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16. Abstract

A standard Texas traffic rail Type T202 27 in. high was strengthened and modified so that it could restrain and redirect school and intercity buses under 60 mph (96.6 km/hr) 15° angle impacts. A semi-elliptical extruded aluminum rail was mounted on cast aluminum posts to increase the rail height to 42 in. (107 cm). Three crash tests were conducted on the bridge rail. The first test was with a 66-passenger school bus weighing 19,690 lb (8,931 kg) and impacting the rail at 54.4 mph (87.6 km/hr) at a 15° angle. The bus was smoothly redirected. The second test was with an 1800 lb (817 kg) minicar with front wheel drive and impacting the rail at 59.4 mph (95.6 km/hr) at a 15° angle. The vehicle was redirected but the small front wheel did penetrate the 13 in. (.33 m) opening under the concrete beam and snagged a post. The third test was with an intercity bus weighing 32,080 lb (14,562 kg) and impacting the rail at 61.1 mph (98.3 km/hr) at a 15° angle. The intercity bus was restrained and smoothly redirected. These tests have shown that a simple and economical rail can redirect school and intercity buses at speeds up to 60 mph (96.6 km/hr) and 15° angle impact. The cost of this rail is estimated at about $41 per foot.

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BRIDGE RAIL TO RESTRAIN AND REDIRECT BUSES

by

T. J. Hirsch
Research Engineer and Principal Investigator

Research Report 230-3

on

Research Study No. 2-5-78-230
Bridge Rail to Contain Heavy Trucks and Buses

Sponsored by

Texas State Department of Highways and Public Transportation

in cooperation with

The United States Department of Transportation
Federal Highway Administration

February 1981

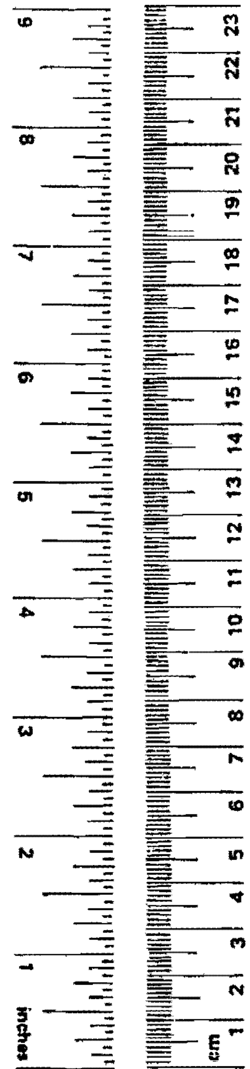
Texas Transportation Institute
The Texas A&M University System
College Station, Texas

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

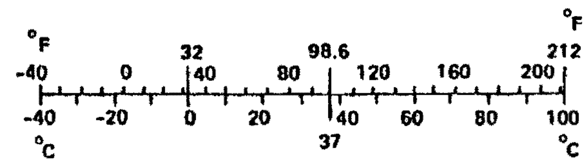
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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, Heavy Vehicles

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IMPLEMENTATION STATEMENT

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

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INTRODUCTION

Research Report 230-2 presented an analytical evaluation of Texas bridge rails to contain buses and trucks. The objective of the 1978-79 research effort was to select an existing Texas bridge rail design and to modify or strengthen it if necessary to give it the capability of redirecting buses and/or trucks.

The basic rail selected was a concrete parapet Texas traffic rail type T202. The T202 rail consists of a concrete beam element 10 in. (.25 m) wide and 14 in. (.36 m) deep mounted 27 in. (.69 m) high on concrete posts located at 10 ft (3 m) center-to-center spacing. The concrete posts are actually 7 in. (.18 m) thick by 5 ft (1.5 m) long concrete walls with 5 ft (1.5 m) openings. This rail has proven to be a very effective and attractive rail in Texas. The 5 ft (1.5 m) openings in the concrete parapet provide visibility and minimize the buildup of trash, dust or snow behind the parapet. The beam element contains considerable reinforcing steel and provides flexibility, thus minimizing cracking of the concrete when the bridge flexes under heavy vehicle wheel loads. Consequently, this concrete parapet does not require frequent joints as most all other concrete rails do. It can be placed in long, continuous lengths giving good structural continuity and strength.

To increase the effective height of this bridge rail, a semi-elliptical extruded aluminum rail was mounted on 15 in. (.38 m) high cast aluminum posts. This particular aluminum rail is currently used on the Texas traffic rail type T4 and is very popular along the Texas gulfcoast where corrosion can be a problem.

DESCRIPTION OF BRIDGE RAIL

The T202 concrete parapet and T4 aluminum rail make a combination bridge rail 42 in. (1.07 m) high with excellent strength and functional properties as shown by Figures 1 and 2. A detailed description of this modified T202 bridge rail is presented in Appendix A. A summary of further modifications made to the T202 concrete and T4 aluminum rail are given below.

The longitudinal reinforcing in the beam of the T202 rail was increased from six ½ in. diameter steel bars to eight 5/8 in. diameter steel bars. The rectangular spiral reinforcing steel was doubled by reducing the pitch from 6 in. (15 cm) to 3 in. (7.6 cm). The spacing of the cast aluminum posts on the T4 rail was increased from 8 ft-3 in. (2.51 m) to 10 ft (3.05 m) to match the spacing of the concrete posts (wall segments) on the T202 concrete rail.

This modified T202 bridge rail, shown by Figures 1 and 2, was installed on a typical Texas bridge slab which was designed and reinforced in accordance with the AASHTO Standard Specifications for Highway Bridges (3)*. This was considered important because previous research (1) and past experience have indicated that bridge slabs designed in accordance with AASHTO specifications are weaker than the bridge rail post. Failure or serious cracking will usually occur in the bridge slab and not in the post. This usually creates a costly maintenance problem following serious vehicle impacts.

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*Numbers in parentheses, thus (3), refer to corresponding items in reference list.

The reinforcing steel used in the concrete slab was grade 40. Tensile tests on the steel indicated an average yield strength of 61 ksi (42.1 kN/cm^2) and an ultimate strength of 97 ksi (67 kN/cm^2). The reinforcing steel used in the rail was grade 60 with a specified minimum yield strength of 60 ksi (41.4 kN/cm^2). The concrete for the deck and rail was 6 and 6.5 sacks per cubic yard, respectively. Each had a compressive strength of 3900 psi (2690 N/cm^2) at the time of the crash test.

The completed bridge rail installation is shown in Figure 3.

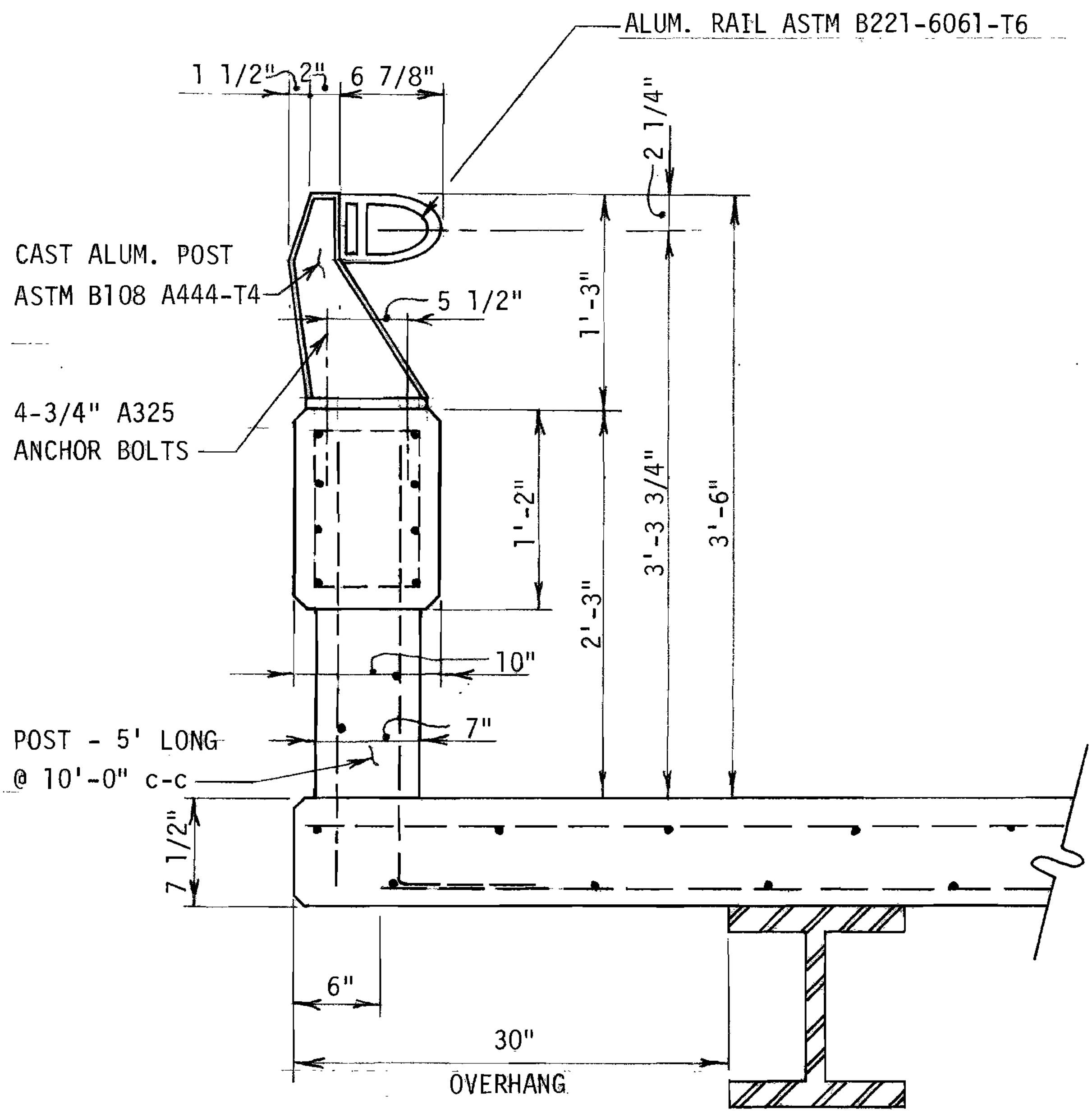
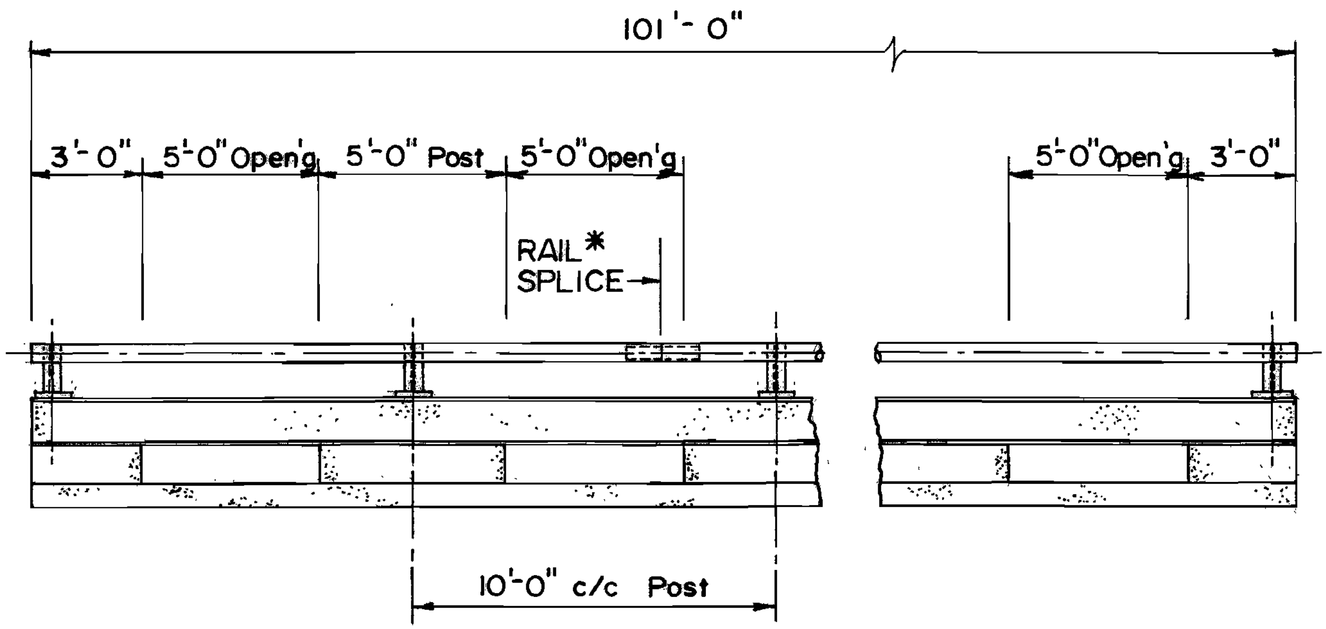


Figure I Cross Section of Modified T202 Bridge Rail



* Splice may be at any location but no more than one in any four adjacent panels.

Figure 2 Elevation of the modified T202 Bridge Rail

VEHICLE CRASH TESTS

Previous structural analyses of this bridge rail (1) indicated that it was capable of redirecting a typical 66-passenger, 20,000 lb (9,072 kg) school bus, as shown in Figure 7. The research plan was to impact the bridge rail with a 20,000 lb (9,072 kg) school bus at 60 mph (96.6 km/hr) and 15^{o}. If the rail survived this test, then it would be impacted with a 32,000 lb (14,515 kg) intercity bus at 60 mph (96.6 km/hr) and 15^{o}. The Federal Highway Administration further recommended that the rail be impacted with an 1800 lb (817 kg) minicar at 60 mph (96.6 km/hr) and 15^{o}.

A summary of the three crash tests conducted on this bridge rail is shown by Table 1. This table also presents a summary of the pertinent data collected. Appendix A presents a detailed description of the bridge rail installation. Appendix B presents a more detailed description of the buses and car used in the tests. Appendix C presents sequential photographs of the crash tests and also more detailed photographs of damage to the bridge rail after test 5. Appendix D presents the more detailed electronic data concerning accelerations, roll, pitch and yaw of the vehicles during the crash tests.

Test No. 3 - School Bus

In test No. 3, a 1970 Ford, 66-passenger school bus weighing 19,690 lb (8,931 kg) impacted the bridge rail at 54.4 mph (87.6 km/hr) at 15^{o}. The bus was smoothly redirected and departed the rail at an angle of 3.5^{o}. The bus was very stable during the test, with a maximum roll angle of 13^{o}. No passengers (simulated by sandbags placed unrestrained on the seats) were ejected from the bus. The light damage to the school bus is shown by Figure 7. The very light damage to the bridge rail is shown by Figures 3, 4, 5 and 6. Note the location of the school bus after the test in Figures 3 and 4. The residual deflection in the aluminum rail was only 2 in. (5.1 cm) and nil in the concrete beam or parapet. The concrete bridge deck supporting posts 4, 5, and 6 were cracked slightly as shown by Figure 6. The bridge deck was repaired prior to test No. 4 by injection of epoxy glue. Figure 8 shows the repaired concrete deck and beam at post No. 4. Total cost of the epoxy injection done by a subcontractor was $2400.

Test No. 4 - Honda Civic

In test No. 4 a 1974 Honda Civic weighing 1800 lb (817 kg) impacted the bridge rail at 59.4 mph (95.6 km/hr) and 15^{0}. The precise point of impact was at midspan between posts No. 4 and 5 (see Figure 8). The purpose of this test was to see if the 13 in. (33 cm) wheel with an overall diameter of 22 in. (56 cm) would penetrate the 13 in. (33 cm) clear opening between the bridge deck and concrete beam and snag on a concrete post.

During impact the Honda was redirected and the right front wheel did contact the concrete post. The wheel was bent back and jammed against the front passenger compartment wall as shown in Figure 10. This metal wall had a dent about 4 in. (10 cm) deep. Other damage to the vehicle was as shown in Figure 10. Damage to the bridge rail or concrete deck was nil, and no repairs were required (see Figure 9).

Test No. 5 - Intercity Bus

In test No. 5 a 1962 GM coach intercity bus weighing 32,080 lb (14,562 kg) impacted the bridge rail at 61.1 mph (98.3 km/hr) and 15^{0} angle. The intercity bus was restrained and smoothly redirected. The bus experienced a maximum roll angle of 21^{0} and departed the rail at an 8.5^{0} angle, remaining stable throughout the test. Damage to the bus can be seen in Figure 12.

simulated passengers (sandbags) were ejected through the bus side windows (see Figure 12). It should be remembered that this was a 1962 intercity bus and was not designed and constructed to the current Federal Motor Vehicle Safety Standards (FMVSS Standard No. 205, Jan. 1, 1968, and FMVSS Standard No. 217, Sept. 1, 1973).

Although damage to the bridge rail and concrete deck were substantial (see Figure 13), the structural system held together to restrain and redirect the bus. It appears that this impact was fairly close to the limit of this bridge rail-slab system.

Table 1. Summary and Results of Crash Tests.

TEST NO.	3	4	5
VEHICLE DATA	1970 Ford School Bus 66 Passenger	1974 Honda Civic	1962 GM Coach Intercity Bus PD4106
MASS - kg (lb)	8,931 (19,690)	817 (1800)	14,562 (32,080)
FILM DATA			
Speed - km/hr (mph)			
Initial	87.6 (54.4)	95.6 (59.4)	98.3 (61.1)
Parallel	84.2 (52.3)	76.3 (47.4)	85.8 (58.5)
Departure	74.4 (46.2)	69.9 (43.4)	78.6 (48.8)
Angle - degrees			
Impact	15°	15°	15°
Departure	3.5°	6.5°	8.5°
Roll, max.	13°	11°	21°
Time - sec			
to Parallel	0.408	0.103	0.322
of Contact	0.806	0.394	1.037
Barrier Displacement - cm (in.)			
Dynamic (alum. rail only)	9.1 (3.6)	nil	111 (44)
Residual (alum. rail only)	5.1 (2.0)	nil	64 (25)
Distance to Parallel - m (ft)			
Longitudinal	9.4 (30.8)	2.33 (7.64)	11.2 (36.6)
Lateral	1.48 (4.86)	0.45 (1.47)	2.3 (7.6)
Deceleration, Avg. g's			
Longitudinal	0.46	1.9	0.54
Lateral	1.4	5.4	1.1
Resultant	1.4	5.7	1.2
ACCELEROMETER DATA 100 hz lo-pass max. flat filter			
Max. Avg. 0.050 Sec Deceleration			
Longitudinal, g's	1.7	6.6	.96
Lateral, g's	4.9	12.2	3.3
Resultant, g's	5.0	13.9	3.4
Deceleration Avg. over Contact Time			
Longitudinal, g's	0.42	2.2	.26
Lateral, g's	1.3	3.6	1.1
Resultant, g's	1.4	4.2	1.1
Peak Deceleration			
Longitudinal, g's	2.9	20.9	2.7
Lateral, g's	16.0	28.9	7.2
Resultant, g's	16.3	35.7	7.6
VEHICLE DAMAGE CLASSIFICATION			
TAD	1-RFQ4	1-RFQ4	1-RFQ4
SAE	01RFEE8	01RFEE7	
REMARKS	Bus smoothly redirected. Very stable; little roll angle.	Honda redirected. Right front wheel contacted post & bent back.	Bus smoothly redirected. Stable with moderate roll angle.

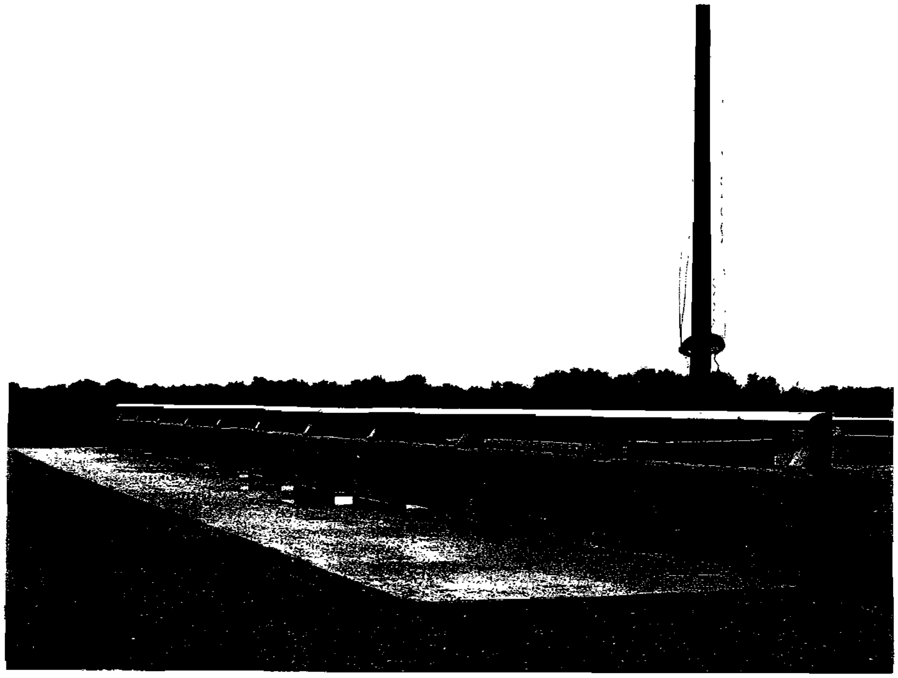


Figure 3. Front View Before and After Photographs of Bridge Rail for Test 3.

Figure 4. End View Before and After Photographs of Bridge Rail for Test 3.

Figure 5. Closeup Before and After Photographs of Bridge Rail for Test 3.

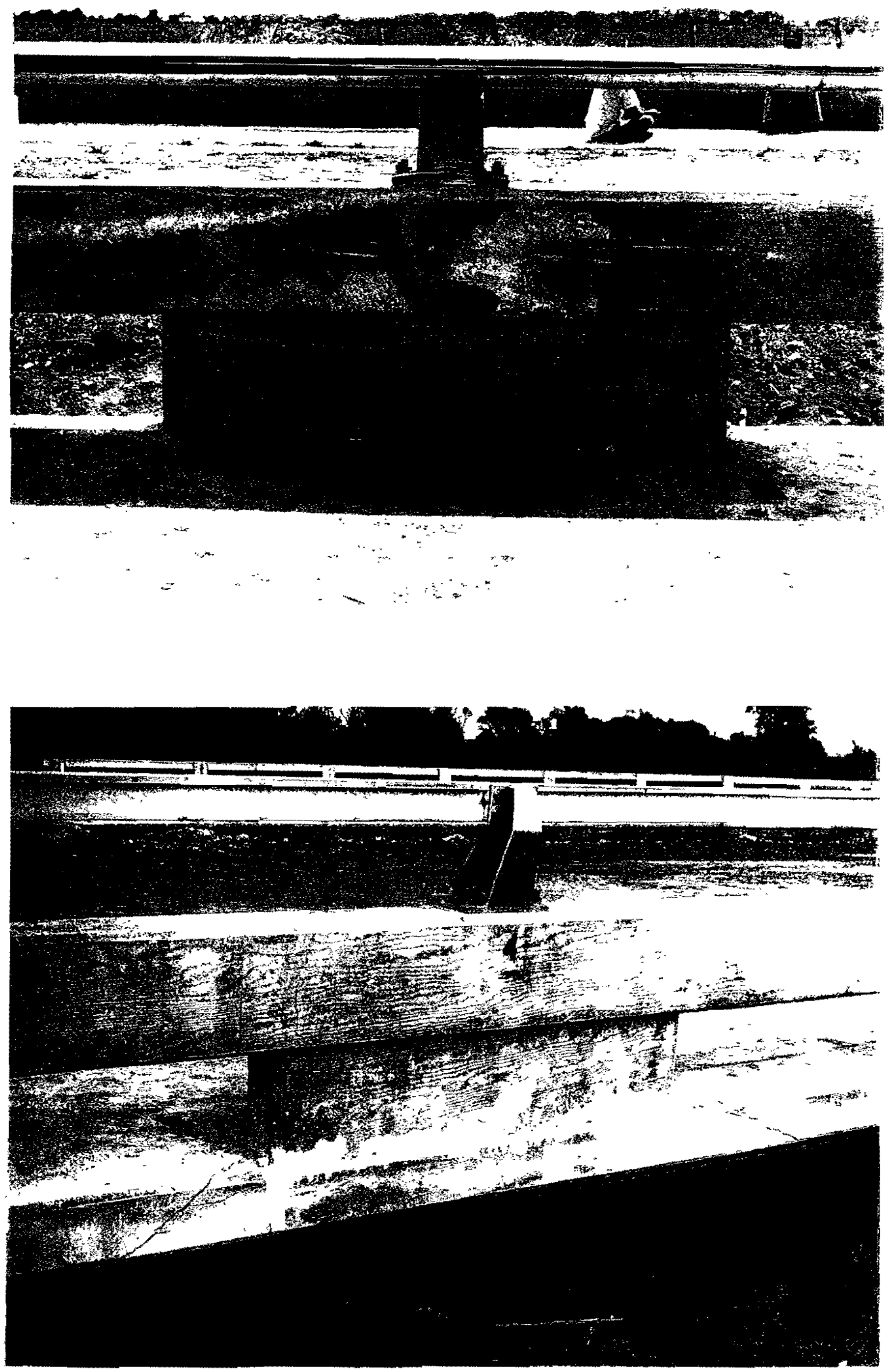


Figure 6. Damage to Post 4 and Cracked Bridge Slab at Post 4 After Test 3.

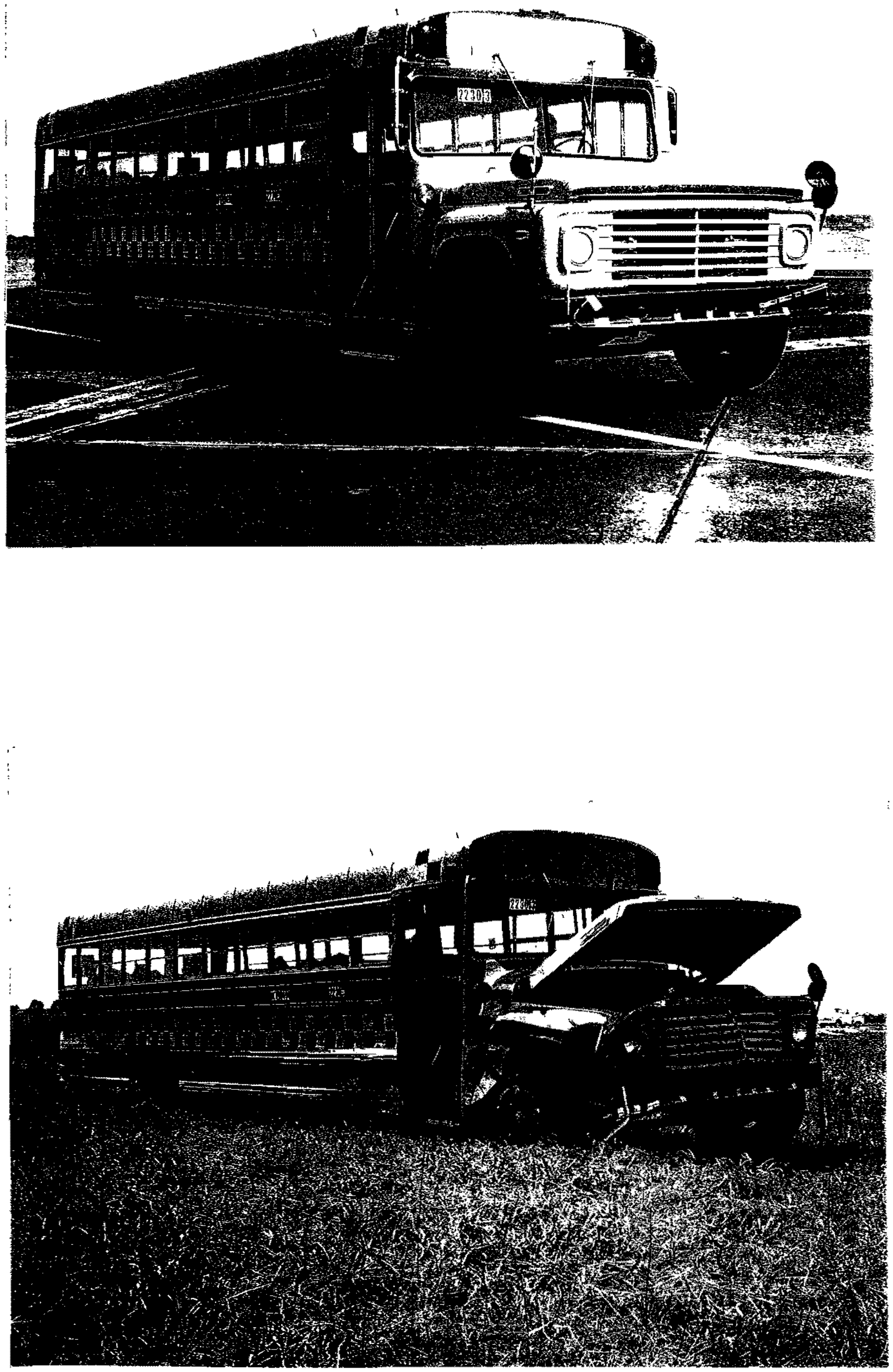


Figure 7. Before and After Photographs of 20,000 lb School Bus for Test 3.

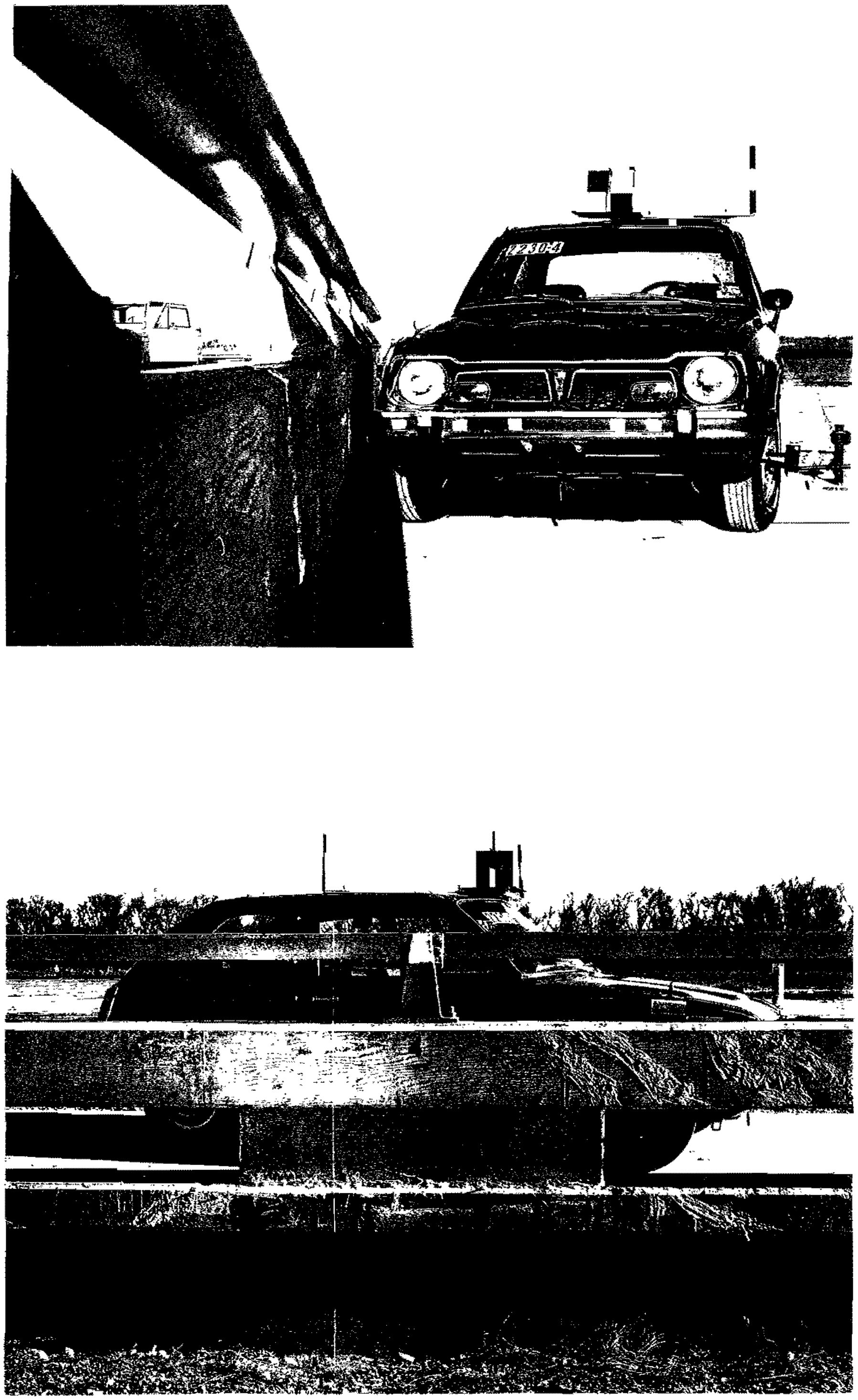


Figure 8. Bridge Rail and Honda Before Test 4.

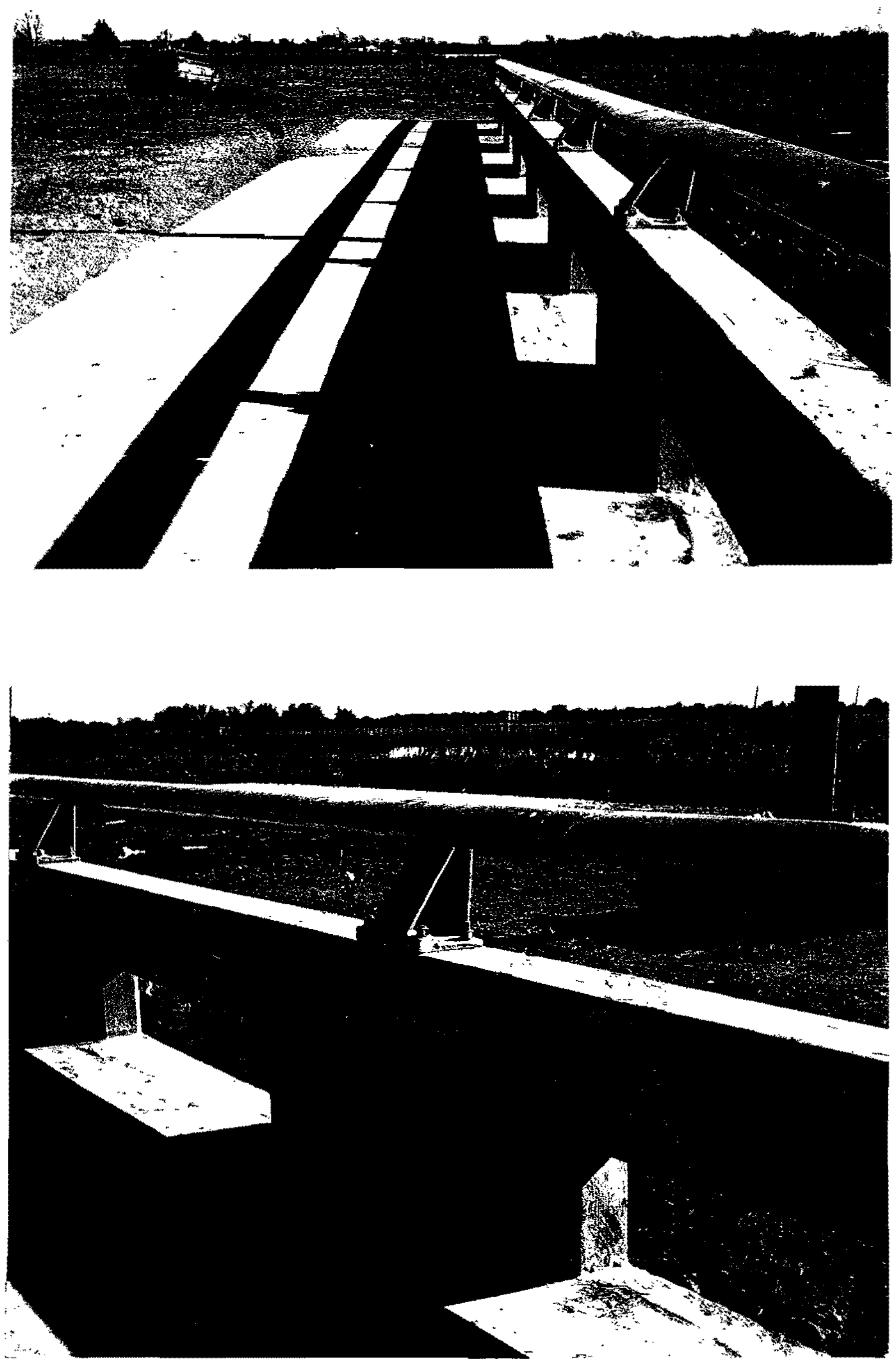
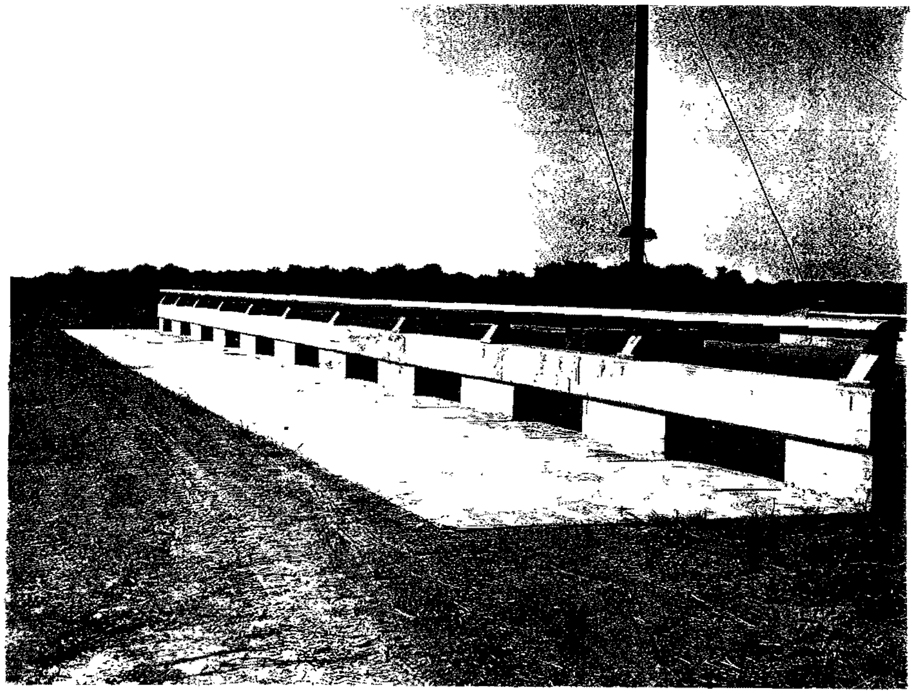


Figure 9. Bridge Rail and Post No. 5
After Test 4.

Figure 10. Vehicle Before and After Test 4.



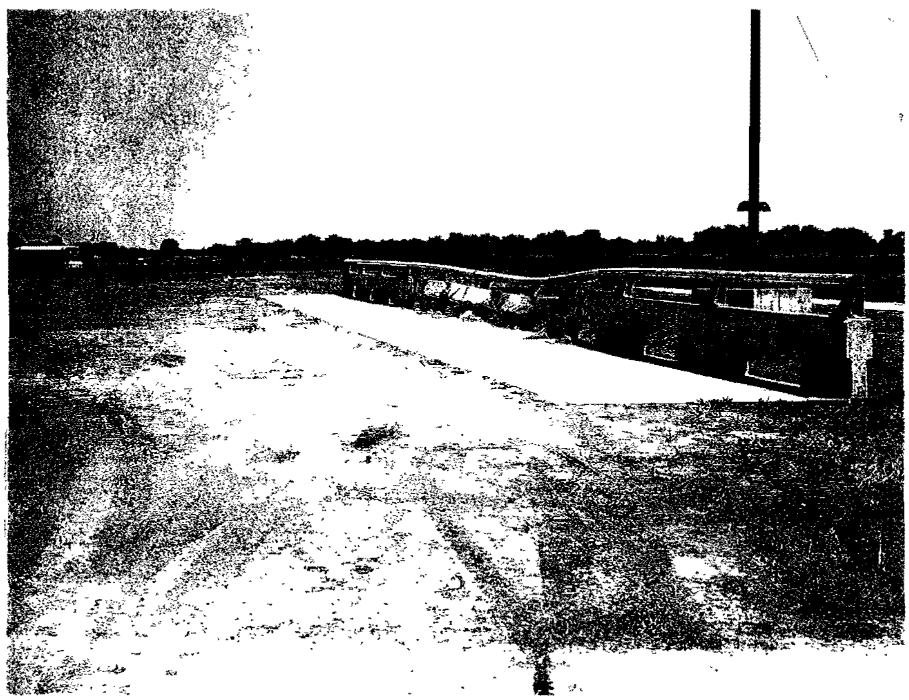


Figure 11. Bridge Rail Before and After Test 5.

Figure 12. Vehicle Before and After Test 5.

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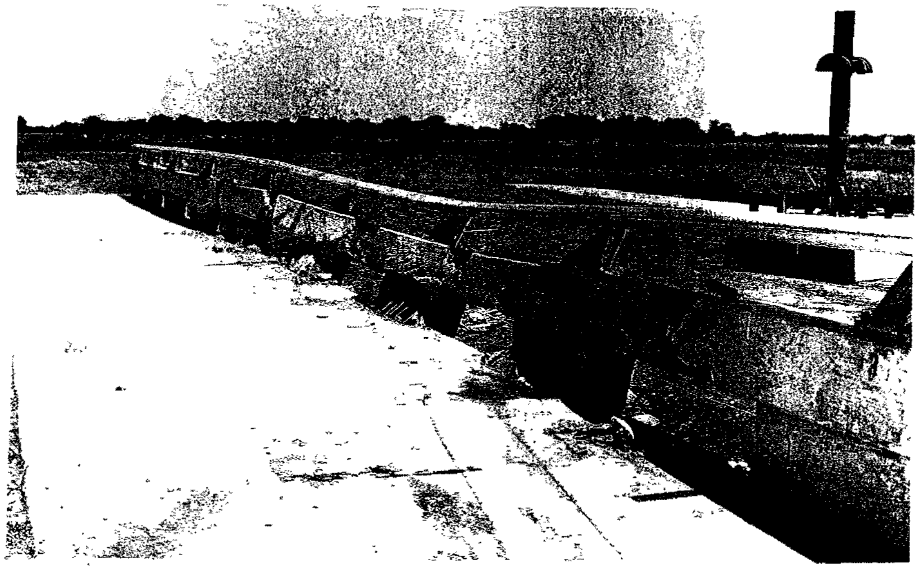
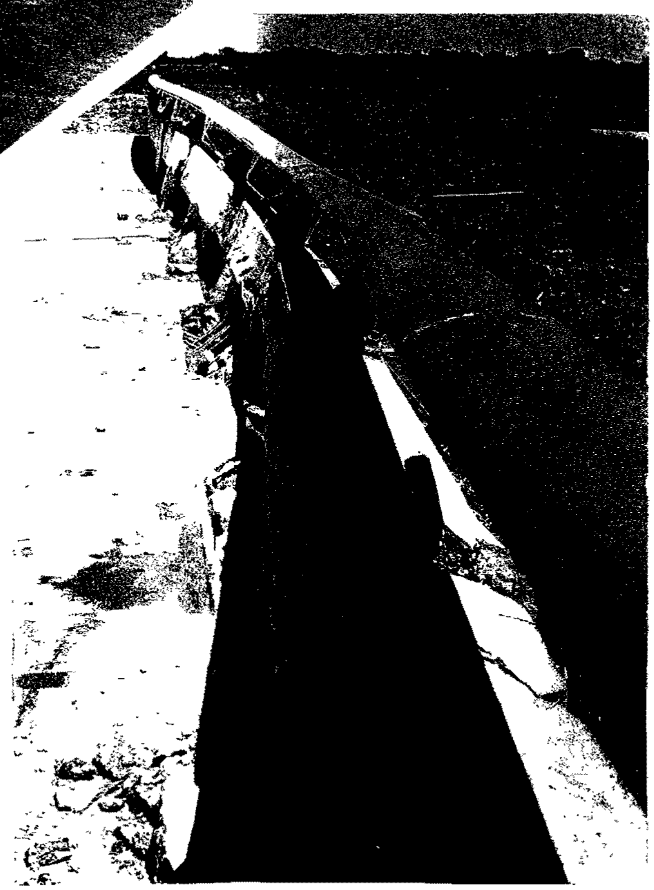


Front of Rail

Back of Rail



Close-up of Rail

Figure 13. Damaged Bridge Rail, Test 5.

DISCUSSION OF RESULTS

It will be noted that in the description of the vehicle crash tests and the tabulated results in Table 1, no discussion of the vehicle acceleration data was presented. The reason for this is that Transportation Research Circular No. 191 (2) does not recommend using minicars or buses as crash test vehicles. Consequently, no safety evaluation guidelines for accelerations on minicars or buses are presented in TRC No. 191.

A new proposed "Recommended Procedures for Safety Evaluation of Highway Appurtenances" (11) does recommend using minicars and intercity buses as crash test vehicles. Impact severity criteria are presented for the minicar such as the Honda Civic. These criteria are that the impact velocity of a hypothetical front seat passenger against the vehicle interior, calculated from vehicle accelerations and 24 in. (61 cm) forward and 12 in. (30 cm) lateral displacement, shall be less than 40 ft/sec (12 m/sec) longitudinal and 30 ft/sec (9 m/sec) lateral. Furthermore, the guidelines state that the vehicle's highest 10 ms average acceleration subsequent to instant of hypothetical passenger impact should be less than 20 g's longitudinal and 20 g's lateral.

In crash test 4 with the Honda Civic, the hypothetical passenger impact velocity with the vehicle interior was 23 ft/sec (7 m/sec) longitudinal and 22 ft/sec (6.7 m/sec) lateral. The vehicle's highest 10 ms accelerations subsequent to passenger impact was 1 g longitudinal and 4 g's lateral. All of these values are well within the recommended guidelines from reference 11.

While the acceleration measurements on the Honda Civic in test 4 appear acceptable by the current guidelines, some concern still exists about the significance of the front wheel snagging on the post under the 13 in. (33 cm) clear opening. In this design (Figure 1) the concrete posts were set back 1.5 in. (3.8 cm) from the beam face. In future designs this post set-back distance will be increased to minimize the amount of wheel snagging. Some observers have suggested that the 13 in. (33 cm) clear opening also be reduced. When heavy trucks and buses impact this bridge rail, it is believed that the tires protrude under the 13 in. (33 cm) opening and this tends to hold them down and prevents vehicle ramping or climbing tendency observed in impacts with smooth vertical or near vertical walls.

It is believed that this front wheel snagging is more of a problem with front wheel drive minicars than with other small vehicles. The rigid drive shaft and engine literally forces the front wheel to rotate and protrude under the rail when the opening is higher than the center of the wheel.

SUMMARY AND CONCLUSIONS

A standard Texas traffic rail Type T202 was strengthened and modified so that it could restrain and redirect school and intercity buses under 60 mph (96.6 km/hr) 15^{o} angle impacts. The T202 rail consists of a concrete beam element 10 in. (.25 in.) wide by 14 in. (.36 m) deep mounted 27 in. (.69 in.) high on concrete posts located at 10 ft (3 m) center-to-center spacing. The concrete posts are actually 7 in. (.18 in.) thick by 5 ft (1.5 m) long concrete walls with 5 ft (1.5 m) openings. To increase the effective height of the modified T202 bridge rail to 39.75 in. (1 m), a semi-elliptical extruded aluminum rail was mounted on 15 in. (.38 in.) high cast aluminum posts.

Three crash tests were conducted on the bridge rail. The first test was with a 66-passenger school bus weighing 19,690 lb (8,931 kg) and impacting the rail at 54.4 mph (87.6 km/hr) at a 15^{o} angle. The bus was smoothly re-directed with minimal damage to the bus and rail.

The second test was with an 1800 lb (817 kg) minicar with front wheel drive and impacting the rail at 59.4 mph (95.6 km/hr) at a 15^{o} angle. The vehicle was redirected but the small diameter right front wheel did penetrate under the 13 in. (.33 m) clear opening between the deck and concrete beam and snagged a concrete post. Damage to the vehicle was moderate and to the rail nil.

The third test was with an intercity bus weighing 32,080 lb (14,562 kg) and impacting the rail at 61.1 mph (98.3 km/hr) at a 15^{o} angle. The intercity bus was restrained and smoothly redirected. Damage to the bus was moderate and damage to the rail severe.

These tests have shown that a fairly simple and economical rail can redirect school and intercity buses at speeds up to 60 mph (96.6 km/hr) and 15^{o} angle impact. The cost of this rail is estimated at about $41 per foot in 1980.

REFERENCES

1. Hirsch, T. J., "Analytical Evaluation of Texas Bridge Rails to Contain Buses and Trucks", Research Report 230-2, Texas Transportation Institute, Texas A&M University, August 1978.

2. "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", TRB Circular No. 191, Washington, D.C., February 1978.

3. Standard Specifications for Highway Bridges, Twelfth Edition, American Association of State Highway and Transportation Officials, Washington, D.C., 1977.

4. Wiles, E. O., Bronstad, M. E., and Kimball, C. E., "Heavy Vehicle Crash Test Evaluation of Concrete Safety Shape", presented at the Annual Meeting of the Highway Research Board, Washington, D.C., January 1977.

5. Hirsch, T. J. and Post, E. R., "Truck Tests on Texas Concrete Median Barrier", Research Report 146-7, Texas Transportation Institute, Texas A&M University, December 1972.

6. "Tentative Service Requirements for Bridge Rail Systems", NCHRP Report 86, Washington, D.C., 1970.

7. Kimball, C. E., Bronstad, M. E., et al., "Development of a New Collapsing Ring Bridge Rail System", Report No. FHWA-RD-76-39, Federal Highway Administration, January 1976.

8. Bloom, J. A., Rudd, T. J., and Labra, J. J., "Establishment of Interim Guidelines for Bridge Rails Required to Contain Heavy Vehicles", Report No. FHWA-RD-75-45, Vol. I, Report No. FHWA-RD-75-46, Vol. II, and Report No. FHWA-RD-75-47, Vol. III, Federal Highway Administration, Washington, D.C., November 1974.

9. Buth, C. E., unpublished vehicle crash test data from DOT-FHWA-11-9181 being conducted at the Texas Transportation Institute, College Station, Texas, October 1978.

10. 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, October 1978.

11. "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances", Draft No. 4, NCHRP Proj. 22-2(4), Southwest Research Institute, San Antonio, Texas, December 1980.

APPENDIX A

BRIDGE RAIL DESCRIPTION

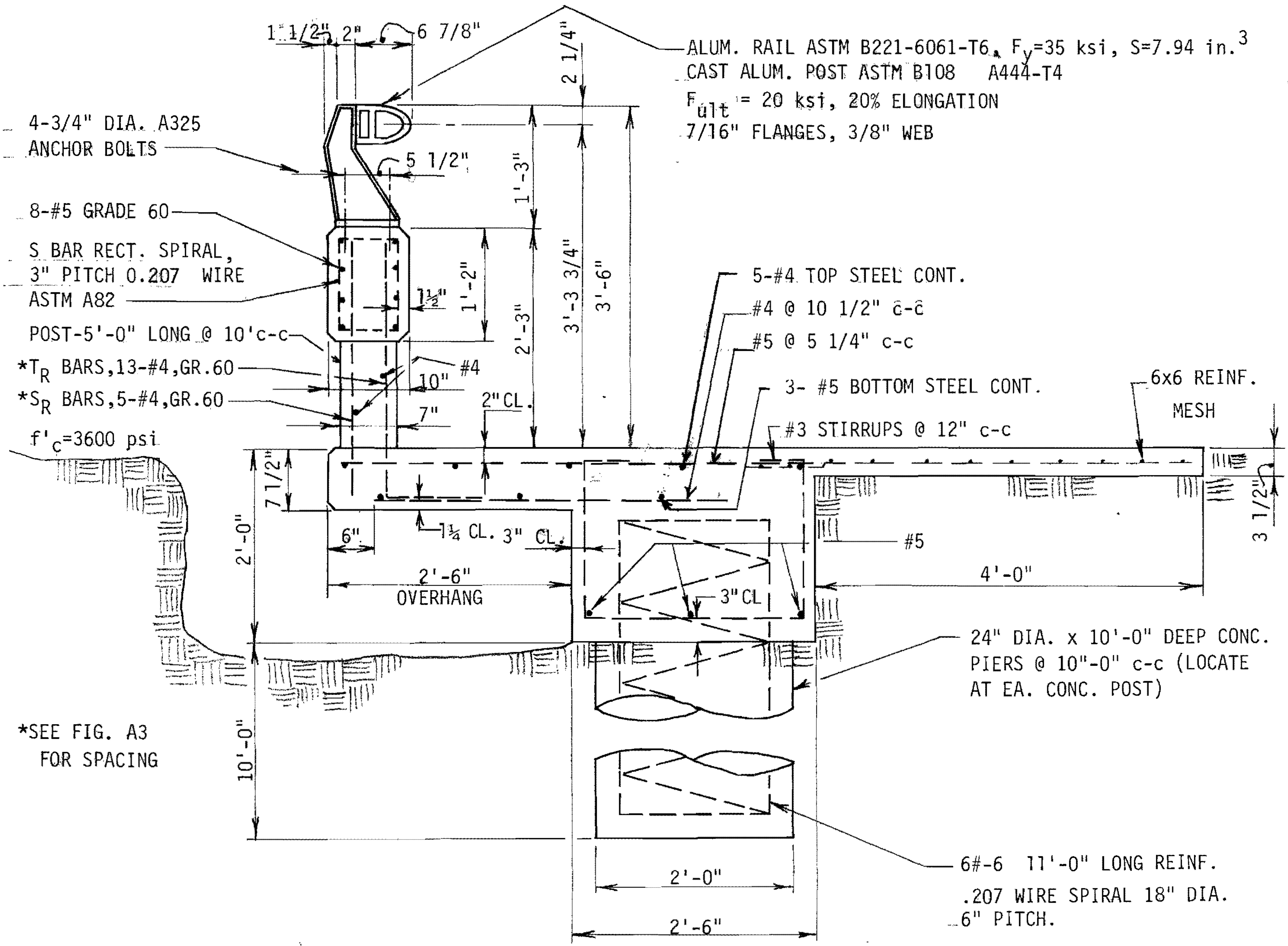
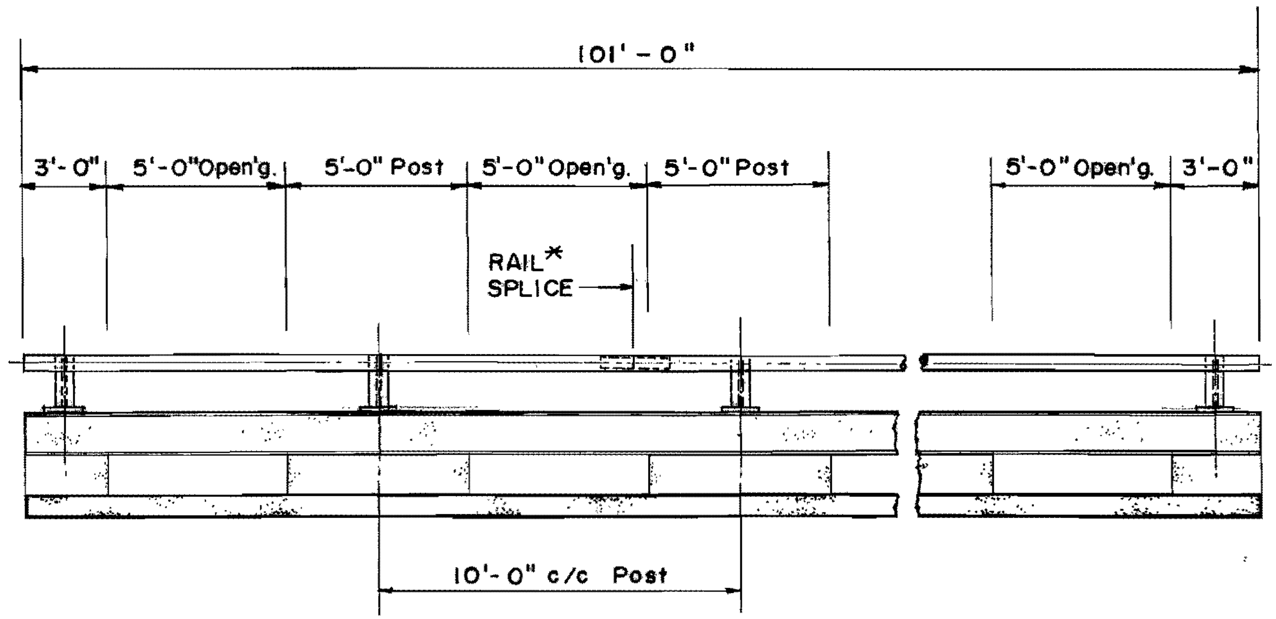


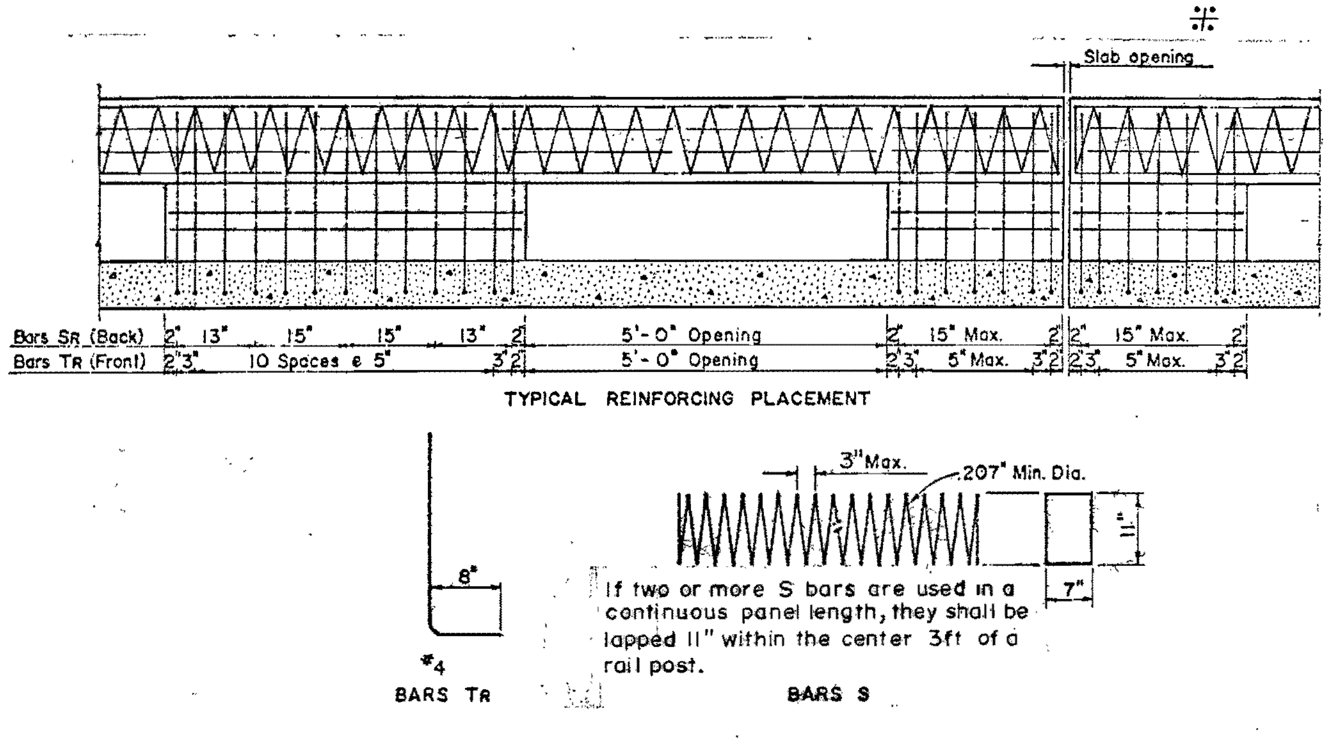
Figure A1. Cross Section of Modified T202 Bridge Rail



* Splice may be at any location but no more than one in any four adjacent panels.

Figure A2 Elevation of the

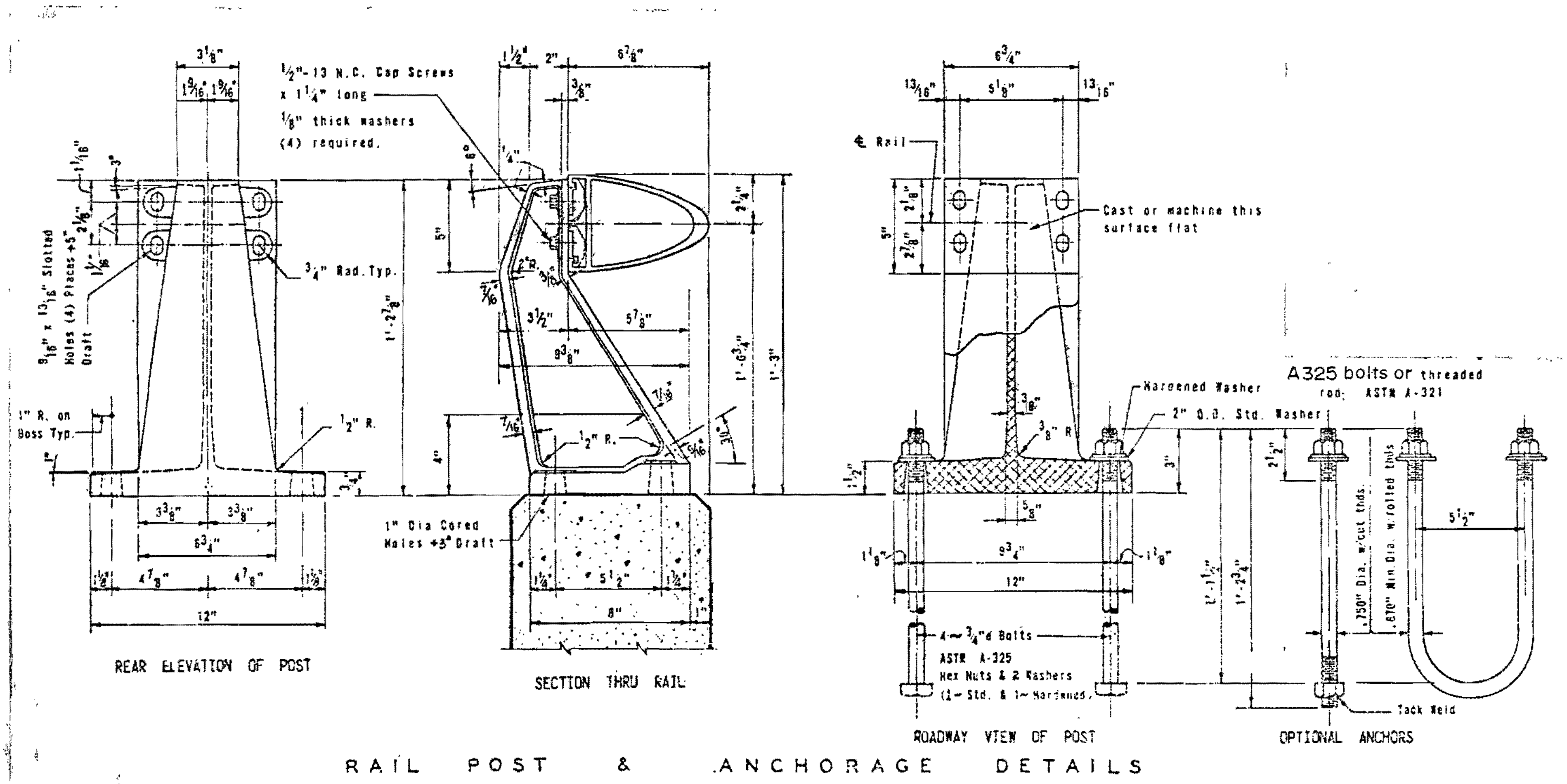
Modified T202 Bridge Rail



#: Opening shall occur only at armour joint openings in slab.
Rail shall be continuous over all slab construction joints.

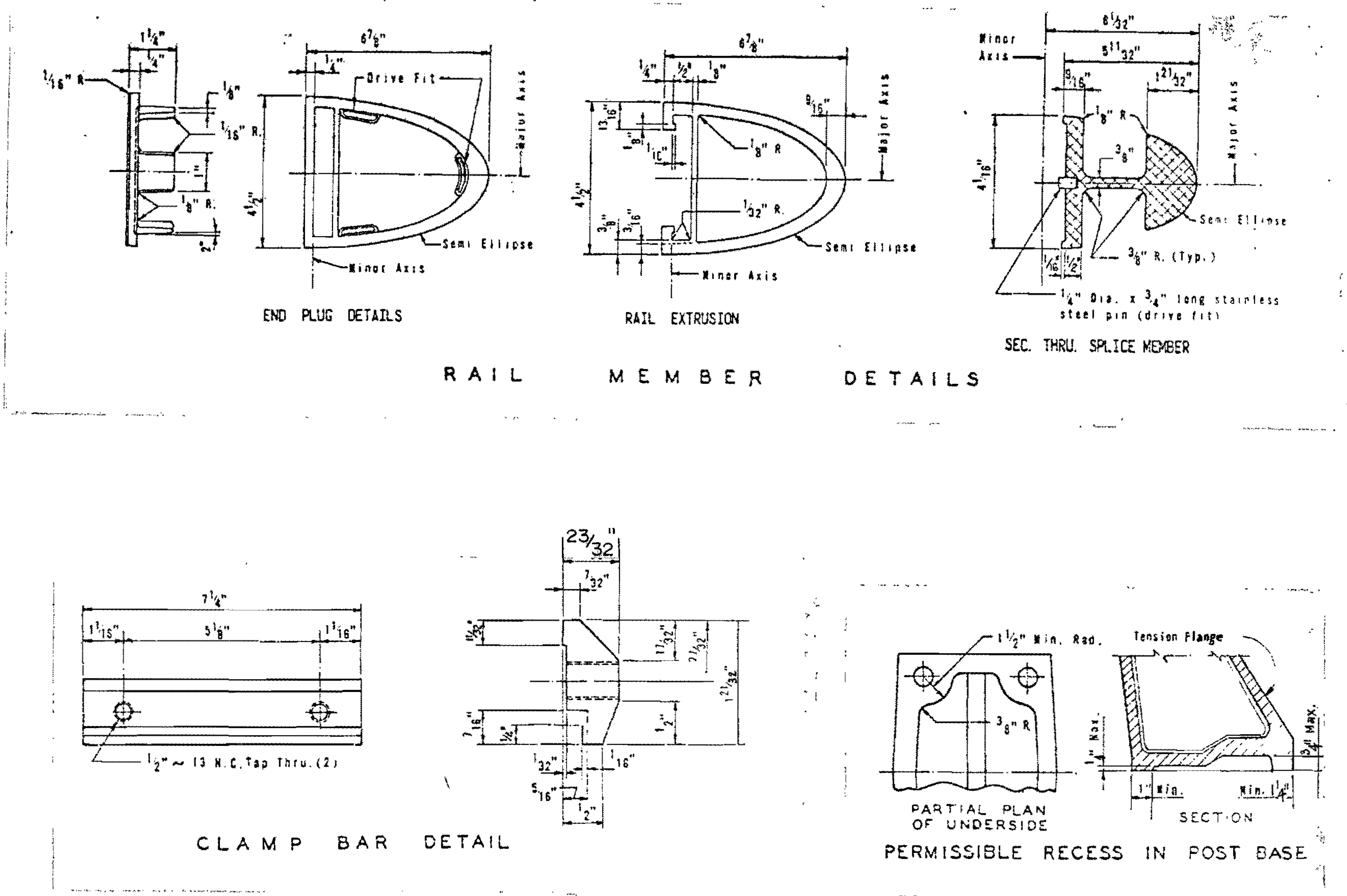
(Ref: DHT Type T202 Traffic Rail)

Figure A3. Steel Reinforcing Details



(Ref: DHT Type T4 Traffic Rail)

Figure A4. Aluminum Top Rail

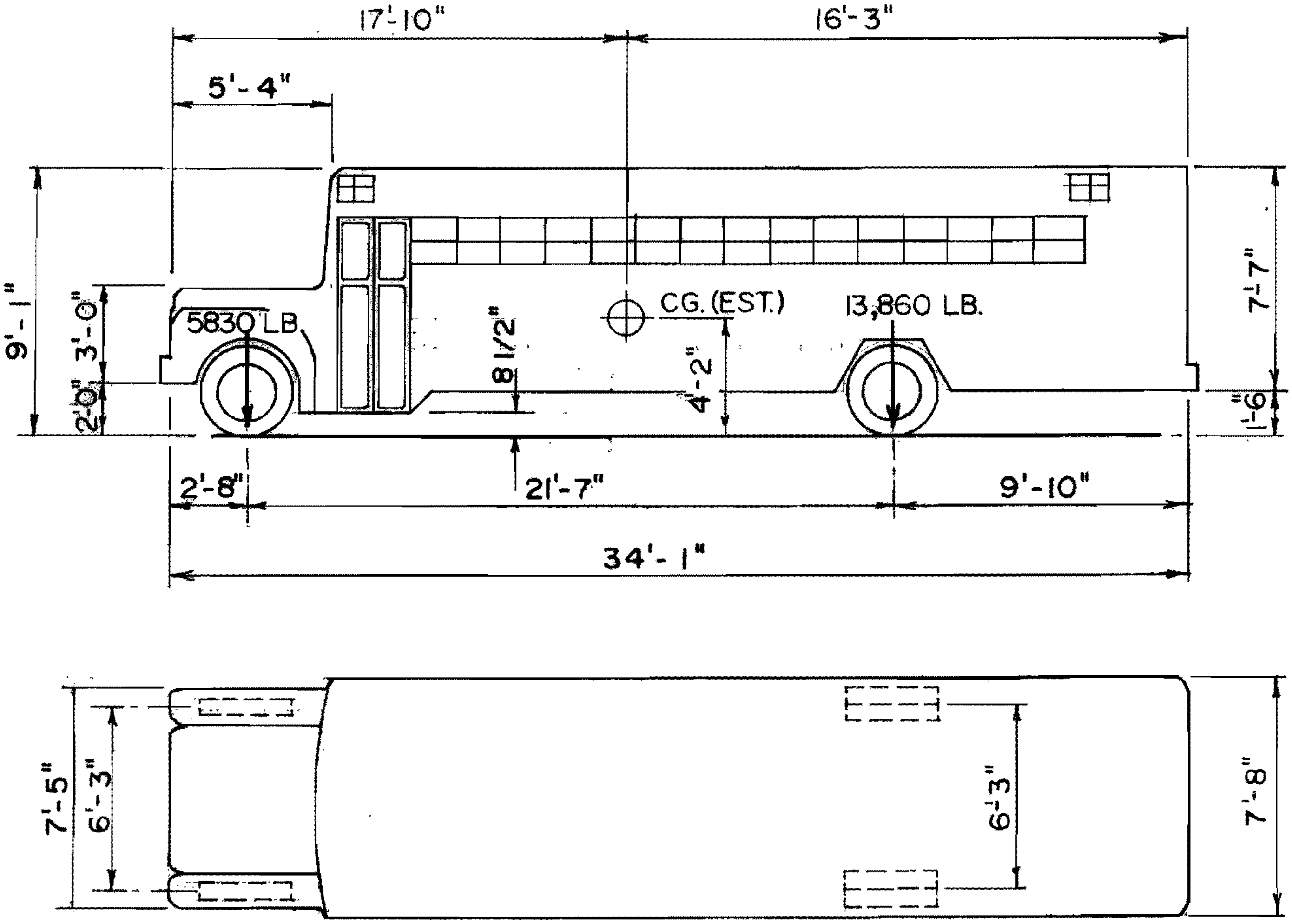


(Ref: DHT Type T4 Traffic Rail)

Figure A5. Rail Details

APPENDIX B

VEHICLE DIMENSIONS AND PROPERTIES

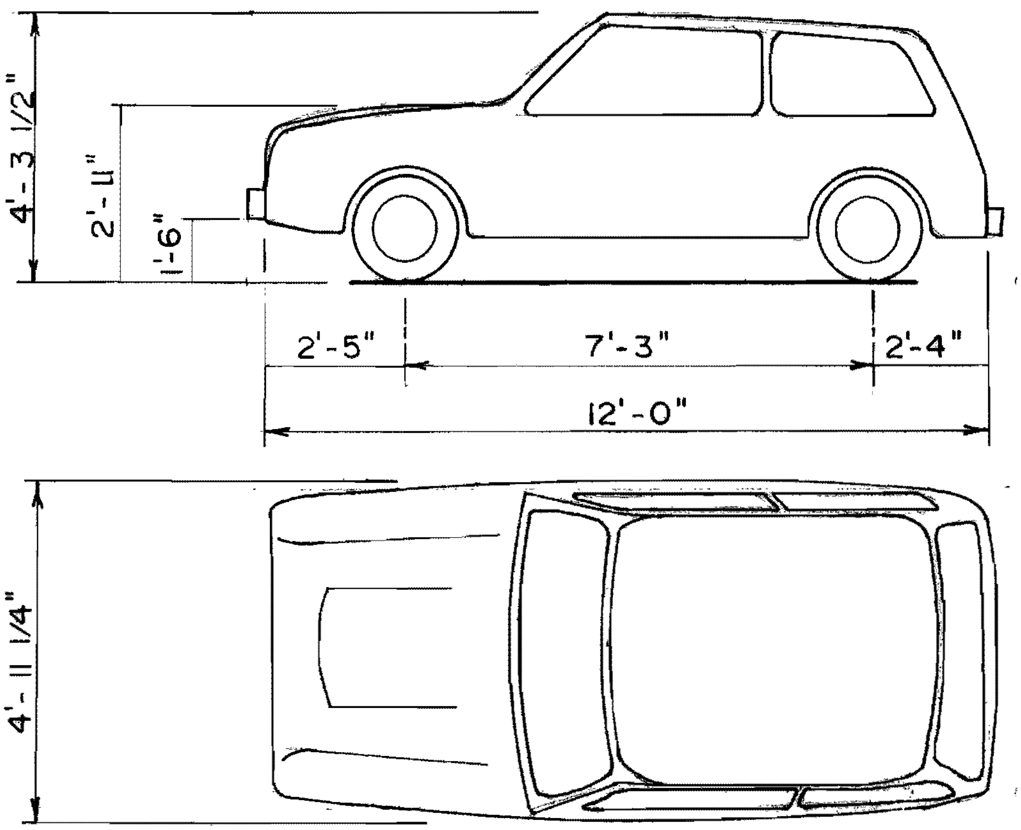


1970 FORD 66 PASSENGER SCHOOL BUS

EMPTY WEIGHT = 12,800 LBS.
PASSENGERS(SAND BAGS UNRESTRAINED IN SEATS) = 6,890 LBS.
TOTAL WEIGHT = 19,690 LBS.
CENTER OF GRAVITY HEIGHT LOADED = 50 IN. ± (EST.)

FIGURE B1. SCHOOL BUS PROPERTIES FOR CRASH TEST 3.

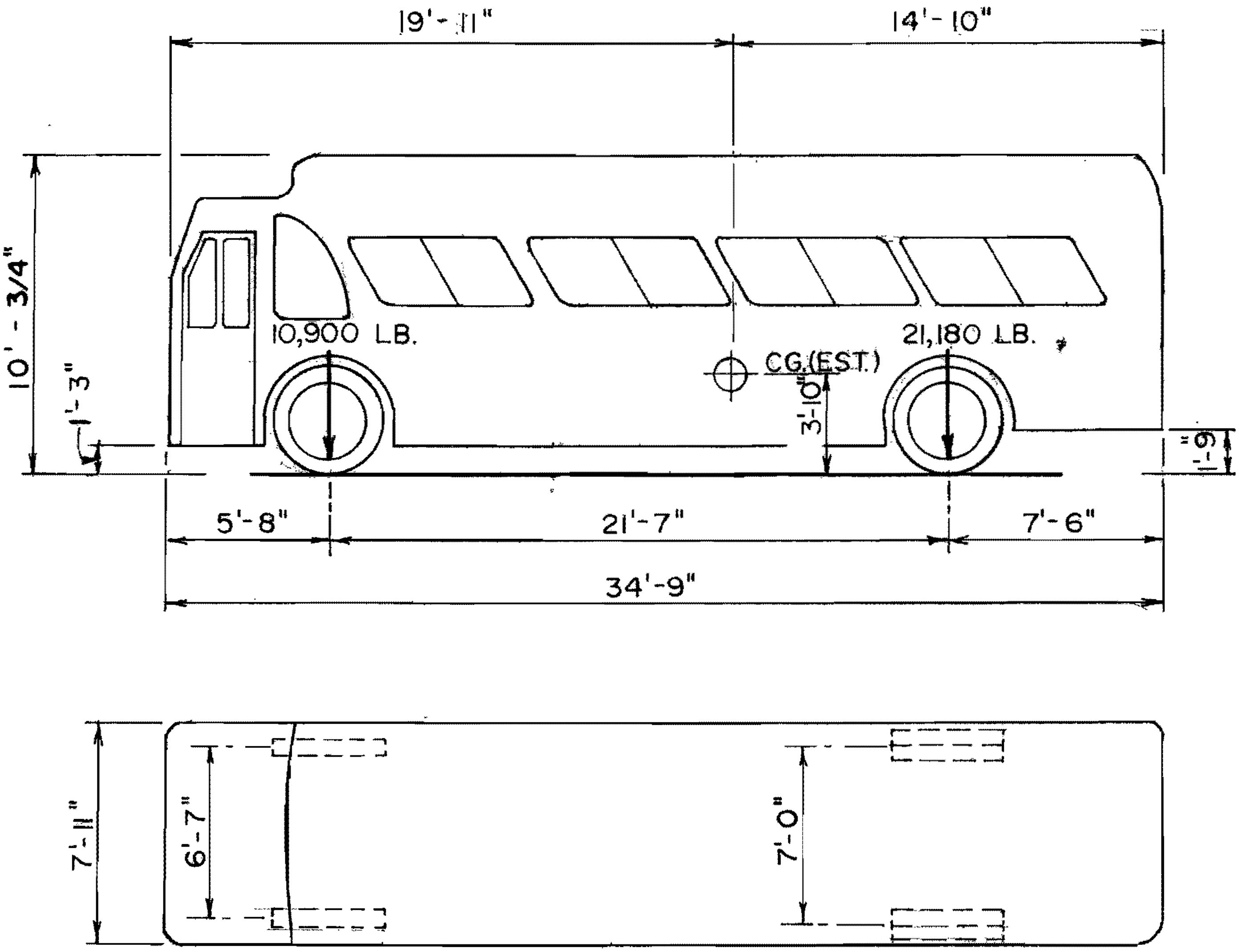
1 LB. = .4536   1 IN. = 2.54 CM.   1 FT. = .3048 M.



1974 HONDA CIVIC
TOTAL WEIGHT = 1800 LB.

FIGURE B2. MINICAR PROPERTIES FOR CRASH TEST 4.

1 LB. = .4536 KG. 1 IN. = 2.54 CM. 1 FT. = .3048 M.



1962 GMC COACH - PD4106

CENTER OF GRAVITY HEIGHT LOADED = 46 IN.±(EST.)

UNLOADED WEIGHT	= 20,780 LB.
PASSENGER WEIGHT *	= 6,080 LB.
BAGGAGE WEIGHT	= 5,220 LB.
TOTAL LOADED WEIGHT	= 32,080 LB.

FIGURE B3. INTERCITY BUS PROPERTIES FOR CRASH TEST 5.

1 LB. = .4536 KG. 1 IN. = 2.54 CM. 1 FT. = .3048 M.

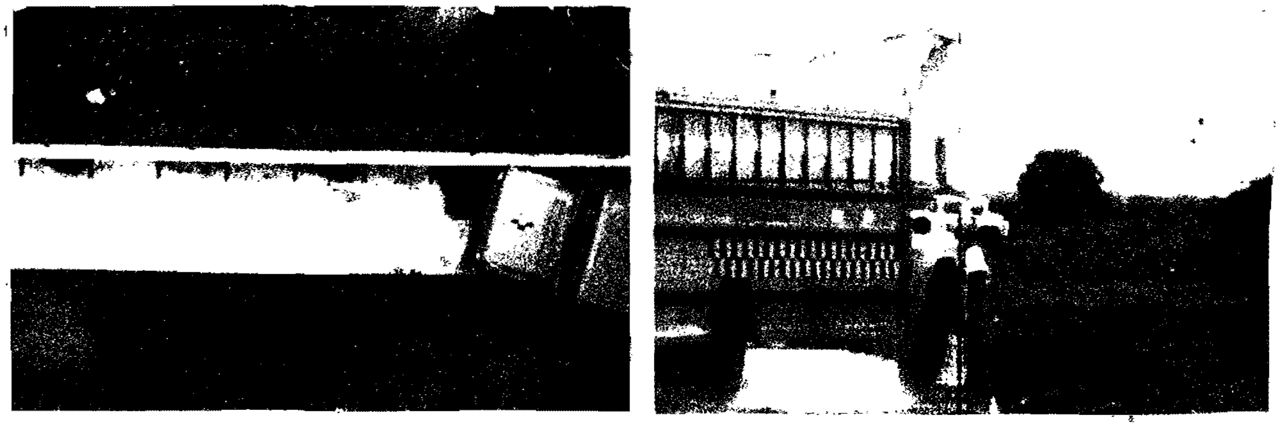
* (SAND BAGS UNRESTRAINED IN SEATS)

APPENDIX C

SEQUENTIAL PHOTOGRAPHS OF CRASH TESTS

AND

PHOTOGRAPHS OF DAMAGE TO BRIDGE RAIL AFTER TEST 5



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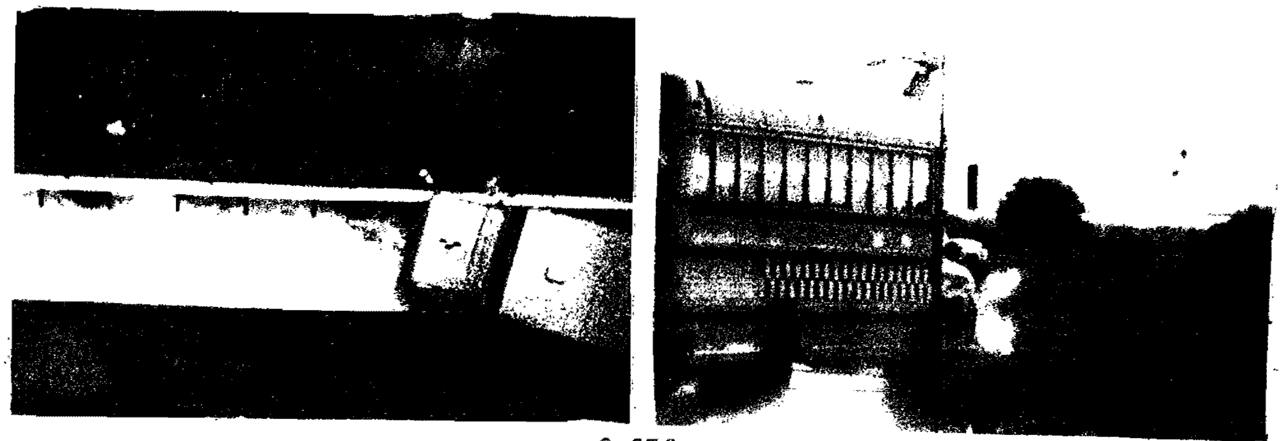

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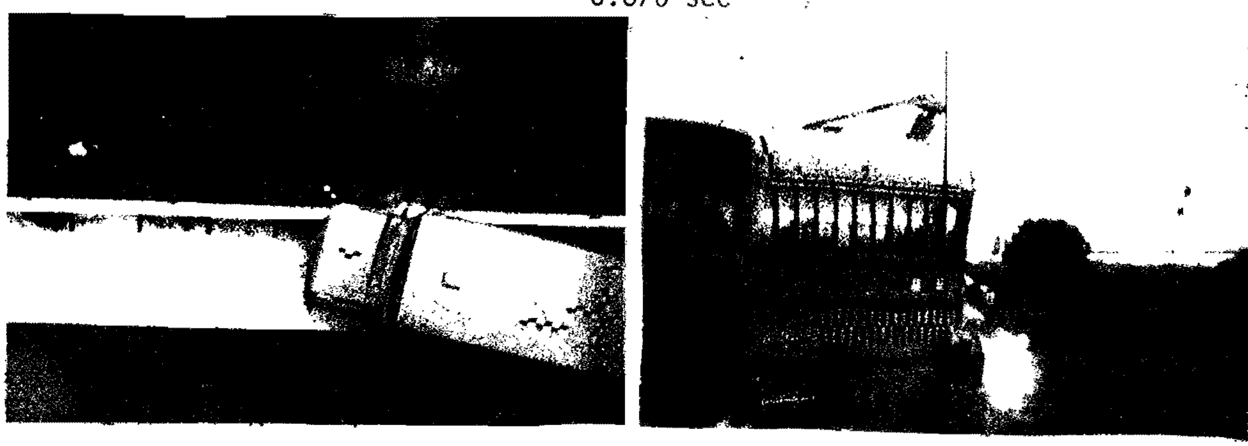

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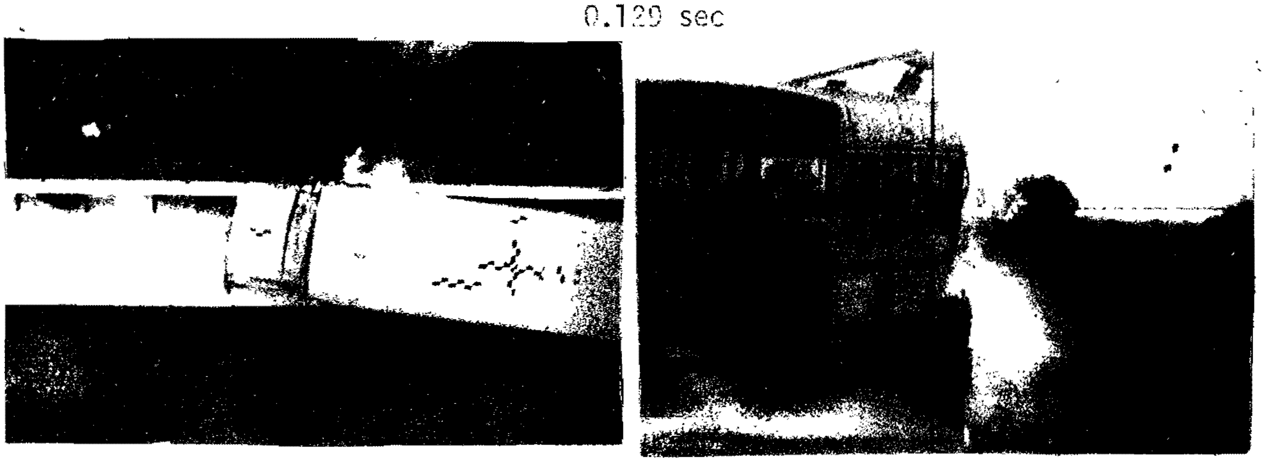

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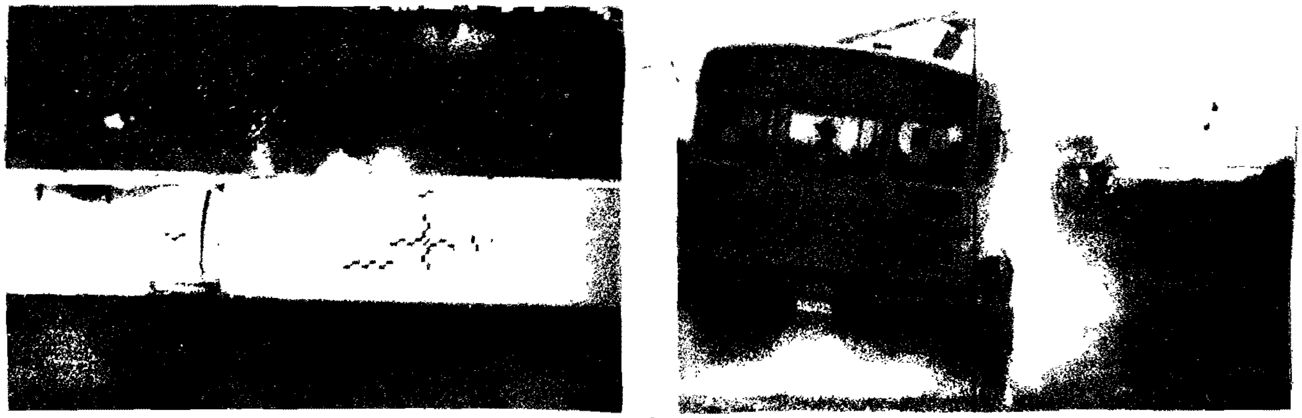
Figure C1. Sequential Photographs for Test 3.



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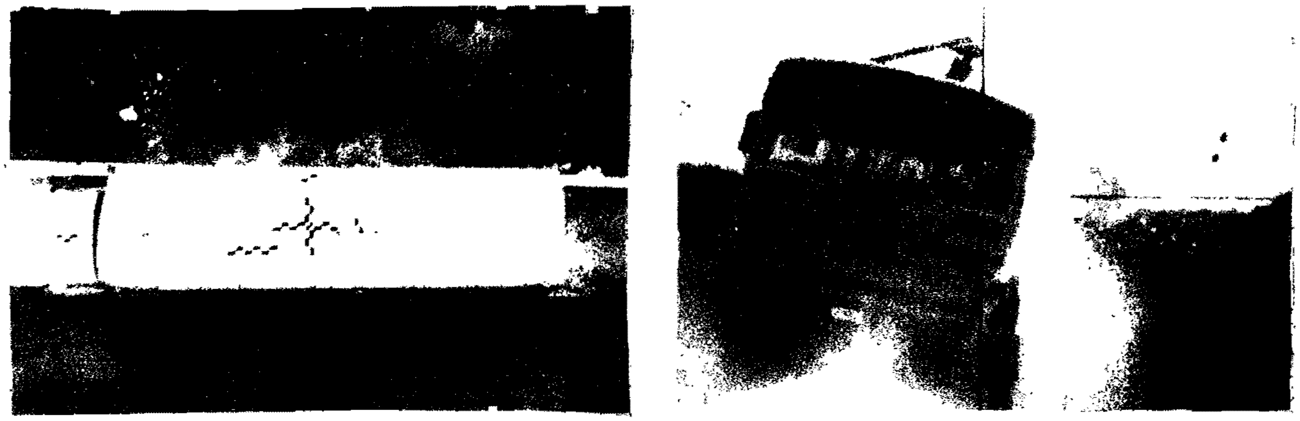

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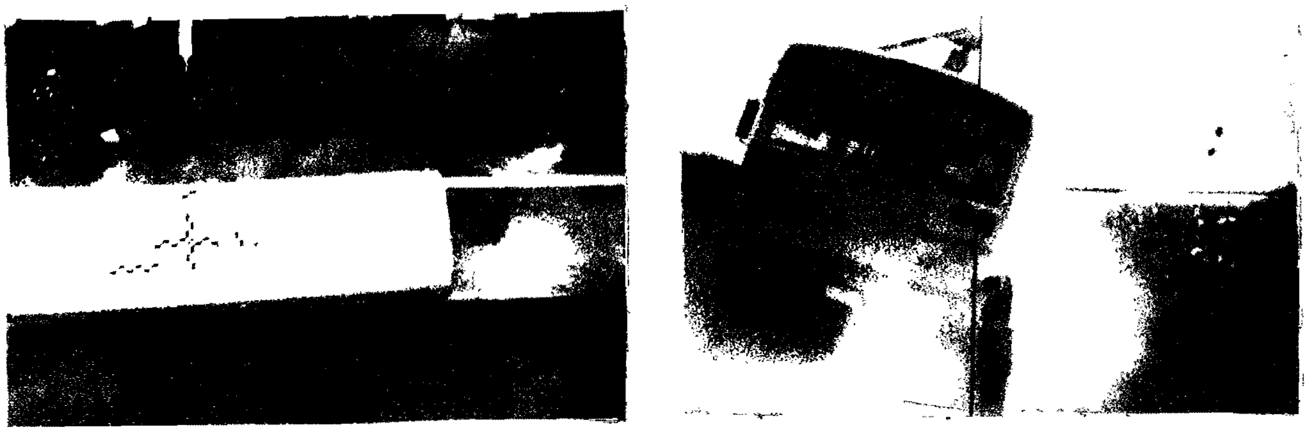
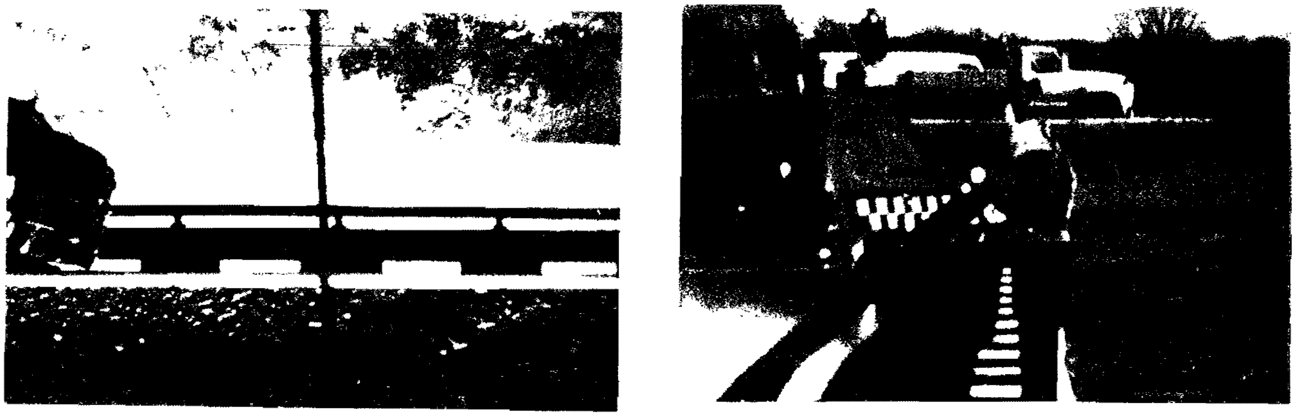


0.494 sec

0.634 sec

Figure C1. Sequential Photographs for Test 3. (con't)

12-100



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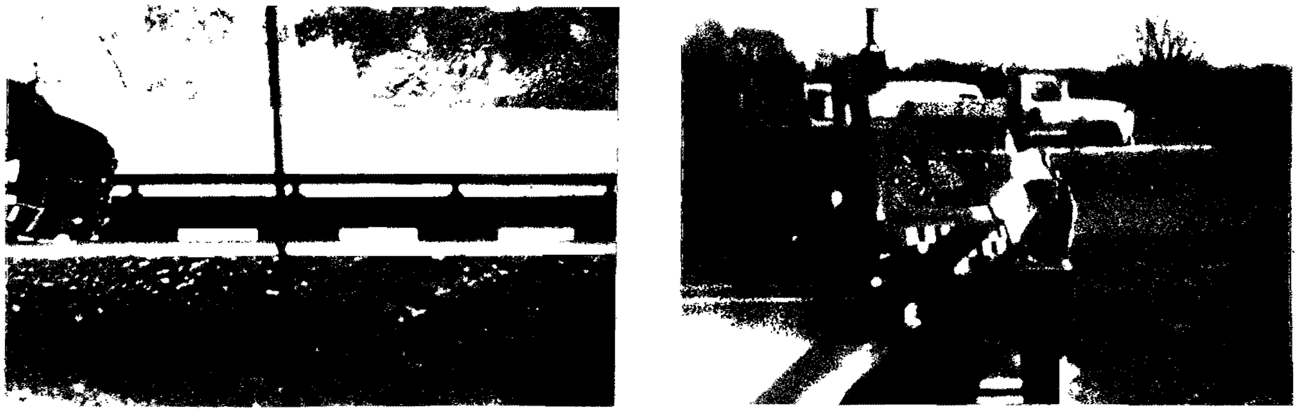

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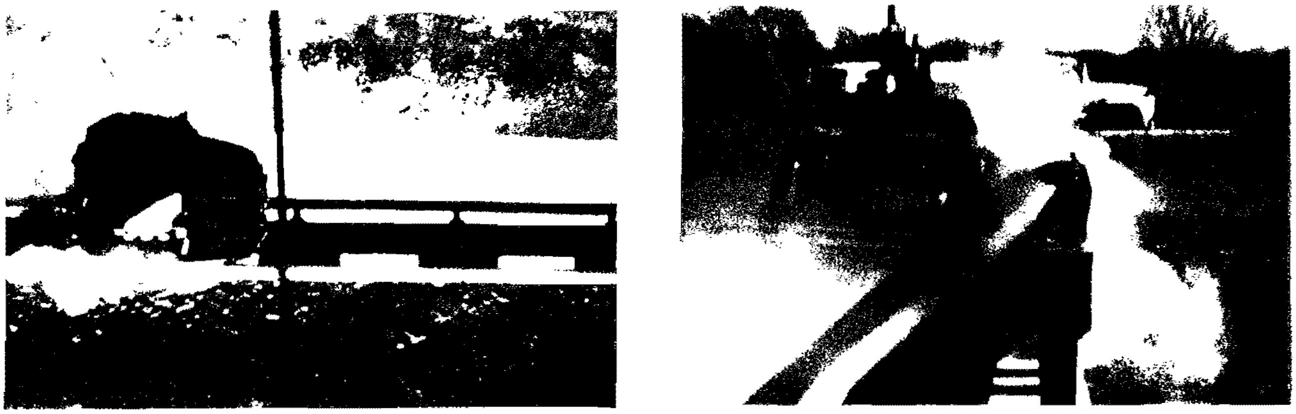
0.069 sec

0.103 sec

Figure C2. Sequential Photographs for Test 4.



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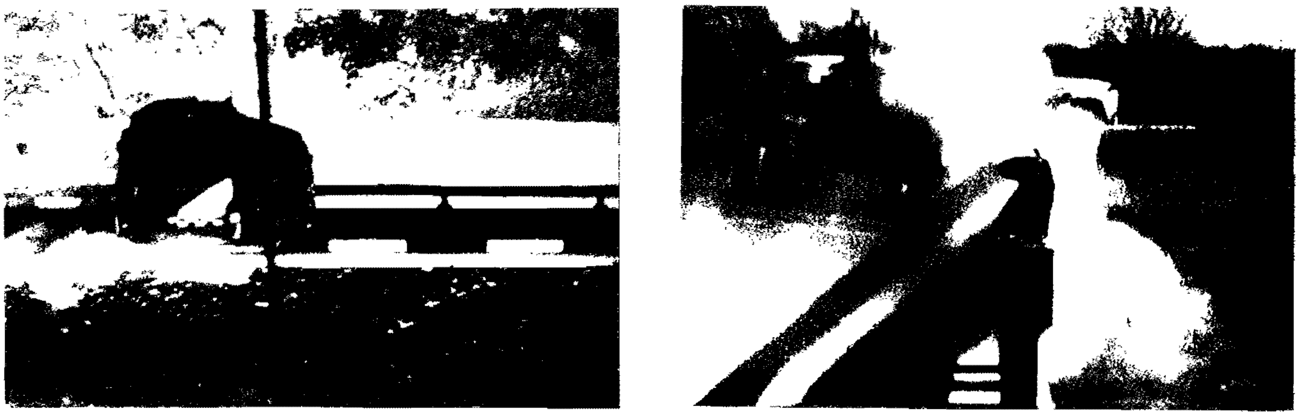

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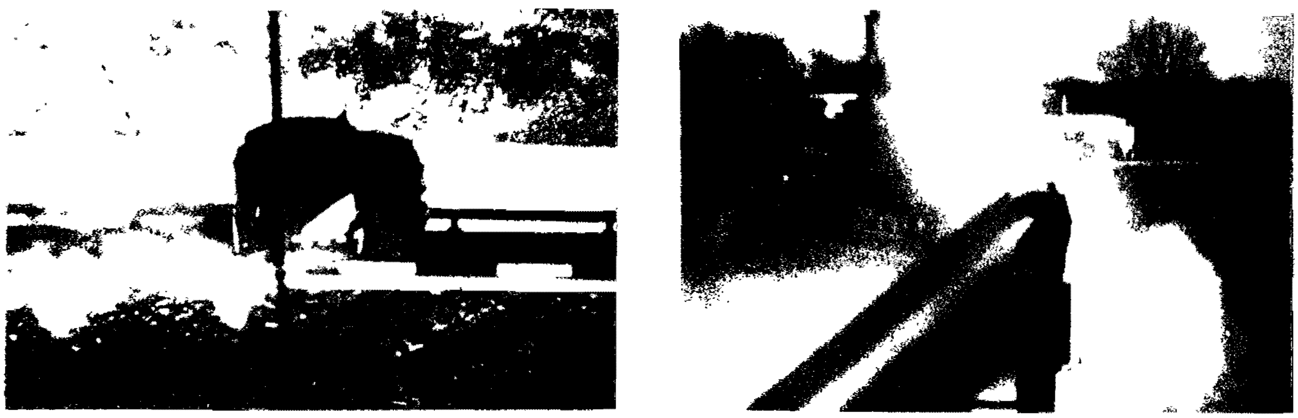

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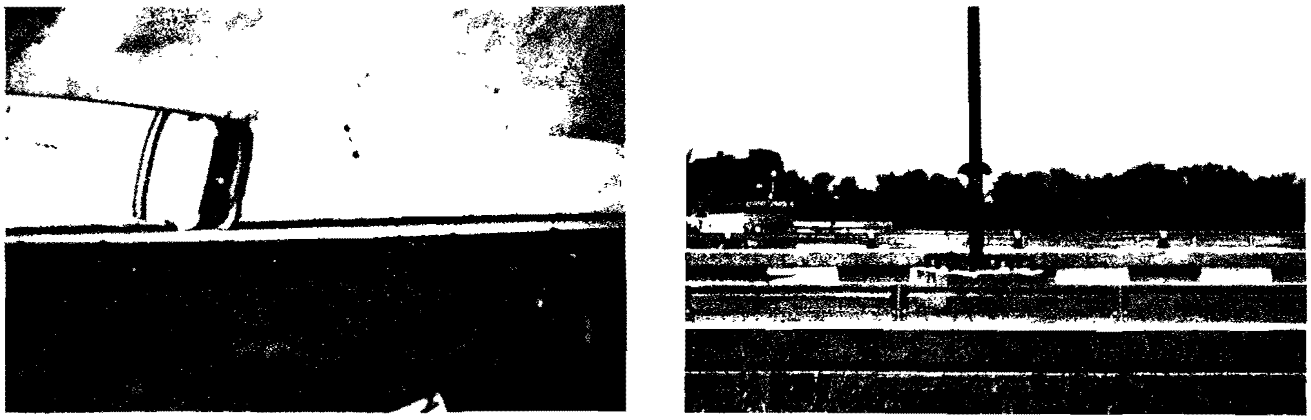
0.324 sec

Figure C2. Sequential Photographs for Test 4. (con't)



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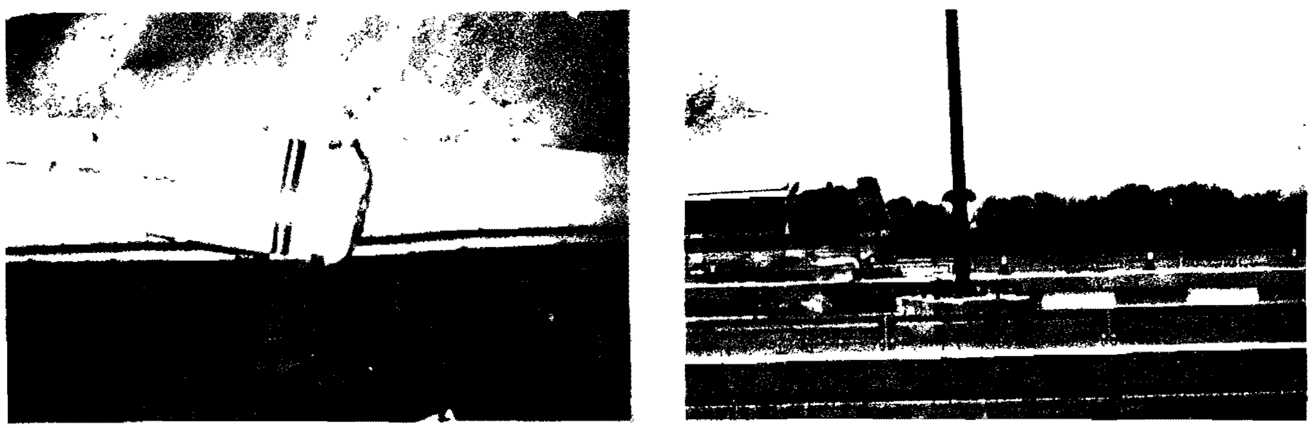

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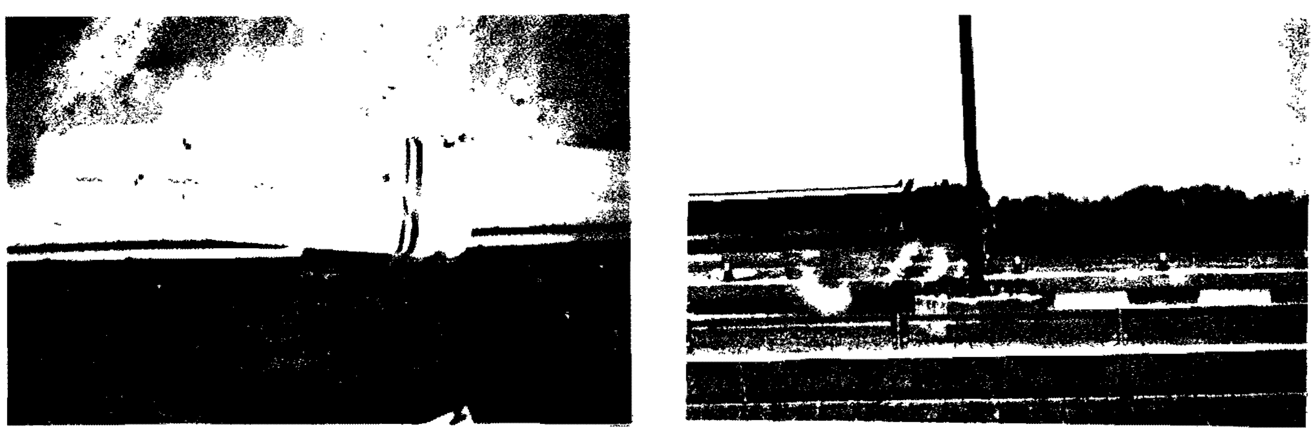

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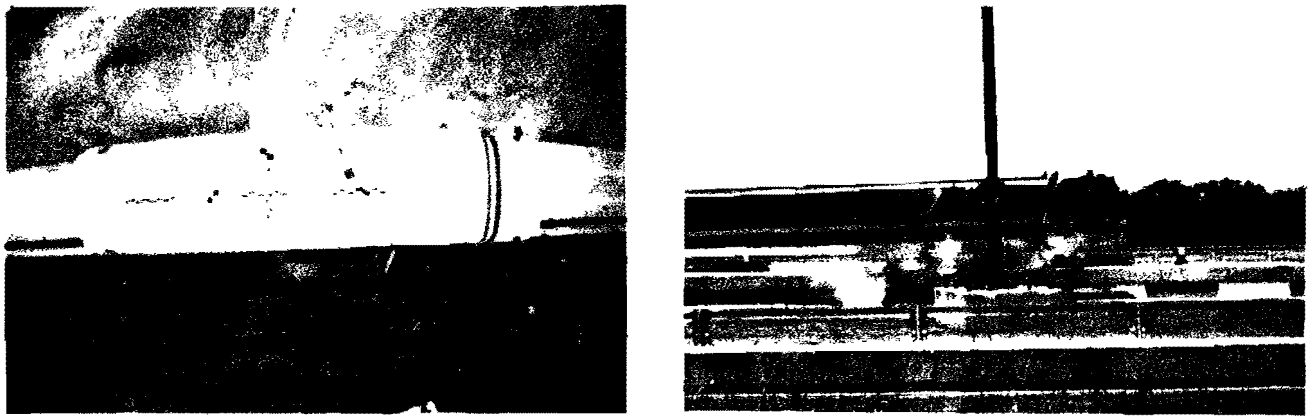
Figure C3. Sequential Photographs for Test 5.



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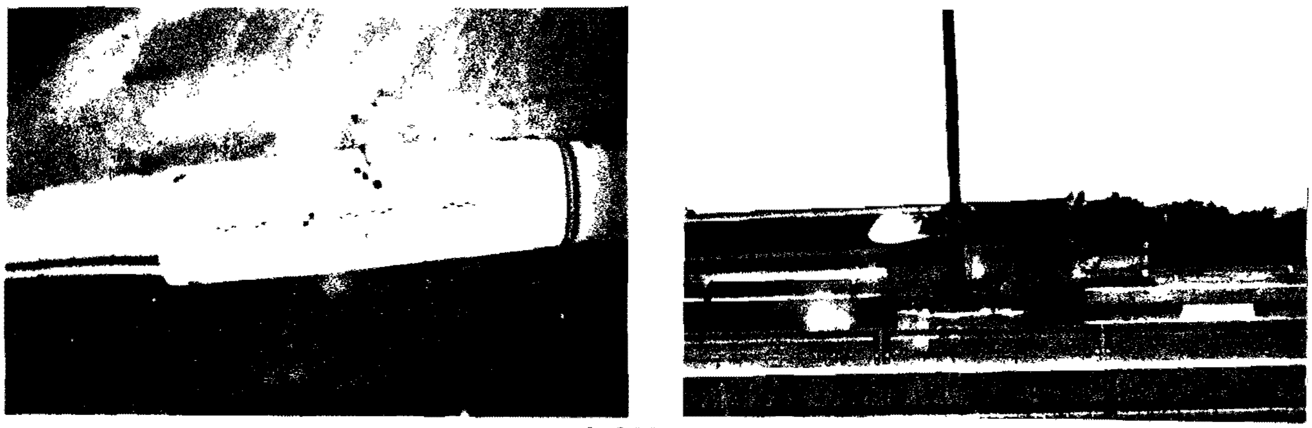

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0.408 sec

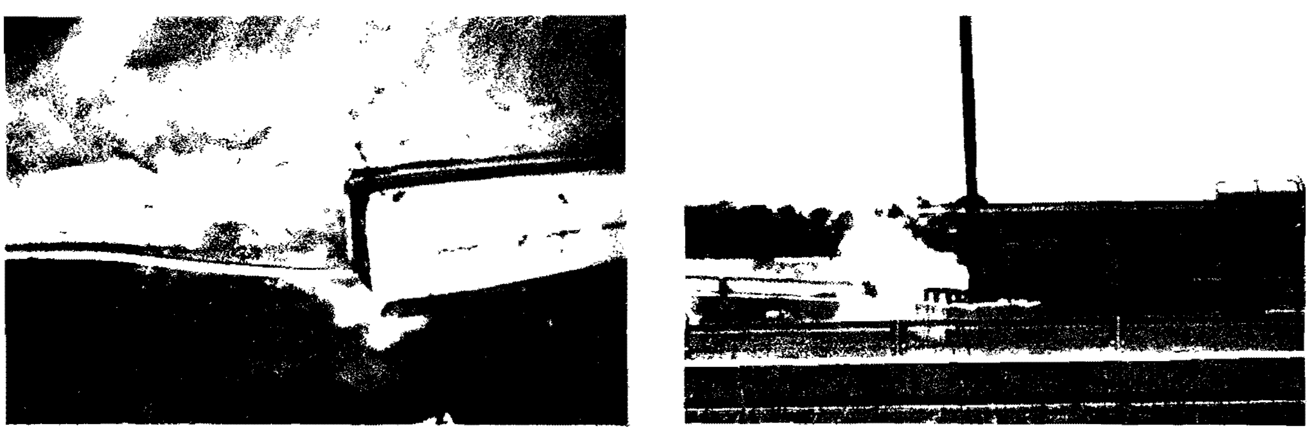

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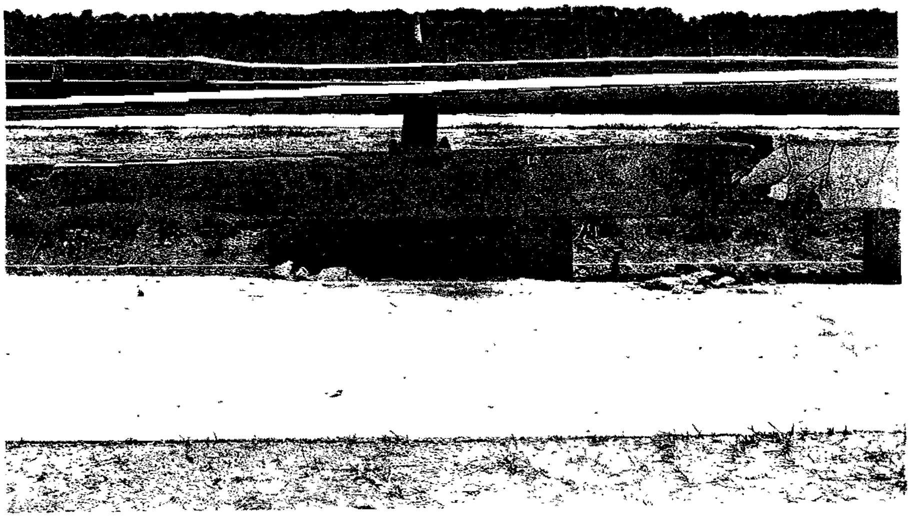
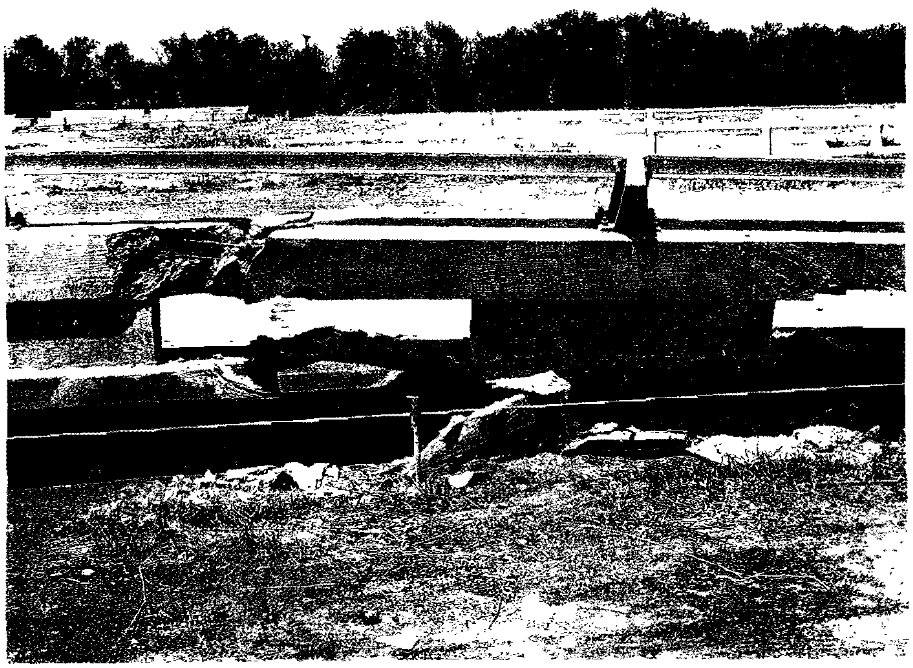
Figure C3. Sequential Photographs for Test 5. (con't)

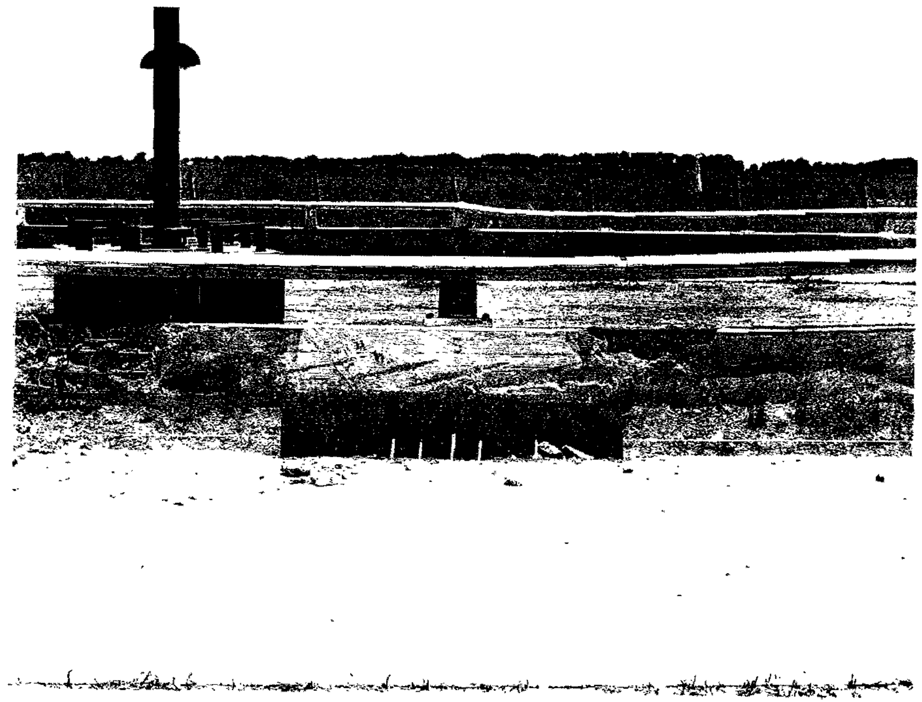


Front of Rail

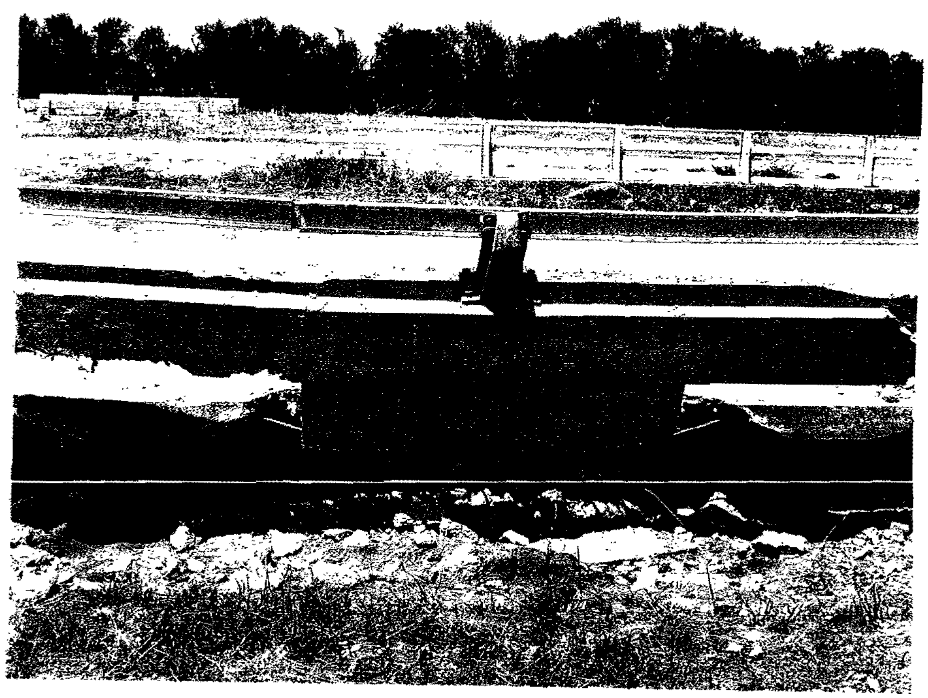


Back of Rail

Figure C4. Damage to Bridge Rail at Post No. 4, Test 5.

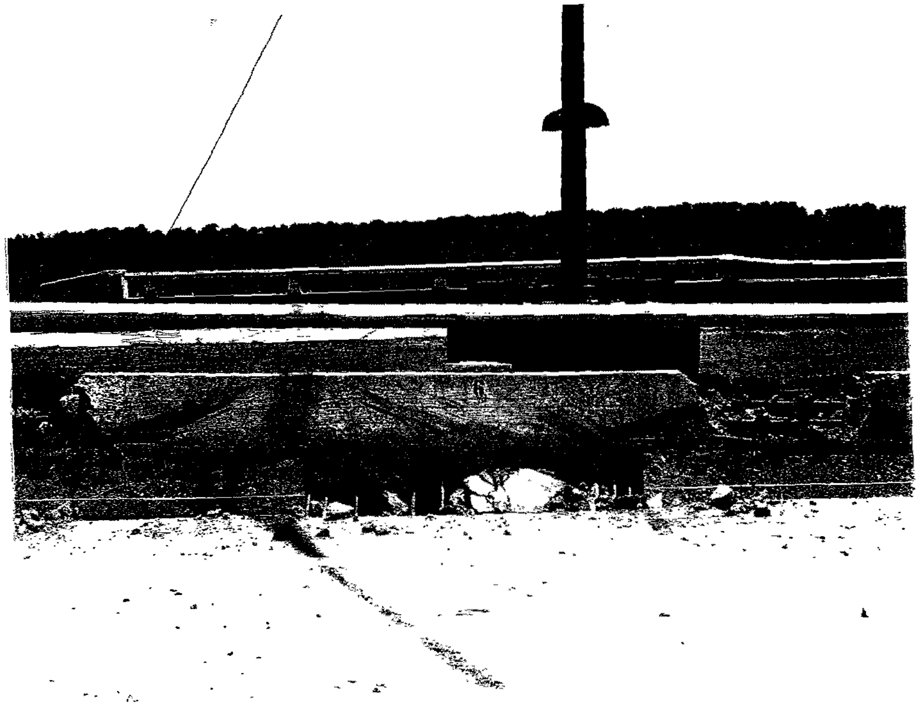


Front of Rail

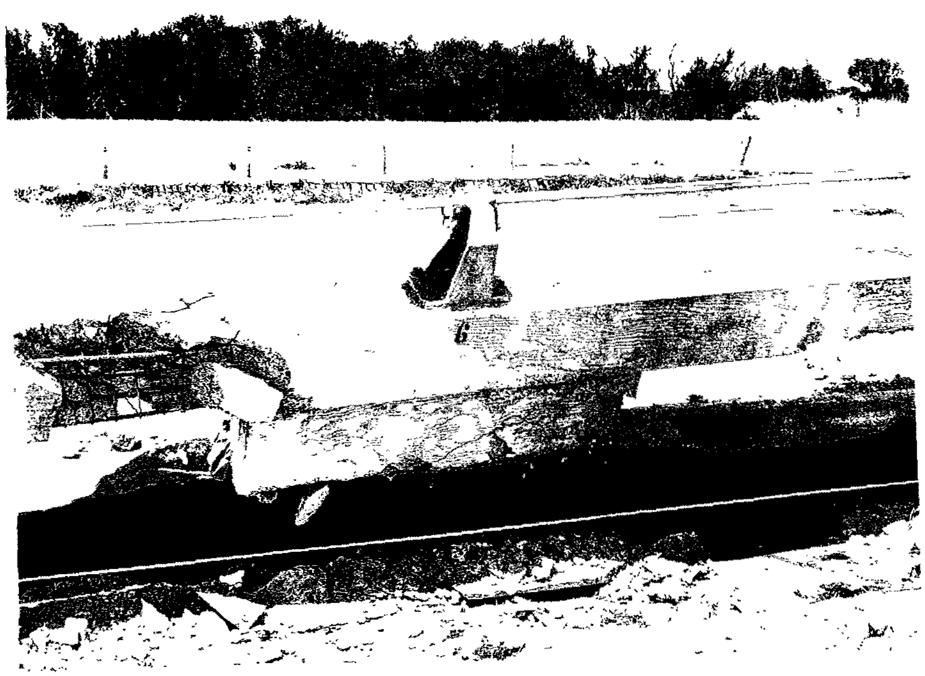


Back of Rail

Figure C5. Damage to Bridge Rail at Post No. 5, Test 5.

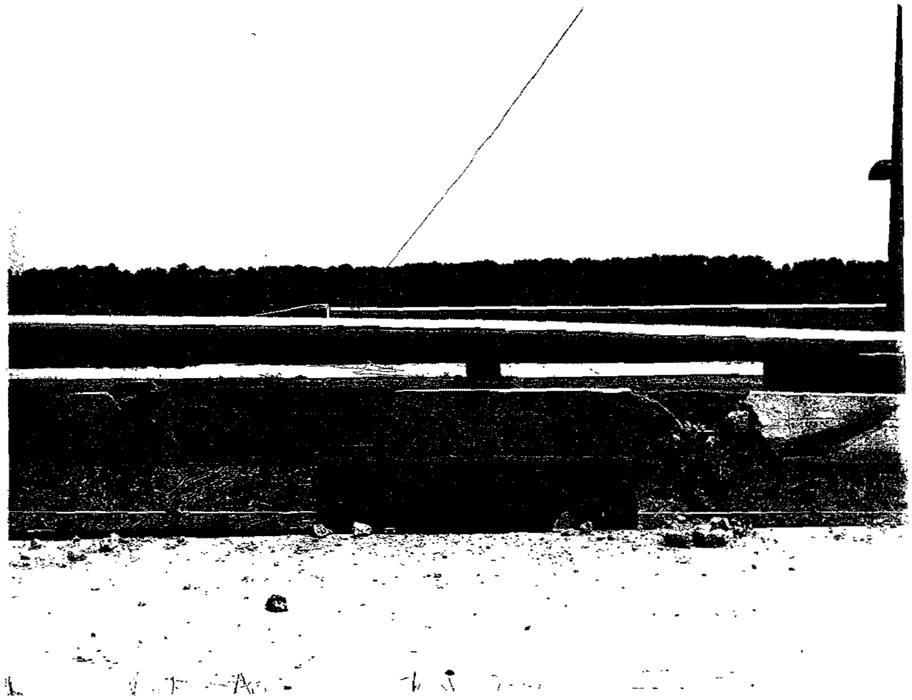


Front of Rail

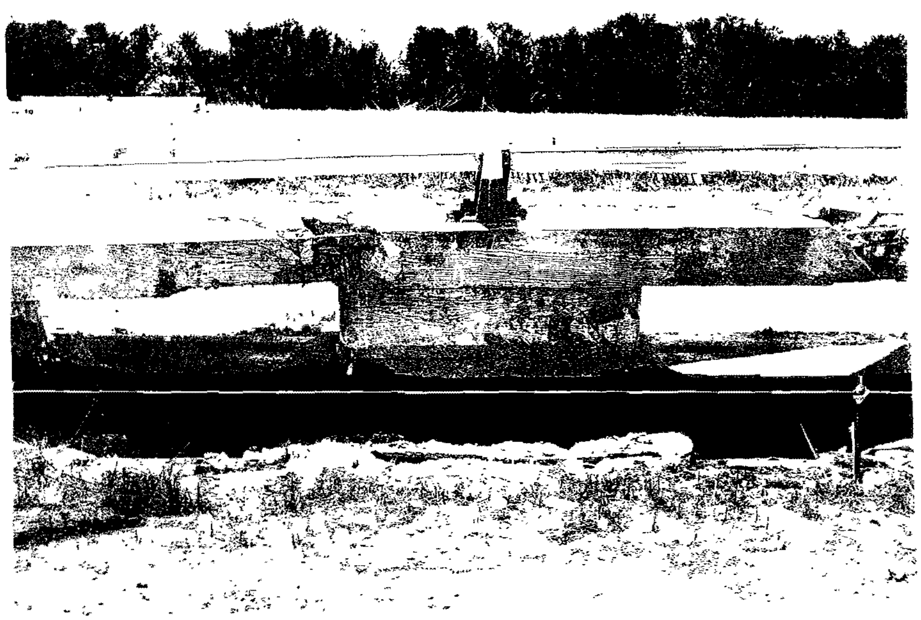


Back of Rail

Figure C6. Damage to Bridge Rail at Post No. 6, Test 5.

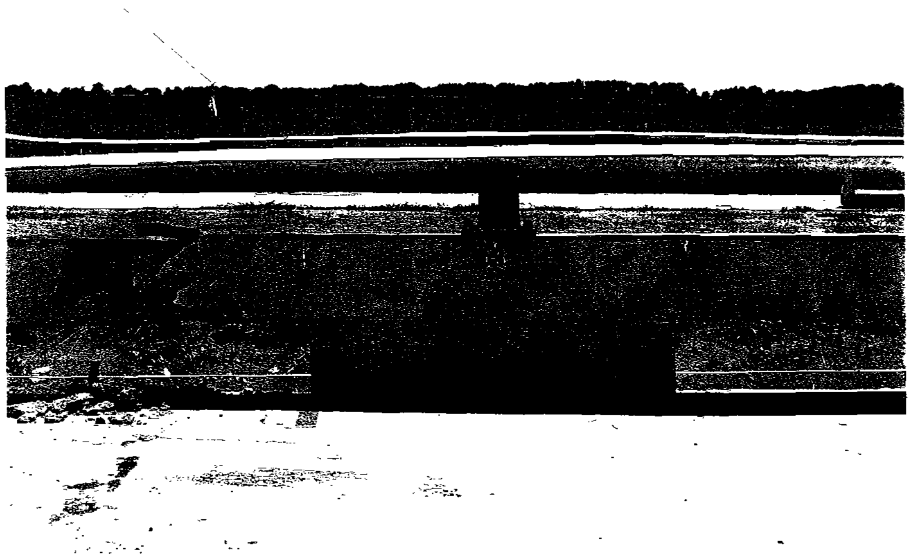


Front of Rail

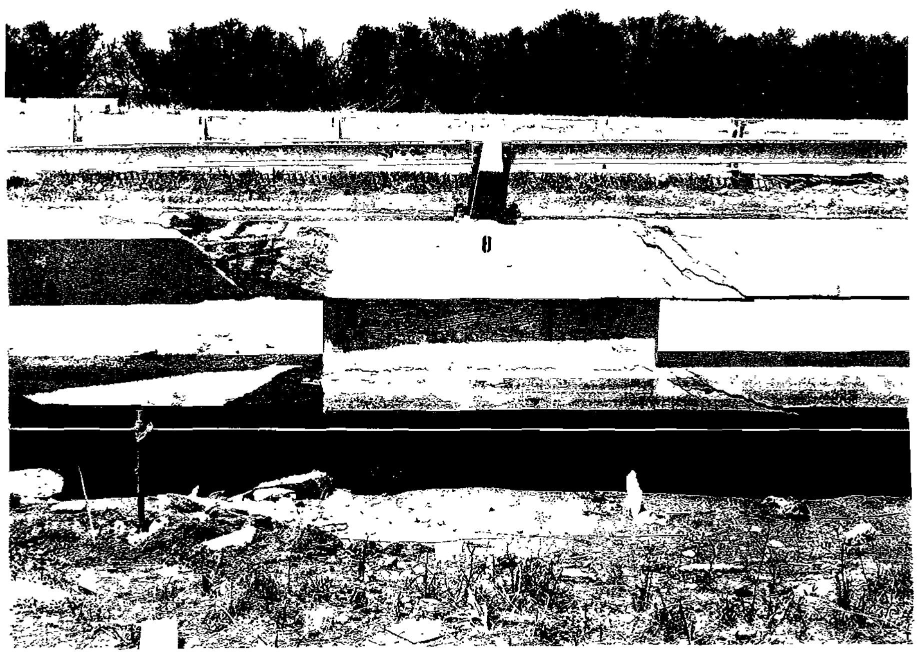


Back of Rail

Figure C7. Damage to Bridge Rail at Post No. 7, Test 5.



Front of Rail
(Post No. 3)



Back of Rail
(Post No. 8)

Figure C8. Damage to Bridge Rail at Post Nos. 3 and 8, Test 5.

APPENDIX D

ELECTRONIC ACCELEROMETER, ROLL, PITCH AND YAW DATA

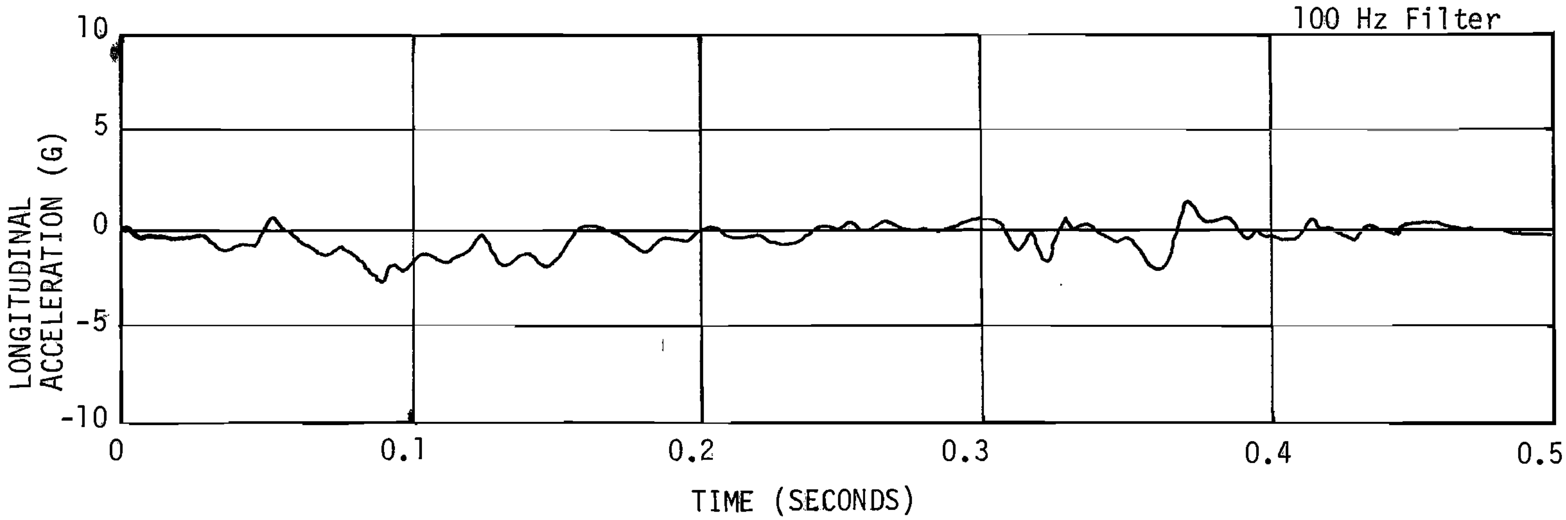


Figure D1. Vehicle Longitudinal Acceleration Trace for Test 3.

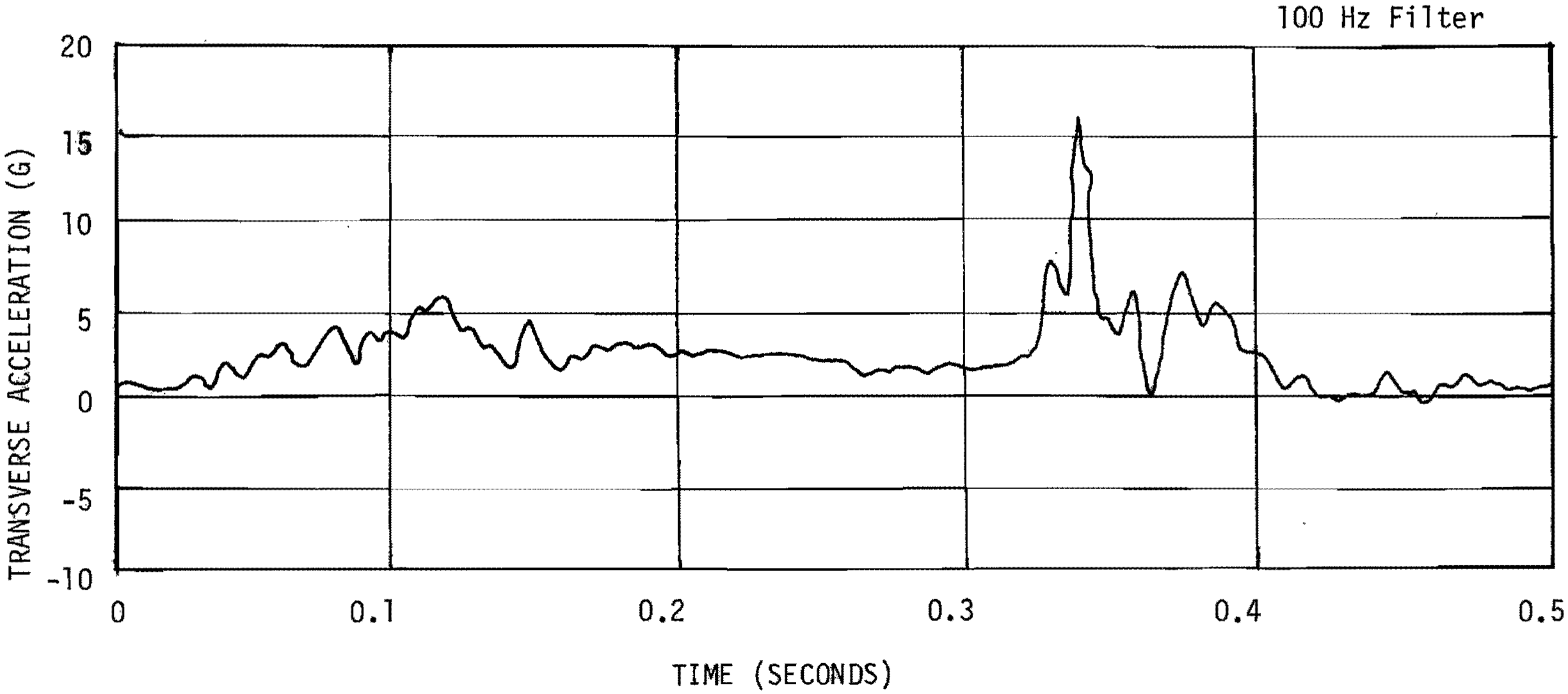


Figure D3. Vehicle Transverse Acceleration Trace for Test 3.

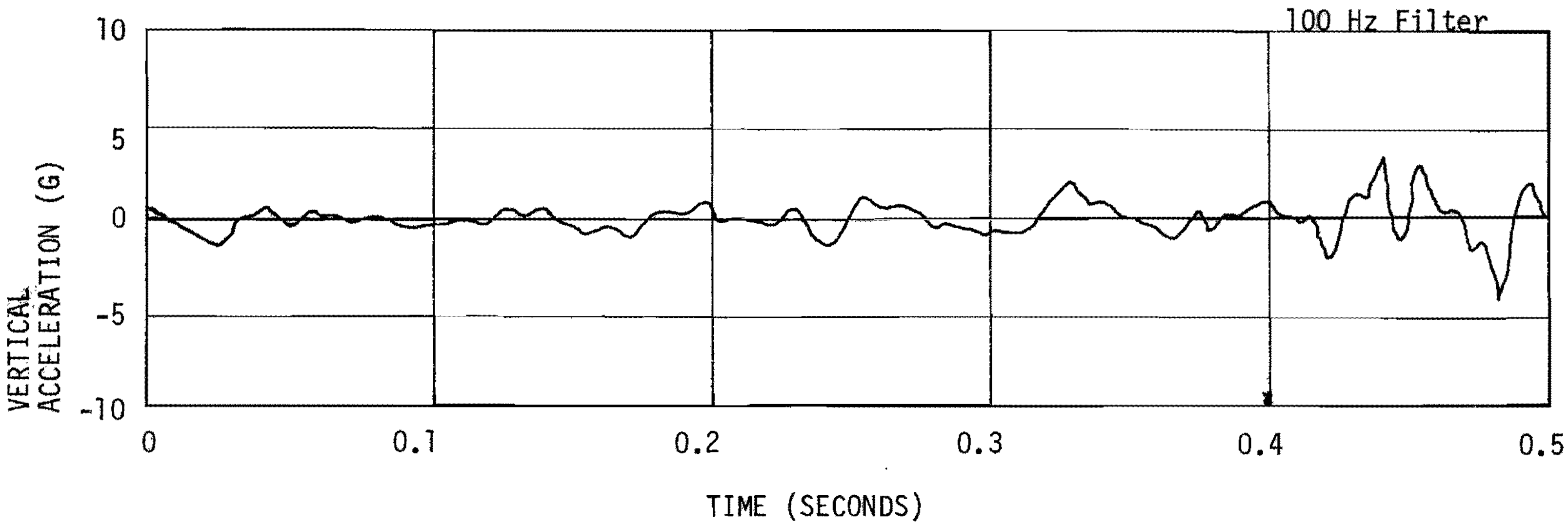


Figure D3. Vehicle Vertical Acceleration Trace for Test 3.

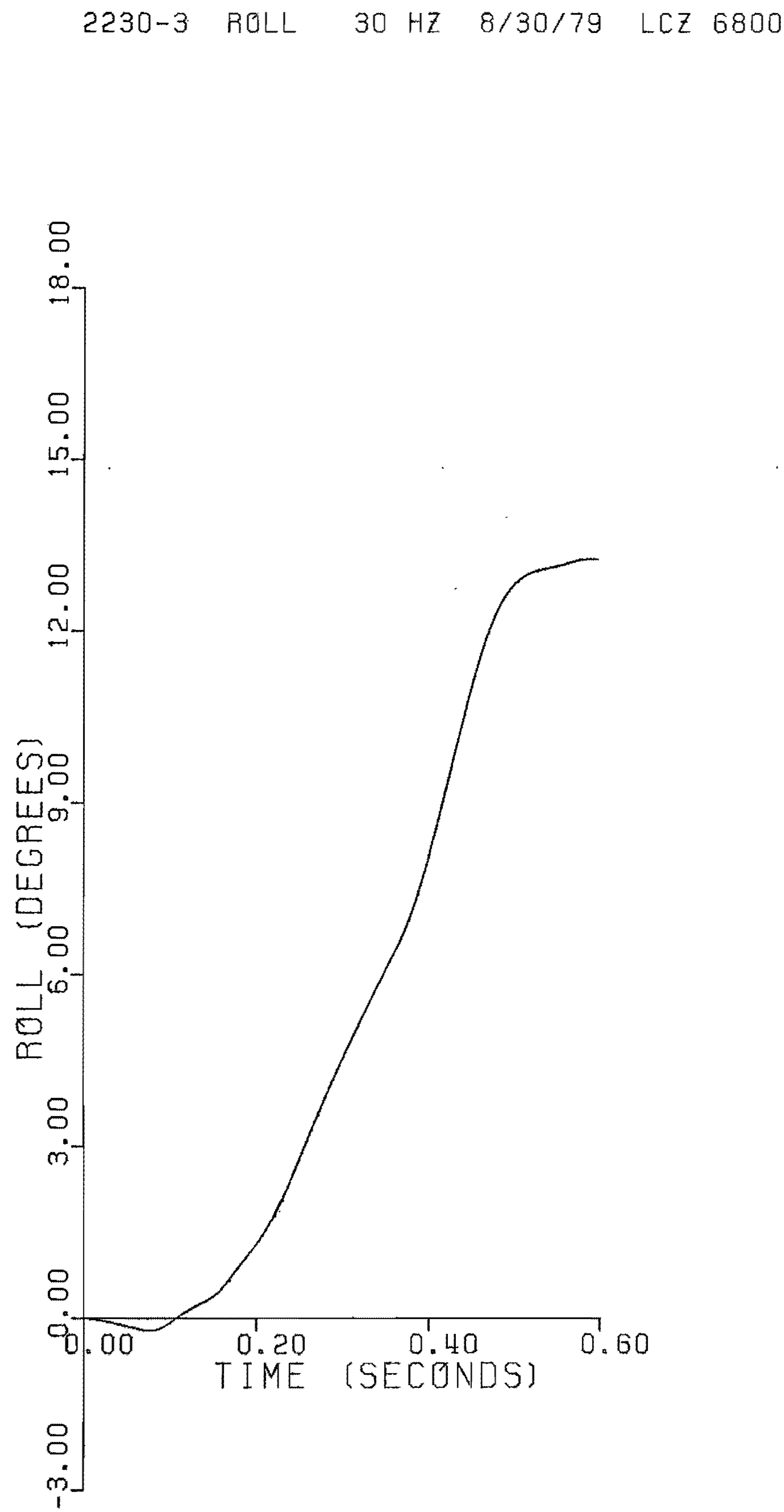


Figure D4. Roll versus Time for Test 3.

2230-3 PITCH 30 HZ 8/30/79 LCZ 6800

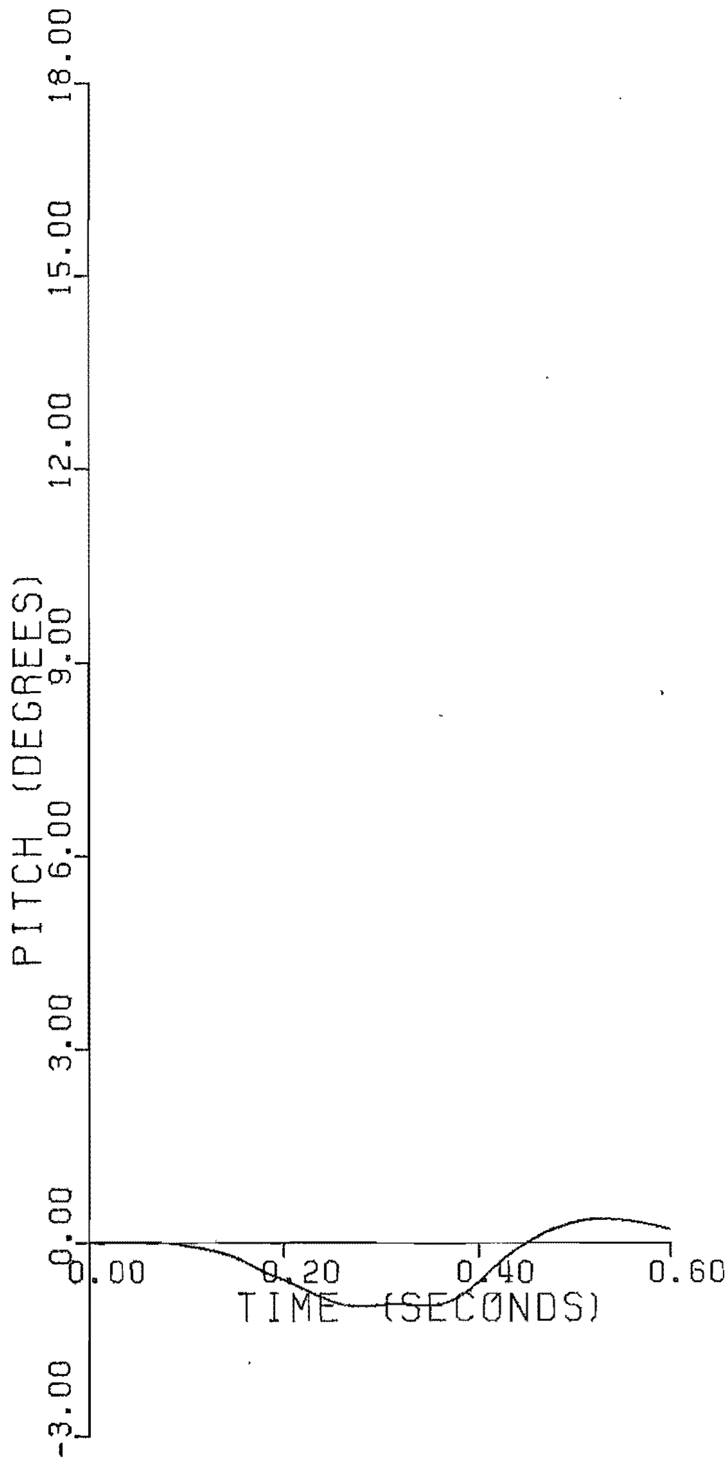


Figure D5. Pitch versus Time for Test 3.

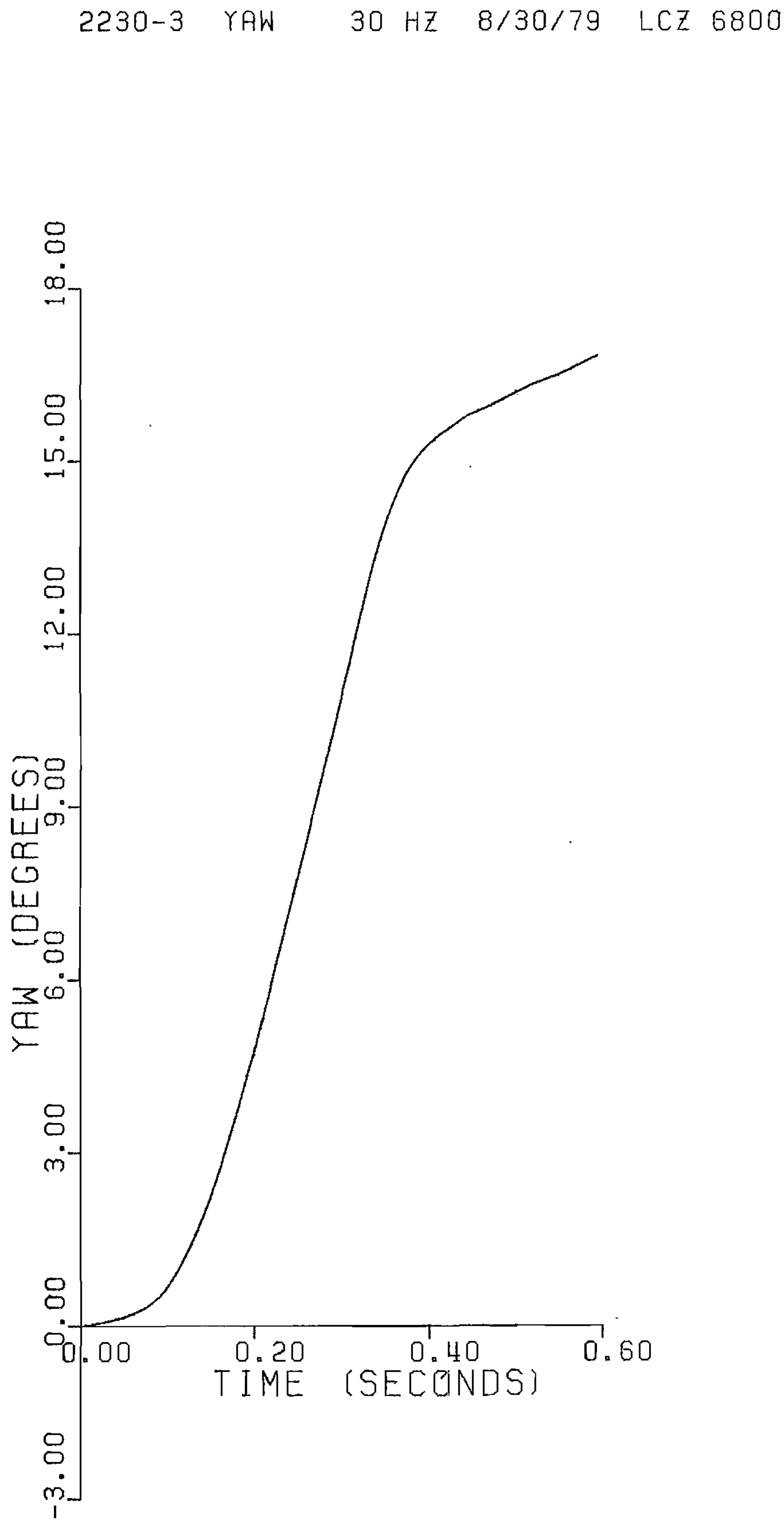


Figure D6. Yaw versus Time for Test 3.

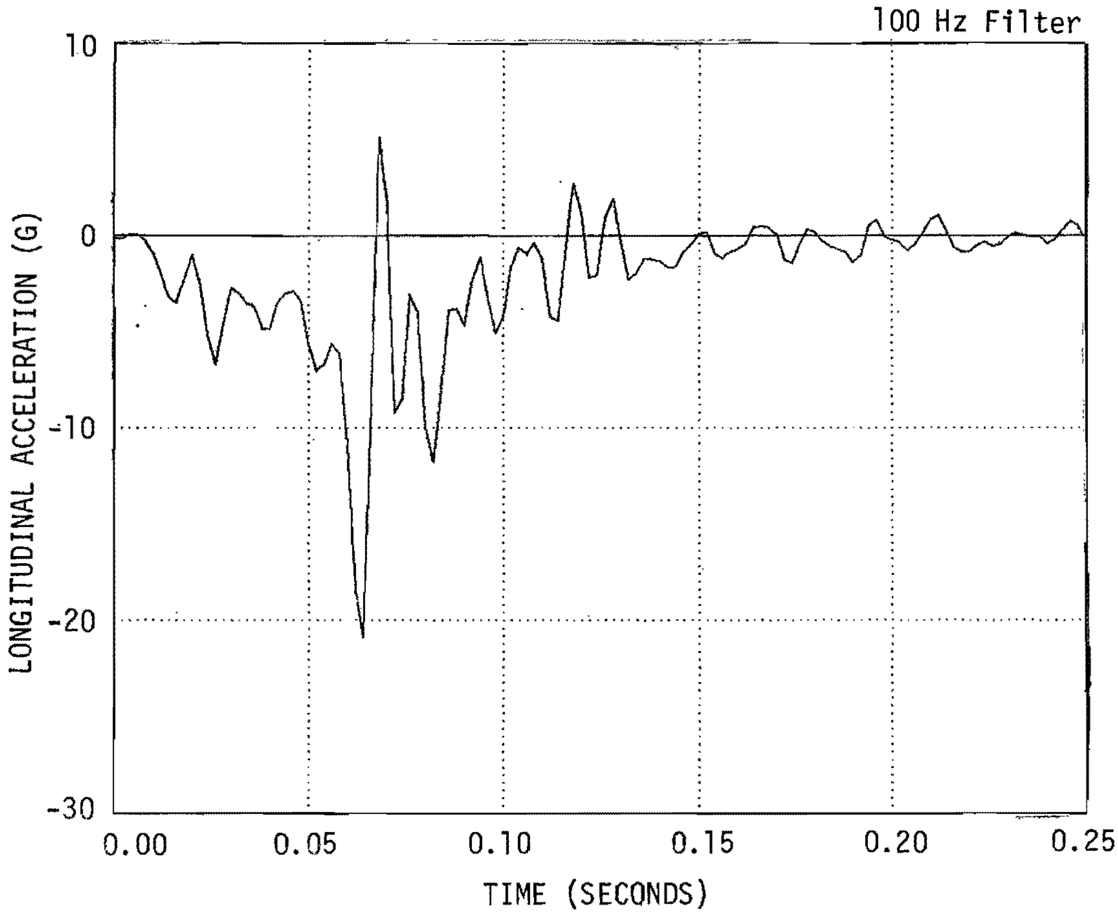


Figure D7. Longitudinal Accelerometer Trace for Test 4.

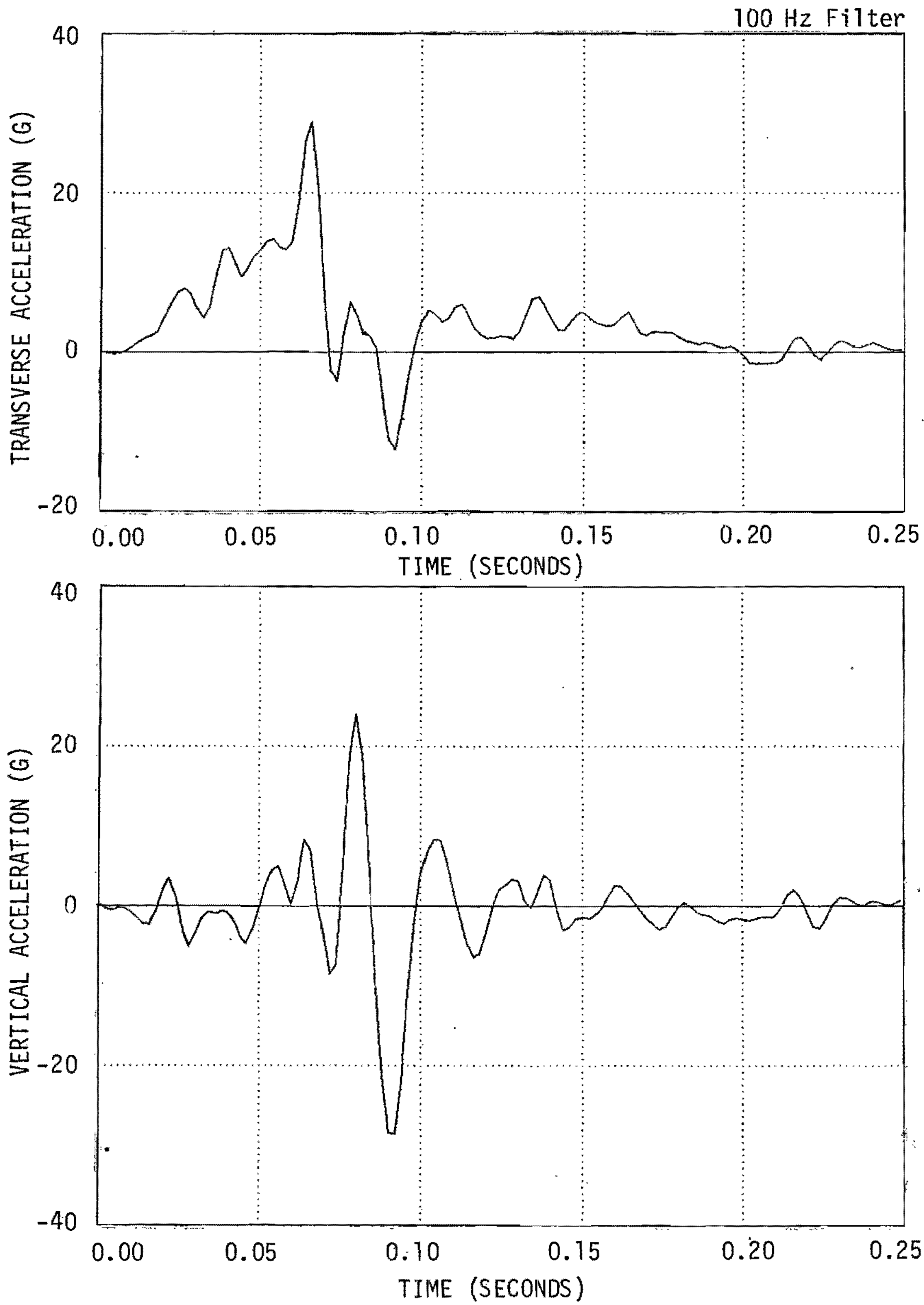


Figure D8. Transverse and Vertical Accelerometer Traces for Test 4.

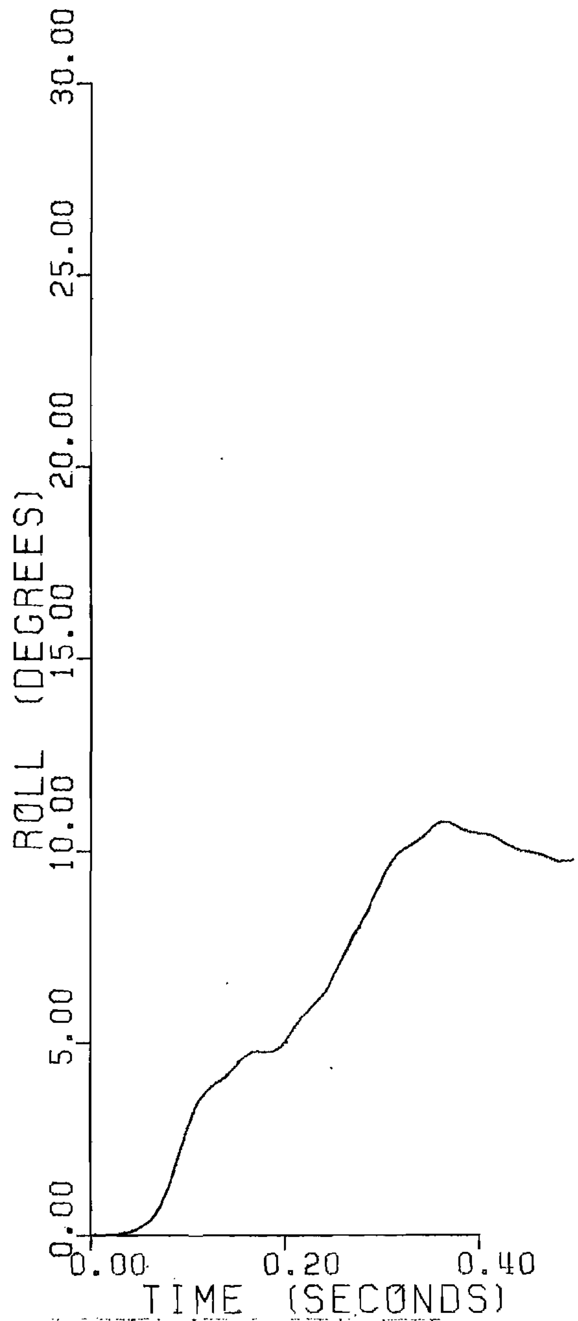


Figure D9. Roll Versus Time for Test 4.

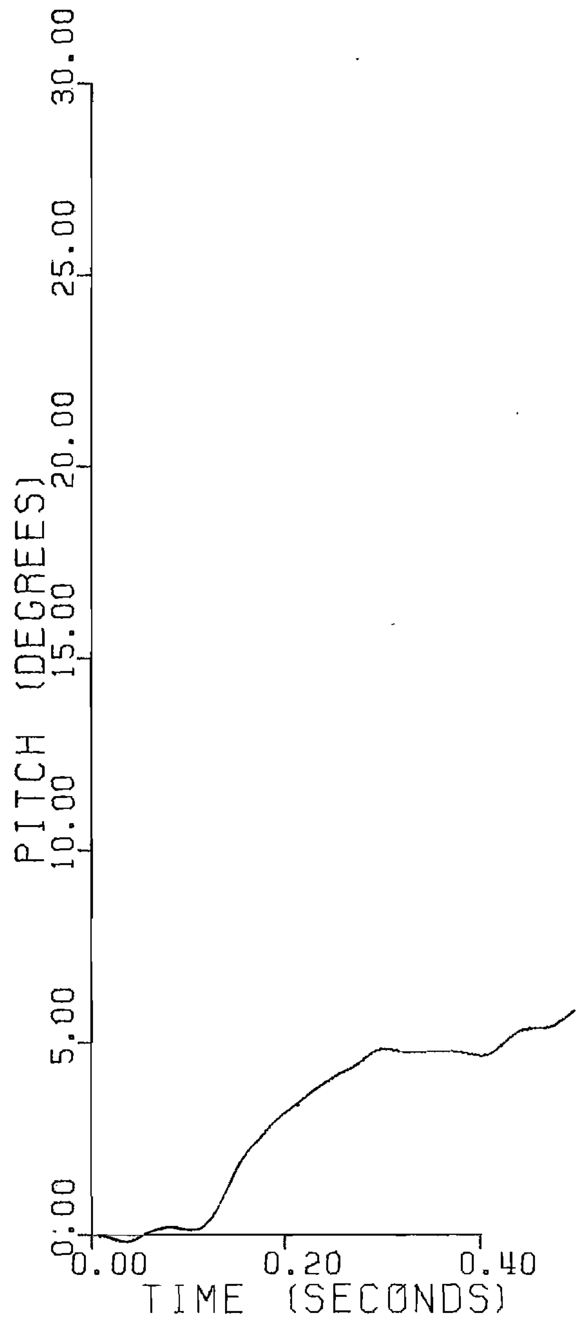


Figure D10. Pitch Versus Time for Test 4.

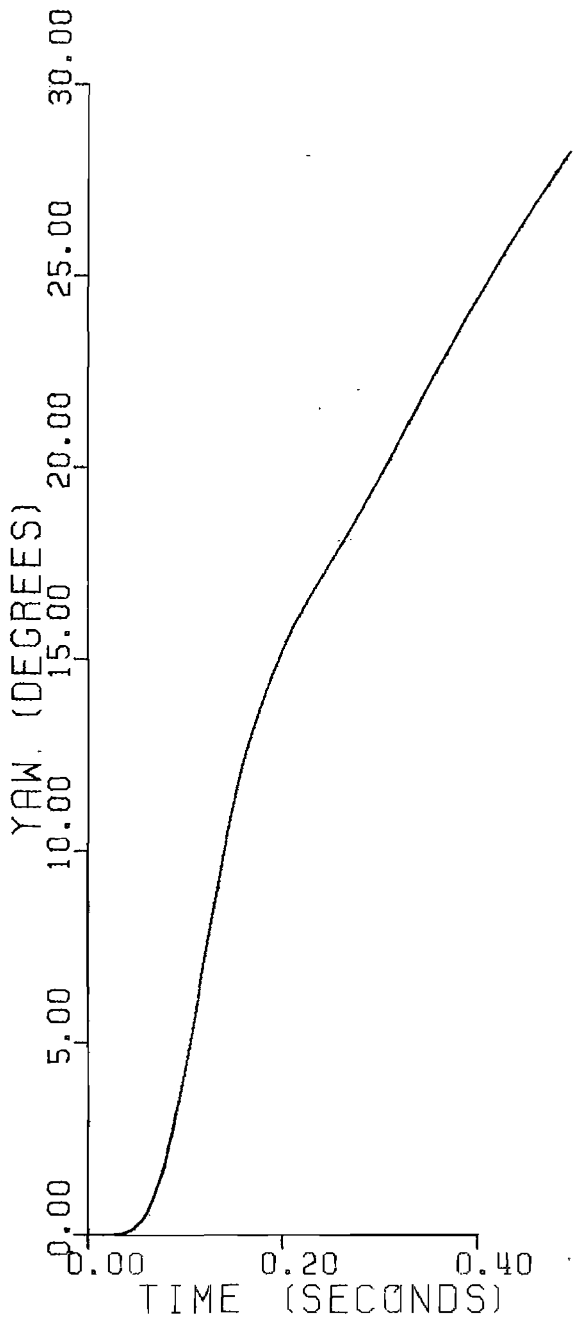


Figure D11. Yaw Versus Time for Test 4.

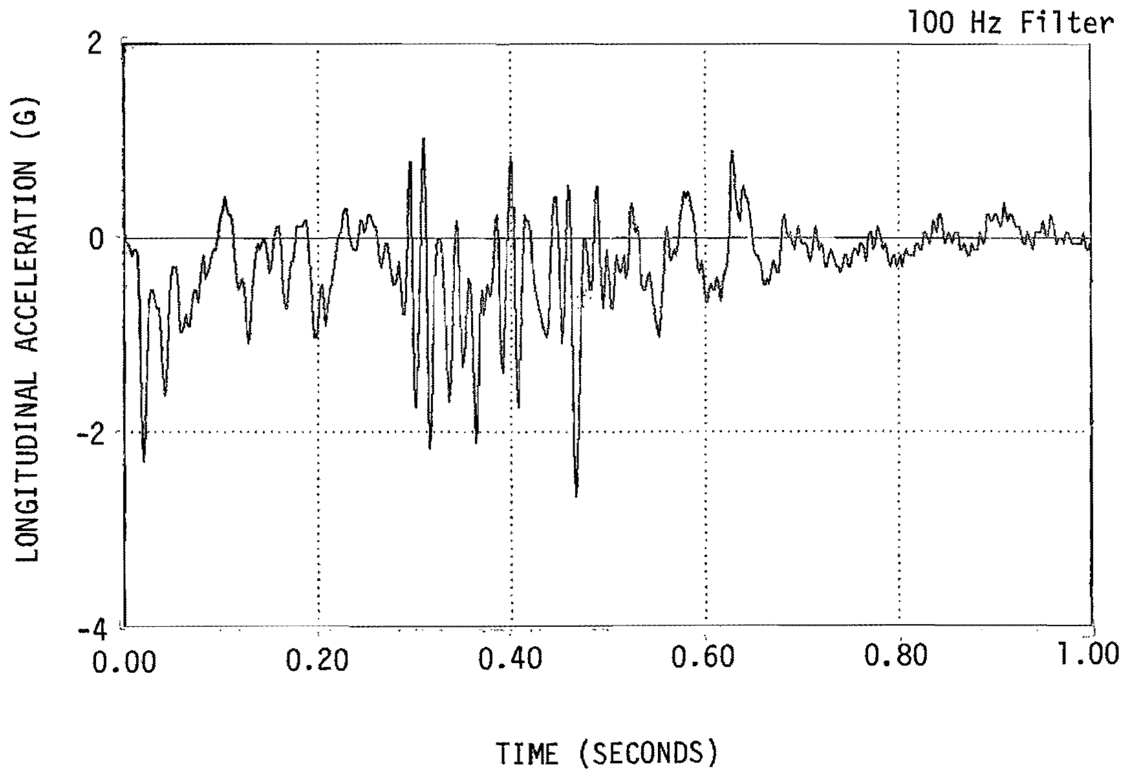


Figure D12. Vehicle Longitudinal Acceleration for Test 5.

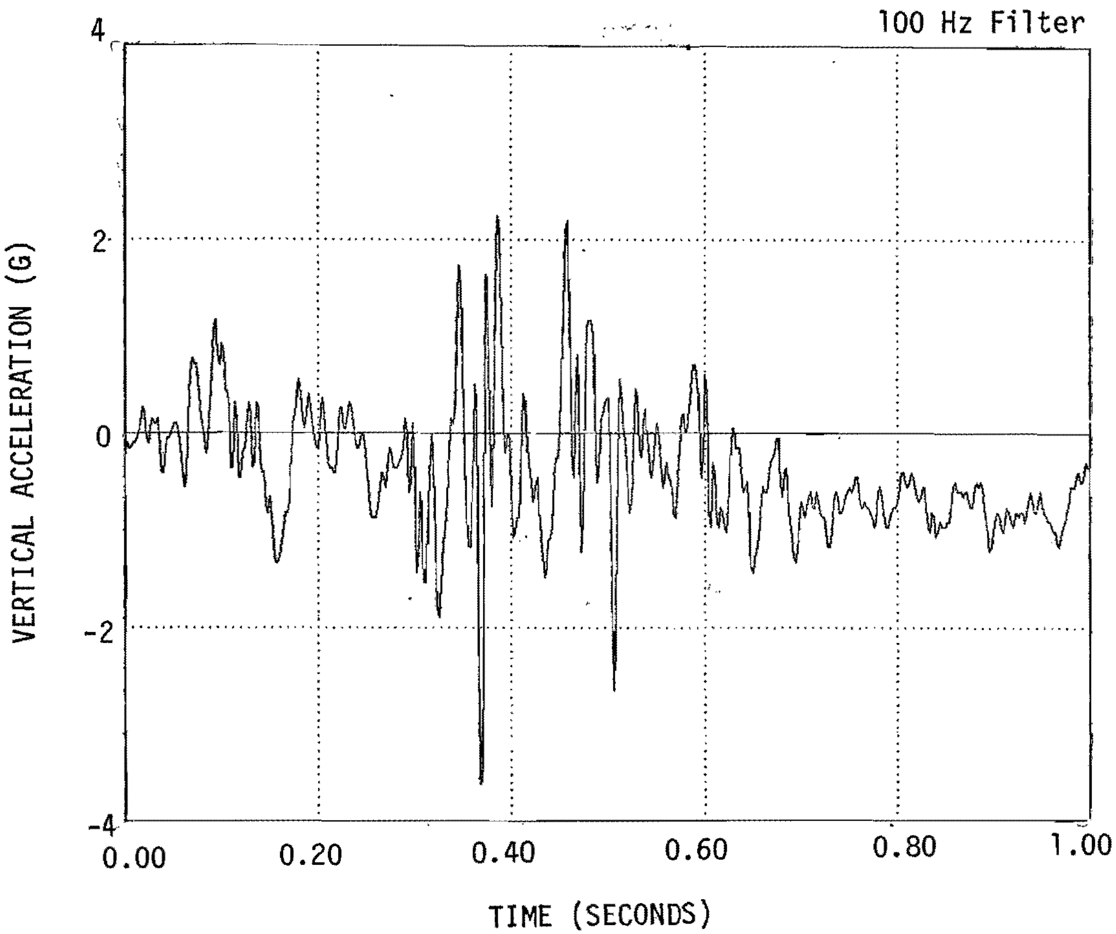


Figure D13. Vehicle Vertical Acceleration for Test 5.

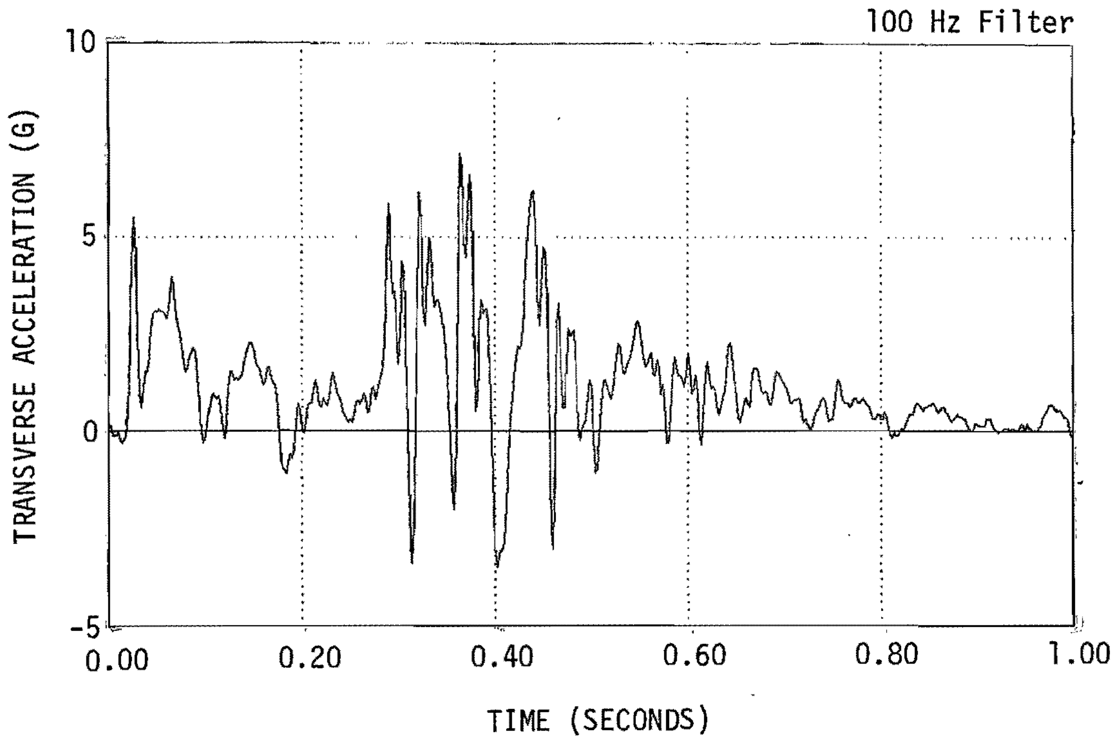


Figure D14. Vehicle Transverse Acceleration for Test 5.

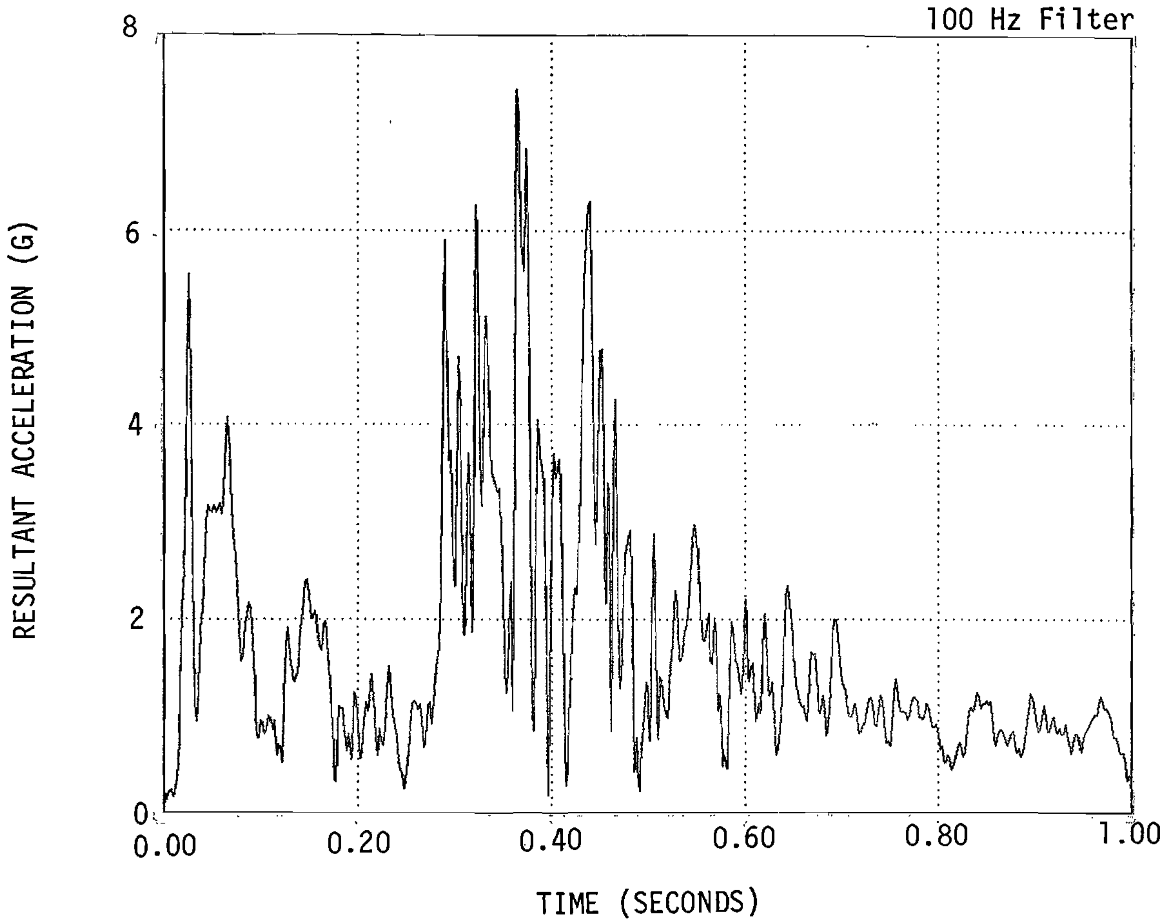


Figure D15. Vehicle Resultant Acceleration for Test 5.

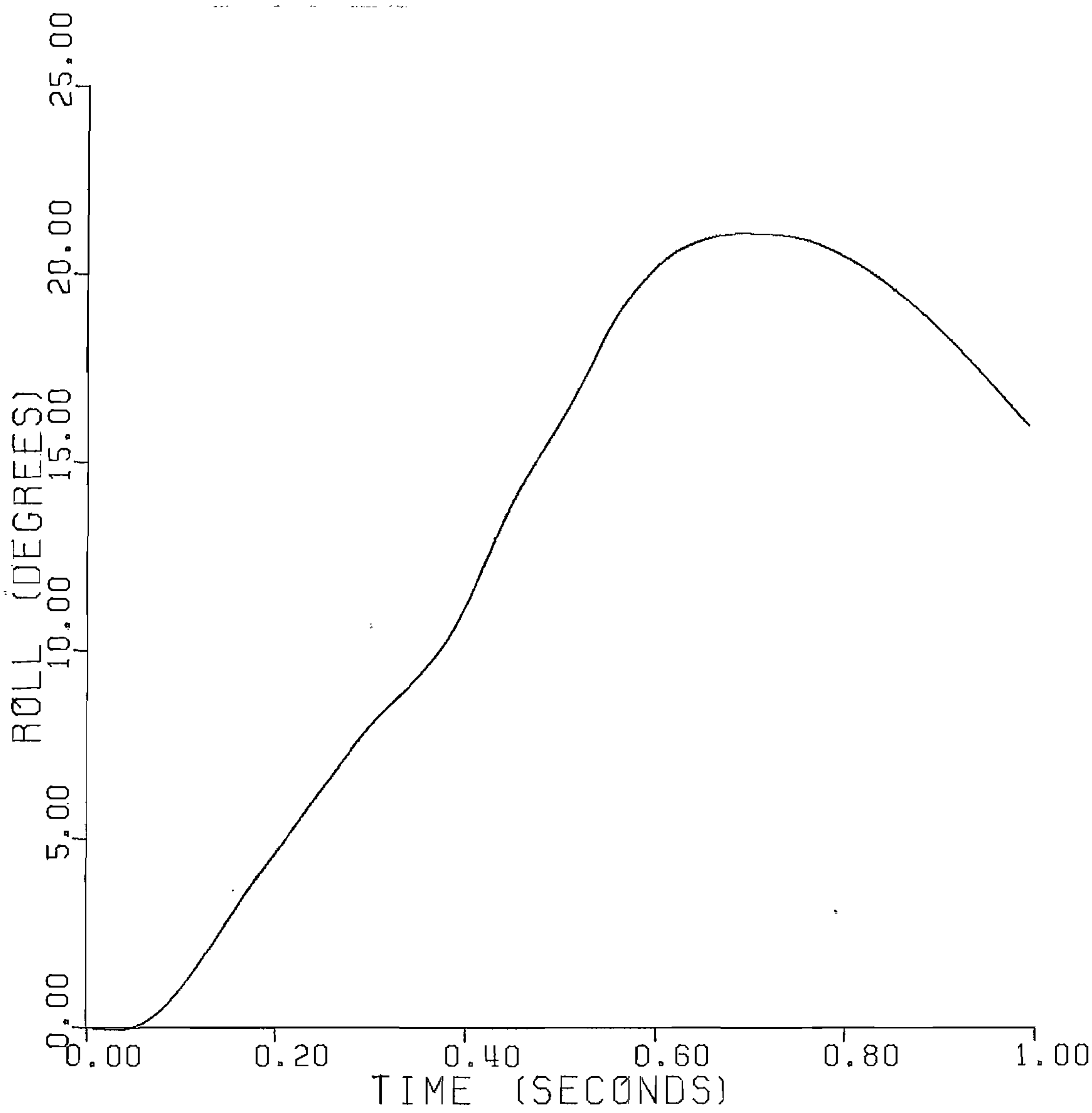


Figure D16. Vehicle Roll for Test 5.

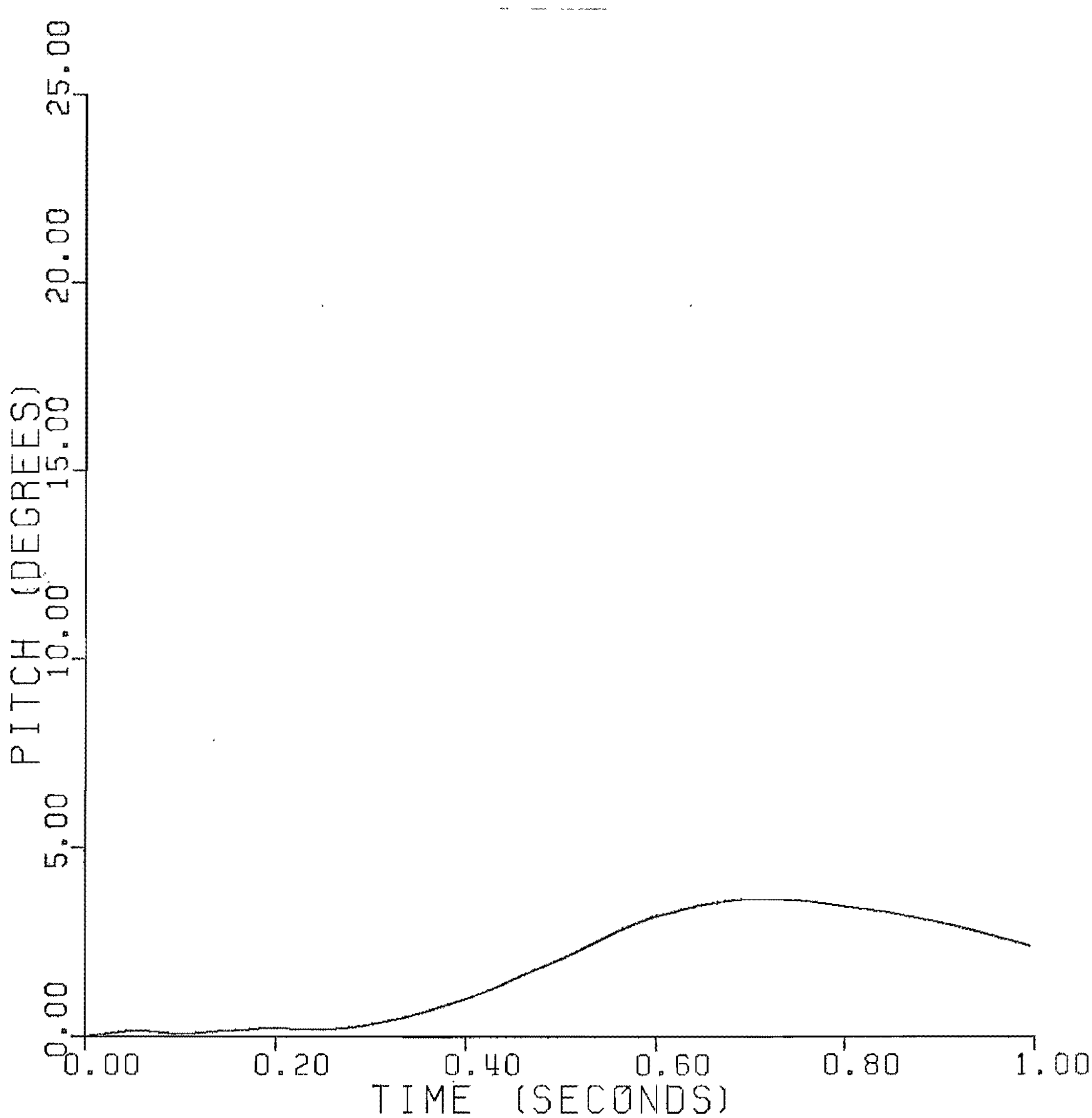


Figure D17. Vehicle Pitch for Test 5.

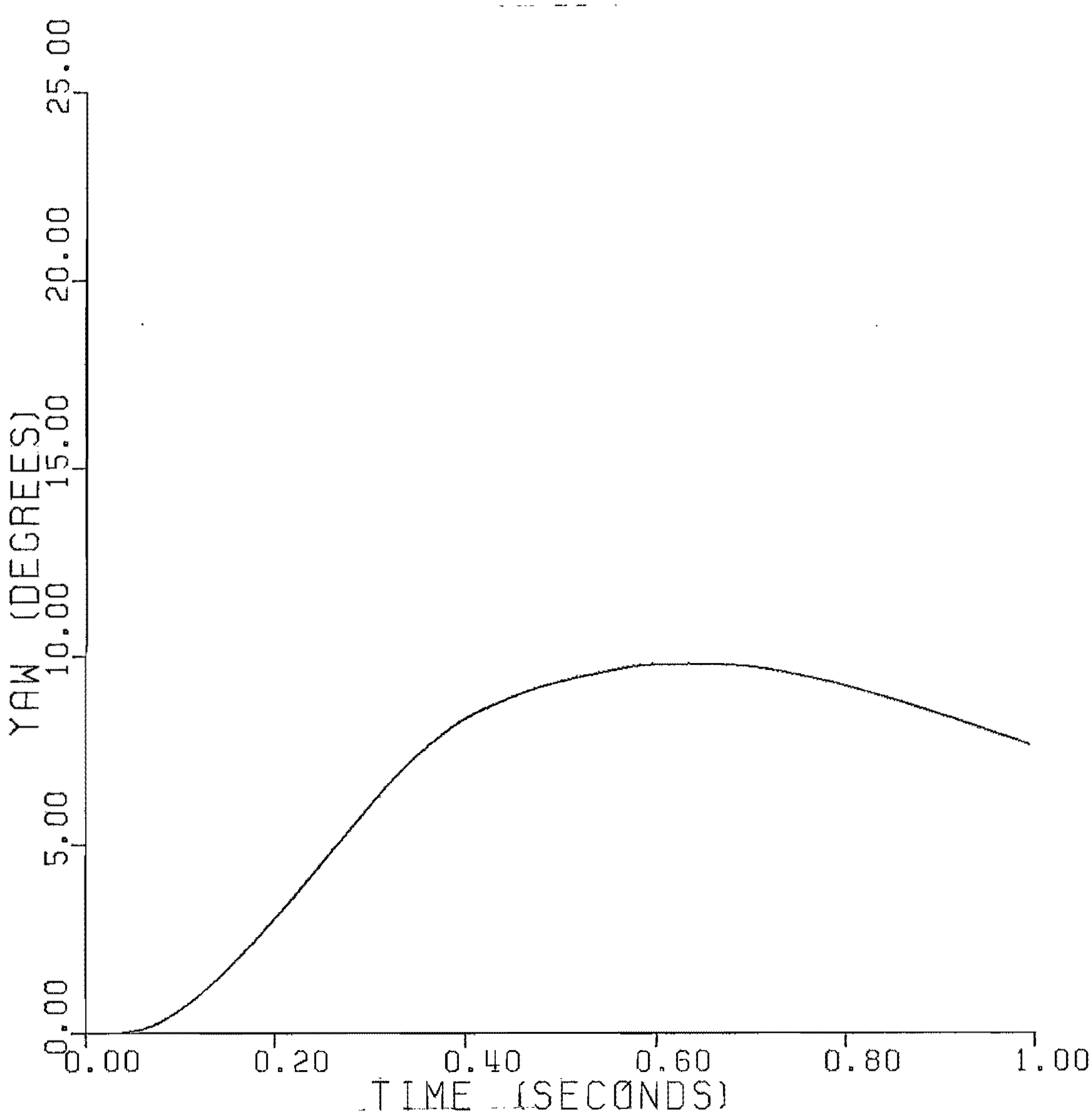
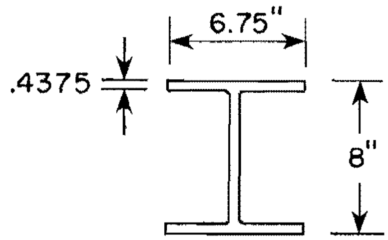


Figure D18. Vehicle Yaw for Test 5.

APPENDIX E

STRUCTURAL ANALYSIS OF BRIDGE RAIL
(After Ref. 1)

T4 CAST ALUM. POST - ASTM B108 A444 T-4



F_{uH} = 20 Ksi 20% elong.

$$Z = 6.75 \times .4375\ (8 - .4375) + \frac{.375 \times 7.375^2}{4}$$

$$= 22.33 + 5.10$$

$$Z = 27.43\ in^3$$

$$M_p = Z\sigma_y = 27.43 \times 20 = 548.6\ K\text{-}in$$

$$P_p = \frac{548.6\ K\text{-}in}{12} = \underline{\underline{45.7}}\ Kips$$

Anchor Bolts A325 3/4" $\frac{28}{.7}$ = 40 Kips each

$$a_b = \frac{80\ Kips}{12" \times .85 \times 3.6} = 2.18\ in$$

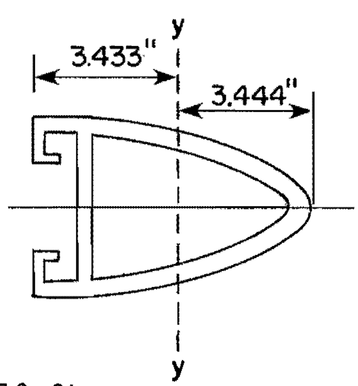
$$M_b = 80\ Kips\ (6.75 - 1.09) = 452.8\ K\text{-}in$$

$$P_p = \frac{452.8\ K\text{-}in}{12.75\ in} = 35.5\ Kips = P_p$$

Alum Post

Anchor Bolts weak link

EXTRUDED ALUM. RAIL - ASTM B221 - 6061 - T6



$I_y = 27.02\ in^4$ F_y = 35 Ksi

$A = 4.896\ in^2$

$$S = \frac{I_y}{3.444} = 7.85\ in^3$$

Shape Factor $\frac{Z}{S}$ = 1.25

1.27

L = 10 ft

$Z = 1.25\ S = 9.81\ in^3$ Assume 1.25 for this shape

$$M_p = \sigma_y Z = 35 \times 9.81 = 343.4\ K\text{-}in = 28.6\ K\text{-}ft = M_R$$

T202 CONCRETE POST

$$13 - \#4 \qquad A_s = 13 \times .2 = 2.6 \text{ in}^2$$

$$a = \frac{A_s\ f_y}{.85\ fc'\ b} = \frac{2.6 \times 60}{.85 \times 3.6 \times 60} = .85 \text{ in}$$

$$M_p = .9 \times 2.6 \times 60\ (5.5 - .4\ 2) = 713 \text{ K-in}$$

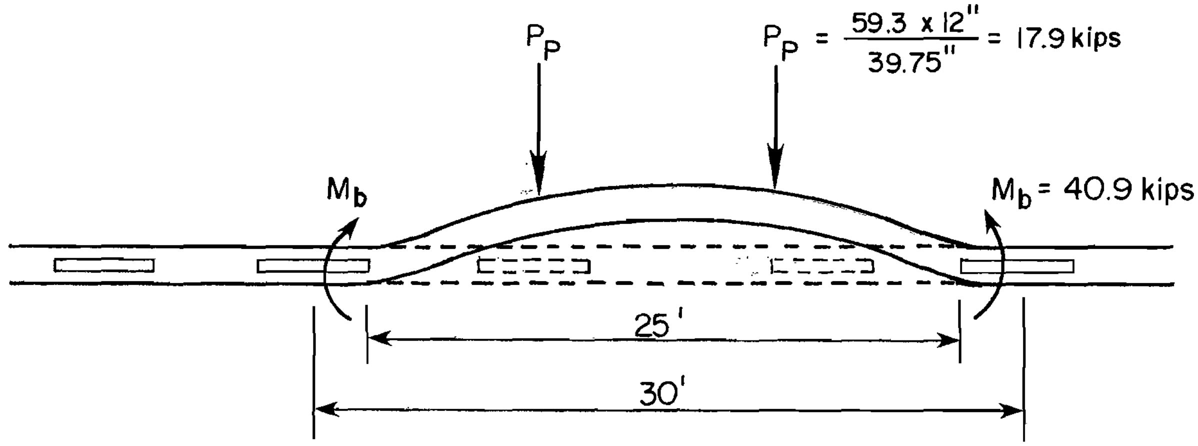
M_p = 59.4 K-ft Post Moment Concrete

T202 BEAM with 8 - #5 Bars   Grade 60

$$a = \frac{A_s f_y}{.85\ fc'\ b} = \frac{(4 \times .31)\ 60}{.85 \times 3.6 \times 14} = 1.74''$$

$$M_b = .9 \times 60 \times 1.24\ (8 - .67) = 490.8\ \text{K-in}$$

$$M_b = 40.9\ \text{K-ft}$$



Conc. Beam

$$(w\ell)_{uH} = \frac{8\ M_b}{L - \ell/2} = \frac{8 \times 40.9}{25' - 10/2} = 16.4\ \text{Kips}$$

Al. Beam

$$(w\ell)_u H = \frac{8 \times 28.6}{25 - 10/2} = 11.4\ \text{Kips}$$

$$R = 17.9 + 17.9 + 16.4 + 11.4 = 63.6\ \text{Kips}$$

$$H = \frac{35.8'' \times 39.75'' + 16.4 \times 20'' + 11.4 \times 39.75''}{63.6} = 34.7''$$

$R = 17.9 + 17.9 + 11.4 = 47.2$ Kips $H = 39.75''$

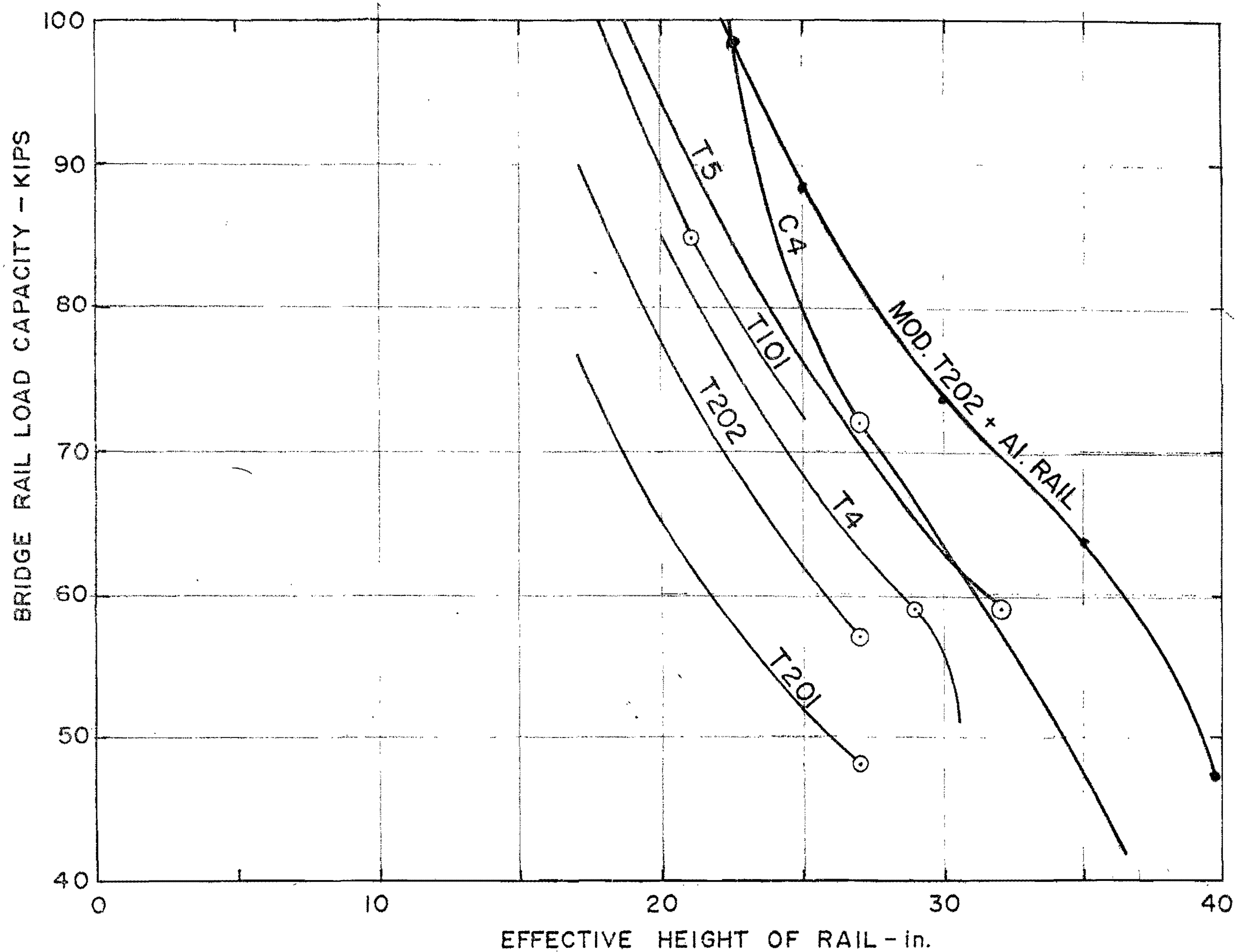


FIGURE EI. SUMMARY OF STRENGTH AND EFFECTIVE HEIGHT EVALUATION OF TEXAS BRIDGE RAILS.