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TEXAS
TRANSPORTATION
INSTITUTE

STATE DEPARTMENT
OF HIGHWAYS AND
PUBLIC TRANSPORTATION

COOPERATIVE
RESEARCH

BRIDGE RAIL TO CONTAIN AND REDIRECT 80,000 LB TANK TRUCKS

in cooperation with the
Department of Transportation
Federal Highway Administration

RESEARCH REPORT 911-1F
STUDY 2-15D-83-911
BRIDGE RAIL

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16. Abstract

A standard Texas type T5 traffic rail was modified to increase its height and strength to contain and redirect an 80,000 lb (36,300 kg) tank-type tractor-trailer at 50 mph (80.5 km/h), 15^{o} impacts. The concrete parapet was increased to 48 in. (122 cm) high, and a concrete beam was mounted on concrete posts on 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 (80.5 km/h) and 15^{o} 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.

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BRIDGE RAIL TO CONTAIN AND REDIRECT 80,000 LB TANK TRUCKS

by

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Research Report 911-1F

on

Research Study No. 2-15D-83-911
Design and Crash Test of Bridge Rail to Contain 80,000 Tank Trucks

Sponsored by

District 15 (San Antonio) of the
Texas State Department of Highways and Public Transportation

in cooperation with the

U.S. Department of Transportation

January 1984

Texas Transportation Institute
Texas A&M University
College Station, Texas

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

KEY WORDS

Bridge Rails, Traffic Barriers, Highway Safety, Trucks, Heavy Vehicles

ACKNOWLEDGMENTS

This research study was conducted under a cooperative program between the Texas Transportation Institute (TTI), the Texas State Department of Highways and Public Transportation (TSDHPT), and the Federal Highway Administration (FHWA). Mr. Raymond Stotzer, District Engineer in San Antonio, Texas, and Mr. Frank Holzman, District Supervising Designing Engineer in San Antonio, Texas, initiated and were involved in all phases of this study. Mr. Robert L. Reed, Engineer of Bridge Design, TSDHPT, and Mr. John J. Panak, Supervising Designing Engineer, TSDHPT, were also closely involved in all phases of this study.

IMPLEMENTATION STATEMENT

As of the writing of this report none of the findings or conclusions presented have been implemented.

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INTRODUCTION

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 as well understood or researched as those involved in the design of passenger car rails. Therefore, it was the objective of this project to design, build, and test a bridge rail to contain and redirect an 80,000 lb (36,287 kg) tank-type tractor-trailer, as shown in Figure 5. The design was based on data presented in References (1), (2), (3), (4), and (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 90 in. (229 cm) high on concrete posts on top of the parapet. The concrete posts are 8 in. (20 cm) thick by 5 ft (1.5 m) long concrete walls located at 10 ft (3 m) center-to-center spacing. This produces 5 ft (1.5 m) openings 21 in. (53 cm) high. The beam element contains a large amount of reinforcing steel, providing both flexibility and strength, thus minimizing 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, giving good structural continuity and strength. The thickness of the bridge deck below the concrete parapet was increased to 12 in. (4.7 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-trailer vehicles occur when the tandem axles of the tractor and the front of the trailer impact the bridge railing. 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 had an even smaller impact with the traffic rails tested in the past. Knowing that the total loaded weight on the tandem axles of the tractor would be approximately 34,000 lb (15,436 kg) (see Fig. 5), it was assumed that 10,000 lb (4540 kg) of this load (empty load) would probably be transferred to the rail through the wheels and the axles. The remaining 24,000 lb (10,896 kg) (pay load) would be transferred to the rail through the tank 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's. Therefore, equivalent static design forces of 60,000 lb (27,240 kg) (10,000 lb x 6 g's) applied at a height of 21 in. (53 cm) and 144,000 lb (65,376 kg) (24,000 lb x 6 g's) applied at a height of 84 in. (213 cm) were used to design the rail using yield line theory for reinforced concrete. These procedures are outlined in Research Report 230-2, "Analytical Evaluation of Texas Bridge Rails to Contain Buses and Trucks" (2).

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*Underscored numerals in parentheses refer to corresponding items in the references.

DESCRIPTION OF THE BRIDGE RAIL AND DECK MODIFICATIONS

The modified T5 rail has a 16 in. (41 cm) thick, 21 in. (53 cm) tall concrete beam mounted on top. This modified bridge rail makes a combination bridge rail 90 in. (229 cm) tall suitable to retain large 80,000 lb (36,287 kg) tank-type trucks or tractor-trailers impacting at 15° and 50 mph (80.5 km/h). Drawings of this rail are shown in Figures 1, 2, and 3. Figure 4 contains photographs comparing the size of this bridge rail with a 1979 Ford Thunderbird and the tank-type tractor-trailer. The bridge rail was constructed on a 14° curve, and the deck had a superelevation of 0.055 ft per ft (0.055 m per 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 which was heightened to 48 in. (122 cm) 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 #6 stirrups spaced at 8 in. (20 cm) as shown, and ten #8 longitudinal bars were used.

The concrete post was 21 in. (53 cm) high, 8 in. (20 cm) thick and 60 in. (152 cm) long with a 60 in. (152 cm) open space between each post. Each concrete post was anchored to the concrete rail by means of sixteen #7 bars (eight traffic side and eight field side).

The concrete beam on top of the posts was 16 in. (41 cm) thick and 21 in. (53 cm) high for the entire length of the rail. It contained #3 closed stirrups spaced at 8 in. (20 cm) center-to-center and ten #8 longitudinal bars.

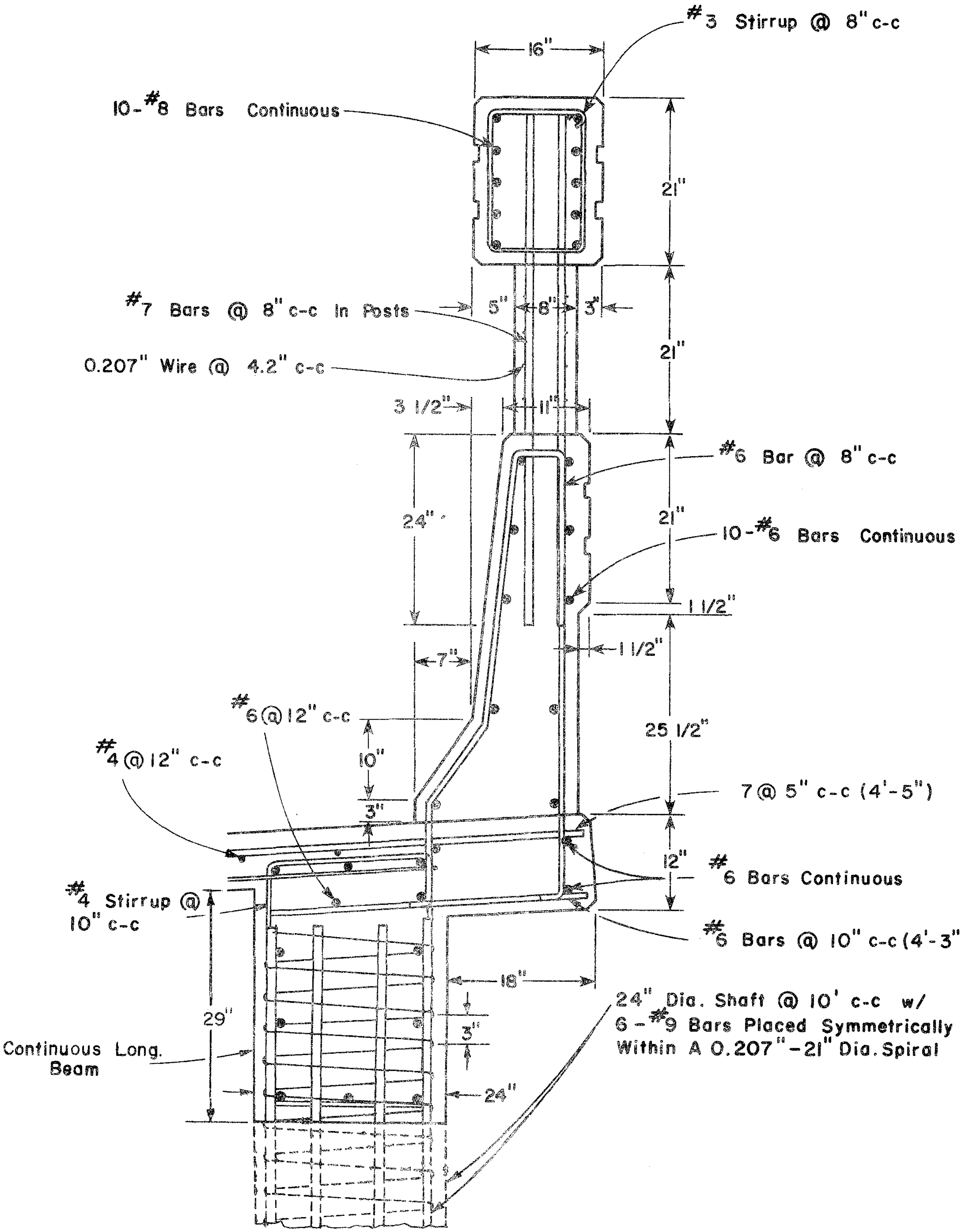


Figure 1. Cross Section of the Modified T5 Bridge Rail and Modified Bridge Deck.

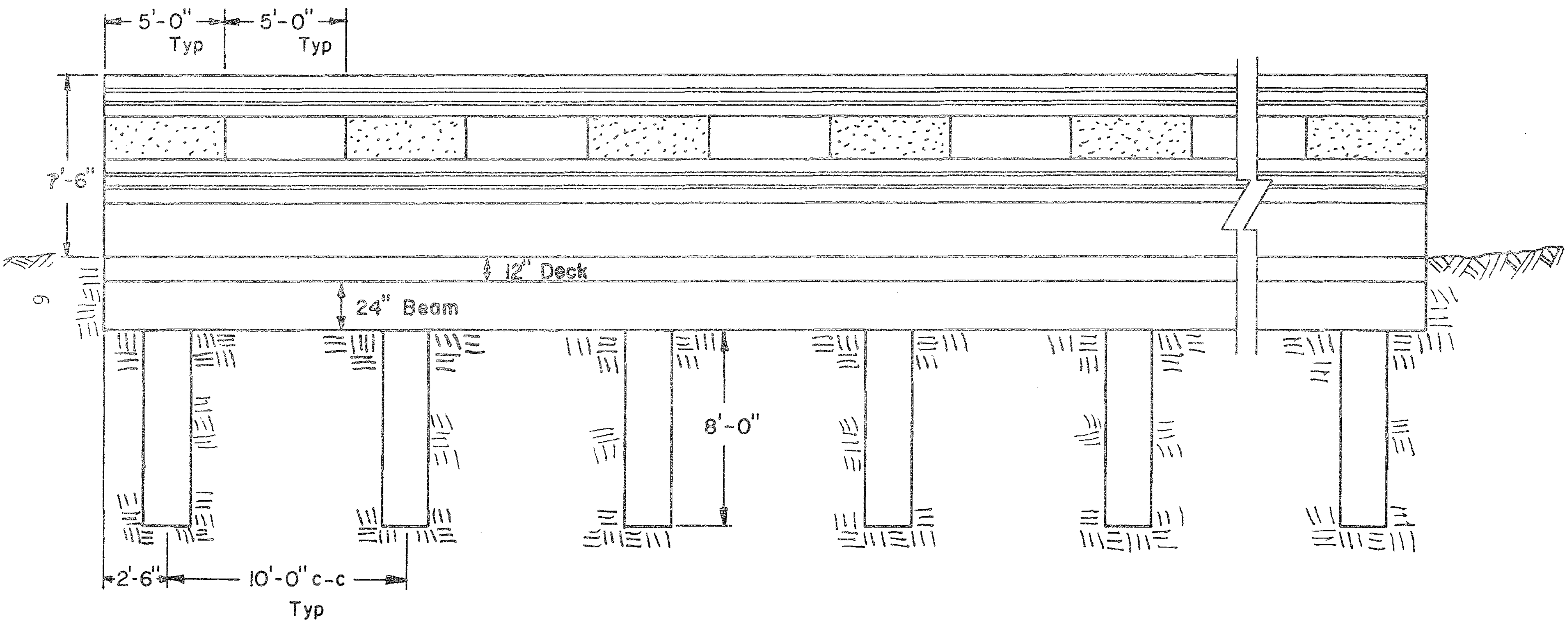


Figure 2. Elevation (from field side) of the Modified T5 Bridge Rail.

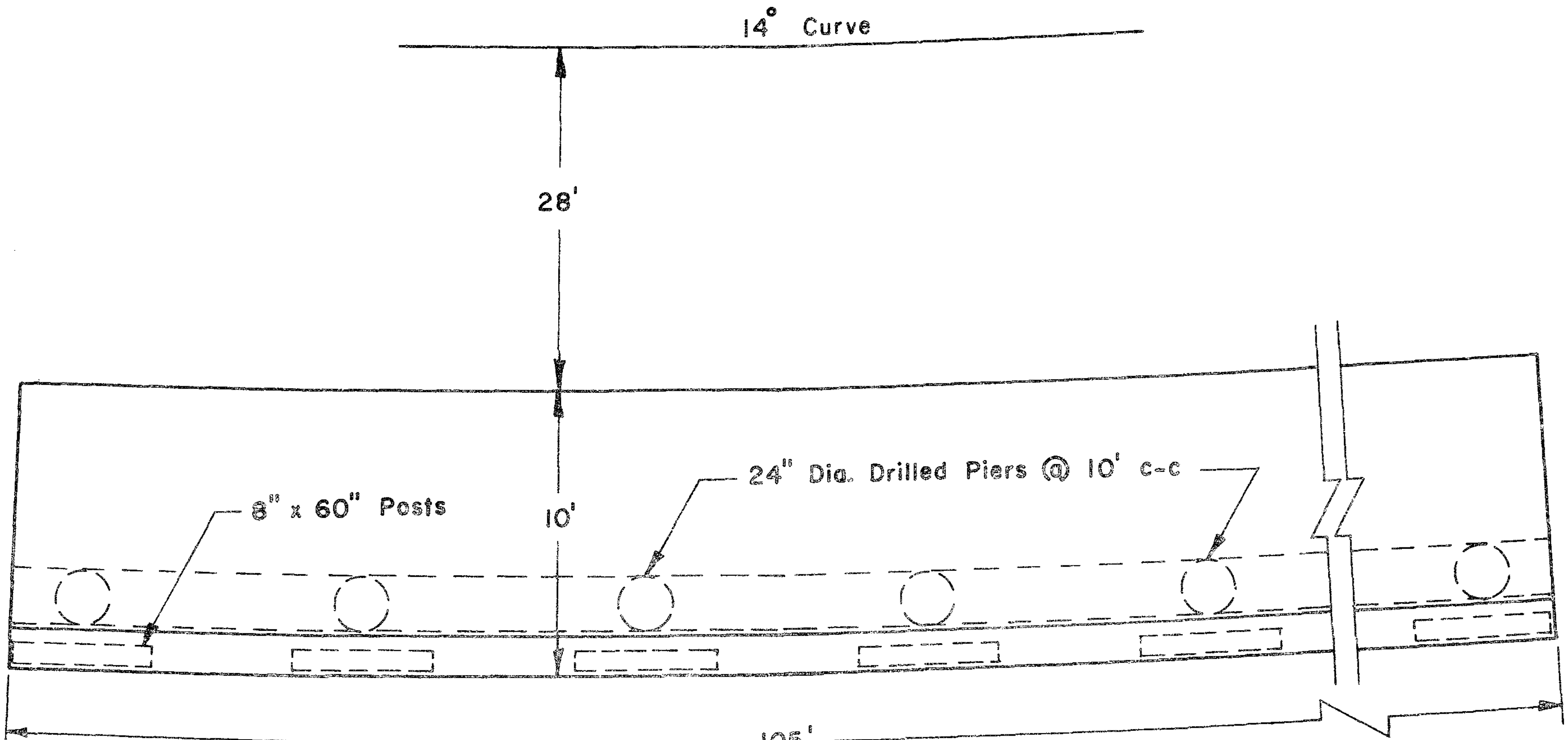


Figure 3. Plan View of Modified T5 Bridge Rail, Modified Bridge Deck, and Pier System.

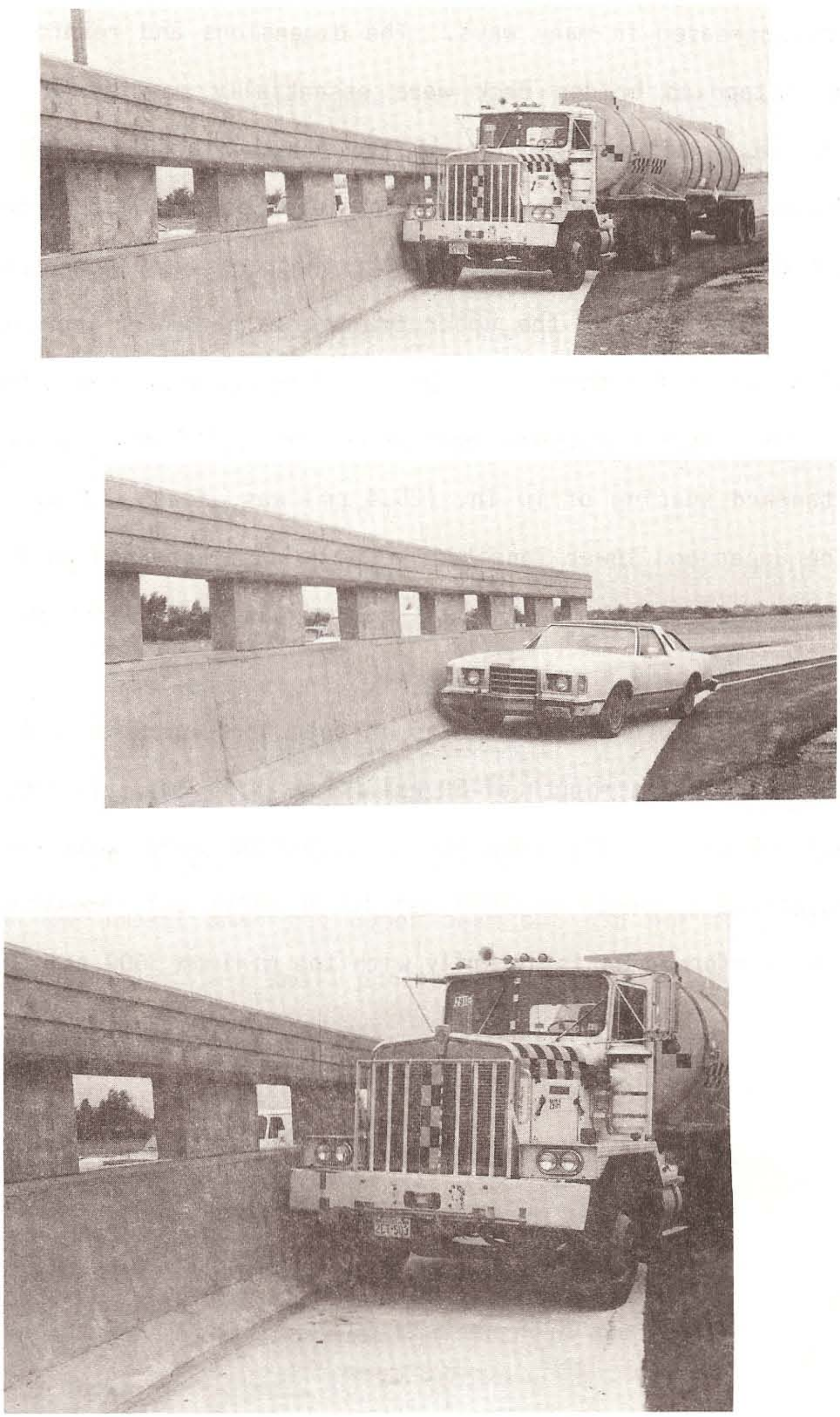


Figure 4. Comparison of Thunderbird and 80,000 lb Tank Truck with Modified Rail

The strength of the Texas standard 7 in. (18 cm) thick bridge deck 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 1. The length of the cantilever portion was decreased from 30 in. (76 cm) to 18 in. (46 cm), and the thickness was increased to 12 in. (30.5 cm). The size of the upper transverse bars was increased from #5's to #7's, while the standard 5 in. (12.7 cm) spacing was retained. The size of the lower transverse bars was increased from #4's to #6's, while the standard spacing of 10 in. (25.4 cm) was, again, retained. The size of the upper and lower longitudinal bars was increased to #6's from #4's and #5's, respectively, while the spacing was increased from 12 in. (30.5 cm) 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/sq cm). It should be noted that all of the 28-day compressive strengths were well above the minimum specified strength of 3600 psi (0.25 kN/sq cm), however, the rail would have performed satisfactorily with the minimum 3600 psi (0.25 kN/sq cm).

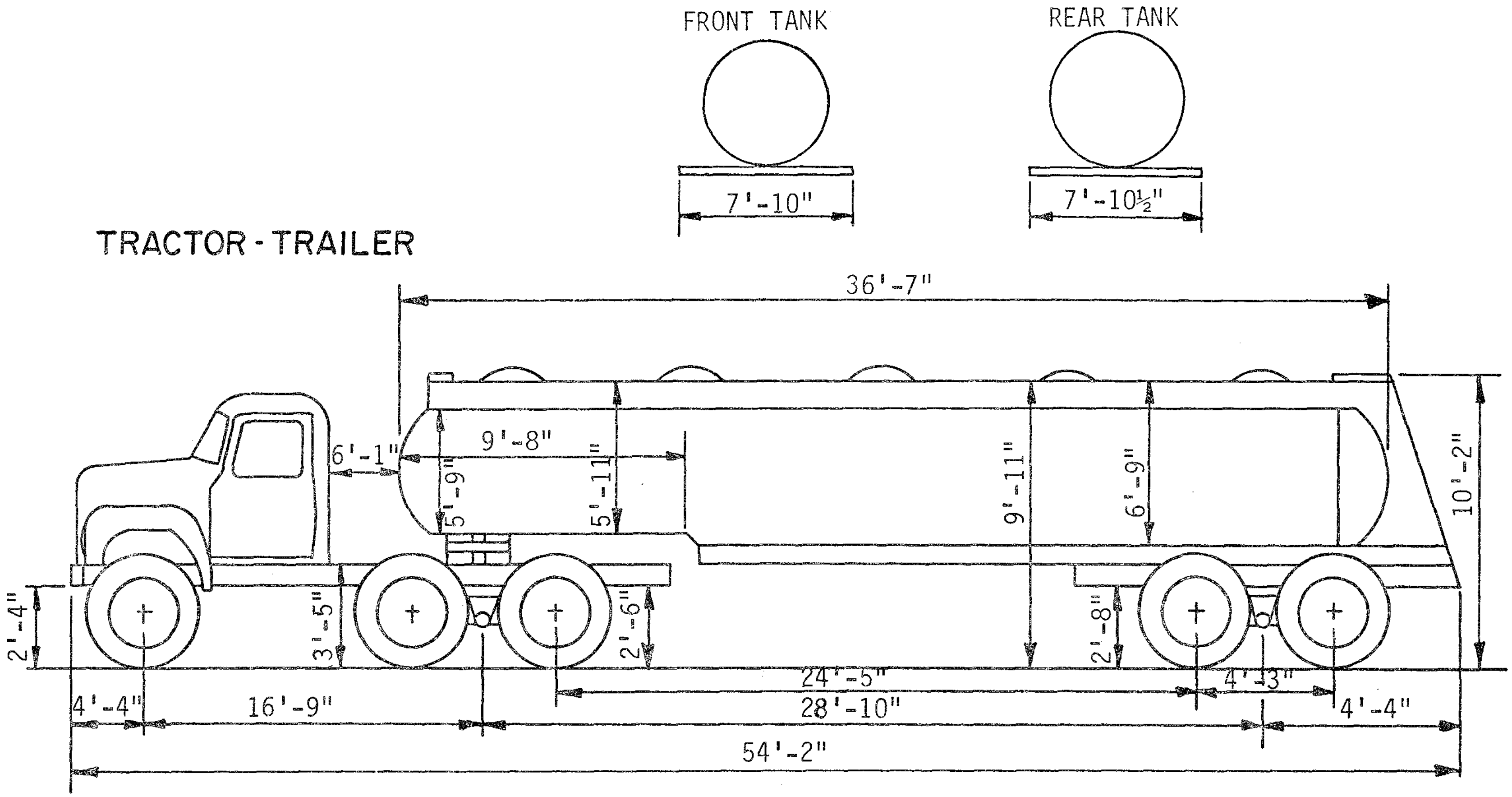
TRUCK CRASH TEST

This bridge rail system was designed to contain and redirect an 80,000 lb (36,287 kg) tank-type tractor-trailer. A simulated bridge deck with this rail system was built at the Texas Transportation Institute Proving Grounds and tested with a 1980 Kenworth tractor-trailer ballasted with water to 80,120 lbs (36,384 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 5 and 6. Before and after test photographs of the truck are presented in Figures 7 and 8.

The truck impacted the rail at 51.4 mph (82.7 km/h) and 15° angle. 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. dia.) 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 showing the overhead and frontal view of the crash test are shown in Appendix A.

The truck was equipped with roll, pitch, and yaw rate gyros and x, y, and z accelerometers located above the tractor tandem wheels. Graphs of



EMPTY WEIGHTS

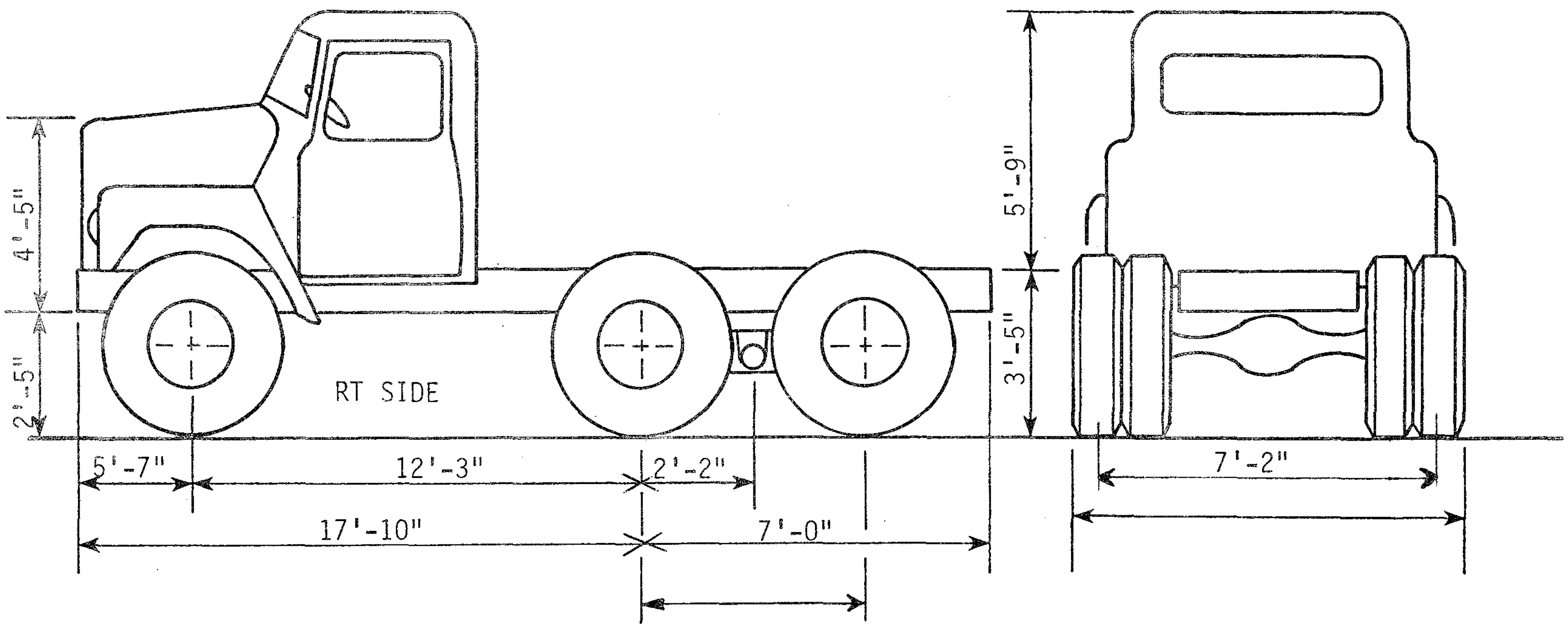
Weight on front axle	10,590
Weight on center axles	8,030
Weight on rear axles	9,700
Total Empty Weight	28,320

LOADED WEIGHTS

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

Figure 5. Tractor-Trailor Loaded Dimensions, Empty Weights, and Loaded Weights.

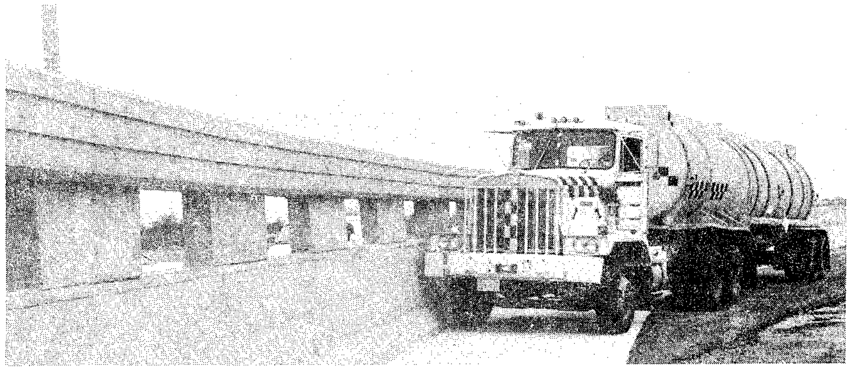
TRACTOR



EMPTY WEIGHTS

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 Weights			TOTAL 18,620

Figure 6. Empty Tractor Dimensions and Weights.



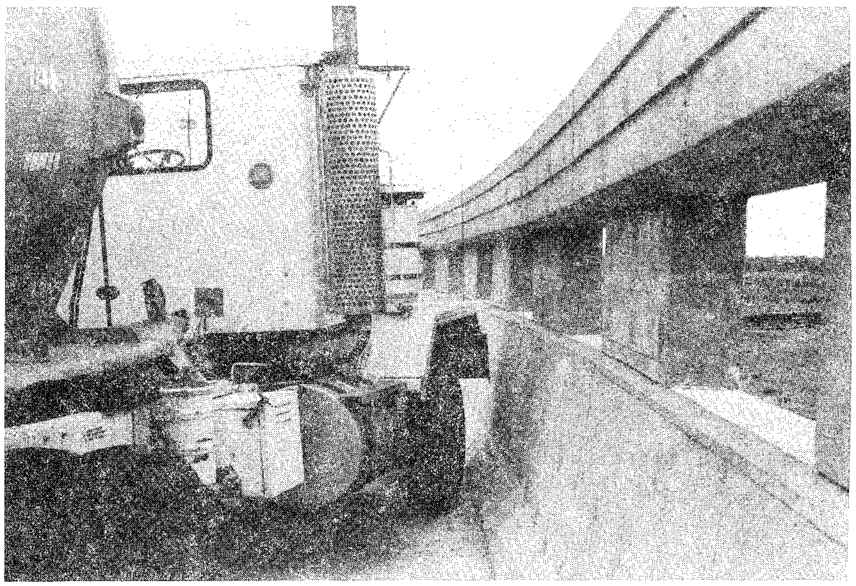


Figure 7. 80,000 lb Tank Truck before Test

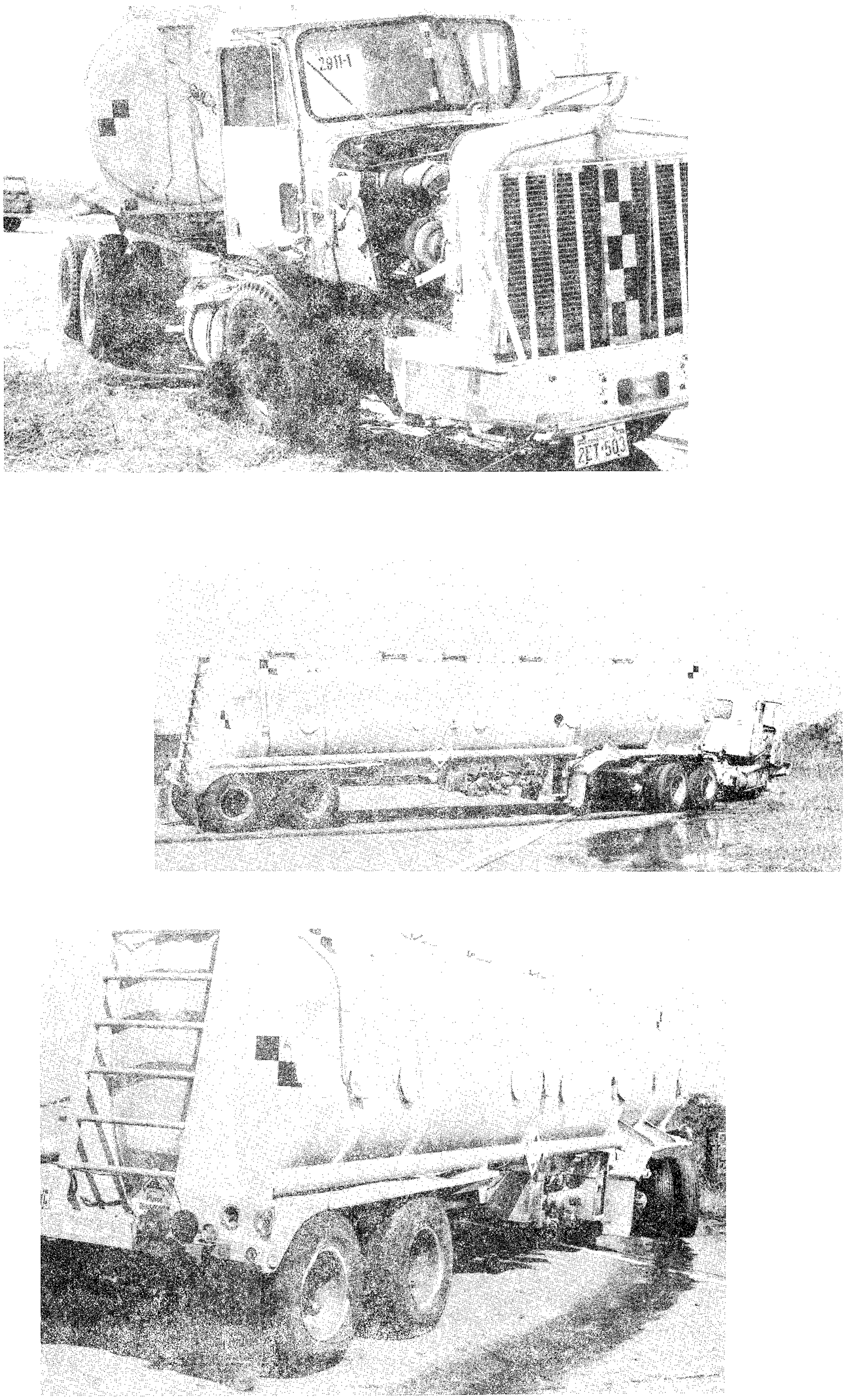


Figure 8. 80,000 lb Tank Truck after Test

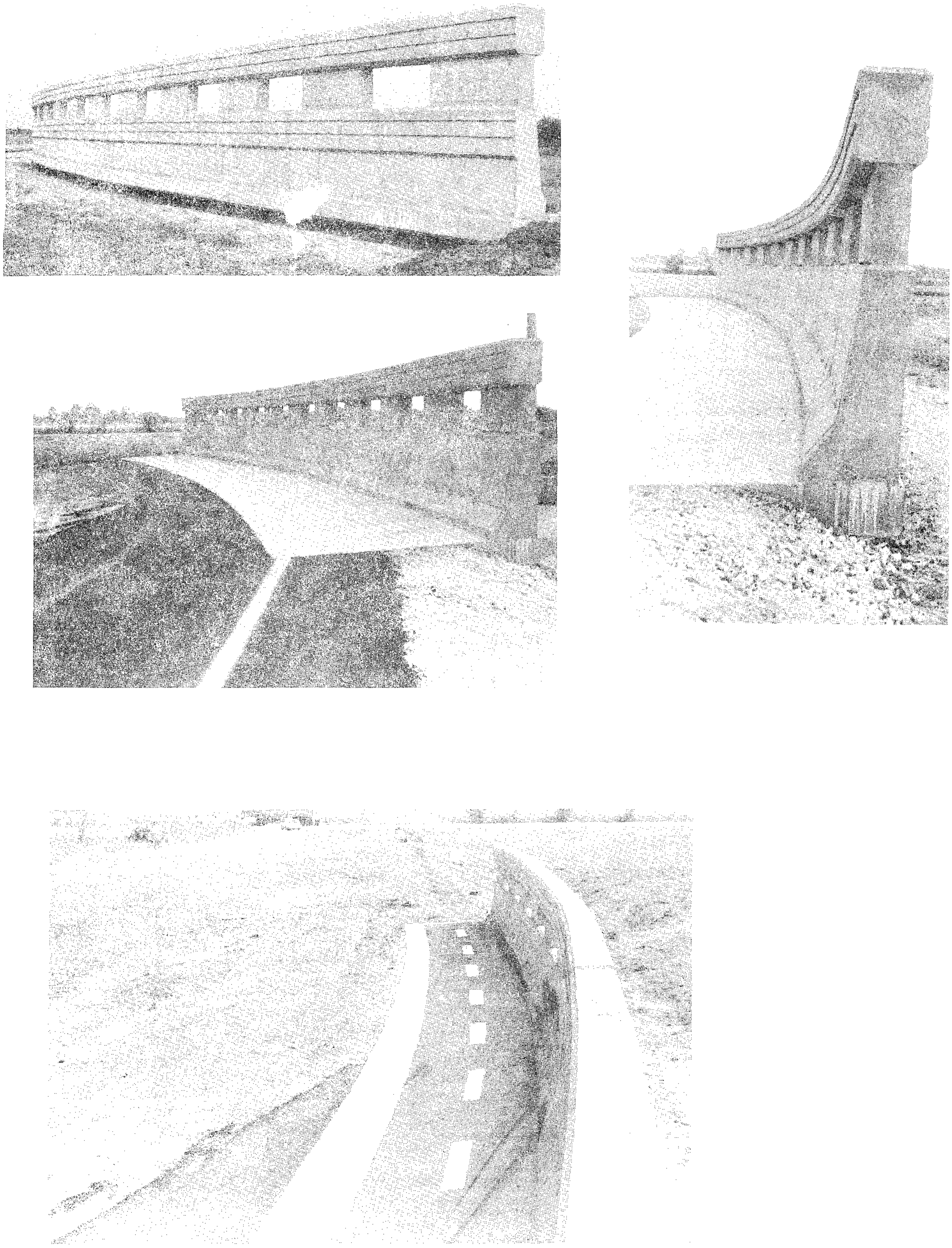


Figure 9. Bridge Rail Before and After Test

Table 1. Summary and Results of Crash Tests.

TEST NUMBER	1
VEHICLE DATA	Tractor-Trailer (Tank Type) 1980 Kenworth
MASS - kg (lb)	36,384 (80,120)
SPEED - km/hr (mph)	82.7 (51.4)
FILM DATA	
Angle - degrees	
Impact	15^{o}
Roll, max.	
Truck	17^{o}
Trailer	15^{o}
Barrier Displacement - cm (in.) (dynamic)	10.2 (4.0)
ACCELEROMETER DATA (located over tractor tandem axles)	
100 hz lo-pass max. flat filter	
Max. Avg. 0.050 Sec Acceleration	
Longitudinal, g's	-1.77
Lateral, g's	5.54
Peak Acceleration	
Longitudinal, g's	10.49
Lateral, g's	18.56

the filtered data from this instrumentation are presented in Appendix B.

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

DISCUSSION OF RESULTS

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

1. "Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation."

2. "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."

3. Vehicle, cargo, and debris shall be contained on traffic side of 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 accelerometer data. The recommended threshold values for the flail space evaluation of passenger cars are 40 fps and 30 fps, respectively, for the longitudinal and lateral occupant impact velocity, and 20 g's 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 fps, and the highest 10 msec average occupant acceleration after contact was -1.83 g's. The lateral occupant impact velocity was 8.03 fps, and the highest 10 msec average acceleration was 11.16 g's. Even though these recommended threshold values do not apply to large trucks, they were presented here for comparison purposes only.

The design intent of the upper concrete beam centered at 79.5 in. (202 cm) was to allow the tank trailer to strike this beam and thus provide a resistance to overturning by the trailer.

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

SUMMARY AND CONCLUSIONS

A standard Texas traffic rail type T5 concrete safety shape was modified by increasing its height and strength so that it could restrain and redirect an 80,000 lb (36,287 kg) tank-type truck or tractor-trailer. The concrete parapet was increased to 48 in. (122 cm) high. A concrete beam element 16 in. (41 cm) wide and 21 in. (53 cm) deep was mounted on concrete posts on top of the concrete parapet to achieve a total rail height of 90 in. (229 cm). The concrete posts were 8 in. (20 cm) thick, 5 ft (1.5 m) long and 21 in. (53 cm) high with 5 ft (1.5 m) openings between each post. The rail was constructed vertically on a 14° curve with the deck superelevated 0.055 ft per ft (0.055 m per m).

The crash test was conducted on this bridge rail with an 80,120 lb (36,384 kg) tank-type tractor-trailer impacting the rail at 51.4 mph (82.7 km/h) and at an impact angle of 15°. 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.

REFERENCES

1. Hirsch, T. J. and Arnold, A., "Bridge Rail to Restrain and Redirect 80,000 lb Trucks," Research Report 230-4F, Texas Transportation Institute, Texas A&M University, Nov. 1981.
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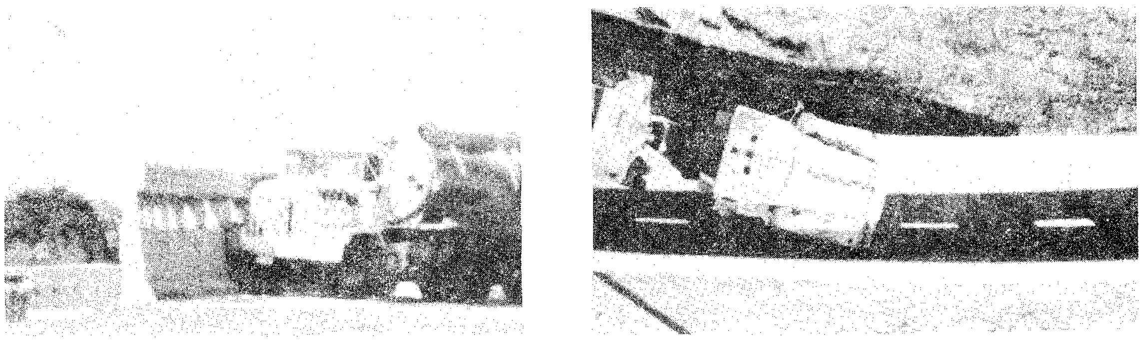
3. Hirsch, T. J., "Bridge Rail to Restrain and Redirect Buses," Research Report 230-3, Texas Transportation Institute, Texas A&M University, Feb. 1981.
4. Noel, J. S., Buth, C. E., and Hirsch, T. J., "Loads on Bridge Railings," Transportation Research Record No. 796, 1981.
5. Hirsch, T. J., Panak, J. J., and Buth, C. E., "Tubular W-Beam Bridge Rail," Research Report 230-1, Texas Transportation Institute, Texas A&M University, Oct. 1978.
6. Michie, Jarvis D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230, Transportation Research Board, National Research Council, Washington, D.C., Mar. 1981.

APPENDIX A

SEQUENTIAL PHOTOGRAPHS OF CRASH TEST



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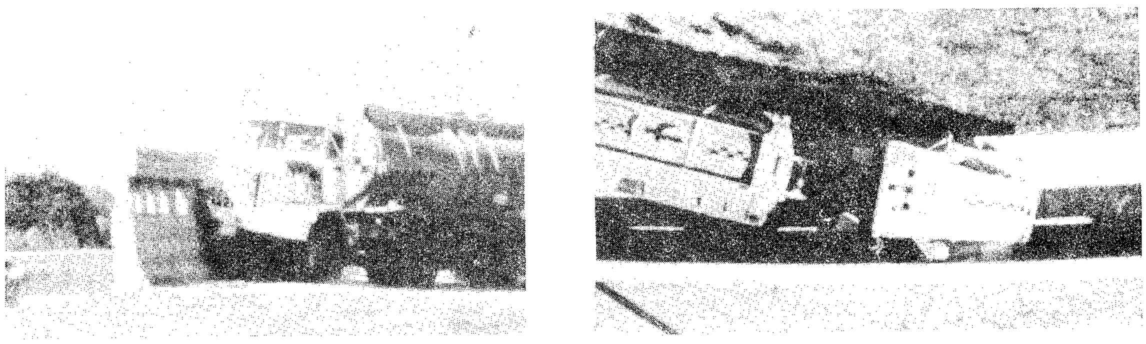

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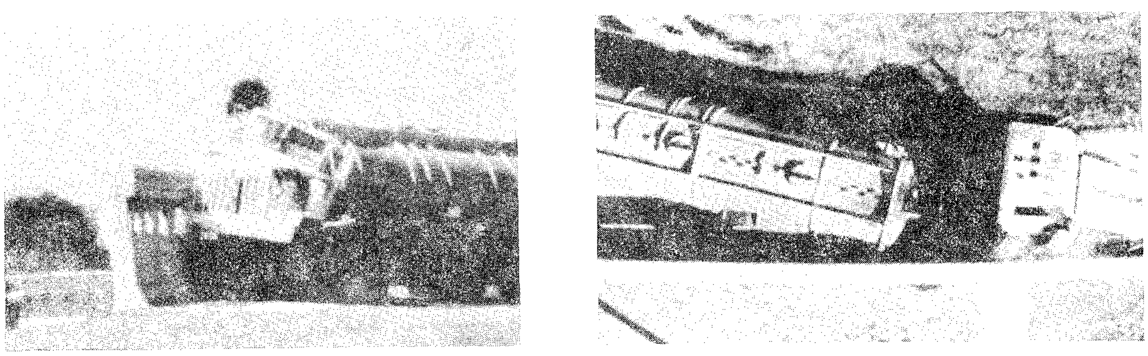

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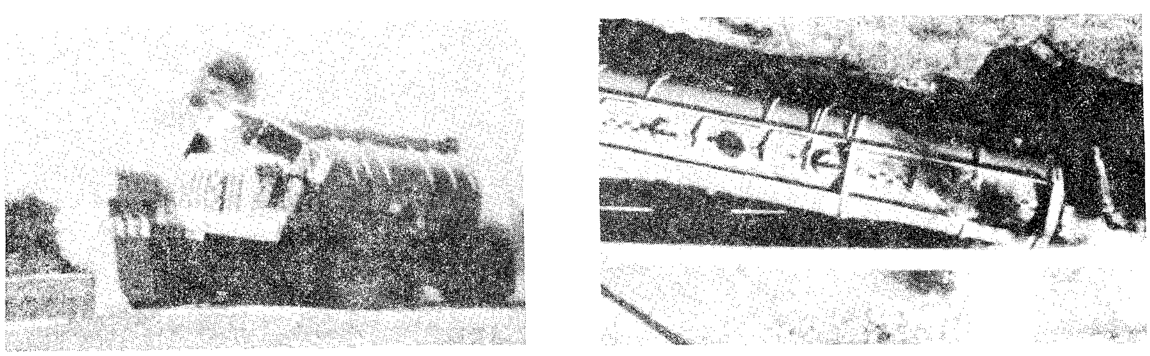

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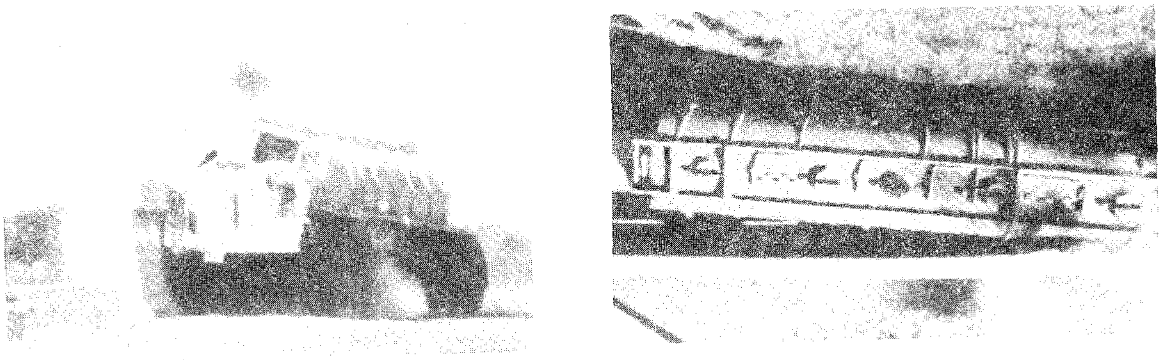
Figure A1. Sequential Photographs for Test 2911-1.



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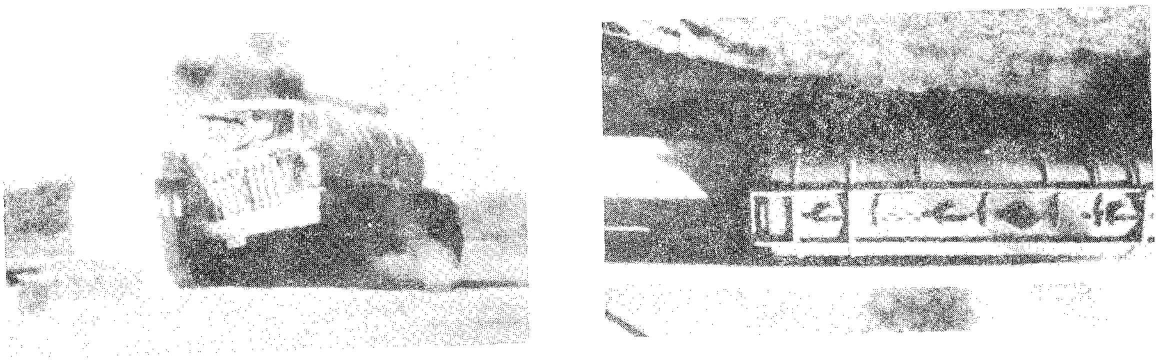

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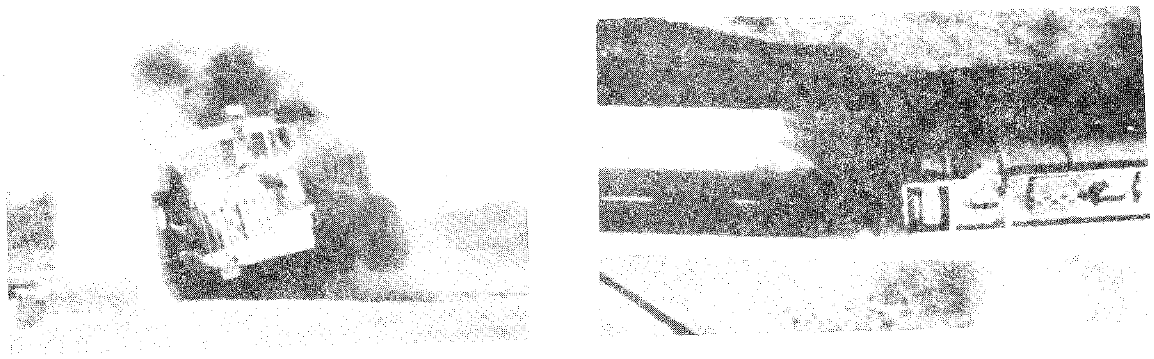

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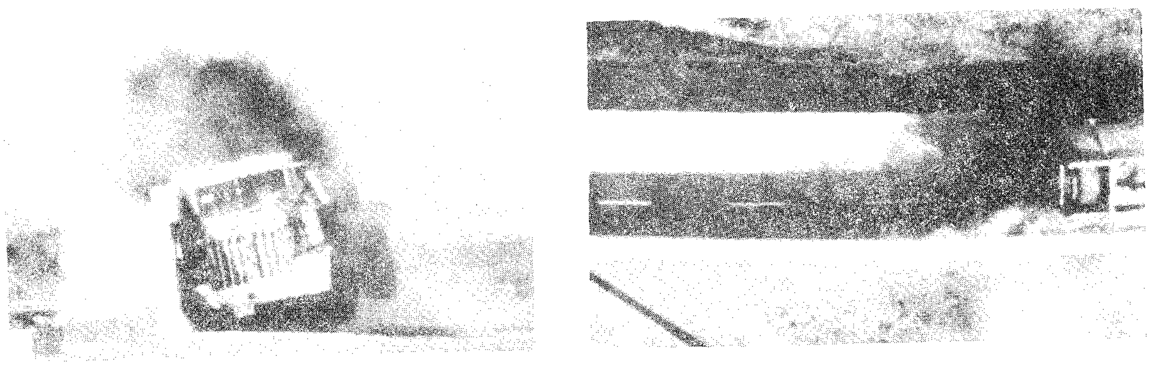

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Figure A1. Sequential Photographs for Test 2911-1. (Continued)

APPENDIX B

ACCELEROMETER ROLL, PITCH,

AND YAW DATA

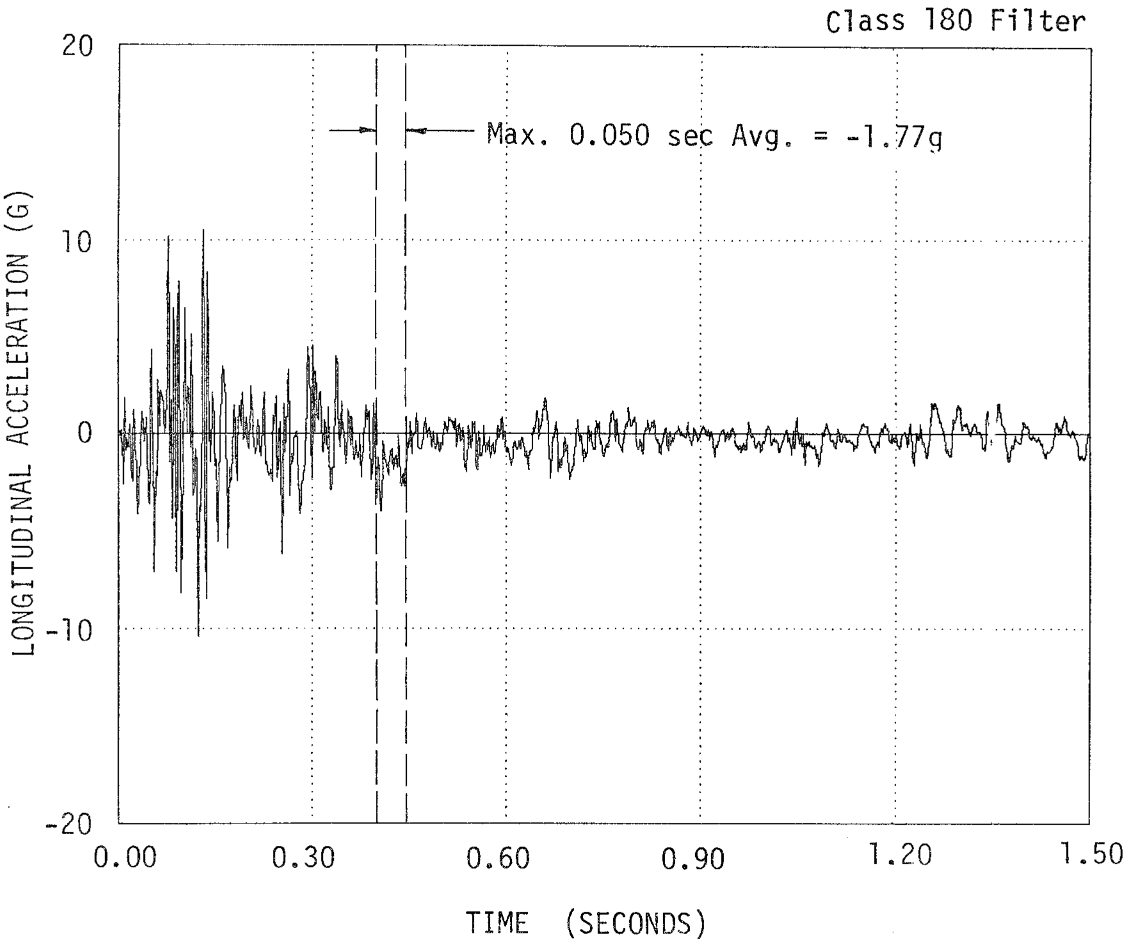


Figure B1. Vehicle Longitudinal Accelerometer Trace for Test 2911-1.

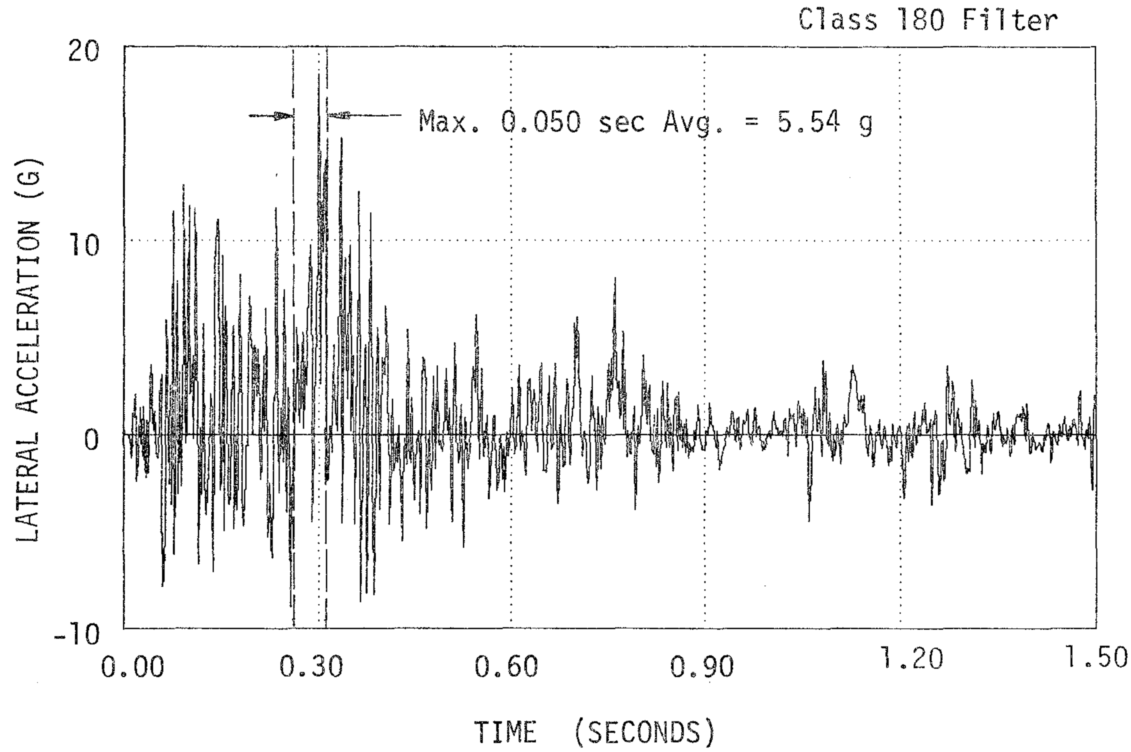


Figure B2. Vehicle Lateral Accelerometer Trace for Test 2911-1.

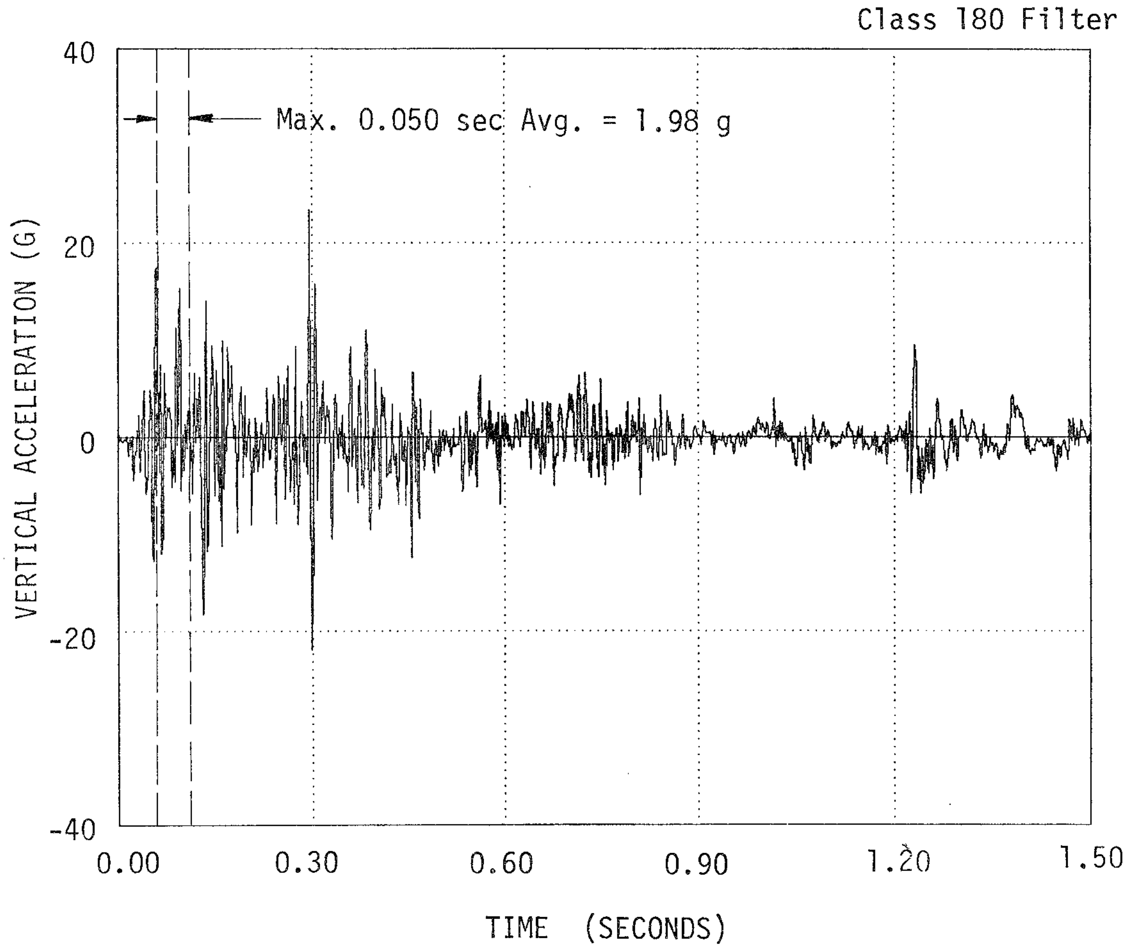


Figure B3. Vehicle Vertical Accelerometer Trace for Test 2911-1.

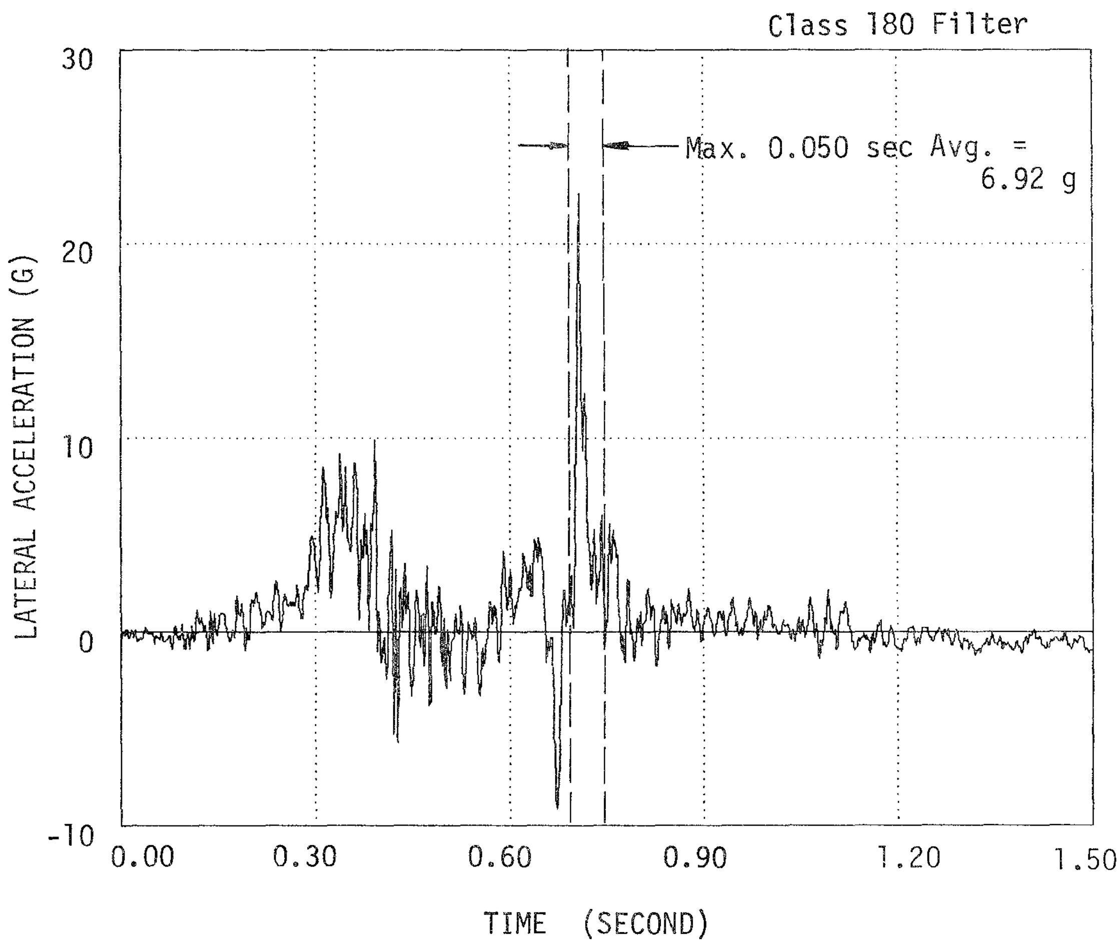


Figure B4. Trailer Lateral Accelerometer Trace for Test 2911-1.

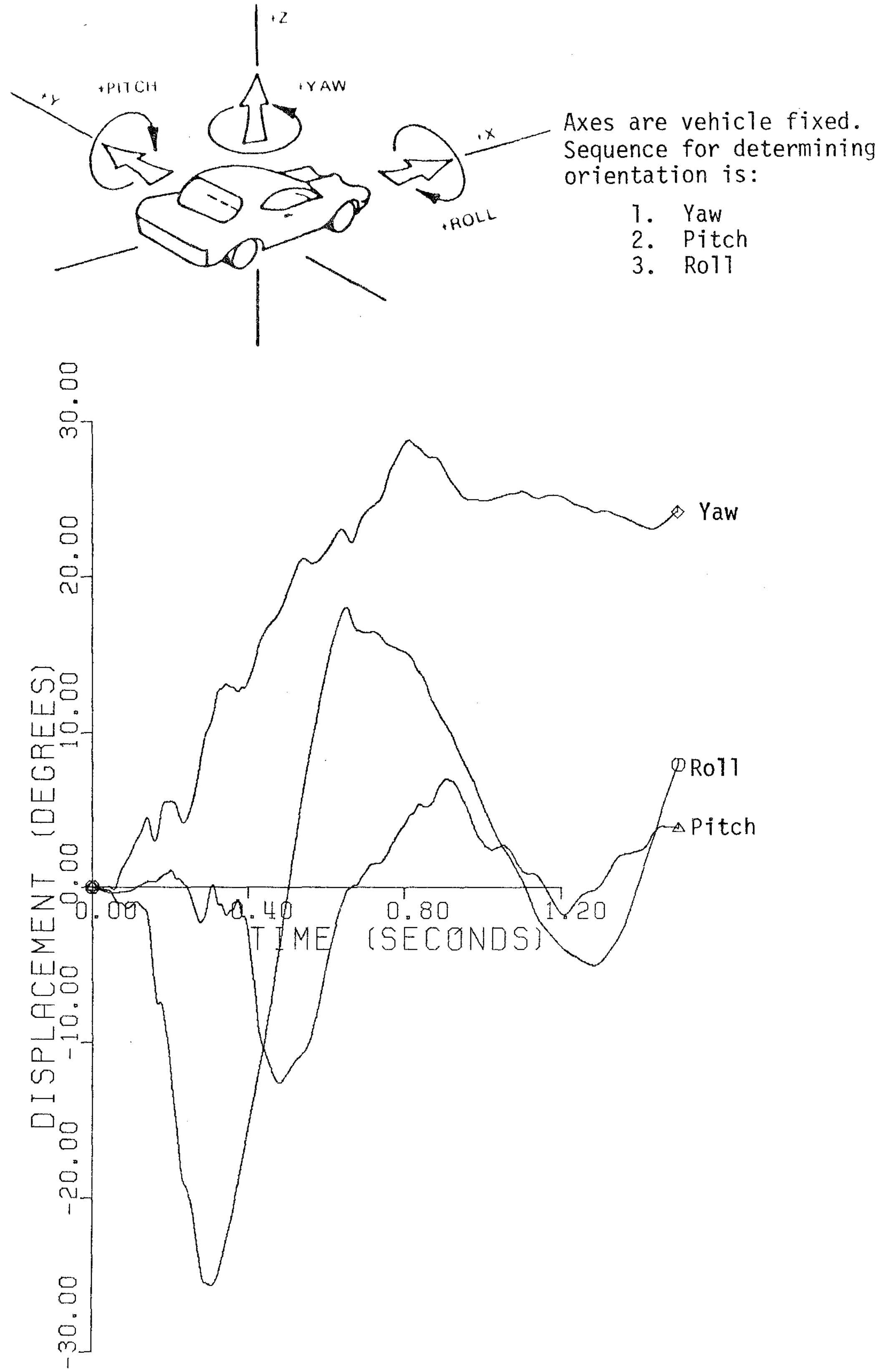
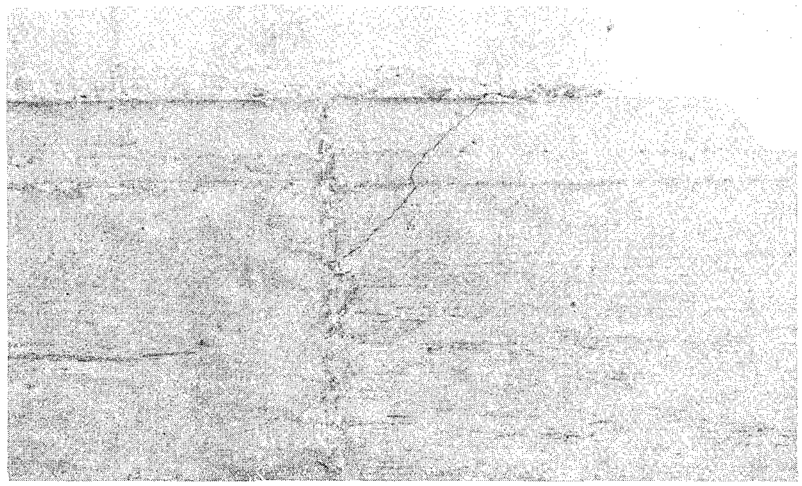


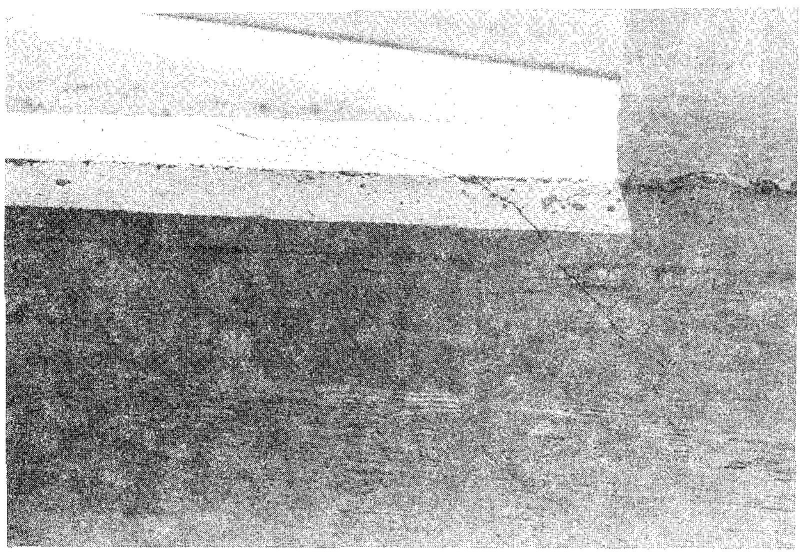
Figure B5. Vehicle Angular Displacements for Test 2911-1.

APPENDIX C

POST AND RAIL CRACK PATTERNS

4 ft. (1.2 m) Downstream from Impact





19 ft. (5.8 m) Downstream from Impact

19 ft. (5.8 m) Downstream from Impact

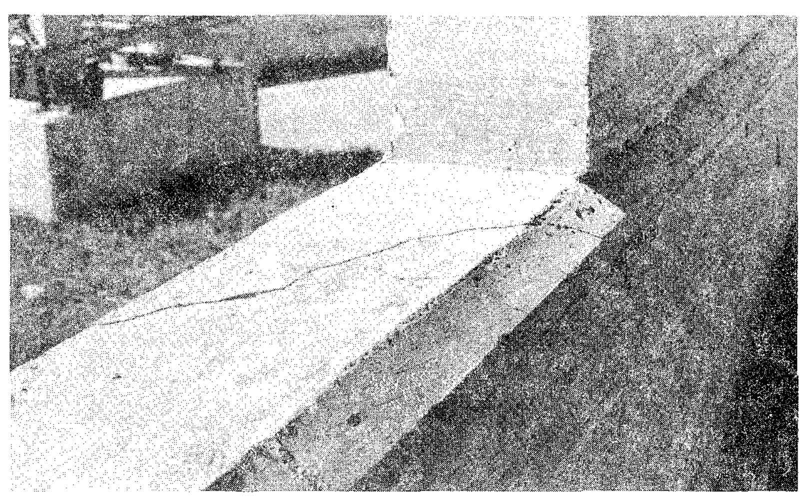
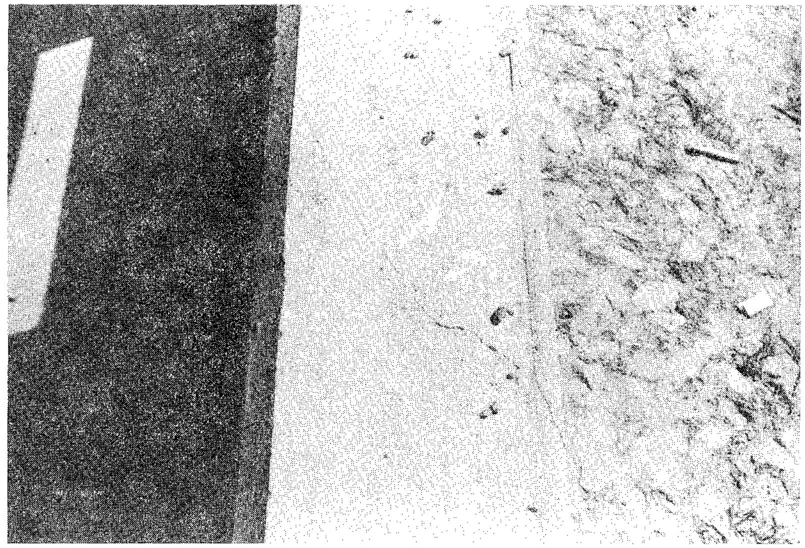


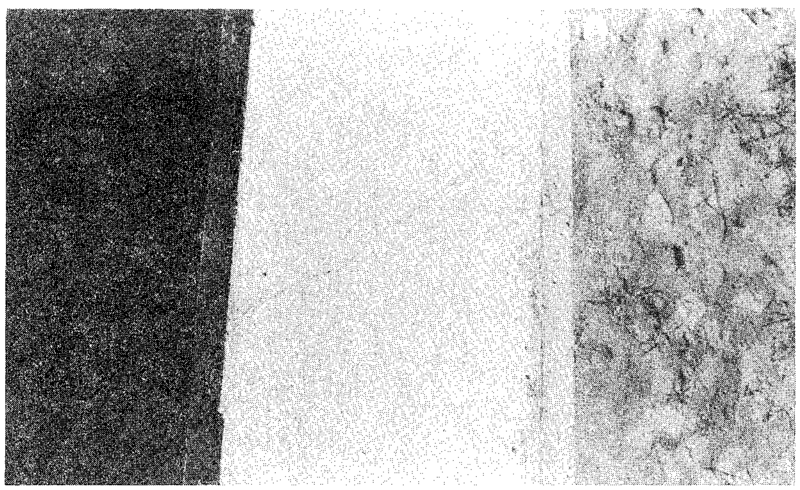
Figure C1. Crack Patterns on Traffic Side of the Rail After Test

0 ft. (0 m) Downstream
from Impact

(Traffic Side)



(Traffic Side)



20 ft. (6.1 m)
Downstream from
Impact

22 ft. (6.7 m) Downstream
from Impact

(Field Side)

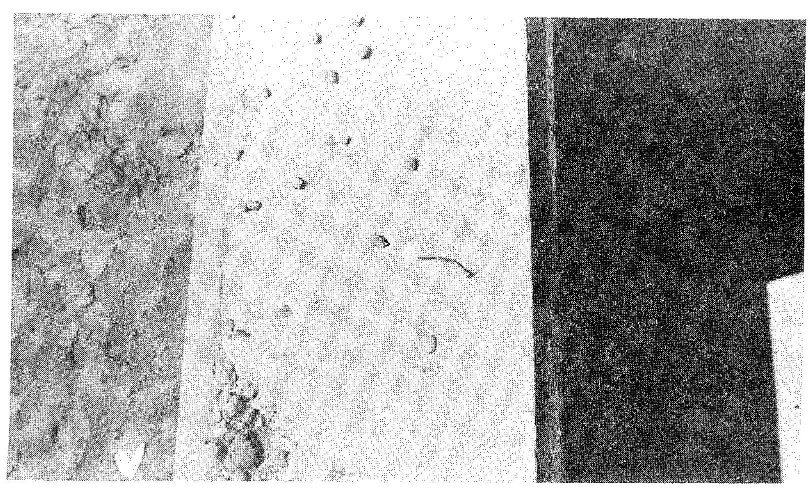
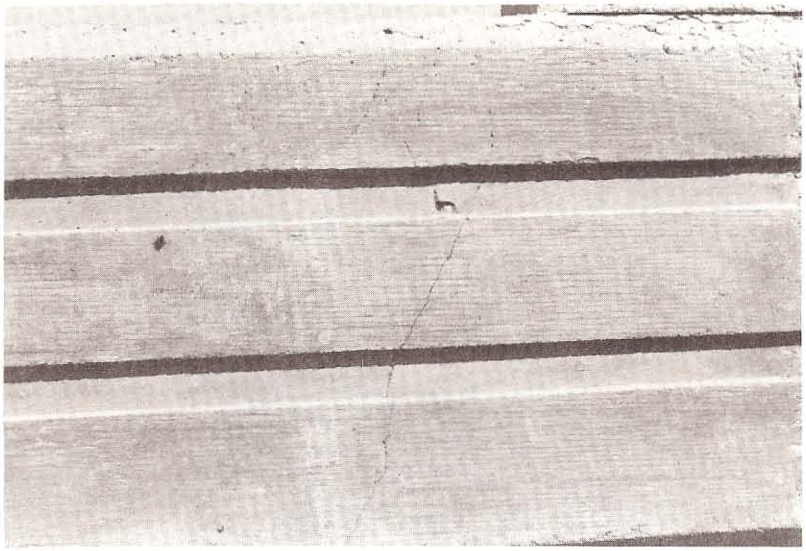
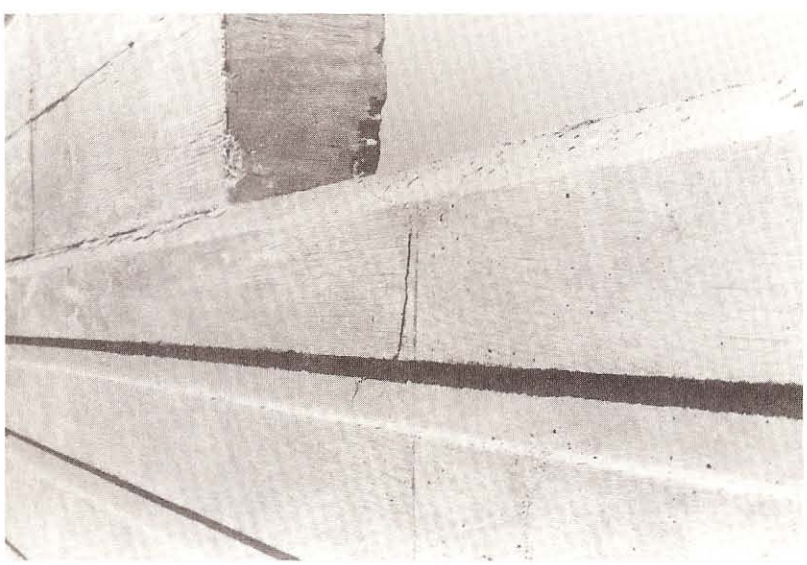


Figure C2. Crack Patterns on Top of the Beam After the Test



3 ft. (0.9 m) Downstream from Impact



10 ft. (3.1 m) Downstream from Impact

Figure C3. Crack Patterns on Field Side of the Rail After Test

APPENDIX D

CONCRETE STRENGTHS

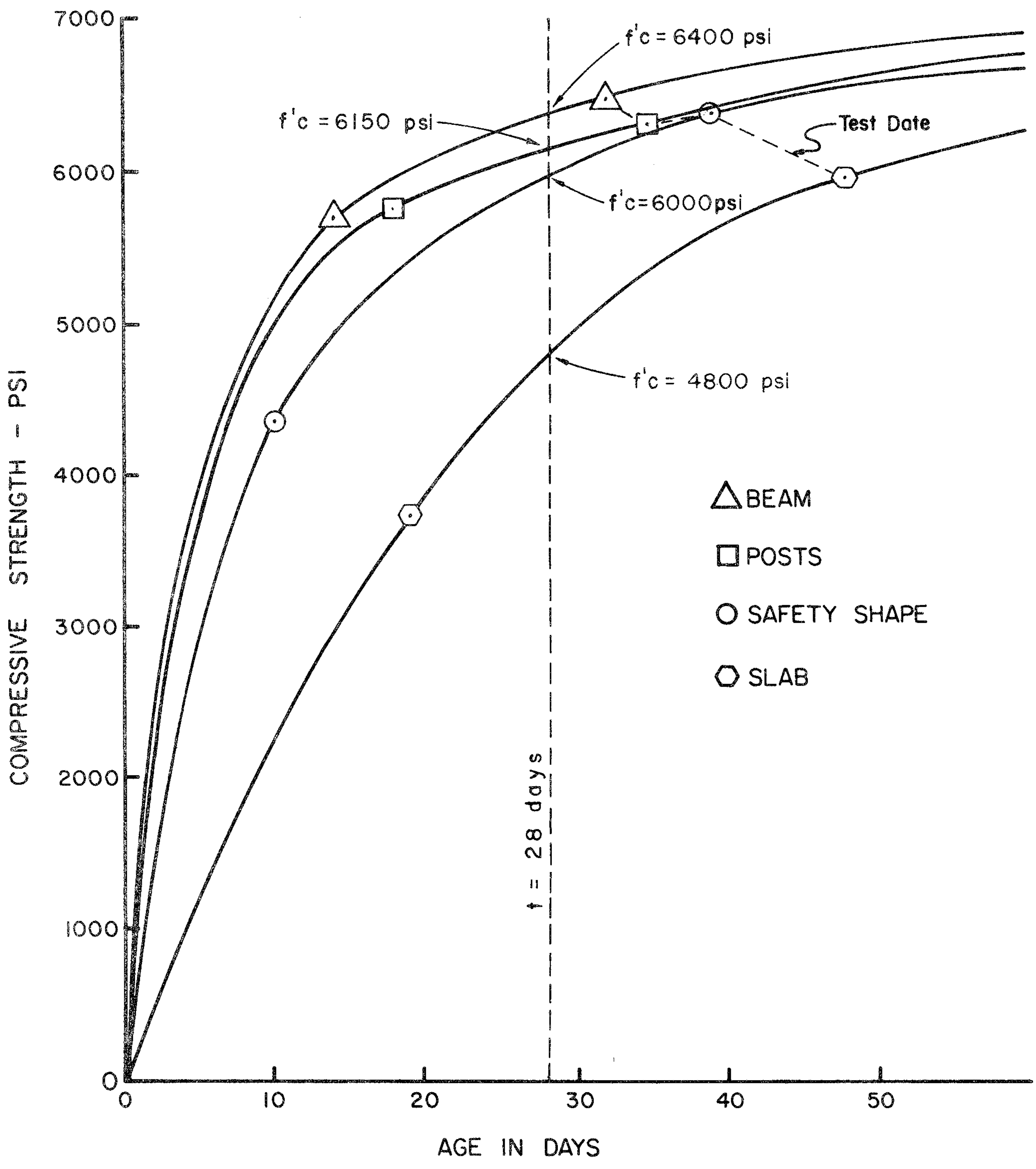


Figure D1. Concrete Compressive Strength of Various System Components.