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Publication of this paper sponsored by Committee on Safety Appurtenances.

Heavy-Vehicle Tests of Tubular Thrie-Beam Retrofit Bridge Railing

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A retrofit modification has been developed for a current concrete parapet design that has a narrow walkway configuration to improve its safety performance with impacting vehicles. The retrofit was originally developed for and tested with subcompact and standard-sized automobiles; the successful results indicated that the design might also perform with heavier vehicles that weigh up to 40 000 lb (18 144 kg). An earlier paper covered the automobile tests performed with the original retrofit system. Reported here are findings from six vehicle crash tests performed with the retrofit system—four tests with the original design and two tests with a modified design necessitated when vehicle rollovers occurred during the test series. The modified retrofit system successfully redirected a 40 000-lb intercity bus that impacted at 56.3 mph (90.6 km/h) and a 14.5° angle. In addition, it redirected a minicompact automobile that impacted at 58.1 mph (93.5 km/h) and an 18.8° angle; the vehicle exhibited no tendency to wedge under the higher rail design. Tests were documented by using both vehicle accelerometers and high-speed photography.

In a 1976 Federal Highway Administration report (1), existing bridge-rail designs used along the nation's highways are reviewed in terms of current safety performance criteria. Since the majority of these designs were found to be deficient in performance and their replacement to be cost-prohibitive, a methodology for upgrading their performance by retrofitting was developed. One existing design common to many states was a concrete parapet that has a curb and a narrow walkway. Although aluminum and concrete retrofits were developed for this particular bridge rail, the most promising retrofit system appeared to be a steel system that used a back-to-back triple-corrugated beam rail or tubular Thrie beam. Impact tests that used subcompact and standard-sized automobiles were successful, and it appeared that this system might be capable of performance with a heavier vehicle such as a school bus or an intercity bus. This paper presents the results of the continuation program that used heavy vehicles.

ORIGINAL DESIGN

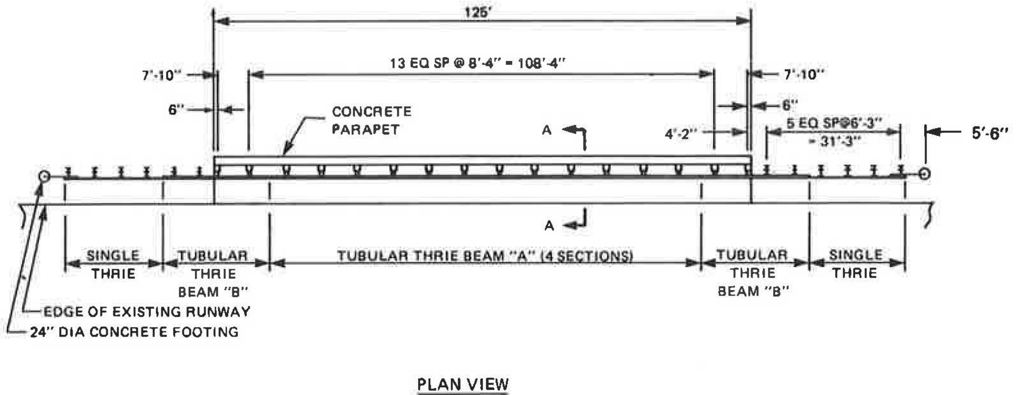
As shown in Figure 1, the original concrete parapet was 25 in (635 mm) high and was located behind a walkway 18 in (457 mm) wide that had a curb 10 in (254 mm) high. This configuration was retrofitted with a tubular Thrie beam 20 in (508 mm) wide attached to the concrete by means of TS6x6x0.1875 box-beam posts spaced at 8.33-ft (2.54-m) intervals and with intermediate collapsing-tube elements 6 in (152 mm) in diameter. The front of the tubular Thrie beam was located in line with the curb face. Rail height was 32 in (813 mm).

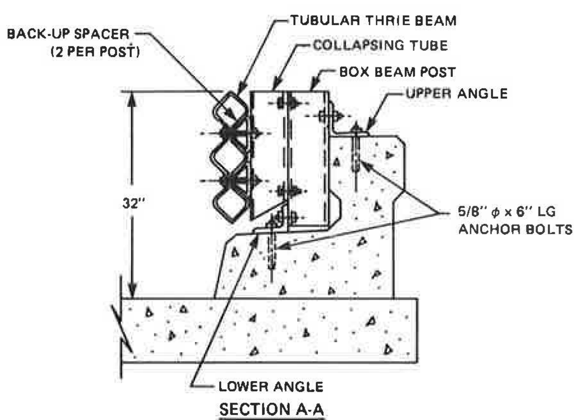
The original test installation design was 125 ft (38 m) long and each end was transitioned off the simulated bridge deck into a single Thrie beam 25 ft (7.6 m) long on soil-mounted W6x8.5 steel posts. Each end of the rail was anchored by using a standard 0.75-in (19-mm) cable attached to a concrete footing 24 in (610 mm) in diameter.

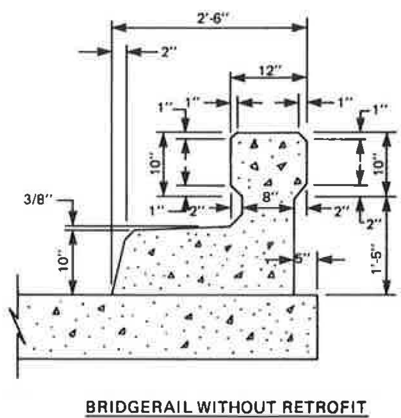
MODIFIED DESIGN

Modification to the original retrofit design was deemed desirable when the large vehicle rolled on its side after redirection in the third and fourth tests of the series. These rollovers were attributed to two factors--insufficient rail height and the yield of the collapsing tubes that allowed rail deflection and corresponding vehicle body roll while the nonyielding curb face kept the vehicle wheels along a fixed trajectory. As shown in Figure 2, significant changes to the barrier system were that the beam rail height was increased to 38 in (965 mm) and the 6-in (152-mm) diameter collapsing tube on each post was replaced by a 3-in (76-mm) diameter tube and a TS6x6x0.1875 box-beam spacer. This latter modification projected the beam rail 3 in in

Figure 1. Test installation—initial retrofit of concrete parapet that has narrow walkway.







Note: All bolts have 5/8-in diameter.
1 ft = 0.3 m; 1 in = 25 mm.

Figure 2. Modified retrofit design.

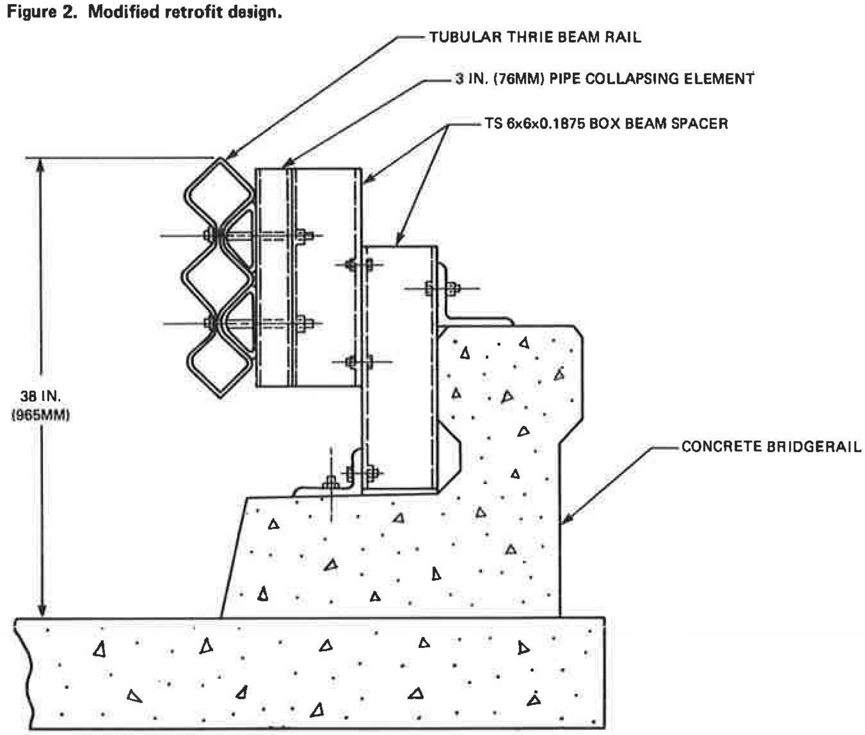


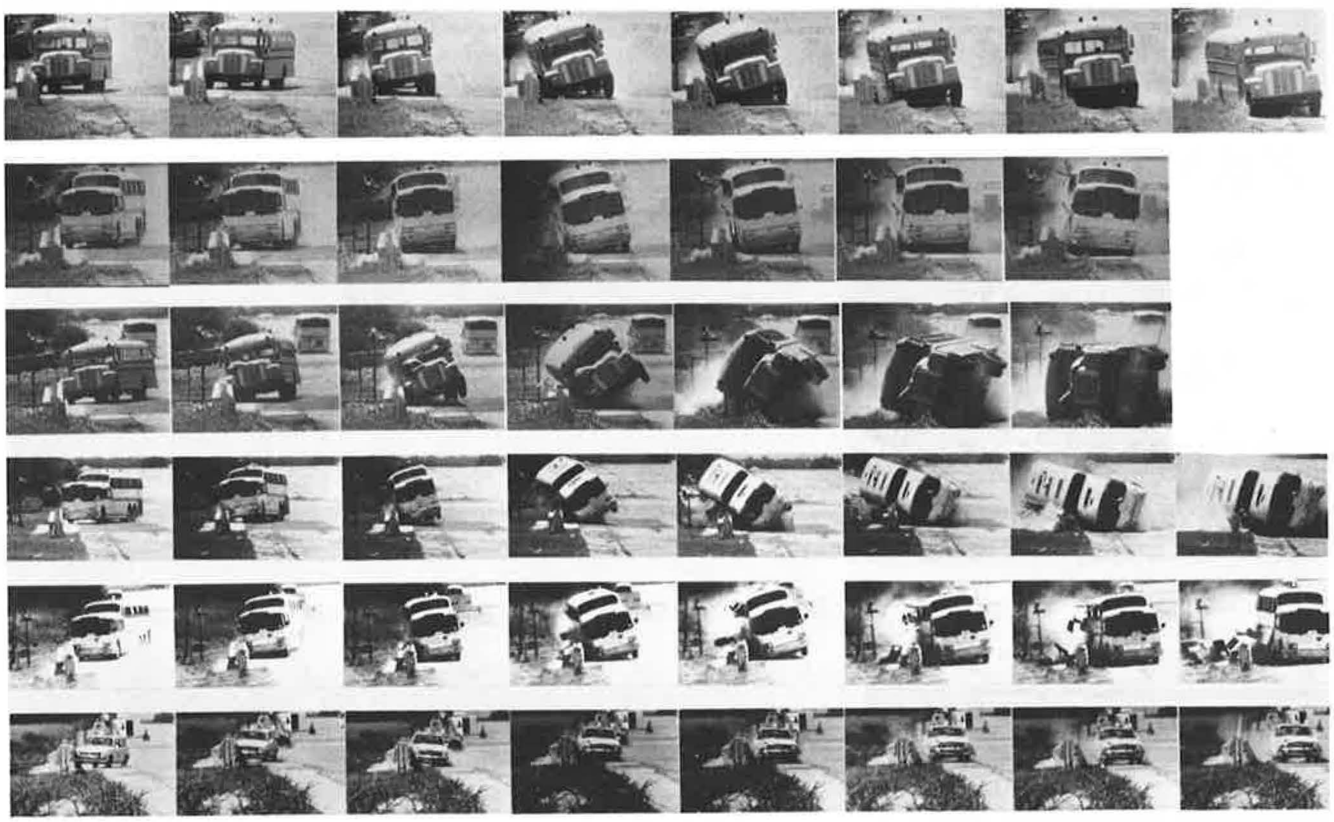
Table 1. Summary of test results.

Test	Barrier Design	Vehicle	Ballast Added (lb)	Vehicle Weight Including Ballast (lb)	Impact Speed (mph)	Impact Angle (°)	Vehicle Acceleration[a] (g) Lateral	Vehicle Acceleration[a] (g) Longitudinal	Maximum Roll Angle (°)	Maximum Permanent Barrier Deflection (in)
RF-24	Original	1963 International chassis with Wayne school bus body	7 200	23 000	58.3	6.8	1.4/2.7	-4.6/-0.3	17	5.4
RF-25	Original	1954 GMC Scenicruiser	10 200	40 000	57.2	7.6	1.9/1.7	-0.7/-0.7	10	5.5
RF-26	Original	Same as in RF-24	7 200	23 000	57.1	14.7	2.9/3.9	-6.6/-2.1	90	6.8
RF-27	Original	Same as in RF-25	10 200	40 000	59.7	17.6	0.8/ND[b]	-1.5/ND[b]	90	8.8
RF-28	Modified	1953 GMC Scenicruiser	10 200	40 000	56.3	14.5	1.8/4.1	-4.6/-4.6	14	10.0
RF-29	Modified	1976 Honda Civic	0	1 840	58.1	18.8	6.5/9.6	-4.0/-1.8	0	0

Note: 1 lb = 0.45 kg; 1 mph = 1.6 km/h; 1 in = 25 mm.

[a]Measured by movies/electronics (50-ms average). [b]ND = no data.

Figure 3. Impact sequence for tests RF-24 through RF-29 (top to bottom).



front of the curb face. In addition, intermediate posts (with spacers but without collapsing tubes) were placed midway between the existing posts. These intermediate posts were for severe impacts only, in which front-rail deflections were 3 in or greater, and then presented an effective post spacing of 4.17 ft (1.27 m).

TEST PROGRAM

A series of six vehicle tests was performed; the first four used the original barrier design, whereas the last two used the modified design. A summary of test results is contained in Table 1 and a brief description of each test follows.

Test RF-24

In the initial test of the program, a 23 000-lb (10 433-kg) school bus that impacted the installation at 58.3 mph (93.8 km/h) and a 6.8° angle was readily redirected although it reached a 17° roll angle as shown in Figure 3 (first row). Maximum barrier deflection was 5.37 in (136 mm); seven tube elements required replacement after the test. As shown in Figure 4, the bus received only minor damage and was reusable for test RF-26 after the front fender and bumper had been repaired.

Test RF-25

In this test a 40 000-lb (18 144-kg) intercity bus impacted the barrier at 57.2 mph (92.0 km/h) and a 7.6° angle. As shown in Figure 3 (second row), the barrier was deflected 5.50 in (140 mm), and the bus rolled to a maximum of 10° (toward the barrier) as it was being redirected. Six tube elements required replacement prior to further testing and, as shown in Figure 5, damage to the bus was minimal (mostly sheet-metal damage and a bent wheel); it was reus-

Figure 4. Vehicle and barrier damage, test RF-24.

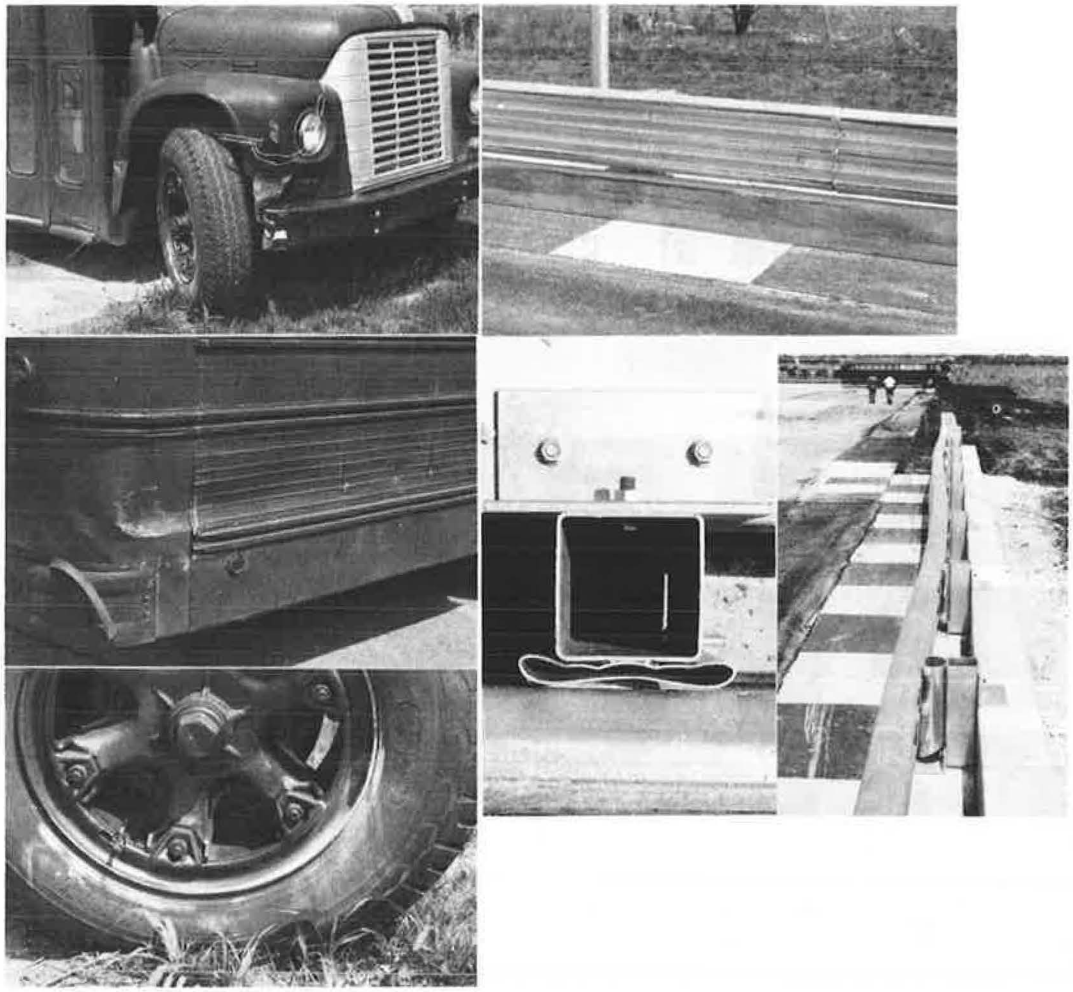


Figure 5. Vehicle and barrier damage, test RF-25.

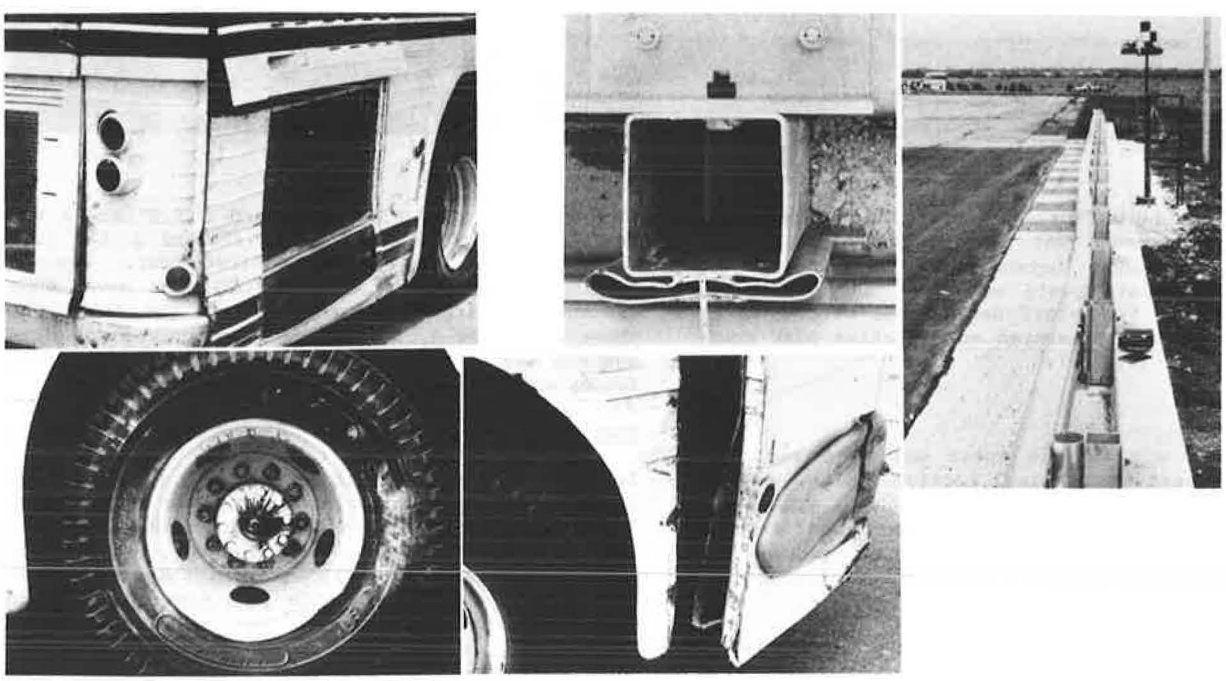


Figure 6. Vehicle and barrier damage, test RF-26.

Figure 7. Vehicle damage, test RF-27.

Figure 8. Installation damage, test RF-27.

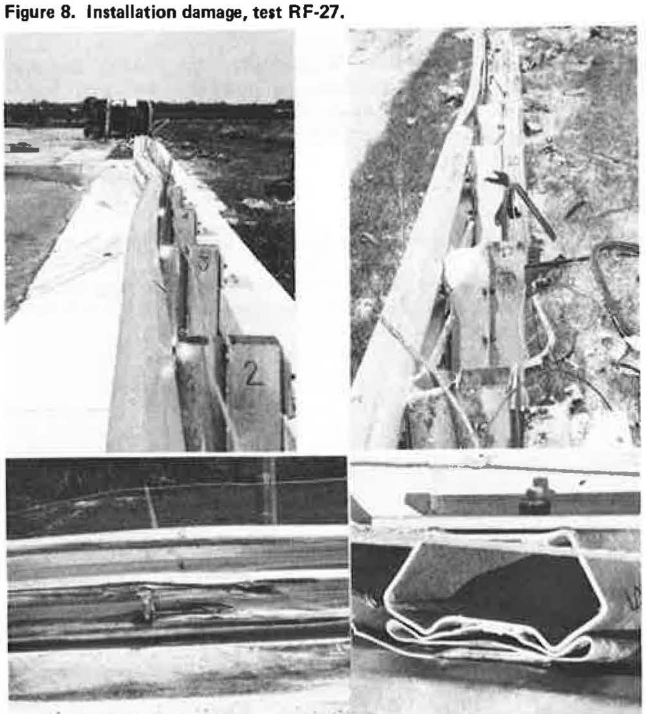


Figure 9. Vehicle damage, test RF-28.

Figure 10. Barrier damage, test RF-28.

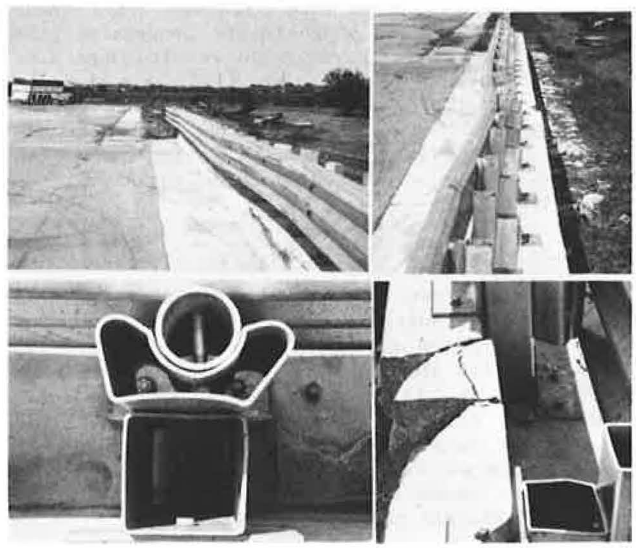
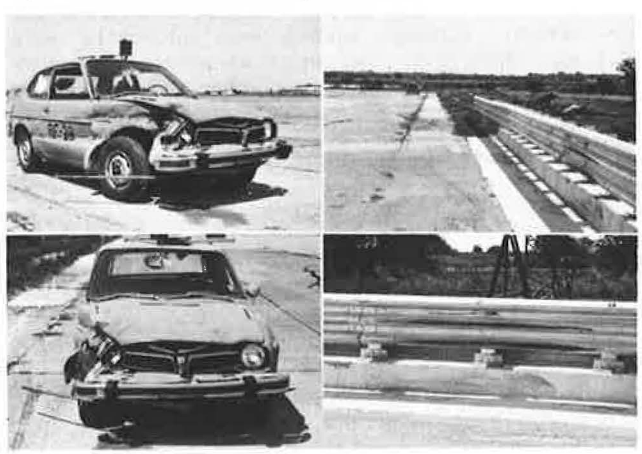


Figure 11. Vehicle and barrier damage, test RF-29.



able for test RF-27 after the damaged wheel had been replaced.

Test RF-26

This was a test at a steeper angle (15°) then that of the original design by using the vehicle from RF-24. Impact conditions were 57.1 mph (91.9 km/h) and a 14.7° angle. As shown in Figure 3 (third row) the school bus initially rolled toward the barrier as the front end was being redirected and continued that roll as the rear section impacted. The result was that the bus rolled on top of the barrier and slid on it until the downstream end was reached. At that point the bus dropped to grade and continued sliding an additional 95 ft (29 m). Figure 6 shows the extensive body damage sustained by the bus in the rollover. It also shows the barrier damage, which included deformation to six collapsing-tube elements, two tubular Thrie-beam rail sections, and one post.

Test RF-27

The intercity bus used for RF-25 was reused for this test. Impact conditions were 59.7 mph (96.1 km/h) and a 17.6° angle. As shown in the sequential photographs of Figure 3 (fourth row), results were similar to those of test RF-26; i.e., the vehicle rolled on top of the barrier, slid along it to the end, dropped to grade, and continued sliding an additional 102 ft (33 m). Figures 7 and 8 show the extensive vehicle and barrier damage sustained during the test.

Test RF-28

This was the first test of the modified retrofit design. Test conditions were similar to those of RF-27 in which the rollover occurred. As shown in Figure 3 (fifth row) the bus impacted at 56.3 mph (90.6 km/h) and a 14.5° angle and was smoothly redirected after reaching a maximum roll angle of 14°. The bus was only moderately damaged, as shown in Figure 9, and was driven from the test site. Figure 10 shows the damage sustained by the retrofit system and by the concrete parapet.

Test RF-29

Since the rail height had been increased to 38 in (965 mm), this test was necessary to ensure that smaller automobiles would not become wedged under the front rail of the system. Impact conditions for the 1840-lb (835-kg) minicompact automobile were 58.1 mph (93.5 km/h) and an 18.8° angle. As shown in Figure 3 (bottom row), the vehicle was smoothly redirected and there was no apparent snagging. Figure 11 shows the sheet-metal damage of the vehicle (confined mostly to the right front fender) and the rail and curb scuffing sustained by the barrier. The vehicle suspension and drive train were undamaged, and the vehicle was driven from the test site.

CONCLUSIONS

From the six tests performed, it appears that the tubular Thrie-beam retrofit is quite capable of redirecting the school-bus and intercity-bus classes of test vehicles but that some modifications are required in the original design to prevent the vehicle from rolling on top of the barrier. The following observations were made concerning the retrofit barrier:

1. The original design 32 in (813 mm) high is capable of redirecting heavy vehicles and, at shallow angles, vehicle roll is slight. However, at sharper angles (approximately 15°) vehicle rollover occurs during redirection.
2. Retrofits that use the modified design 38 in (965 mm) high not only will redirect a heavy vehicle but will also greatly reduce its roll angle.
3. The modified design performs well with a minicompact automobile; i.e., redirection occurs and there is no tendency to underride or snag the barrier.
4. Higher bending stresses are placed on the concrete parapet by the modified design, as shown by the concrete failure during test RF-28.
5. The reduced post spacing (by use of interim posts) in the modified design was successful in achieving a stiffer barrier for heavy vehicles. This is shown by the smaller rail deflection of test RF-28 [6.88 in (175 mm)] compared with the 8.75-in (222-mm) deflection measured following test RF-27. It was observed after test RF-28 that three interim posts had been contacted by the tubular Thrie-beam rail and that they provided backup support.
6. Some tuning of the 3-in (76-mm) tube element in the modified design might offer better collapse and energy absorption properties (for automobiles) than the tube that has a 0.216-in (5.5-mm) thick wall that brinells into the box-beam spacer instead of deforming.

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Publication of this paper sponsored by Committee on Safety Appurtenances.