CHAPTER 6

VERTICAL ALIGNMENT

INTRODUCTION

Unless otherwise indicated, the profile grade represents the elevation of the top of the subgrade at the roadway centerline. The finished gradeline (finished surface) and elevations will be shown on the plans for bridge replacement and urban grading projects. For divided highways, a vertical alignment should be shown on the plans for each direction of travel.

The profile grade line is a series of tangents connected by parabolic arcs. The point where tangents intersect is known as the vertical point of intersection (V.P.I.).

The stationing of each V.P.I. is identified to the nearest 1’ (urban) or 10’ (rural) intervals and the elevation should be identified to the nearest 0.01’.

The slope or grade of each tangent is expressed in percent rise (+) or fall (-) to the forth decimal place.

Each parabolic vertical curve is identified by a curve length, usually defined to the nearest one hundred feet.

VERTICAL ALIGNMENT CONTROLS

Terrain

Terrain classifications (level, rolling, or mountainous) pertain to the general character of a specific route corridor. Selection of terrain is somewhat objective, but is normally an obvious choice. There may be more than one terrain classification at different points along a highway segment. If there is more than one type of terrain within the project limits, the designer should consider maintaining consistent design. South Dakota’s river breaks may be considered rolling or mountainous where steeper grades are necessary.

Ties with Adjoining Projects

A smooth transition shall be provided to adjoining projects. Therefore, adequate space shall be provided on the plans to plot the survey lines into adjoining projects for a smooth transition.

If the alignment of the adjoining project does not meet current standards, use a connecting grade which can be used when the adjoining project is reconstructed and which satisfactorily adjoins the existing alignment.

To obtain a smooth transition to adjoining projects, a spline curve may be required. A spline curve is produced by plotting an exaggerated vertical scale profile (for example 1" = 1' vertical and 1" = 50' horizontal). This creates a maximized view of the location where the project ties into an adjoining project. Then points along the curve can be established to ensure a smooth transition to the existing highway. When a spline curve is used, show the roadway elevations every 25' on the profile.

A spline curve is not required if the design gradeline can be tied into the existing surface with a 1” in 40’ rate of change tolerance.

Smooth Grade Line

To obtain a smooth grade line, changes in grade should be gradual and consistent with the type of highway and the character of the terrain as shown in Figure 6-1. Numerous breaks and short lengths of grade tangents should be avoided.

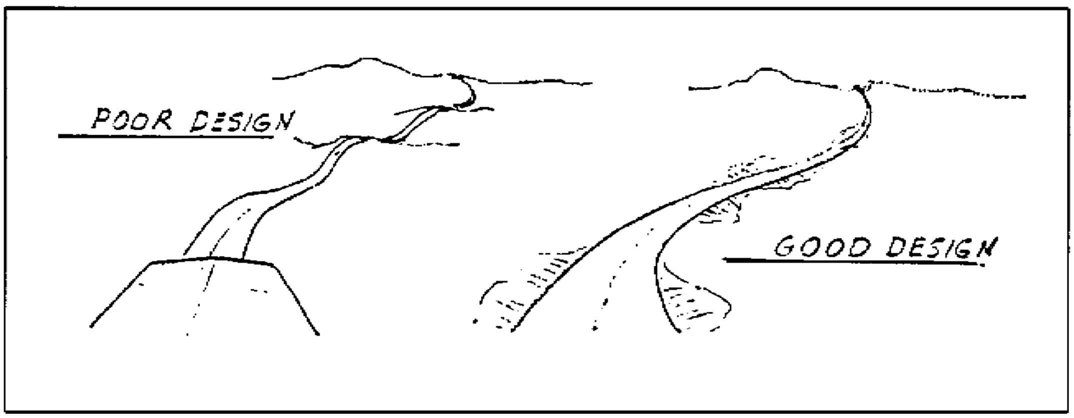
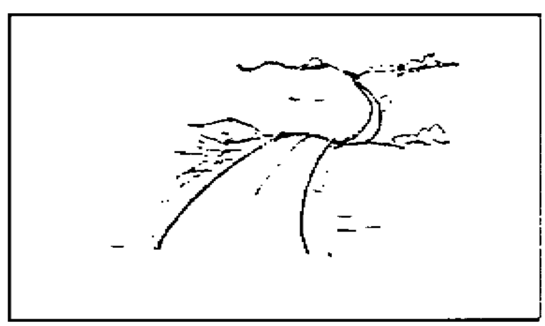


Figure 6-1 **Contrast of Poor Grade Line Design (Left) with Preferred Grade Line Design (Right)**

Hidden Dips

The "roller coaster" or "hidden dip," as shown in Figure 6-2, should be avoided. They are often proposed in the interest of economy, but they are aesthetically undesirable and extremely hazardous.

Figure 6-2 Example of a Hidden Dip



Broken Back Grade Lines

Avoid "broken back" grade lines (two crest or sag vertical curves separated by a short tangent as shown in Figure 6-3). One long vertical curve is more desirable. When two sag vertical curves form a broken back curve, the broken-back appearance is particularly noticeable and not pleasing to the eye. If a broken back curve is unavoidable, it is desirable to provide at least a 400' tangent between two vertical curves.

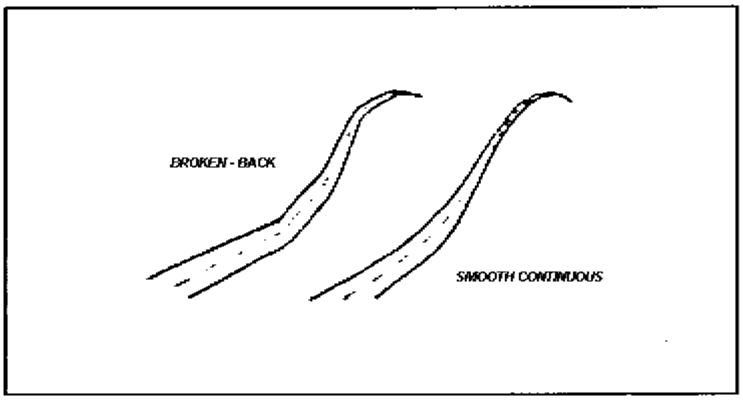


Figure 6-3 Broken Back (Left) Versus Smooth Continuous (Right) Grade Line

Intersecting Road

Where at-grade-intersections occur on roadway sections with moderate to steep grades, adjusting the profile of the minor intersecting roadway should be considered first, but adjustments to the mainline profile can be made to reduce gradient. A flat gradient is beneficial for all vehicles making turns and serves to reduce the potential hazards.

Intersecting roads (local government on and off system roads) may be designed to a 30 mph design speed. Some situations may require the design speed to be reduced. The Local Roads Plan is an agreement between the FHWA and SDDOT that establishes design standards for local government on and off system roads The Local Roads Plan is available via the internet at http://www.sddot.com/business/local/docs/localroadsplan.pdfor through the SDDOT Office of Local Government Assistance.

Coordination of Horizontal & Vertical Alignment

Proper relationships between vertical and horizontal curvature result in an aesthetic and easy-to-drive facility. On the other hand, there are some relationships or combinations which make driving more difficult and less safe.

The horizontal and vertical alignments should be in balance as shown in Figure 6-4. A generous flowing alignment in one plane is not compatible with small and frequent breaks in the other.

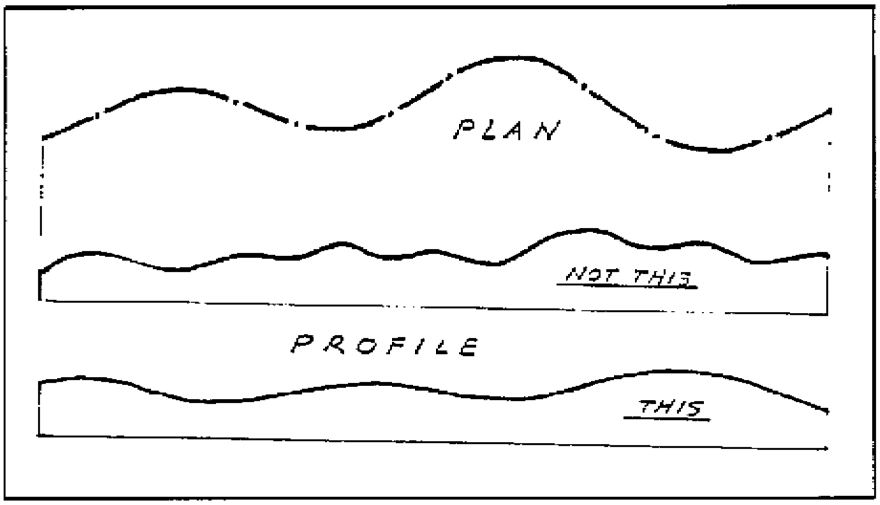


Figure 6-4 Balanced Vertical and Horizontal Alignments

A road in which the crest disappears into the sky as shown in Figure 6-5 can be disconcerting to the driver. It would be more appealing to have the view above the crest backed by a backdrop of landscape.

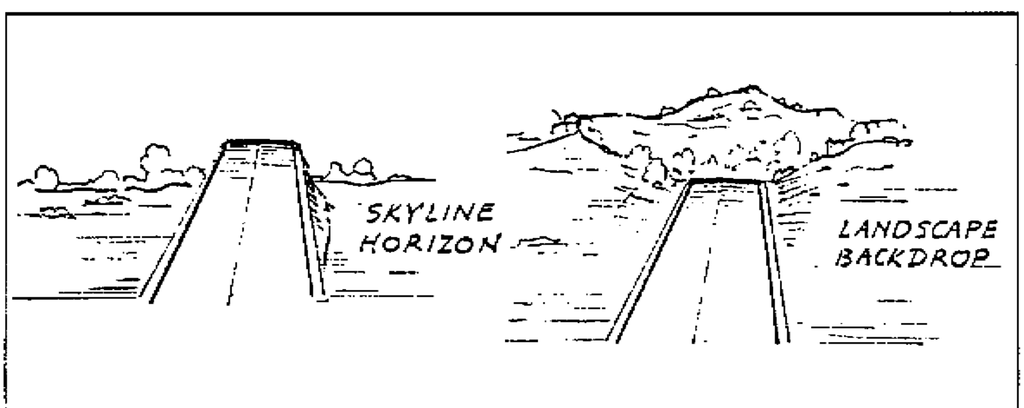
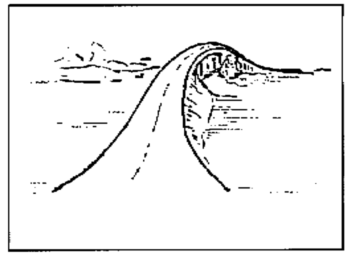


Figure 6-5 Landscape Backdrop is also a Safety Feature

A profile on a pronounced crest along a horizontal curve as shown in Figure 6-6, particularly in flat terrain, produces a disturbingly awkward appearance in a foreshortened view. Use of longer and flatter approach gradients, coupled with special grading and planting on inside of the curve may reduce the undesirable effect.

Figure 6-6 **Example of Undesirable Effect of a Profile on a Pronounced Crest**



Avoid simultaneous vertical and horizontal curvatures shown in Figure 6-7. When unavoidable, make sure that the curve lengths (both vertical and horizontal) are well above the minimum permitted by standards. When horizontal and vertical curves are in the same location, the horizontal and vertical curve geometrics (i.e. vertical and horizontal PI Sta's and curve lengths) should be similar.

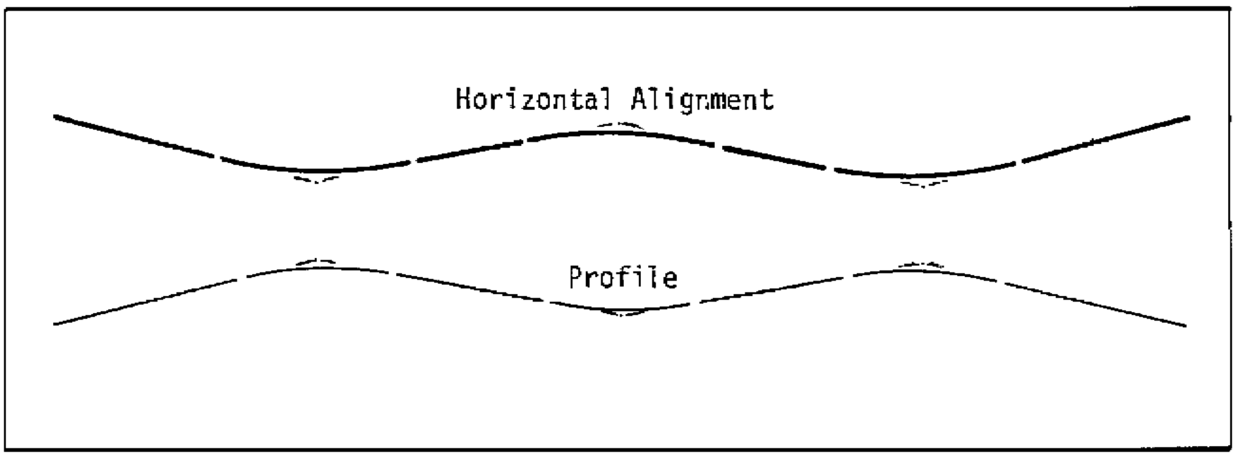


Figure 6-7 **Simultaneous Vertical and Horizontal Curvature**

Balancing Earthwork

Usually, projects should be designed to produce balanced earthwork. Excavated material from within the limits of the regular typical section should be the amount needed to construct embankments to the designed grade.

This can be approximated by placing a template of the typical roadway section on the cross sections at several points and adjusting the height of the template until cut and fill appear to be balanced. The elevations marked on the working profile will help establish a proper grade for balance.

Subsequent slight modifications of profile grade are often necessary to attain frequent balance points of one half mile or less (desired) and one mile (maximum).

Adjusting the profile grade up or down is one way to balance the earthwork so that excavation within the project limits will be adequate to construct the designed embankments. In some instances, particularly in rolling or mountainous terrain, this is practical as long as the previously mentioned criteria for gradeline elevations are not compromised.

Where feasible, deeper cuts, wider or deeper ditch bottoms, and/or flattening or daylighting the backslopes in cut areas can be considered to reduce or eliminate the amount of borrow or waste material on a project. Note that it may be more economical to borrow material than to attempt to balance a project. Borrow material should be limited to no more than one mile haul from the borrow area.

MAXIMUM GRADES

The criteria for maximum grades are derived from studies examining the operating characteristics of typical heavy trucks.

TABLE 6-1 **Maximum Grades on Construction/Reconstruction Projects for Interstate and State Highways (Rural Arterials)**

Type Of Terrain	Design Speed (mph)								
	40	45	50	55	60	65	70	75	80
	Maximum Grade (%)[a]								
Level	5	5	4	4	3	3	3	3	3
Rolling	6	6	5	5	4	4	4	4	4
Mountainous	8	7	7	6	6	5	5	5	5

[a] Maximum grades may be 1% steeper for the following: urban conditions, 2 lane rural (less than or equal to 500 ft tangent), and divided highways

TABLE 6-2 **Maximum Grades on Construction/Reconstruction Projects for Urban Arterials**

Type Of Terrain	Design Speed (mph)						
	30	35	40	45	50	55	60
	Maximum Grade (%)[a]						
Level	8	7	7	6	6	5	5
Rolling	9	8	8	7	7	6	6
Mountainous	11	10	10	9	9	8	8

[a] Maximum grades for urban conditions may be 1% steeper for the following: short lengths (less than or equal to 500 ft tangent) and for one-way downgrades

Table 6-3 and 6-4 shows the maximum grades permitted for Resurfacing, Restoration, and Rehabilitation (3R) projects.

TABLE 6-3 **Maximum Grades for 3R Projects on the National Highway System other than the Interstate**

Type Of Terrain	Design Speed (mph)[a]										
	30	35	40	45	50	55	60	65	70	75	80
	Maximum Grade (%)[b]										
Level	8	7	5	5	4	4	3	3	3	3	3
Rolling	9	8	6	6	5	5	4	4	4	4	4
Mountainous	11	10	8	7	7	6	6	5	5	5	5

[a] The design speed equals the current posted speed.
[b] Maximum grades may be 1% steeper for the following: urban conditions, 2 lane rural (less than or equal to 500 ft tangent), and divided highways

TABLE 6-4 **Maximum Grades for 3R Projects other than the National Highway System**

Type Of Terrain	Design Speed (mph)[a]								
	30	35	40	45	50	55	60	65	70
	Maximum Grade (%)[b]								
Level	7	7	7	7	6	6	5	4	4
Rolling	9	9	8	8	7	7	6	5	5
Mountainous	10	10	10	10	9	9	8	6	6

[a] The design speed equals the current posted speed.
[b] Maximum grades may be 1% steeper for the following: urban conditions, 2 lane rural (less than or equal to 500 ft tangent), and divided highways.

MINIMUM GRADES

The use of minimum grades can help facilitate adequate drainage. The lateral crown slope originally constructed may be reduced over time because of irregular swell, consolidation, surface rutting, maintenance operations or resurfacing; therefore, a minimal longitudinal grade may be desirable. The following criteria and guidance for minimum grades should be used:

- **Curbed Roadways:** 0.5 percent; however, grades may be reduced to 0.3 percent in special cases to match existing elevations to entrances, buildings, etc. and/or meet ADA requirements on pedestrian access routes.
- **Uncurbed Paved Roadways:**
  0.3 percent; however, flat grades may be acceptable if sufficient pavement cross slope is provided to drain the surface laterally. In flat topography, a highway with a consistent grade line following the ground line, utilizing special ditch grades to convey runoff is superior to a “rolling” profile comprised of nominally more desirable grade values. If practical, establishing a slight grade is desirable to move surface water longitudinally in cases when pavement surface imperfections exist (e.g. rutting).
- **Uncurbed Unpaved Roadways:** 0.5 percent. This may be reduced to 0.3 percent in special cases.

MINIMUM DITCH GRADES

Special attention should be directed to minimum ditch grades in areas of expansive soils. These areas will be identified in the soils design letter. Water ponding has a very detrimental effect on the subgrade. To ensure continuing flow, ditch grades should have a minimum gradient of at least 0.3 percent -- preferably 0.5 percent or steeper. This may require some special warping of ditch grades when the roadway profile cannot be adjusted accordingly.

VERTICAL CURVES

Vertical curves are used to effect gradual changes between tangent grades at their point of intersection. They have the properties of a simple parabolic curve -- the vertical offsets from the tangent grade vary with the square of the horizontal distance from the curve end (point of tangency).

Vertical curves that are offset below the tangent are crest vertical curves. Those that are offset above the tangent are sag vertical curves. Example vertical curves are shown in Figures 6-8 and 6-9.

The minimum lengths of crest vertical curves are determined mainly by sight distance requirements. These lengths generally are satisfactory from the standpoint of safety, comfort, and convenience. Decision Areas, such as approaches to ramp exit gores, may require longer vertical curves to achieve adequate sight distance. Generally, vertical curves in rural areas should be at least 800 feet long to avoid the appearance of an angular break in the alignment, even though sight distance criteria may permit a shorter curve.

Passing sight distance can seldom be attained by lengthening a crest vertical curve. The use of excessively long vertical curves often reduces the length of passing opportunities on the adjacent tangent sections on either side of the crest. A vertical curve should not exceed 2000 feet.

Vertical Curve Design

The principal concern in the design of vertical curves is to ensure that at least the minimum stopping sight distance is provided. The values set forth in the design standards for sight distance apply to vertical curves.

For stopping sight distance, the height of eye and the object are 3.5 ft and 2.0 ft respectively. The line of sight should not be obstructed by the crest of the curve (Figure 6-10). Nighttime driving conditions govern sag vertical curves. The designated sight distance should be illuminated by the headlight beam with an assumed upward divergence of 1 degree (Figure 6-10).

For passing sight distance, the controls are different. The height of eye remains at 3.5 ft, but the height of object (oncoming car) is 3.5 ft as seen in Figure 6-10.

By analyzing the requirements relating to sight distances (Tables 6-5, 6-6, and 6-7) and the characteristics of the curve, determinations can be made as to the minimum permissible length of curve for particular situations.

Grade changes without vertical curves are not recommended for rural grade design or bridges and any other locations that require detailed grades (i.e. spline curves).

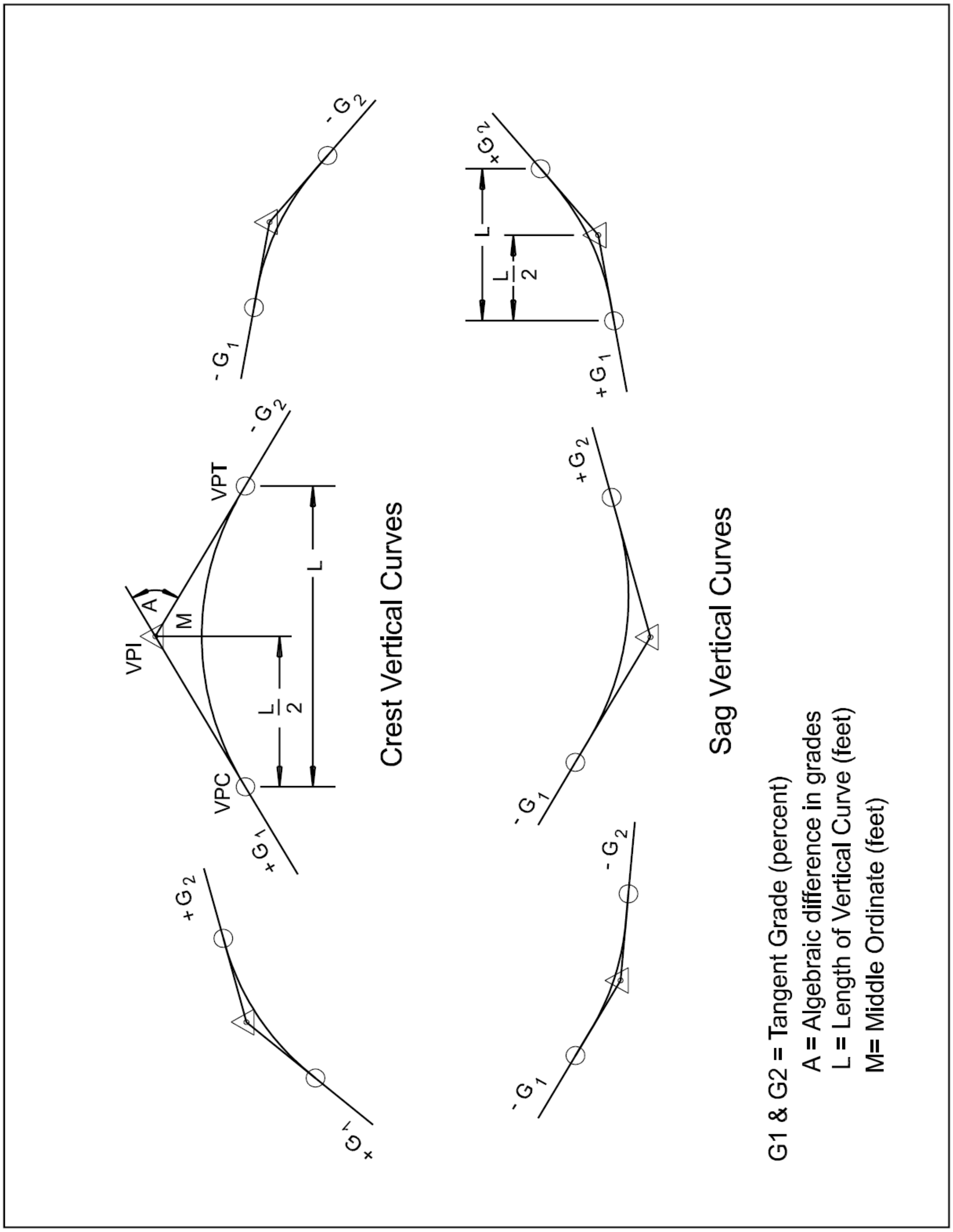


Figure 6-8 **Types of Vertical Curves**

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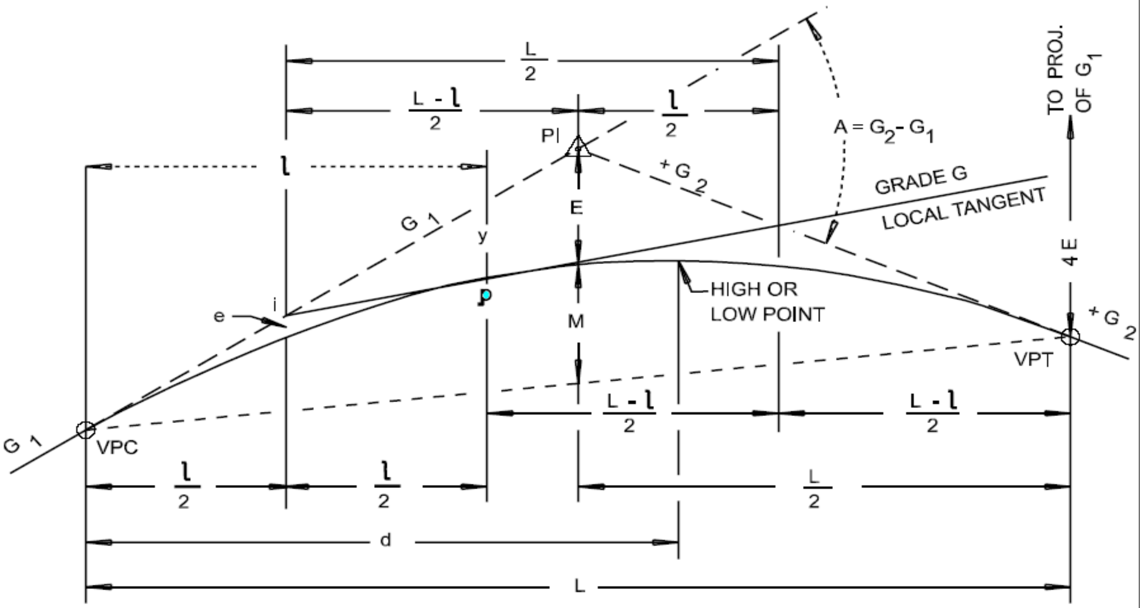

$$A = G_2 - G_1$$

$$E = \frac{AL}{800}$$

$$E = M$$

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

$$y = \frac{l^2}{\left(\frac{L}{2}\right)^2} E = \frac{A\, l^2}{200L}$$

$$g = G_1 - \frac{Al}{L} \quad G_1 - \frac{l}{K}$$

$$d = \frac{G_1 L}{A} = G_1 K$$

NOTE:

DISTANCES L, l, d, E, y, ETC. ARE IN FEET.

GRADES G_1, G_2, A AND G ARE IN PERCENT.

Figure 6-9 **General Properties of Vertical Curves**

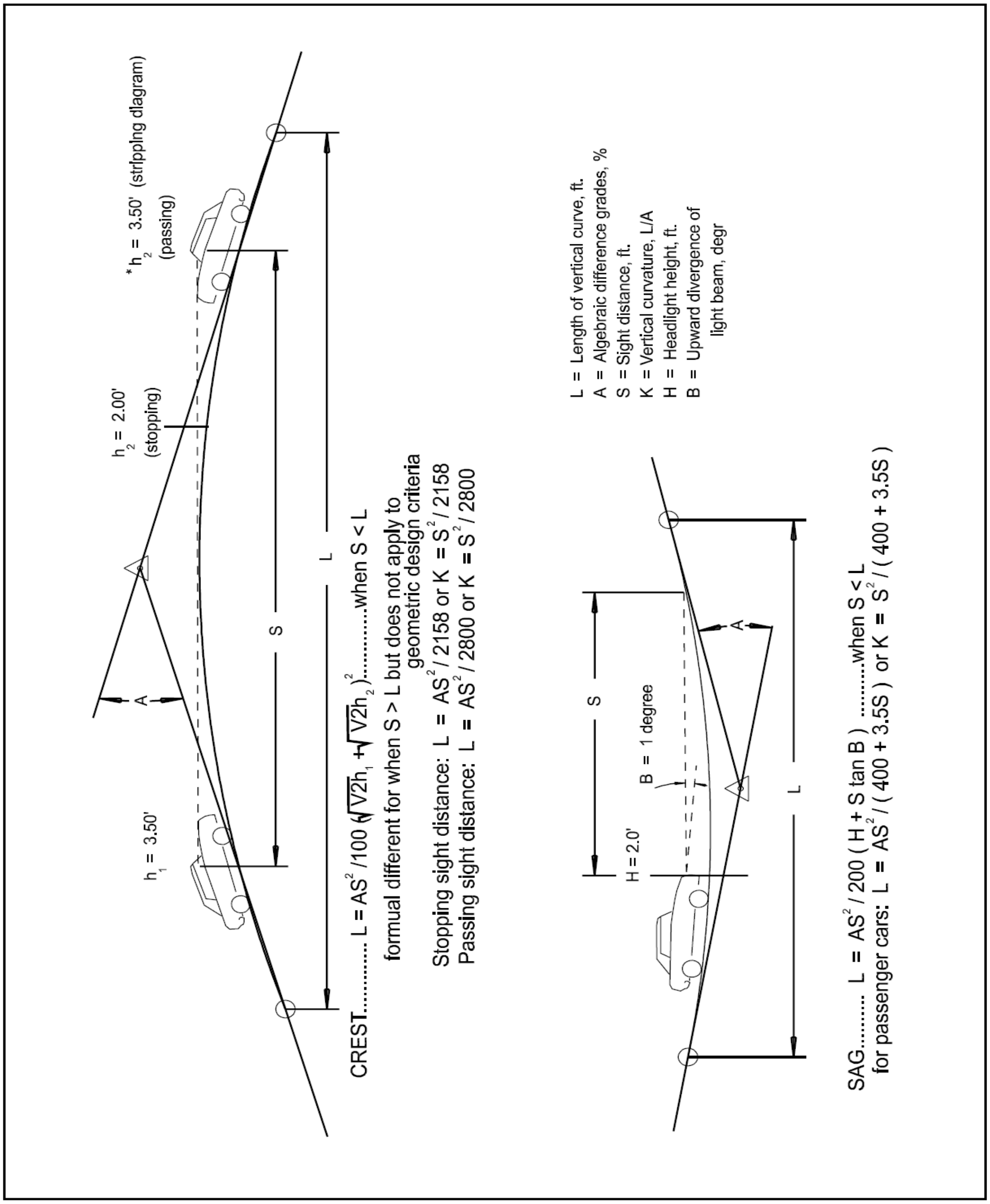

Figure 6-10 **Relationship between Vertical Curve Properties and Sight Distance**

The rate of change of grade along a vertical curve is constant and is measured by dividing the algebraic difference between the grades (A) by the length of the curve in feet (L). This value (A/L) gives the percent change in grade per horizontal foot of curve.

The reciprocal of this value (L/A) represents the horizontal distance required to effect a 1-percent change in the gradient along the curve. The expression L/A is termed K, and is useful for determining minimum lengths of vertical curves. Based on the geometrics of each sight distance condition and assumption, formulas are used to compute values of K for each design speed.

★ The minimum length of a vertical curve is computed by the following formula.

$$L = KA \qquad K = L/A$$

Where: L = minimum length of vertical curve in feet
A = algebraic difference in grades in percent (G_2-G_1)
K = a constant value for the design speed

Established values of K are shown in Table 6-5 and 6-6 for a minimum stopping sight distance. Similar K values are shown in Table 6-7 as minimum criteria for passing sight distance. The minimum permissible vertical curve length is found by multiplying the algebraic difference in grade by the selected K factor. Vertical curves that are longer than the minimum should be used. The length is typically rounded off to an even multiple of 100 feet.

Effect of Grade on Stopping

In some situations, the designer should consider providing stopping sight distances greater than the design values in Table 6-5 and 6-6. For example, when horizontal sight restrictions occur on downgrades, particularly at the ends of long downgrades where truck speeds closely approach or exceed those of passenger cars, greater stopping sight distances should be provided. The greater eye height of the truck driver is of little value, even when the horizontal sight obstruction is a cut slope. Additional information including design criteria can be found under the section on Stopping Sight Distance from Chapter 3 of the current AASHTO publication *A Policy on Geometric Design of Highways and Streets*.

Table 6-5 **Stopping Sight Distance for Crest Vertical Curves**

Design Speed (mph)	Minimum Stopping Sight Distance (ft)	K Value for Crest Vertical Curve
30	200	19
35	250	29
40	305	44
45	360	61
50	425	84
55	495	114
60	570	151
65	645	193
70	730	247
75	820	312
80	910	384

Table 6-6 **Stopping Sight Distance for Sag Vertical Curves**

Design Speed (mph)	Minimum Stopping Sight Distance (ft)	K Value for Sag Vertical Curve
30	200	37
35	250	49
40	305	64
45	360	79
50	425	96
55	495	115
60	570	136
65	645	157
70	730	181
75	820	206
80	910	231

Table 6-7 **Passing Sight Distance**

Design Speed (mph)	Minimum Passing Sight Distance (ft)	K Value for Crest Vertical Curve
30	500	89
35	550	108
40	600	129
45	700	175
50	800	229
55	900	289
60	1000	357
65	1100	432
70	1200	514
75	1300	604
80	1400	700

NOTE: Length of minimum vertical curve in feet required to meet criteria is computed by multiplying the algebraic difference in grades by the value of the coefficient "K." Longer curves are desirable. Normally the length should be rounded to an even multiple of 100 feet.

Striping Diagram (Title Sheet)

Vertical curves designed in accordance with the criteria in the preceding section will, in all cases, provide adequate stopping sight distance. It is not often practicable to provide passing sight distance. On some projects with relatively high traffic volumes, the lack of sufficient passing opportunities can cause problems with traffic operations and the level of service. A key factor in analyzing these potential conditions is the percentage of restricted passing within the limits of the highway section.

A practical approach for this determination is to measure the length of all "non-passing" locations (sight distance less than 1200 feet) and subtract this length from the total length of the highway section. The remainder is available for passing and is the basis for computing the percent of passing sight distance.

Measurements of non-passing lengths can be made directly from the profile using a straightedge and the prescribed criteria of 3.5 feet for the height of eye and 3.5 feet for height of object. This criteria is different than checking for design passing sight distance. These measurements should be coordinated with similar measurements of horizontal sight distance restrictions before computing the percent available passing sight distance as shown in Figure 6-11.

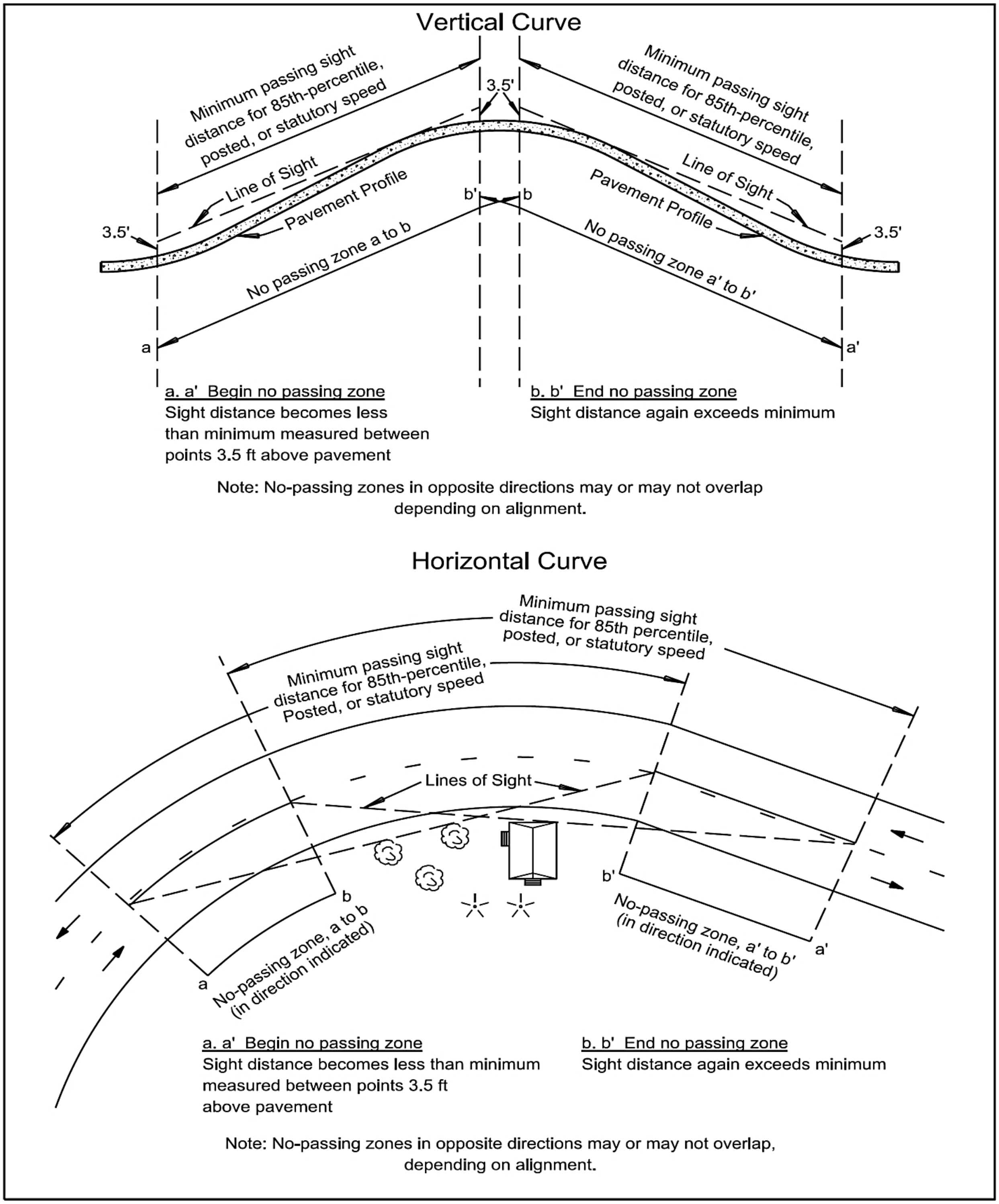

Figure 6-11 **Method of Locating and Determining the Limits of No-Passing Zones of Vertical and Horizontal Curves**

As a general guide, the percent of restricted passing lengths (less than 1200 feet sight distance) should not exceed the values shown below.

Table 6-8 **Percent Restricted Passing Lengths**

ADT	New Construction	Reconstruction
Under 250	70	80
250 - 500	60	70
500 - 1000	40	50
1000 - 1500	20	30
Over 1500	10	20

Similarly, passing sight distance on a horizontal curve is the distance measured along the center line (or right hand lane line of a three-lane highway) between two points 3.5' above the pavement on a line tangent to the embankment or other obstruction that cuts off the view on the inside of the curve as shown in Figure 6-11.

The beginning of a no-passing zone (point "a," Figure 6-11) is that point at which the sight distance first becomes less than 1200' with the height of eye at 3.5' and the height of object at 3.5'. The end of the zone (point "b") is that point at which the sight distance again becomes greater than the minimum specified. The zones identified during the design should be checked and adjusted by field measurements before actual markings are placed.

Vertical Curve Elevations

The computed tangent elevations represent profile grade elevations except at points within the limits of vertical curves. This data can be obtained by various computer programs.

URBAN DESIGN

The design of vertical alignment for urban projects frequently involves consideration of special problems such as existing street intersections and adjacent property development.

Where controlling factors are not severe, the normal practice of carrying the profile grade on the centerline or on the median edges of pavement will be satisfactory. When outside controls are significant, it may be necessary to supplement the main profile with other elevation controls, such as gutter-line profiles or top-of-curb profiles. When this is necessary, the supplemental controls should be clearly shown on the typical sections and the profile sheets.

Special attention must be given to existing features when designing urban grades, especially when a street is being widened near an existing driveway. Driveway grades should be kept even and moderate, either up or down. Angular breaks must be kept flat enough with adequate clearance so that the undercarriage or bumpers of vehicles will not "drag."

When roadside development is extensive and the general elevation is higher on one side than on the other, an unsymmetrical section may be required. The crown point (and profile grade) may be offset from the centerline so the total drop from the crown line to the gutter line will be more than normal on one side and less than normal on the other. This practice should be avoided if possible. If a low gradeline is needed for geometric purposes, a retaining wall may also be used to produce the required unsymmetrical section.

Grades

As noted under Table 6-2, grades less than 500 feet in length may be 1% steeper than indicated by design standards.

The use of spline curves is helpful to lay grades in urban areas where it is necessary to meet numerous required elevations in relatively short distances.

The centerline, pavement edges, and gutter lines can be shown as spline curves, with the beginning and end of the spline curve tied into the gradeline. Elevations along the spline curve should be shown at 25 foot intervals on the profile. Match curb returns to existing curb and gutter at locations shown in the cross section notes.

Surface Drainage

Gradelines should be established to make the top of curb coincide with the natural ground. This permits adjacent surface drainage to flow into the gutter for controlled outlet at specified locations.

If possible, avoid setting the grade so high that water becomes impounded at the back of the curb. If this situation cannot be avoided, provide an area drain to intercept the water.

Gutters should be placed on a grade of 0.5 percent for drainage, however may be reduced to 0.3 percent in special cases as outlined under the Minimum Grades section.

Long vertical curves tend to create drainage "flat spots." For this reason, vertical curves on urban street sections are usually considerably shorter than comparable locations on rural roads. For urban grading design in which the design speed is less than 45 mph, it is generally acceptable to design a sag or crest vertical point of intersection without a vertical curve only if the change in grade is 1.0 percent or less.

When using vertical curves for urban grade design, the K-value should be a maximum of 167 to ensure there is drainage in curb and gutter sections (See the South Dakota Drainage Manual). Vertical curves used in curb and gutter sections shall be reviewed to avoid level sections of gutter or low spots in the gutter that do not have outlets. Vertical curves may be shortened to avoid level sections of gutter and low spots.

Existing Roadside Development

Occasionally, a situation will arise where extensive development exists on both sides of the street and the ground or development on one side is higher than on the other. In this situation, a grade line may fit the development on one side but result in extensive property damage to the development on the other side. An unsymmetrical section may be used. The total drop from the centerline to gutter will be greater than normal on one side and less than normal on the other side or the entire surface may be drained to the low side.

The grade line shall be placed so that the curb and gutter on the project will meet the curb and gutter existing on intersecting cross streets.

GRADELINE ELEVATIONS

In the process of designing vertical alignment, several factors about gradeline elevations should be kept in mind.

Railroad Grade Crossings

The finished grade line (top of the surface) must match the elevation of the top of the rail at railroad grade crossings. See Figure 6-12 for gradeline guide. When designing the profile grade, these factors need to be considered:

- Pavement structure thickness (top of subgrade to top of surface)
- Skew of the crossing
- Gradient of rails (Shoulders of roadway will have to be splined in to match railroad grade)
- The crossing surface should be at the same plane as the top of the rails for a distance of 2 feet outside the rails.

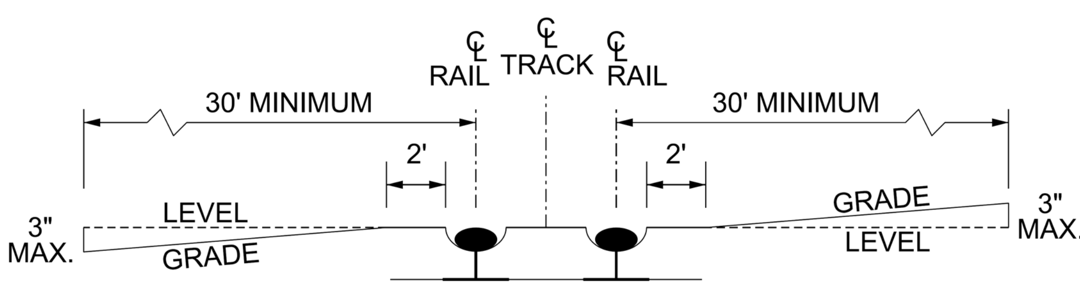

Figure 6-12 **Railroad Highway Grade Crossing**

Drainage Structures

A minimum of 1 foot of cover must be provided over pipe culverts, measured from the low point of the subgrade shoulder to the top of the pipe. The minimum vertical clearance required from design high water to the top of subgrade is 1 foot for pipe culverts.

For drainage areas above 1000 acres, the Office of Bridge Design will attempt to meet the following two goals:

- freeboard of 3' from the high water of the 25 year event to the top of subgrade
- no overtopping as a result of the 100 year event

If these goals are not being met, a recommendation will be made from the Office of Bridge Design to increase the structure opening or raise the gradeline to try to meet these goals.

During preliminary design, if precise drainage structure controls have not yet been established, practical allowances for feasible drainage structures should be considered in grade design.

Grade design in the vicinity of bridges should be coordinated with bridge design to ensure adequate high water clearance.

Soils Conditions

Areas of poor or wet soil conditions and recommended fill heights will be indicated in the soils letter. These controls should influence design of the grade line.

Snow Drift Areas

Snow drift issues on the highway surface can be minimized by constructing the roadway higher than the adjacent terrain. The finished grade should be a minimum of 2 feet above the natural ground on the windward side of the highway. Prevailing winds are from the northwest. The designer should ask field personnel to identify potential snow drift problem areas during the preliminary design inspection.

Vertical Clearances

When establishing the vertical gradeline, pay close attention to overhead structures. The following are vertical clearance guidelines for bridge structures, utility lines and airways.

Bridge Structures: The minimum vertical clearance as allowed by FHWA is 16' for bridge structures over traveled roadways and 23' - 3 ½" for vertical clearance over operating railroads.[1]

When setting the preliminary gradeline for grade separation bridge structures, the rule of thumb is to establish an elevation difference of 24' between the top of finished surface to the top of finished surface. The 24' allows 17' of vertical clearance and 7' for the bridge superstructure depth (i.e. girders, deck thickness, cross slope, etc.).

When setting the preliminary gradeline for structures over railroads, an elevation difference of 30' - 3 ½" between the top of finished surface and the top of rail may be used as a preliminary baseline. The 30' - 3 ½" allows for 23' - 3 ½" of vertical clearance above the top of the rail and an additional 7' for the bridge superstructure depth. The designer will contact the Highway Rail Safety Engineer to confirm whether additional vertical clearance is needed over the railroad.[2]

If additional vertical or horizontal clearance over the rail tracks is requested by the railway company, the Highway Rail Safety Engineer will decide whether FHWA approval for the additional requested clearance is needed.[3] The Highway Rail Safety Engineer will notify the designer whether or not additional minimum vertical and horizontal clearance over the operating railroad is needed, and if so, will indicate the required minimums. The grading designer will work with the Office of Bridge Design to adjust the gradeline to meet horizontal and vertical minimums.

Note: To establish the preliminary gradeline where there are overhead structures, preliminary superstructure depths should be obtained from the Office of Bridge Design during the establishment of the preliminary gradeline. The above

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[1] The Code of Federal Regulations requires a minimum vertical clearance of 7.1 meters above the top of rails. (23 CFR 646.212(a)(3) app. B (2017))

[2] The Code of Federal Regulations also requires that the minimum vertical clearance for structures complies with AASHTO LRFD Bridge Design Specifications. (23 CFR 625.4(b) (2017)) In section 2.3.3.4 of the AASHTO LRFD Bridge Design Specifications the following vertical clearance requirements are provided. Vertical clearance requirements over operating railroads will meet design standards as recommended by AASHTO and AREMA. Structures must be designed to pass over a railroad in accordance with the standards established by the railroad in its normal practice, and structures shall comply with applicable federal, state, county, and municipal laws.

[3] The CFR indicates that additional costs incurred for additional requested clearance that will solely benefit the railroad, will be at the cost of the railroad or subject to justification to and approval by FHWA and the operating highway agency. Therefore, if additional vertical clearance beyond 23' – 3 ½" is requested by the railroad or if the railroad indicates that the minimum clearance under normal operating procedures exceeds 23' 3 ½", then the Rail Safety Engineer will initiate the approval process through FWHA to determine, whether the railroad is responsible for the additional costs and how much additional costs will be incurred. (FHWA Memorandum Guidelines for the Design and Construction of Grade Separation Highway Structures over or under Railroads (April 16, 2013))

assumptions in regard to clearance for superstructures can be made if preliminary superstructure depths are not yet available from the Office of Bridge Design.

For Construction/Reconstruction projects the following guidelines shall be used when a new structure is placed. The specified vertical clearances are the distance from top of pavement to the bottom of girder, and are to be maintained over the entire finished roadway width.

- 17' clearance over all roadways (interstate and non-interstate) – allows for future full depth (up to 1') overlay or resurfacing

- 16'-4" minimum clearance for non-interstate if costs or geometrics become unreasonable – allows for future 4" AC overlay or resurfacing

Note: If the existing structure is retained on the overhead road, the vertical clearance can be reduced to 14'-4" on **low volume** urban and rural routes. The 14'-4" would allow for future 4" AC overlay or resurfacing. The Designer shall confirm with the Office of Bridge Design that this reduction is acceptable.

For Surfacing/Resurfacing projects guidelines for the interstate system are as follows:

- <u>Existing structure and new surfacing</u> - If the surfacing is being removed then 16'-4" is the minimum clearance required. Plans should be developed requiring a minimum of 16'-6" clearance. If the existing clearance is 16'-4" (for example) and lowering the grade to achieve a 17' clearance can be done without affecting drainage or causing other problems then the plans would require the contractor to achieve a 17' clearance.

- <u>Existing structure and existing surfacing to remain</u> - If there is an existing asphalt concrete overlay and the clearances are at the 16' minimum clearance allowed by FHWA and the project includes placement of a layer of asphalt concrete such that the thickness of the layer would increase the total thickness of the roadway surface and reduce the clearance, the existing clearances will be maintained by milling the existing asphalt concrete enough to allow placement of the layer of asphalt concrete at the specified thickness.

- **Utility Lines:** Per SDCL 31-26-19, the minimum height of utility lines shall not be less than 18 feet from the ground, over or across any public highway. While establishing the vertical alignment for a reconstruction project and conflicts occur with this criterion, coordination should be made with the Utility Coordinator to determine cost estimates whether to adjust the vertical alignment or have the utility line relocated.

The National Electrical Safety Code requires greater clearance than the specified SDCL for specific utility lines. The designer will contact the Utility Coordinator to determine what clearance to use for each utility line.

- **Airways:** Highway construction in the vicinity of airports must be designed to provide adequate clearance between the highways and the navigable airspace. The designer will contact Aeronautics within the Office of the Secretary-Air, Rail and Transit, if the proposed project is within 4 miles of an airport and contains the following:

    - A proposed structure that will penetrate an imaginary 100:1 surface within 20,000 feet of a public use airport. This is measured from the closest point of an airport runway and the difference between the runway end elevation and top elevation of structure.

    - A structure that is more than 200 feet above the ground.

    - Any Right of Way issues concerning a public use airport.

    - Lighting or signals

    - It is anticipated that a crane will be used during construction.

CLIMBING LANE CRITERIA

The freedom and safety of operation on two-lane highways is governed by the extent and frequency of passing sections. Operation can also be impacted by heavily loaded vehicles. On two-lane highways with grades of sufficient length, heavily loaded vehicle traffic may operate at speeds that impede following vehicles.

In the past, provision of extra climbing lanes to improve safe operation has been rather limited because of extra construction cost. However, because of the increasing number of serious crashes occurring on grades, these lanes are more commonly included in original construction plans and additional lanes on existing highways built as safety improvement projects.

Three conditions, reflecting economic conditions, should be satisfied to justify climbing lanes. These include the following:

1. Upgrade traffic flow rate > 200 vehicles per hour (VPH).

   The upgrade traffic flow rate is the design hourly volume for traffic flow one way. Multiply the design hourly volume-two way (DHV) from the project scope or the Roadway Information System database maintained by the office of Transportation Inventory by 0.6 (50 to 70 percent range) to obtain the upgrade traffic flow rate.

2. Upgrade truck flow rate > 20 VPH.

   From traffic data received use trucks % (T DHV) and multiply by condition 1 above. Note: Recreational vehicle (RV) traffic is not included with the percentage of trucks, therefore if condition 2 does not exist with given truck %, this condition may be satisfied if a significant part of traffic is RV.

3. One of the following conditions exist:

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

      Determine speed reduction using Figure 3-28 (typical heavy truck) or Figure 3-29 (typical recreational vehicle) from Chapter 3 of the current AASHTO publication *A Policy on Geometric Design of Highways and Streets* and the designed percent upgrade and length of grade.

   b. Level-of-service (LOS) E or F exists on the grade.

      LOS based on average traveling speed for a two-lane highway.

   c. A reduction of two or more levels-of-service is experienced when moving from the approach segment to the grade.

Additionally, the occurrence of trucks stalling on hills during winter driving conditions (spinning out) may be considered if the 3 former factors are not all satisfied.

Determine using "Analysis of Trucks Determining Climbing Lanes" on the following pages.

Analysis of Trucks Determining Climbing Lanes

If all three of the above mentioned conditions exist an analysis shall be completed to determine the location of "Climbing Lanes." The figures noted are from Chapter 3 of the current AASHTO publication *A Policy on Geometric Design of Highways and Streets*.

Figures 3-24 and 3-25 can be used to determine truck speeds through a critical grade. The typical vehicle used for this analysis is 200 lb/hp. Figure 3-26 can be used to show effects of critical length grades on recreational vehicles.

The average running speed as related to design speed can be used to approximate the speed of vehicles entering the critical length of grade (i.e. beginning an uphill climb). This estimate is subject to adjustment as approach conditions may determine. Where vehicles approach on nearly level grades, the running speed can be used directly. For a downhill approach it should be increased somewhat, and for an uphill approach it should be decreased.

The critical length of grade in Figures 3-24, 3-25, and 3-26 are derived as the length of a tangent grade. Where a vertical curve is part of a critical length of grade, an approximate equivalent tangent grade length must be used. Where the condition involves vertical curves with tangents of both positive or negative grades and the algebraic difference in grades is not too great, the measurement of critical length of grade may be made between the vertical points of intersection (VPI). Where vertical curves with both a positive and negative tangents are involved, particularly where the algebraic difference in grades is appreciable, about one-quarter of the vertical curve length may be considered as part of the grade under consideration. The critical lengths described above are seen in Figure 6-12 of this chapter.

When warranted, begin the climbing lane when the truck speed is reduced 10 mph below the average running speed for all traffic. The end of the climbing lane should extend until trucks obtain a speed within 10 mph of the average running speed for all traffic or until sufficient sight distance is available. Note that climbing lanes should be a minimum of 0.5 miles long excluding tapers to be effective.

Climbing Lane Geometrics

For lane and shoulder widths refer to Chapter 7 – Cross Sections
Super elevation rate - same as adjacent roadway Tapers:

- Add Lane - 25:1 or at least 300'
- Drop Lane - 50:1 or at least 600'

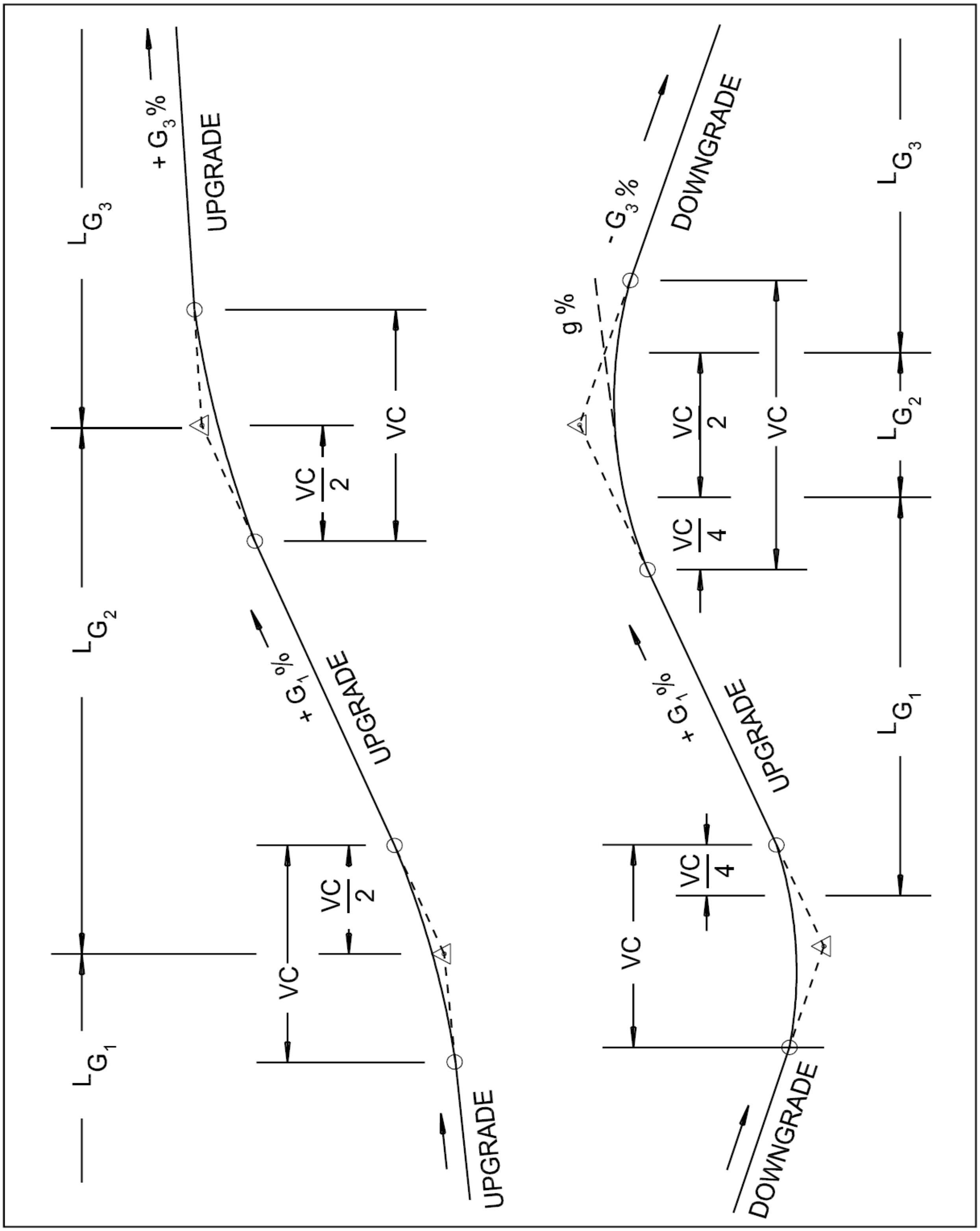

Figure 6-13 **Critical Length Computations**

TRUCK ESCAPE RAMP CRITERIA

Where long descending grades exist or where topographic and location controls require such grades on new alignment, the design and construction of an emergency escape ramp at an appropriate location is desirable for the purpose of slowing and stopping an out-of-control vehicle away from the main traffic stream. The principal factor used by the SDDOT in warranting a truck escape ramp is the history of runaway truck crashes. Other factors to be considered are site conditions of grade length, percent of grade, and a combination of horizontal alignment and end-of-grade conditions.

To design an escape ramp, a detailed analysis is needed. Length will vary depending on speed and grade. To calculate the stopping length, use the equations in Figure 6-14. These equations were taken from the section on Emergency Escape Ramps from Chapter 3 of the current AASHTO publication *A Policy on Geometric Design of Highways and Streets*. Various alternatives are also detailed in the National Cooperative Highway Research Program (NCHRP) Synthesis #178, and should also be used for design considerations.

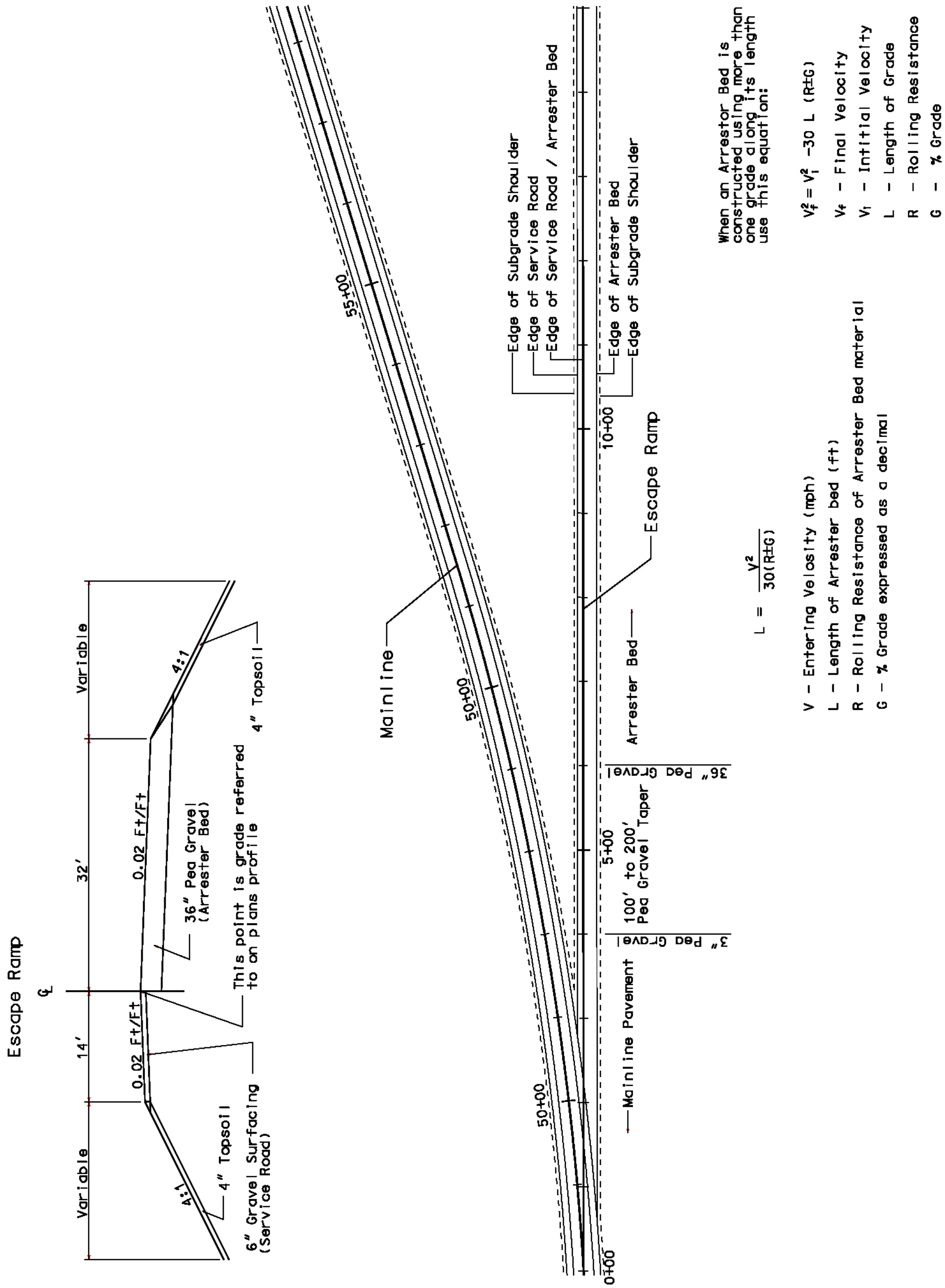

Figure 6-14 **Escape Ramp Layout**