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16. Abstract

Whereas standard roadway design ensures that stopping sight distance (SSD) is provided at all locations along a roadway, there is no standard established for when decision sight distance (DSD) is needed with respect to traffic signals. A "reduced decision zone" (RDZ) was identified in the research as the location along a roadway with a vertical curve and a traffic signal beyond the curve where SSD is provided but DSD is not. Essentially, motorists within the RDZ are provided with SSD for unexpected stopping but are not provided with the added decision-making and response time that DSD might otherwise provide as they approach the vertical curve and the downstream traffic signal. Contained within this report are techniques for determining whether an RDZ exists along an existing roadway or has the potential to exist in a proposed design. It is suggested that intersections not be located within the RDZ.

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GUIDELINES FOR USING DECISION SIGHT DISTANCE AT SIGNALIZED INTERSECTIONS NEAR VERTICAL CURVES

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GUIDELINES FOR USING DECISION SIGHT DISTANCE AT SIGNALIZED INTERSECTIONS NEAR VERTICAL CURVES

INTRODUCTION

As a motorist travels any stretch of roadway, there is a certain distance ahead of the motorist's vehicle that can be clearly seen. This distance is known as the sight distance at a particular location along the roadway. The sight distance at a point is dependent upon the direction of travel of the vehicle.

In order to safely travel a given route, a motorist must be able to see a potentially harmful object or situation, comprehend the required action needed to avoid a collision, and take the appropriate action. The combination of these three steps results in guidelines for minimum sight distance required in certain situations. These guidelines are provided in *A Policy on Geometric Design of Highways and Streets*, better known as the *Green Book*, published by the American Association of State Highway and Transportation Officials (AASHTO) (*1*).

EXISTING PRACTICE AND GUIDELINES

Stopping Sight Distance

The most basic sight distance guideline provided is stopping sight distance (SSD). The SSD is the distance required, at a given speed, for a motorist to recognize a stationary object in the roadway and come to a complete stop prior to striking the object. Based on previous studies, AASHTO recommends using a perception-reaction time of 2.5 seconds and a deceleration rate of 11 feet per second squared. In addition, a driver's eye height of 3.5 feet and an object height of 2.0 feet are recommended. Using these recommended values, the design guidelines for required SSD at various speeds are shown in Table 1 (*1*).

Decision Sight Distance

While the provision of SSD should be sufficient in most cases for the average driver to comprehend a possible conflict and appropriately react, there are circumstances where additional sight distance is needed. When additional distance is necessary, the guidelines for decision sight distance (DSD) should be used. The TxDOT *Roadway Design Manual* defines DSD as follows:

> *Decision sight distance is the distance required for a driver to detect an unexpected or otherwise difficult-to-perceive information source, recognize the source, select an appropriate speed and path, and initiate and complete the required maneuver safely and efficiently (2).*

Table 1. Recommended Stopping Sight Distance Guidelines Provided by AASHTO (*1*).

Design Speed (mph)	Stopping Sight Distance (ft)
15	80
20	115
25	155
30	200
35	250
40	305
45	360
50	425
55	495
60	570
65	645
70	730
75	820
80	910

The main difference between the DSD and SSD criteria is the complexity of the situation that the driver is faced with. The added complexity requires additional perception-reaction time prior to applying the brakes to begin to slow the vehicle to a stop. The existing guidance as to when DSD should be used rather than SSD is rather vague. However, signalized intersections near crest vertical curves present a wide range of complexities that emphasize the need to provide DSD. Unexpected or unusual situations that a driver approaching a signalized intersection on the far side of a crest vertical curve may experience include:

- The intersection and traffic signals are not visible; however, the back of the queue from the signalized intersection is reached.
- The intersection and traffic signals are not visible, and the queue on downgrade of the curve not visible.
- The queue on the downgrade of the curve is not visible, but signal head(s) at the downstream intersection is (are) visible; the queue would be especially unexpected if the visible signal head was green.

Under normal driving conditions (i.e., in the absence of a vertical curve), objects downstream of the driver are visible and discernable in a sequential manner. This allows the driver to comprehend and react to each object one at a time. However, because the crest of a vertical curve can limit the driver's sight distance, several objects downstream of the crest become visible at one time as the driver passes through the zone of decreased visibility. Objects could include driveways, billboards, street lighting, roadway geometry changes (e.g., left turn pockets), stopped vehicles, traffic signals, etc. Under this circumstance, the driver is required to process and respond to each object simultaneously. The additional demand placed on the driver is translated into additional time needed before the appropriate reaction can be made.

AASHTO's *Green Book* (*1*) provides guidelines on the minimum sight distance required to account for the increased decision time needed for complex maneuvers and various design speeds. The guidelines are provide for different types of maneuvers, but those that are applicable to the signal-near-vertical-curve scenario are Case A, stop on a rural road, and Case B, stop on an urban road. For rural roads, an additional 0.5 seconds of reaction time is provided over the normal 2.5 seconds provided for SSD. For roads in urban areas, the additional time provided jumps to 9 seconds. The reason for the large jump in reaction time is presumed to be the large increase in the number of objects competing for the driver's attention that exist in the urban (or suburban/urban fringe) environment and that are not present in rural environments. The *Green Book* guidelines are shown in Table 2 (*1*).

Table 2. Decision Sight Distance Guidelines Provided by AASHTO (*1*).

Design Speed (mph)	Decision Sight Distance (ft) Avoidance Maneuver A	Decision Sight Distance (ft) Avoidance Maneuver B
30	220	490
35	275	590
40	330	690
45	395	800
50	465	910
55	535	1030
60	610	1150
65	695	1275
70	780	1410
75	875	1545
80	970	1685

Avoidance Maneuver A: Stop on Rural Road – t = 3.0 s
Avoidance Maneuver B: Stop on Urban Road – t = 9.1 s

Due to the additional complexities that the driver is faced with as he or she approaches a signalized intersection near a vertical curve, it is recommended that, whenever possible, DSD be provided on the approach to the signalized intersection. If DSD is not or cannot be provided, an advance warning device should be used to alert motorists before they enter the zone along the approach where DSD is not provided.

Existing Vertical Curve Design

The AASHTO *Green Book* (*1*) provides guidelines for the design of vertical curves on highways and streets. The TxDOT *Roadway Design Manual* (*2*) follows the same guidelines as those presented in the *Green Book*. Vertical curves are designed as simple parabolas such as the one shown in Figure 1. Restrictions are placed on the minimum length of vertical curve, L, that can be used to connect two given grades at a given design speed. These restrictions are based on ensuring that SSD is provided at all points along the curve. Figure 2 is the chart that is used to determine the minimum length of vertical curve, L, that can be used for a given design speed, V, and algebraic difference in grade, A (*2*).

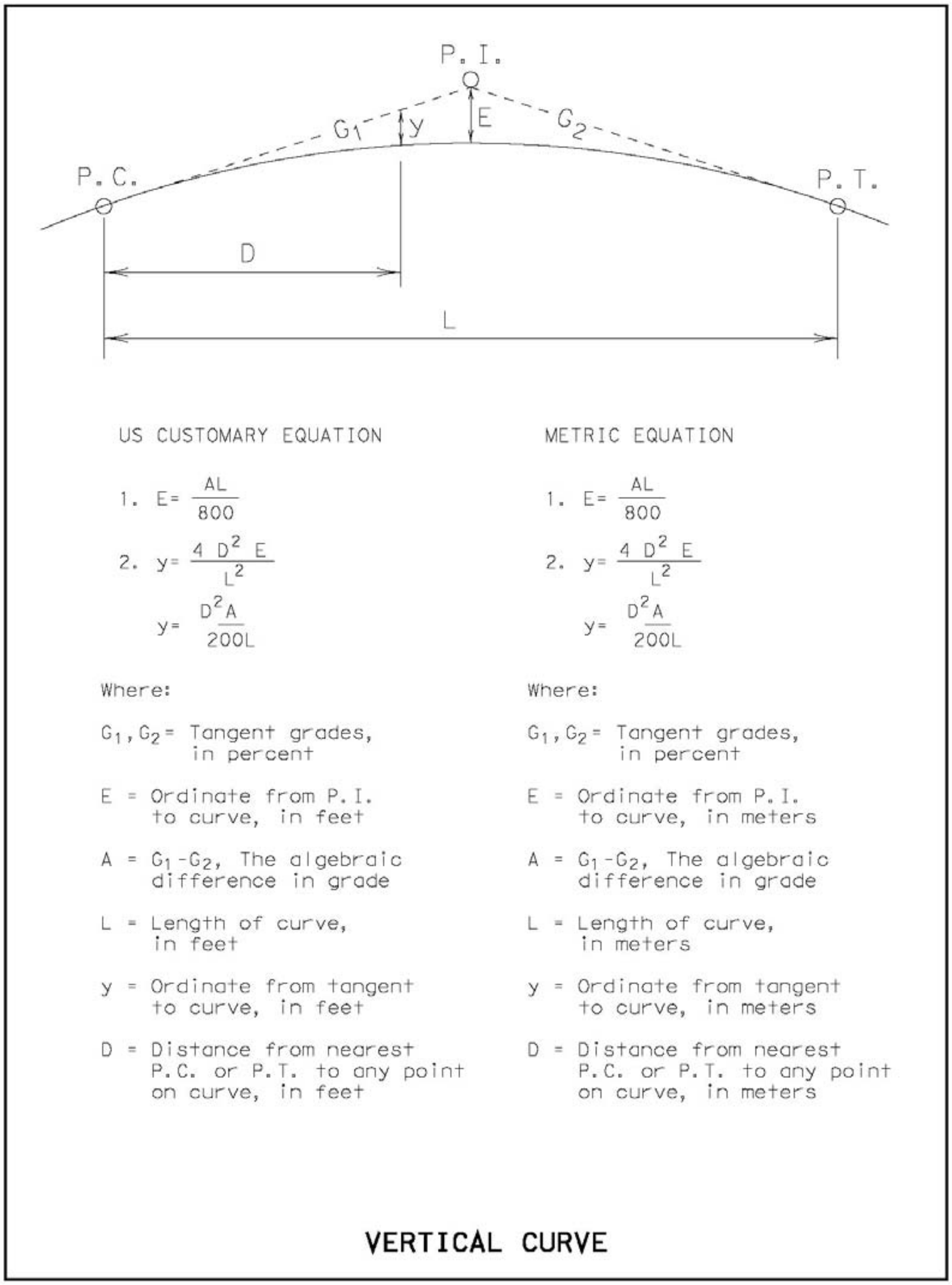
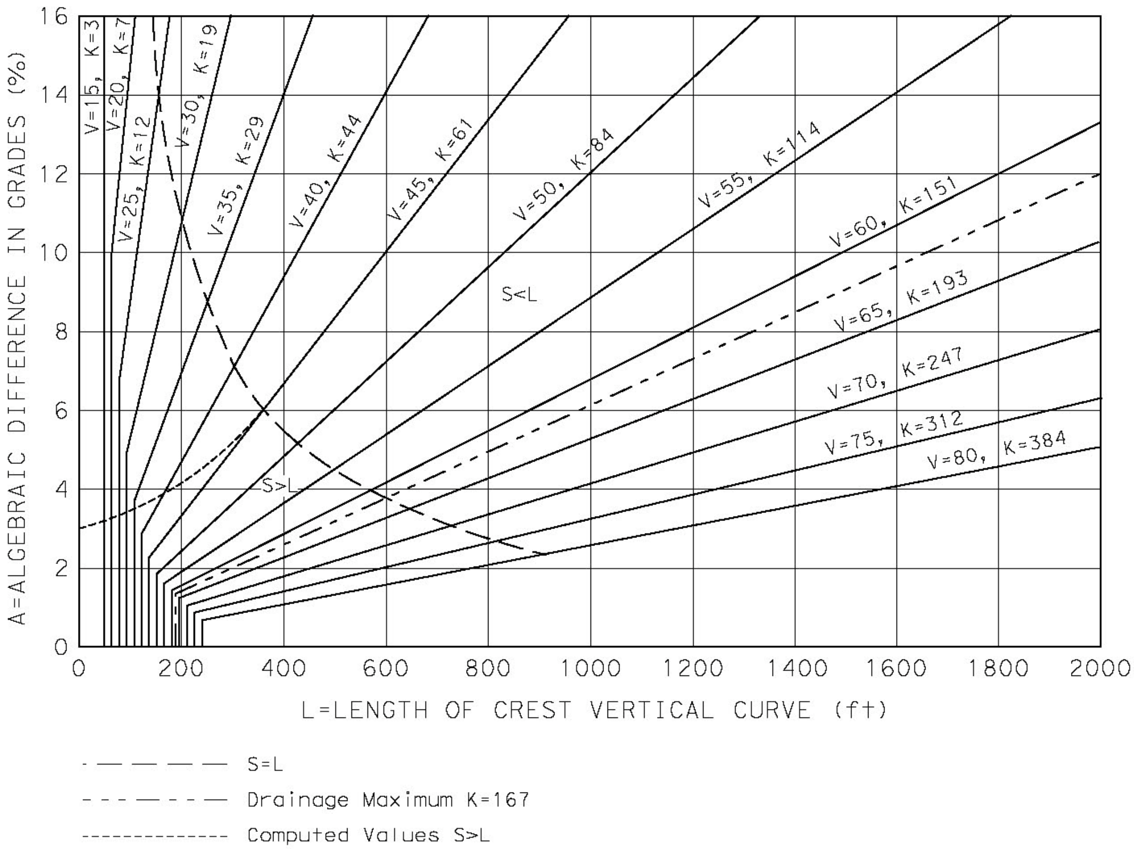


Figure 1. Design of Typical Vertical Curve from TxDOT *Roadway Design Manual (2)*.



Design Controls for Crest Vertical Curves (US Customary)

Figure 2. Minimum Lengths of Vertical Curves to Provide Stopping Sight Distance from TxDOT *Roadway Design Manual (2).*

PROPOSED GUIDELINES FOR USING DECISION SIGHT DISTANCE IN INTERSECTION DESIGN

Vertical curves that are designed based on the minimum values provided in Figure 1 are adequate in most situations because they ensure that SSD is provided. However, in those locations where signalized intersections (or other areas of high complexity and visual noise) are located in close proximity to the vertical curve, there will be portions on the approach to those intersections where the recommended DSD is not provided.

Graphically, sight distance at any point along the roadway near a vertical curve is represented by the length of the sight line that extends from a point at driver's eye height (3.5 feet above the roadway) at the vehicle's location, is tangent to the crest of the curve, and terminates at a point where it is object height (2 feet above the roadway). Using the mathematical relationships shown in Figure 1, equations were developed that can determine the sight distance at any point on the roadway, on the tangent prior to the vertical curve, or on the vertical curve itself. Using these equations, the location of a Reduced Decision Zone (RDZ) for vertical curves designed to meet the minimum lengths were determined and are shown in Figure 3 (for various design speed and grade combinations).

The RDZ represents the portion along the roadway where high concentrations of visual noise or complex environments, such as a signalized intersection, should not be located. Sight distances along the roadway are less than that required for DSD to all points within the RDZ. In the course of the design process, if it is determined that a certain combination of curve length and grade would result in locating an intersection or potential back of queue from an intersection within this zone, the designer should select a different curve design if possible. Since the RDZ is dependent upon the definition of DSD, the location would vary depending on whether it was a rural or urban application. The RDZ graph for the rural case (Case A) is shown in Figure 3 and the urban case (Case B) is shown in Figure 4.

In both cases the location of the RDZ is provided with respect to the location of the vertical point of intersection (VPI) of the vertical curve. This point was selected because it is usually fixed in design based on the natural curvature properties of the land. Negative values represent distances prior to the VPI as the vehicle is traveling toward the intersection. Positive values are distances after the VPI as the vehicle is traveling toward the intersection. The range for the RDZ is between the two lines at the particular design speed for a given algebraic difference in grade.

GUIDELINES FOR USING DECISION SIGHT DISTANCE IN INTERSECTION OPERATIONS/SAFETY ANALYSIS

The charts and methodology used above for roadway design could also be applied in operational and safety analyses of signalized intersections. The charts can be used to identify those locations where an intersection or back of queue has been located within the RDZ on an approach to the intersection. Those locations in which DSD is not provided to the intersection would be candidates for additional countermeasures to alert motorists at the appropriate location of the presence of the downstream signal or back of queue.

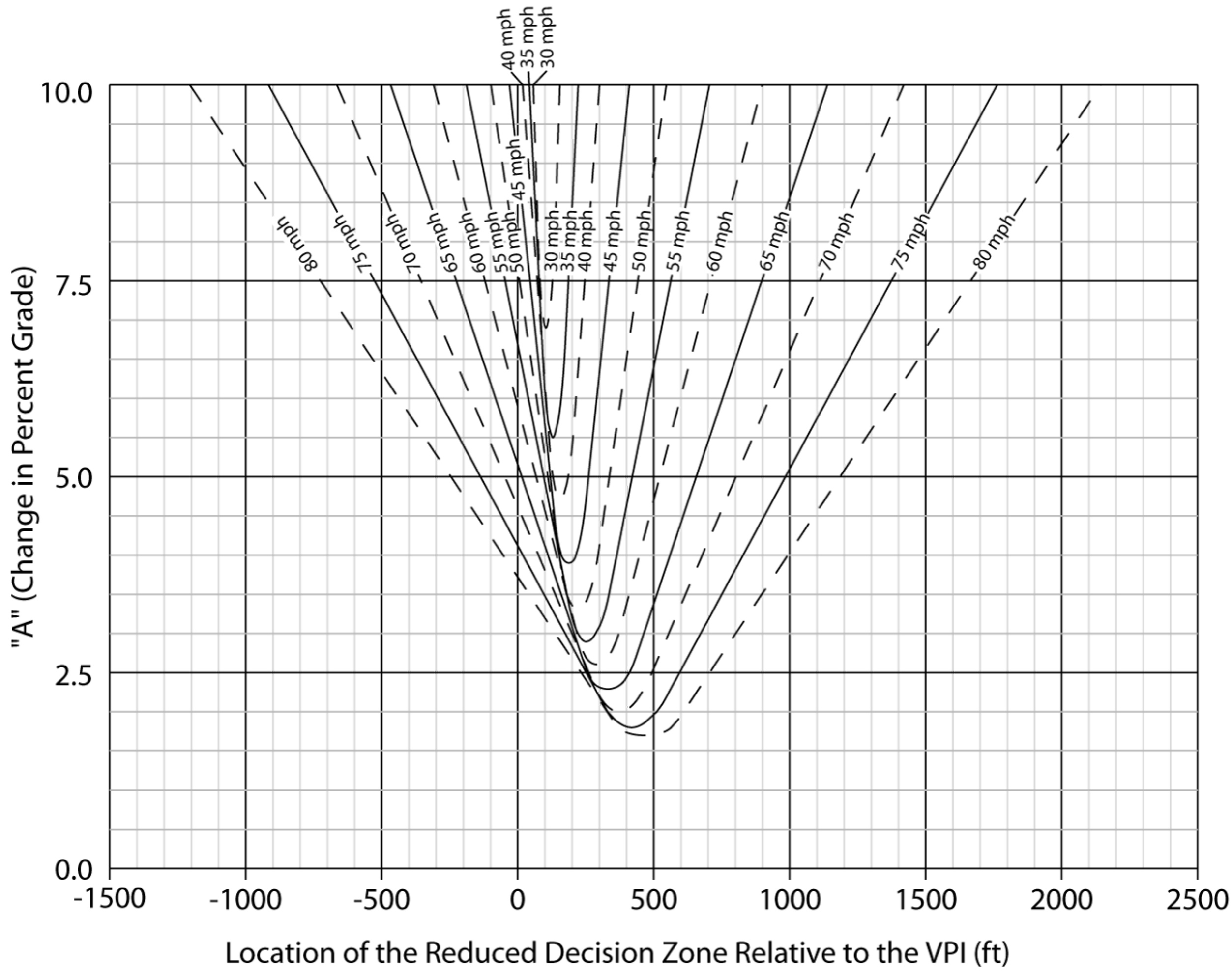


Figure 3. Reduced Decision Zone Location for Rural Roadway Applications.

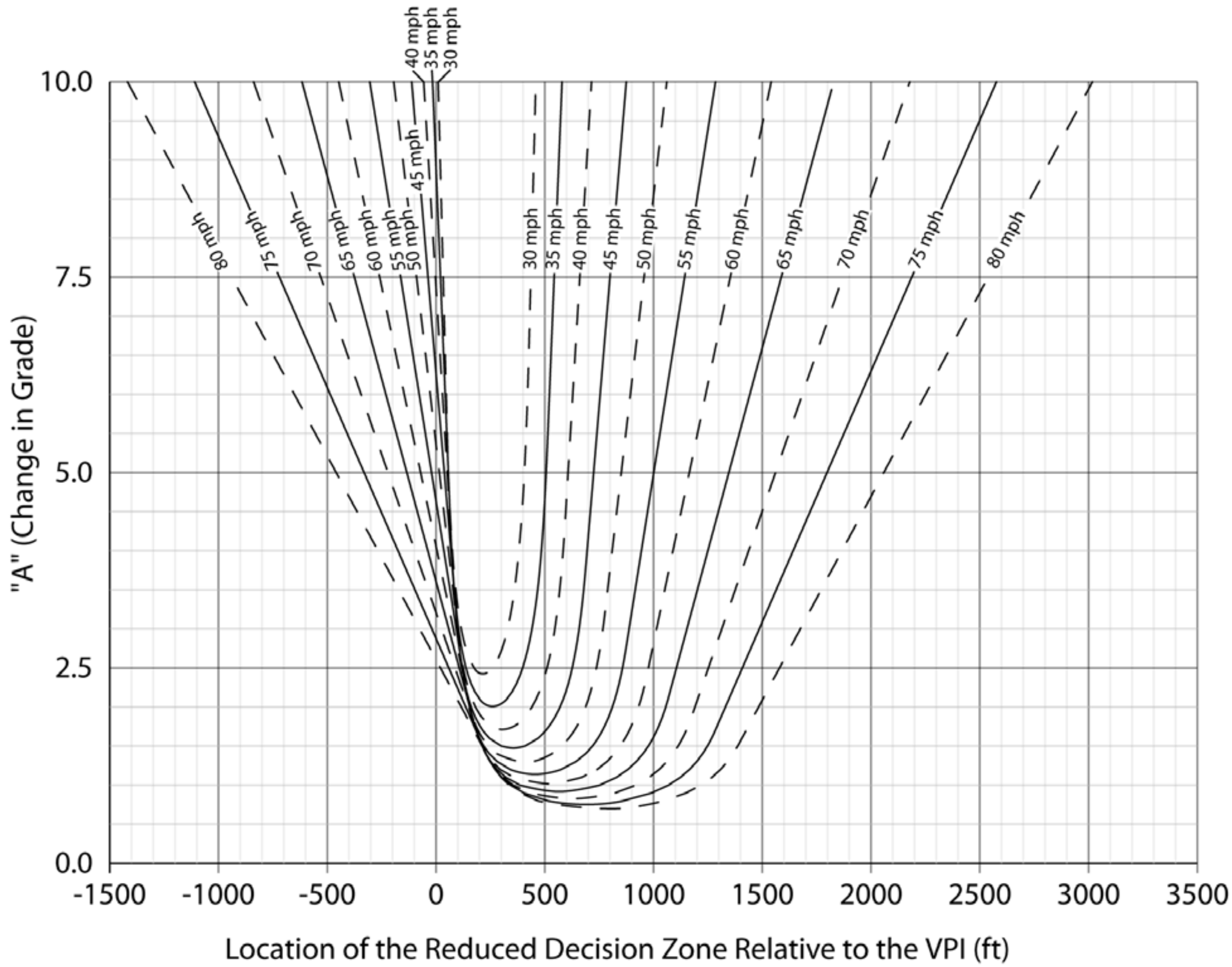


Figure 4. Reduced Decision Zone Location for Urban Roadway Applications.

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2. *Texas Roadway Design Manual*. Texas Department of Transportation, Austin, Texas, April 2004 (Revised). http://manuals.dot.state.tx.us/dynaweb/coldesig/rdw