Aesthetically Pleasing Concrete Beam-and-Post Bridge Rail

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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. The objective of this research study was to develop aesthetically pleasing, structurally sound railings that can serve as alternative railings in urban areas. A new type of open concrete bridge rail—Texas Type T411—is presented. This bridge rail is constructed of reinforced concrete 32 in. high by 12 in. thick and contains 8-in.-wide by 18-in.-high openings at 18-in. center-to-center longitudinal spacing. The bridge rail was crash-tested and evaluated in accordance with *NCHRP Report 230* for Service Level 2. Two crash tests were required—a 4,500-lb passenger car striking at 60 mph and a 25-degree impact angle and an 1,800-lb passenger car striking at 60 mph and a 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 impact velocities and 10-msec occupant ridedown accelerations were within the limits specified in *NCHRP Report 230*. The vehicle trajectory at loss of contact indicates no intrusion into adjacent traffic lanes (exit angles of 0 degree and 5.9 degrees). These test data also met the occupancy safety evaluation guidelines in the 1989 AASHTO *Guide Specifications for Bridge Railings*.

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 effect 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.

An attempt is being made to develop one or more new concrete, steel, and aluminum railings or combination railings, some with curb and sidewalk.

A new type of open concrete bridge rail—Texas Type T411—is presented. The research study advisory committee reviewed design sketches of 22 different bridge rail designs before selecting the new Texas Type T411 as its top 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 the Dallas District, one bridge design engineer from the Dallas District, and three bridge design engineers from Austin headquarters.

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DESCRIPTION OF TEXAS TYPE T411 BRIDGE RAIL

Texas Type T411 bridge rail is constructed of reinforced concrete 32 in. high by 12 in. thick and contains 8-in.-wide by 18-in.-high openings at 18-in. center-to-center longitudinal spacing. Figures 1 and 2 present a plan view, elevation, and cross section of the T411 rail. The bridge deck is an 8-in.-thick typical Texas bridge slab design in accordance with AASHTO specifications (*1*).

Figure 3 shows a photograph of the bridge rail installation before crash testing. The installation is 75 ft 10 in. long. The three pilasters are not super-strong posts, as they appear to be. They contain styrofoam blocks 10.5 in. by 13 in. by 21 in. (void), which means that the pilasters are similar to the 8-in. by 18-in. openings. The use of the pilasters is optional because they did not contribute to the bridge rail strength as built and crash-tested.

This bridge rail was designed using a failure mechanism (or yield line) method of analysis (*2*). The design strengh of the concrete was $f_c = 3{,}600$ psi and the yield strength of reinforcing steel was $f_y = 60{,}000$ psi. The top beam was nominally 7 in. wide and 11 in. thick ($b = 7$ in. and $d = 8.25$ in.), yielding an ultimate moment capacity of 20.0 kip-ft. The posts are 10 in. wide and 10 in. thick ($b = 10$ in. and $d = 8$ in.), yielding an ultimate moment capacity of 20.6 kip-ft. With a moment arm of 2.2 ft, each post could resist a lateral load of about 9.5 kips. Figures 4 and 5 present a summary of the failure mechanism analysis of the strength of the T411 bridge rail. The failure load would be about 65.9 kips or more. Five posts would crack, and a 9-ft. length of bridge rail would be involved.

Concrete specimens taken from the simulated bridge deck yielded a compressive strength of 4,880 psi at 28 days of age. The compressive strength of the concrete rail was 5,110 psi at 28 days of age.

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* (*3*) for Service Level 2. Two crash tests were required—Test 10 with a 4,500-lb passenger car striking at 60 mph and a 25-degree impact angle and Test S13 with an 1,800-lb passenger car striking at 60 mph and a 20-degree impact angle.

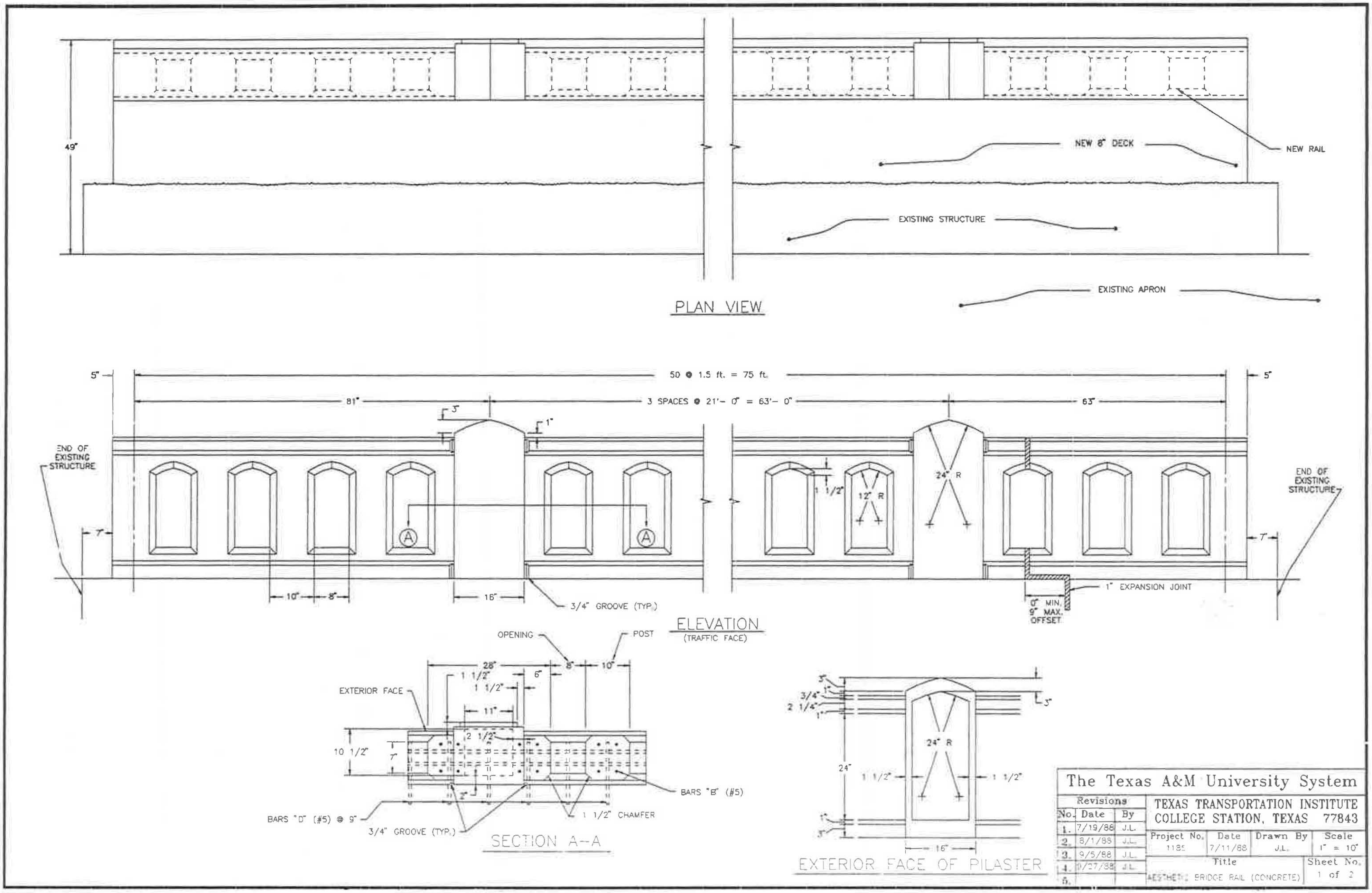
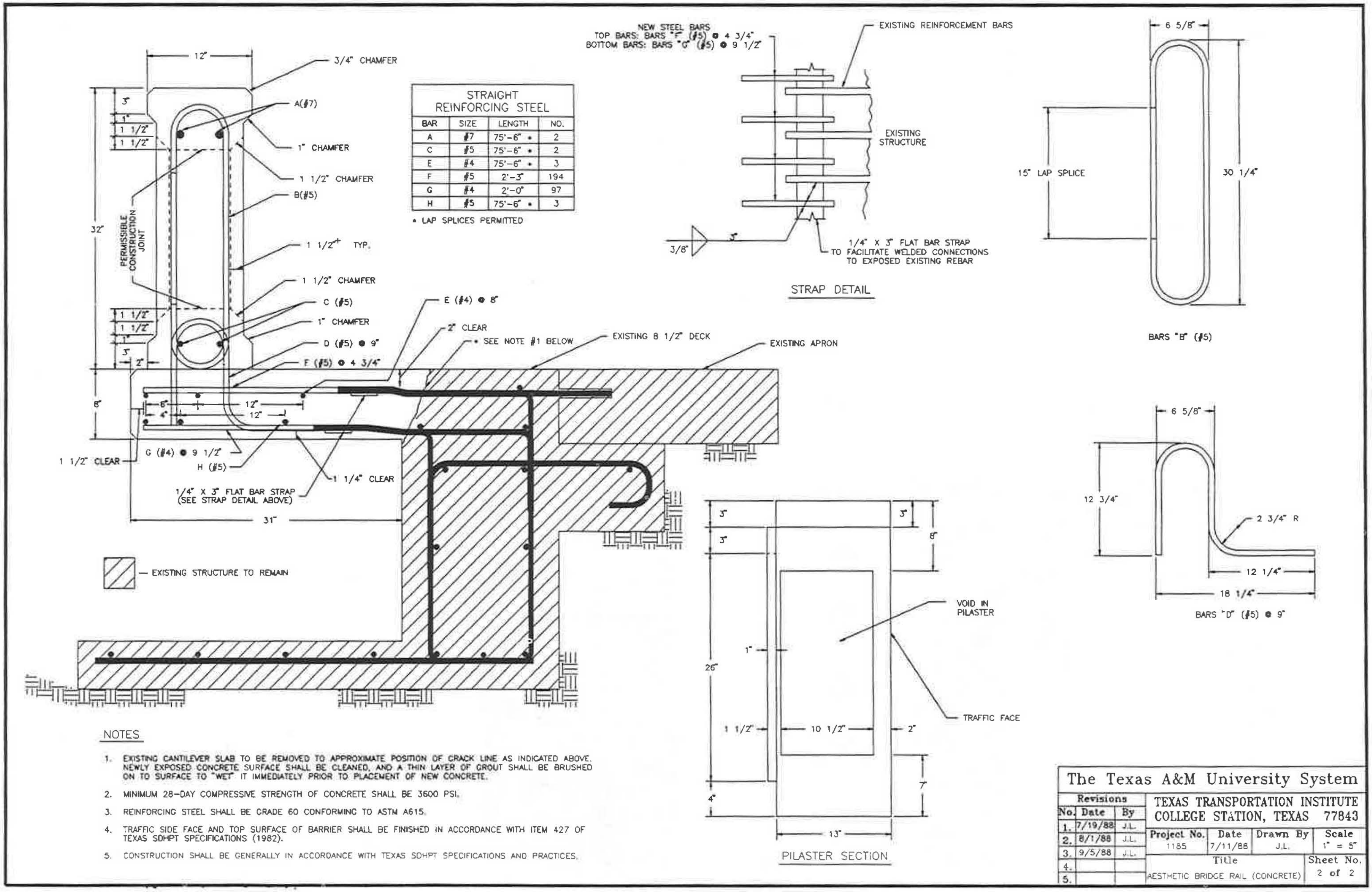


FIGURE 1 Texas Type T411 bridge rail—plan and elevation.



STRAIGHT REINFORCING STEEL

BAR	SIZE	LENGTH	NO.
A	#7	75'-6" *	2
C	#5	75'-6" *	2
E	#4	75'-6" *	3
F	#5	2'-3"	194
G	#4	2'-0"	97
H	#5	75'-6" *	3

* LAP SPLICES PERMITTED

NOTES

1. EXISTING CANTILEVER SLAB TO BE REMOVED TO APPROXIMATE POSITION OF CRACK LINE AS INDICATED ABOVE. NEWLY EXPOSED CONCRETE SURFACE SHALL BE CLEANED, AND A THIN LAYER OF GROUT SHALL BE BRUSHED ON TO SURFACE TO "WET" IT IMMEDIATELY PRIOR TO PLACEMENT OF NEW CONCRETE.
2. MINIMUM 28-DAY COMPRESSIVE STRENGTH OF CONCRETE SHALL BE 3600 PSI.
3. REINFORCING STEEL SHALL BE GRADE 60 CONFORMING TO ASTM A615.
4. TRAFFIC SIDE FACE AND TOP SURFACE OF BARRIER SHALL BE FINISHED IN ACCORDANCE WITH ITEM 427 OF TEXAS SDHPT SPECIFICATIONS (1982).
5. CONSTRUCTION SHALL BE GENERALLY IN ACCORDANCE WITH TEXAS SDHPT SPECIFICATIONS AND PRACTICES.

FIGURE 2 Texas Type T411 bridge rail—cross section.

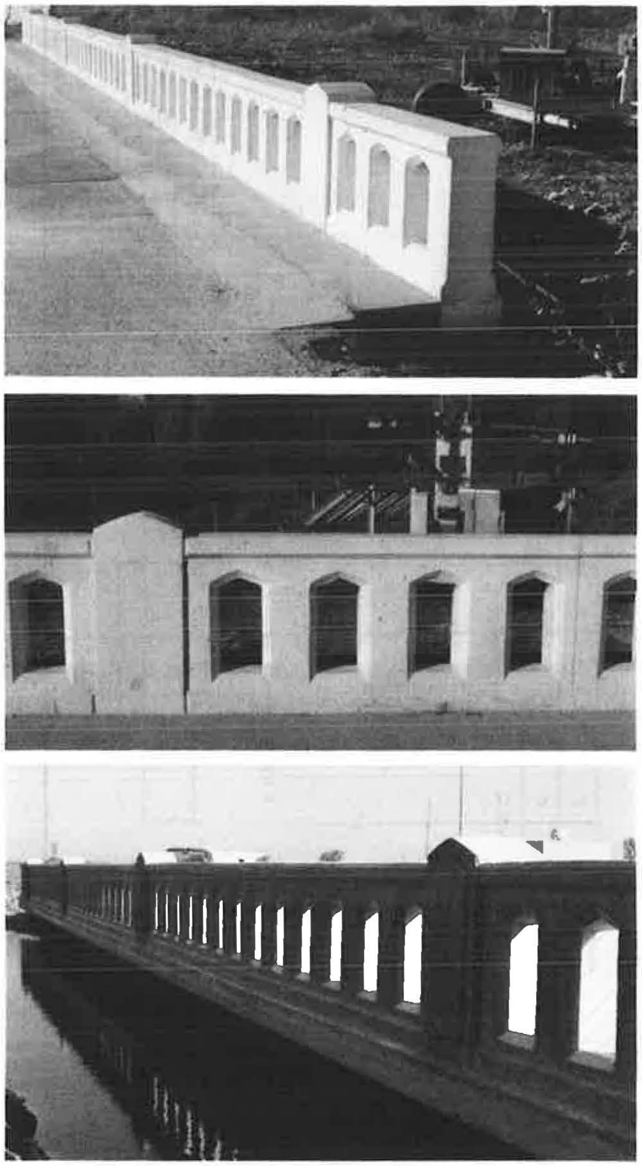


FIGURE 3 Installation before Test 1185-1.

Honda Crash Test (Test 1185-1)

The 1980 Honda Civic (Figure 6) was directed into the bridge rail using a reverse tow and guidance system. Test inertia mass of the vehicle was 1,800 lb. The lower edge of the vehicle bumper was 14.25 in. high, and the top of the bumper was 19.25 in. high. The vehicle was freewheeling and unrestrained just before impact.

The speed of the vehicle at impact was 60.2 mph and the angle of impact was 21.2 degrees. The vehicle struck the bridge rail approximately 22 ft from the end. The right front wheel made contact with the bridge rail shortly after impact. The vehicle began to redirect at 0.039 sec. By 0.052 sec the vehicle had deformed to the A-pillar, which allowed the windshield to begin to pop out, and at 0.075 sec the windshield broke. At 0.378 sec the vehicle was traveling almost parallel with the bridge rail and its speed was about 39.3 mph. The front of the vehicle remained in contact with the bridge rail until it rode off the end at 0.974 sec at a speed of 30.2 mph. When the brakes were applied, the vehicle yawed clockwise and subsequently came to rest 100 ft from the point of impact.

As can be seen in Figures 7 and 8, the rail sustained minimal cosmetic damage. Tire marks on the face of the bridge rail extended from the point of impact to the end of the rail. Some scraping and gouging along the edges of the portholes and of the first pilaster beyond impact occurred. The vehicle was in contact with the bridge rail for 53 ft. 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 11.0 in. The drive axle universal joint and right strut were damaged. The instrument panel in the passenger compartment was bent as well as the floor pan and roof, and the windshield was broken. The right front rim was bent and the tire was damaged. 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.

Test Results

Impact speed was 60.2 mph and the angle of impact was 21.2 degrees. Occupant impact velocity was 28.6 ft/sec in the longitudinal direction and 16.6 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were -2.0 *g* (longitudinal) and 3.6 *g* (lateral). These data and other pertinent information from the test are summarized in Figure 10.

These data were further analyzed to obtain 0.050-sec average accelerations versus time. The maximum 0.050-sec averages measured at the center of gravity were -13.5 *g* (longitudinal) and 11.3 *g* (lateral).

Conclusions

The bridge rail contained and smoothly 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 occupant impact velocities and 10-msec occupant ridedown accelerations were within the limits specified in *NCHRP Report 230*. The vehicle trajectory at loss of contact indicates no intrusion into adjacent traffic lanes (exit angle 0 degree).

These test data were also evaluated using the occupant safety evaluation guidelines in the 1989 AASHTO *Guide Specifications for Bridge Railings* (*4*). The effective coefficient of friction *u* was found to be 0.54, or marginal for this test.

Cadillac Crash Test (Test 1185-2)

The 1980 Cadillac Sedan DeVille (Figure 11) was directed into the bridge rail using a reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 lb. The lower edge of the vehicle bumper was 12.5 in. high, and the top of the bumper was 21.0 in. high. The vehicle was freewheeling and unrestrained just before impact.

The speed of the vehicle at impact was 62.2 mph and the angle of impact was 26.0 degrees. The vehicle struck the bridge

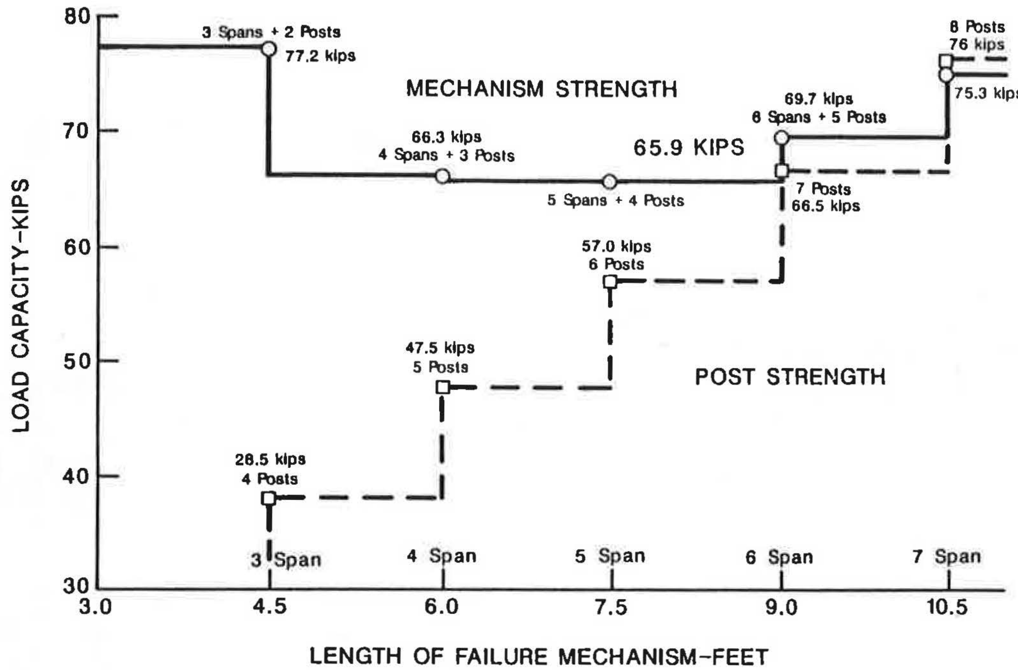
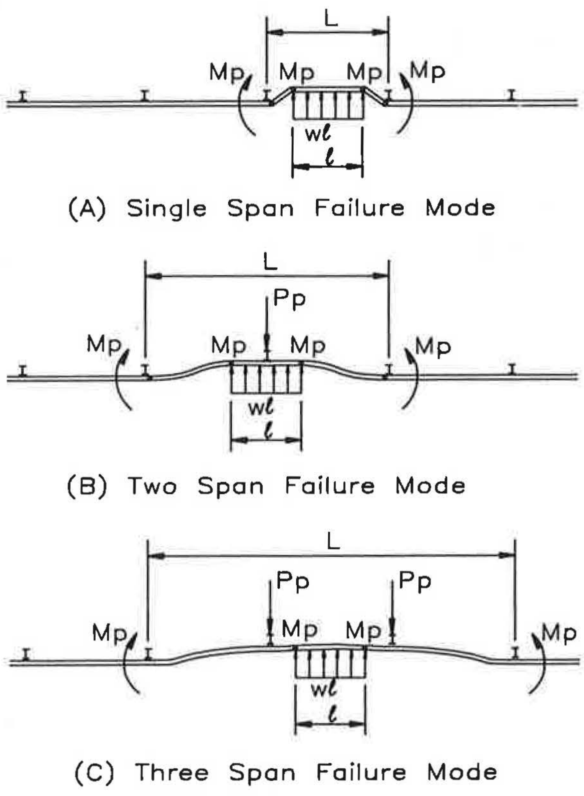


FIGURE 4 Failure mechanism analysis for Texas Type T411 bridge rail.



Mp = plastic moment capacity of rail = Mult.

Pp = ultimate load capacity of a single post

$w\ell$ = total ultimate vehicle impact load $= \frac{8\ Mp}{L - \ell/2} + \Sigma Pp$

$\ell = 3.5$ ft.

PLAN VIEW

FIGURE 5 Possible failure modes for rails.

FIGURE 6 Vehicle–bridge rail geometrics for Test 1185-1.

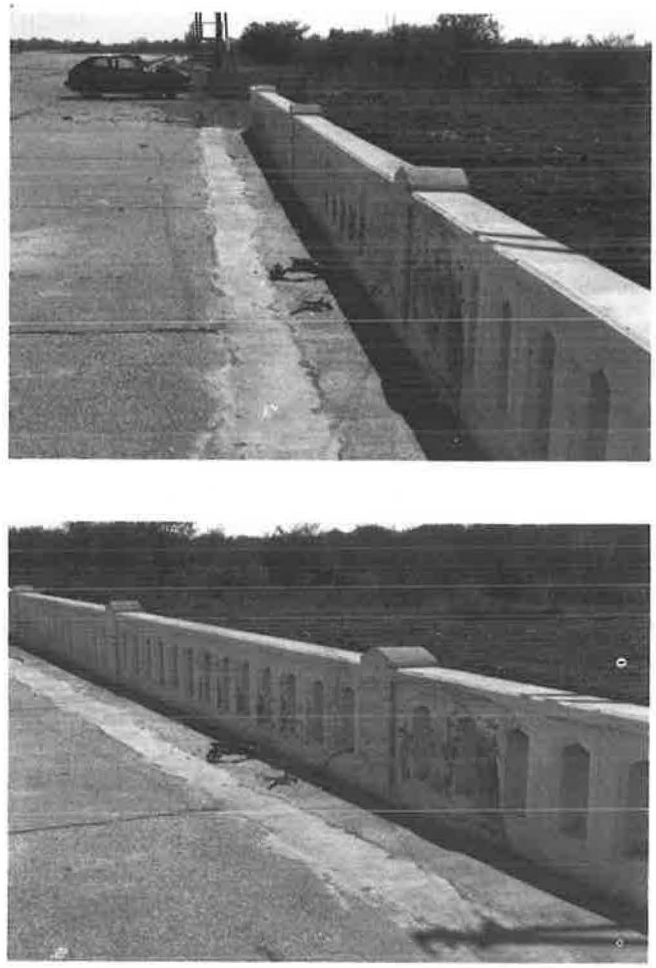


FIGURE 7 Test installation after Test 1185-1.

rail approximately 38 ft from the end. The right front wheel made contact with the bridge rail shortly after impact. The vehicle began to redirect at 0.064 sec. By 0.085 sec the vehicle had deformed to the A-pillar and the windshield broke. At 0.240 sec the vehicle began to move parallel with the bridge rail, traveling at a speed of 41.7 mph. The rear of the vehicle struck the bridge rail at 0.264 sec. The vehicle lost contact with the bridge rail at 0.379 sec, traveling at 38.9 mph and 5.9 degrees. The brakes were then applied; the vehicle yawed clockwise and subsequently came to rest against a safety barrier 125 ft from the point of impact.

As can be seen in Figure 12, the rail sustained minimal cosmetic damage. Tire marks on the face of the bridge rail extended from the point of impact to the end of the rail. Some scraping and gouging along the edges of the portholes and of the first pilaster beyond impact occurred. The vehicle was in contact with the bridge rail for 12 ft.

The vehicle sustained moderate damage to the right side, as shown in Figure 13. Maximum crush at the right front corner at bumper height was 16.0 in. The right A-arm, the tie rod, and the upper and lower ball joints were damaged, and the subframe was bent. The instrument panel in the passenger compartment was bent as well as the floor pan and roof, 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, bumper, right front quarter panel, the right front and rear doors, the right rear quarter panel, and the rear bumper.

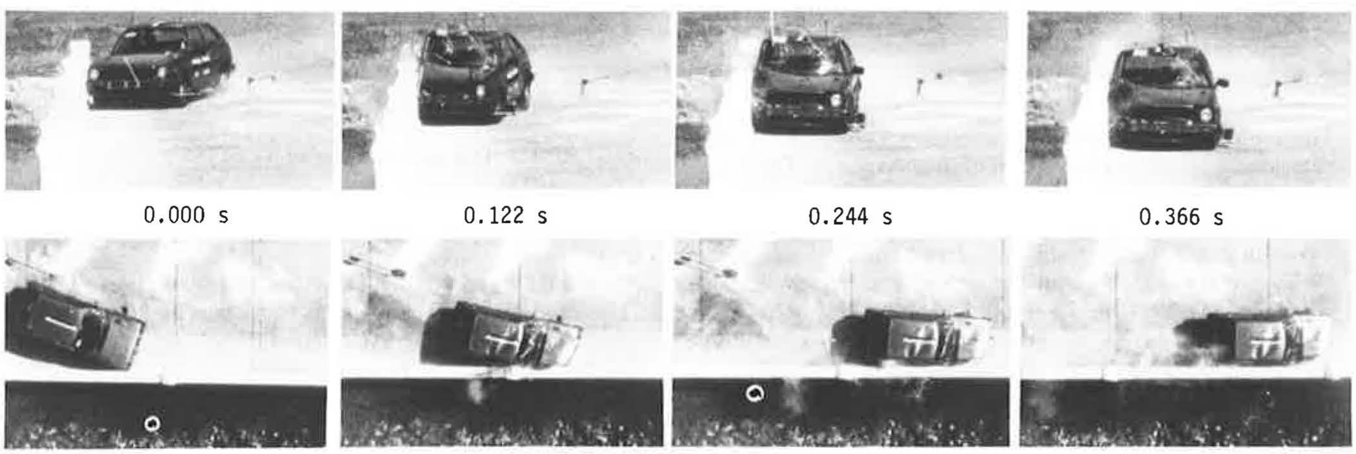
Test Results

Impact speed was 62.2 mph and the angle of impact was 26.0 degrees. The vehicle exited the rail at 38.9 mph and 5.9 degrees. *NCHRP Report 230* describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted at 15-degree impact angles. These limits do not apply to tests conducted at 25-degree impact angles but were computed and reported for information only. Occupant impact velocity was 28.7 ft/sec in the longitudinal direction and 23.0 ft/sec in the lateral direction. The highest 0.010-sec occupant ridedown accelerations were $-12.4\ g$ (longitudinal) and $10.5\ g$ (lateral). These data and other pertinent information from the test are summarized in Figure 14.

These data were further analyzed to obtain 0.050-sec average accelerations versus time. The maximum 0.050-sec averages at the center of gravity were $-12.8\ g$ (longitudinal) and $16.5\ g$ (lateral).

FIGURE 8 Damage to rail at point of impact.

FIGURE 9 Vehicle after Test 1185-1.



Test No.	1185-1
Date	11/29/88
Test Installation . . .	T411 Bridge Rail
Installation length . .	75 ft
Vehicle	1980 Honda Civic
Vehicle Weight	
Test Inertia	1,780 lb
Vehicle Damage Classification	
TAD	01FR5 & 01RFQ5
CDC	01FREK2 & 01RYAW3
Maximum Vehicle Crush .	11.0 in

Impact Speed . . .	60.2 mi/h
Impact Angle . . .	21.2 degrees
Speed at Parallel .	39.3 mi/h
Exit Speed	30.2 mi/h
Exit Trajectory . .	0 degrees
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal . .	-13.5 g
Lateral	11.3 g
Occupant Impact Velocity	
Longitudinal . .	28.6 ft/s
Lateral	16.6 ft/s
Occupant Ridedown Accelerations	
Longitudinal . .	-2.0 g
Lateral	3.6 g

FIGURE 10 Summary of results for Test 1185-1.

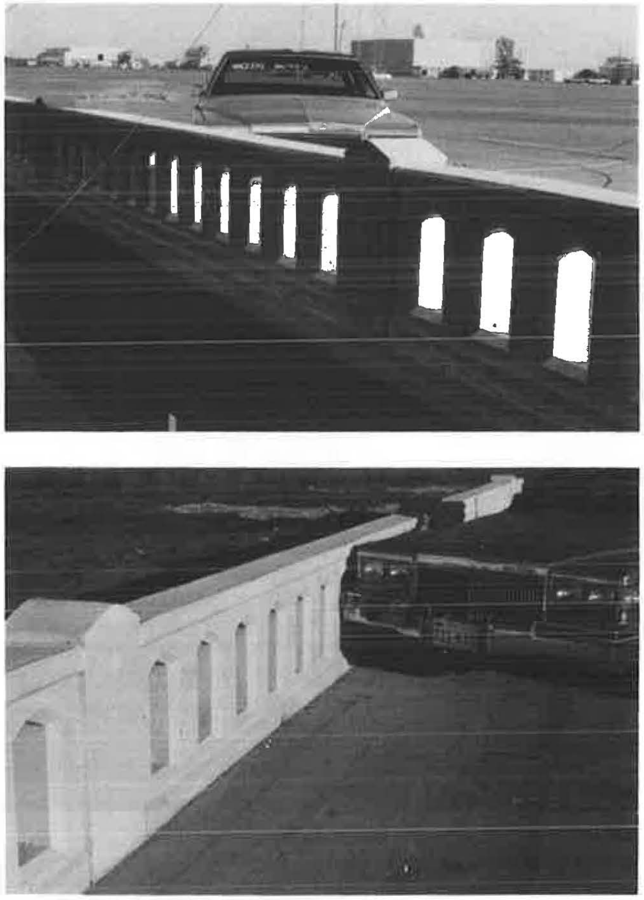


FIGURE 11 Vehicle and bridge rail geometrics for Test 1185-2.

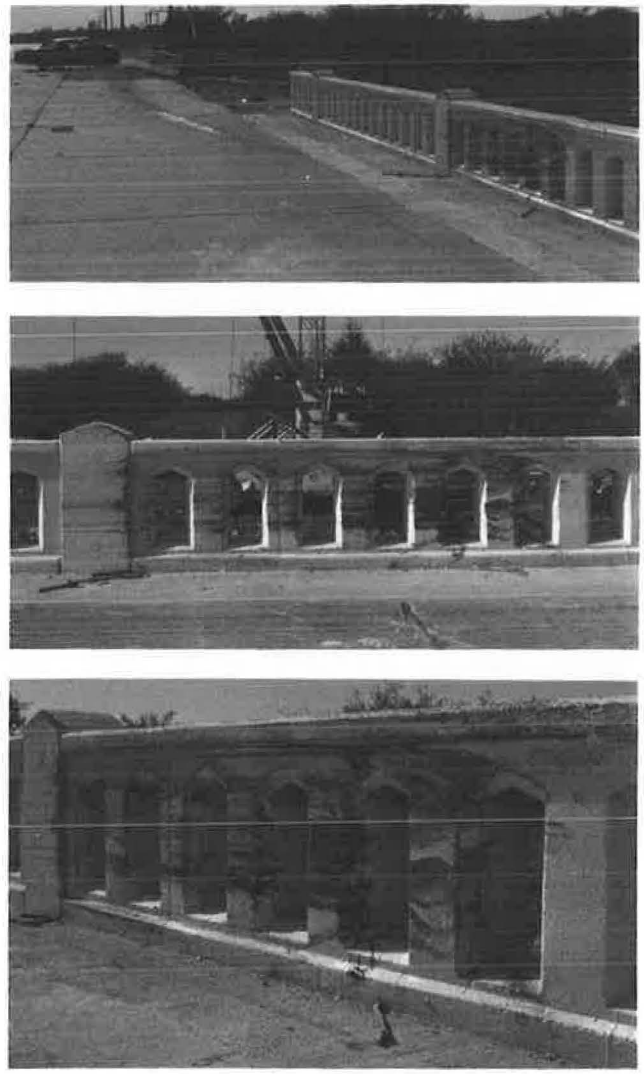


FIGURE 12 Test installation after Test 1185-2.

Conclusions

The bridge rail contained and smoothly redirected the test vehicle with no lateral movement of the bridge rail. The vehicle remained upright and relatively stable during the collision. The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes (exit angle 5.9 degrees). These test data satisfied all the occupant safety evaluation criteria of *NCHRP Report 230* and those in the 1989 AASHTO *Guide Specifications for Bridge Railings*. The effective coefficient of friction u for this test was 0.77, or marginal.

SUMMARY AND CONCLUSIONS

Table 1 compares the vehicle impact behavior of the aesthetic bridge rail, T411, with vehicle impact behavior obtained from several other rigid longitudinal traffic barriers. It can be seen that the change in speeds of the vehicles during impact (23.3 mph and 30.0 mph) were larger than those obtained from the others, but the exit angles (0 degrees and 5.9 degrees) were smaller than those obtained from the others. Because the vehicles did not return to the traffic lanes but stayed against the rail, the larger change in speed is not important.

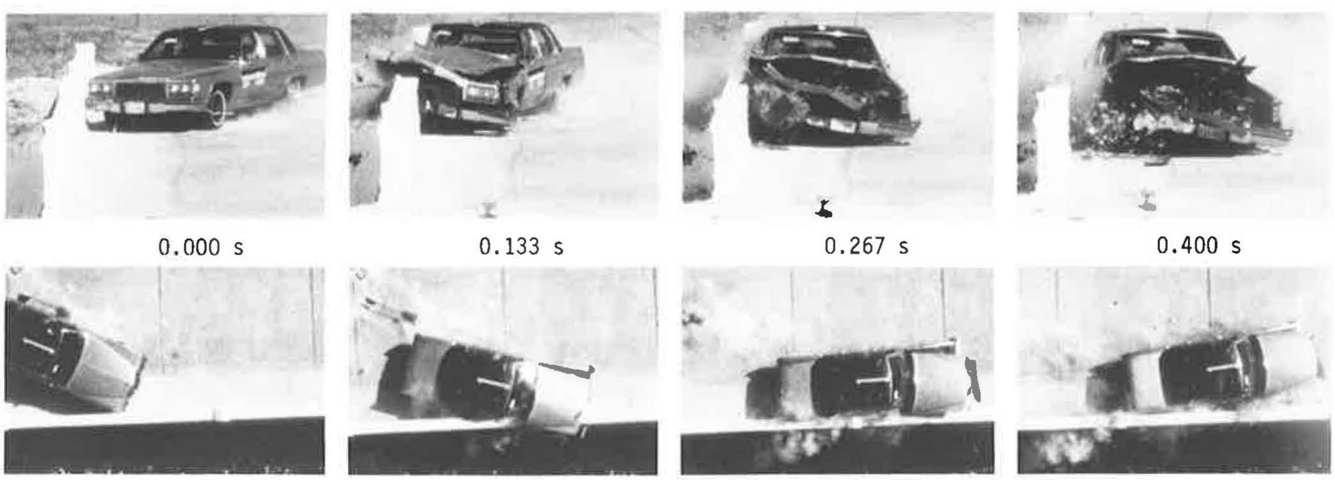
The longitudinal accelerations ($-12.8\,g$ and $-13.5\,g$) were larger than those obtained from the other rails but were acceptable. These larger longitudinal accelerations were expected because the vehicle grinds into the vertical openings. The larger effective coefficients of friction u of 0.54 and 0.77 were also expected and attributed to the vertical openings in the T411 rail. The transverse accelerations of 11.3 g and 16.5 g were about the same as those obtained from the other barriers.

The longitudinal occupant impact velocities of 28.6 ft/sec and 28.7 ft/sec were larger than those obtained from the other rails but were less than the limit of 30.0 ft/sec (*4*). The transverse occupant impact velocities of 16.6 ft/sec and 23.0 ft/sec were less than those obtained from the other rails and smaller than the limit of 25.0 ft/sec (*4*).

The longitudinal ridedown accelerations of $-2.0\,g$ and $-12.4\,g$ were larger than those obtained from the other rails but less than the proposed limit of $-15.0\,g$. The transverse ridedown accelerations of 3.6 g and 10.5 g were smaller than those obtained from the other rails and smaller than the proposed limit of 15.0 g.

It is therefore concluded that the new Texas T411 bridge rail has successfully met the crash test requirements of *NCHRP Report 230*.

FIGURE 13 Vehicle after Test 1185-2.

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Test No. . . . . . . . . . 1185-2
Date . . . . . . . . . . . 12/01/88

Test Installation . . . T411 Bridge Rail
Installation Length . . 75 ft

Vehicle . . . . . . . . . 1980 Cadillac
Vehicle Weight
  Test Inertia . . . . . 4,500 lb
Vehicle Damage Classification
  TAD . . . . . . . . . . 01FR6 & 01RFQ7
  CDC . . . . . . . . . . 01FZEK2 & 01RYAW4
Maximum Vehicle Crush . 16.0 in
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Impact Speed . . . 62.2 mi/h
Impact Angle . . . 26.0 degrees
Speed at Parallel . 41.7 mi/h
Exit Speed . . . . 38.9 mi/h
Exit Trajectory . .  5.9 degrees
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal . . -12.8 g
  Lateral . . . . . 16.5 g
Occupant Impact Velocity
  Longitudinal . . 28.7 ft/s
  Lateral . . . . . 23.0 ft/s
Occupant Ridedown Accelerations
  Longitudinal . . -12.4 g
  Lateral . . . . . 10.5 g
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FIGURE 14 Summary of results for Test 1185-2.

TABLE 1 COMPARISON OF VEHICLE IMPACTS INTO THE AESTHETIC TYPE T411 BRIDGE RAIL WITH VEHICLE IMPACTS INTO OTHER RIGID LONGITUDINAL TRAFFIC BARRIERS

(1) Test No.	(2) Change in Speed mph	(3) Exit Angle degrees	(4) Long. Accel. g's	(5) Trans. Accel. g's	(6) Long. Occupant Impact Vel. fps	(7) Trans. Occupant Impact Vel. g's	(8) Long. Ridedown Accel. g's	(9) Trans. Ridedown Accel. g's	(10) Type Rail
NCHRP 230 Test 10 - 4,500 lb, 60 mph, 25°									
1179-2	14.5	2.0	- 9.7	14.3	23.9	27.3	- 4.9	16.7	Conc. C202
7046-1	15.9	17.5	- 4.8	14.0	19.4	28.2	- 5.4	14.4	Conc. Wall
3451-7	18.5	13.5	- 5.2	6.9	11.9	15.4	-	-	T101
7091-10	12.9	6.3	- 6.3	12.5	18.6	27.0	- 5.9	10.8	IBC
3451-36	17.4	6.3	- 9.1	15.4	10.9	23.0	-	-	Conc. Wall
7091-11	13.4	7.3	- 6.4	11.6	23.2	26.6	- 3.8	10.6	IBC
Avg.	15.4	8.8	- 6.9	12.5	18.0	24.6	- 5.0	13.1	
1185-1	23.3	5.9	-12.8	16.5	28.7	23.0	-12.4	10.5	T411
NCHRP 230 Test 13 - 1,800 lb, 60 mph, 20°									
1179-1	16.8	0.6	-11.2	14.0	23.3	25.7	- 2.0	9.3	Conc. C202
3451-27	13.2	1.0	- 9.2	10.3	18.6	19.5	-	-	Indiana Alum.
3451-28	19.9	3.5	-13.6	10.2	20.1	20.3	-	-	Indiana Alum.
7069-3	7.1	6.2	- 8.0	12.8	19.0	23.7	- 2.1	4.9	Conc. F Shape
7069-5	11.9	6.2	- 8.0	14.0	20.1	26.0	- 1.6	9.4	Conc. Wall
7069-10	10.2	5.2	- 6.4	14.2	16.9	25.1	- 1.4	8.5	Ill. Steel
Avg.	13.2	3.8	- 9.4	12.6	19.7	23.4	- 1.7	8.0	
1185-2	30.0	0	-13.5	11.3	28.6	16.6	- 2.0	3.6	

ACKNOWLEDGMENTS

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