chamfer decreased the strength of the system by decreasing the strength of the rail.

ACKNOWLEDGMENT

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Design and Development of Self-Restoring Traffic Barriers

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ABSTRACT

The development of the self-restoring barrier (SERB) guardrail system for the FHWA demonstrated that a high-performance flexible barrier that was damage resistant was technically and economically feasible. To extend the SERB concept into other applications, FHWA contracted with Southwest Research Institute to design and develop SERB retrofit bridge railing, SERB deck-mounted bridge railing, and SERB median barrier systems. In this paper the SERB retrofit and median barrier designs that have been fully evaluated at this time are described. The SERB bridge rail retrofit, consisting of an articulated tubular Thrie-beam mounted on a narrow safety walk and parapet installation, was subjected to a full range of vehicle impacts from a 40,000-lb (18 000-kg) intercity bus to an 1,800-lb (800-kg) Honda Civic. Results of these 60 mph (95 km/h) tests indicate satisfactory performance. The SERB median barrier concept constructed of single Thrie-beams with internal truss shear webs was successfully evaluated in a test series that included a 40,000-lb intercity bus and an 1,800-lb Honda. Development of the SERB deck-mounted bridge railing is currently in progress.

The popularity of the concrete safety shape barrier is attributed to generally satisfactory performance with a wide range of vehicles and the resulting low damage repair due to these impacts. Design and development of the self-restoring barrier (SERB) guardrail for the FHWA was reported to TRB at the 1981 Annual Meeting (1). The SERB guardrail performance range exceeds that of the concrete safety shape and is damage resistant for the majority of expected impacts. As an extension of the SERB concept, FHWA contracted with Southwest Research Institute (SwRI) to design and develop SERB concepts for bridge railing retrofit, deck-mounted bridge railing, and median barriers.

In this paper the design and development of the SERB bridge rail retrofit and median barrier are described. The SERB deck-mounted bridge railing is currently in the development stage.

OBJECTIVES AND SCOPE

The objectives of this work were to design and develop self-restoring systems to upgrade existing bridge railings, and to design and develop a new self-restoring median barrier system.

Work on the barriers discussed in this paper included designs that used computer simulations, and development that used component and full-scale crash tests; the emphasis of this paper is on the full-scale crash tests. Test vehicles used in the evaluations included

1. A 40,000-lb (18 000-kg) intercity bus,
2. A 20,000-lb (9000-kg) school bus,
3. A 4,500-lb (2000-kg) car, and
4. A 1,800-lb (800-kg) car.

Impact speed was 60 mph (95 km/h) and impact angles were 15 degrees, except for the 25-degree angle used in the 4,500-lb car tests.

With the exception of test SMB-3, each of the test vehicles contained two fully instrumented part 572 anthropometric dummies (50th percentile males).

The 1,800-lb car used in test SMB-3 had only a driver dummy. The dummies were positioned in the driver (restrained) and right front seat (unrestrained) occupant positions for the car tests. In the bus tests the dummies were positioned to represent a restrained driver (lap belt) and an unrestrained passenger. The remaining payload of the bus consisted of loose sand bags placed in the seats and in the cargo compartment (intercity bus only).

FINDINGS

SERB Bridge Rail Retrofit

The retrofit system (as described in Figure 1) was installed on an existing narrow walk and parapet bridge rail. This existing installation is identical to that used for other bridge rail retrofit evaluations (2,3). Six crash tests were conducted on the installation by using a full range of test vehicles.

Test SRF-1

A 1954 GMC model PD4501 Scenicruser bus weighing 40,000 lb (18 000 kg) impacted the railing at 53.3 mph (85.8 km/h) and a 15.5-degree angle. As shown in Figure 2, the bus impacted the tubular Thrie-beam, immediately displacing the rail upward and rearward against the adjacent posts; redirection was accomplished as the bus rolled slightly toward the barrier. As the rear end of the bus impacted the barrier, the roll continued until reaching a maximum value of 15 degrees. The bus then returned to an upright position and left the barrier at a 4-degree

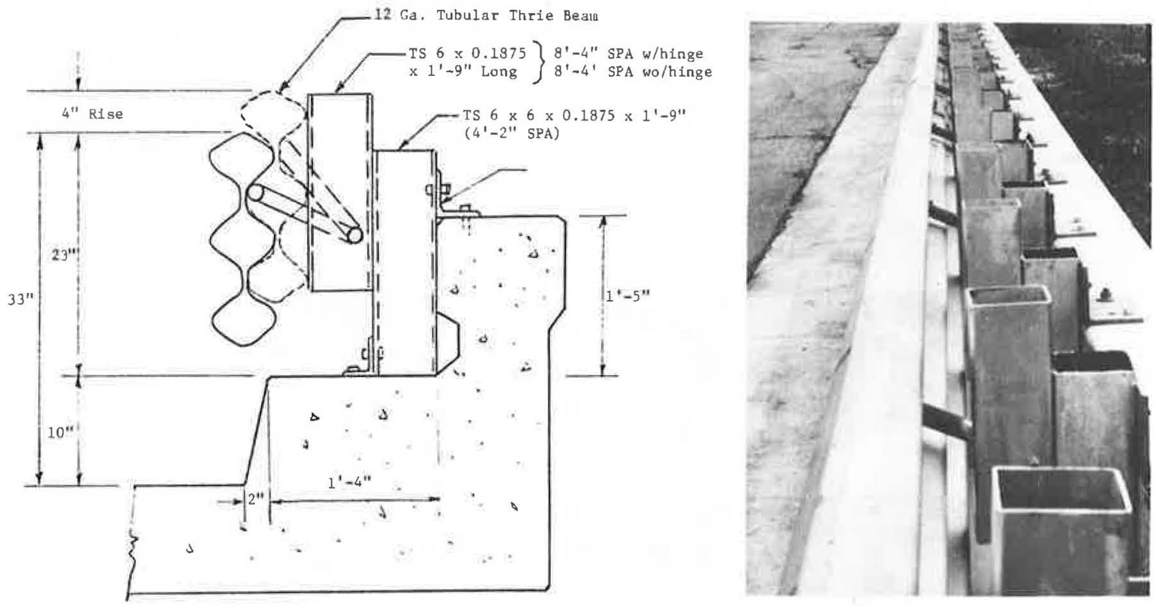


FIGURE 1 SERB bridge rail retrofit.

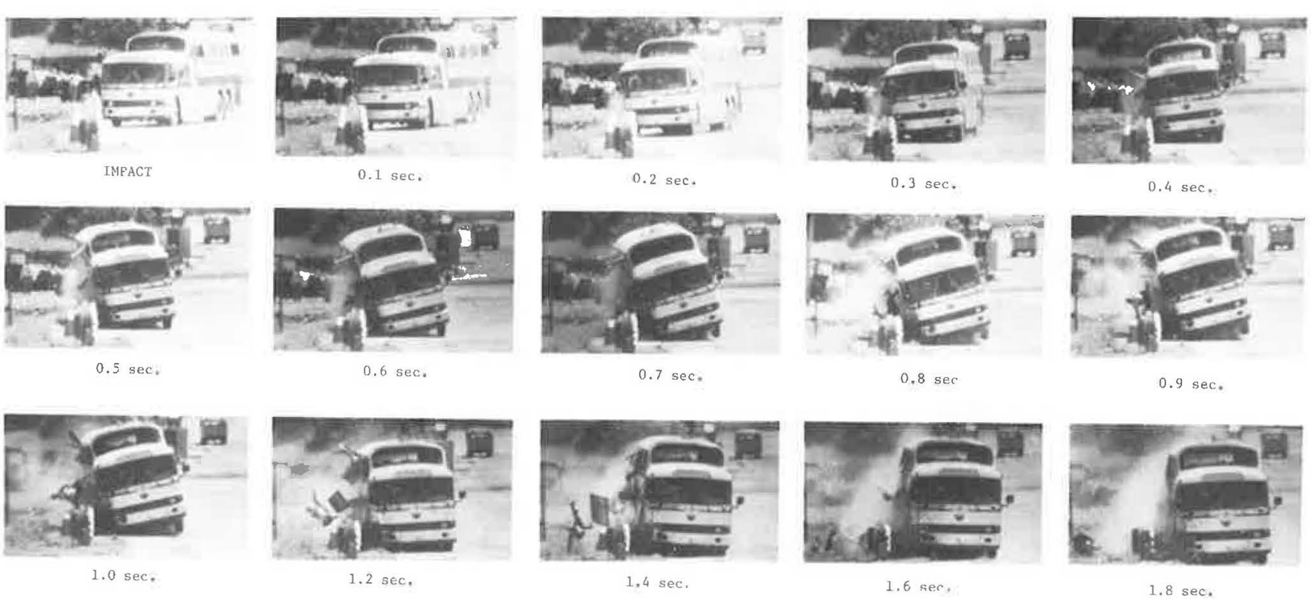


FIGURE 2 Test SRF-1 impact sequence.

angle before being brought to a stop 234 ft (71 m) past the end of the parapet.

As shown in Figure 3, barrier damage was moderate. Some cracking of the concrete parapet was noted. Damage to the vehicle (Figure 3) was most extensive in the areas of the passenger service door and right rear corner. All three outermost wheel rims on the right side were damaged, and one cargo door was torn away.

Test SRF-2

A 1972 Chevrolet/Superior 66-passenger school bus weighing 20,370 lb (9240 kg) impacted the barrier at 58.2 mph (83.7 km/h) and a 14.1-degree angle. As shown in Figure 4, the bus deflected the tubular Thrie-beam upward and rearward until bottoming against the adjacent posts. The bus was redirected with a 12-degree maximum roll angle occurring after the rear end slap. The bus proceeded near parallel to the rail and recontacted the barrier; barrier contact remained until the end of the test installation.

The most severe barrier damage (Figure 5) was sustained by the concrete parapet, which had been cracked in the previous test. Damage to the retrofit system was moderate as shown. Most of the vehicle damage occurred at the right front bumper

FIGURE 3 Photographs after test SRF-1.

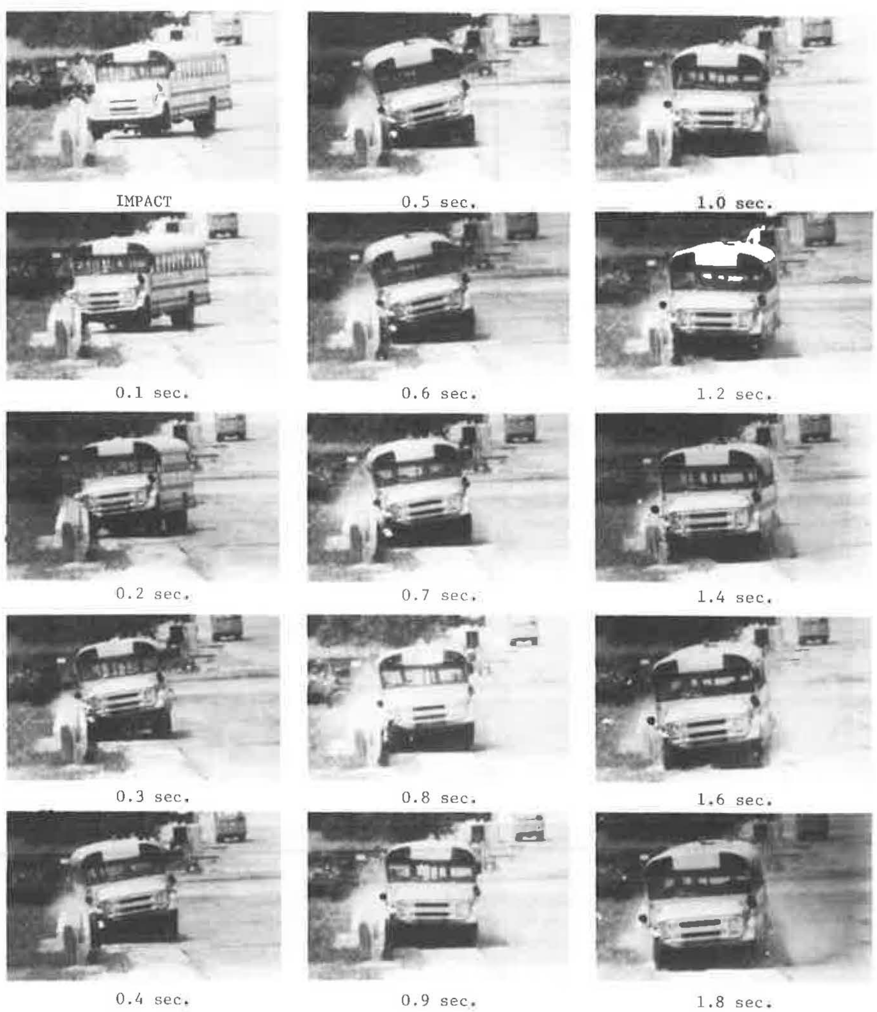


FIGURE 4 Test SRF-2 impact sequence.

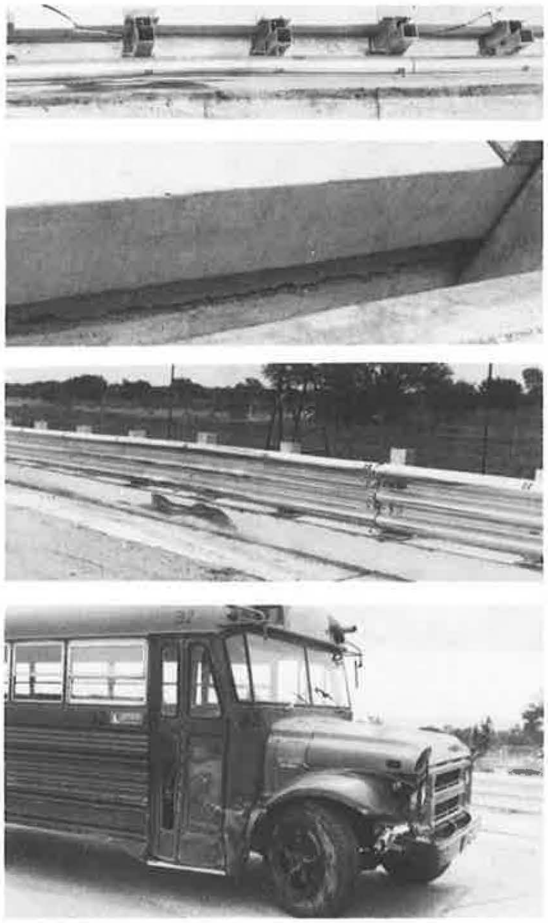


FIGURE 5 Photographs after test SRF-2.

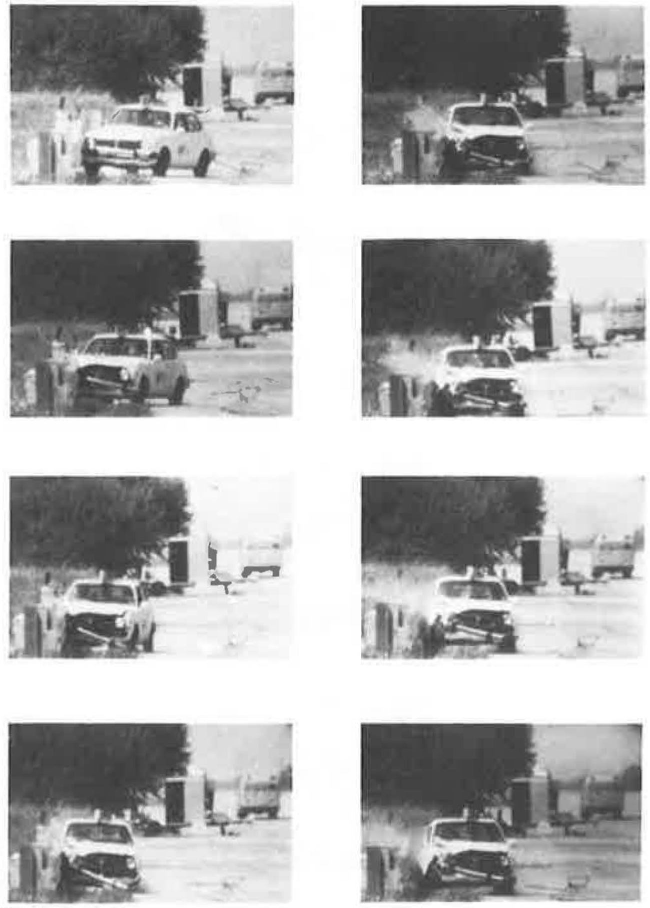


FIGURE 6 Test SRF-3 sequential photographs.

corner and the right rear corner (Figure 5). Although significant suspension damage occurred, the bus was driven back to the impact area under power.

Test SRF-3

The 1978 Honda Civic weighing 2,165 lb (982 kg) impacted the rail at 59.8 mph (96.0 km/h) at an angle of 20 degrees. As shown in Figure 6, the vehicle was smoothly redirected after 10.3 ft (3.1 m) of contact with the barrier.

There was no significant barrier damage or permanent deformation, although the tubular Thrie-beam was displaced rearward and upward during the impact. Some scraping of the beam and tire scuff marks on the curb were evident, as shown in Figure 7. Vehicle damage as shown in Figure 7 consisted of impact-side sheet metal and left bumper support failure. All tires remained inflated. There was some impact-side (right) door deformation due to dummy contact, and the right window was sheltered by the dummy.

Test SRF-4

A 1979 Ford LTD sedan weighing 4,466 lb (2066 kg) impacted the barrier at 59.3 mph (95.5 km/h) at an angle of 25.6 degrees. As shown in Figure 8, the vehicle was smoothly redirected, although considerable vehicle damage resulted. The lower beam corrugation was pushed under some of the post blockouts, causing the system to bind and not fully articulate as designed.

Other than short local deformation in the tubular

FIGURE 7 Photographs after test SRF-3.

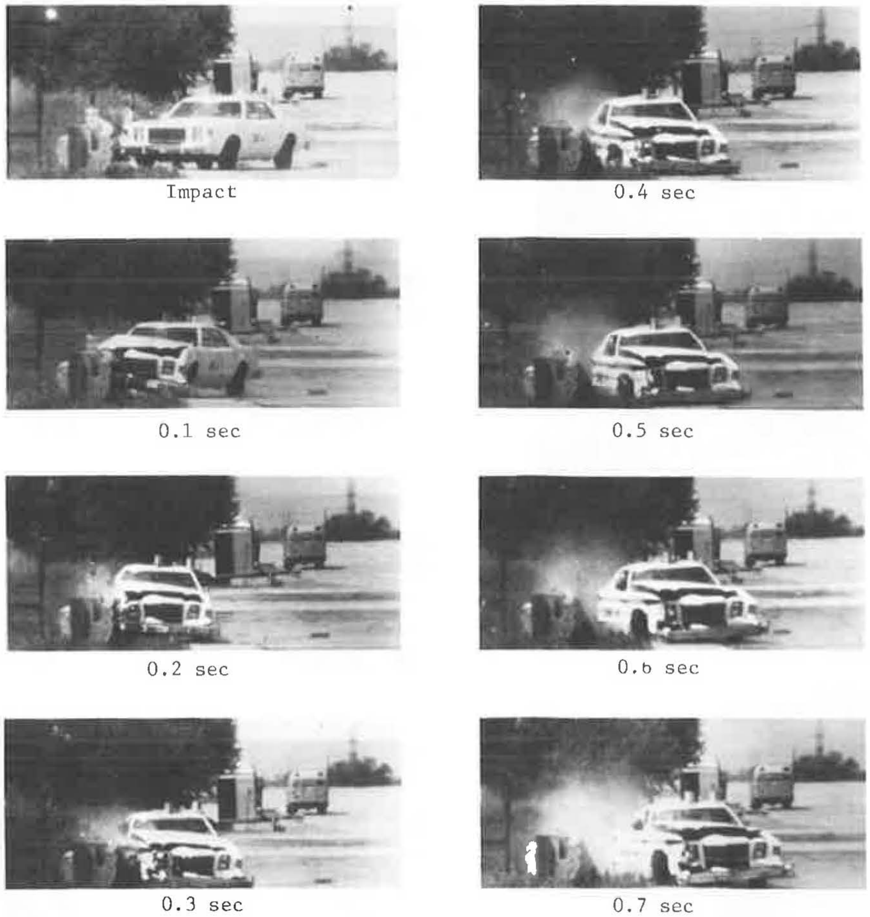


FIGURE 8 Test SRF-4 impact sequence.

beam leading edge on the downstream side of one splice, there was no significant barrier damage (Figure 9). The right front door sprang open during impact, allowing the passenger dummy to fall from the car after the vehicle came to rest. The right front bumper support failed, although the bumper remained on the vehicle. Considerable side sheet-metal and right front wheel suspension damage was evident (Figure 9).

Test SRF-5

The purpose of this test was to evaluate the approach rail and transition to the SERB parapet retrofit installation. The test installation was constructed by using 8x8 wood posts at graduated spacing, as shown in Figure 10. The system is designed to connect to a SERB guardrail approach railing that has a self-restoring stroke of 11 in. (0.3 m). Thus the design effects a transition from a 3-in. (0.1-m) self-restoring stroke on the bridge to the 11-in. stroke of the SERB guardrail.

The 1979 Ford LTD sedan weighing 4,450 lb (2018 kg) impacted the transition just upstream of post 5 (post 11 is the first bridge post). Impact conditions were 59.7 mph (96.1 km/h) and an angle of 25.2 degrees. As shown in Figure 11, there was no evidence of snagging, as the vehicle was smoothly redirected.

Maximum barrier deformations were 6.9 in. (0.2 m) (dynamic) and 4.0 in. (0.1 m) (permanent). As shown in Figure 12, there was no significant damage that would require normal maintenance attention. Signifi-

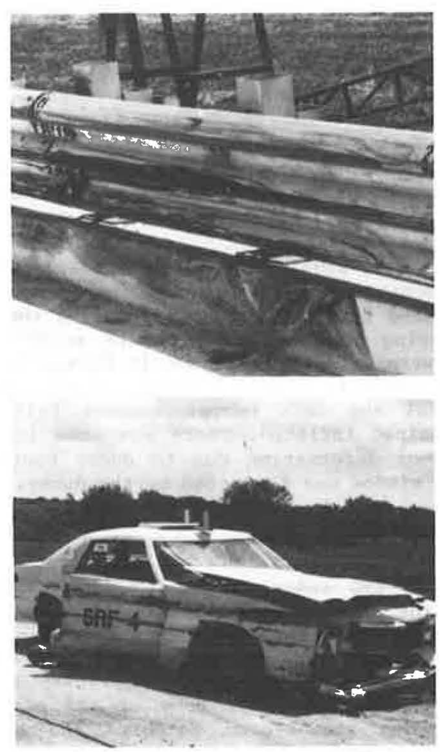


FIGURE 9 Photographs after test SRF-4.

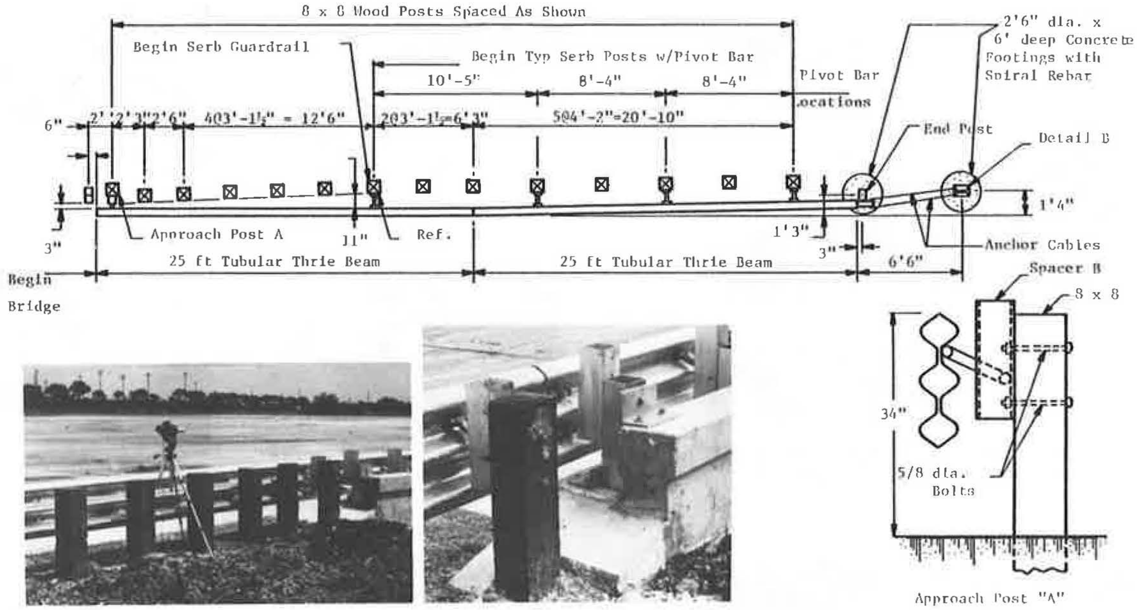


FIGURE 10 Transition drawing and photographs.

FIGURE 11 Test SRF-5 impact sequence.

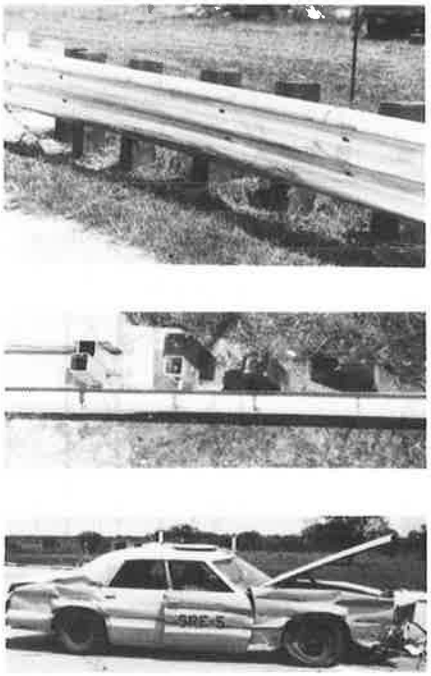
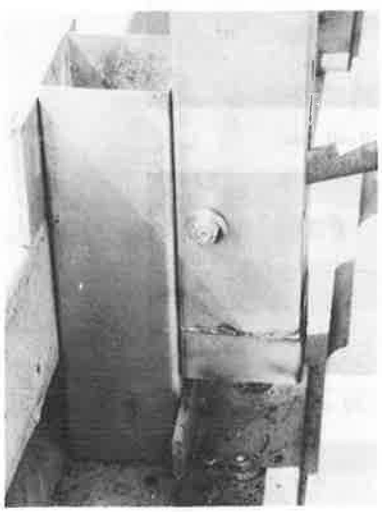


FIGURE 12 Photographs after test SRF-5.



(a) Extended spacer

(b) Overhead view

FIGURE 13 Photographs before test SRF-6.

Impact

0.4 sec

0.1 sec

0.5 sec

0.2 sec

0.6 sec

0.3 sec

0.7 sec

FIGURE 14 Test SRF-6 impact sequence.

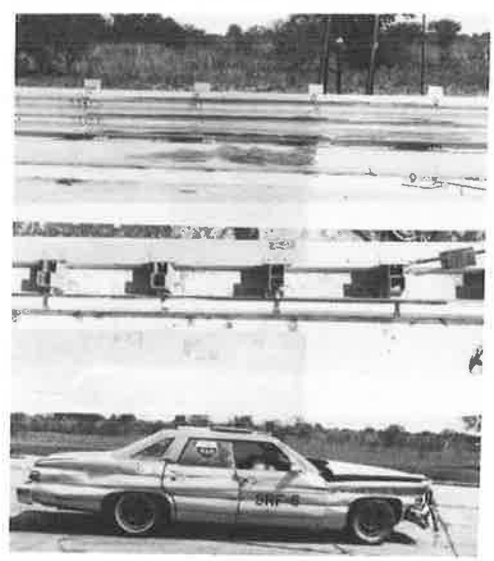


FIGURE 15 Photographs after test SRF-6.

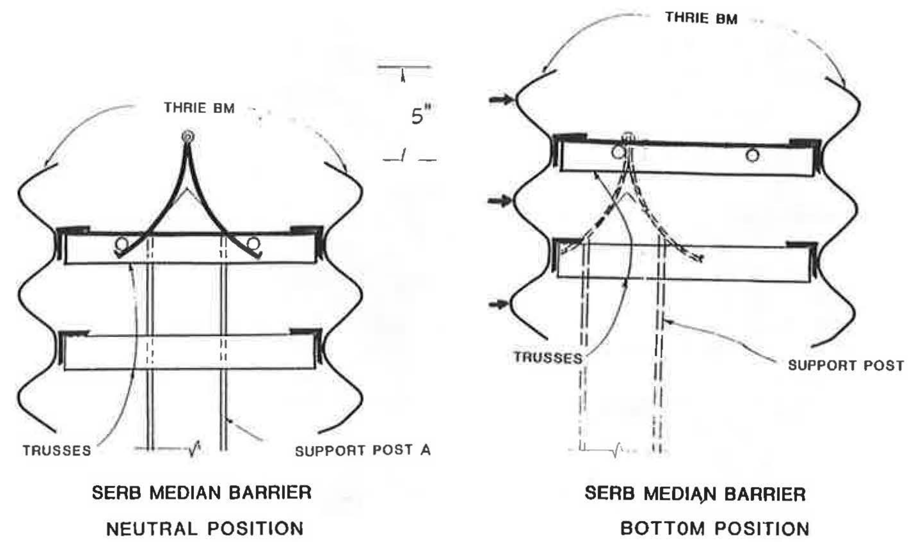


FIGURE 16 SERB median barrier description.

cant bumper damage resulted as both supports failed (Figure 12). The right front door was sprung partly open, although both dummies remained in the vehicle throughout the test.

Test SRF-6

The purpose of this test was to evaluate a design change made to improve the articulation of the tubular Thrie-beam element. The spacers to which the beam is attached by the pivot bars were extended 3 in. (75 mm) below, as shown in Figure 13, to prevent the beam from being pushed under the spacer.

The 4,800-lb (2177-kg) 1976 Buick Le Sabre sedan impacted the modified retrofit at 59.8 mph (96.2 km/h) and an angle of 24 degrees. As shown in Figure 14, the vehicle was smoothly redirected, with considerably less vehicle damage than observed in test SFR-4. Part of this is attributed to vehicle construction differences in the two tests, but it is noteworthy that complete barrier articulation was achieved with the extended spacers.

As shown in Figure 15, there was no significant barrier damage; this is an obvious improvement over the results of test SRF-4 with the shorter spacer. Significant vehicle side and right front damage resulted (Figure 15). All tires remained inflated, and suspension damage was moderate.

SERB Median Barrier

The design criteria for the SERB median barrier were determined by consideration of potential uses of a high-performance median barrier. Many of the potential sites for such a barrier would either have or soon have (because of widening) a narrow median. Accordingly, it was determined that the median barrier would be designed to deflect a maximum of 2 ft (0.6 m) during a 60 mph (95 km/h) impact at 15 degrees with a 40,000-lb (18 000-kg) intercity bus. A large series of parametric cases was conducted by using the BARRIER VII (4) computer code. Based on preliminary cost analyses, the configuration described in Figures 16 and 17 was selected for detailed design and crash-test evaluation. Basically, the SERB median barrier is constructed of two Thrie-beam elements bolted to two truss web members and hung on specially designed posts spaced at 12-ft 6-in. (3.8-m) centers. Intermediate posts also spaced at 12 ft 6 in. make an effective post spacing of 6 ft 3 in. (1.9 m). The design permits a 3.5-in. (8.9-cm) lateral translation and a 6-in. (15-cm) vertical translation before bottoming.

Test SMB-1

The purpose of this test was to evaluate the SERB median barrier system for the design impact conditions of 60 mph (95 km/h), 15-degree angle with a 40,000-lb (18 000-kg) intercity bus. The 1954 Scenicruiser bus impacted the barrier at 56.7 mph (91.1

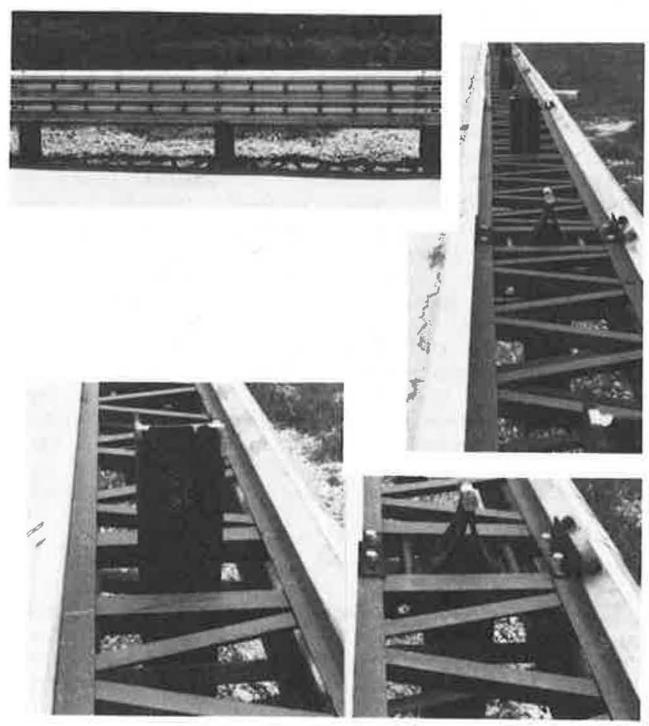


FIGURE 17 SERB median barrier photographs.

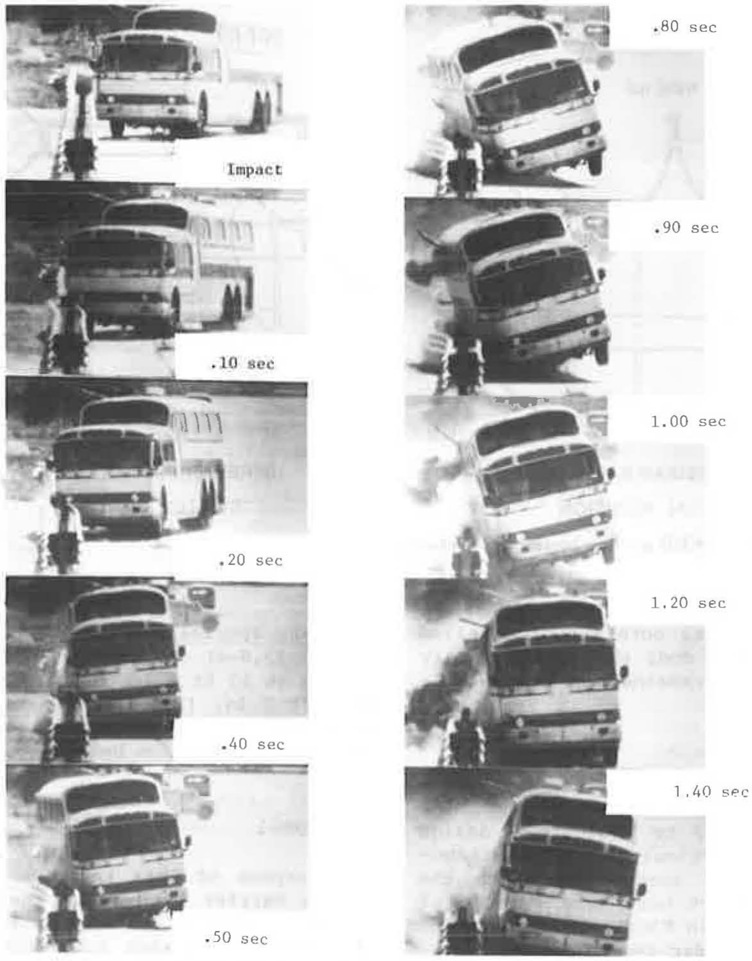


FIGURE 18 Sequential photographs, test SMB-1.

km/h) at a 14.4-degree angle. As shown in Figure 18, the vehicle was smoothly redirected, with a maximum roll angle (toward the barrier) of 16.5 degrees. The maximum dynamic deflection of 2.4 ft (0.7 m) was extremely close to the desired 2-ft (0.6-m) deflection of the design criteria.

Barrier damage was moderate, with damage to three Thrie-beam sections. Although not damaged, posts 14 through 27 were displaced rearward. Damage to the truss system consisted of several bent rollers (at post A) in the impact area. Photographs of the barrier damage are shown in Figure 19. Vehicle damage due to barrier impact was slight. There was sheet-metal damage on the right front corner, and along the right side the sheet metal was deformed. The battery compartment door was detached. All tires remained inflated during and after impact. There was no apparent damage to the running gear (see Figure 17) before a secondary collision with another barrier considerably downstream from the test barrier. This secondary collision caused rollover of the bus.

Test SMB-2

A 1978 Dodge four-door sedan weighing 4,546 lb (2062 kg) impacted the barrier at 58.8 mph (94.6 km/h) and a 25.6-degree angle. As shown in Figure 20, the vehicle was smoothly redirected after a maximum dynamic deflection of 14.2 in. (0.4 m).

Barrier damage consisted of two Thrie-beam sections and seven permanently displaced, but undam-

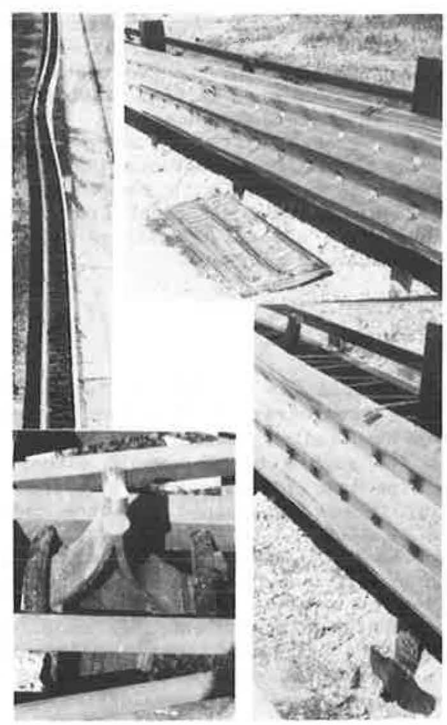


FIGURE 19 Photographs after test SMB-1.

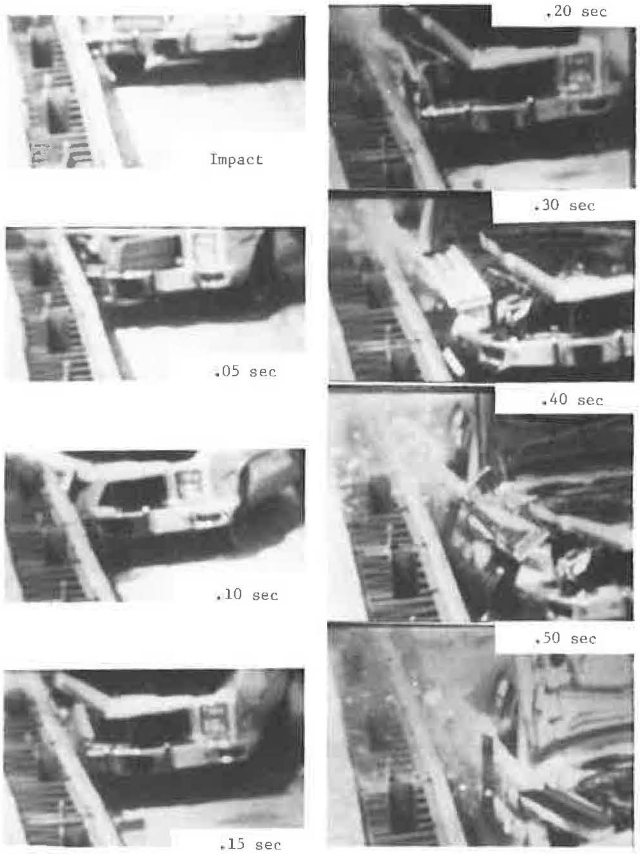


FIGURE 20 Sequential photographs, test SMB-2.

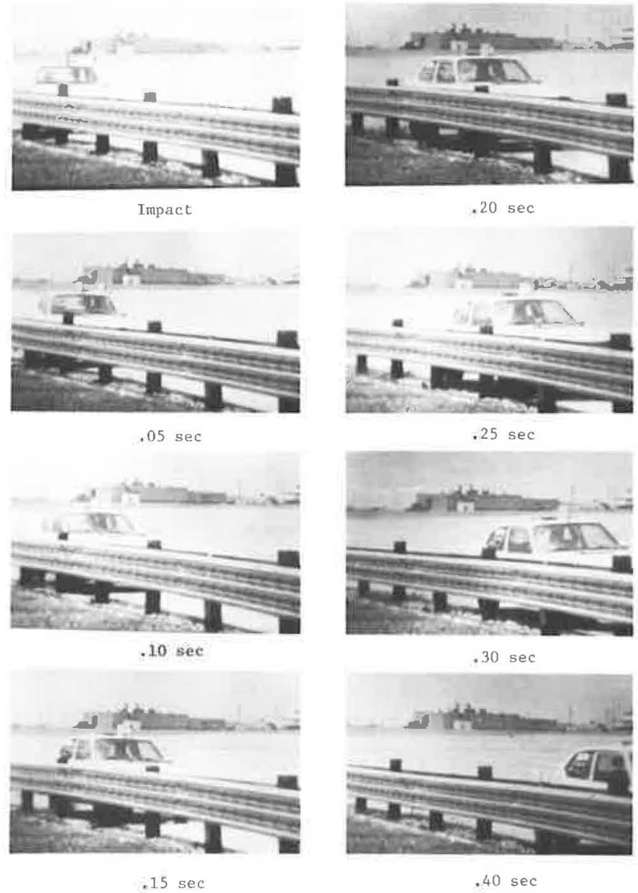


FIGURE 22 Sequential photographs of test SMB-3.

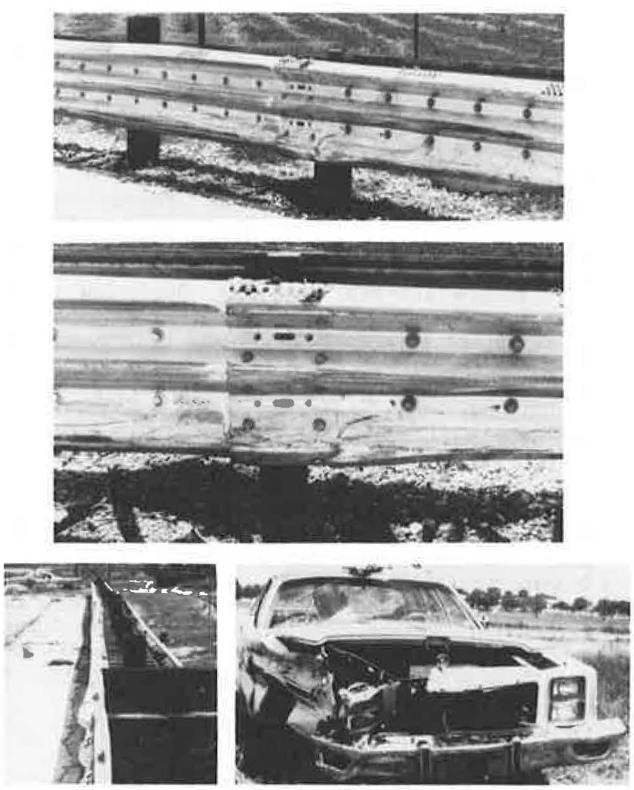


FIGURE 21 Photographs after test SMB-2.

FIGURE 23 Photographs after test SMB-3.

TABLE 1 Summary of Crash Test Results

Test No.	Barrier	Vehicle Weight (lb)	Impact Speed (mph)	Impact Angle (deg)	NCHRP 230 Evaluation Criteria (5)				Remarks
1. Structural Adequacy Tests					Smooth redirection - no rollover, etc.				
SRF-1	SERB Retrofit	40,000	53.9	15.5	Passed				Very smooth redirection with small roll; minimal damage to both vehicle and barrier; some cracking of parapet
SRF-2	SERB Retrofit	20,370	58.2	14.1	Passed				Vehicle remained upright; minimal damage to both vehicle and barrier; parapet cracking
SRF-4	SERB Retrofit	4,466	59.3	25.6	Passed				Some binding of rail due to lower beam corrugation interference with block
SRF-5	SERB Retfofit Transition	4,450	59.7	25.2	Passed				Transition test; smooth redirection
SRF-6	SERB Retrofit Modified	4,800	59.8	24.0	Passed				Retest of SRF-4; complete rail articulation achieved; insignificant barrier damage
SMB-1	SERB Median Barrier	40,000	56.7	14.4	Passed				Actual deflection near design goal; minimal damage to barrier and vehicle
SMB-2	SERB Median Barrier	4,546	58.8	25.6	Passed				Smooth redirection with little barrier damage
					ΔV,* fps		a,* g's		
2. Occupant Risk Tests					Long.	Lateral	Long.	Lateral	
Recommended Values					30	20	15	15	
SRF-3	SERB Retrofit	2,165	59.8	20.0	n.a./21.8 (/16.5)	n.a./24.2 (/18.4)	n.a./-4.0 (-2.6)	n.a./9.5 (10.1)	No barrier damage; smooth redirection - passes criteria based on normalized values
SMB-3	SERB Median Barrier	2,000	59.5	16.5	0/6.1 (0.0/5.7)	18.9/18.6 (15.1/17.4)	0/0	5.8/8.1	No barrier damage; smooth redirection

*film/accelerometer (normalized)

aged, posts. The barrier, as shown in Figure 21, was serviceable after the impact, and no immediate damage repair would be required. Vehicle damage was confined to the right front corner, although the hood came open during the impact. The right front tire was blown out (Figure 21).

Test SMB-3

The 2,000-lb (907-kg) Honda Civic impacted the barrier at 59.5 mph (95.7 km/h) and a 16.5-degree angle, as shown in Figure 22. The rail deflected a maximum 8.9 in. (22.6 cm) rearward and 4.2 in. upward (10.7 cm) before vehicle redirection. No snagging of the rail or posts occurred during the impact, and all tires remained inflated. According to both film and accelerometer data, performance of the test indicated compliance with the requirements of NCHRP Report 230 (5).

The barrier was not structurally damaged; the system was fully restored, as shown in Figure 23. The sheet metal on the front corner and side was damaged (Figure 23). The bumper of the vehicle was subsequently damaged due to contact with another barrier.

CONCLUSIONS

Based on the tests summarized in Table 1, the following conclusions on general performance are made.

1. Performance of the SERB bridge rail retrofit and median barrier systems was demonstrated in the ultimate strength tests by using 40,000-lb (18 000-kg) intercity buses. Both systems contained and redirected the bus while keeping the bus upright. The maximum deflection during the SERB median barrier test was near the design goal of the project.

2. Although some permanent damage was observed in the structural adequacy test using the 4,500-lb (2000-kg) car, both systems were still serviceable after these impacts, and no real need for immediate damage repair would be necessary. Minimal damage repair would be required.

3. Both systems were essentially undamaged in the redirection test with the 1,800-lb (800-kg) class car. As the data in Table 1 indicate, both systems demonstrated conformance with the recommended values of NCHRP Report 230.

4. The transition design tested with the bridge rail retrofit performed satisfactorily.

5. Based on the results of these tests, both systems are recommended for immediate implementation on a trial basis. The modified blockout for the retrofit design is recommended.

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