Aesthetically Pleasing Steel Pipe Bridge Rail

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Research has developed railings to withstand impact loads from vehicles of ever-increasing size; however, aesthetic considerations have been overshadowed by safety and structural requirements. The objective of this research study was to develop aesthetically pleasing, structurally sound railings that can serve as alternative railings in city or urban areas. A new steel pipe bridge rail—Texas Type T421—is introduced. This bridge rail is constructed of 5-in.-diameter steel pipe posts with a 5-in.-diameter steel pipe top rail 32 in. high and a 10-in.-diameter steel pipe lower rail. The bridge rail was crash-tested and evaluated in accordance with NCHRP Report 230. Two crash tests were required—a 4,500-lb passenger car at 60 mph and 25-degree impact angle and an 1,800-lb passenger car at 60 mph and 20-degree impact angle. In both tests, the bridge rail contained and redirected the test vehicle. There were no detached elements or debris to present undue hazard to other traffic. The vehicle remained upright and relatively stable during the collision. The occupant-compartment impact velocities and 10-msec occupant ridedown accelerations were within the normally accepted limits. The vehicle trajectory at loss of contact (exit angles of 5 and 7.6 degrees) indicated no intrusion into adjacent traffic lanes.

Research has developed railing to withstand impact loads from vehicles of ever-increasing size; however, aesthetic considerations have been overshadowed by safety and structural requirements. Engineers often fail to recognize the impact of their structures on the landscape, particularly in city or urban areas. Architects and developers often propose aesthetically pleasing railings that engineers cannot accept because of structural inadequacies. The objective of this research study was to develop aesthetically pleasing, structurally sound railings that can serve as alternative railings.

This study is developing one or more new concrete, steel, and aluminum railings or combination railings, some with curb and sidewalk.

A new steel pipe bridge rail—Texas Type T421—is introduced. The research study advisory committee reviewed design sketches of 22 different bridge rail designs before selecting the new Texas Type T421 as its second priority. The advisory committee was composed of two architects (private consultants from Dallas), two research engineers from Texas Transportation Institute, two highway design engineers from Dallas District, one bridge design engineer from Dallas District, and three bridge design engineers from Austin headquarters.

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DESCRIPTION OF TEXAS TYPE T421 BRIDGE RAIL

This bridge rail is constructed of standard steel pipe 5 or 10 in. in diameter. Figure 1 shows photographs of the steel pipe bridge rail installed on a typical simulated 8-in.-thick concrete bridge deck. Figures 2 and 3a show a cross section and side elevation, respectively, of the T421 bridge rail. The top rail was 32 in. high and used 5-in.-diameter standard steel pipe. The lower rail uses 10-in.-diameter standard steel pipe. The 5-in.-diameter posts are sloping at a 10-degree angle so that the traffic side or face of the two rails is a vertical plane.

The standard steel pipe was of ASTM A53, Type E, Grade B, with a yield strength of 35 kg/in.^{2} and minimum ductility of 15 percent in a 2-in. gauge length. The concrete reinforcing steel was ASTM A615, Grade 60. Concrete cylinders taken from the simulated concrete deck yielded a compressive strength of 3,370 psi at 28 days of age (design f'_c was 3,600 psi).

The anchor bolts were ASTM A-321 threaded rods with tack-welded nuts for heads and with hex nuts and washers. Nuts and washers for anchor bolts were of A-325 requirements. Nuts were tapped or chased after galvanizing. Bolts and nuts had Class 2A and 2B fit tolerances. Details of the base plate are shown in Figure 3b. All other steel was ASTM A36.

This pipe rail was originally designed using steel tubing with a wall thickness of 0.25 in. and a yield strength of 42 kg/in.^{2} with a ductility of 23 percent in a 2-in. gauge length (ASTM A500, Grade B). Plastic analysis of this design yielded a strength of 66 kips at an effective height of 17.5 in. When the rail was fabricated, standard steel pipe was used because it was readily available. Either material should perform satisfactorily.

In the original design, ten 7.5-ft-long bridge rail segments were to be installed for a total length of 75 ft. The fabricator chose to fabricate and install five 15-ft-long segments for a total length of 75 ft, as shown in Figure 4. Figure 3c shows the pipe splice details.

CRASH TESTS

In order to qualify this bridge rail for use on federal-aid highways, it was crash-tested and evaluated in accordance with NCHRP Report 230 (*1*). Two crash tests were required—Test Designation S13 with an 1,800-lb passenger car at 60 mph and 20-degree impact angle and Test Designation 10 with a 4,500-lb passenger car at 60 mph and 25-degree impact angle.

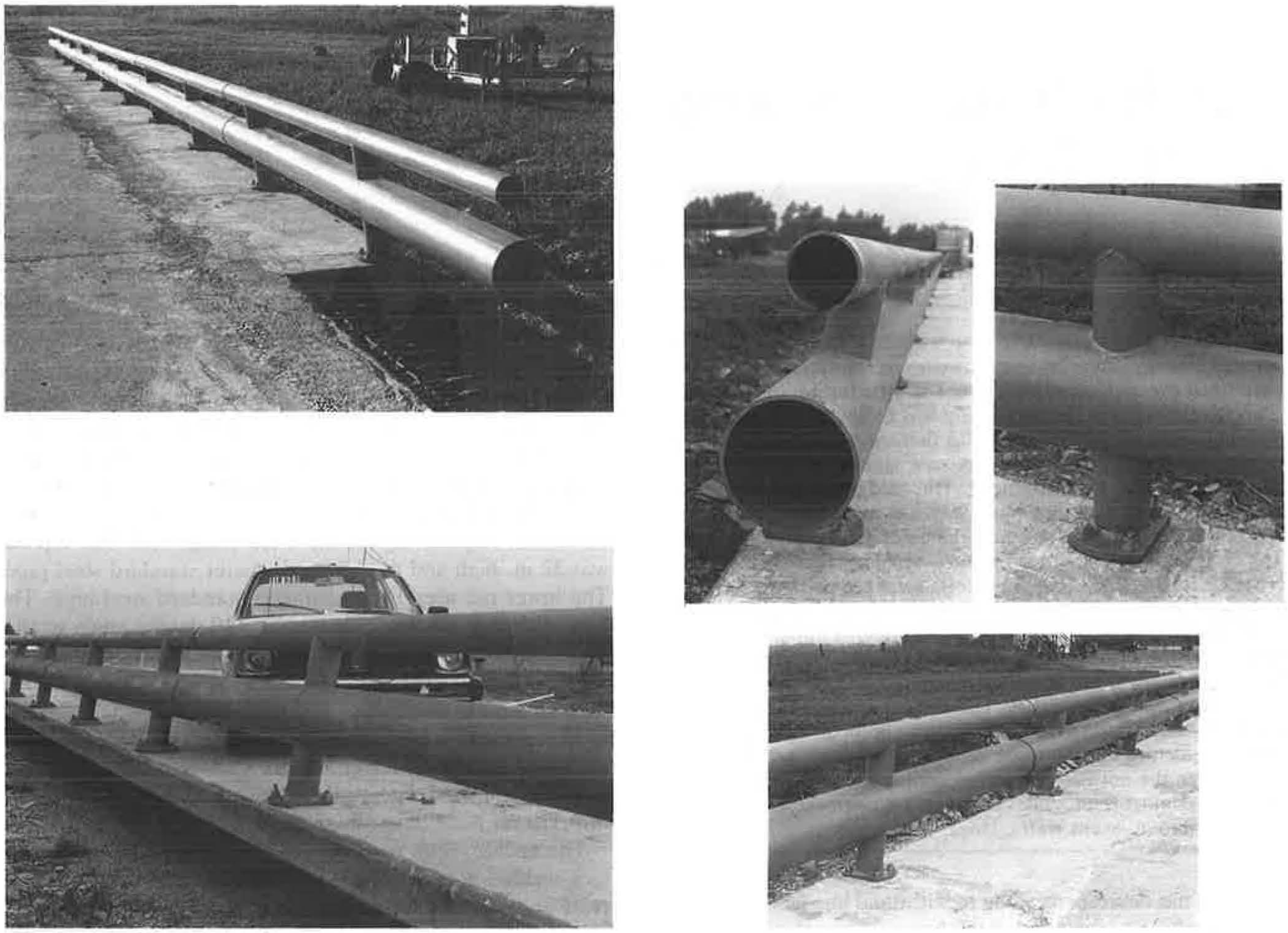


FIGURE 1 T421 bridge rail installation.

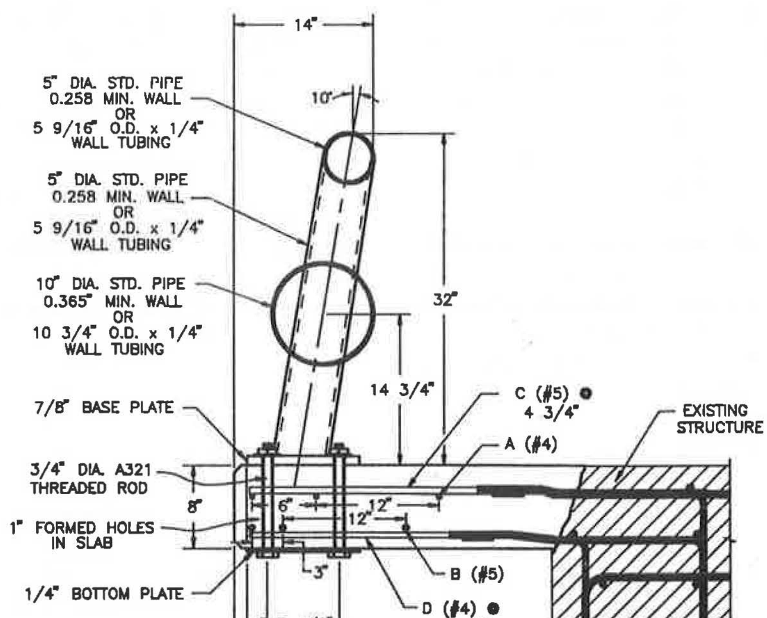


FIGURE 2 Cross-section of T421 bridge rail.

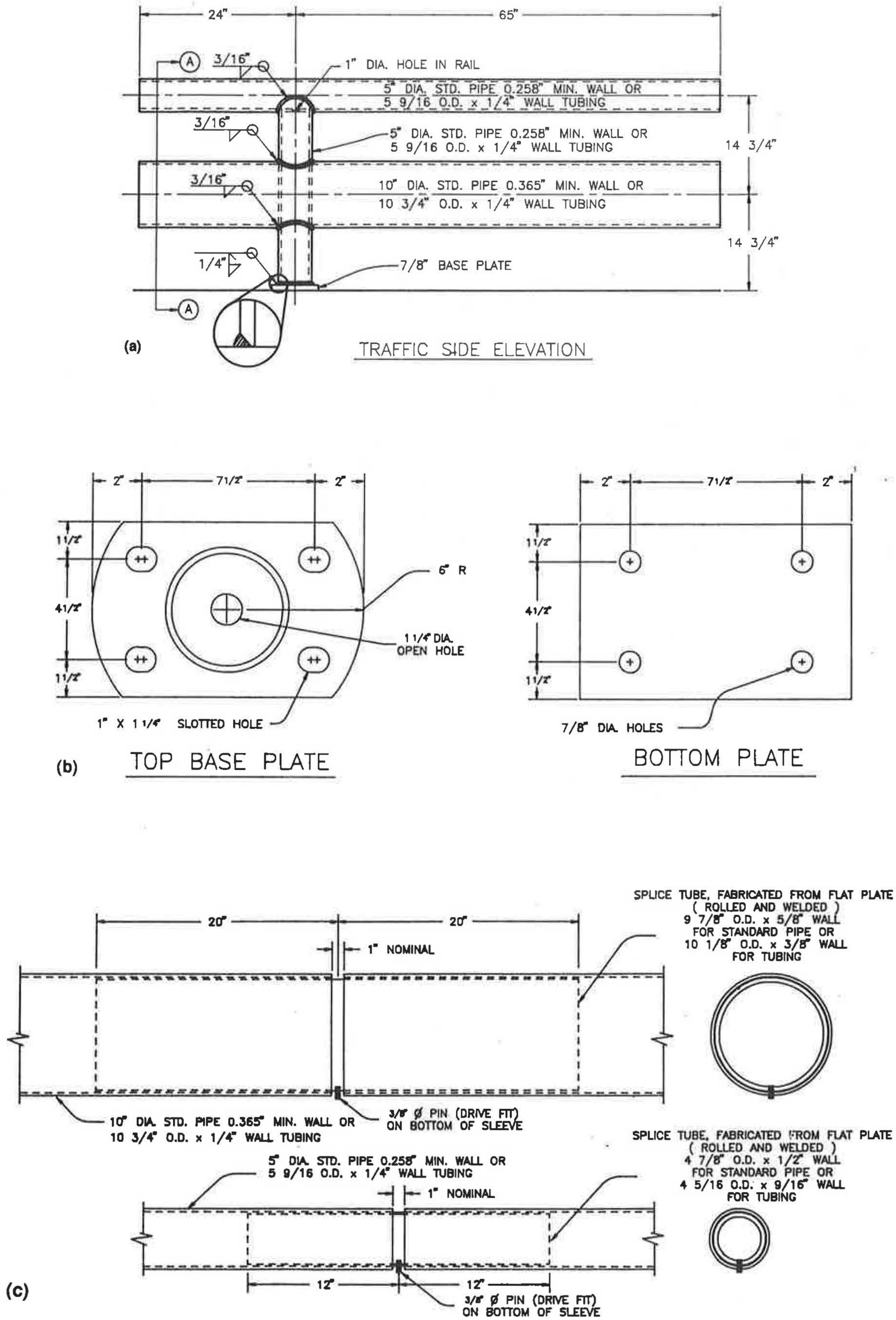


FIGURE 3 T421 bridge rail: (a) elevation of 7.5-ft-long segment, (b) base plate details, and (c) splice details.

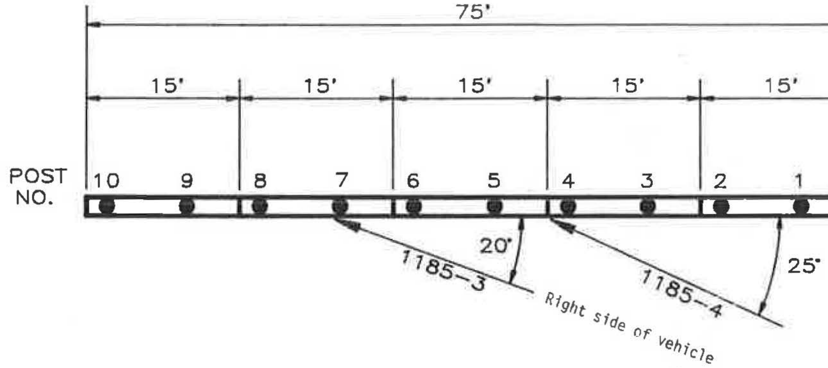
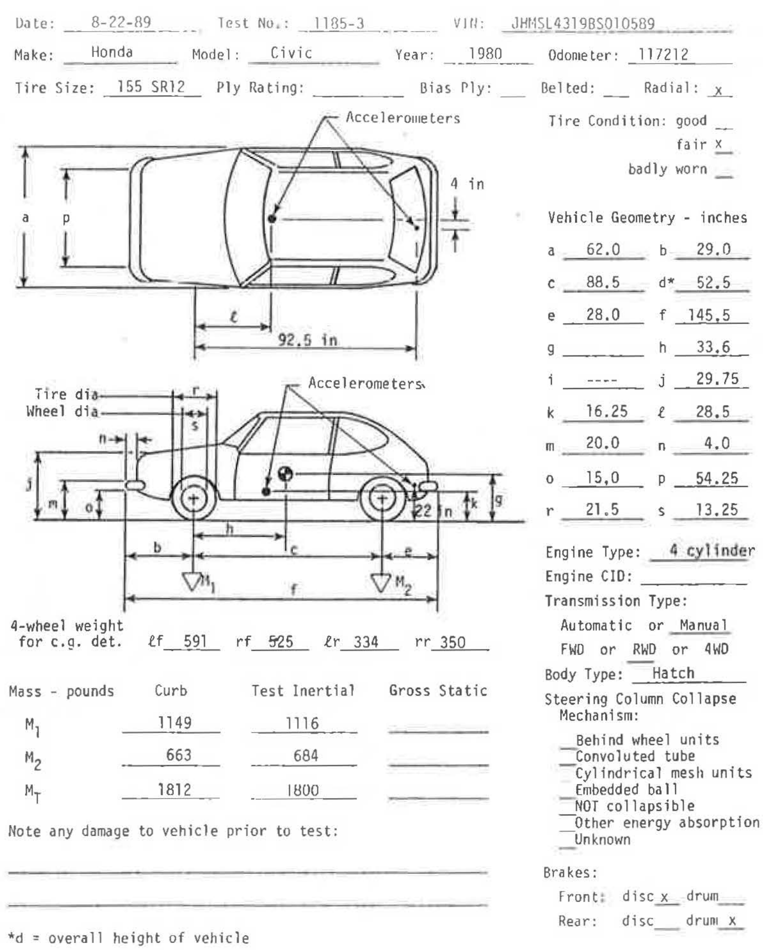


FIGURE 4 Plan view of T421 bridge rail installation and vehicle impact points.

The 1980 Honda Civic (Figure 1) was directed into the T421 bridge rail using a reverse tow and guidance system. Test inertia mass of the vehicle was 1,800 lb (808 kg). The height to the lower edge of the vehicle bumper was 15.0 in. (36.1 cm) and it was 20.0 in. (50.8 cm) to the top of the bumper. Other dimensions and information on the test vehicle are given in Figure 5. The vehicle was free wheeling and unrestrained just before impact.

The speed of the vehicle at impact was 59.7 mph (96.1 km/hr); the angle of impact was 21.4 degrees. The right front bumper of the vehicle impacted the bridge rail 5 ft (1.5 m) upstream of Post 7. The right front wheel made contact with the lower pipe member shortly after impact. The vehicle began to redirect at 0.042 sec. By 0.060 sec, the vehicle had deformed to the A-pillar, which caused the windshield to break. The right front wheel became wedged under the lower pipe member and impacted the lower part of Post 7. At 0.162 sec, the vehicle was traveling parallel with the bridge rail at a speed of 49.7 mph (79.2 km/hr). The vehicle exited the rail at 0.237 sec traveling at 49.2 mph (79.2 km/hr) and 5.0 de-


Date: 8-22-89 Test No.: 1185-3 VIN: JHMSL4319BS010589

Make: Honda Model: Civic Year: 1980 Odometer: 117212

Tire Size: 155 SR12 Ply Rating: ____ Bias Ply: ___ Belted: ___ Radial: x

Tire Condition: good ___ fair x badly worn ___

Vehicle Geometry - inches

a	62.0	b	29.0
c	88.5	d*	52.5
e	28.0	f	145.5
g		h	33.6
i	----	j	29.75
k	16.25	ℓ	28.5
m	20.0	n	4.0
o	15.0	p	54.25
r	21.5	s	13.25

Engine Type: 4 cylinder
Engine CID: ____
Transmission Type:
Automatic or Manual
FWD or RWD or 4WD
Body Type: Hatch
Steering Column Collapse Mechanism:
__Behind wheel units
__Convoluted tube
__Cylindrical mesh units
__Embedded ball
__NOT collapsible
__Other energy absorption
__Unknown

Brakes:
Front: disc x drum ___
Rear: disc ___ drum x

4-wheel weight for c.g. det. ℓf 591 rf 525 ℓr 334 rr 350

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	1149	1116	
M_2	663	684	
M_T	1812	1800	

Note any damage to vehicle prior to test:

*d = overall height of vehicle

FIGURE 5 Vehicle properties (Test 1185–3).

grees. As the vehicle left the test site, the brakes were applied. The vehicle yawed clockwise almost 180 degrees and subsequently came to rest 270 ft (82 m) from the point of impact.

As can be seen in Figure 6, the rail received minimal cosmetic damage. Tire marks appeared 3 in. (7.6 cm) behind the traffic edge of the baseplate of Post 7 before impacting the lower part of the post and riding over the baseplate. The vehicle was in contact with the rail for 9.25 ft (2.8 m).

The vehicle sustained severe damage to the right side, as shown in Figure 7. Maximum crush at the right front bumper heights was 10.0 in. (25.4 cm). The constant velocity joint and right strut were damaged. The right front rim was bent and the tire damaged. The roof was bent and the windshield was broken. There was damage to the hood, grill, bumper, right front quarter-panel, the right door and glass, the right rear quarter-panel, and the rear bumper.

Impact speed was 59.7 mph (96.1 km/hr) and the angle of impact was 21.4 degrees. The vehicle was traveling 49.7 mph (80.0 km/hr) as it became parallel at 0.162 sec. The vehicle exited the rail at 0.237 sec traveling at 49.2 mph (79.2 km/hr) and 5.0 degrees. Occupant impact velocity was 21.8 ft/sec (6.6 m/sec) in the longitudinal direction and 24.5 ft/sec (7.5 m/sec) in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were −3.9 g (longitudinal) and −6.3 g (lateral). These data and other pertinent information from the test are summarized in Figure 8 and Table 1.

These data were further analyzed to obtain 0.050-sec average accelerations versus time. The maximum 0.050-sec average accelerations at the center of gravity were −8.4 g (longitudinal) and 12.7 g (lateral).

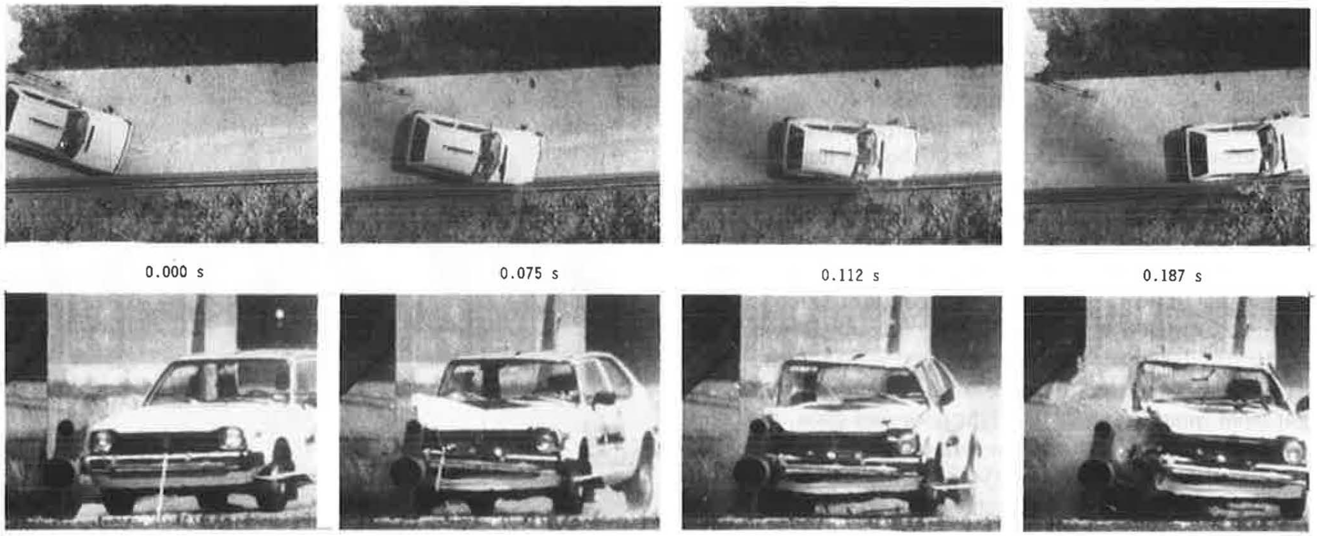
FIGURE 6 T421 bridge rail after Honda impact.

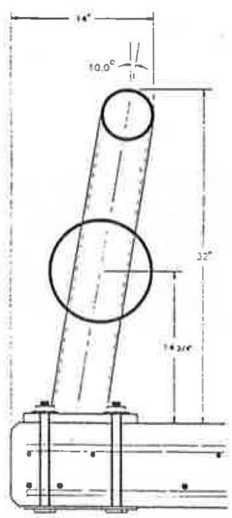
FIGURE 7 Honda before and after impact with T421 bridge rail.

CONCLUSIONS

The T421 bridge rail contained and redirected the test vehicle with no lateral movement of the bridge rail. There were no detached elements or debris to present undue hazard to other traffic. The vehicle remained upright and relatively stable during the collision. The longitudinal occupant-compartment impact velocity and 10-msec occupant ridedown accelerations were within the limits recommended in NCHRP Report 230. The vehicle trajectory at loss of contact was 5 degrees, which was less than the recommended limit of 60 percent of the impact angle (12.8 degrees for this test).

The 1982 Oldsmobile 98 (Figure 9) was directed into the T421 bridge rail using a reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 lb (2,043 kg). The





Test No. 1185-3
Date 08/22/89

Test Installation . . . T421 Bridge Rail
Length of Installation . 75 ft (23 m)

Vehicle . . . . 1980 Honda Civic
Vehicle Weight
  Test Inertia . . . . . 1,800 lb (817 kg)
Vehicle Damage Classification
  TAD . . . . 01FR6 & 01RD6
  CDC . . . . 01FZEK4 & 01RDES4
Maximum Vehicle Crush . 10.0 in (25.4 cm)

Impact Speed . . . 59.7 mi/h (96.1 km/h)
Impact Angle . . . 21.4 degrees
Speed at Parallel . 49.7 mi/h (80.0 km/h)
Exit Speed . . . . 49.2 mi/h (79.2 km/h)
Exit Trajectory . . 5.0 degrees
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal . . -8.4 g
  Lateral . . . . . 12.7 g
Occupant Impact Velocity
  Longitudinal . . 21.8 ft/s (6.6 m/s)
  Lateral . . . . . 24.5 ft/s (7.5 m/s)
Occupant Ridedown Accelerations
  Longitudinal . . -3.9 g
  Lateral . . . . . 6.3 g

FIGURE 8 Summary of results for Test 1185–3.

height of the lower edge of the vehicle bumper was 12.25 in. (31.1 cm) and the height to the top of the bumper was 20.0 in. (50.8 cm). Other dimensions and information on the test vehicle are given in Figure 10. The vehicle was free-wheeling and unrestrained just before impact.

The speed of the vehicle at impact was 62.4 mph (100.4 km/hr) and the angle of impact was 26.6 degrees. The right front bumper of the vehicle impacted the bridge rail 5 ft (1.5 m) upstream of Post 5. The right front wheel made contact with the lower pipe member shortly after impact. The vehicle began to redirect at 0.067 sec. By 0.075 sec, the vehicle had deformed to the A-pillar and the windshield broke. As the vehicle continued forward, the front bumper was forced between the upper and lower pipe member and impacted the middle portion of the post. At the same time, the right front wheel became wedged under the lower pipe element and impacted the lower portion of Post 5. At 0.204 sec, the vehicle traveling at a speed of 47.6 mph (76.6 km/hr) began to move parallel with the bridge rail. The rear of the vehicle impacted the bridge rail at 0.219 sec and the rear bumper was forced between the upper and lower pipe elements and impacted the middle portion of the post. The vehicle lost contact with the bridge rail at 0.348 sec traveling at 44.6 mph (71.8 km/hr) and 7.6 degrees. Shortly after the vehicle left the test site, the brakes were applied; the vehicle yawed clockwise and subsequently came to rest 225 ft (69 m) from the point of impact.

As shown in Figures 11–13, the rail received minor damage and the slab received moderate damage. The vehicle impacted the rail between Posts 4 and 5. The bases on both Posts 4 and 5 were pushed back approximately 0.25 in. (0.6 cm). The bridge deck behind Post 4 was cracked. Tire marks appeared 5 in. (12.7 cm) behind the traffic edge of the baseplate of Post 5 before the tire impacted the lower part of the post. The bridge deck around Post 5 was broken, as shown in Figure 12. There were tire marks on the base of Post 6 and, shortly thereafter, the vehicle left the rail. The vehicle was in contact with the bridge rail for 15.5 ft (4.7 m).

TABLE 1 EVALUATION OF CRASH TEST 1185-3

USUAL CRITERIA	TEST RESULTS	PASS/FAIL
Must contain vehicle	Vehicle was contained	Pass
Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
Passenger compartment must have essentially no deformation	Minimal deformation	Pass
Vehicle must remain upright	Vehicle did remain upright	Pass
Must smoothly redirect the vehicle	Vehicle was redirected	Pass
Effective coefficient of friction (9)		
μ — Assessment	μ — Assessment	
0 - .25 Good .26 - .35 Fair > .35 Marginal	.27 Fair	Pass
Shall be less than		
Occupant Impact Velocity - fps Longitudinal 30, Lateral 25	Occupant Impact Velocity - fps Longitudinal 21.8, Lateral 24.5	Pass
Occupant Ridedown Accelerations - g's Longitudinal 15, Lateral 15	Occupant Ridedown Accelerations - g's Longitudinal -3.9, Lateral 6.3	Pass
Exit angle shall be less than 12.8 degrees	Exit angle was 5.0 degrees	Pass

FIGURE 9 Oldsmobile before and after impact with T421 bridge rail.

The vehicle sustained severe damage to the right side, as shown in Figure 9. Maximum crush at the right front corner at bumper height was 18.0 in. (45.7 cm). The right front axle was pushed back 15.0 in. (38.1 cm). The right A-arm, sway bar, tie rod, and upper and lower ball joints were damaged and the subframe was bent. The instrument panel in the passenger compartment as well as the floor pan and roof was bent, and the windshield was broken. The right front and rear rims were bent and the tires were damaged. There was damage to the hood, grill, front bumper, right front quarter-panel, right front and rear doors, right rear quarter-panel, and rear bumper.

Impact speed was 62.4 mph (100.4 km/hr) and the angle of impact was 26.0 degrees. The vehicle was traveling at 47.6 mph (76.6 km/hr) as it began moving parallel to the bridge rail. The vehicle exited the rail at 44.6 mph (71.8 km/hr) and 7.6 degrees. Occupant impact velocity was 26.8 ft/sec (8.2 m/sec) in the longitudinal direction and 20.1 ft/sec (6.1 m/sec) in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were −6.8 g (longitudinal) and 8.7 g (lateral). These data and other pertinent information from the test are summarized in Figure 14 and Table 2.

These data were then further analyzed to obtain 0.050-sec average accelerations versus time. The maximum 0.050-sec average accelerations at the center of gravity were −16.1 g (longitudinal) and 11.1 g (lateral).

The bridge rail contained and redirected the test vehicle with minimal lateral movement of the bridge rail. The vehicle remained upright and relatively stable during the collision. Occupant-compartment impact velocities and occupant ridedown accelerations were within the limits recommended in NCHRP Report 230. The vehicle trajectory at loss of contact was 7.6 degrees, which was less than the recommended limit of 60 percent of the impact angle (15.6 degrees in this case).

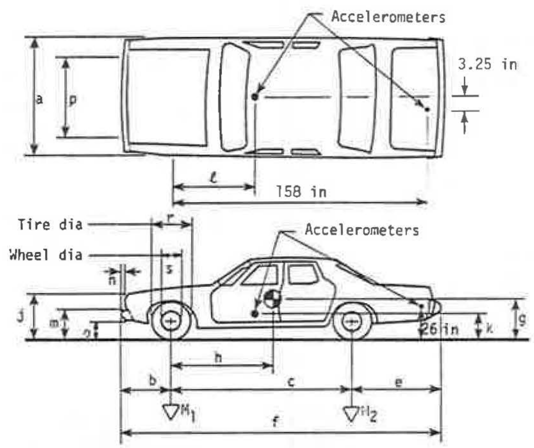
The new aesthetic bridge rail T421 performed well when crash-tested in accordance with NCHRP 230 Tests 10 and

Date: 8-24-89 Test No.: 1185-4 VIN: 1G3AW69N6CM141463

Make: Oldsmobile Model: 98 Year: 1982 Odometer: 29415

Tire Size: P225/75R-15 Ply Rating: ____ Bias Ply: __ Belted: __ Radial: x

Tire Condition: good __ fair x badly worn __



Vehicle Geometry - inches

a 76.0	b 42.0
c 119.0	d* 57.5
e 55.5	f 216.5
g ____	h 51.7
i ----	j 32.0
k 20.0	ℓ 32.25
m 20.0	n 5.0
o 12.25	p 61.5
r 27.75	s 16.5

Engine Type: 8 - diesel

Engine CID: 5.7

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Body Type: 4-door sedan

Steering Column Collapse Mechanism:

__Behind wheel units
__Convoluted tube
__Cylindrical mesh units
__Embedded ball
__NOT collapsible
__Other energy absorption
__Unknown

Brakes:

Front: disc x drum __

Rear: disc __ drum x

4-wheel weight for c.g. det. ℓf 1253 rf 1292 ℓr 992 rr 963

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2458	2545	
M_2	1563	1955	
M_T	4021	4500	

Note any damage to vehicle prior to test:

*d = overall height of vehicle

FIGURE 10 Vehicle properties (Test 1185-4).

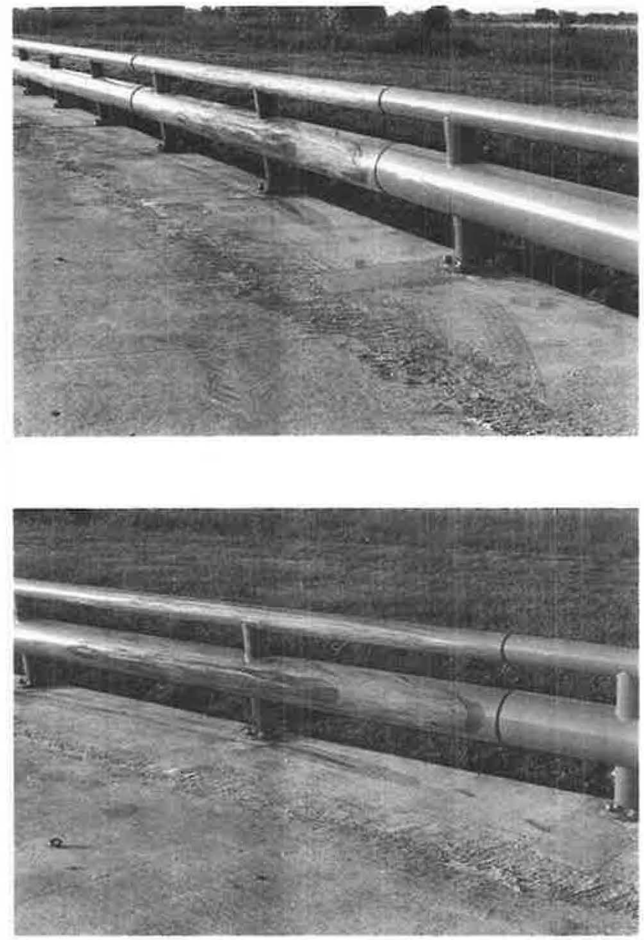


FIGURE 11 T421 bridge rail after Oldsmobile impact.

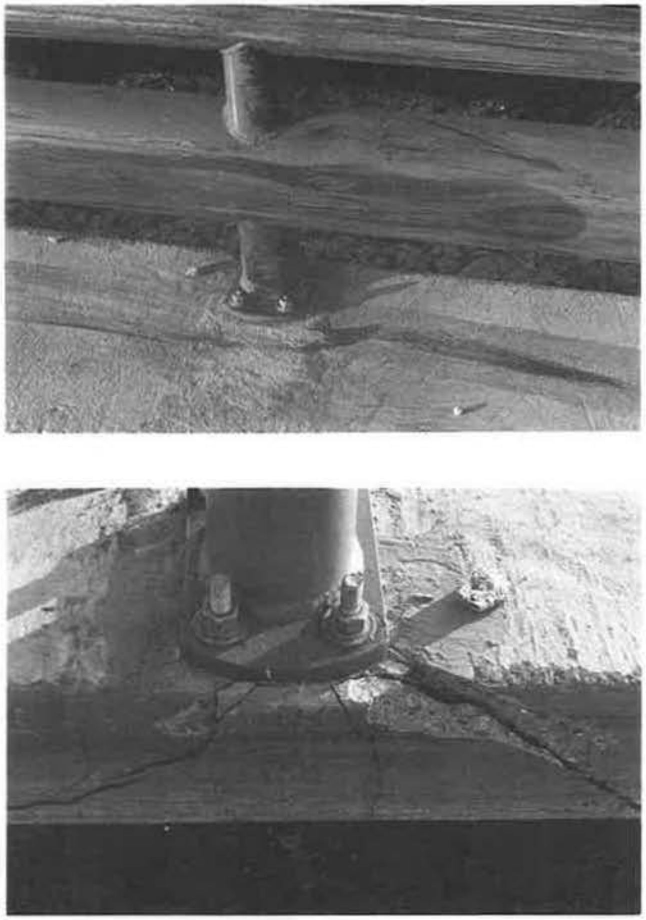


FIGURE 12 Damage at Post 5.

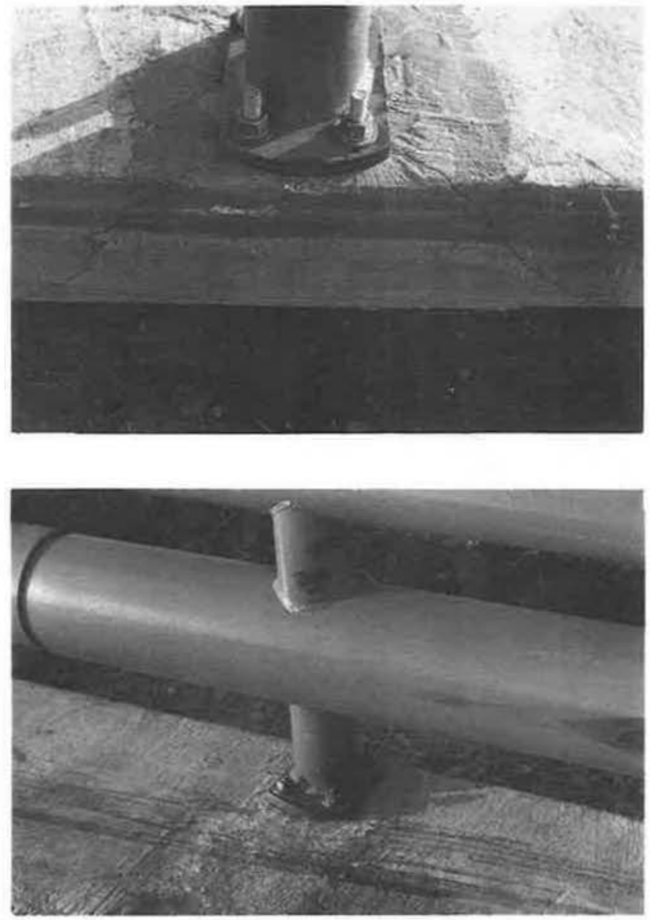
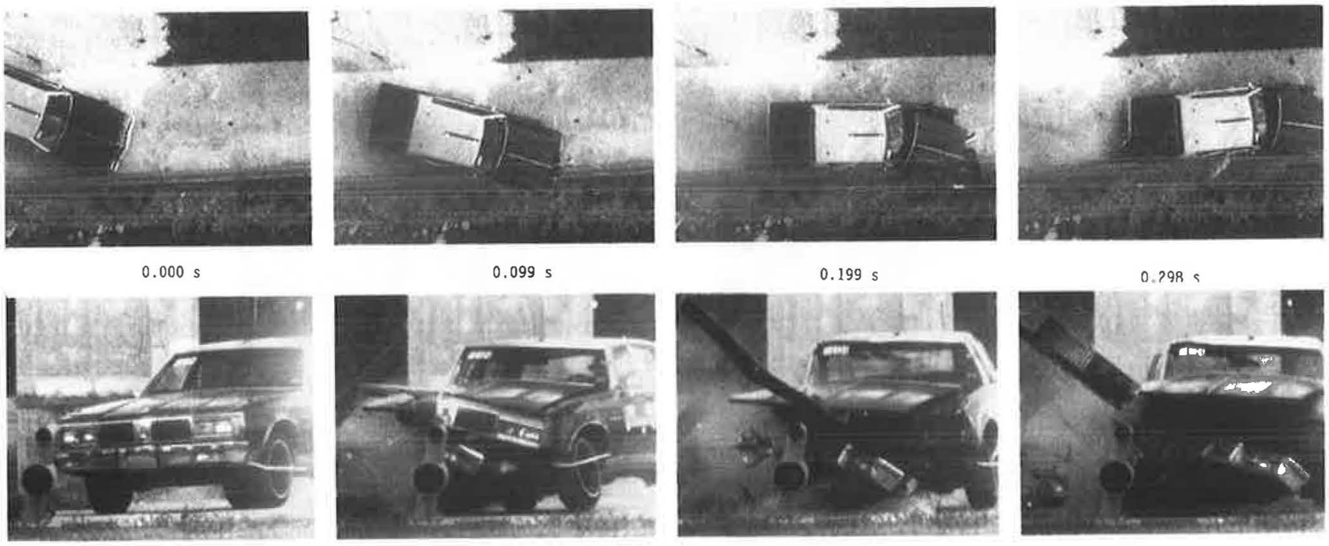
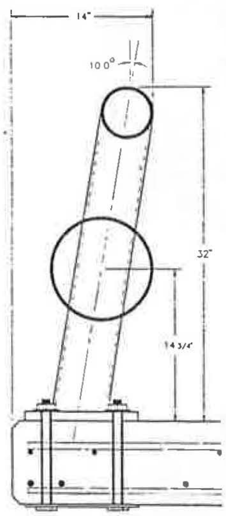


FIGURE 13 Posts 4 and 6 after Oldsmobile impact.





Test No.	1185-4
Date	08/24/89
Test Installation . . .	T421 Bridge Rail
Length of Installation .	75 ft (23 m)
Vehicle	1982 Oldsmobile 98
Vehicle Weight	
Test Inertia	4,500 lb (2,043 kg)
Vehicle Damage Classification	
TAD	01FR6 & 01RD6
CDC	01FZEK4 & 01RDES4
Maximum Vehicle Crush .	18.0 in (45.7 cm)

Impact Speed . . .	62.4 mi/h (100.4 km/h)
Impact Angle . . .	26.6 degrees
Speed at Parallel .	47.6 mi/h (76.6 km/h)
Exit Speed	44.6 mi/h (71.8 km/h)
Exit Trajectory . .	7.6 degrees
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal . .	-16.1 g
Lateral	11.1 g
Occupant Impact Velocity	
Longitudinal . .	26.8 ft/s (8.2 m/s)
Lateral	20.1 ft/s (6.1 m/s)
Occupant Ridedown Accelerations	
Longitudinal . .	-6.8 g
Lateral	8.7 g

FIGURE 14 Summary of results for Test 1185-4.

TABLE 2 EVALUATION OF CRASH TEST 1185-4

USUAL CRITERIA	USUAL TEST RESULTS	PASS/FAIL
Must contain vehicle	Vehicle was contained	Pass
Debris shall not penetrate passenger compartment	No debris penetrated passenger compartment	Pass
Passenger compartment must have essentially no deformation	Minimal deformation	Pass
Vehicle must remain upright	Vehicle did remain upright	Pass
Must smoothly redirect the vehicle	Vehicle was redirected	Pass
Effective coefficient of friction (9)		
μ — Assessment	μ — Assessment	
0 - .25 Good .26 - .35 Fair > .35 Marginal	.29 Fair	Pass
Shall be less than		
Occupant Impact Velocity - fps Longitudinal 30, Lateral 25	Occupant Impact Velocity - fps Longitudinal 26.8, Lateral 20.1	Pass
Occupant Ridedown Accelerations - g's Longitudinal 15, Lateral 15	Occupant Ridedown Accelerations - g's Longitudinal -6.8, Lateral 8.7	Pass
Exit angle shall be less than 16.0 degrees	Exit angle was 7.6 degrees	Pass

S13. It met all of the safety evaluation guidelines of NCHRP 230 (Tables 1 and 2).

None of the pipes incurred any collapse nor was there any yielding of these members. The base plates in Test 10 moved without yielding by virtue of the rotation allowed at the splices. Therefore, repairs of the rail itself would consist of cleaning and repainting after an accident.

Punching shear cracks developed in the bridge deck typical of crash tests on steel beam and post bridge rails. These only occurred from the 4,500-lb car impacting at 62.4 mph and 26.6 degrees. This impact was a very severe impact that most bridge rail installations rarely experience.

The cracking of the concrete deck could be minimized by increasing the edge distance of the posts and base plate from the deck facia and adding some horizontally placed reinforcements perpendicular to the surface cracks.

ACKNOWLEDGMENTS

This research study was conducted under a cooperative program between the Texas Transportation Institute (TTI), the State Department of Highways and Public Transportation (SDHPT), and the FHWA. Dean Van Landuyt, John J. Panak, and Van M. McElroy were closely involved in all phases of this study.

REFERENCE

1. J. D. Michie. *NCHRP Report 230: Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances.* TRB, National Research Council, Washington, D.C., March 1981.

Publication of this paper sponsored by Committee on General Structures.