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TEXAS
TRANSPORTATION
INSTITUTE

STATE DEPARTMENT
OF HIGHWAYS AND
PUBLIC TRANSPORTATION

COOPERATIVE
RESEARCH

TUBULAR W-BEAM BRIDGE RAIL

RESEARCH REPORT 230-1
STUDY 2-5-78-230
BRIDGE RAIL

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16. Abstract

Bridge engineers of the Texas State Department of Highways and Public Transportation (SDHPT) have long desired a low service level bridge rail for use on culverts and low bridges. It was desired that such a rail would be economical and compatible in strength and stiffness with the standard Texas Guard Fence (12 ga. W-beam, mounted on 7 in. diameter timber or W6 x 8.5 steel post at 6 ft-3 in. spacing).

Present bridge rails designed according to AASHTO Standard Specifications for Highway Bridges (12th edition) are expensive, very stiff and rigid, and require special transitions to join them with the standard flexible guardrail on each end.

The Tubular W-Beam bridge rail presented here does not meet the elastic analysis and allowable stress design requirements of AASHTO, but it does meet the full-scale vehicle crash test and performance requirements of such bridge rails and, consequently, is exempt from the allowable stress design requirements.

The Tubular W-Beam bridge rail consists of standard guardrail posts W6 x 8.5 spaced 1.9 m (6 ft-3 in.) with a breakaway welded connection. The breakaway feature is achieved by completely welding up the tension flange and only slightly welding the inside of the compression flange and providing no weld on the web.

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TUBULAR W-BEAM BRIDGE RAIL

by

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Research Report 230-1
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

October 1978

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

ABSTRACT

Bridge engineers of the Texas State Department of Highways and Public Transportation (SDHPT) have long desired a low service level bridge rail for use on culverts and low bridges. It was desired that such a rail would be economical and compatible in strength and stiffness with the standard Texas Guard Fence (12 ga. W-beam, mounted on 7 in. diameter timber or W6 x 8.5 steel post at 6 ft-3 in. spacing).

Present bridge rails designed according to AASHTO Standard Specifications for Highway Bridges (12th edition) are expensive, very stiff and rigid, and require special transitions to join them with the standard flexible guardrail on each end.

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The Tubular W-Beam bridge rail consists of standard guardrail posts W6 x 8.5 spaced 1.9 m (6 ft-3 in.) with a breakaway welded connection. The breakaway feature is achieved by completely welding up the tension flange and only slightly welding the inside of the compression flange and providing no weld on the web.

Since the posts are relatively weak, a strong beam is needed to minimize or control the lateral deflection of the barrier. A Tubular W-Beam was fabricated by welding two standard 12 ga. W-beams back to back. The Tubular W-Beam is about four times stronger than a single W-beam when one compares section moduli. In practice, however, it is much greater than

four times as strong because the Tubular W-Beam does not collapse or lose its shape on vehicle impact as does the standard W-beam. The Tubular W-Beam also has similar benefits as a blocked out rail since it is 15 cm (6.5 in.) thick.

The Tubular W-Beam bridge rail was installed on a simulated bridge 17.4 m (57 ft) long.

The Tubular W-Beam bridge rail met the crash test performance requirements of the AASHTO Standard Specifications for Highway Bridges, 12th Edition, 1977. The new rail smoothly redirected a 2041 kg (4500 lb) vehicle traveling 99.1 km/hr (61.6 mph) and impacting the rail at 27.5 degrees. The 1034 kg (2280 lb) vehicle traveling 93.3 km/hr (58 mph) was also smoothly redirected in a 14-degree impact. This satisfactory performance exempts the rail from the allowable stress requirements of Article 1.1.8 entitled "Railings" of AASHTO.

These crash test results indicate that the Tubular W-Beam rail is compatible in strength and stiffness with the standard Texas Guard Fence and therefore should not require any special transition such as closer post spacing. This bridge rail should be suitable for use on culverts and low bridges.

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, Longitudinal Barriers

ACKNOWLEDGMENTS

This research study was conducted under a cooperative program between the Texas Transportation Institute (TTI), the Texas State Department of Highways and Public Transportation (SDHPT) and the Federal Highway Administration (FHWA). Mr. John F. Nixon (Engineer of Research, SDHPT) and Mr. Robert L. Reed (Engineer of Bridge Design, SDHPT) were closely involved in all phases of this study.

IMPLEMENTATION STATEMENT

As of the writing of this report the TUBULAR W-BEAM BRIDGE RAIL has not been implemented.

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INTRODUCTION

Bridge engineers of the Texas State Department of Highways and Public Transportation (SDHPT) have long desired a low service level bridge rail for use on culverts and low bridges. It is desired that such a rail would be economical and compatible in strength and stiffness with the standard Texas Guard Fence (12 ga. W-beam, mounted on 7 in. diameter timber or W6 x 8.5 steel post at 6 ft-3 in. spacing).

Present bridge rails designed according to AASHTO Standard Specifications for Highway Bridges (12th edition) are expensive, very stiff and rigid, and require special transitions to join them with the standard flexible guardrail on each end.

The Tubular W-Beam bridge rail presented here does not meet the elastic analysis and allowable stress design requirements of AASHTO, but it does meet the full-scale vehicle crash test and performance requirements of such bridge rails (3)* and, consequently, is exempt from the allowable stress design requirements.

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*Numbers in parentheses, thus (3), refer to corresponding items in the References.

BRIDGE RAIL DESCRIPTION AND INSTALLATION

The Tubular W-Beam bridge rail shown by Figure 1 consists of standard guardrail posts W6 x 8.5 spaced 1.9 m (6 ft-3 in.) with a breakaway welded connection. This weak post will develop an ultimate lateral load of about 71.2 kN (16.0 kips) while deflecting laterally about 3.3 cm (1.3 in.) and then break away. The breakaway feature is achieved by completely welding up the tension flange and only slightly welding the inside of the compression flange and providing no weld on the web. Static load test results on this and other post designs are presented in Appendix "C". Dynamic test results on typical guardrail posts are also presented for comparison purposes.

Since the posts are relatively weak, a strong beam is needed to minimize or control the lateral deflection of the barrier. A Tubular W-Beam was fabricated by welding two standard 12 ga. W-beams back to back as shown in Figures 2 and 3. The two beams are staggered longitudinally .38 m (15 in.) in order to achieve a strong, rigid lap splice as shown by Figure 4. The Tubular W-Beam is about four times stronger than a single W-beam when one compares section moduli. In practice, however, it is much greater than four times as strong because the Tubular W-Beam does not collapse or lose its shape on vehicle impact as does the standard W-beam. The Tubular W-Beam also has similar benefits as a blocked out rail since it is 15 cm (6.5 in.) thick.

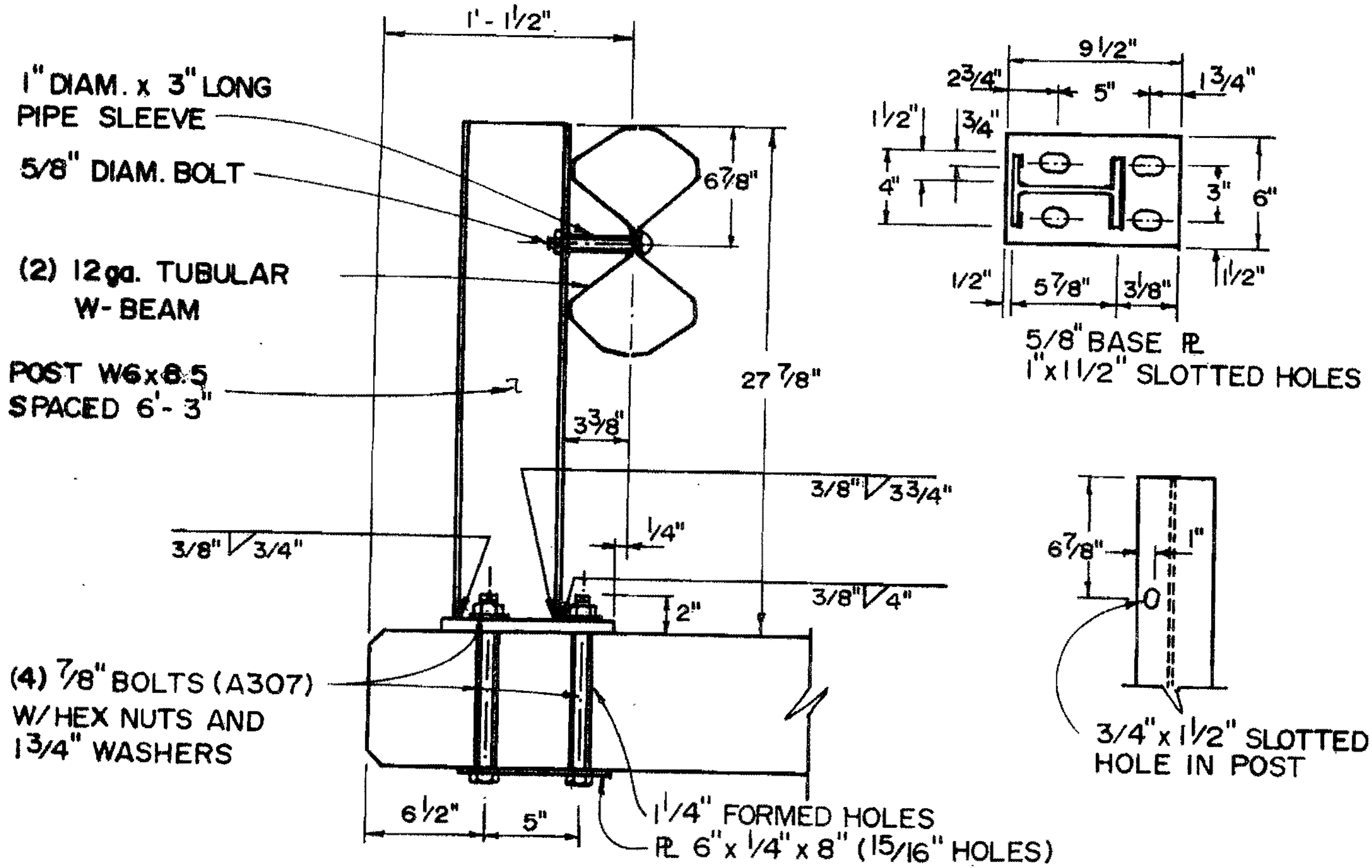
The Tubular W-Beams used in these tests were fabricated by TTI technicians. In order to achieve a good fit at the lap splice and have the 5/8 in. diameter hex head bolts fit in the 5/8 in. recess guardrail nuts, the W-beams were bolted together prior to being welded back to back.

After the W-beams were bolted together, the appropriate nuts were welded to the W-beams as shown by Figures 3 and 4. Then the W-beams were welded together. Since zinc fumes are toxic, precautions should be taken when welding galvanized metal. The bolts could now be removed and the Tubular W-Beam disassembled or re-assembled as desired.

In lieu of the fabrication procedure just described, the splice bolt slots could be enlarged prior to welding on the nuts (Figure 4) or hand holes could be cut in the top and bottom of the Tubular W-Beam segments so the nuts could be held for assembly. Various types of nut retainers are also available commercially and some of these may prove useful in future applications.

Test Installation

The Tubular W-Beam bridge rail was installed on a simulated bridge 17.4 m (57 ft) long as shown by Figure 5. So as not to have a weak W-beam connected directly to a weak bridge rail post, the Tubular W-Beam was extended 3.8 m (12 ft-6 in.) past each end of the bridge and attached to two stronger soil mounted guardrail posts. It is believed that this end detail avoids transition problems. It should be noted on Figure 5 how the post supporting the Tubular W-Beam must be set back 8.25 cm (3.25 in.) from the line of the guardrail posts.



POST IS INTENDED TO BREAK FREE FROM BASE PLATE UNDER IMPACT. IT IS THEREFORE NECESSARY THAT THE WELD SIZES AND LENGTHS SHOWN NOT BE EXCEEDED.

POST HEIGHT SHALL BE INCREASED 2" FOR STRUCTURE WITH PLANNED OVERLAY.

RAILING SHALL HAVE 6'-3" POST SPACING AND MAY BE INSTALLED ON CULVERTS OR BRIDGES WITH STRUCTURE LENGTHS LESS THAN 75 ft.. A MIN OF 25 ft. OF STANDARD GUARDRAIL SHALL BE LOCATED AT EACH RAIL END. ADDITIONAL WOOD OR STEEL POSTS AT 6'-3" CENTERS SHALL BE PLACED AS NEEDED ON THE APPROACHES ALONG WITH APPROPRIATE TERMINAL TREATMENTS.

NO ELASTOMERIC PADS TO BE USED. LEVEL BASE PLATE WITH GROUT IF NECESSARY.

FIGURE 1. TUBULAR W-BEAM BRIDGE RAIL.

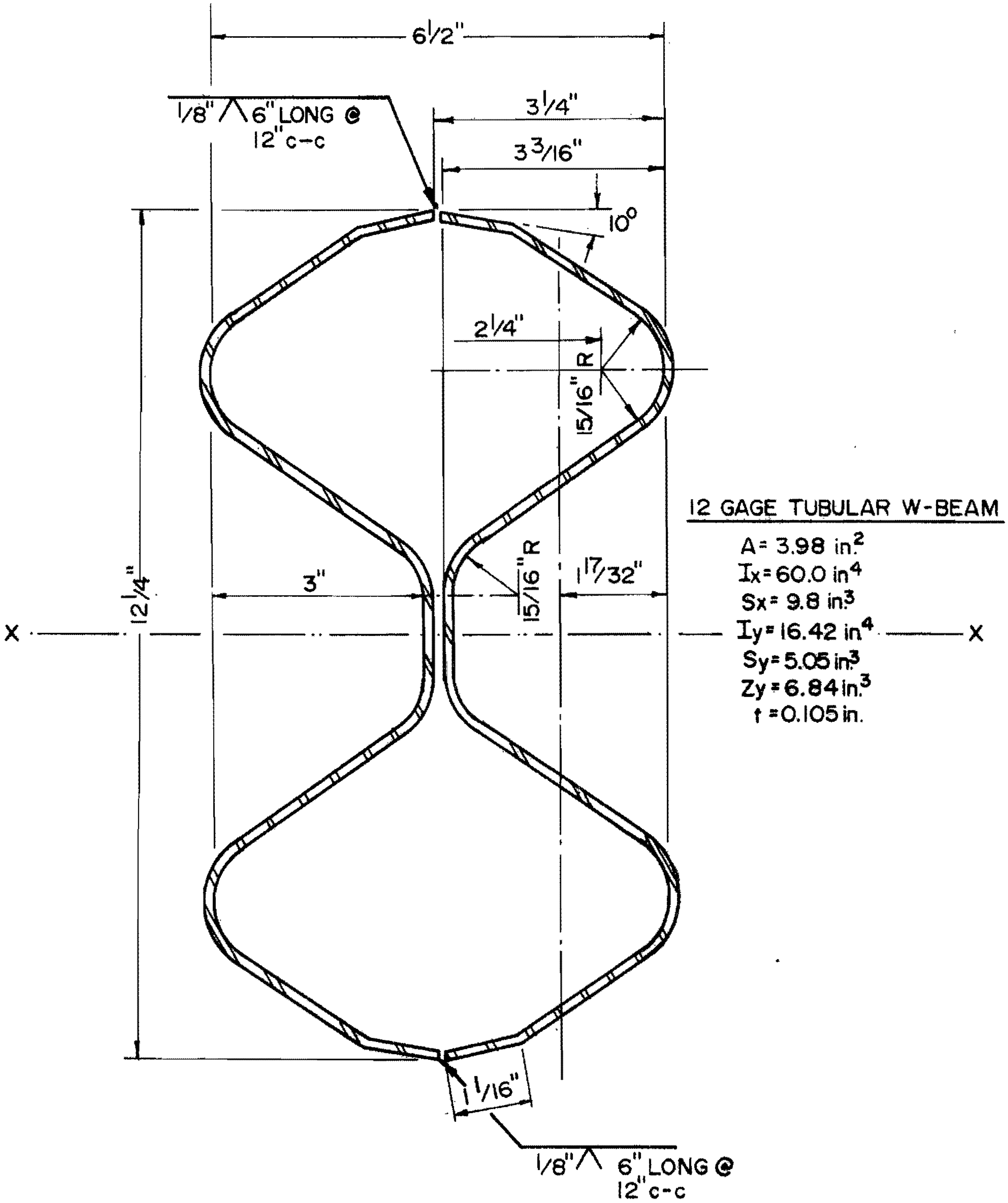


FIGURE 2. 12 GAGE TUBULAR W-BEAM.

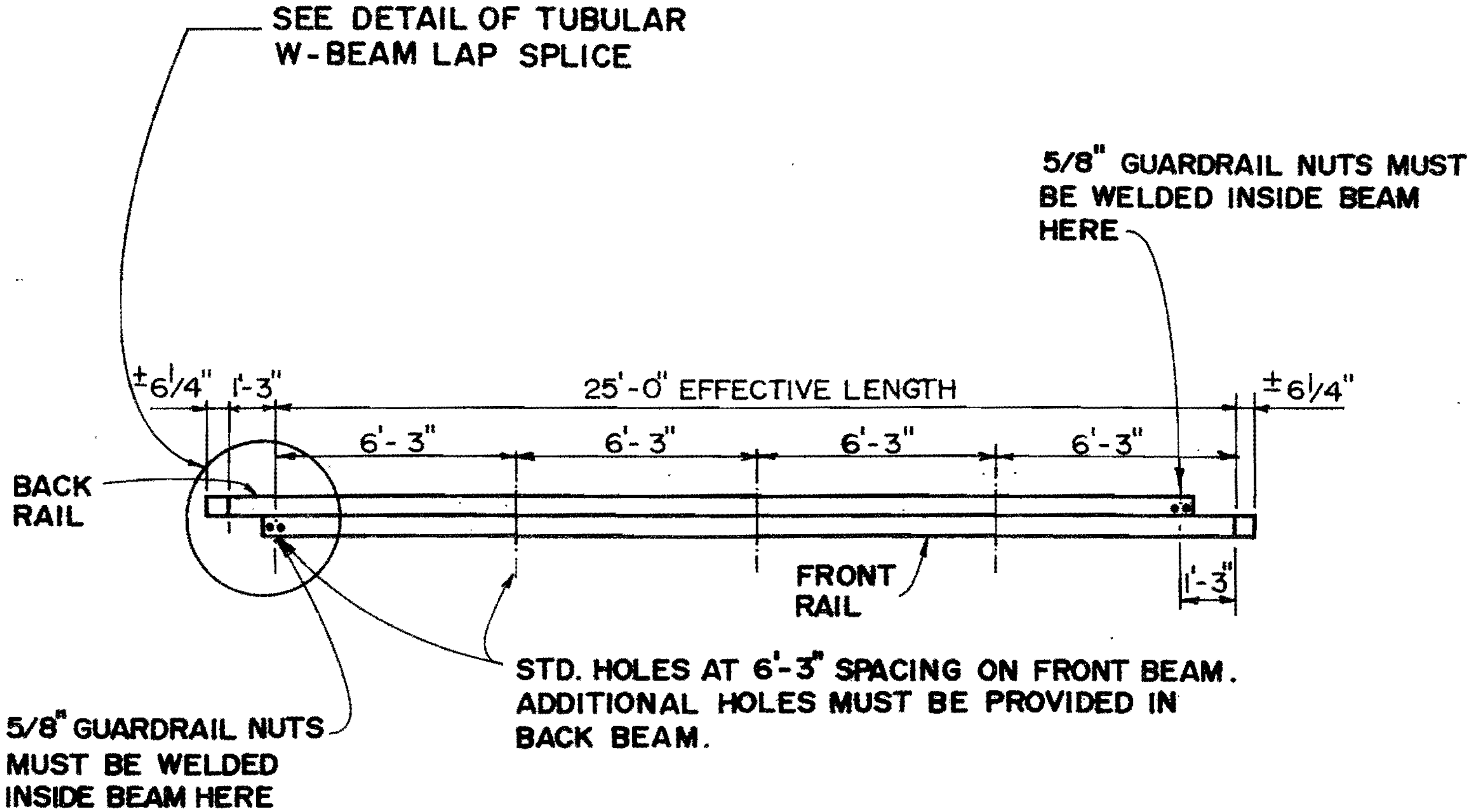


FIGURE 3. PLAN VIEW OF 25' PIECE TUBULAR W-BEAM MAKE-UP.

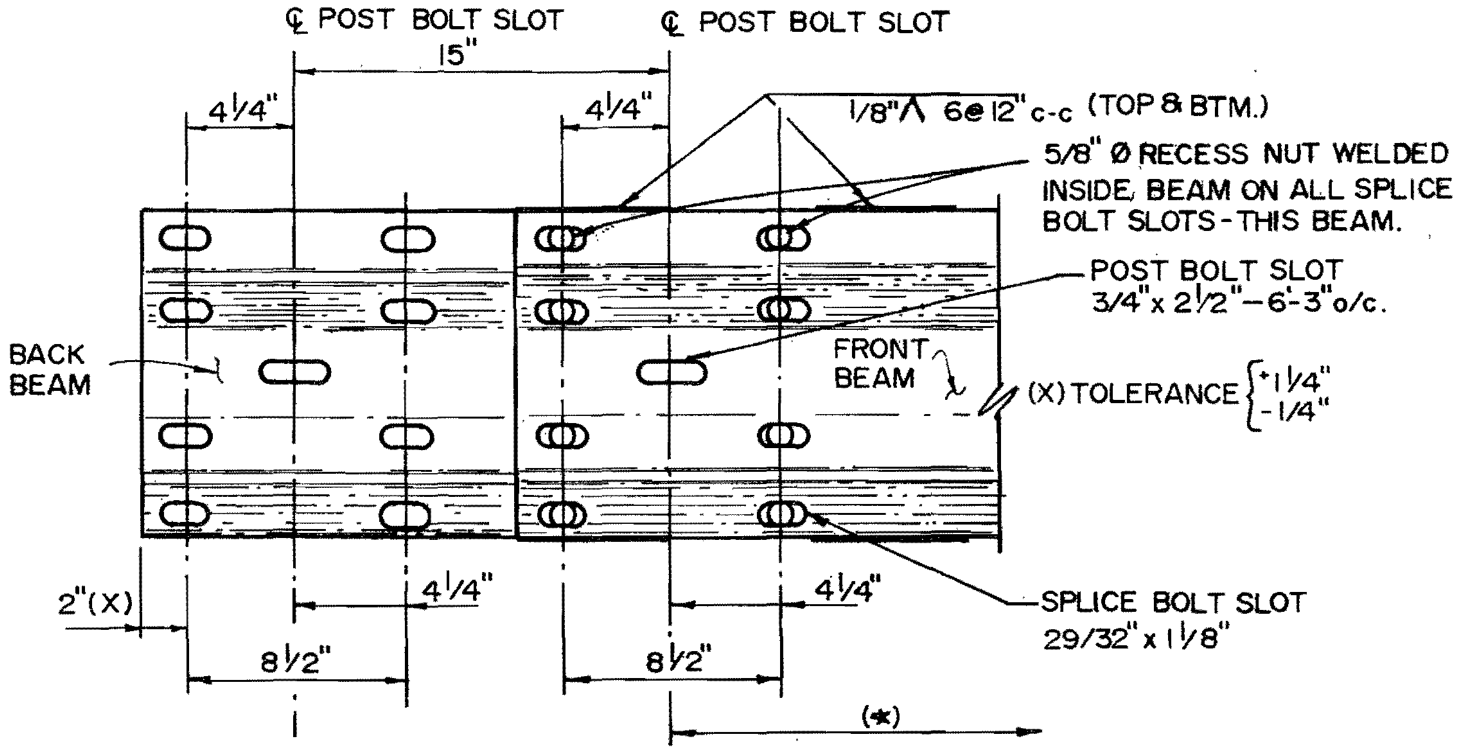


FIGURE 4. TUBULAR W-BEAM LAP SPLICE.

(*) DISTANCE C. TO C. OF END POST BOLT SLOTS 12'-6" OR 25'-0". DISTANCE C. TO C. OF INTERMEDIATE POST BOLT SLOTS 6'-3" UNLESS OTHERWISE SPECIFIED.

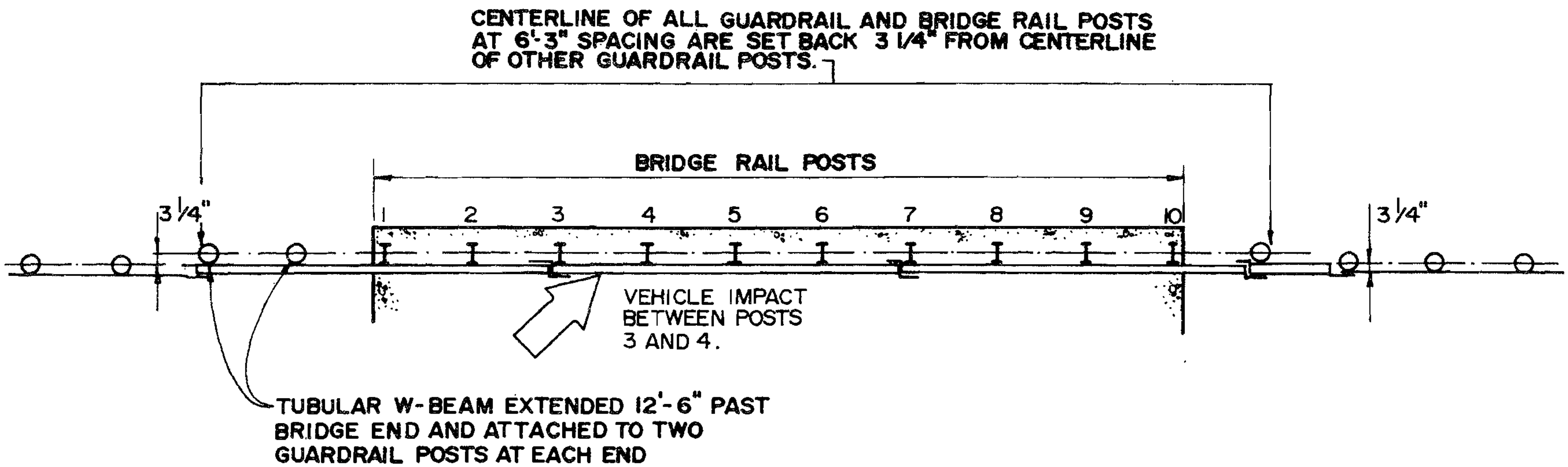


FIGURE 5. PLAN VIEW OF TUBULAR W- BEAM BRIDGE RAIL INSTALLATION.

CRASH TESTS AND RESULTS

The two crash tests recommended by Transportation Research Circular 191 were conducted on this new bridge rail. These tests were a 2041 kg (4500 lb) vehicle traveling 96.5 km/hr (60 mph) impacting the rail at 25 degrees and a 1021 kg (2250 lb) vehicle traveling 96.5 km/hr (60 mph) impacting the rail at 15 degrees. Table 1 presents a summary of the crash test data. Appendix "A" presents sequential photographs of each crash test. Appendix "B" presents a plan view of the bridge rail deformation and vehicle trajectory. Appendix "D" presents the accelerometer traces from accelerometers mounted on the frame of the vehicle near the center of gravity.

Test 1A. Test 1A was an unsuccessful test conducted on an earlier version of a low service level bridge rail shown by Figures 6, 7 and 9. This was a weak post and weak beam system which deflected laterally 1.83 m (6 ft) as shown by Figures 10 and 11 and trapped the vehicle between the rail and bridge slab. The 2041 kg (4500 lb) vehicle traveling 96.5 km/hr (60 mph) and impacting at 26.2 degrees broke all ten posts (see Figure 11), hit the embankment at the end of the bridge, then pitched and rolled over several times (see Figures 8 and 10). These weak W6 x 8.5 posts with very light breakaway welds on the inside of the flanges as shown on Figure 6 only developed an ultimate load of about 42.7 kN (9.6 kips) while deflecting about 3.8 cm (1.5 in.) (see Appendix "C"). From the results of this crash test it became apparent that the breakaway welds on the post tension flange and also the beam or rail member needed strengthening.

TABLE 1. SUMMARY OF CRASH TEST DATA.

TEST NO.	1A	1B	2
TYPE OF RAIL	W-BEAM	TUBULAR W-BEAM	TUBULAR W-BEAM
VEHICLE DATA	Chev. Impala 72	Buick 73	Vega 75
MASS, kg (lb)	2041 (4500)	2041 (4500)	1034 (2280)
FILM DATA			
Speed, km/hr (mph)			
Impact	96.5 (60.0)	99.1 (61.6)	93.3 (58.0)
Parallel	76.7 (47.7)	79.0 (49.1)	88.0 (54.7)
Departure	Veh. trapped & rolled	66.6 (41.4)	84.5 (52.5)
Angle, degrees from rail line			
Impact	26.2	27.5	14.0
Departure	Veh. trapped & rolled	17.5	2.8
Time, sec to parallel	.320	.261	.125
sec of contact	--	.569	.210
Barrier displacement, m (ft)			
Dynamic	1.83 (6.0)	.84 (2.77)	nil
Residual	1.52 (5.0)	.61 (2.00)	nil
Distance to parallel, m (ft)			
Longitudinal	7.53 (24.7)	5.86 (19.23)	3.01 (9.88)
Lateral	2.82 (9.26)	1.55 (5.07)	.34 (1.11)
Deceleration, avg g*			
Longitudinal	.84	1.00	.59
Lateral	2.54	5.33	5.93
Total	2.67	5.42	5.96
ACCELEROMETER DATA (100 hz lo-pass max flat filter)			
Max avg .050 sec deceleration			
Longitudinal, g	2.95	4.86	3.50
Lateral, g	4.29	6.88	6.87
Deceleration, avg. over contact time			
Longitudinal, g	1.76	1.48	1.30
Lateral, g	2.70	2.59	3.48
Peak deceleration			
Longitudinal, g	13.2	18.1	8.10
Lateral, g	10.5	15.4	24.6
VEHICLE DAMAGE CLASSIFICATION			
TAD	R&T6	LFQ5	LFQ5
SAE			
REMARKS	Vehicle was trapped between rail & bridge slab; broke all posts; hit embankment at end of bridge. Car pitched & rolled over.	Smooth Redirection	Smooth Redirection

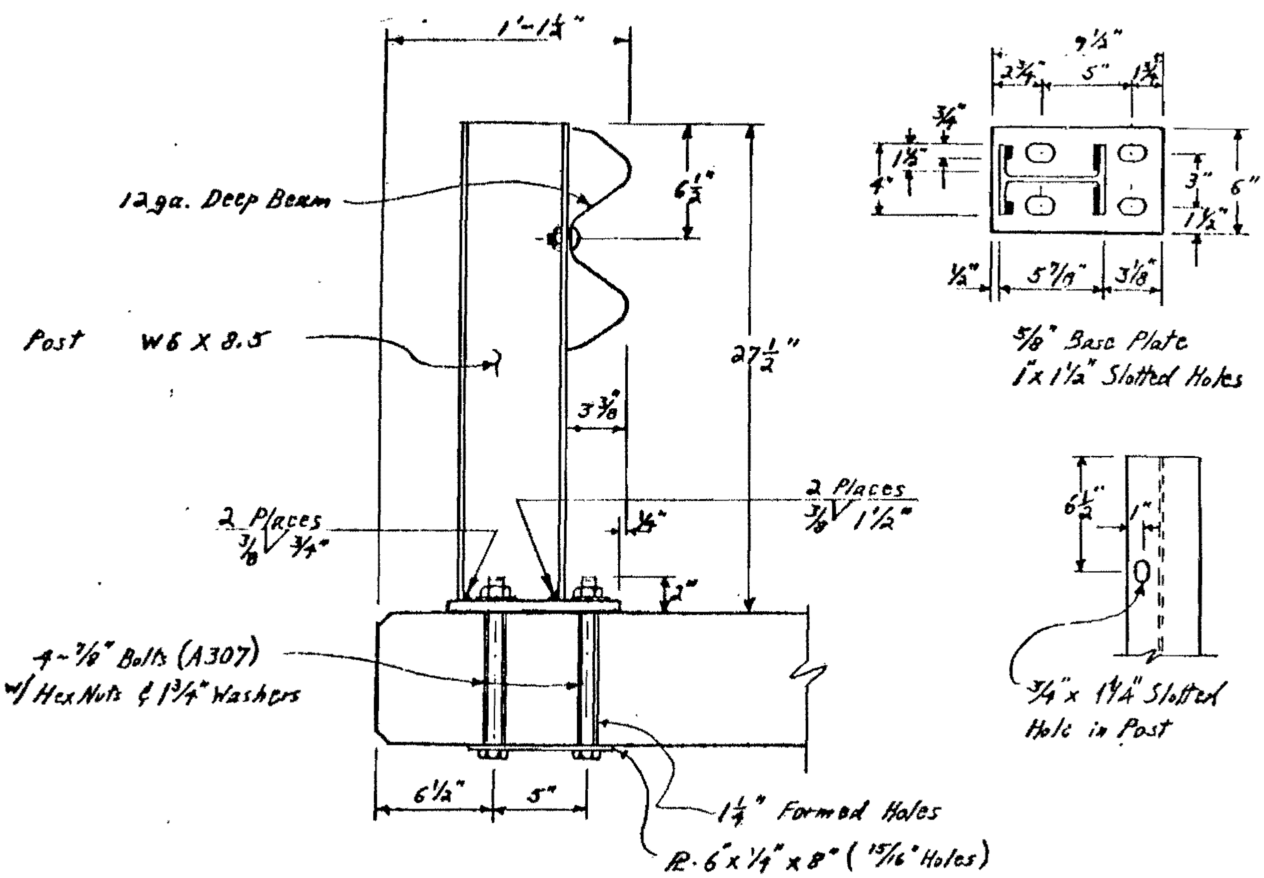
*See Appendix "E" for equations for film analysis.

File 1284

DESIGN JVP DATE May 78
CK. DSN. DATE
DESIGN FOR Low Service Level – Tension Railing

TEXAS HIGHWAY DEPARTMENT
BRIDGE DIVISION

COUNTY Project 230
CONTROL
I.P.E.
HIGHWAY
SHEET 1 OF 1



Post is intended to break free from base plate under impact. It is therefore necessary that the weld sizes and lengths shown not be exceeded.

Railing shall have 6'-3" post spacing and may be installed on culverts or bridges with structure lengths less than 75 ft. A 25 ft standard terminal end section shall be located at each rail end. Additional wood or steel posts at 6'-3" centers shall be placed as needed on the approaches.

No elastomeric pads to be used. Level base plate with grout if necessary.

FIGURE 6. UNSUCCESSFUL BRIDGE RAIL FOR TEST 1A.

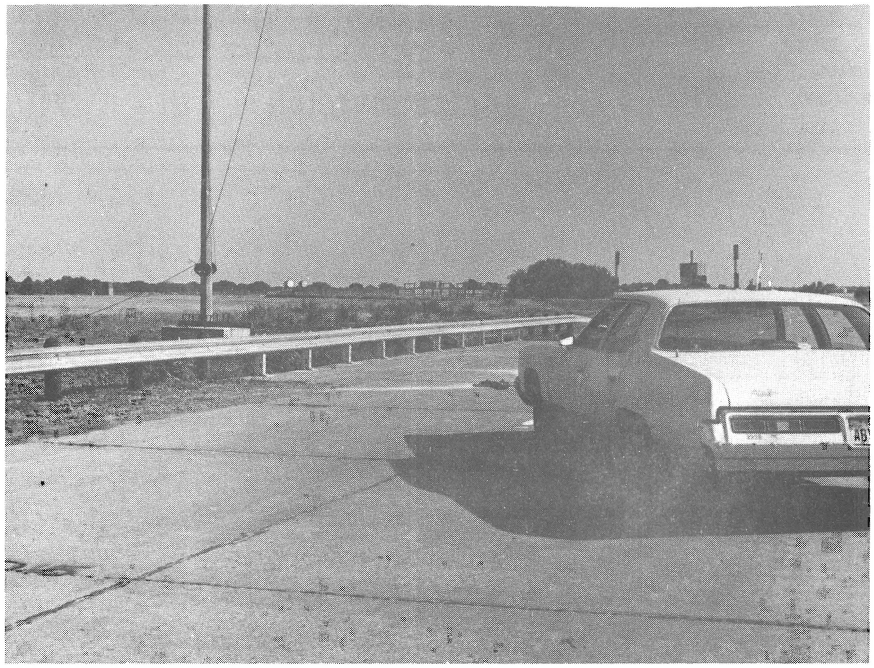


Figure 7. Vehicle and Bridge Rail before Test 1A.

Figure 8. Vehicle after Test 1A.

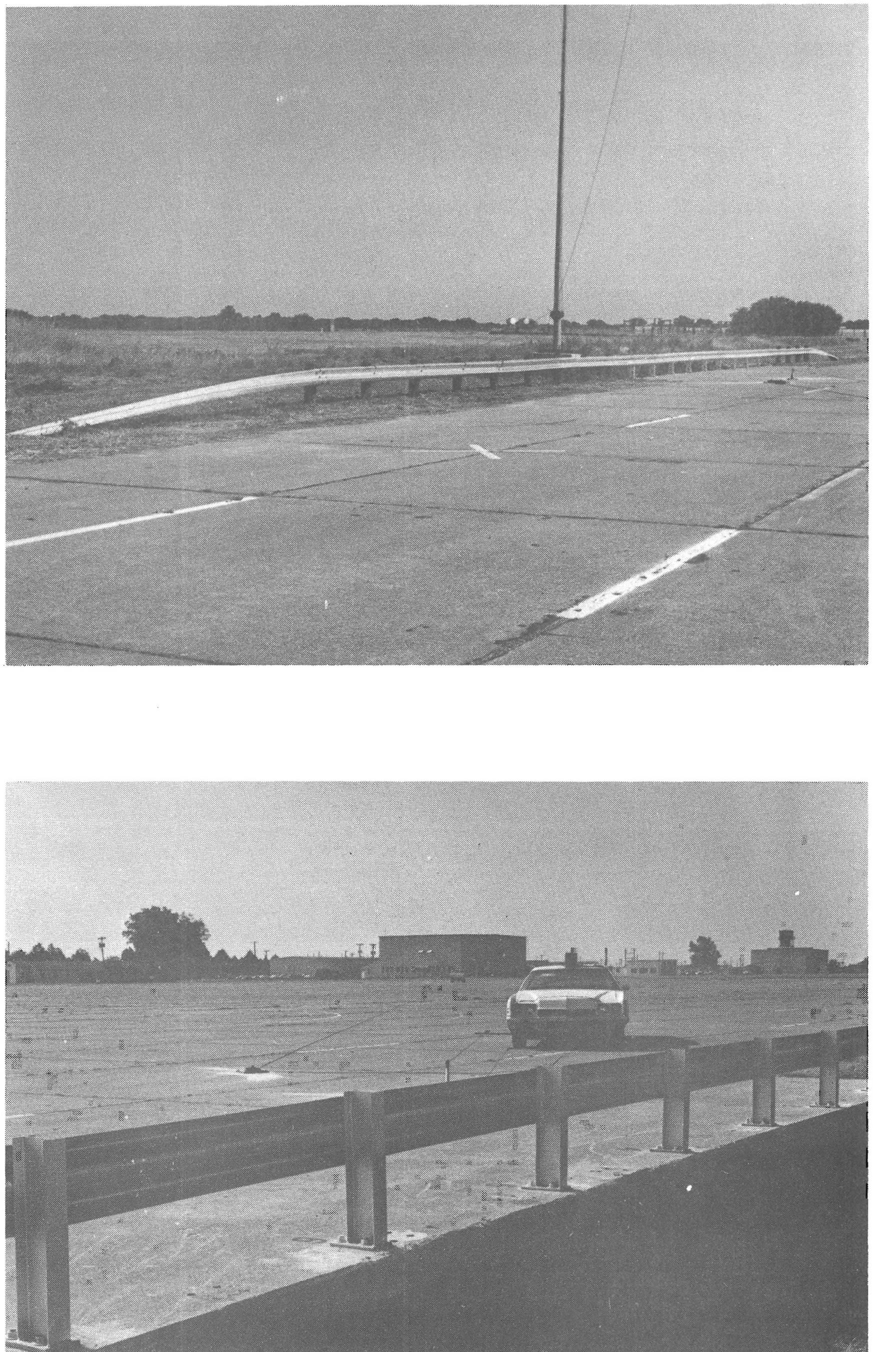


Figure 9. Unsuccessful Bridge Rail
before Test 1A.

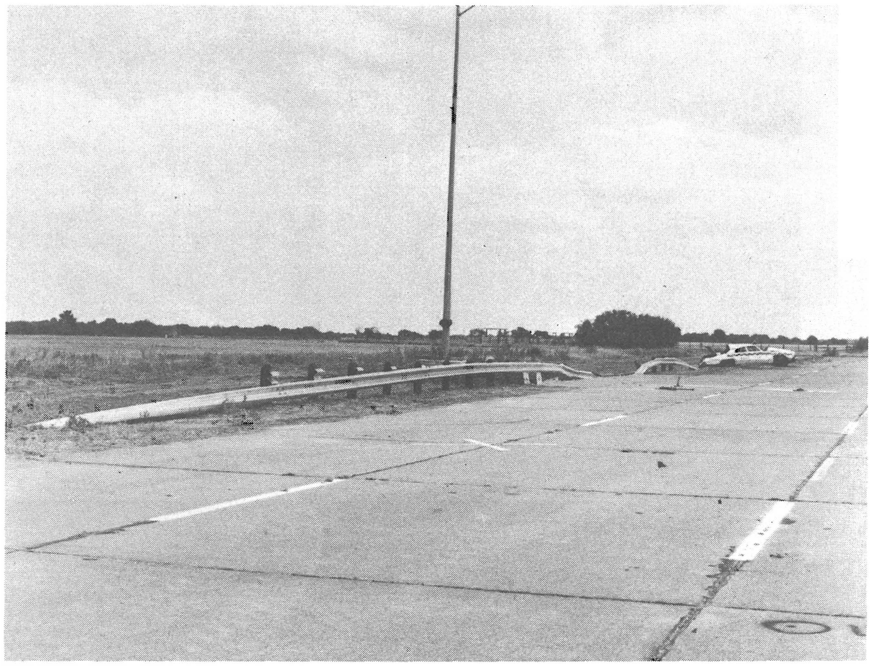


Figure 10. Unsuccessful Bridge Rail after Test 1A.

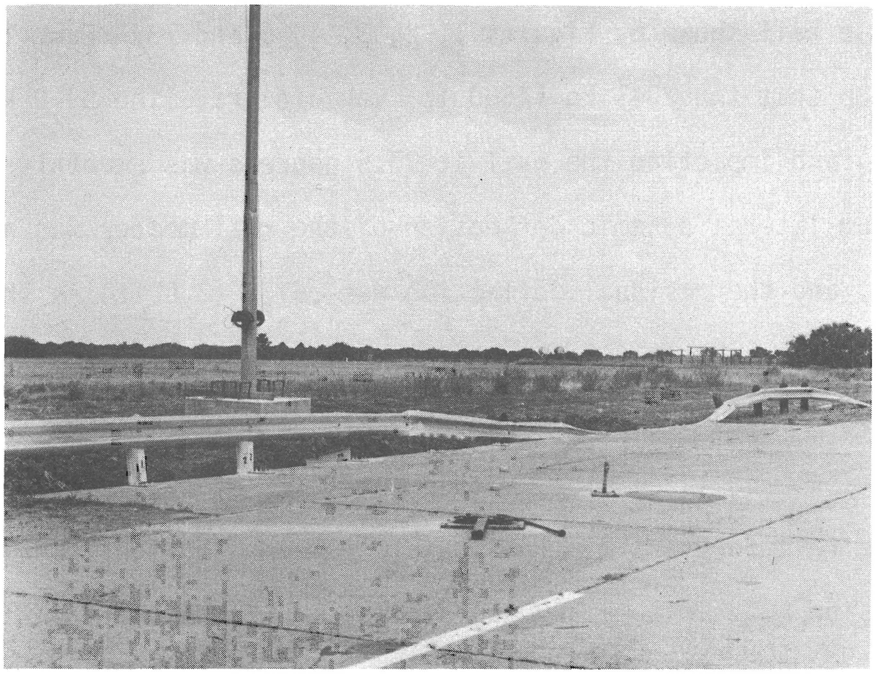


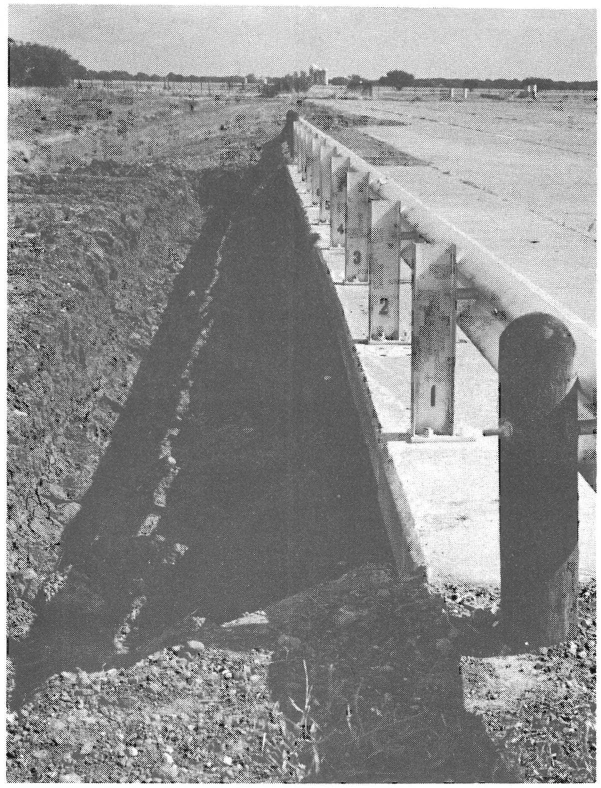
Figure 11. Closeup of Bridge Rail Damage after Test 1A.

Test 1B. Test 1B was the first test conducted on the new Tubular W-Beam bridge rail shown by Figures 1, 2, 3, 4, 5 and 13. From Table 1 it can be seen that the 2041 kg (4500 lb) vehicle traveling 99.0 km/hr (61.6 mph) and impacting the rail at 27.5 degrees was smoothly redirected. The maximum lateral dynamic deflection of the rail member was about 0.84 m (2.77 ft), and the residual deflection was .61 m (2.0 ft) as shown in Figure 14. The vehicle first contacted the rail between posts 3 and 4 (see Figure 15) and posts 4, 5, and 6 broke away clean. Posts 3, 4, 5, 6, and 7 had to be replaced along with about 25 ft of Tubular W-Beam to repair the rail for test 2. The vehicle remained upright and stable after the collision. Vehicle damage was similar to that usually inflicted in such tests and is shown by Figure 12. An interesting observation from the overhead photograph in Figure 15 is that the outside vehicle tires traveled about .37 m (1.2 ft) beyond the edge of the bridge slab and returned.

In a previous guardrail test (7) where a 2037 kg (4490 lb) vehicle traveling 94.4 km/hr (58.7 mph) impacted the guardrail at 25 degrees, the rail had a maximum dynamic deflection of 0.76 m (2.5 ft) and a residual deflection of 0.70 m (2.3 ft). This comparison indicates that the Tubular W-Beam bridge rail is indeed compatible in strength and stiffness to the guardrail, thus eliminating the need for a special transition between the two.

Test 2. Test 2 was conducted on the repaired Tubular W-Beam bridge rail following Test 1B and shown by Figure 17. In this test a 1034 kg (2280 lb) Vega traveling 93.3 km/hr (58 mph) impacted the rail at 14 degrees and was smoothly redirected. The lateral deflection of the rail was nil, and no damage to the rail resulted as shown by Figure 18. Vehicle damage was similar to that usually inflicted in such tests and can be seen in Figure 16.

Figure 12. Vehicle before and after Crash Test 1B on TUBULAR W-BEAM Bridge Rail - 99 km/hr, 27.5°.



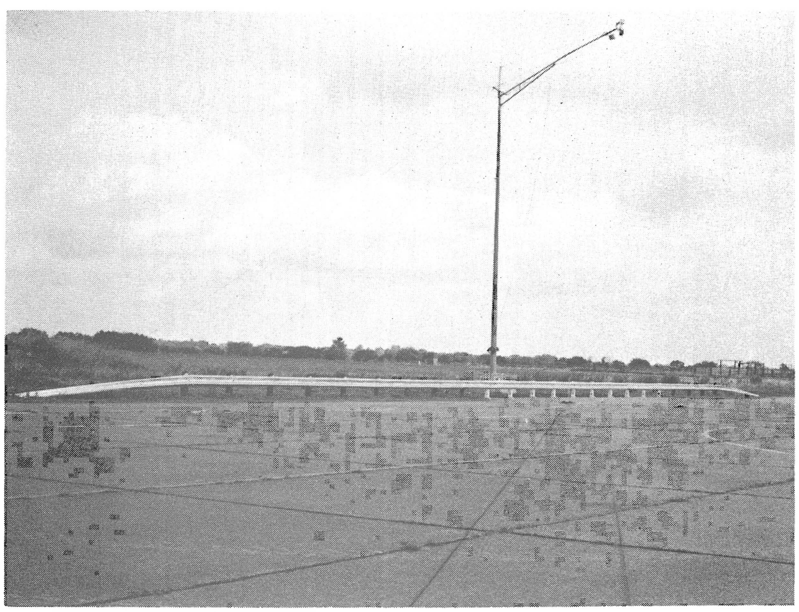


Figure 13. TUBULAR W-BEAM Bridge Rail before Crash Test 1B.

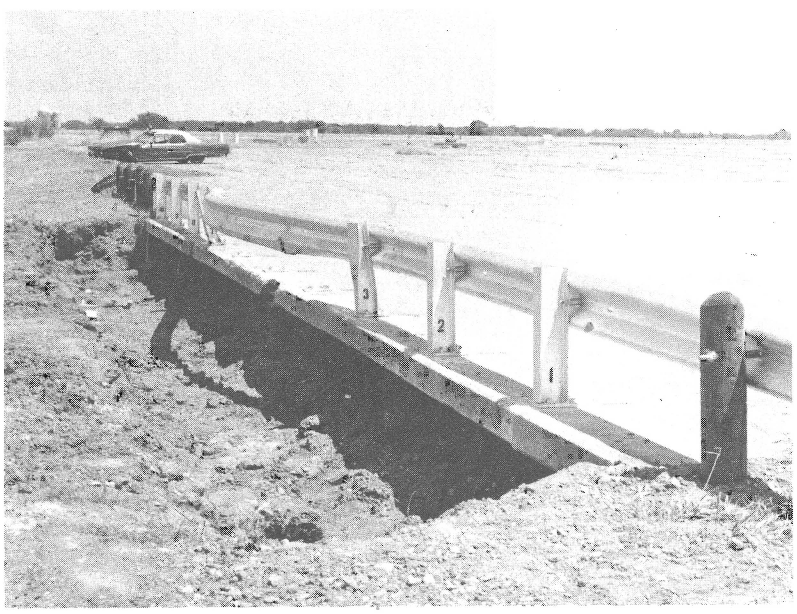
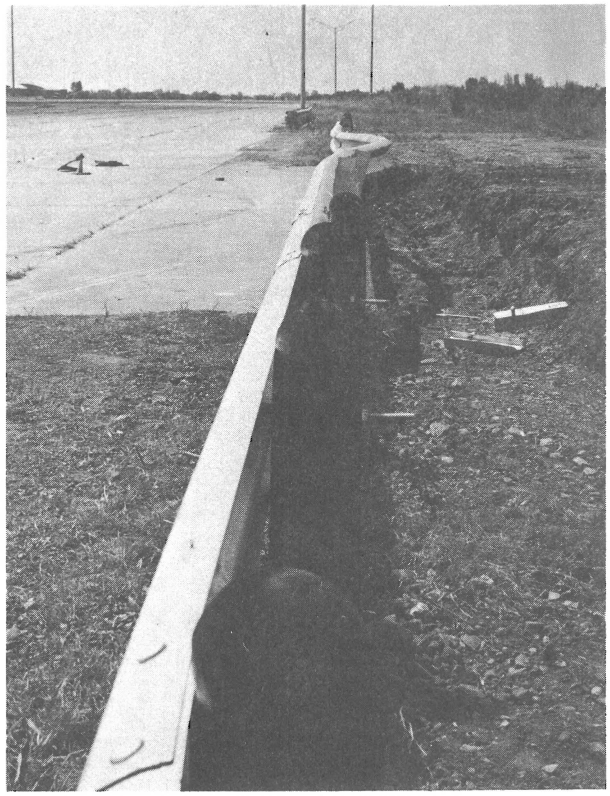


Figure 14. TUBULAR W-BEAM Bridge Rail after Crash Test 1B. (Note 0.61 m (2.0 ft) residual lateral deflection. Posts 4, 5 and 6 broke away.)



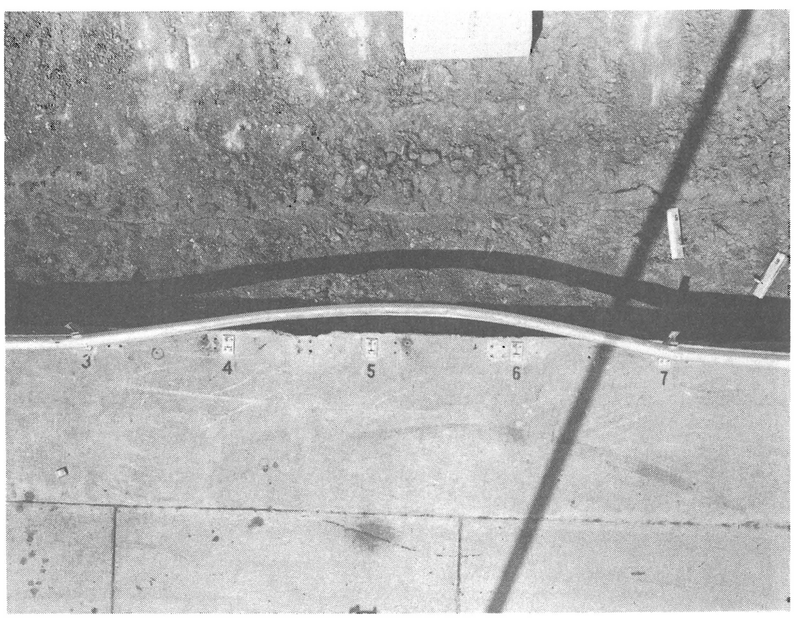


Figure 15. TUBULAR W-BEAM Bridge Rail
after Crash Test 1B.

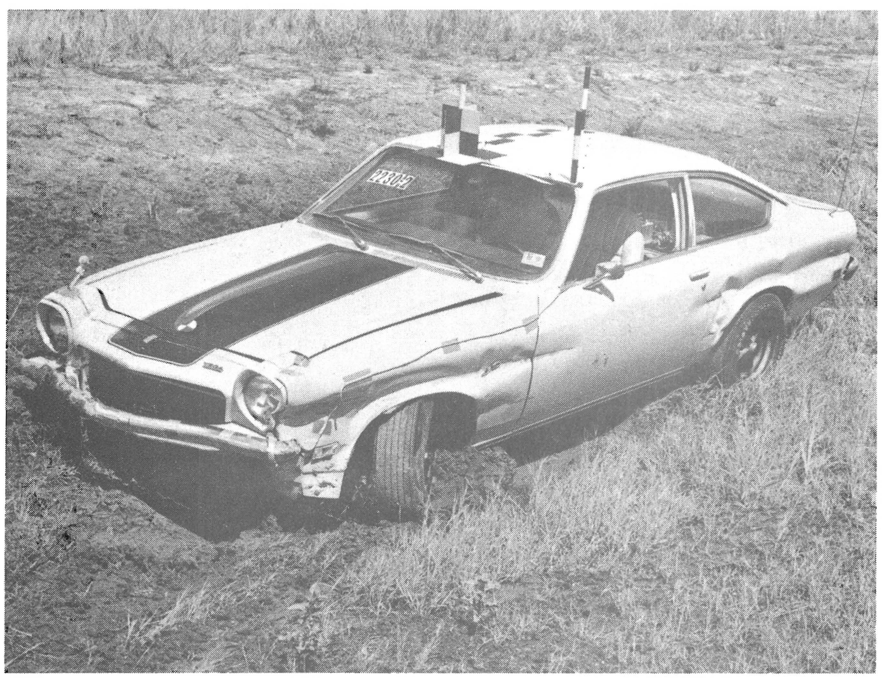
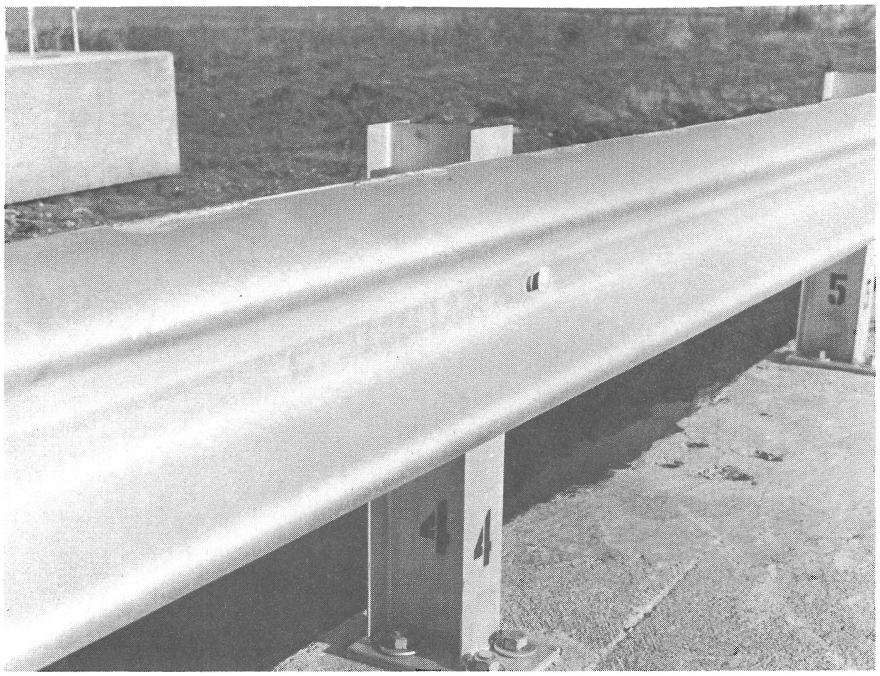


Figure 16. Vehicle before and after Crash Test 2.
(93 km/hr and 14 degree impact angle)



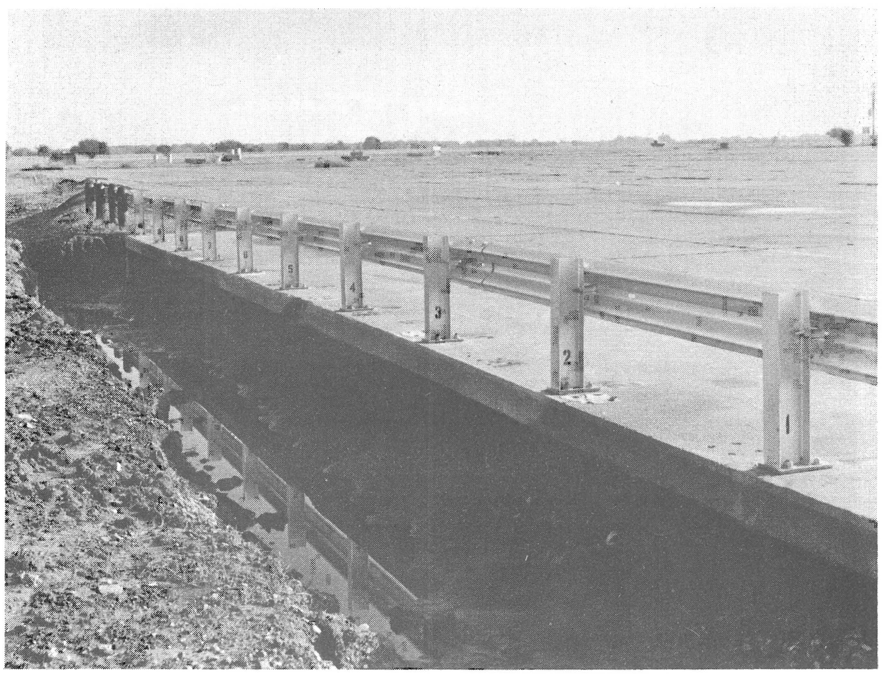


Figure 17. TUBULAR W-BEAM Bridge Rail
before Crash Test 2.

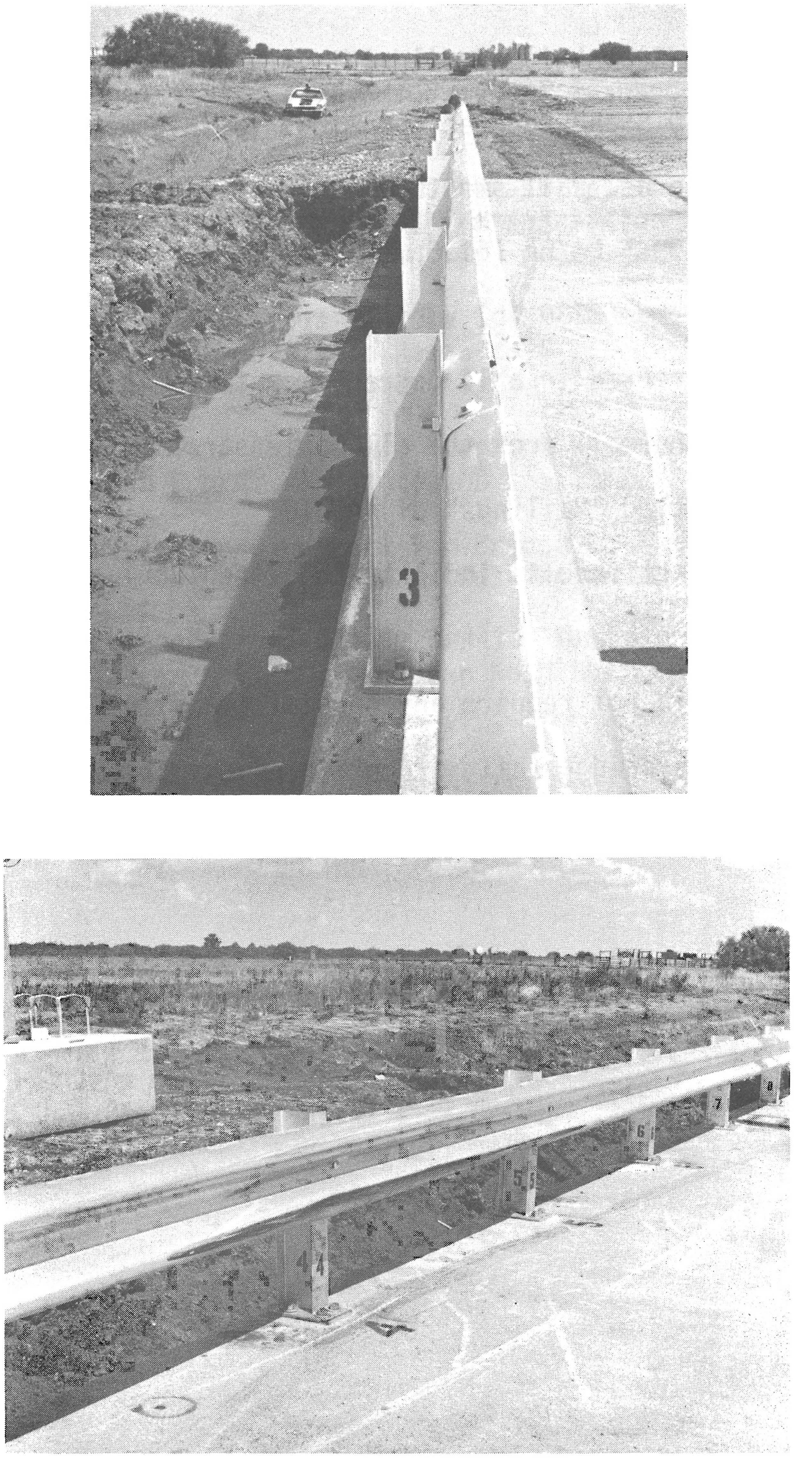


Figure 18. TUBULAR W-BEAM Bridge Rail after Crash Test 2. (Note bolted lap splice (top photo) and no damage to rail.)

SUMMARY AND CONCLUSIONS

The Tubular W-Beam bridge rail meets the crash test performance requirements of the AASHTO Standard Specifications for Highway Bridges, 12th Edition, 1977. The new rail smoothly redirected a 2041 kg (4500 lb) vehicle traveling 99.1 km/hr (61.6 mph) and impacting the rail at 27.5 degrees. The 1034 kg (2280 lb) vehicle traveling 93.3 km/hr (58 mph) was also smoothly redirected in a 14 degree impact. This satisfactory performance exempts the rail from the allowable stress requirements of Article 1.1.8 entitled "Railings" of AASHTO.

These crash test results indicate that the Tubular W-Beam rail is compatible in strength and stiffness with the standard Texas Guard Fence and therefore should not require any special transition such as closer post spacing. This bridge rail is considered suitable for use on culverts and low bridges.

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3. "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances," Transportation Research Circular No. 191, Transportation Research Board, Washington, D.C., 1978.

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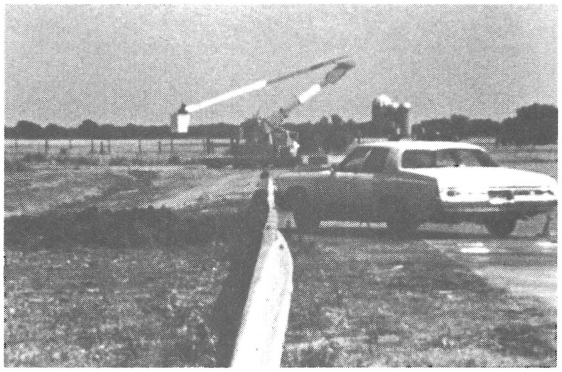
APPENDIX "A"

SEQUENTIAL PHOTOGRAPHS OF CRASH TESTS



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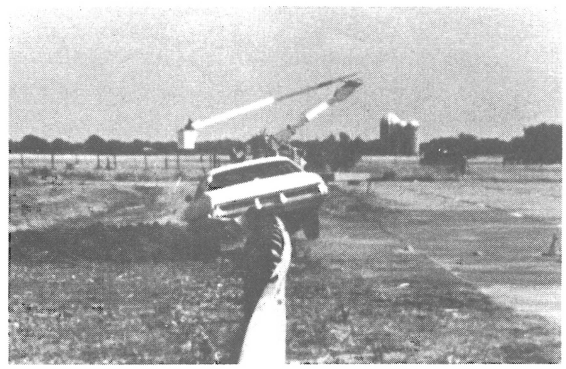

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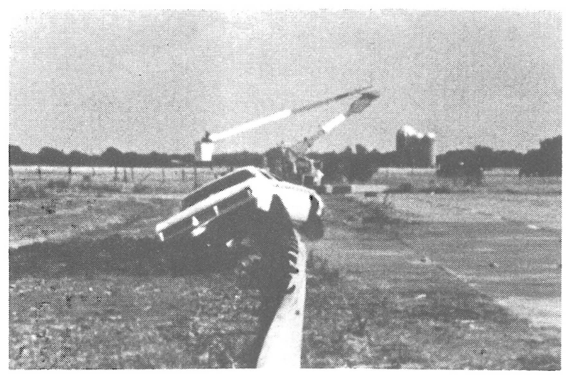
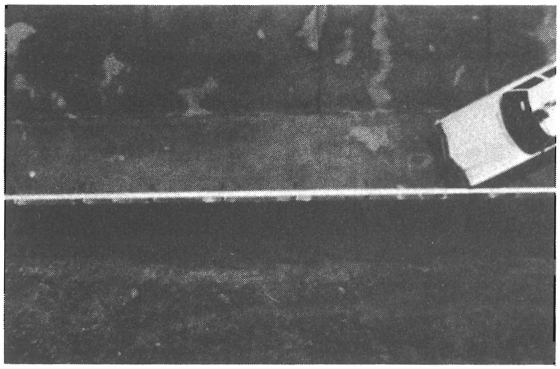
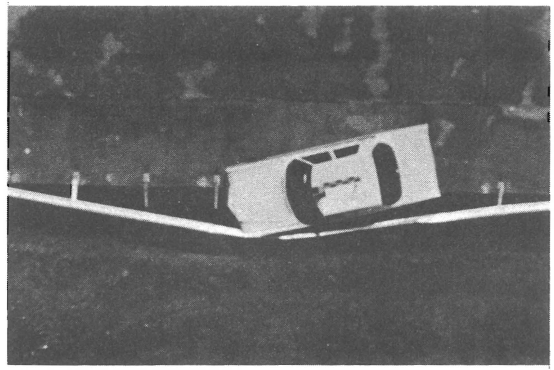


0.400 sec

Figure A1. Sequence Photographs of Crash Test 1A.



0.000 sec



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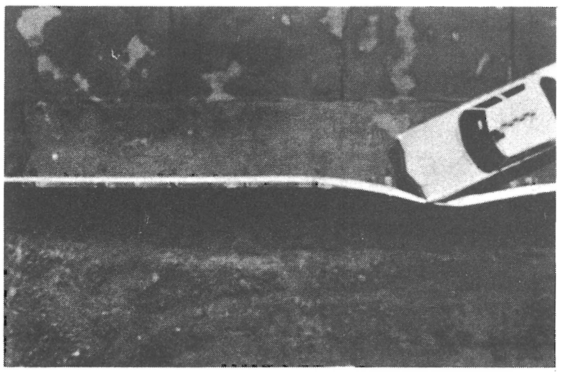
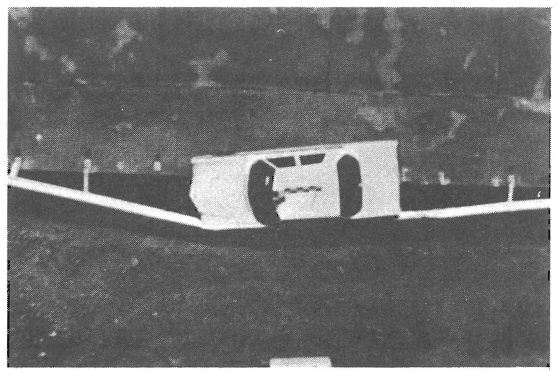


0.067 sec



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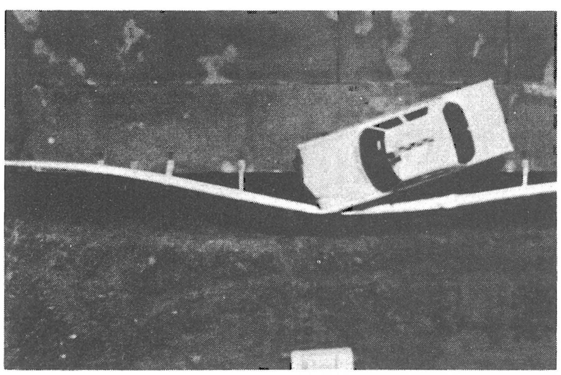
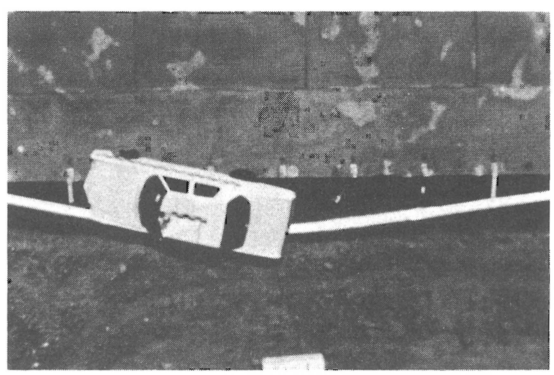
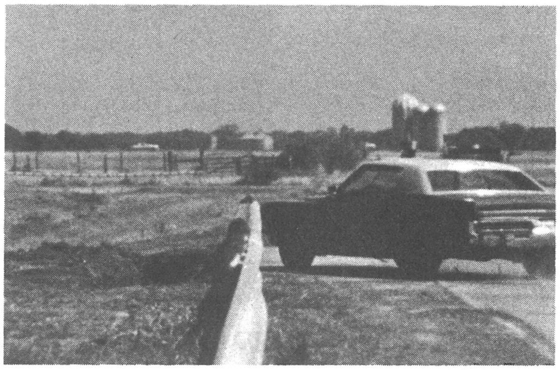


0.173 sec



0.399 sec

Figure A2. Sequence Photographs of Crash Test 1A.



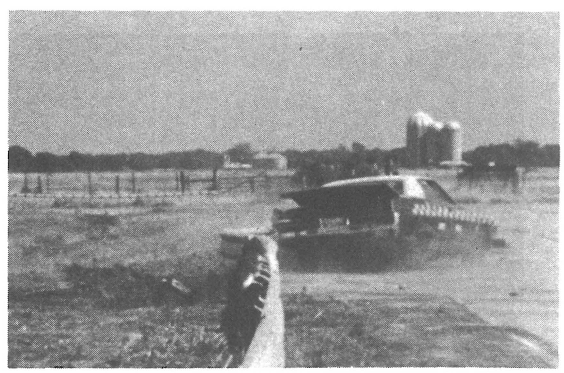
0.000 sec

0.110 sec

0.193 sec

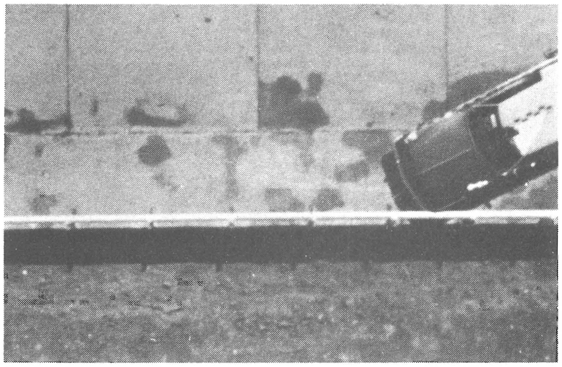
0.261 sec

0.442 sec

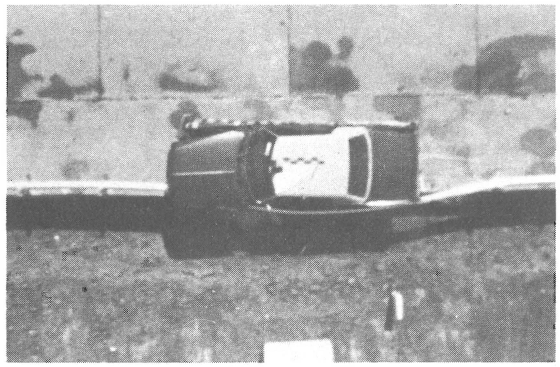


0.567 sec

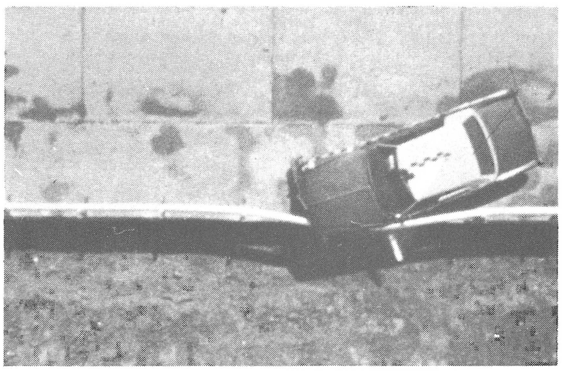
Figure A3. Sequence Photographs of Crash Test 1B.
(2041 kg Veh., 99 km/hr, 27.5 degrees)



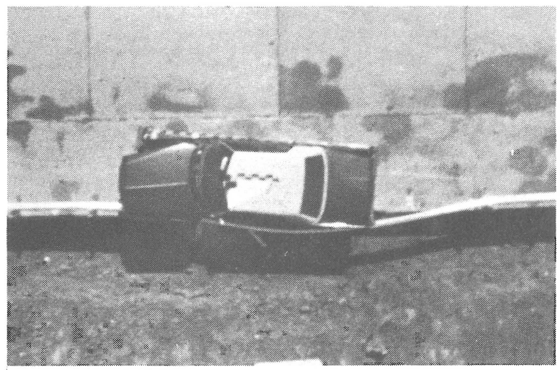
0.000 sec



0.261 sec

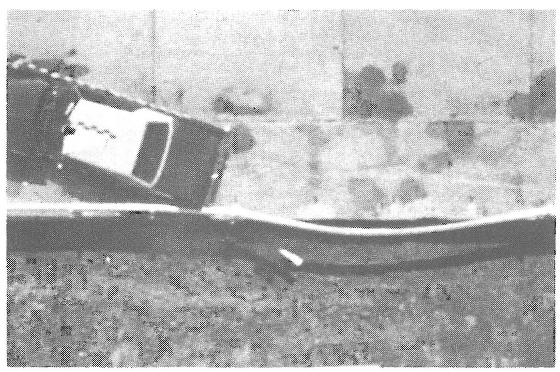


0.110 sec



0.300 sec

0.193 sec



0.567 sec

Figure A4. Overhead Sequence Photographs of Crash Test 1B. (2041 kg Veh., 99 km/hr, 27.5 degrees)

0.000 sec

0.055 sec

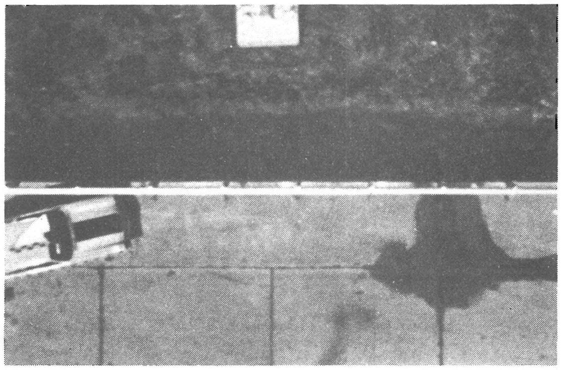
0.108 sec

0.125 sec

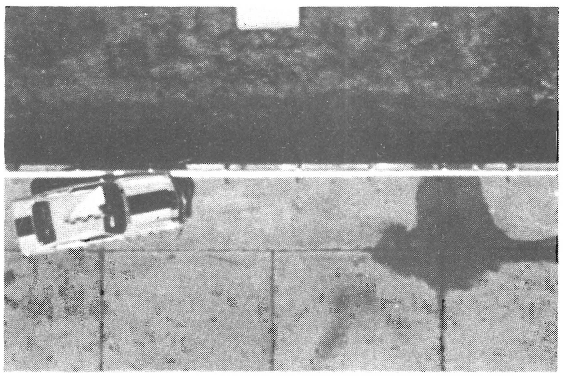
0.178 sec

0.210 sec

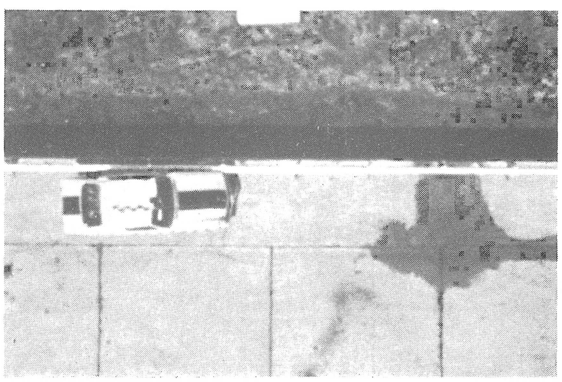
Figure A5. Sequence Photographs of Crash Test 2.
(1034 kg Veh., 93 km/hr, 14 degrees)



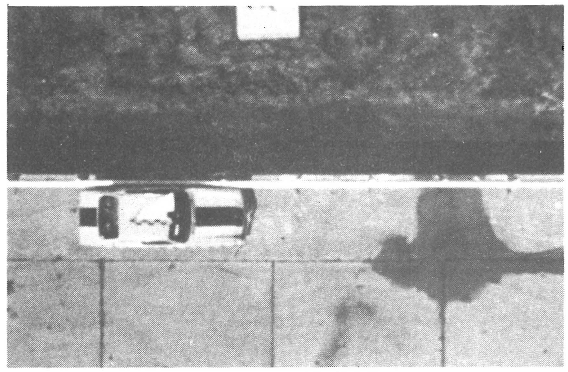
0.000 sec



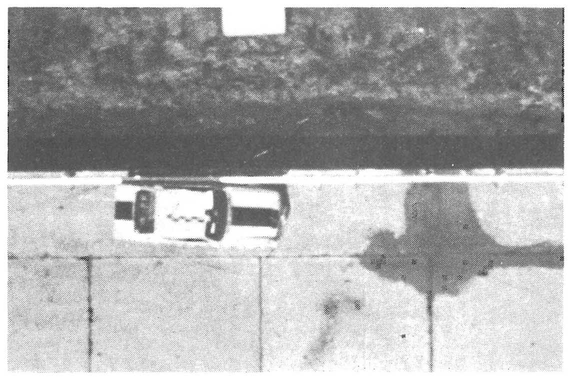
0.055 sec



0.108 sec



0.125 sec



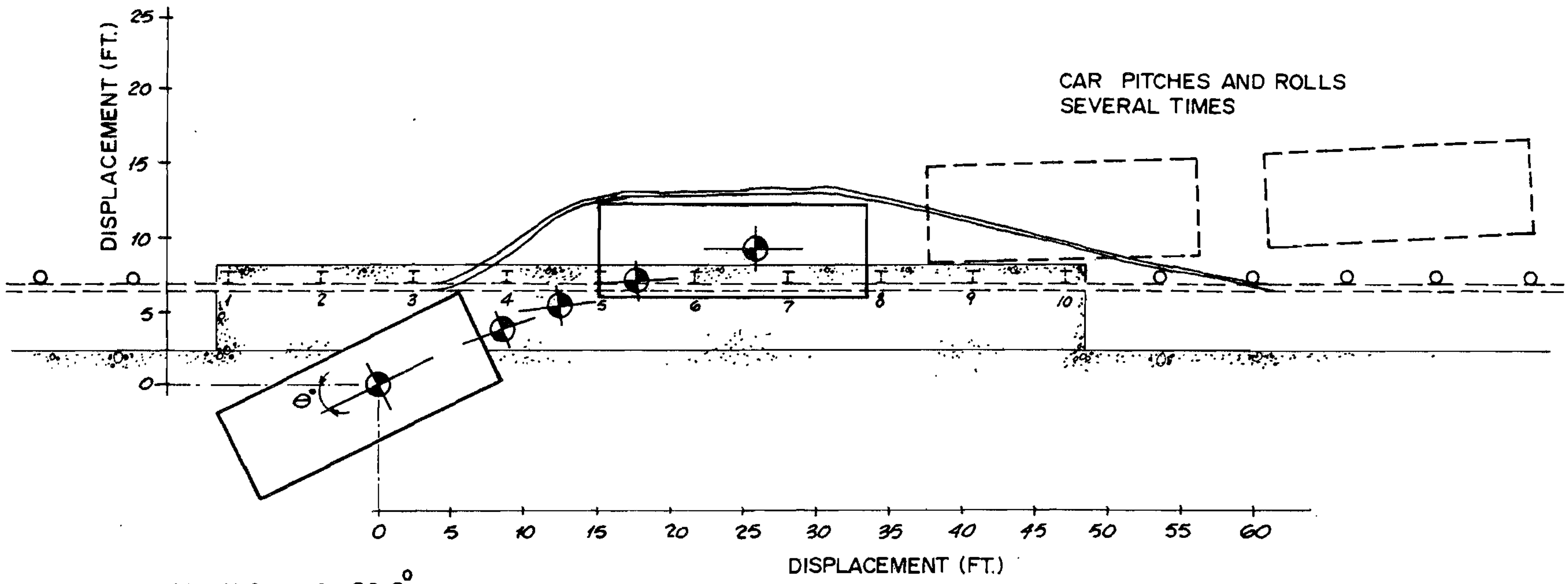
0.178 sec

0.210 sec

Figure A6. Overhead Sequence Photographs of Crash Test 2.
(1034 kg veh., 93 km/hr, 14 degrees)

APPENDIX "B"

PLAN VIEW OF BRIDGE RAIL DEFORMATION
AND VEHICLE TRAJECTORY



IMPACT ANGLE - θ = 26.2°
IMPACT SPEED = 96.5 km/hr. (60mph)

FIGURE B-1. PLAN VIEW OF TEST 1A.

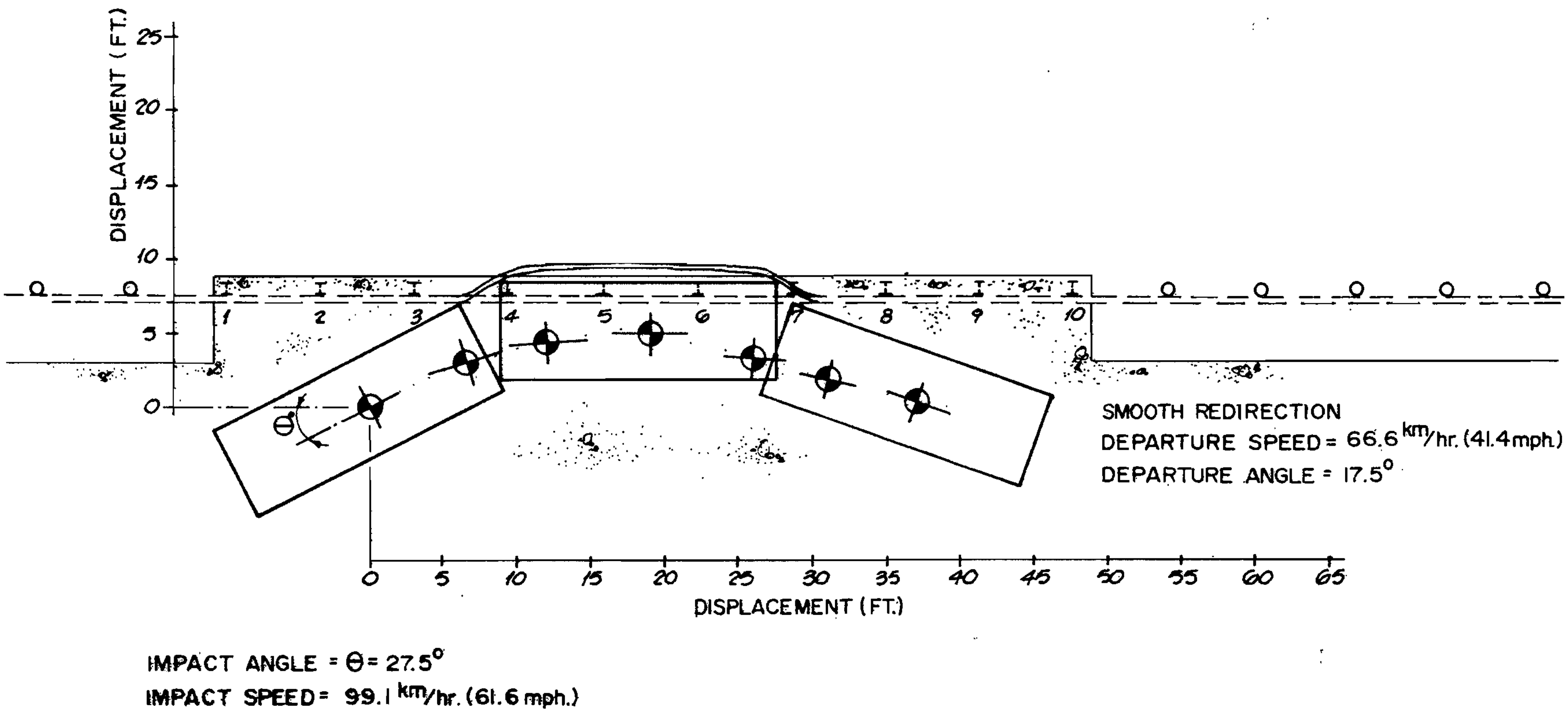


FIGURE B-2. PLAN VIEW OF TEST 1B.

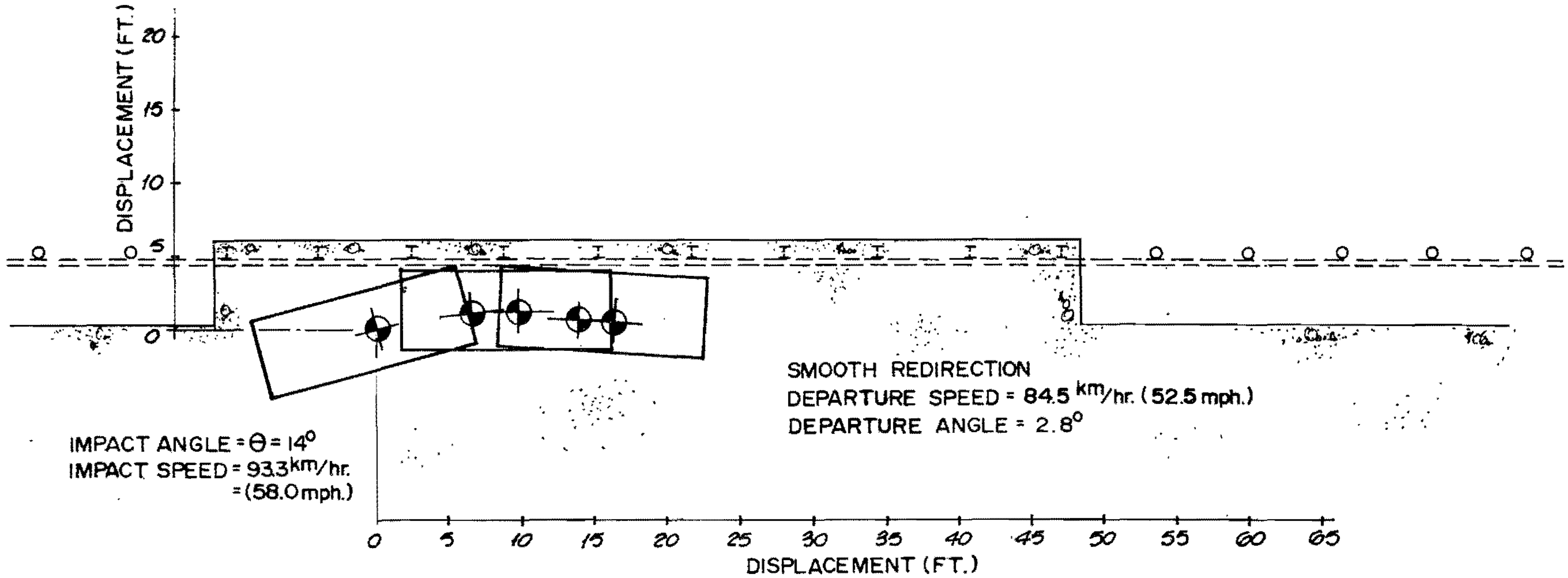


FIGURE B-3. PLAN VIEW OF TEST 2.

APPENDIX "C"

STATIC LOAD TEST RESULTS OF BREAKAWAY
WELDED POSTS AND DYNAMIC TEST RESULTS
OF POSTS IN SOIL

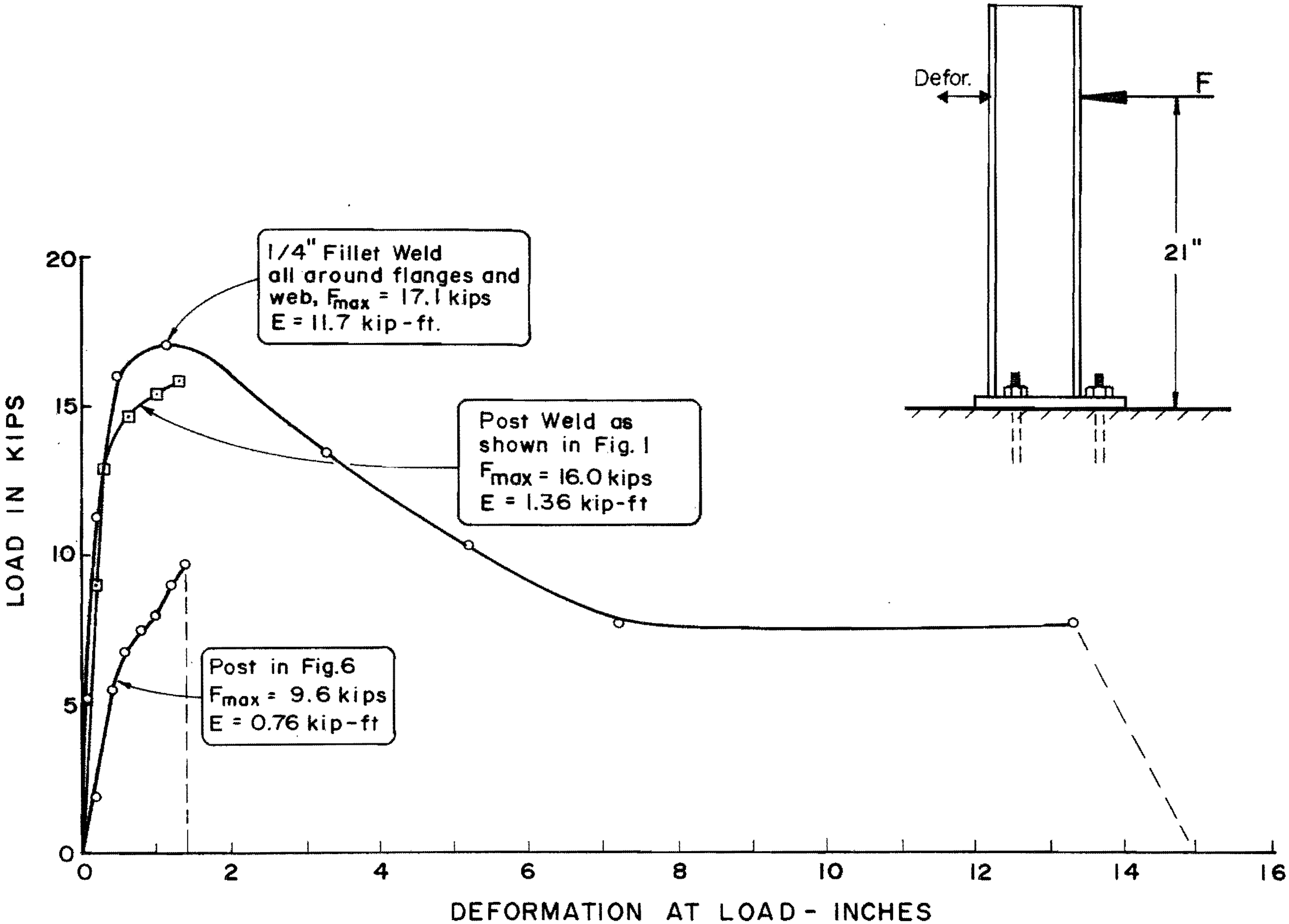


FIGURE C1. STATIC LOAD TEST RESULTS ON W6x8.5 BRIDGE RAIL POSTS.

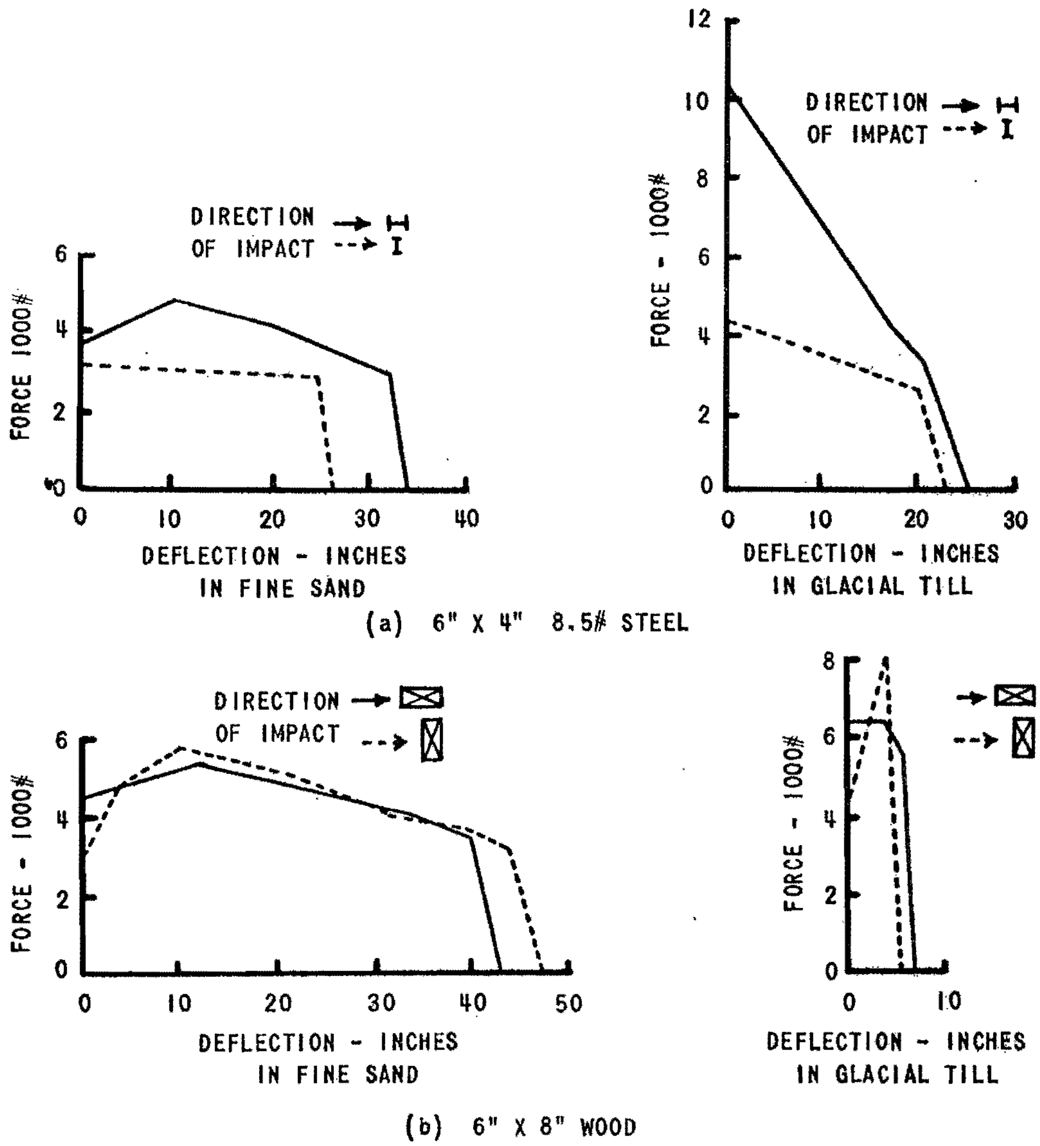


FIGURE C2. DYNAMIC FORCE-DEFLECTION CHARACTERISTICS OF POSTS IN SOIL. (After Ref. 4, NCHRP 36).

APPENDIX "D"

ACCELEROMETER TRACES

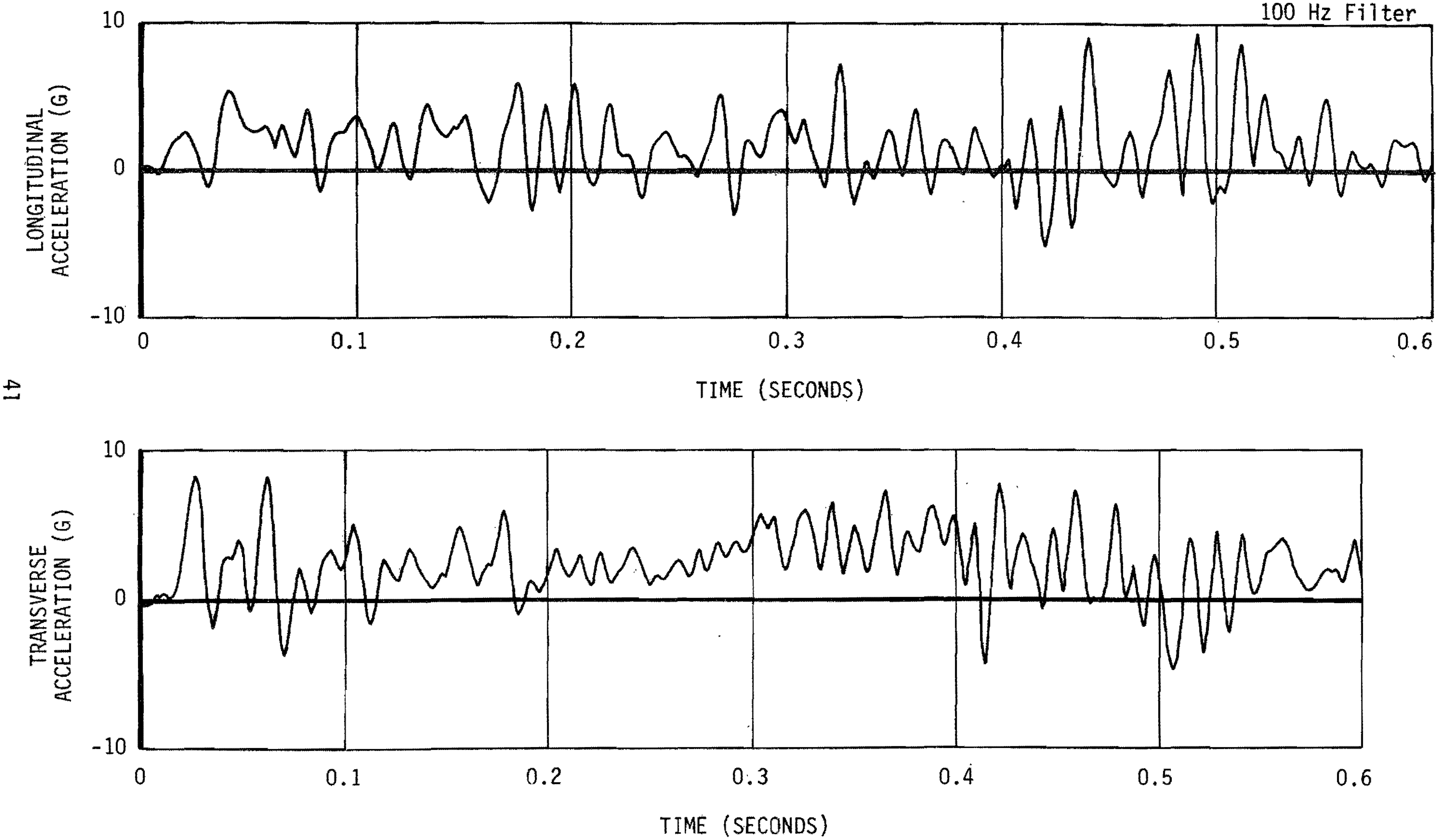


FIGURE D1. VEHICLE ACCELEROMETER TRACES FOR TEST 1a.

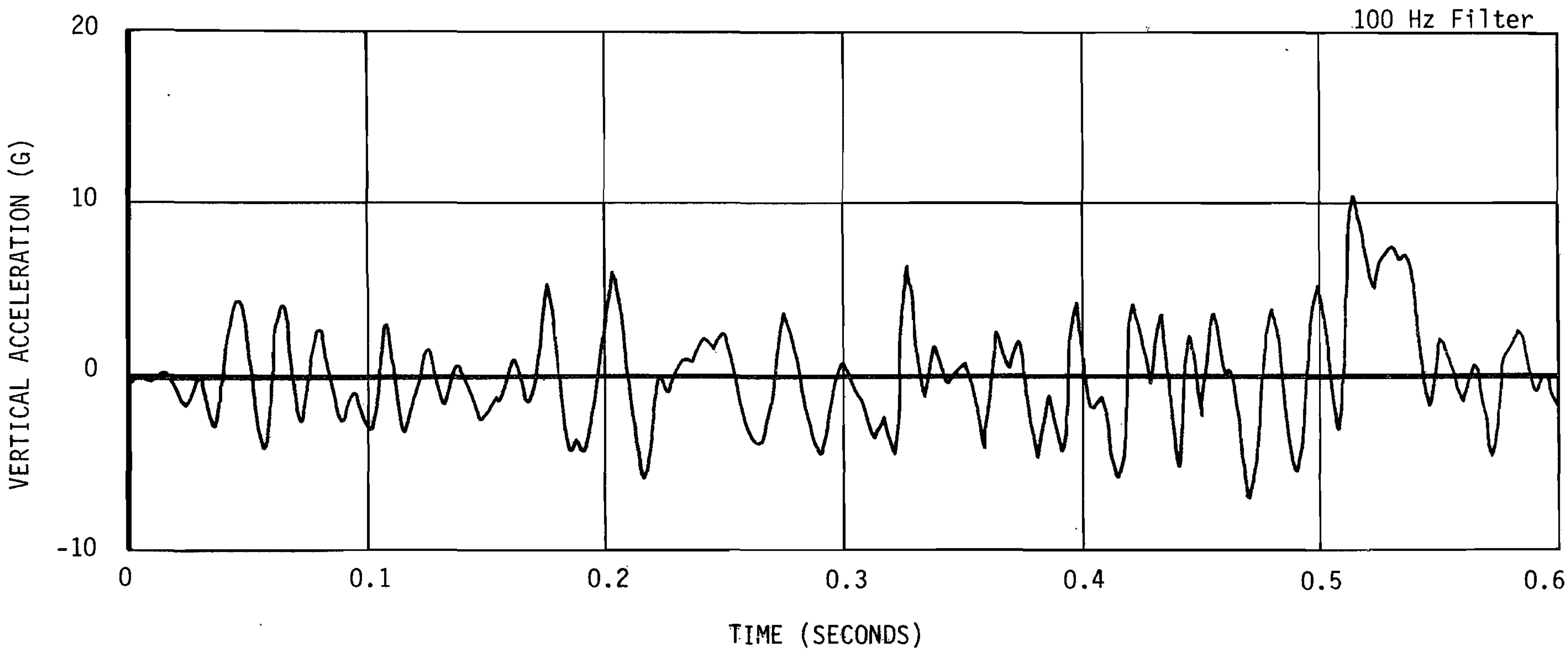


FIGURE D2. VEHICLE ACCELEROMETER TRACES FOR TEST 1a.

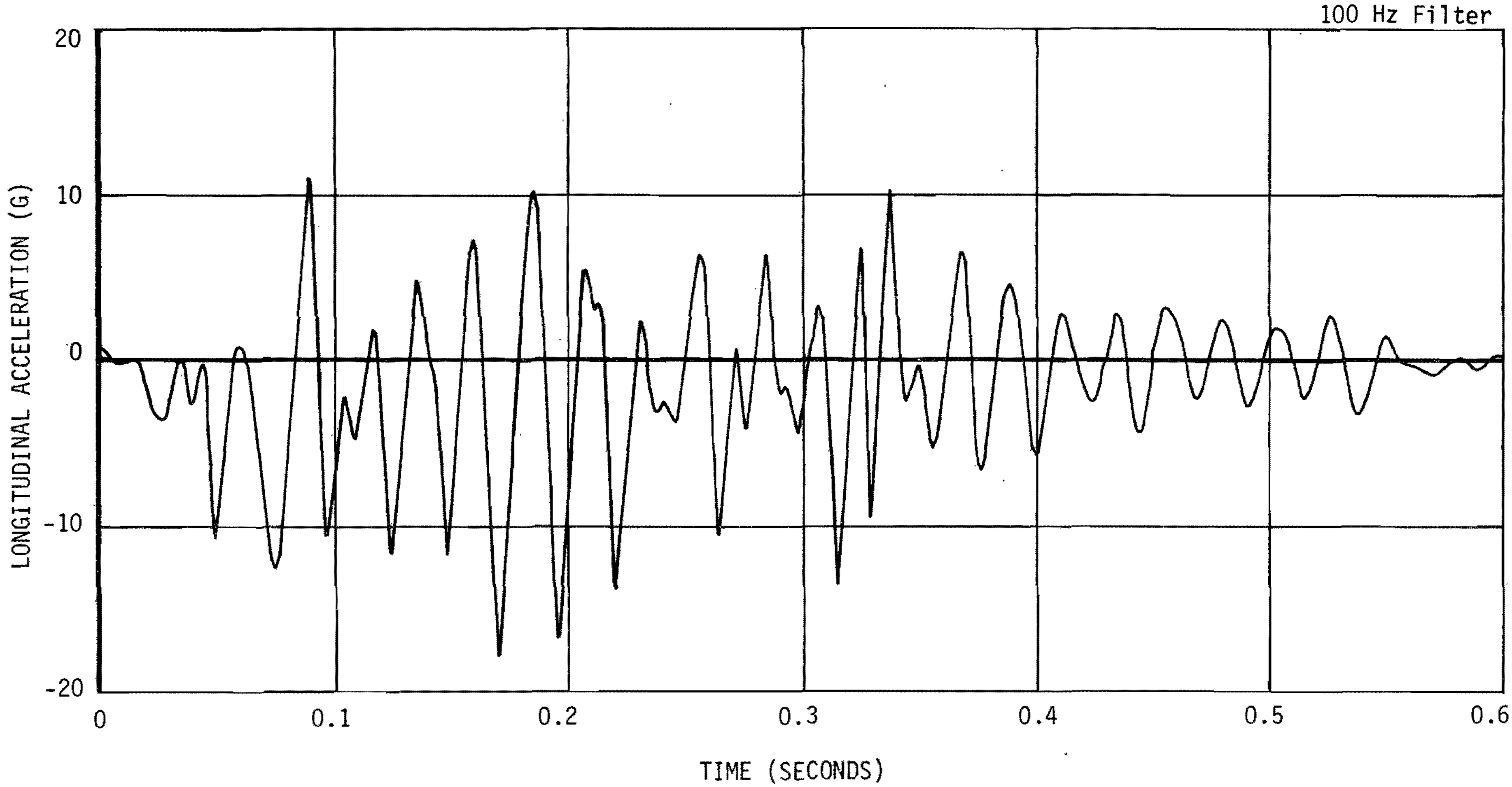


FIGURE D3. VEHICLE ACCELEROMETER TRACE FOR TEST 1b.

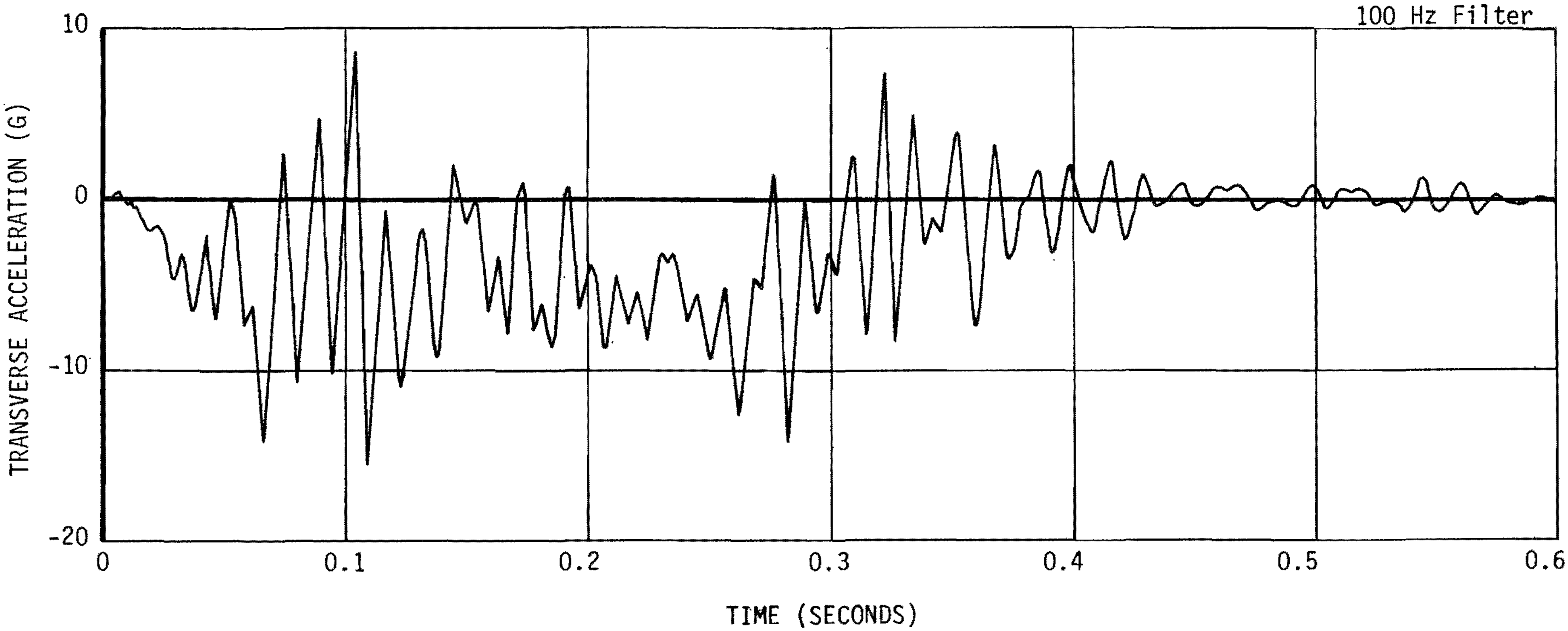


FIGURE D4. VEHICLE ACCELEROMETER TRACES FOR TEST 1b.

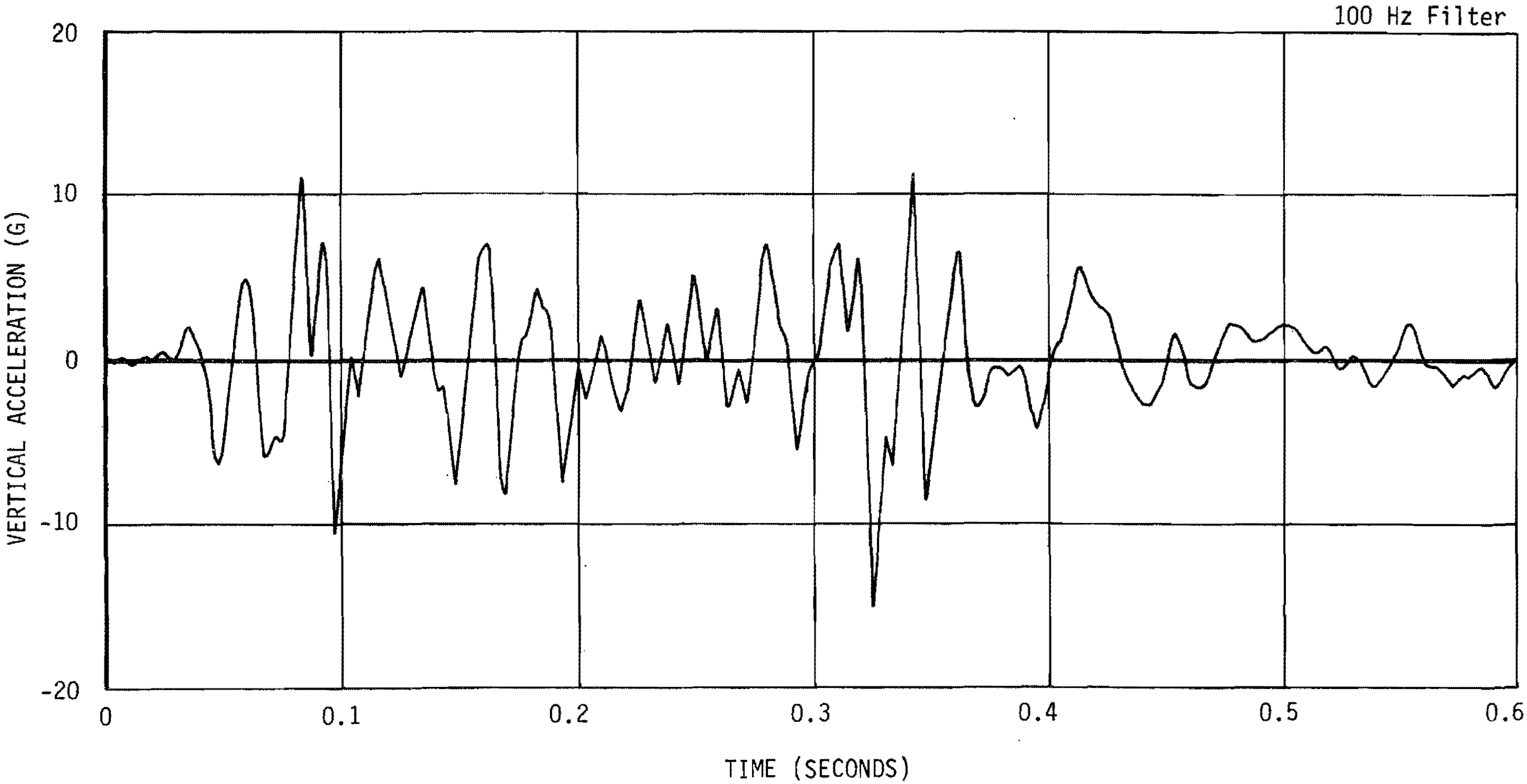


FIGURE D5. VEHICLE ACCELEROMETER TRACES FOR TEST 1b.

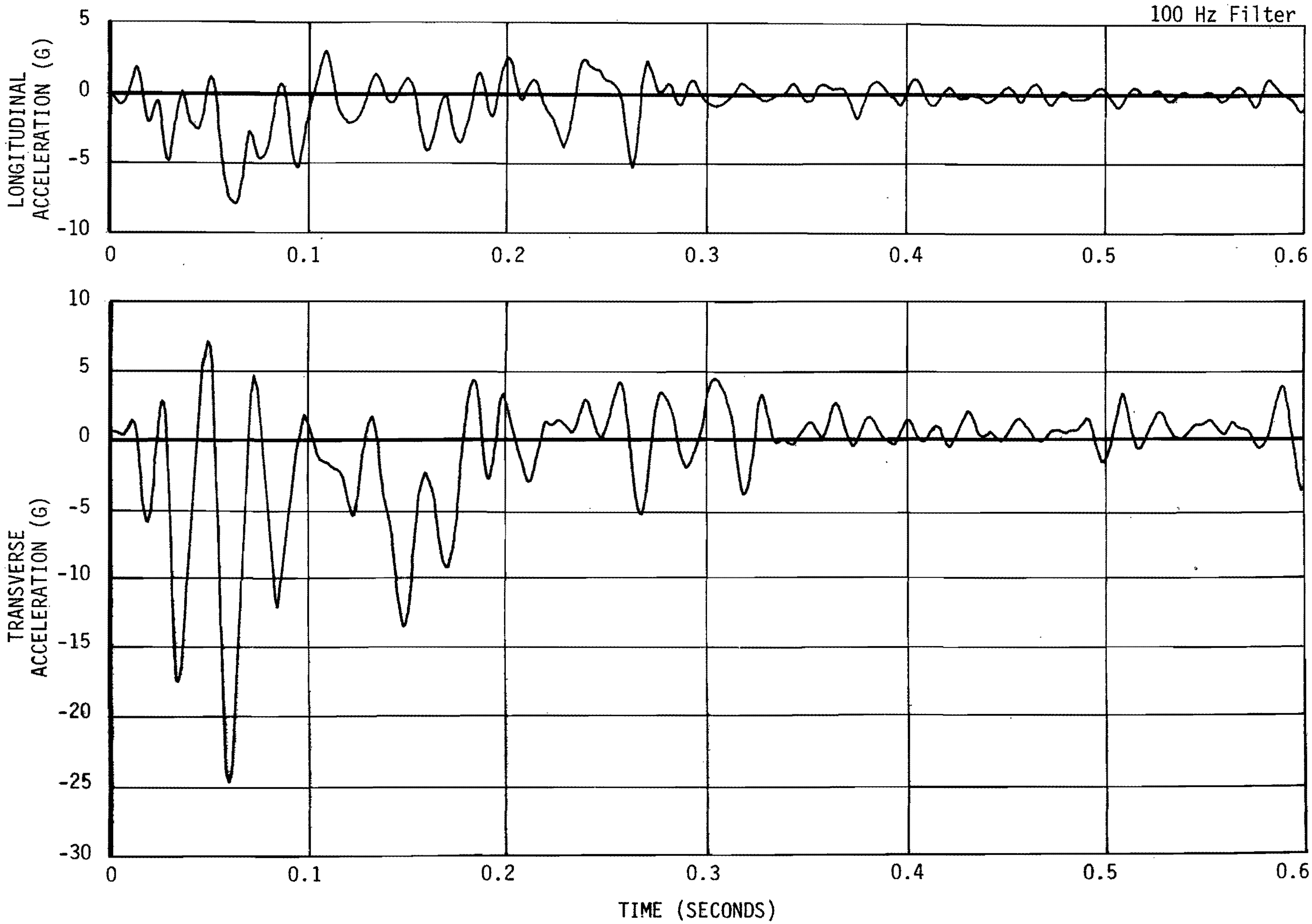


FIGURE D6. VEHICLE ACCELEROMETER TRACES FOR TEST 2.

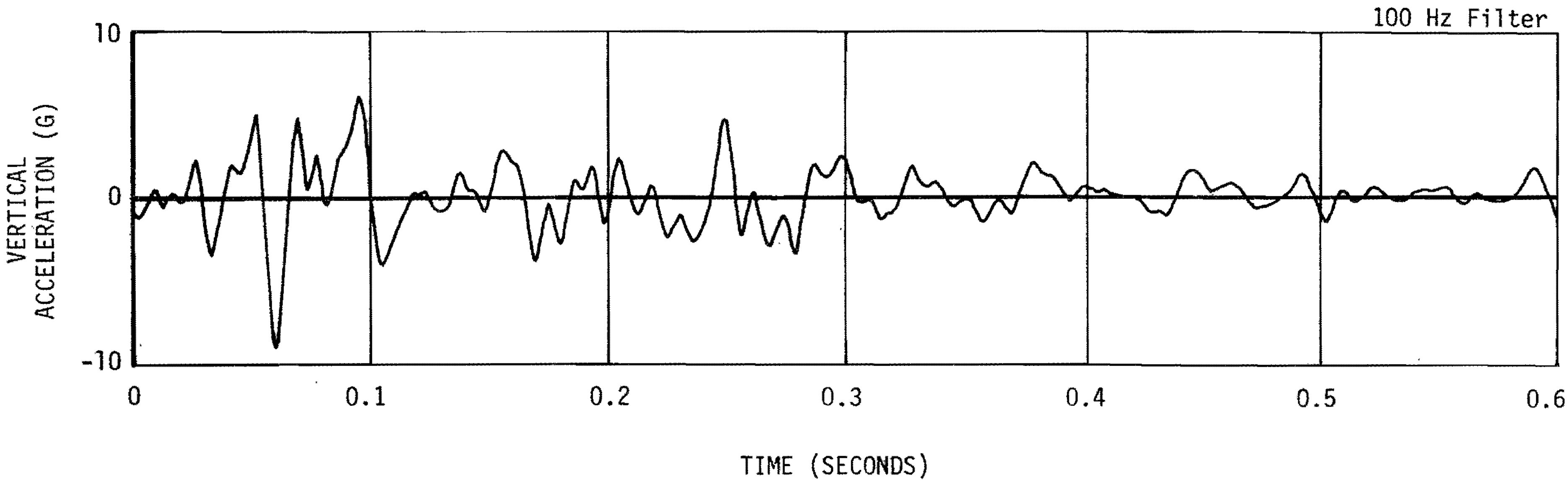
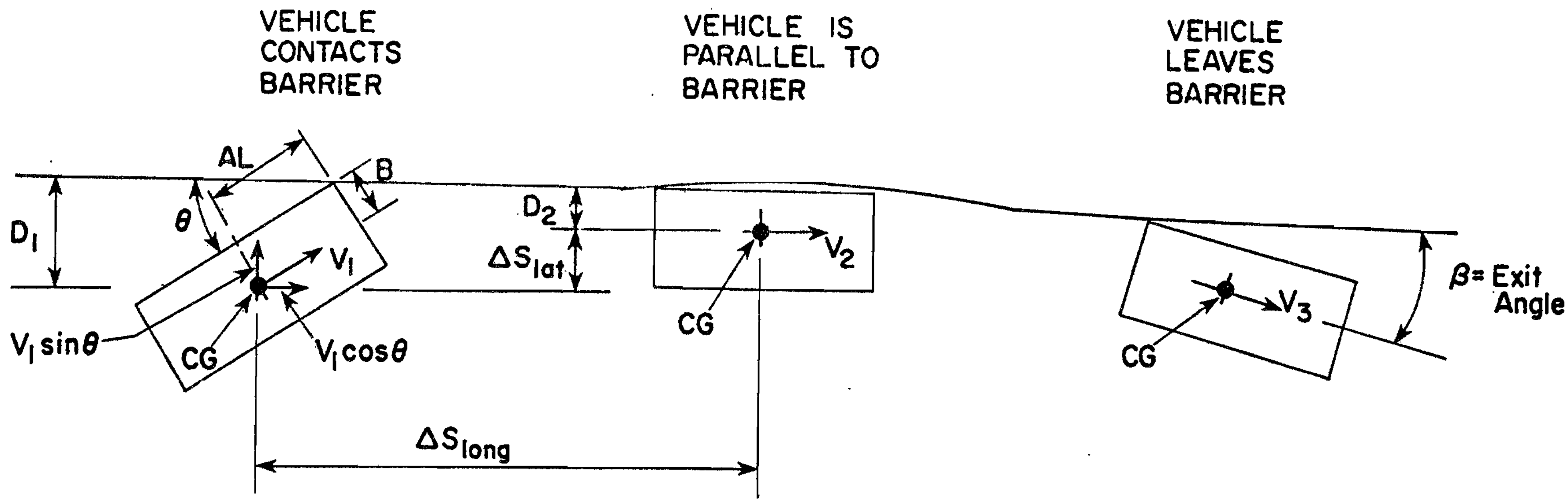


FIGURE D7. VEHICLE ACCELEROMETER TRACE FOR TEST 2.

APPENDIX "E"

EQUATIONS FOR FILM ANALYSIS



GOVERNING EQUATIONS:

(1) $\Delta V = V_3 - V_1$

(2) $\Delta S_{lat} = D_1 - D_2$

(3) $\text{Average } G_{lat} = \dfrac{(V_1 \sin\theta)^2}{2g\Delta S_{lat}}$

(4) $\text{Average } G_{long} = \dfrac{(V_1 \cos\theta)^2 - V_2^2}{2g\Delta S_{long}}$

(5) $\text{Average } G_{total} = \left((\text{Avg. } G_{lat})^2 + (\text{Avg. } G_{long})^2\right)^{1/2}$

FIGURE E1. GEOMETRIC REPRESENTATION OF PHOTOGRAPHIC ANALYSIS.