Performance Level 1 Bridge Railings

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Twenty-three states, FHWA, and the District of Columbia sponsored the project Testing of New Bridge Rail and Transition Designs that was completed in September 1993. Bridge railing for Performance Levels 1, 2, and 3, as specified in the 1989 American Association of State Highway and Transportation Officials *Guide Specifications for Bridge Railings*, were tested under the contract. This paper discusses the design and performance of the two bridge railings tested at Performance Level 1. The Oregon side-mounted railing has been used on small bridges on low-volume rural roads and is typically mounted on pre-stressed deck planks. The W6 × 15 posts are mounted on the side face of exterior planks, and a single thickness of 10-gauge thrie beam is mounted to the posts without blockouts. Height to the top of the rail element is 690 mm (27 in.). The BR27D railing design consists of a concrete parapet with a metal beam-and-post railing mounted on top of the parapet. For testing, it was mounted both on top of a sidewalk and flush on the deck.

In August of 1986, a major pooled-funds project was initiated to evaluate numerous bridge railings and transitions (*1*). When the project was completed in 1993, 37 full-scale crash tests were performed. Bridge railings were evaluated at Performance Levels 1, 2, and 3. Objectives of the study were to develop safer bridge rail and transition designs and improve design guidelines. This report focuses on the performance of the PL1 bridge railings tested under the pooled-funds project.

The first railing discussed is the Oregon side-mounted bridge railing. A single thickness 10-guage thrie beam is mounted on W6 × 15 posts spaced 1.9 m (6.25 ft) on center. Maximum deflection from the pickup crash test was 330 mm (13.0 in.) at the top of the thrie beam. This design is somewhat more flexible than the BR27D that was also tested. The BR27D bridge railing consists of two tubular box members atop a 457-mm (18.0-in.) concrete parapet. Tests were performed with and without a sidewalk. Lateral displacement of the top rail element on both tests was 13 mm (0.5 in.). All railings tested at PL1 under this contract were judged to have acceptable performance.

DESIGN CONSIDERATIONS

The 1989 guide specification sets forth three performance levels for bridge railings (*2*). A 2,452-kg (5,400-lb) pickup truck traveling at 72 km/hr (45 mph) with an impact angle of 20 degrees is used to evaluate the strength and height of a PL1 railing. The required minimum height of the resultant of resisting force provided by the railing to prevent the vehicle from rolling over the railing is at or somewhat below the center-of-gravity of the test vehicle. Height to the center-of-gravity of a typical empty 3/4-ton pickup is about 660 mm (26 in.), and the empty weight is about 2,088 kg (4,600 lb). Onboard instrumentation used in tests increases the weight, and ballast (fixed to the vehicle) is typically used to adjust the test inertia weight to 2,452 kg (5,400 lb). The ballast is positioned to provide a center-of-gravity of the total mass at 690 mm (27 in.) above the ground. The recommended design force of 133 kN (30 kips) used for PL1 railings is a uniformly distributed line force 1.07 m (42 in.) long located at least 610 mm (24 in.) above the roadway surface.

Much of the information used to establish recommended values of design force was developed in two earlier FHWA research studies (*3,4*). In those studies, a rigid flat-faced vertical wall was instrumented with load cells and accelerometers to measure transverse forces during crashes under various impact conditions. The force recommended for design of railings is based on highest 0.050-sec averages of measured forces. It is recommended that no factor of safety (i.e., load factor = 1.0) be used with the values of force in ultimate strength analyses of railings for specified test conditions.

Besides providing adequate strength, a railing system must provide suitable geometrics for interaction with the vehicle. Adequate height must be provided to prevent the vehicle from rolling over the railing. Sufficient frontal area must be provided to adequately engage the vehicle and provide a smooth redirection without too much snagging and longitudinal deceleration.

A yieldline analysis procedure was used for the concrete parapet bridge railing (*5*). The expected yieldline failure pattern for a concrete parapet consists of three yield lines extending from a point directly below the center of the load and at the base of the parapet. One line extends vertically and the other two extend diagonally to the top of the parapet.

A plastic hinge failure mechanism analysis technique was used for metal beam and post systems (*5*). Typical failure mechanisms for such railing systems occur in one, two, or three spans with plastic hinges forming at the mid-length of the railing failure mechanism and at the base of posts within the failure mechanism.

FULL-SCALE CRASH TESTS

Two PL1 designs were evaluated. They were:

1. Oregon side-mounted railing.
2. BR27D on sidewalk and on deck.

A summary of the tests performed is presented in Table 1.

Oregon Side-Mounted Railing

The original design for this railing was proposed by the Oregon DOT. It has been used on small bridges on low-volume rural roads and is typically mounted on pre-stressed deck planks. The W6 × 15 posts are mounted on the side face of exterior planks, and a single thickness of 10-gauge thrie beam is mounted to the posts without blockouts. Height to the top of the rail element is 690 mm (27 in.). A drawing for this railing design is shown in Figure 1.

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TABLE 1 Summary of Full-Scale Crash Tests Performed on Performance Level 1 Railings

RAILING DESIGN	TEST NO.	ACTUAL CONDITIONS	OCCUPANT RISK				PERF.
			Vx(m/s)	Vy(m/s)	Ax(g's/10ms)	Ay(g's/10ms)	
OREGON SIDE-MOUNTED	7069-17	894 kg|84.0 km/h|19.7 deg	5.7	5.8	-1.8	4.5	Accept
	7069-18	2605 kg|74.2 km/h|20.9 deg	5.2	3.6	-3.6	8.8	Accept
BR27D ON SIDEWALK	7069-22	893 kg|83.2 km/h|20.8 deg	3.7	1.9	-4.7	-13.3	Accept
	7069-23	2527 kg|72.9 km/h|20.2 deg	4.0	4.3	-2.3	-10.6	Accept
BR27D ON DECK	7069-30	894 kg|82.4 km/h|20.5 deg	4.9	6.6	-3.6	-6.1	Accept
	7069-31	2527 kg|73.4 km/h|18.8 deg	3.6	3.7	2.2	-8.2	Accept

1 kg = 2.2 lb 1 km = 0.6 mi

Test 7069-17: 817-kg (1,800-lb) Honda Civic, 84.0 km/hr (52.2 mph), 19.7 degrees

The vehicle struck the bridge railing approximately 6.3 m (20.6 ft) from the upstream end. The vehicle lost contact with the bridge railing at 0.26 sec traveling at 68.7 km/hr (42.7 mph) and 7.1 degrees. It was in contact with the railing for 2.8 m (9.3 ft).

The railing received moderate damage (Figure 2). Maximum lateral deflection was 13 mm (0.5 in.) at the top of Post 5. At Post 4, the top anchor bolts connecting the post to the bridge deck showed structural distress. One bolt was pulled from the anchor insert in the concrete. Post 5 was bent outward about 13 mm (0.5 in.) at the top, and the top anchor bolts showed structural distress. One of the bolts in this post was also pulled from the anchor insert.

Examination of anchor bolts in all the posts after the tests shows that the bolts had been cut off during construction and, in some, only three or four threads were engaged in the anchor insert. The plans called for a minimum thread engagement of 22 mm (7/8 in). Evidently, concrete had flowed into the anchors during fabrication of the pre-stressed deck slabs and the anchor bolts had been cut off to prevent them from bottoming out. This was not detected during the construction inspection process. Before the next test, concrete was removed from all anchor inserts and new full-length anchor bolts were installed.

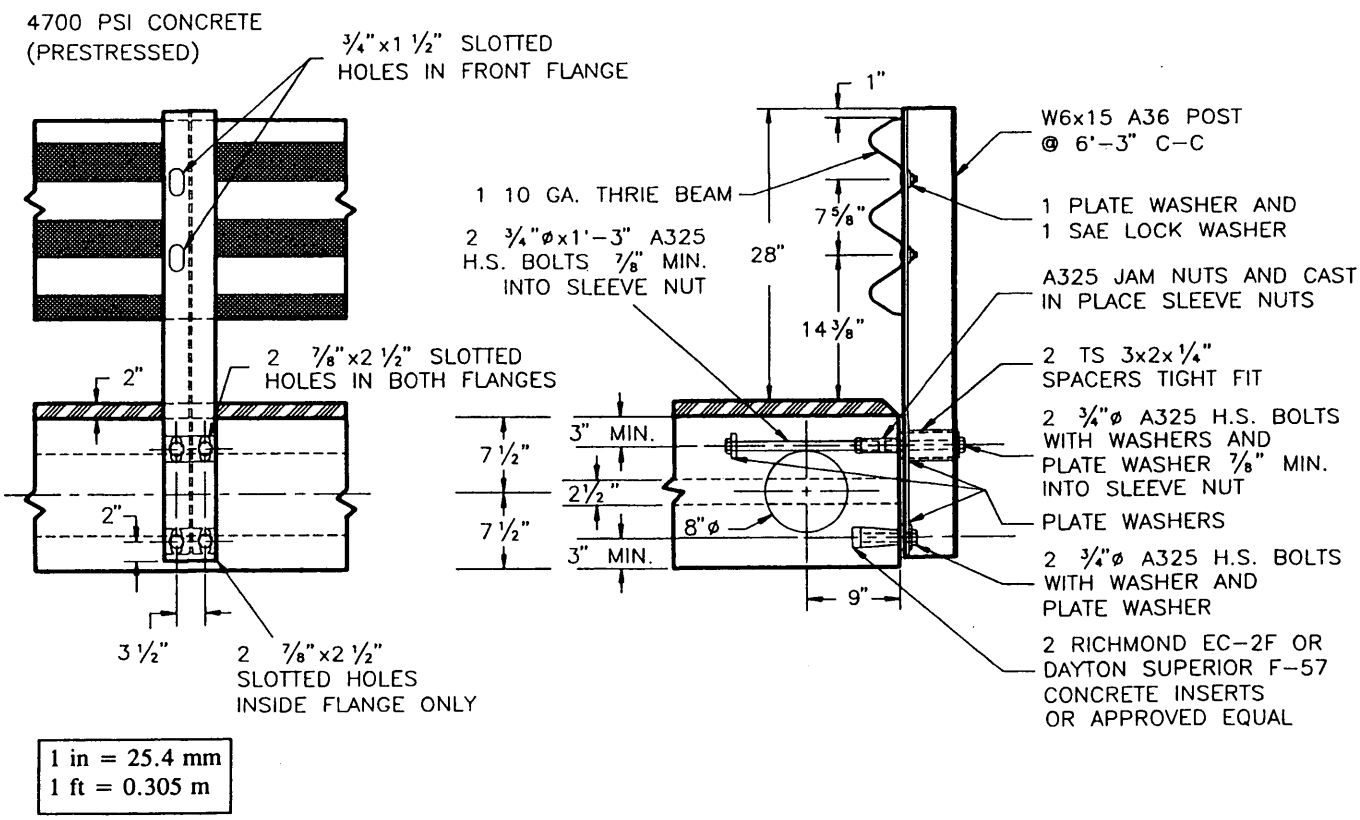


FIGURE 1 Details of Oregon side-mounted bridge railing.

FIGURE 2 Damage to vehicle and railing systems for Test 7069-17.

The vehicle sustained damage to the right side (Figure 2). Maximum crush at the right front corner at bumper height was 229 mm (9.0 in.).

The railing contained the vehicle with minimal lateral movement of the bridge railing. There was no intrusion into the occupant compartment and no deformation of the compartment. The bridge railing smoothly redirected the vehicle, and the effective coefficient of friction was considered fair. The occupant risk factors were within the limits recommended in the 1989 AASHTO guide specifications (*2*). Data and other pertinent information from this test are summarized in Figure 3. The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged to be acceptable.

Test 7069-18: 2,528-kg (5,573-lb) Chevrolet Pickup, 74.2 km/hr (46.1 mph), 20.9 degrees

The vehicle struck the bridge railing approximately 12.6 m (41.3 ft) from the upstream end. The vehicle lost contact with the bridge railing at 0.46 sec traveling at 57.8 km/hr (35.9 mph) and 10.9 degrees. It was in contact with the railing for 5.0 m (16.3 ft).

The railing received moderate damage (Figure 4). At Post 8 the upper deck bolts connecting the post to the bridge deck were bent and the post was bent back 38 mm (1.5 in.) at the bridge deck surface. Post 9 was bent 64 mm (2.5 in.), the upper deck bolt on the right side was bent, and the upper deck bolt on the left side pulled through the outer flange. Post 10 was slightly twisted. Maximum lateral deflection was 330 mm (13.0 in.) at the top of the thrie beam between Posts 8 and 9.

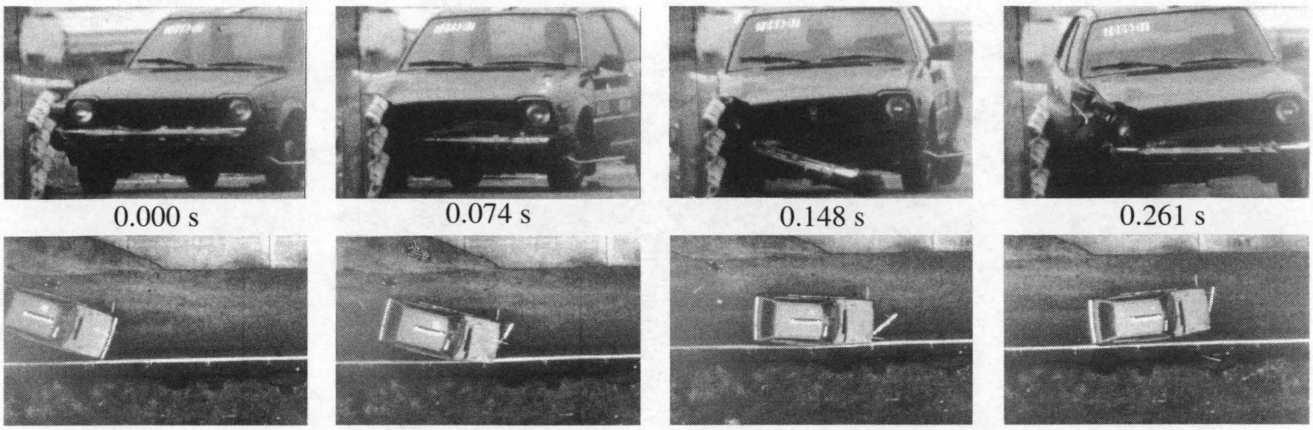
The vehicle sustained damage to the right side as shown in Figure 5. Maximum crush at the right front corner at bumper height was 165 mm (6.5 in.).

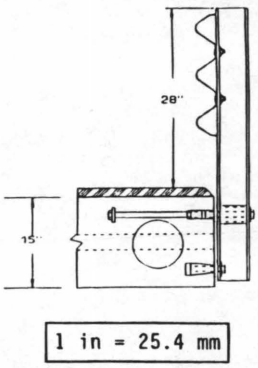
The railing contained the vehicle with minimal lateral movement of the bridge railing. There was no intrusion into the occupant compartment and no deformation of the compartment. The railing smoothly redirected the vehicle, and the effective coefficient of friction was considered fair. The occupant risk factors were within the limits recommended in the 1989 AASHTO guide specifications (*2*). Data and other pertinent information from this test are summarized in Figure 6. The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged to be acceptable.

BR27D on Sidewalk

This railing design concept was selected by the project panel to meet a need for a railing for urban areas. Many states are currently using railing designs that are similar to BR27D in that they consist of a concrete parapet with an open metal railing on top. The BR27D





Test No.	7069-17
Date	05/10/89
Test Installation	Oregon Side-Mounted Bridge Railing
Installation Length	26 m (85 ft)
Test Vehicle	1980 Honda Civic
Vehicle Weight	
Test Inertia	817 kg (1,800 lb)
Gross Static	894 kg (1,970 lb)
Vehicle Damage Classification	
TAD	01FR4 & 01RFQ3
CDC	01FREK2 & 01RFEW3
Maximum Vehicle Crush	229 mm (9.0 in)
Impact Speed	84.0 km/h (52.2 mi/h)
Impact Angle	19.7 deg
Speed at Parallel	70.8 km/h (44.0 mi/h)
Exit Speed	68.7 km/h (42.7 mi/h)
Exit Trajectory	7.1 deg
Vehicle Accelerations (Max. 0.050-sec avg)	
Longitudinal	-5.2 g
Lateral	8.47 g
Occupant Impact Velocity at true c.g.	
Longitudinal	5.7 m/s (18.8 ft/s)
Lateral	5.8 m/s (18.9 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-1.8 g
Lateral	4.5 g

FIGURE 3 Summary of results for Test 7069-17.

consists of two TS 102 × 76 × 6.4-mm (TS 4 × 3 × 1/4-in.) rails attached to TS 102 × 102 × 4.8-mm (TS 4 × 4 × 3/16-in.) posts on 2.0-m (6 ft, 8 in.) centers. The posts are atop a concrete parapet 25 mm (10 in.) wide 457-mm (18.0 in.) tall, that is attached to a 203-mm (8.0-in.) deck.

BR27D was tested to PL1 with and without the curb and sidewalk. A somewhat similar design, BR27C, was tested to PL2 with and without the curb and sidewalk (*1*).

In the analysis and design of BR27D with curb and sidewalk, information on the influence of the curb on vehicle trajectory was needed. Some information on this subject for 1,589-kg (3,500 lb) automobiles was found in the 1977 barrier guide (*6*). No data specifically for vehicles used in tests on BR27D were available. The expected influence of the 200-mm (8.0-in) curb on the trajectory of a Honda Civic, a pickup truck, and an 8,172-kg (18,000-lb) truck was estimated from available data. A design force of 133 kN (30 kips) at 890 mm (35 in) above the top surface of the sidewalk was selected for design of BR27D. A cross section of this railing design is shown in Figure 7.

Test 7069-22: 817-kg (1,800-lb) Honda Civic, 83.2 km/hr (51.7 mph), 20.8 degrees

Upon impact with the curb, the left front tire folded under the vehicle. When the right front wheel reached the top of the curb, the vehicle was totally airborne and remained as such as it struck the concrete parapet at 0.26 sec. The vehicle struck the parapet at Post 5 traveling at a speed of 75.0 km/hr (46.6 mph) and at an angle of 13.4 degrees. The vehicle lost contact with the parapet at 0.61 sec traveling at 65.6 km/hr (40.8 mph) and 6.1 degrees.

The bridge railing system received minimal damage (see Figure 9). There was no measurable permanent deformation to the railing elements and only cosmetic damage to the concrete parapet. There were tire marks on the concrete parapet and on the face of the lower metal railing element in the area of impact, and also on the lower part of Post 6. The vehicle was in contact with the bridge railing for 3.5 m (11.5 ft). Length of contact with the concrete parapet was 2.1 m (7.0 ft).

The vehicle sustained damage to the left side as shown in Figure 8. Maximum crush at the left front corner at bumper height was 152 mm (6.0 in.).

The railing contained the vehicle with no lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The bridge railing smoothly redirected the vehicle. The effective coefficient of friction was considered marginal. The occupant impact velocities and the occupant ridedown accelerations were within the limits. Data and other pertinent information from this test are summarized in Figure 9. Vehicle trajectory

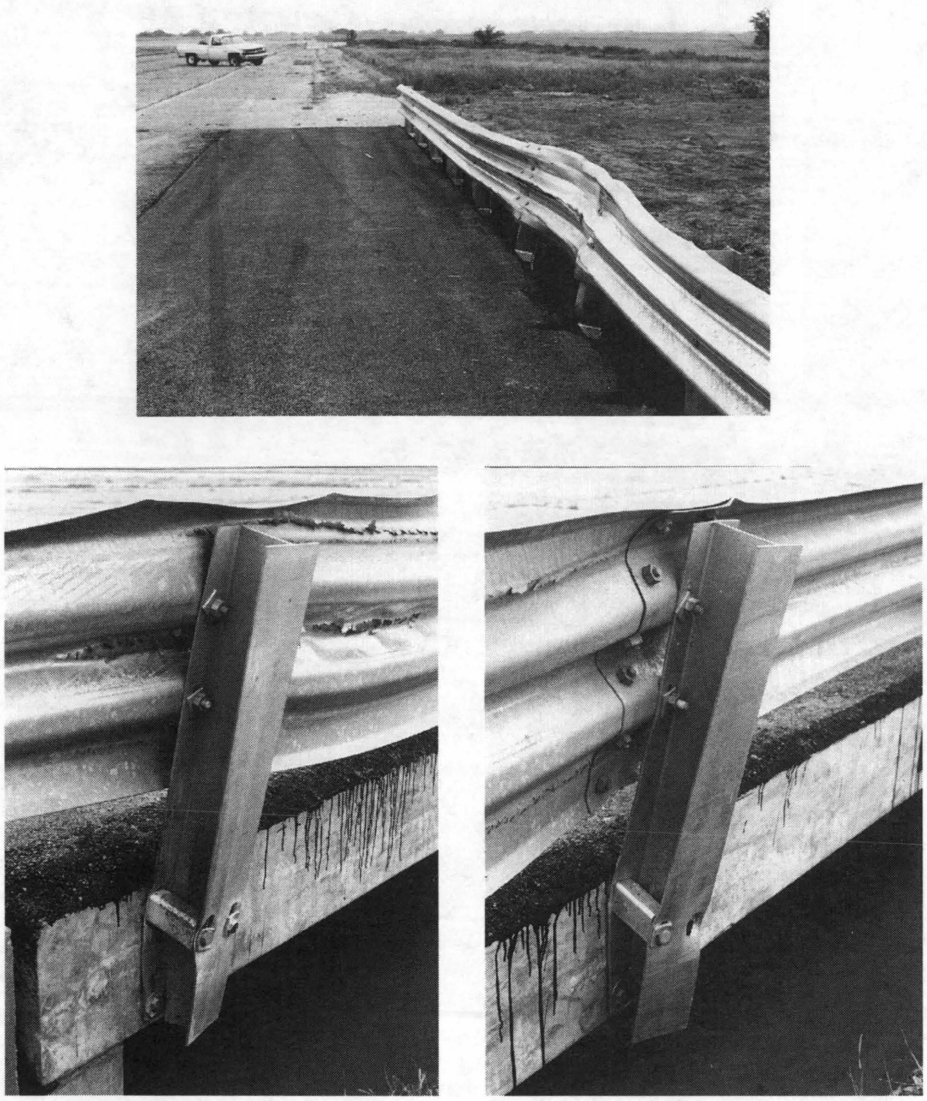


FIGURE 4 Damage to railing in Test 7069-18.

at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged to be acceptable.

Test 7069-23: 2,450-kg (5,400-lb) Chevrolet Pickup, 72.9 km/hr (45.3 mph), 20.2 degrees

The vehicle struck the concrete parapet at 0.22 sec. The vehicle struck the parapet 0.9 m (3 ft) from Post 5 (between Posts 4 and 5) traveling at a speed of 70.5 km/hr (43.8 mph) and at an angle of 19.7 degrees. As the vehicle continued forward, the bumper protruded between the lower metal railing element and the concrete parapet. The vehicle lost contact with the concrete parapet traveling at 59.9 km/hr (37.2 mph) and 5.3 degrees. It was in contact with the railing for 3.9 m (12.8 ft).

The bridge railing received minimal damage (Figure 10). The maximum permanent deformation to the railing element was 13 mm (0.5 in.) between Posts 5 and 6. Posts 5 and 6 were also pushed rearward approximately 5 mm (3/16 in.). There was only cosmetic damage to the concrete parapet. Tire marks were observed on the concrete parapet, on the face of the lower metal railing element in the area of impact, and also on the lower part of Posts 5 and 6.

The vehicle sustained damage to the left side as shown in Figure 10. Maximum crush at the left front corner at bumper height was 318 mm (12.5 in.), and the right side was deformed outward 127 mm (5.0 in.).

The railing contained the vehicle with minimal lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The bridge railing smoothly redirected the vehicle. The effective coefficient of friction was considered good. The occupant impact velocities and the occupant ridedown accelerations were within the limits. Data and other pertinent information from

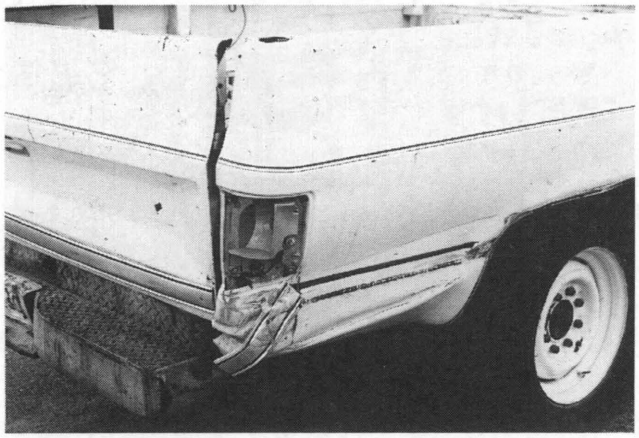


FIGURE 5 Damage to vehicle in Test 7069-18.

this test are summarized in Figure 11. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged to be acceptable.

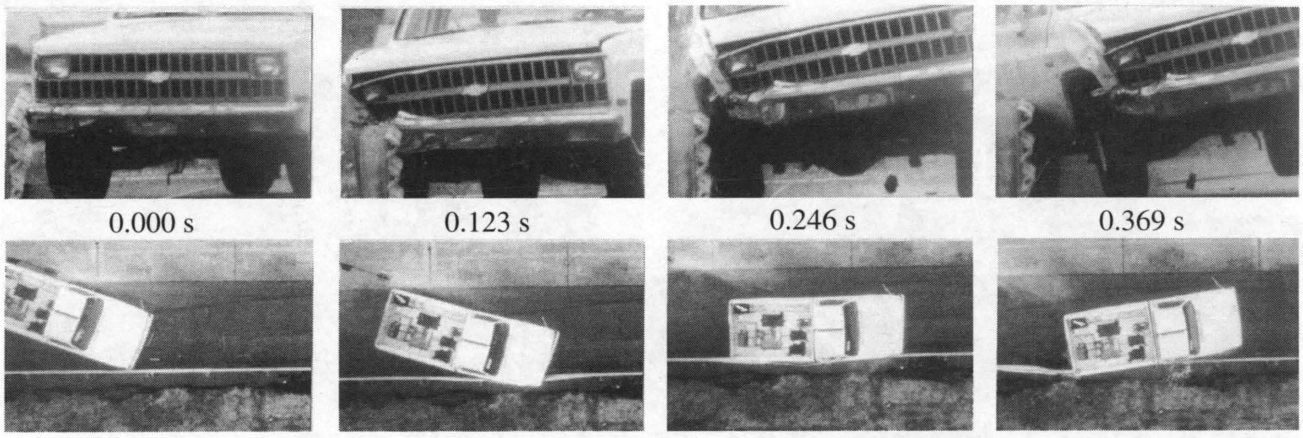
BR27D on Deck

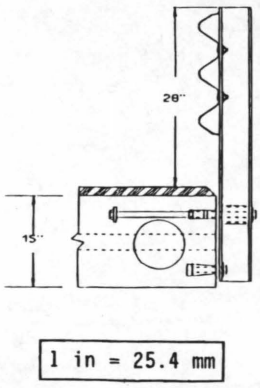
Design of this railing was identical to BR27D on sidewalk. It was mounted on the deck without a curb and sidewalk. A cross section of the prototype test railing is similar to the one shown in Figure 8.

Test 7069-30: 817-kg (1,800-lb) Honda Civic, 82.4 km/hr (51.2 mph), 20.5 degrees

Shortly after impact the vehicle began to redirect. At approximately 0.10 sec after impact the dummy struck the driver-side door and shattered the door glass. The vehicle lost contact with the bridge railing at 0.32 sec traveling at 69.2 km/hr (43.0 mph) and 6.8 degrees. It was in contact with the railing for 2.4 m (8.0 ft).

The bridge railing received minimal damage (Figure 12). There was no measurable permanent deformation to the railing elements





Test No.	7069-18
Date	05/12/89
Test Installation	Oregon Side-Mounted Bridge Railing
Installation Length	26 m (85 ft)
Test Vehicle	1982 Chevrolet Custom Deluxe Pickup
Vehicle Weight	
Test Inertia	2 452 kg (5,400 lb)
Gross Static	2 605 kg (5,737 lb)
Vehicle Damage Classification	
TAD	01RF2 & 01 RFQ3
CDC	01FREK2 & 01RFEW2
Maximum Vehicle Crush	165 mm (6.5 in)

Impact Speed	74.2 km/h (46.1 mi/h)
Impact Angle	20.9 deg
Speed at Parallel	61.5 km/h (38.2 mi/h)
Exit Speed	57.8 km/h (35.9 mi/h)
Exit Trajectory	10.9 deg
Vehicle Accelerations (Max. 0.050-sec avg)	
Longitudinal	-3.8 g
Lateral	6.7 g
Occupant Impact Velocity at true c.g.	
Longitudinal	5.2 m/s (17.1 ft/s)
Lateral	3.6 m/s (11.7 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-3.6 g
Lateral	8.8 g

FIGURE 6 Summary of results for Test 7069-18.

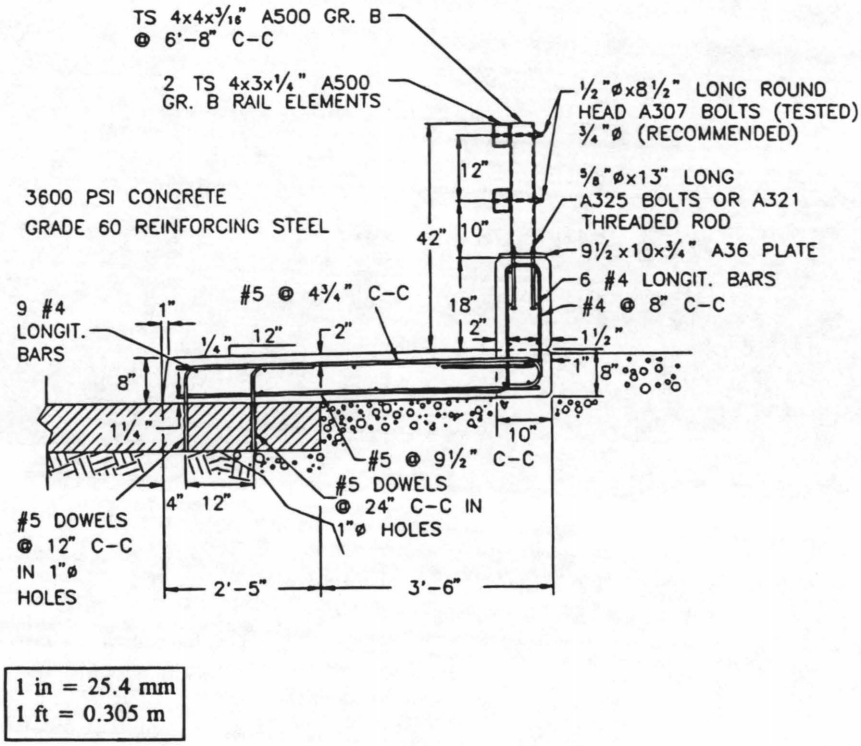


FIGURE 7 Cross section of BR27D bridge railing on sidewalk.

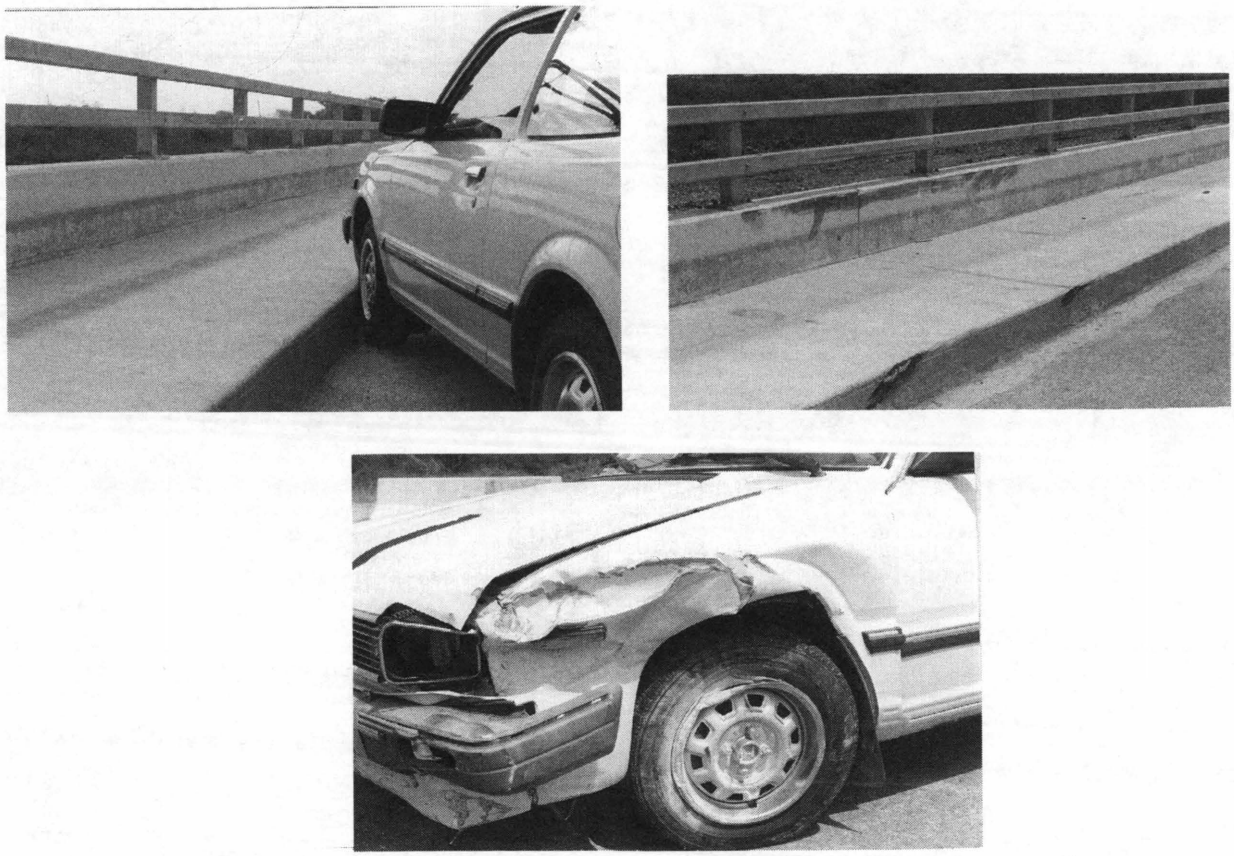
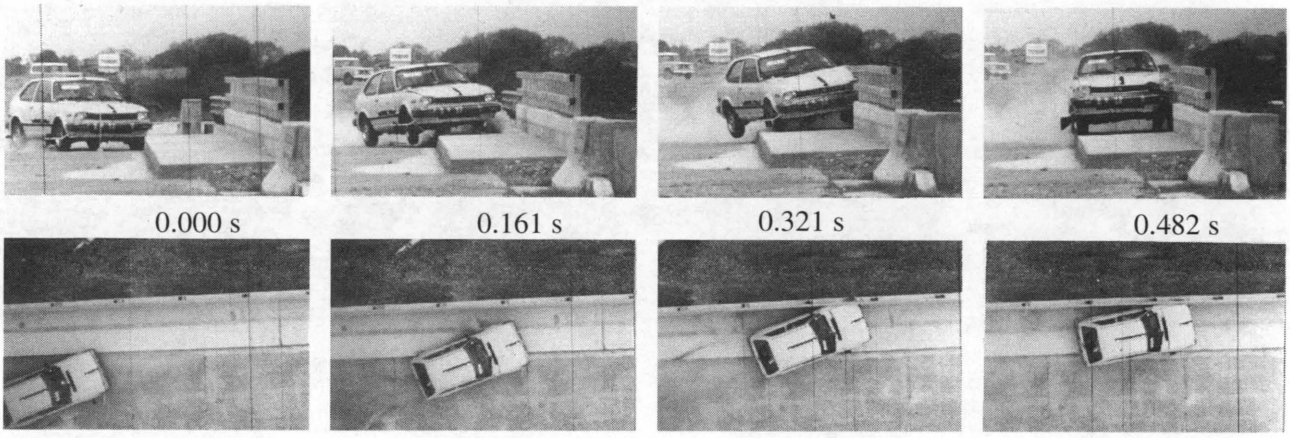
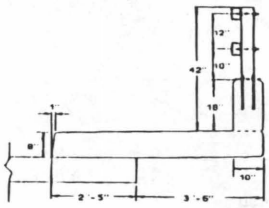


FIGURE 8 Vehicle and railing damage for Test 7069-22.





1 in = 25.4 mm

Test No.	7069-22
Date	03/24/92
Test Installation	BR27D Bridge Railing on sidewalk
Installation Length	30 m (100 ft)
Test Vehicle	1983 Honda Civic
Vehicle Weight	
Test Inertia	817 kg (1,800 lb)
Gross Static	893 kg (1,967 lb)
Vehicle Damage Classification	
TAD	11LFQ3
CDC	11LFEK2 & 11LFES2
Maximum Vehicle Crush	152 mm (6.0 in)

Impact Speed	83.2 km/h (51.7 mi/h)
Impact Angle	20.8 deg
Speed at Parallel	66.0 km/h (41.0 mi/h)
Exit Speed	65.6 km/h (40.8 mi/h)
Exit Trajectory	6.1 deg
Vehicle Accelerations (Max. 0.050-sec avg)	
Longitudinal	-4.4 g
Lateral	-6.8 g
Occupant Impact Velocity at true c.g.	
Longitudinal	3.7 m/s (12.2 ft/s)
Lateral	6.3 m/s (1.9 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-4.7 g
Lateral	-13.3 g

FIGURE 9 Summary of results for Test 7069-22.

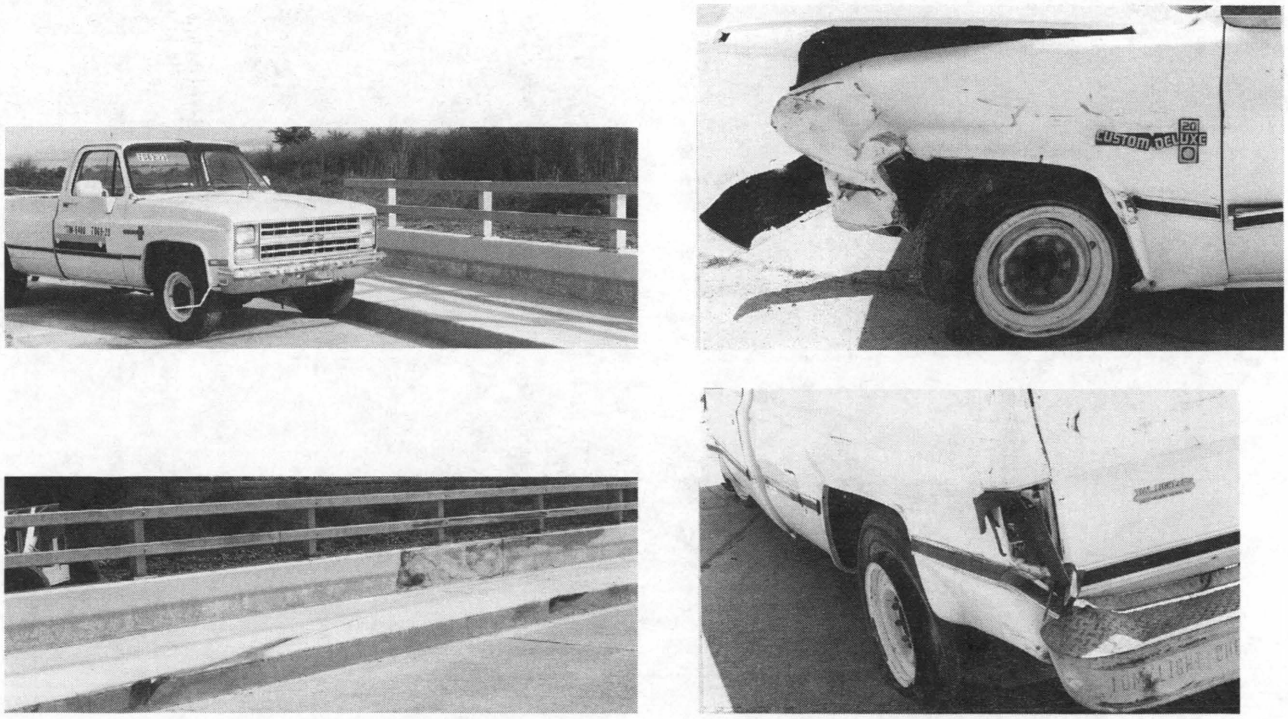
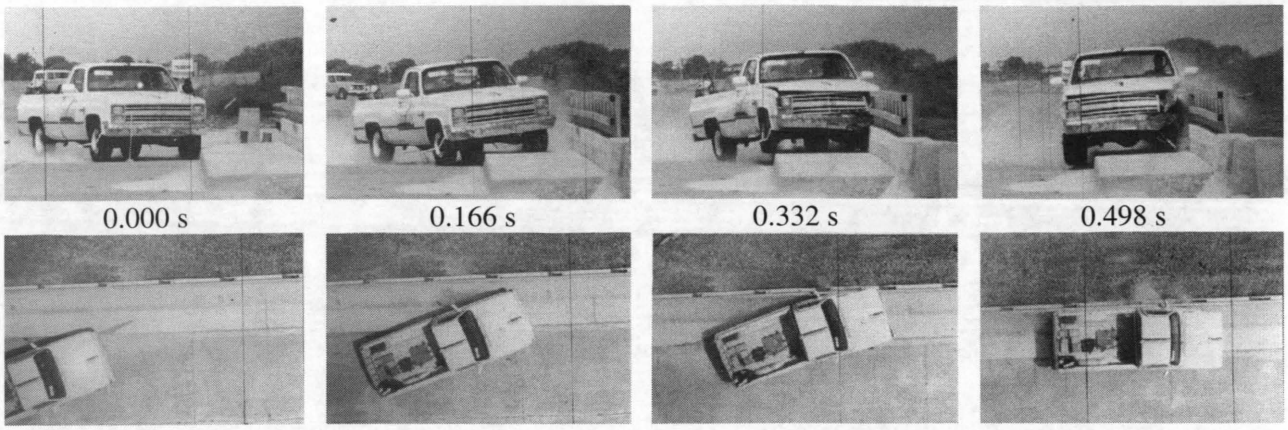
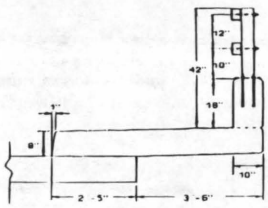


FIGURE 10 Vehicle and railing damage for Test 7069-23.





1 in = 25.4 mm

Test No.	7069-23
Date	03/26/92
Test Installation	BR27D Bridge Railing on sidewalk
Installation Length	30 m (100 ft)
Test Vehicle	1984 Chevrolet Custom Pckup
Vehicle Weight	
Test Inertia	2 452 kg (5,400 lb)
Gross Static	2 527 kg (5,565 lb)
Vehicle Damage Classification	
TAD	11FL4 & 11LD4
CDC	11FLEK2 & 11LDEW3
Maximum Vehicle Crush	318 mm (12.5 in)
Impact Speed	72.9 km/h (45.3 mi/h)
Impact Angle	20.2 deg
Speed at Parallel	64.8 km/h (40.3 mi/h)
Exit Speed	59.9 km/h (37.2 mi/h)
Exit Trajectory	5.3 deg
Vehicle Accelerations (Max. 0.050-sec avg)	
Longitudinal	-3.7 g
Lateral	-7.8 g
Occupant Impact Velocity at true c.g.	
Longitudinal	4.0 m/s (13.2 ft/s)
Lateral	4.3 m/s (14.0 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-2.3g
Lateral	-10.6 g

FIGURE 11 Summary of results for Test 7069-23.

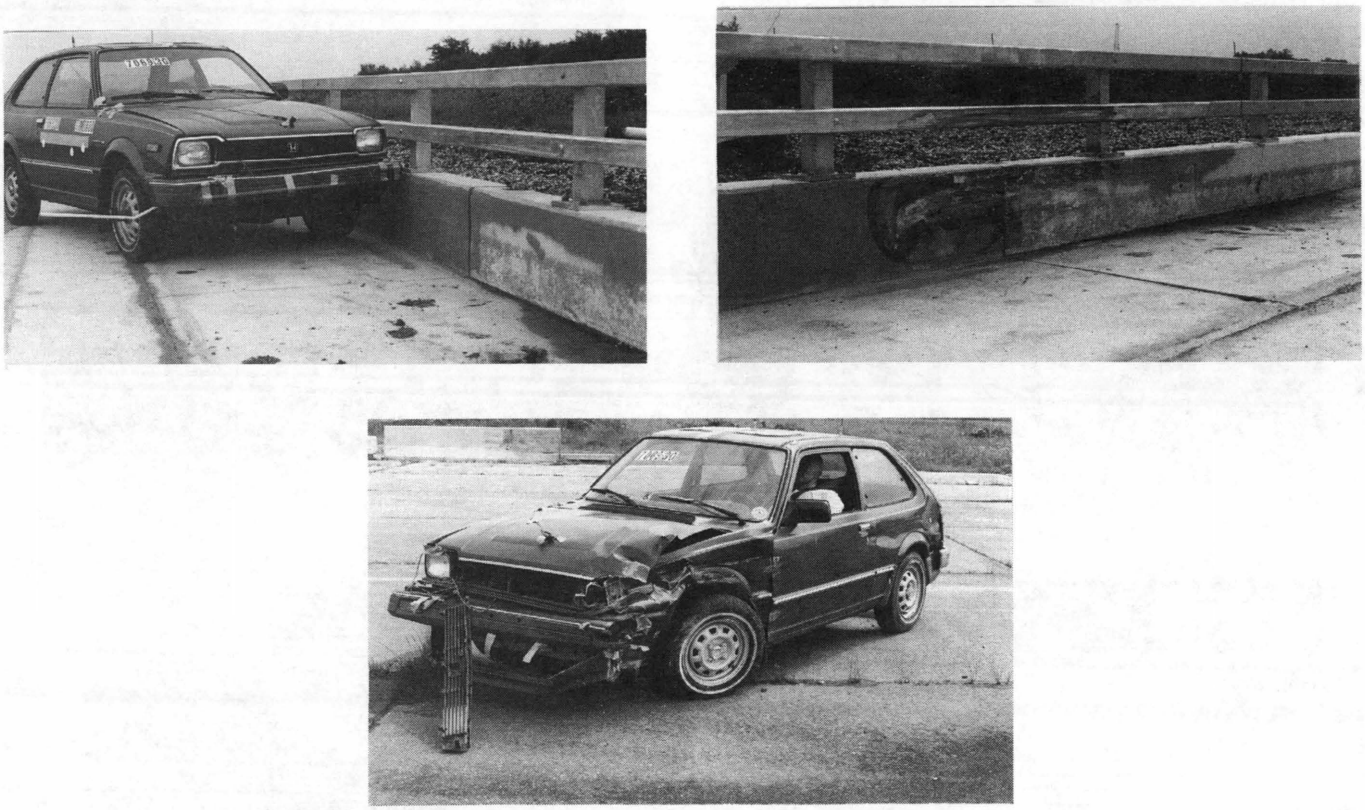


FIGURE 12 Vehicle and railing for Test 7069-30.

and only cosmetic damage to the concrete parapet. Tire marks were observed on the concrete parapet and on the face of the lower metal railing element in the area of impact.

Maximum crush of the vehicle at the left front corner at bumper height was 178 mm (7.0 in.) (Figure 12). The left front strut was damaged and the left front wheel was canted inward at the bottom and pushed back, reducing the wheelbase on the driver side by 57 mm (2.25 in.).

The railing contained the vehicle with no lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The bridge railing smoothly redirected the vehicle. The effective coefficient of friction was considered good. The occupant impact velocities and the occupant ridedown accelerations were within the limits. Data and other pertinent information from this test are summarized in Figure 13. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged to be acceptable.

Test 7069-31: 2,450-kg (5,400-lb) Chevrolet Pickup, 73.4 km/hr (45.6 mph), 18.8 degrees

The vehicle began to redirect at 0.05-sec after impact, and at 0.15 sec the dummy struck the driver-side door and shattered the glass. The vehicle lost contact with the bridge railing at 0.33 sec traveling at 61.1 km/hr (38.0 mph) and 6.2 degrees. It was in contact with the railing for 3.6 m (11.7 ft).

The bridge railing received minimal damage (Figure 14). The maximum permanent deformation to the railing element was 13 mm (0.5 in.) between Posts 5 and 6. There was only cosmetic damage to the concrete parapet. Tire marks were observed on the concrete parapet, on the face of the lower metal railing element in the area of impact, and also on the lower part of Post 6.

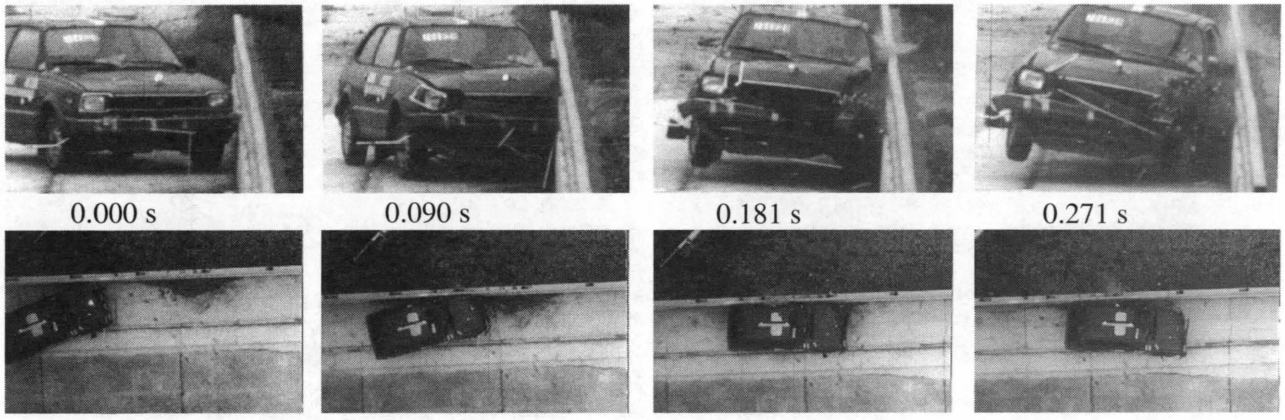
Maximum crush of the vehicle at the left front corner at bumper height was 165 mm (6.5 in.), and the right side was deformed outward 102 mm (4.0 in.) (Figure 14).

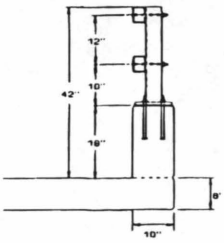
The railing contained the vehicle with minimal lateral movement of the metal railing element of the bridge railing system. There was no intrusion of railing components into the occupant compartment and no debris to present undue hazard to other traffic. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The bridge railing smoothly redirected the vehicle. The effective coefficient of friction was considered good. The occupant impact velocities and the occupant ridedown accelerations were within the limits. Data and other pertinent information from this test are summarized in Figure 15. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes.

Performance of the railing in this test is judged to be acceptable.

SUMMARY

The Oregon side-mounted railing is a rather uncomplicated design that uses mostly standard hardware items. It has adequate strength and height for PL1 and, under more severe impact, exhibits plastic deformation that limits accelerations imposed on the vehicle. Plas-



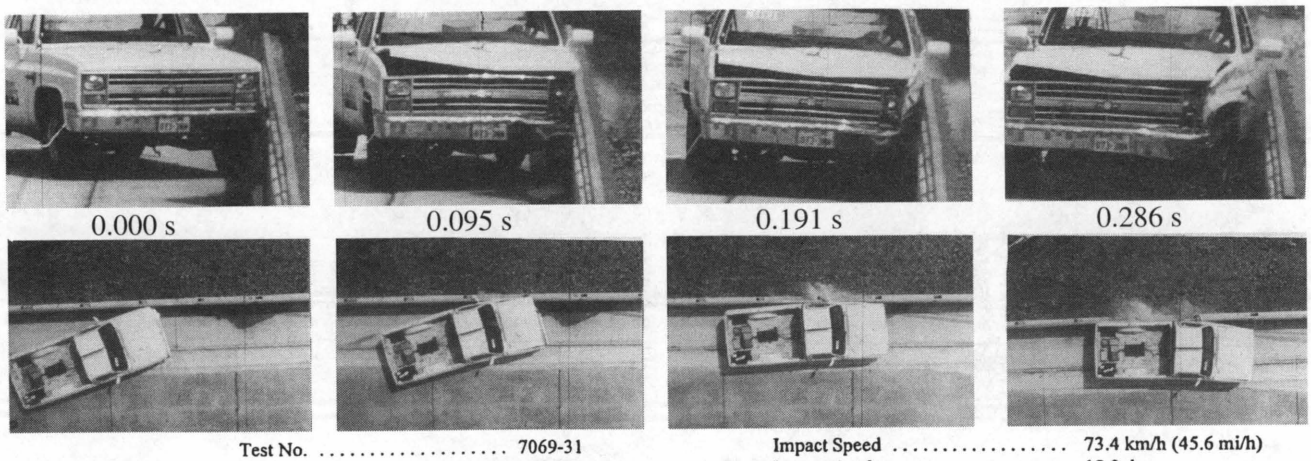


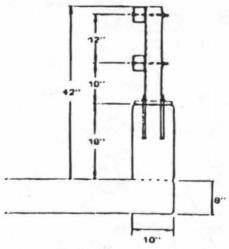
1 in = 25.4 mm

Test No.	7069-30
Date	05/19/92
Test Installation	BR27D Bridge Railing on deck
Installation Length	30 m (100 ft)
Test Vehicle	1983 Honda Civic
Vehicle Weight	
Test Inertia	817 kg (1,800 lb)
Gross Static	894 kg (1,970 lb)
Vehicle Damage Classification	
TAD	11LFQ3
CDC	11FLEK2 & 11LFES2
Maximum Vehicle Crush	178 mm (7.0 in)
Impact Speed	82.4 km/h (51.2 mi/h)
Impact Angle	20.5 deg
Speed at Parallel	70.2 km/h (43.6 mi/h)
Exit Speed	69.2 km/h (43.0 mi/h)
Exit Trajectory	6.8 deg
Vehicle Accelerations (Max. 0.050-sec avg)	
Longitudinal	-7.5 g
Lateral	-12.8 g
Occupant Impact Velocity at true c.g.	
Longitudinal	4.9 m/s (16.0 ft/s)
Lateral	6.6 m/s (21.5 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-3.6g
Lateral	-6.1 g

FIGURE 13 Summary of results for Test 7069-30.

FIGURE 14 Vehicle and railing for Test 7069-31.





1 in = 25.4 mm

Test No.	7069-31
Date	05/21/92
Test Installation	BR27D Bridge Railing on deck
Installation Length	30 m (100 ft)
Test Vehicle	1985 Chevrolet Custom Pickup
Vehicle Weight	
Test Inertia	2 452 kg (5,400 lb)
Gross Static	2 527 kg (5,566 lb)
Vehicle Damage Classification	
TAD	11LFQ3 & 11LD2
CDC	11FLEK2 & 11LDEW2
Maximum Vehicle Crush	165 mm (6.5 in)

Impact Speed	73.4 km/h (45.6 mi/h)
Impact Angle	18.8 deg
Speed at Parallel	65.6 km/h (40.8 mi/h)
Exit Speed	61.1 km/h (38.0 mi/h)
Exit Trajectory	6.2 deg
Vehicle Accelerations (Max. 0.050-sec avg)	
Longitudinal	-4.1 g
Lateral	-7.5 g
Occupant Impact Velocity at true c.g.	
Longitudinal	3.6 m/s (11.7 ft/s)
Lateral	3.7 m/s (12.3 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	2.2 g
Lateral	-8.2 g

FIGURE 15 Summary of results for Test 7069-31.

tic deformation was confined to metal railing components, and no damage was caused to the deck.

Railing design BR27D was tested to PL1 under two situations. First, it was tested when mounted on a sidewalk 1.5 m (5 ft) wide with a curb 203 mm (8 in.) high at the face of the sidewalk. It also was tested when mounted flush on the deck. Acceptable results were obtained in both series of tests. The small car test yielded lower occupant values when the BR27D was mounted with a curb and sidewalk. Redirection was initiated by the curb impact, thus lowering the occupant risk values when the ultimate redirection occurred with the railing. The curb and sidewalk did not affect the pickup tests in either reducing or increasing the occupant risk values. For the most part, the railing functioned as a "rigid" railing with only a small amount of permanent deformation in the metal railing in the more severe tests.

The results of all tests are summarized in Table 1.

CONCLUSIONS

All PL1 bridge railings tested under this contract performed acceptably. There were deflections in the Oregon side-mounted bridge railing, but the deck remained undamaged. The BR27D performed well with and without curb and sidewalk. There were minor deflections in the top rail of this system and cosmetic damage to the concrete section of the rail. All occupant risk values, as summarized earlier, were within acceptable limits.

PL1 bridge rails provide a cost-effective alternative to state agencies when traffic volume, mix, and speed do not warrant the more expensive PL2 and PL3 bridge rails. The Oregon side-mounted railing and the BR27D railing are full-scale crash-tested systems that are ready for use.

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