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16. Abstract

Since the 32 in. (81 cm) high concrete safety shape is a popular median and bridge barrier, it was desirable to see if it could be modified to make it an effective traffic rail for trucks. An 18 in. (46 cm) high metal traffic rail was mounted on top of the 32 in. (81 cm) high concrete safety shape to make a bridge rail 50 in. (127 cm) high to restrain and redirect 80,000 lb. (36,287 kg) van type trucks. The bridge rail was impacted by such a truck at 48.4 mph (77.9 km/h) at an angle of 14.5 degrees. The bridge rail did restrain and redirect the trucks on the simulated bridge. The truck did roll over, however, this was attributed to the 11.3 degree sloping face of the concrete safety shape.

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CONCRETE SAFETY SHAPE WITH METAL RAIL ON TOP TO REDIRECT 80,000 lb TRUCKS

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Research Report 416-1F

on

Research Study No. 2-5-83-416
Modified Type T5 Bridge Rail to Redirect Buses and Trucks

Sponsored by

Texas State Department of Highways and Public Transportation

in cooperation with

The U.S. Department of Transportation
Federal Highway Administration

November 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 views 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 State Department of Highways and Public Transportation (SDHPT) and the Federal Highway Administration (FHWA). Mr. John J. Panak, Supervising Designing Engineer, SDHPT, was 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.

ABSTRACT

Since the 32 in. (81 cm) high concrete safety shape is a popular median and bridge barrier, it was desirable to see if it could be modified to make it an effective traffic rail for trucks. An 18 in. (46 cm) high metal traffic rail was mounted on top of the 32 in. (81 cm) high concrete safety shape to make a bridge rail 50 in. (127 cm) high to restrain and redirect 80,000 lb (36,287 kg) van type trucks. The bridge rail was impacted by such a truck at 48.4 mph (77.9 km/h) at an angle of 14,5 degrees. The bridge rail did restrain and redirect the trucks on the simulated bridge. The truck did roll over, however, this was attributed to the 11.3 degree sloping face of the concrete safety shape.

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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. Several bridge rails have been designed recently which will restrain and redirect large trucks (1 and 2)*.

Since the 32 in. (81 cm) high concrete safety shape is a popular median and bridge barrier, it was desirable to see if it could be modified to make an effective truck traffic rail.

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) van type tractor/trailer, as shown in Figure 5. The design was based on data presented in References (1, 2, 3, 4, 6 and 7).

The rail selected was a modification of the Texas type T5 traffic rail. The modified T5 rail consists of a concrete safety shaped parapet 32 in. (81.3 cm) high with a modified Texas type C4 metal traffic rail mounted on top. The parapet 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 thickness of the bridge deck below the concrete parapet was increased to minimize cracking and provide greater strength.

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

DESIGN TECHNIQUE

Earlier tests 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 Figure 5), it was assumed that 10,000 lb (4,540 kg) of this load would probably be transferred to the rail through the wheels and the axles. The remaining 24,000 lb (10,896 kg) would be transferred to the rail through the bed of the van trailer.

Accelerometer data from past tests indicated that the tandem axles of the tractor would be subjected to a maximum average 50 msec 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. (53.3 cm) and 144,000 lb (65,376 kg) (24,000 lb x 6 g's) applied at a height of 47.6 in. (120.9 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" (3).

DESCRIPTION OF THE BRIDGE RAIL AND DECK MODIFICATIONS

The modified T5 rail has an 18 in. (45.7 cm) tall modified Texas type C4 metal rail mounted on top. This modified bridge rail makes a combination bridge rail 50 in. (127 cm) tall suitable to retain large 80,000 lb (36,287 kg) van type trucks or tractor/trailers impacting at 15 degrees 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 the van type tractor/trailer.

The concrete parapet was basically a standard Texas type T5 traffic rail which was thickened to 10.5 in. (26.7 cm) at the top and 20 in. (50.8 cm) at the bottom. It was anchored to the bridge deck by #5 stirrups spaced at 8 in. (20 cm) as shown, and eight #6 longitudinal bars were used.

The metal rail mounted on top of the modified T5 concrete rail was a standard Texas type C4 metal traffic rail with three modifications. The first modification involved the use of one additional 1 in. (2.54 cm) thick steel post plate (ASTM-A36). This modification brought the total number of post plates used in each post to three. The second modification was the use of 7/8 in. (2.2 cm) diameter ASTM-A325 bolts in place of the standard 3/4 in. (1.9 cm) bolts. The last modification was the reduction of the post spacing from 10 ft (3 m) to 8 ft 4 in. (2.5 m). These modifications were made for the purpose of increasing the strength of the metal rail so that it could provide a greater resistance to overturning by the van trailer.

The metal rail was fabricated from 6 in. (15 cm) diameter standard steel pipe (ASTM A53 Grade B) shaped into an 8 in. X 4-7/8 in. (20 cm X 12.4 cm) ellipse and welded to the modified post mentioned previously.

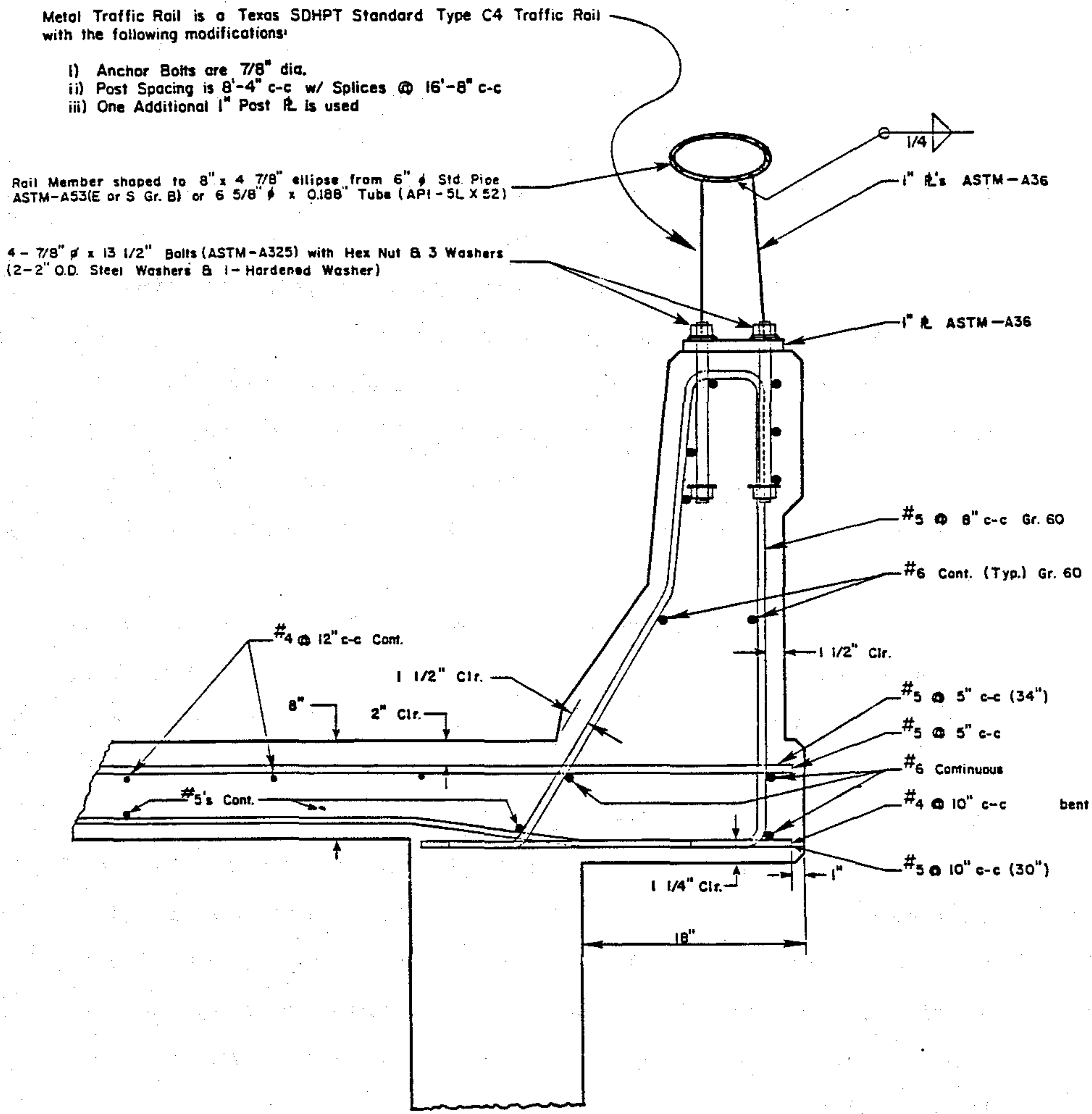


Figure 1. Cross Section of the Modified T5 Bridge Rail.

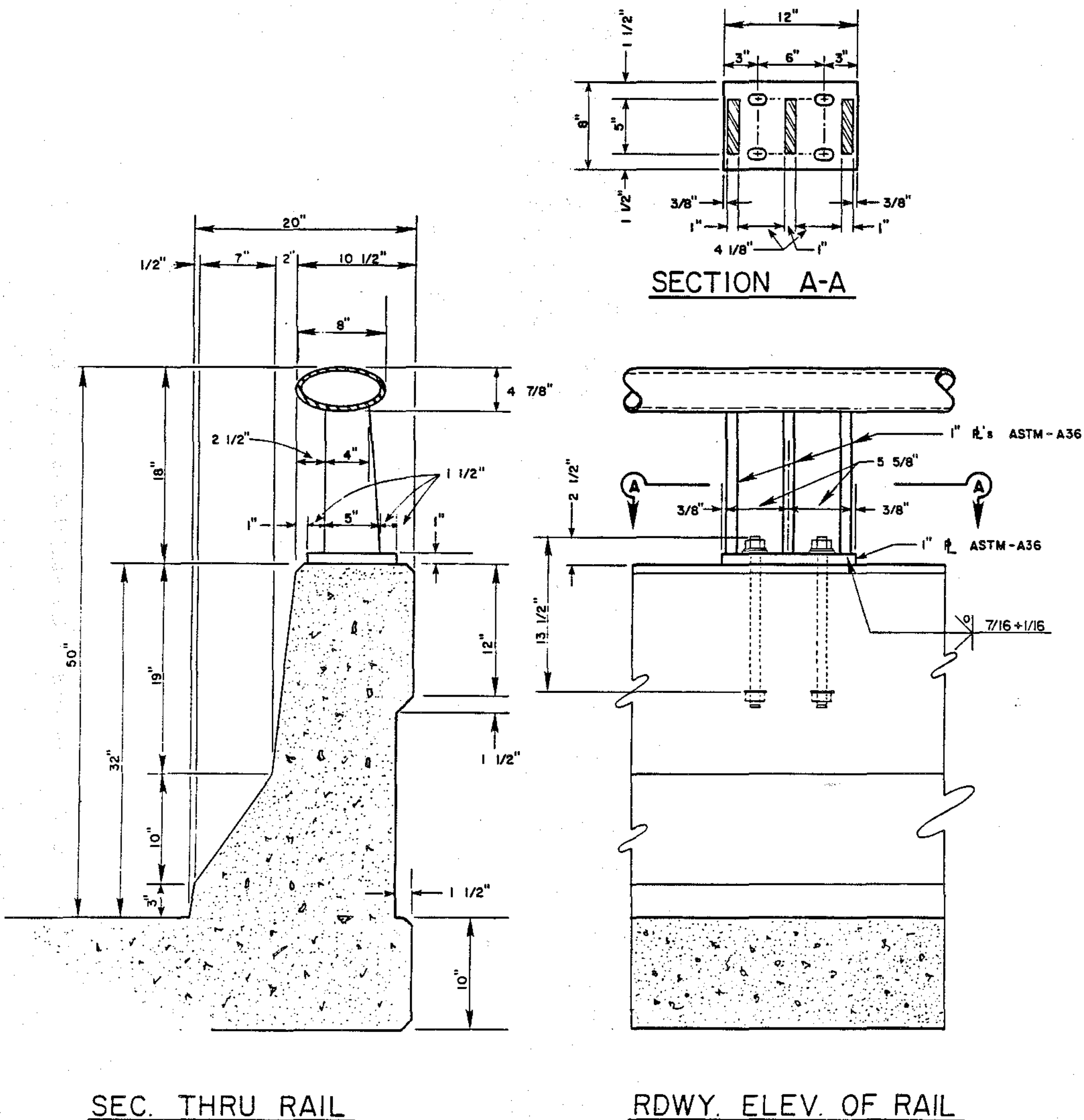
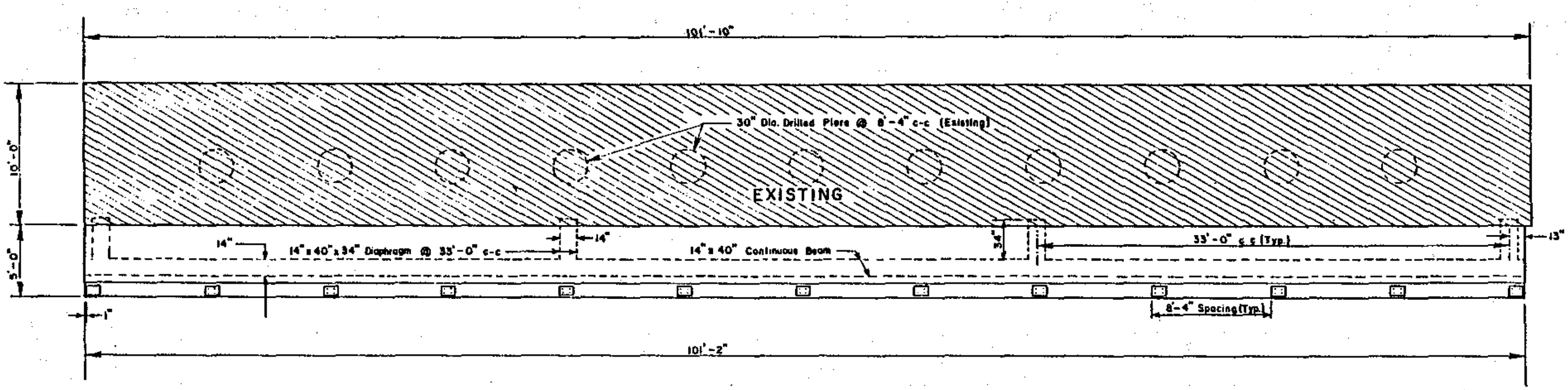


Figure 2. Dimensions and Elevation of the Modified T5 Bridge Rail.



PLAN VIEW

(Metal Rail Member omitted for clarity)

Figure 3. Plan View of the Modified T5 Bridge Rail.

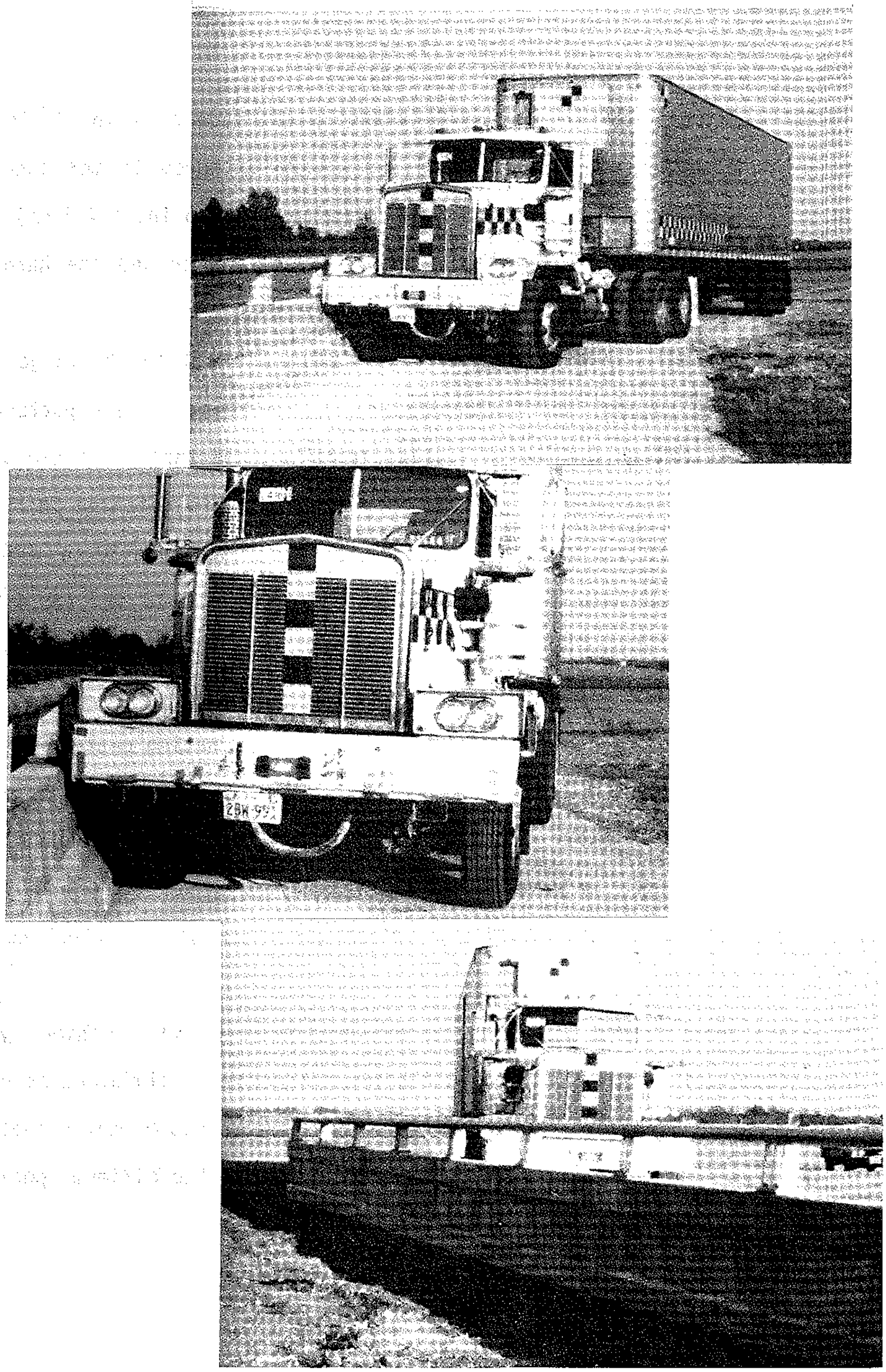


Figure 4. Comparison of 80,000 lb Van Truck with Modified T5 Bridge Rail

These posts were in turn welded to a base plate made of 1 in. (2.54 cm) thick steel plate (ASTM A36). The posts were anchored to the concrete rail by means of four 7/8 in. (2.2 cm) diameter by 13.5 in. (34.3 cm) long A325 bolts. One 2 in. (5.1 cm) diameter steel washer and one hardened steel washer was installed under each bolt nut.

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 10 in. (25.4 cm). The size of the upper transverse bars was maintained at #5's, while the standard 5 in. (12.7 cm) spacing was decreased to 2.5 in. (6.4 cm). The lower transverse reinforcement consisted of an alternating pattern of bent #4's that extended into the lower portion of the bridge deck and straight #5's, each at a spacing of 10 in. (25.4 cm). 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 16.5 in. (41.9 cm)

All reinforcing bars used in the bridge rail had a minimum yield strength of 60 ksi (413.4 MPa), while the bridge deck reinforcement had a minimum yield strength of 40 ksi (275.6 MPa). It should be noted that all of the 28-day compressive strengths were well above the minimum specified strength of 3600 psi (24.8 MPa).

INSTRUMENTATION AND DATA ANALYSIS

The vehicle was equipped with triaxial accelerometers mounted above the tractor tandem wheels. Yaw, pitch and roll were sensed by on-board gyroscopic instruments. The electronic signals were telemetered to a base station for recording on magnetic tape and for display on a real-time strip chart. Provision was made for transmission of calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data.

Tape switches near the impact area were actuated by the vehicle to indicate the elapsed time over a known distance to provide a quick check of impact speed. The initial contact also produced an "event" mark on the data record to establish the instant of impact.

Data from the electronic transducers was digitized, using a Southwest Technical Products 6800 micro-computer, for analysis and evaluation of performance. Several computer programs were used to process various types of data from the test vehicle.

Still and motion photography were used to document the test, to obtain time-displacement data and to observe phenomena occurring during the impact. Still photography was used to record conditions of the test vehicle and bridge rail installation before and after the test. Motion photography was used to record the collision event.

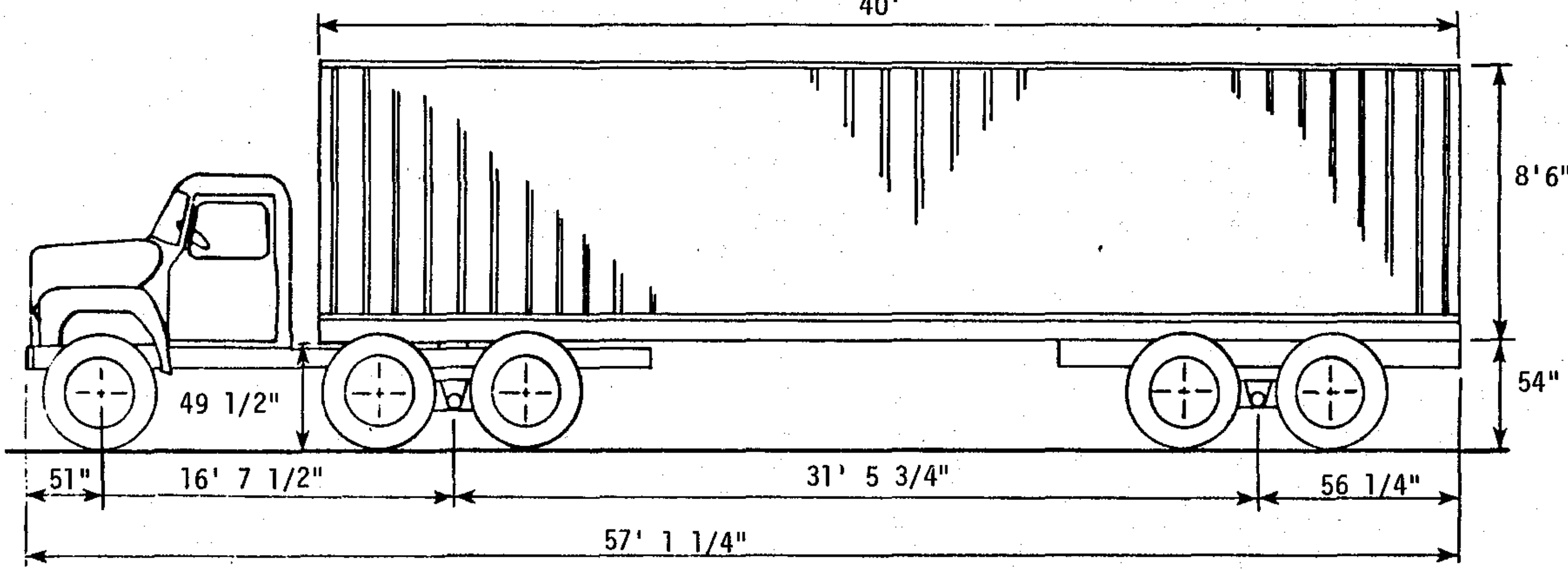
TRUCK CRASH TEST

This bridge rail system was designed to contain and redirect an 80,000 lb (36,287 kg) van type tractor/trailer. A simulated bridge deck with this rail system was built at the Texas Transportation Institute Proving Grounds and tested with a 1981 Kenworth tractor/trailer ballasted with sand bags to 80,080 lbs (36,356 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 48.4 mph (77.9 km/h) and 14.5 degree angle. The impact point was 26 in. (66 cm) downstream from post 5, and the truck was contained and redirected. The truck and trailer did, however, roll 90 degrees and came to rest on its side approximately 175 ft. (53 m) from the impact point. Figure 9 shows the bridge rail and test site immediately after the test. The truck sustained damage to the right front and right tandem wheels. The cab of the truck remained intact. A summary of the crash test data is shown in Table 1.

The bridge deck supporting the rail sustained no damage. The concrete parapet was not significantly damaged while the metal rail experienced damage between posts 5 and 8 (see Fig. 8). It was determined from the overhead film that the metal rail was deflected a maximum of 11 in. (27.9 cm) and sustained a permanent deflection of 6 in. (15.2 cm). The concrete rail was permanently displaced 0.5 in. (1.3 cm). The threads were stripped from the traffic side anchor nuts of post 5 and 6 of the metal rail. Examination revealed that the thread fit was too loose on the

TRACTOR-TRAILER

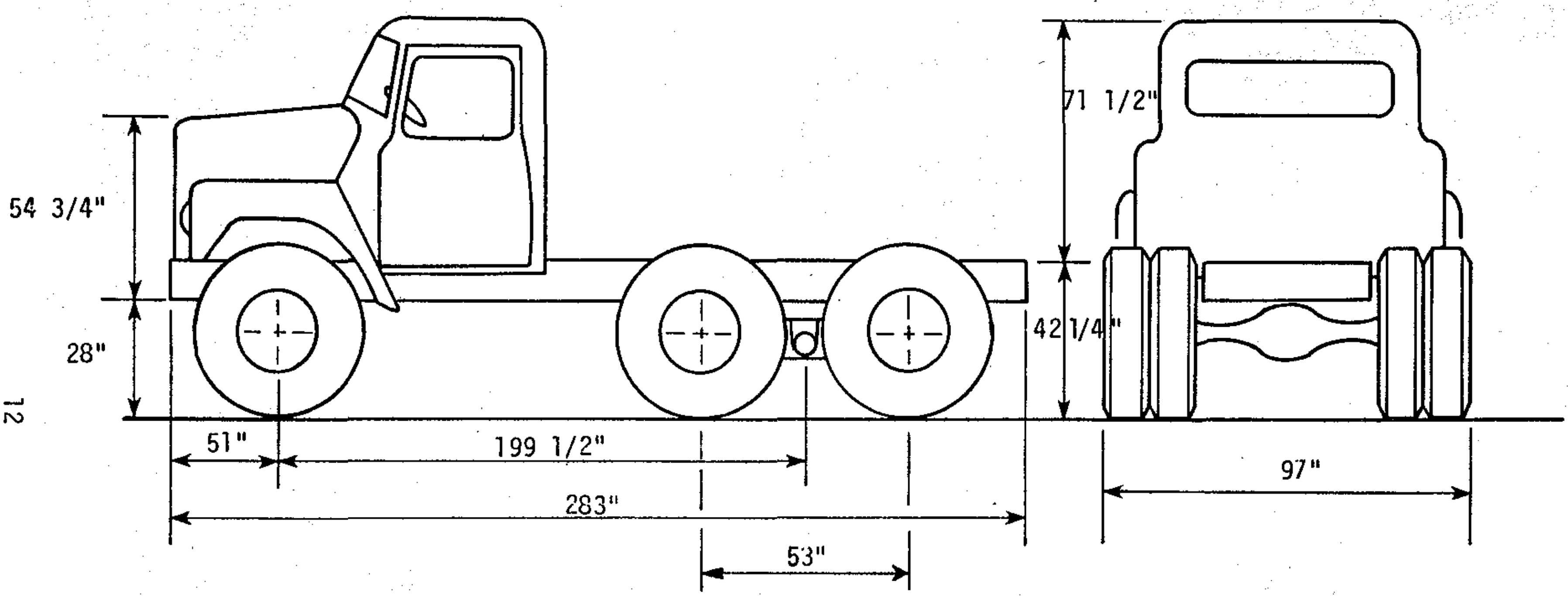


EMPTY WEIGHTS	
Tractor only	18,320 lb
Trailer only	13,760 lb
Total Empty Weight	32,080 lb

LOADED WEIGHTS	
Weight on front axle	12,020 lb
Weight on Center axles	34,170 lb
Weight on rear axles	33,890 lb
Total Loaded Weight	80,080 lb

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

TRACTOR



EMPTY WEIGHTS

Tractor only	18,320 lb
Trailer only	13,760 lb
Total Empty Weight	32,080 lb

Figure 6. Empty Tractor Dimensions and Weights.

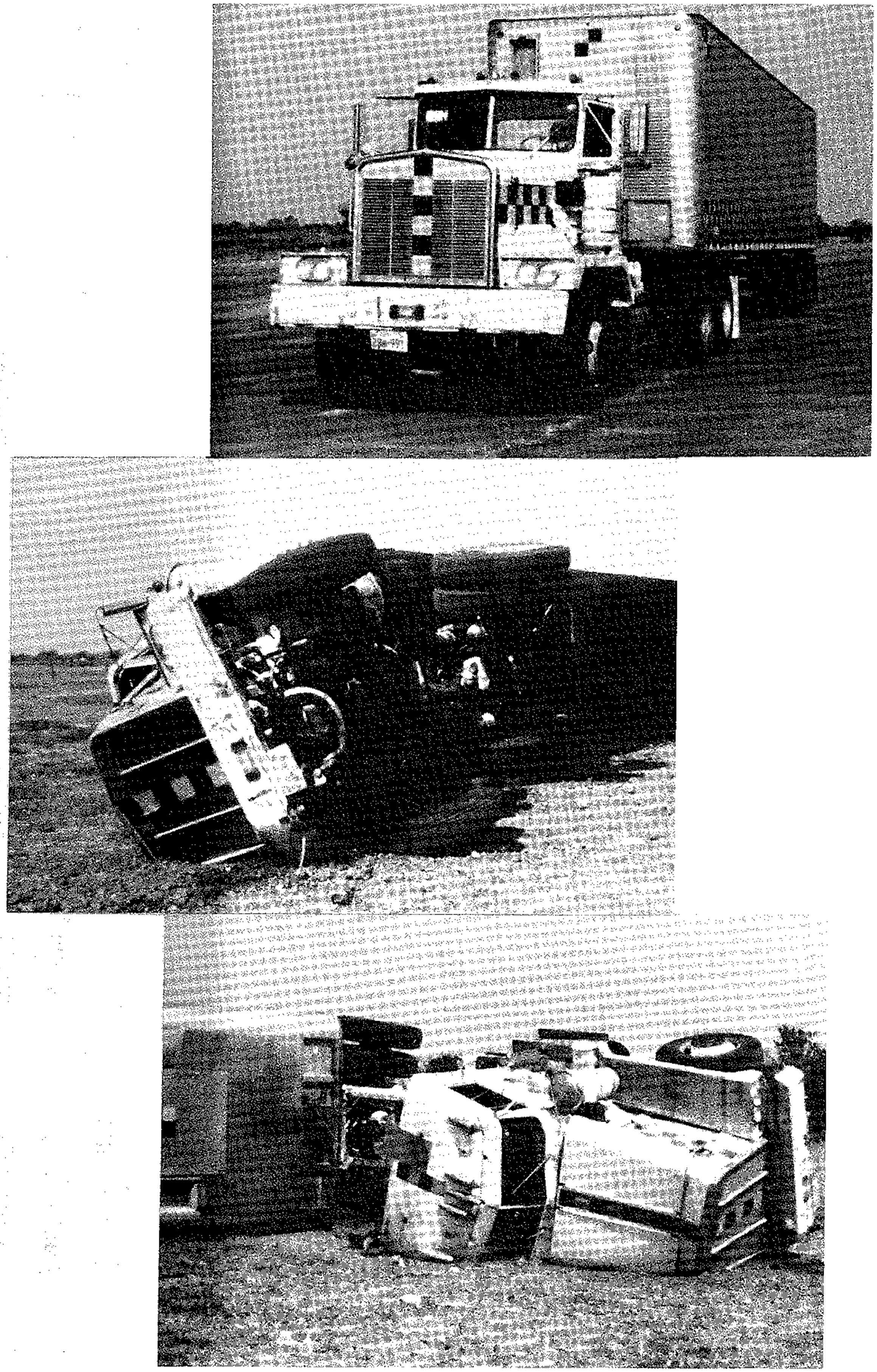
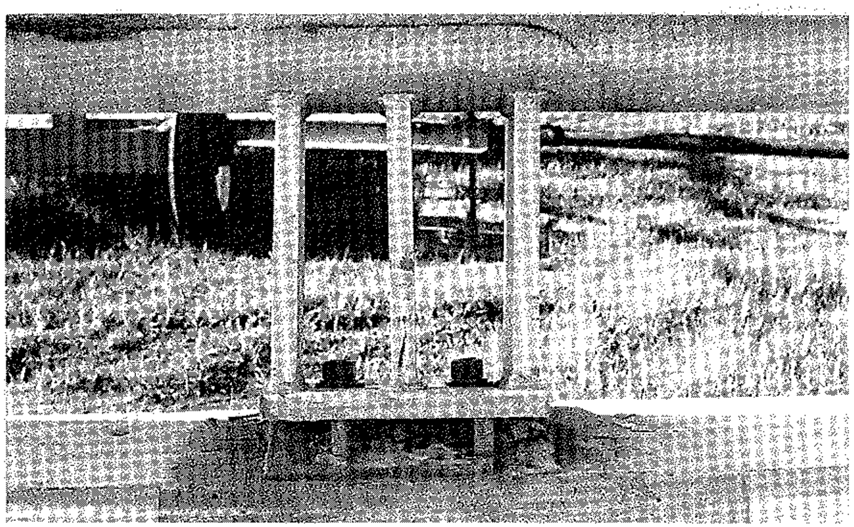
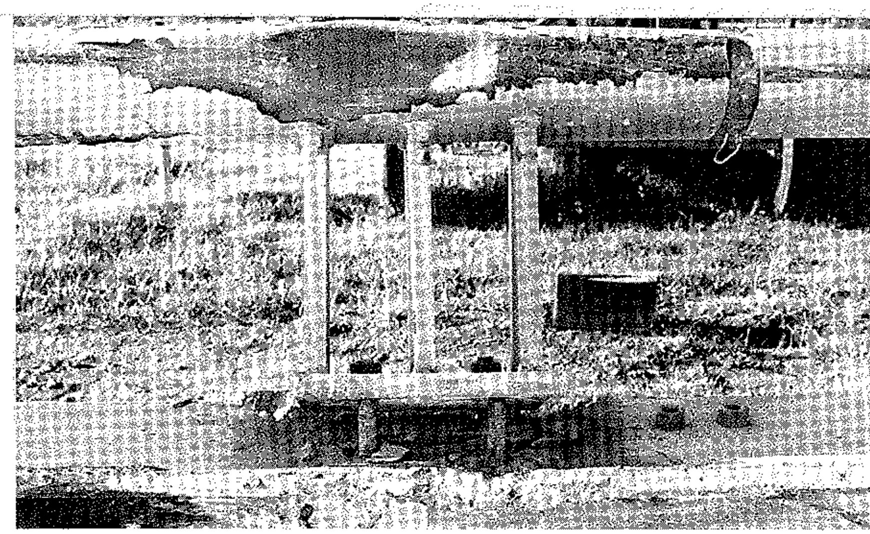


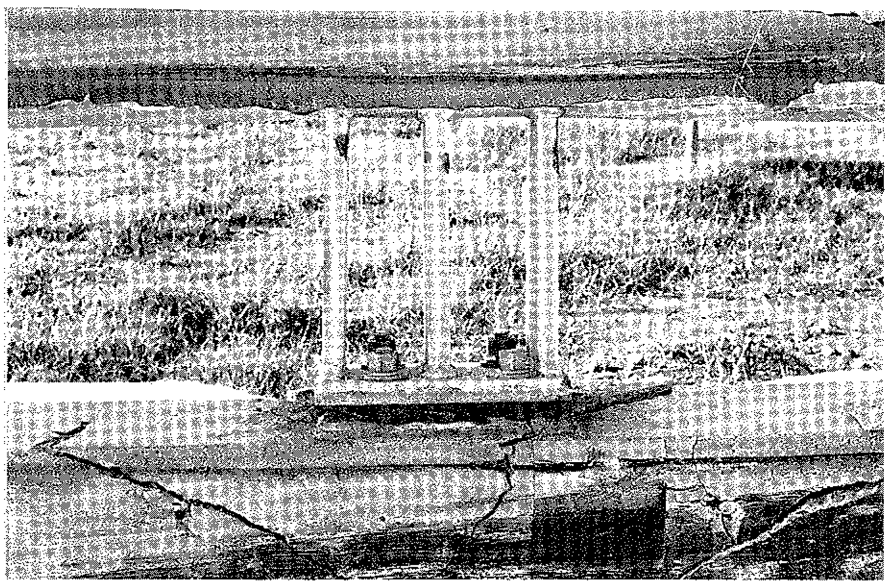
Figure 7. 80,000 lb Truck Before and After Test



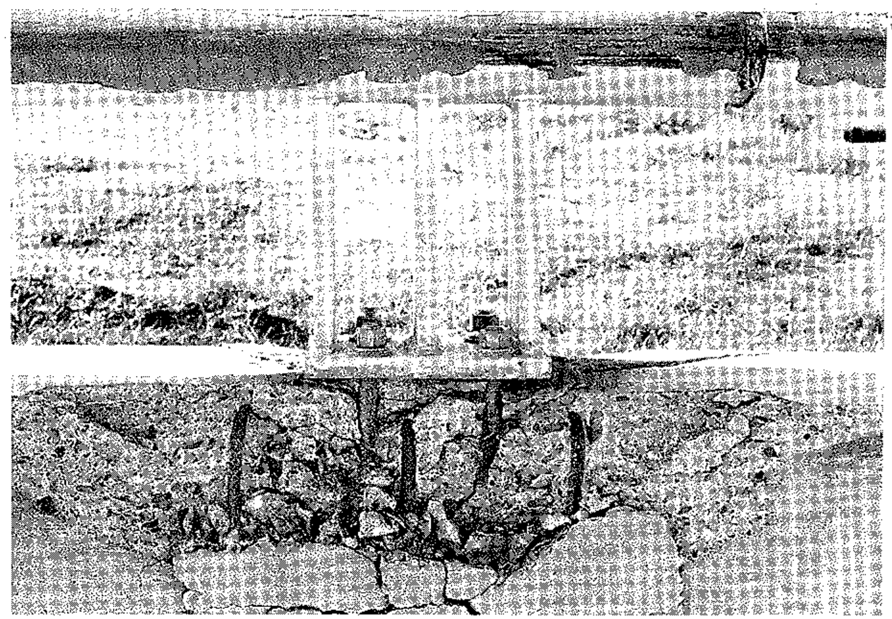
Post 5



Post 6

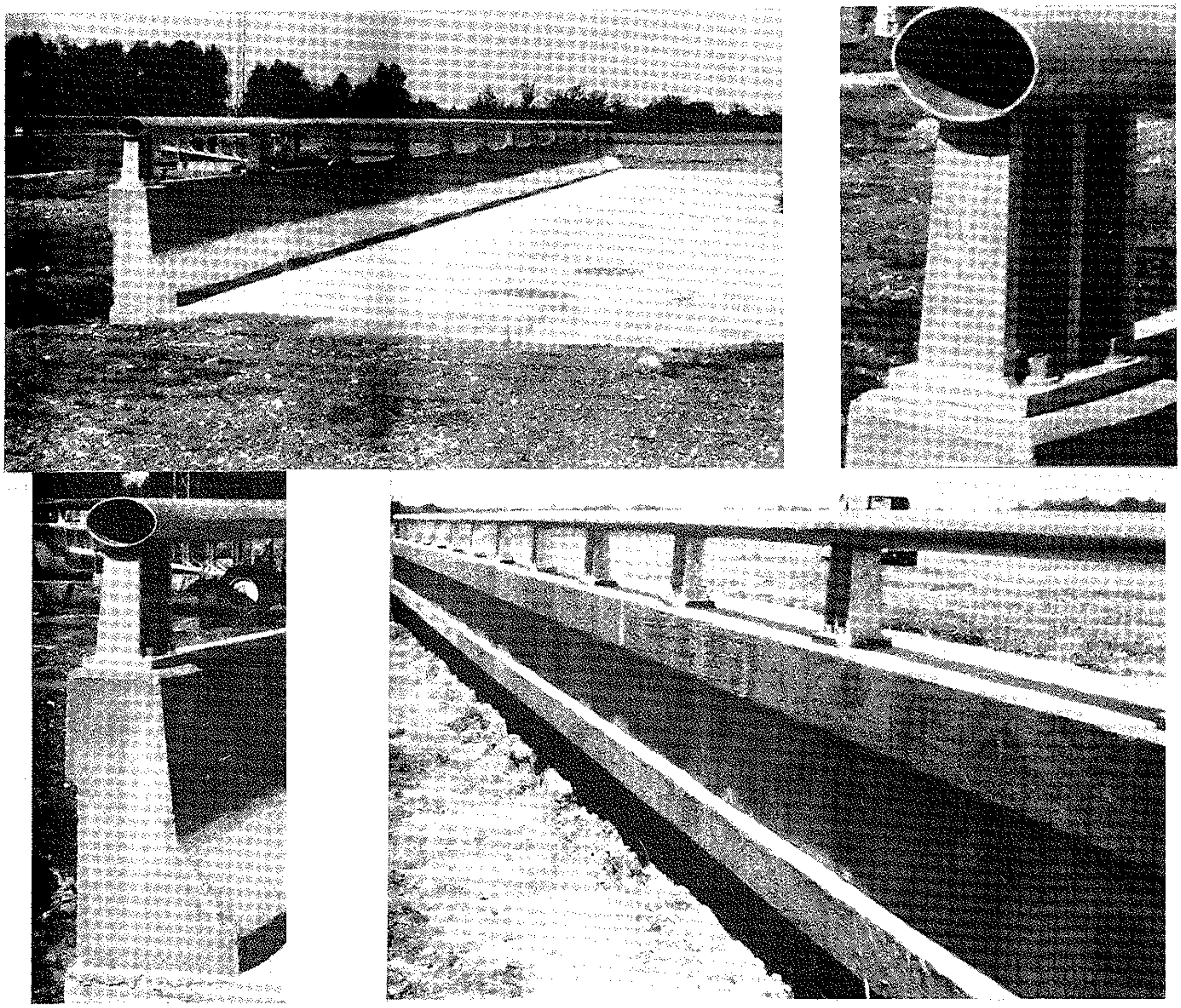


Post 7

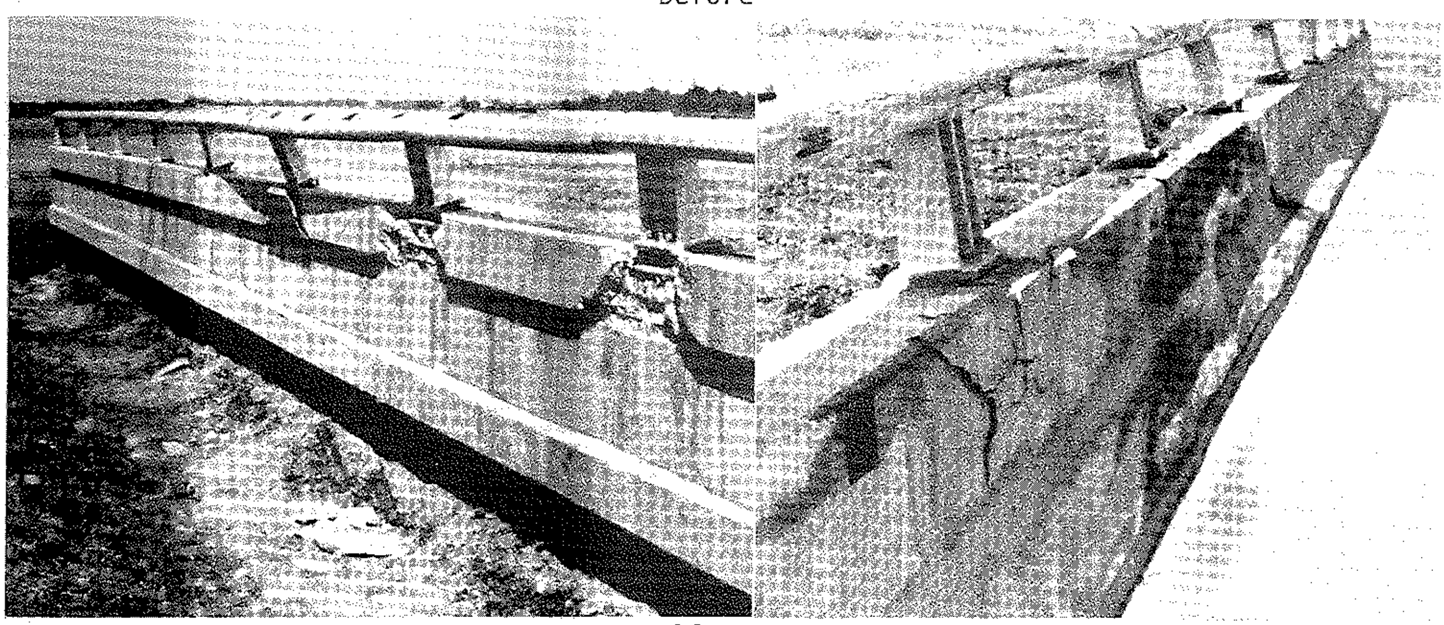


Post 8

Figure 8. Posts 5, 6, 7 and 8 After Test



Before

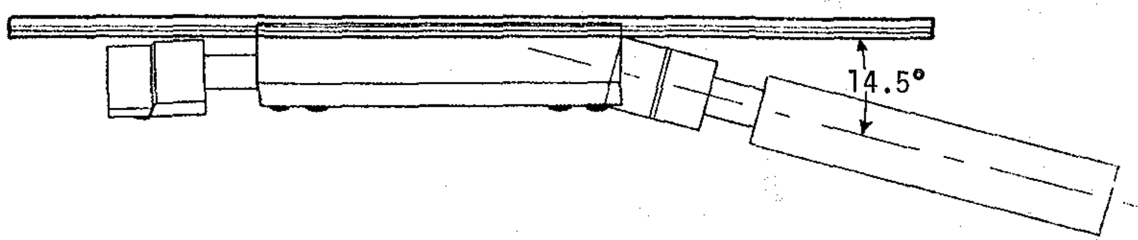


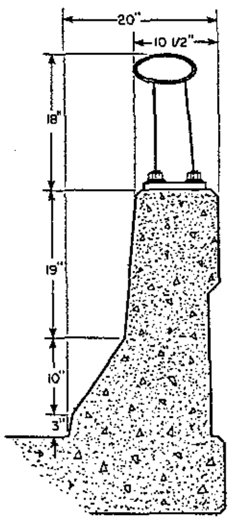
After

Figure 9. Bridge Rail Before and After Test

0.000 sec 0.202 sec 0.399 sec 0.650 sec

Vehicle subsequently rolled 90°





Test No. 2416-1
Date 9/18/84
Test Installation. . . . . Mod. Texas Type T5 Bridge Rail w/Mod. Texas Type C4 Metal Rail
Length of Installation . . . . 101.2 ft (30.8 m)
Metal Rail Deflection
    Permanent . . . . 0.5 ft (0.2 m)
    Maximum . . . . 0.9 ft (0.3 m)
Vehicle. . . . . 1981 Kenworth Tractor with Freuhauf Van-type Trailer

Vehicle Weights
  Empty Weight . . . . 32,080 lbs (14,564 kg)
  Gross Static . . . . 80,080 lbs (36,356 kg)
Impact Speed . . . . 48.4 mph (77.9 km/h)
Impact Angle . . . . 14.5 deg
Tractor Accelerations at Drive Axles
  (Max. 0.050 sec Avg)
  Longitudinal . . . . -2.4 g
  Lateral. . . . . 5.5 g
  Vertical . . . . 3.9 g
  Max. Roll Angle. . . . . . 90 deg

Figure 10. Summary of Data for Test 2416-1.

7/8 in. (2.2 cm) diameter bolts anchoring the metal posts. This problem has occurred with some previous tests and laboratory experiments indicated that the bolts with the improper nut fit developed only 75 percent of the ultimate tensile strength developed by those bolts with proper nut fit. The traffic side anchor bolts of posts 6 and 7 pulled loose from the concrete parapet. Sequential photographs showing the overhead and frontal view of the crash test are shown in Appendix A.

Maximum positive roll of the tractor tandem axles and the trailer was 90 degrees. From the accelerometers, the longitudinal and lateral maximum average 0.050 sec accelerations were -2.4 g's and 5.5 g's, respectively. Graphs of the filtered data from the yaw, pitch and roll rate gyro's and the x, y and z accelerometers are presented in Appendix B.

DISCUSSION OF RESULTS

NCHRP Report 230 (4) recommends the following criteria for tests S20 (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 even though the truck rolled over. The bridge rail contained and redirected the truck and remained totally intact while doing so. The roll over of the truck is attributed to the sloping face of the concrete safety shape. The metal traffic rail is set back 9 1/2 in. (24 cm) from the lower face of the concrete shape 47 1/2 in. (121 cm) below. This means the trailer undergoes a roll angle of 11.3 degrees ($\tan^{-1}$ 9.5/47.5) before it contacts the metal rail. In Reference (1) where the redirection face of the rail was vertical no rollover was experienced.

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 6.59 fps, and the highest 10 msec average occupant acceleration after contact was -2.34 g's. The lateral occupant impact velocity was 15.49 fps, and the highest 10 msec average acceleration was 5.6 g's. Even though these recommended threshold values do not apply to large trucks, they are presented here for comparison purposes only.

SUMMARY AND CONCLUSIONS

A standard Texas type T5 traffic rail was modified by increasing its strength and effective height so that it could restrain and redirect an 80,000 lb (36,287 kg) van type truck or tractor/trailer. The concrete parapet was 32 in. (81.3 cm) tall, while total rail height was 50 in. (127 cm).

The crash test was conducted on this bridge rail with an 80,080 lb (36,356 kg) van type tractor/trailer impacting the rail at 48.4 mph (77.9 km/h) and at an impact angle of 14.5 degrees. The vehicle was restrained, redirected, and came to rest on its side approximately 175 ft. (53 m) from the impact point. While the truck roll over was not desirable, the bridge rail did restrain, redirect, and keep the truck on the bridge.

The four 7/8 in. (2.2 cm) diameter by 13 1/2 in. (34.3 cm) long ASTM-A325 anchor bolts used at each post had two deficiencies. The threads on the bolts were cut too loose (not according to specifications) and permitted the nuts to be stripped off at two posts. The anchor bolts were not long enough to develop their strength. The 13 1/2 in. (34.3 cm) length should be increased to at least 18 in. (46 cm) in length to increase the development length.

This test has shown that a bridge rail can be built with the concrete safety shape on a slightly modified Texas standard bridge deck to contain and redirect large van type tractor/trailer trucks.

The cross-sectional area of this modified rail is approximately 2.8 sq ft (0.26 sq. m) as compared with approximately 2.5 sq ft (0.23 sq m) for a standard Texas traffic rail type T5. The approximate cost of this modified rail would be about $80 per linear foot, while a standard Texas type T5 traffic rail normally costs about $35 per linear foot.

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APPENDIX A

SEQUENTIAL PHOTOGRAPHS FOR TEST 2416-1

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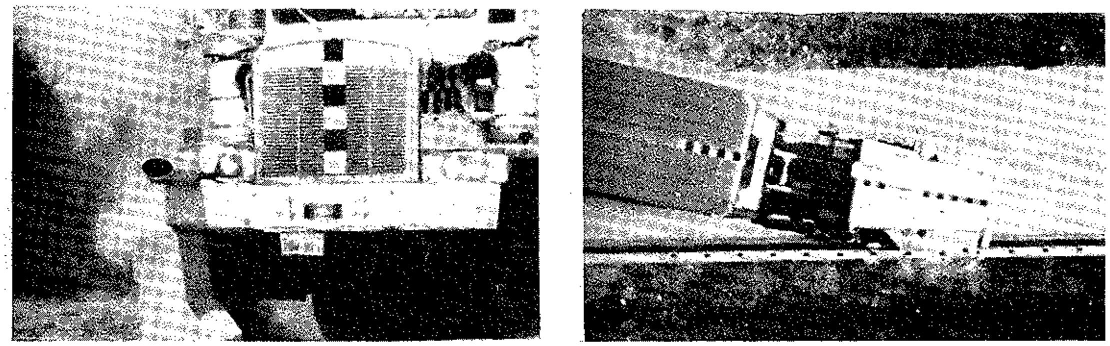

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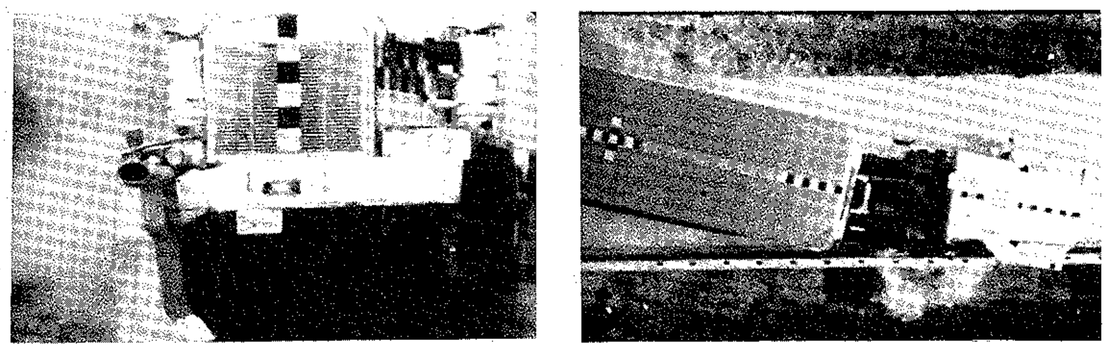

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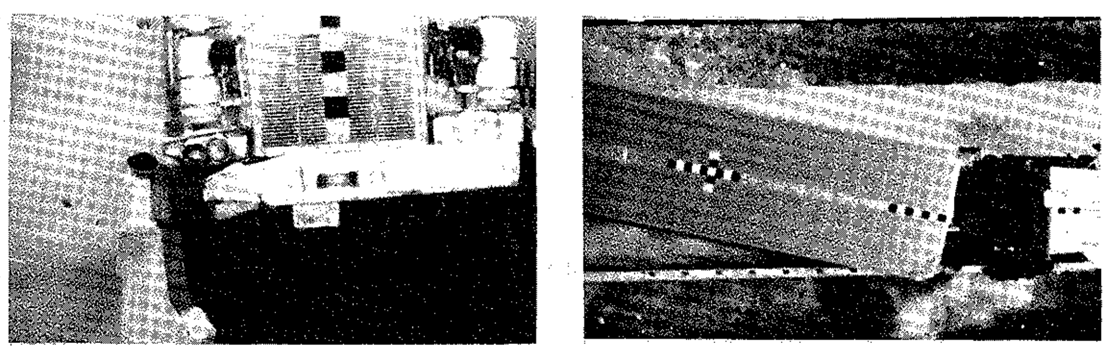

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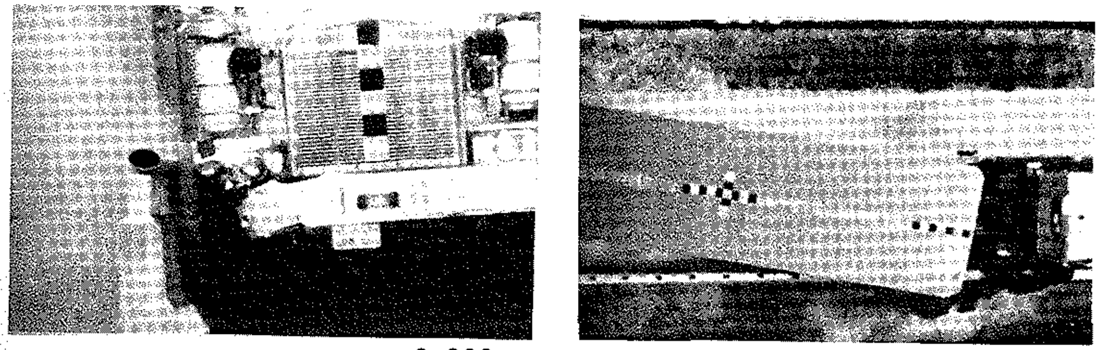
Figure A1. Sequential Photographs for Test 2416-1.



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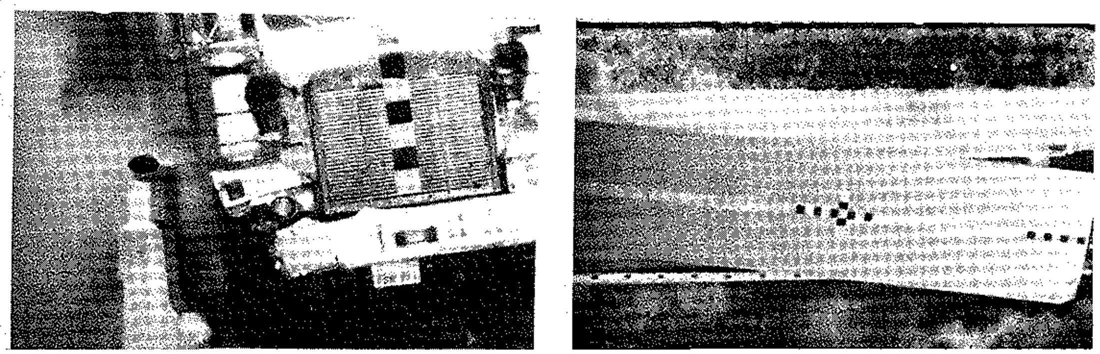

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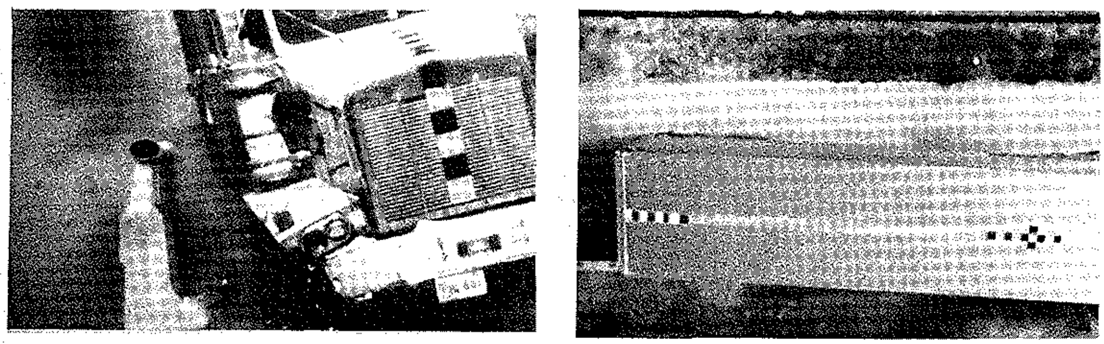
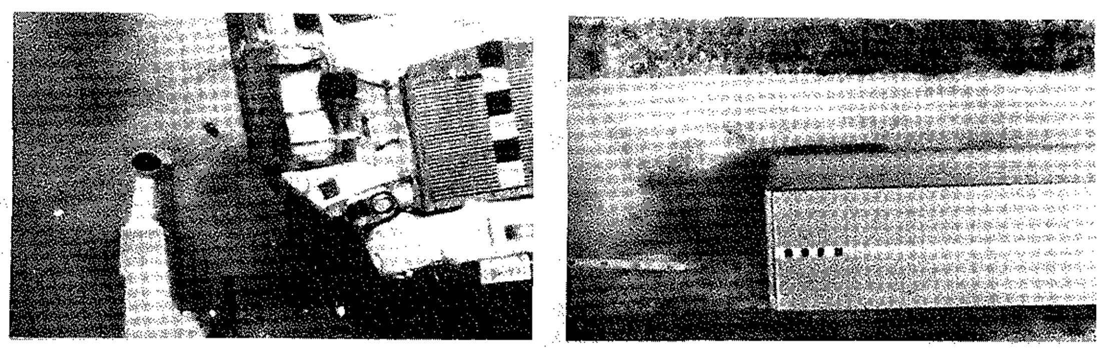


0.650 sec



0.800 sec

Figure A2. Sequential Photographs for Test 2416-1. (Continued)

APPENDIX B

ELECTRONIC ACCELEROMETER, YAW, PITCH and ROLL DATA

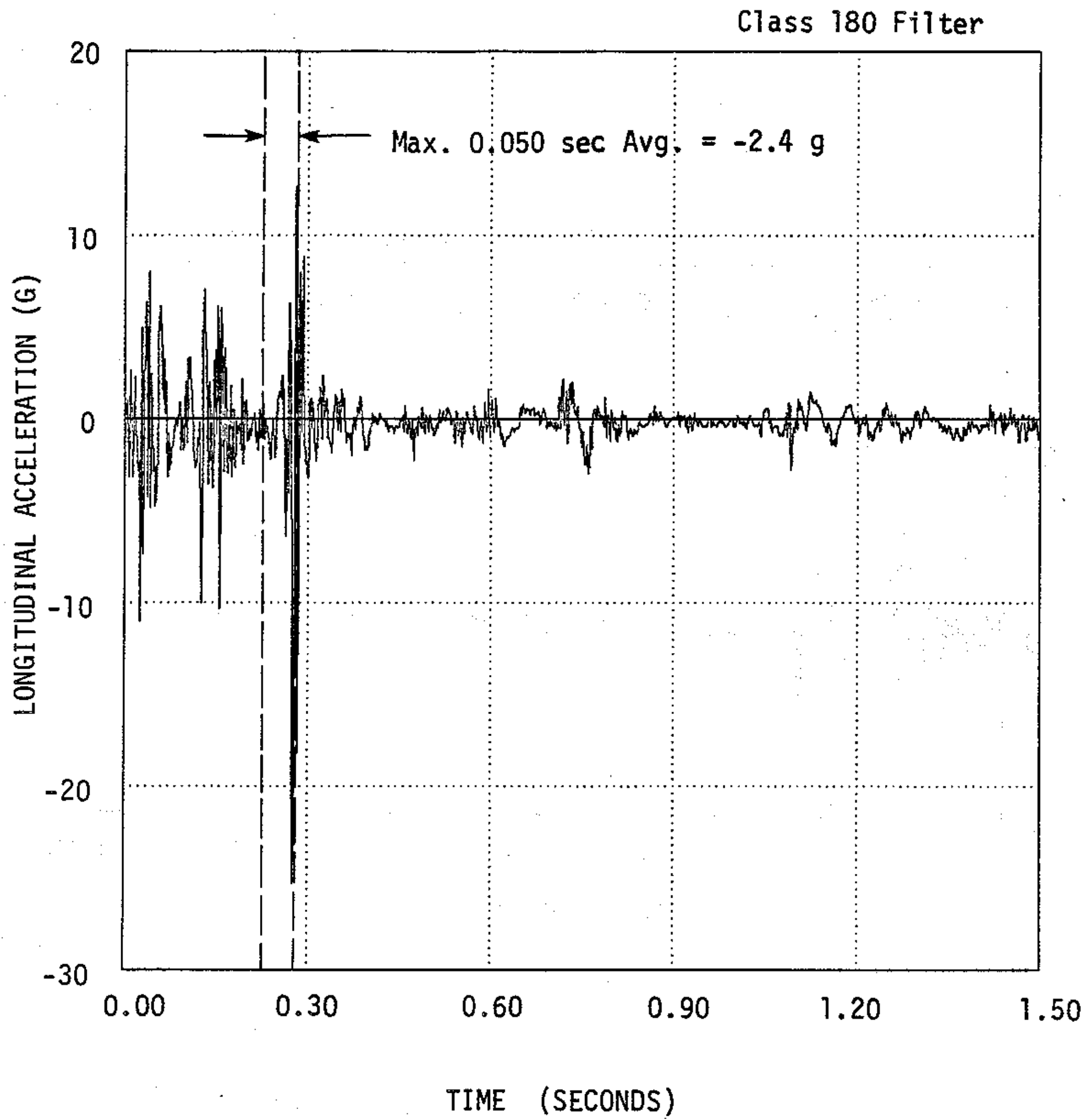


Figure B1. Vehicle Longitudinal Accelerometer Trace for Test 2416-1.

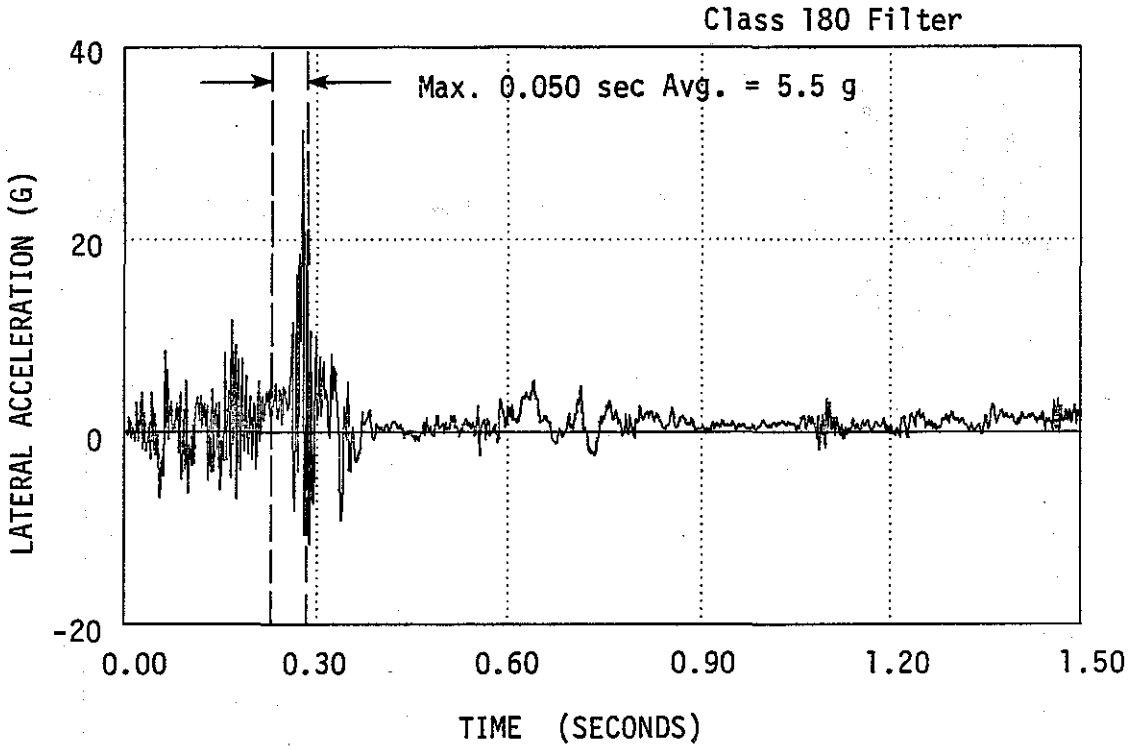


Figure B2. Vehicle Lateral Accelerometer Trace for Test 2416-1.

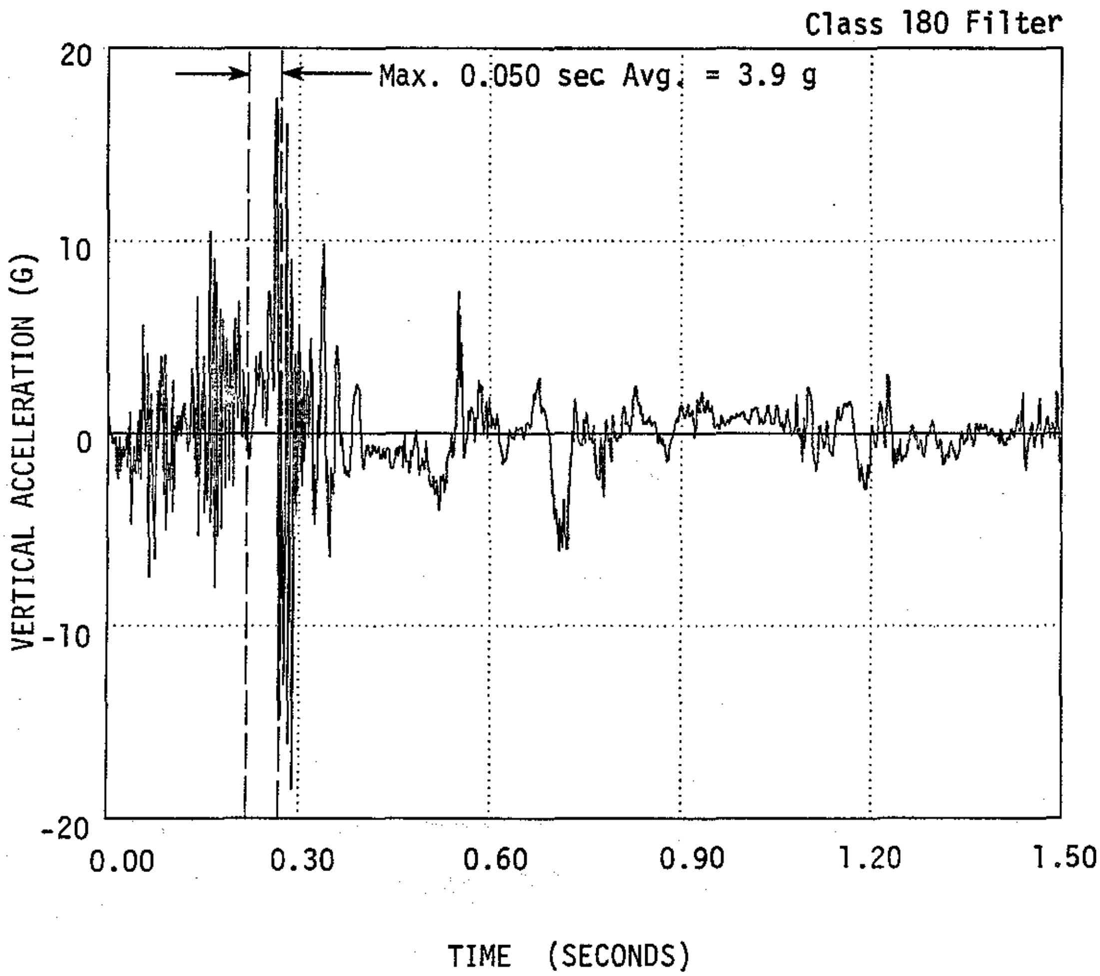
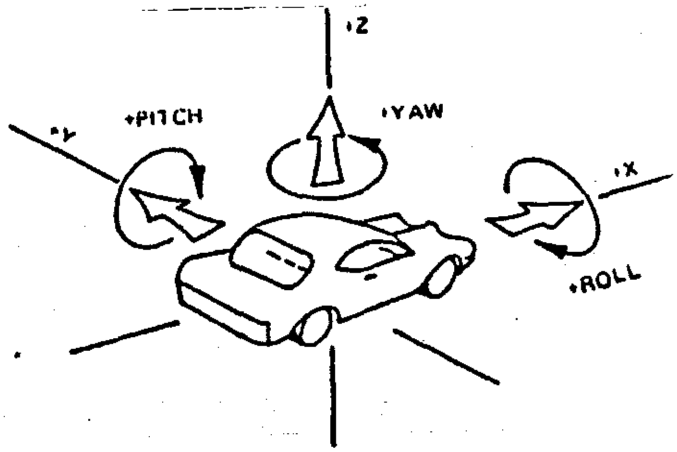


Figure B3. Vehicle Vertical Accelerometer Trace for Test 2416-1.



Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

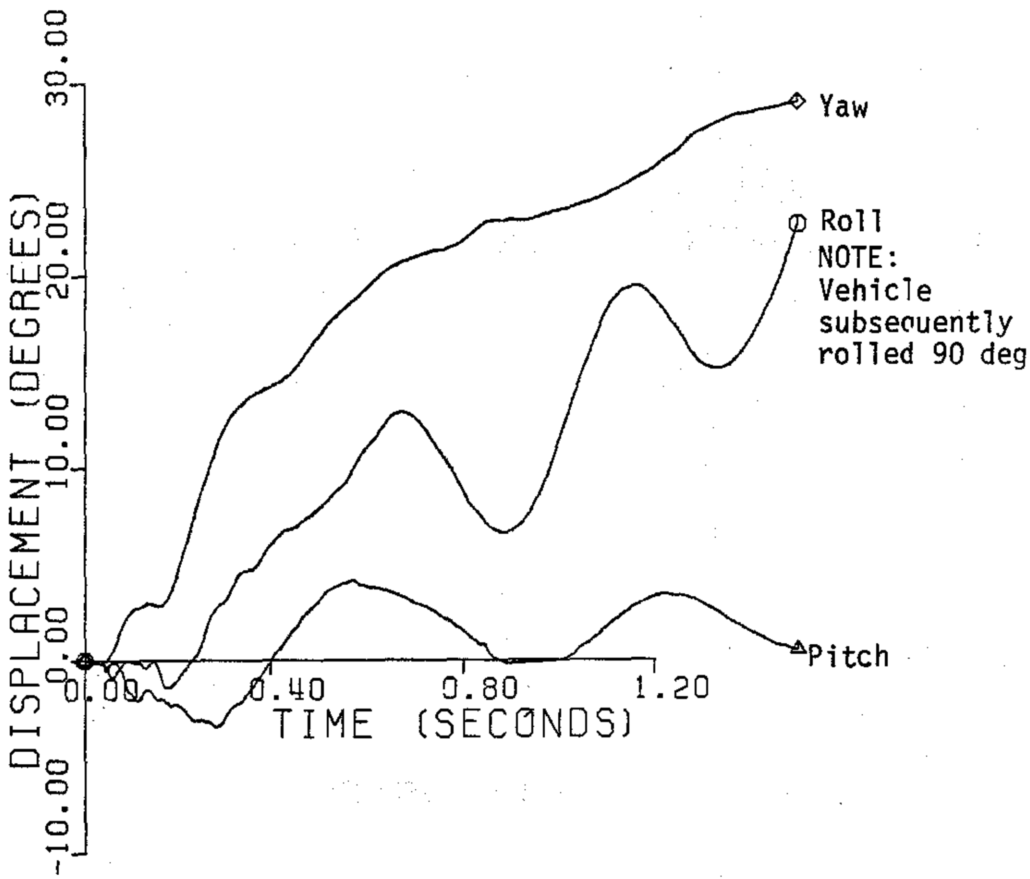
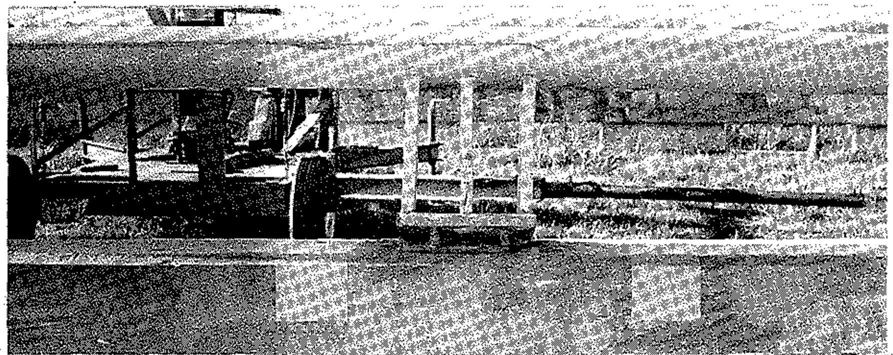


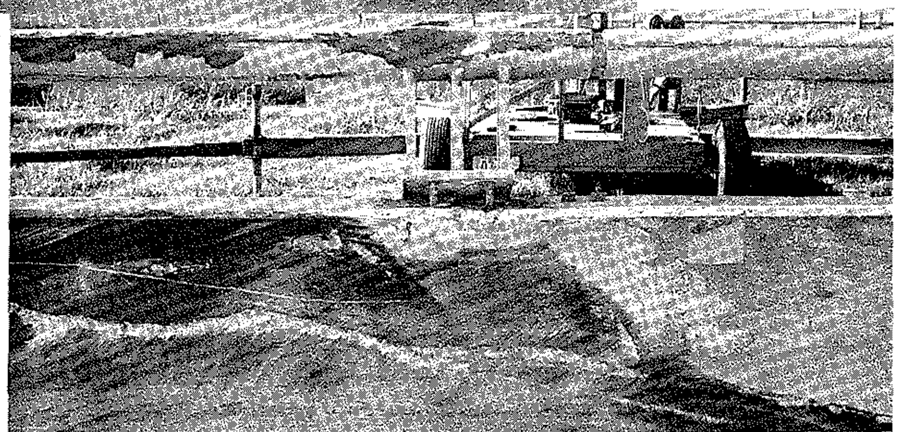
Figure B4. Vehicle Angular Displacements for Test 2416-1.

APPENDIX C

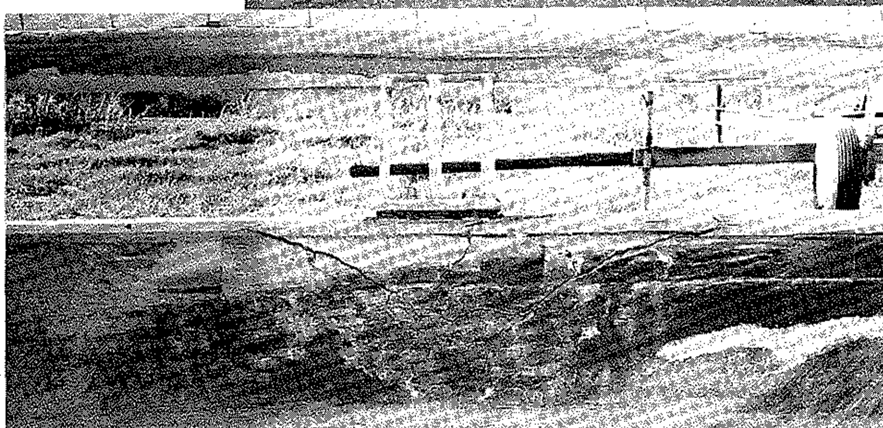
RAIL CRACK PATTERNS



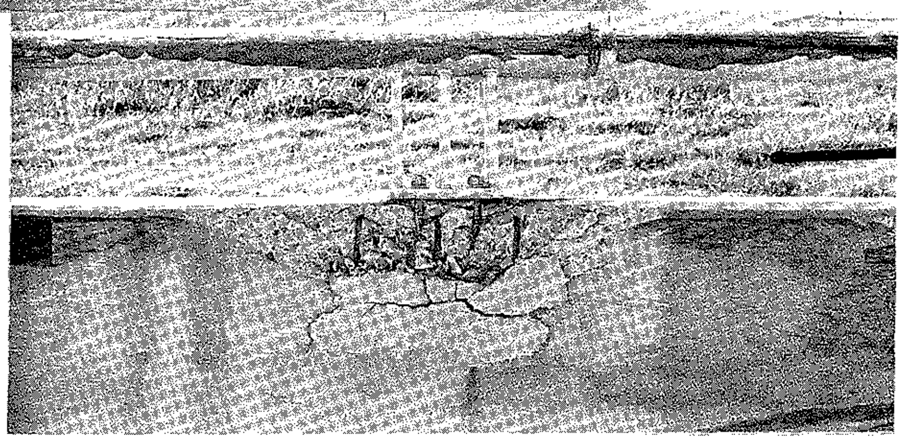
Post 5



Post 6

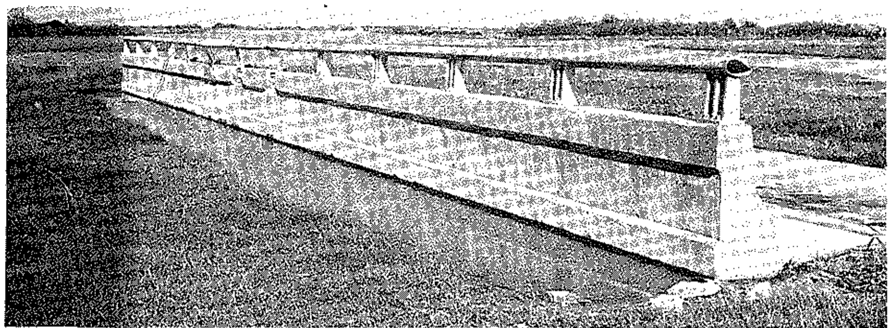


Post 7

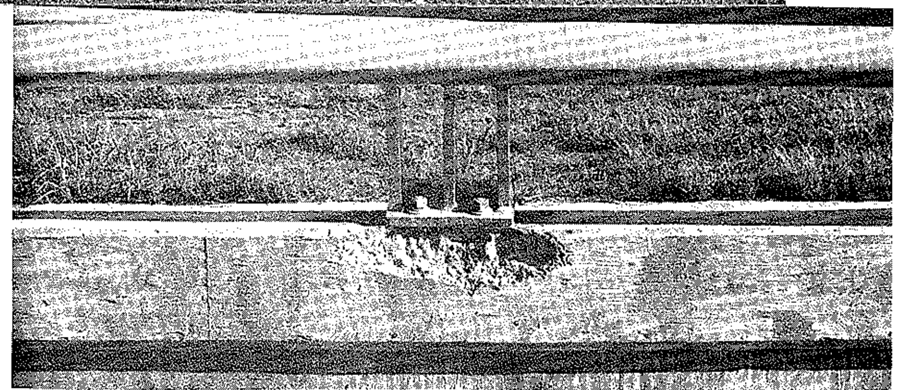


Post 8

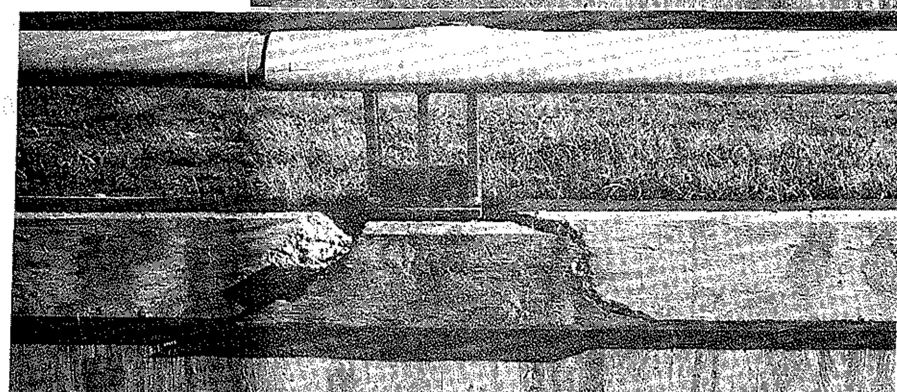
Figure C1. Crack Patterns on Traffic Side of the Rail After Test 2416-1



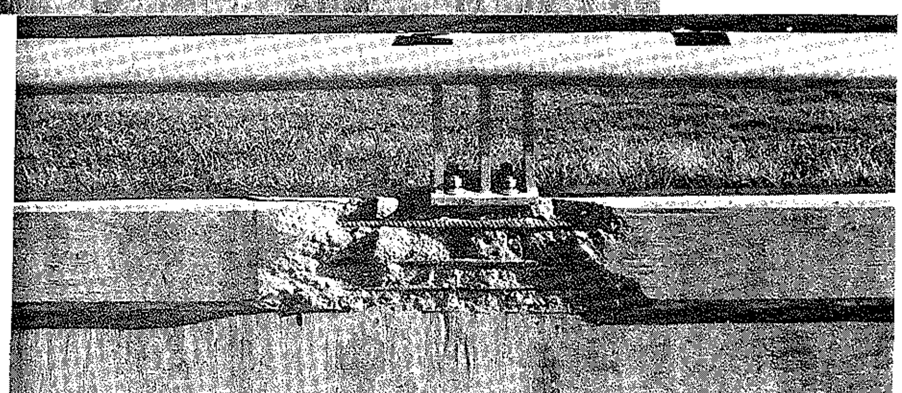
Post 5



Post 6



Post 7



Post 8

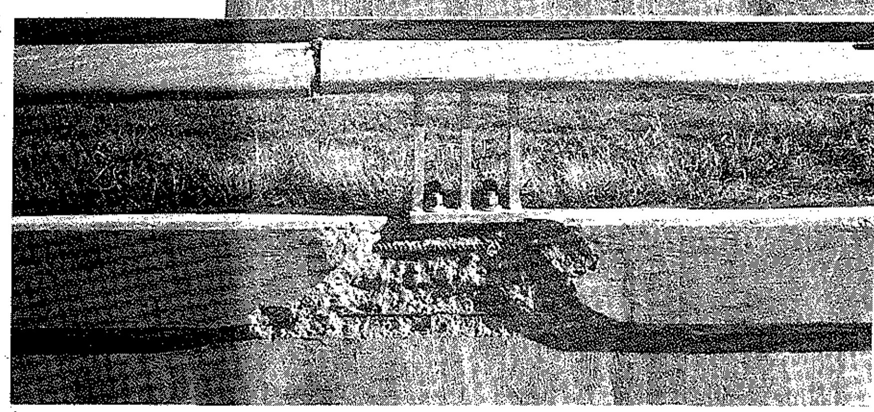


Figure C2. Crack Patterns on Field Side of the Rail After Test 2416-1