

SECTION 4

BASIC GEOMETRIC DESIGN ELEMENTS

4-01 GENERAL

Geometric highway design pertains to the visible features of the highway. It may be considered as the tailoring of the highway to the terrain, to the controls of the land usage, and to the type of traffic anticipated.

Design parameters covering highway types, design vehicles, and traffic data are included in Section 2 GENERAL DESIGN CRITERIA.

This section covers design criteria and guidelines on the geometric design elements that must be considered in the location and the design of the various types of highways. Included are criteria and guidelines on sight distances, horizontal and vertical alignment, and other features common to the several types of roadways and highways.

In applying these criteria and guidelines, it is important to follow the basic principle that consistency in design standards is of major importance on any section of road. The highway should offer no surprises to the driver in terms of geometrics. Problem locations are generally at the point where minimum design standards are introduced on a section of highway where otherwise higher standards should have been applied. The ideal highway design is one with uniformly high standards applied consistently along a section of highway, particularly on major highways designed to serve large volumes of traffic at high operating speeds.

4-02 SIGHT DISTANCES

4-02.1 General

Sight distance is the continuous length of highway ahead visible to the driver. In design, two sight distances are considered: passing sight distance and stopping sight distance. Stopping sight distance is the minimum sight distance to be provided at all points on multi-lane highways and on two-lane roads when passing sight distance is not economically obtainable.

Stopping sight distance also is to be provided for all elements of interchanges and intersections at grade, including driveways.

Table 4-1 shows the standards for passing and stopping sight distance related to design speed.

**Table 4-1
Sight Distances for Design**

Design Speed Mph	Sight Distance in feet	
	Stopping* Minimum	Passing* Minimum
25	155	900
30	200	1090
35	250	1280
40	305	1470
45	360	1625
50	425	1835
55	495	1985
60	570	2135
65	645	2285
70	730	2480

* Not applicable to multi-lane highways.

4-02.2 Passing Sight Distance

Passing sight distance is the minimum sight distance that must be available to enable the driver of one vehicle to pass another vehicle, safely and comfortably, without interfering with the speed of an oncoming vehicle traveling at the design speed, should it come into view after the overtaking maneuver is started. The sight distance available for passing at any place is the longest distance at which a driver whose eyes are 3.5 ft. above the pavement surface can see the top of an object 3.5 ft. high on the road.

Passing sight distance is considered only on two-lane roads. At critical locations, a stretch of four-lane construction with stopping sight distance is sometimes more economical than two lanes with passing sight distance.

4-02.3 Stopping Sight Distance

The minimum stopping sight distance is the distance required by the driver of a vehicle, traveling at a given speed, to bring his vehicle to a stop after an object on the road becomes visible. Stopping sight distance is measured from the driver's eyes, which is 3.5 ft. above the pavement surface, to an object 2 ft. high on the road.

The stopping sight distances shown in Table 4-1 should be increased when sustained downgrades are steeper than 3 percent. Increases in the stopping sight distances on downgrades are indicated in *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2001.

4-02.4 Stopping Sight Distance on Vertical Curves

See Section 4-04 for discussion on vertical curves.

4-02.5 Stopping Sight Distance on Horizontal Curves

Where an object off the pavement such as a longitudinal barrier, bridge pier, bridge rail, building, cut slope, or natural growth restricts sight distance, the minimum radius of curvature is determined by the stopping sight distance.

Stopping sight distance for passenger vehicles on horizontal curves is obtained from Figure 4-A. For sight distance calculations, the driver's eyes are 3.5 ft. above the center of the inside lane (inside with respect to curve) and the object is 2 ft. high. The line of sight is assumed to intercept the view obstruction at the midpoint of the sight line and 2.75 ft. above the center of the inside lane. Of course, the midpoint elevation will be higher or lower than 2.75 ft., if it is located on a sag or crest vertical curve respectively. The clear distance (M) is measured from the center of the inside lane to the obstruction.

The general problem is to determine the clear distance from the centerline of inside lane to a median barrier, retaining wall, bridge pier, abutment, cut slope, or other obstruction for a given design speed. Using radius of curvature and sight distance for the design speed, Figure 4-A gives the middle ordinate (M) which is the clear distance from centerline of inside lane to the obstruction. When the design speed and the clear distance to a fixed obstruction are known, this figure also gives the required minimum radius which satisfies these conditions.

When the required stopping sight distance would not be available because of an obstruction such as a railing or a longitudinal barrier, the following alternatives shall be considered: increase the offset to the obstruction, increase the horizontal radius, or do a combination of both. However, any alternative selected should not require the width of the shoulder on the inside of the curve to exceed 12 ft. because the potential exists that motorists will use the shoulder in excess of that width as a passing or travel lane.

When determining the required middle ordinate (M) distance on ramps, the location of the driver's eye is assumed to be positioned 6 ft. from the inside edge of pavement on horizontal curves.

The designer is cautioned in using the values from Figure 4-A since the stopping sight distances and middle ordinates are based upon passenger vehicles. The average driver's eye height in large trucks is approximately 120 percent higher than a driver's eye height in a passenger vehicle. However, the required minimum stopping sight distance can be as much as 50 percent greater than the distance required for passenger vehicles. On routes with high percentages (10 percent or more) of truck traffic, the designer should consider providing greater horizontal clearances to vertical sight obstructions to accommodate the greater stopping distances required by large trucks. The approximate middle ordinate (M) required for trucks is 2.5 times the value obtained from Figure 4-A for passenger vehicles.

INSERT FIGURE 4-A HERE

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4-03 HORIZONTAL ALIGNMENT

4-03.1 General

In the design of horizontal curves, it is necessary to establish the proper relationship between design speed, curvature and superelevation. Horizontal alignment must afford at least the minimum stopping sight distance for the design speed at all points on the roadway.

The major considerations in horizontal alignment design are: safety, grade, type of facility, design speed, topography and construction cost. In design, safety is always considered, either directly or indirectly. Topography controls both curve radius and design speed to a large extent. The design speed, in turn, controls sight distance, but sight distance must be considered concurrently with topography because it often demands a larger radius than the design speed. All these factors must be balanced to produce an alignment that is safe, economical, in harmony with the natural contour of the land and, at the same time, adequate for the design classification of the roadway or highway.

4-03.2 Superelevation

When a vehicle travels on a horizontal curve, it is forced radially outward by centrifugal force. This effect becomes more pronounced as the radius of the curve is shortened. This is counterbalanced by providing roadway superelevation and by the side friction between the vehicle tires and the surfacing. Safe travel at different speeds depends upon the radius of curvature, the side friction, and the rate of superelevation.

When the standard superelevation for a horizontal curve cannot be met, a design exception will be required. However, the highest practical superelevation should be selected for the horizontal curve design.

A 6 percent maximum superelevation rate shall be used on rural highways and rural or urban freeways, see Figure 4-B. A 4 percent maximum superelevation rate may be used on high speed (greater than 40 mph) urban highways to minimize conflicts with adjacent development and intersecting streets, see Figure 4-C. Low speed (40 mph or less) urban streets can use a 4 percent or 6 percent maximum superelevation rate, see Figure 4-C. The 6 percent maximum superelevation rate for low speed urban streets allows for:

1. a higher threshold of driver discomfort than the 6 percent superelevation rate in Figure 4-B, and
2. application with sharper curvature than the 4 percent maximum superelevation rate in Figure 4-C.

The minimum superelevation to be used is 1.5 percent. On flat radius curves requiring superelevation ranging from 1.5 percent to 2.0 percent, the superelevation should be increased by 0.5 percent in each successive pair of lanes on the low side of the superelevation when more than two lanes are superelevated in the same direction.

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It may be appropriate to provide adverse crown on flat radius curves (less than 2 percent superelevation) to avoid water buildup on the low side of the superelevation when there are more than three lanes draining across the pavement (This design treatment would require a design exception). Another option is to construct a permeable surface course or a high macotexture surface course since these surfaces appear to have the highest potential for reducing hydroplaning accidents. Also, grooving the pavement perpendicular to the traveled way may be considered as a corrective measure for severe localized hydroplaning problems.

Figures 4-B and 4-C give the design values for each rate of superelevation to be used for various design speeds and radii on mainline curves.

1. Axis of Rotation

a. Undivided Highways

For undivided highways, the axis of rotation for superelevation is usually the centerline of the traveled way. However, in special cases where curves are preceded by long, relatively level tangents, the plane of superelevation may be rotated about the inside edge of the pavement to improve perception of the curve. In flat terrain, drainage pockets caused by superelevation may be avoided by changing the axis of rotation from the centerline to the inside edge of the pavement.

b. Ramps and Freeway to Freeway Connections

The axis of rotation may be about either edge of pavement or centerline if multi-lane. Appearance and drainage considerations should always be taken into account in selection of the axis rotation.

c. Divided Highways

(1) Freeways

Where the initial median width is 30 ft. or less, the axis of rotation should be at the median centerline.

Where the initial median width is greater than 30 ft. and the ultimate median width is 30 ft. or less, the axis of rotation should be at the median centerline, except where the resulting initial median slope would be steeper than 10H:1V. In the latter case, the axis of rotation should be at the ultimate median edges of pavement.

Where the ultimate median width is greater than 30 ft., the axis of rotation should be at the proposed median edges of pavement.

To avoid a sawtooth on bridges with decked medians, the axis of rotation, if not already on the median centerline, should be shifted to the median centerline.

(2) Other Divided Highways

The axis of rotation should be considered on an individual project basis and the most appropriate case for the conditions should be selected.

The selection of the axis of rotation should always be considered in conjunction with the design of the profile and superelevation transition.

2. Superelevation Transition

The superelevation transition consists of the superelevation runoff (length of roadway needed to accomplish the change in outside-lane cross slope from zero to full superelevation or vice versa) and tangent runout (length of roadway needed to accomplish the change in outside-lane cross slope from the normal cross slope to zero or vice versa). The definition of and method of deriving superelevation runoff and runout in this manual is the same as described in the AASHTO publication *A Policy on Geometric Design of Highways and Streets*, 2001.

The superelevation transition should be designed to satisfy the requirements of safety and comfort and be pleasing in appearance. The minimum length of superelevation runoff and runout should be based on the following formula:

SUPERELEVATION RUNOFF

$$L_r = (w)(n)(e)(b)/\Delta$$

Where:

L_r = minimum length of superelevation runoff, ft;

Δ = maximum relative gradient, percent (Table 4-2);

n = number of lanes rotated

b = adjustment factor for number of lanes rotated (Table 4-3)

w = width of one traffic lane, ft.

e = design superelevation rate, percent

TANGENT RUNOUT

$$L_t = (L_r)(e_{NC})/e$$

Where

L_t = minimum length of tangent runout, ft.

e_{NC} = normal cross slope rate, percent

e = design superelevation rate

L_r = minimum length of superelevation runoff, ft.

Table 4-2
Maximum Relative Gradient

Design Speed (mph)	25	30	35	40	45	50	55	60	65	70
Maximum Relative Gradient	0.70	0.66	0.62	0.58	0.54	0.50	0.47	0.45	0.43	0.40

Table 4-3
Adjustment Factor for Number of Lanes Rotated

Number of Lanes Rotated (n)	Adjustment Factor (b)
1	1.00
1.5	0.83
2	0.75
2.5	0.70
3	0.67
3.5	0.64

On 3R projects where the existing runoff and runout lengths are shorter than calculated from the formula, the existing runoff and runout lengths may be maintained.

With respect to the beginning or ending of a curve, the amount of runoff on the tangent should desirably be based on Table 4-4. However, runoff lengths on the tangent ranging from 60 to 90 percent are acceptable.

Table 4-4
Percent of Runoff on Tangent

Design Speed Mph	Portion of runoff located prior to the curve			
	Number of lanes rotated			
	1.0	1.5	2.0-2.5	3.0-3.5
25-45	0.80	0.85	0.90	0.90
50-80	0.70	0.75	0.80	0.85

After a superelevation transition is designed, profiles of the edges of pavement and shoulder should be plotted and irregularities removed by introducing smooth curves by the means of a graphic profile. Flat areas which are undesirable from a drainage standpoint should be avoided.

Pronounced and unsightly sags may develop on the low side of the superelevation. These can be corrected by adjusting the grades on the two edges of pavement throughout the curve.

3. Transition Curves and Superelevation

The use of transition curves on arterial highways designed for 50 mph or greater is encouraged. Figures 4D through 4H inclusive indicate the desirable treatment on highway curves including the method of distributing superelevation.

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4-03.3 Curvature

1. General

The changes in direction along a highway are basically accounted for by simple curves or compound curves. Excessive curvature or poor combinations of curvature generate accidents, limit capacity, cause economic losses in time and operating costs, and detract from a pleasing appearance. To avoid these poor design practices, the following general controls should be used.

2. Curve Radii for Horizontal Curves

Table 4-5 gives the minimum radius of open highway curves for specific design speeds. This table is based upon a 6 percent and 4 percent maximum superelevation; it ignores the horizontal stopping sight distance factor.

**Table 4-5
Standards for Curve Radius**

Design Speed (mph)	Minimum Radius of Curve for Rural or Urban Freeways Based on 6% e_{\max} (ft)	Minimum Radius of Curve for Urban Highways Based on 4% e_{\max} (ft)	Minimum Radius of Curve for Low Speed Urban Highways Based on 6% e_{\max} (ft)
25	185	205	135
30	275	300	215
35	380	420	320
40	510	565	450
45	660	730	---
50	835	930	---
55	1065	1190	---
60	1340	1505	---
70	2050	---	---

Every effort should be made to exceed the minimum values. Minimum radii should be used only when the cost or other adverse effects of realizing a higher standard are inconsistent with the benefits. Where a longitudinal barrier is provided in the median, the above minimum radii may need to be increased or the adjacent shoulder widened to provide adequate horizontal stopping sight distance.

The suggested minimum radius for a freeway is 3000 ft. in rural areas and 1600 ft. in urban areas. For a land service highway, the preferred minimum radius is 1600 ft.

and 1000 ft. for design speeds of 60 mph and 50 mph respectively.

Due to the higher center of gravity on large trucks, sharp curves on open highways may contribute to truck overturning. Overturning becomes critical on radii below approximately 700 ft. Where new or reconstructed curves on open highways with radii less than 700 ft. must be provided, the design of these radii shall be based upon a design speed of at least 10 mph greater than the anticipated posted speed.

3. Alignment Consistency

Sudden reductions in standards introduce the element of surprise to the driver and should be avoided. Where physical restrictions on curve radius cannot be overcome and it becomes necessary to introduce curvature of a lower standard than the design speed for the project, the design speed between successive curves shall change not more than 10 mph. Introduction of a curve for a design speed lower than the design speed of the project shall be avoided at the end of a long tangent or at other locations where high approach speeds may be anticipated.

4. Stopping Sight Distance

Horizontal alignment should afford at least the desirable stopping sight distance for the design speed at all points of the highway. Where social, environmental or economic impacts do not permit the use of desirable values, lesser stopping sight distances may be used, but shall not be less than the minimum values.

5. Curve Length and Central Angle

The following is applicable for freeways and rural arterial highways. Desirably, the minimum curve length for central angles less than 5 degrees should be 500 ft. long, and the minimum length should be increased 100 ft. for each 1 degree decrease in the central angle to avoid the appearance of a kink. For central angles smaller than 30 minutes, no curve is required. In no event shall sight distance or other safety considerations be sacrificed to meet the above requirement.

6. Compound Curves

On compound curves for arterial highways, the curve treatment shown in Figures 4D through 4H should be used. For compound curves at intersections and ramps, the ratio of the flatter radius to the sharper radius should not exceed 2.0.

7. Reversing Curves

The intervening tangent distance between reverse curves should, as a minimum, be sufficient to accommodate the superelevation transition as specified in Section 4-03.2, "Superelevation". For design speeds of 50 mph and greater, longer tangent lengths are desirable. A range of desirable tangent lengths are shown in Table 4-6 for high design speeds.

Table 4-6
Desirable Tangent Length Between Reversing Curves

Design Speed (mph)	Desirable Tangent (ft)
50	500-600
60	600-800
70	800-1000

8. Broken Back Curves

A broken back curve consists of two curves in the same direction joined by a short tangent. Broken back curves are unsightly and violate driver expectancy. A reasonable additional expenditure may be warranted to avoid such curvature.

The intervening tangent distance between broken back curves should, as a minimum, be sufficient to accommodate the superelevation transition as specified in Section 4-03.2. For design speeds of 50 mph and greater, longer tangent lengths are desirable. Table 4-7 indicates the desirable tangent length between same direction curves. The desirable tangent distance should be exceeded when both curves are visible for some distance ahead.

Table 4-7
Desirable Tangent Length Between Same Direction Curves

Design Speed (mph)	Desirable Tangent (ft)
50	1000
60	1500
70	2500

9. Alignment at Bridges

Superelevation transitions on bridges almost always result in an unsightly appearance of the bridge and the bridge railing. Therefore, if at all possible, horizontal curves should begin and end a sufficient distance from the bridge so that no part of the superelevation transition extends onto the bridge. Alignment and safety considerations, however, are paramount and shall not be sacrificed to meet the above criteria.

4-04 VERTICAL ALIGNMENT

4-04.1 General

The profile line is a reference line by which the elevation of the pavement and other features

of the highway are established. It is controlled mainly by topography, type of highway, horizontal alignment, safety, sight distance, construction costs, cultural development, drainage and pleasing appearance. The performance of heavy vehicles on a grade must also be considered.

All portions of the profile line must meet sight distance requirements for the design speed of the road.

In flat terrain, the elevation of the profile line is often controlled by drainage considerations. In rolling terrain, some undulation in the profile line is often advantageous, both from the standpoint of truck operation and construction economy. But, this should be done with appearance in mind; for example, a profile on tangent alignment exhibiting a series of humps visible for some distance ahead should be avoided whenever possible. In rolling terrain, however, the profile usually is closely dependent upon physical controls.

In considering alternative profiles, economic comparisons should be made. For further details, see the AASHTO publication: *A Policy on Geometric Design of Highways and Streets*, 2001.

4-04.2 Position with Respect to Cross Section

The profile line should generally coincide with the axis of rotation for superelevation; its relation to the cross section should be as follows:

1. Undivided Highways

The profile line should coincide with the highway centerline.

2. Ramps and Freeway to Freeway Connections

The profile line may be positioned at either edge of pavement, or centerline of ramp if multi-lane.

3. Divided Highways

The profile line may be positioned at either the centerline of the median or at the median edge of pavement. The former case is appropriate for paved medians 30 ft. wide or less. The latter case is appropriate when:

- a. The median edges of pavement of the two roadways are at equal elevation.
- b. The two roadways are at different elevations.

4-04.3 Separate Grade Lines

Separate or independent profile lines are appropriate in some cases for freeways and divided arterial highways.

They are not normally considered appropriate where medians are less than 30 ft. Exceptions to this may be minor differences between opposing grade lines in special situations.

In addition, appreciable grade differentials between roadbeds should be avoided in the vicinity of at-grade intersections. For traffic entering from the crossroad, confusion and wrong-way movements could result if the pavement of the far roadway is obscured due to an excessive differential.

4-04.4 Standards for Grade

The minimum grade rate for freeways and land service highways with a curbed or bermed section is 0.3 percent. On highways with an umbrella section, grades flatter than 0.3 percent may be used where the shoulder width is 8 ft. or greater and the shoulder cross slope is 4 percent or greater. For maximum grades for urban and rural land service highways and freeways, see Table 4-8.

**Table 4-8
Maximum Grades (%)**

Rural Land Service Highways							
Type of Terrain	Design Speed (mph)						
	30	40	45	50	55	60	65
Level	---	5	5	4	4	3	3
Rolling	---	6	6	5	5	4	4
Mountainous	---	8	7	7	6	6	5

Urban Land Service Highways							
Type of Terrain	Design Speed (mph)						
	30	40	45	50	55	60	65
Level	8	7	6	6	5	5	---
Rolling	9	8	7	7	6	6	---
Mountainous	11	10	9	9	8	8	---

Table 4-8
Maximum Grades (%) Continued

* Freeways							
Type of Terrain	Design Speed (mph)						
	40	45	50	55	60	65	70
Level	---	---	4	4	3	3	3
Rolling	---	---	5	5	4	4	4
Mountainous	---	---	6	6	6	5	5

* Grades one percent steeper than the value shown for freeways in Table 4-8 may be used for extreme cases in urban areas where development precludes the use of flatter grades for one-way downgrades except in mountainous terrain.

4-04.5 Vertical Curves

Properly designed vertical curves should provide adequate sight distance, safety, comfortable driving, good drainage, and pleasing appearance. On new alignments or major reconstruction projects on existing highways, the designer should, where practical, provide the desirable vertical curve lengths. The use of minimum vertical curve lengths should be limited to existing highways and those locations where the desirable values or values greater than the minimum would involve significant social, environmental or economic impacts.

A parabolic vertical curve is used to provide a smooth transition between different tangent grades. Figures 4-I and 4-J give the length of crest and sag vertical curves for various design speeds and algebraic differences in grade. The stopping sight distance for these curves are based upon a height of eye of 3.5 ft., and a height of object of 2 ft. The minimum length of vertical curve may also be obtained by multiplying the K value (Fig. 4-I or 4-J) by the algebraic difference in grade. The vertical lines in Figure 4-I and 4-J are equivalent to 3 times the design speed. To determine the length of crest vertical curves on highways designed with two-way left-turn lanes, see Section 6-07.1.

Flat vertical curves may develop poor drainage at level sections. Highway drainage must be given more careful consideration when the design speed exceeds 60 and 65 mph for crest vertical curves and sag vertical curves respectively. The length of sag vertical curves for riding comfort should desirably be approximately equal to:

$$L = AV^2/46.5.$$

L = Length of sag vertical curve, ft.

A = Algebraic difference in grades, percent.

V = Design speed, mph.

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When the difference between the P.V.I. elevation and the vertical curve elevation at the P.V.I. station (E) is 0.0625 ft. (3/4 inch), a vertical curve is not required. The use of a profile angle point is permitted. The maximum algebraic difference in tangent grades (A) that an angle point is permitted for various design speeds is shown in Table 4-9. This table is based on a length of vertical curve of 3 times the design speed.

Table 4-9
Use of a Profile Angle Point

Design Speed (mph)	A_{MAX} %
25	.70
30	.55
35	.50
40	.40
45	.40
50	.35
55	.30
60	.30
65	.25
70	.25

All umbrella section low points in cut and fill sections on freeways and Interstate highways shall be provided with slope protection at each low point in the mainline or ramp vertical geometry as shown in the *Standard Roadway Construction Details*. The purpose of this treatment is to minimize maintenance requirements in addressing the gradual build up of a berm which may eventually contribute to water ponding on the roadway surface and/or erosion of the side slope. The following are some recommended low point treatments:

1. Low Point at Edge of Ramp or Outside Edge of Mainline Pavement

Where practical, an "E" inlet should be provided in the outside edge of pavement at the low point to catch and divert the surface runoff. Provide outlet protection where needed at the pipe outfall.

As an alternative, provide slope protection which shall consist of the following:

a. Fill Section

Slope protection shall consist of a 20 ft. long bituminous concrete paved area between the edge of pavement and the hinge point (PVI) together with a riprap stone flume on the fill slope and a riprap stone apron at the bottom of the slope. The riprap shall only be provided where the fill slope is steeper than 4H:1V. Where there is an inlet in a swale at the low point, center the riprap stone apron around the inlet. Where guide rail exists at the low point, the 10 ft. long paved area shall be constructed instead of the non-vegetative surface treatment under the guide rail.

b. Cut Section

Slope protection shall consist of a 20 foot long bituminous concrete paved area between the edge of pavement and the toe of slope.

2. Low Point at Median Edge of Mainline Pavement

Provide slope protection which shall consist of a 20 foot long by 5 foot wide strip of bituminous concrete pavement adjacent to the inside edge of shoulder. If the fill slope is steeper than 4H:1V, provide riprap stone slope protection as described in "Low Point at Edge of Ramp or Outside Edge of Mainline Pavement".

On two-lane roads, extremely long crest vertical curves over one half mile should be avoided, since many drivers refuse to pass on such curves, despite adequate sight distance. It is sometimes more economical to use four-lane construction, than to obtain passing sight distance by the use of a long vertical curve.

Vertical curves affect intersection sight distance, therefore, utilizing the distances in Figure 6A, an eye height of 3.5 ft. and an object height of 3.5 ft; check for vertical sight distance at the intersection.

Broken back vertical curves consist of two vertical curves in the same direction, separated by a short grade tangent. A profile with such curvature normally should be avoided.

4-04.6 Heavy Grades

Except on level terrain, often it is not economically feasible to design a profile that will allow uniform operating speeds for all classes of vehicles. Sometimes, a long sustained gradient is unavoidable.

From a truck operation standpoint, a profile with sections of maximum gradient broken by length of flatter grade is preferable to a long sustained grade only slightly below the maximum allowable. It is considered good practice to use the steeper rates at the bottom of the grade, thus developing slack for lighter gradient at the top or elsewhere on the grade.

4-04.7 Coordination with Horizontal Alignment

A proper balance between curvature and grades should be sought. When possible, vertical curves should be superimposed on horizontal curves. This reduces the number of sight distance restrictions on the project, makes changes in profile less apparent, particularly in rolling terrain, and results in a pleasing appearance. For safety reasons, the horizontal curve should lead the vertical curve. On the other hand, where the change in horizontal alignment at a grade summit is slight, it safely may be concealed by making the vertical curve overlay the horizontal curve.

When vertical and horizontal curves are thus superimposed, the superelevation may cause

distortion in the outer pavement edges. Profiles of the pavement edge should be plotted and smooth curves introduced to remove any irregularities.

A sharp horizontal curve should not be introduced at or near a pronounced summit or grade sag. This presents a distorted appearance and is particularly hazardous at night.

4-05 CLIMBING LANE

A climbing lane, as shown in Figure 4-K, is an auxiliary lane introduced at the beginning of a sustained positive grade for the diversion of slow traffic.

Generally, climbing lanes will be provided when the following conditions are satisfied. These conditions could be waived if slower moving truck traffic was the major contributing factor causing a high accident rate and could be corrected by addition of a climbing lane.

1. Two-Lane Highways

The following three conditions should be satisfied to justify a climbing lane:

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

A complete explanation and a sample calculation on how to check for these conditions are shown in the section on "Climbing Lanes" contained in "Chapter III, Elements of Design", *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2001.

2. Freeways and Multi-lane Highways

Both of the following conditions should be satisfied to justify a climbing lane:

- a. A 10 mph or greater speed reduction is expected for a typical heavy truck.

INSERT FIGURE 4-K HERE

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- b. The service volume on an individual grade should not exceed that attained by using the next poorer level of service from that used for the basic design. The one exception is that the service volume derived from employing Level of Service D should not be exceeded.

If the analysis indicates that a climbing lane is required, an additional check must be made to determine if the number of lanes required on the grade are sufficient even with a climbing lane.

A complete explanation and a sample calculation on how to check for these conditions are shown in the section on "Climbing Lanes" contained in "Chapter III, Elements of Design", *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2001.

The beginning warrant for a truck climbing lane shall be that point where truck operating speed is reduced by 10 mph. To locate this point, use Exhibit 3-59 or Exhibit 3-63 of the aforementioned AASHTO manual, depending on the weight/horsepower ratio of the appropriate truck. The beginning of the climbing lane should be preceded by a tapered section, desirably 300 ft., however, a 150 ft. minimum taper may be used.

Desirably, the point of ending of a climbing lane would be to a point beyond the crest, where a typical truck could attain a speed that is about 10 mph below the operating speed of the highway. This point can be determined from Exhibit 3-60 of the aforementioned AASHTO manual. If this is not practical, end the climbing lane at a point where the truck has proper sight distance to safely merge into the normal lane, or preferably, 200 ft. beyond this point. For two lane highways, passing sight distance should be available. For freeways and multi-lane highways, passing sight distance need not be considered. For all highways, as a minimum, stopping sight distance shall be available. The ending taper beyond this point shall be according to Figure 4-L.

A distance-speed profile should be developed for the area of a climbing lane. The profile should start at the bottom of the first long downgrade prior to the upgrade being considered for a climbing lane, speeds through long vertical curves can be approximated by considering 25 percent of the vertical curve length (chord) as part of the grade under question.

4-06 LANE TRANSITION

Design standards of the various features of the transition between roadways of different widths should be consistent with the design standards of the superior roadway. The transition should be made on a tangent section whenever possible and should avoid locations with horizontal and vertical sight distance restrictions. Whenever feasible, the entire transition should be visible to the driver of a vehicle approaching the narrower section.

The design should be such that at-grade intersections within the transition are avoided.

Figure 4-L shows the minimum required taper length based upon the design speed of the

roadway. In all cases, a taper length longer than the minimum should be provided where possible.

In general, when a lane is dropped by tapering, the transition should be on the right so that traffic merges to the left.

Superseded

INSERT FIGURE 4-L HERE

Superseded