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16. Abstract

This report documents the results of research performed to develop an improved understanding of delineation needs for bridges and culverts (especially those that are "narrow") and how those needs should best be accommodated through the delineation devices currently available for use in Texas. In this project, bridge and culvert delineation needs were approached from a motorist information need/positive guidance perspective. Considering only the driving maneuvers that must be accomplished in order for a motorist to safely negotiate a bridge or culvert, three different bridge/culvert conditions were identified. The type and location of information that motorists need to accommodate each type of maneuver were then examined, and delineation devices available to convey that information were critiqued. A controlled field study designed to investigate whether the amount and type of delineation provided at each of the three bridge/culvert conditions defined earlier affected driver performance found very few significant effects due to delineation. One exception to this finding was that the addition of a painted edgeline taper with transverse markings upstream of the shoulder drop bridge location resulted in subjects exiting from the shoulder 30 to 35 meters further upstream. Although current practices appear adequate at this time, it was recommended that minor adjustments be made to current TxDOT roadway delineation standard sheets to facilitate the understanding and consistent application of these bridge delineation practices statewide.

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DELINEATION OF BRIDGES AND CULVERTS IN TEXAS

by

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and

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Research Report 1366-1F
Research Study Number 0-1366
Research Study Title: Delineation Guidelines of
Bridges, Culverts, Barriers, and Crash Cushions

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IMPLEMENTATION STATEMENT

The results of controlled field studies conducted as part of this research do not suggest that a dramatic change from current TxDOT policies regarding bridge/culvert delineation is necessary. The results of these studies do suggest the continued use of a tapered edgeline/ transverse marking pattern at shoulder drop bridge locations where accidents are a problem or other evidence exists that drivers are not exiting the shoulder soon enough. It is recommended that minor adjustments be made to current roadway delineation standard sheets to facilitate the understanding and application of bridge delineation practices statewide. Appendix D provides recommended drawings that could be used to establish specific bridge delineation standard sheets.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report is not intended to constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the study was Dr. Gerald L. Ullman, P.E. #66876.

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SUMMARY

This report documents the results of research performed to develop an improved understanding of delineation needs for bridges and culverts (especially those that are "narrow") and how those needs should best be accommodated through the delineation devices currently available for use in Texas. Telephone interviews and site visits to various bridge and culvert locations throughout Texas provided a database of existing delineation practices statewide. Delineation practices vary widely from district to district, and to a lesser degree, can vary from bridge to bridge (of the same type) within a given district as well.

In this project, bridge and culvert delineation needs were approached from a motorist information need/positive guidance perspective. Considering only the driving maneuvers that must be accomplished in order for a motorist to safely negotiate a bridge or culvert, three different bridge/culvert conditions were identified. The type and location of information that motorists need to accommodate each type of maneuver were then examined, and delineation devices available to convey that information were critiqued.

Researchers conducted a controlled field study to investigate whether the amount and type of delineation provided at each of the three bridge/culvert conditions defined earlier affected driver performance. Even under rather adverse conditions studied (degraded delineation, presence of a glare source, and a secondary task activity to perform), very few significant differences were found between several driver performance measures as a function of the delineation treatment examined at a given bridge/culvert test location. It appeared that, for the most part, the various delineation treatments were equally effective in providing information to subjects that they needed to safely traverse the test course. The high rating subjects gave to all the delineation treatments at each of bridge locations tested supported this interpretation of the results.

One performance measure that was found to depend on the type of delineation treatment present was the distance upstream of the bridge where subjects began to exit a shoulder in advance of shoulder drop bridge location. The addition of a painted edgeline taper with transverse markings that began upstream of the bridge location resulted in subjects exiting from the shoulder 30 to 35 meters further upstream. This equates to drivers having an additional 1.0 to 1.5 seconds of travel time (depending on speed) to react to the upcoming loss of the shoulder. It is hypothesized that because the edgeline provides continuous control-level information for the driving task, it is given a high level of priority by approaching motorists.

1. INTRODUCTION

According to the *Roadway Delineation Practices Handbook* (RDPH), the intent of roadway delineation is to help regulate, warn, and provide tracking information and guidance to the driver (*1*). Research over the past several decades clearly indicates that delineation is in general an effective roadway safety treatment and has become an established component of the highway system. However, this does not mean that delineation alone is a panacea for all roadway safety problems. In fact, roadway safety does not automatically improve if additional delineation is added at a point or along a roadway segment. It is even possible that excessive delineation can lead to operational problems in some instances. Hence, the goal of the transportation agency is to utilize an effective system of delineation techniques for a given condition at the least cost (*1*).

STATEMENT OF THE PROBLEM

One type of location where many consider special delineation to be useful and necessary is on the approaches to, and lengths of, roadway bridges and culverts. Bridges and culverts are places where hazards of varying degrees of severity (i.e., headwall abutments, bridge rails, ravines, etc.) are in close proximity to moving traffic. Very little guidance is provided in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*2*), the *Traffic Control Devices Handbook* (TCDH) (*3*) or the RDPH about delineating bridges and culverts. Several reasons exist for this lack of specific delineation criteria. For example, bridge and culvert delineation is a part of the overall delineation system used on a roadway segment, and must be considered in context of that overall system. Furthermore, design characteristics of bridges and culverts can vary widely in terms of width, length, type of bridge railing, end treatments, etc., which may affect the amounts and types of delineation needed or desired by drivers. Lastly, very little is known about how different bridge delineation components and systems affect driver behavior and safety.

In the past, a distinction has been made between normal or regular width bridges and bridges considered to be "narrow." Narrow bridges are specifically discussed in the MUTCD, defined as bridges and culverts having 4.9 to 5.5 meters of pavement available for two-way traffic or having a roadway clearance less than the width of the approach pavement (*2*). The manual specifies advance signing to be provided for these conditions and recommends that supplemental object markers, delineators, and pavement markings also be provided as per engineering judgment.

Although this definition of narrow may be appropriate for certain situations (such as on two-lane, two-way highways without paved shoulders), its relevance to other situations was less clear. For example, numerous bridges in Texas carry two or more travel lanes per direction across a span but have paved shoulders that are slightly smaller than those on the approach to the bridge. Under the MUTCD definition, these bridges are considered to be narrow and are to be signed and delineated as such (although exactly how they should be delineated is not identified). Conversely, bridges on two-lane highways without shoulders that carry a continuous pavement width across their spans only slightly greater than 5.5 meters would not considered to be narrow by the MUTCD definition, even if the bridge rails are located immediately next to the edge of the travel lane. Unfortunately, very little systematic research has been performed to assess the effects, costs, and benefits of different bridge delineation treatments to determine what is truly needed and useful to the driver and practical for the transportation agency to install and maintain.

As part of the Intermodal Surface Transportation Efficiency Act (ISTEA) passed by Congress, the Federal Highway Administration (FHWA) was charged with developing and adopting minimum retroreflectivity standards for traffic control devices (*4*). The impending adoption of retroreflectivity standards for signs and the likely future adoption of similar standards for pavement markings and other reflectors made it imperative that state transportation agencies such as the Texas Department of Transportation (TxDOT) establish better delineation guidelines for various bridge conditions. Such guidelines would help ensure that motorist bridge delineation needs are adequately addressed while at the same time protecting the Department from having to monitor and maintain unnecessary or excessive delineation devices at federally-mandated minimum retroreflectivity levels.

RESEARCH OBJECTIVES

This report summarizes the research performed by the Texas Transportation Institute (TTI) for TxDOT, in cooperation with FHWA, to establish improved delineation guidelines for bridges and culverts. In addition, delineation recommendations were also desired for concrete barriers and crash cushions. The specific objectives of the research were as follows:

1. Develop a clear and consistent definition of a narrow bridge or culvert based on the perceptions and delineation needs of approaching motorists.

2. Identify the most cost-effective delineation treatments for approaches to narrow bridges and culverts based on motorist needs as well as TxDOT installation and maintenance requirements.

3. Identify the most cost-effective delineation treatments for bridge rails, concrete barriers, and crash cushions as a function of roadway type, location, proximity to travel lanes, etc.

4. Develop draft standard sheets for the recommended delineation schemes.

ORGANIZATION OF THIS REPORT

This report consists of five main chapters. Following this introduction, Chapter 2 presents a review of past roadway and bridge/culvert delineation research applicable to this particular project as well as an overview of the different bridge and culvert delineation schemes in use within Texas. Chapter 3 describes an engineering analysis of motorist information/delineation needs for different bridge approach conditions, based on human factors principles of positive guidance. That chapter also includes an analysis of the costs and functions of alternative bridge/culvert delineation devices related to the information needs identified through the positive guidance analysis. Chapter 4 presents the procedures and results of controlled field studies conducted to determine driver response to alternative bridge delineation systems. These studies were conducted at the TTI Proving Grounds at the Texas A&M University Riverside Campus. Chapter 5 presents a summary of the major findings from the research activities and recommendations for bridge and culvert delineation.

2. BACKGROUND

REVIEW OF PAST BRIDGE AND CULVERT DELINEATION RESEARCH

Driver Visibility Needs

As noted in the *Roadway Delineation Practices Handbook,* the ability of a driver to operate a vehicle safely is based on the driver's perception of a situation, his or her level of alertness, the amount of information available about the situation, and the driver's ability to assimilate the information (*1*). The driving task can be defined in terms of three basic components:

- **Control**--The physical manipulation of the vehicle, maintaining lateral and longitudinal control of the vehicle by means of the steering wheel, accelerator, and brake.
- **Guidance**--The selection of a safe speed and path through a decision process involving evaluation of the situational characteristics and the transformation of that decision process into control actions (selecting lane position, headway, passing opportunities, etc.).
- **Navigation**--The planning and execution of the trip from origin to destination.

These three basic components are also hierarchial in nature. Control level actions are more urgent than guidance level actions, which in turn are more urgent than navigation level actions. Stated another way, failure of guidance level information will lead to failures in the navigation actions of the driving task. Similarly, failure of control level actions leads to cascaded failures in both the guidance and navigation level actions.

Delineation systems are implemented on roadways to assist primarily in the control and guidance portions of the driving task. In order for delineation to be effective, the following steps (similar to those identified for motorist response to highway signs) must occur. These steps are as follows:

- the driver detects a change in delineation associated with a necessary change in driving behavior (a turn, a curve, a freeway exit ramp, etc.),
- the driver recognizes the message that the delineation system conveys,
- the driver decides upon the appropriate action,
- the driver initiates a response, and
- the driver completes the vehicle maneuver.

As such, delineation must be both visible to the driver and properly interpreted. Several criteria define delineation visibility. The *Handbook* refers to these in the following manner (*1*):

- **Luminance**--The amount of light a driver receives from the delineation.
- **Contrast**--The ratio of luminance from the delineation to the luminance from its surroundings.

- **Conspicuity**--The likelihood that a driver will notice the delineation or be able to identify it from its surroundings.
- **Legibility**--The probability that a driver will understand the message the delineation is meant to convey.

Depending on the type of delineation device being considered, any one of these criteria can be critical in how effective it is as a traffic control device. Some delineation devices are intended to present only very limited information (i.e., centerline location) and so are very legible to drivers, but are effective only if they exceed some threshold luminance level. Other devices may possess adequate contrast and conspicuity but be a hazard to motorists because they do not provide adequate legibility concerning the proper driver response (such as might occur if old pavement markings are not obliterated within a construction zone, for example). Some of these deficiencies can be overcome by the proper combination of delineation devices. Consequently, it is important to consider delineation effectiveness from a systems perspective, rather than only in terms of individual device performance. Finally, it is also important to remember that more than one type of device may be able to accomplish the same function or purpose. As such, there are typically many possible combinations of delineation devices that can achieve the same driver response objective in a given situation.

Field Evaluations of Bridge/Culvert Delineation

In 1979, Ivey et al. published the results of an extensive study of safety and driver behavior at narrow bridge sites (*5*). Researchers analyzed accident rates at bridges and roadways of various widths and changes in driver lateral position. Changes in lateral position as drivers approached the bridge were taken to indicate that they perceived the bridge as a hazard. The accident data indicated that all narrow bridges were not necessarily hazardous bridges and vice-versa. From their driver behavior research, the researchers concluded that changes in lateral position were a function of both the absolute width of the bridge and the relative width of the bridge (the difference between the bridge width and the width of the approaching roadway). Their data indicated that once the width of both the bridge and the approaching roadway reached somewhere between 9.1 and 12.2 meters, the bridge had no influence upon driver lateral positioning. For bridges less than 8.2 meters (but more than 5.5 meters), the researchers suggested that the ratio of the bridge width to roadway width needed to exceed 1.25 in order for the bridge not to be perceived as narrow by motorists. Also, they suggested that bridges between 5.5 and 7.3 meters be considered restricted-width bridges, but not necessarily hazardous.

The researchers also investigated the effect of bridge improvements (including enhanced delineation treatments) at several bridge sites and found a significant reduction in bridge accidents after the improvements were implemented. They recommended several alternative delineation improvements to assist driver guidance and control tasks approaching narrow or restricted-width bridges. The suggested improvements included:

- edgelines (where they are not used already);
- pavement transition markings (edgeline transition, transverse markings, etc.);
- narrow bridge sign;

- stop or yield signs; and
- advisory speed signs.

Unfortunately, that study provided no specific information on which improvement or combination of improvements was more effective, or under which conditions each improvement was most suited.

More recently, Bowman and Brinkman (*6*) evaluated the effect of various combinations of advance warning (narrow bridge) signs, painted roadway edgelines, raised pavement markers on the edgelines and centerlines, type 2 and 3 object markers, and roadside delineators upon vehicle speeds and lateral placement approaching 18 narrow bridge sites. They concluded that the various delineation treatments tested had very little effect upon average values of these operational measures. Meanwhile, Niessner (*7*) examined the use of raised pavement markers (RPMs) on narrow bridge approaches and concluded that the treatment reduced the frequency of nighttime high-speed vehicles at one of the sites. However, similar changes were not evident at the other sites. This is a common problem when attempting to evaluate delineation treatments in actual field testing. Typically, the effect of the many site-specific factors that affect driving behavior but which cannot be controlled in an actual roadway situation overwhelm any variations that might occur due to differences in the delineation treatments themselves.

Unfortunately, difficulties in delineation evaluation are not limited to the use of operational measures. For example, Niessner also attempted to compare accident frequencies at the narrow bridge sites in order to assess the effect of RPMs on safety. However, since narrow bridges and culverts tend to be located on low-volume rural highways, the accident frequencies in his evaluation were too low to allow meaningful statistical comparisons of delineation effectiveness. Similarly, Niessner also examined accident trends associated with the use of post-mounted delineators (PMDs) on highways in eight states (*8*). Again, the data were inconclusive, although the trend suggested a small reduction in run-off-the-road accidents when PMDs were installed.

Laboratory Evaluations

The literature that deals strictly with delineation systems for bridges or culverts does not describe any laboratory evaluations. However, a number of studies has been performed over the years on roadway delineation in general (i.e., various combinations of painted and raised pavement markings, object markers, post-mounted delineators, etc.) and their effect upon driver control and guidance tasks during curve negotiation and hazard identification. The following represents a compilation of general findings from this body of research:

- Providing drivers a minimum of two seconds preview time of the basic roadway alignment ahead results in optimum vehicle control behavior (as measured by lane-tracking errors, lateral position variability, and steering wheel movements) (*9, 10*). Providing additional preview time (up to about three or four seconds) does not result in additional improvements in control (*10-12*), but has been shown to assist drivers in their guidance decisions (*1*).

- Continuous (short-range) delineation such as centerlines and edgelines are associated with improved vehicle curve tracking scores, whereas discrete delineation, such as post-mounted delineators or chevrons, do not consistently improve driver control behavior (*13*).
- Drivers perceive that post-mounted delineators assist them in making vehicle guidance decisions (*13*).
- Roadside delineator size does not significantly affect a driver's ability to detect changes in roadway alignment, such as at horizontal curves. Spacing of delineators does have an influence, however, with spacings greater than those specified in the MUTCD resulting in poorer alignment recognition accuracy (*14*).
- The brightness of delineation is not as critical as having the information visible at the proper location in the visual field (*10-12)*.
- Unexpected hazards (such as changes in alignment or lane closures that typically exist at work zones) need delineation that provides a preview time of up to 10 to 12 seconds in order for motorists to adequately perceive and react to the hazard (*15*).
- Typically, drivers and traffic experts usually rated delineation systems with larger, brighter, and more frequent delineation elements as higher or most acceptable (*16-19*). Unfortunately, whether or not these systems offer any measurable benefit to the driving task above and beyond a less acceptable delineation system is not answered in this type of evaluation.

Summary

Although the database of research regarding roadway delineation is fairly extensive, relatively few studies focus on how best to properly delineate point hazards such as culvert or bridge ends so that driver control and guidance actions (and presumably safety) approaching and crossing the bridge/culvert structure are optimized at an acceptable cost. Field evaluations do suggest that enhanced delineation (of many different types) at hazardous narrow bridges can reduce accidents. However, exactly which delineation device or devices perform best cannot be ascertained due to the wide variation in site characteristics where the devices are tested (which precludes direct performance comparison across delineation treatments). Other vehicle operation measures in the field also suffer from the influence of site characteristics and make evaluation difficult. Laboratory studies have focused primarily on the effects of delineation on curve negotiation and turning behavior rather than on negotiating safely over bridges or culverts. A major question that has yet to be answered is what level of delineation is actually necessary to safely negotiate bridges and culverts of various designs.

BRIDGE AND CULVERT DELINEATION PRACTICES IN TEXAS

A review of existing delineation practices for both narrow and non-narrow bridges and culverts from a sample of TxDOT districts within Texas indicates that while all bridges and culverts generally receive some type of delineation, the specific system of delineation devices does vary from district to district, and to a lesser degree, from bridge to bridge within a given district. Some degree of variability is to be expected. Bridges themselves have been designed differently over the years (concrete or steel channel bridge rails, guardrail protection of the bridge ends, etc.). Transportation agencies such as TxDOT typically install delineation systems at a location according to practices current at the time of construction. As additional information and experience accumulate, these practices may change over time. It is not economically feasible for agencies to continually change out delineation treatments as these practices change, especially since it is difficult to correlate specific safety or operational benefits to a given delineation treatment.

Generally speaking, delineation of the approach to bridges and culverts consists of lane or centerline markings (usually supplemented with retroreflective raised pavement markers), plus some combination of the following devices:

- type 2 object markers,
- type 3 object markers,
- post-mounted delineators,
- painted edgelines,
- transverse shoulder marking patterns,
- advance warning signs ("Narrow Bridge" W5-2 or W5-2a),
- guardrail reflectors,
- raised pavement markers (on the shoulder), and
- jiggle bars (on the shoulder).

For bridges and culverts on low-volume rural roadways where guardrails do not protect the bridge ends, the simplest system identified consists of a single object marker (Type 2 or 3) positioned at the end of the bridge or culvert on each side of the roadway (see Figures 2-1 and 2-2).

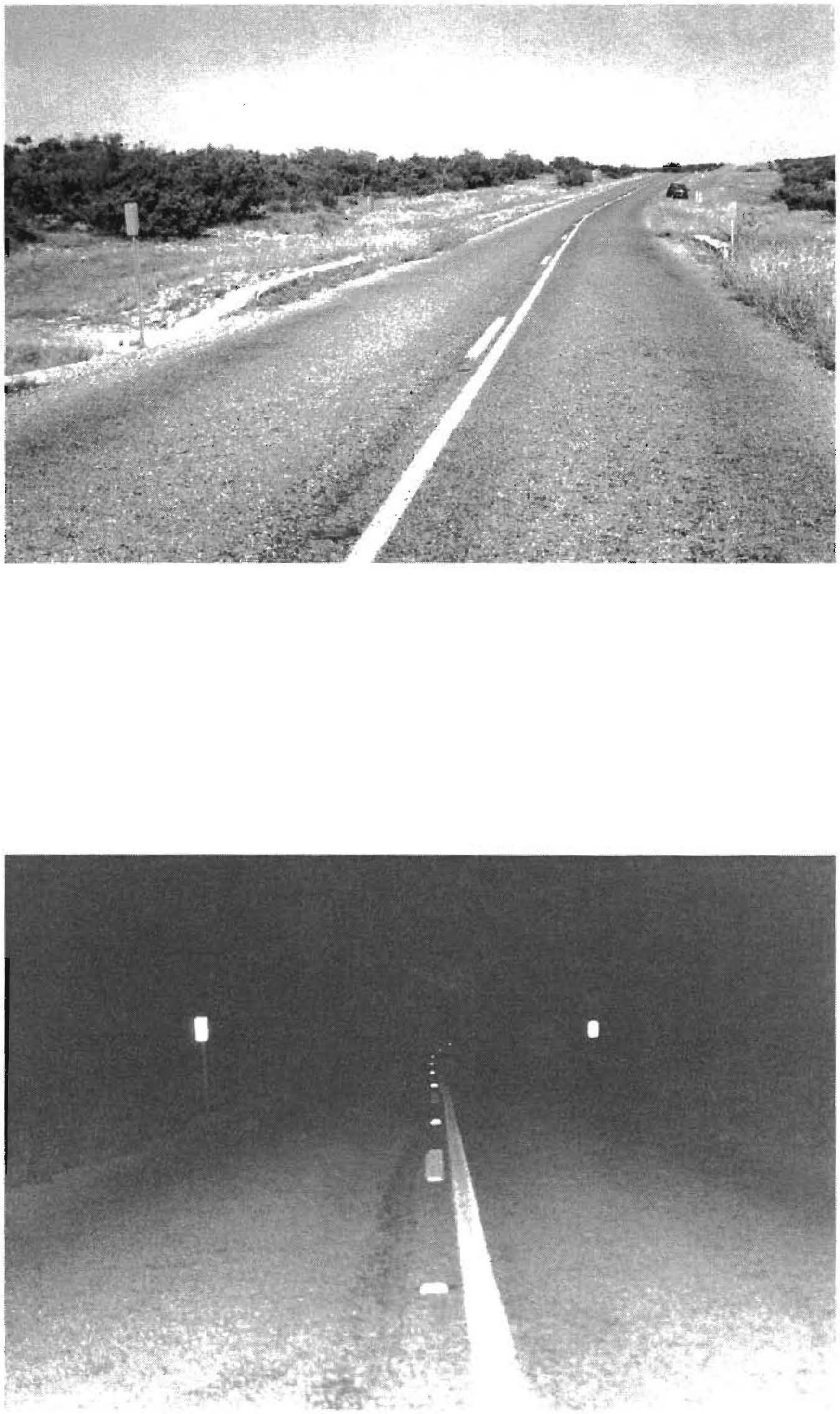


FIGURE 2-1. Type OM-2 Object Markers at Culvert Ends

FIGURE 2-2. Type OM-3L and OM-3R Object Markers at Bridge Ends

FIGURE 2-2. Type OM-3L and OM-3R Object Markers at Bridge Ends

Many districts, however, opt to include three post-mounted delineators spaced approximately 7 to 15 meters apart and positioned along a diagonal away from the abutment (see Figures 2-3 and 2-4). Presumably, this is done to improve the driver's perception of restricted width as they approach the bridge or culvert. A "Narrow Bridge" sign (W5-2 or W5-2a) is sometimes placed upstream of the bridge or culvert. Sometimes, a "Narrow Bridge" sign is used even if the bridge does not fall strictly within the MUTCD definition of a narrow bridge.

For bridges with ends protected by W-beam guardrail, Type 2 or 3 objects are again used to identify the bridge end, and an additional Type 2 object marker is also used to mark the beginning of the guardrail when a turn-down end treatment is used. In many instances, post-mounted delineators behind the approach guardrail or guardrail delineators (both placed 7 to 15 meters apart) are installed to further delineate the guardrail and bridge approach (see Figure 2-5). In one TxDOT district, some bridges located on roadways too narrow to include a continuous edgeline do have short sections of edgeline painted on the approach to the bridge and continuing over the span a short distance (see Figure 2-6).

On both two-lane, two-way, and multi-lane bridges where a paved shoulder is not carried over a bridge span, a transverse marking pattern using painted lines, retroreflective raised pavement markers, and jiggle bars is sometimes placed on the shoulder (see Figure 2-7). This is a fairly elaborate delineation system that provides both visual and tactile information to drivers that they should discontinue driving on the shoulder. According to TxDOT officials, this treatment is most commonly used where an accident problem of vehicles impacting the bridge abutment has been identified.

FIGURE 2-3. Type OM-2 Object Markers and Post-Mounted Delineators at Bridge Ends

FIGURE 2-4. Type OM-3L and OM-3R Object Markers and Post-Mounted Delineators at Bridge Ends

FIGURE 2-5. Type OM-3L, OM-3R, and Type OM-2 Object Markers and Guiderail Delineators at Bridge Ends

FIGURE 2-6. Type OM-2 Object Markers, Post-Mounted Delineators, and a 65-Meter Segment of Edgeline Approaching the Bridge Ends

FIGURE 2-7. Type OM-3L, OM-3R, OM-2 Object Markers, Post-Mounted Delineators, and a Transverse Marking Pattern on Shoulder Approaching the Bridge Ends

3. MOTORIST INFORMATION NEEDS AT BRIDGES AND CULVERTS

INTRODUCTION

One of the objectives of this research project was to establish an improved definition of what constitutes a narrow bridge or culvert from the perspective of motorist delineation needs. Past research has focused on motorist lateral positioning behavior as an indication of whether or not motorists perceive a bridge to be "narrow" (*5*). The argument is if a motorist moves his or her vehicle laterally towards the center of the roadway approaching a bridge or culvert, he or she must perceive the bridge rails or abutments as a hazard. A general relationship was demonstrated between the bridge width and lateral movement near the bridge, which was then used to estimate the bridge width at which a motorist no longer moves laterally (and so presumably does not perceive the bridge as narrow or a hazard). A general relationship between lateral movement and the ratio of the bridge width to the approach roadway width was also demonstrated. In general, the available data suggested that total bridge widths greater than about 9 to 11 meters <u>and</u> bridge width-to-roadway width ratios greater than 1.25 did not cause significant lateral movement and therefore were not perceived to be a hazard or narrow by motorists (*5*). However, there is considerable scatter in the data; some bridges as narrow as 7 meters wide were found to have no effect upon drivers lateral position, whereas some bridges 9 meters wide caused drivers to move laterally nearly 1.2 meters to the centerline as they approached the bridge.

These behavioral criteria do provide some indication of the upper bound of the widths where bridge structures no longer affect drivers. The criteria cannot be applied automatically to all bridges, though, because the database used for their development was limited to bridges up to 11 meters wide on two-lane, two-way highways. The criteria correlate fairly well with analysis procedures found in the 1994 *Highway Capacity Manual* (*20*), which utilize a capacity reduction factor to account for any objects closer than 1.8 meters from a travel lane. Interestingly, a bridge rail's effect upon capacity on a two-lane highway is said to be negligible if the total bridge width is also 11 meters or greater (assuming two 3.7-meter lanes and a 1.8-meter or greater shoulder on each side).

Unfortunately, although useful to the understanding of motorist behavior as they approach and travel over bridges and culverts, there is little evidence to indicate that a driver's lateral position response alone (and thus absolute or relative bridge width) corresponds to the crash history at a bridge site. As stated in the above-referenced research, a narrow or restricted-width bridge or culvert is not necessarily a hazardous bridge and vice-versa. Consequently, researchers should also consider factors other than driver lateral position responses when attempting to determine driver delineation needs at bridges and culverts.

This chapter considers delineation needs for a bridge or culvert from the perspective of what a motorist must do in order to safely negotiate the structure. Although bridge and culvert designs can vary dramatically, the number of different driver maneuvers <u>required</u> as he or she approaches a structure is relatively small. For each of these maneuvers, basic positive guidance procedures (*21*) can be used to gain insight into defining what delineation information drivers need and where that information should be placed.

CATEGORIES OF REQUIRED DRIVING MANEUVERS AT BRIDGES AND CULVERTS

From the standpoint of what a reasonable, safe, and prudent driver must do approaching a bridge or culvert, three basic maneuvers can be identified. These are as follows:

1. A driver approaching the bridge or culvert, properly positioned within the travel lane, can pass over the structure without having to make any adjustments in lane position. Figure 3-1 illustrates this maneuver. The driver may indeed move laterally towards the center of the roadway upon reaching the bridge if unopposed by oncoming traffic (depending on bridge width, driver preferences, approach alignment, etc.), but this maneuver is a function of the driver's degree of comfort with the location of the bridge rail and other roadway/environmental factors rather than a required response in order to safely negotiate the bridge.

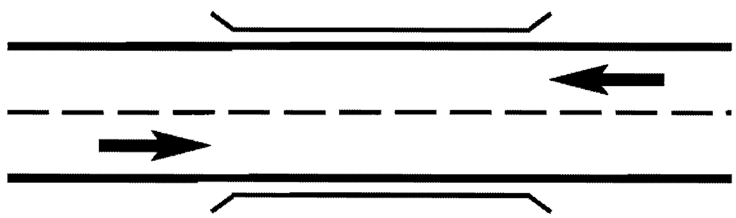


FIGURE 3-1. A Regular (No-Required-Maneuver) Bridge/Culvert

2. The second category involves a driver properly positioned in the travel lane upstream of the bridge who may need to move laterally in order to safely negotiate the bridge. Figure 3-2 illustrates this maneuver. Not all drivers would have to make an adjustment laterally (if they were already located close to the centerline, for example, and in a small vehicle). However, those drivers in larger vehicles and/or traveling in the right portion of the travel lane would be required to make a lateral adjustment.

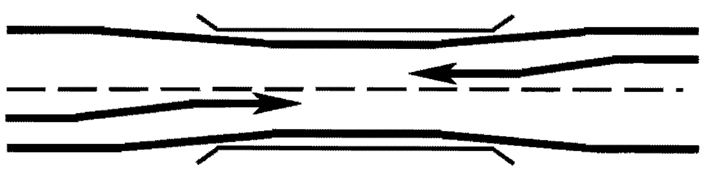


FIGURE 3-2. Narrowed Lane Bridge/Culvert

3. The third and final category involves a driver choosing to travel on the paved shoulder who must completely vacate the shoulder prior to reaching the bridge because the shoulder has not been carried across the span. Figure 3-3 illustrates this condition. This is the most significant category in terms of required lateral movement. Furthermore, the response is required of every driver who is traveling on the shoulder. Meanwhile, motorists already traveling in the regular travel lane are not required to move laterally (although, again, they may do so by choice).

Although the figures all depict bridges on two-lane, two-way highways, the three categories of maneuvers can occur on multilane facilities as well (although a narrowed lane bridge condition may be fairly unlikely on multilane facilities). Also, it is possible that a paved shoulder is not eliminated totally across a bridge span, but reduced in width. This would simply then move the maneuver from the shoulder drop condition to a narrowed lane condition, with the shoulder representing the lane that is narrowed over the bridge or culvert.

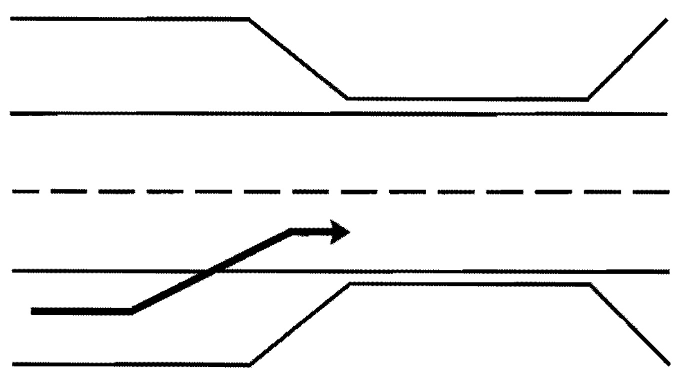


FIGURE 3-3. Shoulder Drop Bridge/Culvert

DRIVER INFORMATION NEEDS AT BRIDGES AND CULVERTS

Positive guidance procedures (*21*) provide a mechanism for assessing information needs and characteristics of different types of roadway hazards (such as bridges and culverts). The model divides the approach to a hazard into five different information handling zones to assess hazard visibility and to identify where hazard-related information should be located. These zones are defined as follows:

- advance zone,
- approach zone,
- non-recovery zone,
- hazard zone, and
- downstream zone.

Figure 3-4 illustrates these various zones. Of these, the middle three zones (approach, non-recovery, and hazard) are the most critical from a hazard delineation system design perspective. Information necessary to make that avoidance maneuver must be properly located within these zones, depending on the type of maneuver that is required by the driver to avoid the hazard.

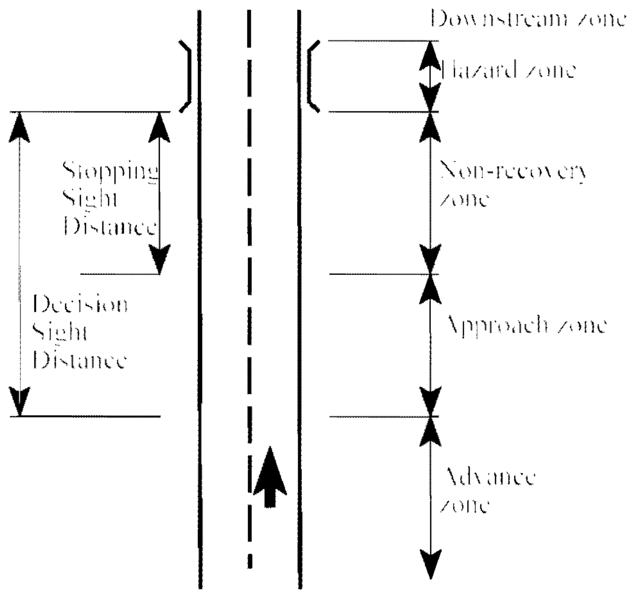


FIGURE 3-4.Information Handling Zones Upstream of a Bridge/Culvert

Positive guidance procedures consider two basic types of hazard avoidance maneuvers to determine appropriate visibility distances and/or locations where hazard information should be received. The first of these is a stop maneuver, applicable to intersections, railroad-grade crossings, and other conditions where a full stop may be required. The second is a speed/path/direction change. According to the positive guidance procedures, drivers having to make a speed/path/direction change maneuver should have information needed to decide that such a maneuver is necessary by the time they reach the non-recovery zone (approximately 170 to 260 meters upstream of the bridge for speeds of 88 to 113 km/h).

Both the narrowed lane and shoulder drop bridge conditions require a path change in order to safely negotiate the bridge structure. Conversely, drivers approaching a regular (nonnarrowed) bridge structure only need to be aware of the presence of a nearby obstacle (i.e., the bridge abutment and railing) to validate the proper positioning of the vehicle. However, there is a major difference in the type of path change required by the narrowed lane and shoulder drop bridge conditions. Specifically, the shoulder drop requires a complete lane shift, compared to a smaller lateral shift in the travel lane for the narrowed lane condition.

From the perspective of the hierarchial driving task model (consisting of control, guidance, and navigation levels of performance as discussed in Chapter 2) the smaller lateral adjustments required in a narrowed lane condition are addressed primarily through minor alterations in the control-level actions of the driving task, whereas a complete lateral shift to an adjacent lane requires guidance-level decisions as well (particularly when and where to begin to vacate the lane). This implies that information needs upstream of the bridge in the approach zone are more significant for the shoulder drop condition than for the narrowed lane condition. Furthermore, one would also expect that the influence of any information presented upstream (primarily to assist in the guidance level of the driving task) would be less for the narrowed lane condition that requires mostly control-level responses than for the shoulder drop condition that also involves guidance-level responses.

Table 3-1 summarizes the costs and some basic characteristics relative to driver perception and performance for the different types of bridge delineation devices observed in use in Texas. Because most delineation devices assist in more than one level of the driving task (i.e., an object marker can be important to the driver during both the guidance and control levels of the driving task), it is difficult to assess the impact or capability of any one device or series of devices with respect to the information needs for a given bridge condition. However, a few general statements can be made about each device's potential role at the three bridge conditions defined previously. The following sections critique the various device that were observed in use at bridge/culvert sites in Texas from a positive guidance perspective.

Regular Bridge Delineation

- **Object Markers**--Both OM-2s and OM-3s serve the same basic function of identifying the presence of a hazard adjacent to the roadway at bridge/culvert locations where no lateral movement by vehicles approaching the bridge is required. Generally speaking, OM-3s will be seen from a greater distance upstream and are designed to inform via the diagonal stripes that drivers should steer to one side of the device (although it is unclear exactly how well drivers understand the meaning of the diagonal stripes).

- **Post-Mounted Delineators**--Mounted either behind a guardrail end treatment or in a flared pattern outward from a bridge abutment (in conjunction with object markers), the devices are intended to call additional attention to the bridge hazard. Placed behind the guardrail, they provide bridge approach alignment information to drivers. Placed in the flared pattern, the devices create a delineation "funnel" to approaching motorists intended to emphasize the close proximity of bridge abutments (see Figure 2-3). This is a form of guidance-level information (although the degree to which it is effective has not been determined objectively).

TABLE 3-1. Characteristics of Alternative Bridge Delineation Devices

Device	Cost	Characteristics
Type OM-2 Marker	$25 ea.	• used to identify presence of an object adjacent to the roadway • quite prevalent on some roadways to denote mailboxes, water inlets, etc.
Type OM-3L/3R Marker	$70 ea.	• can be used to identify objects within or adjacent to roadway • provides information on which side drivers should pass • larger surface area increases its detection distance over OM-2 • intended to be used where added hazard emphasis is needed
Post-Mounted Delineator (PMDs)	$30 ea.	• designed to provide long-range nighttime delineation of roadway alignment • identifies edge of roadway and critical locations (used in series) • serve as surrogate of pavement delineation during periods of rain, fog, or snow (but does not provide same level of control information to drivers)
RRPMs/ Jiggle Bars	$2.50 ea. $8 ea.	• RRPMs provide both short- and long-range visual delineation • RRPMs and jiggle bars provide tactile and auditory feedback as well • fairly expensive to install and maintain
Edgelines/ Shoulder Tranverse Markings	$0.56/m	• provides continuous short-range delineation about roadway alignment • inexpensive • typically obscured at night in rain or snow
Guardrail Delineators	$20 ea.	• mounted lower than height of typical PMDs and OM-2s • not used in conjunction with PMDs behind the guardrail
Advance Signing (Narrow Bridge, Shoulder Ends)	$140 ea.	• intended to complement roadway delineation in special situations • placed stopping sight distance upstream of hazard being identified • more significant information processing time than roadway delineation

- **Guardrail Delineators**--Function similarly to PMDs placed behind a guardrail, giving guidance-level bridge approach alignment information to drivers. The effect of height differential between object markers and delineators upon driver perception and recognition of bridge as hazard is not known.

- **Advance Signing** (narrow bridge if both pavement width and bridge width is less than 5.5 meters)--Gives supplemental warning (guidance-level) information to drivers at a single point upstream of the bridge. Information that a downstream hazard exists is provided within the proper information handling zone (which can change driver expectations and response time), but exactly what the driver must do at the bridge still requires additional information via downstream object markers at the bridge, the centerline or edgeline alignment approaching the bridge, etc.

Narrowed Lane Bridge Delineation

- **Object Markers**--Again, both OM-2s and OM-3s could serve the same basic function of identifying the presence of a hazard adjacent to the roadway at bridge/culvert locations where small lateral movement by vehicles approaching the bridge may be required. From the perspective of the approaching motorist, though, the abutment could appear to be an object within the roadway if the lane restriction were severe enough. In this situation, OM-3s would seem more appropriate, indicating an apparent presence of an object within the roadway and providing positive information concerning where the vehicle should be directed (again, assuming drivers comprehend the directional information from the diagonal stripes).

- **Post-Mounted Delineators**--Mounted either behind a guardrail end treatment or in a flared pattern outward from a bridge abutment (in conjunction with object markers), the devices are intended to call additional attention to the bridge hazard in this situation as well. Placed behind the guardrail, they provide bridge approach alignment information to drivers. Placed in the flared pattern, the devices create a delineation "funnel" to approaching motorists intended to emphasize the close proximity of bridge abutments (see Figure 2-3). Effect of this funnel upon behavior is not known.

- **Guardrail Delineators**--Function similarly to PMDs placed behind a guardrail, giving guidance-level bridge approach alignment information to drivers. The effect of height differential between object markers and delineators upon driver perception and recognition of bridge as a hazard is not known. Also, many narrowed lane bridge/culverts do not have guardrail to mount delineators upon.

- **Advance Signing** (narrow bridge)--Gives supplemental warning (guidance-level) information to drivers at a single point upstream of the bridge. Again, expectancies may be modified (if the sign is seen), but specific actions to be taken (i.e., to move laterally) require additional downstream information.

- **Edgeline Segment** (where edgeline is not provided continuously on roadway)--Can provide control level information continuously to drivers approaching the bridge. The addition of retroreflective raised pavement markers (RRPMs) on the edgeline could provide guidance information as well. Both devices have fairly short service lives relative to object markers, PMDs, or signs, however.

Shoulder Drop Bridge Delineation

- **Object Markers**--OM-2s and OM-3s serve different functions at bridge/culvert locations involving a paved shoulder drop. Since vehicles are legally allowed to travel on paved shoulders in Texas, the bridge abutment at the point of the shoulder drop truly represents an obstacle within the roadway, and so should be delineated by an OM-3R (*2*). Conversely, OM-2s or OM-3s could be used to identify beginning sections of guardrail (if present to protect the bridge abutment). OM-2s are probably better suited for this task, thereby differentiating between the lower degree of hazard presented by the guardrail end (delineated via an OM-2) and the greater hazard that exists at the bridge abutment (and delineated by an OM-3).

- **Post-Mounted Delineators**--Mounted behind a guardrail end treatment are intended to call additional attention to the bridge hazard. They could provide bridge approach alignment information to drivers, alerting the motorist in the shoulder that alignment ahead must change dramatically. Specific layout of the PMDs would depend on the design of the transition guardrail, which could affect how the PMDs are perceived.

- **Guardrail Delineators**--Function similarly to PMDs placed behind a guardrail, giving guidance-level bridge approach alignment information to drivers.

- **Advance Signing** (narrow bridge, shoulder ends ahead)--Gives supplemental warning (guidance-level) information to drivers at a single point upstream of the bridge. Both imply that a restrictive condition is about to be encountered. A "Shoulder Ends" sign, although not currently included in the MUTCD (*2*), provides specific information directed towards a specific group of drivers (those on the shoulder) and implies that an action will be necessary (to move out of the paved shoulder area). Conversely, the "Narrow Bridge" sign does not convey this same type of specific information. According to the MUTCD, all bridges of this type would also be considered narrow.

- **Tapered Edgeline/Transverse Shoulder Markings**--Provides continuous control-level information to move drivers left out of the closed lane. Furthermore, drivers begin receiving this information upstream, in the advance information handling zone. If RRPMs are present, long-range (guidance) information could be available as well. The amount of long-range information reduces over time, however, as the RRPMs degrade.

Summary

For the most part, the same basic types of delineation devices can be used at each of the three types of bridge/culvert conditions that have been defined as part of this research. This is exactly why it is important to try and establish clear and consistent delineation practices for different types of bridge/culvert conditions. From the previous sections, it is quite clear that motorists are required to maneuver their vehicles in very different ways approaching a given bridge/culvert, depending upon its configuration and their approach position. Unfortunately, it is rather difficult for drivers to establish any type of expectancies with respect to what they will be required to do as they approach a bridge/culvert on the basis of what they see. Any one of several devices may be present, alone or in combination with other devices. An OM-3 object marker, for example, might mark the location of a bridge abutment located several meters away from the travel lane or one that is right next to that lane.

One of the big questions that arises, then, is whether differences in how bridges/culverts are delineated has any type of significant effect upon safety and operations of traffic approaching the bridge. Thus, one of the more pressing needs that exists with respect to bridge delineation is to determine if, and to what degree, differing levels of delineation affects driving behavior (and so by inference, safety) at bridge/culvert locations. In the next chapter, the results of a controlled field study are described where differing levels of bridge delineation are evaluated at each of the three different types of bridge conditions described earlier in this chapter. The intent of the study was to determine whether consistent differences in driving behavior approaching these types of bridge/culvert sites could be detected on the basis of the type of delineation system present.

4. CONTROLLED FIELD STUDIES OF ALTERNATIVE BRIDGE AND CULVERT DELINEATION SYSTEMS

INTRODUCTION

The previous chapter described a categorization of bridge and culvert approaches on the basis of the driving maneuver required for motorists to safely negotiate the bridge or culvert structure. In the simplest terms, bridges where the travel lane is narrowed or where a paved shoulder is dropped or reduced dramatically require that motorists be made aware that they need to adjust their travel path either by a smaller lateral shift in the travel lane or a complete movement out of the shoulder. Properly conveying the information about these necessary maneuvers is the task of the delineation system installed at a particular bridge or culvert.

From the review of literature and existing bridge and culvert delineation practices across the state, it is evident that there are several different delineation systems in place which attempt to convey this necessary information to motorists. From a positive guidance perspective, several different devices and/or systems could be argued as adequately providing this necessary information. The real question, though, is whether motorists correctly detect, perceive, and respond to such delineation systems. To determine this, it is necessary to examine how drivers actually react to the different systems. However, this study did not uncover any past research that directly examined these different bridge delineation treatments in a controlled setting, which would allow direct comparisons of driver behavior between treatments. From the standpoint of establishing realistic standards and guidelines for bridge and culvert delineation, it is important to know whether or not these different delineation systems result in observable changes in driver behavior as motorists approach a given type of bridge or culvert. The studies described in this chapter were undertaken in order to investigate that particular question.

STUDY OBJECTIVE

The objective of the controlled field studies was to determine whether a significant difference in driving behavior could be detected as a function of the type of delineation treatment at each of the three different types of bridge/culvert conditions described in Chapter 3 (regular [no-required maneuver], narrowed lane, and shoulder drop bridges).

STUDY METHODOLOGY

Overview

A closed driving course was created at the TTI Proving Grounds on the Texas A&M Riverside Campus in Bryan, Texas, to conduct the controlled field studies. Three test locations were created (corresponding to each of the three bridge/culvert conditions of interest) along the test course. Subjects recruited from the Bryan-College Station area drove the test course under nighttime, dry pavement conditions in a vehicle instrumented to obtain continuous vehicle speed, distance, and lateral position information. Periodically, subjects would approach and pass through one of the test locations, which was outfitted with a delineation treatment of interest. After passing through the test location (during which driver behavioral data were collected), research assistants replaced that delineation treatment with the next treatment of interest. Each subject was exposed to each of the selected delineation treatments at all three bridge/culvert test locations. Analysis-of-variance and other statistical analyses were then conducted to evaluate the statistical significance of any observed differences in several measures of performance as a function of the delineation treatments applied, the age group of the drivers, and any interactions between delineation treatments and age. The following paragraphs provide additional detail about the preparation and conduct of the study.

Researchers designed the study to evaluate both normal roadway markings (centerlines and edgelines, where present) as well as the alternative bridge delineation systems in a used, worn condition. Roadway delineation does not maintain a constant reflectance (and thus visual performance) over time, but instead gradually deteriorates until it becomes necessary to replace it. The worst case situation is a delineation system that is near the end of its service life. By examining the various delineation systems in a deteriorated state, researchers hoped it would be possible to define a minimal level of delineation required, below which vehicle operations degrade.

Site Descriptions

The TTI Proving Grounds are located on a former Air Force base in Bryan, Texas. The facility includes five runways connected by a series of taxiways, allowing for a multitude of driving courses to be created and driving conditions to be simulated. For this study, the researchers used sections of W-beam guardrail, loosely bolted to the pavement, to create three different bridge mock-ups selected to simulate conditions common on rural Texas highways. These mock-ups corresponded to the three bridge and culvert conditions of interest defined previously. Specific descriptions of each mock-up follow.

Condition 1: regular bridge (no lane or shoulder width reduction)

A 30-meter section of W-beam guardrail was placed 0.5 meters away from a 3.7-meter wide travel lane. Figure 4-1 illustrates this simulated bridge location. A painted center line and edgeline were present at this site, both of which were faded an worn. The reflectivity of these worn markings, measured with a portable reflectometer from the TxDOT Testing and Materials Division, was between 100 and 120 millicandela per lux per square meter ($mcd/lx/m^2$).

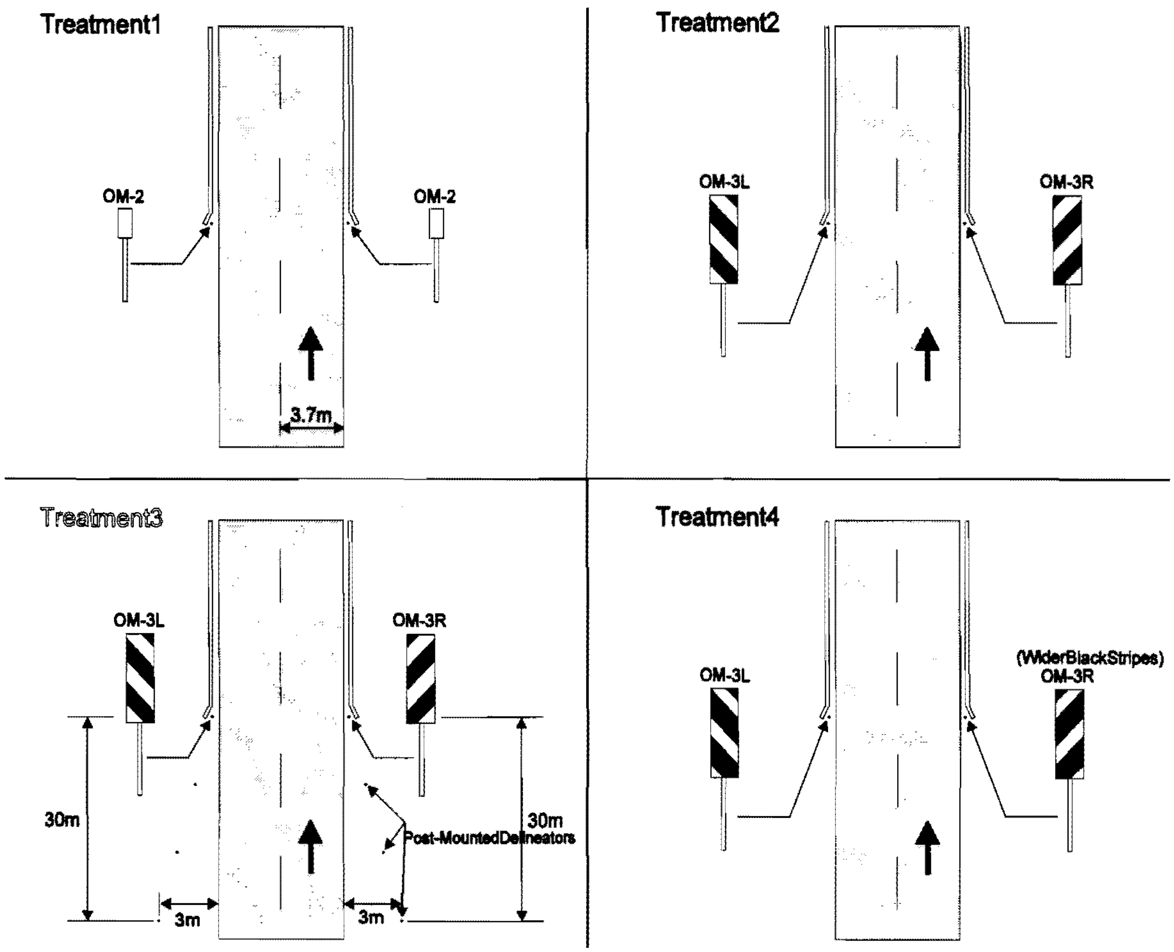


FIGURE 4-1. Delineation Treatments at "Regular Bridge" Test Location

Condition 2: narrowed travel lane

For the second study condition, a 30-meter section of W-beam was used to create a situation in which the travel lane upstream of the bridge was 3.7 meters wide, but which narrowed to approximately 3.0 meters at the simulated bridge. Figure 4-2 depicts this "narrow lane" bridge location. At this location, a degraded center line was provided (similar in condition to the markings in condition 1), but not an edgeline. This is roadway condition is prevalent on rural farm-to-market roads in Texas with travel lanes less than three meters wide.

Condition 3: shoulder drop

For the third condition, a section of a taxiway at the annex was striped as a 3.7-meter lane and a 3.7-meter paved shoulder (markings were again degraded to near the point of required replacement). A 30-meter section of approach W-beam guardrail was placed at the edge of the paved shoulder and transitioned to another 30-meter section of W-beam that was placed next to the 3.7-meter travel lane. This transition was created over a short (six meter) section, as illustrated in Figure 4-3.

The degraded pavement markings described above were an integral part of the study plan, as was the use of bridge delineation devices that were deliberately degraded to the point that they just exceeded the retroreflectivity standards proposed or under development by FHWA (*4*). It was important to evaluate the alternative delineation system treatments in as close to worse case conditions as possible in order to assess whether the treatments provide adequate control and guidance information to drivers throughout the duration of their service life.

Study Procedures

Each subject recruited for the study arrived at the proving ground facility slightly before dusk and was greeted by researchers in a pre-test meeting room. Subjects were given a brief description of their driving task, but were not told what the study was designed to investigate. Subjects then read and were asked to sign an informed consent. Each subject held a valid Texas driver's license. Static visual acuity (corrected) was tested with a standard Snellen chart to verify that each subject could legally (visually) operate a vehicle.

The subject and the study administrator then proceeded to the test vehicle. The vehicle was instrumented with the following equipment:

- a Datron non-contact fifth wheel to measure speed and elapsed distance continuously,
- accelerometers to measure instantaneous vehicle accelerations in the lateral (for lane positioning) and longitudinal (for vehicle acceleration/deceleration) direction,

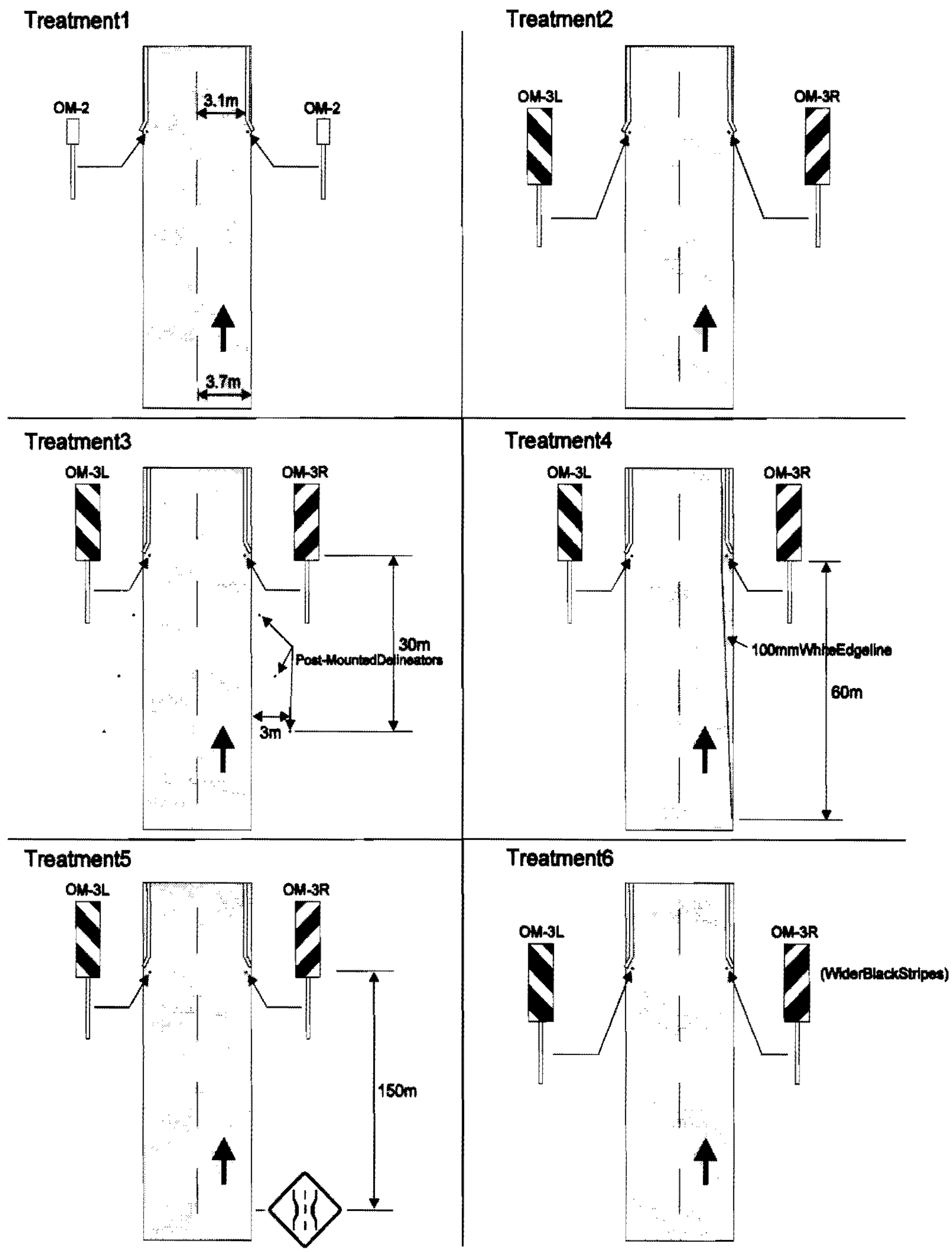


FIGURE 4-2. Delineation Treatments at "Narrow Lane" Bridge Location

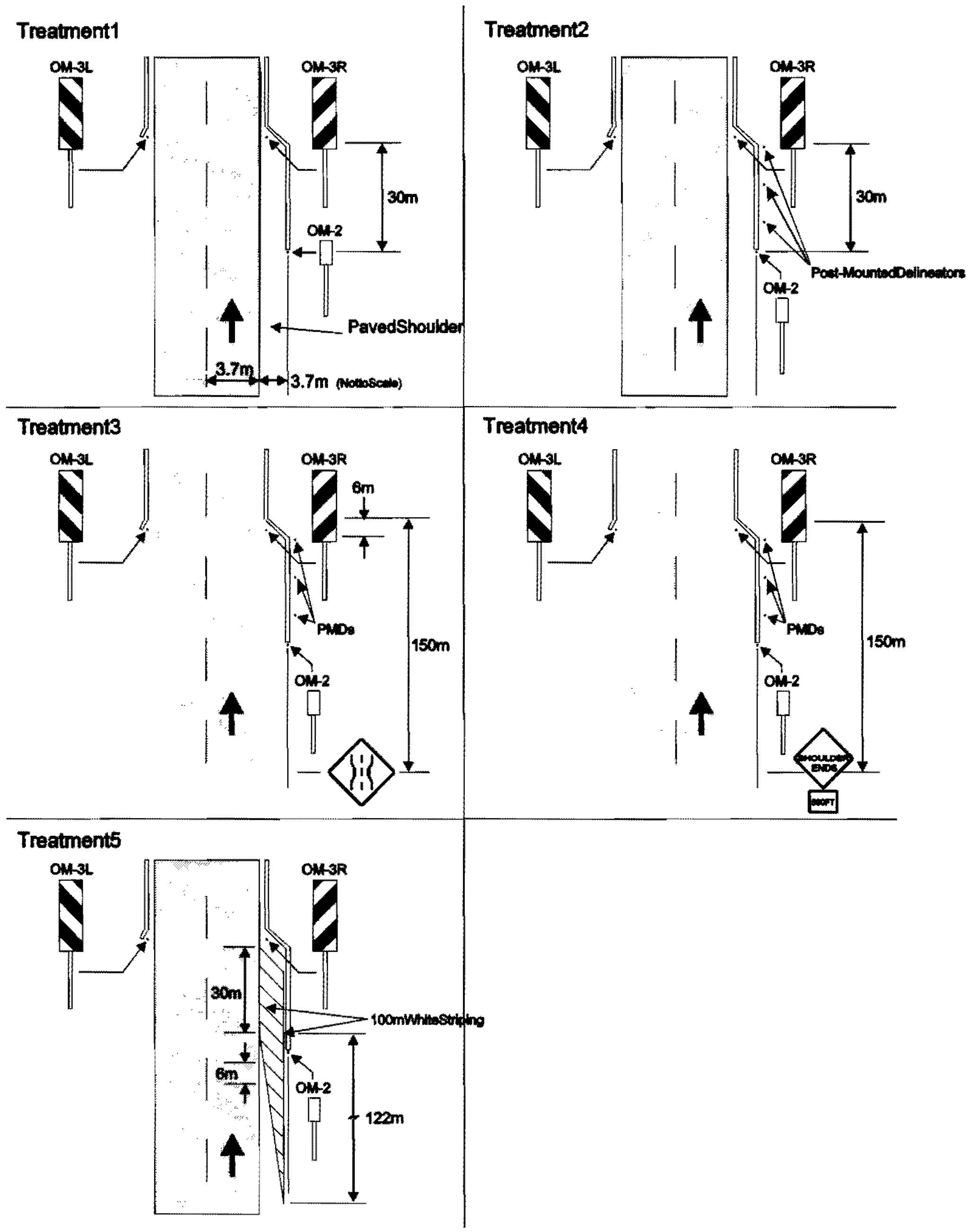


FIGURE 4-3. Delineation Treatments at the "Shoulder Drop" Bridge Location

- a small automatic-iris black-and-white video camera, mounted in the middle of the windshield, looking out over the hood of the vehicle (the video was used to track vehicle lateral position using the test location center and edge lines as reference),
- a VHS recorder and monitor to record and view the image obtained from the video camera (a time and distance stamp from the fifth wheel was placed on the video to allow speed, lateral position, and distance data to be correlated), and
- a portable laptop computer to collect and store the incoming data.

Subjects were told that various types of data about the vehicle would be collected as they drove, but they were not told the specific measures that were being recorded.

In addition to the research equipment, two additional items were installed on the test vehicle for use during these studies. The first was a 12-volt flashlight bulb mounted on a bracket attached to the left front corner of the vehicle in the approximate location of an oncoming vehicle. This light provided a glare source comparable to that produced by an oncoming vehicle on rural highways (see Figure 4-4). Researchers experimented with different wattage bulbs until one was found one that provided approximately the same luminance at the driver's eye as a set of oncoming vehicle headlights on low beam at 61 meters away (473 candela/meter^2). The light source was not illuminated constantly as the subject traveled the test course, but instead was activated prior to approaching and passing by each of the bridge sites (and turned off at some point after passing the bridge).

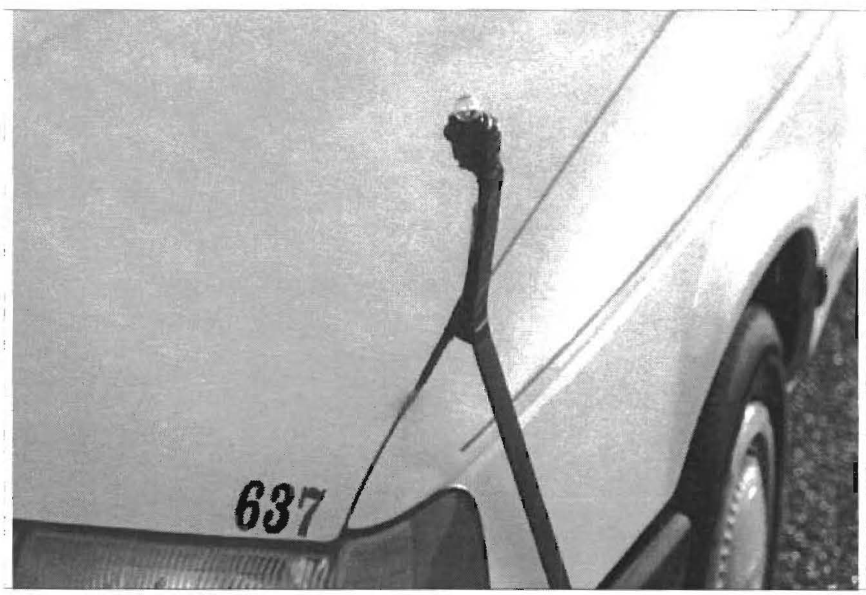


FIGURE 4-4. Glare Source Mounted on Left Front Corner of Instrumented Vehicle

The other item added to the vehicle for this study was designed to increase driver work load by having subjects attend to a secondary task while driving the test course. Subjects were instructed to monitor their rear view mirror to detect and identify one of three colored lights located on a small box mounted in the rear window (see Figure 4-5). One of three lights (selected randomly) illuminated for three seconds with a randomly selected interstimulus interval ranging between three and ten seconds. The subject was to announce out loud the color of the stimulus light whenever he or she saw it illuminated in the rear view mirror.

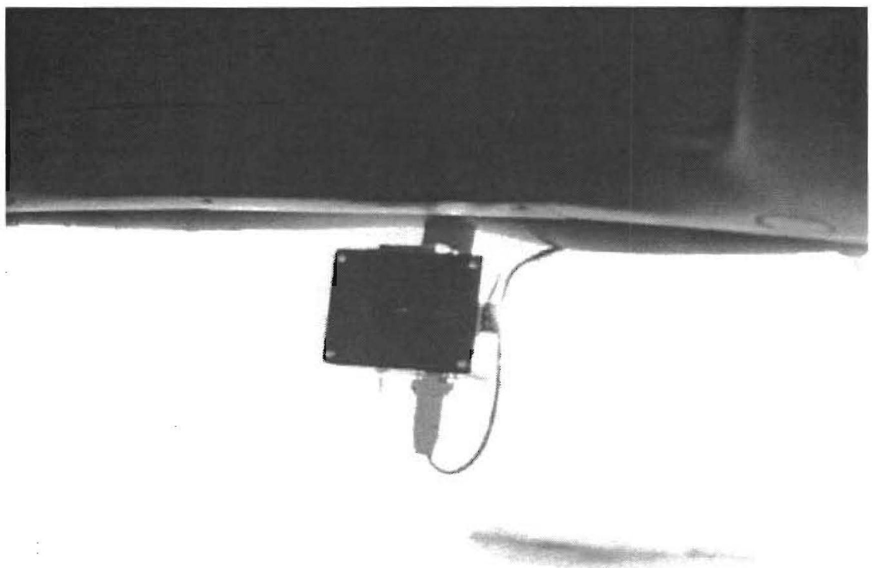


FIGURE 4-5. Secondary Rear-View Mirror Monitoring Task Stimulus

Prior to the initiation of the test, subjects were taken to a non-test location of the proving grounds and allowed to practice driving the vehicle, experience the glare source under driving conditions, and become accustomed to attending to the secondary rearview mirror monitoring task. Once the experiment was begun, subjects traveled the test course until they had approached and passed each bridge condition of interest under each delineation treatment being tested for that condition (a total of 15 bridge location/delineation treatment combinations). Subjects were told to maintain a constant speed of about 90 km/h as much as possible through the course. After passing through a given bridge condition/delineation treatment combination, the survey administrator asked the subject to rate how easy or difficult it had been to tell where he or she was to drive over the last roadway section (which included the bridge condition). Subjects chose one of the following five responses:

- very easy,
- easy,
- neither easy nor difficult,
- somewhat difficult, or
- very difficult.

A second question was then asked: Did you experience any confusion in knowing where to drive at anytime on that last segment? Subjects selected from the following possible answers:

- very confusing, hard to tell what you needed to do,
- a little confusing,
- neither especially confusing nor especially clear,
- fairly clear what you need to do, or
- very clear and obvious what you needed to do.

At the conclusion of the study, subjects returned the vehicle to the pre-study meeting location, were reimbursed $30 for their time and expenses, and left the proving grounds.

Delineation Treatments

The delineation treatments tested for each bridge condition represented a range in both the amount of delineation material involved (discrete and continuous delineation elements, surface area of the delineation elements, number of delineation elements used), their placement within the visual field (on the pavement or on sign posts), and their location on the approach to the bridge (at the bridge, within 30 meters upstream of the bridge, 150 meters upstream of the bridge). Figures 4-1 through 4-3 illustrate the alternative delineation systems investigated by the researchers for each bridge/culvert condition (regular bridge, narrowed lane, and shoulder drop). Generally speaking, these treatments represent the range of actual delineation treatments observed at bridge/culvert sites in Texas.

As can be seen by comparing Figures 4-1 and 4-2, the delineation treatments of the regular bridge and narrowed lane bridge conditions were quite similar. The simplest delineation tested at both locations consisted of Type OM-2 object markers placed on both sides of the road at the beginning of the bridge (Treatment 1). For Treatment 2, these object markers were replaced by the larger Type OM-3L and OM-3R at the beginning of the bridges. Treatment 3 at both locations added three post-mounted delineators on each side of the roadway placed 10 meters apart in a diverging pattern. At the regular bridge location, Treatment 4 was also a Type OM-3L and OM-3R object marker placed on each side of the roadway. However, the stripes on object marker were modified to increase the size of the black stripes (as suggested in the MUTCD to increase the conspicuity of the markers) (*2*). Treatment 4 at the narrowed lane bridge location added a section of 100-mm wide edgeline to the Type OM-3 object markers at the bridge end. This edgeline began at the pavement edge approximately 60 meters upstream of the bridge, narrowed the lane to approximately 0.3 meters inside of the W-beam guardrail at the bridge end, and continuing through the bridge. This created an approximate 2.7-meter travel lane past the bridge. Treatment 5 for the narrowed lane site utilized Type OM-3 markers and a symbolic narrow bridge sign installed 150 meters upstream of the bridge. Finally, Treatment 6 utilized the OM-3 object markers with the larger black stripes, placed on each side of the road at the bridge end.

The treatments at the shoulder drop bridge location were slightly different. For one thing, OM-3s were used in all treatments at the beginning of the bridge (after the transition of W-beam from the edge of the shoulder). As discussed in Chapter 3, the bridge end is located midway between the edge of the travel lane and the edge of the shoulder in this type of bridge configuration. From the perspective of the driving motorist who is utilizing the shoulder (as is allowed in Texas), the bridge end appears as an object located within the roadway and so by MUTCD definition should be delineated with an OM-3 object marker. Also, a section of W-beam was used to transition from the bridge end over to the edge of the shoulder (to simulate a common bridge-end protection scheme), and so needed an OM-2 at the end of the W-beam guardrail.

Treatment 1 at the shoulder drop bridge location consisted only of the Type OM-3 object markers on each side of the road and the OM-2 at the end of the W-beam transition section. Treatment 2 added three PMDs behind the W-beam transition section (spaced at 10 meters) to increase conspicuity. Treatment 3 was identical to Treatment 2 with the addition of a symbolic narrow bridge sign added 150 meters upstream. Treatment 4 was also identical to Treatment 2, but employed a "Shoulder Ends-500 ft" (150 meters) sign in use in some of the TxDOT Districts but not currently in the MUTCD. This sign was also placed 150 meters upstream of the bridge. The final treatment, Treatment 5, was a modified version of the shoulder treatment recommended at narrow bridges less than eight meters wide on two-lane, two-way highways (as denoted on page 22A of the *TxDOT Traffic Engineering Standard Sheets* (*22*)). However, the cross-hatching used for the study was only 100 mm wide, rather than the 300 mm wide stripes recommended in the plans. Furthermore, neither the optional jiggle bars nor the retroreflective raised pavement markers shown in the plans were used. In other words, only the influence of degraded painted lines (with the transverse lines smaller than those now called for) of the marking system were evaluated, independent of any additional benefit that might be added through increased retroreflectivity of RRPMs or tactile feedback from jiggle bars. The length of the shoulder transverse marking pattern was set so that the beginning of the taper coincided with the location where the advance warning signs were positioned in Treatments 3 and 4.

To allow for the treatments involving pavement markings to be tested each night (Treatment 4 at the narrowed lane location and Treatment 5 at the shoulder drop location), researchers cut 100 mm strips of 2.4-meter sections of masonite and painted them with white traffic paint without glass beads. Without the beads, the resulting reflectivity readings were approximately equal to those markings already existing on the road at the bridge locations. During the course of the study each night, research assistants would place the painted masonite strips out in the required pattern at the time called for in the treatment order for that night. After the subject drove past the bridge location, the assistants could then easily remove the strips and set up the next delineation treatment for that location.

Experimental Design

The need to accommodate the increasing number of older drivers using the roadway systems in Texas led the researchers to include a driver age category into the statistical design for the study. Specifically, two age groups were used in the study: drivers younger than 25 and drivers aged 55 or older. Drivers between the ages of 25 and 55 were not included. Previous research has shown that visual capabilities of drivers generally degrade during this phase of life but are quite difficult to predict on the basis of age. A total of 15 subjects were used in the evaluated for each age category (seven males and eight females).

Given the number of drivers to be tested and the number of delineation treatments to be evaluated, researchers designed the experiment to counterbalance the effect of treatment order at any bridge location. That is, each of the treatments at a given bridge location was the first treatment encountered by a subject at that location at least once in the study, was the second treatment encountered at least once, etc. Because of the different information needs and desired behaviors of drivers at the different bridge locations studied, the experimental design did not attempt to compare driver behavior between treatments at different bridge locations (for Treatment 1 at both the regular bridge and narrowed lane locations, for example).

Measures-of-Performance

The data obtained from the instrumented vehicle that the subjects drove during the study included the following:

- speed and cumulative distance traveled (at 1/10th second intervals),
- lateral position within the lane or shoulder (measured approximately every six meters),
- times when the secondary task occurred (i.e., lights in the rearview mirror were illuminated), and
- lateral and longitudinal accelerations (x- and y-coordinate directions), measured with accelerometers.

These data were recorded beginning 300 meters upstream of the bridge. From these data, a number of performance measures were computed and analyzed. These measures included:

- average speed,
- maximum acceleration or deceleration in the longitudinal direction and the distance from the bridge at which this acceleration occurred,
- maximum acceleration to the left (away from the bridge) in the lateral direction and the distance from the bridge at which this occurred,
- acceleration noise for both the longitudinal and lateral directions,
- maximum deviation from the average lateral position in the lane and the distance from the bridge where this maximum lateral position change occurred,
- the lateral position at the beginning of the bridge,
- the variability in the lateral position at the beginning of the bridge,
- the change in lateral position at the bridge relative to the average lateral position,

- the lateral position and change in lateral position 30 meters upstream of the bridge (at the regular bridge and narrowed lane bridge locations only),
- the distance from the bridge at which the subject began to exit the shoulder (shoulder drop bridge location only), and
- the distance traveled while completing the shoulder exit maneuver (shoulder drop bridge location only).

All but one of these measures were then analyzed using two-factor Analysis-of-Variance (ANOVA) statistical techniques. Subject age and delineation treatment were the main factor effects examined in the model, along with any interactions between age and delineation treatment. The evaluation of the variability in lateral positions measured at the beginning of the bridge were evaluated using the Hartley Test of equal variances (*23*). Subject rankings of both the ease and clarity of the overall driving conditions for each delineation treatment (as described in the study procedures) were analyzed using categorical data analysis techniques examining age, delineation treatment, and age/treatment interactions.

STUDY RESULTS

Regular Bridge Location

Appendix A provides statistical summaries of the mean, standard deviations, and ANOVA tables for the various performance measures examined at this bridge location. However, using a 95 percent level of confidence, only one of the measures examined in this study at this location was found to be statistically significant. Specifically, the average lateral position of drivers at the beginning of the bridge was found to depend on the age group of drivers, with those drivers 55 and older positioning themselves further away from the bridge, as depicted in Figure 4-6. Although subject age was significant in describing differences in lateral position observed at this location, the delineation treatment used was not. That is, no consistent differences could be detected in lateral positions at the beginning of the bridge on the basis of what particular delineation treatment was in place when the subject approached and passed through the bridge location.

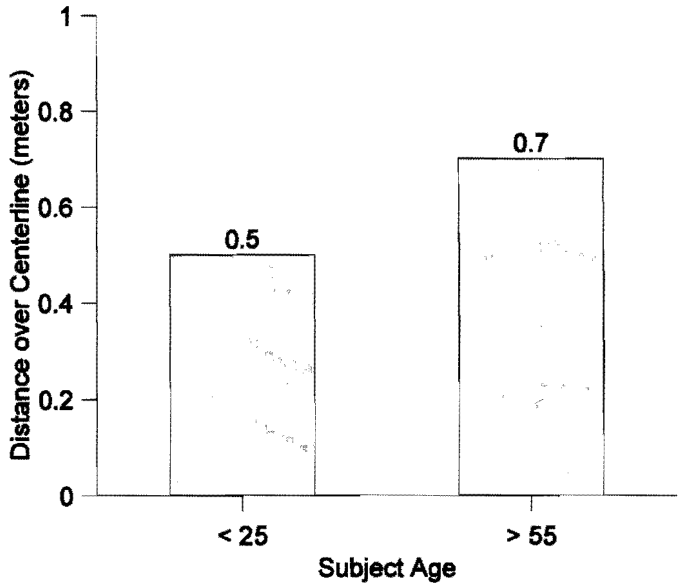
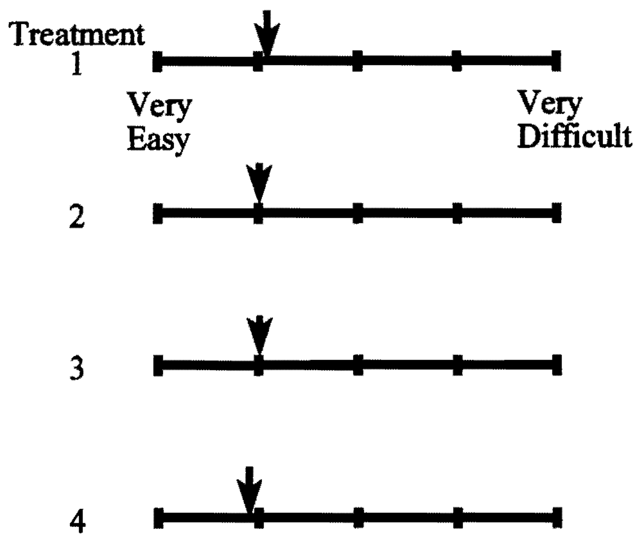


FIGURE 4-6. Effect of Subject Age on Lateral Position at Beginning of the Regular Bridge Location

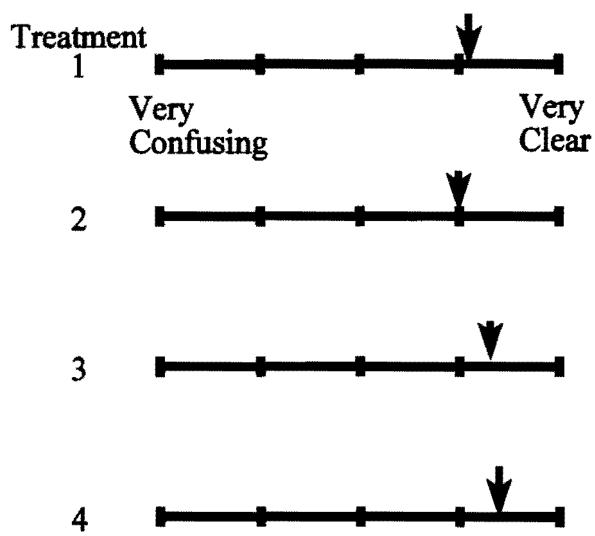
The lateral position value reported in Figure 4-6 is the distance of the left front wheel over the centerline. The fact that drivers, on average, encroached over the centerline should not be taken to indicate potential operational problems with the delineation treatments overall, though. It must be remembered that these studies were conducted on a closed-course facility, unopposed by oncoming traffic. Consequently, there was little incentive for subjects to try to remain in their lane.

It is interesting to note that although lateral position at the beginning of the bridge was found to depend on the age of the subject, the change in lateral position that occurred at this point relative to the average lateral position of the subject approaching the bridge did not. Generally speaking, both the older and younger subject groups moved to the left an average of 0.2 meters by the time they reached the bridge. Also, neither age nor delineation treatment significantly affected lateral positions of drivers measured 30 meters before the bridge.

Subject ratings of how easy it was for them to find their way through the roadway sections and bridge locations were not significantly affected by either age or delineation treatment. Likewise, subject age and delineation treatments were not found to significantly affect the ratings of how clear it was to subjects about where they should drive along the test course. Figure 4-7 summarizes average rankings by treatment number. As can be seen, average ratings were extremely favorable for all treatments.



"How easy or difficult was it for you to tell where you were supposed to drive?"



"Was it confusing or clear about where you were supposed to drive on the segment?"

FIGURE 4-7. Average Subject Ratings by Treatment: Regular Bridge Location

Narrowed Lane Bridge Location

Appendix B contains the statistical summaries (means, standard deviations, ANOVA tables) from this test location. At this location, ANOVA results for two of the measures were found to be statistically significant at a 95 percent level of confidence. First, as with the regular bridge location, the average lateral position of subjects at the beginning of the narrowed lane bridge was found to depend on age, with those subjects 55 and older positioning themselves further away from the bridge (see Figure 4-8). The absolute values shown in Figure 4-8 are somewhat greater than those shown in Figure 4-6 for the regular bridge location, an expected result given the encroachment of the W-beam rail into the travel lane. However, the relative difference in lateral position between age group was almost identical to that observed at the regular bridge location (0.3 meters and 0.2 meters, respectively). Once again, the type of delineation treatment in place at the narrowed lane bridge location did not significantly affect this measure.

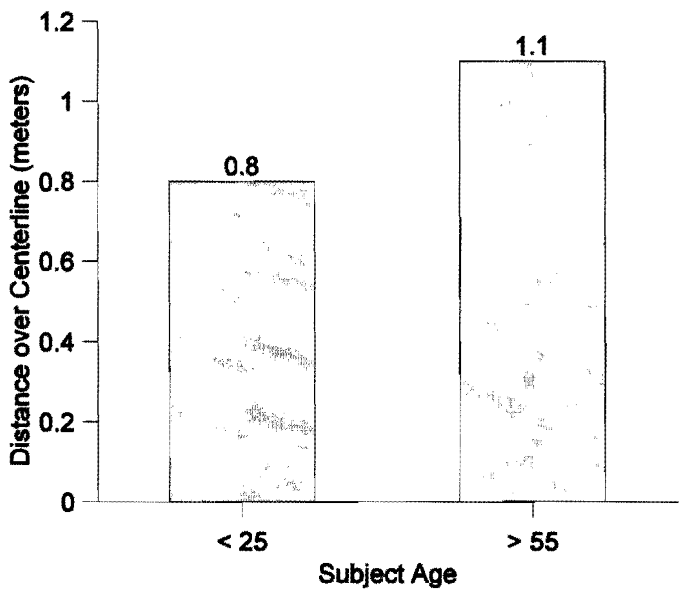


FIGURE 4-8. Effect of Subject Age Upon Lateral Position at Beginning of Narrowed Lane Bridge

Researchers also that found subject age to influence the change in lateral position measured at the beginning of the narrowed lane bridge, relative to the subject's average lateral position approaching the bridge. As Figure 4-9 illustrates, subjects older than 55 consistently moved a slightly greater distance to the left as they crossed the bridge than did subjects younger than 25 (0.4 meters and 0.3 meters, respectively). Meanwhile, subject lateral position 30 meters upstream of the bridge was still dependent upon subject age (see Figure 4-10), but the change in lateral position at that location relative to that subject's average position was not. This suggests that the differential change in lateral position by subject age group happened primarily within 30 meters of the bridge. Again, none of the delineation treatments significantly affected the results.

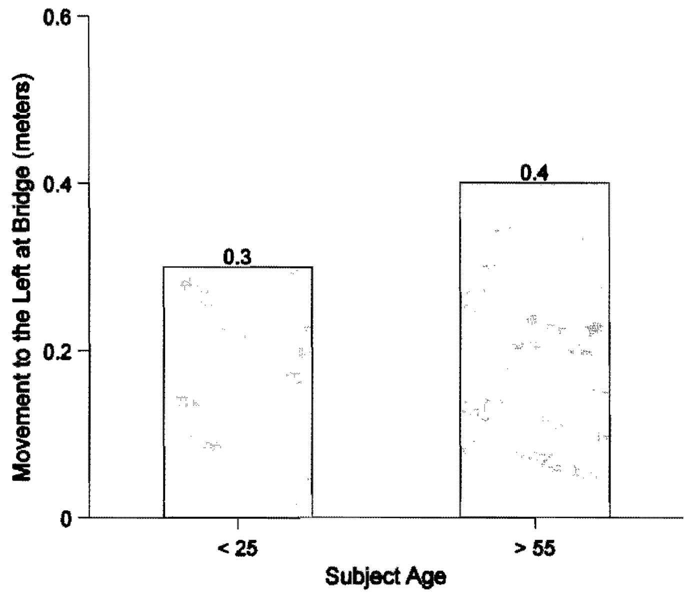


FIGURE 4-9. Effect of Subject Age Upon Change in Lateral Position at Beginning of Narrowed Lane Bridge

Subjects' ratings of how easy it was for them to find their way through the narrowed lane bridge location were not significantly affected by either age or delineation treatment. Likewise, subjects' ages and delineation treatments were not found to significantly affect the ratings of how clear it was to them about where they should drive along the test course. Figure 4-11 illustrates average rankings by treatment number. As can be seen, average ratings were extremely favorable for all treatments. All treatments received somewhere between a "very easy" and "easy" rating in terms of the subject's ability to find their way through the roadway sections. All treatments were also ranked somewhere between "very clear" and "clear" in terms of showing subjects where they should drive.

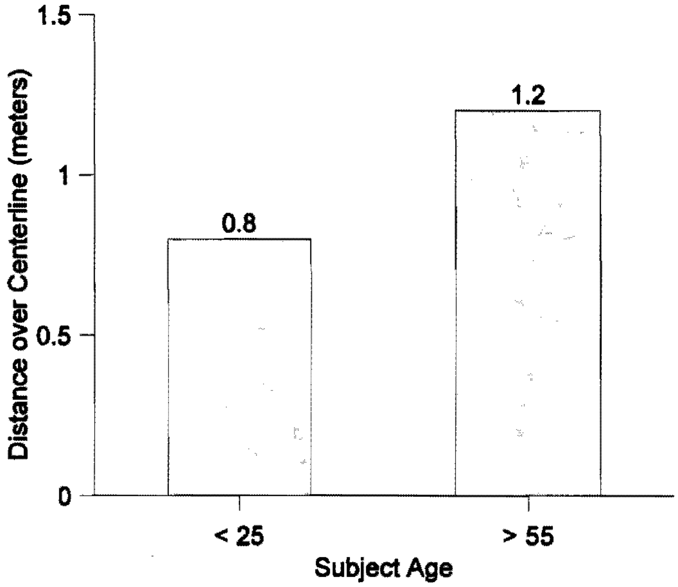
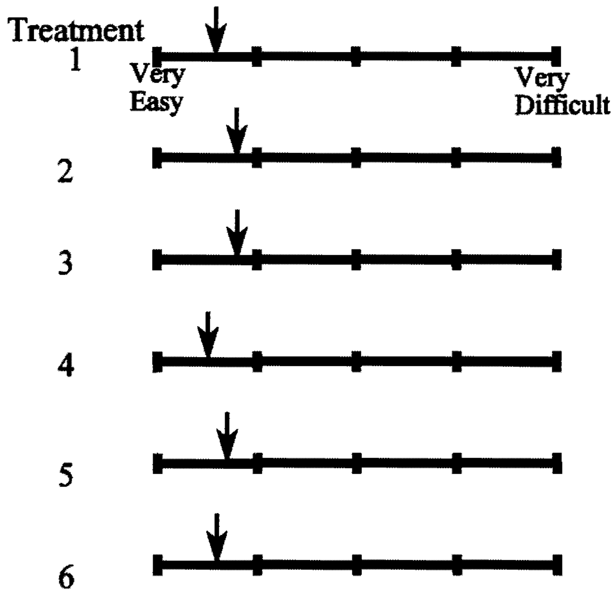
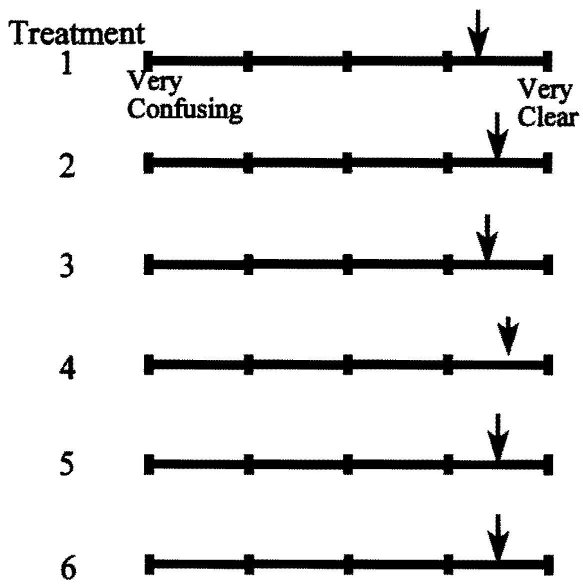


FIGURE 4-10. Effect of Subject Age on Lateral Position 30 Meters Upstream of the Narrowed Lane Bridge



"How easy or difficult was it for you to tell where you were supposed to drive?"



"Was it confusing or clear about where you were supposed to drive on the segment?"

FIGURE 4-11. Average Subjective Ratings of Delineation Treatments at Narrowed Lane Bridge Location

Shoulder Drop Bridge Location

Because of the more dramatic driving maneuvers required to safely negotiate the shoulder drop bridge location, it was possible to examine a few different performance measures than were utilized at either the regular bridge or narrowed lane bridge locations. Specifically, researchers examined 1) the distance upstream of the bridge at which subjects began to make a maneuver to vacate the shoulder and move into the adjacent travel lane, and 2) the distance the subject took to complete that maneuver. These measures were considered in addition to those evaluated for the other two bridge locations.

Appendix C contains the statistical summaries of the performance measures at this bridge location. As with the other two bridge locations in this study, lateral position at the beginning of the bridge was found to be significantly affected by subject age. Again, subjects older than 55 tended to drive slightly more to the left (away from the W-beam) than did subjects less than 25 years, by the distances shown in Figure 4-12. Once more, the specific delineation treatment in place at this location each time the subject traversed that section had no statistically significant influence on lateral position behavior.

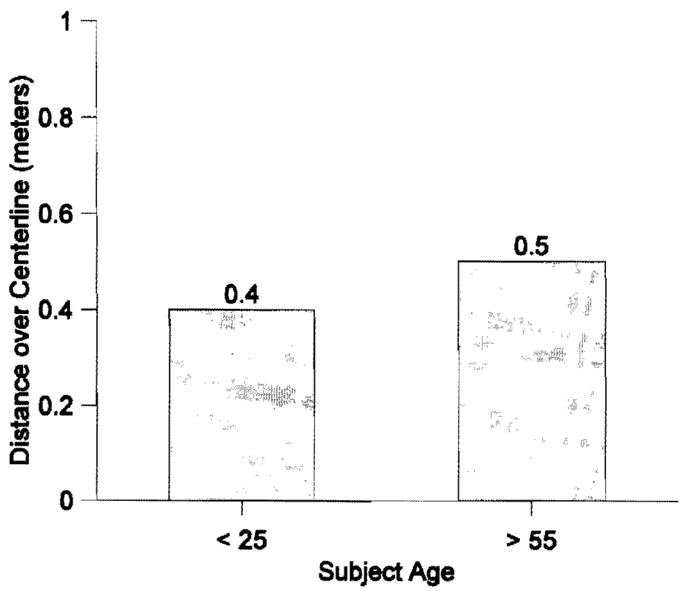


FIGURE 4-12. Effect of Subject Age on Lateral Position at Beginning of the Shoulder Drop Bridge Location

Another factor found at this location to be affected by subject age was the magnitude of the maximum deceleration made. As depicted in Figure 4-13, subjects older than 55 applied, on average, a greater maximum deceleration force to the vehicle somewhere on their approach to the bridge than did subjects younger than 25. It is not known whether the larger decelerations were due primarily to the more complex driving maneuver required at this location or a greater anxiety about traveling in what was said to be a shoulder. Whatever the reason, the effect was statistically significant. However, none of the delineation treatments tested in this research once again had a significant influence upon this performance measure. Also, the location where this deceleration occurred was not statistically significant.

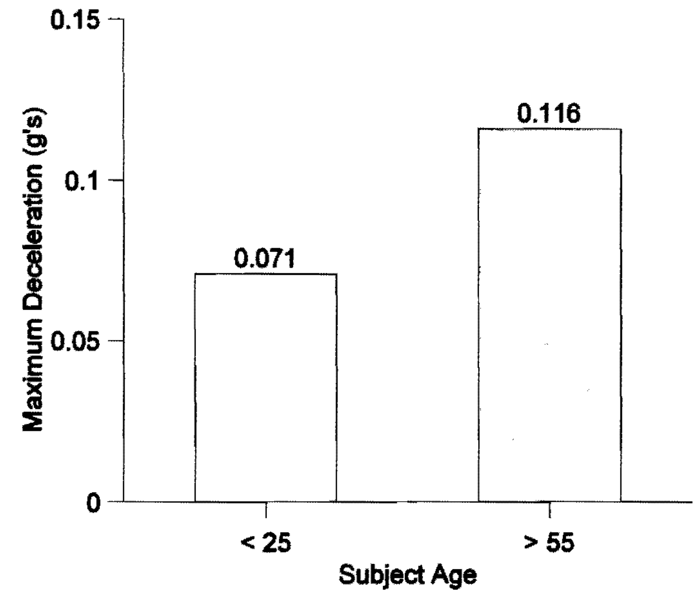
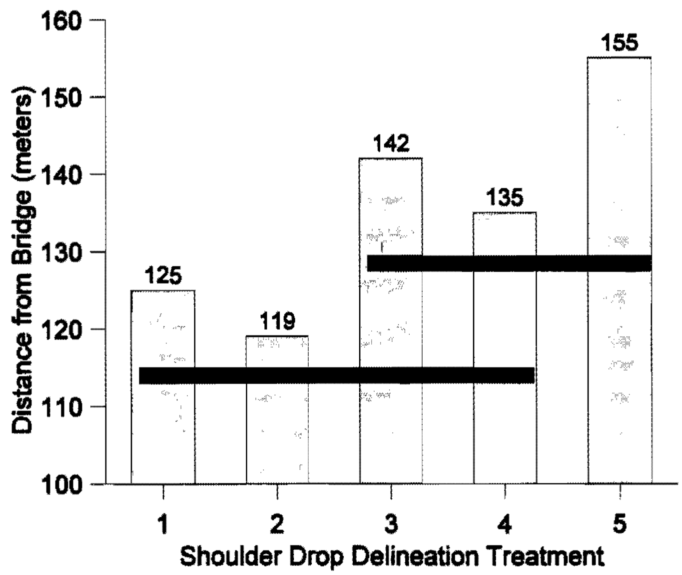


FIGURE 4-13. Effect of Subject Age on Maximum Deceleration Made Approaching Shoulder Drop Bridge Location

At this final bridge location, one performance measure was found to be statistically significant with respect to delineation treatment. The distance from the bridge at which drivers began to exit the shoulder differed significantly depending on which delineation treatment was in place at the location. Interestingly, subject age did not significantly affect this measure. Figure 4-14 illustrates the average distance from the bridge at which subjects began to exit the shoulder. Subjects began this maneuver when Treatments 1 and 2 were in place an average of 125 and 119 meters upstream of the bridge, respectively. Treatments 3 and 4, which were identical to Treatment 2 with the addition of an advance warning sign 150 meters upstream, resulted in average begin-to-exit distances of 142 and 135 meters, respectively. Finally, the average begin-to-exit distance observed for Treatment 5 was 155 meters upstream of the bridge.



Note: Bars connected by horizontal lines are not statistically different from each other.

FIGURE 4-14. Effect of Delineation Treatment upon Location Where Shoulder Exit Maneuver is Initiated at Shoulder Drop Bridge Location

Using these averages to make statistical inferences about the overall driving population, it can be said with a 95 percent level of confidence that drivers will begin to exit the shoulder farther upstream when Treatment 5 is in place at a location than if either Treatments 1 or 2 are in place at that location. The effect of advance signing (Treatments 3 and 4) upon expected driver behavior is less definitive at this time. Statistically speaking, one cannot say whether these treatments will affect shoulder exiting any earlier than Treatments 1 or 2, or any later than Treatment 5. However, the distance values shown in Figure 4-14 are certainly consistent with what would be expected. Subjects were provided with information (in the form of advance warning signs) farther upstream than was received under Treatments 1 and 2, which would be expected to encourage drivers to exit the shoulder sooner (assuming that they correctly received, processed, and responded to the information on the signs).

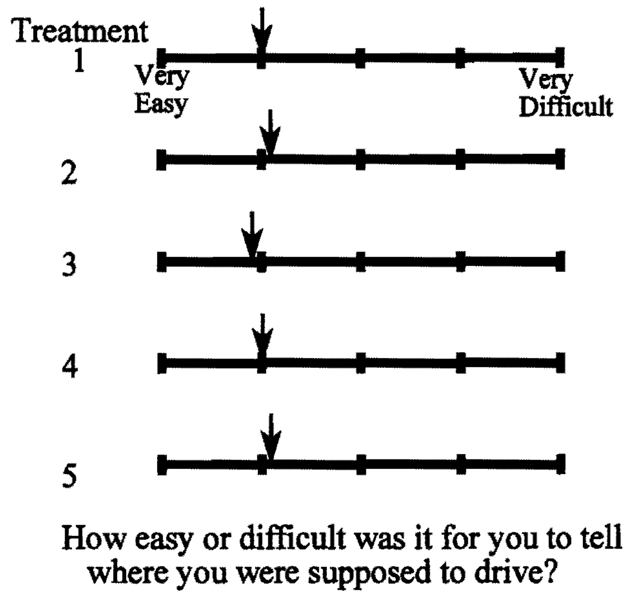
The relationship between the distances obtained under Treatments 3, 4, and 5 is also consistent with what would be expected to occur. Whereas Treatments 3 and 4 do provide information a significant distance upstream of the bridge (as does Treatment 5), this information is in the form of a single point source directed towards the guidance portion of the driving task. Conversely, the pavement markings utilized in Treatment 5 provide continuous positive information (via the taper) to drivers that the shoulder should be vacated. Furthermore, past research suggests that edgelines serve primarily the control function of the driving task (*1*), which would imply that motorists might more readily heed (primacy) to that source of information and may be more likely to react immediately and consistently to that information.

The results of the subject rankings of the delineation treatments at the shoulder drop bridge location did not yield any significant differences with respect to age or treatment type. As illustrated in Figure 4-15, subjects ranked all treatments between "very easy" and "easy" in terms of their ability to tell where they were supposed to drive. Subjects ranked all the treatments between "very clear" and "clear" in terms of knowing what they were supposed to do as they traversed the course.

DISCUSSION

This experiment examined a wide range of existing delineation systems currently being used to delineate both regular bridge/culverts and/or those designated as "narrow" according to the MUTCD definition. Despite taking significant pains to increase the driver work load during subject testing via a glare source and a secondary task monitoring activity as well as utilizing delineation devices that were near the end of their useful service life, very few systematic differences could be detected in the operational measures evaluated at the regular bridge and narrowed lane bridge locations that were attributable to the delineation treatment present at the sites. In other words, these measures were not significantly affected by the type of delineation present, be it the small OM-2 markers at the end of the bridge or the OM-3s used in combination with post-mounted delineators, a short edgeline segment, or an advance warning sign ("Narrow Bridge") positioned far upstream to notify drivers of the upcoming bridge. The lack of significant differences does not automatically imply that the delineation treatments are identical from a driver's response perspective (the operational measures utilized in this study may not have been sensitive enough to the effects of the delineation treatments). However, no evidence is available from these data to support the use of any one of these delineation treatments over the other.

This research did demonstrate a measurable benefit by delineating shoulder drop bridge locations with an edgeline taper/transverse marking delineation pattern. Such a pattern results in motorists exiting the shoulder significantly farther upstream than if only object markers and post-mounted delineators are present at the bridge end and approach guardrail. Typically, this marking pattern is applied only at relatively high-accident bridge locations. The subject responses obtained through the use of this treatment were achieved without the use of RRPMs and/or jiggle bars as are suggested in current TxDOT specifications for this pattern. Furthermore, the transverse markings studied were much more narrow than those now recommended in the specifications. A question thus arises of whether or not the transverse markings are actually required. A TxDOT Maintenance Engineer noted that this particular delineation pattern would be extremely cost-effective to implement at all shoulder drop locations if a simple edgeline taper could be used alone without the transverse ("short") striping that must be done by hand.



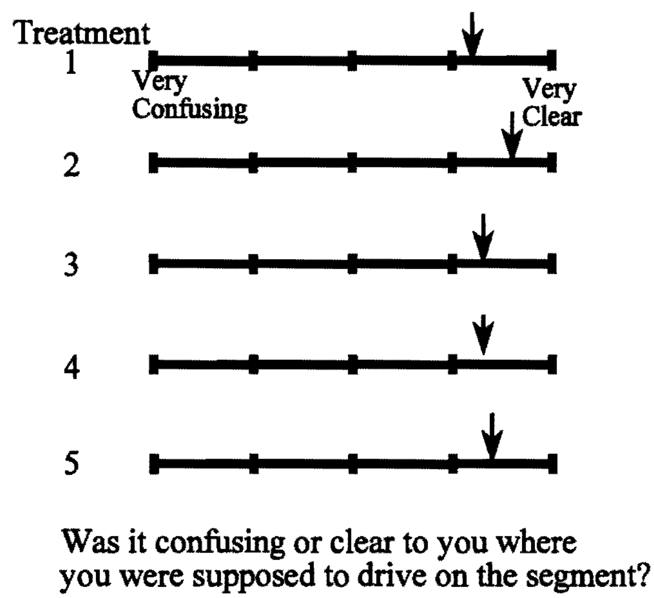


FIGURE 4-15. Subjective Ratings of Delineation Treatments at the Shoulder Drop Bridge Location

5. SUMMARY AND RECOMMENDATIONS

SUMMARY

This report has documented the results of research performed to develop an improved understanding of delineation needs for bridges and culverts (especially those that are "narrow") and how those needs should best be accommodated through the delineation devices that are currently available for use in Texas. Previous research has utilized changes in motorist lateral position as they approach a bridge as an indication of whether or not the bridge is considered hazardous or narrow by those motorists. However, a correlation between bridge width, driver lateral positioning behavior, and the degree of hazard at a bridge site (in terms of accident potential or operational problems) could not be established.

Telephone interviews and site visits to various bridge and culvert locations throughout Texas provided a database of existing delineation practices statewide. As might be expected, delineation practices vary widely from district to district, and to a lesser degree, can vary from bridge to bridge (of the same type) within a given district as well. Differences in bridge ages contribute in part to the range of delineation practices observed. However, the lack of applicability of available delineation guidance to the various bridge/culvert configurations that must be addressed is another reason for this variability.

Researchers for this project approached bridge and culvert delineation needs from a motorist information need/positive guidance perspective. Considering only the driving maneuvers that <u>must</u> be accomplished in order for a motorist to safely negotiate a bridge or culvert, three different bridge/culvert conditions were identified. The type and location of information that motorists need to accommodate each type of maneuver were then examined, and delineation devices available to convey that information were critiqued.

Researchers conducted a controlled field study to investigate whether the amount and type of delineation provided at each of the three bridge/culvert conditions defined earlier affected driver performance. Subjects drove an instrumented vehicle around a test course at the TTI Proving Grounds past mock-ups of each bridge type delineated with one of several alternative treatments. The delineation devices were degraded to the point that they just met minimum requirements for retroreflectivity. Subjects were also exposed to a glare source simulating oncoming traffic and had to attend to a secondary monitoring task while driving. In this way, researchers could investigate delineation effects under less-than-optimum reflectivity and driving conditions.

Even under the conditions studied (where delineation needs would be expected to be higher), researchers found very few significant differences between several driver performance measures as a function of the delineation treatment examined at a given bridge/culvert test location. A consistent difference in the average lateral position of drivers at the beginning of the bridge was detected between those drivers older than 55 years, and those younger than 25 years. However, this difference was similar under all delineation treatments tested. It appeared that, for the most part, the various delineation treatments were equally effective in providing information to subjects that they needed to safely traverse the test course. The high ratings subjects gave to all the delineation treatments at each of bridge locations tested support this interpretation of the results.

One performance measure that was found to depend on the type of delineation treatment present was the distance upstream of the bridge where subjects began to exit the shoulder in advance of the shoulder drop bridge location. The addition of a painted edgeline taper with transverse markings that began upstream of the bridge location resulted in subjects exiting from the shoulder 30 to 35 meters further upstream. This equates to drivers having an additional 1.0 to 1.5 seconds of travel time (depending on speed) to react to the upcoming loss of the shoulder. It is hypothesized that because the edgeline provides continuous control-level information for the driving task, it is given a high level of priority by approaching motorists.

RECOMMENDATIONS

The results of these controlled field studies do not suggest that a dramatic change from current TxDOT policies regarding bridge/culvert delineation is necessary. In actuality, evidence collected in this research suggests that the type of delineation present at bridges where drivers are not required to make adjustment to their travel paths (i.e., regular bridge locations) has little effect upon behavior. A similar result occurs for bridges where some small lateral shift might be necessary due to narrowed lanes across the bridge/culvert. Although not explicitly examined in this research, it is assumed that some type of delineation at bridges does result in improved driver performance in comparison to a no-delineation condition. Furthermore, MUTCD definitions regarding object markers and signing do place some restrictions on the minimum delineation system that can be installed at a location.

The results of these studies do suggest the continued use of a tapered edgeline/transverse marking pattern at shoulder drop bridge locations where accidents are a problem or other evidence exists that drivers are not exiting the shoulder soon enough (such as continuously replacing approach guardrail to the bridge abutment). However, it seems premature to suggest that all bridge locations involving a shoulder drop should utilize this marking pattern. Indeed, most bridges statewide involving a shoulder drop do not have this marking pattern installed and do not suffer from accident problems.

At this time, TxDOT should continue existing practices regarding bridge and culvert delineation. However, it is recommended that minor adjustments be made to current delineation standards (*22*) to facilitate the understanding and application of these practices statewide. Appendix D provides recommended drawings that could be used to establish specific bridge delineation standard sheets. Currently, TxDOT personnel must search for bridge delineation information among several standard sheets (i.e., one for object markers, one for pavement markings, etc.). A single set of drawings that depict the entire delineation system at a bridge for the three different bridge conditions defined in this report would make access and compliance with current practices easier.

6. REFERENCES

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APPENDIX A: STATISTICAL SUMMARIES FOR REGULAR BRIDGE TEST LOCATION

TABLE A-1. Mean and Standard Deviations of Performance Measures: Treatment 1

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.030	0.031	-0.036	0.027
Max. Longitudinal Acceleration	-0.068	0.030	-0.067	0.041
Location of Max. Lat. Acceleration	180.0	85.5	222.4	110.2
Location of Max. Long. Acceleration	167.9	89.5	128.0	112.7
Lateral Position at Bridge	-0.49	0.29	-0.56	0.50
Change in Lateral Position at Bridge	-0.24	0.18	-0.27	0.28
Lateral Position 30 Meters Upstream	-0.48	0.41	-0.50	0.45
Change in Lateral Position Upstream	-0.21	0.19	-0.21	0.26
Maximum Lateral Deviation	-0.52	0.62	-0.72	0.79
Location of Max. Lateral Deviation	87.7	119.1	126.7	123.1

TABLE A-2. Mean and Standard Deviations of Performance Measures: Treatment 2

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	0.021	0.013	-0.041	0.018
Max. Longitudinal Acceleration	-0.071	0.027	-0.048	0.047
Location of Max. Lat. Acceleration	194.8	99.0	217.7	78.3
Location of Max. Long. Acceleration	165.5	106.0	153.2	78.8
Lateral Position at Bridge	-0.55	0.36	-0.76	0.38
Change in Lateral Position at Bridge	-0.12	0.23	-0.36	0.35
Lateral Position 30 Meters Upstream	-0.53	0.32	-0.60	0.51
Change in Lateral Position Upstream	-0.10	0.18	-0.20	0.29
Maximum Lateral Deviation	-0.33	0.13	-0.62	0.25
Location of Max. Lateral Deviation	70.8	105.4	100.0	129.1

TABLE A-3. Mean and Standard Deviations of Performance Measures: Treatment 3

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.033	0.034	-0.024	0.015
Max. Longitudinal Acceleration	-0.068	0.026	-0.064	0.027
Location of Max. Lat. Acceleration	170.0	90.4	176.2	86.4
Location of Max. Long. Acceleration	166.7	89.3	144.9	106.6
Lateral Position at Bridge	-0.55	0.21	-0.80	0.41
Change in Lateral Position at Bridge	-0.21	0.17	-0.18	0.36
Lateral Position 30 Meters Upstream	-0.42	0.35	-0.70	0.59
Change in Lateral Position Upstream	-0.10	0.19	-0.07	0.21
Maximum Lateral Deviation	-0.34	0.15	-0.44	0.28
Location of Max. Lateral Deviation	145.6	114.7	140.2	117.8

TABLE A-4. Mean and Standard Deviations of Performance Measures: Treatment 4

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.025	0.017	-0.038	0.022
Max. Longitudinal Acceleration	-0.060	0.028	-0.054	0.030
Location of Max. Lat. Acceleration	197.2	97.6	197.2	119.6
Location of Max. Long. Acceleration	145.4	100.8	150.0	117.3
Lateral Position at Bridge	-0.53	0.26	-0.64	0.64
Change in Lateral Position at Bridge	-0.21	0.23	-0.32	0.47
Lateral Position 30 Meters Upstream	-0.46	0.27	-0.34	0.88
Change in Lateral Position Upstream	-0.16	0.20	-0.03	0.19
Maximum Lateral Deviation	-0.46	0.40	-0.54	-0.33
Location of Max. Lateral Deviation	100.2	107.5	91.1	120.4

TABLE A-5. ANOVA Results: Regular Bridge Location

Source	DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Max. Lat. Accelerations:					
Model	7	0.0060	0.0009	0.082	0.57
Error	106	0.1103	0.0010		
Total	113	0.1163			
Max. Long. Accelerations:				1.32	0.45
Model	7	0.0050	0.0007		
Error	105	0.0566	0.0005		
Total	112	0.0615			
Location of Max. Lateral Accel.:					
Model	7	195546	27935.2	0.26	0.97
Error	106	11515770	108639.3		
Total	113	11711316			
Location of Max. Long. Accel.:					
Model	7	355139	50734.2	0.51	0.82
Error	105	10422290	99259.9		
Total	112	10777429			
Lateral Position at Bridge:					
Model	1	8.067	8.067	4.95	0.03
Error	106	172.680	1.629		
Total	107	180.747			
Change in Lat. Position at Bridge:					
Model	7	4.06	0.580	0.53	0.81
Error	100	108.72	1.087		
Total	107	112.78			
Lat. Position 30 meters Upstream:					
Model	7	21.33	3.047	1.01	0.43
Error	98	295.70	3.017		
Total	105	317.03			
Change in Lat. Pos. Upstream:					
Model	7	3.66	0.523	1.27	0.27
Error	99	40.78	0.412		
Total	106	44.44			
Maximum Lateral Deviation:					
Model	7	16.909	2.416	1.30	0.26
Error	99	183.611	1.855		
Total	106	200.521			
Location of Max. Lat. Deviation:					
Model	7	736798	105257	0.72	0.66
Error	99	14555060	147021		
Total	106	15291858			

APPENDIX B: STATISTICAL SUMMARIES FOR NARROWED LANE BRIDGE TEST LOCATION

TABLE B-1. Mean and Standard Deviations of Performance Measures: Treatment 1

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	_-0.116	0.162	-0.069	0.030
Max. Longitudinal Acceleration	-0.066	0.014	-0.069	0.052
Location of Max. Lat. Acceleration	196.4	101.9	155.6	90.9
Location of Max. Long. Acceleration	126.7	101.9	149.1	110.6
Lateral Position at Bridge	-0.73	0.18	-1.06	0.35
Change in Lateral Position at Bridge	-0.32	0.13	-0.39	0.21
Maximum Lateral Deviation	-0.40	0.14	-0.53	0.19
Location of Max. Lateral Deviation	60.4	81.7	56.3	130.3

TABLE B-2. Mean and Standard Deviations of Performance Measures: Treatment 2

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.057	0.016	-0.064	0.022
Max. Longitudinal Acceleration	-0.060	0.0185	-0.063	0.039
Location of Max. Lat. Acceleration	94.3	96.6	137.4	92.2
Location of Max. Long. Acceleration	159.3	77.5	128.1	78.3
Lateral Position at Bridge	-0.72	0.27	-1.15	0.41
Change in Lateral Position at Bridge	-0.25	0.22	-0.37	0.39
Maximum Lateral Deviation	-0.38	0.12	-0.65	0.27
Location of Max. Lateral Deviation	40.0	79.4	69.3	126.2

TABLE B-3. Mean and Standard Deviations of Performance Measures: Treatment 3

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.052	0.036	-0.062	0.016
Max. Longitudinal Acceleration	-0.051	0.026	-0.073	0.068
Location of Max. Lat. Acceleration	151.9	108.6	134.8	104.4
Location of Max. Long. Acceleration	117.6	84.6	126.3	97.2
Lateral Position at Bridge	-0.84	0.29	-1.03	0.44
Change in Lateral Position at Bridge	-0.38	0.21	-0.46	0.36
Maximum Lateral Deviation	-0.48	0.15	-0.54	0.55
Location of Max. Lateral Deviation	47.3	116.7	56.6	105.6

TABLE B-4. Mean and Standard Deviations of Performance Measures: Treatment 4

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.053	0.036	-0.059	0.014
Max. Longitudinal Acceleration	-0.064	0.016	-0.058	0.028
Location of Max. Lat. Acceleration	204.9	83.6	146.5	61.8
Location of Max. Long. Acceleration	168.9	123.6	115.6	75.4
Lateral Position at Bridge	-0.66	0.38	-1.08	0.39
Change in Lateral Position Upstream	-0.22	0.16	-0.40	0.23
Maximum Lateral Deviation	-1.51	4.16	-0.57	0.16
Location of Max. Lateral Deviation	39.9	42.3	41.4	101.1

TABLE B-5. Mean and Standard Deviations of Performance Measures: Treatment 5

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.051	0.009	-0.064	0.012
Max. Longitudinal Acceleration	-0.056	0.031	-0.048	0.030
Location of Max. Lat. Acceleration	206.6	80.5	112.8	78.2
Location of Max. Long. Acceleration	162.7	89.3	163.6	88.3
Lateral Position at Bridge	-0.69	0.28	-1.10	0.73
Change in Lateral Position at Bridge	-0.25	0.26	-0.38	0.23
Maximum Lateral Deviation	-0.37	0.32	-0.65	0.19
Location of Max. Lateral Deviation	134.3	130.2	83.0	133.4

TABLE B-6. Mean and Standard Deviations of Performance Measures: Treatment 6

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.050	0.033	-0.069	0.018
Max. Longitudinal Acceleration	-0.054	0.020	-0.051	0.025
Location of Max. Lat. Acceleration	176.1	99.4	147.0	92.7
Location of Max. Long. Acceleration	187.4	65.2	101.6	125.0
Lateral Position at Bridge	-0.74	0.39	-1.16	0.34
Change in Lateral Position at Bridge	-0.34	0.18	-0.37	0.33
Maximum Lateral Deviation	-0.35	0.25	-0.60	0.34
Location of Max. Lateral Deviation	29.9	86.0	44.5	95.9

TABLE B-7. ANOVA Results: Narrowed Lane Bridge Location

Source	DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Max. Lat. Accelerations:					
Model	7	0.0060	0.0009	0.082	0.57
Error	106	0.1103	0.0010		
Total	113	0.1163			
Max. Long. Accelerations:				1.32	0.45
Model	7	0.0050	0.0007		
Error	105	0.0566	0.0005		
Total	112	0.0615			
Location of Max. Lateral Accel.:					
Model	7	195546	27935.2	0.26	0.97
Error	106	11515770	108639.3		
Total	113	11711316			
Location of Max. Long. Accel.:					
Model	7	355139	50734.2	0.51	0.82
Error	105	10422290	99259.9		
Total	112	10777429			
Lateral Position at Bridge:					
Model	1	60.74	60.74	57.36	0.00
Error	157	166.24	1.059		
Total	158	226.98			
Change in Lat. Position at Bridge:					
Model	1	4.81	4.81	7.48	0.01
Error	157	100.92	0.64		
Total	158	105.73			
Lat. Position 30 meters Upstream:					
Model	1	62.59	62.59	36.72	0.00
Error	147	250.56	1.70		
Total	148	313.15			
Change in Lat. Pos. Upstream:					
Model	1	2.239	2.23	3.95	0.05
Error	152	85.80	0.57		
Total	153	88.11			
Maximum Lateral Deviation:					
Model	7	16.909	2.416	1.30	0.26
Error	99	183.611	1.855		
Total	106	200.521			
Location of Max. Lat. Deviation:					
Model	7	736798	105257	0.72	0.66
Error	99	14555060	147021		
Total	106	15291858			

APPENDIX C: STATISTICAL SUMMARIES FOR SHOULDER DROP BRIDGE TEST LOCATION

TABLE C-1. Mean and Standard Deviations of Performance Measures: Treatment 1

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.085	0.040	-0.081	0.036
Max. Longitudinal Acceleration	-0.072	0.064	-0.102	0.085
Location of Max. Lat. Acceleration	116.8	60.3	98.8	49.9
Location of Max. Long. Acceleration	153.60	102.8	76.6	62.8
Lateral Acceleration Noise	0.04	0.062	0.030	0.005
Longitudinal Acceleration Noise	0.030	0.010	0.043	0.027
Lateral Position at Bridge	-0.35	0.23	-0.52	0.37
Change in Lateral Position at Bridge	-0.36	1.19	-0.18	0.82
Location Shoulder Exit Begins	127.2	45.7	122.0	46.6
Length of Shoulder Exit Maneuver	107.0	52.2	115.9	59.8

TABLE C-2. Mean and Standard Deviations of Performance Measures: Treatment 2

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.085	0.028	-0.136	0.203
Max. Longitudinal Acceleration	-0.061	0.034	-0.122	0.097
Location of Max. Lat. Acceleration	78.2	82.7	92.4	52.7
Location of Max. Long. Acceleration	110.9	94.5	97.7	80.3
Lateral Acceleration Noise	0.031	0.006	0.030	0.008
Longitudinal Acceleration Noise	0.020	0.006	0.039	0.029
Lateral Position at Bridge	-0.40	0.25	-0.38	0.52
Change in Lateral Position at Bridge	-0.23	1.23	-0.10	0.94
Location Shoulder Exit Begins	121.6	52.9	114.9	60.0
Length of Shoulder Exit Maneuver	111.2	70.0	106.4	48.4

TABLE C-3. Mean and Standard Deviations of Performance Measures: Treatment 3

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.074	0.016	-0.099	0.045
Max. Longitudinal Acceleration	-0.067	0.033	-0.139	0.097
Location of Max. Lat. Acceleration	110.4	124.0	83.1	96.6
Location of Max. Long. Acceleration	134.7	102.7	118.6	103.4
Lateral Acceleration Noise	0.027	0.005	0.031	0.006
Longitudinal Acceleration Noise	0.022	0.010	0.040	0.023
Lateral Position at Bridge	-0.38	0.26	-0.48	0.42
Change in Lateral Position at Bridge	-0.14	0.94	-0.14	0.38
Location Shoulder Exit Begins	145.9	50.9	137.4	62.9
Length of Shoulder Exit Maneuver	115.2	64.1	127.0	63.5

TABLE C-4. Mean and Standard Deviations of Performance Measures: Treatment 4

Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.080	0.020	-0.085	0.026
Max. Longitudinal Acceleration	-0.097	0.106	-0.108	0.079
Location of Max. Lat. Acceleration	111.1	62.7	116.2	48.3
Location of Max. Long. Acceleration	97.7	103.0	124.5	102.3
Lateral Acceleration Noise	0.030	0.007	0.029	0.005
Longitudinal Acceleration Noise	0.030	0.037	0.038	0.026
Lateral Position at Bridge	-0.40	0.25	-0.59	0.36
Change in Lateral Position at Bridge	-0.20	1.13	-0.09	0.45
Location Shoulder Exit Begins	134.6	47.5	135.0	53.4
Length of Shoulder Exit Maneuver	111.6	57.5	123.9	58.6

TABLE C-5. Mean and Standard Deviations of Performance Measures: Treatment 5

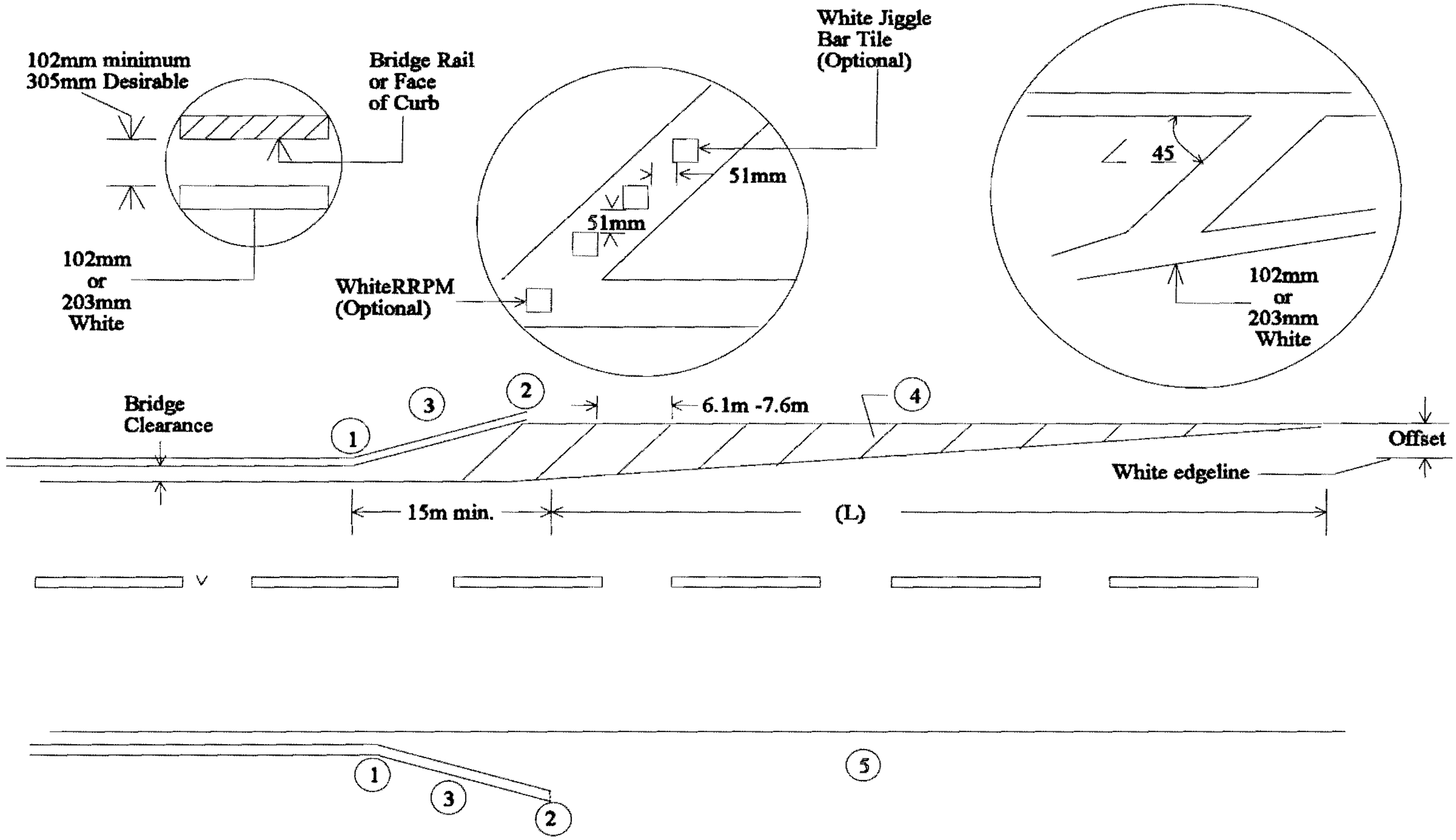
Performance Measures	Drivers < 25		Drivers > 55	
	Mean	Standard Deviation	Mean	Standard Deviation
Max. Lateral Acceleration	-0.138	0.193	-0.101	0.031
Max. Longitudinal Acceleration	-0.058	0.093	-0.109	0.117
Location of Max. Lat. Acceleration	105.1	77.4	178.0	208.6
Location of Max. Long. Acceleration	69.0	102.9	69.9	142.8
Lateral Acceleration Noise	0.028	0.005	0.029	0.005
Longitudinal Acceleration Noise	0.048	0.088	0.043	0.002
Lateral Position at Bridge	-0.42	0.24	-0.61	0.49
Change in Lateral Position at Bridge	-0.28	1.07	-0.01	1.07
Location Shoulder Exit Begins	167.7	61.4	156.4	50.5
Length of Shoulder Exit Maneuver	134.8	60.4	123.4	61.9

TABLE C-6. ANOVA Results: Shoulder Drop Bridge Location

Source	DF	Sum of Squares	Mean Square	F-Value	Prob. > F
Max. Lat. Accelerations:					
Model	9	0.066	0.007	0.88	0.54
Error	131	1.082	0.008		
Total	140	1.148			
Max. Long. Accelerations:				10.76	0.00
Model	1	0.073	0.073		
Error	140	0.956	0.007		
Total	141	1.030			
Location of Max. Lateral Accel.:					
Model	1	2249	2249	0.04	0.85
Error	139	8413008	60525		
Total	140	8415257			
Location of Max. Long. Accel.:					
Model	9	113195	12577	0.11	0.82
Error	131	15580449	118935		
Total	140	15693644			
Lateral Acceleration Noise:					
Model	9	0.0002	0.00002	0.63	0.77
Error	131	0.0052	0.00004		
Total	140	0.0054			
Longitudinal Acceleration Noise:					
Model	9	21591	2399	1.10	0.37
Error	131	285314	2178		
Total	170	306905			
Lateral Position at Bridge:					
Model	1	5.08	5.08	4.12	0.04
Error	126	155.1	1.23		
Total	127	160.2			
Change in Lat. Pos. At Bridge:					
Model	9	27.55	3.06	0.30	0.97
Error	124	1251.35	10.09		
Total	133	1278.9			
Location Shoulder Exit Begins:					
Model	4	299768.2	74942	2.56	0.04
Error	125	3662156	29297		
Total	129	3961923			
Length of Shoulder Exit Maneuver:					
Model	4	70019	17505	0.47	0.76
Error	129	4815460	37329		
Total	133	4885480			

APPENDIX D: RECOMMENDED BRIDGE DELINEATION DRAWINGS

Condition 1: Roadway with Edgeline,Offset >1.2m, Offset-Bridge Clearance >1m



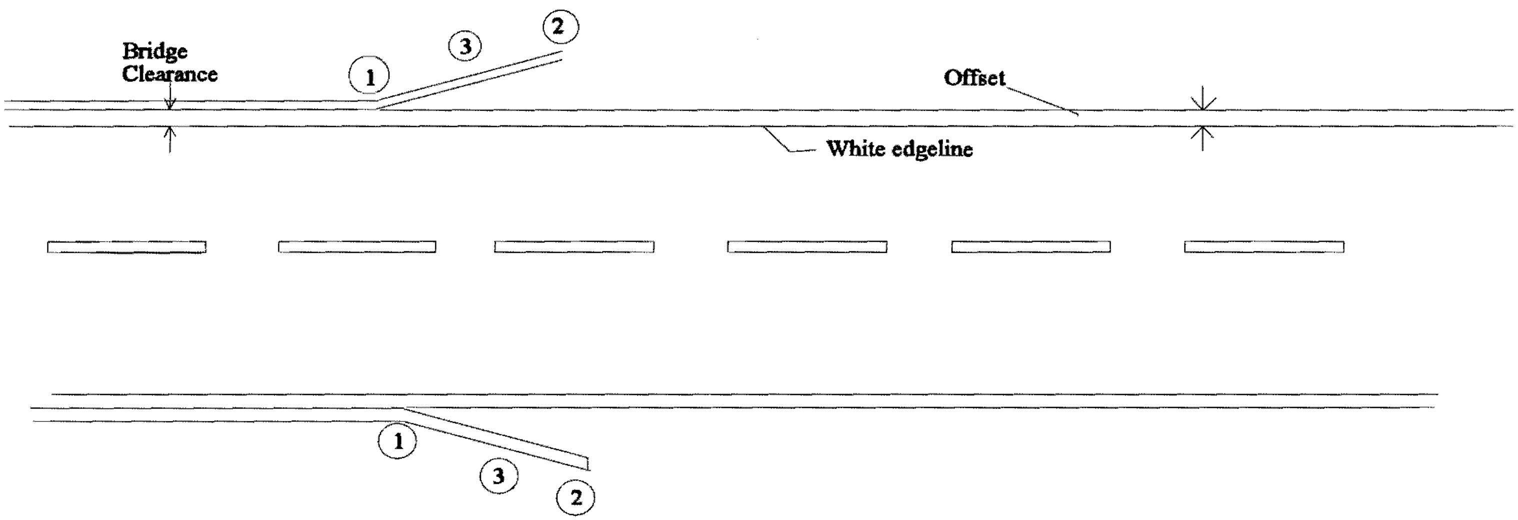
Notes:
1. Type 3 object marker.
2. Type 2 object marker.
3. Optional crosshatching 102mm mimimum width stripe.
   Jiggle bar optional. See inset for arrangement
4. Optional PMD's between the type 3 and type 2 object markers at 7.6m to 15.2m s spacings.
5. On one-way roadways, marking pattern should be replicated on the other side in yellow
   if offset and bridge clearance conditions are met.

TABLE D-1. Taper Lengths (L)

	Minimum Desirable Taper Lengths (L)		
Posted Speed	3.0m Offset	3.4m Offset	3.7m Offset
48 kph	46	50	55
56 kph	62	69	75
64 kph	81	90	98
72 kph	137	151	165
81 kph	152	168	183
89 kph	168	184	201
97 kph	183	201	219
105 kph	198	218	238

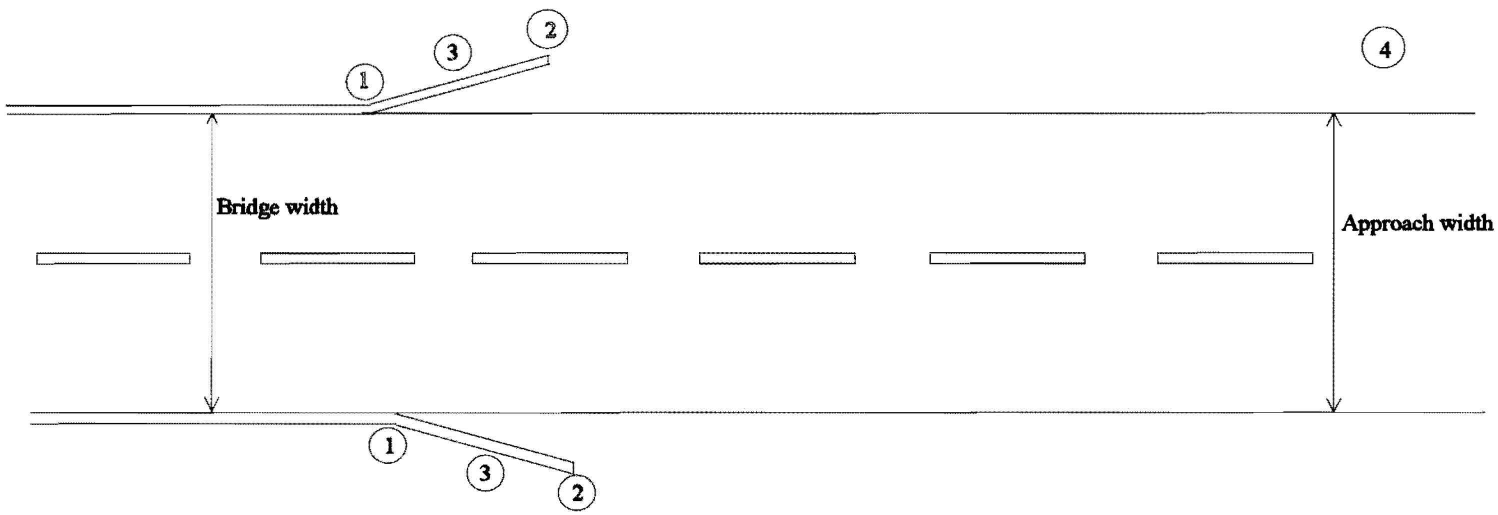
* Formula to be provided
** Taper lengths have rounded off to the nearest meter

Condition 2: Roadways with Edgelines, Offset-Bridge Clearance <1m, No Lane Width Reduction Across Bridge



Notes:
1. Type 2 or Type 3 object marker.
2. Type 2 object marker if guardrail protection for bridge end is provided
3. Optional PMD's at 7.6m to 15.2m spacings.

Condition 3: Roadways Without Edgelines, Approach Width ≥ Bridge Width



Notes:
1. Type 3 object marker.
2. OM-2 object marker at guard rail end, if present.
3. Optional PMD's at 7.6m to 15.2m spacings.
4. If bridge width < 5.5 meters, or if bridge width < approach width. narrow bridge sign (W5-2) should be used.