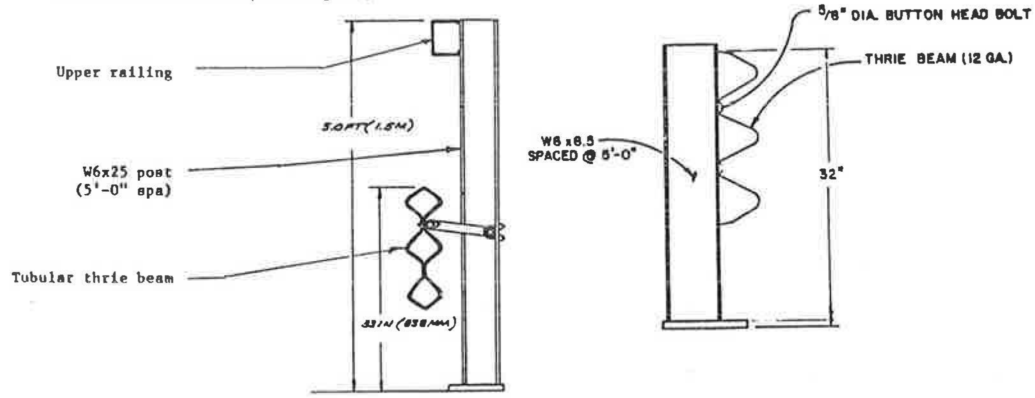
Figure 22. Estimated costs for through truss retrofit railing.

High Performance Retrofit		Low Service Retrofit	
Item	Est. Cost* ($/lin. ft.)	Item	Est. Cost* ($/lin. ft.)
1. Post — $100 ea.	20.70	1. Post — $25 ea.	5.00
2. Upper railing and hardware	4.00	2. Beam — 12 ga thrie & hardware	5.00
3. Tubular thrie beam and hardware	19.00	Total estimated cost	$10.00+
4. *Miscellaneous hardware	1.00		
Total estimated cost	$44.70+		

*Anderson Safeway Guard Rail Corp., Flint, MI
+Does not include installation and post anchorage costs.



1. One-lane structures,
2. Narrow 20-ft (6-m) wide 2-lane structures,
3. Bridges that have automobile traffic only, and
4. Bridges that have posted speed limits of 35 mph (55 km/h) or less that carry truck and bus traffic.

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Bridge Rail to Restrain and Redirect 80,000-lb Trucks

T.J. HIRSCH AND ALTHEA ARNOLD

A standard Texas traffic rail type C202 was modified to increase its height and strength to restrain and redirect an 80,000-lb (36,300-kg) van-type tractor-trailer under 50 mph (80.5 km/h), 15-degree angle impacts. The concrete parapet was increased to 36-in. (91-cm) high, and an elliptical steel rail was mounted on steel posts to increase the rail height to 54 in. (137 cm). One crash test was conducted on the bridge rail. The truck was restrained and redirected smoothly. This test has shown that a simple and economical rail can redirect heavy van-type trucks at speeds up to 50 mph (80.5 km/h) and 15-degree angle impacts. The cost of this rail is estimated at about $80 to $90/ft. Typical passenger car bridge rails in Texas now cost about $25 to $35/ft.

Current bridge rails are designed to restrain and redirect passenger cars. Hirsch (1) presented an analytical evaluation of Texas bridge rails to contain buses and trucks. In another report Hirsch (2) presented the results of crash tests on a modified Texas traffic rail type T202 that successfully redirected a 20,000-lb (9000-kg) school bus and a 32,000-lb (17 400-kg) intercity bus, both at nominally 60 mph (96 km/h) and 15-degree angles. With the increase in the number and size of large trucks the problem of truck-bridge rail collision is becoming more evident. The bridge rail tested here was selected and designed to restrain and redirect an 80,000-lb (36 287-kg) van-type tractor-trailer (3). The design was based on procedures and test data presented by Hirsch (1) and Buth (4).

The basic rail selected was a modification of the concrete parapet, Texas traffic rail type C202. The modified C202 rail consists of a concrete beam ele-

Figure 1. Cross section of modified C202 bridge rail.

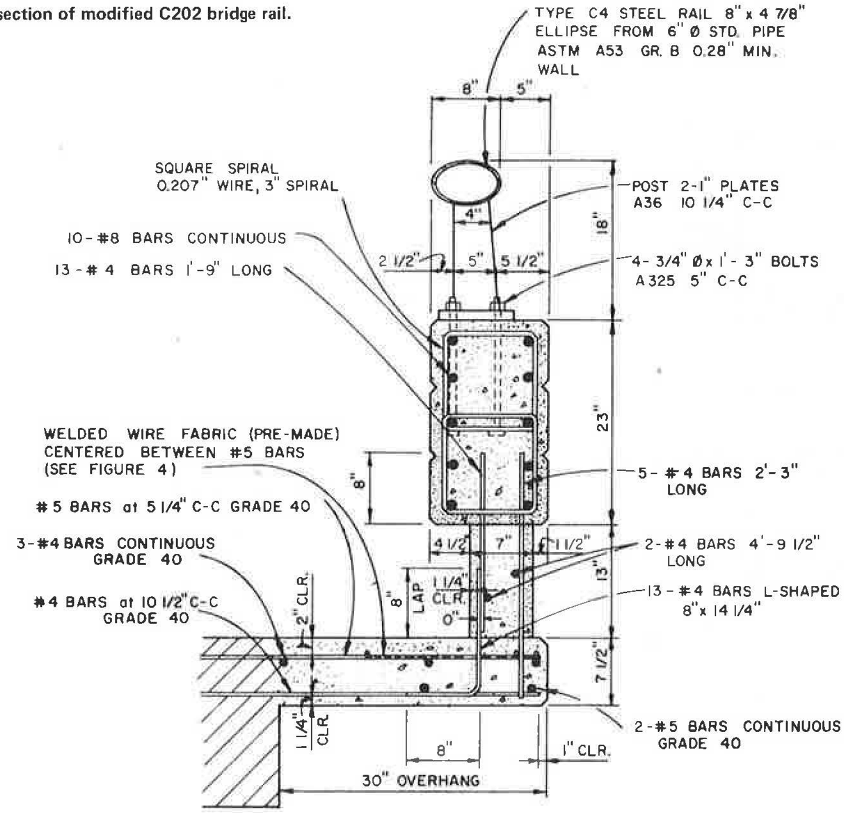
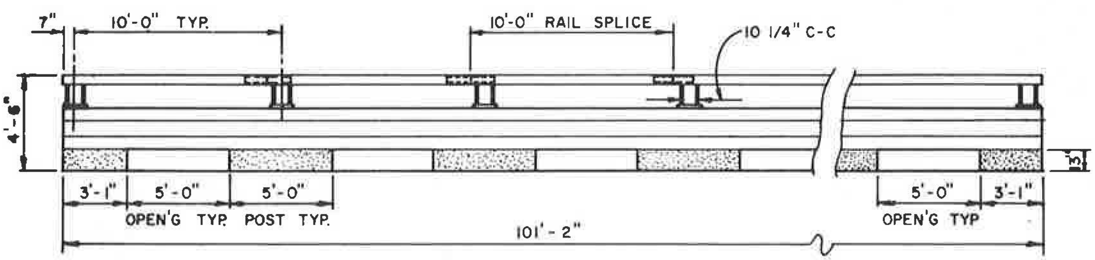


Figure 2. Elevation of modified C202 bridge rail.



ment 13 in. (33 cm) wide and 23 in. (58 cm) deep, mounted 36 in. (91 cm) high on concrete posts located at 10-ft (3-m) center-to-center spacing. The concrete posts are 7 in. (18 cm) thick by 5 ft (1.5 m) long concrete walls with 5-ft (1.5-m) openings. The beam element contains considerable reinforcing steel and provides flexibility, thus cracking of the concrete when impacted by heavy vehicles is kept to a minimum. The modified C202 concrete parapet can be placed in long, continuous lengths that give good structural continuity and strength.

To increase the effective height of this bridge rail another standard Texas steel rail designated as C4 was mounted on top of the concrete rail. The bridge deck strength was also increased in an attempt to reduce cracking or damage when the bridge rail is struck by a heavy vehicle.

BRIDGE RAIL AND DECK MODIFICATIONS

The modified combination rail C202 concrete post-rail has a type-C4 steel rail mounted on top. This modified bridge rail makes a combination bridge rail 54 in. (137 cm) high suitable to retain 80,000-lb (36 287-kg) van-type trucks or tractor-trailers that impact (3) at 15 degrees and 50 mph (80.5 km/h). Drawings of this rail are shown in Figures 1 and 2. Figure 3 contains photographs that compare the size of this combination bridge rail with a Honda Civic, a Plymouth, and a van-type tractor-trailer.

The strength of the standard Texas 7.5-in. (19-cm) thick bridge deck was increased by the addition of welded wire fabric centered under each post and along the deck steel to within 1 in. (2.5 cm) of the edge of the slab. A drawing of the welded wire fabric is shown in Figure 4. The deformed wire has a minimum yield strength of 70 kips/in.^{2} (48.3 kN/cm^2), and the smooth wire has a minimum yield strength of 65 kips/in.^{2} (44.9 kN/cm^2).

The concrete post was 13 in. (33 cm) high x 7 in. (17.8 cm) thick x 60 in. (152 cm) long with a 60-in. (152-cm) open space between each post. Each concrete post was anchored to the bridge deck by means of 13 no. 4 bars (traffic side) and 5 no. 4 bars (field side). The 13 no. 4 bars contained an 8-in. (20-cm) lap splice on top of the bridge deck that was intended as a breakaway connection.

The concrete rail on top of the post was 13 in. (33 cm) thick x 23 in. (58 cm) high for the entire length of the rail. It contained two sections of

Figure 3. Comparison of Honda, Plymouth, and 80,000-lb truck with modified combination rail.

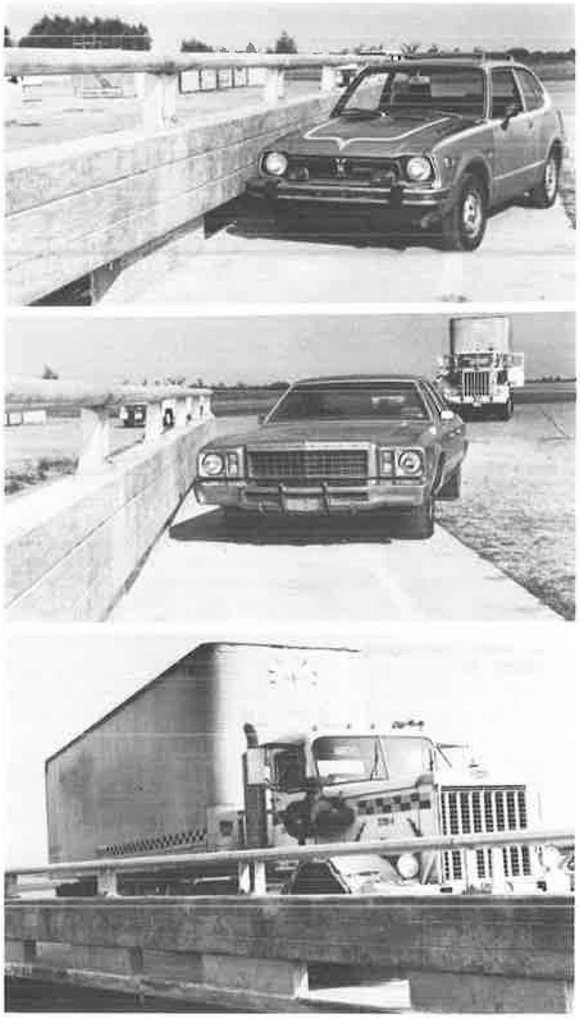
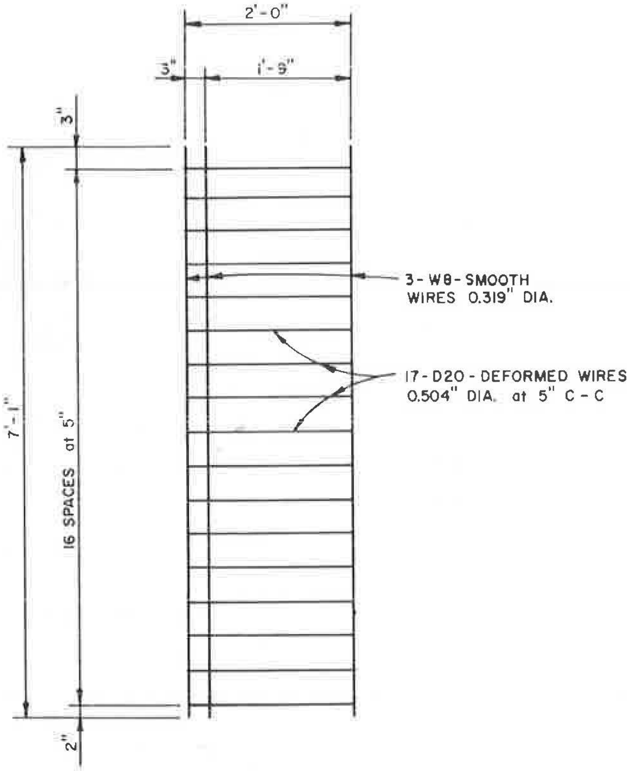


Figure 4. Detail of special slab reinforcement used under each concrete post.



square spiral, as shown, with 10 no. 8 bars along the length of the rail. The twin spirals were used instead of a single spiral because the square spiral was available from a producer of Texas standard pre-stressed square piling that requires this type of spiral.

The steel rail on top of the modified C202 concrete rail was the Texas standard type-C4 steel rail. It was made from 6-in. (15-cm) diameter standard steel pipe (ASTM A53 Grade B) shaped into an 8- x 4-7/8-in. (20- x 12.4-cm) ellipse and welded to a post and base plate made of 1-in. (2.54-cm) steel plates. This post was anchored to the concrete rail by means of four 3/4 in. diameter x 15 in. (38 cm) long A325 bolts. A high-cast steel conical washer was installed under each bolt nut. These washers were evidently the standard being supplied by the fabricator for this type of Texas bridge rail. The standard drawing indicates that only washers are to be supplied.

All steel bars in the concrete post and rail were grade 60, including the bent bars that anchor the post to the deck. The deck steel bars were grade 40. The concrete for the deck, post, and rail was such that its strength was 3,000 psi (2.068 kN/cm^2) at the time of the test.

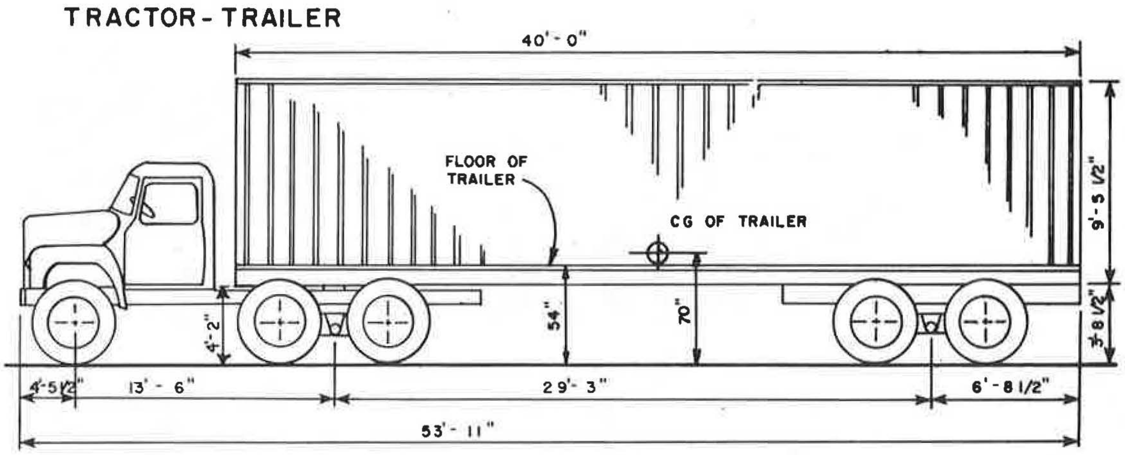
TRUCK CRASH TEST

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 1978 auto car tractor-trailer ballasted with sand bags to 79,770 lb (36 184 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 49.1 mph (79.0 km/h) and 15-degree angle. Impact occurred between posts 3 and 4, and the truck was redirected smoothly. Figure 9 shows the bridge rail and test site immediately after test 6. The truck entry and exit path can be seen clearly. The truck sustained damage to the right front and right tandem wheels. The trailer body bulged out slightly on the right side from the shift in load (sand bags). The trailer body was in contact with the upper railing over a length of approximately 40 ft (12 m) (Figure 8). This point of contact was centered about 4 in. (10 cm) above the trailer floor, which is at 54 in. (137 cm) as shown in Figure 5. A summary of the crash test data is given in the list below.

1. Test number--6;
2. Vehicle--van-type tractor-trailer;
3. Mass--79,700 lb (36 184 kg);
4. Speed--49.1 mph (79.0 km/h);
5. Film angle--15 degrees;
6. Angle of impact departure--6.3 degrees truck, 2.5 degrees trailer;
7. Angle of roll (max)--6.0 degrees truck, 16.5 degrees trailer;

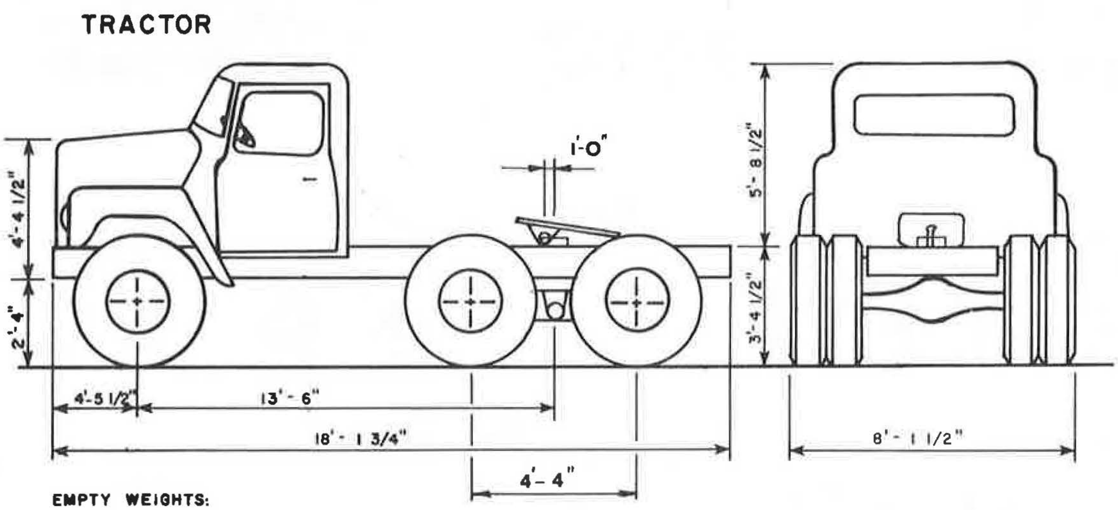
Figure 5. Tractor-trailer loaded dimensions, empty weights, and loaded weights.



EMPTY WEIGHTS:	
Weight on front axle	10,720 lbs
Weight on center axles	13,070
Weight on rear axles	8,880
Total Empty Weight	32,670 lbs

LOADED WEIGHTS:	
Weight on front axle	11,490 lbs
Weight on center axles	33,760
Weight on rear axles	34,520
Total Loaded Weight	79,770 lbs

Figure 6. Empty tractor dimensions and weights.



EMPTY WEIGHTS:	
Weight on front axle	10,320 lbs
Weight on rear axles	8,070
Total Empty Weights	18,390 lbs

8. Time to parallel--0.6 sec;
9. Barrier displacement--1.5 in. (3.8 cm) concrete rail, 12 in. (30.5 cm) steel rail;
10. Distance to parallel--35.6 ft (11.3 m) longitudinal, 2.05 ft (0.65 m) lateral;
11. Accelerometer data (located over the tractor tandem axles)--100 Hz low-pass maximum filter;
12. Maximum average 0.050 sec acceleration--1.68 g longitudinal, 5.94 g lateral, 6.28 g resultant; and
13. Peak acceleration--21.55 g longitudinal, 19.03 g lateral, 31.03 g resultant.

The bridge deck supporting posts 1 through 8 was cracked and damaged; the major portion of the damage centered around post 4. Test results on another ongoing research study have indicated the welded wire fabric shown by Figure 4 did not increase the deck or slab strength significantly. Sequential photographs showing the overhead and frontal view of the crash test are shown in Figure 10.

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 the filtered data from this instrumentation are presented in Figures 11-13.

Other data were gathered on the truck during the test. Maximum roll of the tractor tandem axles was 6 degrees from the roll rate gyros and of the

Figure 7. 80,000-lb truck before test.

Figure 8. 80,000-lb truck after test.

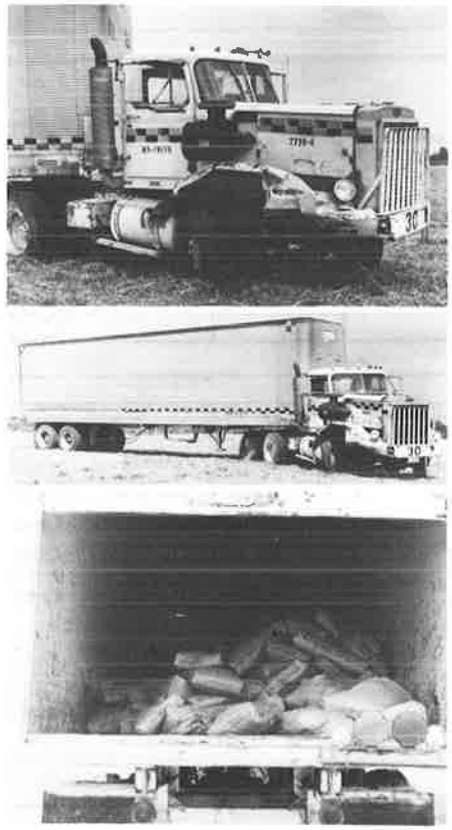


Figure 9. Bridge rail and truck after test.

Figure 10. Sequential photographs of test.

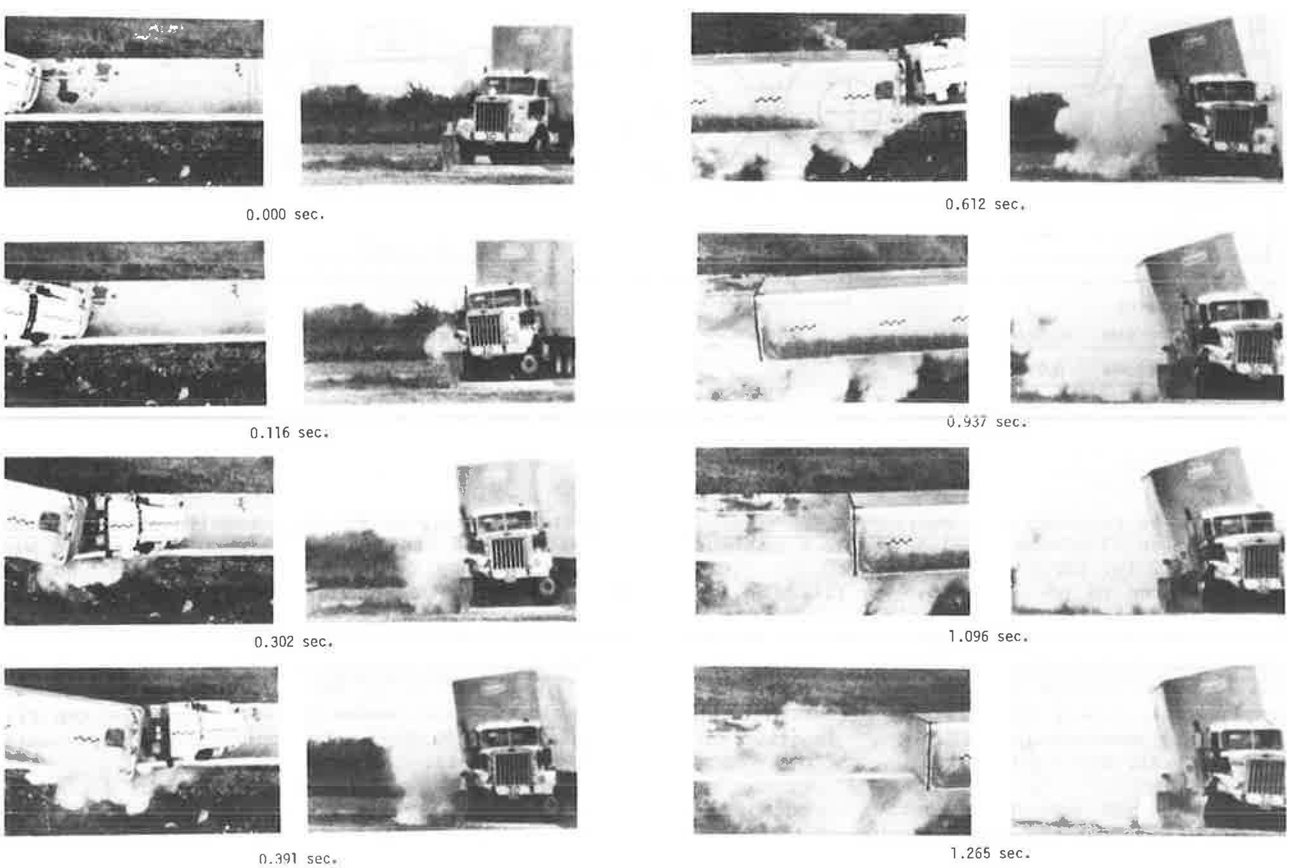


Figure 11. Vehicle longitudinal acceleration.

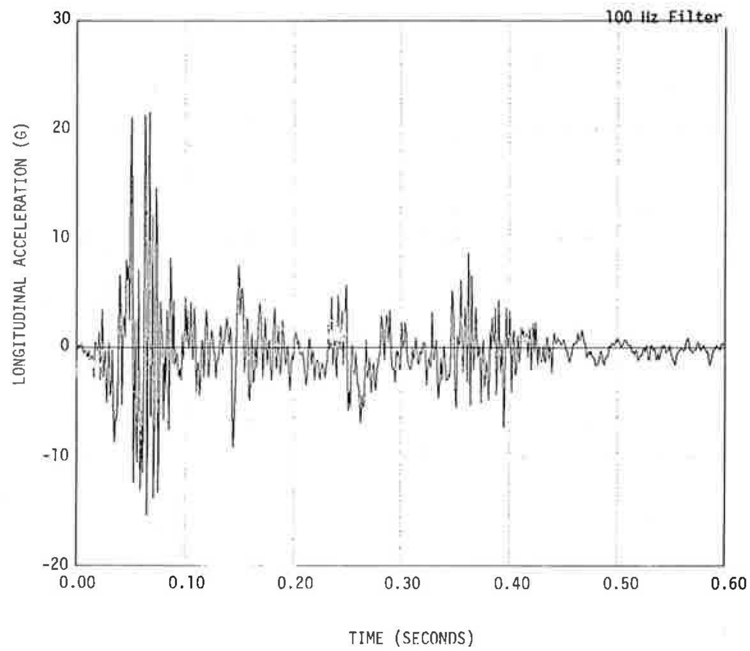


Figure 12. Vehicle transverse acceleration.

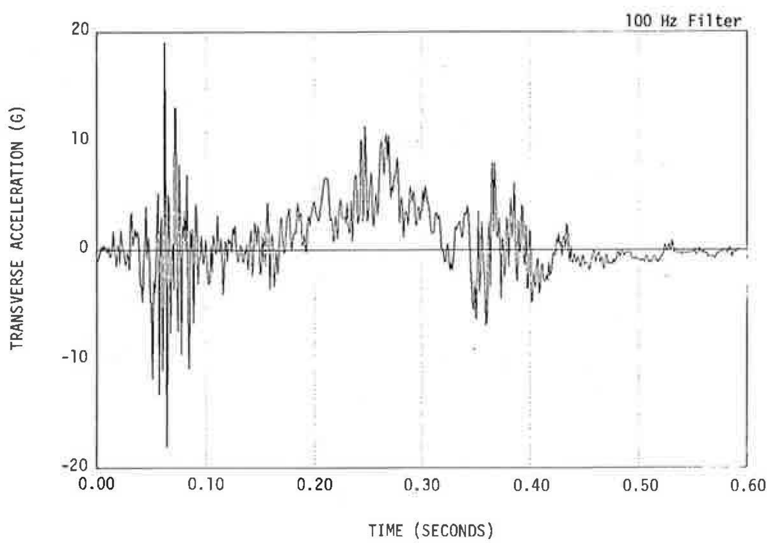
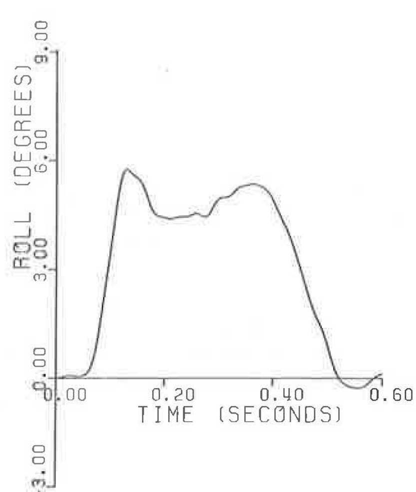


Figure 13. Roll versus time.



trailer 16.5 degrees from the high-speed film. From the accelerometers, the longitudinal, lateral, and resultant maximum average 0.050-sec accelerations were -1.68, 5.94, and 6.28, respectively.

DISCUSSION OF RESULTS

NCHRP Report 230 (3) recommends the following criteria for test S20 (80,000 lb/50 mph/15 degrees):

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.

According to these criteria the test was a success. The bridge rail contained and redirected the truck smoothly. The bridge rail also remained intact.

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 are 40 ft/sec and 30 ft/sec for the longitudinal and lateral occupant impact velocity, and 20 g for the highest 10 msec average after contact. The computed values for this test were well below the recommended values. The longitudinal impact velocity was 7.6 ft/sec, and the highest 10 msec average acceleration after impact was 1.2 g. The lateral impact velocity was 18.3 ft/sec, and the highest 10 msec average acceleration was 3.3 g.

The design intent of the upper C4 rail centered at 51.5 in. (131 cm) was to allow the relatively hard trailer floor to strike this rail and thus provide a resistance to overturning by the trailer. The trailer actually struck this rail about 6 in. (15 cm) above the centroid of the floor system and thus was in the relatively soft sheet metal portion of the trailer body. Some of the 16.5-degree roll angle of the trailer was thus due to this softer impact and some was due to the early fracture of the cast steel washers on the anchor bolts.

SUMMARY AND CONCLUSIONS

A standard Texas traffic rail type C202 was modified by increasing its height and strengthened so that it could restrain and redirect an 80,000-lb van-type truck or tractor-trailer. The modified C202 rail consisted of a concrete beam element 13 in. (33 cm) wide and 23 in. (58 cm) deep, mounted 36 in. (91 cm) high on concrete posts located at 10-ft (3.0-m) center-to-center spacing. The concrete posts were 7 in. (18 cm) thick by 5 ft (1.5 m) long concrete walls with 5-ft (1.5-m) openings between each post. To increase the effective height of the bridge rail, a standard type C4 steel rail was mounted on top of the concrete rail.

The crash test was conducted on this bridge rail with a 79,770-lb (36 184-kg) van-type tractor-trailer impacting the rail at 49.1 mph (79.0 km/h) and 15 degrees. The vehicle was smoothly redirected. Damage to the truck and rail was moderate.

One significant conclusion that can be deduced from this test is that the upper rail centered at 51.5 in. (131 cm) probably would have performed better had it been lower and if the post anchorage cast steel washers had not shattered prematurely. The trailer roll angle (16.5 degrees) probably would have been smaller. Part of the trailer roll angle was due to the rail contacting the soft body sheet metal. Had the upper rail posts been stiffer and if the rail had contacted the trailer floor as was the design intent, the trailer roll angle would have been reduced. Thus, some believe that a better location for the upper rail would have been at a height of about 51 in. (130 cm) rather than the 54-in. (137-cm) height used.

This test has shown that a bridge rail can be built on standard concrete decks to contain large van-type trucks and redirect them without rollover.

The cost of this heavy truck bridge rail is estimated at about $80 to $90/linear ft. The cost of typical metal or concrete bridge rails now in use in Texas is about $25 to $35/linear ft.

ACKNOWLEDGMENT

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Crash Cushion for Narrow Objects

DEAN L. SICKING AND HAYES E. ROSS, JR.

A crash cushion designed for narrow objects such as the end of the concrete safety shaped barrier is described. Features of the cushion are as follows: (a) it meets current safety performance standards, (b) it is constructed of readily available materials (steel barrels, thrie beams, steel channels, and steel cables), and (c) it is relatively inexpensive to install and maintain. Also presented in the paper are results of four full-scale vehicle crash tests conducted in accordance with recommended procedures in Transportation Research Circular 191. The crash cushion met the performance standards of the circular and NCHRP Report 230.

The concrete safety shape barrier (CSSB) has gained widespread use in recent years and has been both a cost-effective and crashworthy system. When the barrier must be terminated within the clear zone, however, the exposed end poses a serious hazard to the motorist. Four acceptable end treatments are now available:

1. Flare the barrier end out of the clear zone (at an acceptable flare angle) or bury the end in a cut slope (this option is available for roadside barrier application only);
2. Use the guardrail energy absorbing terminal (GREAT), which is a proprietary system;
3. Use the median barrier breakaway cable terminal; and
4. Use an approved crash cushion.