Performance Level 3 Bridge Railings

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Many existing bridge railings have been designed to restrain and redirect passenger vehicles. Because of specific site conditions, some locations along the nation's highways require that bridge railings contain and redirect heavier vehicles, such as commercial trucks and buses. These sites include areas where the consequences of failure to contain a vehicle would be severe. Examples include bridges that are grade separation structures crossing heavily congested traffic lanes, areas of reduced radius of curvature, elevated ramps near schools or hospitals, and other areas where additional protection is needed to prevent heavier vehicles from penetrating or rolling over the bridge railing. According to the 1989 American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings,* these sites require Performance Level 3 (PL3) bridge railings. Two PL3 bridge railings were developed under a recently completed pooled funds study sponsored by the Federal Highway Administration, the District of Columbia, and 23 states. The 1.07-m (42-in.) F-shape bridge railing and the 1.07-m (42-in.) concrete parapet were tested and evaluated according to the PL3 requirements of the 1989 AASHTO guide. Both bridge railings performed acceptably.

Many bridge railings throughout the United States have been designed to restrain and redirect passenger cars. Because of specific site conditions, some locations along the nation's highways require bridge railings that are capable of containing and redirecting heavy vehicles, such as commercial buses, truck tractors, and semitrailer combinations. Examples of such locations include bridges that are grade separation structures crossing other densely populated traffic lanes, areas of reduced radius of curvature, elevated ramps near schools or hospitals, and other locations where the consequences of failure to contain a vehicle would be severe.

According to the 1989 American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings (1),* these conditions require Performance Level 3 (PL3) bridge railings. The guide recommends that PL3 bridge railings be used for freeways with variable cross slopes, reduced radius of curvature, higher volumes of mixed heavy vehicles, and maximum tolerable speeds. PL3 bridge railings should also be used where additional protection is needed to prevent heavier vehicles from penetrating or rolling over the bridge railing.

A research study sponsored by the Federal Highway Administration (FHWA), the District of Columbia, and 23 states was recently completed by Texas Transportation Institute. The objective of the study was to develop several bridge railings for each of the three performance levels in the AASHTO guide specifications. Two PL3 bridge railings were developed in this study. The project began in August 1986 while the AASHTO guide specifications were being revised and updated. When the 1.07-m (42-in.) F-shape bridge railing was designed, the proposed 1987 test matrix of the AASHTO guide (Table 1) specified a strength test in which an 18,160-kg (40,000-lb) intercity bus strikes the bridge railing at 96.5 km/hr (60 mph) and at an angle of 15 degrees (*2*). The F-shape bridge railing performed acceptably under those test conditions. However, criteria set forth in the final 1989 AASHTO guide require that a PL3 bridge railing be tested using a 22,700-kg (50,000-lb) van-type tractor-trailer striking the railing at a speed of 80.5 km/hr (50 mph) and at an angle of 15 degrees (Table 2). Therefore, another test was performed under the new conditions, and again the F-shape bridge railing performed acceptably. A 1.07-m (42-in.) vertical-faced concrete parapet, which was designed and tested during the study, also performed acceptably using the 1989 AASHTO guide specifications.

This report documents the design and testing of two PL3 bridge railings: the 1.07-m (42-in.) F-shape bridge railing and the 1.07-m (42-in.) concrete parapet.

DESIGN CONSIDERATIONS

1.07-m (42-in.) F-Shape

The F-shape bridge railing was initially designed to meet Performance Level 3 of the 1987 *Guide Specifications for Bridge Railings.* The railing was first tested with an 18,160-kg (40,000-lb) intercity bus traveling 96.5 km/hr (60 mph) with an approach angle of 15 degrees (1987 guide specifications). The F-shape was later tested with a 22,700-kg (50,000-lb) tractor-trailer at 80.5 km/hr (50 mph) and 15 degrees. Design impact force for the tractor-trailer test was 552 kN (124 kips) of uniformly distributed line force 2.44 m (96 in.) long and 0.96 m to 1.02 m (38 to 40 in.) above the roadway surface (*3,4*).

A cross section of the 1.07 m (42 in.) high F-shape is shown in Figure 1. The cross-sectional width of the railing is 439 mm (17.3 in.) at its base and tapers inward along the height with an increased cross-sectional width at the top of 230 mm (9 in.) along the top 304.8 mm (12 in.) of the rail. The slope at the bottom of the railing minimizes vehicle damage at low-impact angles by causing the tire to ride up the railing and redirect itself back to the pavement. The increased cross-sectional width at the top of the railing acts as a continuous beam and enhances the longitudinal distribution of forces in the parapet and deck.

Four No. 7 longitudinal bars were used in the increased cross-section at the top of the F-shape and four No. 8 longitudinal bars were placed throughout the tapered portion of the railing. The vertical steel consisted of No. 5 bent stirrups spaced at 203 mm (8 in.) on center. Specified concrete strength was 24,804 kPa (3,600 psi). The cantilevered deck was supported on a foundation so that the deck overhang was 991 mm (39 in.).

Analysis of the strength of the railing is based on the yieldline failure pattern shown in Figure 2 (*5*). The length of the yieldline

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TABLE 1 1987 Proposed AASHTO Test Matrix

PERFORMANCE LEVEL	TEST SPEEDS -- mph			
	TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES			
	Small Automobile Wt = 1.8 kips θ = 20 deg	Pickup Truck Wt = 5.4 kips θ = 20 deg	Intercity Bus (loose ballast) Wt = 40.0 kips θ = 15 deg	Van-Type Tractor-Trailer No. 2 Wt = 80.0 kips θ = 15 deg
PL-1	50	45		
PL-2	60	65		
PL-3	60	65	60	
PL-4	60	65		55

Metric Conversion: 1 kip = 454 kg
1 mph = 1.609 km/h

failure pattern depends on the relative bending moment capacities of the various railing elements. The computed cantilever moment capacity of the parapet, M_c, is 69.9 m-kN/m (15.7 ft-k/ft). The average moment capacity of the parapet about a vertical axis, M_w, is 67.6 m-kN/m (15.2 ft-k/ft). The additional average moment capacity of the stiffening beam along the top of the parapet is 32 m-kN (23.6 ft-kips). The length of the yieldline failure pattern, computed from the equation in Figure 2, is 5.4 m (17.6 ft) and the ultimate strength of the parapet is 565.2 kN (127 kips), which is greater than the design force of 552 kN (124 kips).

1.07-m (42-in.) Concrete Parapet

The concrete parapet, shown in Figure 3, is 254 mm (10 in.) wide at the base and 305 mm (12 in.) wide at the top. The "beam" along the top edge enhances the longitudinal distribution of forces within the parapet and the deck. Two types of vertical reinforcing bars are alternated to provide No. 5 bars spaced at 152 mm (6 in.) in the traffic side face.

The design impact force used was 685 kN (154 kips) uniformly distributed over a longitudinal distance of 2.44 m (96 in.) at 864 mm (34 in.) above the deck surface. The currently recommended design force for PL3 [tractor-trailer; 22,700 kg (50,000 lb); 80.5 km/hr (50 mph); 15 degrees] is a uniformly distributed line force of 552 kN (124 kips) distributed over 2.44 m (96 in.) at 0.96 to 1.02 m (38 to 40 in.) above the deck surface. The concrete parapet meets these design requirements.

Analysis of the strength of the railing is based on the yieldline pattern shown in Figure 2. The force from a colliding vehicle is idealized as being a uniformly distributed line load extending 2.4 m (8.0 ft). The load may be applied at any location along the railing.

The length of the yieldline failure pattern depends on the relative bending moment capacities of the various railing elements. The computed cantilever moment capacity of the parapet, M_c, is 95.2 m-kN/m (21.4 ft-k/ft). The moment capacity of the parapet about a vertical axis, M_w, is 73.4 m-kN/m (16.5 ft-k/ft). The additional moment capacity of the stiffening beam along the top of the parapet is 59.6 m-kN (43.9 ft-kips). The length of the yieldline failure pattern, computed from the equation in Figure 2 is 4.9 m (16.2 ft), and the ultimate strength of the parapet is 881 kN (198 kips).

FULL-SCALE CRASH TESTS

Two bridge railing designs, a 1.07-m (42-in.) F-shape and a 1.07-m (42-in.) vertical-faced concrete parapet, were tested and evaluated according to Performance Level 3 of the AASHTO guide. Both in

TABLE 2 1989 AASHTO Test Matrix

PERFORMANCE LEVEL	TEST SPEEDS -- mph			
	TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES			
	Small Automobile Wt = 1.8 kips θ = 20 deg	Pickup Truck Wt = 5.4 kips θ = 20 deg	Medium Single-Unit Truck Wt = 18.0 kips θ = 15 deg	Van-Type Tractor-Trailer Wt = 50.0 kips θ = 15 deg
PL-1	50	45		
PL-2	60	60	50	
PL-3	60	60		50

Metric Conversion: 1 kip = 454 kg
1 mph = 1.609 km/h

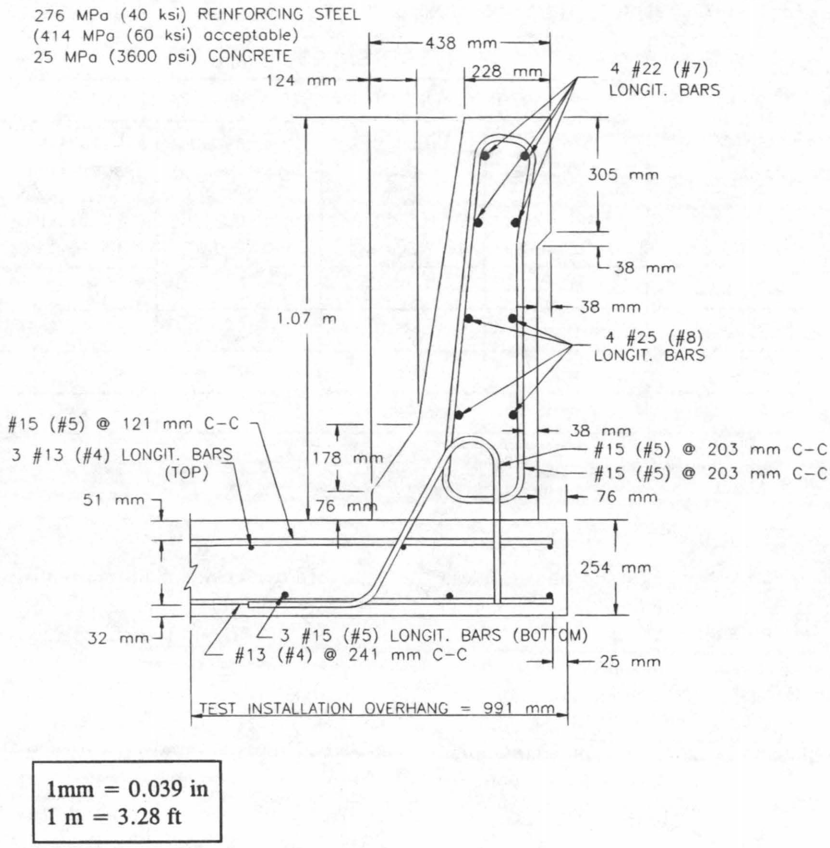


FIGURE 1 Cross section of 1.07-m (42-in.) F-shape bridge railing.

the proposed 1987 and final 1989 AASHTO guide specifications, the PL3 test matrix requires that crash tests be conducted with an 817-kg (1,800-lb) automobile and a 2452 kg (5400-lb) pickup. PL2 crash tests on the 812-mm (32-in.) versions of the F-shape and vertical-faced concrete parapet were conducted earlier in this study (*6*). Because these shorter versions performed acceptably when struck by the small automobile and pickup, it was assumed that these vehicles would perform similarly with the taller versions. Therefore, only the tests with the heavy vehicles were performed on the 1.07-m (42-in.) F-shape and the 1.07-m (42-in.) concrete parapet.

All other testing, evaluation, and reporting requirements were in accordance with specifications established in National Cooperative Highway Research Program Report 230 (*7*). Descriptions of the full-scale crash tests follows.

1.07-m (42-in.) F-shape

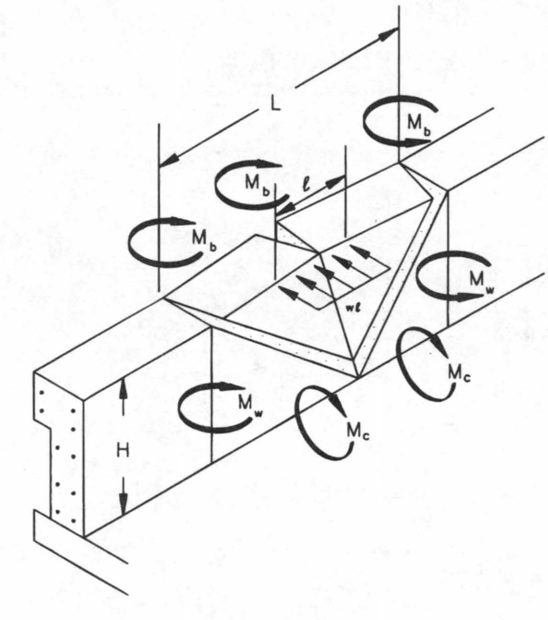
Test 7069-7: 18,414 kg (40,560 lb) Intercity Bus, 89.6 km/hr (55.7 mph), 15.7 Degrees

A 1954 GMC Scenic Cruiser bus was directed into the F-shape bridge railing using a remote control guidance system. Curb weight (empty weight) of the vehicle was 13,547 kg (29,840 lb). The gross static mass of the vehicle (including loose ballast) was 18,414 kg (40,560 lb). The vehicle was free-wheeling and unrestrained just before impact.

The vehicle hit the bridge railing 10 m (35 ft) from the upstream end and was smoothly redirected. It was in contact with the bridge railing for 7.6 m (25 ft), briefly lost contact for 7.9 m (26 ft), struck the bridge railing again, and rode off the end of the railing. The vehicle was tracking at loss of contact and was traveling at 68.4 km/hr (42.5 mph).

There was no measurable movement of the bridge railing; however, a longitudinal hairline crack developed in the bridge deck, starting approximately at the point of impact and extending about 11 m (35 ft) parallel to and nominally 610 mm (24 in.) from the base of the railing. Damage to the bridge railing and vehicle is shown in Figure 4. Maximum crush at the right front corner at bumper height was 102 mm (4.0 in.). The front wheel assembly and suspension were damaged.

The F-shape bridge railing contained and smoothly redirected the vehicle with no lateral movement of the bridge railing. There was no debris or detached elements. There was no intrusion into the occupant compartment, although a minimal amount of deformation occurred on the right door. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The vehicle remained upright and stable during and after the crash. Additional information pertinent to this test is presented in Figure 5. Performance of the bridge railing was judged acceptable, as indicated in Table 3.



$$L = \frac{l}{2} + \sqrt{\left(\frac{l}{2}\right)^2 + 8H\left(\frac{M_b + M_w H}{M_c}\right)}$$

$$(wl)_{ult} = \frac{8M_b}{L - \frac{l}{2}} + \frac{8M_w H}{L - \frac{l}{2}} + \frac{M_c L^2}{H\left(L - \frac{l}{2}\right)}$$

H = height of wall (FT)
L = critical length of wall failure (FT)
l = length of distributed vehicle impact load on railing (FT)
M_b = ultimate moment capacity of beam at top of wall (KFT)
M_c = ultimate flexural resistance of wall about horizontal axis
M_w = ultimate flexural resistance of wall about vertical axis (KFT/FT)
$(wl)_{ult}$ = total ultimate load (KIPS)

FIGURE 2 Yieldline failure mechanism for concrete parapet.

Test 7069-10: 22 700 kg (50,000 lb) Tractor-Trailer, 84.0 km/hr (52.2 mph) 14.0 Degrees

A 1979 International Transtar 4200 tractor with a 13.7-m (45-ft) van-trailer was directed into the F-shape bridge railing using a remote controlled guidance system. Test inertia weight (empty weight) of the vehicle was 13,574 kg (29,900 lb). Gross static mass (loaded weight) of the vehicle was 22,700 kg (50,000 lb). The vehicle was free-wheeling and unrestrained just before impact.

Impact occurred 10.1 m (35 ft) from the upstream end of the bridge railing and the vehicle was smoothly redirected. At 0.260 sec, the right-front corner of the vehicle contacted the bridge railing, and at 0.785 sec the rear wheels made contact with the bridge railing. The vehicle rode against the bridge railing for 22 m (72 ft). As the vehicle rode off the end of the bridge railing, the vehicle trajectory path was 0 degrees.

There was no lateral movement of the bridge railing. A small piece of the top of the bridge railing chipped off where the edge of the trailer hit the railing. Both outside right rear wheel rims of the tractor were bent and the tires deflated (see Figure 6). The front wheel assembly and suspension were damaged. The shock mounts were broken, the tie rods and the steering rod were bent, and the springs were loosened. Maximum crush at the right front corner of the vehicle at bumper height was 457 mm (18.0 in.).

The F-shape bridge railing contained and smoothly redirected the vehicle with no lateral movement of the bridge railing. There was no debris or detached elements. There was no intrusion into the occupant compartment, although minimal deformation of the right door occurred. The vehicle trajectory at loss of contact indicated minimal intrusion into adjacent traffic lanes. The vehicle remained upright and stable during and after the crash. Additional information pertinent to this test is presented in Figure 7. Performance of

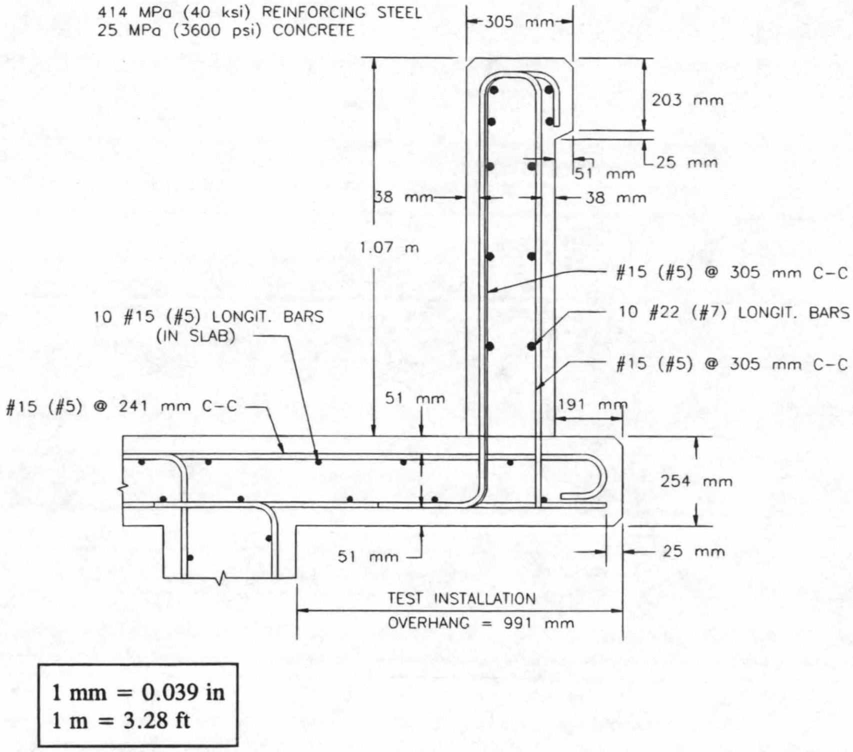


FIGURE 3 Cross section of 1.07-m (42-in.) concrete parapet.

the F-shape bridge railing was judged acceptable, as indicated in Table 4.

1.07-m (42.in.) Concrete Parapet

Only one test was performed on the vertical-faced concrete parapet bridge railing. This test was the 1989 AASHTO PL3 strength test with the 22,700-kg (50,000-lb) tractor-trailer striking the bridge railing at a speed of 80.5 km/hr (50-mph) and at an angle of 15 degrees. The parapet met the requirements for PL3.

Test 7069-13: 22,723 kg (50,050 lb) Tractor-Trailer, 82.7 km/hr (51.4 mph), 16.2 Degrees

A 1979 International Transtar 4200 tractor with a 1977 Pullman van-trailer was directed into the concrete parapet bridge railing using a remote control guidance system. Curb weight (empty weight) of the vehicle was 12,571 kg (27,690 lb). Gross static mass (loaded weight) of the vehicle was 22,723 kg (50,050 lb). The vehicle was free-wheeling and unrestrained just before impact.

The vehicle hit the parapet 7.3 m (24 ft) from the upstream end, and shortly thereafter the vehicle began to redirect. As the vehicle

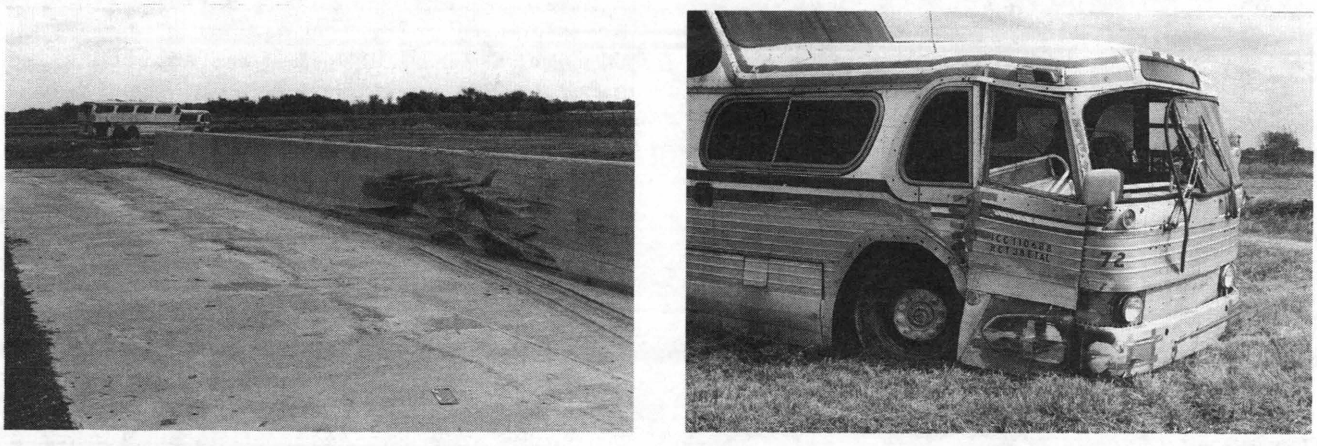
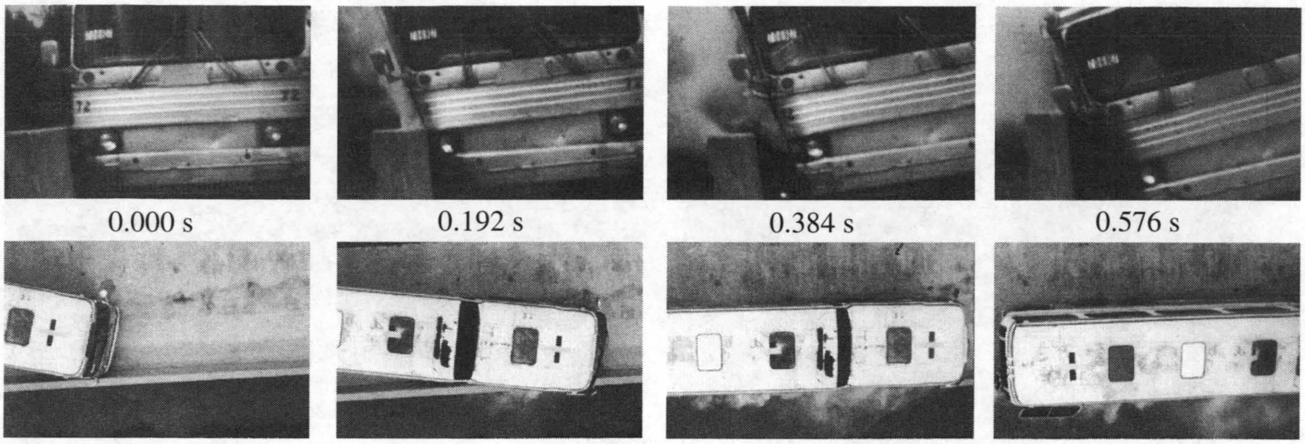
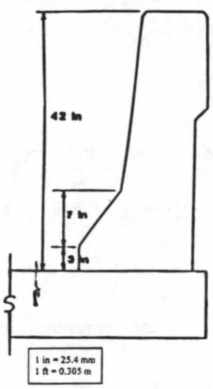


FIGURE 4 Damage to F-shape bridge railing and bus, Test 7069-7.





Test No.	7069-7
Date	11/19/87
Test Installation	1.07 m (42-in) F-shape Bridge Railing
Installation Length	30 m (100 ft)
Test Vehicle	1954 GMC Scenicruiser Bus
Vehicle Weight	
Empty Weight	13 547 kg (29,840 lb)
Test Inertia	18 414 kg (40,560 lb)
Vehicle Damage Classification	
TAD	N/A
CDC	N/A
Maximum Vehicle Crush	102 mm (4.0 in)

Impact Speed	89.6 km/h (55.7 mi/h)
Impact Angle	15.7 deg
Exit Speed	68.4 km/h (42.5 mi/h)
Exit Trajectory	0 deg
Vehicle Accelerations (Max. 0.050-sec avg)	
Longitudinal	-1.5 g
Lateral	6.5 g
Occupant Impact Velocity at true c.g.	
Longitudinal	2.4 m/s (7.9 ft/s)
Lateral	1.6 m/s (5.4 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-2.4 g
Lateral	21.7 g

FIGURE 5 Summary of results for bus test on F-shape bridge railing, Test 7069-7.

TABLE 3 Performance Evaluation for Bus Test on F-Shape, Test 7069-7

	AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright during and after collision	Vehicle remained upright	Pass
E.	Must smoothly redirect vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal	μ — Assessment .31 — Fair	Pass
G.	Shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 2.4 (7.9); Lateral 1.6 (5.4) Occupant Ridedown Accelerations - g's Longitudinal -2.4; Lateral 21.7	N/A
H.	Exit angle shall be less than 12 degrees	Exit angle was 0 degrees	Pass

**A, B, and C are required. D, E, F, and H are desired. G is not applicable for this test.*

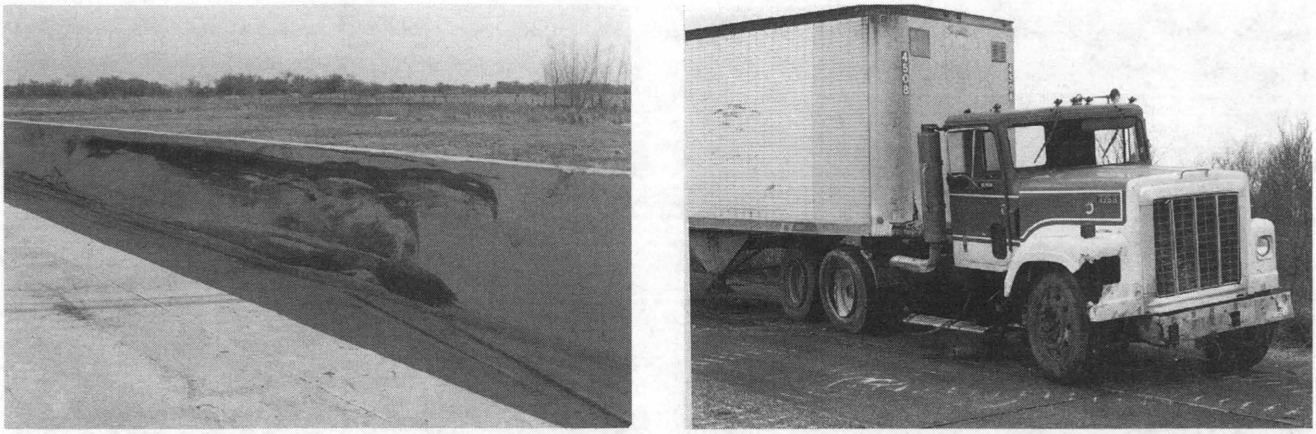
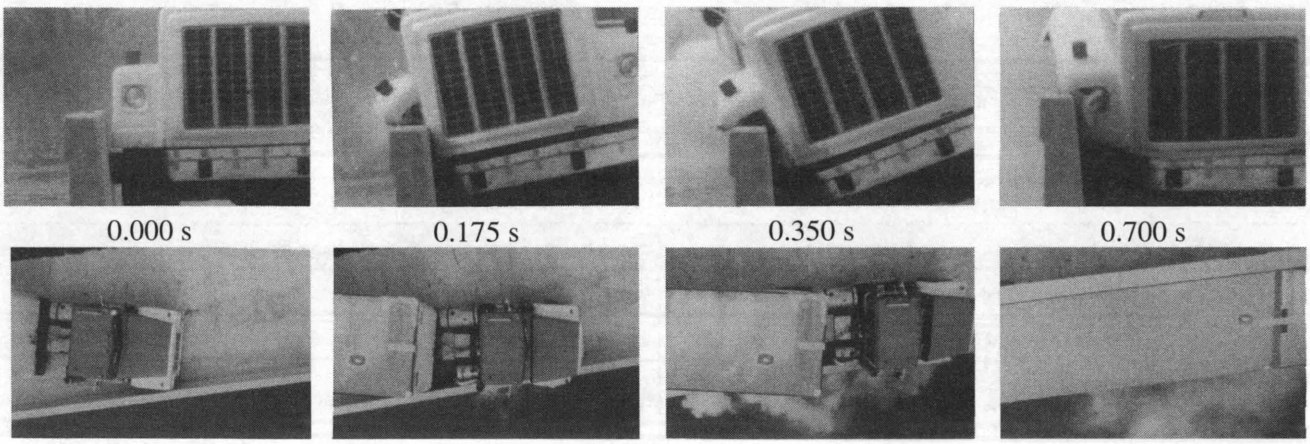


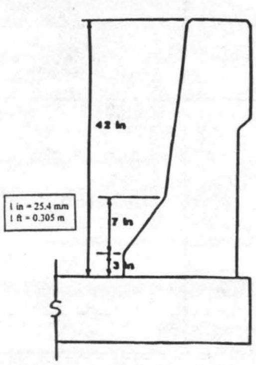
FIGURE 6 Damage to F-shape bridge railing and tractor trailer, Test 7069-10.

continued to ride down the parapet, the trailer began to roll clockwise, attaining a maximum roll of approximately 39 degrees at 1.165 sec The trailer then began to roll counterclockwise, and the vehicle rode off the end of the parapet for a total length of contact of 26 m (85 ft). As the vehicle exited the test area, the brakes on the vehicle were applied and the vehicle subsequently came to rest on its left side.

The parapet received minor damage with a small chip at the top. Damage to the bridge railing and vehicle is shown in Figure 8. The vehicle received damage to the front axle, pitman arm, U bolts, front leaf springs and bolts, front shock mounts, air brake lines, right fuel cell, left rear spring pin and clamp, and exhaust pipe. Maximum crush at the right front corner at bumper height was 457 mm (18.0 in.).

The concrete parapet contained and redirected the vehicle with no lateral movement of the parapet. There was no debris or detached elements. Although minimal deformation occurred on the right door, there was no intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into adjacent traffic lanes. The concrete parapet prevented the vehi-





Test No.	7069-10
Date	3/3/88
Test Installation	1.07 m (42-in) F-shape Bridge Railing
Installation Length	30 m (100 ft)
Test Vehicle	1979 International Transtar 4200 Tractor
Vehicle Weight	
Empty Weight	13 574 kg (29,900 lb)
Test Inertia	22 700 kg (50,000 lb)
Maximum Vehicle Crush	457 mm (18.0 in)

Impact Speed	84.0 km/h (52.2 mi/h)
Impact Angle	14.0 deg
Exit Speed	N/A
Exit Trajectory	0 deg
Vehicle Accelerations (Max. 0.050-sec avg)	
Longitudinal	-2.2 g
Lateral	4.7 g
Occupant Impact Velocity at true c.g.	
Longitudinal	2.8 m/s (9.1 ft/s)
Lateral	2.8 m/s (9.3 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-4.7g
Lateral	3.7 g

FIGURE 7 Summary of results for tractor-trailer test on F-shape, Test 7069-10.

TABLE 4 Performance Evaluation for Tractor-Trailer Test on F-shape, Test 7069-10

AASHTO EVALUATION CRITERIA*		TEST RESULTS	ASSESSMENT
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright during and after collision	Vehicle remained upright	Pass
E.	Must smoothly redirect vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal	μ: Not Available Assessment: N/A	N/A
G.	Shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 2.8 (9.1); Lateral 2.8 (9.3) Occupant Ridedown Accelerations - g's Longitudinal -4.7; Lateral 3.7	N/A
H.	Exit angle shall be less than 12 degrees	about 0 degrees	Pass

**A, B, and C, are required. D, E, F, and H are desired. G is not applicable for this test.*

TABLE 5 Performance Evaluation for Tractor-Trailer Test on Vertical Faced Concrete Parapet, Test 7069-13

AASHTO EVALUATION CRITERIA*		TEST RESULTS	ASSESSMENT
A.	Must contain vehicle	Vehicle was contained	Pass
B.	Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
C.	Passenger compartment must have essentially no deformation	Acceptable deformation	Pass
D.	Vehicle must remain upright during and after the collision	Vehicle remained upright during contact with the bridge railing; however, the vehicle rolled after exiting the installation.	Fail
E.	Must smoothly redirect vehicle	Vehicle was smoothly redirected	Pass
F.	Effective coefficient of friction: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal	μ: .55 Assessment: Marginal	Pass
G.	Shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 3.2 (10.5); Lateral 3.8 (12.5) Occupant Ridedown Accelerations - g's Longitudinal -2.2; Lateral 4.6	N/A
H.	Exit angle shall be less than 12 degrees	about 0 degrees	Pass

**A, B, and C are required. D, E, F, and H are desired. G is not applicable for this test.*

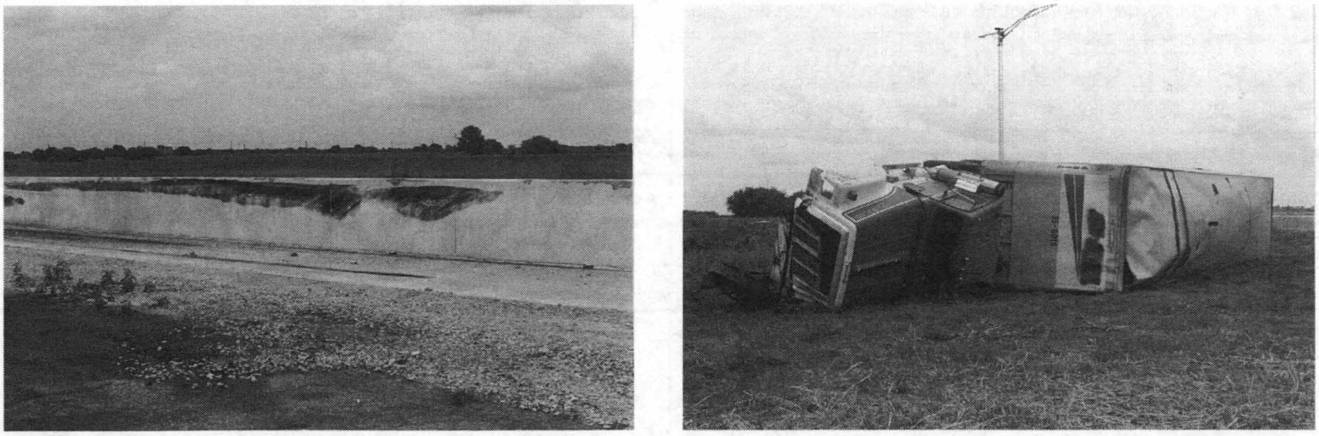
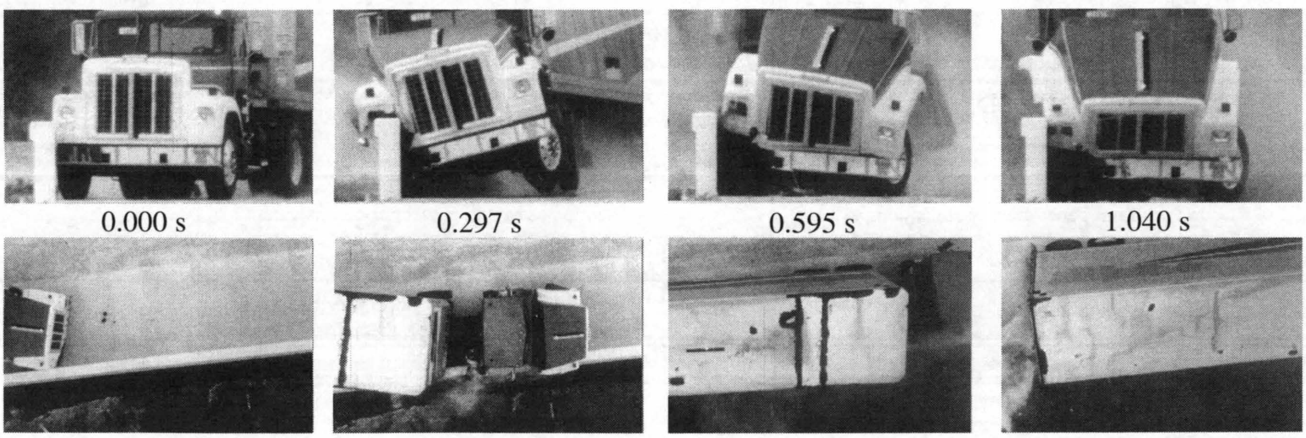


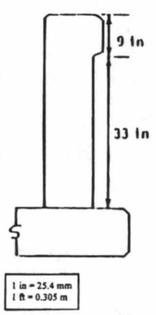
FIGURE 8 Damage to concrete parapet and tractor trailer, Test 7069-13.

cle from penetrating or rolling over the bridge railing. The vehicle remained upright during contact with the bridge railing; however, the vehicle rolled on its side after exiting the installation. As indicated in Table 5, it is desirable, but not required, that the vehicle remain upright after the test. Additional information pertinent to this test is presented in Figure 9. Performance of the concrete parapet bridge railing was judged acceptable.

SUMMARY AND CONCLUSIONS

Two bridge railings meeting the requirements of l/PL3 of the 1989 AASHTO guide specifications have been developed and proven after full-scale crash tests. One is a 1.07-m (42-in.) high F-shape concrete parapet and the other is a 1.07-m (42-in.) high vertical-faced concrete parapet.





Test No.	7069-13
Date	7/11/88
Test Installation	1.07 m (42-in) Concrete Parapet
Installation Length	30 m (100 ft)
Test Vehicle	1979 International Tractor w/van-trailer
Vehicle Weight	
Empty Weight	12 571 kg (27,690 lb)
Test Inertia	22 723 kg (50,050 lb)
Maximum Vehicle Crush	457 mm (18.0 in)

Impact Speed	82.7 km/h (51.4 mi/h)
Impact Angle	16.2 deg
Exit Speed	N/A
Exit Trajectory	0 deg
Vehicle Accelerations (Max. 0.050-sec avg)	
Longitudinal	-3.3 g
Lateral	3.7 g
Occupant Impact Velocity at true c.g.	
Longitudinal	3.2 m/s (10.5 ft/s)
Lateral	3.8 m/s (12.5 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-2.2 g
Lateral	4.6 g

FIGURE 9 Summary of results for tractor-trailer test on concrete parapet, Test 7069-13.

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