

EVALUATION OF A PILOT INSTALLATION  
OF AN ENERGY-ABSORBING BRIDGE RAIL

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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## ABSTRACT

A newly developed bridge rail which uses steel rings that collapse or deform to absorb the energy of an impacting vehicle was retrofitted to the concrete parapet of an existing interstate highway bridge. It was planned that the installation would be evaluated from the standpoint of design, construction, effectiveness, and maintenance requirements. However, as the rail was not struck during the study period, its in-service performance remains untested, and no maintenance has been required. Information is presented on the cost, man-hours required, and problems encountered in the design and construction of the rail.



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INTRODUCTION

In December 1976 an energy-absorbing bridge rail was retrofitted to an existing concrete parapet on a bridge on the southbound lane of Interstate Route 395 just south of Washington, D. C., in Northern Virginia. Under contract with Region 15 of the Federal Highway Administration, the Virginia Highway and Transportation Research Council observed the installation of the rail and monitored its performance for a period of one year after construction. This report covers the information developed during the contract period. Normal construction and design engineering were funded as a safety project by the FHWA and the Virginia Department of Highways and Transportation.

The energy-absorbing rail installed on Route 395 is part of a combination energy-absorbing and high performance system developed by engineers of the FHWA. Recognizing the need for a barrier that would smoothly redirect impacting vehicles while containing even large vehicles, the FHWA designed a system composed of a 5 ft. (1.5 m) high barrier of three box-beam guardrails on wide-flange beam posts, with the lower beam mounted on steel rings that collapse or deform on impact. The new barrier concept was proven through full-scale crash-testing, using vehicles as large as tractor-trailer trucks and interstate buses.(1)

After the controlled testing program, the FHWA initiated Demonstration Project Number 19 to encourage the construction of pilot installations to gather information on costs, design, construction procedures and problems, and maintenance requirements, and to evaluate the effectiveness of the system in service. Retrofitting of the energy-absorbing portion of the system, the lower box beam supported on steel rings, to an existing bridge on Route 395 is one of the installations included under Project 19.

It was found that the installation of the rail, even in one of its first applications, was relatively simple, and cost data indicate that the rail may be a reasonably priced means of upgrading the safety of an existing bridge, a matter of national concern. As the rail has not been struck as of this writing, information on its effectiveness or the degree of maintenance required after a significant impact is unavailable.

## SCOPE

Virginia's evaluation of the energy-absorbing bridge rail was limited to the retrofitting of the system on one bridge on the southbound lane of Route I-395 in Arlington County. Included in the evaluation were the design and installation of the rail and its performance and maintenance requirements for a period of one year after completion.

## TEST BRIDGE

The structure chosen for the experimental energy-absorbing rail was the bridge carrying the southbound lane of Interstate Route 395 (formerly designated Route 95) over Roadway B, Washington Boulevard (NB) and Roadway F, part of a complex interchange just south of Washington, D. C. With a total average daily traffic count of more than 100,000 vehicles per day for both directions, this portion of Route 395 is the busiest highway in Virginia.<sup>(2)</sup>

Details of the bridge and rail are shown on Plan set 213-23A, which is appended to this report. As shown on the plans, the structure is sited essentially on a horizontal curve toward the driver's left. There are three 12-ft.(3.7 m) traffic lanes with a right shoulder of 10 ft.(3 m) width as originally built and an 8 ft.-7 1/2 in.(2.6 m) width after installation of the energy-absorbing rail. As built, the structure had a barrier composed of a 7 in.(0.2 m) high by 8 in.(0.2 m) wide curb on which was a 20 in.(0.5 m) high parapet with an aluminum rail. A W-beam guardrail on steel posts led into the structure and was attached to the parapet. The barrier, which probably affords reasonable containment but poor redirection of vehicles, reflects an older rail standard, because of the time lag between design and construction. Newer rail designs have a sloped face on the parapet, as in the popular New Jersey configuration, to more smoothly redirect impacting vehicles.

The structure for the pilot rail installation was chosen for its high traffic volume and its proximity to the FHWA Region 15 offices, which would allow easy monitoring of construction and maintenance operations. The safety record of the structure, which was opened to traffic in 1973, would not have warranted retrofitting the energy-absorbing rail.

## DATA COLLECTED

All the time and cost data directly related to the design and construction of the rail were collected from the best

available source documents. Attempts were made to eliminate or separate those factors related to peculiarities of the Route 395 site, such as the time spent by the contractor traveling between the bridge and the relatively remote material storage site.

### Engineering

The engineering associated with retrofitting the energy-absorbing rail involved detailing the essentially designed rail to fit the existing Route 395 bridge. It was desirable that modification of the existing bridge beyond attachment of the new rail be avoided, and none was required. The design detailing was performed by the Virginia Department of Highways and Transportation's District Bridge Office at Culpeper and was reviewed by the FHWA. Specific problems solved included the following:

1. Supports for the energy-absorbing rail had to be spaced to avoid the existing aluminum rail, which was left in place. Solution of this problem required three visits by the district bridge engineer to the site to obtain measurements and verify the suitability of detail dimensions.
2. The rail had to be detailed for proper behavior under impact without restricting expansion or contraction of the existing bridge spans.
3. A proper transition between the W-beam guard-rail on the approach roadway and the energy-absorbing bridge rail had to be designed. The use of the "soft" transition, using lightweight posts and larger diameter rings than those supporting the rail, was conceived jointly by engineers from the Department of Highways and Transportation and the FHWA with input from Southwest Research Institute personnel.

The final design is shown on the appended plan set 213-23A. Figure 1 shows a rear view of the transition at the bridge approach. As shown in Figure 2, a photo of the completed rail under traffic, the exit terminal was carried beyond the parapet on lightweight posts and ramped to the pavement.

Time sheets and other records indicate that a total of 233 hours were spent by personnel from the Culpeper District Office in engineering the rail at a cost of approximately \$2,500.



Figure 1. View of the transition between the W-beam approach guardrail (left) and bridge rail at the entry to the structure.

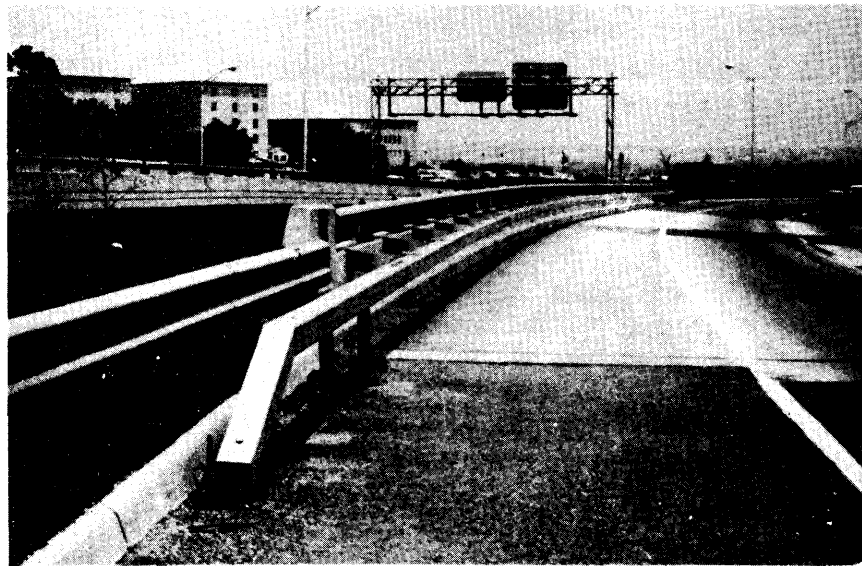


Figure 2. View of the exit terminal of the energy-absorbing rail.



Time contributed by other personnel from the Department or the FHWA in reviewing the plans is not included in these figures. One state inspector, attached to the Fairfax, Virginia, residency, was assigned to the project. He was at the site during all of the construction operations, and some time was spent by the assistant resident engineer and the project engineer in a pre-construction conference and in occasional visits to the site. These normal inspection and administrative requirements, which will vary between agencies, also are not included.

### Cost Data

Cost data were obtained from the bid submitted by the contractor. The information may be limited in its applicability to other projects for two reasons. Only one bid was received in response to the advertisement, and the installation was the first of its type in Virginia. Table 1 shows the cost breakdown submitted by the contractor.

Table 1

Bid Costs, Installation of Energy-Absorbing Rail  
Route 395 (SB) over Roadway B  
Washington Blvd. (NB) and Roadway F

<u>Item</u>	<u>Quantity x Unit Price</u>	<u>Bid Cost</u>
Mobilization	Lump sum	\$ 2,000.00
Energy-Absorbing Bridge Rail	Lump sum	12,370.00
Electronic Sequential Arrow	260 hr. x \$5.00	1,300.00
Concrete Curb Barricade	380 L.f. x \$8.50 (115.2 m x 28.05)	3,230.00
Replacement Parts for Rail*	Lump sum	<u>1,100.00</u>
	TOTAL	<u>\$20,000.00</u>

\*As shown on appended Plans 213-23A, sheet 2 of 4, the replacement rail components included 3 beams "A", 23'-11" (7.25 m) in length; 10 rings of 1'-6" (0.45 m) diameter with support assemblies and hardware; 1 each of the rings of 1'-8", 1'-10", and 2'-0" (0.51, 0.56, and 0.61 m) in diameter with support assemblies and hardware, and 5 splice assemblies with hardware. These items were to be charged against the FHWA research contract rather than construction funds.

As shown in Table 1, \$1,100 of the project cost was for replacement parts that would have been required if the rail, the only one of its type in Virginia, had been damaged. If the cost of these parts were excluded from the bid, as would be possible with wider use of the system, the total cost would be reduced to \$18,900. This cost is considered quite reasonable, particularly for lightweight systems used when a low dead load is required.

### Construction Operations

Construction operations were monitored by research personnel during virtually all of the time that the contractor's forces were working. All operations were photographed and any problems were noted. At ten-minute intervals, the activities of contractor personnel were noted in order to obtain a relatively precise indication of time requirements. The state inspector's diary provided supplemental information.

Construction of the rail took place over a period of about 3 weeks (14 working days) beginning on Tuesday, November 30, 1976. Except for brief instances only a two-man crew was employed, and the job was completed in approximately 175 man-hours of working time. The construction took place during a period of very cold weather at the onset of the severe winter of 1976-77. Morning temperatures were usually in the range of 20°-30°F (-7° - -1°C), and often the high was below freezing.

### Construction Procedure

The sequence of operations on the bridge deck is described below. Barrier placement, Figure 3, was the first step in site preparation. It should be noted that the temporary curb-type barriers used on this installation, shown in the figure, are of a type no longer used or accepted by the Virginia Department of Highways and Transportation or the FHWA. As shown in Figure 3, the barriers were placed with the backs aligned with the edgeline to provide an 8 - 9 ft. (2.4 - 2.7 m) wide work area at the rail. This was believed to be the maximum encroachment on the roadway of an interstate highway for a relatively long period, two to three weeks, during which the barrier would be unattended. Unfortunately, the working space did not allow sufficient width for the contractor to use his crane truck after the rings were attached to the parapet.

The contractor elected to proceed by first attaching all of the collapsible ring supports to the existing concrete parapets. The supports were used as templates to mark the bolt locations, Figure 4, and the holes were easily made using a pneumatic drill, Figures 5 and 6. Each support was attached by

four bolts, two each in the front and top faces of the parapet. It was impossible to locate the holes, Figure 7, to miss the parapet reinforcing steel in every case, and cutting the steel, when encountered, required the use of an electric drill. Bolts, such as the one shown in Figure 8, were hammered into the holes, Figure 9, to expand the base of the serrated sleeve into the concrete. Care had to be taken to fully expand the sleeve before the bolt was removed to attach the support, as it proved impossible to tighten the bolt if the sleeve slipped against the wall of the holes. As indicated in Figure 10, all of the rings were attached to the parapet before any of the rail sections were installed.

Attachment of the rail segments to the rings was more difficult than anticipated, primarily because of an error in fabricating the ring supports. Figure 11, a front view of a typical rail support, shows a weld indicated by the arrow between the bottom flange and the collapsible ring; a similar weld is located between the top flange and the ring. The adverse effect of these welds, which were not called for on the plans, was twofold; they intruded on the space to be occupied by the rail and they tended to draw the flanges toward each other, and thus decrease the width of the opening. Because of these factors, force was required to position the rail segments, Figure 12, and in some instances it was necessary to enlarge the holes in the rails slightly. Some difficulty was also experienced in aligning the rail longitudinally to provide passage for the bolts at the supports. In the future, contractors might consider erecting shorter sections of the complete barrier, both supports and rails, rather than installing all of the supports, particularly on curved bridges.

Splice connections in the rail used plates, shown in Figure 13, with tack-welded nuts on the inner face to facilitate tightening of the bolts from the outside of the rail. Splicing operations are shown in Figures 14 and 15.

Transition between the existing W-beam guardrail and the energy-absorbing rail at the entry end of the bridge, shown earlier in Figure 1, required the realignment or replacement of several posts. No special equipment was used, and the cutting of the concrete apron and hand excavation for the posts, Figure 16, required a considerable amount of time. Installation of the exit terminal, Figure 2, was relatively simple, as the smaller posts could be driven into the earth.

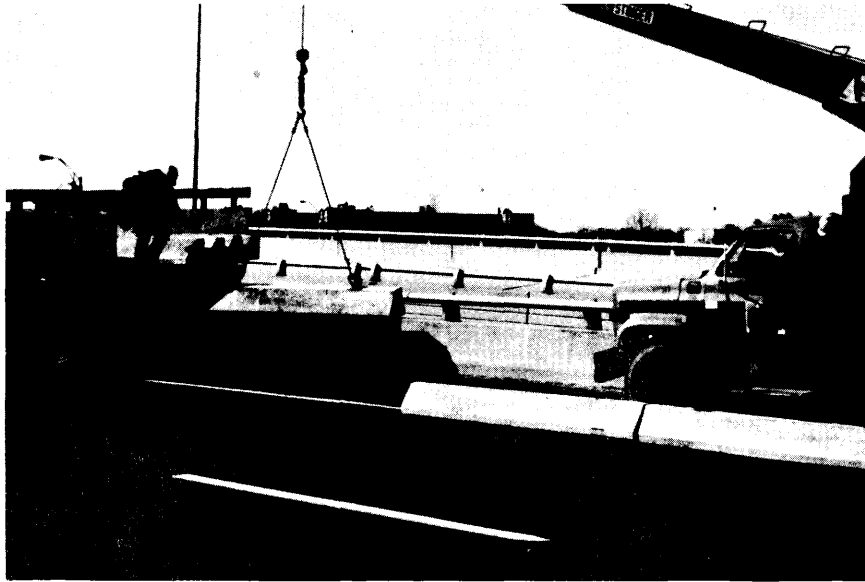


Figure 3. Placement of concrete barriers.

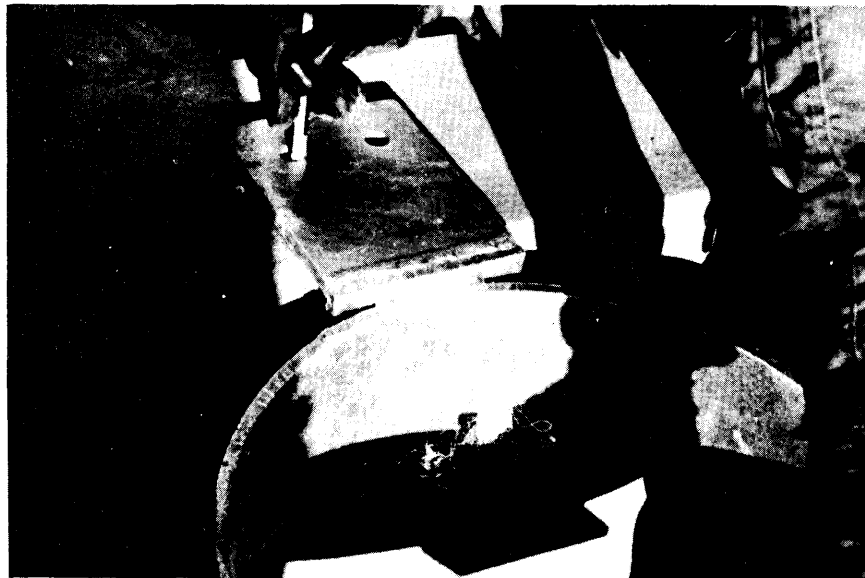


Figure 4. Marking bolt locations at supports.

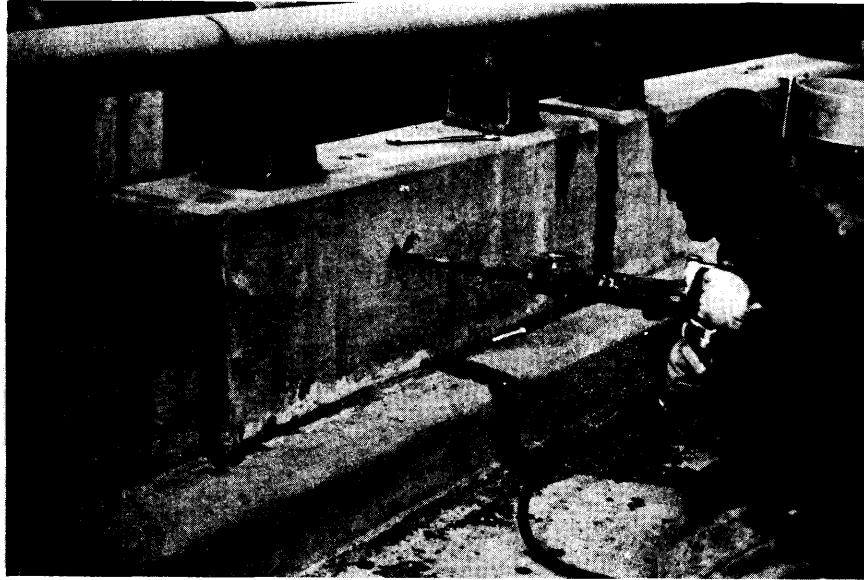


Figure 5. Drilling holes for support bolts, side face of parapet.



Figure 6. Drilling holes for support bolts, top face of parapet.

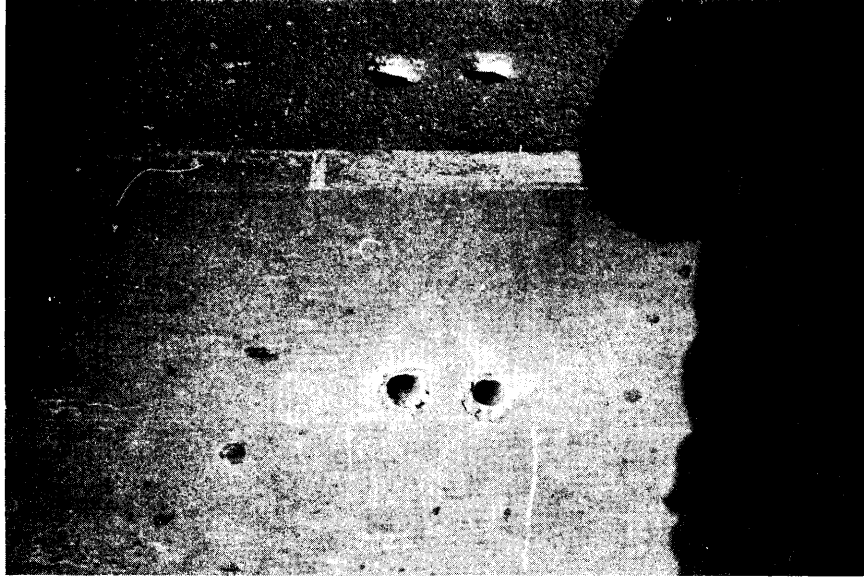


Figure 7. Four bolt holes required in parapet at each support location.

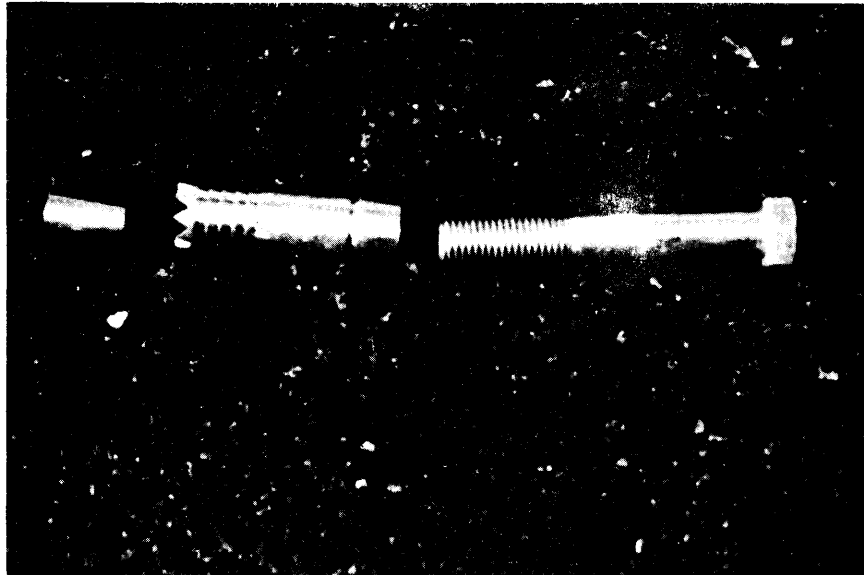


Figure 8. Anchor bolt for support.

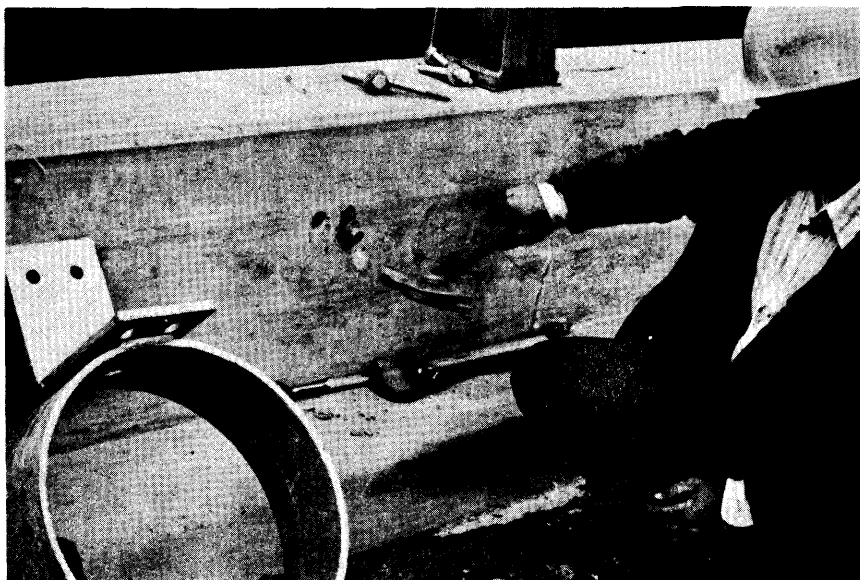


Figure 9. Hammering anchor bolt to set expanding sleeve against side of hole.

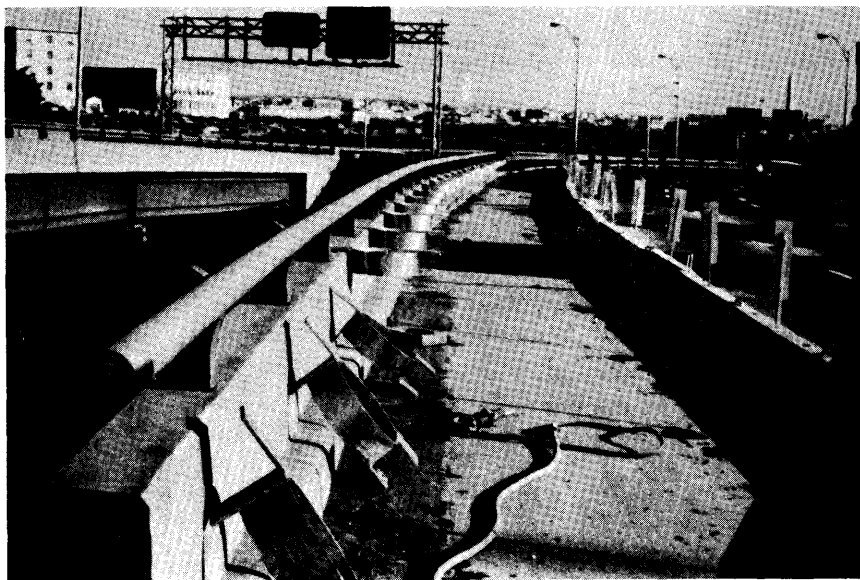


Figure 10. Collapsible ring supports installed before rail sections placed.

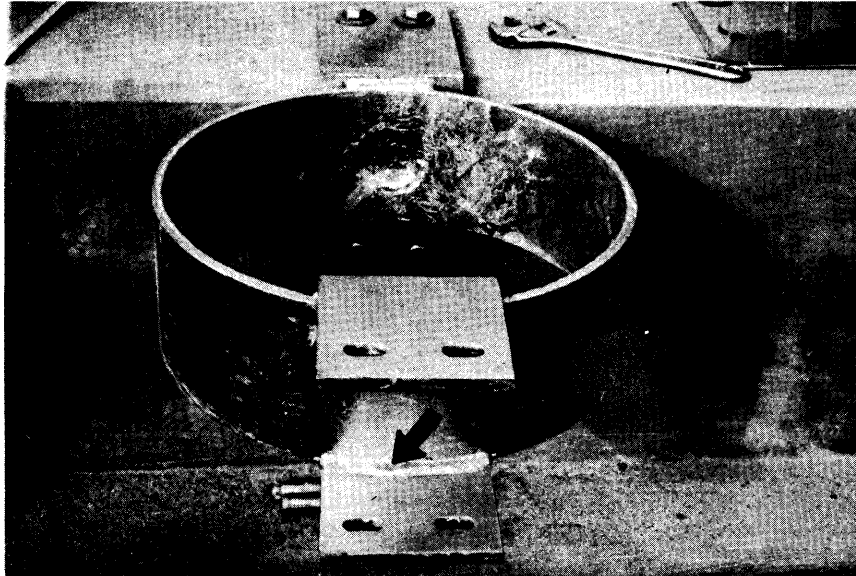


Figure 11. Front view of collapsible ring support showing weld (arrow) erroneously added by fabricator.



Figure 12. Attaching rail to collapsible ring support. Force was required due to presence of weld, Figure 11.



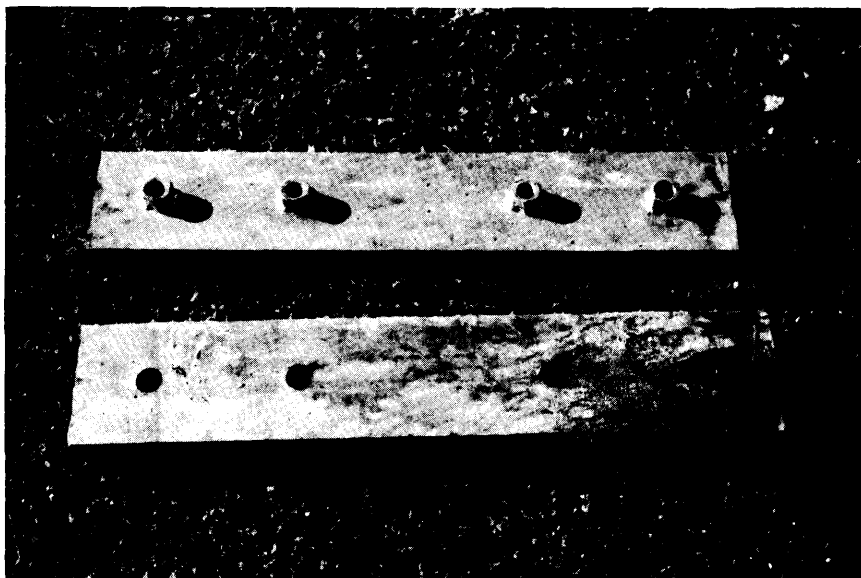


Figure 13. Splice plate for rail sections. Nuts are tack-welded to inner face.

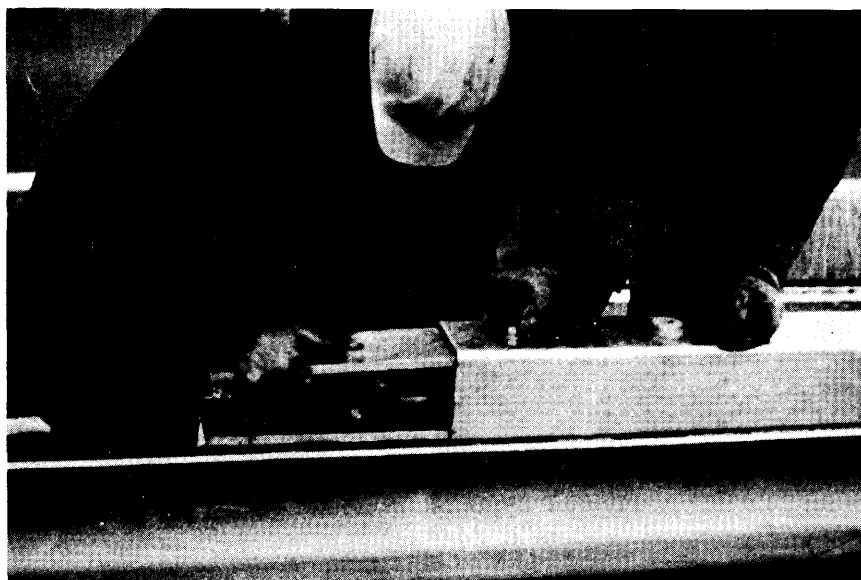


Figure 14. Attaching splice plates to rail section.



Figure 15. Completing rail splice.

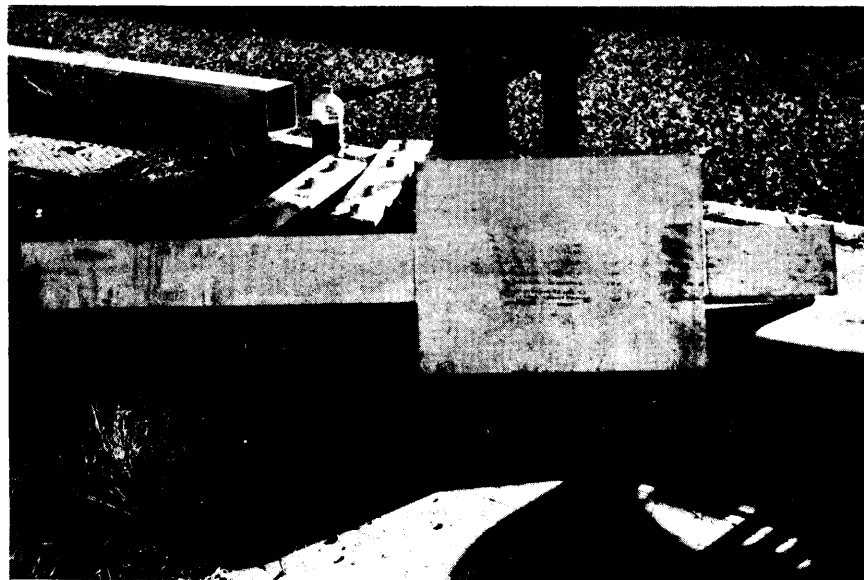


Figure 16. Post with soil-bearing panel for installation at entry end of bridge.

## Time Requirements

The activities of the contractor's personnel were recorded at intervals of ten minutes during working hours. Since only a two-man crew was generally used, the time requirements for the various construction operations, Table 2, can be considered reasonably accurate. Only actual on-site working time is shown; approximately 30 hours of nonrelated personal time, including time used for lunch breaks or arranging motel accommodations, were recorded but are not included in Table 2.

Generally, the contractor's two men were on the site for about 9 hours on Tuesdays, Wednesdays, and Thursdays, and about 6 hours on Fridays and Mondays. Extra manpower was used on Wednesday, December 1, and Tuesday, December 7.

An attempt was made to separate those factors that varied with conditions due to the particular bridge site, and these were recorded in Table 2 as Equipment and Material. The hours shown under this heading reflect the time required to load or unload equipment at the storage yard; to move equipment and supplies from the storage yard to the site; or to purchase or repair equipment. Any downtime of equipment caused by low temperatures was also included under Equipment and Material. The only storage site available to the contractor was the yard of a nearby maintenance headquarters, several minutes driving time away from the bridge, and this fact, coupled with the cold weather, tended to make the time shown under Equipment and Material greater than would be expected normally.

A review of Table 2 indicates that a total of 174.1 man-hours was required to retrofit the energy-absorbing guardrail on the Route 395 bridge. If the 31.7 hours required to install traffic control devices, shown under Barrier Placement, Alignment, and Removal, are deducted, 142.4 man-hours were required to attach the rail. As indicated previously, the hours shown under Equipment and Material were inflated by site and weather conditions, and no doubt the cold also increased the time required for all operations.

Installation of the ring supports is a time-consuming operation and is complicated by the occasional presence of reinforcing steel. The rather high number of hours shown for rail placement would not be expected on future jobs. The man-hours required for this operation were greatly increased by the fabrication error discussed previously, and the time required was also lengthened by the limited width of the working space that required hand-carrying all of the rail sections to their positions.

It is believed that given the factors just discussed, installation of the rail proceeded quite efficiently. It is possible that productivity could have been increased through the use of a three-man crew; the contractor's foreman was of this opinion.

Table 2  
Man-Hour Requirements for Installation

Task	Day														Total Hours Per Operation
	Tues. Nov. 30	Wed. Dec. 1	Thur. Dec. 2	Fri. Dec. 3	Mon. Dec. 6	Tues. Dec. 7	Wed. Dec. 8	Thur. Dec. 9	Fri. Dec. 10	Mon. Dec. 13	Tues. Dec. 14	Wed. Dec. 15	Thur. Dec. 16	Fri. Dec. 17	
Barrier Placement		15.5													15.5
Barrier Alignment			2.2	2.8	0.2										5.2
Barrier Removal														11.0	11.0
Equipment & Material	2.0		2.0	6.0	1.2	3.0	5.7	2.8		0.5	5.5	5.5			34.2
Layout			1.0	0.5		0.3	0.3	1.5	1.0						4.6
Installing Ring Supports			8.9	2.8	5.3		0.8								17.8
Placing Rail						21.6	2.9	2.0		8.0					34.5
Transition (Entry)			0.7				6.8	9.0	2.0		10.0	4.7			33.2
Terminal (Exit)									3.8			0.8			4.6
Cleanup												4.5	5.0		9.5
Final Insp. & Follow-up													4.0		4.0
Total	2.0	15.5	14.8	12.1	6.7	24.9	16.5	15.3	6.8	8.5	15.5	15.5	9.0	11.0	174.1

## Equipment Requirements

The contractor used two vehicles on the project, a boom truck for lifting barricade sections and rail components and a pickup truck for light hauling and towing. An air compressor was required to power the pneumatic drill used in installing the supports, and an electric drill and generator were required to drill through reinforcing steel. A small motorized saw was useful in cutting the concrete apron at the entry approach, and, of course, a variety of small tools were required.

## Effectiveness and Maintenance Requirements

As called for in the research contract, the performance of the rail and its maintenance requirements were monitored for a period of one year after construction. The rail was apparently lightly brushed by a vehicle during that period but no maintenance has been required to date.

The light "brushing" impact slightly marred the surface of the rail over a distance of several feet, as shown in Figure 17, but no deformation of the components was noted. While the effectiveness of the rail under service conditions has not been proved, one must recognize the possibility that the apparently slight impact described above might have been more severe had the vehicle struck the concrete curb and parapet in the original rail.

Figure 17. Scraping of rail surface over distance of several feet caused by light "brushing" impact.

## SUMMARY OF FINDINGS

The first installation of an energy-absorbing bridge rail in Virginia, retrofitted to an existing interstate highway bridge, was completed in 175 man-hours by a two-man crew. It is probable that the construction time was lengthened by the effects of below freezing temperatures much of the time and limited working space. Cost of the rail was \$18,900 plus \$1,100 for replacement components for a total of \$20,000.

Engineering costs were about \$2,500 to cover 233 man-hours required to adapt the designed and tested rail configuration to the existing bridge. Details had to be developed to allow for expansion of the rail and the bridge and for treatments of the rail at both the entry and exit ends of the bridge. No modifications to the existing concrete curb and parapet and aluminum rail were required beyond attachment of the energy-absorbing rail. It would be expected that the time required for engineering would be less for a similar installation in the future.

The rail has been subjected to only a light brushing impact at this writing. No deformation of the components was apparent and no maintenance has been required.

## IMPLEMENTATION

Based on the data gathered during the design and construction of an energy-absorbing rail on Route 395, retrofiting the system to an existing structure appears a practical and reasonably priced means of upgrading rail performance.

While the effectiveness of the rail under service conditions was not tested as no significant impacts occurred, its performance is evidenced by a successful crash-testing program.

## ACKNOWLEDGEMENTS

The research evaluation of the energy-absorbing bridge rail described here was funded as part of Demonstration Project 19 of the Federal Highway Administration, Region 15, Demonstration Projects Division. Project managers during the course of the study were Michael J. Fraher and Joseph B. Policelli. Mr. Fraher assisted in the development of several of the design details early in the study.

The engineering of the rail was performed in the Bridge Office of the Virginia Department of Highways and Transportation's Culpeper District. The assistance of District Bridge Engineer F. L. Prewoznik and Bridge Design Engineer A. R. Harding at Culpeper is greatly appreciated.

The cooperation of Ron B. Ferdig, Ray D. Kellogg, and Joe Bamberger of Transportation Safety Systems, Inc., and Assistant Resident Engineer P. D. Gribok, Project Engineer C. L. Williams, and Project Inspector Wayne F. Baker of the Department of Highways and Transportation's Fairfax Residency was most helpful.

Special thanks are due to Mr. Wayne Baker and Materials Technician James W. French of the Virginia Highway and Transportation Research Council, who kept the records necessary for the successful evaluation of the construction procedure.

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