# Concrete Safety Shape with Metal Rail on Top To Redirect 80,000-lb Trucks

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ABSTRACT

Because the concrete safety shape 32 in. (81 cm) high is a popular median and bridge barrier, it was desirable to see if it could be modified and strengthened to make it an effective traffic rail for trucks. A metal traffic rail 18 in. (46 cm) high was mounted on top of the 32-in. (81-cm) 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 struck by such a truck at 48.4 mph (77.9 km/hr) at an angle of 14.5 degrees. The bridge rail did restrain the truck on the simulated bridge. The truck did roll on its side. This was attributed to the 9.5-in. (24-cm) setback of the metal rail from the sloping face of the concrete safety shape, which produced a roll angle of 11.3 degrees before the vehicle contacted the metal rail. The final position of the truck was parallel to and in front of the rail.

Current bridge rails are designed to restrain and redirect passenger automobiles 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 that will restrain and redirect large trucks have been designed recently (1,2). Because the concrete safety shape 32 in. (81 cm) high 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 automobile 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 1. The design was based on data presented elsewhere (1-7).

The combination rail selected was a modification of the Texas Type T5 traffic rail with a modified Texas Type C4 metal traffic rail mounted on top. The modified T5 rail consists of a concrete safety shaped parapet 32 in. (81.3 cm) high. The concrete parapet was thickened to 10.5 in. (27 cm) at the top and 20 in. (51 cm) at the bottom and contains a large amount of reinforcing steel. This provides both flexibility and strength, thus minimizing cracking of the concrete and permanent deflection of the rail when struck by heavy vehicles. The thickness of the bridge deck below the concrete parapet was increased to minimize cracking and provide greater strength.

## DESIGN TECHNIQUE

Earlier tests have shown that the greatest forces generated during the redirection of tractor-trailer vehicles occur when the tandem axles of the tractor and the front of the trailer strike 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 have an even smaller impact. Given that the total loaded weight on the tandem axles of the tractor would be approximately 34,000 lb (15 436 kg) (Figure 1), 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 elsewhere (3).

## DESCRIPTION OF BRIDGE RAIL AND DECK MODIFICATIONS

The modified T5 rail has a modified Texas Type C4 metal rail 18 in. (45.7 cm) tall mounted on top. This makes a combination bridge rail 50 in. (127 cm) tall that is designed to retain large 80,000-lb (36 287-kg) van-type trucks or tractor-trailers striking at 15 degrees and 50 mph (80.5 km/hr). Drawings of this rail are shown in Figures 2-4. Figure 5 shows photographs that compare the size of this bridge rail with the van-type tractor-trailer.

The concrete parapet was basically a standard Texas Type T5 traffic rail that 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 No. 5 stirrups spaced at 8 in. (20 cm) as shown, and eight No. 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 as shown in Figure 3. The first modification involved the use of one additional steel post plate 1 in. (2.54 cm) thick

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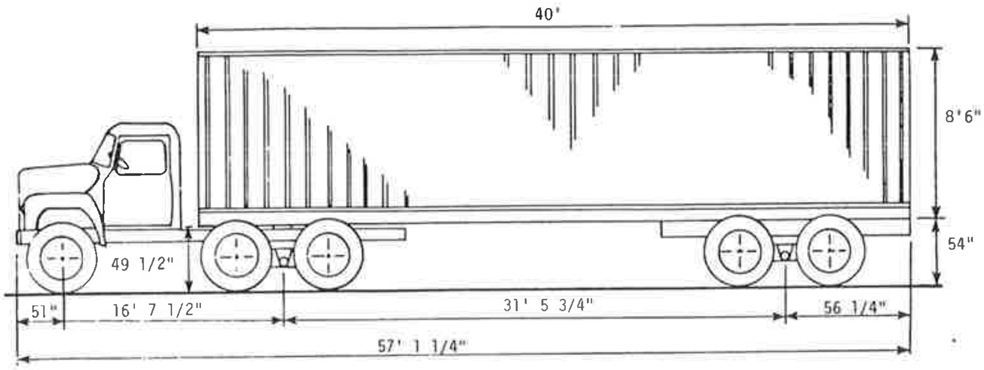



| | |
|---|---|
| EMPTY WEIGHTS | |
| Tractor only | 18,320 lb |
| Trailer only | 13,760 lb |
| Total Empty Weight | 32,080 lb |
| LOADED WEIGHTS | |
| Weight on front axle | 12,020 lb |
| Weight on Center axles | 34,170 lb |
| Weight on rear axles | 33,890 lb |
| Total Loaded Weight | 80,080 lb |

**FIGURE 1** Tractor-trailer loaded dimensions, empty weights, and loaded weights.

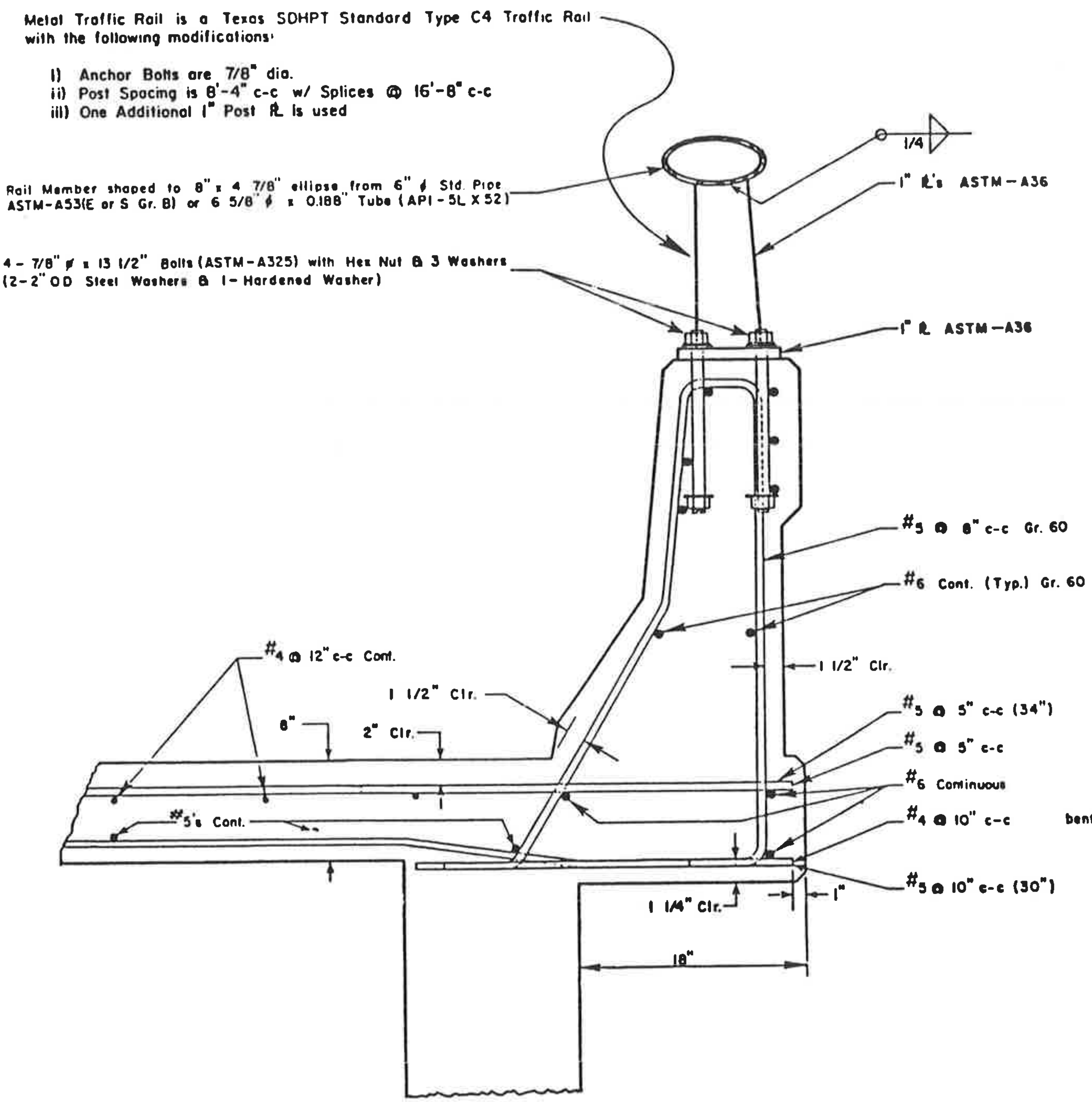



**FIGURE 2** Cross section of the modified T5 bridge rail.

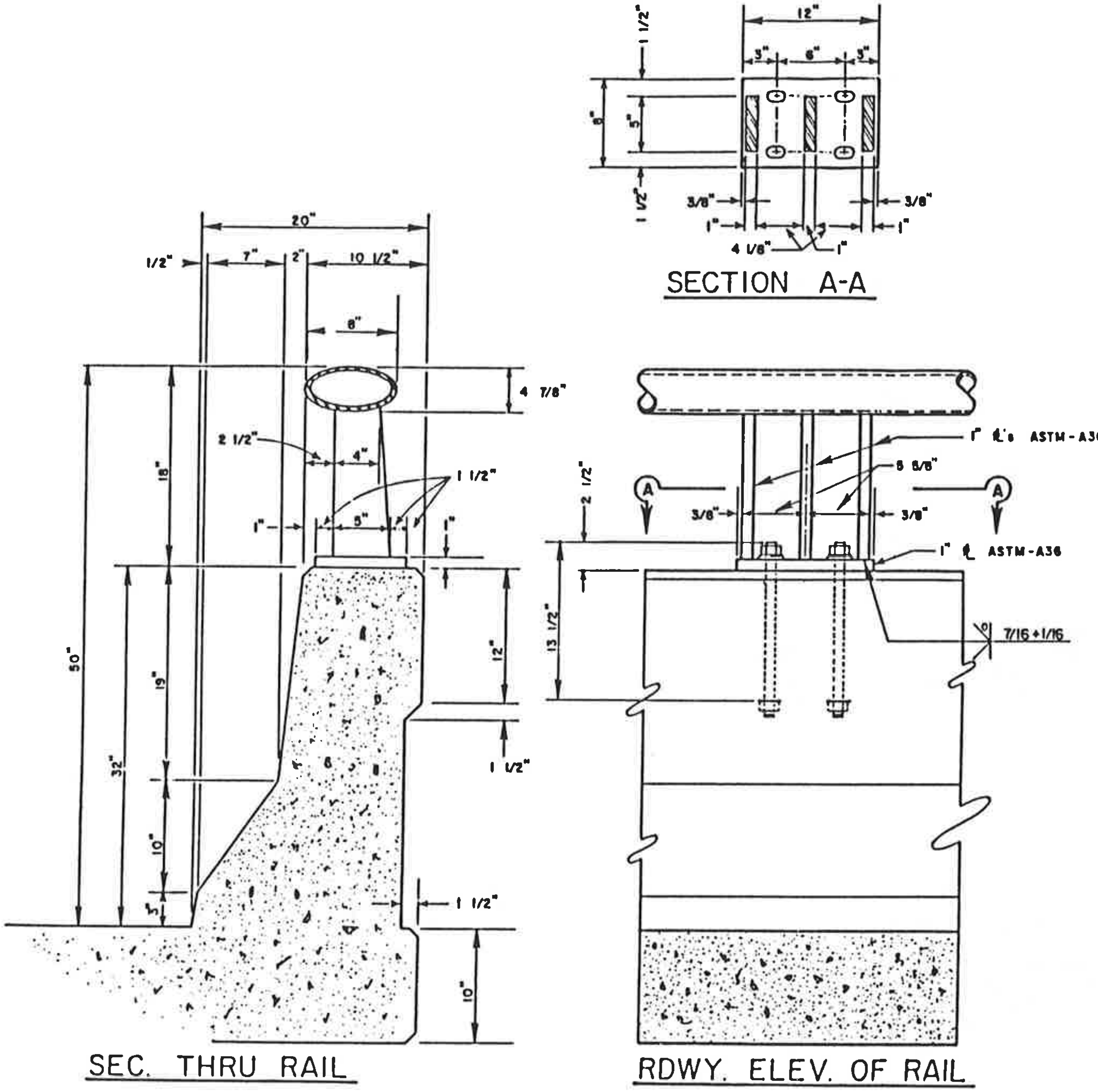


FIGURE 3 Dimensions and elevation of the modified T5 bridge rail.

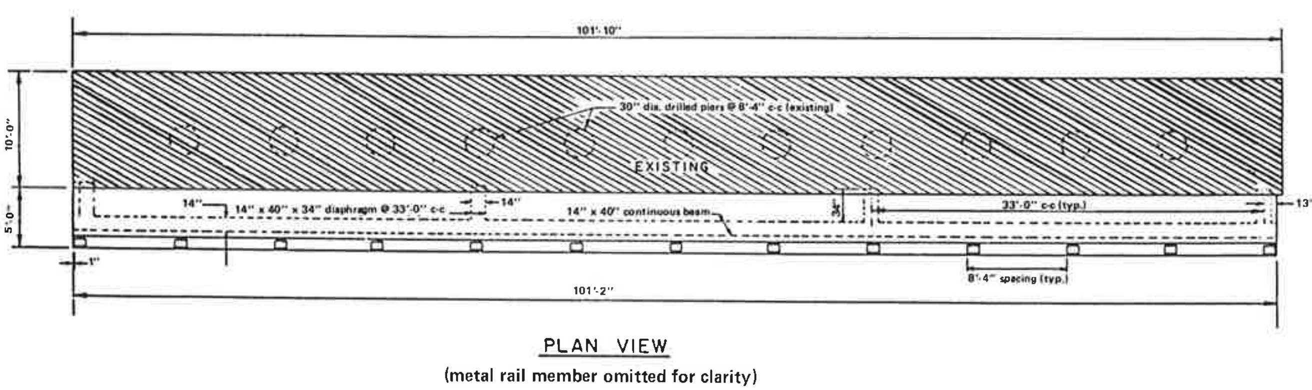


FIGURE 4 Plan view of the modified T5 bridge rail.

FIGURE 5 Comparison of 80,000-lb van-type truck and modified T5 bridge rail.

(ASTM-A36). This modification brought the total number of post plates used in each post to three. The second modification was the use of ASTM-A325 bolts 7/8 in. (2.2 cm) in diameter 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.

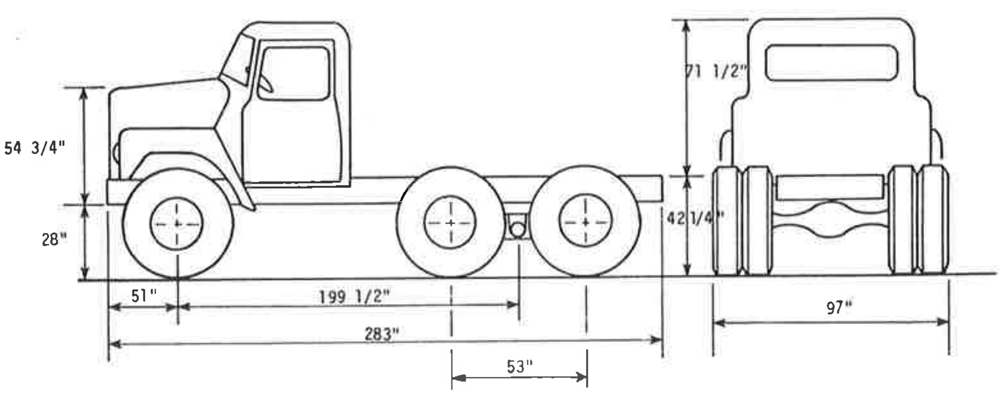
The metal rail was fabricated from standard steel pipe 6 in. (15 cm) in diameter (ASTM A53 Grade B) shaped into an ellipse 8 in. x 4 7/8 in. (20 cm x 12.4 cm) and welded to the modified post mentioned previously. These posts were in turn welded to a base plate made of steel plate 1 in. (2.54 cm) thick (ASTM-A36). The posts were anchored to the concrete rail by means of four A325 bolts 7/8 in. (2.2 cm) in diameter by 13.5 in. (34.3 cm) long. One steel washer 2 in. (5.1 cm) in diameter and one hardened steel washer were installed under each bolt nut.

The strength of the Texas standard bridge deck 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. (46 cm), and the thickness was increased to 10 in. (25.4 cm). The size of the upper transverse bars was maintained at No. 5s, and 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 No. 4s that extended into the lower portion of the bridge deck and straight No. 5s, each at a spacing of 10 in. (25.4 cm). The size of the upper and lower longitudinal bars was increased to No. 6s from No. 4s and No. 5s, and 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), and 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 3,600 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




| 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.

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 microcomputer, 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 that occurred during the impact.

FIGURE 7 80,000-lb truck before and after test.

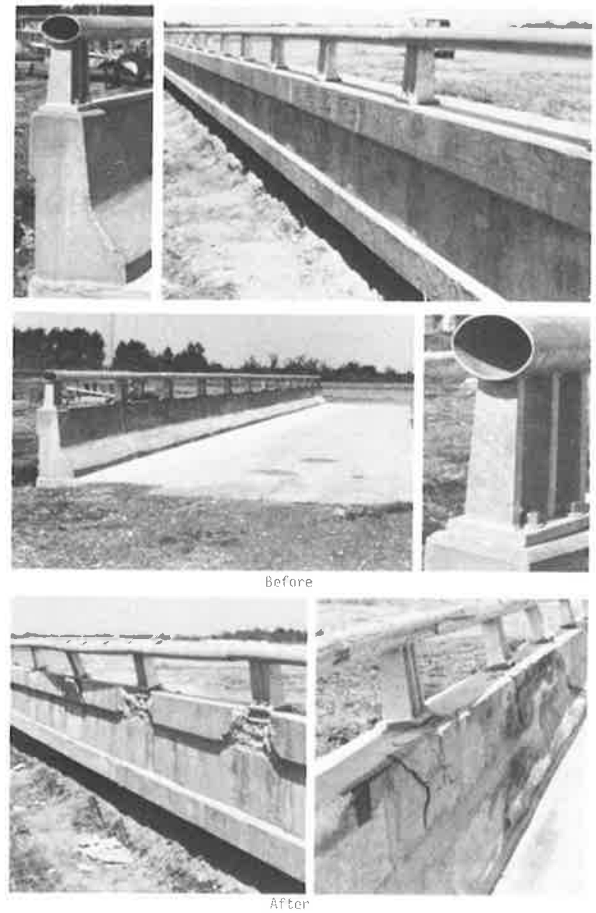


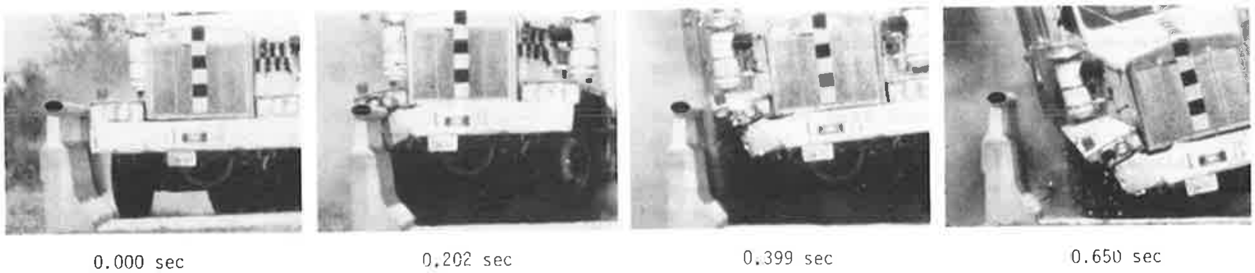

FIGURE 8 Bridge rail before and after test.

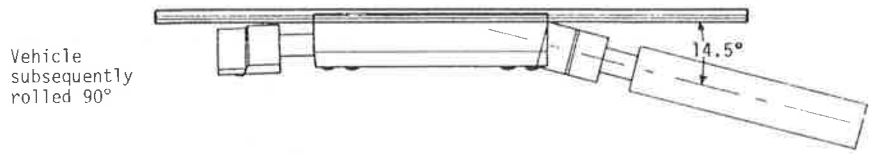
Still photography was used to record conditions of the test vehicle and bridge rail installation before and after the test. Motion photography was used to record the collision event.

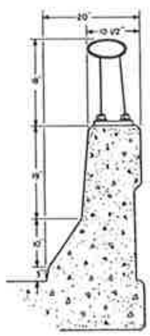
## TRUCK CRASH TEST

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 lb (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 1 and 6. Before-and-after test photographs of the truck are shown in Figure 7.

The truck struck the rail at 48.4 mph (77.9 km/hr) at a 14.5-degree angle. The impact point was 26 in. (66 cm) downstream from Post 5, and the truck was contained and redirected. The tractor-trailer did, however, roll 90 degrees and came to rest on its side approximately 175 ft (53 m) from the impact point. Figure 8 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 Figure 9.



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 9 Summary of data for Test 2416-1.**

The bridge deck supporting the rail sustained no damage. The concrete parapet was not significantly damaged, but the metal rail experienced damage between Posts 5 and 8 (Figure 10). 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 trafficside anchor nuts of Posts 5 and 6 of the metal rail. Examination revealed that the thread fit was too loose on the bolts 7/8 in. (2.2 cm) in diameter

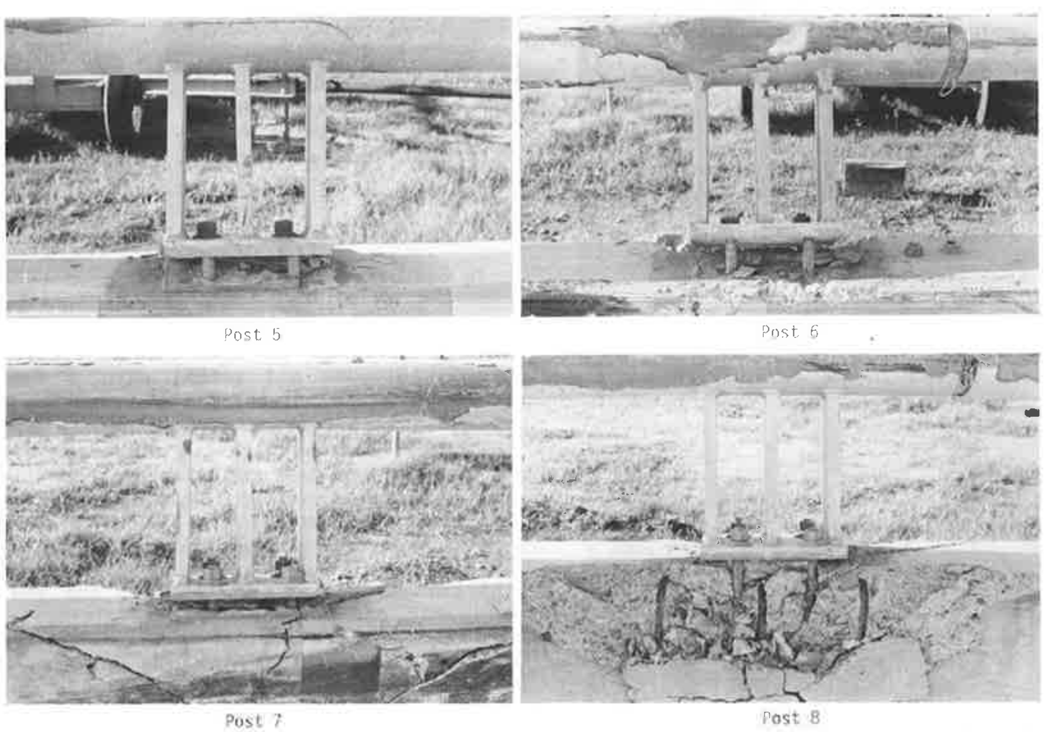



**FIGURE 10 Posts 5-8 after test.**

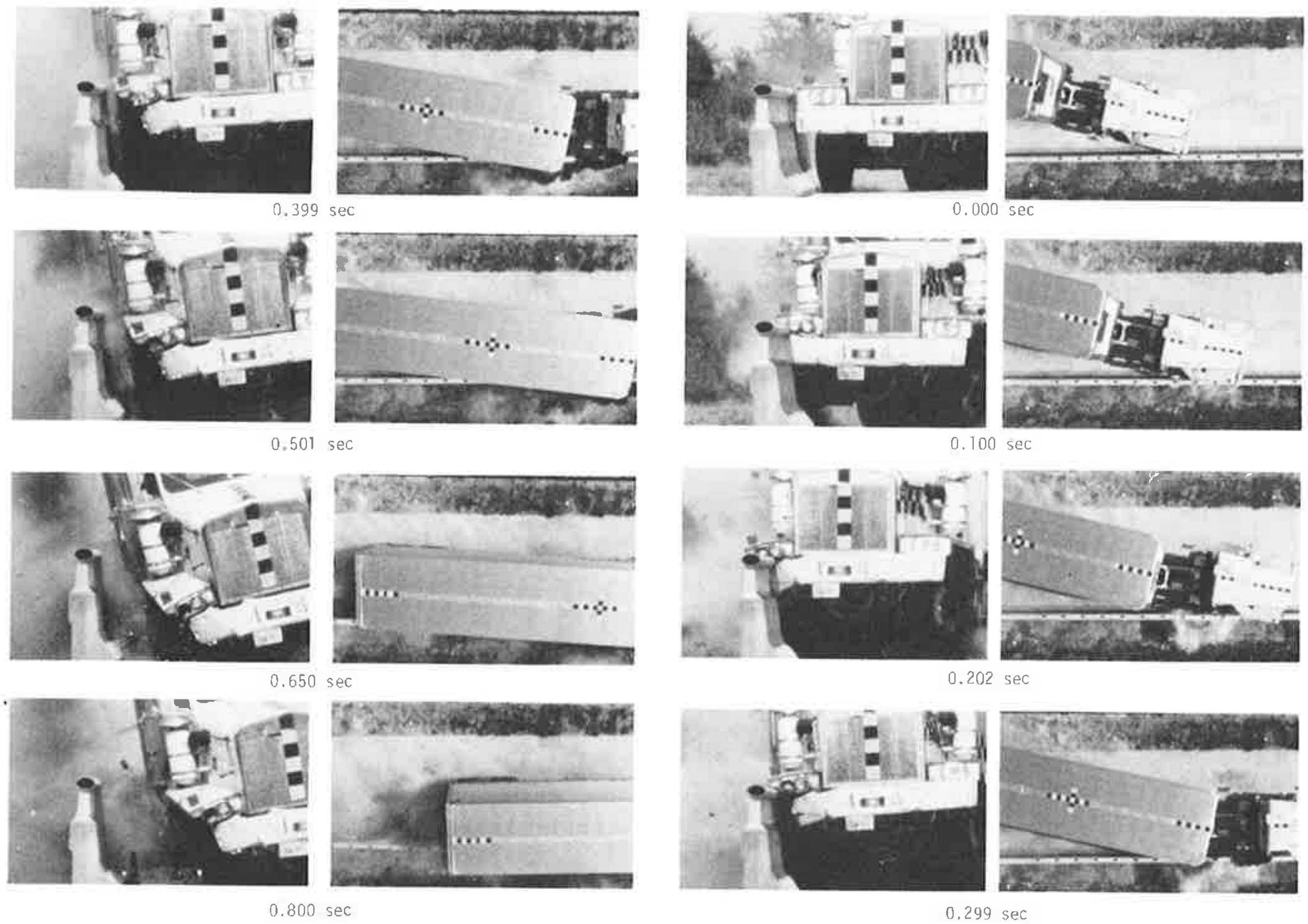



**FIGURE 11 Sequential photographs of Test 2416-1.**

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 trafficside anchor bolts of Posts 6 and 7 pulled loose from the concrete parapet. Figure 11 is sequential photographs showing overhead and frontal views of the crash test.

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 gyroscopes and the x, y, and z accelerometers are shown in Figures 12-15.

## DISCUSSION OF RESULTS

NCHRP Report 230 recommends the following criteria for Test S20 (80,000 lb/50 mph/15 degrees) (5,p.10):

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.

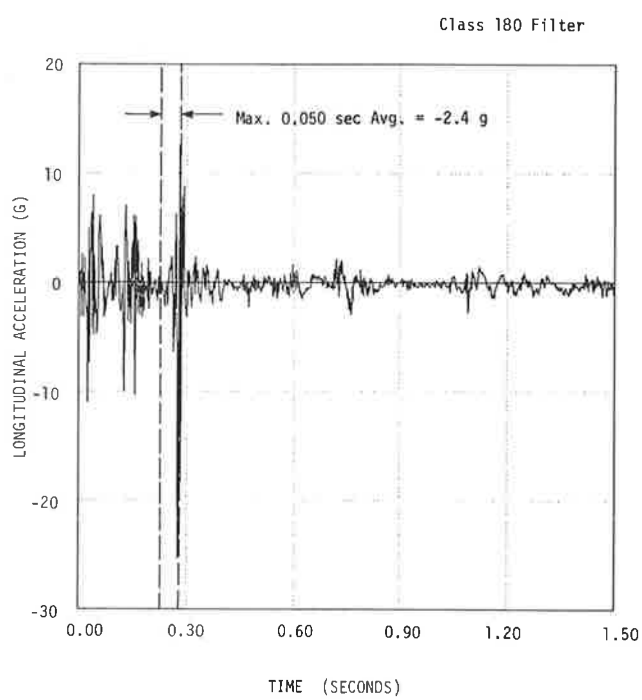



**FIGURE 12 Vehicle longitudinal accelerometer trace for Test 2416-1.**

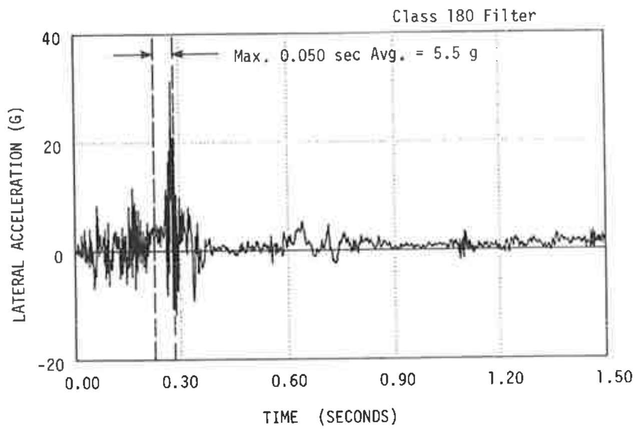



**FIGURE 13 Vehicle lateral accelerometer trace for Test 2416-1.**

According to these criteria the test was a success even though the truck rolled on its side. The bridge rail contained and redirected the truck and remained totally intact while doing so. The roll 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. Hirsch and Arnold (1) report that where the redirection face of the rail was vertical no roll 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 automobiles are 40 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. These recommended

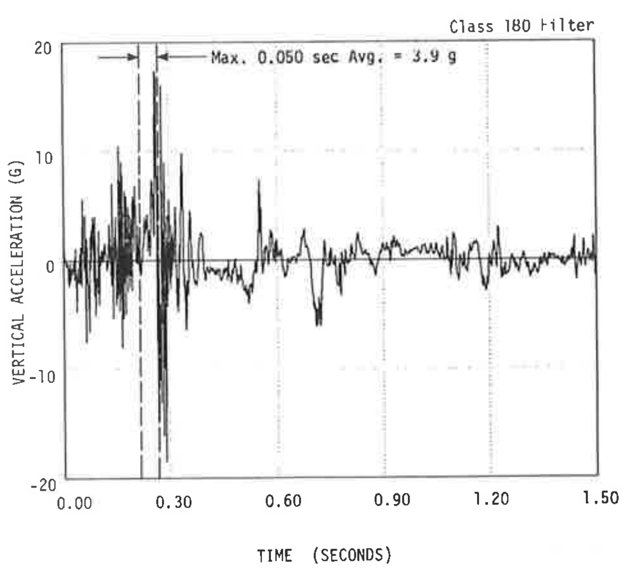



**FIGURE 14 Vehicle vertical accelerometer trace for Test 2416-1.**

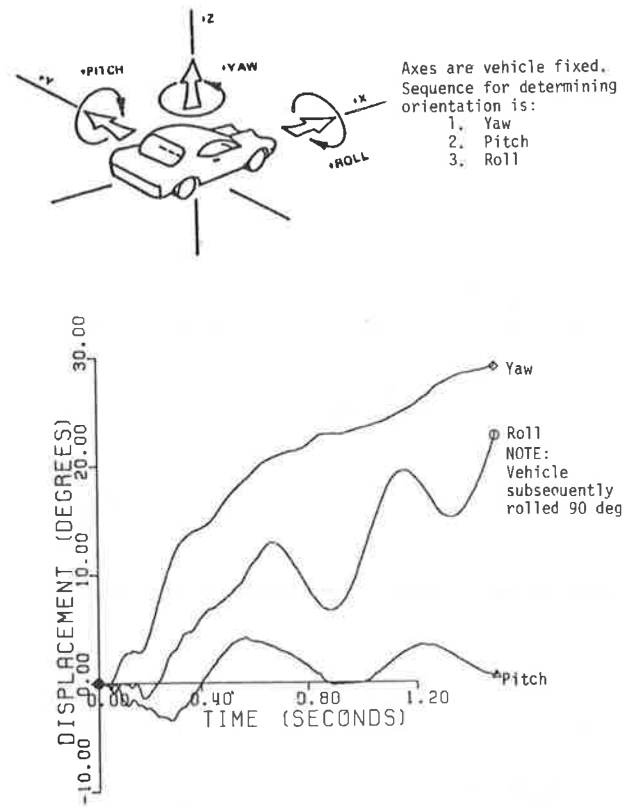



**FIGURE 15 Vehicle angular displacement for Test 2416-1.**

threshold values do not apply to large trucks. They are presented here only for comparison purposes.

## 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, and 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 striking the rail at 48.4 mph (77.9 km/hr) 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. Although the truck rollover was not desirable, the bridge rail did meet the S20 criteria of NCHRP Report 230 (5).

The four ASTM-A325 anchor bolts 7/8 in. (2.2 cm) in diameter by 13 1/2 in. (34.3 cm) long 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 length of 13 1/2 in. (34.3 cm) should be increased to at least 18 in. (46 cm) 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 large van-type tractor-trailer trucks.

The cross-sectional area of this modified concrete safety shape is approximately 2.8 ft² (0.26 m²) compared with approximately 2.5 ft² (0.23 m²) for a standard Texas traffic rail Type T5. The cost of this modified rail would be approximately $80 per linear foot, whereas a standard Texas Type T5 traffic rail normally costs about $35 per linear foot.

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# Crash Cushion Improvement Priority and Performance Evaluation

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ABSTRACT

Traffic impact attenuators play a vital role in highway safety. When properly engineered, located, and maintained, impact attenuators can result in the savings of numerous lives and reductions in property damage. However, there have been widespread improper application and use of impact attenuators. The study on which this paper is based focused on location, design, and maintenance of traffic impact attenuators. As a case study, the current management and operational procedures used for the Highway Safety Appurtenances Replacement program of the District of Columbia were evaluated. Traffic characteristics and roadway environmental features that contribute to roadside collisions were identified and analyzed using a multiple regression technique. The analysis revealed that street light luminance, truck percentage, radius of horizontal roadway curvature, and attenuator offset distance are the factors most correlated to roadside collision incidents.

Impact attenuator systems are defined by AASHTO as "protective systems which prevent errant vehicles from impacting hazards by either smoothly decelerating the vehicle to a stop when hit head-on, or by redirecting it away from the hazard for glancing impacts." Many sources have shown that the installation of impact attenuators has proven to be a cost-effective means of saving lives and reducing the severity of fixed-object accidents. For example, the 1981 Highway Safety Stewardship Report (1) ranked it as the second most effective highway safety improvement, with a benefit-to-cost ratio of 3.1. Despite the effectiveness of impact attenuators, problems in location, design, field inspection, maintenance, and performance evaluation still exist.

In the past most crash cushions were installed at locations where the most obvious crash potential existed. As these obviously dangerous locations are improved, the most cost-effective locations in which to install future impact attenuators become less apparent. It can be difficult to identify these locations through the application of common sense and engineering judgment. Recent field reviews of impact

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