

**CHAPTER FOUR**  
**VERTICAL ALIGNMENT**

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## Chapter Four

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## Chapter Four

# VERTICAL ALIGNMENT

### 4-1 SIGHT DISTANCE

Sight distance is the length of approaching highway which is visible to the driver. When the horizontal alignment is on tangent, the available sight distance is determined by the profile of the highway. On a horizontal curve and level grade, available sight distance is determined by the rate of curvature and the roadside clearance (see Chapter Five). Where a combination of horizontal and vertical curves is present, horizontal curvature, vertical curvature and roadside clearance will all determine the availability of sight distance along the highway.

#### 4-1.01 Stopping Sight Distance

1. **Definition.** Stopping sight distance (SSD) is the sum of the distance traveled during driver perception/reaction time (2.5 seconds) and the distance traveled while braking to a stop.
2. **Criteria.** SSD values are presented in Tables 4-1. The SSD values provided in the table are based on the longitudinal gradient at the site of application. These values represent the minimum distance which should be available to the driver; the designer should provide greater distances, if practical. Note that the grade-adjusted SSD values will only apply to crest vertical curves (see Section 4-2.03).

The designer should note that the application of the grade-adjusted SSD values on crest vertical curves assumes a worst-case condition. The need for additional braking distance would occur if the "object" is located at the point of vertical tangency (PVT) which would result in vehicular braking action on the downgrade portion of the crest vertical curve.

3. **Controlling design criteria.** SSD is a controlling design criteria (see Section 3-7). To determine if a design exception is necessary, the level roadway SSD criteria will apply.
4. **Measurement.** Stopping sight distance is measured from the driver's eye 3.5 ft above the pavement to a 2 ft height of object.

Design Speed (mph)	Downgrades (ft)			Level (ft)
	-9%	-6%	-3%	0%
20	125	120	115	115
25	175	165	160	155
30	225	215	205	200
35	290	270	260	250
40	355	335	315	305
45	430	400	380	360
50	510	475	450	425
55	595	555	520	495
60	690	640	600	570
65	785	730	685	645
70	890	825	770	730

- Notes:**
1. For design speeds of 50 mph or higher, no grade adjustment is necessary for downgrades 1% or flatter.
  2. For design speeds less than 50 mph, no grade adjustment is necessary for downgrades 2% or flatter.
  3. For downgrades intermediate between columns, use a straight-line interpolation to calculate SSD.
  4. Grade adjustments apply to crest vertical curves; they do not apply to sag vertical curves. See Section 4-2 for application of SSD to vertical curves. See Sections 5-2 and 5-3 for SSD application to horizontal curves.

### STOPPING SIGHT DISTANCE

Table 4-1

**4-1.02 Decision Sight Distance**

1. **General Application.** Drivers may be required to make decisions where information is difficult to perceive or where unexpected maneuvers are required. These are areas of concentrated demand where the roadway elements, traffic volumes and traffic control devices may all compete for the driver's attention. This may increase the required driver perception/reaction time. Examples of these locations include freeway exits, freeway lane drops and traffic signals on rural highways. The designer will use his/her judgment to determine which locations warrant decision sight distance.
2. **Criteria.** Table 4-2 provides values for decision sight distance. Note that the application depends upon the type of maneuver and on rural/urban location.
3. **Measurement.** The distance is measured from a 3.5-ft height of eye to a 2-ft height of object.

Design Speed (mph)	Decision Sight Distance for Avoidance Maneuver (ft)				
	A	B	C	D	E
30	220	490	450	535	620
35	275	590	525	625	720
40	330	690	600	715	825
45	395	800	675	800	930
50	465	910	750	890	1030
55	535	1030	865	980	1135
60	610	1150	990	1125	1280
65	695	1275	1050	1220	1365
70	780	1410	1105	1275	1445

**Application**

<i>Avoidance Maneuver A:</i>	<i>Stop on rural road.</i>
<i>Avoidance Maneuver B:</i>	<i>Stop on urban road.</i>
<i>Avoidance Maneuver C:</i>	<i>Speed/path/direction change on rural road.</i>
<i>Avoidance Maneuver D:</i>	<i>Speed/path/direction change on suburban road.</i>
<i>Avoidance Maneuver E:</i>	<i>Speed/path/direction change on urban road.</i>

**DECISION SIGHT DISTANCE****Table 4-2**

**4-1.03 Passing Sight Distance**

1. **General.** Passing sight distance is the distance needed by a passenger car to safely pass another passenger car. This consideration is limited to two-lane, two-way highways.
2. **Criteria.** Passing sight distance values are provided in Table 4-3.
3. **Application.** The designer, where practical, should provide passing sight distance over a high proportion of the highway length. This may involve adjustments to the horizontal and vertical alignment, or additional lanes may be necessary in restricted areas.
4. **Measurement.** Passing sight distance is measured from a 3.5-ft height of eye to a 3.5-ft height of object.
5. **No-Passing Zones.** The percent of "no-passing zones" is a significant adjustment to the level-of-service calculations (capacity) for a general two-lane highway segment. (See the *Highway Capacity Manual*). The designer should realize, however, that the criteria for determining pavement markings for no-passing zones is based on the MUTCD. Although related, these criteria differ from the passing sight distance criteria used in highway design.

<b>Design Speed (mph)</b>	<b>Minimum Passing Sight Distance (ft)</b>
20	710
25	900
30	1090
35	1280
40	1470
45	1625
50	1835
55	1985
60	2135
65	2285
70	2480

**PASSING SIGHT DISTANCE****Table 4-3**

## 4-2 VERTICAL ALIGNMENT

### 4-2.01 Terrain (Definitions)

1. **Level.** Highway sight distances are either long or could be made long without major construction expense.
2. **Rolling.** The natural slopes consistently rise above and fall below the roadway grade and, occasionally, steep slopes present some restriction to the desirable highway alignment.
3. **Mountainous.** Longitudinal and transverse changes in elevation are abrupt, and benching and side hill excavation are frequently required to provide the desirable highway alignment.

For highway design application, the majority of the projects in Maine will be classified as rolling terrain.

### 4-2.02 Grades

#### Maximum Grades

Chapters Seven and Eleven present the Department's criteria for maximum grades based on functional classification, urban/rural location, type of terrain, design speed and project scope of work. The maximum grades should be used only where absolutely necessary. Grades much flatter than maximum normally should be used.

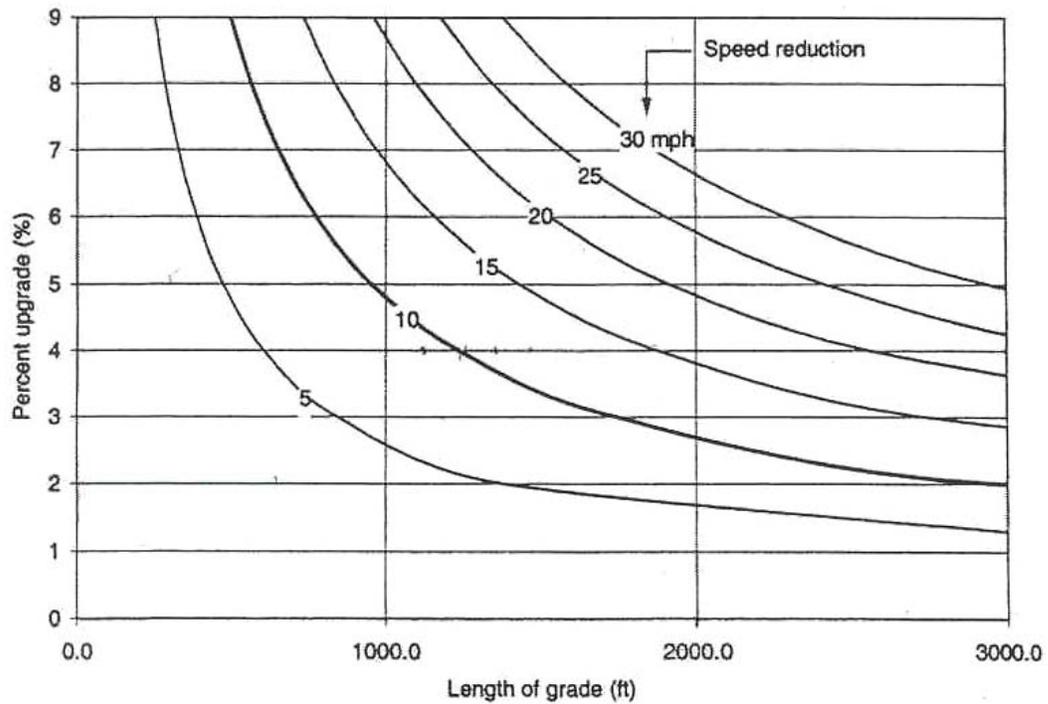
#### Minimum Grades

1. **Curbed Streets.** The centerline profile on highways and streets with curb should have a minimum gradient of 0.25 percent. Desirably, the minimum gradient will be 0.5 percent.
2. **Uncurbed Roads.** On highways without curb, level gradients are acceptable on pavements which are adequately crowned to drain laterally. However, it is desirable to provide approximately a 0.25 percent longitudinal grade. This allows for the possibility that the original crown slope will subsequently be altered as a result of swell, consolidation, maintenance operations or resurfacing.

### **Critical Length of Grade**

In addition to the maximum grade, it is necessary to consider the effect of length of grade upon vehicular operation. The gradient in combination with its length will determine the truck speed reduction on upgrades. The following will apply for the critical length of grade:

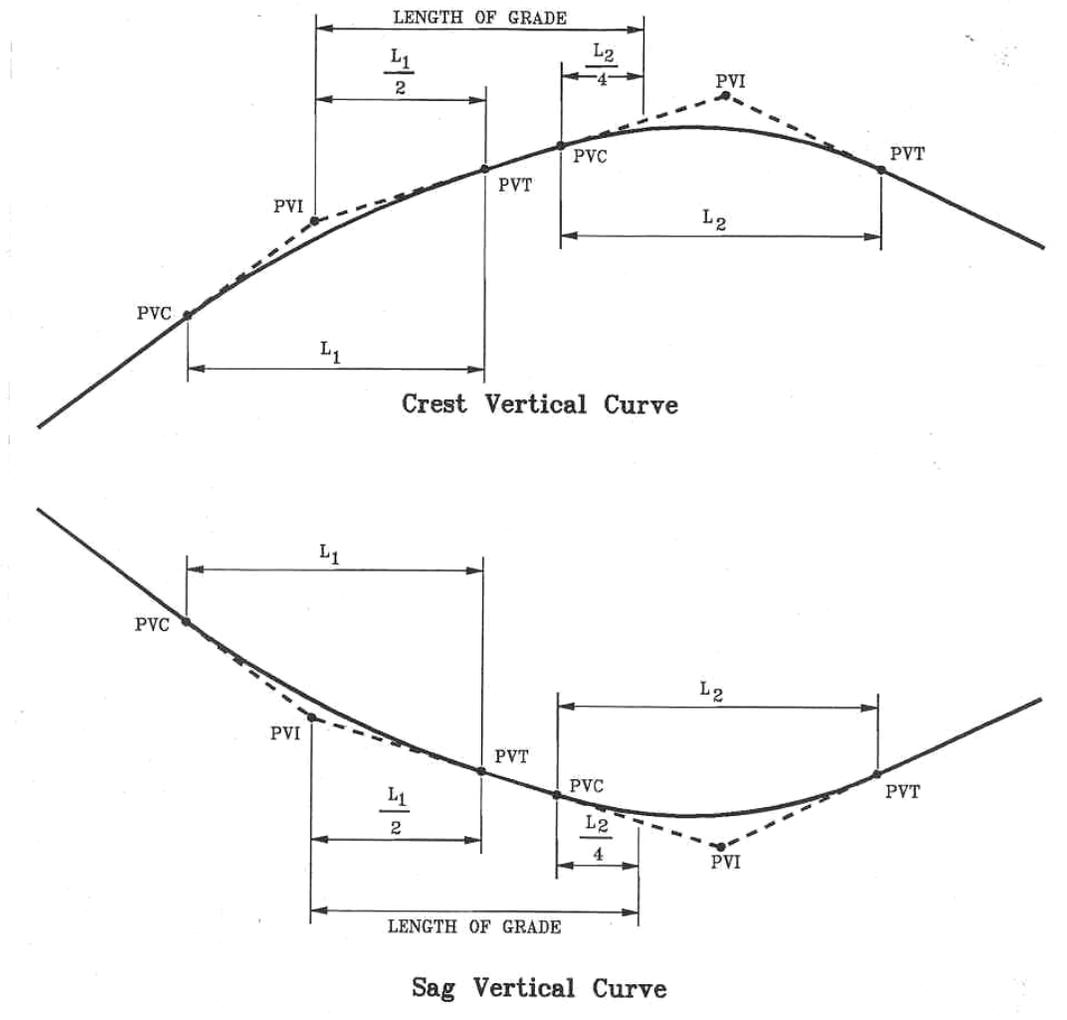
1. **Criteria.** Figure 4-1 provides the critical length of grade for a given percent grade and acceptable truck speed reduction. The figure applies to any design speed. For design purposes, the 10 mph speed reduction curve should be used.
2. **Momentum Grades.** Where an upgrade is preceded by a downgrade, trucks will often increase speed to make the climb. A speed increase of 5 mph on moderate downgrades (3-5%) and 10 mph on steeper downgrades (6-8%) of sufficient length are reasonable adjustments. These can be used in design to allow the use of a higher speed reduction curve in Figure 4-1.
3. **Measurement.** A vertical curve will be a part of the length of grade. Figure 4-2 illustrates how to measure the length of grade for the purpose of determining the critical length of grade from Figure 4-1.
4. **Application.** If the critical length of grade is exceeded, the designer should either flatten the grade, if practical, or should evaluate the need for a truck-climbing lane (see Section 4-2.04).
5. **Highway Types.** The critical length of grade criteria applies equally to two-lane or multilane highways. However, it has greater significance on two-lane highways because an overtaking car may not be able to pass a slow-moving truck. This consideration is reflected in the capacity analysis for truck-climbing lanes.
6. **Example Problems.** Examples 1, 2 and 3 illustrate the use of Figure 4-1 to determine the critical length of grade. In the examples, the use of subscripts 1, 2, etc., indicate the successive gradients and lengths of grade on a highway segment.



1. Typically the 10 mph curve will be used.
2. See examples 1, 2 and 3 for use of figure.

### CRITICAL LENGTH OF GRADE

Figure 4-1



*Notes:*

1. For vertical curves where the two grades are in the same direction, 50% of the curve length will be part of the length of grade.
2. For vertical curves where the two grades are in opposite directions, 25% of the curve length will be part of the length of grade.

**MEASUREMENT FOR CRITICAL LENGTH OF GRADE**

**Figure 4-2**

\*\*\*\*\*

**Example 1**

Given:  $G_1 = 0\%$   
 $G_2 = + 4\%$   
 $L_2 = 1500 \text{ ft (PVI to PVI)}$

Problem: Determine if the critical length of grade is exceeded.

Solution: Figure 4-1 yields a critical length of grade of 1200 ft for a 10mph speed reduction. The length of the grade ( $L_2$ ) exceeds this values, and the designer should flatten the grade, if practical, or evaluate the need for a climbing lane.

**Example 2**

Given:  $G_1 = 0\%$   
 $G_2 = + 5\%$   
 $L_2 = 330 \text{ ft (PVI to PVI)}$   
 $G_3 = + 2\%$   
 $L_3 = 660 \text{ ft (PVI to PVI)}$

Problem: Determine if the critical length of grade is exceeded for the combination of grades  $G_2$  and  $G_3$ .

Solution: Using Figure 4-1,  $G_2$  yields a truck speed reduction of approximately 4 mph.  $G_3$  yields approximately 3.5 mph. The total of 7.5 mph is less than the allowable 10 mph. Therefore, the critical length of grade is not exceeded.

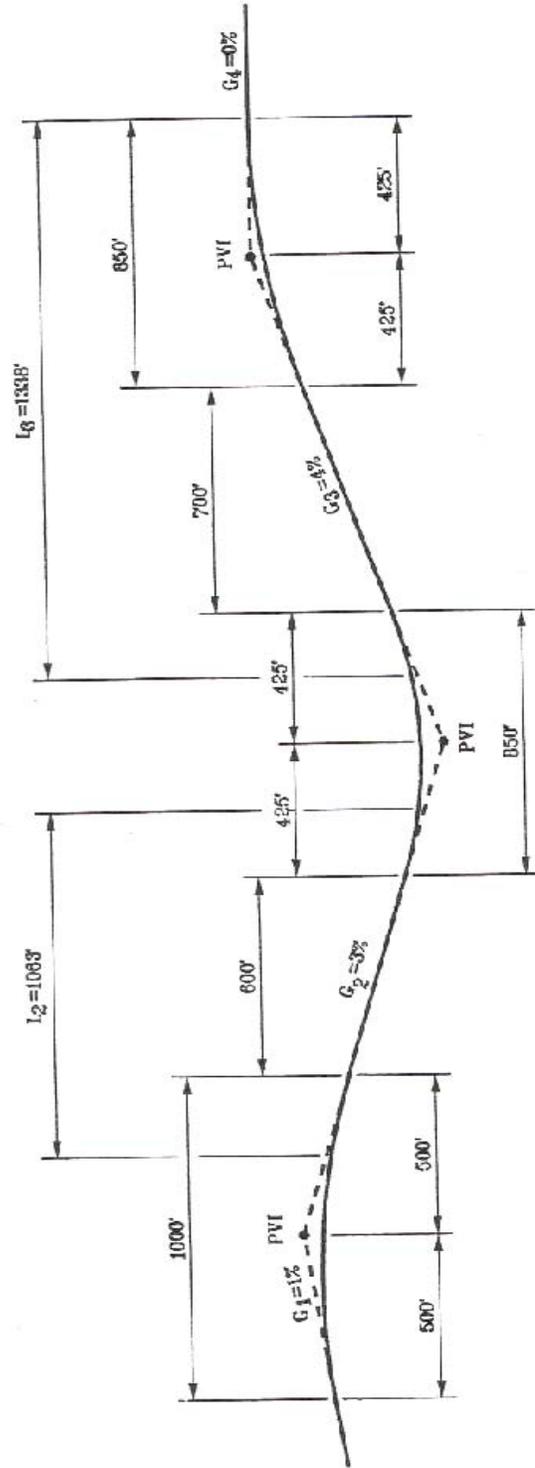
**Example 3**

Given: Figure 4-3 illustrates the vertical alignment on a two-lane rural highway.

Problem: Determine if the critical length of grade is exceeded for  $G_2$  or  $G_3$ .

Solution: Figure 4-2 presents the criteria for determining the length of

Two-lane, Two-way Highway



CRITICAL LENGTH OF GRADE CALCULATIONS (Example 3)

Figure 4-3

$$L_2 = \frac{1000}{4} + 600 + \frac{850}{4} = 1063 \text{ ft}$$

$$L_3 = \frac{850}{4} + 700 + \frac{850}{2} = 1338 \text{ ft}$$

Read into Figure 4-1 for  $G_2$  (3%) and find a critical length of grade of 1750 ft.  $L_2$  is less than this value and, therefore, the critical length of grade is not exceeded.

Read into Figure 4-1 for  $G_3$  (4%) and find a critical length of grade of 1200 ft.  $L_3$  exceeds this value. However, the designer can assume a 5 mph increase in truck speed for the 3% "momentum" grade ( $G_2$ ) which precedes  $G_3$ . Therefore, read into Figure 4-1 for  $G_3$  (4%) and a 15 mph speed reduction curve and find a critical length of grade of 1850 ft. Assuming the benefits of the momentum grade, then, leads to the conclusion that the critical length of grade is not exceeded.

\* \* \* \* \*

### 4-2.03 Vertical Curves

#### Definitions

1. **Vertical Curve.** Vertical curves have the shape of a parabola and are used to produce a gradual change between tangent grades.
2. **Point of Vertical Intersection (PVI).** The PVI is the point where the extension of two tangent grades intersect.
3. **Point of Vertical Curvature (PVC).** The PVC is the point at which the tangent grade ends and the vertical curve begins.
4. **Point of Vertical Tangency (PVT).** The PVT is the point at which the vertical curve ends and the tangent grade begins.
5. **Grade Slopes ( $G_1$  or  $G_2$ ).** The grade slope is the rate of slope between two adjacent PVI's expressed as a percent. The numerical value for percent is the vertical rise or fall in feet for each 100 feet of horizontal distance. Upgrades in the direction of stationing are identified as plus (+). Downgrades are identified as minus (-).

6. **Algebraic Difference (A)**. The value of A is the algebraic difference in percent between two tangent grades.
7. **Length of Vertical Curve (L)**. L is the horizontal distance in feet from the PVC to the PVT.

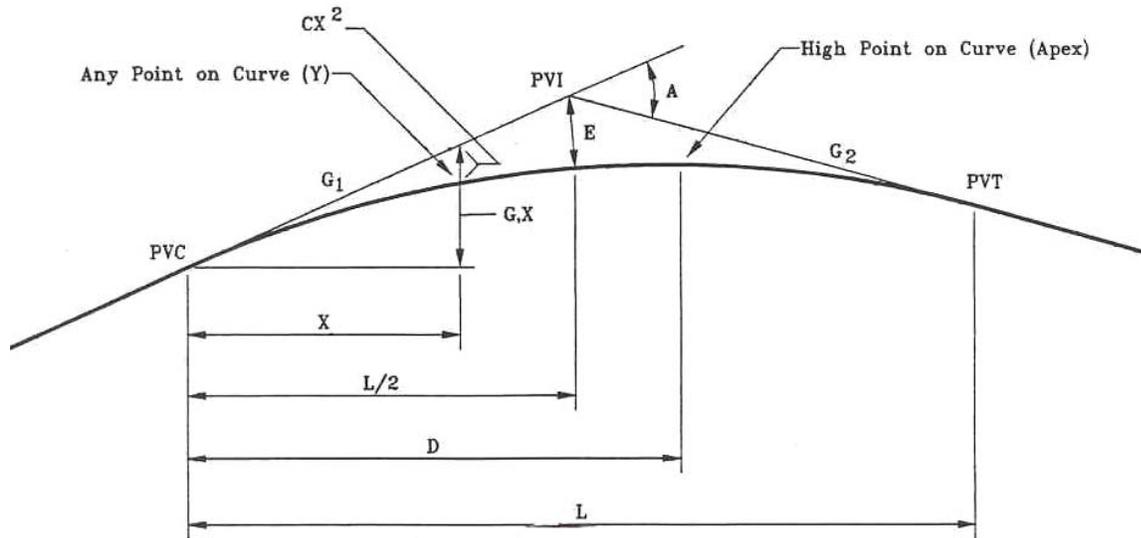
### **Mathematical Computation**

Figure 4-4 illustrates a typical vertical curve. The vertical offset from the tangent to any point on the curve varies as the square of the horizontal distance from the end of curve. Curves which are offset below the tangents are crest vertical curves, and those which are offset above tangents are sag vertical curves.

### **Crest Vertical Curves**

The following factors should be considered in the design of crest vertical curves:

1. **Stopping Sight Distance**. The principal control in the design of crest vertical curves is to ensure that, at a minimum, stopping sight distance (SSD) is available. Desirably, of course, the vertical curve will be designed to provide the largest, practical amount of sight distance. A 3.5 ft height of eye and a 2 ft height of object are used in the design of crest vertical curves. This yields the following procedure for determining the length of a crest vertical curve:
  - a. **Determine the SSD**. The SSD will be selected from Table 4-1. At a minimum, the level SSD criteria will be used. If practical, the grade-adjusted SSD should be used. If so, the designer must consider whether or not the roadway is two-way or one-way. Figure 4-5 illustrates the correct application of the grade correction to a crest vertical curve based on a two-way or one-way operation.
  - b. **Calculate Curve Length**. The following equations will determine the length of the crest vertical curve based on the selected SSD:

1. Legend

X = horizontal distance from PVC to any point on curve (feet)

Y = elevation above sea level of finished grade at any point on curve (feet)

L = horizontal length of curve from PVC to PVT (feet)

D = distance from PVC to high point on crests or low point of sags

$G_1, G_2$  = the percent grades of the two tangents (%). "Upgrades" in the direction of stationing are denoted "positive" (+); "Downgrades" in the direction of stationing are denoted as "negative" (-).

A =  $G_2 - G_1$  = algebraic difference in grades

E =  $AL / 800$  = external offset from the vertical curve to PVI at  $L / 2$  (feet)

2. Elevation Calculations (Known:  $El_{PVI}, G_1, G_2, L, Sta_{PVI}$ )

A. PVC information:

$$Sta_{PVC} = Sta_{PVI} - L / 200$$

$$El_{PVC} = El_{PVI} - G_1 L / 200$$

C. PVC to PVI:

$$Y = (G_1 X / 100) - CX^2 + El_{PVC}$$

$$C = A / 200(L)$$

B. PVT information:

$$Sta_{PVT} = Sta_{PVI} + L / 200$$

$$El_{PVT} = El_{PVI} + G_2 L / 200$$

D. PVI to PVT:

$$Y = [G_2 (L - X) / 100] - C(L - X)^2 + El_{PVT}$$

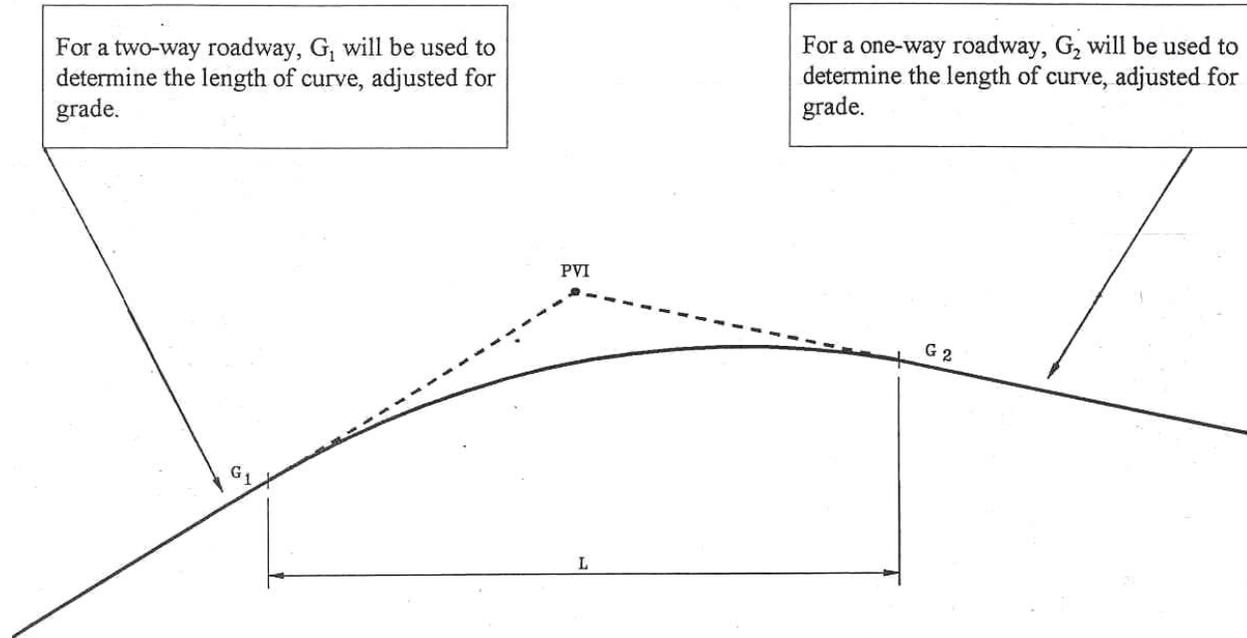
$$C = A / 200(L)$$

3. Distance (D) to High Point (Crests) or Low Point (Sags).

$$D = LG_1 / (G_1 - G_2) \quad \text{where: } D, L, G_1, G_2 \text{ are defined above.}$$

**TYPICAL VERTICAL CURVE****Figure 4 - 4**





- Notes:**
1.  $G_1$  is steeper than  $G_2$ .
  2. For one-way roadway, traffic is moving from left to right in figure.

**APPLICATION OF GRADE ADJUSTMENT  
(Crest Vertical Curves)**

**Figure 4-5**

$$L = \frac{AS^2}{2158} \quad (S < L)$$

$$L = 2S - \frac{2158}{A} \quad (S > L)$$

where: S = available stopping sight distance, feet  
 L = length of crest vertical curve, feet  
 A = algebraic difference in grades, percent

Figure 4-6 provides a graphical representation of the relationship between the algebraic difference (A), the selected design speed (V) and the length of curve (L).

- c. Application. The calculated length of vertical curve should be adjusted to fit field conditions (e.g., driveway controls).

\* \* \* \* \*

#### Example 4

Given: V = 60 mph  
 2-lane, 2-way highway  
 Reconstructed crest vertical curve  
 $G_1 = + 4\%$   
 $G_2 = - 3\%$

Problem: Determine the length of crest vertical curve assuming both the level SSD and grade-adjusted SSD.

Solution: From Table 4-1:  
 level SSD = 570 ft  
 grade-adjusted SSD (4%) = 613 ft

(*Note* Because this is a 2-way highway, the 4% grade will govern for determining the grade-adjusted SSD.)

Assuming  $S < L$ :  $A = G_2 - G_1 = -3 - 4 = -7$  or just 7

$$L = \frac{AS^2}{2158} = \frac{(7)(570)^2}{2158} = 1054 \text{ ft (level SSD)}$$

$$L = \frac{AS^2}{2158} = \frac{(7)(613)^2}{2158} = 1219 \text{ ft (grade - adjusted SSD)}$$

The value for level SSD ( $L = 1054$  ft) can be read (approximately) from Figure 4-6a Crest Vertical Curves.

\* \* \* \* \*

2. **Passing and Decision Sight Distance.** Tables 4-2 and 4-3 provide values for passing sight distance and decision sight distance. Occasionally, it may be warranted to provide these values on crest vertical curves (see Sections 4-1.02 and 4-1.03).
3. **Minimum Length.** The minimum length (in feet) of a new or reconstructed crest vertical curve, regardless of sight distance calculations, is  $L_{\min} = 3 V$ , where  $V$  equals the design speed (mph).
4. **Drainage Maximum.** Drainage should be considered in the design of vertical curves where curbed sections are used. Drainage problems should not be experienced if the crest vertical curve is sharp enough so that an absolute minimum longitudinal grade of 0.25 percent is reached at a point about 50 ft from either side of the apex. To ensure that this objective is achieved, the length of the vertical curve should be:

$$L \leq 200 A, \text{ where } L \text{ is in feet.}$$

For crest vertical curves on curbed sections where this length is exceeded, the drainage design should be more carefully evaluated near the apex.

### **Sag Vertical Curves**

The following factors determine the design of sag vertical curves.

1. **Headlight Sight Distance.** Headlight sight distance is the primary control in the design of sag vertical curves. At a minimum, curves should be designed to provide headlight sight distance equal to stopping sight distance. The height of headlights is assumed to be 2 feet and the height of object is 0 (pavement surface). These criteria yield the following procedure for determining the length of a sag vertical curve:

- a. **Determine the SSD.** The SSD will be selected from Table 4-1 (Stopping Sight Distance). The level SSD criteria will be used; the grade adjustment does not apply to sag vertical curves.
- b. **Calculate Curve Length.** The following equations will determine the length of the sag vertical curve based on the selected SSD:

$$(S > L) \quad L = 2S - \left[ \frac{400 + 3.5(S)}{A} \right]$$

$$(S < L) \quad L = \frac{A(S^2)}{400 + 3.5(S)}$$

where: S = available stopping sight distance, feet  
 L = length of sag vertical curve, feet  
 A = algebraic difference in grades, percent

Figure 4-8 provides a graphical representation of the relationship between the algebraic difference (A), the selected design speed (V), and the length of curve (L).

- c. **Application.** The calculated length of vertical curve should be adjusted to fit field conditions (e.g., driveway controls).

\* \* \* \* \*

### **Example 5**

Given: V = 65 mph  
 New sag vertical curve  
 $G_1 = -4\%$   
 $G_2 = +2\%$

Problem: Determine the length of sag vertical curve for the level SSD.

Solution: From Table 4-1: Level SSD = 645 ft

Assuming  $S < L$ :

$$L = \frac{AS^2}{400 + 3.5S} = \frac{(6)(645)^2}{400 + 3.5(645)} = 939 \text{ ft}$$

This value can be read (approximately) from Figure 4-6 b Sag Vertical Curves.

2. **Decision Sight Distance.** Table 4-2 provides values for decision sight distance. Where decision sight distance is warranted on sag vertical curves, these values should be used in the equations to determine the necessary length of curve at the site.
3. **Comfort Criteria.** On fully lighted sections of highway and where it is impractical to provide the headlight sight distance, it may be warranted to design a sag vertical curve to meet the comfort sag criteria. The length-of-curve equation for the comfort criteria is:

$$L = \frac{AV^2}{46.5}$$

**Where:** A = algebraic difference in tangent grades, percent  
V = design speed, mph

The length of vertical curve required to satisfy comfort criteria is about 50 percent of that required to satisfy the headlight sight distance requirement. Figure 4-8 provides the criteria for the length of sag vertical curves assuming the comfort criteria.

4. **Minimum Length.** The minimum length (in feet) of a new or reconstructed sag vertical curve, regardless of sight distance calculations, is  $L_{\min} = 3V$ , where V equals the design speed (mph).
5. **Drainage Maximum.** On curbed pavements, the drainage criteria for sag vertical curves is the same as that for crest conditions. The design should provide an absolute minimum grade of 0.25 percent within 50 ft of the sag point. To ensure that this objective is achieved, the length of vertical curve should be:

$$L \leq 200A, \text{ where } L \text{ is in feet.}$$

If the length of the sag exceeds this length on a curbed street, the designer should place special emphasis on the drainage design in the sag. Details for the drainage design of sag vertical curves are provided in Chapter Twelve.

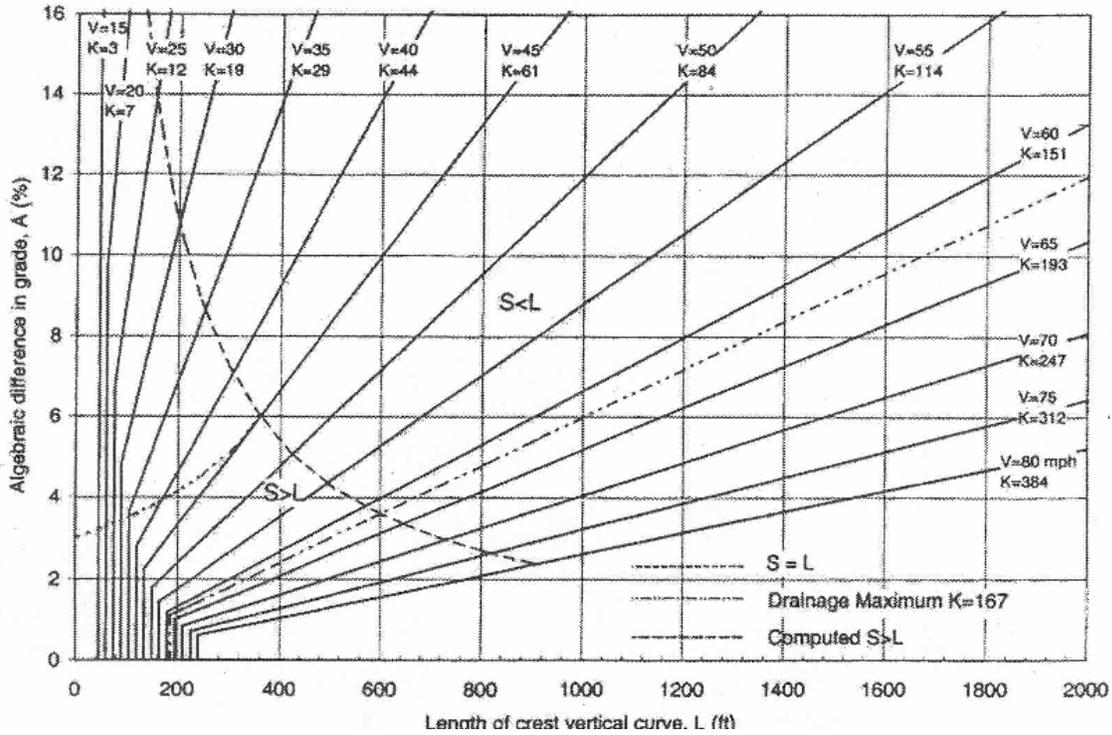


Figure 4-6a Crest Vertical Curves

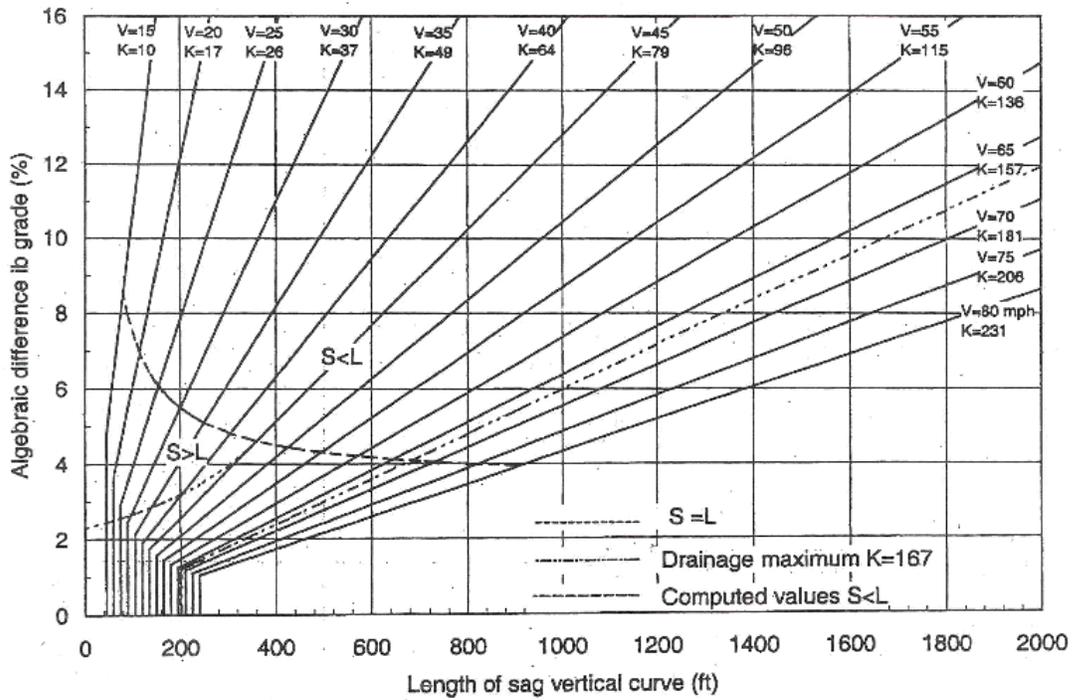
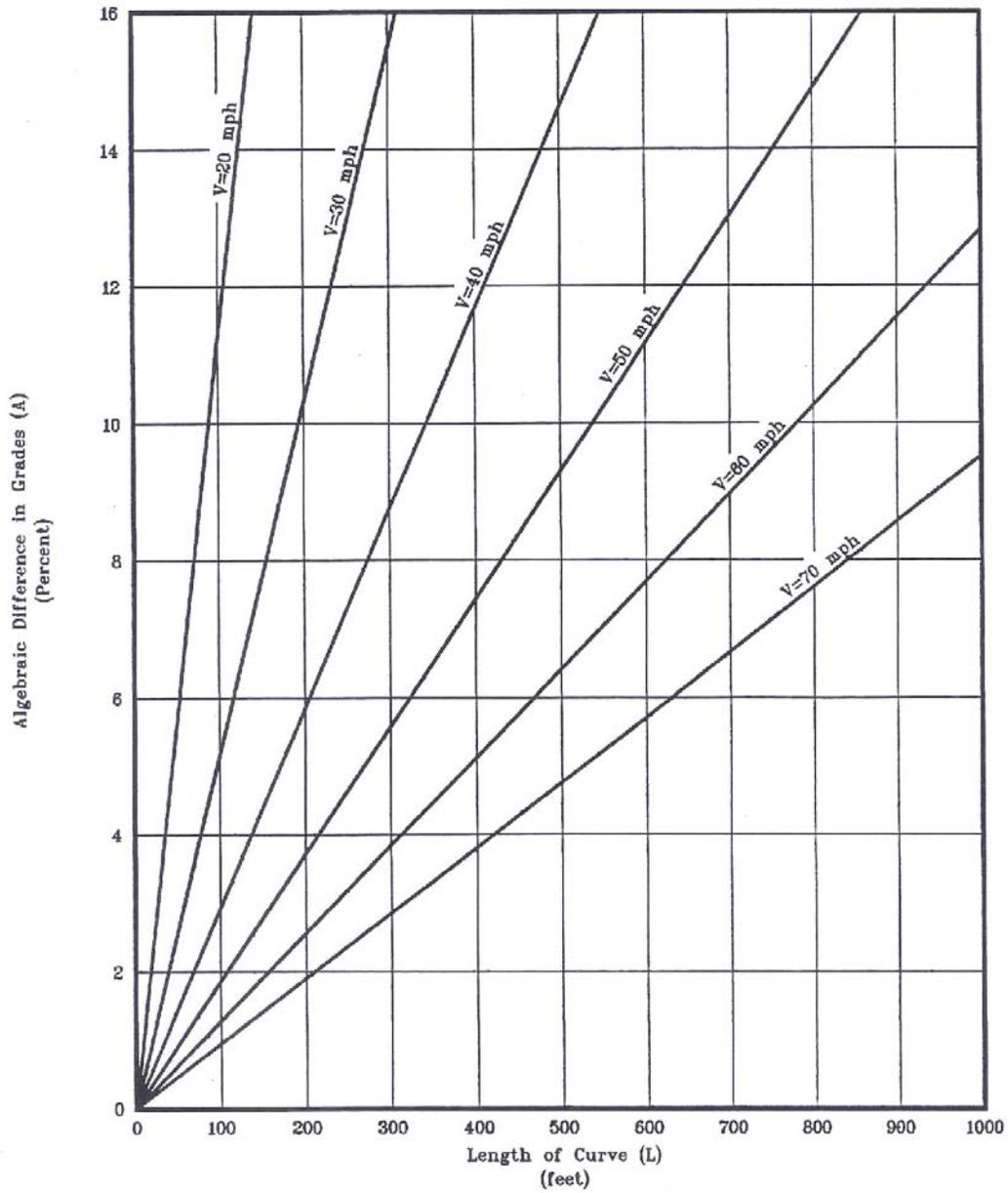


Figure 4-6b Sag Vertical Curves

LENGTH OF VERTICAL CURVES

Figure 4-6



**LENGTH OF VERTICAL CURVES  
(Comfort Criteria)**

Figure 4-7

#### 4-2.04 Truck Climbing Lanes

Climbing lanes can overcome losses in capacity and thereby provide improved operations on grades with both slow trucks and high traffic volumes. The following steps should be used to determine the warrants for a truck climbing lane.

- Step 1: Determine the critical length of grade from Figure 4-1 for a given percent grade and acceptable truck speed reduction. If this value is exceeded, a capacity analysis should be conducted.
- Step 2: The operational objective is that the level of service (LOS) on the grade should be no worse than one level below that of the remainder of the highway segment. For example, if the approaching highway is operating at LOS B, the grade should operate at LOS C or better. If the capacity analysis determines that the grade will operate below this LOS objective for the DHV without a climbing lane, the designer should consider including a climbing lane if the construction costs and impacts (e.g., environmental, right-of-way) are reasonable. The *Highway Capacity Manual* and *AASHTO A Policy on Geometric Design of Highways and Streets* present the detailed methodologies to conduct a capacity analysis on a grade. Table 4-5 summarizes the design criteria for a truck climbing lane.

#### Example 6

- Given: Figure 4-8 illustrates the highway grade under construction. A capacity analysis has determined that a climbing lane is warranted.
- Problem: Develop the details for the truck-climbing lane for the minimum conditions.
- Solution: The design for the climbing lane is illustrated in Figure 4-8. These steps should be followed:

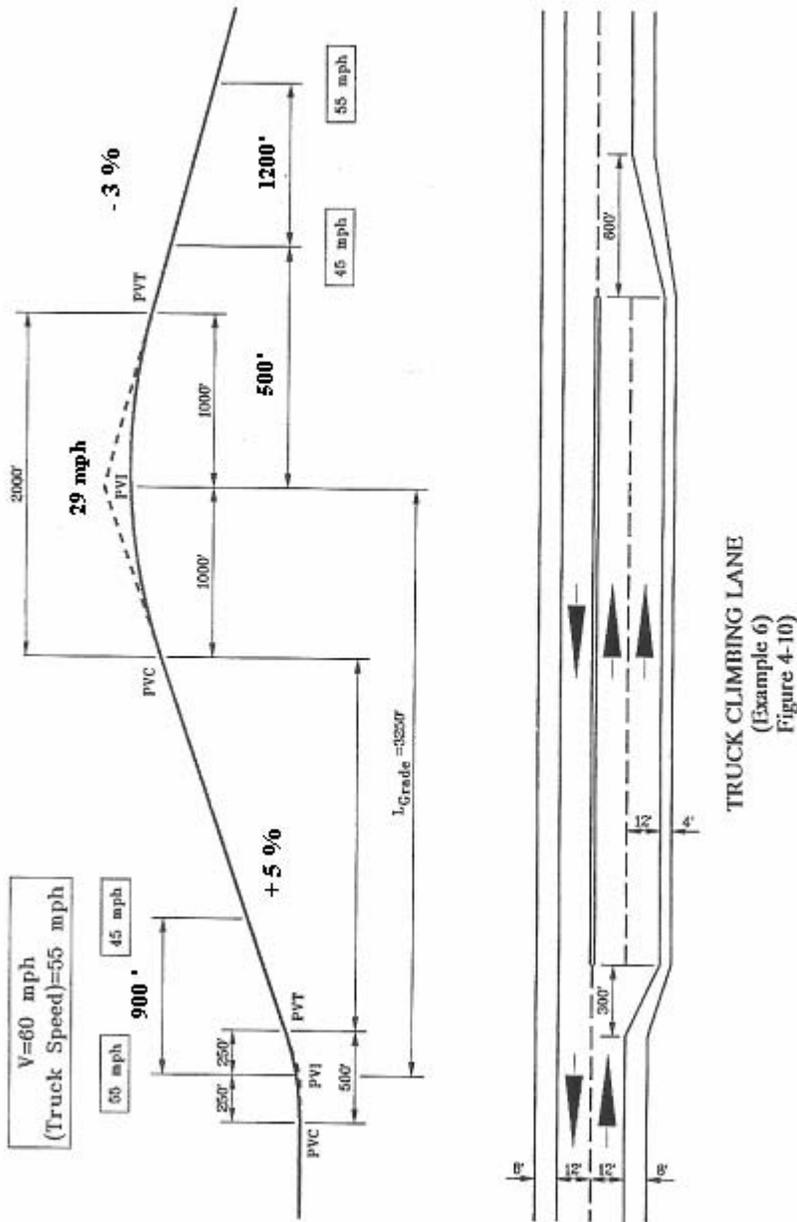
Design Element	Desirable	Minimum
Design Speed	(1)	(1)
Lane Width	Same as approach roadway	Same as approach roadway
Shoulder Width	4 ft	2 ft
Cross Slope on Tangent	Same as adjacent travel lane	Same as adjacent travel lane
Superelevation	(2)	(2)
Beginning of Full-Width Lane	Near the PVT of the grade	To where truck speed is 10 mph below highway design speed (3)
End of Full-Width Lane	To where truck has reached highway design speed	To where truck speed is 10 mph below highway design speed (3), (4)
Minimum Full-Width Length	--	1000 ft
Entering Taper	25:1	150 ft
Exiting Taper	50:1	200 ft

- Notes:**
1. For design speeds equal to or greater than 55 mph use 55 mph for truck design speed. For less than 55 mph, use the design speed.
  2. For horizontal curves to the right, the truck climbing lane will be superelevated the same as the adjacent travel lane. For horizontal curves to the left, the designer will determine the proper Superelevation of the truck climbing lane by reading into Table 5-6 ( $e_{\max} = 6\%$ ) for  $V=30$  mph. The maximum difference in cross slope between the travel lane and truck climbing lane is 4 percent.
  3. Use Figure 4-9 to determine truck deceleration and acceleration rates.
  4. The designer should also consider the available sight distance to the point where the truck will merge back into the through travel lane. At a minimum, this will be stopping sight distance. Desirably, however, the driver will have decision sight distance available to the merging point.

### DESIGN CRITERIA FOR TRUCK CLIMBING LANES

Table 4-5

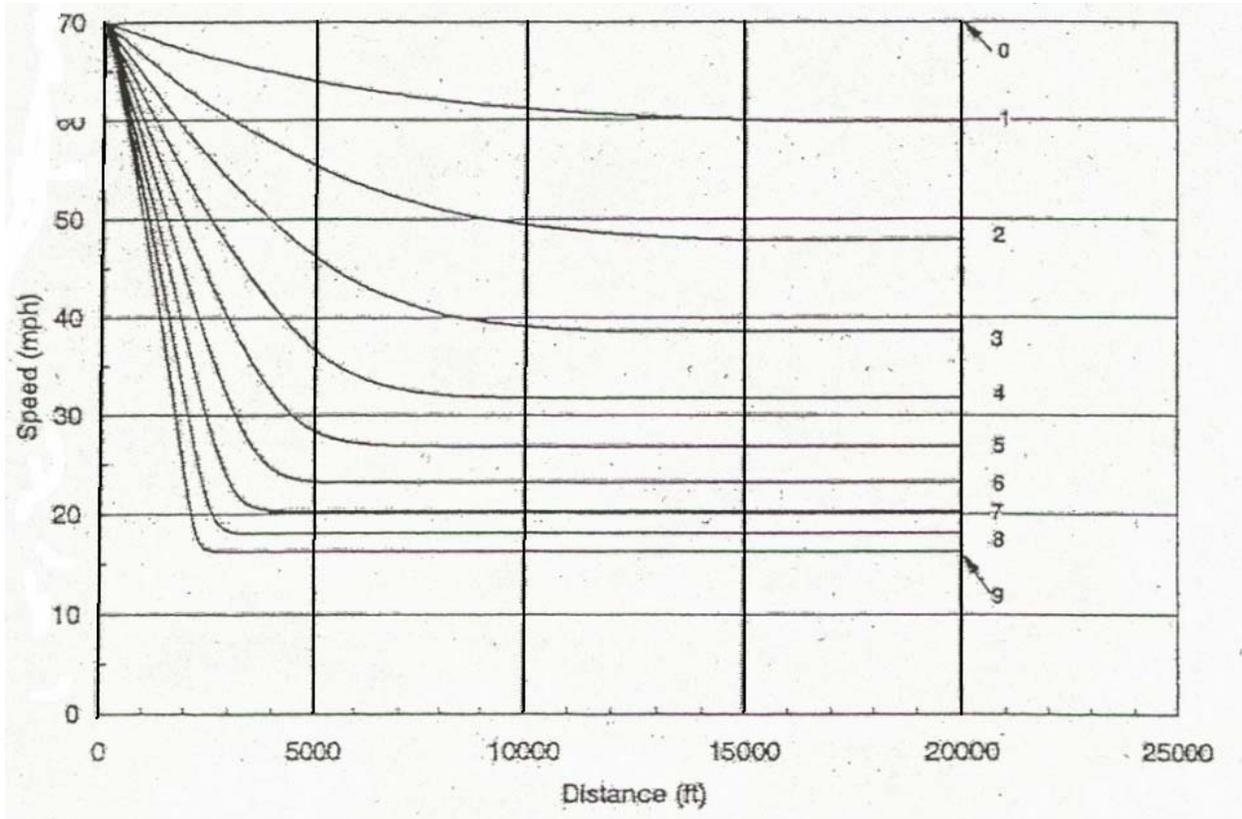
1. **Length of Grade.** To establish a reference point, grades will be assumed to run from PVI to PVI to analyze a truck-climbing lane. Therefore, the length of the +5% grade is 3250 ft.
2. **Truck Speed.** For all highway design speeds above 55 mph, the truck speed for analysis will be 55 mph. For design speeds of 55 mph or less, the truck speed will equal the design speed.
3. **Truck Deceleration.** At a minimum, the full width of the climbing lane will begin where the truck speed has been reduced by 10 mph or, in this example, to 45 mph. Using Figure 4-1 or Figure 4-9 (Note; This figure is based on a start speed of 70 mph), this will occur approximately 900ft from the PVI. The truck speed at the end of the grade (3250 ft) is determined from Figure 4-9. Therefore, the truck speed will be approximately 29 mph when it reaches the PVI.
4. **Truck Acceleration.** At a minimum, the full width of the climbing lane will extend to a point where the truck has accelerated to 45 mph (10 mph below the 55 mph truck design speed). The designer reads into Figure 4-10 at the 29 mph point on the vertical axis over to the dashed line for -3%. This is at approximately 200 feet along the horizontal axis. The -3% line is followed up to 45 mph, which is approximately 700 feet along the horizontal axis. Therefore, the truck will require approximately 500 feet from the PVI to reach 45 mph. The truck will require approximately an additional 1200 ft to reach 55 mph.
5. **Design Details.** Figure 4-8 illustrates the design details for the minimum criteria for the climbing lane.



**Note:** For design speeds above 55 mph, use an initial speed of 55 mph. For design speeds 55 mph and below, use the design speed as the initial speed.

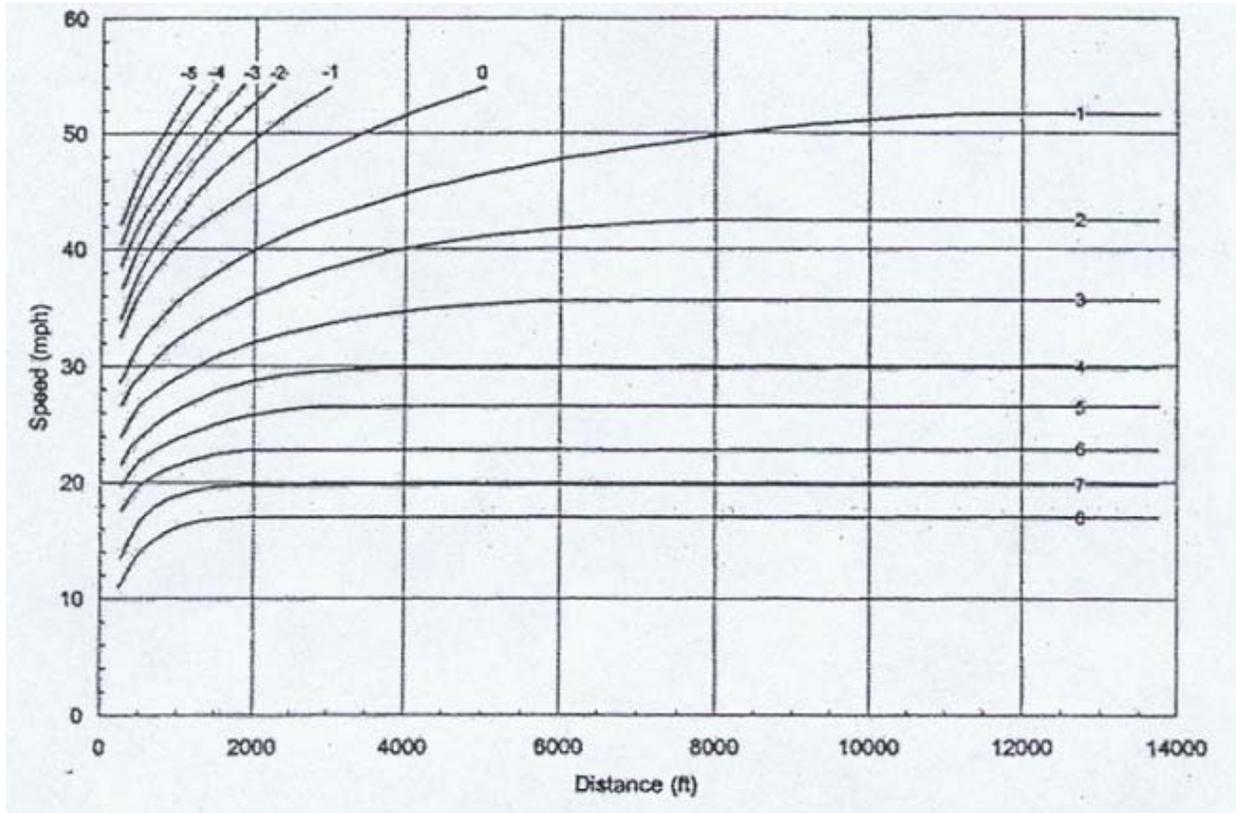
**TRUCK CLIMBING LANE  
(Example 6)**

**Figure 4-8**



**PERFORMANCE CURVES FOR HEAVY TRUCKS**  
**Deceleration (on Percent Upgrades Indicated)**

Figure 4-9



**PERFORMANCE CURVES FOR HEAVY TRUCK**  
**Acceleration (on Percent Grades Up and Down Indicated)**

**Figure 4-10**