Abridgment

Test Evaluation of Tubular Thrie Beam for Upgrading Concrete Bridge Railing

C. E. Kimball, E. O. Wiles, and J. D. Michie, Southwest Research Institute, San Antonio, Texas

Many existing bridge railings were designed and installed before the recent emphasis on vehicle containment and redirection safety. Under a program sponsored by the Federal Highway Administration (FHWA), we have investigated the safety performance of existing bridge railing systems and have developed retrofit designs that will improve the safety performance of the more prevalent installations. The retrofit design described and evaluated in this paper is believed applicable to a large percentage of those concrete baluster installations that do not have curbs or walkways projecting beyond the face of the concrete railing.

DESIGN FEATURES

The primary element of the design is a new beam rail element known as the tubular Thrie beam. It is fabricated by welding two Thrie (or triple corrugated) beams together as shown in Figure 1. The beam is joined to and blocked out from the concrete baluster rail by 15.24-cm-diameter (6-in-diameter) collapsing rings spaced at 2.54 m (8.33 ft); no attempt was made to space the rings to the concrete post in the test installation. Dimensions of the 15.24-cm-diameter (6-in-diameter), 317-cm-thick (0.125-in-thick) by 55.9-cm-long (22-in-long) rings were established by the equation

$$\text{Dynamic ring energy absorbed} = 4.8\,\sigma_o W t^2 \qquad (1)$$

that was empirically established from another FHWA program (1). In this equation, a design energy of 677 909 kJ (60 000 in·lb) was used with a static initial yield stress σ_o of 248 MPa (36 kip/in^2) and ring width W of 55.9 cm (22 in); required ring thickness t in centimeters was determined.

The tubular Thrie beam was extended 2.54 m (8.33 ft) upstream from the bridge end and transitioned to a single Thrie beam that was structurally anchored.

There are four principal attributes of the retrofit design.

1. The 50.8-cm-wide (20-in wide) tubular Thrie section provides a large contact area with the impacting vehicle, which ensures probable contact with the vehicle hard points and minimizes knifing of the beam into the car structure and snagging potential. Also mounting height for optimum contact with a range of vehicles is less critical.
2. The collapsing rings and relatively stiff beam reduce the intensity and distribute impact forces over an increased length of existing bridge railing, which permits upgrading of otherwise understrength installations.
3. The design is somewhat flexible in its adaptation to existing installations.
4. The design encroaches only 30.5 cm (12 in) into existing bridge deck space, which is a most important consideration for narrow bridges.

Although an upstream terminal was not evaluated, the tubular Thrie beam design is considered an integrated bridge railing that is made up of terminal, approach railing, transition, and bridge railing. Baluster rail and retrofit are shown in Figure 2.

TEST PROGRAM

Five tests were performed by using test procedures outlined in National Cooperative Highway Research Program Report 153 (2). Two base-line tests (tests 3 and 4) were performed with the concrete baluster rail with no retrofit. The tubular Thrie beam system was then installed, and two tests (tests 5 and 6) were performed by using the same conditions of tests 3 and 4. Test 7 was a test of the transition from the tubular Thrie beam to a single Thrie that was used as the approach guardrail to the bridge. A summary of test results is given in Table 1.

Test 3

The 2041-kg (4500-lb) 1972 Ford Galaxie impacted the

Publication of this paper sponsored by Committee on Safety Appurtenances.

concrete baluster rail at 97.0 km/h (60.3 mph) and a 30.0-deg angle. As shown in Figure 3, the vehicle impacted the installation approximately 4.3 m (14 ft) upstream of the end post, broke posts 8 and 9 (posts are numbered consecutively beginning at the upstream end), and caused the rail member downstream of posts 7 and 8 to form a plastic hinge that allowed partial penetration of the vehicle through the rail. Maximum 50-ms average accelerations were 10.7 longitudinal *g* and 12.3 lateral *g*.

Test 4

The 966-kg (2130-lb) Toyota Corona impacted the concrete baluster rail at 91.7 km/h (57.0 mph) and a 15.5-deg angle. As shown in Figure 4, the vehicle impacted the installation 7.0 m (23 ft) upstream of the end post and

Figure 1. Tubular Thrie beam retrofit.

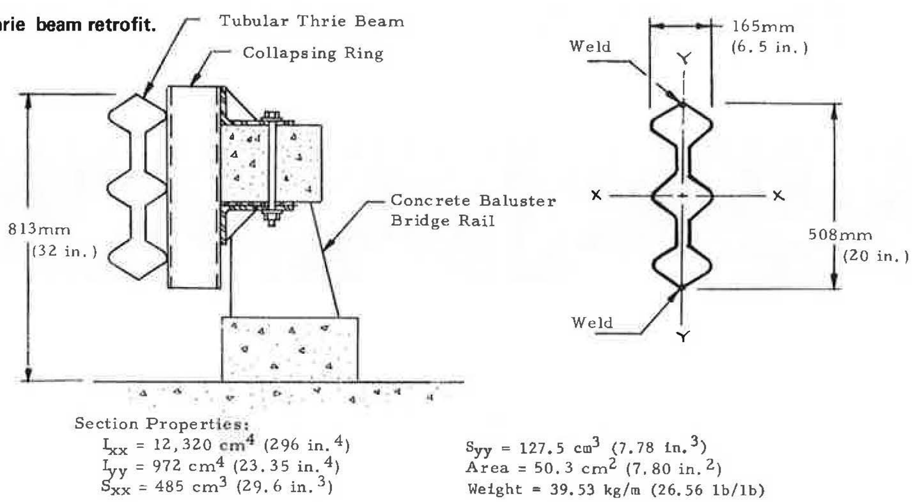


Figure 2. Concrete baluster rail with tubular Thrie beam retrofit.

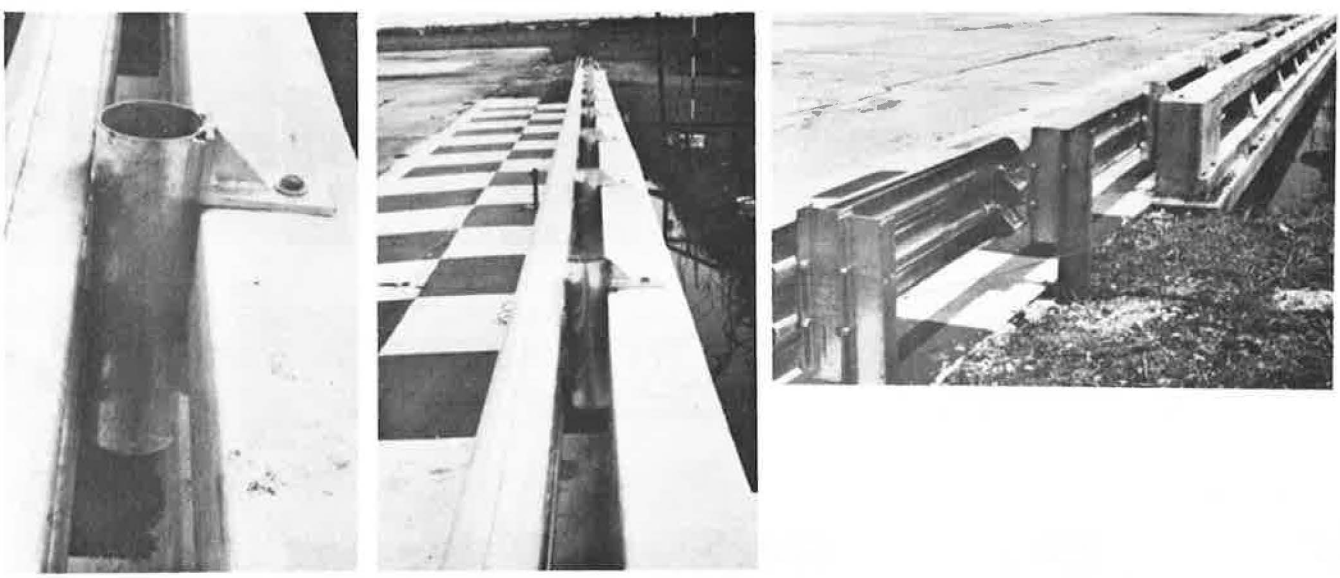


Table 1. Summary of findings.

Test Number	Vehicle Mass (kg)	Impact Speed (km/h)	Impact Angle (deg)	Vehicle Exit Conditions: Angle (deg)	Vehicle Exit Conditions: Speed (km/h)	Max Avg. Vehicle Accelerations[a]: Longitudinal (*g*)	Max Avg. Vehicle Accelerations[a]: Lateral (*g*)	Max Permanent Rail Deflection (cm)
3	2041	97.0	30.0	2.0	49.6	10.7	12.3	–
4	966	91.7	15.5	5.8	74.0	6.7	8.6	–
5	1021	93.3	17.1	6.8	86.9	4.1	8.4	1.27
6	2041	97.5	25.0	6.0	82.0	5.9	11.7	12.7
7	2132	96.7	25.0	10.0	77.2	5.0	10.0	54.9

Notes: 1 kg = 2.205 lb. 1 km/h = 0.621 mph. 1 cm = 0.3937 in.
[a]Maximum acceleration over 50-ms duration obtained from accelerometers or high-speed cine.

was smoothly redirected. Maximum 50-ms average accelerations were 6.7 longitudinal g and 8.6 lateral *g*.

Test 5

Test 5 was the initial test of the tubular Thrie beam retrofit system. The vehicle used was a 1021-kg (2250-lb) 1971 Ford Pinto, and impact conditions were 93.3 km/h (58.0 mph) and a 17.1-deg angle. As shown in Figure 5, the vehicle impacted midway between rings 5 and 6 (rings are numbered consecutively beginning at the upstream end) and was smoothly redirected. Maximum 50-ms average accelerations were 4.1 longitudinal *g* and 8.4 lateral *g*; maximum permanent rail deflection was 1.27 cm (0.5 in). The vehicle was driven back to the impact area after the test.

Test 6

The 2041-kg (4500-lb) 1973 Mercury Monterrey impacted the tubular Thrie beam installation at 97.5 km/h (60.6 mph) and a 25-deg angle. As shown in Figure 6, the vehicle impacted midway between rings 5 and 6, partially collapsed those rings, and was smoothly redirected.

Figure 3. Summary of test 3 results.

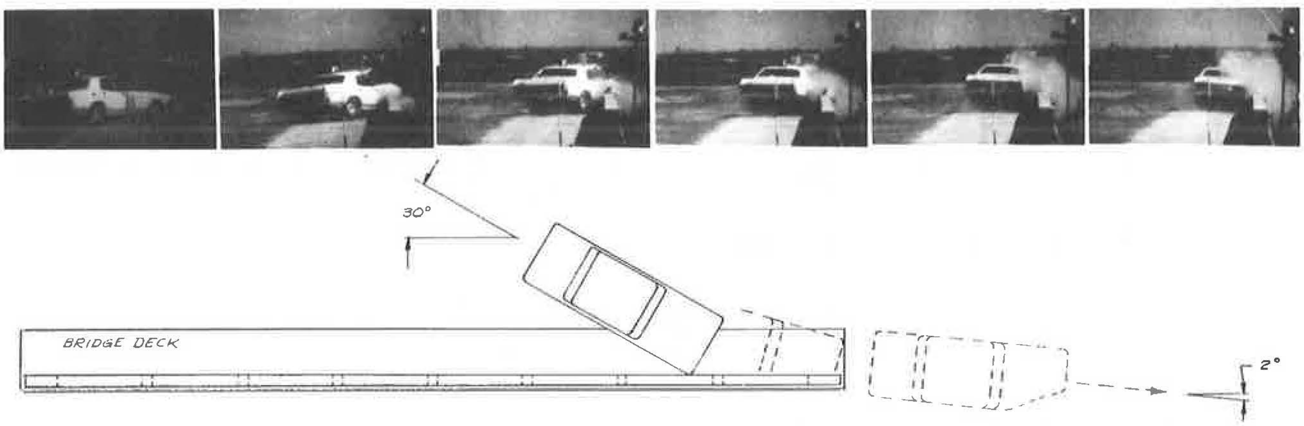


Figure 4. Summary of test 4 results.

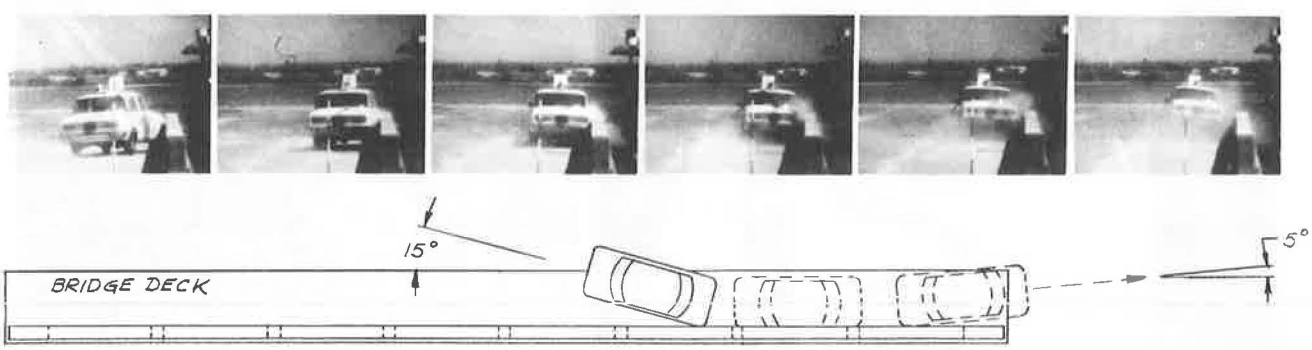


Figure 5. Summary of test 5 results.

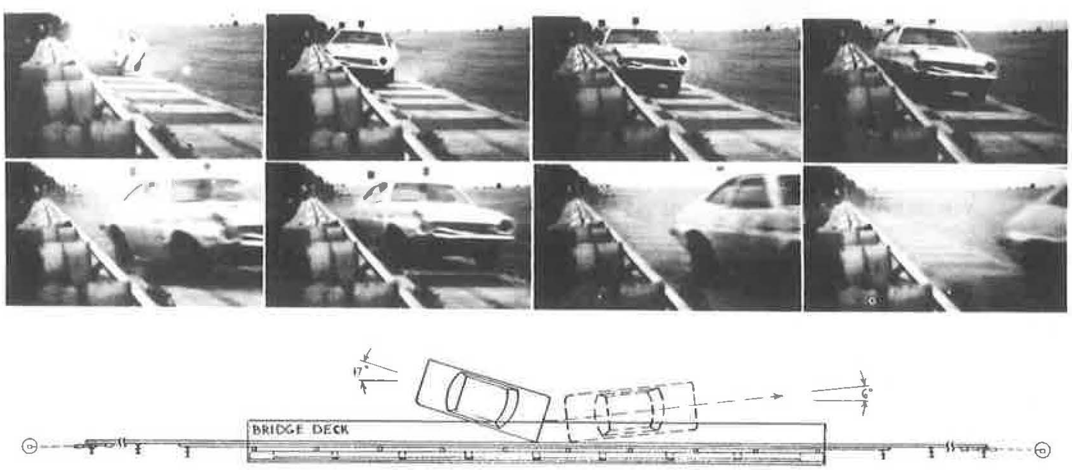


Figure 6. Summary of test 6 results.

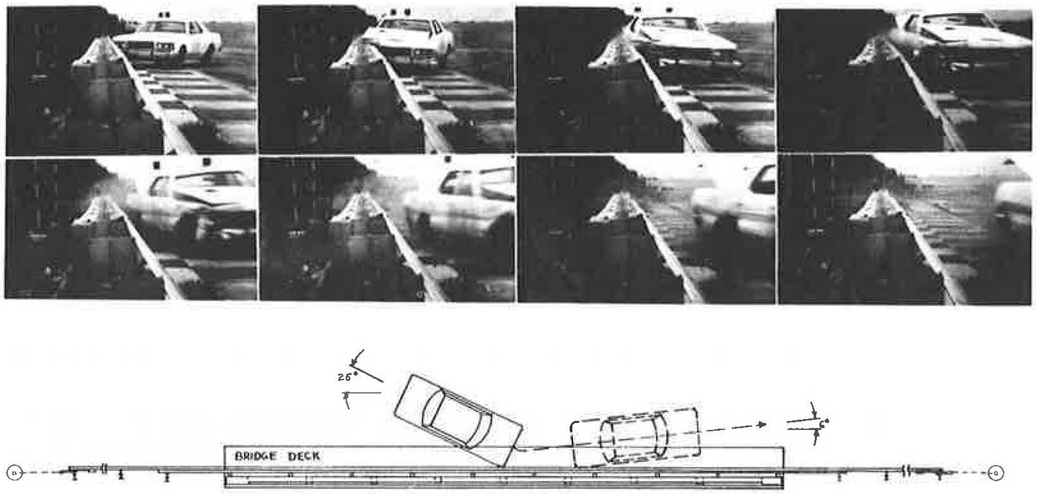
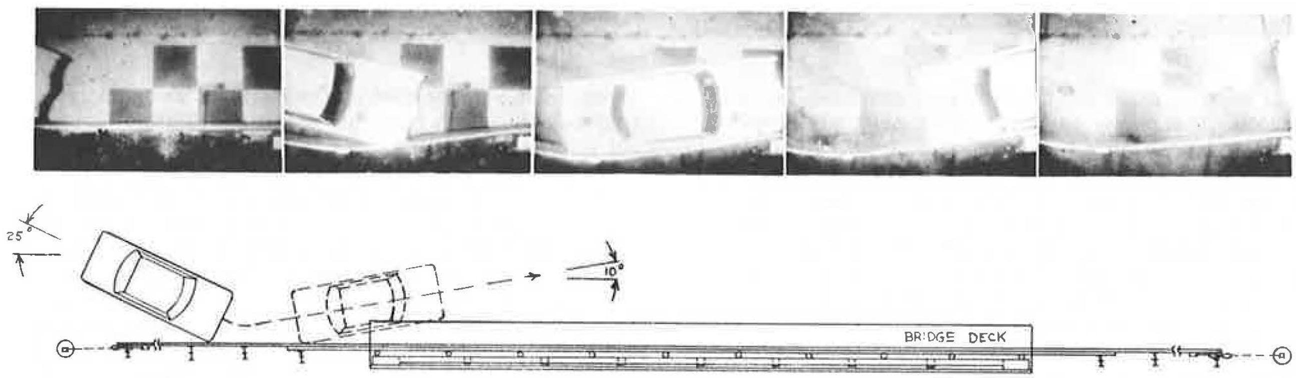


Figure 7. Summary of test 7 results.



Maximum 50-ms average accelerations were 5.9 longitudinal *g* and 11.7 lateral g; maximum permanent rail deflection was 12.7 cm (5.0 in). The vehicle was driven back to the impact area after the test.

Test 7

The 2132-kg (4700-lb) 1969 Cadillac Sedan deVille impacted the single Thrie beam rail in the transition area at 96.7 km/h (60.1 mph) and a 25-deg angle. As shown in Figure 7, the vehicle impacted the rail 1.4 m (4.6 ft) upstream of the second guardrail post off the bridge deck and was smoothly redirected. Maximum 50-ms average accelerations were 5.0 longitudinal g and 10.0 lateral *g*; maximum permanent rail set was 54.9 cm (21.6 in) after reaching a maximum dynamic deflection of 111.2 cm (43.8 in). The vehicle was driven back to the impact area after the test.

CONCLUSIONS

Analysis of data taken from these tests revealed that

1. The tubular Thrie beam increases the strength of the bridge rail;
2. Damage to the vehicle is greatly reduced [all three vehicles tested with the tubular Thrie beam (tests 5, 6, 7) were drivable after the tests];
3. The single Thrie beam to tubular Thrie beam provides a continuous effective guardrail to bridge rail transition; and
4. The tubular Thrie beam and collapsing ring system is an effective retrofit system that minimally encroaches into the bridge deck.

From these findings and results, we believe that the tubular Thrie beam retrofit design is suitable for in-service performance demonstration.

REFERENCES

1. N. Perrone. Thick-Walled Rings for Energy-Absorbing Bridge Rail Systems. Federal Highway Administration, Rept. FHWA-RD-73-49, Dec. 1972.
2. M. E. Bronstad and J. D. Michie. Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances. NCHRP, Rept. 153, 1974.