Development of Combination Pedestrian-Traffic Bridge Railings

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Two bridge railing designs have been developed for use in urban areas. The railings consist of concrete parapets with metal railings mounted on top of the parapet. The parapets facilitate transfer of post loads into the bridge deck and the metal railing portion permits visibility through the railing. The railings were designed by ultimate-strength methods of analysis. Prototypes of each design were subjected to full-scale crash tests when they were mounted on 8-in. (20.3-cm)-high, 5-ft (1.5-m)-wide sidewalks and when they were mounted flush on simulated bridge decks. Acceptable performance was obtained in all tests.

FHWA's requirement that new bridge railing designs be proven through full-scale crash tests has generated a need to develop proven designs that are acceptable and that meet the diverse needs of individual states. Reported herein is a portion of work done in a recent study to develop new bridge railing and transition designs (*1*). The railing designs are intended for use in urban areas where truck traffic is minimal. Two different, although similar, railing designs were developed (*2,3*). Ultimate-strength methods of analysis were used to design the railings. Prototypes of the railings were subjected to full-scale crash tests specified in the 1989 AASHTO *Guide Specifications for Bridge Railings* (*4*), and acceptable performance was obtained in all tests. One railing design was tested to Performance Level 1, and the other design was tested to Performance Level 2. Both railing designs were crash tested, first in a configuration with a raised sidewalk and again later with a flush roadway approach surface.

DESCRIPTION OF BR27D AND BR27C BRIDGE RAILINGS

BR27D Bridge Railing

The BR27D railing was constructed of two A500 rails (grade B, TS 4 × 3 × 1/4 in.) attached to posts (A500 grade B, TS 4 × 4 × 3/16 × 24 in.) mounted atop an 18.0-in. (0.5-m) reinforced concrete parapet. Longitudinal post spacing was 6.7 ft (2.0 m). The vertical clear space between each of the two rail elements and the lower rail element and the concrete parapet was 8.0 in. (0.2 m). The railing installation was constructed on the bridge deck surface and mounted atop a 5.0-ft (1.5-m)-wide sidewalk with an 8-in. (0.2-m)-high curb at the face of the sidewalk. The length of the bridge railing installations was 100 ft (30.5 m). Detailed elevations of the bridge railings are shown in Figures 1 and 2, and photographs of the completed bridge railing installations are shown in Figure 3.

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BR27C Bridge Railing

The BR27C railing was constructed of rails (A500 grade B, TS 4 × 3 × 1/4 in.) attached to posts (A500 grade B, TS 4 × 4 × 3/16 × 18 in.) mounted atop a 24.0-in. (0.6-m) reinforced concrete parapet. Longitudinal post spacing was 6.7 ft (2.0 m), and the vertical clear space between the parapet and the bottom of the rail was 14.0 in. (0.4 m). The railing installation was constructed on the bridge deck surface and mounted atop a 5.0-ft (1.5-m)-wide sidewalk with an 8-in. (0.2-m)-high curb at the face of the sidewalk. The length of the bridge railing installations was 100.0 ft (30.5 m). Detailed elevations of the bridge railings are shown in Figures 4 and 5. Photographs of the completed bridge railing installations are shown in Figure 6.

DESIGN OF RAILINGS

The BR27D railing was designed to meet Performance Level 1 (PL1) of the 1989 *Guide Specifications for Bridge Railings* (*4*). The design force used for this level was 26 kips (115.6 kN) at 32 in. (0.8 m) above the road surface for installations in which a raised sidewalk was not present. A raised sidewalk serves to lift and partially redirect a vehicle and influences the magnitude and location of the collision force.

Ultimate-strength methods of analysis were used to evaluate the strength of the railing (*5*). For the metal upper portion of the railing, plastic hinge failure mechanisms were evaluated. If the failure mechanism occurs between adjacent posts, plastic hinges would form in the rail elements near midspan and at each adjacent post. The strength of such a mechanism in this railing was computed to be 41.2 kips (183.3 kN). If the failure mechanism extends over two spans of the railing, plastic hinges would form in the rail elements at the central post and at the far ends of adjacent spans. A plastic hinge would also form in the central post. The computed strength for such a mechanism is 26.4 kips (117.4 kN). For a plastic mechanism extending over three spans, the computed strength is 28.9 kips (128.5 kN). The mechanism that would form is the one that gives the lowest strength. For the metal portion of this railing, the computed strength would be 26.4 kips (117.4 kN) at 34 in. (0.9 m) above the top of the sidewalk.

The strength of the concrete parapet portion of the railing was evaluated by the yieldline analysis presented by Hirsch (*5*). The computed strength for load applied at the top of the parapet is 122.4 kips (544.4 kN). A portion of the parapet strength is used to support the metal post [8.9 kips (39.6 kN) for this design].

The combined maximum strength of the parapet and metal railing would be 122.4 minus 8.9 plus 26.4 equals 139.9 kips (622.3 kN) at 21 in. (0.5 m) above the sidewalk. If the parapet were only partially loaded, lower strengths at greater heights would be obtained.

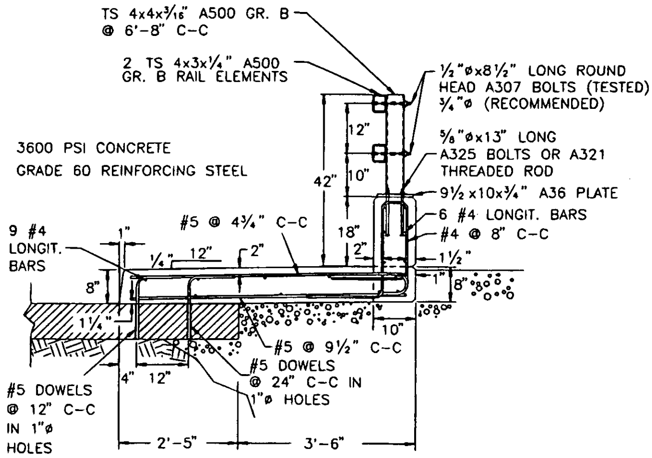


FIGURE 1 Cross section of BR27D bridge railing mounted on sidewalk.

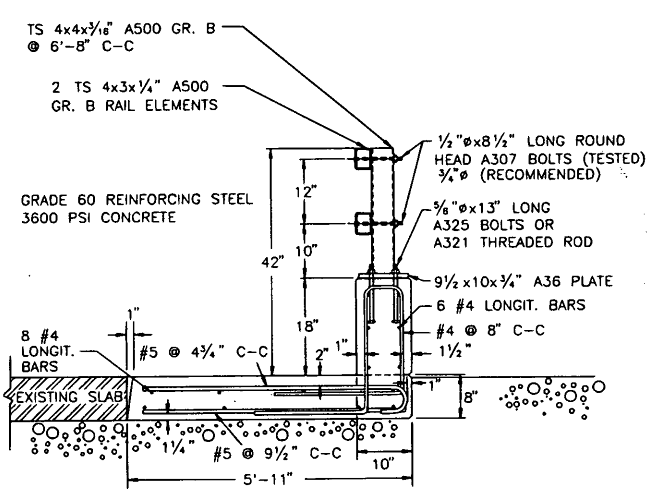


FIGURE 2 Cross section of BR27D mounted flush on deck.

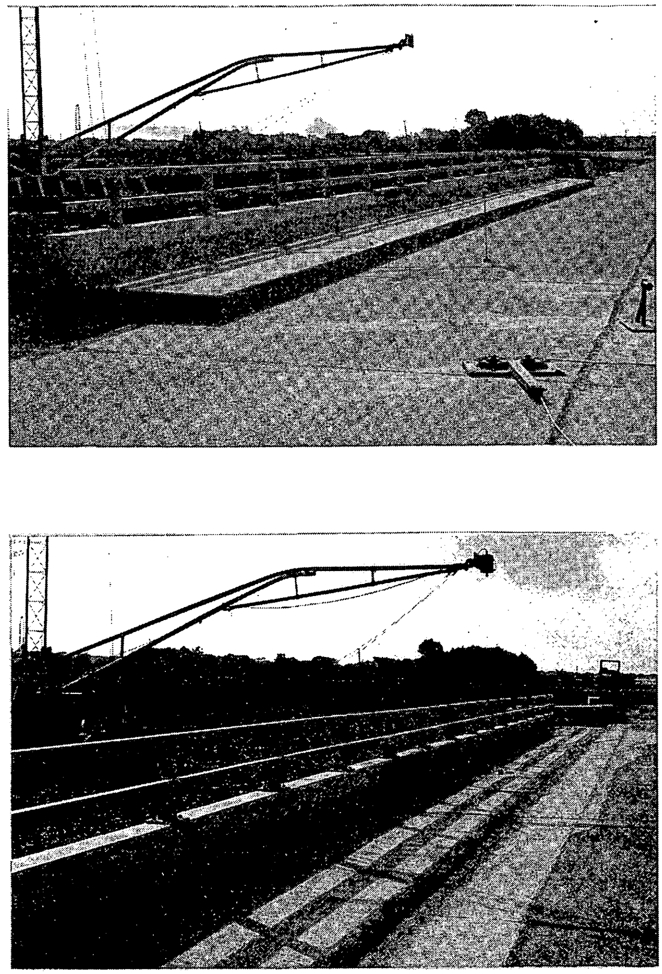


FIGURE 3 BR27D mounted on sidewalk (*top*) and flush on deck (*bottom*).

The BR27C railing was designed to meet PL1 requirements, but it was later tested to Performance Level 2 (PL2) requirements. The design force for the PL2 railings is 56 kips (249.1 kN) at 32 in. (0.8 m) above the road surface for installations in which a raised sidewalk is not present. Ultimate-strength methods of analysis similar to those used for the BR27D railing were used for the BR27C railing. For only the metal railing, a two-span mechanism is the control, and the computed strength is 18.9 kips (84.1 kN) at 40 in. (1.0 m) above the sidewalk. The computed strength of the concrete parapet with force applied at its top edge is 73.3 kips (326.0 kN). The maximum combined strength of the parapet and metal railing is 73.3 minus 10.2 plus 18.9 equals 82 kips (364.7 kN) at 27.7 in. (0.7 m) above the sidewalk. If the parapet were only partially loaded, lower strengths at greater heights would be obtained.

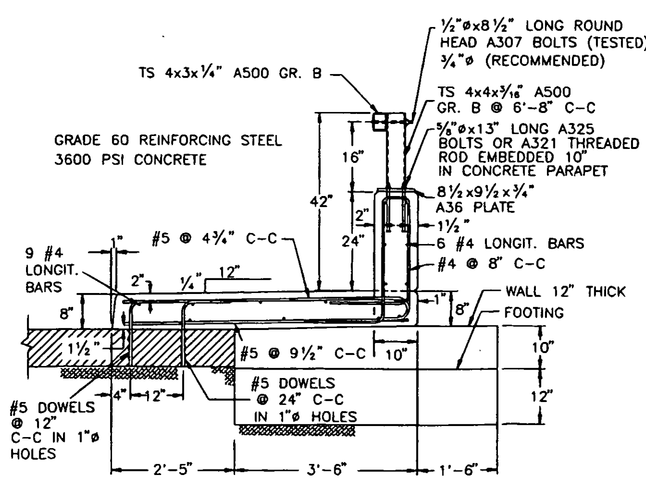


FIGURE 4 Cross section of BR27C mounted on sidewalk.

FULL-SCALE CRASH TESTS

The BR27C and BR27D railings were designed for use in urban areas where truck traffic is minimal. The BR27D railing was tested

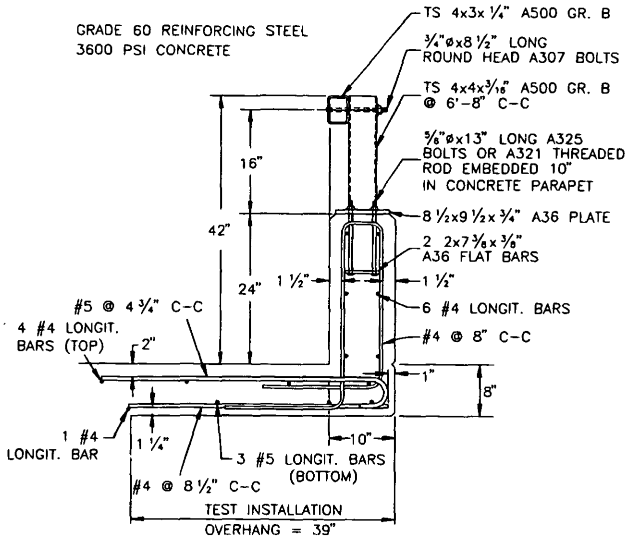


FIGURE 5 Cross section of BR27C mounted flush on deck.

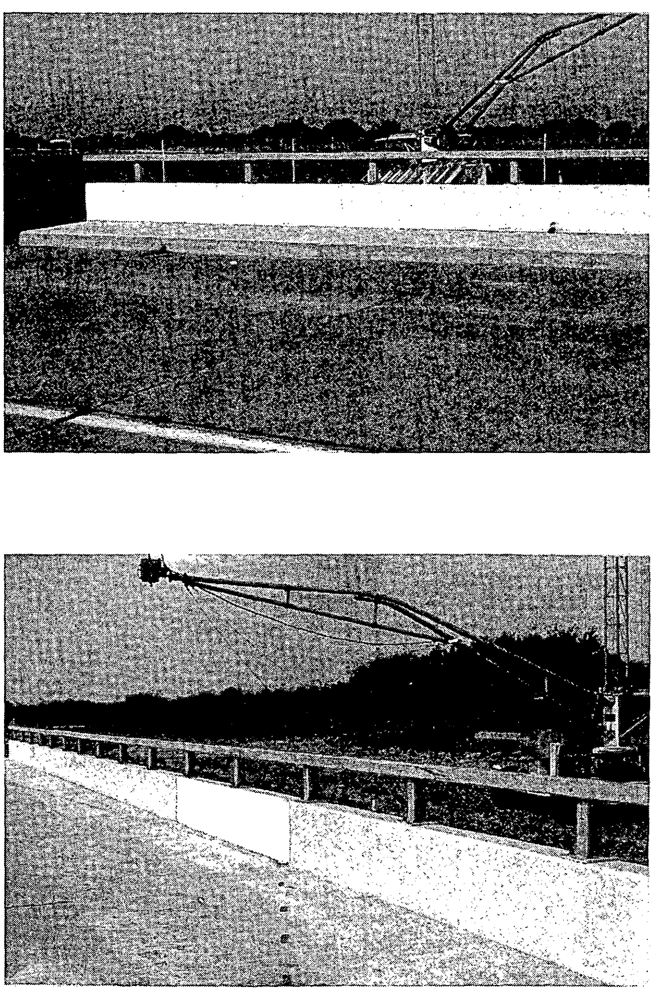


FIGURE 6 BR27C mounted on sidewalk (*top*) and flush on deck (*bottom*).

to PL1 both on the sidewalk (Tests 7069-22 and 7069-23) and on the deck (Tests 7069-30 and 7069-31). The BR27C railing was tested to PL2 both on the sidewalk (Tests 7069-24, 7069-25, and 7069-26) and on the deck (Tests 7069-32, 7069-33, and 7069-34). The sidewalk for both designs was 5 ft (1.5 m) wide, and its face formed an 8-in. (0.2-m)-high curb. All testing was performed in accordance with the test procedures specified in *NCHRP Report 230* (*6*), and the results were evaluated according to the requirements of the AASHTO specifications displayed in Figure 7.

Test Results for BR27D

The BR27D railing designs performed acceptably according to PL1 requirements in both series of tests. Generally, the railing functioned as a "rigid" railing, with only a small amount of permanent deformation in the metal railing in the more severe tests.

BR27D Mounted on Sidewalk

Test 7069-22 Impact with the curb slowed the vehicle to 46.6 mph (75.0 km/hr) and partially redirected the vehicle to 13.4 degrees before it contacted the railing at Post 5. Redirection of the vehicle was relatively smooth, with only minimal intrusion of the bumper between rail elements. There was minimal damage to the bridge railing system, with no measurable permanent deformation to the rail elements. According to the AASHTO specifications for PL1 tests with 1,800-lb (817-kg) vehicles the bridge railing performed acceptably, as shown in Figure 8 and Table 1.

Test 7069-23 As in the first test, impact with the curb partially redirected and slowed the vehicle. The vehicle struck the railing 3 ft from Post 5 (between Posts 4 and 5) traveling at a speed of 43.8 mph (70.5 km/hr) and at an angle of 19.7 degrees. Smooth redirection occurred, with minimal intrusion of the bumper between the lower metal rail element and the concrete parapet. The railing system received minimal damage, and maximum permanent deformation to the rail element was 0.5 in. (13 mm) between Posts 5 and 6. Posts 5 and 6 were displaced rearward approximately 3/16 in. (5 mm) at the anchor bolt holes. The railing performed acceptably according to AASHTO requirements for PL1 tests with 5,400-lb (2452-kg) vehicles (Figure 9 and Table 1).

BR27D Mounted Flush on Deck

Test 7069-30 The vehicle struck the railing system approximately 25.5 ft (7.8 m) from the end of the bridge railing. The railing contained and smoothly redirected the vehicle, with no measurable permanent deformation to the rail elements. As shown in Figure 10 and Table 2, the railing performed acceptably according to PL1 requirements.

Test 7069-31 The pickup struck the railing system approximately 1 ft (0.3 m) downstream of Post 5. Redirection of the vehicle was relatively smooth, with no snagging and minimal lateral movement of the rail element. The railing system received minimal dam-

		TEST SPEEDS—mph[1,2]			
		TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES			
PERFORMANCE LEVELS		Small Automobile W = 1.8 Kips A = 5.4′ ± 0.1′ B = 5.5′ H_{cg} = 20″ ± 1″ θ = 20 deg.	Pickup Truck W = 5.4 Kips A = 8.5′ ± 0.1′ B = 6.5′ H_{cg} = 27″ ± 1″ θ = 20 deg.	Medium Single-Unit Truck W = 18.0 Kips A = 12.8′ ± 0.2′ B = 7.5′ H_{cg} = 49″ ± 1″ θ = 15 deg.	Van-Type Tractor-Trailer[4] 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 No. 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 $\mu = (\cos\theta - V_p/V)/\sin\theta$

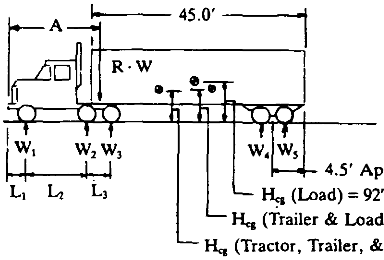
   g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0-ft. longitudinal and 1.0-ft. lateral displacements, shall be less than:

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



Min. Load = 20.5 Kips

$L_1 = 30'' \pm 1''$

$L_2 + \frac{L_3}{2} = 169'' \pm 4''$

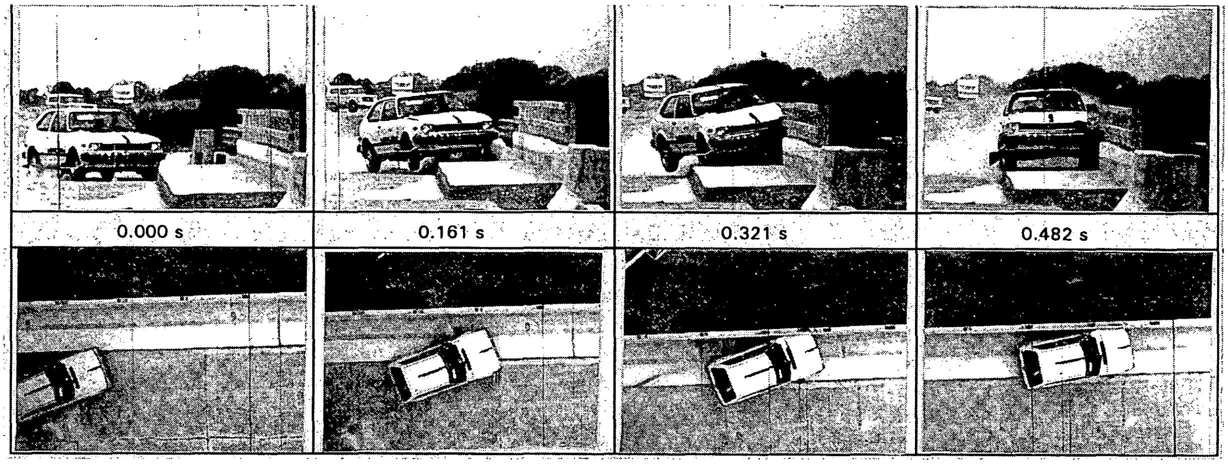
$$A = L_1 + \frac{W_2L_2 + W_3(L_2 + L_3)}{W_1 + W_2 + W_3}$$

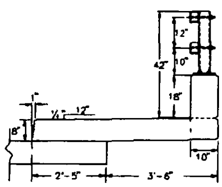
$$R = \frac{W_1 + W_2 + W_3}{W}$$

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

FIGURE 7 Bridge railing performance levels and crash test criteria (*4*).





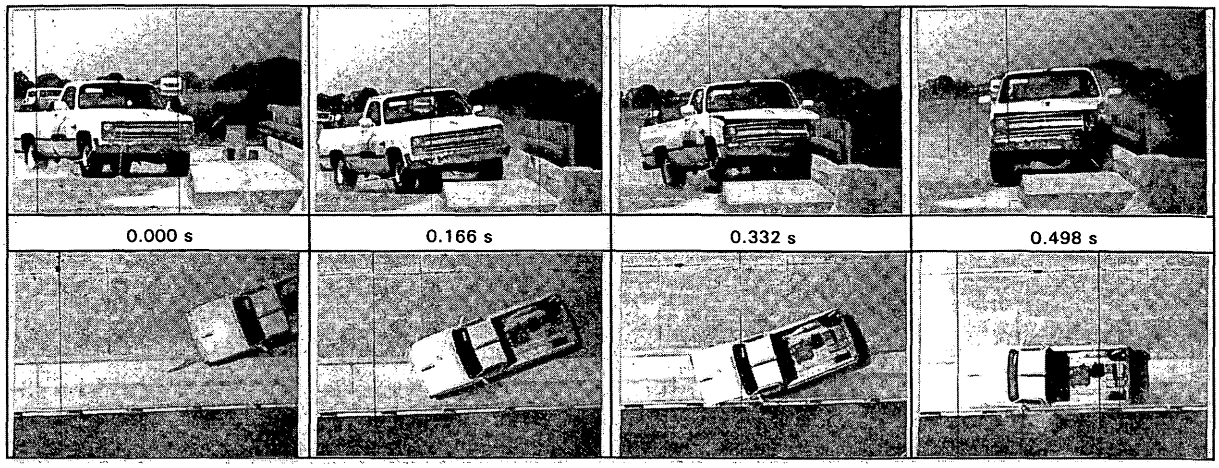
1 in = 25.4 mm
1 ft = 0.305 m

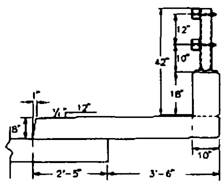
Test No.	7069-22
Date	03/24/92
Test Installation	BR27D Bridge Railing on sidewalk
Installation Length	100 ft (30 m)
Test Vehicle	1983 Honda Civic
Vehicle Weight	
Test Inertia	1800 lb (817 kg)
Gross Static	1967 lb (893 kg)
Vehicle Damage Classification	
TAD	11LFQ3
CDC	11FLEK2 & 11LFES2
Maximum Vehicle Crush	6.0 in (152 mm)
Impact Speed	51.7 mi/h (83.2 km/h)
Impact Angle	20.8 degrees
Speed at Parallel	41.0 mi/h (66.0 km/h)
Exit Speed	40.8 mi/h (65.6 km/h)
Exit Trajectory	6.1 degrees
Vehicle Accelerations (Max 50-ms Avg)	
Longitudinal	-4.4 g
Lateral	-6.8 g
Occ. Impact Velocity	
Longitudinal	12.2 ft/s (3.7 m/s)
Lateral	6.3 ft/s (1.9 m/s)
Occ. Ridedown Acc.	
Longitudinal	-4.7 g
Lateral	-13.3 g

FIGURE 8 Results for Test 7069-22.

TABLE 1 Evaluation of Tests on BR27D Mounted on Sidewalk

EVALUATION CRITERIA	TEST 7069-22	TEST 7069-23	PASS/ FAIL
A. Must contain vehicle	Vehicle contained	Vehicle contained	Pass
B. Debris shall not penetrate occupant compartment	No debris penetrated	No debris penetrated	Pass
C. Occupant compartment must have essentially no deformation	No deformation	No deformation	Pass
D. Vehicle must remain upright	Remained upright	Remained upright	Pass
E. Smooth redirection of vehicle	Relatively smooth redirection	Relatively smooth redirection	Pass
F. Effective coefficient of friction	Marginal	Good	Pass
G. Occupant Impact Velocity (30/25) Occupant Ridedown (15/15)	12.2 ft/s Long 6.3 ft/s Lat -4.7 g Long -13.3 g Lat	13.2 ft/s Long 14.0 ft/s Lat -2.3 g Long -10.6 g Lat	Pass
H. Exit angle less than 12 degrees	Exit angle 6.1 degrees	Exit angle 5.3 degrees	Pass



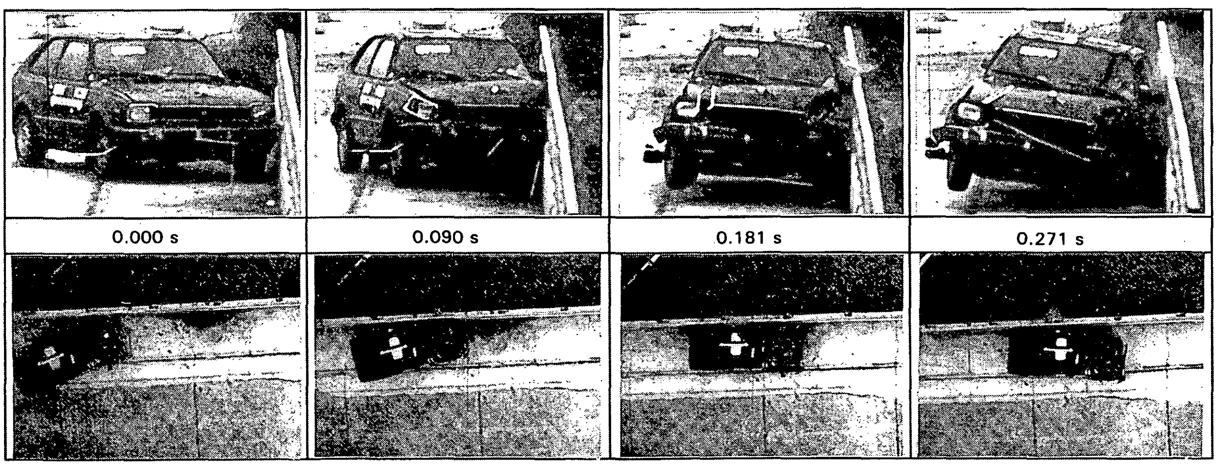


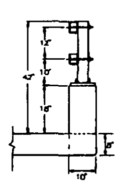
1 in = 25.4 mm
1 ft = 0.305 m

Test No.	7069-23
Date	03/26/92
Test Installation	BR27D Bridge Railing on sidewalk
Installation Length	100 ft (30 m)
Test Vehicle	1984 Chevrolet Custom Pickup
Vehicle Weight	
Test Inertia	5400 lb (2452 kg)
Gross Static	5565 lb (2527 kg)
Vehicle Damage Classification	
TAD	11LFQ4 & 11LD4
CDC	11FLEK2 & 11LFEW3
Maximum Vehicle Crush	12.5 in (318 mm)

Impact Speed	45.3 mi/h (72.9 km/h)
Impact Angle	20.2 degrees
Speed at Parallel	40.3 mi/h (64.8 km/h)
Exit Speed	37.2 mi/h (59.9 km/h)
Exit Trajectory	5.3 degrees
Vehicle Accelerations (Max 50-ms Avg)	
Longitudinal	-3.7 g
Lateral	-7.8 g
Occ. Impact Velocity	
Longitudinal	13.2 ft/s (4.0 m/s)
Lateral	14.0 ft/s (4.3 m/s)
Occ. Ridedown Acc.	
Longitudinal	-2.3 g
Lateral	-10.6 g

FIGURE 9 Results for Test 7069-23.





1 in = 25.4 mm

Test No.	7069-30
Date	05/19/92
Test Installation	BR27D Bridge Railing on deck
Installation Length	100 ft (30 m)
Test Vehicle	1983 Honda Civic
Vehicle Weight	
Test Inertia	1800 lb (817 kg)
Gross Static	1970 lb (894 kg)
Vehicle Damage Classification	
TAD	11LFQ3
CDC	11FLEK2 & 11LFES2
Maximum Vehicle Crush	7.0 in (178 mm)

Impact Speed	51.2 mi/h (82.4 km/h)
Impact Angle	20.5 degrees
Speed at Parallel	43.6 mi/h (70.2 km/h)
Exit Speed	43.0 mi/h (69.2 km/h)
Exit Trajectory	6.8 degrees
Vehicle Accelerations (Max 50-ms Avg)	
Longitudinal	-7.5 g
Lateral	-12.8 g
Occ. Impact Velocity	
Longitudinal	16.0 ft/s (4.9 m/s)
Lateral	21.5 ft/s (6.6 m/s)
Occ. Ridedown Acc.	
Longitudinal	-3.6 g
Lateral	-6.1 g

FIGURE 10 Results for Test 7069-30.

TABLE 2 Evaluation of Tests on BR27D Mounted Flush on Deck

EVALUATION CRITERIA	TEST 7069-30	TEST 7069-31	PASS/ FAIL
A. Must contain vehicle	Vehicle contained	Vehicle contained	Pass
B. Debris shall not penetrate occupant compartment	No debris penetrated	No debris penetrated	Pass
C. Occupant compartment must have essentially no deformation	No deformation	No deformation	Pass
D. Vehicle must remain upright	Remained upright	Remained upright	Pass
E. Smooth redirection of vehicle	Smooth redirection	Relatively smooth redirection	Pass
F. Effective coefficient of friction	Good	Good	Pass
G. Occupant Impact Velocity (30/25) Occupant Ridedown (15/15)	16.0 ft/s Long 21.5 ft/s Lat -3.6 g Long -6.1 g Lat	11.7 ft/s Long 12.3 ft/s Lat 2.2 g Long -8.2 g Lat	Pass
H. Exit angle less than 12 degrees	Exit angle 6.8 degrees	Exit angle 6.2 degrees	Pass

age, with a maximum permanent deformation of 0.5 in. (13 mm) to the metal rail element between Posts 5 and 6. Figure 11 and Table 2 present the results showing that the railing performed acceptably according to the PL1 requirements of the AASHTO specifications.

Test Results for BR27C

After testing of the BR27C railing on sidewalk, two details were changed before testing the BR27C railing mounted flush on deck. The rail-to-post connection bolts were changed from ½ in. (13 mm) in diameter to ¾ in. (19 mm) in diameter, and an anchorage assembly was added at the end of the anchor bolts. These modifications are recommended for both versions of the railing. Both designs of the BR27C railing performed acceptably according to PL2 requirements.

BR27C Mounted on Sidewalk

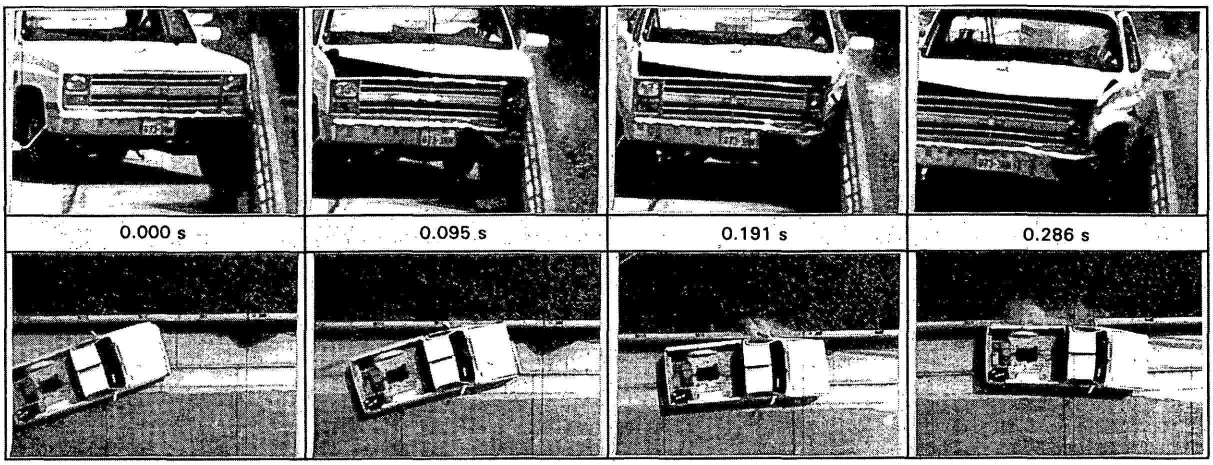
Test 7069-24 Partial redirection and slowing of the vehicle occurred as the vehicle traversed the curb of the sidewalk. The vehicle struck the railing traveling at 55.5 mph (89.3 km/hr) and an angle of 18.1 degrees. Redirection of the vehicle by the railing was relatively smooth. The railing system received minimal damage, with no measurable permanent deformation to the metal rail elements. However, the left corner of the bumper snagged Post 6 (leaving plastic trim), and Posts 5 and 6 were pulled up such that the washers rotated freely under the nuts on the front side of the railing. Although the lateral ridedown acceleration of 17.2 *g* was slightly above AASHTO's recommended 15-*g* limit for the 1,800-lb (817-kg) vehicle, the test was judged acceptable for this category because it was well within the limits of the other three occupant risk factors. See Figure 12 and Table 3 for detailed results.

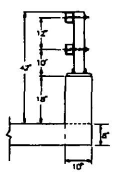
Test 7069-25 Impact with the curb caused minimal redirection and slowing of the vehicle during this test. The vehicle bumper struck the railing near Post 4 at a speed of 59.8 mph (96.2 km/hr) and an angle of 17.9 degrees. Redirection of the vehicle was relatively smooth, with minimal intrusion of the bumper between the concrete parapet and the lower rail element. The railing system received minimal damage, with no measurable permanent deformation to the metal rail elements. However, as in the test with the 1,800-lb (817-kg) vehicle, the left corner of the bumper had snagged Post 5 and pulled it up such that the washer rotated freely under the nut on the left front side of the railing. According to the PL2 limits specified by AASHTO for tests with 5,400-lb (2,452-kg) pickups, the railing performed acceptably. Results are presented in Figure 13 and Table 3.

Test 7069-26 A single-unit truck was used for the third crash test on the BR27C railing on sidewalk. Shortly after impact with the curb the vehicle began a slight counterclockwise yaw and the vehicle bumper struck the railing [3 ft (1 m) downstream of Post 7] traveling at a speed of 47.9 mph (77.1 km/hr) and an angle of 14.4 degrees. During the collision the right front wheel and part of the hub broke loose from the axle, and as the vehicle continued forward the lower edge of the vehicle's cargo box pulled the metal rail off of Posts 10 through 14. The railing system contained the test vehicle with minimal lateral movement of the bridge railing. There was no measurable permanent deformation to the metal rail elements in the immediate impact area; however, the bolts connecting the rail to the posts from Posts 10 through 14 were sheared as a result of vertical load from the cargo box. The railing performed acceptably according to AASHTO PL2 requirements, and results and evaluation are presented in Figure 14 and Table 3.

BR27C Mounted on Deck

Test 7069-32 The vehicle struck the railing system 1.1 ft (0.3 m) downstream from Post 3 [or 17.8 ft (5.4 m) from the end of the bridge railing]. The bridge railing received minimal damage, with no deformation to the metal rail element. There was no intru-

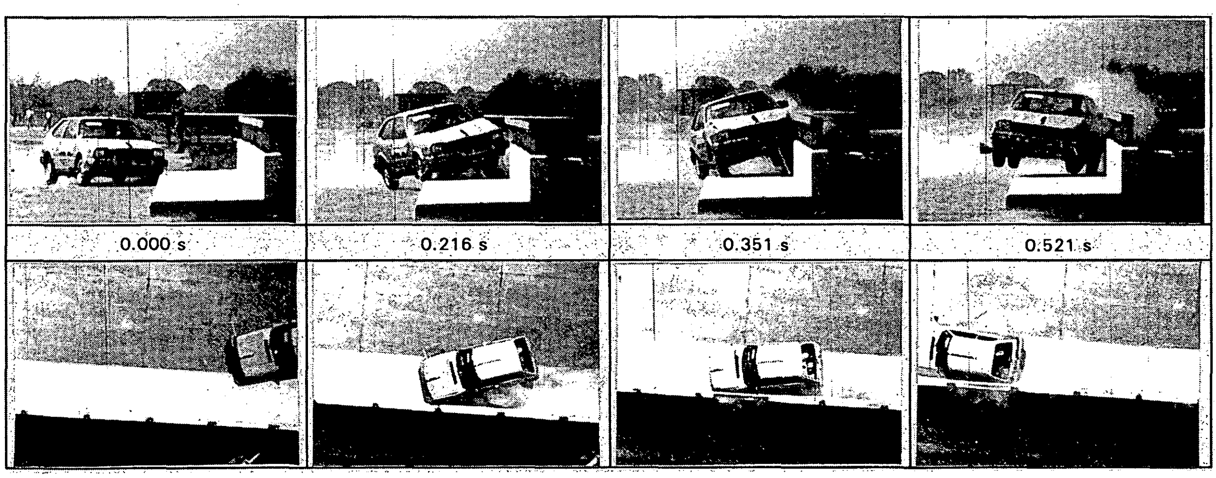


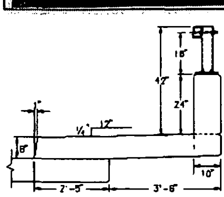


1 in = 25.4 mm

Test No.	7069-31	Impact Speed	45.6 mi/h (73.4 km/h)
Date	05/21/92	Impact Angle	18.8 degrees
		Speed at Parallel	40.8 mi/h (65.6 km/h)
Test Installation	BR27D Bridge Railing on deck	Exit Speed	38.0 mi/h (61.1 km/h)
		Exit Trajectory	6.2 degrees
Installation Length	100 ft (30 m)	Vehicle Accelerations (Max 50-ms Avg)	
Test Vehicle	1985 Chevrolet Custom Pickup	Longitudinal	-4.1 g
Vehicle Weight		Lateral	-7.5 g
Test Inertia	5400 lb (2452 kg)	Occ. Impact Velocity	
Gross Static	5566 lb (2527 kg)	Longitudinal	11.7 ft/s (3.6 m/s)
Vehicle Damage Classification		Lateral	12.3 ft/s (3.7 m/s)
TAD	11LFQ3 & 11LD2	Occ. Ridedown Acc.	
CDC	11FLEK2 & 11LFEW2	Longitudinal	2.2 g
Maximum Vehicle Crush	6.5 in (165 mm)	Lateral	-8.2 g

FIGURE 11 Results for Test 7069-31.





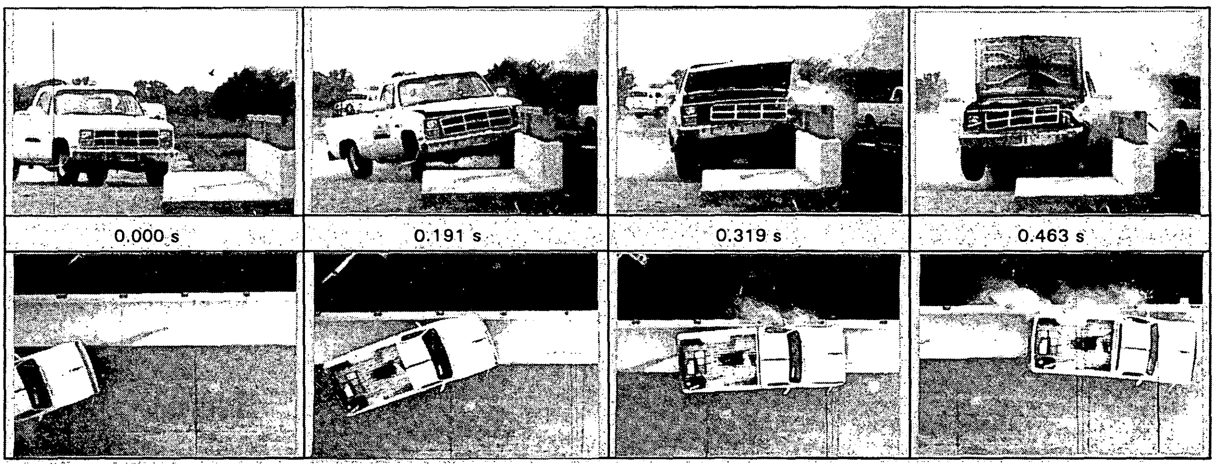
1 in = 25.4 mm
1 ft = 0.305 m

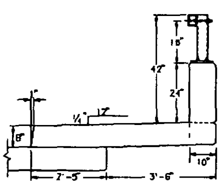
Test No.	7069-24	Impact Speed	61.7 mi/h (99.3 km/h)
Date	03/31/92	Impact Angle	18.7 degrees
		Speed at Parallel	50.9 mi/h (81.9 km/h)
Test Installation	BR27C Bridge Railing on sidewalk	Exit Speed	50.3 mi/h (80.9 km/h)
		Exit Trajectory	1.0 degree
Installation Length	100 ft (30 m)	Vehicle Accelerations (Max 50-ms Avg)	
Test Vehicle	1982 Honda Civic	Longitudinal	-5.6 g
Vehicle Weight		Lateral	-9.3 g
Test Inertia	1800 lb (817 kg)	Occ. Impact Velocity	
Gross Static	1965 lb (892 kg)	Longitudinal	15.3 ft/s (4.7 m/s)
Vehicle Damage Classification		Lateral	6.5 ft/s (2.0 m/s)
TAD	11LFQ3	Occ. Ridedown Acc.	
CDC	11FLEK2 & 11LFES2	Longitudinal	-3.8 g
Maximum Vehicle Crush	7.5 in (191 mm)	Lateral	-17.2 g

FIGURE 12 Results for Test 7069-24.

TABLE 3 Evaluation of Tests on BR27C Mounted on Sidewalk

EVALUATION CRITERIA	TEST 7069-24	TEST 7069-25	TEST 7069-26	PASS/ FAIL
A. Must contain vehicle	Vehicle contained	Vehicle contained	Vehicle contained	Pass
B. Debris shall not penetrate occupant compartment	No debris penetrated	No debris penetrated	No debris penetrated	Pass
C. Occupant compartment must have essentially no deformation	No deformation	No deformation	No deformation	Pass
D. Vehicle must remain upright	Remained upright	Remained upright	Remained upright	Pass
E. Smooth redirection of vehicle	Relatively smooth redirection	Relatively smooth redirection	Relatively smooth redirection	Pass
F. Effective coefficient of friction	Marginal to good	Good	Marginal to good	Pass
G. Occupant Impact Velocity (30/25) Occupant Ridedown (15/15)	15.3 ft/s Long 6.5 ft/s Lat -3.8 g Long -17.2 g Lat	12.9 ft/s Long 19.9 ft/s Lat -4.4 g Long -10.8 g Lat	8.2 ft/s Long 9.4 ft/s Lat -2.9 g Long -6.9 g Lat	Pass
H. Exit angle less than 12 degrees	Exit angle 1.0 degrees	Exit angle 5.4 degrees	Exit angle 0 degrees	Pass



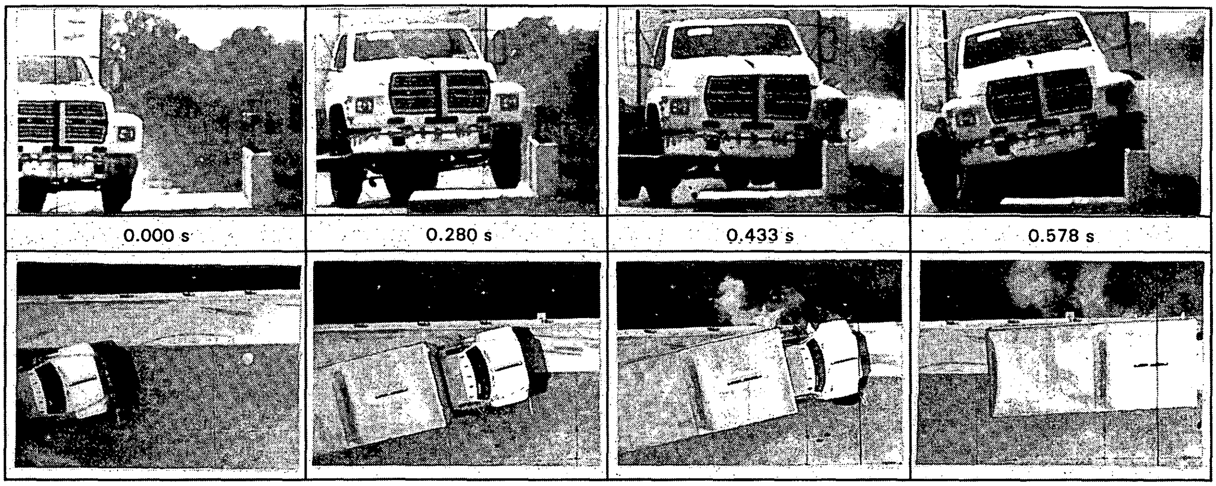


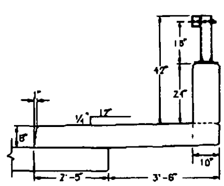
1 in = 25.4 mm
1 ft = 0.305 m

Test No.	7069-25
Date	04/02/92
Test Installation	BR27C Bridge Railing on sidewalk
Installation Length	100 ft (30 m)
Test Vehicle	1984 GMC Sierra Pickup
Vehicle Weight	
Test Inertia	5400 lb (2452 kg)
Gross Static	5568 lb (2528 kg)
Vehicle Damage Classification	
TAD	11LFQ4 & 11LD4
CDC	11FLEK2 & 11LFEW2
Maximum Vehicle Crush	12.0 in (305 mm)

Impact Speed	62.6 mi/h (100.7 km/h)
Impact Angle	19.4 degrees
Speed at Parallel	56.7 mi/h (91.2 km/h)
Exit Speed	53.5 mi/h (86.1 km/h)
Exit Trajectory	5.4 degrees
Vehicle Accelerations (Max 50-ms Avg)	
Longitudinal	-4.6 g
Lateral	-9.3 g
Occ. Impact Velocity	
Longitudinal	12.9 ft/s (3.9 m/s)
Lateral	19.9 ft/s (6.1 m/s)
Occ. Ridedown Acc.	
Longitudinal	-4.4 g
Lateral	-10.8 g

FIGURE 13 Results for Test 7069-25.





1 in = 25.4 mm
1 ft = 0.305 m

Test No.	7069-26
Date	04/08/92
Test Installation	BR27C Bridge Railing on sidewalk
Installation Length	100 ft (30 m)
Test Vehicle	1980 Ford Single-Unit Truck
Vehicle Weight	
Empty Weight	10,550 lb (4790 kg)
Test Inertia	18,000 lb (8172 kg)
Maximum Vehicle Crush	12.0 in (305 mm)

Impact Speed	51.0 mi/h (82.0 km/h)
Impact Angle	13.7 degrees
Speed at Parallel	44.8 mi/h (72.1 km/h)
Exit Speed	N/A
Exit Trajectory	0 degree
Vehicle Accelerations (Max 50-ms Avg)	
Longitudinal	-1.9 g
Lateral	-2.9 g
Occ. Impact Velocity	
Longitudinal	8.2 ft/s (2.5 m/s)
Lateral	9.4 ft/s (2.9 m/s)
Occ. Ridedown Acc.	
Longitudinal	-2.9 g
Lateral	-6.9 g

FIGURE 14 Results for Test 7069-26.

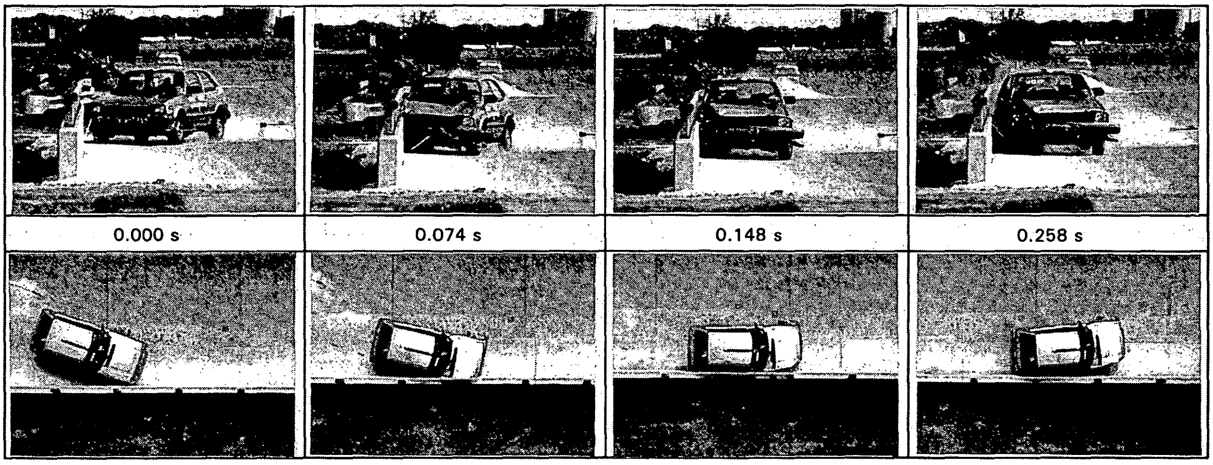
sion of railing components into the occupant compartment, although there was a 1-in. (25-mm) dent into the occupant compartment at the firewall. This deformation into the occupant compartment was deemed as not life-threatening, and therefore the test was judged acceptable for this category. As shown in Figure 15 and Table 4, the railing performed acceptably according to AASHTO PL2 requirements.

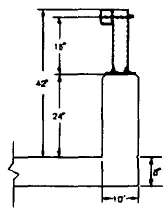
Test 7069-33 The pickup struck the railing 1.9 ft (0.6 m) downstream from Post 3 [or 18.6 ft (5.7 m) from the end of the bridge railing]. Redirection of the vehicle was relatively smooth, with minimal intrusion of the bumper between the parapet and lower metal rail element and slight contact with Post 4. There was 0.5 in. (13 mm) of deformation to the lower metal rail element, and there was a hairline crack in the concrete parapet 17.5 in. (0.4 m) down from Post 3. There was no intrusion of railing components into the occupant compartment, although there was a 0.5-in. (13-mm) dent into the occupant compartment at the firewall. As in the test with the 1,800-lb (817-kg) vehicle, this deformation into the occupant compartment was not considered life-threatening. The railing was judged acceptable according to PL2 requirements, and results and evaluation of the test are shown in Figure 16 and Table 4.

Test 7069-34 A single-unit truck vehicle struck the railing 1.0 ft (0.3 m) downstream from Post 5. As the vehicle struck the railing the bumper rode up the concrete parapet, went between the concrete parapet and lower metal rail element, made contact with Post 6, and then contacted Post 7. The bridge railing received minimal damage, with most being contained within the area around Posts 4, 5, and 6. Cracking occurred in Post 4 and 5 in the heat-affected zone in the post at the post-to-base plate connection. The crack occurred at the corners on the traffic side of the tubular steel element (corner of maximum tensile stress) and extended approximately 1 in. in both directions. There was a hairline crack in the concrete parapet in line with the rear post bolts at Post 4. There was 1.5 in. (38 mm) of deformation to the metal rail element between Posts 4 and 5. As shown in Figure 17 and Table 4, the railing performed acceptably according to the PL2 requirements.

SUMMARY AND CONCLUSION

Two 42-in. (1.1-m)-tall bridge railing designs for use in urban areas were designed and tested. Both designs consisted of concrete parapets with metal railings mounted on top of the parapet. The parapet aids in distributing post loads into the bridge deck and the metal portion of the railing permits visibility through the railing. Ultimate-strength, plastic mechanism methods of analysis were used to design the railings. Prototypes of each railing design were subjected to full-scale crash tests when they were mounted on 8-in. (0.2-m)-high, 5-ft (1.5-m)-wide sidewalks and when they were mounted





1 in = 25.4 mm

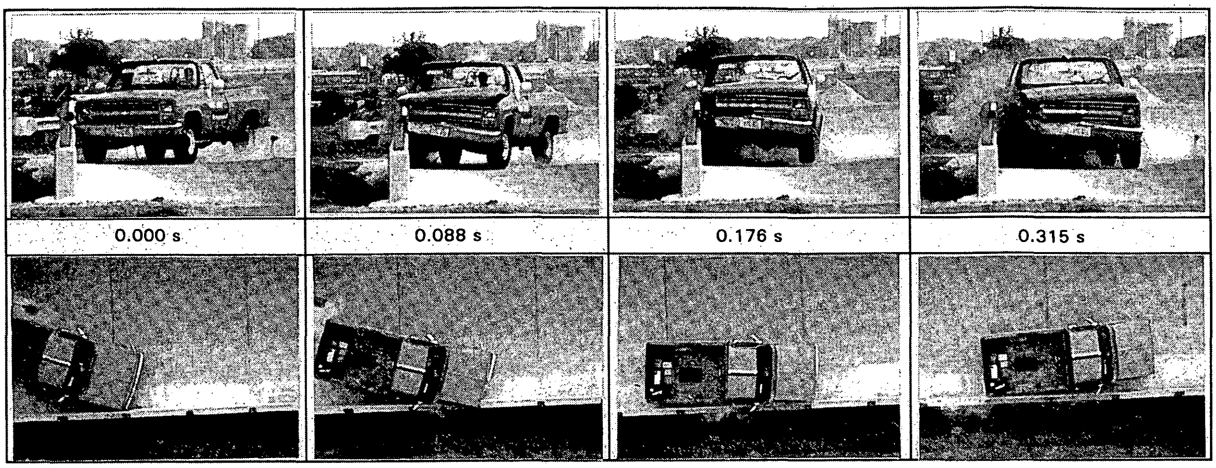
Test No.	7069-32
Date	07/14/92
Test Installation	BR27C Bridge Railing on deck
Installation Length	100 ft (30 m)
Test Vehicle	1983 Honda Civic
Vehicle Weight	
Test Inertia	1800 lb (817 kg)
Gross Static	1970 lb (894 kg)
Vehicle Damage Classification	
TAD	01RFQ5
CDC	01FREK3 & 01RYEW4
Maximum Vehicle Crush	6.5 in (165 mm)

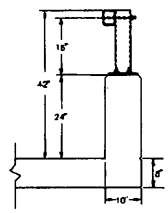
Impact Speed	60.3 mi/h (97.0 km/h)
Impact Angle	19.8 degrees
Speed at Parallel	53.6 mi/h (86.2 km/h)
Exit Speed	50.6 mi/h (81.4 km/h)
Exit Trajectory	6.6 degrees
Vehicle Accelerations (Max 50-ms Avg)	
Longitudinal	-5.7 g
Lateral	12.2 g
Occ. Impact Velocity	
Longitudinal	14.5 ft/s (4.4 m/s)
Lateral	24.6 ft/s (7.5 m/s)
Occ. Ridedown Acc.	
Longitudinal	-1.2 g
Lateral	12.7 g

FIGURE 15 Results for Test 7069-32.

TABLE 4 Evaluation of Tests on BR27C Mounted Flush on Deck

EVALUATION CRITERIA	TEST 7069-32	TEST 7069-33	TEST 7069-34	PASS/ FAIL
A. Must contain vehicle	Vehicle contained	Vehicle contained	Vehicle contained	Pass
B. Debris shall not penetrate occupant compartment	No debris penetrated	No debris penetrated	No debris penetrated	Pass
C. Occupant compartment must have essentially no deformation	Minimal deformation (1 in)	Minimal deformation (0.5 in)	No deformation	Pass
D. Vehicle must remain upright	Remained upright	Remained upright	Remained upright during test period	Pass
E. Smooth redirection of vehicle	Relatively smooth redirection	Relatively smooth redirection	Relatively smooth redirection	Pass
F. Effective coefficient of friction	Good	Good	Marginal	Pass
G. Occupant Impact Velocity (30/25) Occupant Ridedown (15/15)	14.5 ft/s Long 24.6 ft/s Lat -1.2 g Long -12.7 g Lat	11.6 ft/s Long 20.1 ft/s Lat -2.2 g Long 8.1 g Lat	8.2 ft/s Long 13.1 ft/s Lat -1.1 g Long 4.3 g Lat	Pass
H. Exit angle less than 12 degrees	Exit angle 6.6 degrees	Exit angle 6.5 degrees	Exit angle 3.5 degrees	Pass



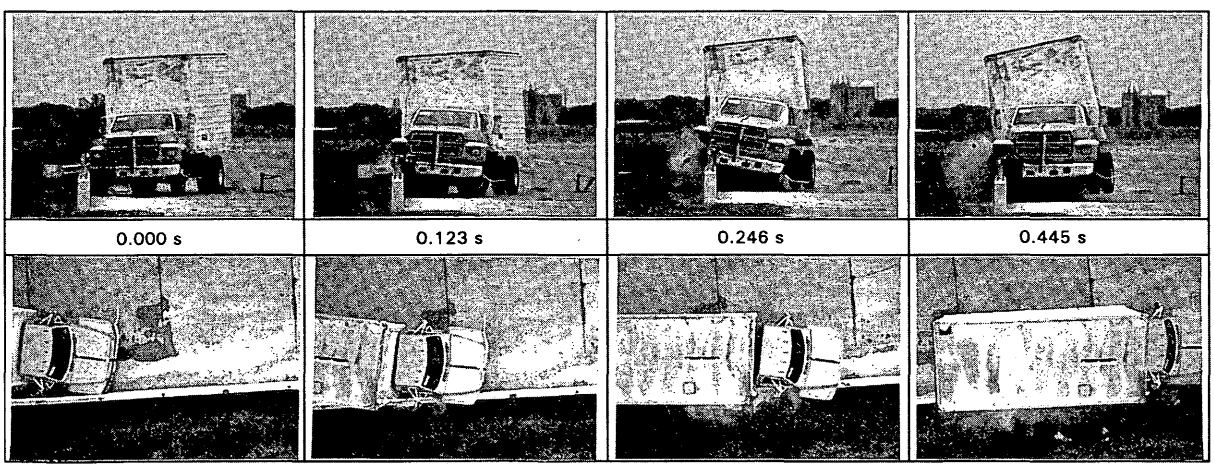


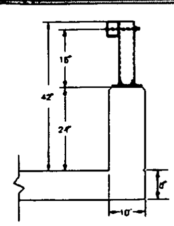
1 in = 25.4 mm

Test No.	7069-33
Date	07/16/92
Test Installation	BR27C Bridge Railing on deck
Installation Length	100 ft (30 m)
Test Vehicle	1985 Chevrolet Pickup
Vehicle Weight	
Test Inertia	5400 lb (2452 kg)
Gross Static	5570 lb (2529 kg)
Vehicle Damage Classification	
TAD	01RFQ4 & 01RD2
CDC	01FREK2 & 01RDEW2
Maximum Vehicle Crush	9.0 in (229 mm)

Impact Speed	55.3 mi/h (89.0 km/h)
Impact Angle	19.6 degrees
Speed at Parallel	47.9 mi/h (77.1 km/h)
Exit Speed	44.8 mi/h (72.1 km/h)
Exit Trajectory	6.5 degrees
Vehicle Accelerations (Max 50-ms Avg)	
Longitudinal	-4.9 g
Lateral	9.3 g
Occ. Impact Velocity	
Longitudinal	11.6 ft/s (3.5 m/s)
Lateral	20.1 ft/s (6.1 m/s)
Occ. Ridedown Acc.	
Longitudinal	-2.2 g
Lateral	8.1 g

FIGURE 16 Results for Test 7069-33.





1 in = 25.4 mm

Test No.	7069-34
Date	08/12/92
Test Installation	BR27C Bridge Railing on deck
Installation Length	100 ft (30 m)
Test Vehicle	1981 Ford Single-Unit Truck
Vehicle Weight	
Test Inertia	10,490 lb (4762 kg)
Gross Static	18,000 lb (8172 kg)
Maximum Vehicle Crush	9.0 in (229 mm)
Max. Perm. Rail Deform.	1.5 in (38 mm)

Impact Speed	52.5 mi/h (84.5 km/h)
Impact Angle	12.8 degrees
Speed at Parallel	46.8 mi/h (75.3 km/h)
Exit Speed	44.6 mi/h (71.8 km/h)
Exit Trajectory	3.5 degrees
Vehicle Accelerations (Max 50-ms Avg)	
Longitudinal	-1.9 g
Lateral	4.3 g
Occ. Impact Velocity	
Longitudinal	8.2 ft/s (2.5 m/s)
Lateral	13.1 ft/s (4.0 m/s)
Occ. Ridedown Acc.	
Longitudinal	-1.1 g
Lateral	5.2 g

FIGURE 17 Results for Test 7069-34.

flush on a simulated bridge deck. Design BR27D was tested to PL1 requirements of the 1989 AASHTO *Guide Specifications for Bridge Railings* (*4*), and BR27C was tested to PL2. Acceptable performances were obtained in all tests.

REFERENCES

1. Buth, C. E., T. J. Hirsch, and W. L. Menges. *Testing of New Bridge Rail and Transition Designs*. Vol. I. Technical Report. Texas Transportation Institute, Texas A&M University, College Station, May 1993.
2. Buth, C. E., T. J. Hirsch, and W. L. Menges. *Testing of New Bridge Rail and Transition Designs*, Vol. III. Appendix B. Texas Transportation Institute, Texas A&M University, College Station, May 1993.
3. Buth, C. E., T. J. Hirsch, and W. L. Menges. *Testing of New Bridge Rail and Transition Designs*, Vol. VIII. Appendix G. Texas Transportation Institute, Texas A&M University, College Station, May 1993.
4. *Guide Specifications for Bridge Railings*. AASHTO, Washington, D.C., 1989.
5. Hirsch, T. J. *Analytical Evaluation of Texas Bridge Rails to Contain Buses and Trucks*. Research Report 230-2. Texas Transportation Institute, Texas A&M University, College Station, Aug. 1978.
6. Michie, J. D. *NCHRP Report 230: Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*. TRB, National Research Council, Washington, D.C., 1981.