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# CHAPTER 4
# CROSS SECTION ELEMENTS

## 4.1 PAVEMENT

### 4.1.1 Surface Type

The selection of pavement type is determined by the volume and composition of traffic, soil characteristics, weather, 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 *Pavement Design Manual* **(1)**.

### 4.1.2 Cross Slope

Design of the pavement cross slope is often a compromise between the need for reasonably steep cross slopes for drainage and relatively flat cross slopes for driver comfort. Pavement superelevation on curves is determined by the speed-curvature relationships given in Chapter 3 and *CDOT Standard Plans - M & S Standards* **(2)**.

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 high and intermediate type undivided pavements, crowned at the center, the designated rate of cross slope is 2 percent.

An overlay may be matched to the existing cross-slope unless the safety assessment report indicates otherwise. The profile grade and pivot point are generally located at the pavement crown.

On divided highways, each one-way pavement has a unidirectional slope across the entire width of pavement. Except as allowed otherwise in 4.3.3. The tangent cross slope is 2 percent, with the profile grade and pivot point located at the inside edge of the inside travel lane. At intersections, interchange ramps or in unusual situations, the crown position may vary depending upon drainage or other 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.

### 4.1.3 Skid Resistance

CDOT’s practice for concrete pavements is to use longitudinal tining. Tining is required for design speeds of 40 mph and greater.

### 4.1.4 Traveled Lane Texturing

Traveled Lane rumble strips should be considered for locations with unanticipated changes to the roadway:

- In advance of a stop sign or lane reduction on a rural multilane or a divided controlled-access arterial and
- Other locations as determined by the Region Traffic Engineer.

See *CDOT Standard Plans – M & S Standards M-614-1* **(2)** for details.

## 4.2 LANE WIDTHS

The basic traveled lane is 12 feet wide for both two-lane and multilane roads. In specific cases, traveled lanes 11 or 10 feet wide may be used (see Table 4-1).

## 4.3 SHOULDERS

### 4.3.1 General Characteristics

A shoulder is the portion of the roadway contiguous with the traveled way for accommodation of stopped vehicles, for emergency use, for bicycle use, and for lateral support of subbase, base, and surface courses.

### 4.3.2 Width of Shoulders

For purposes of this Guide, the shoulder shall be the minimum continuous usable width of shoulder which provides an all-weather surface. The width will vary from 4 to 12 feet, depending on the roadway design type. Shoulders should be paved full-width in accordance with the functional or physical characteristic of the roadway. The shoulder width may be changed where speed-change lanes, climbing lanes, or curb and gutter are used. See Chapter 14 for further information when designing bicycle paths.

### 4.3.3 Shoulder Cross Sections

In most cases, the shoulder slope should be the same as the crown slope of the traveled way. 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 1 percent more than the adjacent lane cross slope to increase the hydraulic carrying capacity of the shoulders. The designer also should consider breaking the shoulder in the opposite direction to reduce water draining across the road and causing icy conditions. Shoulder cross slope may have an algebraic difference of 5 percent from the traveled way cross slope. Greater algebraic differences require rounding outside the travel lane.

### 4.3.4 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 safety edge is required in all projects having roadway pavement. 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 re-enter the roadway safely. See Project Special Detail D-614-1 of the *CDOT Standard Plans - M & S Standards* **(2)** for more information**.**

### 4.3.5 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 accidents on long tangent or monotonous highway sections with a history of run-off -the-road accidents. Rumble strips may also be utilized to minimize run-off-the-road accidents and shall comply with the current *CDOT Standard Plans - M & S Standards* **(2)**.

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, encouraging driver inattentiveness or drowsiness. Under these circumstances, shoulder grooving is highly recommended.

If there is any doubt on the use of rumble strips, then further analysis should be done, taking into consideration run-off -the-road single vehicle accidents, bicycle usage, and other pertinent factors supporting use or non-use. Suggested designs to accommodate rumble strips and a bicycle facility are found in Chapter 14.

Other textures or methods, such as coarse chip seals, may be used in lieu of shoulder grooving on an experimental basis. Chip seals are not recommended in areas with regular bicycle traffic.

### 4.3.6 Turnouts

See section 3.3.8.

## 4.4 TYPICAL SECTIONS

The dimensions of a typical cross section depend upon a number of features that vary with the type of roadway. Geometric design standards as used by CDOT are shown in Table 4-1. The design may be adjusted for specific conditions as indicated in the appropriate chapter of this guide or in the chapter of *PGDHS* **(3)** 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.

| Geometric Design Type[1] | No. of Lanes | Lane Width (ft.) | Shoulder Width (min)[2] (ft.) | | ROW Width (ft.) | | | | Bridges and Grade Separations | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Suggested Minimum | | | | |
| | | | Outside | Inside | Desir. | With Frontage Road | Without Frontage Road | Desir. Access Control | Design Load | Clear Roadway Width |
| Type AA | 6[3] | 12 | Freeways<br>10[4]<br>Arterials<br>10 | <br>10[4]<br><br>8[4] | 300 | 275 | 175 | Full | HS 20-44[5] | See Note 6 |
| Type A | 4[3] | 12 | 10 | 4 | 300 | 250 | 150 | Full[7] | HS 20-44[5] | See Note 6 |
| Type B | 2[3,8] | 12 | 8<br>10[9] | | 250 | 250 | 150 | See Note 7 | HS 20-44[5] | See Note 6 |
| Type C | 2 | 11<br>12 | 6[10]<br>6[10] | | 120 | | 60 | See Note 7 | HS 20-44[5] | See Note 6 |
| Type D | 2 | 10<br>11 | 4<br>4 | | 100 | | 60 | See Note 7 | HS 20-44[5] | See Note 6 |

1. "Types" refers to details shown on Figures 4-1 through 4-5.
2. Shoulder widths may not apply when roadway has curb and gutter, speed-change lanes, etc.
3. See *Highway Capacity Manual* **(4)**.
4. Where the DDHV for truck traffic exceeds 250 veh/h, a paved shoulder width of 12 feet should be considered.
5. Alternate loadings for two 24,000-pound axles shall be used where applicable on the Interstate.
6. Bridge widths will be determined in accordance with requirements set forth in the latest revision of the *PGDHS* **(3)**, *AASHTO Standard Specifications for Highway Bridges* **(5)** and *CDOT Standard Plans - M & S Standards* **(2)**. Special cases will be subject to consideration by the CDOT Staff Bridge Engineer.
7. To be decided on an individual project basis. Interstate requires full access control.
8. Climbing lanes should be provided in accordance with 3.4.5 of this Guide.
9. Minimum 10' shoulder should be used when DHV exceeds 400, except in mountainous terrain where the 8' minimum shoulder will remain standard for DHV over 400.
10. Minimum 3' paved shoulder with 3' gravel shoulder.

For median widths, see chapter for the specific classification of roadway
For maximum grades, see chapter for the specific classification of roadway.
For minimum radius of curve, refer to the *CDOT Standard Plans - M & S Standards* **(2)** and 3.2.3.2 of this Guide.

**Table 4-1 Geometric Design Standards**

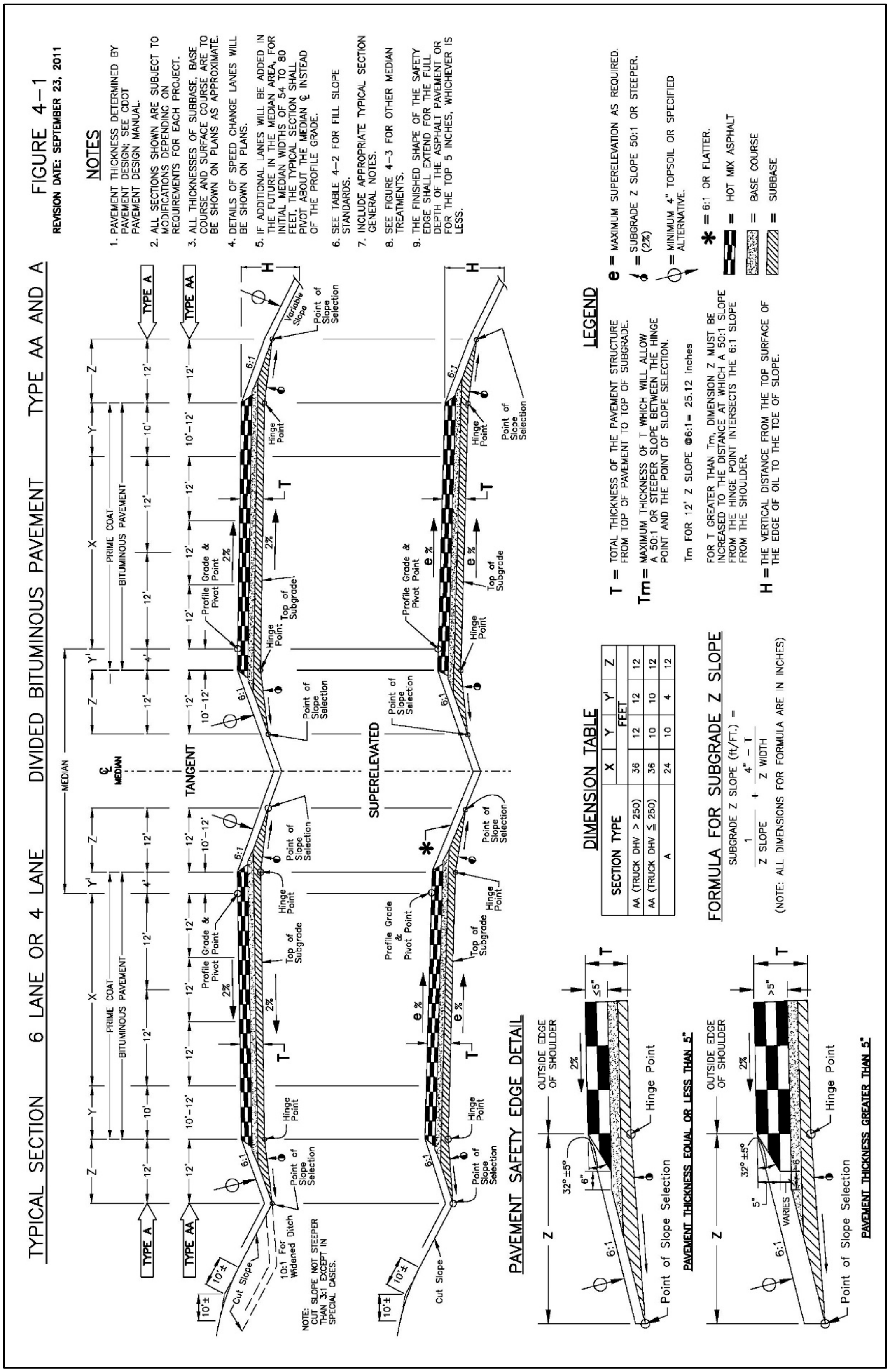


**Figure 4-1 Typical Sections for Divided Bituminous Pavement**

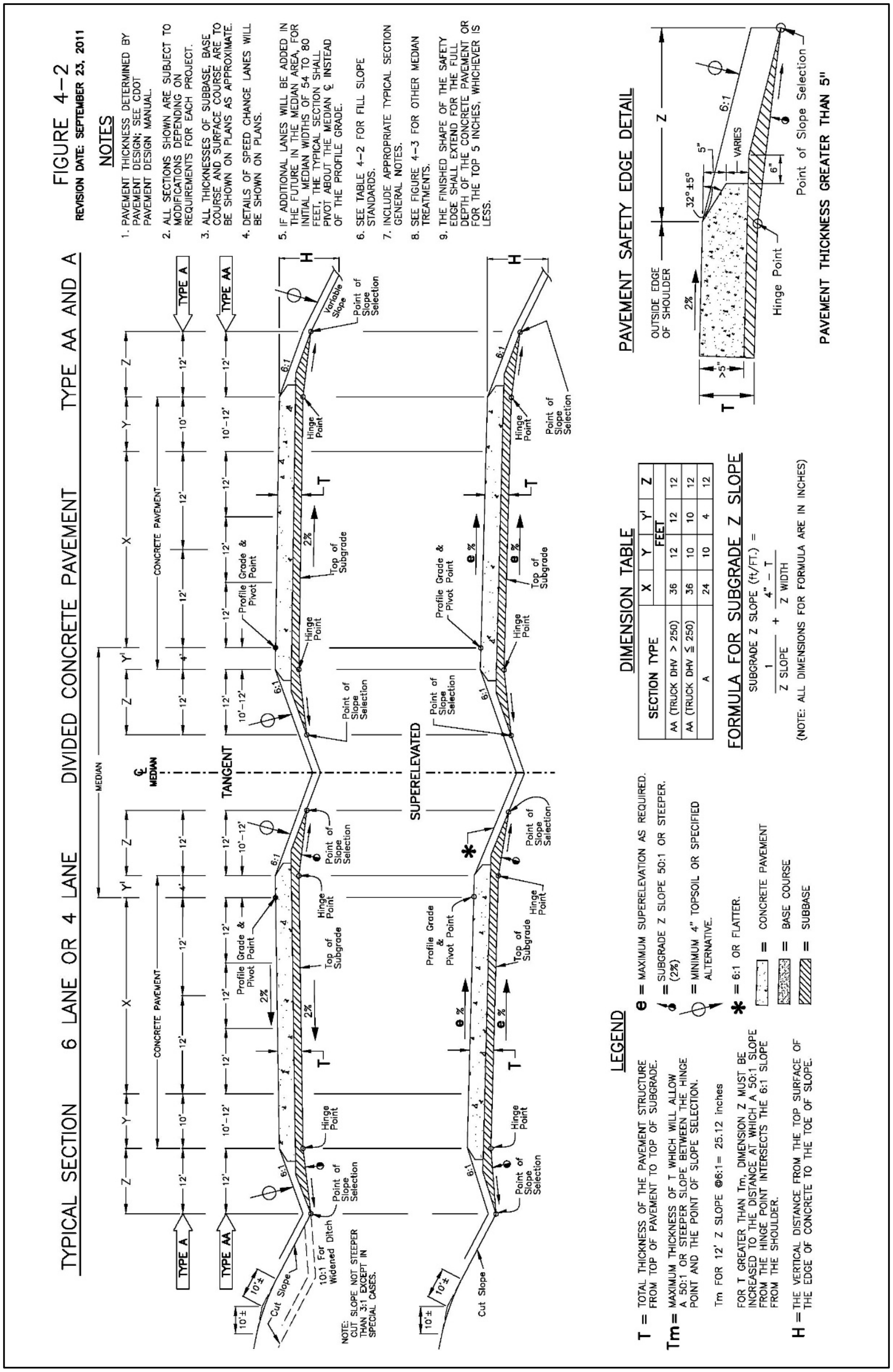


**Figure 4-2 Typical Sections for Divided Concrete Pavement**

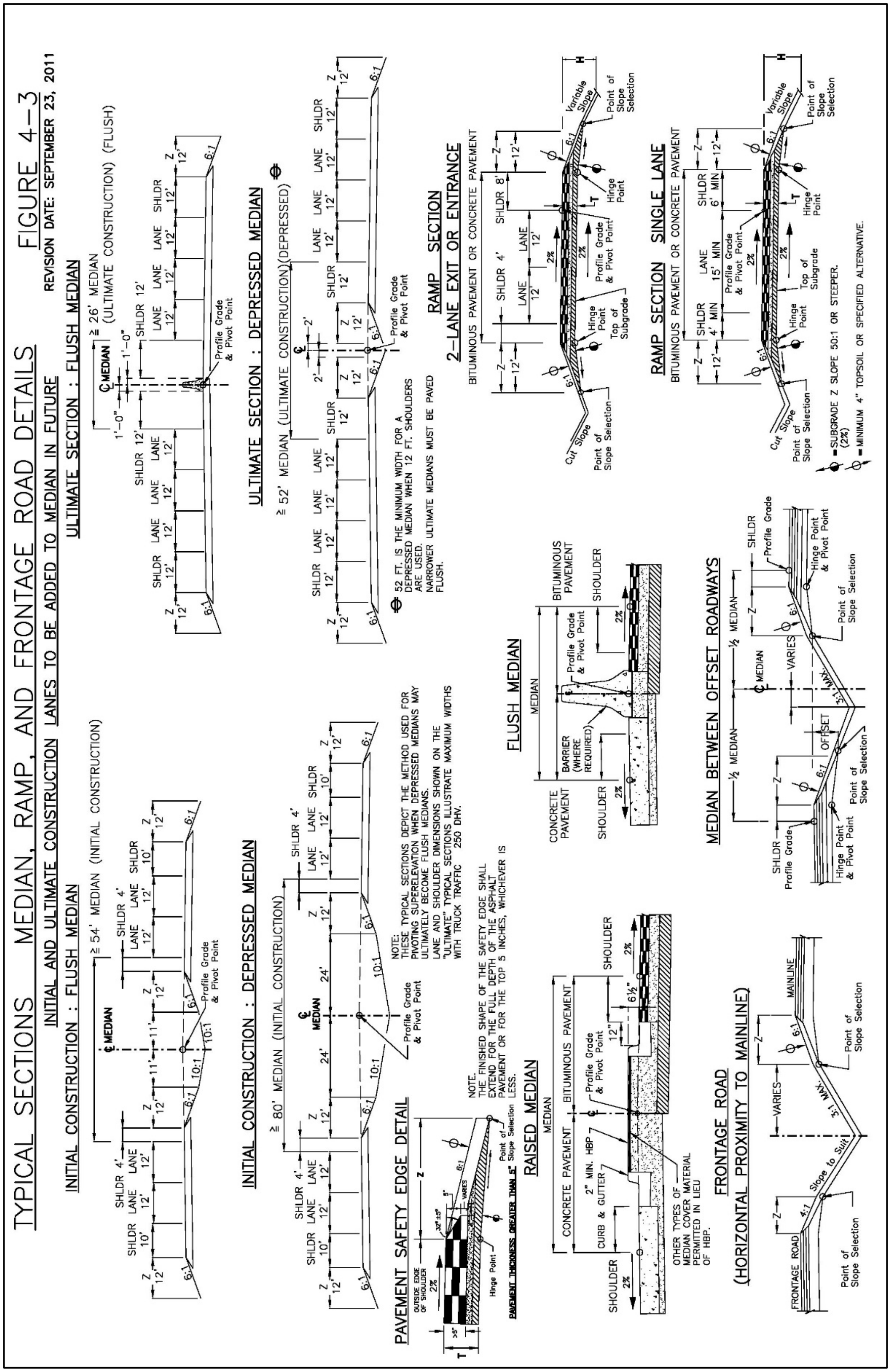


**Figure 4-3 Typical Sections for Medians, Ramps, and Frontage Roads**

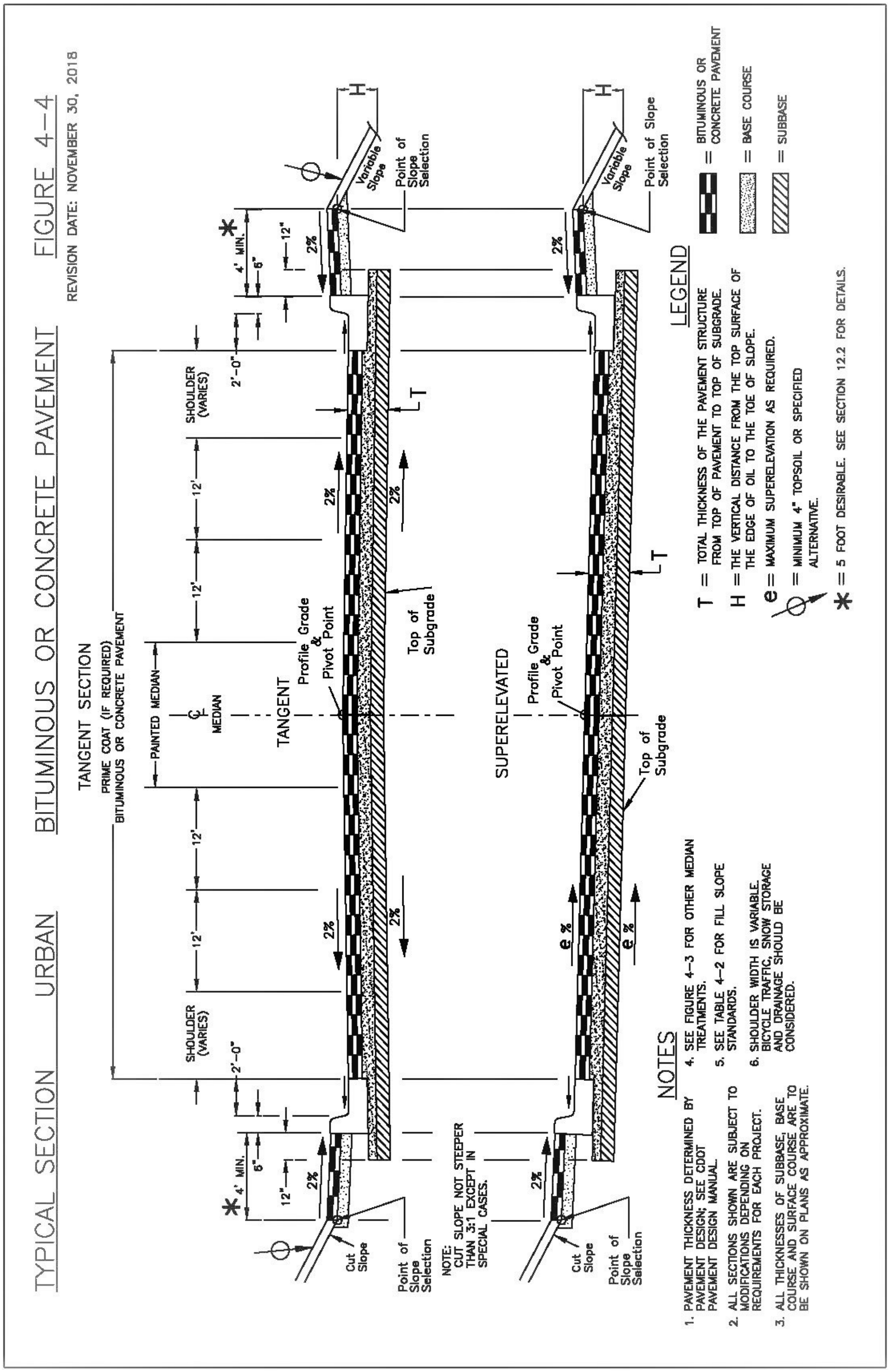


**Figure 4-4 Typical Sections for Urban Bituminous or Concrete Pavement**

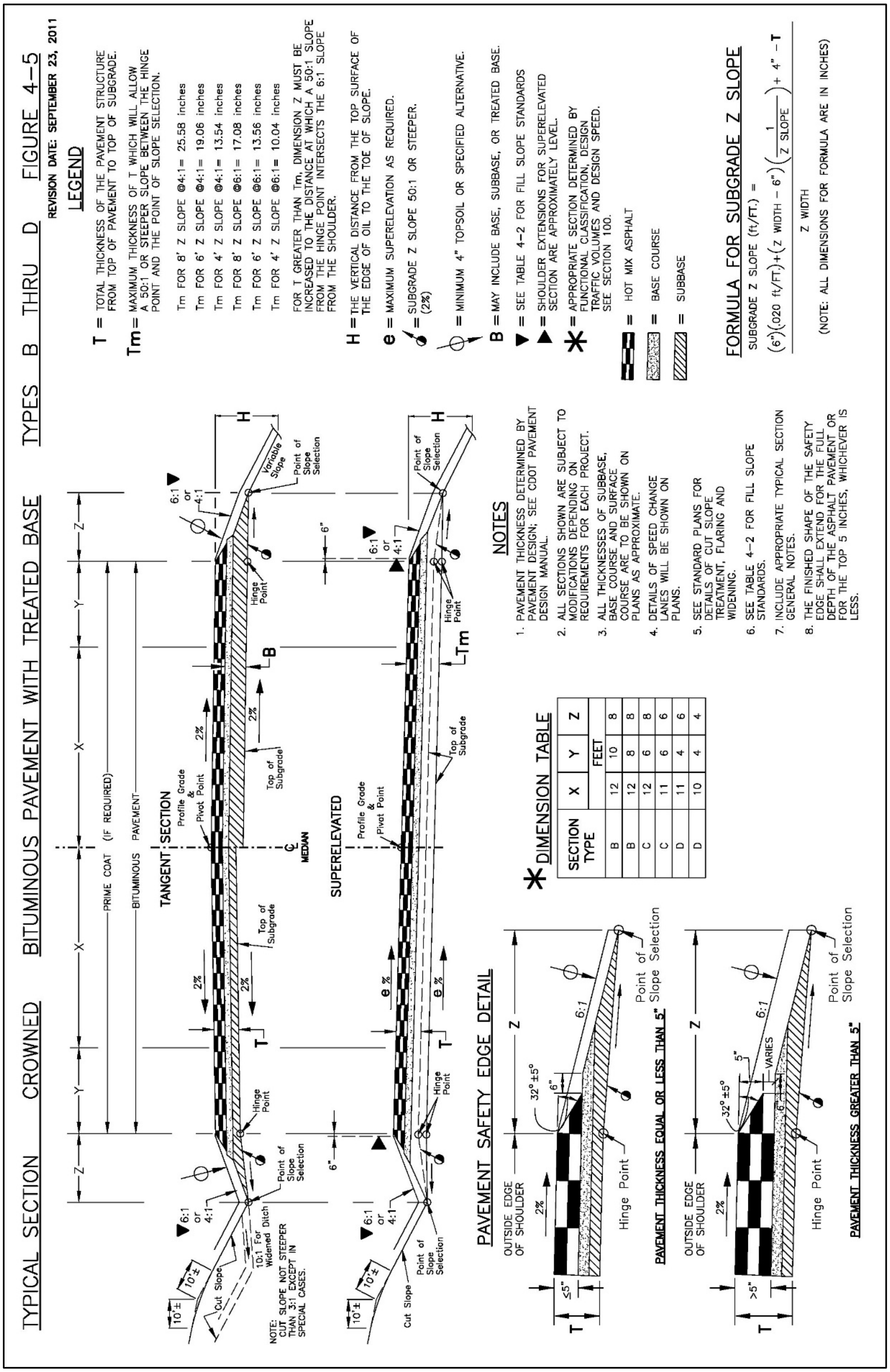


**Figure 4-5 Typical Section for Crowned Bituminous Pavement**

## 4.5 HORIZONTAL CLEARANCE TO OBSTRUCTIONS

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* **(6)**. The Guide should be used as a reference for determination of clear zone for freeways, rural arterials, and high-speed rural collectors. For low-speed, low volume rural collectors and local roads, a minimum of 10 feet should be provided.

For urban arterials, collectors and local streets where curbs are utilized, space for clear zones is generally restricted. A minimum offset distance of 18 inches should be provided beyond the face of the curb to the face of the obstruction, except where *CDOT Standard Plans - M & S Standards* **(2)** specify 24 inches, with wider clear zones provided where practical or where existing hazards require additional clear zone. The designer should consider pole foundation location to avoid interference with back of curb. Where shoulders are provided rather than curbs, a clear zone commensurate with the *AASHTO Roadside Design Guide* **(6)** should be provided. Because of large-vehicle overhang, 3 feet from face of curb is considered minimum clearance in intersections.

## 4.6 CURBS

Curbs serve the following purposes:

- Drainage control
- Pavement edge delineation
- Right of way reduction
- Aesthetics
- Delineation of pedestrian walkways
- Reduction of maintenance operations
- Assistance in orderly roadside development.

Use of curbs on high speed highways is discouraged in the interest of safety. In urban situations, curb is common; in intermediate speed situations, judgment must be exercised.

Curb should be used where required for proper drainage and where needed for channelization or access control.

Curbs may be sloping or vertical types. 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 not be used in front of the face of traffic barriers as the curb vaulting action interferes with the proper action of the barrier. See *CDOT Standard Plans - M & S Standards* **(2)**. 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 should not be located closer to the traveled way than the outer edge of the shoulder. Refer to the *CDOT Drainage Design Manual* **(7)** for minimal longitudinal slope requirements.

One-foot gutter is used with the curb where drainage control is not required; e.g., medians and islands. Sloping curb may be used on islands and medians where crossing is not a problem. Vertical curb should be used wherever random crossing or U-turn movements create a hazard.

Areas which require drainage control should use curb with 2-foot gutter. Cross slope of curb varies depending on whether the water is to flow toward or away from the curb. See *CDOT Standard Plans - M & S Standards* **(2)**. Inlets and storm drains are favored over using valley gutter for carrying drainage across intersections. Radii of curbs in intersections are generally dictated by the type of highway being served.

Normally, the curb and gutter are not considered to be part of the travel lane width; however, there may be exceptions in urban areas. A 2-foot offset from the edge of travel way to the face of outside 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 curb cross sections may be necessary.

Further specific information on curbs may be found in the *CDOT Standard Plans - M & S Standards* **(2).**

## 4.7 DRAINAGE CHANNELS AND SIDESLOPES

### 4.7.1 General Considerations

Modern highway drainage design should incorporate safety, good appearance, 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 sideslopes is important for safety because of their great influence on the sequence of events that can occur when a vehicle leaves the traveled way.

### 4.7.2 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 provide for unusual storm water with minimum 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* **(7)**. Side ditches should be used in all cut sections. Steep-sided channels are more desirable from a hydraulic point of view, but hydraulic performance must be evaluated in light of potential hazards steep slopes pose to errant vehicles. Channels shall be designed in accordance with the *AASHTO Roadside Design Guide* **(6)**.

The depth of channel should be sufficient to remove the water without saturation of the pavement subgrade. The depth of water that can be tolerated, particularly on flat channel slopes, depends upon the soil characteristics.

### 4.7.3 Sideslopes

Sideslopes should be designed to ensure the stability of the roadway and to provide a reasonable opportunity for recovery for an out-of-control vehicle. 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 high, in which case safe transition between fore and backslopes should be provided. Figure 4-6, General Cross Sectional Information, illustrates these three regions.

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:l 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 use of a roadside barrier.

Normally, backslopes should be 3:l 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.

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 the designer should refer to the *AASHTO Roadside Design Guide* **(6)**.

### 4.7.4 Cut Slope Standards

Cut slopes should not be steeper than 3:1 unless material is encountered which will stand on steeper slopes. Flatter slopes should be used in shallow cuts or in soils highly susceptible to erosion.

### 4.7.5 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. See the *AASHTO Roadside Design Guide* **(6)** for guardrail guidelines.

Table 4-2 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.

| **Highway Type** | *** H** | **Terrain** Plains | Rolling and Mountainous |
|---|---|---|---|
| | | **Slope Ratio**** | |
| 4 or more lanes (Z=12' @ 6:1) | ≤ 4' | Z, then 6:1 | Z, then 4:1 |
| | > 4' to 10' | Z, then 4:1 | Z, then 4:1 |
| | > 10' to 15' | Z, then 4:1 | Z, then 3:1 |
| | > 15' | Z, then 3:1 | Z, then 3:1 |
| ‡2 lane (Z=8' @ 6:1 or 6' @6:1 or 4' @ 6:1) | ≤ 4' | Z, then 6:1 | Z, then 4:1 |
| | > 4' to 10' | Z, then 4:1 | Z, then 4:1 |
| | > 10' to 15' | Z, then 4:1 | Z, then 3:1 |
| | > 15' | 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 See Figures 4-1 to 4-5 for determination of Z width.
**May be steeper in special cases.
‡ In constrained situations on a 2 lane roadway, the Z slope may be constructed as steep as 4:1.

**Table 4-2 Fill Slopes**

### 4.7.6 Clearance from Slope to Right of Way Line

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.

### 4.7.7 Slope Benches

The necessity for benches, their width, and vertical spacing should be determined only after an adequate geotechnical materials investigation has been completed. 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.

### 4.7.8 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. See the Slope Rounding details on the typical sections, Figures 4-1, 4-2, and 4-5 and subsection 203.05 of *CDOT Standard Specifications for Road and Bridge Construction,* **(8)**.

## 4.8 ILLUSTRATIVE GENERAL CROSS SECTIONS

Figure 4-6 illustrates typical combinations of the highway elements: lanes, shoulders, side-drainage channels, sidewalks, curbs, and sideslopes.

### 4.8.1 Normal Crown Sections

Figure 4-6 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 as discussed previously in this section.

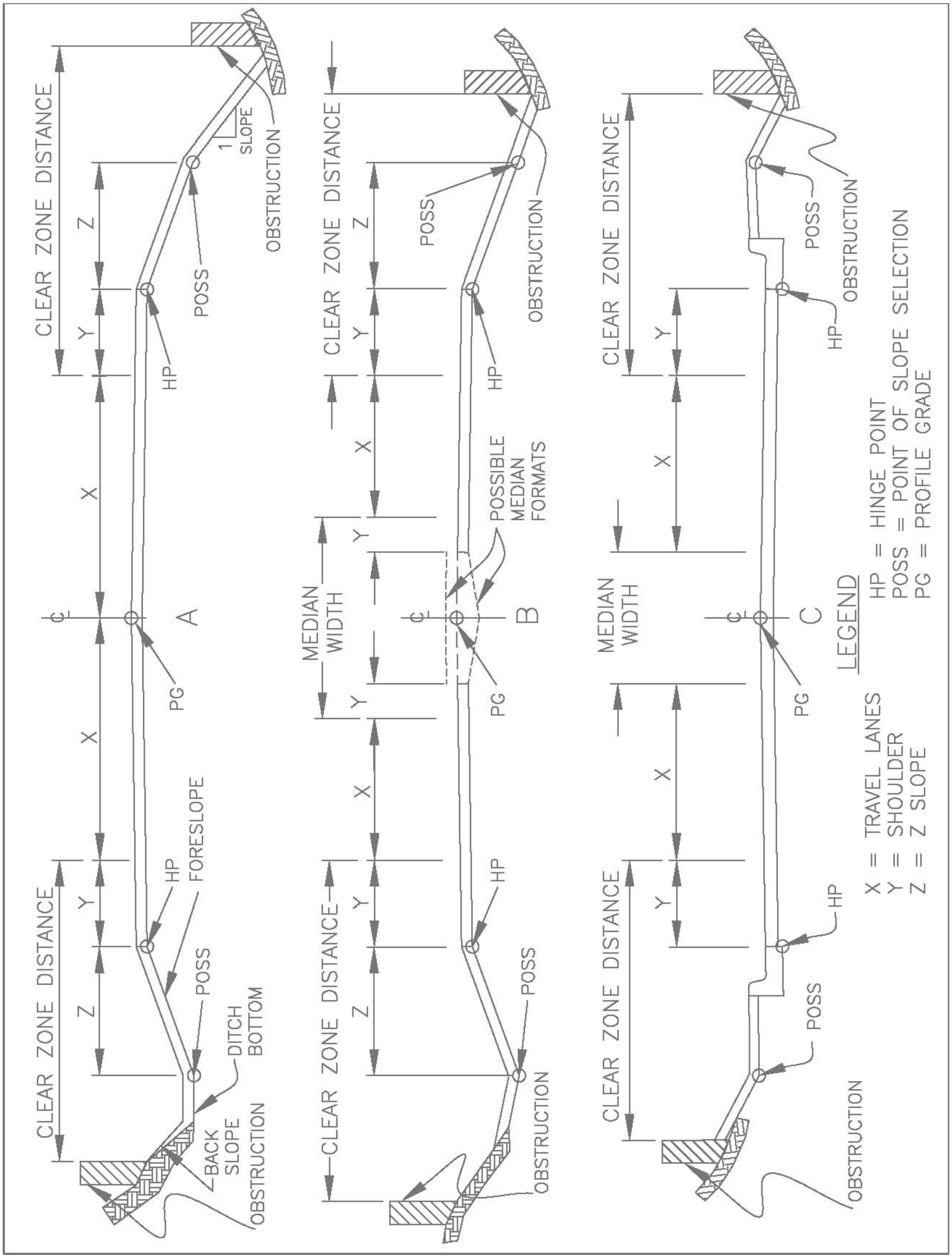


**Figure 4-6 General Cross Sectional Information**

## 4.9 TRAFFIC BARRIERS

### 4.9.1 General Considerations

Traffic barriers are used to minimize the severity of potential accidents involving vehicles leaving the traveled way where the consequences of errant vehicles striking a barrier are less than leaving the roadway. Because barriers are a source of accident potential themselves, their use should be carefully considered. For more detailed information regarding traffic barriers, refer to the *CDOT Safety Selection Guide* **(9)** and the AASHTO *Roadside Design Guide* **(6)**.

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.

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 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* **(2)** from the obstruction.

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:

- 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. See the *CDOT Project Development Manual* **(10)**, Section 2.09.

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 the probability of an accident occurring is low.

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, sloped shoulders, and stepped medians can cause errant vehicles to vault or submarine 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.

### 4.9.2 Longitudinal Barriers

Consider the following:

- Height of the barrier affecting site distance; e.g. glare screen or offset barrier affecting sight distance on curves.
- Wildlife being able to clear barriers.
- Maintenance concerns with snow drifting, ease of maintenance, and continuity of type and material.
- Drainage concerns and icing (barrier shadows).
- Adequate room for entrance gating.
- Context-sensitive solutions - see FHWA *Flexibility in Highway Design* **(11)**.
- Materials selection such as wood vs. steel posts and galvanized vs. corrosion-resistant steel.
- Aesthetics – Consider visual impact of selected type.

See the AASHTO *Roadside Design Guide* **(6)**.

#### *4.9.2.1 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. 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. The designer should refer to the AASHTO *Roadside Design Guide* **(6)** 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.

Short lengths of roadside barriers are discouraged. Where needed in two or more closely spaced locations, the barrier should be continuous.

#### *4.9.2.2 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 accidents 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.

Common types of median separation barrier include:

- 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-chainlink-fence combination.

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 can be used for temporary protection of work areas and for guiding traffic during construction.

### 4.9.3 Bridge Railings

When designing bridge rail, consider protection of pedestrians and cyclists.

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 terminal.

At the juncture between a bridge railing and roadside barrier, incompatibility nearly always exists in the stiffness of the two barrier types. This stiffness must be transitioned over a length and with details that will prevent the barrier system from pocketing or snagging an impacting vehicle. For further information, see the *CDOT Standard Plans - M & S Standards* **(2)**.

### 4.9.4 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.

New highway design should consider alternatives to use of these devices 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.

See the CDOT *Safety Selection Guide* **(9)** for guidance in selecting crash cushions.

## 4.10 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.
- Minimize headlight glare.
- Provide a refuge area for pedestrians (see Chapter 9).
- Provide area for landscaping.

Median width is measured as the distance between the edges of traveled way and includes inside shoulders. 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 aesthetic concerns, economics, Right of way limitations, topography, and at-grade intersection signal operations.

Median widths 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 Region Traffic Engineer.

Medians may be flush, depressed or raised. Advantages of depressed medians include improved drainage and snow removal. 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 be planted. Consider the following: plantings and other landscaping features in median areas may constitute roadside obstacles and may also limit sight distance.

Flush (or painted) medians are often used where two-way left-turn lanes are desired to improve capacity and reduce rear-end accidents. 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 a lane.

Normally, the turn lane should be the same width as the travel lanes. Conditions with high truck or bus movement or conditions with limiting geometry may warrant different widths.

## 4.11 FRONTAGE ROADS

A frontage road is a local auxiliary road located adjacent to a highway. It is primarily used with expressways and freeways although it may be used with any highway.

Among the functions of frontage roads are controlling access, segregating high-speed through traffic from lower speed local traffic, and keeping development in surrounding area from directly affecting the highway.

Specific applications of frontage roads vary with the type of highway. One disadvantage of frontage roads is increased complexity, possibly leading to confusion of drivers.

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 highway. Connection of the frontage road and the main highway is one of the more important aspects of frontage road design. Its cross section is dependent on traffic character, volume, and level of service.

From an operational and safety standpoint, one-way frontage roads are preferable to two-way frontage roads. Location of frontage road terminals is dependent on the type of highway it is associated with and the development of the area it serves.

Traffic operations are improved if the frontage roads are located a considerable distance from the main line at the intersecting cross roads 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 arterial 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 allow for turning movements and provide a minimal amount of vehicle storage.

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 some such situations, outer separations as narrow as 8 feet may operate satisfactorily.

Figures 4-7 through 4-10 in the *PGDHS* **(3)** provide schematics of frontage roads.

## 4.12 OUTER SEPARATIONS

The area between the edge of traveled roadway and edge of traveled way of any street or frontage road is designated as the outer separation. The separation functions as a buffer between 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 be designed to prevent unauthorized access between main line and frontage roads.

| **Type of Frontage Road** | **Separation Width** | |
|---|---|---|
| | **Minimum** | ***Desirable** |
| Two-Way Frontage Roads | 24 feet | ≥ 40 feet |
| One-Way Frontage Roads | 20 feet | ≥ 30 feet |
| Arterial Streets With Frontage Roads | 8 feet | |
| *Use on non-urban highways. | | |

**Table 4-3 Width of Separation for Frontage Roads**

Outer separations must meet clear-zone criteria. See the *PGDHS* **(3)** and AASHTO *Roadside Design Guide* **(6)**.

# 4.13 NOISE CONTROL

## 4.13.1 General Considerations

Noise is 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 highway. The designer should coordinate with the 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 public annoyance; e.g., 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 annoyance level. High 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.

See also Chapter 18.

# 4.14 ROADSIDE CONTROL

## 4.14.1 General Considerations

The efficiency and safety of a highway depend greatly upon the amount and character of roadside interference, most of which originates in vehicle movements to and from business, residences, or other development along the highway. Consult the State Highway Access Code (12) and the Region Access manager for property owner rights of access. Interference resulting from indiscriminate roadside development and uncontrolled driveway connections results in lowered capacity, increased hazards, and early obsolescence of the highway.

See also Chapter 11 and *State Highway Access Code* **(12)** for further information on access.

## 4.14.2 Driveways

Driveway terminals are, in effect, low-volume intersections; thus, their design and location merit special consideration.

Driveways are directly related to the functional classification of the particular roadway. Where driveways might adversely affect the operation of arterials, the driveways become important links on local streets, where the primary function of the street is to provide access to local establishments.

Driveways should be consolidated whenever possible after consulting with the Region Access Coordinator. An important feature of driveway design is the elimination of large graded or paved areas adjacent to the traveled way upon which drivers can enter and leave the facility at will.

See also Chapter 11 for further information on access.

### 4.14.3 Mailboxes

Most vehicles stopped at a mailbox will be 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 the AASHTO *A Guide for Erecting Mailboxes on Highways* **(13)**, the AASHTO *Roadside Design Guide* **(6)**, and the *CDOT Standard Plans – M&S Standards* **(2).** Local postal regulations should be consulted for additional criteria.

## 4.15 TUNNELS

### 4.15.1 General Considerations

Development of streets or highways may require sections be constructed in tunnels to carry either the streets or highways under or through a natural obstacle, or to minimize the impact of the freeway on the community.

A consultant may be required to design the tunnel, which includes but is not limited to lighting, fire prevention, and electrical and ventilation systems.

### 4.15.2 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.

### 4.15.3 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 not only minimize the length but also improve operating efficiency.

### 4.15.4 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 for 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 separation structures because of the greater likelihood of vehicles becoming disabled in the longer lengths.

Normally, pedestrians are not permitted in freeway tunnels; however, space should be provided for emergency walking and for access by maintenance personnel. Raised sidewalks, 2.5 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.

## 4.16 PEDESTRIAN FACILITIES

Appropriate provisions must be made to protect pedestrians from vehicular traffic. Considerations in evaluating the extent of protection required include quantity and variability of pedestrian movement (or activity) and traffic peak and normal volumes, intersection capacity, and site-specific hazards or inconveniences that may influence pedestrian safety.

Suitable treatment may vary from placing a curb or other barrier between the vehicular and pedestrian traffic to construction of a pedestrian overpass or underpass. Pedestrian overpasses and underpasses need to be coordinated with the local agencies and public. When placing pedestrian crossings, care must be exercised to ensure access to persons with disabilities. See *CDOT Standard Plans - M & S Standards* **(2)**, and the requirements of the *Public Rights of Way Accessibility Guidelines (PROWAG)*. For more information contact CDOT's Center for Equal Opportunity.

The project design shall maintain ADA compliant access for and safety of pedestrians, bicyclists, bus stops etc. during construction.

### 4.16.1 Sidewalks

Sidewalks are most often required in areas with high-pedestrian traffic such as school and commercial areas. Rural areas with such development should be considered for sidewalks along with most urban situations. In urban areas, roadways without shoulders generally should have provision for sidewalks. Sidewalks should be considered for bridges, but the specific sidewalk details may vary.

Sidewalk width may vary due to physical limitations, the presence of a separator between sidewalk and roadway, and the type of development the sidewalk serves. Four to eight foot wide sidewalks are normally used in residential areas and often a 2-foot (minimum) planted strip is provided for maintenance. Where this strip is not present, an additional 2 feet of width is recommended. In commercial areas, the sidewalk typically extends the full width between the roadway and the businesses. Design of sidewalk must include provisions for persons with disabilities; usually those provisions are curb ramps.

The designer should check with local agencies for design impacts.

### 4.16.2 Sidewalk Curb Ramps

In general, curb ramps within the project limits shall be brought into compliance with the PROWAG (14) compliant CDOT Standard Plan M-608-1 Curb Ramps. Most projects with curb ramps will be required to address ramps that do not meet the minimum requirements for functionally accessibility (as defined in CDOT's Transition Plan). Additional guidance can be found in CDOT's Transition Plan, Chapter 12 of the CDOT Roadway Design Guide and PD 605.1.

Questions about project specific ramps should be directed to the Region ADA Representative.

## 4.17 BICYCLE FACILITIES

Generally, bicycles can share the roadway with vehicular traffic. In some cases, it is warranted to build separate bikeways. Specific information on warrants and construction requirements for bikeways can be found in Chapter 14.

## 4.18 BUS TURNOUTS

Bus travel is an increasingly important mode of mass transportation. Bus turnouts serve to remove buses from the traffic lanes. The location and design of turnouts should provide ready access in the safest and most efficient manner possible. Coordinate details with the local transit agency. Inter-Governmental Agreements may be required.

### 4.18.1 Freeways

The basic design objective for a freeway bus turnout, when exclusive bus roadways are not provided, is that the deceleration, standing, and acceleration of buses are affected 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. For more details see section 4.19 of the *PGDHS* (**3**).

### 4.18.2 Arterials

The interference between buses and other traffic can be considerably reduced by providing turnouts clear of the lanes for through traffic.

Coordinate details with the local transit agency.

For more information on bus turnouts, see the AASHTO *Guide for Design of High-Occupancy Vehicle and Public Transportation Facilities* **(15).**

### 4.18.3 Park-and-Ride Facilities

Park-and-Ride facilities are designed to accommodate:

- Bus loading and unloading.
- Taxis.
- 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 local transit agency.

Further details and information can be found in the AASHTO *Guide for Design of High-Occupancy Vehicle and Public Transportation Facilities* **(15)**.

## 4.19 ON-STREET PARKING

It can generally be stated that on-street parking decreases through-capacity, impedes traffic flow, and increases accident potential. For these reasons, it is desirable to prohibit parking on urban and rural arterial streets. The *PGDHS* **(3)** provides further definition of on-street parking design considerations.

In the design of freeways and control of access-type facilities, as well as on most rural arterials, collectors and local streets, only emergency stopping or parking should be permitted or considered. However, within urban areas and in rural communities located on arterial highway routes, existing and developing land uses necessitate the consideration of on-street parking.

When on-street parking is to be an element of design, parallel parking should be considered. Angle parking presents special problems because of varying vehicle lengths and sight distance problems.

## REFERENCES


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