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16. Abstract

Since 2003, the Texas Department of Transportation (TxDOT) has embarked on an aggressive campaign to install median barriers to prevent cross-median crashes on freeway facilities statewide. In the few years prior to 2003, virtually all fatalities on interstate facilities (96 percent) were the result of cross-median crashes. TxDOT used special safety funding to accelerate projects and decided to primarily implement high-tension cable/wire rope median barrier systems in lieu of concrete so that more roadway miles could be protected.

This report documents the performance evaluation of various cable barrier systems in Texas. The research evaluated TxDOT's experience with cable barrier systems by analyzing installation cost, recurring maintenance costs and experiences, crash history before and after implementation, and field performance. Some of the key findings include:

- From a capital cost and life-cycle cost perspective, cable barrier is an attractive option compared to concrete median barrier.
- There has been a lack of coordination between TxDOT and emergency responders during the project planning and maintenance phases of cable barrier system projects.
- Maintenance costs and personnel requirements for cable barrier systems can be substantial and constrained maintenance budgets and personnel availability for frequent repair needs are issues.
- Cable barriers are performing extremely well and have had very few cases of penetration unless there were non-standard impact conditions. Researchers believe that the cable barriers are functioning according to their intended design and are restraining vehicles that impact them in fashions similar to NCHRP 350 crash-testing guidelines.
- The installation of cable barriers has produced significant benefits with a reduction of 18 fatalities and 26 incapacitating injuries in the first full year. This reduction equates to an almost $46 million economic benefit based on current crash cost values used in evaluation of projects for safety funding.
- Due to problems experienced in Texas and other states, soil conditions should be considered as part of the project development process for cable barrier system installations.

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- Mr. Jimmey Bodiford, P.E., TxDOT, Fort Worth District – Project Advisor;
- Mr. Brian Crawford, P.E., TxDOT, Abilene District – Project Advisor;
- Mr. Bobby Dye, TxDOT, Design Division – Project Advisor;
- Mr. Darwin Myers, P.E., TxDOT, Dallas District – Project Advisor;
- Mr. Grover Schretter, TxDOT, Fort Worth District – Project Advisor;
- Mr. Lance Simmons, P.E., TxDOT, Atlanta District – Project Advisor; and
- Mr. Tom Yarborough, P.E., TxDOT, Research and Technology Implementation Office – Research Management Committee (RMC) Engineer.

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- representatives of cable barrier manufacturers who answered questions on their products' performance and provided key insights.

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LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ABL	Abilene District
ADT	Average Daily Traffic
AMA	Amarillo District
ASTM	American Society for Testing and Materials
ATL	Atlanta District
AUS	Austin District
B/C	Benefit-Cost
BMT	Beaumont District
BWD	Brownwood District
BRY	Bryan District
CASS	Cable Safety System
CDOT	Colorado Department of Transportation
CSJ	Control Section Job Number
CHS	Childress District
CMB	Concrete Median Barrier
CMC	Cross-Median Crash
CRIS	Crash Records Information System
CRP	Corpus Christi District
DAL	Dallas District
DOT	Department of Transportation
DPS	Department of Public Safety
ELP	El Paso District
FHWA	Federal Highway Administration
FTW	Fort Worth District
GET	Guardrail Extruder Terminal
GIS	Geographic Information System
GSBID	GIS-Based Statewide Barrier Inventory Database
HES	Hazard Elimination Safety
HOU	Houston District
HSIS	Highway Safety Information System
HSRC	Highway Safety Research Center
HTCBS	High-Tension Cable Barrier System
HTML	Hyper-Text Markup Language
IH	Interstate Highway
IM	Interstate Maintenance
INDOT	Indiana Department of Transportation
ISPE	In-Service Performance Evaluation
ITA	Illinois Tollway Authority
LBB	Lubbock District
LBJ	Lyndon Baines Johnson
LCCA	Life-Cycle Cost Analysis
LFK	Lufkin District

LIST OF ABBREVIATIONS (continued)

LP	Loop
LRD	Laredo District
MS	Mow Strip
MVMT	Million Vehicle Miles Traveled
NCDOT	North Carolina Department of Transportation
NCHRP	National Highway Cooperative Research Program
NH	National Highway
ODA	Odessa District
ODOT	Ohio Department of Transportation
PAR	Paris District
PDF	Portable Document Format
PHR	Pharr District
PMC	Project Monitoring Committee
PSI	Pounds per Square Inch
RMC	Research Management Committee
ROW	Right-of-Way
SAT	San Antonio District
SFT	Safety
SH	State Highway
SKT	Socketed
SJT	San Angelo District
SS	Single Slope
STP	Surface Transportation Program
TAMU-K	Texas A&M University-Kingsville
TIG	Technology Implementation Group
TL	Test Level
TRB	Transportation Research Board
TRF	Traffic Operations Division
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
UDOT	Utah Department of Transportation
WAC	Waco District
WFS	Wichita Falls District
WRSF	Wire Rope Safety Fence
WSDOT	Washington State Department of Transportation
YKM	Yoakum District

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND AND SIGNIFICANCE OF RESEARCH

Understanding the Problem

Cross-Median Crashes

When they occur, cross-median crashes (CMCs) are typically very violent in nature and have a high probability of multiple serious injuries and deaths (Figure 1-1). Research shows that CMCs are responsible for a disproportionately high rate of fatalities in Texas and other states. Many of these severe CMCs can be prevented with adequate barrier protection. However, barriers should not be used indiscriminately as they too constitute a hazard to motorists. A barrier is typically warranted when the consequences of encroaching into or across the median are judged to be more severe than striking the barrier.

Figure 1-1. Aerial Photograph of Cross-Median Crash Scene.

Median Barrier Guidelines

Recent research conducted by TTI for TxDOT developed new guidelines to assist highway engineers with the evaluation of median barrier need such that the highest practical level of median safety can be achieved (*1*). The recommended guidelines developed by the TxDOT Project 0-4254, *Evaluation of Median Barrier Guidelines*, were based on analysis of median-related crashes in Texas over a three-year time period (*1*). Researchers used crash data to develop crash statistical models for the various types of median-related crashes. Based on the estimates derived from the frequency and severity models and crash costs used by TxDOT, the research team performed an economic analysis of median barrier need. Finally, researchers developed guidelines for installing median barriers on divided, access-controlled freeways as a function of average annual daily traffic (AADT), median width, and cross-median crash rate.

High-Tension Cable Median Barrier Systems versus Concrete Median Barriers

One of the most relevant parts of the 0-4254 project to this current project is the economic comparison between high-tension cable and concrete median barrier performance based on the benefit/cost (B/C) ratio of the expected benefits accrued from reductions in crash rate and/or severity to the expected costs of installing, operating, and maintaining the project. Overall, TTI found that high-tension cable barriers were more cost-effective than concrete barriers for the entire range of median widths and AADT for which they are applicable. Table 1-1 summarizes the ratio for installing high-tension cable barriers over the mean ratios for concrete barriers. Higher ratios suggest increased favorability of installing the high-tension cable barrier over the concrete barrier, in terms of their mean B/C ratios. Thus, researchers call this ratio the "favorability ratio" of installing cable over concrete barrier.

Table 1-1. B/C Ratios for High-Tension Cable Barriers over Concrete Barriers: Favorability (*1*).

Median Width (ft)	AADT (in 1000)																										
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125
0	0	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.7	0.7
5	0	2.0	1.9	1.7	1.6	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8
10	0	2.1	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8
15	0	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9
20	0	2.2	2.0	1.9	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	0.9
25	0	2.1	2.0	1.9	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0
30	0	2.0	1.9	1.8	1.8	1.7	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.0	1.0
35	0	2.0	1.9	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1
40	0	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.1	1.1	1.1
45	0	1.9	1.8	1.8	1.7	1.7	1.6	1.6	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.1
50	0	1.8	1.8	1.7	1.7	1.7	1.6	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.2	1.2
55	0	1.8	1.8	1.7	1.7	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.2
60	0	1.8	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.2
65	0	1.8	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3
70	0	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.3
75	0	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3
80	0	1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3
85	0	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3
90	0	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
95	0	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
100	0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
105	0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4
110	0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4	1.4
115	0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4	1.4
120	0	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.4
125	0	1.6	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4

*Based on a 4-lane, 65 mph (88 km/hr) posted speed limit scenario
**Due to the deflection characteristic of cable barriers upon impact, installing on medians with a width less than 20 ft is usually not appropriate

Until the recent acceptance of high-tension cable barriers, TxDOT relied almost exclusively on concrete barriers for separating opposing lanes of traffic. Concrete barriers are well suited for use in narrow medians along high-speed, high-volume roadways due to their negligible deflection, low life-cycle cost, and relatively maintenance-free characteristics. However, rigid barriers impose greater decelerations on impacting vehicles than more flexible systems and, depending on the barrier profile and impact conditions, can impart instability to a vehicle as well.

Once a barrier is deemed necessary at a particular location based on factors such as median width, average daily traffic (ADT), design speed, and/or accident history, there are a number of factors involved in the selection of which barrier to use. Weak-post systems are typically less expensive to install than strong-post or rigid concrete barriers due to the use of smaller posts with comparatively large spacing. These flexible systems impart lower deceleration upon the vehicle and its occupants, resulting in a lower impact severity and probability of injury. In addition, due to the contact with numerous posts, these barriers often "capture" a vehicle (i.e., bring it to a safe stop) rather than redirect it back onto the roadway where a secondary crash can result.

The disadvantages of weak-post systems include the additional space required to accommodate the larger deflections, and the comparatively long lengths of barrier that require repair after an impact. In some instances, the damaged section may be rendered nonfunctional until repaired. Unlike roadside guardrail, which commonly shields motorists from discrete hazards (i.e., fixed objects); a median barrier is often required along long stretches of highway to separate opposing traffic and, thereby, prevent crossovers. This extensive application makes the low installation cost of weak-post barriers, particularly cable barriers, very appealing. Some of the drawbacks of weak-post barriers can be minimized by offsetting the median barrier at or near the center of the median. The greater lateral offset reduces the frequency of crashes, thus minimizing repair costs. When repairs are required, they can be accomplished with less risk to maintenance personnel and, depending on the barrier offset, without the need for lane closure or traffic control.

High-tension cable barrier systems are rapidly gaining popularity in median applications. The high tension reduces dynamic deflection and enables the cables to remain elevated after an impact. Thus, the barrier retains much of its functionality and can accommodate additional impacts prior to being repaired. These barriers also have an option for socketing shorter posts in sleeves cast into small concrete footings rather than embedding longer posts directly in the soil. Although the initial installed cost for this option is greater, the socketed posts facilitate rapid repair after an impact, thus reducing the cost and time of repairs. The high-tension barriers usually utilize three or four cables or wire ropes to contain, redirect, and often capture errant vehicles (Figure 1-2). The dynamic deflection is controlled by the amount of cable tension, strength and spacing of support posts, and the connection between the support posts and cables. Depending on the system and its configuration, deflections typically range from 6 to 10 ft. The height of the cables can be configured to provide containment for vehicles ranging from small cars to single-unit trucks. Several systems have been successfully tested and approved for test level 4 (TL-4) of *National Cooperative Highway Research Program (NCHRP) Report 350*, which includes an impact by an 18,000-lb single-unit truck (*2*).

Cable Median Barrier Implementation in Texas

Safety Bond Program. House Bill 3588 gave TxDOT the authority to issue $3 billion dollars in bonds to fund state highway improvement projects. Twenty percent of this total ($600 million) must be used to fund safety projects that reduce accidents or correct hazardous locations on the state system. One of the 15 categories eligible to fund safety projects included the installation of median barriers. To maximize the amount of barrier put in place, TxDOT has started to install cable barrier systems (sometimes referred to as wire rope or wire safety fence) in addition to traditional concrete barriers. Cost data have shown that cable barriers are approximately one-third to one-fifth the cost of concrete barriers per mile, making them a cost-effective option. There have generally been four NCHRP TL-3 cable barrier products installed: (1) Brifen wire rope safety fence, (2) Trinity Industries Cable Safety System (CASS™), (3) Nucor Steel Marion High Tension Cable and (4) Gibraltar (Figure 1-3). Three NCHRP 350 TL-4 systems are also available for use in Texas.

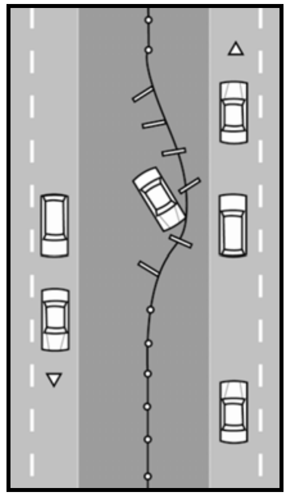

Figure 1-2. Cable Barrier Deflection.

Figure 1-3. TxDOT Approved Cable Barriers (*3*).

AASHTO Cable Median Barrier Technology Implementation Group Participation. TxDOT has been an active participant in the American Association of State Highway Transportation Officials (AASHTO) Technology Implementation Group (TIG) for "Cable

Median Barrier," along with several other states. A July 2005 presentation by Meza provided a synopsis of the cable median barrier experience in Texas (*3*). TxDOT is using approximately $157 million of safety bond money to fund 94 projects to install 738 miles of cable median barrier, with another $30 million for 85 miles of a mixture of concrete and cable median barrier.

TxDOT Fort Worth District Experience. The Fort Worth District has been a leader in the implementation of cable median barrier systems within TxDOT. In September 2005, FHWA sponsored a scanning tour for high-tension cable median barrier. The Scanning Tour Report documented the lessons learned and experiences of three states – Ohio, Oklahoma, and Texas (*4*). The Scanning Tour visited the Weatherford Area Office in the Fort Worth District. The Scanning Tour Report provides in-depth information on the almost 25 miles of cable median barrier installed on IH 20 and IH 30 in Parker County, including design and construction details, system specifications, maintenance experience, and guidance on emergency vehicle access issues (*4*).

Need for In-Service Performance Evaluation

An in-service performance evaluation (ISPE) of the extensive implementation of cable median barrier systems in Texas is a necessary endeavor to ensure that the barrier meets the original expectations of the designers. If researchers discover problems regarding the actual field performance of the system, the whole process can begin with the formulation of new or improved designs. This iterative process results in a more effective type of barrier system. The importance of ISPE has been widely recognized by the roadside safety community. As early as the 1970s, NCHRP Report 118 recommended that "after the system has been carefully monitored and evaluated in-service and its effectiveness has been established, the system is judged to be operational" (*5*). But in practice, there has been much less of an attempt to monitor the performance of cable barrier systems once they have been installed in the field. One purpose of the 0-5609 study is to evaluate how cable barrier performs under field conditions and also to compare its performance to concrete barriers.

This report documents the performance evaluation of the various cable barrier installations in Texas. The research will evaluate TxDOT's experience with cable median barrier by analyzing its installation cost, maintenance costs, maintenance experiences, and crash history before and after implementation.

1.2 RESEARCH WORK PLAN

The work plan for the ISPE portion of the 0-5609 research project involved five primary tasks:

- state-of-the-practice literature review focused on a critical review of recent and ongoing research pertaining to in-service evaluations of cable and wire rope median barriers,
- inventory of cable/wire rope median barrier installations in Texas,
- defining the ISPE process and study locations,
- collection and analysis of evaluation data, and
- perform ISPE and comparison of cable and concrete median barrier performance.

These tasks were performed in order to fulfill the 0-5609 project goal:

> Project Goal: Perform and document an in-service performance evaluation of cable median barrier systems, and develop recommendations and guidelines to direct TxDOT design, maintenance, and operations staff for future installations.

The guidelines developed based on the cable barrier ISPE are provided in the 0-5609-2 research report.

1.3 REPORT ORGANIZATION

The focus of this 0-5609-1 report is to document the cable barrier ISPE results and findings. Chapter 1 (Background and Significance of Research) provides the reader with an understanding of the problem of cross-median crashes and how barrier systems such as cable and concrete can be utilized.

Chapter 2 (Inventory of Cable/Wire Rope Median Barrier in Texas) outlines the results of the inventory of cable and wire rope median barrier installations in Texas. The inventory task focused on obtaining baseline data (e.g., project, installation, barrier and cost), which were utilized in subsequent tasks.

Chapter 3 (In-Service Performance Evaluation Process) describes the ISPE process and the locations selected for inclusion in the cable barrier ISPE.

Chapter 4 (Texas Cable Barrier Performance Evaluation) describes the performance evaluation results for cable barrier systems in Texas. The performance evaluation was divided into four categories: (1) cost; (2) maintenance and repair; (3) safety; and (4) field performance.

Chapter 5 summarizes the key findings, conclusions, and recommendations of the research team based on the in-service performance evaluation of cable median barrier systems in Texas.

1.4 REFERENCES

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[3] R. Meza. *Cable Median Barriers in Texas*. Presentation given to American Association of State Highway and Transportation Officials, July 25, 2005. [Online]: http://www.transportation.org/sites/aashtotig/docs/Texas%20-%20Cable%20Median%20Barriers.pdf. Site Accessed August 14, 2009.
[4] High-Tension Cable Scanning Tour Report. Traffic Operations Laboratory, University of Illinois at Urbana-Champaign, December 2005. [Online]: http://www.dot.state.mn.us/trafficeng/reports/scanningtour/Scanning%20Tour%20Report.pdf. Site Accessed August 14, 2009.
[5] J. D. Michie and M. E. Bronstad, *Location, Selection, and Maintenance of Highway Traffic Barriers.* National Cooperative Highway Research Program Report 118, Transportation Research Board, Washington, D.C., 1971.

CHAPTER 2
INVENTORY OF CABLE/WIRE ROPE MEDIAN BARRIERS IN TEXAS

2.1 PROJECT IDENTIFICATION

The research team performed an inventory of projects that included the installation of cable barrier systems. A secondary effort involved an inventory of concrete median barrier (CMB) installations so that a performance comparison could be conducted. Primary information sources for project identification included:

- safety bond project list,
- projects database maintained by the TxDOT Design Division, and
- review of letting schedules on the TxDOT website.

The project inventory revealed that there were 120 cable barrier projects and 80 concrete median barrier projects in Texas since January 1, 2000.

2.2 PROJECT INVENTORY DATA

Following the initial inventory effort, researchers began populating a Microsoft Access™ database with key data elements for the performance evaluation. The research team divided the data elements into four categories: (1) project data, (2) roadway data, (3) barrier data, and (4) safety data. The research team explains each category in further detail in the following subsections.

Project Data

The project data category includes data fields that describe the basic project identification information. Project data fields in the database include the following:

- project number,
- roadway,
- project limits,
- project description,
- district,
- area office,
- area engineer,
- county, and
- project cost.

The research team gathered these data from the three sources listed in Section 2.1 and entered it into a Microsoft Access™ database. Researchers also utilized the monthly construction reports available from the TxDOT website to identify the area office and engineer for each project so that contact could be made with appropriate personnel for gathering additional data.

Roadway Data

The roadway data category includes data fields that describe the basic cross section and traffic volume characteristics of each project. Roadway data fields in the database include the following:

- station limits,
- reference marker limits,
- average daily traffic,
- median width,
- median cross slope,
- shoulder widths (inside and outside), and
- number of travel lanes.

In addition to the three sources listed in Section 2.1, the research team used electronic sets of project plans, obtained from the TxDOT website, to gather most of the roadway data elements. Figure 2-1 provides an example typical section that researchers used to generate the roadway data elements in Table 2-1.

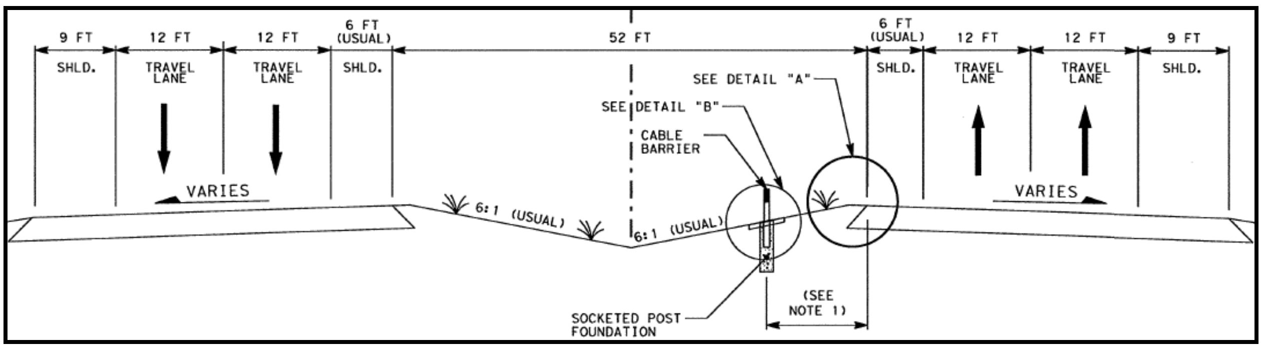


Figure 2-1. Example Typical Section from Online Plans for Extraction of Roadway Data.

Table 2-1. Example Roadway Data Extracted from Figure 2-1.

Data Element	Value
Median width (feet)	64
Median cross slope	6:1
Inside shoulder width (feet)	6
Outside shoulder width (feet)	9
Number of travel lanes	4

Barrier Data

The barrier data category includes data fields that characterize the median barrier system for each project. Barrier data fields in the database include the following:

- type (cable or concrete),
- length,

- placement, and
- cost.

The research team calculated the barrier placement data from project plan sheets to locate the typical offset of the barrier from the inside shoulder. In some cases, researchers had to utilize both the typical section sheets and plan layout sheets to locate the barrier. It is also important to note that barriers sometimes switch sides of the roadway and change in offset from the shoulder; however, the researcher team entered the typical offset value in the placement data field of the Access database. Figure 2-2 provides an example typical section that the research team used to generate the barrier placement data element for each project. In this case, the barrier is typically placed 4 feet from the existing inside concrete shoulder.

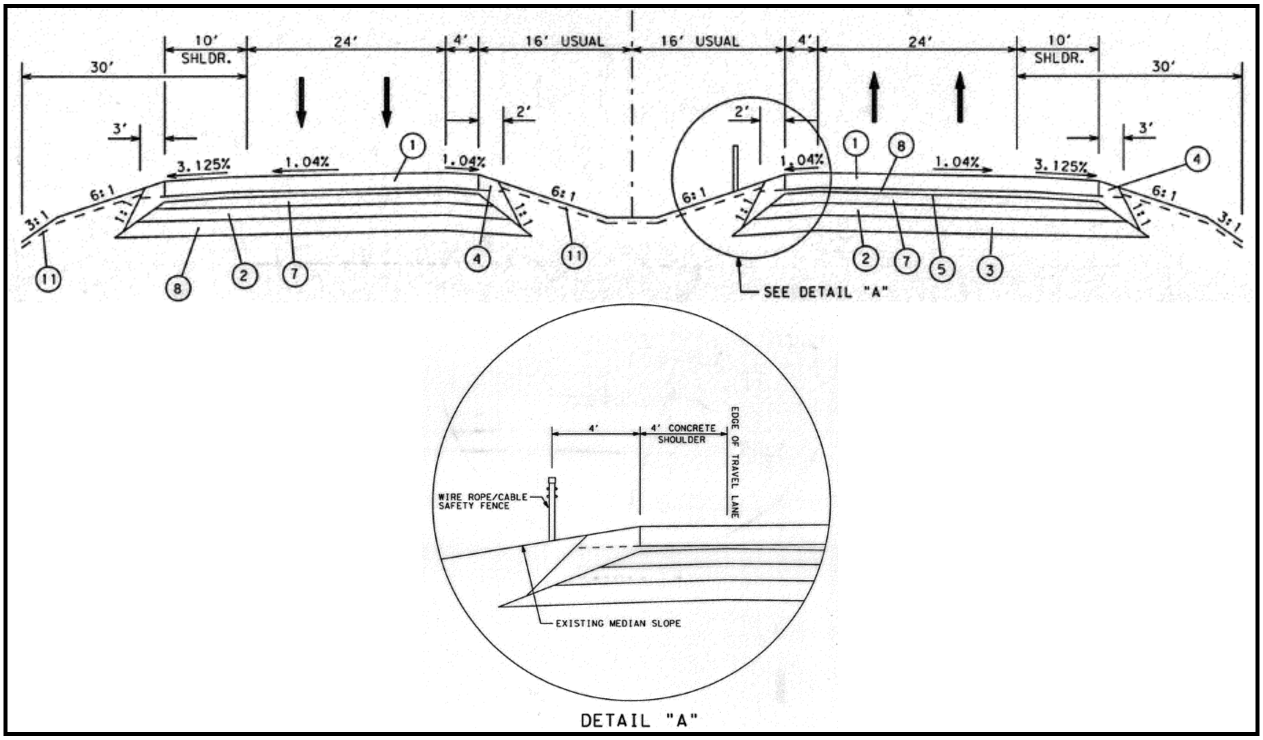


Figure 2-2. Example Typical Section for Extraction of Barrier Placement.

Researchers also included additional data fields for all of the cable barrier projects, such as:

- barrier test level (TL-3 or TL-4),
- barrier manufacturer,
- number of terminal anchors,
- cost per terminal anchor,
- mow strip:
  - type, and
  - cost per mile,
- post type (socketed or direct-driven),
- post spacing, and
- cable barrier system cost per linear foot.

The barrier test level and manufacturer data normally could not be extracted from project plans. The Design Division maintained a database of cable projects that provided this information for almost all of the projects in the inventory. Researchers could utilize the plans to determine the number and placement of terminal anchors, typical mow strip design, and typical post spacing. The research team verified many of these data elements from field observations for projects in the Corpus Christi, Dallas, Fort Worth, and San Antonio Districts. The research team then calculated cost values for the cable barrier system, terminal anchors, and mow strip separately using data from the final monthly construction report for each individual project.

Safety Data

The safety data category includes data fields that are necessary for conducting the safety evaluation. Safety data fields in the database include the following:

- control section,
- job number,
- milepoint limits, and
- barrier installation dates – beginning and ending.

Researchers extracted these safety data elements from TxDOT control section maps, roadway inventory logs, and monthly construction reports.

CHAPTER 3
IN-SERVICE PERFORMANCE EVALUATION PROCESS

3.1 SUMMARY OF KEY CABLE BARRIER IN-SERVICE EVALUATIONS

In the first task, the research team collected and performed a critical review of the existing in-service performance evaluations of high-tension cable barrier systems in the United States. Researchers identified that many states have performed ISPE of high-tension cable barriers. The following subsections provide detailed summaries of ISPEs from six states, including:

- Colorado,
- Illinois,
- Indiana,
- North Carolina,
- Ohio, and
- Washington.

Colorado

The Colorado Department of Transportation (CDOT) began using high-tension cable barriers on a limited basis in 2002. CDOT installed two short sections of the Brifen high-tension cable median barrier on US 285 west of Denver. According to the cable guardrail ISPE report published in 2004, the cable barrier system had only been hit four times (*1*). The CDOT report indicated that three of the crashes were so minor, the vehicles left the scene; in the fourth, the crash was reported but there were no injuries. In recent years, CDOT has expanded the amount of cable median barrier further and will be producing a second research report to document their experience since 2004 (*2*).

Illinois

The Illinois Tollway Authority (ITA) initiated an aggressive program to install high-tension cable barrier systems on over 100 miles of their toll facilities where cross-median crashes were problematic (*3*). Table 3-1 provides a basic description of the almost 105 miles of high-tension cable barrier installed by ITA.

Table 3-1. Illinois Tollway Authority Cable Barrier Site Statistics.

Year	Road Section	Miles	Length (feet)	System Installed	Overall Cost (millions)	Cost per Foot	Placement from Edge of Shoulder (feet)	Post Type
2005	IH 88 M-12	37	159,800	Trinity	$3.3	$20	9	Driven
2006	IH 90 M6-7	35	160,188	Nucor	$2.6	$16	15	Driven
2007	IH 88 M-11	37	183,124	Trinity	$3.5	$19	12	Driven

Impact Statistics
ITA has tracked the impacts to their cable barrier installations over a two-year period between January 1, 2006, and December 31, 2007 (Table 3-2). The data show that there have been 347 impacts on the 109 miles of barrier, with the impacts per mile per year being the highest on the IH 90 site where the daily volume levels are approximately four times higher than the other two sites.

Table 3-2. Illinois Tollway Authority Cable Barrier Impact Data.

Roadway	Section(s)	Daily Volume Range	Number of Impacts	Impacts (Mile/Year)
IH 88	M-12	11,300 – 23,000	68	1.0
IH 90	M-6 and M-7	45,130 – 82,820	259	3.7
IH 88	M-11	11,300 – 23,000	20*	2.2

* The M-11 system has only been in service for a 3-month period (October 2007 – December 2007).

Repair Statistics
ITA also tracked repair costs for their cable barrier systems during the same two-year time period as the barrier impacts (Table 3-3). According to the data, the average cost per impact is approximately $657, and the average cost per mile each year is just over $1,000.

Table 3-3. Illinois Tollway Authority Cable Barrier Repair Data.

	M-12	M-11	M-6	M-7	TOTAL
January 1 – December 31, 2006	$35,660		$46,240	$23,210	$105,110
January 1 – December 31, 2007	$40,190	$15,550	$43,775	$23,220	$122,735
TOTALS	$75,850	$15,550	$90,015	$46,430	$227,845
Average cost / impact					$657

Lessons Learned
According to an ITA report, there have been zero crossover crashes at the three sites. A total of 10 vehicles were not completely restrained by the barrier, traveling over or under the cables. Four cars went under and four cars over the cables; of these, two cars crossed the median into opposing travel lanes. Neither of these two crossings resulted in crashes. The ITA report also showed that two semi-tractor trailers crashed over the top of the barrier; however, both were kept safely in the median.

Indiana

The Indiana Department of Transportation (INDOT) installed an experimental 13-mile section of Brifen wire rope safety fence (WRSF) on IH 65 just north of Indianapolis. INDOT produced an ISPE report in 2006 to document the performance and to determine future policies regarding cable barrier implementation (*4*).

Key Findings
Based on the performance evaluation, INDOT had the following key findings:

- No cross-median crashes have occurred on IH 65 after the WRSF installation.
- The contract price per linear foot for WRSF ($17.95/foot) and w-beam guardrail ($19.00) is practically the same.
- The WRSF has been hit 69 times since it was installed. In 16 cases, the vehicle had minor damage and was able to drive off.
- The original terminal anchor design (48 inches in diameter and 42 inches deep) was inadequate for the soil conditions. INDOT designed a new deeper terminal anchor (13 feet deep) to keep the anchor from moving in the soft soil (see Figure 3-1).
- At least one semi-tractor trailer truck has been stopped by the WRSF.
- No vehicle hitting the WRSF has been directed back into traffic.
- No serious injuries have occurred when vehicles impacted the WRSF.

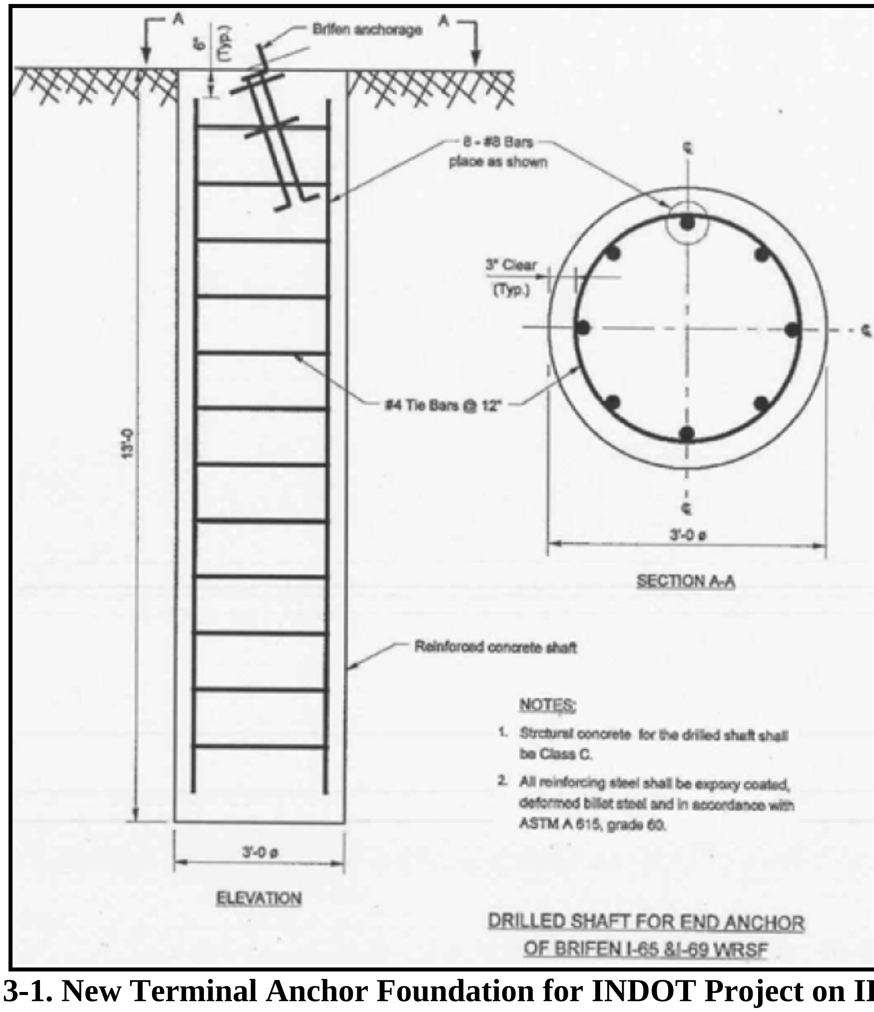


Figure 3-1. New Terminal Anchor Foundation for INDOT Project on IH 65 (*4*).

Key Recommendations
Based on the performance evaluation, INDOT had the following key recommendations to guide future implementation of cable barrier systems:

- WRSF is a cost-effective safety barrier, and they should continue using it to address cross-median crashes.
- Do not use driven posts because the repair costs outweigh the minimal installation cost savings.
- Future designs for foundations should be guided by soil testing at the project site.

North Carolina

Median Barrier Protection

The North Carolina Department of Transportation (NCDOT) has devoted a great deal of time and resources to the investigation of cross-median crashes and development of new median barrier policies since the early 1990s (*5*). During a five-year period (1987 – 1991), 105 motorists were fatally injured in cross-median crashes. NCDOT analyzed the crashes and used the results to identify locations for median barrier installation (*6*). During the study, there were 751 cross-median crashes at locations with no barrier, with 71 involving at least one fatality. Cross-median crashes represented only 3 percent of all interstate crashes but 32 percent of fatalities.

Performance Evaluation

The Highway Safety Research Center (HSRC) at the University of North Carolina performed an ISPE of three-cable median barrier on a segment of I-40 (*7*, *8*). On the IH 40 site, NCDOT installed 6.8 miles of double-run cable barrier (i.e., one barrier on each side of the median) and 1 mile of single-run barrier (i.e., one barrier in the center of the median). The posted speed limit was 65 mph, and the AADT ranged from 106,000 to 119,000 vehicles per day (vpd). In addition, researchers collected data were collected for a 4-mile section of single-run barrier on IH 40 and a 3-mile section of double-run barrier on US 1. Contractors mounted the top cables at a nominal height of 27 inches. During the four-year monitoring period, HSRC found 71 collisions with the barriers, resulting in zero fatalities and only one serious injury. Almost 90 percent involved passenger cars. Seventeen percent of collisions on the single-run barrier resulted in a penetration (i.e., vehicles passed through or across to opposing lanes). HSRC used before and after crash data and comparison site crash data from the Highway Safety Information System (HSIS) to develop regression models for estimating the effects of cable barriers on various crash rates. The models revealed "improved overall safety due to fewer serious and fatal crashes, as well as fewer head-on crashes" after installation of cable barriers. The use of cable median barriers in North Carolina has been estimated to have saved between 25 and 30 lives per year since program inception. The new median barrier policy has been shown by police crash reports to be responsible for a 90 percent reduction in cross-median crashes.

Table 3-4 summarizes the before and after data and demonstrates some very interesting results. On the one hand, the percentage of fatalities was reduced even though the traffic was increasing on the section. The number of crashes probably increased for two related reasons. First, before the installation of the cable median barriers, there was nothing for a vehicle to strike prior to entering the opposing lanes of traffic. Second, many of the median barriers were so-called double-run barriers where the cable median barrier was installed at the shoulder of the median, close to traffic. Since the barrier was close to the traveled way, vehicles that once might have left the road and returned now struck a barrier.

Table 3-4. Cross-Median Crashes before and after Cable Barriers in North Carolina (*5*).

Crash Type	Annual Crashes	Annual Fatal Crashes	
	Number	Number	%
Before cross-median	4.6	0.3	6.5
After cross-median	0.8	0.1	12.5
After cable barrier	67.0	0.6	0.8
Total after crashes	67.8	0.7	1.0

Ohio

There were 11 fatal cross-median crashes on Ohio interstates in a relatively short time period (October 2000 – December 2001). Ohio Department of Transportation (ODOT) officials could not determine any common contributing factors that might explain the reason vehicles were crossing the median (*9*). ODOT decided to install 14.5 miles of Brifen high-tension cable median barrier in an attempt to reduce the frequency of cross-median crashes. Contractors installed the barrier 14 feet from the edge of travel in a 60-foot depressed median with 10:1 slopes. ODOT performed a three-year ISPE to evaluate its performance and to uncover any installation and maintenance issues.

Approximately four crashes per year (12 total) resulted in a penetration of the cable median barrier. At least one of these penetrations involved a semi-tractor trailer. Before the cable barrier installation, the segment of I-65 experienced about seven fatalities per year. After the barrier installation, the data showed that there was one fatality per year and that none of those fatalities involved a crossover related to the cable median barrier.

In 2006, ODOT decided to install another 13 miles of cable median barrier on IH 70 and IH 270 near Cleveland. This area had experienced about six crossover crashes and one fatality per year (*10*, *11*, *12*). In general, ODOT has been installing the high-tension cable median barrier on 60-foot-wide medians with 6:1 slopes or flatter. ODOT typically places the barrier 10 feet from the bottom of the ditch to avoid drainage issues. ODOT places a high priority on placing cable median barriers in medians up to 76 feet wide with traffic volumes over 36,000 vehicles per day. Additionally, they recommend installing cable median barriers in medians between 76 and 84 feet with traffic volumes over 26,000 vehicles per day if there is a crash history problem. The following subsections show some figures that illustrate key findings of the ODOT cable barrier ISPE.

Total Crashes

Figure 3-2 shows a comparison of total crashes before and after installation of WRSF in Ohio. This figure shows that total crashes increased by approximately 7 percent after the barrier installation.

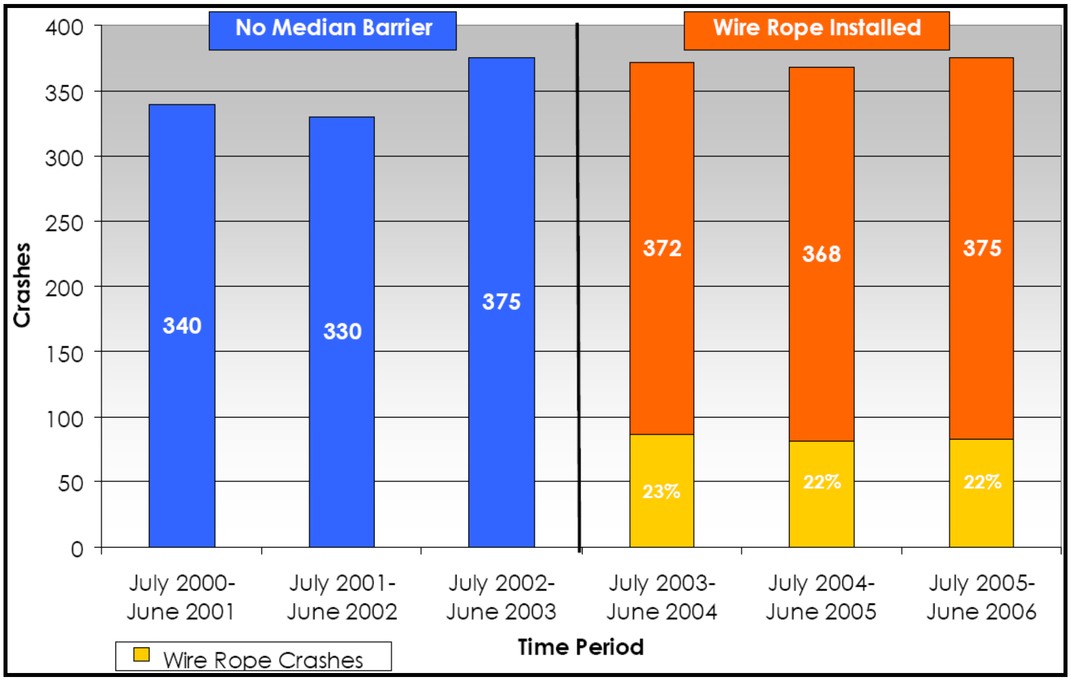


Figure 3-2. Comparison of Total Crashes before and after Installation of WRSF in Ohio.

Road Surface Condition

Figure 3-3 provides a comparison of the road surface condition based on weather conditions for Ohio interstates, the IH 75 site, and for wire rope crashes. It is apparent that when the roadway surface condition is not dry (wet, snow, or ice), the rate of wire rope crashes increases significantly in comparison with Ohio interstates and the IH 75 site.

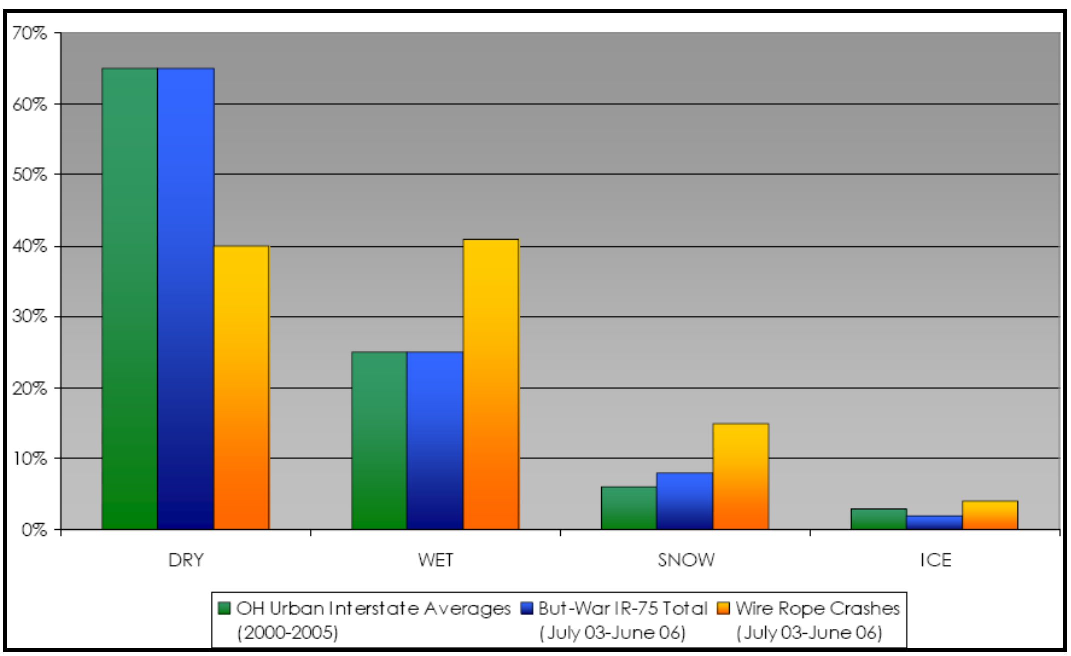


Figure 3-3. Comparison of Roadway Surface Condition for Crashes in Ohio.

Crash Severity

Figure 3-4 compares the severity distribution for crashes for Ohio interstates, the IH 75 site, and for wire rope crashes. This figure illustrates the common finding that installation of cable barrier improves the overall severity distribution. The bottom line in Ohio was that there were no cross-median fatal or incapacitating injuries.

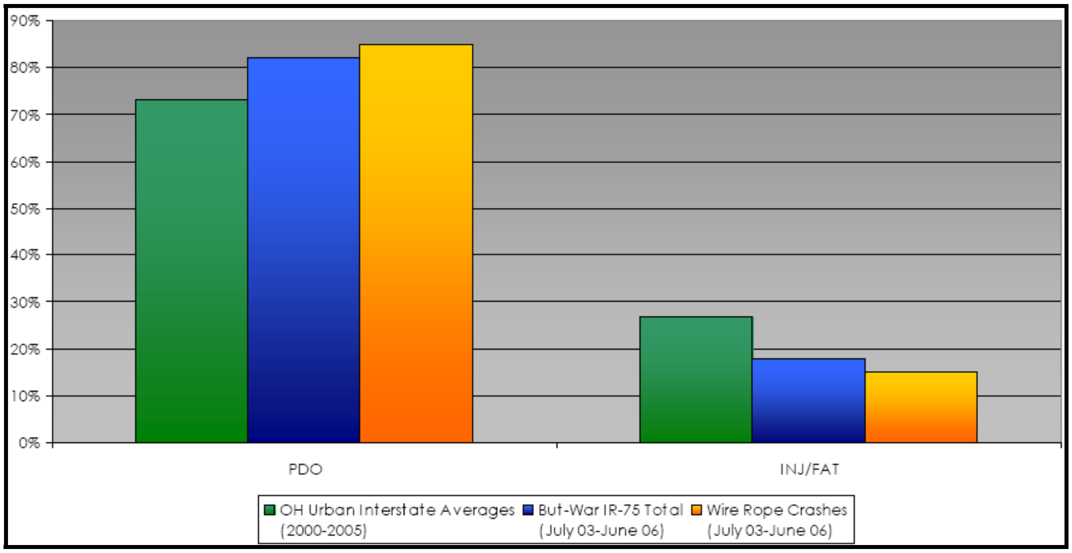


Figure 3-4. Comparison of Severity for Crashes in Ohio.

Other Notable Statistics

There were several other notable statistics derived from the ODOT cable barrier ISPE, including:

- At least 71 percent of the total crashes involved only one vehicle (not including hit-and-run crashes).
- Hit-and-run crashes accounted for 27 percent of the total crashes per year.
- Approximately 28 percent of the wire rope crashes were backside impacts (i.e., vehicles crossed the wider portion of the median before hitting the barrier).

Washington

2003 ISPE

The Washington State Department of Transportation (WSDOT) examined ISPE of the cable barrier by analyzing installation cost, maintenance costs and experiences, and crash history before and after installation (*13*). The ISPE used data from 24.4 total miles of cable barrier located in three sites along IH 5 (see Table 3-5). One of the important aspects of the Washington ISPE data is that crashes and traffic volumes were linked so that crash rates could be calculated. Table 3-5 shows that prior to cable barrier installation, an average of 2.12 crashes occurred for every 100 million vehicles of miles travel (MVMT). Reporting crashes in this way eliminates confusion due to changes in traffic volume during data collection and the growth of traffic. For example, if one crash was observed one year and the next year two were observed, the difference could simply be due to the increase in traffic rather than any intrinsic characteristic of the site.

Table 3-5. Safety Performance Data of Cable Median Barrier in Washington State (*5*).

Crash Type	Annual Crashes		Annual Disabling Injury Crashes			Annual Fatal Crashes		
	No.	Rate*	No.	Rate*	%	No.	Rate*	%
Before cross-median	16.0	2.12	2.2	0.29	13.8	1.6	0.21	10.0
After cross-median	3.8	0.51	0.3	0.04	7.9	0.0	0.0	0.0
Total after crashes	58.6	4.1	0.9	0.06	1.5	0.3	0.02	0.5

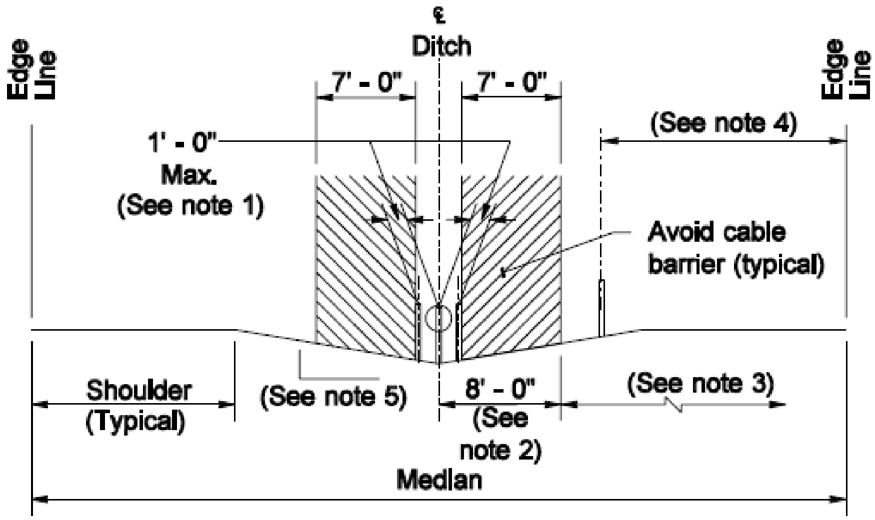
* Crash rates are reported as crashes per 100 MVMT.

The data in Table 3-5 reveal several key findings. First, installing the cable barrier caused the total number of crashes in the median to go up from 2.12 crashes/MVMT to 4.61 crash/100 MVMT, twice the pre-cable median barrier rate. However, the fatal crash rate decreased from 0.21 fatalities/100 MVMT to 0.02 fatalities/100 MVMT after installing the cable barrier. This is a tenfold decrease in fatalities even though total crashes more than doubled. These two statistics illustrate an important point in median barrier design: installing a median barrier will increase the number of crashes since there will be something in the median to hit. When a barrier is installed, especially a very forgiving barrier like a cable median barrier, the number of crashes increases, but the fatalities drop dramatically—by a factor of 10 in the Washington data.

2006 ISPE

WSDOT performed a second evaluation of cable barrier performance in 2006 in response to public safety concerns about a section of I-5 in Marysville (*14*, *15*). While cable barriers appear to be doing a very effective job of reducing CMCs in Washington State, the portions of IH 5 in Marysville still have CMCs even after cable barrier installation. WSDOT's review of crashes in Marysville indicated that 92.4 percent of the vehicles that struck the cable barrier were contained, lower than the 95 percent statewide average. There were 18 penetration events in Marysville where vehicles crossed into opposing lanes, with 3 fatalities. Interestingly, 83 percent of the cable penetrations occurred with vehicles initially traveling southbound even though only 46 percent of cable barrier collisions in the same area involved southbound vehicles.

One detail that was common to many of the Marysville collisions was barrier placement 5 feet from the bottom of the ditch. A series of FHWA-sponsored crash tests in 2004 showed that cable barriers placed 4 feet up the backslope beyond the ditch bottom under-rode the barrier. These results and the Marysville experience convinced WSDOT to change its policy to include a zone from 1 to 8 feet from the bottom of the ditch where cable barrier should not be placed (see Figure 3-5). WSDOT concluded that traffic conditions also appeared to play a role since that segment of IH 5 was characterized by high speed, congestion, and a transition from rural to urban traffic. All these characteristics indicate increased traffic conflicts, which are often the pre-cursor to cross-median crashes. In response, WSDOT installed a second cable barrier on the other side of the median, creating a double-run (*16*). It also increased enforcement in the area to reduce speed and traffic conflicts. WSDOT elected to continue using cable barrier because of its good record in other parts of the state, as well as the lower impact severity of cable collisions in general. Marysville, however, has continued to be a problematic site with a fatal crash occurring in February 2007 (*17*, *18*).



Notes:
(1) Cable barrier may be installed in the center of the ditch. The cable barrier may be offset from the ditch centerline a maximum of 1 foot in either direction.
(2) Avoid installing cable barrier within a 1 foot to 8 foot offset from the ditch centerline.
(3) Cable barrier may be installed a distance of 8 feet or greater from the ditch centerline.
(4) Depending on the system used and post spacing, this distance varies from 6 feet 8 inches to 12 feet.
(5) Applies to slopes between 6H:1V to 10H:1V.

Figure 3-5. WSDOT Placement of Cable Median Barriers in Depressed Medians (*19*).

3.2 DESCRIPTION OF ADOPTED PROCESS FOR TEXAS ISPE

The research team and project monitoring committee (PMC) agreed to adopt an in-service performance evaluation process similar to the one utilized by ODOT (see Section 3.1). The ODOT approach collected and analyzed the following data:

- crash performance, as well as repair problems and costs;
- ongoing maintenance considerations and costs; and
- conclusions (views from safety and maintenance personnel regarding maintenance, repair, and recommendations).

The research team believes that using the same basic process will work well for the evaluation of cable barrier performance in Texas. Specifically, the Texas ISPE will include the following elements:

- initial installation costs:
  - cable barrier systems,
  - anchor/terminal systems,
  - mow strips (concrete and asphalt),
  - miscellaneous elements, and
  - overall median barrier system.

- routine maintenance and repair costs:
  - frequency of barrier impacts,
  - average number of posts damaged,
  - anchor/terminal section impacts and repairs,
  - average cost per impact and per mile per year,
  - average duration of repair,
  - average time between damage and repair,
  - average number of employees per repair, and
  - recovery of repair costs from motorists.

- before and after crash statistics:
  - comparison of injury crashes, and
  - comparison of fatal crashes.

- actual field performance during collisions:
  - analysis of penetration events for passenger cars and trucks,
  - data on cases of re-hit on a damaged section of cable barrier, and
  - other considerations.

3.3 SELECTION OF STUDY SITES

The next step following the adoption of the ISPE process was to select study locations to be included in the Texas ISPE. Researchers based the selection of study sites on several factors, including:

- sites included in the statewide cable barrier inventory conducted as part of Task 3;
- installations that could provide a year or more of data after the completed installation of cable barrier were preferred;
- wide-range of representation of key variables such as:
  - geography,
  - cable barrier placement (shoulder vs. inside the median, distance from edge line),
  - barrier types (system and test level),
  - traffic volume levels (average daily traffic and percent trucks),
  - cross-section (median width, number of lanes, etc.),
  - post spacing,
  - median cross slopes, and
- availability of the data outlined in Section 3.2.

Table 3-6 shows the sites selected for inclusion in the ISPE based on the approved criteria of the research team and PMC. Analysis of the selected sites reveals that:

- The cable barrier systems in the 27 sites all have a year or more of after data since installations were completed by August 2006.
- The sites have a wide-range of representation of key variables, such as:
  - geography: 12 TxDOT Districts;
  - placement: shoulder and mid-median with 8 to 26 foot offsets from the edge line;

- manufacturer: Brifen (21), Trinity (170), GSI/Nucor (151), and Gibraltar (92);
  - test level: 67 percent TL-3 and 33 percent TL-4;
  - traffic volumes: ADTs ranging from 10,000 to 175,000 vpd;
  - median width: 20 to 72 feet;
  - number of lanes: 4 to 8 lane cross sections;
  - post spacing: 6 foot 8 inch to 20 foot spacing; and
  - median cross slopes: flat to 4:1.
- All 27 sites have the majority of data which are outlined in Section 3.1.

These sites should provide the research team with a representative sample of cable barrier installations in Texas.

Table 3-6. Texas Cable Barrier Performance Evaluation Sites.

Site #	Control Section Job Number	District	Highway	Vendor	Length (miles)	Test Level	From Edge (feet)	High ADT (K)
1	2374-02-114	DAL	IH 635	Brifen	4.2	3	10	130
2	0028-11-186, etc.	BMT	IH 10	Trinity	4.5	3	8	74
3	0200-14-065	BMT	US 69	Brifen	4.4	3	8	110
4	0194-02-082	WFS	IH 35	Trinity	17.2	3	8	36
5	0902-00-097	FTW	IH 20/IH 30	Brifen/Trinity	18.6	3	14	77
6	2266-02-095, etc.	FTW	SH 360	Trinity	1.3	3	8-24	50
7	0092-14-074	DAL	IH 45	Brifen	3.1	3	12	78
8	0025-02-168, etc.	SAT	IH 10	GSI/Nucor	81.8	3	16	68
9	0093-01-082, etc.	DAL	IH 45	Gibraltar	15.7	4	8	44
10	0101-01-062	CRP	US 181	Trinity	6.3	3	12-16	10
11	0271-01-069, etc.	YKM	IH 10	Trinity	80.2	3	16-26	47
12	0314-07-032	FTW	IH 20	GSI/Nucor	5.6	3	14	80
13	0495-08-083, etc.	ATL	IH 20	Gibraltar	28.9	3	15-19	35
14	0610-03-074, etc.	ATL	IH 30	GSI/Nucor	43.3	3	15 ½	21
15	2121-01-069,etc.	ELP	IH 10	Gibraltar	12.7	4	8-15	70
16	0008-13-205, etc.	FTW	IH 820	Gibraltar	9.6	3	8	85
17	3136-01-142, etc.	AUS	LP 1, US 183	Gibraltar	5.9	4	8-10	175
18	0043-06-076	WFS	US 287	GSI/Nucor	1.6	3	12	18
19	0253-04-114	SAT	US 281	GSI/Nucor	1.9	3	19	N/A
20	0048-09-027	WAC	IH 35E	Gibraltar	6.8	4	12	30
21	0200-11-089, etc.	BMT	US 69	Trinity	2.4	4	8	103
22	0047-14-061	DAL	US 75	GSI/Nucor	14.3	3	8	65
23	0675-07-080	BRY	IH 45	Trinity	15.1	4	14	47
24	0009-12-204	DAL	IH 30	Trinity	9.4	4	8	86
25	0044-02-075	WFS	US 82	GSI/Nucor	2.0	3	12	37
26	0092-03-047, etc.	DAL	IH 45	Trinity	23.2	4	20	39
27	0014-03-083, etc.	FTW	IH 35W	Gibraltar	12.0	4	12	53

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CHAPTER 4
TEXAS CABLE BARRIER PERFORMANCE EVALUATION

This chapter summarizes activities conducted in the project to evaluate the performance of cable median barrier systems in Texas. The research team organized it into four subsequent sections. Section 4.1 provides information on the installation costs of cable barrier systems in Texas. Section 4.2 summarizes information collected on routine maintenance and repair costs, primarily based on survey responses from maintenance sections throughout the state. Section 4.3 provides the findings from the safety evaluation. Section 4.4 documents some of the actual field performance of cable barrier systems during collisions, with an emphasis on penetration events.

4.1 COST EVALUATION

The research team gathered cost evaluation data for cable and concrete median barrier projects implemented throughout the state of Texas. The research team utilized several available sources for the collection of detailed cost data for the various components of median barrier installation projects. Specifically, the research team used monthly contractor's estimate package reports generated by the TxDOT construction management software package to gather unit costs and quantities for all cable barrier projects. These monthly reports are generated for all construction projects statewide and are available online at the following link: **http://www.dot.state.tx.us/business/cisreports.htm**.

Cable Barrier: Cable Barrier System

The research team analyzed the unit cost data for the bid item described as CABLE BARRIER SYSTEM for each of the 27 Texas sites. TxDOT currently pays for cable barrier systems by the linear foot. Table 4-1 shows the high, low, and weighted average unit cost per linear foot for each of the four cable barrier manufacturers. For further comparison, the research team calculated the cost per mile, which is shown in the three rightmost columns of Table 4-1. For the ISPE sites, the weighted average cost per linear foot was $9.74, which translates to approximately $52,000 per mile. It is important to note that unit costs have dropped significantly over time because of the competition between manufacturers and increased product demand. Table 4-2 shows a comparison of cost per mile data from different states for high-tension cable barrier systems.

Table 4-1. Cable Barrier System Costs – Texas ISPE Sites.

Barrier Manufacturer	Cost per Linear Foot			Cost per Mile		
	High	Low	Weighted Average	High	Low	Weighted Average
Brifen (26.5 mi.)	$17.70	$13.28	$14.67	$93,456	$70,118	$77,458
Gibraltar (91.6 mi.)	$12.00	$8.75	$9.88	$63,360	$46,200	$52,166
Nucor (150.5 mi.)	$13.60	$8.48	$8.66	$71,808	$44,744	$45,725
Trinity (162.7 mi.)	$13.75	$8.85	$9.86	$72,600	$46,728	$52,061
All Combined (431.3 mi.)	$17.70	$8.48	$9.74	$93,456	$44,744	$51,427

Table 4-2. Comparison of Cable Barrier System Costs by State.

State	Cost per Mile
Alabama	$123,000
Colorado	$66,000
Florida	$80,000
Georgia	$227,000
Illinois	$100,000
Indiana	$80,000
Iowa	$170,000
Minnesota	$100,000
Missouri	$80,000
North Carolina	$230,000
Ohio	$72,000
Oklahoma	$84,000
Utah	$65,000
Washington	$65,000

Cable Barrier: Terminal Anchor Cost

The research team analyzed the unit cost data for the bid item described as CABLE BARRIER TERMINAL SECTION for each of the 27 Texas sites. Cable barrier terminals, commonly referred to as terminal anchors, are paid by each one installed. Table 4-3 shows the high, low, and weighted average unit cost per terminal anchor for each manufacturer. For the ISPE sites, the approximate weighted average cost per terminal anchor was $2,500.

Table 4-3. Terminal Anchor Costs – Texas ISPE Sites.

Barrier Manufacturer	Terminal Anchor Cost (Each)		
	High	Low	Weighted Average
Brifen (n=74)	$4,214	$2,200	$3,262
Gibraltar (n=238)	$2,650	$2,000	$2,164
Nucor (n=226)	$3,700	$1,593	$2,692
Trinity (n=368)	$4,492	$2,000	$2,533
All Combined (n=906)	$4,492	$1,593	$2,535

Cable Barrier: Mow Strip Cost

The research team evaluated cost data for the bid items for cable barrier mow strips for each of the 27 Texas sites. Most of the ISPE sites had either an asphalt or concrete mow strip installed with the cable barrier system; however, a few sites utilized socketed or direct driven posts without a mow strip. Table 4-4 shows the high, low, and average cost per mile for both asphalt and concrete mow strips. For the ISPE sites, the weighted average mow strip cost was approximately $25,000 per mile for asphalt and $48,000 per mile for concrete. Most districts have chosen to use concrete over asphalt, particularly when the barrier system is located on the median slope and not directly to the inside shoulder.

Table 4-4. Mow Strip Costs – Texas ISPE Sites.

Asphalt Mow Strip ($ per mile)			Concrete Mow Strip ($ per mile)		
High	**Low**	**Average**	**High**	**Low**	**Average**
$33,260	$20,675	$24,957	$68,678	$38,388	$48,009

Cable Barrier: Total Costs per Mile

Researchers took the various cost components that make up a cable barrier installation (barrier system, terminal anchors, and mow strip) to come up with a total cost per mile based on the average values. The number of terminal anchors per mile varies based on site conditions and design. The research team determined that, on average, Texas sites have utilized four terminal anchors per mile. Using the approximate weighted average for the various components, researchers calculated the total cost per mile to $110,000 (see Table 4-5).

Table 4-5. Texas Cable Barrier – Total Cost per Mile.

Component	Cost per Mile
Cable System	$52,000
Terminal Anchors	4 @ $2,500 = $10,000
Mow Strip (concrete)	$48,000
TOTAL	$110,000

This cost per mile value compares very closely to the value advocated by a recent TxDOT memorandum that provided recommended cost values so that all median cable barrier projects submitted for the 2010 Federal Hazard Elimination Safety (HES) program are evaluated equally (see Appendix A). This memorandum recommended the following items and associated costs for equal comparison:

- $19.00 per linear-foot of cable barrier system, which includes the required mow strip; and
- $4,000 per each anchor (specify the number of anchors).

Using the assumption of four anchors per mile, the total cost based on the memorandum's recommendation is $116,000 per mile, which is very close to the value calculated in Table 4-5.

Concrete Barrier Costs

The cost for concrete median barrier can vary significantly based on the barrier type, quantity needed, and geographic location. In an AASHTO presentation, Meza indicated the following barrier installation costs for concrete median barrier in Texas (*1*):

- pre-cast concrete barrier: $120,000 per mile;
- pre-cast single slope concrete barrier: $210,000 per mile; and
- cast-in-place concrete barrier: $250,000 per mile.

WSDOT has also published barrier installation costs for concrete median barrier, including (*1*):

- pre-cast concrete barrier: $130,000 per mile;
- pre-cast single slope concrete barrier: $237,000 per mile; and
- cast-in-place concrete barrier: $419,000 per mile.

4.2 MAINTENANCE AND REPAIR EVALUATION

Maintenance is one of the primary considerations with performance of cable barrier systems. Since cable barriers cost significantly less to install than concrete barriers, careful evaluation of long-term maintenance cost is important for accurately judging the overall effectiveness.

TxDOT Maintenance Survey

The research team utilized a survey instrument developed for NCHRP Project 210 to gather data from maintenance personnel with responsibility for significant sections of cable barriers (*2*). Researchers made slight modifications to the NCHRP survey to make it more applicable to Texas. Appendix B provides a copy of the survey instrument, which participants could complete online, by electronic mail, or fax.

The survey contained 35 questions on a wide-range of topics related to their experience with maintenance and repair of cable barrier systems installed in their jurisdictions. The research team received survey responses from 32 TxDOT maintenance personnel throughout the state (see Table 4-6). Appendix C provides the results of the maintenance survey. Two of the key survey questions related to penetrations of cable barrier systems by passenger cars and trucks. The research team made contact with each maintenance section that reported a penetration event to gather additional details, if the details were available. Section 4.4 presents this information in additional detail.

Maintenance Repair Logs and Impact Statistics

Researchers were unable to include all 27 ISPE sites in the maintenance evaluation phase, primarily due to data availability. The research team obtained maintenance and repair data from six maintenance sections to analyze impact frequency, repair time, repair personnel, and repair costs. Researchers obtained data from the following maintenance sections:

- Beaumont – Orange County,
- Dallas – Kaufman County,
- Dallas – Navarro County,
- Dallas – Northwest Area,
- Fort Worth – Parker/Palo Pinto County, and
- San Antonio – Boerne.

Impact Frequency

The frequency of impacts to cable barrier systems is dependent on many factors, most notably traffic volume level (ADT) and barrier placement (relative distance from travel lanes). High-tension cable barrier is still a relatively new technology in the United States; however, several states have gathered significant data on cable barrier performance – including the frequency of impacts (see Figure 4-1). Research on locations in Texas has revealed that a good rule of thumb for planning and budgeting purposes is to expect an average of seven impacts per mile per year on a section of cable barrier system (see Figure 4-2). Impact averages ranged from a low of 2.7/mi/yr (Dallas District - Navarro County maintenance section) to a high of 13.0/mi/yr (Beaumont District - Orange maintenance section). This average of seven impacts per mile per year is similar to values in other states such as Ohio (7.6), which performed a detailed three-year in-service evaluation of their high-tension cable barrier systems.

Table 4-6. List of TxDOT Cable Barrier Maintenance Survey Participants.

Number	Name	Maintenance Section	District
1	Russell Luther	Amarillo Expressway	AMA
2	Stephen Metcalf	Marshall	ATL
3	Ira Wisinger	New Boston	ATL
4	Scott Smith	Texarkana	ATL
5	Daniel Bridges	Fredricksburg	AUS
6	Mark Cox	Orange	BMT
7	Brian Dodge	Port Arthur	BMT
8	John Pitre	Beaumont	BMT
9	Bobby Wells	Huntsville	BRY
10	Rodney Chesser	Beeville	CRP
11	Russell Walker	Rockwall	DAL
12	Keith Nabors	Denton	DAL
13	Al Houston	Hutchins	DAL
14	Eddie Gregory	Navarro County	DAL
15	Jan Heady	Kaufman County	DAL
16	Dana Watson	McKinney	DAL
17	Bill Pierce	Ellis County	DAL
18	Robert Saenz	West El Paso	ELP
19	Alan Donaldson	Parker/Palo Pinto	FTW
20	Bryan Anderson	Johnson County	FTW
21	Ralph Garza	South Tarrant	FTW
22	James Hand	North Tarrant	FTW
23	John Solis, III	Raymondville	PHR
24	Hector De Hoyos	Tom Green	SJT
25	Chad Lux	Boerne	SAT
26	William Schuler	West Bexar	SAT
27	Larry Sjelin	Bexar	SAT
28	John Beakley	Hondo	SAT
29	Michelle Stacener	Hill County	WAC
30	Bob Walker	Gainesville	WFS
31	Allan Moore	Vernon	WFS
32	Stephen Werner	Wharton	YKM

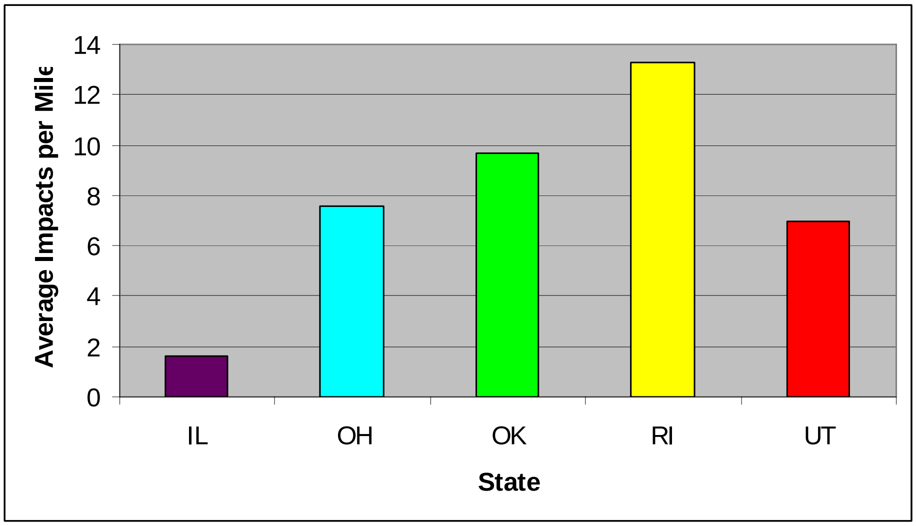

Figure 4-1. Cable Barrier Impact Frequency per Mile in Other States.

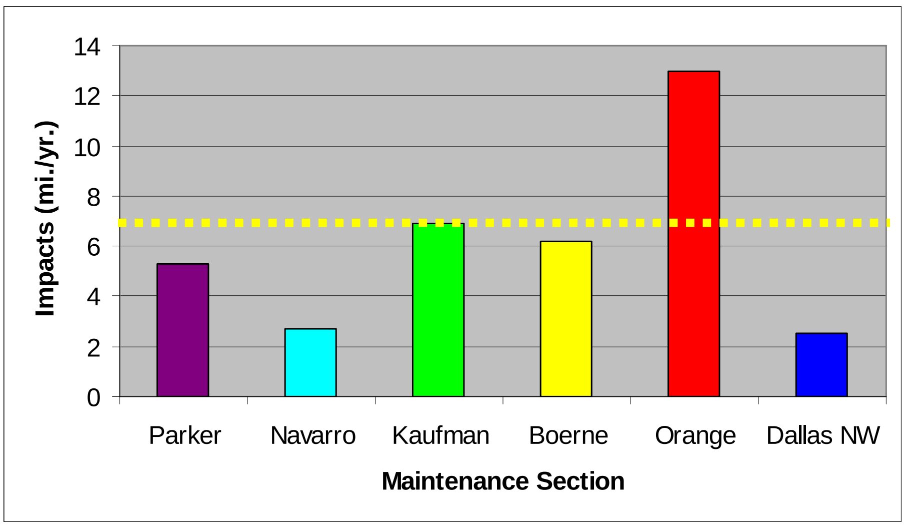

Figure 4-2. Average Cable Barrier Impact Frequency per Mile in Texas.

Road Condition

Previous ISPE analysis of cable barriers has revealed that impacts are much more likely to occur when roadway conditions are wet from rain, ice, or snow. This finding makes sense because vehicles are more likely to lose control and hydroplane into the median when the roadway surface is wet. It also seems logical to make the connection that maintenance and repair activities will likely increase during the seasons of the year where these road conditions are more prevalent. Data from the Weatherford maintenance section supports this assertion, finding that over half (55 percent) of impacts occur when the roadway is wet or icy (Figure 4-3). Again, the Texas data are similar to findings in Ohio where 60 percent of cable barrier impacts on I-75 during a three-year period occurred when the roadway was slick (Figure 4-4) (*3*).

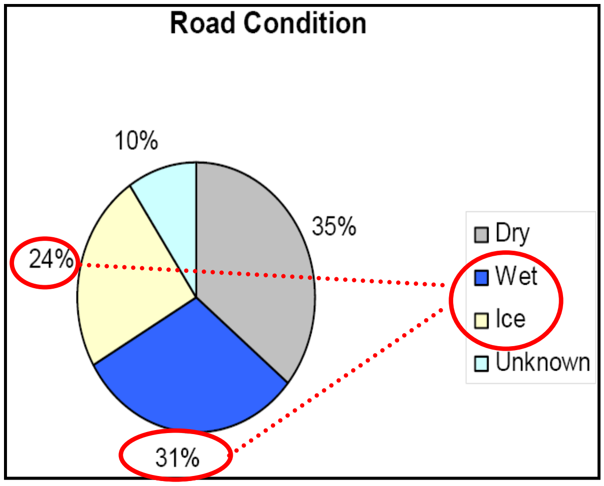

Figure 4-3. Effect of Road Surface Condition on Cable Barrier Impacts in Weatherford.

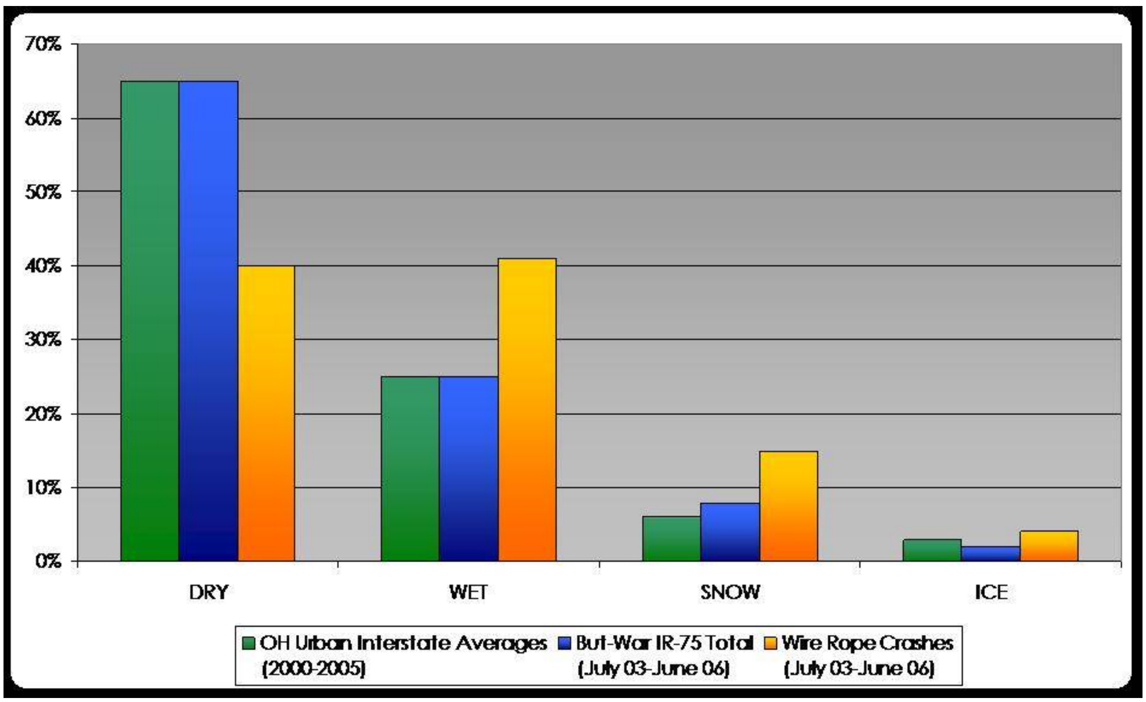

Figure 4-4. Effect of Road Surface Condition on Cable Barrier Impacts in Ohio.

Availability of Crash Reports

Because cable barriers are designed to catch vehicles and minimize the forces put on the occupants, motorists are often able to drive away from the incident scene. Previous studies of cable barrier impacts in other states have shown that 54 percent do not have a police crash report associated with them (*4*). This national statistic is validated by Texas experience, with the Weatherford maintenance section finding that in almost three out of every four cable barrier impacts, the vehicle type is unknown (see Table 4-7). Anecdotal data from other maintenance sections also indicates that in many cases no crash report from law enforcement officials is available because the vehicle or vehicles involved were able to leave the incident scene. This statistic means that TxDOT maintenance personnel will have to rely on other techniques (drive-along, motorist reports, etc.) to identify that the cable barrier system has been damaged.

Table 4-7. Vehicle Type from Cable Barrier Impacts on IH 20 in Weatherford, Texas.

Vehicle Type	Frequency (%)
Car	9
Truck/Sport-Utility Vehicle	14
Semi-Tractor Trailer	3
Unknown	74
TOTAL	100

Typical Post Damage

The number of posts that need to be replaced in a cable barrier impact is a good indicator of damage level and correlates strongly to the amount of repair time that will be necessary. Several states have collected data on the average number of damaged posts per impact, with Ohio reporting an average of 5.7 and Washington an average of 6.5. The research team analyzed the maintenance and impact data from the six maintenance sections and found that an average of 7.3 posts are damaged, with a low average of 5.2 in a rural location and a high average of 14.1 in an urban location (Figure 4-5). The maintenance data showed that the highest number of damaged posts for a single impact was 77 on IH 10 in the San Antonio District.

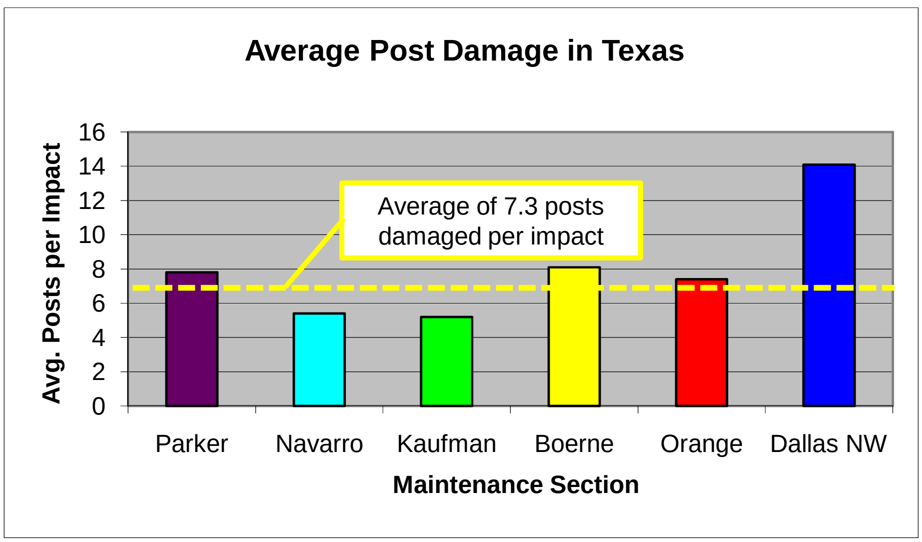

Figure 4-5. Average Post Damage from Cable Barrier Impacts in Texas.

Repair Time

The amount of time spent on repairing damaged cable barrier systems is an important element to track and evaluate. Cable barrier system manufacturers market the ease of repair and maintenance of their products. Researchers utilized two sources of data to assess the average repair time for cable barrier systems in Texas:

- cable barrier maintenance survey (see Appendix B), and
- data from repair logs from four maintenance sections.

The 32 responses from the cable barrier survey estimated that 100 minutes were spent on site for an average level of repair. Similarly, the data from repair logs in the Dallas Northwest, Kaufman County, Navarro County, and Parker County maintenance sections showed that 85 minutes were spent on site for an average repair (Figure 4-6).

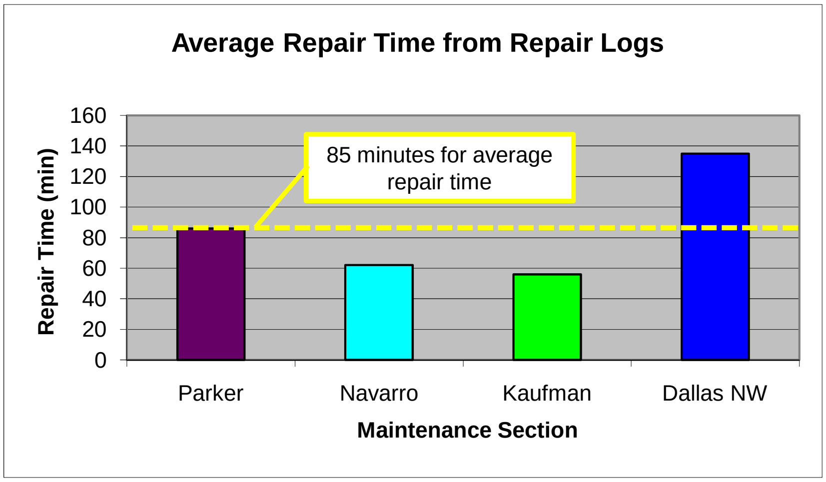

Figure 4-6. Average Repair Time from Maintenance Repair Logs.

Several states have also evaluated the amount of time that elapsed between when the cable barrier system was damaged and when repairs were completed. These evaluations showed that the elapsed time ranged from 4–6 days in Ohio and 2–14 days in Washington. One TxDOT maintenance section provided sufficient data to assess the amount of time that elapsed between when the cable barrier system was damaged and when the repairs were completed (Figure 4-7). This data showed that the average elapsed time was approximately 5 days, with a high value of 26 days. Further analysis by researchers indicated that 60 percent of the repairs were completed in less than a 3-day timeframe.

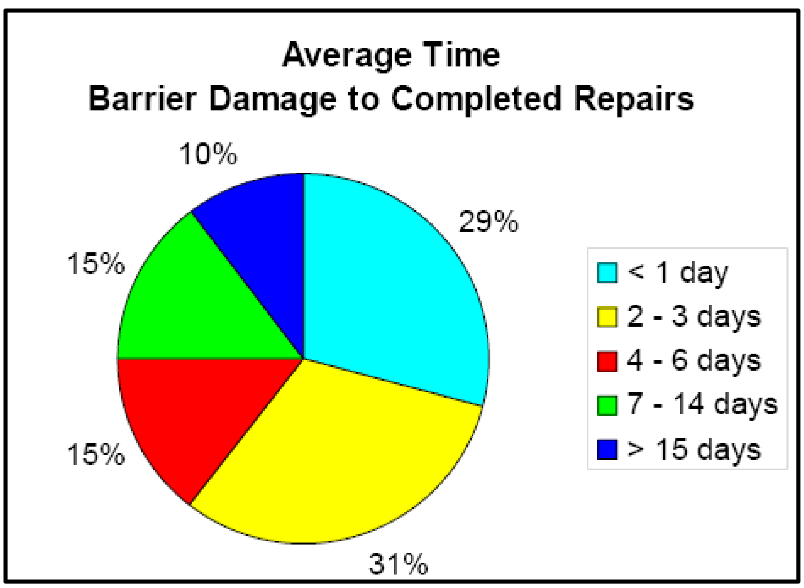

Figure 4-7. Average Time from Barrier Damage to Completed Repair in Kaufman, Texas.

Repair Personnel
The amount of personnel needed to repair damaged cable barrier systems is another important element to track and evaluate. Cable barrier system manufacturers also publicize that many maintenance and repair activities can be accomplished with one employee. The research team collected data from several maintenance sections to assess the average number of repair personnel needed for cable barrier systems in Texas. The number of personnel needed for repairs ranged from a low of 2.2 to a high of 3.5, with an average of approximately 2.8 (Figure 4-8).

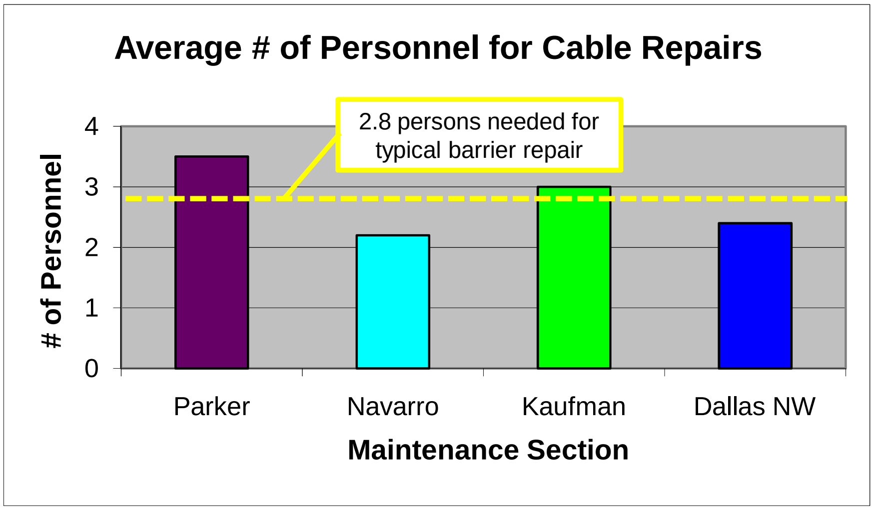

Figure 4-8. Average Number of Repair Personnel for Cable Barrier Repairs.

Repair Costs
Limited funding and resources for maintenance activities make it important to adequately gauge the costs of repairs for cable barrier systems. Data from several TxDOT maintenance sections revealed that average costs ranged from $400 to $900 dollars per repair, including labor, equipment, and materials (Figure 4-9). The average repair cost for cable barriers for each impact based on Texas data was $635. National data fall into this range and are close to the Texas average, with Ohio reporting an average repair cost of $631 and Washington reporting $800 (*5*).

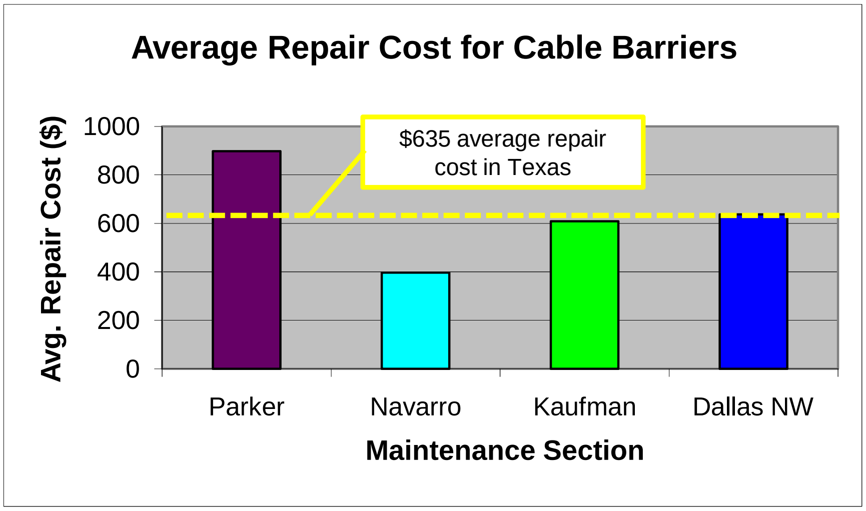

Figure 4-9. Average Repair Cost for Cable Barriers per Impact.

The research team also analyzed and compared Texas cable median barrier costs per mile versus those from other states. Table 4-8 provides maintenance costs per mile per year for four states and two TxDOT maintenance sections that closely monitored their overall spending.

Table 4-8. Average Annual Maintenance Costs per Mile Comparison.

State	Cost (mile/year)
Minnesota	$5,000 - $7,000
Missouri	$6,000 - $10,000
Ohio	$4,500 - $6,800
Washington	$2,520
Texas – Parker County	$4,500
Texas – Kaufman County	$4,000

This table shows that TxDOT maintenance costs are below the values being experienced in other states. Now that TxDOT has over 700 miles of high-tension cable barrier installed throughout the state, the yearly statewide maintenance expenditure will likely be around $3 to $4 million dollars based on the per mile cost shown in Table 4-8.

Barrier Removal. There is a tradeoff in the benefits a cable barrier system provides by prevention of cross-median crashes versus the likely increase in total crashes and associated maintenance and repair costs. As indicated previously in this chapter, the maintenance costs for cable barrier systems can be significant. In one situation, TxDOT decided to remove a section of cable barrier in the Kaufman County portion of the Dallas District (*6*).

The Kaufman County area engineer decided to remove the cable barrier along IH 20 from SH 34 to the Van Zandt County line (11.84 miles) starting at the beginning of April 2008. TxDOT removed this section in an effort to reduce maintenance and replacement costs along this stretch of IH 20. The area office had spent $85,800 in maintenance repairs for the section being removed, which equates to more than one-third of all area office cable barrier costs for the 50 miles installed along US80, US175, and IH 20. TxDOT engineers determined after several studies of the system that safety would still be maintained because of the wide medians along this 12-mile stretch of IH 20 (*6*). It should be noted that the median width in this location is typically 76 feet and that the typical barrier placement was only 8 feet offset from either the westbound or eastbound main lanes (see Figure 4-10). In summary, the fact the cable barrier system was placed in locations with wide medians and would not be a safety concern led to the removal after maintenance and replacement issues became apparent due to its close proximity to the travel lane.

Life-Cycle Cost Comparison of Cable vs. Concrete Median Barrier Systems

Life-Cycle Cost Analysis (LCCA) is an indispensable technique that employs well-established principles of economic analyses to evaluate long-term performance of competing investment options. The LCCA process is performed by summing up the discounted money equivalency of all benefits and costs that are expected to be incurred in each option. The investment option that yields the maximum gains to society is considered the optimal option.

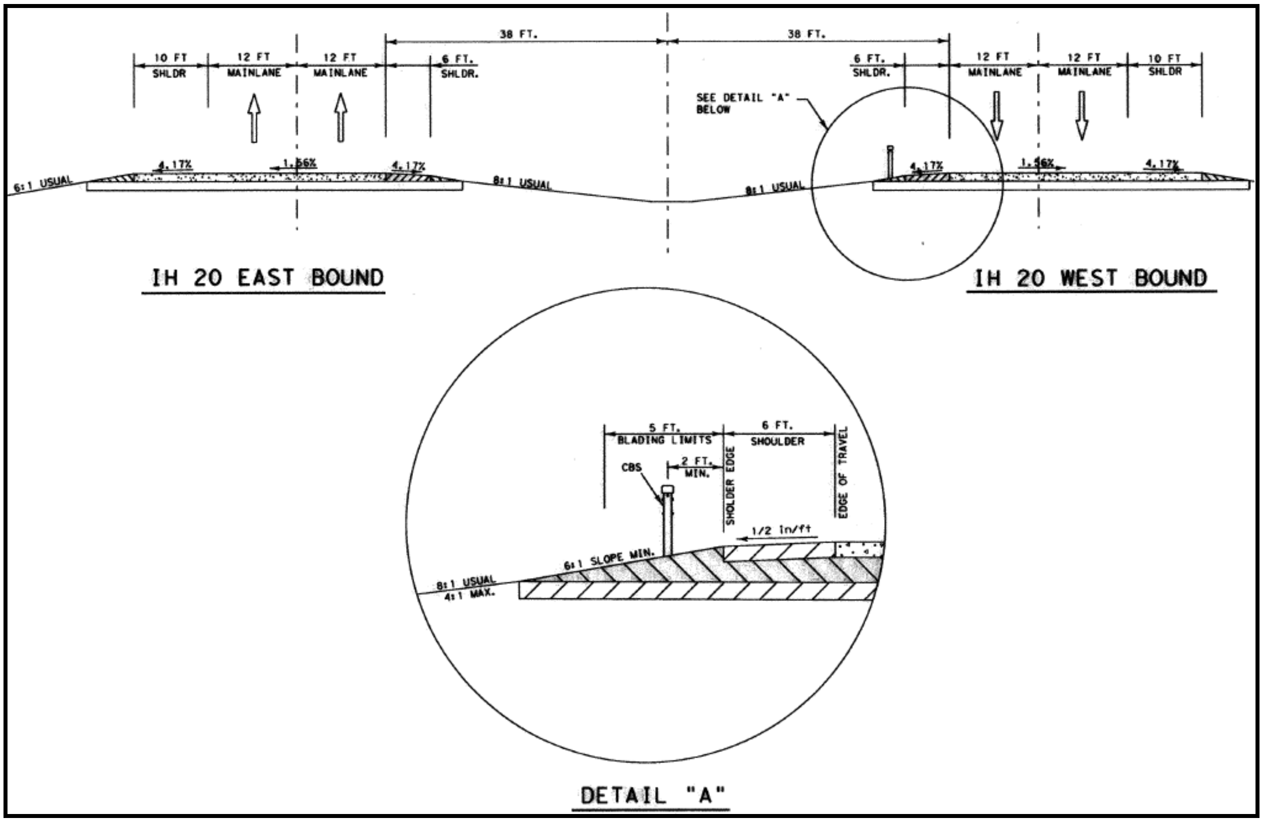

Figure 4-10. Typical Section for IH 20 Barrier Removal Site in Kaufman County.

For the purposes of comparing cable versus concrete median barrier, the research team made the assumption that the benefits to society (reduced fatalities and injuries) for both barrier types were essentially equal. The research team based this assumption on Texas data that revealed a less than 1 percent penetration rate for cable barrier systems versus the 0.3 percent value for concrete median barrier reported in previous TxDOT research (*7*). The life-cycle component that is left is essentially comparing the costs of high-tension cable barrier versus the three most common types of concrete median barrier used in Texas. Researchers used the installation costs reported earlier in this chapter and made the following assumptions:

- 5-mile project to install a longitudinal median barrier system;
- Discount rate = 5 percent;
- Project life = 15 years;
- Recurring cost (cable) = $4,250/mile/year; and
- Recurring cost (concrete) = $250/mile/year.

Table 4-9 compares the life-cycle costs in present value dollars and shows that cable barrier systems are the superior option from a cost-perspective over concrete median barrier with the assumptions used in the analysis.

Table 4-9. Life-Cycle Costs of Cable vs. Concrete Barrier Installation for a 5-mile Project.

Barrier	Installation Cost	Recurring Cost	Discount Rate	Time (years)	Life-Cycle Cost
High-Tension Cable	$550,000	$21,250	5%	15	$8,250,000
Concrete: Pre-cast Portable	$600,000	$1,250	5%	15	$8,600,000
Concrete: Pre-cast Single Slope	$1,050,000	$1,250	5%	15	$15,000,000
Concrete: Cast-in-Place	$1,250,000	$1,250	5%	15	$17,900,000

4.3 SAFETY EVALUATION

Safety improvement is another primary factor to consider in evaluating the performance of cable barrier systems. Engineers have designed cable barriers to prevent CMCs that often result in severe injuries and fatalities. Since prevention of CMCs is the primary objective of cable barriers, their effectiveness should be judged predominantly on the fulfillment of this objective. According to Barton, 96 percent of interstate system fatalities in Texas prior to 2003 were CMC-related (*8*). Evaluating the safety of various engineering countermeasures can be difficult when research conditions are favorable and particularly difficult when there are obstacles. The two significant obstacles for evaluating the safety performance of cable barriers in Texas included:

- Timing: first cable barrier system implemented in summer of 2003 and the majority of projects not completed until late 2006; and
- Data availability: certified crash data has not been available after calendar year 2001.

As part of the 80th legislative session, Texas lawmakers transferred the responsibility for maintaining and updating state crash records from the Department of Public Safety (DPS) to TxDOT on October 1, 2007 (*9*). Both of these agencies have been working on a large project to develop the Crash Records Information System (CRIS) tool for updating and maintaining statewide crash records. For this project, the research team relied on the TxDOT Traffic Operations Division (TRF) for conducting the safety evaluation of cable barrier systems.

March 2007 Preliminary Safety Evaluation

In the absence of full crash data, the research team relied on an informal study conducted by the TxDOT districts in March 2007 (Appendix D). This informal study evaluated fatal CMCs for one-year pre-installation and one-year post-installation for sites where cable barriers had been installed using safety bond funding. Of the 493 miles in the evaluation, almost two-thirds (335 miles) had the one-year of post-installation data available. The other 158 miles either were still under construction or did not have the full year of post-installation data available. The results were extremely positive, with CMC fatalities being virtually eliminated. The first year post-installation results revealed that fatal CMCs were reduced from approximately 47 crashes to 1 crash and from 52 total fatalities to 1 fatality.

July 2008 Safety Evaluation

TRF recently completed a study showing reduced traffic fatalities in Texas (*10*). TRF specifically evaluated cable barrier installations statewide. The districts were surveyed on the location of all median cable barriers and asked for the date the installation began and date the installation was completed for locations with median cable barrier. Based on the district information, TRF included locations that had a minimum of one-year post completion time as of May 2008 in the study. For each identified location, TRF calculated the 12-month (complete calendar months) pre-construction start time period and the 12-month (complete calendar months) post-completion time period. TRF then performed a before and after comparison of head-on fatal and incapacitating crashes. The TRF study noted that head-on crashes include opposite direction/CMC and opposite direction wrong-way on one-way road crashes. According to the study, TxDOT has installed a total of 407 miles of cable barrier that has been in place for a minimum of one year. Table 4-10 provides the results from the before and after comparison of these locations. This table shows that the installation of cable barriers has produced significant benefits by a reduction of 18 fatalities and 26 incapacitating injuries. This reduction equates to almost a $46 million economic benefit based on the current crash cost value ($1,040,000) for fatal and incapacitating injuries that TxDOT uses to evaluate potential safety projects for funding. The full data for each site is shown in Appendix E.

Table 4-10. Cable Barrier Safety Evaluation by Traffic Operations Division – July 2008.

	One-Year Pre-Construction Start (BEFORE)	**One-Year Post-Installation Completion (AFTER)**
Fatal crashes	14	1
Fatalities	19	1
Incapacitating injury crashes	11	0
Incapacitating injuries	27	1

Comparison to Other Cable Barrier Safety Evaluations

According to Ray, the safety performance of cable roadside and median barriers has been studied perhaps more than any other guardrail system (*4*). Ray determined that the earliest studies were performed almost three decades ago in New York State, and the most recent studies are ongoing efforts in states like North Carolina, Arizona, Washington, South Carolina, and Texas.

The performance of both low- and high-tension cable median barriers has been examined to some degree in at least 10 states. Table 4-11 shows a list of states that report using cable barrier to some degree, along with a comparison of before and after CMCs. As shown in Table 4-11, most states have observed very high reductions in the number of cross-median crashes. While most of the states reporting 100 percent reductions have either relatively small inventories of the barrier or have not been installing cable median barriers for very long, many states with long histories of using cable median barriers report cross-median crash reductions of more than 90 percent. Missouri, for example, has used low-tension cable median barriers for nearly 20 years on a large portion of its divided highway system, and it reports a 92 percent reduction in CMCs. The values in Table 4-11 are most likely underestimates since they do not account for the growth in traffic. In Arizona, for example, traffic was increasing at almost 30 percent each year on the highways where cable median barriers were installed, so the actual performance is much better than the 59 percent reduction in Table 4-11.

Table 4-11 demonstrates that cable median barriers do in fact reduce the number of fatal cross-median crashes. Every state that has used cable median barrier and studied its performance has reported a reduction of at least 40 percent and usually closer to 95 percent. While a 95 percent reduction of these types of crashes is a significant achievement, cable median barriers are not 100 percent effective. Unfortunately, no traffic barrier system is completely effective.

Table 4-11. Performance of Cable Barriers – Reduction in Cross-Median Crashes (*4*).

State	Annual Before (No.)	Annual After (No.)	Reduction
Fatal Cross-Median Crashes			
Alabama	47.5	27	43%
Arizona	1.7	0.7	59%
Missouri	24.0	2	92%
North Carolina	2.1	0	100%
Ohio	40.0	0	100%
Oklahoma	0.5	0	100%
Oregon	0.6	0	100%
Utah	15	0	100%
Washington	4.4	0.4	91%
Cross-Median Crashes			
Florida	--	--	70%
North Carolina	25.4	1	96%
Ohio	371	27.5	93%
Utah	114	55	52%
Washington	42.4	11.2	74%

4.4 FIELD PERFORMANCE EVALUATION

The final activities performed by researchers in the ISPE process involved the collection and analysis of field performance data. The data collection effort focused on two areas: penetration event data and a roadside barrier inventory. Researchers gathered penetration event data from questions in the maintenance survey and the roadside barrier inventory based on site visits.

Penetration Event Data

The research team first analyzed available data to determine the effectiveness of Texas cable barriers in capturing errant vehicles. The research team established that the working definition of a cable barrier penetration event is where a vehicle or vehicles are not restrained prior to entering the opposing travel lanes (see Figure 4-11 and Figure 4-12). Based on this definition, researchers determined that penetrations occur in less than 1 percent of cable barrier impacts in Texas. This finding is consistent with cable barrier effectiveness data from other states recently reported by Ray (see Table 4-12) (*4*). The maintenance survey revealed that seven maintenance sections reported one or more penetration event by passenger cars. Similarly, eight maintenance sections reported one of more penetration event by trucks. The research team contacted the survey respondents, typically the maintenance section supervisors, to gather any available details.

Figure 4-11. Example of a Passenger Car Cable Barrier Penetration Event.

Figure 4-12. Example of a Semi-Tractor Trailer Cable Barrier Penetration Event.

Table 4-12. Performance of Cable Barriers: Vehicle Capture Effectiveness (*4*).

State	Collisions No.	Penetrations No.	Effectiveness %
Arkansas	490	25	94.9
Iowa	20	0	100
North Carolina	71	5	93.0
New York	99	4	96.0
Ohio	372	4	98.9
Oklahoma	400	1	99.8
Oregon	53	3	94.3
Rhode Island	22	0	100
South Carolina	2,500	10	99.6
Utah	18	2	88.9
Washington	774	41	94.7

Regarding the passenger car penetration events where additional information was provided, key findings included:

- Several passenger cars were already vaulting, rolling, or without tires on the ground.
- One involved improper installation of wedges by the contractor.
- Several were under-rides with vehicles with low bumper heights (e.g., Chevrolet Corvette and Mitsubishi Eclipse).
- Many were not penetrations (the cable barrier system successfully stopped the vehicle(s) from entering the opposing travel lanes).

Regarding the truck penetration events where additional information was provided, researchers determined the following key findings:

- One involved a jackknifed truck going over the cable barrier on IH 35 near the Medina River in the San Antonio District.
- One involved a northbound semi-trailer truck on IH 35 near Gainesville in the Wichita Falls District.
  - The truck swerved to miss a vehicle parked on the shoulder and lost control.
  - A cable caught the back wheel and had a dynamic deflection of 22 feet into the southbound travel lanes.
  - A southbound pick-up truck drove under the semi-trailer truck and resulted in a fatality for the pick-up truck driver.
  - 85 posts were knocked down in this incident.
- One involved a semi-trailer truck on IH 635 (LBJ Freeway) in the Dallas District:
  - 90 degree impact angle,
  - 10 posts knocked down, and
  - two people who had abandoned their box truck disabled on the left shoulder were killed when the semi-trailer truck went through the cable barrier system.

Most of the detailed data collected on penetration events in Texas to date have shown the incidents to have conditions such as high impact angles where the presence of a cable barrier would not be expected to restrain the vehicle from crossing into the opposing travel lanes. The research team believes that the cable barriers are functioning according to their intended design and are restraining vehicles that impact them in fashions similar to NCHRP 350 guidelines.

Roadside Barrier Inventory

In one of the final efforts of the ISPE, the research team collected information (such as photos of impact locations) via site visits of cable barrier locations in the Corpus Christi, Dallas, Fort Worth, and San Antonio Districts. Researchers used the electronic plans from the TxDOT website to capture typical section and barrier placement data. Members of the research team drove to cable barrier sites and took digital photographs and movies to document placement, emergency crossover, barrier damage, and any other visible issues. Researchers integrated this information into the Geographic Information System (GIS) to do a pilot demonstration of a roadside barrier asset management system. Figure 4-13, Figure 4-14, and Figure 4-15 provide typical photographs of some of the documented damage, success stories, and issues.

Figure 4-13. IH 30 in Rockwall – Top Cable Is Not Tensioned.

Figure 4-14. IH 20 in Kaufman – Restraint of Semi-Tractor Trailer during Ice Storm.

Figure 4-15. IH 820 Northwest Loop in Fort Worth – Damage Is Not Repaired.

GIS-Based Statewide Barrier Inventory
The research team developed a GIS-based Statewide Barrier Inventory Database (GSBID), which required integrating GIS and median barrier inventory data together. Researchers used ArcView 9.2, a GIS software, to accomplish the integration. GSBID provides a powerful and user-friendly platform that shows the location and other detailed information about the existing and planned median barrier sites in Texas from 2001 to 2008. GSBID contains a total of 192 segments, including both cable and concrete median barrier projects. Among the median barriers in the database, 114 are cable barriers (Brifen, Gibraltar, Trinity, Nucor), and the other 78 are concrete. The research team used 57 fields to record barrier information, such as control section job number, barrier types, barrier products, typical post spacing, typical barrier placement from inside/outside shoulder, barrier cost, route name, mile post/reference marker, project description, traffic volumes, number of lanes, median and shoulder widths, etc.

Major Features
Researcher designed the GSBIS to help users easily find barrier placement locations along the highway by providing an accurate map view. Besides offering text information as other databases do, this GSBIS also includes multimedia data collected in site visits, such as picture, video, and crash records (electronic table format). Moreover, through the powerful function integrated in ArcGIS, users can easily perform various query functions on GSBIS, and the query results are then highlighted on the map view.

Feature 1 **–** User-friendly access to GSBIS: the user can display detailed median barrier information with just the click of a mouse at the barrier location.

Based on the GSBIS design, users have a direct map view about the median barrier distribution along the Texas highway and can see detailed information about the barrier they are interested in with just one click of a mouse on the map. The exhibit of such map view is a line shapefile of median barriers as an additional layer above the Texas highway shapefile (see Figure 4-16). When a user clicks on a certain segment, a table including the barrier information is displayed.

Feature 2 **–** Multiple sources data integration: a well-designed hyperlink in HTML format was used to integrate the multimedia data, such as picture, video, and crash record, into GSBID.

Besides the text information, researchers also integrated multimedia data such as typical section images, site visit pictures, and videos into the GIS framework. The research team integrated these multimedia data through the hyperlink of ArcGIS and displayed in a hyper-text markup language (HTML) format. Figure 4-17 and Figure 4-18 show the hyperlink example of a cable barrier in San Antonio. Through this external hyperlink, users can easily acquire different types of data, such as basic information (i.e., location and length), typical section images, picture and video from the site visit, and the crash records, by clicking corresponding buttons.

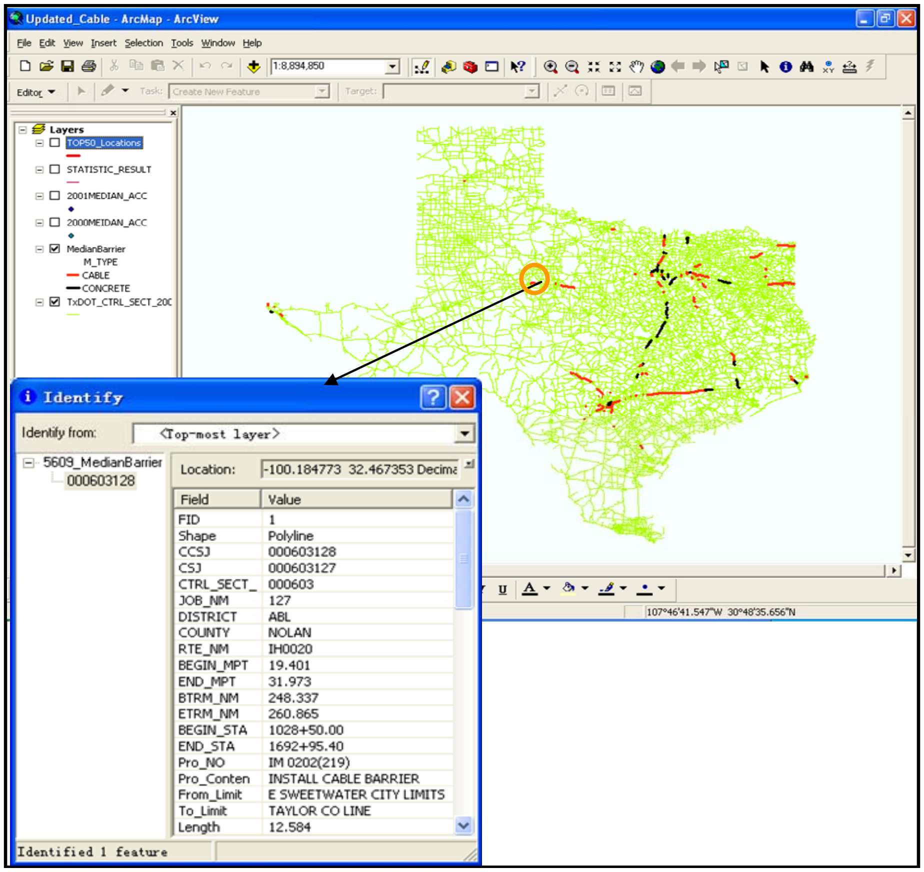

Figure 4-16. GSBIS Screenshot Showing Query Function of IH 20 Cable Site in Abilene.

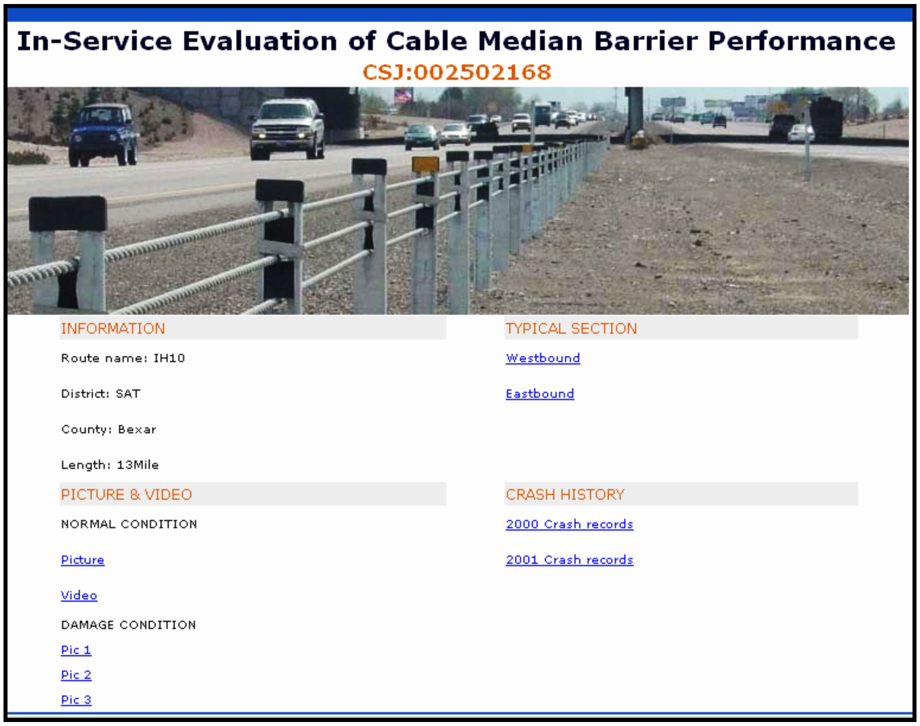

Figure 4-17. Screenshot Showing the Hyperlink Function of Site in San Antonio.

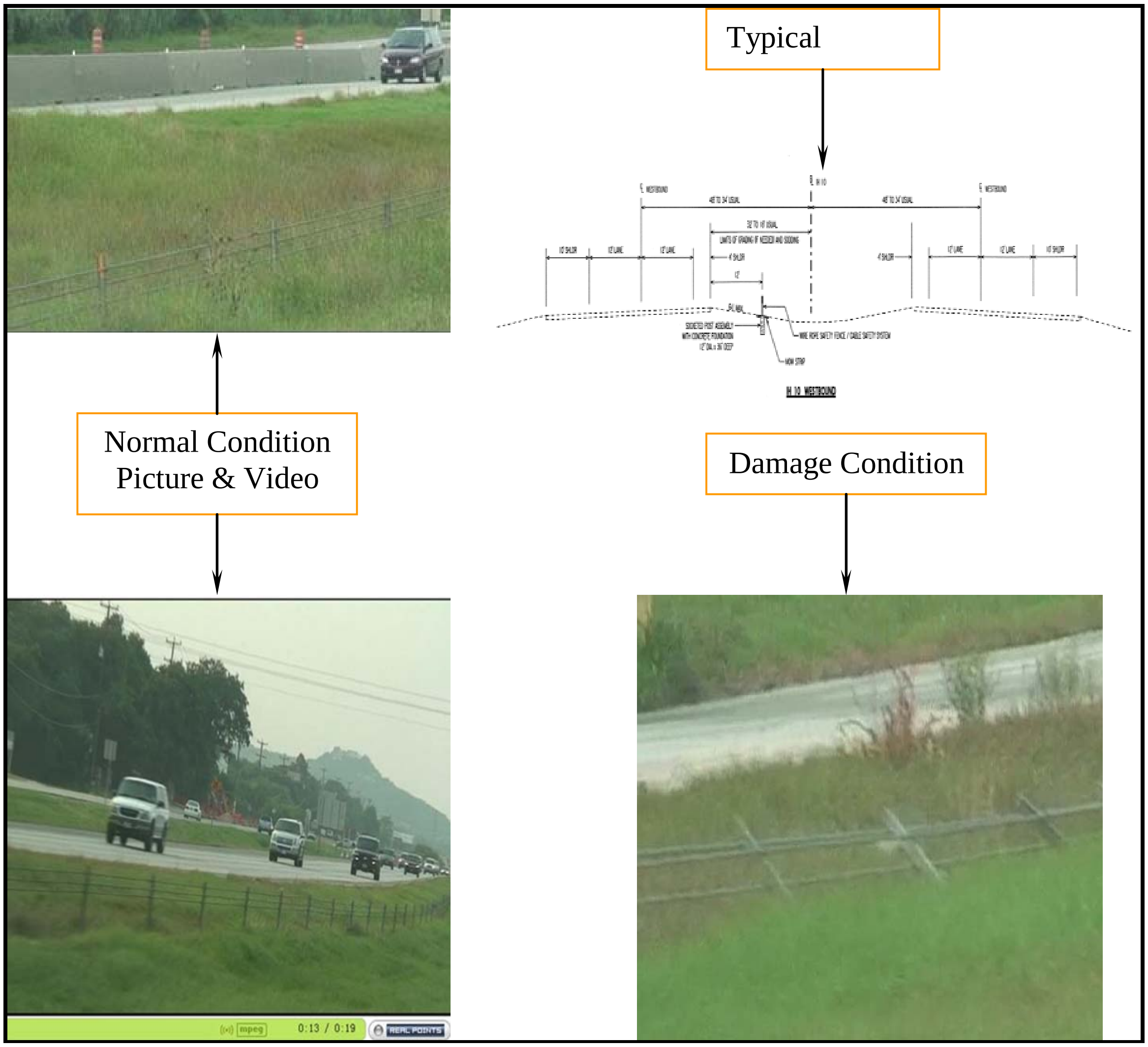

Figure 4-18. Screenshot Showing the Hyperlink Function with Site Data Loaded.

Influence of Soil Conditions on Barrier Performance

Background

In the final effort of the ISPE, the research team collected and synthesized information on the influence of soil conditions on cable barrier system performance. The cable barrier maintenance survey results (Appendix C) revealed that several TxDOT districts have had issues with soil conditions affecting performance, most notably with the terminal anchor systems.

Since cable barrier systems are being placed in existing medians, engineers have several options for lateral placement. ISPE have shown better performance when they are placed closer to the travel way. There are two major contributions that are believed to help performance in this location:

- flatter, paved approaches to the system provide better vehicle interaction; and
- better soil conditions adjacent to the roadway and away from ditch bottoms.

However, as design engineers move the systems closer to the travel way, the number of impacts increase, resulting in increased maintenance costs. In an effort to balance these consequences, most states have opted to place the systems approximately 8 to 12 feet from the travel lane.

Some problems have been identified through the in-service performance evaluations in other states. One of the primary issues identified was anchor movement. The high tension systems are nominally tensioned to 5,600 lb at 70 degrees Fahrenheit. Normal temperature swings cause variations in the cable tension. Some systems use individual anchors for each cable, and some systems anchor all cables at single anchors. The Trinity and Nucor systems use single anchors for each cable, and the Gibraltar system terminates all cables at a single anchor point. These three are the primary systems used in Texas, and they terminate to concrete drilled shafts. The anchor terminal designs for these systems are shown in Figure 4-19 and Figure 4-20.

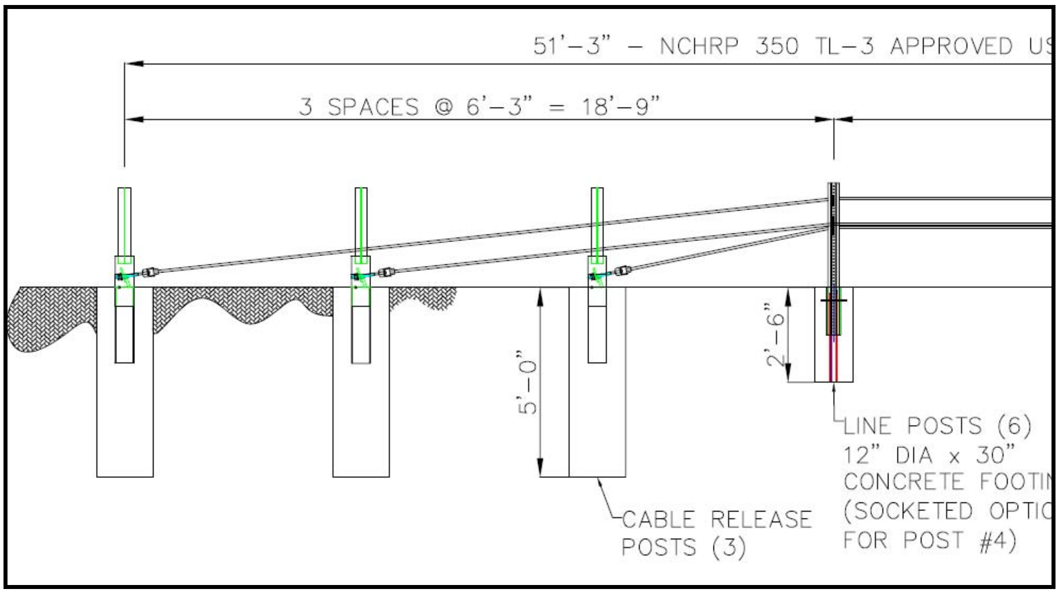

Figure 4-19. Trinity and Nucor Cable Barrier Anchor Terminal.

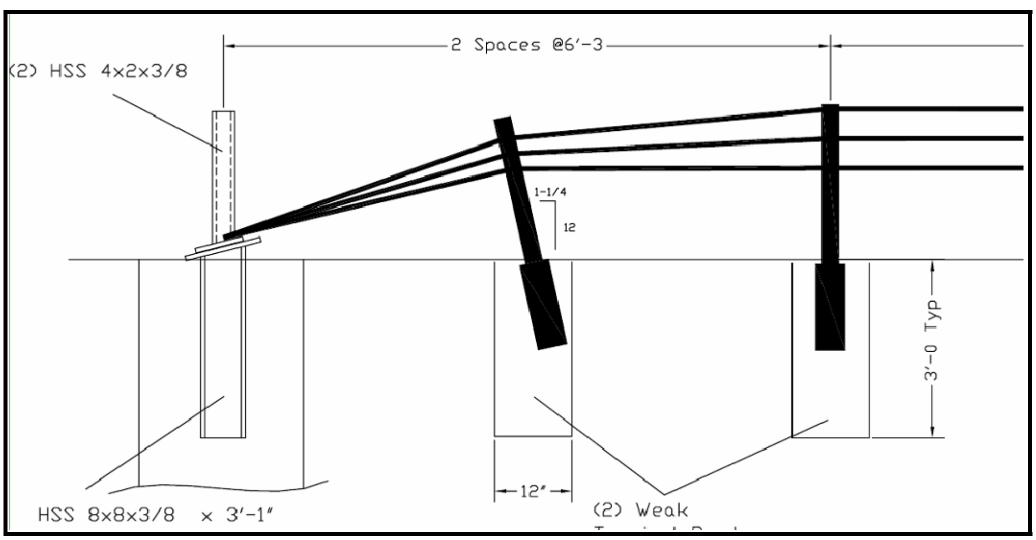

Figure 4-20. Gibraltar Cable Barrier Anchor Terminal.

The federal government requires that all highway safety barriers be tested to NCHRP Report 350 criteria. This document specifies that all systems will be tested in standard soil. NCHRP 350 specifies that standard soil is an AASHTO M-147-65 (1990) or a well-graded road base material. This soil is considered a very strong soil. Obviously, field site conditions vary from the tested conditions. Since several of the systems were developed by independent manufacturers, the same design basis was not used in the development of the anchor design, which is believed to have precipitated the problem experienced by TxDOT and other states.

Discussion of Soil Condition Problems in Texas

The primary problem seen in Texas and other states related to soil conditions is failures of short, laterally-loaded drilled shafts anchoring cable median barrier systems in areas with anchor foundations located in high-plasticity clay soils (Figure 4-21), which indicates that the problem has both components in the geotechnical and roadside safety engineering field. As mentioned previously, anchor movement and field conditions (primarily soil type) are two of the biggest problem areas for cable barrier systems. The cable barrier systems installed in the Kaufman County area of the TxDOT Dallas District experienced significant anchor movement and failure, as seen in by a photo from a site visit in Figure 4-21. Some of the contributing factors to the anchor failure are believed to be: (1) high-plasticity clay soil type coupled with undersized drilled shaft and anchor foundations, (2) installation beginning in summer of 2006 with high temperatures, and (3) winter with low temperatures and icy conditions in February 2007 after the barrier was complete.

It is important to realize that a key consideration for installation of cable in lieu of concrete median barrier is the significantly lower cost (cable barriers cost approximately one-third as much as concrete barrier per mile). The drilled shaft and anchor represent a significant cost component for cable barrier systems; and when the anchor foundation fails, the barrier system cannot maintain adequate tension to capture errant vehicles and prevent cross-median crashes. In the Kaufman County case, there were two options designed to keep the cable barrier anchors functional, and both added significant cost to the typical manufacturer anchor design. Option 1 involved removal of the existing anchor and installation of a new 30 inch diameter drill shaft, 14 feet deep. Option 2 involved drilling a new 24 inch diameter drill shaft; 14 feet deep, in front of the existing anchor and connecting with rebar dowels, as shown in Figure 4-22.

Currently, the TxDOT Design Division memorandum on cable barrier systems does not provide any guidance on soil considerations for barrier performance (*11*). In the foundation design chapter of the TxDOT Geotechnical Manual, it recommends that an engineer should "*study all the available soil data, and choose the type of foundation most suitable to the existing soil conditions and the particular structure*" (*12*). Currently, study of soil data is not done in the case of cable barrier installation in Texas because TxDOT does not require it; therefore, it allows manufacturers to use their standard designs.

Figure 4-21. Anchor Failure on IH 20 Cable Barrier System in Kaufman County.

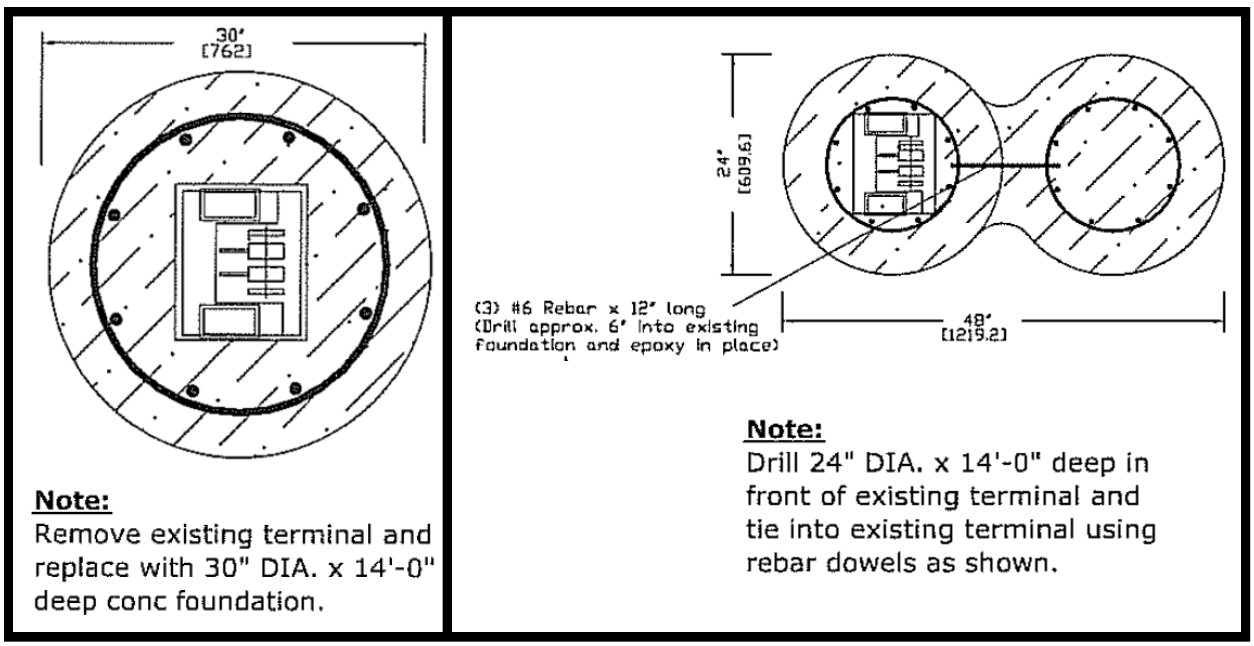

Figure 4-22. Kaufman County Anchor Repair (Option 1 Left Panel, Option 2 Right Panel).

Progress of Other States Dealing with Soil Conditions

It should be noted that some states have developed specifications and procedures to address soil considerations for cable barriers (see Appendix F). The Arizona Department of Transportation has a standard specification that indicates that "*the cable barrier manufacturer or vendor shall satisfy themselves that the soil conditions at the end-anchor locations provide the necessary strength to support their standard end anchor. If, based on a soils report supplied by the contractor (a copy of the soils report shall be sent to the Engineer), the manufacturer decides a modified end-anchor is required due to soil considerations, four sets of shop drawings shall be submitted to the Engineer for review and approval a minimum of four weeks prior to beginning end-anchor construction*" (*13*). Florida and Indiana DOT have cable barrier special specifications that contain geotechnical design parameters based on whether or not the cables are anchored into a single terminal or multiple terminals (*14*, *15*). Also, Dr. Dean Sicking from the University of Nebraska gave a presentation at the 2007 Transportation Research Board (TRB) mid-year Roadside Safety Design committee meeting entitled *Foundation Design for Tension Cable Systems* that is a good resource for understanding design considerations applicable to this problem (*16*).

Further Research in Texas

This current research did not have the scope or necessary resources to address the geotechnical issues identified during the ISPE process. TxDOT has a current request for proposal (RFP) on the design of short laterally loaded drilled shafts in high-plasticity clay projected to begin in September 2008. This project has a strong emphasis on developing a design procedure that will help TxDOT and other states improve the performance of cable barrier systems that are placed in challenging soil conditions.

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CHAPTER 5
SUMMARY AND CONCLUSIONS

This chapter summarizes the key findings and conclusions and recommendations of the research team based on the in-service performance evaluation of cable median barrier systems in Texas. Section 5.1 summarizes the key findings and Section 5.2 outlines the conclusions and recommendations.

5.1 SUMMARY OF KEY FINDINGS

This section provides a summary of many of the key findings from the in-service performance evaluation of cable barrier systems in Texas. The research team separated the key findings from the cost, maintenance and repair, safety, and field performance evaluation.

Cost Evaluation

- The unit costs for cable barrier systems have dropped significantly over time because of the competition between manufacturers and increased product demand in Texas and nationwide.
- The cost of cable barrier implementation in Texas compares very favorably to other states. The cost per mile in Texas for high-tension systems is the lowest in the nation based on just the cable barrier system ($52,000 per mile).
- Cable barrier terminals, commonly referred to as terminal anchors, had a weighted average cost of $2,500 for the Texas in-service performance evaluation sites (see Figure 5-1).
- Mow strips, particularly the concrete ones, are approximately equivalent in average cost per mile as the cable barrier system component ($48,000) (see Figure 5-2).
- Comprehensive cable barrier installation costs are significantly below all types of concrete median barrier, particularly if single-slope or cast-in-place concrete barrier is used.

Figure 5-1. Cable Anchor Terminals
(Left: Trinity/Nucor; Center: Gibraltar; and Right: Brifen).

Figure 5-2. Cable Barrier System on State Highway 71 near Bastrop.

Maintenance and Repair Evaluation

- A significant number of maintenance sections (32) completed a comprehensive survey related to maintenance and repair activities for cable barrier systems in their jurisdiction. Key findings included:
  - The majority of locations (69 percent) do not have breaks in the cable median barrier to allow crossovers for patrol and other emergency enforcement vehicles, and only a few maintenance sections (9 percent) have held special training or informational sessions for emergency responders.
  - Soil and weather conditions have caused problems with post sockets (75 percent) and terminal anchor foundations (31 percent).
  - There have been a significant number of cases (75 statewide) where a damaged section of cable barrier has been hit a second time.
  - State maintenance personnel typically repair cable barrier systems most of the time (78 percent) versus private contractor personnel (22 percent).
  - State maintenance personnel are pleased with the difficulty level of repair activities (75 percent easy to average difficulty) and availability of repair parts.
  - Almost half (47 percent) of maintenance sections do not currently attempt to recover costs of barrier damage and/or repair costs from motorists who caused the damage.
  - Several comments suggested that placement of the barrier too close to the travel lanes is causing maintenance difficulties such as unnecessary lane closures and more frequent impacts.
- Research on locations in Texas has revealed that a good rule of thumb for planning and budgeting purposes is to expect an average of seven impacts per mile per year on a section of cable barrier system. This average of seven impacts per mile per year is similar to values in other states such as Ohio (7.6), which performed a detailed three-year in-service evaluation of their high-tension cable barrier systems.
- There are two basic types of cable repairs: vehicle impact (see Figure 5-3) and turnbuckle cable separation (see Figure 5-4). The turnbuckle cable separation type is a more difficult repair.

Figure 5-3. Simple Repair of Impact on IH 10 in Boerne.

Figure 5-4. More Difficult Repair with Turnbuckle-Cable Separation on IH 10 in Boerne.

- Analysis of cable barriers has revealed that impacts are much more likely to occur when roadway conditions are wet from rain, ice, or snow (Figure 5-5). This finding makes sense because vehicles are more likely to lose control and hydroplane into the median when the roadway surface is wet. It also seems logical to make the connection that maintenance and repair activities will likely increase during the seasons of the year where these road conditions are more prevalent.

Figure 5-5. Weather Conditions Have a Significant Impact on Cable Barrier Impacts.

- Data from Texas and other states show that barrier placement influences barrier impacts. Barriers placed near travel lanes are impacted on a more frequent basis than those placed closer to the center of the median.
- Because cable barriers are designed to catch vehicles and minimize the forces put on the occupants, motorists are often able to drive away from the incident scene. Studies of cable barrier impacts have shown that over half do not have a police crash report associated with them. This statistic means that TxDOT maintenance personnel will have to rely on other techniques (drive-along, motorist reports, etc.) to identify that the cable barrier system has been damaged.
- Research on locations in Texas has revealed that a good rule of thumb for planning and budgeting purposes is to expect an average of seven posts per impact need replacement.
- Maintenance personnel should expect to spend an average of 90 minutes on-site for a typical repair using two to three personnel.
- In the majority of cases (60 percent), cable barrier system repairs are completed within a three-day time period from when the damage is identified.
- Data show that an average barrier impact costs approximately $685 to repair and that TxDOT should expect to spend between $4,000 and $4,500 per mile each year repairing cable barrier systems.
- One area office removed a 12-mile section of cable barrier system due to high maintenance and repair costs in an area where the median width was sufficient and removal did not compromise safety.
- A life-cycle cost comparison of cable versus concrete median barriers showed that cable barriers have a lower overall cost over a 15-year lifespan.

Safety Evaluation

- There were two significant obstacles for evaluating the safety performance of cable barrier systems in Texas: (1) timing; and (2) data availability.
- For this project, the research team relied on two safety studies conducted by TxDOT personnel – a preliminary evaluation by the districts in March 2007 and a second informal study by the Traffic Operations Division in July 2008.
- Both of the TxDOT safety studies focused on comparison of fatal and incapacitating injury cross-median crashes and did not evaluate the effect of cable barrier installation on total crashes.
- The preliminary evaluation by the districts showed very good safety results, with a 98 percent reduction in cross-median fatalities.
- The most recent informal study also revealed positive safety results, with a 93 percent reduction on cross-median fatalities.
- The installation of cable barriers has produced significant benefits by a reduction of 18 fatalities and 26 incapacitating injuries (Figure 5-6) in the first full year. This reduction equates to almost a $46 million economic benefit based on the current crash cost value ($1,040,000) for fatal and incapacitating injuries that TxDOT uses to evaluate potential safety projects for funding.

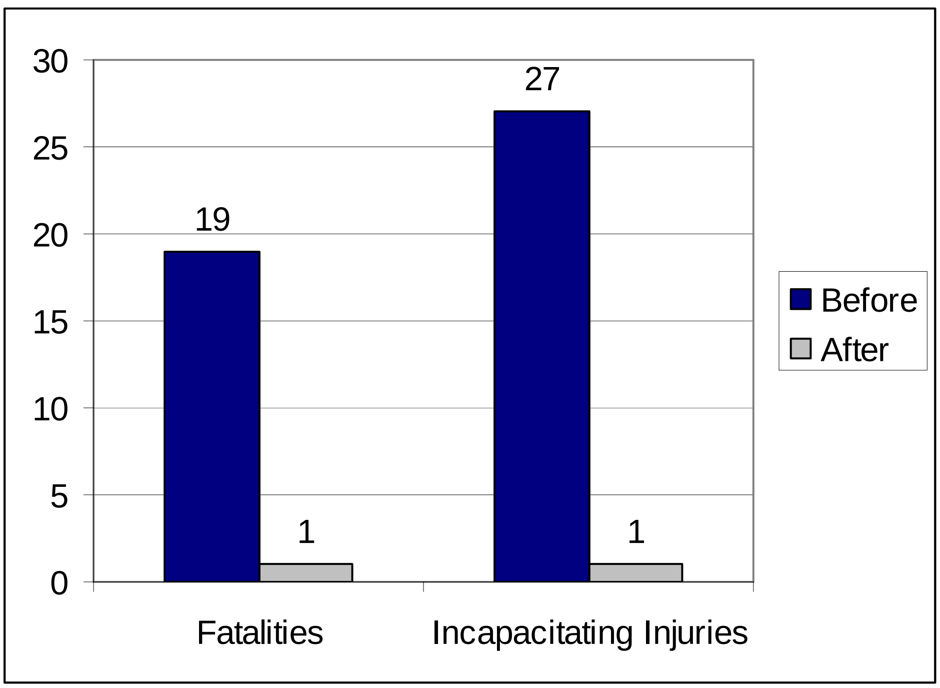

Figure 5-6. Fatal and Incapacitating Injuries before and after Cable Barrier Installation.

Field Performance Evaluation

- The research team determined that penetrations occur in less than 1 percent of cable barrier impacts in Texas. This finding is consistent with cable barrier effectiveness data from other states (see Table 4-12).

- Most of the detailed data collected on penetration events in Texas to date has shown the incidents to have non-standard conditions (Figure 5-7) such as:
    - high impact angles,
    - vehicle already rolling or vaulting prior to the barrier,
    - vehicles with low bumper heights,
    - excessive speed, and
    - improper installation of wedges in one case.
- Researchers successfully built a prototype GIS-based statewide median barrier platform that incorporated many disparate data into an integrated system.
- The research team identified that there has been a significant problem with failures of short, laterally-loaded drilled shafts anchoring cable median barrier systems in areas with anchor foundations located in high-plasticity soils.

Figure 5-7. Non-Standard Impact Conditions: Low Bumper and High Impact Angle.

5.2 CONCLUSIONS AND RECOMMENDATIONS

Based on the key findings from the in-service performance evaluation of cable barrier systems, the research team offers the following conclusions and recommendations.

Conclusions

- From a capital cost and life-cycle cost perspective, cable barrier is an attractive option compared to concrete median barrier.

- Mow strips are a costly component of cable barrier system implementation; however, they provide excellent maintenance-related benefits and should continue to be required on new installations.
- There has been a lack of coordination between TxDOT and emergency responders during the project planning and maintenance phases of cable barrier system projects.
- Maintenance costs and personnel requirements for cable barrier systems can be substantial, and constrained budgets can cause consideration of barrier removal if safety is not adversely impacted.
- Barrier placement is an extremely important design consideration, with safety and maintenance performance being significantly affected.
- Cable barriers are performing extremely well and have had very few cases of penetration unless there were non-standard impact conditions. The research team believes that the cable barriers are functioning according to their intended design and are restraining vehicles that impact them in fashions similar to NCHRP 350 crash testing guidelines.
- Cable barriers are making a significant contribution to the reduction of fatal and incapacitating injuries on state roadways, effectively eliminating 96 percent of these injury types caused by cross-median crashes.
- The GIS-based barrier inventory developed during this research is a good demonstration of the capability of this type of application for management of roadside safety devices such as cable median barrier systems.
- Due to problems experienced in Texas and other states, soil conditions should be considered as part of the project development process for cable barrier system installations.

Recommendations

- Continue to install cable barrier systems in medians that meet guidance criteria.
- Increase coordination with emergency service providers during the project planning and maintenance phases to ensure that their needs are considered, and where practical, implemented.
- Continue to closely-monitor the maintenance and repair activities of cable barrier systems throughout the state to gain an understanding of cost over a longer period of time.
- Consider implementation of a statewide maintenance contract for cable barrier maintenance and repair. The South Carolina DOT is a good example of this private contracting approach, with a $2 million per year contract for almost 500 miles of cable barrier that requires repairs be completed within 96 hours following official notification.
- Cable barriers should be placed as far from the traveled way as possible while maintaining the proper operation and performance of the system. The more lateral offset afforded a driver, the better the opportunity for the driver to regain control of the vehicle in a traversable median and avoid a barrier impact.
- TxDOT should continue to perform annual updates of the safety evaluation to make sure the benefits of cable barrier systems are documented.

- Expand the development of the prototype GIS-based barrier inventory to include additional data and other types of roadside safety devices.
- Conduct further research to address the geotechnical issues identified during the in-service performance evaluation so that soil conditions can be appropriately addressed prior to installation of cable barrier systems.

APPENDIX A

Cost Estimates for Cable Barrier Projects for Safety Funding

MEMORANDUM

TO: All District Engineers

DATE: June 16, 2008

FROM: John A. Barton, P.E. John A. Barton, P.E.

SUBJECT: Cost Estimates for Median Cable Barrier Projects Submitted for 2010 HES Program Call

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On January 17, 2008, the Traffic Operations Division sent a memorandum announcing the program call for the 2010 Federal Hazard Elimination (HES) Program. Districts were encouraged to submit project proposals that address safety issues both on and off the state highway system. The objective of this program is to reduce the number and severity of crashes. Median barrier projects for divided roadways are to be considered when submitting projects.

There are several options that may be considered when installing a median cable barrier system. Some of these include whether to install a three or four cable system and whether or not to include a mow strip. In order to ensure that all cable barrier projects are evaluated equally, please include the following items and associated costs in your project estimate on the Safety Evaluation Report.

- $19.00 per linear foot of cable barrier system which includes a required mow strip
- $4,000 per each anchor (please specify the estimated number of anchors)

If lower item costs for cable barrier systems or anchors are submitted, they will be revised accordingly before a Safety Improvement Index value is calculated. As always, mobilization and traffic control costs are required in the project estimate.

The deadline for project submission is July 15, 2008.

If you have any questions, please contact Debra Vermillion at (512) 416-3137 or Carlos A. Lopez at (512) 416-3200.

cc: Administration
Owen Whitworth, AUD
Mark A. Marek, P.E., DES
Carlos A. Lopez, P.E., TRF
Debra Vermillion, TRF

APPENDIX B

Texas Cable Barrier Maintenance Survey Questionnaire

Survey Objective

This survey is being conducted as part of TxDOT research project 0-5609 ***In-Service Evaluation of Cable Median Barrier Performance***. The primary research objective is to develop recommendations and guidelines to direct TxDOT staff for future cable median barrier installations. This survey is being conducted to identify maintenance experiences with the use of cable barrier systems in Texas.

Participation Consent

You have been contacted because you are a maintenance supervisor of a section with responsibility for roadways with cable barrier systems deployed in the field. Gathering information on the performance and maintenance experience of the cable barrier systems in your section is critical to this research.

Would you like to participate in this survey?

☐ Yes, I would like to participate and receive a free copy of the *Maintenance Guidebook*
☐ No

If we have any follow up questions or need some more information, may we contact you via phone call or email?

☐ Yes ☐ No

Survey Instructions

For your convenience, the survey has been divided into two sections.

Section I requires a minimal amount of writing as most of the questions can be answered by checking the right option or filling in the blanks.

Section II of the survey may require short answers for some of the questions. If you feel that you would rather give your answer for some of these questions over the phone than to write up a response, simply write "*contact for answer*" in the space allocated. Once we receive your replies, we will call you to get your verbal response for such questions. We will then type up your verbal response and seek your approval before using it in the survey.

Contact Information

District: _____

Maintenance Section: _____

Contact Name: _____

Contact E-mail: _____

Contact Phone: _____

Return Instructions

Once the survey has been completed, there are several return options:

1. E-mail to s-cooner@tamu.edu
2. Fax to (817) 461-1239 Attention: Scott Cooner
3. Mail to 110 N. Davis Drive, Suite 101 – Arlington, TX 76013

***** We would like to receive completed surveys by July 30, 2007 *****

SECTION I

Please write "n/a" if the requested information is not available or unknown.

1. Are there any High Tension Cable Barrier Systems installed in your maintenance section?
   ☐ Yes ☐ No

   If you answered '*Yes*'
   - Which systems were installed and what is the approximate number of miles installed, or expected to be installed by the end of the year 2007?
     ☐ Brifen (Brifen USA, Inc) _____miles
     ☐ CASS (Trinity Highway Safety Products, Inc.) _____miles
     ☐ US High Tension Cable System (Nucor Steel Marion Inc.) _____miles
     ☐ Safence (Blue Systems) _____miles
     ☐ Gibraltar Cable Barrier System (Gibraltar) _____miles
   - Are the cables used in high tension systems prestretched?
     ☐ Yes ☐ No

2. Are breaks in the cable median to allow crossovers for patrol and other emergency vehicles provided?
   ☐ Yes ☐ No

   If you answered '*Yes*'
   - Were special training or informational sessions offered to the emergency responders or the police?
     ☐ Yes ☐ No

3. Have there been any penetrations of passenger vehicles through the cable barrier systems in your maintenance section?
   ☐ Yes ☐ No

   If you answered '*Yes*'
   - What is the total number of penetrations of this type? _____

4. Have there been any penetrations of trucks through the cable barrier systems in your maintenance section?
   ☐ Yes ☐ No

   If you answered '*Yes*'
   - What is the total number of penetrations of this type? _____

5. Has the cable barrier system generally remained capable of vehicle redirection between the time of an initial impact and the start of repairs?
   In the impact location: ☐ Yes ☐ No ☐ Unknown
   Up or downstream of the impact location: ☐ Yes ☐ No ☐ Unknown

6. Was any cracking, spalling, break-offs, etc. observed in the concrete sockets installed in your section?
   ☐ Not Applicable
   As a result of impact: ☐ Yes ☐ No
   As a result of weather: ☐ Yes ☐ No

7. Have wet medians, poor soils, and/or frost resulted in barrier shifting or foundation heaving in your maintenance section?
   ☐ Yes ☐ No ☐ Unknown

   If you answered '*Yes*'
   - Has this affected performance of the cable barriers? ☐ Yes ☐ No

8. Approximately how many cases of a re-hit on a damaged cable barrier have you had? _____

9. Who typically repairs the cable barrier systems in your maintenance section?
   ☐ State personnel
   ☐ Contract forces
   ☐ Others (*please explain*) _____

10. How would you rate the level of difficulty in repairing the cable barrier systems?
    ☐ Easy ☐ Average difficulty ☐ Somewhat difficult ☐ Very difficult

11. How would you rate the availability of repair parts for the cable barrier systems?
    ☐ Always available ☐ Average availability ☐ Somewhat difficult ☐ Very difficult

12. How would you rate the delivery time of repair parts for the cable barrier systems?
    ☐ Short ☐ Average ☐ Long ☐ Very Long

13. Has your section recorded any data regarding maintenance cost of the cable barriers (i.e. cost per mile/year)?
    ☐ Yes (*please specify cost*) _____
    ☐ No

14. Have the system anchors remained stable for the cable barrier systems used in your maintenance section?
    ☐ Yes ☐ No

15. Do you experience breaking/failure of sockets under pre-impact conditions (for example, due to water expansion in socket, cable tension on curves, etc.)?
    ☐ Rarely ☐ Occasionally ☐Usually ☐ Always

16. Do you experience breaking/failure of spring compensators under pre-impact conditions?
    ☐ Rarely ☐ Occasionally ☐ Usually ☐ Always

17. Do you experience turnbuckle movement (due to vibration) in the cable barrier system?
    ☐ Rarely ☐ Occasionally ☐ Usually ☐ Always

18. Is the cable tension checked after performing any repairs?
    ☐ Yes ☐ No

19. Does the cable hold correct tension after an impact from an errant vehicle?
    ☐ Yes ☐ No

20. Compared to other barriers, how would you rate the level of difficulty caused by the cable barrier systems to mowing operations?
    ☐ Easy ☐ Average difficulty ☐ Somewhat difficult ☐ Very difficult

21. How much time is spent on-site for an average level of repair? _____

22. Have any repairs required cable replacements?
    ☐ Yes (*approximately how many*) _____
    ☐ No

23. Have any repairs required replacement of anchor foundations?
    ☐ Yes (*approximately how many*) _____
    ☐ No

24. Have any repairs required replacement of anchors?
    ☐ Yes (*approximately how many*) _____
    ☐ No

25. Do maintenance personnel prefer working on a ☐ mid-median installation or a ☐ shoulder installation?

26. Does the cable generally hold specified tension over time?
   ☐ Yes ☐ No ☐ Unknown

27. Do you have any methods/procedures in place to monitor cable tension for installed barriers over time?
   ☐ Yes ☐ No

28. Does your maintenance section have a tension meter and other specialized tools necessary for repairs?
   ☐ Yes ☐ No

29. Which cable barrier system requires the least amount of maintenance time?
   ☐ Brifen (Brifen USA, Inc)
   ☐ CASS (Trinity Highway Safety Products, Inc.)
   ☐ US High Tension Cable System (Nucor Steel Marion Inc.)
   ☐ Safence (Blue Systems)
   ☐ Gibraltar Cable Barrier System (Gibraltar)
   ☐ Unknown

SECTION II

This section may require short answers for some of the questions. If you feel that you would rather give your answer for some of these questions over the phone than to write up a response, simply write "contact for answer" in the space allocated. Once we receive you replies, we will call you to get your verbal response for such questions. We will then type up your verbal response and seek your approval of it before using it in the survey.

30. Has your maintenance section encountered any problems with the installation of mow strips (if used)?
   ☐ Yes (*please explain*) _____
   ☐ No
   ☐ Not applicable

31. Please describe any difficulties that your maintenance section has encountered with the installation of the cable barriers. _____

32. How has maintenance personnel trained to repair cable barrier systems? _____

33. Does the cable barrier system cause complications for other maintenance operations?
   ☐ Yes (*please explain*) _____
   ☐ No

34. Do you keep an inventory of repair parts?
   ☐ Yes ☐ No

   If you answered '*Yes*'
   - Do you keep an inventory of cables? ☐ Yes ☐ No
   - What is your procedure for estimating the inventory of parts to maintain? _____
   - Where are the different repair parts stored? _____
   - Which repair parts are stored outdoors? _____
   - Which repair parts are stored indoors? _____

35. Has there been any attempt to recover costs of barrier damage and/or repair costs from motorists who cause the damage?
   ☐ Yes ☐ No

   If you answered '*Yes*', please explain: _____

APPENDIX C

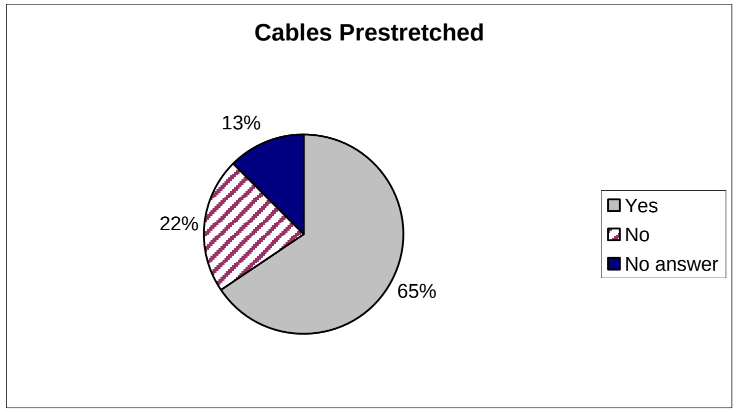
Texas Cable Barrier Maintenance Survey Results

Question 1: Are there any high-tension cable barrier systems installed in your maintenance section?

	Frequency	%
Yes	32	100
No	0	0
Total	32	100

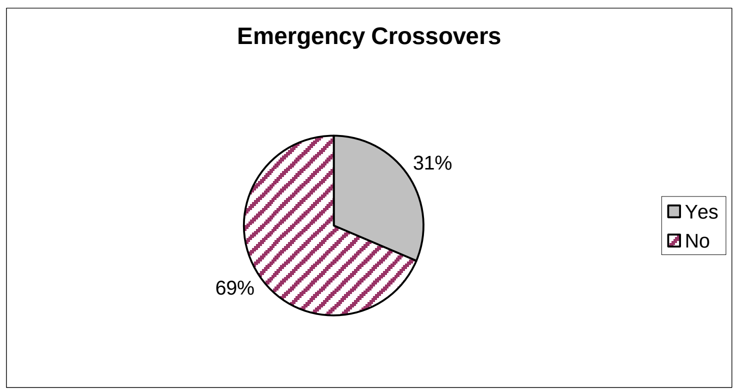
1B: Are the cables used in high-tension systems prestretched?

	Frequency	%
Yes	21	65.625
No	7	21.875
No answer	4	12.5
Total	32	100



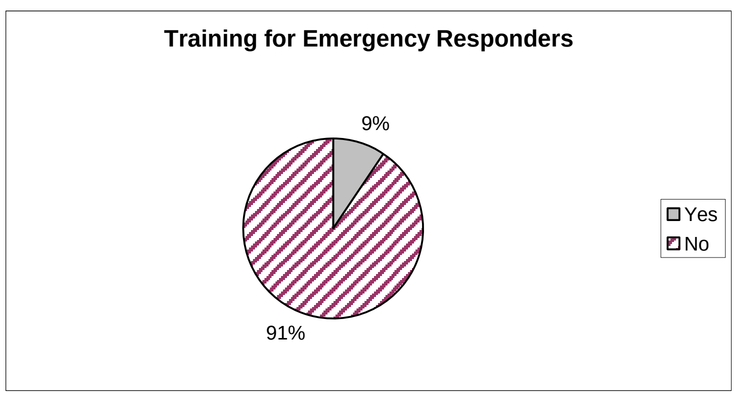
Question 2: Are breaks in the cable median to allow crossovers for patrol and other emergency vehicles provided?

	Frequency	%
Yes	10	31.3
No	22	68.8
Total	32	100



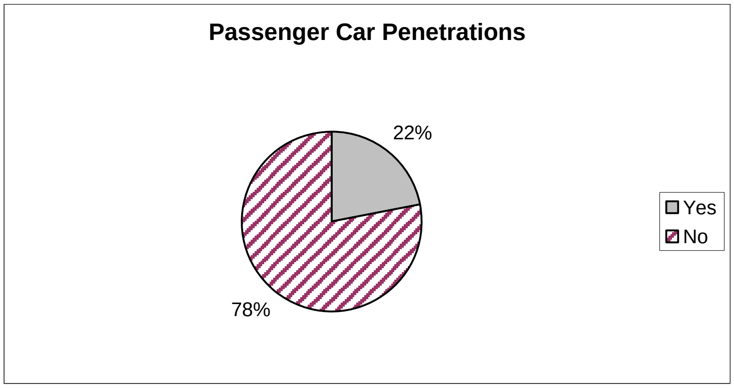
2B: Were special training or informational sessions offered to emergency responders or the police?

	Frequency	%
Yes	3	9.4
No	29	90.6
Total	32	100



Question 3: Has there been any penetrations by passenger vehicles through the cable barrier systems in your maintenance section?

	Frequency	%
Yes	7	21.9
No	25	78.1
Total	32	100

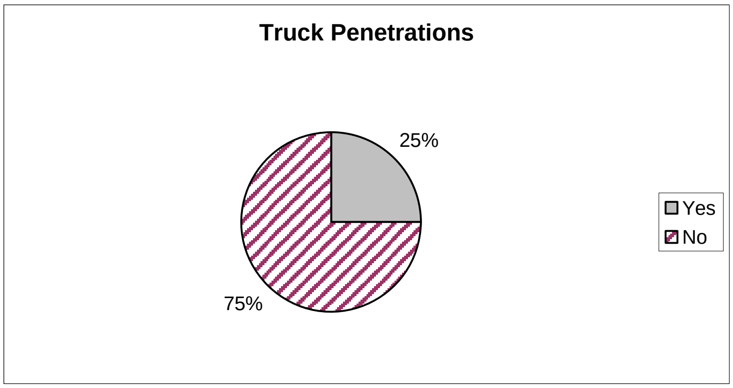


3B: What is the total number of penetrations of this type?

	Frequency
Total	15

Question 4: Has there been any penetrations by trucks through the cable barrier systems in your maintenance section?

	Frequency	%
Yes	8	25.0
No	24	75.0
Total	32	100



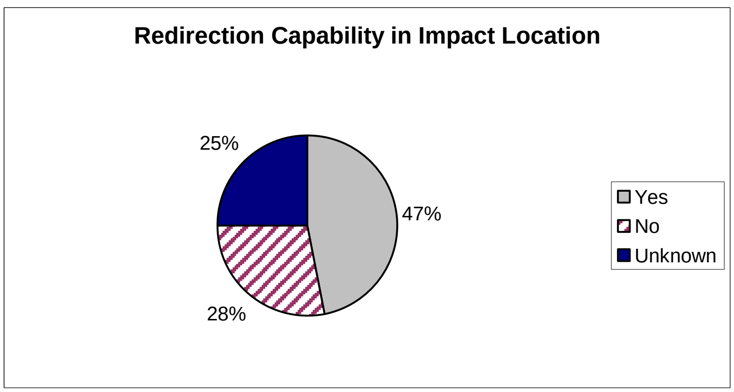
4B: What is the total number of penetrations of this type?

	Frequency
Total	12

Question 5: Has the cable barrier system generally remained capable of vehicle redirection between the time of an initial impact and the start of repairs?

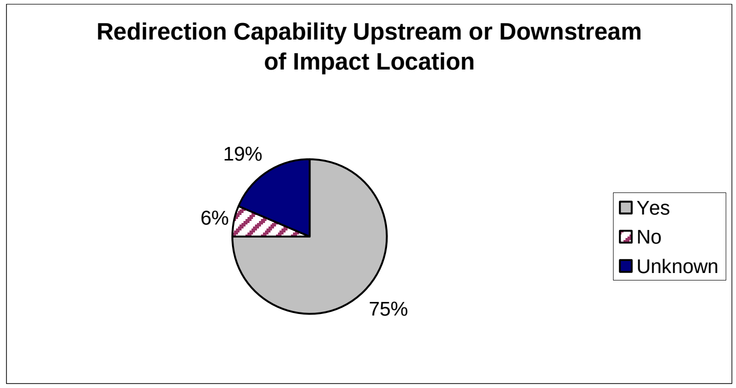
A. In the impact location?

	Frequency	%
Yes	15	46.9
No	9	28.1
Unknown	8	25.0
Total	32	100.0



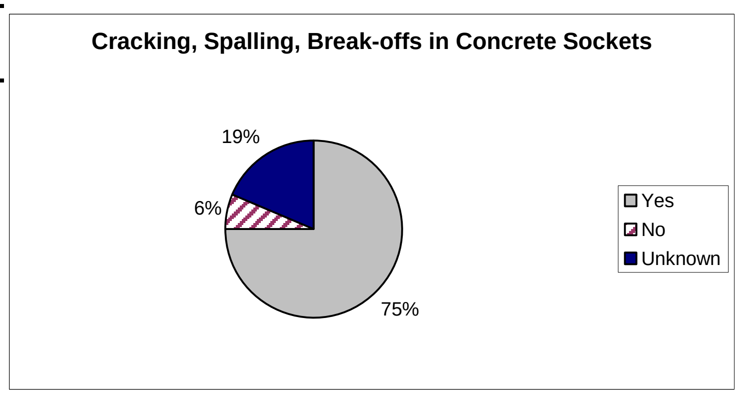
B. Upstream or downstream of the impact location?

	Frequency	%
Yes	24	75.0
No	2	6.3
Unknown	6	18.8
Total	32	100.0



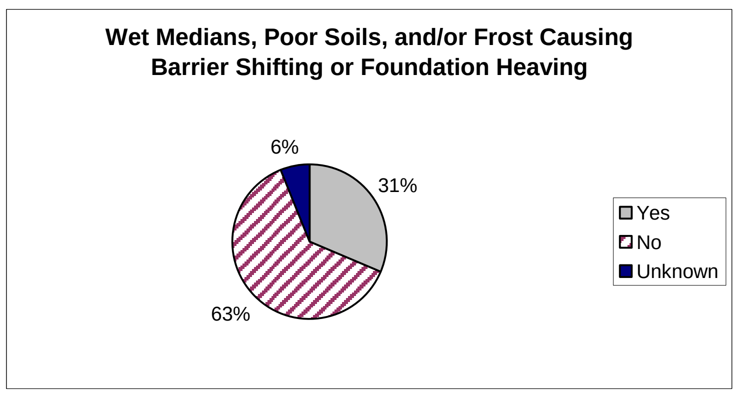
Question 6: Was any cracking, spalling, break-offs, etc. observed in the concrete sockets installed in your section?

	Frequency	%
Yes	24	75.0
No	2	6.3
Unknown	6	18.8
Total	32	100.0



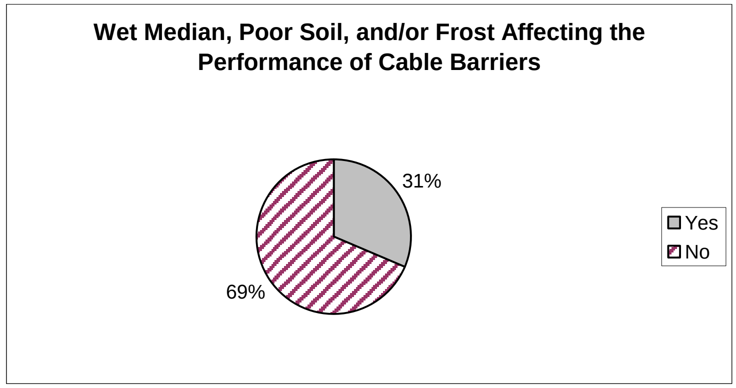
Question 7: Have wet medians, poor soils, and/or frost resulting in barrier shifting or foundation heaving in your maintenance section?

	Frequency	%
Yes	10	31.3
No	20	62.5
Unknown	2	6.3
Total	32	100.0



7B: Has this affected the performance of the cable barriers?

	Frequency	%
Yes	10	31.3
No	22	68.8
Total	32	100



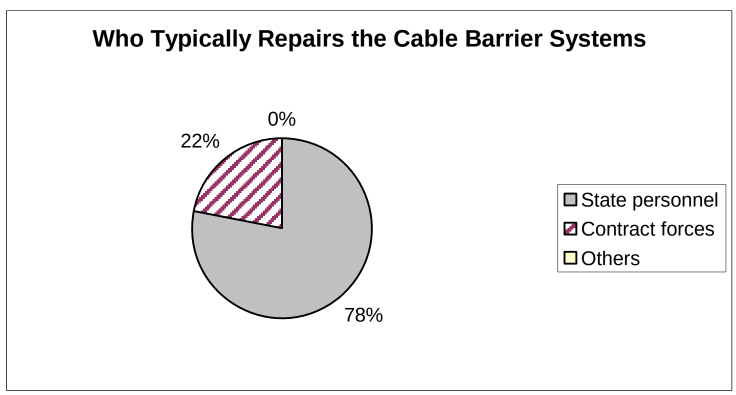
Question 8: Approximately how many cases of re-hit on a damaged barrier have you had?

Re-hit Cases	Frequency
Unknown	10
None	6
N/A	1
0	3
1	3
2	3
3	1
4	1
5	1
9	1
20	1
25	1
Total	75

**** Total known cases of re-hit on a damaged barrier = 75 ****

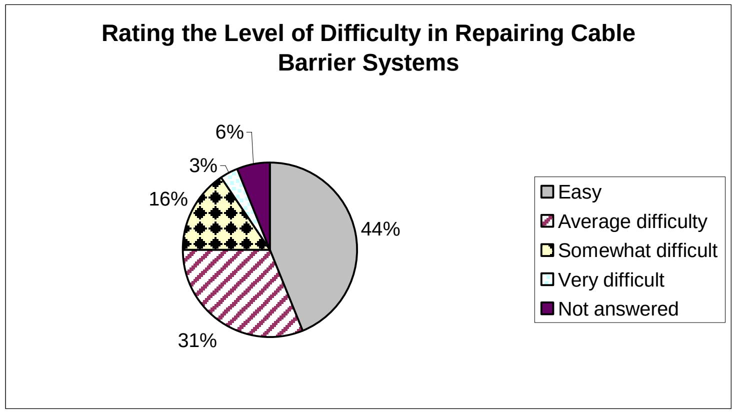
Question 9: Who typically repairs the cable barrier systems in your maintenance section?

	Frequency	%
State personnel	25	78.1
Contract forces	7	21.9
Others	0	0.0
Total	32	100.0



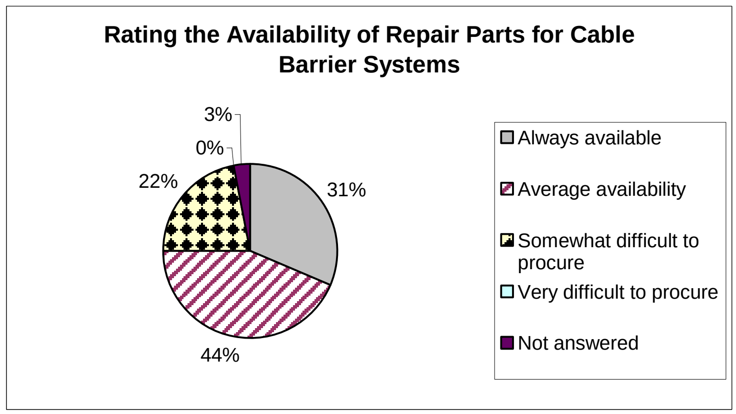
Question 10: How would you rate the level of difficulty in repairing the cable barrier systems?

	Frequency	%
Easy	14	43.8
Average difficulty	10	31.3
Somewhat difficult	5	15.6
Very difficult	1	3.1
Not answered	2	6.3
Total	32	100.0



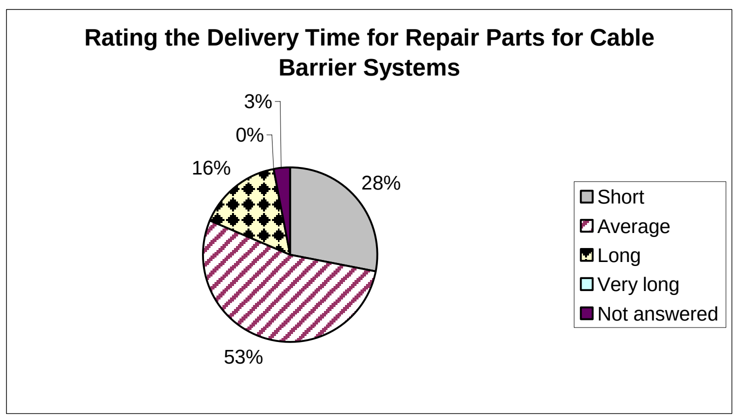
Question 11: How would you rate the availability of repair parts for the cable barrier systems?

	Frequency	%
Always available	10	31.3
Average availability	14	43.8
Somewhat difficult to procure	7	21.9
Very difficult to procure	0	0.0
Not answered	1	3.1
Total	32	100.0



Question 12: How would you rate the delivery time for repair parts for cable barrier systems?

	Frequency	%
Short	9	28.1
Average	17	53.1
Long	5	15.6
Very long	0	0.0
Not answered	1	3.1
Total	32	100.0

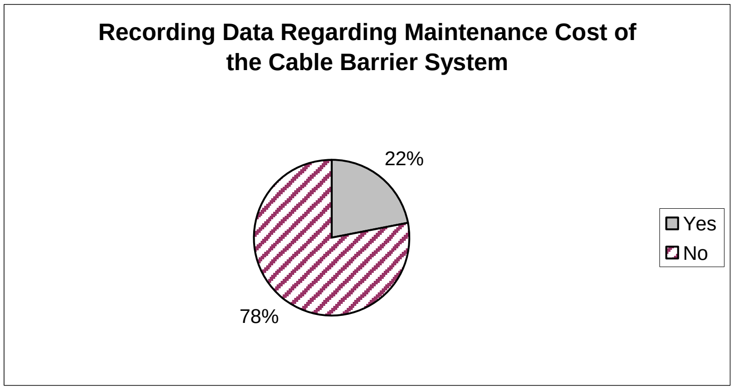


Question 13: Has your section recorded any data regarding maintenance cost of the cable barrier system (i.e., cost per mile per year)?

	Frequency	%
Yes	7	21.9
No	25	78.1
Total	32	100

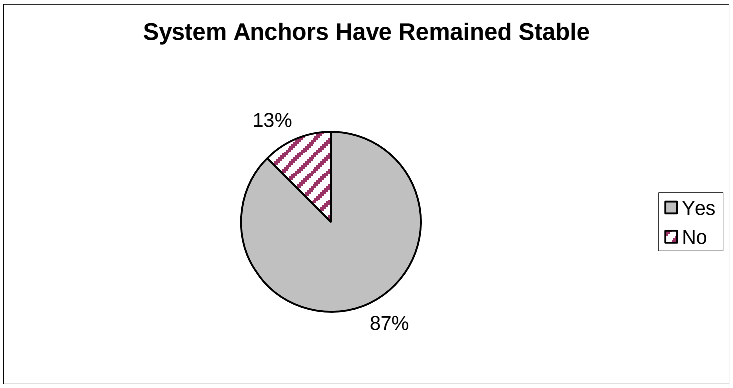
Yes - Reported Values

1	$8,370
2	$7,122
3	$10,000
4	Ongoing
5	Pull records
6	$22,334
7	$227



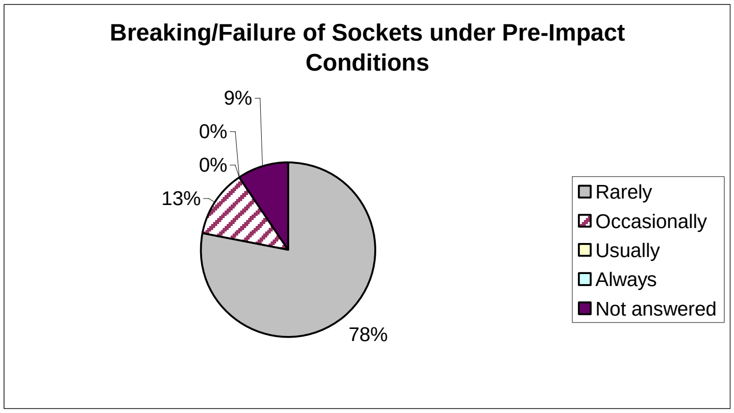
Question 14: Have the system anchors remained stable for the cable barrier systems used in your maintenance section?

	Frequency	%
Yes	28	87.5
No	4	12.5
Total	32	100



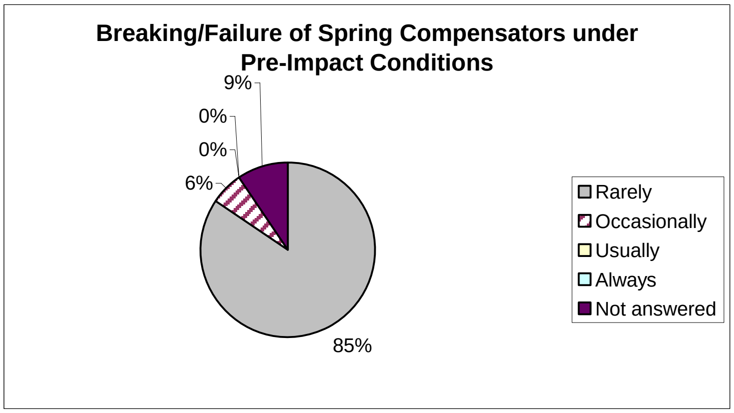
Question 15: Do you experience breaking/failure of sockets under pre-impact conditions (for example due to water expansion in socket, cable tension on curves, etc.)?

	Frequency	%
Rarely	25	78.1
Occasionally	4	12.5
Usually	0	0.0
Always	0	0.0
Not answered	3	9.4
Total	32	100.0



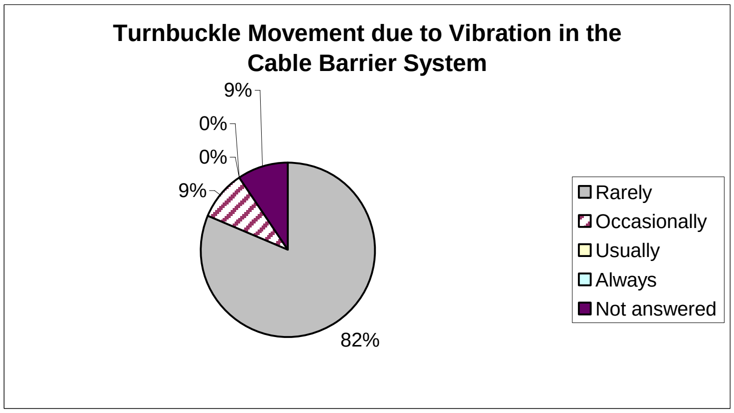
Question 16: Do you experience breaking/failure of spring compensators under pre-impact conditions?

	Frequency	%
Rarely	27	84.4
Occasionally	2	6.3
Usually	0	0.0
Always	0	0.0
Not answered	3	9.4
Total	32	100.0



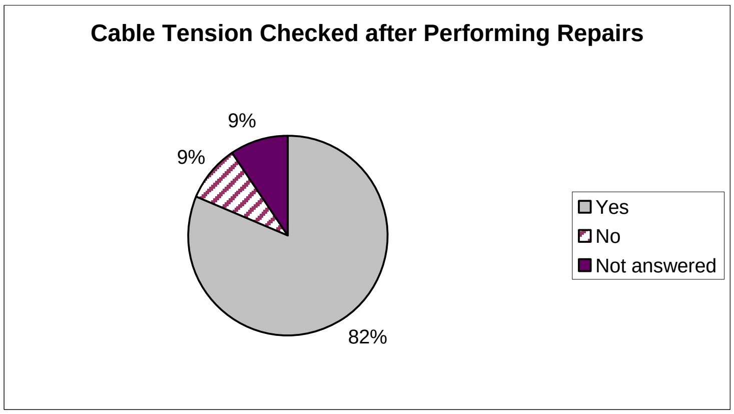
Question 17: Do you experience turnbuckle movement (due to vibration) in the cable barrier systems?

	Frequency	%
Rarely	26	81.3
Occasionally	3	9.4
Usually	0	0.0
Always	0	0.0
Not answered	3	9.4
Total	32	100.0



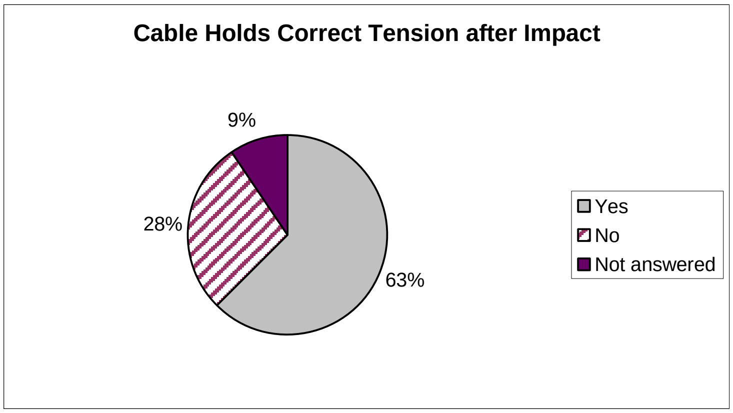
Question 18: Is the cable tension checked after performing any repairs?

	Frequency	%
Yes	26	81.3
No	3	9.4
Not answered	3	9.4
Total	32	100.0



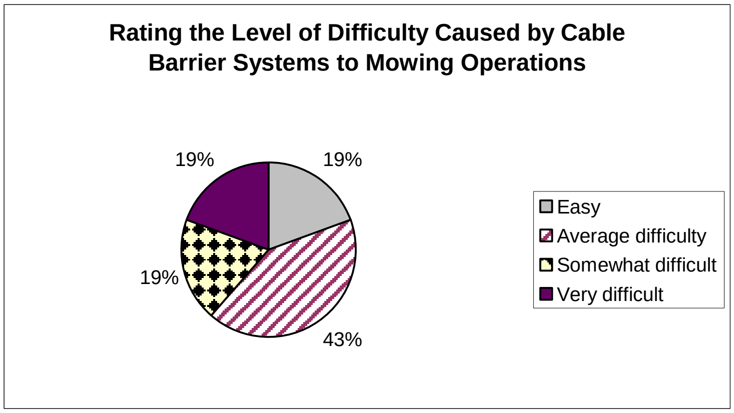
Question 19: Does the cable hold correct tension after an impact from an errant vehicle?

	Frequency	%
Yes	20	62.5
No	9	28.1
Not answered	3	9.4
Total	32	100.0



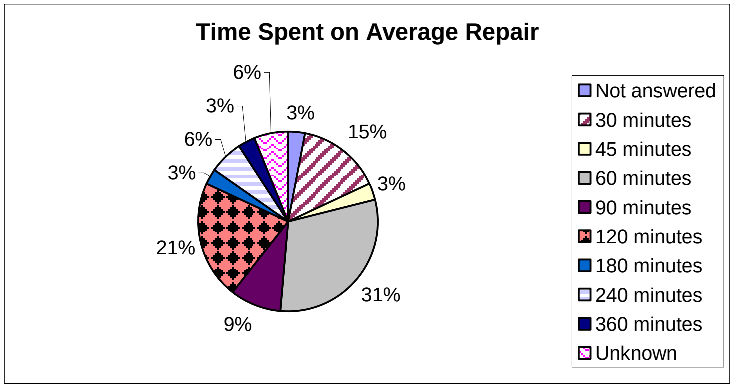
Question 20: Compared to other barriers, how would you rate the level of difficulty caused by the cable barrier systems to mowing operations?

	Frequency	%
Easy	6	18.8
Average difficulty	13	40.6
Somewhat difficult	6	18.8
Very difficult	6	18.8
Not answered	1	3.1
Total	32	100.0



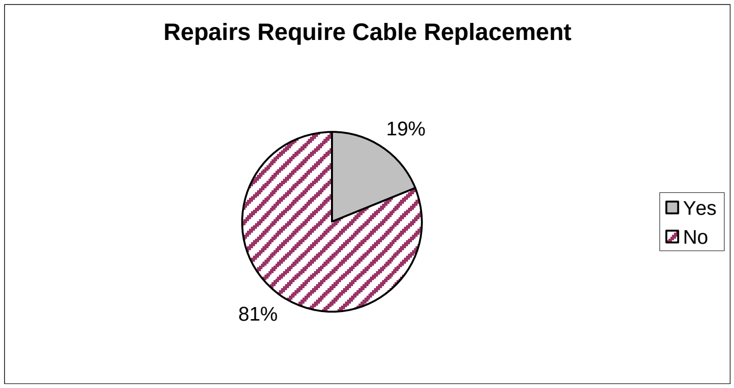
Question 21: How much time is spent on-site for an average level of repair?

	Frequency	%
Not answered	1	3.0
30 minutes	5	15.2
45 minutes	1	3.0
60 minutes	10	30.3
90 minutes	3	9.1
120 minutes	7	21.2
180 minutes	1	3.0
240 minutes	2	6.1
360 minutes	1	3.0
Unknown	2	6.1
Total	33	100.0



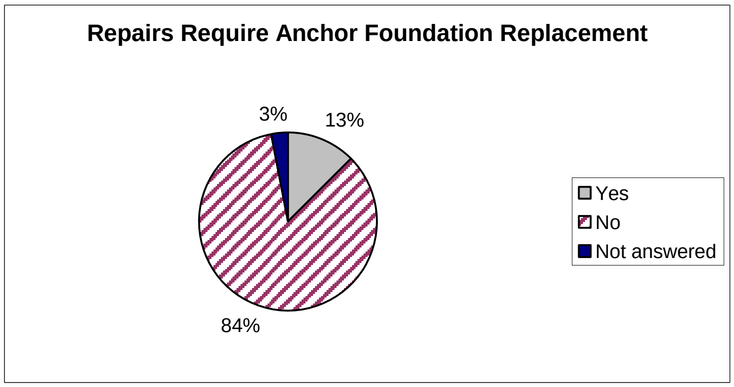
Question 22: Have any repairs required cable replacements?

	Frequency	%
Yes	6	18.8
No	26	81.3
Total	32	100.0
How many?	9	



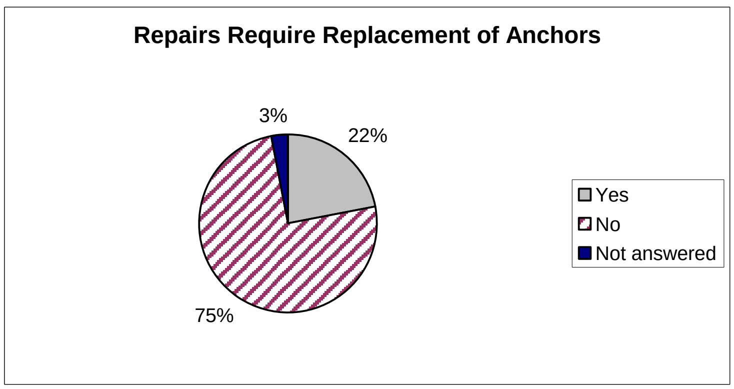
Question 23: Have any repairs required replacement of anchor foundations?

	Frequency	%
Yes	4	12.5
No	27	84.4
Not answered	1	3.1
Total	32	100.0
How many?	5	



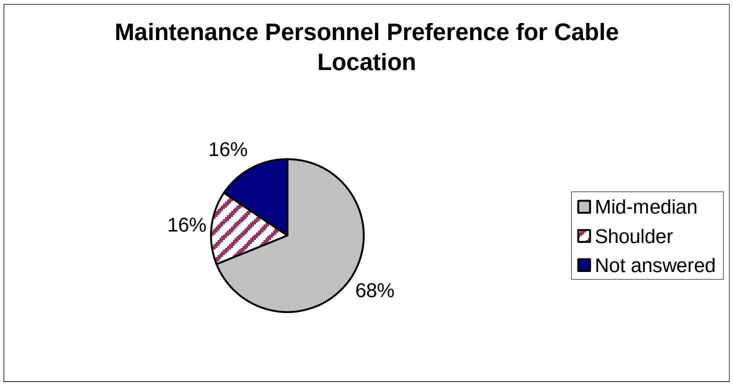
Question 24: Have any repairs required replacement of anchors?

	Frequency	%
Yes	7	21.9
No	24	75.0
Not answered	1	3.1
Total	32	100.0
How many?	12	



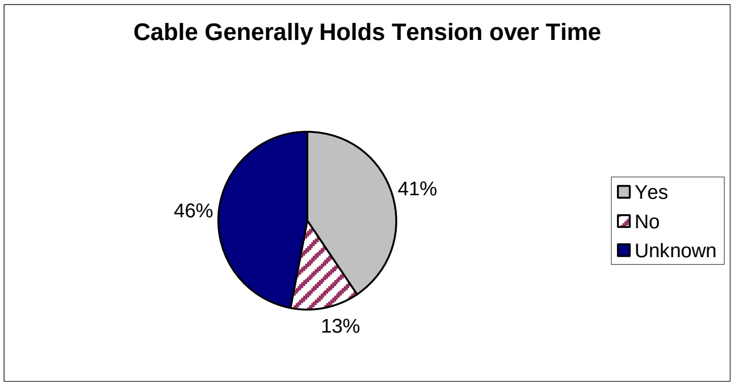
Question 25: Do maintenance personnel prefer working on a mid-median installation or a shoulder installation?

	Frequency	%
Mid-median	22	68.8
Shoulder	5	15.6
Not answered	5	15.6
Total	32	100.0



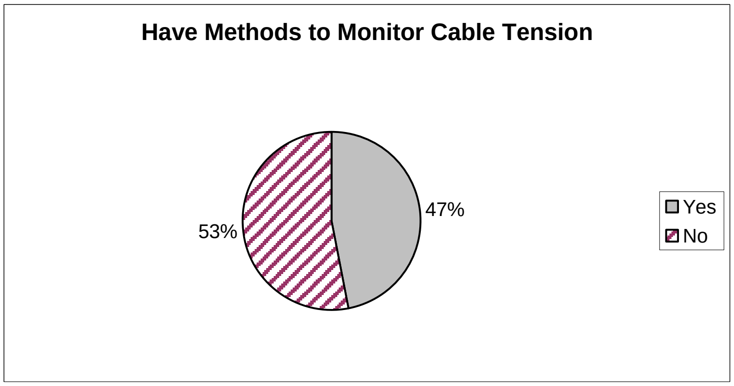
Question 26: Does the cable generally hold specified tension over time?

	Frequency	%
Yes	13	40.6
No	4	12.5
Unknown	15	46.9
Total	32	100.0



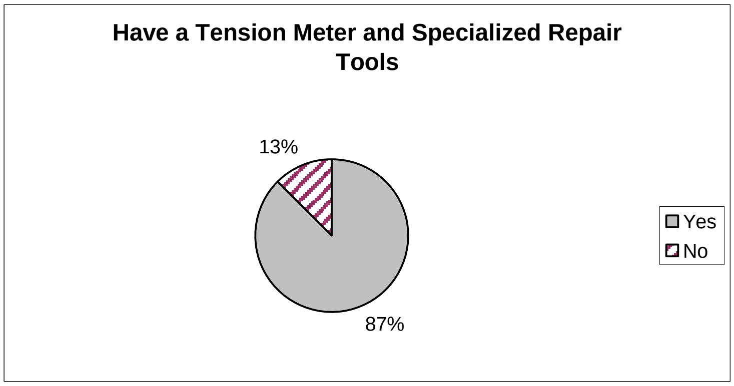
Question 27: Do you have any methods/procedures in place to monitor cable tension for installed barriers over time?

	Frequency	%
Yes	15	46.9
No	17	53.1
Total	32	100



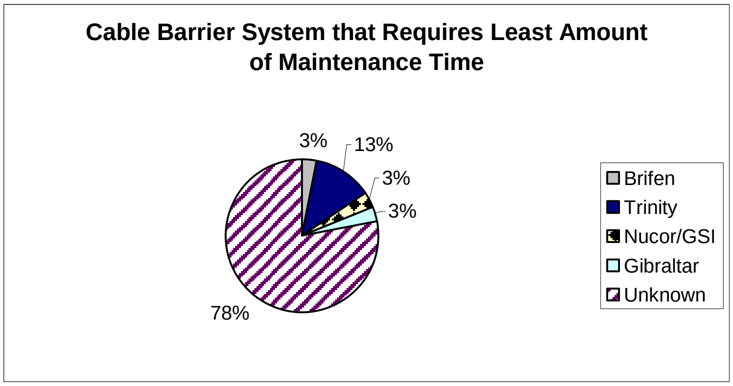
Question 28: Does your maintenance section have a tension meter and other specialized tools necessary for repairs?

	Frequency	%
Yes	28	87.5
No	4	12.5
Total	32	100



Question 29: Which cable barrier system requires the least amount of maintenance time?

	Frequency	%
Brifen	1	3.1
Trinity	4	12.5
Nucor/GSI	1	3.1
Gibraltar	1	3.1
Unknown	25	78.1
Total	32	100.0

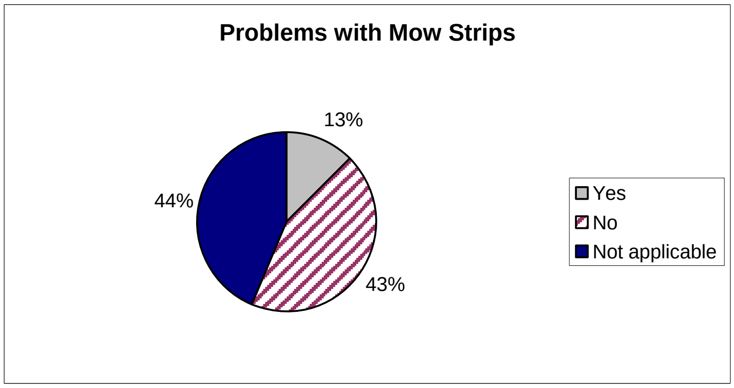


Question 30: Has your maintenance section encountered any problems with the installation of mow strips (if used)?

	Frequency	%
Yes	4	12.5
No	14	43.8
Not applicable	14	43.8
Total	32	100.0

Problems:

1) Installed 2-foot and should have been 3-foot
2) Herbicide, mowing and weedeating from contractors
3) Undesirable vegetation



Question 31: Please describe any difficulties that your maintenance section has encountered with the installation of cable barriers?

1) Broke off posts are hard to remove, cable twisting on post, being able to pull cable up or down to attach to post due to contour of terrain and tension on cable
2) Come-a-longs appear to be inefficient
3) When we had to replace an anchor it was somewhat difficult to find something that could safely stretch the cable, but we were able to find something suitable
4) All repairs are completed through contract
5) Improper installation by the contractor
6) Location of cable barrier is too close to the roadway
7) Need more training for more personnel
8) Not able to work in center median as easily as before
9) The anchors are moving and several have pulled out of the ground
10) Time consuming because of hits on a regular basis
11) We only perform repairs
12) The mow strip is too close to main lane of traffic. When we mow the center median, we have to furnish the contractor 2 truck-mounted attenuators, due to the mowers in the lane of traffic. I believe that they should have been closer to the center of the ditch and not 6 foot off the edge or they should be on the edge.
13) Installations have been completed through contracts
14) Mowing
15) Manual work invites finger-pinching maneuvers
16) Not a one man job as described, areas on curves make it difficult to pull cable

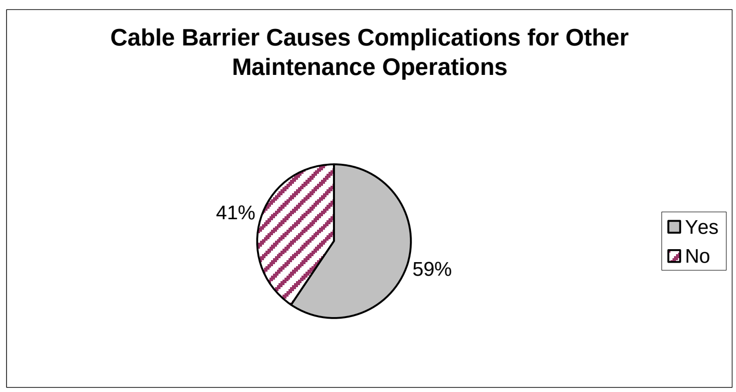
Question 32: How has maintenance personnel trained to repair cable barrier systems?

Manufacturer training -
Contractor training -
On-the-job training -
Video -

Question 33: Does the cable barrier system cause complications for other maintenance operations?

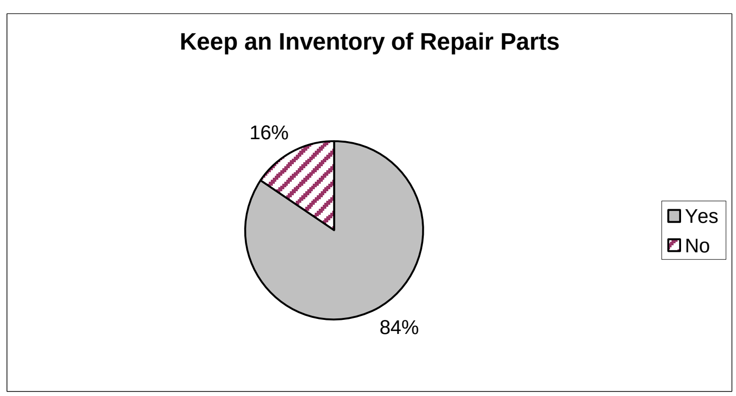
	Frequency	%
Yes	19	59.4
No	13	40.6
Total	32	100

List of Complications:	
Mowing, weedeating	11
Complicated ditch work procedures	1
Repairing potholes next to shoulder	1
Mow strips are too narrow	1
Traffic control for emergency responders	1
Continual hits cause extra work	1
Not having crossovers makes winter difficult	1



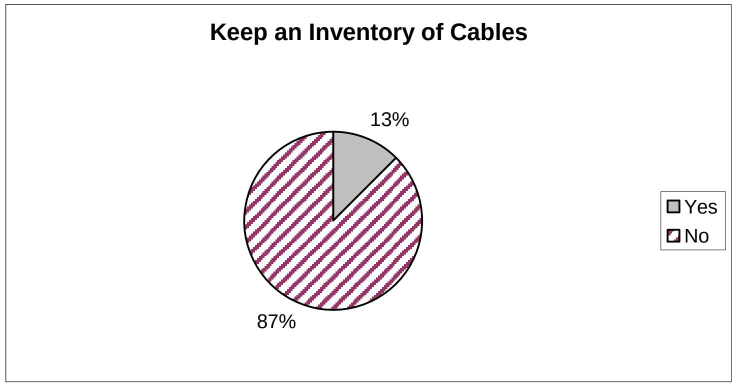
Question 34: Do you keep an inventory of repair parts?

	Frequency	%
Yes	27	84.4
No	5	15.6
Total	32	100



34A: Cables?

	Frequency	%
Yes	4	12.5
No	28	87.5
Total	32	100

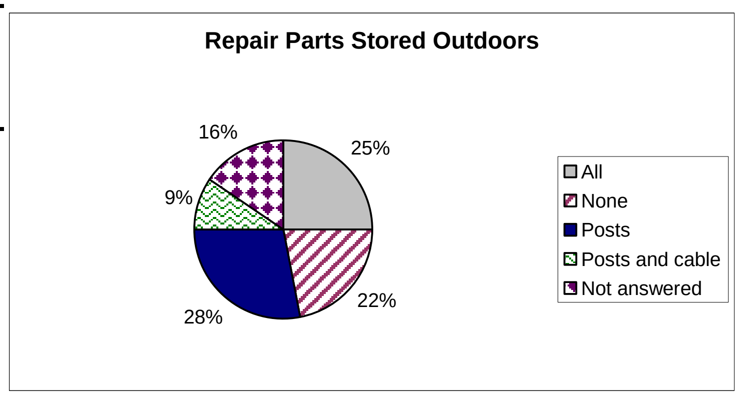


34B: What is your procedure for estimating the inventory of parts to maintain?

1) Keep enough parts to fix a major impact promptly
2) Parts to repair line post
3) Average use of supplies
4) We usually keep 100 posts, clamps, etc. in stock, not really a procedure but has worked so far
5) Inventory is based on repair information gathered during a 90 day period
6) Based on other maintenance sections prior experience
7) Number of hits over time factoring delivery time
8) Past history
9) What was used in the average first hit
10) No procedure yet, just getting started
11) We keep 1 complete part kit plus around 100 post with various parts at all time
12) Varies according to amount of hits
13) We order parts through our warehouse
14) Based on the average number of hits we have had per week and over time
15) Don't have one until we get a history of the hit. We were doing by just cross over history
16) Estimate the parts needed for a weeks worth of repairs then maintain a months supply
17) History of hits
18) Depends on the frequency of repairs
19) Based on average parts needed on previous repairs
20) We order parts when we get close to running out
21) Based on usage
22) Rate of usage
23) Parts, that are keep in stock and inventoried once a month
24) We only keep posts based on an average repair, keep a minimum number in stock. All other repairs are contracted
25) Reorder at 75 to keep 75 on hand always
26) Recent accident history
27) History of hits

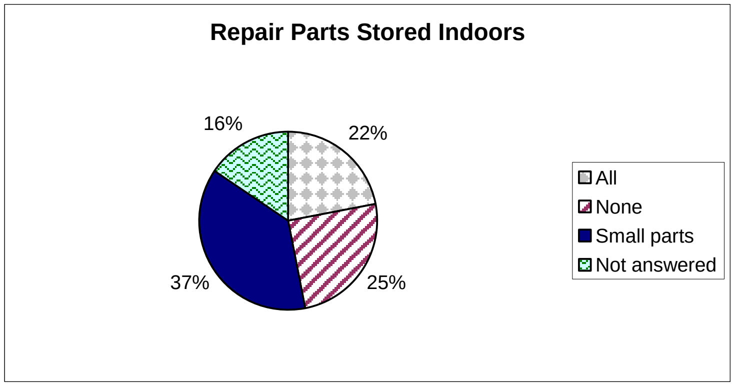
34D: Which repair parts are stored outdoors?

	Frequency	%
All	8	25.0
None	7	21.9
Posts	9	28.1
Posts and cable	3	9.4
Not answered	5	15.6
Total	32	100.0



34E: Which repair parts are stored indoors?

	Frequency	%
All	7	21.9
None	8	25.0
Small parts	12	37.5
Not answered	5	15.6
Total	32	100.0

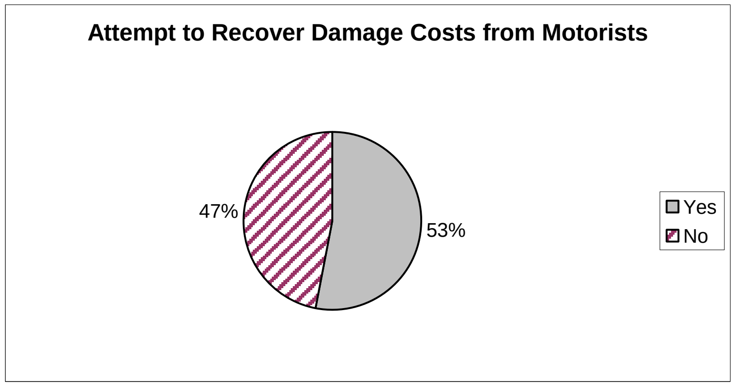


Question 35: Has there been any attempt to recover costs of barrier damage and/or repair costs from motorists who cause the damage?

	Frequency	%
Yes	17	53.1
No	15	46.9
Total	32	100

35b: Explain

1) Open damage claims from police reports
2) Complete a 4-10 account
3) When responsible party information is available



APPENDIX D

District Evaluation of Cable Barrier Safety Bond Projects

						One Year Pre-Installation		One Year Post Installation		Comments
Dist	HWY	Project Limits	CSJ	Month Let	Project #	Cross-Median Fatal Crashes	Cross-Median Fatalities	Cross-Median Fatal Crashes	Cross-Median Fatalities	
ATL	IH 30	SH 98 TO ARKANSAS STATE LINE	0610-06-074 etc.	July-05	STP 2005(402)SFT	1	1	0	0	
ATL	IH 20	GREGG COUNTY LINE TO .2 MILES W OF FM 31	0495-08-083 etc.	July-05	STP 2005(401)SFT	2	2	0	0	
ATL	IH 20	.2 MILES W OF FM 31 TO LOUISIANA STATE LINE	0495-10-076	July-05	STP 2005(401)SFT	2	3	0	0	
ATL	IH 30	FRANKLIN COUNTY LINE TO MORRIS COUNTY LINE	0610-03-074	July-05	STP 2005(402)SFT	2	2	0	0	
AUS	LP 1	.1 MILES N OF FH 734 TO RM 2222 (SECTIONS EXEMPTED)	3136-01-142	August-05	STP 2005(845)SFT	0	0	N/A	N/A	Completed May 2006
AUS	US 183	.1 MILES N OF LP 360 TO .3 MILES N OF FM 1325 (SE)	0151-06-126	August-05	STP 2005(845)SFT	0	0	N/A	N/A	Completed May 2006
BRY	IH 45	SH 30 TO MONTGOMERY COUNTY LINE	0675-07-080	December-05	STP 2006(092)SFT	0	0	N/A	N/A	Under Construction
CRP	US 181	SOUTH Y BEEVILLE TO WALTON ST	0101-01-062	June-05	STP 2005(444)SFT	0	0	0	0	
DAL	US 75	GRAYSON COUNTY LINE TO US 380	0047-14-061	November-05	STP 2006(031)SFT	1	1	N/A	N/A	Completed February 2007
DAL	IH 35 W	TARRANT COUNTY LINE TO IH 35E	0081-13-043	March-06	STP 2006(365)SFT	0	0	N/A	N/A	Under Construction
DAL	IH 45	NAVARRO COUNTY LINE TO DALLAS COUNTY LINE	0092-05-045 etc.	January-06	STP 2006(094)SFT	1	1	N/A	N/A	Completed February 2007
DAL	US 175	DALLAS COUNTY LINE TO FM 148	0197-03-059	April-06	SFT 197-3-59	0	0	N/A	N/A	Under Construction
DAL	US 175	FM 2860 TO .6 MILES E OF SH 274	0197-05-049	April-06	SFT 197-5-49	0	0	N/A	N/A	Under Construction
DAL	US 175	E OF SH 274 TO LACY CREEK BRIDGE	0197-05-050	April-06	SFT 197-5-50	0	0	N/A	N/A	Under Construction
DAL	US 80	.4 MILES E OF FM 688 TO SP 557	0095-04-062	April-06	SFT 95-4-62	0	0	N/A	N/A	Under Construction
DAL	IH 20	SP 557 TO FM 429	0495-01-051	April-06	SFT 495-1-51	0	0	N/A	N/A	Under Construction
DAL	IH 20	FM 429 TO VAN ZANDT COUNTY LINE	0495-01-052	April-06	SFT 495-1-52	0	0	N/A	N/A	Under Construction
DAL	IH 20	FM 1641 TO SP 557	0095-14-018	April-06	SFT 95-14-18	0	0	N/A	N/A	Under Construction
DAL	IH 45	FREESTONE COUNTY LINE TO CHAMBERS CREEK	0166-01-044 etc.	June-05	STP 2005(457)SFT	0	0	0	0	
DAL	IH 30	SH 205 TO HUNT COUNTY LINE	0009-12-204	January-06	STP 2006(093)SFT	2	2	0	0	
ELP	IH 10	NEW MEXICO STATE LINE TO LP 375	2121-01-069	July-05	STP 2005(716)SFT	0	0	0	0	
ELP	IH 10	FM 659 TO FM 1281	2121-04-075	July-05	STP 2005(716)SFT	0	0	0	0	
ELP	US 54	HONDO PASS TO SUN VALLEY	0167-01-096	July-05	STP 2005(716)SFT	0	0	0	0	
FTW	IH 20	SP 312 TO FM 1884	0314-07-032	July-05	STP 2005(792)SFT	0	0	0	0	
FTW	IH 35 W	BNSF RAILROAD OVERPASS TO SH 174 OVERPASS	0014-03-083	February-06	SFT 14-3-83	3	3	0	0	
FTW	IH 35 W	HILL COUNTY LINE TO SH 81 INTERCHANGE	0014-22-023	February-06	SFT 14-22-23	0	0	0	0	
FTW	IH 35 W	NE 28TH TO WESTERN CENTER	0014-16-250	August-06	SFT 14-16-250	0	0	N/A	N/A	Under Construction
FTW	IH 820	IH 30 TO LAKE WORTH BRIDGE	0008-15-038	August-06	SFT 8-15-38	0	0	N/A	N/A	Under Construction
FTW	IH 35 W	WESTERN CENTER TO US 287	0014-16-251	August-06	SFT 14-16-251	0	0	N/A	N/A	Under Construction
FTW	IH 820	LAKE WORTH BRIDGE TO IH 35W	0008-14-104	August-06	SFT 8-14-104	0	0	N/A	N/A	Under Construction
FTW	IH 35 W	US 287 TO DENTON COUNTY LINE	0081-12-040	August-06	SFT 81-12-40	0	0	N/A	N/A	Under Construction
FTW	IH 820	PIPELINE RD TO SH 10	0008-13-204	August-06	SFT 8-13-204	2	2	N/A	N/A	Under Construction
FTW	IH 820	SH 121 TO RANDOL MILL RD	0008-13-203	August-06	SFT 8-13-203	0	0	N/A	N/A	Under Construction
FTW	IH 820	SH 180 TO WILBARGER RD	0008-13-205	August-05	STP 2005(854)STP	1	1	0	0	
FTW	IH 820	IH 20 TO IH 30	0008-15-037	August-05	STP 2005(854)STP	2	2	0	0	
FTW	IH 20	IH 20/820 INTERCHANGE TO .5 MILES W OF HULEN ST	0008-16-034	August-05	STP 2005(854)STP	0	0	0	0	
LRD	IH 35	US 83 TO 1 MILE N OF US 83	0018-05-066	September-06	SFT 18-5-66	0	0	N/A	N/A	Under Construction
SAT	IH 37	3 MILES W OF US 281 TO 5 MILES W OF US 281	0073-05-063	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	US 281	.6 MILES S OF FM 1470 TO .9 MILES S OF FM 1470	0073-03-056	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	SH 16	TIMBER CREEK TO WAXWING RD	0613-02-052	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	IH 35	.4 MILES W OF LP 353 TO .1 MILES E OF LP 353	0017-09-088	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	IH 10	1.3 MILES S OF BOERNE STAGE RD TO 3.1 MILES S OF SAME	0072-08-116	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	IH 10	1.7 MILES N OF SAN ANTONIO CITY LIMIT TO .7 MILES N OF SAME	0072-08-117	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	US 90	HUNT LN TO IH 410	0024-08-120	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	SH 16	.7 MILES N OF RANCH PKWY TO .3 MILES S OF SAME	0291-09-126	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	IH 37	1.2 MILES S OF PRIEST-MATHIS TO SOUTHTON RD	0073-09-028	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	IH 410	IH 35 TO VALLEY HI	0521-05-130	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	SH 16	.1 MILES N OF LP 1604 TO .1 MILES N OF SMITH RD	0613-01-054	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	**IH 10**	**KENDALL COUNTY LINE TO 1.3 MILES S OF BOERNE STAGE RD**	**0072-07-053**	**June-05**	**STP 2005(375)SFT**	**1**	**2**	**0**	**0**	
SAT	IH 35	SH 132 TO BENTON CITY RD	0017-03-059	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	US 281	COMAL COUNTY LINE TO MARSHALL RD	0253-04-133	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	IH 35	.5 MILES W OF MEDINA RIVER TO .1 MILES N OF IH 410	0017-02-066	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	IH 10	.3 MILES W OF IH 410 TO .2 MILES E OF FM 2538	0025-02-168	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	IH 410	.9 MILES E OF CHAVANEAUX RD TO SH 16	0521-05-131	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	US 90	MONTGOMERY RD TO .3 MILES E OF MEDIO CREEK	0024-07-051	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	LP 1604	BABCOCK RD TO REGENCY BLVD	2452-02-075	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	IH 10	1 MILE W OF FM 2438 TO FM 2438	0535-02-038	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	IH 10	CHAPARRAL TO .4 MILES E OF FM 775	0025-03-084	June-05	STP 2005(375)SFT	1	2	0	0	
SAT	IH 10	GREGORY FORD RD TO FM 1104	0535-02-039	June-05	STP 2005(375)SFT	1	1	0	0	
SAT	IH 10	.2 MILES E OF BS 123B TO .2 MILES E OF SH 123	0535-01-056	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	**IH 10**	**KERR COUNTY LINE TO .8 MILES E OF US 87**	**0142-15-022**	**June-05**	**STP 2005(375)SFT**	**3**	**5**	**0**	**0**	
SAT	IH 10	.7 MILES W OF SH 80 TO SAN MARCOS RIVER	0535-02-040	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	**IH 10**	**CIBOLO CREEK TO BEXAR COUNTY LINE**	**0072-06-067**	**June-05**	**STP 2005(375)SFT**	**0**	**0**	**0**	**0**	
SAT	IH 35	.2 MILES N OF FM 3352 TO .2 MILES S OF US 57	0017-06-077	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	IH 35	.6 MILES S OF SH 132 TO .5 MILES N OF SH 123	0017-05-087	June-05	STP 2005(375)SFT	0	0	0	0	
SAT	US 90	.2 MILES W OF CR 154 TO .3 MILES W OF CR 105	0024-05-087	June-05	STP 2005(375)SFT	0	0	0	0	
WAC	IH 35 E	IH 35W TO ELLIS COUNTY LINE	0048-09-027	October-05	STP 2005(953)SFT	0	0	N/A	N/A	Completed April 2006
WFS	US 82	.1 MILES E OF WICHITA COUNTY LINE TO 1.3 MILES E OF FM 2393 (VARY)	0044-02-075	January-06	STP 2006(186)SFT	0	0	N/A	N/A	Completed August 2006
WFS	US 70	DUGAN CREEK TO LP 145	0043-06-076	September-05	STP 2005(914)SFT	0	0	N/A	N/A	Completed May 2006
YKM	IH 10	GONZALES COUNTY LINE TO COLORADO COUNTY LINE	0535-06-040 etc.	June-05	STP 2005(349)SFT	3	3	0	0	
YKM	IH 10	CALDWELL COUNTY LINE TO FAYETTE COUNTY LINE	0535-04-029 etc.	June-05	STP 2005(349)SFT	3	3	1	1	
YKM	IH 10	FAYETTE COUNTY LINE TO AUSTIN COUNTY LINE	0535-08-074 etc.	June-05	STP 2005(349)SFT	16	16	0	0	
Totals						**47**	**52**	**1**	**1**	

APPENDIX E

Division Evaluation of Cable Barrier Projects Statewide

news

Texas Department of Transportation

125 E. 11th Street
Austin, Texas 78701-2483
(512) 463-8588 FAX (512) 463-9896

TxDOT's five goals: reduce congestion • enhance safety • expand economic opportunity • improve air quality • increase the value of transportation assets.

July 3, 2008

Traffic fatalities down in Texas

AUSTIN - In 2007, 96 fewer lives were lost on Texas roadways, resulting in a 2.7 percent decrease in the total number of traffic fatalities suffered in the state.

In recent years, TxDOT has provided hundreds of millions of dollars specifically targeted for transportation safety.

The 2004 Safety Bond Program funded 644 projects to widen narrow two-lane highways, to install dedicated left-turn lanes, to install median barriers and other important highway safety improvements. TxDOT's annual Highway Safety Improvement Program also funds hundreds of projects that improve highway safety for all public roads.

"Improving safety is our most important goal," said Amadeo Saenz, TxDOT's executive director. "This decrease in total traffic fatalities demonstrates that the major investments we have made in transportation safety are producing real and significant results for our citizens. Every life saved on our highways represents a real tragedy that Texas families have not had to endure. This is a major step forward."

TxDOT's Texas Traffic Safety Program also provides approximately $50 million per year to improve driver behavior by decreasing dangerous actions such as driving while intoxicated, increasing safety belt compliance, and enforcing speed limits.

"Making sure the public has the safest transportation system possible is at the center of everything we do," said Saenz. "It is extremely gratifying to see these positive results in part from our implementation of the Safety Bond Program. The ability to issue these bonds has allowed us to target high-risk locations and get projects on the ground faster."

The Safety Bond Program allows TxDOT to issue general obligation bonds secured by the state highway fund to accelerate transportation projects, with twenty percent of the bonds earmarked for safety projects.

"It is extremely encouraging to see the overall number of traffic fatalities decrease, especially considering how fast our state's population is increasing" Saenz said. "We have more drivers and vehicles than at any other time in our history."

In 2007, Texas had more than 20 million vehicles registered. The total number of motor vehicles registered in Texas during 2000 was 14.2 million.

As part of its efforts to make Texas highways as safe as possible, TxDOT has installed more than 400 miles of additional median cable barrier. These devices, designed to prevent head-on collisions when an errant vehicle crosses a median into oncoming traffic, prevented 18 fatalities and 26 serious injuries during the first year of their use in Texas.

- more -

The American Association of State Highway and Transportation Officials recently adopted a national goal to reduce the traffic fatalities by 1,000 per year. The Texas decrease in traffic fatalities for 2007 allows the state to contribute approximately 10 percent to this important national safety goal.

TxDOT also collects and analyzes crash data as part of its mission to improve transportation safety.

The 3,422 traffic fatalities suffered in Texas during 2007 means there is still work to do.

How to Stay Safe

- Buckle up.
- Obey speed limits.
- Don't drink and drive.
- Designate a driver.
- Call a cab.
- Spend the night where you are, if possible.

- 30 -

About the Texas Department of Transportation

The Texas Department of Transportation is responsible for maintaining nearly 80,000 miles of road and for supporting aviation, rail and public transportation across the state. TxDOT and its 15,000 employees strive to empower local leaders to solve local transportation problems, and to use new financial tools, including tolling and public-private partnerships, to reduce congestion and pave the way for future economic growth while enhancing safety, improving air quality and increasing the value of the state's transportation assets. Find out more at www.txdot.gov

For more Information call TxDOT's Government & Public Affairs Division at (512) 463 – 8588.

District	HWY	Cont-Sect.	Mileage	Begin Install Date	Before Fatal Crashes	Before Fatalities	Before Incap. Crashes	Before Incap. Injuries	End Install Date	After Period	Fatal Crashes	Fatalities	Incap. Crashes	Incap. Injuries
AMA	IH 27	0168-09	2.65	11/10/06	0	0	0	0	11/21/06	12/1/06 - 11/30/07	0	0	0	0
ATL	IH 20	0495-08	16.891	4/10/06	0	0	1	1	6/29/06	7/1/06 - 6/30/07	0	0	0	0
ATL	IH 20	0495-09	6.856	3/16/06	1	1	0	0	5/1/06	5/1/06 - 4/30/07	0	0	0	0
ATL	IH 20	0495-10	15.454	10/11/05	0	0	0	0	4/1/06	4/1/06 - 3/31/07	0	0	0	0
ATL	IH 30	0610-03	20.53	10/19/05	1	1	0	0	10/24/06	11/1/06 - 10/31/07	0	0	0	0
ATL	IH 30	0610-06	13.606	5/16/06	0	0	0	0	9/22/06	10/1/06 - 9/30/07	0	0	0	0
ATL	IH 30	0610-07	11.859	11/22/05	0	0	0	0	5/23/06	6/1/06 - 5/31/07	0	0	0	0
AUS	US 183	0151-06	1.6	9/24/05	0	0	0	0	5/23/06	6/1/06 - 5/31/07	0	0	0	0
AUS	LP 1	3136-01	7	9/24/05	0	0	0	0	5/23/06	6/1/06 - 5/31/07	0	0	0	0
BMT	US 69	0200-11	2.209	1/30/06	0	0	0	0	6/2/06	6/1/06 - 5/31/07	0	0	0	0
BMT	US 69	0200-14	0.227	1/30/06	0	0	0	0	6/2/06	6/1/06 - 5/31/07	0	0	0	0
BMT	US 69	0200-14	5.337	7/19/04	0	0	0	0	9/24/04	10/1/04 - 09/30/05	0	0	0	0
BMT	IH 10	0028-11	5.077	2/28/05	0	0	0	0	7/18/05	8/1/05 - 7/31/06	0	0	0	0
CRP	US 181	0101-01	6.347	8/22/05	0	0	0	0	12/7/05	12/1/05 - 11/30/06	0	0	0	0
DAL	IH 45	0166-01	5.986	11/7/05	0	0	0	0	8/11/06	9/1/06 - 8/31/07	0	0	0	0
DAL	IH 45	0093-01	9.768	11/7/05	0	0	0	0	8/11/06	9/1/06 - 8/31/07	0	0	0	0
DAL	IH 45	0092-06	4.837	11/7/05	0	0	1	1	8/11/06	9/1/06 - 8/31/07	0	0	0	0
DAL	IH 30	0009-12	10.606	4/6/06	1	1	0	0	12/11/06	1/1/07 - 12/31/07	0	0	0	0
ELP	IH 10	2121-01	6	8/31/05	0	0	0	0	6/2/06	6/1/06 - 5/31/07	0	0	0	0
ELP	IH 10	2121-03	1.013	8/31/05	0	0	0	0	6/2/06	6/1/06 - 5/31/07	0	0	0	0
ELP	IH 10	2121-04	5.687	8/31/05	1	1	0	1	6/2/06	6/1/06 - 5/31/07	0	0	0	0
ELP	US 54	0167-01	3	8/31/05	0	0	0	0	6/2/06	6/1/06 - 5/31/07	0	0	0	0
FTW	IH20	0008-16	4.39	1/13/06	0	0	0	0	4/11/06	5/1/06 - 4/30/07	0	0	0	0
FTW	IH820	0008-15	3.165	1/13/06	0	0	0	0	4/11/06	5/1/06 - 4/30/07	0	0	0	0
FTW	IH820	0008-13	3.266	1/13/06	0	0	0	0	4/11/06	5/1/06 - 4/30/07	0	0	0	0
FTW	IH20	0314-07	4.937	10/18/05	0	0	0	0	2/9/06	2/1/06 - 1/31/07	0	0	0	0
FTW	IH30	1068-01	2.058	11/9/04	0	0	0	0	7/20/05	8/1/05 - 7/31/06	0	0	0	0
FTW	IH30	1068-05	1.138	11/9/04	0	0	0	0	7/20/05	8/1/05 - 7/31/06	0	0	0	0
FTW	IH20	0008-03	7.035	11/9/04	3	4	0	0	7/20/05	8/1/05 - 7/31/06	0	0	0	0
FTW	IH20	0314-07	7.41	11/9/04	0	0	2	5	7/20/05	8/1/05 - 7/31/06	0	0	0	0
FTW	SH360	2266-02	3.422	11/10/04	0	0	0	0	1/22/07	2/1/07 - 1/31/08	0	0	0	0
SAT	IH 37	0073-05	2	4/24/06	0	0	0	0	10/19/06	11/1/06 - 10/31/07	0	0	0	0
SAT	SH 16	0613-02	0.4	4/3/06	0	0	0	0	10/9/06	10/1/06 - 9/30/07	0	0	0	0
SAT	US 281	0073-03	0.3	4/4/06	0	0	0	0	10/13/06	11/1/06 - 10/31/07	0	0	0	0
SAT	IH 10	0072-07	7.4	9/7/05	1	1	2	7	6/29/06	7/1/06 - 6/30/07	0	0	0	0
SAT	IH 10	0072-08	1.8	9/7/05	0	0	0	0	6/29/06	7/1/06 - 6/30/07	0	0	0	0
SAT	IH 10	0072-08	1	9/7/05	1	2	0	0	6/29/06	7/1/06 - 6/30/07	0	0	0	0
SAT	IH 10	0025-02	13	5/3/06	0	0	1	1	11/3/06	11/1/06 - 10/31/07	0	0	0	0
SAT	IH 35	0017-02	3.3	12/20/05	1	2	0	0	8/17/06	9/1/06 - 8/31/07	0	0	0	0
SAT	IH 35	0017-03	8.5	12/20/05	1	3	1	3	8/17/06	9/1/06 - 8/31/07	0	0	0	0
SAT	IH 35	0017-09	0.5	12/20/05	0	0	0	0	8/17/06	9/1/06 - 8/31/07	0	0	0	0
SAT	IH 37	0073-09	8.6	4/5/06	0	0	0	0	10/18/06	11/1/06 - 10/31/07	0	0	0	0
SAT	IH 410	0521-05	4.9	2/20/06	0	0	1	1	9/5/06	9/1/06 - 8/31/07	0	0	0	0
SAT	IH 410	0521-05	4.4	4/28/06	0	0	0	0	10/30/06	11/1/06 - 10/31/07	0	0	0	0
SAT	LP 1604	2452-02	1.4	11/10/05	0	0	0	0	7/11/06	8/1/06 - 7/31/07	0	0	0	0
SAT	SH 16	0291-09	1	11/16/05	0	0	0	0	8/7/06	8/1/06 - 7/31/07	0	0	0	0
SAT	SH 16	0613-01	1.8	3/30/06	0	0	0	0	10/6/06	10/1/06 - 9/30/07	0	0	0	0
SAT	US 281	0253-04	4.1	11/1/05	0	0	0	0	7/25/06	8/1/06 - 7/31/07	0	0	0	0
SAT	US 90	0024-07	4.8	3/1/06	0	0	0	0	9/20/06	10/1/06 - 9/30/07	0	0	0	0
SAT	US 90	0024-08	0.6	3/1/06	0	0	0	0	9/20/06	10/1/06 - 9/30/07	0	0	0	0
SAT	IH 35	0017-06	2.4	2/6/06	0	0	0	0	8/17/06	9/1/06 - 8/31/07	0	0	0	0
M	IH 10	0025-03	1.3	6/5/06	0	0	0	0	11/10/06	11/1/06 - 10/31/07	0	0	0	0
SAT	IH 10	0535-01	1.2	6/8/06	0	0	0	0	11/13/06	12/1/06 - 11/30/07	0	0	0	0
SAT	IH 10	0535-02	1	6/9/06	0	0	1	3	11/15/06	12/1/06 - 11/30/07	0	0	0	0
SAT	IH 10	0535-02	1.3	6/9/06	0	0	0	0	11/15/06	12/1/06 - 11/30/07	0	0	0	0
SAT	IH 10	0535-02	1.5	6/9/06	0	0	0	0	11/15/06	12/1/06 - 11/30/07	0	0	0	0
SAT	IH 10	0535-02	2.1	6/22/06	0	0	0	0	11/15/06	12/1/06 - 11/30/07	0	0	0	0
SAT	IH 10	0142-15	1.9	9/6/05	0	0	0	0	5/9/06	5/1/06 - 4/30/07	0	0	0	0
SAT	IH 10	0072-06	6.9	9/7/05	0	0	0	0	6/29/06	7/1/06 - 6/30/07	0	0	0	0
SAT	IH 35	0017-05	1.1	2/7/06	0	0	0	0	8/11/06	9/1/06 - 8/31/07	0	0	0	0
SAT	US 90	0024-05	3	3/20/06	0	0	0	0	10/3/06	10/1/06 - 9/30/07	0	0	0	0
WAC	IH35E	0048-09	7.91	1/11/06	0	0	0	0	4/18/06	5/1/06 - 4/30/07	0	0	0	0
WFS	IH 0035	0194-02	5.47	10/1/04	0	0	0	0	3/1/06	4/1/06 - 3/31/07	0	0	0	0
WFS	IH 0035	0195-01	12.949	10/1/04	0	0	0	0	3/1/06	4/1/06 - 3/31/07	0	0	0	0
WFS	US 82/277	0044-02	2.5	5/1/06	0	0	0	0	8/1/06	9/1/06 - 8/31/07	0	0	0	0
WFS	US 287	0043-06	1.761	1/6/06	1	1	0	0	4/17/06	5/1/06 - 4/30/07	0	0	0	0
YKM	IH 10	0535-04	10.546	9/13/05	0	0	0	0	5/1/06	5/1/06 - 4/30/07	0	0	0	0
YKM	IH 10	0535-05	11.59	9/13/05	1	1	1	3	5/1/06	5/1/06 - 4/30/07	0	0	0	0
YKM	IH 10	0535-06	11.303	9/13/05	0	0	0	0	9/29/06	10/1/06 - 9/30/07	0	0	0	0
YKM	IH 10	0535-07	11.492	9/13/05	0	0	0	0	9/29/06	10/1/06 - 9/30/07	1	1	0	1
YKM	IH 10	0535-08	17.614	9/13/05	0	0	0	0	9/29/06	10/1/06 - 9/30/07	0	0	0	0
YKM	IH 10	0271-01	14.447	9/13/05	0	0	0	0	9/29/06	10/1/06 - 9/30/07	0	0	0	0
YKM	IH 10	0271-02	6.878	9/13/05	1	1	0	1	9/29/06	10/1/06 - 9/30/07	0	0	0	0
			407.321		**14**	**19**	**11**	**27**			**1**	**1**	**0**	**1**

APPENDIX F

Guidance from Other States on Soil Conditions

ARIZONA DEPARTMENT OF TRANSPORTATION

http://www.azdot.gov/Highways/RdwyEng/RoadwayDesign/SpecialProvisions/Docs/HP905HTCBL High-TensionCableBarrier.doc

THIS RECOMMENDED SPECIAL PROVISION SHOULD BE USED IN CONJUNCTION WITH HIGH-TENSION MEDIAN CABLE BARRIER

(HP905HTCBL, 7/24/08)

SECTION 905 - GUARDRAIL:

ITEM 9050??? – MEDIAN CABLE BARRIER (HIGH TENSION):
ITEM 9050??? – MEDIAN CABLE BARRIER TERMINAL ASSEMBLY:

Description:

The work shall consist of installing Median Cable Barrier (High Tension) and Median Cable Barrier Terminal Assemblies, including all necessary excavation, backfill, shoulder build-up, compaction, materials, tools, equipment, and labor; and providing two (2) manufacturer-supported training sessions.

The cable barrier and terminal assemblies shall be installed at the locations shown on the project plans, and in accordance with the manufacturer's instructions, the plan details, and these specifications.

Definitions:

Run: Continuous section of median cable barrier from end-anchor to end-anchor, inclusive.

Segment: Length of cable barrier, including wire rope, delineation, line posts, post caps, sleeve covers, and cast-in-place line post foundations between terminal assemblies.

End-Anchor: Concrete foundation and cable attachment hardware at termini of each run.

Terminal Assembly: End-anchor, wire rope, delineation, non-line posts, and cast-in-place non-line post foundations at the beginning and end of each segment.

Materials:

The materials used shall meet the manufacturer's requirements and specifications for their NCHRP Report 350, TL-3 approved system. The system shall consist of 4 pre-stretched cables with maximum post spacing of 10 feet. Each cable shall be individually anchored.

Only a Median Cable Barrier system shown in Category V-4 on the Approved Products List of the Product Resource Investment Deployment and Evaluation (PRIDE) Program shall be installed. Line posts consisting of I-post design shall not be used. Post and end-anchor foundations shall be cast-in-place. Post sleeves shall be galvanized steel.

The cable shall be ¾ inch, 3 x 7, pre-stretched galvanized wire rope meeting the requirements of AASHTO Designation M 30/ ASTM Designation A 741, Type 1, Class A coating, having a Modified Breaking Strength equal to 39,000 pounds. The cables shall be pre-stretched to a minimum wire rope modulus of elasticity of 19,000,000 psi in accordance with ISO 12076-202 Wire Rope Modulus of Elasticity "Initial (as manufactured), with no bedding (or pre-stretching) of the rope permitted in testing.

Only swaged fittings shall be provided. Field-installed, galvanized-steel fittings (i.e., turnbuckles and splices) shall be one-inch diameter. Factory applied or stainless steel fittings shall be per the manufacturer's specifications. Fully fitted ropes shall develop a Minimum Breaking Load (MBL) of 36,800 pounds.

The manufacturer shall submit a *Certificate of Compliance* in accordance with Section 106.05(B) of the Standard Specifications.

Construction Requirements:

Prior to providing the cable barrier, the selected manufacturer shall thoroughly review the plans and, if appropriate, provide recommendations for adjusting the placement of the cable barrier based upon details of their specific system. This may include anchor locations, length of need adjustments, possible extension of bridge or roadway concrete median barrier, post type or spacing adjustments for roadway curvature, or post type or spacing adjustments for reduced dynamic deflection at locations shown on the plans. The project design engineer should be contacted at an early date for coordination of plan details and required adjustments needed prior to ordering the cable. The manufacturer shall provide special details as needed to assist in any required adjustments.

Training

The contractor shall sponsor and arrange for two (2) manufacturer-supported training sessions, the first during cable-barrier installation and the second before cable-barrier acceptance. Course content and materials (handouts and trainer's reference works) shall be certified by the manufacturer as appropriate for their system. The certification letter shall be presented to the Engineer a minimum of two weeks prior to holding the initial training session. An electronic version of the course materials shall be provided to the Engineer on the day of the training.

The Installation Training shall be held prior to the beginning of cable barrier construction; the proposed date shall be submitted to the Engineer a minimum of 30 calendar days prior to the training session date for review and approval. The training shall have the following participants:

- Prime Contractor's Field Superintendent, or designated representative(s);
- Cable Barrier Sub-Contractor's Field Supervisor, or designated representative(s);
- Engineer, or designated representative(s); and
- Construction inspector(s).

The training should be limited to twelve participants selected by the Engineer; the Engineer shall have final approval of participants. Every participant shall be provided with a complete set of course handouts, the manufacturer's installation manual, and the manufacturer's plans for the approved system. The training course and accompanying course material shall cover, at a minimum, the following subjects:

- Description and function of the system components;
- Sequence of construction operations;
- Manufacturer's instructions and specifications for the following:
    - End-anchor and post foundation installation , including, but not limited to foundation sizes, steel reinforcement, concrete design strength, curing time, concrete testing, and locations;
    - Terminal Assembly installation;
    - Cable Barrier system installation;
    - Cable tensioning;
- Discussion of critical tasks;
- Installation inspection; and
- Group quiz and review of answers.

The Maintenance Training shall be held a minimum of two days prior to acceptance of the system; the proposed date shall be submitted to the Engineer a minimum of 30 calendar days prior to the training session date for review and approval. The training shall have the following participants:

- District Maintenance Engineer, or designated representative(s);
- District Maintenance Superintendent, or designated representative(s);
- Maintenance contractor field supervisor, or designated representative(s);
- District maintenance personnel; and
- Maintenance contractor personnel.

The training should be limited to twenty participants selected by the Engineer; the Engineer shall have final approval of participants. Every participant shall be provided with a complete set of course handouts, the manufacturer's maintenance manual, and the manufacturer's plans for the approved system. The training course and accompanying course material shall cover, at a minimum, the following subjects:

- Description of the system components;
- Discussion of critical features;
- Inspection:
    - Median Cable Barrier;
    - Terminal Assembly;
- Median Cable Barrier component replacement;
- Terminal Assembly replacement;
- Cable tension monitoring and re-tensioning;
- Freeing captured vehicles;
- Field splicing of cable; and
- Group quiz and review of answers.

Site Conditions:

Final grading of the median shall be completed prior to beginning construction of the post foundations or end-anchors.

For end-anchor locations, the cable barrier manufacturer or vendor shall satisfy themselves that the soil conditions at the end-anchor locations provide the necessary strength to support their standard end anchor. If, based on a soils report supplied by the contractor (a copy of the soils report shall be sent to the Engineer), the manufacturer decides a modified end-anchor is required, four sets of shop drawings shall be submitted to the Engineer for review and approval a minimum of four weeks prior to beginning end-anchor construction.

Where the new system adjoins an existing, compatible system by the same manufacturer, the Engineer may direct the contractor to connect directly to the existing system. The plans shall be submitted to the Engineer for review and approval a minimum of four weeks before the beginning of median cable barrier installation.

Installation:

Installation of the median cable barrier system shall be in accordance with the manufacturer's instructions and specifications.

Tensioning:

Tensioning of the cables shall be in accordance with the manufacturer's instructions and specifications. Tension charts shall have a minimum range of 20º F to 180º F.

Cable tension shall be deemed acceptable when the following three conditions are met:

1. The entire system is initially tensioned to full compliance in accordance with the manufacturer’s specifications.
2. A minimum of 14 days after the initial tensioning, a second tensioning shall be done with successive tension measurements at every turnbuckle on each cable being adjusted to the manufacturer’s specifications.
3. The manufacturer certifies that the full cable system has been tensioned in accordance with their specifications and complies with the manufacturer's tension requirements.

Tension Log:

The manufacturer shall provide a recommended tension chart for their system with the base condition being a cable temperature of 70º F. The chart shall be indexed using cable temperature, in degrees Fahrenheit, as the independent variable and tension, in pounds (force), as the dependent variable. Tension measurements shall be taken in the vicinity of every turnbuckle on each cable within a segment as directed by the manufacturer.
(Required for systems not previously installed on Arizona State Highways)
The median cable barrier manufacturer shall provide one new, calibrated tension meter as part of the deliverables. The meter shall bear a serial number and be accompanied by a current Certificate of Calibration from a National Institute of Standards and Testing accredited laboratory. Said tension meter shall remain with the Engineer at project completion.

The contractor shall maintain a tension log showing project name, time and date, weather conditions, segment termini, cable temperature, tension measurement location, and actual tension reading. The person(s) performing the testing shall sign the tension log daily. The log, along with the manufacturer's recommended tension chart, shall be delivered to the Engineer prior to the cable barrier sub-contractor leaving the project.

Delineation:

Beginning with the first vertical post in each direction of a run, post-mounted delineators shall be spaced at intervals no greater than 40 feet on tangents and curves with a radius of 3500 feet or greater, and 20 feet on curves having a radius less than 3500 feet. Delineation shall be visible from both directions of traffic unless otherwise shown on the plans; delineators in each direction shall have a minimum reflective area of 12 square inches. Delineators shall conform to Standard Specifications Sections 703 and 1007 and be of the same sign sheeting requirement as warning signs.

Maintenance:

During the construction contract period, the contractor shall maintain the integrity of the installed system when adjacent lanes are open to traffic. Upon notice of a hit on the median cable barrier system, in the form of a telephone call, e-mail, or letter from the Engineer, the contractor shall mark the affected area within 8 hours. Vertical panels, Type II barricades, or cones may be used to mark the area. Knocked-over posts shall be replaced within 48 hours of contractor notification. If an end-anchor is struck and the cables disengaged, the system must be returned to operation within 12 hours. The contractor shall identify the responsible contact person for this activity to the Engineer at the beginning of the median cable barrier construction.

Method of Measurement:

Median Cable Barrier (High Tension) will be measured by the linear foot along the centerline of the line posts, to the nearest foot, for each segment length.

Median Cable Barrier Terminal Assembly will be measured by the unit each, including the end-anchor, wire rope, non-line posts, and non-line post foundations.

No measurement or direct payment will be made for the cost of the training sessions, the cost being considered incidental to the price for the Median Cable Barrier (High Tension) item.

No measurement or direct payment will be made for the cost of the soils report, the cost being considered incidental to the price for the Median Cable Barrier Terminal Assembly item.

No measurement or direct payment will be made for additional posts, footings and sleeves provided by the manufacturer to meet deflection criteria, curve spacing criteria or other special application criteria required by their system.

Basis of Payment:

The accepted quantities of Median Cable Barrier (High Tension), measured as provided above, will be paid for at the contract unit price per linear foot, complete-in-place, including installing all line posts with foundations and caps (when shown on manufacturer's plans), wire rope, fittings, delineation, excavation, backfill, compaction, shoulder build-up, materials, labor, equipment, manufacturer-supported trainings, and tension meters.

The accepted quantities of Median Cable Barrier Terminal Assembly, measured as provided above, will be paid for at the contract unit price per each, complete-in-place, including soils report, end-anchor, all non-line posts with foundations and caps (when shown on the manufacturer’s plans), wire rope, fittings, delineation, excavation, backfill, compaction, shoulder build-up, materials, labor, and equipment.

A Median Cable Barrier Terminal Assembly with a modified end-anchor shall be paid for at 1.2 times the bid price of a Median Cable Barrier Terminal Assembly.

HIGH TENSION CABLE BARRIER SYSTEM.

(REV 9-20-07)

Page 613. The following new Section is added after Section 538.

SECTION 540
HIGH TENSION CABLE BARRIER SYSTEM

540-1 Description.

Furnish and install pre-stretched, high tension cable barrier systems in accordance with the requirements of the Contract Documents and the manufacturer's recommendations.

Meet the NCHRP-350 Test Level 3 (TL-3) requirements for roadside barriers. Unless otherwise specified, install high tension cable barrier of the three or four rope type, capable of roadside or median installation.

Use only one manufacturer's cable barrier system for the entire Contract.

At least ten days prior to installation of the system, furnish the following information to the Engineer:

(a) Manufacturer's product brochure, specifications and requirements.

(b) Four sets of erection drawings that clearly depict the installation details for the proposed cable barrier system components, including terminals, terminal transitions, line posts, and cables.

(c) Copy of the NCHRP-350 certification/acceptance letter for the proposed cable barrier system.

(d) Draft copy of the proposed cable Tension Log (blank sample).

(e) Design calculations for the post and end terminal footings. The design of each end terminal footing is to be based on the following soil parameters:

1. Saturated unit weight of 112.4 pounds per cubic foot
2. Design water table at the ground surface
3. Effective unit weight of 50 pounds per cubic foot
4. Angle of internal friction of 30 degrees
5. Cohesion of 0
6. Factor of Safety against overturning or pullout of 1.5

For soils meeting the above properties, use a design soil modulus value (k) of 7 pounds per cubic inch (psi/inch depth) when using Terzaghi's passive wedge-type failure method or 25 pounds per cubic inch when using the p-y method (COM 624, FB-Pier, L-pile, etc.) to evaluate the lateral loading response of the end anchor pile or shaft.

Designs of end terminal footings and cable connection to the footings shall be based on either: 1) If all cables are anchored in a single footing, a minimum total equivalent horizontal static load of 50,000 pounds and the commensurate vertical component associated with the net cable angle from horizontal; or 2) If cables are anchored in multiple footings, a minimum equivalent horizontal static load of 15,000 pounds per cable and the commensurate vertical component associated with this force and each cable's angle from horizontal.

627-R-546 CABLE BARRIER SYSTEM

(Adopted 01-25-08)

The Standard Specifications are revised as follows:

SECTION 627, BEGIN LINE 1, INSERT AS FOLLOWS:

SECTION 627 – CABLE BARRIER SYSTEM

627.01 Description

This work shall consist of furnishing and installing a high-tension cable barrier system in accordance with 105.03.

627.02 General Requirements

The cable barrier system shall consist of four pre-stretched, individually anchored wire ropes in tension between safety terminals and held in position by intermediate line posts. The system shall be selected from the Department's list of approved Cable Barrier Systems. The Contractor shall use the selected system for the entire contract.

The Department will make geotechnical information available for the approximate locations of the safety terminals and representative locations of the intermediate line posts. The Contractor shall be responsible for obtaining any additional geotechnical information required by the cable barrier system manufacturer to complete design of line post and safety terminal foundations or other components of the system.

The Contractor shall provide the following to the Engineer a minimum of 14 days prior to installation of the system:

(a) A copy of the FHWA acceptance letter for the cable barrier system.

(b) Two copies of the manufacturer's product brochure, specifications and installation and maintenance manuals.

(c) Four copies of erection drawings clearly depicting installation details, including safety terminals, terminal transitions, intermediate line posts and cables.

(d) A copy of the design drawings and calculations for safety terminal and intermediate line post foundations for the soil conditions on the project. Design drawings and calculations shall be stamped by a professional engineer.

(e) Documentation that the Contractor's work force on the project has received training by the manufacturer in the proper installation of the system, including safety terminals, intermediate line posts, cables and tensioning of cables.

Safety terminal foundations shall at a minimum be designed to resist movement in the soil due to system tensioning and impacts to the system at the NCHRP 350 test level specified. Design of the safety terminal foundations shall include a factor of safety of 1.5 for overturning and pullout.

If all cables are to be anchored to a single foundation, the design of safety terminal foundations and cable connections shall be based on a minimum total equivalent horizontal static load of 50,000 lbf (222.4 kN) and the commensurate vertical component associated with the net cable angle from horizontal.

If cables are to be anchored in multiple foundations, the design of safety terminal foundations and cable connections shall be based on a minimum equivalent horizontal static load of 15,000 lbf (66.7 kN) per cable and the commensurate vertical component associated with this force and each cable's angle from horizontal.

Threaded terminals shall be of the swaged or wedge lock type. Only one field-installed swage connection will be allowed per cable per run. All other swage connections shall be factory installed.

Intermediate line post spacing shall be such that the maximum dynamic deflection is no greater than 8 ft (2.4 m), but in no case shall the spacing be greater than 16 ft (4.9 m). Post spacing may be adjusted, as allowed by the manufacturer, to avoid conflicts with utilities, drainage structures, underdrain outlets and other permanent obstructions.

Intermediate line posts shall be of a socket tube and post design where the socket is part of the line post foundation and line posts are inserted into the socket. Posts shall have a means of holding the wire ropes at the design height. The post and socket design shall include a means of excluding debris from entering the socket.

Foundations for intermediate line post sockets shall be cast-in-place concrete a minimum of 3'-6" (1070 mm) deep and a minimum of 14 in. (350 mm) in diameter centered about the socket. Concrete foundations shall be reinforced as required by the manufacturer.

A minimum of 8 in.^{2} (5000 mm^2) of retroreflective sheeting shall be applied on the side facing approaching traffic of each line post in cable height transition sections and to every fourth intermediate line post in full height cable sections. The color of the sheeting shall match the color of the nearest adjacent traffic pavement marking.

MATERIALS

627.03 Materials

Materials shall be in accordance with the following:

Concrete, Class A 702
Reinforcing Steel 910.01

Cables shall meet the manufacturer's specifications. In addition, cables shall be 3/4 in. (19 mm) 3 X 7 zinc-coated wire rope in accordance with AASHTO M 30-02 (2006) Type 1, Class A and shall have a minimum breaking strength of 39,000 lbf (173.5 kN). Wire rope shall be pre-stretched to exhibit a minimum modulus of elasticity of 11,805,000 psi (81393 Mpa).

Intermediate line posts shall meet the manufacturer's specifications. In addition, posts shall be zinc-coated steel meeting the requirements of ASTM A-36 and AASHTO M 111M / M 111-04 after fabrication.

Threaded terminals, turnbuckles and anchor fittings shall meet the requirements of ANSI B1.13M and be zinc-coated in accordance with AASHTO M232-06 (M 232M) after fabrication and shall develop a minimum breaking strength of 36,800 lbf (160.1 kN). Turnbuckles may be either the open or closed body type and shall allow for a minimum of 6 in. (150 mm) of penetration from each end. Anchor fittings at the termination of each cable barrier run shall be of the same size and type used in connection to the turnbuckles.

Concrete for safety terminal and intermediate line post foundations shall be Class A.

Retroreflective sheeting shall be in accordance with AASHTO M-268 Type IV for adhesive sheeting.

A Type A certification in accordance with 916 shall be provided with each spool of wire rope cable prior to installation. The certification shall include the thickness of zinc coating, the minimum breaking strength, the modulus of elasticity and the force applied to pre-stretch the wire rope.

A Type C certification in accordance with 916 shall be provided for intermediate line posts, threaded terminals, turnbuckles, anchor fittings and retroreflective sheeting prior to installation.

CONSTRUCTION REQUIREMENTS

627.04 Construction

All site work, including grading and placing of fill shall be completed and approved by the Engineer prior to installation of the cable barrier system.

Installation of the cable barrier system shall be in accordance with the manufacturer's recommendations and these specifications.

The top of cast-in-place concrete safety terminal foundations and intermediate line post foundations shall be finished no lower than flush with final grade and no higher than 1 in. (25 mm) above final grade. Intermediate line post foundations shall be installed such that line posts will be plumb when installed in the socket. Safety terminal foundation concrete shall be cured for a minimum of 168 hr in accordance with 702.22 prior to tensioning of wire ropes.

A D2 delineator with post shall be placed in accordance with 804 in front of each safety terminal foundation.

Turnbuckles and other fittings shall be placed so as not to interfere with each other or with the intermediate line posts.

A manufacturer's representative shall be present during tensioning of the system. Tensioning shall be done in accordance with the manufacturer's specifications and using a tension chart provided by the manufacturer. The tension testing device shall be calibrated no more than one month prior to beginning tensioning and a copy of the calibration shall be provided to the Engineer. The temperature of the bottom wire rope shall be measured and recorded and used to determine the required tension values for the wire ropes from the manufacturer's chart. A copy of the chart shall be provided to the Engineer prior to tensioning.

The Contractor shall maintain a tensioning log in a format acceptable to the Engineer to record, at a minimum, the following:

(a) The date tensioning is performed
(b) The ambient air temperature at the time of tensioning
(c) The temperature of the bottom wire rope at the time of tensioning
(d) The model and serial number of the tension testing device used
(e) The location of each safety terminal in the run being tensioned
(f) The location where tensioning is being performed
(g) A diagram showing the number assigned to each of the four wire ropes
(h) The wire rope number being tensioned
(i) The maximum stress applied to each wire rope
(j) The final stress applied to each wire rope

The tensioning log shall be signed by the person overseeing the tensioning and submitted to the Engineer upon completion of each day's tensioning.

The tension in the cable barrier system shall be tested and retensioned as necessary no sooner than 15 days after initial tensioning. Retensioning shall be performed when the test indicates that tension is less than 90% of the manufacturer's recommended tension for the given cable temperature.

A tensioning log for all runs retensioned shall be completed and signed by the person overseeing the tensioning and submitted to the Engineer upon completion of each day's retensioning.

The Department may have non-inspection personnel on-site during the project to observe the installation of the cable barrier system. The Contractor shall provide for the manufacturer's representative to be on-site to instruct Department personnel in the proper installation and repair procedures for the system.

The Contractor shall repair any portion of a cable barrier system, including wire ropes, intermediate line posts, safety terminals, retroreflective sheeting and hardware that is damaged as a direct result of traffic during the life of the contract. Damage shall be repaired within seven days of notification by the Engineer. Responsibility for repairs will be in accordance with 107.18.

The Contractor may request final inspection and final acceptance of completed runs of cable barrier in accordance with 105.15(a).

The Contractor shall provide a spare parts package for the selected cable barrier system. The spare parts package shall include sufficient quantity of the following parts to replace 10% of the total number of like parts required in the original contract quantities.

(a) Intermediate line posts and all associated hardware.
(b) Intermediate line post sockets and all associated hardware.
(c) Retroreflective sheeting.

In addition, the spare parts package shall include the following.

(a) One of each of the manufacturer's tools required to replace intermediate line posts.
(b) One tension testing device as produced by or recommended by the manufacturer.
(c) One complete set of manufacturer's installation and repair manuals.

Prior to final acceptance of the contract, the spare parts package shall be delivered to a location within the District to be determined by the Engineer.

627.05 Method of Measurement

Cable barrier system will be measured by the linear foot (meter) for the type specified, complete in place. Measurement will be made between the centers of the two safety terminal foundations at the extreme ends of each run.

Safety terminals will be measured per each for the type specified, complete in place. One safety terminal will include all foundations and hardware necessary to anchor all 4 wire ropes at one end of a cable barrier run.

Safety terminal foundations, intermediate line posts, line post foundations, cable tensioning and retroreflective sheeting will not be measured separately for payment.

D2 delineators will be measured in accordance with 804.06.

Spare parts package will be measured per each, complete and delivered to the Department.

627.06 Basis of Payment

Cable barrier system will be paid for at the contract unit price per linear foot (meter) for the type specified.

Safety terminals will be paid for at the contract unit price per each for the type specified.

D2 delineators will be paid in accordance with 804.07.

Spare parts package will be paid for at the contract unit price per each.

Payment will be made under:

Pay Item	***Pay Unit Symbol***
Cable Barrier System, Type TL- _____ (test level)	*LFT (m)*
Cable Barrier System, Type TL- _____, Spare Parts (test level)	*EACH*
Safety Terminal, Type TL-_____ (test level)	*EACH*

The cost of wire rope cables, intermediate line posts, line post foundations, cable tensioning, retroreflective sheeting and all equipment, parts and labor, including the cost of the manufacturer's representative, necessary to furnish and install the cable barrier system shall be included in the cost of the pay item for cable barrier system.

The cost of safety terminal foundations, including reinforcing steel and all necessary cable anchor hardware, shall be included in the cost of the pay item for safety terminal.

The cost of obtaining any necessary additional geotechnical information and the cost of designing the safety terminal foundations shall be included in the cost of the pay item for safety terminal.

The cost of spare parts package shall include all costs necessary to deliver the spare parts to the designated location in the District.