# A Low-Maintenance, Energy-Absorbing Bridge Rail

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ABSTRACT

A low-maintenance, energy-absorbing bridge rail has been developed for use in high traffic volume situations where the cost of repairing conventional bridge rails has become prohibitively expensive. The new bridge rail is designed to meet or exceed current bridge rail design guidelines. It incorporates railings and posts made of steel tubing and rubber energy absorbers and is designed to be installed on new or existing standard bridge decks. Results of crash tests show that the bridge rail can smoothly redirect a 4,500-lb (2043-kg) automobile impacting at a velocity of 60 mph (96.6 km/hr) and an angle of 25 degrees and remain in service with no maintenance. If exposed to a more severe impact, the bridge rail may have to be repaired, but the bridge deck will remain undamaged. Finally, the new energy-absorbing rail occupies less bridge deck area than do conventional bridge rails.

Bridge rails currently in use are capable of smoothly redirecting automobiles that strike them. However, virtually all types of bridge rails require some type of repair when they are subjected to moderate to severe impacts. The types of damage normally incurred include damage to the bridge rail, bridge rail posts, and bridge deck. The damage is more prevalent with metal bridge rails, but even concrete parapet bridge rails are susceptible to damage when exposed to severe impacts. In many cases the costs associated with bridge rail repair can be greater than the original installation costs. Repair and maintenance costs can become overwhelming on high-volume, multilane expressways where bridge rails are subjected to a greatly increased risk of impact. There is a need for an alternative bridge rail that can redirect errant automobiles without being damaged.

The research reported in this paper was directed toward development of a low-maintenance, energy-absorbing bridge rail that meets or exceeds current bridge rail design criteria. The bridge rail developed incorporates structural steel tube railing and post members and rubber energy absorbers. Further, the bridge rail is designed to be installed on standard Texas State Department of Highways and Public Transportation (SDHPT) bridge decks. No special deck reinforcement is required. Therefore the bridge rail can be installed on either new or existing bridge decks. This paper is a discussion of the development and testing of the new bridge rail.

## DEVELOPMENT OF THE ENERGY-ABSORBING BRIDGE RAIL

The objective of the research presented in this paper was to develop an energy-absorbing bridge rail that conforms to current bridge rail design standards and that can withstand the impact of a 4,500-lb (2043-kg) automobile traveling at a velocity of 60 mph (96.6 km/hr) and impacting at an angle of 25 degrees with no damage. Further, it was desired to develop a bridge rail that can be installed on either new or existing bridge decks. Development of the energy-absorbing bridge rail involved a study of related bridge rail test results, a conceptual design of the bridge rail, and static testing of critical components.

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### Previous Research

Results of crash tests on different types of conventional bridge rails show that current deck-to-post and deck-to-concrete parapet connections are not capable of transferring the loads associated with severe automobile impacts into the bridge deck without significant damage to either the bridge rail or the bridge deck (1,2). This was found to be the case with both steel and concrete bridge rails. Further, it was found that the accelerations associated with vehicles striking many conventional bridge rails exceed the limits set forth in NCHRP Report 230 (3).

Results of the previous research have shown that the performance of bridge rails can be improved by incorporating an energy-absorbing mechanism. These results show both that vehicular accelerations can be reduced and that the magnitudes of the forces transferred to the bridge slab can be attenuated through the use of an energy-absorbing bridge rail (4-7). However, the initial costs associated with the different types of energy-absorbing bridge rails surveyed are much higher than the initial costs associated with conventional bridge rails. In addition, none of the energy-absorbing bridge rails surveyed was maintenance free following the large automobile crash test. Further, none of the energy-absorbing rails surveyed can be attached to standard bridge decks. Therefore the previously developed energy-absorbing bridge rails have not gained widespread acceptance.

### New Bridge Rail

The decision was made early in this project to develop an energy-absorbing bridge rail that employs a stiff rail supported at regular intervals by flexible energy-absorbing supports. Figure 1 shows an idealized section of the new energy-absorbing bridge rail. This arrangement allows impact forces to be spread over a greater distance along the length of the bridge rail than is the case for conventional bridge rail systems that employ flexible rail sections and stiff posts. Consequently, more of the

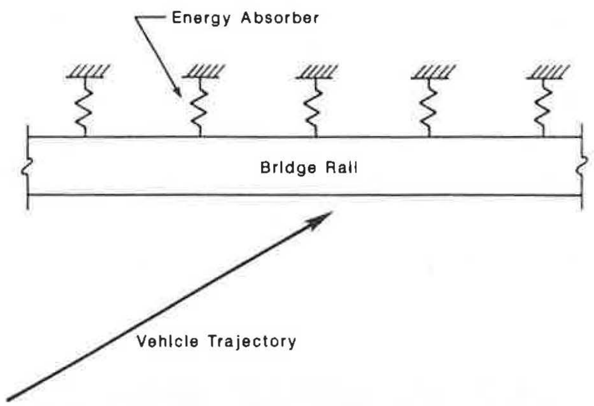



**FIGURE 1 Idealized energy-absorbing bridge rail.**

bridge deck is brought into action to resist impact forces.

Conceptually, the bridge rail could be made of either concrete or steel. The authors opted to use a bridge rail made of two square steel tubes that are stacked one on top of the other and skip welded along their length. This type of bridge rail is not susceptible to local crushing or buckling problems before development of full plastic flexural capacity. Similar rails have been used in two other recent Texas Transportation Institute (TTI) projects (8,9). Further, the steel tubes needed to fabricate the rail are commonly available in a wide range of sizes.

In previously developed energy-absorbing bridge rails, the energy-absorbing element has been a steel member that absorbs energy by either crushing or deforming (4-7). The authors chose to use rubber energy absorbers in the development of the bridge rail presented herein. The rubber energy absorbers used are primarily manufactured for use in marine dock-fendering systems. Rubber energy absorbers of this type are available from a variety of manufacturers. The rubber used is highly resilient, it remains elastic when subjected to large strains, and it is resistant to the elements of nature. Further, it is readily available in a wide range of different geometries. A cylindrical rubber energy absorber was chosen for the current application.

To complete the system, the energy absorbers needed to be supported in a manner that allowed the impact loads to be transferred into the bridge deck. There are several different ways in which this could be accomplished. One way would be to mount the energy absorbers to the face of a concrete parapet. This option would be acceptable if the rail were to be mounted on a new bridge, but this approach would be prohibitively expensive for a retrofit operation. Therefore the authors chose to support the rubber energy absorbers with steel posts.

Conventional steel bridge posts are welded to base plates that are attached to the bridge deck with anchor bolts. Previous tests on conventional bridge posts show that the bridge deck is severely cracked and spalled before the post reaches its full potential (1). As a result, severe damage is often done to the bridge deck in even moderate impacts. As stated earlier, one of the major objectives of this project was to prevent damage to the bridge deck. To accomplish this, a new bridge post design was developed.

Figure 2 is a sketch of the new bridge post developed for this project. The bridge post is attached to the deck with three bolts that pass through the deck. The mounting holes in the bridge deck can be cast during construction or they can be drilled

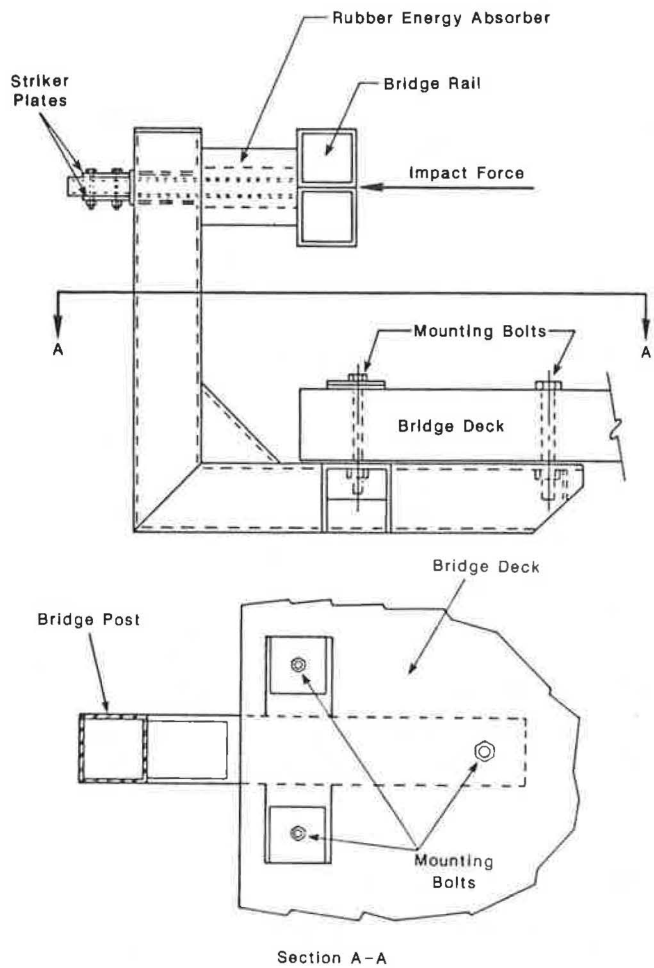



**FIGURE 2 Energy-absorbing bridge post.**

after construction. When the post is subjected to a lateral force, both a shear force and a moment must be transferred into the bridge deck. The post is designed such that the bolt farthest from the edge of the slab transfers the shear into the deck. This is accomplished by control of the mounting hole tolerances. The moment is transferred into the deck through a couple that develops between the inboard contact force and the tensile forces in the two bolts near the edge of the deck. The inboard force is transferred to the bottom of the deck through a neoprene bearing pad. The outboard force is transferred to the top of the deck through base plates that rest on neoprene bearing pads. In both cases the load experienced by the bridge deck is a compressive load as shown in Figure 3. The magnitudes of the contact stresses are controlled by the sizes of the bearing areas.

The weight of the rail is supported by a square steel tube that passes through the center of the cylindrical energy absorber and through a sleeved opening in the post, as shown in Figure 2. During installation of the bridge rail the energy absorber is compressed slightly and striker plates are attached to the back side of the support tube with bolts. The entire assembly is then held firmly in place by the compressive force locked into the energy absorber. The sleeved opening is larger than the support tube so that when the rail is subjected to a lateral force the impact force is transferred to the post through the energy absorber as the support tube passes freely through the post.

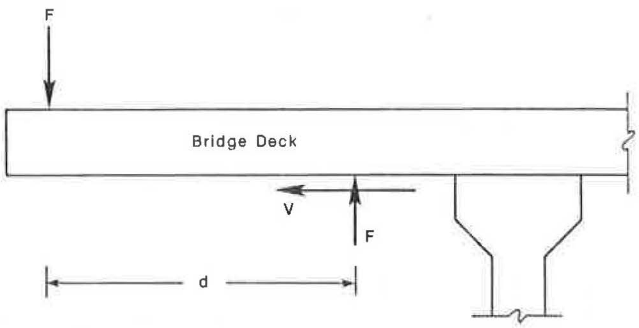



FIGURE 3 Forces exerted on bridge deck.

In selecting the final member sizes for the energy-absorbing bridge rail, the authors relied on structural analysis techniques for beams on elastic foundations, results generated using the BARRIER VII crash simulation program (10), results of selected static tests, and engineering judgment. As a result of these considerations, the bridge rail was made of 6- x 6- x 1/4-in. (15.2- x 15.2- x 0.64-cm) steel tubing and the bridge posts were fabricated using 7- x 7- x 1/4-in. (17.8- x 17.8- x 0.64-cm) steel tubing. The cylindrical rubber energy absorbers chosen had 8-in. (20.3-cm) outer diameters, 4-in. (10.2-cm) inner diameters, and were 10 1/2 in. (26.7 cm) long. Complete fabrication details of the final energy-absorbing bridge rail are available elsewhere (11).

Static Bridge Post Tests

Before construction of the prototype bridge rail, a series of static tests was conducted to verify the combined performance of the post, energy absorber, and bridge deck. These tests were conducted using energy-absorbing bridge posts that were mounted on a short section of bridge deck overhang 7.5 in. (19.1 cm) thick. This bridge deck section was constructed using standard details (11). Mounting holes for the bridge posts were cast into the bridge deck section. Load was applied to the bridge post with a horizontal hydraulic cylinder mounted so that the line of action of the applied load was 21 in. (53.3 cm) above the bridge deck. Results of the tests show that

1. The rubber energy absorber-plunger mechanism operates smoothly even when the lateral load contains a significant longitudinal component;
2. The onset of major yielding in the post occurs at a lateral load of 25,000 lb (115.6 kN);
3. The ultimate strength of the post is 29,000 lb (129.0 kN);
4. Failure of the post was the result of multiple plastic hinges that formed at different points on the post; and
5. There was no cracking in the bridge deck section at the ultimate load.

These results verified that the new bridge post performed as designed.

FULL-SCALE CRASH TEST RESULTS

Full-scale testing of the energy-absorbing bridge rail was conducted at the TTI proving grounds in Bryan, Texas. All tests were run in accordance with criteria presented in NCHRP Report 230 (3). The purpose of the tests was to evaluate the performance of the energy-absorbing bridge rail in terms of structural adequacy, occupant risk, and vehicle exit trajectory.

The tests were conducted using the 59-ft (18-m) section of the energy-absorbing bridge rail shown in Figure 4. NCHRP Report 230 specifies that a 75-ft (22.9-m) section of the bridge rail should be tested; however, it is the opinion of the authors that the performance of the bridge rail is not affected by this deviation. Further, the acceptance of the shorter section allowed the use of an existing standard SDHPT bridge deck.

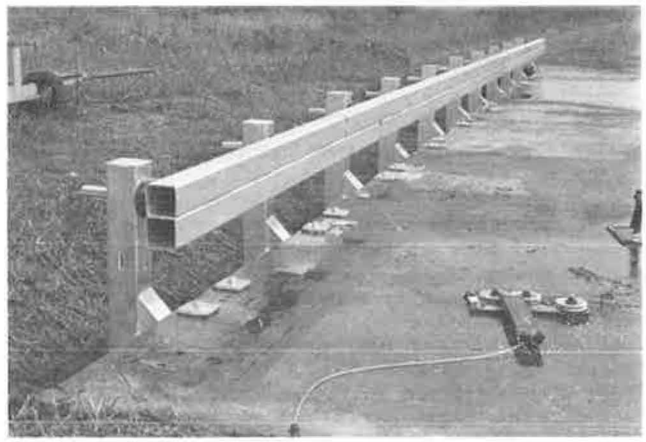


FIGURE 4 59-ft (18-m) section of energy-absorbing bridge rail.

The bridge deck used is approximately 15 years old and has been used in at least three other TTI bridge rail tests. As a result, the bridge deck has accumulated a significant amount of cracking and spalling, which is typical of actual bridge deck damage. Figure 5 shows an example of the worst bridge deck damage before testing. The energy-absorbing bridge rail was mounted on the existing deck so that this worst area of spalling was located between two posts. No attempt was made to repair any of the cracked or spalled areas in the bridge deck. The necessary mounting holes were drilled in the deck using a coring machine without regard for the place-

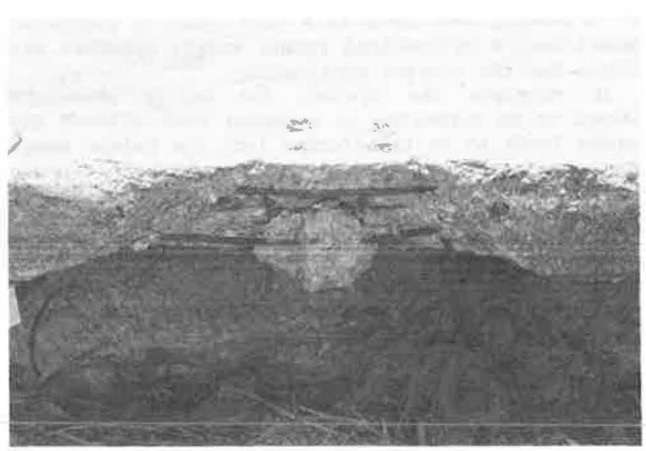


FIGURE 5 Example of worst bridge deck damage before testing.

FIGURE 6 Test vehicle after Test 1.

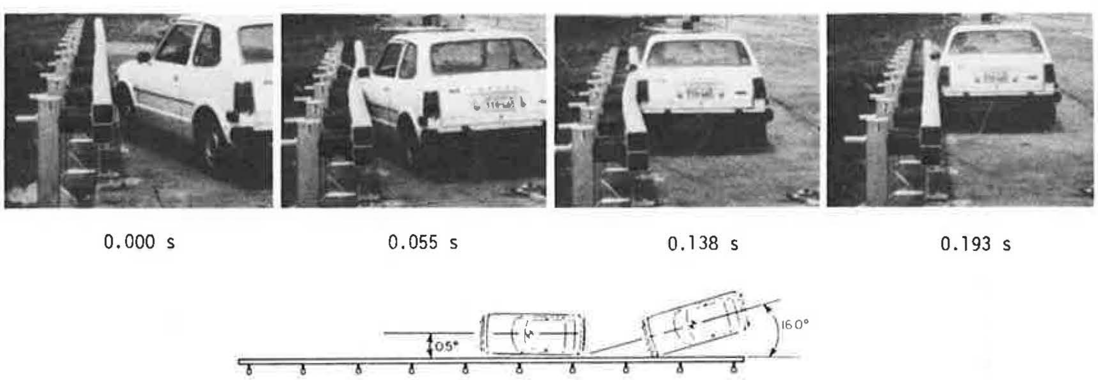
FIGURE 7 Bridge rail after Test 1.

ment of internal reinforcement. This procedure would be typical of a retrofit operation.

Two tests involving a full-sized automobile and a subcompact automobile were conducted on the bridge rail. The tests were conducted in order of increasing severity using the same bridge rail. Complete photographic and accelerometer data are available elsewhere (11). Short discussions of the test results are presented next.

In Test 1 a 1,802-lb (818-kg) Honda Civic struck the energy-absorbing bridge rail at a velocity of 62.6 mph (101 km/hr) and an angle of 16 degrees. Figures 6 and 7 show the test vehicle and bridge rail after the test. Figure 8 shows a summary of the test results. The test vehicle was smoothly redirected with an exit angle of only 0.5 degrees. The damage to the impacting automobile was considered moderate given the severity of the impact. The maximum dynamic deflection of the bridge rail was 4.6 in. (11.7 cm) and the permanent deflection of the face of the rail was 0.6 in. (1.52 cm). This permanent deflection was the result of slack in the post-to-deck connections. The bridge deck experienced no cracking or spalling as a result of this test.

In the second test, a 4,500-lb (2043-kg) Oldsmobile Delta 98 struck the bridge rail at a velocity of 61.0 mph (98.1 km/hr) and an impact angle of 25.5 degrees. The same bridge rail used in Test 1 was used in Test 2. Figures 9 and 10 show the test vehicle and bridge rail after the test. Results of this test are summarized in Figure 11. In this test the automobile was smoothly redirected with an exit angle of only 2.0 degrees. In the opinion of the authors, the damage done to the vehicle was significantly less than would be expected if the automobile struck a rigid bridge rail such as a concrete parapet. The maximum dynamic deflection of the energy-absorbing bridge rail was 7.2 in. (18.3 cm) and the permanent deflection relative to the original face of the rail




| | |
|---|---|
| Test No. . . . . . . . . . | 2417-1 |
| Date . . . . . . . . . . . | 5/21/85 |
| Rail . . . . . . . . . . . | Low-maintenance, energy-absorbing bridge rail |
| Post . . . . . . . . . . . | 7x7x¼ in Structural Steel Tube |
| Post Spacing . . . . . . | 6.25 ft (1.91 m) |
| Length of Installation . | 59 ft (18 m) |
| Rail Deflection | |
| Maximum . . . . . . | 0.38 ft (0.12 m) |
| Permanent. . . . . . | 0.05 ft (0.02 m) |
| Vehicle. . . . . . . . . | 1979 Honda Civic |
| Vehicle Weight | |
| Test inertia . . . . | 1,802 lb (818 kg) |
| Gross static . . . . | 1,972 lb (895 kg) |

| | |
|---|---|
| Impact Speed. . . . . . . | 62.56 mi/h (100.7 km/h) |
| Impact Angle. . . . . . . | 16.0 degrees |
| Exit Angle. . . . . . . . | 0.5 degrees |
| Change in Velocity. . . . | 7.79 mi/h (12.5 km/h) |
| Change in Momentum. . . . | 639 lb-s |
| Occupant Impact Velocity | |
| Longitudinal. . . . . | 11.7 fps (3.6 m/s) |
| Lateral . . . . . . . | 20.4 fps (6.2 m/s) |
| Occupant Ridedown Acceleration | |
| Longitudinal. . . . . | -0.6 g |
| Lateral . . . . . . . | 8.7 g |
| Vehicle Damage Classification | |
| TAD . . . . . . . . . | 11LD4 |
| VDI . . . . . . . . . | 11LDES2 |

FIGURE 8 Summary of test results of Test 1.

FIGURE 9 Test vehicle after Test 2.

FIGURE 10 Bridge rail after Test 2.

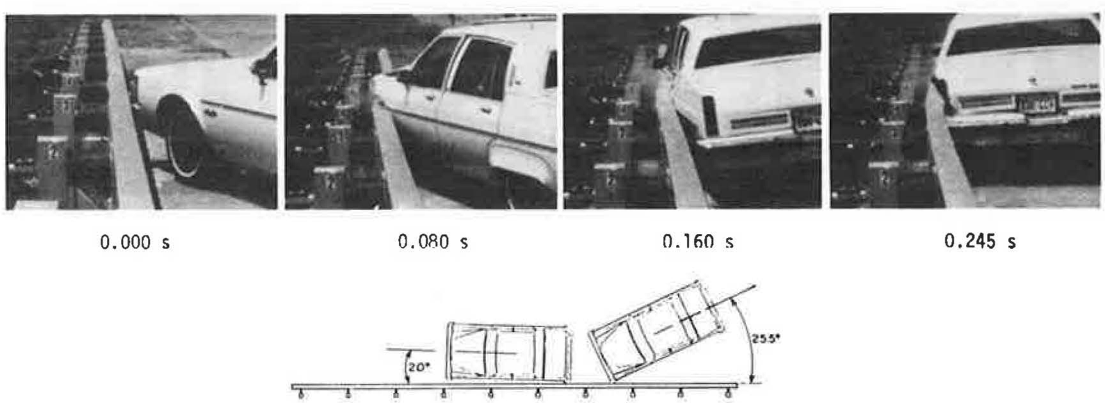
was 0.96 in. (2.4 cm). This permanent deflection was the result of connection slack coupled with a slight amount of yielding in the bridge rail. The bridge deck sustained no damage or cracking during the second test. No maintenance would have been required to keep the bridge rail in service following this impact.

## CONCLUSIONS

A low-maintenance, energy-absorbing bridge rail has been developed for use in high traffic volume situations where the cost of repairing conventional bridge rails has become prohibitively expensive. The new bridge rail is designed to meet or exceed all current bridge rail design guidelines for safety and to smoothly redirect a 4,500-lb (2043-kg) automobile traveling at 60 mph (96.6 km/hr) and an impact angle of 25 degrees with no damage done to either the bridge rail or the bridge deck.

A prototype bridge rail has been subjected to two full-scale crash tests involving a 1,800-lb (817-kg) automobile and a 4,500-lb (2043-kg) automobile as prescribed in NCHRP Report 230 (3). Results from both of these tests were within the acceptable limits for roll, pitch, yaw, acceleration, and velocity changes. The vehicles were smoothly redirected throughout the collisions with extremely shallow exit angles. The final vehicle trajectory after impact was parallel to the barrier face. Following the large automobile impact the bridge rail had less than 1 in. (2.54 cm) of permanent lateral deformation, the bridge deck was undamaged, and no maintenance would have been required to keep the bridge rail in service.

Although the new energy-absorbing bridge rail system is a significant departure from conventional bridge rails, it has many advantages. Static data show that even if the new bridge post is taken to




Test No. . . . . . . . . . 2417-2
Date . . . . . . . . . . . 5/24/85
Rail . . . . . . . . . . . Low-maintenance, energy-absorbing bridge rail
Post . . . . . . . . . . . 7x7x¼ in Structural Steel Tube
Post Spacing . . . . . . 6.25 ft (1.91 m)
Length of Installation . 59 ft (18 m)
Rail Deflection
  Maximum . . . . . . 0.60 ft (0.18 m)
  Permanent. . . . . . 0.08 ft (0.02 m)
Vehicle. . . . . . . . . 1980 Oldsmobile Ninety-eight
Vehicle Weight . . . . . 4,500 lb (2,043 kg)

Impact Speed. . . . . . . 61.0 mi/h (98.1 km/h)
Impact Angle. . . . . . . 25.5 degrees
Exit Angle. . . . . . . . 2.0 degrees
Change in Velocity. . . . 14.36 mi/h (23.1 km/h)
Change in Momentum. . . . 2,943 lb-s
Occupant Impact Velocity
  Longitudinal. . . . . 18.9 fps (5.8 m/s)
  Lateral . . . . . . . 28.5 fps (8.7 m/s)
Occupant Ridedown Acceleration
  Longitudinal. . . . . -2.5 g
  Lateral . . . . . . . 10.0 g
Vehicle Damage Classification
  TAD . . . . . . . . . 10LD7
  VDI . . . . . . . . . 10LDES3

FIGURE 11 Summary of results of Test 2.

failure the bridge deck will not be damaged. This means that regardless of the impact severity, no bridge deck repair will be required. In addition, no special deck reinforcements or modifications are required so that the bridge rail can easily be retrofitted onto an existing bridge deck. Finally, because of the unique design of the bridge post, less bridge deck space is required for the new energy-absorbing bridge rail than is required for conventional bridge rails. This could be of major importance in retrofit operations where additional lane width is desirable.

## ACKNOWLEDGMENTS

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