TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM

PROJECT SUMMARY REPORT

Project Summary Report 0-4084-S
Project 0-4084: Countermeasures to Reduce Crashes at Signalized Intersections near Vertical Curves

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Improving Driver Perception of Signals near Vertical Curves

Within the state of Texas, the standards and guidelines provided in the *Texas Manual on Uniform Traffic Control Devices* (TMUTCD) direct most of the decision making concerning the type and placement of roadside signing. However, there are some instances in which complexities of the driving environment indicate that supplemental devices be used even beyond those required and suggested by the TMUTCD.

In the case where signalized intersections are located beyond crest vertical curves, the TMUTCD provides for upstream use of SIGNAL AHEAD text or symbolic advanced warning signing where the signal heads for the intersection are not visible for some minimum distance upstream of the intersection. However, the TMUTCD's placement distances of SIGNAL AHEAD advanced warning signs extend to only 650 feet (for a speed of 65 mph) from the primary traffic control device (i.e., the traffic signal). Therefore the possibility exists that even the advanced warning sign may not be fully visible to motorists approaching the intersection because their line of sight is limited by the vertical curve upstream of the signal. Also, the queue of vehicles from the signal may extend far enough back from the signal that even an advanced warning sign would provide insufficient notice to

Figure 1. Signal Located on the Far Side of Vertical Curve.

approaching motorists. Figure 1 shows a typical case where the SIGNAL AHEAD sign is properly located according to the TMUTCD; however, because it is behind the curve, it is not able to provide information to the driver before the vertical curve where it is needed.

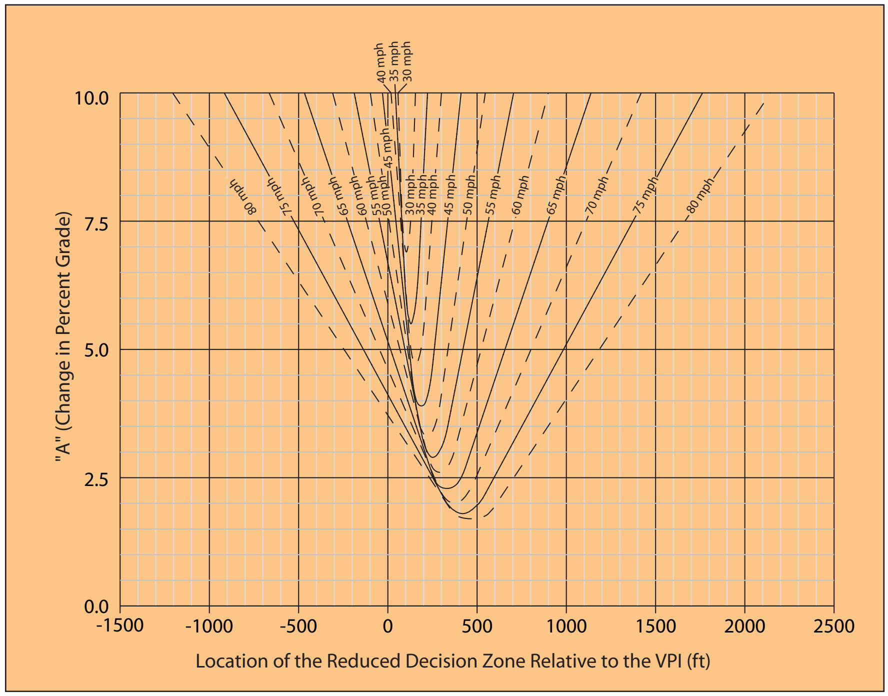

Figure 2. Reduced Decision Zone for Rural Curves.

What We Did…

Researchers began this investigation by identifying 28 potential project site locations from the hundreds around the state where signalized intersections occur downstream of crest vertical curves. Crash records for these 28 sites were taken from the official crash database of the Texas Department of Public Safety and compared to control sites — signalized intersection locations in similar areas with similar volumes, but without nearby vertical curves. The crash comparison revealed no apparent increase in crash rates where decision sight distance was not provided due to the presence of a crest vertical curve upstream of a signalized intersection.

The next task for project researchers involved a detailed investigation of stopping sight distance (SSD) and decision sight distance (DSD). Roadway design standards ensure that SSD is available at all locations. However, there is limited guidance within design manuals to indicate when more sight distance may be necessary. In the case of DSD, extra sight distance is provided so that motorists have more time to process downstream roadway information. As stated in the Texas Department of Transportation's *Roadway Design Manual*, "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."

To identify locations along the roadway where SSD is provided but DSD is not, researchers used vertical curve geometry with standard driver eye height (i.e., 3.5 feet) and standard object height (i.e., 2 feet). Ultimately, the research team was able to identify a reduced decision zone (RDZ) along the approach to the signal where a crest vertical curve limited sight distance. Looking within the RDZ, drivers had SSD but not the extra response time provided by DSD. Researchers were also able to identify where the downstream standard 2-foot object would be located along the roadway when a driver within the RDZ could not see it.

The research team next devoted its attention to identifying the most appropriate type of countermeasure to use to alert approaching motorists to a signal or signalized intersection queue beyond a crest vertical curve. Based on both national and state signing standards and guidelines and documented studies of various types of countermeasures — including various types of signing, signing with flashers, rumble strips, and supplemental signal heads — researchers identified BE PREPARED TO STOP signing (TMUTCD W20-7b) as the preferred countermeasure.

To test their findings and signing suggestions, researchers performed before-and-after studies at three sites in Austin and San Antonio, Texas. Researchers collected speed data at strategic points upstream, at the signing location, and downstream of the location where signing was installed to determine whether or not motorists responded to the advanced warning sign message.

What We Found…

The crash analysis did not indicate crash increases where signals were located near vertical curves because existing roadway design standards ensure that SSD

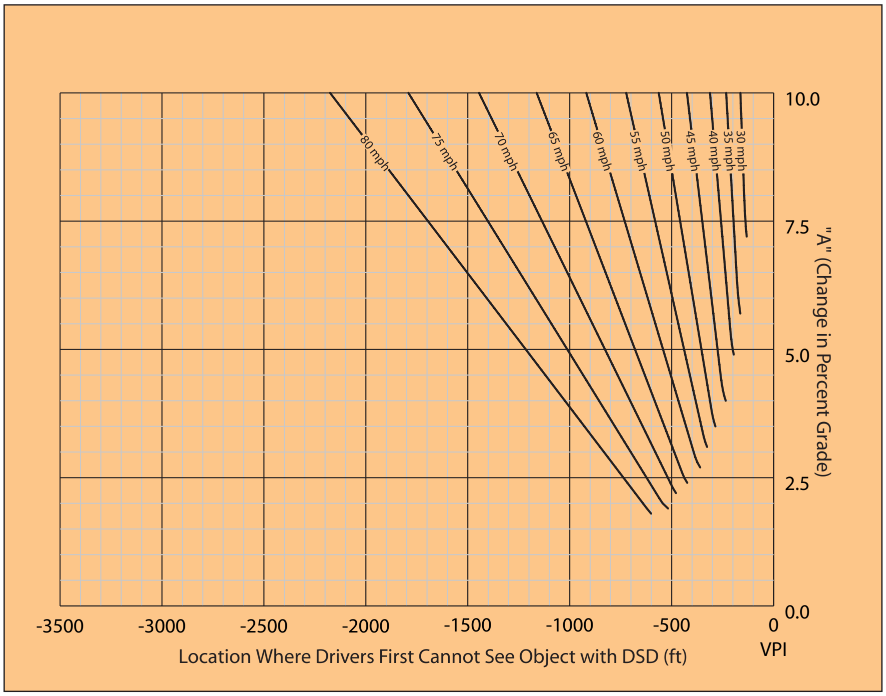

Figure 3. Countermeasure Placement for Rural Curves.

is always provided, and because existing signing standards require that either a minimum signal head visibility distance or advanced warning signing be provided. In other words, existing standards appear adequate in most situations. However, the crash analysis results should not overshadow the presence of the RDZ identified in this research or preclude the vigilance of the traffic engineer in addressing concerns about queues from signals not being visible to approaching motorists.

Applying both rural and urban design standards for DSD, researchers developed relationships to define the locations, or zone, along the signalized intersection approach with a vertical curve where a standard object within the RDZ cannot be seen by a driver. The graph of rural conditions is shown in Figure 2. For any approach speed and change in grade associated with the crest vertical curve, the figure shows the first and last points along the roadway where a 2-foot object cannot be seen with DSD by upstream drivers. All locations are referenced to the vertical point of intersection (VPI) of the vertical curve.

Researchers expanded their analysis of the RDZ to identify the location of the driver when the downstream object within the RDZ is first obscured by the vertical curve. Again, separate relationships were developed for rural and urban conditions, as the DSD criteria are different based on whether or not the roadway is located in an urban area. Figure 3 contains the graph developed for rural conditions. The figure pinpoints the location where drivers first cannot see the standard object height with DSD.

The before-and-after field tests of advanced warning signing indicated that the only significant speed difference at each of the project sites was a minor speed reduction, though whether drivers slowed approaching the signing or downstream of the signing varied by site.

The Researchers Recommend…

As a result of the literature review and examination of state and national signing requirements and guidelines, researchers recommend the BE PREPARED TO STOP sign (TMUTCD W20-7b) for advanced warning of signalized intersections or queues that are obscured by crest vertical curves. The TMUTCD requires that the BE PREPARED TO STOP sign be located upstream of a SIGNAL AHEAD text (W3-3a) or symbolic (W3-3) sign that is already correctly situated along the approach.

Object locations within the RDZ developed in this project should be used during design to identify locations where reduced decision zones exist. During the design process, the roadway engineer can avoid the location of intersections within these zones either by relocating the intersection or by changing the grades to reduce the size of the reduced decision zone.

Researchers recommend the use of the driver location graphs for the RDZ when placing advanced warning signing. A sign legibility distance of 175 feet should be removed from the location of the driver identified in the graphs. As a result, the sign would be located where it is understood by drivers just as they lose DSD perception of objects within the RDZ.

Finally, researchers recommended that in locations where the queue from the signal extends into an RDZ, active flashers be used only if they are tied to both the signal and a queue detection system. An alternative and less expensive mode of operation for this situation is simply to operate the flashers in a continuously flashing mode.

For More Details. . .

Report 4084-1, *Improving Safety at Signalized Intersections near Vertical Curves*

Report 4084-P1, *Guidelines for the Use of Countermeasures to Reduce Crashes on Approaches to Signalized Intersections near Vertical Curves*

Report 4084-P2, *Guidelines for Using Decision Sight Distance at Signalized Intersections near Vertical Curves*

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The objective of this research project was to investigate countermeasures that could be used to provide motorists with advance information of traffic signals or queues created by those signals that are located beyond the motorists' line of sight due to a crest vertical curve. Two products were required for this project: 1) guidelines for the use of countermeasures to reduce crashes o

intersections near vertical curves. These products are available for implementation by traffic signal engineers for the purpose of providing motorists with advance warning of traffic signals located beyond the crest of a vertical curve, pending review and approval by TxDOT traffic signal operations personnel.

For more information, contact Mr. Wade Odell, P.E., RTI Research Engineer, at (512) 465-7403 or email wodell@dot.state.tx.us.

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