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16. Abstract <p>Since Texas and many other states have literally thousands of turned down end guardrails installed on their highways, Texas Transportation Institute and Texas highway engineers have been seeking a relatively simple method of modifying the turned down end treatment which would eliminate or greatly minimize the probability of a vehicle ramping and rolling over. Recent tests conducted by the Texas Transportation Institute indicate that a relatively simple solution has been found.</p> <p>To modify the standard rail the 5/8 inch diameter bolts were removed from the first five (5) posts. With these bolts removed the rail will drop to the ground when the turned down terminal piece is struck by a vehicle. This action eliminates the undesirable vehicle ramp and roll over behavior. In order to hold the rail at the proper height (27 inches in Texas) before and during vehicle angle impact along the "length of need", "back-up plates" are bolted to the first five (5) posts.</p> <p>The test program includes the four (4) crash tests recommended by NCHRP 153 for longitudinal barrier terminals and two other additional tests. All tests have been successful and no vehicle roll over has resulted.</p>					
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IMPROVED END TREATMENT
FOR METAL BEAM GUARDRAIL

by

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Research Report 189-1(Final)

on

Research Study No. 2-10-76-189
Development of Effective Highway Safety Appurtenances

Sponsored by

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Texas A&M University
College Station, Texas

ABSTRACT

Since Texas and many other states have literally thousands of turned down end guardrails installed on their highways, Texas Transportation Institute and Texas highway engineers have been seeking a relatively simple method of modifying the turned down end treatment which would eliminate or greatly minimize the probability of a vehicle ramping and rolling over. Recent tests conducted by the Texas Transportation Institute indicate that a relatively simple solution has been found.

To modify the standard rail the 5/8 inch diameter bolts were removed from the first five (5) posts. With these bolts removed the rail will drop to the ground when the turned down terminal piece is struck by a vehicle. This action eliminates the undesirable vehicle ramp and roll over behavior. In order to hold the rail at the proper height (27 inches in Texas) before and during vehicle angle impact along the "length-of-need", back-up plates are bolted to the first five (5) posts.

The action of this modified rail terminal is quite simple. When a vehicle tire or bumper pushes down on the turned down terminal the rail will quickly drop from the first 5 posts allowing the vehicle to pass over the rail without the violent ramping effect of a rigid turn down. If the vehicle bumper engages the rail at the length of need and pushes it laterally against the back-up plates on the posts, the rail is held at the proper height and the vehicle is redirected. The back-up plate resists the downward tension force component of the turned down terminal.

The test program included the four (4) crash tests recommended by NCHRP 153 for longitudinal barrier terminals plus some additional tests. All tests have been successful and no vehicle roll over has resulted.

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

Guardrails, Traffic Barriers, Terminals, Crash Tests, Highway Safety

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This research study was conducted under a cooperative program between the Texas Transportation Institute (TTI), the State Department of Highways and Public Transportation (SDHPT) and the Federal Highway Administration (FHWA). Mr. John F. Nixon (Engineer of Research SDHPT), Mr. Harold Cooner (Senior Design Engineer SDHPT) and Mr. David Hustace (Senior Research Engineer SDHPT) were closely involved in all phases of this study. The crash tests were carried out by personnel of the Highway Safety Research Center of TTI.

IMPLEMENTATION STATEMENT

The modified turned down guardrail terminal with back-up plates, nonstructural clips, and mounted on round timber posts at 6 ft. 3 in. centers has been approved for use on Federal Aid Projects in the Texas Division, Federal Highway Administration.

The American Association of State Highway and Transportation Officials (AASHTO) has included this turned down guardrail terminal in its "Guide for Selecting, Locating, and Designing Traffic Barriers" as an EXPERIMENTAL SYSTEM. An EXPERIMENTAL SYSTEM is one that has performed satisfactorily in full-scale crash tests and promises satisfactory in-service performance.

The Texas Department of Highways and Public Transportation is in the process of installing this modified turned down terminal in several districts.

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INTRODUCTION

The flex-beam or steel W-beam guardrail has been used extensively on our highways. In the late 1950's and early 1960's highway engineers began to recognize the dangers of guardrail ends. Spectacular accidents where the guardrail end pierced and ran through vehicles served to intensify the search for safer guardrail end treatments. The Texas Highway Department was one of the first to turn down and anchor the ends of the guardrail in 1961. This treatment eliminated the spectacular vehicle piercing and impalement accident, quickly anchored and developed the guardrail tensile strength necessary for effective vehicle redirection, and was relatively simple to accomplish. Many other states adopted this "Turned Down End" guardrail treatment because of these apparent merits. Through the years the turned down terminal attachment has generally displayed excellent in-service performance for the angle as well as end-on impacts.

However, in the late 1960's the California Division of Highways and the Southwest Research Institute conducted several crash tests (4, 6)* on the turned down end guardrail treatment and found that this treatment could launch an impacting vehicle and cause it to roll over. As a result of these crash tests, highway engineers began to search for other safer end treatments. Several alternative end treatments have been developed (9) but even these have had certain deficiencies.

Since Texas has literally thousands of guardrails with turned down ends installed on its highways, Texas Transportation Institute engineers and Texas highway engineers have been seeking a relatively simple method of

*Numbers in parenthesis thus (4, 6) refer to corresponding item in References.

modifying the turned down end treatment which would eliminate or greatly minimize the probability of a vehicle ramping and rolling over. Recent tests conducted by the Texas Transportation Institute indicate that relatively simple solutions have been found.

MODIFIED TEXAS TURNED DOWN END TREATMENT

The Texas standard metal beam guard fence with turned down end treatment is described in Figure 1. As evidenced by the drawing, this guardrail may be installed on either timber or steel posts, and blockouts for the rail are optional. In some earlier installations, an intermediate post at mid-span of the 25 ft. turned down section was employed. The two 12 ft. 6 in. post spacings at the beginning of the length-of-need are prevalent in many existing installations.

The design chosen for modification testing and evaluation in this study was the nonblocked out rail mounted on 7 in. diameter timber posts. This design is by far the most prevalent in existing installations and thereby offered the greatest potential of cost-effective improvements in highway safety. The rail-to-post bolted connection used in this design is shown in Figure 2.

Modifications to this design were developed to preclude launching and rollover of the vehicle as a result of impacts with the turned down section. A number of modifications were proposed and analyzed. The modified design concept chosen for full-scale testing and evaluation was essentially as shown in Figures 3 and 4. The rail-to-post connection for the first five posts was modified as shown in Figure 4. A standard W-section backup plate one foot long is bolted to the post using the standard 5/8 in. diameter bolt, but the main continuous rail element is not connected with this bolt. The rail element simply nests in the backup plate and is lightly held in place with a clip made of 1/8 in. by 3/4 in. mild steel strap 8 in. long. This

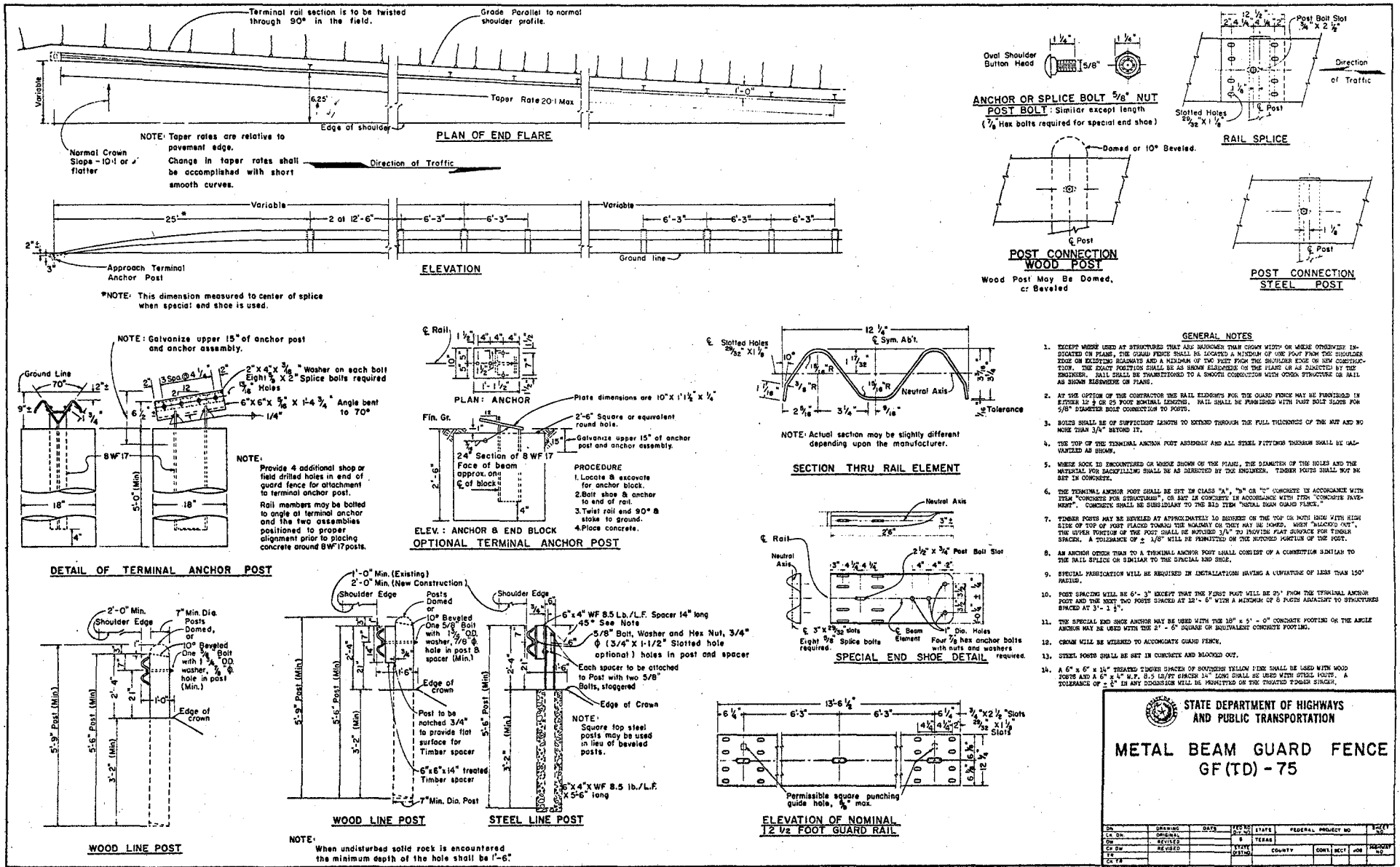


FIGURE 1. SDHPT STANDARD DRAWINGS FOR METAL BEAM GUARD FENCE.

connection is sufficiently weak to allow the rail to be depressed downward under a small vertical load.

With these bolts removed the rail will drop to the ground when the turned down terminal piece is struck by a vehicle. This action eliminates the undesirable vehicle ramp and rollover behavior. The backup plates hold the rail at the proper height (27 in. in Texas) before and during vehicle angle impact along the "length-of-need". The backup plate is 12 in. long for posts 1 through 4 and 6 in. long at post 5 where the first standard lap splice occurs. At post 1 the standard lap splice is modified by reversing the splice bolts and placing the nuts on the outside of the rail.

The action of this modified rail terminal is quite simple. When a vehicle tire or bumper pushes down on the turned down terminal the rail will quickly drop from the first 5 posts allowing the vehicle to pass over the rail without the violent ramping effect produced by a rigid turn-down terminal. If the vehicle bumper engages the rail at the length-of-need (or any other high point) and pushes it laterally against the backup plates on the posts, the rail is held at the proper height and the vehicle is redirected. The backup plate resists the downward tension force component of the turned down terminal.

CRASH TEST RESULTS

A total of seven full-scale vehicle crash tests were conducted on the modified design of the Texas turned down guardrail and variations thereof between July 30 and August 24, 1976. The test conditions and results obtained are summarized in Table 1 and discussed in detail in the following pages. Accelerometer traces obtained from vehicle mounted accelerometers are presented in Appendix B. Photographs from selected frames from high-speed data film are presented in Appendix A.

Test 1

The guardrail installation evaluated in this test was a variation of the final proposed modified design described in the previous section. In this installation, posts number 2 and 4 (Figure 3) were omitted. Backup plates, 6 in. long in this installation, were used on posts number 1, 3, 5, 6 and 7. The remainder of the rail was installed in accordance with the standard drawings in Figure 1. This installation is shown in Figure 5.

In this test, a 2280 lb Vega (1971) impacted the turned down terminal section of the guardrail at 17.5 degrees and 63.2 mph (101.7 km/hr). The impact point was midway between the end anchor and beginning of length-of-need. Upon impact, the right front wheel of the test vehicle mounted the turned down section. As the vehicle continued forward, the W-section disengaged the backup plates and was pushed down. The vehicle rode over the rail, impacted the first post breaking it near ground level and continued upright on its path for several hundred feet behind the rail.

metal plate

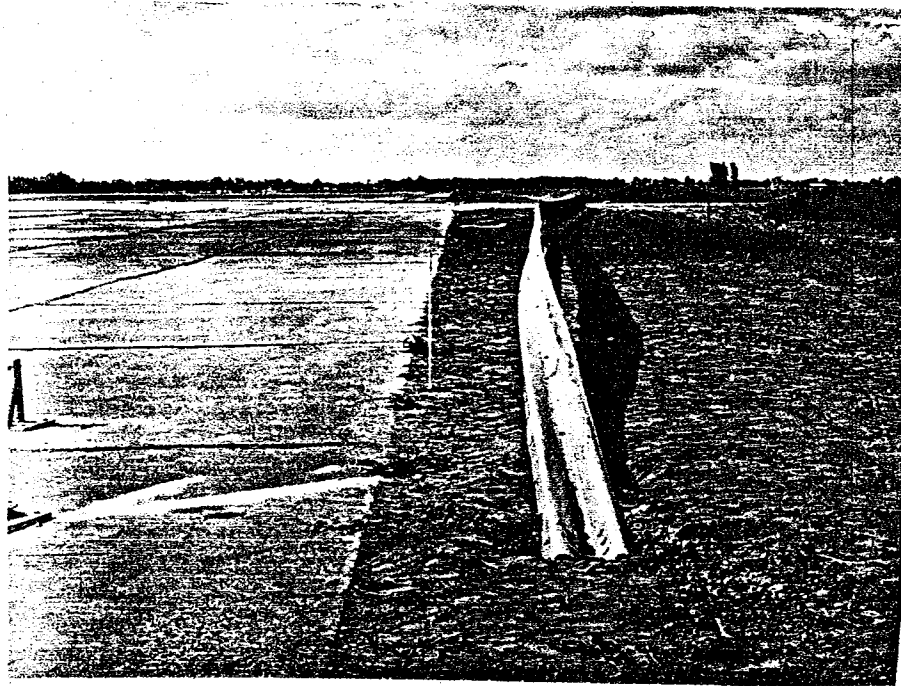
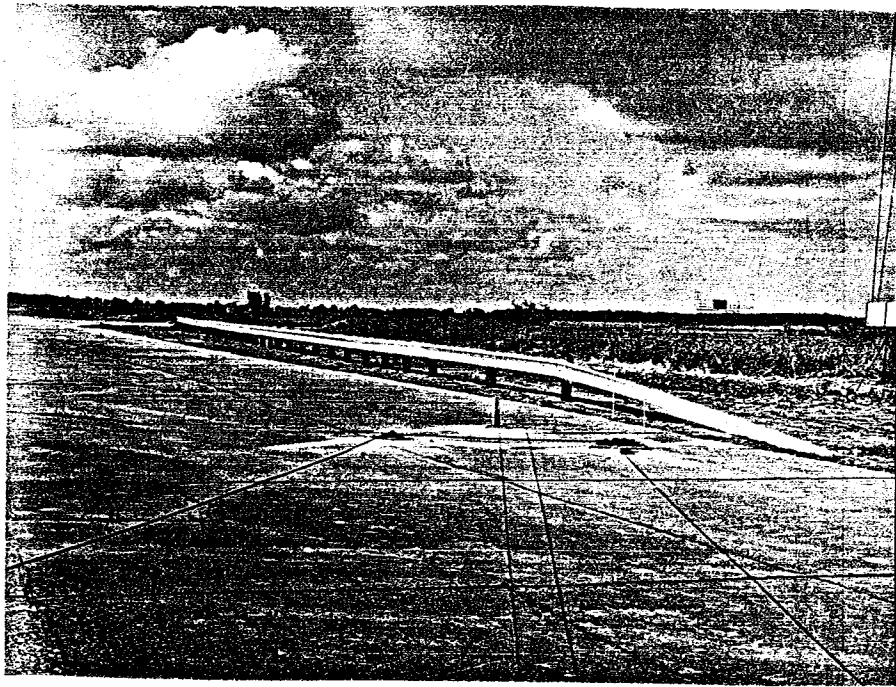


FIGURE 5. GUARDRAIL TEST SITE PRIOR TO TEST 1.

Right front bumper and wheel will engage terminal
midway between first post and terminal anchor.

After crossing the rail, the vehicle was airborne for a short distance then exhibited oscillatory roll displacement (see Appendix A). The maximum roll displacement was about 29 degrees. The vehicle did not roll over, and performance of the terminal and vehicle were considered good. The critical roll angle of such a Vega is about 53.4 degrees before rollover is possible. Results of this test are summarized in Table 1. Accelerometer traces obtained from vehicle mounted accelerometers and sequential photographs are presented in the Appendices. The TAD (1) vehicle damage classification was FC-2 (Figure 6). Photographs of the rail after the test are shown in Figures 7 and 8. One post and two 25 ft. pieces of W-section had to be replaced to repair the guardrail.

Test 2A

The guardrail installation for this test was identical to that for Test 1 except that 1/8 in. by 3/4 in. mild steel straps were added at the rail-to-post connections with backup plates. Photographs of this installation are shown in Figures 9 and 10.

In this test, a heavy 4560 lb. Chrysler (1970) impacted the guardrail at an angle of 27.5 degrees and 55.2 mph (88.8 km/hr) at a point 1 ft. upstream of the beginning of length-of-need. Behavior of the rail was similar to that in Test 1 in that the rail was depressed and the vehicle rode over it. Results of the test are summarized in Table 1. Some partial redirection (yaw displacement) of the vehicle occurred during interaction with the rail (see Appendix A). The vehicle was partially airborne upon exiting the rail and exhibited oscillatory roll motion reaching a maximum

metal plate



BEFORE



AFTER

Bumper damage by impact with first post which broke away.

FIGURE 6. TEST VEHICLE BEFORE AND AFTER TEST 1.

metal plate

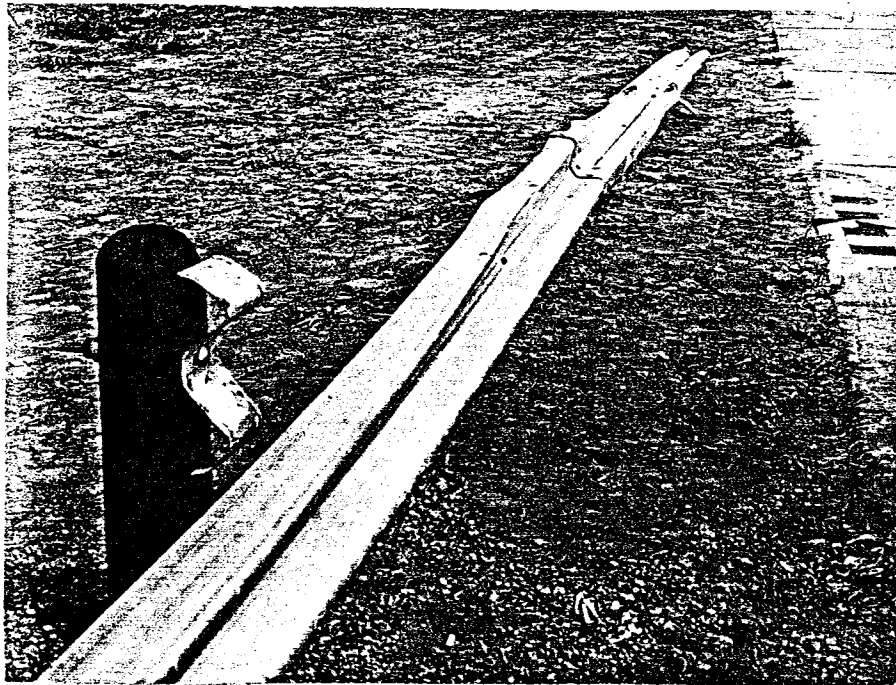
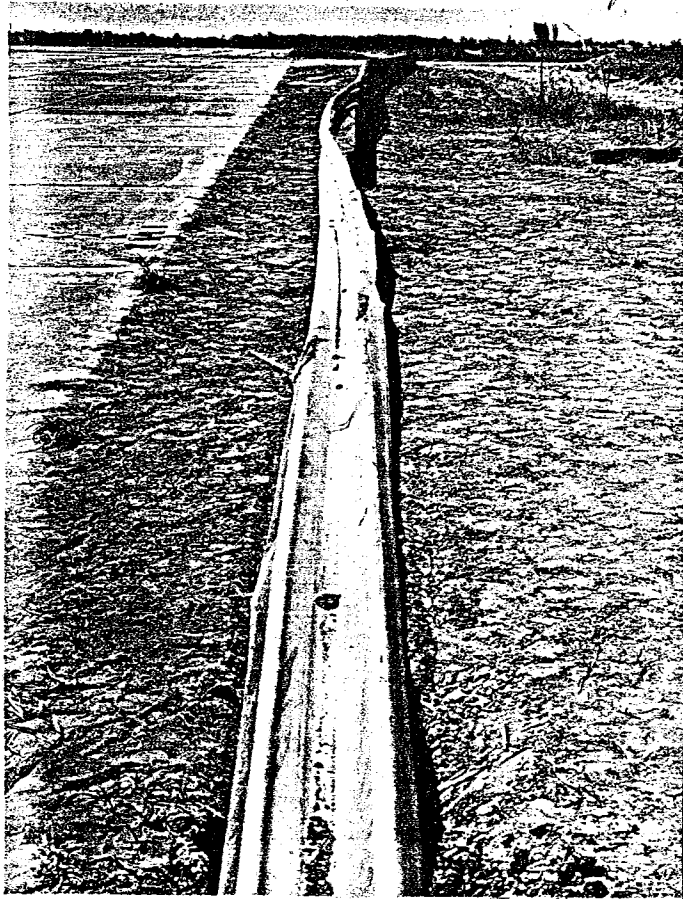
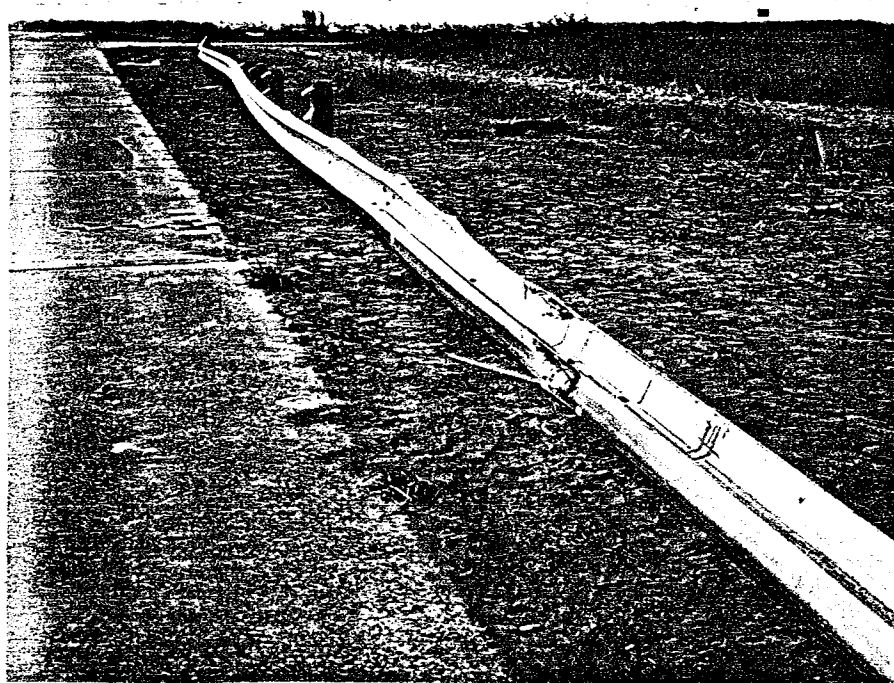
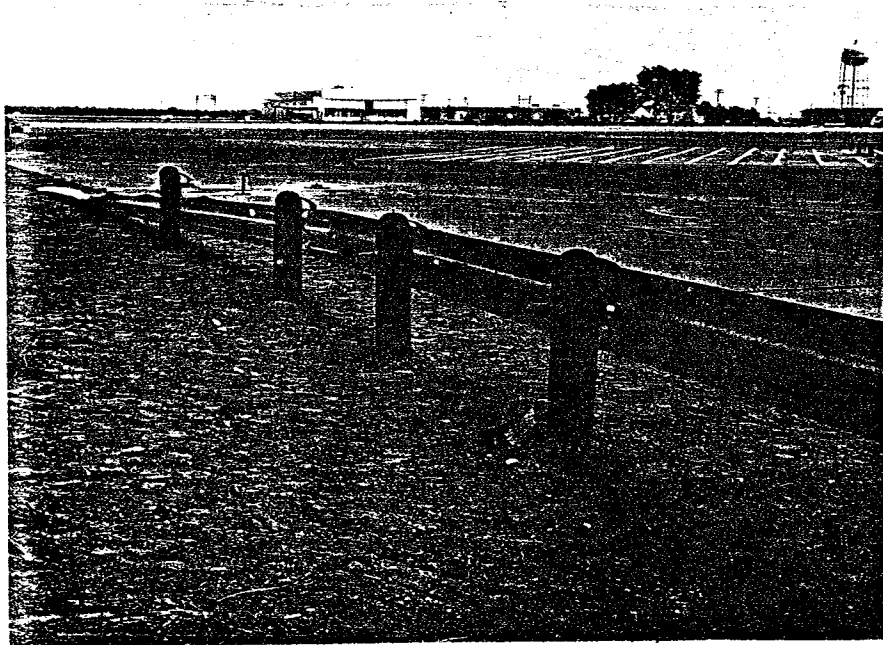


FIGURE 7. GUARDRAIL'S TURNED DOWN END AFTER TEST 1.

15
130

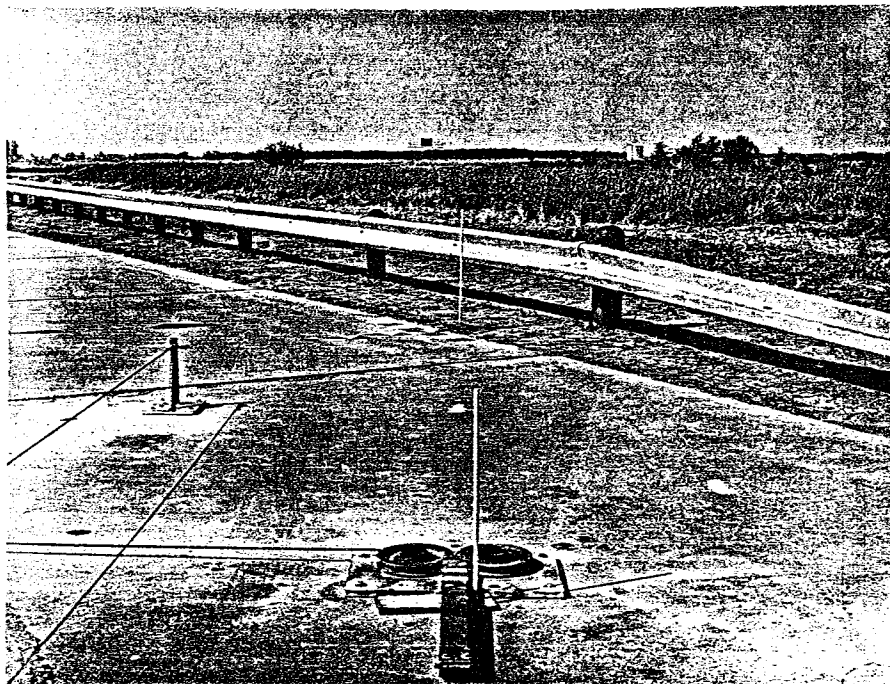
metal plate



Posts shown are numbers 3, 5, 6, and 7. Post no. 1 was knocked out by vehicle.

FIGURE 8. GUARDRAIL TEST SITE AFTER TEST 1.

metal plate



Left to Right - Posts nos. 1, 3, 5, 6, 7, 8, etc.

FIGURE 9. GUARDRAIL TEST SITE PRIOR TO TEST 2.

15
1140

metal plate

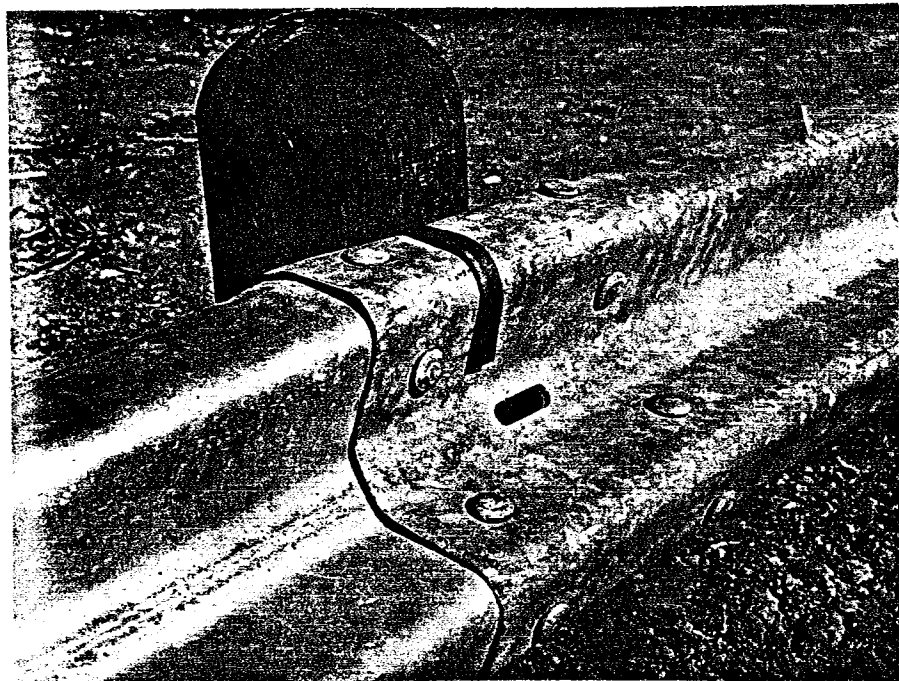
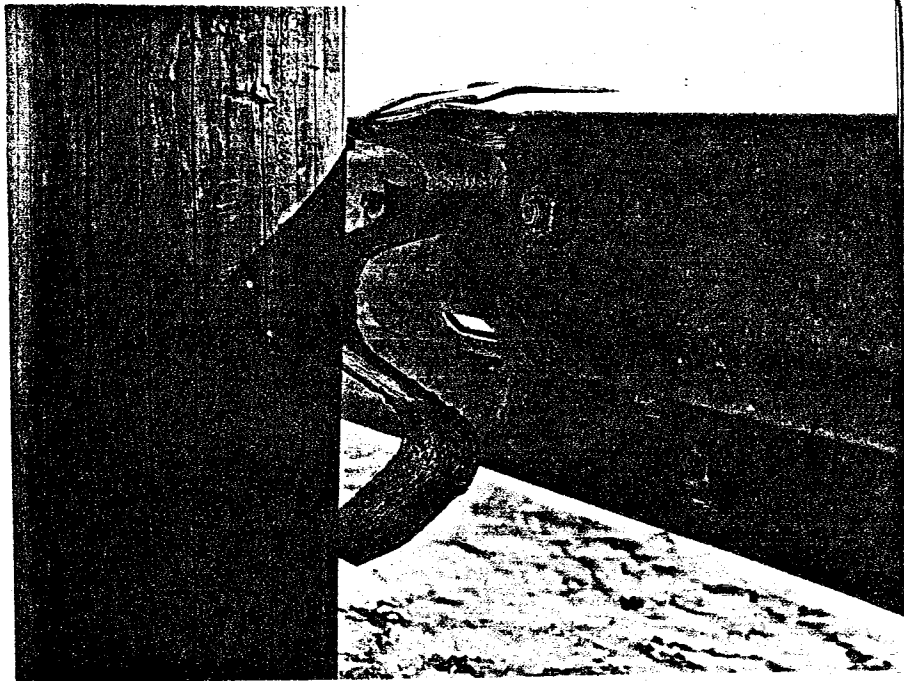


FIGURE 10. PHOTOGRAPHS OF THE RAIL-POST HARDWARE PRIOR TO TEST 2.
POST NO. 1.

8/11/45

of approximately 45 degrees. The critical roll angle for such a heavy car is about 60 degrees. The vehicle did not roll over, and performance was considered acceptable because the actual impact point was a foot upstream of the beginning of length-of-need. With this location of the impact point which was on the terminal, redirection is not a necessary requirement. Damage to the rail is shown in Figures 12 and 13. The first post was displaced laterally. The second post was displaced and fractured. It was necessary to replace two posts and two pieces of the W-section to repair the rail. Before and after test photographs of the test vehicle are shown in Figure 11.

The original objective of Test 2A was to impact the rail along the "length-of-need" and obtain a redirection of the vehicle. The vehicle, however, pushed down the rail and rode over it without rollover. This happened for several apparent reasons: (1) the vehicle's right front bumper actually impacted the rail 1 ft. upstream of post no. 1 on the terminal and not on the "length-of-need", and (2) the rail was only 24 in. high at post no. 1 as a result of repairs after Test 1 (see Figure 10), consequently the Chrysler bumper got on top of the terminal and pushed it down. Several modifications were made in the installation and in the conduct of Test 2B to eliminate these shortcomings. Test 2A was still considered a success in that the vehicle struck the terminal, pushed it down, and rode over it without experiencing rollover.

Test 2B

As a result of the barrier and vehicle behavior in Test 2A several changes were made in the guardrail and test procedure.

metal plate



FIGURE 11. TEST VEHICLE BEFORE AND AFTER TEST 2 A.

12
135

metal plate

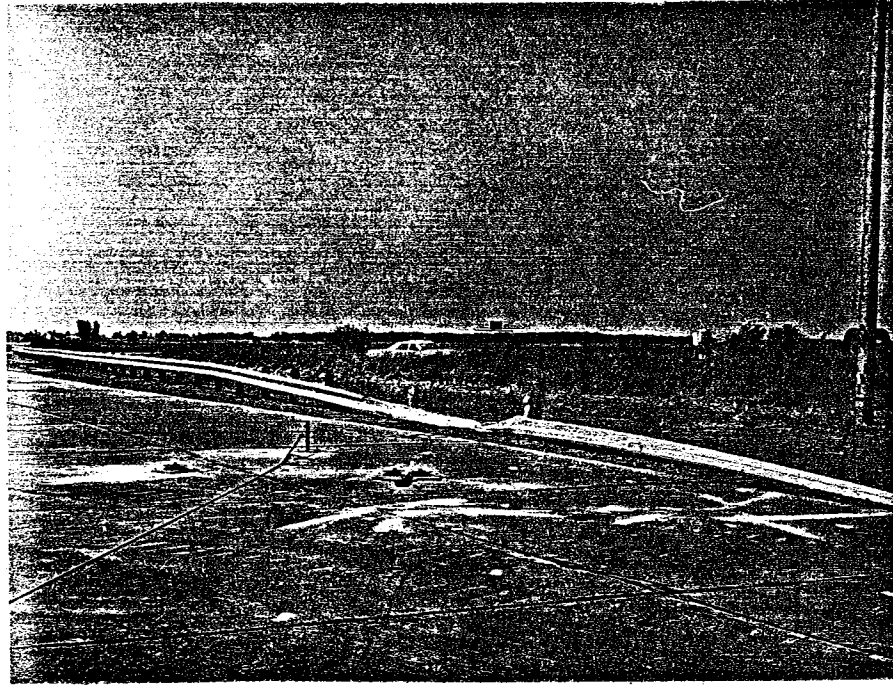


FIGURE 12. GUARDRAIL TEST SITE AFTER TEST 2A.

10
T20

metal plate

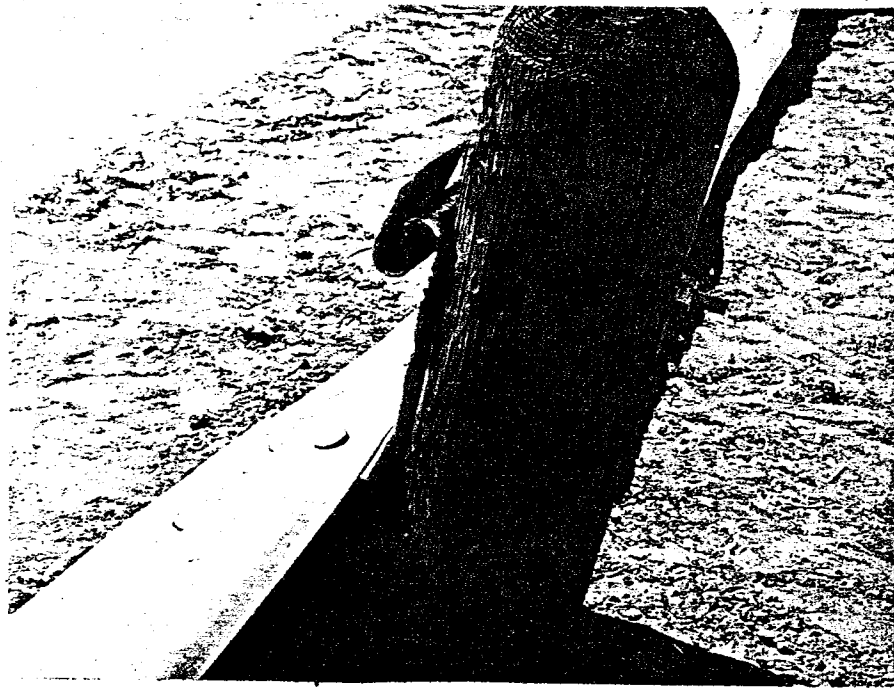
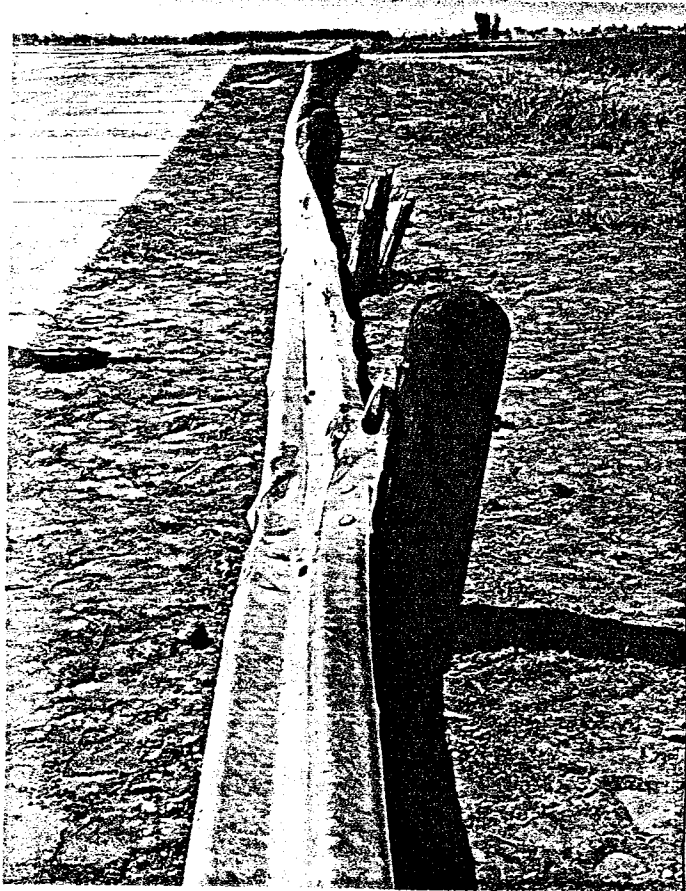


FIGURE 13. PHOTOGRAPHS OF THE GUARDRAIL AND POSTS NEAREST THE POINT OF IMPACT AFTER TEST 2A.

- (1) The vehicle impact point was moved 1 ft. downstream from post no. 1 into the "length-of-need".
- (2) Care was taken in the repair of the rail and terminal to insure the rail was 27 in. high at post no. 1. During installation the terminal piece of rail was bolted to post no. 1, then pre-twisted through an angle of slightly more than 180° to achieve a 90° twist permanent set in the terminal piece. Then when the bolt was removed from post no. 1 and backup plates installed, a neater fit and closer dimensional tolerance were obtained.
- (3) The length of the backup plates was increased from 6 in. to 12 in. and posts no. 2 and 4 were added to make the guardrail post spacing a uniform 6 ft. 3 in. throughout. This was done to strengthen and stabilize the rail for vehicle redirection when impacted on the "length-of-need".

These slight modifications would have no influence on the results of Test 1 since when the vehicle engaged the terminal and pushed it down, the rail rotated away from the posts and backup plates (see Figures 7 and 8).

The installation was impacted with a heavy 4490 lb. Oldsmobile at an angle of 25 degrees at 58.7 mph (94.4 km/hr). The impact point was 1 ft. downstream of the beginning of length-of-need. The guardrail contained and redirected the vehicle without adverse pocketing and snagging and, therefore, the performance was good. Sequential photographs of this test are given in Appendix A. The vehicle departed the rail at an angle of 17.5 degrees at a speed of 36.1 mph (58.1 km/hr). Damage to the front wheel caused the vehicle to follow a curved path and return back to the

metal plate

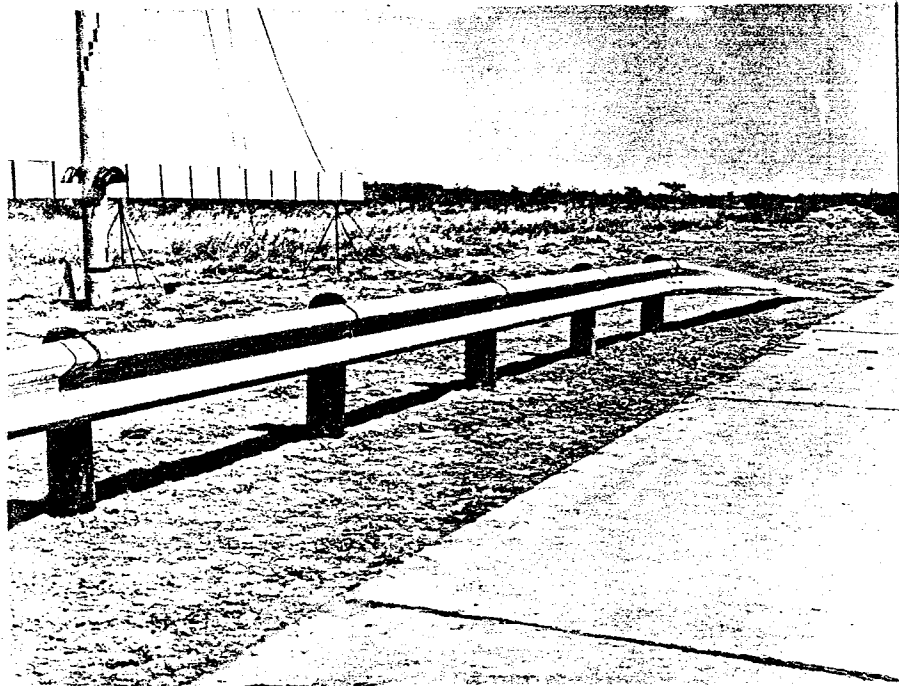
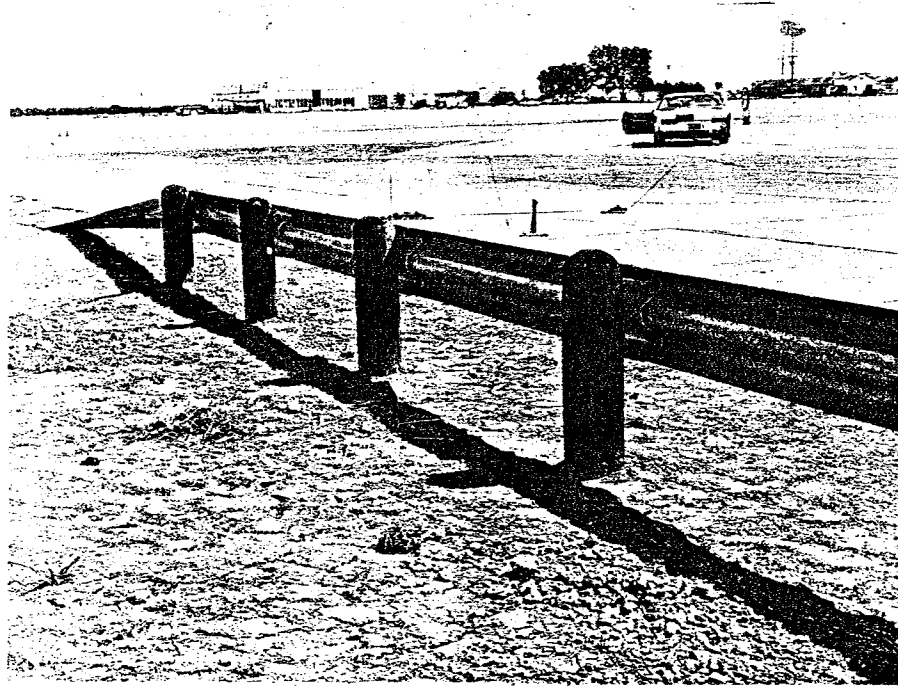


FIGURE 14. GUARDRAIL TEST SITE PRIOR TO TEST 2B.

11/125

metal plate



FIGURE 15. PHOTOGRAPH OF THE RAIL-POST HARDWARE
PRIOR TO TEST 2B.

guardrail with another impact approximately 200 ft. downstream. During redirection, some interaction between the vehicle front wheel and the guardrail posts did occur but no snagging effect was evident. Damage to the vehicle (TAD classification, RFQ 5) is shown in Figure 16. Photographs of the guardrail after the test are shown in Figure 17. As evidenced by this figure, the rail remained nested in the backup plates and at the intended height. Post number 3 was broken off at ground level and posts number 2 and 4 were bent back considerably.

Repairs to the rail consisted of replacing one post and one 25 ft. section of flexbeam rail. This test at the beginning of length-of-need was considered very successful.

Test 3

The guardrail installation for this test, shown in Figure 18, was identical to that for Test 2B.

Test 3 was essentially a head-on test of the terminal with a small vehicle. The 2250 lb. Vega (1971) impacted the terminal at a negative angle of 3.5 degrees at 29.5 mph (47.5 km/hr). Upon initial contact with the turned down terminal section, the vehicle began to ride up as shown in the sequential photographs in Appendix A. The rail disengaged from the backup plates and was depressed. The right front corner of the vehicle bumper impacted the first post splitting it vertically. The vehicle continued forward, riding over the rail and returning to the roadway side of the guardrail. The vehicle finally came to rest against the rail in the position shown in Figure 19.

metal plate

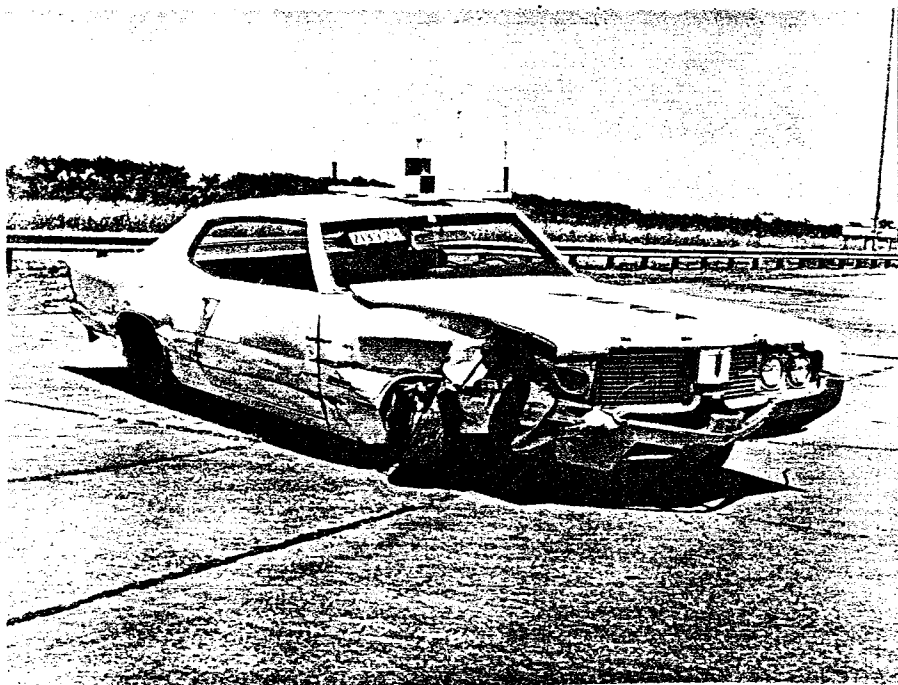
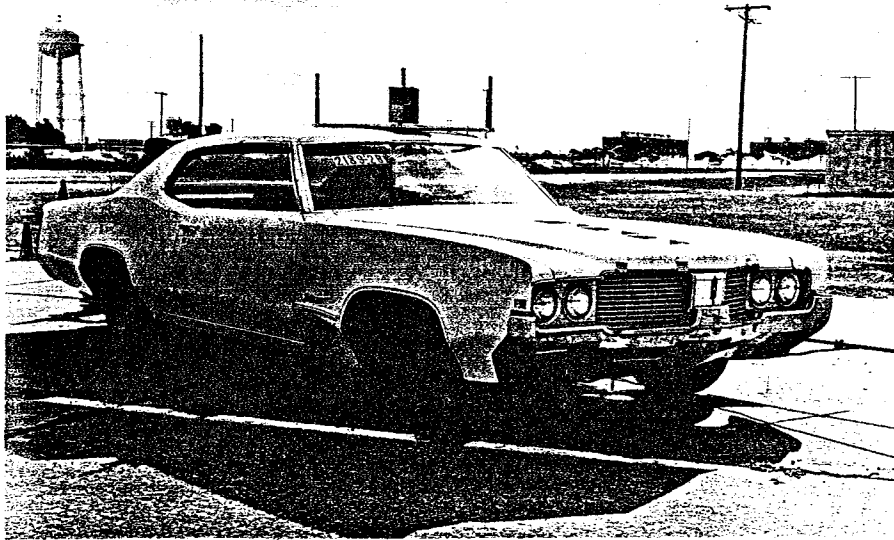


FIGURE 16. TEST VEHICLE BEFORE AND AFTER TEST 2B.

metal plate

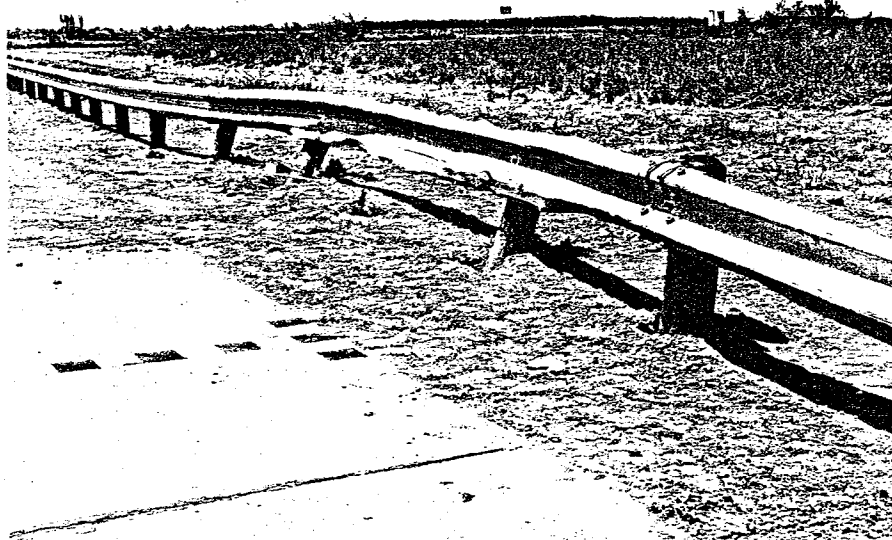


FIGURE 17. PHOTOGRAPHS OF THE GUARDRAIL AND POSTS
NEAREST THE POINT OF IMPACT AFTER TEST 2B.

metal plate

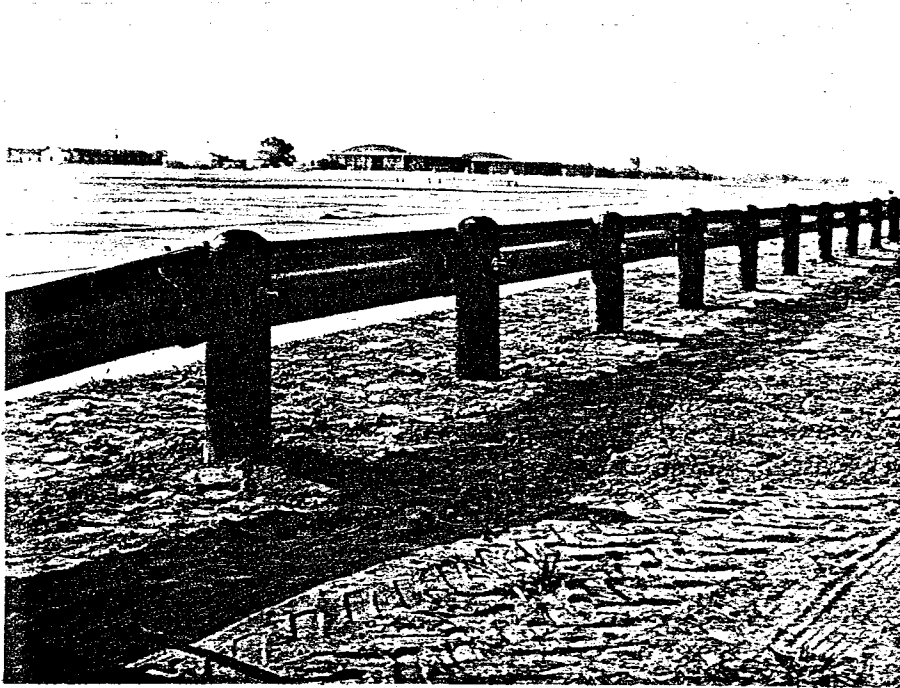
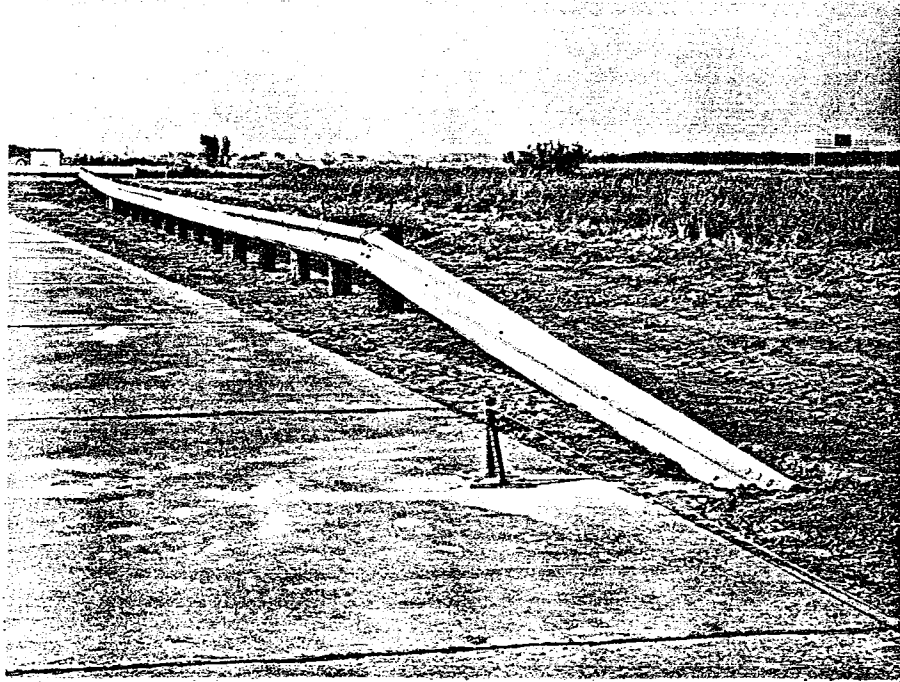


FIGURE 18. GUARDRAIL INSTALLATION BEFORE TEST 3.

metal plate



FIGURE 19. TEST VEHICLE AFTER TEST 3.

Performance of the rail in this test was very good. The maximum .050 sec average longitudinal deceleration was less than 2.0 g's and all peak values were less than 5.0 g's. The TAD vehicle damage classification was RF-1 (Figure 20). Damage to the rail is shown in Figure 21. Repair of the rail necessitated replacement of one post and one backup plate.

Prior to this test it was anticipated that the vehicle would remain straddle of the rail and knock down several posts. This did not happen however. For three different tests a vehicle has impacted the terminal rail, pushed it down and rode over it without a vehicle rollover.

Test 4

The rail was again reconstructed with the same details employed as in Tests 2B and 3. This installation is shown in Figure 22.

In this essentially head-on test a 4560 lb. Chrysler (1970) impacted the turned down terminal at an angle of 5.5 degrees at 55.3 mph (89.0 km/hr). This test was conducted to answer several questions. They are as follows:

- (1) Would the modified terminal produce vehicle ramping and roll over in a head-on impact?
- (2) Would the vehicle become captured by the rail (remain straddle of the rail)?
- (3) How far would the vehicle travel after initial head-on impact?

Upon impact, the vehicle depressed the rail down in a manner similar to the initial behavior during Test 3. The vehicle continued straddle of the rail exhibiting low amplitude oscillatory pitching and rolling motion and eventually came to rest on top of the rail approximately 188 ft. from

metal plate

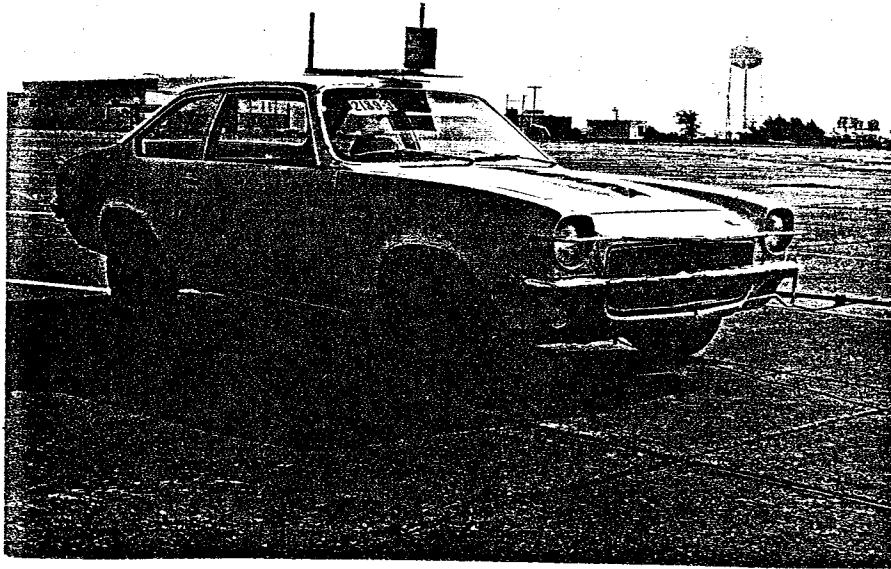
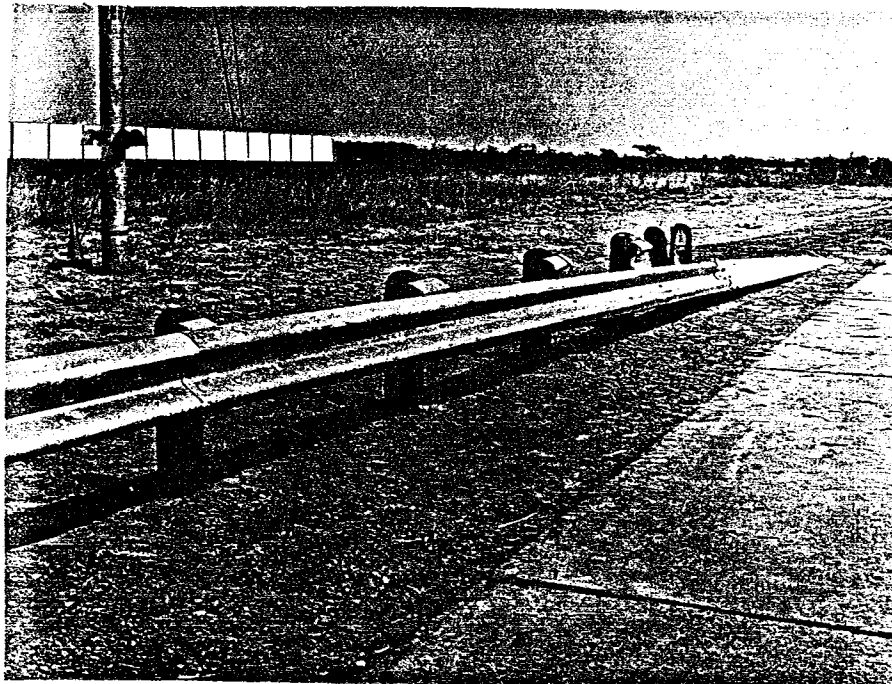
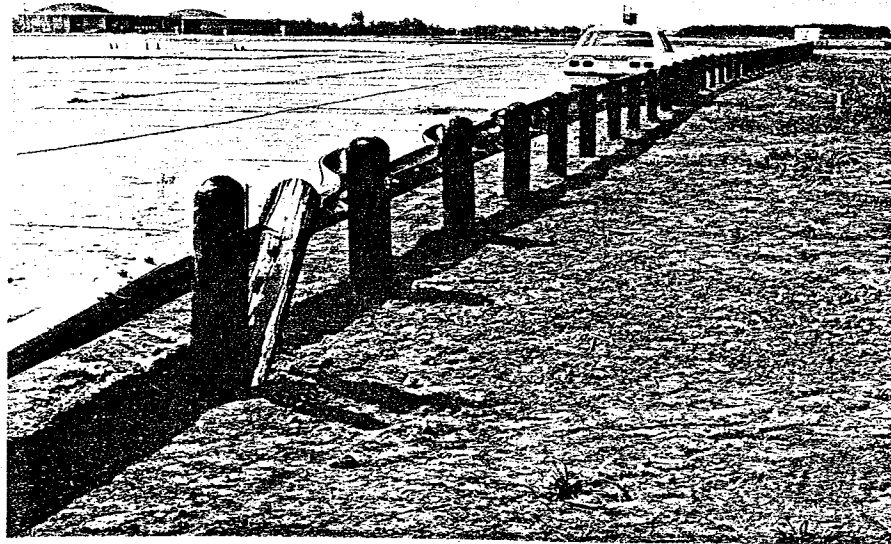


FIGURE 20. TEST VEHICLE BEFORE AND AFTER TEST 3.

10
140

metal plate



Note that when the rail was depressed it rotated away from the posts and off the backup plates.

FIGURE 21. GUARDRAIL TEST SITE AFTER TEST 3.

11
130

metal plate

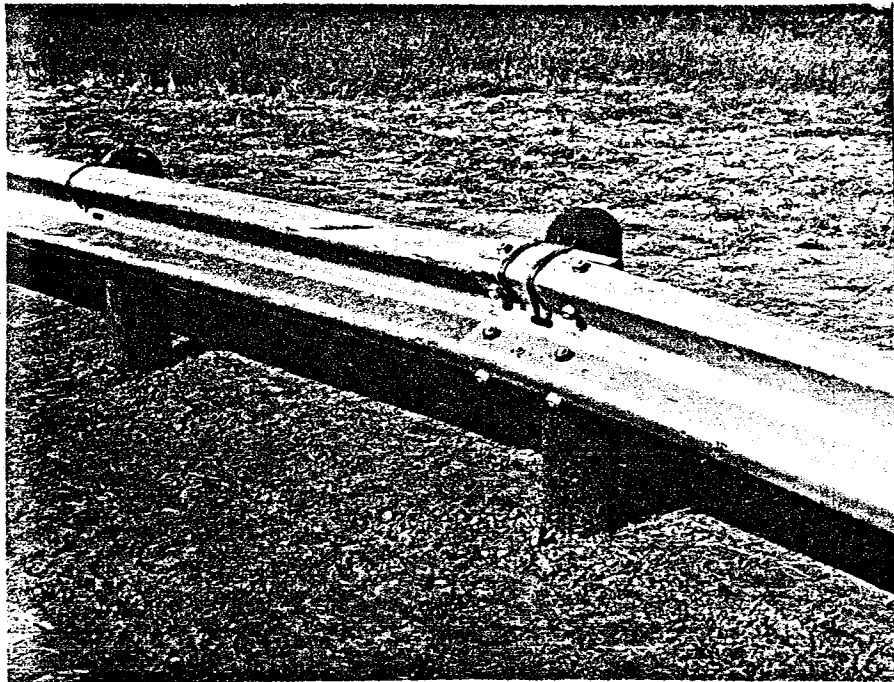
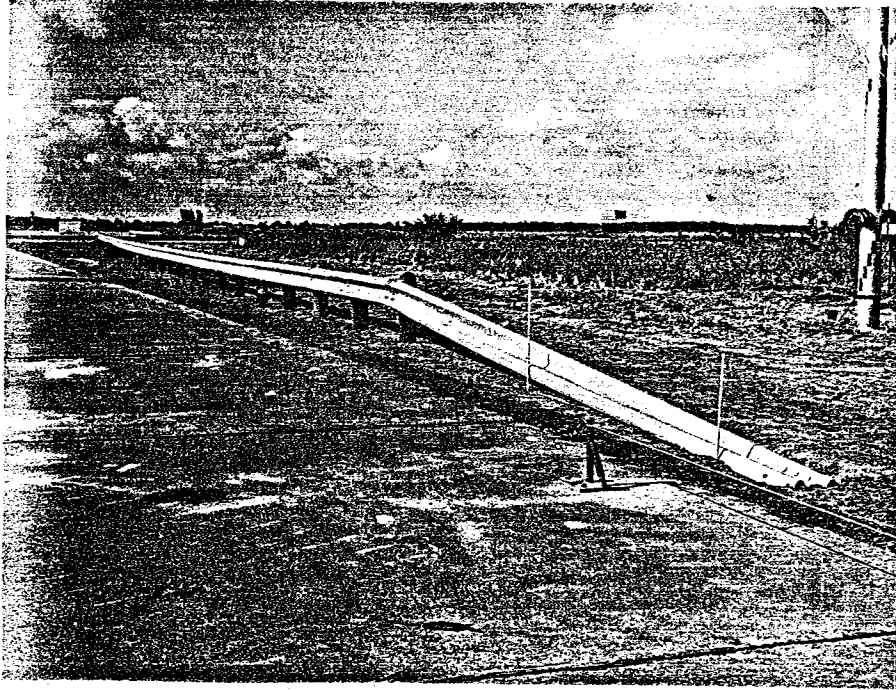


FIGURE 22. GUARDRAIL TEST SITE PRIOR TO TEST 4.

the end anchor (Figure 23). Twenty-six posts were split, broken, or bent over by the vehicle. The average longitudinal deceleration was 0.54 g's over the stopping distance. The maximum .050 sec average longitudinal deceleration was approximately 3 g's and peak values were all below 6 g's (see Appendix B). Extensive damage to the undercarriage of the vehicle occurred (Figure 24). Repair of the guardrail required replacing twenty-six posts and eight 25 ft. sections of rail.

Figure 25 shows the vehicle speed at various distances from the beginning of the guardrail. This figure permits one to estimate the vehicle speed at any point after it becomes a captive of the rail.

Test 5

For Test 5 posts number 2 and 4 were removed to give the same post arrangement as shown on the Texas Standard drawings (Figure 1). All backup plates were removed. This installation is shown in Figure 26. Steel, althread bolts $\frac{1}{4}$ in. in diameter with 1.25 in. outside diameter flat washers were installed at posts 1, 3, 5, 6 and 7 (first 5 posts) as shown by Figure 27.

A small car (1971 Vega) was slowly driven onto the end of the rail to obtain some indication of the ease with which the terminal rail could be stripped off the bolt and washer and depressed. From this low speed trial, it appeared that performance in this respect might be satisfactory in a higher speed impact. (Figure 28)

The rail was impacted with a 4490 lb. Dodge (1968) at 23 degrees and 55.8 mph (94.1 km/hr) into the length-of-need. The impact point was

metal plate

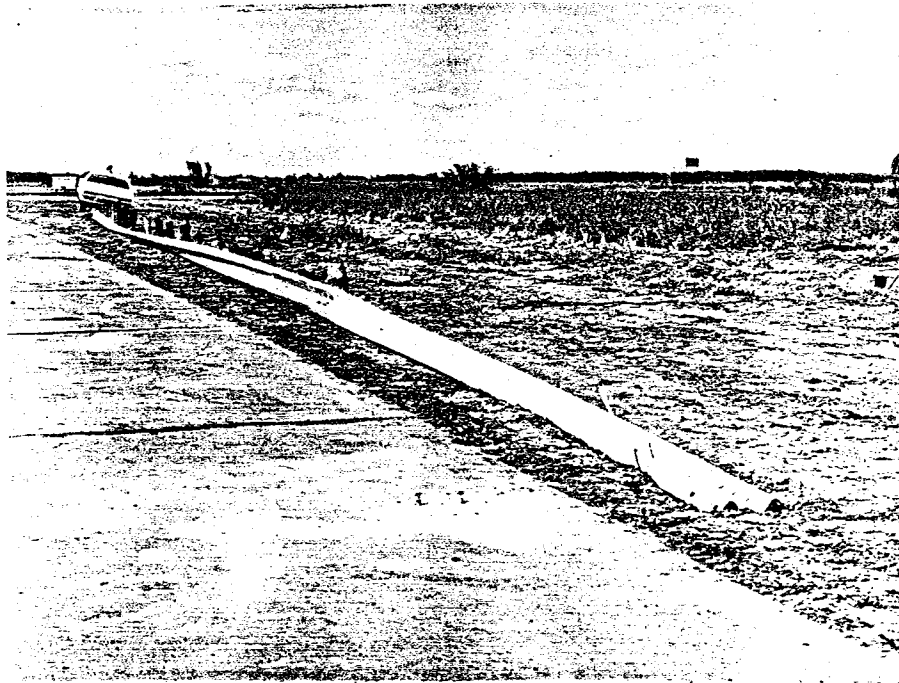
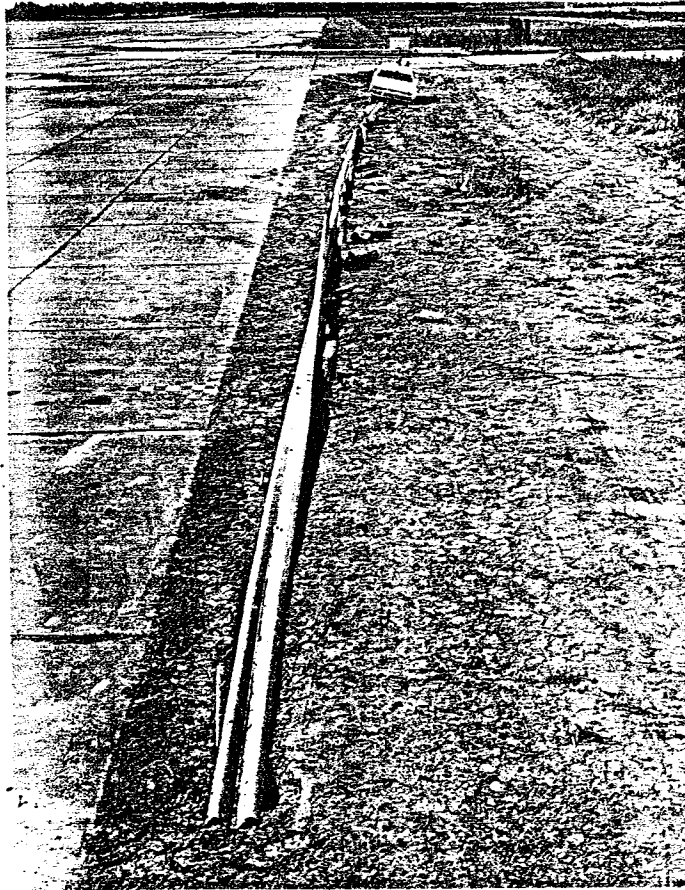


FIGURE 23. GUARDRAIL TEST SITE AFTER TEST 4.

12
125

metal plate

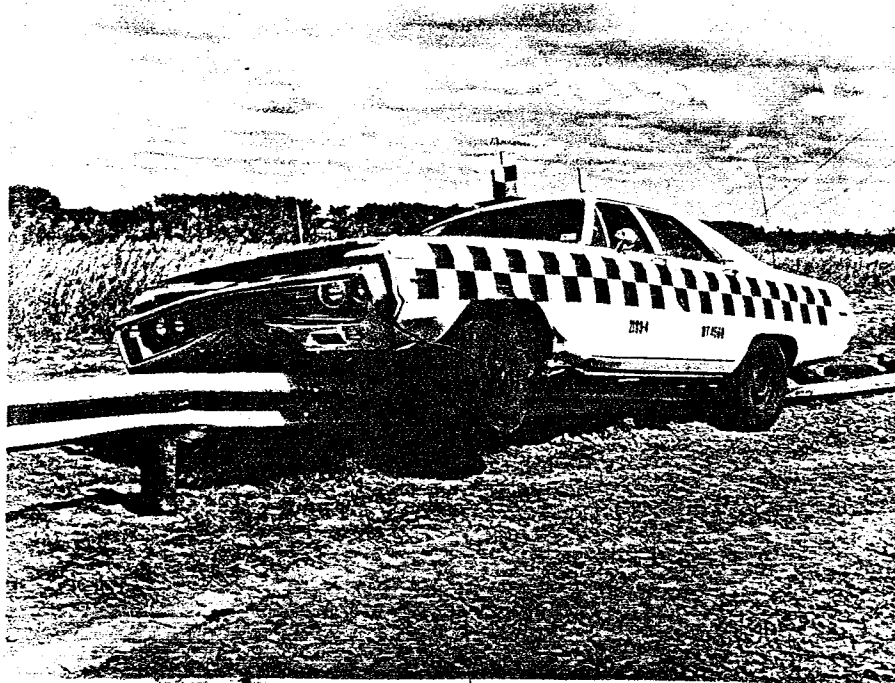


FIGURE 24. TEST VEHICLE BEFORE AND AFTER TEST 4.

12
133

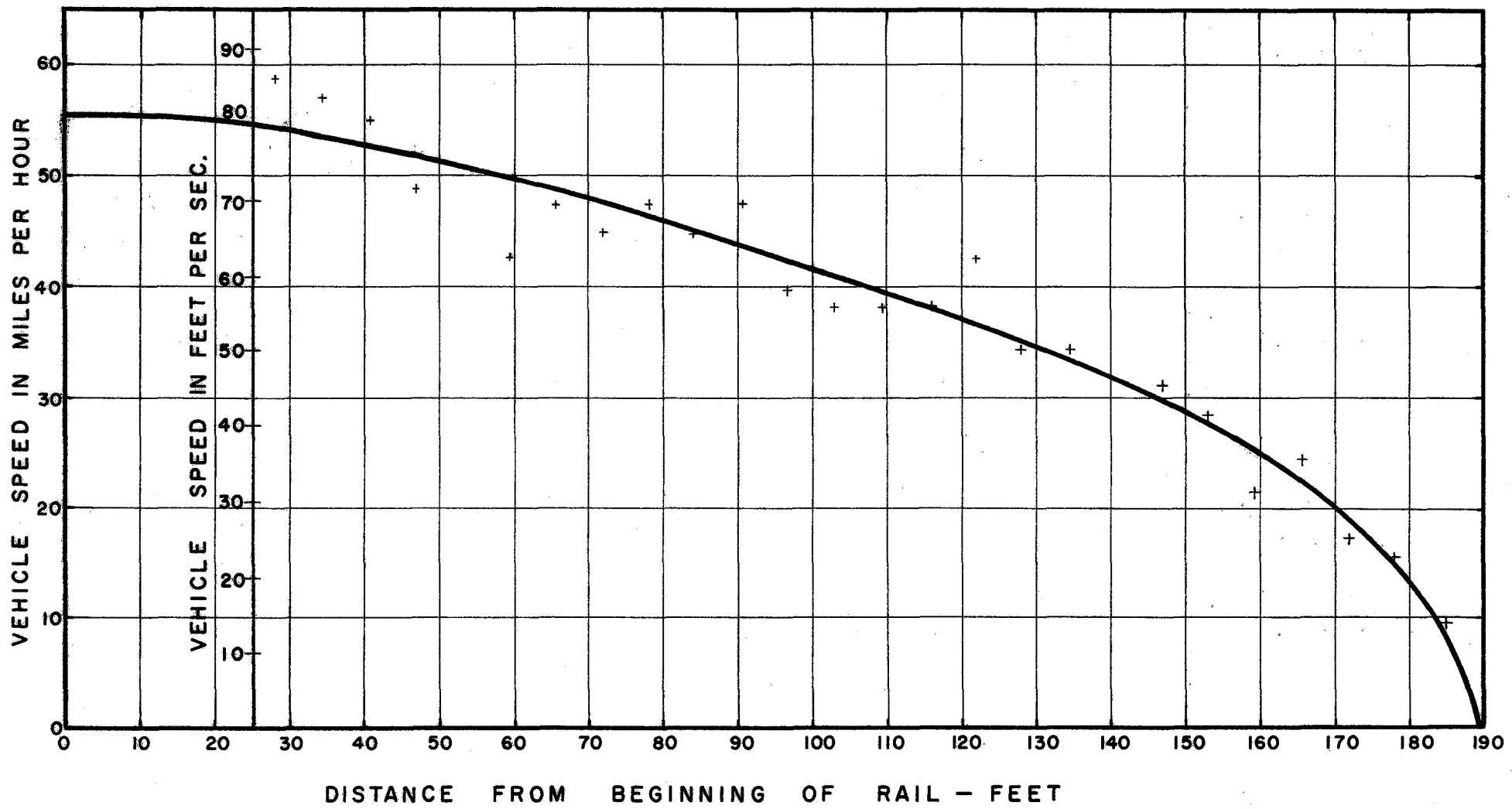


FIGURE 25. VEHICLE SPEED vs. DISTANCE FROM BEGINNING OF RAIL
TEST 2189-4

metal plate

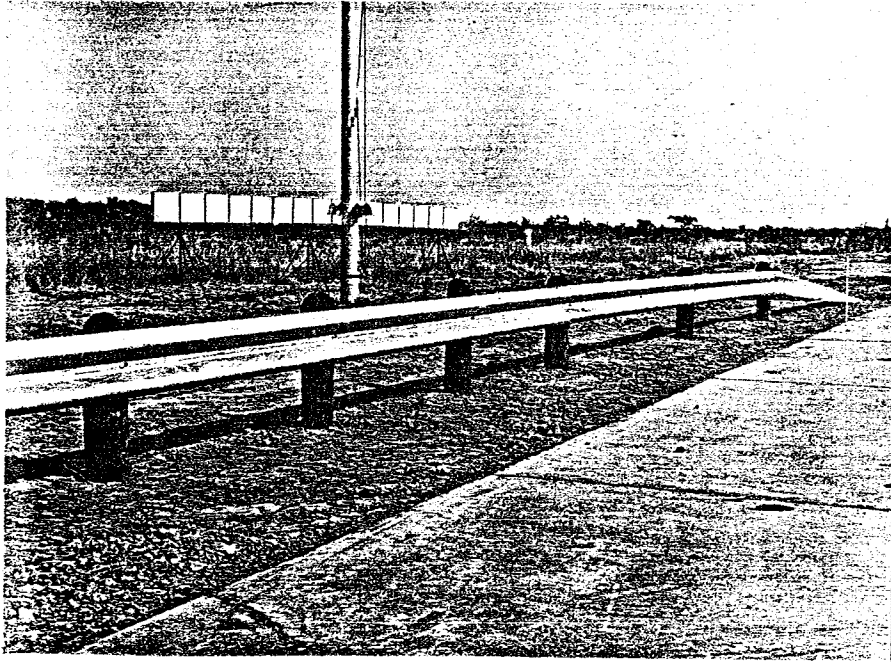


FIGURE 26. GUARDRAIL TEST SITE PRIOR TO TEST 5.

10
135

metal plate

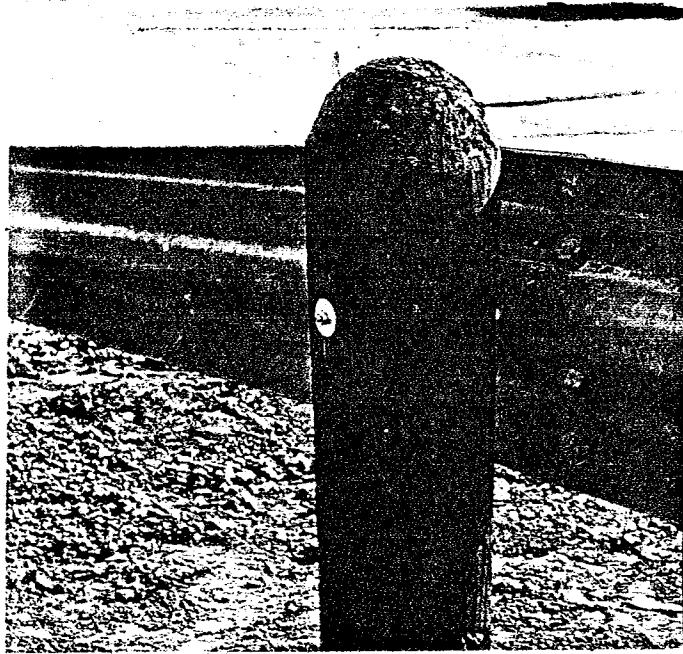


FIGURE 27. | PHOTOGRAPHS OF THE RAIL-POST HARDWARE
PRIOR TO TEST 5.

metal plate



FIGURE 28. PHOTOGRAPHS OF DEPRESSED RAIL POSITION AFTER LOW-SPEED TRIAL TEST.

approximately 1 ft. downstream of the beginning of length-of-need (first post). The vehicle was redirected as intended and exited the rail at 7.5 degrees at 39.3 mph (63.2 km/hr). The maximum .050 sec average longitudinal and lateral decelerations were 3.3 and 7.0 g's, respectively. After exiting the rail, the vehicle followed a long curved path with a minor secondary impact with the rail approximately 175 ft. downstream (Figure 29). Not only did the rail contain and redirect the vehicle but it did so with relatively low deceleration levels.

Photographs showing the behavior of posts number 1 and 3 are given in Figure 30. Photographs of the test vehicle before and after the test are shown in Figure 31.

This test verified that the $\frac{1}{4}$ in. diameter bolts will hold the rail at the proper height and that the two 12 ft. 6 in. post spacings are adequate to achieve vehicle redirection.

Test 6

Test 6 was conducted on essentially the same modified terminal and rail as in Test 5 except althread bolts $\frac{3}{16}$ in. in diameter were used on the first five posts (see Figure 32). The first two post spaces at the beginning of length-of-need were 12 ft. 6 in. and all others were at 6 ft. 3 in. as shown in Figures 33 and 34.

In this test a 2270 lb. Vega (1971) impacted the turned down terminal section at 15 degrees and 59.7 mph (96.1 km/hr). The impact point was midway between the end anchor and beginning of length-of-need. The purpose of this test was to see if the small diameter ($\frac{3}{16}$ in.) althread bolts

metal plate

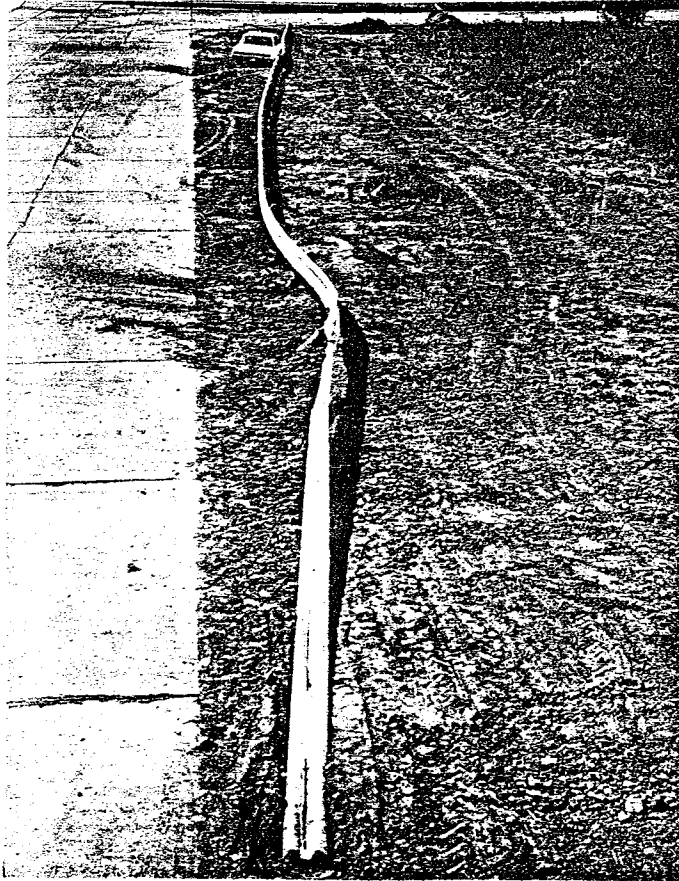


FIGURE 29. GUARDRAIL TEST SITE AFTER TEST 5.

15
120

metal plate

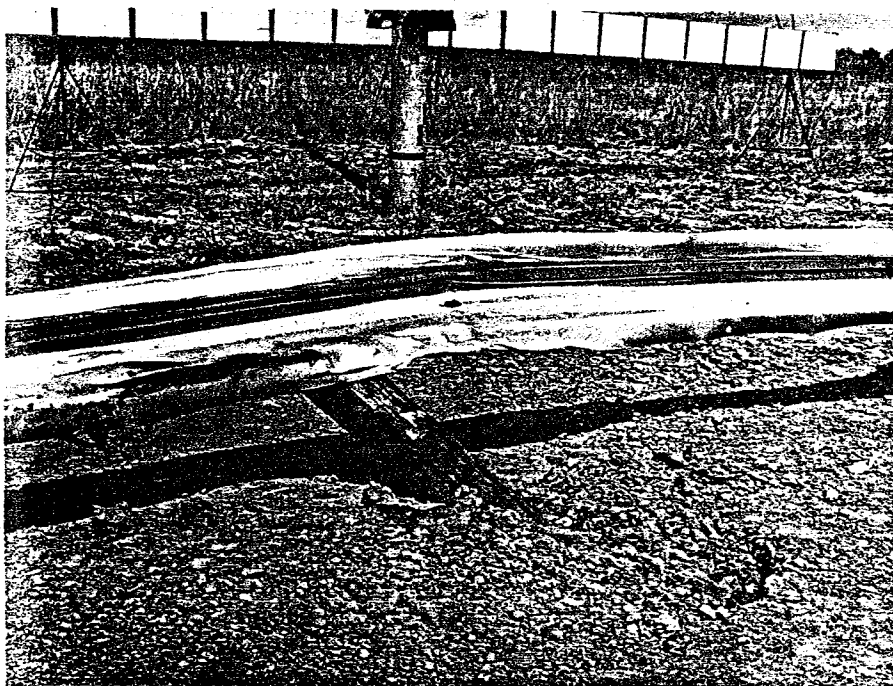
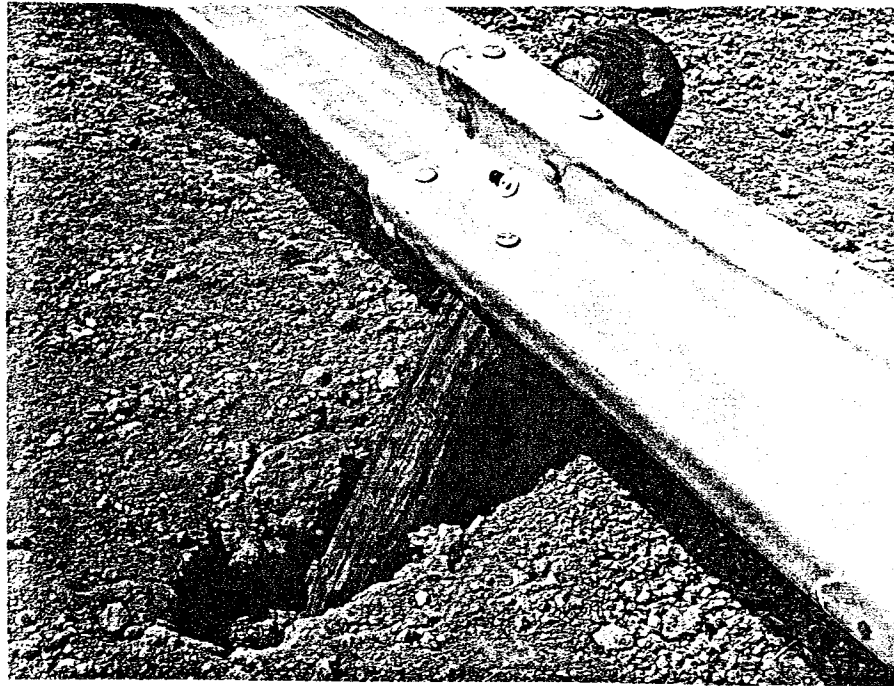


FIGURE 30. PHOTOGRAPHS OF POSTS NUMBER 1 and 3 AFTER TEST 5.

10
140

metal plate

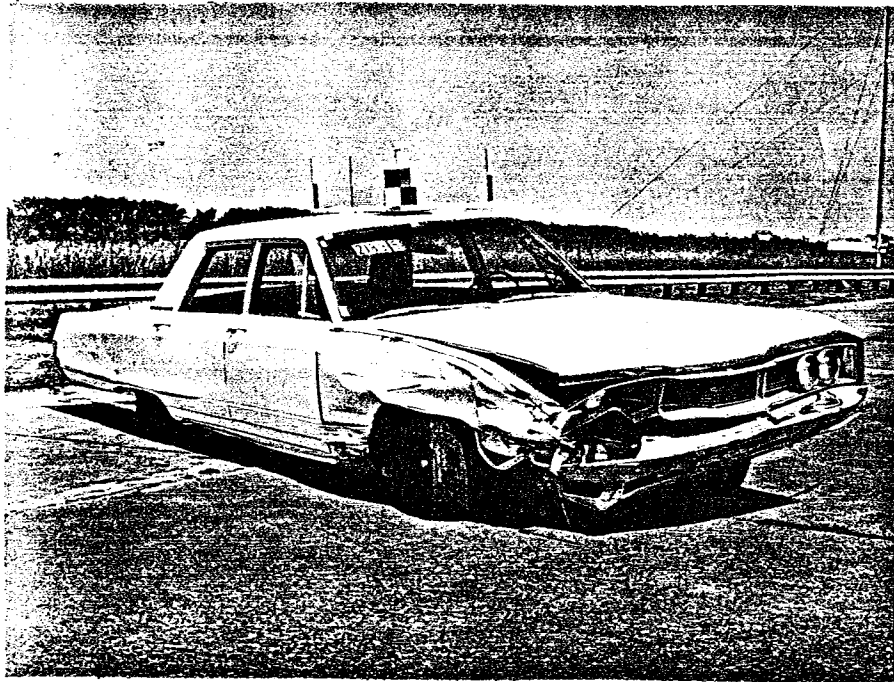
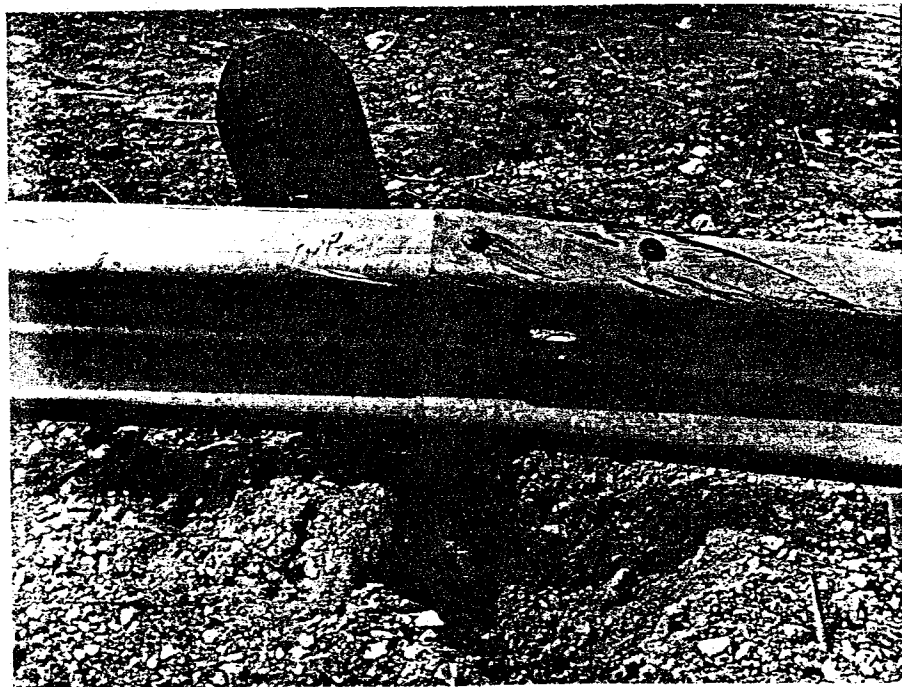
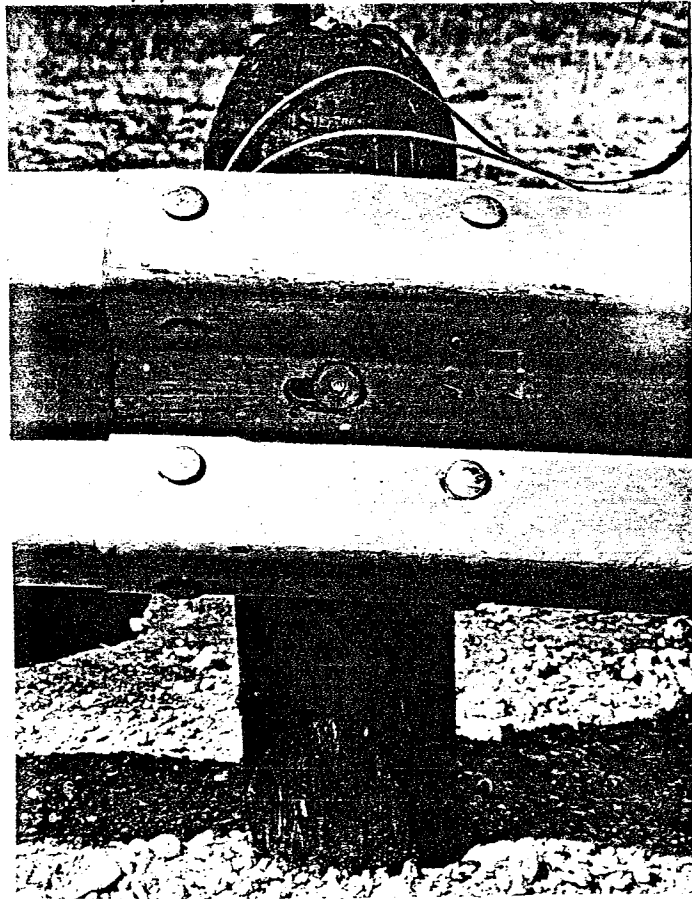


FIGURE 31. TEST VEHICLE BEFORE AND AFTER TEST 5.

metal plate



Direction
of Travel

FIGURE 32. POST NO. 1 BEFORE AND AFTER TEST 6.

11/14/5

metal plate

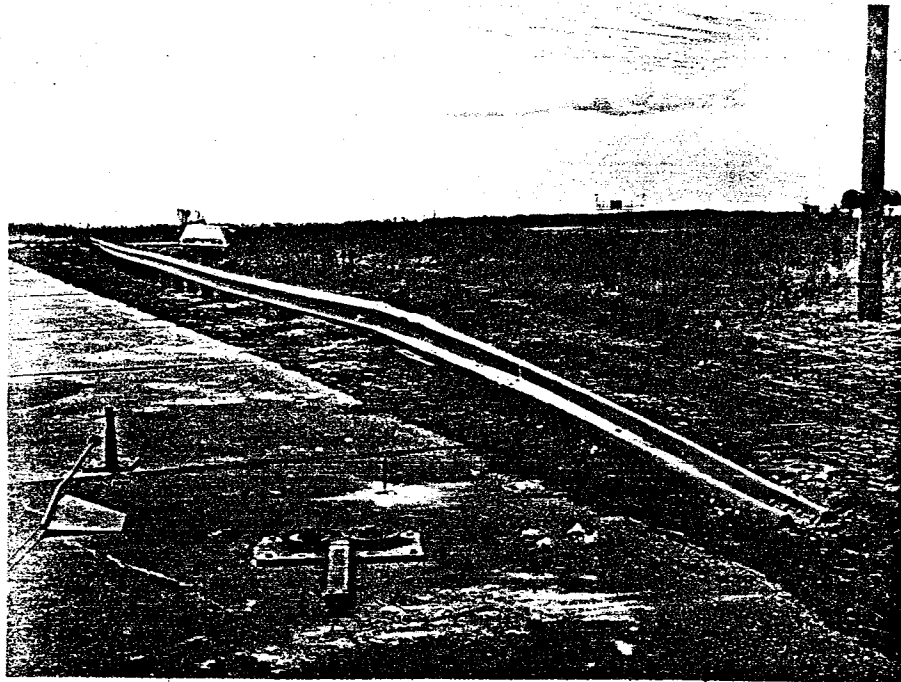
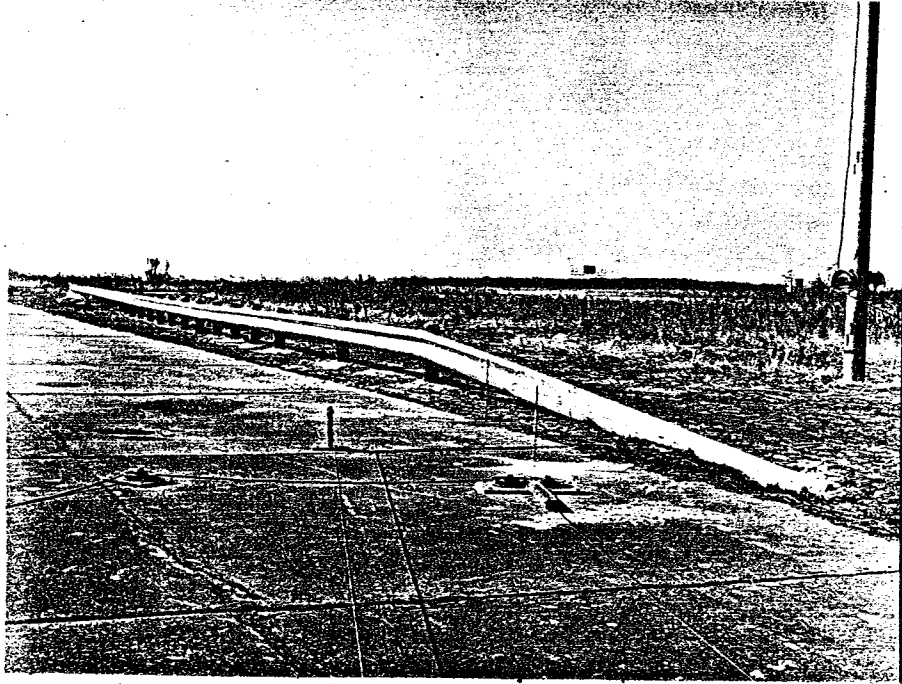


FIGURE 33. TURNED-DOWN END GUARDRAIL
BEFORE AND AFTER TEST 6.

metal plate

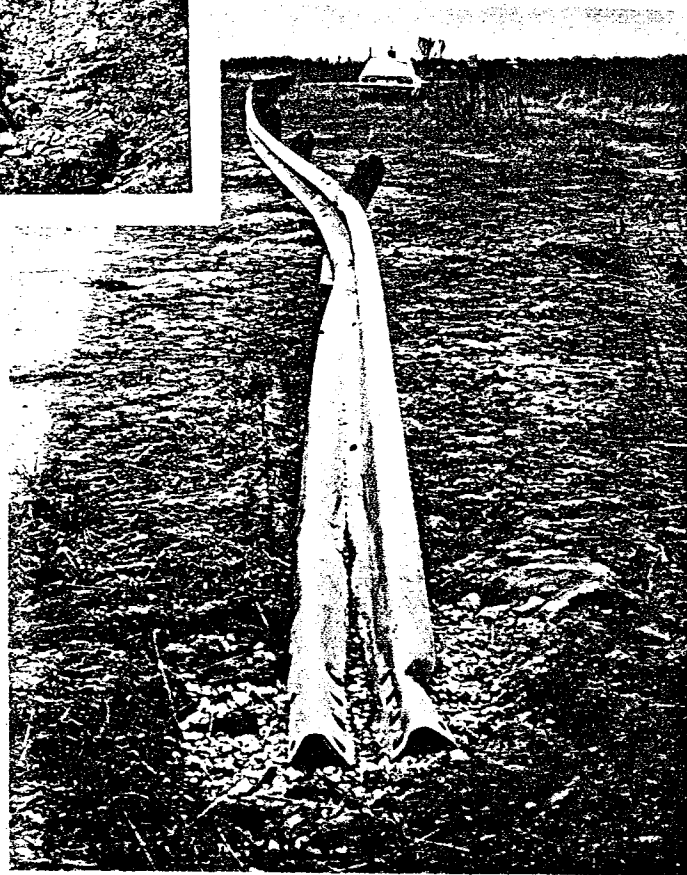
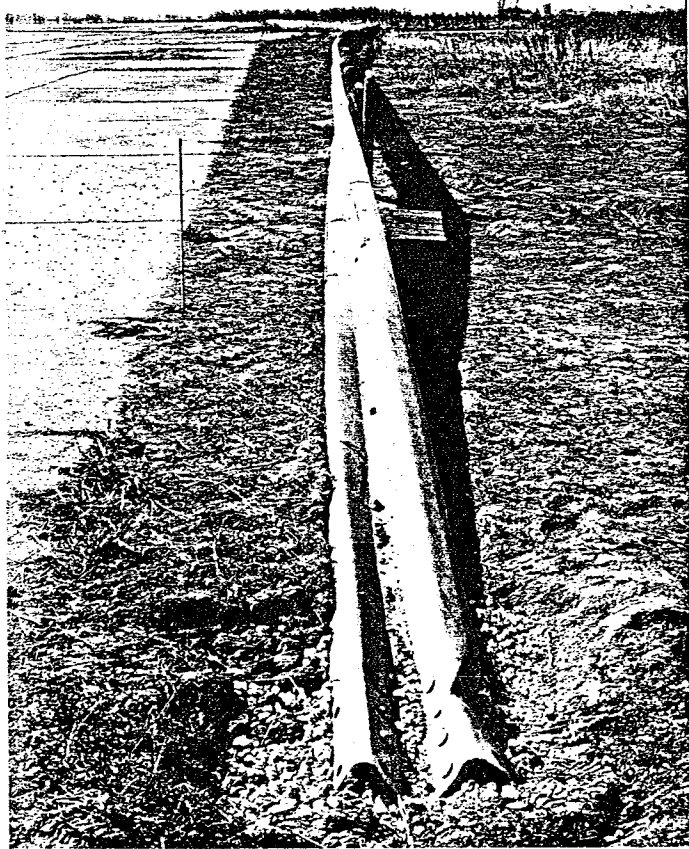


FIGURE 34. TURNED-DOWN END GUARDRAIL
BEFORE AND AFTER TEST 6.

would allow the rail to fall quickly to the ground as in Test 1 and eliminate or minimize the severe vehicle ramping and potential rollover behavior.

Immediately after initial impact, the rail did not drop quickly to the ground as intended and this caused the vehicle to vault several feet into the air. While the vehicle ended up right side up, its maximum roll angle during the collision event was 76° . The critical roll angle of such a vehicle would be about 60° , however because of complex dynamic behavior, the vehicle did right itself after the 76° maximum roll angle.

Damage to the vehicle is shown by Figure 35. Damage to the guardrail and terminal is shown by Figures 33 and 34.

metal plate



FIGURE 35. TEST VEHICLE BEFORE AND AFTER TEST 6.

SUMMARY AND CONCLUSIONS

Since the early 1960's the Texas Department of Highways and Public Transportation has used the turned down terminal on its guardrails. Through the years this hardware has generally displayed good in-service performance. In the late 1960's the California Division of Highways and Southwest Research Institute conducted several tests which indicated this turned down terminal could potentially launch an impacting vehicle and cause it to roll over.

A relatively simple method of modifying the turned down end guardrail terminal has been developed which will eliminate or greatly minimize the probability of a vehicle ramping and rolling over. Hardware employed in the modified design is either standard guardrail components (ARBA Tech. Bulletin No. 268) or items that are readily available commercially. This effective design is shown by Figures 3 and 4.

To modify the standard turned down guardrail design the 5/8 in. diameter bolts were removed from the first five posts. With the bolts removed the rail will be depressed to the ground when the turned down terminal piece is impacted by a vehicle. This action eliminates the undesirable violent vehicle ramp and rollover behavior. In order to hold the rail at the proper height (27 in. in Texas) before and during the vehicle angle impact along the length-of-need, backup plates are bolted to the first five posts.

Successful crash tests as required by NCHRP Report 153 have been conducted to verify this behavior. In three of the tests conducted, the vehicle impacted the modified terminal, depressed the rail, and rode over it without vehicle rollover.

These tests have demonstrated that the undesirable vehicle rollover can be designed out of the very effective turned down guardrail terminal. In the head-on test at 60 mph with a large vehicle, the car remained straddle of the rail and rode down it for a distance of 188 ft. before stopping. Highway engineers should keep this in mind when using the turned down terminal with rails tied to rigid bridge piers or other rigid objects. In Texas, the ends of such guardrails are now normally flared away from the roadway and it is unlikely that a vehicle can impact the end head-on and become captured in this manner.

Undoubtedly, the hardware used here can be improved upon. One possibility is the use of a "very weak" bolt (such as the 3/16 in. and 1/4 in. diameter althread bolt) in connecting the guardrail to the post. Tests 5 and 6 were conducted to evaluate the possibility of using such a weak rail to post connection. Test 5, the 60 mph (96 km/hr) - 25 degree redirection test was very successful. However, Test 6, the 60 mph (96 km/hr) - 15 degree angle test into the turned down terminal, did not produce as good results as obtained in Test 1. At the present time the weak bolt connection on the first five posts is not recommended.

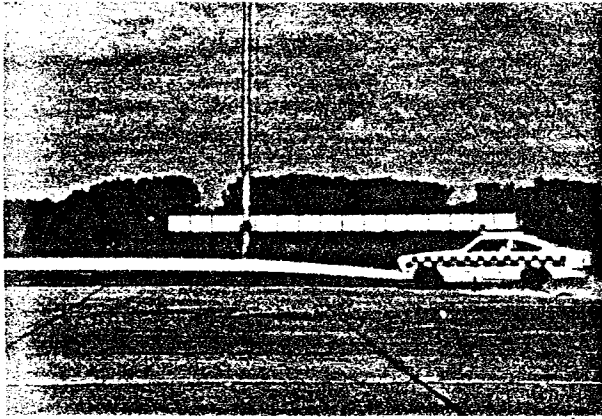
To increase the applications of this guardrail terminal concept, addition tests are recommended using steel posts such as the W6 x 8.5 and also using blocked out rails. Since other states are using guardrail mounting heights of 30 and 33 in. these should also be checked out with additional tests.

REFERENCES

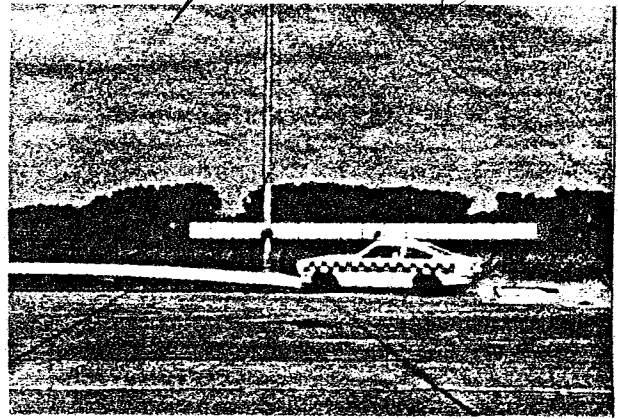
1. Bronstad, M. E. and Michie, J. D., "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", NCHRP Report 153, Transportation Research Board, Washington, D.C. 1974.
2. Texas State Department of Highways and Public Transportation, Highway Design Division Operations and Procedures Manual Appendix A, Section A-300 Roadside Design Guidelines, 1972 Edition.
3. Beaton, John L., Nordlin, Eric F., and Field, Robert N., "Dynamic Tests of Corrugated Metal Beam Guardrail", Highway Research Record No. 174, Highway Research Board, 1967.
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5. Tutt, Paul R. and Nixon, John F., "Roadside Design Guidelines", Highway Safety, Highway Research Board Special Report 107, August 1969.
6. Michie, Jarvis D. and Bronstad, Maurice E., "Guardrail Performance: End Treatments", Report of Southwest Research Institute, August 1969.
7. Michie, Jarvis D., Calcote, Lee R., and Bronstad, Maurice E., "Guardrail Performance and Design", NCHRP Report 115, Highway Research Board, 1971.
8. Michie, Jarvis D., and Calcote, L. R., "Location, Selection, and Maintenance of Highway Guardrails and Median Barriers", NCHRP Report 54, Highway Research Board, 1968.
9. Michie, J. D. and Bronstad, M. E., "Guardrail Crash Test Evaluation - New Concepts and End Designs", NCHRP Report 129, Highway Research Board, 1972.

APPENDIX A
SEQUENTIAL PHOTOGRAPHS

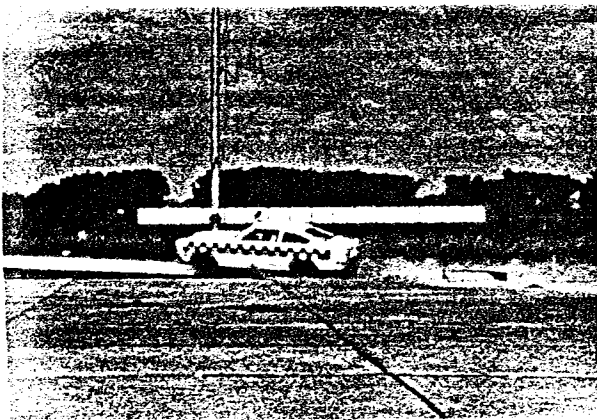
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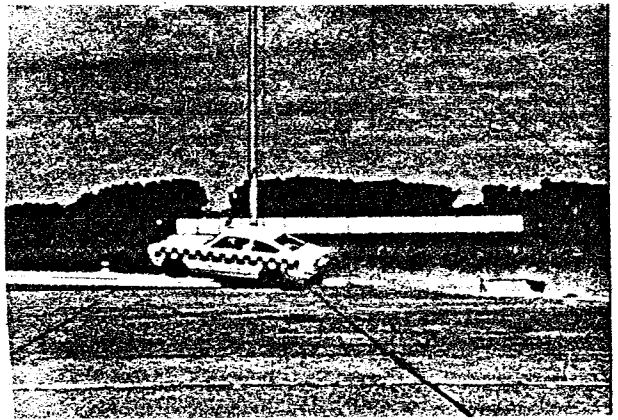
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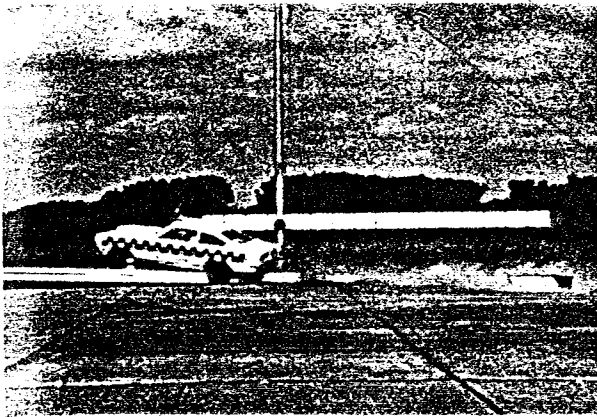
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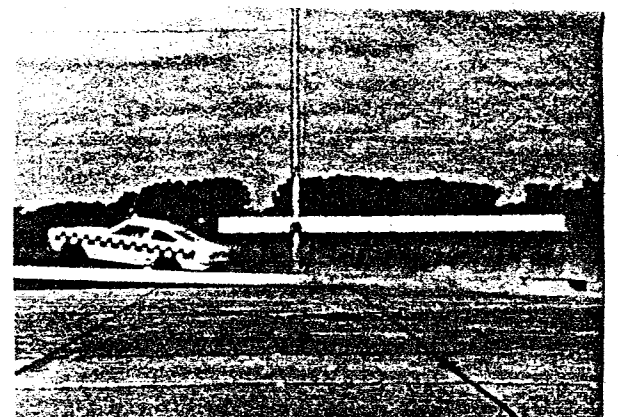
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0.232 SEC



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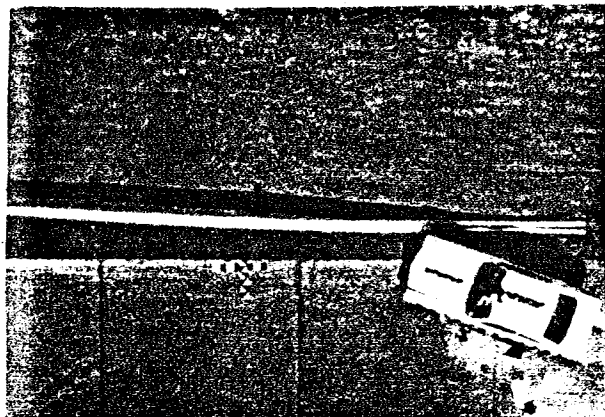


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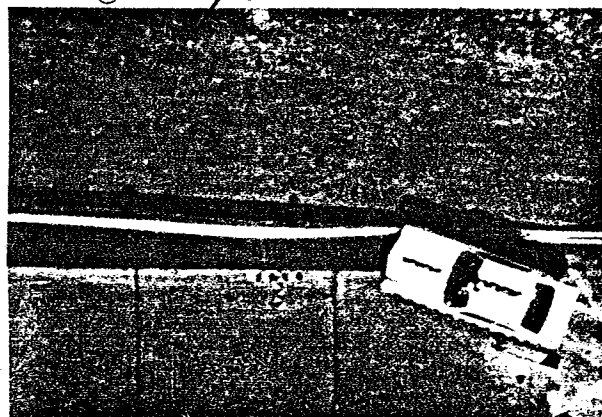
FIGURE A-1. SEQUENTIAL PHOTOGRAPHS DURING TEST 1.
(Side view)

12
130

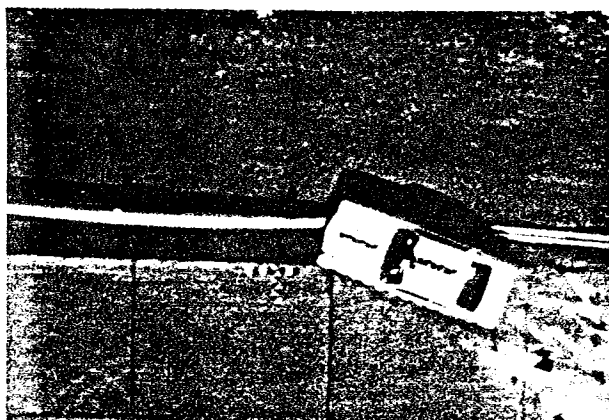
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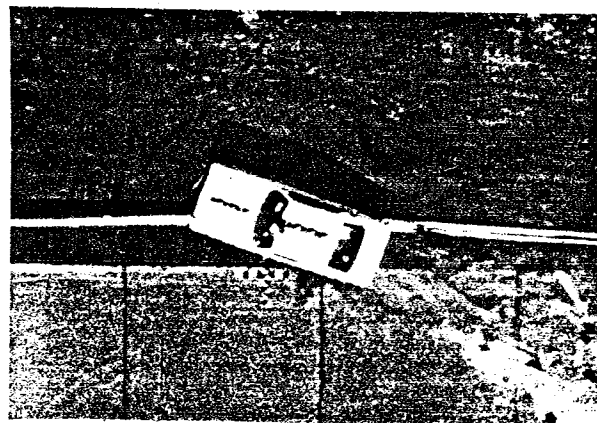
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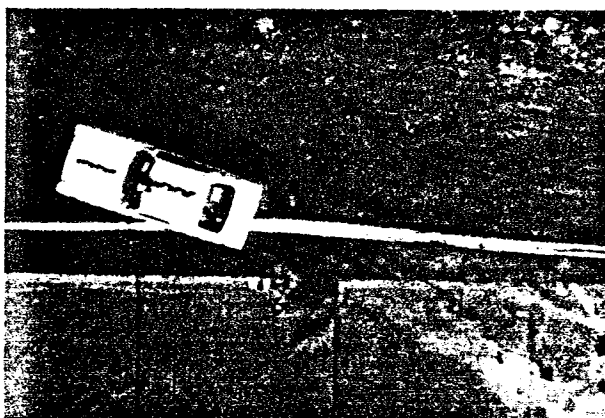
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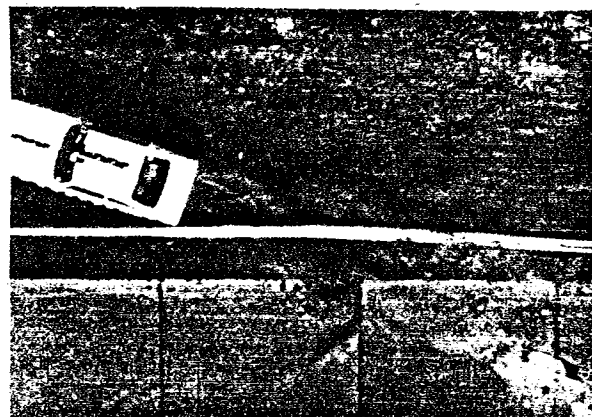
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0.199 SEC



0.324 SEC



0.400 SEC

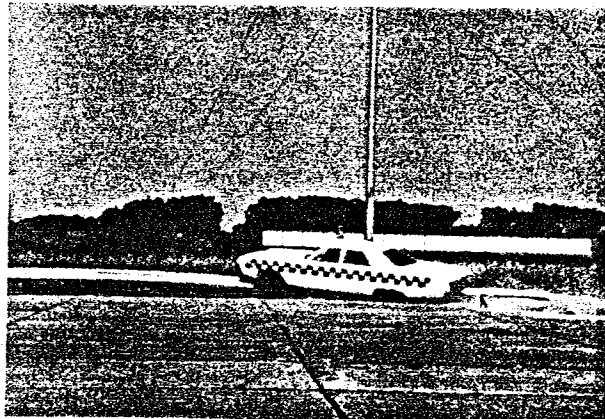
FIGURE A-2. SEQUENTIAL PHOTOGRAPHS DURING TEST 1.
(Overhead view)

12
125

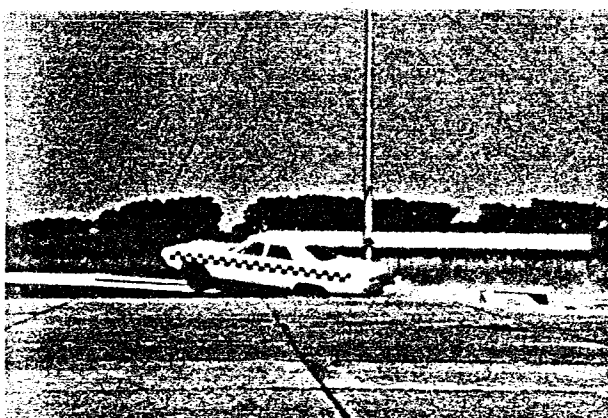
metal plate



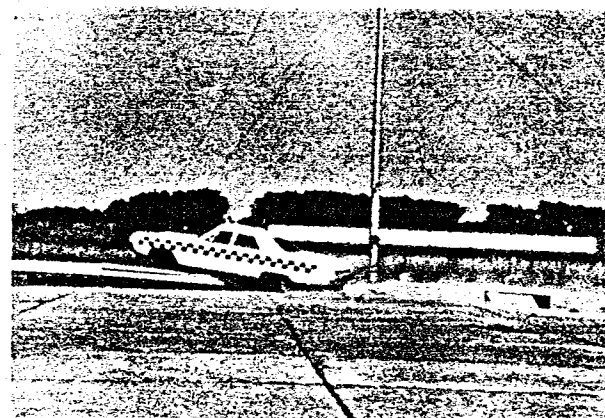
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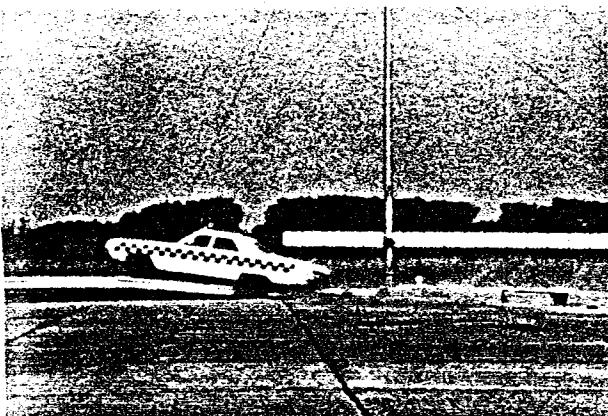
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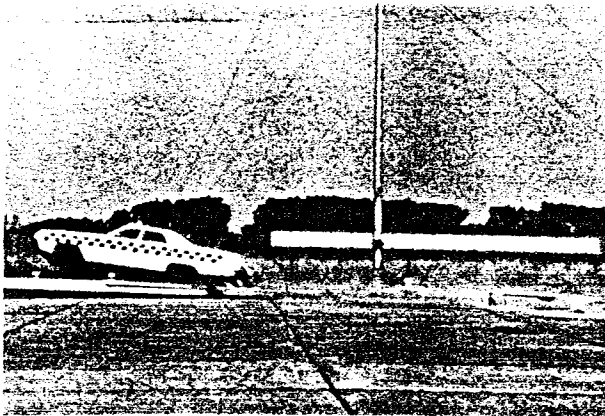
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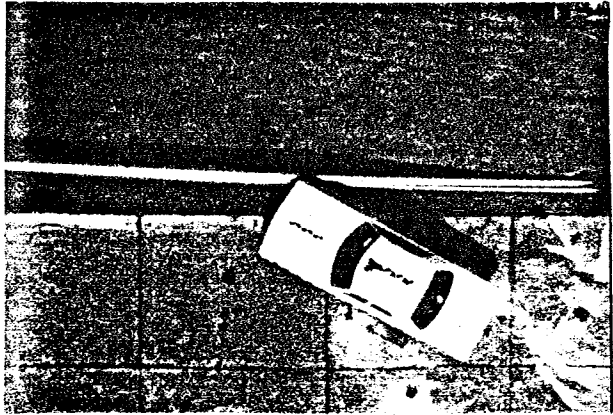


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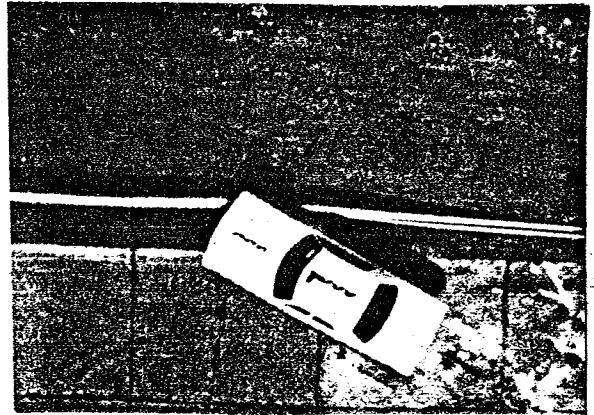
FIGURE A-3. SEQUENTIAL PHOTOGRAPHS DURING TEST 2A.
(Side view)

12
120

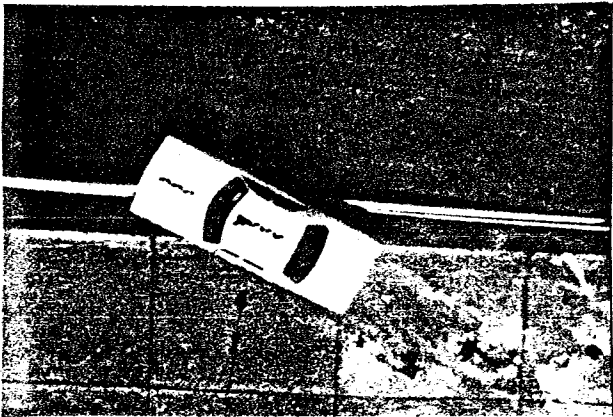
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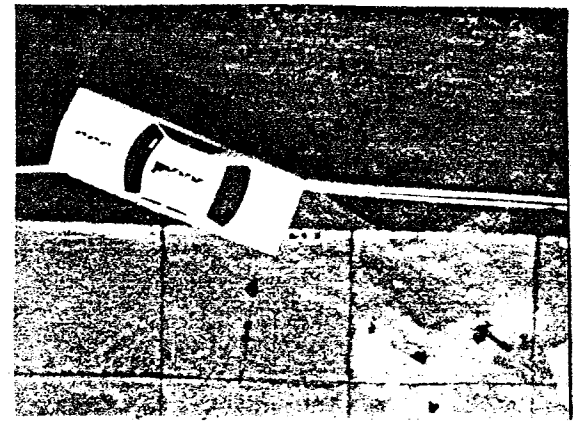
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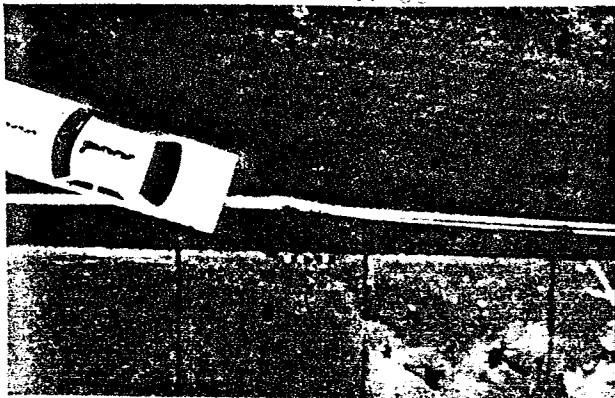
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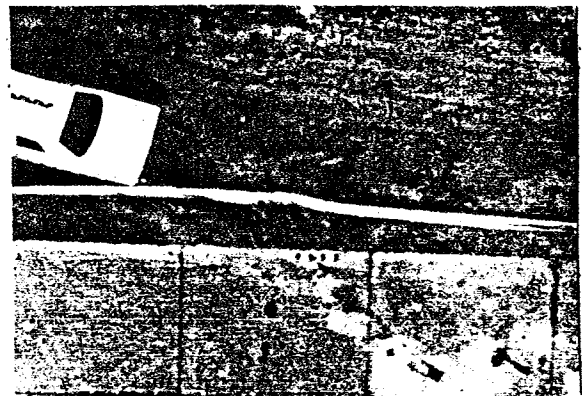
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0.349 SEC



0.448 SEC

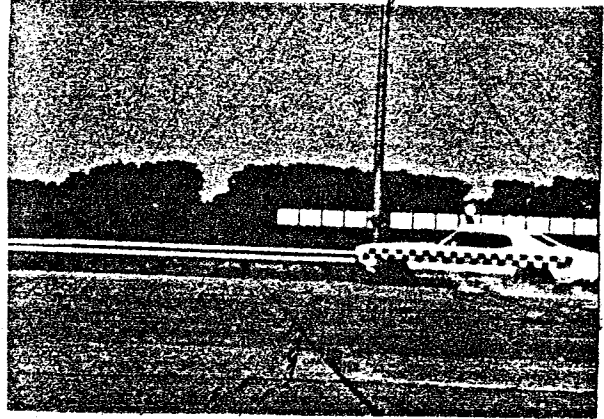
FIGURE A-4. SEQUENTIAL PHOTOGRAPHS DURING TEST 2A.
(Overhead view)

$\frac{8}{130}$

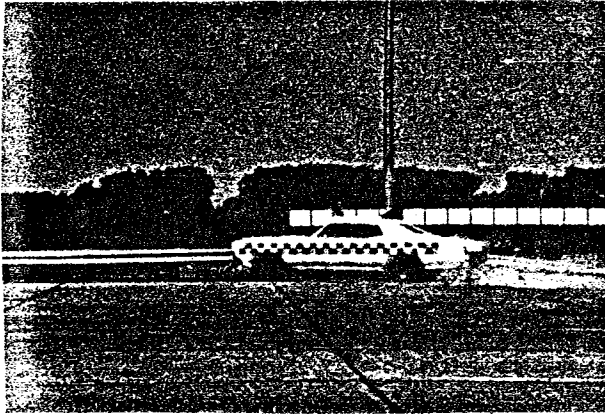
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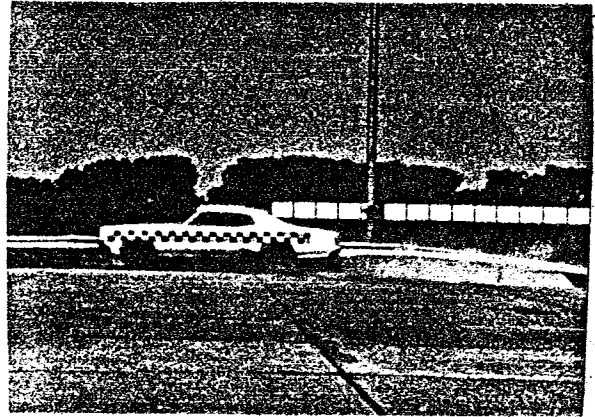
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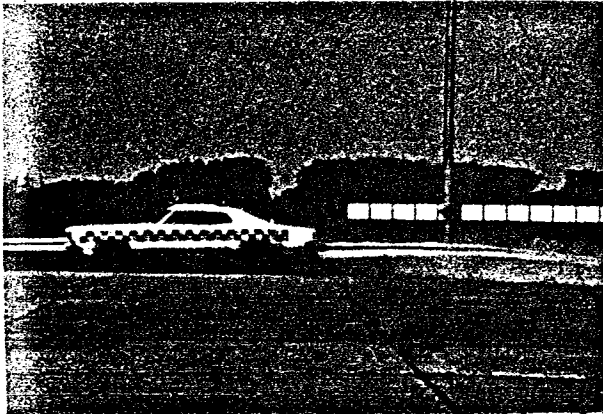
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0.137 SEC



0.266 SEC



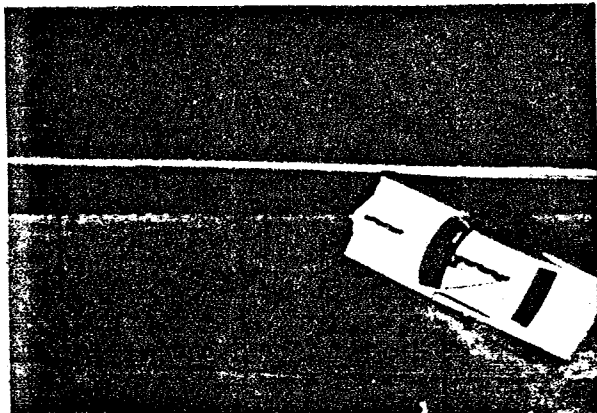
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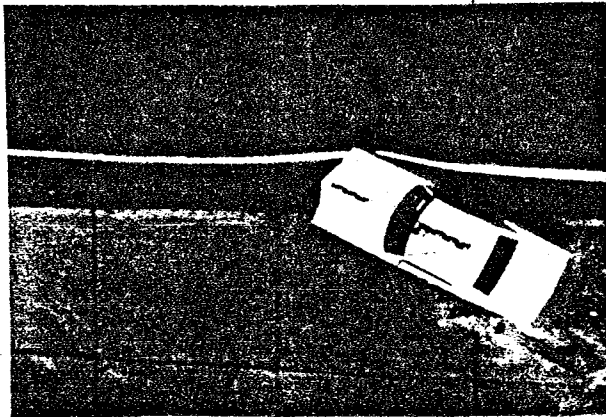
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FIGURE A-5. SEQUENTIAL PHOTOGRAPHS DURING TEST 2B.
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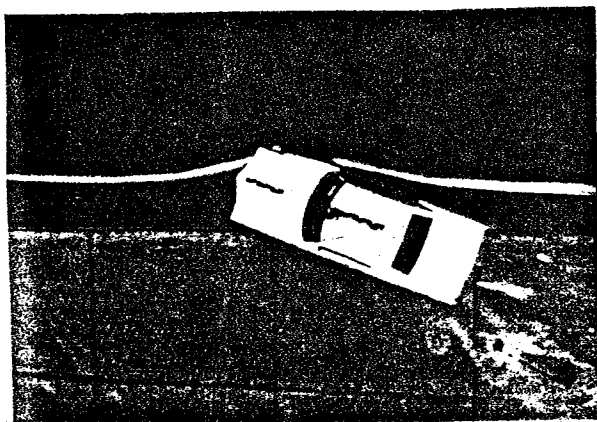
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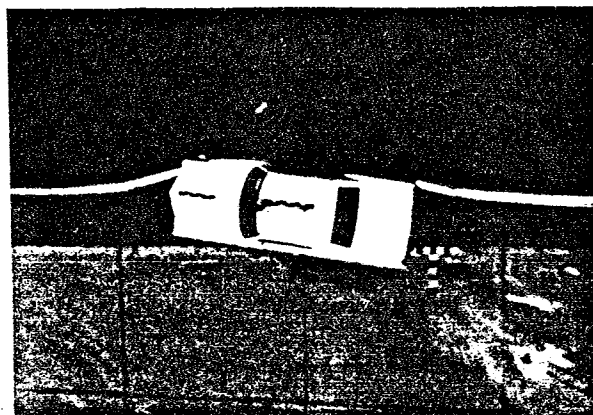
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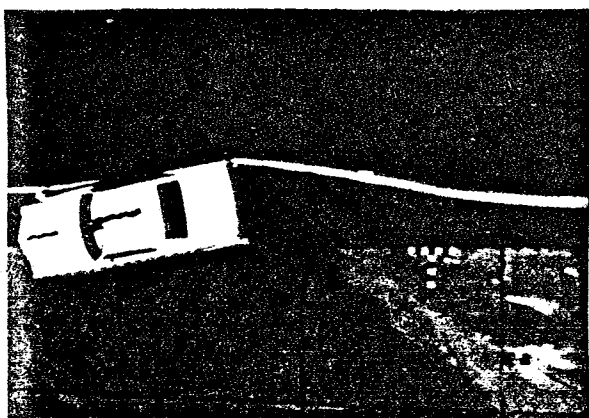
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0.236 SEC



0.444 SEC

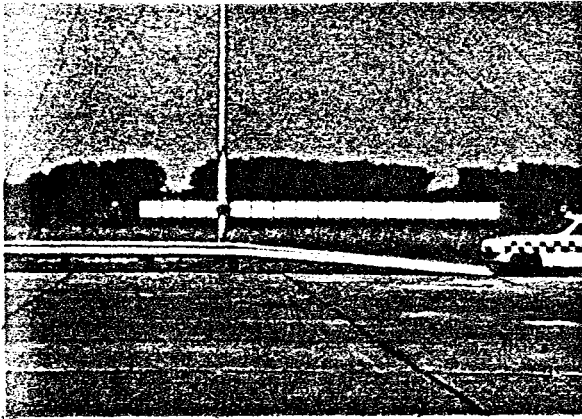


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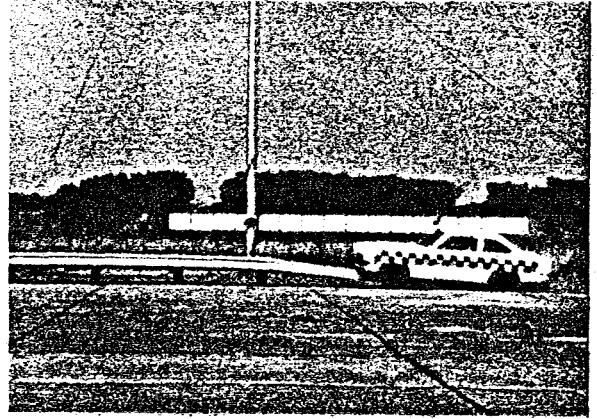
FIGURE A-6. SEQUENTIAL PHOTOGRAPHS DURING TEST 2B.
(Overhead view)

12
130

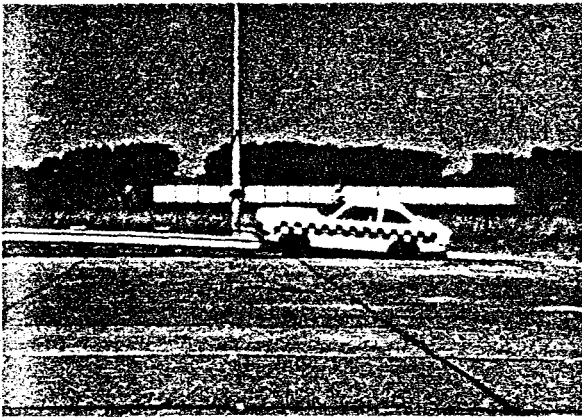
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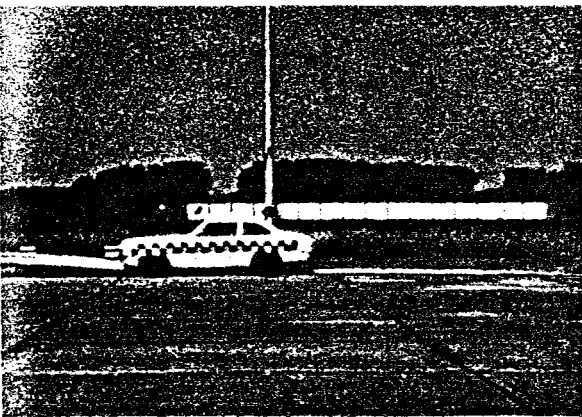
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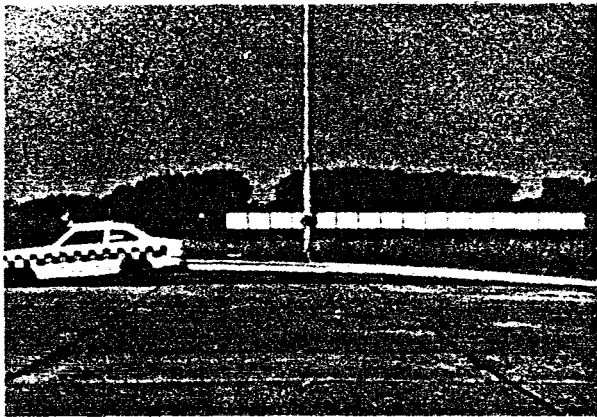
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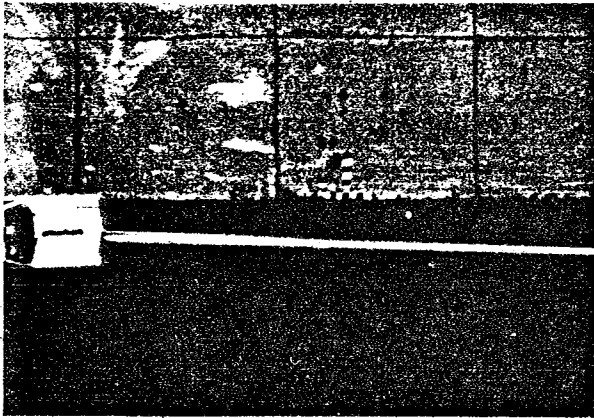
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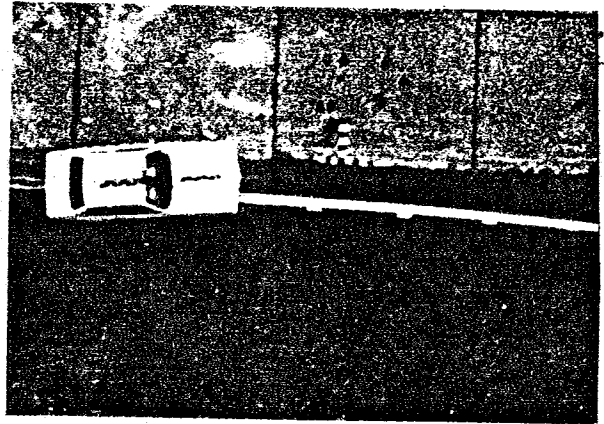
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FIGURE A-7. SEQUENTIAL PHOTOGRAPHS DURING TEST 3.
(Side view)

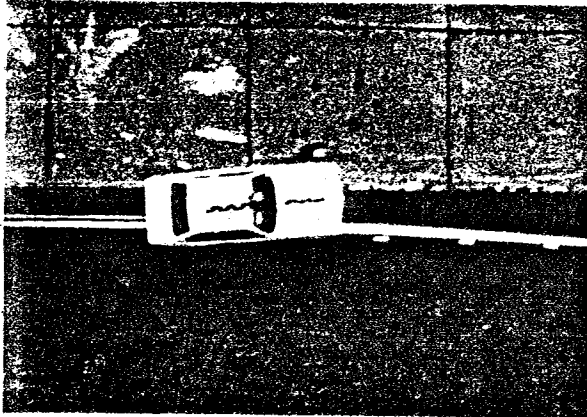
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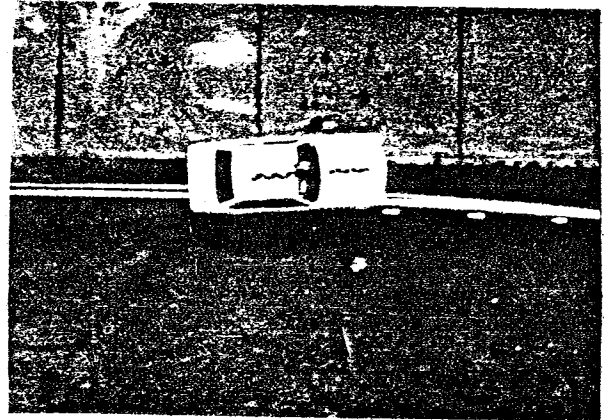
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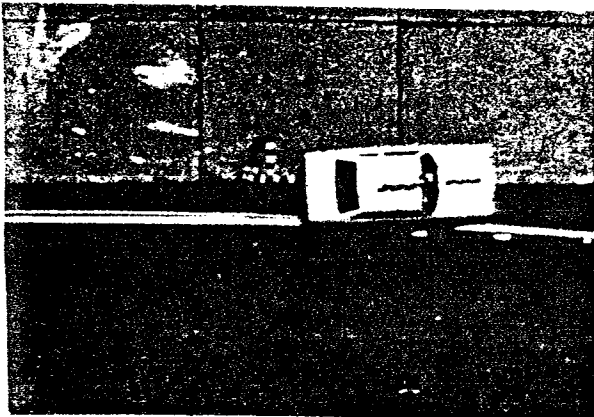
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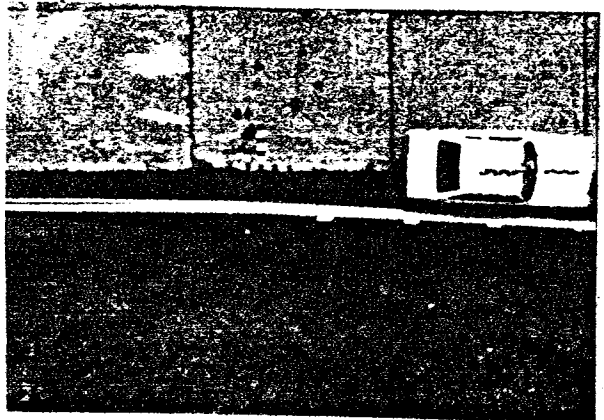
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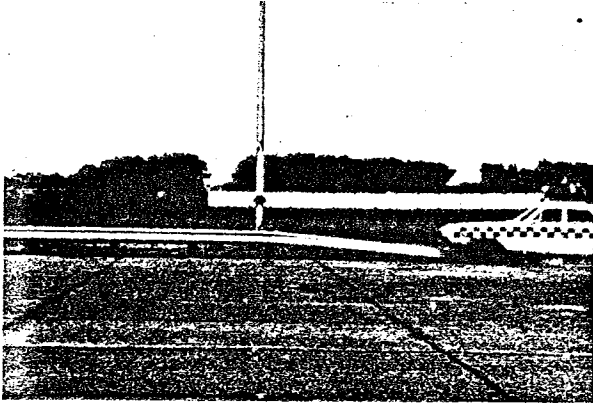
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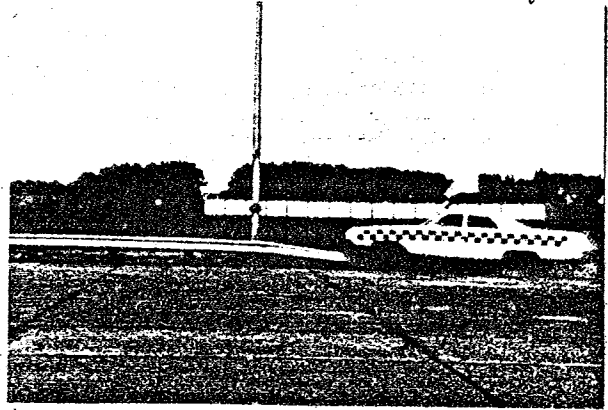
1.092 SEC

FIGURE A-8. SEQUENTIAL PHOTOGRAPHS DURING TEST 3.
(Overhead view)

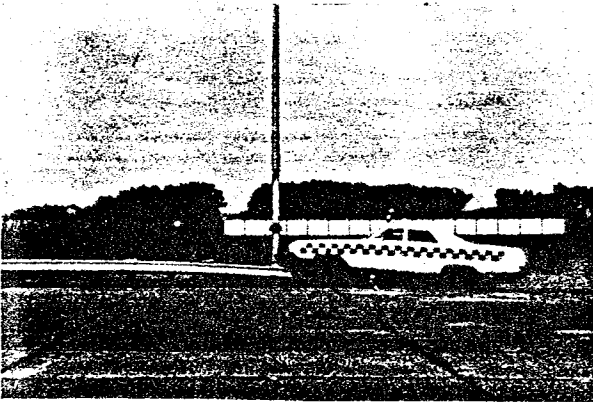
metal plate



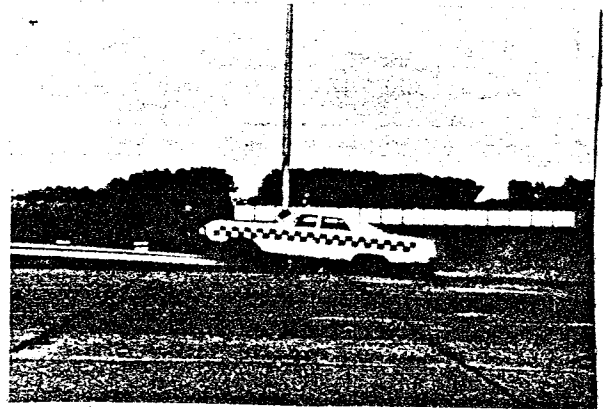
0.000 SEC



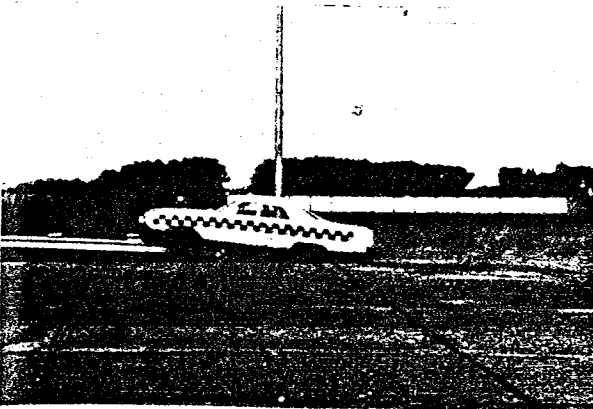
0.092 SEC



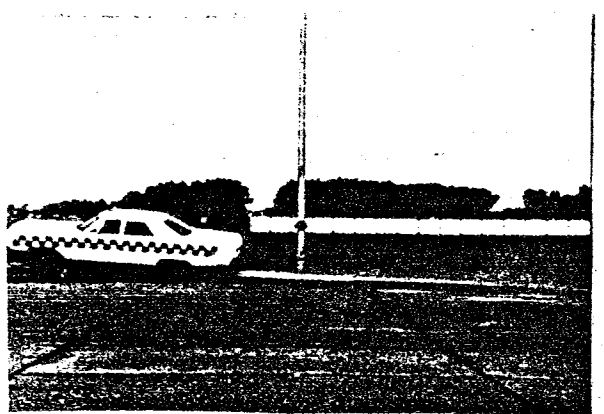
0.166 SEC



0.265 SEC



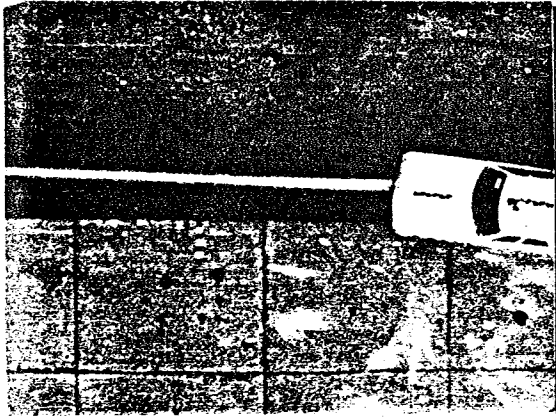
0.324 SEC



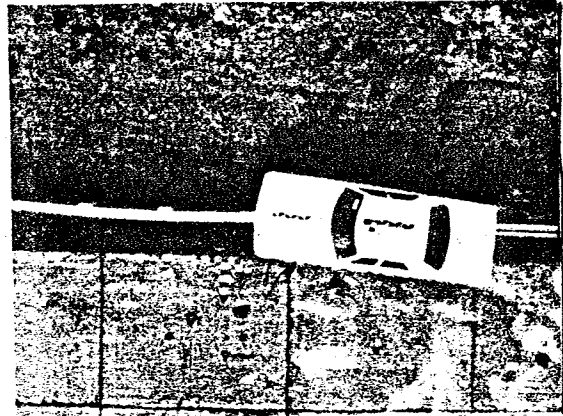
0.507 SEC

FIGURE A-9. SEQUENTIAL PHOTOGRAPHS DURING TEST 4.
(Side view)

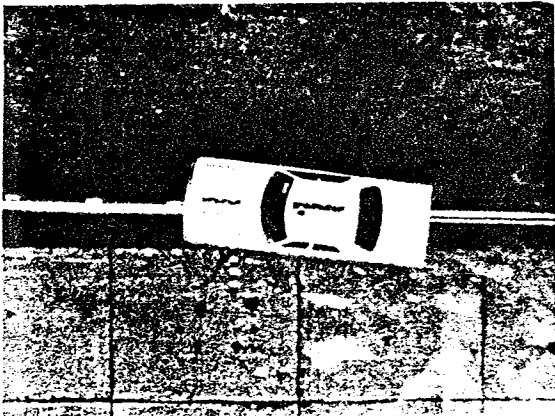
metal plate



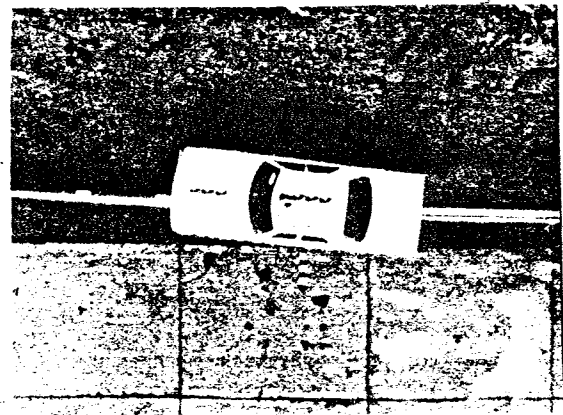
0.000 SEC



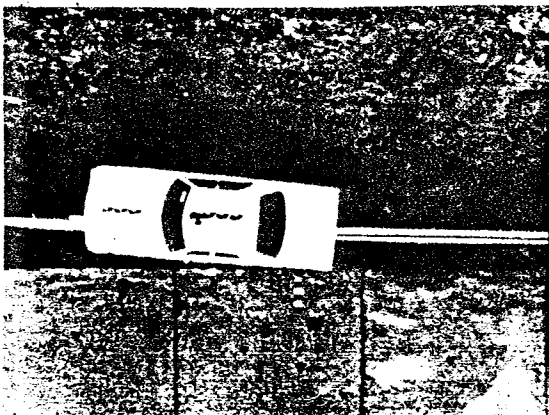
0.159 SEC



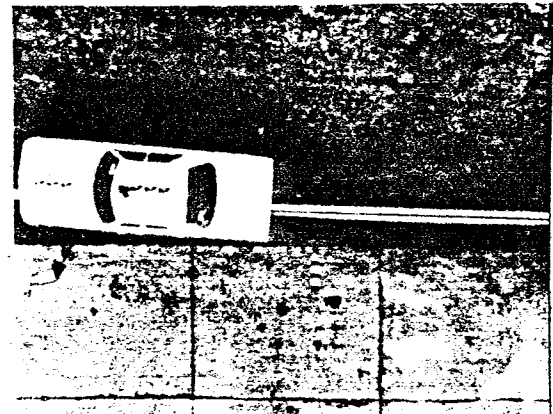
0.233 SEC



0.315 SEC



0.399 SEC



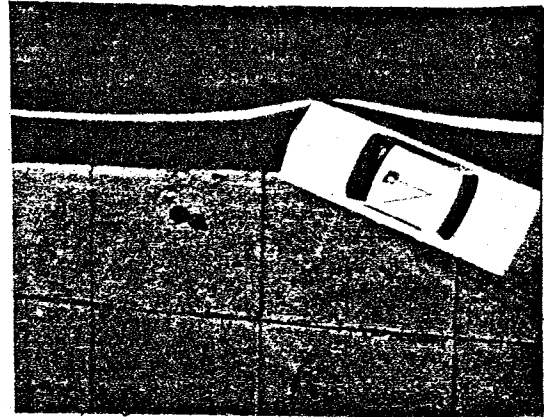
0.491 SEC

FIGURE A-10. SEQUENTIAL PHOTOGRAPHS DURING TEST 4.
(Overhead view)

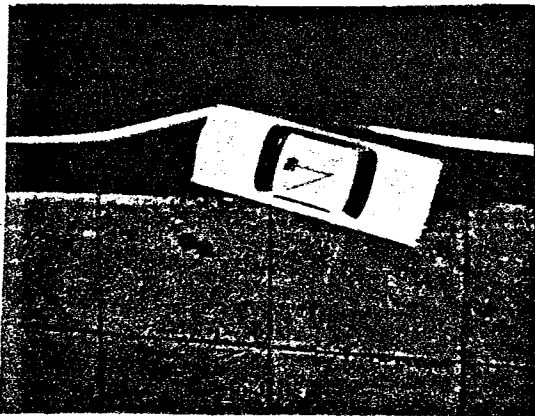
metal plate



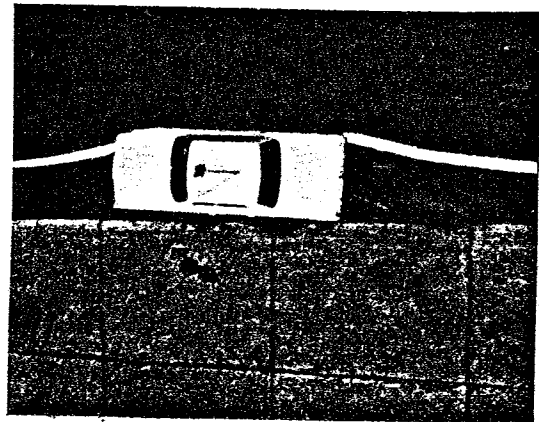
0.000 SEC



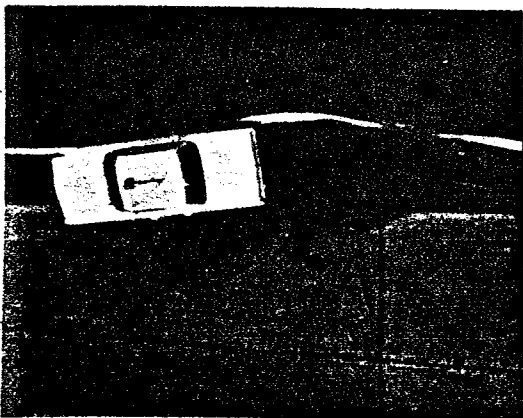
0.075 SEC



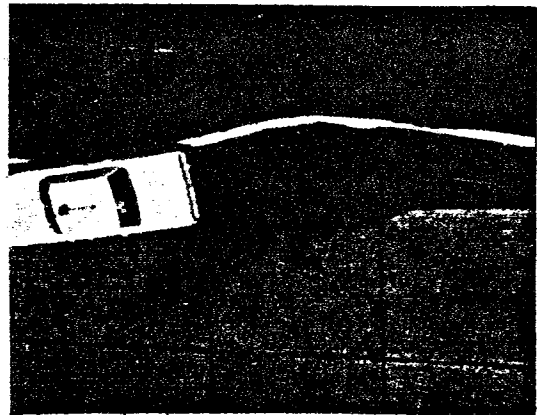
0.175 SEC



0.274 SEC



0.523 SEC



0.623 SEC

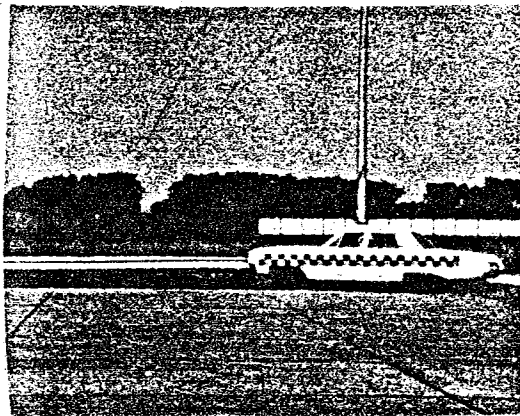
FIGURE A-11. SEQUENTIAL PHOTOGRAPHS DURING TEST 5.
(Overhead view)

12
125

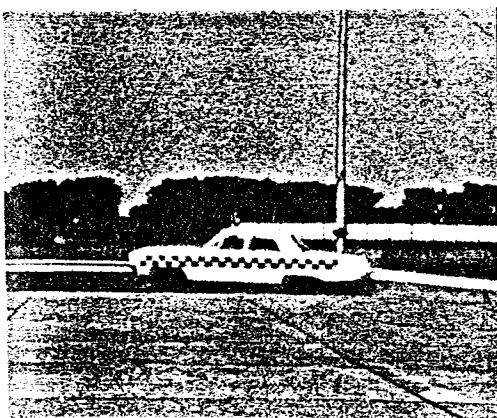
metal plate



0.000 SEC



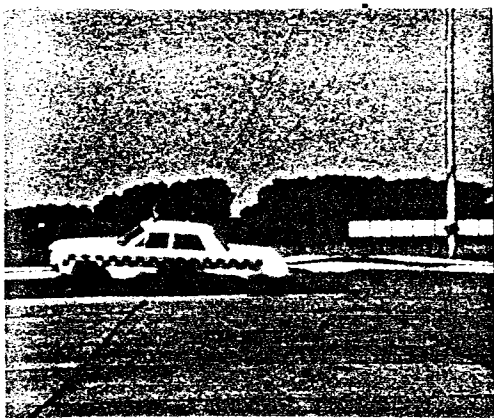
0.103 SEC



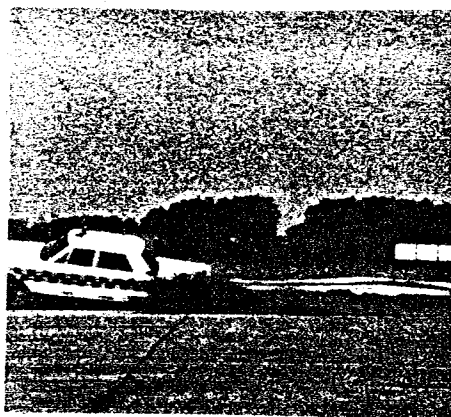
0.205 SEC



0.334 SEC



0.439 SEC

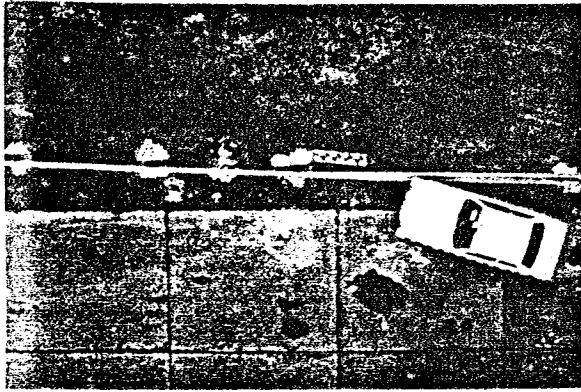


0.591 SEC

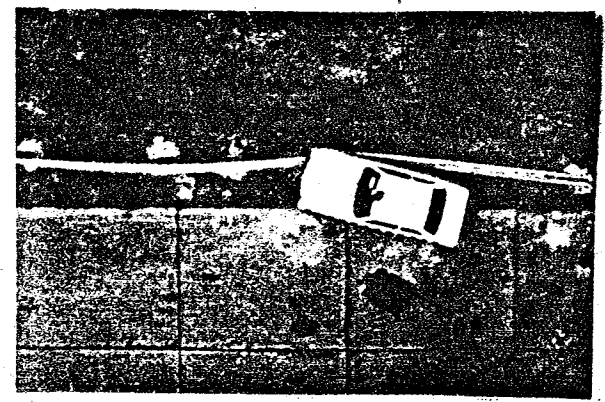
FIGURE A-12. SEQUENTIAL PHOTOGRAPHS DURING TEST 5.
(Side view)

10
115

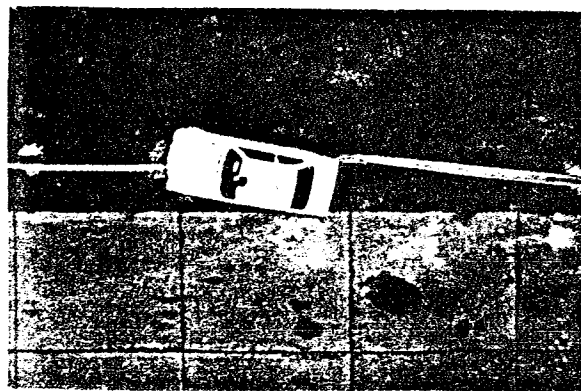
01206-1
metal plate



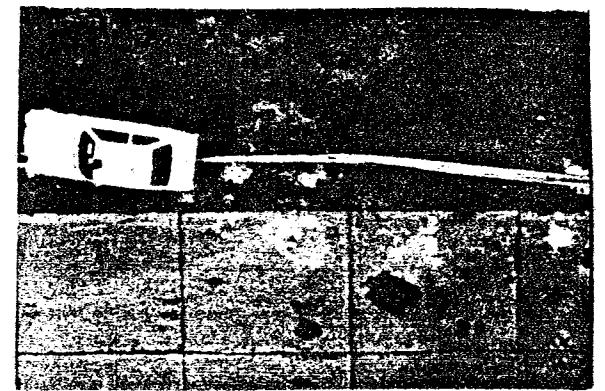
0.000



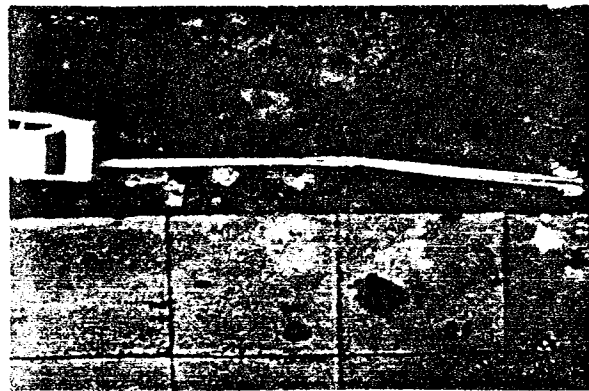
0.116



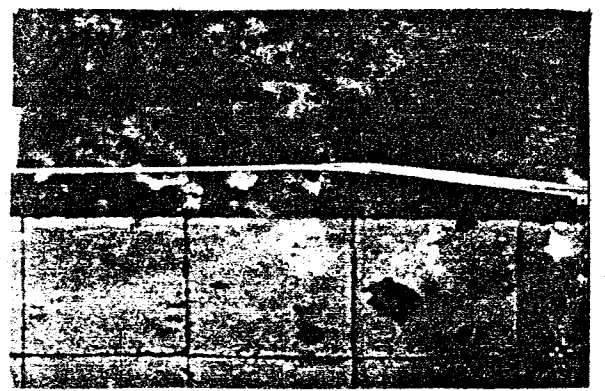
0.267



0.429



0.593

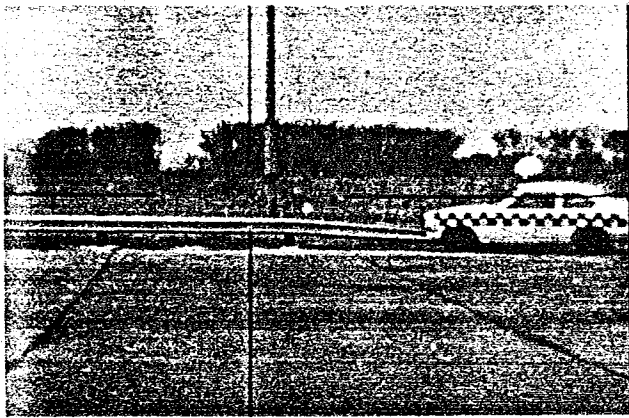


0.661

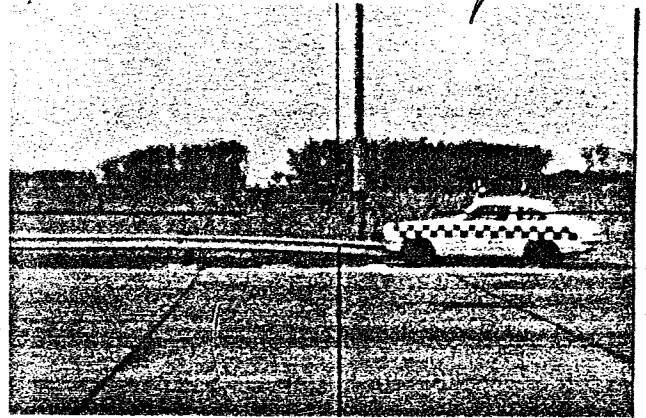
FIGURE A-13. SEQUENTIAL PHOTOGRAPHS OF TEST 6.
(Overhead view)

11
115

metal plate



0.0 sec



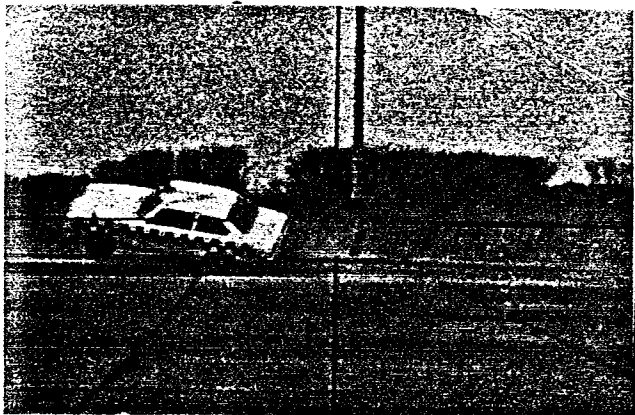
.116 sec



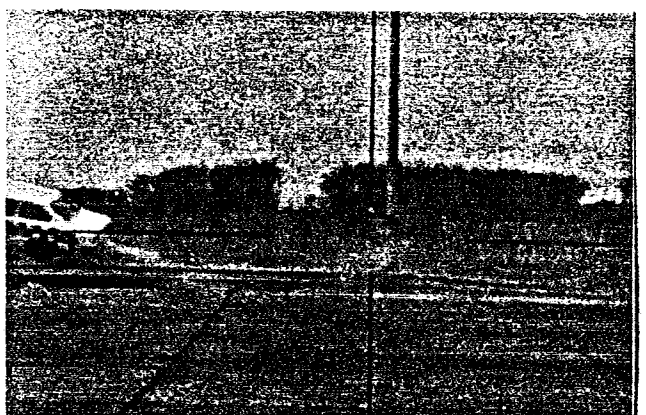
.267 sec



.324 sec



.429 sec



.661 sec

FIGURE A-14. SEQUENTIAL PHOTOGRAPHS OF TEST 6. (SIDE VIEW)

APPENDIX B

ACCELEROMETER TRACES

ACCELEROMETER TRACES

Accelerometer traces obtained from vehicle mounted accelerometers for each of the tests are presented on the following pages. Accelerometers, oriented so as to measure longitudinal and transverse accelerations, were mounted on each side of the test vehicle in the floor of the passenger compartment near the longitudinal position of the vehicle center of gravity. Signals from these accelerometers were telemetered to a receiving station and recorded on FM magnetic tape. Filtered analog traces were then produced from these magnetic tape records. The filter used was a 100 hertz low pass filter with a roll-off of 48 decibels per octave.

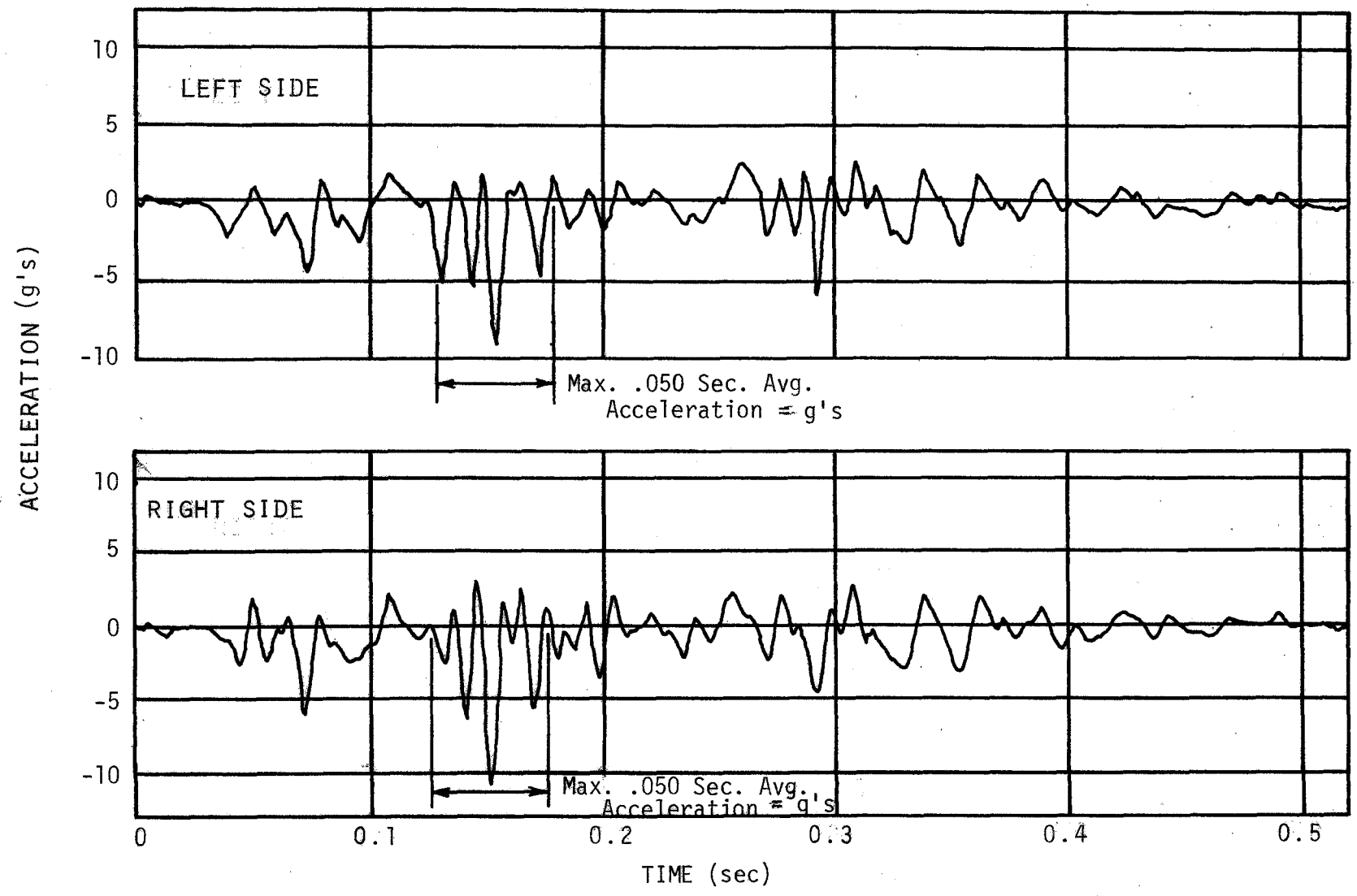


FIGURE B1. LONGITUDINAL VEHICLE ACCELEROMETER TRACES FOR TEST 1.
(100 Hz low pass filter)

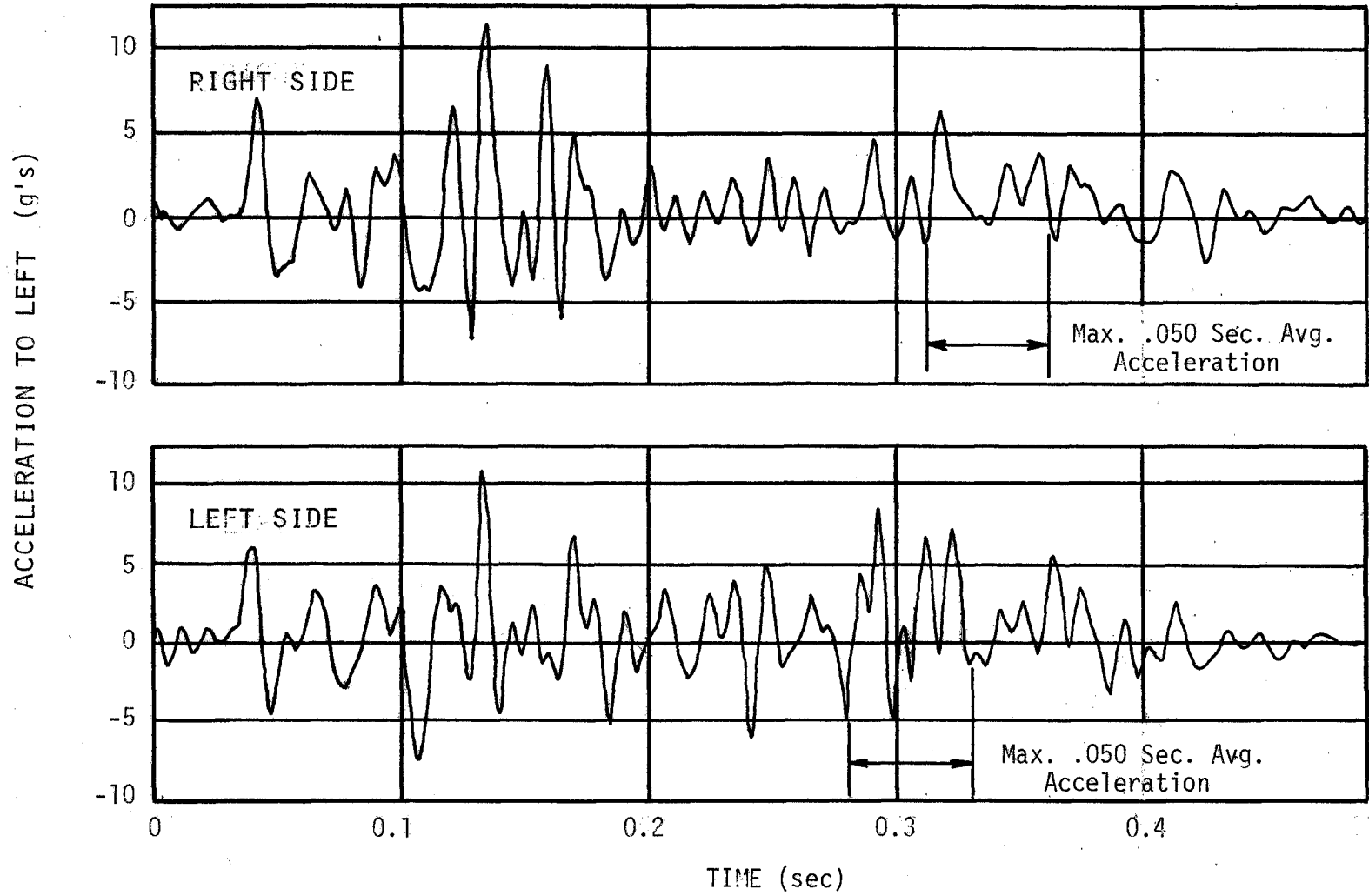


FIGURE B2 . TRANSVERSE VEHICLE ACCELEROMETER TRACES FOR TEST 1.
(100 Hz low pass filter)

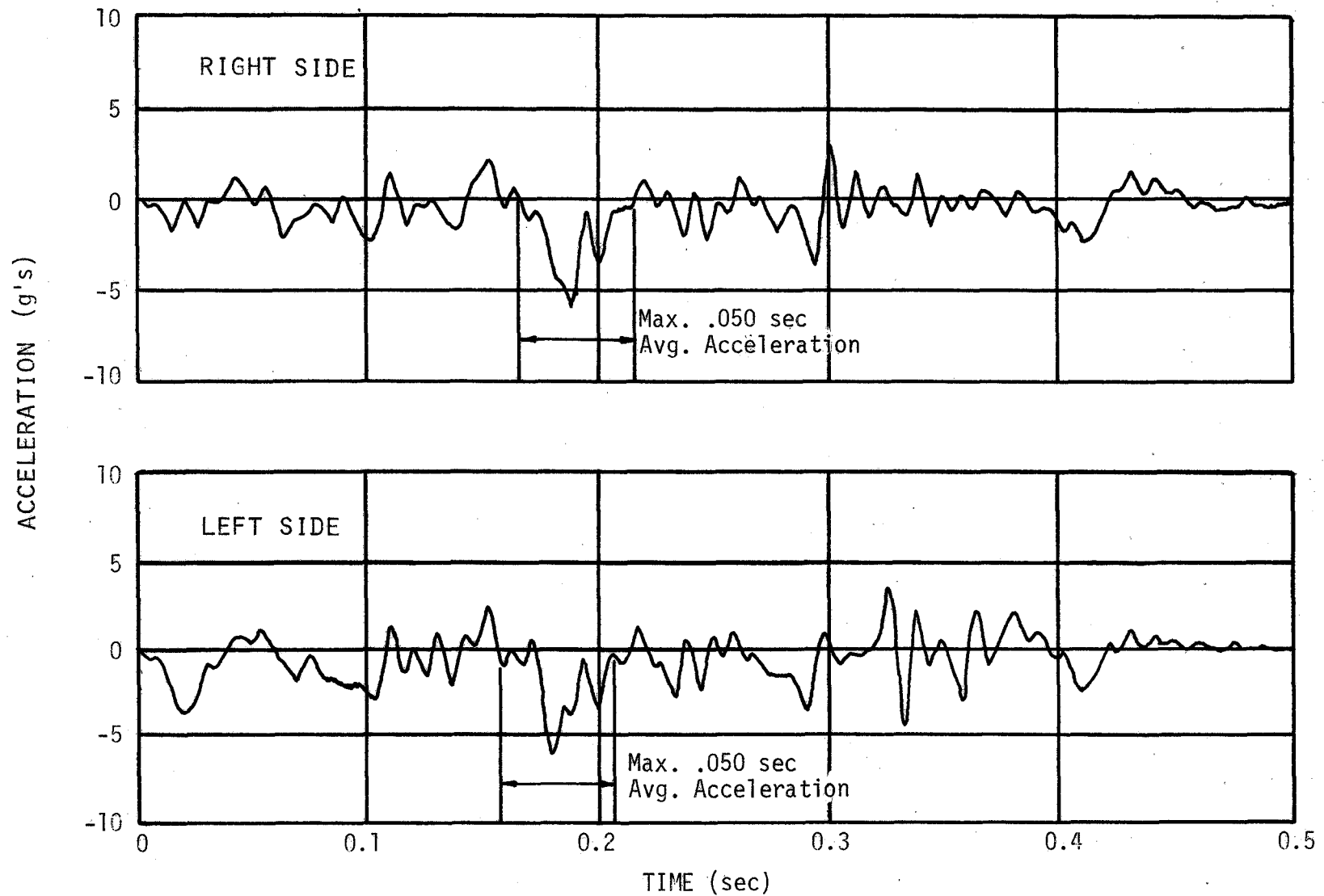


FIGURE B3. LONGITUDINAL VEHICLE ACCELEROMETER TRACES FOR TEST 2.
(100 Hz low pass filter)

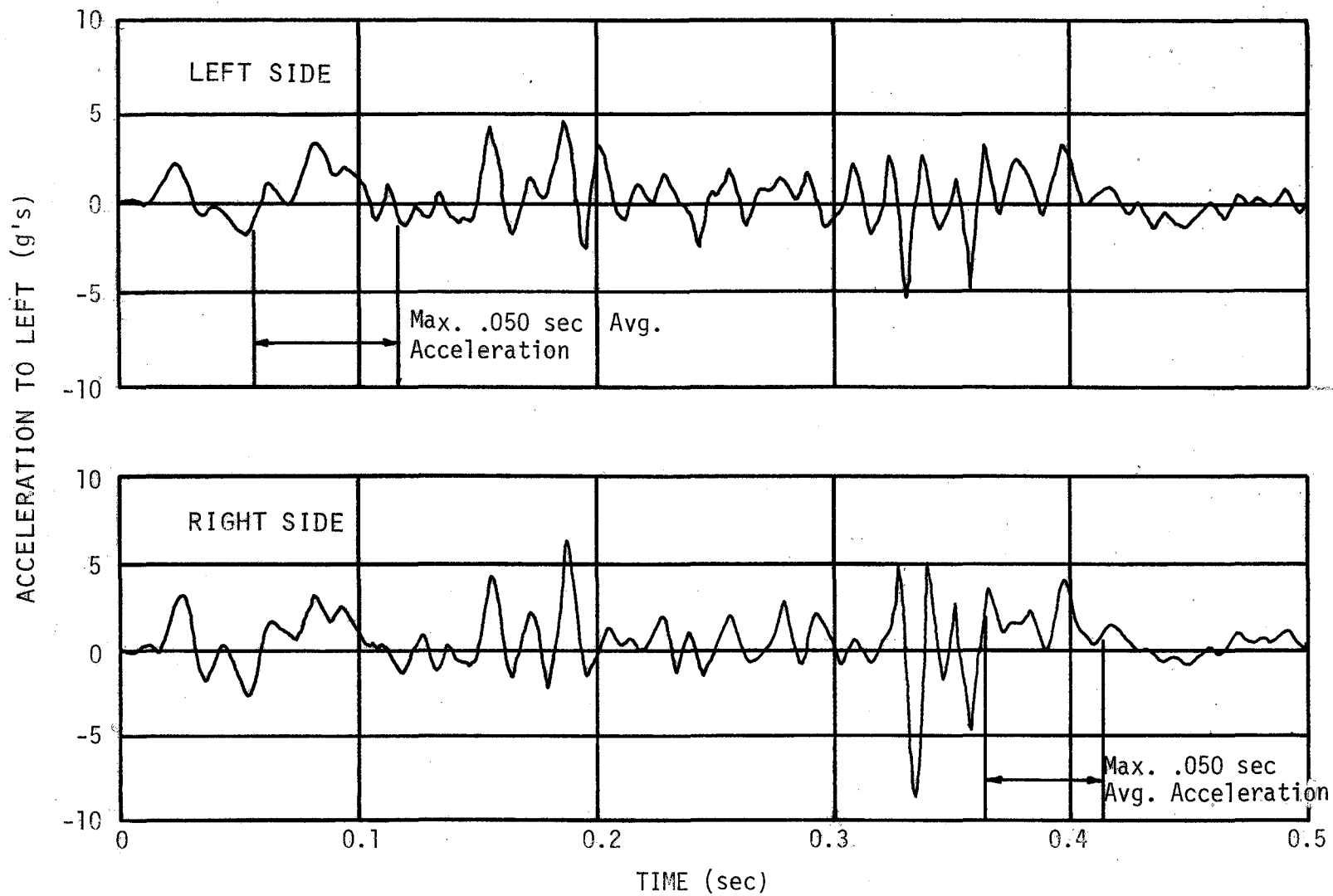


FIGURE B4. TRANSVERSE VEHICLE ACCELEROMETER TRACES FOR TEST 2.
(100 Hz low pass filter)

ACCELERATION (g's)

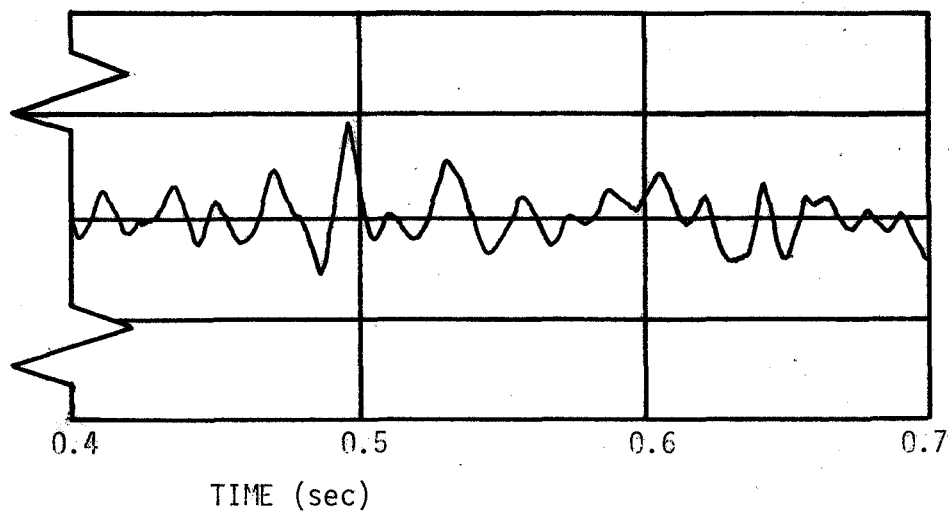
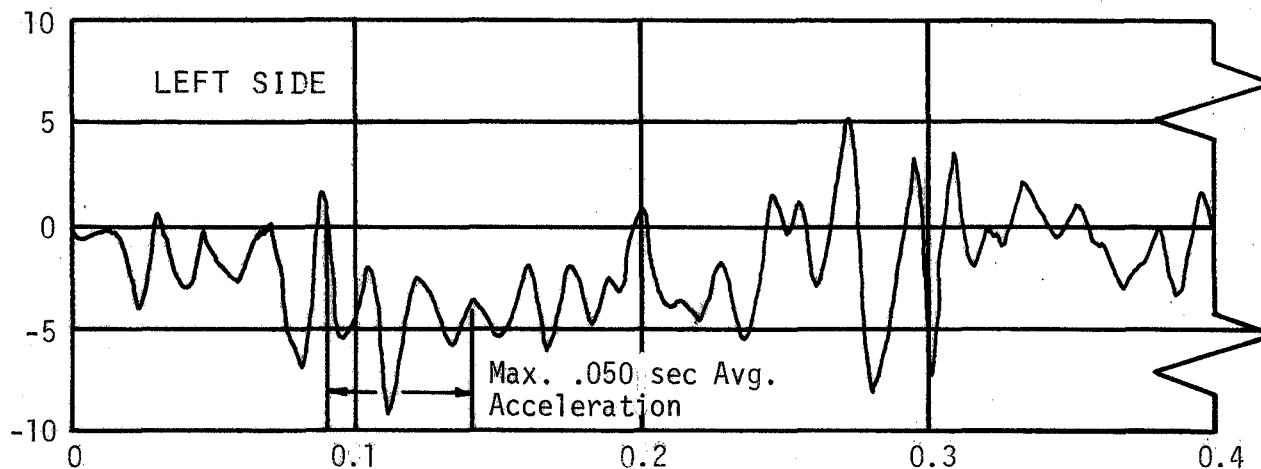


FIGURE B5. LONGITUDINAL VEHICLE ACCELEROMETER TRACES FOR TEST 2b.
(100 Hz low pass filter)

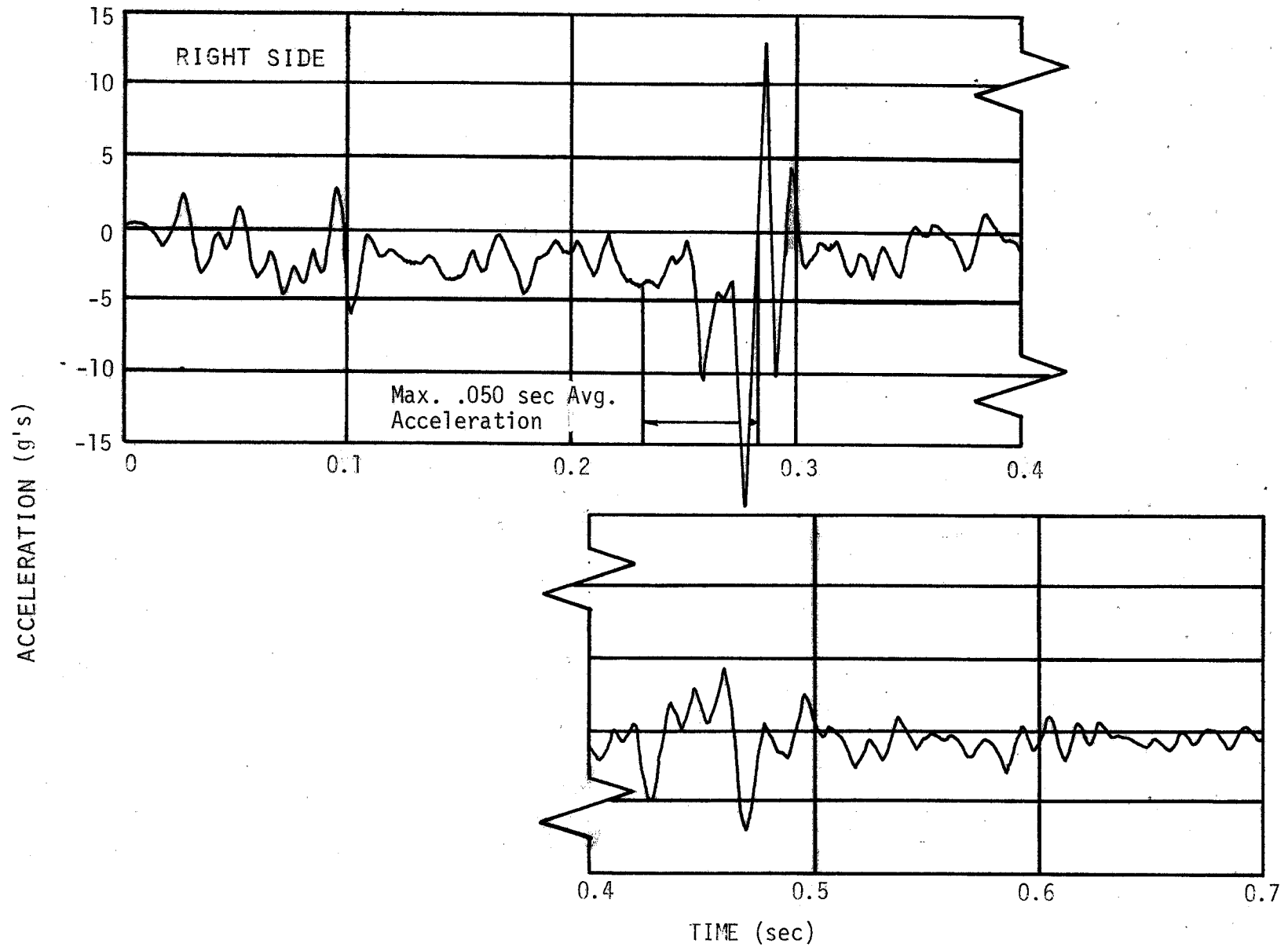


FIGURE B5. CONTINUED. LONGITUDINAL VEHICLE ACCELEROMETER TRACES FOR TEST 2B.
(100 Hz low pass filter)

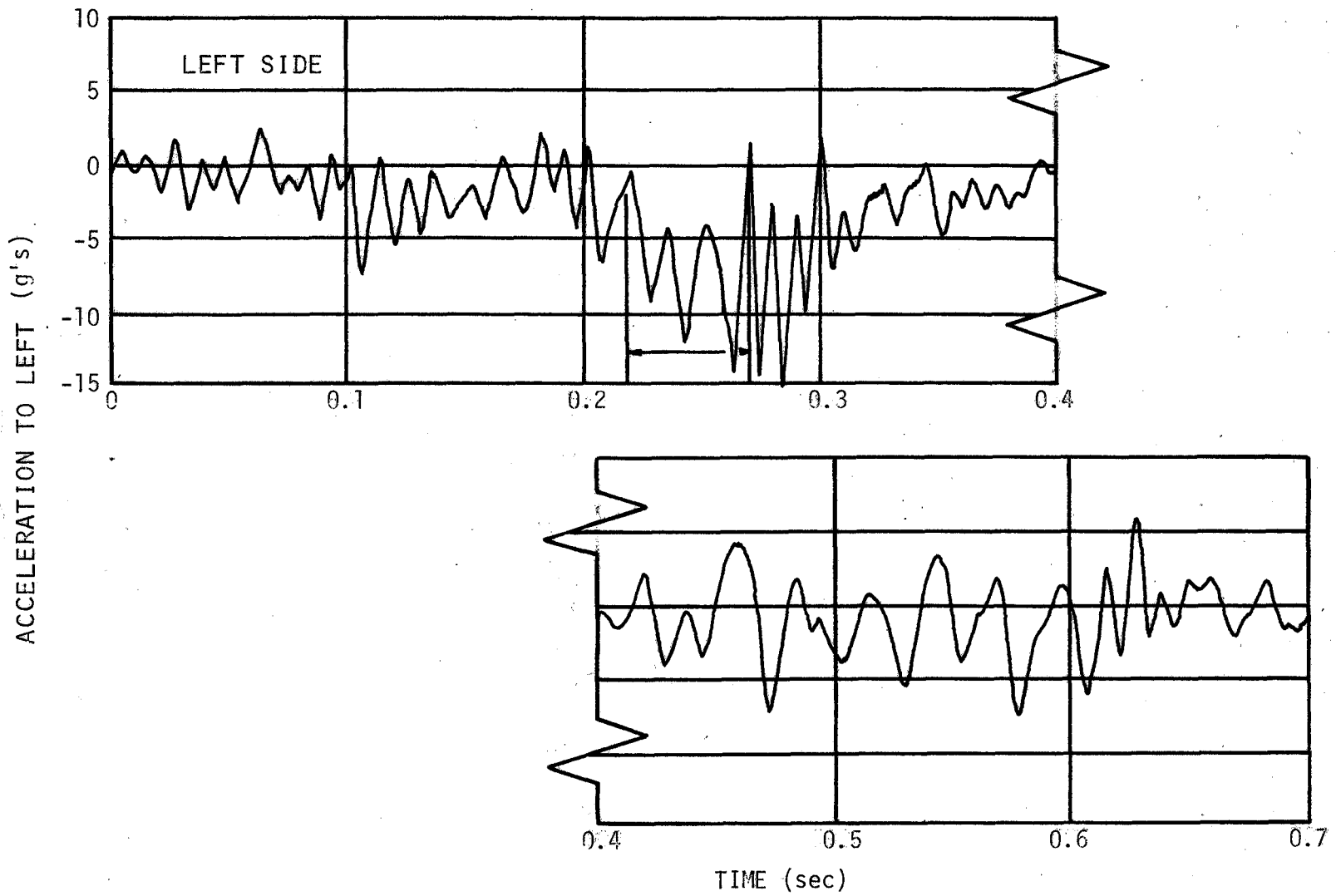


FIGURE 66. TRANSVERSE VEHICLE ACCELEROMETER TRACES FOR TEST 2b.
(100 Hz low pass filter)

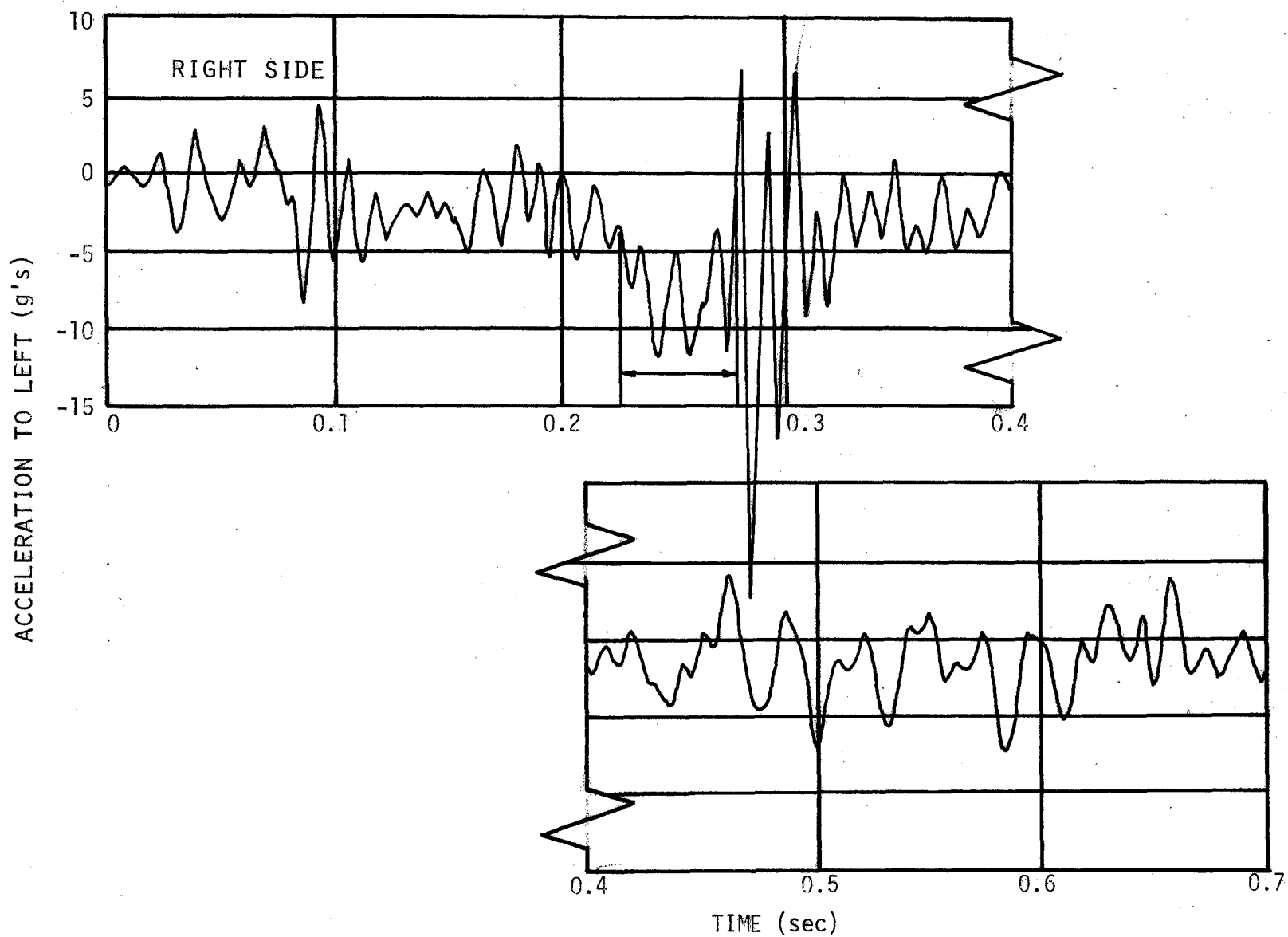


FIGURE B.5. CONTINUED. TRANSVERSE VEHICLE ACCELEROMETER TRACES FOR TEST 2B
(100 Hz low pass filter)

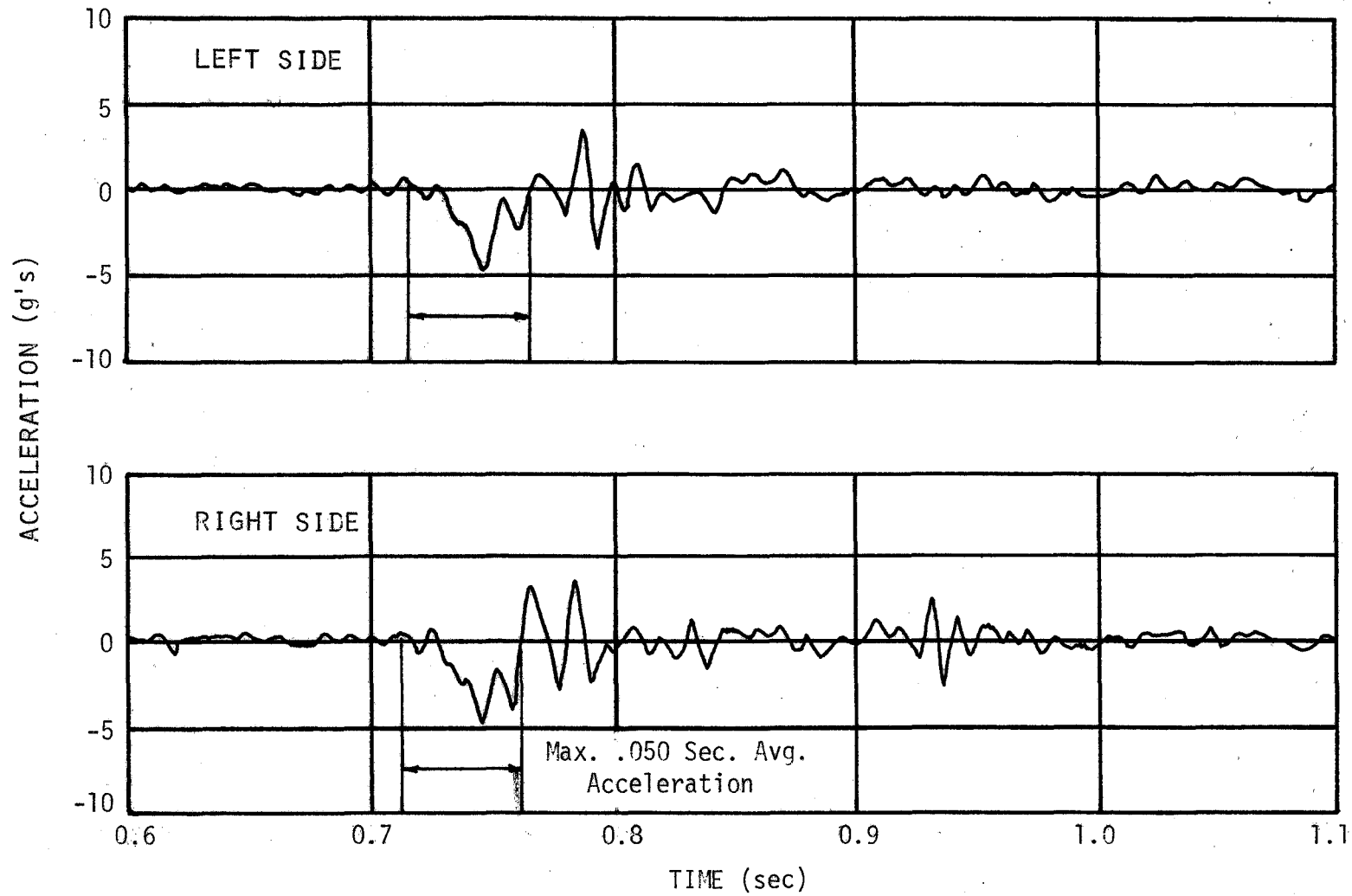


FIGURE B7. LONGITUDINAL VEHICLE ACCELEROMETER TRACES FOR TEST 3.
(100 Hz low pass filter)

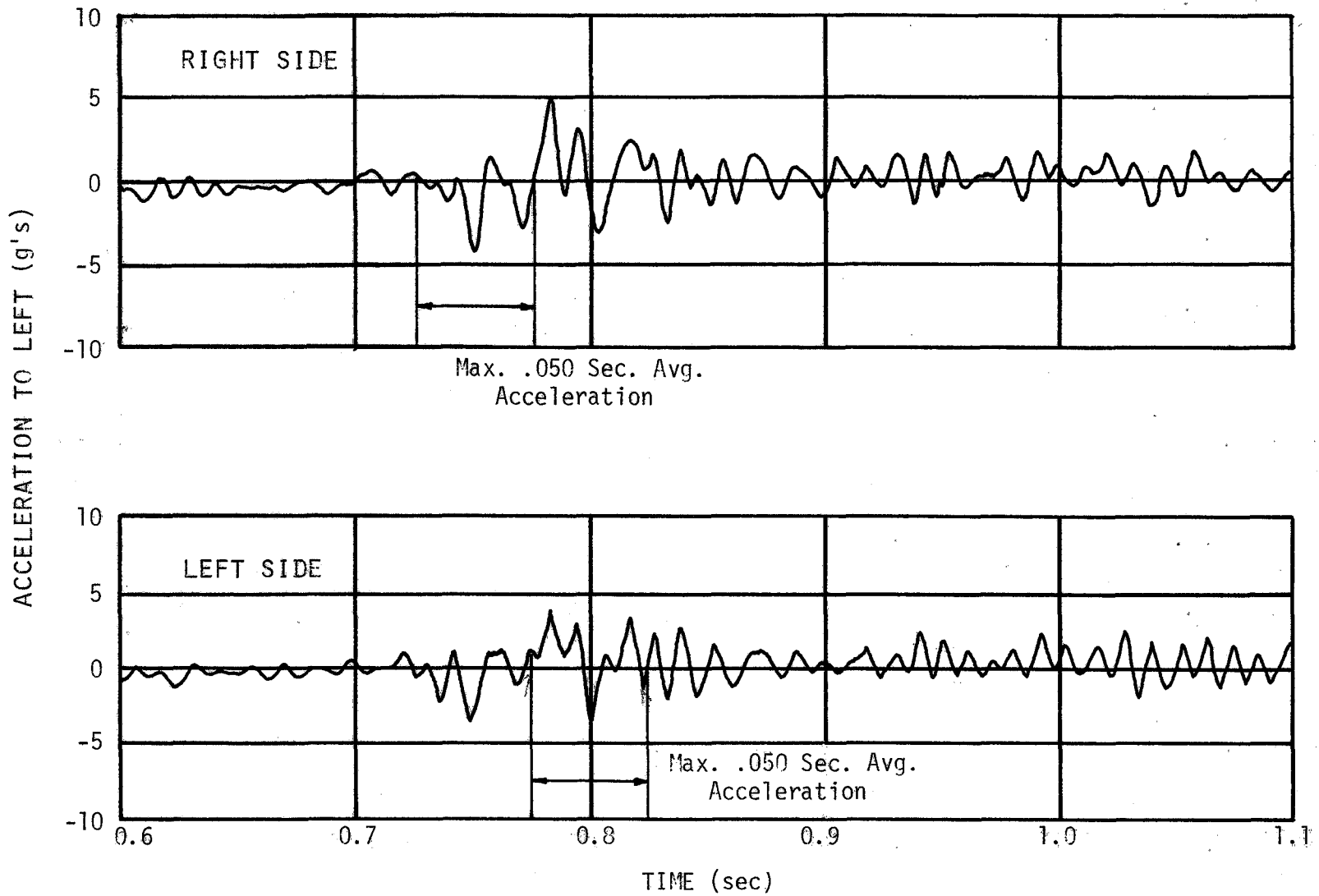
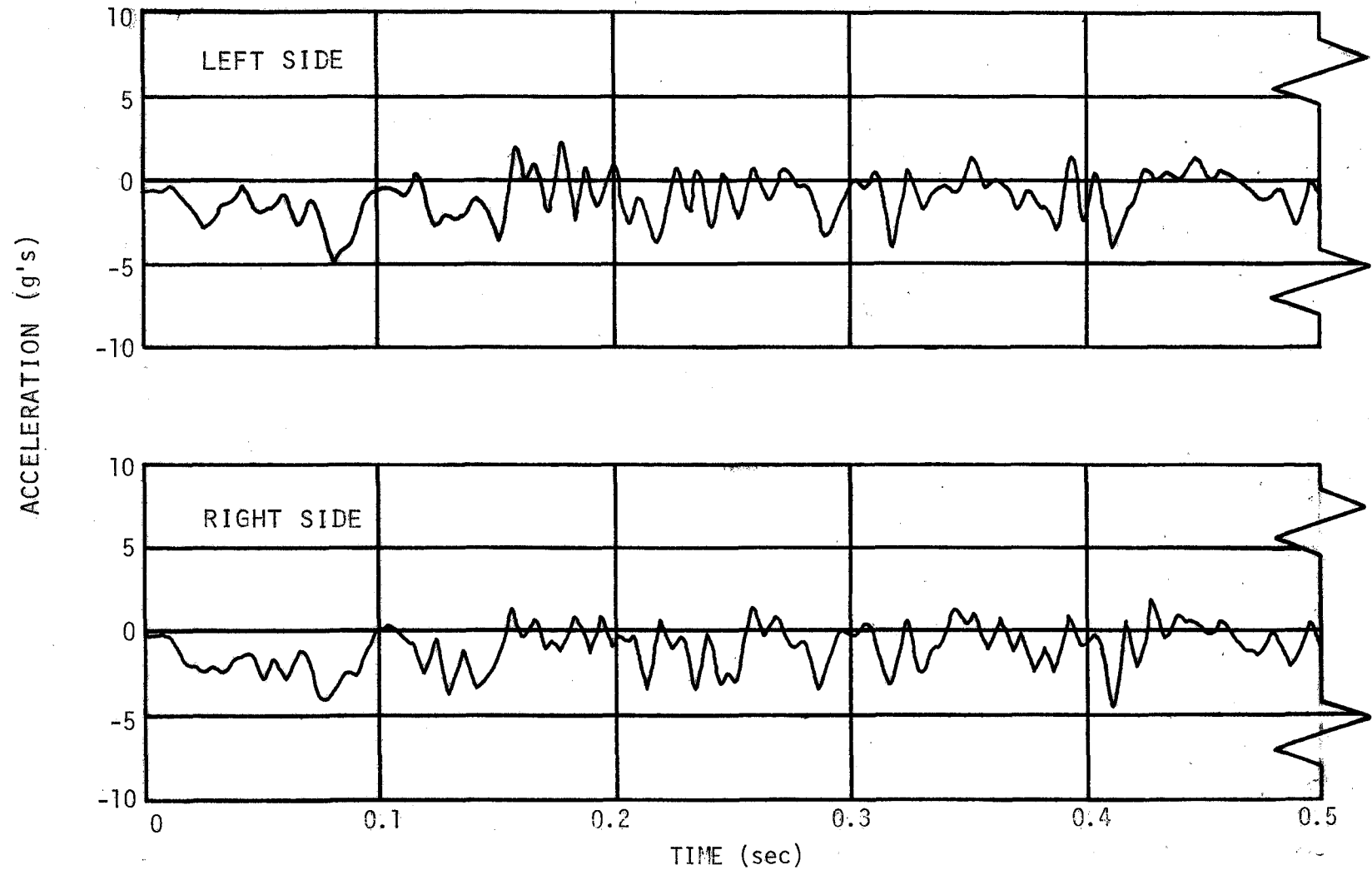


FIGURE B8. TRANSVERSE VEHICLE ACCELEROMETER TRACES FOR TEST 3.
(100 Hz low pass filter)

2184-4
LONG



08

FIGURE B9. LONGITUDINAL VEHICLE ACCELEROMETER TRACES FOR TEST 4.
(100 Hz low pass filter)

2189-4
LONG.
REP. SAMPLE

ACCELERATION (g's)

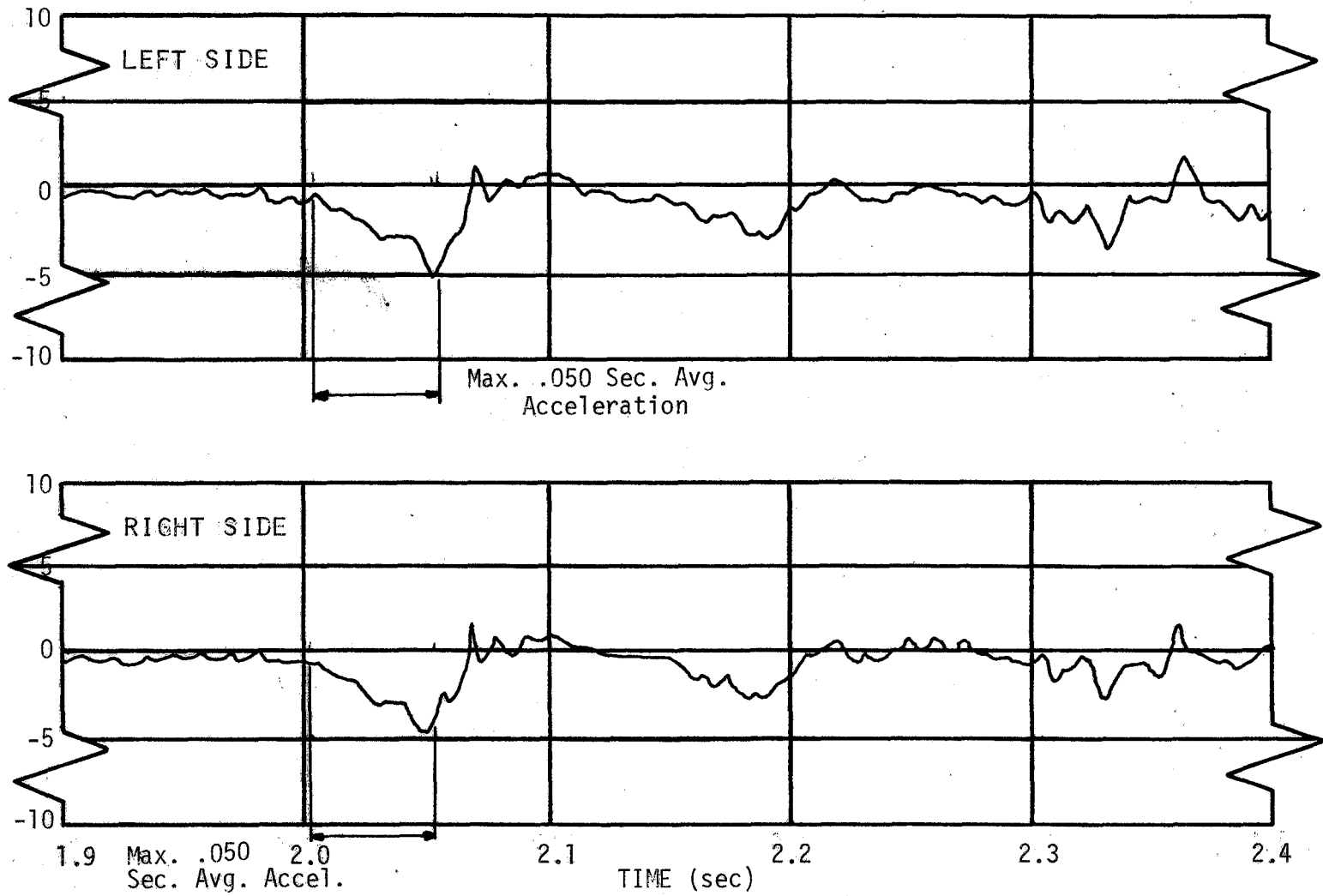


FIGURE B9. CONTINUED. LONGITUDINAL VEHICLE ACCELEROMETER TRACES FOR TEST 4
(100 Hz low pass filter)

2189-A
TRANS

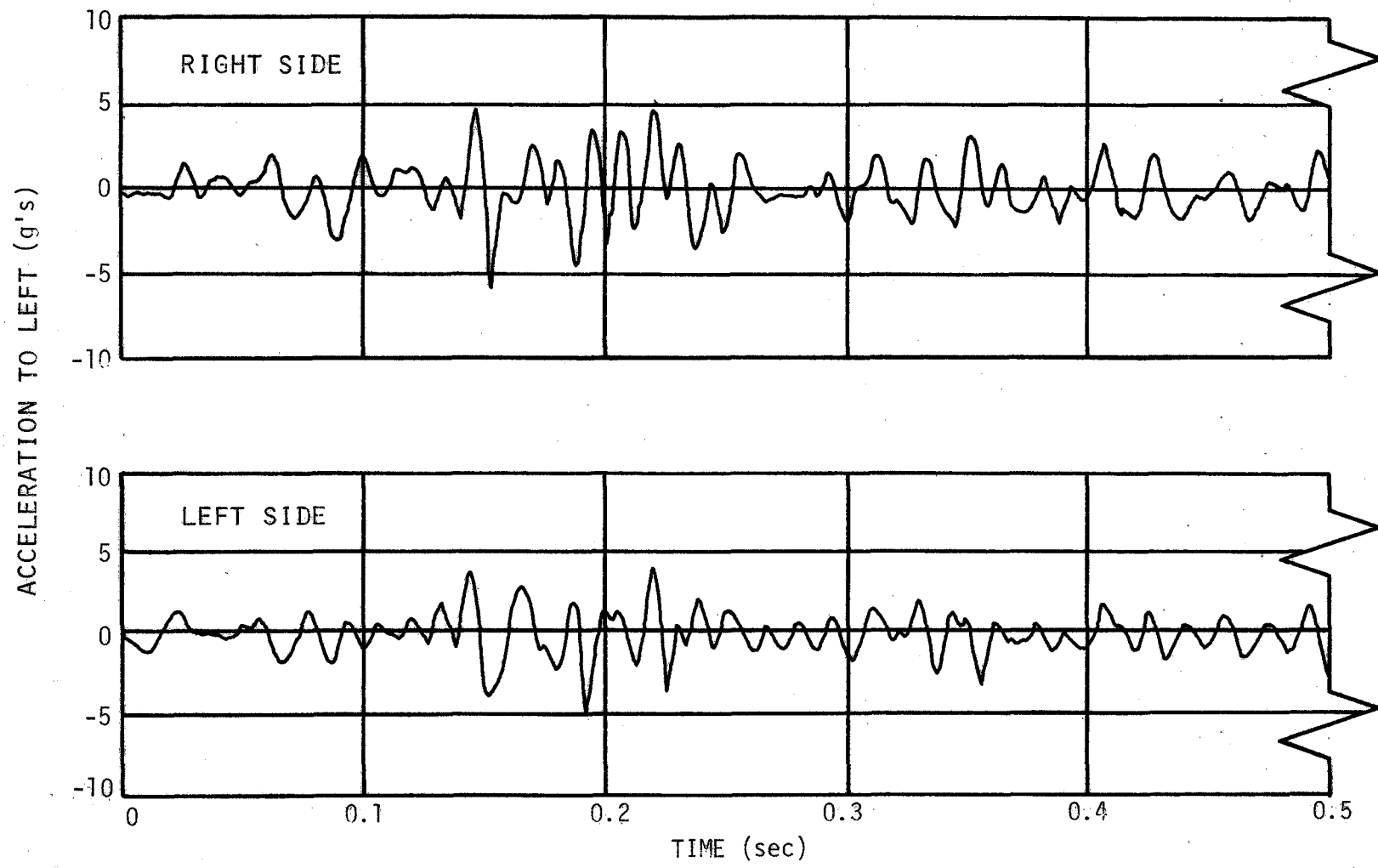


FIGURE B10. TRANSVERSE VEHICLE ACCELEROMETER TRACES FOR TEST 4.
(100 Hz low pass filter)

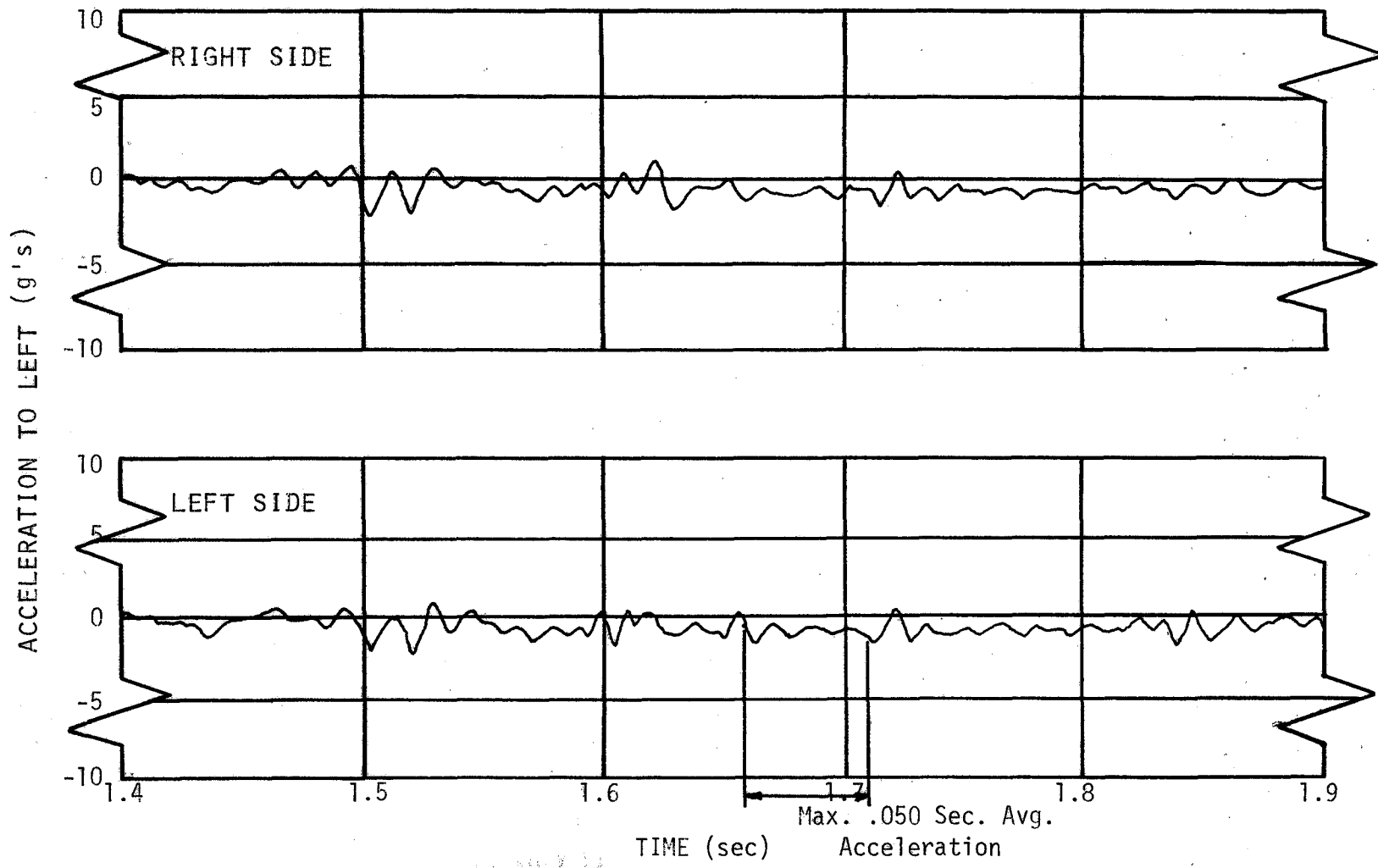


FIGURE B10. CONTINUED. TRANSVERSE VEHICLE ACCELEROMETER TRACES FOR TEST 4.
(100 Hz low pass filter)

2189-4
TRANS.
REP. SAMPLE

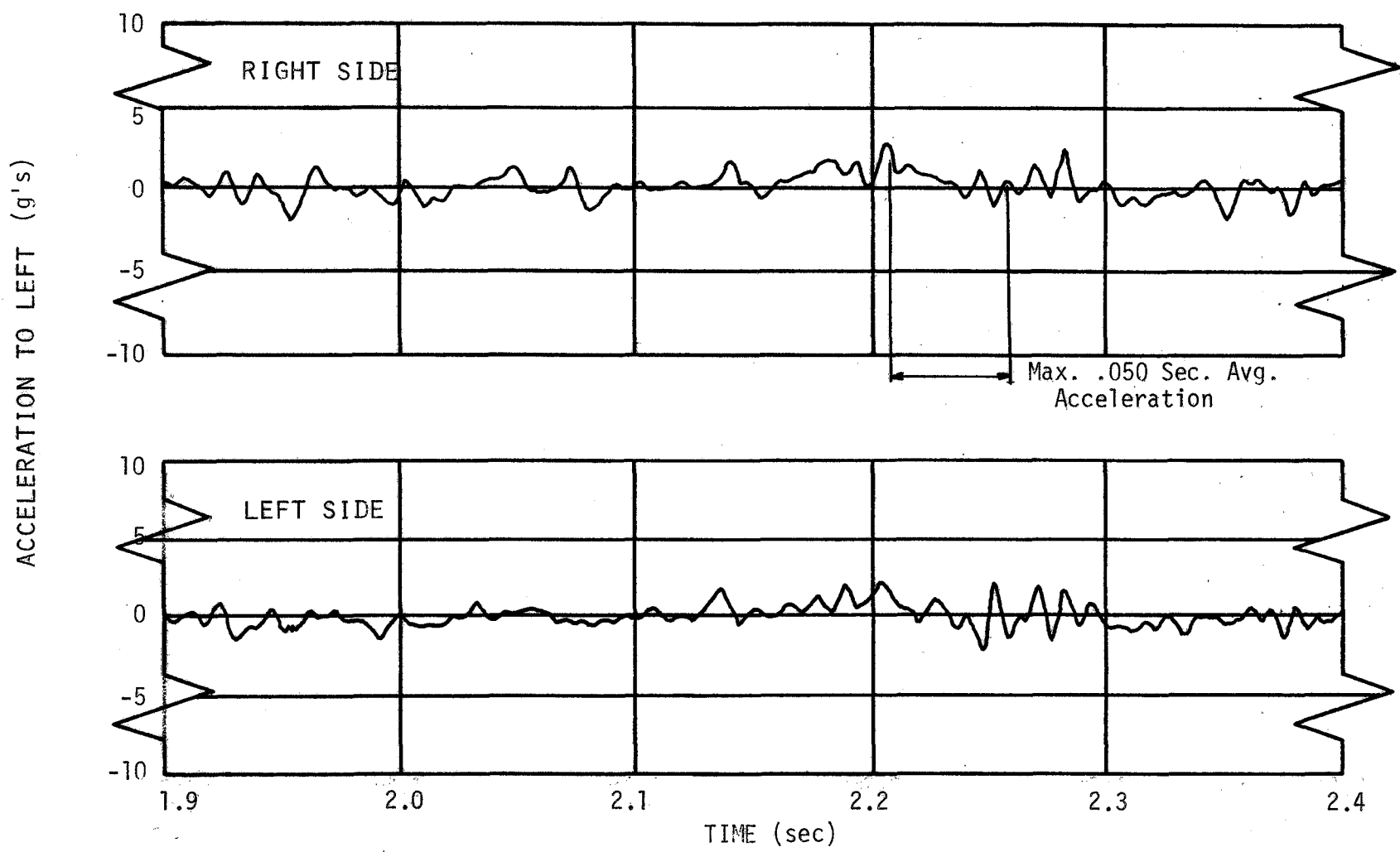


FIGURE B10. CONTINUED. TRANSVERSE VEHICLE ACCELEROMETER TRACES FOR TEST 4.
(100 Hz low pass filter)

84

max
.050 sec
1666-1716

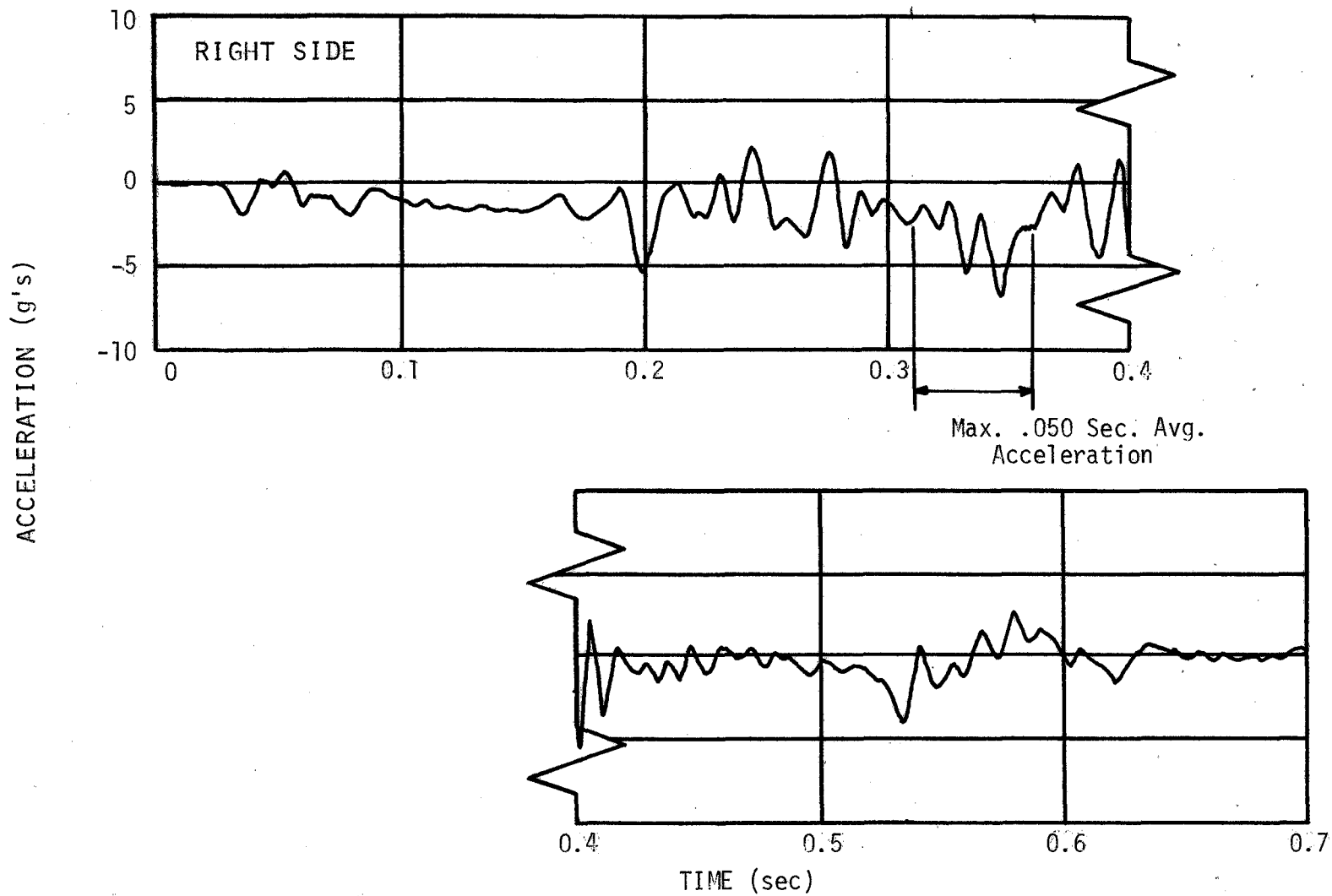


FIGURE B11. LONGITUDINAL VEHICLE ACCELEROMETER TRACES FOR TEST 5.
(100 Hz low pass filter)

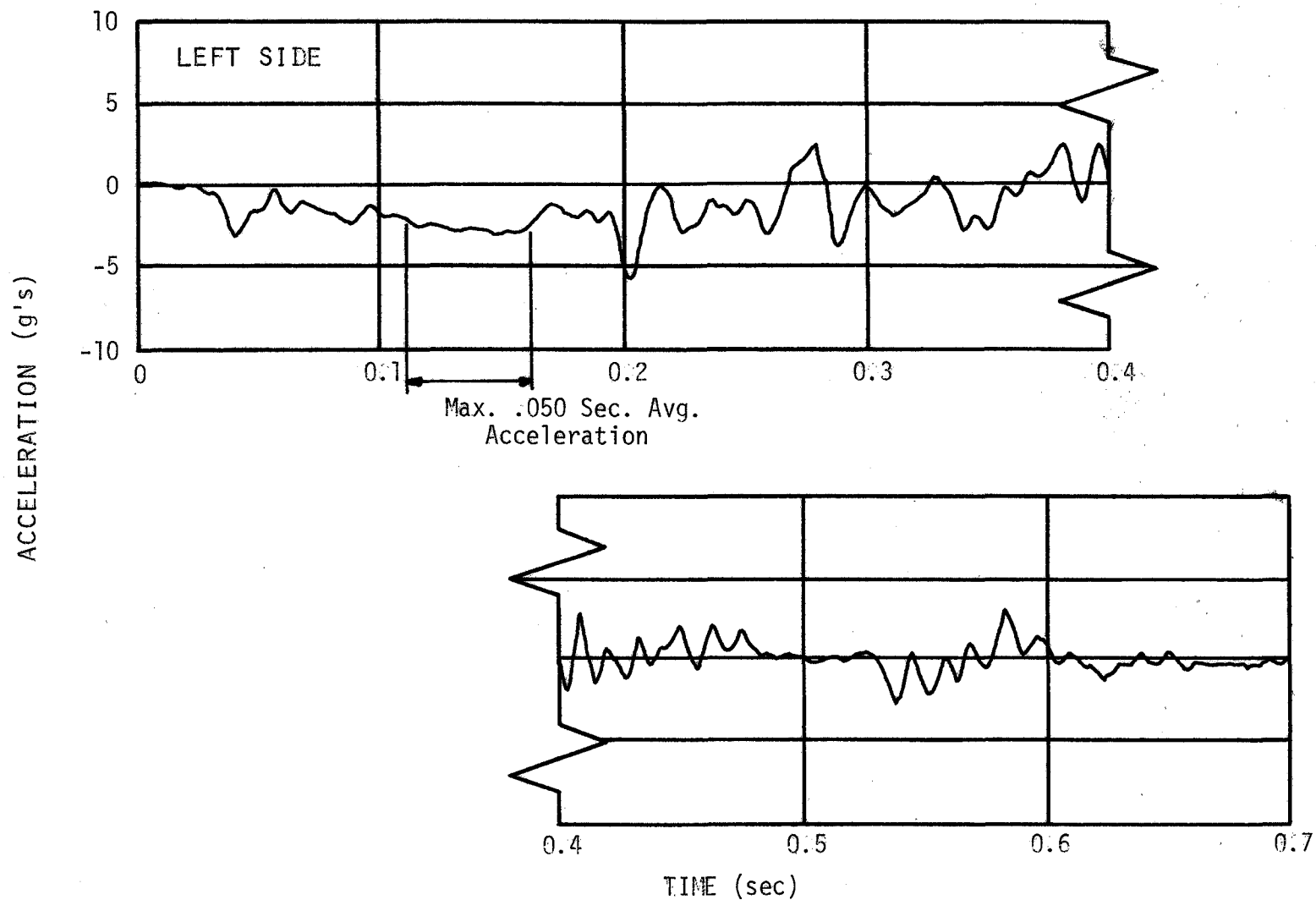


FIGURE B11. CONTINUED. LONGITUDINAL VEHICLE ACCELEROMETER TRACES FOR TEST 5.
(100 Hz low pass filter)

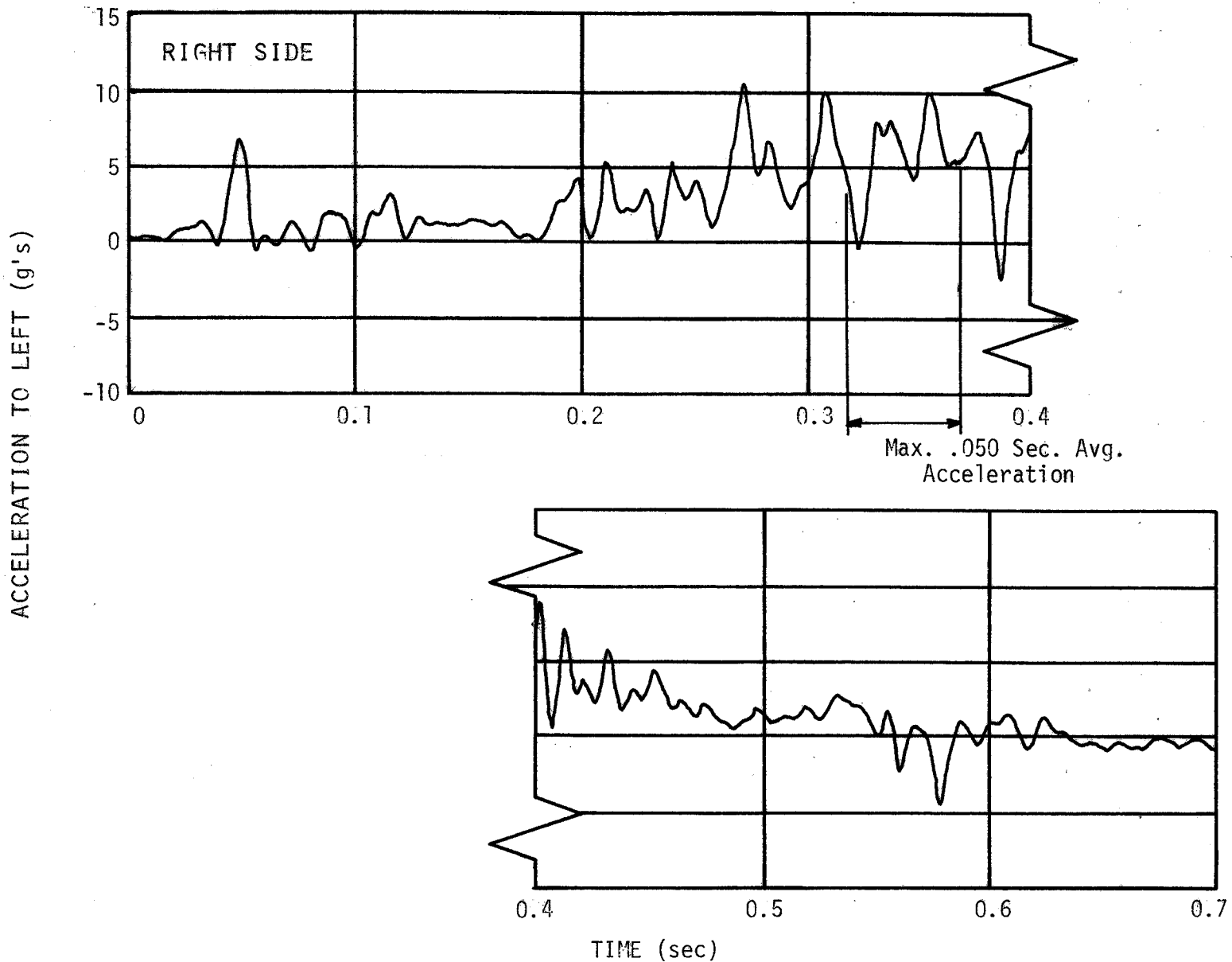


FIGURE B12. TRANSVERSE VEHICLE ACCELEROMETER TRACES FOR TEST 5.
(100 Hz low pass filter)

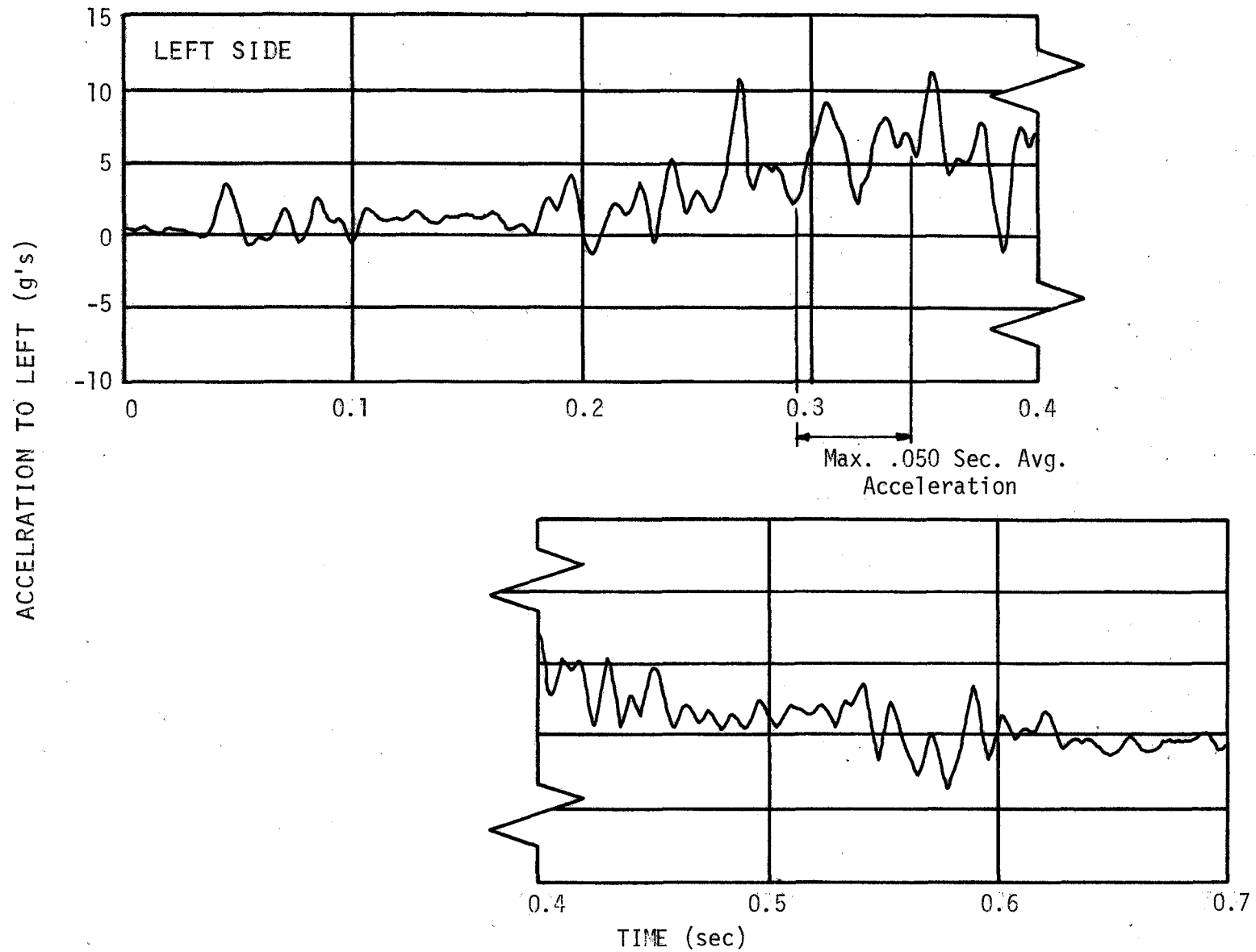
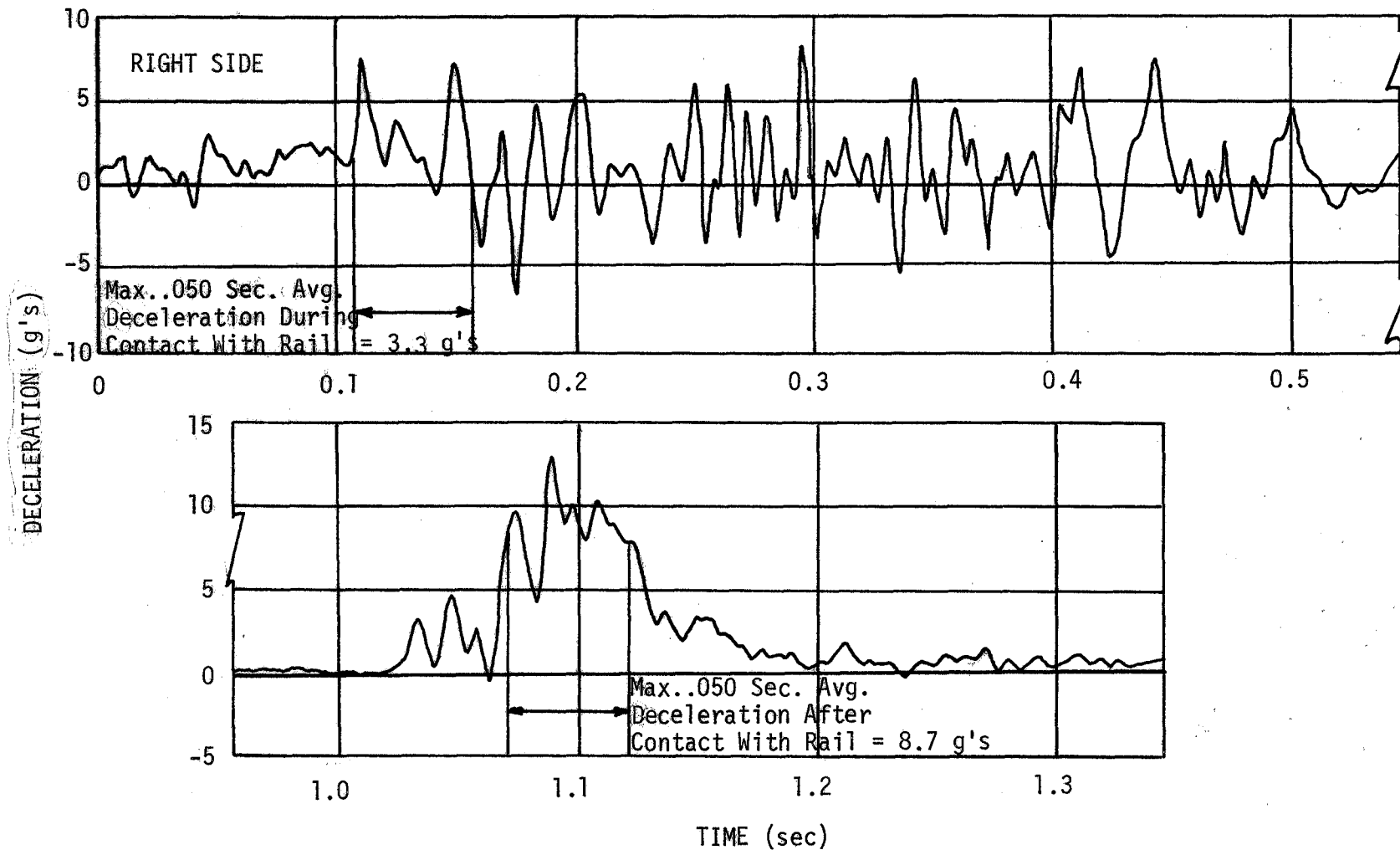


FIGURE B12. CONTINUED. TRANSVERSE VEHICLE ACCELEROMETER TRACES FOR TEST 5.
(100 Hz low pass filter)



B13
FIGURE B13. LONGITUDINAL VEHICLE ACCELEROMETER TRACE FOR TEST 6.
(80 Hz filter)

06

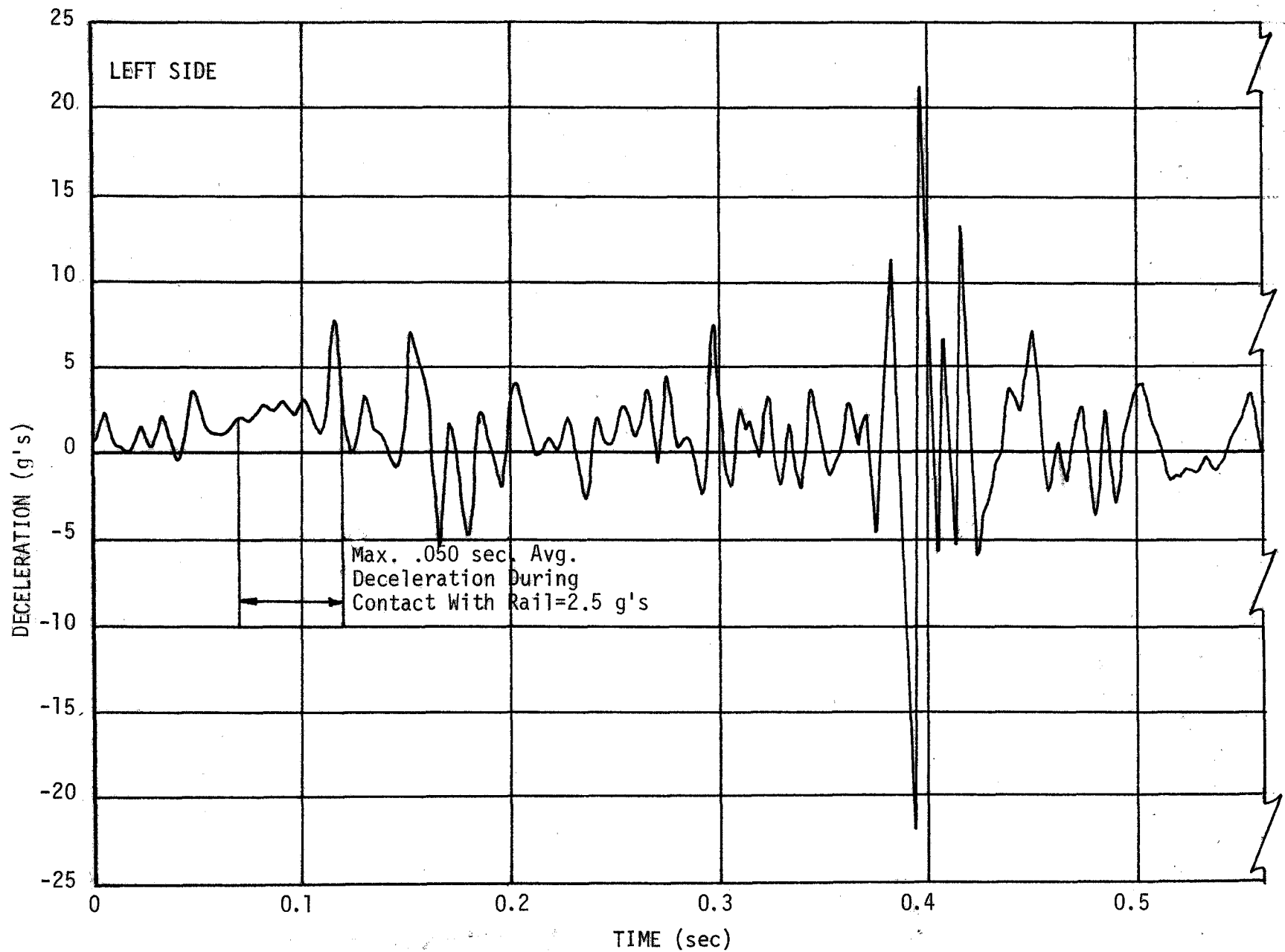


FIGURE B13 CONTINUED. LONGITUDINAL VEHICLE ACCELEROMETER TRACE FOR TEST 6.
(80 Hz filter)

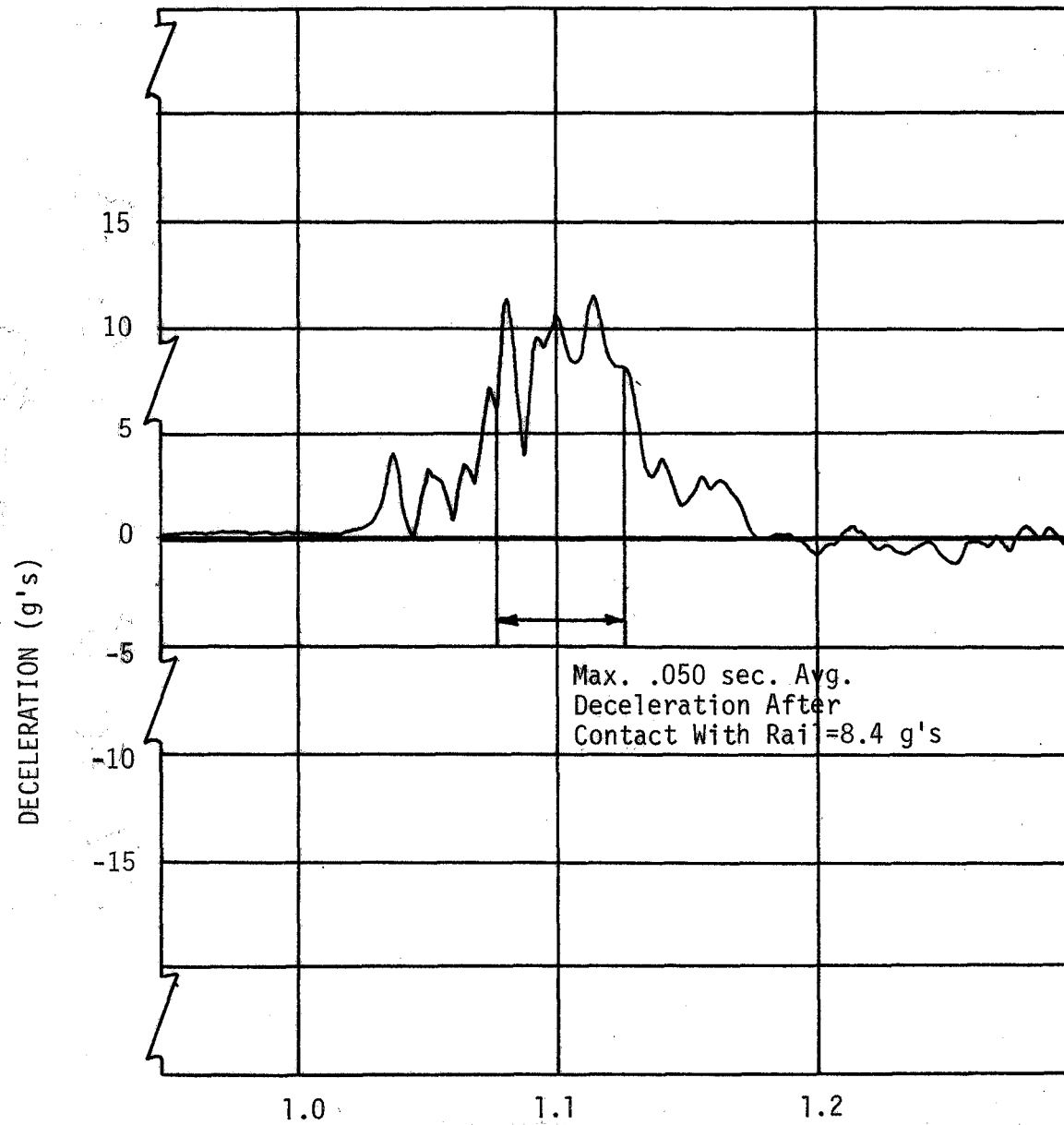
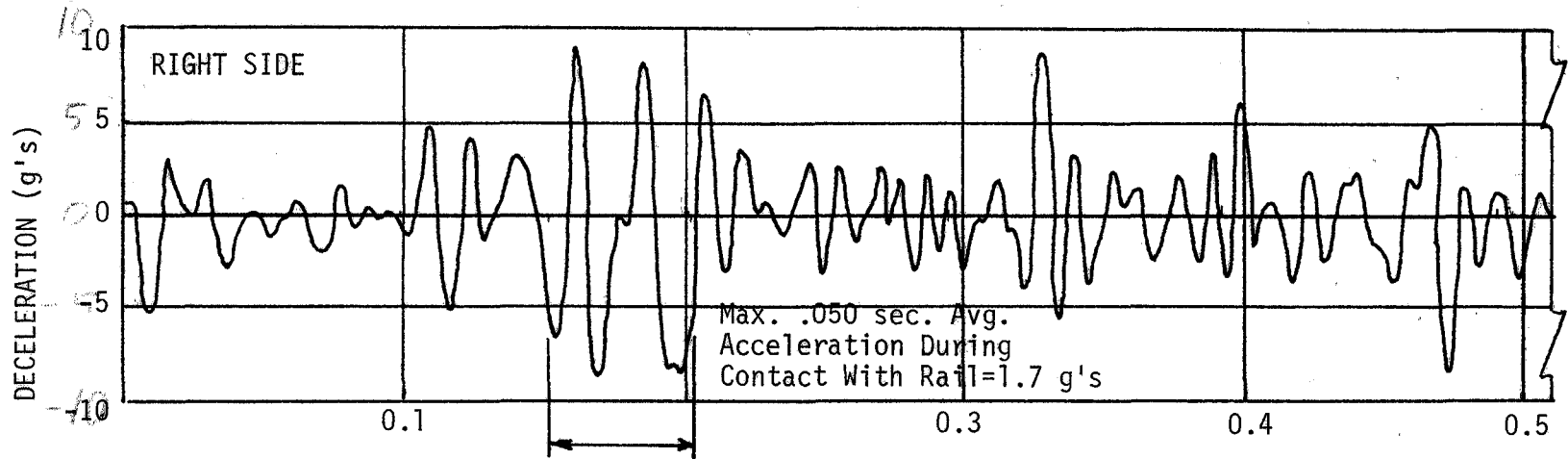


FIGURE B13 CONTINUED. LEFT LONGITUDINAL TRACE, continued

DECELERATION (g's)



92

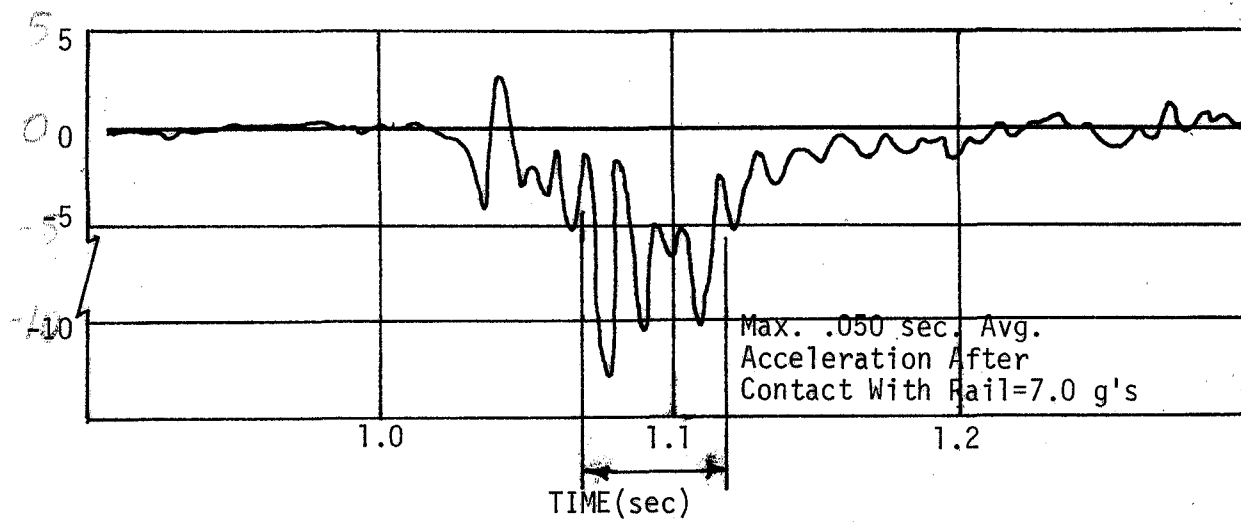


FIGURE B14. TRANSVERSE ACCLEROMETER TRACE FOR TEST 6. (80 Hz Filter)

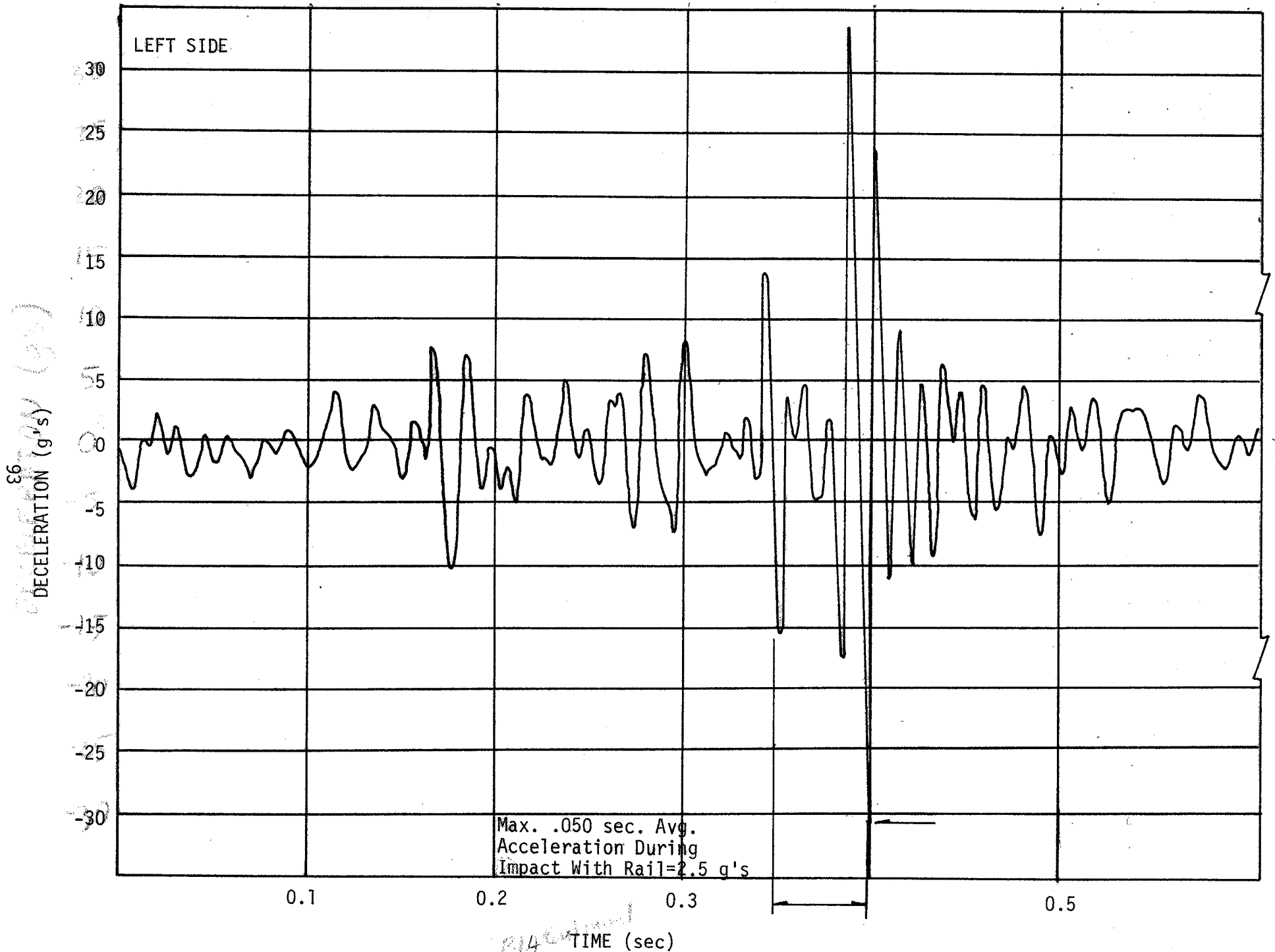
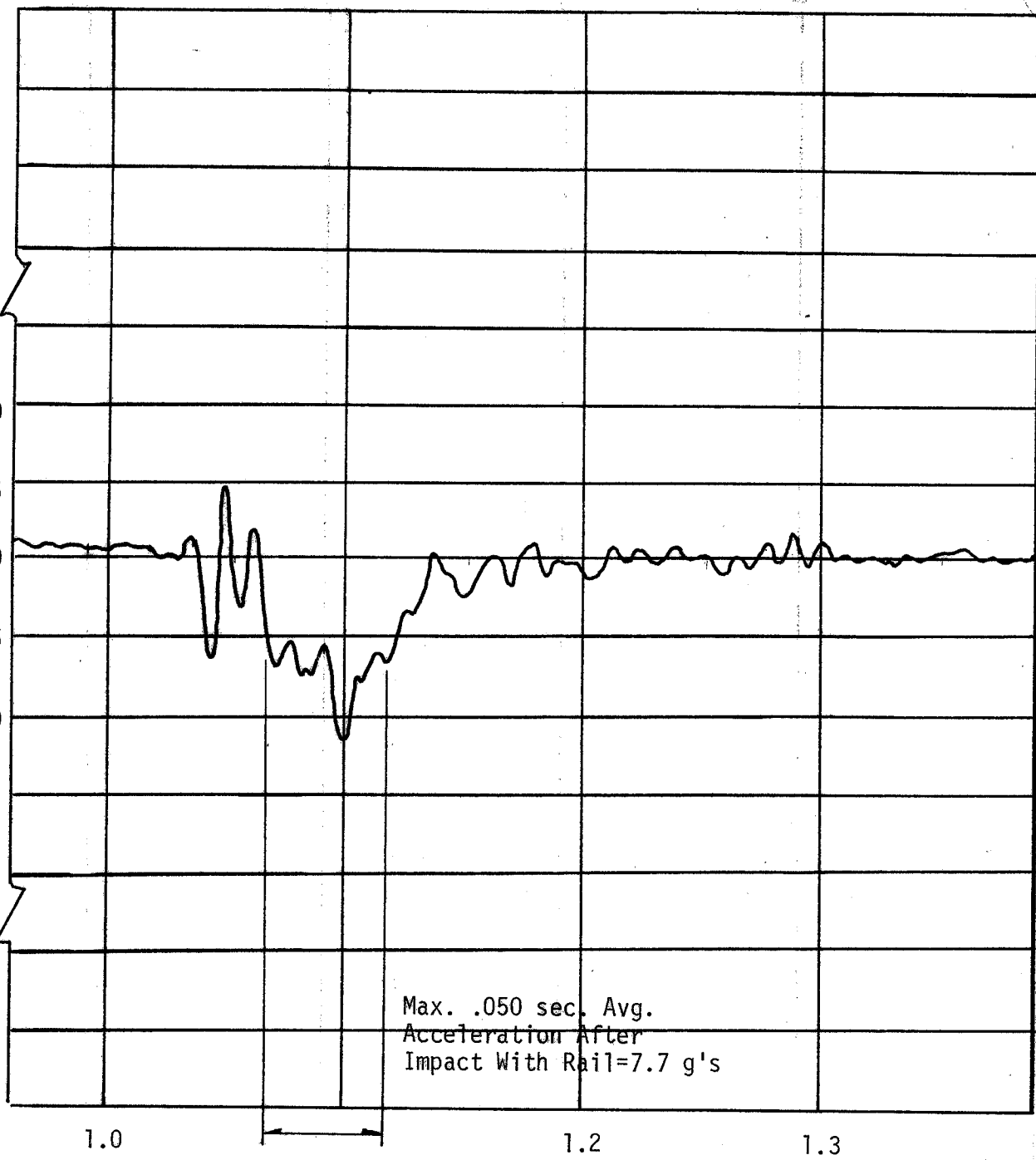


FIGURE B14 CONTINUED. TRANSVERSE ACCELEROMETER TRACE FOR TEST 6.
(80 Hz FILTER)

DECELERATION (g's)

10
5
0
-5
-10



Max. .050 sec. Avg.
Acceleration After
Impact With Rail=7.7 g's

FIGURE B14 CONTINUED.

B14 continued
LEFT TRANSVERSE ACCELEROMETER TRACE, continued