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16. Abstract

The objective of this study was to develop a safe end treatment for W-Beam-On-Barrels Barrier (WBBB). The WBBB terminal currently used in Texas was first tested and found to be unacceptable in terms of impact performance. A modified terminal consisting of a stand up barrier end attached to a steel drum by a W-beam end section (buffer) was then developed.

Two full scale vehicular crash tests were conducted to evaluate the impact behavior of the design. Since the WBBB is a low performance level, temporary barrier it was decided that test conditions (vehicle weight, impact speed and impact angle) recommended for higher performance level permanent roadside appurtenances were not appropriate. The basic difference between the selected conditions and those recommended for permanent installations involved the impact speed. A 50 mph (80.5 km/h) impact speed was used in lieu of the 60 mph speed used for permanent installations. As a result of the crash testing it was concluded that the design was acceptable in terms of impact performance.

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DEVELOPMENT OF A SAFE END TREATMENT FOR W-BEAM-ON-BARRELS BARRIER

by

Dean L. Sicking
Hayes E. Ross, Jr.
and
Bill Gaugler

Research Report 262-6F

Research Study No. 2-18-79-262
Safety Devices for Highway Work Zones

Sponsored by

Texas State Department of Highways and Public Transportation
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

November 1984

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

KEY WORDS

End Treatment(s), Crash Test(s), Construction, Work Zones(s), Temporary Safety, Low Performance Level, Barrier(s)

ACKNOWLEDGMENTS

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INTRODUCTION

A W-beam-on-barrels barrier (WBBB) has been successfully crash tested for use in construction zones (1) and is currently used widely across Texas. However, a safe end treatment for the WBBB has never been developed. The end treatment currently used in Texas has never been crash tested, and some contractors have reportedly installed the end treatment incorrectly thereby significantly reducing its effectiveness. This study was undertaken to evalute potential safety and construction problems associated with the W-beam-on-barrels barrier end treatment currently used on Texas highways and, if necessary, develop a safe alternative to the existing design.

Prior to the start of the study, a survey was taken to determine the nature and extent of construction problems associated with the existing WBBB terminal. Three major metropolitan highway districts within Texas were contacted and it was reported that although the end treatment was difficult to install, the terminal was constructed correctly at most sites. Visits to five construction sites utilizing the WBBB confirmed the results of the survey. Thus it was concluded that the existing end treatment for the WBBB is generally installed correctly, and its crashworthiness should be studied further.

TEXAS WBBB END TREATMENT

The WBBB end treatment currently used in Texas is essentially a tapered terminal where the end of the W-beam rail is bent down to the ground. In addition to the taper, the rail end is flared away from the travelway approximately 4 ft (1.2 m) over a distance of approximately 50 ft (15.1 m). The end of the W-beam is held in place by three steel drums at the nose containing 4 in. (10.2 cm) of sand. A 25 ft (7.7 m) section of unsupported rail separates the three steel drums at the nose of the treatment and the beginning of the length of need for the barrier. Figure 1 shows drawings of the existing WBBB terminal design and Figure 2 shows photographs of the constructed end treatment. Note that steel barrels at the beginning of the length of need of the barrier are full of sand as shown in Figure 3. Preliminary analysis of the impact performance of the existing end treatment for WBBB was inconclusive. Therefore, full-scale crash testing of the design was undertaken to accurately determine the crashworthiness of the terminal.

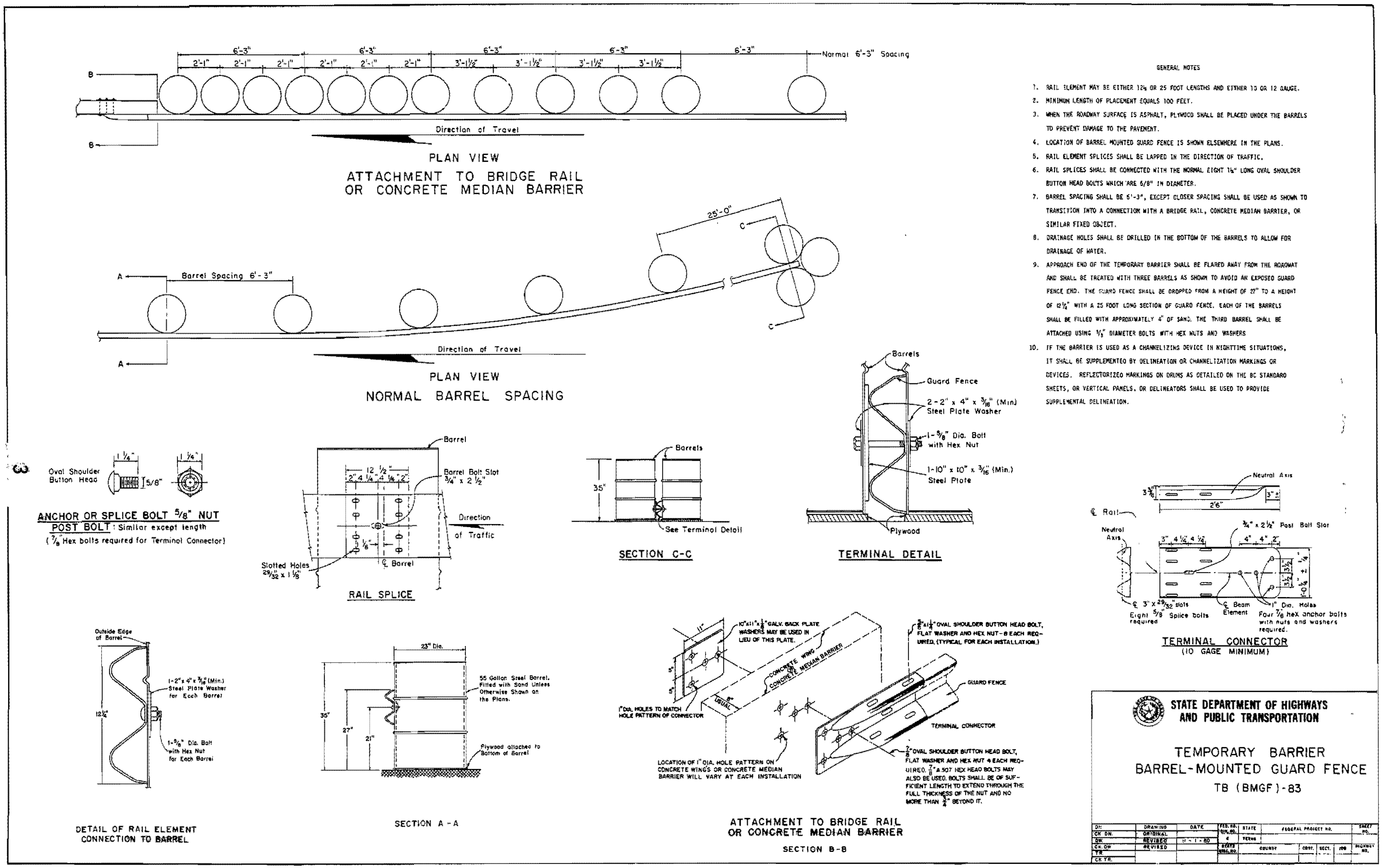
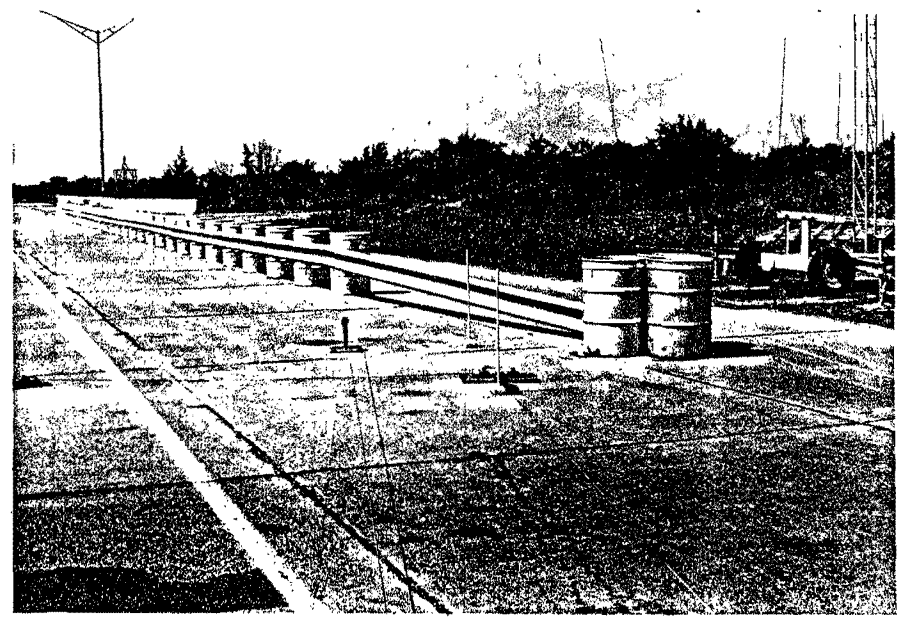


Figure 1. Existing W-Beam on Barrel Configuration

Flared Offset

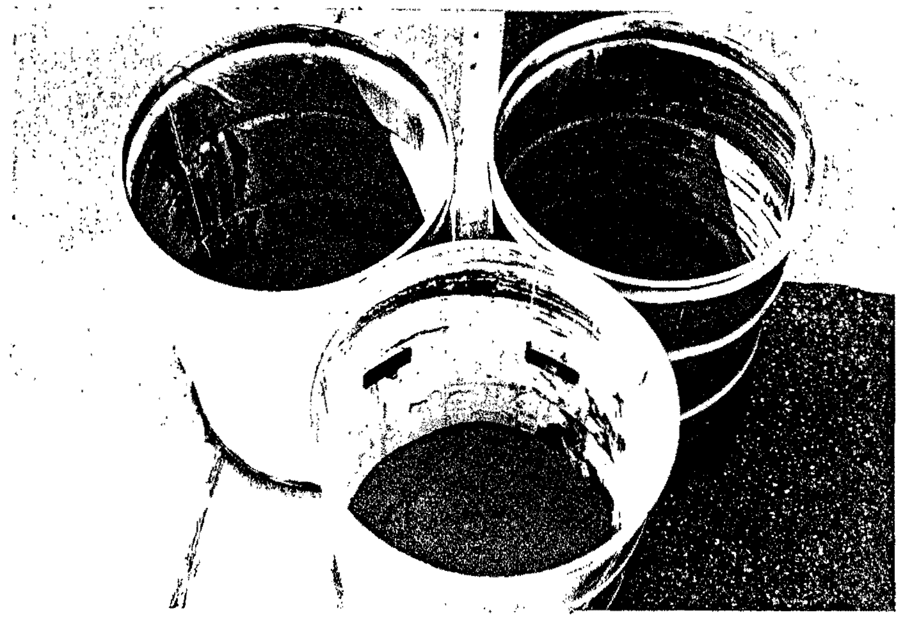
3-Barrel Nose Terminal



W-Beam Drop From 27" to 12.75"

Figure 2. Existing W-Beam on Barrel End Treatment

Typical Level-Full



Nose Terminal Level-4 inches

Figure 3. Sand Level in Barrels Existing End Treatment

IMPACT PERFORMANCE CRITERIA

Present test standards contained in NCHRP Report 230 (2) recommend that temporary barriers be designed for impact conditions equal to those for permanent barriers. However, the W-beam-on-barrels barrier is a low service level, temporary barrier capable of redirecting a 4500 lb vehicle impacting at 45 mph and 15 deg (3). Although NCHRP Report 230 recommends test standards for a low service level barrier, no test standards are given for barriers of the level of service offered by the WBBB. Therefore, selection of crash test conditions (vehicle size, impact speed, and impact angle) was made jointly by TTI and SDHPT engineers. Factors considered in the selection process included the level of service of W-beam-on-barrels barrier, test standards for higher service end treatments, traffic speeds in work zones, and the state of the art regarding temporary end treatments. As a result of this process, test conditions described in the following section were chosen. Results of each test were evaluated in terms of the recommended performance criteria (structural adequacy, severity, and post impact trajectory) presented in reference 2.

CRASH TEST RESULTS

Two full-scale crash tests were conducted to evaluate the performance of the W-beam-on-barrel end treatment shown in Figure 2. Sequential photos of the tests are given in Appendix A. Appendix B shows accelerometer traces and roll, pitch, and yaw angles versus time after impact.

Test 12*. In the first test a 2410 lb (1095 kg) vehicle impacted the three-barrel end cluster at 48 mph (77 km/h) and an impact angle of 0°. The centerline of the impacting vehicle was offset 15 in. (38 cm) from the center nose of the end treatment. Upon impact the 25 ft (7.7 m) section of unsupported W-beam buckled through the bolt holes midway between the end of the terminal and the beginning of the length of need. The vehicle then rode up onto the clustered barrels and dragged them along as the test vehicle continued to travel behind the barrier. The test vehicle came to rest approximately 55 ft (17 m) from the point of impact. Figure 4 summarizes the results of test 12.

The longitudinal occupant impact velocity measured during the test was 31 ft/sec (9.6 m/sec). This value is only slightly higher than the recommended maximum longitudinal impact velocity of 30 ft/sec (9.3 m/sec) and is much lower than the maximum allowable limit of 40 ft/sec (12.3 m/sec) (2). The measured lateral occupant impact velocity was 6 ft/sec (1.9 m/sec), which is much lower than the recommended limits (2). Longitudinal and lateral ridedown accelerations of 3.8 and 2.1 g's, respectively, were also well below recommended limits (2). Figures 5 and 6 show the test vehicle before and after the test. Figure 7 shows the damage to the test

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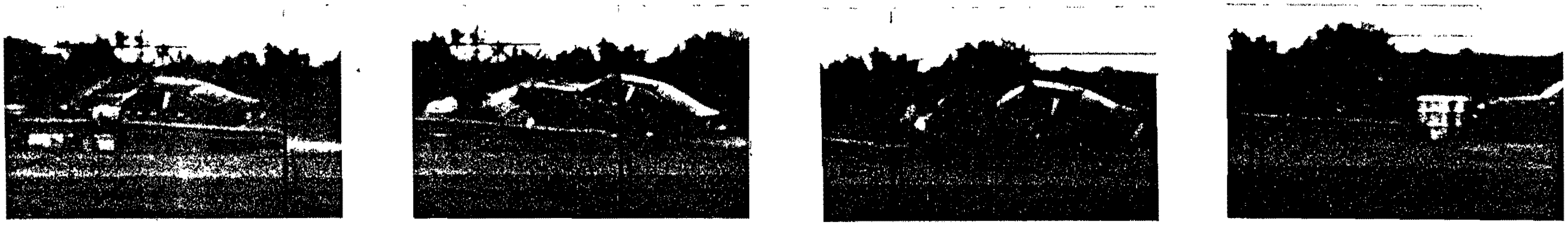
*Tests 1 through 11 were conducted during previous research (see Research Reports 2262-1 through 2262-5), and were unrelated to the work reported herein.



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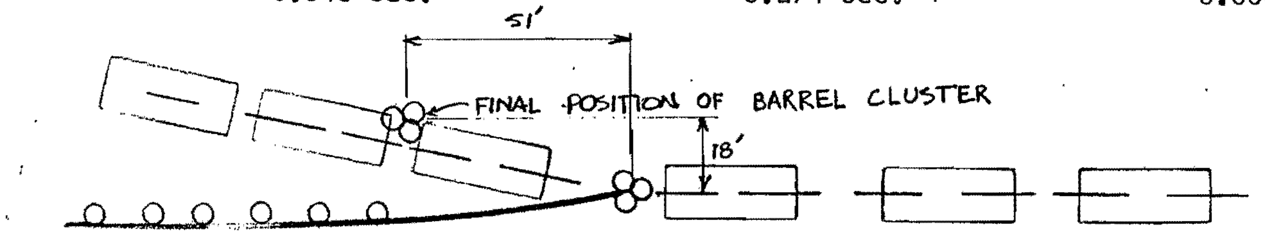


Test No.	2262-12
Date	6-11-84
Installation	
Drawing No	TB(BMGF)-83
Beam Rail	
Member	12 ga. W-Beam
Length of Segments-ft(m)	
First Segment	25(7.62)
Remaining Segments. .	6.25(1.91)
Maximum Deflection . . .	18(5.49)
Vehicle	
Model.	1975 Pontiac Astre
Mass-lb(kg).	2410(1095)
Maximum Roll Angle (degrees).	23

Speed-mph(kph)	
Impact.	47.6(76.7)
Exit.	17.8(28.7)
Angle-deg	
Impact.	0.0
Occupant Impact Velocity-fps(m/s)	
Forward	31.07(9.47)
Lateral	6.01(1.83)
Occupant Ridedown Accelerations-g's	
Forward	3.76
Lateral	2.03
Vehicle Damage	
TAD	1-FR-3
VDI	01FRMW2

Figure 4. Summary of Test 12

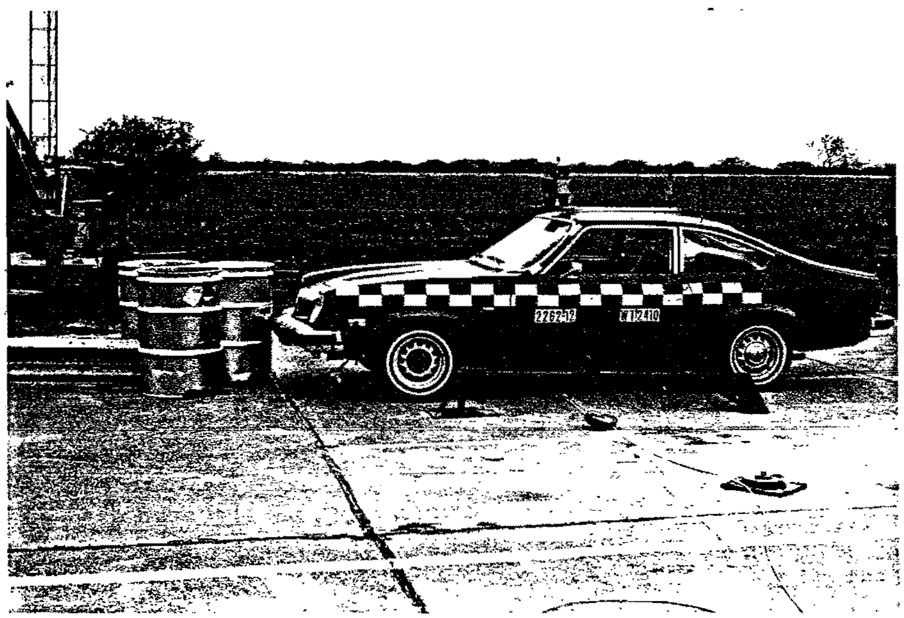


Figure 5. Test Vehicle Before Test 12

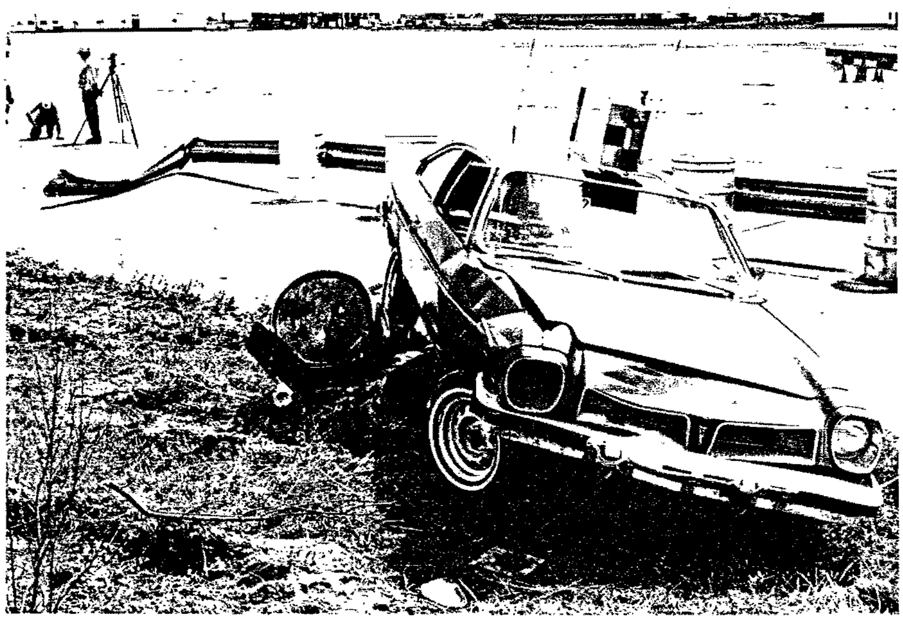


Figure 6. Test Vehicle After Test 12

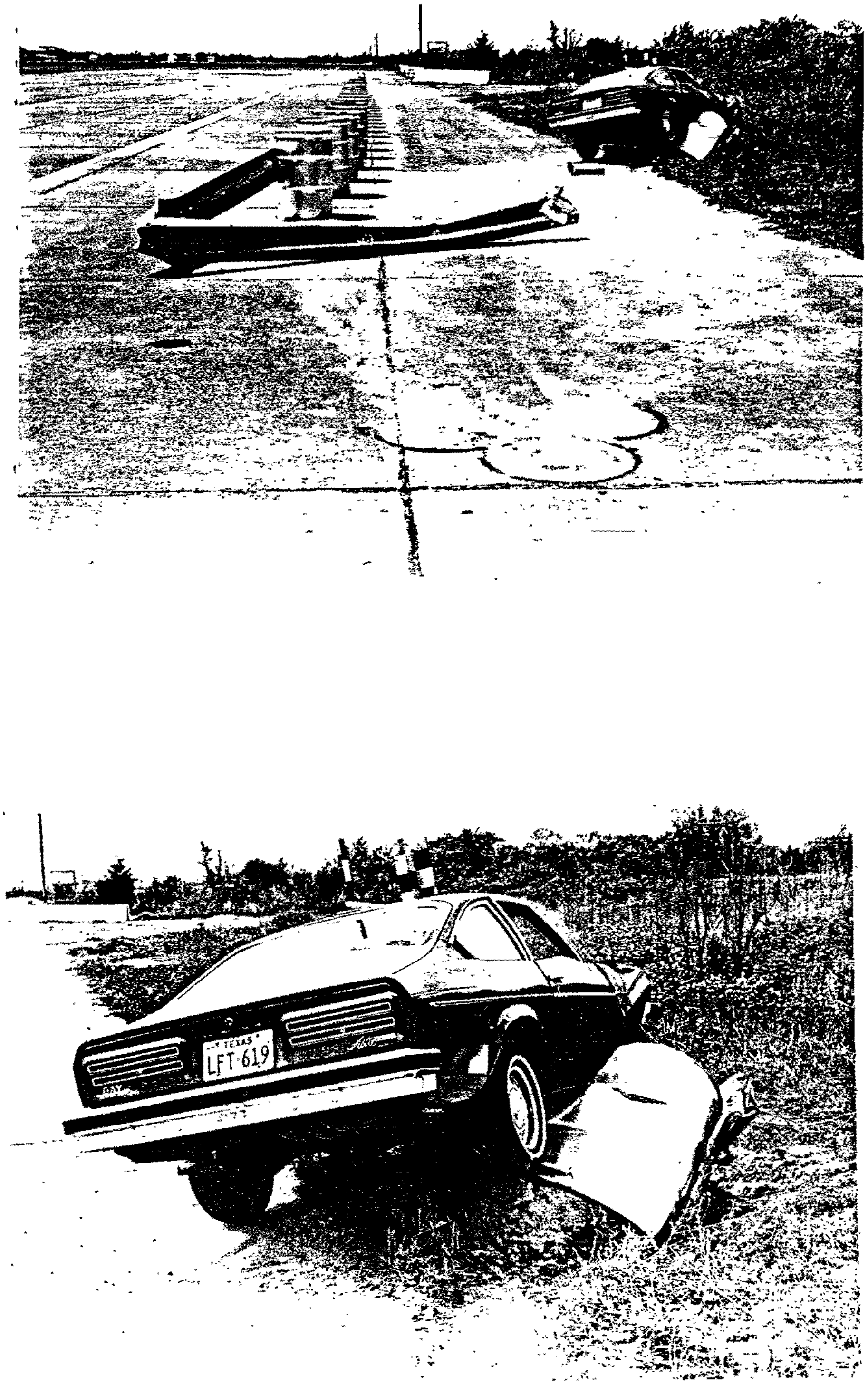


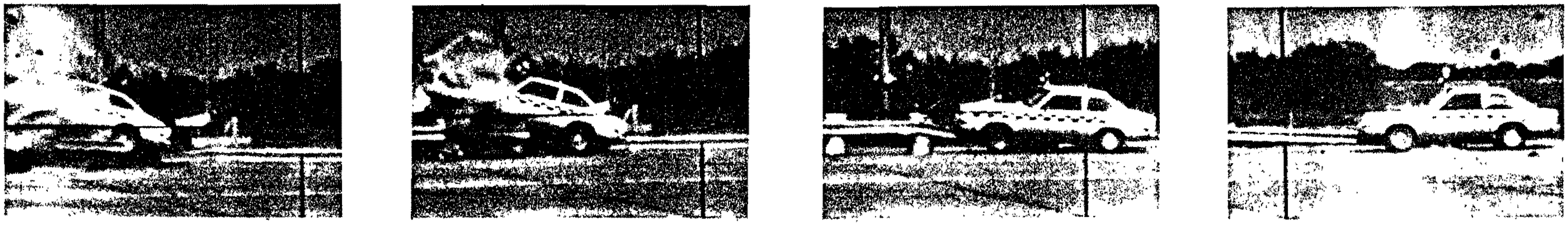
Figure 7. Existing WBBB After Test 12

installation. This test was considered to be a success since impact severity measures were within acceptable limits and the test passed normal structural adequacy and post impact vehicle trajectory criteria.

Test 13. The second test involved a 2250 lb (1021 kg) vehicle impacting the end treatment midway between the nose and the beginning of the length of need. The test vehicle impacted the terminal at 49.7 mph (80 km/h) and an angle of 15 deg. relative to the longitudinal barrier. Upon impact, the W-beam at the point of contact was pushed down to the ground where it remained in an upright position. The test vehicle's left front tire then climbed over the guardrail and the rail lifted the front of the vehicle off the ground. As the vehicle approached the beginning of the length of need, the front bumper was raised to a height of approximately 27 in. (69 cm). The test vehicle's front bumper struck the first barrel full of sand near the top of the steel drum. The vehicle then ramped over the barrier and rolled a complete revolution before coming to rest on its tires approximately 75 ft (23 m) from the point of impact.

Figure 8 summarizes the results of test 13. Although, as shown in Figure 8, impact severity evaluation criteria were within recommended limits, the test was considered to be a failure since the vehicle rolled over. Figures 9 and 10 show the test vehicle before and after the test, and Figure 11 shows test installation damage.

Test 14. After review of the results of test 13, it was concluded that the WBBB end treatment must be modified to prevent impacting vehicles from mounting the bent down guardrail. The end treatment was then modified as shown in Figures 12 and 13. As shown in Figure 12 the bent down rail was raised to the normal height of the W-beam, and the cluster of barrels at the nose of the terminal was replaced with a single barrel. A standard W-beam



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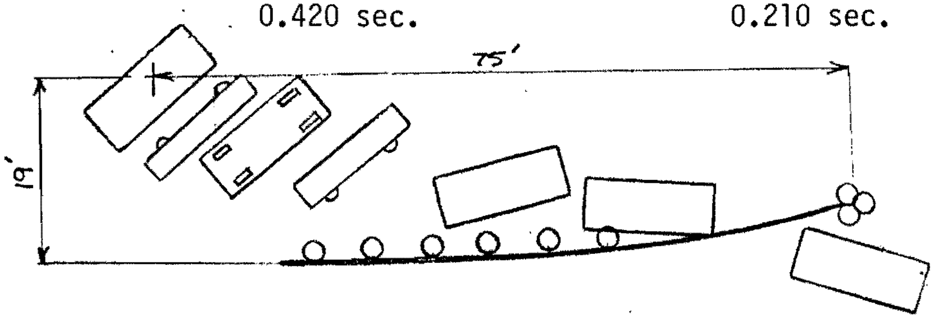


Test No.	2262-13
Date	6-14-84
Installation	
Drawing No	TB(BMGF)-83
Beam Rail	
Member	12 ga. W-Beam
Length of Segments-ft(m)	
First Segment	25(7.62)
Remaining Segments. .	6.25(1.91)
Maximum Deflection . . .	9.20(2.80)
Vehicle	
Model.	1977 Pontiac Astre
Mass-lb(kg).	2550(1159)

Note : Vehicle Rolled Over

Speed-mph(kph)	
Impact.	49.7(80.0)
Exit.	28.0(45.0)
Angle-deg	
Impact.	15.0
Occupant Impact Velocity-fps(m/s)	
Forward	27.06(8.25)
Lateral	6.29(1.92)
Occupant Ridedown Accelerations-g's	
Forward	6.27
Lateral	8.59
Vehicle Damage	
TAD	10-L&T-4
VDI	10LYA03

Figure 8. Summary of Test 13

Figure 9. Test Vehicle Before Test 13

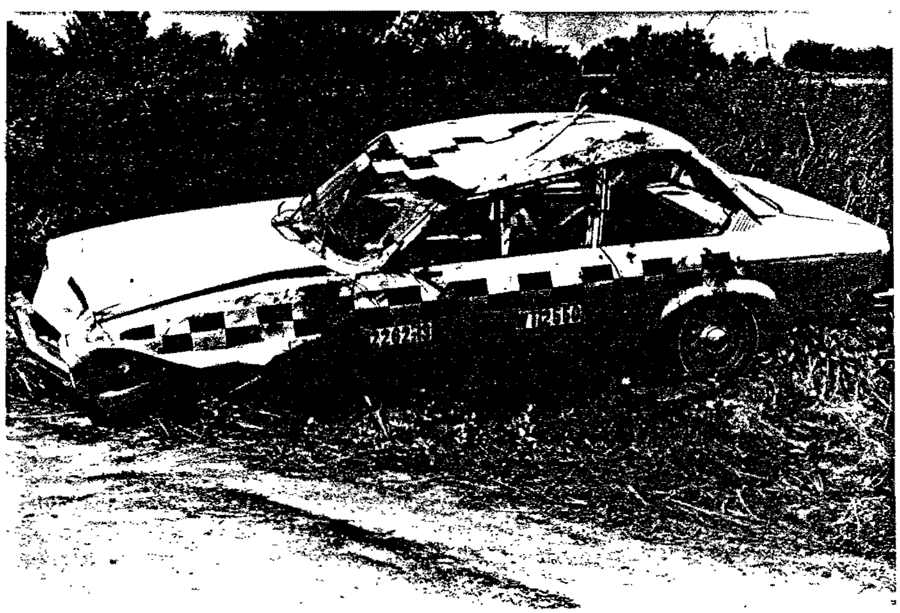
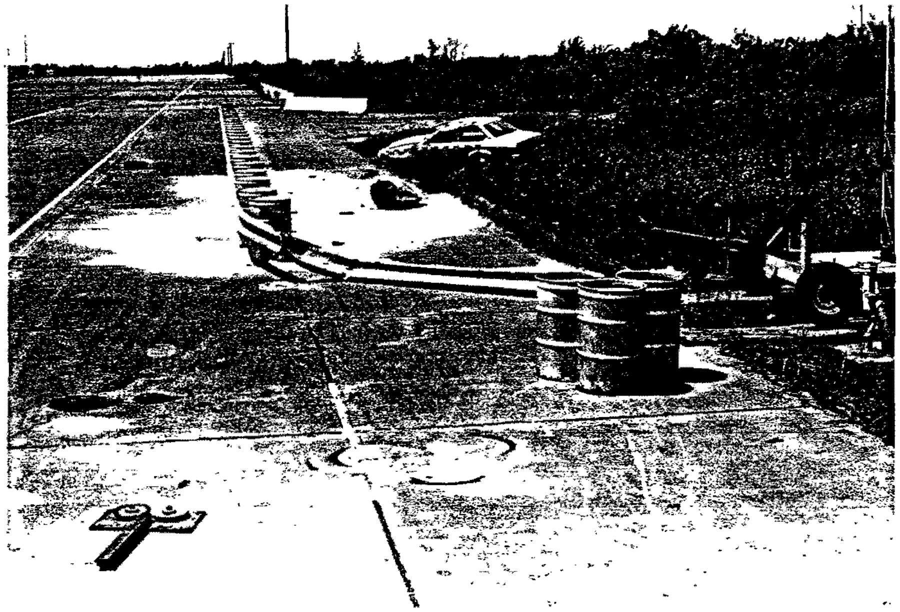


Figure 10. Test Vehicle After Test 13



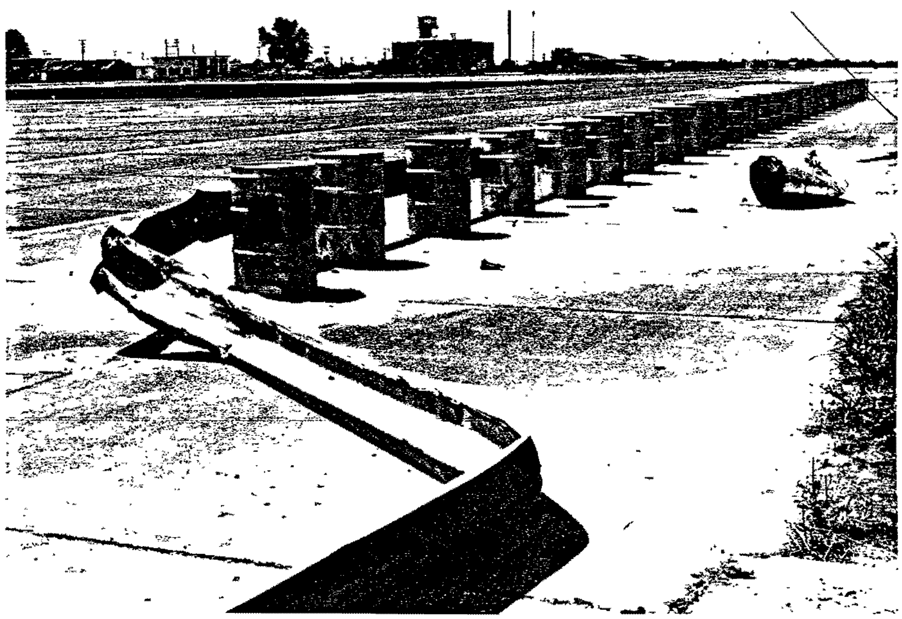


Figure 11. Existing WBBB After Test 13

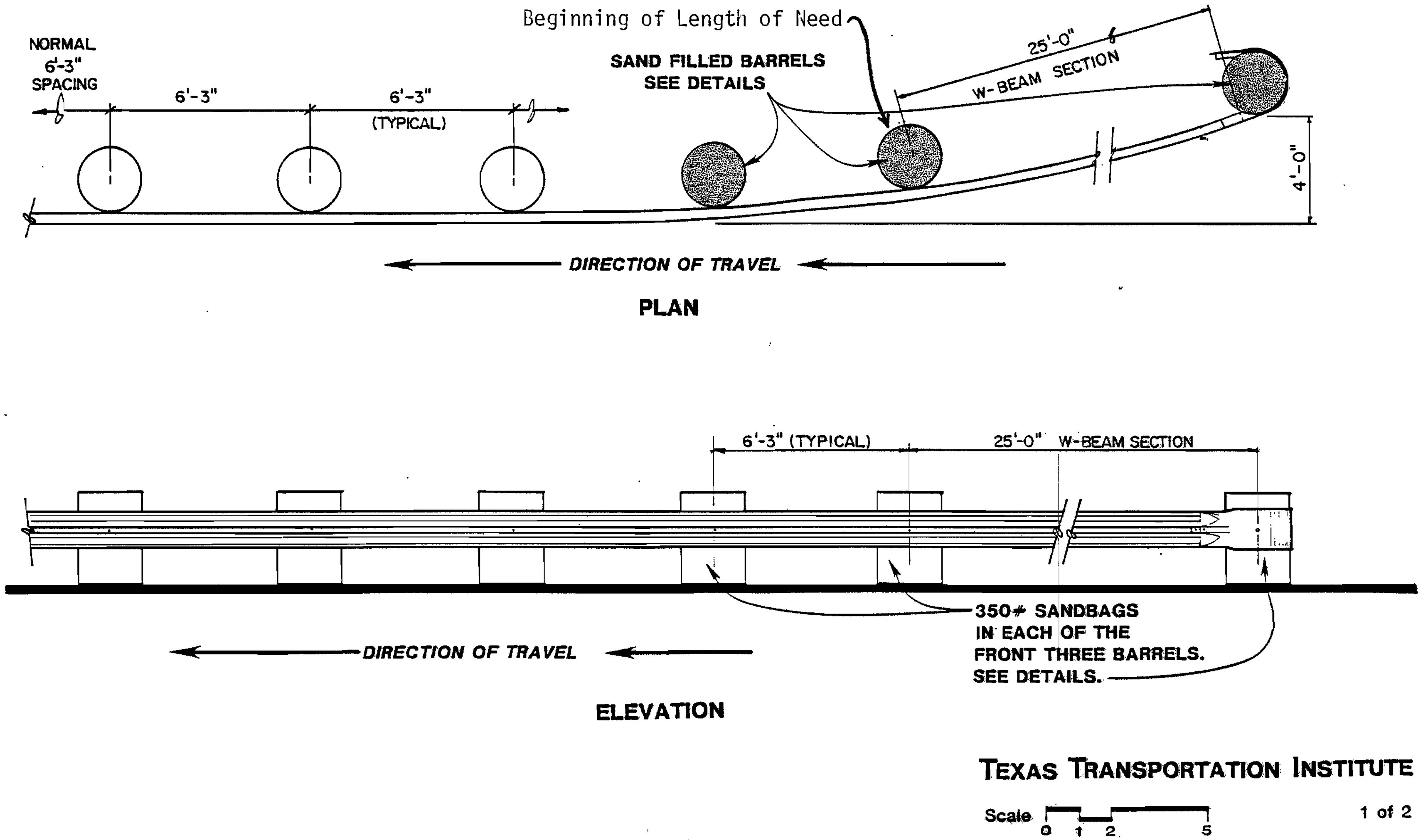


Figure 12. Construction Drawings of Modified WBBB Terminal

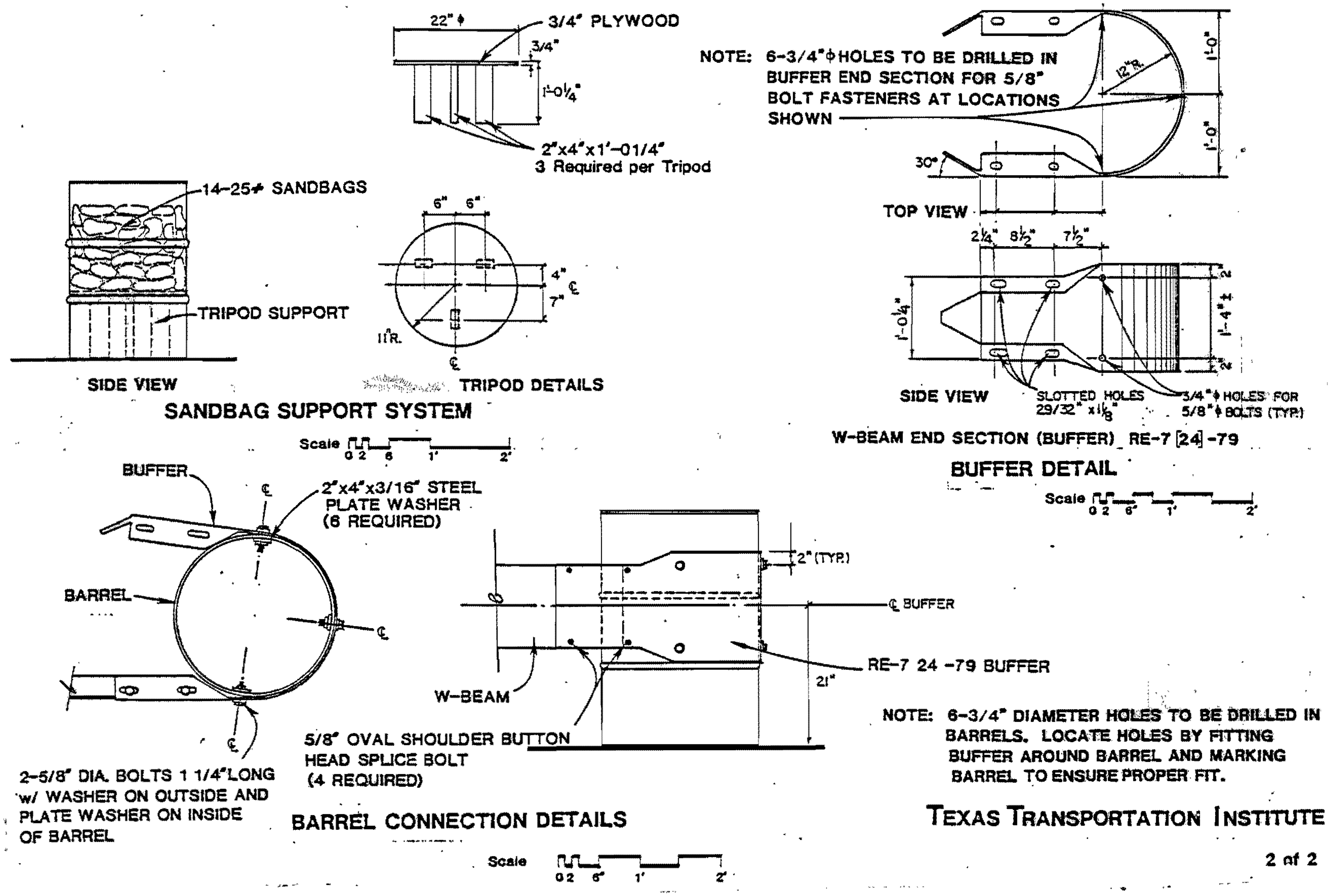
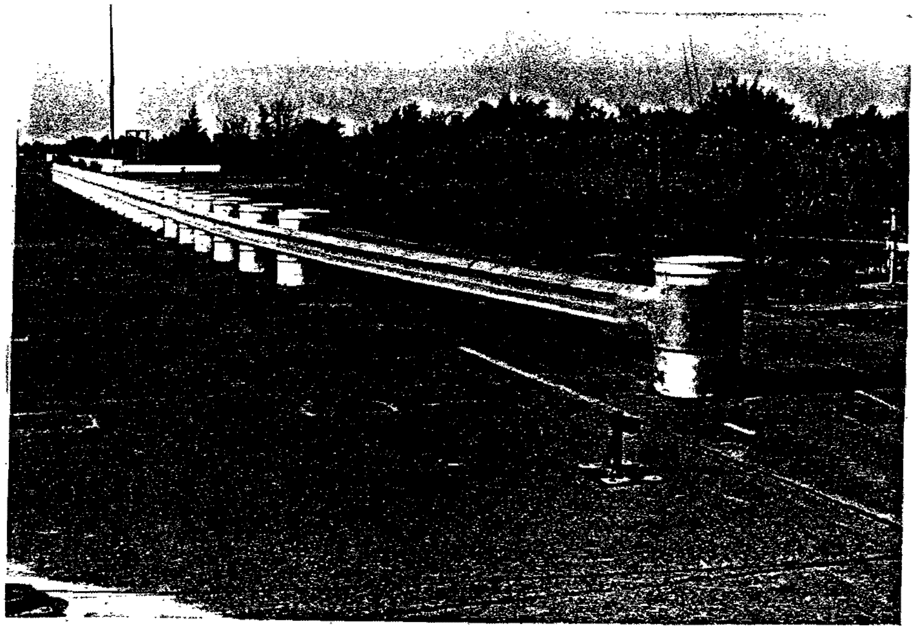


Figure 12. Construction Drawings of Modified WBBB Terminal (cont.)



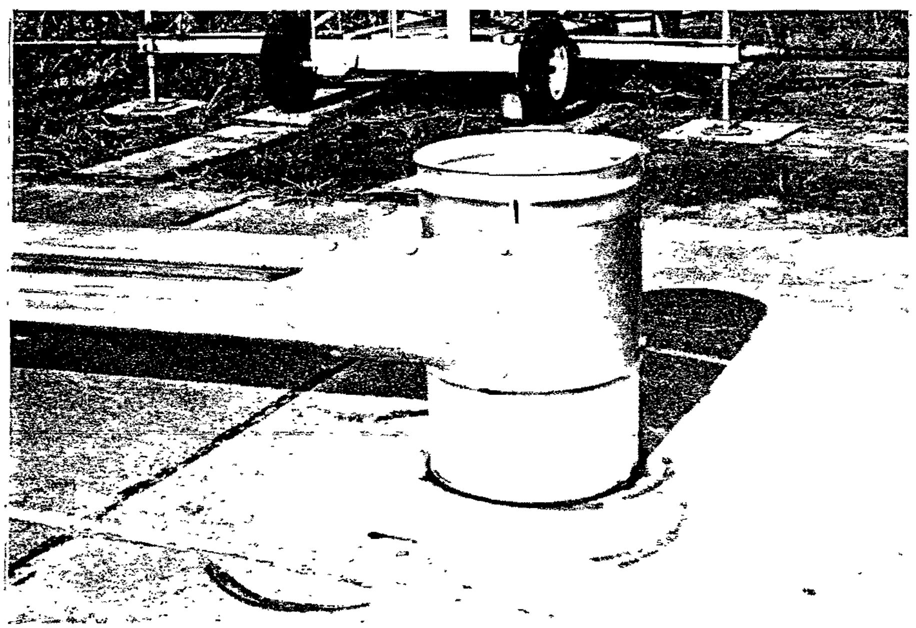
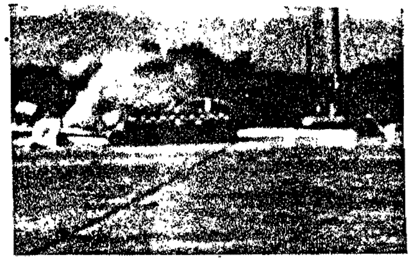


Figure 13. Modified WBBB Terminal

buffered end section normally used in the breakaway cable terminal was wrapped around the leading barrel to prevent the end of the rail from spearing impacting vehicles. Further, 350 lb (159 kg) of sand was placed in the leading barrel and the first two barrels after the beginning of the length of need. The sand in these barrels was put in bags for ease of handling and the bags were placed on wooden pedestals to raise the center of gravity of the barrels to a height of approximately 22 in. (56 cm). Raising the center of gravity of the leading barrels should reduce the possibility of an impacting vehicle vaulting over the barrels and becoming airborne. The beginning of the length of need for the modified terminal is the point of attachment of the second steel drum.

Test 13 was then repeated to determine if the modifications to the WBBB terminal would prevent vehicle rollover. A 1974 Chevrolet Vega weighing 2453 lb (1115 kg) impacted the modified end treatment at 47 mph (76 km/h) with an impact angle of 15° relative to the centerline of the road. The impact point was midway between the nose of the terminal and the beginning of the length of need. Upon impact the test vehicle began to redirect while pushing the light barrel away from the roadway. The test vehicle was then traveling parallel with the roadway approximately on the centerline of the W-beam-on-barrels barrier. The test vehicle then impacted the first barrel full of sand head-on and was brought to a quick stop. A summary of test 14 is shown in Figure 14.

The forward and lateral occupant impact velocities were 16.7 and 8.4 ft/sec (5.2 and 2.6 m/sec), respectively, while the forward and lateral ridedown velocities were 11.4 and 9.2 g's, respectively. These values are well below the recommended values cited in NCHRP Report 230. Figures 15 and 16 show the test vehicle before and after testing. As illustrated, the



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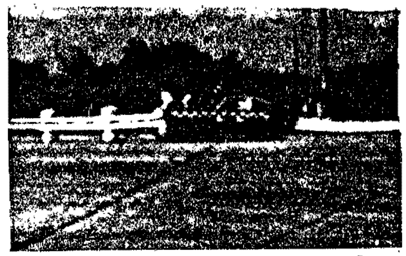

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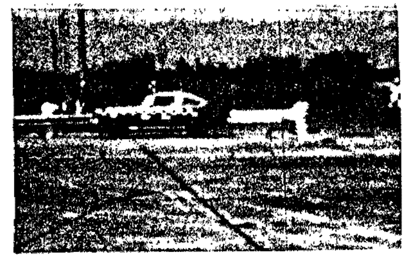

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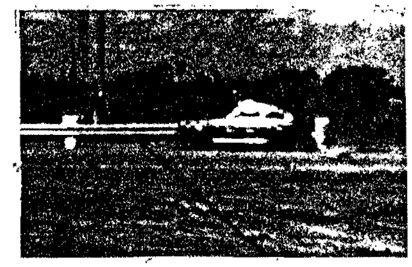

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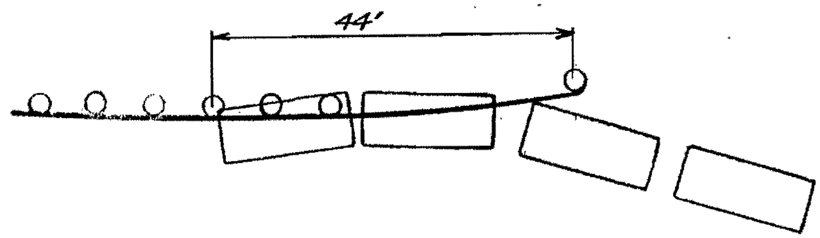
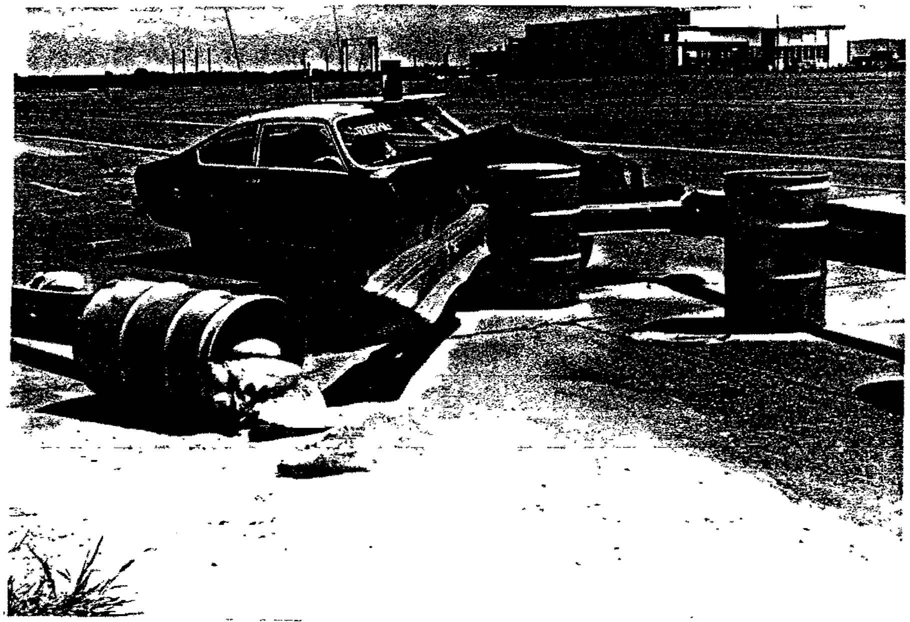


Test No.	2262-14	Speed-mph(kph)	
Date	8-10-84	Impact.	47.3(76.2)
Installation		Exit.	11.9(19.2)
Drawing No		Angle-deg	
Beam Rail		Impact.	15.0
Member	12 ga. W-Beam	Occupant Impact Velocity-fps(m/s)	
Length of Segments-ft(m)		Forward	16.69(5.09)
First Segment	25(7.62)	Lateral	8.41(2.56)
Remaining Segments. .	6.25(1.91)	Occupant Ridedown Accelerations-g's	
Maximum Deflection . . .	30.5(9.30)	Forward	11.43
Vehicle		Lateral	9.24
Model.	1974 Chevrolet Vega	Vehicle Damage	
Mass-lb(kg).	2453(1115)	TAD	1-FR-5
Maximum Roll Angle (degrees).	4.1	VDI	01FZMW3

Figure 14. Summary of Test 14

Figure 15. Test Vehicle Before Test 14



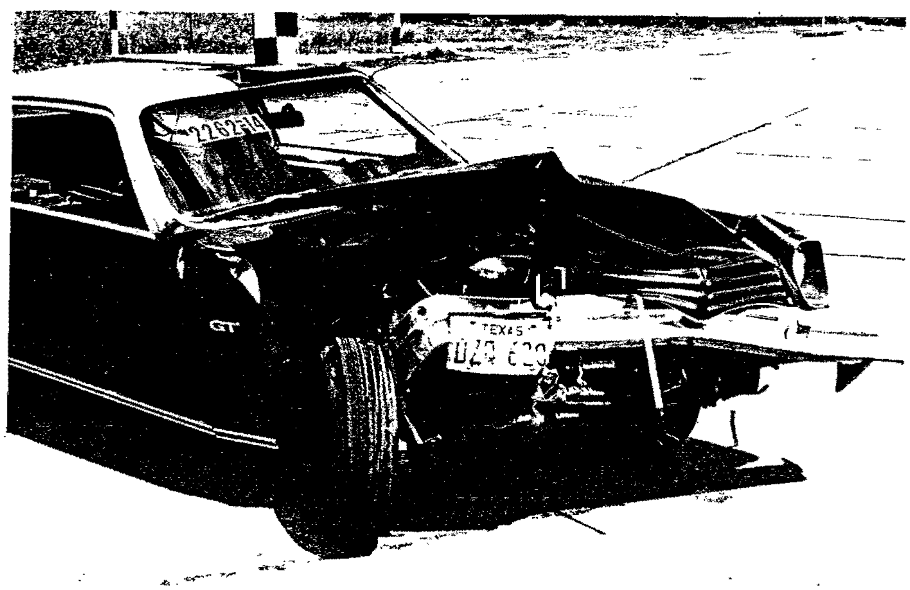
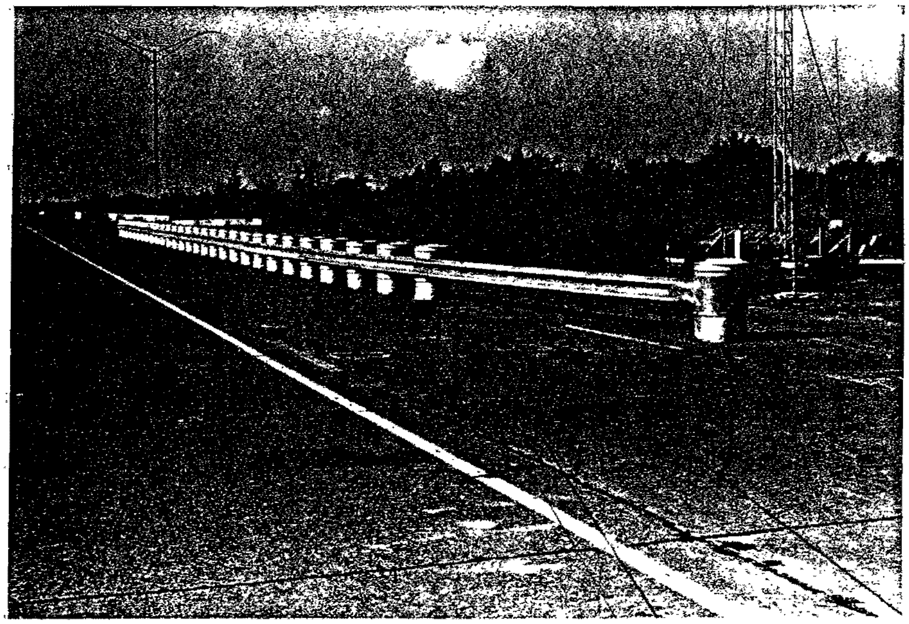


Figure 16, Test Vehicle After Test 14

vehicle suffered extensive damage to the front and was not operable. Figure 17 shows photos of the test installation before and after impact. This test was determined to be successful because all measures of impact severity were within acceptable limits, the modified terminal exhibited no structural inadequacy, and vehicle post impact trajectory was acceptable.

Test 15. The final test of the WBBB end treatment investigated the head-on impact characteristics of the modified terminal. This test involved a 2453 lb (1153 kg) vehicle impacting the nose of the end treatment at 46 mph (74 km/h). The angle of impact was 0° with respect to the roadway and the point of impact was offset 15 in. (38 cm) to the right of the vehicle centerline. When the test vehicle impacted the terminal, the 25 ft (7.7 m) section of unsupported rail buckled at the quarter point between the leading barrel and the beginning of the length of need for the barrier. The test vehicle was then redirected behind the barrier and dragged the leading barrel to a stop approximately 65 ft (20 m) from the point of impact.

Figure 18 shows a summary of test 15. As shown in this figure the longitudinal occupant impact velocity was 35 ft/sec (10.8 m/sec), which is above the recommended limit of 30 ft/sec (9.3 m/sec) but below the maximum allowable limit of 0 ft/sec (12.3 m/sec) (2). All other measures of impact severity shown in Figure 18 were well below the recommended values. Figures 19 and 20 show the damage incurred by the test vehicle, and Figure 21 shows the damage sustained by the test installation. Although the longitudinal occupant impact velocity was above recommended limits for this test, the test was considered to be a success because the impact velocity was within maximum acceptable limits and the test passed all other methods of evaluation.



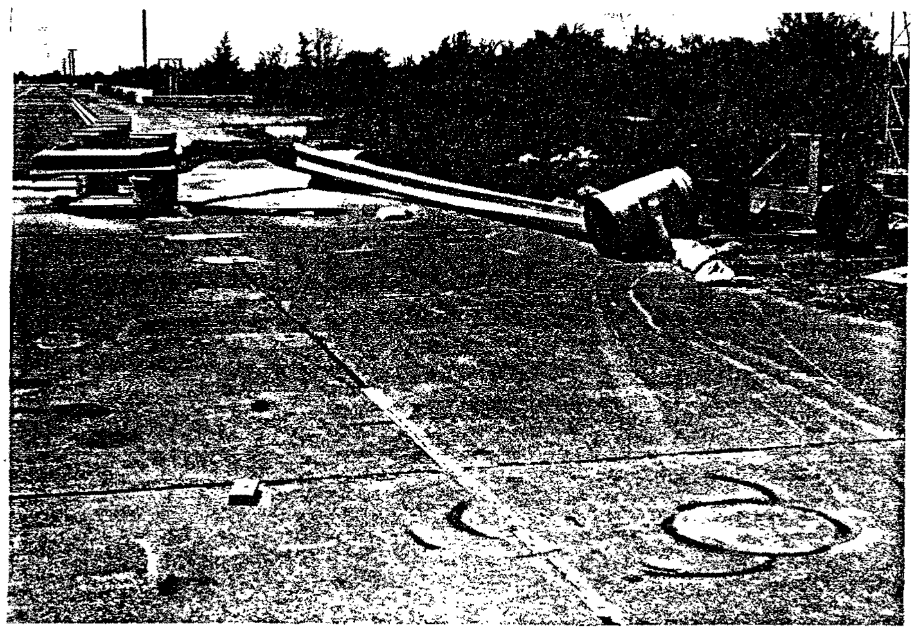
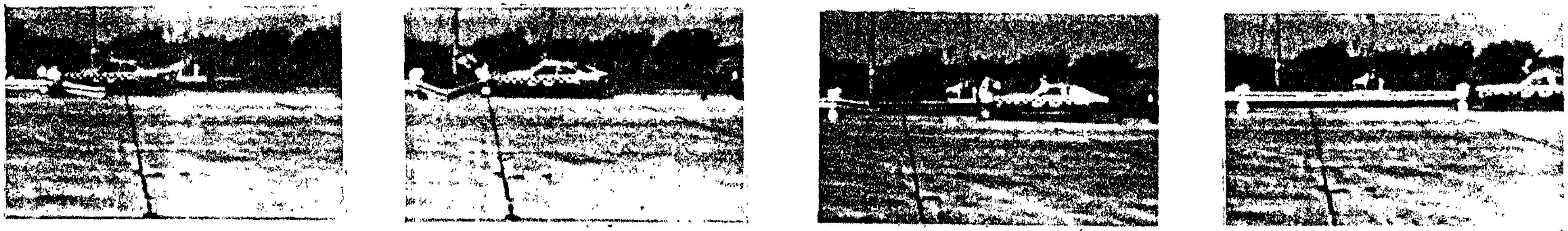


Figure 17. Modified Barrier Before & After Test 14



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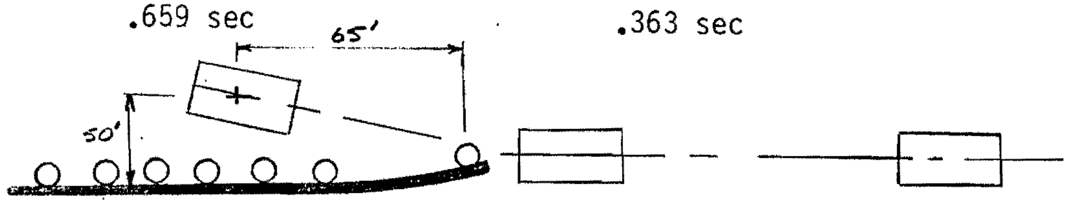


Test No.	2262-15
Date	8-14-84
Installation	
Drawing No	
Beam Rail	
Member	12 ga. W-Beam
Length of Segments-ft(m)	
First Segment	25(7.62)
Remaining Segments	6.25(1.91)
Maximum Deflection	40.0(12.2)
Vehicle	
Model	1975 Chevrolet Vega
Mass-lb(kg)	2453(1115)
Maximum Roll Angle (degrees)	3.6

Speed-mph(kph)	
Impact	45.5(73.3)
Exit	20.6(33.2)
Angle-deg	
Impact	0.0
Occupant Impact Velocity-fps(m/s)	
Forward	34.81(10.61)
Lateral	6.39(1.95)
Occupant Ridedown Accelerations-g's	
Forward	4.08
Lateral	1.50
Vehicle Damage	
TAD	12-FC-4
VDI	12FCMN5

Figure 18. Summary of Test 15

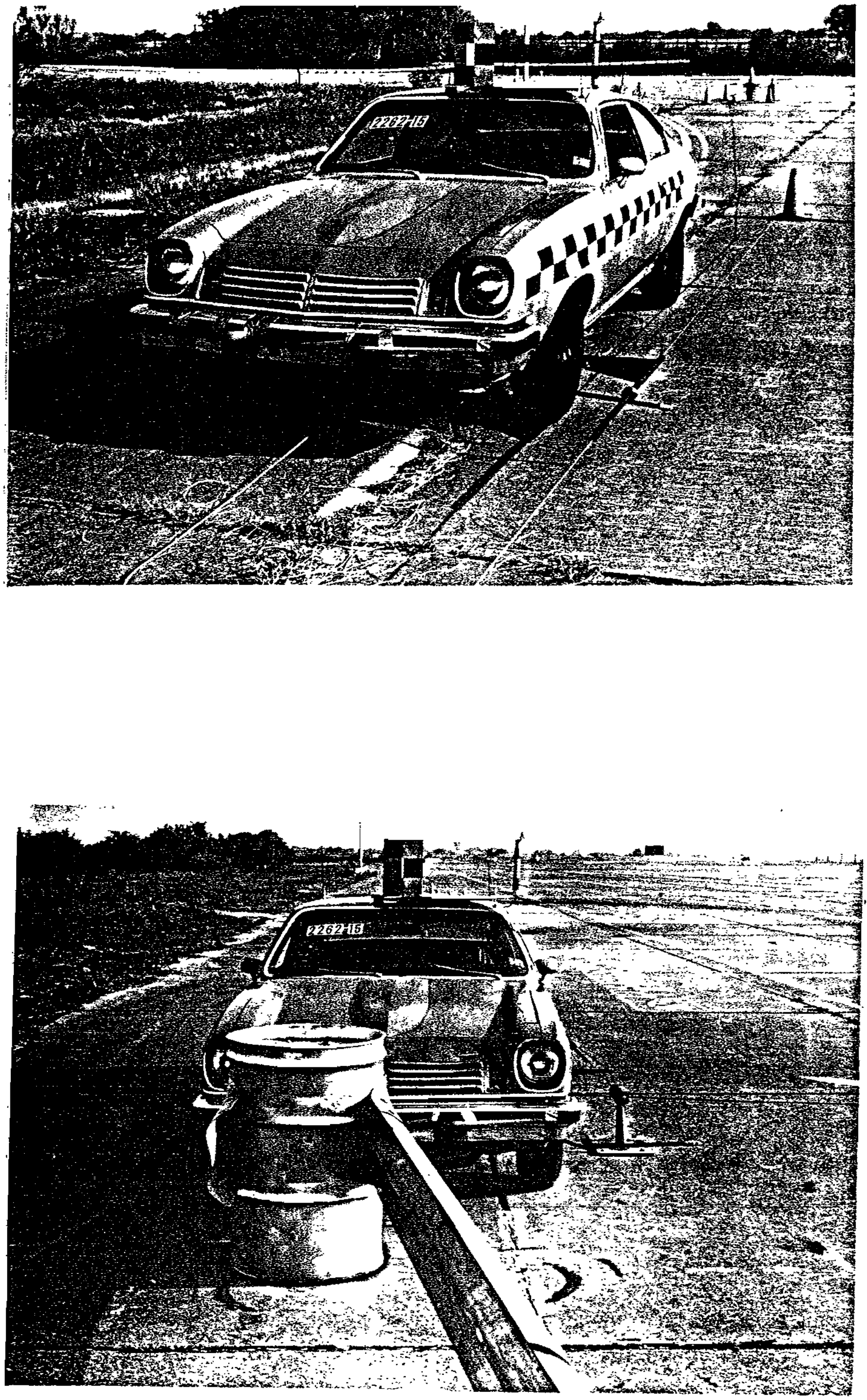


Figure 19. Test Vehicle Before Test 15

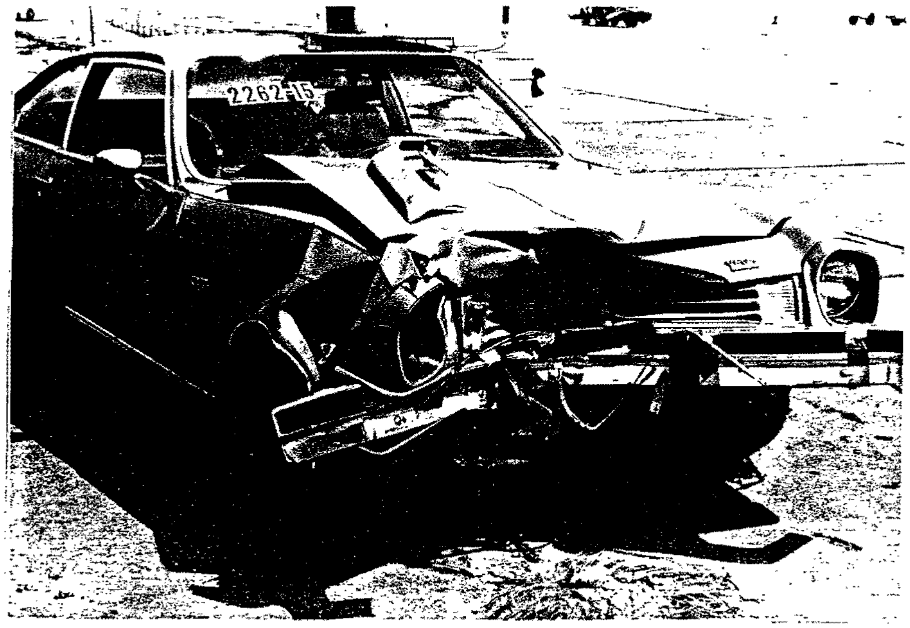
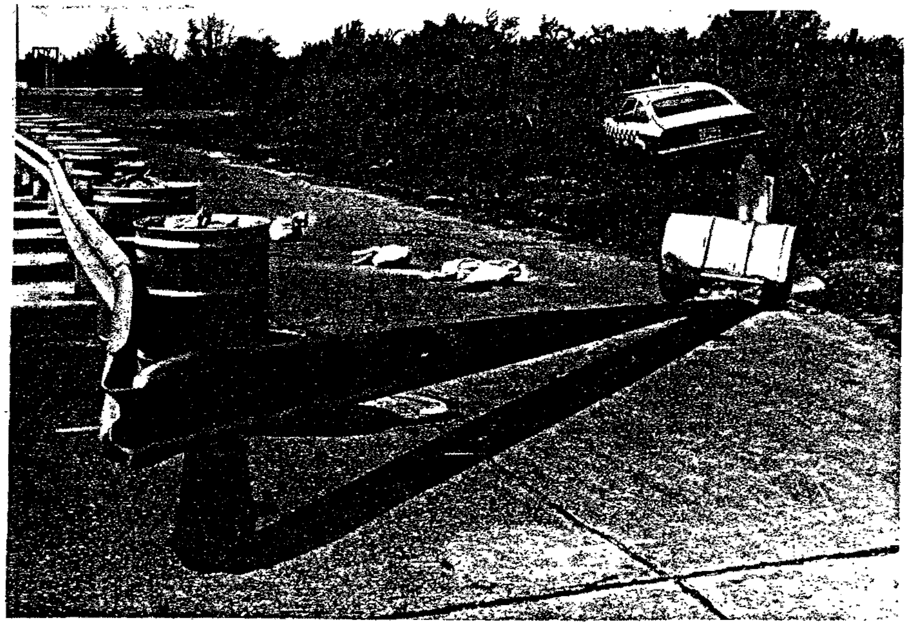


Figure 20. Test Vehicle After Test 15



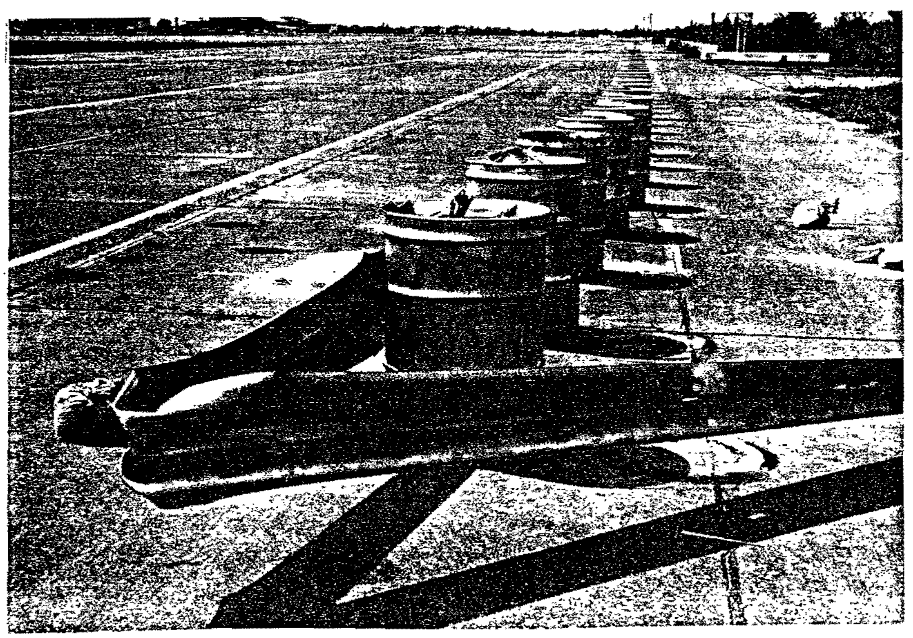


Figure 21. Modified WBBB After Test 15

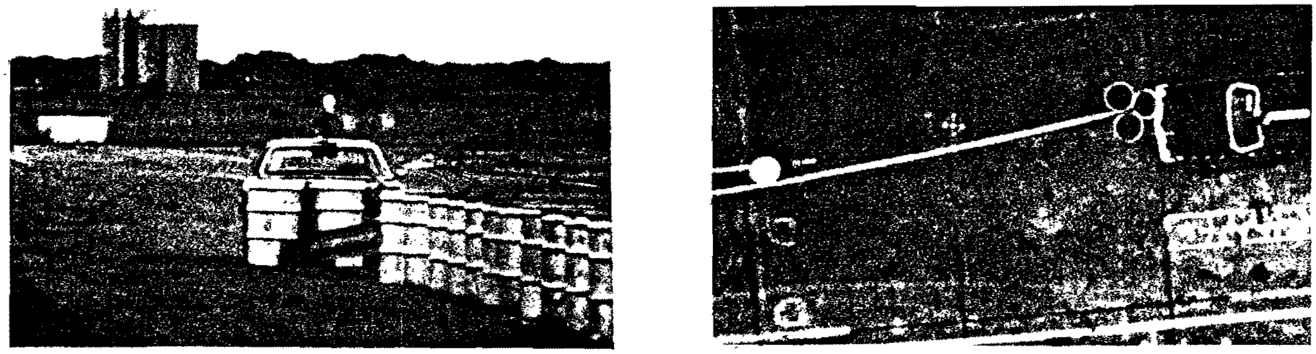
SUMMARY AND CONCLUSIONS

The W-beam-on-barrels barrier has been shown to be a cost beneficial, low service, temporary barrier and is used widely across Texas. No safe end treatment for the WBBB had been previously tested successfully. The end treatment currently used in Texas, shown in Figures 1, 2, and 3, utilized a bent-down guardrail element with a cluster of three steel drums at the end to hold the rail in place and cushion head-on impacts. This end treatment, although difficult to construct, was found to be installed correctly by most contractors using the WBBB, and it contains no obvious safety problems. Therefore, this end treatment was selected for full-scale crash test evaluation.

Two full-scale crash tests were conducted to evaluate the impact behavior of the existing terminal. Since the W-beam-on-barrels barrier is intended for low service level applications, it was decided that test conditions (vehicle weight, impact speed, and impact angle) recommended for permanent barriers were not appropriate. The basic difference between the selected conditions and those recommended for permanent installations involved the impact speed. A 50 mph (80 km/h) impact speed was used in lieu of the 60 mph (97 km/h) speed used for permanent barriers. The second crash test of the terminal resulted in test vehicle rollover.

The end treatment design was modified as shown in Figures 12 and 13 to prevent vehicles impacting the side of the terminal from becoming airborne and rolling over. Important features of the modification include raising the end of the rail to a height of 27 in. (69 cm) and replacing the three-barrel cluster at the nose of the terminal with a single barrel. As shown in Figure 12, a W-beam buffer end section was used to prevent the guardrail from spearing an impacting vehicle. Two crash tests of the modified end treatment verified the crashworthiness of the new design. In conclusion, the modified end treatment developed under this study has been shown to be a crashworthy terminal for the W-beam-on-barrels barrier.

APPENDIX A - SEQUENTIAL PHOTOGRAPHS



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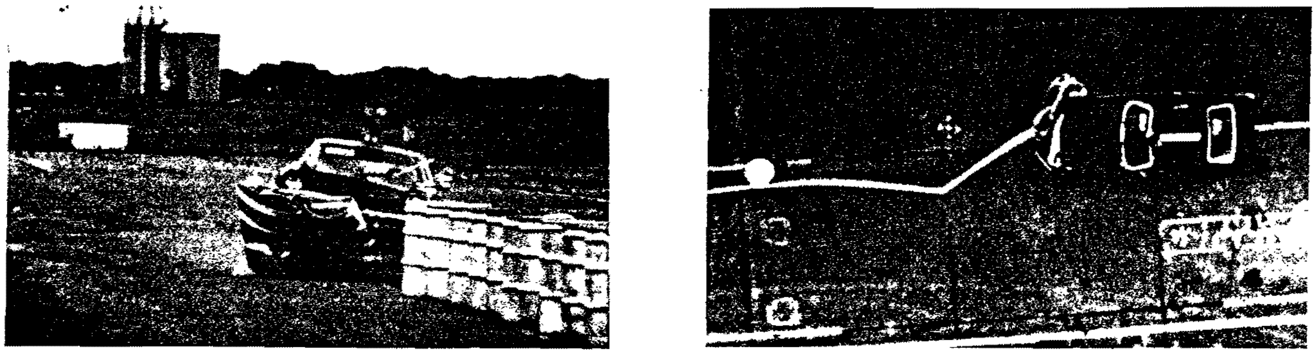

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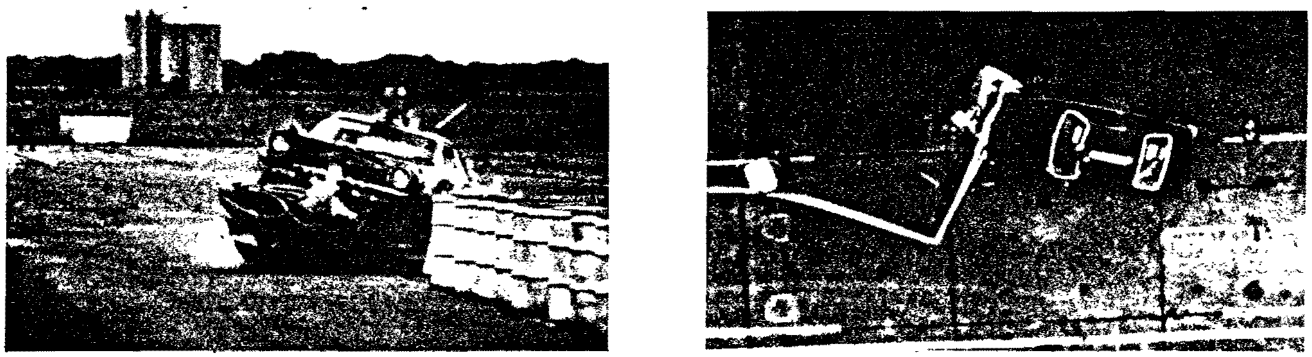

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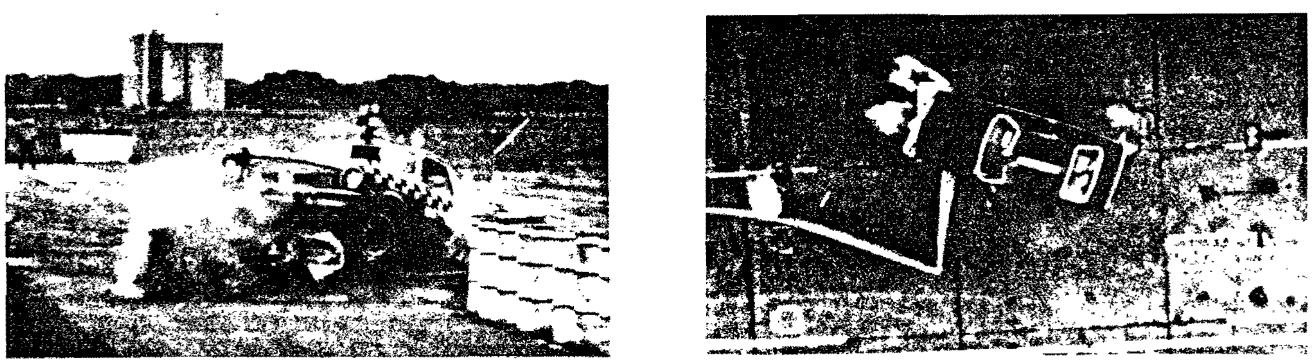

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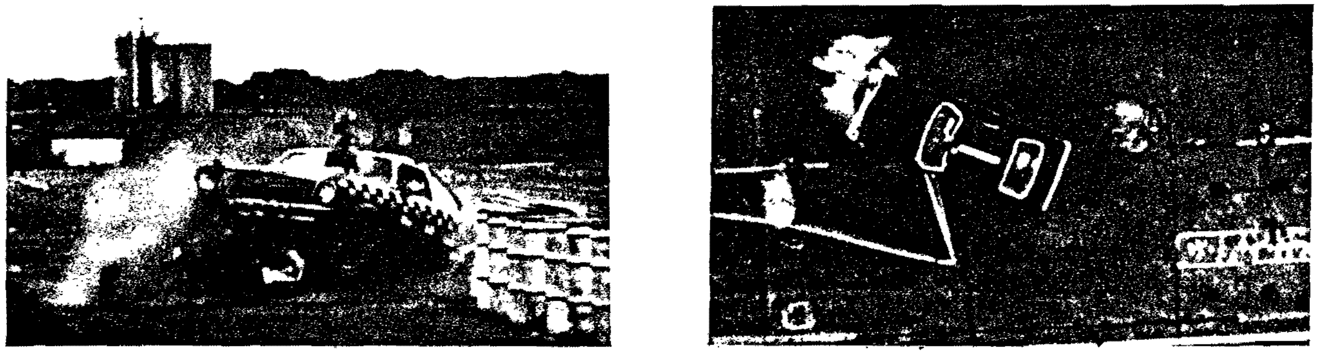
Figure 22. Sequential Photographs for Test 12.



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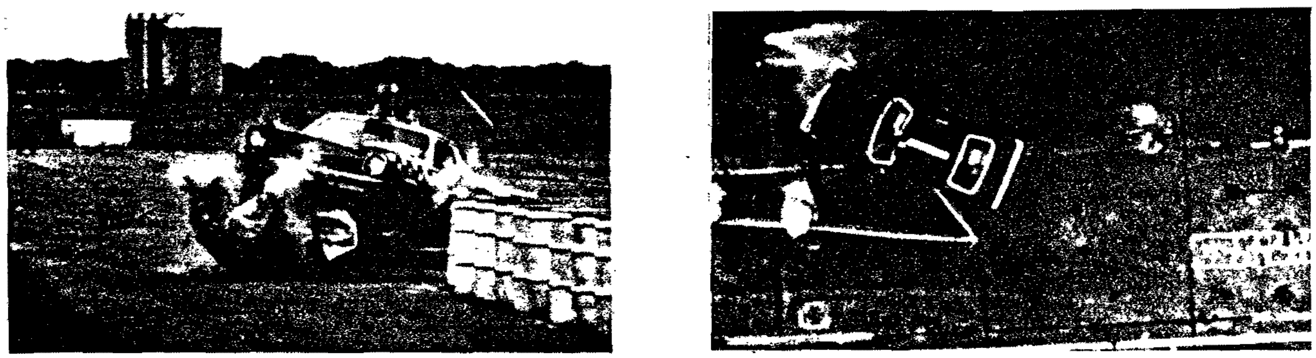

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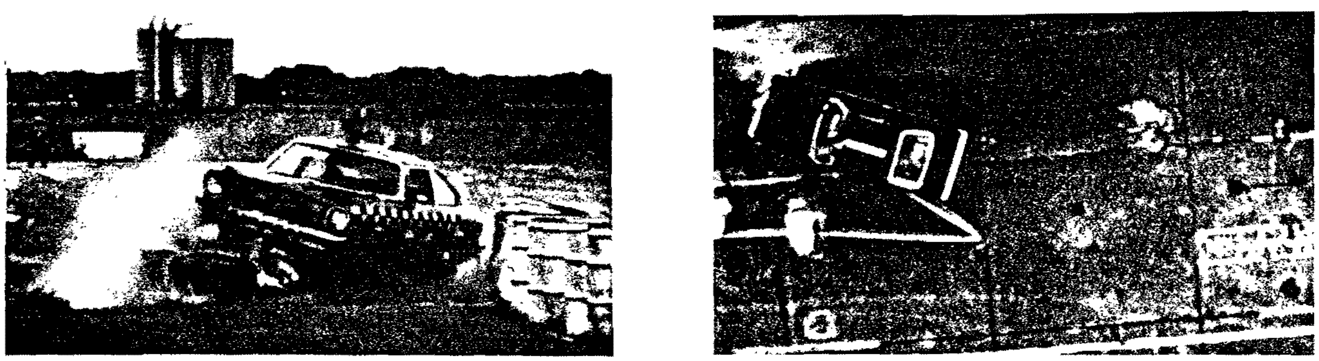

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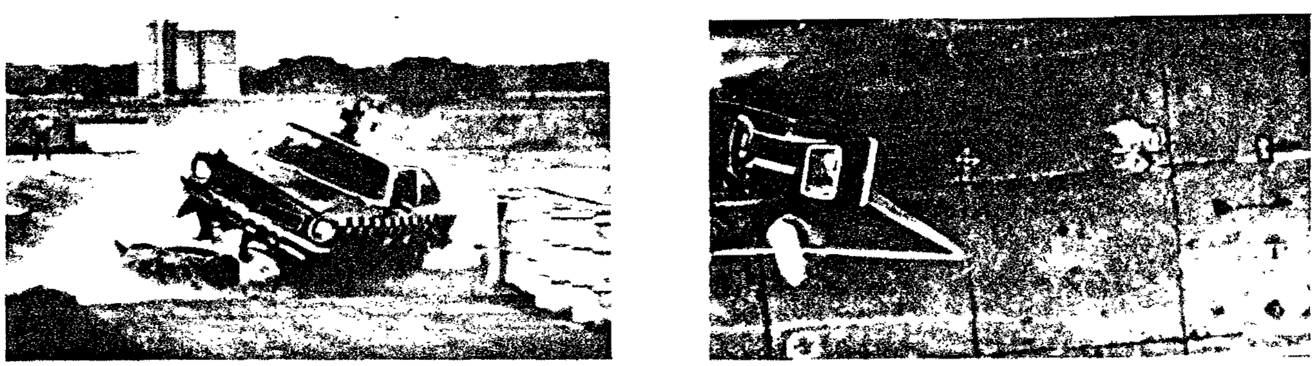

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Figure 23. Sequential Photographs for Test 12. (cont.)

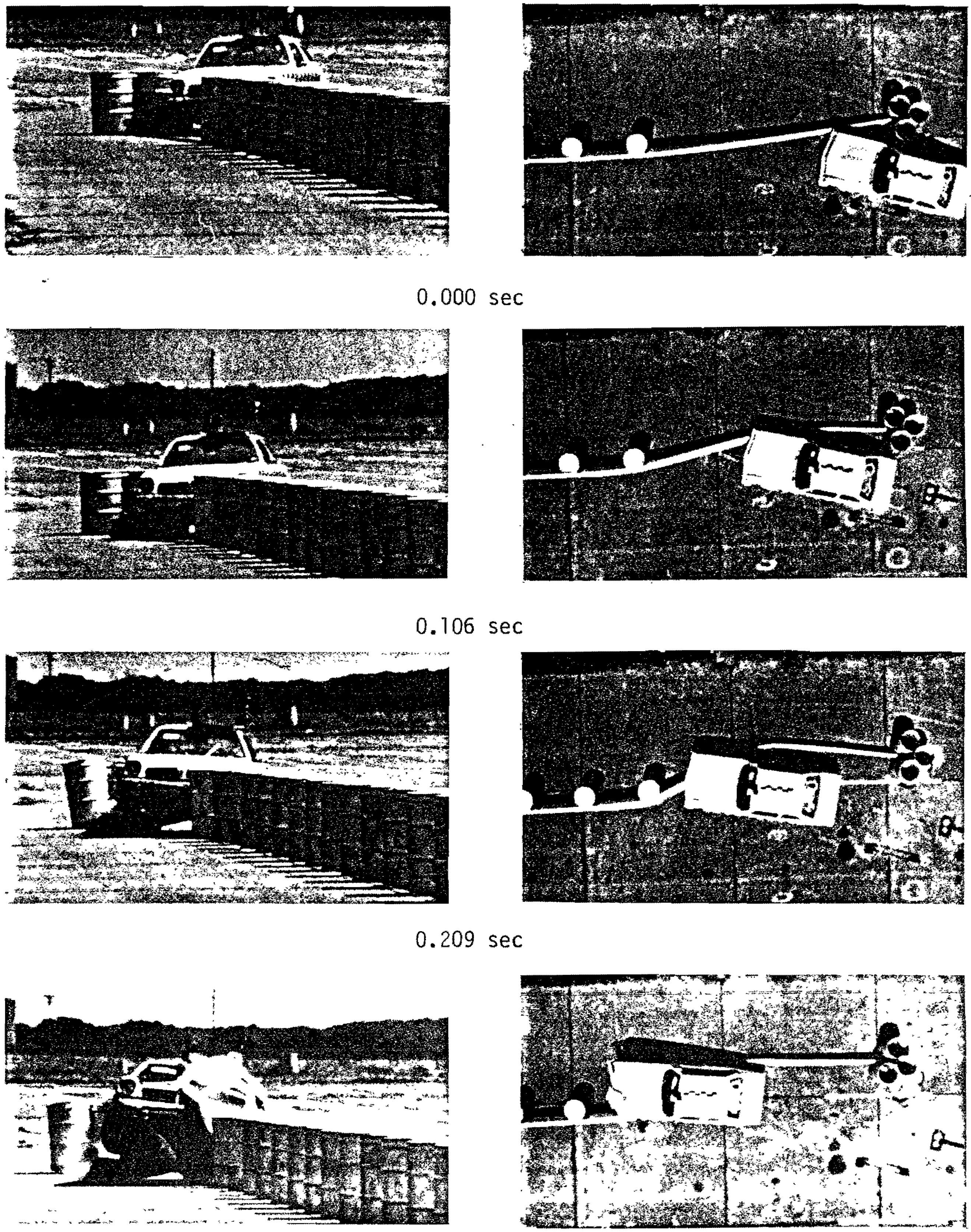
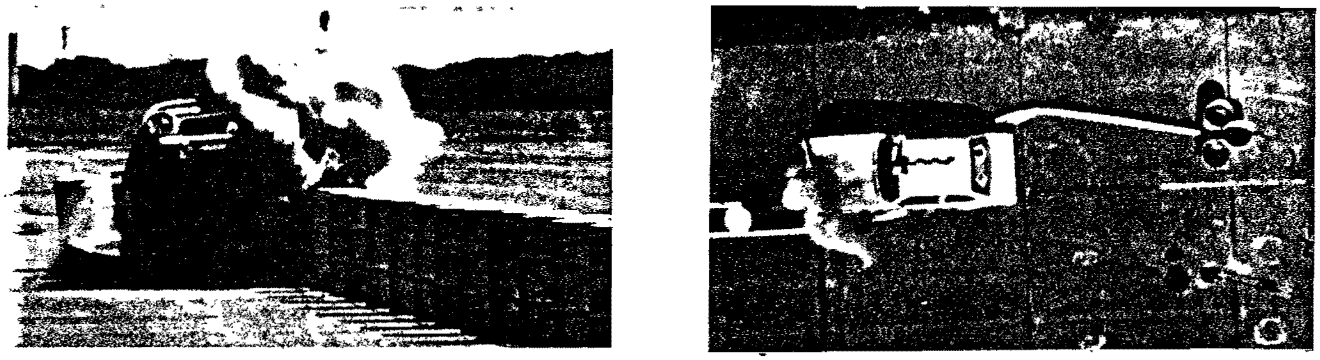


Figure 24. Sequential Photographs for Test 13.



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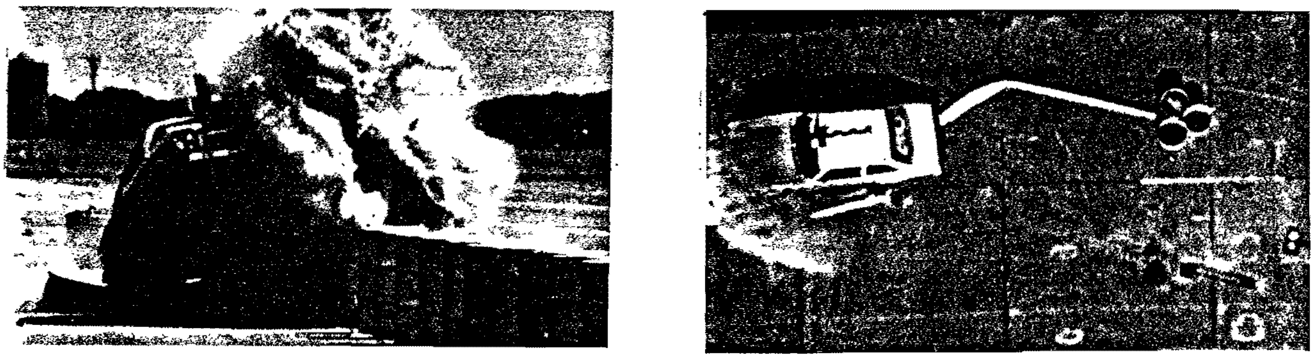

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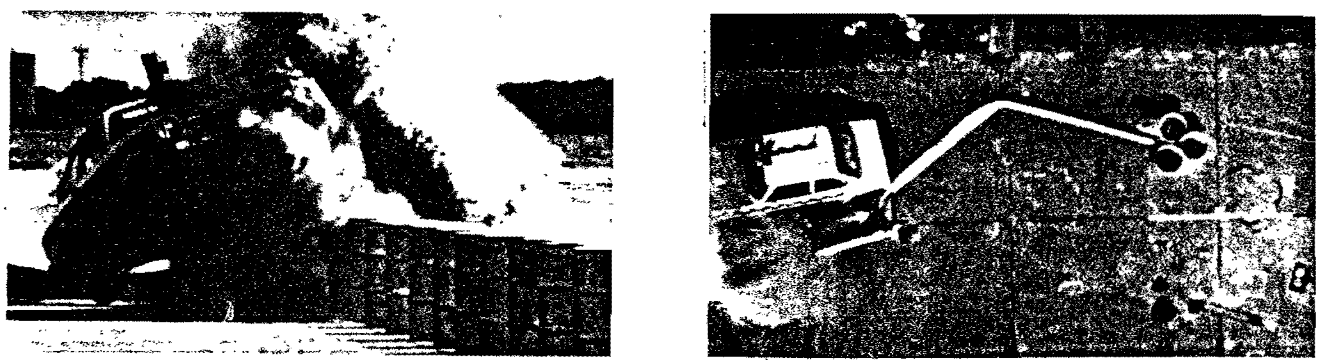

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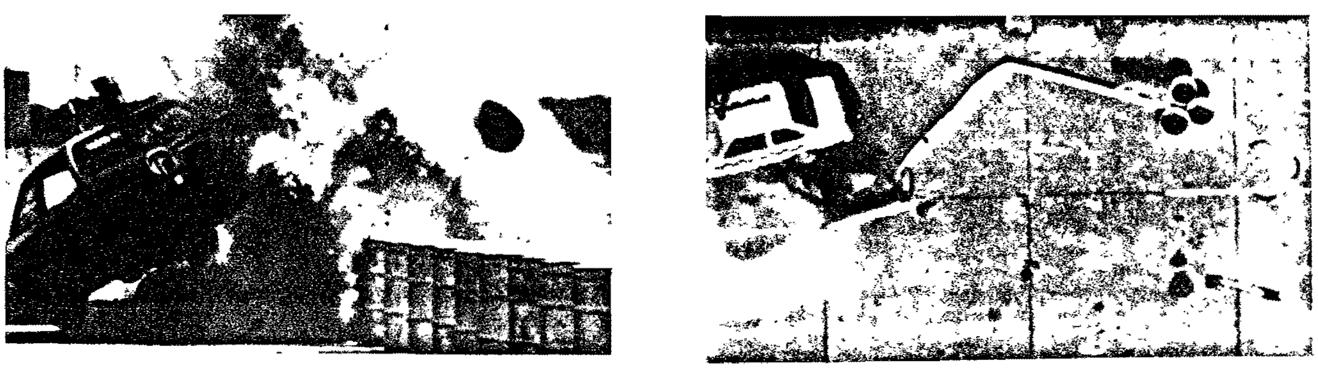

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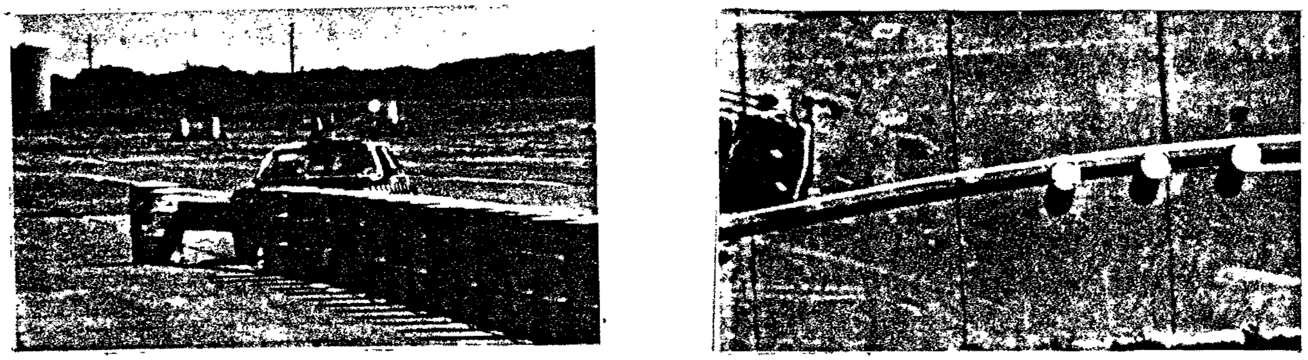
Figure 25. Sequential Photographs for Test 13. (cont.)



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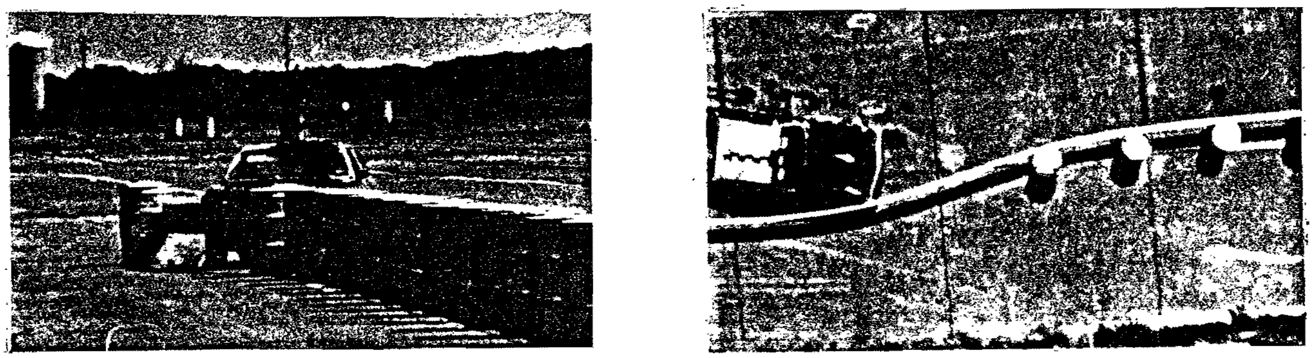

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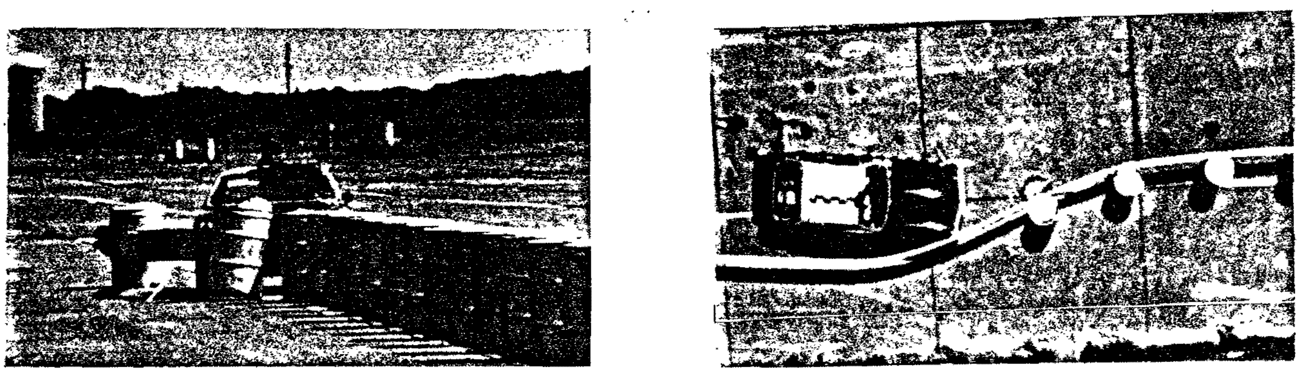

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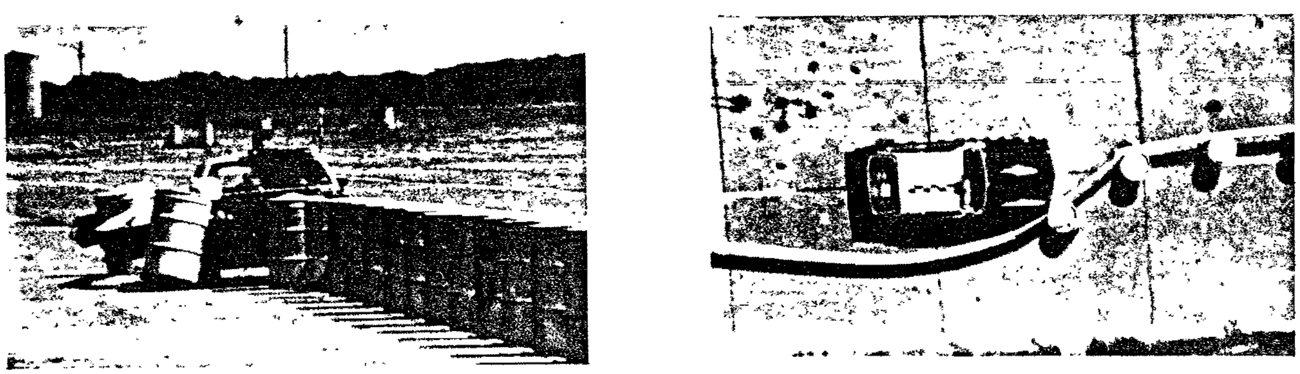

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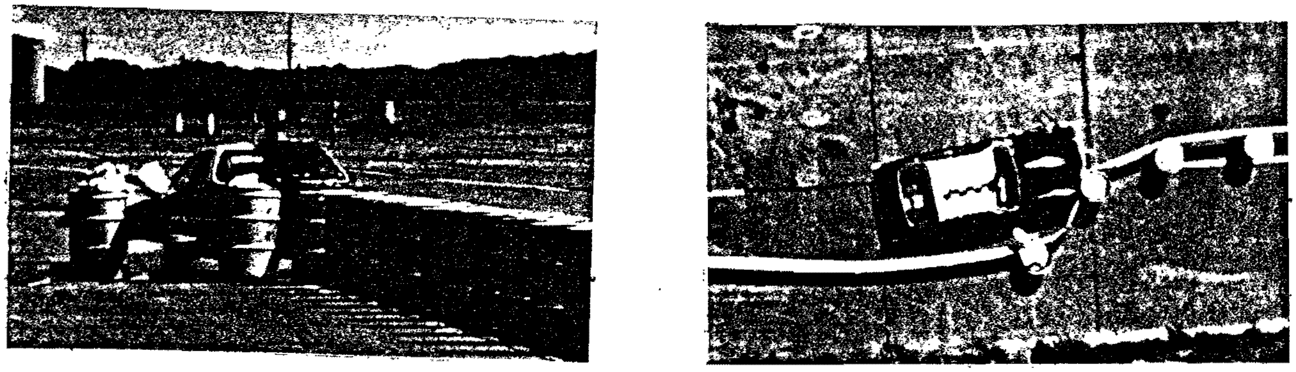
Figure 26. Sequential Photographs for Test 14



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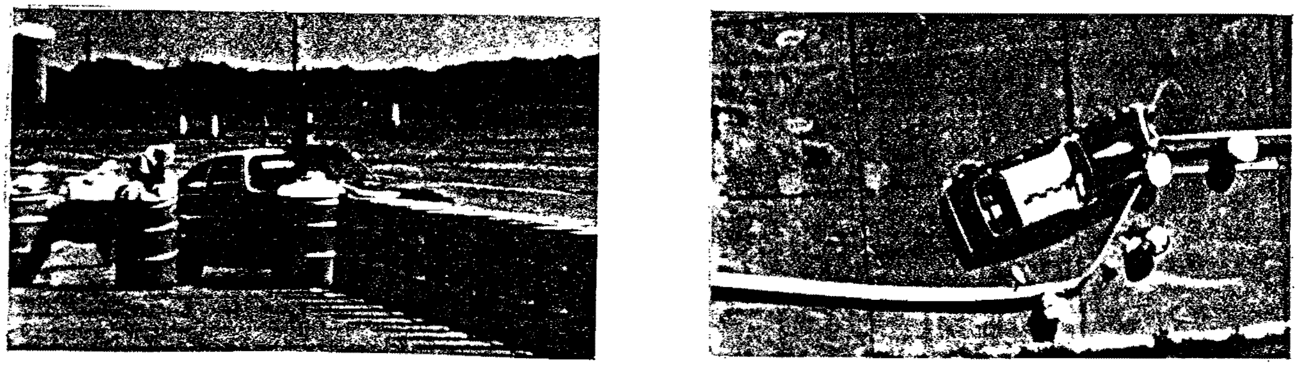

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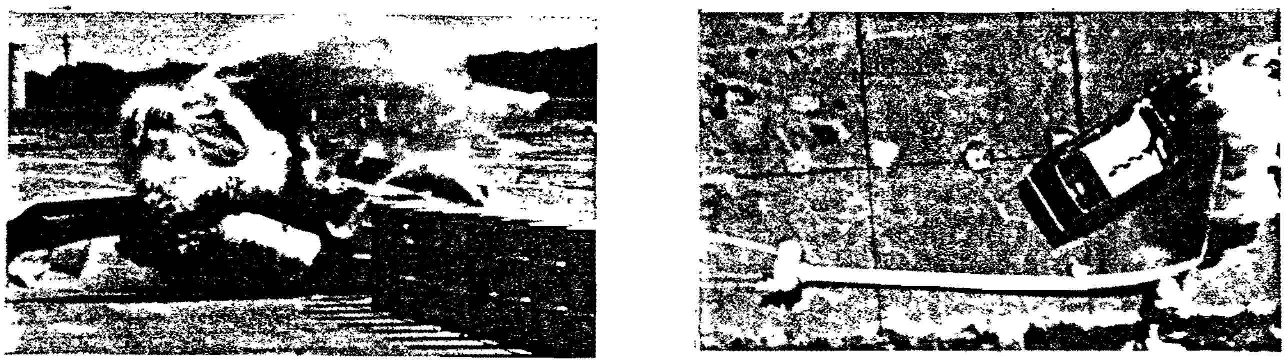

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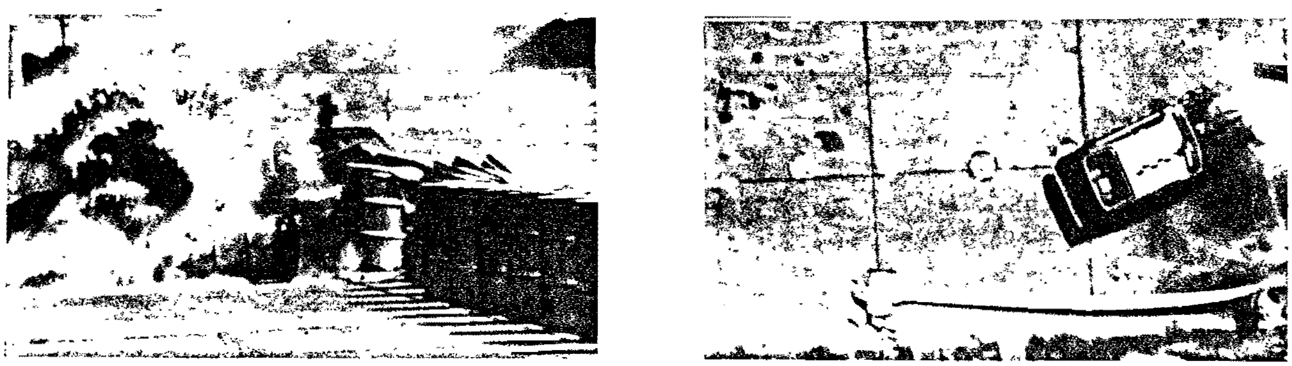

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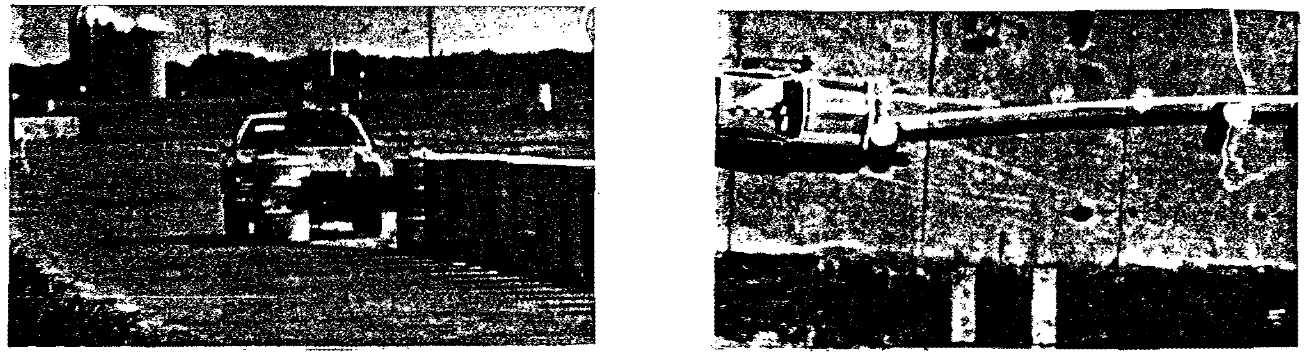
Figure 27. Sequential Photographs for Test 14 (cont.)



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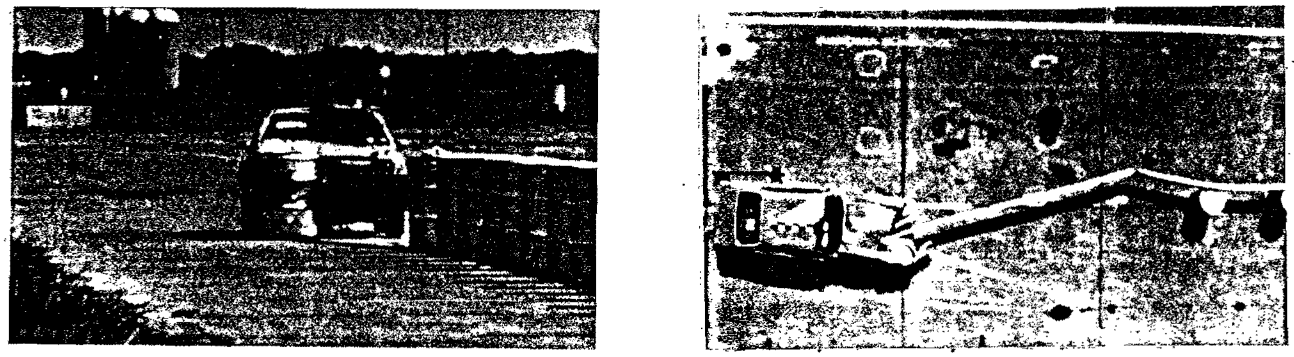

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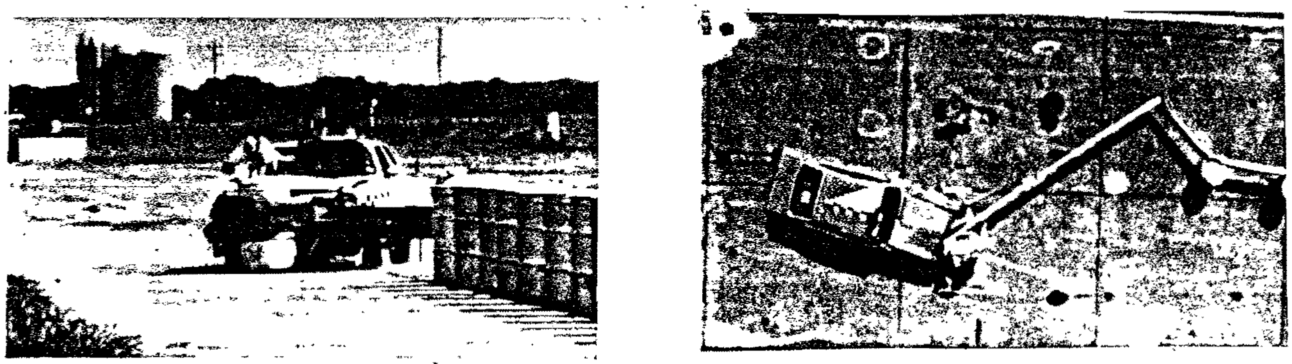

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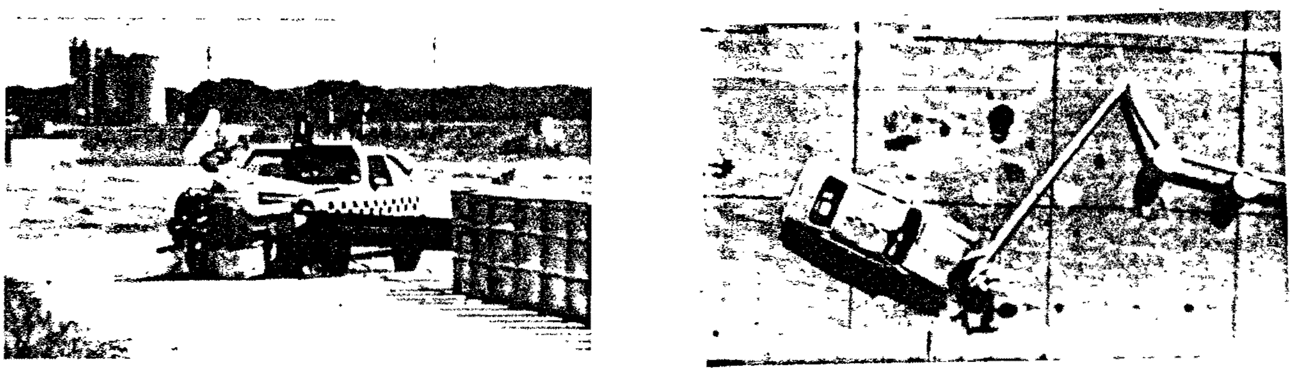

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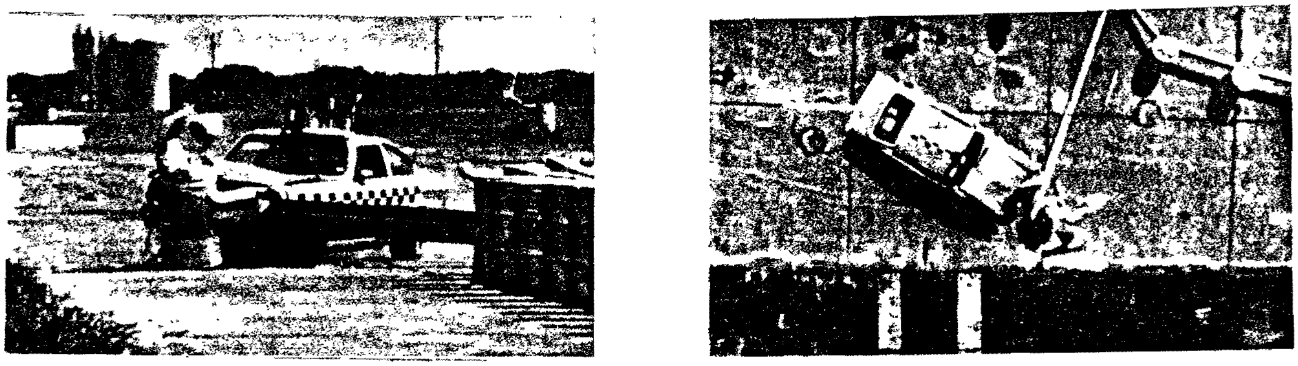
Figure 28. Sequential Photographs for Test 15



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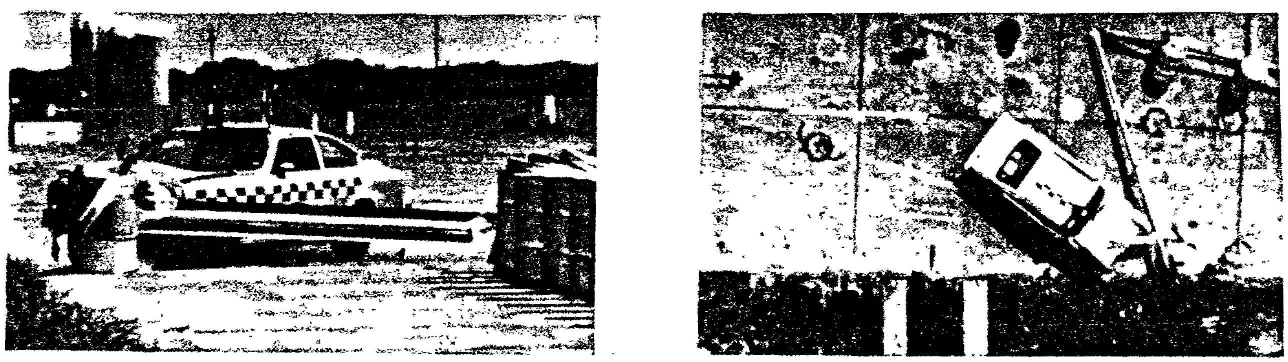

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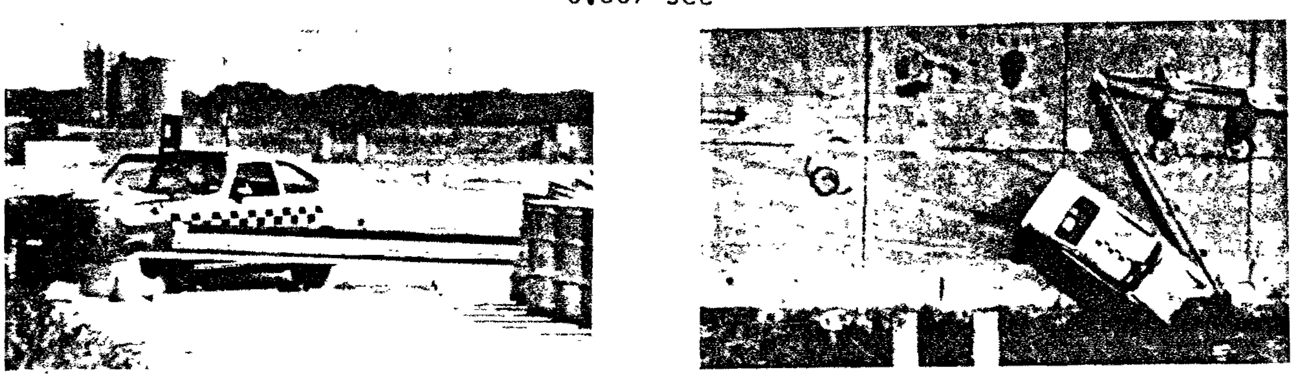

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Figure 29. Sequential Photographs for Test 15 (cont.)

APPENDIX B - ACCELEROMETER TRACES AND ROLL, PITCH, AND YAW RATES

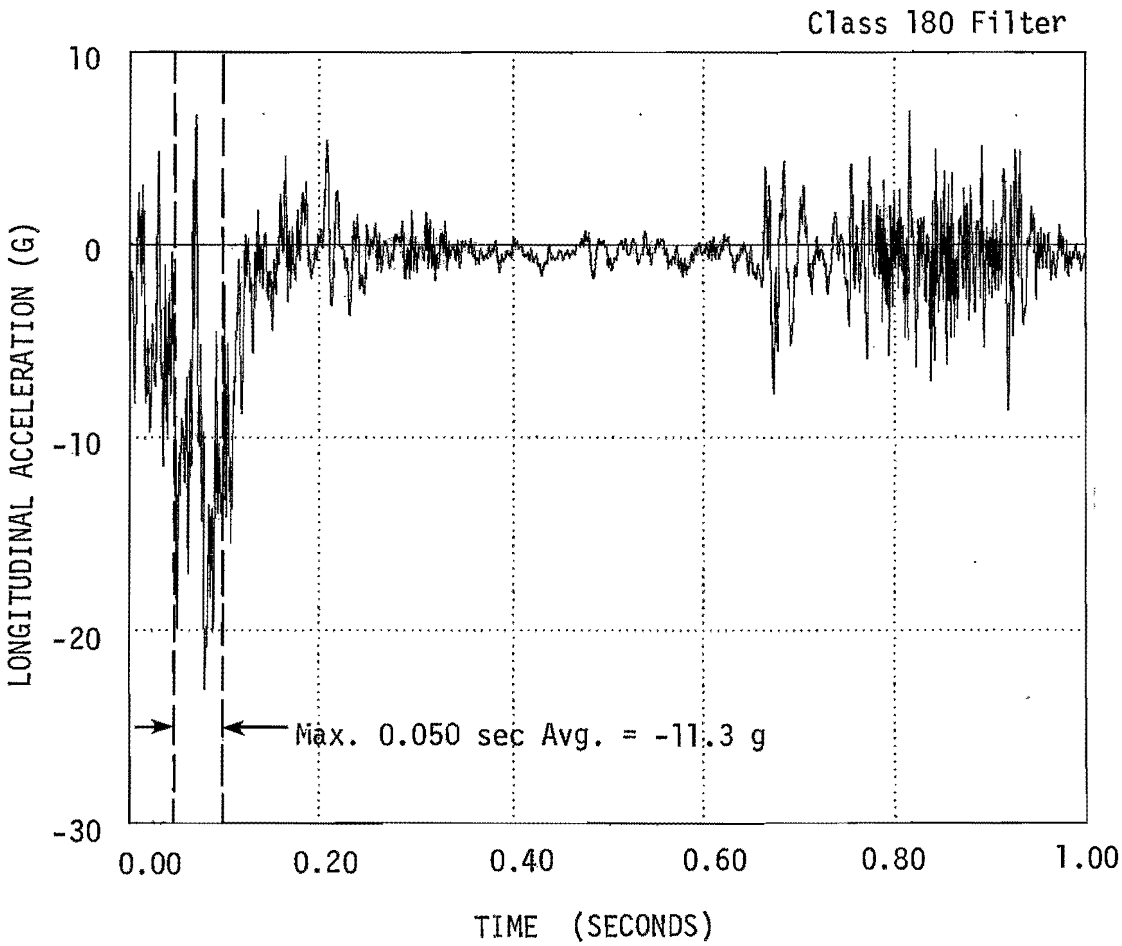


Figure 30. Vehicle Longitudinal Accelerometer Trace for Test 2262-12.

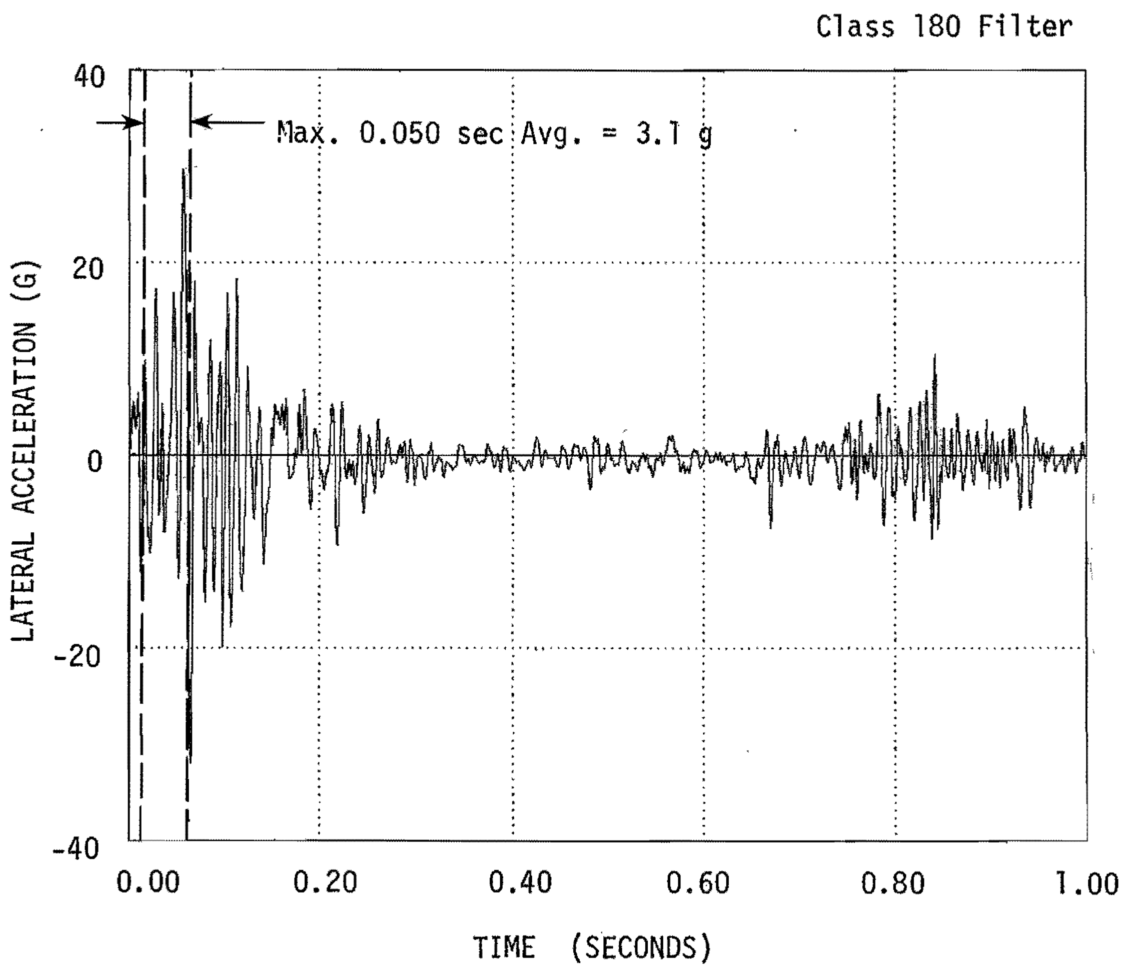


Figure 31. Vehicle Lateral Accelerometer Trace for Test 2262-12.

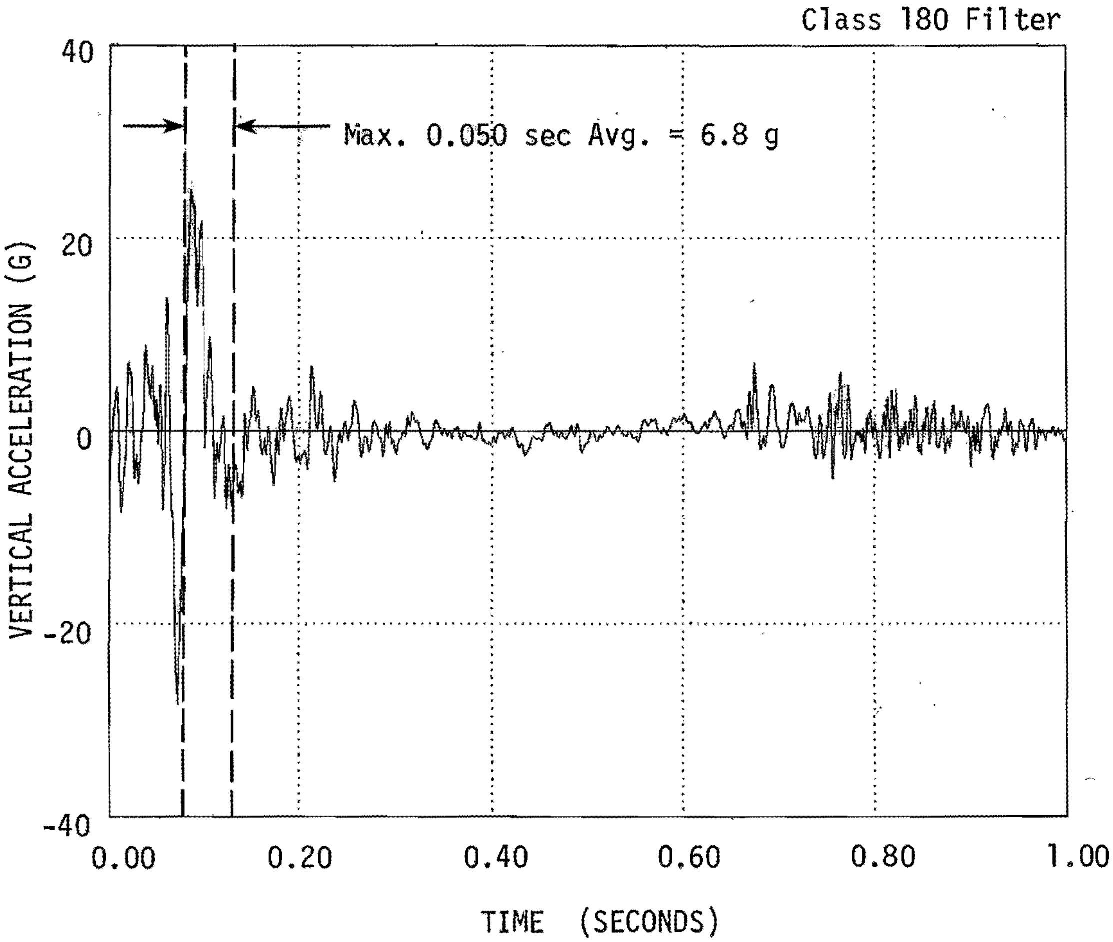


Figure 32. Vehicle Vertical Accelerometer Trace for Test 2262-12.

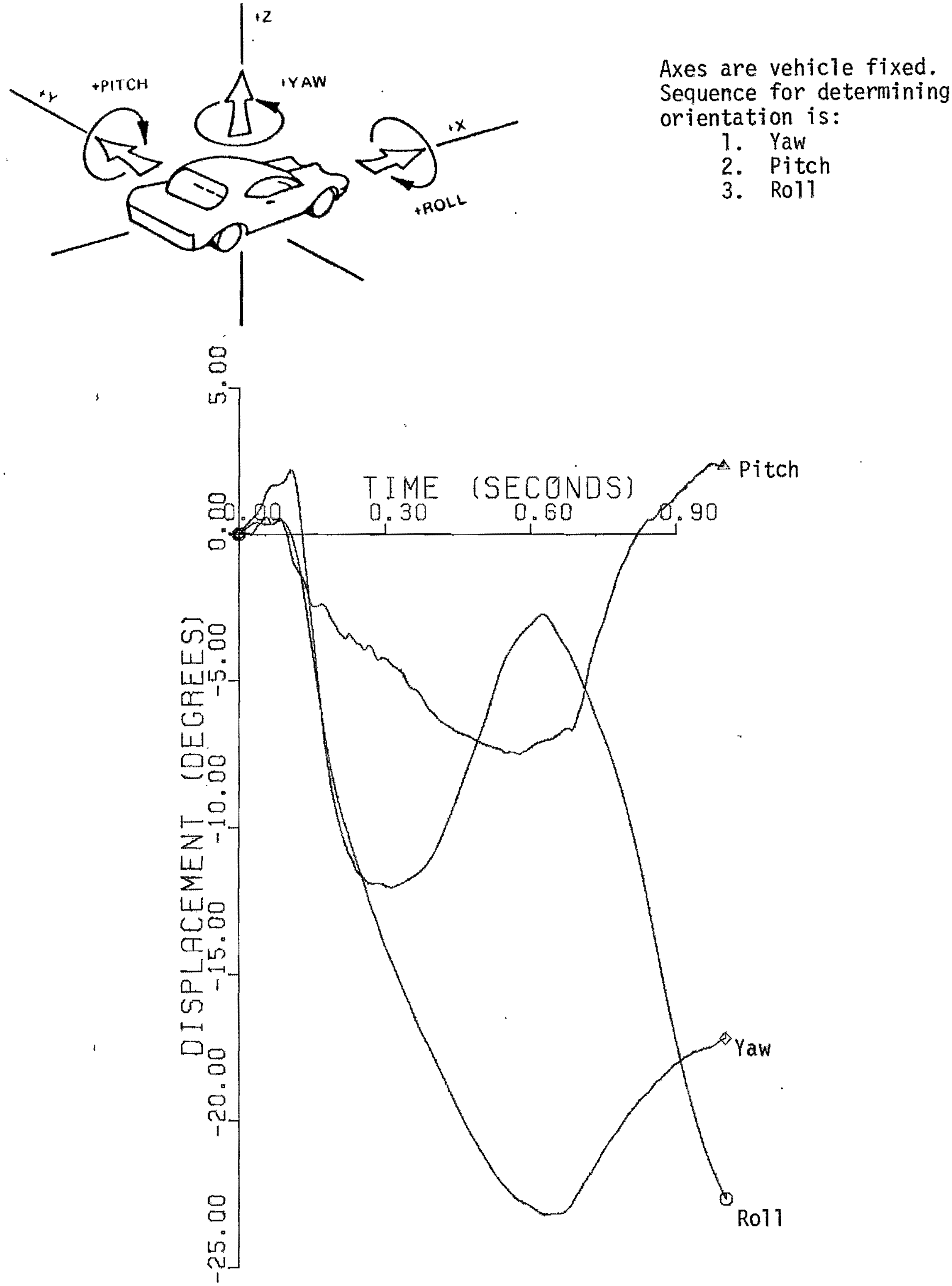


Figure 33. Vehicle Angular Displacements for Test 2262-12.

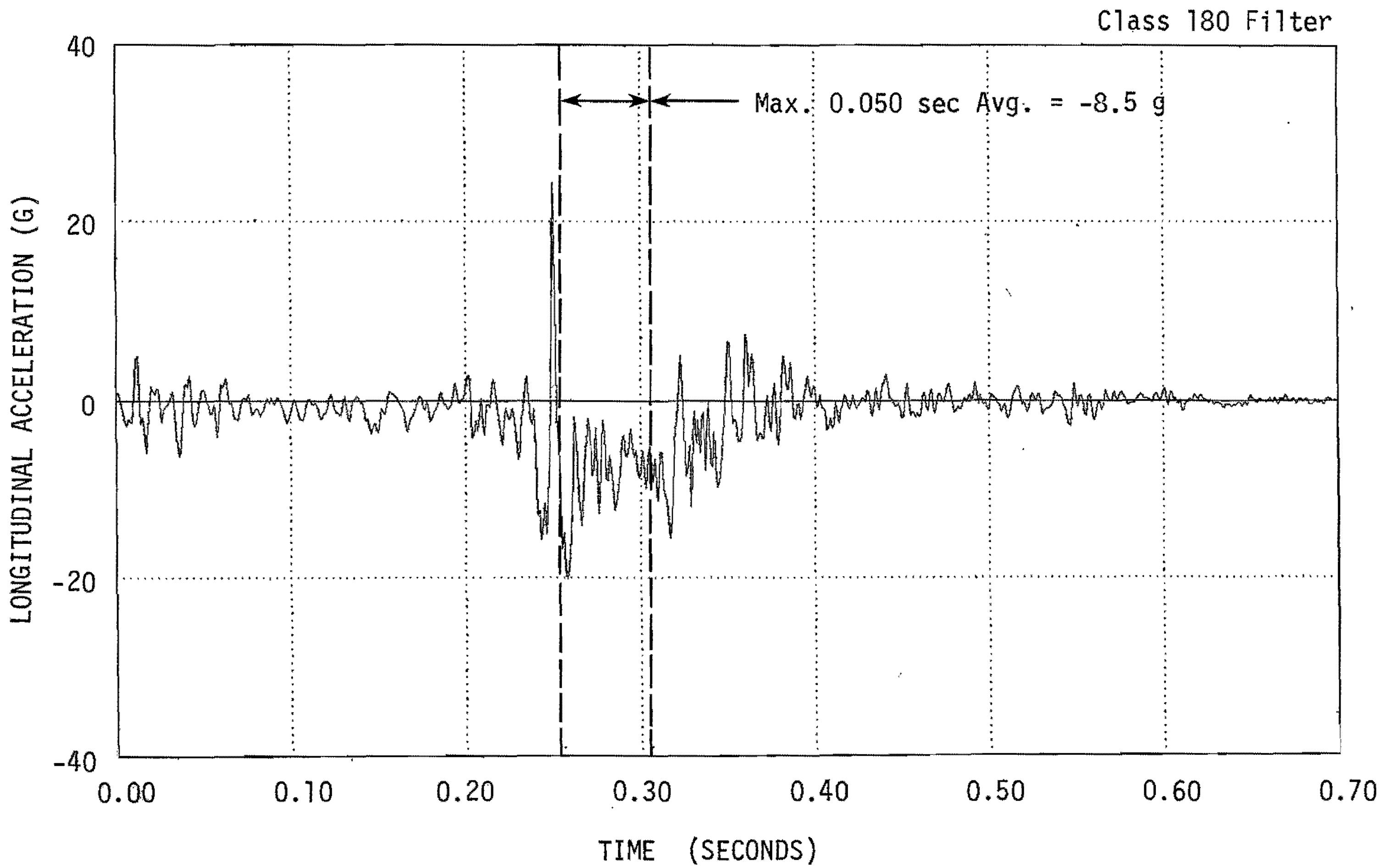


Figure 34. Vehicle Longitudinal Accelerometer Trace
for Test 2262-13.

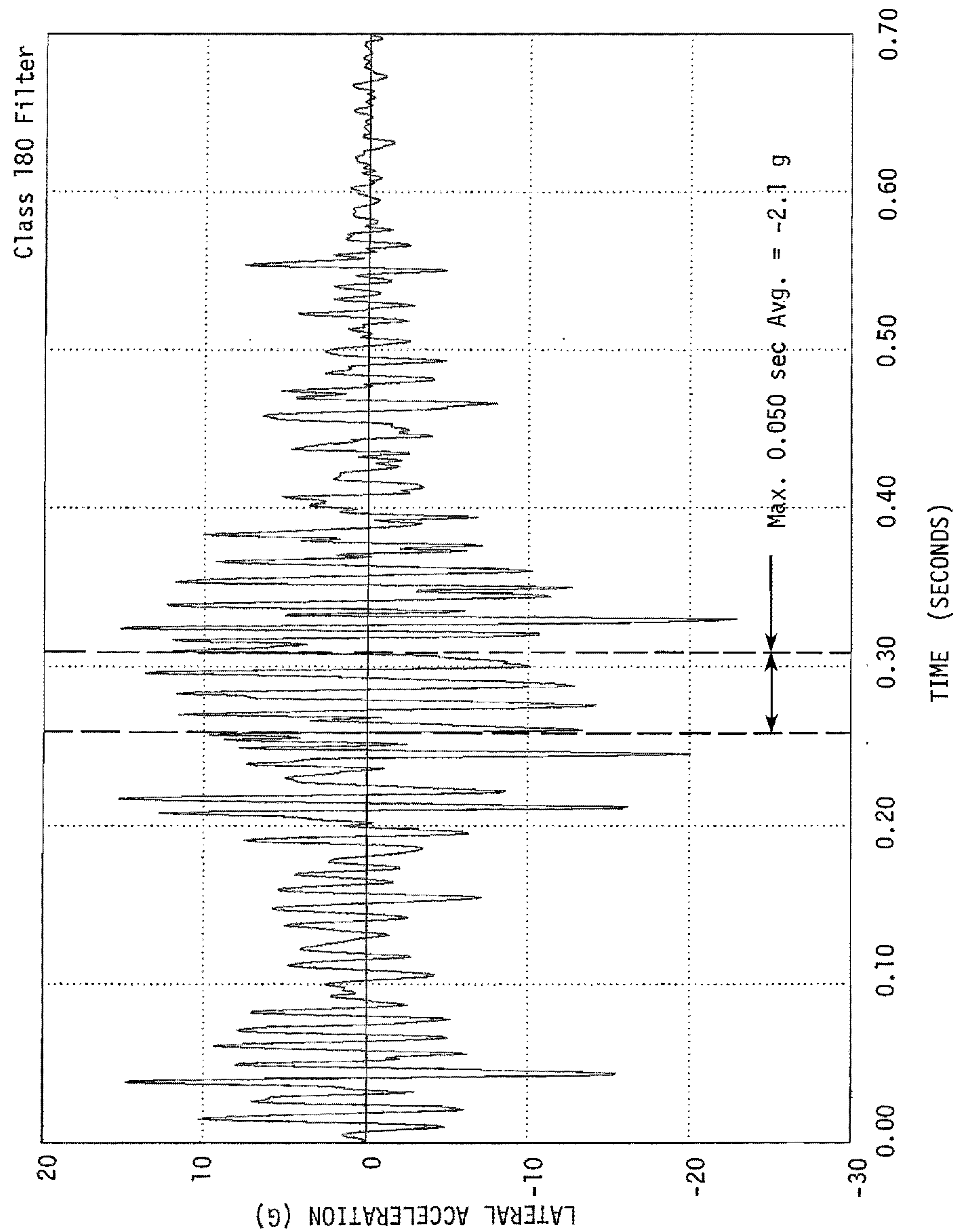


Figure 35. Vehicle Lateral Accelerometer Trace for Test 2262-13.

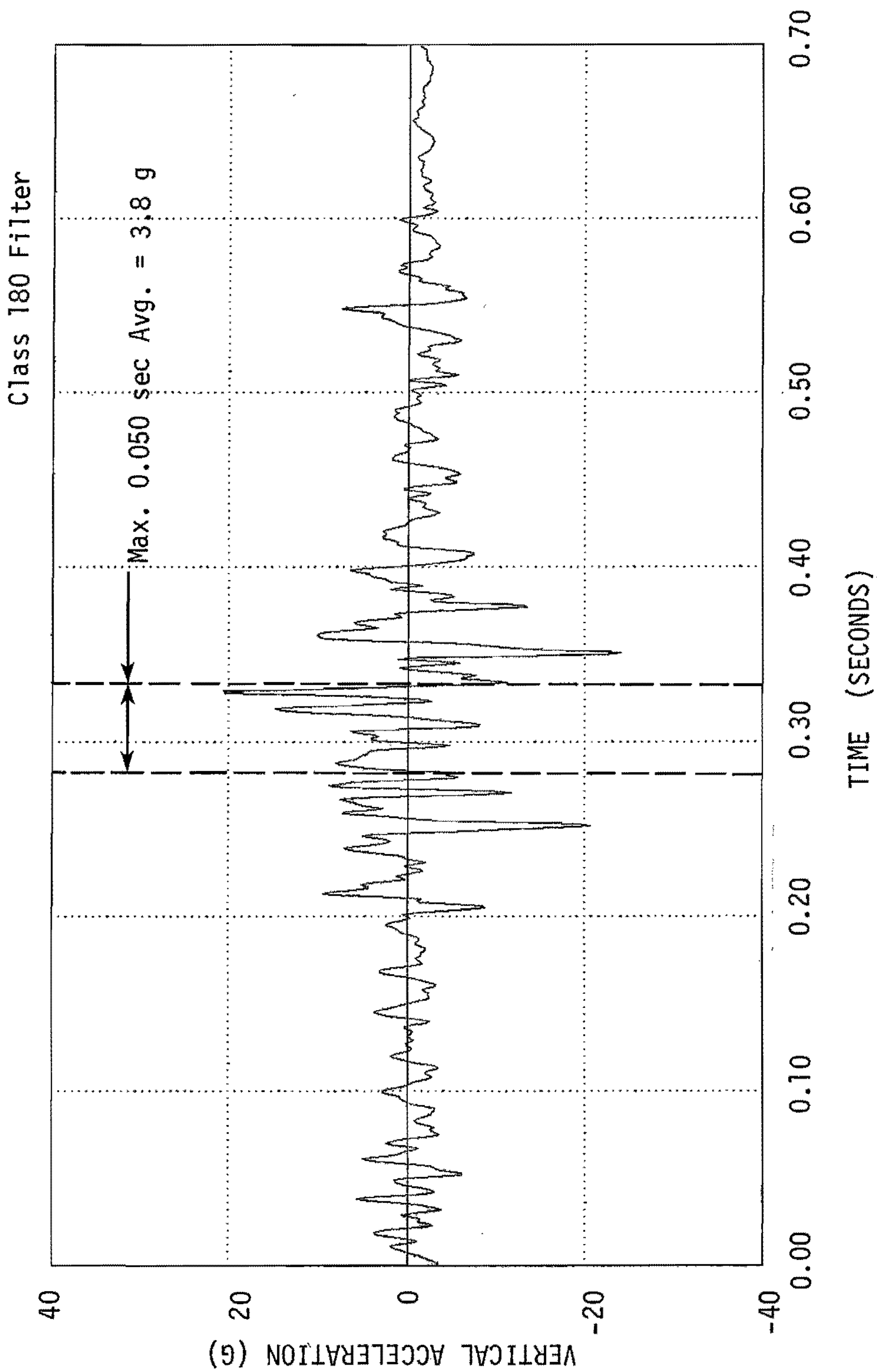
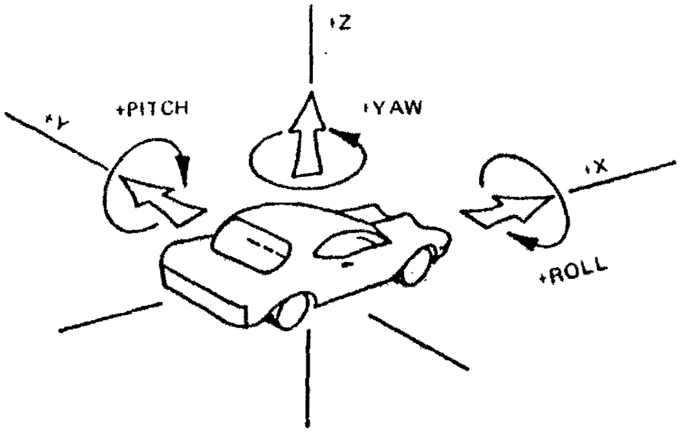


Figure 36. Vehicle Vertical Accelerometer Trace for Test 2262-13.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

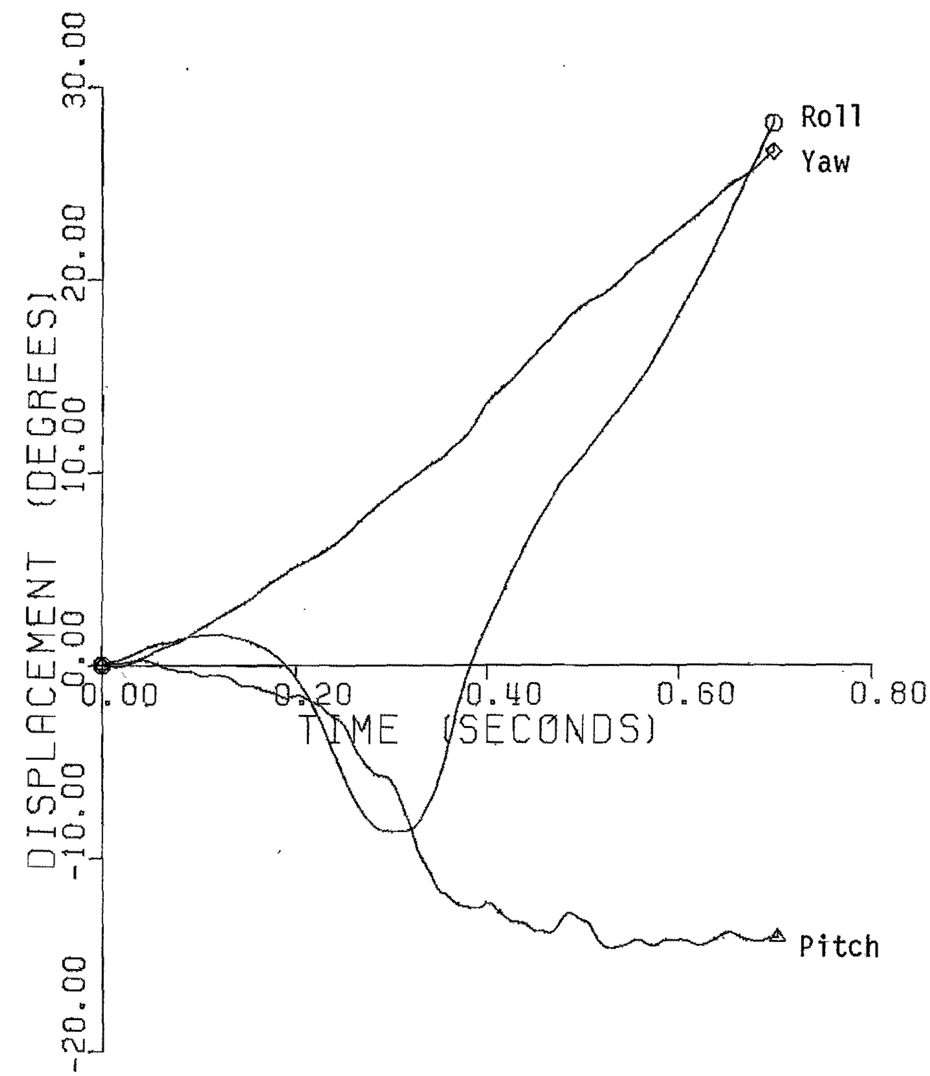


Figure 37. Vehicle Angular Displacements for Test 2262-13.

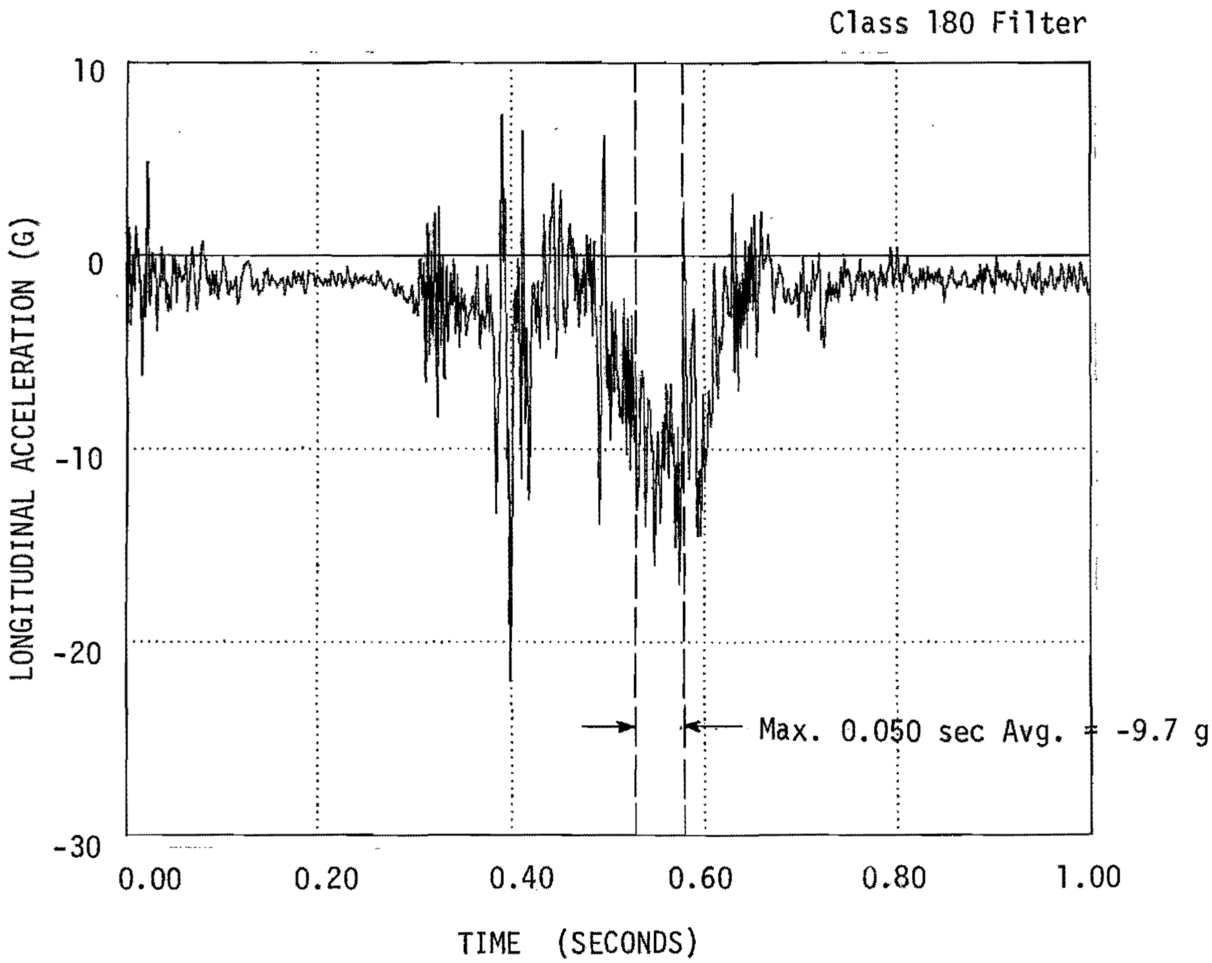


Figure 38. Vehicle Longitudinal Accelerometer Trace for Test 2262-14.

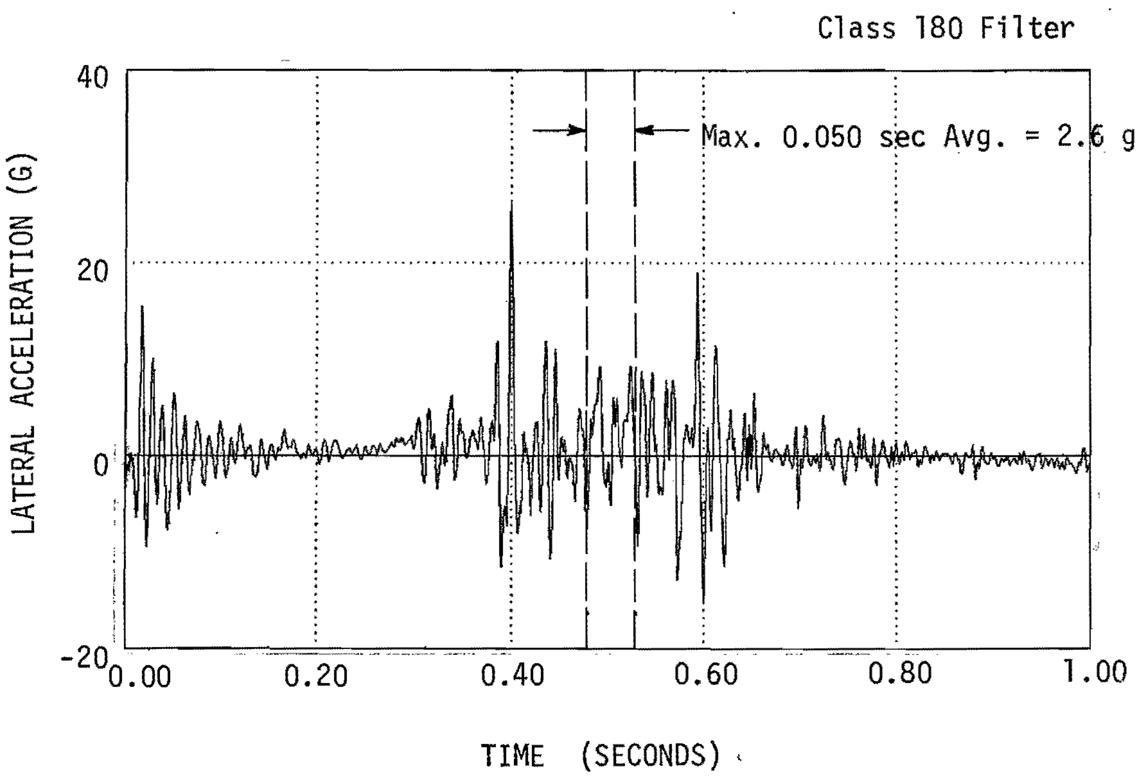


Figure 39. Vehicle Lateral Accelerometer Trace for Test 2262-14.

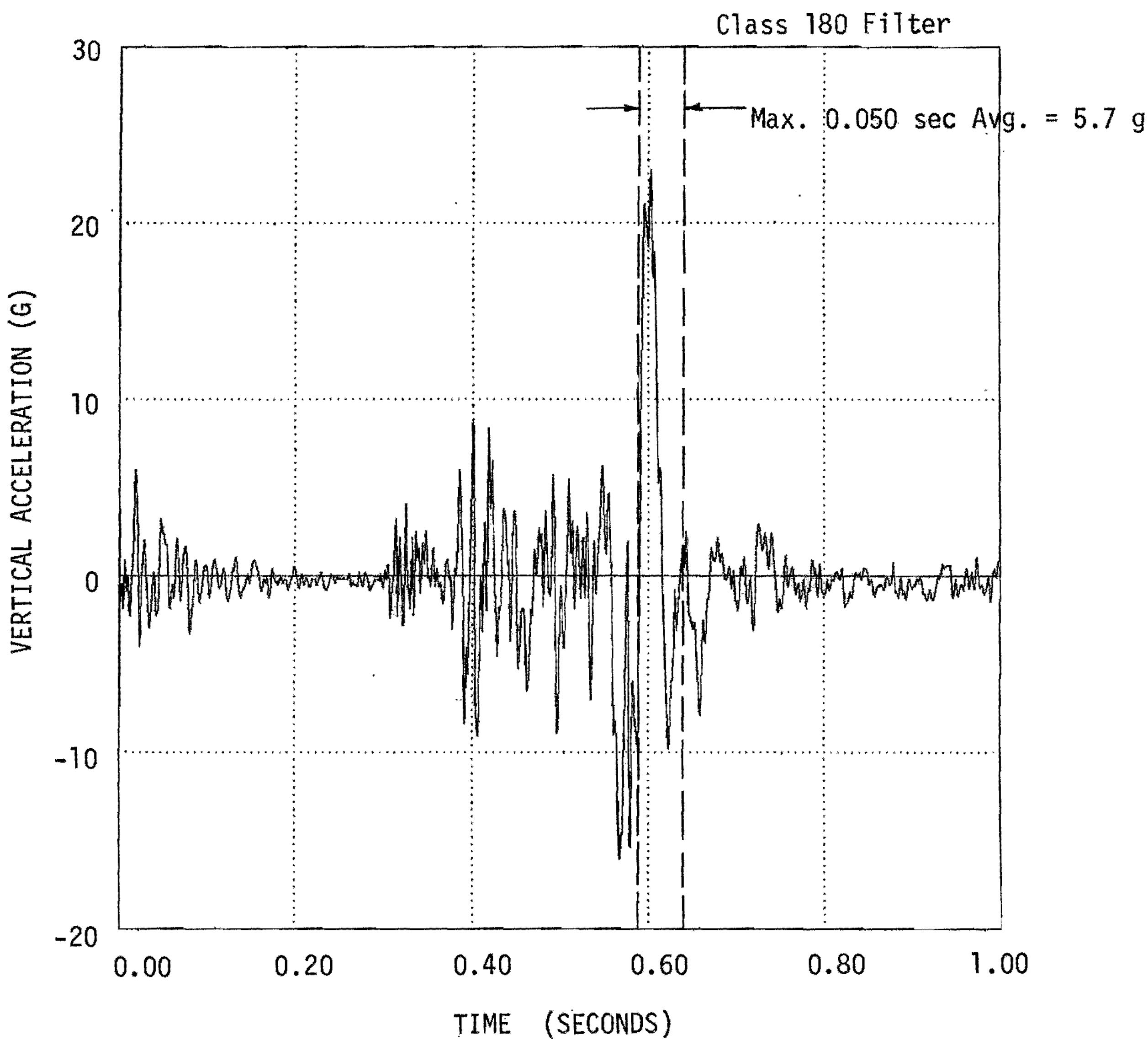
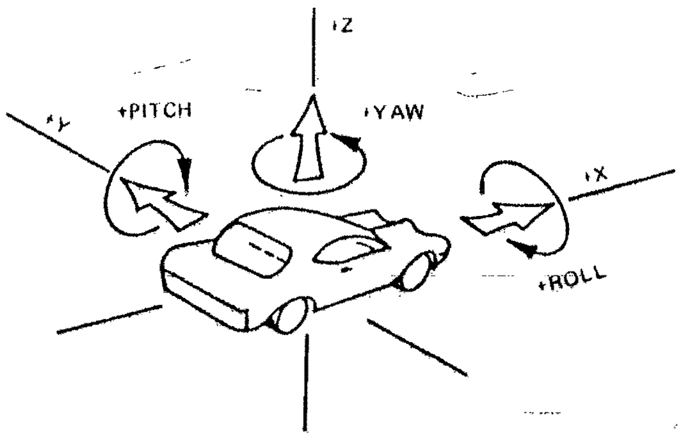


Figure 40. Vehicle Vertical Accelerometer Trace for Test 2262-14.



Axes are vehicle fixed.
Sequence for determining orientation is:
1. Yaw
2. Pitch
3. Roll

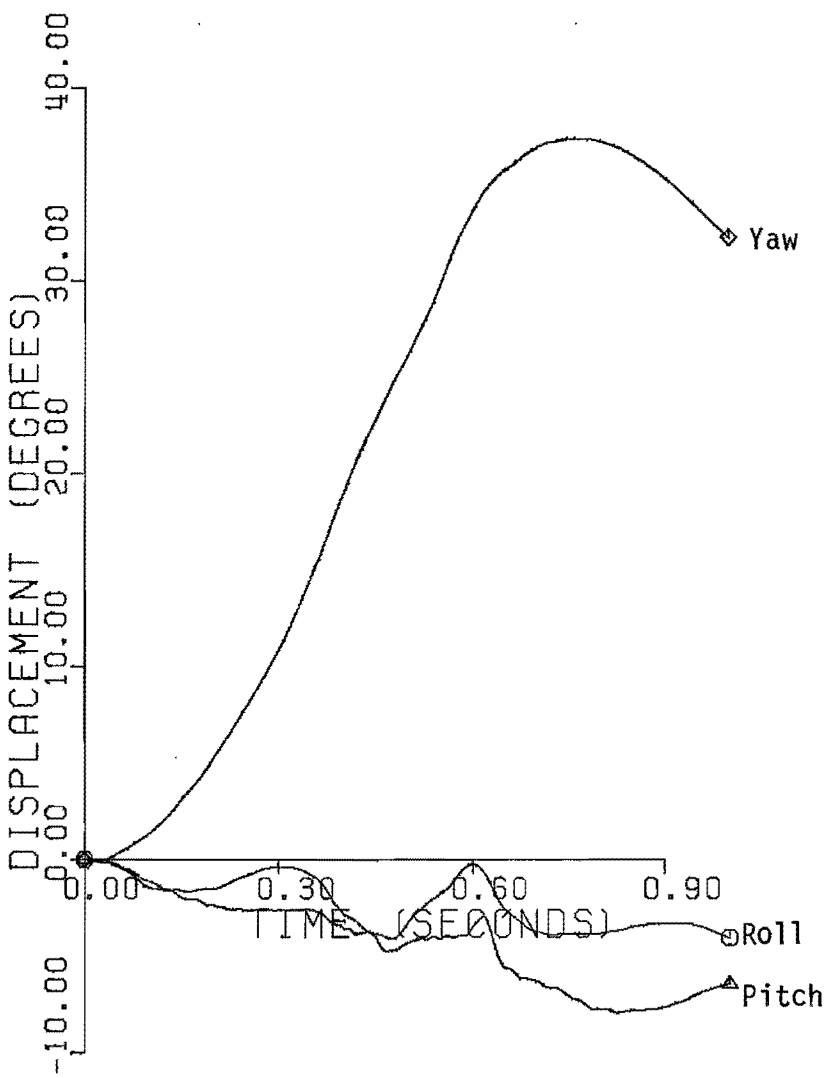


Figure 41. Vehicle Angular Displacements for Test 2262-14.

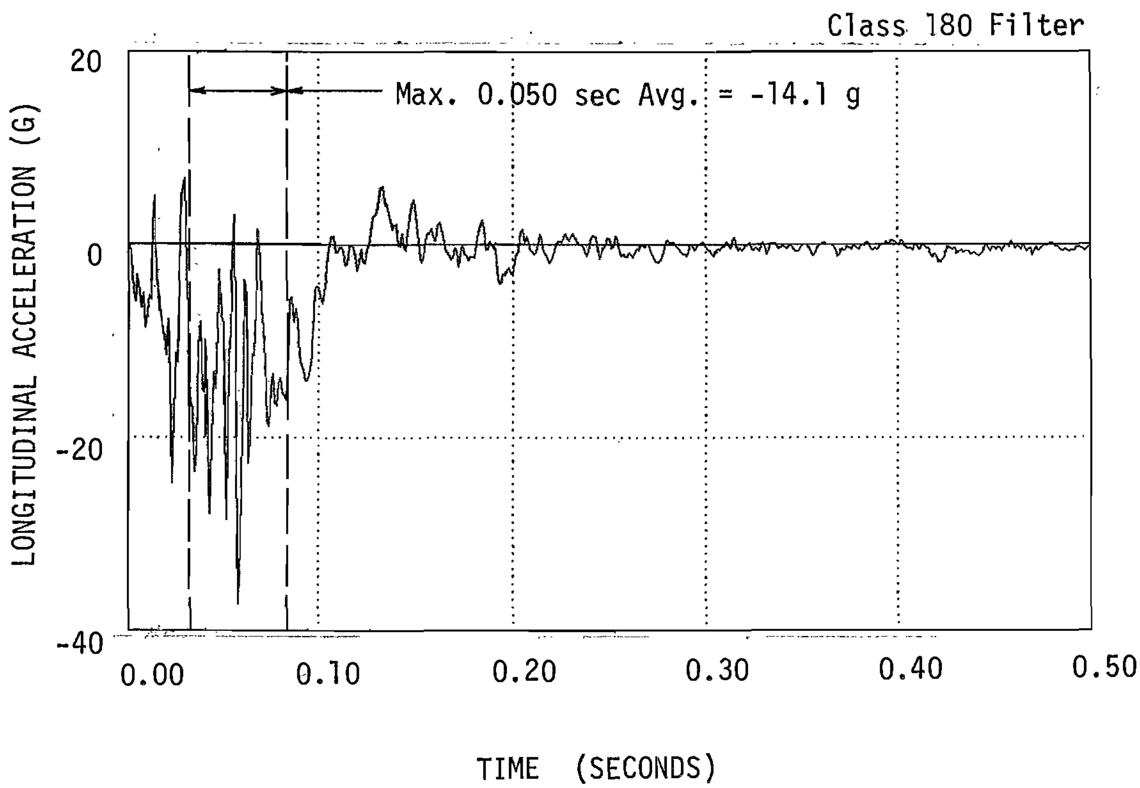


Figure 42. Vehicle Longitudinal Accelerometer Trace for Test 2262-15.

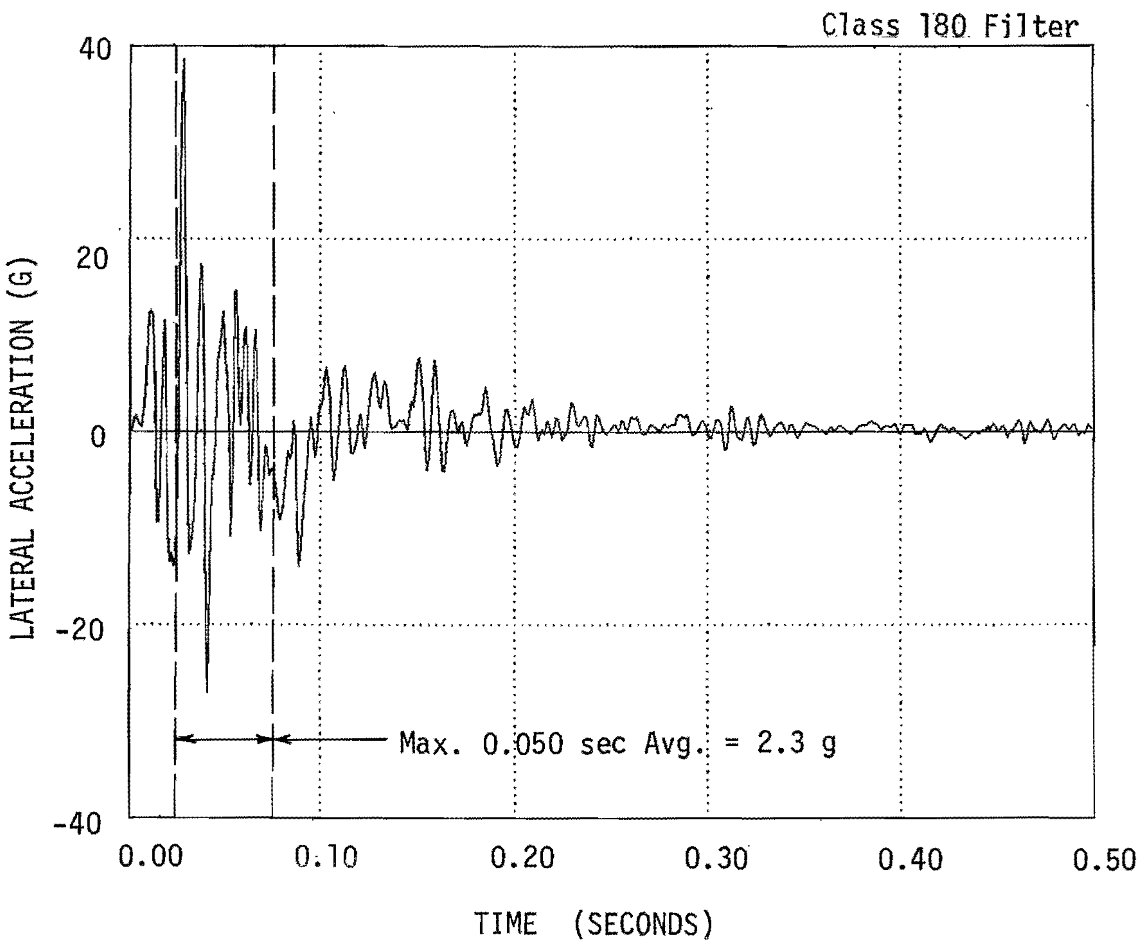


Figure 43. Vehicle Lateral Accelerometer Trace for Test 2262-15.

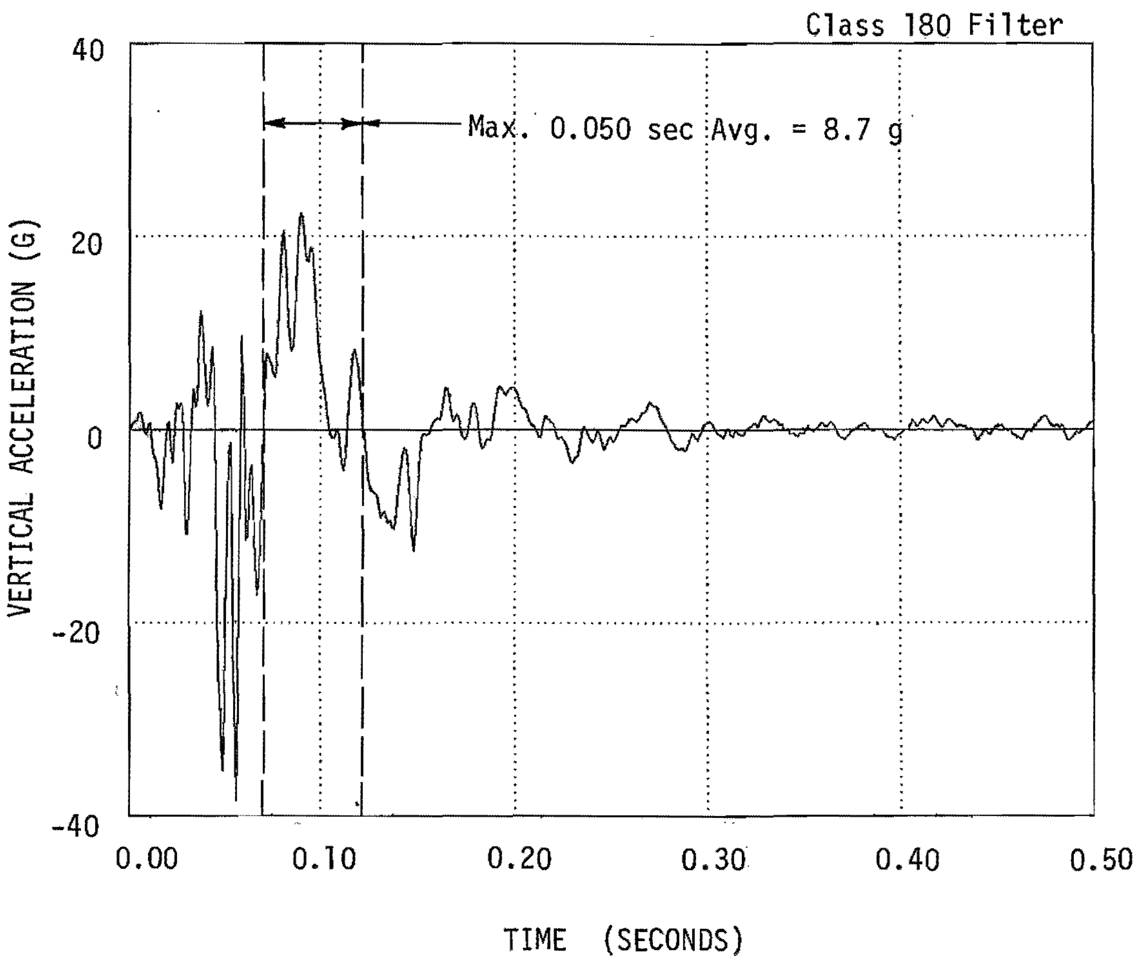
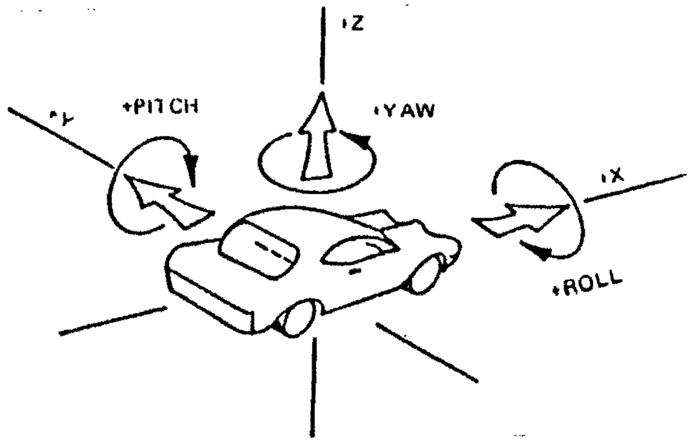


Figure 44. Vehicle Vertical Accelerometer Trace for Test 2262-15.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

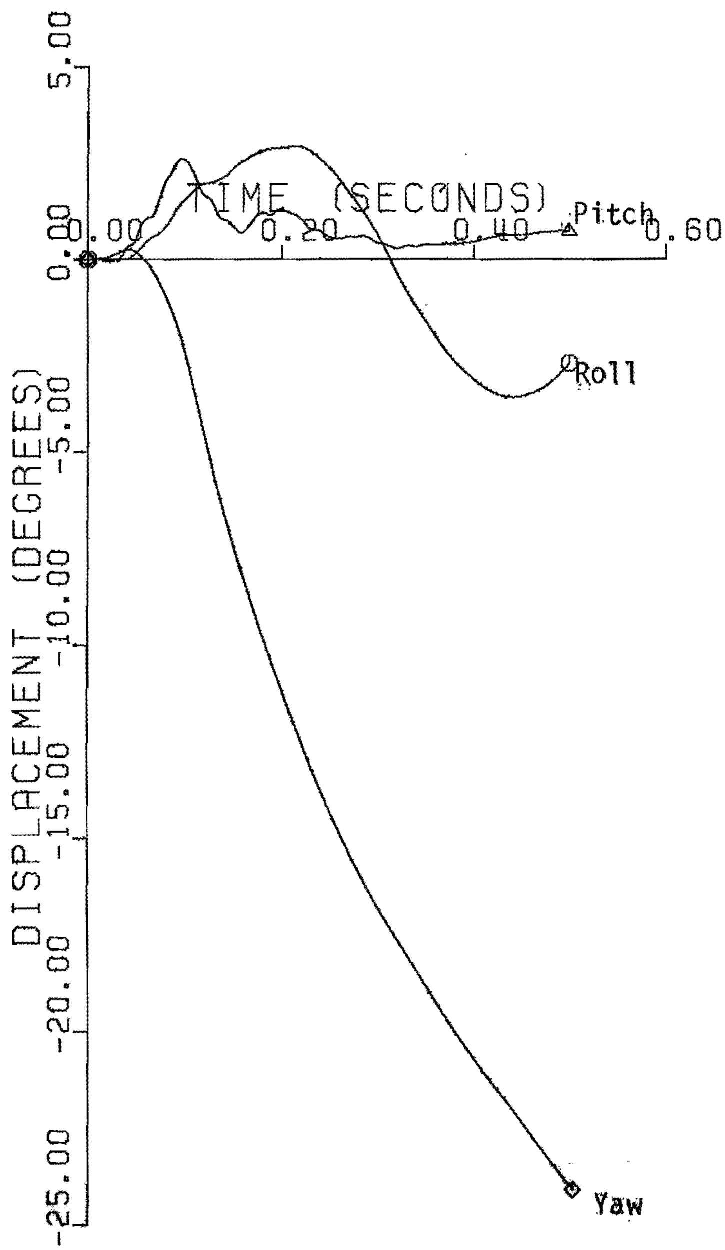


Figure 45. Vehicle Angular Displacements for Test 2262-15.

REFERENCES

1. Ross, H. E., Jr., and Sicking, D. L., "Guidelines for Use of Temporary Barriers in Work Zones," Research Report 4151-1, Texas Transportation Institute, Texas A&M University, July 1983.

2. Michie, Jarvis D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," National Cooperative Highway Research Program Report 230, March 1981.

3. Bronstad, M. E. and Kimball, C. E., "Temporary Barriers Used in Construction Zones," FHWA/RD-80/095, Southwest Research Institute, Dec. 1980.