

1. Report No. FHWA/TX-10/0-5609-2		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle DEVELOPMENT OF GUIDELINES FOR CABLE MEDIAN BARRIER SYSTEMS IN TEXAS				5. Report Date February 2009 Published: December 2009	
				6. Performing Organization Code	
7. Author(s) Scott A. Cooner, Yatin K. Rathod, Dean C. Alberson, Roger P. Bligh, Stephen E. Ranft, and Dazhi Sun				8. Performing Organization Report No. Report 0-5609-2	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. Project 0-5609	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080				13. Type of Report and Period Covered Technical Report: September 2006 – February 2008	
				14. Sponsoring Agency Code	
15. Supplementary Notes Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration. Project Title: In-Service Evaluation of Cable Median Barrier Performance URL: <a href="http://tti.tamu.edu/documents/0-5609-2.pdf">http://tti.tamu.edu/documents/0-5609-2.pdf</a>					
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 development of guidelines for use of cable barrier systems in Texas. The research team performed a comprehensive review of currently available guidance on cable barrier systems. The guidelines review included four broad categories:  <ul style="list-style-type: none"> <li>• guidance on barrier selection,</li> <li>• guidance on barrier design,</li> <li>• guidance on barrier placement, and</li> <li>• guidance on general system considerations.</li> </ul> The development of guidelines for cable median barrier systems in Texas concentrated on existing information in state departments of transportation (DOT) design manuals and memorandums, manufacturer product manuals, and completed studies – including the results of the in-service performance evaluation in Texas. The development of consistent and practical guidelines for the use of cable barrier systems is necessary so that TxDOT design, operations and maintenance staff can make sound decisions. Since the use of cable barrier systems is still a relatively new practice in Texas, the guidance is timely because many districts continue to look for sites and funding for implementation. This report is written primarily to convey the cable barrier system guidelines.					
17. Key Words Cable Barrier, Wire Rope, Median Barrier, Safety, and Guidelines			18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 <a href="http://www.ntis.gov">http://www.ntis.gov</a>		
19. Security Classif.(of this report) Unclassified		20. Security Classif.(of this page) Unclassified		21. No. of Pages 88	22. Price



**DEVELOPMENT OF GUIDELINES FOR  
CABLE MEDIAN BARRIER SYSTEMS IN TEXAS**

by

Scott A. Cooner, P.E.  
Research Engineer  
Texas Transportation Institute

Yatin K. Rathod, E.I.T.  
Associate Transportation Researcher  
Texas Transportation Institute

Dean C. Alberson, P.E.  
Research Engineer  
Texas Transportation Institute

Roger P. Bligh, P.E.  
Research Engineer  
Texas Transportation Institute

Stephen E. Ranft, E.I.T.  
Assistant Research Specialist  
Texas Transportation Institute

and

Dr. Dazhi Sun  
Assistant Professor  
Texas A&M University-Kingsville

Report 0-5609-2  
Project 0-5609

Project Title: In-Service Evaluation of Cable Median Barrier Performance

Performed in cooperation with the  
Texas Department of Transportation  
and the  
Federal Highway Administration

February 2009

Published: December 2009

TEXAS TRANSPORTATION INSTITUTE  
The Texas A&M University System  
College Station, Texas 77843-3135



## **DISCLAIMER**

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration (FHWA) and/or Texas Department of Transportation (TxDOT). This report does not constitute a standard or regulation, and is not intended for construction, bidding, or permit purposes. Products mentioned in this report are for informational purposes only and do not imply endorsement by the Texas Transportation Institute (TTI). The engineer in charge of this project was Scott A. Cooner, P.E. #86225 (Texas).

## ACKNOWLEDGMENTS

The Texas Transportation Institute and Texas A&M University-Kingsville (TAMU-K) performed the activities reported herein as part of a project entitled *In-Service Evaluation of Cable Median Barrier Performance*, which was sponsored by TxDOT and the FHWA. Mr. Scott A. Cooner, P.E., of the Texas Transportation Institute, served as research supervisor, and Mr. Rohit Parikh, P.E., of the Texas Department of Transportation, Fort Worth District, served as the project director.

In addition to the project director, the authors wish to acknowledge the members of the Project Monitoring Committee (PMC), who provided assistance and guidance throughout the project activities. These PMC members were:

- Ms. Rory Meza, P.E., TxDOT, Design Division – Program Coordinator;
- 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.

The authors also appreciate the following important contributions to the research team:

- Ms. Debra Vermillion (TxDOT Traffic Operations Division) and her staff for providing and assisting in the analysis of crash data for the cable barrier safety evaluation;
- Ms. Emily Margrett of the TxDOT General Services Division for providing electronic plan sets for numerous projects throughout the state;
- Ms. Jan Heady (TxDOT Dallas District) for providing timely information and photographs on terminal anchor issues and designs in Kaufman County;
- Mr. Frank Julian (FHWA) for sharing information on cable barrier deployment status and guidance gained throughout the United States;
- numerous TxDOT maintenance staff members who participated in surveys and provided key in-service performance data on projects in their jurisdictions; and
- representatives of cable barrier manufacturers who answered questions on their products' performance and provided key insights.

The authors also recognize the editorial, data collection, and other essential support activities of Mrs. Christy Harris of the Texas Transportation Institute.

# TABLE OF CONTENTS

	<b>Page</b>
List of Figures .....	viii
List of Tables .....	x
List of Abbreviations .....	xi
1 INTRODUCTION .....	1-1
1.1 Background and Significance of Research .....	1-1
1.2 Research Work Plan.....	1-2
1.3 Report Organization.....	1-3
References .....	1-4
2 STATE-OF-THE-PRACTICE LITERATURE REVIEW .....	2-1
2.1 Background Information.....	2-1
2.2 Approved Cable Barrier Systems.....	2-7
2.3 Review of State Experiences .....	2-11
2.4 Review of Current Guidance on Cable Barrier Systems .....	2-12
References .....	2-45
3 GUIDELINES FOR CABLE BARRIER SYSTEM IMPLEMENTATION .....	3-1
3.1 Guidelines Framework.....	3-1
3.2 Guidance on Barrier Selection.....	3-2
3.3 Guidance on Barrier Design.....	3-6
3.4 Guidance on Barrier Placement .....	3-12
3.5 Guidance on General System Considerations.....	3-17
References .....	3-21

## LIST OF FIGURES

Figure		Page
2-1	Aerial View of Cross-Median Crash Scene in Dallas, Texas.....	2-2
2-2	Photograph from I-35 Cross-Median Crash in Hewitt, Texas.....	2-2
2-3	Graphic Showing Deflection Design of Cable Barrier Systems.....	2-3
2-4	Cable Barrier Implementation in the United States.....	2-7
2-5	U.S. Low-Tension Cable Barrier System.....	2-7
2-6	Brifen Wire Rope Safety Fence.....	2-8
2-7	Gibraltar Cable Barrier System.....	2-9
2-8	Nucor SAFERoads Cable Barrier System.....	2-10
2-9	Trinity CASS Barrier.....	2-11
2-10	Median Barrier Installation Guidelines from the 1996 Roadside Design Guide.....	2-14
2-11	2006 AASHTO Roadside Design Guide – Guidelines for Median Barrier.....	2-15
2-12	Cross-Median Crashes in North Carolina Compared to the RDG Chart.....	2-16
2-13	Recommended Guidelines for Installing Median Barriers on High-Speed Roadways in Texas.....	2-17
2-14	<i>NCHRP 350</i> Test Levels.....	2-19
2-15	Cable Height.....	2-20
2-16	Load versus Displacement of Wire Rope.....	2-21
2-17	Impact with Bridge Pier on I-45 in Corsicana, TX.....	2-23
2-18	Location Illustrating Cable Barrier Interaction with Other Safety Devices.....	2-23
2-19	Motorcycle-Cable Barrier Impact Model.....	2-25
2-20	Motorcycle Rider Fatalities by Year in the United States.....	2-26
2-21	Successful Capture of Large Vehicle on I-20 in Kaufman County, TX.....	2-27
2-22	Successful Capture of Large Vehicles on I-20 in Parker County, TX.....	2-28
2-23	Washington State DOT Cable Barrier Placement Guidelines.....	2-31
2-24	Vehicle Trajectory Trace in Median Wider than 30 Feet.....	2-32
2-25	Desirable Barrier Placement in Non-Level Medians in Texas.....	2-33
2-26	Cable Barrier Placement on Curves.....	2-34
2-27	Deflection of Concave versus Convex Impacts of Cable Barrier.....	2-34
2-28	Colorado DOT Pamphlet.....	2-37
2-29	Trinity and Nucor Cable Barrier Anchor Terminal.....	2-38
2-30	Gibraltar Cable Barrier Anchor Terminal.....	2-39
2-31	Brifen Cable Barrier Anchor Terminal.....	2-39
2-32	Recommended Cable Barrier Overlap Length.....	2-39
2-33	High Grass and Vegetation around a Cable Barrier System.....	2-40
2-34	Concrete Mow Strip in Texas.....	2-40
2-35	Example Photograph of Dislodged Anchor Terminal in Rhode Island.....	2-42
2-36	Example Photograph of Anchor Terminal Failure System in Texas.....	2-42
2-37	Picture Showing Delineators Inset in Cable Barrier Posts.....	2-43
2-38	Picture Showing Special Extended Delineators.....	2-43
2-39	Picture Showing a Typical Emergency Crossover.....	2-44



## LIST OF FIGURES (continued)

Figure		Page
3-1	Posts in Concrete Drilled Shafts with Sockets .....	3-8
3-2	Use of Parallel Runs on US75 Project in Collin County, TX.....	3-9
3-3	Good Example: Spacing between Cable Barrier and Metal Beam Guard Fence .....	3-10
3-4	Example to Avoid: Inadequate Spacing between Cable Barrier and MBGF .....	3-11
3-5	Anchor Terminals Too Close to Guardrail End Treatments Can Cause Problems .....	3-11
3-6	Example to Avoid: Shoulder Placement in Wide Median Creates Nuisance Hits .....	3-13
3-7	Preferred Cable Barrier Placement within a V-Ditch.....	3-14
3-8	Acceptable Cable Barrier Placement within a V-Ditch .....	3-15
3-9	Example of Consequence of Having Anchor Terminal Unprotected.....	3-18

## LIST OF TABLES

Table		Page
1-1	Recent Growth in Cable Barrier Systems.....	1-1
2-1	AASHTO Cable Median Barrier Technology Implementation Group Members .....	2-4
2-2	Rapid Increase in Cable Barrier Installations in the United States.....	2-6
2-3	States with Cable Median Barrier Policies in Their Standards .....	2-17
2-4	Severity and Location of North Carolina Motorcycle Crashes .....	2-25
2-5	Severity and Barrier Type of North Carolina Motorcycle Crashes .....	2-26
2-6	Slope versus Performance or Success for Cable Barriers in Missouri .....	2-30
2-7	Multiplying Factors for Barrier Design Deflections.....	2-35
2-8	Existing TxDOT Guidance on Post Spacing on Horizontal Curves.....	2-35
3-1	Categories for Guidelines for Cable Barrier System Implementation.....	3-1
3-2	Life-Cycle Costs of Cable versus Concrete Barrier for a 5-Mile Project.....	3-5

## LIST OF ABBREVIATIONS

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
B/C	Benefit/Cost
Caltrans	California Department of Transportation
CASS	Cable Safety System
CMB	Concrete Median Barrier
CMCs	Cross-Median Crashes
DOT	Department of Transportation
DPS	Department of Public Safety
FARS	Fatal Analysis Reporting System
FHWA	Federal Highway Administration
GET	Guardrail Extruder Terminal
GIS	Geographic Information System
HTCBS	High-tension Cable Barrier System
ISO	International Organization for Standardization
ISPE	In-Service Performance Evaluation
ksi	Kips per Square Inch
MBGF	Metal Beam Guard Fence
MC	Motorcycle Crashes
MoDOT	Missouri Department of Transportation
mph	Miles per Hour
NCAC	National Crash Analysis Center
NCDOT	North Carolina Department of Transportation
NCHRP	National Highway Cooperative Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PMC	Project Monitoring Committee
psi	Pounds per Square Inch
RMC	Research Management Committee
RDG	Roadside Design Guide
ROW	Right-of-Way
SUV	Sport Utility Vehicles
TAMU-K	Texas A&M University-Kingsville
TIG	Technology Implementation Group
TL	Test Level
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
U.S.	United States
WRSF	Wire Rope Safety Fence
WsDOT	Washington State Department of Transportation



# CHAPTER 1 INTRODUCTION

## 1.1 BACKGROUND AND SIGNIFICANCE OF RESEARCH

Transportation agencies have deployed a variety of cable barrier systems (proprietary and generic) across the country. In general, issues have emerged concerning performance characteristics. In addition, design differences among various available systems contribute to different performance characteristics, implementation, and maintenance requirements. Transportation agencies need a better understanding of the link between placement and performance of these systems to ensure that they will meet expectations. As a result, research is necessary to:

- identify both commonalities and differences,
- address knowledge gaps, and
- provide guidance that will optimize performance of these systems for different field conditions.

Under a recent National Cooperative Highway Research Program (NCHRP) project, Alberson et al. identified six cable barrier systems installed in the United States (U.S.) (1). They are:

- U.S. Low-Tension Cable Barrier System,
- Brifen Wire Rope Safety Fence (WRSF),
- Blue Systems Safence 350 Wire Rope Barrier,
- Nucor High-Tension Cable Barrier System,
- Trinity Industries Cable Safety System (CASS), and
- Gibraltar Cable Barrier System.

The U.S. has utilized the first system on the list for the last 20 years in its current configuration. It is low tension and non-proprietary. The other five systems are all high tension and proprietary. TTI has been tracking the amount of high tension cable barriers installed in the U.S. since April 2006. Table 1-1 shows the trend in wire rope barrier usage as reported by the respective manufacturers.

**Table 1-1. Recent Growth in Cable Barrier Systems.**

Barrier Type	April 2006	September 2006	January 2008	April 2008
Safence 4		17	110	185
Brifen	287 323	405	440	
Gibraltar	195 395	540	685	
Nucor	221 340	403	453	
Trinity	341 570	825	912	
<b>Total Miles</b>	<b>1,048 1,64</b>	<b>5 2,28</b>	<b>3</b>	<b>2,675</b>

Texas has been responsible for a significant portion of the growth in cable barrier system deployment nationally, with almost \$200 million spent on deployment of approximately 800 miles in the last five years. This rapid growth has allowed the department to gain valuable experience and also provides a significant test bed for developing lessons learned and guidance for future projects.

The development of consistent and practical guidelines for the use of cable barrier systems is necessary so that TxDOT design, operations and maintenance staff can make sound decisions. Since the use of cable barrier systems is still a relatively new practice in Texas, the guidance is timely because many districts continue to look for sites and funding for implementation. Researchers wrote this report primarily to convey the cable barrier system guidelines.

## 1.2 RESEARCH WORK PLAN

The 0-5609 research project involved a joint effort between TTI and Texas A&M University-Kingsville. The work plan for the 0-5609 research project involved the following 13 primary tasks:

1. Develop project website to help facilitate overall project management and information sharing.
2. Conduct 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.
3. Perform an inventory of cable/wire rope median barrier installations in Texas.
4. Define the in-service performance evaluation (ISPE) process and study locations.
5. Collect key evaluation data for evaluation of cable median barrier performance.
6. Create geographic information system (GIS)-based statewide cable barrier inventory database.
7. Conduct the ISPE and barrier comparison.
8. Prepare the ISPE report (see 0-5609-1 research report).
9. Develop the *Cable Median Barrier Maintenance Guidebook* (see 0-5609-P1).
10. Perform analysis on the GIS database.
11. Develop guidelines for cable median barrier system implementation.
12. Develop training materials including a hands-on training module that transportation agencies can use to train maintenance staff in the use of the *Cable Median Barrier Maintenance Guidebook* (see 0-5609-P2).
13. Prepare the 0-5609 project deliverables.

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.

---

This report focuses on reporting the results of tasks 2, 11, and 13 from the previous list.

### 1.3 REPORT ORGANIZATION

The focus of this 0-5609-2 report is to document the recommended cable barrier system guidelines. [Section 1.1](#) (Background and Significance of Research) provides the reader with an understanding of the need for developing consistent and practical guidelines for cable barrier system use in Texas.

[Chapter 2](#) (State-of-the-Practice Literature Review) outlines the results of a comprehensive state-of-the-practice literature review of cable barrier systems. The research team concentrated the literature review on four subject areas, including:

- background information,
- approved cable barrier systems,
- review of state experiences, and
- review of current guidance on cable barrier systems.

[Chapter 3](#) (Guidelines for Cable Barrier System Implementation) explains the guidelines development process used by the research team. Researchers developed the guidelines based on the review of existing state experiences and policies and the in-service performance evaluation in Texas.

## REFERENCES

1. D.C. Alberson, N.M. Sheikh, and L.S. Chatham. *Guidelines for the Selection of Cable Barrier Systems – Generic Design vs. High-Tension Design*, NCHRP Project 20-7(210) Final Report, National Cooperative Highway Research Program, Washington, D.C., July 2007.



## CHAPTER 2

### STATE-OF-THE-PRACTICE LITERATURE REVIEW

This chapter presents the results of a comprehensive state-of-the-practice review of cable barrier systems. The research team concentrated the literature review on four subject areas, including:

- background information,
- approved cable barrier systems,
- review of state experiences, and
- review of current guidance on cable barrier systems.

The following subsections provide a summary of key information for each of the four subject areas.

#### 2.1 BACKGROUND INFORMATION

Cable barriers are not a new concept, as they have been used on the nation's highways since as early as the 1930s. The early designs were simply wooden support posts and a single loosely attached cable. Their use has increased over the last three decades with strides in design and effectiveness, and they are an available option for a roadway safety device (1). Because of the increasing number of cross-median crashes (CMCs), caused in part by increasing lane densities and higher speeds resulting from increasing suburbanization, state departments of transportation are considering installing more cable barriers. Additionally, it is a foregone conclusion that the American Association of State Highway and Transportation Officials (AASHTO) will modify the current median barrier warrants pending the completion and adoption of a current NCHRP research project. The new warrants will be more conservative, i.e., requiring barrier use in more locations (2).

##### **Cross-Median Crashes**

For the purposes of this project, the research team developed the following definition of a cross-median crash:

*A crash where a vehicle departs from its traveled way to the left, traverses the median separation between the highway's directional lanes, and collides with a vehicle traveling in the opposite direction.*

When they occur, CMCs are typically very violent in nature and have a high probability of multiple serious injuries and deaths (Figure 2-1). Research shows that CMCs are responsible for a disproportionately high rate of fatalities in Texas and other states. Transportation professionals believe that adequate barrier protection can prevent many of these severe CMCs. However, transportation agencies should not use barriers 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 2-1. Aerial View of Cross-Median Crash Scene in Dallas, Texas.**

### *CMCs in Texas*

Previous research in Texas revealed that over 40 percent of CMCs involve one or more incapacitating and/or fatal injuries (3). In the last five years, Texas has also experienced two high-profile CMCs that involved multiple fatalities and included formal investigations by the National Transportation Safety Board (NTSB), as follows:

- I-35 in Hewitt, Texas: in February 2003, a motorcoach traveling northbound in reduced visibility due to fog, haze, and heavy rain crossed the median and entered the southbound main lanes where it collided with two other passenger vehicles (see [Figure 2-2](#)). According to the NTSB report, there were a total of seven fatalities and many other serious injuries in this incident (4).
- US75 in Sherman, Texas: in September 2004, a semi-tractor trailer traveling northbound crossed the median and entered the southbound main lanes where it collided with two other passenger vehicles. According to the NTSB report, there were a total of 10 fatalities, two serious injuries, and one minor injury in this incident (5).

These two incidents highlight the potentially severe consequences that can occur when a vehicle crosses an unprotected median at a high rate of speed.



**Figure 2-2. Photograph from I-35 Cross-Median Crash in Hewitt, Texas.**

## Cable Barrier Design Considerations

Cable barrier systems currently used for protection against CMCs have been tested and received *NCHRP 350* approval for crash worthiness, including having *NCHRP 350* certified end treatments. The cable barrier systems currently available for this use satisfy either Test Level-3 (TL-3) or Test Level-4 (TL-4) of the six test levels identified by NCHRP. The test levels vary by specific vehicle types, impact angles, and travel speeds. TL-3 is the most common, as it establishes safety criteria for small cars (approximately 1,800 lb) and pickup trucks (approximately 4,400 lb) moving at 60 mph (6, 7). Current versions of cable barriers feature strands of tensioned cable secured along a series of metal posts. The system is designed so the posts and the wire cables absorb the energy of a vehicle striking the barrier (Figure 2-3). After striking the barrier, the vehicle is guided along by the cables until it slows to a stop, with the goal of keeping the vehicle from crossing over into opposing traffic. An added benefit of cable barrier systems is that they are flexible and do not deflect errant vehicles back into the same-direction traffic stream as do traditional concrete median barrier (CMB) or metal beam systems.

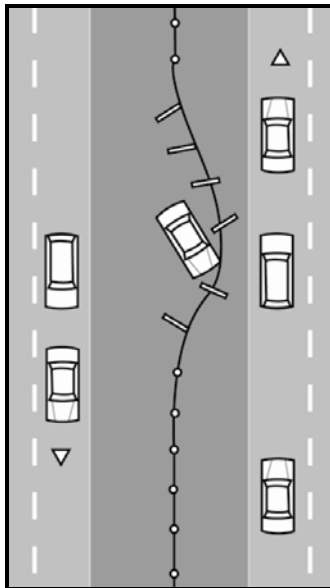


Figure 2-3. Graphic Showing Deflection Design of Cable Barrier Systems.

## Cable Barrier Technology Implementation Group

AASHTO currently administers a program, Technology Implementation Group (TIG), to support the implementation of proven innovative new technologies or engineering procedures (8). Each TIG typically has one or several lead agencies that seem to be ahead of the pack in adopting the innovation. There is a TIG for cable median barriers led by the North Carolina Department of Transportation (NCDOT). Table 2-1 shows the representatives on the cable median barrier TIG. Readers can access the AASHTO Cable Barrier TIG website at the link below:

- <http://tig.transportation.org/?siteid=57&pageid=1031>

The TIG continues to gather information and experiences in the following five key categories:

- Background and problem identification:
  - assess magnitude of the problem (crash analyses),
  - build an action plan to solve the problem (compare state to current standards),
  - convince peers and upper management of the problem and action plan, and
  - move forward with the problem solution.
- Roadway design issues:
  - cable type (high-tension or low-tension),
  - cable placement – slope issues (high-tension or low-tension),
  - cable barrier design issues, and
  - transition from cable to other types of barrier systems.
- Maintenance issues:
  - barrier hits per mile and frequency of repairs to cable barrier,
  - recovery of maintenance cost from drive-away vehicles (leave the scene after impact),
  - cable downtime, and
  - mowing concerns.
- Benefits and evaluation:
  - effects of fatal crashes and fatal injuries,
  - long-term barrier evaluation (three or more years after installation), and
  - lower severity on crashes into barrier system.
- System threats:
  - cable penetration crashes,
  - median berm crashes,
  - effects of median barrier on highway speeds,
  - effects of median barrier on emergency response times, and
  - emergency crossover issues and concerns.

**Table 2-1. AASHTO Cable Median Barrier Technology Implementation Group Members.**

Name	Agency	Section
Kevin Lacy	North Carolina DOT	Traffic Engineering
Terry Hopkins	North Carolina DOT	Traffic Engineering
Brian Mayhew	North Carolina DOT	Traffic Engineering
Shawn Troy	North Carolina DOT	Traffic Engineering
Brian Murphy	North Carolina DOT	Traffic Engineering
Roger Thomas	North Carolina DOT	Roadway Design
Scott Capps	North Carolina DOT	Maintenance
William Hunter	University of North Carolina	Highway Safety Research Center
Dick Albin	Washington State DOT	Roadway Design
Dean Focke	Ohio DOT	Office of Roadway Engineering
Rob Clayton	Utah DOT	Traffic and Safety Division
Rory Meza	Texas DOT	Roadway Design Division
Frank Julian	FHWA	Safety and Highway Design Team – Atlanta, Georgia
Dick Powers	FHWA	Office of Safety Design – Washington, D.C.
Joseph Geigle	FHWA	North Carolina Division

## Scanning Tour Report

The states of Illinois, Iowa, Minnesota, and Wisconsin were interested in installing and/or expanding the use of high-tension cable barriers for cross median protection on their highways. These states took part in a Scanning Tour sponsored by the FHWA with the objectives of:

- learning lessons from other states who already have experience in the use of high-tension cable barrier systems (HTCBS), and
- obtaining information on system characteristics and performance from the visited states and from companies that manufacture HTCBS.

The Scanning Tour included visits to Ohio, Oklahoma, and Texas in the fall of 2005. The agenda also included visits to cable manufacturing companies. Scanning tour team members observed four proprietary HTCBS that meet *NCHRP 350* criteria for TL-3. Medina and Benekohal produced a final report documenting the results of the Scanning Tour in December 2005 (9). This report concludes that the cable barrier systems observed in the Scanning Tour seemed to perform similarly for passenger vehicles. Performance at redirecting or stopping vehicles is excellent, and the team found no major drawback of using HTCBS. Key scan tour findings included:

- Crash severity is reduced significantly compared to other barrier systems.
- No fatalities have been recorded on crashes at locations with high-tension cable barriers.
- Very few crashes result in barrier penetration.
- The barriers have been able to stop vehicles exceeding design characteristics. Eighteen-wheeler trucks are among those vehicles stopped by the high-tension cable barriers.
- Selection of the high-tension cable system is based on a bidding process. Bidding specifications are not the same among the visited states, but all of them require a specific maximum dynamic deflection.
- Warrants for installation of median cable barriers tend to consider a severe crash history and also depend on roadway geometry and traffic volumes.
- High-tension cable barriers can be installed on the shoulder or on the median slope. Mid-slope barriers are recommended to be installed on slopes no steeper than 6:1.
- States visited preferred socketed posts over driven posts. Higher initial cost of sockets embedded on concrete foundations balances out over time, mainly because post replacement is easier.

Medina and Benekohal concluded that states are still in the learning process, but information gathered during the Scanning Tour provided valuable knowledge on system characteristics, performance, and maintenance (9). They also determined that some issues pertaining to optimum cable location, long-term benefit-cost analysis, TL-3 versus TL-4 requirements, and 3-cable versus 4-cable systems, among others, need more research to be determined precisely.

## Overview of Current Cable Barrier Implementation

Previous studies have surveyed state DOTs several times about the use of cable barriers. Ray and McGinnis performed the first survey, documented in NCHRP Synthesis 244 (10). Low-tension cable barriers were used at that time in North Carolina, Washington, South Dakota, and Missouri. By 2004 at least 14 states reported using some type of cable barrier, including:

- Alabama,
- Arizona,
- Iowa,
- Mississippi,
- Missouri,
- Nebraska,
- Nevada,
- New York,
- North Carolina,
- Oklahoma,
- South Carolina,
- Texas,
- Washington, and
- Wisconsin (11).

In another 2004 study, New Jersey and Minnesota also indicated occasional use of three kinds of cable barriers (12). Most recently in 2006, an NCHRP study by Alberson found that most states use cable barriers. Table 2-2 shows the rapid increase in the number of miles of cable barrier installed in the U.S. between May 2006 and January 2008 (13). Figure 2-4 shows the status of high-tension cable barriers as of April 2008 according to Frank Julian of the FHWA, including:

- 38 red states with cable installed;
- five blue states without cable installed (California, Delaware, Kansas, Massachusetts, and New Hampshire);
- six yellow states with pending projects (Alaska, Connecticut, Louisiana, Nebraska, New York, and Michigan); and
- one state (Hawaii) not responding.

**Table 2-2. Rapid Increase in Cable Barrier Installations in the United States (2).**

Barrier	May 2006 (miles)	September 2006 (miles)	January 2008 (miles)	Increase (%)
Safence 4		17	110	2,650
Brifen 287		323	405	41
Gibraltar 195		395	540	177
Nucor Steel Marion	221	340	403	82
Trinity Industries	341	570	825	142
Total Miles Installed	1,048	1,645	2,283	118

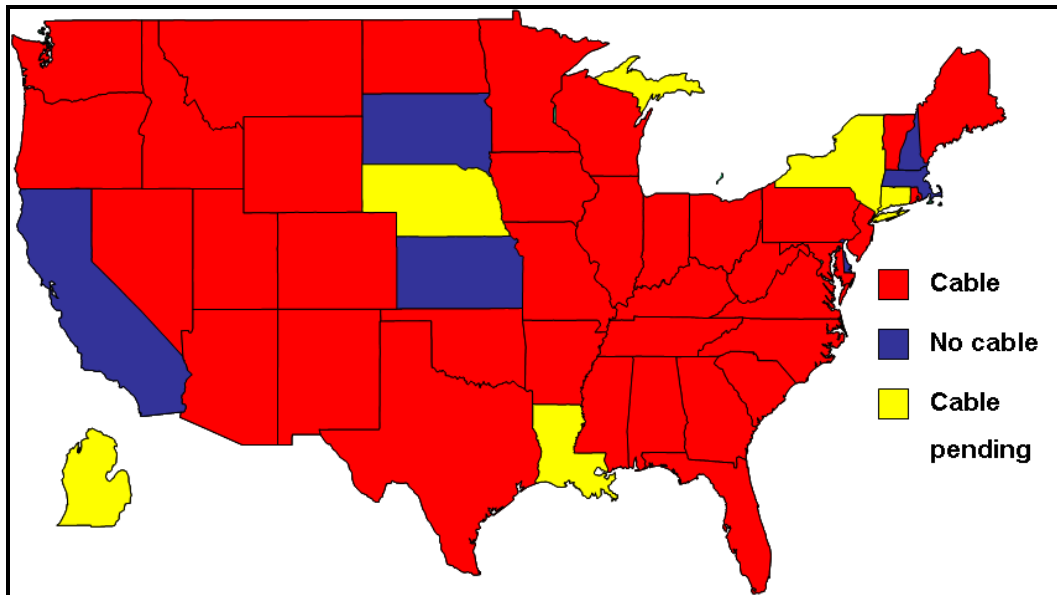


Figure 2-4. Cable Barrier Implementation in the United States (13).

## 2.2 APPROVED CABLE BARRIER SYSTEMS

### Low-Tension Cable Barrier Systems

Low-tension is also referred to as the U.S. generic system and is not exclusively manufactured or marketed by any single company. In this type of system, used for some 20 years in New York and Missouri, the cables are only put under enough tension to eliminate sag between posts. The barrier design utilizes large springs at either end of the cable run that are compressed to achieve the low tension in the system. With the system under low tension, there can be as much as 12 feet of deflection upon impact by an errant vehicle. As a result, the individual cable runs are usually limited to 2,000 feet (6). AASHTO specifies low-tension cable barrier systems are intended for use on 1V:6H slopes. The Missouri DOT installed 80 miles of cable in the median of I-70 on slopes up to 1V:5H. A comparison study between the two designs did not show significant differences (14). In the case of high-tension systems, they are *NCHRP 350 TL-3* approved for use of slopes between 1V:6H and 1V:4H (6). The U.S. low-tension cable barrier system is shown in Figure 2-5.



Figure 2-5. U.S. Low-Tension Cable Barrier System.

## High-Tension Cable Barrier Systems

Today, state departments of transportation appear to prefer the high-tension cable barrier systems in new installations in efforts to prevent crossover median crashes. These systems consist of three or four pre-stretched cables of any chosen length supported by weak metal posts. Tension placed on the cables is in the range of 2,000 to 9,000 lb. Upon being hit by an errant vehicle, the system can deflect about 8 feet and damage several posts in the immediate vicinity. Since the system remains under high tension, the remainder of the cable run will continue to function as intended. TxDOT currently approves the use of four HTCBS, as follows (15):

- Brifen Wire Rope Safety Fence,
- Gibraltar,
- Nucor SAFERoads, and
- Trinity Industries Cable Safety System.

### *Brifen Wire Rope Safety Fence*

Developed in the United Kingdom in 1989, the Brifen Wire Rope Safety Fence barrier commonly uses four interwoven cables (Figure 2-6). The Brifen WRSF uses an exclusive S-shape post in its TL-3 version, and the manufacturer recommends using only pre-stretched cables. The barrier posts are either installed by being driven with a soil plate or into concrete foundations with a minimum strength of 3500 lb per square inch (psi). The four-cable system has three lower cables interwoven around the posts with the upper cable threaded through a slot in the top of the post. The end treatment (i.e., anchor) for the WRSF extends 19 posts in total – 4 posts for the wire rope gating terminal and 15 posts for the transition to the line posts.



**Figure 2-6. Brifen Wire Rope Safety Fence.**

The Brifen WRSF is a symmetric design that can be used for either roadside or median applications. Transportation agencies can use the system on medians with a cross slope as steep as 4:1. The Brifen USA website (<http://www.brifenus.com/>) provides detailed technical information on the cable barrier product, including:

- presentation file with overall product overview;
- videos:



- TL-4 crash testing,
- *NCHRP 350* end anchor,
- installation, and
- repair; and
- pictures:
  - crash testing,
  - impacts,
  - large vehicle performance,
  - used in 30 countries, and
  - end anchor (16).

### *Gibraltar Cable Barrier System*

The Gibraltar Cable Barrier System is manufactured in Burnet, Texas, and consists of three 3×7, 0.75-inch pre-stretched galvanized wire ropes (Figure 2-7). The Gibraltar barrier uses a combination steel “hairpin,” lock plate, and cold formed steel C-posts to support the ropes. The barrier ropes are installed in a straight line with the posts alternating on each side of the ropes throughout the length of need. The system is accepted for use at both TL-3 and TL-4 and on slopes up to 4H:1V. All ropes terminate at a single 2 foot diameter by 6 foot deep concrete footer. The Gibraltar website (<http://www.gibraltartx.com/index.htm>) provides detailed technical information on the cable barrier product, including (17):

- drawings:
  - TL-3, TL-4 and transition to W-beam barrier;
- videos:
  - car test, truck test, cargo truck test, truck test with 30 foot post spacing, 4:1 up slope car test, 4:1 down slope car test, 4:1 slope truck test;
- acceptance letters;
- performance evaluation;
- photo gallery:
  - longitudinal section, terminal section, post crash, special features; and
- installation and maintenance guide.



**Figure 2-7. Gibraltar Cable Barrier System.**

### *Nucor High-Tension Cable Barrier*

The Nucor Steel Marion U.S. High-Tension System, also called the SAFERoads System, uses three cables (Figure 2-8). The system uses U-shaped hook bolts to support the cables. The posts can be driven in soil or installed in sleeves set in asphalt or concrete foundations. The manufacturer recommends using non pre-stretched cable but can provide pre-stretched cable upon request. The system is typically anchored with TTI's proprietary Cable Guardrail Terminal End (18, 19). The manufacturer recommends locating the upper and lower cables on the side closest to the roadway, leaving the middle cable on the opposite side.



**Figure 2-8. Nucor SAFERoads Cable Barrier System.**

The U.S. High-Tension System is a symmetric design that can be used for either roadside or median applications. The manufacturer's general notes indicate that the cable system should be installed on shoulders or medians with slopes of 6:1 or flatter without obstructions, depressions, etc. that may significantly affect the stability of an errant vehicle. The Nucor website (<http://www.gsihighway.com/nucor.htm>) provides detailed technical information on the cable barrier product, including:

- FHWA acceptance letters;
- drawings;
- installation manual;
- specifications;
- W-beam transition;
- news section with links to articles about product performance in the field;
- research section with links to websites with relevant cable barrier studies; and
- crash test, maintenance, and impact videos and pictures (20).

### *Trinity Cable Safety System*

The Cable Safety System barrier manufactured by Trinity Industries uses three strands of pre-stretched cable with wave-shaped slots for the cable to pass through the supporting post (Figure

2-9). Barrier posts can be installed in steel sockets that can either be cast into concrete cylinders or driven directly into the soil. The CASS system uses a guardrail terminal end developed by TTI to anchor the barrier system (18, 19). The Trinity Industries website (<http://www.highwayguardrail.com/products/cb.html>) provides detailed technical information on the CASS product, including:

- features and benefits,
- installation and repair advantages,
- installation instructions,
- specifications, and
- drawings (21).

The system can be used for either roadside or median applications since it has a symmetric design. There are three versions available for the CASS system with the only variation being the post spacing.



**Figure 2-9. Trinity CASS Barrier.**

### **2.3 REVIEW OF STATE EXPERIENCES**

The research team also spent an extensive amount of time and effort reviewing the experience of other state departments of transportation with cable barrier systems. This exercise helped to gather information on lessons learned and other valuable data. The 0-5609-1 report provides a detailed summary of key in-service performance evaluations from six states (22), including:

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

## **Washington State Department of Transportation – Comprehensive Review**

In response to a directive from the governor, the Washington State Department of Transportation completed an extensive study to evaluate their cable median barrier program following a fatal cross-median collision on I-5 in Marysville in February 2007 (23). This study relied on expert input, and one of the study deliverables was a letter report containing a comprehensive review of other states' use of cable median barriers. This document is an excellent resource that summarizes the experience of 23 states with implementation of cable barrier systems.

### **NCHRP 20-7(210) Project**

One of the research team members supervised a recently completed NCHRP study entitled *Guidelines for the Selection of Cable Barrier Systems: Generic Design vs. High-Tension Design* (2). The objective of this study was to develop preliminary guidelines for the selection and use of cable barrier systems based on a state-of-the-practice review of cable barrier installations. The research team conducted an extensive literature search and review to identify the types of cable barrier systems currently in use. The scope of this review included benefits of using cable barriers, available guidelines, policies or procedures related to barrier placement, and issues related to the maintenance and in-service performance of the cable barriers. Additionally, a comprehensive survey was conducted to identify experiences, practices, and design and construction standards for the use of cable barrier systems.

## **2.4 REVIEW OF CURRENT GUIDANCE ON CABLE BARRIER SYSTEMS**

The research team performed a comprehensive review of currently available guidance on cable barrier systems. As detailed earlier in this chapter, the use of cable barrier systems by states has rapidly increased – particularly over the last five-year time period. Even though some states continue to use the non-proprietary low-tension system, there is an increased usage of the proprietary high-tension systems. To date, TxDOT has exclusively used high-tension cable barrier systems and started with a 1-mile test section on I-820 in north Fort Worth in the summer of 2003. High-tension cable barrier systems are still a relatively new device in Texas and in the United States; therefore, guidance is still rapidly evolving.

Researchers developed appropriate categories for the review of existing guidelines based on an ongoing NCHRP study. The guidelines review included the following four broad categories:

- guidance on barrier selection,
- guidance on barrier design,
- guidance on barrier placement, and
- guidance on general system considerations.

Because TxDOT exclusively utilizes high-tension cable barrier systems, the research team decided to limit the guidelines review to this type of cable barrier system. Researchers focused the guidelines review effort on state DOT design manuals and memorandums, manufacturer product manuals, and completed research studies.

## Guidance on Barrier Selection

The research team discovered a significant amount of guidance regarding the selection of a cable barrier system for application in a roadway median. The guidance review revealed three primary barrier selection considerations, including:

- guidelines on the use of median barriers,
- guidelines on test level selection, and
- guidelines on cost-benefit analysis.

### *Guidelines on the Use of Median Barriers*

Traditionally, the warrants for median barriers involve a combination of median width and traffic volume to identify locations where median barriers should be located. Transportation professionals have developed two general approaches to aid in the selection of barriers: installation guidelines and cost-effectiveness. Using installation guidelines is when *certain geometric and operational characteristics of a site are examined to determine if it is appropriate to place a guardrail in a particular location* (24). Guidelines for installing barriers began with Highway Research Board Supplemental Report 81 in 1964; later updated in NCHRP Reports 36, 54, and 118; and then revised and published as the 1977 AASHTO Barrier Guide (25). The Barrier Guide was superseded by the 1989, 1996, 2002, and 2006 Roadside Design Guides (RDG). These guidebooks have also included cost-effectiveness procedures, providing methods for allocating funding based on the benefit-cost effectiveness of projects.

The 1977 Barrier Guide suggested installation guidelines for median barriers based on average daily traffic (ADT) volume and median width (25). These guidelines were applicable to “high-speed, controlled access roadways which have relatively flat, unobstructed medians.” They were based on a California report in 1968 (“Median Barrier Warrants”), Research Report 140-8 by TTI in 1974 (“Warrants for Median Barriers in Texas”), and the judgment of the AASHTO Task Force for Traffic Barrier Systems (26, 27). For all ADTs, median barriers were optional for median widths of 30 feet or more. For medians wider than 50 feet, barriers were generally not necessary, “unless there is an adverse history of across-the-median accidents” (28). Where median barriers were installed, the guide suggested using a rigid or semi-rigid barrier in medians up to 18 feet wide, any type of barrier except the 2-cable MB-1 in medians 18 to 30 feet wide, and semi-rigid or flexible barrier in medians 30 to 50 feet wide.

The California Department of Transportation (Caltrans) reinvestigated its median barrier policy in the late 1980s and early 1990s and revised its guidelines in 1991 after becoming concerned that cross-median crashes were an emerging problem (29). The median barrier guidelines for freeways used by Caltrans in 1991 took into account the number of cross-median crashes, traffic volume, and median width. The report stated, “a rate of 0.50 cross-median crashes per mile per year of any severity or 0.12 fatal cross-median crashes involving opposing vehicles justifies further analysis to determine the advisability of a barrier” (30). The authors noted that these rates provide “slim statistical evidence” and that “locations where conditions may be conducive to cross-median crashes need to be separated from those with random occurrences” (31). The point, as noted in some of the studies to be discussed later, is that median crossover crashes occur more

or less randomly in the highway network. Cross-median crashes most often occur as a result of conflict between vehicles on the road rather than as a result of a characteristic of the road or roadside (e.g., a sharp curve or super elevation). It is, therefore, difficult to predict where cross-median crashes will occur.

The 1991 Caltrans recommendations also stated that a barrier should be considered if the median was 45 feet wide or narrower and met the minimum traffic volume criteria. In 1991, concrete barriers were installed in medians up to 36 feet wide, and thrie-beam barriers were used in wider medians. While the California study and change of policy did not address cable median barriers per se, it did open up the discussion on the national level about using median barriers in medians where they had previously been considered unnecessary.

The 1996 version of the AASHTO RDG median barrier guidelines indicated that barriers were “not normally considered” on 50-foot (i.e., 15 meter) or wider medians, as shown in [Figure 2-10](#). They were optional for median widths of 30 to 50 feet (i.e., 10 to 15 meters). The 2002 version of the AASHTO RDG median barrier guidelines is identical to the 1996 RDG, with the minor exception that it provides installation and placement guidelines in U.S. Customary Units (i.e., inches and feet) and Standard International units (i.e., meters) ([32](#)). In 2006 a revision was published for the Median Barrier chapter of the RDG (see [Figure 2-11](#)). In this revision, the “Barrier Optional” area between 30 to 50 feet (10 to 15 meters) was changed to “Barrier Considered.” The intent of this change was to encourage more use of the median barrier.

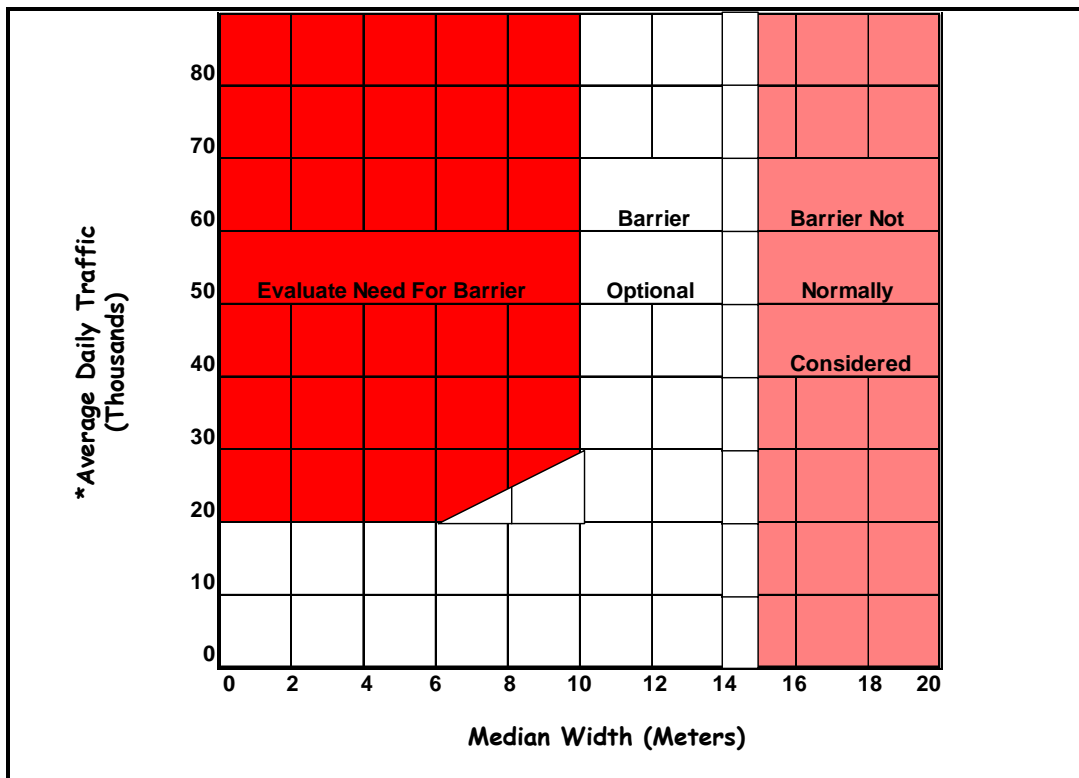


Figure 2-10. Median Barrier Installation Guidelines from the 1996 Roadside Design Guide.

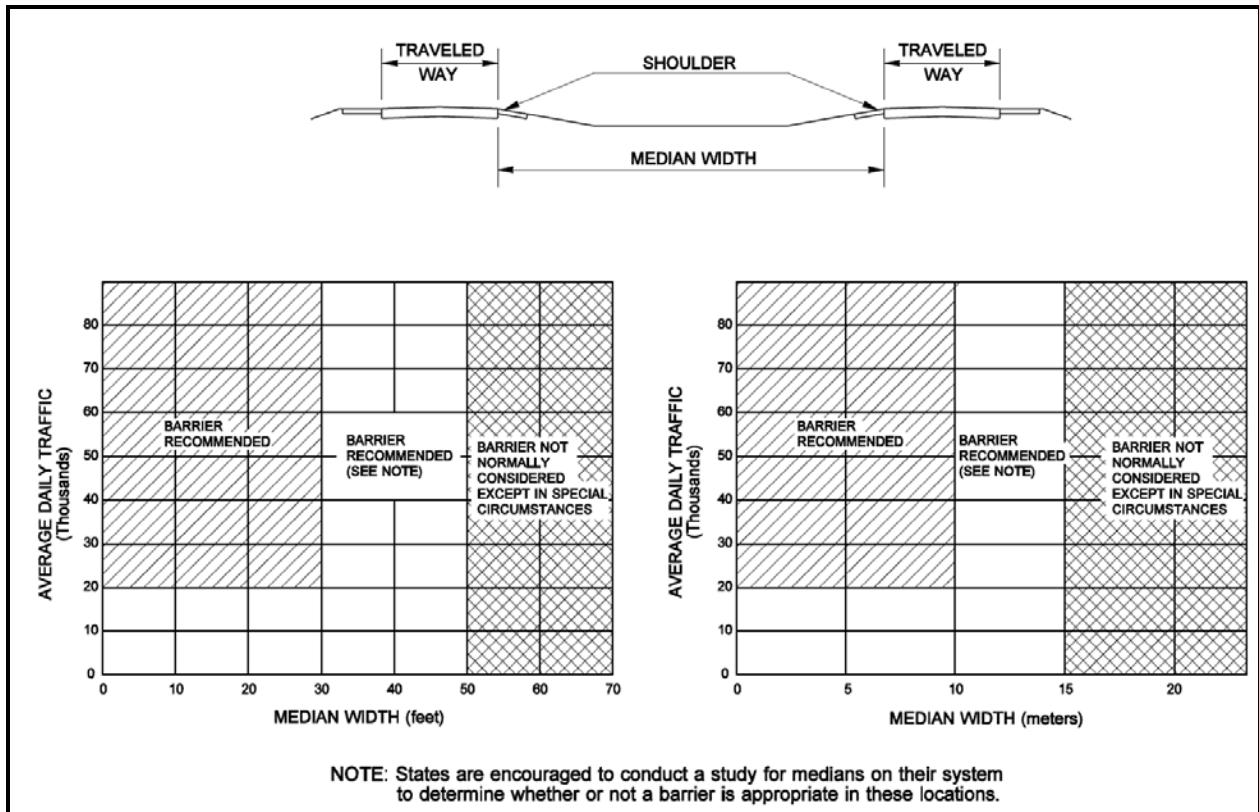
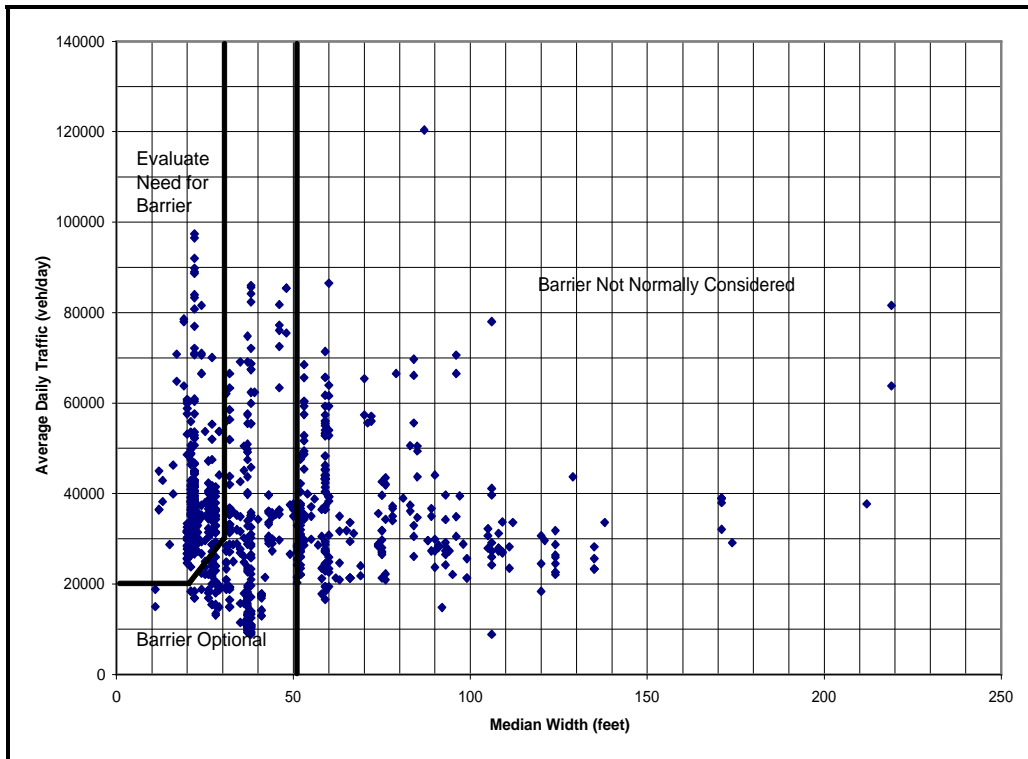


Figure 2-11. 2006 AASHTO Roadside Design Guide – Guidelines for Median Barrier (33).

North Carolina began examining its median barrier policy in the early 1990s after recognizing a significant number of cross-median crashes occurring, especially on urban freeways. Figure 2-12 shows this graphically where crashes are plotted on the typical RDG installation guideline. Clearly, there were numerous cross-median crashes even in wide medians where the RDG did not normally recommend median barriers. Other plots, similar to Figure 2-12, have been developed for California, New Jersey, Ohio, and Pennsylvania with identical results (2). Texas also examined its median barrier policy in 2002 in a study by Bligh et al. that showed that cable median barriers were more cost-effective than concrete for most median width and volume combinations (3).

Results such as these caused some roadside safety engineers to question whether the RDG guidelines were still appropriate for more modern, high-volume, high-speed conditions. North Carolina began installing test sections of cable barriers in about 1991 and kept careful track of all median crashes in the study areas (34). As a result, North Carolina changed its median barrier location policy such that all medians less than 70 feet wide should have median barriers. For very narrow medians, a concrete median barrier is necessary, but when there is sufficient room for lateral deflection, the cable median barrier is the preferred solution because it is more flexible and forgiving. While the research described above convinced many states that the current AASHTO policy was not doing enough to prevent cross-median crashes, the national consensus in the roadside safety community (as documented in the RDG) is still that median barriers are optional in medians wider than 30 feet. Many states have opted to provide additional protection by adopting policies that recommend the use of barriers in medians wider than 30 feet.



**Figure 2-12. Cross-Median Crashes in North Carolina Compared to the RDG Chart.**

Many states use cable median barriers, but relatively few have incorporated details into their design standards or standard plans. At this point in time, most states treat cable median barriers on a case-by-case basis and develop project plans accordingly. Table 2-3 shows states that have incorporated cable median barriers into their standard plans and drawings, and summarizes their policies. As shown in Table 2-3, most states use cable median barriers beginning with median widths in the range of 30 to 50 feet, most often 36 feet. Medians narrower than 30 feet are not wide enough to allow the cable median barrier enough room to deflect laterally during an impact without encroaching into the opposing lanes. Cable median barriers should be about 12 feet from the edge of the lane to prevent a vehicle crossing from the other side from entering the opposing lanes. Since divided highway shoulders are generally 8 feet wide, the median barrier in this case would be 4 feet from the edge of the shoulder and 12 feet from the edge of the lane. Using this logic, the smallest median where a cable median barrier could be used would be about 24 feet. There are a variety of maximum median widths in use in the different states. Some states use cable median barriers on all urban highways with medians wider than 30 feet regardless of the width. Many other states use cable median barriers in medians as wide as 75 feet.

*Current TxDOT Guidance*

In July 2008, the TxDOT Design Division issued a memorandum to provide updated guidelines for the use of median barriers on high-speed highways in Texas (35). TxDOT engineers should use this guidance to determine the need for median barriers. Figure 2-13 shows the recommended guidelines for installing median barriers on high-speed roadways. This guidance is based on median width and corresponding average annual daily traffic (AADT) and will be incorporated in the next update of the TxDOT Roadway Design Manual (36).

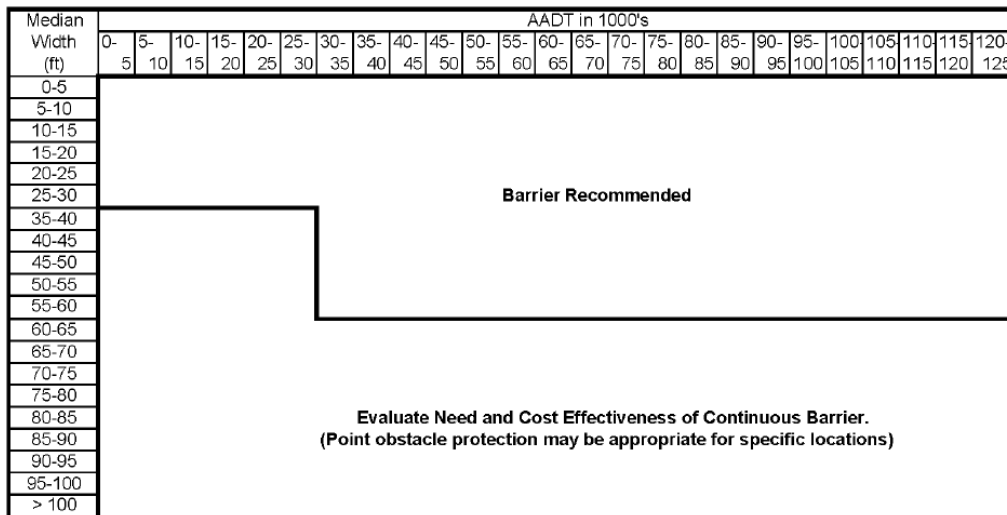


**Table 2-3. States with Cable Median Barrier Policies in Their Standards (37).**

State	Installation Guidelines				Max. Slope (H:V)	Cable Barrier Type	Location
	Median Width		Min. Traffic Volume (veh/day)	Crash Rate			
	Min. (ft)	Max. (ft)					
AZ	30	75	All urban		6:1	LT33	CM
DL 50		--					
VA --		40					
OH --		76	36,000		6:1	HT	GT8BD
NC 36		70			6:1	LT	SDR/SSR/CM
OR 30		--					
MO 36		60	20,000	0.8 CMC/100MVMT	6:1	LT30/HT	CM/GT14S/SDR
NY 36		72	20,000		6:1	LT30	CM/SSR/SDR
NY 36		72	20,000		10:1	HT	CM
KY				0.12 fatal CMC/mi/yr			
WA 30		50			6:1	LT30/HT	CM/GT8BD

CM = center of median  
 GT8BD = greater than 8 feet from the bottom of the ditch  
 HT = High-tension cable median barrier  
 LT = Low-tension cable median barrier

LT30 = 30-inch low-tension cable barrier  
 LT33 = 33-inch low-tension cable barrier  
 SDR = Shoulder double run  
 SSR = Shoulder single run  
 GT14S = Greater than 14 feet from edge of the nearest shoulder



**Figure 2-13. Recommended Guidelines for Installing Median Barriers on High-Speed Roadways in Texas (35).**

*General Cable Barrier Selection Factors*

According to the NCHRP 210(07) project survey, state DOT representatives also indicated that the following factors influence their decision to use cable barrier systems:

- lower installation cost and a better benefit-cost ratio,
- ease of repair after an impact,
- reduced snow buildup in areas of high snow drifting,

- ability of the high-tension system to retain some functionality after impact,
- ability to use on relatively higher median cross-slopes (6H:1V or flatter),
- better aesthetic and “see-through” appearance, and
- lower crash severity (2).

In a related question, the representatives were asked why they selected a cable barrier system as opposed to some other system. The reasons indicated by the respondents were as follows:

- reduced cost,
- ease of maintenance,
- better aesthetics and “see-through” appearance,
- reduced snow buildup in areas of high snow drifting,
- ease of snow plowing operations,
- lower crash severity,
- relatively greater flexibility in placement, and
- ability to allow for lateral drainage (2).

### *Guidelines on Test Level Selection*

Cable barrier systems, like other roadside safety devices, must comply with crashworthiness standards established in *NCHRP 350*. Within *NCHRP 350* are six separate test levels representing different vehicles, impact angles, and speeds (Figure 2-14). TL-3 is probably the most common, as it establishes the safety criteria for both small cars (1,800 lb car) and pickups at 60 miles per hour (mph). This category of traffic accounts for the vast majority of all vehicle traffic in Texas. Currently, HTCBS are approved at both TL-3 and TL-4. The difference between TL-3 and TL-4 is the addition of a 17,600 lb single-unit truck with a 15 degree impact angle at 50 mph. Four states currently require all cable barriers to meet the TL-4 designation.

### *Cost*

Researchers determined that the final, and often controlling, barrier selection criterion is cost. The research team reviewed many documents that indicate that the cost per mile of cable barrier ranges from 0.25 to 0.50 the cost per mile of concrete median barrier. Researchers also found several reports that indicate that the substantial savings on the initial installation cost for cable barrier is somewhat offset by increased maintenance costs over the long run.

The 0-5609-1 research report provided a detailed cost analysis of the various cable system components, including the barrier, terminal anchors, mow strip, and also a life-cycle cost comparison of cable versus concrete barrier performance (22). In 1998, Sposito and Johnston from the Oregon DOT conducted an in-service evaluation of the low-tension weak-post three-cable median barrier installations in Oregon (38). They found the initial installation cost for a cable barrier system was 70 percent less than that of a concrete barrier system. The annual maintenance cost of the cable barrier system (\$3,240/mile) was significantly higher than the concrete barrier (\$56/mile). However, the discrepancy between the installation cost of the cable barrier and concrete barrier was so large that it would take \$6200/mile of annual cable barrier maintenance cost to equate the concrete barrier installation in 30 years of service life.

Test Level	Vehicle	Angle	Speed
1	1800 lb Car	20°	30 mph
	4400 lb Pickup	25°	30 mph
2	1800 lb Car	20°	45 mph
	4400 lb Pickup	25°	45 mph
3	1800 lb Car	20°	60 mph
	4400 lb Pickup	25°	60 mph
4	1800 lb Car	20°	60 mph
	4400 lb Pickup	25°	60 mph
	17,600 lb Single-Unit Truck	15°	50 mph
5	1800 lb Car	20°	60 mph
	4400 lb Pickup	25°	60 mph
	80,000 lb Semi Truck (Cargo)	15°	50 mph
6	1800 lb Car	20°	60 mph
	4400 lb Pickup	25°	60 mph
	80,000 lb Semi Truck (Tanker)	15°	50 mph

**Figure 2-14. NCHRP 350 Test Levels (7).**

It is recognized that at this point in time, the prevalent method used by different states in selecting different cable barriers is based on a bidding process where the contractor selects the system that gets installed rather than the state DOT (9). In the case of proprietary high-tension systems, a low-bid contracting process often governs the actual selection. However, the bidding specifications only include a small part of the above criteria, and they are not the same among states, though most of them require a maximum dynamic deflection. For instance, cable barrier selection follows a bidding process with specified post spacing in Oklahoma but with price and maximum deflection in Texas. Therefore, it is worthwhile to develop some uniform selection guidance for the different cable barrier systems to assist in future decision-making.

One final significant finding related to barrier cost is that increased competition and usage have driven down overall implementation costs. In Texas, Meza compiled historical unit cost data that revealed that as competition between the barrier manufacturers increased, the unit costs for cable barrier and terminal anchors decreased by 25 to 50 percent (15).

### **Guidance on Barrier Design**

The research team uncovered considerable guidance on the design of cable median barrier systems. The guidance review revealed six primary barrier design considerations, including:

- number, height, and tension of cables;
- post spacing and dynamic deflection;
- pre-stretching and run length;
- coordinating with other safety devices/fixed objects; and
- impacts from motorcycles and vehicles exceeding design loads.

### *Number, Height, and Tension of Cables*

The number, height (Figure 2-15) and initial and long-term tension properties of a cable barrier are important design elements. Cable barrier systems must maintain sufficient tension to have the capability to capture vehicles and prevent cross-median crashes. According to Alberson et al., Brifen was the first high-tension system in the U.S. market, and their original system was installed with four pre-stretched wire ropes (2). Subsequent high-tension systems introduced in the U.S. market were successful in capturing or redirecting errant vehicles with three wire ropes. Crash tests show capture or redirection with a single wire rope on the 3/4 ton pickup; however, the single wire rope that captures the pickup will likely not be the same rope that would capture a small passenger vehicle. The upper ropes generally serve to capture or redirect the taller vehicles and the lower ropes engage the lower profile vehicles. Some states are adding a fourth rope for added protection against crossovers. There is some indication that placing a fourth rope lower than 21 inches for vehicles traversing ditches may also prevent breach through underride of the system. When wire rope systems are placed on backslopes near ditch bottom, compressed suspensions allow some vehicles to underride current rope placements.



**Figure 2-15. Cable Height.**

### *Post Spacing and Dynamic Deflection*

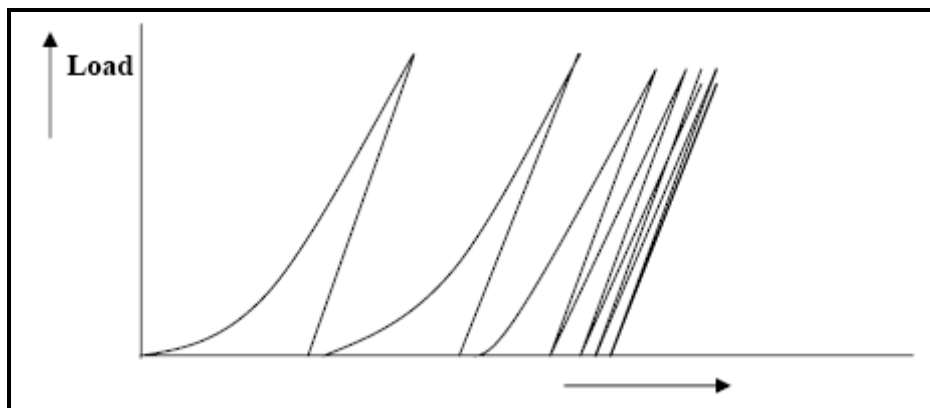
Post spacing correlates to expected deflections under impact conditions. Since all cable barrier systems use different post hardware, different connections to posts and even different wire ropes in some instances, the deflections for each respective system under different post spacings can only be correlated for specific systems. Generally speaking, the lower the post spacing, the lower the deflections will be found for similar vehicles under similar impact conditions. Some states have limited the maximum post spacing to 20 feet while others have limited it to 30 feet. There is some concern with larger post spacing that performance may be diminished due to terrain effects and vehicle engagement may be compromised by the increased flexibility associated with greater post spacings. In general, dynamic deflection distance is known to increase with longer spacing

between posts. What is not known, but strongly suspected, is that longer post spacing may also affect the propensity for vehicles to penetrate the cable barrier, i.e., by underide or traveling between the cables. The Guidance on Barrier Placement section of this chapter will further discuss placement considerations related to vehicle underide.

The FHWA maintains a website that contains all of the official acceptance letters for federally approved roadside safety devices. As of September 2009, 40 acceptance letters for cable barriers ([http://safety.fhwa.dot.gov/roadway\\_dept/policy\\_guide/road\\_hardware/listing.cfm](http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/listing.cfm)) can be downloaded from the website. Cable barrier systems have been tested and accepted with post spacing ranging from 6.5 feet to 32.5 feet. The FHWA recommends that highway agencies specify the post spacing when bidding on cable barrier systems. The conventional range for cable post spacing is 6.5 to 15 feet. In general, most states specify a maximum dynamic deflection of 8 feet for cable barrier systems, based on crash test performance requirements.

### *Pre-Stretching and Run Length*

There is considerable variation in the effective modulus of elasticity among the wire ropes used on the highway today. The effective modulus determines how much a given wire rope will stretch under a given load. The more a rope stretches under load, the higher the associated deflections. In 2002, the International Organization for Standardization (ISO) developed a standard for “Steel Wire Ropes – Determination of the actual modulus of elasticity” (39). The actual cross sectional area of steel in the wire rope is used for the computation of stress in that cross section and then divided by the associated strain under given loads. Construction stretch, the seating of wires and strands during loading, has a significant impact on the effective modulus of elasticity of a given rope. Pre-stretching the rope can minimize construction stretch. There are varying opinions about how this is best achieved. If one plots the load versus the displacement of wire rope subjected to repeated loadings, the construction stretch is depicted by the offset in each subsequent loading cycle. When the construction stretch is completely removed, there is no offset in the load path for subsequent loadings. Figure 2-16 shows a graphic depicting repeated loading and was provided by Brifen representatives.



**Figure 2-16. Load versus Displacement of Wire Rope (2).**

Some manufacturers achieve pre-stretching on long load beds and others through a series of tensioned sheaves during the manufacturing process. Different methods achieve different results. It is interesting to note that a non-pre-stretched wire rope will have an effective modulus of

11,000 kips per square inch (ksi) to 13,000 ksi. The researchers tested the rope after two years in the field and found almost a 50 percent increase in the effective modulus due to cyclic loading from temperature variations and proper field monitoring of the system. Perhaps the single greatest benefit from pre-stretched ropes is the decreased maintenance during the first two years of service. As construction stretch is removed, tension in the ropes decreases. Therefore, non-pre-stretched wire ropes require more monitoring and maintenance in the early years. Currently, TxDOT requires that all cable barrier systems be pre-stretched prior to field installation (40).

From a purely theoretical standpoint, the length of wire rope runs is unlimited. If the installer provides adequate mechanisms for tensioning the system, i.e., appropriate number of turnbuckles for types of ropes used, the construction and elastic stretch within the system can be accommodated. However, transportation agencies should consider emergency access and possible excessive lengths of out-of-service barriers due to high severity impacts. Coordination with local emergency services should be a part of any median barrier plan. While all system performance may not be lost from high severity impacts, the possibility of barrier penetration and crossover accidents increases with longer runs of wire rope barrier that have reduced tension due to previous impacts. The NCHRP 210(07) survey provided data from a number of state DOTs regarding the length of the longest run of cables between the anchors of a cable barrier system in their state (2). Forty-two percent of the participants indicated that the longest run of cables was less than 5,000 feet. About 23 percent of the states indicated the longest run to be between 5000 and 10,000 feet. The longest reported cable run among all participants was 41,000 feet (Trinity Industries system), followed by a 32,000-foot run (Brifen USA system). The current TxDOT guidance indicates that the maximum run of cable barrier between anchors should be approximately 10,000 feet (40).

#### *Coordinating with Other Safety Devices and Fixed Objects*

Another important design consideration for cable barrier systems is accounting for the interaction with other roadside safety devices and fixed objects. Common roadside safety devices such as W-beam guardrails and concrete barriers and fixed objects such as mainline bridge piers will often affect the design and placement of cable barrier systems in the median.

**Accommodating Mainline Bridges.** The NCHRP 210(07) survey asked participating states how mainline bridges were accommodated when using cable barrier systems (2). Nineteen percent of the respondents indicated not having encountered such a situation, while the majority indicated either tying the cable barrier into another *NCHRP Report 350* approved bridge terminal device or terminating it behind that device. Fifty-seven percent specifically indicated tying into or terminating behind the W-beam guardrail terminals. Guidance on cable barrier placement is important because impacts to bridge piers can cause substantial damage (see [Figure 2-17](#)).



**Figure 2-17. Impact with Bridge Pier on I-45 in Corsicana, TX.**

**Coordinating with Other Safety Devices.** The NCHRP 210(07) survey also asked participating states how they coordinated with other safety barriers or impact attenuators installed on the roadways (2). Methods similar to what were used for accommodating mainline bridges were employed. Most states indicated terminating the cable barrier behind the safety device or just before the device. In cases of the W-beam guardrail, several states indicated tying the cables into the guardrail. Two of the states specifically indicated that they avoid mixing two types of systems and therefore do not tie the cable barrier into the guardrail system. One of the states indicated that for two-sided attenuators, it terminates the barrier short of the device. However, for a one-sided guardrail system, it ties into the cable barrier. Another state indicated that the locations where a cable barrier is terminated before a safety device are used for crossovers by emergency and patrol vehicles. [Figure 2-18](#) shows a Texas location where the cable barrier system continued behind the W-beam guardrail barrier system in order to provide protection to the center bridge columns.



**Figure 2-18. Location Illustrating Cable Barrier Interaction with Other Safety Devices.**

**Coordinating with Fixed Objects.** The NCHRP 210(07) survey also asked participating states how their states typically coordinated with existing fixed objects such as bridge piers, inlets, sign bridges, etc. (2). Most of the states indicated using other types of hardware to protect the existing fixed objects and then either tying into this hardware or terminating the cable barrier behind the protection hardware. W-beam guardrail was the most commonly used protection hardware among the participating states. The FHWA Office of Safety Design issued a memorandum in May 2006 that provided detailed guidance on cable barrier transitions to W-beam guardrail (41). Some of the states indicated that whenever possible, cable barriers continue through the fixed object at some lateral offset that is sufficient to allow the design deflection.

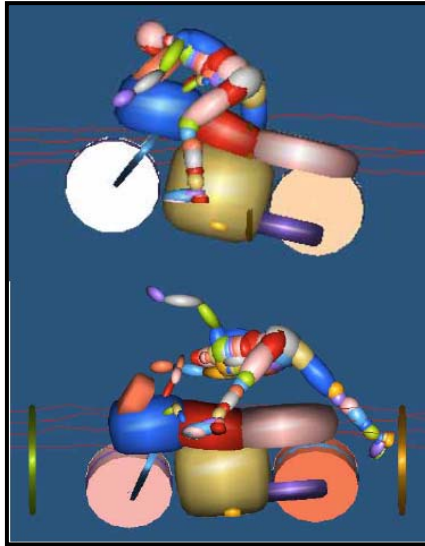
**General Guidance on Coordinating with Other Safety Devices and Fixed Objects.** The research team found several states in addition to Texas (40) with published design guidelines specific to cable barrier systems, notably Florida (42), Indiana (43), Illinois (44) and Missouri (7). Researchers found that the most prominent general guidance on coordinating with other safety devices and fixed objects was to have a 10 to 12 foot lateral clearance between the cable barrier system and any rigid obstacle.

#### *Impacts from Motorcycles and Vehicles Exceeding Design Loads*

One of the commonly cited disadvantages of cable barriers is their perceived lack of performance related to impacts from motorcycles and vehicles exceeding design loads (i.e., anything heavier than a 17,600 lb single-unit truck). The research team spent considerable time trying to gather and review data on these two issues, with somewhat limited success. At this point in time, there is not much published data on how cable barriers perform after impacts by motorcycles and vehicles exceeding design loads. However, researchers did gather a sizeable amount of anecdotal data regarding both subjects in Texas. This is a significant issue because national data show that the percentages of motorcycles and heavy vehicles continue to grow.

**Motorcycle Impacts.** Many motorcyclist safety groups have expressed concerns about cable barriers and motorcycle safety. There is a perception among motorcyclists that cable barriers are not designed to protect them and could potentially cause harm if they impact the barrier. The research team found that the subject of motorcycle impacts on cable barrier systems has not received much attention in the United States. The Washington State DOT (WsDOT) examined motorcycle collision data from Washington State, from other states, and internationally. WsDOT did not find any verifiable data that support the concern that cable barriers pose an increased risk for motorcyclists when compared to other barriers (37). Furthermore, WsDOT concluded that motorcyclists are relatively unprotected because they drive vehicles that do not have many of the safety features found in cars (seat belts/airbags). Consequently, the injury rate that occurs when motorcyclists hit any type of barrier is much higher than the rate when automobiles hit the barrier. In most instances, this occurs because the deceleration forces in a collision are imparted directly on the rider, rather than absorbed by the vehicle and its restraint systems. This is not true in Europe and other international locations such as Australia and New Zealand, where considerable scientific attention has been focused on the concerns of the motorcycle community with cable barrier system performance (45, 46, 47, 48). There is still no conclusive evidence that cable barrier systems are more hazardous to motorcyclists than any other type of roadside barrier system.





**Figure 2-19. Motorcycle-Cable Barrier Impact Model (48).**

This subject is important in Texas because of the significant mileage of cable barrier systems that has been deployed and the increasing number of fatalities involving motorcyclists. According to the fatal crash statistics available from the Texas Department of Public Safety (DPS) and the Fatal Analysis Reporting System (FARS), motorcycle fatalities in Texas have almost doubled from the 2000 calendar year (196) to the 2005 calendar year (365). The North Carolina DOT recently performed a comprehensive study of statewide motorcycle guardrail crashes between January 1, 2000, and December 31, 2007 – a total of eight years (49). The North Carolina researchers made an effort to distinguish the type of guardrail involved in each crash (cable, concrete, W-beam, wood), the barrier placement (shoulder or median), and the crash severity (K = fatal, A = incapacitating, B = non-incapacitating, C = possible injury and PDO = property damage only). The data showed that guardrail crashes made up 2.1 percent of the total number of motorcycle crashes (MC) and almost 5 percent of the fatal motorcycle crashes over the eight-year period (see Table 2-4). Cable barriers only accounted for less than 5 percent (24 of 503) of the motorcycle barrier impacts in North Carolina (see Table 2-5). According to Ray et al., North Carolina had the most miles of cable barrier (600) of any state in 2006 (23). This type of analysis shows that cable barriers, at least in North Carolina, are infrequently impacted by motorcycles, with approximately three crashes per year on a similar amount of barrier to what is in Texas.

**Table 2-4. Severity and Location of North Carolina Motorcycle Crashes (49).**

Placement	K	A B C		PDO	Total		% of Total Motorcycle Crashes
Shoulder	25 93		189	56	31	394	1.6
Median	22 27		44	13	3	109	0.4
<b>Total</b>	47 120		233	69	34	503	2.1
<b>% of Total MC</b>	4.9 4.1		2.0	1.2	1.0	2.1	
<b>Total MC Crashes</b>	969	2,954 11,4	68 5,59 8	3,242	24,321		

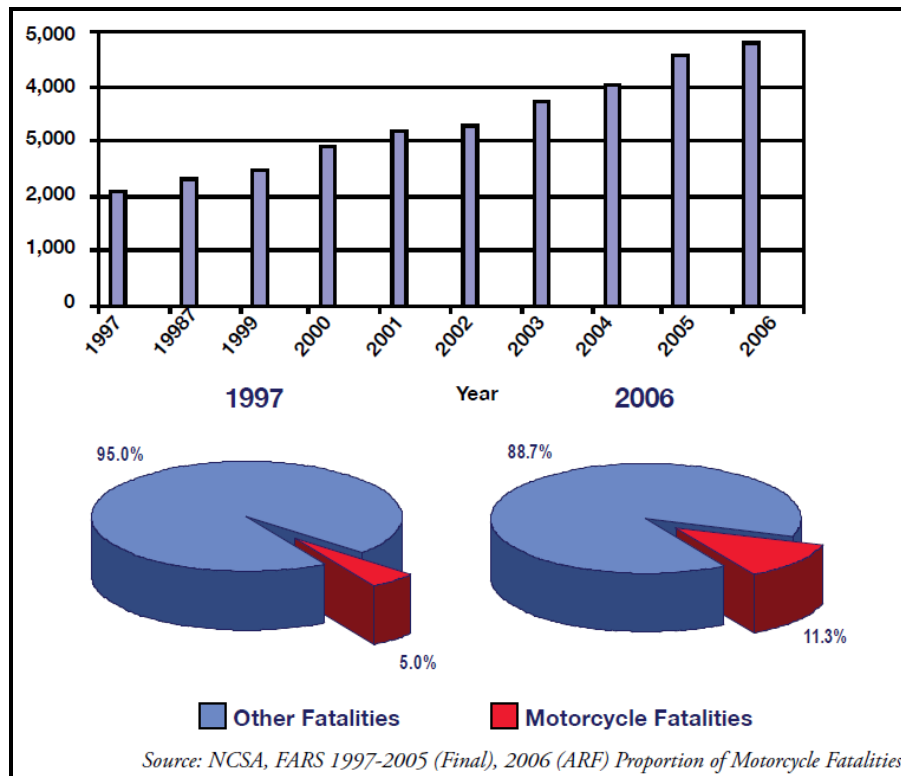
NOTE: Statewide crashes between January 1, 2000, and December 31, 2007.

**Table 2-5. Severity and Barrier Type of North Carolina Motorcycle Crashes (49).**

Barrier Type	K	A B C			PDO	Total	% of Total Barrier Motorcycle Crashes
Cable	6	5 8 4			1	24	4.8
Concrete	4 10		18	2	0	34	6.8
W-Beam	37 105		207	63	32	444	88.2
Wood	0	0 0 0			1	1	0.2
<b>Total</b>	<b>47 120</b>		<b>233</b>	<b>69</b>	<b>34</b>	<b>503</b>	<b>100.0</b>

NOTE: Statewide crashes between January 1, 2000, and December 31, 2007.

National data compiled by the National Highway Traffic Safety Administration (NHTSA) reinforces the Texas experience regarding the growing safety problem with motorcycles (50). Motorcyclist fatalities have increased 127 percent between 1997 and 2006, from 2,116 in 1997 to 4,810 in 2006 (see Figure 2-20). In 2006, motorcycle rider fatalities continued their nine-year increase, reaching almost 5,000 and exceeding the number of pedestrian fatalities for the first time since NHTSA began collecting fatal motor vehicle crash data in 1975. In 2005, the motorcycle fatality rate was 73 per 100,000 registered motorcycles. By comparison, the fatality rate the same year for passenger vehicles per 100,000 registrations was 14. Much of the increase in motorcycle fatalities can be attributed to their increasing popularity due to economic savings (fuel price and capital cost). Between 1997 and 2005, motorcycle registrations jumped 63 percent, from 3.8 million in 1997 to 6.2 million in 2005.



**Figure 2-20. Motorcycle Rider Fatalities by Year in the United States (50).**

### *Vehicles Exceeding Design Loads*

As with motorcycles, the research team found that the subject of impacts on cable barrier systems by vehicles exceeding design loads has not received much attention in the United States. Although there is a lack of published research, researchers did uncover considerable anecdotal evidence regarding cable barrier performance with vehicles exceeding design loads. Alberson found that 73 percent of respondents indicated that they had experienced one or more impacts in their state where high-tension cable barriers were successful in containing vehicles exceeding the design speed and vehicle mass (13). The experience in Texas has been favorable with vehicles exceeding design loads. The majority of TxDOT districts surveyed indicated having one or more successful containments of a vehicle exceeding 17,600 lb. Figure 2-21 shows a photograph of a semi-tractor trailer that was captured by the cable barrier system on I-20 in Kaufman County. Another example is the event shown in Figure 2-22, where the cable barrier system performed well on I-20 in Parker County by capturing two large vehicles prior to them crossing into the opposing travel lanes. The Oregon DOT produced a technical services bulletin entitled *Guidance on the Use of Cable Barrier on Highways* in September 2007 (51). This document provided some guidance on the relationship between cable barrier usage and vehicles exceeding design loads, stating:

*Care must be taken on interstate highways and freight routes where truck mix tends to be higher than the norm, to account for the fact that no cable system has been tested against semi trucks. A semi truck can stretch cable many times more than the design-tested deflection, and will usually hold the cable at maximum deflection until the truck and cable are untangled from each other. The design should account for extra deflection if there is a site-specific history of truck cross-over incidents. For extra measure of protection the designer should consider use of NCHRP Test Level 4 system in cases like this.*



**Figure 2-21. Successful Capture of Large Vehicle on I-20 in Kaufman County, TX.**



**Figure 2-22. Successful Capture of Large Vehicles on I-20 in Parker County, TX.**

### **Guidance on Barrier Placement**

The research team discovered a significant amount of guidance regarding the placement of cable barrier systems in medians. Placement of cable median barrier is thought to be more complex than most roadside hardware. This belief is because, unlike typical strong-post guardrails, cable barriers are generally located farther away from the edge of the traveled way, and they are almost always installed in association with some type of depressed median with a drainage function. Strong-post guardrails are most often installed at the edge of the shoulder, so the approach slope is generally nearly flat and the surface is generally paved or a well-compacted base material. Cable barriers, on the other hand, may be at the edge of the shoulder, in the center of the median in the middle of the drainage feature, or somewhere on the grassy slope of a depressed median. Cable barriers may be more prone to performance problems precisely because they are often positioned farther from the traveled way and on slopes. Vehicle trajectories will be affected by the slope, and there is more chance for a vehicle to strike the barrier at difficult impact conditions involving non-tracking and out-of-position suspensions. Anecdotally, approximately a dozen litigation actions have been brought in Arizona regarding cable median barrier failures, and all of them involve some combination of non-standard impact conditions (i.e., non-tracking, out-of-position suspension/bumpers, high speed, and high impact angles) and non-standard vehicles (i.e., sport utility vehicles [SUVs], towing trailers, convertibles, etc.). Cable barriers may be more susceptible to these untested scenarios because of the decisions about where to place the barrier in the median. The guidance review revealed three primary placement considerations:

- median slopes,
- lateral placement, and
- coordination with roadway alignment.

#### *Median Slopes*

As with most roadside safety devices, the slope of the depressed median ditch is an important placement issue. Generally, the *AASHTO Roadside Design Guide* recommends that barriers not

be placed on slopes greater than 10:1, but the 2002 RDG specifically states that cable barriers are effective on slopes up to 6:1. As shown in [Table 2-3](#), most states allow location of cable barriers on slopes 6:1 or flatter, and some even consider using cable barriers on slopes as steep as 5:1 (e.g., Missouri). Good performance during vehicle impacts is achieved through proper interaction of the cables with the vehicle. On steep cross sections/ditches, greater than 6:1, vehicles can become airborne; therefore, placement is critical to prevent system override or underride. Manufacturers typically test the worst case where acceptable performance can be achieved. If the manufacturer successfully tests its system at some distance off the break point on a 4:1 slope, distances less than the tested distance are considered less critical. Since vehicle suspension affects back slope barrier placement, one must consider the overall ditch configuration for traffic in both directions. Placement too near the ditch bottom can allow underride, and at some distance from the ditch bottom there is override potential due to rebound.

#### *Missouri DOT Evaluation on Slopes Steeper than 6:1*

The Missouri Department of Transportation (MoDOT) performed an in-service performance evaluation of cable median barrier performance on slopes steeper than 6:1 ([52](#)). The background of this ISPE was that MoDOT received a design exception from the FHWA to place cable median barriers on slopes as steep as 5:1 on the I-70 safety project. Two years later, the FHWA refused a design exception to place cable median barriers on any slope steeper than 6:1 on an I-44 safety project. MoDOT officials believed that cable median barriers were already in place and performing well on slopes steeper than 6:1. With nothing more than sweeping generalities to back this claim, MoDOT commissioned a study to truly gauge performance.

**MoDOT Slope ISPE Overview.** Cable barriers were first installed in Missouri on I-44 in 1999. Currently, MoDOT has cable barriers along I-70 and at some locations on I-270, I-44, I-55, and I-435, with more proposed. Cable barriers are intended for use on a maximum 6:1 slope. In practice, however, slopes as flat as 6:1 do not always exist. In the interest of practicality, MoDOT installed cables in the medians with slopes steeper than 6:1. This slope ISPE determined the actual performance of cable barriers on different slopes. For the purpose of this study, when a vehicle crashed into a cable barrier, the performance of the cable barrier was defined either as a “success” or “failure.” “Success” meant that the vehicle did not make it to the opposing travel lanes. “Failure” meant that the vehicle went through the cable barrier system and reached the opposing travel lanes. The MoDOT investigators identified 1,402 cable barrier crashes from 1999 to 2005. Among the 1,402 crashes included, 67 of them were considered to be failures, which gave an average 95.2 percent success rate. Field surveys determined the cross section at the crash locations. After collection of geometric data, the MoDOT investigators conducted a data analysis, tying the crashes to cross section data to the performance of cable barriers. With 1,400 potential sites to survey, I-44 was chosen as a sample because the median slope varies most along the stretches with cable barrier installed. One-hundred and forty sites along I-44 were surveyed to obtain median slope data for 225 crashes. The median slopes surveyed range from 2.7:1 to 24.1:1, with a median value of 6.2:1 and an average of 6.4:1.

**MoDOT Slope ISPE Findings.** Among the 225 cable barrier crashes, 103 of them happened on median slopes steeper than 6:1, with seven failures (see [Table 2-6](#)). These failures result in a success rate of 93.2 percent for the cable barrier on slopes steeper than 6:1. The other

122 crashes happened on median slopes equal to or flatter than 6:1, with 10 failures. These failures result in a success rate of 91.8 percent for the cable barriers on slopes equal or flatter than 6:1. Because the success rate is similar, design guidelines could be revised to allow installation on steeper slopes without re-grading them to a 6:1 slope.

**Table 2-6. Slope versus Performance or Success for Cable Barriers in Missouri (52).**

Slope	Total Count of Crashes	Count of Failure	Fail Rate (%)	Count of Success	Success Rate (%)
<b>S &lt; 3 (Steeper)</b>	1	0 0 1			100
<b>4 &gt; S ≥ 3</b>	15 0		0	15	100
<b>5 &gt; S ≥ 4</b>	30	3	10 27	90	
<b>6 &gt; S ≥ 5</b>	57 4		7	53	96
<b>7 &gt; S ≥ 6</b>	57 5		8.8	52	91.2
<b>8 &gt; S ≥ 7</b>	29 0		0	29	100
<b>9 &gt; S ≥ 8</b>	22 1		5	21	95
<b>10 &gt; S ≥ 9</b>	6	3 50		3 50	
<b>10 &gt; S (Flatter)</b>	8	1 12.5		7 87.5	
<b>Total</b>	225 17		7.6	208	92.4

Based upon preliminary data, the MoDOT ISPE offered the following two conclusions:

- There is a high success rate of cable barriers preventing vehicles encroaching into opposing lanes. Missouri experienced an average of 95.2 percent success rate with reported cable barrier crashes on five interstate highways over a period of seven years.
- From the data collected on I-44, median slope does not have a sole effect on the success or failure of the barrier. The success rate on medians steeper than 6:1 is 1.4 percent higher than on the flatter medians. Assuming a 5 percent significance level, statistically there is no difference between the two groups. With a confidence level of 95 percent, the MoDOT study concluded that the steepness of the slope alone does not cause the cable barrier to fail any more or less.

### *Lateral Placement*

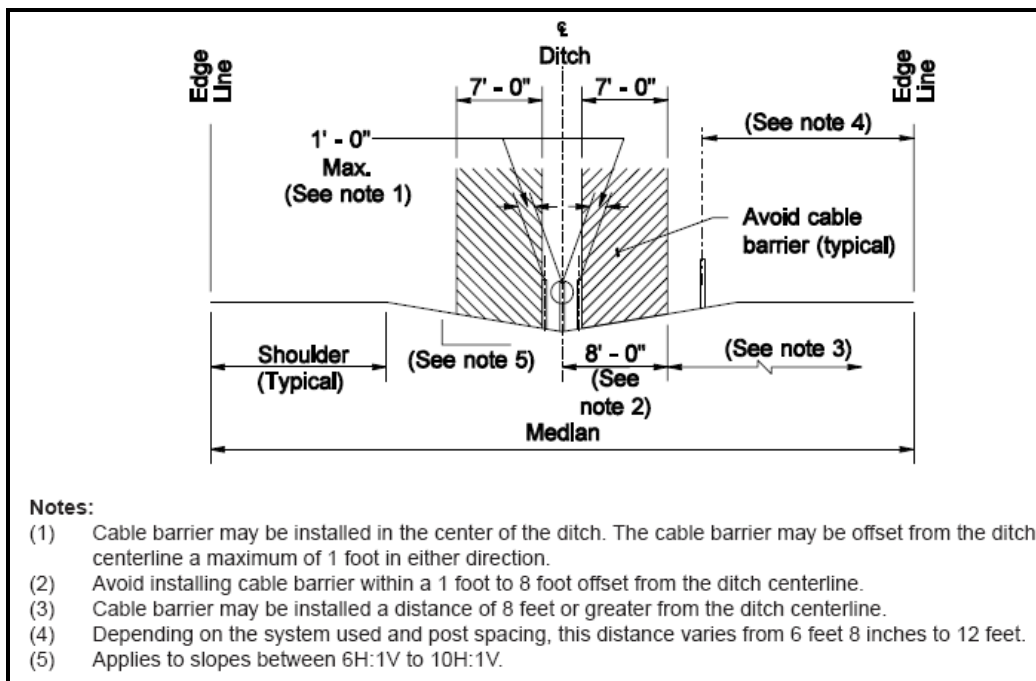
The research team identified the following two primary concerns regarding the lateral placement of cable barrier systems in roadway medians:

1. barrier performance in effectively preventing vehicles from crossing the median into the opposing travel lanes, and
2. frequency of vehicle impacts based on the relative proximity of the barrier to travel lanes.

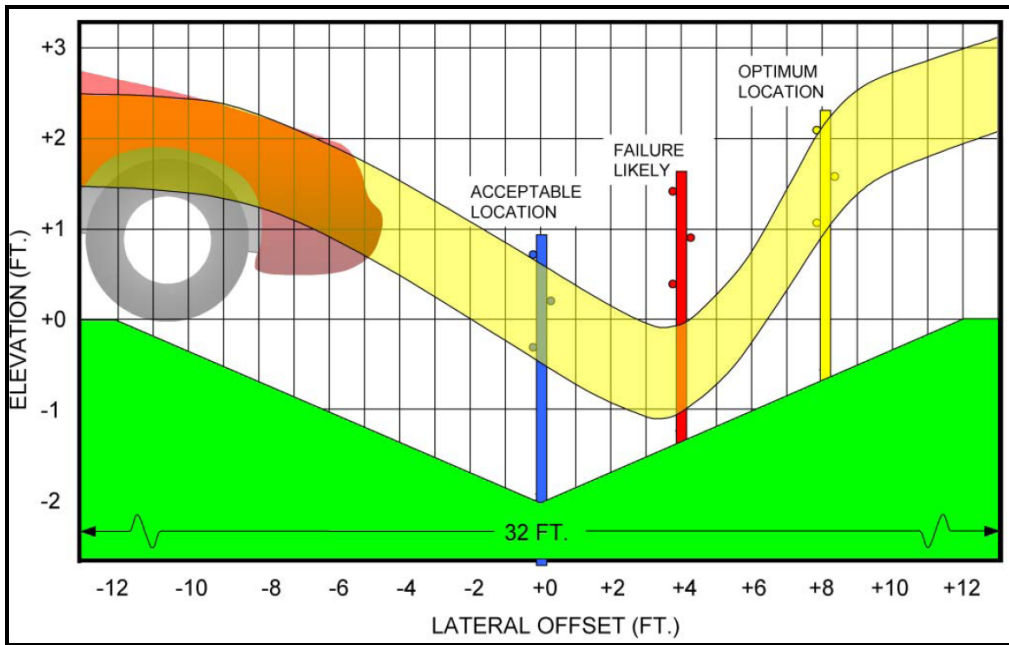
Researchers synthesized current practice and guidance on each of these two concerns.

**Placement Effect on Barrier Performance.** The primary objective of cable barrier systems is to prevent crashes that would be more severe if a barrier were not present. Roadway safety professionals have to also consider the effect of barrier placement on overall performance, particularly the ability to effectively prevent cross-median crashes. The primary placement consideration for these professionals is that cable barrier systems need to be located in order to accommodate their inherent design features (e.g., deflection, need for two cables for effective capture, etc.). There is a considerable diversity of thought regarding the placement of cable median barriers within the median cross section for depressed medians with 6:1 or flatter slopes. Some states always put the barrier essentially in the center of the median (e.g., Arizona), which generally corresponds to the centerline of the ditch in a depressed median. Other states place the barrier at least 8 feet from the centerline of the ditch (e.g., Washington) since it has been demonstrated in one crash test that the bumper height may be too low in this area after the vehicle has crossed the ditch bottom. Since cable median barriers can be struck from either side, both sides of the median must be considered as approach slopes.

Based on the limited testing done at the National Crash Analysis Center (NCAC) at George Washington University (53), some states (e.g., Texas and Washington) have adopted the policy shown in Figure 2-23 where the cable barrier can be located within one foot of the center of the ditch or it must be at least 8 feet from the center of the ditch (23, 40). Figure 2-24 illustrates how a vehicle traverses a median and shows acceptable placement — placement where failure is likely — and the optimum location (54). On the other hand, since the cable barrier can be struck from either side, it must be far enough from the opposite traveled way to prevent encroachment. Generally, states have indicated the barrier must be at least 14 feet from the nearest traveled way. Therefore, recommending lateral placement of cable barriers has become somewhat complicated.



**Figure 2-23. Washington State DOT Cable Barrier Placement Guidelines (23).**



**Figure 2-24. Vehicle Trajectory Trace in Median Wider than 30 Feet (54).**

**Placement Affects Impact Frequency.** Another important placement objective, from both a safety and economic standpoint, is that barriers should be located so that impacts are minimized. All roadside safety features are subject to impact by vehicles. Lateral placement of the cable barrier systems is critical to performance and minimizing impacts with the system. Common sense indicates that performance is generally enhanced when the system is placed on flat, level terrain, and this is typically found closer to the roadbed. However, when the system is placed farther from the travel lanes, the number of impacts will be minimized by allowing errant drivers space and time to recover. This ability to recover is more likely in wider medians, and cable barrier systems are often utilized in medians up to 70 feet in total width. Ideally, cable barrier systems should be placed as far from the travel lanes as possible in a location where they will still perform according to their optimum design.

**Current TxDOT Guidance.** In July 2008 a TxDOT memorandum recommended that as a general rule, a barrier should be placed as far from the traveled way as possible while maintaining the proper operation and performance of the system (35). Figure 2-25 provides the most recent version of the desirable barrier placement in non-level (i.e., depressed, constant slope, and raised) medians in Texas. This guidance does not apply to slope conditions steeper than 6:1 (the TxDOT Design Division can be contacted for assistance in the proper location of the barrier along the slope).

#### *Coordination with Roadway Alignment*

The two primary considerations for placement of cable barrier related to roadway alignment are horizontal and vertical curves. Each geometric condition presents different challenges from a barrier placement perspective.



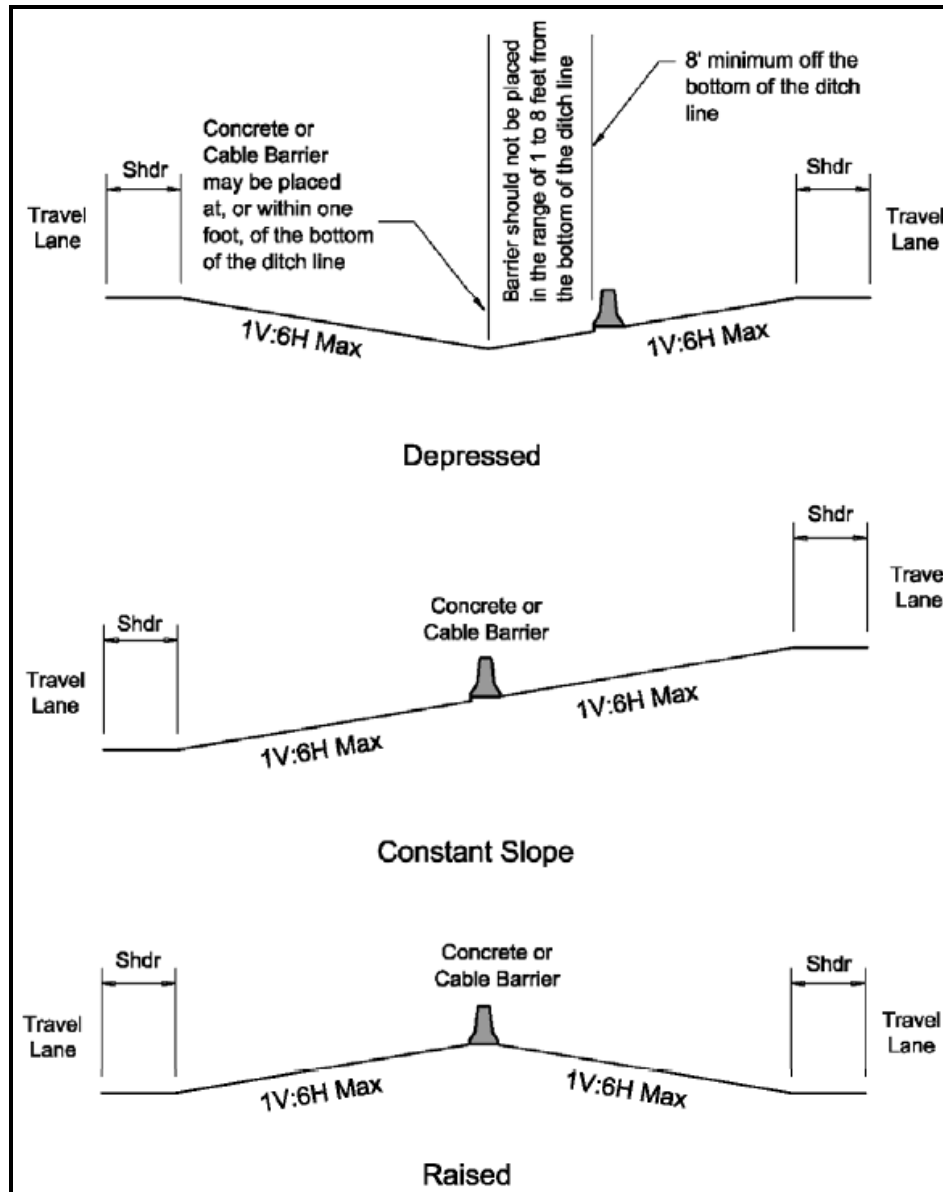
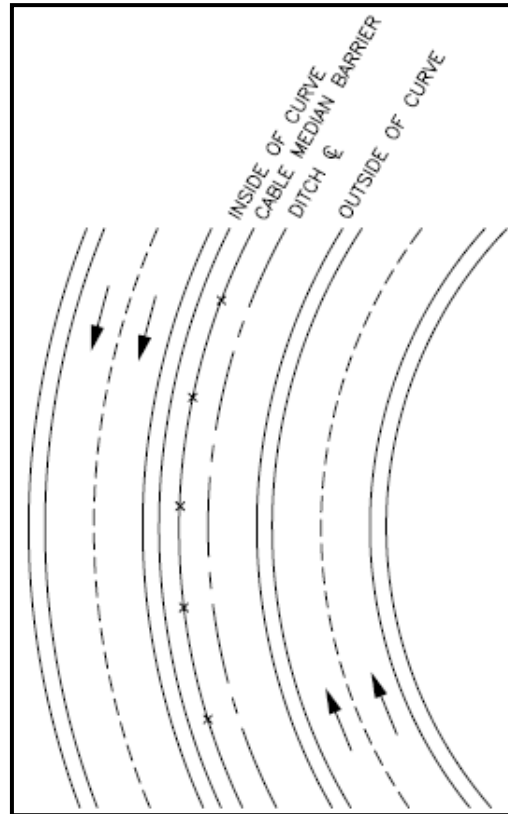


Figure 2-25. Desirable Barrier Placement in Non-Level Medians in Texas (35).

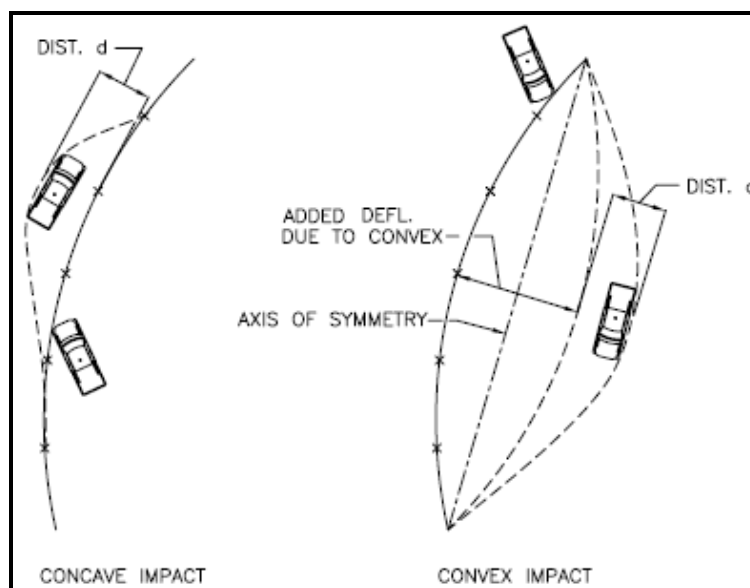
**Placement Considerations for Horizontal Curves.** According to Alberson et al., there are two major items to consider when horizontal curves are encountered — horizontal placement and expected deflections (2). Numerous crash evaluations have shown a higher frequency of vehicles inadvertently leave the roadway on the outside versus the inside of the same horizontal curve. Therefore, when placing cable barrier systems offset from the ditch bottom, the barrier should be placed toward the inside rather than the outside of the curve, as shown in Figure 2-26.

Alberson et al. also concluded that horizontal curvature has a direct impact on deflection associated with vehicle impacts (2). Since almost all the redirection is accomplished by tension in the wire rope, one can envision the differences associated with impacts on the concave and convex sides of the system. When the system is impacted on the concave side, the wire ropes are aligned tangent to the curve during impact; therefore, the system tensioning is continuous.

Impacts on the convex side must take the wire ropes through a zone of low or negligible tension until tension is re-established in a straight line to the nearest undamaged anchor. Consequently, the distance associated with low or negligible tension adds directly to overall system deflection distance. [Figure 2-27](#) shows this performance aspect.



**Figure 2-26. Cable Barrier Placement on Curves (2).**



**Figure 2-27. Deflection of Concave versus Convex Impacts of Cable Barrier (2).**

If a barrier is placed to minimize impacts/increase recovery areas in curves, additional deflection distance will be necessary for impacts on the convex side of the system. Alberson et al. reviewed the increased deflections associated with horizontal curvature, and deflection magnification factors were developed through a parametric study of Barrier7 runs on concave impacts on low-tension cable barriers with standard post spacing of 16 feet (5 meter) (19). Table 2-7 reproduces the results of the parametric study.

**Table 2-7. Multiplying Factors for Barrier Design Deflections (2).**

Barrier Length (meters)	Degree of Curvature (degrees)								
	0°	0.5°	1°	1.5°	2°	2.5°	3°	3.5°	4°
30	0.85	0.88	0.89	0.91	0.91	0.93	0.95	0.97	0.99
60	0.96	0.98	1.01	1.05	1.08	1.12	1.17	1.21	1.26
90	1.00	1.06	1.11	1.14	1.17	1.23	1.28	1.33	1.39
120	1.08	1.11	1.17	1.21	1.29	1.32	1.35	1.48	1.55
150	1.11	1.16	1.20	1.25	1.34	1.38	1.49	1.56	1.68
180	1.14	1.19	1.25	1.30	1.38	1.49	1.57	1.69	1.77
210	1.17	1.20	1.28	1.38	1.46	1.53	1.66	1.74	1.84
240	1.18	1.21	1.35	1.42	1.50	1.57	1.70	1.80	1.91
270	1.18	1.28	1.35	1.43	1.51	1.62	1.75	1.84	1.98
300	1.18	1.29	1.37	1.45	1.57	1.67	1.77	1.88	2.12
330	1.18	1.30	1.37	1.46	1.59	1.71	1.81	1.95	2.18
360	1.19	1.30	1.39	1.48	1.62	1.74	1.86	2.01	2.24
390	1.19	1.30	1.39	1.49	1.64	1.76	1.90	2.07	2.42
420	1.19	1.30	1.41	1.50	1.66	1.80	1.95	2.23	2.50
450	1.19	1.30	1.43	1.56	1.69	1.83	2.00	2.26	2.54

Note: Baseline for design deflections is a 90 m barrier length with no curvature.

Current TxDOT guidance recommends closer post spacing through curves and placing the cable barrier system on the convex side to allow maximum median availability for deflection (40). Table 2-8 shows the recommended post spacing based on the radius of the horizontal curve.

**Table 2-8. Existing TxDOT Guidance on Post Spacing on Horizontal Curves (40).**

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

**Placement Considerations for Vertical Curves.** According to Alberson et al., some of the cable barrier systems have limited upward capability for carrying vertical loads (2). As such, vertical sag curves may allow the wire ropes to lift or partially lift out of the post and increase the likelihood of vehicle underride. On socketed systems, there is generally no attachment of the posts to the sockets. Therefore, if the wire ropes are more firmly attached to the post, they may lift the post out of the socket on vertical sag curves and increase the opportunity for vehicle underride. Some manufacturers have attempted to lengthen the top of the socket sleeve for bolting purposes; however, the extended sleeve portion is often damaged during impact, rendering the bolting mechanism unusable. TxDOT guidance recommends avoiding sag vertical alignments with radii of less than a K-value of 11 (40).

Another consideration related to vertical alignment is that the placement of the cable system should take into account the drainage facilities located in the median. Cross drainage structures such as box culverts with less than 36 inches of cover pose a challenge for placing posts. Current TxDOT guidance indicates that structures of less than 16 feet can be spanned, and construction of these runs of cable should take these structures into account prior to setting post locations.

### **Guidance on General System Considerations**

The research team discovered a significant amount of guidance regarding general system considerations related to application of cable barrier systems. The guidance review revealed five primary general system considerations, including:

- maintenance,
- anchor terminals,
- mowing requirements,
- soil conditions,
- delineation, and
- emergency vehicle access.

All of these considerations are important to the overall success of cable barrier system implementation. The research team briefly highlights some of the issues and guidance for each of these considerations in the following subsections.

#### *Maintenance*

Maintenance issues for cable barrier systems might be the most overlooked issue because of the overwhelming desire to install as much barrier as possible to prevent cross-median crashes. Many sources have found that cable barrier systems are anywhere from 25 to 33 percent of the cost per mile for installation as compared to concrete median barriers. In addition to the low initial cost advantage, cable barrier systems are also considered aesthetic and provide a lower risk of injury when struck because of the longer deflection and dissipation of kinetic energy. These advantages have to be weighed against the long-term cost of maintaining the barriers. Several studies have reported typical ranges of maintenance cost for cable barrier systems, typically on a per impact or per mile per year basis.

The NCHRP 20-7(210) study performed by Alberson et al. collected a wealth of maintenance-related information from 27 states with installed cable barrier systems that will be helpful in the current project (2). Some of the maintenance-related information included:

- preferred barrier location for repair personnel;
- post type (socketed vs. direct driven vs. mow strip);
- longest cable lengths between anchors;
- cable tension measurement methods;
- typical time required for tensioning;
- reasons for barrier penetration;
- effect on impact severity;

- barrier functionality after impact;
- crashes with vehicles exceeding design loads;
- lateral barrier deflection;
- damage to concrete sockets;
- effects of wet medians, poor soils, or frost;
- vehicle redirection back into traffic;
- repair material quality, availability, and level of difficulty;
- pre-impact damage; and
- mowing and snow plowing operations.

**Limited Guidance.** The research team found limited published guidance related to maintenance of cable barrier systems, except for what manufacturer manuals contain. While state DOTs have produced some detailed guidance on barrier selection, design, and placement, not much attention has been given to maintenance-related guidelines. MoDOT has produced maintenance planning guidelines for cable barrier systems that are somewhat generic. Researchers did find that several states, including Colorado (55) and Kentucky (56), have produced pamphlets to educate emergency response agencies about the issue of cutting the cable when a vehicle is entangled after an impact (see Figure 2-28).



Figure 2-28. Colorado DOT Pamphlet.

## Anchor Terminals

Researchers found that the consideration of anchor terminals has received a significant amount of attention recently. The currently available guidance related to anchor terminals concentrated on three categories:

- placement,
- spacing/run length, and
- footing design.

**Anchor Placement.** Terminal anchors are an extremely important part of a cable barrier system because they effectively hold down the barrier and keep the wire ropes in tension. The high-tension cable barrier systems utilize several different types of standard terminal anchor designs. Some cable barrier systems use individual anchors for each wire rope, and some systems anchor all wire ropes at single anchors. The Trinity and Nucor systems (Figure 2-29) use single anchors for each wire rope, and the Gibraltar (Figure 2-30) and Brifen (Figure 2-31) systems terminate all wire ropes at a single anchor point. These are the primary systems used in Texas, and they terminate to concrete drilled shafts. Several states, including Texas, have addressed the issue of where to place anchors for the best overall effectiveness (40). Generally, anchor terminals for cable barriers should be placed behind some protection, such as a metal beam guard fence, when possible so that they are protected from possible hits. Cable anchor terminals are also gating, which means that they will not prevent a vehicle from going through. Current TxDOT guidance suggests that if switching the cable barrier from one median side to the other and the terminals are not protected, overlapping runs of cable barrier is recommended to provide adequate protection from possible crossovers (Figure 2-32).

**Anchor Spacing – Run Length.** The research team found existing guidance on the minimum and maximum recommended spacing between anchor terminals for cable barrier systems. The distance between anchor terminals is also commonly referred to as a cable run. From a purely theoretical standpoint, the length of wire rope run is unlimited. If the installer provides adequate mechanisms for tensioning, i.e., appropriate number of turnbuckles for types of ropes used, the construction and elastic stretch within the system can be accommodated.

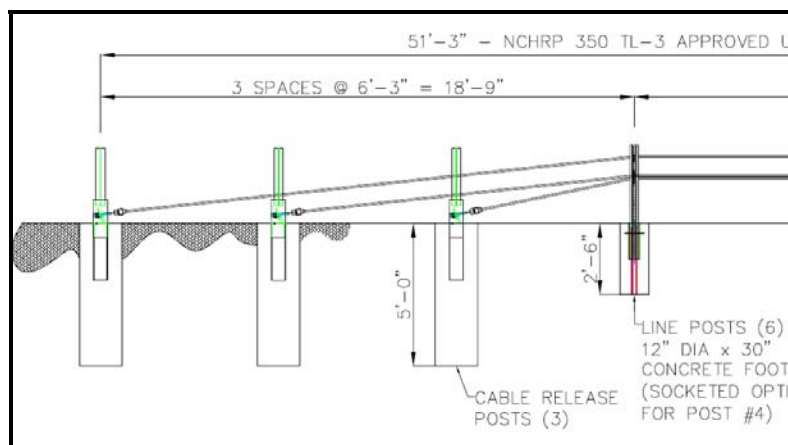


Figure 2-29. Trinity and Nucor Cable Barrier Anchor Terminal.

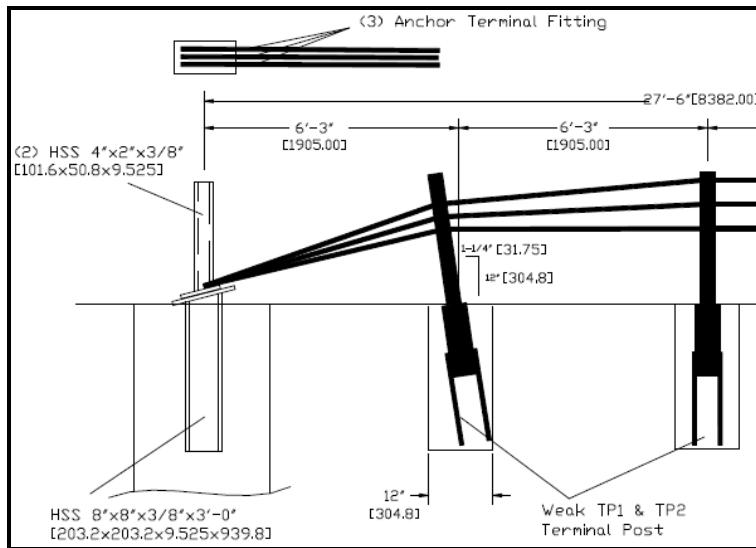


Figure 2-30. Gibraltar Cable Barrier Anchor Terminal.

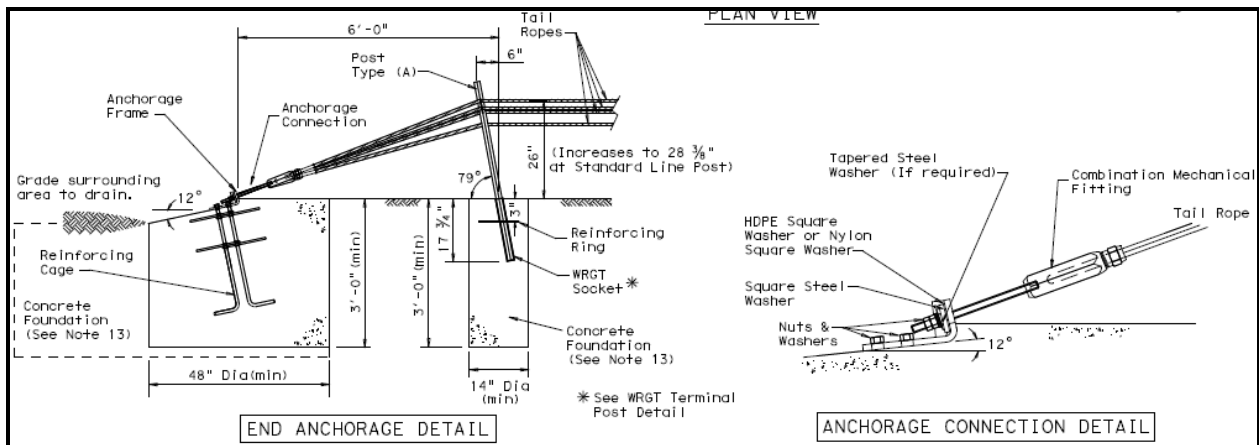


Figure 2-31. Brifen Cable Barrier Anchor Terminal.

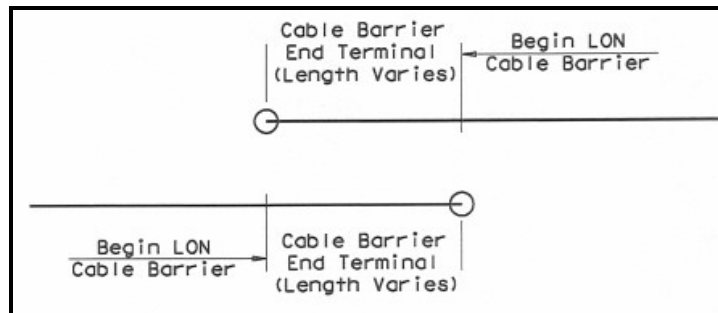


Figure 2-32. Recommended Cable Barrier Overlap Length (40).

A recommended maximum run of cable barrier between anchors should be approximately 10,000 feet. This length allows for proper tensioning of the system and reasonable construction installation time to get a run in operation. Runs of shorter and longer lengths between anchors may be appropriate in specific locations, and each run should be determined to meet the field

situations, such as the location of bridge piers and other structures that conflict with the system performance. Due to the length needed for transition sections from terminal anchors to the standard cable section, cable barriers are not well suited for short barrier runs. The minimum length of a run should be 1,000 feet.

### *Mowing Requirements*

While cable barrier systems have many inherent advantages over other median barriers, there can be significant difficulty associated with mowing requirements (Figure 2-33). The Wisconsin DOT recently completed a synthesis report entitled *Managing Vegetation under Cable Median Barriers: Mow Strip Design and Practices* (57). This synthesis focused on addressing the difficulties associated with removing grass and other vegetation that may grow under cable barriers. A common solution employed throughout the United States is a mow strip – a narrow piece of pavement or other material placed directly beneath the barrier to prevent the growth of vegetation and facilitate mowing (see Figure 2-34).



**Figure 2-33. High Grass and Vegetation around a Cable Barrier System.**



**Figure 2-34. Concrete Mow Strip in Texas.**



The research team determined the following typical guidance on use of mow strips for cable barrier systems:

- width = 4 feet (widths ranged from 2 to 6 feet);
- thickness = 3 inches (thicknesses ranged from 2 to 6 inches); and
- material = concrete (asphalt and aggregate were other materials).

Current TxDOT guidance related to mowing requirements suggests (40):

*For future maintenance considerations, the Maintenance Division encourages the use of mow strips to reduce future hand mowing or herbicide operations. Distance between the edge of travel lanes and the cable barrier should consider mower widths.*

This guidance does not offer a specific distance sufficient to handle typical mowing operations.

#### *Soil Conditions*

Another general consideration in the deployment of cable barrier systems is related to soil conditions. *NCHRP Report 350* requires that all systems be installed in standard soil for full-scale crash testing (58). However, *NCHRP Report 350* also states in section 2.2.1:

*Impact performance of some features depends on dynamic soil structure interaction. Longitudinal barriers with soil-embedded posts and soil-embedded support structures for signs and luminaires are such features. When feasible, these features should be tested with soil conditions that replicate typical in-service conditions.*

Additionally, since crash test installations are installed for relatively short periods of time, long term effects may not be captured in crash test installations. In-service evaluation reports have revealed that a number of states (Indiana [59], Rhode Island [60], and Texas) have experienced movement of anchor terminal foundations in a few of the different systems (see Figure 2-35 and Figure 2-36). High plasticity and/or highly saturated soils have typically been the problem areas. Transportation agencies should determine soil properties before placement of the systems. Proper design of the anchor footings will increase performance of the system over its life. If the project engineer designs the footing for the expected maximum sustained static tension load (cold weather), agencies can expect good performance under most dynamic load conditions.

NCHRP Report 210-7 recommends that **terminal anchor sections and sockets be designed for prevailing conditions at installation locations** (2). Furthermore, this report indicates that continuous mow strips have also eliminated socket and anchor movements in weaker soil conditions. It should be noted that some states have developed specifications and procedures to address soil considerations for cable barriers. The Arizona DOT 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. (61)*

Florida and Indiana DOTs 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 (42, 43). Also, Dr. Dean Sicking from the University of Nebraska gave a presentation at the 2007 Transportation Research Board 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 soil conditions (62).



**Figure 2-35. Example Photograph of Dislodged Anchor Terminal in Rhode Island (60).**



**Figure 2-36. Example Photograph of Anchor Terminal Failure System in Texas.**

Currently, the TxDOT Design Division memorandum on cable barrier systems does not provide any guidance on soil considerations for barrier performance (40). 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” (63). Currently, study of soil data is not done in the case of cable barrier installation in Texas because TxDOT does not require it, therefore allowing manufacturers to use their standard designs. TxDOT is sponsoring a currently ongoing research project entitled *Design of Short, Laterally-Loaded Drill Shafts in High-Plasticity Clay* (Project 0-6146) that will provide detailed guidance to address the issue of soil conditions’ effect on cable barrier system design and implementation.

### *Delineation*

Proper delineation of roadside safety hardware is important so that nuisance hits by motorists can be avoided, particularly at night. The research team identified that state DOTs are using several techniques to delineate cable barrier systems, including:

- yellow reflective tape on the cable barrier posts (Figure 2-37), and
- yellow reflective tape on special reflective white poles extending up from the cable barrier posts (Figure 2-38).

Current TxDOT guidance indicates that delineation should be at 100-foot spacing, unless otherwise approved by the project design engineer (40).



**Figure 2-37. Picture Showing Delineators Inset in Cable Barrier Posts.**



**Figure 2-38. Picture Showing Special Extended Delineators.**

### *Emergency Vehicle Access*

The research team identified a number of issues related to emergency service providers and cable barrier systems. Researchers believe the primary issue relates to the provision of breaks in the barrier that allow emergency vehicles such as police, fire, and ambulances to safely access the other direction of travel (Figure 2-39). The second product of this research, the *Cable Median Barrier Maintenance Manual*, deals extensively with the maintenance-related aspects of coordinating with emergency service providers, including:

- joint training,
- vehicle removal procedures,
- cost recovery from responsible parties, and
- provision of emergency turnarounds/crossovers.

This section only addresses the last bullet in the previous list – the design guidance and policies related to the provision of emergency turnarounds (sometimes referred to as emergency crossovers).



**Figure 2-39. Picture Showing a Typical Emergency Crossover.**

A review of state guidelines and policies revealed that the maximum distance between emergency turnarounds typically varies between 1 to 5 miles. Research shows that states use different methods for handling crossovers. Some states allow a gap for crossovers by terminating and restarting the cable barrier. Some other states use a staggering technique, in which the ends of two cable barrier installations are installed at a lateral offset from each other. This technique minimizes the window through which an errant vehicle can cross over the median at design speed and encroachment angle. Overlapping the ends of two cable barrier installations is another

technique employed by some of the states. In this method some lateral gap is left between the overlapping ends of the two installations. The gap can be used by patrol or emergency vehicles to cross over after making an S-turn. Some states indicated switching sides of the median at a crossover location in addition to staggering and/or overlapping the barriers.

## REFERENCES

1. *Roadside Design Guide*, Third Edition. American Association of State Transportation and Highway Officials, Washington, D.C., 2006.
2. D.C. Alberson, N.M. Sheikh, and L.S. Chatham. *Guidelines for the Selection of Cable Barrier Systems – Generic Design vs. High-Tension Design*, NCHRP Project 20-7(210) Final Report, Prepared for NCHRP, July 2007.
3. R.P. Bligh, S. Miaou, D. Lord, and S.A. Cooner. *Median Barrier Guidelines for Texas*, Research Report 0-4254-1, Texas Transportation Institute, College Station, TX, August 2006. [Online]: <http://tti.tamu.edu/documents/0-4254-1.pdf>. Link Accessed November 30, 2009.
4. *Motorcoach Median Crossover and Collision with a Sport Utility Vehicle – Hewitt, Texas – February 14, 2003*. Highway Accident Report, National Transportation Safety Board, Report No. NTSB/HAR-05/02, July 12, 2005. [Online]: <http://www.nts.gov/publictn/2005/HAR0502.pdf>. Link Accessed November 30, 2009.
5. P.J. Kostowski. *Sherman, Texas – Motor Carrier Group Chairman’s Factual Report*, National Transportation Safety Board, September 2004. [Online]: [http://www.dallasnews.com/sharedcontent/dws/spe/2006/transportation/chairmans\\_report.pdf](http://www.dallasnews.com/sharedcontent/dws/spe/2006/transportation/chairmans_report.pdf). Link Accessed November 30, 2009.
6. Roadside Hardware Homepage – Federal Highway Administration. [Online]: [http://safety.fhwa.dot.gov/roadway\\_dept/policy\\_guide/road\\_hardware/](http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/). Link Accessed November 30, 2009.
7. Missouri Department of Transportation, Engineering Policy Guide 606.2 – Guard Cable, October 2006. [Online]: [http://epg.modot.org/index.php?title=606.2\\_Guard\\_Cable](http://epg.modot.org/index.php?title=606.2_Guard_Cable). Link Accessed November 30, 2009.
8. Cable Barrier Technology Implementation Group Homepage. American Association of State Highway and Transportation Officials. [Online]: <http://tig.transportation.org/?siteid=57&pageid=1031>. Link Accessed November 30, 2009.
9. High-Tension Cable Scanning Tour Report. Traffic Operations Laboratory, University of Illinois at Urbana-Champaign, December 2005. [Online]: <http://ict.illinois.edu/TOL/TOLseries18.htm>. Link Accessed November 30, 2009.
10. M.H. Ray and R.G. McGinnis. *Guardrail and Median Barrier Crashworthiness*, NCHRP Synthesis 244, Transportation Research Board, Washington, D.C., 1997.
11. E.T. Donnell and W. Hughes. *State Transportation Agency Median Design and Safety Practices: Results from a Survey*. Paper Submitted for Presentation at the 84<sup>th</sup> Annual Transportation Research Board, Washington, D.C., 2005.
12. W. Hughes, M.J. Smith, D. Stewart, D. Harkey and D. Reinfurt. *Improved Guidelines for Median Safety – Interim Report*, National Highway Cooperative Research Program 17-44, October 1997.
13. D.C. Alberson. *The State-of-the-Practice of Cable Barrier Systems*. Presentation at Guardrail Committee Meeting, 2008, ATSSA 38<sup>th</sup> Annual Convention and Traffic Expo, New Orleans,

- Louisiana. [Online]: [http://atssa.com/galleries/clean\\_titles/Cable%20barrier%20-%20State%20of%20the%20practice%20ATSSA.pdf](http://atssa.com/galleries/clean_titles/Cable%20barrier%20-%20State%20of%20the%20practice%20ATSSA.pdf). Link Accessed November 30, 2009.
14. J. Jones. *In-Service Performance Evaluation of Cable Median Barrier on Slopes Steeper than 6:1*. Presentation at the Transportation Research Board Roadside Safety Design Mid-year Meeting, Rapid City, South Dakota, July 9, 2007.
  15. A. Meza. *Cable Median Barriers in Texas*. Presentation to AASHTO Cable Median Barrier Technology Implementation Group, 2005. [Online]: <http://www.transportation.org/sites/aashtotig/docs/Texas%20-%20Cable%20Median%20Barriers.pdf>. Link Accessed November 30, 2009.
  16. Brifen USA Inc. Wire Rope Safety Fence website. [Online]: <http://www.brifenus.com/>. Link Accessed November 30, 2009.
  17. Gibraltar, Inc. website. [Online]: <http://www.gibraltartx.com/index.htm>. Link Accessed November 30, 2009.
  18. C.E. Buth et al. *NCHRP Report 350 Testing and Evaluation of the ET-PLUS with Steel Cable Release Posts and Steel Yielding Terminal Posts*. Texas Transportation Institute, Texas A&M University System, College Station, TX, October 2001.
  19. D.C. Alberson, R.P. Bligh, C.E. Buth, and D.L. Bullard, Jr. *A Review of Cable/Wire Rope Barrier Design Considerations*. Transportation Research Board, 2003 Annual Meeting, Washington, D.C.
  20. Nucor U.S. High-Tension System website. [Online]: <http://www.hightensioncable.com/>. Link Accessed November 30, 2009.
  21. Trinity Industries, Inc. Highway Products Division website – Cable Barriers. [Online]: <http://www.highwayguardrail.com/products/cb.html>. Link Accessed November 30, 2009.
  22. S.A. Cooner, Y.K. Rathod, D.C. Alberson, R.P. Bligh, S.E. Ranft, and Dazhi Sun. *Development of Guidelines for Cable Median Barrier Systems in Texas*, Research Report 0-5609-1, Texas Transportation Institute, College Station, TX, August 2009. [Online]: <http://tti.tamu.edu/documents/0-5609-1.pdf>. Link Accessed November 30, 2009.
  23. M.H. Ray, J.R. Batiste, and D.B. MacDonald. *Cable Median Barrier: Reassessment and Recommendations*. Washington State Department of Transportation and Washington State Patrol, June 2007. [Online]: <http://www.wsdot.wa.gov/Projects/CableBarrier/Report2007.htm>. Link Accessed November 30, 2009.
  24. M.D. Graham et al. “New Highway Barriers: Practical Application of Theoretical Design,” *Transportation Research Record* 174, Washington, D.C., 1967.
  25. *Guide for Selecting, Locating and Designing Traffic Barriers*. American Association of State Highway and Transportation Officials, 1977.
  26. Traffic Department. “Median Barrier Warrants,” Caltrans, 1968.
  27. H.E. Ross, Jr. *Impact Performance and Selection Criterion for the Texas Median Barriers*. Research Report 140-8, Texas Transportation Institute, Texas A&M University, 1974.
  28. John Baxter (FHWA). “Generic Cable Barriers,” Memorandum to Resource Centers, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., 12 September 2005.
  29. L.L. Seamons and R.N. Smith. “Past and Current Median Barrier Practice in California,” California Department of Transportation, Sacramento, CA, June 1991.

30. California Department of Transportation – Traffic Manual, May 2004. [Online]: <http://www.dot.ca.gov/hq/traffops/signtech/signdel/trafficmanual.htm>. Link Accessed November 30, 2009.
31. F.G. Wright (FHWA). Letter to Graham Sharp, FHWA Approval Letter HS10-B82, Brifen LTD, 10 April 2001.
32. Richard Powers (FHWA). Letter to Mary Viparina, Assistant State Engineering, Arizona Department of Transportation, August 2005.
33. Task Force for Roadside Safety. *Roadside Design Guide*, American Association of State Highway and Transportation Officials, Washington, D.C., 2006.
34. G. Strasburg and L.C. Crawley. “Keeping Traffic on the Right Side of the Road,” *Public Roads*, January/February issue, Federal Highway Administration, Washington, D.C., 2005.
35. M.A. Marek. *Median Barrier Guidance*, Memorandum to All District Engineers, Texas Department of Transportation, July 21, 2008.
36. Roadway Design Manual, Texas Department of Transportation, March 2009. [Online]: <http://onlinemanuals.txdot.gov/txdotmanuals/rdw/rdw.pdf>. Link Accessed November 30, 2009.
37. M.H. Ray. “Cable Median Barrier – Reassessment and Recommendations,” Report for Governor of the State of Washington, June 2007.
38. E. Sposito and S. Johnston. “Three-Cable Median Barrier Final Report,” #OR-RD-99-03, Oregon Department of Transportation, Salem, Oregon, July 1998.
39. International Standard. “Steel wire ropes – Determination of the actual modulus of elasticity,” *ISO 12076*, August 2002.
40. M.A. Marek. *Cable Barrier Systems*, Texas Department of Transportation, June 21, 2006. [Online]: [http://www.transportation.org/sites/aashtotig/docs/Texas%20Cable%20Barrier%20Systems%20Memo%20\(2006\).pdf](http://www.transportation.org/sites/aashtotig/docs/Texas%20Cable%20Barrier%20Systems%20Memo%20(2006).pdf). Link Accessed November 30, 2009.
41. J.R. Baxter. *Cable Barrier Transitions to W-Beam Guardrail*. Federal Highway Administration, Office of Safety Design, May 2006. [Online]: <http://transportation.org/sites/scohts/docs/Cable%20Barrier%20Transitions.pdf>. Link Accessed November 30, 2009.
42. D.C. O’Hagan. *High-Tension Cable Barriers*. Florida Department of Transportation, Roadway Design Bulletin 07-08, October 25, 2007. [Online]: <http://www.dot.state.fl.us/rddesign/updates/files/RDB07-08.pdf>. Link Accessed November 30, 2009.
43. R.L. VanCleave. *High-Tension Cable Barrier System*. Indiana Department of Transportation, Design Memorandum No. 08-08 – Technical Advisory, May 16, 2008. [Online]: <http://www.in.gov/dot/div/contracts/standards/memos/2008/0808-ta.pdf>. Link Accessed November 30, 2009.
44. *Median Barriers and Glare Screens*. Illinois Department of Transportation, BDE Procedure Memorandum Number 39-08, March 1, 2008. [Online]: <http://www.dot.state.il.us/desenv/pdf/PM%2039-08.pdf>. Link Accessed November 30, 2009.
45. T. Selby. *Motorcyclists and Wire Rope Barriers – Positioning Paper*. Transit New Zealand, November 2006. [Online]: <http://www.transportation.org/sites/aashtotig/docs/New%20Zealand%20Motorcycle%20Report%20-%20November%202006.pdf>. Link Accessed November 30, 2009.

46. T. Pieglowski. *The Influence of Wire Rope Barriers on Motorcyclists*, Master's Thesis, Lulea University of Technology, 2005. [Online]: <http://epubl.luth.se/1402-1617/2005/233/LTU-EX-05233-SE.pdf>. Link Accessed November 30, 2009.
47. *Guidelines for PTW-Safer Road Design in Europe*. Association des Constructeurs Europeens de Motocycles, 2006. [Online]: <http://www.acembike.org/html/docs/ACEM%20publications/ACEMInfrastructurehandbook.pdf>. Link Accessed November 30, 2009.
48. F.A. Berg et al. *Motorcycle Impacts into Roadside Barriers – Real-World Accident Studies, Crash Tests and Simulations Carried Out in Germany and Australia*, 2005. [Online]: <http://www-nrd.nhtsa.dot.gov/pdf/nrd-01/esv/esv19/05-0095-O.pdf>. Link Accessed November 30, 2009.
49. B. Robinson. *Motorcycle Guardrail Crashes in North Carolina*. Prepared by Safety Evaluation Group, Traffic Systems Management Section, Transportation Safety and Mobility Division, North Carolina Department of Transportation, December 2008.
50. M. Jordan. *Motorcycle Safety in the United States*. Presentation at Lifesavers 2008 National Conference on Highway Safety Priorities, April 2008. [Online]: <http://www.lifesaversconference.org/handouts2008/Jordan.ppt>. Link Accessed November 30, 2009.
51. E.L. Fischer. *Guidance on the Use of Cable Barrier on Highways*. Technical Bulletin RD 07-08(B), Oregon Department of Transportation, Traffic-Roadway Section, September 5, 2007. [Online]: [http://www.oregon.gov/ODOT/HWY/ENGSERVICES/docs/tech\\_bull/TB\\_RD\\_07-08b.pdf](http://www.oregon.gov/ODOT/HWY/ENGSERVICES/docs/tech_bull/TB_RD_07-08b.pdf). Link Accessed November 30, 2009.
52. J. Yin, T. Chojnacki, and M. Campbell. *Median Guard Cable Performance in Relation to Median Slope*. In-House Study, Organizational Results Section, Missouri Department of Transportation, November 2006. [Online]: <http://library.modot.mo.gov/RDT/reports/Ri06014/ss07006.pdf>. Link Accessed November 30, 2009.
53. Cable Median Barrier Simulation Project Update, National Crash Analysis Center, George Washington University, July 2007.
54. J. Jones et al. *A Comprehensive Analysis of and Direction for MoDOT's Cable Median Barrier Program*. Report submitted to Kevin Keith, Chief Engineer, Missouri Department of Transportation, July 31, 2007. [Online]: [http://epg.modot.mo.gov/files/6/6d/Guard\\_Cable\\_Program\\_2007.pdf](http://epg.modot.mo.gov/files/6/6d/Guard_Cable_Program_2007.pdf). Link Accessed November 30, 2009.
55. *Please Don't Cut the Cable: Important Information for Emergency Responders*, educational pamphlet, Colorado Department of Transportation, Safety and Traffic Engineering, Denver, Colorado. [Online]: [http://www.dot.state.co.us/Traffic\\_Manuals\\_Guidelines/Informational\\_Brochures/CO\\_Cable\\_Rail\\_Pamphlet.pdf](http://www.dot.state.co.us/Traffic_Manuals_Guidelines/Informational_Brochures/CO_Cable_Rail_Pamphlet.pdf). Link Accessed November 30, 2009.
56. *Don't Cut the Cable*, educational pamphlet, Kentucky Transportation Cabinet, February 2008. [Online]: [http://highwaysafety.ky.gov/files/incident\\_management/dont\\_cut\\_the\\_cable.pdf](http://highwaysafety.ky.gov/files/incident_management/dont_cut_the_cable.pdf). Link Accessed November 30, 2009.
57. *Managing Vegetation under Cable Median Barriers: Mow Strip Design and Practices*. Transportation Synthesis Report, Wisconsin Department of Transportation, Research and Library Services, December 2007. [Online]:



- <http://on.dot.wi.gov/wisdotresearch/database/tsrs/tsrmowstrips.pdf>. Link Accessed November 30, 2009.
58. H.E. Ross, Jr., D.L. Sicking, R.A. Zimmer, and J.D. Michie. *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.
  59. D. Ward. *Evaluation of Brifen's Wire Rope Safety Fence*. Indiana Department of Transportation, Interim Report, September 2006. [Online]: <http://www.transportation.org/sites/aashtotig/docs/INDOT%20Evaluation.pdf>. Link Accessed November 30, 2009.
  60. Rhode Island Department of Transportation. *Cable Guardrail Evaluation – U.S. Route 1 Median Mooresfield Road to Government Center South Kingstown*. Report prepared by Research and Technology Section, April 2005. [Online]: [http://www.dot.ri.gov/documents/engineering/research/PE/Reports/Cable\\_Guardrail.pdf](http://www.dot.ri.gov/documents/engineering/research/PE/Reports/Cable_Guardrail.pdf). Link Accessed November 30, 2009.
  61. Arizona Department of Transportation. *Special Provision for High-Tension Cable Median Barrier – Section 905*. Arizona Department of Transportation, May 21, 2007.
  62. D.L. Sicking. *Foundation Design for Tension Cable Systems*. Presentation at the Transportation Research Board Roadside Safety Committee Mid-Year Meeting, Rapid City, South Dakota, July 2007.
  63. W.R. Cox. *Geotechnical Manual*, Texas Department of Transportation, August 2006. [Online]: <ftp://ftp.dot.state.tx.us/pub/txdot-info/gsd/manuals/geo.pdf>. Link Accessed November 30, 2009.



## CHAPTER 3




### GUIDELINES FOR CABLE BARRIER SYSTEM IMPLEMENTATION

This chapter contains the deliverable of Project 0-5609 – the recommended guidelines for cable barrier system implementation in Texas. The research team developed these guidelines to provide a source for sound decision-making on existing and future projects. Researchers intend for the recommended guidelines to capture the mainstream guidance on how to implement cable barrier projects that are successful in enhancing the safety of the traveling public. Since the use of cable barrier systems is still a relatively new practice in Texas, the guidance is timely because many districts continue to look for sites and funding for implementation. The research team is writing this chapter primarily to convey the cable barrier system guidelines.

#### 3.1 GUIDELINES FRAMEWORK

Researchers based the recommended guidelines on a comprehensive review of state DOT experiences and policies on cable median barrier and the results of the in-service evaluation of cable barrier systems in Texas. The guidelines are relevant to existing, retrofit, and new safety projects that install a cable barrier system in a roadway median. The research team organized the guidelines for cable barrier system implementation into four broad categories, as outlined in [Table 3-1](#):

**Table 3-1. Categories for Guidelines for Cable Barrier System Implementation.**

Symbol	Broad Category	Sub-Areas
	Barrier Selection	<ul style="list-style-type: none"> <li>• Use of cable barriers</li> <li>• Test level selection</li> <li>• Cost-based selection</li> </ul>
	Barrier Design	<ul style="list-style-type: none"> <li>• Number of cables and cable height</li> <li>• Post spacing and dynamic deflection</li> <li>• Pre-stretching and run length</li> <li>• Coordinating with other safety devices/fixed objects</li> <li>• Impacts from motorcycles and vehicles exceeding design loads</li> </ul>
	Barrier Placement	<ul style="list-style-type: none"> <li>• Median slopes</li> <li>• Lateral placement</li> <li>• Coordination with roadway alignment</li> <li>• Other considerations</li> </ul>
Various	General System Considerations	<ul style="list-style-type: none"> <li>• Maintenance</li> <li>• Anchor terminals</li> <li>• Mowing requirements</li> <li>• Soil conditions</li> <li>• Delineation</li> <li>• Emergency vehicle access</li> </ul>

The remainder of this chapter synthesizes the recommended guidelines for each of the four categories listed in [Table 3-1](#). The research team highlights the recommended guideline for cable barrier system implementation in Texas in shaded text boxes.

Researchers want to emphasize that one of the other, separate deliverables of this research project is a *Cable Median Barrier Maintenance Manual* that focuses on TxDOT maintenance personnel responsible for the repair and general maintenance of cable barrier systems installed in their maintenance section (1). The manual provides maintenance personnel with general guidance regarding the maintenance and repair of cable barrier systems based on information collected in state and national surveys. Since the *Cable Median Barrier Maintenance Manual* contains sufficient detail on maintenance and repair-related guidance, the research team did not include it in this current research report.

### 3.2 GUIDANCE ON BARRIER SELECTION

From a practical standpoint, guidance on the important factors in the selection of a median barrier system is significant. The research team found that median barrier selection guidance is still evolving; however, this subject has received considerable attention in this decade, as states are increasingly conscious of the need for safety programs that can yield sizeable benefits. An ongoing NCHRP study, Project 22-25, currently addresses this topic area (2). For the purposes of this document, the research team development of barrier selection guidelines produced information in the following three subcategories:

- use of cable barriers,
- test level selection, and
- cost-based selection.

#### Guidelines for the Use of Cable Barriers

Having guidance for when it is appropriate to use barriers in roadway medians dates back almost 50 years. Traditionally, the guidelines for using median barriers have involved a combination of median width and traffic volume to identify locations for installation. Some states have also utilized crash rate thresholds for cross-median crashes as another installation indicator.

Transportation professionals have developed two general approaches to aid in the selection of barriers: installation guidelines and cost-effectiveness. This section strictly deals with installation guidelines. AASHTO publishes the most prominent guidelines for use of median barriers in the Roadside Design Guide (see [Figure 2-11](#)) (3). Many states strictly follow the AASHTO median barrier installation guidelines (previously referred to as median barrier warrants); however, some states publish their own guidance in their roadway design manuals (see [Table 2-3](#)).

#### *Recommended Guidance*

In July 2008, the TxDOT Design Division issued a memorandum to provide updated guidelines for the use of median barriers on high-speed highways in Texas (4). The research team recommends that TxDOT engineers use this guidance to determine the need for median barrier (see Guideline 1). [Figure 2-13](#) (previous chapter) shows the recommended guidelines for

installing median barriers on high-speed roadways. This guidance basically indicates that barrier installation is recommended when the median width is less than 30 feet for all roadways, regardless of traffic volume level. For median widths between 30 to 60 feet, barrier installation is recommended as long as the average annual daily traffic level exceeds 30,000 vehicles per day. For all other cases, the existing guidance indicates that a project engineer evaluate the need and cost-effectiveness of a continuous barrier for reducing the occurrence of cross-median crashes. This evaluation may consider the following:

- type of median (flush, depressed [V-ditch or flat-bottom]);
- width of the median;
- traffic volumes, including estimated traffic growth and percent trucks;
- types and severity of crashes;
- posted speed limit;
- type of facility, including controlled access or non-controlled access with crossovers;
- roadway alignment;
- ramp locations; and
- elimination of barrier gaps.

Continuous barriers should be limited to areas where they are needed to reduce cross-median crashes and should not be used for:

- point obstacles (i.e., overhead sign bridges, etc.); or
- in areas of lesser concern (i.e., wider medians, forested areas, etc.).

The research team agrees with TxDOT's decision to incorporate this guidance in the next update of the TxDOT *Roadway Design Manual* (5).



**Guideline 1: Utilize the recommended guidelines for installing median barriers on high-speed roadways in Texas, as shown in Figure 2-13.**

While the guidance contained in Guideline 1/[Figure 2-13](#) is not specific to what type of barrier is recommended for installation, Guidelines 2, 3, and 4 specifically address the use of cable barrier. Some states use cable barriers for roadside applications in addition to median protection. The Florida DOT has made extensive use of cable barrier systems in various areas of their state to protect motorists from ending up in canals located on the outside of the roadway (6). The research team recommends using cable barrier only for roadway medians in Texas.



**Guideline 2: Cable barrier is for use only in roadway medians in Texas.**

Some states, notably Oregon, and international agencies (Australia and Sweden) have experimented with the use of cable barrier systems in narrow roadway medians (7, 8). This type of application is not standard and requires specialized design (notably decreased post spacing) in order to reduce the typical barrier deflection. Researchers recommend that TxDOT use cable

barrier only on median widths greater than 25 feet. This guidance is based on the design properties of cable barrier systems, previously described in [Chapter 2](#) of this report, and the assertion that other barrier systems are more appropriate. Rigid barriers such as concrete median barrier or thrie-beam would need to be used for median widths of 25 feet or less.



**Guideline 3: Cable barrier is for use only on medians greater than 25 feet in Texas. Median widths of 25 feet or less require the use of a more rigid barrier, such as a concrete median barrier.**

Finally, cable barrier systems have some limitations as a choice for application in roadway medians if the depressed median ditch has slopes steeper than 6:1. Some states, notably Missouri, have shown success with the use of cable barrier on 5:1 slopes (9); however, the research team does not advocate this for Texas. The research team provides further guidance on the effect of median slope on cable barrier placement in [Section 3.4](#) of this chapter.



**Guideline 4: A 6:1 approach slope to the cable barrier system from both approach directions is required.**

### Guidelines for Test Level Selection

Currently, high-tension cable barrier systems are approved at both TL-3 and TL-4. The difference between the two types is that TL-4 systems are designed and tested to capture a 17,600 lb single-unit truck with a 15 degree impact angle at 50 mph in addition to the car and pickup vehicles that TL-3 systems are designed for. The research team did not find any existing state policies or guidelines that specifically addressed when to select TL-4 cable barrier systems over TL-3 systems. The Indiana DOT cable barrier guidelines suggest that priority for median barrier protection should be given to areas with high truck volumes (10 percent or greater) (10). There is a slight cost differential (approximately 8 percent using Texas data) for selecting TL-4 over TL-3 cable barrier systems. The current TxDOT guidance indicates that the selection of TL-4 cable barrier over TL-3 barrier is at the district's option – with any decision to apply TL-4 being made based on site conditions, local traffic and economy, using engineering judgment (4). The research team believes that the most important factor is the local traffic conditions – particularly the presence of single-unit trucks and other heavy vehicles, as suggested by the Indiana guidance. Based on this assertion, the research team recommends that facilities having greater than 10 percent trucks receive greater consideration for TL-4 usage (Guideline 5).



**Guideline 5: Roadway facilities with truck percentages of 10 percent or more should receive greater consideration for the use of TL-4 cable barrier systems instead of TL-3.**

### Guidelines for Cost-Based Selection

One of the fundamental questions at the beginning of this research project was to determine when it is more appropriate to use cable barrier versus concrete median barrier. Until the summer of 2003, TxDOT had never utilized anything other than concrete barrier for longitudinal median

protection. A previous TxDOT research project (0-4254) performed a theoretical economic comparison between high-tension cable and concrete median barrier performance (11). TTI researchers based the comparison on the benefit/cost (B/C) ratio of the expected benefits accrued from reductions in crash frequency and/or severity to the expected costs of installing, operating, and maintaining the project. Overall, TTI found that cable barriers were more cost-effective than concrete barriers for the entire range of median widths and AADT for which they are applicable.

The ISPE of cable barrier performance reported in the 5609-1 report built on the theoretical comparison by utilizing actual cost data from cable barrier projects in Texas implemented between 2003 and 2008 for life-cycle costs (12). 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 (11). The life-cycle component that is left essentially compares 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 in the 5609-1 report (12) 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 3-2 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 3-2. Life-Cycle Costs of Cable versus Concrete Barrier 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

This comparison revealed that from both a capital and life-cycle cost perspective, cable barrier is an attractive option compared to concrete median barrier. Specifically, cable barrier systems are significantly more attractive versus permanent concrete barrier options based on life-cycle cost; however, pre-cast portable concrete barrier is not significantly different. Many TxDOT districts no longer have large stockpiles of pre-cast portable concrete barrier for use on median safety projects because they have been depleted. Based on all of these data, the research team determined that cable barrier systems are almost always a more cost-effective option for installation from both a capital and life-cycle cost perspective, which allows for installation of a greater number of miles for the same funding level (Guideline 6).



**Guideline 6:** Cable barrier systems offer significant cost savings over other median barrier systems such as concrete, which allows for installation of a greater number of miles for the same funding level.

### 3.3 GUIDANCE ON BARRIER DESIGN

For the purposes of this document, the research team developed barrier design guidelines in the following five subcategories:

- number of cables and cable height,
- post spacing and dynamic deflection,
- pre-stretching and run length,
- coordinating with other safety devices/fixed objects, and
- impacts from motorcycles and vehicles exceeding design loads.

#### Number of Cables and Cable Height

The original U.S. generic three-cable system has been joined by proprietary systems with three and four cables. The additional cable on proprietary systems either enhances TL-3 performance or, if used to increase the overall height of the barrier, can allow for TL-4 performance. The FHWA issued a July 2007 memorandum entitled *Cable Barrier Considerations* that provided guidance in several critical areas related to the growing use of cable barrier systems in the last decade (13). This memorandum recommended that four cable systems should use an end anchor terminal that provides for a separate anchor connection for each cable or that has been crash tested at the trailing end (Guideline 7).



**Guideline 7:** Four cable systems should use an end anchor terminal that provides for a separate anchor connection for each cable or that has been crash tested at the trailing end.

#### Guidelines for Post Spacing and Dynamic Deflection

The spacing between posts and the resulting dynamic deflection after impact are interrelated design elements for cable barrier systems. Cable barrier systems have been tested and accepted with post spacing ranging from 6.5 feet to 32.5 feet. In general, cable barrier experts know that deflection distance increases with longer spacing between posts. What is not known, but strongly suspected, is that longer post spacing may also affect the propensity for vehicles to penetrate the cable barrier, i.e., by underride or traveling between the cables. The FHWA recommends that state DOTs specify the post spacing when cable barrier systems are bid (13) (Guideline 8). The conventional range for cable post spacing is 6.5 to 15 feet.





**Guideline 8:** Post spacing for cable barrier systems should be specified when they are put out for bid.

TxDOT has already incorporated Guideline 8 into its standard operations with adoption of the July 2006 Statewide Special Specification 5367 (4), “Cable Barrier System” (14). This new specification required:

- use of pre-stretched cable,
- cable barrier system has passed *NCHRP 350* (15) with an 8-foot maximum deflection,
- adding the bid code for post spacing specified, and
- adding locating delineators at a maximum spacing of 100 feet.

Although cable barrier systems have been tested to a maximum deflection of 8 feet, these tests are not based on larger vehicles and represent only a single series of tests. The “design deflection” noted in each FHWA acceptance letter is the *minimum* deflection distance that transportation agencies should provide to fixed object hazards and is based on the test using a 4,400 lb pickup truck. The deflection distance recorded in FHWA letters relates to the length of the test installation. For example, if a 300-foot-long barrier system is tested and the design deflection recorded, the actual deflection under similar impact conditions will be greater if the barrier length between tiedowns (anchor terminals) exceeds 300 feet. Future crash test criteria will specify a minimum installation length for test sections on the order of 600 feet to better determine the deflection that transportation agencies can normally expect (13). Because of the likely potential for more deflection in field impacts, the research team recommends maintaining a minimum clear distance of 12 feet from the edge of the travel lane to the cable barrier system (Guideline 9).



**Guideline 9:** A minimum clear distance of 12 feet should be maintained from the edge of the travel lane to the cable barrier system.

Another design feature related to posts for cable barrier systems that is not specified by the barrier manufacturers is whether they are directly driven into the soil or placed in concrete drill shafts with sockets. The research team recommends that TxDOT continue to require that all cable barrier systems be placed in concrete drill shafts with sockets for ease of repair and maintenance (see [Figure 3-1](#)) (Guideline 10).



**Guideline 10:** The posts for all cable barrier systems should be placed in concrete drill shafts with sockets.



**Figure 3-1. Posts in Concrete Drilled Shafts with Sockets.**

## **Guidelines for Pre-Stretching and Run Length**

### *Pre-Stretching of Cables*

The previous chapter discussed the technical issues related to whether or not cables are pre-stretched prior to installation in the field. The research team recommends the use of only pre-stretched cable in Texas (Guideline 11). As stated previously, TxDOT has already incorporated Guideline 8 into its standard operations with adoption of the July 2006 Statewide Special Specification 5367 (04). The primary advantage of using pre-stretched cable is reduced maintenance requirements during the first two years of service. As construction stretch is removed, tension in the wire ropes decreases. Therefore, non pre-stretched wire ropes require more monitoring and maintenance in the early service years. Pre-stretched cables also have the advantage of reduced dynamic deflection by reducing the “play” between the individual wire strands in the bundle that forms the cable prior to installation.




**Guideline 11: Use only pre-stretched cable.**

### *Cable Run Length*


The research team recommends that the maximum run of cable barrier between terminal anchors should be approximately 10,000 feet (Guideline 12). This length allows for proper tensioning of the system and reasonable construction installation time to get a run in operation. Runs of shorter and longer lengths between terminal anchors may be appropriate in specific locations, and each run should be determined to meet the field situations, such as the location of bridge piers and other structures that conflict with the system performance. Due to the length needed for

transition sections from terminal anchors to the standard cable section, cable barriers are not well suited for short barrier runs. The minimum length of a run should be 1,000 feet (Guideline 12).

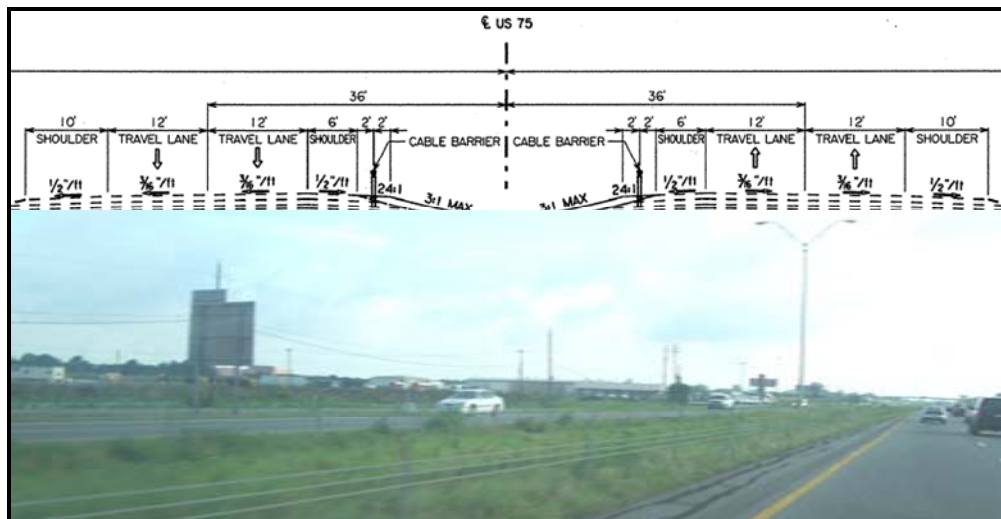


**Guideline 12:** Cable barrier runs should be a minimum of 1,000 feet and maximum of 10,000 feet in length.

In certain situations, such as areas of differential profile grades or narrower medians, cable barrier systems may not function well. In these cases, parallel installations of cable barrier could be utilized; however, this is not desirable (4). Parallel installations may also be appropriate when objects such as high-mast light poles are located in the middle of the roadway median (Guideline 13). The ideal location for each of the parallel runs is 2 feet from the edge of the roadway shoulder. This location maximizes the distance from the through traffic while still taking into account the bumper height of the errant vehicle. In the double or parallel configuration, all cables should be placed on the traffic face of the posts. TxDOT engineers have utilized this type of design on US75 in Collin County – control section job number 0047-14-061 (see Figure 3-2).



**Guideline 13:** Parallel runs of cable barrier may be appropriate for situations such as differential profile grades, narrow medians, or when objects such as high-mast light poles are located in the middle of the roadway median.



**Figure 3-2. Use of Parallel Runs on US75 Project in Collin County, TX. Guidelines for Coordinating with Other Safety Devices/Fixed Objects**

Another important design consideration for cable barrier systems is accounting for the interaction with other roadside safety devices and fixed objects. Common roadside safety devices such as W-beam guardrail and concrete barrier and fixed objects such as mainline bridge piers will often affect the design and placement of cable barrier systems in the median. Similar to guidance on the clear distance from a travel lane, the research team recommends maintaining a minimum of 12 feet between the cable barrier system and any obstruction being protected (Guideline 14).



**Guideline 14:** A minimum clear distance of 12 feet should be maintained between the cable barrier system and any obstruction being protected.

If an obstruction currently protected by metal beam guard fence (MBGF) is located within a run of cable barrier, and there is a minimum of 12 feet clear from the cable barrier to the obstruction, the MBGF can be removed. If there is less than 12 feet clear from the cable barrier to the obstruction, it is recommended that the MBGF be left in place and the cable barrier be placed such that there is a minimum of 2.5 feet (6 feet preferred) from the back of the MBGF posts to the barrier (Guideline 15). [Figure 3-3](#) provides a good example of the preferred design and [Figure 3-4](#) shows an example to avoid. Cable barrier should be a minimum of 6 feet behind guardrail extruder terminals (GET) to allow for extrusion and gating of the end treatment (see [Figure 3-5](#)) (Guideline 16).



**Guideline 15:** Cable barrier systems should be placed such that there is a minimum of 2.5 feet (6 feet preferred) from the back of the metal beam guard fence posts to the barrier.



**Figure 3-3. Good Example: Spacing between Cable Barrier and Metal Beam Guard Fence.**



**Guideline 16:** Cable barrier systems should be a minimum of 6 feet behind guardrail extruder terminals to allow for extrusion and gating of the end treatment.



**Figure 3-4. Example to Avoid: Inadequate Spacing between Cable Barrier and MBGF.**



**Figure 3-5. Anchor Terminals Too Close to Guardrail End Treatments Can Cause Problems.**

### **Guidelines for Impacts from Motorcycles and Vehicles Exceeding Design Loads**

From a media/public relations perspective, most of the attention afforded to cable barrier systems has been extremely positive. Members of motorcycle safety groups have often expressed their dislike for cable barriers. The ISPE of cable barrier performance in Texas did not reveal any

issues with motorcycle impacts or crashes. This ISPE did show that there were several crashes involving vehicles exceeding design loads that resulted in barrier penetrations; however, there were more cases of successful vehicle captures. The research team recommends that TxDOT continue to closely monitor overall cable barrier performance statewide with a sufficient detail to evaluate if any significant issues with either impacts from motorcycles or vehicles exceeding design loads arise (Guideline 17).



**Guideline 17:** Continue to monitor overall cable barrier performance statewide and evaluate impacts from motorcycles and vehicles exceeding design loads.

### 3.4 GUIDANCE ON BARRIER PLACEMENT

Roadside safety experts agree that placement of cable median barrier is more complex than most roadside safety hardware because of the many unique performance requirements. The research team discovered a significant amount of guidance regarding the placement of cable barrier systems in medians. The guidance review revealed three primary placement considerations:

- median slopes,
- lateral placement, and
- coordination with roadway alignment.

There is one guideline that is generic in nature and supersedes all of the other barrier placement guidelines. The most recent TxDOT design memorandum suggests that as a general rule, a barrier should be placed as far from the traveled way as possible while maintaining the proper orientation and performance of the system (4) (Guideline 18). This placement philosophy is predicated on the idea that 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. Minimizing “nuisance” hits is an important consideration because barrier maintenance can become costly and time consuming if barriers are not optimally located. [Figure 3-6](#) shows a picture of an example to avoid if possible. This is a situation where there is a wide, flat median and the cable barrier system was placed right on the shoulder close to the travel lanes. This type of placement led to many nuisance hits at this location.



**Guideline 18:** As a general rule, a cable barrier system should be placed as far away from the traveled way as possible while maintaining the proper orientation and performance of the system.



**Figure 3-6. Example to Avoid: Shoulder Placement in Wide Median Creates Nuisance Hits.**

### **Guidelines for Median Slopes**

The slope of a depressed median is extremely important to the performance of a cable barrier system. Where possible, transportation agencies should install barriers on relatively flat, unobstructed terrain (10:1 or flatter). Agencies may also choose to place barriers on 6:1 maximum slopes, as shown in [Figure 2-25](#) in the previous chapter (Guideline 19).



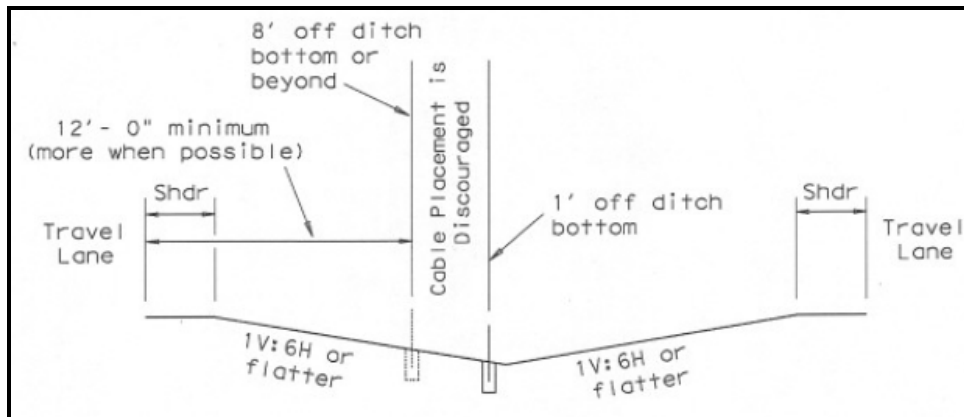
**Guideline 19: Cable barrier systems should be installed on relatively flat, unobstructed terrain if possible (10:1 or flatter), and may be placed on 6:1 maximum slopes if necessary.**

### **Guidelines for Lateral Placement**

The primary objective of cable barrier systems is to prevent crashes that would be more severe if a barrier were not present. Roadway safety professionals have to also consider the effect of barrier placement on overall performance, particularly the ability to effectively prevent cross-median crashes. The primary placement consideration for these professionals is that cable barrier


systems need to be located in order to accommodate their inherent design features (e.g., deflection, need for two cables for effective capture, etc.). There is a considerable diversity of thought regarding the placement of cable median barrier within the median cross section for depressed medians with 6:1 or flatter slopes. Guidelines 20 and 21 provide the preferred (Figure 3-7) and acceptable (Figure 3-8) lateral placement of cable barrier systems based on the best evidence available to date (16). Placing the system in the area of 1 to 8 feet from the bottom of the ditch on the 6:1 slope is not encouraged (Figure 3-7). A vehicle's suspension is compressed when it hits the bottom of the ditch, and the front bumper may not recover to the bottom cable height within this area. Tests show that placing the cable 1 foot from the ditch bottom does not capture the vehicles tested.

 **Guideline 20: The preferred placement of cable barrier within a V-ditch should not be in the area of 1 to 8 feet from the bottom of the ditch.**

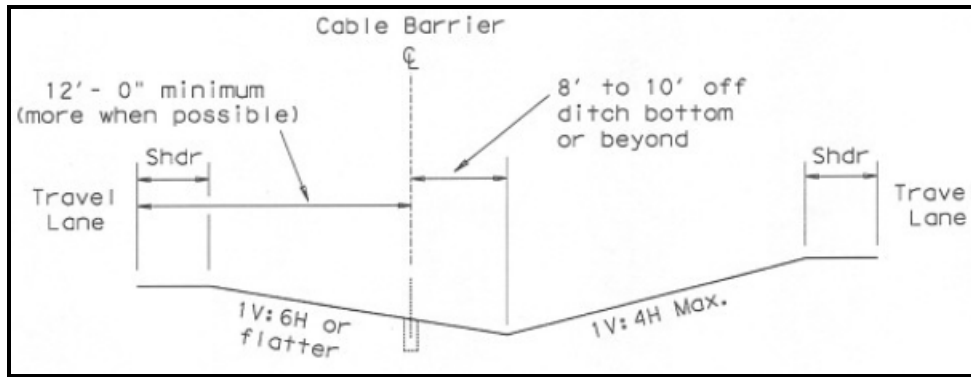


**Figure 3-7. Preferred Cable Barrier Placement within a V-Ditch (16).**

If the slopes in the median are steeper than 6:1 and barrier is needed, agencies should consider the slopes to meet the requirements or could choose to fill in the median to place a split level concrete barrier. If this type of consideration or other options are not feasible, placement of cable barrier on slopes up to 4:1 is an alternative to consider. MoDOT has had some success on 5:1 slopes, as noted previously in Chapter 2 (17). There is some flexibility on the median slope opposite the cable barrier placement. A maximum 4:1 slope may be retained as long as the cable barrier is placed on the 6:1 slope at a distance of 8 to 10 feet from the ditch bottom (Figure 3-8).

 **Guideline 21: The acceptable placement of cable barrier allows a maximum 4:1 slope if the cable barrier is placed on the 6:1 slope at a distance of 8 to 10 feet from the ditch bottom.**





**Figure 3-8. Acceptable Cable Barrier Placement within a V-Ditch (16).**

### **Guidelines for Coordination with Roadway Alignment**

The two primary considerations for barrier placement related to alignment are horizontal and vertical curves. Each condition presents different challenges from a placement perspective.

#### *Placement Guidelines for Horizontal Curves*

The research team developed three guidelines related to cable barrier system placement on horizontal curves. Guideline 22 advocates that reduction of the typical post spacing for cable barrier systems is an effective countermeasure for dealing with expected deflection from impacts. [Table 2-8](#) in the previous chapter shows the recommended post spacing adjustments to account for the barrier deflection characteristics. Guideline 23 recommends that when installing cable barrier systems near a shoulder around a curve, consider placing it where the near traffic is making a left-hand curve (inside of the curve relative to near traffic – convex side). This placement may reduce nuisance hits and allow more vehicles leaving the opposing travel lanes to come to a safe stop in the median before impacting the cable barrier. Finally, the research team suggests exercising care when placing barriers in superelevated sections (Guideline 24), with the primary objective being to place the barriers for optimum containment of errant vehicles.



**Guideline 22: Closer post spacing through horizontal curves is recommended based on the radius of curvature.**



**Guideline 23: Placement of cable barrier on the convex side (i.e., inside of the curve relative to near traffic) is recommended to allow maximum median availability for deflection and allow maximum space for vehicle recovery for vehicles leaving the opposing travel lanes.**



**Guideline 24: Care should be exercised when placing cable barriers in superelevated sections.**

## Placement Guidelines for Vertical Curves

Cable barrier systems need consistent height of cables to perform according to their intended design; therefore, they do not accommodate abrupt changes in vertical alignment very well. Crossing of abrupt sags will leave the lowest cable too high. Crossing of abrupt crests will place severe downward stress on cable supports and will result in low cable height after one impact. The research team believes these issues are minimized with an installation along or near a shoulder; however, they often have to be addressed for locations closer to the median center. Breaking and overlapping the runs of cable barrier at crests or sags is a strategy to minimize this effect and may also be coordinated with the changes in the preferred side of installation.

Current guidance indicates that special attention should be placed on sag vertical alignments. The cables and/or posts placed in sockets are freestanding (not held down by the system) and will come to taut elevation between two tangent points when the cable is tensioned, creating a larger difference from the ground line to the bottom cable than allowed by the manufacturer's installation manual. Transportation agencies should avoid placement on sag vertical alignments with radii of less than a K-value of 11 (Guideline 25). Grading may be required to ensure a consistent height of the barrier above the ground.



**Guideline 25: Placement of cable barrier systems on sag vertical alignments with a radii of less than a K-value of 11 should be avoided.**

## Other Considerations

The research team developed two additional placement guidelines dealing with the presence of drainage and utility facilities in the project right-of-way (ROW). The placement of cable barrier systems should take into consideration the drainage facilities located in the median. Cross drainage structures with less than 36 inches of cover pose a challenge for placing posts. Current guidance indicates that structures of less than 16 feet can be spanned and construction of these runs of cable should take these structures into account prior to setting the post locations (Guideline 26). Transportation agencies need awareness that horizontal alignment and lateral placement of the cable barrier system may be affected by the presence of underground utilities. This is especially true in the vicinity of terminal anchors, since their foundations routinely go down 6 to 8 feet below grade. The designer should follow the TxDOT *Plans, Specifications and Estimates (PS&E) Preparation Manual* guidance on identifying utilities within the project and the quality level of utility locates required (18) (Guideline 27).



**Guideline 26: Cross drainage structures with less than 36 inches of cover pose a challenge for placing cable barrier posts. Structures of less than 16 feet can be spanned in order to avoid post placement into the drainage structure.**



**Guideline 27:** Designers should follow the *Plans, Specifications and Estimates (PS&E) Preparation Manual* guidance on identifying utilities within the project and the quality level of utility locates required.

### 3.5 GUIDANCE ON GENERAL SYSTEM CONSIDERATIONS

The research team discovered that some guidance for cable barrier systems did not fit nicely into the selection, design, or placement categories. Researchers developed guidance on general system considerations in the following five subcategories, including:

- maintenance,
- anchor terminals,
- mowing requirements,
- soil conditions,
- delineation, and
- emergency vehicle access.

All of these considerations are important to the overall success of cable barrier system implementation.

#### Guidelines for Maintenance

As noted previously in this chapter, the research team focused particular attention on the development of guidance for maintenance and repair-related considerations for cable barrier systems. The subject of maintenance received focused attention because transportation agencies cite it is a frequent need after installing the cable barrier systems in the field. The *Cable Median Barrier Maintenance Manual* contains 25 guidelines written to help TxDOT maintenance personnel effectively manage and repair the cable barriers installed in their districts (1).

The only subject not addressed specifically in the *Cable Median Barrier Maintenance Manual* is the development of educational materials for emergency response agencies about the issue of cutting the cable when a vehicle is entangled after an impact (1) (Guideline 28). The research team recommends that TxDOT develop educational materials similar to Colorado (19) (see Figure 2-28) and Kentucky (20).



**Guideline 28:** Emergency response agencies should have educational materials to provide them with clear and concise guidance on when and how to safely cut the cable when a vehicle is entangled after an impact.

#### Guidelines for Anchor Terminals

When ending a run of cable barrier, the cable barrier terminals should be located, when possible, behind some protection, such as the MBGF at the end of bridges. The terminals are *NCHRP 350* crash tested and approved and can be placed in locations with no protection, but since they

provide anchorage for the cable barrier system, protecting them from possible hits is recommended (15). These terminals are also gating (meaning they will not prevent a vehicle from going through). Figure 3-9 shows an example of the consequences – loss of tension in the wire ropes – after an unprotected anchor terminal is impacted.



**Figure 3-9. Example of Consequence of Having Anchor Terminal Unprotected.**

If switching the cable barrier from one median side to the other and the terminals are not protected, current guidance recommends that the runs of cable barrier be overlapped to provide adequate protection from possible crossovers (Guideline 29). The Indiana DOT has developed a procedure for calculating the minimum distance between the terminal anchors in each direction (10). The minimum distance for the terminal anchor located at the incoming end should be at least the runout length used for calculating the guardrail length of need. Current practice advocates that an overlap distance of 500 feet should be used for a median width up to 60 feet, a design speed of 70 mph, and AADT > 6,000. For the anchor located at the outgoing end, the minimum overlap distance should be two times the anchor length. Changing the lateral offset of a cable barrier at the terminal anchor located at the outgoing end is the preferable method.



**Guideline 29:** If switching the cable barrier from one median side to the other and the terminals are not protected, overlapping the runs of cable barrier is recommended to provide adequate protection from possible crossovers.

Cable tension produces high-static loads on anchor foundations, while loads from impacts produce wide-ranging dynamic loads. When considering designing the anchor terminal footer, transportation agencies need to be pragmatic and allow for a reasonable amount of anchorage movement. The most important design criteria is to keep the static loads well below the ultimate

strength to assure that there is not ongoing deflection of the anchor resulting in cable tension loss and ultimately anchor pull-out and system failure (Guideline 30).



**Guideline 30:** Footings for terminal anchors should be designed to keep static loads well below the ultimate strength.

### Guidelines for Mowing Requirements

One of the difficulties with cable barrier systems is removing grass and other vegetation that may grow under them. A common solution employed throughout the U.S. is a mow strip – a narrow piece of pavement or other material placed directly beneath the barrier to prevent the growth of vegetation and facilitate mowing. Because mowing and herbicide operations are a life-of-the-facility considerations, researchers recommend the use of mow strips to reduce the need for spending extra resources on mowing requirements (Guideline 31). Also, TxDOT should consider accommodating mower widths between the travel lane edge and the cable barrier (Guideline 32).



**Guideline 31:** For future maintenance considerations, the use of mow strips is encouraged to reduce future hand mowing or herbicide operations.



**Guideline 32:** Distance between the edge of a travel lane and the cable barrier should consider mower widths.

### Guidelines for Soil Conditions

In order to avoid problems such as anchor failure, socket spalling, etc., the research team recommends that transportation agencies consider soil conditions in the design process. This recommendation is supported by a number of existing state DOTs that already have requirements in place and by a recent NCHRP study (21). Anchor foundations and sockets should be designed for prevailing soil conditions at installation locations (Guideline 33). Soil parameters for the design of post and terminal anchor footings can be given in a special specification for cable barriers. Where cable barriers are to be placed on the roadway shoulder, no soil borings will be required. Where the cable barrier is to be placed beyond the shoulder point (in the median or outside the roadway), obtain 20 foot deep soil borings in the vicinity of each proposed end terminal to verify that the existing soil is equal to or stronger than the soil parameters given in the specification. In addition to the soil borings at the terminal anchors, a geotechnical assessment of the soils along the cable barrier alignment between the anchor locations should occur. This assessment may be done using any of the normal preliminary investigation methods (topographical maps, aerial photos, geological maps and reports, etc.) as well as original roadway plans. As a minimum, a visual assessment in the field is required. Transportation agencies should investigate areas that appear to have high organic content or that are saturated for extended periods by taking site-specific borings as needed. Record soil data location and

content in the plans. As noted in [Chapter 2](#), an ongoing TxDOT research project (0-6146) focuses on addressing soil conditions with a specific emphasis on design for cable barriers.



**Guideline 33:** Anchor foundations and sockets should be designed for prevailing soil conditions at installation locations.

Frost heave can have a significant impact on shallow foundations. Depending on location, frost depth in the United States varies from 0 to almost 8 feet. Even if the base of the footing is below frost depth, there is no assurance that shear forces on the side of the footer will not force it out of the ground over time. Given the small vertical loads on cable posts, small foundations located in areas prone to frost heave (cold temperatures, silty fine grained soils, available water) are going to have significant propensity to move dramatically. When these conditions are present, the cable barrier system design should take them into consideration (Guideline 34). Frost heave is most likely to affect cable barrier placements in the panhandle area of the state.



**Guideline 34:** Cable barrier system design should account for the potential for frost heave.

### Guidelines for Delineation

Proper delineation of roadside safety hardware is important so that nuisance hits by motorists can be avoided, particularly at night. Cable barrier systems are less conspicuous to motorists, even during daylight conditions. Delineation should be at 100-foot spacing, unless otherwise approved by the project design engineer (Guideline 35). Contractors should furnish the delineators as shown on the plans and in accordance with TxDOT Item 658, “Delineator and Object Marker Assemblies” (see <http://www.dot.state.tx.us/DES/specs/2004/04light2.htm#658>).



**Guideline 35:** Delineation of cable barrier should be at 100-foot spacing, unless otherwise approved by the engineer.

### Guidelines for Emergency Vehicle Access

Very long runs of cable barrier inhibit turnarounds by police and emergency first responders. Researchers recommend providing breaks in the cable barrier (designated crossovers, staggering technique, etc.) at least once every three miles. The *Cable Median Barrier Maintenance Manual* deals extensively with subjects regarding coordination with emergency service providers (1).



**Guideline 36:** The maximum distance between breaks in the cable barrier system that allow emergency vehicle access should be three miles.

## REFERENCES

1. S.A. Cooner, Y.K. Rathod, D. Sun, and S.E. Ranft. *Cable Median Barrier Maintenance Manual*, Report 0-5609-P1, Texas Transportation Institute, College Station, TX, August 2008. [Online]: <http://tti.tamu.edu/documents/0-5609-P1.pdf>. Link Accessed November 30, 2009.
2. *Development of Guidelines for the Selection, Use, and Maintenance of Cable Barrier Systems*. National Cooperative Highway Research Program, Active Project 22-25. [Online]: <http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=1640>. Link Accessed November 30, 2009.
3. Task Force for Roadside Safety. *Roadside Design Guide*, American Association of State Highway and Transportation Officials, Washington, D.C., 2006.
4. M.A. Marek. *Median Barrier Guidance*. Memorandum to All District Engineers, Texas Department of Transportation, July 21, 2008.
5. Roadway Design Manual, Texas Department of Transportation, March 2009. [Online]: <http://onlinemanuals.txdot.gov/txdotmanuals/rdw/rdw.pdf>. Link Accessed November 30, 2009.
6. D. Kring. *I-75 Alligator Alley Cable Safety Barrier*. Florida Engineering Society Journal, January 2005, p. 18.
7. B. Schmidt. *Cable Barrier Tried on U.S. 26*. The Oregonian, September 17, 2007.
8. M. Larrison, N. Candappa, and B. Corben. *Flexible Barrier Systems along High-Speed Roads: A Lifesaving Opportunity*. Report No. 210, Prepared by Monash University Accident Research Centre for VicRoads, December 2003. [Online]: <http://www.monash.edu.au/muarc/reports/muarc210.pdf>. Link Accessed November 30, 2009.
9. J. Yin, T. Chojnacki, and M. Campbell. *Median Guard Cable Performance in Relation to Median Slope*. In-House Study, Organizational Results Section, Missouri Department of Transportation, November 2006. [Online]: <http://library.modot.mo.gov/RDT/reports/Ri06014/ss07006.pdf>. Link Accessed November 30, 2009.
10. R.L. VanCleave. *High-Tension Cable Barrier System*. Indiana Department of Transportation, Design Memorandum No. 08-08 – Technical Advisory, May 16, 2008. [Online]: <http://www.in.gov/dot/div/contracts/standards/memos/2008/0808-ta.pdf>. Link Accessed November 30, 2009.
11. R.P. Bligh, S. Miaou, D. Lord, and S.A. Cooner. *Median Barrier Guidelines for Texas*. Research Report 0-4254-1, Texas Transportation Institute, College Station, TX, August 2006. [Online]: <http://tti.tamu.edu/documents/0-4254-1.pdf>. Link Accessed November 30, 2009.
12. S.A. Cooner, Y.K. Rathod, D.C. Alberson, R.P. Bligh, S.E. Ranft, and Dazhi Sun. *Development of Guidelines for Cable Median Barrier Systems in Texas*, Research Report 0-5609-1, Texas Transportation Institute, College Station, TX, August 2009. [Online]: <http://tti.tamu.edu/documents/0-5609-1.pdf>. Link Accessed November 30, 2009.
13. J.A. Lindley. *Cable Barrier Considerations*. Memorandum to Division Administrators, Federal Highway Administration, July 20, 2007.
14. M.A. Marek. *Statewide Special Specification 5367 (4)*. “Cable Barrier System,” Texas Department of Transportation, Special Provision Memorandum 30-06, July 28, 2006. [Online]: <ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/chngmemo/de-30-06.pdf>. Link Accessed November 30, 2009.

15. H.E. Ross, Jr., D.L. Sicking, R.A. Zimmer, and J.D. Mitchie. *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993. [Online]:  
[http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rpt\\_350-a.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_350-a.pdf). Link Accessed November 30, 2009.
16. M.A. Marek. *Cable Barrier Systems*. Texas Department of Transportation, June 21, 2006. [Online]:  
[http://www.transportation.org/sites/aashtotig/docs/Texas%20Cable%20Barrier%20Systems%20Memo%20\(2006\).pdf](http://www.transportation.org/sites/aashtotig/docs/Texas%20Cable%20Barrier%20Systems%20Memo%20(2006).pdf). Link Accessed November 30, 2009.
17. J. Yin, T. Chojnackim, and M. Campbell. *Median Guard Cable Performance in Relation to Median Slope*. In-House Study, Organizational Results Section, Missouri Department of Transportation, November 2006. [Online]:  
<http://library.modot.mo.gov/RDT/reports/Ri06014/ss07006.pdf>. Link Accessed November 30, 2009.
18. *PS&E Preparation Manual*. Texas Department of Transportation, May 2007. [Online]:  
<http://onlinemanuals.txdot.gov/txdotmanuals/pse/pse.pdf>. Link Accessed November 30, 2009.
19. *Please Don't Cut the Cable: Important Information for Emergency Responders*, educational pamphlet, Colorado Department of Transportation, Safety and Traffic Engineering, Denver, Colorado. [Online]:  
[http://www.dot.state.co.us/Traffic\\_Manuals\\_Guidelines/Informational\\_Brochures/CO\\_Cable\\_Rail\\_Pamphlet.pdf](http://www.dot.state.co.us/Traffic_Manuals_Guidelines/Informational_Brochures/CO_Cable_Rail_Pamphlet.pdf). Link Accessed November 30, 2009.
20. *Don't Cut the Cable*, educational pamphlet, Kentucky Transportation Cabinet, February 2008. [Online]:  
[http://highwaysafety.ky.gov/files/incident\\_management/dont\\_cut\\_the\\_cable.pdf](http://highwaysafety.ky.gov/files/incident_management/dont_cut_the_cable.pdf). Link Accessed November 30, 2009.
21. D.C. Alberson, N.M. Sheikh, and L.S. Chatham. *Guidelines for the Selection of Cable Barrier Systems – Generic Design vs. High-Tension Design*. NCHRP Project 20-7(210) Final Report, Prepared for NCHRP, July 2007.