STATE OF TENNESSEE
DEPARTMENT OF TRANSPORTATION
DESIGN DIVISION
NASHVILLE, TENNESSEE 37243-0348

INSTRUCTIONAL BULLETIN NO. 11-13

Regarding Guidelines for Design of Truck Climbing Lanes

Effective immediately, Section 2-150.00 is added to Chapter 1, Section 2, of the Roadway Design Guidelines. This guidance applies for roadway projects with truck-climbing lanes.

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CS:ARH

2-150.00 TRUCK-CLIMBING LANES

It is desirable to provide a truck-climbing lane as an added lane for the upgrade direction of a highway where the grade, traffic volumes and heavy-vehicle volumes combine to degrade traffic operations from those on the approach to grade. This section discusses guidelines for determining the location of truck-climbing lanes, critical lengths of grade, design criteria for truck-climbing lanes and guidance on how to develop truck speed profiles. For additional guidance on these topics, see the AASHTO *A Policy on Geometric Design of Highways and Streets.*

2-150.01 LOCATION GUIDELINES

A truck-climbing lane may be necessary to allow a specific upgrade to operate at an acceptable level of service. The following criteria will apply:

1. Two-Lane Highways – On a two-lane, two-way highway, a truck-climbing lane should be considered if the following conditions are satisfied:

   - the upgrade traffic flow is in excess of 200 veh/h; <u>and</u>
   - the heavy-vehicle volume (i.e., trucks, buses and recreational vehicles) exceeds 20 veh/h during the design hour; <u>and</u>
   - one of the following conditions exists:
     + the critical length of grade is exceeded for the 10 mph speed reduction curve (see Figure 2-8), or
     + the level of service (LOS) on the upgrade is E or F, or
     + there is a reduction of two or more LOS when moving from the approach segment to the upgrade; and
   - the construction costs and the construction impacts (e.g., environmental, right-of-way) are considered reasonable.

2. Multilane Highways – A truck-climbing lane should be considered on a multilane highway if the following conditions are satisfied:

   - The directional service volume for LOS D is exceeded on the upgrade; <u>and</u>
   - the directional service volume exceeds 1000 veh/h/lane; <u>and</u>
   - one of the following conditions exists:
     + the critical length of grade is exceeded for the 10 mph speed reduction curve (see Figure 2-8), or
     + the LOS on the upgrade is E or F, or

+ there is a reduction of one or more LOS when moving from the approach segment to the upgrade; and

- the construction costs and the construction impacts (e.g., environmental, right-of-way) are considered reasonable.

Also, truck-climbing lanes should be considered where the above criteria are not met and if there is an adverse crash experience on the upgrade related to slow-moving heavy vehicles.

2-150.02 CAPACITY ANALYSIS

See the *Highway Capacity Manual 2010* for guidance on conducting capacity analyses for climbing lanes on two-lane and multilane highways.

2-150.03 CRITICAL LENGTH OF GRADE

The critical length of grade is the maximum length of a specific upgrade on which a truck can operate without an unreasonable reduction in speed. The highway gradient, in combination with the length of the grade will determine the truck speed reduction on upgrades.

The following will apply to the critical length of grade:

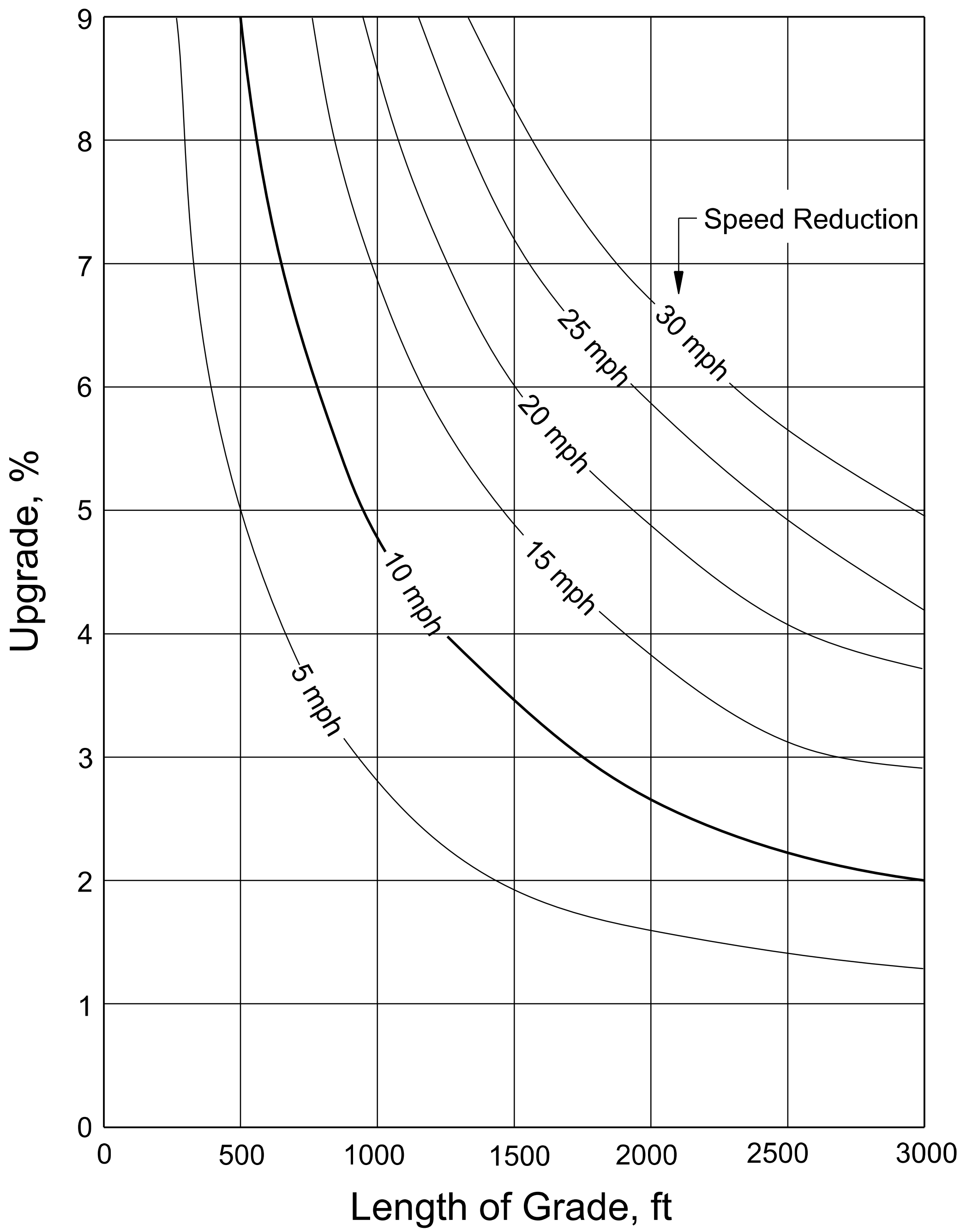
1. Design Vehicle – Figure 2-8 presents the critical length of grade for a 200 lb/hp truck. This vehicle is representative of size and type of a heavy vehicle normally used for design on main roads.

2. Criteria – Figure 2-8 provides the critical lengths of grade for a given percent grade and acceptable truck speed reduction. Although these curves are based on an initial truck speed of 70 mph, they apply to any design or posted speed. For design purposes, use the 10 mph speed reduction curve in the figure to determine if the critical length of grade is exceeded.

3. Momentum Grades – Where an upgrade is preceded by a downgrade, trucks will often increase their speed to ascend the upgrade. 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 to the initial speed. This assumption allows the use of a higher speed reduction curve in Figure 2-8. However, the designer should also consider that these speed increases may not always be attainable. If traffic volumes are sufficiently high, a truck may be behind another vehicle when descending the momentum grade, thereby restricting the increase in speed. Therefore, only consider these increases in speed if the highway has a Level of Service C or better.

4. Measurement – Vertical curves are part of the length of grade. Figure 2-9 illustrates how to measure the length of grade to determine the critical length of grade using Figure 2-8.

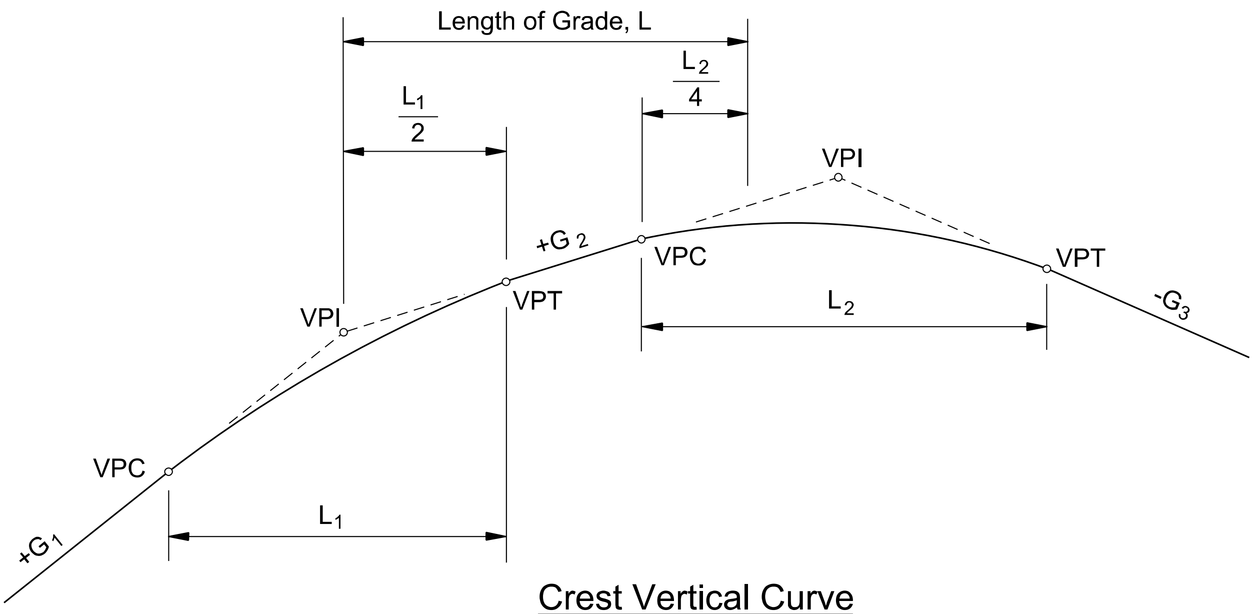
5. Application – If the critical length of grade is exceeded, flatten the grade, if practical, or evaluate the need for a truck-climbing lane. Typically, only two-lane highways have operational problems that require truck-climbing lanes.



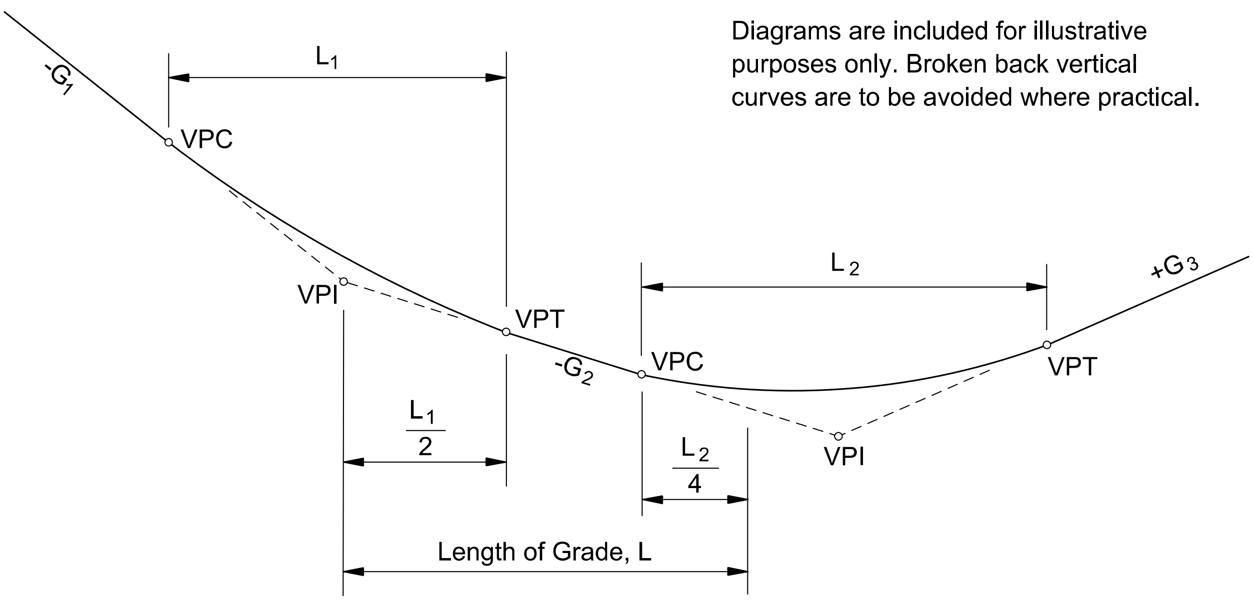
Notes:

1. *Typically, the 10 mph curve will be used.*
2. *See examples in Section 2-150.03 for use of figure.*
3. *Figure is based on a truck with initial speed of 70 mph. However, it may be used for any design or posted speed.*
4. *This figure is based on a 200 lb/hp heavy vehicle.*
5. *Figure is from the AASHTO A Policy on Geometric Design of Highways and Streets.*

Figure - 8
Critical Length of Grade for Design



Crest Vertical Curve



Sag Vertical Curve

Notes:

1. *For vertical curves where the two tangent grades are in the same direction (both upgrades or both downgrades), 50% of the curve length will be part of the length of grade.*
2. *For vertical curves where the two tangent grades are in opposite directions (one grade up and one grade down), 25% of the curve length will be part of the length of grade.*

Figure - 9
Measurement for Length of Grade

6. Highway Types – The critical-length-of-grade criteria applies equally to two-lane or multilane highways, and applies equally to urban and rural facilities

7. Alternative Critical Lengths of Grades – In many design situations, Figure 2-8 may not be directly applicable to the determination of the critical length of grade for one of following reasons:

   - The truck population for a given site may be such that a weight/power ratio is either less than or greater than the 200 lb/hp design vehicle (e.g., coal mining trucks, gravel trucks).
   - The truck speed at the entrance to the grade may differ from the 70 mph assumed in Figure 2-8.
   - The profile may not consist of a constant percent grade.

   For these situations, the designer may want to consider using the software program Truck Speed Profile Model (TSPM) described in NCHRP Report 505 *Review of Truck Characteristics as Factors in Roadway Design* to determine the applicable critical length of grade. This program may be used to generate speed truck profiles for any specified truck weight/power ratio, initial truck speed and sequence of grades.

8. Example Problems – Examples No. 1 and No. 2 illustrate the use of Figure 2-8 to determine the critical length of grade. Example No. 3 illustrates the use of Figures 2-8 and 2-9. In the examples, the use of subscripts 1, 2, etc., indicate the successive gradients and lengths of grade on the highway segment.

Example No. 1

Given: Level Approach
G = +4%
L = 1500 ft (length of grade)
Rural Principal Arterial

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

Solution: Figure 2-8 yields a critical length of grade of 1200 ft for a 10-mph speed reduction. The length of grade (L) exceeds this value. Therefore, flatten the grade, if practical, or evaluate the need for a truck-climbing lane.

Example No. 2

Given: Level Approach
G_1 = +4.5%
L_1 = 500 ft
G_2 = +2%
L_2 = 700 ft
Rural Arterial with a significant number of heavy trucks

Problem: Determine if the critical length of grade is exceeded for the combination of grades G_1 and G_2.

Solution: From Figure 2-8, G_1 yields a truck speed reduction of 5 mph. G_2 yields a speed reduction of approximately 3 mph. The total of 8 mph is less than the maximum 10 mph speed reduction. Therefore, the critical length of grade is not exceeded.

Example No. 3

Given: Figure 2-10 illustrates the vertical alignment on a low-volume, two-lane rural collector highway with no large trucks.

Problem: Determine if the critical length of grade is exceeded for G_2 or for the combination upgrade G_3 and G_4.

Solution: Use the following steps:

Step 1. Determine the length of grade using the criteria in Figure 2-9. For this example, the following calculations are used:

$$L_2 = \frac{1000}{4} + 600 + \frac{800}{4} = 825 \text{ ft}$$

$$L_3 = \frac{800}{4} + 700 + \frac{400}{2} = 1100 \text{ ft}$$

$$L_4 = \frac{400}{2} + 300 + \frac{600}{4} = 650 \text{ ft}$$

Step 2. Determine the critical length of grade in both directions. Use Figure 2-8 to determine the critical length of grade.

- For trucks traveling left to right, enter into Figure 2-8 the value for G_3 (3.5%) and L_3 = 1100 ft. The speed reduction is 7.0 mph. For G_4 (2%) and L_4 = 650 ft, the speed reduction is approximately 3.5 mph. The total speed reduction on the combination upgrade G_3 and G_4 is 10.5 mph. This exceeds the maximum 10 mph speed reduction. However, on low-volume roads, one can assume a 5 mph increase in truck speed for the 3% "momentum" grade (G_2), which precedes G_3. Therefore, a speed reduction may be as high as 15 mph before concluding that the combination grade exceeds the critical length of grade. Assuming the benefits of the momentum grade, this leads to the conclusion that the critical length of grade is not exceeded.

- For trucks traveling in the opposite direction, on Figure 2-8, enter in the value for G_2 (3%) and determine the critical length of grade for the 10 mph speed reduction (i.e., 1700 ft). Because L_2 is less than 1700 ft (i.e., 825 ft), the critical length of grade for this direction is not exceeded.

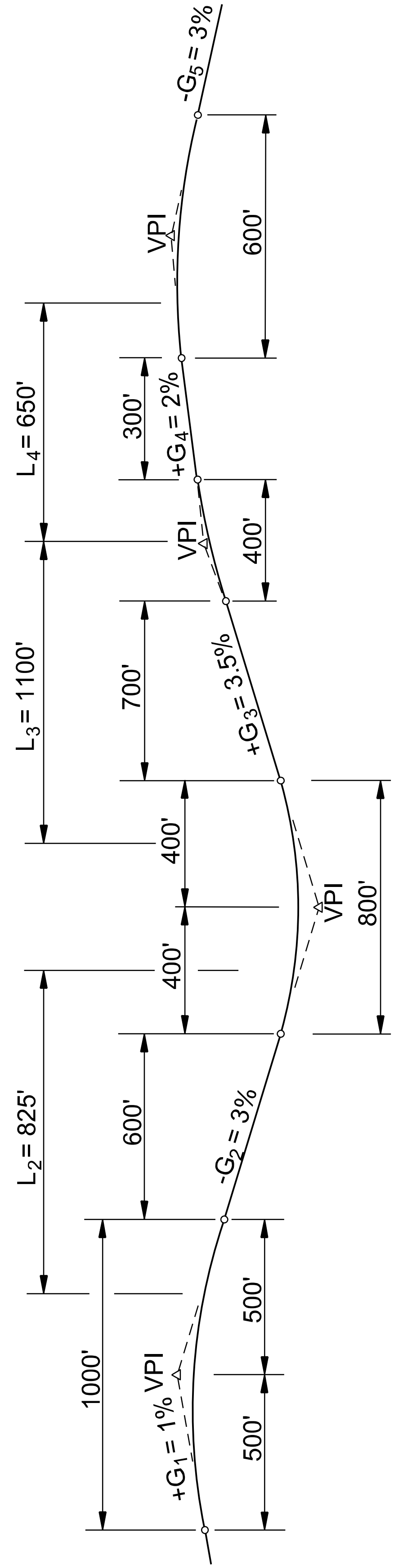


Figure - 10
Critical Length Of Grade Calculations
(Example No. 3)

2-150.04 DESIGN GUIDELINES

Table 2-1 summarizes the design criteria for a truck-climbing lane. Also, consider the following:

1. Design Speed – For entering speeds equal to or greater than 70 mph, use 70 mph for the truck design speed. For speeds less than 70 mph, use the roadway design speed or the posted speed limit, whichever is less. Under restricted conditions, the designer may want to consider the effect a momentum grade will have on the entering speed. See Comment 3 in Section 2-150.03 for additional information on momentum grades. However, the maximum speed will be 70 mph.

2. Cross Slope – On tangent sections, the truck-climbing lane cross slope will typically be the same as that of the adjacent travel lane.

3. Superelevation – For horizontal curves, superelevate the truck-climbing lane at the same rate as the adjacent travel lane.

4. Performance Curves – Figure 2-11 presents the deceleration and acceleration rates for a 200 lb/hp truck.

5. End of Full-Width Lane – In addition to the criteria in Table 2-1, ensure that there is sufficient sight distance available to the point where the truck, RV or bus will begin to merge back into the through travel lane. At a minimum, this will be stopping sight distance. Desirably, the driver should have decision sight distance available to the roadway surface (i.e., height of object = 0.0 ft) at the end of the taper. See the AASHTO *A Policy on Geometric Design of Highways and Streets* for decision sight distance values.

   The full-lane width should be extended beyond the crest vertical curve and not ended just beyond the crest of the grade. Also, desirably the full-lane width should not end on a horizontal curve.

6. Signing and Pavement Markings – Contact the ITS, Traffic and Standards Section for signing and pavement marking guidance for truck-climbing lanes.

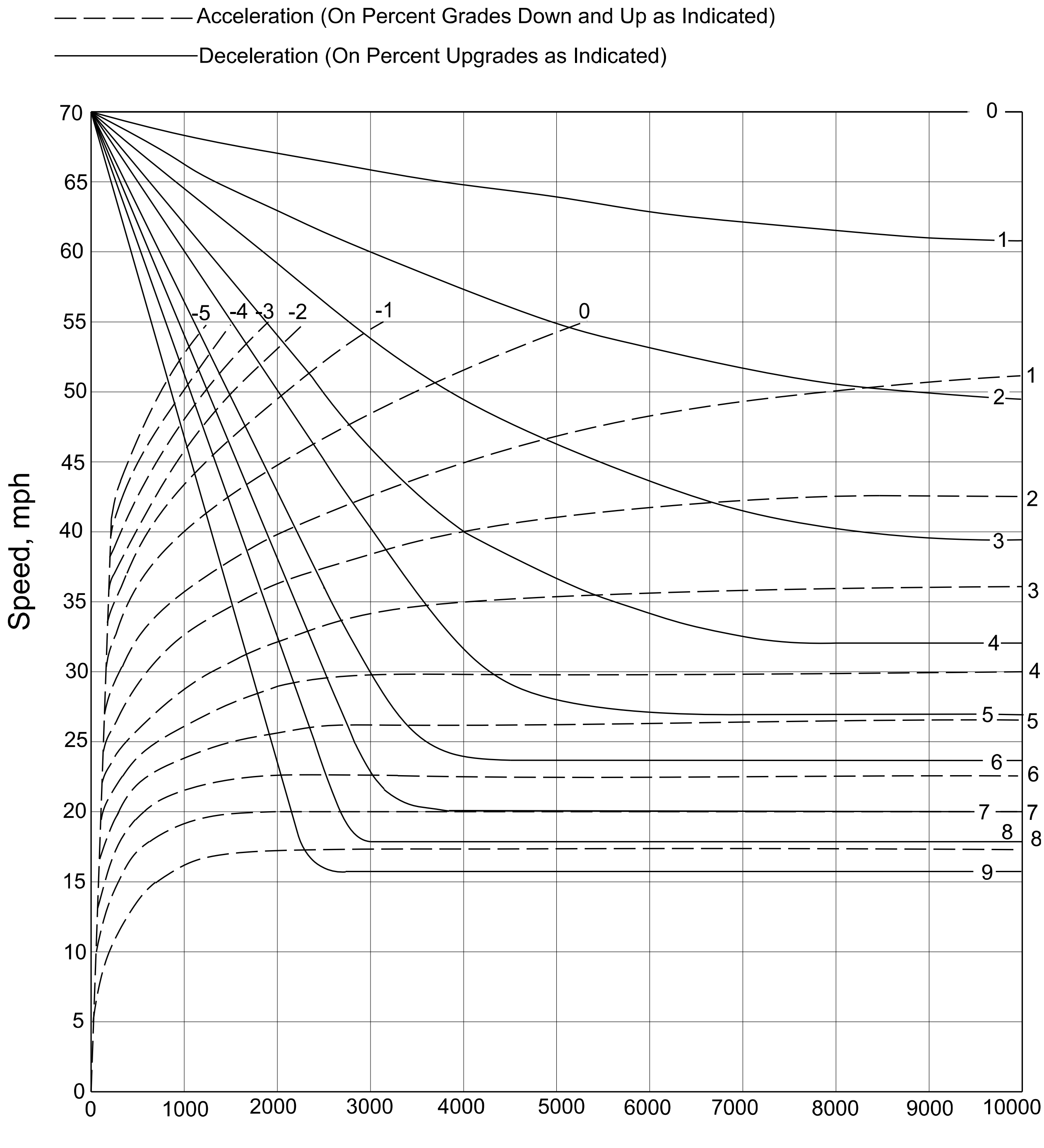
Design Element	Desirable	Minimum
Lane Width	12 ft	Width of adjacent lane
Shoulder Width	Same width as approach shoulder	Interstate: 6 ft Other Highways: 4 ft
Cross Slope on Tangent	0.02 ft/ft	0.02 ft/ft
Beginning of Full-Width Lane (1)	Location where the truck speed has been reduced to 10 mph below the posted speed limit	Location where the truck speed has been reduced to 45 mph
End of Full-Width Lane (2)	Location where truck has reached highway posted speed or 55 mph, whichever is less	Location where truck has reached 10 mph below highway posted speed limit
Entering Taper	25:1	300 ft
Exiting Taper	Interstate: 70:1 Other Highways: 600 ft	50:1
Minimum Full-Width Length	1000 ft or greater	Interstate Only: 1000 ft

Notes:

1. *Use Figure 2-11 to determine truck deceleration rates. In determining the applicable truck speed, the designer may consider the effect of momentum grades.*

2. *Use Figure 2-11 to determine truck acceleration rates. Also, see Comment 5 in Section 2-150.04.*

Table - 1
Design Criteria for Truck-Climbing Lanes



Notes:

1. *For entering speeds equal to or greater than 70 mph, use an initial speed of 70 mph. For speeds less than 70 mph, use the design speed or posted speed limit as the initial speed.*
2. *Figure is from the AASHTO A Policy on Geometric Design of Highways and Streets.*

Figure -11
Performance Curves for Trucks
(200 lb/hp)

2-150.05 DOWNGRADES

Truck lanes on downgrades are not typically considered. However, steep downhill grades may also have a detrimental effect on the capacity and safety of facilities with high traffic volumes and numerous heavy trucks. Although specific criteria have not been established for these conditions, trucks descending steep downgrades in low gear may produce nearly as great an effect on operations as an equivalent upgrade. The need for a truck lane for downhill traffic will be considered on a site-by-site basis.

2-150.06 TRUCK SPEED PROFILE

For highways with a single grade, the critical length of grade and deceleration and acceleration rates can be directly determined from Figure 2-11. However, most highways have a continuous series of grades. Often, it is necessary to find the impact of a series of significant grades in succession. If several different grades are present, then a speed profile may need to be developed.

The following example illustrates how to construct a truck speed profile and how to use Figure 2-11.

Example No. 4

Given: Level Approach
G_1 = +3% for 800 ft (VPI to VPI)
G_2 = +5% for 3200 ft (VPI to VPI)
G_3 = -2% beyond the composite upgrade (G_1 and G_2)
V = 60 mph design speed with a 55 mph posted speed limit
Rural Principal Arterial

Problem: Using the criteria in Table 2-1 and Figure 2-11, construct a truck speed profile and determine the beginning and ending points of the full-width climbing lane.

Solution: Apply the following steps:

Step 1: Determine the truck speed on G_1 using Figure 2-11 and plot the truck speed at 200 ft increments. See Figure 2-12. Assume an initial truck speed of 55 mph. Move horizontally along the 55 mph line to the 3% deceleration curve. This is approximately 2800 ft along the horizontal axis. This is the starting point for G_1.

Distance From VPI_1 (ft)	Horizontal Distance on Figure 2-11 (ft)	Truck Speed (mph)	Comments
0	2800	55	VPI_1
200	3000	54	
400	3200	53	
600	3400	52	
800	3600	51	VPI_2

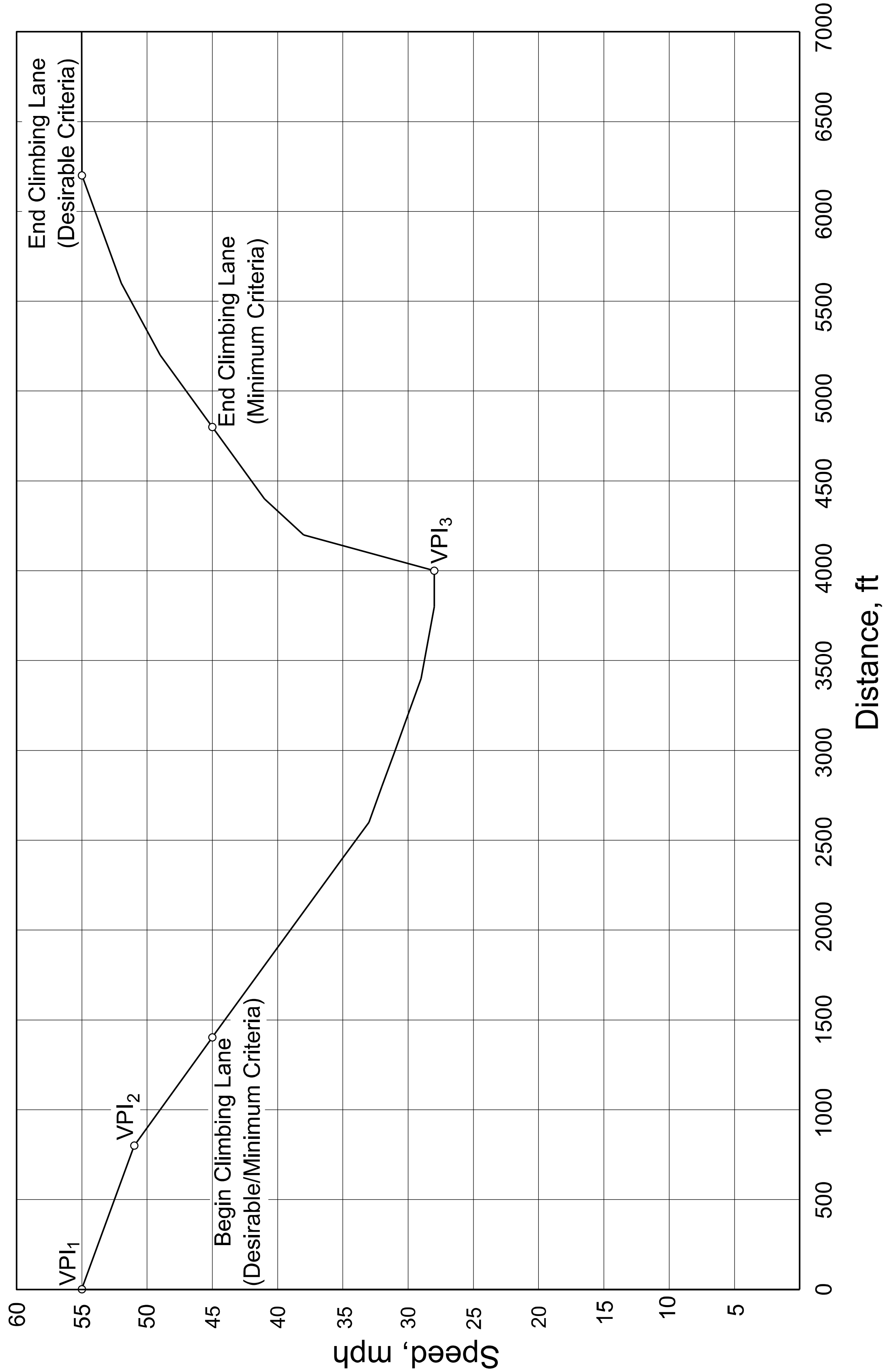


Figure - 12
Truck Speed Profile
(Example No. 4)

Step 2: Determine the truck speed on G_2 using Figure 2-11 and plot the truck speed at 200 ft increments in Figure 2-12. From Step 1, the initial speed on G_2 is the final speed from G_1 (i.e., 51 mph). Move right horizontally along the 51 mph line to the 5% deceleration curve. This is approximately 1900 ft along the horizontal axis. This is the starting point for G_2.

Figure 2-12 Distance From VPI_1 (ft)	Horizontal Distance on Figure 2-11 (ft)	Truck Speed (mph)	Comments
800	1900	51	VPI_2
1000	2100	49	
1200	2300	47	
1400	2500	45	
1600	2700	43	
1800	2900	41	
2000	3100	39	
2200	3300	37	
2400	3500	35	
2600	3700	33	
2800	3900	32	
3000	4100	31	
3200	4300	30	
3400	4500	29	
3600	4700	29	
3800	4900	28	
4000	5100	28	VPI_3

Step 3: Determine the truck speed on G_3 using Figure 2-11 until the truck has fully accelerated to 55 mph, and plot the truck speed at 200 ft increments in Figure 2-12. The truck will have a speed of 28 mph as it enters the 2% downgrade at VPI_3. Read into Figure 2-11 at the 28 mph point on the vertical axis and move over horizontally to the -2% line. This is approximately 150 ft along the horizontal axis. This is the starting point for G_3.

Figure 2-12 Distance From VPI_1 (ft)	**Horizontal Distance on Figure 2-11 (ft)**	**Truck Speed (mph)**	**Comments**
4000	150	28	VPI_3
4200	350	38	
4400	550	41	
4600	750	43	
4800	950	45	
5000	1150	47	
5200	1350	49	
5400	1550	50	
5600	1750	52	
5800	1950	53	
6000	2150	54	
6200	2350	55	

Step 4: Determine the beginning and end of the full-width climbing lane. From Table 2-1, the desirable and minimum beginning of the full-width lane will be where the truck has reached a speed of 45 mph (10 mph below the posted speed). This point occurs 1400 ft beyond VPI_1.

For ending the full-width climbing lane, the desirable criteria from Table 2-1 is where the truck speed has reached the posted speed limit (55 mph) or 6200 ft beyond the VPI_1. The minimum criteria is where the truck has reached a speed of 45 mph (10 mph below the posted speed). This occurs at 4800 ft beyond VPI_1.