

CHAPTER 9 INTERSECTIONS

9.0 INTRODUCTION

Intersections are intended to operate with vehicles, pedestrians, and bicycles proceeding in many directions, often at the same time. At such locations, traffic movements on two or more facilities are required to occupy a common area. It is this unique characteristic of intersections, the repeated occurrence of conflicts, that is the basis for most intersection design standards, criteria, and proper operating procedures.

An intersection is defined as the general area where two or more highways join or cross, including the roadway and roadside facilities for traffic movements within it. Each highway radiating from an intersection and forming part of it is an intersection leg. The common intersection of two highways crossing each other has four legs. It is not recommended that an intersection have more than four legs.

An intersection is an important part of a highway 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 highways concerned and may involve turning movements between these highways. These movements may be handled by various means, such as signals, signing, and channelization, depending on the type of intersection.

9.1 GENERAL DESIGN CONSIDERATIONS AND OBJECTIVES

The main objective of intersection design is to reduce the potential conflicts between motor vehicles, bicycles, pedestrians, and facilities while facilitating the convenience, ease, and comfort of the people traversing the intersection. The design should be fitted closely to the natural transitional paths and operating characteristics of the users.

Five basic elements enter into design considerations of intersections:

- Human factors
- Traffic considerations
- Physical elements
- Economic factors
- Functional intersection areas

Although intersections have many common factors, they are not subject to class treatment, and they must be treated as individual problems.

9.2 TYPES AND EXAMPLES OF INTERSECTIONS

9.2.1 General Considerations

The basic types of at-grade intersections are the T-intersection (with multiple variations of angular approach), the four-leg intersection, the multi-leg intersections and roundabouts (see Chapter 19 and the FHWA Roundabout Guide). In each particular case, the type is determined primarily by the number of intersecting legs, the topography, the traffic pattern, and the desired type of operation.

A basic intersection type can vary greatly in scope, shape, and degree of channelization. Once the type of intersection is established, the design controls and criteria covered in Chapter 2 and the elements of intersection design given in Chapter 3 as well as in this chapter must be applied to arrive at a suitable geometric plan.

Each type of intersection is discussed separately in Chapter 9 of the *PGDHS (1)*, and likely variations of each are demonstrated. It is not practical to discuss 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 (2), which shows examples in detail that are not included in this Guide.

9.3 CAPACITY ANALYSIS

Capacity and level of service analysis is one of the most important considerations in the design of intersections. This subject is discussed at length in Chapter 2 of the *PGDHS (1)* and is discussed throughout this chapter as it relates to the various elements of intersection design. 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 6 of the *Highway Capacity Manual (3)*.

9.4 ALIGNMENT AND PROFILE

9.4.1 General Considerations

Horizontal and vertical alignment and cross-sectional features affect driver and/or vehicle behavior at and on the approach to the intersection, and therefore are important design considerations. 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 and with a minimum of interference by other users.

As a rule, alignment and grade are subject to greater restriction at or near intersecting roads than on the open road. Their combination at or near the intersection must produce traffic lanes that are clearly visible to the operators at all times and plainly understandable for any desired direction of travel, free from unexpected hazards, and consistent with the portions of the highway just traveled.

9.4.2 Alignment

Both individual vehicle operations and the nature of vehicle conflicts are affected by the angle of intersection. Roads intersecting at acute angles require extensive turning roadway areas and tend to restrict visibility, particularly for drivers of trucks. When a truck turns on an obtuse angle, the driver has blind areas on the right of the vehicle. Acute-angle intersections increase the exposure time of the vehicles crossing the main traffic flow and may increase the accident potential. Angles of 75 to 90 degrees are generally considered desirable. Although not desirable, a 60-degree angle is considered acceptable. New intersections should not include skewed angles less than 60 degrees without special design and control features to mitigate the effects of the skew. See Exhibit 9-69 in the *PGDHS (1)*. These may include more positive traffic control (all stop, traffic signals) and/or geometric improvements such as greater corner sight distance.

Geometric counter measures, although expensive, are generally the best solution in designing skewed-angle intersections. Reconstruction should reflect traffic patterns at the intersection as well as constraints such as available right of way. The practice of realigning roads intersecting at acute angles in the manner shown in Chapter 9 of the *PGDHS (1)* has proven to be beneficial.

Special care should be taken in designing intersections near horizontal curves. The driving task of tracking the curve takes up much of the driver's focus, leaving less attention for conflict resolution.

9.4.3 Profile

In general, grades for intersecting roads should be as flat as possible to provide for storage platforms and sight distance. Approach grades greater than 6 percent on low-speed highways should be avoided. For high-speed highways, grades greater than 3 percent should be avoided. Most vehicle operators are unable to judge the increase or decrease in stopping or accelerating due to steep grades. Their normal deductions and reactions thus may be in error at a critical time. Therefore, on grades steeper than 3 percent, the grade adjustment factors need to be applied to other design elements to produce conditions equivalent to those on level highways.

The effect of grade on acceleration can be expressed as a factor as shown in Table 10-5.

The profile gradelines and cross sections on the intersection legs should be adjusted for a distance back from the intersection, generally 20 feet, to provide a smooth junction and proper drainage. Normally, the gradeline of the major highway should be carried through the intersection, and that of the crossroad should be adjusted to it.

Changes from one cross slope to another should be gradual. Intersections with a minor road crossing a multilane divided highway with a narrow median and superelevated curve should be avoided whenever possible because of the difficulty in adjusting grades to provide a suitable crossing.

9.5 INTERSECTION CURVES

9.5.1 Widths for Turning Roadways at Intersections

The pavement and roadway widths of turning roadways at intersections are governed by the volumes of turning traffic and the types of vehicles to be accommodated and may be designed for one-way or two-way operation depending on the geometric pattern of the intersection. Widths determined for turning roadways are also applied on all roadways within an intersection. The turning radii and the pavement cross slopes are functions of design speed and type of vehicles. Pavement widths for turning roadways are classified as shown in Table 9-1 below.

Radius on Inner Edge of Pavement (ft)	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 (Feet) for Design Traffic Conditions								
	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 1 Side 2 Sides	Add 1 foot Add 2 feet			None Add 1 foot			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									

Table 9-1 [Exhibit 3-51(1)] Design Widths of Pavements for Turning Roadways

9.5.1.2 Widths Outside Traveled Way

The roadway width for a turning roadway, as distinct from pavement width, includes the shoulders or equivalent lateral clearance outside the edges of pavement.

Table 9-2 (below) is a summary of the range of design values for the described general turning roadway conditions. 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 highway. The widths shown are for usable shoulders. Where roadside barriers are provided, the width indicated should be measured to the face of the barrier, and the graded width should be about 2 feet greater. Turning movements should be checked with modeling software.

Turning Roadway Condition	Shoulder Width or Lateral Clearance Outside of Traveled Way Edge (feet)	
	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.		

Table 9-2 [Exhibit 3-52 (1)] Range of Usable Shoulder Widths or Equivalent Lateral Clearances Outside Turning Roadways, Not on Structure

9.5.2 Minimum Designs for Sharpest Turns

After the lane width has been determined, site conditions along with traffic and island requirements will 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 with the design for the commercial vehicle (SU) considered the desirable minimum.

Curbs along the edges of pavements of sharp intersection curves result in some restriction of vehicles making the turn. A design vehicle making its minimum turn will need to be maneuvered carefully to avoid scraping or jumping the curb. For this reason, when curbs are used, 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 [see Exhibits 9-21 through 9-28 of the *PGDHS (1)*], 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 *PGDHS (1)*. The paths indicated, which are slightly greater than the minimum paths of nearly all vehicles in each class, are the minimums attainable at speeds less than 10 mph. In each case, these widths must be increased to address turning movements of vehicles over 10 mph operating speed. 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 9 inches. Although not shown separately in the figures in the *PGDHS (1)*, these edge designs also apply for left turn layouts such as a left turn to leave a divided highway at a very low speed. The designer should allow for an occasional large truck to turn by swinging wide and encroaching on other traffic lanes without disrupting traffic significantly. The designer should

analyze the likely paths and encroachments that will result when a turn is made by a large vehicle.

The design should be modified where alignment conditions such as curvature prior to or at the end of the turn provide the assumed positioning. Superimposing the appropriate design-vehicle turning template is the most expeditious way to customize a design for special conditions.

Figures and data for three-centered curves (symmetrical and asymmetrical) are shown in Figures 9-1A, 9-1B, and 9-2, below, and Exhibit 9-20 in the *PGDHS (1)*.

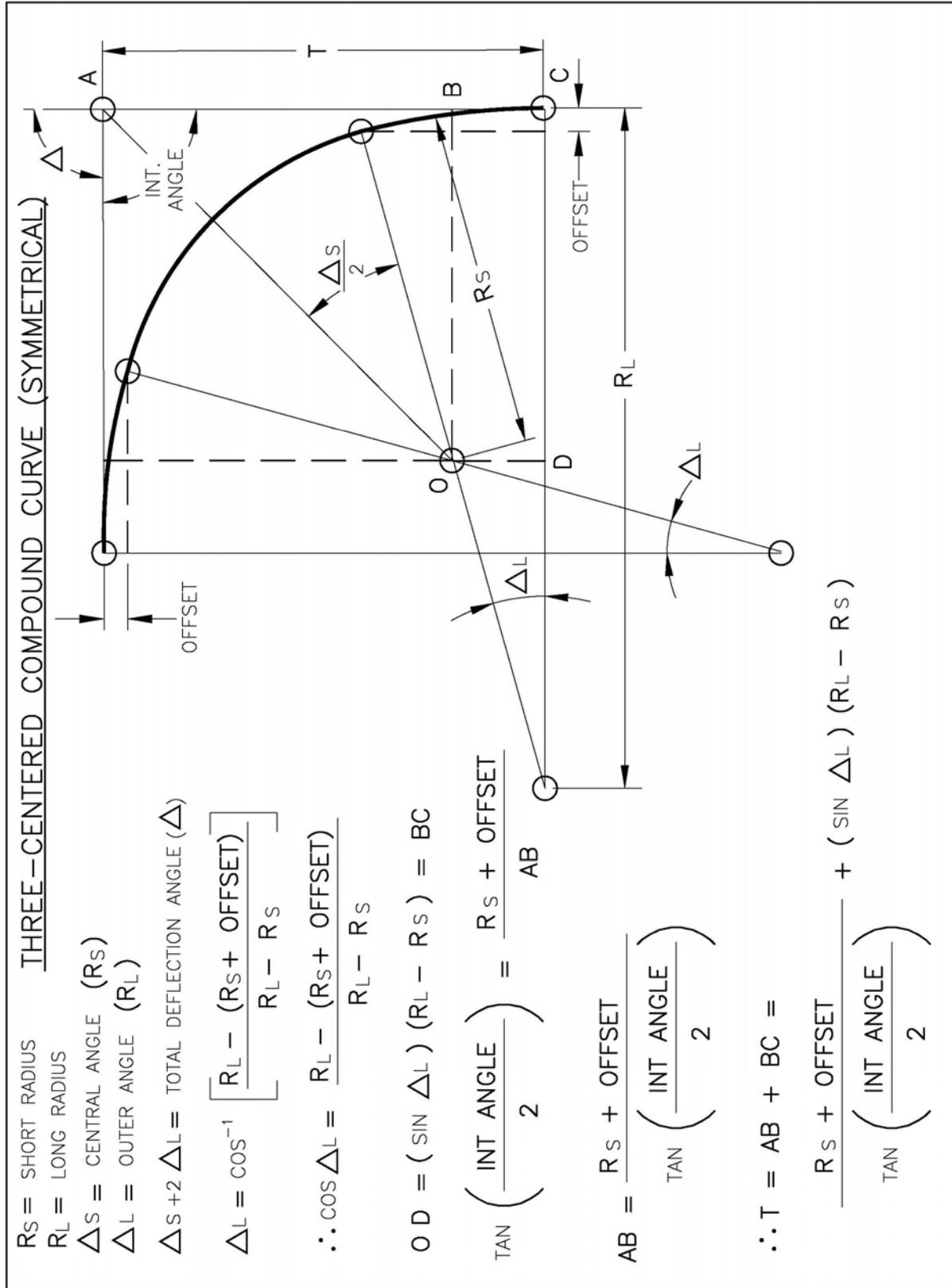


Figure 9-1A Three-Centered Compound Curve (Symmetrical)

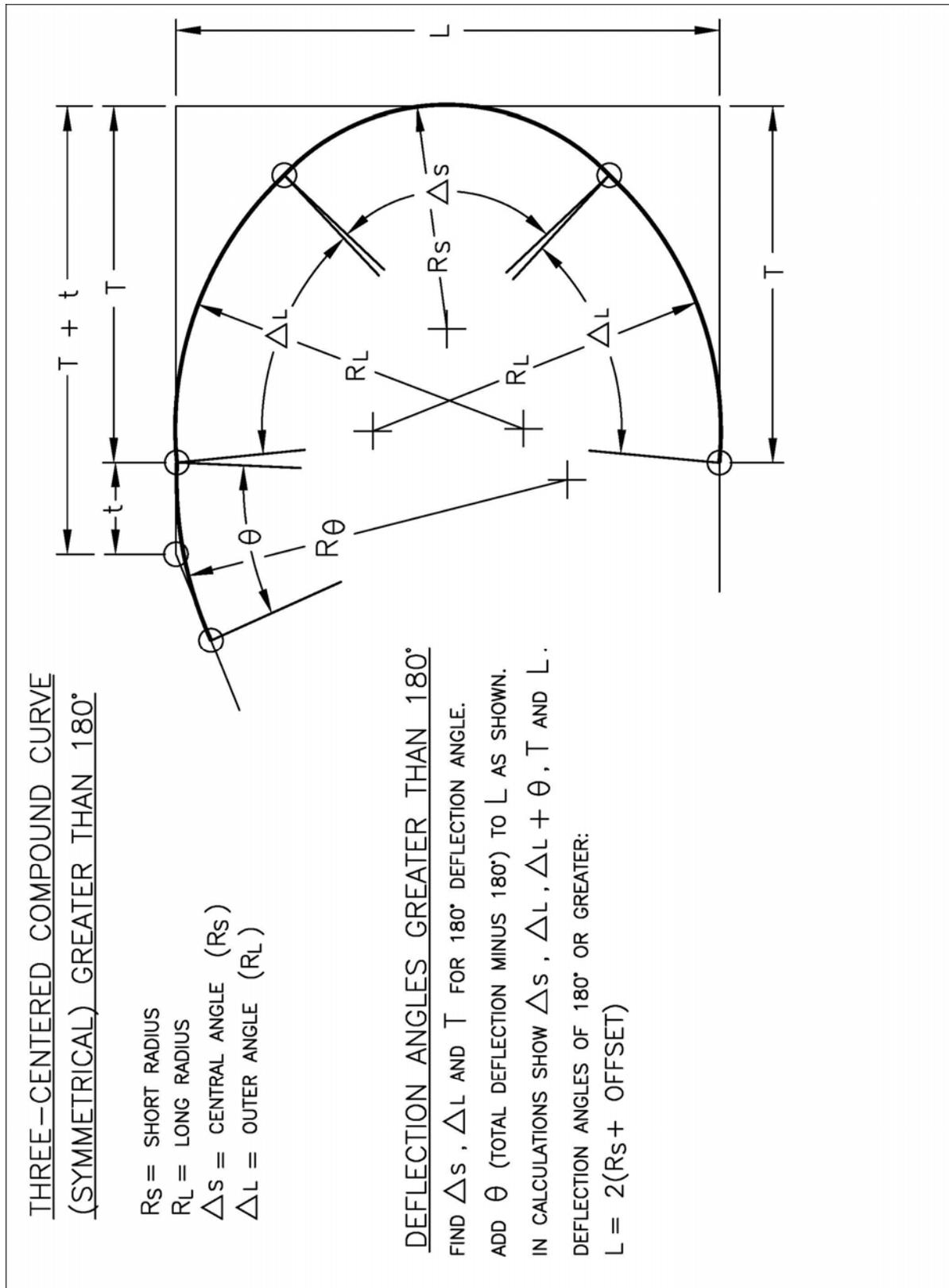


Figure 9-1B Three-Centered Compound Curve (Symmetrical) Greater than 180°

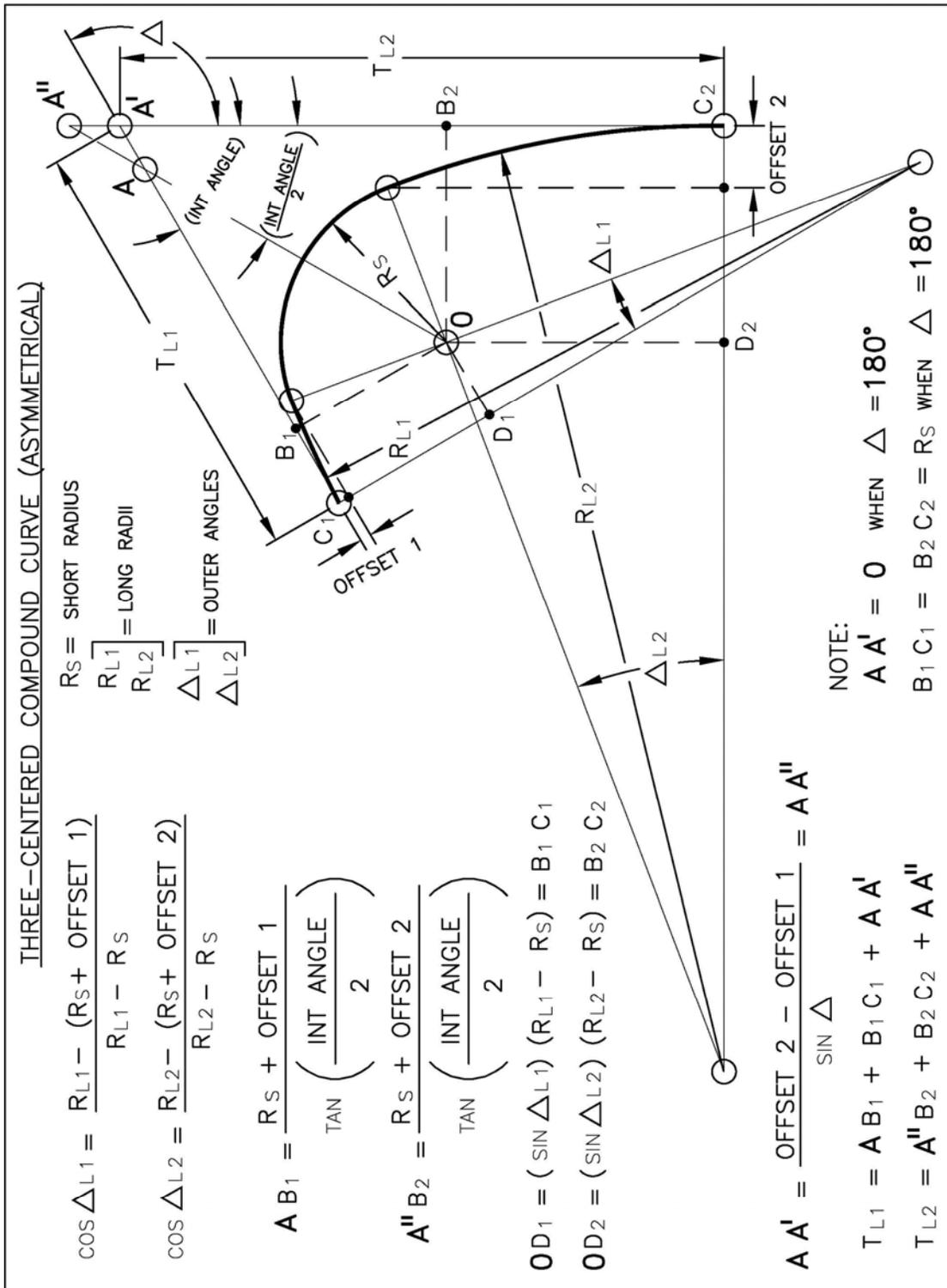


Figure 9-2 Three-Centered Compound Curve (Asymmetrical)

9.5.2.1 Design Vehicles

A description of the design vehicles used for intersection design is given in Chapter 2. For a thorough discussion and dimensions of the design vehicles, see Chapter 2 of the *PGDHS (1)*.

Select a design vehicle that is the largest vehicle that normally uses the intersection. The primary use of the design vehicle is to determine turning radius requirements for each leg of the intersection. It is possible for each leg to have a different design vehicle. Table 9-3 shows the minimum design vehicles. As justification to use a smaller vehicle, include a traffic analysis showing that the proposed vehicle is appropriate.

Intersection Type	Design Vehicle
Junction of Major Truck Routes	WB-67
Junction of State Highways	WB-50
Ramp Terminals	WB-50
Other Rural	WB-50
Industrial	WB-40
Commercial	SU ⁽¹⁾⁽²⁾
Residential	SU ⁽¹⁾⁽²⁾
<p>⁽¹⁾To accommodate pedestrians, the P vehicle may be used as the design vehicle if justification with a traffic analysis is documented.</p> <p>⁽²⁾When the intersection is on a transit or school bus route, use the BUS design vehicle as a minimum.</p>	

Table 9-3 (WSDOT) Intersection Design Vehicle

To minimize the disruption to other traffic, design the intersection to allow the design vehicles to make each turning movement without encroaching on curbs, opposing lanes, or same-direction lanes at the entrance leg.

Design each turning movement so the largest vehicle that is anticipated to regularly use the intersection can make the turn without leaving the paved shoulders or encroaching on a sidewalk. Use the WB-67 as the largest vehicle at all State highway to State highway junctions.

9.5.2.2 Effect of Curb Radii on Turning Paths

The widths for various angles of intersecting streets occupied by turning vehicles are shown in Exhibit 9-31 and 9-32 of the *PGDHS (1)*. 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 angle of intersection, number of pedestrians, width and number of lanes on the intersecting streets, and amount of speed reductions.

Consider the following:

- Radii of 15 to 25 feet are adequate for passenger vehicles. These radii may be provided at minor cross streets where there is little occasion for trucks to turn or at minor intersections where there are parking lanes. Where the street has sufficient capacity to retain the curb lane as a parking lane for the foreseeable future, parking should be restricted for appropriate distances from the crossing.
- Radii of 25 feet or more at minor cross streets should be provided on new construction and on reconstruction where space permits.
- Radii of 30 feet or more at major cross streets should be provided where feasible so that an occasional truck can turn without too much encroachment.
- Radii of 40 feet or more, and preferably three-centered compound curves or simple curves with tapers to fit the paths of appropriate design vehicles, should be provided where large truck combinations and buses turn frequently. Longer radii are also desirable where speed reductions would cause problems.
- Curb radii should be coordinated with crosswalk distances or special designs to make crosswalks safe for all pedestrians.

9.6 TYPES OF TURNING ROADWAYS

9.6.1 Oblique-Angle Turns

The designs given in Exhibit 9-31 of the *PGDHS (1)* 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 highway.

9.6.2 Development of Superelevation at Turning Roadway Terminals

Superelevation commensurate with curvature and speed seldom is practical at 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.

9.6.3 General Procedure

The method of developing superelevation at turning roadway terminals is illustrated in Exhibits 9-45 through 9-49 of the *PGDHS (1)*.

9.7 ISLANDS

9.7.1 General Characteristics

An at-grade intersection in which traffic is directed into definite paths by islands is termed a channelized intersection.

An island is a defined area between traffic lanes for control of vehicle movements. Within an intersection, a median or an outer separation is considered an island. This definition makes evident that an island is no single physical type. It may range from an area delineated by a curb to a pavement area marked by paint.

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 (ADA requirements should be considered.)
- 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 from one intersection to another. Further variations occur at 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.

Where various intersections are involved in a given project and the warrants are sufficiently similar, in order to enhance driver expectancy, it is desirable to provide a common geometric design for each intersection.

Painted, flush medians and islands may be preferred to the curbed type 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

Painted islands may also be placed at the pavement edge. At some intersections, both curbed and painted islands may be desirable. All pavement markings should be reflectorized. The use of thermoplastic striping and other forms of long-life markings also may be desirable. For the various types and shapes of islands, see Exhibit 9-35 of the *PGDHS (1)*.

9.7.2 Island Size and Designation

Islands should be sufficiently large to command attention. The smallest curbed island that normally should be considered is one that has an area of approximately 50-square feet for urban and 75-square feet for rural intersections. However, 100-square feet are preferable for both. Accordingly, triangular islands should not be less than about 12 feet, and preferably 15 feet, on a side after rounding of corners. Elongated or divisional islands should be not less than 4-feet wide and 20 to 25 feet long.

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. Curbed divisional islands introduced at isolated intersections on high-speed highways should be at least 100 feet and preferably several hundred feet in length. Details of triangular curbed islands and their size designation are shown in Chapter 9 of the *PGDHS (1)*.

9.7.3 Delineation

Islands should be delineated or outlined by a variety of treatments, depending on their size, location, and function. The type of area in which the intersection is located, rural versus urban, also governs the design. In a physical sense, islands can be divided into three groups:

- Raised islands outlined by curbs.
- Islands delineated by pavement markings, buttons, or raised (jiggle) bars placed on all paved areas.

- 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 small-curbed islands is effected primarily by curbs. Large curbed islands 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, island curbs should nearly always be a sloping type, except where there is a definite need for a vertical curb, as at structures or pedestrian crossings. In special cases, vertical curbs are suitable, commonly of heights not more than 6 inches. Vertical or sloping curb could be appropriate in urban areas, depending on the condition. High-visibility curbs are advantageous at critical locations or on islands and roadway forks approached by high-speed traffic.

Curbed islands are sometimes difficult to see at night because of the glare from oncoming headlights or from distant luminaires or roadside businesses. Accordingly, where curbed islands are used, the intersection should have fixed-source lighting or appropriate delineation.

Delineation and warning devices are especially pertinent at approach ends of median curbed islands, which are 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 or to jiggle bars that may be crossed readily even at considerable speed. This section should be as long as practicable.

9.7.4 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. Island curbs are introduced rather suddenly and should be offset from the edge of through traffic lanes even if they are sloping. A sloping curb at an island need not be offset from the edge of a turning roadway, except to reduce its vulnerability. Consider plowable end treatments. Vertical curbs should be offset from the edges of through and turning roadway pavements.

See Exhibit 9-41 in the *PGDHS (1)*.

9.7.5 Right-Angle Turns With Corner Islands

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 see Exhibits 9-37 through 9-41 of the *PGDHS (1)*.

9.7.6 Oblique-Angle Turns With Corner Islands

Minimum design dimensions for oblique-angle turns, determined on a basis similar to that for right-angle turns, are given in Table 9-4. 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.

Angle of Turn (degrees)	Design Classification	Three-Centered Curve		Width of Lane (ft)	Approximate Island Size (sq ft)
		Radii (ft)	Offset (ft)		
75	A	150-75-150	3.5	14	60
	B	150-75-150	5.0	18	50
	C	180-90-180	3.5	20	50
90	A	150-50-150	3.0	14	50
	B	150-50-150	5.0	18	80
	C	180-65-180	6.0	20	125
105	A	120-40-120	2.0	15	70
	B	100-35-100	5.0	22	50
	C	180-45-180	8.0	30	60
120	A	100-30-100	2.5	16	120
	B	100-30-100	5.0	24	90
	C	180-40-180	8.5	34	220
135	A	100-30-100	2.5	16	460
	B	100-30-100	5.0	26	370
	C	160-35-160	9.0	35	640
150	A	100-30-100	2.5	16	1400
	B	100-30-100	6.0	30	1170
	C	160-35-160	7.1	38	1720
<p>A - Primarily passenger vehicles: permits occasional design single-unit truck to turn with restricted clearances.</p> <p>B - Provides adequately for SU: permits occasional WB-50 to turn with slight encroachment on adjacent traffic lanes.</p> <p>C - Provides fully for WB-50.</p>					
<p>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.</p>					

Table 9-4 [Exhibit 9-42(1)] Typical Designs for Turning Roadways

In Table 9-4, 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 individual design to fit 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 sharpest turning paths of the selected vehicles, and arrangements of curves on the inner edge of traveled way to fit these paths, generally control the design. The resulting island size is greater than the minimum. The size of the islands for the large turning angles in Table 9-4 is indicative of the otherwise unused and uncontrolled areas of traveled way that are eliminated by the use of islands.

9.8 INTERSECTION SIGHT DISTANCE

9.8.1 General Considerations

Conflicts between vehicles at intersections are resolved by providing appropriate sight distances and traffic controls. The avoidance of accidents and the efficiency of the traffic operations still depend on the judgment, capabilities, and response of the individual driver. The sight distance considered safe is directly related to vehicle speeds and to the resultant distances traversed during perception, reaction time, and braking.

Each vehicle approaching an intersection must have an unobstructed sight distance along all legs of the cross road and across its included corners for a distance sufficient to allow the drivers to see each other in time to prevent a collision.

Each driver can either:

- Accelerate
- Slow down
- Stop

After a vehicle has stopped at an intersection, the driver must be able to make a safe departure through the intersection area. Figures 9-3A and B indicate these maneuvers as well as the sight distances that must be provided for vehicles approaching on the major highway from either direction. Distance “b” is the length of roadway traveled by the respective vehicle on the 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.

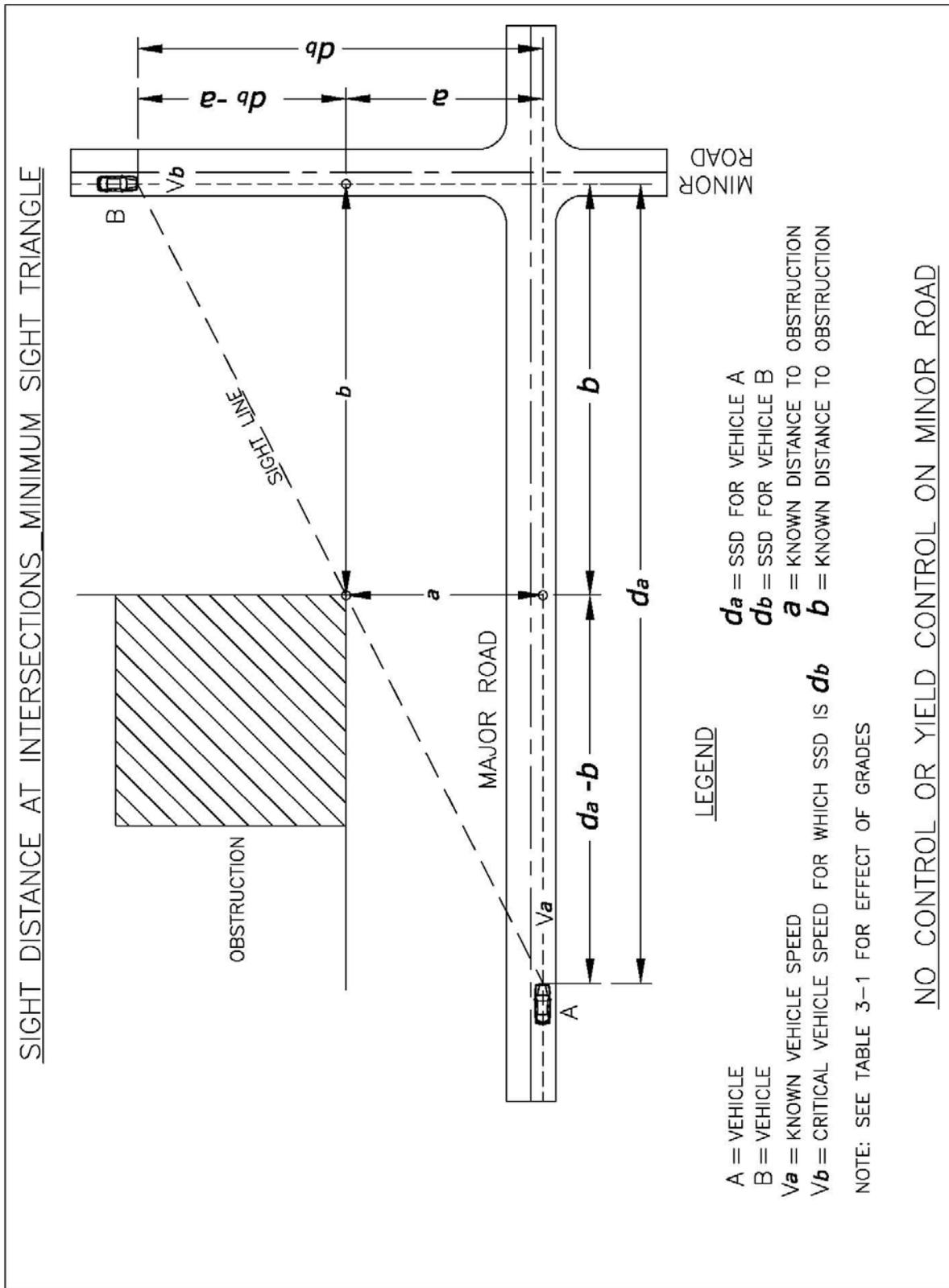


Figure 9-3A Sight Distance at Intersections, Minimum Sight Triangle

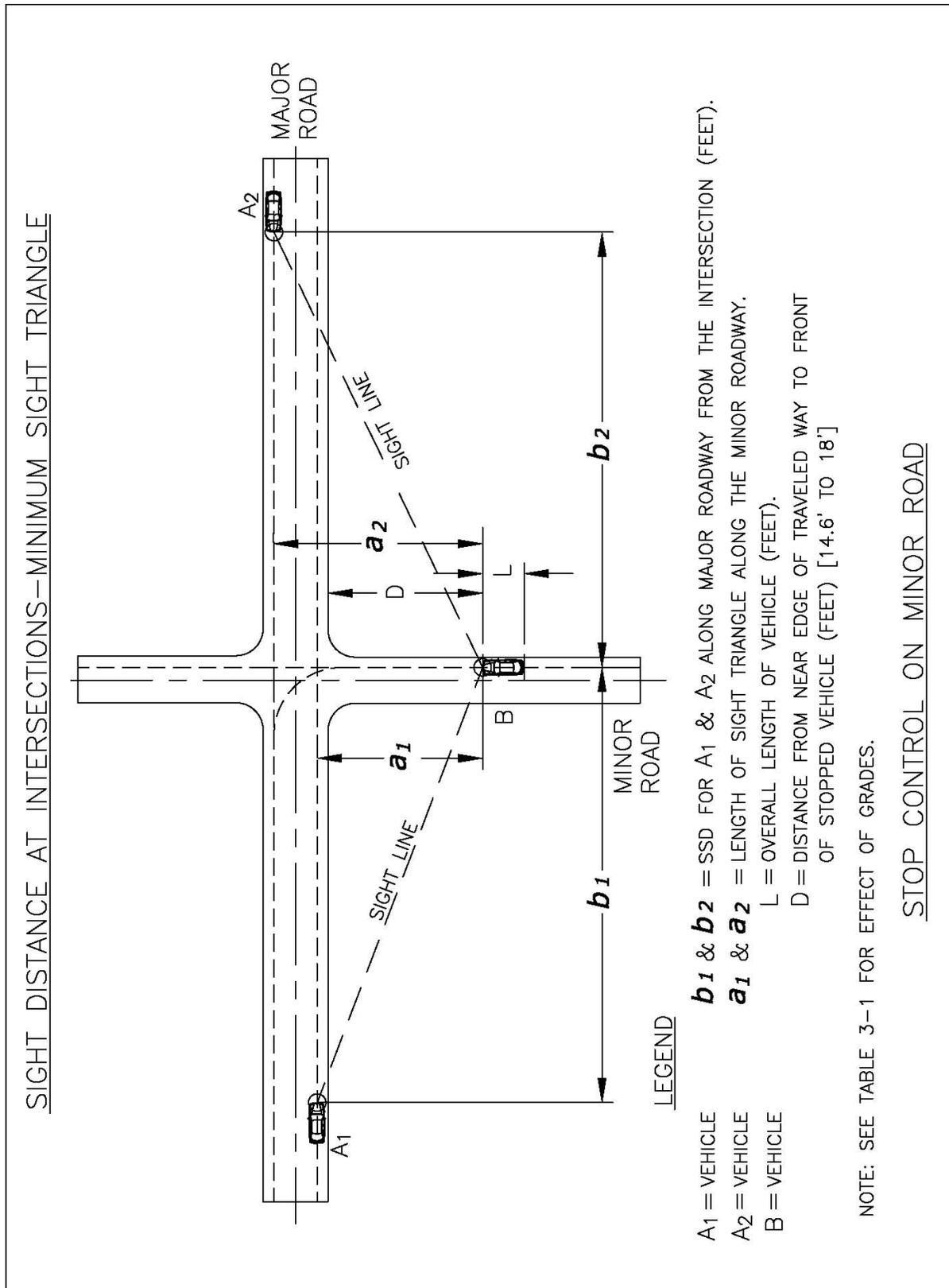


Figure 9-3B Sight Distance at Intersections, Minimum Sight Triangle

9.8.2 Intersection Control

The recommended dimensions of the sight triangles 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 at intersections are presented in Chapter 9 of the *PGDHS (1)* 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

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

9.8.3 Effect of Skew

See page 677 of the *PGDHS (1)*.

9.9 STOPPING SIGHT DISTANCE AT INTERSECTIONS FOR TURNING ROADWAYS

The values for stopping sight distance as computed in Chapter 3 for open highway conditions are applicable to turning roadway intersections of the same design speed.

See also Exhibit 9-70 in the *PGDHS (1)* and Table 3-1.

9.10 DESIGN TO DISCOURAGE WRONG-WAY ENTRY

An inherent problem of intersections is the possibility of a driver entering one of the exit terminals from the crossroad and proceeding along the major highway in the wrong direction in spite of signing. This wrong-way entrance is becoming more of a problem with the increased number of intersections. 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 Exhibits 9-71 and 9-72 of the *PGDHS (1)*.

9.11 SUPERELEVATION FOR CURVES AT INTERSECTIONS

9.11.1 General Design Considerations

Providing proper drainage and the matching of grades and cross slopes can create problems on low-speed turning roadways. See Exhibits 9-44 to 9-49 of the *PGDHS (1)*.

9.12 CHANNELIZATION

Channelization is the separation or regulation of conflicting traffic movements into delineated paths of travel by traffic islands or pavement marking to facilitate the safe and orderly movements of vehicles, bicycles, and pedestrians.

9.13 SPEED-CHANGE LANES AT INTERSECTIONS

See section 9.18.

9.14 MEDIAN OPENINGS

See Exhibits 9-79 through 9-83 in the *PGDHS (1)*.

Medians were discussed in Chapter 4 chiefly as an element of the cross section. General ranges in width were given, and the width of the median at intersections was treated briefly. For intersection conditions, 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.

9.14.1 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 *PGDHS (1)*. 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 Exhibit 9-76 of the *PGDHS (1)*. 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 for accommodation of more than one type of vehicle at the usual 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 vehicles with some swinging wide.
- One of 50 feet accommodates SU vehicles and occasional WB-40 vehicles with some swinging wide.
- One of 75 feet accommodates WB-40 and WB-50 vehicles with minor swinging at the end of the turn.

See Exhibits 9-77 to 9-83 of the *PGDHS (1)*.

9.14.2 Shape of Median End

One form of a median end at an opening is a semicircle. 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.

Alternate minimum designs for median ends to fit the design control radii of 40, 50, 75 and 100 feet are shown in Chapter 9 of the *PGDHS (1)*. See Exhibits 9-78, 9-81, 9-82 and 9-83 of the *PGDHS (1)*.

9.14.3 Median Openings Based on Control Radii for Design Vehicles

A 75-foot control radius is sufficiently large to accommodate a WB-40 design vehicle, and the minimum path of the WB-50 vehicle indicates that it can also use this design without undue encroachments. The left turn to leave the divided highway can be made within a two-lane crossroad. In the left turn to enter the divided highway, the WB-50 vehicle would encroach on the adjacent lane about 2 feet. This encroachment can be avoided by swinging wide at the beginning of the turn.

9.14.4 Effect of Skew

A control radius for design vehicles as the basis for minimum design of median openings results in lengths of openings that increase with the skew angle of the intersection. See Exhibits 9-84 through 9-86 of the *PGDHS (1)* for details of the effect of skewed crossings on the length of median openings.

In general, the asymmetrical bullet nose end is preferable.

9.15 ABOVE MINIMUM DESIGNS FOR DIRECT LEFT TURNS

See Exhibit 9-87 of the *PGDHS (1)*.

9.16 INDIRECT LEFT TURNS AND U-TURNS

9.16.1 General Design Considerations

At intersections where the median is too narrow to provide a lane for left-turning vehicles and the traffic volumes or speeds, or both, are relatively high, safe, efficient operation is particularly troublesome. Vehicles that slow down or stop in a lane primarily used by through traffic to turn left greatly increase the potential for rear-end collisions. The necessity to turn left in the urban or heavily developed residential or commercial sectors also presents serious problems with respect to safety and efficient operation. Chapter 9 of the *PGDHS (1)* shows several options that may be considered for indirect left turns on high-speed/high-volume highways.

In special circumstances, there may be a need to include U-turns in the design if alternative access to businesses or homes is not available.

Normally U-turns should not be permitted from the through lanes. For a satisfactory design for U-turn maneuvers, 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 roadway of the opposing traffic lanes.

9.17 FLUSH OR TRAVERSABLE MEDIANS

The foregoing discussion on design for indirect left turns U-turns with raised curb medians brings into focus the difficulties involved in providing access to abutting property, 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.

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 should be considered when a history of midblock accidents involving left-turning vehicles exists, driveways are closely spaced, and/or strip development or multiple-unit residential land use exists along the corridor.

A number of studies have evaluated the cost-effectiveness of two-way left-turn lanes. Based on these studies, the following warrants and guidelines are suggested for their application:

- Annual Average Daily Traffic (AADT) - four lane – between 10,000 and 20,000 vehicles, or two lane – between 5,000 and 12,000 vehicles.

- Left-turn volumes - 70 midblock turns per 1,000 feet, or at least 20 percent of total volume in peak hour.
- Minimum length - 1,000 feet, or two to three blocks

In general, two-way left-turn lanes can be considered when operating speeds are 50 mph or less. Lane widths in use range from 10 to 16 feet. Table 9-5 provides suggested lane widths for various types of highways. New designs should strive for lane widths of 12 to 14 feet.

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)	10 absolute minimum, 12 desirable
30 to 40	Business (passenger cars, some trucks)	12 minimum, 14 desirable
	Industrial (many large trucks)	14 to 16
40 to 50	Business	12 minimum, 14 desirable

Table 9-5 [From NCHRP Report 279 (2)] **Lane Widths for Continuous Two-Way Left-Turn Lanes**

Conversion of existing cross sections is generally more constrained. However, narrow widths should be avoided except for 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 two-way left turn lane 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.

9.18 AUXILIARY LANES

The primary purpose of auxiliary lanes at intersections is to provide storage for turning vehicles, both left and right. 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, auxiliary lanes may be provided for bus stops or for loading and unloading passengers from passenger cars.

A speed change lane is an auxiliary lane, including 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 on high-volume highways where a change in speed is necessary for vehicles entering or leaving the through traffic lanes.

9.18.1 General Design Considerations

Desirably, the total length of the auxiliary lane should be the sum of the length for three components. Where intersections occur as frequently as four per mile, it is customary to forego most of the deceleration length and to provide only the storage length plus taper. Each component of the auxiliary length is discussed in the following section.

Auxiliary lanes should be at least 10-feet wide and desirably should equal that of the through lane. Where curbing is to be used adjacent to the auxiliary lane, an appropriate curb offset should be provided. 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 definitely. 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.

Deceleration lanes always are advantageous, particularly on high-speed roads, because the driver of a vehicle leaving the highway has no choice but to slow down on the through traffic lane if a deceleration lane is not provided. The failure to brake by the following drivers because of a lack of alertness causes many rear-end collisions.

Acceleration lanes are not always necessary at stop-controlled intersections where entering drivers can wait for an opportunity to merge without disrupting traffic. Acceleration lanes are advantageous on highways without stop control and on all high-volume roads even with stop

sign control where openings between vehicles in the peak hour traffic streams are infrequent and short.

Consult with the Region Traffic Engineer who will determine the need for auxiliary lanes by calculating the highway capacity and determining if the capacity could be improved by the addition of acceleration and deceleration lanes.

9.18.2 Deceleration Length

Provision for deceleration 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 (see the CDOT Access Code (4) for guidance on warrants). The total length required is that needed for a safe and comfortable stop from the design speed of the highway. Deceleration requirements are as shown in Exhibit 10-71 through 10-73 of the *PGDHS (1)*.

On many arterial facilities, it will not be feasible to provide the full length for deceleration. In such cases, it must be accepted that at least a part of the deceleration be accomplished before entering the auxiliary lane. Braking is assumed to begin where two-thirds of the lane width is developed. However, the lengths given in Exhibit 10-73 of the *PGDHS (1)* should be accepted as a desirable goal and should be provided where practical and feasible. Deceleration lengths shown are applicable to both left- and right-turning lanes, but speed is usually lower in the right lane than in the left lane. A 10 mph differential is commonly considered acceptable on arterial roadways.

On deceleration lanes, where it is necessary to store stopped vehicles, additional length shall be provided to accommodate the average number of vehicles anticipated.

Design Speed (MPH)	30	35	40	45	50	55	60	65	70	75
Deceleration Length (Feet)	235	280	320	385	435	480	530	570	615	660
These approximate lengths are based on grades less than 3 percent.										

Table 9-6 [Exhibit 10-73 (1)] Desirable Deceleration Length for Stop Condition

If adjustment is needed for a grade greater than 3 percent, refer to Table 10-5.

9.18.3 Storage Length

The auxiliary lane should be sufficiently long to store the number of vehicles likely to accumulate during a critical period. The storage length should be sufficient to avoid the possibility of left-turning vehicles stopping in the through lanes. The storage length should be sufficiently long so that the entrance to the auxiliary lane is not blocked by vehicles standing in the through lanes 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 checked.

There are several techniques used to determine the necessary storage length. The required storage length for an unsignalized intersection is in accordance with Table 9-7 below.

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 percent of turning vehicles.						

Table 9-7 [State Highway Access Code Table 4-8 (4)] Storage Lengths for Auxiliary Lanes

A left-turning volume of 200 vehicles per hour, or more, could not complete the turn without difficulty unless the volume of opposing 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 (3)*.

Check with local agencies to ascertain their established minimum lengths for lanes with low turn volumes.

The important factors which determine the 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. Coordinate with the Traffic Engineer.
- To reduce the total length of queues formed in the left-turn lane, it is a desirable 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 percent. Permissive turns are not allowed where multiple left-turn lanes exist.

9.18.4 Acceleration Length

Acceleration lanes are used when there is a free-flow right and the *Highway Capacity Manual (3)* dictates. For warrants see Chapter 11. For design, see Table 9-8.

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 percent.										

Table 9-8 [Exhibit 10-70 (1)] Desirable Acceleration Length From Stop Condition

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 (see the CDOT *Access Code* (4) for guidance on warrants). The total length required is that needed for a safe and comfortable speed required to enter the through lanes. Acceleration requirements are as show in Exhibit 10-69 through 10-71 of the *PGDHS* (1).

9.18.5 Taper

To develop the width needed for auxiliary lanes, a transition must be effected. This transition, or taper, allows a driver to recognize that an exclusive lane is being developed and also 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 *PGDHS* (1). Recommended taper ratios for speed-change lanes are given in Table 9-9.

Design 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.										

Table 9-9 [State Highway Access Code Table 4-6 (4)] Taper Length and Ratio for Parallel-Type Entrance

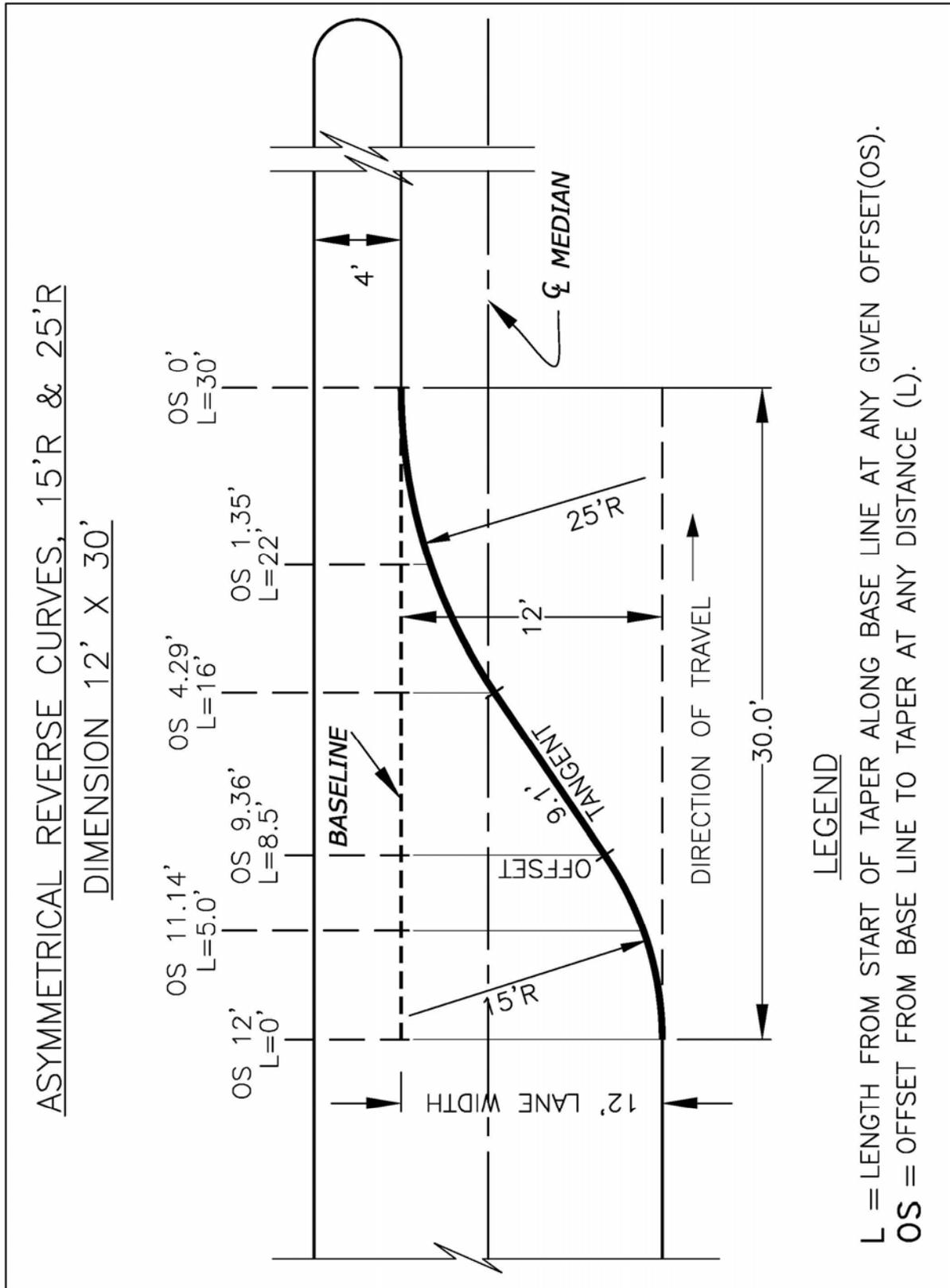


Figure 9-5 (CDOT) Median Bay Taper

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 horizontal or crest vertical curves exist, consider using a bay taper for more visible definition.

9.18.5.1 Elements of Left-Turn Design (Redirect Taper)

Section 3B.10 “Approach Markings for Obstructions,” the *Manual on Uniform Traffic Control Devices (MUTCD)* (5) recommends the following for design speeds equal to or greater than 45 mph:

$$L = WS$$

Where: L = length of taper, ft
 S = design speed, mph
 W = offset, ft

For design speeds equal to or less than 40 mph, the *MUTCD* recommends:

$$L = \frac{WS^2}{60}$$

The departure taper should be designed in concert with the left-turn lane on the opposite approach. The departure taper should begin opposite the beginning of the left-turn lane, and continue to a point at least opposite the approach taper. Extension of the departure taper beyond the approach nose of a raised median channelization is recommended wherever possible.

9.18.6 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 9-6A and 9-6B.

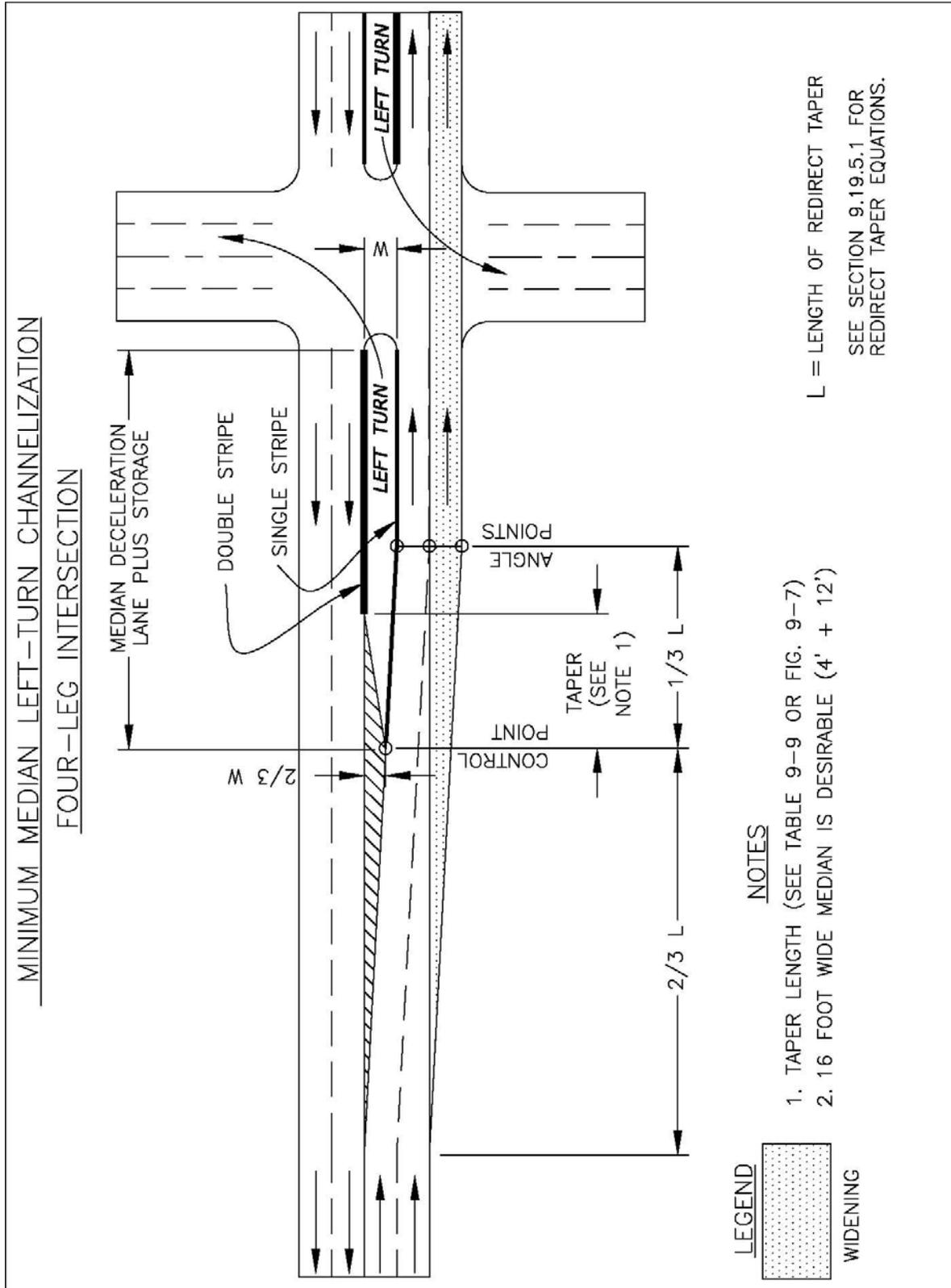


Figure 9-6A Minimum Median Left-Turn Channelization, Four-Leg Intersection

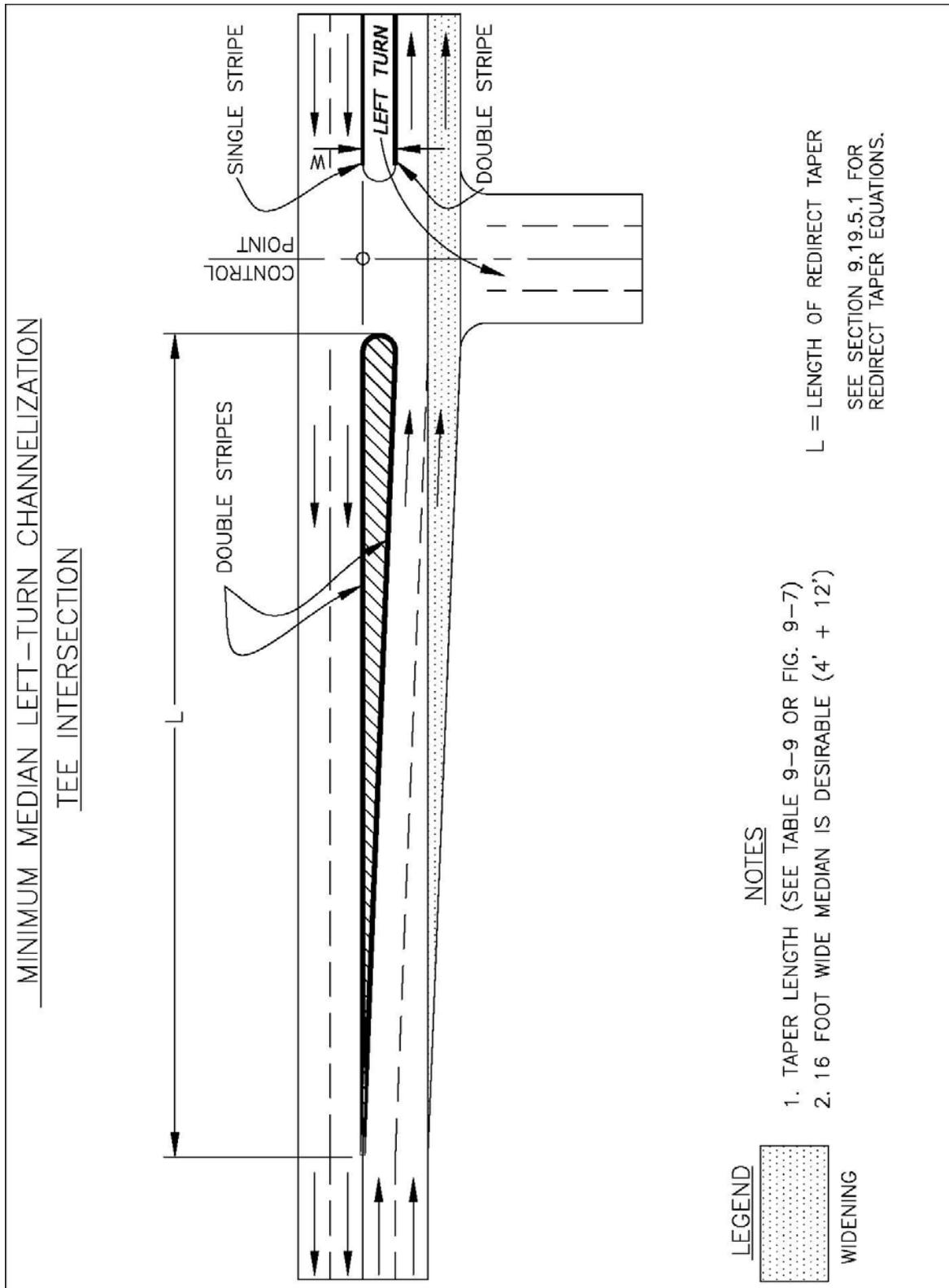


Figure 9-6B Minimum Median Left-Turn Channelization, Tee Intersection

Analysis of left-turn involved conflicts 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.

9.18.6.1 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 are usually not a problem, separate left-turn lanes can, in most cases, be easily provided.

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.

9.18.7 Median Double Left and Triple Left Turn Lanes

Double left turns 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 directions. 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 percent of that of a single median lane. Because of the high turning volumes, double turning lanes should only be used with fully protected signal phasing. Where turning lanes are designated for two-lane operation, the storage length is reduced to approximately 0.6 of that required for single-lane operation.

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.

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 (6)*.

9.18.8 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. Figures 9-7A and 9-7B (below) 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 9-7C below shows a design for a median left turn lane with a median greater than 18 feet.

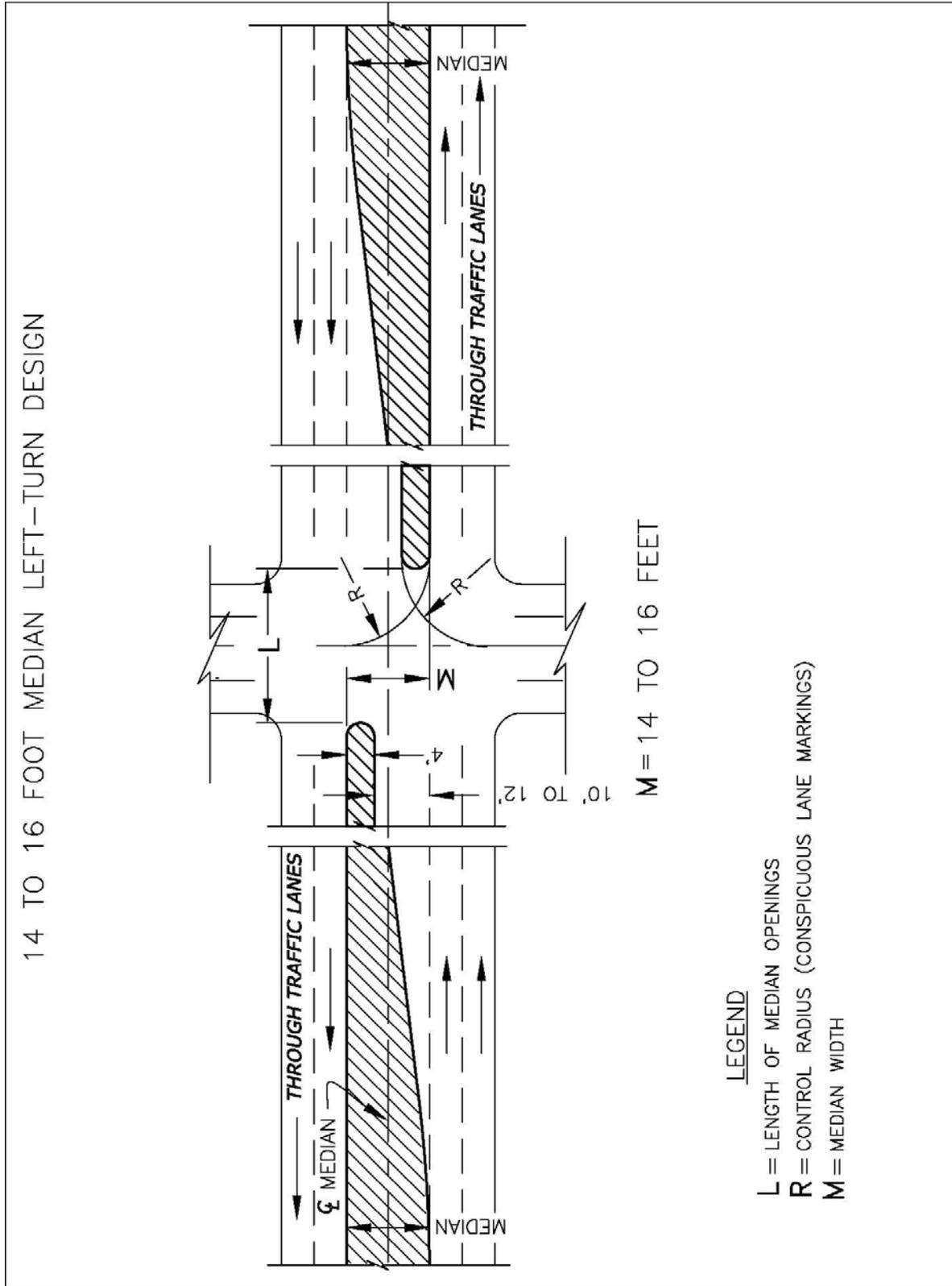


Figure 9-7A (Exhibit 9-96) 14 to 16-Foot Median Left-Turn Design

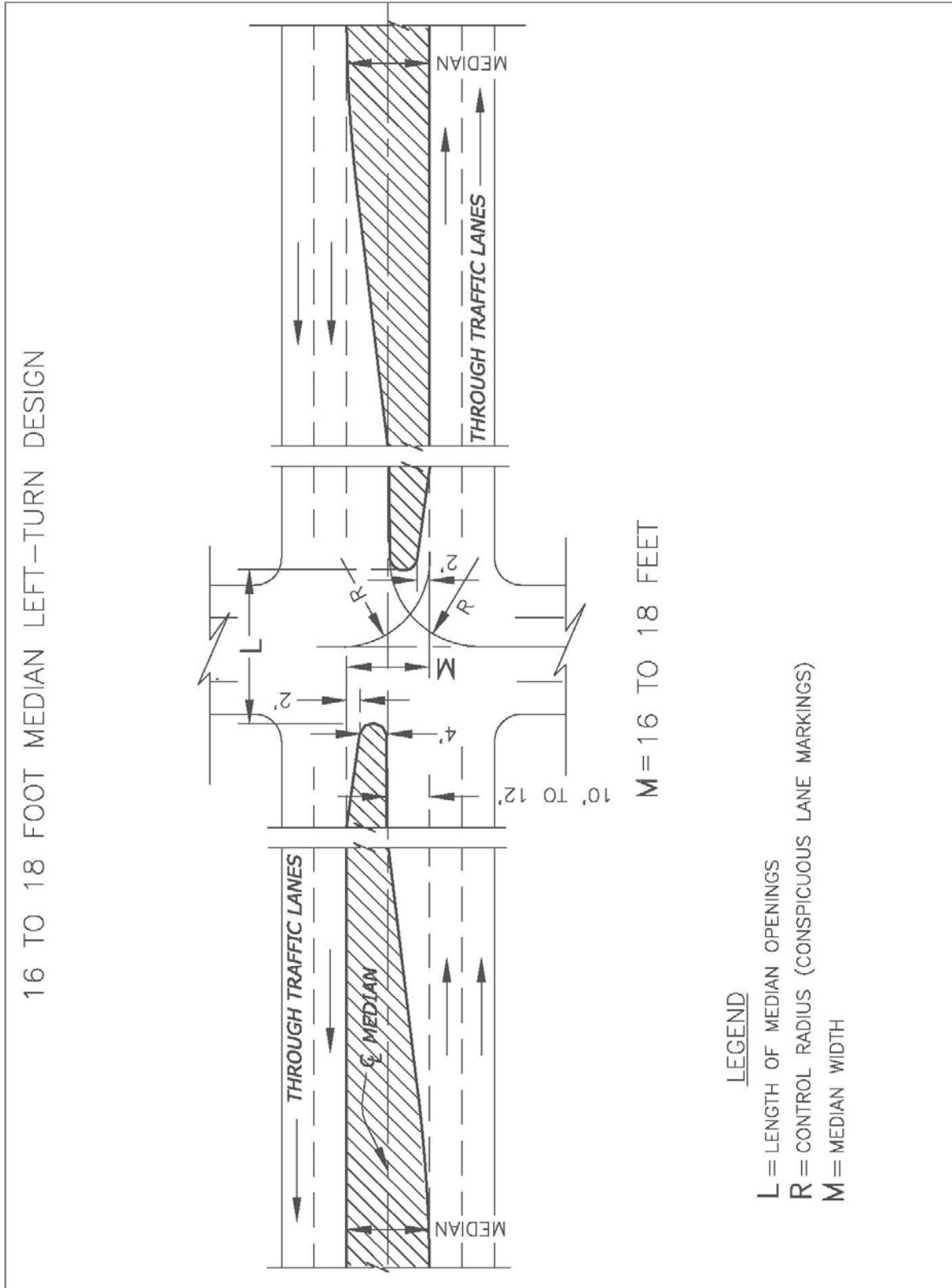


Figure 9-7B (Exhibit 9-96) 16 to 18-Foot Median Left-Turn Design

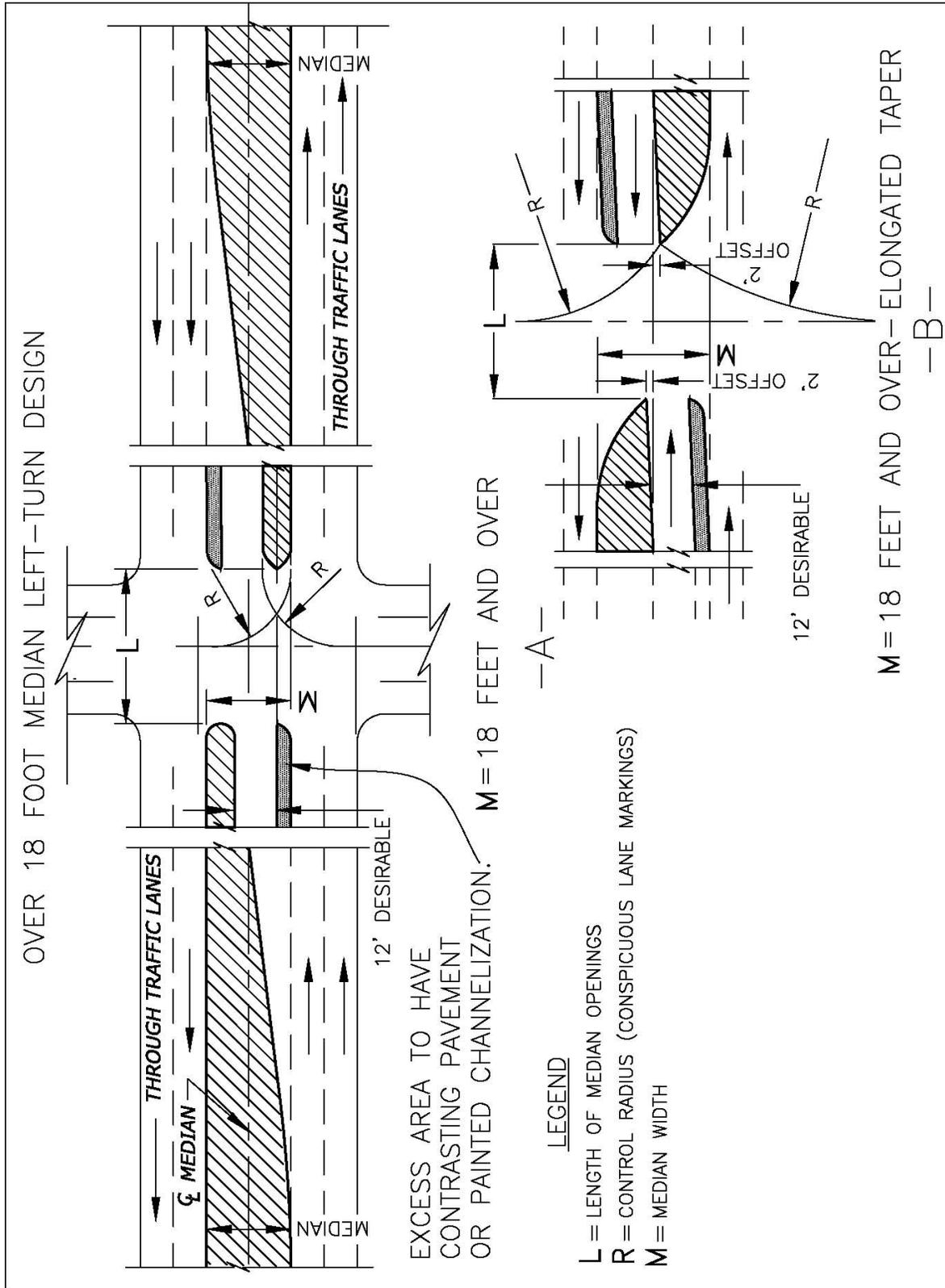


Figure 9-7C (Exhibit 9-97) Median Left Turn Design for Median Width Greater Than 18 Feet

9.18.9 Median End Treatment

The form of treatment given 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. To serve these purposes satisfactorily, a minimum narrowed median width of no less than 4 feet is recommended, and a median 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 12 feet.

For medians wider than about 18 feet as shown in Figure 9-7C and in Exhibit 9-97 in the *PGDHS (1)*, 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 will place the vehicle waiting to make the turn as far to the left as practical and thus provide appropriate 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.

9.19 RIGHT-TURN LANES

9.19.1 General

Separate right-turning lanes shall be used for minor intersections that are skewed and all major intersections. 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.

9.19.2 Tapers

Refer to section 9.18.5.

9.19.3 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 see the Highway Capacity Manual (3).

9.19.4 Length

Right-turn lanes at stopped approaches should be of sufficient length to enable right-turning vehicles to bypass queued through and/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 9.18.2 for left-turn lanes. Signal timing, pedestrian activity, and vehicle arrival patterns are the most important aspects for consideration when designing the length. Normally, a minimum storage length of 100 feet should be provided in addition to the taper.

9.19.5 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 shall be 200 feet.

Consider operational effects of barrier curbs on drivers. Right-turn lanes adjacent to such curbs should be designed to full widths to negate the constricting effects of the curb. This is particularly important if the gutter width dimension is nominal. An additional factor in

establishing a right-turn lane is consideration of the location of bus stops. It may be necessary, e.g., to relocate a bus stop to midblock or to the far side if a right-turn lane is introduced.

9.19.6 Shoulders

See subsection 9.5.1.2

9.20 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 the major facility. Short lengths of frontage roads may be desirable along urban arterials to preserve the capacity and safety of the arterial through control of access. Much of the improvement in capacity and safety may be offset by the added hazard introduced where the frontage road and arterial intersect the at-grade crossroad. The added hazard results in part from the increase in the number of conflicting movements and from the confusing pattern of roadways and separations, which lead to wrong-way entry. Inevitably, where an arterial is flanked by frontage roads, the problems of design and traffic control at intersections are far more complex than where the arterial consists of a single roadway. Three intersections (two, if there is only one frontage road) actually exist at each cross street.

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 *PGDHS (1)*.

9.21 BICYCLES AT INTERSECTIONS

When on-street bicycle lanes and/or off-street bicycle paths enter an intersection, the design of the intersection should be modified accordingly. Further Guidance in providing for bicycles at intersections can be found in the *AASHTO Guide for Development of Bicycle Facilities (7)*.

9.22 WHEELCHAIR RAMPS AT INTERSECTIONS

When designing a project that requires curbs and adjacent sidewalks to accommodate pedestrian traffic, proper attention should be given to the requirements of persons with mobility impairments who depend on wheelchairs and other mobility devices. See also Chapter 11.

9.23 LIGHTING AT INTERSECTIONS

Lighting may affect the safety of highway and street intersections as well as efficiency of traffic operations. Statistics indicate that the non-daylight accident 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 accidents. 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. See section 3.7.

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 planned location of intersection luminaire supports should be designed to present the least possible hazard to out-of-control vehicles. The breakaway support base should not be used within limits of an at-grade intersection, particularly in densely developed areas with adjacent sidewalks. When struck, these light standards could be a problem for pedestrians and compound damage to adjacent property and other vehicles. See the *AASHTO Roadside Design Guide*(8) for further design guidance.

9.24 DRIVEWAYS

Driveways are, in effect, at-grade intersections and should be designed consistent with the intended use. The number of accidents is disproportionately higher at driveways than at other intersections; thus, their design and location merit special consideration.

See Exhibit 9-101 in the *PGDHS* (1). The regulation and design of driveways are intimately linked with the right of way and zoning of the roadside. On new highways, the necessary right of way can be obtained to provide the desired degree of driveway regulation and control. In many cases, additional right of way can be acquired on existing highways or agreements can be made to improve existing undesirable access conditions. Often the desired degree of driveway control must be effected through the use of police powers to require permits for all new driveways and through adjustments of those in existence. Coordinate with the Region Access Unit. See *CDOT Standard Plans - M & S Standards* (9) and the *Access Code* (4) for design information on driveways.

9.25 RAILROAD-HIGHWAY GRADE CROSSINGS

A railroad-highway crossing, like any highway-highway intersection, involves either a separation of grades or a crossing at-grade. The horizontal and vertical geometrics of a highway approaching an at-grade railroad crossing should be constructed in a manner that does not divert a driver's attention from roadway conditions. Coordinate early and often with the Railroads. For further information on railroad crossings, refer to the *PGDHS* (1).

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