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In-Service Evaluations of Experimental Traffic Barriers

An Interim Report

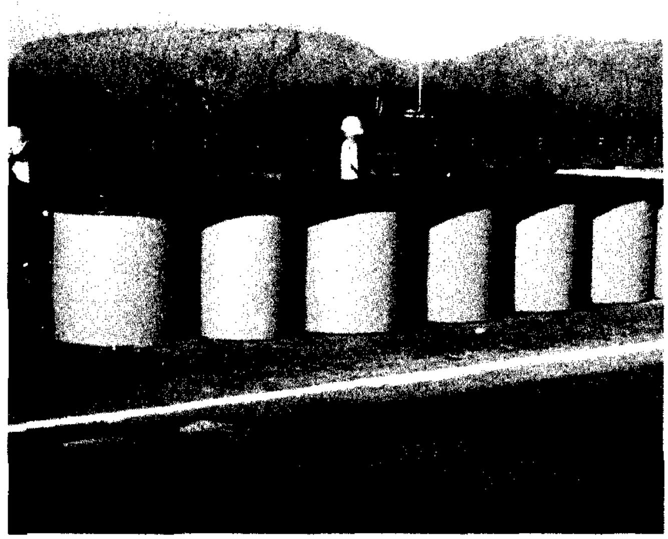
FHWA-DP64/EP 7-1

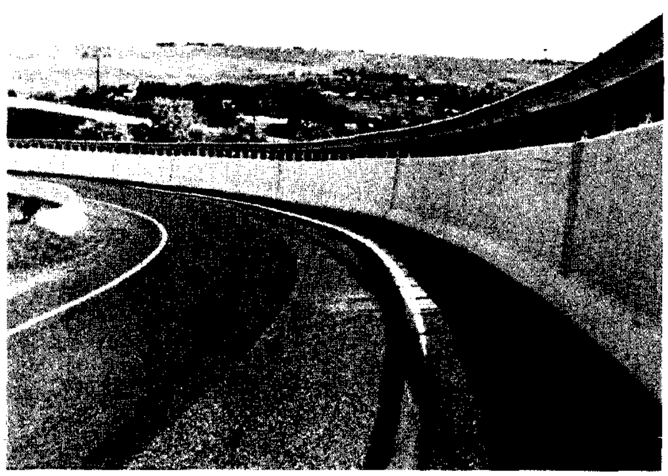
Demonstration
Projects Division

April 1986

U.S. Department
of Transportation

**Federal Highway
Administration**





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15. Supplementary Notes

This report is a summary of information provided by State highway agency personnel in Alabama, Colorado, Connecticut, Florida, Idaho, Illinois, Iowa, Maryland, Michigan, New York, North Carolina, Pennsylvania, Rhode Island, and Washington.

16. Abstract

The 1977 "AASHTO Guide for Selecting, Locating, and Designing Traffic Barriers" defines an experimental barrier as one "that has performed successfully in full-scale crash tests and promises satisfactory in-service performance." This report summarizes available information on several experimental barrier systems that have been recently installed throughout the country.

Included are cost, construction, and performance data on the following experimental barriers:

(1) Self-Restoring Barrier (SERB) Guardrail
(2) Service Level 1 (SL1) Bridge Rail
(3) Connecticut Impact Attenuation System (CIAS)
(4) SENTRE Guardrail Terminal
(5) Colorado Type 3F Median Barrier End Treatment
(6) Two high-performance truck barriers (Idaho and Pennsylvania)
(7) IBC Sand-Filled Median Barrier
(8) Modified Thrie Beam Guardrail

The last two barriers are presently classified as operational by the Federal Highway Adminstration.

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Unclassified	Unclassified	59	

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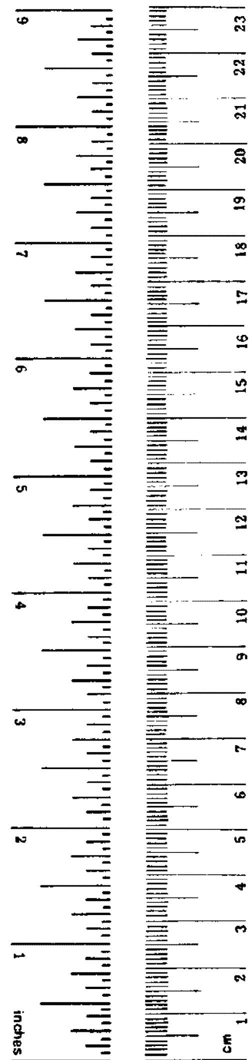
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

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cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

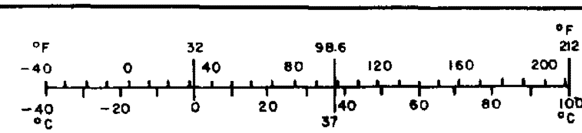

TABLE OF CONTENTS

I. INTRODUCTION

The 1977 "AASHTO Guide for Selecting, Locating, and Designing Traffic Barriers" classifies barrier systems as **operational, experimental,** or **research and development.** An **operational** system is defined as one that has performed satisfactorily in full-scale crash tests and has demonstrated satisfactory in-service performance. An **experimental** system is one that has performed satisfactorily in full-scale crash tests and promises satisfactory in-service performance. A **research and development** system is one that has had insufficient full-scale crash testing to be classified as experimental.

An operational system may be used on any highway project without restriction. An experimental barrier can be installed on Federal-aid projects only if the State highway agency requests and receives approval by the FHWA Division Administrator, agrees to evaluate its performance over a specified period of time, and prepares an evaluation report. The information contained in these evaluation reports provides a basis for determining if and when an experimental barrier should be declared operational by FHWA's Headquarters office.

This report summarizes evaluation information on several experimental barriers that have been installed throughout the country. Its purpose is twofold: to provide design engineers with current information on the costs and in-service performance of specific barriers, and to encourage additional installations where appropriate.

Eight different barriers are included in this report:

1. Self-Restoring Barrier (SERB) Guardrail
2. Service Level 1 (SL1) Bridge Rail
3. Connecticut Impact Attenuation System (CIAS)
4. SENTRE Guardrail End Treatment
5. Colorado Type 3F Median Barrier End Treatment
6. Truck Barriers
   a. Idaho
   b. Pennsylvania
7. Mark VII Sand-Filled Median Barrier[1]
8. Modified Thrie Beam Guardrail[2]

[1] This barrier is currently classified as operational, but additional experimental installations may be considered on a case-by-case basis.

[2] This barrier is currently classified as operational.

II. SELF-RESTORING BARRIER (SERB) GUARDRAIL

The Self-Restoring Barrier (SERB) Guardrail is a high-performance roadside barrier designed to be maintenance-free for most impacts, yet capable of containing and redirecting large vehicles. It consists of a tubular thrie beam rail element supported from 8 inch x 8 inch wood posts by steel pivot bars and cable assemblies. When hit by a vehicle, the rail deflects backwards and upwards, returning to its original position after the vehicle has been redirected. The SERB guardrail functioned as intended in a series of full-scale tests with vehicles ranging in size from a 2,100 pound automobile to a 40,000 pound intercity bus. No other barrier system in common use can accommodate both large and small vehicles, yet be relatively "forgiving" for most passenger car impacts and require little or no maintenance after repeated hits by automobiles.

Four pilot SERB guardrail installations were initially installed and evaluated under FHWA's Demonstration Projects Program. Details on each of these sites are contained in Report No. FHWA-DP-939-1, "Self-Restoring Barrier (SERB) Guardrail: An Interim Report on Its Installation in Four States", dated May 1984. The following information is a summary and update of the material included in that report plus previously unpublished information on subsequent installations in other States.

INSTALLATION NO. 1 - CHICAGO, ILLINOIS

Location

The SERB guardrail is located along the Austin Avenue exit ramp from the eastbound John F. Kennedy Expressway (I-90). This ramp carries an estimated 5,800 vehicles per day with 3 percent heavy commercial traffic. It is tangent for about 700 feet before curving sharply to the right to connect with a frontage road that is parallel to the expressway. The SERB guardrail was installed along a sharp horizontal curve having a radius of approximately 60 feet. It replaced a strong post W-beam guardrail which constantly needed repair and was sometimes penetrated by errant motorists. Figure 1 shows this installation shortly after its completion in January 1983.

FIGURE 1: Completed SERB near ramp terminus.

Cost

The total in-place cost for this 125 foot long installation (including end anchors and the approach transition) was approximately $98 per linear foot. The end anchorage costs of almost $2000 significantly increased the cost per foot of this short section of barrier. Installation required 13 working days, using primarily a 3-man crew.

Performance

Before the final inspection, the SERB was impacted near one of the modified splices and "jammed" when it deflected backwards and upwards so it did not revert to its original position. The 8 inch x 8 inch wood post was deflected about 6 inches, but even in this position, the railing was still functional. Since then, the SERB has been struck repeatedly. As can be seen from Figures 2 and 3, it currently needs to be repaired since several posts have been damaged and much of the mounting hardware has been destroyed. In spite of the numerous hits, the SERB guardrail has not been penetrated nor has it caused any serious reported injuries. It is noteworthy that no repairs were performed on this barrier until it had been in place over three years.

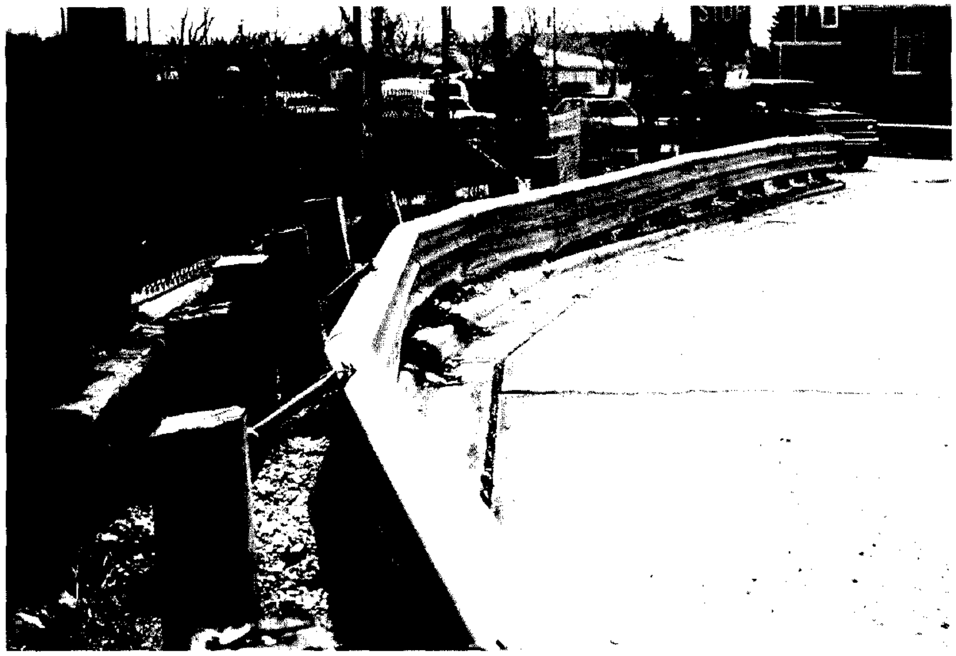

FIGURE 2: Although one post has been broken and much of the mounting hardware is damaged, the SERB guardrail remains an effective barrier.

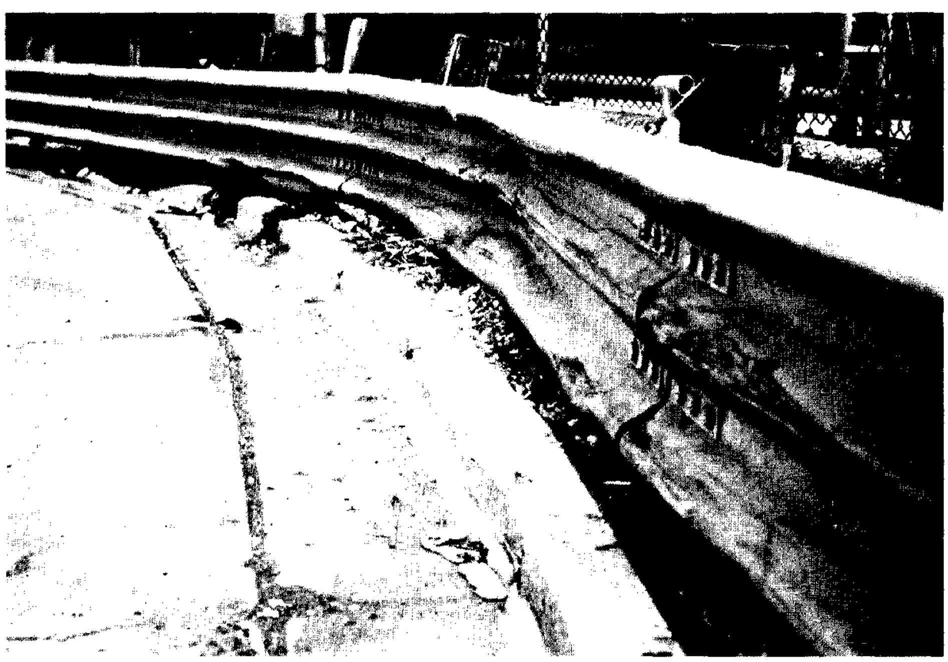

FIGURE 3: Once-straight section of tubular thrie beam has been "curved" by numerous hits.

Discussion

This site was originally selected to determine if the SERB guardrail would function satisfactorily when installed along a short radius curve. Although the rail has not been penetrated and has not required continuous maintenance, the cumulative damage to the system was considerable, and sections of the barrier were replaced in-kind after three years of service. The repair work reportedly cost $5,226 and was accomplished with no significant problems.

INSTALLATION NO. 2 - ARLINGTON, VIRGINIA

Location

The installation site is the ramp connecting southbound traffic on the George Washington Memorial Parkway traffic with the southbound lanes of Interstate I-395. This ramp has a relatively sharp curve (175 foot radius) to the left near its midpoint. The SERB guardrail was installed within an existing run of standard W-beam railing. The concrete footings for the two SERB end posts were eliminated to reduce the stiffness of the system at those points and to simplify the transition section from W-beam to SERB guardrail.

Cost

For the 250 feet of SERB barrier installed, the total bid price (including end anchors) was $75 per linear foot. The bid price for the SERB guardrail itself, exclusive of the end anchors, was $53 per foot. It took a 5-man crew 5 working days to finish the job.

Performance

Since it was completed, the barrier has been struck several times. This was evidenced by slack in several of the restraining cables, by scrapes and paint transfer marks on the thrie beam, and by debris (e.g., automobile trim and shattered turn-signal lenses) in the gutter. The system has worked well since the barrier was installed and has remained fully functional. The only impact resulting in an accident report involved a motorcycle which was moderately damaged. Its operator received minor injuries which did not require hospitalization. None of the automobile hits were reported, thus confirming the forgiving nature of the SERB guardrail.

Discussion

The installation has performed remarkably well since its completion in early 1983. Repeated hits, however, caused several of the lag bolts (used to attach one end of the restraining cables to the wood posts) in the immediate impact area to loosen and eventually pull out. This problem was solved by using longer cables which extended over the top and down the back side of the support posts. This modication is shown in Figure 4, and has been the only maintenance performed on the SERB to date.

FIGURE 4: Extended restraining cable prevents lag-bolt pullout, but back edge of post should be reinforced to eliminate problem shown above.

INSTALLATION NO. 3 - LONG ISLAND, NEW YORK

Location

The Seaford-Oyster Bay Expressway (Route 135)/Sunrise Highway (Route 27) interchange was selected by New York State DOT personnel for the SERB installation. The barrier was erected in the northwest quadrant between the Route 135 southbound exit ramp to Route 27 westbound and the opposing loop entrance ramp. Traffic volume was 5,750 vehicles per day with a peak-hour count of 710 vehicles. Truck traffic was about 10 percent of the total.

The design was a double-faced barrier consisting of the SERB guardrail on the critical approach side and a standard blocked-out W-beam railing on the side along the loop ramp, using the same wood posts that supported the SERB. Figure 5 shows the completed installation.

FIGURE 5: Completed SERB installation. Parked automobile indicates 40 degree angle of impact.

Cost

The in-place cost for this 250 foot installation was $80.48 per foot, including the end anchors. The tubular thrie beam rails were set in 2 1/2 working days by State maintenance personnel once the posts were in place.

Performance

In its first year of service, this SERB sustained 18 hits. Only two of these were investigated by local police; there were no injuries reported. Both of these accidents involved passenger cars - a 2,165 pound 1983 Subaru and a 2,800 pound 1983 Mercury Cougar - which hit the rail at approximately 40 degree angles. In both cases, the SERB attenuated the force of the impacts and redirected the cars parallel to the rail. The only permanent damage to the SERB guardrail after its first year in place is the dent in the rail element shown in Figure 6.

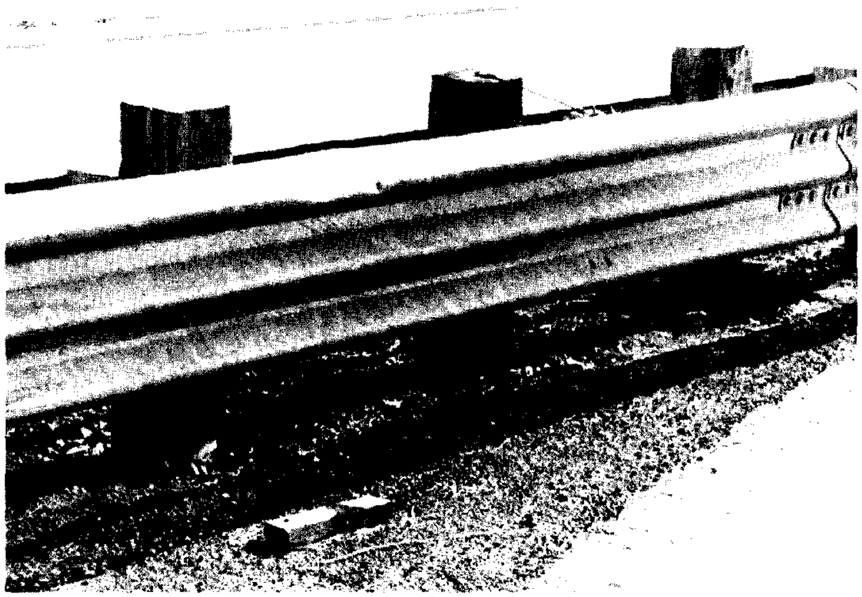

FIGURE 6: Total permanent damage after one years' service and approximately 20 hits.

Discussion

This installation has proven so successful from a zero-maintenance, no injury standpoint, that NYSDOT Region 10 has included another SERB installation in a major interchange project currently under construction.

INSTALLATION NO. 4 - DENVER, COLORADO

Location

The site chosen for the Colorado SERB installation was along Interstate 70, westbound, approximately 20 miles west of Denver near the bottom of a 2-mile, 6 percent downgrade. The SERB installation is on the outside of a left curve having an approximate 760-foot radius. Three hundred feet of Modified Thrie Beam guardrail is attached to the upstream end of the SERB guardrail and another 200 feet is on the departure end. The ADT on this section of the Interstate is 20,400, and approximately 6 percent of the vehicles are trucks. The original installation is shown in Figure 7.

Cost

Since the total cost of the installation included the 500 foot Modified Thrie Beam guardrail in addition to the SERB guardrail, the State had to estimate the in-place costs for each barrier system separately. The in-place cost of the SERB guardrail was estimated at $71.80 per foot.

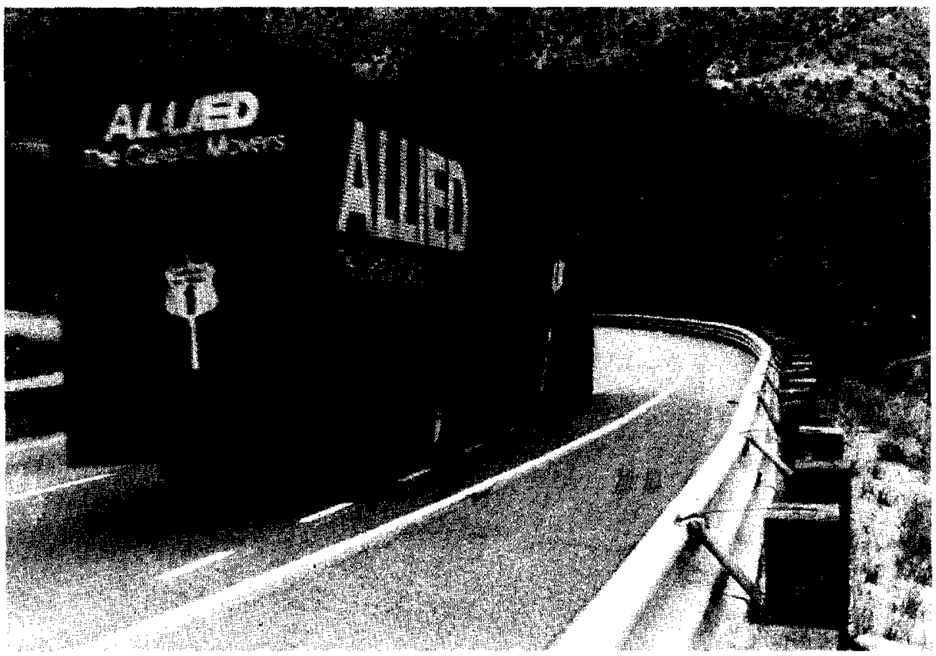

FIGURE 7: Completed SERB along I-70 in Colorado.

Performance

Limited accident experience has shown that the SERB is performing as designed and, despite numerous hits, has required no maintenance to date. A reported accident occurred on March 4, 1984, involving a 1981 Chevrolet Citation. The center rib of the guardrail was distorted on each side of the splice in the area of impact and the pivot bar was dented by the rail corrugation when the rail deflected and moved upwards. The SERB rail reverted to its normal position and no repair work was required.

INSTALLATION NO. 5 - HAYWOOD COUNTY, NORTH CAROLINA[1]

Location

This installation (Figure 8), along I-40 in Haywood County, is 1,650 feet long. At the upstream end, the SERB is connected to a tubular thrie beam retrofit bridge rail. At the downstream end it is spliced to a 500-foot thrie beam barrier.

FIGURE 8: SERB begins at bridge and extends 1,650 feet.

Cost

The SERB was included as a separate bid item in a multi-million dollar 3R/4R construction project. The lowest overall bidder for the project bid $50 per foot for the SERB. The third overall lowest bidder had a bid price of $45 per foot.

Performance

The eight-bolt connection between the SERB guardrail and the collapsible-ring bridge rail is shown in Figure 9. At the downstream end, the SERB guardrail was not originally anchored. To connect it, about 2 feet of the thrie beam

[1] This installation was not one of the original pilot sites.

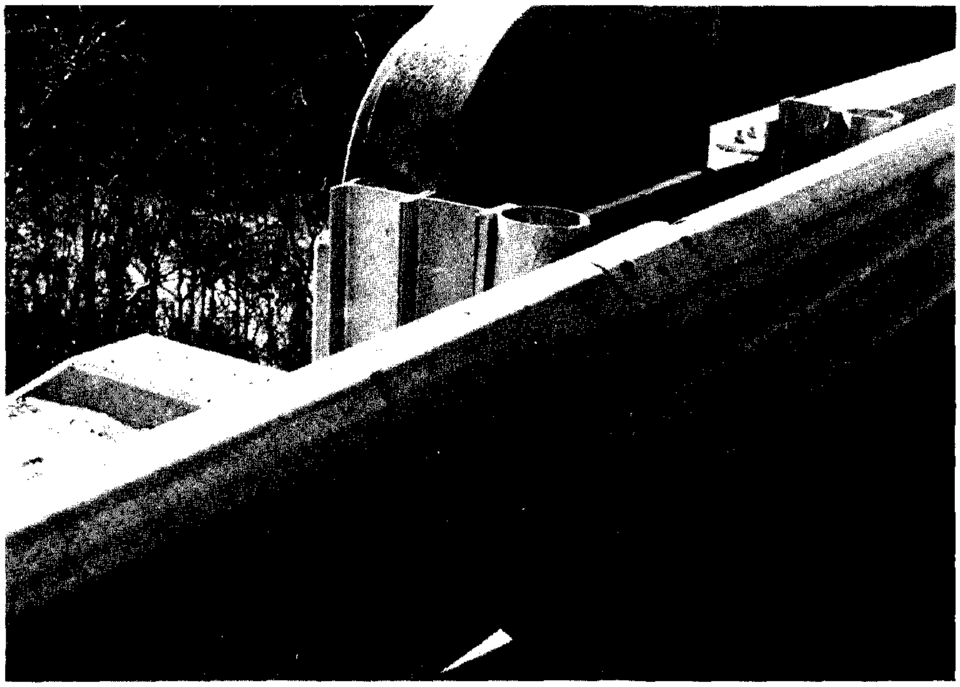

FIGURE 9: Connection between retrofit bridge railing and SERB guardrail.

rail was inserted into the tubular thrie beam of the SERB and reinforced with a 2-foot long back-up plate with two bolts holding the two rails together. The State later decided to modify the downstream end of the SERB by providing a separate anchorage. The tensile strength provided by the cable anchor is needed for effective performance, particularly if the barrier is hit by a large vehicle. To date, this SERB installation has not been hit.

INSTALLATION NO. 6 - OMAHA, NEBRASKA[2]

Location

The Nebraska Department of Roads installed 200 feet of SERB guardrail along the right-hand side of a left exit ramp from U.S. Route 75 (Kennedy Expressway) to Interstate 80 in Omaha. This installation is shown in Figures 10 and 11.

[2] This installation was not one of the original pilot sites.

FIGURE 10: SERB begins at gore area and extends along the right side of the ramp.

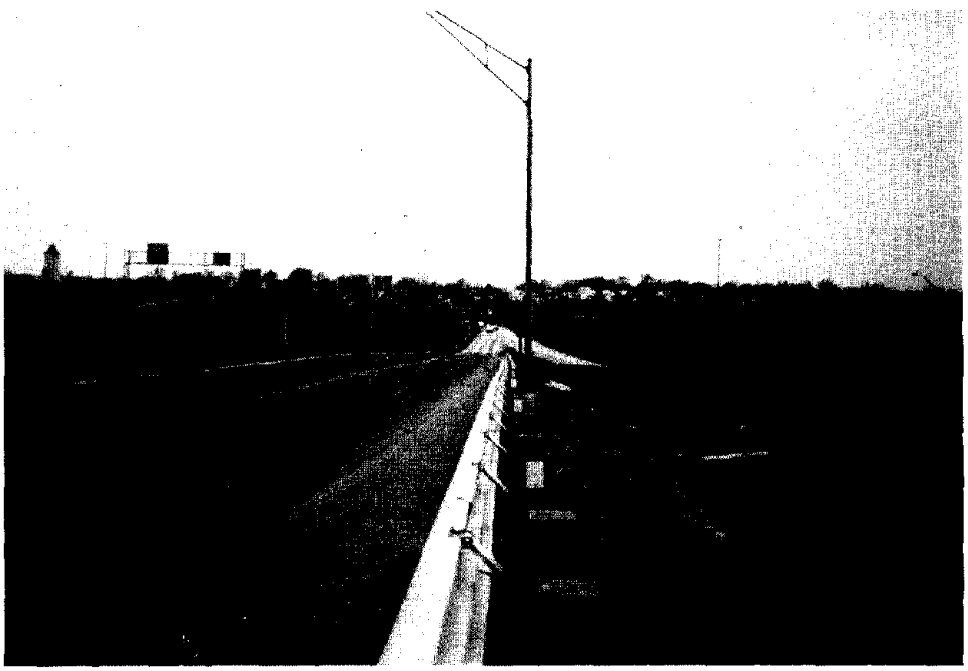

FIGURE 11: Modified Thrie Beam was installed on less critical side of ramp, opposite SERB.

Cost

The bid price for this 200-foot section of SERB was approximately $43 per linear foot.

Performance

Since this installation was only recently completed (January 28, 1986), detailed construction and/or accident data are not yet available.

Summary

Based on almost 3 years of experience at the four pilot installations sites, the following statements can be made regarding the SERB guardrail:

1. The SERB guardrail costs approximately twice as much as a standard 32 inch high concrete safety shape, but performs better for high-angle impacts by absorbing much of the collision energy. While its cost makes it unattractive for widespread usage, its performance makes it ideally suited for locations having above average accident concentrations and where existing barriers require repeated maintenance.

2. For passenger vehicle impacts, the SERB has proven itself to be virtually maintenance-free when installed in a straight line or around a curve with a radius as short as 175 feet. It can also be installed along a much tighter curve (e.g., 60 foot radius) but requires proportionally more repairs following repeated hits. No injuries have been reported to date as a result of any SERB guardrail impacts.

3. Additional research is underway to simplify the original end anchorage design by utilizing standard barrier hardware, and to develop a modified splice design that will permit easier installation of the SERB on curves and facilitate repair work after major impacts.

III. SERVICE LEVEL 1 (SL1) BRIDGE RAIL

The use of current AASHTO Bridge Rail Specifications results in bridge rail designs that are intended to prevent penetration by full-sized passenger cars. These bridge railings are generally rigid systems and are usually expensive to build. While such railings are clearly warranted on high-type roadways, their use on low-volume roads and streets may not be cost-effective. An alternate railing system, called a Service Level 1 (or SL1) Bridge Rail, was tested and developed for possible use at selected locations. Details of the full-scale tests and the SL1 design are contained in NCHRP Report 239, "Multiple-Service-Level Highway Bridge Railing Selection Procedures".

Essentially, the SL1 Bridge Rail consists of a single thrie beam rail element supported by steel or wood posts. It is a semi-flexible system, designed to deflect upon impact. Full-scale crash tests with passenger cars at 15 degrees and 60 mph and with a 20,000 pound school bus at 7 degrees and 45 mph produced excellent results. The post-to-base plate connection was designed to prevent bridge deck damage resulting from a collision with the rail and to facilitate repair work to the bridge rail after impact.

Two States have installed SL1 Bridge Rails to date: Iowa on several bridge replacement projects, and Washington as a retrofit design on two existing timber bridges. Cost and construction information on these applications are as follows:

IOWA

Location

SL1 Bridge Rails were included as bid items on five bridge replacement projects on county roads in Wapello, Butler, Floyd and Cerro Gordo Counties.

The new bridge in Wapello County was a 28-foot by 115-foot double tee with a 13-foot clearance from the top of the deck to the channel bottom. It replaced a 14-foot long, 71-foot steel truss structure. The county road on which the new bridge is located carries an estimated ADT of 60 at a 55 mph speed limit. The completed structure is shown in Figure 12.

FIGURE 12: Completed SL1 Bridge Rail.

The Butler County project was a 30-foot by 125-foot concrete slab which replaced a 20-foot by 64-foot I-beam bridge. The new structure is located in the flood plain of the Cedar River's West Fork and acts as an overflow structure during peak flows. Highway ADT is 660 vehicles and the speed limit is 55 mph.

The Floyd County bridge was a 28-foot by 125-foot concrete slab structure which replaced a narrow timber trestle bridge. The new structure is 12 feet above the channel bottom. The average daily traffic on this bridge is 55 vehicles per day.

Two bridge replacement projects in Cerro Gordo County utilized the SL1 rail. In both cases, 16-foot wide pony trusses were replaced with 25.8-foot wide quad-tee structures, 45 feet and 152 feet long, respectively. Both bridges carried an estimated 50 vehicles per day.

Cost

The unit bid prices for the SL1 railings on the five bridges listed above ranged from $25.80 to $38.50 per linear foot. This cost does not include the approach guardrail which in each instance was a standard W-beam installation on wood posts. It should be noted that only the 45 foot long structure had a bid price higher than $29 per foot for the SL1 railing.

Performance

Since the completion of the bridges in 1985, no accidents have occurred and no routine maintenance has been required. An evaluation of each of these installations is continuing and significant information will be reported as it becomes available.

Discussion

The installations in Iowa show that the SL1 rail can be used on several types of bridge construction as an alternate to the concrete safety shape or a rigid steel bridge rail. Locating the anchor bolts for the base plates (see Figure 13) is the

FIGURE 13: On new construction, accurate placement of the base plate anchor bolts is essential.

most critical factor during construction. They must be accurately spaced to accommodate the 8-foot, 4-inch post spacing and must protrude far enough from the edge of the deck so the base plate can be firmly attached. In one case, the base plates were extended from 7 inches to 9 inches and the anchor bolt holes were lowered 2 inches so the bolts could be placed to obtain adequate concrete cover and to avoid the deck reinforcing steel. In another case, a separate steel angle was needed at each post to provide adequate bearing for the base plates (see Figure 14).

FIGURE 14: Since this bridge deck was only 5 inches thick, a separate steel angle was used at each base plate to prevent its bending when the SL1 rail is hit.

WASHINGTON

Location

During 1985, the Washington State Department of Transportation installed SL1 Bridge Railings on two existing timber structures on U.S. Route 101. Both bridges previously had wood railings as shown in Figures 15 and 16. Each bridge was 28 feet wide and carried an estimated 2,250 vehicles per day.

Cost

State forces were used to install the new SL1 bridge rail systems. Materials costs for the SL1 alone totaled $10,845 for both bridges, or approximately $34 per linear foot. Labor and equipment costs have not yet been finalized.

FIGURE: 15: Middle Nemah River Bridge prior to SL1 Bridge Rail installation.

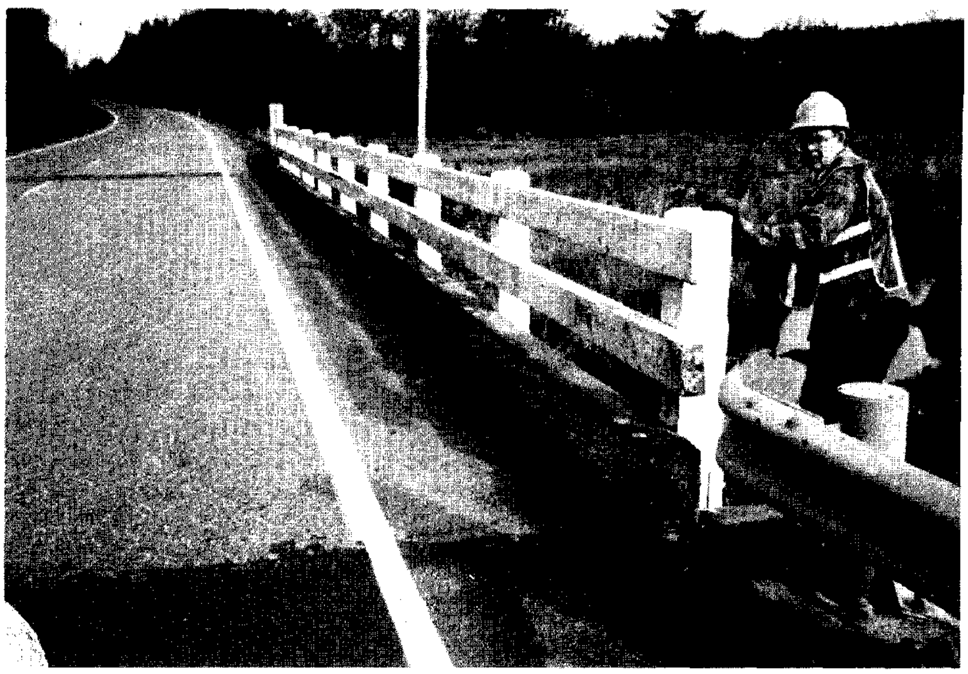

FIGURE: 16: Jorgenson Slough Bridge prior to Service Level 1 (SL1) retrofit.

Discussion

The major problem encountered in this retrofit project was designing a special connection detail to which the base plate could be bolted. The final design is shown in Figure 17.

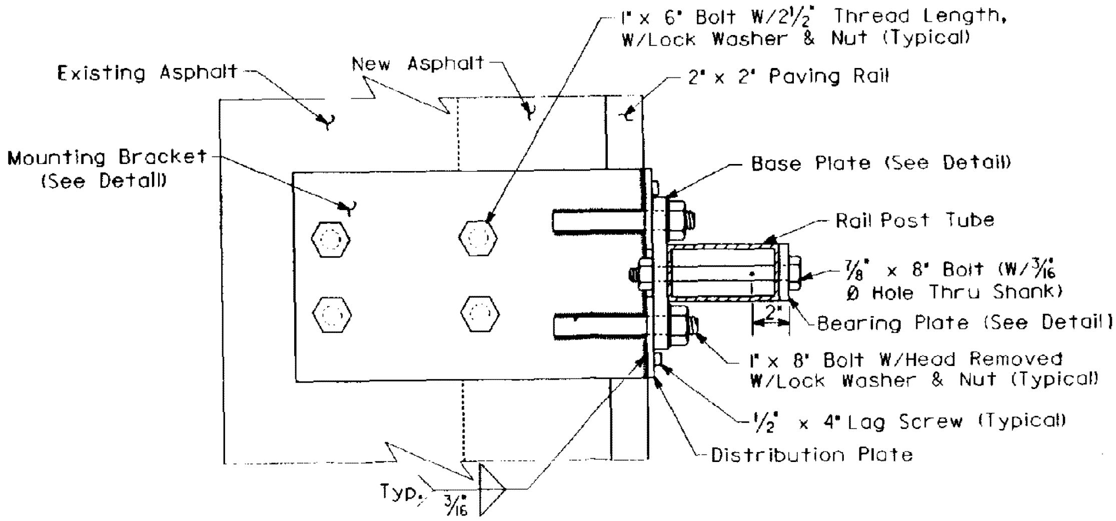

FIGURE 17: Special design required for SL1 retrofit rail base plate connection on existing timber bridge increased cost significantly.

This special type of connection greatly increased both the materials and labor costs for work on the two bridges. Specific design criteria for the base plate connection to the bridge and for the post connection to the base plate are needed. These would enable the designer to use the most economical connection possible for each type of bridge utilizing an SL1 retrofit railing.

The completed installation over the Jorgenson Slough is shown in Figure 18.

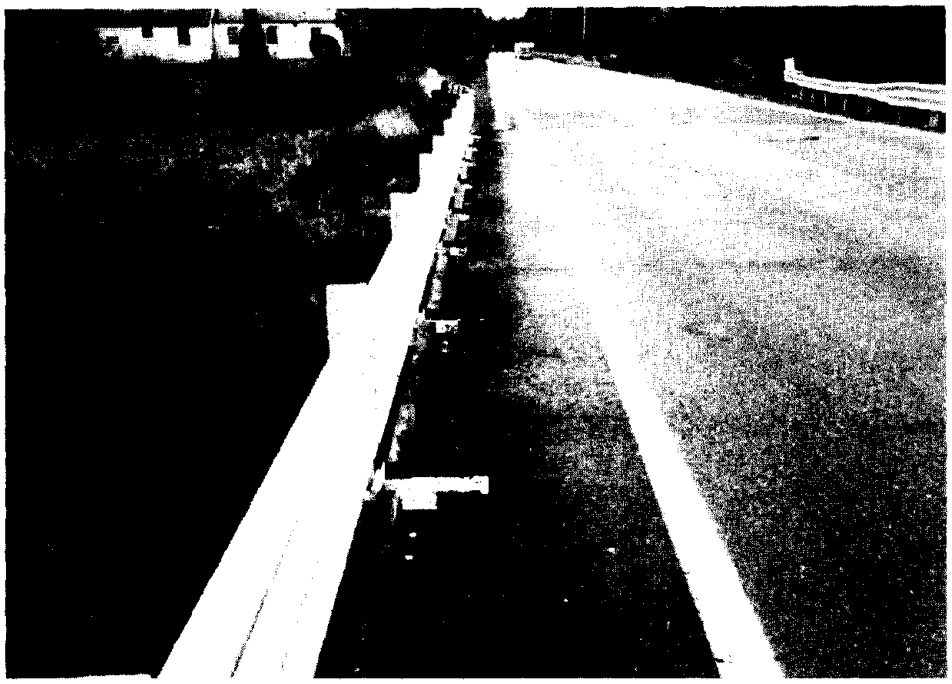

FIGURE 18: Completed SL1 at Jorgenson Slough.

SL1 Summary

The experiences of Iowa and Washington State with the Service Level 1 Bridge Rail suggest the following:

1. The SL1 railing is relatively inexpensive and easy to install. It allows the full use of the bridge deck because it is mounted on the outside face of the deck. Since no curb is necessary, rain, snow, or debris does not accumulate at the curb line (see Figure 19). This is a safety factor as well as a design feature that should minimize long-term bridge deck deterioration.

2. The SL1 bridge rail can be adopted for retrofit applications on a variety of existing timber bridges. In most cases, a railing such as this is the only practical alternative to doing nothing or replacing the entire structure, a concern that often arises during the design phase of resurfacing, restoration or rehabilitation (3R) highway projects. Specific design criteria for the base plate connection should be developed so the SL1 can be readily modified for use on existing timber bridges having unique deck/ stringer geometry.

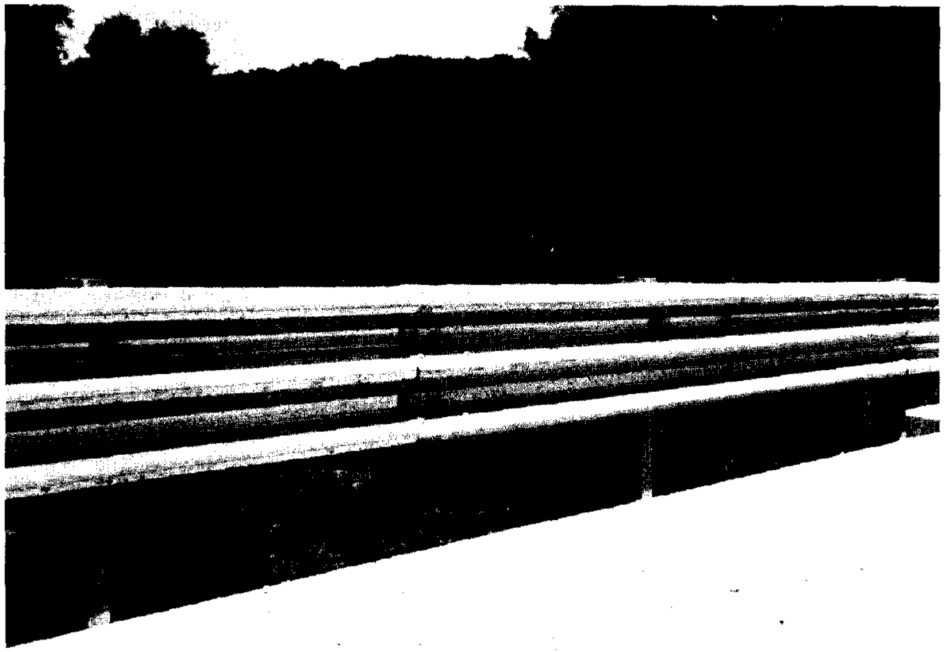

FIGURE 19: SL1 design allows full width use of bridge deck and prevents debris accumulation at curb line.

3. For construction of new concrete bridges, vertical slots should be used in the base plates instead of the original 1-inch diameter anchor bolt holes. This would allow some flexibility in setting the anchor bolts to obtain adequate concrete cover, while avoiding any reinforcing steel in the bridge deck. It would also allow the bridge rail posts to be adjusted vertically, thereby making exact anchor bolt placement somewhat less critical.

4. The post spacing should be reduced from its 8-foot, 4-inch distance to the standard 6-foot, 3-inch spacing for which the thrie beam is punched. This would eliminate the need to drill holes in the field. However, full-scale crash testing or computer simulations may be needed to verify acceptable crash performance before this recommendation can be implemented.

5. Current AASHTO bridge rail specifications do not address the multiple service level concept. Until the SL1 design receives AASHTO sanction, it should be treated as a design exception or experimental feature when used on a Federal-aid project. Its use should be limited to relatively low-volume bridges that do not have adverse geometrics or significant accident histories.

IV. CONNECTICUT IMPACT ATTENUATION SYSTEM (CIAS)

There are a number of crash cushion systems currently in widespread use which are capable of either entrapment or redirection of errant vehicles but not both. The Connecticut Impact Attenuation System (CIAS) is a non-proprietary impact attenuator designed to provide both capabilities by "capturing" an errant vehicle which impacts the system from the front or sides and by redirecting an errant vehicle when the impact point is near the rear of the system. Entrapment is accomplished by the use of thin-walled steel cylinders which, when hit, collapse within acceptable deceleration levels. Redirection is accomplished by the use of steel tension straps and compression pipes inside the cylinders in the last three rows. These can be clearly seen in Figure 20.

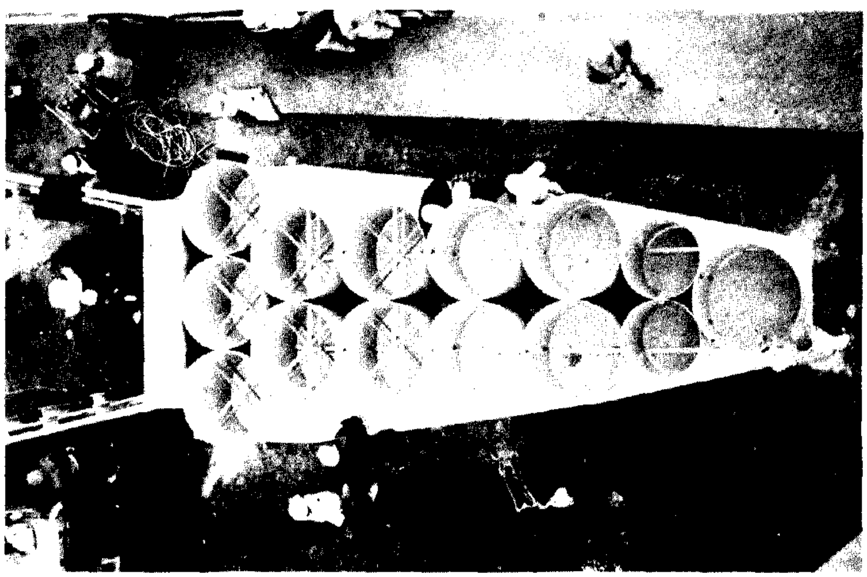

FIGURE 20: CIAS unit during installation.

The CIAS is an array of 14 thin-walled, seam-welded, tubular members formed from straight (A-36) steel-plate sections. The individual cylinders are bolted together as shown in Figure 21 and then attached to a 10-foot concrete backup wall. There are seven rows, with one tube in the first row, three tubes in the last row adjacent to the backup structure and two tubes in each of the other five rows. Each steel tube is 4 feet high and 4 feet in diameter except those in the second row which are 3 feet in diameter. The entire system rests on two steel rails which are secured to a concrete pad. Two of the four installations are shown in Figures 22 and 23.

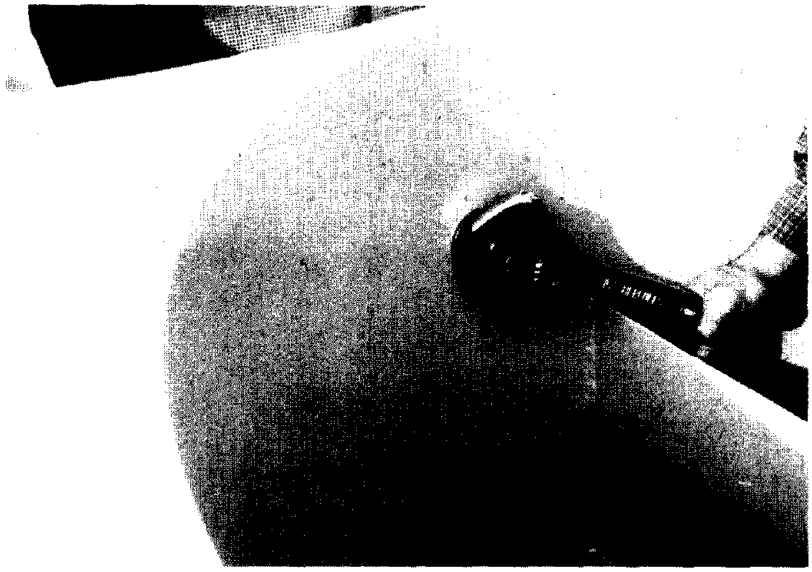

FIGURE 21: Individual cylinders are bolted to each other and to backup wall.

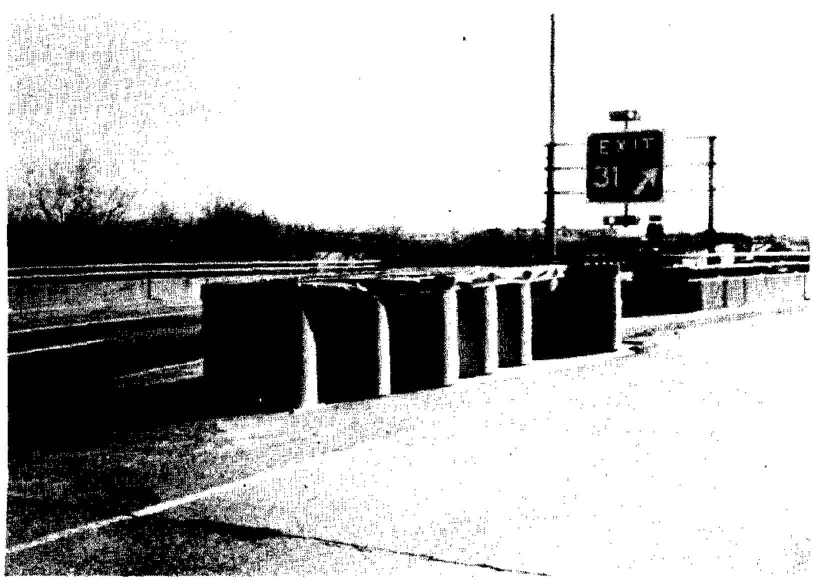

FIGURE 22: Completed CIAS unit in Hartford.

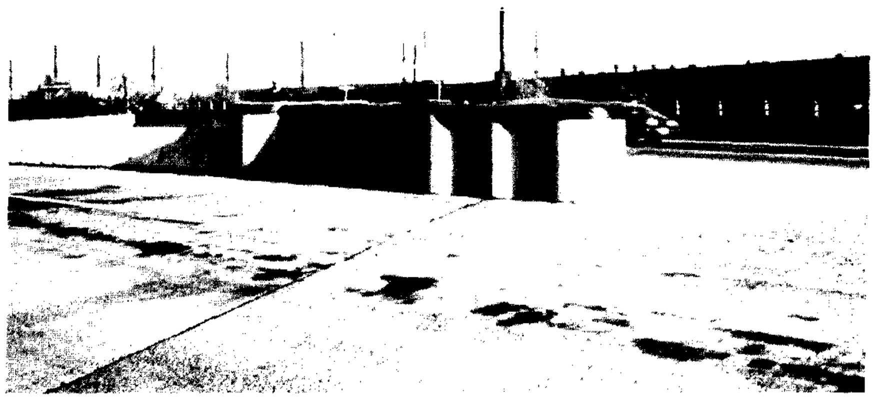

FIGURE 23: Completed CIAS unit in New Haven.

Location

Four sites were selected for CIAS installation in Connecticut:
Site 1 - Gore at I-91 SB and Exit to State Street, Hartford.
Site 2 - Gore at Route 2 EB and Exit to I-84, East Hartford.
Site 3 - Gore at I-91 NB and Exit 5 to State Street, New Haven
Site 4 - Gore at I-91 NB and Exit 6 to Willow St., New Haven
Traffic volumes at these locations ranged from 48,700 to 101,700 vehicles per day. From 1979 through 1983, a total of 66 accidents were reported at the four locations.

Construction

Except for a few minor differences, the construction at all four sites was typical. One of the sites required construction of a concrete pad as well as a backwall. At this location, a 6-inch thick concrete pad reinforced with welded wire fabric was installed to support the cylinders. Approximately 2 feet from the backwall, the slab thickness was increased from 6 inches to 9 inches. This increase in thickness was required to tie the backwall into the slab to prevent the backwall from overturning when the CIAS unit is hit. The necessary vertical backwall reinforcing was tied into the lower reinforcing bars located in the thickened section (see Figure 24). At the other sites, vertical holes were drilled 6 inches into the existing concrete slab to accept the 7/8-inch round, 2-foot, 10-inch long dowels used to secure the backwall. This detail is shown in Figure 25.

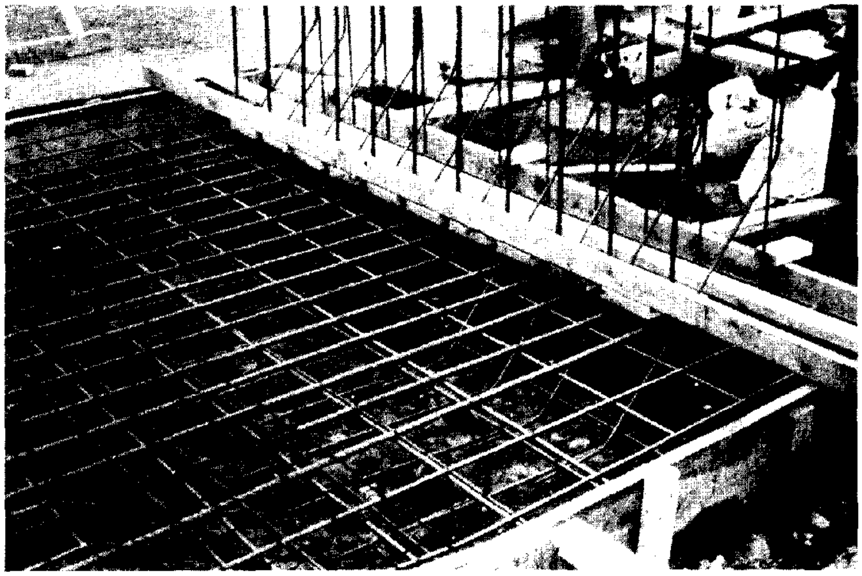

FIGURE 24: Construction of backwall and pad.

Prior to inserting the dowels, the holes were filled with an epoxy cement. A concrete base or pad is necessary because the two steel rails which support the entire weight of the steel cylinders would gradually penetrate a softer base or even an asphalt pavement. The purpose of the steel rails is to minimize frictional drag of the cylinders as they collapse and slide backwards.

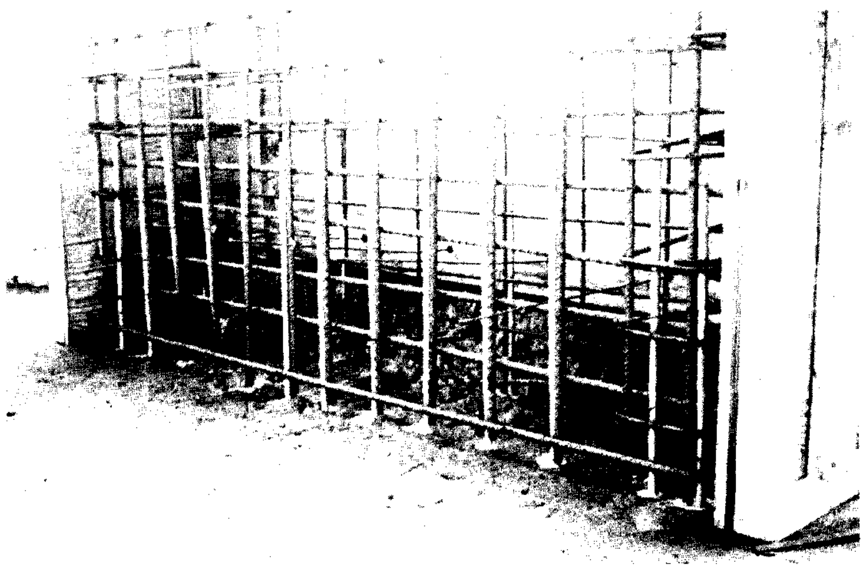

FIGURE 25: Construction of backwall at a location with an existing concrete pad.

The main difficulty encountered during construction was drilling through the steel rebars in the backup wall for the anchor bolts. The low-speed, water-cooled, diamond-impregnated core bits used initially wore rapidly and frequently broke off inside the hole. The use of a high-speed, water-cooled, carbide-insert core bit was more productive. At one site on a bridge, the installation straddled a bridge expansion joint which could cause considerable stresses in the steel rails when the underlying deck expands or contracts. The solution was to cut a slot in lieu of a circular hole at the leading end of the rails which permitted slab movement without stresses being developed in the rails. Having the fabricator of the steel cylinders pre-drill the bolt holes and mark each cylinder by a two-letter designation greatly aided the assembly of the units.

Costs

The fabrication of the CIAS units was done by a local steel fabricator under a separate contract award which amounted to $4,600.40 per system. Competitive bids were received for the installation of the system which included site preparation and required traffic control. Bid prices ranged from $16,000 to $31,000. The high bids for installation are attributed to unfamiliarity with the system. It is expected that the cost for installation will decrease in future contracts. All work was completed within the alloted contract time of 30 days.

Performance

Since their installation in late 1984, several of the CIAS units have been hit, both end-on (Figure 26) and along the side (Figure 27). In fact, at least 10 hits have been noted. Eight of these were hit-and-run accidents, indicating satisfactory crash cushion performance and requiring little maintenance. However, two hits did require replacement of the entire units. One of these accidents involved a Toyota pickup and the second (see Figure 28), a Buick sedan. Neither driver was reported to be injured.

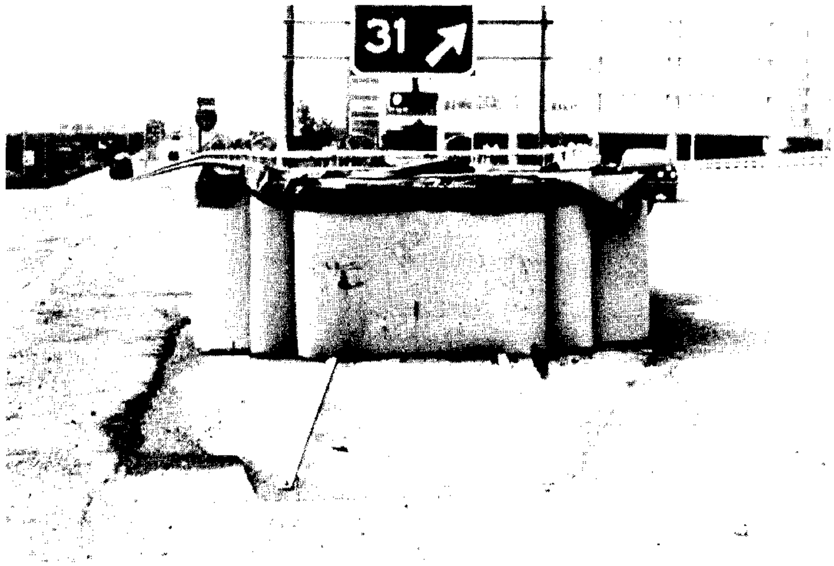

FIGURE 26: This is the result of an end-on crash into the unit shown in Figure 22. CIAS collapsed uniformly as it slid on steel rails.

FIGURE 27: Result of side impact into unit shown in Figure 23.

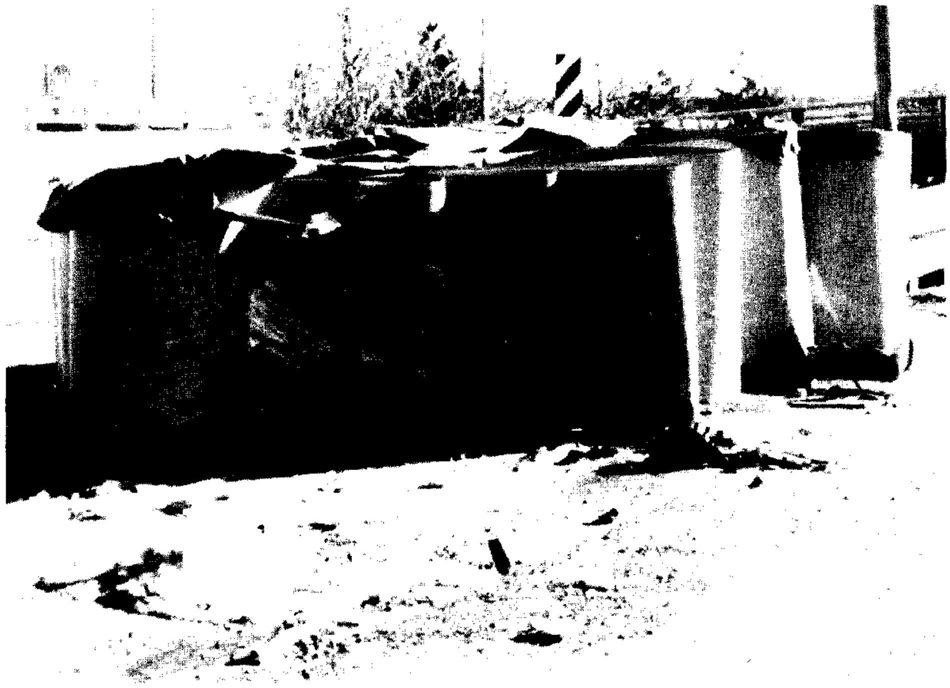

FIGURE 28: This CIAS required complete removal and replacement with a spare unit.

Summary/Recommendations

For future installations, the following comments should be considered:

1. Drilling holes through the backwall can be avoided by setting the anchor bolts in the back-up wall before the concrete is placed.

2. Settlement of the steel rails into an asphalt surface can be minimized by setting the cylinders on two channel irons, sized to prevent settlement into the asphalt. This would eliminate the need for an expensive concrete pad at many locations.

3. While sand-filled systems are not repairable and have to be replaced as a result of only minor or brush hits, the CIAS can normally be repaired in-place by pulling or jacking the dented units. After major impacts, there is no scattered debris. Crushed units can be replaced in kind and re-rolled off-site for later re-use.

V. SENTRE GUARDRAIL END TREATMENT

The SENTRE is an experimental proprietary guardrail terminal developed by Energy Absorption Systems, Inc. It can be connected to the ends of new or existing guardrail systems. It is designed to prevent vaulting, ramping or spearing of vehicles impacting the end of a guardrail system. A SENTRE unit consists of Thrie beam fender panels, steel support posts with slip bases, a redirecting cable and sand-filled boxes which help dissipate a portion of the collision energy. When hit end-on, the fender panels telescope longitudinally and the cable redirects the vehicle behind the rail and away from the "hard spot" at the end of the standard guardrail section. The SENTRE can be installed either parallel to the travelled-way or with a 4-foot offset.

INSTALLATION NO. 1 - MARYLAND

Location

In October 1985, 14 SENTRE end treatments were installed along a 6-mile section of Route 165, a two lane rural highway just north of Route 23 near Jarrettsville, Maryland. No flare was provided in any of the installations. Figure 29 shows one of the units under construction.

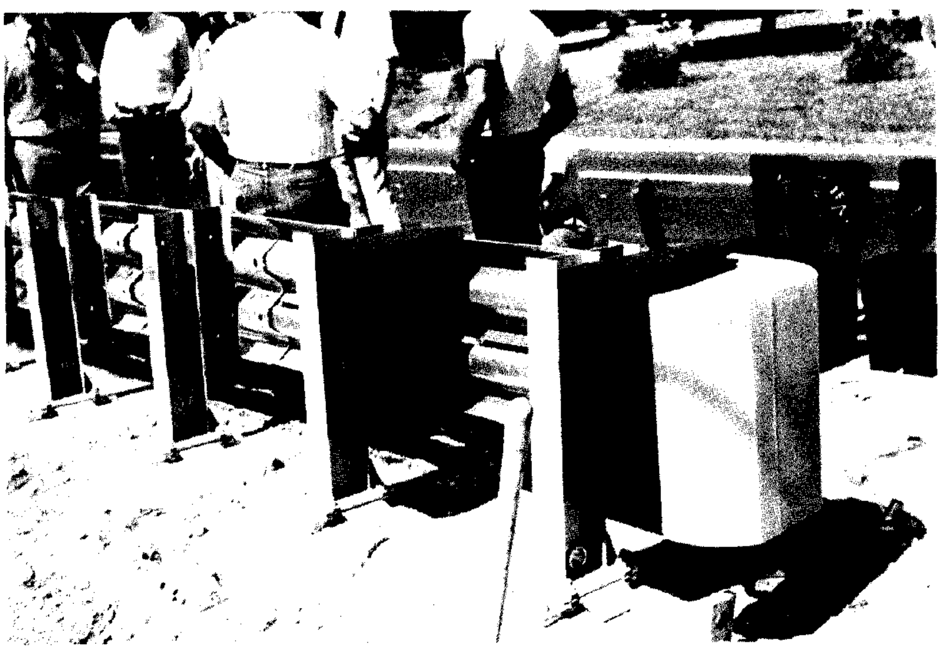

FIGURE 29: SENTRE under construction. Anchor and redirecting cables are not yet in place.

Cost

Cost of materials and labor for each SENTRE installation was \$4,100. On the average, a 6-man crew finished one installation per day.

Discussion

A problem was encountered with the treatment of the redirecting cables at cut sections because, over the ditch lines, the cables are stretched 6 inches or more above the ground. These exposed cables could cause accidental tripping of people on foot or on horseback. This problem was remedied by placing two rows of plastic tubular markers on each side of the exposed cables to warn people of their presence. In fill sections, the redirecting cables were buried about 2 inches into the ground along the slope line.

Performance

On September 27, 1985, a SENTRE unit located along the northbound lane was hit by a car travelling southbound. The car crossed the northbound lane and after hitting the SENTRE about 15 feet upstream, slid along the railing against the direction of the thrie beam fender panel overlaps and sheared off the top portion of one rail. Three blockouts, one post, and one plastic sand container were damaged and needed replacement. On October 31, 1985, the same SENTRE installation, after having been repaired, was hit head-on by a car travelling northbound, causing considerable damage to the SENTRE but no serious injuries to the operator. The vehicles involved in both accidents were driveable following the collisions. Damage to the SENTRE unit from the second accident is shown in Figure 30.

FIGURE 30: SENTRE collapsed as designed when hit.

INSTALLATION NO. 2 - ALABAMA

Although the State plans to install 29 SENTRE units as experimental features, information on only six was available for inclusion in this report. These six were constructed as end anchors for standard W-beam guardrail on U.S. Route 231 and on Interstate 85. U.S. 231 has an ADT of 20,000 vehicles per day. The section of I-85 where the SENTRE units were installed carries 54,000 vehicles per day, 5 percent of which are trucks. Figure 31 shows one of the completed units.

Cost

A 3-man crew consisting of a foreman and two unskilled laborers installed the six SENTRE units. The contractor's bid price was $3,570 for each installation.

Discussion

Installation of the SENTRE units was completed on October 26, 1985. Construction procedures were in accordance with the manual provided by the supplier, Energy Absorption Systems, Inc. The holes for the post foundations were first drilled with an auger and then dug by hand. The footings at one site had to be re-excavated later due to heavy rainfall. No other

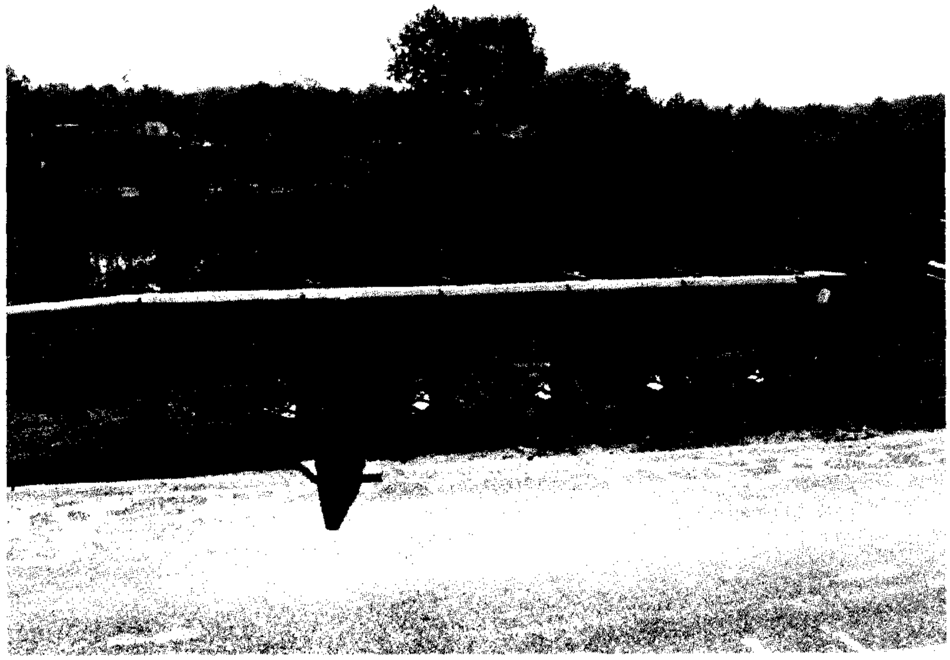

FIGURE 31: Completed SENTRE unit.

construction problem was noted. There were reported accidents at the project sites but none involved the SENTRE installations. Since so much time was spent in constructing the isolated concrete footings for each installation, other foundation alternatives should be explored. One suggestion made was to use a common footing for all five posts.

SENTRE Summary/Recommendations:

1. Most of the work to install the SENTRE involves excavation, forming and pouring the footings and anchorages for each unit. Once that is accomplished, the SENTRE can be assembled very quickly.

2. The SENTRE combines the capabilities of a guardrail end anchor and a crash cushion and has performed as designed in the few instances where it has been hit. Repairs to damaged units were relatively simple and several parts were reuseable following a crash.

3. The SENTRE can be used as an end treatment for both thrie beam guardrail and W-beam guardrail, using a manufactured transition section in the latter case.

VI. COLORADO TYPE 3F MEDIAN BARRIER END TREATMENT

The Colorado Type 3F Median Barrier End Treatment is used in areas where two parallel W-beam guardrails meet. This typically occurs when guardrails are used to shield bridge piers (see Figure 32) or the opening between twin bridges on divided highways. It is similar in construction and configuration to the Bullnose Attenuator shown in the 1977 "AASHTO Guide for Selecting, Locating, and Designing Traffic Barriers"(page 214), except that the radius of the nose in the Colorado Type 3F is shorter and the first 25-foot sections of W-beam rail have flattened cross-sections at the second, third, and fourth posts. These flattened sections are not bolted to the second and fourth posts so that for head-on impacts, the rail will form an "accordion-like" collapse mechanism moving outward at these posts. These details are shown in Figure 33.

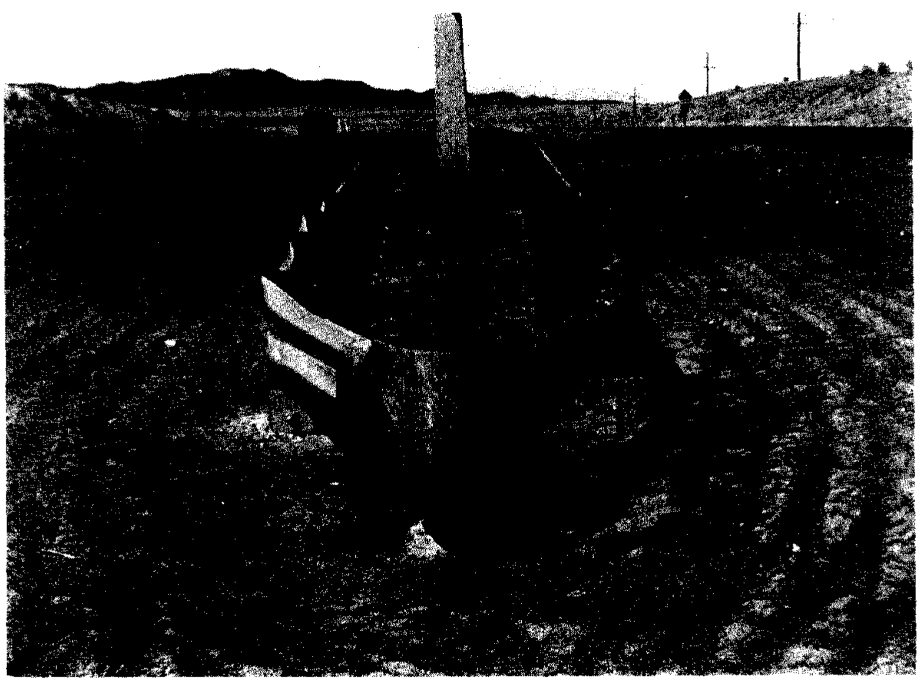

FIGURE 32: Installed 3F End Treatment.

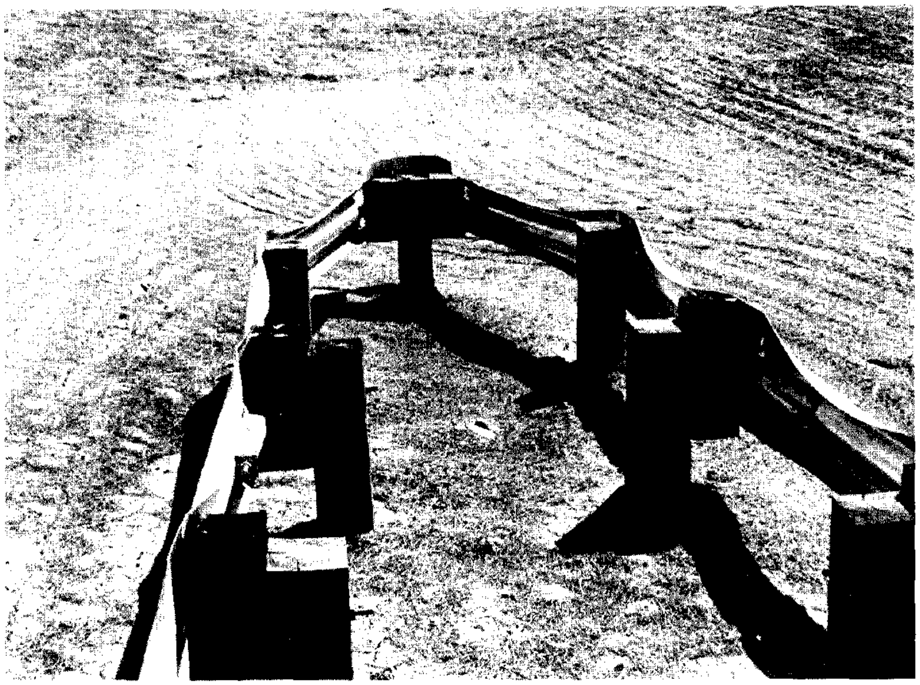

FIGURE 33: Note cable anchors and flattened sections.

The design was developed (1) to provide an end anchor of sufficient strength to ensure proper impact performance of the downstream W-beam barrier and (2) to perform like a crash cushion when hit head-on, bringing both small and large automobiles to a safe stop by permitting a controlled penetration.

Locations

There are 22 Type 3F median end treatments presently in place in Colorado which are being evaluated. Most of these are located along Interstate Routes 25 and 76.

Cost

The Colorado Type 3F Median End Treatment has been bid on a lump sum basis. The average installed cost per end treatment was $814 in 1982 and $1,258 in 1983.

Discussion

So far, there have been only two reported accidents involving the Type 3F median end treatment. These occurred at the same location on two different occasions. The repair cost after the first accident (see Figure 34) was $783 and the second, $885. The first accident was an end-on hit at 30 mph. The

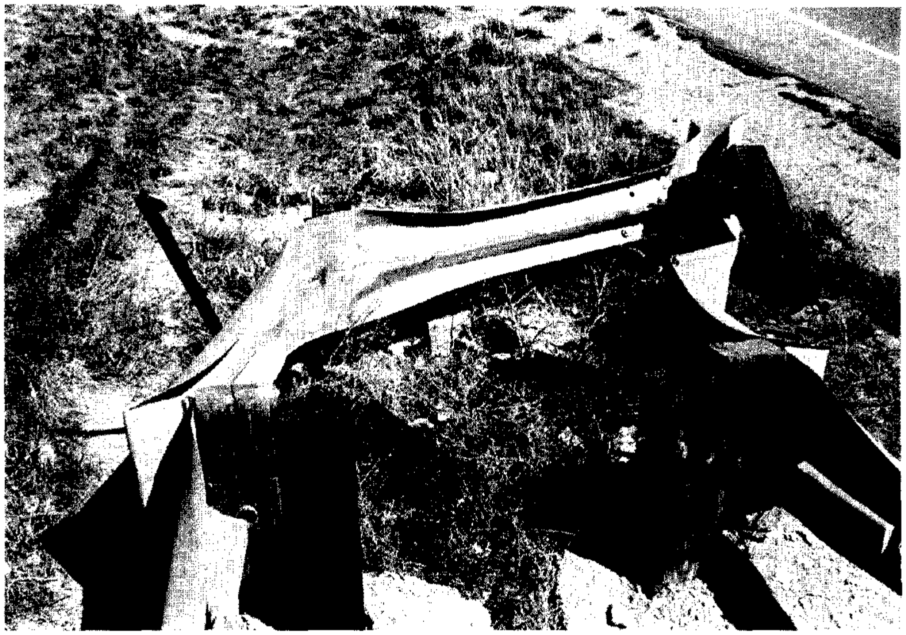

FIGURE 34: Extent of damage from end-on hit.

vehicle suffered moderate damage but insufficient information was recorded as to the driver's injuries. The Type 3F median end treatment performed as designed. Little information was available about the second accident except that the impact was from the side at an estimated speed of 40 mph. It was observed that the performance of the Type 3F median barrier with this type of impact was similar to that of a standard W-beam guardrail.

Summary/Conclusions

The Type 3F median end treatment installations have only received one significant hit so there is limited data available to evaluate the effectiveness of the design. In this one instance, the guardrail performed well. The cost for repairs to the Type 3F median guardrail is almost as much as the initial installation cost which is true of any breakaway-type installation. However, the system uses standard barrier hardware making both initial and repair costs relatively low.

There are several advantages to using a guardrail envelope to shield median hazards. Since the entire area is surrounded by guardrail, a vehicle cannot get behind a railing as sometimes happens with a single run of barrier. Also, a shorter overall length of railing can be used in some instances. For wider medians, several States routinely use the bullnose design mentioned above, and have reported satisfactory performance. The Colorado system appears better suited for narrow medians where the built-in hinges increase the likelihood of satisfactory end-on performance.

For both types of installation, final grading of the median is critical to prevent a vehicle from hitting the guardrail too high and going over it, or to prevent a car from "submarining" underneath the W-beam. Ideally, the approaches to the installation should be essentially flat, and free from ditches, dikes, and drainage structures. This condition contributed to the successful performance shown in Figure 34 and below in Figure 35.

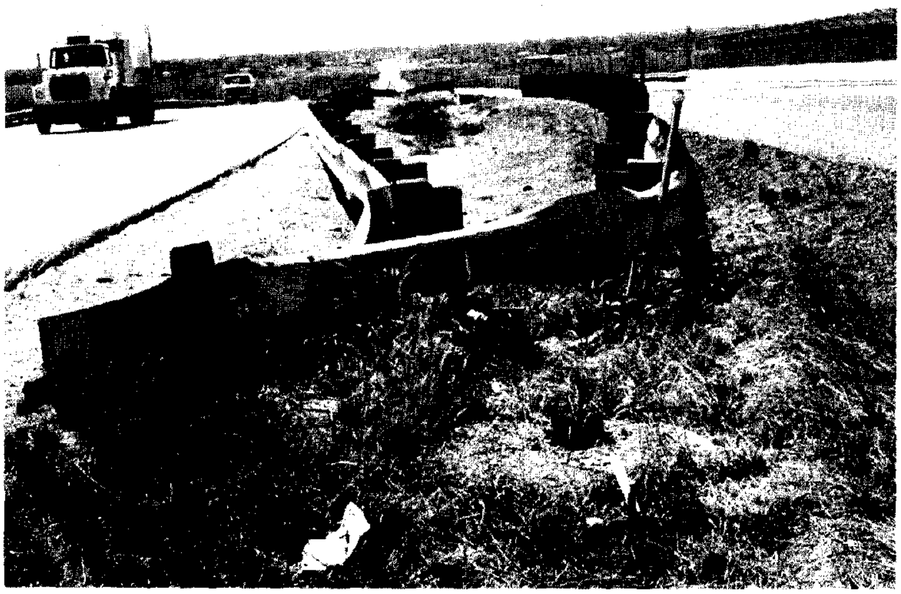

FIGURE 35: Impacting vehicle was safely decelerated without vaulting the guardrail.

VII. TRUCK BARRIERS

Although it is not cost-effective to design and construct barriers capable of retaining and redirecting heavy vehicles at all locations, there are specific sites where the combination of adverse geometrics, large vehicle concentrations, and accident histories warrant the use of high-performance barriers. While several semi-rigid barriers, such as the SERB guardrail and the SERB median and bridge rail (retrofit) systems, have been sucessfully crash-tested with 40,000 pound intercity buses, only rigid barriers have generally been tested for effectiveness against tractor-semitrailer combinations. In one series of tests, it was shown that an 80,000 pound tractor-semitrailer could be redirected by a 42-inch high concrete safety shape barrier when the cargo in the trailer was tied down and its center of gravity was 64 inches or less above the pavement. To counteract the overturning moment of trucks with higher centers of gravity and/or unrestrained loads, an even higher wall is recommended. At least two such barriers have been constructed.

INSTALLATION NO. 1 - IDAHO

Location

Since its opening in late 1977, the Lewiston Hill grade on U.S. Route 95 near Lewiston, Idaho, has been the location of 25 truck accidents. Seven of these occurred on a direct connection left-exit ramp at the bottom of the 6.7-mile long, 6 to 7 percent downgrade. These accidents resulted in 8 fatalities. To reduce accident severities at this location, the Idaho Transporation Department designed and constructed a 64-inch high concrete safety barrier for 1,100 feet along this ramp. The concrete wall is buttressed by an earth berm and topped with a metal W-beam guardrail, raising its total height to 91 inches. The base width of the wall is 42 inches and its top width is 28 inches. The back face is vertical. Figure 36 clearly shows the site geometrics as well as the completed barrier.

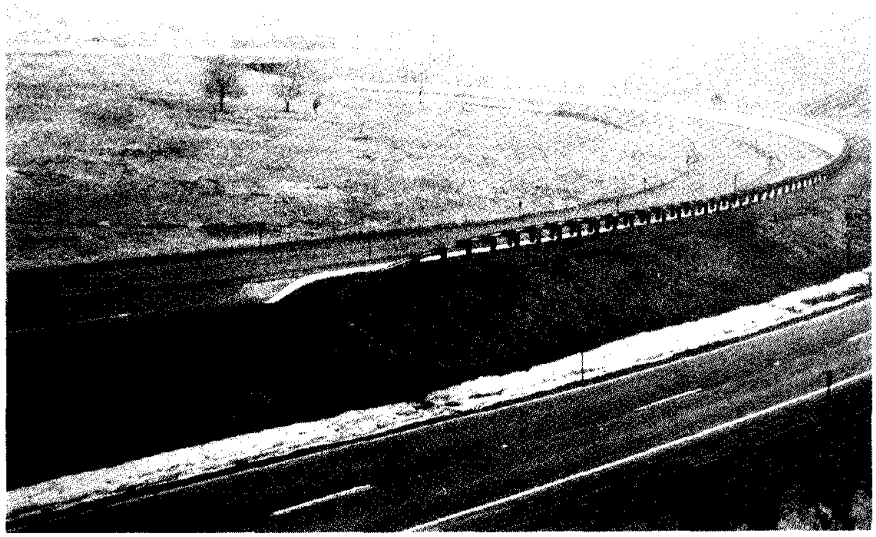

FIGURE 36: Concrete truck barrier along U.S. Route 95 in Lewiston, Idaho.

Construction

Work started on June 6, 1984, with the construction of the earth berm and removal of some existing barrier rail.

Alexander Construction Company received its custom made metal forms for the cast-in-place barrier and began setting forms and steel reinforcement and placing concrete on July 2, 1984. The metal forms were held to plan width with 5/8-inch diameter threaded-bolt stock at 3-foot centers along the top and bottom. These bolts were inserted through holes in the forms into connectors and tightened. The reinforcing steel cage was constructed outside the forms and wire-tied to plan dimensions. The completed steel cage was then slid into the end of the constructed forms and spot welded to the splice bars extending from the previous placement and to the form spacers. The metal forms were set for line and grade, and nailed to the pavement base with 30 penney spikes. The reinforcement steel was checked for plan clearances and approved for concrete placement. At the end section for each day's concrete placement, a metal bulkhead was connected to the metal forms to construct a 3 inch x 9 inch key-way . The lateral reinforcement steel extended 19 inches through the bulkhead to allow for splicing on the next placement. Figures 37 through 40 show the construction sequence.

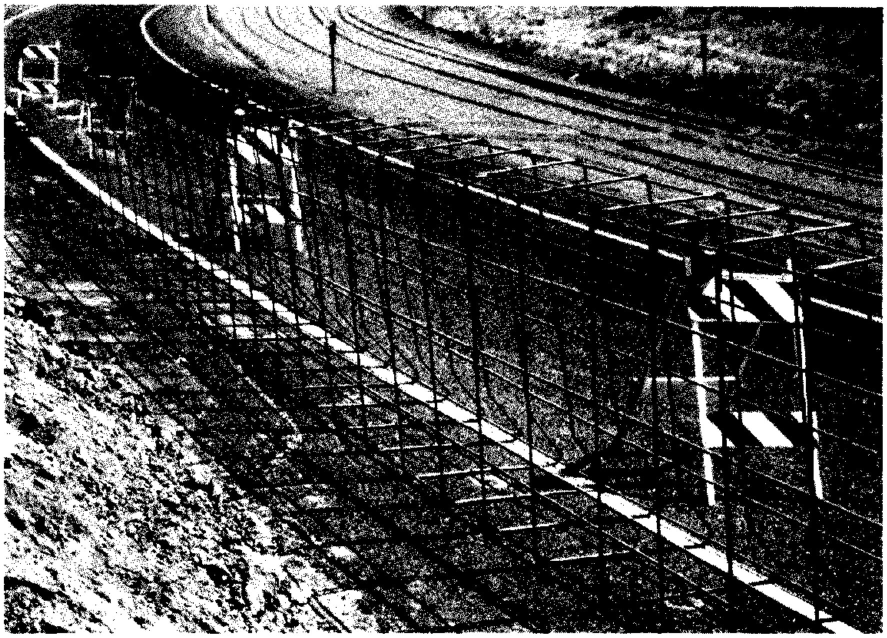

FIGURE 37: Rebar cage was fabricated on-site...

FIGURE 38: ...then placed into steel forms.

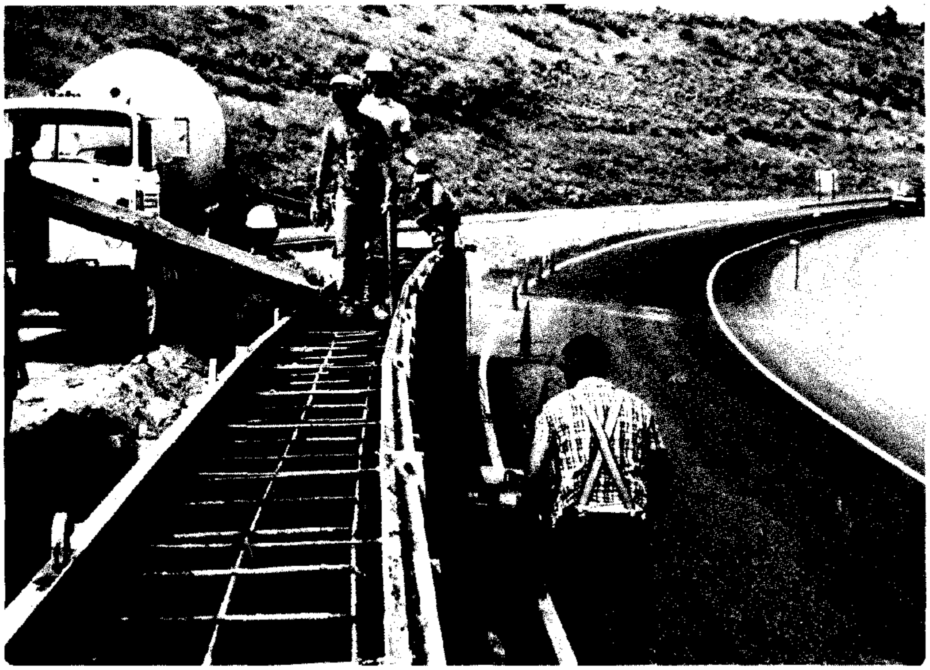

FIGURE 39: Concrete placement was followed ...

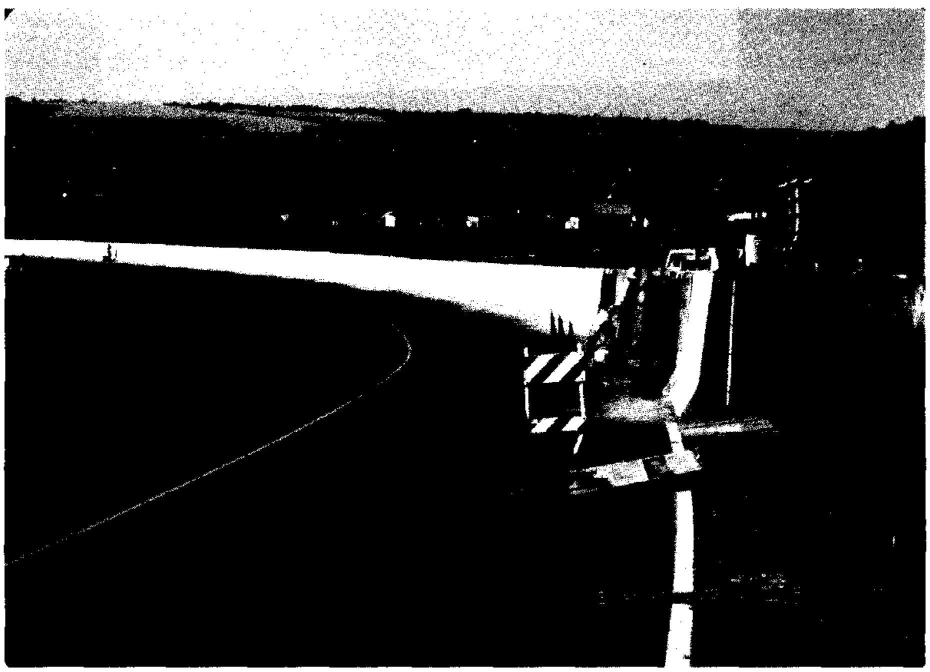

FIGURE 40: ...by stripping the forms and spraying the wall with curing compound.

Cost

The total cost for the Idaho truck barrier was $136,806. This included the cast-in-place concrete safety shape, the earth berm behind the wall, adjustment of an existing sprinkler system, the installation of a W-beam railing on top of the wall, and traffic control. The barrier required 0.49 cubic yards of concrete and 15.76 pounds of #4 reinforcing bars per linear foot. The metal beam guardrail along the top was bid at a unit price of $15 per foot, and is included in the total cost per foot of $125 for the 1,100-foot long installation.

Performance

To determine the effectiveness of the barrier, a video camera was mounted on a nearby structure. A recorder located in the District Two Office operates during daylight hours. The video tape is automatically rewound and restarted each six hours. The rewind process takes 4 1/2 minutes. The TV monitor, also located in the District Office, is viewed daily to check all equipment and to ensure that the camera remains focused. If an accident occurs, the tape is removed and replaced with a new one before it is automatically erased at the end of six hours. The video camera placement is shown in Figure 41.

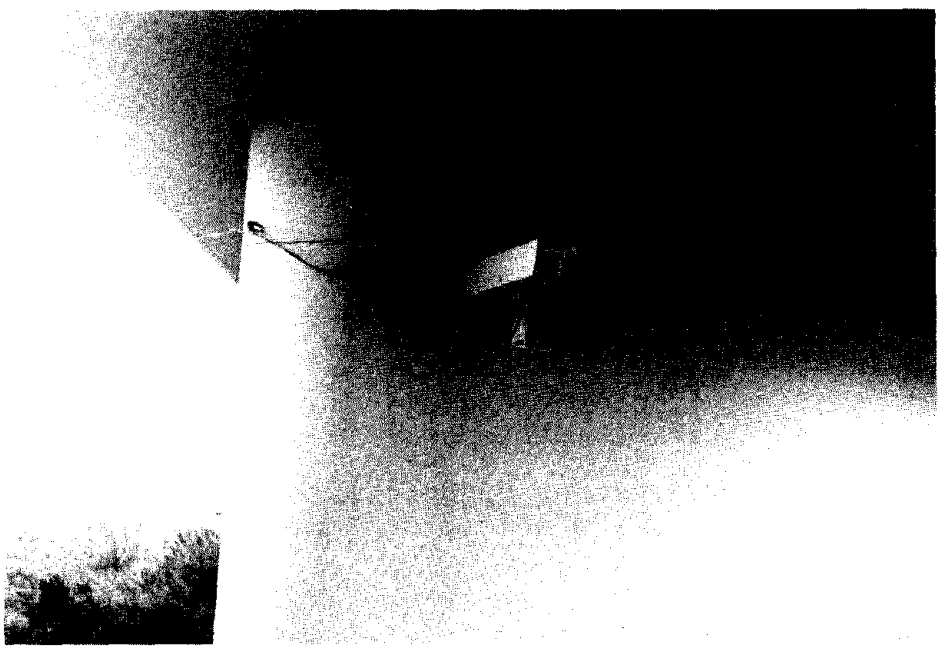

FIGURE 41: On-site camera monitors daytime activities.

On June 4, 1985, an impact occurred at night when the recorder was turned off. Since the vehicle was not disabled, the operator and the type of vehicle involved were not identified although the vehicle was certainly some type of tractor-trailer combination. From skid marks, the angle of impact was estimated to be 15 to 20 degrees and the speed assumed to be 50 mph or higher. An investigation of the wall indicated that the trailer was leaning to the right at the time of impact because the guardrail was hit first and then the concrete barrier was struck while the trailer wheels were still a few feet from the base of the wall. The trailer and tractor tires then hit the wall and scraped it before the vehicle was redirected to the travel lane. The metal guardrail on top of the wall was pushed back approximately 3 inches from the concrete barrier, as shown in Figure 42. There was no need to do any repair work on the truck barrier as a result of this incident. Some scrape marks can be seen in Figure 43.

FIGURE 42: Extent of deformation. Post between block-outs rests on top surface of concrete wall.

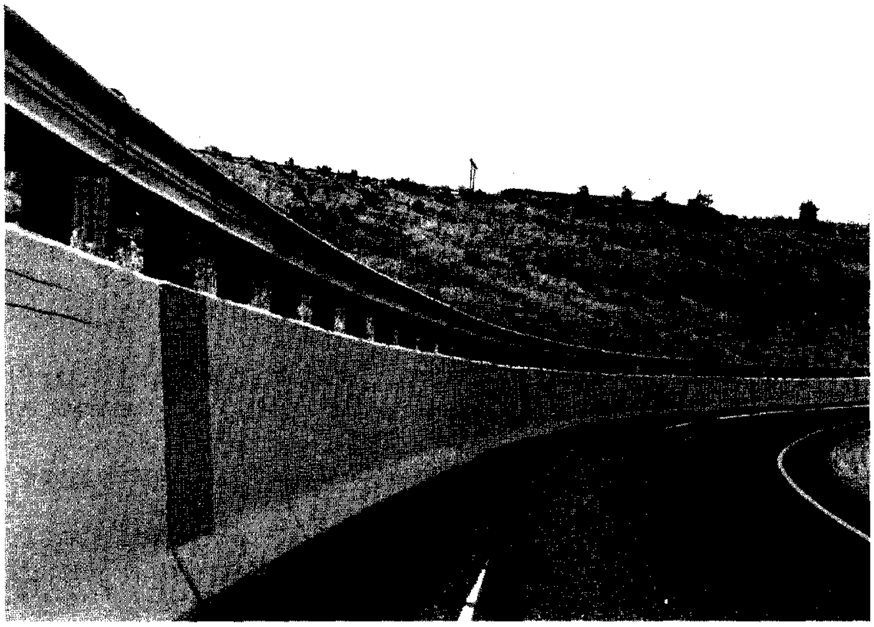

FIGURE 43: Some scrapes can be seen on barrier near center of photograph.

Summary

Based on the performance described above, the Lewiston truck barrier appears to be working as intended. The use of an earth berm behind the wall eliminated the need for an expensive footing, thus keeping the cost very low for a barrier of this type. It also appears that the W-beam along the top limits large vehicle roll and contributes significantly to overall barrier performance by minimizing rebound. The video monitoring system will be operated for at least one more year in a continuing attempt to record an actual truck impact.

INSTALLATION NO. 2 - PENNSYLVANIA

Location

The interchange between I-70 and I-79 in southwestern Pennsylvania's Washington County had been the scene of numerous truck accidents between 1979 and 1983. Twenty-two of twenty-five total reported accidents during this period involved single-unit trucks or tractor-trailer combinations, accounting for one fatality and 30 personal injuries.

The interchange configuration requires all northbound I-79 traffic to slow to approximately 25 mph to negotiate a loop ramp to enter I-70 westbound. This ramp is at the bottom of a downgrade and hidden from view by the I-70 overpass bridges.

Although the ultimate solution is reconstruction of the interchange to permit a direct movement, the cost of this option prevents its timely implementation. The State DOT decided to construct a 90-inch high concrete safety shape barrier along the outside of the loop ramp to prevent encroachments into the opposing ramp and to lessen the severity of heavy vehicle accidents.

Construction

Work on the 90-inch truck barrier began in early 1985. As can be seen in Figure 44, a large footing was required to prevent the barrier from overturning when struck by the design vehicle - an 80,000 pound tractor-trailer impacting at a 15 degree angle and a speed of 60 mph.

The 90-inch barrier was completed in June of 1985 and the ramp was then reopened to traffic.

Cost

The low bid for this project was $607,000 and included several items incidental to the 90-inch wall. Considering only items for excavation, structural concrete, reinforcing steel, and paint for the truck barrier, the approximate cost of 650 feet of wall was $520 per linear foot. The completed barrier is shown in Figure 45.

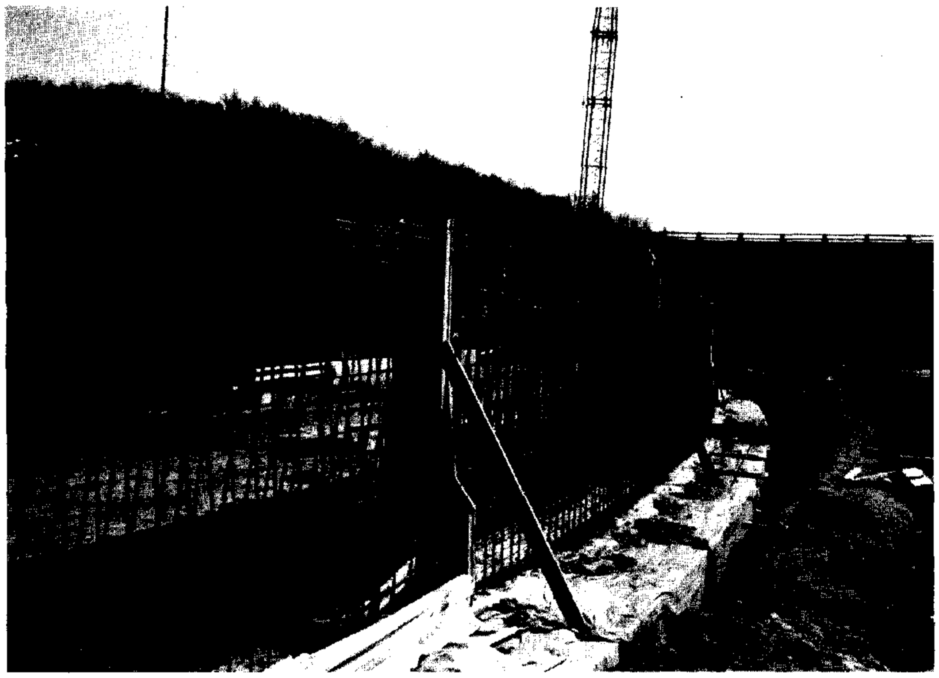

FIGURE 44: The need for a large footing, a safety shape on both sides of the barrier, and a significant amount of reinforcing steel resulted in a relatively high cost.

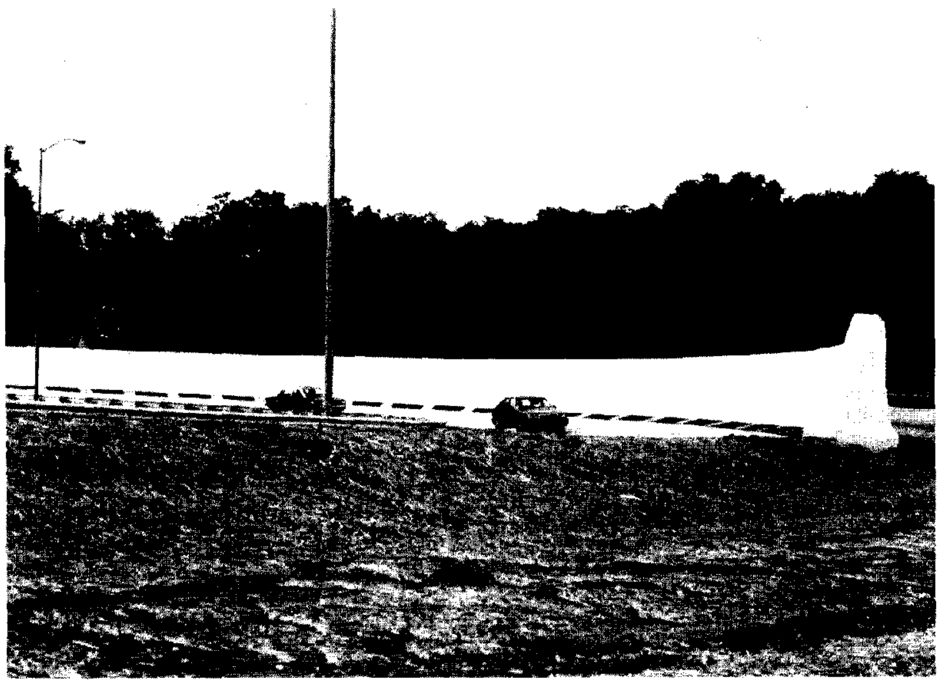

FIGURE 45: Completed barrier dwarfs passenger cars.

Performance/Summary

Since the ramp was reopened, there have been four reported accidents involving tractor-trailers. In two of these accidents, the trucks rolled over and in one case, a tractor-trailor pushed a car into the wall. Review of the State police accident reports revealed that one of the trucks which overturned entered the curve on the right hand side of the ramp and was rolling onto its left side before it actually contacted the barrier. The second tractor-trailer that overturned struck the wall and then rolled onto its right side, away from the barrier. This rollover was possibly caused by the left side of the tractor riding up on the sloped lower face of the concrete, combined with the subsequent rebound when the trailer hit the upper section of the wall. The third combination rig that struck the wall slid along the barrier for approximately 100 feet before coming to rest upright in the grassed infield beyond the barrier. Of the five occupants in the tractor-trailers in these four accidents, four were unijured and one received injuries described in the police report as moderate (first overturning accident). Two of the four occupants of the passenger car received minor injuries in that accident.

Pennsylvania Department of Transportation traffic engineers have noted a tendency for drivers to slow down when they first see the new wall. The white coating makes it highly visible to approaching motorists, as can be seen in Figure 46.

FIGURE 46: Concrete wall becomes highly visible as motorists approach loop ramp.

VIII. MARK VII SAND-FILLED MEDIAN BARRIER

The IBC Mark VII is a new median barrier system developed by the International Barrier Corporation (IBC) of Toronto, Canada. It consists of continuous, free-standing steel panels, 42 inches high forming a trough that is filled with sand. A non-structural sheet metal lid covers the sand. For most impacts, the sheet metal side deforms locally and the sand is compressed, thus attenuating some of the impact force. For severe impacts, particularly with larger vehicles, the entire barrier will move laterally, absorbing energy until redirection is obtained as the full tensile strength of the system is realized. The IBC barrier was originally developed and used for over-the-road motor racing courses. When crash-tested by the International Barrier Corporation and the Calspan Advanced Technology Center in 1981, the IBC traffic barrier successfully redirected a 20,000 pound school bus impacting at 53 mph and 15 degrees.

Location

A section of IBC Mark VII barrier approximately one mile long was constructed on I-95 in Broward County near Fort Lauderdale, Florida, in 1983 (see Figure 47). New Jersey

FIGURE 47: Completed section of IBC Barrier.

barriers (CMB) adjacent to the IBC barrier on each end were monitored to compare the effectiveness of the two systems. For evaluation, the project was divided into three parts. The section where the most cross-median accidents had occurred was selected for installation of the IBC barrier. This was between the Sterling Road Overpass (milepost 5.18) and the Griffin Road Overpass (milepost 6.10). The IBC section is both on a tangent and along a slight curve. Two one-mile control sections of CMB installed on each end of the IBC were included in monthly inspections. Accident reports for the entire project length were analyzed for assessment of damage costs to the barrier.

Cost

The installed cost of the IBC barrier in Florida (bid price) was $46.36 per linear foot, of which $38 was for materials and $8.36 was for installation.

Discussion

The 209 accidents that occurred during the period from September 4, 1983, to September 4, 1985, were analyzed. The vehicle overturning accident was the most severe type of accident observed. All 12 of the overturning accidents happened along the CMB. Periodic inspections recorded 88 impacts along the IBC barrier which included dents and scratches. Of these, 30 were reportable accidents, a ratio of 2.9 to 1. On the 2-mile control sections of CMB there were 81 recorded impacts, 44 of which were reportable accidents or a ratio of 1.8 to 1. The Florida Department of Transportation (FDOT) reports that the cost of a reportable accident (property damage and personal injury) is $8,119 for the IBC and $9,456 for the NJ safety shape, utilizing the 1984 National Safety Council cost of $9,300 per injury and the actual vehicle damage estimated by the reporting officer. Average vehicle damage costs are estimated at $1,246 for the IBC barrier and $2,386 for the NJ barrier.

Tractor-trailers struck both type barriers during the evaluation period. The truck which struck the CMB received damages estimated at $15,000; the barrier received no damage. The driver was reported as having a possible injury. The truck which struck the IBC received damages estimated at $4,000 and the barrier damage was estimated to be $2,250. This driver was also reported as having a possible injury. Additional details of these two accidents were not included in the FDOT report.

The maintenance cost for the concrete barrier could not be based on the experience in Broward County since the CMB experienced only one impact with significant damage and this was not repaired. However, the cost of repairing a CMB had been previously documented by the Tampa, Jacksonville, and South Dade Maintenance units. The average cost per repair including labor and overhead was $1,801. Only $174 of this cost was for materials. There were no impacts on the IBC barrier that required immediate repair. Of the 77 hits on the metal wall, 2 hits would warrant scheduling a maintenance crew for repair but this would be of low priority. The District Maintenance Office defined three categories of impacts:

A. **Minor Impacts,** which have resulted in dents and/or scraping of the galvanized coating. These can be repaired with the use of one of the many commercially-available field applied zinc-rich paints which would prevent corrosion.

B. **Heavy Impacts,** which result in major distortion of the impacted face panel without reduction of the structural integrity of the barrier. These can be repaired with "cover panels" designed to be installed over the damage for esthetic reasons. Figure 48 shows the type of damage resulting from a heavy impact.

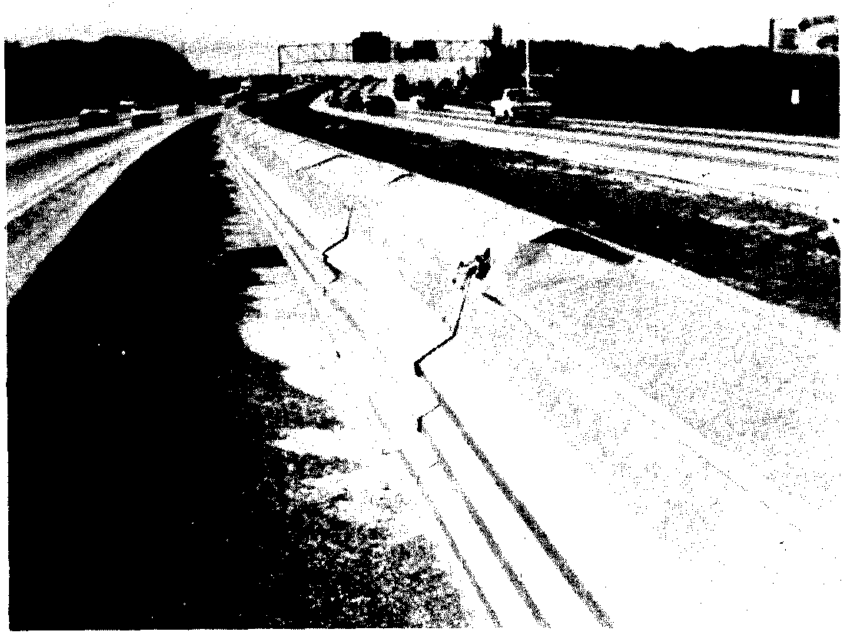

FIGURE 48: This type of damage would not require repair except for esthetic reasons.

C. **Major Impacts,** which result in both distortion and translation of the barrier across the ground. Repair entails the following steps:

1. Remove lids and empty sand from areas to be repaired and adjacent units if required.

2. Remove damaged sections. Assemble and replace damaged sections.

3. Align damaged sections and tighten bolts.

4. Refill with sand and replace lids.

During the first year there have been many hits on the metal barrier, but none that would normally have been scheduled for repair. However, to determine costs, some repairs were performed. Although touch-up maintenance was not performed, it was estimated that 2 days per year would be required. Annual cost, including maintenance of traffic, for a crew of four would be $415.20. Benefits, overhead, and supervision increase this cost to $1,199. Material is estimated to be $50. Thus, total cost for touchup maintenance would be $1,249 per mile.

It is estimated that repairs necessitated by a major accident would occur once per year. To determine this cost, the actual cost of repairs made on the IBC barrier during the study period was documented, using State forces cost estimate sheets. Costs of repair for one accident were $1,671 for labor, $560 for materials, and $432 for equipment, or $2,663 total.

Summary/conclusions

At the conclusion of the 2-year evaluation period, the Florida Department of Transportation concluded that "the IBC and CMB barriers perform satisfactorily as median barriers. The annual cost of the IBC barrier, considering construction and maintenance costs, is higher than the CMB. There was no significant difference in the average injury severity nor ratio of injury accidents to total accidents between the two barriers. The average vehicle damage was less for vehicles striking the IBC than those striking the CMB barrier.

Although the ratio of rollover accidents per accident is quite low (1.07), there were 12 rollover accidents during the 2-year period over the 7.78-mile length of CMB as compared to no rollovers for the 0.95-mile of IBC. The IBC barrier is acceptable for use and should compete with the CMB on a construction bid price basis."

In response to a letter from the International Barrier Corporation, the Federal Highway Administration stated:

> "Based on crash tests and on available evaluations of IBC traffic barrier installations in Canada and Florida, we find the IBC traffic barrier to be acceptable as an operational barrier for Federal-aid highway projects if a State highway agency proposes its use. If a State elects to allow general use of the IBC barrier we will expect the barrier to be selected only after competitive bidding of alternate barrier designs, as would be the case for any proprietary product. We believe the IBC barrier has been demonstrated to have performance characteristics for automobiles and school buses that are comparable to the standard (32 inch) concrete safety-shaped barrier. Thus, bidding the IBC barrier in competition with this barrier would be appropriate.
>
> In addition, we will allow a limited number of experimental installations of the IBC barrier if a State highway agency (including the Florida Department of Transportation) determines it wants further evaluation before allowing its general use. This means the product could be purchased and installed through sole-source, rather than competitive, procurement in accordance with Title 23, Code of Federal Regulations, Section 635.411. The length of the IBC barrier for experimental installations would have to be proposed by a State and agreed to by our Division Administrator in that State."

IX. MODIFIED THRIE BEAM GUARDRAIL

Since its nationwide adoption, the standard W-beam guardrail has been widely used as a traffic barrier. However, because the W-beam element is only 12 1/4 inches deep, its mounting height is critical - if it is too low, vehicles can go over it and if it is too high, vehicles may snag on the support posts. Even when properly installed, a W-beam guardrail may not perform well when struck by vehicles larger or higher than full-sized passenger cars.

To override these shortcomings, a triple corrugated metal beam guardrail, called thrie beam, was developed. The thrie beam rail is similar in cross-section to W-beam rail but with an additional corrugation, making its total depth 20 5/8 inches. While the thrie beam guardrail proved generally superior to W-beam for passenger car impacts, subsequent testing of a 20,000 pound school bus resulted in the bus rolling onto its side as it left the rail.

To improve heavy vehicle performance, a modified spacer block was developed. This M14x17.2 spacer has a triangular notch cut from its web (see Figure 49). At a mounting height of 35 1/4 inches, this barrier successfully contained and redirected a 20,000 pound school bus and a 32,000 pound intercity bus, both impacting at about 60 mph and 15 degree angles. The spacer design allows the lower portion of the thrie beam and the flange of the spacer block to bend in during a collision,

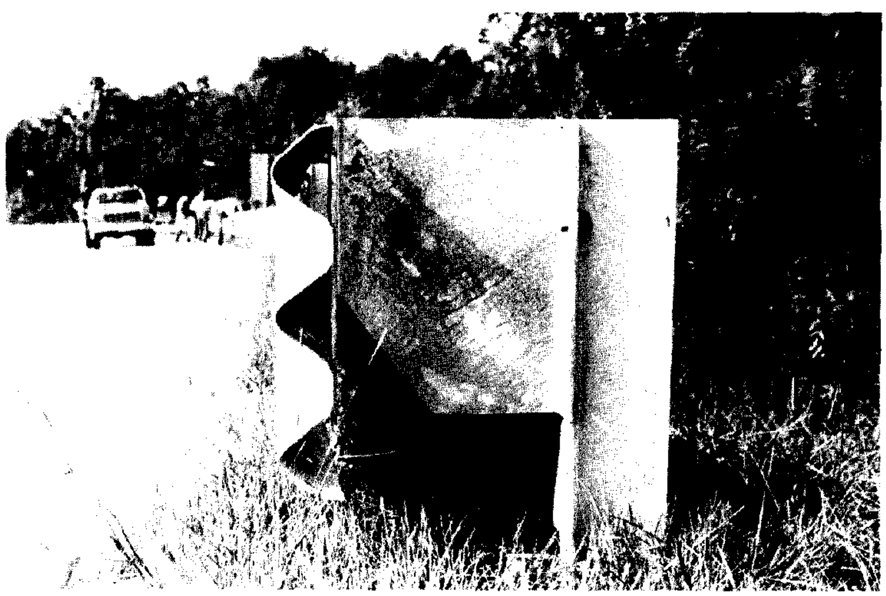

FIGURE 49: View during construction showing modified spacer block, thrie beam rail and steel post.

keeping the rail face vertical in the impact zone as the posts rotate in the soil. This raises the actual height of the rail and further minimizes the likelihood of a vehicle going over it.

The first three Modified Thrie Beam guardrail installations in the country were in Colorado, Rhode Island, and Michigan. Brief summaries of each of these installations follow:

INSTALLATION NO. 1 - COLORADO

Location

This Modified Thrie Beam installation consists of a 300-foot section and a 200-foot section on each end of a 500-foot SERB installation on I-70 at Floyd Hill, west of Denver (details on the SERB guardrail are included in Section II). The installation, shown in Figure 50, was completed in late 1983.

FIGURE 50: Modified Thrie Beam guardrail in advance of SERB guardrail.

Cost

Because the SERB guardrail and the Modified Thrie Beam guardrail were installed at the same time under a single project, exact cost data for each type of barrier is not available. However, it is estimated that the in-place cost for the Modified Thrie Beam was $15 per linear foot.

Performance

To date, there have been three recorded hits on the Modified Thrie Beam. One impact was at the downstream transition section between the SERB and the Modified Thrie Beam. The force of impact was absorbed by the thrie beam and there was no observed damage. The vehicle involved was a 1973 Datsun sedan. There was also a hit near the upstream end of the Modified Thrie Beam which resulted in a minor scrape on the lower part of the rail. The flange of the special blockout was bent, but there was no displacement of the steel support posts.

INSTALLATION NO. 2 - RHODE ISLAND

Location

There were two installations completed in Rhode Island, one on Interstate 95, south of Providence (Route 3 interchange) and one on Route 4, just north of the Route 401 crossing in Warwick.

At the first location, the 700-foot installation is in the median along a right-hand curve with a radius of approximately 2,160 feet (see Figure 51). The W-beam guardrail / rub-rail that was replaced by the Modified Thrie Beam had been frequently hit in the past. The 1984 AADT for both directions was 23,760. About 15 percent of this total was truck and bus traffic.

At the second site, the Modified Thrie Beam guardrail is on the left side of the northbound lanes at a curve to the right, with an approximate radius of 930 feet (see Figure 52). There were frequent hits on the W-beam guardrail that was replaced by the Modified Thrie Beam . The 1983 AADT for both directions of flow was 40,100.

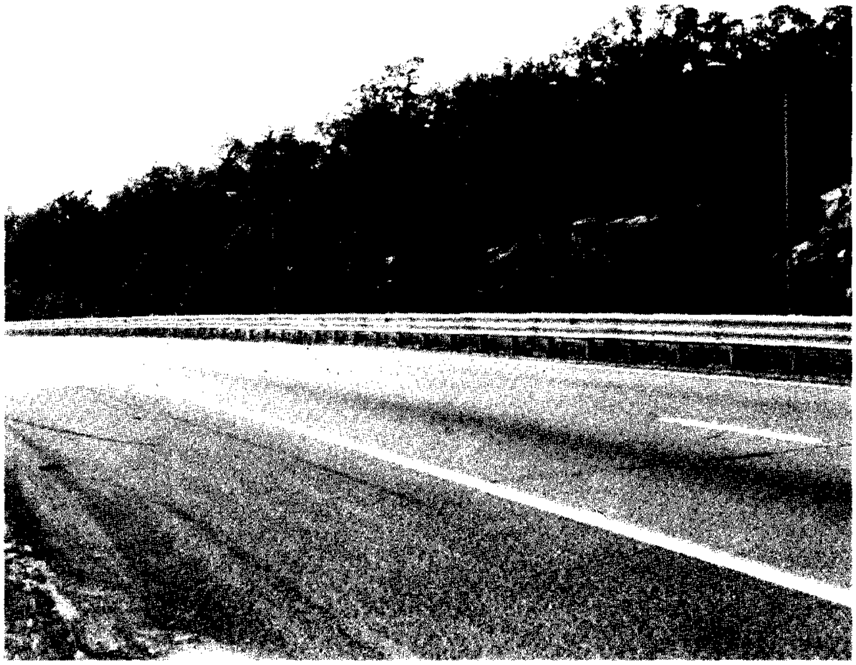

FIGURE 51: Modified Thrie Beam used as a median barrier. At this site, a W-beam and rub-rail are still being used for opposing traffic.

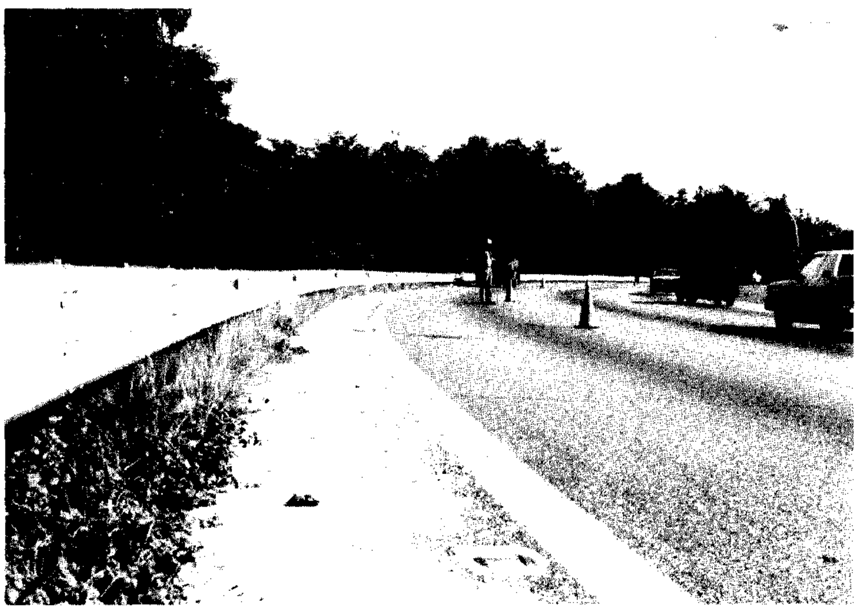

FIGURE 52: Completed Modified Thrie Beam.

Construction Costs

For both installations, the Modified Thrie Beam was inserted into the existing run of W-beam railing. The total cost of the two installations was $19,888 for 1,237.5 feet which included removal of existing barriers. The unit cost was $16.07 per linear foot. For comparison, the cost for standard W-beam on the same contract was about $10 per linear foot. It was found that the Modified Thrie Beam can be readily installed in conjunction with standard W-beam guardrail using a standard W-beam to thrie beam transition section. Figure 53 shows the 3-man crew installing the Modified Thrie Beam.

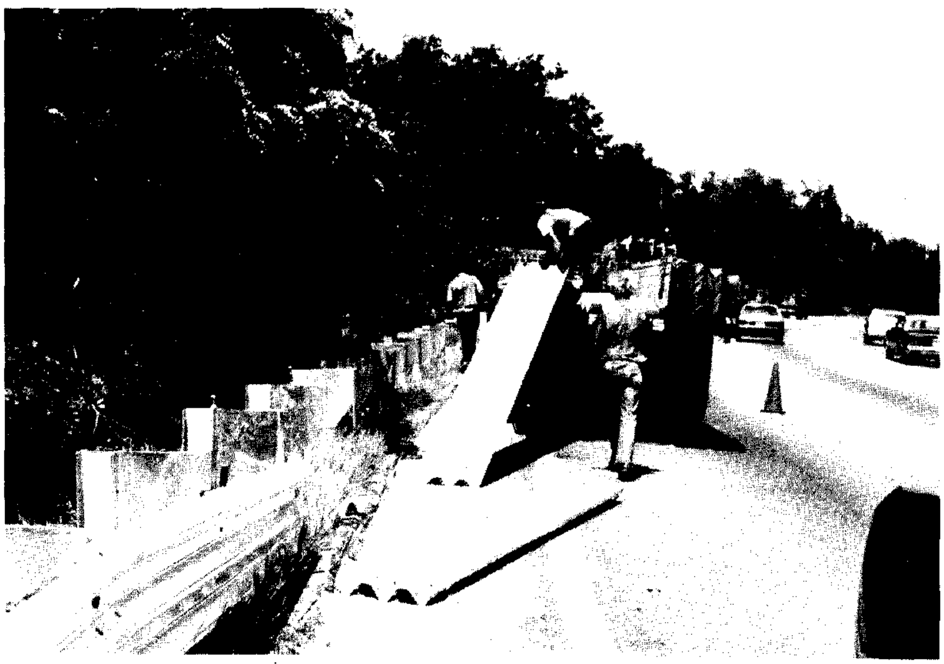

FIGURE 53: Installation required no special equipment or techniques and was easily done with a three-man crew.

Performance

The installations were completed in August 1984, and as of January 11, 1985, there had been no evidence of the barrier being hit at either location.

INSTALLATION NO. 3 - MICHIGAN

Location

The Michigan DOT has installed three separate sections of Modified Thrie Beam guardrail: along Interstate 196 and U.S. Route 131 in Grand Rapids (850 linear feet and 1,000 linear feet, respectively) and on Interstate 496 in Lansing (this 350-foot section was used as a bridge approach rail). The latter installation uses a SENTRE guardrail terminal at its upstream end and steel support posts (see Figure 54). Two of these installations used wooden posts to support the thrie beam. The spacer blocks were bolted through these posts, using 10-inch long, 5/8-inch diameter bolts, as can be seen in Figure 55. At each location, the 34-inch high Modified Thrie Beam replaced a type C guardrail consisting of a blocked-out W-beam set 33 inches high with a second W-beam rail element used as a rub-rail.

FIGURE 54: Modified Thrie Beam on steel posts used as a bridge approach rail.

FIGURE 55: Modified Thrie Beam on 8-inch x 6-inch wood posts in Grand Rapids, Michigan.

Cost

The in-place cost of the new rail ranged from a low of $14 per linear foot to a high of $17 per foot. Michigan type C railing typically costs approximately $15 per foot for comparable lengths.

Performance

To date, none of the installations in Michigan has been hit.

Modified Thrie Beam guardrail summary/recommendations

Based on both the controlled crash testing and the preliminary evaluation data from the pilot installations, the Federal Highway Administration's Office of Engineering no longer considers the Modified Thrie Beam guardrail to be experimental. It can be used as an operational barrier on Federal-aid highway projects. The following observations are pertinent:

1. The Modified Thrie Beam guardrail performs substantially better than a standard thrie beam guardrail. Both are superior to W-beam guardrail, particularly for vehicles significantly smaller or larger than full-sized passenger cars.

2. Modified Thrie Beam guardrail is simple to install. It has only an incremental price increase over standard thrie beam, although it may cost 30 to 50 percent more than a standard W-beam installation.

3. Repair costs for Modified Thrie Beam guardrail may be considerably less than other metal beam guardrail systems because the Modified Thrie Beam is not damaged in shallow-angle impacts. Even for moderate to severe crashes, the barrier remains functional and does not usually require immediate repair.

4. Modified Thrie Beam guardrail is generally easier and less expensive to install and maintain than a W-beam/rub-rail system. It is recommended for use at locations where an inexpensive, high-performance barrier requiring minimal maintenance is needed.