by adding a specific community logo in the upper portion of the ellipse.

Figure 13-7 Examples of Bike Route Signs

U.S. Bicycle Route Signs are reserved for routes on the national cycling route network that are designated as U.S. Bicycle Routes. These routes consist of interstate long-distance cycling routes and may consist of different bicycle facility types. As of 2022, Colorado does not have any designated U.S. Bike Routes. AASHTO approved the use of a marker design for these routes that is included in the MUTCD. It is illustrated in Figure 13-8.

Figure 13-8 U.S. Bike Route Sign

M1-8a

13.2.5 Shared Lanes

A shared lane is a lane of a traveled way used for both bicycle and motor vehicle modes that may be either marked or unmarked. Shared lanes are typically marked where there is a desire to increase awareness of bicyclists on a roadway where physical separation is desired, but not necessarily feasible. Shared lanes are not recommended on facilities where posted speeds are 35 mph or higher (FHWA, [2009] 2022).

Where shared lanes are proposed, travel lane widths should generally be the minimum widths appropriate for the context of the roadway. Generally shared lanes are less than 14 feet wide. In the past, it was common practice to provide wide curb lanes or lanes that exceed 14 feet in width with the expectation that motorists could pass a bicyclist without encroaching into the adjacent lane. However, research finds that this configuration does not allow for adequate passing space and motorists generally do not recognize that the additional space is dedicated for bicycle use. Additionally, wider travel lanes are associated with increases in motor vehicle speeds, which reduce comfort and safety for bicyclists and other roadway users. Therefore, wide curb lanes are not recommended for bicycle accommodation. Where wide curb lanes exist, roadways should be striped to reduce the wide lanes to minimum lane widths. Additional space may be repurposed for other use such as bike lanes, wider sidewalks, etc.

Providing a constrained-width or minimum-width bike lane is preferred to a wide outside lane. However, constrained-width or minimum-width bike lanes should only be used in constrained locations after all travel lanes have been narrowed to minimum widths appropriate for the roadway context. For bicycle lanes adjacent to on-street parking, designers should follow guidance in Section 13.2.6.1.

The *Highway Capacity Manual* method can be used to determine the minimum level of accommodation for bicycles along a bike facility. On local roadways with low volumes and speeds, a shared lane may be all that is needed to comfortably accommodate bicyclists. They are also an option on roadways where it may be infeasible to provide bike lanes or paved shoulders, or to adjust lane widths to provide a wide curb lane.

In these latter cases, there are multiple options for traffic control devices that are described in the following subsections, particularly if the roadways are identified as priority routes in an adopted bicycle plan.

13.2.5.1 Shared Lane Signage

On constrained roadways with posted speed limits of 35 mph and below, the roadway lane may be signed as a shared lane using signage and shared lane bicycle markings. Signage options include:

The MAY USE FULL LANE sign (R4-11) (Figure 13-9)may be used on roadways where a travel lane is too narrow for motorists to overtake a bicyclist without changing lanes (FHWA, [2009] 2022). Rather than provide wider lanes to allow passing, which causes safety issues, this sign may inform users that bicyclists have the legal right to claim the lane. Additional guidance on the MAY USE FULL LANE sign is provided in the MUTCD.

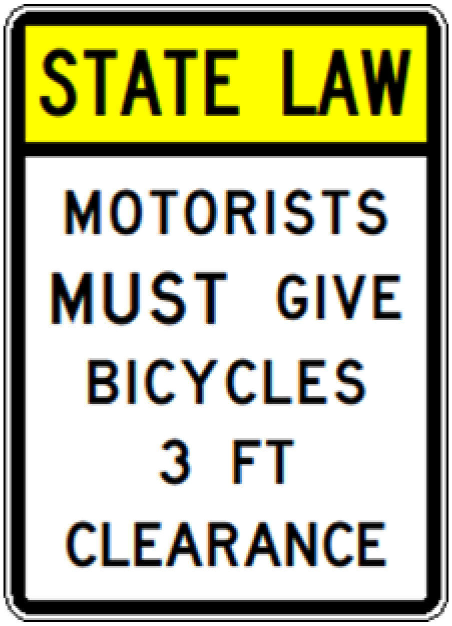
Figure 13-9 May Use Full Lane Sign

A SHARED LANE MARKING (refer to Section 13.2.5.2.2) may be used in conjunction with the MAY USE FULL LANE sign.

STATE LAW MOTORIST MUST GIVE BICYCLES 3 FT CLEARANCE

Per CRS 42-4-1003, the driver of a motor vehicle overtaking a bicyclist proceeding in the same direction shall allow the bicyclist at least a 3-foot separation between the right side of the driver's vehicle, including all mirrors or other projections, and the left side of the bicyclist at all times. As an alternative to SHARE THE ROAD signage (refer to Section 13.2.5) The STATE LAW MOTORIST MUST GIVE BICYCLES 3 FT CLEARANCE sign (Figure 13-10) may be used to remind motorists that they must maintain a safe distance while passing a bicyclist.

Figure 13-10 Bicycle 3-Foot Clearance Sign



SHARE THE ROAD Sign Assembly (W11-1 + W16-1P)

In situations where there is a need to warn drivers to watch for bicycles traveling along the highway, the SHARE THE ROAD sign assembly may be considered (refer to Figure 13-11).

The SHARE THE ROAD sign assembly may be installed on CDOT-maintained roadways at the discretion of each region's Traffic Engineer. To have maximum effect, these signs should be used with discretion. Consideration for placement should be given where:

- A relatively high number of cyclists can be expected on the roadway.
- The roadway cannot be improved for bicyclists.
- The road narrows for a short distance and a motorist and bicyclist may unexpectedly find themselves using the same roadway such as at the end of a bike lane or bridge approach.
- There has been a history of high numbers of bicycle crashes.

The Share the Road sign assembly may also be appropriate in the following situations:

- Designated bike routes and trails that are placed on short stretches of a major roadway that has not been improved for bicycling.
- Roadway where a known conflict problem exists.
- Roadway sections adjacent to shared-use paths where some bicyclists choose to ride on the roadway.

Figure 13-11 Share the Road Sign Assembly

W11-1

W16-1P

On approaches to bridges, tunnels, or any other section where motorists and bicyclists have reduced sight distance or where operating widths must be less than desirable due to right of way or actual roadway geometry restrictions, a SHARE THE ROAD sign assembly may be appropriate. In these cases, consider adding flashing beacons to the assembly that can be actively or passively triggered by bicyclists. The duration of the flashing beacon's activation should be such that a motorist passing the active flashing beacon is likely to pass the bicyclist who activated the treatment within the area of limited sight distance. This duration can be calculated using the following equation:

$$t_f = 1.47\left(\frac{l_c}{S_b} - \frac{l_c}{S_m}\right)$$

Where:

t_f = duration of flashing (sec)
l_c = length of constrained area (ft)
S_b = speed of bicyclist (mph)
S_m = speed of motorists (mph)

The recommended assumed speed of the bicyclist on flat terrain for this application is 10 mph. This is the observed average speed of bicyclists (FHWA, 2004). Adjustments for grade should be made, particularly on uphill sections, where bicyclists are traveling slower than average speeds.

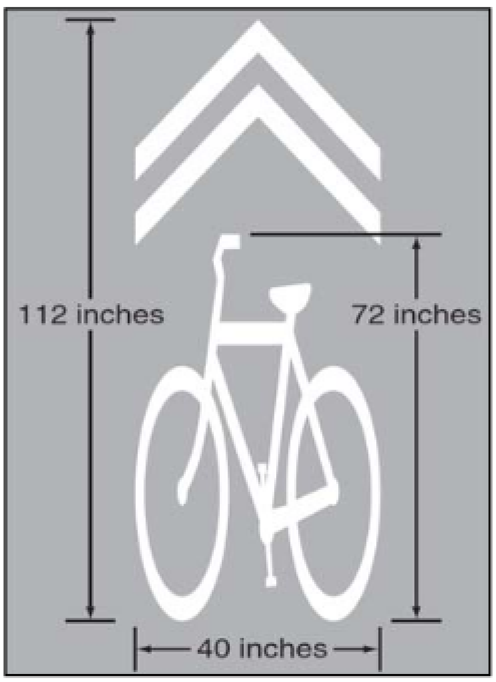
A SHARED LANE MARKING (refer to Section 13.2.5.2) may be used in conjunction with the SHARE THE ROAD sign assembly.

13.2.5.2 Shared Lane Markings

SHARED LANE MARKINGS (Figure 13-12) are intended to perform any of several functions listed in the MUTCD:

- Assist bicyclists with lateral positioning in a shared lane with on-street parallel parking to reduce the chance of a bicyclist impacting the open door of a parked vehicle.
- Assist bicyclists with lateral positioning in lanes that are too narrow for a motor vehicle and a bicycle to travel side by side within the same traffic lane.
- Alert road users of the lateral location bicyclists are likely to occupy within the traveled way.
- Encourage safe passing of bicyclists by motorists.
- Reduce the incidence of wrong-way bicycling.

Figure 13-12 Shared Lane Marking



Refer to the MUTCD for proper placement of SHARED LANE MARKINGS.

SHARED LANE MARKINGS should not be used on constrained facilities, on designated bike routes, or on higher-speed roadways (> 35 mph) with designated bike lanes. Traffic calming or signal improvements should be considered in conjunction with SHARED LANE SIGNING.

13.2.6 Paved Shoulders

Paved shoulders are the portion of the roadway that accommodates stopped or parked vehicles, emergency vehicles, farm equipment or other slow-moving vehicles. Shoulders also accommodate bicyclists and pedestrians where sidewalks do not exist. Paved shoulders have been shown to provide safety benefits for all users and double as an important option for providing comfort and safety for bicyclists on roadways that meet any of the following conditions:

- Traffic volumes that exceed 3,000 vehicles/day.
- Motor vehicle speeds greater than or equal to 50 mph.
- Inadequate sight distances for the typical operating speed or grades in excess of 5%.
- High percentages (> 10%) of heavy vehicles.

Gravel shoulders are not acceptable as bicycle facilities. Adding or widening of paved shoulders may be subject to Municipal Separate Storm Sewer System (MS4) permitting requirements, which could substantially increase retrofit costs.

To accommodate bicyclists, paved shoulders with rumble strips at least 4 feet wide should be provided. Chapter 7 provides CDOT's minimum standard shoulder widths.

13.2.6.1 Additional Width

When local shoulder widths exceed the planned or typical CDOT shoulder, the designer should consider designing to the local requirements.

Jurisdictions may have adopted a minimum bicycle level of service for their roadways. CDOT projects within these jurisdictions should be designed to meet the adopted minimum bicycle level of service unless the available budget prohibits this action. Table 13-3 uses the aforementioned *Highway Capacity Manual* method to provide the maximum design daily traffic, a given speed limit, percent heavy vehicles, and shoulder width, Table 13-3 provides the maximum number roadway AADT that will provide a selected bicycle Level of Service. Additionally, Figure 13-13 shows preferable shoulder widths based on volume and speed of the roadway for the Highly Confident Bicyclist on rural roads.

Scenic Byways plans may also specify wider shoulders and should be accommodated during design.

Table 13-3 Maximum Motor Vehicle Service Volumes for Given Bicycle LOS Grades

Adopted Bicycle Level of Service = B

	Speed Limit (or Design Speed)		35				Speed Limit (or Design Speed)		45			
	Percent Heavy Vehicles						Percent Heavy Vehicles					
Shoulder width, ft	2	4	6	8	10	12	2	4	6	8	10	12
4	13300	7500	4500	3600	3100	2700	11200	6200	3900	3400	3000	2500
6		26400	10100	4800	3700	3200		16400	6600	4200	3500	3000
8				27000	8100	3700				12200	3900	3400

	Speed Limit (or Design Speed)		55				Speed Limit (or Design Speed)		65			
	Percent Heavy Vehicles						Percent Heavy Vehicles					
Shoulder width, ft	2	4	6	8	10	12	2	4	6	8	10	12
4	9900	5600	3800	3300	2800	2400	8900	5200	3700	3200	2700	2300
6		12200	6100	3900	3400	2800	29900	10300	5600	3800	3300	2800
8			29900	7600	3800	3300			22400	5200	3800	3200

Adopted Bicycle Level of Service = C

	Speed Limit (or Design Speed)		35				Speed Limit (or Design Speed)		45			
	Percent Heavy Vehicles						Percent Heavy Vehicles					
Shoulder width, ft	2	4	6	8	10	12	2	4	6	8	10	12
4			12700	5100	3700	3100		21200	7100	4400	3500	2900
6				24900	7300	3700				11600	3900	3400
8											22400	4700

	Speed Limit (or Design Speed)		55				Speed Limit (or Design Speed)		65			
	Percent Heavy Vehicles						Percent Heavy Vehicles					
Shoulder width, ft	2	4	6	8	10	12	2	4	6	8	10	12
4		15800	6500	4100	3400	2800		12700	6100	3900	3200	2700
6			27600	7100	3800	3200				5200	3700	3100
8					12000	3800					7600	3600

Adopted Bicycle Level of Service = D

	Speed Limit (or Design Speed)		35				Speed Limit (or Design Speed)		45			
	Percent Heavy Vehicles						Percent Heavy Vehicles					
Shoulder width, ft	2	4	6	8	10	12	2	4	6	8	10	12
4					9300	3700				14700	4100	2900
6						13900					20700	4400
8						15100						

	Speed Limit (or Design Speed)		55				Speed Limit (or Design Speed)		65			
	Percent Heavy Vehicles						Percent Heavy Vehicles					
Shoulder width, ft	2	4	6	8	10	12	2	4	6	8	10	12
4				9000	3900	3200			26200	6200	3800	3100
6					11300	3700					7100	3500
8						16600						9500

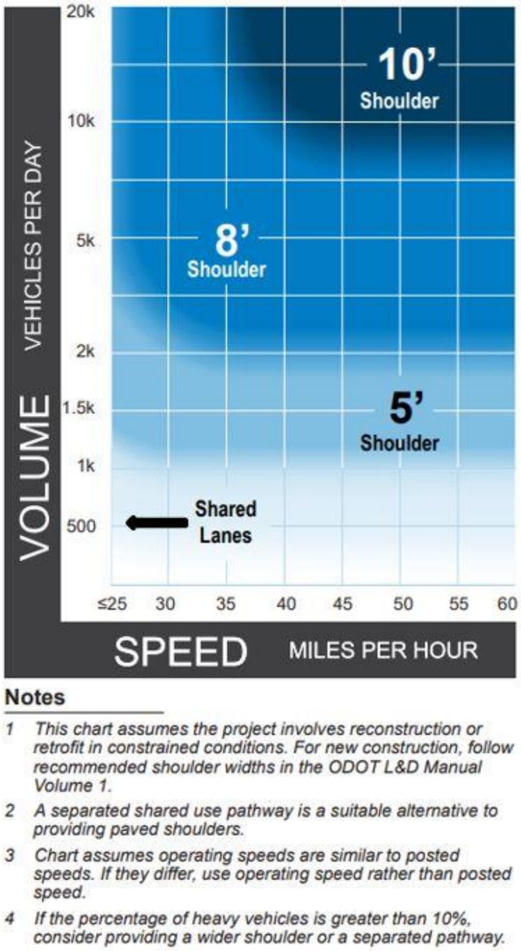
Notes:

Volumes are based upon a two-lane roadway. For maximum service volumes on a four-lane or six-lane roadway double or triple the values accordingly.

Values are established using the Highway Capacity Manual methodology for roadway links.

Table assumes the following: K = 0.10; D= 0.53; PHF = 1; PavCon = 4; Outside lane width = 12 feet

Figure 13-13 Shoulder Widths to Accommodate Highly Confident Bicyclists on Rural Roadways



Source: FHWA Bikeway Selection Guide (FHWA, 2019).

13.2.6.2 Shoulder Pavement Quality

Shoulder surface conditions and pavement smoothness are important factors for bicyclist comfort, control, and safety. Surface defects can contribute to bicycle crashes. In addition to the quality of the shoulder pavement, the shoulder should be maintained to remove debris such as gravel or glass. Surfaces adjacent to shoulders should also be addressed to avoid drop offs where erosion may have washed away adjacent unpaved surfaces.

13.2.6.3 Shoulders on Steep Grades

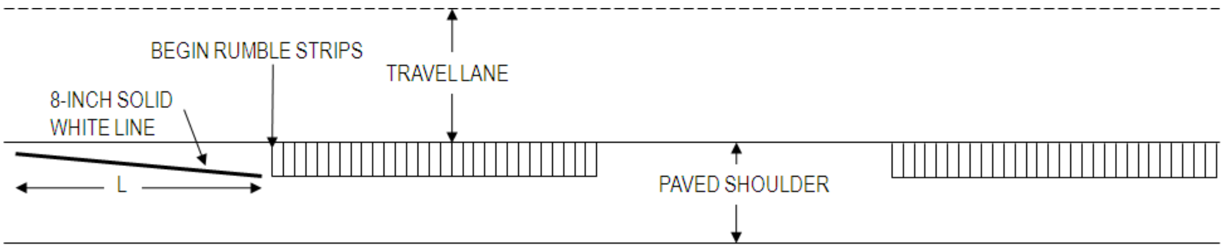
The additional effort required of bicyclists riding uphill frequently results in a greater side-to-side sweep width than those riding on a flat roadway. A bicyclist riding downhill on a steep grade also may need additional space to maintain a comfortable distance from the edge of the pavement and adjacent vehicles. Consequently, on roadways with significant grades or long grades, shoulders of 6 feet or greater width should be provided.

13.2.6.4 Rumble Strips

Where appropriate, rumble strips should be installed per CDOT Standard Plan No. M-614-1. On roadways where bicycle demand exists, continuous rumble strips should not be used. Rumble strips shall not be installed on shoulders less than 6 feet wide when guardrail is placed at the edge of the shoulder. Gaps in rumble strips should also be provided at locations where driveways, intersections, or other locations exist where bicycles are likely to leave the shoulder.

Rumble strips should be placed as closely as possible to the right edge of the roadway edge line. A minimum 4-foot clear shoulder should be provided to the right of the rumble strips. A warning marking as shown in Figure 13-14 should be placed in advance of each rumble strip installation.

Figure 13-14 Advance Warning Stripe for Rumble Strips



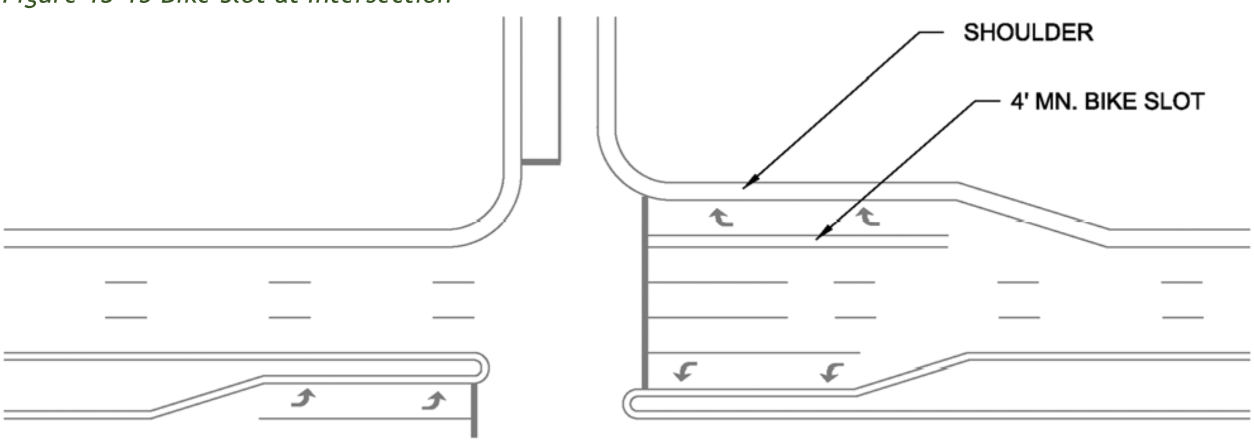
L = 20 *W

Where W = width of rumble strip

13.2.6.5 Shoulders at Intersections

At intersections with right-turn lanes, a paved shoulder is typically continued along the outside of the right-turn lane. Some through bicyclists may continue to ride along the shoulder even though it compromises their safety at the intersection. Consequently, a 4-foot minimum space (bike slot) should be striped between the right-turn lane and the through lanes. This is illustrated in Figure 13-15.

Figure 13-15 Bike Slot at Intersection



13.2.7 Bike Lanes

Bike lanes are one-way bikeways designated for the preferential use of bicyclists. Bike lanes will typically carry bicycle traffic in the same direction as adjacent motor vehicle traffic. In most cases, bike lanes should be provided on both sides of two-way streets. They may be placed on the left side of one-way streets if the predominant travel paths or conflict points suggest this is a desirable option.

13.2.7.1 Bike Lane Width

Table 13-4 prescribes typical widths for bike lanes that will generally accommodate a bicyclist's operating space, passing distance, and shy distances to vertical elements.

Table 13-4 One-Way Standard Bike Lane Width Criteria

Bike Lane Description	Minimum Width (ft)	Constrained Width (ft)
Adjacent to curb[1] or edge of pavement	5	4
Between travel lanes or buffers	5	4
Adjacent to parking[2]	6	5
Intermediate or sidewalk level raised bike lane[1]	5.5	5
To allow side-by-side bicycling or passing	8	7

[1] Exclusive of the gutter unless the gutter is integrated into the full width of the bike lane.

[2] Raised bike lanes adjacent to parking should have a minimum width of 7 feet.

The width of a bicycle lane does not include the width of gutter adjacent to a curb. Where a bicycle lane is adjacent to the gutter, the width of a bike lane should be measured from the edge of the gutter to the center of the bike lane line. Where a bicycle lane is located next to a curb without a gutter, the bike lane width should be measured from the face of curb to the center of the bike lane line. On streets with on-street parking, the bike lane width should be measured from the center of the parking stripe to the center of the bike lane line.

Additional bicycle lane width should be considered in the following conditions:

- Locations with high parking turnover
- Where side-by-side bicycle travel is desired
- Where roadways have sharp drop offs or irregular edges
- Where bicycle lanes are positioned between two moving travel lanes such as a turn lane and a through lane at an intersection
- On roadways that have more than 5% heavy vehicles, posted speeds of 30 mph or over 6,000 AADT

On extremely constrained low-speed roadways with curbs, but no gutter and where the preferred bike lane width cannot be achieved after narrowing all other travel lanes, turn lanes, on-street parking widths, and median widths, a 4-foot-wide bike lane can be used.

Where wider bike lanes are feasible, a buffer should be considered to reduce instances of a motorist attempting to use the bike lane as a travel lane or parking lane.

As mentioned in Section 13.2.6.1, adopted bicycle plans and Scenic Byway plans should be consulted to determine if wider bike lanes are specified or if a wider bike lane is needed to meet an adopted bicycle level of service standard.

On roadways with narrow parking lanes, wider bike lanes (6 or 7 feet wide) should be considered to provide space for bicyclists to avoid opening car doors. On roadways with on-street parking where there is high frequency of parking turnover, a 13 feet minimum width is recommended between the face of curb and the left side of the bike lane.

On roadways where significant volumes of bicyclists are expected, creating a potential need for passing maneuvers, 6- or 8-foot bike lanes should be considered.

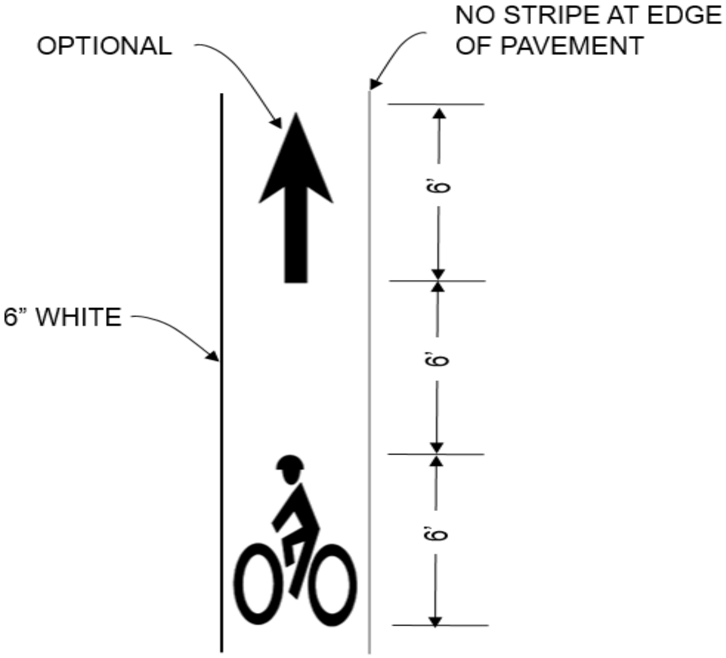
Wide shoulders or bike lanes have the potential to be interpreted by motorists as additional general-purpose travel lanes or parking lanes. This can be discouraged by using designated or buffered bike lanes (Section 13.2.7.5).

Additional width should be considered on roadways with steep or long grades. An alternative option to a wider lane is to remove the bike lane on the downhill side of the road and mark with Bicycle May Use Full Lane signs (R4-11) and Shared Lane Markings. The space gained from removing the bike lane on the downhill side of the road should be used to increase the bike lane width on the uphill side of the road.

13.2.7.2 Designating Bike Lanes

Bike lanes shall be designated with the bicycle symbol with the directional arrow being optional (Figure 13-16). Although use of the directional arrow is optional, it is strongly recommended to better communicate the requirement for bicyclists to ride with traffic as the law requires.

Figure 13-16 Detail of Bike Lane Designation



Bicycle lane markings should be placed after intersections and major driveways. In rural areas, the maximum spacing of bike lane markings should not exceed 1,320 feet. In urban areas, the spacing should not exceed 600 feet.

The 6-inch white stripe on the left of the bike lane should become a dotted (2-foot line with a 4-foot gap) at improved bus stops with alighting pads to clarify that buses are to move right to allow transit riders to disembark off of the roadway.

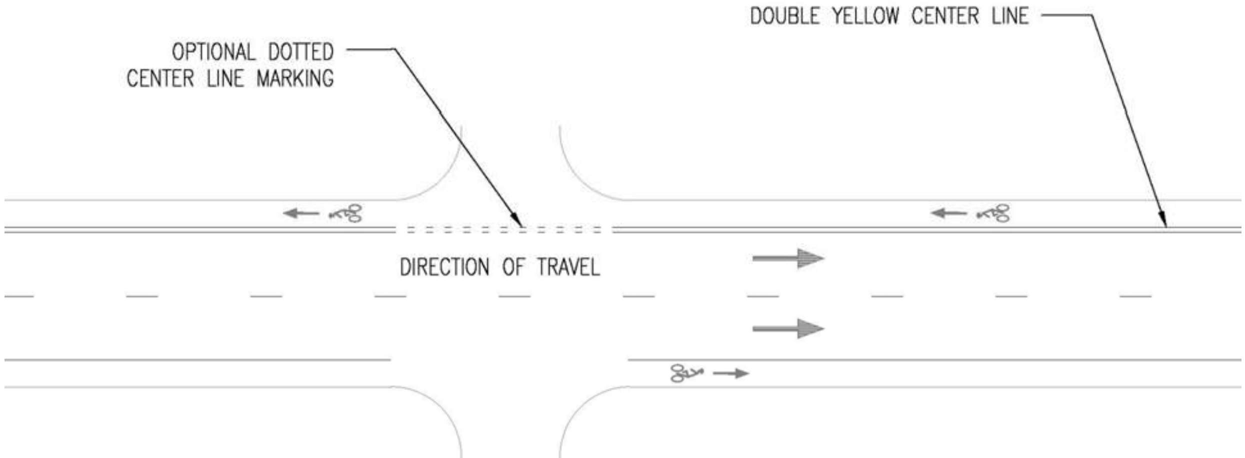
13.2.7.3 Contraflow Bike Lanes

A contraflow bicycle lane is an area of the roadway designated to allow bicyclists to travel in the opposite direction of traffic on a roadway that restricts motor vehicle travel to one direction. These may be used to make convenient connections for bicyclists along otherwise one-way streets. If used, a contraflow bicycle lane should be marked so that bicyclists in the contraflow lane travel on the bicyclists' right-hand side of the road.

Where used, a contraflow bicycle lane shall be separated from opposite-direction travel by use of a solid double yellow center line marking, or a painted or raised median island (Figure 13-17).

The required widths of a contraflow bike lane match Figure 13-17. However, if a median is used, appropriate shy distances from curb and gutter must be considered.

Figure 13-17 Example Contraflow Bicycle Lane Markings



ONE WAY (R6-1 or R6-2) signs should not be used where signs that regulate turns from streets or driveways that intersect with a roadway with a contraflow bicycle lane. TURN PROHIBITION signs (R3-1 or R3-2) with a supplemental message EXCEPT BICYCLES (or the word "EXCEPT" over the bicycle symbol) plaques should be used. If DO NOT ENTER signs (R5-1) are used, an EXCEPT BICYCLES plaque should be placed under the Do Not Enter sign.

A bicycle lane for travel in the same direction as the general purpose lanes may be relocated from the right side of the roadway to the left side of the general purpose travel lanes.

13.2.7.4 Bike Lanes at Driveways and Intersections

In Colorado, bicycles are vehicles when riding on the street (C.R.S., Section 42-4-1412). Therefore, bike lane striping and marking at intersections should be designed to guide bicycle operations the same as vehicles, and to safely manage the conflict points with vehicles at driveways and intersections.

Bicyclists are required to ride on the right-hand side of the rightmost lane in the direction they are traveling. Bicyclists may use left- and right-turn lanes to make turns. Bicyclists are not required to ride at the right edge of the pavement; they may move left to pass slower vehicles, to make a left turn, or to avoid debris or obstacles on the pavement (C.R.S., Section 42-1-102).

For both motor vehicles and bicycles, the approach to a right turn and the right turn should be made from as close as practicable to the right-hand curb or edge of the roadway (C.R.S., Section 42-4-901(1)). Motorists must yield to bicyclists in the bike lane to make a right turn (C.R.S., Section 42-4-1007(1)(a)). The white solid bike lane striping either terminates or becomes dotted on the approach to the right turn at the intersection. Changing the line pattern from a solid line to a dotted line indicates that the motorist can cross the line to make a right turn (MUTCD) and indicates that the bicyclist is entering a potential conflict area. The length of the dotted line can vary based on the speed of the roadway at the approach. A minimum 60-foot dotted line (or gap in the bike lane) should be provided; this is based upon a 1:12 taper rate and a 5-foot bike lane. An

18:1 taper rate or 24:1 taper rate (75-ft and 100-ft) or longer dotted length of bike lane can be used on higher speed roadways.

Where motorists cross a bike lane to move into a right-turn lane, is the BEGIN RIGHT TURN LANE YIELD TO BIKES sign (R4-4) (Figure 13-19, Figure 13-23, Figure 13-24, and Figure 13-26). However, in the trap lane condition (Figure 13-21), the through bicyclist must cross the motorist's path to continue through the intersection. In this case, the bicyclist must yield to the motorist before moving left; therefore, the R4-4 is not appropriate in these conditions.

On retrofit projects, it may not be possible to include bike lanes that pass through existing intersections with turn lanes. In this case, the bike lane should be terminated in advance of the intersection and SHARED LANE MARKINGS should be considered for the left side of the right-turn lane. An example of this marking is shown in Figure 13-31 in Section 13.2.7.5.

In locations with significant numbers of right-turning bicyclists, an additional bike lane for right turning bicyclists can be provided. Right-turn bike lanes may be considered with high-volume, high-speed right-turn lanes. These bike lanes should include right-turn arrows and the text message ONLY.

By riding in the roadway in a predictable and consistent manner, bicyclists are more visible. This increased visibility has been shown to reduce crashes compared to riding on a sidewalk or pathway next to the roadway (FHWA, 1997) (FHWA, 1996) (ITE, 1994) (TRB, 1998) (TRB, 2006).

13.2.7.4.1 Bike Lanes at Continuous Flow Intersections

At continuous flow intersections, a bike lane is provided for through bicyclists. Two options are available for left-turning bicyclists:

- Left-turning bicyclists may ride through the intersection or in the left-turn lanes. Additional bike lanes for left-turning bicyclists may be considered.
- Left-turning bicyclists may make two consecutive through movements obeying all traffic control devices (C.R.S., Section 42-4-1412(8)). A staging area for the bicyclists to wait between through movements should be provided.

Dedicated right-turn lanes for bicyclists should also be considered at continuous flow intersections.

Figure 13-18 Typical Bike Lane - Major Intersection, No Right-Turn Lane - Curb and Gutter

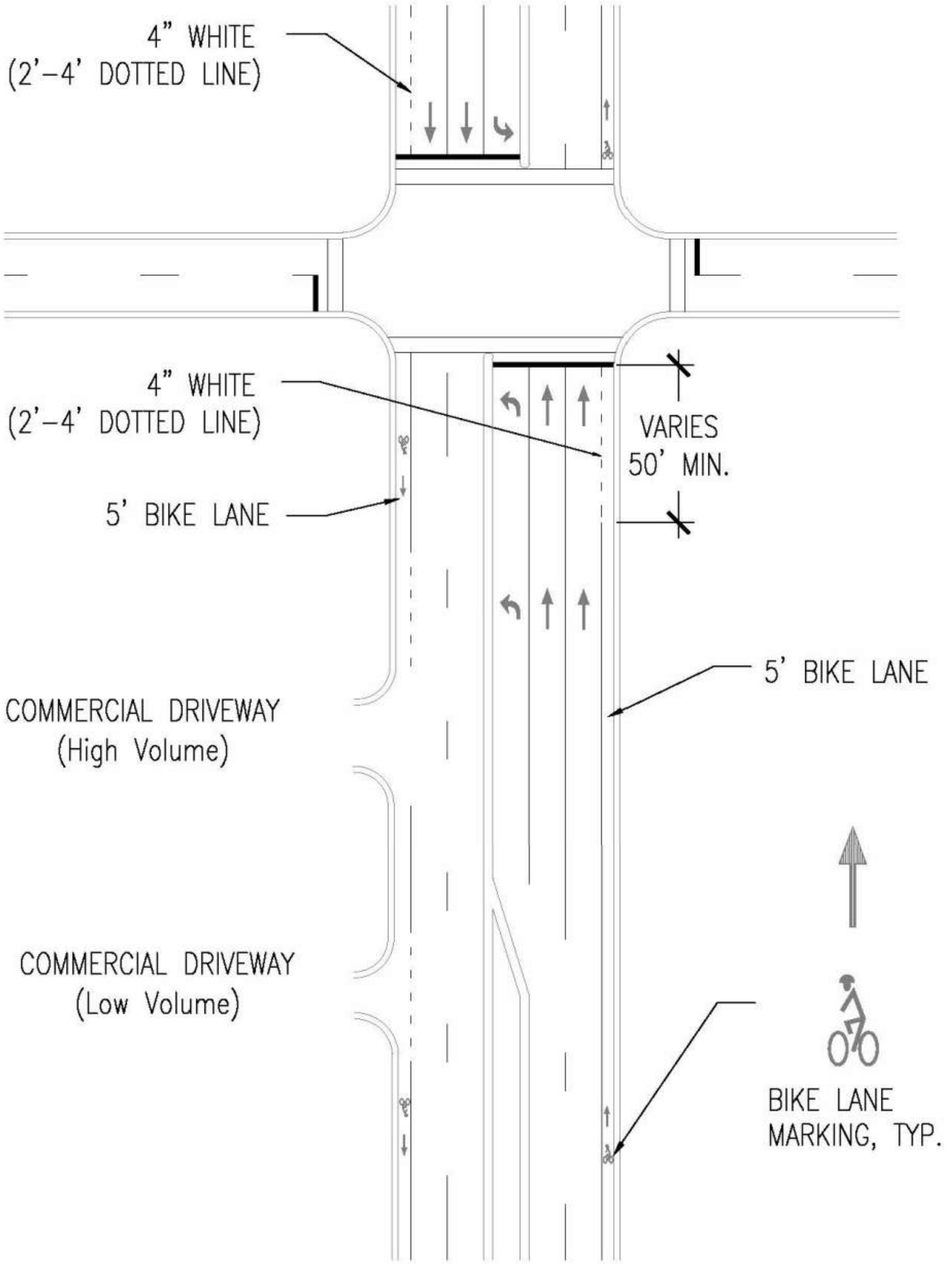


Figure 13-19 Typical Bike Lane - Major Intersection, Right-Turn Lane

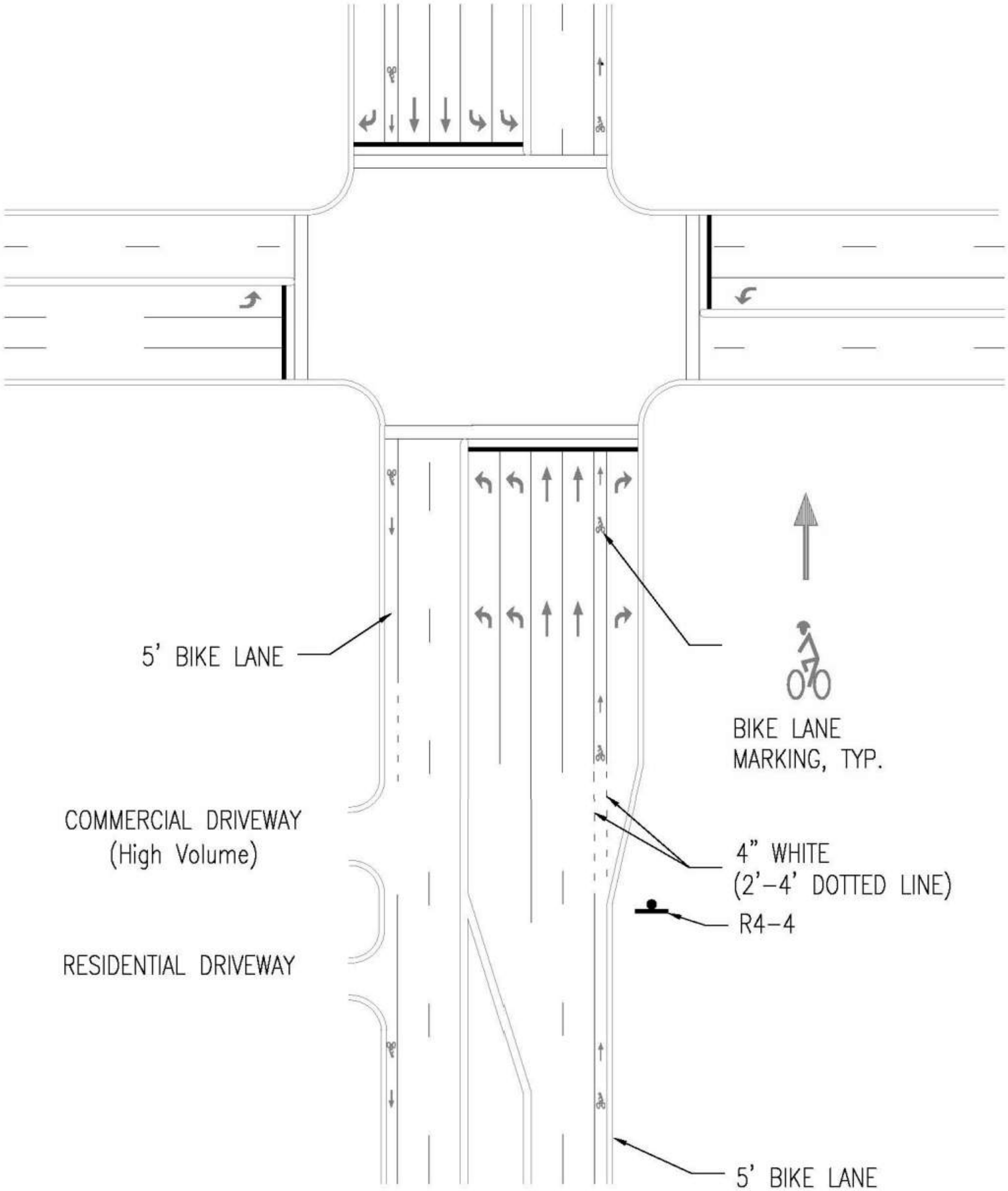


Figure13-20 Typical Bike Lane – Major Intersection, No Right-Turn Lane, On-Street Parking

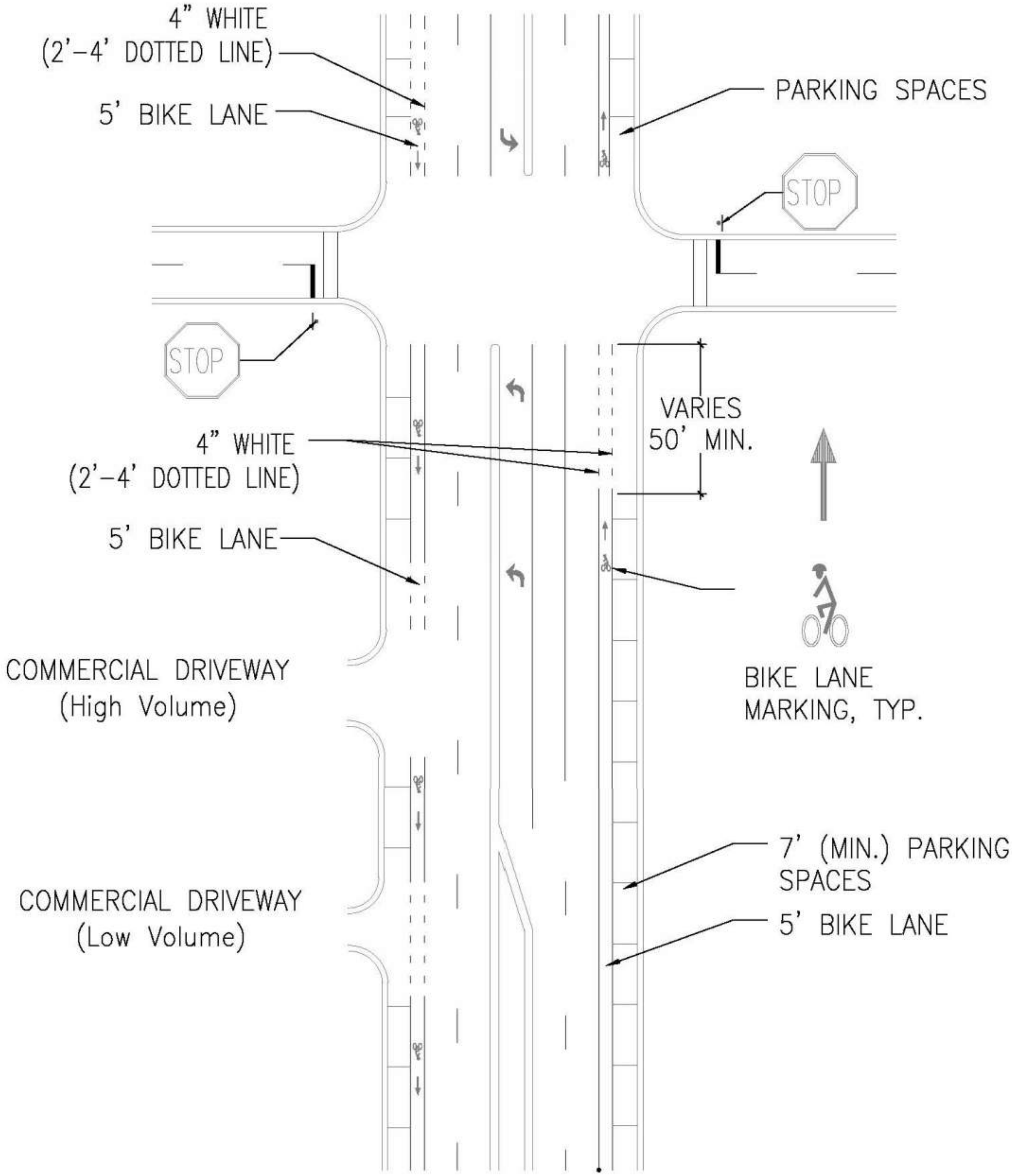


Figure 13-21 Typical Bike Lane – Major Intersection, Right Turn Trap Lane, Bus Stop

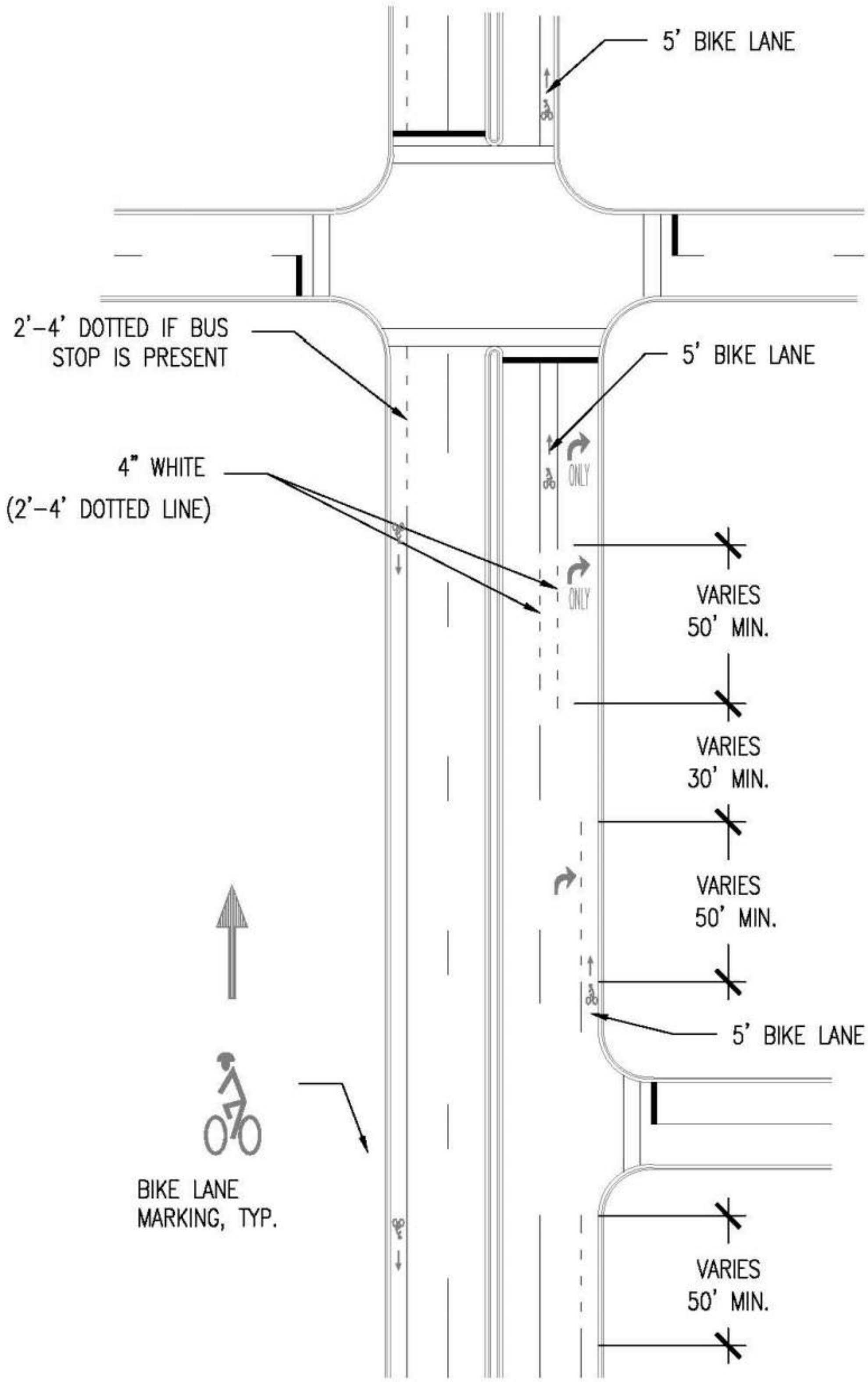


Figure 13-22 Typical Bike Lane – Tee Intersection, Right Turn Must Turn Right, Bus Stop

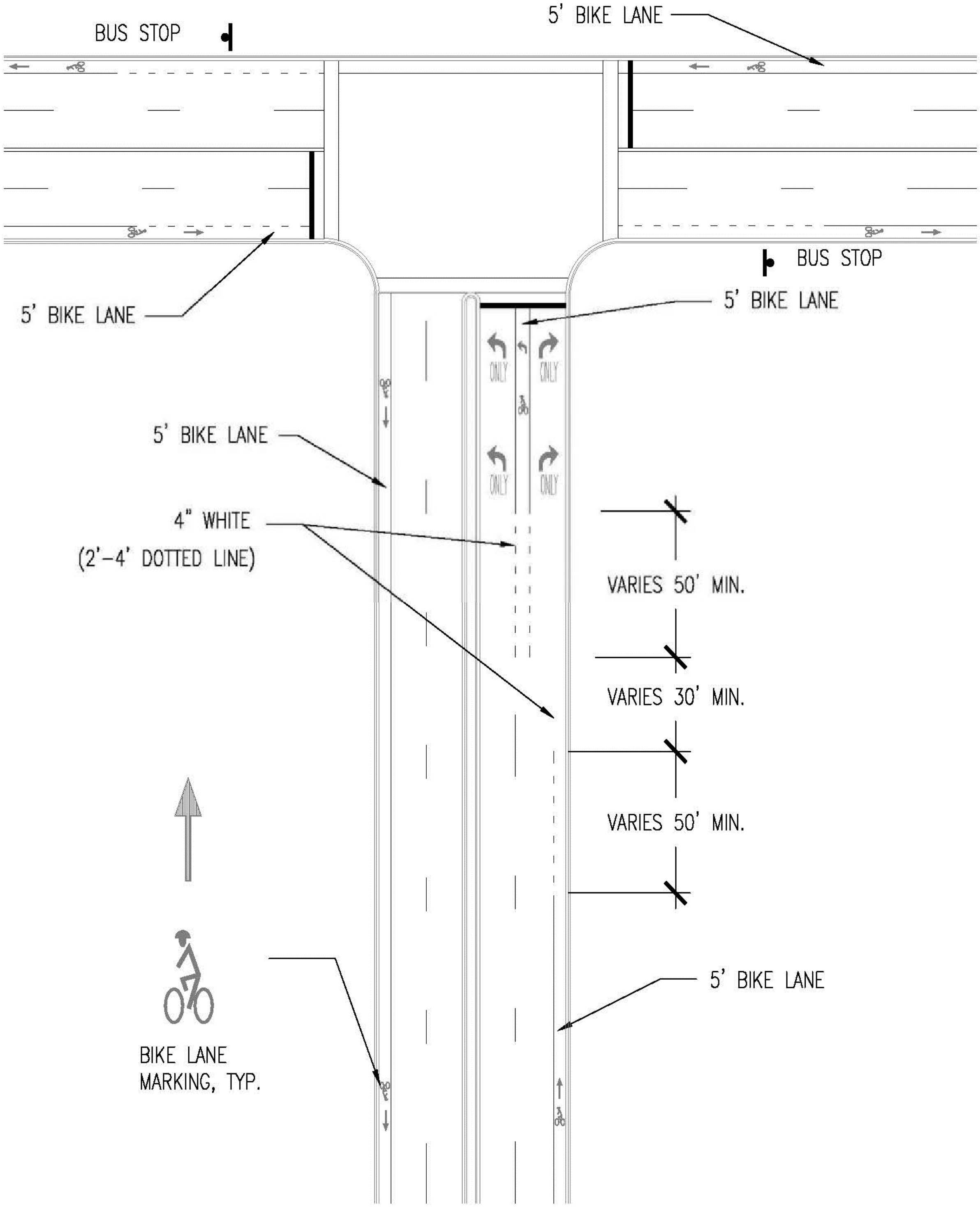


Figure 13-23 Typical Bike Lane – Tee Intersection, Right-Turn Lane, Bus Bay

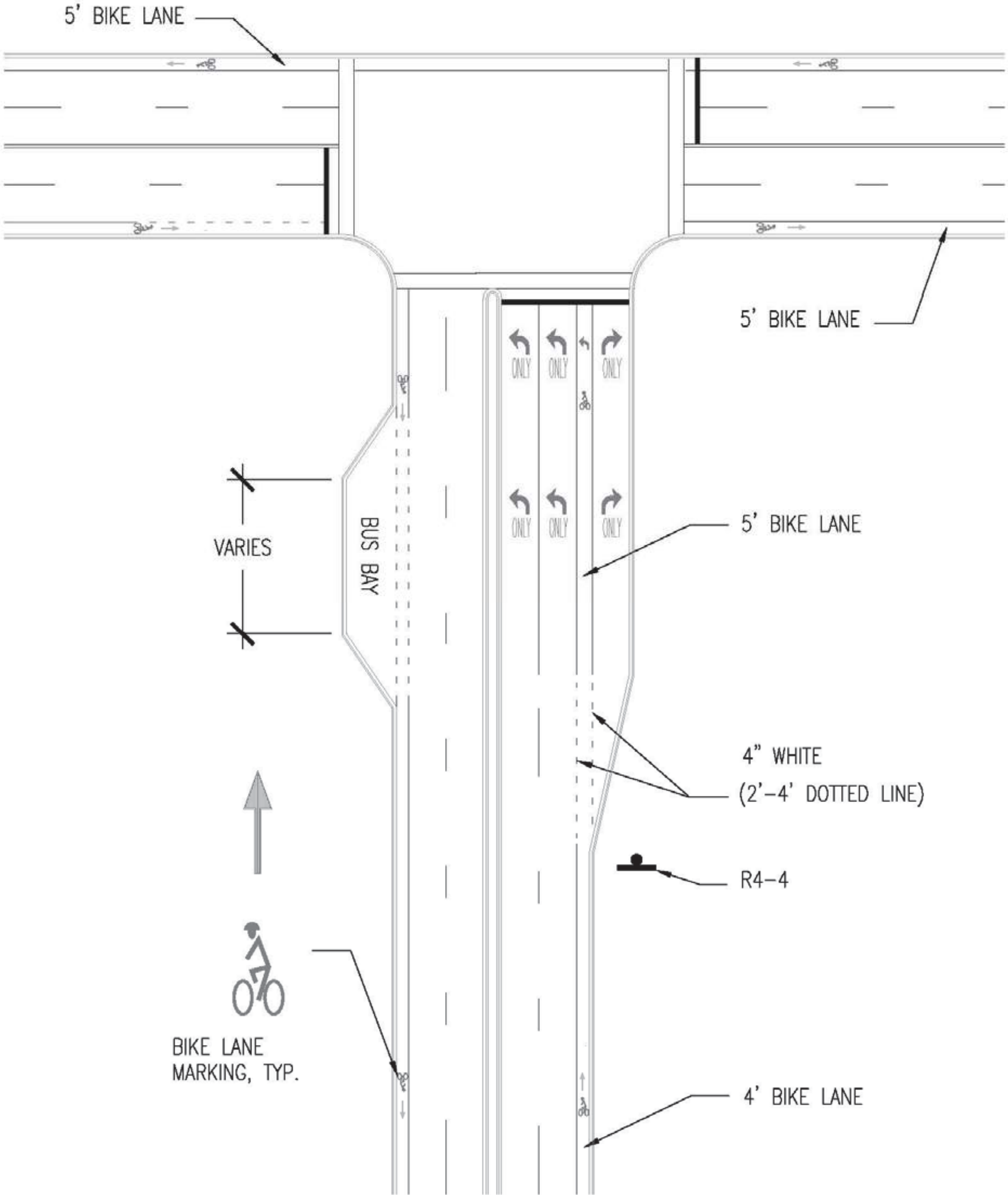


Figure 13-24 Typical Bike Lane – Compact Interchange

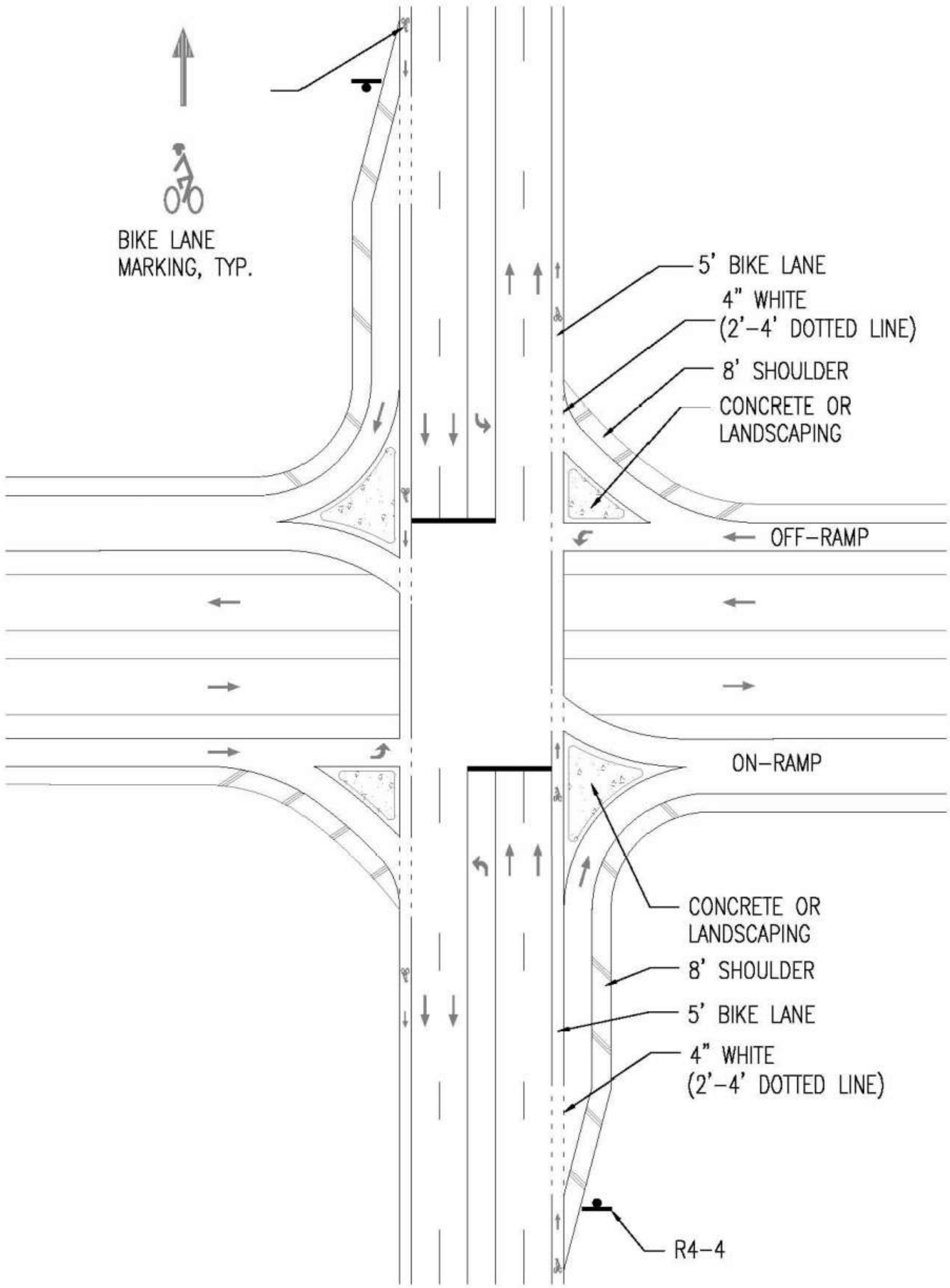


Figure 13-25 Typical Bike Lane – Rural Interchange

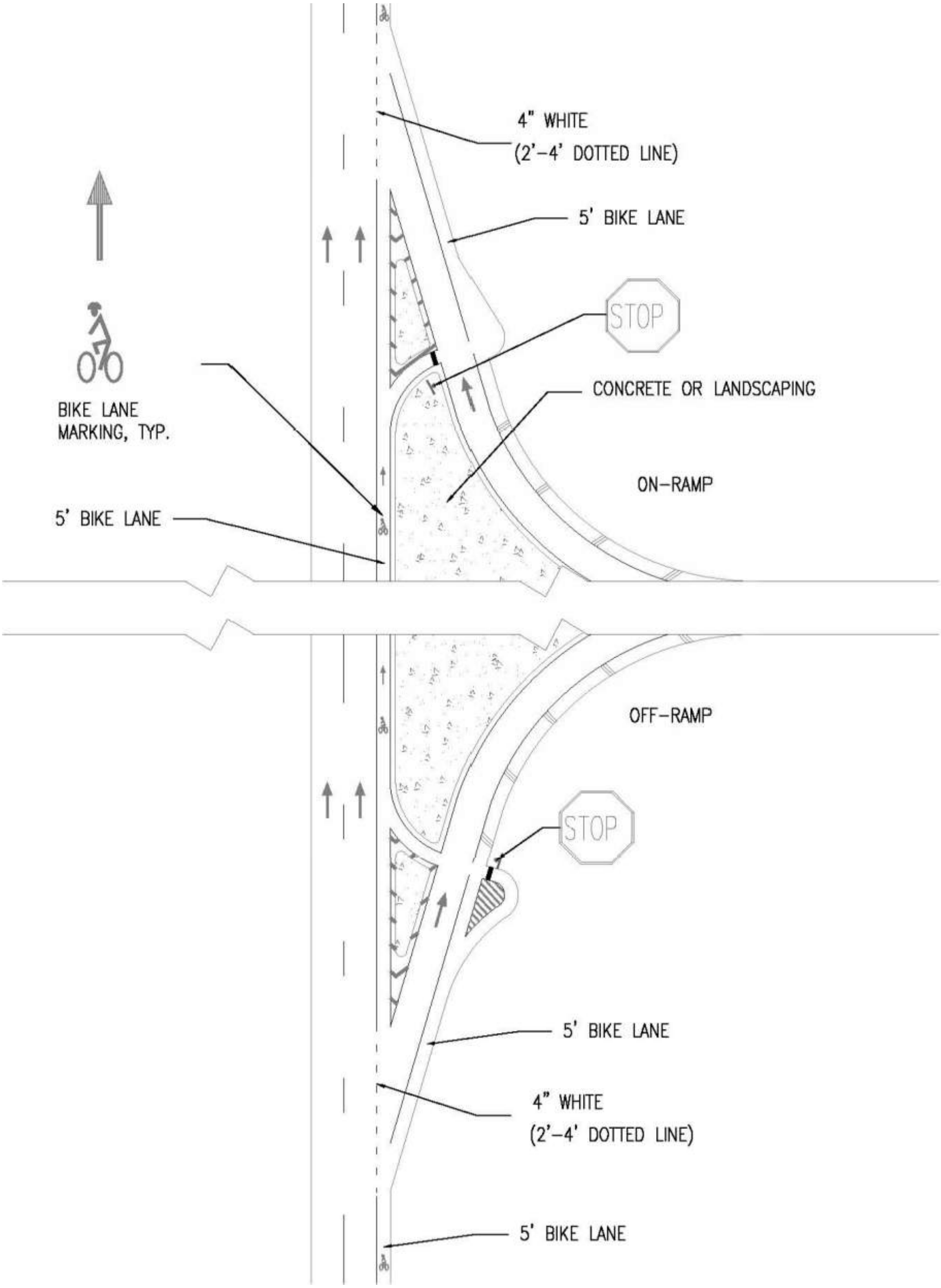
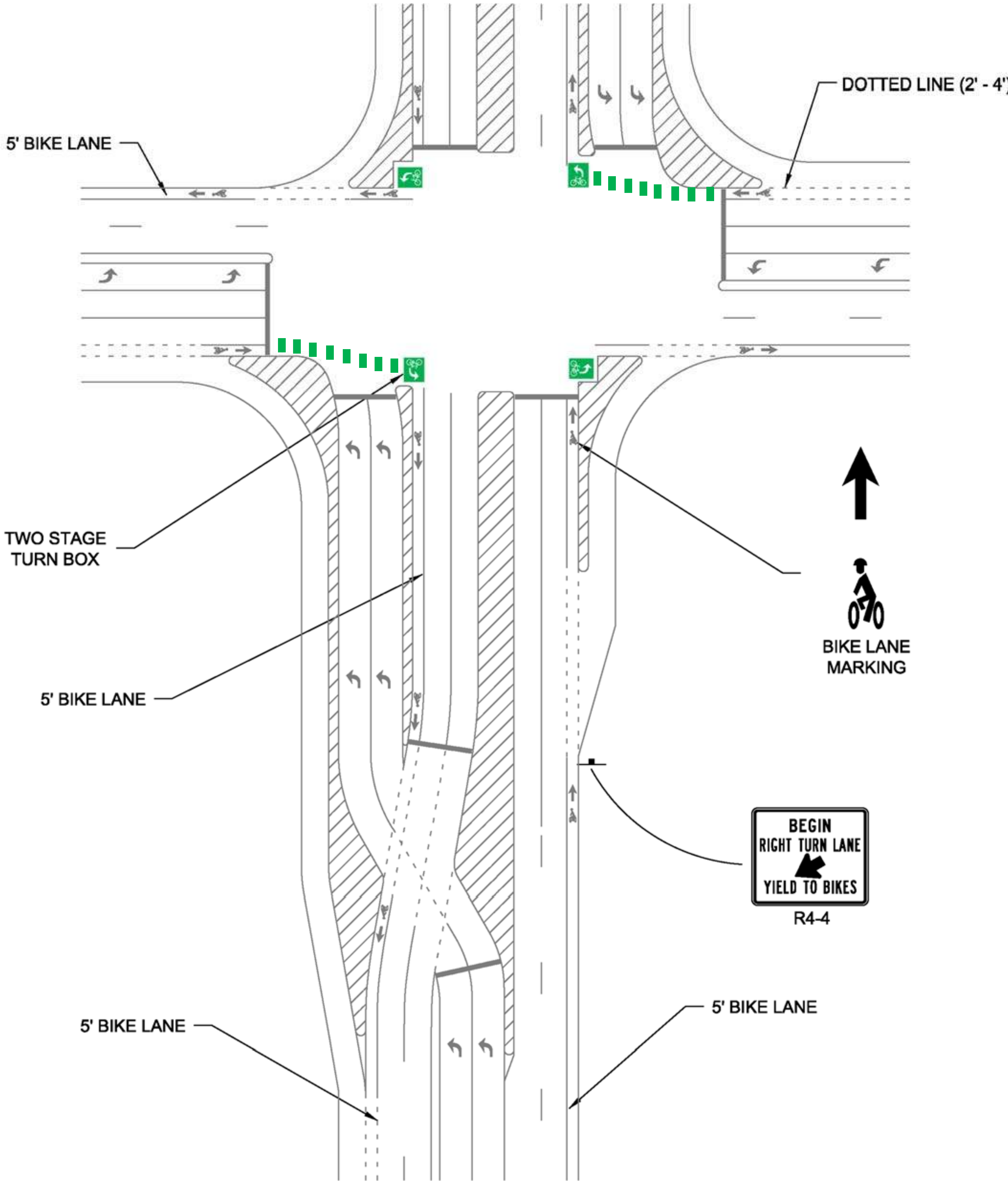


Figure 13-26 Typical Bike Lane – Continuous Flow Intersection



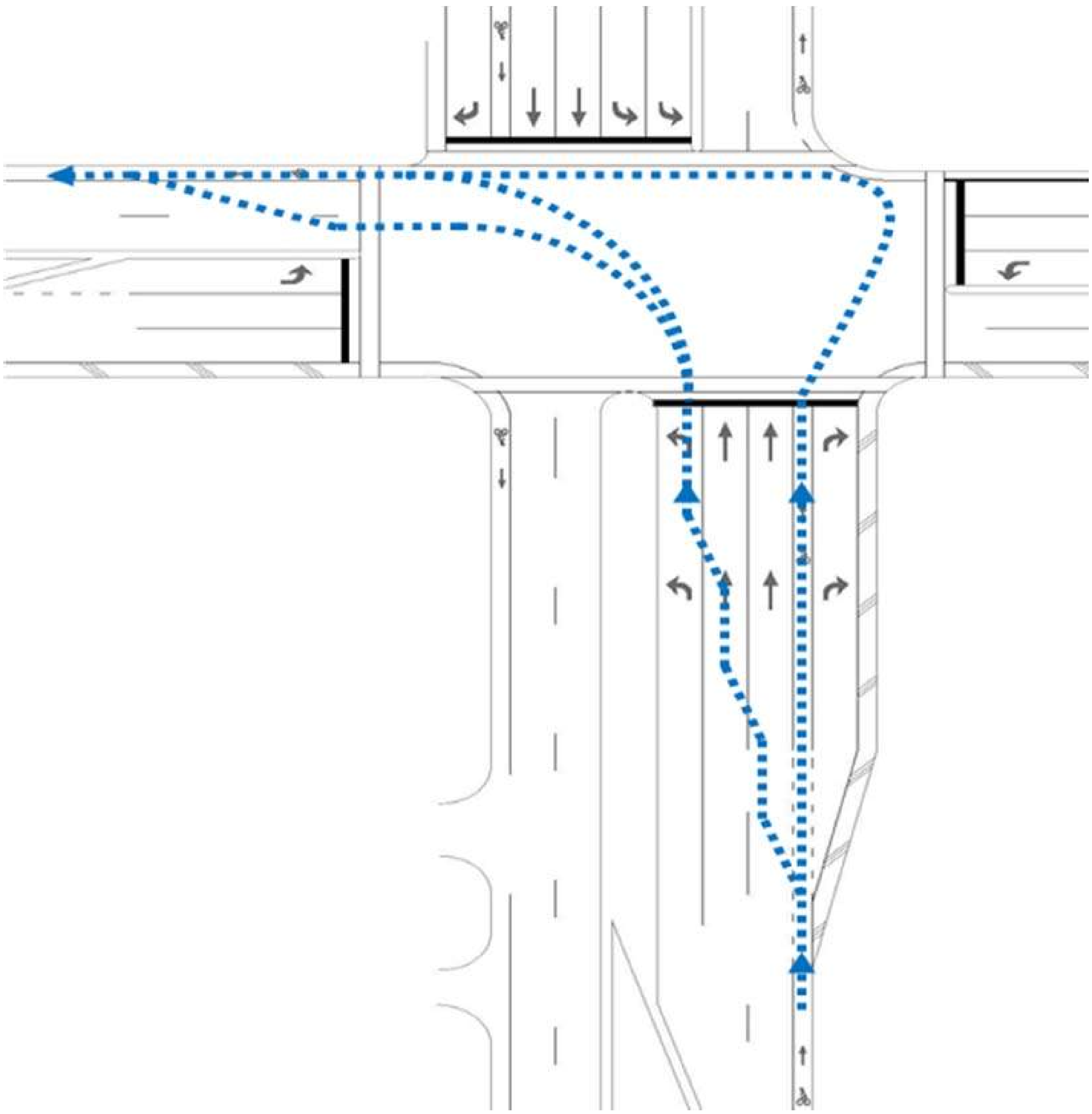
13.2.7.4.2 Two-Stage Turn Queuing Box

Making a left turn by merging across traffic to a left-turn lane may be inconvenient, uncomfortable, or unsafe for bicyclists. The Colorado Revised Statutes (C.R.S. Section 42-4-

1412(8)(a)) allows a bicyclist to turn left by merging to a left-turn lane and turning just as any other vehicle, or by making a two-stage left turn as follows and as shown in Figure 13-27:

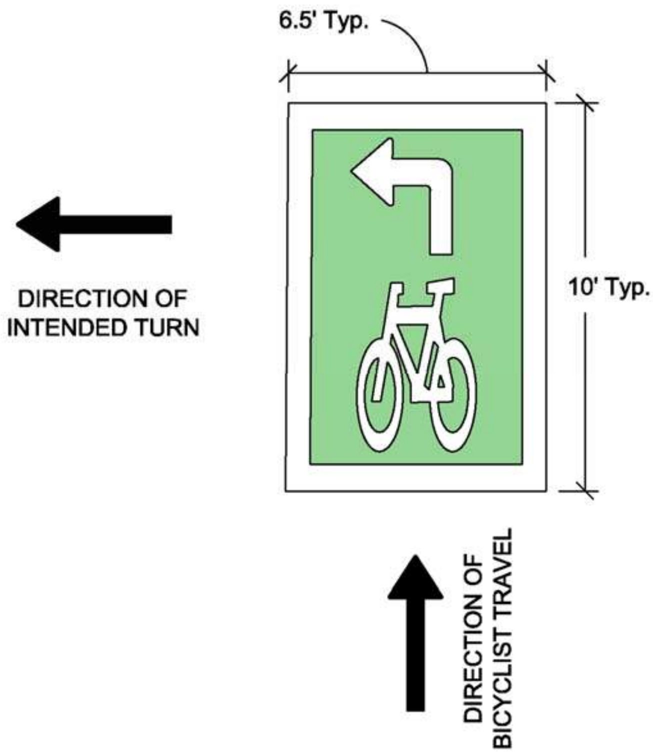
- A person riding a bicycle or electrical assisted bicycle intending to turn left shall approach the turn as closely as practicable to the right-hand curb or edge of the roadway. After proceeding across the intersecting roadway to the far corner of the curb or intersection of the roadway edges, the bicyclist shall stop, as much as practicable, out of the way of traffic. After stopping, the bicyclist shall yield to any traffic proceeding in either direction along the roadway that the bicyclist had been using. After yielding and complying with any official traffic control device or police officer regulating traffic on the highway along which the bicyclist intends to proceed, the bicyclist may proceed in the new direction.[1]

Figure 13-27 Common Maneuvers for Bicyclists Turning Left at an Intersection



A two-stage turn queuing box is a designated area at an intersection where a bicyclist can wait before proceeding in a different direction of travel. It facilitates the two-stage turn described in the statutes. A two-stage turn queuing box should be located outside of the path of turning traffic so that it does not conflict with the right turn on red movement. A NO TURN ON RED (R10-11) sign should be installed where a two-stage turn queuing box is not located outside the path of right-turning traffic. A two-stage turn queuing box should be located downstream of the crosswalk and stop line. A bicycle symbol should be placed in the two-stage turn queuing box oriented in the direction in which the bicyclists enter the box, along with an arrow showing the direction of turn (Figure 13-28).

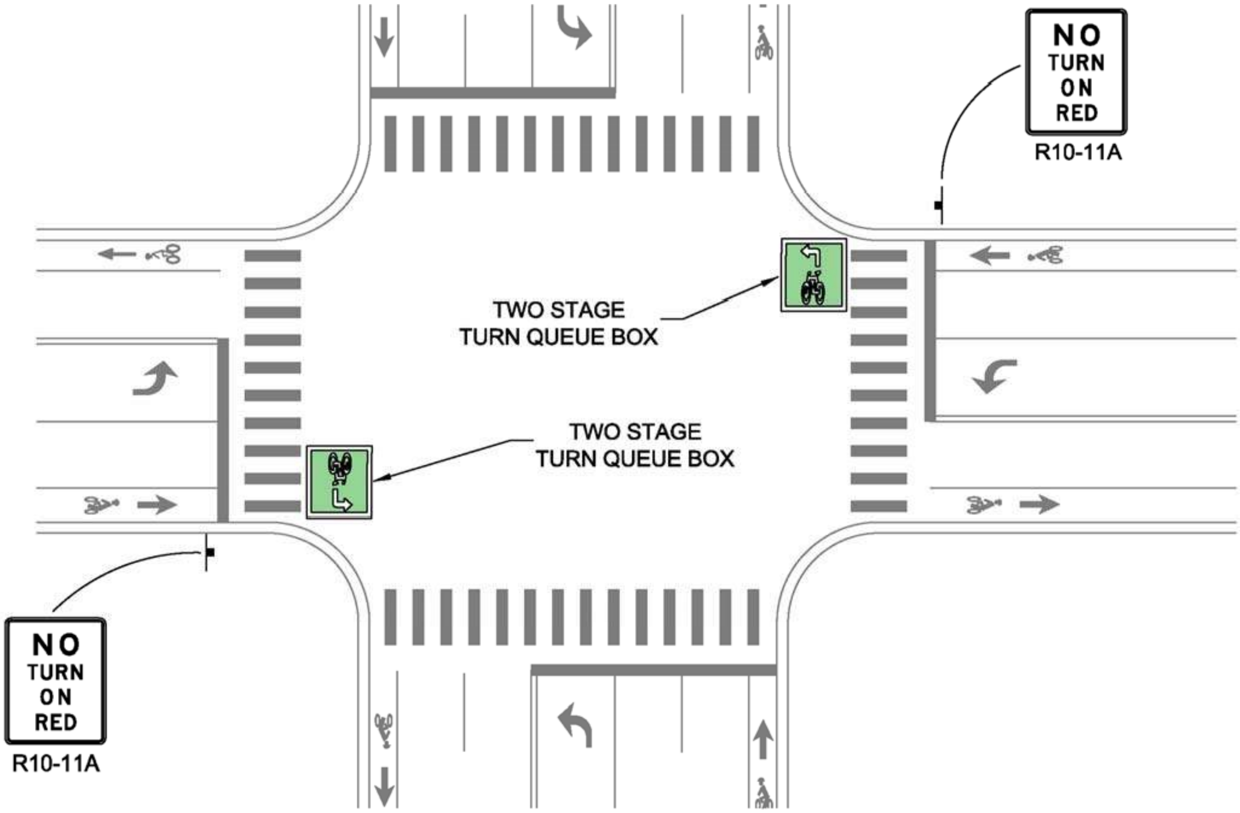
Figure 13-28 Two-Stage Left-Turn Box



Passive detection of bicycles in the two-stage turn queuing box should be provided if detection is required to actuate the signal which allows bicyclists to cross. A two-stage turn queuing box is most commonly used for left turns, but it may be used for right turns from the left side of a one-way roadway. Green-colored pavement may be used within the two-stage turn queuing box.

Two-stage bike boxes at an intersection are shown in Figure 13-29.

Figure 13-29 Example of Two-Stage Turn Queuing Box at an Intersection

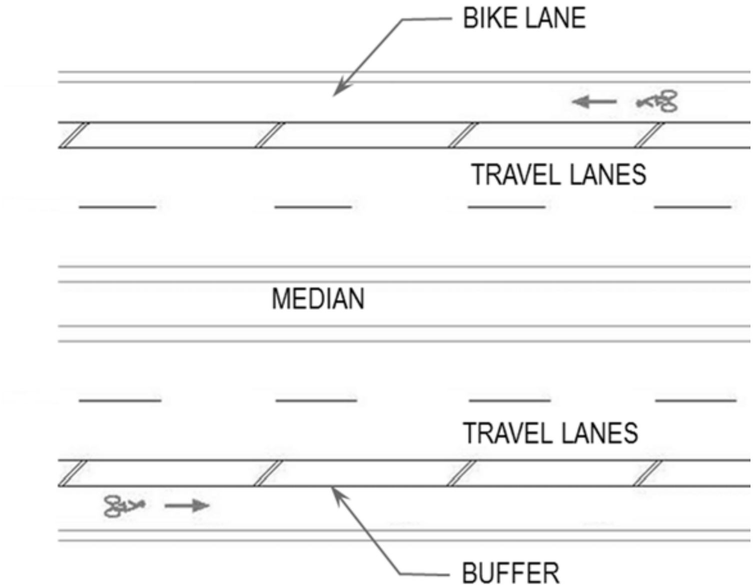


13.2.7.5 Buffered Bike Lanes

Increasing the lateral separation between motor vehicles and bicycles increases comfort for bicyclists. Where space is available, bike lanes can be improved through the provision of a painted buffer between the bike lane and the adjacent general-purpose lane or parking lane by a pattern of standard longitudinal markings. Buffered bike lanes appeal to a wider bicyclist user group because they provide greater shy distance between motor vehicles and bicyclists, and reduce the possibility of a wide bicycle lane being misconstrued as a travel or parking lane.

The buffer markings consist of two longitudinal white lines and may incorporate an interior diagonal cross hatch or chevron (Figure 13-30). These transverse markings shall be included when the buffer space is greater than 3 feet in width. The minimum buffer width should be no less than 18 inches. The spacing for transverse markings will vary based upon the speed of the adjacent roadway, on higher speed roadways less frequent hatching may be needed. The width of the buffer will vary depending upon conditions such as motor vehicle speed, percentage of heavy vehicles, roadway cross slopes, and desired level of accommodation for bicycles. Guidelines for buffered preferential lanes can be found in the MUTCD in Section 3D-01. The FHWA *Separated Bike Lane Planning and Design Guide* (FHWA, 2008) and the NACTO *Urban Bikeway Design Guide* (NACTO, 2013) offer further design guidance for buffered bicycle lanes.

Figure 13-30 Buffered Bike Lane



A buffer can also be provided between a parking lane and a bike lane to reduce the potential for a bicyclist to ride in a parked car's door swing zone. A buffer area provides a greater separation between the bicycle lane and adjacent lanes than is provided by a single normal or wide lane line.

Guidelines for buffered bicycle lanes can be found in the MUTCD Section 3D-01. Further design guidance for buffered bicycle lanes can be found in the FHWA *Separated Bike Lane Planning and Design Guide* (FHWA, 2008) and the NACTO *Urban Bikeway Design Guide* (NACTO, 2014)

13.2.7.5.1 Buffered Bike Lanes at Intersections

Buffered bike lanes at intersections should be striped similarly to non-buffered bike lanes at intersections. As described in Section 13.2.7.4, prior to intersections, the bike lane markings are discontinued or dotted to support the legal requirements for turning motorists and to help inform bicyclists that they are entering a potential conflict area. Figure 13-31 illustrates a buffered bike lane at an intersection where the buffer and bike lane width become a right-turn lane.

At locations where it is desirable to include a right-turn lane, but there is not enough cross section width to provide both a bike lane and a turn lane, SHARED LANE MARKINGS can be used to guide bicyclists to the left side of a designated right-turn lane (Figure 13-32). This option should only be used where there is a receiving bike lane or shoulder on the far side of the intersection.

Figure 13-31 Detail of Typical Buffered Bike Lane Designation

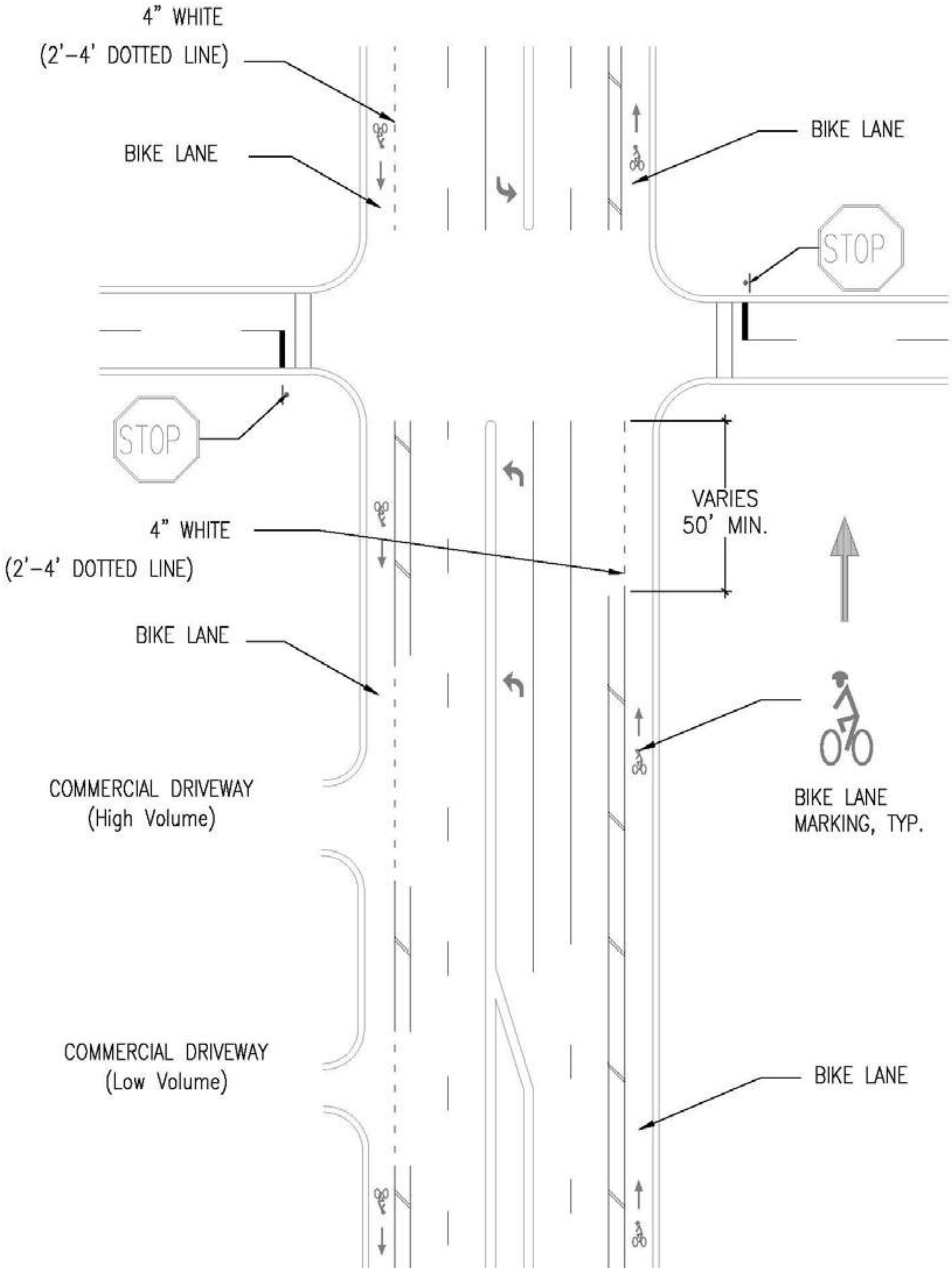
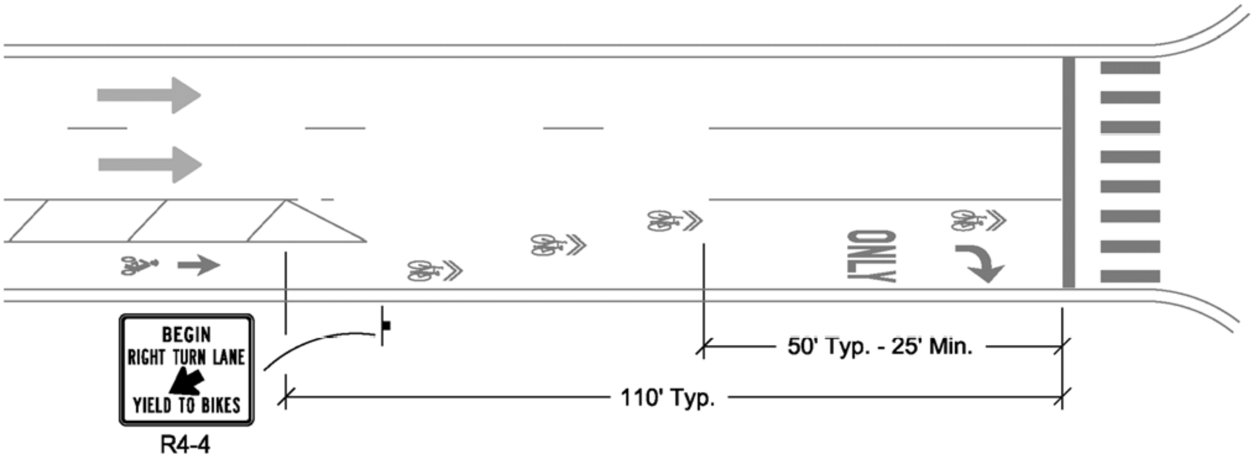


Figure 13-32 Sample Buffered Bike Lane Transition at Intersection with Right-Turn Lane



13.2.8 Detection of Bicycles at Signalized Intersections

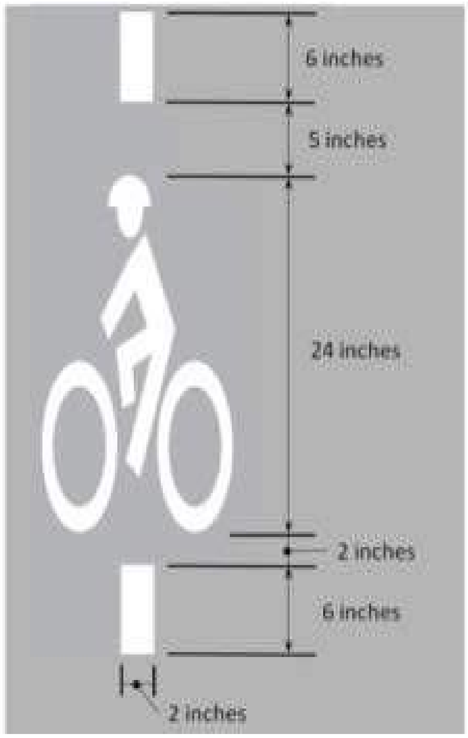
Various detection technologies can be used to detect bicyclists at intersections. The most common in Colorado are video, radar, infrared, and loop detection.

- Video detection is effective if bicyclists are using a travel lane. In addition, it is a good practice to provide a bike box, marking, or signage where the bicyclist is to stop and be detected. This may exclude right-turn lanes but should include left-turn lanes.
- Radar detection is a newer form of detection that has the capability to distinguish between user types. If signal operations require a distinction between bicyclists and motorists, radar detection systems should be used.
- Infrared detection is a common detection method that allows bicyclists to be detected through fog, snow, and other environmental factors that can impair the ability of video. This perception results from bicyclists not waiting in an optimal spot for detection (SRF, 2003).
- Calibrating loop sensitivity to detect bicycles is a principal challenge of signal hardware design, which has led to development of numerous loop configuration solutions. The 6-foot-by 40-foot quadrupole loops shown on standard drawing S-613-43 Traffic Loop and Miscellaneous Signal Details should be capable of detecting bicycles.

There are two basic strategies to improve detection of bicycles: to direct bicyclists to the area of optimal loop sensitivity, or to place new loops in spots where cyclists are likely to be waiting, such as in the bike lane or at the right edge of the pavement. It is recommended that these strategies be used before investing in a new technology. The technology already in place at many intersections should be capable of detecting bicycles. New loops should be of a type that detect bicycles.

The simplest way to detect bicycles at traffic signals is to mark the spot on the roadway where the loop will best detect the bicycle. The MUTCD provides for a symbol that may be placed on the pavement to indicate the optimum position for a bicyclist to actuate the signal for conventional inductive loops (MUTCD). Used in conjunction with the Bicycle Signal Actuation sign (R10-22) MUTCD) (Figure 13-33), this symbol increases the ability of the loops to detect bicycles.

Figure 13-33 Bike Detection Symbol and Bicycle Signal Actuation Sign



13.2.8.1 Signal Detection in Bike Lanes

Signal detection within a bicycle lane should be considered where a signal change is needed to allow a bicyclist to travel safety through an intersection.

A successful loop type for bike lanes is a quadrupole loop of reduced size (2 feet x 10 feet). These loops are highly sensitive to objects in the area immediately above them, but detection falls off rapidly outside of this sensitivity field; this means that cars in adjacent lanes will not be detected. Refer to Section 13.2.7 for more alternatives on bike detection technologies.

Bike phase signal activations can be used at busy intersections with high bicycle volumes. The "bike phase" of the signal is activated by the bicycle lane detection.

13.2.8.2 Signal Timing for Bicycles

The MUTCD requires that traffic signal timing and actuation be reviewed and adjusted to consider the needs of bicyclists. Meeting the needs of bicyclists on bikeways means providing adequate minimum green times and adequate change periods.

The minimum green time allows bicyclists to start from a stopped condition, cross, and clear the intersection. For the crossing of narrow roadways, bicyclists may not accelerate to full speed before clearing the intersection. On wider roadways, bicyclists may accelerate to full speed and may require additional time to finish crossing and clear the intersection. The equations to calculate minimum green time are as follows:

$$G_{min} = 1.0 + 1.15\sqrt{W + 6} \qquad \text{Where W} \leq 72 \text{ feet}$$

$$G_{min} = 10.8 + \frac{(W - 72)}{14.7} \qquad \text{Where W} > 72 \text{ feet}$$

and
G_{min} = minimum green time (sec)
W = width of intersection (ft)

Typically, the minimum change period is calculated using the following equation:

$$CP = \left[t + \frac{1.47v}{2(a + 32.2g)}\right] + \left[\frac{W + L_v}{1.47v}\right]$$

Where:
CP = change period (yellow change plus red clearance intervals), (sec)
t = perception-reaction time to the onset of a yellow indication, s, assume 1 (sec)
v = approach speed (mph)(assume 10 MPH for a bicycle)
a = deceleration rate in response to the onset of a yellow indication, (ft/sec), (assume 5 ft/sec for a bicycle)
g = grade, with uphill positive and downhill negative (percent grade / 100), (ft/ft)
W = width of intersection (ft)
Lv = length of vehicle, (ft) (assume 6 ft for bicycle)

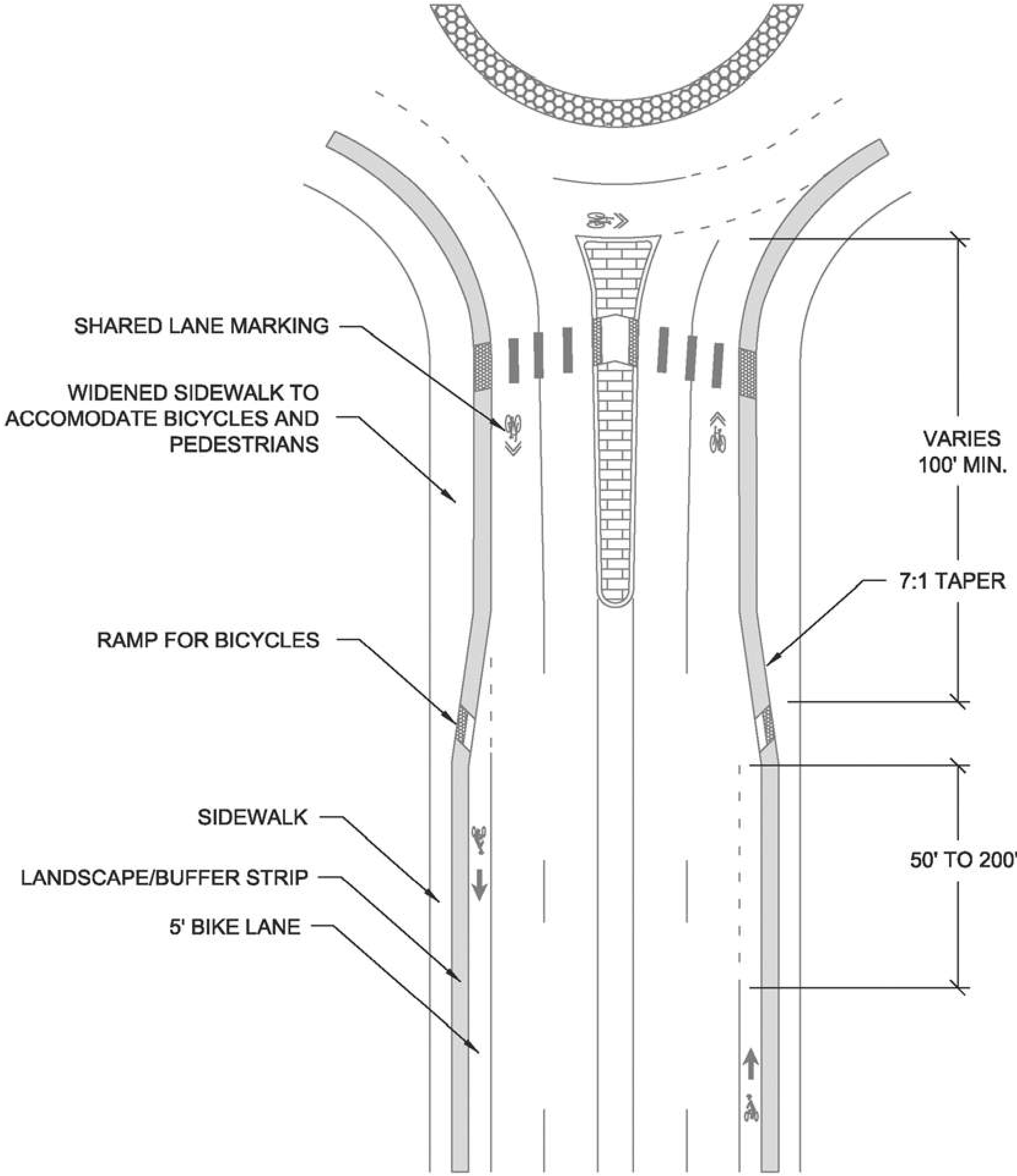
At a wide intersection, the clearance interval for motorists may not be long enough to allow bicyclists to cross the intersection. Advance detection in bike lanes or on shoulders can extend the green time so that bicyclists can clear the intersection before the cross traffic gets a green signal. An alternative is a bicycle-specific signal (refer to Section 13.3.16.8) with a plaque that states “Bicycle Signal”.

At installations where visibility-limited signal faces are used, signal faces shall be adjusted so bicyclists can see the signal indications. If the visibility-limited signal indications cannot be adjusted for the bicyclist, separate signal indications shall be provided for the bicyclist.

13.2.9 Bike Lanes at Roundabouts

Bike lanes are not carried through roundabouts. The MUTCD states that bike lane markings should stop at least 100 feet prior to the approach of a roundabout. At the end of a bike lane, a pathway must be provided for bicyclists to exit the roadway if they choose. A SHARED LANE MARKING may be used through the roundabout. Figure 13-34 is an example of a multilane roundabout with a bike lane.

Figure 13-34 Multilane Roundabout



13.2.10 Separated Bike Lanes (Cycle Track)

Separated bike lanes, also known as cycle tracks, are bicycle lanes that are separated from general travel lanes and sidewalks. They are not the same as shared-use paths because separated bike lanes are bicycle-only facilities. They are distinct from buffered bike lanes because there is a physical separator, such as a raised island or on-street parking, between the bike lane and outside travel lane. Operationally, two-way cycle tracks can be very challenging, particularly at intersections with driveways and streets.

For guidance on the design of cycle tracks, refer to the AASHTO *Guide for the Development of Bicycle Facilities* (AASHTO, 2012), the FHWA *Separated Bike Lane Planning and Design Guide* (FHWA, 2008), and the NACTO *Urban Bikeway Design Guide* (NACTO, 2014).

13.2.11 Bicycle Boulevards

A bicycle boulevard is a local street or series of contiguous street segments designed to prioritize bicycle travel and discourage motor vehicle throughput and speeds. Local vehicle access is maintained along the bicycle boulevards. Bicycle boulevards are not used on CDOT-owned roadways. However, they may be used to improve an adjacent, alternative route where bicycle accommodation cannot be met on the CDOT roadway (refer to Section 13.2.12).

Bicycle boulevards are often used on low-volume, very low speed local streets. SHARED LANE MARKINGS may be used along bike boulevards. Often bicycle boulevards have bicycle-friendly traffic calming or treatments (e.g., speed cushions, mini traffic circles, chicanes) to reduce motor vehicle speeds along the roadway. Some portions of a bike boulevard may be on busier roads with bike lanes. To discourage through movements of motorized vehicles, traffic diverters should be used at intersections. Bicycle boulevards can also be created by connecting the ends of cul de sac roadways with a grid pattern as it reduces turning movements and makes the route more intuitive. Because bike boulevards typically serve as bike routes, wayfinding signage should be provided.

One of the challenges to implementing bike boulevards is how to safely accommodate bicyclists at the crossing of major roadways. At intersections, the bicycle boulevard should be given priority over side streets. Improvements to signal timing and detection or enhanced crossing treatments (e.g., activated beacons, raised medians) where there are no traffic signals make a bicycle boulevard more appealing to bicyclists.

Another challenge is that residents who live along the route may be opposed to altering the facility to accommodate the boulevard. Motorists who travel the route may oppose the modification because of the altered travel patterns. Designers should be aware of these challenges and plan for early and sustained public outreach to the neighbors, communities, and municipalities within the project's area.

13.2.12 Alternative Routes

In some instances, it may not be possible to improve the roadway to accommodate bicyclists. In these cases, it may be possible to improve an adjacent street as an alternative route for bicyclists. Alternative routes could be improved using some of the treatments described in this chapter. The land use context and transit access along the parallel route should appeal and attract bicyclists from the primary route. Additional signage should also be considered to direct the bicyclists to the alternative route. Another key factor for parallel routes is the distance. Research indicates that for an alternative low-stress route to be viable, the trip length should not increase more than 30% (Broach et al, 2012).

Several factors must be addressed when considering whether an alternative route provides a suitable accommodation for bicyclists:

- *Geometric delay.* This is the delay caused to bicyclists by increased distance they must travel to use the alternative route. If an alternative route significantly increases the distance and time a bicyclist must travel to access a destination, it is less likely to be used.
- *Control delay.* This is the delay caused by increasing the number of STOP signs or red traffic signals along a route. Often the primary corridor is given most of the green time at signals and does not often have to stop at minor street intersections. If the alternative route is a local street with stops at every cross street and gets minimal green time at signalized intersections, bicyclists are less likely to use it.
- *Access to destinations.* An alternative route must provide access to the trip destinations along the primary corridor, or it will not be a practical option for bicyclists.
- *Safety.* An alternative route considered for improvement should be subject to a safety assessment. This would include reviewing crashes along the route as well as identifying potential safety concerns associated with accessing the primary corridor from the alternative route.

13.2.13 Other Roadway Considerations

13.2.13.1 Roadway Cross Slope

The typical cross slopes for roadways usually accommodate bicyclists. Cross slopes of 5% or less are desirable for bicycles. However, the AASHTO *Guide for the Development of Bicycle Facilities* (AASHTO, 2012) allows superelevation rates up to 8%.

13.2.13.2 Drainage Inlets and Utility Covers

Placement of drainage inlet grates should be avoided within a bicycle facility regardless of whether that facility is a bike lane, shoulder, or shared lane. If this is not possible, drainage inlet grates should be safe for bicyclists. Utility covers and drainage grates should be installed to be flush with the pavement. The construction of new roadway facilities should consider the use of curb inlets rather than gutter pan drop inlets.

Drainage inlet grates with slots or gaps parallel to the roadway can trap a bicycle's front wheel and seriously damage the bicycle or injure the bicyclist. These types of grates should be replaced with bicycle-safe grates that maintain the required hydraulic capacity for the inlet (Figure 13-35).

A bicycle-safe grate should have, at a minimum, bars perpendicular to the travel direction at a 4-inch center-to-center spacing

For safety considerations, a utility cover or drainage inlet located on a bicycle facility that has a gap or opening parallel to the roadway should be replaced or corrected as soon as possible. If a drop inlet with parallel slots cannot be replaced, an obstruction marking should be placed on the pavement prior to the inlet (Figure 13-36).

Figure 13-35 Bicycle Compatible Drainage Grates

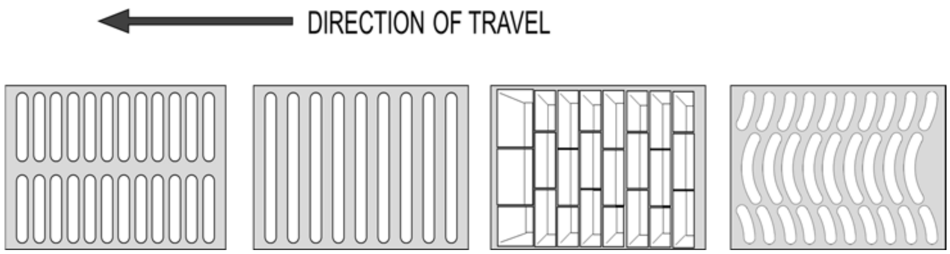
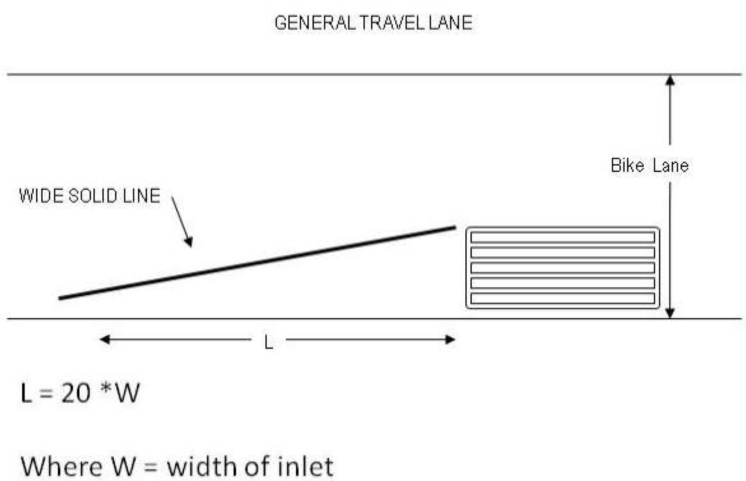


Figure 13-36 Bicycle Obstruction Marking in Advance of a Drop Inlet

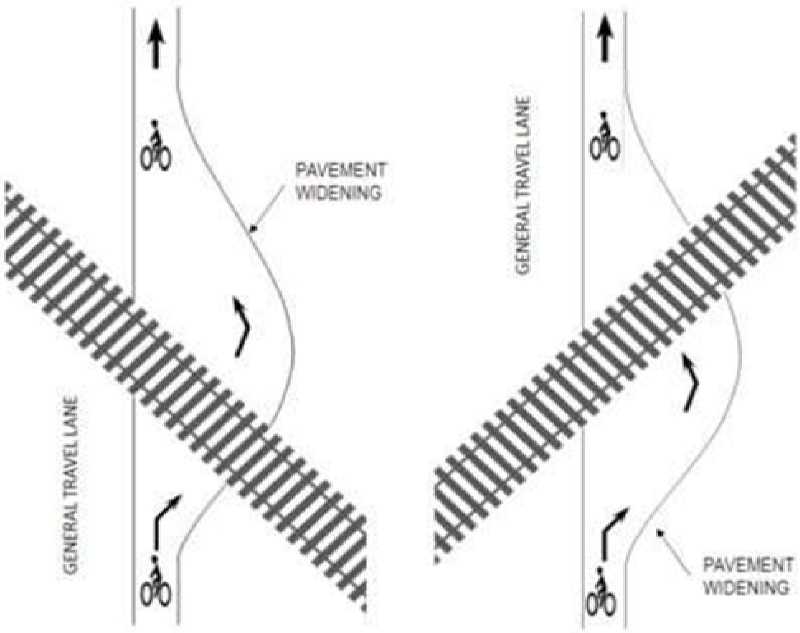


13.2.13.3 Railroad Crossings

Ideally, travel ways and bicycle facilities should cross rail lines between 60 and 90 degrees so that bicyclists can avoid catching their wheels in the flange and lose their balance. The design of the crossing should also evaluate the fastest path a bicyclist can take through the crossing.

At railroad crossings with crossing angles less than 45 degrees, it is recommended that the bicycle path be modified so that the bicyclist is able to cross the tracks at a right angle. The simplest approach is to provide additional pavement width at the crossing. Figure 13-37 shows two scenarios with potential skewed crossing treatments. Pavement markings can be provided to direct bicyclists to the preferred path of travel. Additionally, SKEWED CROSSING warning signs (W10-12) should be considered for the approach to the crossing.

Figure 13-37 Potential Treatments at a Skewed Railroad Crossing



13.2.13.4 Bridges and Tunnels

The FHWA *Accommodating Bicycle and Pedestrian Travel: A Recommended Approach* Policy Statement (FHWA, 2010) states, "A bridge that is likely to remain in place for 50 years should be built with sufficient width for safe bicycle and pedestrian use (sidewalks and shoulders) in anticipation that facilities will be available at either end of the bridge even if that is not currently the case."

Bridge designs should provide adequate width for current and future anticipated bicycle and pedestrian volumes. Widths should meet or exceed the minimums for shoulders, bike lanes, separated bike lanes, and shared-use path design discussed in other sections. Additionally, the operating space of a bikeway recognizes that bicyclists will not travel immediately against a railing, barrier, or other continuous vertical element and a shy distance should be provided.

Bridge railings need to be taller to prevent a bicyclist that hits the barrier from going over the barrier. The barrier should be at least 42 inches tall.

Tunnels should be designed to accommodate bicyclists and pedestrians. The vertical clearance should be at least 10 feet, however, in constrained locations where the ends of the tunnel are visible from either side, the vertical clearance may be as low as 8 feet.

Lighting in tunnels should be provided to allow users to see the paved surface and identify any hazards ahead of them, allow users to identify others around them including their relative speed and direction of travel, illuminate walls and other fixed objects, and create a visually appealing or interesting space to reduce the sense of enclosure.

13.3 Shared-Use Paths

Shared-use paths are physically separated from motorized vehicular traffic by a physical barrier or clear space. They are often on their own alignments but may be located within the right of way of an adjacent roadway.

Shared-use paths are intended for use by many modes (e.g., pedestrians, persons with disabilities, bicyclists, etc.) and must be made ADA compliant to the maximum extent feasible (refer to Section 13.3).

13.3.1 Surface Treatments

Shared-use paths typically are surfaced with hot mix asphalt (HMA) or concrete pavement. HMA may be a less expensive alternative, but its life span is shorter and maintenance costs tend to be higher over the life of the pavement compared to concrete pavement. Concrete pavement tends to resist deformation from vegetation better than HMA and has a more appealing appearance.

13.3.1.1 Paved Shared-Use Paths

Most CDOT shared-use path projects are paved. Asphalt and Portland cement concrete are the two most common surfaces for shared-use paths. Asphalt may be a less expensive alternative, but its life span is shorter and maintenance costs tend to be higher over the life of the pavement when compared to concrete pavement. Additionally, concrete pavement tends to resist deformation and vegetation growth better than asphalt and is more visually appealing. For rigid pavement design information, refer to the CDOT *M-E Pavement Design Manual* (CDOT, 2021). The Materials Engineer should be consulted for flexible pavement design information. On Portland cement concrete pavements, the transverse joints should be saw cut, rather than tooled, to provide for a smoother riding surface. Skid resistance should not be reduced, and broom finish or burlap drag surfaces should be provided. Paved paths should be designed to sustain vehicle loads for occasional maintenance, patrol, emergency or other vehicles that are permitted to use the path.

Where paved shared-use paths cross unpaved roadways or driveways, the roadway or driveway should be paved 20 feet on each side of the shared-use path to minimize debris accumulation on the path.

13.3.1.2 Unpaved Shared-Use Paths

In areas where path use is expected to be primarily recreational, unpaved surfaces may be acceptable. Materials should be chosen to ensure the ADA requirements for a firm, stable, slip-resistant surface are met. Even when ADA criteria is met, some users, such as in-line skaters, kick scooters, and skateboarders, may be unable to use unpaved shared-use paths.

For unpaved shared-use paths, grades of greater than 3% may result in erosion problems and bicycle handling difficulty. Additionally, snow plowing may be impractical on unpaved shared-use paths.

13.3.2 Design Speed

Similar to roadways, the design speed selected for shared-use paths dictates other design criteria (e.g., sight distance, curve alignments). Consequently, the selection of an appropriate design speed is important to maximize the flexibility of a shared-use path.

Design speeds range from 12 to 30 mph. Increments of 2 mph should be used for design speeds less than 20 mph and increments of 5 mph should be used for design speeds above 20 mph.

An 18 mph design speed is generally sufficient for most shared-use paths in relatively flat areas (generally less than 2% grades). If it is expected that there is significant use by recumbent bicyclists, the minimum design speed should be to 18 mph (FHWA, 2004). Additionally, many e-bike users may travel at speeds of 20 mph or more on flat terrain. However, the presence of e-bikes does not mean that a 20 mph design speed must be selected for all bikeways.

Design speeds lower than 18 mph may be used in areas where the bicycle users are expected to be made up of lower-speed users, such as children. A design speed less than 14 mph should be used only in unusual circumstances. Justification based upon environmental context and user types should be provided when using a design speed less than 14 mph.

Lowering bicyclist and motorist operating speeds allows bicyclists and motorists more time to perceive potential conflicts. Geometric design and traffic control devices should be used in advance of crossing points or hazards (refer to Section 13.3.10.6).

Where sustained grades exceeding 4% in excess of 300 feet in length are required, a higher design speed should be used. Design speeds should be based upon the anticipated travel speeds of bicyclists traveling downhill. The maximum design speed used in all but the most unusual cases should be 30 mph.

13.3.3 Sight Distance

As stated in Chapter 6 of this Guide, a critical element in assuring safe and efficient operation of a vehicle on a highway is the ability to see ahead. Sight distance is the distance along a roadway or path throughout which an object of specified height is continuously visible to a bicyclist. Sight distance of sufficient length must be provided to allow a bicyclist to avoid striking unexpected objects in the traveled way. In a vertical plane, this distance is dependent on the height of the bicyclist’s eye above the road or path surface, the specified object height above the road surface, and the height and lateral position of obstructions such as cut slopes, guardrail, and retaining walls within the bicyclist’s line of sight. Horizontal alignment, including the routing of a path around visual screens, can also impact sight distance and should be considered.

13.3.3.1 Stopping Sight Distance

Stopping sight distance is the sum of two distances:

- The distance a bicycle travels from the instant the bicyclist sights an object necessitating a stop to the instant the brakes are applied (brake reaction distance), and

- The distance required to stop the bicycle from the instant brake application begins (braking distance).

Stopping sight distance is measured from the bicyclist's eyes (assumed to be 4.5 feet above the pavement) to an object flush with the surface of the shared-use path. If it is found that there is a high number of recumbent cyclists, an eye height of 2.8 feet should be used (FHWA, 2004). Distances greater than the minimum stopping sight distance provide an additional measure of safety and should be considered where practical.

On downhill grades, gravity acts against braking forces and increases the distance required to stop. On uphill grades, gravity reduces the distance required to stop. The effect of grades is represented in stopping sight distance values.

The equation for stopping sight distance, assuming a 2.5-second reaction time, is

$$S = 3.67V + \frac{V^2}{30(f + G)}$$

Where,

S = stopping sight distance (ft)
V = design speed (mph)
f = friction factor (assume 0.16 for a typical bicycle)
G = grade in (ft/ft)

Table 13-5 shows stopping sight distances for level roadways and roadways with grade for various design speeds. Refer to Chapter 6 for adjustments for grades.

Table 13-5 Stopping Sight Distance for Bicycles

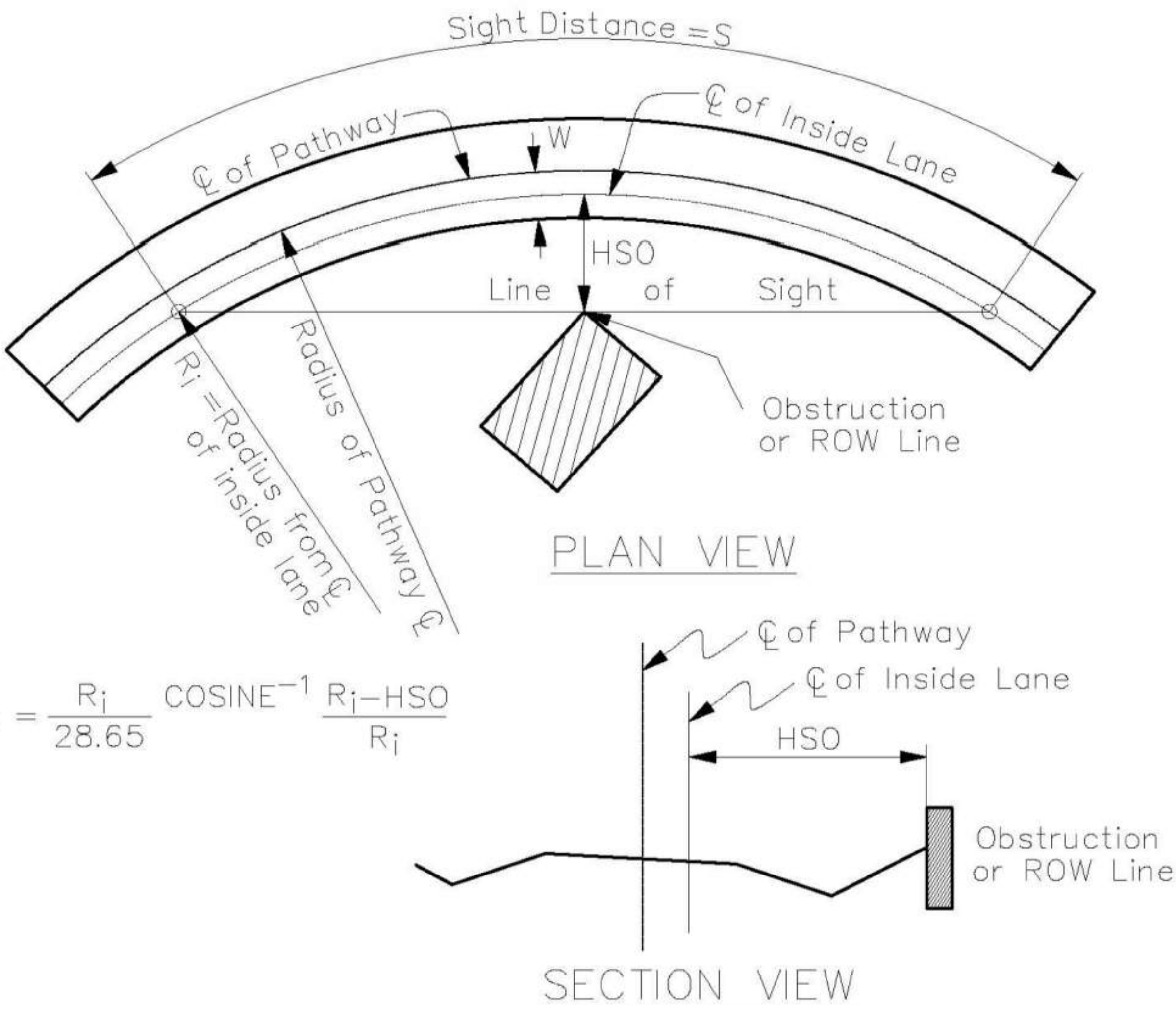
--	Stopping Sight Distance (Design Values)						
Design Speed (mph)	**No Grade Adjustment**	**% Down Grade**			**% Up Grade**		
--	--	3	6	9	3	6	9
8	43	46	51	60	41	40	38
10	58	63	71	85	55	52	51
12	75	81	93	113	70	66	64
14	93	102	117	145	86	82	78
16	113	125	145	181	104	98	93
18	134	150	175	221	123	116	110
20	157	176	207	264	144	135	127
25	222	253	301	390	202	187	176
30	298	341	411	539	268	247	231

13.3.3.2 Sight Distance on Horizontal Curves

Sight distance on horizontal curves on shared-use paths may be obtained with the aid of Figure 13-38 and Table 13-6. The line of sight is assumed to intercept the obstruction at the midpoint of the sight line and at the surface of the center of the inside lane. The middle horizontal sightline offset (HSO) is obtained from the equation in Figure 13-38 and from Table 13-6.

The stopping sight distance in Table 13-6 is the stopping sight distance determined using the equation or table from Section 13.3.3.1. The minimum radii for horizontal curves are addressed in Section 13.3.7.

Figure 13-38 Stopping Sight Distance on a Shared-Use Path Horizontal Curve



$$S = \frac{R_i}{28.65} \text{COSINE}^{-1} \frac{R_i - HSO}{R_i}$$

Table 13-6 Minimum Horizontal Clearance for Horizontal Sightline Offset for Horizontal Curves

		Stopping Sight Distance												
		20	40	60	80	100	125	150	175	200	225	250	275	300
Curve Radius (ft)	15	3.2	11.5	21.2	28.3	29.7	22.8	10.7	1.5	1.1	9.8	21.9	29.5	27.6
	20	2.4	9.2	18.6	28.3	36.0	40.0	36.4	26.6	14.3	4.2	0.0	3.4	13.1
	25	2.0	7.6	15.9	25.7	35.4	45.0	49.8	48.4	41.3	30.3	17.9	7.3	1.0
	35	1.4	5.6	12.1	20.5	30.0	42.5	54.0	63.0	68.6	69.9	66.8	59.7	49.5
	50	1.0	3.9	8.7	15.2	23.0	34.2	46.5	58.9	70.8	81.4	90.1	96.2	99.5
	75	0.7	2.7	5.9	10.4	16.1	24.6	34.5	45.5	57.4	69.7	82.2	94.5	106.2
	100	0.5	2.0	4.5	7.9	12.2	18.9	26.8	35.9	46.0	56.9	68.5	80.6	92.9
	125	0.4	1.6	3.6	6.3	9.9	15.3	21.8	29.4	37.9	47.3	57.5	68.3	79.7
	150	0.3	1.3	3.0	5.3	8.3	12.8	18.4	24.8	32.1	40.3	49.1	58.7	69.0
	175	0.3	1.1	2.6	4.6	7.1	11.0	15.8	21.4	27.8	34.9	42.8	51.3	60.5
	200	0.2	1.0	2.2	4.0	6.2	9.7	13.9	18.8	24.5	30.8	37.8	45.4	53.7
	225	0.2	0.9	2.0	3.5	5.5	8.6	12.4	16.8	21.9	27.5	33.8	40.7	48.2
	250	0.2	0.8	1.8	3.2	5.0	7.8	11.2	15.2	19.7	24.9	30.6	36.9	43.7
	300	0.2	0.7	1.5	2.7	4.2	6.5	9.3	12.7	16.5	20.9	25.7	31.0	36.7
	350	0.1	0.6	1.3	2.3	3.6	5.6	8.0	10.9	14.2	17.9	22.1	26.7	31.7
	400	0.1	0.5	1.1	2.0	3.1	4.9	7.0	9.5	12.4	15.7	19.4	23.4	27.8
	450	0.1	0.4	1.0	1.8	2.8	4.3	6.2	8.5	11.1	14.0	17.3	20.8	24.8
	500	0.1	0.4	0.9	1.6	2.5	3.9	5.6	7.6	10.0	12.6	15.5	18.8	22.3
	600	0.1	0.3	0.7	1.3	2.1	3.3	4.7	6.4	8.3	10.5	13.0	15.7	18.7
	700	0.1	0.3	0.6	1.1	1.8	2.8	4.0	5.5	7.1	9.0	11.1	13.5	16.0
	800	0.1	0.3	0.6	1.0	1.6	2.4	3.5	4.8	6.2	7.9	9.7	11.8	14.0
	900	0.1	0.2	0.5	0.9	1.4	2.2	3.1	4.3	5.6	7.0	8.7	10.5	12.5
	1000	0.1	0.2	0.5	0.8	1.2	2.0	2.8	3.8	5.0	6.3	7.8	9.4	11.2

13.3.3.3 Sight Distance on Vertical Curves

Sight distance on vertical curves is required so that bicyclists see objects on the path over the crest of vertical curves or obstacles that are located beyond overhanging visual obstructions on sag vertical curves. The method of calculating sight distance for bicyclists on vertical curves is essentially the same as that used for calculating the sight distance for motorists (Refer to Section Chapter 6 of this Guide); however, the user's eye height and object height need to be modified for bicycle-specific values. Stopping sight distance is measured when the eye height and the height of the object are 4.5 feet (for a typical bicycle rider) and 0 feet (flush with the pavement surface), respectively.

When S is less than L,

$$S = 30\sqrt{\frac{L}{A}}$$

When S is greater than L,

$$S = \frac{L}{2} + \frac{2025}{A}$$

Where,

S = stopping sight distance (ft)
L = length of crest vertical curve (ft)
A = algebraic difference in grades (%)

Table 13-7 is used to select the minimum length of vertical curve necessary to provide minimum stopping sight distance at various speeds on crest vertical curves (Figure 13-39). Note that this table is for regular bicycles. For recumbent bicycles, the values would need to be recalculated using equations 3-14 and 3-42 in the 2018 AASHTO GDHS (AASHTO, 2018).

Figure 13-39 Sight Distance on Crest Vertical Curves

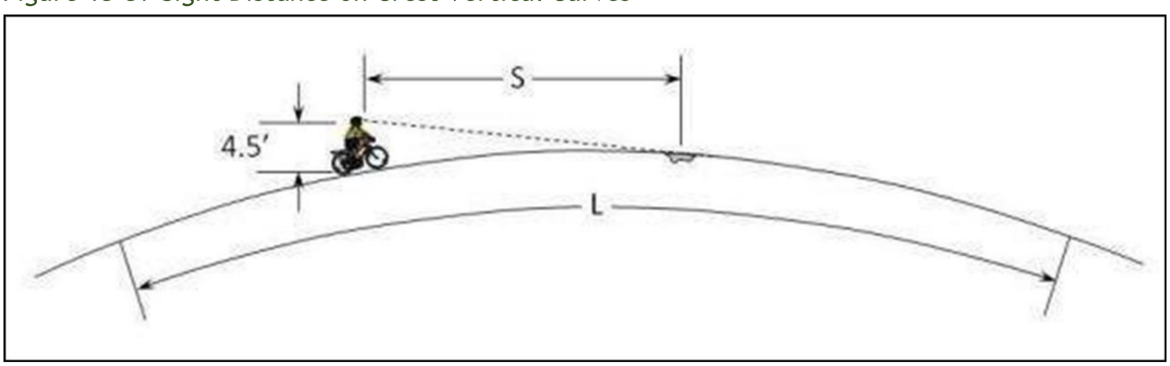


Table 13-7 Minimum Length of Crest Vertical Curve Based on Stopping Sight Distance

A (%)	S = Stopping Sight Distance (ft)														
	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300
2												30	70	110	150
3								20	60	100	140	180	220	260	300
4						15	55	95	135	175	215	256	300	348	400
5					20	60	100	140	180	222	269	320	376	436	500
6				10	50	90	130	171	216	267	323	384	451	523	600
7				31	71	111	152	199	252	311	376	448	526	610	700
8			8	48	88	128	174	228	288	356	430	512	601	697	800
9			20	60	100	144	196	256	324	400	484	576	676	784	900
10			30	70	111	160	218	284	360	444	538	640	751	871	1000
11			38	78	122	176	240	313	396	489	592	704	826	958	1100
12		5	45	85	133	192	261	341	432	533	645	768	901	1045	1200
13		11	51	92	144	208	283	370	468	578	699	832	976	1132	1300
14		16	56	100	156	224	305	398	504	622	753	896	1052	1220	1400
15		20	60	107	167	240	327	427	540	667	807	960	1127	1307	1500
16		24	64	114	178	256	348	455	576	711	860	1024	1202	1394	1600
17		27	68	121	189	272	370	484	612	756	914	1088	1277	1481	1700
18		30	72	128	200	288	392	512	648	800	968	1152	1352	1568	1800
19		33	76	135	211	304	414	540	684	844	1022	1216	1427	1655	1900
20		35	80	142	222	320	436	569	720	889	1076	1280	1502	1742	2000
21		37	84	149	233	336	457	597	756	933	1129	1344	1577	1829	2100
22		39	88	156	244	352	479	626	792	978	1183	1408	1652	1916	2200
23		41	92	164	256	368	501	654	828	1022	1237	1472	1728	2004	2300
24	3	43	96	171	267	384	523	683	864	1067	1291	1536	1803	2091	2400
25	4	44	100	178	278	400	544	711	900	1111	1344	1600	1878	2178	2500

The primary control for designing sag vertical curves for roadways is the limitations of headlamp lighting at night. This control is reasonable for cars because they are required to have operating headlamps, and headlamps are typically adjusted with a reasonable degree of consistency. Bicyclists riding between sunset and sunrise are required to have a headlamp so that the bicyclists are visible to other roadway users (FHWA, 2006). There is a wide variety of headlamp designs, and the light they provide for bicyclists to see the path in front of them is widely variable. Consequently, using headlamp limitations as a design control is not practical for shared-use paths.

A sag curve on a shared-use path must be designed so that it provides the minimum stopping sight distance described for in Section 13.3.3.1. In most cases, meeting these criteria is not problematic. One common exception is when a path is depressed through an undercrossing. In this case, sight distances should be checked to ensure that any overhanging structure does not limit the stopping sight distance to less than what is required.

13.3.3.4 Sight Distance at Intersections

The discussion on intersection sight distance in Chapter 8 of this Guide is also applicable to shared-use paths. Also applicable are the procedures to determine sight distances at intersections presented in Chapter 8 of the 2018 AASHTO GDHS (AASHTO, 2018), using the appropriate design speed for the shared-use path approaches to the intersection, for each of the cases below:

- Case A - Intersections with no control (not typically used on shared-use paths).
- Case B - Intersections with stop control on the minor road.
- Case B3 – Crossing maneuver from the minor road.
- Case C – Intersections with yield control on the minor road.
- Case C1 – Crossing maneuver from the minor road.
- Case D – Intersections with traffic signal control.

Checking the sight distances for vehicles turning onto or off of the shared-use path is typically not necessary. The minor roadway may be either the shared-use path or the roadway.

13.3.4 Shared-Use Path Width

The minimum width of pavement for a two-directional shared-use path is 10 feet.

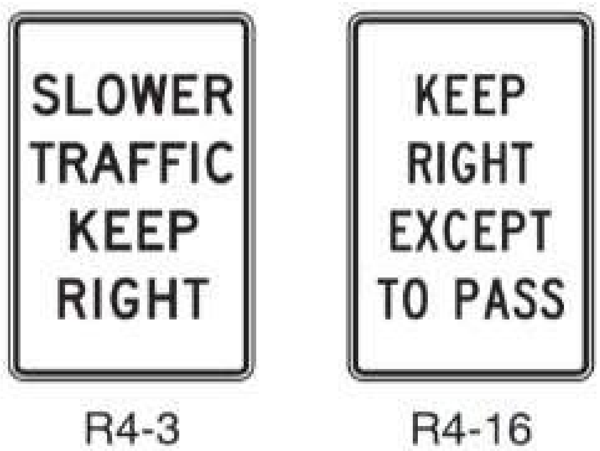
Additional width may be appropriate depending on the volume of users and mix of users on the shared-use path. The FHWA has developed a level of service shared-use path calculator that may be helpful in determining the appropriate width for a path based on the relative number of users expected (FHWA, 2006) (MUTCD). Pathways of up to 14 feet are recommended in locations that are anticipated to have high volumes (greater than 300 users in the peak hour), or with a high percentage of pedestrians (greater than 30%). An 11-foot shared-use path allows a bicyclist to pass another traveling in the same direction at the same time someone is approaching from the opposite direction (FHWA, 2006). Wider paths should be considered where there is expected significant use by in-line skaters, hand cyclists, adult tricyclists (FHWA, 2004), or on steep grades and through curves.

A minimum shared-use path width of 8 feet may be used only for short sections of constrained conditions and where the following conditions apply:

- Bicycle traffic is expected to be low, even on peak days or during peak hours
- Pedestrian use of the facility is not expected to be more than occasional
- Horizontal and vertical alignments provide safe and frequent passing opportunities
- The path is not regularly subjected to maintenance vehicle loading conditions that would cause pavement edge damage.

In most cases, it is not necessary to designate separate spaces for different users on shared-use paths. Slower path users tend to keep right while higher speed users pass on the left. If additional encouragement is necessary, PATH USER POSITION (R4-3 or R4-1) signs may be installed to remind users of this required behavior (refer to Figure 13-40) (U.S. Access Board, 2007).

Figure 13-40 Path User Position Signs



In cases where there are high path volumes it may be appropriate to separate directions on the path with a yellow centerline stripe. In areas with adequate sight distance a broken line (3-foot segment with a 9-foot gap) may be provided.

On the approach to conflict points, substandard curves, locations where sight distances cannot be maintained, or other potential hazards, a single solid yellow centerline stripe and an appropriate sign should be installed. The solid stripe should extend a distance at least equal to the stopping sight distance in advance of the conflict point or hazard.

Where users are split onto separate paths, mode specific guide signs should be used to denote the preferred path for each user type (Figure 13-41). SELECTIVE EXCLUSION signs (U.S. Access Board, 2007) can be used to indicate where various users are not permitted (Figure 13-42).

Figure 13-41 Selective Exclusion Signs

Figure 13-42 Mode Specific Guide Signs

13.3.5 Cross Slope

The cross slope of a shared-use path must be designed so that rain and snow melt drain from the pavement surface. Consequently, a minimum cross slope of 1% should be maintained on shared-use paths. Shared-use paths are not typically crowned; a uniform cross slope is maintained across the path.

Because shared-use paths are intended to be used by pedestrians and persons with disabilities, they must comply with the cross slope requirements of the ADA. Therefore, the maximum cross slope for a shared-use path is 2%.

13.3.6 Clearances

Just as minimum clear recovery areas and clear zones to obstructions are provided for roadways, horizontal clearance is required to signs, poles, drop-offs and other path-side obstructions and hazards.

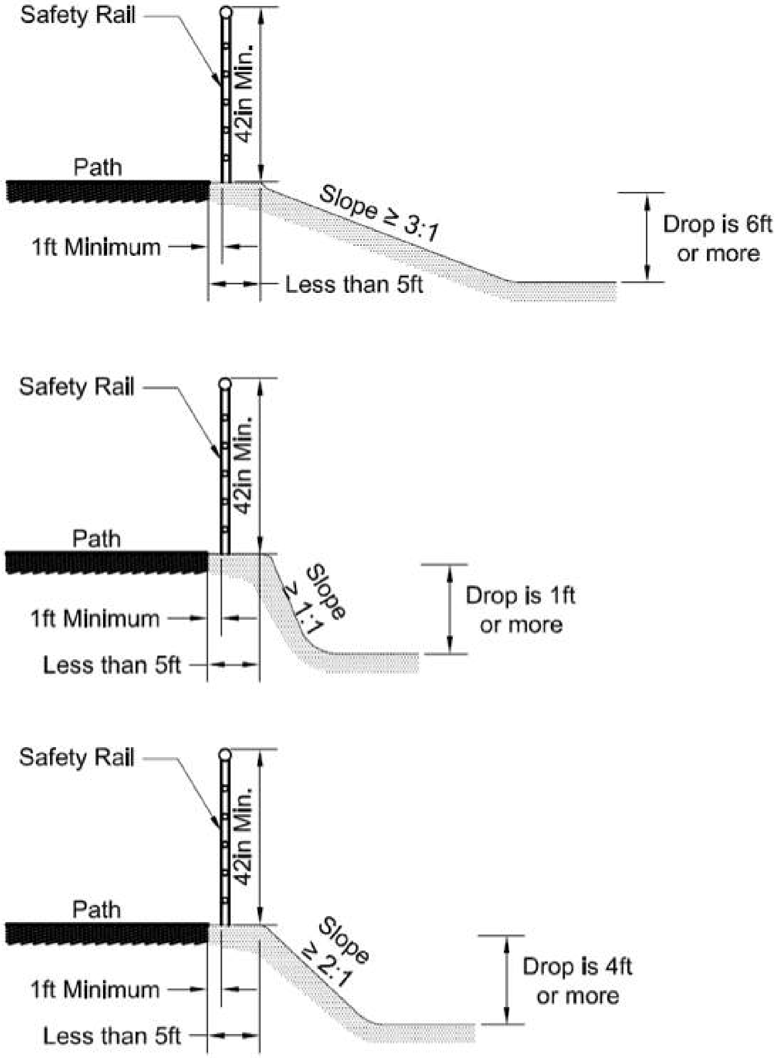
Where practical, a graded shoulder free of obstructions at least 3 feet wide with a maximum cross slope of 6:1 should be maintained on each side of the shared-use path pavement. Under constrained conditions, minimum clear space of 2 feet should be provided to vertical obstructions. If a smooth protective railing is provided, this clearance may be reduced to 1 foot. Where minimum clearance cannot be provided to obstructions, path users should be warned of the upcoming obstruction. Warnings for lateral obstructions can include warning signs, edge line striping, lighting, reflectors, or a combination thereof. When a barrier, railing, or fence is a vertical obstruction, the barrier should be flared so the approach end is at least 3 feet from the edge of the path.

Embankments and sheer drop-offs are particularly hazardous to shared-use path users. If possible, a 5-foot separation should be provided to embankments with slopes greater than 4:1 and drop-offs. Where this separation cannot be maintained, a suitable barrier such as a railing or fence should be provided at the top of the slope. Specifically, barriers should be placed to separate shared-use paths from embankments and drop-offs under the following conditions (refer to Figure 13-43):

- Slopes 3:1 or steeper, with a drop of 6 feet or greater.
- Slopes 2:1 or steeper, with a drop of 4 feet or greater.
- Slopes 1:1 or steeper, with a drop of 1 foot or greater.
- Slopes 3:1 or steeper, adjacent to a parallel water hazard, roadway, or other obvious hazard.

When used, barriers next to a shared-use path shall be a minimum of 42 inches high.

Figure 13-43 Conditions Where Barriers to Embankment are Recommended



Openings between horizontal or vertical members on railings should be small enough that a 4-inch sphere cannot pass through them in the lower 27 inches. For the portion of railing that is higher than 27 inches, openings may be spaced such that an 8-inch sphere cannot pass through them. This specification is to prevent children from falling through the openings.

Some Colorado jurisdictions require a rub rail at a height where a bicyclist's handlebar may come into contact with a railing or barrier. A rub rail is a smooth surface installed at a height of 36 inches to 48 inches to reduce the likelihood that a bicyclist's handlebars are caught by the railing. Local requirements should be consulted.

The minimum vertical clearance to obstructions is 100 inches, the operating height for a bicyclist.

13.3.7 Horizontal Alignment of Shared-Use Paths

The discussion of horizontal alignment provided in Chapter 6 is also applicable to shared-use paths. Typically, simple horizontal curves should be used on shared-use paths.

Because a shared-use path is also a pedestrian facility, paths must be designed to be compliant with the applicable sections of the ADA. Consequently, the maximum superelevation allowed on a shared-use path is 2%. If separate pathways for pedestrians and bicyclists are provided, the superelevation allowed for the bicycle path may be increased up to 8%.

The minimum radius recommended for shared-use paths is provided in Table 13-8. If the minimum curve radius cannot be met, a centerline stripe and TURN or CURVE WARNING sign (W1 series) shall be installed.

The AASHTO *Guide for the Development of Bicycle Facilities* (AASHTO, 2012) provides an alternative method for calculating minimum radii, which may yield a smaller required radius. It is based upon the lean angle of a bicycle.

Table 13-8 Minimum Radii and Superelevation for Bicycle Only Paths

e	R (feet) for Design Speed (mph)								
(%)	8	10	12	14	16	18	20	25	30
-2.0	14	22	33	47	64	85	109	192	316
-1.5	14	22	33	46	63	83	107	188	308
0.0	13	21	31	44	60	79	101	176	286
1.5	12	20	30	42	57	74	96	165	267
2.0	12	20	29	41	56	73	94	162	261
2.2	12	20	29	41	55	73	93	161	259
2.4	12	19	29	41	55	72	93	160	256
2.6	12	19	29	40	55	72	92	158	254
2.8	12	19	29	40	54	71	91	157	252
3.0	12	19	28	40	54	71	91	156	250
3.2	12	19	28	40	54	70	90	155	248
3.4	12	19	28	40	53	70	89	154	246
3.6	12	19	28	39	53	69	89	153	244
3.8	12	19	28	39	53	69	88	151	242
4.0	12	19	28	39	52	69	88	150	240
4.2	11	19	27	39	52	68	87	149	238
4.4	11	18	27	38	52	68	87	148	236
4.6	11	18	27	38	51	67	86	147	234
4.8	11	18	27	38	51	67	85	146	233
5.0	11	18	27	38	51	66	85	145	231
5.2	11	18	27	37	51	66	84	144	229
5.4	11	18	27	37	50	66	84	143	227
5.6	11	18	26	37	50	65	83	142	226
5.8	11	18	26	37	50	65	83	141	224
6.0	11	18	26	37	49	64	82	140	222
f = Friction Factor	0.33	0.32	0.31	0.30	0.29	0.28	0.26	0.24	0.21

13.3.8 Vertical Alignment of Shared-Use Paths

Where technically feasible, the maximum continuous grade on a shared-use path should be limited to 5%. Where right of way, topography, or geometric constraints make the provision of a continuous grade less than 5% impractical, grades should be minimized.

Where potential grades exceed 5%, intermittent level resting intervals should be considered. Where provided, resting intervals shall be full width of the shared-use path and 60 inches long. Alternatively, a 36-inch-wide resting interval may be located adjacent to the shared-use path. Recommended maximum distance between resting areas is 200 feet.

Shared-use paths located along roadways may follow the grade of the road. Where grades exceed 5%, resting intervals should be provided.

Where sustained grades exceeding 4% in excess of 300 feet in length are required, an increased design speed should be used. Additionally, consider providing the following mitigating measures:

- HILL WARNING signs (W7-5) (Figure 13-44).
- Wider clear recovery areas adjacent to the shared-use path
- An additional 6 feet of width to allow some users to dismount and walk their bicycles.

Figure 13-44 Bicycle Hill Warning Sign

Alternatively, consider installing a series of switchbacks to reduce the longitudinal grade.

Except for ramps on structures, transitions between grades with more than 2% algebraic difference should be made with vertical curves. The minimum length for a vertical curve on a shared-use path is 3 feet.

On unpaved shared-use paths, grades greater than 3% are not recommended. Grades exceeding 3% can create maintenance (erosion) problems and cause bicycle handling problems for some bicyclists.

In flat terrain, the grade of the shared-use path may be controlled by drainage considerations.

13.3.9 Intersections with Shared-Use Paths

The background information provided in Chapter 8 of this Guide is applicable to intersections of shared-use paths with roadways or other shared-use paths.

The fundamental design of intersections requires that users be able to:

- Perceive the intersection and the potential conflicts
- Understand their obligations to yield
- Fulfill the obligation to yield

The design criteria in this section are intended to support these three fundamental concepts.

When designing shared-use path intersections, the sight distance criteria provided in Section 13.3.3.4 and Chapter 8 of this Guide are applicable. Only the design speeds of the intersecting approach legs - using the bicycle as a design vehicle for pathway approaches - are adjusted when applying these criteria to shared-use paths.

At shared-use path intersections with roadways or with other shared-use paths, one facility should be given priority over the other. Four-way stop control should not be used at intersections of shared-use paths.

According to the MUTCD,

> When placement of STOP or YIELD signs is considered, priority at a shared-use path/roadway intersection should be assigned with consideration of the following:
>
> A. Relative speeds of shared-use path and roadway users;
>
> B. Relative volumes of shared-use path and roadway traffic; and
>
> C. Relative importance of shared-use path and roadway.
>
> Speed should not be the sole factor used to determine priority, as it is sometimes appropriate to give priority to a high-volume shared-use path crossing a low-volume street, or to a regional shared-use path crossing a minor collector street.
>
> When priority is assigned, the least restrictive control that is appropriate should be placed on the lower priority approaches. STOP signs should not be used where YIELD signs would be acceptable.

The primary consideration in the assignment of traffic control type (STOP rather than YIELD signs) at intersections is the availability of adequate sight distance for approaching users. If sight triangles cannot be maintained to provide for yield control, STOP signs must be used. A detailed discussion of sight triangles is provided in Section 13.3.9.1.

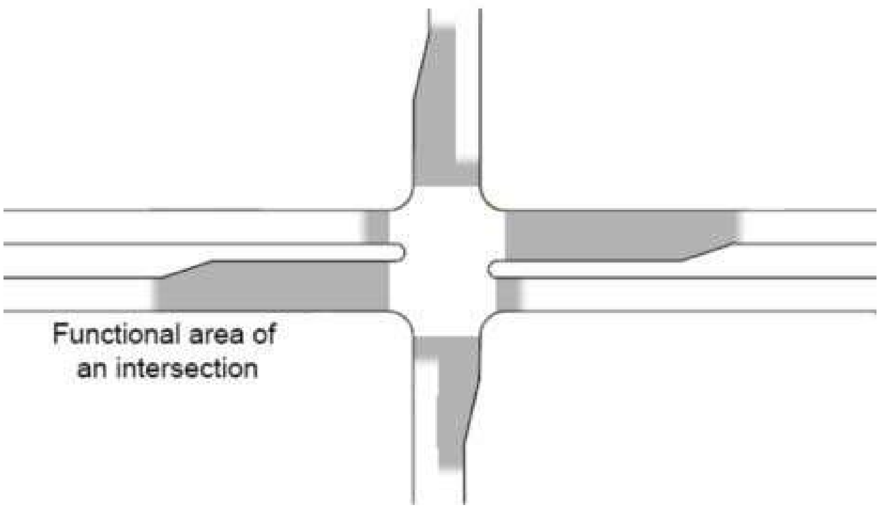
Where a shared-use path crosses a roadway, detectable warnings shall be installed. Where two shared-use paths intersect, the approach that is required to yield the right of way should have detectable warnings installed.

Roundabouts can be used at the intersection of two shared-use paths. A minimum width of 8 feet should be maintained around the circulating pathway. Splitter islands and central islands on roundabouts for shared-use paths should be curbed.

Traffic control for shared-use path approaches to intersections is provided in Section 13.3.9.2.

Intersections of shared-use paths with roadways should be located outside of the functional area of the intersection of two roadways (Figure 13-45). If a shared-use path crosses a roadway within the functional area of an intersection, the path should either be diverted to outside the functional area of the intersection or moved to the intersection and treated as a side path crossing (refer to Section 13.3.13.1).

Figure 13-45 Functional Area of an Intersection



Traffic signals can be warranted where shared-use paths cross roadways, based on any of the nine warrants described in the MUTCD. For the School Crossing and Pedestrian Volume warrants, all path users may be counted as pedestrians. For the Eight-Hour Vehicular Volume, Four-Hour Vehicular Volume, and Peak Hour warrants, only bicycles are counted as vehicles on the path approaches.

Where signals are installed for shared-use paths, signal timing shall accommodate the needs of bicyclists and pedestrians.

13.3.9.1 Required Sight Triangles at Shared-Use Path Intersections

The decision to use a STOP sign as opposed to a YIELD sign is primarily determined by the available sight distance required for bicyclists at the intersection.

The procedures to determine sight distances at intersections presented in Chapter 9 of the 2018 AASHTO GDHS (AASHTO, 2018) apply to bicycle facilities and roadways. In this section, the requirements for each of the following cases is discussed for both stop and yield control:

- Case B3 – Stop Controlled crossing maneuver from the minor road.
- Case C1 – Yield Controlled crossing maneuver from the minor road.

For Case B3 where the path is under stop control, the required sight distance at the intersection is a function of the time it takes the slowest design user to cross the street or cross to a refuge island in the middle of a divided roadway. In most cases the slowest design user is the pedestrian.

However, since shared-use path crossings of roadways are almost always marked with crosswalks, the sight distance must allow for a motorist to observe and yield to a pedestrian approaching and crossing at the shared-use path-roadway intersection. To calculate the required sight triangle, it should be assumed the pedestrian is standing behind the shared-use path yield or stop line.

For Case B3 where the road is under stop control, the sight distance should be calculated as provided in the 2018 AASHTO GDHS (AASHTO, 2018) using the shared-use path design speed as the speed on the major road. By applying equation 9-1 from the 2018 AASHTO GDHS:

$$ISD = 1.47V_{path}t_g$$

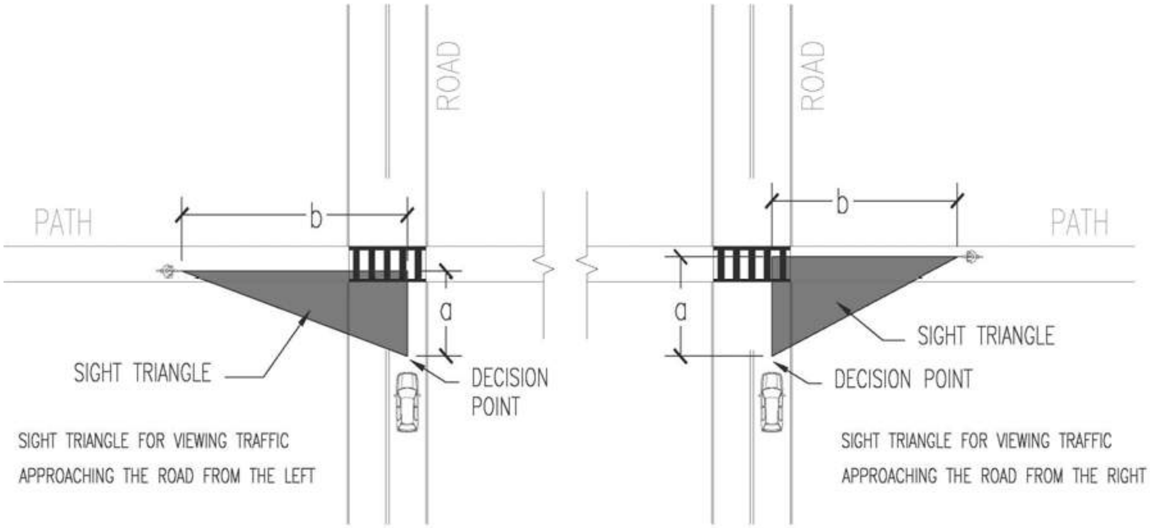
Where,
ISD = intersection sight distance (ft)
V_{path} = design speed of path (mph)
t_g = time gap for minor road vehicle to enter and cross path (sec)

The 2018 AASHTO GDHS provides a time gap (t_g) of 6.5 seconds for passenger cars, 8.5 seconds for single-unit trucks, and 10.5 seconds for a combination truck to cross a two-lane roadway based upon observational studies. Consequently, they are conservative for crossing of most shared-use paths. However, on multilane roadways where advance STOP or YIELD lines are used, additional time should be allowed, as follows: 1.3 seconds additional for a 30-foot advance line and 1.8 seconds for a 50-foot advance line for passenger cars (2.1 seconds and 2.9 seconds for trucks, respectively).

Additionally, where approach grades exceed 3%, add 0.1 second for each percent grade.

The clear sight triangle is that space that should be kept free of obstructions that might block approaching driver’s view of any potentially conflicting path users. Figure 13-46 illustrates the needed dimensions for calculating the sight triangle for Case B3 where motorists are required to stop. Table 13-9 provides the values for those dimensions.

Figure 13-46 Illustration of Intersection Sight Triangle Dimensions



Case B3, Motorist Required to Stop

a = assumed distance to driver's eye
b = intersection sight distance

Table 13-9 Intersection Sight Distance

--	Intersection Sight Distance for Passenger Cars (distance *b*)		
--	Distance to Stop Bar		
Design Speed of Path (mph)	**4 feet**	**30 feet**	**50 feet**
8	80	95	100
10	100	115	125
12	115	140	150
14	135	165	175
16	155	185	200
18	175	210	220
20	195	230	245
25	240	290	310
30	290	345	370
Assumed distance to driver's eye (distance *a*)	14.5 feet	40.5 feet	50.5 feet

For Case C3 where the path is under yield control, sight triangles are calculated assuming that the yielding approaches will decelerate to 60% of the design speed on the approach to the intersection and that the approaches with priority will not decelerate. Sight distances are calculated based upon the time taken for the vehicle on the minor road to cross the intersection. The travel time to reach and clear the major road from the decision point on the minor approach is calculated using the following equations:

$$t_g = t_a + \frac{w + L_a}{0.88V_{minor}}$$

Where,

$$t_a = \frac{1.47(V_{minor} - V_r)}{a_m}$$

and

t_g = time gap for minor road vehicle to reach and clear the major road (sec)
t_a = travel time for minor road vehicle to reach the major road while decelerating (sec)
w = width of intersection to be crossed (ft)
L_a = length of design vehicle (ft)
V_{minor} = design speed of minor facility (mph)
V_r = reduced speed of minor approach (60% design speed)(mph)
a_m = acceleration rate assumed for minor approach (assume 5 ft/sec/sec)
The length of the sight triangle along the major approach is calculated using the equation:

$$b = 1.47V_{major}t_g$$

where,
b = sight distance required along major approach (ft)
V_{major} = design speed of major facility (mph)

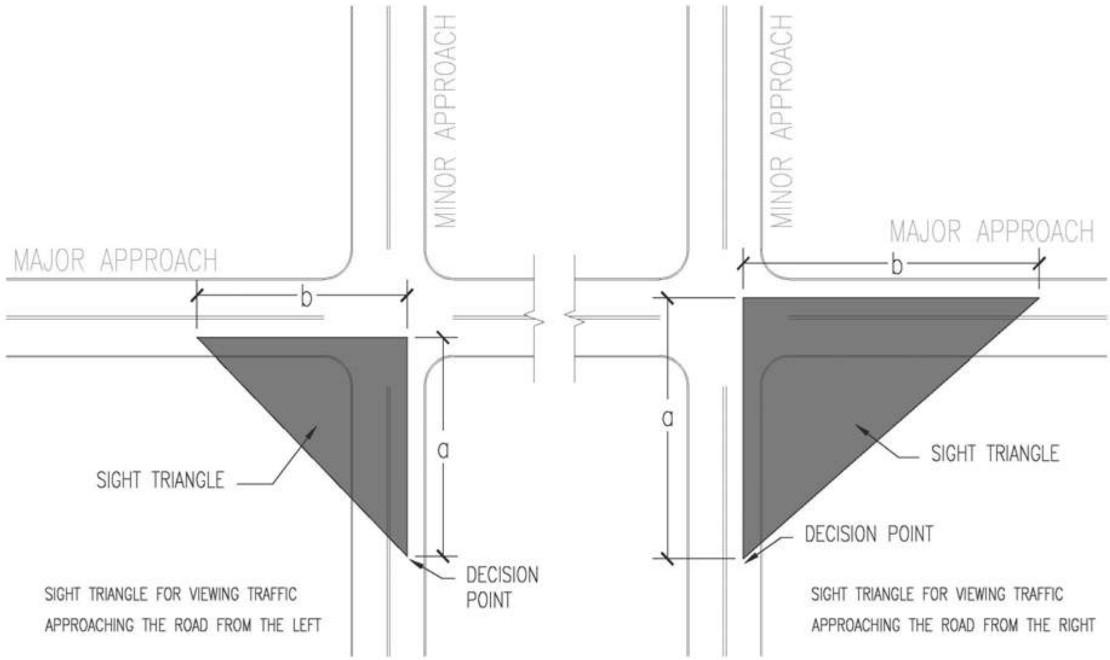
The sight distance required along the minor approach (a) can be obtained from Table 13-10.

Table 13-10 Required Sight Distance for Minor Leg of Yield Control

Design Speed of Minor Leg (mph)	Sight Distance (ft)
12	62
14	71
16	80
18	90
20	100
25	130
30	160
35	195
40	235
45	275
50	320
55	370

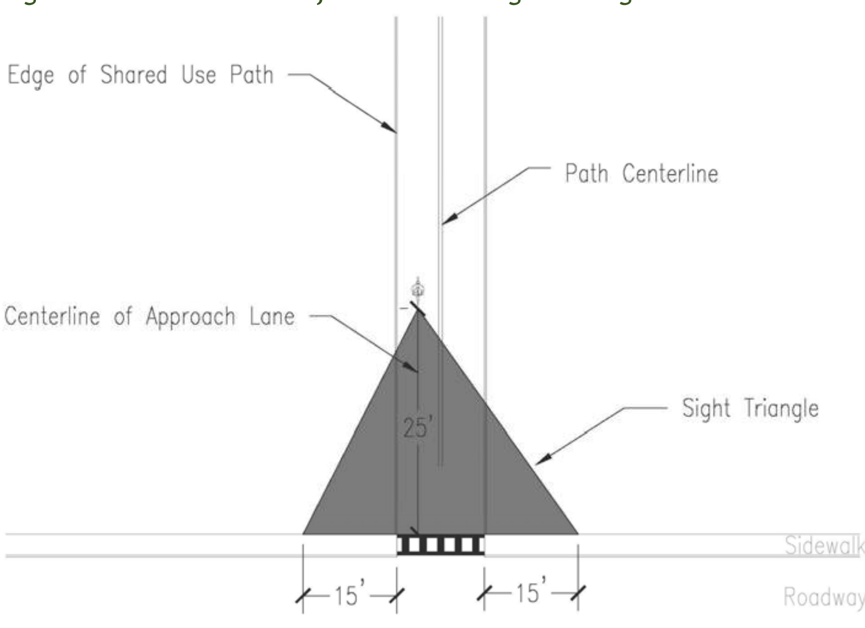
Figure 13-47 illustrates the dimensions for yield control intersections. Users are not shown on the graphic because either approach (major or minor) could be the shared-use path.

Figure 13-47 Illustration of Intersection Sight Triangle Dimensions Case C3, Yield Condition



Where a shared-use path approaches a walkway and is required to stop, the legs of the sight triangle should extend 25 feet back from the edge of the sidewalk along the shared-use path, and 15 feet back from the edge of the shared-use path along the sidewalk (Figure 13-48).

Figure 13-48 Illustration of Intersection Sight Triangle Dimensions Path Approaching Sidewalk



13.3.9.2 Traffic Control at Intersections with Shared-Use Paths

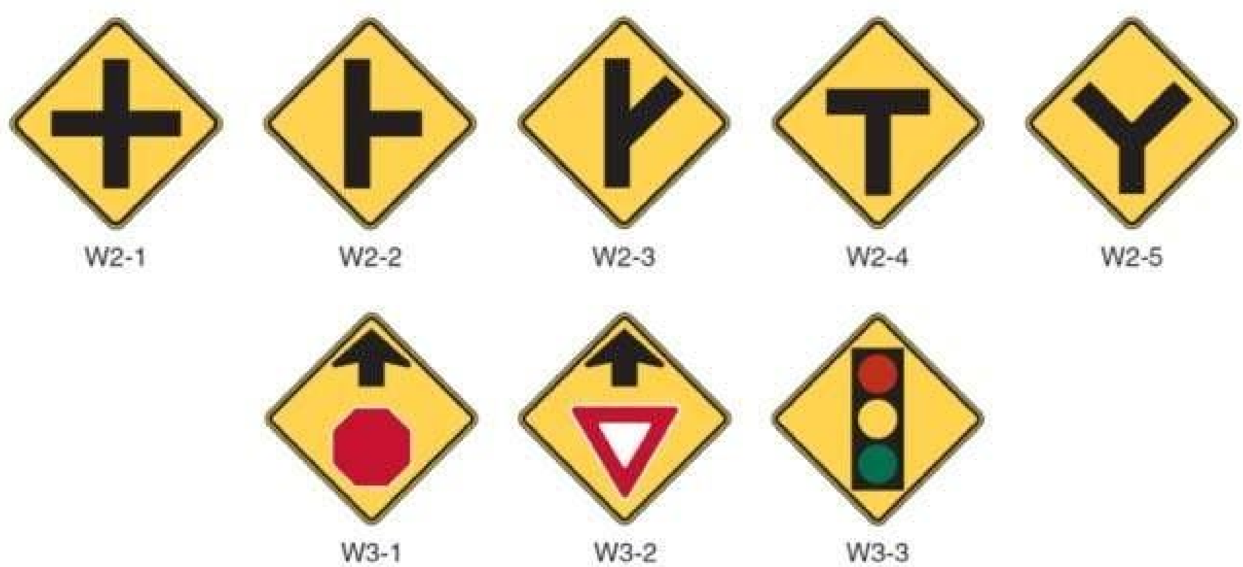
The traffic control provided on shared-use paths at intersections with other paths or roadways is similar to that provided at the intersection of two roadways.

STREET NAME signs (D1-3) should be included for shared-use path users.

On the approach to any intersection, a solid yellow centerline should be striped on the approach to the intersection for a distance equal to the stopping sight distance of the shared-use path.

An INTERSECTION WARNING (W2 series) or ADVANCE TRAFFIC CONTROL (W3 series) sign may be used on a roadway, street, or shared-use path in advance of an intersection to indicate the presence of an intersection and the possibility of turning or entering traffic. However, these signs are not required unless the engineering judgment determines that the visibility of the intersection is limited on the shared-use path approach to the intersection. When deciding whether to install advance signs, the designer should ensure that intersections and intersection traffic control are visible from at least the stopping sight distance in advance of the intersection. Figure 13-49 shows W2 and W3 series signs.

Figure 13-49 Intersection Warning (W2 Series) and Advance Warning Signs (W3 Series) Signs



Where the shared-use path user is to yield or stop (with either a STOP sign or a signal) at the intersection, YIELD signs and YIELD lines or STOP signs and STOP lines shall be installed on the path approach to the intersection. YIELD or STOP lines shall be placed 4 feet in advance of the intersecting travel way or sidewalk.

For signal control intersections, bicycle detection and push buttons for pedestrians should be installed on the path approaches.

On the motor vehicle approach, signing and striping vary depending on which facility is given priority at the intersection. If the path is given priority at the intersection, then the roadway approaches should be signed and marked as they would be on the approach to any intersection with similar control (YIELD, STOP, or signal control). If the roadway is given priority at the intersection, traffic control appropriate for a midblock crossing must be installed (refer to Section 13.4.8 and Section 13.4.9). At trail crossings, the TRAIL CROSSING (W11-15 and W11-15p) sign assembly (Figure 13-50) should be used instead of the PEDESTRIAN CROSSING sign (W11-2).

Figure 13-50 Trail Crossing Assembly

At any activated crossing (e.g., a hybrid beacon), if the bicyclist is required to cross the roadway in stages, additional activation mechanisms (e.g., loops, video detection, radar, push buttons) must be placed in the median. Signing should be provided to make bicyclists aware of any requirement on their part to activate multiple crossings

13.3.9.3 Reducing Speeds on the Approach to Intersections

As stated in Section 13.2.8, users of intersections must be able to perceive a conflict, understand their obligation, and be able to fulfill their obligation to yield or stop. Slowing drivers and path users down on the approach to intersections can provide more time for users to perceive and understand their obligations.

Horizontal deflection on the approach to an intersection, either through a series of low design speed curves or a chicane (i.e., horizontal curvature), can be incorporated to reduce bicycle speeds. Examples of these geometric design techniques are provided in Figure 13-51 and Figure 13-52. Care should be taken to end chicanes at least 30 feet from bollards or intersecting sidewalks or roadways to allow the user to dedicate their attention to navigating the curves in the shared-use path first, followed by the approaching intersection (rather than simultaneously).

Figure 13-51 Chicane on Approach to Intersection

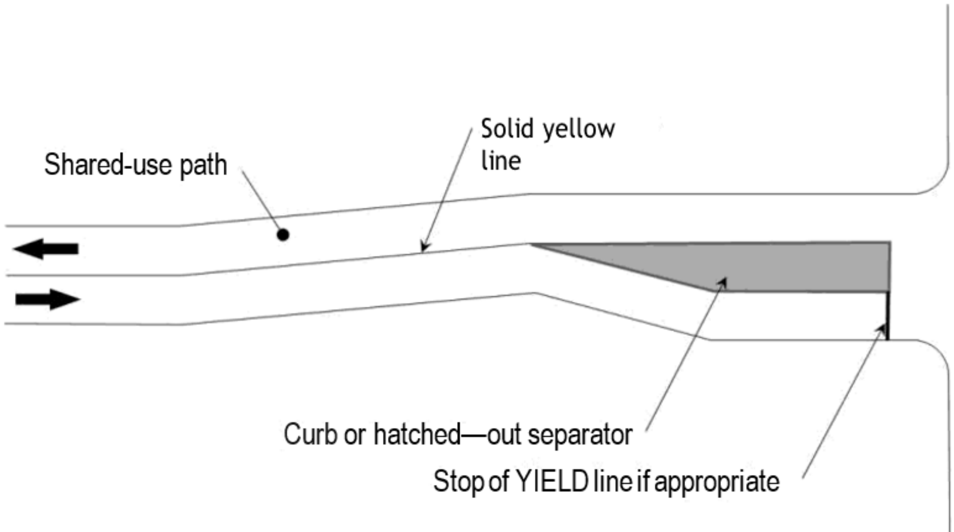
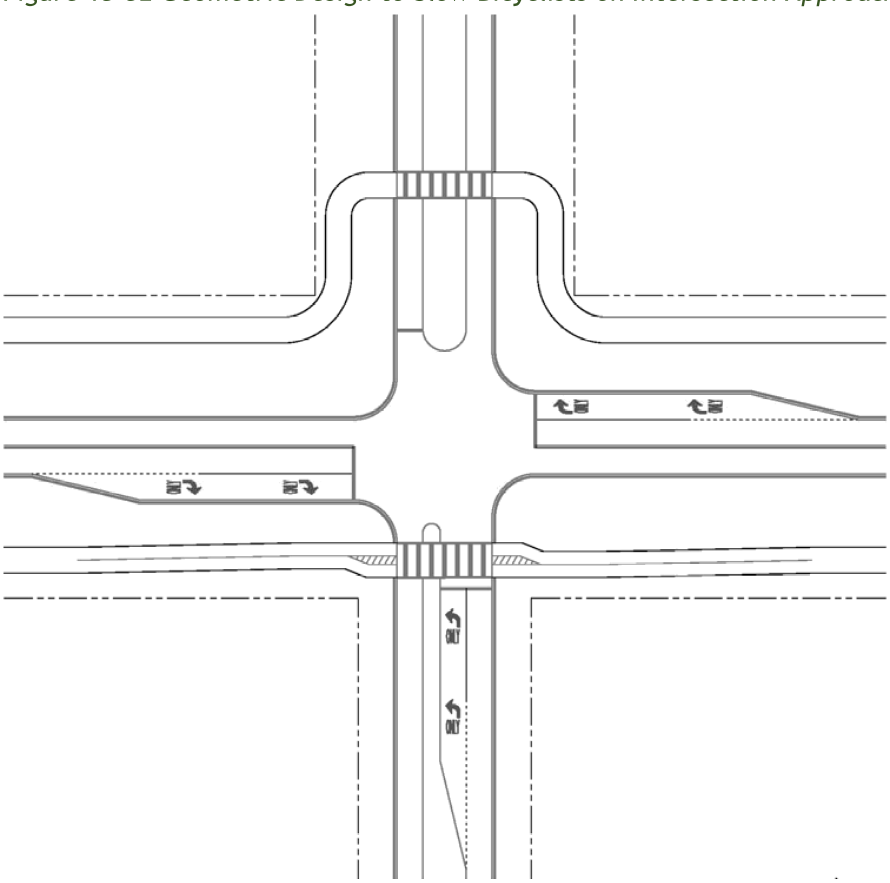


Figure 13-52 Geometric Design to Slow Bicyclists on Intersection Approaches



13.3.9.4 Curb Ramps

Where a shared-use path crosses a roadway, it is considered a pedestrian crossing location, and ADA-compliant curb ramps (if curbs are present) shall be installed. The width of the ramp, not inclusive of the flares or curb returns, must be the full width of the approach path. Refer to Section 13.3.9.4.

Detectable warnings shall be placed at the base of the curb ramps across the entire width of the ramps or across the entire width of the path on the approach to crossings where no curbs are present.

13.3.9.5 Prevention of Motor Vehicle Encroachment onto Shared-Use Paths

On some shared-use paths, encroachment by motor vehicles may be a concern. If the primary cause of encroachment is a lack of understanding on the part of the motorists of the non-motorized nature of the facility, consider the installation of NO MOTOR VEHICLES (R5-3) signs at the shared-use path access points (Figure 13-53).

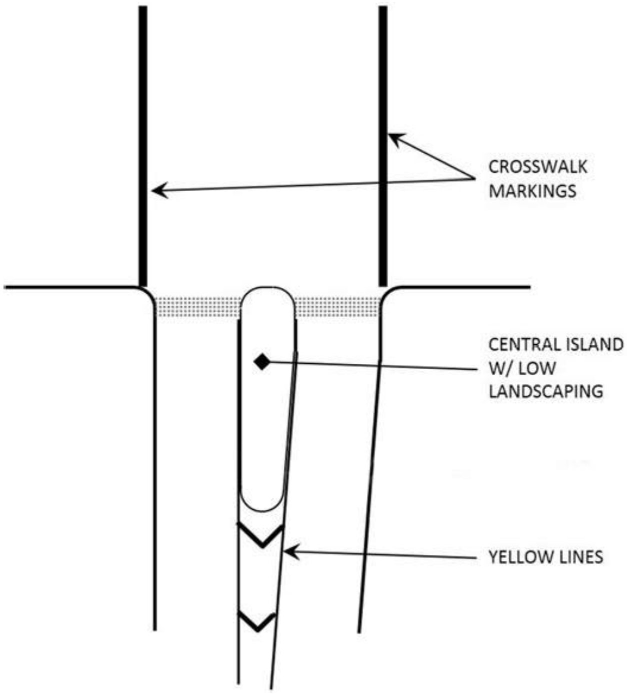
Figure 13-53 No Motor Vehicles Sign (R5-3)

Physical barriers can limit motor vehicle access to a shared-use path, but they are often ineffective in prohibiting access to motor vehicles. Motorists, and more frequently all-terrain vehicles, often go around or damage barriers intended to limit motor vehicle access. Barriers can, however, present obstructions to shared-use path users. Consequently, their use should be limited.

One method of discouraging access to motorists is the use of a low, central, dividing island on the shared-use path approach to intersections. Combined with tight curb radii, this method can be quite effective. The island should be designed so that emergency and maintenance vehicles can access the path by straddling the island. The width of the path on either side of the island should be at least 6 feet wide; in constrained conditions, the path may be narrowed to 5 feet wide on either side of the dividing island. Where divisional islands are provided, solid yellow lines are to be provided in advance of and on either side of the island.

Tight curb radii, such as 2 feet, at path-roadway intersections can reinforce the non-motorized nature of shared-use paths (Figure 13-54).

Figure 13-54 Example of Schematic Path Entry



If bollards are used to restrict motor vehicle access at intersections of roadways with paths, a 6-foot clear space should be provided between bollards. If more than one bollard is used, then an odd number of bollards should be used so that one bollard is in the center of the path. Obstruction striping shall be installed around the bollards. Around the *central* bollard, the obstruction striping shall be yellow to denote opposite directions of travel on either side of the bollard. Additional bollards shall have white obstruction markings (Figure 13-55). Solid lines on the approach to the bollard should extend a distance equal to the stopping sight distance in advance of the bollards.

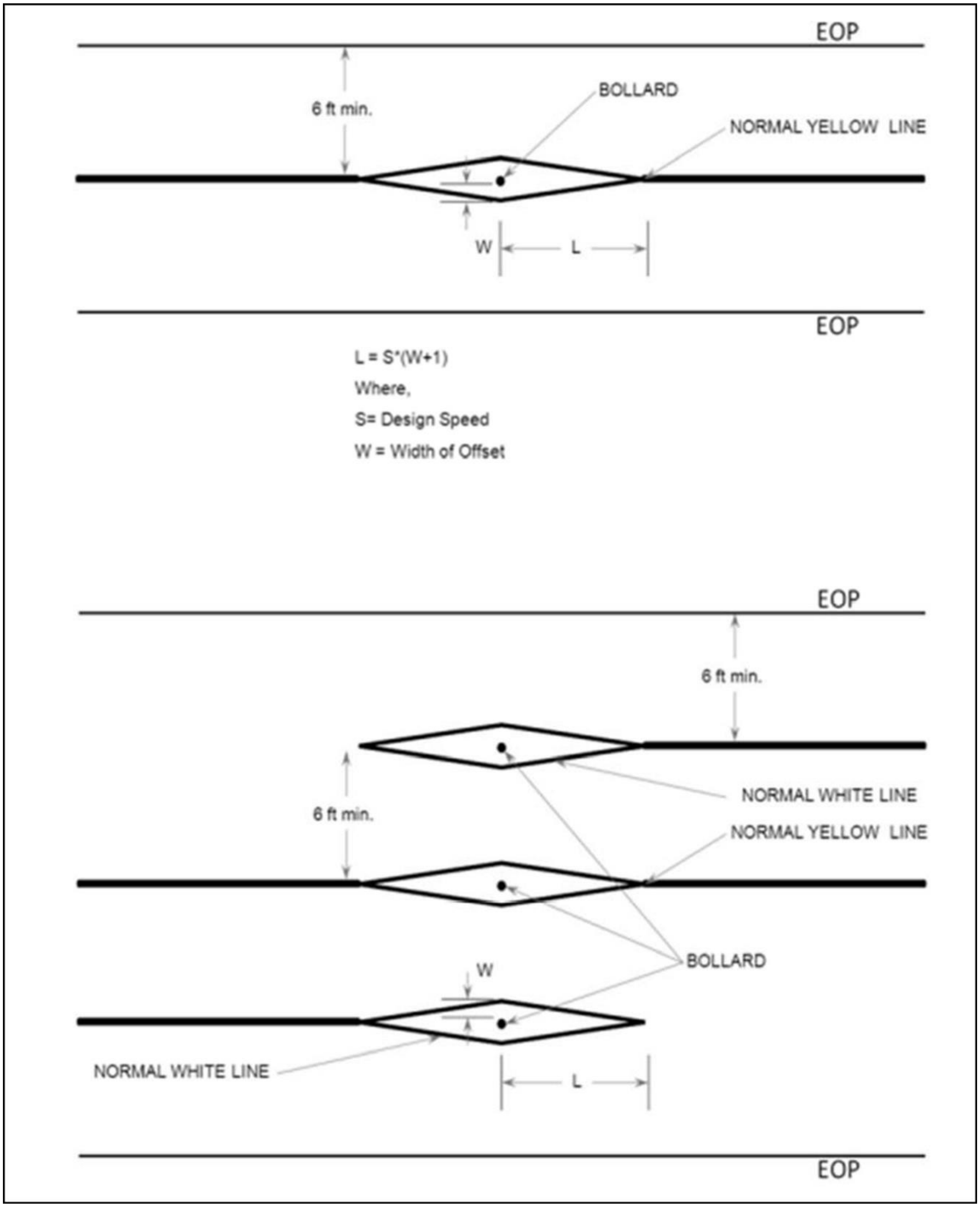
Directional arrows may be placed on the approach to the paths between the bollards to prevent confusion of path users. Where used, bollards shall be marked with retroreflective material on both sides or with the appropriate object marker, as shown in the MUTCD. In addition, bollards should be:

- Visible from a distance equal to or greater than the stopping sight distance.
- At least 40 inches high.
- Have a minimum diameter of 4 inches.
- Be set back 30 feet from the through lanes on the adjacent roadway.

If used, bollards shall be placed where motorized vehicles cannot easily bypass them.

Bollards should be installed so that they can be removed by emergency or maintenance personnel. Any hardware used to secure the bollard should be flush with the surface of the bollard or ground so as not to create an additional obstruction.

Figure 13-55 Obstruction Striping Around Bollards on Shared-Use Paths



13.3.10 Underpass and Overpass Structures

To maintain the continuity of a shared-use path, some structures may be required. When deciding between a tunnel and an overpass, the characteristics of each crossing should be considered before determining which structure is most appropriate. Each structure type has benefits and drawbacks that need to be considered for each individual location. Constraints such as right of way, topography, and utility conflicts may dictate whether an overpass or underpass is more appropriate.

Overpasses generally provide good visibility of surrounding areas which may lead to a greater sense of security, they are well lit during daylight hours, and they more easily accommodate drainage. Conversely, overpasses typically require a greater elevation change and may be more difficult for users to traverse, they are exposed to the elements, and speeds on the downward approaches can be hazardous.

Underpasses often exhibit contrasting characteristics to overpasses. They are protected from the elements and often require less ramping or changes in elevation, typically making them easier to traverse. Underpasses can have drainage challenges, utility conflicts, and may require construction phasing. Underpass design and layout should also consider user safety. Limited visibility through a closed structure may have a negative impact on user’s perception of personal safety. When an underpass is long, wider openings, additional width, or flared ends may be appropriate to improve natural lighting and visibility. Lighting may also be required within the underpass. Approaches and grades should be evaluated to provide the maximum possible field of vision towards the underpass.

13.3.10.1 Width and Clearance for Structures Serving Shared-Use Paths

All bridges and tunnels serving shared-use paths should carry the width of the approach path and the minimum clear space of 2 feet on each side of the path across the structure. Carrying the clear space across the structure provides maneuvering space for bicyclists to avoid pedestrians or stopped bicyclists, as well as necessary horizontal shy distance from railing, walls, or barriers.

If the full path width and clear space cannot be carried across a structure, railings with proper flared ends should be provided to reduce the path width on approaches (refer to Section 13.2.6).

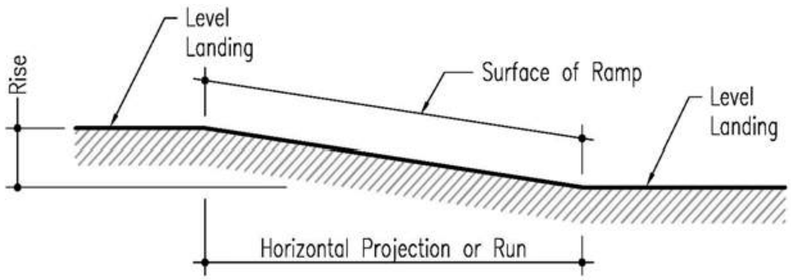
Access by emergency or maintenance vehicles should be considered when establishing the clearances of structures serving shared-use paths. Motor vehicles authorized to use the path may dictate the vertical and horizontal clearances.

A vertical clearance of 10 feet is desirable for enclosed structures and tunnels. If access for motor vehicles is not required, the minimum vertical clearance should be 8 feet under constrained conditions. Designers may want to consider providing 8.3 feet (100 inches), which is the operating height of a bicyclist, when on a shared-use path (AASHTO, 2012).

13.3.10.2 Grades on Structures Serving Shared-Use Paths

All structures serving shared-use paths must be ADA compliant. Cross slopes shall not exceed 2%. If approach grades exceed 5%, they shall be designed as ramps. Resting intervals measuring 60 inches in the direction of travel along the path and full width of the structure shall be provided a maximum of every 30 inches of rise. Refer to Figure 13-56.

Figure 13-56 Maximum Spacing of Resting Intervals on Shared-Use Path Structure Ramps



Slope	% Grade	Maximum Rise In.	Maximum Horizontal Projection Ft.
1:12 to > 1:16	8.33% to > 6.25%	30	30
1:16 to > 1:20	6.25% to > 5.00%	30	40

Components of a Single Ramp Run and Sample Ramp Dimensions

13.3.10.3 Railings on Structures Serving Shared-Use Paths

Railings on shared-use path structures shall be designed to comply with Section 13.3.6.

13.3.10.4 Railroad Crossings

Where possible, shared-use paths should be aligned to cross railroad tracks at near right angles. Where this cannot be accomplished and the crossing angle is less than 45 degrees, SKEWED CROSSING signs (W10-12) shall be placed on the path approaches to the rail crossing.

A railroad-path crossing, like a railroad-highway crossing, requires at-grade or grade-separated crossings. The horizontal and vertical geometrics of a path approaching an at-grade railroad crossing should be constructed in a manner that does not divert a path user's attention from path surface conditions.

The same types of crossing treatments used for roadway crossings of railroads can be used on shared-use paths, ranging from the required CROSSBUCK sign (R15-1) to full signals and gates.

Where active traffic control devices are not used, a CROSSBUCK ASSEMBLY shall be installed on each approach to a pathway grade crossing. The CROSSBUCK ASSEMBLY may be omitted at station crossings and on the approaches to a pathway grade crossing that are located within 25 feet of the traveled way of a highway-rail or highway-light-rail-transit grade crossing. Pathway grade crossing traffic control devices should be located a minimum of 12 feet from the center of the nearest track. If used at a pathway grade crossing, an active traffic control system shall include flashing-light beacons for each direction of the pathway. A bell or other audible warning device shall also be provided.

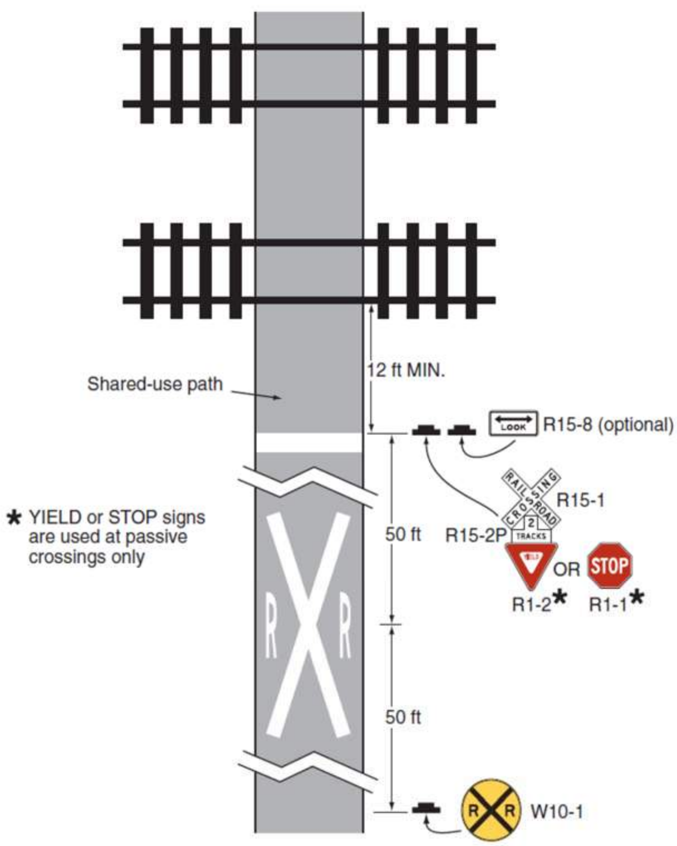
Advance pavement markings and signs shall be used on the approach to railroad crossings (Figure 13-57). The minimum sizes of pathway grade crossing signs shall be as shown in the shared-use path column in Table 9B-1 of the MUTCD.

If used, swing gates should open away from the tracks so that pathway users can quickly push the gate open when moving away from the tracks. If used, swing gates should automatically return to the closed position after each use.

To meet the requirements of Proposed Guidelines for Pedestrian Facilities in the Public Right-of-Way (PROWAG), path surfaces shall be flush with the tops of rails (U.S. Access Board, 2011). Openings for wheel flanges at path crossings of freight rail track shall be 3 inches maximum. Openings for wheel flanges at path crossings of non-freight rail track shall be 2.5 inches maximum.

It is recommended to coordinate early and often with the railroad owner to determine the appropriate and required design elements.

Figure 13-57 Example Signage and Markings at a Shared-Use Path Crossing of Railroad



13.3.10.5 Utilities

As discussed in Section 13.2.13.2, drainage structures and utility lids should not be placed in shared-use path. Where it is unavoidable, drainage grates should be of a bicycle friendly design, and utility covers should be flush with the surface of the path (refer to Section 13.2.13.2 for examples of bicycle-friendly grates).

Utilities that are higher than ground level, such as backflow preventers or valves, should be treated as vertical obstructions and addressed as discussed in Section 13.3.6.

13.3.10.6 Traffic Calming on Shared-Use Paths

In areas with frequent crossing conflicts with motor vehicles, it may be desirable to limit the path user's speed (refer to Section 13.3.2). Design features are recommended to reduce speeds on shared-use paths.

Signing is not an effective method for reducing speeds for two reasons: bicyclists, like motorists, operate at a speed they feel comfortable with on a facility, and most bicyclists do not have speedometers installed on their bicycle. Vertical traffic calming treatments (speed humps, tables, or pillows) are not recommended on shared-use paths because they are a safety hazard for bicyclists.

Horizontal alignment is the recommended method for reducing speeds on shared-use paths. A series of low design speed curves or a chicane along a path, much like those described in Section 13.3.9.3 can be used to reduce speeds at non-intersection areas. Advance striping and signage should supplement the trail calming features— either appropriate CURVE WARNING signs or a general text sign indicating that path is a reduced speed zone.

13.3.11 Wayfinding on Shared-Use Paths

The bicycle wayfinding signs described in Section 13.2.4 may be used on shared-use paths.

Additional wayfinding signing on shared-use paths is often appropriate. On independent alignment paths, information such as the distance between trail heads, or to the next water fountain or restroom facilities are important to path users. Much as Motorists Service signs provide expressway users information on what amenities are available at interchanges, signs may be appropriate to inform path users of the proximity of dining establishments, bike shops, or other destinations of particular interest to path users.

13.3.12 Shared-Use Paths Adjacent to the Roadway (Sidepaths)

The term sidepath refers to a shared-use path located immediately adjacent and parallel to a roadway. All design criteria associated with shared-use paths apply to sidepaths.

Ideally, shared-use paths are constructed in their own rights-of-way. However, in some cases a shared-use path may be designed adjacent to a roadway. Such cases might include:

- Where the public desires a low-stress facility to ride on adjacent to a busy or high-speed roadway
- As a temporary facility where a roadway cannot be modified to include bike facilities
- As a connecting facility along a longer shared-use path.

It is likely the last condition will be the one that most designers are requested to address. As discussed in Section 13.3.13, the perception of a sidepath as a low-stress facility does not necessarily equate to it being a safer facility. For reasons of safety or convenience, a sidepath may not be used by more traffic savvy bicyclists. A sidepath should not be considered a permanent alternative to an on-street facility; rather it should be considered as temporary or a supplemental facility to serve a specific design user type.

13.3.13 Safety Considerations of Sidepaths

Locating a sidepath immediately adjacent to a roadway can create operation concerns. The AASHTO *Guide for the Development of Bicycle Facilities* (2012) summarizes many of the problems that may occur in Section 5.2.2. The more prevalent concerns are:

- Unless separated, they require one direction of bicycle traffic to ride against motor vehicle traffic, contrary to normal rules of the road.
- When the path ends, bicyclists going against traffic tend to continue to travel on the wrong side of the street. Likewise, bicyclists approaching a shared-use path often travel on the wrong side of the street in getting to the path. Wrong-way travel by bicyclists is a major cause of bicycle/automobile crashes and should be discouraged at every opportunity.
- At intersections, motorists entering or crossing the roadway often do not notice bicyclists approaching from their right, as they are not expecting contra-flow vehicles. Motorists turning to exit the roadway may likewise fail to notice the bicyclist. Even bicyclists coming from the left often go unnoticed, especially when sight distances are limited.
- Signs posted for roadway users are backwards for contra-flow bike traffic; therefore, these cyclists are unable to read the information without stopping and turning around.
- When the available right of way is too narrow to accommodate all highway and shared-use path features, it may be prudent to consider a reduction of the existing or proposed widths of the various highway (and bikeway) cross sectional elements (e.g., lane and shoulder widths, etc.). However, any reduction to less than 2018 AASHTO GDHS criteria (or other applicable) design criteria must be supported by a documented engineering analysis.
- Many bicyclists use the roadway instead of the shared-use path because they have found the roadway to be more convenient, better maintained, or safer. Bicyclists using the roadway may be harassed by some motorists who feel that in all cases bicyclists should be on the adjacent path.
- Although the shared-use path should be given the same priority through intersections as the parallel highway, motorists falsely expect bicyclists to stop or yield at all cross streets and

driveways. Efforts to require or encourage bicyclists to yield or stop at each cross street and driveway are inappropriate and frequently ignored by bicyclists.

- Stopped cross street motor vehicle traffic or vehicles exiting side streets or driveways may block the path crossing.
- Because of the proximity of motor vehicle traffic to opposing bicycle traffic, barriers are often necessary to keep motor vehicles out of shared-use paths and bicyclists out of traffic lanes. These barriers can represent an obstruction to bicyclists and motorists.

Additional potential operational and design problems associated with sidepaths include the following:

- Because utilities are often located in the right of way, it can be difficult to meet clearance and radii requirements within the available space.
- In addition to traveling in a direction not expected by motorists exiting driveways or side streets, bicyclists riding on sidepaths are also traveling at speeds significantly greater than those of pedestrians. This makes them less likely to be seen by motorists exiting the side street who may be looking immediately to their right for pedestrians.
- If a sidepath is created in a location where there would otherwise be a sidewalk (i.e., a residential neighborhood or an urban commercial district), higher volumes of pedestrians are likely and thus conflicts with pedestrians are likely to increase. While this concern could be mitigated by widening the path, this may increase bicyclists' speeds in off-peak periods, exacerbating the problem of higher speed cyclists approaching conflict points.
- Most roadways have destinations on both sides of the roadway. Since a sidepath serves only one side of the road, this requires sidepath users to cross the roadway midblock to access their destinations or to cross at intersections and ride on a sidewalk (if available) on the opposite side of the road. The former, while not difficult on low volume, low speed streets can be difficult on higher volume, higher speed roadways where sidepaths are likely to be built. The latter may not be legal in some locations.
- The proximity of sidepaths to the roadway may result in bicyclists riding at night being subject to glare from approaching car headlamps. This can make it difficult for the bicyclist to see hazards on the trail surface.

Operational problems associated with the visibility of the path user by motorists are most likely to be more significant on higher-speed, higher-volume, multilane roadways where motorists are focused on the motor vehicle traffic in the travel lanes (TRB, 2006).

13.3.13.1 Potential Mitigation Measures to the Operational Challenges of Sidepaths

Despite the safety, operational, and design challenges with sidepath design, there are times when they are unavoidable. They are often the preferred facility of the public. It may not be possible to improve the roadway to provide an adopted target level of bicycle accommodation. Alternatively, they may be the only way to complete a bicycle network or close a gap in an otherwise continuous facility. Consequently, sidepath design must include measures to help minimize the operational challenges described in the previous section. The following geometric measures are the ones most likely to improve the operations and safety at sidepath conflict points.

- Divert the sidepath away from the parallel roadway at conflict points. Ideally, the path should be moved far enough away to function as a midblock crossing and be provided with the appropriate traffic control. At a minimum, enough space should be provided for one vehicle (25 feet) to queue between the roadway intersection and the crossing sidepath.
- Reduce the speeds of users on the sidepath. This can be done through horizontal alignment as described in Section 13.3.9.4.
- Reduce motor vehicle speeds at conflicts points. This can be accomplished by designing for the smallest design vehicle likely to commonly turn at the drive or intersection (AASHTO, 2018) and using the minimum radii provided for in Chapter 8 of this Guide.
- If feasible, reduce the operating speeds on the adjacent roadway.
- Where possible, eliminate conflicts with motor vehicles. Access management techniques, such as reducing the number of driveways or installing raised medians, reduces the potential conflict locations.
- Keep sight lines clear so that motorists approaching the conflict can clearly see the path users and path users can see approaching motorists. This requires limiting parking and landscaping around the conflict points. Proper sight distance should be provided.
- Where a sidepath crossing of a side street cannot be separated from the intersection of the side street and the roadway parallel to the sidepath by at least a car length, the crossing should be designed to be close to the adjacent road.
- At signalized intersections, consider installing blank-out signs, to be activated by path users (e.g., push buttons or loops) to alert motorists of their presence. NO RIGHT ON RED blank-out signs are appropriate for the near side street approach. YIELD TO PEDS IN CROSSWALK are appropriate for the adjacent right-turn, through-right, and opposing left-turn movements.

Individually, the above measures may not be sufficient to ensure the safety of sidepath users. It is likely that a combination of treatments is required (TRB, 2006). An additional measure is to provide signage to warn motorists of the adjacent path as shown in Figure 13-58.

Figure 13-58 Example Adjacent Path Sign

Unless they are moved to a midblock location, intersections of sidepaths with side streets and driveways are to be given the same priority as the parallel roadway. Installing STOP or YIELD signs at these locations is not an effective method of slowing or stopping path users at side streets and driveways. If path users perceive the signs as overly restrictive, they might not comply with them. Furthermore, motorists may yield to path users and wave them through in conflict with the sign priority at the intersection. The overuse of these signs may decrease their effectiveness at locations where compliance with STOP or YIELD signs is critical to the path users' safety.

13.3.14 Sidepath Clearance to the Adjacent Roadway

The minimum midblock separation between a roadway and sidepath is 5 feet from the back of curb or from the edge of pavement if no curb is present.

If 5 feet of separation cannot be provided, a suitable barrier should be provided. If placed, the barrier should be consistent with the requirements of Section 13.3.6. The location of the barrier shall not impair sight distance at intersections.

On low-speed roadways (45 mph or less), it is not necessary for the barrier to be designed to redirect errant motorists toward the roadway unless other conditions require a crashworthy barrier. If the railing cannot be designed so as to not be a hazard to motorists, it shall be protected by a guardrail or barrier wall.

It is not acceptable to mount a railing on top of a guardrail unless it has been appropriately crash tested.

On higher-speed roadways, barriers between the roadway and sidepaths must be crashworthy.

At some locations where the pathway is located more than 5 feet from a roadway, a guardrail may be placed between the roadway and the sidepath to protect motorists from an object in the clear zone. When a guardrail is located within 3 feet of the shared-use path, the back of the guardrail should be considered a vertical obstruction next to the path.

Snow storage should be considered when designing sidepaths. A separation distance of 8 feet is desirable to accommodate snow storage. Where space is limited, overall road cross section design must consider the likely amount of removed snow, the space needed to store it, and how snow will be managed. When snow is stored in the separation area between the road and shared-use path, at least three-fourths of the path should remain usable. The placement of barrier between the roadway and the shared-use path must consider the needs of snow removal and drainage.

13.3.15 Equestrian Facilities

Equestrian facilities may be included on some shared-use path projects. Shared bicycle, pedestrian, and equestrian use is relatively common. Care must be taken when designing these facilities to minimize the potential conflicts between equestrians and other users as horses can startle, compromising safety for their riders and other users. Where possible, separate trails or bridle paths should be provided for equestrian use.

For a complete discussion of equestrian planning and design, the designer should refer to the USDA document *Equestrian Design Guidebook for Trails, Trailheads, and Campgrounds* (USDA, 2007). The criteria contained within this section assumes an equestrian path is within the same right of way, but adjacent to a shared-use path.

13.3.16 Other Considerations on Bicycle Facilities

Where shared-use paths are used at night, lighting should be provided at intersections with roadways. The lighting should be consistent with requirements for roadway intersections contained in Section 5.0 of the CDOT *Lighting Design Guidelines for the Colorado Department of Transportation* (CDOT, 2019) or, as necessary, the AASHTO *Roadway Lighting Design Guide* (AASHTO, 2018). The CDOT *Lighting Design Guidelines for the Colorado Department of Transportation* is based upon the AASHTO *Roadway Lighting Design Guide* (AASHTO, 2018) and the IESNA (Illuminating Engineering Society of North America) recommended practices.

Even where paths are not open at night, it may be advisable to light roadway crossings. On-street bicycle lanes shall be lit to the same level as the adjacent roadway.

13.3.16.1 Maintenance of Traffic

Portable and permanent sign supports should not be located on bicycle facilities or areas designated for bicycle traffic. If the bottom of a secondary sign mounted below another sign is mounted lower than 7 feet above a pathway, the secondary sign should not project more than 4 inches into the pathway facility.

Bicyclists should not be exposed to unprotected excavations, open utility access, overhanging equipment, or other such conditions. Except for short duration and mobile operations, when a highway shoulder is occupied, a SHOULDER WORK sign (W21-5) should be placed in advance of the activity area. When work is performed on a paved shoulder 8 feet or more in width, channelizing devices should be placed on a taper having a length that conforms to the MUTCD requirements of a shoulder taper.

If a designated bike route is closed because of the work being done, a signed alternate route should be provided. The MUTCD includes approved Detour signs for bicycle facilities (Figure 13-59). Bicyclists should not be directed onto a sidewalk or exclusive pedestrian path.

Figure 13-59 Bicycle Facility Detour Signs

To maintain the systematic use of the fluorescent yellow-green background for pedestrian, bicycle, and school warning signs in a jurisdiction, the fluorescent yellow-green background for pedestrian, bicycle, and school warning signs may be used in Temporary Traffic Control zones.

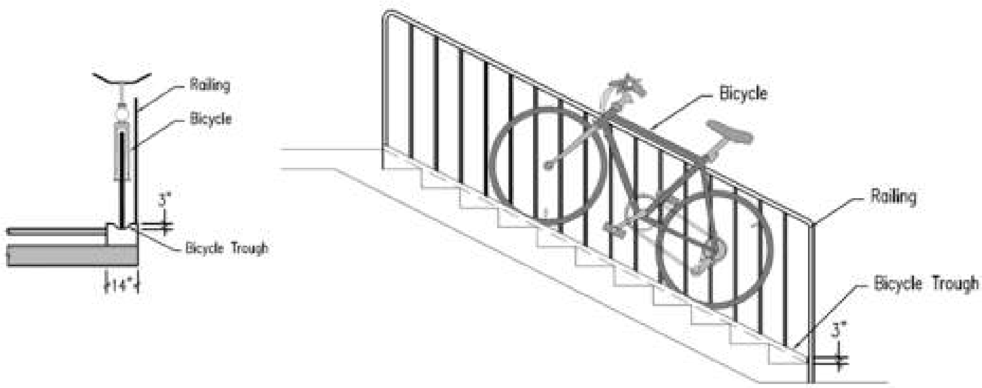
13.3.16.2 Integration of Bicycles with Transit

Integration of bicycling with transit can increase the utility and extend the range of both modes. Bicyclists sometimes cite trip length, steep grades, and weather as reasons they do not use bicycling as a mode of transportation. By integrating bicycling and transit services, these barriers (real or perceived) can be overcome.

Bicycle racks on, or bicycle space within, transit vehicles can help integrate bicycling and transit. Providing short- and long-term bicycle parking (MUTCD) is a key aspect in making this integration.

Where a change in grade occurs at a transit station, some modifications may be considered to make the station accessible to bicyclists. Retrofitting a bicycle channel onto an existing staircase is one technique to improve bicycle access (City of Toronto, 2008) (Figure 13-60).

Figure 13-60 Bicycle Channel



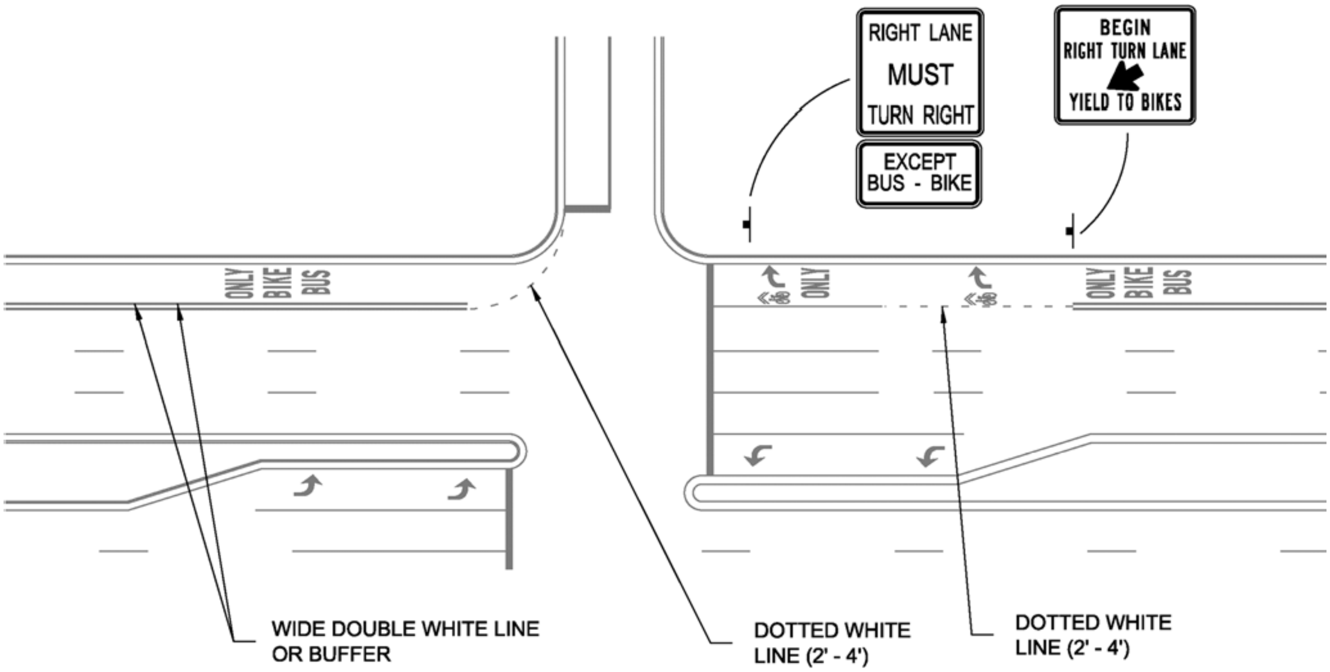
13.3.16.3 Shared Bicycle Facilities with Bus Transit

Shared bicycle-bus transit facilities can take multiple forms.

Ideally, a bus facility - exclusive busway or dedicated bus lanes - would be constructed with separate bicycle facilities. For an exclusive busway, this means the shared-use path adjacent the busway. Bicycle lanes can be installed adjacent to, and to the left of, a dedicated bus lane (assuming a right-side bus lane).

A shared bike-bus lane is one where bicycles use the same lane as the buses. Signage and symbols are used to mark that bicycles can use the designated bus lane (Figure 13-61). A sign similar to the Mandatory Movement Lane Control sign for a bus lane (R3-5gP) could be used. This sign would signify that the facility is both a bike lane and a bus lane.

Figure 13-61 Shared Bus Buffered Bike Lane



13.3.16.4 Shared Bicycle Facilities with Light Rail

If shared-use paths are constructed adjacent to a light rail transit line, special consideration must be given to crossings near the rail stops. Treatments to slow bicyclists should be installed in advance of these crossings. Shared-use paths adjacent to light rail should be located at least 5-feet clear of the dynamic envelope of the light rail transit vehicle. This results in the shared-use path being at least 11 feet clear of the rail line.

Barriers, as described in Section 13.3.6 should be provided between the light rail transit facility and the path where practical.

13.3.16.5 Innovative Signage and Markings

Numerous design treatments and traffic control devices are being used or tested to determine their effectiveness in promoting bicycling and improving bicycle safety. Several of these are discussed in this section.

The decision to use any of these treatments should be made in cooperation with local jurisdictions. Additionally, a justification for using the treatment should be included in the project file, including any research or supporting documents justifying the use of the treatment. Use of non-standard treatments require approval of the Resident Engineer. The headquarters Bicycle and Pedestrian Coordinator must be consulted on the use of these treatments to ensure uniform application throughout the state. Some treatments may require approval from FHWA.

13.3.16.6 Colored Bike Lanes

This treatment has obtained an Interim Approval from the FHWA for application. The interim approval assumes that the green coloring supplements bike lane striping and marking either at conflict areas or continuously along a bike lane. Where bike lanes are designated with dotted lines (i.e., at intersections), the green paint may be continuous. Coloring of bike lanes is a supplemental treatment and should be used to emphasize the presence of properly designed bike lanes. For further information, refer to MUTCD—Interim Approval for Optional Use of Green Colored Pavement for Bike Lanes (IA-14) (FHWA, 2011).

13.3.16.7 Bike Boxes

A bike box is a designated area for bicyclists at the head of a traffic lane at a signalized intersection that provides bicyclists with a safe, visible way to get ahead of traffic queues. It is located between the advance motorist stop line and the crosswalk or intersection. Designed to be used during the red phase, the box is intended to reduce car-bike conflicts, increase bicyclist visibility, and provide bicyclists with a head start when the light turns green. Bike boxes allow bicyclists to group together to clear an intersection quickly and may minimize impediments to other traffic at the onset of the green indication. Pedestrians may also benefit from reduced vehicle encroachment into the crosswalk when bike boxes are present.

At intersections with high numbers of conflicts between right-turning motorists and bicyclists, treatments other than or in addition to the bicycle box should be used. These may include separating conflicting traffic with a leading or exclusive signal and separating turning traffic from through traffic using exclusive turn lanes.

A bike box should be created by placing a stop line for motor vehicles a minimum of 10 feet in advance of the crosswalk or intersection. A minimum of one bicycle symbol marking should be placed in the bicycle box. A NO TURN ON RED sign should be installed wherever a bike box is placed in a lane from which turns on red would otherwise be permitted.

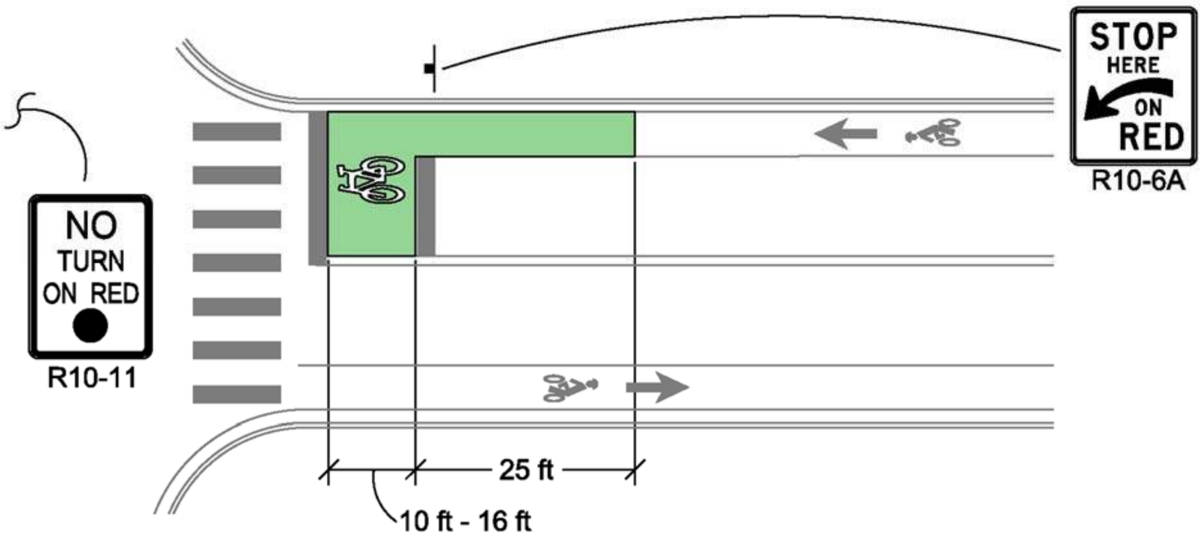
One concern about the use of bike boxes is how conflicts are addressed when the bicyclist arrives at the intersection just as the traffic signal is turning green for motorists. Motorists are not likely to expect a cyclist to move left from the bike lane when the light turns green. In Europe, where this treatment originates, motorists are given a yellow signal prior to the traffic signal turning green; this serves as a warning to the approaching bicyclist. Often, exclusive bicycle signals are provided for bicyclists when using the bike box treatments.

Another operational consideration is that of right-turning motorists who are required to approach the intersection from as close to the right-hand edge of the roadway as is practicable before making a right turn. In this situation, motorists may block the bike lane and thus the bicyclists' access to the bike box.

A request to experiment must be submitted to FHWA prior to implementing bike boxes.

Striping and marketing for a bike box are illustrated in Figure 13-62.

Figure 13-62 Example Striping and Marking for a Bike Box



13.3.16.8 Bicycle Signals

The MUTCD allows the use of standard signal heads to control exclusive bicycle traffic movements. The use of bike-specific signal heads requires the use of directional signal heads, so it is clear which signal is meant for whom. A BIKE SIGNAL (tentatively an R10-10b) sign must be installed immediately adjacent to every bicycle signal face that is intended to control only bicyclists.

FHWA issued an interim approval memorandum for the use of bicycle signals (MUTCD—Interim Approval for Optional Use of a Bicycle Signal Face (IA-16)) (FHWA, 2013). These signals could be used to provide a leading bicycle interval at a traffic signal, an exclusive bicycle phase, an exclusive left-turn phase for bicycles on side paths, or as a signal for shared-use paths.

The FHWA interim approval states:

> The use of a bicycle signal face is optional. However, if an agency opts to use bicycle signal faces under this Interim Approval, such use shall be limited to situations where bicycles moving on a green or yellow signal indication in a bicycle signal face are not in conflict with any simultaneous motor vehicle movement at the signalized location, including right (or left) turns on red.

The interim approval includes signal design, mounting, and operational requirements.

13.3.16.9 Maintenance of Bicycle Facilities

Maintenance of pavement surfaces is critical to safe and comfortable bicycling. Some of the following design treatments help minimize maintenance needs:

- Place public utilities, such as manhole covers and drainage grates, outside of bikeways.
- Ensure that drainage grates, if located on or near a bikeway, have narrow openings and that the grate openings are placed perpendicular to the riding surface (Figure 13-29).

- Design of appropriate cross slopes to help to keep the riding surface clear of debris and water.

13.3.16.9.1 Snow and Ice Control

Roads should be designed to provide snow storage. The roadside should have adequate space to place plowed snow so that it does not block an adjacent shared-use path or bike lane. Separation between road and path allows for snow storage.

13.4 Pedestrian Facilities

Pedestrians and their interactions with vehicular traffic are major considerations for highway planning and design (AASHTO, 2018). Pedestrians are part of every roadway environment and should be accommodated in all roadway designs. According to the 2018 AASHTO GDHS:

> Because of the demands of vehicular traffic in congested urban areas, it is often very difficult to make adequate provisions for pedestrians. Yet provisions should be made, because pedestrians are the lifeblood of our urban areas, especially the downtown and other retail areas.

Therefore, all design projects on CDOT facilities shall include accommodations for pedestrians.

13.4.1 General Pedestrian Considerations

Pedestrian accommodations can take any number of forms. In urban areas, pedestrian accommodations are most likely sidewalks or shared-used paths. In rural areas with lower traffic volumes and light pedestrian traffic, paved shoulders may be used to accommodate pedestrians. CRS 42-4-805 states:

"Pedestrians walking or traveling in a wheelchair along and upon highways where sidewalks are not provided shall walk or travel only on a road shoulder as far as practicable from the edge of the roadway."

As such, if the intended pedestrian accommodation is a shoulder, the shoulder shall be designed to meet ADA and PROWAG requirements. The degree of pedestrian accommodation provided is influenced by the existing and future land use patterns surrounding the facility.

13.4.1.1 Accommodating Pedestrians in the Right of Way

The level of accommodation for pedestrians can be measured by a number of methods ranging from subjective to objective.

Often, as part of downtown redevelopment projects or Safe Route to School projects, a walking audit, which includes subjective and objective analyses, will need to be performed. A walking audit documents recommended improvements to the roadway and pedestrian facilities to improve pedestrian accommodation. Any such local plans should be reviewed and the recommendations addressed in the design plans to the maximum extent feasible.

The *Highway Capacity Manual* (TRB, 2022) establishes an objective method for determining the level of pedestrian accommodation based upon the geometric and operational characteristics of the roadway being analyzed. This method is based on numerous research projects that quantified which factors influence how pedestrians perceive a roadway and sidewalk safety and comfort. This method is often used by agencies to set minimum target levels of accommodation for pedestrian facilities. The model for links (roadway segments between intersections) includes the following factors:

- Presence and width of a sidewalk.
- Width of the outside lane.
- Presence and width of a paved shoulder or bike lane.
- Presence and width of a parking lane.
- Percent of parking occupied by parked cars.
- Presence of trees or a barrier between the sidewalk and the roadway.
- Operating speeds on the roadway.
- Traffic volume on the roadway.

The primary geometric conditions that are influenced by design are the presence of a sidewalk, sidewalk width, and the separation of the sidewalk from the outside lane. This *Highway Capacity Manual* method is a useful tool for designing cross sectional geometry to meet a target level of pedestrian accommodation.

The *Highway Capacity Manual* (TRB, 2022) also provides a method for determining the level of service based upon sidewalk congestion. This methodology should be used to ensure that there is adequate sidewalk width where high volumes of pedestrians are expected.

13.4.1.2 Operating Characteristics of Pedestrians

There is no single type of design pedestrian. Pedestrians have varying degrees of physical and cognitive abilities. It is important to recognize this diversity during facilities design.

Typical pedestrian walking speeds range from approximately 2.5 feet per second to 6.0 feet per second. The MUTCD states that a speed of 3.5 feet per second should be used for calculating pedestrian clearance intervals at pedestrian signals while a speed of 3.0 feet per second should be used for the total pedestrian crossing phase (MUTCD). Seasonal factors, such as ice and snow, can reduce travel speeds below the recommended speeds.

The space taken up by a single stationary person can be approximated by an ellipse of 1.5 feet x 2 feet, with a total area of 3 square feet. In evaluating a pedestrian facility, the *Highway Capacity Manual* (TRB, 2022) assumes an area of 8 square feet, including a buffer zone, for each pedestrian (ODOT, 1995). Two pedestrians walking side by side require a minimum of 4.7 feet of width. Two people in wheelchairs passing each other need a minimum of 5 feet of width; if each has an assistive animal, 8 feet of width is required.

According to the AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* (AASHTO, 2004),

> In 1994, an estimated 7.4 million persons in the United States used assistive technology devices for mobility impairments, 4.6 million for orthopedic impairments, 4.5 million for hearing impairments, and 0.5 million for vision impairments. These numbers are expected to increase because there is a positive correlation between an increase in age and an increase in the prevalence rate of device usage. For example, persons who are 65 years and over use mobility, hearing, and vision assistive devices at a rate four times greater than the total population (TRB, 2009).

These pedestrians shall be considered in the design of pedestrian facilities.

13.4.1.3 Americans with Disabilities Act Requirements

The Americans with Disabilities Act (ADA) mandates the accommodation of persons with disabilities in pedestrian facility design through the provision of pedestrian access routes.

A pedestrian access route is a continuous and unobstructed walkway within a pedestrian circulation path that provides accessibility.

The standards for accessible routes are set by the U.S. Access Board in the Americans with Disabilities Act Architectural Guidelines for Buildings and Facilities (ADAAG) (U.S. Access Board, 2002). ADA standards for new construction and alterations were primarily developed for buildings and site work and are not easily applied to the public right of way. In 2011, the U.S. Access Board released the PROWAG (U.S. Access Board, 2011). It is identified as best practice for accessible pedestrian design and was formally adopted by CDOT as the standard for curb ramps. The criteria contained within this Guide comply with PROWAG; notations are made when they vary from ADAAG.

All newly designed and newly constructed pedestrian facilities located in the public right of way y shall comply with these requirements. All altered portions of existing transportation facilities located in the public right of way shall comply with these requirements to the maximum extent feasible.

If it is technically infeasible to comply with the requirements of the ADA, documentation shall be made to the file to fully justify any non-compliant features of a design. Right of way acquisition does not qualify as technically infeasible, but shall be purchased if needed to make a curb ramp compliant.

13.4.1.4 Curb Ramps and Blended Transitions

Curb ramps shall be installed where a pedestrian access route crosses a raised curb that vertically separates pedestrians from vehicles. Where sidewalks are not separated from the roadway with curb, such as on roadways with open shoulders, the at-grade connection between the sidewalk and roadway is referred to as a blended transition.

Refer to Chapter 12 of this Guide and the latest edition of the CDOT M&S Standards for more information.

13.4.1.5 Vertical Changes in Grade

The maximum instantaneous elevation change on a pedestrian access route without a treatment is one-quarter inch. Changes in level between one-quarter to one-half inch shall be beveled at a slope of no greater than 2:1. The bevel shall be applied across the entire vertical surface discontinuity. Changes in elevation greater than one half inch shall be designed with a maximum slope of 5%.

13.4.2 Sidewalks

When the design is in any of the urban context classifications for roads or streets, sidewalks are required on both sides of CDOT roadways.

Sidewalk surfaces shall be firm, stable, and slip resistant. Concrete sidewalks shall have a broom finish perpendicular to dominant pedestrian direction of travel to increase skid resistance.

The pedestrian access route along a sidewalk should be designed to maximize straight through movements by pedestrians without the need to divert around utilities, street furniture, or driveways.

Adopted pedestrian plans shall be consulted to determine if a roadway is to be designed with pedestrian facilities. CDOT projects should implement relevant pedestrian plan facility recommendations to the maximum extent possible.

Sidewalks should be provided on those projects where other factors indicate a need.

13.4.2.1 Separation from Roadway

The separation of a sidewalk from a roadway is an important factor in the perceived safety and comfort of a pedestrian facility (TRB, 2022). The greater the separation from the roadway, the more pleasant the facility and, consequently, the more likely it is to be used by pedestrians.

Separation from the roadway provides benefits beyond the perceived safety and comfort of the pedestrian. Safety is improved by increasing separation from the roadway, particularly on roadways without curb and gutter. A buffer area provides a place to construct curb ramps and driveways outside of the sidewalk area, making it easier to comply with ADA. Buffer areas can also be used for snow storage. Utility poles, parking meters, and signs can be placed in a sufficiently wide buffer, thus ensuring the complete sidewalk width is available for pedestrians.

13.4.2.2 Separation from Roadway with Curb and Gutter

If a roadway is included in an adopted pedestrian plan, the designed separation of the pedestrian facility from the roadway should comply with target values presented in the plan. Target values may be in the form of adopted minimum separations distances (for example, a buffer, shown in

Figure 13-62) or in target level of service values. For minimum level of service values, the separation needs to be calculated based upon roadway and traffic characteristics.

The minimum setback of a sidewalk from the back of curb to accommodate the construction of a perpendicular curb ramp outside of the sidewalk is 7.9 feet. Where possible, this separation should be provided between the back of curb and sidewalk on curb and gutter projects.

The minimum width of setback to a sidewalk on an arterial roadway with curb and gutter is 6 feet. Under constrained conditions, this may be reduced to 5 feet. The minimum width of setback to a sidewalk on a local or collector roadway with curb and gutter is 4 feet. In extremely constrained conditions, after all motor vehicle travel lane widths have been reduced to their minimums, this may be reduced to 2 feet.

Minimum separation to the sidewalk may be dictated by requirements for snow storage. Regional snow storage requirements should be considered when determining the minimum setback.

Where local jurisdictions are required to maintain the buffer and sidewalk area, maintenance agreements should be obtained during pre-construction.

13.4.2.3 Separation from Roadway without Curb and Gutter

If the project’s limits are included in an adopted pedestrian plan, the separation of the pedestrian facility from the roadway should comply with target values presented in the plan.

Sidewalks on roadways without curb and gutter should be placed as far from the roadway as practical in the following sequence of desirability (FHWA,2009):

- As near the right of way line as possible.
- Outside of the clear zone.
- Five feet from the shoulder point.
- As far from edge of traffic lane as practical.

13.4.2.4 Sidewalk Width

The minimum width for sidewalks on CDOT projects is 5 feet exclusive of the width of the curb.

Under constrained conditions, the minimum width may be reduced to 4 feet exclusive of the width of the curb. This is the minimum pedestrian access route width allowed by PROWAG (U.S. Access Board, 2011). The ADAAG allows for a minimum accessible route of 3 feet in width (U.S. Access Board, 2002) for on-site building facilities. Where less than 5 feet continuous width is provided, passing spaces shall be provided at intervals of 200 feet maximum. Passing spaces shall be a minimum of 5 feet wide for a distance of 5 feet parallel to the sidewalk direction.

13.4.2.5 Protruding Objects

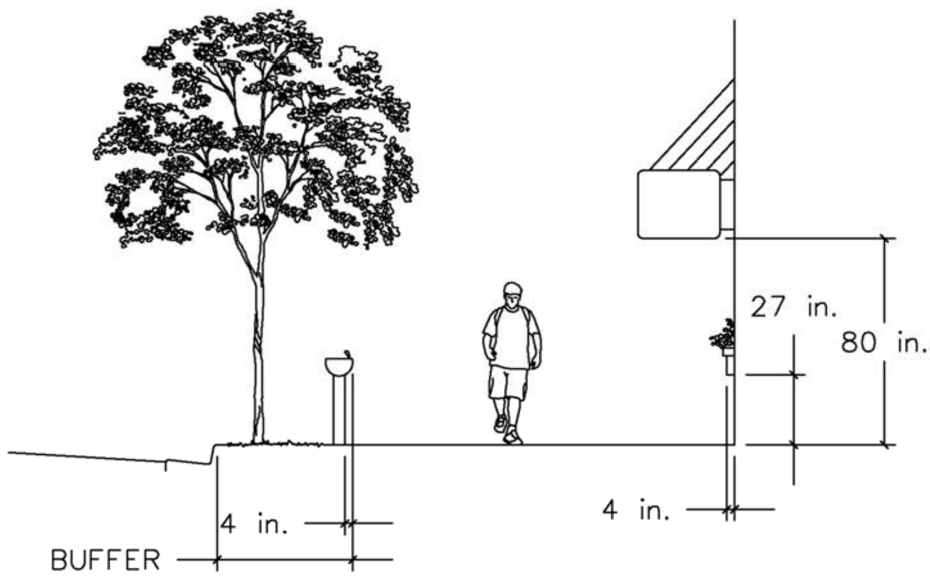
Protruding objects, including pedestrian amenities such as street furniture, water fountains, and informational kiosks, shall not reduce the width of the sidewalk to less than 4 feet.

Objects with leading edges more than 27 inches and not more than 80 inches above the sidewalk shall not protrude more than 4 inches into the clear pedestrian path (Figure 13-63). Objects protruding more than 4 inches into the pedestrian path at more than 27 inches above the sidewalk may not be detectable by cane. Maintaining at least 80 inches clear to overhangs provides clear space to walk under protrusions for most pedestrians.

Objects mounted on free-standing posts or pylons, 27 inches minimum and 80 inches maximum above the sidewalk, shall not overhang into the clear pedestrian path more than 4 inches beyond the post or pylon base measured 6 inches above the sidewalk. Where a sign or other obstruction is mounted between posts or pylons and the clear distance between the posts or pylons is greater than 12 inches, the lowest edge of such sign or obstruction shall not be more than 27 inches or less than 80 inches above the sidewalk.

Where the vertical clearance to an obstruction is less than 80 inches, guardrails or other barriers shall be provided. The leading edge of such guardrail or barrier shall be located not more than 27 inches above the sidewalk.

Figure 13-63 Protruding Objects



13.4.3 Grade and Cross Slopes

The grade of a sidewalk should not exceed the general grade established for the adjacent street or highway.

On structures and constructed approaches thereto, with grades exceeding 5%, pedestrian ramps with a maximum slope of 8.33% and a maximum rise of 30 inches between resting intervals shall be provided. Resting intervals shall be a minimum of 5 feet measured longitudinally along the sidewalk.

The maximum cross slope for a sidewalk is 2%. Care must be taken such that the cross slope and longitudinal grade provide adequate drainage for rain and snowmelt from the sidewalk.

13.4.4 Driveways

Where a driveway crosses a sidewalk, the path of the pedestrian across the driveway must comply with the width and cross slope requirements of Section 13.4.2.4 and Section 13.4.3.

13.4.5 Sidewalk Lighting

Sidewalk alignments must be considered when designing the roadway lighting pattern. Sidewalks along roadways should be illuminated to the same level as the adjacent roadway. This is important as pedestrians coming from the side of the road to cross must be adequately illuminated to be visible to motorists.

Roadway lighting designed to light just the travel lanes to design levels may not provide adequate illumination for sidewalks. In these cases, supplemental lighting should be provided.

This lighting shall be consistent with requirements for walkways contained in Section 5.11 of the CDOT *Lighting Design Guidelines for the Colorado Department of Transportation* (CDOT, 2019), or, as necessary, the AASHTO *Roadway Lighting Design Guide* (AASHTO, 2018).

13.4.6 Transit Stops

Where possible, transit waiting areas should be located outside of the sidewalk. Transit pads shall be connected to the street, sidewalk, or pedestrian path by an *accessible* route.

Bus stop boarding and alighting areas shall provide a clear length of 8 feet minimum, measured perpendicular to the curb or roadway edge, and a clear width of 5 feet minimum, measured parallel to the roadway.

13.4.7 Pedestrian Crossings of Roadways

Careful design of roadway crossings is critical to pedestrian mobility and safety. Pedestrian crossings should be designed so that they are convenient for users otherwise pedestrians might choose to cross at other locations, outside the protection of a crosswalk.

ADA-compliant curb ramps or blended transitions shall be installed wherever a pedestrian access route crosses a roadway.

13.4.8 Pedestrian Crossings at Intersections

Motorists approaching intersections are primarily concerned with conflicts with other motorists. Consequently, it is important that pedestrians waiting at intersections and approaching motorists have adequate sight distance to allow each user to make appropriate decisions.

In urban areas, the minimum curb radii allowed for the design vehicle, as found in Chapter 8 of this Guide, should be used. This reduces vehicle speeds and pedestrian crossing distances. Curb extensions should be considered to reduce crossing distances at intersections on streets with on-street parking.

13.4.8.1 Pedestrian Crossings at Uncontrolled Approaches to Intersections

Designated pedestrian crossings of uncontrolled approaches to intersections should be designed as midblock crossings. Guidance on these crossings can be found in Section 13.4.9.

13.4.8.2 Pedestrian Crossings at Stop and Yield Control Intersections

In urbanized areas, marked crosswalks should be provided wherever a sidewalk crosses a street under stop or yield control. STOP or YIELD lines shall be placed a minimum of 4 feet in advance of the crosswalks.

On multilane roadways under yield control, YIELD lines should be placed 30 feet in advance of the near edge of the intersecting roadway. This advance placement is to improve the visibility of crossing pedestrians to motorists.

13.4.8.3 Pedestrian Crossings at Signal Control Intersections

If an intersection under signal control has sidewalks, marked crosswalks should be provided. In urban areas, pedestrian signals are recommended at all intersections where sidewalks on the approaches to a signalized intersection. STOP lines shall be placed a minimum of 4 feet in advance of the crosswalks. Consideration may be given to providing advance right-turn STOP lines to improve the visibility of pedestrians coming from the motorist’s left.

Pedestrian push buttons shall be accessible to pedestrians via an accessible pedestrian route in compliance with the ADA.

PROWAG requires that whenever pedestrian signals are installed, accessible pedestrian signal push button be installed (U.S. Access Board, 2002). At intersections with high volumes of right-turning traffic, raised right-turn channelization islands should be provided to allow pedestrians to cross the right-turning traffic independently of the rest of the intersection. Single right-turn channelization islands should be under yield control and have YIELD lines a minimum of 4 feet in advance of the crosswalk. Pedestrian crossings, crosswalks, and W11-2 (PEDESTRIAN CROSSING sign) should be placed on the approach end of the channelization island to maximize visibility to motorists. Where there is concern about motorists yielding to pedestrians, a raised crossing between the sidewalk and the channelization island should be considered to improve visibility of the pedestrians and reduce motor vehicle speeds in that conflict area. Space should be provided beyond the crosswalk for a single motor vehicle to store. Pedestrian signal heads for crossing of the through lanes shall be placed on the concrete channelization island.

Painted channelization islands do not provide the pedestrian advantages of raised channelization islands. Signal poles cannot be placed in painted islands. Consequently, the pedestrian signal necessarily applies to the entire crossing, not just the through lanes. This precludes the use of yield control on the slip lane and the right turn must be signalized.

At multilane right-turn channelization islands, PROWAG requires the use of APS across the turn lanes (U.S. Access Board, 2002). Refer to the MUTCD Section 4.E.

At intersections with high volumes of pedestrians, consideration should be given to restricting the right turn on red movement. NO RIGHT ON RED blank-out signs may be used to restrict right turns only when pedestrians have pushed the pedestrian push button. This minimizes the delay to motorists due to the right-turn restriction.

Additionally, YIELD TO PEDS IN CROSSWALK blank-out signs can be used to remind motorists turning right-on-green and taking permissive left-turn movements of the law that requires motorists to yield to pedestrians in the crosswalk.

Another method to reduce pedestrian conflicts with turning motorists is to use a leading pedestrian interval. Where leading pedestrian intervals are used, APS should be considered.

13.4.8.4 Pedestrian Crossings at Roundabouts

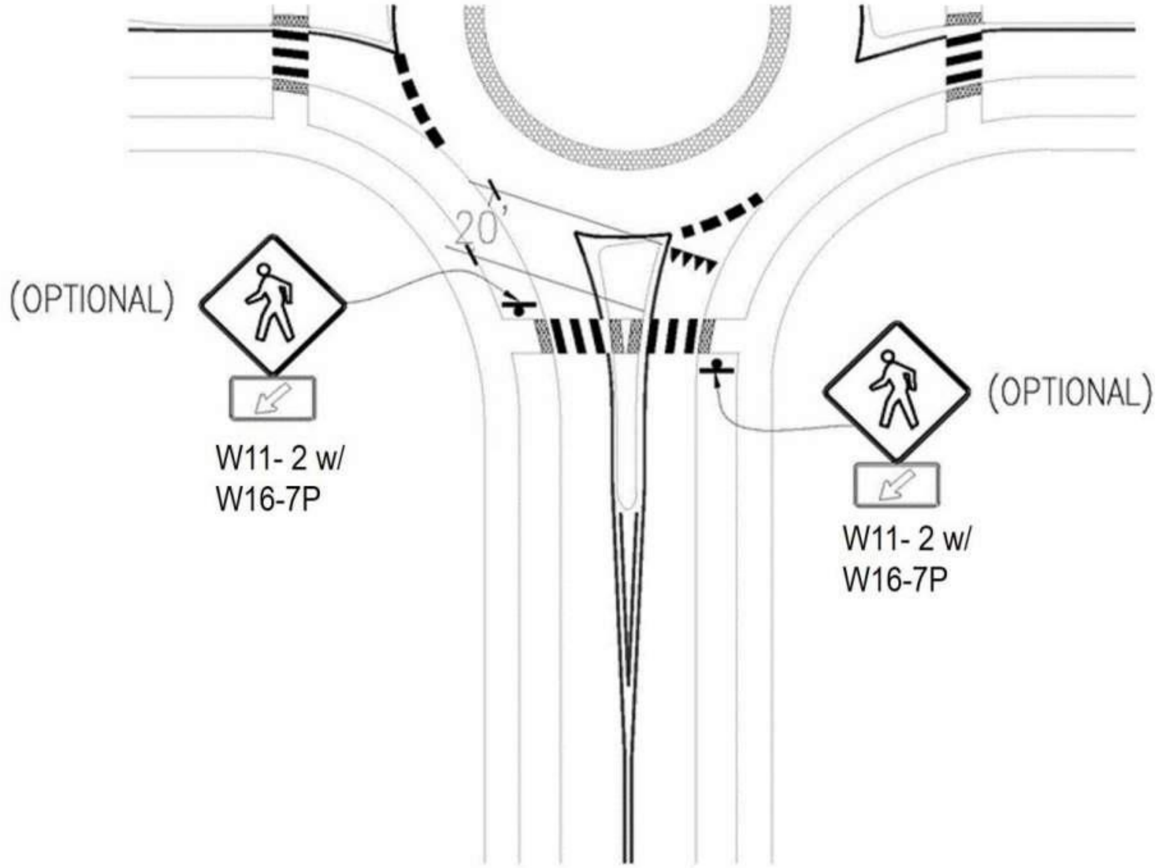
Research suggests that properly designed single-lane roundabouts have fewer pedestrian conflicts and crashes than typical signalized intersections (FDOT,2010). To accommodate pedestrians, roundabouts should be designed to reduce speeds of approaching vehicles. Design speeds through single-lane roundabouts of 12 to 22 mph are typical.

Crosswalks at roundabouts shall be placed a minimum of 20 feet back from the circulating roadway (Figure 13-64).

In areas prone to snow where the crosswalks may not be visible in winter, the W11-2 (PEDESTRIAN CROSSING) sign assembly should be installed at the crosswalks.

PROWAG requires crosswalks across multilane approaches to roundabouts to be provided with APS (U.S. Access Board, 2002).

Figure 13-64 Location of Pedestrian Crossings at Roundabouts



13.4.9 Pedestrian Crossings at Midblock Locations

When pedestrian crossing volumes meet the warrants for signalized pedestrian crossings, the installation of traffic signals for pedestrians should be considered.

The minimum clear width between crosswalk lines is 6 feet.

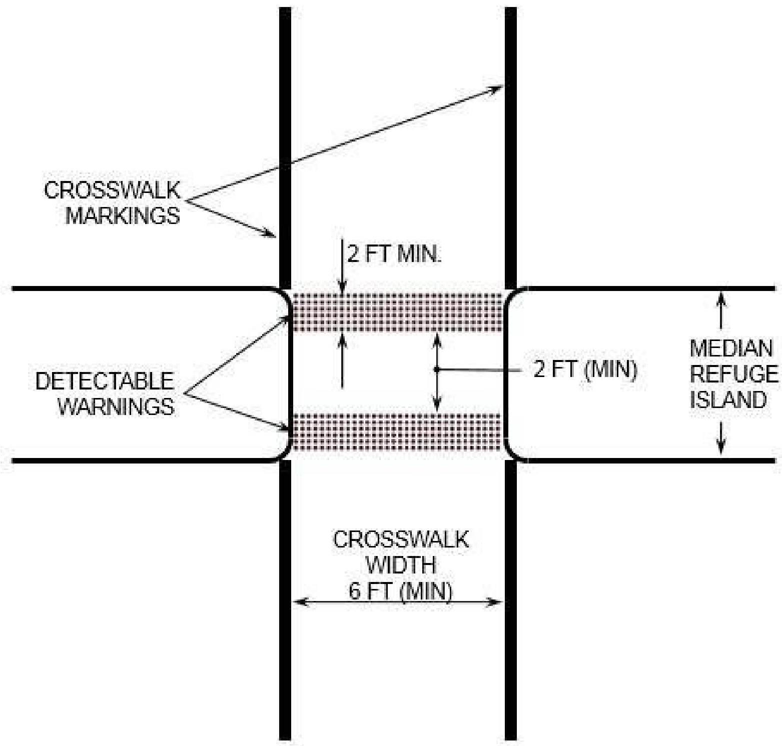
The MUTCD provides information on what type of traffic control devices may be used at midblock crossings. However, other than requiring crosswalk markings and PEDESTRIAN WARNING (W11-2) signs, it provides no clear guidance about the conditions in which any particular traffic control devices are recommended to be used to ensure that a motorist yields. The following section provides guidance in this regard. The tables provided should not be taken as requirement, rather as guidance for determining appropriate levels of traffic control at midblock crossings.

White, retroreflective crosswalk pavement markings shall be installed at all midblock crossings.

Raised median pedestrian refuge islands should be installed at all midblock crossing locations where the pedestrian must cross four or more lanes of traffic. The minimum raised separation width between travel lanes for a pedestrian refuge island is 6 feet. For shared-use path crossings, the desirable minimum width of a refuge island is 10 feet. Where crossings are cut through median refuge islands, detectable warnings shall be installed: 2 feet of detectable warnings, 2 feet flat surface minimum, and 2 feet of detectable warnings. Refer to Figure 13-65.

Ideally, raised islands should extend along the roadway in advance of the crossing to the STOP or YIELD line.

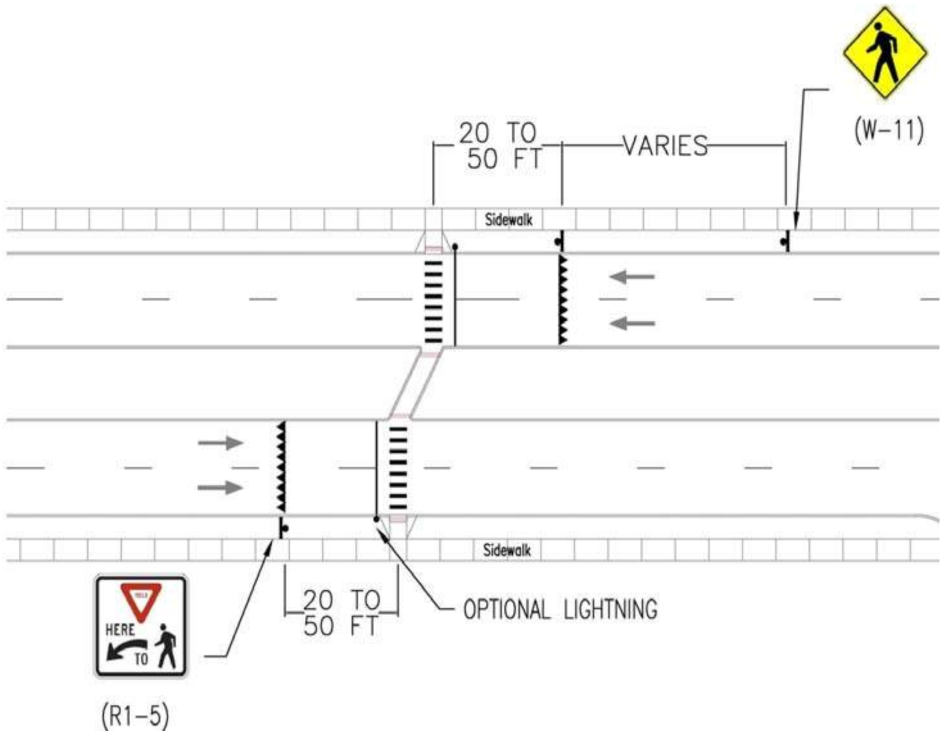
Figure 13-65 Detectable Warning Placement in Median Refuge Islands



An angled cut through of the median provides additional space for pedestrians to stage and encouraging pedestrians to look toward oncoming traffic (Figure 13-66).

Advance STOP or YIELD lines shall be installed at all midblock crossing locations where the pedestrian must cross four or more lanes of traffic.

Figure 13-66 Angle Cut through a Median



13.4.9.1 Rapid Rectangular Flashing Beacons

While not yet included in the MUTCD, Rapid Rectangular Flashing Beacons (RRFB) have been shown to improve motorist yielding at midblock crossings. Research suggests motorist yield rates are ranging from 80% to 97% three years after deployment. To date, this appears to be the most effective combination of traffic control devices that do not actually require the motorist to stop. This treatment has an Interim Approval from FHWA for its application (MUTCD—Interim Approval for Optional Use of Pedestrian-Actuated Rectangular Rapid Flashing Beacons at Uncontrolled Marked Crosswalks (IA-21) (FHWA, 2018).

The RRFB treatment is a combination of signing, markings, and pedestrian-activated strobe and feedback devices. Signing for the RRFB typically includes advance PEDESTRIAN WARNING signs (W11-2) with AHEAD supplemental plaques (W16-9p), and PEDESTRIAN WARNING signs (W11-2) with down arrow supplemental plaques (W16-7p). Pavement markings include yield lines and solid white lane lines (on divided multilane roads); the length of these lines is dependent upon the design stopping sight distance for the roadway. The pedestrian activated treatments would be the W11-2 signs with built in rectangular strobe flashers. Additionally, pedestrian visible strobes and a recorded message inform pedestrians when the crossing is activated and instruct them to wait for motorists to yield.

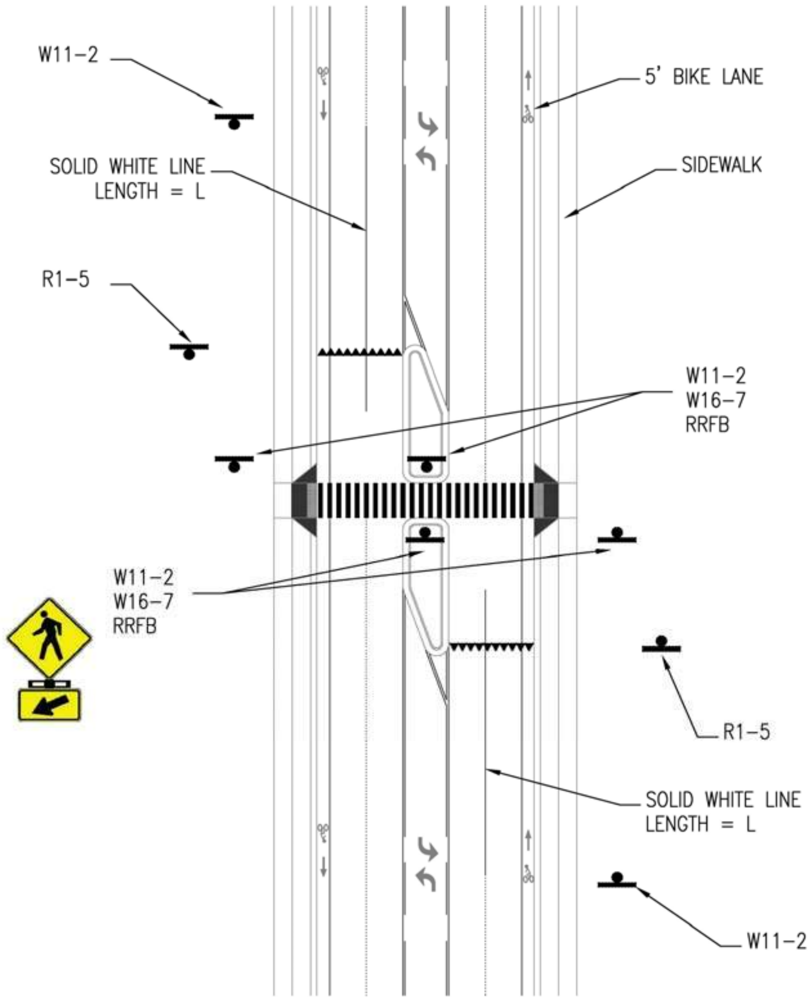
The RRFB should not be used on roadways with more than four through lanes. Raised medians should be provided at crossings using the RRFB to provide a space for left-hand signs to be installed.

The R1-5 (YIELD HERE TO PED) shall be placed so that it does not restrict motorists' visibility of the RRFB at the crosswalk.

For the placement of advance stop lines and advance warning signs, refer to the MUTCD.

High visibility crosswalks are to be used with the RRFB crossing treatment, as shown in Figure 13-67.

Figure 13-67 Rapid Rectangular Flashing Beacon



Timing of the flashing beacon should allow for pedestrians to scan for motorists, step from the side of the road, and completely cross the street. Depending upon pedestrian volumes, 5 to 10 seconds should be provided for pedestrians to scan for gaps and enter the roadway. For areas with very high pedestrian volumes (more than 10 pedestrians per crossing), additional startup time should be provided. A speed of 3.5 feet per second should be assumed for pedestrians unless there is a high number of children or elderly pedestrians expected to use the crosswalk.

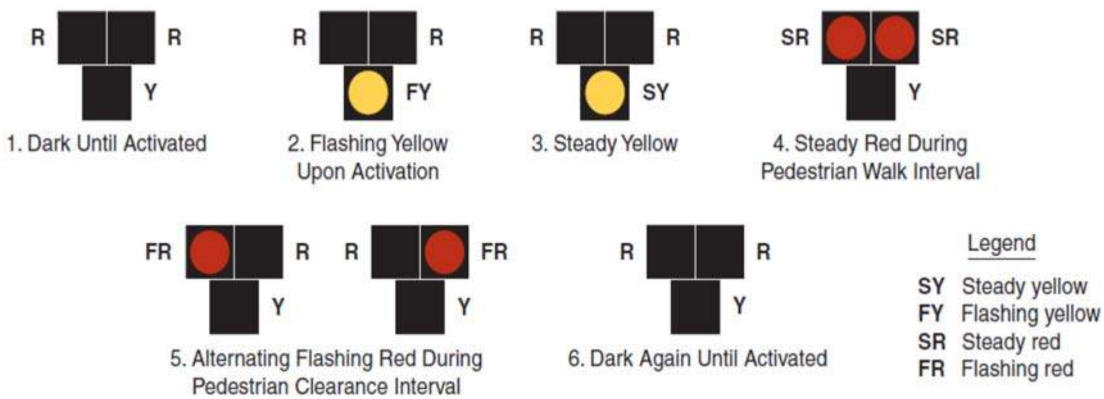
13.4.9.2 Pedestrian Hybrid Signals (HAWK Signals)

PEDESTRIAN HYBRID BEACONS are pedestrian-activated beacons that warn motorists that pedestrians are crossing the street and indicate that motorists are required to stop for pedestrians (FHWA,2009). They do not require the satisfaction of traffic signal warrants. Chapter 4F of the MUTCD does provide some guidance regarding the volume of pedestrians crossing a roadway that would merit the consideration of a PEDESTRIAN HYBRID BEACON (FHWA,20002000).

PEDESTRIAN HYBRID BEACONS are required for use on unsignalized designated crossings of roadways with six or more lanes.

The signal sequence for a pedestrian hybrid signal is shown in Figure 13-68.

Figure 13-68 Pedestrian Hybrid Beacon Sequence



13.4.9.3 Guidance for Traffic Control Selection at Midblock Crossings

The recommended traffic control method is determined by the traffic volume levels in the lanes being crossed. The threshold volumes for low- to medium-volume is determined using the amount of time a pedestrian can expect to wait for an adequate gap in traffic to cross the street. The medium- to high-volume threshold is based upon a midblock crossing safety study prepared by the University of North Carolina's Highway Safety Research Center (FHWA,2009). Depending on whether the street being crossed is low, medium or high volume, the corresponding value listed in Table 13-11 should be referenced to determine the recommended traffic control devices for the crossing.

Table 13-11 Referral Table for Midblock Crossing Treatments

Traffic Volume in Lanes Being Crossed	Recommended Traffic Control
< 6,700 vehicles per day	Refer to Table 13-13
6,700 – 12,000 vehicles per day	Refer to Table 13-14
>12,000 vehicles per day	Refer to Table 13-15

Three tiers of traffic control device packages were identified for these guidelines: static signs, activated signs, and hybrid beacons. The components of each of these packages are provided in Table 13-12.

Table 13-12 Traffic Control Devices Tiers

Preferred Traffic Control Devices	Midblock Crossing Traffic Control Devices Tier		
--	Static Signs	Activated Signs	Stop Controlled
Marked Crosswalks	✓	✓	✓
Bicycle or Pedestrian Warning sign with Trail Xing Sign (W11-15) w/ (W11-15) Or Arrow (W16-7p)	✓	✓	✓
Advance Yield or Stop Lines	✓	✓	✓
Trail Xing Sign (advance) and TRAIL XING Pavement Marking	✓	✓	✓
Yield or Stop Here to Ped Signs (R1-5)(R1-5)	✓	✓	✓
RRFB crossing: Ped Xing Signs (W11-2) with rapid rectangular flashing beacons, and solid centerlines on approaches		✓	
Pedestrian Hybrid Beacon			✓

The matrices on the following pages present packages of traffic control devices recommended for specific roadway conditions. While providing guidance, there are sometimes field conditions which make the strict adherence to any typical signing and marking scheme impractical. Therefore, when applied at new locations, each location should be reviewed in the field to ensure the proposed treatments are appropriate.

If sight distance is limited, additional traffic control may be appropriate.

Additional traffic control may be appropriate in areas where expected pedestrians are predominately school children or individuals with mobility impairments.

General notes for the Crossing Treatment Guidelines matrices shown in Table 13-13, Table 13-14, and Table 13-15.

- Each column in the table represents a package of traffic control devices recommended for the specific crossing condition.
- Volumes in the title cells assume a daily to peak hour volume factor of 0.97.
- The designation of “YES” for the median assumes there is potential for installing a raised median at the crossing location and that one will be installed. Raised medians that can be used as pedestrian refuges (6 feet wide or wider in the direction of the roadway cross section) will require less restrictive motor vehicle traffic controls in conjunction with the midblock crossings. Wider refuge islands, 10 feet or more, should be considered to accommodate bicycle with trailers and recumbent bicycles.
- On roadways with two-way left-turn lanes, refuge islands should be installed at crossing locations to improve pedestrian refuge safety.
- On multilane roadways with medians on the approach, crossing signs for motorists should be placed in the medians as well as on the side of the roadway.
- The use of angled cuts through the median (sometimes referred to as Danish offsets) should be considered at all crossings with raised medians for two reasons. First, the offset through the median directs the path users’ attention toward the traffic about to be crossed. Secondly, of particular importance when using these tables for shared-use path intersections, by providing an angled cut through the median, longer users (tandems, cargo bikes, & bicycles with trailers) will be better accommodated than in a narrower median.
- When advance yield lines are used on the approach roadways, they should be used in conjunction with solid lane lines. The lane lines should extend a distance equal to the stopping sight distance back from the yield lines. This is to enable law enforcement officers to determine when a motorist fails to yield when he could have done so.
- On six-lane, undivided roadways, strong consideration should be given to providing a signalized crossing of the roadway for pedestrians. Until such time as this can be achieved, aggressive channelization should be used to divert pathway users to the nearest safe crossing.

This guidance assumes that lighting is provided for crossings at night.

Table 13-13 Roadway Volume Less Than 650 Vehicles Per Hour (vph) or 6,700 Vehicles Per Day (vpd)

	Lanes	2 lanes						4 lanes					
	Median	No			Yes			No			Yes		
	Speed	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph
Taffic Control Devises Package	Static Signs	✓			✓	✓		✓			✓		
	Rectangular Rapid Flashing Beacon		✓	✓			✓		✓	✓		✓	✓
	Hybrid Beacon												

Table 13-14 Roadway Volume Greater than 650 vph (6,700 vpd) and Less Than 1,150 vph (12,000 vpd)

	Lanes	2 lanes						4 lanes						6 lanes					
	Median	No			Yes			No			Yes			No			Yes		
	Speed	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph
Taffic Control Devises Package	Static Signs	✓			✓						✓								
	Rectangular Rapid Flashing Beacon		✓	✓		✓	✓	✓				✓	✓						
	Hybrid Beacon								✓	✓				✓	✓	✓	✓	✓	✓

Table 13-15 Roadway Volume Greater Than 1,150 vph (12,000 vpd)

	Lanes	2 lanes						4 lanes						6 lanes					
	Median	No			Yes			No			Yes			No			Yes		
	Speed	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph	≤ 30 mph	35–40 mph	≥ 45 mph
Taffic Control Devises Package	Static Signs				✓														
	Rectangular Rapid Flashing Beacon	✓	✓	✓		✓	✓	✓			✓	✓	✓						
	Hybrid Beacon								✓	✓				✓	✓	✓	✓	✓	✓

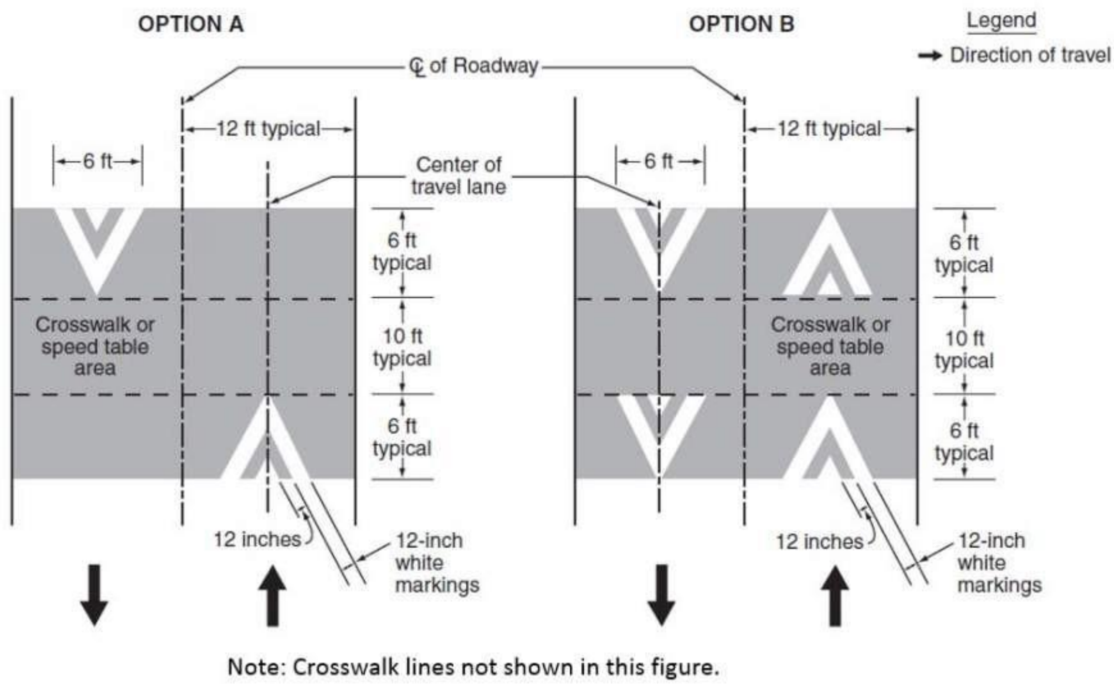
13.4.9.4 Additional Treatments at Midblock Crossings

On roadways with on-street parking, mid-block curb extensions should be considered to reduce pedestrian crossing distances and improve pedestrian and motorist sight lines. Drainage must be addressed when designing curb extensions.

On lower speed and volume arterials and collector streets, raised crosswalks should be considered. Raised crosswalks decrease motorist speeds, resulting in greater yielding rates. Snowplow operators have reported problems plowing over raised crosswalks; the use of short vertical curves instead of grade break lines may address this operational problem. Drainage must be considered when designing raised crosswalks.

The approach slopes for raised crosswalks shall be marked in accordance with the required markings required by MUTCD for raised pedestrian crossings shown in Figure 13-69.

Figure 13-69 Approach Slope Markings for Raised Pedestrian Crossings



13.4.9.5 Signalized Pedestrian Crossings

Where signal warrants for pedestrian crossings are met, the installation of traffic signals should be considered. At midblock locations accessible pedestrian signals shall be provided.

Where accessible pedestrian signals are to be installed, they shall comply with all the requirements of the MUTCD.

13.4.9.6 Grade-Separated Pedestrian Crossings

In some locations, a grade-separated crossing is the only practical method for pedestrians to cross a roadway, for example across an expressway or where children must cross major arterials. When appropriately designed, grade-separated pedestrian crossings improve the mobility and safety of pedestrians.

Attributes of a grade-separated pedestrian crossings include the following (AASHTO,2004):

- The facility must be located where it is needed and will be used.
- Crossing structures must be built with adequate widths based on perceptions of safety, as well as pedestrian volumes.

- The design must be accessible for all users.
- Barriers and railings must be provided to add an increased sense of safety to the pedestrian.
- The facility must be illuminated to provide an increased level of security to the pedestrian.

Where grade-separated crossings are installed, approaches must meet grade criteria provided in Section 13.4.3.

Where the designer has a choice between a tunnel and an overpass, an overpass is often preferable. Overpasses have security advantages. Additionally, lighting is often a requirement for tunnels and may not be necessary for an overpass. Drainage may also be easier to accommodate on overpasses. Underpasses are often more difficult to construct because of utility conflicts or phasing issues. Additionally, pedestrians are more likely to use an overpass than an underpass. However, overpasses have significantly greater vertical clearance requirements. Overpasses are required to be 17 feet 6 inches above the roadway surface compared to underpasses where the roadway is required to be 10 feet above the path surface.

When considering a grade-separated pedestrian crossing, a feasibility study shall be conducted. This study would quantify current and future pedestrian use, as well as alternatives for at-grade crossings.

Contrasting crosswalk coloring is often requested in downtown areas. The use of contrasting coloring does not eliminate the requirement to mark crosswalks with white, retroreflective pavement markings.

13.4.9.7 Sidewalk Crossings of Rail Lines

Where sidewalks cross railroad tracks, appropriate crossing treatments shall be provided.

Of particular importance to individuals with mobility impairments is the interface between the rails and the sidewalk. Sidewalk surfaces should be flush with the tops of rails. Openings for wheel flanges at pedestrian crossings of freight rail track should be 3 inches maximum. Openings for wheel flanges at pedestrian crossings of non-freight rail track should be 2.5 inches maximum.

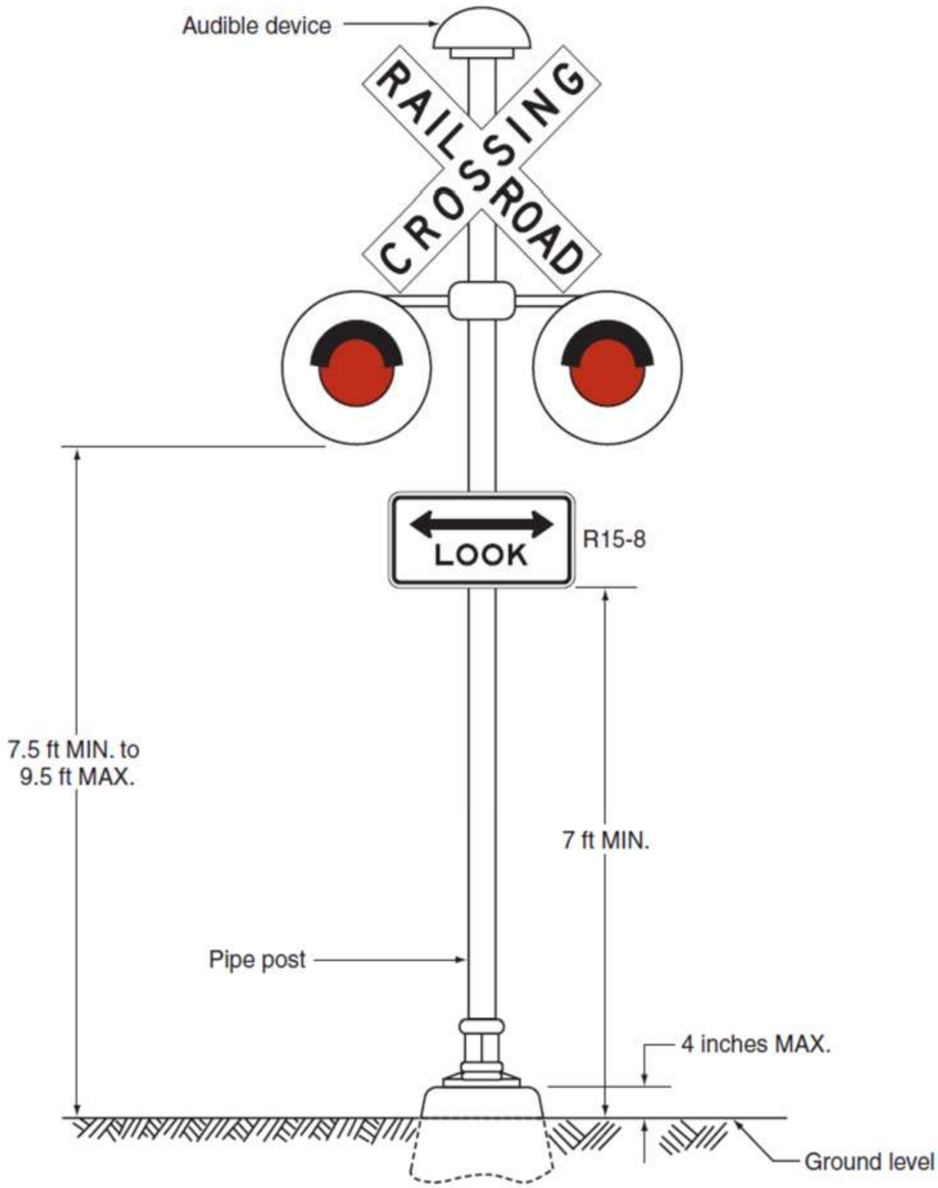
Detectable warnings should be placed on the approaches to all rail crossings unless the rail crossing is included within a roadway crossing. The detectable warning surface should be located so that the edge nearest the rail crossing is 6 feet minimum and 15 feet maximum from the centerline of the nearest rail. The rows of truncated domes in a detectable warning surface should be aligned to be parallel with the direction of wheelchair travel.

At light-rail transit (LRT) rail line crossings, pedestrian signal heads must comply with the provisions of the MUTCD.

Where a sidewalk crosses a light rail transit line, flashing-light signals (Figure 13-70) with a CROSSBUCK (R15-1) sign and an audible device should be installed at pedestrian crossings where an engineering study has determined that the sight distance is not sufficient for pedestrians and bicyclists to complete their crossing prior to the arrival of the LRT traffic at the crossing, or where LRT speeds exceed 35 mph.

If an engineering study shows that flashing-light signals with a CROSSBUCK sign and an audible device would not provide sufficient notice of approaching light rail trains, the LOOK (R15-8) sign, pedestrian gates, or both, should be considered.

Figure 13-70 Example of Flashing -Light Signal Assembly for Pedestrian Crossings



13.4.10 Other Pedestrian Considerations

13.4.10.1 Traffic Calming

The Institute of Transportation Engineers (ITE) uses the following definition for traffic calming: "Traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior to improve conditions for non-motorized street users." (Lockwood, 1997).

Traffic calming features are used on roadways to slow traffic speeds. Vertical and horizontal alignment and increased side friction are used to physically restrict the speeds motorists are comfortable driving. Thus, traffic calming is self-enforcing.

Traffic calming is often used in combination with lane narrowing, raised medians, landscaping, and lighting. While these additional treatments do not compel motorists to slow down, they may provide a visual cue to drive more slowly.

By reducing speeds, the number of traffic crashes is reduced and those crashes that do occur are often less severe than on streets without traffic calming. By reducing speeds, pedestrians' perceptions of safety and comfort are improved as well.

ITE and FHWA produced the document *Traffic Calming: State of the Practice* (FHWA,1999) for informational purposes. While it does not include recommendations on the best course of action or the preferred application of the data, it does provide an excellent resource for those considering the application of traffic calming treatments.

13.4.10.2 Pedestrian Amenities

Pedestrian amenities can provide a more pleasant walking environment and thus encourage more pedestrian activity. Pedestrian amenities can include aesthetic paving treatments, street furniture, shade trees, enhanced lighting, landscaping, informational signing, and public art. Because transit users begin and end their trips as pedestrians, amenities, particularly street furniture, and informational signing, can encourage more transit use. Prior to installing pedestrian amenities, a maintenance agreement should be executed with the local jurisdictions that will maintain those amenities.

If aesthetic paving treatments are used, they shall be firm, stable, and slip resistant. Cobbles or other treatments that create a vibratory surface for wheelchair users shall not be used within the pedestrian walkway; they may be used in border areas.

Pedestrian amenities shall be designed so that they do not reduce the pedestrian access route to less than 4 feet and shall meet all the criteria of Section 13.4.2.5.

Shade trees and landscaping should not restrict intersection sight triangles, or restrict pedestrian or motorists sight distances at midblock crossings.

13.4.10.3 Pedestrian Wayfinding

Pedestrian wayfinding provides information on walk routes to destinations and attractions. Pedestrian wayfinding can encourage pedestrian activity and transit use. Local jurisdictions should be consulted concerning the design or visual theme of pedestrian signage. The development of pedestrian routes should include the participation of local agencies and walking interest and advocacy groups.

The MUTCD does not provide specific signs to be used for pedestrian wayfinding. However, standard alphabets with a minimum text height of 2 inches should be used for pedestrian signs to ensure legibility.

13.4.10.4 On-Street Parking

On-street parking significantly improves the safety and perception of comfort for pedestrians. On-street parking provides an additional buffer between the travel lanes and the sidewalk and often results in reduced motor vehicle travel speeds, encouraging a more pedestrian-friendly environment.

In areas with on-street parking, curb extensions should be considered to restrict parking near intersections and midblock crossing locations to improve the motorist-pedestrian line of sight at the crossing. Additionally, curb extensions reduce the crossing distance and the amount of time the pedestrian is required to spend at street-level, improving their perception of comfort. Drainage patterns need to be considered during the design of curb extensions.

13.4.11 School Areas

School zones represent a particular challenge to pedestrian facility design. Children are the most unpredictable, least traffic savvy of pedestrians.

Special consideration should be given to designing pedestrian facilities near schools. Sidewalks should be located as far from the roadway as possible. In some locations, it may be advisable to channelize school children with fences or other barriers. These barriers should be designed so they do not hinder sight distance.

If midblock crossings are installed for school crossings, enhanced treatments should be considered. Roadway volume thresholds for Table 13-13, Table 13-14, and Table 13-15 should be reduced by 20%. School children shall not have to cross more than two lanes of traffic without a traffic signal. On roadways with raised pedestrian refuge islands, a four-lane divided roadway is the maximum width crossing without a traffic signal that may be provided specifically for school children.

Reduced speed zones should be considered in school zones. When using the SCHOOL SPEED LIMIT ASSEMBLY, the use of timed flashers is recommended (Figure 13-71). The use of the WHEN CHILDREN PRESENT (S4-3) plaque is not recommended.

Figure 13-71 School Speed Limit Assembly

Consideration should be given to restricting right turn on red during periods when students are walking to and from school. Use of the WHEN CHILDREN PRESENT (S4-3) plaque is not recommended. Consideration should be given to using designated times for the no right on red or using blank-out signs pre-timed to school walking periods. Designers should also consider eliminating right-turn on red all together in school zones.

Pedestrian staging areas at intersections and midblock crossings should accommodate the expected volume of students waiting to cross.

Student drop-off and pickup areas should be contained within the school site. If there is an area for street-side drop-off and pickup is permitted, it shall not require students to make an unsupervised crossing of a roadway.

13.4.12 Maintenance of Traffic

The following section is taken from the MUTCD. It includes the guidance and standard sections from the MUTCD. For support text, refer to Section 6D of the MUTCD.

13.4.12.1 Pedestrian Considerations in Temporary Traffic Control Zones

Advance notification of sidewalk closures shall be provided by the maintaining agency or contractor.

If the temporary traffic control (TTC) zone affects the movement of pedestrians, adequate pedestrian access and walkways shall be provided. If the TTC zone affects an accessible and detectable pedestrian facility, the accessibility and detectability shall be maintained along the alternate pedestrian route.

The following three items should be considered when planning for pedestrians in TTC zones:

- Pedestrians should not be led into conflicts with vehicles, equipment, and operations.
- Pedestrians should not be led into conflicts with vehicles moving through or around the worksite.

- Pedestrians should be provided with a convenient and accessible path that replicates as nearly as practical the most desirable characteristics of the existing sidewalks or footpaths.

A pedestrian route should not be severed or moved for non-construction activities such as parking for vehicles and equipment.

To accommodate the needs of pedestrians, including those with disabilities, the following considerations should be addressed when temporary pedestrian pathways in TTC zones are designed or modified:

- Provisions for continuity of accessible paths for pedestrians should be incorporated into the TTC plan.
- Access to transit stops should be maintained.
- A smooth, continuous hard surface should be provided throughout the entire length of the temporary pedestrian facility. There should be no curbs or abrupt changes in grade or terrain that could cause tripping or be a barrier to wheelchair use. The geometry and alignment of the facility should meet the applicable requirements of the ADAAG (U.S. Access Board, 2002).
- The width of the existing pedestrian facility should be provided for the temporary facility if practical.

Traffic control devices and other construction materials and features should not intrude into the usable width of the sidewalk, temporary pathway, or other pedestrian facility. When it is not possible to maintain a minimum width of 5 feet throughout the entire length of the pedestrian pathway, a 5-foot x f5-foot passing space should be provided at least every 200 feet to allow individuals in wheelchairs to pass.

Blocked routes, alternate crossings, and sign and signal information should be communicated to pedestrians with visual disabilities by providing devices such as audible information devices, accessible pedestrian signals, or barriers and channelizing devices that are detectable to the pedestrians traveling with the aid of a long cane or who have low vision. Where pedestrian traffic is detoured to a TTC signal, engineering judgment should be used to determine if pedestrian signals or accessible pedestrian signals should be considered for crossings along an alternate route.

When channelization is used to delineate a pedestrian pathway, a continuous detectable edging should be provided throughout the length of the facility such that pedestrians using a long cane can follow it. These detectable edgings should comply with the provisions of the MUTCD.

Signs and other devices mounted lower than 7 feet above the temporary pedestrian pathway should not project more than 4 inches into accessible pedestrian facilities.

Fencing should not create sight distance restrictions for road users. Fences should not be constructed of materials that would be hazardous if impacted by vehicles. Wooden railing, fencing, and similar systems placed immediately adjacent to motor vehicle traffic should not be used as substitutes for crashworthy temporary traffic barriers.

Ballast for TTC devices should be kept to the minimum amount needed and should be mounted low to prevent penetration of the vehicle windshield.

Movement by work vehicles and equipment across designated pedestrian paths should be minimized and, when necessary, should be controlled by flaggers or TTC. Staging or stopping of work vehicles or equipment along the side of pedestrian paths should be avoided, since it encourages movement of workers, equipment, and materials across the pedestrian path.

Access to the work space by workers and equipment across pedestrian walkways should be minimized because the access often creates unacceptable changes in grade, and rough or muddy terrain, and pedestrians tend to avoid these areas by attempting non-intersection crossings where no curb ramps are available.

A canopied walkway may be used to protect pedestrians from falling debris, and to provide a covered passage for pedestrians. Covered walkways should be sound construction and adequately lighted for nighttime use.

When pedestrian and vehicle paths are rerouted to a closer proximity to each other, consideration should be given to separating them by a temporary traffic barrier. If a temporary traffic barrier is used to shield pedestrians, it should be designed to accommodate the specific site conditions.

Guidance for locating and designing temporary traffic barriers can be found in Chapter 9 of AASHTO's Roadside Design Guide (AASHTO, 2011).

Short intermittent segments of temporary traffic barrier shall not be used because they nullify the containment and redirective capabilities of the temporary traffic barrier, increase the potential for serious injury both to vehicle occupants and pedestrians, and encourage the presence of blunt, leading ends. All upstream leading ends that are present shall be appropriately flared or protected with properly installed and maintained crashworthy cushions. Adjacent temporary traffic barrier segments shall be properly connected in order to provide the overall strength required for the temporary traffic barrier to perform properly.

Normal vertical curbing shall not be used as a substitute for temporary traffic barriers when temporary traffic barriers are needed.

If a significant potential exists for vehicle incursions into the pedestrian path, pedestrians should be rerouted Figure 13-72) or temporary traffic barriers should be installed.

Tape, rope, or plastic chain strung between devices are not detectable, do not comply with the design standards in the ADAAG, and should not be used as a control for pedestrian movements (U.S. Access Board, 2002). In general, pedestrian routes should be preserved in urban and commercial suburban areas. Alternative routing should be discouraged. The highway agency in charge of the TTC zone should regularly inspect the activity area so that effective pedestrian TTC is maintained.

Figure 13-72 Pedestrian Facility Detour Sign

13.4.12.2 Accessibility Considerations

The extent of pedestrian needs should be determined through engineering judgment or by the individual responsible for each TTC zone situation. Adequate provisions should be made for pedestrians with disabilities.

When existing pedestrian facilities are disrupted, closed, or relocated in a TTC zone, the temporary facilities shall be detectable and include accessibility features consistent with the features present in the existing pedestrian facility. Where pedestrians with visual disabilities normally use the closed sidewalk, a barrier that is detectable by a person with a visual disability traveling with the aid of a long cane shall be placed across the full width of the closed sidewalk.

If a pushbutton is used to provide equivalent TTC information to pedestrians with visual disabilities, the pushbutton should be equipped with a locator tone to notify pedestrians with visual disabilities that a special accommodation is available, and to help them locate the pushbutton.

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Bridges

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Chapter

14

14 Bridges

14.1 Introduction

This chapter addresses the basic issues the roadway designer must consider when designing a roadway project that includes major or minor structures. It also describes the required coordination with the other specialty groups in CDOT.

14.2 Scope of Work Development

Refer to the CDOT *Bridge Design Manual*, Policies and Procedures, Section E (CDOT, 2023) for the minimum project scoping requirements for structures.

The Staff Bridge Branch plays an active and early role in the development of the project-specific activities related to highway structures. The Staff Bridge Unit Leader designates an experienced Staff Bridge employee to assist the Project Manager in the project scoping. The designated person is normally the Staff Bridge Unit Leader whose unit performs the structural design. When a consultant does the structural design, the Staff Bridge Unit Leader assigned to the project assists in the scoping and review of the design.

The designated Staff Bridge employee, in conjunction with the Project Manager, identifies the structure-related activities necessary for a project.

The Staff Bridge employee, jointly with the Project Manager, develops a detailed list of the specific information that is needed by the structural design team from others (for example, roadway plan and profile, geotechnical report, architectural treatment guidelines) and establishes a schedule for receipt of this information by the structural design team.

The Staff Bridge employee and the Project Manager establish a schedule for the submittals that are to be made by the structural design team. Refer to Section 14.8.

14.3 Definitions

For additional definitions of structures managed by CDOT and assigned a structure number or structure ID, refer to the CDOT *Bridge Design Manual* Section Policies and Procedures, D (CDOT, 2023).

14.3.1 Major Structures

Major structures are bridges and culverts with a total length greater than 20 feet measured along the centerline of the roadway between the inside face of abutments, inside faces of the outermost walls of culverts, or spring lines of arches. Major structures also include culverts with multiple pipes where the clear distance between the centerlines of the exterior pipes, plus the radius of each of the exterior pipes, is greater than 20 feet. Refer to CDOT *Bridge Design Manual*, Section Policies and Procedures, D (CDOT, 2023).

14.3.2 Minor Structures

Minor structures are bridges, culverts, or a group of culverts that have a length greater than or equal to 4 feet and less than or equal to 20 feet measured along the centerline of the roadway between the inside face of abutments, inside faces of the outermost walls of culverts, or spring lines of arches. Refer to CDOT *Bridge Design Manual*, Section Policies and Procedures, D (CDOT, 2022).

14.3.3 Special Inlet or Outlet

Special inlets or outlets are those with features beyond the customary headwalls, wings, and aprons, as provided in the CDOT Standard Plans - M & S Standards (CDOT, 2019). Examples are trash grates, energy dissipaters, trash walls, integral check dams, steeply sloping inverts, varying culvert size at the culvert end, and non-standard apron details.

14.3.4 Standard CBCs vs. Non-Standard CBCs

Standard concrete box culverts (CBC) are those covered by the current CDOT Standard Plans - M & S Standards without modifications (CDOT, 2019). This does not preclude using the CDOT Standard Plans - M & S Standards as work sheets to provide for custom design and details (CDOT, 2019).

Currently, the CDOT Standard Plans - M & S Standards (CDOT, 2019) are limited to “cell” spans 20 feet and less and opening heights up to 10 feet, typical fill heights between 0 and 20 feet (less for the longer spans and up to 30 feet for triple CBCs), full floor without piles, no change in cross section, and live load of HL-93 Truck, HL-93 Tandem, Colorado Permit Truck, and national rating load (NRL).

Non-standard CBCs are those not described in the CDOT Standard Plans - M & S Standards (CDOT, 2019) in all structural respects. Typically, non-standard CBCs should be used only when standard CBCs cannot reasonably meet the site requirements for loading, span, height, or structural configuration.

14.3.5 Walls

As defined in CDOT *Bridge Design Manual* Section Policies and Procedures, D (CDOT, 2018); and CDOT *Retaining and Noise Wall Inspection and Asset Management Manual* (CDOT, 2016), walls are classified as follows:

- *Retaining Walls.* Walls retaining soil measuring at least 4 feet in height from the finished grade to the top of the wall at any point along the length of the wall.
- *Bridge Walls.* Retaining walls that contribute to the stability of the bridge or bridge approach. Bridge walls exclude wingwalls and culvert headwalls.
- *Noise Walls.* Noise walls of all types including other highway partitions and walls that do not typically retain soil.

14.4 Roadway Elements of Design,

14.4.1 Bridge Roadway Width

The curb-to-curb width of a bridge should carry the full-approach roadway width across the structure. The full-approach roadway width should include the number and width of travel lanes, width of shoulders, and width of guardrail offset prescribed for the particular functional classification of highway defined for the project. Also, it may include any additional roadway width needed for a median, acceleration or deceleration lanes, other auxiliary lanes, bike lanes, and pavement widening on curves. Where possible, avoid tapering medians, acceleration lanes, deceleration lanes, and other auxiliary lanes across a structure or having the transition for pavement widening on the structure.

Where there is combination curb and gutter construction, the gutter pan width shall be part of the shoulder area on the bridge. If that shoulder is being used for a bike lane, the gutter pan should be outside the bike lane area. The flow-line of roadway curb and gutter and the flow-line of the bridge curb should be aligned. This may be accomplished with a 10-foot transition at the approach to the structure. This policy applies to all structures with either concrete or asphalt approach roadways.

For bridges with approach shoulders less than 8 feet, other than those on the mainline of an interstate or other divided highway, the guardrail offset should be 2 feet as specified in M 606-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019).

14.4.2 Cross Slope

The cross slope on bridge decks shall be, in all cases, consistent with the cross slope of the adjoining roadway. Where possible, avoid having the transition from normal cross slope to full superelevation on a bridge.

14.4.3 Median

The Staff Bridge Branch should be consulted to determine median treatment. Undercrossing roadways may require additional median width to accommodate placement of bridge pier columns.

14.4.4 Horizontal Alignment

The horizontal alignment of bridges should be consistent with the adjoining roadway. Where possible, avoid alignments that place spiral curves on structures. More requirements for bridge horizontal alignment can be found in the CDOT Bridge Design Manual, Section 2 (CDOT, 2022).

14.4.5 Vertical Alignment

The vertical alignment of bridges should be consistent with the adjoining roadway. In determining vertical alignment, possible structure depths should be discussed with the Project Structural Engineer so that a variety of structure types that are not limited by the lack of sufficient vertical clearance can be considered. Where possible, avoid alignments that place the bottoms of sag vertical curves on structures. The recommended minimum grade for drainage is 0.5%. For more information refer to the CDOT *Bridge Design Manual*, Section 2 (CDOT, 2022).

14.4.6 Bridge Skew Angle

As defined in the CDOT *Bridge Design Manual*, Section 4 (CDOT, 2022), bridge skew angles are measured between a line normal to the layout lines (either tangents or chords) or girder lines and the centerlines of bearing of bridge spans or other transverse reference lines. Usually, structures are skewed so that the centerlines of the substructure elements (abutments, piers, culvert walls) are parallel to the feature intersected by the roadway alignment. Where possible, avoid horizontal alignments, such as spirals, that increase the number of different skew angles at the various points of intersection on a bridge. Set the skew angle as close to 0 degrees as possible but less than 50 degrees.

14.4.7 Bridge Sidewalks and Bikeways

The Accommodating Bicycle and Pedestrian Travel: US DOT Policy Statement on Bicycle and Pedestrian Accommodation Regulations and Recommendations states: “Transportation agencies are encouraged, when possible, to avoid designing walking and bicycling facilities to the minimum standards. For example, shared-use paths that have been designed to minimum width requirements will need retrofits as more people use them. It is more effective to plan for increased usage than to retrofit an older facility. Planning projects for the long-term should anticipate likely future demand for bicycling and walking facilities and not preclude the provision of future improvements.” (USDOT, 2010)

The clear walkway shall meet Proposed Rule Public Right of Way Accessibility Guidelines (PROWAG) (U.S Access Board, 2011). Additional width (up to 12 feet) may be required in a commercial area or near a school or for a shared pedestrian-bikeway facility. The minimum sidewalk width on a bridge shall be 5 feet.

For high-speed (greater than 45 mph), high-volume (greater than 50,000 annual average daily traffic) roadways or those without an approach curb, an approved traffic barrier shall be placed between the travel way and the sidewalk or bikeway.

Bridge railings need to be raised to provide appropriate protections for the pedestrian and cyclist using the bridge as a crossing. Bridge railing height can vary from 30 to 42 inches tall depending upon the type of barrier being considered. When a pedestrian walkway or shared-use path is incorporated into the bridge structure, the barrier height needs to be increased to a minimum of 42 inches above the shared-use path surface. This would also apply to a bike lane on the bridge requiring the barrier to be a minimum of 42 inches tall from the surface of the bike lane. When assessing barrier types for a bicycle or shared-use path facility, the designer should consider pedal strike, handlebar strike, and fall hazards. Refer to Chapters 12 and 13 of this Guide for additional information on pedestrian and bicycle accommodations and the CDOT *Bridge Design Manual* Section 2 (CDOT, 2022).

14.4.8 Embankment Slopes at Bridge Approaches

Embankment slopes at bridge approaches should be 2:1 or flatter. For an interstate undercrossing and other high-speed under crossings, a 4:1 slope should be placed within the clear zone between the bottom of the outside ditch and the start of the 2:1 slope. Slopes should be designed for adequate drainage (refer to Section 14.6.2). More detailed information is shown in the CDOT *Bridge Design Manual*, Section 2 (CDOT, 2023) and the AASHTO *Roadside Design Guide* (AASHTO, 2011).

14.4.9 Clearance to Structures and Obstructions

Minimum horizontal and vertical roadway clearances to structures and obstructions are shown in Table 3-3 of this Guide.

If the bridge is spanning a waterway or other natural environment, the designer should consider whether the bridge will need clearance to accommodate a future connection to a shared-use path and the characteristics of the predominant shared-use path user, such as pedestrians, bicycles, or people riding horses to inform the clearance height.

Unusual clearance problems at a structure should be discussed with the Staff Bridge Branch early in the design process so that effective solutions are found. More detailed information on bridge clearances is shown in the CDOT *Bridge Design Manual*, Section 2 (CDOT, 2022).

14.5 Roadway Design Submittal to Bridge/Structure Designer

14.5.1 Purpose

Normally, the Project Structural Engineer must rely on other members of the design team for site information, horizontal and vertical alignments, hydraulic requirements, and roadway templates.

Well-scoped projects and adequate preliminary information eliminate the need for supplemental survey requests. With electronic surveys, special care must be taken during data collection to obtain adequate site information.

14.5.2 Project Scoping

Refer to Section 1 of the *CDOT Project Development Manual* (CDOT, [2013] 2022) and the CDOT *Bridge Design Manual* Section Policies and Procedures, E1 (CDOT, 2023).

14.5.3 Survey Requests for Bridges

The Project Structural Engineer should be contacted and requested to provide survey requirements prior to making the request for survey. Refer to the CDOT *Survey Manual* (CDOT, 2021).

14.5.4 Roadway Design Submittal to Project Structural Engineer

The roadway design submittal should provide sufficient information to locate the structure vertically and horizontally, as well as to determine the size of structure required. At a minimum, the following must be provided:

- Typical Sections of Upper and Lower Roadways.
- Roadway Plan and Profile Sheets showing proposed alignments.
- Preliminary Hydraulics Recommendations for any structure over a waterway.
- Bridge Situation Sheet showing topography and contours at 2-foot intervals.
- Locations of all known utilities.
- Any applicable Corridor Design Concepts or special architectural features.
- Preliminary Form 463, Design Data.

Submittals in the electronic format must use the CDOT configuration and include all cross-referenced MicroStation drawings. The files must not contain LISP files, special character sets, fonts, shape files, or other customized information required to access the drawing files.

Drawings that represent field data surveyed or proposed design alignments should be represented within the drawing files at true scale and in the correct project coordinate locations. The Staff Bridge Branch shall be contacted for other requirements and submittal formats.

All alignments must be included in the electronic files. Paper copy listings of all points, curves, and horizontal and vertical alignments with stations and coordinates must be provided. A list of which files contain alignments and surfaces would be helpful.

Refer to the CDOT *Bridge Design Manual*, Section Policies and Procedures, E1 (CDOT, 2022).

14.6 Hydraulics Reports

14.6.1 Stream and River Crossings

Although hydraulics reports are written by the hydraulics designer, they are the result of a coordinated, cooperative, multidisciplinary effort. After a joint site visit by the hydraulics designer and bridge designer, a joint memo must be prepared by the hydraulics designer and sent to the Project Manager stating the concerns, conclusions, or issues discussed at the site review. The hydraulics designer provides the bridge designer the hydraulics information needed to start the design of the structure.

After geotechnical borings are taken and analyzed, but prior to the submittal of the Foundation Report, the bridge, hydraulics, and geotechnical engineers discuss bridge site scour conditions.

The Hydraulics Design Engineer then prepares a Final Hydraulics Report and the Bridge Hydraulic Information Plan Sheets.

For more information, refer to the CDOT *Drainage Design Manual* (CDOT, 2019) and the CDOT *Bridge Design Manual* (CDOT, 2023).

14.6.2 Roadside and Bridge Deck Drainage

The Roadway Design Engineer, Hydraulics Design Engineer, and Project Structural Engineer should coordinate and analyze roadway and deck drainage requirements. Problems have occurred where drainage was not adequately addressed. Problems ranged from loss of material around guardrail posts to total loss of embankment and slope paving.

Consideration of drainage is needed where the water flows around the abutment wingwalls or ends and where water may cross an expansion device. Discharging drainage from the structure directly into waterways usually is not permitted, and the handling of drainage should be coordinated with the Region Planning/Environmental Program Manager.

14.7 Special Requirements

14.7.1 Permits

Consider the following regarding permits:

- Coordinate with the Region Planning/Environmental Manager; and the materials and geotechnical, and project structural engineers to obtain all necessary environmental permits. Refer to the CDOT *Project Development Manual* (CDOT, [2013] 2022).
- Construction access to the streambed.
- Right-of-entry permits.
- Temporary easements.
- Maintenance access.

14.7.2 Environmental

It is possible to locate a structure virtually anywhere. However, impact to the environment may weigh in the structure location decision and determine the type of construction. The extent of allowable construction impact to the site must be known to accommodate those limitations in the structure design.

Where a structure is located, and what the structure is founded on affects the construction time required and the cost of a project. Landfills and sites where settlement is likely to occur are less desirable structure locations. Recreational uses of the feature spanned by the structure (e.g., kayak, pedestrian, equestrian), as well as the ability of the structure to accommodate recreational use, must be thoroughly investigated so that specific elements can be integrated into the structure design.

Anticipation of dewatering activities for deep foundations should be checked for water quality and the impacts of settlement to surrounding buildings and the roadway.

Whenever environmental concerns need to be accommodated by the structure, they must be made known early, prior to the start of the structure design.

14.7.2.1 Historic Requirements

Determining whether the existing structure is historic can be a time-consuming process. This determination can also affect the design of a new structure. Early identification of the structure's historic relevance is critical during the initial scoping of the project so that the design schedule accommodates the coordination required. Refer to Section 3.08 of the CDOT *Project Development Manual* (CDOT, [2013] 2022).

14.7.3 Aesthetics

There is a limit to the number of aesthetic treatments eligible for federal funding that can be incorporated into a new structure. The designer should consult with the Staff Bridge Branch and FHWA for eligibility. Consultation with the Colorado Bridge Enterprise program may also be necessary to determine what aesthetic treatments may be allowed. Refer to Section 5.05 of the CDOT *Project Development Manual* (CDOT, [2013] 2022).

14.7.3.1 Structural Coatings

The appropriate type of coating treatment should be discussed early in the process with Region Maintenance and the Staff Bridge Branch.

14.7.4 Utilities

The location and elevation of all utilities in the vicinity of a structure must be known prior to the start of the final structure design. Frequently, conflicts with utilities can be avoided simply by designing around them. Utilities that must remain in service during construction may require temporary support and additional construction staging. The designer should coordinate with the

Staff Bridge Branch as soon as possible if utilities are to be located on the structure. Refer to the CDOT *Bridge Design Manual* (CDOT, 2022).

14.7.5 Construction

14.7.5.1 Detours and Staging

The most desirable construction detour method is to route the traffic around the structure site. However, replacement of a structure and structure widening usually requires traffic to be shifted during construction to create a safe work zone.

Construction staging allows a structure to be built in stages while maintaining traffic. Careful planning must go into the construction staging since the feature spanned by the structure will pass beneath throughout construction. Adequate spacing between the construction stages is required to accommodate placement of temporary barriers and allow sufficient room to work on the structure.

Detour and staging concepts must be developed early because they are necessary for the development of the Structure Selection Report and associated bridge general layout.

Refer to Chapter 6 of this Guide and Section 8.02 of the *CDOT Project Development Manual* (CDOT, [2013] 2022).

14.8 Foundations and Structures

The Staff Bridge Branch and the Geotechnical Branch work together to determine the feasible foundation type. A foundation investigation request from the Project Structural Engineer must be addressed to the Resident Engineer who is responsible for site staking and access clearance. Drilling shall not commence until the Geotechnical Engineer has been notified that access is cleared.

Refer to Sections 5.06 and 6.03 of the CDOT *Project Development Manual* (CDOT, [2013] 2022).

14.9 Structural Design Submittals

The “structure design team” referred to in this section is either the Staff Bridge Branch Design Unit or the consultant firm performing the structural design for the project.

Project submittals by the structure design team are listed below. Except for the last bullet, these submittals are made to the Resident Engineer who makes the necessary distributions. Time frames in parentheses indicate the minimum time required by the project structural engineer to complete the submittal once all necessary information is received. Refer to the CDOT *Bridge Design Manual*, Section Policies and Procedures, E (CDOT, 2023), for additional information.

If the submittal requires review and comment, the normal time frame allowed for the review is given. Prompt and thorough review of the submittals is necessary to ensure adherence to the project schedule. Changes introduced after the Field Inspection Review can result in a considerable amount of additional design time for the structural design team.

The project structural engineer is responsible for:

- *Structure Selection Report.* This report is required for all structures and retaining walls. The report provides the structure type recommended by the structural design team and includes structure general layouts (including retaining walls) and preliminary cost estimates. After the report has been reviewed, it is revised to include all necessary changes and decisions. This updated report identifies the final structure type approved for the project (if different than recommended) and includes the associated General Layout and preliminary cost estimate. This report includes pertinent hydraulic and foundation report information. (Two weeks)
- *Request for foundation investigation.* The structural design team initiates the foundation investigation by identifying the test holes needed as early in the project as is practical. This request is sent to the Resident Engineer with a copy to either CDOT's Geotechnical Engineer in the Materials and Geotechnical Branch or the consultant geologist, as applicable.
- *General Layouts for the Field Inspection Review.* The General Layout in the final Structural Selection Report may be used for the Field Inspection Review set of plans if it has not been revised following review of the Structure Selection Report.
- *Advance Plans and Specifications.* To reduce or eliminate the need to discuss specific structural design details during the Final Office Review, this optional early review of structural details can be conducted. This review also allows changes that require structural redesign to be made without disrupting the post Final Office Review project schedule. (Three weeks)
- *Complete Plans and Specifications for the Final Office Review* set of plans.
- *Final Plans and Specifications* for the advertisement set of plans.
- *Submittal of the structural records on the project.* This submittal is made to the Bridge Management System unit of the Staff Bridge Branch by the structural design team. This project submittal includes the Structure Selection Report, structural design notes, and design check notes, the bridge rating package, and the correspondence file regarding structures.
- *Structural Field Packages.* Submitted to Resident Engineer for use by the Project Engineer to check quantities and assist with resolving questions about the quantity calculations. This includes a copy of the foundation report. The field package may be requested at any time after advertisement of the project.

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Chapter

15

15 Traffic and Safety Engineering

15.1 Introduction

The mission of CDOT's Traffic Safety and Engineering Services Branch is to strategically reduce traffic crashes and resulting deaths, injuries, and property damage; and to improve the flow of traffic through effective application of traffic engineering principles. This chapter addresses most, but not all, important design issues related to providing a safer transportation system.

15.2 Roadway Safety

Major factors affecting highway safety are the roadway geometrics and roadside features, driver ability and attentiveness, environmental and contextual factors, and vehicle characteristics. Highway safety is greatly influenced by variations among drivers (human factors), and driver expectations. The driver’s knowledge and driving experience in a given environment or roadway condition are also key determinants of a roadway’s safety performance. However, there are other factors, such as highway design, that have a tangible impact on safety.

Design consistency in terms of roadway geometrics, typical section, and hazard elimination, mitigation, or shielding should be consistent throughout a corridor to minimize unexpected conditions. Advance warnings of changing conditions should be provided as a last resort when mitigation of the hazard is not possible.

The designer should request a Traffic Operations Evaluation from the Region Traffic Representative for a safety and traffic operations analysis of their project to determine if a more detailed safety assessment report is required. The report or analysis includes recommendations for safety improvements based on evaluation of the crash data within a project’s limits. The designer should document decisions to apply or not to apply any given safety feature in accordance with the CDOT *Project Development Manual* (CDOT, [2013] 2022).

Primary references for safer designs are the AASHTO *Highway Safety Design and Operations Guide* (AASHTO, 1997), and the AASHTO *Roadside Design Guide* (AASHTO, 2011).

15.2.1 Bicycle and Pedestrian Safety

The safety of bicyclists and pedestrians should be considered during scoping and design of all new projects including resurfacing. Shoulder rumble strips are effective as a roadway departure mitigation, but on rural highways should only be used on roads with a 4-foot-wide or wider paved shoulder. Rumble strips on a narrow shoulder (less than 4 feet wide) force bicyclists into the through lanes of traffic, which creates a speed differential hazard with vehicles. Bicyclists and pedestrian traffic during construction should also be a major consideration during the design scoping of all projects to resolve access issues with the temporary conditions of the roadway.

Refer to Chapter 13 of this Guide for additional information on designing for bicyclist and pedestrian safety.

15.2.2 Animal-Vehicle Collisions

In many rural areas of Colorado, particularly on the Western Slope, animal-vehicle collisions (AVC) are frequently the highest crash type on many roadways. The designer must closely evaluate the crash data and safety analysis from the Operations Evaluation to determine if the number of AVCs warrants mitigation. Wildlife fencing can effectively mitigate these crash types. Safe passage (overpasses and underpasses) is even more effective of a collision countermeasure and may be needed where it is necessary to maintain habitat connectivity and migratory patterns. Wildlife specific signing and warning systems can also be utilized. CDOT has worked extensively with Colorado Parks and Wildlife to analyze critical habitat corridors on the Western Slope, and are expanding the analysis to include roadways on the eastern slope. Early communication with the Region Environmental Program Manager and the Region Traffic Engineer helps to identify if a project needs mitigation for AVCs.

Use this link to access CDOT's wildlife prioritization studies, data and tools: https://www.codot.gov/programs/research/pdfs/2022/wildlife-prioritization

15.2.3 Railroad-Highway Grade Crossings

Railroad-highway grade crossings involve two distinct modes of transportation with different operating authorities and operating characteristics. A roadway and a railway may intersect at-grade, or may be grade-separated by a structure that carries the roadway over or under the railroad. Most of Colorado's railroad-highway grade crossings are at grade.

A railroad-highway grade crossing is characterized by continuous vehicular traffic, interrupted periodically by a train's passage. The intermittent nature of train operations may dull a driver's awareness to a train's possible approach. Some drivers are tempted to disregard warnings and try to beat a train through the crossing. Except in unusual circumstances, trains have the right-of-way because of their huge mass and very long stopping distances. Safety at railroad-highway grade crossings is of utmost importance. The roadway design should include appropriate features to discourage risky driver behaviors, to provide sufficient advance notice of the grade crossing and of a train's approach or presence, and, as appropriate, to physically prohibit vehicles from entering the crossing.

Railroad grade crossings and crossing requirements are administered by the Colorado Public Utilities Commission (PUC). If a project is going to modify, improve, or adversely impact a rail crossing, the project manager must advise the Region Utility Engineer and the CDOT Railroad Program Manager who may also communicate with the PUC Engineer to discuss expectations and options for a crossing modification. It is important to begin this discussion very early in the project development cycle to avoid delays to the overall project schedule.

Use this link to access more information on railroad clearances: *https://www.codot.gov/business/project-management/execute-fir-for-ad/railroad-utilities*

Strategies for improving railroad-highway grade crossing safety include upgrading warning devices and improving the geometry, sight distance, and ride quality of the crossing. Active grade crossings contain train-activated devices that warn drivers of the approach or presence of a train. When new devices, such as gate supports, are installed, they may become roadside hazards and warrant shielding from errant vehicles.

The project manager must also determine if the crossing location is also frequented by bicyclists and pedestrians. If bicycle and pedestrian activity is frequent, safety improvements may be necessary for those multimodal uses. Improvements can include trail crossing gates, truncated domes, aligning bike crossings to be perpendicular to the rails, and other warning systems. Refer to Chapter 13 of this Guide for more information.

Passive grade crossings lack warning devices and rely on signs and pavement markings to identify the crossing location. Passive grade crossings have a higher risk for crashes because there is less direct control over driver actions. Where passive grade crossings remain in place, enhanced sign systems and improved driver sight distance to see approaching trains may increase driver awareness and responsiveness.

Active railroad-highway grade crossings that are located adjacent to a signalized roadway intersection increase the complexity of signing and signals. Drivers may receive conflicting information from such closely spaced signals, or traffic stopped at the adjacent signalized intersection may queue back onto the grade crossing. Consideration should be given to interconnecting the traffic control signal with the active control system of the railroad crossing and providing a "pre-emption" sequence. With pre-emption, the approach of a train causes the traffic signals to enter a special mode to control traffic movements in coordination with the train's passage through the crossing. Traffic control signals near railroad-highway grade crossings shall conform to Section 8C.09 of the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (FHWA, [2009] 2022); and pre-emption shall conform to Section 4D.27 of the

MUTCD. A Systems Engineer Analysis can help to identify the optimal Intelligent Transportation System (ITS) and signal solution to accommodate a railroad crossing at or near a signalized intersection.

When a railroad-highway grade crossing is located within the limits of a rehabilitation project, the crossing, along with any existing devices, should be relocated or reconfigured as necessary to be compatible with changes to the highway. A safety assessment of the existing crossing should also be conducted and, to the extent feasible, the project should include any appropriate crossing safety improvements.

Closing unnecessary grade crossings improves safety by eliminating the potential for vehicle-train crashes and by concentrating limited safety funds on the remaining crossings. Guidance for eliminating and consolidating railroad-highway grade crossings is provided in AASHTO *Highway-Rail Crossing Elimination and Consolidation* (AASHTO, 1995). While closing a crossing may be the preferred option for a project, the project manager should have a thorough conversation with the Region Utility Engineer, and the Railroad Program Manager to understand the timeline and effort required to complete a crossing closing. This should be completed early in the project development process to account for negotiations, administrative hearings, and time for a final determination to be made.

All projects involving work on railroad property or adjustments to railroad facilities require a written contract between CDOT, the railroad, and any other involved local agencies. Any changes to a grade crossing's operating characteristics must be coordinated with the PUC. The CDOT Railroad and Utilities Program within the Project Development Branch administers the highway-rail grade crossing program and is CDOT's point of contact with the railroad, the PUC, and local agencies on all railroad contracts.

For additional guidance on railroad-highway grade crossing components, safety assessment, safety measures, project development, and traffic control, refer to:

- FHWA *Railroad-Highway Grade Crossing Handbook*, Third Edition (FHWA and FRA, 2019).
- FHWA *Guidance on Traffic Control Devices at Highway-Rail Grade Crossings* (FHWA, 2002).
- *Manual on Uniform Traffic Control Devices* (MUTCD) Part 8 (FHWA, [2009] 2022).
- CDOT *Railroad Manual* (CDOT, 2017).

15.2.4 Roadway Geometry Considerations

Horizontal curves typically have crash rates from 1.5 to 4 times higher than tangent sections. Crash rates tend to increase due to reduced sight distance associated with either a reduced curve radius or an increased deflection angle. Therefore, it is usually beneficial to maximize curve radii and minimize deflection angles when designing alignments. The use of spiral curves can help to mitigate some of the safety problems associated with horizontal curves by:

- Providing a safer path for the driver from a tangent position to a curve position

- Providing a location for the required length of transition from normal crown to full superelevation.

The attributes of spiral curves are explained in Section 6.2.4.2 of this Guide and Chapter 3 of the A Policy on Geometric Design of Highways and Streets (2018 AASHTO GDHS) (AASHTO, 2018).

Vertical curves can also lead to higher crash rates due to the reduced sight distance imposed by the crest of a vertical curve. Accordingly, the designer should minimize the severity of vertical curvatures in the alignment design. Intersections and roadway accesses located on or near vertical curves should be investigated thoroughly and avoided when practical alternatives can be found.

Designers should also review all existing curves on a roadway segment for large differences between posted speeds versus curve design speeds. Any major differences should warrant consideration of reduced speed limits, advisory signage, chevrons, and the addition of guardrail.

15.2.5 Intersections

Intersections are major points of conflict. Safety measures that can reduce conflict, particularly from left turns, include roundabouts, medians, offset left turns to improve driver sight distance and visibility, protected left-turn phasing of signals, and auxiliary lanes among other measures. Left-turn lanes should be designed with an offset to provide for proper sight distance to oncoming traffic when a vehicle is in the opposing left-turn lane. Safer methods for accommodating pedestrian and bicycle traffic movements through the intersection should also be considered (refer to Chapter 13 of this Guide). All-way stops or roundabouts may sometimes be desirable alternatives to traffic signals. Criteria for all-way stops are found in Section 2B of the (MUTCD) (FHWA, [2009] 2022). Further information on roundabout design is found in Chapter 9 of this Guide and the FHWA *Roundabouts: An Informational Guide* (FHWA, 2000).

“Stop Ahead” warning signs should be placed ahead of intersections where the driver may not anticipate the required stop or where sight distance is obstructed. For additional emphasis, a yellow beacon above the “Stop Ahead” sign, a red beacon above the “Stop” sign, or both can be considered. Recently the addition of embedded LED borders for stop signs or advanced warnings signs have greatly improved driver compliance at intersections. The designer should discuss if these options are appropriate with the region traffic engineering staff.

The designer must consider the corner radii and sight distances at intersections. A large corner radius can increase the roadway crossing width, making it more hazardous for pedestrian crossing, and also tends to increase vehicle speed through intersection corners. There are various options for intersection corners and shorter pedestrian crossings. Taking the time to understand the vehicles using the intersection and the corner and crossing options can help to make the intersection safer for all users. Designing a corner with too small a radius can cause maneuverability and safety problems for large vehicles and pedestrians, increasing the potential for pedestrian conflicts when large vehicles track over the adjacent curb and sidewalk.

As part of a project, traffic signals should be replaced or modified to comply with current standards, including PROWAG, and to meet design traffic demands.

It is essential to have proper application of traffic control devices to designate right of way and safe movement of all traffic, including pedestrians and bicyclists. Refer to the standards published in the latest edition of the MUTCD (FHWA, [2009] 2022).

If a designer or design team is considering a new intersection or significant changes to the operations or geometry of an intersection, a request to utilize the CDOT Intersection Control Assessment Tool or "ICAT" should be submitted to the Region and HQ Traffic Operations teams. CDOT's ICAT quantitatively evaluates several intersection control scenarios (alternatives) and ranks these alternatives based on their operational and safety performance. Implementing a performance-based procedure such as ICAT creates a transparent and consistent approach to consider intersection alternatives based on metrics such as safety, operations, cost, and social, environmental, and economic impacts.

Use this link to access more information on CDOT's Intersection Control Assessment Tool (ICAT): https://www.codot.gov/programs/maintenance-operations/tsmo-evaluation

Use this link to access more information on FHWA's Capacity Analysis for Planning of Junctions (CAP-X) Tool: https://www.fhwa.dot.gov/software/research/operations/cap-x/

15.2.6 Multimodal Traffic Control Devices

Over the last few years there has been an increased focus on safety for the most vulnerable road users—pedestrians and bicyclists. Many studies and efforts have been tested to improve driver compliance as well as pedestrian and bicyclist compliance to prevent bicycle and pedestrian crashes. Below are several types of traffic control devices specifically focused on improving bicycle and pedestrian safety at roadway crossings.

15.2.7 Pedestrian Crossing Safety Devices

There is a multitude of devices and methods to improve pedestrian safety at crossings including improved markings, signing, and lighting. Below are some additional measures that can be investigated where there is high pedestrian activity, or a safety analysis has identified the need to improve pedestrian safety at a crossing location.

- *Pedestrian flashing beacons.* Can be installed in advance of a pedestrian crossing to warn motorist of the presence of a pedestrian. These can be static flashing devices or pedestrian activated devices to provide a more dynamic warning which may increase driver compliance over the continual flashing device.

- *Rectangular Rapid Flashing Beacons (RRFB).* This is a pedestrian actuated enhancement for pedestrian crossings. RRFBs have been found to reduce pedestrian vehicle crashes by up to 47%. Typically, these are used on roadways with a posted speed limit of less than 40 MPH. On multi-lane roadways a refuge median and the addition of median RRFBs in each direction is highly recommended to maintain compliance from all lanes of traffic when pedestrians are present.

Use this link to access more information on RRFBs:
https://highways.dot.gov/safety/proven-safety-countermeasures/rectangular-rapid-flashing-beacons-rrfb

- *Pedestrian Hybrid Beacons (PHB) -* Pedestrian hybrid beacons are a modified signal system specifically for pedestrian crossings that are activated by the pedestrian to obtain driver compliance to stop for the pedestrian crossing maneuver. PHBs are more common on high volume roadways with multiple lanes of traffic and on roadways where the posted speed limit is over 35 MPH, but they can also be used on roadways with posted speed of 35 MPH or less. Warrants for the installation of PHBs can be found in the MUTCD Chapter 4F (FHWA, [2009] 2022). PHBs have been found to reduce pedestrian crashes by up to 69% and overall crashes by 29%.

Use this link for more information on PHBs:
https://safety.fhwa.dot.gov/provencountermeasures/ped_hybrid_beacon.cfm

- *Leading Pedestrian Interval (LPI) -* An LPI gives pedestrians the opportunity to enter the crosswalk at a signalized intersection 3-7 seconds before vehicles are given a green indication. This helps to better establish the pedestrian's presence in the intersection to the motorists making them more visible before right or left turns are made by vehicles. LPIs have shown a 13% decrease in pedestrian vehicle crashes at intersections.

Use this link for more information on LPIs:
https://safety.fhwa.dot.gov/provencountermeasures/lead_ped_int.cfm

15.2.8 Bicycle Safety Devices

- *Bicycle shared lane markings (SLM) or "Sharrows."* Markings used to indicate a shared lane for bicyclists and motorists where there is insufficient room to add a bike lane outside of the travel lane. Typically, these are used on roadways with a posted speed of 35 mph or less in urban corridors. These should only be used if there is no other alternate location to provide bike refuge on the roadway section and the project manager shall discuss all options with the region traffic engineer before implementing this in the project design.

Use this link for more information from NACTO on SLMs:
https://nacto.org/publication/urban-bikeway-design-guide/bikeway-signing-marking/shared-lane-markings/

- *Bicycle lanes.* Most fatal and serious injury crashes with bicyclists occur at non-intersection locations where a motorist overtakes a bicycle. The speed differential along with the difference in mass between the vehicle and bicyclist can lead to serious injury or death. Providing a bike lane can reduce crashes up to 49% on urban 4-lane undivided collectors and 30% on urban 2-lane undivided collectors. The project manager should carefully investigate the presence and use of the roadway by bicyclists to determine if additional countermeasures to improve bicyclist safety are appropriate. There are also several different types of bike lanes to consider including buffered bike lanes and separated bike lanes.

Use this link for more information from FHWA on Bicycle Lanes:
https://safety.fhwa.dot.gov/provencountermeasures/bike-lanes.cfm

Use this link to access FHWA's Bikeway Selection Guide:
https://safety.fhwa.dot.gov/ped_bike/tools_solve/docs/fhwasa18077.pdf

- *Bicycle signal phasing.* There are several options to consider for bicycles at intersections.
  - *Lead bike interval.* Provides a bicyclist a three second head start crossing the intersection before vehicles receive the green indication.
  - *Exclusive bicycle phasing.* Installation of a bicycle signal head will allow fully protected bicycle phases to operate at intersections independent from the normal signal phasing for vehicles. During this type of phasing "scramble" phasing is prohibited (allowing all direction of bike traffic to move at the same time).
  - *Bicycle detection.* Bike boxes with detection for bicyclists will allow the signal to detect the presence of a bicyclist to change the signal phasing when a vehicle is not present.

Use this link to access FHWA's MUTCD Interim Approval for optional Use of a Bicycle Signal Face (IA-16):
https://mutcd.fhwa.dot.gov/resources/interim_approval/ia16/

Use this link to access ITE's Signal Timing and Phasing for Bicycles:
https://www.ite.org/technical-resources/topics/complete-streets/bicycle-signals/signal-timing-and-phasing-for-bicycles/

15.2.9 Interchanges

Interchanges do not always have the same direct conflict potential as intersections, but the vehicle merge areas often show a higher frequency of crashes.

A large portion of truck crashes occurs at interchanges. The potential for overturning of high-profile vehicles increases on circular (clover leaf) ramps. Adequate signing, careful attention to merging patterns, and ramp geometrics can mitigate these problems. These concepts are detailed in Chapter 10 of the *Highway Capacity Manual* (TRB, 2022).

If a designer or design team is considering a new interchange or significant changes to the operations or geometry of an interchange, a request to utilize the CDOT Intersection Control Assessment Tool or "ICAT" should be submitted to the Region and HQ Traffic Operations teams. CDOT's ICAT quantitatively evaluates several intersection control scenarios (alternatives) and ranks these alternatives based on their operational and safety performance. Implementing a performance-based procedure such as ICAT creates a transparent and consistent approach to consider intersection alternatives based on metrics such as safety, operations, cost, and social, environmental, and economic impacts.

Use this link for more information on CDOT's ICAT:
https://www.codot.gov/programs/maintenance-operations/tsmo-evaluation

Use this link to access more information on FHWA's Capacity Analysis for Planning of Junctions (CAP-X) Tool:
https://www.fhwa.dot.gov/software/research/operations/cap-x/

15.2.10 Context Sensitive Solutions

Safety is a challenge to be addressed on every project. It may not be the primary driver for a given project, but it should be a consideration in the development and evaluation. Context Sensitive Solutions (CSS) equally address safety, mobility, and the preservation of scenic, aesthetic, historic, environmental, and other community values. To balance these values the design process should be flexible in adherence to standards and criteria. A successful context-sensitive solution produces transportation designs that address both safety and feasibility. CSS maintains safety and mobility as a priority, yet recognizes that these are achieved in varying degrees with alternative solutions. Utilizing the CSS philosophy, CDOT design professionals determine which solution best fits, given the site's conditions and context. CSS is about making good engineering decisions within the context of the roadway and surroundings the road supports.

NCHRP Report 480, A Guide to Best Practices for Achieving Context Sensitive Solutions (CSS) (TRB, 2003) discusses two types of safety: nominal safety and substantive safety. “Nominal safety” equates adherence to standards or design policy with achieving safety and considers substandard designs to be unsafe. Under the nominal safety concept, a roadway designed to current or modern criteria would be characterized as ‘safe’. However, engineers should also consider substantive safety in the design process. Substantive safety refers to the actual (or expected) crash frequency and severity for a highway or roadway.

These two types of safety should be considered when addressing a safety problem. The solution should balance cost, environment, and other stakeholder values. High-crash locations with substandard design features should be prioritized for improvement. Locations that are nominally safe, but substantively less safe also should be considered.

For every project, the setting and character of the location, the values of the community, and the needs of highway users should be balanced.

Consider the following:

- Flexibility provided within the standards.
- Design exceptions where there are environmental or contextual concerns.
- Opportunities to re-evaluate decisions made in the planning phase.
- Design speed that is appropriate for contextual area it supports.
- Flexibility to modify existing horizontal and vertical geometry, cross section, and design for resurfacing, restoration, and rehabilitation (3R) improvements where it is known that the roadway may not integrate well with the surrounding area it supports.
- Alternative standards for differing contextual corridors or scenic routes.
- Safety and operational impact of various design features and modifications.

These concepts are discussed in detail in NCHRP Report 480, A Guide to Best Practices for Achieving Context Sensitive Solutions (CSS) (TRB, 2003) and *Flexibility in Highway Design* (FHWA, 1997). Additional information on context-sensitive solutions can be found in the following references:

- NCHRP Report 480, A Guide to Best Practices for Achieving Context Sensitive Solutions (FHWA, 2003).
- NCHRP Report 374, Effect of Highway Standards on Highway Safety (TRB, 1995).
- NCHRP Project 430, Improved Safety Information to Support Highway Design (TRB, 1999).
- NCHRP Report 362, Roadway Widths for Low-Traffic-Volume Roads (TRB, 1994).
- FHWA IHSDM: Interactive Highway Safety Design Model (FHWA, n.d.).

- FHWA, Prediction of the Expected Safety Performance of Rural Two-Lane Highways (FHWA, 2000).
- CDOT Chief Engineer's Policy Memo 26, Context Sensitive Solutions (CSS) Vision for CDOT (CDOT, 2005).

15.2.11 Work Zone Safety

Proper traffic control, delineation, and channelization are critical to achieving safety in work zones. A work zone can pose additional hazards to the motorist and cause risk to workers. All traffic control devices must meet the guidelines in the AASHTO *Manual for Assessing Safety Hardware* (MASH) (AASHTO, 2016), NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features (TRB, 1993) and the MUTCD (FHWA, [2009] 2022). Refer also to Section 20.5.1 of this Guide.

15.2.12 Lane Closure Strategies

Each of the CDOT Regions has established work zone lane closure strategies that consider traffic volume throughout the day and seasonally on all roadways across the state. The designer shall carefully consider the lane closure guidance on when lane closures may be allowed or adjust their project to support night work if that is required for a closure.

Use this link to access more information on CDOT's Work Zone Safety Program and access to the individual Region Lane Closure Policies: *https://www.codot.gov/safety/traffic-safety/performance/work-zone-safety*

15.2.13 CDOT Work Zone Safety and Mobility Procedures

Refer to CDOT Procedural Directive 1502.1, Traffic Control for Planned and Unplanned Work.

The FHWA rule on Work Zone Safety and Mobility led to the development and implementation of CDOT Policy Directives, as well as new procedures, specifications, and training requirements. CDOT implemented a Transportation Management Plan that lays out a set of coordinated strategies, describes how these strategies will be used to manage the work zone impacts of a project, and details training requirements.

In 2019, CDOT updated Procedural Directive 1502.1, Traffic Control for Planned and Unplanned Work. This procedural directive applies to all engineering work on roadways. Within this procedural directive, there is a guidance table on traffic control expectations based upon anticipated duration of the closure.

Use this link for more information on CDOT's Procedural Directive 1502.1 Traffic Control for Planned and Unplanned Work: Policies and Procedures — Colorado Department of Transportation (codot.gov)

15.2.14 Temporary Speed Limit Reductions

Refer to CDOT Procedural Directive 1502.2, Temporary Reduction in Speed Limits.

Whenever a planned work zone strategy includes a reduction in the posted speed limit the project needs to submit a Form 568 to the Region Traffic Engineer for approval. Procedural Directive 1502.2 details the requirements for requesting a speed limit reduction and to whom the speed reduction needs to be distributed to. This may seem to be a task to be left to the construction project engineer but when designing detours or temporary roadway conditions this needs to be considered for proper inclusion in the temporary roadway design.

15.2.15 Smart Work Zone Deployments

A Smart Work Zone is a toolbox of technologies that assess work zone conditions to generate actionable intelligence that improves the efficiency and safety of traveling public and workers in the work zone. The toolbox can include the applications of computers, communications, sensor technology, applications, software, connected or non-connected equipment, data collection, traffic control centers, and/or automation depending on the size, needs, and complexity of the project.

Smart Work Zones, if properly designed and implemented, will:

- Better inform motorists and reduce their frustrations.
- Encourage motorists to take alternate routes.
- Reduce congestion and allow more freely flowing traffic.
- Clear incidents more quickly, thereby reducing secondary incidents.
- Make work zones safer for highway workers and motorists.

Whenever a planned work zone strategy includes smart work zone, the project team or designer needs to contact the Region and Headquarters traffic and ITS personnel as early as possible.

15.2.16 Roadway Shoulders

Refer to CDOT Policy Directive 902.0, Shoulder Policy (CDOT, 1999).

15.3 Reducing Run-Off-The-Road-Crashes

Apply the following improvements where appropriate to reduce the frequency and severity of run-off-the-road crashes:

- Removing obstacles from the roadside.
- Redesigning the obstacle.
- Relocating obstacles from the clear zone.
- Installing breakaway devices that reduce impact severity (MASH) (AASHTO, 2016) and NCHRP Report 350 (TRB, 1993).

- Shielding obstacles with guardrail that meets MASH compliance.
- Improving delineation.
- Cable rail installation.
- Upgrading guardrail to MASH compliance.
- Using rumble strips there is a minimum 4-foot shoulder.
- Applying textured shoulder treatment.
- Eliminating shoulder drop-offs, using safety edge technology.
- Correcting superelevation.
- Improving the pavement condition.
- Improving the roadway geometry.
- Flattening slopes.
- Maintaining the clear zone.

15.3.1 Rumble Strips

Studies have shown that rumble strips can reduce the frequency of run-off-the-road crashes by 36% on rural two-lane roads and up to 17% on urban freeways (FHWA Proven Safety Countermeasures). Centerline rumble strips can reduce sideswipe opposite direction crashes by up to 45% on rural two-lane roads and 64% on urban two-lane roads (FHWA Proven Safety Countermeasures). Rumble strips alert drivers when their vehicles stray onto the shoulder or over the centerline of the roadway. Rumble strips can also provide protection for pedestrians and bicyclists on the shoulder by discouraging motorists from straying onto the shoulder and provide an audible notice to pedestrians and bicyclists. Improperly installed rumble strips can force the bicyclist into the travel lane causing conflict with the motorists. Shoulder rumble strips should only be placed on shoulders with a minimum 4-foot shoulder or wider.

In more densely populated areas, the installation of rumble strips may cause noise issues with the residents. The engineer should take this into consideration using a context sensitive analysis to determine the safety benefit versus impact to the residents. In recent years, a new type of rumble strip with reduced noise impacts has been used. The modified rumble strip is a sinusoidal “football” shape that quiets the sound of the tires when contacting the indentation in the roadway. Also known as a “mumble strip,” it still creates the tactile feeling in the vehicle and some noise, but is generally not as loud as traditional rumble strips.

CDOT received approval to install rumble strips on all highways using FHWA Highway Safety Improvement Program (HSIP) funding as well as being eligible to use FASTER Safety Mitigation funding to help expedite the installation of these proven safety measures. Coordinate with the Region Traffic Engineer to inquire about possible funding for the installation of rumble strips.

Use this link to access more information from FHWA on Longitudinal Rumble Strips: *https://safety.fhwa.dot.gov/provencountermeasures/fhwasa18029/ch2.cfm*

15.3.1.1 General Criteria

Refer to Standard Plan M-614-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) for rumble strip details.

To maximize a smooth shoulder surface suitable for bicycle use, rumble strips should be installed adjacent to the edge of the travel lane per CDOT Standard Plan M-614-1 (CDOT, 2019). AASHTO considers a 4-foot width on the shoulder beyond the rumble strip to be the minimum for safe bicycling. Refer to AASHTO's *Guide for the Development of Bicycle Facilities* (AASHTO, 2012).

Rumble strips should be used on rural highways at locations where run-off-the-road type crashes are most likely to occur. These locations should include:

- On long tangents to avoid lane departures and side-swipe opposite direction crashes.
- Through horizontal curves to prevent lane departures.
- Along steep fill slopes.
- At approaches to narrow bridges.
- At documented high-crash locations.

Rumble strips should not be used where guardrail is installed on shoulders that are less than 6 feet wide. When rumble strips are discontinued for guardrail or narrow shoulders, the rumble strip should end at least 250 feet prior to the beginning section of the guardrail or the narrowing of the shoulder. This will allow bicyclists room to reposition their bikes on the shoulder.

Rumble strips are not normally used in urban areas because of the noise they cause and the frequent use of the roadway shoulder for turning or parking.

Centerline rumble strips are frequently used to mitigate head-on, sideswipe opposite, and opposite side run-off-the-road crashes in areas with a history of these types of crashes, mountainous areas, or areas where sight distance is constrained. When used, centerline rumble strips should be installed in "no passing" zones but may continue into "passing" zones.

15.3.1.2 Installation on Interstate Highways

Rumble strips should be installed on the inside (left) shoulders of all rural Interstate highways and rural freeways with depressed medians as shown on Standard Plan M-614-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) and may be continuous as determined by the designer.

They should be installed on the outside (right) shoulders providing the shoulder width is 6 feet or greater.

15.3.1.3 Installation on Narrow Shoulders

Where the system-wide evaluation indicates a significant history of run-off-the-road crashes, rumble strips may be considered if bicycle traffic can still be accommodated. Consider applying edge rumble strips only in high-crash locations rather than over the entire length of the roadway.

Before installing rumble strips on narrow shoulders, the designer should weigh the benefits to motorists, versus the reduction in usable bicycle riding width. Installation of rumble strips on shoulders which are 4 feet wide or narrower will provide bicycles with less than the AASHTO recommended 4-foot clear bike path and will have a negative impact on bicycle travel.

For further information on rumble strips, refer to the FHWA Rumble Strip Web Page (FHWA, n.d.) and to NCHRP Synthesis 191 Use of Rumble Strips to Enhance Safety (TRB, 1993).

15.4 Roadside Safety

Roadside safety is improved by reducing the likelihood of a vehicle leaving the roadway and by minimizing or eliminating the hazards faced by an errant vehicle that leaves the roadway. This section discusses the methods and tools used to improve roadside safety. Additional strategies can be found at the joint AASHTO-NCHRP web site for implementing the NCHRP Project 17 – 18, Strategic Highway Safety Plan (AASHTO, 2009).

CDOT has adopted the AASHTO *Roadside Design Guide* (AASHTO, 2011) for use in determining barrier warrants, length of needed barrier, and overall roadside design considerations. Some of the items that are covered are:

- Barrier types and characteristics.
- Methods for mitigation of obstacles.
- Clear zone concept.
- Embankments and cut slopes.
- Fixed objects.
- Shoulder drop-offs.

CDOT Standard Plans - M & S Standards (CDOT, 2019) contain design and typical installation details for guardrail, end treatments and transitions. The guardrail details in the Standard Plans may not fit all situations. The designer needs to evaluate each location carefully to determine if the standard can be used or if a special detail needs to be created for the locations in question. A new item or design adaptation not covered by CDOT Standard Plans - M & S Standards (CDOT, 2019) is not necessarily precluded from use. Consult the AASHTO *Roadside Design Guide* (AASHTO, 2011) or contact the Standards and Specifications Unit in Project Development for additional information.

Refer to the CDOT Safety Selection Guide, which is on the CDOT web site, and contact the Standards Engineer to determine the acceptability of any alternative design.

Use this link to access more information regarding CDOT's Safety Selection Guide: https://www.codot.gov/business/designsupport/design-docs/selection-guide

15.4.1 Unique Hazards

Special situations may occur where protection is desirable even though not required; for example, where there is a potential obstacle that is not within the clear zone, or where there are objects with historic, environmental or economic significance. The designer needs to carefully consider all alternatives in these situations. Because adding a barrier is a hazard to the motorist, the designer should consider other options before deciding to add a barrier in a special circumstance.

15.4.2 Guardrail

Guardrail should be installed only at specific locations where roadside hazards warrant, and after all other possible mitigation measures have been considered. CDOT uses two primary types of guardrail: strong-post W-Beam (Type 3) and F-shaped concrete barrier (Type 7). Refer to M&S Standards. Modified Thrie-Beam (Type 6), 3- and 4-strand cable guardrail, and other types are also used in special situations. A fully functional guardrail installation will consist of a transition (if changing rail rigidities), a run of computed length of need, and end treatments. Guardrail shall meet MASH standards for all new installations.

In 2021, CDOT issued the Guardrail System Field Guide for Construction Engineers and Inspectors, this guide should be used by the designer to help identify the need to install new guardrail, or to repair or replace existing guardrail. This guide will be essential to the designer to have at the field scoping and field inspection review to evaluate the existing guardrail for replacement with MASH compliant guardrail or repair and replacement with NCHRP 350-approved guardrail.

Use this link to access CDOT's Guardrail Systems Field Guide: https://www.codot.gov/programs/tetp/assets/2018-2019/guardrail-field-guide.pdf

15.4.2.1 Review of Crash History

For 3R projects, guardrail may be warranted in locations where there is a history of frequent run-off-the-road crashes. At least three years (but preferably five years) of the most recent crash data should be analyzed to determine if there is a need for guardrail.

15.4.2.2 Maintaining Continuity

Driver expectation is often a key component in determining guardrail placement. Consider how the placement of guardrail will affect the driver's perception of both the area where the guardrail is placed and the surrounding areas. Maintaining continuity of roadside characteristics is important and can affect the designer's guardrail decisions in many ways. Guardrail choices made for the first section of a corridor will affect the options available for guardrail in the subsequent sections. A decision should be made early in the scoping process on how the corridor will be designed to create a consistent type of roadway.

If a proposed guardrail installation is only marginally warranted, but the rest of the section has guardrail, then installing the guardrail may be appropriate. Placing guardrail, widening shoulders, or straightening horizontal curves may not be advisable for short sections of roadway when it will likely cause a motorist to exceed the safe operating conditions of adjacent segments yet to be improved. Improving safety in a corridor may sometimes be done in short sections, but the overall corridor safety should be maintained during the process. If isolated segments of a corridor are upgraded, a letter outlining the decision should be included in the project file.

15.4.2.3 Determination of Length

The procedure for determining the length of need for guardrail is contained in the AASHTO *Roadside Design Guide* (AASHTO, 2011). Length of need calculations are a critical step in guardrail design development. If the designer is unsure about how to determine length of need, they should reach out to their region traffic program for support.

15.4.2.4 Offset

Standard Plans M-606-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) lists recommended offsets. As a general rule, if the shoulder width is 6 feet or less, the guardrail should be offset an additional 2 feet from the edge of the paved shoulder. If the shoulder width is 8 feet or greater, no additional offset is required. The 2-foot offset is intended to provide additional width for opening the door of a parked or stranded vehicle. If the guardrail is offset from the edge of pavement the design should include a safety edge on the new pavement to prevent vertical drop offs that could catch the wheel of an errant vehicle leaving the paved shoulder.

Use this link to access more information regarding CDOT's Safety Edge for Pavement Detail (D-614-1): *https://www.codot.gov/business/designsupport/2019-and-2012-m-standards/2019-m-standards-plans/2019-project-special-details/d-614-1*

In most cases, new guardrail should not be installed on the z-slope or side slope unless the slope is 10:1 or flatter. Where necessary, installations may be made on slopes as steep as 6:1, but only if they are located so that the errant vehicle is in its normal attitude at the moment of impact.

In general, the placement recommendations shown in the AASHTO *Roadside Design Guide* (AASHTO, 2011), Table 5.5, should be followed.

15.4.2.5 Access Treatments

Short gaps between guardrail sections should always be avoided. Such gaps may allow vehicles to pass behind the rail or strike end treatments, which will cause greater damage than impacting the rail.

Short gaps should be addressed when designing access treatments. Some rules to follow include:

- Move accesses, if possible, to avoid gaps in guardrail.
- Remove obstacles around accesses (flatten slopes, relocate mailboxes, etc.).
- Install Type 3J End Anchorage and 3K Terminal, provided obstacles are cleared behind the rail (refer to details in the CDOT Standard Plans - M & S Standards) (CDOT, 2019).
- Install standard Type 3 guardrail with appropriate end treatments.
- Install Type 3 guardrail with reduced post spacing (refer to detail in CDOT Standard Plans - M & S Standards) (CDOT, 2019).

15.5 Traffic Engineering Plans

Traffic control plans should include a "Schedule of Construction Traffic Control Devices," construction traffic control plans, detour routes, temporary as well as permanent signing, striping, pavement markings, and signal plans.

15.5.1 Source Documents

Many documents and manuals govern how a set of traffic plans is prepared.

While the list below includes the main sources of information for the traffic engineer, it is not exhaustive. Traffic control and operations is an ever-changing field of engineering and the use of the latest state-of-the-art techniques (Smart Work Zones, for example) is encouraged. Refer also to the references provided for this Guide.

- AASHTO *Highway Safety Design and Operations Guide* (AASHTO, 1997).
- AASHTO *Roadside Design Guide* (AASHTO, 2011).
- CDOT Standard Plans ("S" Standards, which are a part of the M & S Standards) (CDOT, 2019).
- Colorado Supplement to the Standard Highways Signs (CDOT, 2012).
- CDOT Procedural Directive 1502.1, Traffic Control for Planned and Unplanned Work.
- CDOT Procedural Directive 1502.2, Temporary Reduction in Speed Limits.
- *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (FHWA, [2009] 2022).
- CDOT Recommended Pavement Marking Practices (CDOT, 1998). Copies of this guideline are available from the Safety and Traffic Engineering Section.

- FHWA 2012 Supplement to Standard Highway Signs (FHWA, 2012).
- FHWA Standard Highway Signs (FHWA, 2012).
- CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022).
- AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals (AASHTO, 2020).
- Colorado Supplement to the MUTCD (CDOT, 2009). Sets forth additions, deletions or changes to the MUTCD required by the peculiarities of Colorado State Law.
- ITE *Traffic Control Devices Handbook* (ITE, 2013).
- ITE *Traffic Engineering Handbook* (ITE, 2009).
- ITE *Transportation Planning Handbook* (ITE, 2009)

15.6 Construction Traffic Control

15.6.1 Construction Traffic Control Plan

The Construction Traffic Control Plan (TCP) is a strategy for safely moving traffic through a work zone. The Safety and Traffic Engineering Branch provides standards to be used for developing the TCP.

The components of a typical TCP are:

- Schedule of Construction Traffic Control Devices/Tabulation of Traffic Engineering items.
- Construction Signing Plan.
- Detour Routes.
- Tabulation of Signs.
- Permanent/Existing Signing Plan.
- Cross sections at Class III and overhead sign locations.
- Standard Overhead Sign Bridges/Standard Overhead Sign Cantilever/Standard Overhead Sign Butterfly.
- Tabulation of Pavement Markings.
- Pavement Marking Plan
- Signal Plan.
- List of Standard Special Provisions.
- List of Project Special Provisions.
- Detailed Sign Layouts.

Information contained in a TCP typically includes:

- Placement and maintenance of traffic control devices.
- Methods and devices for delineation and channelization.

- Construction scheduling.
- Application for number and types of traffic control management teams (Traffic Control Supervisors, Technicians, Flaggers, AFADs, TCS Helpers) for different strategies, phases, and situations.
- Application and removal of pavement markings.
- Roadway construction lighting requirements.
- Traffic regulations.
- Uniformed traffic control (surveillance).
- Inspection activities.

The TCP should be developed during the initial planning stages of any scheduled activity and should be considered in all decisions related to the activity. The Region Traffic Engineering Section will work closely with the Project Manager to develop a sound TCP for all construction activities. The TCP is included in the Contract Plan Package along with the specifications for the project.

The MUTCD (FHWA, [2009] 2022) and CDOT Standard Plans – M & S Standards (CDOT, 2019) provide a framework to develop a sound and effective TCP for all construction projects. Refer to Section 20.3 and Section 3.10 "Noise Analysis" of the *CDOT Project Development Manual* (CDOT, 2013, rev. 2022).

15.6.2 Construction Signing and Striping

Construction signing is an essential and integral part of any highway construction project. Part 6 of the MUTCD (FHWA, [2009] 2022) and the "S" Standards of the CDOT Standard Plans – M & S Standards (CDOT, 2019) provide examples of typical construction signing, methods of erection and signing placement to address a variety of typical construction activities. Construction signs are typically placed on the roadway for a short period of time, therefore avoiding the need for standard durable panel material. Section 630 of the CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022) governs the choice of construction sign panel material.

The typical construction signing placement presented in the MUTCD (FHWA, [2009] 2022) and Standard Plan S- 630-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) and typical striping layout presented in Standard Plan S-627-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019), are designed to assist those involved with construction traffic control, but are not intended to replace sound engineering judgment or the experience of a qualified traffic engineer.

15.6.3 Temporary Pavement Markings

Proper temporary striping is a key component of highway projects, particularly for delineation of passing and no-passing zones. Temporary pavement markings are used to supplement drums or traffic cones in a construction work zone or as provisional markings on a roadway. Temporary markings may be categorized as "Full-Compliance," "Interim" or "Control Points." Full Compliance markings are those meeting all the requirements of Part 3 of the MUTCD (FHWA, [2009] 2022).

When appropriate, interim markings, such as paint or removable pressure sensitive tape, are used until full-compliance markings are installed. Control points are placed for the purpose of guiding the installation of interim or full-compliance pavement markings.

In work zones where traffic is redirected for more than one-day, temporary pavement markings are typically placed along tapers and tangents, but may be placed elsewhere in the project if the need arises. Temporary pavement markings may be white or yellow depending on the type of marking (i.e., centerline, edge line, lane line or channelizing line) they replace. When construction is completed, temporary pavement markings should be easy to remove without damaging or scarring the roadway surface. In most cases, temporary pavement markings shall be removed and full compliance markings installed prior to final project acceptance or acceptance of a phase of construction.

Estimates for temporary pavement marking quantities, whether they are paint or removable tape, shall be itemized on the Tabulation of Traffic Engineering Items plan sheet.

15.6.4 Channelizing Devices

Channelizing devices are designed to warn drivers of potential obstacles created by construction or maintenance operations on or near the traveled way, to protect workers in the work zone, and to guide and direct drivers and pedestrians safely past work zone hazards. These devices may be used to provide a smooth and gradual transition in moving traffic from one lane to another, onto a bypass or detour or in reducing the width of a lane. Channelizing devices should always be preceded by a system of warning devices adequate in size, number, and placement for the roadway. Channelizing devices shall be designed in a way that minimizes damage to vehicles that inadvertently strike them.

Taper design is one of the most important elements within the system of construction traffic control devices. A poorly designed taper will almost always produce undesirable traffic operations, congestion, or possibly crashes. Tapers may be necessary in both the upstream and downstream directions of traffic depending on the construction activity. Tapers are classified as merging tapers, shifting tapers, shoulder tapers and two-way traffic tapers. Examples of tapers and formulas for calculating their minimum desirable lengths are found in the Standard Plan S-630-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019).

A variety of channelizing devices have been approved by CDOT for use in construction projects. These channelizing devices include:

- Traffic cones
- Tubular markers
- Vertical panels
- Drums
- Barricades
- Concrete barriers
- Water-filled barriers

Traffic cones are typically reserved for lane closures and other construction activities during daylight hours. Traffic cones with retroreflective bands are also allowed for nighttime use, but only during working hours. The remaining channelizing devices listed above have been approved for both day and nighttime construction activities. Details regarding the placement of channelizing devices can be found in the MUTCD (FHWA, [2009] 2022) and in the CDOT Standard Plans – M & S Standards (CDOT, 2019).

Quantities for all channelizing devices required on a construction project are tabulated in the Schedule of Construction Traffic Control Devices.

15.6.5 Special Devices

Other special traffic control devices may include speed warning signs, variable message signs (VMS) and flashing arrow panels. Requirements for the use of these devices are addressed in Part 6 of the MUTCD (FHWA, [2009] 2022), current CDOT standards and specifications, and under any current CDOT Smart Work Zone guidelines.

15.6.6 Construction Staging/Phasing

Most highway construction projects require the maintenance of traffic throughout the work zone. The Region Traffic Engineering Section will work closely with the design and construction engineers to develop a construction staging concept that can expeditiously complete the project while safely and efficiently conveying traffic through the work zone. Construction signing plans should detail the construction signing schemes for all the planned phases of the project.

Full road closures for construction may help to expedite a project and minimize the duration of traffic impacts. This shall only be considered as a last resort. If a full closure is necessary, this shall be clearly documented and may require public engagement to inform key constituents and stakeholders why the closure is necessary and that all other options have been considered before coming to this conclusion. The design engineer shall inform the resident engineer, traffic engineer, program engineer, and region communications manager of this desired action early on in the project in order to fully consider all options before this decision is finalized.

15.6.7 Construction at or Near Railroad-Highway Grade Crossings

Highway construction at or near railroad-highway grade crossings may require special traffic control measures to preserve highway and traffic safety, protect workers, and provide for the safe passage of trains through the project work zone. Construction traffic control activities involving railroads may occur on:

- Railroad-highway grade crossing safety projects.
- Other projects requiring work on or near railroad tracks or property.
- Railroad-highway grade separation structure projects.

Refer to the MUTCD Section 6G.18 (FHWA, [2009] 2022) for standard guidance for work in the vicinity of grade crossings; and MUTCD Figure 6H-46 (FHWA, [2009] 2022) for typical application of construction traffic control devices at grade crossings. It is necessary to prevent vehicles from stopping on tracks, and to prevent the queuing of stopped vehicles across the tracks.

Highway projects involving work on or near railroad tracks or crossings may, in addition to necessary traffic control measures at grade crossings, also require the use of railroad flaggers. Railroad flaggers are railroad employees who are authorized to stop or direct train traffic on the affected tracks. Whenever the highway work may pose a danger to trains or interfere with normal train movements (construction equipment near tracks, bridge demolition work, etc.), the railroad company will require a railroad flagger to be stationed at the project site. The flagger will monitor site conditions and exert positive control over trains passing through the project.

Railroad flagging requirements, if any, will be set forth in the project special provisions, and flaggers will be paid out of project funds in accordance with the special provisions. Railroad flagging rates (daily or hourly) will be specified by the railroad company.

Highway construction on railroad overpass structures may also require the use of railroad flaggers to guard against hazards to trains such as falling debris, bridge falsework, or construction equipment.

The required contract (refer to Section 20.1.2) among CDOT, the railroad, and involved local agencies will set forth traffic control responsibilities, coordination requirements, and railroad flagging requirements. The designer should request a contract from the Project Development Branch well in advance of planned construction to allow sufficient time for contract development and execution. CDOT field construction personnel should closely coordinate traffic control with railroad and local agency representatives.

15.7 Permanent Signing

15.7.1 Uniform Standard Regulatory and Warning Signs

Additional information on both signing and pavement markings can be found on the CDOT website at the following location.

Use this link to access more information regarding CDOT's Signing and Pavement Markings: https://www.codot.gov/safety/traffic-safety/design/signing-and-markings

CDOT has adopted the MUTCD (FHWA, [2009] 2022) guidelines for the placement of permanent regulatory and warning signs on the State highways. Signing shall be in conformance with the MUTCD Parts 2 and 3 (FHWA, [2009] 2022). Proper installation and consistency of signs provide guidance and information to safely travel a section of roadway. Signs should be clear and positioned for adequate response time, particularly on high-speed roadways. Detailed layouts and standard sizes for these signs can be found in the FHWA Standard Highway Signs (FHWA, 2004). For further details including ground sign placement, consult the MUTCD (FHWA, [2009] 2022) and Standard Plan S-614-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019). All signs must meet the requirements for crashworthiness in MASH (AASHTO, 2016) and NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluation of Highway Features (TRB, 1993). Refer to applicable "S" Standards in the CDOT Standard Plans – M & S Standards (CDOT, 2019) and CDOT Specifications for currently accepted sign designs. Refer to the Structure Management Manual (SMM) for low vertical clearance bridge signage.

The Tabulation of Signs sheet provided for permanent signing on the project lists the panel sizes, post lengths, sign locations and color, MUTCD code (FHWA, [2009] 2022), foundation requirements, and quantities required on a construction project.

Signs should be replaced on a project when damaged, faded, or no longer meet retroreflective requirements. For most new construction or reconstruction projects, signs should be updated or replaced. The designer should check with the Region Maintenance or Traffic Engineering Section for the replacement schedule. For overlay projects, the designer should examine the condition of existing signs to determine if replacement is needed. Signs that are more than ten years old will usually require replacement.

Signing is used for a wide range of purposes. The designer will follow the "S" Standards in the CDOT Standard Plans – M & S Standards (CDOT, 2019) and the MUTCD (FHWA, [2009] 2022) when determining the signing requirements for a project.

15.7.2 Special Signs

Special signs are those not designated with a sign code in the MUTCD (FHWA, [2009] 2022). These signs may include construction signs indicating detours or hours of operations or permanent signs such as guide signs, specific information signs, or other special interest signs. The Region Traffic Section will provide detailed sign layouts for all special signs. Legends shall consist of either upper or lowercase characters provided in the 2012 Supplement to Standard Highway Signs (FHWA, 2012), with letter sizes following the guidelines in Part 2 of the MUTCD (FHWA, [2009] 2022)).

Special signs are tabulated on the Schedule of Construction Traffic Control Devices, or the Tabulation of Signs provided in each contract plan package.

Only symbols that have been approved by FHWA may be used on special signs.

15.7.3 Sign Classifications

Permanent sign panels placed on the State highway system are classified as Class I, II or III.

Class I sign panels are single-sheet aluminum with a minimum thickness of 0.080 inches. Class I panels are flush mounted directly to wooden, U-2 steel, or tubular steel posts, as directed in Standard Plan S-614-2 of the CDOT Standard Plans – M & S Standards (CDOT, 2019).

Class II sign panels are also single-sheet aluminum with minimum thicknesses of 0.100 inches mounted on wooden, U-2 steel, or tubular steel posts, however, Class II signs are mounted with one or two aluminum backing zees as outlined in Standard Plan S-614-3 of the CDOT Standard Plans – M & S Standards (CDOT, 2019).

Class III signs are guide or informational signs constructed of 0.125-inch minimum thickness sheet aluminum and mounted with backing zees. Class III signs may be located either on overhead sign structures according to the Standards for Overhead Sign Structures or on the ground using wooden, tubular steel, or W-beam shaped steel posts.

15.7.4 Ground Sign Supports and Foundations (Class III)

Determining the requirements for Class III ground sign supports and foundations is the responsibility of the designer. Standard Plan S-614-6 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) provides data for determining sign supports and concrete footing sizes for all Class III ground sign installations. Class III panels may require either wooden, tubular steel, or W-beam shaped steel supports depending on the panel size and the applied moment due to wind loads. CDOT Standards use a design wind speed of 90 mph for wind loading in most locations. Breakaway sign support requirements are found in Standard Plan S-614-5 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) for both wood and steel sign supports.

Material quantities for sign supports and concrete footings are detailed on the Tabulation of Signs provided in the plans for any permanent signing project done by the Safety and Traffic Engineering Branch.

15.7.5 Overhead Sign Structures

Overhead sign structures used on the State highway system are classified into three categories:

- Sign bridges
- Cantilever sign structures
- Butterfly sign structures

The type of overhead sign structure required for a project is covered in Standard Plan S-614-50 of the CDOT Standard Plans – M & S Standards (CDOT, 2019), and depends on the location and the number of sign panels needed. Once the panel sizes and span lengths are known, the structural and foundational requirements of the structure are determined using the CDOT Standard Plans – M & S Standards (CDOT, 2012) developed by Staff Bridge Branch.

Standard Plan S-614-50 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) should be included in all plans that require overhead sign structures. Plan sheets for overhead sign structures not found in the CDOT Standard Plans – M & S Standards (CDOT, 2019), including cantilevers and butterfly sign structures, can be obtained from the Staff Bridge Branch.

15.7.6 Cross Sections at Class III and Overhead Sign Structure Locations

Cross sections are required for Class III and larger sign installations using appropriate stationing. Cross sections should extend 50 to 100 feet beyond the edge-of-traveled way, depending on the lateral placement of the sign. All features such as curb and gutter, guardrail, ditches, fences, right of way lines, bikeways, and roadways should be indicated. Class III panels should be detailed on the cross sections and placed the appropriate lateral distance from the edge-of- traveled way.

The bottom of the panel shall be located in accordance with Standard Plan S-614- 1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019).

For sign bridge structures, a cross section from the median centerline to 41 feet beyond the edge-of-traveled way should be obtained.

15.8 Specifications

15.8.1 Standard Specifications

All standard specifications for traffic control devices related to construction are found in the most current version of the CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022).

15.8.2 Standard Special Provisions

Traffic Standard Special Provisions are additions and revisions to the CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022) initiated by Safety and Traffic Engineering and approved by the Joint CCA/CDOT Specifications Committee. These provisions are unique to a selected group of projects or are intended for temporary use. Standard Special Provisions to be used on construction projects can be accessed on the Construction Specifications Web Page (CDOT, n.d.).

15.8.3 Traffic Project Special Provisions

Traffic Project Special Provisions are additions and revisions to the CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022) unique to a particular project. They are available for use on a project-by-project basis and are posted on the CDOT Safety and Traffic Engineering Web Page (CDOT, n.d.).

15.9 Signals

15.9.1 Signal Plans

Traffic signals play an important role in the safe and steady flow of traffic at intersections or junctures. The MUTCD Part 4 (FHWA, [2009] 2022) provides the criteria for the design and installation of traffic signals. The traffic signal plan sheets provided by the Region Traffic Section will show the placement of the signal poles, heads, conduit, pull boxes and all other related signal equipment. Standard Plans S-614-40 and S-614- 40A of the CDOT Standard Plans – M & S Standards (CDOT, 2019) provide details of the signal equipment required by CDOT.

When designing sidewalks and channelization islands, consideration of Americans With Disabilities Act (ADA) standards, Public Rights-of-Way Accessibility Guidelines (PROWAG) and the needs of able-bodied pedestrians should be taken into account. Poles, boxes and other related equipment should be placed so that pedestrians have unobstructed walkways.

15.9.2 Warrant Studies

Properly designed traffic signals make intersections safer and more efficient by improving traffic flow. However, signals are not cure-alls for improving traffic flow and reducing crashes at all intersections. Traffic signals should be warranted before they can be installed. Specific criteria are given in Part 4 of the MUTCD (FHWA, [2009] 2022) for the installation of traffic signals. Even if an intersection meets warrant criteria, careful consideration should be given to other traffic control options such as roundabouts before a signal is decided upon.

15.10 Pavement Markings

15.10.1 Permanent

Additional information on both signing and pavement markings can be found on the CDOT website at the following location.

Use this link to access more information regarding CDOT's Signing and Pavement Markings: https://www.codot.gov/safety/traffic-safety/design/signing-and-markings

Adequate pavement markings have been a cost-effective means of enhancing both traffic safety and mobility. CDOT requires centerline, edge line, auxiliary lane, crosswalk and other pavement markings on all roads under its jurisdiction. CDOT requires durable pavement markings on all mainline Interstate projects and on other selected roadways where traffic volumes are high or non-durable markings have not been cost-effective. "Durable" pavement marking materials are those materials capable of providing a longer service life than conventional paint.

General guidelines for the selection of pavement marking materials for roadway projects can be found in the CDOT Pavement Marking Practices Guide on the CDOT website below.

Use this link to access more information regarding CDOT's Pavement Marking Practices Guide: https://www.codot.gov/safety/traffic-safety/assets/documents/pavement-marking-practices

Other considerations in the selection process may include the desire to use materials that are lead- free, materials that contain lower levels of volatile organic compounds (VOC), or materials that do both. The MUTCD (FHWA, [2009] 2022)) and Standard Plan S-627-1 of the CDOT Standard Plans – M & S Standards (CDOT, 2019) outline the details and requirements for the proper selection and installation of all pavement markings. Refer to Section 627 of the CDOT Standard Specifications for Road and Bridge Construction (CDOT, 2022).

Tabulation of Pavement Marking quantities will be included in the plan sheets provided by the designers and reviewed by the Region Traffic Engineering Section for most construction projects.

Chapter 16
Noise Guide

Legend

	Multimodal Application Example
	Context-Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context-Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO-Specific Information

Chapter

16

16 Noise Guide

16.1 Introduction

Noise generated by highway traffic can cause varying reactions by the public involving physical, physiological, and psychological effects. Highway traffic noise should be considered in roadway design.

This chapter is intended to help designers understand issues related to highway traffic noise. This includes understanding the applicable federal and state regulations and guidelines, traffic noise analyses for specific projects, highway traffic noise mitigation measures, and construction noise mitigation measures.

Whether a project is required to build noise mitigation (e.g., noise walls) is determined by a project-specific noise analysis. Noise analyses are only required for some projects, as described in Section 16.3. Project construction generates noise, so projects must comply with local and/or state noise regulations and mitigate construction noise, as described in Section 16.11.

This chapter contains a summary of basic concepts and supplements existing published material. If more detail is needed concerning any of the following specific subjects, consult the references provided at the end of this chapter. If regulations or guidance is revised or published after the date this chapter was published, it takes precedence if it conflicts with this chapter.

16.2 Noise Fundamentals

Noise is defined as unwanted or excessive sound. Sound (or noise) levels are measured in units of decibels (dB), which are measured on a logarithmic scale. This scale condenses a large range of several magnitudes of sound pressure levels. Sound is composed of various frequencies, but the human ear does not respond to all frequencies. It has been found that the A-scale on a sound-level meter best approximates the frequency response of the human ear. Sound pressure levels measured on the A-scale of a sound meter are abbreviated dBA.

Because the sound intensity of highway traffic is not constant, a descriptor is needed to describe the source in a steady-state condition. An equivalent sound level is the steady-state, A-weighted sound level. It contains the same amount of acoustic energy as the actual time-varying, A-weighted sound level over a specified period of time. CDOT uses a time period of one hour. The descriptor is the hourly equivalent sound level, which is represented as $L_{eq}(h)$.

Since noise levels in the decibel scale are logarithmic, they cannot be added arithmetically. For example, adding two 70-dB sources results in a noise level of 73 dB. Any doubling of a noise source, such as doubling the volume of traffic on a roadway or moving the existing traffic twice as close to a neighborhood, increases the overall decibel level 3 dB. Studies have shown that a 3-dB change in noise levels is barely detectable by the human ear, even though the overall sound energy has doubled. It normally takes a 5-dB change in noise levels to be perceptible to most people. A 10-dB change in noise levels is normally perceived as either a doubling or a halving of the perceived “loudness” of noise levels. Frequency changes, however, may be detectable by people even if the overall dB levels are unchanged.

16.3 Noise Regulations

Regulations that govern highway traffic noise for Federal-aid projects are contained in Part 772 of Title 23 of the Code of Federal Regulations (23 CFR 772), which describes the analysis of highway traffic noise and the evaluation of potential noise mitigation. Federal Highway Administration (FHWA) will not approve plans or specifications for any federally aided highway project unless the project includes building noise abatement[1], if abatement was found to be feasible and reasonable in the project’s noise analysis, as described in Section 16.4.

Projects must comply with 23 CFR 772 if either of the following are true for highway or multimodal projects:

- Requires FHWA approval[1] regardless of funding sources (refer to 23 CFR 772.7[a]).
- Funded with Federal-aid highway funds (dollars provided to CDOT by FHWA).

Although adherence to 23 CFR 772 is only required for those two criteria per Section 772.7, CDOT’s *Noise Analysis and Abatement Guidelines* (NAAG) (CDOT, 2020) broadens the applicability of traffic noise analyses in the following two situations:

- FHWA noise regulation does not apply but the project adds capacity via through lanes, if the lane(s) requires additional pavement beyond the existing roadway geometry profile, which includes medians and inside.

[1] “Noise abatement” and “noise barrier” are terms that mean the same thing and are used interchangeably

[2] FHWA approval refers to FHWA "signing off" on a project, whether literally (an actual signature on an EA or EIS) or figuratively (such as for programmatic CatExs that don't require individual signatures but are authorized as a group). FHWA approval can also refer to a design variance, air space lease (lease of interstate right of way to third party), federal land transfer (Forest Service and Bureau of Land Management), or change in interstate access (crossing the A-line, moving the A-line, or new or revised interchange). An IAR (Interstate Access Approval) under CDOT’s 1601 process requires FHWA approval. Form 128 and and a CatEx are not the same thing. Projects using a “NEPA-like” process per CDOT’s Stewardship Guide do not require an FHWA approval. The noise regulation applies to all FHWA CatExs, but not to NEPA done for other federal agencies.

- FHWA noise regulation does not apply but the project is adjacent to a prior project to which the regulation applied and for which noise abatement was built, if the current project is Type I.

If 23 CFR 772 applies either under Section 772.7 or under the two criteria that broadens applicability under the *Environmental Stewardship Guide*, projects are classified as Type I, Type II or Type III. The project type will be determined in conjunction with a CDOT noise specialist.

Type I projects require noise analysis, which may lead to the project being required to include noise mitigation. Type I criteria are in 23 CFR 772. Clarification is available in Section 3.1.1 of CDOT *Noise Analysis and Abatement Guidelines* (NAAG) (CDOT, 2020). A project is Type I if it meets any of the following criteria:

- Construction of a new roadway in a new location (examples: roads, streets, freeways, expressways, and interstates.
- The physical alteration of an existing highway where there is either:
  - Substantial Horizontal Alteration. A project that halves the distance between the traffic noise source and the closest receptor between the existing condition to the future build condition;
  - Substantial Vertical Alteration. A project that removes shielding therefore exposing the line-of-sight between the receptor and the traffic noise source. This is done by either altering the vertical alignment of the highway or by altering the topography between the highway traffic noise source and the receptor.
- The addition of a through-traffic lane(s). This includes the addition of a through-traffic lane that functions as a high-occupancy vehicle (HOV) lane, high-occupancy toll (HOT) lane, bus lane, or truck climbing lane.
- The addition of an auxiliary lane, except when the auxiliary lane is a turn lane.
- The addition or relocation of interchange lanes or ramps added to a quadrant to complete an existing partial interchange.
- Restriping existing pavement for the purpose of adding a through-traffic lane or an auxiliary lane.
- The addition of a new or substantial alteration of a weigh station, rest stop, ride-share lot, or toll plaza

Type II projects are defined as the construction of noise abatement on existing highways (“retrofit” projects) in absence of major highway construction. State funding has been unavailable for this program in Colorado since 1999. Unless funding is reinstated, which is not expected, no project will be Type II.

A Type III project is any project that does not meet criteria for either a Type I or Type II project. Noise analyses are not required for Type III projects. Noise mitigation is not considered for Type III projects.

Use this link to access the most recent CDOT Noise Analysis and Abatement Guidelines (CDOT, 2020): *https://www.codot.gov/programs/environmental/noise/regulations-guidelines-policies*

16.4 Noise Analysis

Procedures for conducting project level highway traffic noise analyses are provided in the CDOT *Noise Analysis and Abatement Guidelines* (NAAG) (CDOT, 2020). The guidelines are compliant with 23 CFR 772 and approved by FHWA. Additional guidance is available from FHWA (FHWA, 2011) and FTA (FTA, 2018).

As part of the noise analysis for highway projects, noise levels are modeled for the worst-noise hour. This is when noise levels are highest. It is also when the highest number of vehicles is traveling at the highest possible speed. This is not necessarily the peak travel hour or rush hour, because there may be periods of congestion when traffic tends to slow, resulting in lower noise levels. For highways that tend to be congested at peak hour, the worst-noise hour is the period either just before or just after peak hour.

Noise levels for the design year are compared to impact criteria to determine if the project will cause noise impacts to noise sensitive receptors. The project also causes noise impacts if the design year noise levels are 10 dB or more higher than existing noise levels, which generally only occurs if a new road is being built in a new location. If the project does not result in noise impacts, noise mitigation is not considered. Noise mitigation is evaluated if the project results in noise impacts. If noise mitigation is found to be feasible and reasonable, the proposed noise mitigation must be included in the final plans and constructed with the project to obtain FHWA approval.

Noise analyses are conducted as part of the National Environmental Policy Act (NEPA) process. The first analysis is usually conducted when design is in early stages (e.g., 30% design). The resulting traffic noise technical report indicates in a section called “Statement of Likelihood” if any noise barriers are recommended.

When the project reaches final design, an evaluation is done to determine if the original analysis is still valid or if the project noise model needs to be updated, which would include potential changes in traffic data. If a model update is required, the number and location of recommended noise barriers might change from the original noise analysis. Noise barriers that are recommended by this evaluation need to be modeled based on the project final design to determine the final barrier location, height, and length.

The final design evaluation, which culminates in a Noise Verification (email, memo, or report), considers things such as:

- Whether the project type (Type I or Type III) changed.
- Whether the final design changed enough from the design in the original noise analysis to affect the analysis and thus trigger a new noise analysis (e.g., traffic predictions for the final design have doubled or more, changes for the final design constitute a Type I project on its own).
- Whether the area around the project changed enough from what was considered in the original noise analysis to affect the noise analysis and thus triggers a new noise analysis (e.g., new development near the project).
- Whether benefitted receptors of recommended noise barriers vote for or against recommended barriers. If more than 50% of the responding benefited receptors support the proposed noise barrier, it will be built.

16.5 Optional Highway Traffic Noise Mitigation Measures Under 23 CFR 772

The FHWA noise regulation, 23 CFR 772, allows several noise mitigation measures to be used as mitigation for impacted receptors. Some of these measures are optional; only noise barriers (berms, walls, or a combination) must be considered (refer to Section 18.5). If analyzing an optional mitigation measure, a determination as to the validity and practicality of successfully implementing the measures must be made by a CDOT engineer.

Vegetation is not an optional measure. It does not function as noise mitigation unless it consists of 200 to 300 feet of dense, permanent foliage ground floor to tree top coverage of at least 16 feet high. While vegetation can be of aesthetic and psychological benefit and can enhance an area where it is placed and successfully maintained, it is usually only provided for visual, privacy, or aesthetic treatment.

Pavement type not an optional measure. It is often cited as a possible means to reduce highway traffic noise. The majority of noise emitted from highways is due to the tire-pavement interaction. Research on this issue has been ongoing since the 1970s. The effect of different pavements over long periods, 20 years or more, has still not been clearly established. Studies have indicated that open-graded asphalt pavements, when first placed, can produce a benefit of 2 to 5 dBA of noise level reduction. However, after 6 months to 2 years, the aggregate becomes polished and voids in the pavement fill so noise reduction benefits are lost. Concrete pavement, while perhaps louder than asphalt when it is initially placed, will become quieter over time. Longitudinal tining or diamond grinding of the concrete, where possible, results in reduced noise levels compared to smooth concrete surfaces. Transverse tining, or tining of the concrete perpendicular to the direction of travel, creates an annoying high-pitched whine and should not be used.

FHWA policy says that pavement type cannot be used as noise mitigation in lieu of other feasible and reasonable noise abatement measures. Noise mitigation must provide a “readily perceptible” noise reduction over a long period of time (20 years), and it is difficult to forecast the overall pavement condition under a future condition. Noise may be used as a factor to be considered in pavement selection if the life cycle cost analysis among pavement options yields similar results.

Allowed optional noise mitigation measures are traffic management, alterations of horizontal or vertical alignments, acquisition of property or property rights, and noise insultation, The costs of these measures, as with noise barriers, may be included in Federal-aid participating project costs.

16.5.1 Traffic Management Measures

Traffic management measures may reduce traffic noise levels. Examples include:

- Traffic control devices.
- Signing for prohibition of certain vehicle types.
- Time-use restrictions for certain vehicle types.
- Modified speed limits.
- Exclusive lane designations.

The feasibility of providing specified truck routes or utilizing lane restrictions on truck usage should be determined on a case-by-case basis.

Lowering speed limits can reduce noise and is cited by the public as a mitigation method. However, generally a speed reduction of at least 20 mph is needed to sufficiently decrease noise levels. Therefore, this option has operational issues.

16.5.2 Alteration of Horizontal or Vertical Alignments

Altering the design of the roadway can be very effective in reducing noise levels and noise impacts. Although several techniques are possible, certain projects and areas will not be conducive to some or any of these mitigation measures. In most cases, reductions in noise levels are based on increasing the distance between the roadway and the receptors, or by providing for terrain between the highway and receptors.

Proper siting of highway alignment in relationship to noise sensitive areas is the most effective way to reduce noise impacts. Any increase in the distance between the highway and receptors will reduce noise levels. For divided highways, use of natural terrain features and barriers to separate the individual roadway sections can provide additional noise reduction.

If the roadway can be depressed through a cut section, noise levels will be reduced for the area that is shielded by the adjacent slope. This is most effective when vehicles can be screened from view. Elevated sections of roadway create a shadow zone for receptors that are close to the embankment or structure. Noise is reduced in shadow zones. However, elevated sections may cause slight noise increases to receptors farther from the roadway due to the loss of shielding by adjacent structures.

In some cases, especially where there is a high percentage of heavy truck traffic, grade reductions can reduce noise levels due to the reduction in the need for vehicles (especially heavy trucks) to accelerate and decelerate. This is particularly useful on long downgrades where trucks are inclined to engage their engine compression (e.g., “Jake”) brakes. However, there is a tradeoff with this option: gentler grades have the potential to increase noise levels due to the longer exposure time.

16.5.3 Acquisition of Property or Property Rights

In undeveloped areas, the acquisition of additional right of way or development rights can be an effective means of providing a buffer between the highway and any future land development. The purpose of this practice is to prevent dwellings from being constructed in areas in which the future noise levels would approach or exceed NACs, while also providing an improved roadside appearance.

This measure, however, can become very expensive due to rising land costs and is almost never an option in areas that are already developed because the cost for acquiring already developed property (e.g., homes, businesses) is prohibitive.

Property owners cannot receive Federal funds as monetary compensation in lieu of noise abatement. FHWA regulations prohibit the use of Federal funds for such purposes, since they do nothing to reduce the noise levels or abate the highway noise impacts.

16.5.4 Noise Insulation

Insulation of buildings can greatly reduce traffic noise, especially when windows are sealed, and cracks and other openings are filled. However, once windows are sealed, an air conditioning system will likely be necessary. New buildings can have sound absorbing material installed in the walls during construction. Noise insulation does nothing to improve the noise levels at adjacent outdoor use areas.

Federal funding can only be used for noise insulation for Activity Category D receptors, which are listed in Table 1 of the NAAG. These are auditoriums, day care centers, hospitals, libraries, medical facilities, places of worship, public meeting rooms, public or nonprofit institutional structures, radio studios, recording studios, schools, and television studios. These receptors might also be Activity Category C; the noise analysis determines which they are, as specified in 23 CFR 772.11(c)(2)(iv). If this option must be considered because no other feasible or reasonable mitigation measures are available, the condition of the structure, its amenities, and overall use characteristics must be thoroughly evaluated. Determinations such as these must be completely documented and are done on a case-by-case basis. Post installation maintenance and operational costs for noise insulation are not eligible for Federal-aid funding.

The only situation in which noise insulation would be considered for private dwellings is if extraordinary traffic noise impacts are found. Such a situation might exist where the projected noise levels are 75 dBA or greater or where the projected increase over existing levels is 30 dBA or more and no other possible abatement is reasonable and feasible. Under these conditions the project may use state and/or local agency funding to implement an insulation abatement solution only if the mitigation meets reasonable and feasible abatement criteria as is required for conventional noise mitigation. This determination must be made on a case-by-case basis by FHWA in consultation with CDOT.

16.6 Noise Barriers

Construction of noise barriers is the most common noise abatement method. Essentially, a noise barrier is a solid structure that is constructed for the purpose of reducing noise levels. It may be a wall, a berm, or a combination of both. Most sound waves are either reflected or absorbed by the barrier surface. Sound can also be transmitted through the barrier, which is why the barrier must be constructed without gaps and be sufficiently dense. That is why most privacy fences do not function well as noise barriers.

Noise barriers are designed to reduce noise beginning at the first-row receptors, which are receptors closest to the barrier. Barriers may benefit receptors beyond the first row, depending on the configuration of the development. Normally, barriers are effective for receptors within 300 feet of the noise source if they are high enough to block the view of the roadway and are long enough to prevent sound from bending around the ends.

A noise reduction benefit of 5 dBA is generally fairly simple to achieve; however, a 7 dBA reduction is required at a minimum of two receptors along the wall in order for the barrier to be found reasonable.

16.6.1 Noise Walls

Noise walls are a common means for reducing roadway noise levels. They can be constructed from a variety of materials. Although many wood walls were constructed in the past, life cycle and maintenance issues have resulted in the majority of new walls being constructed out of concrete, masonry block, or brick. The CDOT *Landscape Architecture Manual* (CDOT, 2020) no longer allows wood to be used. Walls are preferred in many areas because they can be constructed where a limited amount of space precludes construction of an earth berm or a wall-berm combination.

Most noise walls are ground mounted. In some situations, a barrier needs to be placed on a structure. This is most common for highway bridges when the barrier needs to be constructed on the bridge to prevent a major gap in the barrier.

Figure 16-1 Cast-in-Place Masonry I-76 East of York Street

Figure 16-2 Post-and-Panel Noise Barrier Mounted on Type 7 Barrier: US-6 in Lakewood

16.6.2 Berms

Earth berms are a good alternative to noise walls, since they have a more natural appearance and are aesthetically pleasing. Berms should be considered in areas where sufficient right of way is available to install them. This will help preserve the corridor visual and environmental qualities.

Feasibility of berm construction should be considered within the highway overall grading and drainage plan, particularly if an irrigation system will be part of the project. One advantage of berm construction is that a variety of materials, such as soil, stone, rock, or rubble can be used. Typically, berms can be constructed from surplus material available directly on the project site or from waste material from other areas. This can result in decreased costs compared to the cost of a noise barrier.

Slopes of an earth berm need to consider the context classification and facility type of the project. The slopes and location of the berm shall be defined by the roadside design guide prior to the noise analysis.

16.6.3 Combination Barriers

For areas where a full berm cannot be constructed, such as a situation where there is limited right of way, a combination barrier can be constructed. This involves building up the earth berm to a desired height and constructing a wall on the berm. The soil in the berm must be stable enough to support a wall structure foundation. Berms and noise walls may also be alternated, side by side.

Figure 16-3 Recycled Sand Berm: I-70 East of Vail

Figure 16-4 Combination Barrier: I-25 at Exit 188

16.7 General Design Guidelines

The following are general considerations for noise barrier design:

- Barriers should not be installed where they will present a safety hazard. A desirable location is just inside of the right of way line or outside the clear zone. If a barrier needs to be located inside of the clear zone, a guardrail or other traffic barrier may be warranted, and the barrier material should meet minimum impact standards to prevent shattering. Light reflected to motorists should be minimized.
- A barrier should not block the line-of-sight between a vehicle on a ramp and approaching vehicles on a major roadway. For entrance and exit ramps, ramp intersections and intersecting roadways, the proper barrier location should be determined based on stopping distance requirements. Barrier end points should be approved by the CDOT Region Traffic Engineer.
- Barriers which are oriented in an east-west fashion and have a long barrier face should have the shadow cast checked for encroachment into the shoulder or near traffic lane. Since barriers obstruct light as well as noise, special consideration should be given to icing or other environmental conditions caused by the barrier placement. This consideration should also be given to shadow coverage in adjacent yards and parking lots. This should not be an issue with barriers that are oriented north-south.
- Protrusions on barriers near traffic lanes or facings which can become missiles in a crash or create excessive glare should be avoided.
- Positive mechanical connection of the individual noise barrier panels to the posts is required when the noise barrier is on a bridge or retaining wall in the vicinity of pedestrian or vehicular traffic or immediately adjacent to private property.
- Provisions may be necessary to allow firefighters or HAZMAT crews access to fire hydrants on the opposite side of the barrier. This should be coordinated with the appropriate jurisdictional entity.
- Drainage considerations need to be taken into account to assure soil stability.
- For noise wall structural design considerations, refer to the AASHTO *LRFD Bridge Design Specifications (AASHTO, 2020)*. Some structural aspects to consider on a project –specific basis are: Can the barrier be easily mounted to a bridge? Can it be retrofitted in the future? Does it accommodate through-the-wall access doors? Is it capable of supporting signs or lighting? It is preferred that signs and lighting have their own foundations.
- Barriers should be integrated with other project elements, such as foundations impacts on underground facilities and barrier impacts to overheat facilities.

Project environmental documents or noise analysis studies, if available, specify recommendations regarding general locations, noise reductions, barrier heights, and barrier lengths. These are some of the considerations that are taken into account when the acoustical analyst arrives at barrier recommendations:

- The barrier should be high enough and long enough to cause an effective “sound shadow zone” for the adjacent receptors. Receptors located within the shadow zone do not have direct line-of-sight to the noise source (highway).
- The barrier location should take advantage of local terrain conditions to benefit from higher elevations if possible.
- Normally, the noise barrier should not exceed a height of 20 feet above the traveled way, nor should it be shorter than 8 feet. If the barrier is constructed on the shoulder, 12 feet is a recommended maximum height. Special geographic considerations, however, may warrant taller walls or allow a shorter wall to provide the desired noise reduction.
- The design plans should always indicate the top and bottom elevations of the barrier.
- The relationship between the height of the barrier and its noise reduction characteristics is not linear. As a rule, a barrier breaking the line-of-sight will provide a 5-dBA reduction, with an additional 1-dBA reduction resulting with each additional 2 feet in height. At the receptor end, the line-of-sight is always checked from a point 5 feet above the ground elevation, which approximates the height of the average human ear.
- Building the barrier closer to either the receptor or the noise source provides more noise reduction compared to locating the barrier in the middle between the receptor and source. However, this is not practical in all cases.
- To prevent noise from flanking around the barrier ends, the barrier should extend past the end receptor at least four times the perpendicular distance from the receptor to the barrier. If this is not possible, the barrier can be bent back towards the receptor (wrapping the barrier) in order to reduce noise at the receptor. Also, combining the barrier with natural terrain features and existing structures may help reduce noise at the receptors.
- When barriers are placed opposite each other on different sides of the same highway (parallel barriers), there is the possibility for degradation of the performance of the barrier system if the width-to-height ratio (distance between the barriers vs. the barrier height) is 10:1 or less due to multiple reflections. In these cases, raising the barrier heights or providing absorptive treatments may need to be considered.
- Noise absorption (materials or treatments) should be considered for single highway barriers that have the potential to reflect noise into unprotected areas.
- Gaps in the noise barrier can significantly degrade barrier performance. These include breaks for structures, drainage ditches, emergency accesses, frontage roads, driveways, and ramps. If barrier gaps are inevitable, degradation in the barrier performance can be reduced by providing tight fitting access doors, using small openings for drains and culverts, wrapping the barrier back toward the receptors, or overlapping two barrier segments. If overlapping barriers are used, the length of the overlap should be at least four times the width of the gap or opening to prevent any further degradation in the barrier’s performance.

16.8 General Visual Quality of Noise Walls

The *FHWA Highway Noise Barrier Design Handbook* (FHWA, 2000) emphasizes the need for considering visual quality in the noise wall design process. The basis of the handbook is that in addition to meeting technical requirements, noise walls should be functional as well as aesthetically pleasing. Historic, natural, cultural, and architectural considerations of the surrounding area are part of the selection and design process. Two approaches or design philosophies are to design the wall to blend into surroundings or to design it to be a prominent feature in the landscape. In the planning and design phase visual and environmental effects on both sides of the noise wall should be considered. The ultimate design is dependent on many factors including the location, site constraints, and stakeholder meetings. A successful design approach will be multidisciplinary and include stakeholders, maintenance personnel, architects, planners, landscape architects, roadway engineers, acoustic engineers and structural engineers. The approach should also consider impacts to all stakeholders, including travelers and adjacent land users.

Noise wall design should consider the experience of motorists utilizing the roadway. Noise barriers create an enclosed corridor for travelers. For the motorist, noise walls can inhibit wayfinding as well as block previously existing views of surrounding community, vegetation, and background landscape including mountains and sky. The visual effect of the noise barrier on the driver depends on the speed of the vehicle, the height of the barrier, the distance of the barrier from the roadway, and the surface texture of the barrier. If vehicles are generally moving rapidly, close to the barrier, drivers do not notice the details of the barrier. If vehicles move more slowly, or if the barrier is further away, the details of the barrier are more noticeable and therefore more important. If the barrier is higher and closer to the driver, and particularly if it is on both sides of the roadway, it may produce a tunnel effect in which drivers perceive themselves as being uncomfortably enveloped by the barrier.

Another important consideration in noise barrier design is the impact on adjacent land users. A primary factor is the scale of the noise barrier in relationship to land uses and activities adjoining the highway right of way. A high noise barrier alongside low, single-family residences could have a severe visual effect or create shadows that affect property owners and vegetation by reducing overall sunlight. In general, a barrier should be located a distance of at least four times its height from residences to prevent the alteration of local microclimates, the area between the wall should be landscaped, and maintenance access should be considered. In areas where noise barriers are visible from adjacent residential land use, landscaping should also be utilized to screen views of the wall where feasible. Landscape Architects should be consulted in selecting plantings and spacing for screening and landscaping should be integrated with both the general highway environment and surrounding uses.

Impacts on both sides of the wall - both travelers and neighboring uses - should always be considered. The character of the adjacent land use should be considered in designing a noise wall. For land uses characterized as noxious per local land use codes (i.e. heavy industrial, automotive, outdoor storage or heavy rail), noise walls can provide an additional benefit of screening visual and olfactory impacts from the roadway while reducing ambient noise on both sides of the wall.

16.8.1 Visual Impact Assessment Process

An important step in the planning and design of noise walls (aka sound walls) is conducting a Visual Impact Assessment (VIA) for the proposed project site. VIAs are a required clearance in NEPA projects. CDOT developed VIA Guidelines in 2019 to address the issue of FHWA's 2015 VIA Guidelines being interpreted inconsistently. CDOT's VIA guidelines can now be found on the CDOT Landscape Architecture website. Consideration of a proposed project in relation to the neighborhood, community and geographic context are part of the VIA process. Both beneficial and detrimental visual impacts to the neighborhood context and passing motorists are documented in the VIA.

The steps in the VIA process involve scoping, conducting an inventory of existing conditions, determining the environment affected by the proposed project, evaluating impacts to views, and identifying mitigation measures. One of the key elements of the VIA process is scoping the character of the community or sense of place. CDOT's VIA Guidelines go into more detail for each stage of the process.

Early on in the VIA inventory process, the project site and surroundings are categorized as rural, suburban or urban in character. Each of these categories has unique environmental, social and cultural characteristics that should be considered in design. Consideration of how noise barriers fit into the setting and their relationship with the community is important. Rural environments are characterized by open spaces, sparse trees, native shrubs and grasses, and expansive views of the sky and surrounding landscape. Noise barriers in these areas should be constructed so that they blend in with the natural environment. Adjacent areas should be planted with native plants in natural or random groupings. In contrast, urban environments are characterized by geometric lines, orderly development, human activity, and spaces confined by structures, trees, and pavement. Random, natural groupings of plant materials can be used to soften the geometric lines of noise barriers in these areas, or geometric shapes and hard lines can be used to emphasize the noise wall as a work of art or focal point in the landscape. Suburban environments usually are more built-out than rural but with less building density than urban environments. In suburban environments, a major environmental concern is fragmentation of wildlife habitat. Noise walls can address visual concerns while doubling as a barrier for wildlife to redirect them to underpasses or overpasses where they can cross a road safely. It is important to consider how noise walls can serve a wide range of functional purposes besides improving safety, noise reduction and visual screening.

Involving other agencies and the public throughout the VIA process is key to gaining a well-rounded understanding of the site and appeasing opposition to the project. Public involvement from community stakeholders allows for input and feedback to help inform design elements and community preferences. Landscape inventory data, renderings and virtual flythroughs are useful tools to visualize both existing conditions and proposed elements at public meetings, open houses and workshops. Through meetings and workshops, citizen stakeholders can provide input on preferred wall type, materials, colors, plantings, and textures, and better understand the visual impact of noise barriers. Many objections from the public relate to a loss of scenic views or to the overbearing appearance of a noise barrier. A barrier is more likely to be accepted by the public if it complements the character and context of the community. Including community leaders and representatives in the design process enables them to share their ideas and discuss how local character might be incorporated into the noise wall design. This community outreach process is described in the Chief Engineer's Policy Memo 26 (Context Sensitive Solutions [CSS] Vision for CDOT). Citizen participation in the design process results in fewer post- construction complaints and greater project acceptance.

16.8.2 Visual Design Elements of Noise Walls

In addition to outlining process, CDOT's VIA design guidelines can be used to inform design and select measures to mitigate visual impacts of the project. Landscape elements such as trees and shrubs can be incorporated into the design to enhance important views or buffer views deemed by the public as unsightly. By following certain visual design principles throughout the project, an aesthetically pleasing wall can be built without excessive additional expense. Collaboration with a Landscape Architect can help incorporate design elements and mitigation measures to eliminate any discomfort or claustrophobia caused by noise walls. Such design elements include line, form, scale, color, and texture that contrast or complement the surrounding environment depending on the impact desired.

Landscape plantings may be the most effective and economical means available to reduce adverse visual impacts of a noise barrier. Landscape plantings can help link the structure of the wall with the natural surroundings. Plantings provide a soft, living, dynamic element in a hard-edged manmade environment and provide both a psychological and visual relief to adjacent communities. Plant materials can provide a variety of color and texture and can have positive effects on scale and dominance. Vegetation can also provide shade, reduce reflection of noise and light, cool an otherwise paved surface, provide slope stabilization, slow and filter stormwater runoff and reduce erosion.

Figure 16-5 Landscaping: Integration With Existing Vegetation

Figure 16.6 Landscaping: Integration With Existing Vegetation

Existing vegetation should be salvaged early in the design process, if feasible, to best ensure a project blends in with its surroundings. A landscape architect or specialist should conduct a field review to flag significant trees and shrubs to save prior to setting final wall alignment. If salvaging existing vegetation is infeasible, planting new trees, shrubs, vines, and grasses can provide important design elements of line, form, color, and texture and help mitigate problems with scale and dominance of the noise wall in the landscape. Shrub and tree massing can create a natural transition area for the end of a wall. The following design elements should be considered in noise wall planning and design:

- Design offsetting recesses or planting pockets within the noise wall line. Small jogs can provide protected microclimates and visually soften wall impacts on the motorist.
- Provide open planting areas on both sides of the wall within the ROW to use vines and shrubs in combination to reduce the dominance of a wall.
- Reduce the visual dominance by providing planting areas on both sides of the wall.
- Reinforce rhythm and sequence by use of trees to provide vertical elements in predominantly horizontal walls.
- Provide appropriate soil amendments and mulches for successful for low cost and attractive solutions that help plant establishment and growth.
- Walls should tie into and match the color and texture of existing structures, such as bridges, bridge abutments, and retaining walls.
- Emphasize continuity and consistency for noise walls being incorporated into multiple projects along a corridor.

Generally speaking, noise walls should appear to be part of or complement the existing landscape; they should not give the impression that they were placed as an afterthought. They should begin and end in a natural transition, if possible, from the ground level to the desired height. Where space allows, the best transition is tapering the end of a wall with a natural earth berm or terrain feature. Through this technique, the wall appears to originate from the landscape rather than being dropped onto it. If there are no terrain features in the area, a “step-down” technique at the end of the barriers can provide a similar effect. Any tapering of the wall should be gradual to a point where the wall is no longer visually dominant.

Figure 16-7 Barrier End Treatment: Berming

Figure 16-8 Barrier End Treatment: Stepped Panel

Earth berms are a good alternative to noise walls, since they have a more natural appearance and are aesthetically pleasing. Berms should be considered in areas where sufficient right of way is available to install them. A large amount of right of way will help preserve the corridor's visual and environmental qualities. Feasibility of berm construction should be considered within the highway overall grading and drainage plan, particularly if an irrigation system will be part of the project. One advantage of berm construction is that a variety of materials, such as soil, stone, rock, or rubble, can be used. Typically, berms can be constructed from surplus material available directly on the project site or from waste material from other areas. This can result in decreased costs compared to the cost of a noise barrier. Slopes of an earth berm should be 2:1 or flatter, for safety and erosion control purposes, although a 3:1 slope is preferable. The ends of the berm should have a lead-in slope of 10:1 and curve toward the highway. Berms can be either vegetated or seeded. Slope stabilization should be done as soon as possible after construction.

Figure 16.9. Barrier End Treatment: Buried Into Existing Ground

It is important to note that unlike earth berms, vegetation does not function as noise mitigation unless it consists of 200 to 300 feet of dense, permanent foliage ground floor to treetop coverage of at least 16 feet high. While vegetation can be of aesthetic and psychological benefit and can enhance an area where it is placed and successfully maintained, it is usually only provided for visual, privacy, or aesthetic treatment.

Figure 16.10. Landscaping: Supplementing Vegetation

Figure 16.11. Landscaping: Supplementing Vegetation

For further discussion on planting design, refer to the CDOT *Landscape Architecture Manual*. Keep in mind that the landscape plan and planting plan shall be determined in consultation with, and approved by, the Region or HQ Landscape Architect during the design phase. The landscape architect can assist with plant selection and design as well as considerations for successful establishment and long-term maintenance.

16.9 General Maintenance Guidelines for Noise Walls

When considering materials and construction of a noise barrier, maintenance factors should be addressed, and any fatal flaws identified as early as possible to prevent problems in either construction or maintenance and operations. Examples include maintenance of the barrier, protective coatings, replacement of materials damaged by impact, cleaning of the barrier, graffiti prevention and removal, snow storage, and de-icing of the roadway in the winter months if shadowing is a problem. Plantings should be tolerant of the roadside environment and require little to no maintenance. It is particularly important to maintain a stock of replacement materials (i.e., posts, panels, blocks), which are compatible with the barrier in case damage does occur. Additional quantities should be considered in the construction package for contingency purposes. Maintenance staff should be part of the design team.

Consider access to the barrier backside for maintenance needs. Access can be provided with an access road, a walk path, gates, or access panels built into the barrier. Access must be designed so that it does not compromise the noise reduction effectiveness of the barrier. If the barrier is constructed on the right of way line, provisions should be made to coordinate the location of the access points with the appropriate agencies or landowners. While access for maintenance crews should be facilitated, access to overnight camping or potential vandals should be limited. Tall growing plantings can create spaces that are easy to hide in, which can lead to increased litter and crime. For the reasons stated above, low-growing plantings along noise walls are preferred despite the potential noise mitigation benefits of taller plantings.

16.10 General Materials Guidelines for Noise Walls

To ensure that all materials used to build noise walls meet acoustic requirements, material information and test results must be submitted to the CDOT Product Evaluation Coordinator for approval to be added to CDOT's Approved Products List. To be approved, the material must meet testing requirements, as described in Section 18.6.1. CDOT also evaluates materials based on additional criteria for which testing methods do not apply, as described in Section 18.6.2.

CDOT may request to view, in person, a sample or a full size section of the barrier product, at CDOT's discretion. Tests shall be performed by a certified independent third party. To obtain valid results, specimens that get tested should be taken from a finished production run product and not from small handmade pieces that were specifically made to be tested.

16.10.1 Acoustic Testing Requirements

Materials shall have a minimum acceptable Sound Transmission Class (STC) of 30, as tested using ASTM E90 and ASTM 413 or a CDOT approved equivalent specification.

Materials shall have a minimum Noise Reduction Coefficient (NRC) of 0.70 if seeking an "absorptive" classification, as tested using ASTM C423 or a CDOT approved equivalent specification. Materials that are not tested or do not meet this requirement shall be classified as "reflective." A material may be tested and classified as absorptive on the roadway side only or on both the roadway and residential sides.

16.10.2 Additional Considerations for Noise Barrier Materials

- Materials must be acoustically durable over the design life. Absorptive surface treated walls must resist degradation of sound-absorbing properties after installation. The materials should not require cleaning in order to maintain sound-absorbing properties.
- Project plans should indicate if the noise wall surface is reflective or absorptive.
- Project plans shall indicate aesthetic and material requirements.
- Noise wall materials of concrete panels, masonry blocks, or brick are used most frequently because of their life cycle cost and maintenance considerations. Noise walls are generally built using concrete. Concrete durability properties and coating properties for concrete are not unique to noise walls. If noise walls are designed with another material, durability and coating properties would be examined on a case-by-case basis. The CDOT *Landscape Architecture Manual* (CDOT, 2020b) does not allow use of wood.
- Barriers shall be designed and constructed without gaps, or, if an opening is required, the gap shall be minimized.
- Generally, barrier heights are a minimum of 8 feet and a maximum of 20 feet. For barriers constructed on the shoulder, 12 feet is a recommended maximum height. Project design may adjust these dimensions if required.
- Materials must be resistant to impact or easily replaceable or repairable using CDOT-owned equipment.
- Surface texture, coating, or combination thereof of walls in areas subject to graffiti should make the graffiti difficult to place and easy to remove. Details of the process to remove graffiti should be provided to CDOT.

Pre-approved absorptive and reflective noise wall materials are included in CDOT's Approved Products List.

Use this link to access CDOT's Approved products List:
https://www.codot.gov/business/apl

16.11 Construction Noise

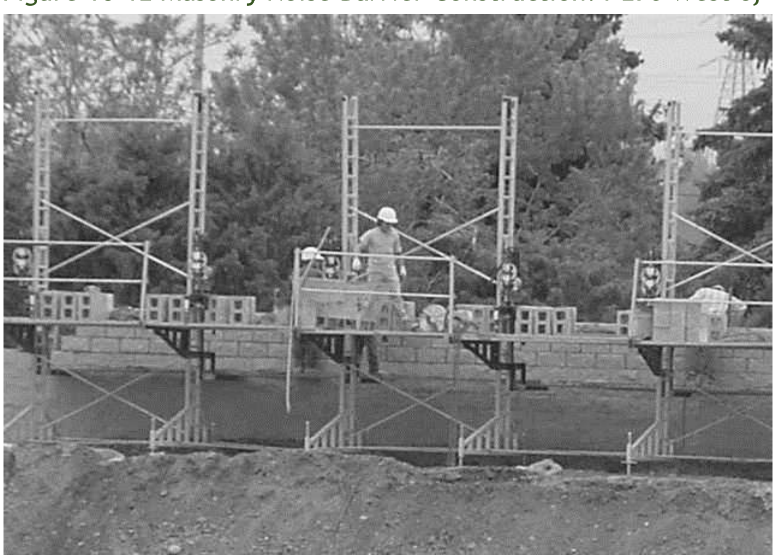
The approach to construction noise should be general in scope and consider the temporary nature of construction activities. Although the public generally views construction noise as a short-term issue that is tolerable and necessary, types of activities that are expected to be performed and equipment that will be used should be disclosed.

Although a detailed analysis of mitigation measures is not generally required, the noise analysis identifies low-cost, practical mitigation measures that can be included on the project. Examples are limiting work to daytime hours, ensuring that equipment uses properly maintained mufflers, the use of temporary noise barriers or screening, modification of backup alarm systems, location of haul roads, construction of feasible and reasonable noise barriers as soon as possible, and public outreach. Noise mitigation may be a larger issue on large, complex projects in urban areas. For these projects, a more detailed discussion is necessary and may require a separate report detailing monitoring and mitigation measures.

Colorado Noise Statute 25-12-103 addresses maximum permissible noise levels from construction projects. The applicable local government agency may also have more restrictive requirements regarding construction noise, which would supersede the state statute. Compliance with the restrictions of local agency noise ordinances is required unless a variance has been approved. Such a variance may be needed if the work will be very extensive or lengthy.

Use this link to access CDOT's noise resources:
https://www.codot.gov/programs/environmental/noise

Figure 16-12 Masonry Noise Barrier Construction: I-270 West of York Street



Chapter 17
Construction Specifications

Legend

	Multimodal Application Example
	Context Sensitive Solutions Application Example
	Performance-Based Practical Design Application Example
	Multimodal (MM)
	Context Sensitive Solutions (CSS)
	Performance-Based Practical Design (PBPD)
	Web link for additional information
	AASHTO Specific Information

Chapter

17

17 Construction Specifications

17.1 Introduction

This chapter defines Standard Specifications and Special Provisions. It provides details on the format and guidelines for writing Special Provisions and describes the approval process for both Standard and Project Special Provisions.

17.2 Specifications - General

17.2.1 Definition

"Specifications" is a general term applying to all directions, provisions, and requirements pertaining to the performance of the work and payment for the work on a construction project.

17.2.2 Importance and Characteristics of Well-Written Specifications

Well-written specifications are essential to the efficient construction of a successful project. Well-written specifications inform the Contractor of the work to be performed, the conditions and restrictions on performance of the work, the expected quality of the work, and the manner in which the work will be measured for payment.

With the increased complexity and specialization in modern construction and the need for the Project Engineer to focus on legal requirements and administration, use of the phrase "as directed by the Engineer" should be minimized. Work requirements must be clearly stated in the specifications.

Well-written specifications:

- Are clear, concise, and technically correct.
- Do not use ambiguous words that could lead to misinterpretation.
- Are written using simple words in short, easy to understand sentences.
- Use technically correct terms, not slang or "field" words.
- Avoid conflicting requirements.
- Do not repeat requirements stated elsewhere in the Contract.
- Do not explain or provide reasons for a requirement.
- State construction requirements sequentially.
- Avoid the use of ambiguous phrases such as "and/or" and "him/her.

Furthermore, the phrases "approved by the Engineer" or "accepted by the Engineer" should be avoided. These should be used only when the Engineer will actually accept or approve the work. In such phrases, "approved" and "accepted" are synonymous; there is no difference in the responsibility taken by the Engineer.

17.2.3 Basic Specification Policy

Some of CDOT's established policies for the development and use of construction specifications are described below. These policies are based on federal and state laws and regulations, CDOT Policy and Procedural Directives, directions from the Chief Engineer, and established CDOT practice.

17.2.3.1 Standards and Specifications Unit

The Standards and Specifications Unit in the CDOT Project Development Branch oversees the development and implementation of construction specifications. This unit writes and revises the CDOT Standard Specifications for Road and Bridge Construction (commonly called the Standard Specifications) and CDOT Supplemental Specifications, issues Standard Special Provisions, and prepares or reviews Project Special Provisions. Note that the Standard Specifications are updated every few years.

*Use this link to access CDOT's construction specifications: Construction Specifications — Colorado Department of Transportation (codot.gov)*https://www.codot.gov/business/designsupport/other-specifications/fipi

At the link, there are folders for Standard Specifications by the year they were issued. A project will typically use the Standard Specifications in the most recent year or folder. The folders contain the Standard Specifications, guidance documents about the specifications, significant changes to the specifications from the prior version, and links to the Standard Special Provisions and to Project Special Provisions.

CDOT Procedural Directive 513.1 - Construction Project Specifications (CDOT, 2016) states that the Standards and Specifications Unit is to review and approve all new Project Special Provisions and newly revised Project Special Provisions that contain significant changes and initiate a formal review process when necessary. The Standards and Specifications Unit should be given at least two weeks to review proposed Project Special Provisions before they are incorporated into the construction project documents for advertisement.

The CDOT Specification Committee (described in Procedural Directive 513.1 [CDOT, 2016]) assists the Standards and Specifications Unit with the review and development of formal specification changes that may be controversial or have a significant impact on the highway construction industry.

17.2.3.2 Liquidated Damages, Penalties, and Incentives

Specifications that assess penalties to the Contractor should not be used. The only deductions that can be made from monies due the Contractor are:

- Liquidated damages based on additional engineering costs to CDOT.
- Incentives and disincentives based on either the quality of the work or incurred road user costs.
- Price adjustments based on the quality of the work.

In each case, the deduction amount included in the specification must be accurately calculated and documented in the project file. Remediation specified for non-specification work should not be harsh or punitive, but should accurately represent the actual loss of value to the Department or to the road user.

17.2.3.3 Uniformity

CDOT strives to achieve statewide uniformity in the use and application of specifications. Frequent changes to specifications and differences in specifications from project to project and Region to Region lead to misinterpretation, inconsistent enforcement, higher bid prices, and Contractor claims. As much as possible, the Standard Specifications, Standard Special Provisions, and formally issued sample Project Special Provisions and Special Provision Work Sheets should not be changed.

17.2.3.4 Warranties and Guaranties

In accordance with the 23 Code of Federal Regulations (CFR) Part 635.413, warranties or guarantees are allowed on federal aid projects, however, their inclusion within the Contract must be limited to a “specific product or feature” and cannot “place an undue obligation on the Contractor for items or conditions over which the Contractor has no control.” Warranties for items of maintenance are not eligible for federal participation and will not be allowed. Allowing the use of a “General Warranty” by making the item non-participating is not an acceptable solution since this is viewed as circumventing the federal requirements. CDOT applies this policy to all projects including those that are not federally funded or are not on the National Highway System (NHS).

Warranties must be for a specific feature or product, and the specification must clearly define the performance indicators and the corrective action required. All warranty specifications shall be sent to the CDOT Standards & Specifications Unit for review and approval four weeks prior to inclusion in a project for advertisement.

Generally, it is difficult to establish warranties on projects where the warranty period extends beyond the final acceptance date of the project. When a project is accepted, the project is closed within a matter of months, and this leaves no recourse to enforce the warranty. Quality standards and specifications that outline expectations for a project are a stronger method to gain a quality product.

17.2.3.5 Proprietary Items

The use of trade or brand names or the direct reference to patented or proprietary materials, specifications, or processes should be avoided in contracts. This applies to all projects, NHS and non-NHS, regardless of funding source. Generic construction specifications should be developed that will obtain the desired results, as well as assure competition among equivalent materials or products. There are instances, however, where a particular proprietary product must be specified for use on a project.

If only patented or proprietary products are acceptable, they shall be bid as alternatives with all, or at least a reasonable number of acceptable materials or products listed. A reasonable number would be to specify in the contract two or three equally suitable products and include the term "or approved equal." Note that additional wording must be added to the specifications to more clearly define the phrase "or approved equal." An example of this is the following:

> For an alternative material to be considered an approved equal, the product shall have been lab tested and field trialed by the National Transportation Product Evaluation Program (NTPEP) and approved by CDOT's Materials and Geotechnical Program.

Use this link for more information about the NTPEP evaluation program:
*http://www.ntpep.org/Pages/RSCPReports.aspx*https://www.codot.gov/business/designsupport/other-specifications/fipi

If a product is on the approved Finding in the Public Interest (FIPI) list, it will be noted in the specification and the term "or approved equal" is not to be used. Also, if four or more products are specified, the term "or approved equal" should not be used and neither a FIPI nor Certification is necessary. Therefore, when the use of a patented or proprietary (trade name) item is essential and only one item is to be specified in the Contract for synchronization reasons or if no equally suitable alternative exists, then a Certification is necessary. However, if only one item is to be specified in the Contract when there are equally suitable products, or if two or three items without the phrase "or approved equal" are to be specified in the Contract, then a FIPI is necessary.

The Certification Process requires that the Residency Engineer (for project specific), Program Engineer (for regionwide use), or Branch Manager (for statewide use) prepare documentation (CDOT Form 1381) that shows:

1. that no equally suitable alternative exists; or
2. that the item is essential for synchronization with existing transportation facilities.

Once the documentation (CDOT Form 1381) is complete, it shall be submitted to the Standards and Specifications Unit Manager for review and posting. Refer to Design Bulletin 2020-02 for further clarification.

For more guidance on the use of proprietary items, including development of the certification or FIPI, refer to Subsection 2.24.01 of the CDOT *Project Development Manual* (CDOT, [2013] 2022).

Use this link for more information on the FIPI process, certification process, and the current products approved by CDOT
https://www.codot.gov/business/designsupport/other-specifications/fipi

17.2.3.6 Materials-Methods vs. End-Result Specifications

Materials-methods and end-result are the two basic types of construction specifications. Materials-methods specifications describe in detail the materials, workmanship, and processes the Contractor shall use during construction. Materials-methods specifications restrain contractor innovation and obligate the owner to accept the work if the specified materials and processes are used. End-result specifications describe the desired result or quality of the final product to be achieved. End-result specifications encourage contractor innovation and allow the owner to accept or reject the final product. Current CDOT specifications include both types and, in some cases, a combination thereof. End-result specifications are preferred.

Process Control/Owner Acceptance (PC/OA) is a type of end-result specification. PC/OA specifications require the Contractor to perform all testing necessary for control of production while the owner (CDOT) performs the testing necessary to determine acceptance, rejection, or price adjustment of the product. Acceptance, rejection, or price adjustment is usually based on a statistical analysis of the test results. CDOT currently uses PC/OA specifications for pavements.

17.2.3.7 Pay Items

The specifications establish the pay items under which the Department will pay the Contractor for work completed. Readily identifiable and measurable items of work should not be made subsidiary to other items but should be paid for under separate pay items. Use of lump sum pay items should be minimized. Pay items with subsidiary items and lump sum pay items are difficult for contractors to bid and difficult for the Project Engineer to administer during construction, especially in cases of changed conditions or changed quantities.

Payment for work by force account should be minimized. Force account work involves additional paperwork and often has a higher cost than if the work had been paid for under a bid item.

During the design phase, there are times the designer needs to create force account pay items for such items, as utilities, fuel cost adjustments, quality incentives, other material incentives, reimbursements for tribal fees or other pass-through payments necessary to complete specialized work by others (not the Contractor). Generally, the designer is guided by support staff on the necessity for force account pay items and the amount to budget for each specific force account item.

17.2.3.8 Reference Specifications

AASHTO (American Association of State Highway and Transportation Officials) is the preferred reference for citations. Other national standard references such as American Society for Testing and Materials (ASTM) may be used when there is no AASHTO specification available.

17.2.3.9 Laws, Statutes, and Regulations

Subsection 107.01 of the Standard Specifications requires the Contractor to be fully informed of, and comply with, all applicable laws and regulations. Generally, specifications that apply, interpret, or enforce laws and regulations should not be used.

17.3 Standard Specifications

Work on CDOT construction projects is controlled by the Standard Specifications. Except where necessary when citing reference specifications (Refer to Section 17.2.3.8), the Standard Specifications contain only English units of measure. Refer to Section 17.7.

17.3.1 Organization

The Standard Specifications are organized into seven Divisions made up of Sections. Division 100 covers contractual procedures, general and legal responsibilities of the Contractor, prosecution of the work, control of the work and materials, and measurement and payment for the work, including force account work. Divisions 200 through 600 cover construction details for specialized areas. Division 700 covers details for the materials. The Standard Specifications Division are:

DIVISION 100 - GENERAL PROVISIONS

DIVISION 200 - EARTHWORK

DIVISION 300 - BASES

DIVISION 400 - PAVEMENTS

DIVISION 500 - STRUCTURES

DIVISION 600 - MISCELLANEOUS CONSTRUCTION

DIVISION 700 - MATERIALS

17.3.1.1 Section Parts

Each Section of the construction details, Sections 201 through 641, is organized into the following five parts, in the following order:

DESCRIPTION

This part consists of short, succinct statements summarizing the work covered by this Section of the Standard Specifications. The description should not contain details, materials or construction requirements, or explanations of measurement and payment.

MATERIALS

This part either specifies the materials requirements for the work within this Section, or refers to subsections in the Materials Details in Sections (701 through 717) that contain those requirements.

CONSTRUCTION REQUIREMENTS

This part consists of the required construction procedures or end results of the work to be performed under this Section of the Standard Specifications. Specific construction details are specified in this part.

METHOD OF MEASUREMENT

This part describes the methods and the units by which the work under this Section of the Standard Specifications will be measured for payment to the Contractor.

BASIS OF PAYMENT

This part establishes the pay items for work accomplished under this Section of the Standard Specifications and, when necessary, explains what is included in the payment for those pay items.

17.3.1.2 Subsections

Subsections run consecutively through each Section (the parts are listed in Section 17.3.1.1). The first subsection is xxx.01, the second xxx.02, etc., where xxx is the Section number.

Subsections are broken into smaller parts by consecutive numerical or alphabetical characters and indented.

Numbers in parentheses are also used to identify items in a list, regardless of the placement of the list within the subsection.

Refer to Figure 17-1 for an example.

Figure 17-1 Subsection Organization Example

XXX.XX Subsection Name, If Any. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes.

XXX.XY Subsection Name, If Any. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes.

(a) Subsection name, if any. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. THIS IS HOW A LIST IS FORMATTED:

(1) This is an item in a list.
(2) This is an item in a list.
(3) This is an item in a list.

(b) Subsection name, if any. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes.

1. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes.

2. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes.

A. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes.

B. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes.

(1) This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes.

(c) Subsection name, if any. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes. This is where the subsection text goes.

17.4 Supplemental Specifications

Supplemental Specifications are additions and/or revisions to the Standard Specifications that are formally adopted subsequent to the issuance of the printed book. Supplemental Specifications apply to all CDOT construction projects in the same manner as the Standard Specifications. The Contract will clearly identify when Supplemental Specifications are in effect.

When a new set of Standard Specifications is issued, the Supplemental Specifications are also revised, making the prior versions no longer valid. As a designer, it is imperative to know the exact year of Standards that are being used and to use the Supplemental Specifications that correspond to the Standard Specifications. Failure to do this can create conflicting specifications which can lead to delays and claims on a project during construction.

17.5 Special Provisions

Special Provisions are additions and revisions to the Standard and Supplemental Specifications covering conditions unique to an individual project or group of projects. Special Provisions apply to a particular construction project only when included in the Contract for that project. Special provisions fall into one of two categories: Standard Special Provisions or Project Special Provisions. Special provisions are developed and implemented according to Procedural Directive 513.1, Construction Project Specifications (CDOT, 2016).

17.5.1 Organization of Text

The revised or added specification text should be organized under each heading according to the conventions used in the Standard Specifications.

17.5.2 Margins

The margins used in Special Provisions are 0.75 inch for left and right and 0.5 inch for top and bottom.

17.5.3 Text

Bold and italicized characters should not be used in the body of the text to emphasize or draw attention to a particular requirement. Underlining is not used in the Standard Specifications and should not be used in Special Provisions.

Titles preceded by (a), (b), etc. should be italicized (refer to Figure 17-1).

Text should be bold where it would be in the Standard Specifications. Such locations include section headings, subsection numbers, subsection titles, and table headings.

17.5.4 Standard Special Provisions

Standard Special Provisions are additions and revisions to the Standard and Supplemental Specifications, which are unique to a selected group of projects or are intended for temporary use. Standard Special Provisions are dated and formally issued by the CDOT Project Development Branch with specific instructions for their use. They are to be used without modification. The

Standards and Specifications Unit of the Project Development Branch should be contacted if a project has special circumstances that may require modification of a Standard Special Provision.

17.5.4.1 Fonts

The font used for Standard Special Provisions is Trebuchet MS 14 for headers and Trebuchet MS 12 for body.

17.5.5 Project Special Provisions

Project Special Provisions are additions and revisions to the Standard Specifications and Supplemental Specifications unique to a particular project. The writing style used for Project Special Provisions should be consistent and uniform.

17.5.5.1 Criteria

- Write a Project Special Provision only if the subject has not been adequately covered in the plans, Standard Specifications, or Standard Special Provisions.
- Write clear, enforceable requirements that will be interpreted the same way by both the Engineer and the Contractor.
- State the correct pay items. The name of the pay item must be consistent throughout the plans, specifications, and estimate. If the bid item is not listed in the current CDOT Item Book, the Project Manager should contact the Engineering Estimates and Market Analysis Unit and the Standards and Specifications Unit.
- Make sure that Project Special Provisions do not conflict with other parts of the plans and specifications.
- Use end-result rather than materials-methods requirements where possible.
- Specify a requirement; don’t make a suggestion or give an explanation.
- Use the verb “will” when stating actions that will be taken by CDOT and “shall” when the action is to be taken by the Contractor. For example, refer to the following statements in Subsection 108.03 of the Standard Specifications regarding the project schedule:
  - "The Project Schedule shall show all activities required by all parties to complete the work.” [Contractor's responsibility]
  - "The Engineer’s review of the schedule will not exceed 10 calendar days. " [Engineer's responsibility]

Refer to the following statements in Subsection 601.05 of the Standard Specifications:

  - "Except for Class BZ concrete, the slump of the delivered concrete shall be the slump of the approved concrete mix design plus or minus 2.0 inches." [Contractor's responsibility]
  - "Acceptance will be based solely on the test results of concrete placed on the project." [Engineer's responsibility]

- Use the appropriate Standard Special Provisions as written; don't write a Project Special Provision that covers the same issue without consulting the Standards and Specifications Unit.
- Do not use Project Special Provisions with guaranty or warranty clauses unless they fall within the guidelines described in the 23 CFR Part 635.413. Check with the Standards and Specifications Unit to ascertain if policies and procedures have been implemented pertaining to the use of the warranty provision. Refer to Section 17.2.3.4.
- Do not use proprietary items except as outlined in Section 17.2.3.5.

17.5.5.2 Format and Style

Project Special Provisions should conform to the conventions used in the Standard Specifications. Refer to the examples for each type described in Section 17.5.5.5.

17.5.5.3 Fonts

The font used for Standard Special Provisions is Trebuchet MS 14 for headers and Trebuchet MS 12 for body.

17.5.5.4 Titles

The title, capitalized and centered at the top of the page, should identify the Section of the Standard Specifications being revised and the subject of the revision. On multiple page Special Provisions, the page number pertaining to the Special Provision should be centered on the first line of the title, on every page.

17.5.5.5 Types of Special Provisions

The basic types of Special Provisions are described below with an example following. Use the example headings, or a variation thereof, for the appropriate type of Special Provision (xxx represents the section number).

Type 1 - Revision of Various Subsections

- Begin a Special Provision that revises one or more subsections with the following heading:

  Section xxx of the Standard Specifications is hereby revised for this project as follows:

  Follow that statement with the appropriate one or more of the following headings, or variation thereof:

  Subsection xxx.xx shall include the following:

  Delete Subsection xxx.xx and replace it with the following:

  In Subsection xxx.xx delete the nth paragraph and replace it with the following: Subsection xxx.xx, nth paragraph shall include the following:

  In Subsection xxx.xx, nth paragraph, delete the nth sentence and replace it with the following:

When appropriate, follow each heading with the added or revised text.

Include related changes to separate parts of a Section in a single Special Provision, e.g., when revising CONSTRUCTION REQUIREMENTS and the related MATERIALS part.

Refer to Figure 17-2 for an example.

Figure 17-2 Type 2 – Deletion and Replacement of an Entire Section Example

REVISION OF SECTION 202

REMOVAL OF ASPHALT MAT

Section 202 of the Standard Specifications is hereby revised for this project as follows:
Subsection 202.01 shall include the following:
This work includes removal and disposal of existing asphalt mat within the project limits as shown on the plans or at locations directed by the Engineer.

In subsection 202.02 delete the seventh paragraph and replace with the following:

The existing asphalt mat which varies in thickness from 2.5 inches to 6 inches shall be removed in a manner that minimizes contamination of the removed mat with underlying material. The removed mat shall become the property of the Contractor and shall be either disposed of outside the project site, or used in one or more of the following ways:

(1) Used in embankment construction in accordance with subsection 203.06.
(2) Placed in bottom of fills as approved by the Engineer.
(3) Recycled into the hot mix asphalt.
(4) Placed in the subgrade soft spots as directed by the Engineer.

Subsection 202.11 shall include the following:
The removal of the existing asphalt mat will be measured by the square yard of mat removed to the required depth and accepted.

Subsection 202.12 shall include the following:
Payment will be made under:

Pay Item	**Pay Unit**
Removal of Asphalt Mat	Square Yard

Unless otherwise specified in the Contract, the disposal of the asphalt mat or its use in other locations on the project will not be measured and paid for separately but shall be included in the work.

Type 2 - Deletion and Replacement of an Entire Section

Begin a Special Provision that deletes and replaces an entire Section with the following:

> Section xxx of the Standard Specifications is hereby deleted for this project and replaced with the following:

Follow this statement with the revised text of the Section. Organize the text into the five main parts: DESCRIPTION, MATERIALS, CONSTRUCTION REQUIREMENTS, METHOD OF MEASUREMENT, and BASIS OF PAYMENT.

Refer to Figure 17-3 for an example.

Figure 17-3 Revision of Various Subsections Example

REVISION OF SECTION
306 RECONDITIONING

Section 306 of the Standard Specifications is hereby deleted for this project and replaced with the following:

DESCRIPTION

306.01 This work consists of ripping and pulverizing the existing asphalt mat, regrading and compacting the subgrade with moisture and density control, and placing the pulverized bituminous material as a modified base course atop the subgrade, in accordance with the specifications, at locations shown, and in conformity with the details shown on the plans or as staked.

CONSTRUCTION REQUIREMENTS

306.02 The existing mat shall be ripped, pulverized, and placed in windrows. The maximum particle size of the pulverized bituminous material shall be 1.5 inches.

The top 4.5 inches of the subgrade material shall then be removed and disposed of at the location designated on the plans. The top 6 inches of the remaining subgrade material shall be scarified, shaped, and compacted using moisture and density control. The subgrade surface shall not vary above or below the lines and grades staked by more than 1 inch. The surface will be tested prior to placement of the pulverized bituminous material.

The pulverized bituminous material shall then be placed as shown on the plans and compacted using moisture and density control.

METHOD OF MEASUREMENT

306.03 Reconditioning will be measured by the square yard of roadway treated, complete and accepted.

BASIS OF PAYMENT

306.04 The accepted quantities of reconditioning will be paid for at the contract unit price per square yard for reconditioning.

Payment will be made under:

Pay Item	**Pay Unit**
Reconditioning	Square Yard

Payment for reconditioning will be full compensation for all work necessary to complete the item including ripping and pulverizing the existing asphalt mat, excavation and disposal of subgrade material, scarifying and compacting the subgrade, placing and compacting the pulverized bituminous material, blading, shaping, haul, and water.

Type 3 - Addition of a New Section

Begin a Special Provision that adds a new specification Section with the following:

> Section xxx is hereby added to the Standard Specifications for this project as follows:

Follow this statement with the text of the new Section. Organize the text into the five main parts: DESCRIPTION, MATERIALS, CONSTRUCTION REQUIREMENTS, METHOD OF MEASUREMENT, and BASIS OF PAYMENT.

Refer to Figure 17-4 for an example.

Figure 17-4 Addition of a New Section Example

SECTION 621 TEMPORARY BRIDGE

Section 621 is hereby added to the Standard Specifications for this project as follows:

DESCRIPTION

621.01 This item includes loading, transporting, erecting, maintaining, removing, and returning the temporary bridge.

MATERIALS

621.02 The temporary bridge is a Bailey Bridge in the possession of the Department. The Department will not charge a rental fee for the use of this bridge on this project.

CONSTRUCTION REQUIREMENTS

621.03 The Contractor shall load and return the temporary bridge at the following site:

[INSERT SPECIFIC LOCATION]

The Contractor shall make arrangements with Department maintenance personnel at least five days prior to the loading and returning dates.

The temporary bridge shall be erected at the location and in conformity with the lines and grades shown on the plans or established.

The Contractor shall replace all structural parts that are missing or damaged when the bridge is returned. The Contractor shall band all components together before returning the bridge for storage.

The Contractor shall return the temporary bridge within 30 days after the new structure is opened to traffic.

METHOD OF MEASUREMENT

621.04 Temporary Bridge will not be measured, but will be paid for on a lump sum basis.

BASIS OF PAYMENT

621.05 The completed and accepted work for the temporary bridge will be paid for at the contract lump sum price. This price shall include all labor, equipment, and materials required to load, transport, erect, maintain, remove, and return the temporary bridge.

Payment will be made under:

Pay Item	**Pay Unit**
Temporary Bridge	Lump Sum

Type 4 - Addition of Changes Not Tied to Specific Subsections

Begin a Special Provision that adds text throughout the Section and that does not tie in well to the existing subsections (such as requirements for a new item or type of construction) with the following:

> Section xxx is hereby revised for this project to include the following:

Follow this statement with the new text organized into the five main parts: DESCRIPTION, MATERIALS, CONSTRUCTION REQUIREMENTS, METHOD OF MEASUREMENT, and BASIS OF PAYMENT.

Special Provision Type 1 is the preferred and most commonly used type of Special Provision. Samples of each type of Special Provision appear in Subsection 16.8.

Refer to Figure 17-5 for an example.

Figure 17-5 Addition of Changes Not Tied to Specific Subsections Example

REVISION OF SECTION 210

RESET IMPACT ATTENUATOR

Section 210 of the Standard Specifications is hereby revised for this project to include the following:

DESCRIPTION

This work consists of resetting impact attenuators in accordance with these specifications and in conformity with the lines and details shown on the plans or established.

MATERIALS

The impact attenuators are the types shown at the various locations on the plans.

CONSTRUCTION REQUIREMENTS

The site shall be prepared to receive the reset impact attenuator by filling, excavating, smoothing and all other work necessary for the proper installation of the attenuator.

The impact attenuator shall be installed in accordance with the manufacturer's recommendations.

METHOD OF MEASUREMENT

Reset impact attenuator will be measured by the number of attenuators as shown on plans, reset and accepted, including site preparation and all necessary hardware.

BASIS OF PAYMENT

The accepted quantities will be paid for at the contract unit price for the pay item listed below.

Payment will be made under:

Pay Item	Pay Unit
Reset Impact Attenuator	Each

Special provisions revising any of the Sections 201 through 641 should be written so that the revised or added specification text is incorporated into the appropriate subsections under one or more of the five main parts. New main parts should not be established except in the rare instance of adding an item for design to be performed by the Contractor.

The organization used for the Standard Specifications for Road and Bridge Construction should be followed for the added or revised text of Project Special Provisions. The part of the subsection being revised should be identified and the new or revised text should be made to fit that part. The text or breakdown character should start at the left margin and not be indented.

17.5.6 Use of New or Revised Project Special Provisions

New and newly revised Project Special Provisions that contain significant changes must be reviewed by the Standards and Specifications Unit in the Project Development Branch. These should be submitted electronically in the format described above and with sufficient review time (normally two weeks). The Project Manager should be prepared to explain the engineering or project management considerations that justify the use of the Project Special Provision.

The Standards and Specifications Unit will review the proposed special provision for conformance to CDOT policy and FHWA regulations, potential controversy, clarity, grammar, punctuation, and format. The Standards and Specifications Unit will respond with approval, suggested changes, or a statement that the special provision should not be used. When the Standards and Specifications Unit determines that a proposed special provision is controversial or addresses an issue with broad impact, it may initiate a more formal review process to be completed before the proposed special provision can be used on CDOT construction projects.

If the proposed Project Special Provision covers an issue that could have statewide implications, the Branch Manager or Region Transportation Director should request review by the appropriate CDOT Technical Committee or submit a Form 1215 - Submittal of New Specification or Specification Change (CDOT, n.d.) to the Standards and Specifications Unit.

17.5.7 Special Provision Package

The Contract documents for each CDOT construction project include a set of special provisions accompanying the plan sheets. This set of special provisions consists of an index of the Project Special Provisions and an index of the applicable Standard Special Provisions followed by the Project and Standard Special Provisions. The project manager inserts the Project Special Provisions listed on the index.

When preparing the special provision package for a project, the project number and code should be listed on the left and the date on the right at the top of each Project Special Provision page.

The page number should be centered at the bottom of each page. The Index and Project Special Provision pages should be numbered consecutively, beginning with Page 1.

17.6 Construction Specifications Website

The Standards and Specifications Unit maintains Special Provisions on the CDOT website.

17.6.1 Accessing the Website

Use this link to access CDOT's construction specifications: [Construction Specifications – Colorado Department of Transportation (codot.gov)](https://www.codot.gov/business/designsupport/other-specifications/fipi)https://www.codot.gov/business/designsupport/other-specifications/fipi.

17.6.2 Contents of the Website

The Specifications page on the CDOT website contains:

- Standard Specifications Text
- Current Standard Special Provisions
- Project Special Provision Work Sheets
- Sample Project Special Provisions
- Materials Specifications Check List
- Design/Build Special Provisions
- Fuel Cost Adjustment
- Asphalt Cement Cost Adjustment
- Past Davis-Bacon Minimum Wage Decisions
- Innovative Contract Provisions
- Phased Funding Special Provisions
- Warranted HBP Special Provisions
- Significant Changes found in the Standard Specifications

The following information is also available:

- Creating a Special Provision Package for a CDOT Project
- Guidelines for Writing Construction Specifications (this document)
- Specification Changes Under Consideration

17.6.3 Project Special Provision Work Sheets

Work sheets available on the website include those for frequently used Project Special Provisions and instructions for index pages, Notice to Bidders, Commencement and Completion of Work, and Traffic Control Plan - General.

17.6.4 Updates

The Standards and Specifications Unit notifies users of updates to the website by e-mail.

17.7 Use of Metric and English Units

The Standard Specifications and Standard Special Provisions used with it contain only English units. Project Special Provisions should contain only English units, except where metric units are required to conform to reference specifications.

17.8 Writing Style

Traditionally, specifications are written in the indicative mood, either active or passive voice.

- Active voice:

  The Contractor shall place the aggregate to a depth of 6 inches and compact it to a density of 95 percent.

- Passive voice:

  The aggregate shall be placed to a depth of 6 inches and compacted to a density of 95 percent.

Some states have rewritten their standard specifications in the imperative mood, active voice. This style of writing replaces the lengthy "the Contractor shall" sentences with short sentences giving direct instructions.

- Imperative mood, active voice:

  Place the aggregate to a depth of 6 inches and compact it to a density of 95 percent.

However, CDOT has not adopted the imperative mood style in the Standard. The book is written in the indicative mood, either active voice (where possible) or passive voice (where necessary).

Special provisions should match the style of the Standard Specifications. In special provisions, use short simple sentences in the active voice wherever possible. Use the imperative mood only if it is preceded by an introductory statement clarifying that the text makes a requirement on the Contractor. An example that appears in Subsection 209.05 of the Standard Specifications is the following:

> Magnesium Chloride dust palliative shall be applied as follows:
>
> 1. Scarify the top 2 inches of the existing road surface and wet with water to approximately four percent moisture content, or as directed.
> 2. Apply the magnesium chloride dust palliative in two applications of 0.25 gallon per square yard in each application.
> 3. Allow to soak for 30 minutes after each application.
> 4. Roll the surface with a pneumatic tire roller, as specified in the Contract.
> 5. Do not permit traffic on the treated surface until approved.

Other protocols for grammar, syntax, and format that have been applied in the Standard Specifications and that should be applied to special provisions appear in Table 17-1.

Table 17-1 Spec Book Grammar, Syntax, and Format Protocol

Item	In Text	In Tables (and Tabular Lists)	In Lists (Consisting of Text)
Numbers	For counts from 1 to 10 use words: three hours, four posts; Counts over 10 use digits: 24 hours, 14 posts; where one of each is related, use digits for both: 6 to 12 hours. For dimensions & measurements use digits: 6 inches, 7 cubic yards.	Use digits	For counts from 1 to 10 use words: three hours, four posts; Counts over 10 use digits: 24 hours, 14 posts; where one of each is related, use digits for both: 6 to 12 hours. For dimensions & measurements use digits: 6 inches, 7 cubic yards.
Ordinal numbers	Use words: first, fifth, twentieth	Use symbols: 1^{st}, 5^{th}, 20^{th}	Use words: first, fifth, twentieth
Large numbers & money	Do not reiterate in Parentheses: $80,000 - not $80,000 (eighty thousand dollars)	Do not reiterate in Parentheses: $80,000 - not $80,000 (eighty thousand dollars)	Do not reiterate in Parentheses: $80,000 - not $80,000 (eighty thousand dollars)
Dimensions	Use words: foot, yard, inches	May use abbreviation (ft., yd.) or symbol (',")	Use words
Areas	Use words: square foot, square yard	May use abbreviation: sq. ft., sq. yd.	Use words
Volumes	Use words: cubic yard, cubic feet, gallons	May use abbreviation: cu. yds. cu. ft., gal.	Use words
Densities/ rates	Use words: pounds per cubic yard, gallons per square yard	May use abbreviations: lbs./cu. yd., gal./sq. yd.	Use words
Temperature	Use symbol: °F	Use symbol: °F	Use symbol: °F
Ranges	Use "to" not "-": 180 to 190 °F, 6 to 12 inches	Use "to" or "-": 180 - 190 °F, 6 to 12"	Use "to" not "-": 180 to 190 °F, 6 to 12 inches
SI sieve sizes	Use symbols: 19.0 mm, 300 µm	Use symbols: 19.0 mm, 300 µm	Use symbols: 19.0 mm, 300 µm
SAE sieve sizes	Use words: 2 inch, ½ inch, No. 30, No. 100	Use symbols: 2", ½", #30, #100	Use symbols: 2", ½", #30, #100

Item	In Text	In Tables (and Tabular Lists)	In Lists (Consisting of Text)
Right of Way	Use words or abbreviation: Right of Way, ROW	Use abbreviation: ROW	Use abbreviation: ROW
Dual Units, e.g., sieve sizes	SI first with SAE in parentheses: 25.0 mm (1 inch)	SI first with SAE in parentheses: 25.0 mm (1 inch)	SI first with SAE in parentheses: 25.0 mm (1 inch)
CDOT Forms	Use just the form No.: Form 463	Use just the form No.: Form 463	Use just the form No.: Form 463
Other Forms	Identify the originating organization: FHWA Form 1273	Identify the originating organization: FHWA Form 1273	Identify the originating organization: FHWA Form 1273
Percentages	Use word: 12 percent, 25 percent	Use symbol: 12 %, 25%	Use word: 12 percent, 25 percent
Ratios	Use colon: 1:1, 1½:1	Use colon: 1:1, 1½:1	Use colon: 1:1, 1½:1
Use of "and/or"	Do not use "and/or": alternatives are: "a, b, or both" and "a, b, c, or a combination thereof". Sometimes "a, b, or c" works just as well.	Does not usually appear in tables.	Do not use "and/or": alternatives are: "a, b, or both" and "a, b, c, or a combination thereof". Sometimes "a, b, or c" works just as well.
Use of "noun(s)"	Avoid use of "noun(s)". Can often use just the singular or plural; or rewrite the sentence: workers [however many], each worker.	Does not usually appear in tables.	Avoid use of "noun(s)". Can often use just the singular or plural; or rewrite the sentence: workers [however many], each worker.
Use of "under Item XXX"	Avoid use of this construction. Instead of "will be paid for under Item 613" use "will be paid for in accordance with Section 613."	Does not usually appear in tables.	Avoid use of this construction. Instead of "will be paid for under Item 613" use "will be paid for in accordance with Section 613."

Item	In Text	In Tables (and Tabular Lists)	In Lists (Consisting of Text)
Use of the word "any"	Avoid using the word "any", especially where it can be inferred that the Contractor chooses an alternative. Any is a vague word that can mean: all, a selected alternative, every, a specific one, etc. Examples: "The Contractor shall remove any laitance" reads better as "The Contractor shall remove all laitance"; "Any source of borrow other than an available source will be known as a contractor source" reads better as " Sources of borrow other than an available source will be known as Contractor sources."	Does not usually appear in tables.	Avoid using the word "any", especially where it can be inferred that the Contractor chooses an alternative. Any is a vague word that can mean: all, a selected alternative, every, a specific one, etc. Examples: "The Contractor shall remove any laitance" reads better as "The Contractor shall remove all laitance"; "Any source of borrow other than an available source will be known as a contractor source" reads better as " Sources of borrow other than an available source will be known as Contractor sources."
Use of shall & will	When the helping verb "shall" is used in a sentence, it normally indicates that the Contractor is required to perform the stated action in the manner prescribed. When the helping verb "will" is used in a sentence, it normally indicates an action that is intended to be performed by the Engineer or his representative as appropriate.	Does not usually appear in tables.	When the helping verb "shall" is used in a sentence, it normally indicates that the Contractor is required to perform the stated action in the manner prescribed. When the helping verb "will" is used in a sentence, it normally indicates an action that is intended to be performed by the Engineer or his representative as appropriate.
Referring to plans and specifications	In most cases, refer to "in the Contract". When it is necessary to refer specifically to plans or specifications use: "in the specifications" or "on the plans".	Does not usually appear in tables.	In most cases, refer to "in the Contract". When it is necessary to refer specifically to plans or specifications use: "in the specifications" or "on the plans".

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