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REFERENCES

1. J.E. Bryden and K.C. Hahn. Crash Tests of Light-Post Thrie-Beam Traffic Barriers. Research Report 85. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, March 1981.
2. J.E. Bryden and K.C. Hahn. Crash Tests of Box-Beam Upgradings for Discontinuous-Panel Bridge Railing. Research Report 92. Engineering Research and Development Bureau, New York State Department of Transportation, Sept. 1981.
3. J.D. Michie and M.E. Bronstad. Upgrading Safety Performance in Retrofitting Traffic Railing Systems. Report FHWA-RD-77-40. Southwest Research Institute, San Antonio, Tex., Sept. 1976.
4. M.E. Bronstad, L.R. Calcote, C.E. Kimball, Jr., and C.F. McDevitt. Development of Retrofit Railings for Through Truss Bridges. In Transportation Research Record 942, TRB, National Research Council, Washington, D.C., 1983, pp. 1-10.
5. R.M. Olson et al. Texas T-1 Bridge Rail Systems. Technical Memorandum 505-10. Texas Transportation Institute, Texas A&M University System, College Station, April 1971.
6. J.D. Michie. Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances. NCHRP Report 230. TRB, National Research Council, Washington, D.C., March 1981.
7. Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances. Transportation Research Circular 191. TRB, National Research Council, Washington, D.C., Feb. 1978.
8. A Guide to Standardized Highway Barrier Rail Hardware. Technical Bulletin 268-B, AGC Standard Form 131. American Road and Transportation Builders Association, Washington, D.C., June 1979.
9. D.L. Ivey, C.F. McDevitt, R. Robertson, C.E. Buth, and A.J. Stocker. Thrie-Beam Guardrails for School and Intercity Buses. In Transportation Research Record 868, TRB, National Research Council, Washington, D.C., 1982, pp. 38-44.
10. Performance of a Thrie-Beam Steel-Post Bridge-Rail System. Research Report 118. Engineering Research and Development Bureau, New York State Department of Transportation, Albany.

Bridge Rail to Contain and Redirect 80,000-lb Tank Trucks

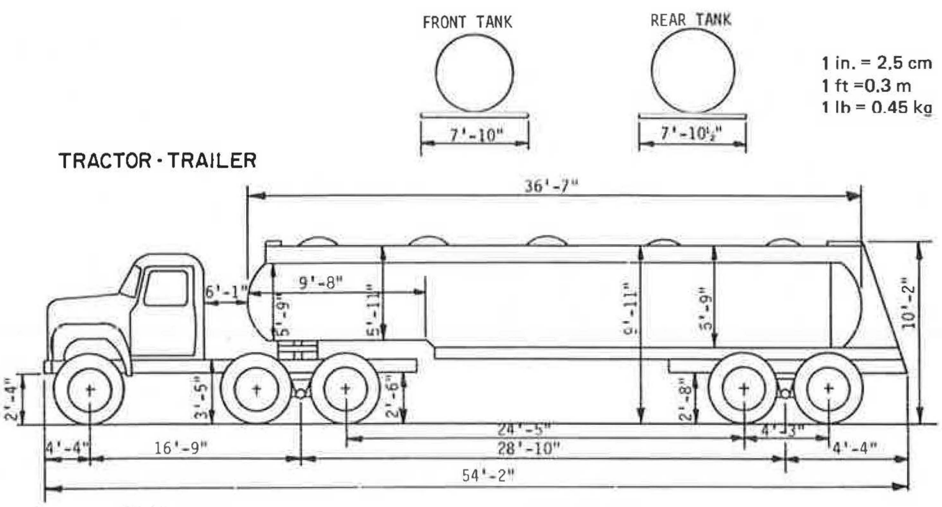
T. J. HIRSCH and W. L. FAIRBANKS

ABSTRACT

A standard Texas Type T5 traffic rail was modified to increase its height and strength to contain and redirect an 80,000-lb (36 297-kg) tank-type tractor-trailer at 50-mph (80.5-km/hr), 15-degree impacts. The height of the concrete parapet was increased to 48 in. (122 cm), and a concrete beam was mounted on concrete posts on the top of the parapet to achieve a total rail height of 90 in. (229 cm). One crash test was conducted on the bridge rail. The truck was contained and smoothly redirected. This test has shown that a bridge rail can redirect heavy tank-type trucks at speeds up to 50 mph and 15-degree impacts. The cost of this rail is estimated at about $125 per foot. Typical passenger car bridge rails in Texas now cost about $35 per foot.

Current bridge rails are designed to restrain and redirect passenger cars only. Collisions of large trucks with these bridge rails have in the past led to catastrophic accidents. Concern for the reduction of the severity of these accidents has led highway designers to devote more attention to the containment and redirection of large trucks at selected locations.

The factors involved in the design of bridge rails to contain and redirect large trucks are not nearly so well understood or researched as those involved in the design of passenger car rails.



EMPTY WEIGHT	
Weight on front axle	10,590
Weight on center axles	8,030
Weight on rear axles	9,700
Total Empty Weight	28,320

LOADED WEIGHT	
Weight on front axle	12,070
Weight on center axles	34,050
Weight on rear axles	34,000
Total Loaded Weight	80,120

FIGURE 1 Tractor-trailer loaded dimensions, empty weight, and loaded weight.

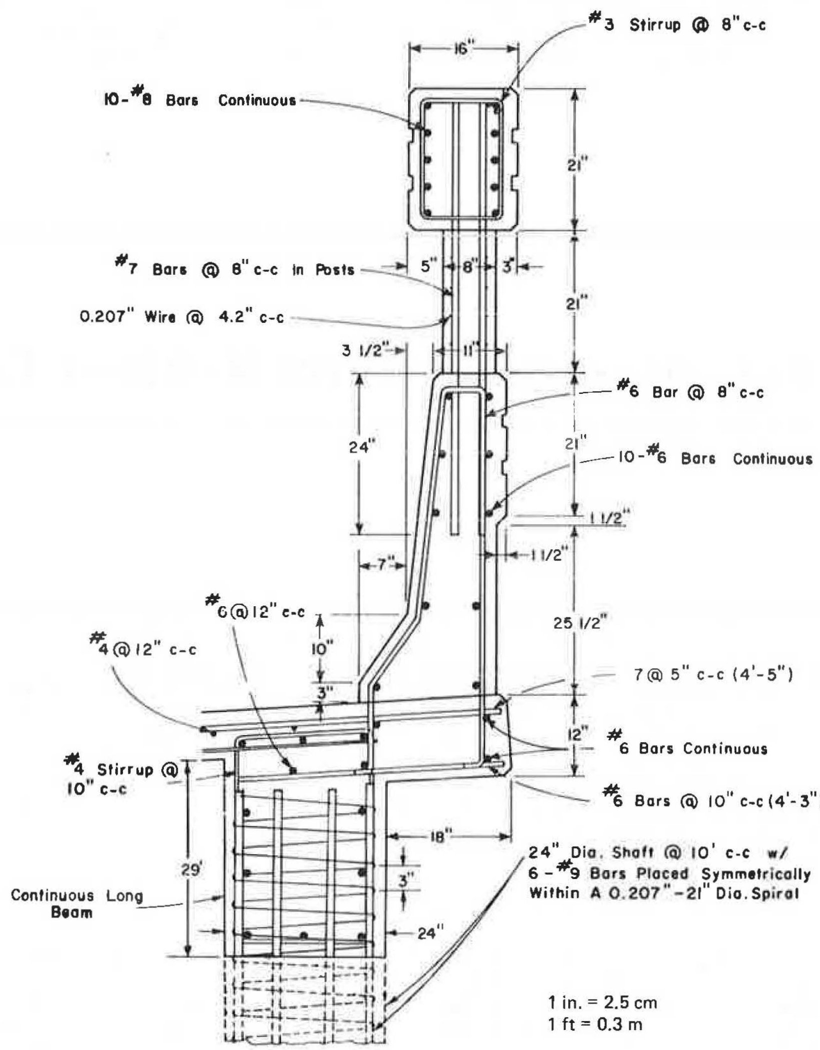


FIGURE 2 Cross section of modified T5 bridge rail and bridge deck.

Therefore, it was the objective of this project to design, build, and test a bridge rail to contain and redirect an 80,000-lb (36 297-kg) tank-type tractor-trailer, as shown in Figure 1. The design was based on data presented elsewhere (1-5).

The rail selected was a modification of the Texas Type T5 traffic rail. The modified T5 rail consists of a concrete safety-shaped parapet 48 in. (122 cm) high and a concrete beam element 16 in. (41 cm) wide and 21 in. (53 cm) deep. The concrete beam is mounted at a height of 90 in. (229 cm) on concrete posts on top of the parapet. The concrete posts are concrete walls 8 in. (20 cm) thick by 5 ft (1.5 m) long located at 10-ft (3-m) center-to-center spacing. This produces 5-ft (1.5-m) openings 21 in. (53 cm) high between posts. The beam element contains a large amount of reinforcing steel, which provides both flexibility and strength and thus minimizes cracking of the concrete and permanent deflection of the rail when impacted by heavy vehicles. The modified T5 concrete parapet can be placed in continuous lengths, which gives good structural continuity and strength. The thickness of the bridge deck below the concrete parapet was increased to 12 in. (30 cm) to minimize cracking.

The beam-and-post design was selected because of its open and aesthetic appearance. The concrete safety-shaped parapet was selected because of its past acceptable safety performance.

DESIGN TECHNIQUE

Earlier tests (1) have shown that the highest forces generated during the redirection of tractor-trailers occur when the tandem axles of the tractor and the front of the trailer impact the bridge railing. With the traffic rails tested in the past, a relatively small part of the total kinetic energy is expended in the redirection of the front axle of the tractor, and the rear tandem axles of the trailer tend to have an even smaller impact. With the knowledge that the total loaded weight on the tandem axles of the tractor would be approximately 34,000 lb (15 426 kg) (Figure 1), it was assumed that 10,000 lb (4540 kg) of this load (empty weight) would probably be transferred to the rail through the wheels and the axles. The remaining 24,000 lb (10 889 kg) (payload) would be transferred to the rail through the trailer.

Accelerometer data from past tests indicated that the tandem axles of the tractor would be subjected to a 50-msec average lateral acceleration of about 6 g. Therefore, equivalent static design forces of 60,000 lb (27 223 kg) (10,000 lb x 6 g) applied at a height of 21 in. and 144,000 lb (65 335 kg) (24,000 lb x 6 g) applied at a height of 84 in. (213 cm) were used to design the rail by using yield line theory for reinforced concrete. These procedures are outlined in Texas Transportation Institute (TTI) Research Report 230-2 (2).

DESCRIPTION OF BRIDGE RAIL AND DECK MODIFICATIONS

The modified T5 rail has a concrete beam 16 in. wide and 21 in. deep mounted on top. This modified bridge rail makes a combination bridge rail 90 in. high suitable to retain large 80,000-lb tank-type trucks or tractor-trailers impacting at 15 degrees and 50 mph. Drawings of this rail are shown in Figures 2, 3, and 4. The size of this bridge rail is compared with a 1979 Ford Thunderbird and the tank-type tractor-trailer in Figure 5. The bridge rail was constructed on a 14-degree curve, and the deck had a superelevation of 0.055 ft/ft (0.017 m/m). The rail was mounted vertically. The bridge rail was constructed in this manner, at the request of the sponsors, to closely simulate an expected installation in San Antonio, Texas.

The concrete parapet was basically a standard Texas Type T5 traffic rail that was heightened to 48 in. and thickened to 11 in. (28 cm) at the top and 20.5 in. (52 cm) at the bottom. It was anchored to the bridge deck by No. 6 stirrups spaced at 8 in. (20 cm) as shown, and 10 No. 8 longitudinal bars were used.

The concrete post was 21 in. high, 8 in. thick, and 5 ft long with 5-ft openings between posts. Each concrete post was anchored to the concrete rail by means of 16 No. 7 bars (8 on the traffic side and 8 on the field side).

The concrete beam on top of the posts was 16 in. wide and 21 in. deep for the entire length of the rail. It contained No. 3 closed stirrups spaced at 8 in. center to center and 10 No. 8 longitudinal bars.

The strength of the Texas standard bridge deck, which is 7 in. (18 cm) thick, was increased in many ways. The dimensions and reinforcement pattern of the standard bridge deck were essentially maintained throughout except in the cantilever portion of the deck. These changes are detailed in Figure 2. The length of the cantilever portion was decreased from 30 in. (76 cm) to 18 in., and the thickness was increased to 12 in. (30.5 cm). The size of the upper transverse bars was increased from No. 5 bars to No.

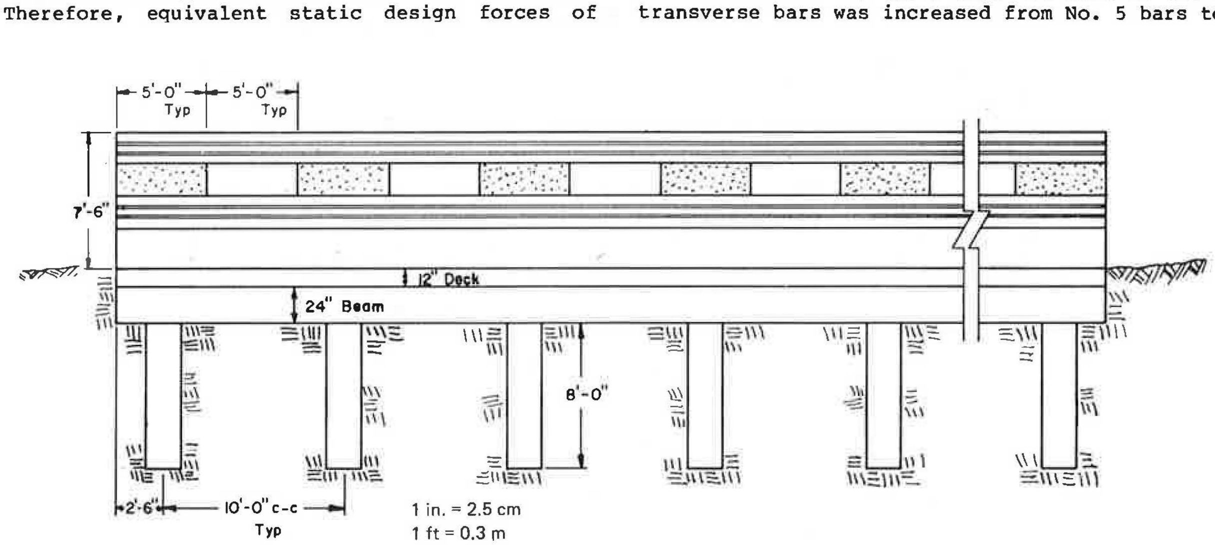


FIGURE 3 Elevation (from field side) of modified T5 bridge rail.

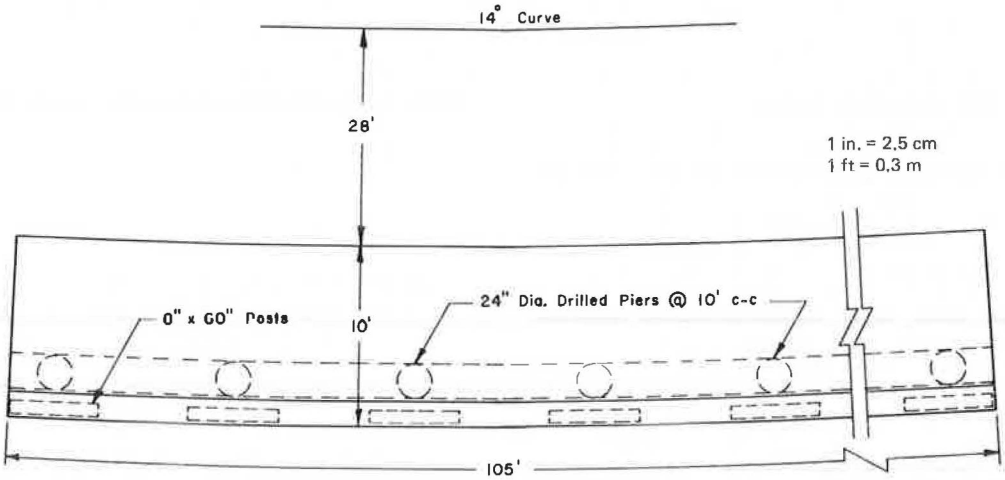


FIGURE 4 Plan view of modified T5 bridge rail, bridge deck, and pier system.

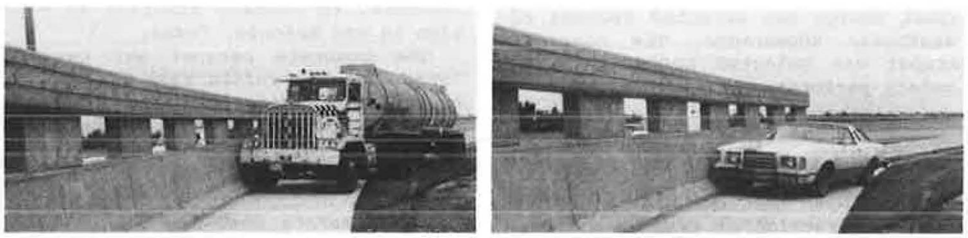


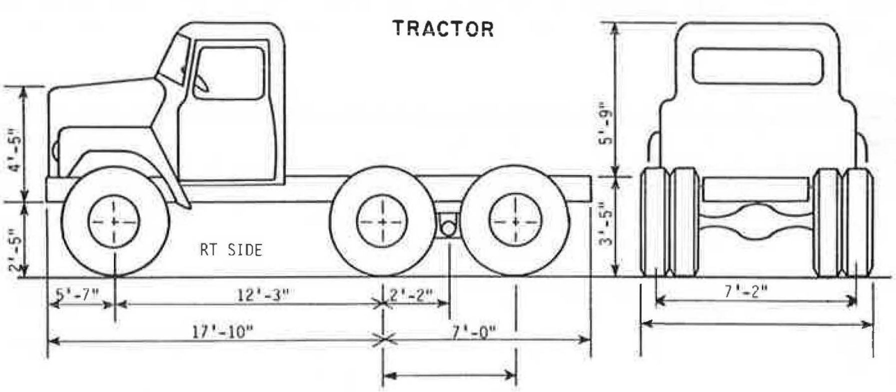
FIGURE 5 Comparison of Thunderbird and 80,000-lb tank truck with modified rail.

7, and the standard 5-in. (12.7-cm) spacing was retained. The size of the lower transverse bars was increased from No. 4 to No. 6, and the standard spacing of 10 in. (25.4 cm) was again retained. The size of the upper and lower longitudinal bars was increased to No. 6 from No. 4 and 5, respectively, and the spacing was increased from 12 to 17.5 in. (44.5 cm).

All reinforcing bars used in both the bridge deck and the rail had a minimum yield strength of 60 ksi (41.4 kN/cm^2). It should be noted that all of the 28-day compressive strengths were well above the minimum specified strength of 3,600 psi (0.25 kN/cm^2); however, the rail would have performed satisfactorily with the minimum 3,600 psi.

TRUCK CRASH TEST

This bridge rail system was designed to contain and redirect an 80,000-lb tank-type tractor-trailer. A simulated bridge deck with this rail system was built at the TTI proving grounds and tested with a 1980 Kenworth tractor-trailer ballasted with water



EMPTY WEIGHT

Weight on front axle:	Left 5,390	Right 5,200	Total 10,590
Weight on rear axles:	L F 2,040	R F 2,040	Total 4,080
	L R 1,960	R R 1,990	Total 3,950
Total Empty Weight			TOTAL 18,620

FIGURE 6 Tractor dimensions and weight after crash test.

to 80,120 lb (36 352 kg). Drawings showing the dimensions of this vehicle along with loaded and unloaded weights on each axle or pair of axles are shown in Figures 1 and 6. Photographs of the truck before and after the test are presented in Figures 7 and 8.

The truck impacted the rail at 51.4 mph (82.7 km/hr) and an angle of 15 degrees. The impact point was at the upstream edge of post 5, and the truck was smoothly redirected and remained upright. Figure 9 shows the bridge rail and test site immediately after the test. The truck entry and exit path can be seen clearly. The truck sustained damage to the right front and right tandem wheels. The cab of the truck remained intact. The trailer body was dented by the impact with the upper beam but did not rupture. The trailer did, however, sustain a small puncture (1/4 in. in diameter) from the exhaust stack of the truck immediately following impact. A summary of the crash test data is shown in Table 1.

The bridge deck supporting the rail was not significantly damaged. It was determined from the overhead film that the upper beam was deflected a maximum of 4 in. (10 cm) and sustained a permanent deflection of 0.6 in. (2 cm). Sequential photographs of the overhead and frontal views of the crash test are shown in Figure 10.

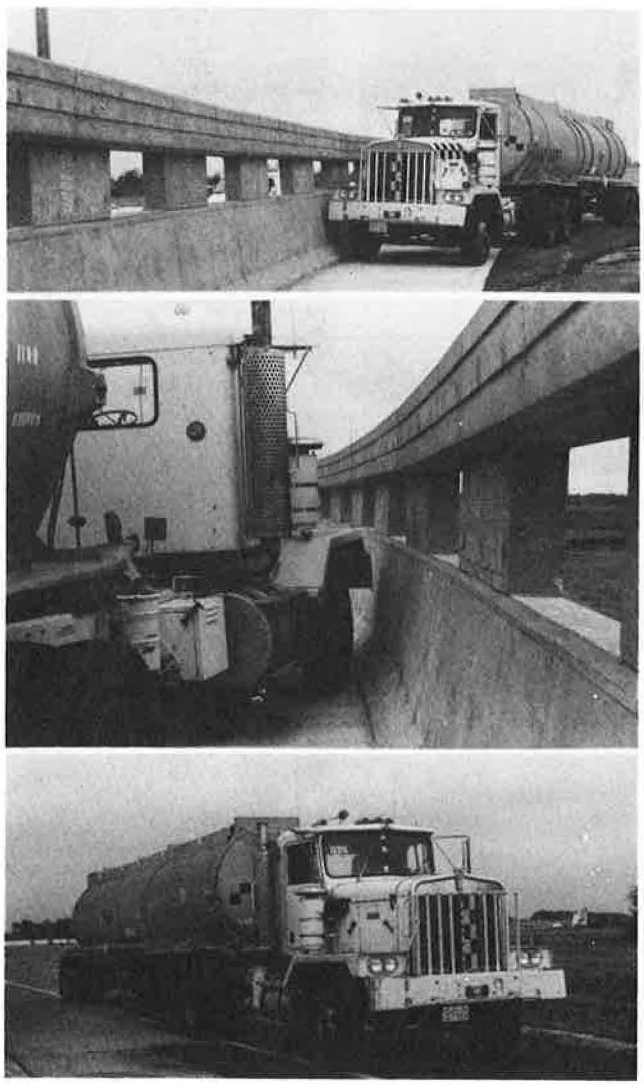


FIGURE 7 Tank truck weighing 80,000 lb before test.

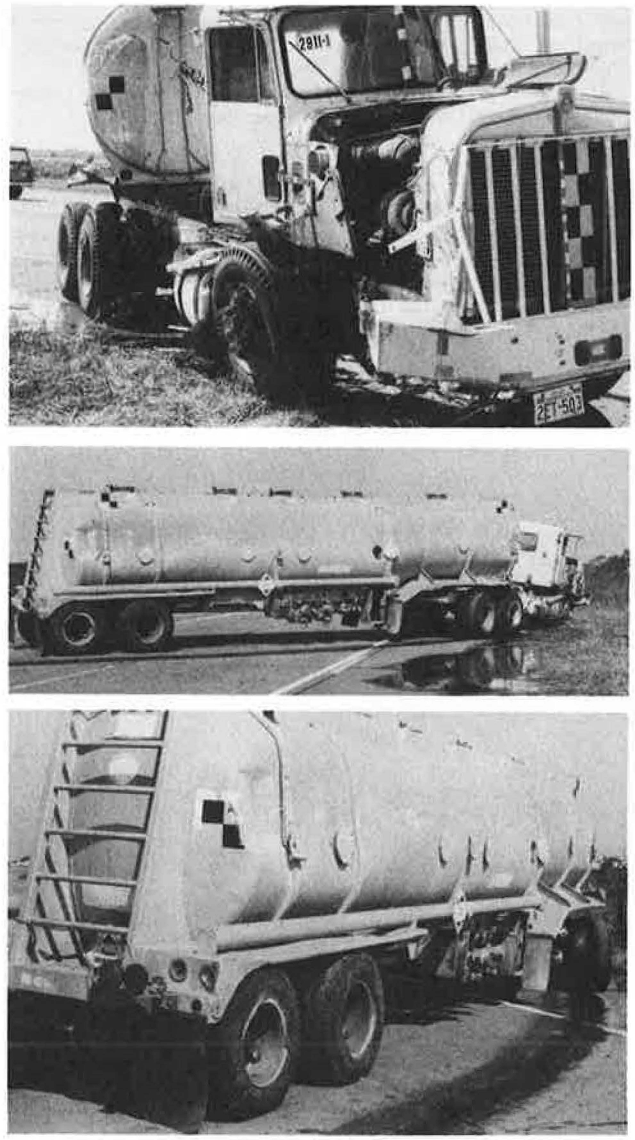


FIGURE 8 Tank truck weighing 80,000 lb after test.

The truck was equipped with roll, pitch, and yaw rate gyroscopes and x, y, and z accelerometers located above the tractor tandem wheels. Graphs of the filtered data from this instrumentation are presented in Figures 11-15.

Other data were gathered on the truck during the test. Maximum positive roll of the tractor tandem axles was 17 degrees from the roll rate gyroscopes and that of the trailer was approximately 15 degrees from the high-speed film. From the accelerometers, the longitudinal and lateral maximum average 0.050-sec accelerations were -1.77 *g* and 5.54 *g*, respectively.

DISCUSSION OF RESULTS

NCHRP Report 230 (6) recommends the following criteria for Test S21 (80,000 lb/50 mph/15 degrees):

1. The test article should smoothly redirect the vehicle; the vehicle should not penetrate or go over the installation;
2. Detached elements, fragments, or other debris

from the test article should not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic; and

3. Vehicle, cargo, and debris should be contained on the traffic side of the barrier.

According to these criteria, the test was a success. The bridge rail contained and smoothly redirected the truck and remained totally intact while doing so.

Impact severity as defined by the occupant flail space approach was also computed from the accelerom-

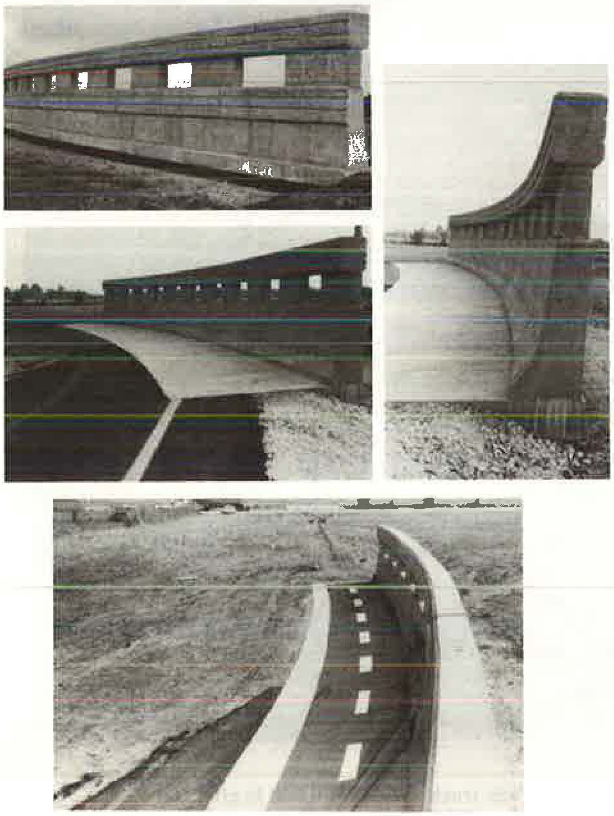


FIGURE 9 Bridge rail before and after test.

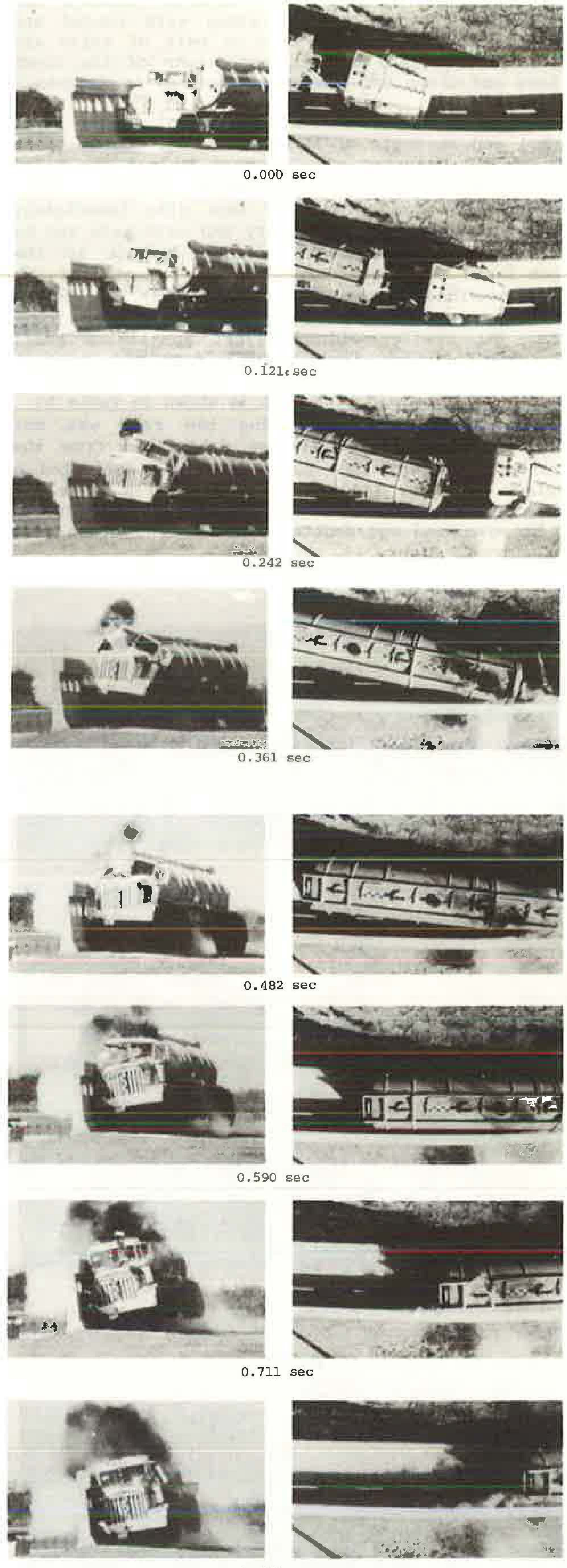


FIGURE 10 Sequential photographs of test.

TABLE 1 Summary and Results of Crash Tests

Test Parameter	Test Results
Vehicle data	
Type	Tractor-trailer (tank type), 1980 Kenworth
Mass (lb)	80,120
Speed (mph)	51.4
Film data	
Angle (degrees)	
Impact	15
Roll, maximum	
Truck	17
Trailer	15
Barrier displacement (in.) (dynamic)	4.0
Accelerometer data (located over tractor tandem axles), 100-Hz lo-pass maximum flat filter	
Maximum avg 0.050-sec acceleration *(g)*	
Longitudinal	-1.77
Lateral	5.54
Peak acceleration *(g)*	
Longitudinal	10.49
Lateral	18.56

Note: 1 lb = 0.45 kg; 1 mph = 1.61 km/hr; 1 in. = 2.5 cm.

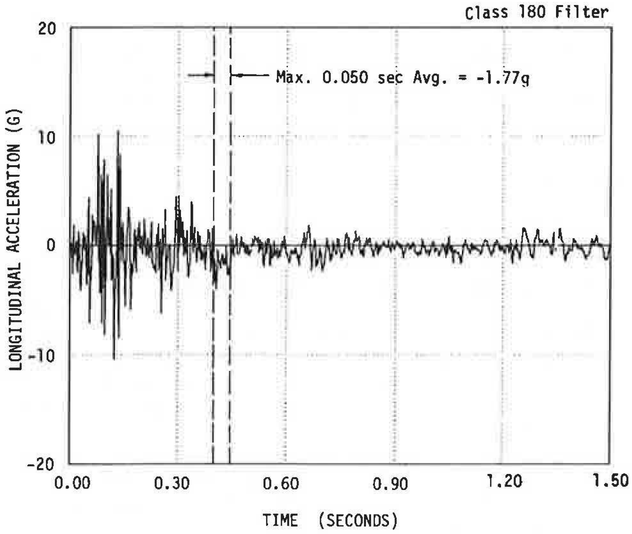


FIGURE 11 Vehicle longitudinal accelerometer trace of test.

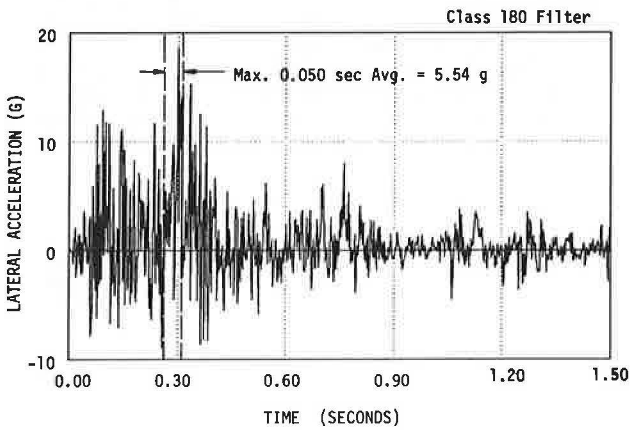


FIGURE 12 Vehicle lateral accelerometer trace of test.

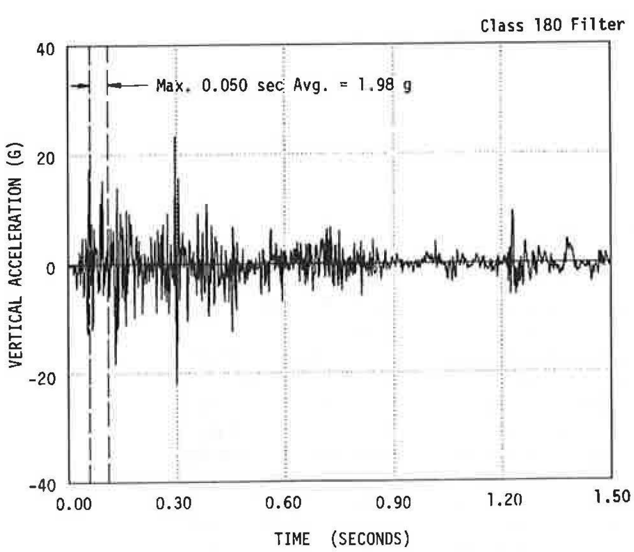


FIGURE 13 Vehicle vertical accelerometer trace of test.

eter data. The recommended threshold values for the flail space evaluation of passenger cars are 40 and 30 ft/sec for the longitudinal and lateral occupant impact velocity, respectively, and 20 g for the highest 10-msec average deceleration after contact. The computed values for this test were well below these recommended values. The longitudinal occupant impact velocity was 7.2 ft/sec, and the highest 10-msec average occupant acceleration after contact was -1.83 g. The lateral occupant impact velocity was 8.03 ft/sec, and the highest 10-msec average acceleration was 11.16 g. Even though these recommended threshold values do not apply to large trucks, they were presented here for comparison purposes.

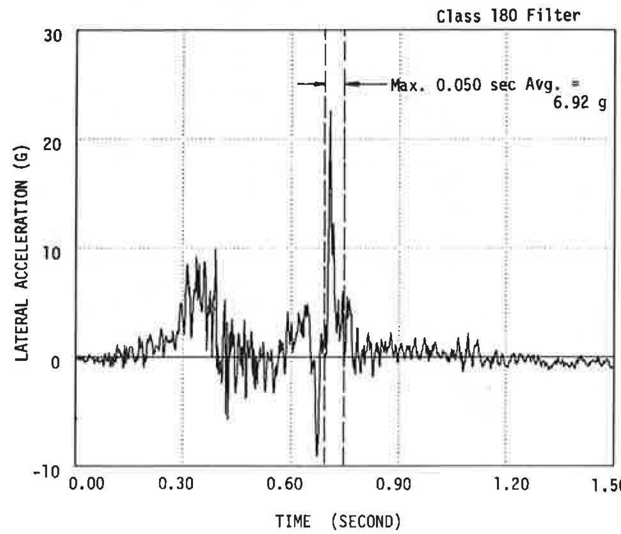


FIGURE 14 Trailer lateral accelerometer trace of test.

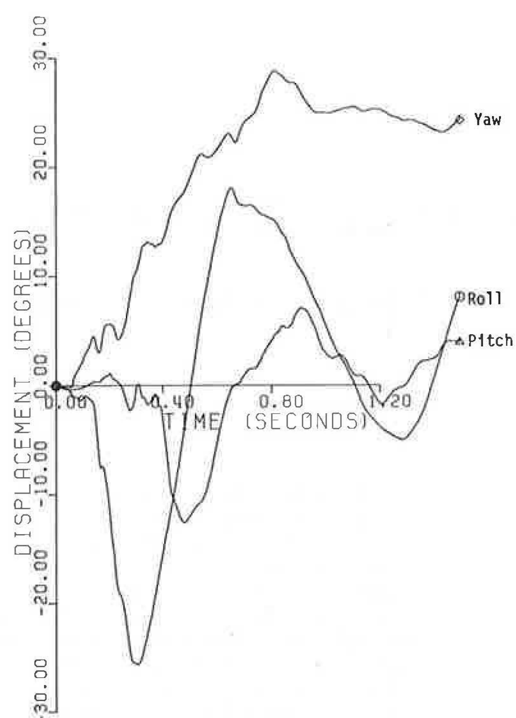


FIGURE 15 Vehicle angular displacement of test.

The upper concrete beam centered at 79.5 in. (202 cm) was designed so that the tank trailer would strike it and be prevented from overturning.

The cross-sectional area of this modified rail is approximately 7.6 ft^2 (0.7 m^2) as compared with approximately 2.6 ft^2 (0.2 m^2) for a standard Texas Type T5 traffic rail. The approximate cost of this modified rail would be about $125 per linear foot, whereas a standard Texas Type T5 traffic rail normally costs about $35 per linear foot.

SUMMARY AND CONCLUSIONS

A standard Texas Type T5 traffic rail concrete safety shape was modified by increasing its height and strength so that it could restrain and redirect an 80,000-lb tank-type truck or tractor-trailer. The height of the concrete parapet was increased to 48 in. A concrete beam element 16 in. wide and 21 in. deep was mounted on concrete posts on top of the concrete parapet to achieve a total rail height of 90 in. The concrete posts were 8 in. thick, 5 ft long, and 21 in. (53 cm) high with 5-ft (1.5-m) openings between the posts. The rail was constructed vertically on a 14-degree curve with the deck superelevated 0.055 ft/ft.

The crash test was conducted on this bridge rail with an 80,120-lb tank-type tractor-trailer impacting the rail at 51.4 mph and at an impact angle of 15 degrees. The vehicle was smoothly redirected.

This test has shown that a bridge rail can be built on a slightly modified Texas standard bridge deck to contain large tank-type tractor-trailer trucks and redirect them without rollover.

ACKNOWLEDGMENT

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REFERENCES

1. T.J. Hirsch and A. Arnold. Bridge Rail to Restrain and Redirect 80,000 lb Trucks. Research Report 230-4F. Texas Transportation Institute, Texas A&M University, College Station, Nov. 1981.
2. T.J. Hirsch. 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.
3. T.J. Hirsch. Bridge Rail to Restrain and Redirect Buses. Research Report 230-3. Texas Transportation Institute, Texas A&M University, College Station, Feb. 1981.
4. J.S. Noel, C.E. Buth, and T.J. Hirsch. Loads on Bridge Railings. In Transportation Research Record 796, TRB, National Research Council, Washington, D.C., 1981, pp. 31-35.
5. T.J. Hirsch, J.J. Panak, and C.E. Buth. Tubular W-Beam Bridge Rail. Research Report 230-1. Texas Transportation Institute, Texas A&M University, College Station, Oct. 1978.
6. J.D. Michie. Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances. NCHRP Report 230. TRB, National Research Council, Washington, D.C., March 1981.

Roadside Barriers for Bridge-Pier Protection

JAMES E. BRYDEN and RICHARD G. PHILLIPS

ABSTRACT

Seven full-scale crash tests were conducted to evaluate a concrete bridge-pier protection barrier. This barrier consists of four concrete half-section safety-shape barriers placed in front of the pier and flaring back from the pavement edge. The end of the concrete barrier is protected by a 6 by 6-in. box-beam guiderail bolted to the concrete. The barrier was impacted at various points with either 1,800- or 4,500-lb sedans at 15 and 25 degrees and a speed of about 60 mph. The original design caused vehicles to roll over when the concrete barrier was impacted at 25 degrees near the first bridge pier. The design was modified by extending the box beam across the face of the barrier directly in front of the piers. This eliminated the rollover problem and strengthened the barrier, resulting in performance in compliance with the standards in NCHRP Report 230.