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High Tension Cable Median Barrier: A Scanning Tour Report

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16. Abstract The Illinois Department of Transportation (DOT) coordinated a scanning tour to identify effective and efficient approaches of reducing the number and severity of freeway median crossover crashes. Representatives from Illinois, Iowa, Minnesota, and Wisconsin DOTs, and the University of Illinois, visited Ohio, Oklahoma, and Texas to learn from their experiences in the use of high-tension cable barriers, and to gather information on system characteristics and performance from the states and two manufacturers of high-tension cable barrier systems. Field- installed high-tension cable barrier systems from four manufacturers were observed: U.S. High Tension Cable System, Brifen WRSF, CASS, and Safence. These cable barrier systems seem to perform similarly when hit by passenger vehicles. The performance at redirecting or stopping vehicles was reported to be excellent, and no major drawback of using high-tension cable barrier systems was found. It was reported that crash severity was reduced significantly compared to other barrier systems and no fatalities had been recorded on crashes at locations with high- tension cable barriers. Some issues pertaining to optimum cable location, long-term benefit-cost analysis, TL-3 versus TL-4 requirements, 3-cable versus 4-cable systems, and others need additional exploration and experience to be addressed more precisely.			
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Executive summary

The States of Illinois, Iowa, Minnesota, and Wisconsin are interested in installing and/or expanding the use of high-tension cable barriers for cross median protection on their highway systems.

These states took part in a scanning tour with the following objectives: 1) to learn from other states that already have experience in the use of high-tension cable barriers, and 2) to gather information on system characteristics and performance from the states visited and companies that manufacture high-tension cable barrier systems.

The Scanning Tour was founded by the Federal Highway Administration (FHWA) and took place from August 29, 2005 to September 2, 2005. The Tour included visits to Ohio, Oklahoma, and Texas DOTs and some of the cable systems manufacturing companies in those states.

Four proprietary high-tension cable barrier systems were observed: U.S. High Tension Cable System, Brifen WRSF, CASS, and Safence. These systems meet NCHRP 350 criteria for test level 3 (TL-3)¹, which is the main required standard in the visited states. The cable systems use ¾-inch diameter 3 x 7 strand cable ropes (may or may not be pre-stretched depending on the system) and weak posts to guide the cables through and maintain cable height.

The observed cable barrier systems seem to perform similarly when hit by passenger vehicles. The performance at redirecting or stopping vehicles was reported to be excellent, and no major drawback of using high-tension cable barrier systems was found.

It was reported that crash severity was reduced significantly compared to other barrier systems, no fatalities had been recorded on crashes at locations with high-tension cable barriers, and very few crashes had resulted in barrier penetration.

The selection of high-tension cable systems is based on a bidding process, but bidding specifications are not the same among the states though they all require a specific maximum dynamic deflection. Warrants for installation of median cable barrier generally depend on crash history, and are also dependent on roadway geometry and traffic volumes.

High-tension cable barriers may be installed on the shoulder or median, and are recommended for slopes no steeper than 6:1. The states visited preferred socketed posts over driven posts even though the former had a higher installation cost due to embedding the sockets in concrete foundations. The high initial cost seems to balance out over time mainly because post replacement is easier.

¹ The Brifen system has also been accepted at TL-4

The information gathered in this Scanning Tour provided valuable knowledge on the system characteristics, performance, and maintenance, although the states visited are still going through the learning process. Some issues including optimum cable location, long-term benefit-cost analysis, TL-3 versus TL-4 requirements, and 3-cable versus 4-cable systems, and others, need more exploration and experience to be determined precisely.

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Introduction

Illinois, Iowa, Minnesota, and Wisconsin, are interested in installing and/or expanding the use of high-tension cable barriers for cross median protection on their highway systems. Both the Division and National FHWA representatives supported the idea of a scanning tour and helped to secure funding for it. Representatives from these four states participated in a scanning tour of sites in Ohio, Oklahoma, and Texas from August 29, 2005 to September 2, 2005. The purposes of the Scanning Tour were:

- To learn from other states who already have experience in the use of high-tension cable barriers, and
- To obtain information on system characteristics and performance from the visited states and companies that manufacture high-tension cable barrier systems.

A severe crash may occur when a vehicle crosses the median and hits an opposing vehicle. Median barriers are installed to prevent cross median crashes. Median barriers may not reduce the frequency of crashes due to lane departure, but they can prevent the cross median head-on crashes. Also, collisions with rigid barriers, such as concrete, may result in severe injury, either from the collision itself or from a secondary collision if the vehicle is reflected back into traffic.

Median barrier systems using high-tension cable are currently used in many states across the U.S. They are designed not only to reduce the number of cross median crashes, but also crash severity. Cable barriers can deflect more than other type of barriers such as W-beam barriers to reduce the severity of the impact. Cable barriers are also more adaptable to variations in the terrain profile and slopes compared to beamguard barriers, may withstand a second hit before repairs, usually require less grading and drainage work, and to some people they may be aesthetically more pleasing than other barrier systems. However, there are still questions about their performance, cost, installation, and maintenance that need to be answered.

Participants

The following participants came from the Illinois, Minnesota, Iowa, and Wisconsin Departments of Transportation and the University of Illinois:

Name, Position	Agency
David Piper, Safety Design Engineer	Illinois DOT
Deanna Maifield, Methods Engineer	Iowa DOT
Chris Poole, Office of Design	Iowa DOT
Gary Dirlam, District Traffic Engineer	Minnesota DOT
John Hanzalik, Metro Highway Maintenance Supervisor	Minnesota DOT
John Bridwell, Standards Development Engineer	Wisconsin DOT
Peter Amakobe, Standards Development Engineer	Wisconsin DOT
Juan Medina, Graduate Research Assistant	University of Illinois

The University of Illinois was responsible for preparing this report.

Agenda

The agenda included meetings and field visits with DOT representatives, and visits to cable systems manufacturing companies. The following is a summary of the main activities during the Scanning Tour:

Ohio (August 29th – 30th, 2005)

- *Meeting at Ohio DOT and field visit:*
Visited site: I-270 and Tuttle Crossing Blvd - U.S. High Tension Cable System²
Contact person: Dean Focke, PE Roadway Standards Engineer
Ohio DOT.
- *Visit to NUCOR Marion Steel Inc. plant:*
Contact person: Rich Mauer, National Sales Manager, Marion Steel Company

Oklahoma (August 30th – September 1st, 2005)

- *Meeting at Oklahoma DOT and field visit:*
Visited sites: - State Highway 75 – Hefner Parkway (Brifen)
- I-35 (Brifen)
Contact person: Faria Emamian, P.E. Engineer Manager,
Oklahoma DOT
- *Visit to Brifen USA:*
Contact person: Jerry Emerson, P.E. Marketing Engineer Brifen
USA

Texas (September 1st – 2nd, 2005)

- *Meeting at Texas DOT (Weatherford Area Office) and field visit:*
Visited site: I-20 (CASS – Brifen)
Contact person: Jimmey Bodiford, P.E. Area Engineer

The complete list of participants in each of the meetings can be found in **Appendix 1.**

² Rainy weather did not permit any close inspection of the installed U.S. High Tension Cable System

Brief Introduction to High Tension Cable Barrier Systems

Four different proprietary high tension cable barrier systems were observed in the Scanning Tour and will be discussed in this report: U.S. High Tension Cable System, Brifen WRSF, CASS, and Safence. The four systems meet NCHRP 350 criteria for test level 3 (TL-3). A modified version of Brifen WRSF also meets the requirements for test level 4 (TL-4). These cable systems use ¾-inch diameter 3 x 7 strand cable ropes (pre-stretched or not pre-stretched depending on the system) and weak posts to guide the cables and maintain cable height.

The basic characteristics of the four systems are briefly described in this section. More information can be found in the manufacturers' product literature and in the NCHRP test conditions and results published by FHWA.

A summary of the systems characteristics and their performance in NCHRP 350 test type 3-11 is presented in Table 1. The table only includes information from official acceptance letters issued by the FHWA to the manufacturers that have been posted on the FHWA official website as of October 2005. This website is continuously updated and it can be visited to obtain the latest information on system designs and variations.

http://safety.fhwa.dot.gov/roadway_dept/roadHardware/longbarriers.htm

System	U.S. High Tension Cable System	Brifen WRSF	CASS	SAFENCE
Manufacturer	NUCOR Marion Steel Inc.	Brifen USA	Trinity Industries Inc.	Blue Systems AB
# of Cables	3	4	3	4
Cable Diameter	19mm diameter (3x7 strands/cable)			
Cable tensioning	Non-prestretched / Prestretched	Prestretched	Prestretched	Prestretched
TL-3 Post Shape	U-channel (Rib-Bak)	S-shape	C-channel	I-post or C-post
Cable Height Above the Ground	750mm, 650mm, 545mm	720mm, 675mm, 510mm (Height #1) or 720mm, 600mm, 460mm (Height #2)	750mm, 640mm, 530mm	720mm, 640mm, 560mm and 480mm
NCHRP 350 test 3-11 Approved	Yes	Yes	Yes	Yes
Post Spacing	2m or 3.8m or 5.1m	3.2m or 2.4m	2m or 3m or 5m	2.5m
Dynamic Deflection	1.6m (2m post spacing) 1.8m (3.8m post spacing) 2.31m (5.1m post spacing)	2.4m and 2.6m (3.2m post spacing, Height#1 and Height#2 respectively) 2.7m (2.4m post spacing Height#2)	2.06m (2m post spacing) 2.4m (3m post spacing) 2.8m (5m post spacing)	2.7m

Table 1. Systems characteristics and performance on NCHRP 350 Test 3-11

U.S. High Tension Cable System

The U.S. High Tension Cable System is a three-cable system. It is currently produced by NUCOR Marion Steel Inc., and uses Rib-Bak™ cable line posts and 0.25-inch diameter

U-shaped hook bolts to guide the cables at the desired height. The manufacturer describes two procedures to install the posts: (1) directly embedded in the ground (driven), or (2) using cast-in-place or pre-cast concrete socket foundations. When using concrete foundations, it is important to get the socket flush with the concrete in order to avoid having the top portion of the socket exposed and to allow posts to shear off rather than bend. It is recommended that the foundation reinforcing bars be tied together to assure their proper placement and the resistance of the foundation.

The manufacturer recommends using non pre-stretched cable, but pre-stretched cable can be supplied upon request. A template to attach the hook bolts at the correct height is helpful in the installation process because the posts have one hole every inch.



Figure 1. U.S. High Tension Cable System

The system is typically tensioned at 5,600 lb, and anchored with a Texas Transportation Institute's (TTI) proprietary Cable Guardrail Terminal End. TTI's end treatment was designed for rocky or hard soils, and is NCHRP 350 approved (details on TTI's end treatments can be found in acceptance letter of U.S. High Tension Cable System – FHWA website). Upper and lower cables are recommended to be located on the side of the post closest to the roadway, leaving the middle cable on the opposite side.

For details on the most recent information about the NUCOR Marion Steel Inc. cable system, contact Rich Mauer, National Sales Manager, Marion Steel Company, or visit the following websites:

- Official website: <http://nsmarion.com/>
- Multi-state distributor of NUCOR system: <http://www.gsihighway.com/nucor>

Brifen Wire Rope Safety Fence (Brifen WRSF)

Brifen USA manufactures four-cable and three-cable systems, both are NCHRP 350 approved. The sites visited had only installed the four-cable system. The Brifen (**British**

Fence) WRFS uses an exclusive S-shape post in its TL-3 version. The manufacturer recommends only pre-stretched cables.



Figure 2. Brifen Wire Rope Safety Fence System

Posts are installed in concrete foundations with a minimum strength of 3,500 PSI or can be driven using a post with a soil plate. In the four-cable system, the three lower cables are interwoven around the posts and the upper cable is placed in a slot on the top of each post. The end treatment is a customary part of the design and extends 19 posts in total: 4 posts for the Wire Rope Gating Terminal (WRGT), and 15 posts for the transition to the line posts.

For detailed information on the Brifen system, contact Jerry Emerson, P.E. Marketing Engineer Brifen USA

Official website in USA: <http://www.brifenus.com/>

CASS

CASS (Cable Safety System) is a three-cable system by Trinity Industries, Inc. It uses pre-stretched cable, and the posts have an opening in the upper part to accept the cables, which are kept in correct position by wider slot sections at specified cable heights, a plastic cap on the top of the post, plastic spacer blocks, and a steel strap. Posts are installed in steel sockets that can be either driven directly into the soil, or cast in concrete cylinders. TTI's Cable Guardrail Terminal Ends are used to anchor the system.



Figure 3. CASS System

For more information on the CASS system contact Rich Figlewicz, Consultant-Highway Safety Products Division, Trinity Industries Inc.

Official website: <http://www.highwayguardrail.com/>

SAFENCE

Safence is a 4-cable WRSF system originally developed in Sweden by Blue Systems AB in 1993. Cables in the Safence system are factory pre-stretched. It uses I-section or C-section posts, which can be driven directly in the soil or installed in concrete cylinders. Spacers are placed between the cables to maintain adequate separation. Up to date, crashworthy end terminals have not been developed and tested.



Figure 4. Safence System

For more information on the Safence system, contact Michael Kempen, Vice President Safence.

Official website: <http://www.bluesystems.se/indexe.htm>

State Visits

The important factors in selecting the sites visited were:

- Variety and length of cable barrier systems installed,
- Experience in maintaining the systems (time after installation),
- Travel time to installation sites, and
- Travel time and accessibility to manufacturing companies.

Ohio, Oklahoma, and Texas, were chosen based on these criteria.

This selection allowed the Scanning Tour to learn about experiences with the three most commonly used cable barrier systems in the U.S.: Brifen Wire Rope Safety Fence (Brifen WRSF), U.S. High Tension Cable System, and CASS. A short section of a less commonly used system -Safence- was also observed in Oklahoma. The Scanning Tour also visited the production plants of the U.S. High Tension Cable System and Brifen USA.

In addition to the abovementioned systems, a fifth cable system called Gibraltar was recently approved by FHWA at TL-3 and TL-4 conditions. At the time the Scanning Tour took place, however, DOTs did not have enough experience using the Gibraltar system to schedule a field visit and gather information on installation, performance, and maintenance.

Ohio

Selection and Application

The use of high tension cable in Ohio was motivated by a series of 11 median crossover accidents that caused 14 fatalities in a 12-mile segment of I-75 starting in October 2001. Crashes were considered unrelated to highway geometry because no common crash cause could be identified.

Ohio DOT considered using standard W-beam barriers, concrete barriers, and high-tension cable barriers to prevent more median crossover crashes. Ohio DOT had removed the generic (low-tensioned) cable system from its standards in 1965 because of safety and maintenance concerns. The generic cable system does not protect against second hits until it has been repaired. Also, Ohio DOT did not have personnel with knowledge on the generic cable system.

Given these options, and based on a combination of estimated costs and expected performance, Ohio DOT decided that the most appropriate barrier for median crossover protection along I-75 was the high-tension cable.

Ohio DOT decided to install the Brifen WRSF system, because at the time it had been proven for more than 15 years in European countries and Australia, and it works under specified maximum deflections. The system is also NCHRP Report 350 accepted, and reduces the concerns of second hits. Ohio DOT was able to draw on the experiences of North Carolina and South Carolina. Also, Oklahoma DOT provided information on the Brifen system, since they installed the first segment in the United States.

Estimations made by Ohio DOT indicate that cable median barrier systems are more cost effective and less damaging to vehicles than many other median barrier systems. Cable systems are said to be much cheaper than concrete barriers and prevent vehicles from bouncing back into the road lanes.

Moreover, geometric characteristics on Ohio's freeways are favorable to cable barrier systems, where most freeway medians are 60 feet or more in width, with slopes of 6:1 or flatter, and with a traversable ditch, usually located in the center of the median.

The reduction in the number and severity of the crashes is Ohio DOT's primary safety objective. The "ODOT Business Plan 2004 & 2005" specifies these goals, among others:

- To reduce the frequency of crashes by 10 percent,
- To reduce rear-end crashes by 25 percent,
- To reduce the crash fatalities to not exceed one fatality per 100 MVMT.

Median barriers in Ohio have helped address these goals by reducing the annual number of deaths caused by median crossover crashes by 17 (16 percent of the total number of crash fatalities).

Warrants and Criteria

Warrants, based on a benefit-cost analysis, are used to select candidate locations for cable barriers, rather than deciding on a case-by-case basis. High priority is given to installations on multilane roadways with median widths less than 76 feet, and traffic volumes exceeding 36,000 AADT. Multi-lane roadways with median widths between 76 feet and 84 feet, traffic volumes greater than 26,000 AADT, and with a poor crash history are also considered for high-tension cable installation.

High-tension cable barriers are also considered for add-lane projects on freeways, if the new traffic lanes are added on the median side. The resulting reduced median width may meet barrier warrants.

Ohio DOT has also decided to retrofit safety "hot spots" with cable barriers to reduce the severity of crashes. On the other hand, cable barriers are not considered for roadside

protection, because the numerous driveways in non-fully controlled roadways would require more end terminals, and ultimately more expensive systems.

Design and Construction

Ohio DOT designs high-tension cable barriers specifically for each site. No standard detail drawings have been developed yet. Cable barrier is bid based on maximum dynamic deflection and NCHRP 350 test level (TL-3 is currently used as the standard because most hits don't involve trucks). No differences between 3-cable and 4-cable systems are specified in the bidding process.

Ohio DOT originally believed that the ideal location for cable median barrier was the bottom of the median ditch. However, some concerns arose because the drainage structures are often installed at the same location, and mud and wet conditions can make repairs very difficult for maintenance crews. To avoid these problems, the cable barrier is placed at least 8 feet from the bottom of the median ditch, although Ohio DOT doesn't recommend the use of mid-slope barrier at locations where the median slope is steeper than 6:1. Mid-median or a single run of a shoulder mounted barrier are the current preferred placement locations. Shoulder mounted cable barriers may require dual runs, one on each side of the median, as the cable system has not been tested for hits coming up ditch on the backside.

Current Installations

To date, three different high-tension cable systems have been installed in Ohio: Brifen WRSF, U.S. High Tension Cable System, and CASS. In general, it is highly recommended to use socketed posts instead of driven posts for all systems, despite some difficulties pulling posts out of the sockets in wet conditions.

Brifen System

A Brifen WRSF cable barrier was installed in the median along 14 miles on I-75 by the year 2003. I-75 is a six-lane freeway with 4-foot paved median shoulders and a 60-foot wide ditched median with 6:1 slopes. The barrier was installed on the side of the median slope at 10 feet off the center of the ditch, with a post spacing of 10 feet 6 inch, and a design deflection of 7.9 feet. The barrier flips sides depending on the existing structures along the road. Existing barriers were kept separate from cable system.

Climate conditions in Ohio are suitable for the standard Brifen installation, where the frost line and the depth of concrete posts are both 36 inches.

Most of the Brifen posts were originally driven on the median slopes, but based on the maintenance experience after several hits, it was decided to install concrete foundations on those damaged locations and use socketed posts to facilitate repairs.

Since the Brifen system was installed, about 200 hits have been reported, with no fatalities and one penetration.

In January 14, 2004, a passenger car destroyed 14 Brifen posts and penetrated the barrier. The cause of the penetration was not clear from the site evidence. Cables sagged to approximately one-half of the correct height. District 8 did repairs two months after the accident. According to information provided by Richard Butler from Brifen USA, the concrete foundations were retrofitted, and yielded due to their lack of depth and low resistance. This condition caused the concrete footers to move in the soil, thus not allowing the posts to bend, and creating a ramp for the vehicle to “ride up” and over the system.

U.S. High Tension Cable System

U.S. High Tension Cable System was installed in the median along 12 miles of I-270 by October 2004. The posts were placed at the edge of the paved shoulder and socketed in concrete foundations. Post spacing is 6.5 feet for a design deflection of 6.5 feet. More than 30 hits have been registered since installation with no fatalities or penetrations.

U.S. High Tension Cable System posts shear as a consequence of a hit, allowing cables to maintain their height. However, posts at some locations have bent, allowing the concrete foundation to be pulled out of the soil. Other posts have also sheared off at the bottom of the sleeve, particularly during the spring thaw. Installing the locking bolts in the U.S. High Tension Cable System can increase repair time, but they hold the cable at its proper height more securely than the other systems. Otherwise, the high-tension cable can cause the posts to “float” where the barrier crosses local depressions.

Many of the TTI anchor foundations were redesigned and retrofitted by the cable manufacturer because some concrete foundations became loose and moved. A check using Marion Steel’s meter revealed that in one occasion the cable was not properly tensioned, but no conclusive causes were found. Tension checks need to be conducted on a regular basis to ensure proper service conditions. It was observed that Ohio DOT overlapped ends of cable barrier behind the guardrail at some locations.

Rainy weather did not permit any close inspection of the installed U.S. High Tension Cable System.

CASS System

Three miles of the CASS system were completed in October 2004. The barrier was placed at the edge of the paved shoulder on an asphalt mow strip. Posts were installed in sockets with concrete foundations and spaced 10 feet with a design deflection of 7.9 feet. Anchor movement has not been a problem, even though the anchor system is also based on the same TTI design used for the U.S. High Tension Cable System. At some locations, CASS posts have bent inside the socket. Based on information provided by CASS manufacturer, posts will bend 99.9 percent of the time at or near ground level, and they are not intended to shear.

About 25 hits have been recorded in the 3-mile stretch with the CASS system with no fatalities or penetrations.

Maintenance

At locations with cable barrier, about 12 percent of the crashes resulted in injuries (mostly minor injuries), and no fatalities have been recorded. The total number of crashes has increased by about 30 percent since the cable installations, and according to Ohio DOT, this increase was attributable to the cable presence.

A document titled “Ohio DOT Field Visits to Cable Median Barrier Projects” contains detailed information on the observations and results of several field visits during February and March 2005 (See Appendix 2). The report concluded that all high-tension cable barrier systems being used are performing satisfactorily and there is no clear preference for one particular system.

State Maintenance forces repair the Brifen cable installation in Ohio. Typically, repairs are done 1 or 2 weeks after a crash in good weather, and up to 2 months after a crash in bad weather conditions. Most crashes require 4 - 5 posts to be replaced, but as many as 43 posts have been damaged in one crash on the Marion system³. A worker was injured during one repair of the Brifen system because an improper weaving technique was used.

Mowing and snow plowing is a concern that is recommended to be addressed at the design stage. With regards to Ohio DOT, snow plowing has always been done for the full shoulder width, thus top mounted barriers are subject to snow damage.

Emergency Vehicles

In relation to response times of emergency vehicles, roadway conditions in areas where high-tension cable barriers have been installed are favorable, since interchanges are typically closely spaced. However, in some cases emergency crossovers are located every 1½ miles and the cable runs are terminated at those crossovers.

Visit to NUCOR Marion Steel Inc.

NUCOR Marion Steel Inc. is the current producer of the U.S. High Tension Cable System. On June 3, 2005, NUCOR bought Marion Steel Inc. and about two months later it also bought SAFERoads, which previously manufactured and sold the system. NUCOR Marion Steel Inc. is committed to continue the production and development of the U.S. High Tension Cable System.

The visit to the NUCOR Marion Steel plant, in Marion, OH, was divided into three main parts:

- A meeting with the company representatives,
- A tour through the plant, and
- An inspection of a short piece of the U.S. High Tension Cable System installed in the company parking lot.

³ In a related comment, it was mentioned that Minnesota State Patrol tags damaged items with the accident report number to facilitate the insurance claims. Funds are returned to the district budget

Details on installation procedures and characteristics of The U.S. High Tension Cable System are included in the product Installation Manual. However, since some of the comments and recommendations given by the company representatives on the use and installation of the U.S. High Tension Cable System are not contained in the Installation Manual, they are included here:

- Development efforts on the U.S. High Tension Cable System are focused on the improvement of the post resistance and stiffness. More resistant and brittle posts will break off rather than bend.
- NUCOR Marion Steel Inc. hopes to reduce the dynamic deflection to 3 feet within the next 3 years. However, it was pointed out that less deflection results in more vehicle damage because less energy is being absorbed by the cable system.
- Limiting the distance between end treatments to ½ mile is preferable. This recommendation helps to control deflections, and also reduces the amount of system that can be taken out by a hit on a terminal.
- For concrete foundations, it is advisable to punch the holes in the soil instead of drilling them, because it compacts the soil in the hole and leaves less spoil.
- Latest version of the post sleeve is cheaper but more flexible because of its cylindrical shape. The previous version was square.
- NUCOR Marion Steel Inc. is supportive of the use of driven posts. Their posts are often driven in other applications such as signage support.
- Using reinforcing bars in the concrete foundations is highly recommended by NUCOR Marion Steel Inc. to increase longevity.
- Representatives from NUCOR Marion Steel Inc. recommended non pre-stretched cable over pre-stretched cable. It was stated that after a number of crashes, the standard cable would be stretched as much as the pre-stretched cable. The manufacturer said that eventually both will be equivalent and the initial cost of the pre-stretching process does not result in system benefits.
- NUCOR Marion Steel Inc. is coming out with a new digital tension meter manufactured by DILLON Inc.

The main processes in the NUCOR Marion Steel plant to manufacture steel, and obtain different forms of steel elements for the cable barrier systems are shown in **Appendix 3.**

Oklahoma

Selection and Application

The first installation of high-tension cable barrier for median crossover crashes in the United States was completed in Oklahoma in 2000. A median crossover barrier was required along the Lake Hefner Parkway in State Highway 74, Northwest Oklahoma City, in response to a series of crossover crashes that left 4 fatalities between June 1997 and May 2000. At this location, State Highway 74 is a six-lane freeway with a grass median between 36 feet and 42 feet wide, and with volumes of 108,000 AADT as of 2000, and increasing.

Local residents were concerned about blocking the scenic view of the lake, for which concrete or guardrail barriers were not deemed a viable option. High-tension cable systems were considered appropriate because they not only can reduce crash severity, but also complied with the aesthetic requirements.

Oklahoma DOT selected Brifen WRSF, and FHWA approved the experimental use of the high-tension cable in a 1,000-foot section. A private contractor carried out the installation. At the time, the end terminals were not NCHRP 350 approved, thus existing structures or additional barriers shielded the end terminals.

Deflections are an issue for the generic cable because it limits the locations where this system could be used. Oklahoma DOT stated that while the generic cable typically deflects between 11 feet and 12 feet, deflection for the Brifen high-tension cable system is about 6 feet to 8 feet. Also, in contrast to the generic cable system, high-tension cable is designed to remain serviceable after a first hit.

Warrants and Criteria

Priority for median barrier installation is set based on location, frequency, and severity of crashes. For location selection, the Traffic Engineering Division prepares a series of maps showing the locations of crossover collisions (a crossover collision was defined as “run-off road left” followed by a collision on the other side). These locations were then ranked by severity index, and selected in priority order.

Design and Construction

Cable system selection follows a bidding process with specified post spacing. There is not a consensus on whether the number of cables used by the system should be part of the specifications or not. Satisfactory experiences in Ohio with 4-cable systems, and the elevated number of truck crashes, have suggested that continuation with this type of cable barriers can be positive. However, not enough experience on 3-cable systems has been acquired yet.

Current Oklahoma DOT standards require the systems to be NCHRP 350 TL-3 approved. There is some interest in moving to TL-4 requirements, but future change to TL-4 need to be further studied because the cable height would be raised and performance with small cars is a concern.

Location of the barrier has been a major concern and is currently determined in a case-by-case basis. Oklahoma DOT has observed a tradeoff between barriers at or near the median center, which can reduce the potential for nuisance hits, and barriers on the edge of shoulders, which can reduce the amount of sand and fine particles getting into the foundation sleeves, easing post replacement. At some locations where the cable barrier has been placed near the median center, median drains were adjusted to allow the cables to maintain a level profile while maintaining hydraulic capacity. In some cases, steep median slopes have been reduced to a maximum of 6:1 for cable installation.

Barrier posts are installed in socketed concrete foundations. Driving posts can reduce initial costs, but it is believed that maintenance costs could be higher in the long run. Oklahoma DOT prefers “punched-in” holes to drilled holes. As mentioned previously, this method compresses the soil around the hole and improves resistance.

The use of high strength concrete, instead of reinforcing bars for post foundations in the Brifen system, has shown good results. No broken foundations have been reported up to date. CASS installation used reinforcing bars in footings, but no data is available for evaluation yet.

Existing safety devices, such as sand barrels or guardrail barriers, remained in place after cable installation and were shielded by the cable. Mow strips have been placed under the cable barrier in two installations, but Oklahoma DOT doesn’t believe it is essential for the cable systems in all projects. It is recommended to place reflective tape on the plastic cap of the posts to reduce hits at night and help emergency vehicles to identify crossover points.

Current Installations

Currently, there are three different high-tension cable systems installed in the Oklahoma City Metropolitan area: Brifen WRSF, Safence, and CASS System (See [Appendix 4](#)). Oklahoma DOT designed the installations for Brifen and Safence systems, but the manufacturer – Trinity Industries Inc, designed the CASS installation. In terms of performance, Oklahoma DOT indicated satisfactory results for all three systems. Crash reports summarized below included data as of July 31, 2005, and can be found in detail in [Appendix 5](#).

Brifen System

The first Brifen test installation was extended from 1,000 feet to 7 miles in 2001. Cable was installed in two sections of 2 miles and 5 miles long between end treatments. No negative experiences have been reported due to the long cable runs. The barrier was not located at the center of the median, as the first 1,000-foot stretch was, but on a paved mowing strip just outside the southbound shoulder. This placement was also preferred over the center median because the drainage inlets created a slope too steep for an adequate installation (see photographic material in [Appendix 6](#)).

Oklahoma DOT provided to the Scanning Tour participants two reports about the Brifen installations:

- “Brifen Wire Rope Safety Fence Final Report” by Faria Emamian P.E. Engineer Manager in Oklahoma DOT, dated March 2003 – this report includes a detailed collision analysis, and maintenance and repair issues on the 7-mile stretch on the Lake Hefner Parkway (See Appendix 7).

- “Oklahoma DOT Experience with Brifen Wire Rope Safety Fence on Lake Hefner Parkway in Oklahoma City”, by Randy B. Lee, P.E. Division IV Traffic Engineer in Oklahoma DOT, dated June 24, 2004 – Mr. Lee was involved in the maintenance of the Brifen installation. The report includes some comments on the system (See Appendix 8).

Some of the most relevant comments from these two documents, as well as additional information provided by Oklahoma DOT related to the Brifen installation are described below:

- As of May 10, 2004, a total of 238 hits have been reported in the system, requiring replacement of 1279 posts, for an average of 5.3 posts per hit.
- As of June 24, 2004, the average cost charged by the maintenance contractor for the replacement of each post was \$51.00.
- No fatalities and 3 injuries have been reported. This represents a significant reduction in crash severity compared to a similar time frame before the barrier installation.
- It was estimated that police accident reports have only been filed on approximately 30 percent of the hits, indicating very light vehicle damage.
- One person using only hand tools usually makes a 5-post repair in 15 minutes. It is not recommended, however, to lift the cables by hand for safety of workers.
- The system has remained serviceable after multiple hits at the same location.
- The use of long distances between anchors has not generated any loss of cable tension, nor turnbuckle damage after the hits.
- The largest vehicle to impact the barrier was a full size school bus, which was redirected safely after the driver had a heart attack.
- In a few cases, cables dropped down to the ground when many posts were knocked out. (Repairs were made within 2 hours, as required by the contract for these types of hits). It should be noted that typical hits don't have this effect on the cable barrier.

- The mow strip placed under the cable system (4 feet wide and 4 inches thick) is not effective since hand mowing is still needed. A soil herbicide is mentioned as a possible solution.
- Low front vehicles, such as sports cars, can potentially penetrate the barrier because their suspension is compressed at the bottom of the ditch and the bumper can override the lower cable.

A second installation using the Brifen system was completed in September 30th, 2004, along 6.3 miles on I-35 in the Norman area, Cleveland County. Twenty one hits have been reported since installation, with one property damage crash and no fatalities or injuries. During the last 5 years prior to the barrier installation, 6 fatal, 16 injury, and 9 property damage crashes were reported in this stretch of road.

SAFENCE

A one-mile test of the Safence system was installed as a demo, promoted by the manufacturer, along I-35 north of Purcell, McClain County (see Appendix 6). The barrier was completed on the same date Brifen's second installation was completed, September 30, 2004. Because of its short length, only 3 crashes have been reported since cable installation, all of them without injuries or significant vehicle damage. During the last five years prior to the barrier installation, 1 fatality, 5 injuries, and 1 property damage crash were reported in this stretch of road. Similar concerns to those found in Texas when lifting CASS cables by hand for maintenance activities may be expected with the Safence system (See CASS System Section in Texas Visit below).

CASS System

The CASS system was recently installed (August 26, 2005) on I-35, McClain County. Up to date, no crash data is available to provide performance results on this system. A total of 3 fatal, 1 injury, and 3 property damage crashes were reported the last five years prior to the barrier installation.

Maintenance

The maintenance on the Brifen systems is contracted out. Oklahoma DOT does the maintenance on the other systems. Repair parts have been readily available and are delivered in a timely manner. The average repair takes about 20 minutes. So far, the repairs have only involved replacing posts and some of the hardware associated with posts.

Maintenance staff generally prefers the cable barrier to be located in the middle of the median. There have been no significant wintertime maintenance problems.

See Appendix 9 for Oklahoma's Questionnaire responses.

Emergency Vehicles

To minimize the effect of the limited number of crossovers for emergency responders, Oklahoma DOT has considered the option of flipping side of the roadside barrier and overlapping the end treatments at the flip points to provide turnarounds. This would be done at overhead bridges or other sites where topography provides convenient turnaround locations.

Visit to Brifen USA Inc. in Oklahoma City, OK

Brifen representatives met with the Scanning Tour at the Brifen USA plant, located in Oklahoma City. Some of the comments discussed in the meeting prior to the plant visit, as well as recommendations and comments at the plant are included below:

- Brifen recommends the use of pre-stretched cable for the barriers. The pre-stretching process takes slack out of the cable and equalizes loads in the 21 wires of the rope.
- There is a mini-anchor effect generated by the cable weaving. Friction between cable and post dissipates some energy from hits. Testing has shown that tension from a test-level impact does not transfer beyond 70 posts from the impact location. This helps to keep the effect of a hit under a limited section in a long stretch of the Brifen system.
- Crash tests were performed on 600-meter sections (about 2,000 feet), which is considerably longer than the 100-meter sections used in standard NCHRP 350 TL-3 test.
- Although early systems were installed with 14-inch by 36-inch foundations, the standard is now 12 inches by 30 inches as tested with the TL-4 system. TL-4 version was reinforced with a u-shaped rebar ring welded to the bottom of the steel socket. Driven posts are available, but not recommended due to higher maintenance costs.
- It was not recommended to use pre-cast concrete footings because it is not easy to perfectly match the footing volume with the volume of the hole in the ground. As a consequence, footing can become loose and move after an impact.
- Turnbuckles can be placed at posts. Special posts with extra wide slots are provided in such cases. However, no more than 2 turnbuckles should be placed within 10.5 feet to avoid a single crash hitting more than one connection.
- Brifen uses solid body turnbuckles, which are claimed to be sturdier than open body turnbuckles.
- Standard line posts can be used down to a 200-meter radius (about 656 feet).

- Construction inspection is very important.
- For median locations it is recommended to install the Brifen WRSF at least 10 feet from the bottom of the ditch on a slope no steeper than 6:1.
- A black plastic “excluder” (resembles a black Frisbee) is placed at the base of the post and covers the sleeve. It is meant to keep out larger objects. Finer elements may get into socket, but there is no need to clean them other than when the posts are being replaced after a hit.
- There have been 300 hits on the Hefner Parkway system, which is at the shoulder. The proportion of hits has been roughly 2:1 nearside vs. far side.
- Minnesota DOT asked if a TL-5 test would be conducted. Brifen doesn’t think the investment is justified. Also, there are some substantiated reports of the TL-3 system containing and redirecting trucks well beyond the TL-3 weight.
- It is possible to terminate a Brifen barrier by connecting it to a guard rail.
- Current cost per post is \$18.30. Other parts cost less than \$5 per post (as of August 2005).
- During the field trips, it was observed that the top of the concrete foundations are constructed with a convex top (or dome). The height of this dome needs to be limited because it affects the ground clearance of the bottom rope, which is critical.

Texas

The Scanning Tour visited the Weatherford Area Office in Texas⁴. This office is part of the Forth Worth District of the Texas DOT. It is located west of Fort Worth and is responsible for two counties – Parker and Palo Pinto. There are 52 maintenance, and 19 Design/Construction employees on staff.

Selection and Application

In Texas, the Safety Bond Program, approved by voters in 2003, is providing safety improvement projects totaling over \$600 millions. Reduction in the crash frequency and severity is one of the primary goals of the Safety Bond Program. It was mentioned that almost all fatalities (about 96 percent) in the interstate system had been cross median related.

⁴ Due to time constraints, a visit to the Trinity Industries Inc. facilities in Dallas, TX, was not possible for this Scanning Tour. However, representatives from Trinity Industries Inc. have been supportive to this Scanning Tour and provided the participants with information on their CASS system.

Warrants and Criteria

Median barrier projects are supported by warrants. The Weatherford Area Office, in coordination with the Traffic Section at the Forth Worth District Office, analyzes traffic reports and crash data to prepare a list of the candidate locations for improvements. Currently, cable median barriers are warranted on freeways only, in particular, freeways with medians narrower than 44 feet (measured between edge stripes).

Cable barriers are thought to be cost-effective. The improvement in safety translates in lower crash severity and reduction in total expenses, but a precise evaluation will require more time and data to account for maintenance costs in the long run. Under a high hit rate, it is expected that cable barriers are more expensive compared to concrete barriers. However, low severity of crashes with cable barriers seems to be also a decisive factor in its favor.

Design and Construction

Selection of cable system is based on a bidding process. Requirements for bidding companies are based on price, NCHRP 350 TL-3 approval, and maximum deflection (typically 8 feet). No distinction is made between 3-cable and 4-cable systems in the bidding process. TXDOT has not planned to change NCHRP 350 requirements from TL-3 to TL-4 because cable performance under TL-3 has been satisfactory for all types of vehicles.

TXDOT specifications for cable barrier systems are included in the Special Specification 5084, Miscellaneous Constructions Section, in the document “Texas DOT specification 2004”. A copy of the specification sheet was provided to the Scanning Tour (See Appendix 10).

Cable barriers are preferred near, but offset from the edge of the shoulders. Brifen and CASS systems were installed at about 14 feet from the edge of the inside travel lane, where typical median shoulder is 6 feet wide. This placement provides a more consistent profile than installations in the center of the median, because it prevents difficulties caused by drainage structures and uneven ground, and reduces chances of weaker soils at foundation depth. Sharp changes in the profile cause significant variations in the height of the cable above the ground, since the system is under high tension and cable tends to follow a straight line rather than the actual profile line over short distances.

The longest run of cable between anchors is about 4 miles. The stretches of cable are installed from bridge to bridge with no crossovers, except for one location, and barrier is usually lapped behind the approach guardrail or is shadowed by the downstream end of the bridge.

On future works, a more convenient layout for emergency vehicles has been planned. Cable will change median sides at each overhead structure, and end points will overlap to allow crossovers.

A 4-foot wide by 3-inch thick asphalt mow strip was constructed to help reduce cable barrier maintenance. It is believed that the strip also makes cable barrier more noticeable for first responders, who may suddenly need to cross the median in the case of an emergency situation. Reflective tape on top of the posts is also recommended to increase barrier salience and avoid such situations.

It was recommended to control the water level at mow strip to avoid premature asphalt deterioration and additional maintenance. Even though cable barrier doesn't need to be mowed because of the asphalt strip, TXDOT protects the installation from damages caused by mowing contractors by charging them \$100 per post damaged.

Drilling post foundations was the leading activity during installation. About 50 12-inch-diameter holes were drilled per day/drill truck. Posts were installed in reinforced sockets with concrete foundations, including locations with hard rocky soils. A defective 36-inch foundation on sandy soil was reported pushed out of the ground in I-635, near Dallas.

To adequately secure the turnbuckle connections, Brifen recommends fully engaging the threads into the turnbuckle before making final connections. Because cable is pre-stretched, it doesn't need much length to be pulled out to achieve the required tension, and not much more thread engagement will be gained while tensioning.

During these initial installations, it has proven important to be familiar with system details during the installation process, in order to timely address contractor's questions. Representatives from Brifen and CASS were also present during installation to give technical support as needed. At one location, a Brifen anchor foundation was built with flat top instead of a 12-degree inclination. Brifen took engineering responsibility and corrected the structure using a special wedge. In some situations, installation misunderstandings or errors were avoided by active on-site guidance to the contractor from manufacturer's representatives. Some examples of these misunderstanding or errors were related to the purpose of the inspection hole in the field splice, the number of required bolts for the anchor, and the requirement for threads showing beyond the shoulder of the nuts.

The contractor is responsible for any damage to the barrier prior to final acceptance. This contractual requirement protects DOT from additional costs during installation, but it may delay completion of functional smaller sections of barrier, and encourage contractor to finish all post installations first, and only put the cable up just before project acceptance. This was noticed to be an issue in the Weatherford Area Office projects.

In order to incrementally open barrier to service, future modifications in long projects may include accepting small road sections as soon as the cable installation is completed. The contractor put up all the posts before installing the cable on the first 21 miles installed in their area. On future projects they will accept completed segments.

Current Installations

21 miles of cable barrier were installed in Parker County: Brifen (10.5 miles) and CASS (10.5 miles), both on I-20 and I-30 (see photographic material in Appendix 11 and Texas DOT design examples in Appendix 12). Post spacing was 10 feet 6 inch in the Brifen system and 10 feet in the CASS system. The complete project cost was \$1.4 million for the 21-mile roadway stretch, where typical volumes are close to 68,000 AADT.

It was decided to install cable barrier along I-20 in Parker County for the following reasons:

- History of crashes, including crossover and head-in crashes (An average of 2 to 4 crashes were reported each week).
- The junction between I-20, I-30, and I-820, is very complex and generates a concentration of crashes in the surrounding areas.

Despite few very specific cases with minor issues, performance of both Brifen and CASS systems is similar and very satisfactory. No vehicles have penetrated the barrier.

Press reaction to cable performance has been balanced. Initially, poor press pointed out concerns due to lost time for emergency response. However, good comments have been written after significant crashes that did not go through the median. It seems that cable barriers have good acceptance among the public in general. The community has demanded cable installation at some locations with severe crash history.

Brifen

As many as 30 posts or more have been taken out in the Brifen system after a hit, but about 15-20 posts are damaged by an average hit in both systems. Performance of the high-tension cable systems is kept up to date by filling out a repair log and an accident report form for each hit (See Appendix 13). Funds recovered after damage claims are deposited into the General Fund unless damage is higher than \$25,000.

Some crashes have reportedly left the Brifen cable laid down after some impacts. TXDOT has observed sag in both systems after a few significant hits, but sag has been more common in Brifen. No detailed information was given on the actual cause of the sag in Brifen system, but the cable straightening when taking posts out (loosening the weaving), and the fact that bigger vehicles have hit Brifen and damaged more posts, may both be contributing factors to this issue.

On one occasion the Brifen system was hit by a large truck. The system stopped the vehicle, but a cable came loose from the turnbuckle. The male end of the threaded connection was left intact after the separation, and it seemed that the connection failed because it was shallowly threaded. A special splice piece was fabricated to repair the separated cable.

At a few locations, Brifen posts have bent and become stuck inside sockets on impact, making it difficult to pull them out and complete the maintenance. The plastic spacer pegs used in the Brifen system have broken off easily. An increase of the pressure on the

pegs caused by the weight of the cable or changes in elevation may be enough to overcome the peg resistance. Dust covers in the Brifen system are reportedly difficult to get off the posts, and sometimes it is more troublesome to reuse them than place new covers instead. Richard Butler from Brifen USA commented that the problem with the posts was related to component manufacturing tolerances and that it was corrected. The chemistry of the dust covers was modified to eliminate difficulties removing them from the posts.

The Brifen spreader bar is useful for replacing posts when 2 workers are doing the repairs, but the bar is not required if a 4-person crew is on the job. Special attention needs to be given to the cable weaving when replacing many posts in the Brifen system. A recommendation to ease the weaving process is to replace posts every other position, and then weave the cable as the intermediate posts are placed. Failing to follow an adequate weaving technique may cause significant delays to repairs.

CASS System

The CASS system has also been hit by large vehicles. In August 2005, two 18-wheelers and a GMC Jimmy SUV were involved in an incident on I-20. The cable system prevented an 18-wheeler from crossing the median. The cost repair was estimated at about \$2,000, and no injuries were reported.

Posts in CASS system beyond the actual impact zone can be opened up at the top during the collision. Sometimes the posts can be straightened back, but need to be replaced otherwise. Trinity Industries Inc. does not recommend trying to straighten bent posts. Plastic spacers between cables in the CASS system are compressed and sometimes bent. In the Texas installation, CASS cables are too tight to be lifted by hand. When repairing the system, it is not recommended to lift cables over the post by hand because this places hands and backs in potentially vulnerable situations.

Maintenance

Maintenance is carried out by State forces, which were initially trained by manufacturers. Current TXDOT maintenance employees are now training new workers, assuring knowledge transfer over time.

Repairs are generally done the next working day, during daytime. Partial repairs are recommended in bad weather conditions to at least insure cable height is correct until the full repair is done. Wintertime issues are not a significant concern for cable barriers in Texas because there is usually not significant snow accumulation or frost heave effect.

Additional mechanical assistance, such as boom trucks or tripods, will facilitate the repairs significantly, in particular to pull stuck Brifen posts, and to lift and place cables in the slot of CASS posts.

Cable tension is not commonly re-checked after repairs, but some readings have been taken in the field. Differences in the readings from CASS (Digital) or Brifen (Analog) meters have been found to be about 500 lb, but it is not known which meter is more

accurate. As a preventive measure, TXDOT recommends requiring the meter manufacturer to calibrate the device before delivery, preferably in the United States.

A stock of repair parts is continuously kept indoors in the Weatherford Area Office (posts are stored outside). A customized trailer with individual compartments is currently used to carry all parts, including posts, with a capacity of about 40 posts. Parts for both Brifen and CASS are purchased directly from the manufacturers, which offer lower prices than third-party suppliers.

From the maintenance point of view, cable systems are effective but intensive to maintain. However, workers believe reduction in fatalities is worth the additional maintenance work compared to other types of barriers. It was also noted that maintenance crews would rather respond to repair the cable system than to provide traffic control for a fatal crash response.

Emergency Vehicles

TXDOT recommends informing first responders about the need to keep cable barrier systems and to avoid cutting cables, as well as offering educational sessions to tow truck drivers and other interested groups. It is also advisable not to loosen the turnbuckle once the cable is in place because pulling it back to its previous tension is very difficult. TXDOT conducts meetings with Fire Departments and tow companies on a regular basis to reinforce the message and since the two companies have considerable turn over in personnel.

General Conclusion

Based on the experiences shared by DOTs in Ohio, Oklahoma, and Texas, as well as the product information provided by manufacturers of the U.S. High Tension Cable, CASS, and Brifen systems, the following general conclusions can be drawn on the high-tension cable barrier for median crossovers:

- In recent years, there seems to be an increasing trend in median crossover crashes in all 3 states visited and all 4 states that sent representatives to the tour.
- The median cross over protection systems can reduce the fatalities and life changing injuries due to median crossover crashes.
- High-tension cable systems have been successfully used for median crossover protection on highways with wide medians and flat median slopes. There is potential for use in other conditions, but more experience and performance testing in the U.S. are needed.
- The general performance of the cable barrier systems, at redirecting or stopping vehicles, seems to be excellent.
- All cable barrier systems observed in the Scanning Tour (Brifen, U.S. High Tension Cable System, CASS, and Safence) seem to be perform similarly when hit by passenger vehicles. Further experience and testing is needed to quantify system capacity for heavy vehicles.
- No major drawback of high-tension cable barrier systems was found. Installation and maintenance issues can be improved with experience.

- While maintenance of the barrier system requires workers to be exposed to highway traffic, traffic control and cleaning up after vehicle crashes also requires workers to be exposed to highway traffic. Repairing the barrier is a more satisfying job knowing that the barrier prevented severe injury or even death.
- Warrants for installation of median cable barrier tend to a severe crash history. Such a large potential for installation forces decision makers to take care of worst cases first.
- States are still in the learning process. Information gathered in this Scanning Tour provided valuable knowledge on system characteristics, performance, and maintenance.
- This Scanning Tour has been very useful to guide the participant states in all aspects related to the use of high-tension cable systems in their roadway systems. Similar scanning tours are recommended in the future for addressing particular issues in transportation.

In addition to those lessons learned, more experience and data is needed to draw conclusions or make improvements on the following aspects:

- The in-service performance evaluation (ISPE) for any system has not been completed. Performance in the long run is not known.
- Results from long-term benefit-cost analyses are not yet known.
- Differences in performance and long-term maintenance issues between cable systems (3-cable and 4-cable systems) are not completely clear.
- Designs for cable systems at points of interaction with other structures such as guardrail, bridge piers, or sand barrels, are not completely standardized.
- Practices dealing with crossover requirements from first responders and crossover gaps are still being improved.
- Guidelines for optimum location of cable barriers in various types of median widths and slopes need to be developed.
- It is not known how updates in NCHRP 350 criteria can affect the systems and their usage.
- A new national guideline for median barrier warrants by AASHTO is anticipated. The guideline is a tool that can help states in identifying their needs for median barriers. It will also provide States the flexibility to customize their warrants based on local data and factors such as highway systems, crash history, politics, and public opinion.

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