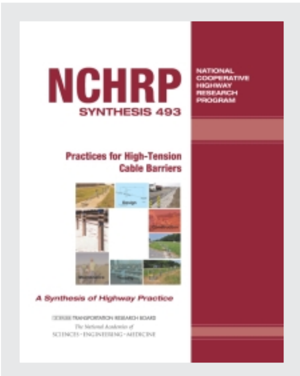

Practices for High-Tension Cable Barriers

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP SYNTHESIS 493

Practices for High-Tension Cable Barriers

A Synthesis of Highway Practice

Consultants
Richard D. Powers
and
Karen Boodlal
KLS Engineering

Subscriber Categories
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TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2016
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research is the most effective way to solve many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation results in increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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Cover figure: Photo montage (*top left corner*) high-tension cable barrier by Brifen; (*top middle*): sketch taken from the *AASHTO Roadside Design Guide*; (*top right*) high-tension cable barrier–CASS by Trinity Highways; (*middle row, left*): Safence high-tension cable barrier by Gregory Highway Industries; (*middle row, right top*): cable installation; (*middle row, right bottom*): Nucor Steel Marion high-tension cable by Nucor; (*bottom, left*): high tension maintenance repairs; (*bottom, middle*): Dick Powers conduction training; (*bottom, right*): Gibraltar high-tension cable barrier.

FOREWORD

Highway administrators, engineers, and researchers often face problems for which information already exists, either in documented form or as undocumented experience and practice. This information may be fragmented, scattered, and unevaluated. As a consequence, full knowledge of what has been learned about a problem may not be brought to bear on its solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem.

There is information on nearly every subject of concern to highway administrators and engineers. Much of it derives from research or from the work of practitioners faced with problems in their day-to-day work. To provide a systematic means for assembling and evaluating such useful information and to make it available to the entire highway community, the American Association of State Highway and Transportation Officials—through the mechanism of the National Cooperative Highway Research Program—authorized the Transportation Research Board to undertake a continuing study. This study, NCHRP Project 20-5, "Synthesis of Information Related to Highway Problems," searches out and synthesizes useful knowledge from all available sources and prepares concise, documented reports on specific topics. Reports from this endeavor constitute an NCHRP report series, *Synthesis of Highway Practice.*

This synthesis series reports on current knowledge and practice, in a compact format, without the detailed directions usually found in handbooks or design manuals. Each report in the series provides a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems.

PREFACE

Donna L. Vlasak
Senior Program Officer
Transportation Research Board

This synthesis reports on the current state of the practice for high-tension cable barriers (HTCB) used in the medians of access-controlled roadways in the United States. Information on high-tension cable barrier systems related to state agency specifications, special provisions, design standards, and installation and maintenance concerns was collected. Because all of the HTCB systems currently eligible for use on public roads in the United States are proprietary, information was also obtained from each of the manufacturers of these systems.

Information was acquires from the responses to a questionnaire. Additional information is offered in a literature review and six case examples.

Richard D. Powers and Karen Boodlal, KLS Engineering, collected and synthesized the information and wrote the report. The members of the topic panel are acknowledged on the preceding page. This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As progress in research and practice continues, new knowledge will be added to that now at hand.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

PRACTICES FOR HIGH-TENSION CABLE BARRIERS

SUMMARY

From the first experimental installation of the high-tension Brifen wire rope safety fence in 2000 in the median of the Lake Hefner Parkway in Oklahoma City, Oklahoma, the use of high-tension cable barriers (HTCB) has significantly increased throughout this country. As more state agencies became alarmed at the number of serious cross-median crashes, existing warrants for the use of median barriers were reexamined and many states realized that previous guidelines were inadequate. Because HTCB was found to be the most cost-effective barrier to install in existing medians, its use proliferated, along with the number of proprietary systems that soon became available. With this increased usage, some design, installation, and performance issues came to light.

This synthesis study was conducted to identify and report on the current state of the practice for HTCBs used in medians of access-controlled roadways in the United States. Information on HTCB systems related to state agency specifications, special provisions, design standards, and installation and maintenance concerns was collected. Because all HTCB systems currently eligible for use on public roads in the United States are proprietary, information was also obtained from each of the manufacturers of these systems.

Most of the information presented in this report was obtained through a survey sent electronically, through the AASHTO Subcommittee on Design, to all state highway agencies. Responses to the questionnaire were received from all 50 states, for a response rate of 100%. Additional information was obtained through a literature review.

The survey revealed that HTCB was allowed or in use in all but eight states and the District of Columbia. Although the majority of users allow a contractor to select the system that is ultimately installed, some limit the systems to those on their approved products lists. Because all of the currently eligible HTCB systems are proprietary, the states cannot specify only one particular design without a formal request for a public interest finding from FHWA. Typically, each state does call for a *NCHRP Report 350* or AASHTO *Manual for Assessing Safety Hardware* (MASH) Test Level (TL) 3 or 4 design and most require a 4-cable system. Some states specify a design deflection and, in many cases, a maximum post spacing. Warrants for median barriers are based on those in the AASHTO *Roadside Design Guide*, separate state warrants, crash histories, or some combination of these.

Several states reported initial problems with terminal anchor movement owing to poor soil conditions, high static loads, and impact loading. As a result, most state agencies now require the manufacturer to design the anchors based on on-site soil conditions. When the line posts are set in socketed concrete foundations, these foundations are generally designed for each project as well. Such foundations may vary from 12 to 15 in. in diameter and from 2 to 4 ft in depth. Because of the extremely high tension in the cables, posts that are not in a direct line with the end anchors in a run may have a tendency to deflect when along a horizontal curve or pull out of the ground when the posts traverse a sag vertical curve. In such cases, adjustments can be made to the design by decreasing the post spacing throughout horizontal curves and by increasing the resistance of the posts to uplift in sag vertical curves.

The location of the HTCB anchors is also an important consideration. Cable runs must be terminated to provide emergency vehicle access to the opposite traffic lanes and whenever median bridge piers or highway overpasses are shielded with semi-rigid or rigid barriers. In the first instance, offsetting the downstream run of cable from the upstream run will normally provide adequate overlap to prevent a cross-median crash. When the existing barrier is in place, the HTCB can be terminated in advance of the stiffer barrier, or extend behind or in front of the existing barrier, depending on site conditions such as existing offsets and side slopes. A fourth option is to connect the cables directly to an existing w-beam installation such as one used to shield a bridge end.

One state noted issues on its first HTCB installation as a result of a general unfamiliarity with the system, both on the part of the contractor as well as state agency personnel. Because most state agencies now require training by the manufacturer on each project and because HTCB is no longer a new technology in most states, a lack of experience no longer appears to be a significant concern. Anchor block movement was also noted as an initial concern by some agencies; however, most now require a custom design based on existing soil conditions.

Unlike other barrier systems, HTCB designs require some degree of on-going maintenance. In addition to repairing crash damage, the tension in each cable must be periodically monitored and adjusted as needed. Each contractor must tension the cables after installation according to manufacturer specifications and recheck it after several weeks. Once the project is accepted, state or contract maintenance personnel are expected to recheck the tension on a periodic basis and record the results on a tension log. Twelve states reported that maintenance is done exclusively by their own employees and seven that all such work was done by contract. For the remainder of the states, maintenance work was divided between state and contract personnel.

More than half of the survey respondents reported that they have developed specifications or special provisions for HTCB. These documents are not product-specific, but generally apply to any eligible cable system that is selected by a contractor. Several state agencies rely entirely on the manufacturer specifications and installation and maintenance manuals, having none of their own. Example state documents were selected from the material provided by the states. These ranged in length from one or two pages to more than a dozen. The most comprehensive special provisions addressed the following items:

- A description of the work to be performed.
- Materials specifications, often including the test level and minimum number of cables, as well as a copy of the FHWA eligibility letter(s).
- A manufacturers' representative on site to oversee the installation and address any issues that may arise.
- Manufacturer training provided to construction and state personnel. Some states require that every crew member be certified that he or she has been trained on all aspects of the system's installation. Many require that maintenance and emergency responders also receive appropriate training.
- Plans and shop drawings must be site-specific, particularly regarding end anchor and post-foundation designs. Some agencies require these designs to be signed and sealed by an engineer licensed in their state.
- Limited geotechnical information may be provided by a state; however, it remains the contractor's responsibility to coordinate with the system manufacturer to determine if additional soil borings and related data are needed to design the concrete foundations.
- General HTCB system design specifies the criteria for foundation designs such as design loads, factors of safety, and, in some cases, the design method to be used to check for foundation movement, uplift, and overturning.
- Concrete foundation construction is generally not specified separately in an HTCB special provision; however, at least one state includes details usually found in a concrete specification.

- HTCB construction and installation essentially requires the installation to be in conformance with the plans, any special provisions that exist, and shop drawings prepared by or for the manufacturer of the system being installed.
- At least one state requires reference markers to be placed on the anchors with control reference markers nearby to monitor possible anchor movement over time. Movement is not to exceed 1 in. over the first 12 months following installation.
- Measurement and payment is similar in the majority of states. Typically, the HTCB itself is paid for per linear foot installed, exclusive of the end anchors that are paid per each. One state pays per linear foot, including the end anchors, and one state pays for the steel portions of the end anchors per each, but the foundation concrete is paid per cubic yard.

Much has been learned about HTCB design and performance since 2000. Foundation pullouts can be minimized by designing these features for the specific soil conditions in which they are placed. The performance of cable barriers on slopes has been investigated and placement guidelines have been established to minimize the likelihood of vehicle overrides and underrides. *NCHRP Report 711: Guidance for the Selection, Use, and Maintenance of Cable Barrier Systems*, provides detailed information on all aspects of HTCB design and placement. Additional information may be acquired by a comprehensive in-service performance evaluation to determine if there remain significant concerns or issues that might be addressed through additional research.

CHAPTER ONE

INTRODUCTION

BACKGROUND

High-tension cable barriers (HTCBs) are relatively inexpensive when compared with w-beam or concrete barriers and can be installed either in a median or along the outside shoulder of a highway. However, the most common applications today are in medians of divided roadways, and this synthesis will focus on that type of installation. Median cross-over crashes are typically violent collisions, usually resulting in severe injuries both to occupants of the errant vehicle and to innocent persons in the opposing traffic stream. Cable barriers function by capturing or redirecting impacting vehicles to prevent these vehicles from intruding into the opposing traffic lanes. They are flexible systems compared with w-beam and concrete and thus deflect a greater lateral distance when impacted at high angles while at the same time reducing occupant impact forces significantly over more rigid barrier designs. Compared with other barrier types, HTCB can be installed (with limitations) on nonlevel terrain and generally requires minimal grading and drainage work. Despite more than a decade of increased use in the United States, there are still some concerns over HTCB selection, design, installation, and maintenance that need to be addressed.

Although several state transportation agencies had used some type of generic low-tension cable barrier for many years, it was not until the year 2000 that a HTCB was first installed in the United States. Since then, the use of HTCB as a median barrier has spread to nearly every state in the country. Five propriety systems have been deemed eligible for federal funding by FHWA, based on successful full-scale crash testing conducted under *NCHRP Report 350* (Ross et al. 1993) or AASHTO *Manual for Assessing Safety Hardware* (MASH) guidelines. There are currently no generic HTCB systems eligible for use in the United States. Prior to 2010, these FHWA eligibility letters (formal notification from FHWA that the hardware met all appropriate criteria and could be used on public roads) were previously referred to as acceptance or approval letters and are still referred to as such in some state departments of transportation (DOTs) specifications and special provisions. The five systems currently eligible for federal reimbursement are shown in Figure 1. In addition, a more detailed description of each system, as well as manufacturers' specifications for each system, can be found in Appendix C.

As is the case with many new roadside safety features, limited in-service performance evaluations and anecdotal evidence revealed that there were some issues with HTCB design and placement that required addressing to ensure optimal performance in the field. Consequently, several research studies were undertaken to answer some of these issues. As a result, several states have developed specifications (and in some cases special provisions) addressing the design and placement of HTCB. Because these documents were developed independently, they are not consistent from state to state. This study was initiated to document existing state specifications and special provisions relating to HTCB.

As noted previously, all HTCB designs currently eligible for use on public roads in the United States are proprietary. Thus, the physical design details and all material specifications have been determined by the individual manufacturers and verified through full-scale crash testing and cannot be changed or modified by state DOTs. Therefore, it is important that at a minimum any state specifications address the following types of issues:

- Use of HTCB,
- Specific design [e.g., number of cables, Test Level (TL), length, and lateral placement],
- Anchor and footing designs, and
- Training requirements [DOT personnel, emergency medical technician (EMT), police].

SCOPE

As the number of HTCB installations continues to increase, various design features and current practices can be summarized here to document the state of the practice and to suggest further research. The primary objective of this Synthesis study is to document existing transportation agency specifications and special provisions governing the use of HTCB in each state. Objectives include identifying warrants and design criteria currently used nationwide and identifying any continuing installation, construction, or maintenance areas of concern that may warrant additional study.

STUDY APPROACH

The development of a standardized specification for HTCB involved the following basic tasks:

- Creation of a survey form for distribution to all state DOTs to ascertain the current state of the practice.
- Collection and review of all materials supplied from the manufacturers of HTCB currently in use in the United States.
- Review of FHWA acceptance and eligibility letters for HTCB.
- Review of pertinent research efforts and selected in-service evaluation studies for HTCB.

Brifen

CASS

Gibraltar

Safence

Nucor

FIGURE 1 Five high-tension cable systems.

- Summary of state DOT responses to survey questionnaire.

ORGANIZATION OF THE REPORT

The information contained in this synthesis report was collected in several ways: a literature search, a survey of state transportation agencies, FHWA eligibility letters, and manufacturers' practices, and is presented in the following chapters:

- Chapter one–Introduction
- Chapter two–Literature Review
- Chapter three–Summary of State Survey Responses
- Chapter four–Case Examples
- Chapter five–Conclusions

CHAPTER TWO

LITERATURE REVIEW

This chapter summarizes the findings of the literature search regarding high-tension cable barrier practices, with the study's primary objective being to summarize transportation agency specifications and special provisions. The reports collected for this study were from individual states, including:

- Development of Guidelines for Cable Median Barrier Systems in Texas, TTI
- The Advisability of Expanding the Use of Cable Median Barriers in Illinois, IDOT
- Study of High-Tension Cable Barriers on Michigan Roadways, MDOT
- Cable Median Barrier Program in Washington State, WSDOT
- Evaluation of Wisconsin Cable Median Barrier Systems: Phase 2, WIDOT
- *NCHRP Report 711: Guidance for the Selection, Use, and Maintenance of Cable Barrier Systems.*

The relevant information regarding HTCB specifications, maintenance, and construction is provided here. It can be noted that there is some amount of overlap in the areas covered; therefore, there is not a clear distinction between reports.

DESIGN ISSUES

Barrier Placement

To achieve the highest level of performance, it is important that barriers be placed on near-level terrain and with adequate clear space behind to allow for dynamic deflection during impacts. Generally, this location is found close to the travel lane where the barrier may experience frequent nuisance hits. Michigan DOT notes minimum offsets from the edge of the travelled way ranging from 8 ft to 12 ft and on slopes ranging from 4H:1V to 10H:1V. On a 6H:1V slope, barriers should not be placed from 1 ft to 8 ft from the ditch centerline (*NCHRP Report 711*) (Marzougui 2012). Barriers placed along the centerline of median ditches in poor or saturated soil conditions have experienced cable barrier foundation and anchor failures. The most common recommendations are "center of median" and/or "greater than 8 ft from the bottom of the ditch," which is consistent with the Texas report and the *AASHTO Roadside Design Guide* (2011). *NCHRP Report 711* contains specific guidance on the placement of cable barriers on slopes (Marzougui 2012). Figures 2 and 3 show examples of placement guidelines from this report. In both figures, the cross-hatched area indicates those locations where barrier underride or override, as indicated, is a possibility.

Placement for Horizontal Curves

Based on numerous crash studies, there is a higher frequency of vehicles leaving the roadway on the outside of the curve versus the inside of the same horizontal curve. Therefore, when installing barrier offset from the ditch bottom, the barrier is to be placed toward the inside rather than the outside of the curve (Texas DOT), as shown in Figure 4 (Cooner et al. 2009). Currently, TxDOT guidance recommends closer post spacing through curves, as shown in Table 1. Locating the barrier on the convex side provides clear space for deflection when impacted on that side and maximum recovery area for any vehicle running off the outside of the same curve. Although such placement will reduce nuisance hits and can provide an obstacle-free recovery area in a wide median, it may allow a vehicle in a high-speed encroachment to overturn in an uneven or soft median or possibly deflect the cable into the inside lane of opposite direction traffic.

Figure 5 shows that placing the HTCB on the concave side of a curve, while increasing the likelihood of impacts, results in good performance when it is struck. On a sharp curve, loss of several posts can result in the cables falling onto the shoulder when several posts are hit (as seen here) or, in extreme cases, onto the roadway itself.

Anchor Placement and Run Length

End anchors are critical in any cable barrier system, because they provide the means to tension the cables. Standard terminal anchors for each HTCB system vary from designs with each cable connected to individual anchors to designs where all the cables are attached to a single anchor. Cable anchors are gating, so they will not prevent a vehicle from going into the area behind and beyond the anchor. They should be placed in locations where direct impacts are least likely to occur whenever practical. In situations where the cables are switched from one median side to another, they should be overlapped to prevent possible crossovers (Cooner et al. 2009).

The distance between anchor terminals for cables is referred to as a cable run. The maximum run of cable barrier between

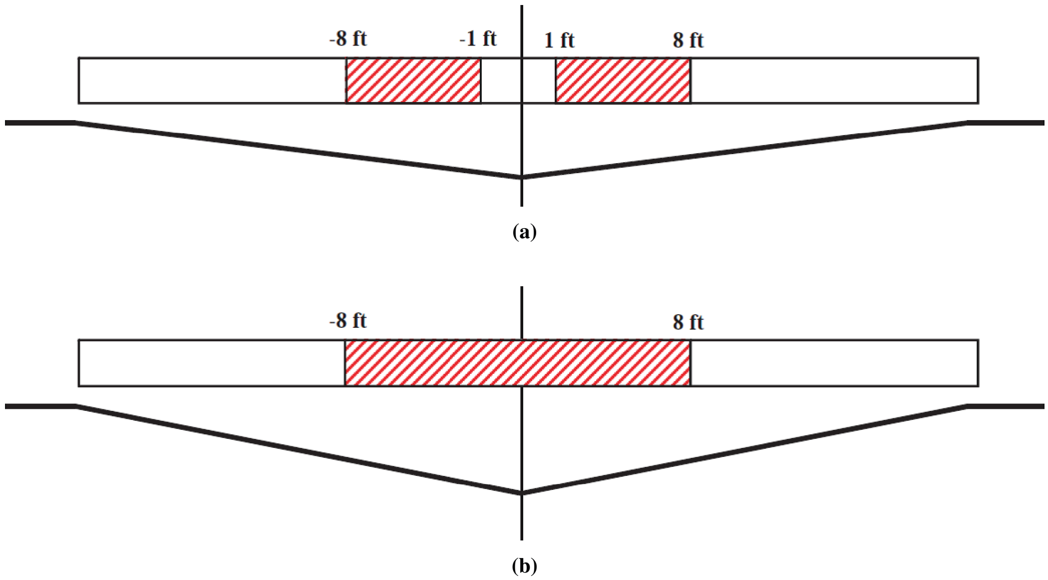

FIGURE 2 Underride criteria for V-shaped medians (Figure 6.1 from *NCHRP Report 711*) (Marzougui et al. 2012).

anchors that would allow for proper tensioning is approximately 10,000 ft and the minimum run length is 1,000 ft (Cooner et al. 2009). *NCHRP Report 711* recommends a minimum 1,000 ft spacing based on economics since the cost of anchorages is relatively high compared with the cable runs themselves (Marzougui 2012).

Emergency Vehicle Access

Crossover locations must be provided at regular intervals to allow access for emergency vehicles to respond to an incident or an emergency, necessitating a break in the run of cable. The Texas DOT report noted that the maximum distance between emergency turnarounds varied from 1 to 5 miles (Cooner et al. 2009).

Soil Conditions

NCHRP Report 350 requires that all systems be installed in standard soil for full-scale crash testing (Ross et al. 1993). Highly plastic and/or highly saturated soils have been problem areas. It is important that transportation agencies determine the soil properties before placement of systems (Cooner et al. 2009).

MAINTENANCE AND CONSTRUCTION

Anchors

Under certain soil conditions, the anchor sizes recommended by the manufactures were inadequate and were pulled from the ground after an impact. Wisconsin noted that when barriers are installed in the median centerline or ditch line where the soil is unstable and saturated anchors and post bases tend to displace. Illinois DOT (IDOT) has since revised their specifications to require a specific design calculation and method; this required steel reinforced concrete drilled foundations from 10 to 15 ft deep and two and a half feet or more in diameter at some locations.

Posts

Replacing posts after an impact was an initial concern, with the degree of difficulty based on how the post bent, sheared,

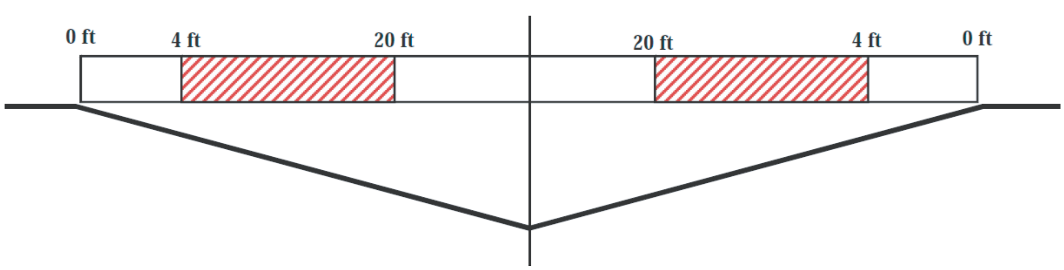

FIGURE 3 Override criteria for V-shaped medians steeper than a 6H:1V slope (Figure 6.2 from *NCHRP Report 711*) (Marzougui et al. 2012).

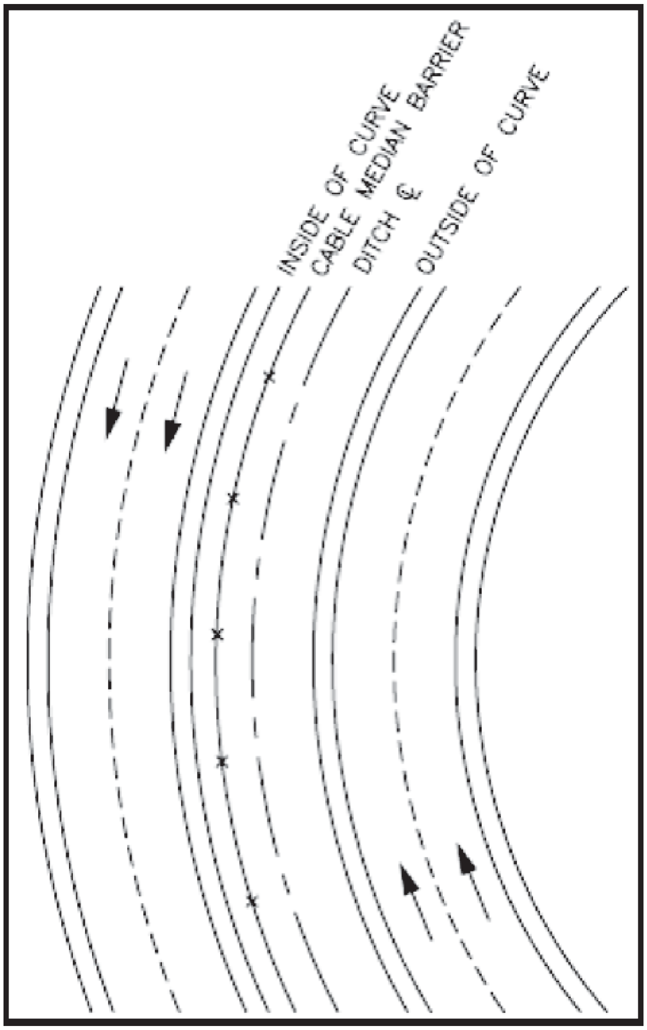

FIGURE 4 Recommended cable barrier placement on a horizontal curve (Figure 2-26 from Cooner et al. 2009).

or buckled. Socketed posts are generally easier to remove than those placed directly in concrete or driven. Illinois found that the initial construction cost for driving posts into the ground or through a relatively thin, paved mow strip with hydraulic equipment was less compared with the socketed posts. However, replacing driven posts generally required more time and machinery, and exposed maintenance personnel to heavy traffic for extended periods of time, whereas socketed posts

TABLE 1
TXDOT'S RECOMMENDED POST SPACING VS. CURVE RADIUS

Radius (feet)	Post Spacing
650–2,500	6'-8"
2,501–5,500	10'
>5,500	As shown in details

Table 2-8 of TxDOT Report.

FIGURE 5 Impacted cable on outside of curve.

can be removed and replaced manually without the need for post-driving equipment (CH2MHILL 2009).

Frozen or Wedged Posts

Posts can be difficult to remove with the socketed systems when they become wedged into the sleeves after an impact or ice and freezing temperatures makes them difficult to remove; this can be an issue for all colder climate states. Illinois tried prying techniques, heat application to the post, and salt solutions around the post in order to remove damaged posts. Socketed posts are still preferred by most Illinois districts and are called for in the standard specifications; however, individual districts are allowed to choose driven posts, if preferred by their maintenance personnel. Posts that fail as a result of shear rather than bending are often more difficult to remove from sockets (CH2MHILL 2009).

Mowing and Weed Control

Illinois has placed extra pavement underneath the barrier to reduce mowing and weed control. The Texas DOT report notes the following typical guidance on use for mow strips (Cooner et al. 2009):

- Width—4 ft (widths ranging from 2 to 6 ft);
- Thickness—3 in. (thickness ranged from 2 to 6 in.); and
- Material—concrete (asphalt and aggregate were other materials).

Resurfacing and Pavement Rehabilitation

Illinois noted that in locations where cables are placed near the shoulder; for example, placed within 4 ft of the shoulder of a relatively steep slope (steeper than 6:1), several challenges were presented (CH2MHILL 2009):

- For resurfacing projects—the height of the cables needed to be adjusted accordingly.

- Spot pavement repairs, such as patching—cable barrier can interfere with the space needed for the construction equipment and may require removal, resulting in an increase in construction cost for the pavement patching work.
- Enforcement vehicle—this restricts the space available for enforcement vehicles to safely park on the inside (median) shoulder.

Enforcement and Emergency Response

Police and other emergency responders need information and training to avoid cutting the cables after a crash except in extreme emergency situations. This saves the time and expense of replacing entire segments of cables (CH2MHILL 2009). Based on the response of emergency responders in Michigan, their main issues were the increased time needed to reverse direction resulting from the large distances between crossovers, difficulty removing vehicles in the event of a crash, and the need to close lanes because of the barrier's close proximity to the edge of the roadway. MDOT requires that the cable manufacturers provide training to agency staff and local emergency first responders as part of every cable barrier installation (Savolainen 2014).

NCHRP Report 711: Guidance for the Selection, Use, and Maintenance of Cable Barrier Systems (Marzougui et al. 2012) summarized the use of cable barriers and the introduction and use of HTCB. Also included in the report are detailed descriptions and information on the systems currently implemented in the United States. Based on state transportation agency surveys, specific concerns with HTCB were identified. Finite element analysis (FEA) was used to develop solutions to many of the expressed concerns, most notably barrier lateral placement in sloping medians. A summary of recommended guidelines was included as Appendix E in the report and were categorized as follows:

- Planning and Feasibility (Use)
- Cable Barrier Design
- Deployment
- Cost and Benefits Analysis
- Construction
- Maintenance and Operations..

Many of the proposed guidelines are general or address-specific design concepts and details that are decided by the state transportation agency before a project goes to bid. Those Items that would normally be included in the specifications accompanying the bid package (PS&E) are listed here:

- Acceptance criteria (*NCHRP Report 350* or MASH)
- Test Level (normally TL-3 or TL-4)
- Number of cables
- Post spacing
- Post footings
- Maximum deflection
- End anchor and post footing designs (based on soil analyses)
- Mow strips
- Construction tolerances (cable heights)
- Cable tension
- Training emergency responders.

NCHRP Report 711 is currently under review by the AASHTO Technical Committee for Roadside Safety with the expectation that its pertinent findings and recommendations will be included in the next edition of the AASHTO *Roadside Design Guide.*

CHAPTER THREE

SUMMARY OF STATE SURVEY RESPONSES

This chapter summarizes the results of the state survey that was distributed on January 16, 2015, to the AASHTO Subcommittee on Design. The primary purpose of this survey was to identify the current state of the practice with respect to specifications and special provisions governing the use of HTCB in each state. The survey was divided into three parts:

- Specifications and Design Issues
- Construction Concerns
- Maintenance Practices.

All 50 states responded to the questionnaire (100% response rate). The District of Columbia does not have any HTCB installations. Of the 50 respondents, 41 completed all three sections of the survey. A copy of the survey instrument is attached as Appendix A. The responses are summarized and some illustrated graphically in this chapter.

SPECIFICATIONS AND DESIGN-RELATED SURVEY RESPONSES

Currently there are five proprietary systems that have been successfully crash tested by *NCHRP Report 350* (Ross et al. 1993) or MASH criteria:

- Brifen—Wire Rope Safety Fence
- Trinity Highway Products—CASS
- Gregory Highway Products—Safence
- Nucor Steel Marion—Cable Barrier System
- Gibraltar—Cable Barrier System.

Question 2 of the survey asked what HTCB systems are currently eligible for use by your agency, providing the responders with an option to select multiple systems as well as an option for "None" if they do not currently use HTCB. The District of Columbia is included under "None" category. Table 2 shows what systems are being used by the states and Figure 6 illustrates the number of HTCB systems being used by states.

As shown in Figure 6, some states allow the use of all the HTCB systems, whereas others limit use to selected manufacturers whose systems are approved for use by the state agency. Questions 9 and 10 ask if their agencies specify a minimum number of cables and a test level, because all of the HTCB designs can be either three- or four-cable configurations and a TL-3 or a TL-4 system. Table 3 summarizes the states' responses.

As previously stated, all HTCB systems currently eligible for federal funding are proprietary, and it is imperative that the material specifications and the placement of the barrier conform to the system as it was tested. In other words, if a state develops its own specification, it cannot conflict with the manufacturers' specifications or placement recommendations. The state DOTs that have not developed their own specifications rely solely on those provided by the various manufacturers. Of the states that do have specifications, their content and detail vary greatly—from a one- or two-page document to a few that exceed 30 pages.

The contractor can generally select the system to be installed in the lengths and locations shown on the plans. The controlling factor for this selection is the inclusion of the system on the state's approved product list. Based on the survey, the majority of the states reported that their design is independent of the system ultimately used; however, Alabama, Maryland, and Montana responded that their designs are specific to an HTCB system. Maryland previously stated that the HTCB systems are being used as pilot projects and Montana noted that there was only one HTCB design installed in the state as of the survey date.

Questions 3 and 6 asked if the agency currently has specifications or special provisions for HTCB. Eight states responded that they have both a special provision and specifications, ten states have developed specifications for HTCB that are not product-specific, 17 states use special provisions, four of which are used on a project to project basis and the remaining 13 apply to all eligible HTCB systems. Seven states have neither specifications nor special provisions for HTCB, but rely solely on the manufacturers' specifications and installation manuals (Figure 7).

Questions 11 and 12 asked what warrants the use of an HTCB in a median and what the design for a specific project is based on. Most of the states decide when HTCB or other types of barriers are warranted in the median of a divided highway by using a combination of the AASHTO *Roadside Design Guide Warrants*, agency-developed warrants, crash history, and other information. Some of the other selection criteria were using engineering judgment, a Time-of-Return analysis or the RSAP cost–benefit analysis, and width of median. Figure 8 depicts these responses.

Question 13 asked states if HTCB end anchors are designed on a project-by-project basis based on soil condi-

TABLE 2
HTCB BEING USED BY STATE

HTCB Manufacturers	No. of States
Brifen	40
Trinity	38
Gibraltar	35
Nucor	26
Gregory	25
None	9

tions. Thirty-one states responded that they require the manufacturers of the systems to design the anchors and 11 use the HTCB manufacturer's standard crash-tested anchor design.

Question 15 asked how is the placement and spacing of the HTCB anchors determined. Sixteen states reported spacing is determined by the agency based on the state's specifications and 19 require the manufacturer to recommend anchor placement and spacing. Some states set minimum and maximum cable runs between anchors. Utah DOT has installed runs ranging from 2,000 ft to more than 45,000 ft. In most cases the need for emergency vehicle crossovers limits the practical length of barrier between anchors.

Although most HTCB systems allow driven posts, most state agencies reported the use of socketed posts to facilitate repair and replacement after an impact. Twenty-five states that responded to Question 16 noted that they required the manufacturer to design the size and depth of the footings based on existing soil conditions, but that 15 states used whatever design was used in the crash testing of the system; that is, a "standard" design. Maine reported that it uses only driven posts.

Because of the high tension in all proprietary cable systems, posts that are not in a direct line with the end anchors may be subjected to additional forces. Posts along a horizontal curve will have greater lateral forces, possibly resulting in leaning posts. Posts located at the bottom of a sag vertical curve may be pulled upward, effectively raising the cable heights above the ground line. Similarly, cables on posts near the top of a crest vertical curve may be lowered, depending on the cable-to-post connection and post embedment details. Sixteen states responding to Question 16 reported that they follow the manufacturers' recommendations in such cases, five modify the design in-house, and 19 do not make any modifications to standard post design or spacing. Nevada requires a design modification for any post spacing exceeding 10.5 ft and Texas requires modifications for some horizontal curves.

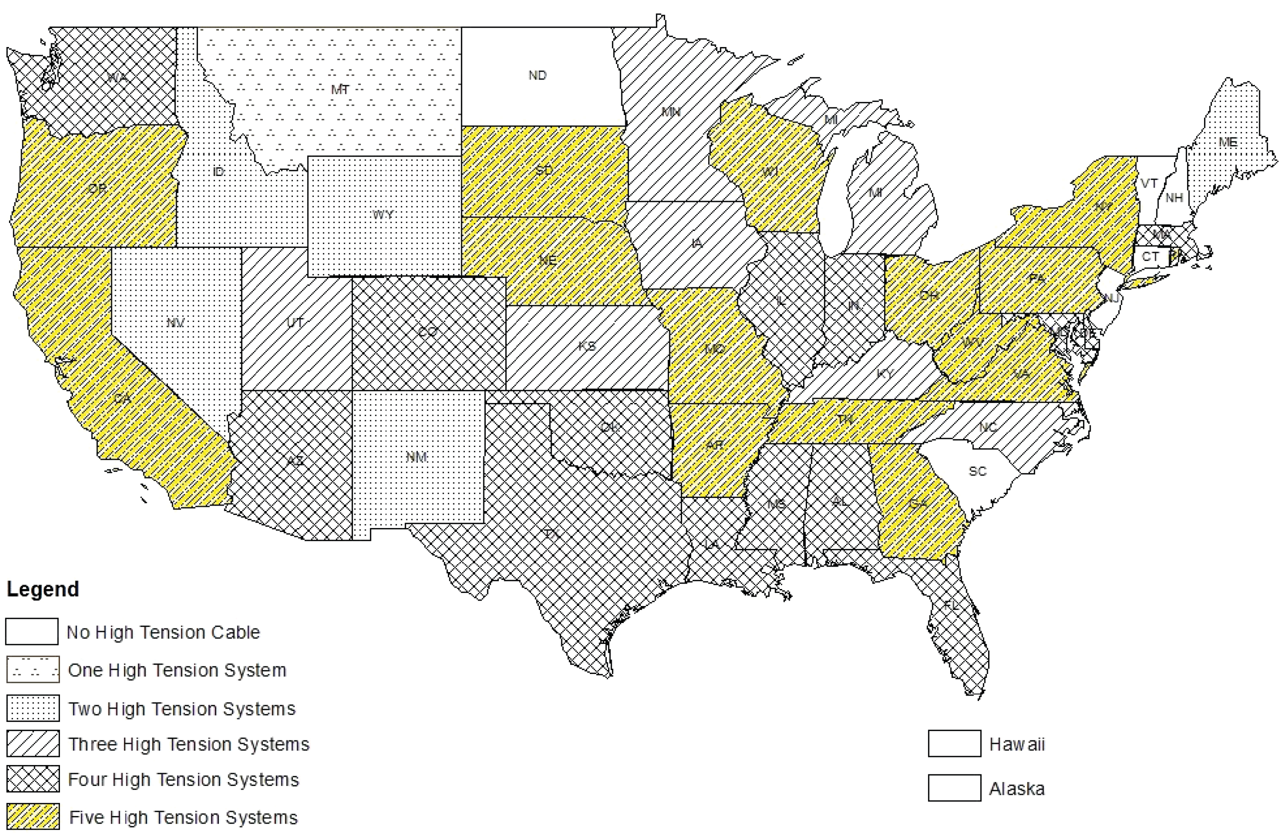

FIGURE 6 HTCB currently in use.

TABLE 3
NUMBER OF CABLES AND TEST LEVELS BY STATE

Cables/Test Levels	No. of States
Minimum number of cables—3	8
Minimum number of cables—4	24
Do not specify a minimum number of cables	10
Minimum system Test Level—3	28
Minimum system Test Level—4	19
Do not specify a minimum Test Level	2

High-tension cable barriers are most commonly used in freeway medians to prevent crossover crashes. However, freeway facilities generally include median bridge piers and twin bridge overpasses that can only be shielded with semi-rigid or rigid barriers. Question 20 of the asked how the state DOTs addressed the interface or overlap of the two different systems. Essentially four choices exist:

1. Terminate the cable barrier in advance of the stiffer system.
2. Terminate the cable barrier behind the stiffer system.
3. Connect the cable barrier to the stiffer system (excluding concrete barrier).
4. Terminate the cable barrier in front of the stiffer system (excluding concrete barrier).

Figure 9 shows the first option. Because the downstream terminal is a gating design, this treatment can leave a gap in median coverage, especially if located on the outside of a horizontal curve. If both terminals are impacted, it becomes a greater maintenance concern as well.

Figure 10 illustrates the second option. If the metal beam guardrail is long enough to shield the opening between the twin bridges, this design can work well. It is important that the HTCB be offset from the guardrail to reduce the chances of an impacting vehicle rebounding from the cable into the field side of the w-beam.

Figure 11 shows Option 3, connecting the cables directly to a w-beam, thus eliminating the need for a separate HTCB

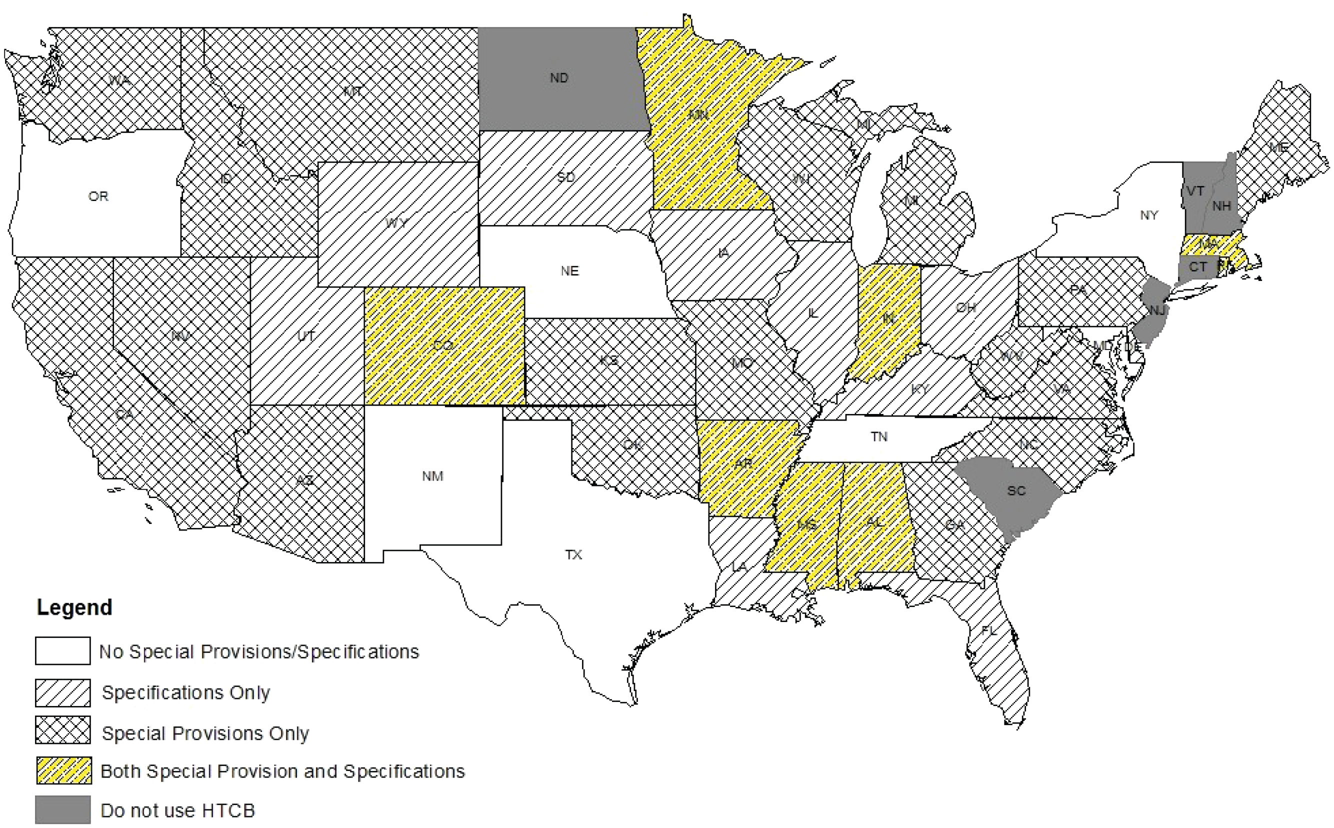

FIGURE 7 HTCB special provision and specifications by state.

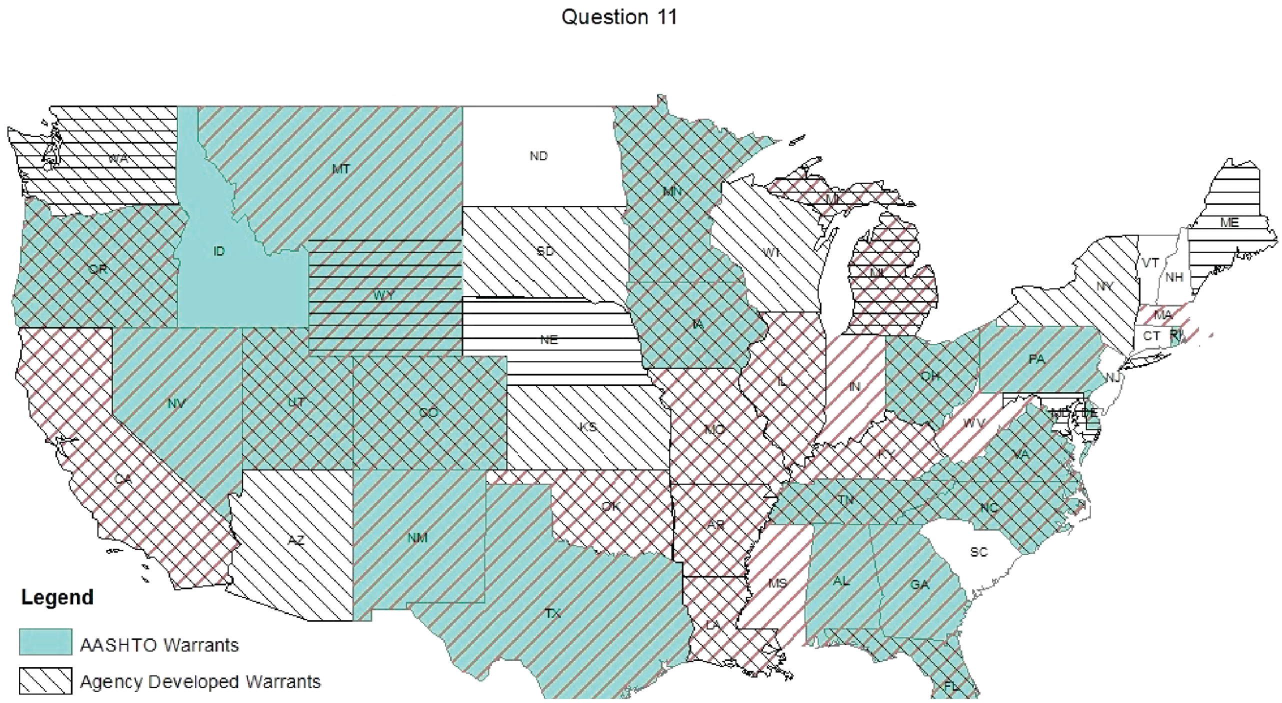

FIGURE 8 Warrant factors by state.

anchor. This design is best suited for use at locations where a new HTCB can be connected to an existing w-beam installation shielding a bridge end, when the w-beam is structurally connected to the bridge. Some state agencies have experienced problems with w-beam post movement caused by the high tension in the cables. A short section of w-beam should not be installed in place of a crashworthy HTCB anchor as was done in Figure 12. The inadequate performance of this design is seen in Figure 13. *NCHRP Report 711* recommends a minimum of 75 ft of w-beam downstream from the last cable anchor when connecting to w-beam (Marzougui et al. 2012).

The last option is effective as long as the cable is extended to the beginning length of need of the w-beam and the w-beam terminal is a minimum of 4 ft behind the cable, as shown in Figure 14. The only disadvantage to this design is that the cable terminal is in a vulnerable position and, if struck, the cable tension would be lost. Whenever practical, HTCB terminals are to be located in areas where they are least likely to be hit by errant motorists.

Although the state responses to this question varied in detail, at least one of these four alternatives was used in each state. Two states reported that they do not allow any overlap,

FIGURE 9 Terminating the HTCB in advance of w-beam.

FIGURE 10 Terminating the HTCB behind w-beam.

FIGURE 11 HTCB connected directly to w-beam.

FIGURE 13 Inadequacy of HTCB connection to short run of w-beam.

ending the HTCB in advance of any w-beam or concrete barrier and providing an acceptable terminal or crash cushion on the stiffer barrier. The majority of the reporting states indicated that the preferred treatment is to terminate the HTCB behind an existing barrier, taking into consideration the lateral distance between the two systems and the likelihood of an impacting vehicle being "trapped" between them. Only a few states noted that they flare the approach end/terminal of the w-beam rail and connect the HTCB cables directly to the guardrail itself, thus eliminating the need for a separate cable anchor. The rest of the respondents indicated that the HTCB overlapped the road side of the w-beam and was terminated with its own anchor.

The survey asked responders to identify any design-related concerns that were not specifically addressed in the questionnaire. Most expressed concerns related to HTCB placement on slopes, an issue that has received a significant attention and been the subject of several research efforts, some of which are on-going. Others asked about anchor design for various soil conditions or the possibility of developing anchors that did not require concrete foundations, thus making them easier to construct and maintain and repair.

CONSTRUCTION-RELATED SURVEY RESPONSES

Few construction issues were noted by respondents. One state reported that neither the construction contractor nor DOT personnel had any previous exposure to HTCB installation and relied heavily on the system manufacturer for advice. The only other common concern was movement in the anchor blocks or failure of the post footings in crashes. However, these are primarily design or maintenance issues and not directly applicable to system installation.

MAINTENANCE-RELATED SURVEY RESPONSES

Unlike most longitudinal barriers, HTCB systems do require continuing observation and actions after installation to maintain optimal performance.

FIGURE 12 Short section of w-beam installed as an "anchor."

FIGURE 14 HTCB terminated in front of w-beam.

TABLE 4
STATES WITH 100% AGENCY OR CONTRACTOR PERSONNEL MAINTAINING HTCB

Agency Staff (100%)	Arkansas, Colorado, Kansas (with exception of terminals), Maine, Minnesota, Montana, Nebraska, New Mexico, New York, Utah, Washington State, Wisconsin
Contractor Staff (100%)	Arizona, Idaho, Mississippi, North Carolina, Rhode Island, Tennessee, Virginia

The survey asked responders to identify who is responsible for maintaining HTCB after it is installed. Twelve states reported that their state (or in one instance, county) personnel are 100% responsible for maintaining HTCB after it is installed. Seven states reported that the work was done solely by contract, as shown in Table 4.

The remainder of the responding states reported a split responsibility between maintenance forces and contractor personnel, with the state/contract ratio ranging from 5%/95% to 95%/5% (Table 5).

The survey asked how frequently the cable tension was checked; however, there may have been some confusion with this question because only 20 states reported that the cable tension was checked after the initial installation. At opposite ends of the spectrum, one state reported checking tension every week and one every 2 years. Most states did report that the cable tension was checked following minor and/or major repairs (Table 6).

Because of the high tension in the HTCB systems and the relatively recent introduction of these designs in the United States, training is highly desirable for all persons involved in installation, maintenance, and repair. In addition to state DOT personnel, police and emergency responders need to have a working knowledge of the systems whenever a vehicle becomes entangled in the cables in a crash. Virtually all state specifications or special provisions require the cable manufacturer to provide pre-installation training for the contractor and state inspectors. At least one state required that all members of the installation crew be certified by the manufacturer as successfully completing training. Most states also offered training to police personnel and emergency responders upon completion of an installation, and some provided such training when requested. Only two states noted that no training was provided to police or EMT personnel.

Slightly less than one-third of the state respondents added comments or concerns related to maintenance issues. By far the most common complaint was that the many added miles of median barrier resulted in an increased number of impacts that required repair. Several northern tier states acknowledged that there were many hits during the winter months and that repairs were difficult under frozen-ground conditions. Others noted that spare parts were often difficult to obtain, especially when multiple proprietary systems were in use in a particular state. None of the states identified extracting vehicles trapped by the cables as a concern; however, one did indicate a serious injury to a maintenance worker when a cable snapped during accident clean-up. Although not mentioned in the survey responses, anecdotal evidence has shown vehicle extraction to be a concern in other states.

TABLE 5
STATE MAINTENANCE: PERCENTAGE BY AGENCY AND CONTRACTOR STAFF

States	Agency Staff	Contractor
Alabama	75%	25%
Delaware	95%	5%
Florida	~10%	~90%
Iowa	20%	80%
Illinois	10% (est.)	90% (est.)
Indiana	90%	10%
Kentucky		100%
Louisiana	5%	95%
Michigan	94%	6%
Ohio	20%	80%
Oklahoma	70%	30%
Texas	40%	60%
West Virginia	30%	70%

TABLE 6
FREQUENCY OF CABLE TENSION CHECKED BY STATES

Frequency	State Response
After Installation	20
Every 6 Months	1
Every Year	9
Every 2 Years	1
After Minor Repairs	13
After Major Repairs	23
Other	Illinois, Oklahoma noticeable sag North Carolina—weekly Colorado—per manufacturers recommendations Florida—not currently specified Idaho—none currently installed

CHAPTER FOUR

CASE EXAMPLES

More than half of the survey respondents provided copies or links to their existing specifications or special provisions governing the selection and installation of HTCB. This chapter includes summary descriptions of the content of these documents from selected states. As noted in chapter three, some states have not developed a specification, but rely solely on the manufacturers' specifications and installation manuals. Some states use very concise specifications, whereas a few have developed extensive documents covering design, installation, and maintenance of HTCB systems.

Specifications or special provisions were selected from the following six states, both to represent a geographical distribution across the country and to show the diversity that currently exists among state agencies: Rhode Island, West Virginia, Florida, Michigan, Colorado, and Washington. As noted previously, before 2010, FHWA eligibility letters were referred to as acceptance or approval letters and are still referred to as such in some of these DOT specifications and special provisions.

RHODE ISLAND

This specification (Code 901.9901, Tensioned Cable Guardrail, and Code 901.9902, Tensioned Cable Guardrail Terminal) was the most condensed version submitted, consisting of only two pages. Its major headings were Description, Materials, Basis of Acceptance, Construction Methods, and Method of Measurement and Basis of Payment.

The description of the work simply states that it "consists of furnishing and installing a complete and operational Tensioned Cable Guardrail . . . and Terminal at the locations designated on the Plans and/or as directed by the Engineer, in accordance with these Specifications." Under the Materials heading, this specification requires only that the selected system and terminal must meet either *NCHRP Report 350* (Ross et al. 1993) or MASH test and evaluation criteria at TL-3, that the cable and other steel components be galvanized or stainless, and that the appropriate class of concrete be used for anchorages and footings.

Under Basis of Acceptance, the specification reiterates that the system selected must have been accepted by FHWA and that it have a maximum design deflection of 8 ft. It also requires a manufacturer's certification confirming that all hardware furnished has the same physical properties as the tested and approved design, and that the product is suitable for the project site and will perform acceptably after installation. The specification also requires the manufacturer to calculate and submit the required embedment depth for all concrete footings and to provide installation and maintenance guidelines to state personnel.

The Construction Methods section of the specification requires the contractor to "coordinate with a designated representative of the manufacturer relative to the installation . . . specified in the Contract. The manufacturer . . . shall provide any instructions and drawings that are necessary in order to properly complete installation along each alignment shown on the Plans. The Contractor shall furnish the Engineer with (these) instructions and plans prior to installation." The specification also requires the line posts to be set in sockets with a concrete footing and allows minor adjustment of post spacing to span drainage features, provided the design deflection is maintained.

The Method of Measurement/Basis of Payment section is virtually the same for all state specifications for HTCB. The barrier proper is measured and paid for by the linear foot, excluding the end anchors, which are paid for as a separate line item.

WEST VIRGINIA

West Virginia has added information on HTCB under its Special Provision Section 607, Guardrail. The Section headings include Description, Materials, Erecting Rail Elements, and Method of Measurement/Basis of Payment.

The Description section identifies the work to be done as ". . . constructing high-tension cable guardrail by furnishing and installing posts, cables, end anchors, and any special connections and fittings which may be required in the contract documents." It also requires that the selected system be one that has been accepted by the FHWA as a TL-4 barrier on slopes of 6:1 and a TL-3 barrier on slopes of 4:1. It should use four cables, have a design deflection of 8 ft or less, and a maximum post spacing of 12 ft. A 3-ft by 3-in. deep concrete mow strip is required.

Under Materials, the Special Provision states that ". . . all materials used for construction of High-tension Cable Guardrail shall meet the manufacturers' requirements. The Contractor will provide certification of training from the Manufacturer in the system they are bidding. Prior to construction, the Contractor shall provide the Engineer with three (3) copies of the manufacturer's most current product manuals covering installation and maintenance of the installation and signed certification statements for all materials to be incorporated into the installations." The Special Provision requires that ". . . end terminal installations shall be to the manufacturer's specification for site-specific soil conditions," and requires that "the contractor will guarantee movement of less than one inch of all end anchors within the first two years of installation."

The section on Erecting Rail Elements essentially requires the barrier to be installed according to the plans or as directed by the Engineer and cautions that the proper height of each cable is critical. It further states that the "wire rope shall be placed and tensioned per manufacturer's recommendations" and that the tensioning be rechecked and adjusted if necessary 2 to 3 weeks after the initial tensioning. It further requires that a manufacturer's representative be present during the initial installation of the system components, and upon completion of the installation, "a manufacturer's representative shall inspect with the installer and certify in writing that the high-tension cable guardrail was installed in accordance with the design and the manufacturer's recommendations."

Method of Measurement/Basis of Payment section was again per foot of installed barrier, with the end anchors a separate bid item. The West Virginia Special Provision also requires the contractor to supply the state with a tension meter, 10% of all the hardware and line posts installed, and two full anchor assemblies as incidental to the bid items.

FLORIDA

Florida's specification is found in Section 540, High-tension Cable Barrier System, consisting of several categories: Description, Materials, Shop Drawings and Design Calculations, Design Criteria, Manufacturer's Installation Representative, Construction Requirements, and Method of Measurement/ Basis of Payment. In addition to the specification, Florida DOT has also produced a companion document identified as Design Standards Index D450, which provides detailed design guidance, including placement guidelines for high-tension cable barrier at typical locations.

Under Description, the contractor must "furnish and install high-tension cable barrier (HTCB) systems in accordance with the requirements of the Contract Documents, the Design Standards Index D450, and the Manufacturer's recommendations." Furthermore, the system selected must be one included in FDOT's Innovative Product List, meet *NCHRP Report 350* (Ross et al. 1993) or MASH TL-4 test and evaluation criteria, have an FHWA eligibility letter, and use four cables, with a minimum top cable height of 33 in. and a maximum bottom cable height of 21 in. Both height measurements are to be taken at a post.

Section 540-2, Materials, provides specifications for the wire rope, all required fittings, line posts and sockets, end terminals, barrier delineators, and reinforced foundations. Line posts are to be set in steel sleeves encased in reinforced concrete foundations, with a maximum post spacing of 16 ft. The posts must meet the manufacturer's specifications and be consistent with the size and shape specified in the FHWA eligibility letter. The end terminal used must also have an FHWA eligibility letter and its concrete foundation size must be determined by the manufacturer or the specialty engineer, ". . . whichever is more stringent and sufficient to prevent movement in the soil after tensioning the cables."

Shop drawings must contain construction specifications and all design details, including post lengths and height, post spacing, cable heights, and detailed drawings and locations for all connection hardware. Of particular importance are the foundation dimensions and reinforcing steel for all concrete foundations, including end terminal anchors and transition line posts, and all line posts. The design calculations must be signed and sealed by a professional engineer licensed in the state of Florida and must include end terminal and line post foundation designs prepared by the contractor's specialty engineer. In addition, design tables including cable tension as a function of cable temperature must be included.

Florida DOT has very specific requirements for the design of end terminal foundations, summarized as follows:

- Use geotechnical information provided in the plans and/or furnished by the contractor if required by the manufacturer.
- Minimum design load for end anchor based on the cumulative tension expected at zero degrees Fahrenheit.
- Analyze lateral deflection of the end anchor using the P-Y Method.
- Limit lateral deflection to one inch at the ground line, using a factor of safety of 2.0.
- Analyze overturning resistance using Broms' Method with a factor of safety of 2.0.
- Analyze the uplift resistance using the Alpha or Beta Methods (reference FHWA-NHI-10-016) with a factor of safety of 2.0.
- Determine steel reinforcement for the terminal anchor using the AASHTO Load Resistance Factor Design (LRFD) Bridge Design Specifications.

Line post foundations should be based on the soil most predominant in Florida, a cohesionless sand with a friction angle of 30 degrees and a weight of 112 pounds per cubic foot (unsaturated) or 50 pounds per cubic foot (saturated). If the geotechnical data provided in the plans do not meet these soil conditions, a line post foundation design must be submitted to the engineer. The foundation design must allow the posts to reach their plastic strength limit or fracture before the foundations deflect one inch. The foundations must also be designed to prevent overturning, using the Broms' Method with a factor of safety of 1.5. Reinforcing steel must be designed using the AASHTO LRFD Specifications to resist external loads or temperature and shrinkage strains, whichever requires the most reinforcing.

Section 540.4 requires a manufacturer's representative be on the jobsite prior to and during the initial work related to layout, installation of the end anchorage, post sleeves, and post hardware, as well as cable attachment and tensioning. The representative must also provide "a written letter . . . to the Engineer stating that the Contractor's installation process follows the requirements outlined in the manufacturer's installation manual and that the construction personnel received adequate training for the installation and tensioning of the cable barrier system."

Section 540.5, Construction Requirements, provides standard guidelines for basic layout, site preparation, and installation, including allowable tolerances for system components. The requirements for initial and final cable tensioning, however, are quite detailed and summarized here:

- Use certified and calibrated tension meter specified by the manufacturer.
- Provide calibration certificates to the engineer 30 days before installation.
- Determine required tension based on cable temperature at time of testing.
- Tension cables systematically in accordance with manufacturer's specifications.
- Re-test and re-tension as needed between 2 and 3 weeks after initial tensioning.
- Complete a tension log detailing all pertinent information on the time, temperature, location, and results of each reading and the model and serial number of the tension meter used.
- Provide the engineer with two copies of the tension logs for initial, final, and any intermediate re-tensioning.
- Deliver two tension meters and any additional tools needed for system maintenance to the Department before final acceptance.

Method of Measurement/Basis of Payment is based on the linear footage of installed HTCB, exclusive of the end anchors. Florida divides the end terminal payments into two categories, the first being the End Terminal Assemblies, which includes end terminal posts and hardware required by the manufacturer for a complete and functioning end terminal system meeting an FHWA eligible design. The second pay category is the End Terminal Foundation based on the cubic yards of concrete used and includes reinforcing steel, labor, materials, and equipment needed to complete the drilled shaft. The quantity to be paid will be based on the foundation dimensions shown on the approved shop drawings.

MICHIGAN

Michigan DOT has developed the most comprehensive series of Special Provisions addressing HTCB. In addition to a basic Special Provision covering HTCB in general, the state has separate documents for HTCB Spare Parts and Repairs During Construction, Maintenance, and Repair of HTCB After Construction, HTCB Training Sessions, and Removing, Salvaging, and Reconstructing HTCB.

Although the Special Provision for HTCB addresses the items contained in many state specifications or special provisions, generally in much greater detail, it also includes items that may be unique to Michigan. The specific categories include:

- Description
- Materials
- Manufacturer's Representative
- Consultation and Training
- Plans and Shop Drawings
- Geotechnical Information
- General HTCB System Design
- Concrete Foundation Construction
- HTCB Construction/Installation
- Cable Terminal Foundation Monitoring
- Measurement and Payment.

The Description states that the "work consists of constructing high-tension cable barrier (HTCB) as shown on the plans, (and) according to the manufacturer's details and specifications, and this special provision. If the requirements of this special provision conflict with the requirements of the manufacturer's details, comply with the requirements of this special provision."

Under Materials, the contractor must select the HTCB system to be installed from the three proprietary systems used by Michigan DOT, and provide "written certification to the Engineer that all components supplied by the manufacturer meet manufacturer's specifications and this special provision." The system selected must meet or exceed *NCHRP Report 350* (Ross et al. 1993) or MASH at TL-3 when installed on slopes of 1V:4H or flatter, and TL-4 when installed on slopes of 1V:6H or flatter. FHWA eligibility letters must be provided to the engineer for the HTCB and its end terminals. The Materials section concludes with detailed specifications for each of the separate elements (e.g., cable, posts, fittings, reflective sheeting, and concrete.

Prior to cable barrier installation, the name, telephone number, e-mail address, and a resume of the manufacturer's representative assigned to the project must be provided to the engineer. This individual must be employed by the cable barrier manufacturer. The contractor is prohibited from acting in this capacity. The engineer has the right to reject a manufacturer's representative if he fails to demonstrate thorough knowledge of the system being installed or fails to comply with the special provision. The representative must travel to the project site to inspect the installation and discuss any issues that arise when so requested by the engineer. He must also meet on site with the engineer no later than 5 days after initial cable tensioning to inspect the entire installation. Any deviations from manufacturer's specifications must be reported directly to the engineer.

Under Consultation and Training, the special provision states that

> [T]he manufacturer must provide training with respect to the design, installation, operation, and maintenance of the cable barrier system. Training and consultation must be at a location in the State of Michigan deemed acceptable by MDOT. The manufacturer must issue a dated certificate to each individual that has undergone formal training. Prior to installation of the cable barrier system, provide written certification from the manufacturer to the Engineer that the entire work force to be used for installing the system has received the training and necessary aids to install the system. This work force training must include installation of the foundations, end terminals, posts, cables, turnbuckles, reflectors, miscellaneous hardware, and tensioning the cables. The written certification must contain a list of individuals trained and certified by the manufacturer.

As noted previously, Michigan DOT has a separate Special Provision for Training and it requires the manufacturer to conduct a minimum of four training sessions. Session 1 is intended primarily for maintenance forces, emergency first responders, and tow truck operators. This training session is conducted in an office or classroom setting prior to cable barrier installation, unless otherwise specified by the engineer. It addresses issues such as safely removing vehicles caught in the cables and a list of actions that should or should not be taken after an impact. Session 2 is primarily for construction and maintenance forces and is held in a classroom setting. This session covers basic maintenance such as tensioning the cables, splicing them when necessary, use of the tension meter, and any other specialty tools that may be needed for the system. Session 3 is for the same participants from Session 2 and consists of hands-on training at the installation site and gives each person the opportunity to splice cables, adjust tension, and to perform other tasks needed for barrier repair, as well as for routine maintenance. Session 4 requires training for repairs to the system during cold weather. It is conducted on site when practicable, but may be presented to maintenance forces in a classroom setting.

Plans and Shop Drawings must be submitted in paper and electronic format to the project engineer, the Michigan DOT Regional Soils Engineer, Construction Field Services Engineer, Operations Field Services Division, and the Design Division at least 30 days before barrier installation. Each set of plans must include detailed shop drawings of the cable system, design calculations and notes, and any construction specifications. The drawings for each cable run must include cable heights, post lengths (total and above ground), post spacing, detailed drawings of all posts and hardware, turnbuckle locations, overall barrier length, end terminal design and locations, and foundation design. The end terminal foundation design must show all dimensions and steel reinforcement layout and be signed and sealed by a professional engineer licensed in Michigan. In addition, the plans must include the following:

- A report detailing the methodology and geotechnical data used to design line post foundations and end terminal foundations.
- A table showing the recommended post spacing as a function of roadway curvature.
- A table and/or a graph showing impact deflection (at TL-3) as a function of post spacing.
- A table showing the recommended cable tension as a function of cable temperature.
- A signed certification letter from the manufacturer indicating the cable system conforms to this special provision.
- Appropriate FHWA acceptance letters for the system, including its end anchors.

Limited Geotechnical Information is provided to the contractor by Michigan DOT and it ". . . may be used for design purposes at the manufacturer's discretion. It is expressly understood that the Department will not be responsible for interpretations or conclusions drawn from geotechnical information furnished by the Department . . . Soil data furnished by the Department represent conditions at specific locations. No inference should be made that subsurface conditions are the same at other locations." The contractor is advised to "contact the manufacturer prior to bidding and determine if additional geotechnical data is required." If so, the contractor must "obtain and furnish additional geotechnical data . . . and laboratory tests required for the manufacturer to complete design of end terminal foundations or other components of the cable barrier system."

Under General HTCB System Design, Michigan DOT requires that the following criteria be met:

- The minimum design load for end terminal and cable connections to the foundation must be based on the theoretical cumulative cable tension expected at –25°F.
- Each foundation must be designed using the P-Y Method when checking the theoretical deflection and must use the Broms Design Method when checking overturning.
- Each foundation must be designed using the geotechnical data furnished by the department and/or the contractor, as determined by the manufacturer.
- A minimum factor of safety of 2.5 against overturning using the Broms Design Method must be used.
- End terminal deflection must not be greater than 0.5 in. when subjected to the minimum end terminal design load described in this special provision, using a minimum factor of safety of 1.0 in the foundation deflection analysis.
- End terminal foundations must be designed to resist uplift and/or downward forces using a minimum factor of safety of 2.0 and the Beta and Alpha Methods (FHWA-IF-99-025).
- Steel reinforcement must be designed using appropriate AASHTO guidelines.
- Drilled shaft concrete foundations must be used for all end terminal and post foundations. A rectangular reinforced concrete cap may be used to connect two or more cylindrically shaped end terminal foundations, but it must have a minimum depth of 48 in.

The section on Concrete Foundation Construction goes into significant detail on the construction specifications for all footings and foundations, including drilled shaft procedures, steel reinforcement, and concrete placement. Michigan DOT requires that the bottoms of all concrete foundations, including line post and end terminal foundations, be a minimum of 48 in. below ground level. In addition, the minimum diameter for all foundations is 15 in.

The section on HTCB Construction/Installation basically requires that the cable barrier system be installed according to the plans, this special provision, and the shop drawings developed by the manufacturer for this project. Post spacing is limited to a maximum of 10.5 ft, unless otherwise specified on the plans developed by the Department or directed by the engineer. Upon completion of the barrier, and after the concrete end anchor foundation has reached a minimum compressive strength of 3000 psi, each cable is tensioned as specified by the manufacturer, based on the cable temperature. Final tensioning is required a minimum of 2 weeks after the initial tensioning and adjusted as needed. The contractor must then "submit written certification to the Engineer indicating the date of initial cable tensioning, date of final tensioning, the ambient and cable temperatures on each of these dates, and the tension in the cables on each of these dates."

Michigan mandates Cable Terminal Foundation Monitoring, requiring the contractor to furnish and install three reference markers on each end terminal foundation to monitor longitudinal and lateral foundation movement over time. Two control reference markers must also be installed. Initial observation is to be made within a minimum of 2 weeks after initial cable tensioning, and follow-up observations (to measure any lateral, longitudinal, vertical, and/or rotational movement) be made 12 months after the initial observations, or as directed by the engineer. All observations are required to be conducted by a professional surveyor licensed in the state of Michigan. Any end terminal foundation movement exceeding 1 in. within 12 months of final cable tensioning and resulting in any tension reduction to the cable system requires repair and retensioning of the cables at no additional cost to the department.

Measurement and Payment is similar in Michigan to most other states. The HTCB is paid on the linear footage of cable barrier actually installed, exclusive of the end anchors. The end anchors are bid per each. Bid prices for the anchor blocks are based on conservative foundation designs developed by the manufacturer in conjunction with geotechnical consultants prior to bidding. Michigan does not allow any additional payment for constructing cable barrier foundations with dimensions and/or depths different from those used by the bidder for bidding and estimating purposes.

Michigan DOT's Special Provision for High-tension Cable Barrier Spare Parts and Repairs During Construction requires the contractor to obtain a spare parts package, unique to the system selected for installation, to make repairs to any section of barrier damaged before final acceptance of the project. Any such parts not used during construction become the property of the department upon completion of the project.

The Special Provision for Maintenance and Repair of High-tension Cable Barrier After Construction covers the requirements for routine maintenance of completed installations and any repairs necessitated by crash damage. The contents of this document are similar to those in the Michigan DOT's Special Provision for High-tension Cable Barrier insofar as materials and installation methods are concerned. However, it requires all contractors to have adequate experience in maintaining each of the HTCB systems included in a contract as well as a certification letter from each manufacturer that the contractor has received appropriate training in that system. The contractor must also maintain a spare parts inventory for each of the systems that he or she will be required to maintain. In addition to repair work, the contractor also conducts routine maintenance on all cable barrier runs approximately once every 12 months unless otherwise directed by the engineer. Annual maintenance includes checking and adjusting cable tension as needed, exercising and lubricating turnbuckles, repairing any damaged galvanized surfaces, and reporting any damage noted to the engineer. The contractor must receive the engineer's authorization before initiating repair work.

DOT
DEPARTMENT OF TRANSPORTATION

COLORADO

Section 606 of Colorado's Standard Specifications addresses cable barriers. Its primary categories include Description, Materials, Construction Requirements, and Method of Measurement/Basis of Payment. In addition to the specification, Colorado DOT has also produced a concise Cable Barrier Guide that provides a comprehensive summary of all pertinent issues regarding the use and design of HTCB in the state.

Under Section 606, the Description and Materials sections are direct: it states that the work "consists of the installation of Tensioned Cable Barrier at locations shown on the plans" and the materials must be those needed for a four cable, FHWA-approved TL-4 system that is included on Colorado DOT's approved product list. Socketed posts and pre-stretched cables are also required.

Colorado DOT Construction Requirements are similar to those of other state agencies and require that the barrier be installed in accordance with the details shown on the plans and in accordance with the manufacturer's recommendations. Design deflection is not to exceed 9 ft and the maximum post spacing allowed is 20 ft. The contractor must be adequately trained to ensure proper installation and the manufacturer's representative must check the completed installation, including cable tension, and provide a signed statement that all has been installed correctly and is functional.

The specification requires the contractor to "conduct a soil survey based on at least one test boring every mile and at anchor sites to identify the soil type, classification, and load-bearing capacity. The Contractor shall submit the results of this soil survey to the Manufacturer so that adjustments can be made to the size or type of footing. A copy of this survey shall also be submitted to the Engineer for the project records." Colorado DOT requires a minimum concrete footing size of 14 in. in diameter and 3 ft in depth for line posts. The Colorado specification also requires the contractor to deliver spare parts to a designated Colorado DOT maintenance facility. These parts consist of one complete end anchorage unit and all parts required for repair of 1,500 ft of barrier.

Method of Measurement/Basis of Payment is again by the linear foot for the barrier proper and separate payment for each end anchor unit. Colorado does allow for additional payment for concrete if the post and end anchorage footings required based on soil borings are larger than those originally specified in the contract.

WSDOT

WASHINGTON STATE

Washington State's Special Provision for HTCB includes a description of the work, materials, construction, additional components, and pay items. The work description requires supplying and constructing high-tension cable barrier systems, including all hardware, terminals, and transition sections in conformity with the lines and grades as staked. System selection requires a four-cable design compliant with *NCHRP Report 350* TL-3 or TL-4, with a top cable height of not less than 35 in. and a bottom cable height of no more than 19 in. (Ross et al. 1993). Shop drawings and installation procedures must be furnished to the engineer at least ten days prior to installation work.

This Special Provision requires that a manufacturer's representative, or an installer who has been trained and certified by the unit's manufacturer, shall supervise assembly and installation at all times. A copy of said certification must be provided to the engineer before installation. All installation, including anchors and transitions, shall follow the manufacturer's recommendations. Any contractor-proposed modifications to the plans must be submitted to the engineer for approval at least ten days prior to work in the affected section. Line posts shall be socketed in concrete footings in a size recommended by the manufacturer.

Washington also requires the contractor to deliver spare parts for future maintenance. These include 100 line posts and associated attachment hardware, 20 sockets when steel sockets are used in the initial installation, 50 ft of cable, and three cable splices and turnbuckle assemblies (four of each for a four-cable system). A tensioning device recommended by the manufacturer must also be delivered to the state. The state has a single pay item for HTCB, per linear foot, for the entire barrier installation from end to end (including transition sections, cable-to-guardrail terminals, foundations, end anchors, and all associated hardware). The additional HTCB components (i.e., spare parts) are billed as a lump sum item.

CHAPTER FIVE

CONCLUSIONS

The primary objective of this synthesis report was to identify the range of appropriate topics for inclusion in specifications and special provisions relating to the selection, design, installation, and maintenance of high-tension cable barrier (HTCB) systems. To gather data for this effort, a literature review was conducted and a survey form sent electronically to all 50 state transportation agencies, and a 100% response rate was obtained. In addition, information was obtained from each of the manufacturers of the five systems currently deemed eligible for federal reimbursement by FHWA. The information thus obtained has been reviewed and summarized for this report.

CONCLUSIONS

As noted in chapter four, existing state specifications and special provisions for HTCB vary in content and detail from a few pages to more than 30 pages, whereas some agencies rely entirely on the specifications and installation guidelines provided by the manufacturer of each proprietary system. Because the Michigan guidelines were the most comprehensive, each of the following headings corresponds to those in that state's Special Provision. The commentary under each heading is intended to serve as a guideline for any agency desiring to create or modify its own specification or special provision for HTCB.

Description

Most state specifications reviewed simply require that the HTCB be installed as shown on the plans and according to the manufacturer's specifications or as directed by the project engineer. Some agencies also include the required characteristics of the barrier; for example, either a three or four cable design and the *NCHRP Report 350* or AASHTO *Manual for Assessing Safety Hardware* (MASH) test level. Other state agencies include these system characteristics under the Materials heading.

Materials

Because all of the HTCB systems are proprietary, the materials, including cables, posts, connection hardware, and end anchors, must meet the manufacturers' specifications for the system that was tested and for which an FHWA eligibility letter was issued. Some agencies refer to the manufacturers' specifications and certifications for all hardware items, whereas others identify each component separately and list the appropriate ASTM or other standard to which the item must comply.

Manufacturer's Representative

Most agency specifications or special provisions require that a representative with thorough knowledge of the system being installed be identified for the project and be acceptable to the project engineer. Many specifications require that this person be on site before beginning work and for all major phases of the installation. Some require the representative to be present for the final tensioning and certify to the project engineer that all work has been completed in accordance with the manufacturer's specifications and installation manuals.

Consultation and Training

Many state agency specifications require the manufacturer to provide training to the contractor's installation crew. Michigan requires that each member of the workforce be issued a certificate indicating completion of such training. Michigan Department of Transportation (DOT) also has a special provision requiring several training sessions, both in the classroom and on site, for emergency medical services personnel, tow truck operators, and state construction and maintenance workers.

Plans and Shop Drawings

The requirements for plans and shop drawings are relatively similar for most state agencies and require detailed dimensions and locations for all barrier runs and end anchorages. These drawings typically show post lengths, spacing, and heights above ground, as well as individual cable heights and all connection details, splice locations, and miscellaneous hardware. It is important that the shop drawings also include an end terminal anchor design based on existing soil conditions. Some agencies require that all design calculations be included and that the final foundation design be signed and sealed by a professional engineer licensed in that agency's state. Florida and Michigan specify the methods to be used to calculate the theoretical anchor deflection and overturning potential with assigned factors of safety. Florida sets the design load based on cable temperature of 0°F, whereas Michigan uses –25°F.

Geotechnical Information

Most DOTs now recognize the importance of designing end anchor foundations and line post footings for on-site soil conditions. Many state agencies provide limited soil data to the contractor, usually with a caveat that it may not be representative of all soil conditions on the project. It remains the contractor's responsibility, in conjunction with the manufacturer, to determine if additional soil borings are needed to design the terminal anchorage blocks or post footings. Because of its extreme weather conditions, Michigan requires that post footings be 15 in. in diameter and be set 48 in. in the ground. At least one manufacturer includes three "standard" terminal anchor designs in its installation manual based on soil conditions ranging from a strong soil to one that is completely saturated.

General HTCB System Design

Most state agencies do not have a separate section for design per se, but refer to the Plans, Manufacturers' Guidelines, and Shop Drawings prepared for the project. Michigan DOT includes its design criteria for foundation designs in this section.

Concrete Foundation Construction

Michigan is the only state that includes detailed specifications for foundation and footing concrete in its special provisions.

HTCB Construction and Installation

Most agency specifications require that the HTCB be installed according to the plans and the shop drawings developed by the manufacturer for each project. They also detail the procedure for the initial tensioning upon completion of the project and the timing for re-checking and adjusting the tension as needed within a specified time period. One agency, at this point, requires a certification from the manufacturer stating that the installation was installed in accordance with the design and the manufacturer's recommendations.

Cable Terminal Foundation Monitoring

Michigan appears to be the only state that requires that each anchor foundation be monitored for movement by installing three reference markers on each terminal anchor and two control markers nearby. All surveying work must be done by a surveyor licensed in Michigan. Anchor movement of more than 1 in. over the first 12 months following final cable tensioning and resulting in any tension loss in the system must be addressed at no cost to the department.

Measurement and Payment

Most agencies pay for the length of barrier installed, exclusive of end anchorages, at the bid price per linear foot. Anchorages are each bid as a unit price. Washington State, however, has a single bid price per linear foot for the HTCB installation from end to end, including transition sections, cable-to-guardrail connections, foundations, end anchors, and all associated hardware. Florida pays for the HTCB per linear foot, exclusive of the end anchors, but divides the end anchor payment into two categories—the first being a unit price payment for the end terminal assembly including the end terminal posts and associated hardware, and the second being a price based on the cubic yards of concrete needed for the end anchorage block, including reinforcing steel, labor, and equipment need for its installation.

Several state agencies also require the contractor to furnish a spare parts package to the DOT upon completion of a project. These packages generally consist of all the materials needed to repair a specified amount of damage; for example, 500 ft of HTCB or a specific length of cable and number of posts, sockets, connection or attachment hardware, and end anchor components. (Note: Replacement parts stockpiled by the contractor to repair or replace safety hardware damaged before project acceptance are eligible for federal funding and any such parts not needed during construction may be retained by the contracting agency for future repairs. In addition, federal-aid highway funds (except Interstate funds) may be used to repair damaged safety features that meet current standards when hit and to upgrade substandard installations after a crash. In the latter case, where state agencies collect the cost of replacement from the responsible party, federal-aid participation is limited to the betterment costs.) At least one new and calibrated tension meter is generally specified as well. The spare parts package can be paid as a lump sum item or a unit price item for each component supplied.

On-Going Research

Under its Regional Pooled Fund Program, the Midwest Roadside Safety Facility (MwRSF) at the University of Nebraska–Lincoln initiated development of a generic four-cable, high-tension median barrier. The goal of this effort is to produce a nonproprietary design that can be placed on a 1V:4H slope and prevent penetration by most passenger vehicles. The safety improvements included wider cable spacing, increased cable heights, modified post cross sections, and optimized cable-to-post attachments. This project is expected to continue through 2015 and possibly beyond. Further information on this effort may be found on the MwRSF website at http://mwrsf.unl.edu/reportresult.php?reportId=18&search-textbox=cable.

RESEARCH SUGGESTIONS

Because HTCB has now been in use in the United States for more than a decade, many of the earlier concerns have been addressed to some extent. The two major issues were terminal anchor and post foundation failures and barrier penetrations primarily resulting from the lateral placement of the cable on median slopes. The foundation problems appear to have been addressed. Most agencies require foundation designs to be based on an analysis of common soil conditions on each project. *NCHRP Report 711* provided specific guidelines on optimum barrier placement on slopes to minimize vehicle underrides and/or overrides.

NCHRP Report 711 also identified topics to be considered for further study. The first of these addressed the need for detailed in-service performance evaluations for the various HTCB systems currently installed. Although each of the proprietary systems performed similarly in controlled crash tests, there may be differences in crash performance and subsequent repair efforts in the field. If so, the information gathered in evaluation reports could be very useful to each state agency as additional HTCB projects are developed. The following items are suggested for inclusion in any such evaluation efforts:

- Manufacturer;
- Number of cables and height of each;
- Run length between anchors;
- Lateral distances from edge of shoulder and/or from ditch bottom;
- Slope from edge of shoulder to barrier;
- Impact conditions; that is, impact speed and angle and vehicle type;
- Long-term performance of materials (corrosion);
- Reusability of hardware; and
- Maintenance concerns.

The second topic suggested for additional study was development of a revised testing matrix and evaluation criteria that would allow the performance of a specific cable barrier design on slopes to be considered in the selection process.

Another issue that could be addressed is the effect that impact loading might have on the end anchor foundation designs. The states that require site-specific designs and the manufacturers appear to use the forces exerted on the anchors by static cable tensioning alone to design the foundations against movement, uplift, and overturning.

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Ross, H.E., Jr., D.L. Sicking, R.A. Zimmer, and J.D. Michie, *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features*, Transportation Research Board, National Research Council, Washington, D.C., 1993, 142 pp.

Savolainen, P.T., T.J. Gates, B.J. Russo, and J.J. Kay, *Study of High-Tension Cable Barriers on Michigan Roadways*, Report MDOT ORBP Project Number: OR10-036, Wayne State University, Detroit, Mich., Oct. 24, 2014.

APPENDIX A

NCHRP Synthesis Topic 46-14 Survey Questionnaire

Dear AASHTO Subcommittee on Design Member:

The Transportation Research Board is preparing a synthesis entitled "Practices for High-Tension Cable Barriers (HTCB)." This is being done for The National Cooperative Highway Research Program, under the sponsorship of the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration.

This survey is the key part of the Synthesis project and is intended to identify the current state-of-the-practice with respect to specifications and special provisions governing the use of HTCB in each State. It will provide information on warrants for the use of cable barrier in highway medians, HTCB selection, and current practices regarding HTCB design, installation, and maintenance. In addition to compiling the survey results, the final report will include a literature review and, based on information from survey respondents, several examples of state procedures (case studies). As a result of this effort, information regarding all phases of HTCB usage should become more readily available to individuals and agencies interested in the state-of-the-practice nationwide.

Please note that this survey is intended to be completed by each State agency that uses HTCB in its median. It consists of three sections addressing Specification and Design Issues, Construction Concerns and Maintenance Practices. After you or the appropriate person in your agency has completed the Specifications and Design section, please forward the partially completed survey form to the appropriate persons in your agency's Construction Division for completion of the next section and subsequent forwarding to Maintenance for completion of the last section and submission to TRB.

Your cooperation in completing the questionnaire at the following link will ensure the success of this effort.

http://www.surveygizmo.com/s3/1953659/NCHRP-Synthesis-46-14-Survey

Please compete and submit this survey by Friday, 13 February 2015.

If you have any questions, please contact our project manager, Karen Boodlal, at karen1.boodlal@kls-eng.com or (703)-858-1356.

Thank you for your assistance.

Jon

This survey consists of three sections: Design, Construction, and Maintenance. It has been sent directly to members of the AASHTO Subcommittee on Design. Please complete Section 1 and forward the survey form to the appropriate individual in your agency's construction section. That individual will complete Section 2 and forward the survey form to maintenance for completion and submission to NCHRP.

SECTION 1: DESIGN

1. What State/Agency do you represent?

2. What High Tension Cable Barrier (HTCB) designs are eligible for use by your agency? (please check all that apply)

- ☐ Brifen - Wire Rope Safety Fence
- ☐ Trinity Highway Products - CASS
- ☐ Gregory Highway Products - Safence
- ☐ Nucor Steel Marion - Cable Barrier System
- ☐ Gibraltar - Cable Barrier System
- ☐ None

3. Has your agency developed specifications for High Tension Cable Barrier (HTCB)?

- ○ Yes, Specifications have been developed for each eligible system
- ○ Yes, Specifications have been developed but are not product specific
- ○ No, use manufacturers specifications
- ○ No

4. Please provide a link to your HTCB specifications, if applicable.

Browse... Choose File No file selected Upload

5. Please provide a link to your HTCB standard drawings, including HTCB end terminals, if applicable

Browse... Choose File No file selected Upload

6. Has your agency developed HTCB Special Provisions?

- No
- Yes, Universal - Apply to any/all HTCB designs
- Yes, Project by Project basis
- Yes, Product specific
- Other

7. Please provide a link to HTCB Special Provisions, if applicable.

Browse... Choose File No file selected Upload

8. Has your agency performed an In-Service Performance Evaluation on any HTCB installation? If yes please provide a link to the report.

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9. Does your agency specify the minimum number of cables used?

- [ ] No
- [ ] Yes, 3 cables
- [ ] Yes, 4 cables

10. Does your agency specify the minimum system Test Level?

- [ ] No
- [ ] Yes, Test Level 3
- [ ] Yes, Test Level 4

11. How does your agency decide when HTCB or other barrier type is warranted in a highway median? (please check all that apply)

- [ ] Use AASHTO Roadside Design Guide Warrants
- [ ] Use agency developed warrants
- [ ] Crash History
- [ ] Other ______

12. The design for a specific project is based on:

- ○ a specific HTCB system
- ○ design independent of the system ultimately used

13. Are HTCB end anchors designed on a project-by-project basis based on soil type/conditions?

- ○ Yes, designs are done by agency
- ○ Yes, designs are done by HTCB manufacturer of the system being installed
- ○ No, a standard design is used

14. If yes, please attach details

Browse... Choose File No file selected Upload

15. How do you determine the placement and spacing of HTCB end anchors?

- ○ Done by agency based on state's specifications
- ○ Done by HTCB manufacturer of the system being installed
- ○ Other

16. Are socketed line posts designed on a project-by-project basis based on soil type/condition?

- ○ Yes, designs are done by agency
- ○ Yes, designs are done by HTCB manufacturer
- ○ No, there is no specific design
- ○ Socketed posts not used

17. If yes, please attach details.

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18. Is there any design modification (post spacing) for horizontal or vertical curves?

- Yes, designs are done by agency
- Yes, designs are done by HTCB manufacturer
- No, there is no specific design
- Other

19. If yes, please attach details.

Browse... Choose File No file selected Upload

20. How do you address the interface/overlap of HTCB with a metal beam or concrete barrier?

21. Are there any design-related issues that you believe need to be addressed by additional research?

22. Attach photos of typical concerns.

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23. Please enter your contact information (email/contact number) *

SECTION 2: CONSTRUCTION

24. Has your agency experienced any challenges related to HTCB installation?

- Not aware of any issues
- Yes

25. If yes, please describe any issues and how there were addressed?

26. Attach photos of typical concerns.

Browse... Choose File No file selected Upload

27. Please enter your contact information (email/contact number) *

SECTION 3: MAINTENANCE

28. HTCB repair work is done by (please specify percentage)?

Agency Staff

Contractor

29. Provide a link to typical repair contract (if applicable)

Browse... Choose File No file selected Upload

30. How frequently is the cable tension checked? (please check all that apply)

- ☐ After installation
- ☐ Every 6 months
- ☐ Every year
- ☐ Every 2 years
- ☐ After minor repairs
- ☐ After major repairs
- ☐ Other ________

31. Have your agency personnel, police, and EMT personnel been trained in the proper ways of removing vehicles entangled in the cables and releasing tension when necessary? (if yes, please specify how often it is offered)

Agency Personnel ________

Police Personnel ________

EMT Personnel ________

32. Has your agency experienced any challenges related to maintenance of any HTCB?

- ○ Yes
- ○ Not aware of any issues

33. If yes, please describe the issues and how they were addressed.

34. Please attach photos of typical concerns, if available.

Browse... Choose File No file selected Upload

35. Please enter your contact information (email/contact number) *

APPENDIX B

List of Respondents

Alabama
Alaska
Arizona
Arkansas
California
Colorado
Connecticut
Delaware
Florida
Georgia
Hawaii
Idaho
Illinois
Indiana
Iowa
Kansas
Kentucky
Louisiana
Maine
Maryland
Massachusetts
Michigan
Minnesota
Mississippi
Missouri
Montana
Nebraska
Nevada
New Hampshire
New Jersey
New Mexico
New York
North Carolina
North Dakota
Ohio
Oklahoma
Oregon
Pennsylvania
Rhode Island
South Carolina
South Dakota
Tennessee
Texas
Utah
Vermont
Virginia
Washington
West Virginia
Wisconsin
Wyoming

APPENDIX C

Manufacturers Summary

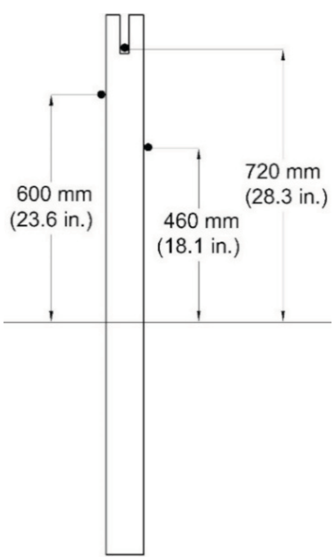
Brifen Wire Rope Safety Fence (WRSF)

Brifen was the first high-tension cable barrier system used in the U.S., installed in Oklahoma City in 2000. As reported in the survey, there are currently 40 states that use this WRSF system, comprising 95.2 percent of all the states that use high-tension cable systems (42).

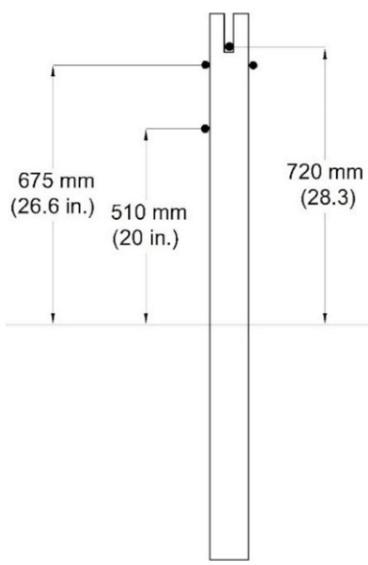
This system uses S- or Z-shaped posts and interweaves the cables between adjacent posts, resulting in a design that absorbs the energy of an impacting vehicle at each post. Each cable is placed on the opposite side of the posts from the cable below it, except for the top cable which is set into the slot at the top of each post. The lower cables are not attached to the posts, but rest on a small nylon "locating pegs" to position the cables at their proper heights. Cables are securely anchored to a single end terminal located at each end of the run.

System Configurations

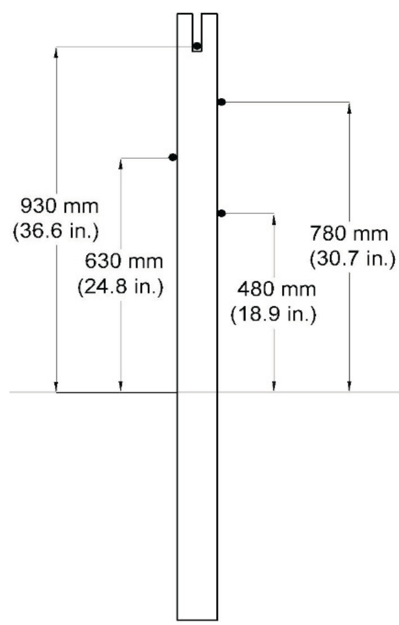
It has been crash tested with both three- and four-cable configurations as shown below and is considered eligible by FHWA as either a *NCHRP Report 350* TL-3 and TL-4 system.



TL-3 – Three Cable
FHWA Eligibility Letter – B-82C
(May 26, 2005)
Cable Heights above ground
- Top Cable at 720 mm (28.3 in.)
- Middle Cable at 600 mm (23.6 in.)
- Bottom Cable at 460 mm (18.1 in.)



TL-3 – Four Cable
FHWA Eligibility Letter – B-82
(April 10, 2001)
Cable Heights above ground
- Top Cable at 720 mm (28.3 in.)
- Two Middle Cables at 675 mm (26.6 in.)
- Bottom Cable at 510 mm (20 in.)



TL-4 – Four Cable*
FHWA Eligibility Letter – B-82B
(March 27, 2005)
Cable Heights above ground
- Top Cable at 930 mm (36.6 in.)
- Two Middle Cables at 780 mm (30.7 in.) and 630 mm (24.8 in.)
- Bottom Cable 480 mm (18.9 in.)

*TL-4 WRSF, four-cable system is acceptable as a TL-3 barrier when placed no further than 1.2 m (4 feet) down a 1V:4H slope (for adjacent traffic impacts) and no closer than 3 m (10 feet) from the ditch bottom for opposite-side impacts (FHWA B-82-B).

System Components

- **Cable**

  The Brifen WRSF is made up of 21-wire, 3/4 in. (19 mm) diameter galvanized wire rope and has a minimum breaking strength of = 17.7 tonnes (39,000 pounds). To reduce stretching during impact, the cables are prestretched during manufacturing to exhibit a minimum modulus of elasticity of 11,805,090 pounds/in^2 (8300 kg/mm^2) after prestretching. Cables are tensioned based on the ambient temperature and this tension varies from 5700 pounds at 0°F to 2700 pounds at 100°F. It is important that cables be placed at the design height above the ground with a maximum deviation of ± 1 in. (25.4 mm). Generally, the cable heights are measured from the ground level beneath the line of WRSF, but when the horizontal distance from the WRSF is 2 feet (609.6 mm) or less from the edge of pavement, the cable heights are measured from the edge of the pavement.
- **Line Posts**

  Posts have rounded edges on the traffic approach side and can be installed in a concrete socketed foundation, directly driven, set in driven socket foundations or surface mounted.

  Posts in concrete socketed foundations are the most commonly used option, as shown in this picture. The foundation has a 355.6 mm (14 in.) minimum diameter and its depth is determined by a geotechnical analysis.

  Post spacings are typically 3.2 m (10.5 ft), but the system has also been tested and is FHWA accepted with 2.4 m (7.87 ft) and 6.4 m (21 ft) spacings. Rope connection hardware (turnbuckles) are also tested and accepted for placement at a line post in the length of need.
- **End Anchor Terminal**

  The Wire Rope Gating Terminal (WRGT) is a crashworthy terminal (*NCHRP Report 350*, TL-3) and can be placed anywhere within the clear zone. It anchors all the ropes to one large reinforced concrete foundation offset 2 feet (609.6 mm) away from the line of barrier. There are two *NCHRP Report 350* versions of this terminal: WRGT-FL and WRGT-RD. The WRGT-FL uses 4 special posts (Posts 1 thru 4) placed in socketed foundations. The Post 1 socket is placed at an angle towards the anchor. Each of the four posts has a weakening cut just above the ground line, which must be placed towards the anchor. Posts 2 and 3 do not have a slot at the top of the post.

  The WRGT-RD uses the standard line posts (with top slots) for posts 2 thru 4. This terminal met all the *NCHRP Report 350* requirements except for the head-on impacts. It is typically placed near departing ends of bridges (or other shielded locations) and on downstream ends if outside the clear zone for opposite-direction traffic.

  For all these terminals it is preferred that the concrete foundation be placed in excavations of natural undisturbed ground. The foundation sizes vary and depend on the soil type and condition, water table depth, temperature extremes, etc. Soil testing should be performed based on state policy or Brifen requirements.

BRIFEN Tension Cable Barrier System Specification (04/23/04)

1.0 Description

This specification covers all materials used in the installation of Wire Rope Safety Fence (WRSF) together with construction methods for installation.

2.0 General

The WRSF described by these specifications shall be of the four (4) rope type, capable of roadside or median mounting, meeting NCHRP 350 TL3. The manufacturer shall provide a FHWA letter of acceptance prior to approval. The type and design of the WRSF shall have been in use for a minimum of three (3) years and show proof there of. Only designs which incorporate "interwoven" technology may be used whereby a minimum of three (3) of the four (4) ropes are each woven on alternating sides of sequential line posts for the entire segment length. Each rope beginning with the bottom rope is placed on the opposite side of the next higher rope.

3.0 Materials

All materials used in this construction shall comply with the following requirements:

3.1 Wire Rope

(a) The galvanized wire rope shall be ¾" (19mm) 3 X 7 construction meeting AASHTO M 30-92 (2000)/ASTM A741-98 Type 1 Class A coating except as modified below:

Table 1 Type 1 Breaking Strength Minimum = 39,000 pounds (17.7 tonnes)

(b) In addition to this provision, the wire rope shall be prestreched during manufacture to exhibit a minimum modulus of elasticity of 11,805,090 pounds/in^2. (8300 kg/mm^2) after prestretching.

3.2 Fittings

(a) **Threaded Terminals** (swaged type) shall be furnished and may be shop or field swaged. Threaded terminals shall be Right Hand (RH) or Left Hand (LH) threaded M24 X 3 pitch to ANSI B1.13M.

The body of the threaded terminal shall provide a minimum of 5.9 inches (150 mm) wire rope engagement depth. Fully fitted ropes shall develop a Minimum Breaking Load (MBL) of 36,800 pounds (16.7 tonne.) Threaded terminals shall be galvanized, after threading, to ASTM A-153.

(b) **Turnbuckle or Rigging Screws**, as they are sometimes called, shall be of the size and shape as shown in the plans. One end of the rigging screw shall be threaded RH and the other end LH to ANSI B1.13M M24 X 3 to accept threaded rope terminals. Rigging screws shall be of the solid or closed body type with two (2) inspection holes to determine threaded rope terminal penetration. They shall allow for a minimum of six (6) inches (150mm) of penetration from each end. Rigging screws shall develop minimum tensile load without yielding to 36,800 pounds (16.7 tonne) and shall be galvanized to ASTM A-153 after threading.

(c) **Mechanical Anchor Fittings** shall be provided at the Standard End Terminal ends of each wire rope. They shall be of a cylindrical barrel design with an interior tapered bore into which the wire rope is inserted from the narrower end. A set of grooved wedges are inserted from the opposite end between the barrel and the wire rope. A cap is then screwed in place compressing a coil spring against the wedges preventing accidental release of the wedges while tension in the wire rope pulls the wedges tighter around the wire rope. This mechanical fitting shall be coated with Tufftride and Wax oil for protection. The mechanical fitting shall insure infinite adjustment along the wire rope for proper length and shall develop minimum tensile load of the entire wire rope of 36,800 pounds (16.7 tonne) without yielding. They shall be capable of release and reuse.

(d) **Tensile Rods with Combination Mechanical Fittings** shall be provided at the WRGT End Terminal ends of each wire rope. The combination mechanical fitting shall be of a cylindrical design into which the wire rope is inserted, and threaded to accept the tensile rod. The fitting shall insure proper adjustment of the wire rope for length and shall develop minimum tensile load of the entire wire rope of 36,800 pounds (16.7 tonne) without yielding. They shall be capable of release and reuse.

3.3 Line Post

(a) All posts shall be of the size and shape shown in the plans. Posts shall have rounded edges on the traffic approach side. They shall typically be available in a socketed version for use when a metal sleeve is installed in the ground for insertion of the post. They shall also be available, if specified, in a driven post version with a welded soil plate. All required welding shall be by Certified Welders to AWS D1.1. Posts and soil plates shall be ASTM A-36 steel galvanized to A-123, after fabrication. All posts shall have a means of holding the wire ropes at the design height without metal hooks or other metal hardware.

For socketed posts, a low-density polyethylene excluder profiled to fit tightly around the post shall be provided to prevent debris from entering the socket. All posts shall be furnished with a low density polyethene post cap. If specified, the post cap shall be provided with retro-reflective sheeting properly sized to fit the traffic approach side of the post cap and meeting AASHTO M-268 Type Four (4) adhesive sheeting. Minimum size shall be $7.875/in^2$. If so specified, plans shall indicate sheeting color, post pattern, and whether required on one or both sides of the cap.

When socketed posts are required, sockets conforming to the plans shall be provided. Sockets shall be fabricated from ten (10) gauge, hot rolled mild steel galvanized to ASTM A-123, after fabrication. An eight (8) inch diameter (200mm) reinforcing ring with four (4) inch (100mm) overlap made from number three (3) deformed rebar shall be furnished for installation in post concrete foundations as shown in the plans or this reinforcement may be formed as a box shape with approximately ten (10) inch (250mm) diagonal dimension and four (4) inch (100mm) overlap.

3.4 End Terminals

Two types shall be available; the Standard End Terminal for use outside the clear zone or if appropriately shielded from impact by traffic; and the WRGT End Terminal for use both within and outside the clear zone. The WRGT End Terminal is accepted by FHWA as meeting NCHRP-350 TL-3.

1. <u>Standard End Terminal</u>
   This end terminal incorporates two separate concrete foundations, each of which anchors two wire ropes, and includes two deflection posts placed in sockets which are set in concrete foundations.

(a) **Fabricated anchor frames and deflection posts with sockets** shall be of the size and shape as shown in the plans. Anchor frames and deflection posts shall be fabricated from materials meeting ASTM A-36 and galvanized after fabrication to A-123. All welding is to be per AWS D1.1. All deflection posts shall be placed in sockets set in concrete foundations.

(b) **Safety Check Ropes** shall be furnished for each of the ¾" (19mm) wire rope's end anchor termination. Safety check ropes shall be 5/16" (8mm) galvanized 6 X 19 construction with eye terminals on each end. Each main wire rope is fed through one end of their respective safety check rope prior to end anchorage termination with mechanical fitting. The other end of the safety check rope is attached to the end anchorage by use of a screw pin shackle. Assembled safety check ropes shall develop minimum breaking load of 8,150 pounds (3.7 tonne).

(c) **Heavy Duty Steel Washers and HDPE Plastic Washers** shall be furnished at each slotted end anchor point. They shall be of the size and shape shown in the plans. Heavy steel washers shall be fabricated from ASTM A-36 material, galvanized after fabrication, to A-123.

2. <u>WRGT End Terminal</u>
All four wire ropes of this NCHRP-350 complaint end terminal shall be anchored into one concrete foundation; four special posts placed in sockets set in concrete foundations shall be included

(a) **Fabricated anchor components** shall be of the size and shape shown in the plans. The 4-slot breakaway anchorage frame assembly, reinforcing cage, posts and sockets shall be fabricated from materials meeting ASTM A-36 and galvanized after fabrication to A-123. All welding is to be per AWS D1.1. All posts shall be placed in sockets set in concrete foundations.

(b) **Heavy Duty Steel Washers and HDPE Plastic or Nylon Washers** shall be furnished at each slotted end anchor point. They shall be of the size and shape shown in the plans. Heavy steel washers shall be fabricated from ASTM A-36 material galvanized after fabrication to A-123.

(c) **FHWA Acceptance** letter shall be provided by the manufacturer.

3.5 Concrete

It is preferred that the concrete for end terminal foundations be placed in excavations of natural, undisturbed ground, to the size and shape shown in the plans. If over-excavation is unavoidable, then either extra concrete may be used to completely fill the excavation, or else the end terminal foundations shall be formed, cast, and backfilled per Agency specifications to minimum density of 95% after form removal. Cost for excavation, concrete, forming, and backfilling shall be included in the bid price for a complete & functional End Terminal.

All concrete used in the installation of the WRSF shall be 4,000 PSI meeting all requirements of Agency specifications. Refer to applicable sections of Portland cement concrete specifications.

4.0 Construction Methods

4.1 Description

This work consists of furnishing all labor, materials, equipment, and performing all operations in connection with the installation of a complete and operational WRSF.

4.2 General

The alignment and location of the WRSF shall be according to the plans or as directed by the Engineer. Extreme care shall be taken to insure proper wire rope height. Edge drop-offs and other depressions between edge of traveled way and WRSF shall be filled and the area graded smooth. Compacted earth, asphalt millings or other material may be used as directed by the Engineer. Posts shall be of the type specified and spaced as shown in the plans. Posts shall be set plumb, in line, to provide an aesthetically pleasing line of sight. Wire rope shall be placed per manufacturer's recommendations and be tensioned immediately after initial installation. Tension shall be rechecked three (3) to five (5) days after initial tensioning on segment lengths over 2,500 feet (760m) and adjusted, if necessary. A tension log form shall be completed showing the time, date, location, ambient temperature, and final tension reading, signed by the person performing the tension reading. This log shall be furnished to the Engineer upon completion of work. This form shall also include the WRSF manufacturer's recommended tension chart.

4.3 Basis of Acceptance

Basis of acceptance of the WRSF furnished shall be based on the following:

1. Prequalification as set forth under this specification, Section 2.0 above.

2. Visual inspection of all items furnished for condition and conformance with dimensional and other requirements.

3. Receipt of manufacturer's certification and material test reports for wire rope, posts, and anchor frames.

4. Determination (at project site prior to installation) of the weight of galvanized coating by means of a magnetic gauge.

4.4 Method of Measurement

Unless otherwise specified by the Engineer, WRSF will be measured complete in place and the measurement will be in two (2) parts:

(a) The line post length of need section shall be measured to the nearest linear foot (meter), not including End Terminals on each segment. Unless specified otherwise in the contract documents, socket-type posts shall be used.

(b) WRSF End Terminal units, either Standard or WRGT, will be measured separately by the unit. One End Terminal unit is required for each end of the WRSF. The contract documents shall specify the type and number of end terminals being used.

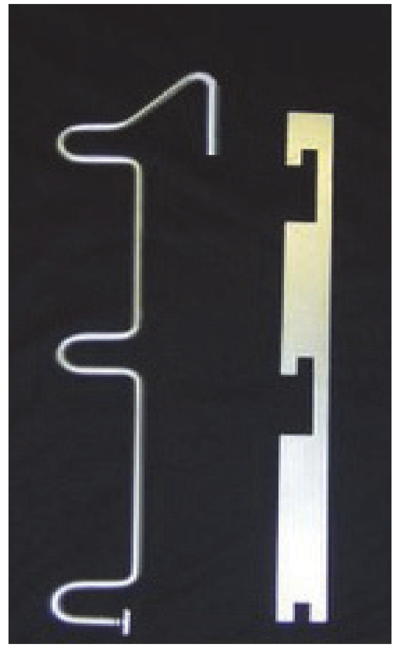
4.5 Basis of Payment

Work completed, measured and accepted as provided above will be paid for at the contract unit price bid per linear foot (meter) for WRSF and per each WRSF End Terminal Unit. The price bid shall be full compensation for furnishing all material; for installing all posts with caps, wire rope and reflectors (if specified in plans); for excavation, concrete and backfill; and for all labor, equipment, tools, and incidentals necessary to complete the work. Payment will be made under:

Description	Pay Unit
WRSF Socketed Line Post System	**Linear Foot (Meter)**
WRSF Driven Line Post System	**Linear Foot (Meter)**
WRSF End Terminal (Standard)	**Each**
WRSF End Terminal (WRGT)	**Each**

Gibraltar High-Tension Cable

As shown from the survey, currently 35 states use this system, comprising 83.3 percent of all the states that use high-tension cable barrier (42). The system uses a distinctive steel hairpin and lockplate design that connects the cables to the C-channel posts. Posts are placed so the adjacent posts are on the opposite sides of the cables, in an alternating pattern.

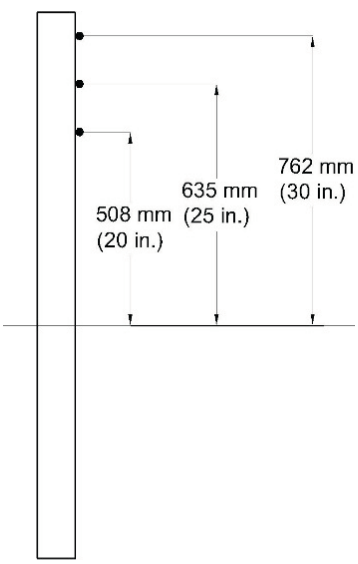


System Design

It is available in both three- and four-cable configurations as shown below and is considered eligible by FHWA as a *NCHRP Report 350* TL-3 or TL-4 system.

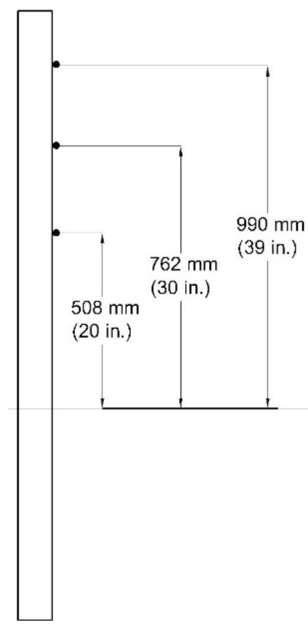
System Components

- **Cable**
  The cable is made up of 21 strands (3 × 7 configuration), ¾ in. (19 mm) diameter galvanized wire rope and has a minimum breaking strength of 18 tonnes (39,900 pounds). The cables are available prestretched and non-prestretched.
- **Line Posts**
  The posts for the Gibraltar system alternate on the sides of the cable; therefore, post holes are augured 2 inches off the center line, on alternating sides with the "open" seam of the C-Section post, facing the center line. Line posts can be socketed or directly driven.



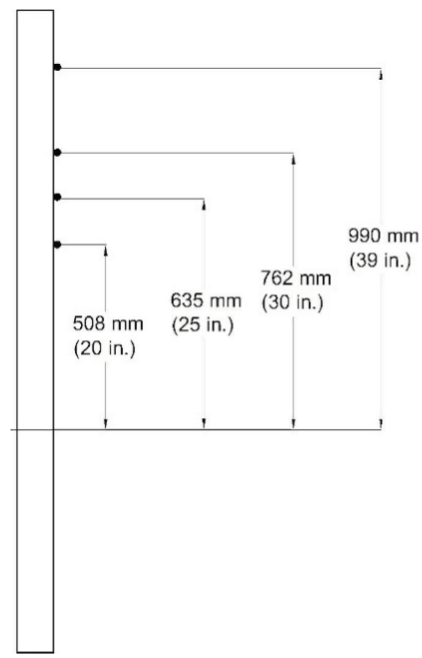
TL-3 – Three Cable
FHWA Eligibility Letter – B-137
(June 13. 2005)
Cable Heights above ground
- Top Cable at 762 mm (30 in.)
- Middle Cable at 635 mm (25 in.)
- Bottom Cable at 508 mm (20 in.)

Test Level 3 when placed on 6(H):1(V) or flatter



TL-4 – Three Cable
FHWA Eligibility Letter – B-137A
(September 9, 2005)
Cable Heights above ground
- Top Cable at 990 mm (39 in.)
- Middle Cables at 762 mm (30 in.)
- Bottom Cable at 508 mm (20 in.)

Test Level 4 when placed on slopes of 6(H):1(V) or flatter; Rated TL-3 when placed on 4(H):1(V) slope



TL-4 – Four Cable
FHWA Eligibility Letter – B-137B
(April 3, 2006)
Cable Heights above ground
- Top Cable at 990 mm (39 in.)
- Two Middle Cables at 762 mm (30 in.) and 635 mm (25 in.)
- Bottom Cable 508 mm (20 in.)

Test Level 4 when placed on slopes of 6(H):1(V) or flatter; Rated TL-3 when placed on 4(H):1(V) slope

When solid rock is encountered:

For a socketed post—continue digging hole, 15-in. deep into the rock or to the required depth shown on plans, whichever comes first.

For driven post—drill a 4-in. diameter hole 18-in. deep into the rock or to the required depth shown on the plans, whichever comes first.

For an anchor post, continue digging hole, 30-in. deep into rock or to the required plan depth shown on the plans, whichever comes first.

Post spacing can be varied between 3 m (10 ft) and 9 m (30 ft) with this system.

- **End Anchor Terminal**

Gibraltar's end anchor terminal section *NCHRP Report 350* approved. It is crashworthy and can be installed in

the clear zone. The end anchor consists of an in-ground anchor post, a cable release post and four terminal posts. The end terminal section is 27.5' in length. End anchors should be installed in AASHTO standard soils and be well drained. If soils do not meet these criteria, then soil testing should be done by the DOT or contractor, as per the state's specifications.

Gibraltar High Tension Cable Barrier System Specification (02/12/2014)

1.0 Description. This work shall consist of all labor, equipment, and materials to install a 3-strand high-tension cable barrier system by furnishing and installing posts, cables, end anchors, and any special connections and fittings which may be required in the contract documents and per the manufacturer's recommendations. The high-tension cable barrier system shall be approved by the U.S.DOT Federal Highway Administration for installation on slopes no steeper than 4(H):1(V) and also in accordance with the criteria contained in *NCHRP Report 350*, Test Level 4 when placed on slopes of 6(H):1(V) or flatter and Test Level 3 when placed on 4(H):1(V) or flatter. Acceptable systems and products shall include either a concrete socketed line post system, direct driven post system, or a driven socketed system design. All steel items are to be hot dipped galvanized. The high-tension cable barrier system shall be constructed as shown on the plans, with a maximum deflection of 9 ft 3 in.

2.0 Construction Requirements. Line posts shall be provided in accordance with the manufacturer's shop drawings and shall be placed plumb. Spacing of the posts, sockets, and/or concrete footings shall be according to the manufacturer's recommendations based on deflection requirements.

3.0 Anchor Assemblies. An anchor assembly as specified in the manufacturer's shop drawing shall be constructed at each end termination of the cable barrier run. The anchor assembly shall be approved by the U.S.DOT FHWA and also be in accordance with *NCHRP Report 350*, Test Level 3 criteria. Anchors shall be constructed in firm, stable, undisturbed soil to the minimum dimension shown on the shop drawings. Each end anchor shall be constructed according to the manufacturer's recommendations for the site specific soil conditions.

4.0 Cable Tensioning. The cable height above finish grade shall be in accordance with the manufacturer's shop drawings. The cable shall be tensioned immediately after initial installation. Tension shall be rechecked and adjusted, if necessary, three to five days after initial tensioning. A tension log form shall be completed showing the time, date, location, cable and ambient temperatures, and final tension reading, signed by the person performing tensioning, and furnishing to the engineer upon completion of the work.

5.0 Delineators. High-tension cable barrier systems shall be delineated with retro-reflective sheeting. The sheeting shall provide a minimum of (10) square inches of area and shall be applied to the last five posts at each anchor section and to the line posts throughout the remainder of the installation at a maximum spacing of 60 feet. The delineation shall be attached near the top and side of the posts as recommended by the manufacturer. The sheeting shall be type III or IV, yellow or white, and shall be the same color as the adjacent pavement edge line markings.

6.0 Installation Training. Provide training by the manufacturer prior to construction of the high-tension cable barrier for the contractor, sub-contractor, and DOT personnel involved in the work. A supervisor, certified by the manufacturer, shall be on site during all phases of installation of the high-tension cable barrier. Additionally, after the system has been completed, training shall be provided to any maintenance personnel, emergency response persons (police, fire, ambulance), as well as towing companies in the area. The training sessions shall be scheduled by the contractor in cooperation with the DOT on a date and location approved by the engineer.

7.0 Tensioning Tools and Repair Tools. One set of any special tools necessary for the tensioning of the cable system as recommended by the manufacturer or as necessary to repair and re-tension after damage to the system shall be provided to the engineer and retained by the DOT maintenance personnel at the completion of the contract.

8.0 Spare Parts. Spare parts will be provided consisting of enough parts to repair 10% of the total project LON. The parts will consist of posts, hairpins, and lock-plates, along with the above ground parts for one terminal section. The spare parts shall be delivered to the DOT maintenance office upon completion of the project.

9.0 Method of Measurement. High-tension cable barrier system will be measured by the linear foot and be the length of installation not including lengths of the high-tension cable barrier terminal sections. High-tension cable barrier terminal sections will be measured per each.

10.0 Basis of Payment. High-tension cable barrier, measured as prescribed above, shall be paid for at the contract bid prices per linear foot, which shall be full compensation for all materials, equipment, tools, staking, lay out, and labor necessary to complete installation of the high-tension cable barrier, including post foundations, delineation, other hardware, excavation and backfilling, and training necessary to complete the work.

Cable barrier terminal sections, measured as prescribed above, shall be paid for at the contract bid price per each, which price shall be full compensation for all materials, equipment, tools, staking, lay out, and labor necessary to complete installation of the high-tension cable barrier terminal sections, including post foundations, delineation, anchors, reinforced steel, other hardware, and any excavation and backfilling, and training necessary to complete the work.

Spare parts, measured as prescribed above, shall be paid for at the contract bid price per each lump sum, which shall be full compensation for all materials once delivered to the DOT maintenance office per the direction of the engineer.

Safence

The Safence High-tension Cable System is manufactured and produced by Gregory Industries. As reported in the survey, 25 of 42 states (59.5 percent) that use HTCB use this system.

System Configurations

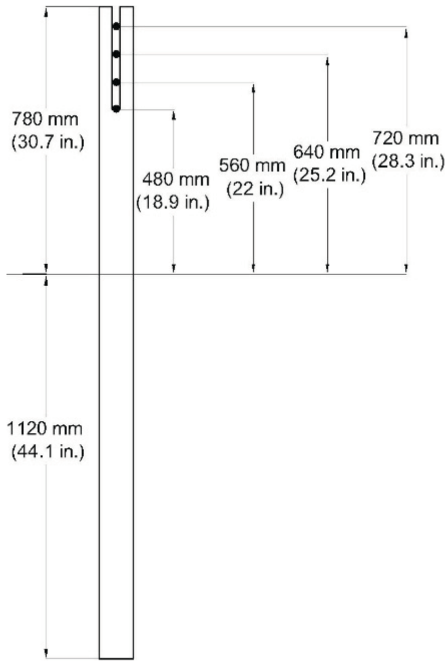
Safence has been crash tested with both three- and four-cable configurations as shown below and is considered eligible by FHWA as a *NCHRP Report 350* TL-3 and TL-4 design, and as a MASH TL-3 system.

The system configurations using the C-post with a vertical slot at the top of the post are shown below. The direct driven option is shown, but a socketed post design is also available with a 450 mm (17.7 in.) socket and 1230 mm (48 in.) long C-Posts.

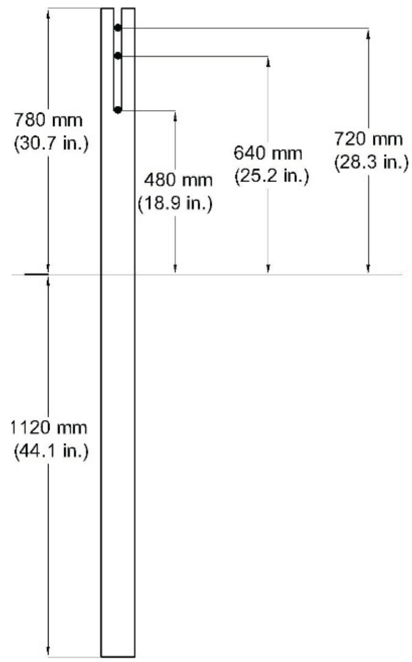
A MASH TL-3 system and a NCHRP 350 TL-3 system were tested with 3 cables (with a 4 cable option) when placed 4 feet from the hinge point on a 1V:4H slope. The posts can be driven directly into the ground or placed in sockets (Reference FHWA eligibility letters B-88-F, December 23, 2008 and B-88-G, August 18, 2011). The MASH design had cable heights of 500 mm (19.7 in.), 785 mm (30.9 in.), and 975 mm (38.4 in.), with an option of adding a fourth cable midway between the two upper cables. The *NCHRP Report 350* design used stiffened posts and a bottom cable mounted on the field side of the posts at 490 mm (19.3 in.). The upper cables were at the same heights as those in the aforementioned MASH test.

System Components

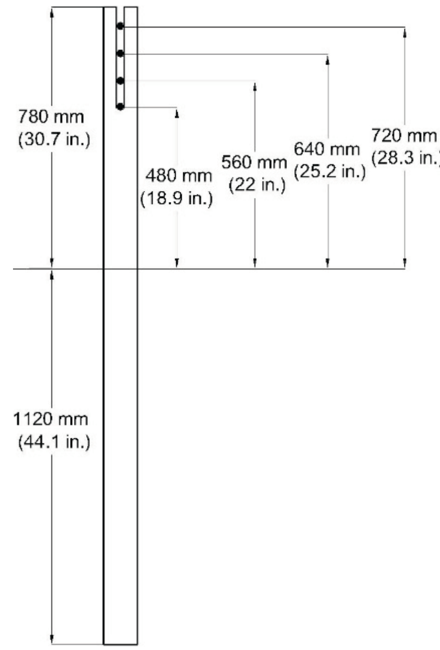
- **Cable**
  Pre-stretched (recommended) or standard cable is ¾ inch 3 × 7 steel cable manufactured in accordance with ASTM A741, AASHTO M30, Type 1, and Class A coating and tensioned per Safence tensioning chart. The cable shall have a minimum breaking strength of 17.7 tonnes (39,000 pounds).
- **Line Posts**
  The C-posts are a cold-rolled design fabricated from ASTM A50 steel and galvanized per ASTM A123. Each post is slotted to hold the cables within the posts. Post spacing can be varied, on deflection requirements. Posts can be directly driven or set in socketed foundations. For socketed post foundations, a concrete footing with a minimum 12 in. diameter and a 24 in. depth, with a plastic or steel sleeve is used. The concrete foundation can either be precast or cast-in-place on site. Geotechnical reports may be needed to determine if additional depth is needed due to weak or saturated soil conditions.



TL-3 – Four Cable
FHWA Eligibility Letter – [B-88A]
(January 28, 2004)
Cable Heights above ground
- Top Cable at 720 mm (28.3 in.)
- Two Middle Cables at 640 mm (23.6 in.) and 560 mm (22 in.)
- Bottom Cable at 480 mm (18.9 in.)



TL-4 – Three Cable
FHWA Eligibility Letter – [B-88D]
(December 27, 2006)
Cable Heights above ground
- Top Cable at 720 mm (28.3 in.)
- Middle Cable at 640 mm (25.2 in.)
- Bottom Cable at 480 mm (18.9 in.)

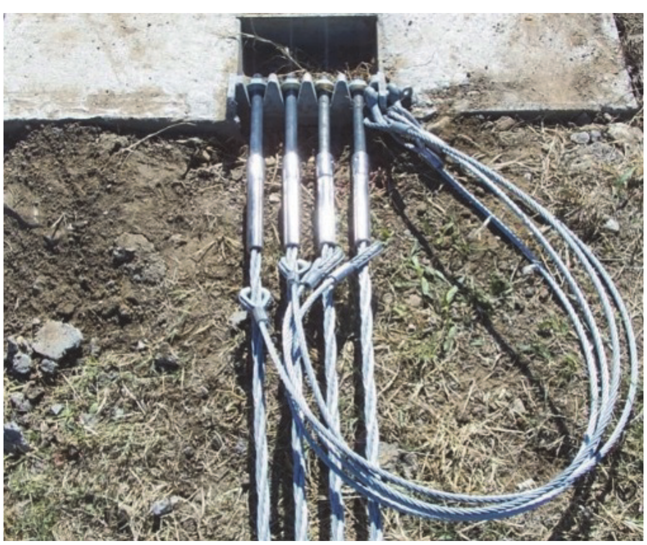


TL-4 – Four Cable
FHWA Eligibility Letter – [B-88E]
(July 31, 2007)
Cable Heights above ground
- Top Cable at 720 mm (28.3 in.)
- Two Middle Cables at 640 mm (25.2 in.) and 560 mm (22 in.)
- Bottom Cable at 480 mm (18.9 in.)

- **End Anchor Terminal**

  The system uses non-releasable anchors, so the cables are likely to remain under tension after an impact. It is a *NCHRP Report 350* TL-3 compliant design as a gating end terminal. The anchor block can be either prefabricated or cast on-site. Concrete shall be 3000 psi minimum and reinforced according to plan details. The End Terminals are installed in alignment with the barrier and each cable is attached to the anchor assembly.

  For all these terminals it is preferred that the concrete foundation for the end terminal be placed in excavations of natural undisturbed ground. The foundation sizes vary depending on the soil type and condition, water table depth, and temperature extremes. Soil testing should be performed based on state policy.



SAFENCE High-tension Cable Barrier System Specification (08/10/2009):

Description:

The SAFENCE High-tension Cable Barrier (HTCB) is a *NCHRP Report 350* approved TL-3 or TL-4 barrier that can be configured for use with three or four cables for median or shoulder applications, adopted new MASH standards for future testing procedures and product development. Safence (HTCB) contains errant vehicles through the help of lateral forces, which gradually redirect or capture the vehicle. Accomplished through the use of Safence (HTCB) end terminal and recommended post spacing to meet deflection requirements.

Materials:

Cable:

Pre-stretched (recommended) or standard cable which shall be ¾ inch 3 × 7 steel cable manufactured in accordance with

ASTM A741, AASHTO M30, Type 1, and Class A coating and tensioned per Safence tensioning chart.

Post:

C-post is of cold rolled design fabricated from ASTM A50 steel and galvanized per ASTM A123. Each post shall be slotted to hold cable within the post. Varying post spacing dependent upon working with requirements. C-post may be direct driven or socketed to meet states specifications.

Post Hardware:

A stiffening plate is added at ground level for resistance to bending with a steel hook added to the top to retain the cable within the post center slot. Plastic hardware is added within the post to keep cable heights consistent throughout the system whether it's three or four cable with a stainless steel stiffening frame added between top and second cable for post strength.

Cable Hardware:

Machine swaged fittings recommended for added durability and safety. Shall be placed no more than 492 feet from end terminal and 1,000 feet or less thereafter.

End Terminals:

Safence Inc. *NCHRP Report 350* compliant gating end terminal proven not to release ropes in crash testing approach impacts. Non-release capabilities retain ropes for secondary impacts. Length of terminal 39.36 feet.

Concrete:

Concrete shall be 3000 psi minimum and reinforced according to plan details.

Tested with a minimum of 24″ concrete foundations.

<u>Installation:</u>

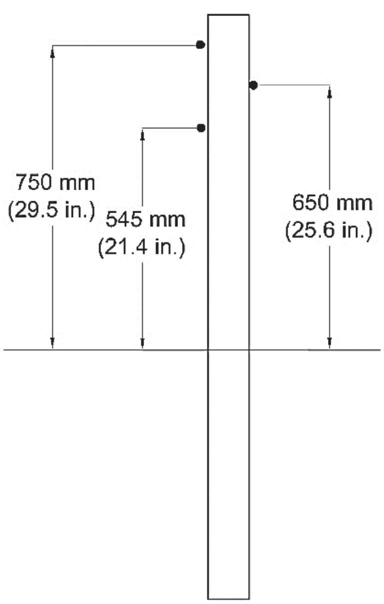
The installation of the Safence High-tension Cable Barrier System shall be according to the manufacturer's installation manual and standard drawings and state specifications. Measurement will be by the linear foot between end terminals. End terminals will be measured per unit.

Nu-Cable™

Nu-Cable high-tension cable barrier by Nucor Steel Marion, Inc., as reported in the survey, is currently being used by 61.9 percent (26 of 42) of states that use high-tension cable barrier. The system uses Rib-Bak®U-channel posts and standard (non-prestretched) or prestretched cables. Locking hook bolts are used to connect the cables to the posts.

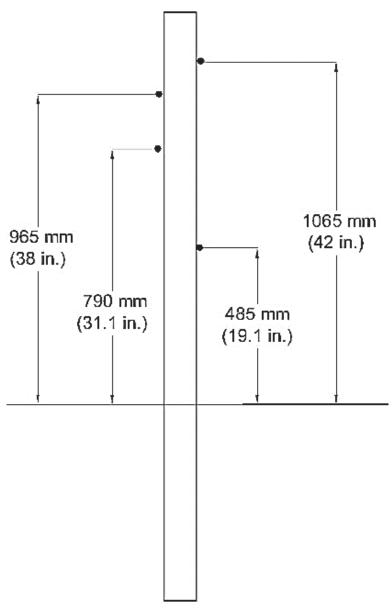
System Configurations

It has been crash tested with both three- and four-cable configurations as shown below and is considered eligible by FHWA as both *NCHRP Report 350* TL-3 and TL-4 systems. For the four-cable design, the lower two cables are attached using locking



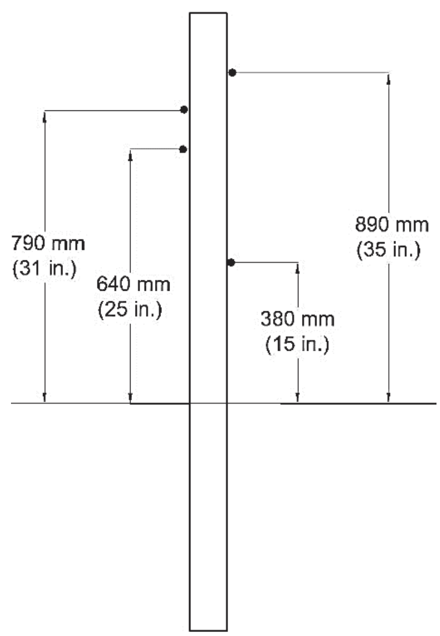
TL-3 – Three Cable
FHWA Eligibility Letter – B-96
(August 30, 2002)

Cable Heights above ground
- Top Cable at 750 mm (29.5 in.)
- Middle Cable at 650 mm (25.6 in.)
- Bottom Cable at 545 mm (21.4 in.)



TL-3 – Four Cable
FHWA Eligibility Letter – B-193 (July 27, 2009)

Cable Heights above ground
- Top Cable at 1065 mm (42 in.)
- Two Middle Cables at 965 mm (38 in.) and 790 mm (31.1 in.)
- Bottom Cable at 485 mm (19.1 in.)



TL-4 – Four Cable
FHWA Eligibility Letter – B-167
(January 24, 2008)
FHWA Eligibility Letter – B-184
(December 9, 2008)

Cable Heights above ground
- Top Cable at 890 mm (35 in.)
- Two Middle Cables at 790 mm (31 in.) and 640 mm (25 in.)
- Bottom Cable at 380 mm (15 in.)

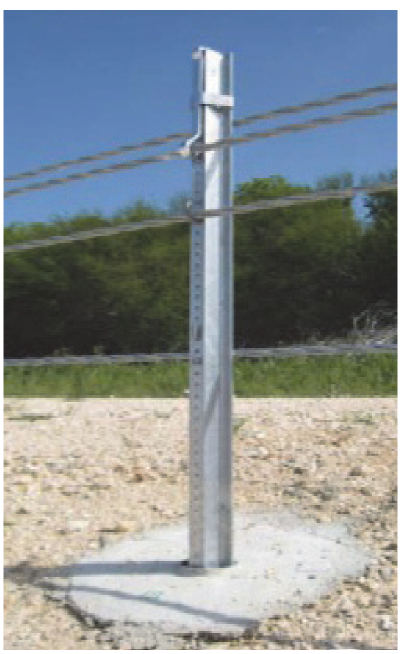
hook bolts and the top two cables are supported by a top clip attached at the top of the U-post section.

System Components

- **Cable**

  The cable is made up of 21 stands (3 × 7 configuration) of ¾″ (19 mm) diameter galvanized wire rope with a minimum breaking strength of = 17.7 tonnes (39,000 pounds). The cables are available prestretched and non-prestretched.
- **Line Post**

  The Nucor system uses Rib-Bak® U-channel posts and can be installed in a concrete socketed foundation, precast socketed foundation, and driven steel socket foundation, or they can be directly driven into the ground.



Direct-Driven Line posts can only be used on the TL-3 systems. The post used is 1829 mm (72 in.) long with no soil plate and is driven to a depth of 991 mm (39 in.) into natural *NCHRP Report 350* strong soil. If rock is encountered, follow state's procedure or drill a 4 in. diameter hole to accommodate a minimum of 15 in. of the line post.

Concrete Socketed Foundations utilize a steel or plastic socket set into a 12 in. diameter × 30 in. deep (305 mm × 762 mm) concrete footing. The concrete footing is strengthened with a steel reinforcing ring and two steel dowels.

Post spacing can be varied between 5 m (16 ft-5 in.) and 6 m (20 ft).

- **End Anchor Terminal**

  There are two types of anchors that are available and have been accepted by FHWA and tested to *NCHRP Report 350* TL-3 criteria: Nu-Ten and CRP (Cable Release Post) End Terminals.

The Nu-Ten End Terminal is a crashworthy terminal and can be placed anywhere within the clear zone. It is used to anchor all the cables to one foundation. It utilizes a trigger post, which will disconnect all the cables upon impact.

The CASS Cable Terminal (CCT) is the same terminal used with the CASS cable barrier system by Trinity Highway Industries. It consists of three Cable Release Posts and six S3 x 5.7 posts. For the TL-3 system the latter posts are 5 ft-3 in. long and for the TL-4 system their lengths vary between 5 ft-3 in. to 5 ft-11 in. The cables are connected to the posts 1 thru 6 with a special patented hook bolt that tapers each cable down to terminate at a cable release post.

End anchors should be installed in AASHTO standard soils and be well drained. If soil does not meet these criteria, then soil testing should be done by the DOT or contractor, as per state's specifications, to determine the appropriate anchor size.

Date acquired: 06/2015

NUCOR US HIGH TENSION CABLE BARRIER SPECIFICATION

DESCRIPTION:
The NUCOR US High Tension Cable Barrier System is an NCHRP 350 tested high-tension cable barrier system approved for use in roadway medians and on roadway shoulders.

MATERIALS:
Materials shall be as described on the manufacturer's standard and as follows:

Cable
The cable shall be 3/4 inch 3x7 steel cable manufactured in accordance with ASTM A741, AASHTO M30, Type I, Class A coating.

Posts
Rib-Bak U-channel cable line posts shall conform to the physical properties of ASTM A499, and the chemical properties of ASTM A1. In addition they shall have a minimum yield of strength of 80,000psi and tensile strength of 100,000psi. All posts shall be galvanized per ASTM A123.

Cable Hardware
All fittings shall be designed to develop 25,000 lbs. tensile strength. Wedge type cable socket fittings shall be of the open end type and shall permit visual inspection of the cable end and wedge after installation. Malleable iron fittings shall conform to the requirements of ASTM A47. Cast steel fittings shall conform to the requirements of AASHTO M 103, grade 70-36.

Locking Hook Bolts
Special locking hook bolts shall be manufactured from ASTM A307 Grade C carbon steel. Nuts shall be ASTM A563 Grade A Heavy Hex. Special locking hook bolts and nuts shall be galvanized per ASTM A153.

Delineators
Delineators shall be 3M Type III / IV High Intensity Prismatic adhesive reflective sheeting. Delineators shall be installed with 3M Primer 94 Adhesive.

Concrete
Concrete shall be 3000 psi minimum. Concrete is to be reinforced according to plan details.

Soil Conditions
NCHRP 350 Strong Soil (S1) is required for use with 6 foot direct driven line posts, 30 inch socketed line post foundations, or 5 foot concrete CRP post foundations. If the soil is of lesser strength than NCRHP 350 Strong Soil (S1) but stronger than NCHRP 350 Weak Soil (S2) an 8 foot direct driven line post, 36 inch socketed line post foundation, or 8 foot concrete CRP post foundation should be used. If soil is NCHRP 350 Weak (S2) soil or weaker contact manufacturer for appropriate foundation sizing.

INSTALLATION:
The NUCOR US High Tension Cable Barrier System shall be installed according to the manufacturer's latest standard sheet and installation manual.

MEASUREMENT:
Measurement will be by the linear foot of cable barrier, complete in place, measured along the centerline of the barrier between cable barrier end terminals. Cable Barrier End Terminals will be measured by the unit, complete in place.

PAYMENT:
Payment will be made for the work performed and the materials furnished at the unit prices bid for "Cable Barrier System", and for "Cable Barrier End Terminal".

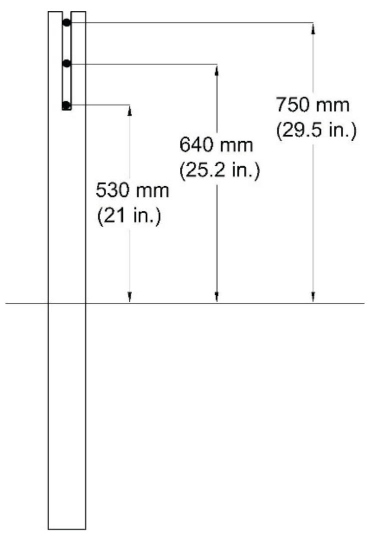
Trinity Highway Cable Safety System (CASS™)

Based on the survey, currently 38 of the 42 states (90.5 percent) using HTCB use the CASS™. This system uses Steel Yielding Cable Posts (SYCP), that are designed with a proprietary wave-shaped slot and weakening holes on the post at the ground line (for some systems). The cables are placed into these slots and are separated by plastic spacers at a specific design height giving the system the mechanism to restrain or redirect an errant vehicle.

System Configurations

The original CASS™ design used C-shaped posts with three cables and was tested to *NCHRP Report 350* TL-3, but was later tested with an S4 7.7 lb. I-post that has weakening holes through each flange at ground level. System details are shown below:

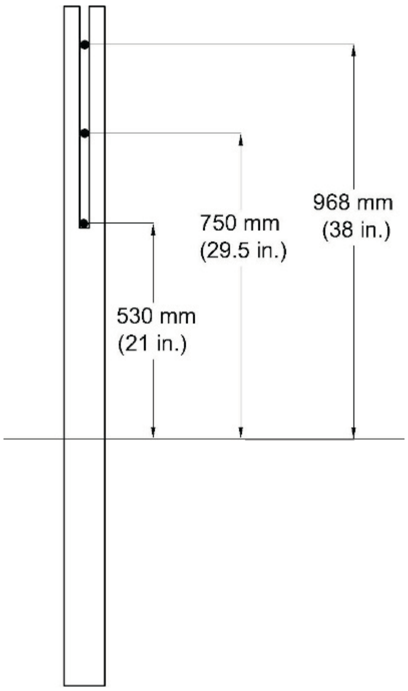
Additional designs using both three- and four-cable configurations and considered eligible by FHWA as a *NCHRP Report 350* TL-3 or TL-4 system are shown below. All these systems use the I-Post design with weakening holes. These systems were also tested on a 1V:6H slope.



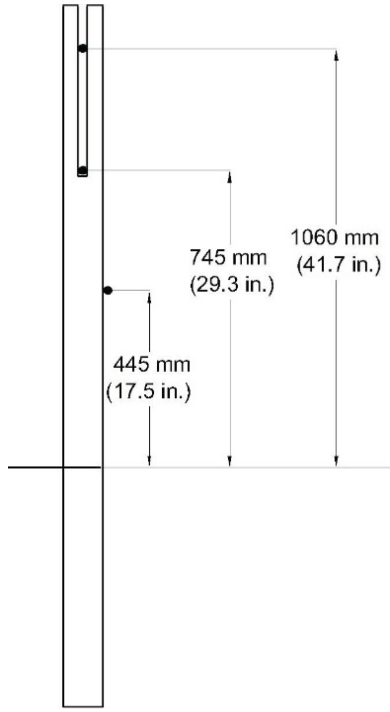
TL-3 – Three Cable (C- & I-Post)
FHWA Eligibility Letter – B-119
(May 13, 2003) – C-Post Design
FHWA Eligibility Letter – B-141
(Nov 17, 2005) – I-Post Design
with weakening holes.

Cable Heights above ground

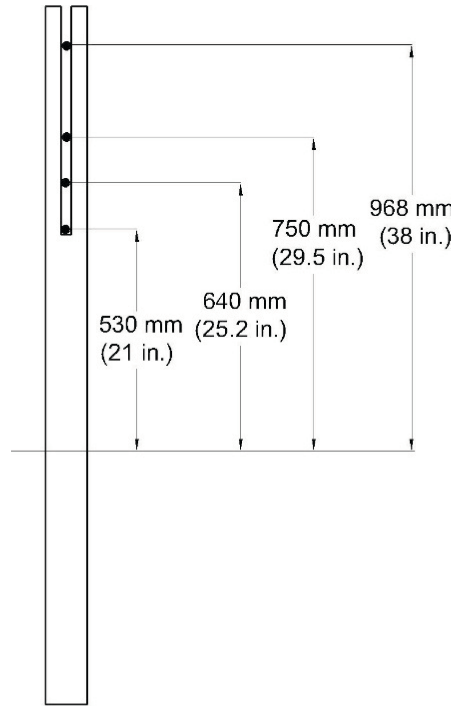
- Top Cable at 750 mm (29.5 in.)
- Middle Cable at 640 mm (25.2 in.)
- Bottom Cable at 530 mm (21 in.)



TL-4 – Three Cable
FHWA Eligibility Letter – B-141
(Nov 17, 2005)
Cable Heights above ground
- Top Cable at 968 mm (38 in.)
- Middle Cable at 750 mm (29.5 in.)
- Bottom Cable at 530 mm (21 in.)



TL-4 – Three Cable*
FHWA Eligibility Letter – B-141D
(March 19, 2009)
Cable Heights above ground
- Top Cable at 1060 mm (41.7 in.)
- Middle Cable at 745 mm (2 9.3 in.)
- Bottom Cable at 445 mm (17.5 in.)



TL-4 – Four Cable
FHWA Eligibility Letter – B-157
(April 23, 2007)
Cable Heights above ground
- Top Cable at 968 mm (38 in.)
- Two Middle Cables at 750 mm (29.5 in.) and 640 mm (25.2 in.)
- Bottom Cable 530 mm (21 in.)

*System variations:
- TL-4 – Three cable on a 1V:6H (shown above)
- TL-3 – Three cable system on a 1V:4H Slope – B-141C (Nov. 14, 2008)
- TL-4 – Four cable system with the addition of a 4th cable at 950 mm (37.4 in.) on a 1V:6H – B-141D
- TL-3 – Four cable system with the addition of a 4th cable at 950 mm (37.4 in.) on a 1V:4H – B-141D

Another design of the CASS™ system is shown below where the top two cables are positioned in the wave-shaped slot and the bottom two cables are supported by hook bolts on a S3 5.7 lb I-post.

System Components

- **Cable**

  The CASS™ uses a 19 mm (¾ in.) diameter, 3 × 7 strand pre-stretched (recommended) or standard cable with a minimum breaking strength of 17.5 tonnes (38,600 lb).

  Pre-Stretched Cable. The cable tension should be checked at least once a year. The tension value is based on either the ambient air temperature or the cable temperature, which can be taken using a thermometer for the air temperature or an infrared thermometer for the cable temperature.

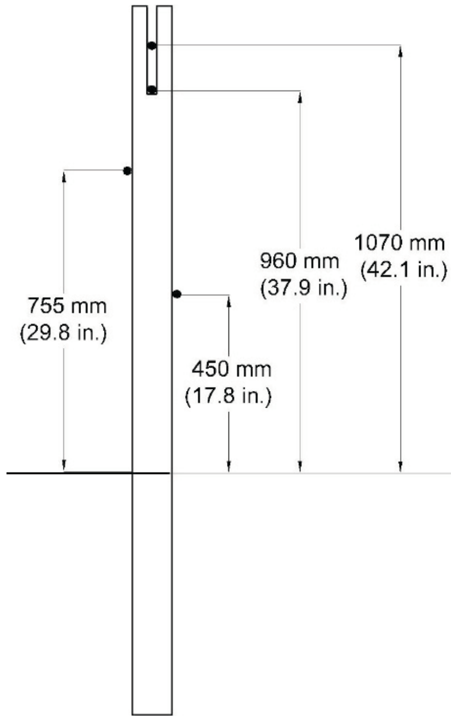
  Standard Cable. The cable tension should be checked at least twice a year. The tension value is based on either the ambient air temperature or the cable temperature, which can be taken using a thermometer for the air temperature or an infrared thermometer for the cable temperature.

- **Line Posts**

  The system line posts can be driven, placed in a driven sleeve, enclosed in a sleeve in a concrete footing (poured or pre-cast), or mounted to a concrete surface.

  For curves the post spacing may need to be reduced based on the radius and will be the same for both pre-stretched and standard cable.

  Post spacing are varies between 2 m (6.5 ft) and 9.7 m (32 ft).



TL-3 – Four Cable on 1V:4H*
TL-4 – Four Cable on 1V:6H
FHWA Eligibility Letter – B-141F
(October 1, 2010)

Cable Heights above ground
- Top Cable at 1070 mm (42.1 in.)
- Two Middle Cables at 960 mm (37.9 in.) and 755 mm (29.8 in.)
- Bottom Cable at 450 mm (17.8 in .)

*MASH tested as TL-3 system – B-232 (May 4, 2012)

- **End Anchor Terminal**

There are two methods to terminate the CASS system barrier: a *NCHRP Report 350* Cable Terminal or a non-*NCHRP Report 350* Cable Anchor.

The CASS™ Cable Terminal (CCT) consists of Cable Release Posts (CRP) and six S3 x 5.7 posts. The cables are connected to the terminal line posts with a special patented hook bolt that tapers each cable down to terminate at a cable release post.

The CASS™ Cable Anchor (CCA) anchors all the cables to one anchor block. This is not a crash tested system so it must be installed outside the clear zone or where it is effectively shielded from traffic.

Additional options are available to connect the cables directly to w-beam or Thrie-beam guardrail or box beam or a rigid barrier wall system.

The end terminals and line post foundation sizes vary, depending on the soil type and condition, water table depth, and temperature extremes. Soil testing should be performed using the state policy and specifications. For a standard line post, soil borings are required to be a minimum depth of 5 ft and for end terminals a minimum depth of 10 ft.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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