Performance Level 2 Bridge Railings

C. E. Buth, T. J. Hirsch, and C. F. McDevitt

The highway profession is in the process of upgrading performance of bridge railing systems. In 1989 the American Association of State Highway and Transportation Officials adopted the *Guide Specifications for Bridge Railings*. That document addresses bridge railing systems for three levels of performance. Proof of performance should be demonstrated by full-scale crash tests set forth in that guide, and there is a general trend toward full-scale crash testing of new highway safety hardware in the highway industry. Performance level selection procedures included in the guide indicate that a performance level 2 (PL 2) railing is needed on many new bridge structures. This level has a strength test with an 18,000-lb single-unit truck striking the railing at 50 mph and at a 15-degree angle. The specified height of the center of gravity of the test truck is 49 in. Other tests with smaller vehicles are also required of a PL 2 railing. Four railing designs have been tested in a continuing pooled-funds study involving 23 states, the District of Columbia, and the Federal Highway Administration. The railings included one steel beam-and-post design and three concrete parapet designs. Performance of these railings in full-scale tests indicates that they are all acceptable for PL 2 of the 1989 guide specifications. All railings were sufficiently strong that no structural distress was observed except in the bolted rail-to-post connections in the metal railing. In all tests except one, vehicles were contained and redirected with reasonably good stability in roll and tracking with small exit angles and acceptable collision severity values. The exception was the 18,000-lb truck test on the New Jersey safety shape concrete parapet. In this test the vehicle finally rolled onto its side (away from the railing). This is considered acceptable behavior.

The Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), the National Cooperative Highway Research Program (NCHRP), and individual states have had a continuing research program on bridge railing systems including warrants, designs, testing, and evaluation of performance. In 1989 AASHTO adopted the *Guide Specifications for Bridge Railings* (*1*). This document brought together many results of recently completed and continuing research studies in a form ready for implementation by practicing highway designers.

A major pooled-funds project to study bridge railings and transitions was begun in August 1986. The project is sponsored by FHWA, the District of Columbia, and 23 states. The purpose of the study is to develop and prove, through full-scale crash tests, a collection of railing designs that would meet the needs of many of the states. Railings of different styles and various materials are to be developed so that the needs in the various climates will be best served by selections from the collection of satisfactory designs. Also, railing designs are to be developed for the various performance levels that are needed for different facilities and traffic conditions.

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The recently adopted *Guide Specifications for Bridge Railings* includes three performance levels. These levels are defined by full-scale crash test conditions and performance evaluation criteria. The guide also recommends a procedure for determining which performance level is appropriate for a given facility and traffic condition. This procedure appears to indicate that a performance level 2 (PL 2) railing would be needed on many new and replacement bridges. As seen in Table 1, PL 2 requires a strength test with an 18,000-lb single-unit truck striking at 50 mph and at a 15-degree angle.

This paper presents the results of work performed to develop and test four railing designs to meet PL 2 requirements.

DESIGN CONSIDERATIONS

Some of the early work performed under the pooled-funds bridge rail study was devoted to consideration of test vehicles and impact conditions that would be appropriate for performance levels for bridge railings. This involved study of the collision forces generated by the various vehicles at differing impact speeds and angles and the required railing heights to provide acceptable containment and redirection of the vehicles. Much of the input information for this task was taken from two earlier studies wherein full-scale collisions were performed on an instrumented concrete wall (*2,3*). This and other FHWA in-house work finally resulted in definition of the performance levels shown in Table 1.

Data from these earlier studies indicated that the longtime standard test with a 4,500-lb automobile striking at 60 mph and at a 25-degree angle generated a maximum 0.050-sec average impact force of approximately 56 to 60 kips (two separate tests) at a height above the surface of approximately 20 in. This height was measured on the flat-faced, vertical, rigid wall, and it is not necessary to provide a resisting force at that height in order to prevent rollover of the vehicle. A resisting force at a somewhat lower height is adequate because the weight of the vehicle itself resists rollover. Tests with a 20,000-lb school bus striking a 42-in.-high instrumented wall at 58 mph and 16 degrees produced a maximum 0.050-sec average impact force of approximately 74 kips at a height of approximately 23 in. Tests with an 18,000-lb single-unit truck striking a 90-in.-high instrumented wall at 51.6 mph and 16.8 degrees produced a maximum 0.050-sec average impact force of approximately 90 kips at a height of 47 in. above the road surface. If this PL 2 truck had struck a 42-in.-high wall, the estimated impact force would be reduced to about 62 kips. Because the truck cargo box had a 50-in.-high clearance above the roadway, the impact force would only be distributed over the 42-in. tire diameter. This force with a load factor of 1.0 has been used in designing bridge railings for vehicle impacts.

TABLE 1 PERFORMANCE LEVELS FOR BRIDGE RAILINGS

		TEST SPEEDS–mph[1,2]			
		TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES			
		Small Automobile	Pickup Truck	Medium Single-Unit Truck	Van-Type Tractor-Trailer[4]
PERFORMANCE LEVELS		W = 1.8 Kips A = 5.4' ± 0.1' B = 5.5' H_{cg} = 20" ± 1" θ = 20 deg.	W = 5.4 Kips A = 8.5' ± 0.1' B = 6.5' H_{cg} = 27" ± 1" θ = 20 deg.	W = 18.0 Kips A = 12.8' ± 0.2' B = 7.5' H_{cg} = 49" ± 1" θ = 15 deg.	W = 50.0 Kips A = 12.5' ± 0.5' B = 8.0' H_{cg} = See Note 4 R = 0.61 ± 0.01 θ = 15 deg.
PL-1		50	45		
PL-2		60	60	50	
PL-3		60	60		50
CRASH TEST EVALUATION CRITERIA[3]	Required	a, b, c, d, g	a, b, c, d	a, b, c	a, b, c
	Desirable[5]	e, f, h	e, f, g, h	d, e, f, h	d, e, f, h

Notes:

1. Except as noted, all full-scale tests shall be conducted and reported in accordance with the requirements in NCHRP Report N0. 230. In addition, the maximum loads that can be transmitted from the bridge railing to the bridge deck are to be determined from static force measurements or ultimate strength analysis and reported.
2. Permissible tolerances on the test speeds and angles are as follows:

Speed	-1.0 mph	+2.5 mph
Angle	-1.0 deg.	+2.5 deg.

   Tests that indicate acceptable railing performance but that exceed the allowable upper tolerances will be accepted.
3. Criteria for evaluating bridge railing crash test results are as follows:
   a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.
   b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.
   c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.
   d. The vehicle shall remain upright during and after collision.
   e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle or, in the case of a combination vehicle, the rear of the tractor or trailer does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.
   f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ:

μ	Assessment
0-0.25	Good
0.26-0.35	Fair
>0.35	Marginal

   where $\mu = (\cos\theta - V_p/V)/\sin\theta$

   g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0-ft. longitudinal and 1.0-ft. lateral displacements, shall be less than:

Occupant Impact Velocity--fps	
Longitudinal	Lateral
30	25

   and the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than:

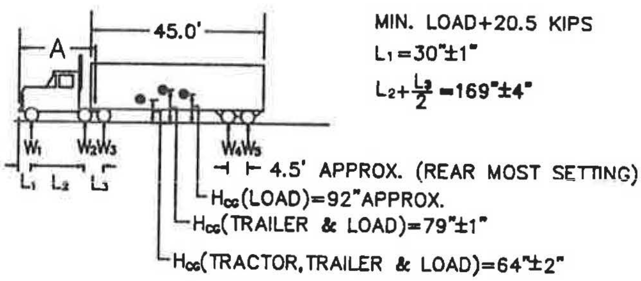
Occupant Ridedown Acceleration--g's	
Longitudinal	Lateral
15	15

   h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft. plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20-ft. from the line of the traffic face of the railing. The brakes shall not be applied until the vehicle has traveled at least 100-ft. plus the length of the test vehicle from the point of initial impact.

(continued on next page)

TABLE 1 (*continued*)

4. Values A and R are estimated values describing the test vehicle and its loading. Values A and R are described in the figure below and calculated as follows:



$$A = L_1 + \frac{W_2 L_2 + W_3 (L_2 + L_3)}{W_1 + W_2 + W_3}$$

$$R = \frac{W_1 + W_2 + W_3}{W}$$

$$W = W_1 + W_2 + W_3 + W_4 + W_5$$

= TOTAL VEHICLE WEIGHT

5. Test articles that do not meet the desirable evaluation criteria shall have their performance evaluated by a designated authority that will decide whether the test article is likely to meet its intended use requirements.

For metal beam-and-post railing systems, plastic mechanism analysis and design procedures with yield strengths of the materials were used. The applied load was assumed to be two line loads, each uniformly distributed along rail elements over a length of 42 in. The portion of load applied to each rail element was in the same ratio as its respective bending strength. Plastic hinges were assumed at the centers of the loads and at the ends of the rail element failure mechanisms. Plastic hinges were also assumed at the bases of all posts within the length of the failure mechanism.

For concrete parapet railings, yield line theory with unreduced ultimate strength bending moment capacities was used. The applied load was assumed to be a line load uniformly distributed along the top edge of the parapet over a 42-in. length of parapet. The failure pattern consisted of three yield lines extending from a point centered directly below the load and at the base of the parapet. One yield line extended vertically and the other two extended diagonally to the top edge of the parapet.

FULL-SCALE CRASH TESTS

Four railing designs for PL 2 have been tested and evaluated. They include

- Illinois 2399-1 metal railing,
- 32-in. vertical concrete parapet,
- 32-in. F-shaped concrete parapet, and
- 32-in. New Jersey safety shape concrete parapet.

A summary of the tests performed is presented in Table 2.

Illinois 2399-1 Metal Railing

This railing design was adapted from an existing design used by Illinois as a retrofit railing. It could also be used in new construction. The design load used for this railing was a 56,000-lb line load uniformly distributed over a 42-in. length of railing at 29 in. above the road surface. The posts used were W 6 × 25 rolled shapes spaced at 6 ft 3 in. W 6 × 15 posts would have had sufficient strength, but Illinois Department of Transportation engineers chose to retain the W 6 × 25 shape for other considerations. Total geometric height of the railing on the 7-in. curb is 32 in. A cross section of this railing is shown in Figure 1, and the prototype test installation is shown in Figure 2. After final selection of member sizes, a strength analysis based on a plastic mechanism and yield strengths of the materials indicated an ultimate load for the expected failure mechanism of approximately 80 kips, suggesting that the railing was somewhat overdesigned for strength. However, its height was marginal.

Three full-scale crash tests were performed on a prototype railing: (a) an 1,800-lb automobile striking at 60 mph and 20 degrees, (b) a 5,400-lb pickup truck striking at 65 mph and 20 degrees, and (c) an 18,000-lb single-unit truck striking at 50 mph and 15 degrees. The railing performed acceptably in all three tests.

Tests 7069-1 (1795-lb Automobile, 58.7 mph, 20.0 degrees)

The vehicle struck the railing midway between the sixth and seventh posts from the upstream end and was smoothly redirected. It was in contact with the railing for a distance of 9.7 ft and exited 0.226 sec after impact at an angle of 5.2 degrees. The vehicle was stable throughout the collision and was tracking on loss of contact with the railing.

Damage to the vehicle is shown in Figure 3. Maximum crush of the right front corner at bumper height was 8 in. There was no measurable movement or deformation of the railing.

Data and other pertinent information from this test are summarized in Figure 4. The effective coefficient of friction was calculated to be 0.28. Occupant impact velocity was 16.9 ft/sec in the longitudinal direction and 25.1 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were −1.4 *g* (longitudinal) and 8.5 *g* (lateral). The maximum 0.050-sec average accelerations of the vehicle were −6.4 *g* (longitudinal) and 14.2 *g* (lateral).

The barrier contained and smoothly redirected the vehicle with no lateral movement of the barrier. There were no detached

TABLE 2 FULL-SCALE CRASH TESTS

Test Number	VEHICLE Model	Test Inertia Wt (lbs)	Gross Static Wt (lbs)	IMPACT CONDITIONS Speed (mph)	Angle (deg)	Railing Design
1	1980 Honda Civic W.B. = 88 in.	1,975	1,961	58.7	20.0	Ill. 2399-1
2	1981 Chevrolet Pickup C-20 W.B. = 132 in.	5,450	5,797	63.6	19.2	Ill. 2399-1
15	1980 Ford 7000 SU Truck W.B. = 205 in.	12,320	18,000	50.8	15.1	Ill. 2399-1
5	1981 Honda Civic W.B. = 88.7 in.	1,800	1,965	60.5	21.0	32 in. Vertical Parapet
6	1982 Chevrolet Pickup C-20 W.B. = 132 in.	5,420	5,759	59.7	20.2	32 in. Vertical Parapet
16	1982 Ford 7000 SU Truck W.B. = 205 in.	13,820	18,000	50.0	14.0	32 in. Vertical Parapet
3	1980 Honda Civic W.B. = 88 in.	1,800	1,966	60.1	21.4	32 in. F-shape
4	1981 Chevrolet Pickup C-20 W.B. = 132 in.	5,440	5,780	65.4	20.4	32 in. F-shape
11	1982 Ford 7000 SU Truck W.B. = 220 in.	11,000	18,000	52.1	14.8	32 in. F-shape
14	1981 Chevrolet Pickup C-20 W.B. = 132 in.	5,390	5,724	57.7	20.6	32 in. New Jersey
12	1982 GMC 7000 SU Truck W.B. = 203 in.	10,900	18,000	51.6	15.5	32 in. New Jersey

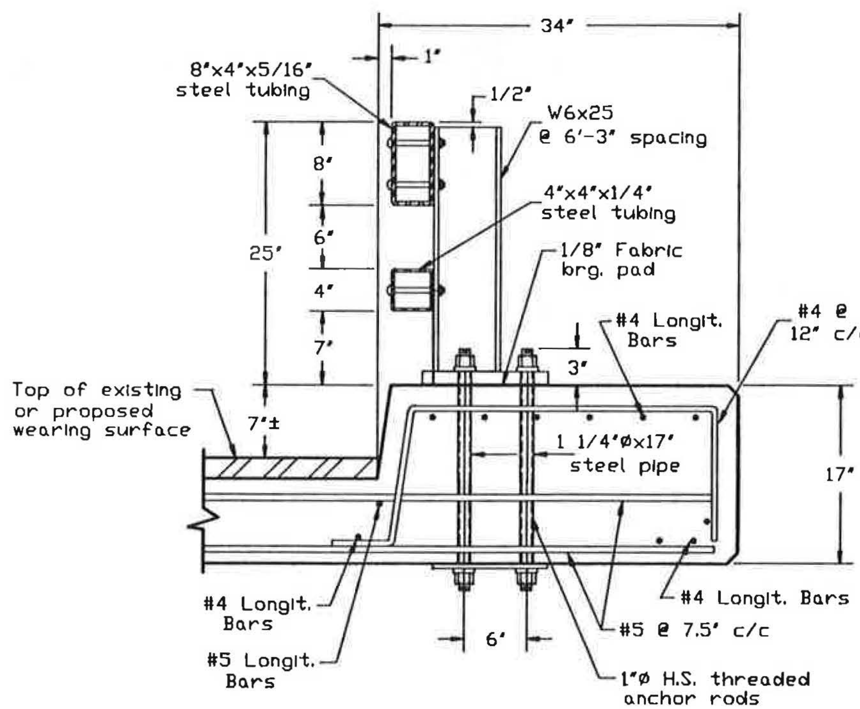
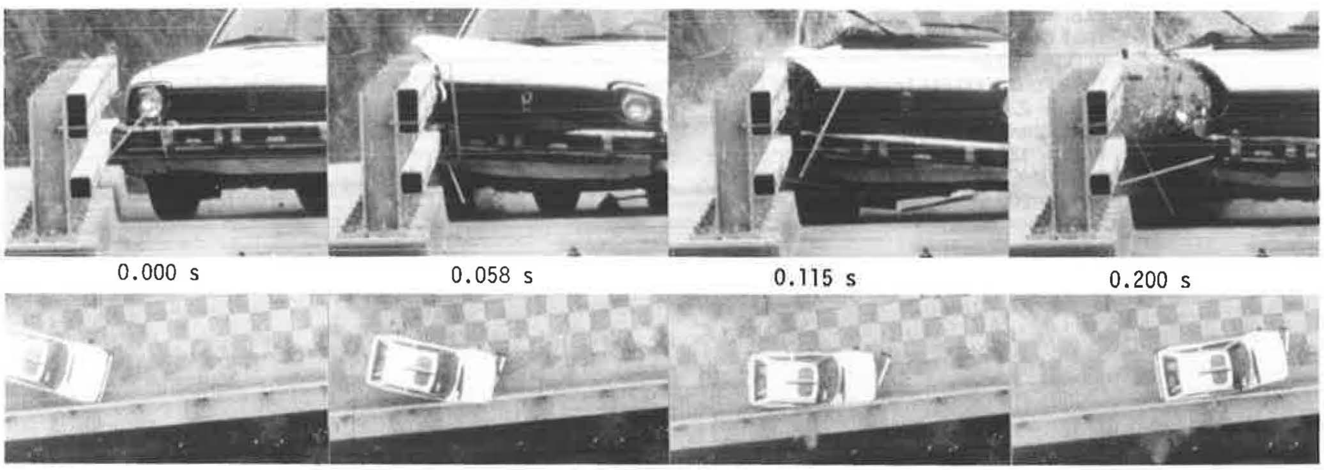
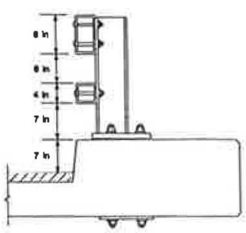


FIGURE 1 Illinois 2399-1 railing.

FIGURE 2 Prototype test installation of Illinois 2399-1 railing.

FIGURE 3 Vehicle after Test 7069-1 (1,795 lb, 58.7 mph, 20.0 degrees).





Illinois 2399
Bridge Rail

Test No.	7069-1
Date	7/14/87
Test Installation . .	Illinois 2399 Bridge Rail
Installation Length .	100 ft (30 m)
Vehicle	1980 Honda
Vehicle Weight	
Test Inertia	1,795 lb (815 kg)
Gross Static	1,961 lb (890 kg)
Vehicle Damage Classification	
TAD	01RFQ5
CDC	
Maximum Vehicle Crush	8.0 in (20.3 cm)
Maximum Dynamic Rail Deflection	Nil
Maximum Permanent Rail Deformation	None

Impact Speed. . .	58.7 mi/h (94.4 km/h)
Impact Angle. . .	20.0 deg
Exit Speed. . . .	48.5 mi/h (78.0 km/h)
Exit Angle. . . .	5.2 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal. .	-6.4 g
Lateral	14.2 g
Occupant Impact Velocity	
Longitudinal. .	16.9 ft/s (5.2 m/s)
Lateral	25.1 ft/s (7.7 m/s)
Occupant Ridedown Accelerations	
Longitudinal. .	-1.4 g
Lateral	8.5 g

FIGURE 4 Summary of results for Test 7069-1.

elements or debris. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire collision. Performance of the railing was considered acceptable.

Test 7069-2 (5,450-lb Pickup Truck, 63.6 mph, 19.2 degrees)

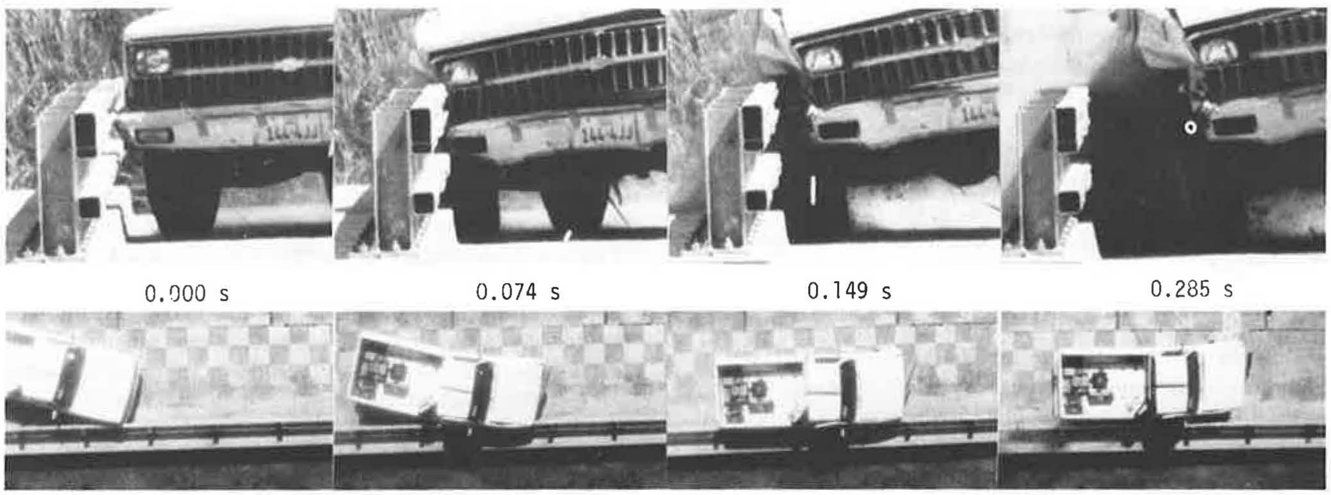
The vehicle struck the railing midway between the sixth and seventh posts from the upstream end and was smoothly redirected. It was in contact with the railing for a distance of 14.5 ft and contact ended 0.234 sec after impact. On loss of contact, the vehicle yaw angle was 1.0 degree and its trajectory was 5.8 degrees relative to the railing.

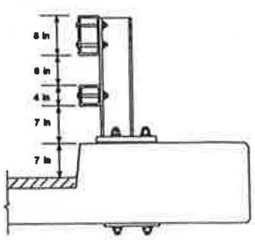
Exterior damage to the vehicle is shown in Figure 5. Both right side wheels and the front suspension were damaged. Also, the cab was twisted and the frame was permanently deformed.

Damage to the railing is shown in Figure 6. Maximum dynamic deflection of the railing was 2.4 in. and maximum permanent deflection was 0.5 in. The front of the baseplate

FIGURE 5 Damage to vehicle in Test 7069-2 (5,450 lb, 63.6 mph, 19.2 degrees).

FIGURE 6 After-test photograph at railing in Test 7069-2.





Illinois 2399
Bridge Rail

Test No. 7069-2
Date 7/24/87
Test Installation . . Illinois 2399 Bridge Rail
Installation Length . 100 ft (30 m)
Vehicle . . . . 1981 Chevrolet Pickup
Vehicle Weight
  Test Inertia . . . . 5,450 lb (2,474 kg)
  Gross Static . . . . 5,797 lb (2,632 kg)
Vehicle Damage Classification
  TAD 01RD4
  CDC . . . .
Maximum Vehicle Crush 5.0 in (12.7 cm)
Maximum Dynamic Rail
  Deflection . . . . . 2.4 in (6.1 cm)
Maximum Permanent Rail
  Deformation . . . . 0.5 in (1.3 cm)

Impact Speed. . . 63.6 mi/h (102.3 km/h)
Impact Angle. . . 19.2 deg
Exit Speed. . . . 57.6 mi/h (92.7 km/h)
Exit Trajectory . 5.8 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . -3.8 g
  Lateral . . . . 14.3 g
Occupant Impact Velocity
  Longitudinal. . 8.5 ft/s (2.6 m/s)
  Lateral . . . . 24.6 ft/s (7.5 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . -1.1 g
  Lateral . . . . 12.8 g

FIGURE 7 Summary of results for Test 7069-2.

on Post 6 was pulled up slightly and the concrete was chipped around the bolts at the rear of the baseplate.

The effective coefficient of friction was calculated to be 0.03. Occupant impact velocity was 8.5 ft/sec in the longitudinal direction and 24.6 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were −1.1 *g* (longitudinal) and 12.8 *g* (lateral). The maximum 0.050-sec averages were −3.8 *g* (longitudinal) and 14.3 *g* (lateral). These data and other pertinent information from the test are summarized in Figure 7.

The barrier contained and smoothly redirected the vehicle with minimal lateral movement of the barrier. There were no detached elements or debris. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period. Performance of the railing in this test was judged acceptable.

Test 7069-15 (18,000-lb Single-Unit Truck, 50.8 mph, 15.1 degrees)

The vehicle struck the rail approximately 26 ft from the upstream end between Posts 4 and 5. Shortly after impact, the right front tire made contact with the lower rail element and began to ride the curb. As the vehicle continued its forward motion into the rail, the right front tire pushed the lower rail element down. Before becoming parallel to the railing, the left side of the vehicle became airborne. The wheels returned to the pavement just before the vehicle lost contact with the railing. Maximum roll angle of the vehicle was approximately 23 degrees. The vehicle was in contact with the railing all the way to the downstream end (approximately 74 ft).

Damage to the vehicle is shown in Figure 8. The frame of the truck was permanently deformed. The cargo box was torn during the test; as the vehicle left the rail, the load shifted and tore open the right side of the cargo box.

Damage to the railing in the vicinity of Post 6 is shown in Figure 9. The bolts connecting the lower rail element to the post were sheared on Posts 3 through 7, apparently because of vertical downward load. At Post 5, the bolt on the upper rail element was sheared and the face of the rail element itself was gouged. The flange on Post 6 was bent and the concrete curb was cracked at Posts 6 through 9. The top of Post 8 was deformed by the edge of the cargo box on the truck.

The exit angle was 0 degree. The effective coefficient of friction was calculated to be 0.11. Occupant impact velocity was 9.8 ft/sec in the longitudinal direction and 12.4 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were −2.5 *g* (longitudinal) and 7.4 *g* (lateral). These data and other pertinent information from the test are summarized in Figure 10.

The bridge rail contained and smoothly redirected the vehicle with minimal lateral movement of the bridge rail. There was no intrusion into the occupant compartment and very little deformation of the compartment. The vehicle trajectory at loss of contact indicated no intrusion into adjacent traffic lanes and the vehicle remained stable during the collision. Performance of the railing was judged acceptable.

FIGURE 8 Photograph of vehicle after Test 7069-15 (18,000 lb, 50.8 mph, 15.1 degrees).

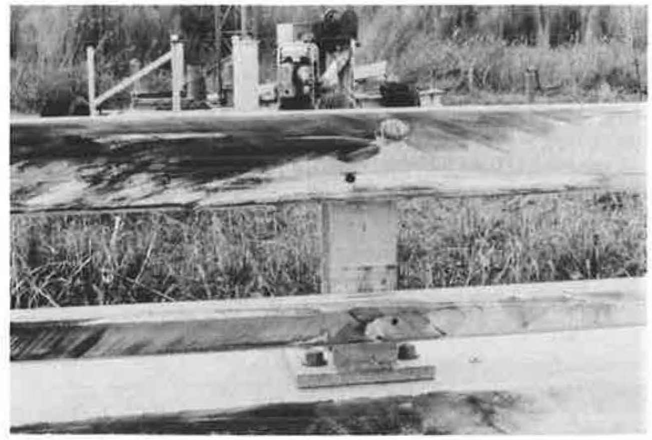


FIGURE 9 Damage to railing at Post 6.

Thirty-two-in. Vertical Concrete Parapet

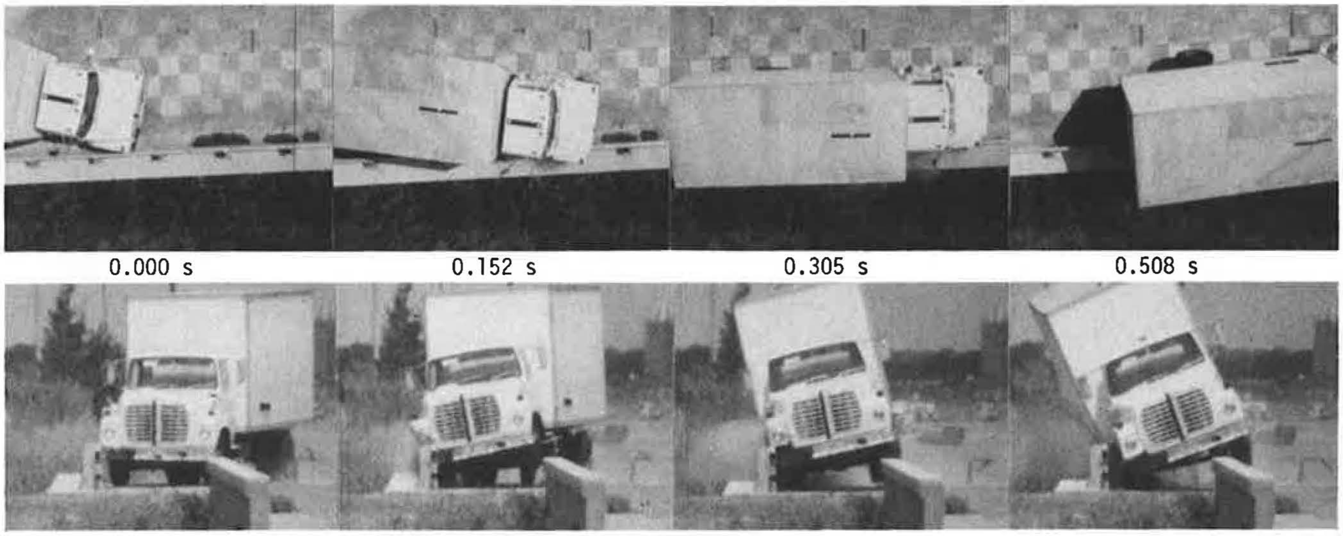
This railing was designed with a thickened section at the top of the parapet to provide additional strength and stiffness along the top edge (Figure 11). This produces a greater length of failure mechanism, which allows a greater length of parapet to carry and distribute the applied load to the deck. This railing was originally designed before the final test matrix in the 1989 guide specifications was established. When the railing was designed, the strength test requirement for a PL 2 railing was a 5,400-lb pickup truck striking at 65 mph and 20 degrees. The design force used for this test was 56 kips distributed over 42 in. and applied 29 in. above the road surface. A strength analysis of the final design showed it would resist 57 kips applied near the top (approximately 30 in.). The yield line failure mechanism, if it occurred, would be expected to extend over a 7- to 10-ft length of railing, and the railing load transferred into the deck would be expected to extend over approximately 15 ft.

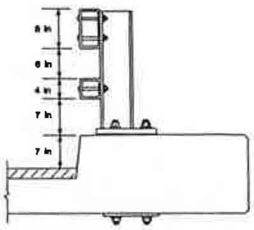
Three full-scale crash tests were performed on a prototype railing: (a) an 1,800-lb automobile striking at 60 mph and 20 degrees, (b) a 5,400-lb pickup truck striking at 65 mph and 20 degrees, and (c) an 18,000-lb single-unit truck striking at 50 mph and 15 degrees. The railing performed acceptably in all three tests.

Test 7069-5 (1,800-lb Automobile, 60.5 mph, 21.0 degrees)

The impact point for this test was at midlength of the railing. The vehicle was smoothly redirected and was stable throughout the collision. It was in contact with the railing for a distance of 10.3 ft. The vehicle lost contact with the railing 0.236 sec after impact and exited with a yaw angle of 3.5 degrees and a trajectory of 6.2 degrees.

Damage to the vehicle is shown in Figure 12. Maximum crush of the right front corner at bumper height was 5 in. Damage to the railing was cosmetic only and is shown in Figure 13.





Test No. 7069-15
Date 9/13/88
Test Installation . . Illinois 2399 Bridge Rail
Installation Length. . 100 ft (30 m)
Vehicle . . . . 1980 Ford 7000 Single-Unit Truck
Vehicle Weight
  Test Inertia . . . . 12,320 lb (5,593 kg)
  Gross Static . . . . 18,000 lb (8,172 kg)
Maximum Vehicle Crush. 10.0 in (25.4 cm)

Impact Speed. . . 50.8 mi/h (81.7 km/h)
Impact Angle. . . 15.1 deg
Exit Speed. . . . N/A
Exit Trajectory . 0 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . -1.9 g
  Lateral . . . . 4.9 g
Occupant Impact Velocity
  Longitudinal. . 9.8 ft/s (3.0 m/s)
  Lateral . . . . 12.4 ft/s (3.8 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . -2.5 g
  Lateral . . . . 7.4 g

FIGURE 10 Summary of results for Test 7069-15.

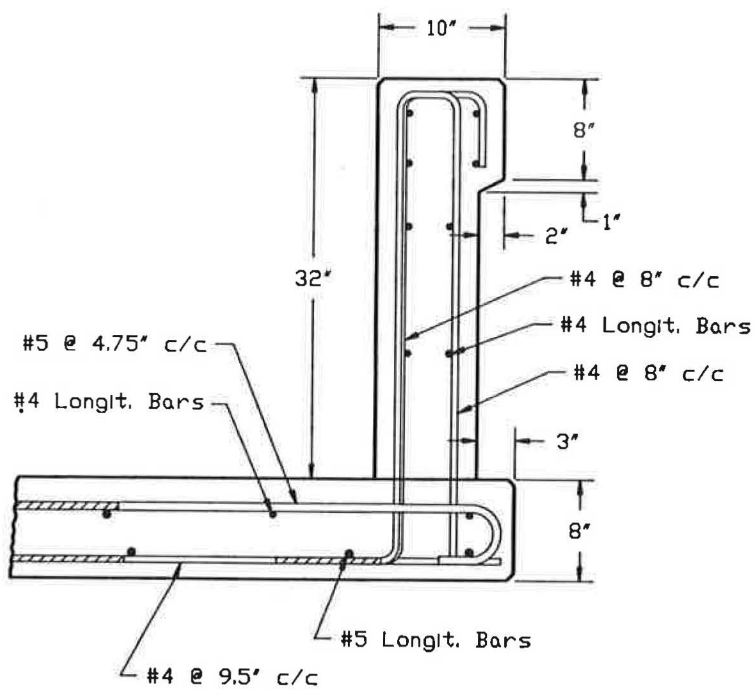


FIGURE 11 Thirty-two-in. vertical concrete parapet.

FIGURE 12 Vehicle after Test 7069-5 (1,800 lb, 60.5 mph, 21.0 degrees).

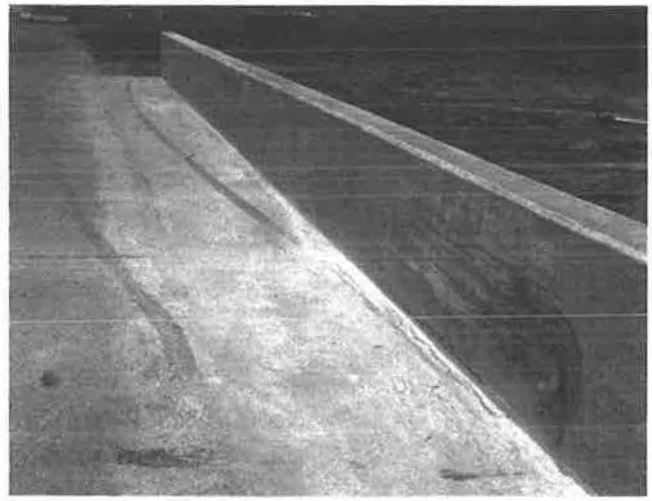
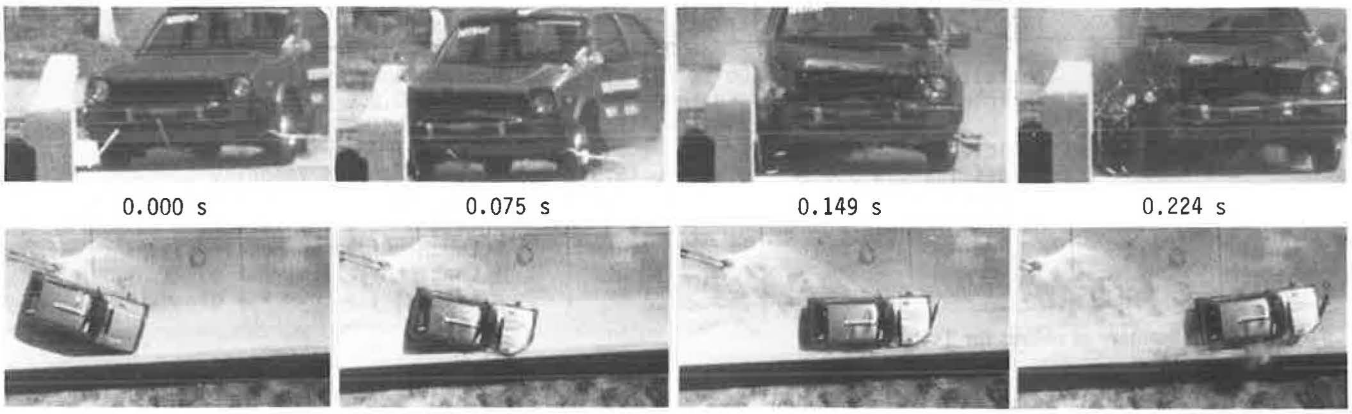
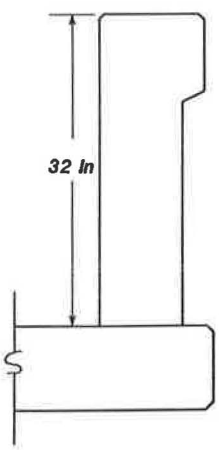


FIGURE 13 Vertical concrete parapet after Test 7069-5.





Test No. 7069-5
Date 9/24/87
Test Installation . . . 32 in Vertical Wall
Installation Length . 100 ft (30 m)
Vehicle . . . . 1981 Honda Civic
Vehicle Weight
Test Inertia . . . . . 1,800 lb (817 kg)
Gross Static . . . . . 1,965 lb (892 kg)
Vehicle Damage Classification
TAD 01RFQ4
CDC . . . .
Maximum Vehicle Crush 5.0 in (12.7 cm)

Impact Speed. . . 60.5 mi/h (97.3 km/h)
Impact Angle. . . 21.0 deg
Exit Speed. . . . 48.6 mi/h (78.2 km/h)
Exit Trajectory . 6.2 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . -8.0 g
Lateral . . . . 14.0 g
Occupant Impact Velocity
Longitudinal. . 20.1 ft/s (6.1 m/s)
Lateral . . . . 26.0 ft/s (7.9 m/s)
Occupant Ridedown Accelerations
Longitudinal. . -1.6 g
Lateral . . . . 9.4 g

FIGURE 14 Summary of results for Test 7069-5.

Exit speed at time of contact (0.236 sec) was 48.6 mph and the vehicle trajectory was 6.2 degrees with a vehicle yaw angle of 3.5 degrees. The effective coefficient of friction was calculated to be 0.22. Occupant impact velocity was 20.1 ft/sec in the longitudinal direction and 26.0 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were -1.6 g (longitudinal) and 9.4 g (lateral). These data and other pertinent information from the test are summarized in Figure 14.

The railing contained and smoothly redirected the vehicle with no lateral movement. There were no detached elements or debris. There was no intrusion into the occupant compartment although some deformation of the compartment occurred. The vehicle trajectory indicated no intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire collision. Performance of this railing was judged acceptable.

Test 7069-6 (5,400-lb Pickup Truck, 59.7 mph, 20.2 degrees)

The vehicle struck the railing at midlength and was smoothly redirected. It was in contact with the railing for a length of 10.5 ft. Loss of contact between the railing and the vehicle occurred at 0.418 sec. The vehicle exited with a yaw angle of 5.6 degrees and a trajectory of 6.4 degrees relative to the railing.

Damage to the vehicle is shown in Figure 15. Note that the right front wheel was separated at the welds connecting the outer and inner portion, allowing the outer portion of the wheel and tire to separate from the vehicle. The front suspension was damaged. The cab was twisted and the frame was permanently deformed. No structural distress was noted in the parapet (Figure 16).

The effective coefficient of friction was calculated to be 0.32. Occupant impact velocity was 18.6 ft/sec in the longitudinal direction and 21.1 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were −5.5 *g* (longitudinal) and 8.6 *g* (lateral). These data and other pertinent information from the test are summarized in Figure 17.

The barrier contained and smoothly redirected the vehicle with minimal lateral movement of the barrier. There were no detached elements or debris. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period. Performance of the barrier was acceptable in this test.

Test 7069-16 (18,000-lb Single-Unit Truck, 50 mph, 14.0 degrees)

The impact point for this test was approximately 20 ft from the upstream end of the railing. Shortly before the vehicle became parallel to the railing, its left side became airborne.

FIGURE 15 Vehicle after Test 7069-6 (5,400 lb, 59.7 mph, 20.2 degrees).

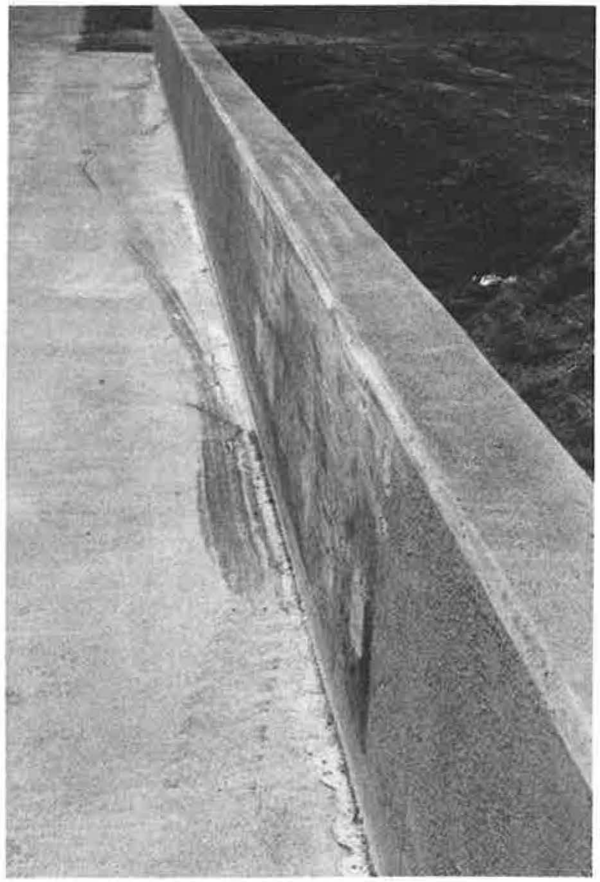


FIGURE 16 Vertical concrete parapet after Test 7069-6.

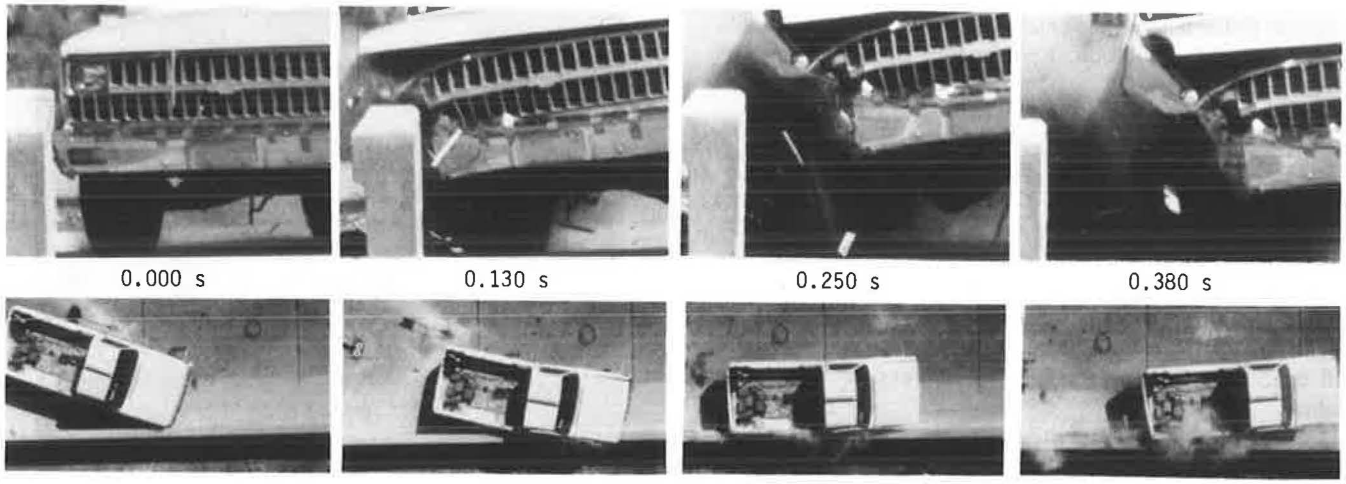
As the vehicle continued along the railing, it also continued to roll toward the railing and attained a maximum roll angle of approximately 17.6 degrees. During the collision, the lower edge of the cargo box was bearing on and sliding along the top surface of the railing. This undoubtedly helped stabilize the vehicle and may or may not occur in other railing designs. On passing the downstream end of the railing, the vehicle was steered to the right and followed a curved path, finally rolling onto its left side.

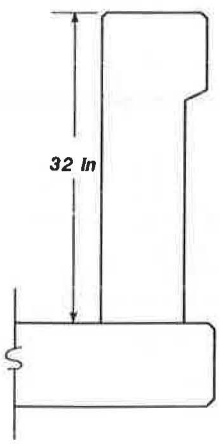
The vehicle sustained damage to its right side during interaction with the railing, as indicated in Figure 18. Maximum crush at the right front corner at bumper height was 10.0 in.

As can be seen in Figure 19, the bridge rail sustained cosmetic damage. Tire marks on the face extended to the top edge for about 30 ft. The box of the vehicle scraped the top of the bridge rail for another 15 ft. The vehicle was in contact with the bridge rail for about 45 ft.

The effective coefficient of friction was calculated to be 0.41. The vehicle left the bridge rail traveling at 34.2 mph. Occupant impact velocity was 10.9 ft/sec in the longitudinal direction and 11.8 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were −2.3 *g* (longitudinal) and 8.4 *g* (lateral). These data and other pertinent information from the test are summarized in Figure 20.

The bridge rail contained and smoothly redirected the vehicle with no lateral movement of the bridge rail. There was no intrusion into the occupant compartment and very little deformation of the compartment. The vehicle trajectory at loss of contact indicated no intrusion into adjacent traffic





Test No.	7069-6
Date	10/08/87
Test Installation	32 in Vertical Wall
Installation Length	100 ft (30 m)
Vehicle	1982 Chevrolet Pickup
Vehicle Weight	
Test Inertia	5,420 lb (2,461 kg)
Gross Static	5,759 lb (2,615 kg)
Vehicle Damage Classification	
TAD	01RD4
CDC	
Maximum Vehicle Crush	9.0 in (22.9 cm)

Impact Speed	59.7 mi/h (96.1 km/h)
Impact Angle	20.2 deg
Exit Speed	47.0 mi/h (75.6 km/h)
Exit Trajectory	6.4 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal	-5.7 g
Lateral	13.1 g
Occupant Impact Velocity	
Longitudinal	18.6 ft/s (5.7 m/s)
Lateral	21.1 ft/s (6.4 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-5.5 g
Lateral	8.6 g

FIGURE 17 Summary of results for Test 7069-6.

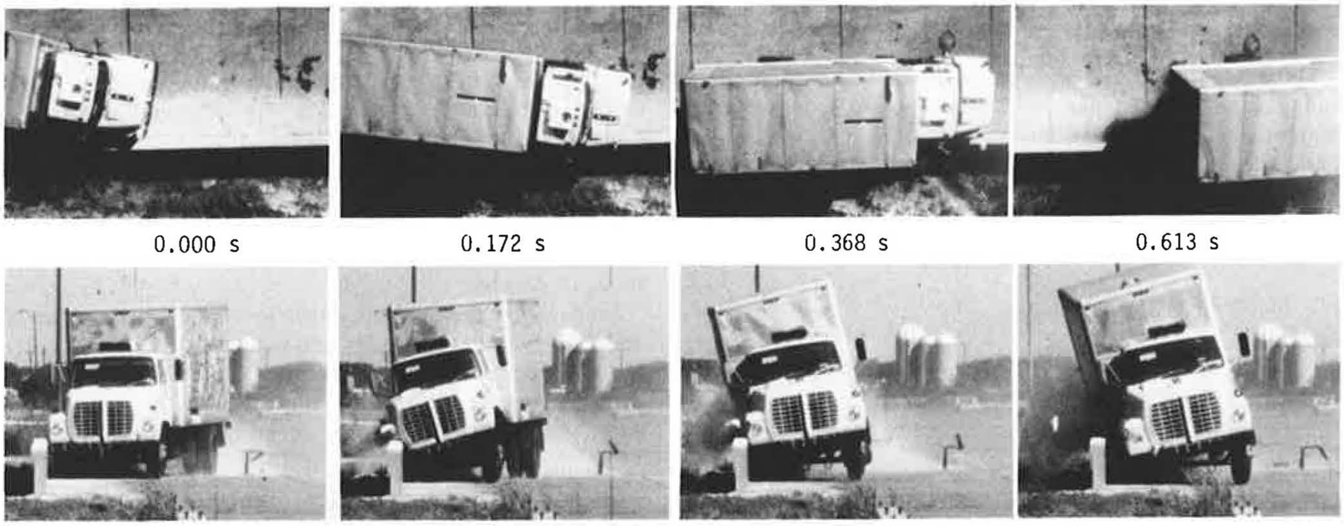
FIGURE 18 Damage to vehicle in Test 7069-16 (18,000 lb, 50 mph, 14 degrees) after being uprighted.

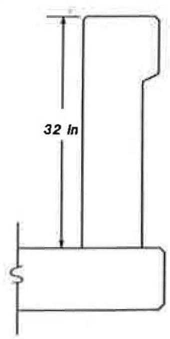
FIGURE 19 Thirty-two-in. vertical parapet after Test 7069-16.

lanes; however, the vehicle did not remain upright after the collision. Performance of the railing was judged acceptable.

Thirty-two-in. F-Shaped Concrete Parapet

The median barrier version of the F-shape was developed by Southwest Research Institute as an alternative to the New Jersey safety shape. The same F-shaped traffic face was used in the bridge parapet railing evaluated in the study reported herein. This railing was designed for an impact by a 5,400-lb pickup truck traveling 65 mph and striking at an angle of 20 degrees. The design load was 56 kips of line load uniformly distributed over a longitudinal distance of 42 in. and applied 29 in. above the road surface. A cross section of the prototype design is shown in Figure 21.





Test No.	7069-16	Impact Speed. . .	50.0 mi/h (80.5 km/h)
Date	10/13/88	Impact Angle. . .	14.0 deg
Test Installation . .	32-in Vertical Wall Bridge Rail	Exit Speed. . . .	34.2 (55.0 km/h)
Installation Length. .	100 ft (30.5 m)	Exit Trajectory .	5 deg
Vehicle	1982 Ford 7000 Single-Unit Truck	Vehicle Accelerations (Max. 0.050-sec Avg)	
Vehicle Weight		Longitudinal. .	-1.7 g
Test Inertia	13,820 lb (6,274 kg)	Lateral	4.6 g
Gross Static	18,000 lb (8,172 kg)	Occupant Impact Velocity	
Maximum Vehicle Crush.	10.0 in (25.4 cm)	Longitudinal. .	10.9 ft/s (3.3 m/s)
		Lateral	11.8 ft/s (3.6 m/s)
		Occupant Ridedown Accelerations	
		Longitudinal. .	-2.3 g
		Lateral	8.4 g

FIGURE 20 Summary of results for Test 7069-16.

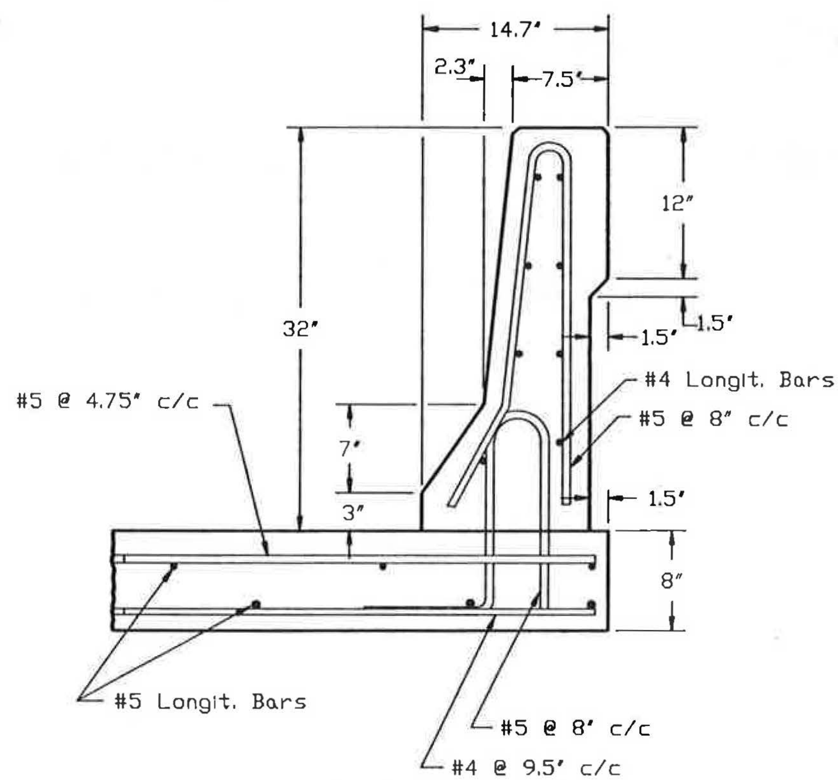


FIGURE 21 Thirty-two-in. F-shaped concrete parapet.

Three full-scale crash tests were performed on a prototype railing: (a) an 1,800-lb automobile striking at 60 mph and 20 degrees, (b) a 5,400-lb pickup truck striking at 65 mph and 20 degrees, and (c) an 18,000-lb single-unit truck striking at 50 mph and 15 degrees. The railing performed acceptably in all three tests.

Test 7069-3 (1,800-lb Automobile, 60.1 mph, 21.4 degrees)

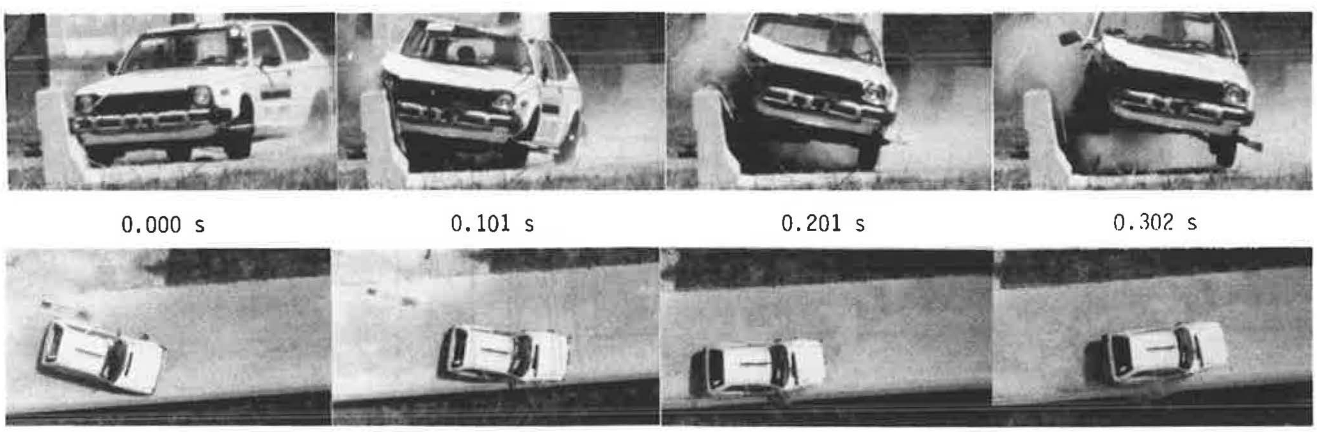
The impact point for this test was at midlength of the railing. The vehicle was smoothly redirected and lost contact with the railing 0.276 sec after impact. The exit yaw angle of the vehicle was 0.9 degree and its trajectory was 6.2 degree relative to the railing. The vehicle was in contact with the railing for 10.3 ft. During redirection, the right side of the vehicle was lifted by the sloping face of the railing. Tire marks on the railing indicate that the right side of the vehicle was lifted about 17 in. The vehicle was banked with a maximum roll angle of about 11 degrees.

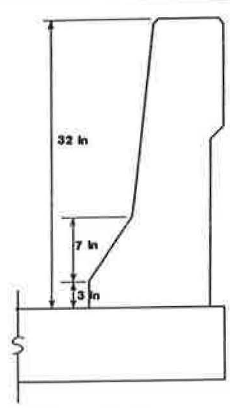
Damage to the vehicle is shown in Figure 22. Damage to the railing was cosmetic only and is shown in Figure 23.

The effective coefficient of friction was calculated to be 0.33. Occupant impact velocity was 19.0 ft/sec in the longitudinal direction and 23.7 ft/sec in the lateral direction. The highest

FIGURE 22 Damage to vehicle in Test 7069-3 (1,800 lb, 60.1 mph, 21.4 degrees).

FIGURE 23 Thirty-two-in. F-shape after Test 7069-3.





32 in F-Shape
Bridge Rail

Test No. 7069-3
Date 7/28/87
Test Installation . . 32 in F-Shape Bridge Rail
Installation Length . 100 ft (30 m)
Vehicle . . . . 1980 Honda 1300 DX
Vehicle Weight
Test Inertia . . . . 1,800 lb (817 kg)
Gross Static . . . . 1,966 lb (893 kg)
Vehicle Damage Classification
TAD 01RFQ4
CDC . . . .
Maximum Vehicle Crush 9.0 in (22.9 cm)

Impact Speed. . . 60.1 mi/h (96.7 km/h)
Impact Angle. . . 21.4 deg
Exit Speed. . . . 53.0 mi/h (85.3 km/h)
Exit Trajectory . 6.2 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . -8.0 g
Lateral . . . . 12.8 g
Occupant Impact Velocity
Longitudinal. . 19.0 ft/s (5.8 m/s)
Lateral . . . . 23.7 ft/s (7.2 m/s)
Occupant Ridedown Accelerations
Longitudinal. . -2.1 g
Lateral . . . . 4.9 g

FIGURE 24 Summary of results for Test 7069-3.

0.010-sec occupant ridedown accelerations were −2.1 *g* (longitudinal) and 4.9 *g* (lateral). These data and other pertinent information from the test are summarized in Figure 24.

The railing contained and smoothly redirected the vehicle with no lateral movement of the barrier. There were no detached elements or debris. There was no intrusion into the occupant compartment although some deformation of the compartment occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and reasonably stable during the entire collision. Performance of the railing was judged acceptable.

Test 7069-4 (5,440-lb Pickup Truck, 65.4 mph, 20.4 degrees)

The railing contained and smoothly redirected the pickup truck in this test. The vehicle began to ride up the barrier face immediately after initial contact, and the right front tire was deflated during interaction with the railing. Just before becoming parallel with the railing, the vehicle became airborne and rose approximately 1 ft above the pavement surface. On exiting, the vehicle returned to the pavement surface in a stable condition. The exit yaw angle was 0.4 degree and the exit trajectory was 7.4 degrees.

After-test photographs of the vehicle and barrier are shown in Figures 25 and 26, respectively.

The effective coefficient of friction was calculated to be 0.31. Occupant impact velocity was 12.5 ft/sec in the longitudinal direction and 24.1 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were −1.2 *g* (longitudinal) and 5.9 *g* (lateral). These data and other pertinent information from the test are summarized in Figure 27.

The barrier contained and smoothly redirected the vehicle with minimal lateral movement of the barrier. There were no detached elements or debris. There was no intrusion into the occupant compartment although some deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period. Performance of the railing was judged acceptable.

FIGURE 25 Damage to vehicle in Test 7069-4 (5,440 lb, 65.4 mph, 20.4 degrees).

FIGURE 26 Thirty-two-in. F-shape after Test 7069-4.

Test 7069-11 (18,000-lb Single-Unit Truck, 52.1 mph, 14.8 degrees)

The impact point was approximately midlength of the railing. On contact the right front wheel began to ride up the face of the railing, and subsequently the left front tire came off the pavement surface. As the vehicle yawed to become parallel to the railing, the left rear wheels came off the pavement surface and the vehicle continued to roll, reaching a maximum roll angle of 31 degrees. The lower edge of the cargo box contacted and slid along the top surface of the railing.

The vehicle sustained extensive damage to the right side, as shown in Figure 28. Maximum crush at the right front corner at bumper height was 20.0 in. The front axle was torn loose, which caused damage to the springs, shackles, U-bolts, and tie rods. The steering arm and cylinder were damaged and the oil pan was dented. The fuel tank broke loose from the truck.

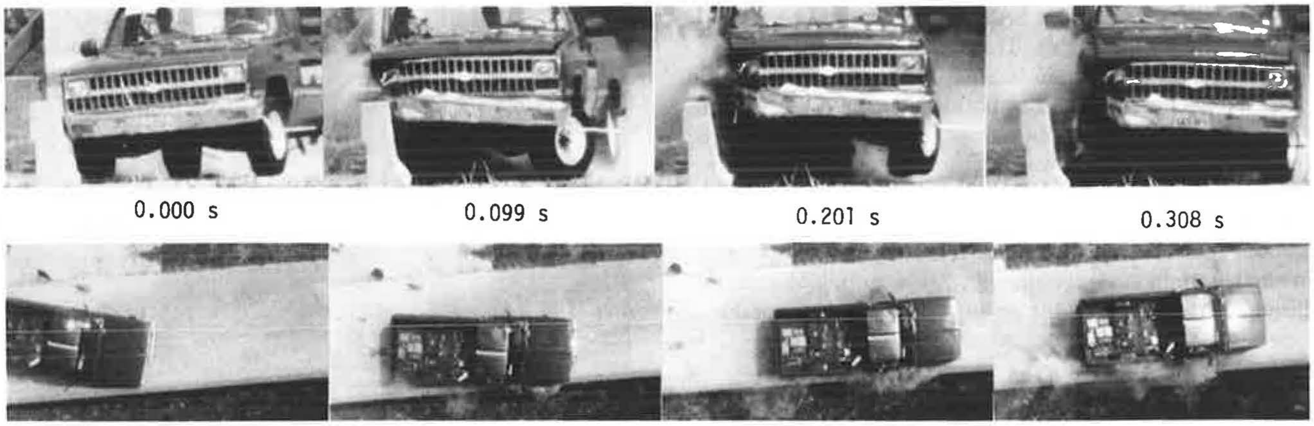
As can be seen in Figure 29, the rail sustained cosmetic damage. There were tire marks on the face of the bridge rail and along the top. The top of the bridge rail was scraped along the remaining length from the lower edge of the cargo box of the truck. The vehicle was in contact with the bridge railing for 39 ft.

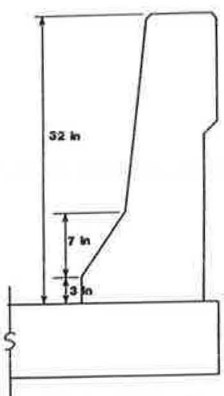
The exit speed was not available. Exit angle was about 0 degree. The effective coefficient of friction was calculated to be 0.12. Occupant impact velocity was 5.7 ft/sec in the longitudinal direction and 8.2 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were 1.3 *g* (longitudinal) and 5.4 *g* (lateral). These data and other pertinent information from the test are summarized in Figure 30.

The barrier contained and smoothly redirected the vehicle with no lateral movement of the barrier. There were no detached elements or debris. There was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the entire test period. Performance of the railing was judged acceptable.

New Jersey Safety Shape Concrete Parapet

The New Jersey safety shape median barrier has been in use for many years and is currently used for some applications by





Test No. 7069-4
Date 7/30/87
Test Installation . . 32 in F-Shape Bridge Rail
Installation Length . 100 ft (30 m)
Vehicle . . . . 1981 Chevrolet Pickup
Vehicle Weight
Test Inertia . . . . 5,440 lb (2,470 kg)
Gross Static . . . . 5,780 lb (2,624 kg)
Vehicle Damage Classification
TAD 01RD4
CDC . . . .
Maximum Vehicle Crush 5.0 in (12.7 cm)

Impact Speed. . . 65.4 mi/h (105.2 km/h)
Impact Angle. . . 20.4 deg
Exit Speed. . . . 56.9 mi/h (91.6 km/h)
Exit Trajectory . 7.4 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . -4.7 g
Lateral . . . . 13.1 g
Occupant Impact Velocity
Longitudinal. . 12.5 ft/s (3.8 m/s)
Lateral . . . . 24.1 ft/s (7.3 m/s)
Occupant Ridedown Accelerations
Longitudinal. . -1.2 g
Lateral . . . . 5.9 g

FIGURE 27 Summary of results for Test 7069-4.

FIGURE 28 Vehicle after Test 7069-11 (18,000 lb, 52.1 mph, 14.8 degrees).

virtually every state. Many states use a concrete parapet type bridge with the safety shape on the traffic face. Such a railing with a 6-in. top width was tested and evaluated. A cross section of this railing with steel reinforcement is shown in Figure 31. A strength analysis of the final prototype design indicated that its ultimate strength by yield line theory was about 52 kips.

Two full-scale crash tests were performed on the prototype installation: (a) a 5,390-lb vehicle striking at 57.7 mph and 20.6 degrees and (b) an 18,000-lb vehicle striking at 51.6 mph and 15.5 degrees. The railing performed satisfactorily in both tests.

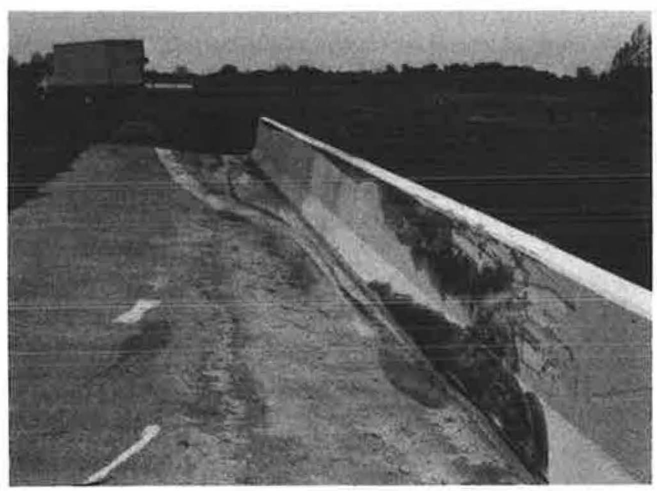
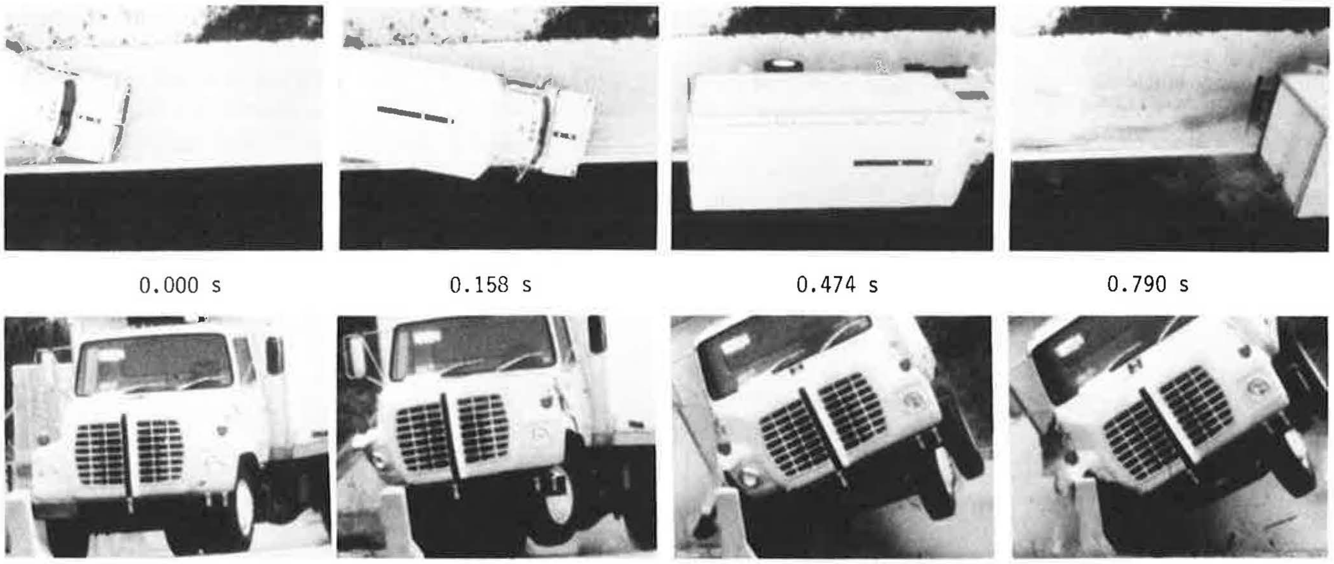
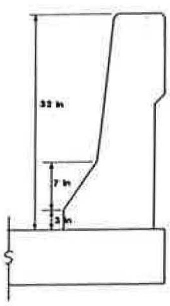


FIGURE 29 Thirty-two-in. F-shape after Test 7069-11.

Test 7069-14 (5,390-lb Vehicle, 57.7 mph, 20.6 degrees)

The vehicle began to ride up the face of the railing shortly after contact. Just after becoming parallel with the railing, the vehicle became airborne and reached a maximum height of approximately 23 in. above the deck. While still airborne





Test No. 7069-11
Date 3/30/88
Test Installation . . 32 in F-Shape Bridge Rail
Installation Length. . 100 ft (30 m)
Vehicle . . . . 1982 Ford 7000 Single-Unit Truck
Vehicle Weight
  Test Inertia . . . . 18,000 lb (8,172 kg)
  Gross Static . . . . 18,000 lb (8,172 kg)
Maximum Vehicle Crush. 20.0 in (50.8 cm)

Impact Speed. . . 52.1 mi/h (83.8 km/h)
Impact Angle. . . 14.8 deg
Exit Speed. . . . Not Available
Exit Trajectory . 0 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
  Longitudinal. . -1.4 g
  Lateral . . . . 3.9 g
Occupant Impact Velocity
  Longitudinal. . 5.7 ft/s (1.7 m/s)
  Lateral . . . . 8.2 ft/s (2.5 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . 1.3 g
  Lateral . . . . 5.4 g

FIGURE 30 Summary of results for Test 7069-11.

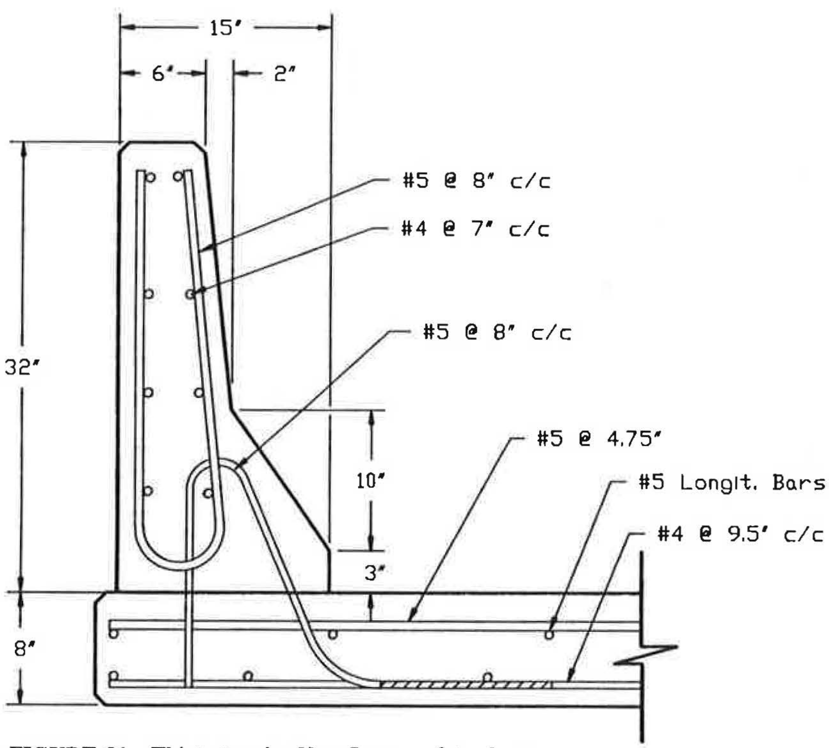


FIGURE 31 Thirty-two-in. New Jersey safety shape.

and traveling at 35.8 mph with a heading of 0.9 degree and a trajectory of 0.9 degrees, the vehicle lost contact with the railing. The vehicle rose approximately 23 in. above the pavement. Approximately 15 ft of railing was in contact with the vehicle (Figure 32).

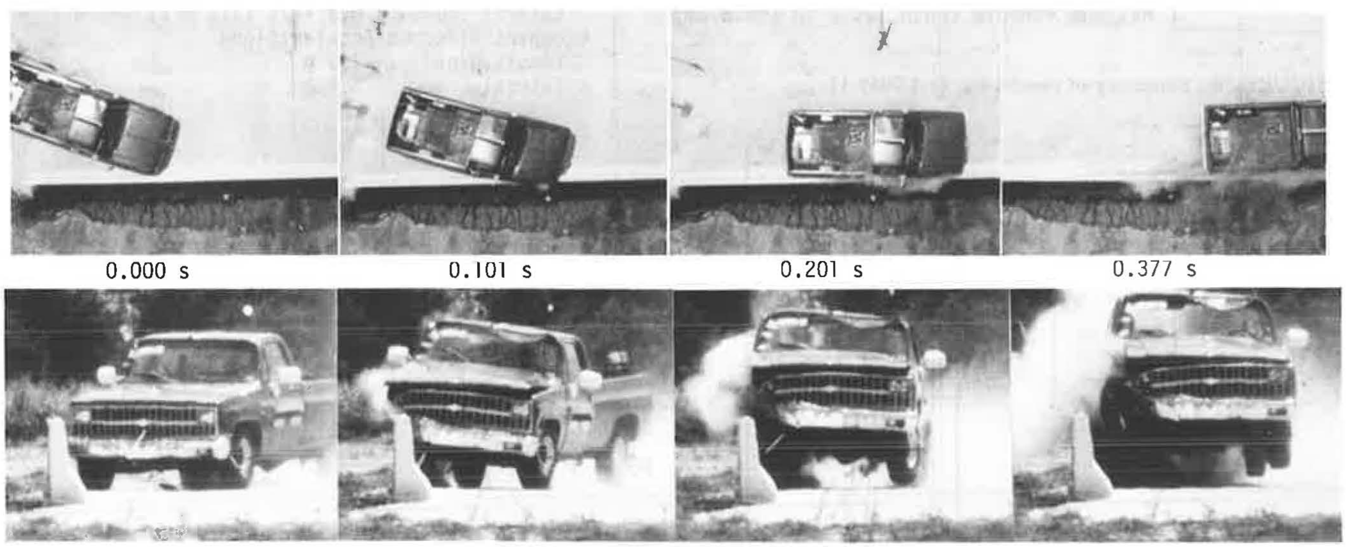
Damage to the vehicle is shown in Figure 33. Maximum crush at the right front corner at bumper height was 12 in.

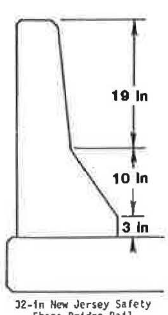
The effective coefficient of friction was calculated to be 0.83. Occupant impact velocity was 17.8 ft/sec in the longitudinal direction and 18.7 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were −5.1 *g* (longitudinal) and 9.2 *g* (lateral). These data and other pertinent information from the test are summarized in Figure 34.

The bridge rail contained and smoothly redirected the vehicle with no lateral movement of the bridge rail. There was no intrusion into the occupant compartment and minimal deformation of the compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during the collision. Performance of the railing was judged acceptable.

FIGURE 32 Thirty-two-in. safety shape railing after Test 7069-14.

FIGURE 33 Damage to vehicle in Test 7069-14 (5,390 lb, 57.7 mph, 20.6 degrees).





Test No. 7069-14
Date 8/11/88
Test Installation . . 32-in New Jersey Safety Shape Bridge Rail
Installation Length. . 100 ft (30 m)
Vehicle . . . . 1981 Chevrolet Custom Deluxe C-20 truck
Vehicle Weight
  Test Inertia . . . . 5,390 lb (2,447 kg)
  Gross Static . . . . 5,724 lb (2,599 kg)
Maximum Vehicle Crush. 12.0 in (30.7 cm)

Impact Speed. . . 57.7 mi/h (92.8 km/h)
Impact Angle. . . 20.6 deg
Exit Speed. . . . 35.8 mi/h (57.6 km/h)
Exit Trajectory . 0.9 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . -6.6 g
  Lateral . . . . 7.3 g
Occupant Impact Velocity
  Longitudinal. . 17.8 ft/s (5.4 m/s)
  Lateral . . . . 18.7 ft/s (5.7 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . -5.1 g
  Lateral . . . . 9.2 g

FIGURE 34 Summary of results for Test 7069-14.

Test 7069-12 (18,000-lb Single-Unit Truck, 51.6 mph, 15.5 degrees)

Shortly after contact the right front wheel began to ride up the face of the railing, and the axle broke loose from the vehicle. The left front wheel became airborne, and the front of the vehicle continued to ride up as the vehicle began to yaw to become parallel with the railing. The front of the vehicle reached a maximum height of about 44 in. above the pavement surface. The vehicle continued to roll toward the railing, reaching a maximum angle of 44 degrees. When the vehicle slid off the end of the railing, it rolled back away from the railing and came to rest on its left side.

As can be seen in Figure 35, the rail sustained cosmetic damage. There were tire marks on the face of the bridge rail and along the top. The top of the bridge rail was scraped along the remaining length from the undercarriage of the truck. The vehicle was in contact with the bridge rail for 77 ft.

The vehicle sustained damage, as shown in Figure 36. Maximum crush at the right front corner at bumper height was 8.0 in. The front axle was torn off the vehicle and the undercarriage was damaged. There was damage to the U-bolts, Pittman arm rod, steering arm, brake lines, and leaf spring bolts. The outer right rear wheel rim was bent and the tire was damaged. The fuel tank was also damaged.

The exit speed and the effective coefficient of friction were not attainable. The vehicle did not become parallel while in contact with the bridge rail. Occupant impact velocity was 13.4 ft/sec in the longitudinal direction and 10.2 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were $-3.0\ g$ (longitudinal) and $4.9\ g$ (lateral). These data and other pertinent information from the test are summarized in Figure 37.

The bridge rail contained and smoothly redirected the test vehicle with no lateral movement of the bridge rail. There was no intrusion into the occupant compartment and very little deformation of the compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes; however, the vehicle did not remain upright after collision. Performance of the railing was judged acceptable.

FIGURE 35 Thirty-two-in. New Jersey safety shape railing after Test 7069-12.

FIGURE 36 Damage to vehicle in Test 7069-12 (18,000 lb, 51.6 mph, 15.5 degrees).

SUMMARY

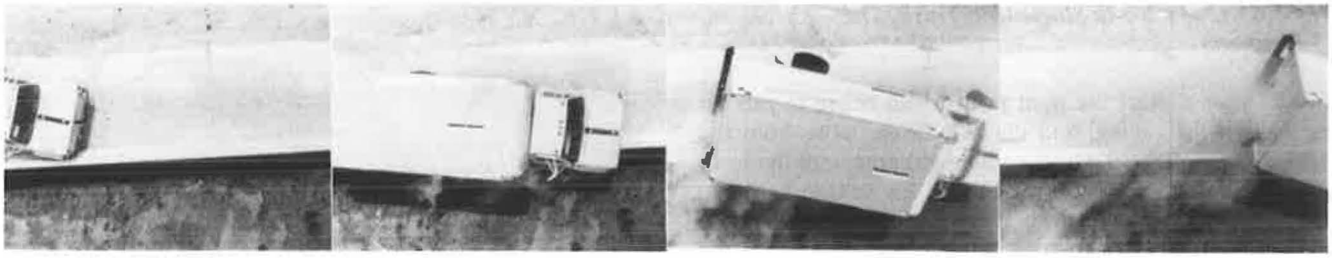
It is generally thought that the AASHTO *Guide Specifications for Bridge Railings*, if followed, will produce a general improvement of the performance of bridge railing systems. The performance level selection criteria given in that guide appear to indicate that a PL 2 bridge railing design should be used on much of the nation's highway system.

Four PL 2 railing designs have been developed and proven through full-scale crash tests. All the railings had a total geometric height of 32 in. Test results indicate that this is probably the minimum height for a PL 2 railing, at least for the types of railings tested. Some innovative designs of lesser height might be made to function suitably, but they should be subjected to full-scale testing to prove their performance.

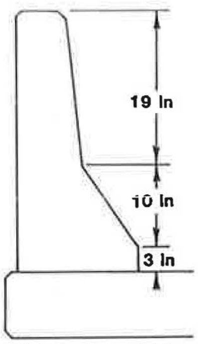
Of the railing designs reported herein, one was a steel beam-and-post system with tubular rail elements mounted on wide flange posts mounted on a curb. The other three were concrete parapets: a vertical face, an F-shape, and the standard New Jersey safety shape. All had suitable height and geometric features as indicated by full-scale tests evaluated in accordance with the 1989 guide specification. The strengths of the railing systems were adequate and possibly on the conservative side. Extensive structural distress of the railings was not experienced in the tests. Virtually no cracking occurred in the concrete railings during full-scale tests, which indicates that the forces applied to the railings were significantly less than their ultimate strengths.

Some differences in performance of the three concrete parapet railings should be observed. The two parapets with sloped faces, the New Jersey safety shape and the F-shape, both caused the automobile and pickup test vehicles to ride up the face and become airborne. The vertical parapet did not produce this effect. However, the forces generated on these vehicles by the vertical parapet were generally slightly more severe. In all cases, stability of the vehicle was considered acceptable.

In tests with 18,000-lb single-unit trucks on the 32-in. vertical parapet and the 32-in. F-shape, the vehicles remained generally stable during interaction with the railing, although roll displacements were significant. The vehicle did finally roll onto its left side in the test on the 32-in. vertical parapet



0.000 s 0.304 s 0.608 s 0.912 s



32-in New Jersey Safety Shape Bridge Rail

Test No. 7069-12
Date 6/22/88
Test Installation . . 32-in N.J. Safety Shape Bridge Rail
Installation Length. . 100 ft (30 m)
Vehicle . . . . 1982 GMC Single-Unit Truck
Vehicle Weight
Test Inertia . . . . 10,900 lb (4,949 kg)
Gross Static . . . . 18,000 lb (8,172 kg)
Maximum Vehicle Crush. 8.0 in (20.3 cm)

Impact Speed. . . 51.6 mi/h (83.0 km/h)
Impact Angle. . . 15.5 deg
Exit Speed. . . . N/A
Exit Trajectory . 2.0 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . -3.2 g
Lateral . . . . 2.5 g
Occupant Impact Velocity
Longitudinal. . 13.4 ft/s (4.1 m/s)
Lateral . . . . 10.2 ft/s (3.1 m/s)
Occupant Ridedown Accelerations
Longitudinal. . -3.0 g
Lateral . . . . 4.9 g

FIGURE 37 Summary of results for Test 7069-12.

because of its curved path. In the test on the 32-in. New Jersey safety shape, the vehicle rode up the barrier more and rolled onto its side. This difference in behavior is thought to be the result of the geometry of the face of the railing. However, the make of the vehicle used on the New Jersey safety shape was different from the others, and differences in the vehicle may have had some influence. All vehicles met the test vehicle specifications in the AASHTO *Guide Specifications for Bridge Railings*.

REFERENCES

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