

CABLE GUARDRAIL EVALUATION
U.S. ROUTE 1 MEDIAN
MOORESFIELD ROAD TO GOVERNMENT CENTER
SOUTH KINGSTOWN

April 2005



**RESEARCH AND
TECHNOLOGY**

Prepared for the Rhode Island Department of Transportation
by:

The Research and Technology Section

With Assistance from The Construction, Highway Engineering, MIS and Traffic Research Sections

Disclaimer

This document was developed by the Rhode Island Department of Transportation. The contents of this document and any opinions expressed herein are solely the responsibility of the authors. It is not intended to constitute a standard nor should it be treated as one. Products are only mentioned if considered necessary for the purpose of accurate reporting. As such, no conclusions should be drawn as to the fitness of the products listed for any given application.



We would like to dedicate this report to Major George Ley, who is currently serving our country in the war in Iraq as an engineer in the Reserves. George was the Resident Engineer under whose watch the cable guardrail system was first installed. We deeply appreciate his sacrifice; being away from home, family and friends, working in a foreign land under dangerous conditions to keep America safe. We wish him well and hope that he will soon be safely returned to us.

Acknowledgements

This report was produced by Research and Technology and was a joint effort with the Construction and Highway Engineering sections, with the assistance of Crossman Engineering. The efforts of Mr. Michael Gannon (of Highway), Mr. George Ley, Mr. Rex Sullivan (both of Construction) and Mr. Jon Vernava (Crossman) in providing information and support were instrumental in creating this report. We would also like to thank Steve Kut and Bill Lincourt of MIS/GIS and Mike Sprague of Traffic research for their help developing the accident tracking system.

Cable Guardrail Installation on Route 1 Median

Table of Contents

I.	<i>Introduction</i>	1
II.	<i>Preliminary Engineering</i>	1
III.	<i>Design</i>	3
	A. <i>Site Characteristics</i>	
	B. <i>Planning</i>	
	C. <i>Engineering</i>	
	D. <i>Design Approvals</i>	
	E. <i>Design Bid Analysis</i>	
IV.	<i>Construction Operations</i>	7
	A. <i>Traffic Control/Setup</i>	
	B. <i>Pre-Construction Survey</i>	
	C. <i>Construction Sequence</i>	
	D. <i>QA/QC</i>	
V.	<i>Performance</i>	12
VI.	<i>Analysis and Conclusions</i>	17
VII.	<i>Questions and Answers From RIDOT/Trinity CASS Meeting</i>	18
VIII.	<i>Recommendations</i>	21
	<i>Endnotes and References</i>	22
	<i>Appendix A: Cable Guardrail System Details</i>	A1
	<i>Appendix B: Accident Data Collection</i>	B1
	<i>Appendix C: Analysis of Temperature-Based Cable Expansion/Contraction</i>	C1

List of Tables and Figures

<i>Figure 1 - Post, Installed and Complete</i>	1
<i>Figure 2 - Deflection vs. Post Spacing (Trinity CASS)</i>	5
<i>Figure 3 - Anchor Point</i>	8
<i>Figure 4 - Installed End Posts</i>	8
<i>Figure 5 - Installed Standard Posts (without cable)</i>	9
<i>Figure 6 - Placing the Cable</i>	9
<i>Figure 7 - Pulling the Cable</i>	10
<i>Figure 8 - Adjusting Tension with the Turnbuckles</i>	10
<i>Figure 9 - Checking with the Tension Meter</i>	11
<i>Figure 10 - Impacted section of Cable Guardrail</i>	13
<i>Figure 11 - Post After Impact (Inset - Crack at Bottom of the Cable Slot)</i>	14
<i>Figure 12 - Kink in Cable After Impact</i>	15
<i>Figure 13 - Removal of Excess Concrete from Shear Bolt Mounting Hole</i>	15
<i>Figure 14 - Dislodged Footing</i>	16
<i>Figure A1 - System Overview</i>	A2
<i>Figure A2 - Posts</i>	A3
<i>Figure A3 - End Section</i>	A4
<i>Figure B1 - Aerial View of Accident Locations</i>	B3
<i>Figure B2 - Accident Reporting Form for Database</i>	B4
<i>Figure B3 - Typical Accident Report</i>	B5
<i>Table 1 - Bid Analysis Summary</i>	6
<i>Table 2 - Summary of Accident Data</i>	12

I. Introduction

The intersection of Route 1 and Mooresfield Road (Route 138) was planned for improvements to accommodate current and future traffic capacity. It was decided to expand the project and install a guardrail system in the median to reduce crossover accidents. As part of the installation of the barrier, several turnarounds were to be closed as a further safety measure. Because of the closures and to maintain mobility with the section of road, “jug handle” turns and emergency turnarounds were also designed into the planned improvements¹. As the guardrail system that was selected was relatively new and innovative, this report was developed to document the process by which the system was selected, designed and installed into the project, as well as issues that have arisen since it was installed. The Trinity system has been used in Colorado, Illinois, Ohio, Oregon, Utah and Washington.

II. Preliminary Engineering

A high tension cable barrier system with reduced dynamic deflection was approved in 2001² for use in median applications on the National Highway System by the Federal Highway Administration. Since then, four manufacturers have received acceptance of their product as a National Cooperative Highway Research Program (NCHRP) Report 350 test level 3 (TL-3) bi-directional (median) traffic barrier. These systems utilize either 3 or 4 steel cables that are aligned by steel line posts. Post lengths are typically 4 to 5 feet, with varying cable heights set between 1.5 and 2.5 feet. NCHRP-approved post spacing varies from 6.6 feet to 16.4 feet. Posts are either driven into the ground with soil plates or are set into a socket within a concrete base (the latter was used on Route 1, see Figure 1).

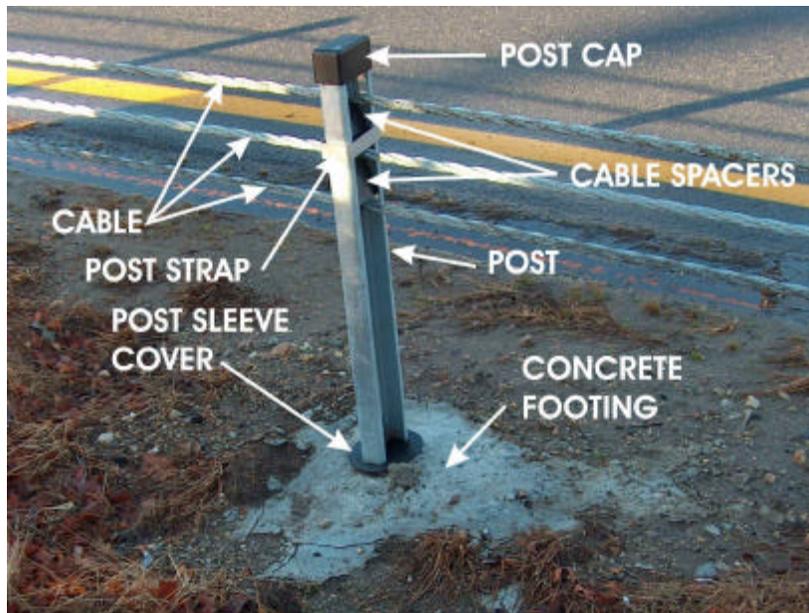


Figure 1 – Post, Installed and Complete

NCHRP-350 crash test 3-11 is performed for a 4,500 pound test vehicle (i.e. pick-up truck) traveling at approximately 66 miles per hour with a 26 degree approach angle. Maximum dynamic deflection results from this test for the four approved products range from 6.2 feet to 7.9 feet.

Cable Guardrail Installation on Route 1 Median

Shorter post space distances result in smaller deflections. Acceptance letters, product details, and test results were obtained from FHWA on the world wide web by selecting the cable barrier keyword at the following address:

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

The range of bid prices for cable barrier installation in states such as Ohio and Colorado were typically between \$13.00 and \$20.00 per linear foot. Variables that contribute to the range of bid prices among different contracts include post spacing, post foundation type, and labor costs.

Four systems, each from a different vendor, were considered: Blue Systems Safence, Brifen Wire Rope Safety Fence (WRSF), Marion Steel Wire Rope Barrier (WRB) and Trinity Systems Cable Safety System (CASS).

Following is a general list of advantages and disadvantages that are characteristic of cable barrier systems:

Advantages

- Cost of installation is inexpensive compared with other barrier systems;
- Forces on the occupants of the vehicles during a crash are low compared with other types of barriers;
- Cable barriers have good crash test performance (up to a 4,500 pound pick-up); and
- System is aesthetically appealing.

Disadvantages

- Barrier damage is increased in a typical accident, when compared to other systems
- Damaged installations need to be repaired or replaced quickly since the damaged run may be ineffective until repaired
- A minimum clear space is required behind the barrier for cable deflection; and Periodic retensioning of the cables is required³

Studies in other states have shown that median barrier reduces the number of fatal crashes, but increases the number of accidents resulting in injury and property damage. For example, the Oregon Department of Transportation installed cable barrier in the median of Interstate 5 in December 1996. A review of accidents was conducted for the period between 1987 and March 1998 and indicated that the accident rate with cable barrier, 40 per year, was much higher than the historical accident rate of 1.0 per year without cable barrier. The study concluded that “the most likely explanation for the increase in accidents is vehicles that drove into the median prior to the barrier installation, and reentered the roadway without incident, are now impacting the cable system.” The number of fatal accidents in that study, however, was reduced from an average of 0.6 fatalities per year to 0 fatalities per year during the period after installation of the cable barrier.⁴

III. Design

A. Site Characteristics

U.S. Route 1 (Tower Hill Road) in South Kingstown is a 4-lane, divided roadway that receives an Average Annual Daily Traffic of approximately 29,000 vehicles. This study roadway segment is a portion of the Route 4 and U.S. Route 1 corridor that connects Kent County and coastal Washington County. The roadway functions as both a major corridor for statewide commuters, industry, and tourists; and as a principal arterial.

The current version of the roadway was originally constructed about fifty years ago. Since 1960, traffic volumes have increased by 400%, but average operating speeds remain higher than the posted speed limit. Accident history in the project area indicates the recurrence of both injury-producing and fatality-producing accidents due to median crossovers. The design goal was to prevent future crossover accidents by incorporating a longitudinal barrier system into the roadway median.

A typical section of the roadway consists of four 12-foot travel lanes, 10-foot low-speed shoulders, and no high-speed shoulder. A 15-foot grassed median divides the northbound and southbound lanes of travel. The median slopes toward its center, where catch basins collect storm water runoff. A concrete drain pipe trunk line runs longitudinally beneath the median centerline and connects these catch basins.

B. Planning

The Rhode Island Department of Transportation (the Department) has worked closely with representatives from the Town of South Kingstown since the 1980s in order to define a plan for the future of the roadway corridor. The Town has maintained a concern for both safety and aesthetic character of the road through this scenic area. Therefore, a barrier system was sought for this construction contract that could prevent crossover accidents within the limited median width and still maintain the visual appeal of the roadway corridor.

Several alternative systems that the Department has used in the past were considered, including concrete median barrier, standard steel beam guardrail, rustic steel beam guardrail, and steel-backed timber guardrail. In Winter 2002, the Federal Highway Administration recommended that the Department also consider bi-directional cable barrier systems, which had been recently approved for median applications along National Highway System roads. All of these barrier systems could provide some protection from crossover-type accidents, but only some were considered visually acceptable. These were the rustic steel beam guardrail, the steel-backed timber guardrail and the steel cable barrier. In Spring 2002, the Department presented barrier options to the Town during a public informational meeting. Among the three choices, the steel cable barrier was identified by the majority of attendees as the system that was least obtrusive and would provide the best opportunity for landscaping. Installation of this system was also expected to be achieved within the existing grass median with relatively low impact, effort, and cost.

C. Engineering

The final design incorporated substantial review of engineering criteria as well as public opinion. The Route 1 cable barrier geometric design was defined by the roadway cross-sectional characteristics, horizontal alignment, and intersection locations. The location of existing intersections and proposed public and emergency-only turnarounds controlled the placement of barrier terminals. The radius of the horizontal curves are long enough to accommodate the cable barrier system. The direction of curvature was considered in the lateral placement of the barrier in order to maximize the clearance for deflection on the outside of curves.

The primary constraints were due to cross-section concerns, specifically median width, median cross-slope, and the presence of drain pipe. Since there is only a 15-foot median separating opposing high-speed lanes and the cable barrier deflection is typically greater than 6 feet, the ideal placement for the barrier would have been within the central 3 feet of the median. However, the posts could not be placed so close to the median centerline due to the presence of the closed drainage system and associated drainage ditch. A subsurface utility engineering consultant was contracted in order to confirm the exact location of the drain pipes. The resulting layout aligned the posts at a 2.5-foot offset parallel to the centerline in order to avoid any physical conflicts with the drainage system.

This final design placed the barrier system 5 feet from the near-side high-speed travel lane on a slope that is generally flatter than 6:1. According to the AASHTO Roadside Design Guide Subsection 5.6.2.2, cable guardrail has performed well even on 6:1 slopes. However, an errant vehicle approaching from the side opposite the cable barrier location could produce a deflection greater than the provided 5-foot setback. Reducing the post spacing was considered, but after consulting with the manufacturers, this option was not pursued because none of the products have met NCHRP-350 criteria at that spacing (Figure 2 shows deflection vs. post spacing for the system used; EN 1317 is a European barrier standard). Two primary concerns were that the deceleration forces and the occupant impact velocities would be higher than allowed. After careful consideration, the Department sought and received design concurrence from the FHWA based upon the premise that the barrier still provides a significant safety upgrade to the corridor by reducing the potential for head-on collisions due to vehicle crossovers. A post spacing of 6.6 feet was selected for the design of the system.

Cable Guardrail Installation on Route 1 Median

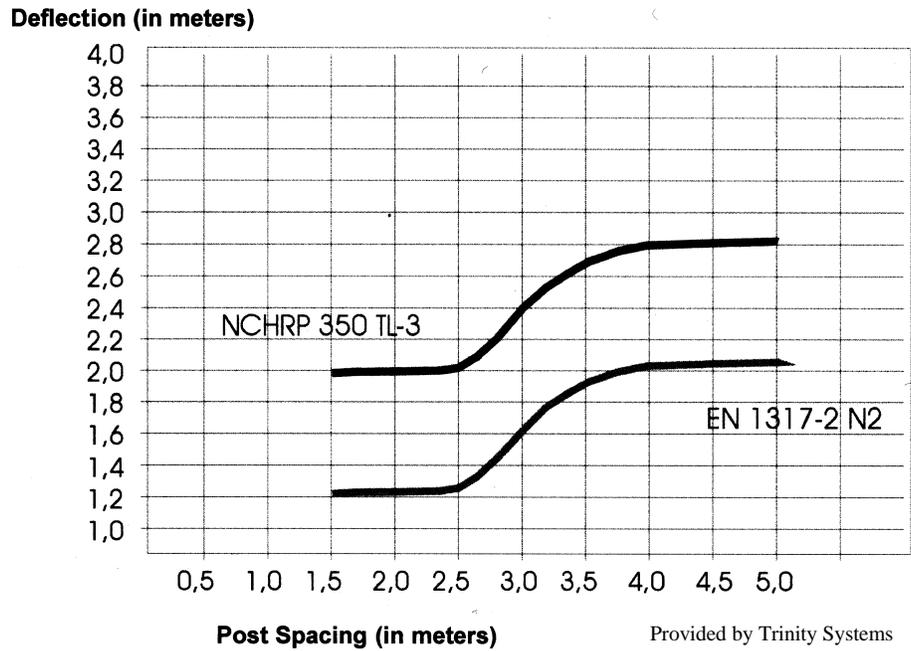


Figure 2 – Deflection vs. Post Spacing (Trinity CASS)⁵

D. Design Approvals

- Fall 2002: RIDOT received concurrence from government officials from the Town of South Kingstown.
- Winter 2002/2003: RIDOT reviewed cable barrier design criteria with FHWA.
- Winter 2003/ 2004: RIDOT received concurrence from FHWA.
- March 2004: Contract Bid Opening (Four bidders)

The extended periods of time between approvals was due to the revision in the project scope. The original project incorporated only the new intersection design. Because of the request by the town to address the issues relating to the median (crossovers and closing the turnarounds), the scope expanded significantly. Essentially, a new project had to be designed from scratch for the median work (including the design of the “jug handles”) and the existing design (which was nearly complete in all respects) then had to be folded into it.

E. Design Bid Analysis

The contract unit bid price for the tensioned cable barrier on the Route 1 project was \$36.00 per linear foot, exclusive of the terminal section. This was the first contract to install this product in Rhode Island; and, as a result, the bid price was higher than previous bid prices in other states. Another factor that likely affected the Route 1 project bid price was the sharp rise in steel prices that occurred prior to the bid process. The cost is expected to decrease in future contracts now that contractors are familiar with the product. Note that there was only a single subcontractor for all of the four contractors that had bid on the project.

Cable Guardrail Installation on Route 1 Median

ITEM	CONTRACT DESCRIPTION	AVG UNIT	QUANTITY	ENGINEER'S UNIT PRICE	UNIT PRICE	ALL BIDS	DIFFERENCE
107	CABLE G-RAIL TERMINAL	EA	14	\$2,000	\$4,925	\$ 5,318	\$40,950
108	CABLE GUARDRAIL	LF	15,225	\$16.00	\$36.00	\$37.75	\$304,500
121	PRECAST MEDIAN BARRIER	LF	645	\$60.00	\$100.00	\$ 63.75	\$25,800
149	MAINTENANCE OF TRAFFIC	LS	1	\$125,000	\$334,460	\$254,865	\$209,460

Table 1 – Bid Analysis Summary

A more detailed analysis is provided below:

ITEM No. 107: "TENSIONED CABLE GUARDRAIL TERMINAL": The Engineer's Estimate for this item was \$2,000.00/EA, while D=Ambra Construction Corporation's bid was \$4,925.00/EA. The average of all bidders' for this item was \$ 5,318.00/EA with three of the four bidders having the same bid as D=Ambra and the other being higher. Because this item has not been previously used in the State of Rhode Island, the unit price of \$2,000.00 was based upon average bid prices from contracts within the states of Arizona, Colorado and Utah as well as information provided by the manufacturers. Recent unprecedented increases in steel prices as well as this contract calling for night work may have also influenced the actual bid prices on this contract. Based on the above, we feel our estimated price should have been higher and foresee no problems with this item as it is bid.

ITEM No. 108: "TENSIONED CABLE GUARDRAIL": The Engineer's Estimate for this item was \$16.00/LF, while D=Ambra Construction Corporation's bid was \$36.00/LF. The average of all bidders' for this item was \$37.75/LF with all four other bidder's submitting a higher bid than our estimate. Because this item has not been previously used in the State of Rhode Island, the unit price of \$ 16.00/LF was based upon average bid prices from contracts within the states of Arizona, Colorado and Utah as well as information provided by the manufacturers. Recent unprecedented increases in steel prices as well as this contract calling for night work may have also influenced the actual bid prices on this contract. Based on the above, we feel our estimated price should have been higher and foresee no problems with this item as it is bid.

For comparison, the approximate average unit prices for installation of alternative bi-directional barrier systems in Rhode Island are as follows:

- Standard Steel Guardrail (double-faced) - \$30/LF
- Rustic Steel Guardrail (double-faced) - \$40/LF
- Steel Backed Timber Guardrail (double-faced) - \$60/LF
- Precast concrete median barrier - \$65/LF

Of the four products initially considered, Safance and WRSF did not have the requisite NCHRP 350 approvals (both are now approved). The Contractor winning the bid selected Trinity's CASS.

IV. Construction Operations

A. TRAFFIC CONTROL/SETUP

The traffic control setup consisted of a typical work zone closure, with the high speed lane used for the work zone. The low speed lane and paved shoulder provided two lanes for traffic flow through the work zone. Fluorescent cones, arrow boards and appropriate temporary construction signs as well as a portable changeable message board were used for the "Lane Shift" setup. Two police details with cruisers were employed to assist with traffic control. Traffic control was a separate bid item for the contract as a whole and not specifically included for the guardrail installation.

B. PRECONSTRUCTION SURVEY

The contractor was required to notify any affected utilities within the work zone through the "Dig-Safe" process. The RIDOT Survey section provided the starting and ending stations of the guardrail system using the project plans for reference. The contractor did the construction layout in order to determine post spacing and terminal end section anchor spacing using the approved shop drawings. A string line was run off known references and the positioning of guardrail was determined from the line.

C. CONSTRUCTION SEQUENCE

The contractor installed the terminal end section footings first (see Figure 3). Then an auger truck was used to excavate the footing hole to a depth of thirty inches, the reinforcing steel and hardware was positioned in the hole and followed by the concrete placement. Next, the excavation of the intermediate posts using an auger truck and two man crew began. Once a sufficient number of holes were excavated another crew of 2 to 3 laborers began placement of the concrete footings for the intermediate posts. The concrete was purchased from a local RIDOT approved facility (Cardi Corporation) and delivered using a front discharge concrete truck. The concrete used was a RIDOT Class XX ¾" (4000 psi), cured for three days prior to proceeding with the installation. A plumb bob was used to set the post sleeves true into the concrete while it was in the plastic state. Once the footings were installed, the contractor began installing the posts and associated hardware (see Figures 4 & 5). The cables were strung (see Figure 6) and finally tensioned to a predetermined cable tension based on ambient temperature (see Figures 7). Tensioning was performed by using turnbuckles installed between each 1000 foot length of cable (see Figure 8). A tension meter purchased from the manufacturer was required to test the tension (see Figure 9).

Cable Guardrail Installation on Route 1 Median



Provided by Trinity System

Figure 3 - Anchor Point⁶



Provided by Trinity Systems

Figure 4 - Installed End Posts⁶

Cable Guardrail Installation on Route 1 Median



Provided by Trinity Systems

Figure 5 - Installed Standard Posts (without cable)⁶



Figure 6 - Placing the Cable

Cable Guardrail Installation on Route 1 Median



Figure 7 - Pulling the Cable



Figure 8 – Adjusting Tension with the Turnbuckles

Cable Guardrail Installation on Route 1 Median



Figure 9 – Checking with the Tension Meter

The first section of guardrail (run #7) was 2553 linear feet (LF) along with two end sections. Installation took 5 working days and one day for tensioning. The second and third sections (runs #5 and # 6) were installed concurrently (3787 LF + 888 LF) for a total of 4675 LF, with four end sections. It took 8 working days to construct and one day for tensioning. Manufacturer's representatives were available continuously to provide technical assistance and advice.

Typically, the crew consisted of 7 laborers supported by an auger truck and several flatbed or stake body trucks.

Cleanup of the site consisted of removal of spoil piles from the augering, miscellaneous raking and restoration of the median island. Cleanup was done as the operation progressed and as time allowed. A final check and cleanup of the site was performed the last two days using available manpower.

The total length of guardrail installed to this point is 7,228 feet, with six end sections.

D. QA/QC

Because the system installation was new to Rhode Island, there was significant *QA/QC* support from the manufacturer's representatives, COSCO Corporation general superintendent and RIDOT staff. Areas for concentration are post location, spacing and height, end section foundation placement and details and cable tensioning.

Cable Guardrail Installation on Route 1 Median

V. Performance

To date there have been twenty locations requiring repairs due to traffic accidents. Typically, the contractor was notified of the damage and they mobilized to make repairs. Repairs include traffic control and setup, replacement of the damaged hardware and rechecking and re-tensioning of the cables as required. Accident and available repair information, up to the time of the writing of this report are summarized in the table below. Note that these are based on the submitted costs for the repairs. This was the best data that could be compiled by the Resident Engineer, but there are some gaps as the need for some of the information was not known at the time the data was collected. Payment was made at the bid price for installation of the barrier per linear foot. In Appendix B, Figure B1 shows an aerial view of the accident locations.

Accident Number	Quantity (LF Repaired)	Estimated Number of Posts Replaced	Accident Date	Date Repairs Completed	Repairs Costs (\$) ⁽²⁾	Traffic Control Cost (\$)	Replacement Cost/Post (\$)	Guardrail Run Number	Estimated Location of Accident
1	60	8	No Report	9/16/04	1F, 1L – 4hr \$192.40	None	24.05	7	No Info
2	100	14	10/2/04	10/7/04	1F, 1L, 8hr \$544.05	392.00	66.86	6	Sta. 522+00 ±100'
3	45	5	10/9/04	10/16/04	1OP, 1L, 4hr \$186.20 ⁽³⁾	None	37.24	5	Sta. 482+00 ±100'
4	75	10	No Report	12/8/04	2F, 2L, 8hr 1 StkTruck 1 AugrTruck \$757.60 ⁽³⁾	392.00	60.51	6	Sta. 493+00 ±100'
5	45 ⁽¹⁾	5	11/13/04	12/8/04				5	Sta. 483+88 to 484+33
6	6	1	No Report	12/8/04				7	Sta. 536+50 ±100'
7	24	3	12/3/04	12/8/04				6	Sta. 483+00 ±100'
8	25	3	No Report	12/17/04	2F, 2L, 5hr \$473.56 ⁽³⁾	None	157.84	⁽³⁾	"Near Fire Station"
9			No Report	12/17/04				⁽³⁾	"South County Com."
10	32	4	12/27/04	1/19/05	2F, 2L 1 StkTruck 1 AugrTruck 1 ArrowBd \$757.60 ⁽³⁾	392.00	28.30	6	Sta. 508+50 to 508+90
11	104	15	12/22/04	1/19/05				6	Sta. 510+00 to 511+10
12	20	2	No Report	1/19/05				6	Sta. 514+00 to 514+20
13	12	1	No Report	1/19/05				7	Sta. 526+75 to 526+90
14	85	12	1/2/05	1/19/05				7	Sta. 531+25 to 532+05
15	50	6	12/26/04	1/19/05				7	Sta. 538+20 to 538+70
16	32	4	2/1/05	⁽⁴⁾	⁽⁴⁾	⁽⁴⁾	⁽⁴⁾	7	Sta. 536+00 ±100'
17	13	1	2/5/05	⁽⁴⁾	⁽⁴⁾	⁽⁴⁾	⁽⁴⁾	6	Sta. 523+75 ±100'
18	33	4	3/1/05	⁽⁴⁾	⁽⁴⁾	⁽⁴⁾	⁽⁴⁾	7	Sta. 536+50 ±100'
19	20	2	3/10/05	⁽⁴⁾	⁽⁴⁾	⁽⁴⁾	⁽⁴⁾	6	⁽⁵⁾
20	26	⁽⁵⁾	3/10/05	⁽⁴⁾	⁽⁴⁾	⁽⁴⁾	⁽⁴⁾	6	⁽⁵⁾

Table 2 – Summary of Accident Data

Cable Guardrail Installation on Route 1 Median

Notes: 1] End Section, 2] F – Foreman, L – Laborer, Op – Vehicle Operator, 3] Cost for repaired sections not individually known for cumulative repairs, 4] This work has not been completed as of the time of the writing of this report 5] This information is not yet available

The Route 1 cable barrier system has demonstrated similar performance characteristics to the results in Oregon (see Section II) since its installation in September 2004. The number of impacts has been high relative to the number of median-related accidents that were previously reported. The cable barrier contractor has returned to the project area several times to repair the damaged sections.

The components of the system generally appeared to function as intended (see Figures 10 and 11). Both the standard and end section posts failed as designed, with no apparent damage to the cable. As of the writing of this report, there have been no fatalities, no known serious injuries and no vehicle crossovers resulting from collisions with the system.



Figure 10 – Impacted section of Cable Guardrail

Cable Guardrail Installation on Route 1 Median



Figure 11 – Post After Impact (Inset – Crack at Bottom of the Cable Slot)

There was at least one instance where one of the concrete post foundations was shifted, apparently the result of an accident. However, one of the end section concrete anchors became dislodged (pulled out) from the ground. This is not believed to be the result of an accident. In another case, the cable was seen to have a kink in it due to an impact (see Figure 12). It is not known whether this would have any effect on the cable's mechanical properties. When repairing the end section, there was some difficulty replacing the shear bolts, due to excess concrete collected around the base anchor brackets during placement (see Figure 13). This required a laborious process to chisel away the concrete, in order to reinstall the posts and cable ends. This substantially increased the time required to make the repair.

Some of the post footings were pulled out of the ground on impact (see Figure 14). While it did not happen in every accident, the purpose of using the footings is to allow the posts to fail, but still have an intact insertion point for the new posts. The intent was to make the repair process as rapid as possible.

Cable Guardrail Installation on Route 1 Median



Figure 12 – Kink in Cable After Impact



Figure 13 – Removal of Excess Concrete from Shear Bolt Mounting Hole

Cable Guardrail Installation on Route 1 Median



Figure 14 – Dislodged Footing

VI. Analysis and Conclusions

Overall, the system is doing what it is expected to do. There have been no documented crossovers and no serious injuries or fatalities, despite a significant number of collisions in the seven months after installation. Aside from the problems on the end section, repair of damage has not been labor or equipment intensive. There have been at least one instance where the concrete base for the posts has shifted during an impact. That would seem to be atypical, but it does call into question the effect of soil conditions on the reaction of the system.

When the guardrail is impacted and posts are damaged, the system loses some effectiveness for future collisions as a function of the number of posts lost in proximity to the damaged area. While the system still provides a measure of protection, it is important to repair the guardrail in order to restore it to a proper level of performance.

There may be more reported accidents with the guardrail system in place. Previously, there was no barrier in the median. Because a vehicle traveling onto an unprotected median may be able to recover and drive off, having the cable guardrail in place may capture those vehicles. Even if the vehicle is not caught, damage to the guardrail will require a response that would not be necessary if there were only tire marks in the median.

More information needs to be developed on the cable displacement versus temperature. Cable that is tensioned at 80°F temperatures may shrink by as much as four inches over every 1000 feet at 40°F. For runs of several thousand feet, this may make re-tensioning the cable after repairing an end section very difficult. This was seen during the repair of guardrail in December.

VII. Questions and Answers From RIDOT/Trinity CASS Meeting

1] Could intermediate tension points or posts be built into the system to limit the length of the system affected by the loss of an end section?

This may be something for us to consider. It would allow for support / tension to remain in the cables if the closest end terminal were to be hit. The recommendation would be to place such a tension point about 100' away from the end terminal. Cable clamps and a retaining plate could be used on each of the three cables to allow it to retain tension against the CASS post at that point.

2] Water collects inside the footing post sleeves; what about rusting of the sleeves and posts?

CASS parts are galvanized to Type 1 specifications like most guardrail parts. As with guardrail that is cut or drilled, minor scratches inside of the sleeve will "heal" as the zinc flows back over the scratch. As far as knowing how long CASS components will "live" in the field without rusting we will need to monitor existing installations, the longest of which have now been our UT and MN sites.

3] Could hook bolts be used as a replacement for the u-bolts on the line posts in end sections?

As with all parts of CASS we are constantly looking for ways to maintain the original crashworthy integrity of the system while streamlining manufacturing and installation costs, especially with the end terminal. Right now we are not looking to change the hook bolts, since there are only 18 of them per each terminal. If we do replace them their substitute would have to allow for a positive attachment to the six line posts since the cables at that point in the system are under a great deal of tension.

4] How does the loss of posts after an impact on a radius section affect the tension (performance) of the cable system?

The tightest recommended radius with CASS is 650' (200m.) at a 10' (3m.) post spacing. We can probably go with a tighter radius with 2m. post spacing but, quite frankly, even a 650' radius is not usually encountered on our highways. After a typical hit that takes down 6, 7, or 8 posts the cable remains under tension at approximate design heights of 21", 25", and 29" inches and straightens itself out between the closest remaining upstream and downstream posts. While theoretically the tension is lessened in that short distance it remains able to deflect a vehicle which may impact the system prior to repair. We have not measured tension in the "straight line" portion of the cable in a radius, but have checked the tension after the posts have been replaced and the cable re-hung and have found the tension to be in accordance with the temperature-tension chart.

If you were to remove posts for 200' or so, the weight of the cables would overcome the tension and the cables would start to lie on the ground. This is beneficial where you may want to create an emergency turnaround in the median. Vehicles can drive over the downed cables and they can later be restored by replacing the posts and lifting the cables back into place....without having to re-tension .

5] What is the effect of soil properties and conditions in the choice of driven posts vs. embedded sleeves?

Cable Guardrail Installation on Route 1 Median

As with most highway safety appurtenances CASS posts are recommended to be placed in a standard (strong) NCHRP 350 soil. During testing, CASS posts were either driven directly into the soil (63" posts) or placed in a steel sleeve (47" posts). In all phases of testing, including both crash tests and weighted pendulum tests (820 kg. weight), the posts failed predictably; bending at ground level on either the weak sides or strong sides.

If it were felt that the soil was too weak for a driven sleeve application we would recommend either a concrete footing, or, perhaps, a sleeve with a soil plate, especially for an end terminal application. We do not yet have an installation in which the posts have been driven directly into the soil as the highway entities that we have dealt with have opted for ease of post removal.

6] Could a concrete block be used for the NCHRP 350 approved end terminal cable release posts?

One item under consideration for the crashworthy end terminal (CCT) is to do away with three separate concrete footings for the cable release stub posts and pour one large concrete block instead. The lower attachment hinge points for the upper release posts would then have a welded steel footplate which would be bolted / anchored to the block. We already have FHWA approval to use CASS by means of footplate attachments and drawings are available.

7] In the event of an impact how is the integrity (not just tension) of the cable checked?

If a kink or some other aberration (other than obvious fraying or other such strand separation) should show up in the cable after an impact we do not at present have any means of determining if the cable is still useful. There are a couple of methods of replacing the cable section if an area is suspect. If the kink or damage is in the end terminal cable, that section of cable has a specific part number for upper, middle, or lower and can be ordered and replaced. If a suspect area is in the CASS cable run then: (a) a new 1,000' section can be ordered and replaced, or (b) the bad area can be cut out and a new short section of cable spliced in using 2 left-handed fittings, 2 right-handed fittings, and 2 turnbuckles.

As far as knowing how many times an area of cable can be hit before failure occurs, our best way of eventually knowing this is to monitor our frequently impacted sites, as in UT and MN. We also do not know how many impacts are occurring that are outside the parameters of NCHRP 350 TL-3. We are beginning to see that we have some margin of safety in the current design that will accept over-design impacts.

8] What are typical installation costs?

- I. Ohio, Lorain County, September 2004
Cable-only job, 13,000' 3 runs
3 meter post spacing, concrete footings
no traffic protection required
\$23 / linear foot
- II. Utah, June 2004
Cable-only job, 2,400' 1 run
3 meter post spacing, concrete footings

Cable Guardrail Installation on Route 1 Median

no traffic protection required, non-union labor
\$17.88 / linear foot

- III. Florida, bid February 2005
Cable + guardrail job, 56,000' 7 runs
3 meter post spacing, concrete footings
traffic protection bid separately
\$19.10 / linear foot
crashworthy ends \$2,900 each

VIII. Recommendations

- Geotech – Soils: There should be a geotechnical survey and analysis of the soil conditions prior to installation. While using a two foot deep concrete base may give some short term stability to the system, an impact or shifting over time may reveal problems that were not anticipated during the design and construction phase. Soil type and strata variations, potential moisture content and environmental changes can all affect the bearing capacities of the soil surrounding the footings. Guidelines should be provided by the manufacturer on how to design for varying soil conditions.
- Footing Concrete Pours: A better method for placing the concrete in the augured holes should be developed. The photos of the dislodged footings show that the concrete has not taken the form of the cylinder as it should since the hole is drilled. It appears to be more conical in shape (see Figure 14 on page 16). It is likely that the sides of the hole are collapsing, either due to instability of the soil (as a function of the time between auguring and concrete placement) or from the weight of the flowing concrete. In either case, the footing will not have the expected resistance to rotation on impact. A tremie chute could be used, with the bottom of the tube supporting the sides of the hole during placement. The chute would then be pulled up and moved to the next hole. A time limit for placement after drilling is also suggested.
- Post Footings: The concrete footings for the post holes should be crowned after the post sleeves are placed in the fresh concrete. Crowning the concrete would improve drainage away from the sleeves and reduce the potential for corrosion.
- Anchor Footings: Based on the problems encountered during the repair of the end section, a detail should be developed for placement of the end section mounting brackets in the concrete anchor point to maintain clear access to shear bolt holes. It is also recommended that instead of a individual foundation for each anchor point, that a single block be cast, with the anchors connections still staggered as in the current design. This would have to be accepted by the manufacturer, to assure that the crashworthiness of the system is not negatively affected.
- Repair Response Time: Given the current intervals between an accident and the repair of the damaged section, it is suggested that a departmental policy for a time frame to repair the guardrail be put into place. The time allowed could vary, depending on the type of damage and how it affects the crashworthiness of the guardrail. End section impacts would be considered more important to address. While damage that does not involve the end sections do not prevent the system from serving its intended purpose, the effectiveness can be reduced, especially in locations more prone to impacts. It is also suggested that this policy be implemented for the installation of the guardrail for the next phase of the project.
- Accident study: An evaluation program like that proposed in Appendix B would give a more objective measure of the cost/benefit ratio of the guardrail. To compare the effectiveness of the cable, accident data could be collected from one to two years prior to the installation of the guardrail. Data could also be collected now for sections to be

Cable Guardrail Installation on Route 1 Median

installed in the future. The coordination of this effort would probably be best suited to an entity outside the department, like URI.

- Cable Displacement: Adding anchor posts along the run, to eliminate the cumulative effects of shrinkage of the cable, could be used to reduce the associated problems. This would also have to be accepted by the manufacturer. A further discussion of these issues is provided in Appendix C.

Endnotes and References:

¹ State of Rhode Island Department of Transportation Highway Construction Project, Reconstruction of Route 4 and U.S. Route 1, Improvements to U.S. Route 1 From Mooresfield Road to Government Center, North Kingstown and South Kingstown, Rhode Island, RI Contract Number 2004-CH-019, RI Federal Aid Project Numbers NHS-0004 (010) and NHSG-0004 (011)

² FHWA Web Site, List of cable barrier NCHRP 350 approval letters,
http://safety.fhwa.dot.gov/roadway_dept/road_hardware/listing.cfm

³ M.H. Ray, Ph.D., P.E. and R.G. McGinnis, Ph.D., P.E. NCHRP Synthesis 244: *Guardrail and Median Barrier Crashworthiness*. Ch. 3, pp. 29-37. National Academy Press, Washington, D.C., 1997.

⁴ B. Sposito, E.I.T. and S. Johnston, P.E. *Three-Cable Median Barrier Final Report*. Ch. 3, p. 9. Oregon Department of Transportation, Research Unit, Salem, OR, 1998.

⁵ CASS Cable Safety System Product Manual, Trinity Industries, Inc.

⁶ CASS Installation Presentation, Trinity Industries, Inc.

APPENDIX A
CABLE GUARDRAIL SYSTEM DETAILS

APPENDIX B
ACCIDENT DATA COLLECTION

Cable Guardrail Installation on Route 1 Median

Figure B1 shows an aerial view of the accident locations. Figure B2 is the proposed input form for the accident reporting database. Figure B3 shows a typical report for an accident involving the cable guardrail.

Database Overview for Proposed Study:

Introduction – The objective for creating the database is to study the efficiency of the cable guardrail by performing a limited study.

Accident Study –

- A. Injury to passengers
- B. Damage to vehicle
- B. Damage to Guardrail

Procedure –

- A. Creation of database
- B. Location of accidents (using project plan as reference)
- C. Coordination of data collection between police (state, municipal) and RIDOT (Construction, Maintenance, Traffic Research), possibly done by URI
- D. Research and Technology consulted with Traffic Research (under Traffic Management) to create data structure for database

Objective –

Determine if the cable guardrail functions as intended over the long term; repair data will be taken into account, including costs and number of posts damaged.

Conclusions –

- A. Effectiveness of the guardrail (preventing crossovers, minimizing injuries)
- B. Accident density and ability of guardrail to absorb repeated impacts close proximity
- C. Detail of repairs and costs



Figure B1 – Aerial View of Accident Locations

Cable Guardrail Installation on Route 1 Median

Reporting Entry

Accident Reporting Information

Accident ID: Guardrail ID: Road Name:

Accident Date: Begin Station: Begin Feet:

City/TownName: End Station: End Feet:

Vehicle Information

Vehicle Type:

 Sedan/Coupe/Wagon

 Van/Minivan

 SUV/Pickup

 Commercial

 Motorcycle

 Unknown

Vehicle Weight (lbs):

Location Information

Direction:

 East

 West

 North

 South

Accident Location:

 Straight

 Curve

 End Section

Time of Day:

 Day

 Dawn/Dusk

 Night

 Unknown

Weather:

 No Adverse

 Rain

 Sleet/Hail

 Snow

 Fog/Mist

 Cloudy

 Crosswinds

 Unknown

Accident Information

Impact Result:

 Stop

 Cross Median

 Redirect

 Unknown

Redirect:

 Normal Stop

 Spin

 Flip

 Drive Away

 Unknown

Vehicle Damage:

 None

 Light

 Moderate

 Severe

 Unknown

Speed at Impact (MPH):

 Angle of Impact (Deg):

 Number of Posts Hit:

 Single Vehicle:

Photo Record:

Occupant Information

Driver Injury:

 None

 Light

 Moderate

 Severe

 Fatal

 Unknown

Passenger Injury:

 None

 Light

 Moderate

 Severe

 Fatal

 Unknown

Driver Condition at Impact:

 Normal

 Asleep

 Impaired

 Unknown

Record: 1 of 17

Figure C2 – Accident Reporting Form for Database

Report Number

04-1048-AC

Conditions Supplemental to
the State of Rhode Island

UNIFORM ACCIDENT REPORT

Accident Conditions (All Pages)

Box 1	Type of Roadway 3 Divided w/ Barrier	Box 6	Light Condition 1 Daylight
Box 2	Traffic Controls 1 No Controls	Box 7	Traffic Condition 2 Medium
Box 3	Road Surface 2 Asphalt	Box 8	Type of Location 2 Rural
Box 4	Road Condition 3 Snow or Slush	Box 9	Initial Collision 9 Ran off Road
Box 5	Weather Condition 3 Sleet or Hail		

Unit Number 1 Conditions (Page 1)

Box 10a	Non M/V Collision 1 Guard Rail
Box 11a	Vehicle Action Prior to Accident 1 Straight
Box 12a	Physical Condition of Driver 1 Appeared Normal
Box 13a	Chemical Test Data
Box 14a	Chemical Test Results

Unit Number	Sex	Seat Location	Ejected	Seat Belt Use	Injury Code	Helmet									
Unit 1	M Male	<table border="1"> <tr><td>1</td><td>2</td><td>3</td></tr> <tr><td>4</td><td>5</td><td>6</td></tr> <tr><td>7</td><td>8</td><td>9</td></tr> </table>	1	2	3	4	5	6	7	8	9	Y Yes N No	1 Shoulder (2 Pt) 2 Lap (2 Pt) 3 Lap/Shoulder (3 Pt)	4 Child Restrain 5 Not Used 6 Unknown 1 Bleeding/Broken Bones 2 Bruises/Abrasions 3 No Visible Injury/Complaints of Pain 4 Fatal 5 No Injury	Y Yes N No
1	2	3													
4	5	6													
7	8	9													
Unit 2	F Female														
Unit 3 (etc.)															

Cable Guardrail Installation on Route 1 Median

NARRATIVE FOR PATROLMAN [REDACTED]

Page: 1
11/18/2004

Ref: 04-1048-AC

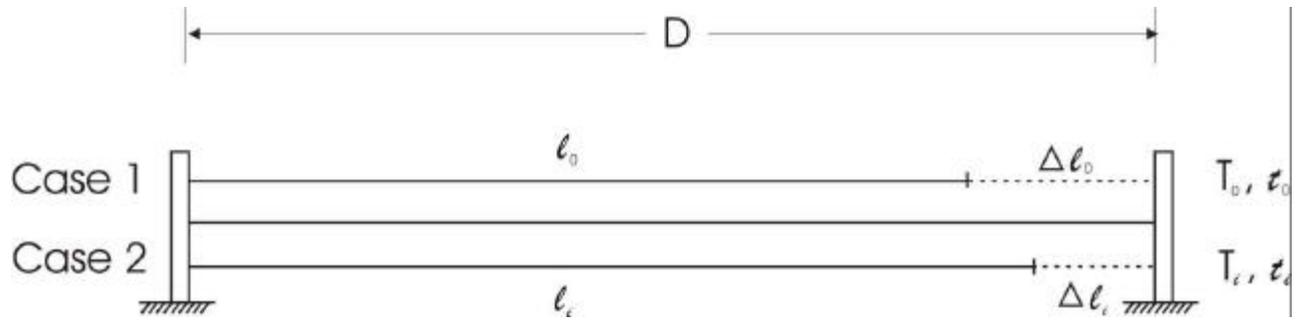
RI PASSENGER REGISTRATION BJ-449 OWNED BY [REDACTED], OPERATED BY [REDACTED]

[REDACTED] WAS TRAVELING NORTH ON ROUTE 1 BY THE TOWER HILL FIRE DEPARTMENT WHEN SHE LOST CONTROL OF THE VEHICLE AND RAN OFF THE ROAD STRIKING THE MEDIAN GUARD RAIL. [REDACTED] CAME TO REST TANGLED UP IN THE GUARD RAIL IN THE MEDIAN FACING SOUTHEAST. THERE WERE NO INJURIES. AAA TOWED THE VEHICLE WHICH SUSTAINED HEAVY DAMAGE. DAMAGE INCLUDES THE PASSENGER FRONT HEADLIGHT AND TIRE, PASSENGER SIDE, AND BOTTOM DAMAGE.

[REDACTED] 11/13/2004

APPENDIX C
ANALYSIS OF TEMPERATURE-BASED CABLE EXPANSION/CONTRACTION

Cable Guardrail Installation on Route 1 Median



- 1] Let l_0 be the length of wire @temp t_0 @ installation
- 2] l_0 is tensioned to T_0 to span length 'D' with an elastic extension of Δl_0
- 3] Let l_i be the length of l_0 @ temp t_i , with a tension T_i and extension Δl_i
- 4] Let 'a' be the cross-sectional area of the wire; α is the temperature coefficient for the steel

a) $D = l_0 + \Delta l_0 = l_i + \Delta l_i$ Equation of Compatibility

b) $E = \frac{T/a}{\Delta l/l}$

c) $l_2 = l_1 (1 + \alpha \Delta t)$ where:

t_1 = initial temperature

t_2 = final temperature

Δt = temperature difference $t_2 - t_1$

Case 1 @ installation:

$$D = l_0 + \Delta l_0$$

from b) $\Delta l_0 = \frac{T_0/a}{E} \cdot l_0$

$$\therefore D = l_0 \left(1 + \frac{T_0/a}{E} \right)$$

eqn. 1

Cable Guardrail Installation on Route 1 Median

Case 2:

$$D = l_j + \Delta l_j$$

$$l_j = l_0 + l_0 \alpha (\Delta t) \quad \text{where } \Delta t = (t_j - t_0)$$

$$= l_0 (1 + \alpha \Delta t) \quad \text{eqn. 2}$$

$$\Delta l_j = l_j \frac{T_i/a}{E} \quad \text{eqn. 3}$$

$$D = l_j + \Delta l_j = l_0 (1 + \alpha \Delta t) + l_0 (1 + \alpha \Delta t) \left(\frac{T_i/a}{E} \right) = l_0 (1 + \alpha \Delta t) \left(1 + \frac{T_i/a}{E} \right)$$

Equating D from Case 1 and Case 2:

$$l_0 \left(1 + \frac{T_0/a}{E} \right) = l_0 (1 + \alpha \Delta t) \left(1 + \frac{T_i/a}{E} \right)$$

$$T_0 + T_0/a = T_i + T_i/a + E a \alpha \Delta t + T_i \alpha \Delta t$$

$$T_0 = T_i (1 + \alpha \Delta t) + E a \alpha \Delta t$$

or
$$T_i = \frac{T_0 - E a \alpha \Delta t}{1 + \alpha \Delta t} \quad \dots \text{ I}$$

$$\Delta l_j = \frac{l_0}{E a} (T_0 - E a \alpha \Delta t) \quad \dots \text{ II}$$

Eqn. I = Gives the tension in the cable at any temperature t_j

Eqn. II = Gives the strain length of the cable at a temperature t_j