*Abridgment*

# Full-Scale Tests of a Modified Collapsing-Ring Bridge Rail System

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A need exists for a bridge rail system that not only can withstand impacts by large vehicles such as buses and trucks but also does not impart high accelerations to impacting smaller vehicles. Accordingly, a concept known as the collapsing-ring bridge rail system (CRBRS) has been developed that appears to be capable of fulfilling that need. A paper discussing 10 tests of the CRBRS is available from the Transportation Research Board (TRB) (1). This paper presents information on subsequent design modifications and testing. A significant improvement in barrier performance resulted from these modifications. For the first time in history, a 31 751-kg (70 000-lb) vehicle was used to evaluate a traffic barrier.

## BACKGROUND

The design premise of the CRBRS is to dissipate vehicle impact energy by collapsing, thick-walled steel rings. As shown in Figure 1, the CRBRS has been designed as a three-stage barrier.

1. Reduction in impact severity, compared with that for conventional nondeflecting bridge rail designs, was sought for vehicles in the weight range of 907 to 1814 kg (2000 to 4000 lb) when they impact the system at 96.6 km/h (60 mph) and 25 deg through the plastic deformation of the collapsing ring as shown in Figure 1a.
2. Redirection of vehicles involved in impacts as severe as an 11 340-kg (25 000-lb) school bus impacting the railing at 96.6 km/h (60 mph) and 20 deg together with having the outer railing system elements behave as a conventional nondeflecting bridge rail as shown in Figure 1b was desired.
3. Controlled dynamic displacement of the outer rail system was desired to permit containment in impacts as severe as those involving an 18 144-kg (40 000-lb) intercity bus or an 18 144-kg (40 000-lb) tractor-trailer truck at 96.6 km/h (60 mph) and 15 deg, as shown in Figure 1c.

As discussed in the earlier TRB paper (1), results of the initial 10-test program of the CRBRS revealed that leaning of the backup posts as they pivoted about the outside baseplate bolt attachment caused heavy vehicles to reach high roll angles during stage 3 (severe) impacts as shown in Figure 1. To eliminate this pivoting, the Federal Highway Administration incorporated the following design changes as shown in Figure 2:

1. Post baseplate thickness was increased from 1.27 cm (½ in) to 2.54 cm (1 in).
2. Two 2.86-cm-diameter (1⅛-in-diameter) outside holes in the W 30.48 × 182.88-cm (W 12 × 72-in) stub beams were slotted.

In addition, to strengthen the system the top rail size was increased from TS 15.2 × 15.2 × 0.47 cm (TS 6 × 6 × 0.187 in) to TS 20.3 × 15.2 × 0.63 cm (TS 8 × 6 × 0.250 in). Thus lateral translation of the system was facilitated because the posts were released from the slotted stub beam when the front bolts failed in tension.

## TEST RESULTS

Results of the four-test series are summarized in Table 1. Where applicable, results of previous similar tests with the original design are shown for comparison. Comparisons are made for vehicle exit angle, exit speed, and maximum average vehicle accelerations.

Test 11 was a repeat of test 9, which was the most severe (in terms of barrier damage) of the initial series. Test 12 provided data on performance of CRBRS when impacted by a very heavy [31 751-kg (70 000-lb)] vehicle. Test 13 was performed with no repair of barrier damage sustained in test 12. Test 14 was a repeat of test 10. Further details of the entire test program are available elsewhere (2).

### Test 11

The GMC Scenicruiser bus was ballasted to 18 144 kg (40 000 lb) with 2721 kg (6000 lb) in the passenger compartment and 1905 kg (4200 lb) in the cargo compart-

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ments (in test 9 all ballast was contained in the cargo compartments). The bus impacted the front rail at 86.7 km/h (53.9 mph) and a 15.1° angle. As shown in Figure 3, impact occurred approximately 0.9 m (3 ft) upstream of post 6. The bus completely collapsed the rings in the impact zone and rolled toward the rail, and the rear of the bus impacted the outer rail system. The redirected bus reached a maximum roll of 8 deg (toward the rail) as shown in Figure 3 before returning to an upright position. Maximum 50-ms average accelerations were 1.2 longitudinal *g* and 2.1 lateral *g*; maximum permanent deflections of the three box beam rails were 49.5 cm (19.5 in) on the top rail, 49.3 cm (19.4 in) on the mid rail and 88.9 cm (35.0 in) on the front rail. The inboard (traffic side) baseplate bolts (2 per post) of posts 3 through 10 failed in tension, and the posts were displaced

**Figure 1. Collapsing-ring energy absorption concept.**

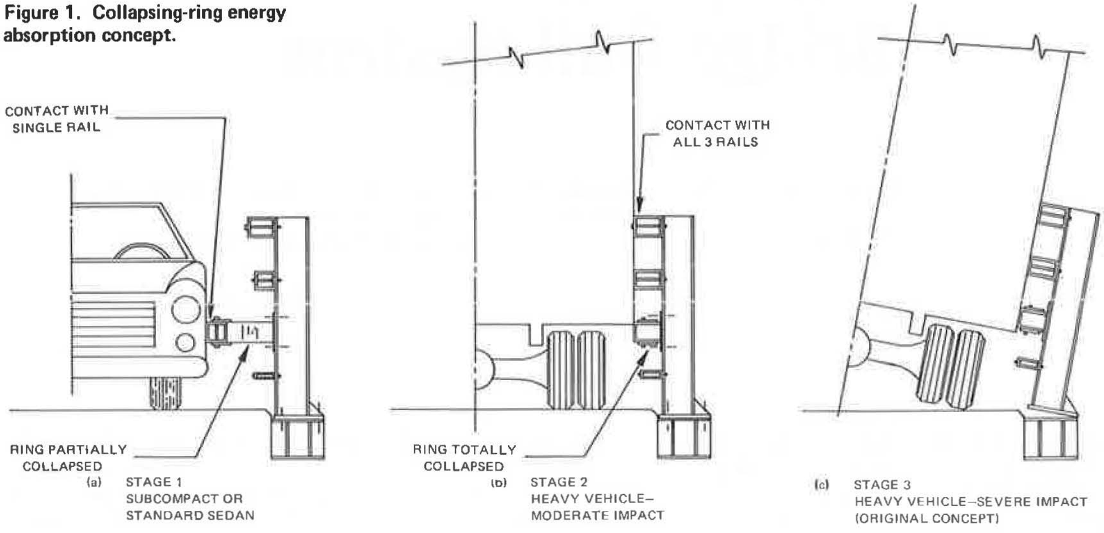
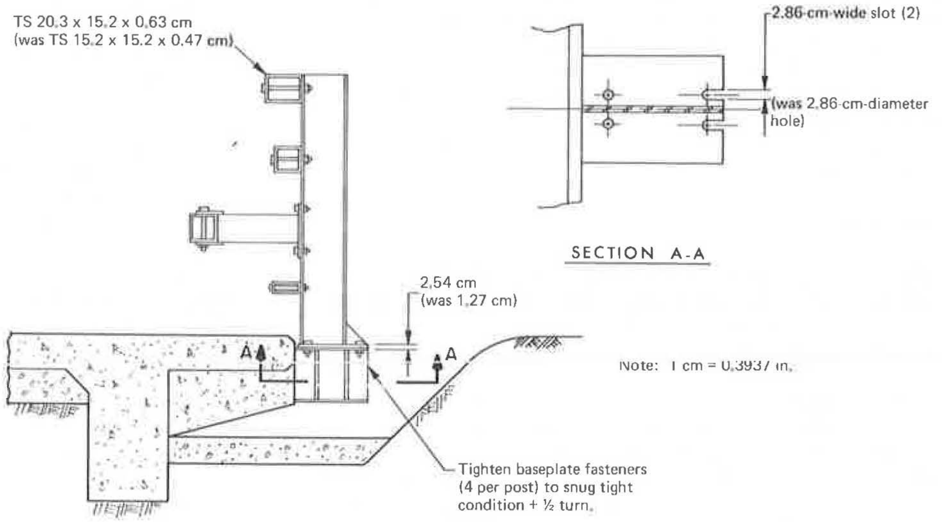


**Figure 2. Modifications made to CRBRS for tests 11 through 14.**



Note: 1 cm = 0.3937 in.

**Table 1. Summary of vehicle crash results.**

| Test Number | Vehicle Weight (kg) | Vehicle Description | Vehicle Impact Conditions Speed (km/h) | Vehicle Impact Conditions Angle (deg) | Vehicle Exit Conditions Speed (km/h) | Vehicle Exit Conditions Angle (deg) | Max Avg. Vehicle Acceleration[a] Longitudinal (*g*) | Max Avg. Vehicle Acceleration[a] Lateral (*g*) | Max Beam Rail Deflections Dynamic (cm) | Max Beam Rail Deflections Permanent (cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 18 160 | Intercity bus | 86.7 | 15.1 | 80.0 | 7.9 | -1.2 | 2.2 | 121.9 | 88.9 |
| 9[b] | 18 160 | Intercity bus | 87.4 | 19.1 | 68.9 | 13.2 | -1.4 | 2.6 | 153.4 | 137.2 |
| 12[c] | 31 780 | Tractor-trailer truck | 71.4 | 10.0 | 69.2 | 3.0 | -3.0 | 5.0 | 30.0 | 24.9 |
| 13 | 1 998 | Standard sedan | 99.8 | 22.7 | 82.4 | 7.1 | -5.3 | 7.7 | 53.3 | 48.3 |
| 14 | 18 160 | Tractor-trailer truck | 91.7 | 15.6 | 83.2 | 3.0 | -1.1 | 7.8 | 145.8 | 135.6 |
| 10[b] | 18 160 | Tractor-trailer truck | 88.7 | 19.0 | 74.7 | 11.0 | -3.6 | 8.9 | 121.9 | 58.9 |

Note: 1 kg = 2.2 lb. 1 km/h = 0.621 mph. 1 cm = 0.3937 in.

[a] Maximum acceleration over 50-ms duration obtained from high-speed cine.

[b] Original design test.

[c] Cine analysis not performed for test 12 because of data camera malfunction; values shown are from speed trap, tire mark measurements, or accelerometers.

Figure 3. Comparison of vehicle roll in tests 9 and 11.

Test 9

Test 11

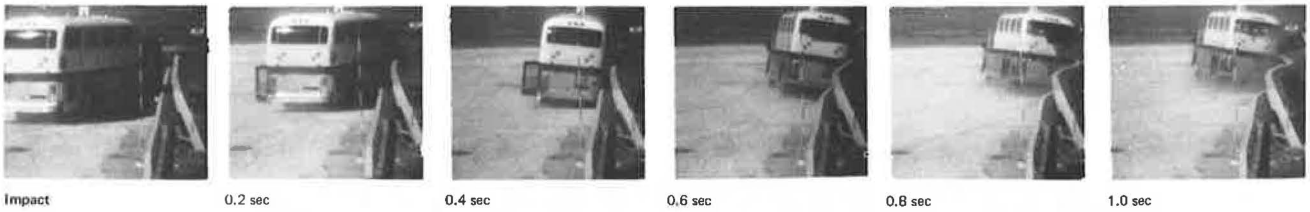
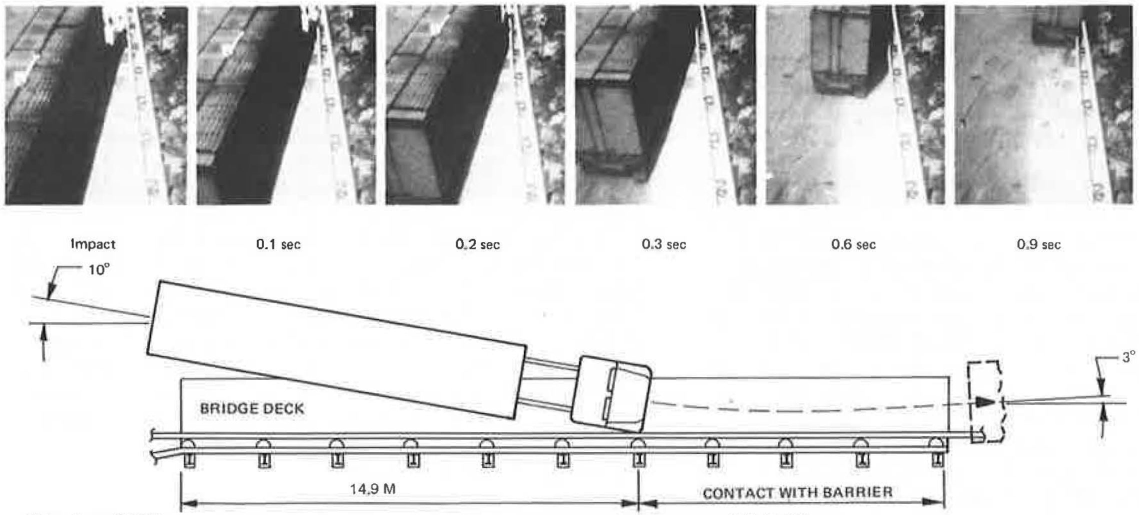
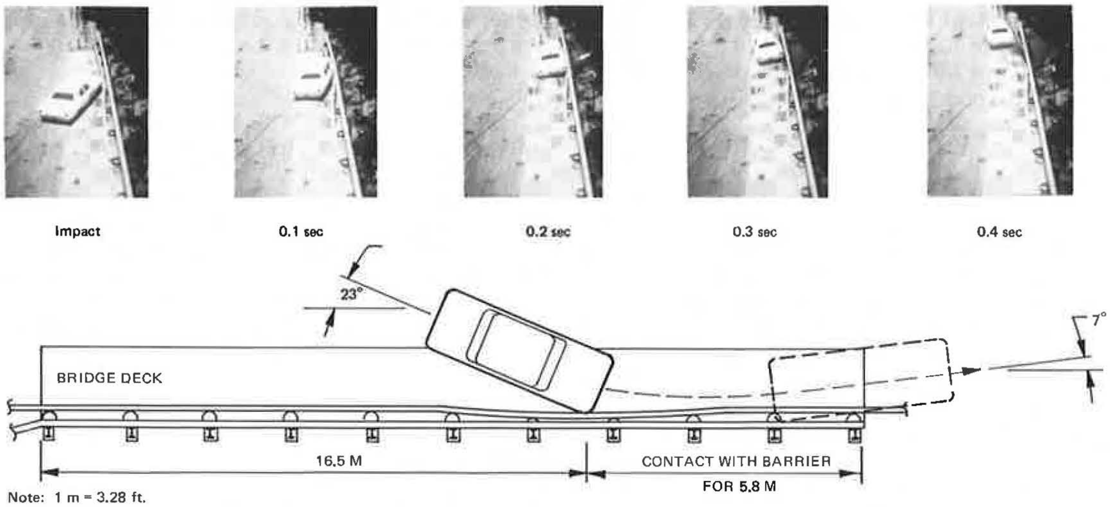


Figure 4. Summary of results for full-scale crash test 12.



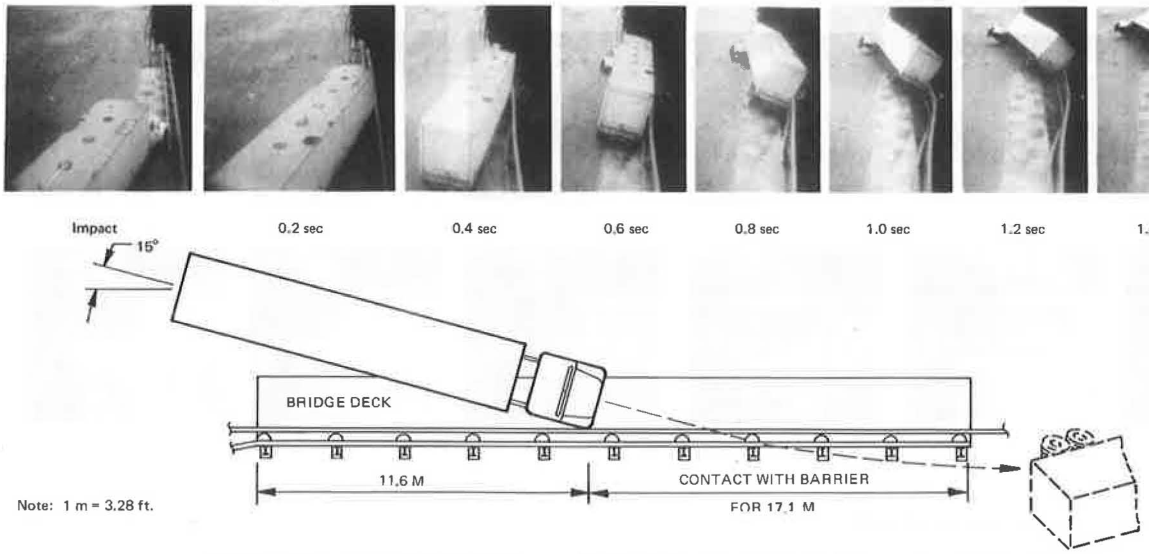
Note: 1 m = 3.28 ft.

Figure 5. Summary of results for full-scale crash test 13.



Note: 1 m = 3.28 ft.

Figure 6. Summary of results for full-scale crash test 14.



Note: 1 m = 3.28 ft.

laterally (as designed); maximum baseplate displacement was 54.9 cm (21.6 in). The vehicle was drivable following the test and returned from the test site to Southwest Research Institute under its own power.

Test 12

The 31 751-kg (70 000-lb) tractor-trailer truck containing 21 319 kg (47 700 lb) of ballast consisting of 45-kg (100-lb) bags of sand evenly distributed on the trailer floor impacted the front rail at post 7 with a speed of 71.4 km/h (44.4 mph) and an impact angle of 10 deg. As shown in Figure 4, the truck partially collapsed the rings in the impact zone and rolled toward the rail, and the trailer contacted the top rail continuously between posts 7 and 10. Then the redirected truck returned to an upright position and was braking to a stop when the tractor veered to the right about a hundred meters downstream of the bridge deck. This severe turn caused the trailer to overturn onto its left side; the tractor remained upright as the frame twisted 90 deg. Maximum accelerations were 5.0 longitudinal *g* and 3.0 lateral *g*; maximum permanent deflections were 24.6 cm (9.7 in) on the front rail and 1.27 cm (0.5 in) on the top rail. Inspection of the inboard baseplate bolts (two per post) revealed that those of post 8 had failed in tension and those of posts 5 through 10 were loose, which indicates that some elongation had occurred. No lateral displacement of the post baseplates was observed.

Test 13

The 1996-kg (4400-lb) Ford Custom Sedan impacted the damaged front rail (installation damage of test 12 was not repaired) 0.9 m (3 ft) upstream of post 8 at a speed of 99.8 km/h (62.0 mph) and a 22.7-deg angle as shown in Figure 5. The vehicle completely collapsed the ring on post 8 and was smoothly redirected. Maximum 50-ms average accelerations were 5.3 longitudinal *g* and 7.7 lateral *g*; maximum permanent deflections were 2.3 cm (0.9 in) on the top rail, 3.8 cm (1.5 in) on the mid rail, and 48.3 cm (19.0 in) on the front rail. The inboard baseplate bolts of post 9 failed in tension (those of post 8 had failed in the previous test), and posts 7, 8, and 9 were displaced laterally. Maximum displacement was 26.7 cm (10.5 in).

Test 14

The 18 144-kg (40 000-lb) tractor-trailer truck containing 9072 kg (20 000 lb) of ballast evenly distributed on the trailer floor impacted the front rail midway between posts 5 and 6 at a speed of 91.7 km/h (57 mph) and a 15.6-deg angle and initiated a slight roll toward the barrier as it was redirected. This roll continued as the trailer impacted the two upper rails which caused the entire rig to roll onto its right side as shown in Figure 6. Maximum 50-ms average accelerations were 1.1 longitudinal *g* and 7.8 lateral *g*. The inboard baseplate bolts of posts 3 through 11 failed in tension and those posts were displaced laterally; maximum displacement was 135.6 cm (53.4 in). In addition, the front rail and guardrail and guardrail posts downstream of the bridge deck failed.

## DISCUSSION OF RESULTS

Analysis of these four additional tests (tests 11 through 14) revealed six things.

1. The modified or translating basepost design was effective in reducing heavy vehicle roll angles. A comparison of the modified and original designs revealed that the vehicles reached a maximum roll angle of 20° and 8° for tests 9 and 11 respectively.
2. Although the end results of tests 10 and 14 were similar (vehicle rollover), the rollover that occurred during test 14 was much less violent and is attributed partially to an unanchored end. A downstream end anchor similar to that at the upstream end is recommended.
3. The modified post provides forgiving stroke when less than the total 45.7-cm (18-in) stroke of the ring is available for energy absorption. This was demonstrated in test 13 when the vehicle impacted a partially deflected, previously damaged barrier and caused no significant increase in vehicle accelerations over those recorded in similar tests.
4. The CRBRS can restrain articulated vehicles weighing up to 31 751 kg (70 000 lb) in 72.4-km/h (45-mph), 10-deg collisions and 18 144 kg (40 000 lb) in 88.5-km/h (55-mph), 14-deg impacts.
5. Successful redirection of an 18 144-kg (40 000-lb) intercity bus in an 86.9-km/h (54-mph) impact at 15 deg was demonstrated. This vehicle was able to be started and driven away from the test site.
6. System repair costs were less for the modified

CRBRS because the same posts were used for all four tests (no post damage was sustained) and only rail sections and rings required replacement.

## REFERENCES

1. C. E. Kimball, M. E. Bronstad, J. D. Michie, J. A. Wentworth, and J. G. Viner. Development of a New Collapsing-Ring Bridge Rail System. TRB, Transportation Research Record 566, 1976, pp. 31-43.
2. C. E. Kimball, M. E. Bronstad, J. D. Michie, J. A. Wentworth, and J. G. Viner. Development of a New Collapsing Ring Bridge Rail System. Federal Highway Administration, Rept. FHWA-RD-76-39, Jan. 1976.