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16. Abstract

Full-scale crash testing was completed in this project to assure that a previously developed low-profile end treatment complies with test level 2 criteria for terminals and redirective crash cushions as presented in NCHRP Report 350. Together, the new end treatment and the low-profile barrier provide an innovative barrier system acceptable for use on most local and collector roads and many work zones depending upon applicable guidelines. The tip of the end treatment has a minimum height of 102 mm that transitions to a maximum height of 510 mm in a distance of 4.6 m. The 510 mm end of the end treatment connects to the previously developed 510 mm low-profile barrier. The overall length of the end treatment is 6.1 m. The primary advantage of the low-profile barrier system is that the 510 mm height of the system is less than the traditional concrete barrier height of 810 mm. The reduced height provides enhanced driver visibility that should lead to a reduced number of accidents in highway work zones and other appropriate locations. The performance of the low-profile end treatment was demonstrated through a series of five full-scale crash tests. On the basis of the results of these crash tests, coupled with the results of previous tests on the low-profile barrier, the complete low-profile barrier system including the end treatment is recommended for implementation, pending the concurrence of FHWA, in situations that are consistent with NCHRP Report 350 test level 2 applications.

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COMPLIANCE TESTING OF AN END TREATMENT FOR THE LOW-PROFILE CONCRETE BARRIER

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Report 1403-S
Research Study Number 0-1403
Research Study Title: Development of a High-Speed Low-Profile Concrete Barrier

Sponsored by the
Texas Department of Transportation

April 1998

TEXAS TRANSPORTATION INSTITUTE
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IMPLEMENTATION RECOMMENDATIONS

1. This research report presents the results of a sequence of crash tests that show that the previously developed low-profile portable concrete barrier system complies with test criteria presented in NCHRP Report 350 for test level 2 conditions. These results suggest that the low-profile barrier system is suitable for use on most local and collector roads and many work zones. Therefore, it is recommended that the low-profile barrier continue to be used in low-speed work zones as previously recommended.

2. In addition, based on guidelines presented in NCHRP Report 350, the low-profile barrier is also suitable for other applications depending upon traffic conditions, site conditions, traffic volume and mix, and the cost effectiveness of safety alternatives. Therefore, it is recommended that TxDOT review the guidelines for use of the low-profile barrier system and extend its use where applicable.

DISCLAIMER

The contents of this report reflect the views of the authors who are solely responsible for the facts and accuracy of the data, and the opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. In addition, the above assumes no liability for its contents or use thereof. The engineer in charge of the project was W. Lynn Beason, P.E. # 55905.

ACKNOWLEDGMENT

This study was sponsored by the Texas Department of Transportation (TxDOT). This particular effort was conducted in cooperation with Messrs. James Koch and Doug Day of TxDOT. Previously conducted crash tests cited in this report were conducted in cooperation with Messrs. Mark Marek and Gary Humes of TxDOT. In addition, the efforts of Hayes E. Ross, Jr., Don L. Ivey, Todd Guidry, and Kenneth Scheffler helped to make the concept of a low-profile barrier system a reality. Their comments, suggestions, and cooperative spirits were appreciated.

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SUMMARY

Full-scale crash testing was completed in this project to assure that a previously developed low-profile end treatment complies with test level 2 criteria for terminals and redirective crash cushions as presented in NCHRP Report 350. Together, the new end treatment and the low-profile barrier provide an innovative barrier system acceptable for use on most local and collector roads and many work zones depending upon applicable guidelines. The tip of the end treatment has a minimum height of 102 mm that transitions to a maximum height of 510 mm in a distance of 4.6 m. The 510 mm end of the end treatment connects to the previously developed 510 mm low-profile barrier. The overall length of the end treatment is 6.1 m. The primary advantage of the low-profile barrier system is that the 510 mm height of the system is less than the traditional concrete barrier height of 810 mm. The reduced height provides for enhanced driver visibility that should lead to a reduced number of accidents in highway work zones and other appropriate locations. The performance of the low-profile end treatment was demonstrated through a series of five full-scale crash tests. On the basis of the results of these crash tests, coupled with the results of previous tests on the low-profile barrier, the complete low-profile barrier system including the end treatment is recommended for implementation, pending the concurrence of FHWA, in situations that are consistent with NCHRP Report 350 test level 2 applications.

I. INTRODUCTION

A low-profile portable concrete barrier (PCB) system, including a longitudinal barrier and a sloped end treatment, was previously developed by researchers at the Texas Transportation Institute (TTI) in cooperation with engineers of the Texas Department of Transportation (TxDOT) during the early 1990's. The low-profile PCB is a 510-mm tall longitudinal barrier that is produced in 6.1 m segments. The primary advantage of the low-profile PCB system is that it provides a reasonable amount of redirective capability for certain applications while greatly enhancing visibility when compared to conventional 810-mm tall barriers.[1,2]

The low-profile PCB system has been shown to be highly effective for low-speed work zone applications through a series of five low-speed, full-scale crash tests that were performed prior to the introduction of National Cooperative Highway Research Program (NCHRP) Report 350.[3] Based on results of these tests, the low-profile PCB was recommended for use in low-speed (less than or equal to 75 km/h) applications.[1,2] As a result of this effort, the low-profile PCB system was put into widespread use in urban work zone applications throughout the state of Texas. Subsequent experience with the low-profile barrier system has been favorable.

In 1993 new full-scale crash test recommendations for the evaluation of highway safety hardware were introduced by the NCHRP in the form of NCHRP Report 350.[3] These new criteria can be used to evaluate the performance of both the low-profile longitudinal barrier and the low-profile end treatment. Results of previously conducted tests on the longitudinal barrier portion of the low-profile PCB system were sufficient to demonstrate that it complies with the NCHRP Report 350 level 2 criteria. However, results from previously conducted tests on the low-profile end treatment were not sufficient to demonstrate that it complies with the NCHRP Report 350 level 2 criteria. The purpose of this report is to review previous crash test results and introduce new results that show that the low-profile end treatment meets level 2 impact criteria presented in NCHRP Report 350. As stated in NCHRP Report 350, compliance with the level 2 impact criteria suggests that the low-profile PCB system is suitable for use on most local and collector roads and many work zones, depending upon the controlling guidelines.

The remainder of this report is divided into four major sections. The next section presents a brief review of the low-profile PCB and the results of prior testing as related to NCHRP Report 350 test level 2 criteria. This is followed by a section that presents a review of the low-profile end treatment and the results of prior testing as related to NCHRP Report 350 test level 2 criteria. The next section presents a discussion of the results of the full-scale crash tests that are used to document the performance of the low-profile end treatment. The final section of this report presents a discussion of the results and major conclusions.

II. REVIEW OF LOW-PROFILE PCB

There are many work zone situations where the longitudinal barrier that separates the primary flow of traffic from the work zone must be interrupted by frequent openings to allow cross-traffic vehicle access. Figure 1 presents the geometry associated with a longitudinal barrier that incorporates such an interruption. The problem is that if the height of the longitudinal barrier obscures a clear view of oncoming vehicles, the operator of the cross-traffic vehicle may enter the roadway and become involved in a preventable accident. This is particularly a problem at night when the only apparent visual cues are those provided by the headlights of oncoming vehicles.

Examination of vehicular geometrics shows that the distance from the roadway to the center of the headlight is at least 610 mm.[1] This minimum headlight height is suggested by American Association of State Highway and Transportation Officials (AASHTO)[4] and its implementation has been confirmed by a limited survey conducted by TTI researchers.[1] Therefore, if normal concrete barriers that have a height of 810 mm are used in this situation, the headlights of an oncoming vehicle are hidden from the cross-traffic vehicle operator.

If the cross-traffic vehicle operator is to have an unobstructed view of the oncoming vehicle headlights, the barrier height cannot exceed the headlight height. Therefore, the maximum allowable height of a low-profile PCB is 610 mm. If the low-profile PCB is located on a cresting vertical curve, the sight distance can be limited by even a 610 mm barrier. The degree of limitation depends upon the particular geometric conditions. Based on a detailed geometric analysis, TTI researchers and TxDOT engineers concluded that a barrier height of 510 mm provides a reasonably unobstructed view of the roadway for the cross-traffic vehicle operator.[1]

The low-profile PCB cross-section developed in a previous project is shown in Figure 2. In addition, Figure 2 presents the cross-section of the popular 810 mm New Jersey safety shape for comparison purposes. The height of the low-profile PCB is 510 mm. The width of the low-profile PCB at the top of the barrier is 710 mm and the width at the bottom is 660 mm. This geometry results in a negative slope on the impact face of the low-profile PCB. It is believed that the negative barrier face slope helps to reduce the tendency of a vehicle to rise during impact. Hence, the stability of the impacting vehicle is enhanced.

The low-profile PCB segments are fabricated in 6.1 m segments. Each segment has a mass of approximately 5000 kg. The barrier segments are connected with a specially developed connection scheme. Figure 3 presents a sketch of the end of a typical low-profile PCB segment. A trough and two bolt holes are cast into each end of the PCB segment as shown in Figure 3. The connection is accomplished by aligning the ends of two PCB segments and inserting two threaded bolts through the connection hole. The trough is utilized to gain access to the

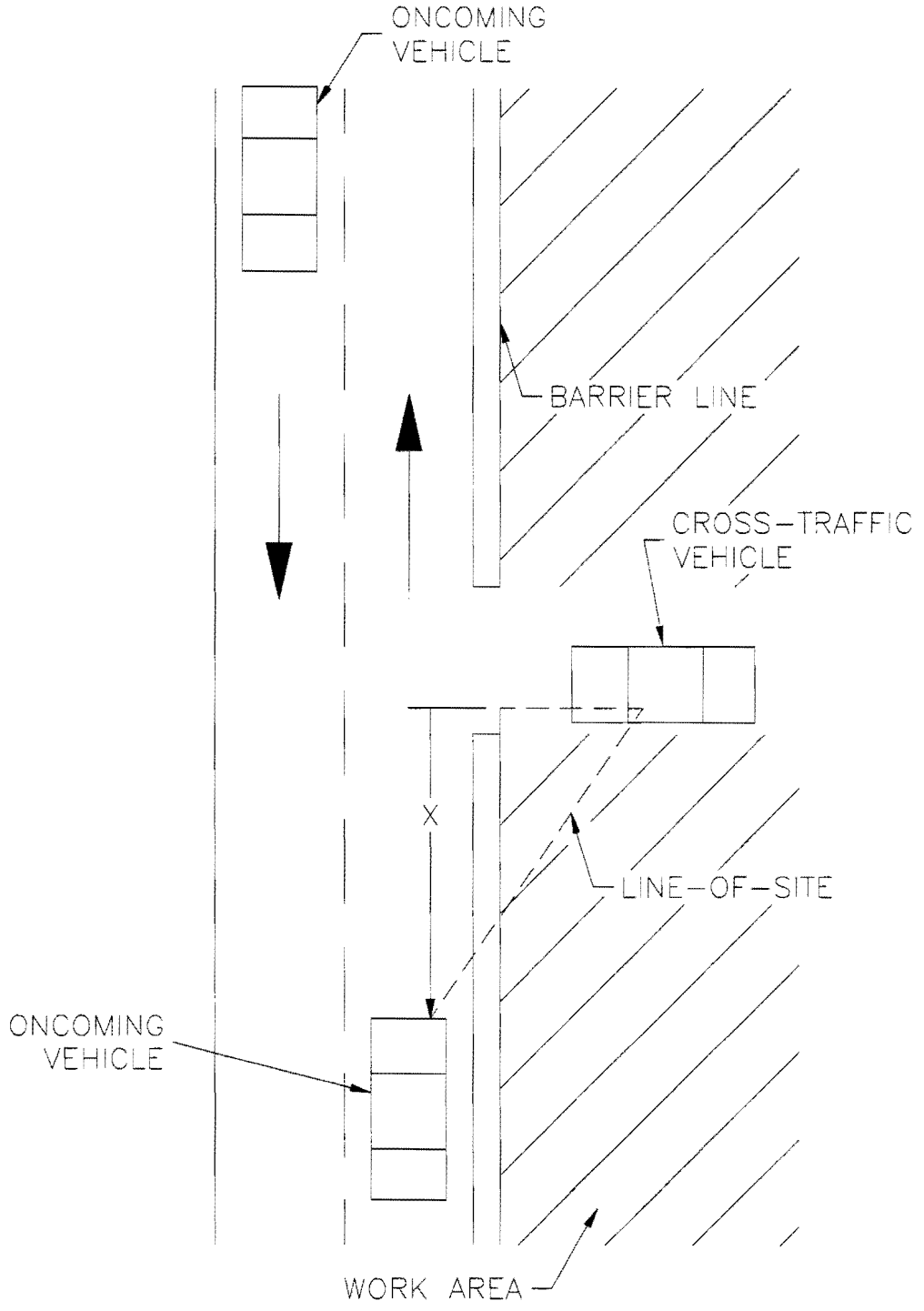


Figure 1. Geometry of Sight-Distance Problem

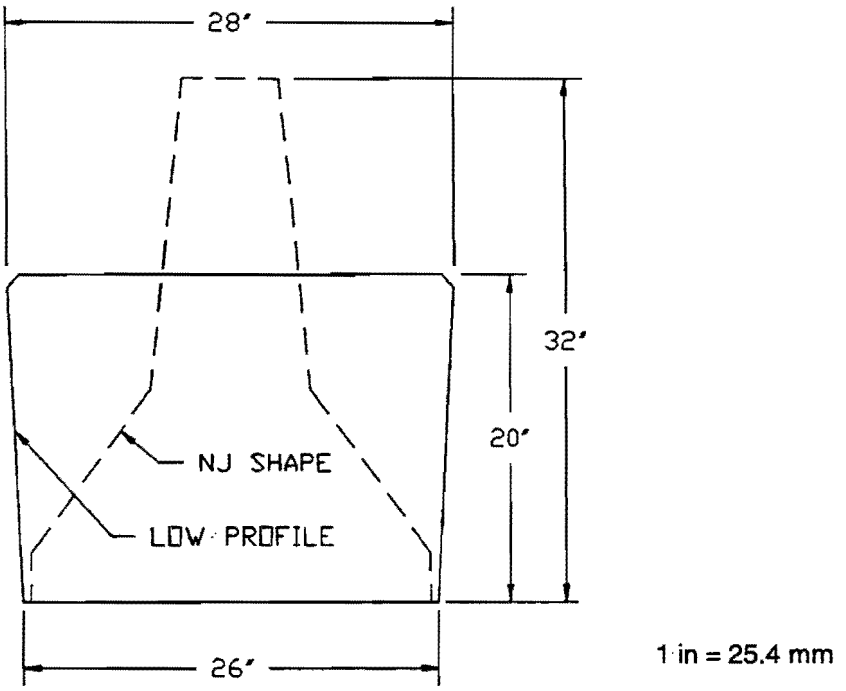


Figure 2. Cross-Section of Low-Profile PCB

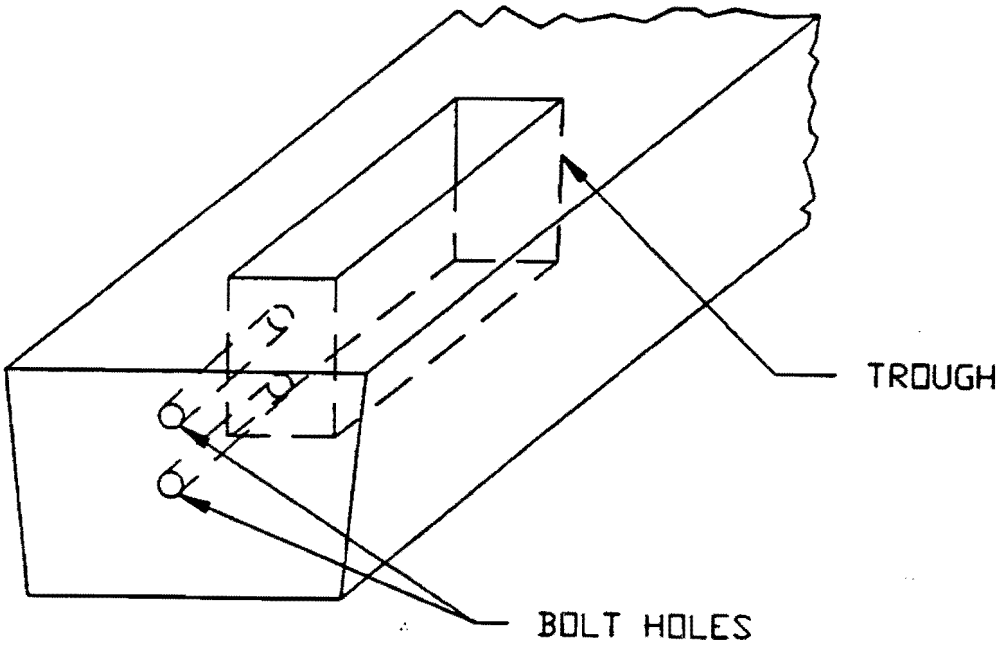


Figure 3. Low-profile PCB connection

connection bolts. The bolts are fastened securely in place by tightening nuts on both ends of the bolts. When the connection is loaded, a moment develops between the tensile forces in the bolts and the compressive forces in the extreme fibers of the concrete as shown in Figure 4. The moment capacity of the connection coupled with the mass of the low-profile PCB segments results in a barrier system that significantly limits lateral displacements associated with level 2 impacts.

NCHRP Report 350 presents two specific sets of crash test criteria to qualify the length of need of a test level 2 longitudinal barrier. These are described below.

NCHRP Report 350 test designation 2-10: This test involves an 820-kg passenger vehicle impacting the longitudinal barrier with a nominal speed and angle of 70 km/h and 20 degrees. This test is intended to evaluate the overall performance of the length of need of the longitudinal barrier and occupant risk.

NCHRP Report 350 test designation 2-11: This test involves a 2000-kg pickup truck impacting the longitudinal barrier with a nominal speed and angle of 70 km/h and 25 degrees. The purpose of this test is to evaluate the strength of the longitudinal barrier in containing and redirecting the 2000-kg pickup truck.

The low-profile PCB was originally subjected to two full-scale crash tests to evaluate its performance. The test conditions selected for this evaluation were based on engineering judgment and general guidelines presented in National Cooperative Highway Research Program (NCHRP) Report 230[5]. The first test involved a 2043 kg pickup that impacted the low-profile PCB with a speed of 73 km/h and at an angle of 25 degrees. The purpose of this test was to evaluate the strength of the barrier and the ability of the system to redirect a full-sized vehicle. These test conditions are slightly more severe than those for specified for NCHRP Report 350 test designation 2-10. The second test involved an 817 kg small passenger car that impacted the low-profile PCB with a speed of 73 km/h and at an angle of 20 degrees. The purpose of this test was to evaluate the effect of the PCB on the stability of an errant small car. These test conditions are about the same as those specified for NCHRP Report 350 test designation 2-11. In both full-scale crash tests, the vehicles were smoothly redirected. The largest lateral deflection of the low-profile PCB was 127 mm, which resulted from the pickup impact. There was no measurable lateral deflection as a result of the small car impact. Data collected from both tests fall within acceptable limits of occupant and vehicle accelerations presented in NCHRP Report 350. Based on these results, the low-profile PCB has been recommended for continued use as a NCHRP Report 350 test level 2 longitudinal barrier.[1]

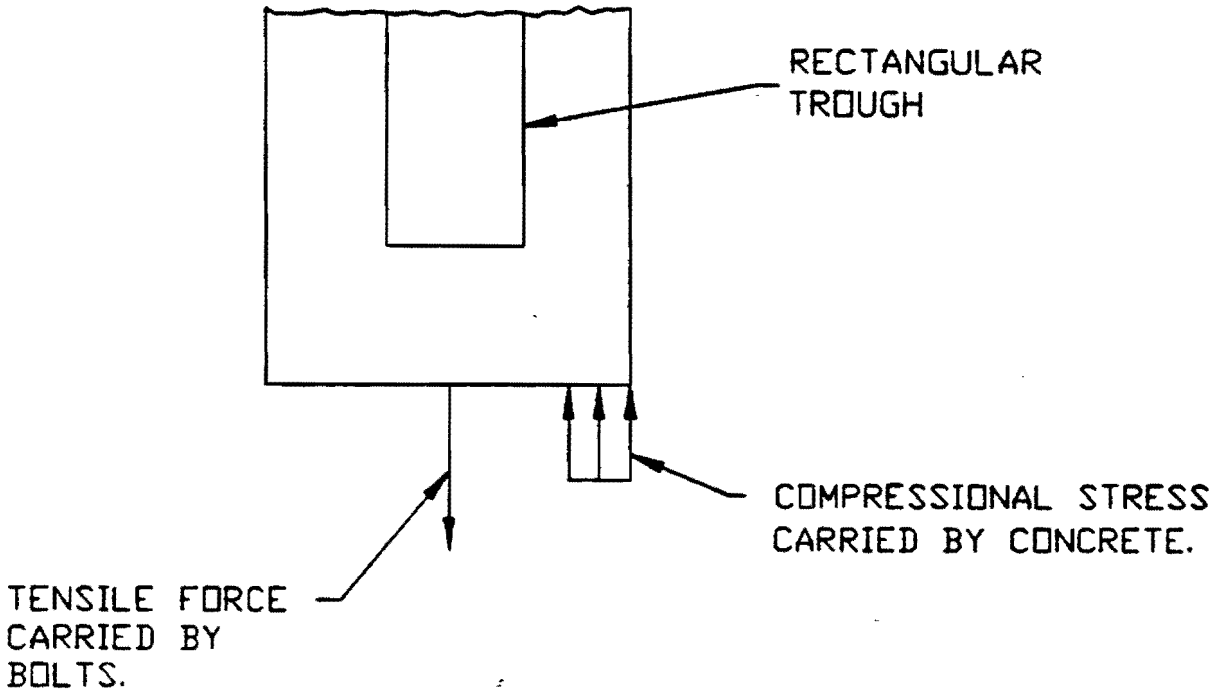


Figure 4. Loading on PCB Connection

III. LOW-PROFILE END TREATMENT

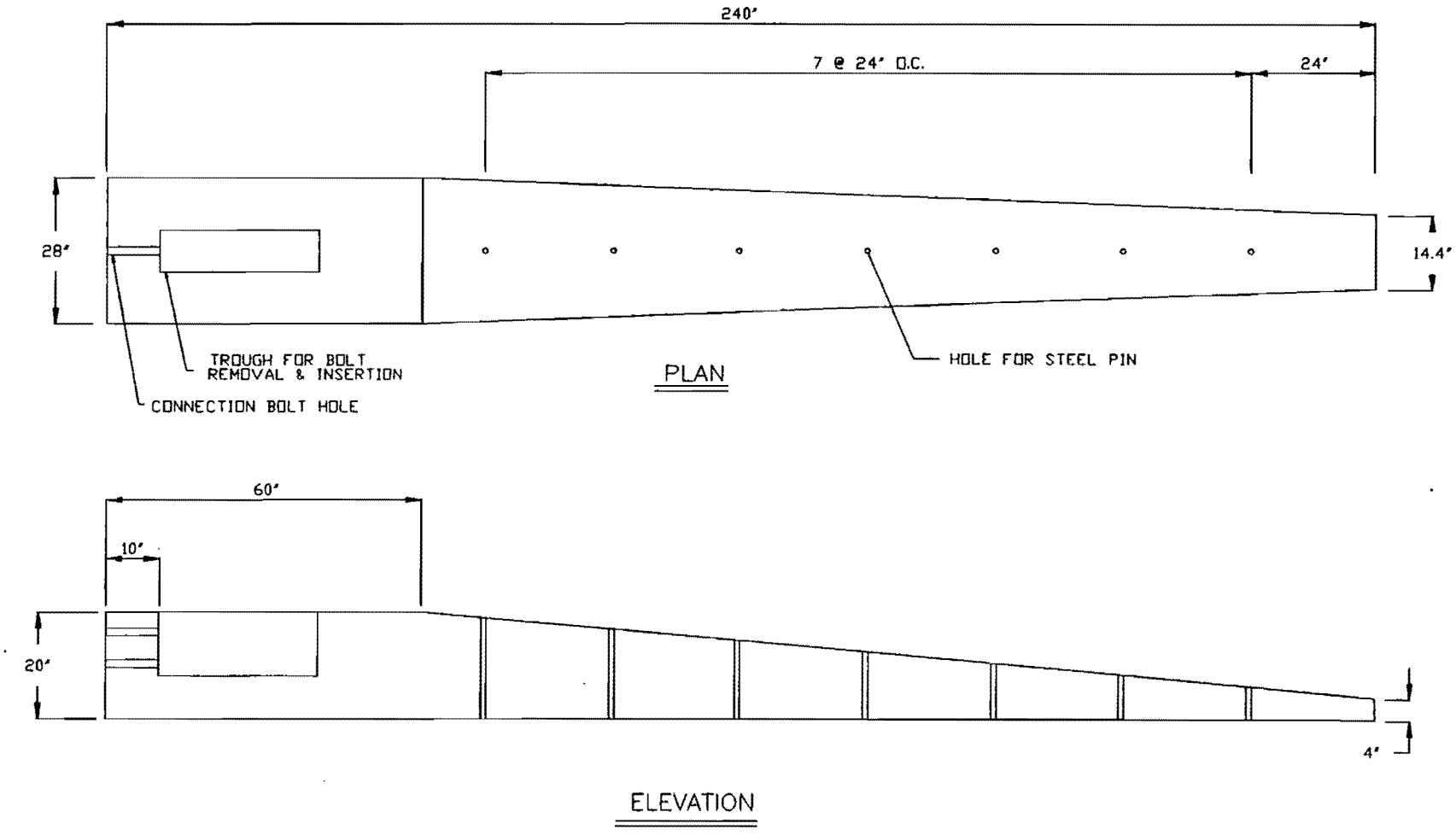
Following the development of the low-profile PCB, a low-profile end treatment was developed for use with the low-profile PCB as shown in Figure 5. The low-profile end treatment is constructed in lengths of 6.1 m so that it has the same length as a low-profile PCB segment. The connection end of the low-profile end treatment is 510 mm high so that its height matches with that of the low-profile PCB. In addition, the connection end of the end treatment incorporates the same bolted connection developed for use with the low-profile PCB so that it may be connected directly to the low-profile PCB. The height of 510 mm is maintained for a distance of 1.5 m along the length of the end treatment from the connection end. Then, the height of the end treatment is reduced linearly from 510 mm to 102 mm at the opposite end of the low-profile end treatment. In addition to a reduction of barrier height in the remaining 4.6 m of the end treatment, the widths of the barrier top and bottom are symmetrically tapered to 365 mm and 356 mm respectively so that the negative slope of the impact face (1:20) of the end treatment is maintained throughout its length.

The low-profile end treatment is reinforced appropriately so that the flexural capacity throughout the length of the end treatment is sufficient to minimize cracking during transport and handling. The end treatment is anchored to the pavement by inserting steel pins through precast holes in the end treatment at 610 mm intervals from the end of the end treatment as shown in Figure 5. Complete fabrication details for the low-profile end treatment are presented elsewhere.[2]

NCHRP Report 350 level 2 impact criteria are considerably more involved for terminals such as the low-profile end treatment than for longitudinal barriers such as the low-profile PCB. Based upon information presented in NCHRP Report 350, the low-profile end treatment is classified as a gating terminal or device. Gating devices are "designed to allow controlled penetration of the vehicle when impacted between the end and the beginning of the length of need of the device". The length of need of the low-profile barrier system is defined to coincide with the connection between the end of the low-profile end treatment and the low-profile PCB. NCHRP Report 350 presents seven different sets of crash test conditions for the evaluation of test level 2 gating end treatments. These sets of test conditions are referred to as test designations 2-30 to 2-35 and 2-39. Each of these different test conditions is discussed below.

NCHRP Report 350 test designation 2-30: This test involves an 820-kg passenger vehicle impacting the end treatment at a nominal speed and angle of 70 km/h and 0 degrees with the quarter point of the vehicle aligned with the centerline of the end treatment. This test is intended to evaluate occupant risk and vehicle trajectory.

NCHRP Report 350 test designation 2-31: The test involves a 2000-kg pickup truck impacting the end treatment at a nominal speed and angle of 70 km/h and 0 degrees with the centerline of the vehicle aligned with the centerline of the end of the treatment.



1 in = 25.4 mm

Figure 5. Geometry of Low-Profile End Treatment

The purpose of this test is to evaluate the capacity of the end treatment to absorb the kinetic energy of the 2000 kg vehicle (structural adequacy criteria) in a safe manner (occupant risk). However, in this case, the purpose of the test is to evaluate occupant risk and vehicle trajectory criteria.

NCHRP Report 350 test designation 2-32: This test involves na 820-kg passenger vehicle impacting the end treatment at a nominal speed and angle of 70 km/h and 15 degrees with the centerline of the vehicle aligned with the centerline of the nose of the end treatment. This test is intended primarily to evaluate occupant risk and vehicle trajectory criteria.

NCHRP Report 350 test designation 2-33: This test involves a 2000-kg pickup truck impacting the end treatment at a nominal speed and angle of 70 km/h and 15 degrees with the centerline of the vehicle aligned with the centerline of the nose of the end-treatment. This test is intended primarily to evaluate occupant risk and vehicle trajectory criteria.

NCHRP Report 350 test designation 2-34: This test involves an 820-kg passenger vehicle impacting the end treatment at a nominal speed and angle of 70 km/h and 15 degrees with the front corner of the vehicle aligned with the critical impact point of the end treatment. The test is intended primarily to evaluate occupant risk and vehicle trajectory.

NCHRP Report 350 test designation 2-35: This test involves a 2000-kg pickup truck impacting the end treatment at a nominal speed and angle of 70 km/h and 20 degrees with the front corner of the vehicle impacting at the beginning of the length of need (LON). Test 2-35 is intended primarily to evaluate the ability of the end treatment to contain and redirect (structural adequacy) the pickup truck within vehicle trajectory criteria.

NCHRP Report 350 test designation 2-39: This test involves a 2000-kg pickup truck impacting the end treatment from the reverse direction at a nominal speed and angle of 70 km/h and 20 degrees at the mid-length of the end treatment. Test 2-39 is intended to evaluate the performance of the end treatment for a "reverse" hit.

Prior to the introduction of NCHRP Report 350, the low-profile end treatment was subjected to three full-scale crash tests.[1,2] The first test previously conducted on the low-profile end treatment involved an 817 kg passenger car that impacted the end treatment at a point 2.0 m from the end of the end treatment with an angle of 15 degrees. This test was originally intended to evaluate the performance of the end treatment with an impact at the midway point between the tip of the barrier and the beginning of the length of need. At the time this test was conducted it was viewed as the critical impact for a small car impact. While there is room for discussion regarding the location of the critical impact point, results from computer simulations suggest that the critical impact point lies between this point and the end of the barrier. Therefore, the results of this test are applicable to NCHRP Report 350 test designation 2-34, although the test results were judged by the researchers to not be sufficient to fully comply with test designation 2-34.

The second test involved an 820 kg passenger car that impacted the end treatment with an end-on impact such that the centerline of the right wheel was aligned with the centerline of the end treatment.[2] NCHRP Report 350 test designation 2-30 requires only that the centerline of the vehicle be offset from the centerline of the barrier by an amount equal to ¼ of the width of the vehicle. The offset distance was greater than ¼ of the width of the vehicle because the researchers believed that lining up the passenger-side wheels with the centerline of the end treatment presents a more severe impact than that described in test designation 2-30. Hence, it is believed that results of this test are more severe than the requirements of test designation 2-30. The third and final previously conducted test involved a 2043 kg pickup truck that impacted the end treatment with an end-on impact such that the centerline of the vehicle was aligned with the centerline of the end treatment. These test conditions are essentially the same as those specified in NCHRP Report 350 test designation 2-31.

Examination of the above tests reveals that results from previously conducted tests are not sufficient to demonstrate that the low-profile end treatment can meet NCHRP Report 350 test level 2 requirements. Thus, additional test results are required. The next section presents a review of the three previously conducted low-profile end treatment tests along with additional end treatments to develop a case that the low-profile end treatment does comply with NCHRP Report 350 test level 2 requirements.

IV. FULL-SCALE CRASH TESTING OF LOW-PROFILE END TREATMENT

As stated in the previous section, NCHRP Report 350 requires a total of seven tests to assure that the low-profile end treatment complies with level 2 crash test criteria. This includes test designations 2-30 through 2-35 and test designation 2-39. Further, a brief review of the results discussed in the previous section suggests that the number of prior tests conducted are not sufficient to demonstrate that the low-profile end treatment complies with NCHRP Report 350 test level 2 requirements.

While additional testing is required, it is the opinion of the writers that NCHRP Report 350 test designations 2-33, 2-35, and 2-39 can be waived. All three of these tests involve a 2000-kg pickup truck. Test designation 2-33 is essentially a repeat of test designation 2-32 except that it involves a 2000-kg pickup instead of an 820-kg passenger vehicle. The 820-kg passenger vehicle was extremely stable during the 2-32 impact. Clearly the pickup will result in more stable impacts than the small vehicle will under these conditions because of the pickup's increased ground clearance and stiffer suspension. Therefore, it is recommended that test designation 2-33 be waived. Test designation 2-35 involves a 2000-kg pickup impacting at the beginning of the length of need. In this case the length of need for the low-profile barrier system is defined to coincide with the connection point between the PCB and the end treatment. Since the cross-section of the connection end of the end treatment is identical to the PCB cross-section, and since the lateral deflection of the end treatment is limited by steel pins, this test will essentially be a repeat of NCHRP Report 350 test designation 2-31, which was highly successful. Therefore, it is recommended that test designation 2-35 be waived. Test designation 2-39 involves a reverse impact of a 2000-kg pickup at the midpoint of the end treatment. The height of the end treatment at this point is 273 mm. Based upon crash test results associated with the development of the ADIEM, it is likely that the barrier height will not redirect the pickup.[6] The front impact wheel should mount the end treatment at the point of impact and the geometrics of the end treatment are such that the downstream height of the end-treatment quickly reduces so there is nothing further to destabilize the impacting vehicle. Hence it is clear that the vehicle will gate harmlessly over the end treatment. This outcome is acceptable. Therefore, it is recommended that test designation 2-39 be waived.

This leaves four sets of test conditions that must be satisfied to show that the low-profile end treatment complies with NCHRP Report 350 level 2 test conditions. These include test designations 2-30 through 2-32 and test designation 2-34. Test designation 2-34 involves an impact at the critical impact point as determined by the investigators. Because location of the critical impact point is subject to judgment, results of two different crash tests are offered to assure that the critical impact point was fully bracketed. Therefore, the results of a total of five different crash tests are offered to establish the NCHRP Report 350 test level 2 performance of the low-profile end treatment. These tests include two new crash tests and the three previously conducted crash tests.

All of the crash tests were performed using the same constant slope low-profile end treatment that was connected to a low-profile PCB installation that incorporated four barrier segments. The barrier installation was placed on the existing concrete surface at the TTI Proving Ground. There were no positive attachments of the four low-profile PCB segments to the roadway. However, the end treatment was secured to the roadway with 32-mm steel pins as indicated in Appendix A. The steel pins were dropped into drilled holes in the roadway surface with no grout or other positive attachment. Following each test, cosmetic repairs were performed on the low-profile end treatment to prepare for the next test.

Test statistics for the five crash tests discussed above are summarized in Table 1. All testing was performed in accordance with procedures specified in NCHRP Report 350 and detailed in Appendix B. Sequential photographs of the tests are presented in Appendix C. Plots of roll-pitch-yaw and accelerometer traces are presented in Appendix D. The test results are presented in the order as defined in NCHRP Report 350.

NCHRP REPORT 350 TEST DESIGNATION 2-30 (TEST 1949A-2)

A 1988 Yugo GVL was directed into the low-profile end treatment. Figure 6 presents a view of the end treatment prior to the impact. Figures 7 and 8 show the vehicle prior to impact. The test inertial weight of the vehicle was 817 kg and its gross static weight was 893 kg. The height to the lower edge of the vehicle bumper was 343 mm and it was 483 mm to the top of the bumper. Additional dimensions and information on the test vehicle are presented in Figure 68 of Appendix E. The vehicle was directed into the end treatment using a cable reverse tow and guidance system and was released to free-wheeling and unrestrained just prior to impact.

Test Description

The vehicle impacted the end treatment end-on with the centerline of the right wheel aligned with the centerline of the end treatment. The vehicle impacted the end treatment with a speed of 72.6 km/h. The angle of impact was 0 degrees. As the vehicle rode up the barrier, it remained stable and continued on a straight path. The right rear tire mounted the end of the end treatment at 0.137 s. The tires on the right side of the vehicle lost contact with the end treatment at 0.341 s. At 0.428 s, the vehicle reached a maximum roll angle of approximately 28 degrees. The tires touched down on top of the barrier at 0.457 s and immediately thereafter passed over the connection of the end treatment to the main body of the low-profile PCB traveling at a speed of 71.1 km/h and a 0.3 degree angle. The right side of the vehicle continued riding along the top of the main body of the low-profile barrier until the right rear wheel dropped off the barrier at 0.823 s with the vehicle traveling at 65.3 km/h. The exit angle was 2.0 degrees. The brakes were applied at 0.833 s after impact, the vehicle yawed clockwise and came to rest facing the end treatment 54 m downstream from the initial impact. Sequential photographs of the impact are shown in Figures 38 and 39 of Appendix C.

Table 1. Summary of Crash Test Results.

	1949A-2	1949A-3	414036-2	1949A-1	414038-1
Vehicle Weight, kg	817	2043	820	817	
Impact Speed, km/h	72.6	74.8	68.9	71.9	
Impact Angle, degrees	0	0	15.1	16.3	
Exit Angle, degrees	2	0	7.7	6.1	
Displacement, mm	0	0	0	0	
Occupant Impact Velocity, m/s					
Longitudinal	1.9	1.9	No contact	4.1	
Lateral	0	0.4	No contact	5.5	
Occupant Ridedown Acceleration, g's					
Longitudinal	-0.6	4.1	N/A	-1.9	
Lateral	0	2.1	N/A	-4.5	
Vehicle Damage Classification					
TAD	N/A	N/A	01RFQ0	11LFQ1	01RFQ1
CDC	12FRWU1	00UDCU1	01FRLU0	11LFEW2	01UDCW1

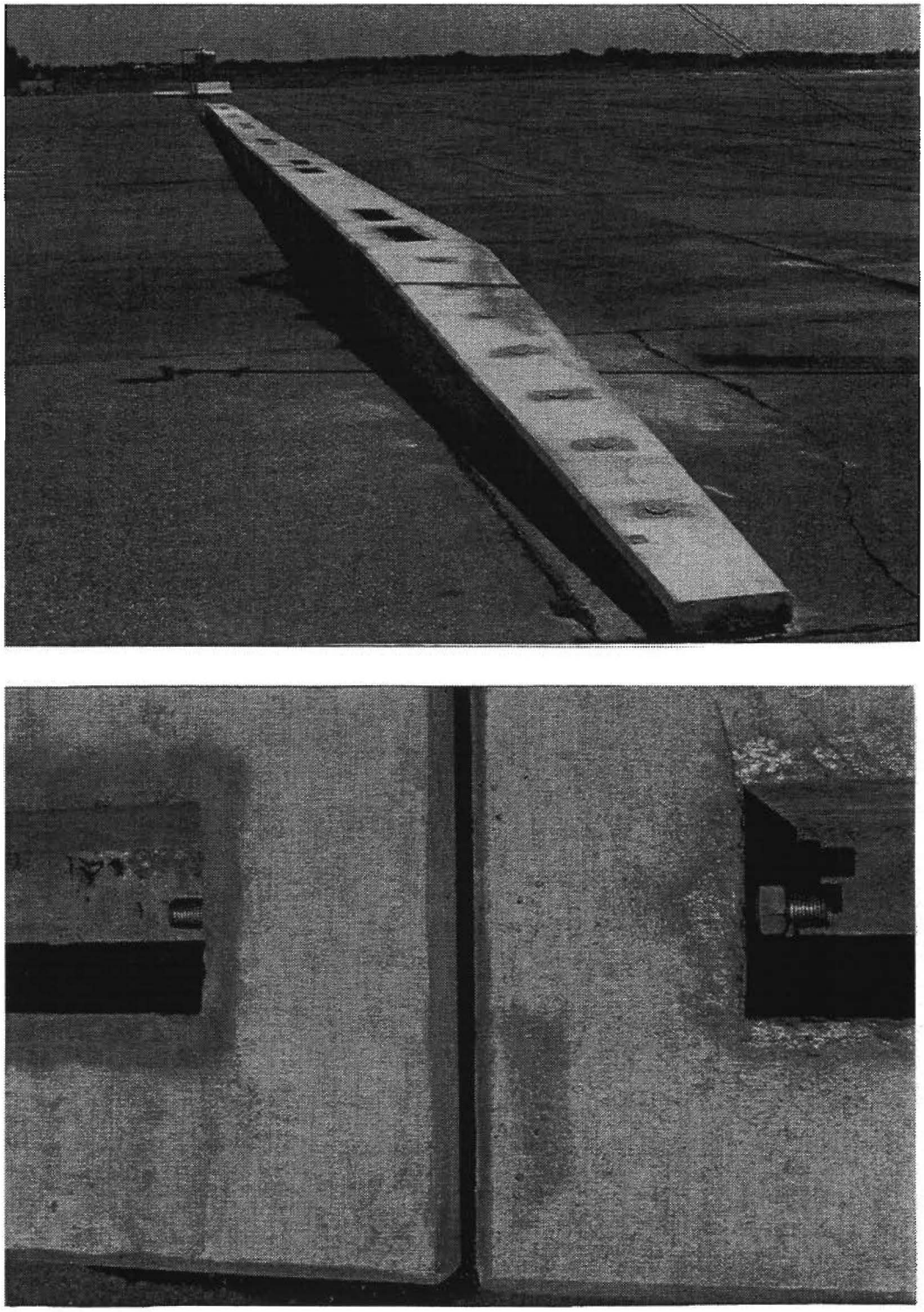


Figure 6. Low-Profile End Treatment Before Test 1949A-2

Figure 7. Vehicle/End Treatment Geometrics for Test 1949A-2

Figure 8. Vehicle Before Test 1949A-2

Damage to Test Installation

The end treatment received minimal damage. Cosmetic damage (i.e., tire marks) occurred, as shown in Figure 9, and there was a hairline crack across the end treatment at the first bolt location on the end treatment (0.8 m from the end). Theend treatment showed no movement. The vehicle was in contact with the installation for 14.1 m.

Vehicle Damage

The vehicle sustained damage to the right front wheel as shown in Figure 10. There was no direct crush to the vehicle. The only other damage was a small dent in the roof on the rear passenger side. The dent measured 150 mm x 100 mm x 60 mm and was considered to be due to the twisting motion induced in the vehicle body as the right side of the vehicle traversed the end treatment.

Occupant Risk Values

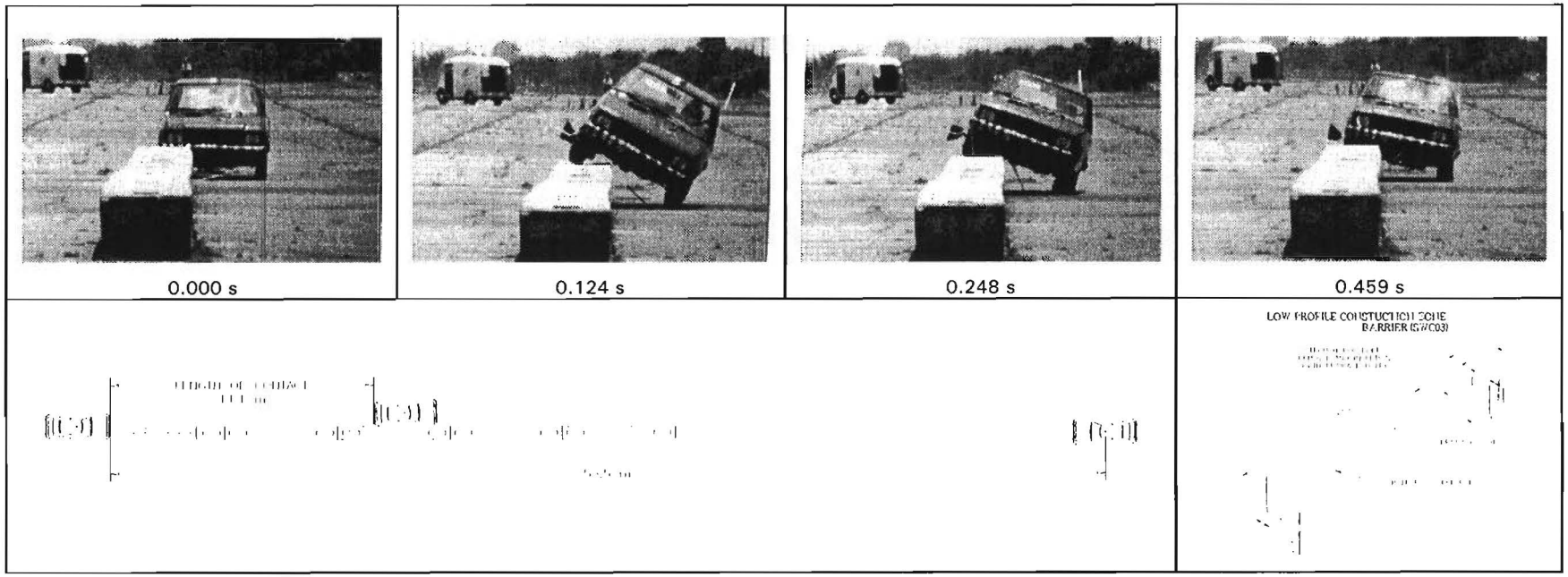
Data from the accelerometer located near the center of gravity were digitized for evaluation, and occupant risk factors were computed as follows. Longitudinal occupant impact velocity was 1.9 m/s and there was no contact in the lateral direction. The highest 0.010-s average longitudinal ridedown acceleration was -0.6 g. These and other pertinent data from this test are presented in Figure 11. Vehicular angular displacements are displayed in Figure 48 in Appendix D, and vehicular accelerations versus time traces filtered at Class 180 are presented in Figures 49 through 51 in Appendix D. The maximum 0.050-s average accelerations measured near the center of gravity of the vehicle were -0.6 g (longitudinal) and -1.0 g (lateral).

Summary of NCHRP Report 350 test 2-30

After impact, the vehicle redirected and did not penetrate, vault or roll over the barrier. There was no measurable movement of the barrier. There were no detached elements or debris to show potential for penetration of the occupant compartment or to present undue hazard to other traffic. The vehicle remained upright and stable during impact with the barrier and after exiting the test installation. The vehicle trajectory at loss of contact indicates minimum intrusion into the adjacent traffic lanes.

Figure 9. Low-Profile End Treatment After Test 1949A-2

Figure 10. Vehicle After Test 1949A-2



General Information
- Test Agency . . . . . Texas Transportation Institute
- Test No. 1949A-2
- Date 06/26/92

Test Article
- Type . . . . . End Treatment
- Name . . . . . Low-Profile End Treatment
- Installation Length (m) 30.5
- Size and/or dimension and material of key elements . . . . . 102-mm to 510-mm High Constant Slope Concrete End Treatment, 6.1-m Long

Soil Type and Condition . . . . . Concrete Pavement, Dry

Test Vehicle
- Type . . . . . Production
- Designation 820C
- Model . . . . . 1988 Yugo GVL
- Mass (kg) Curb 819
  - Test Inertial 817
  - Dummy 76
  - Gross Static 893

Impact Conditions
- Speed (km/h) 72.6
- Angle (deg) . . . . . 0 - rt qtr

Exit Conditions
- Speed (km/h) 65.3
- Angle (deg) 2.0

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 1.9
  - y-direction . . . . . No contact
- Ridedown Accelerations (g's)
  - x-direction . . . . . -0.6
  - y-direction . . . . . N/A
- Max. 0.050-s Average (g's)
  - x-direction . . . . . -0.6
  - y-direction . . . . . -1.0
  - z-direction 3.3

Test Article Deflections (m)
- Dynamic . . . . . nil
- Permanent . . . . . nil

Vehicle Damage
- Exterior
  - VDS . . . . . N/A
  - CDC 12FRWU1
- Maximum Exterior Vehicle Crush (mm) 0
- Interior
  - OCDI RF0000000
- Max. Occ. Compart. Deformation (mm) 0

Post-Impact Behavior (during 1.0 s after impact)
- Max. Roll Angle (deg) . . . . . -27
- Max. Pitch Angle (deg) . . . . -5
- Max. Yaw Angle (deg) 20

Figure 11. Summary of Results for Test 1949A-2

NCHRP REPORT 350 TEST DESIGNATION 2-31 (TEST 1949A-3)

In this test, a 1984 Chevrolet C-20 pickup was directed into the low-profile end treatment. Figure 12 presents a view of the end treatment prior to the impact. Figure 13 shows the vehicle prior to impact. The test inertial weight of the vehicle was 2043 kg and its gross static weight was 2043 kg. The height to the lower edge of the vehicle bumper was 445 mm and it was 679 mm to the top of the bumper. Additional dimensions and information on the test vehicle are given in Figure 69 in Appendix E. The vehicle was directed into the end treatment using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact.

Test Description

The vehicle impacted the end treatment end-on with the centerline of the vehicle aligned with the centerline of the end treatment. The vehicle made contact with the barrier 1168 mm from the end of the end treatment traveling at a speed of 74.8 km/h. The angle of impact was 0 degrees. As the vehicle rode up the end treatment, the left and then the right wheels lost contact with the roadway. The vehicle became totally airborne at 0.156 s after impact. The vehicle remained airborne as it passed over the connection of the end treatment to the main body of the low-profile barrier at 0.444 s traveling at a speed of 70.6 km/h. The left front A-arm of the vehicle touched down on the top edge of the barrier at 0.499 s and the rear of the vehicle came down on the top edge of the barrier at 2.005 s. The brakes were applied at 2.76 s after impact, the vehicle yawed counterclockwise and subsequently came to rest 99 m down and 6 m in front of the point of impact. Sequential photographs of the impact are shown in Figures 40 and 41 in Appendix C.

Damage to Test Installation

As can be seen in Figure 14, the end treatment received minimal damage. There was cosmetic damage (i.e., tire marks) and the edges of the end treatment were chipped. A minor crack occurred around the location of the steel pin in the end treatment. There was no movement of the end treatment.

Vehicle Damage

As shown in Figures 15 and 16, the vehicle sustained damage to the undercarriage only. The cross member, lower A-arms and differential housing were scraped as the vehicle straddled the installation.

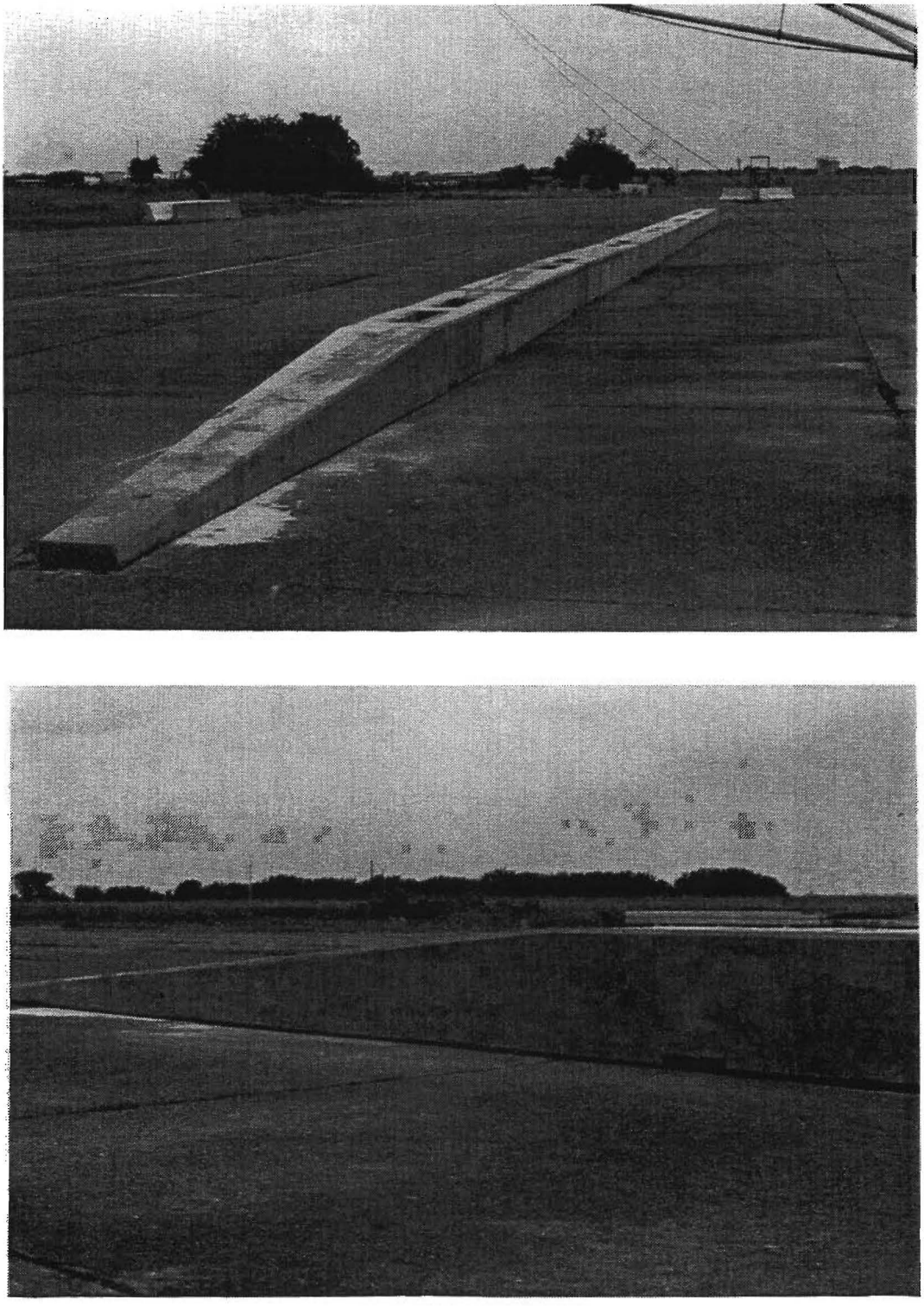


Figure 12. Low-Profile End Treatment Before Test 1949A-3

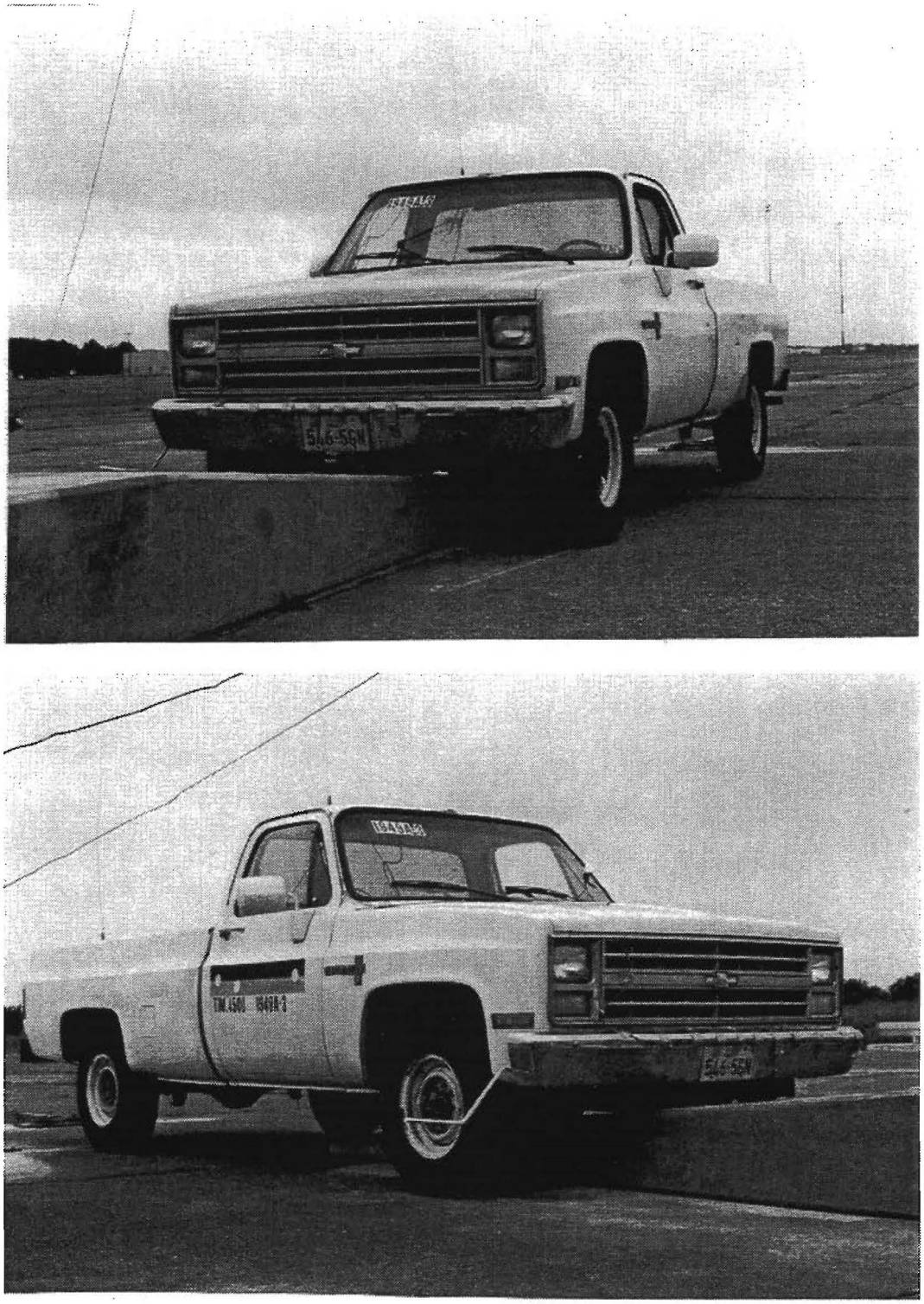


Figure 13. Vehicle/End Treatment Geometrics for Test 1949A-3

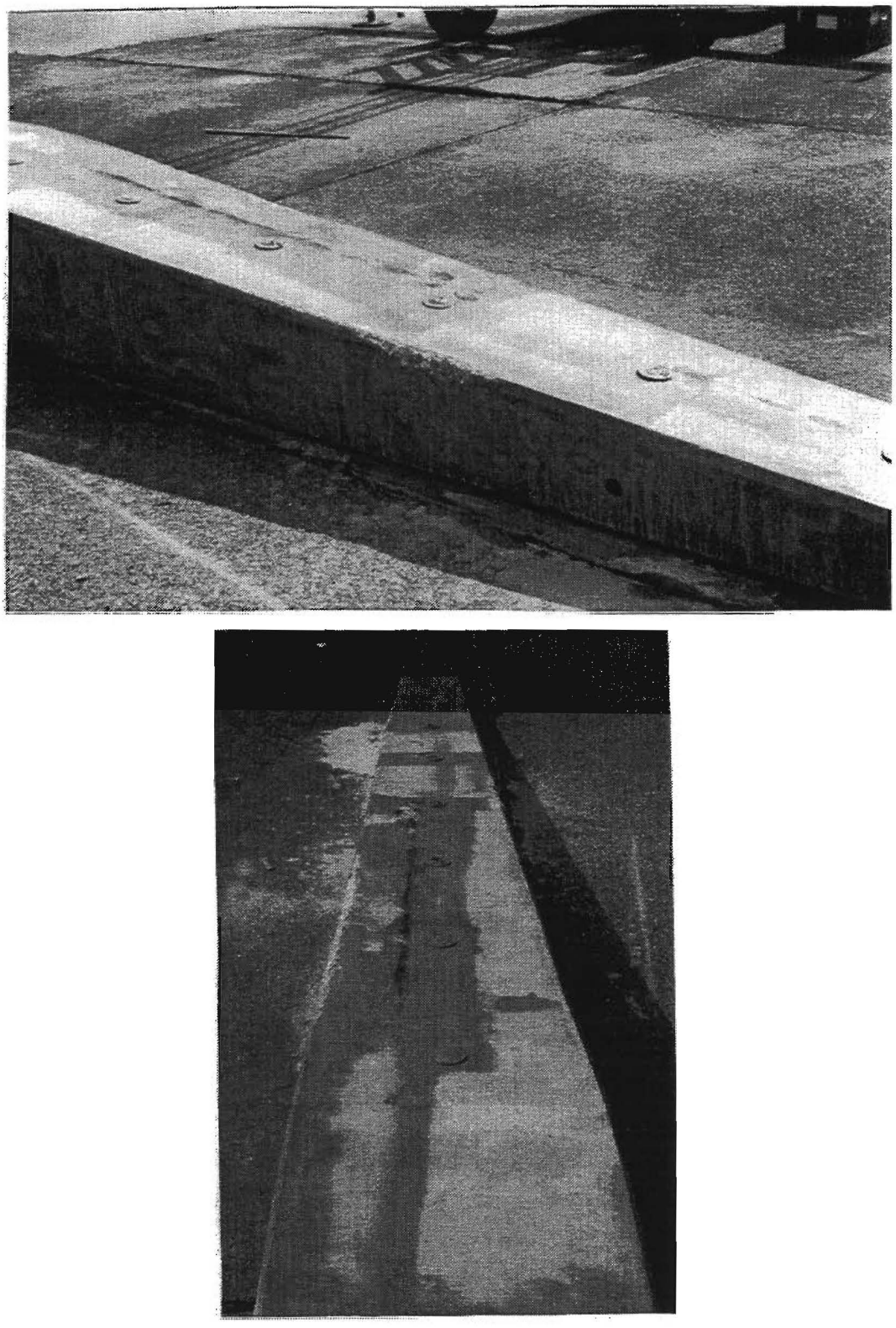


Figure 14. Low-Profile End Treatment After Test 1949A-3

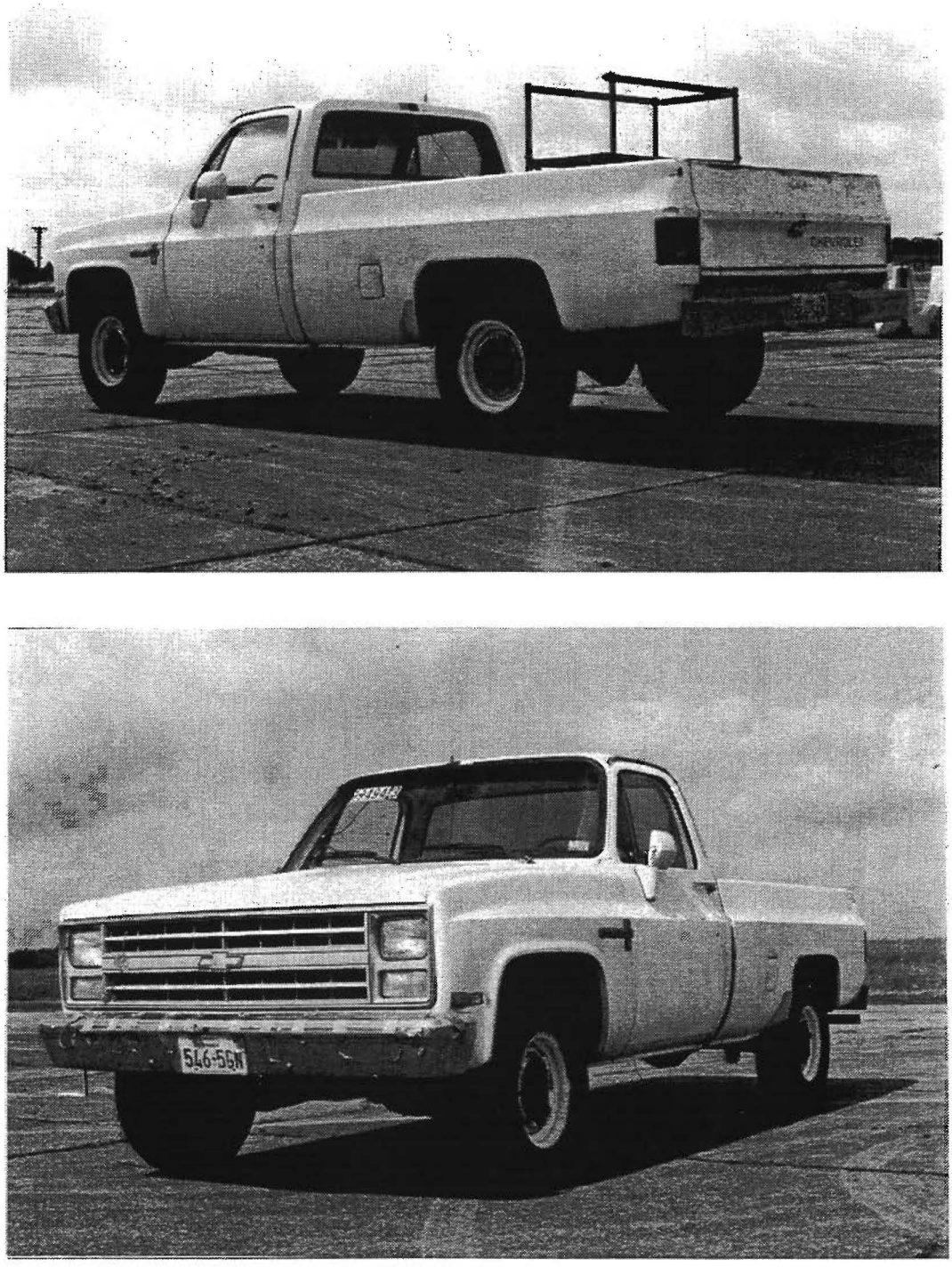


Figure 15. Vehicle After Test 1949A-3

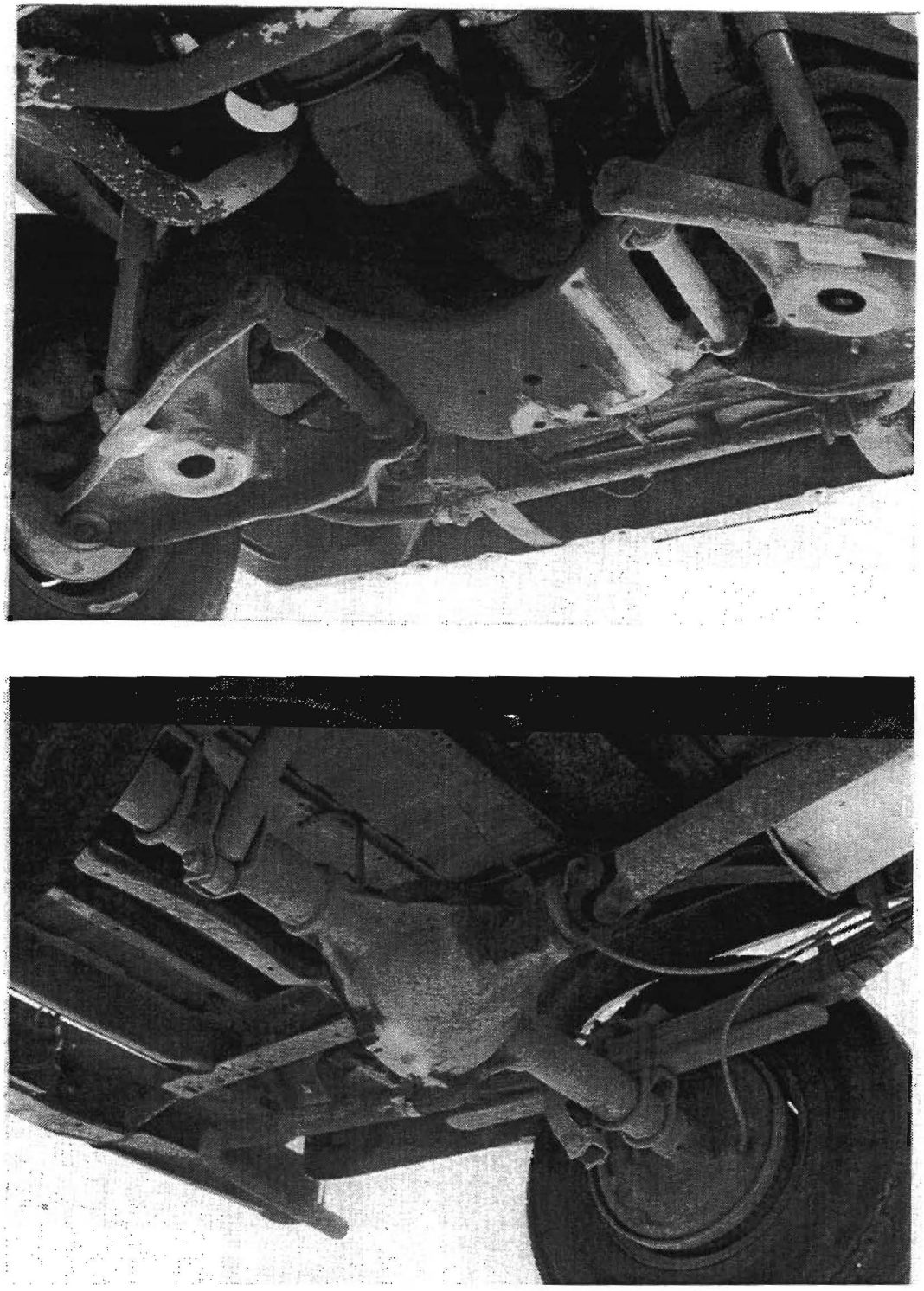


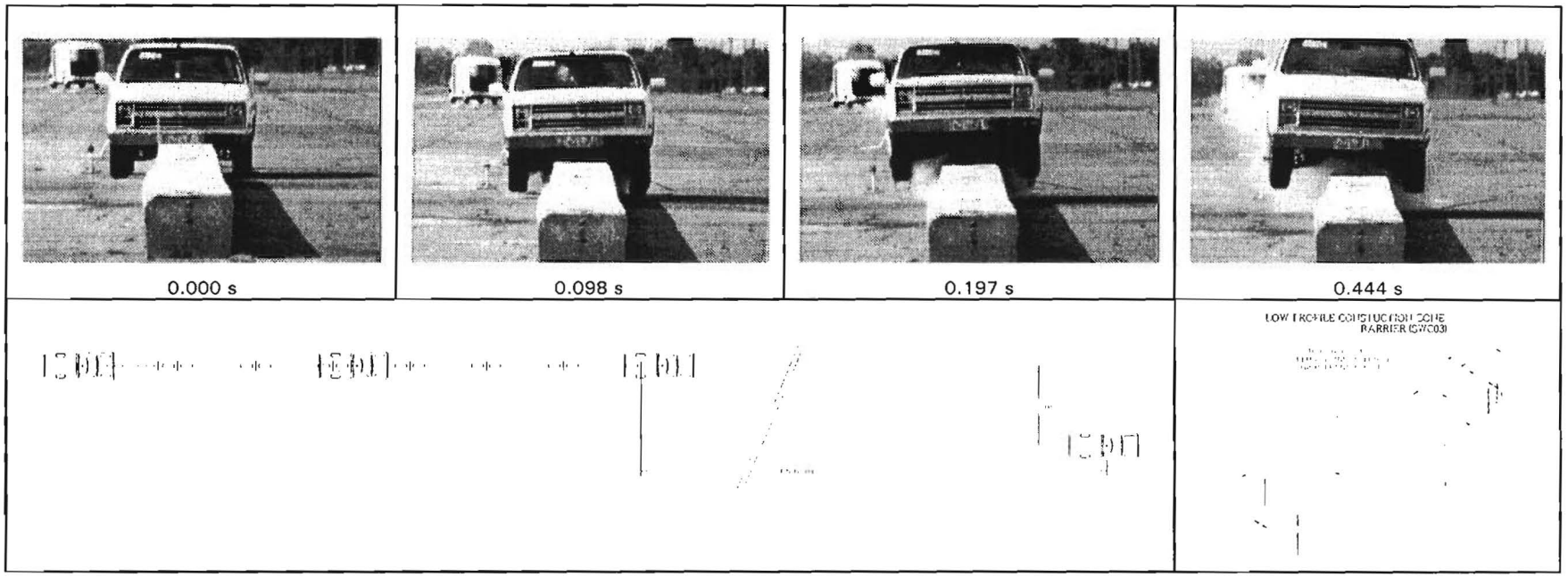
Figure 16. Damage to Undercarriage of Vehicle After Test 1949A-3

Occupant Risk Values

Data from the accelerometer located near the center of gravity were digitized for evaluation and occupant risk factors were computed as follows. The longitudinal occupant impact velocity was 1.9 m/s and the highest 0.010-s average ridedown acceleration was 4.1 g. In the lateral direction, the occupant impact velocity was 0.4 m/s and the ridedown acceleration was 2.1 g. These and other pertinent data from this test are presented in Figure 17. Vehicular angular displacements are displayed in Figure 52 in Appendix D, and vehicular accelerations versus time traces filtered at Class 180 are presented in Figures 53 and 55 in Appendix D. The maximum 0.050-s average accelerations measured near the center of gravity of the vehicle were -1.8 g (longitudinal) and 1.2 g (lateral).

Summary of NCHRP Report 350 test 2-31

After impact, the vehicle redirected and did not penetrate, vault, or roll over the barrier. There was no measurable movement of the barrier. There were no detached elements or debris to show potential for penetration of the occupant compartment or to present undue hazard to other traffic. The vehicle remained upright and stable during impact with the barrier and after exiting the test installation. There was no deformation or intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicates minimum intrusion into adjacent traffic lanes.



General Information
- Test Agency . . . . . Texas Transportation Institute
- Test No. 1949A-3
- Date 06/30/92

Test Article
- Type . . . . . End Treatment
- Name . . . . . Low-Profile End Treatment
- Installation Length (m) 30.5
- Size and/or dimension and material of key elements . . . . . 102-mm to 510 mm-High Constant Slope Concrete End Treatment, 6.1-m Long

Soil Type and Condition . . . . . Concrete Pavement, Dry

Test Vehicle
- Type . . . . . Production
- Designation 2000P
- Model . . . . . 1984 Chevrolet C-20
- Mass (kg) Gross 2121
  - Test Inertial 2043
  - Dummy . . . . . No dummy
  - Gross Static 2043

Impact Conditions
- Speed (km/h) 74.8
- Angle (deg) . . . . . 0 -cntr/cntr

Exit Conditions
- Speed (km/h) 70.6
- Angle (deg) . . . . . approx. 0

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 1.9
  - y-direction 0.4
- Ridedown Accelerations (g's)
  - x-direction 4.1
  - y-direction 2.1
- Max. 0.050-s Average (g's)
  - x-direction . . . . . -1.8
  - y-direction 1.2
  - z-direction 3.3

Test Article Deflections (m)
- Dynamic . . . . . nil
- Permanent . . . . . nil

Vehicle Damage
- Exterior
  - VDS . . . . . N/A
  - CDC 00UDCU1
- Maximum Exterior Vehicle Crush (mm) 0
- Interior
  - OCDI RF0000000
- Max. Occ. Compart. Deformation (mm) 0

Post-Impact Behavior (during 1.0 s after impact)
- Max. Roll Angle (deg) 20
- Max. Pitch Angle (deg) . . . . -7
- Max. Yaw Angle (deg) . . . . -7

Figure 17. Summary of Results for Test 1949A-3

NCHRP REPORT 350 TEST DESIGNATION 2-32 (TEST 414038-2)

The low-profile end treatment installation was repaired as shown in Figure 18 and used for this test. A 1990 Ford Festiva, shown in Figures 19 and 20, was used for this crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. The height to the lower edge of the vehicle bumper was 370 mm and it was 530 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix E, Figure 70. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Test Description

The vehicle, traveling at 68.91 km/h, impacted the nose of the end treatment at 15.06 degrees with the right quarter point of the vehicle aligned with the centerline of the end treatment. As the left front vehicle tires began to roll up the end treatment at 0.032 s, the vehicle began to pitch upward. The vehicle continued up the end treatment and the left front tire rolled off the barrier and at 0.251 s the rear wheel lost contact with the barrier. The vehicle was traveling at 63.15 km/h and was exiting behind the barrier at 7.72 degrees. The vehicle continued behind the installation. Brakes on the vehicle were applied at 2.5 s and the vehicle subsequently came to rest 64.0 m down and 13.7 m behind the low-profile barrier. Sequential photographs of the test period are shown in Figures 42 and 43 of Appendix C.

Damage to Test Installation

The end treatment was not damaged as shown in Figures 21 and 22. Tire marks were found on the top surface from 1.37 m from the end to 2.46 m. The undercarriage scraped the end treatment from 300 mm from the end to 1880 mm. There were tire marks on the pavement 15.2 m down from impact where the vehicle touched ground.

Vehicle Damage

As shown in Figure 23, there was no body damage to the vehicle. The undercarriage was scraped only, with no other damage to the suspension or other components under the vehicle. No measurable crush to the exterior of the vehicle and no deformation of the occupant compartment occurred.

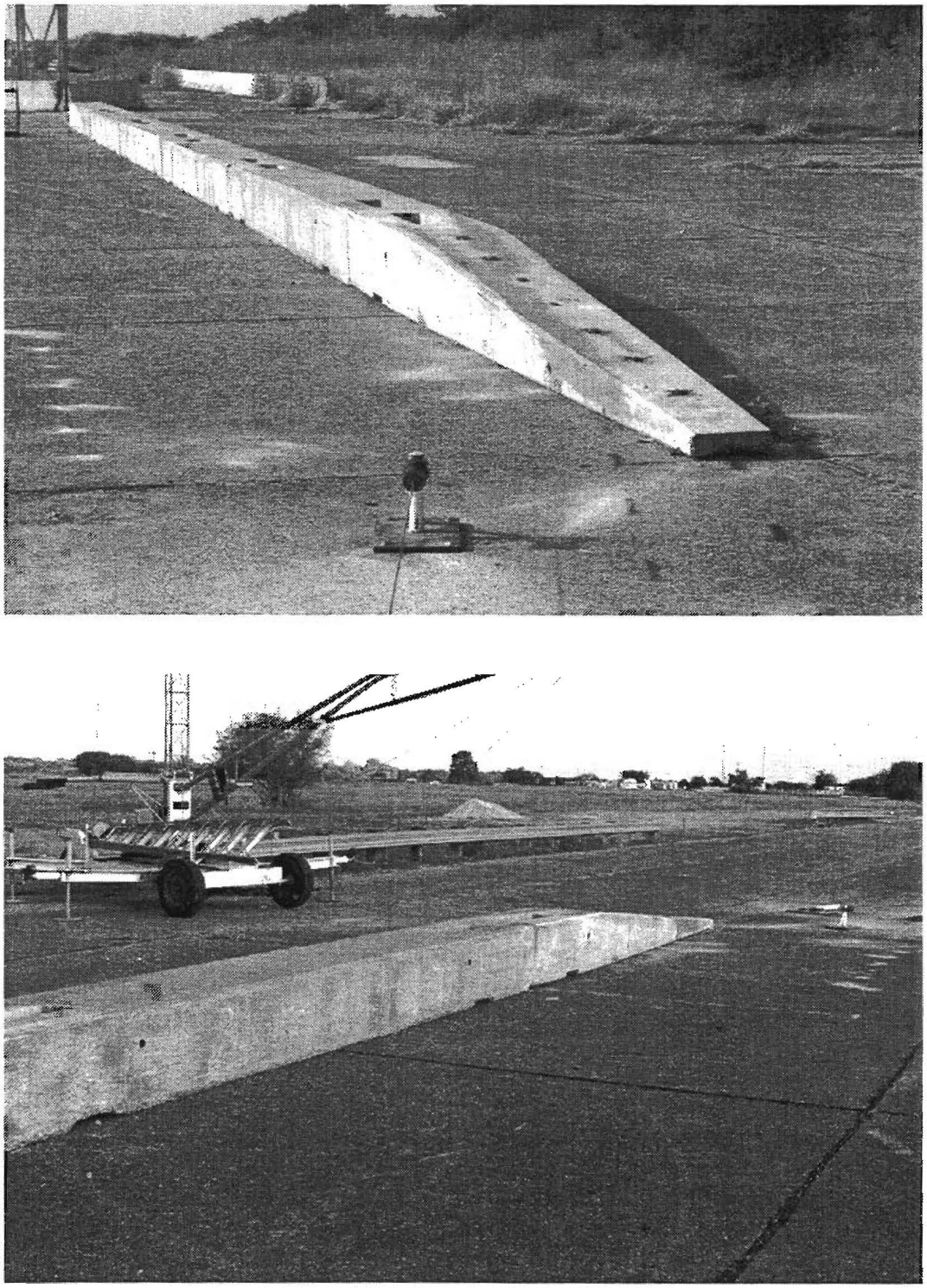


Figure 18. Low-Profile End Treatment Installation Before Test 414038-2

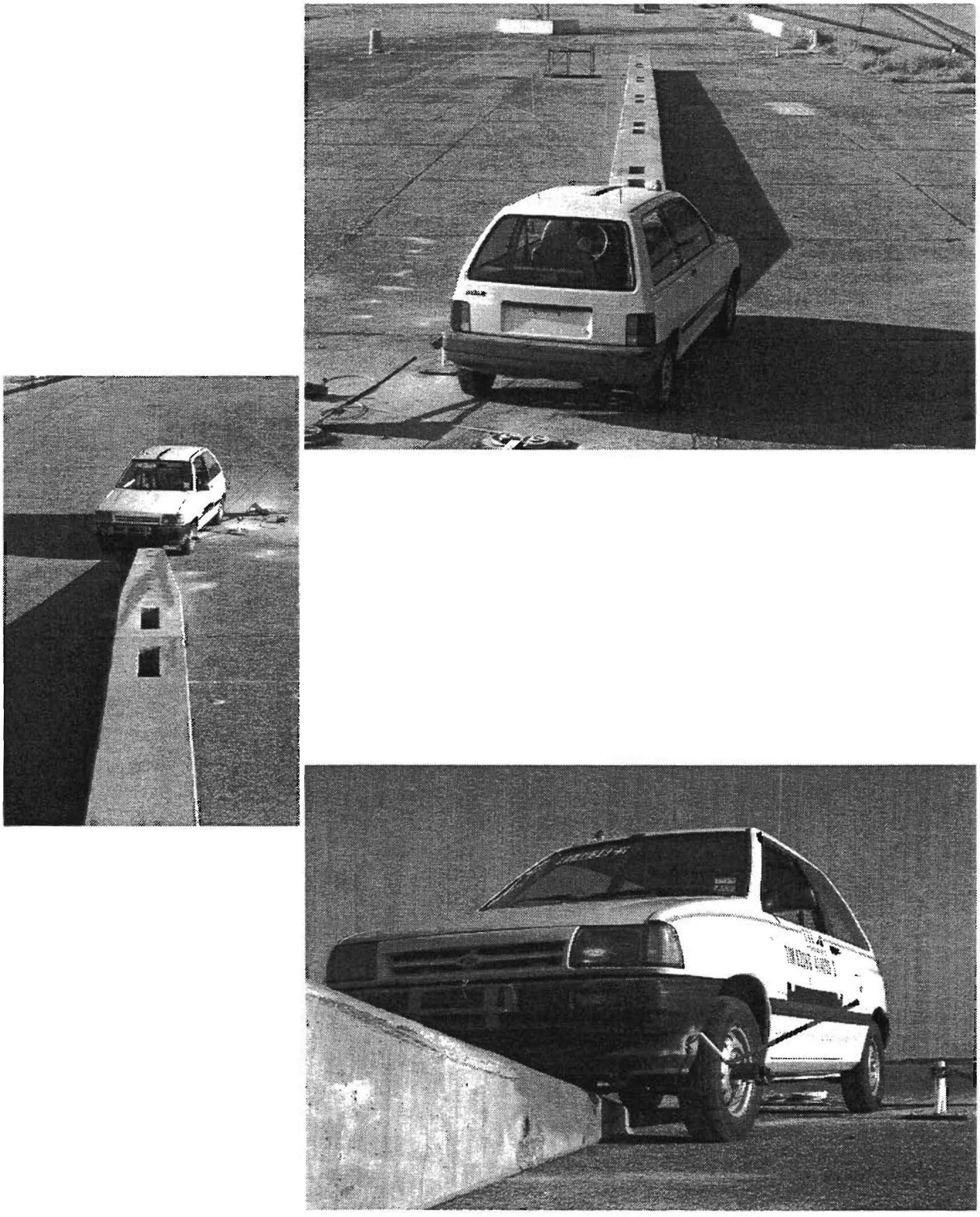


Figure 19. Vehicle/Installation Geometrics for Test 414038-2

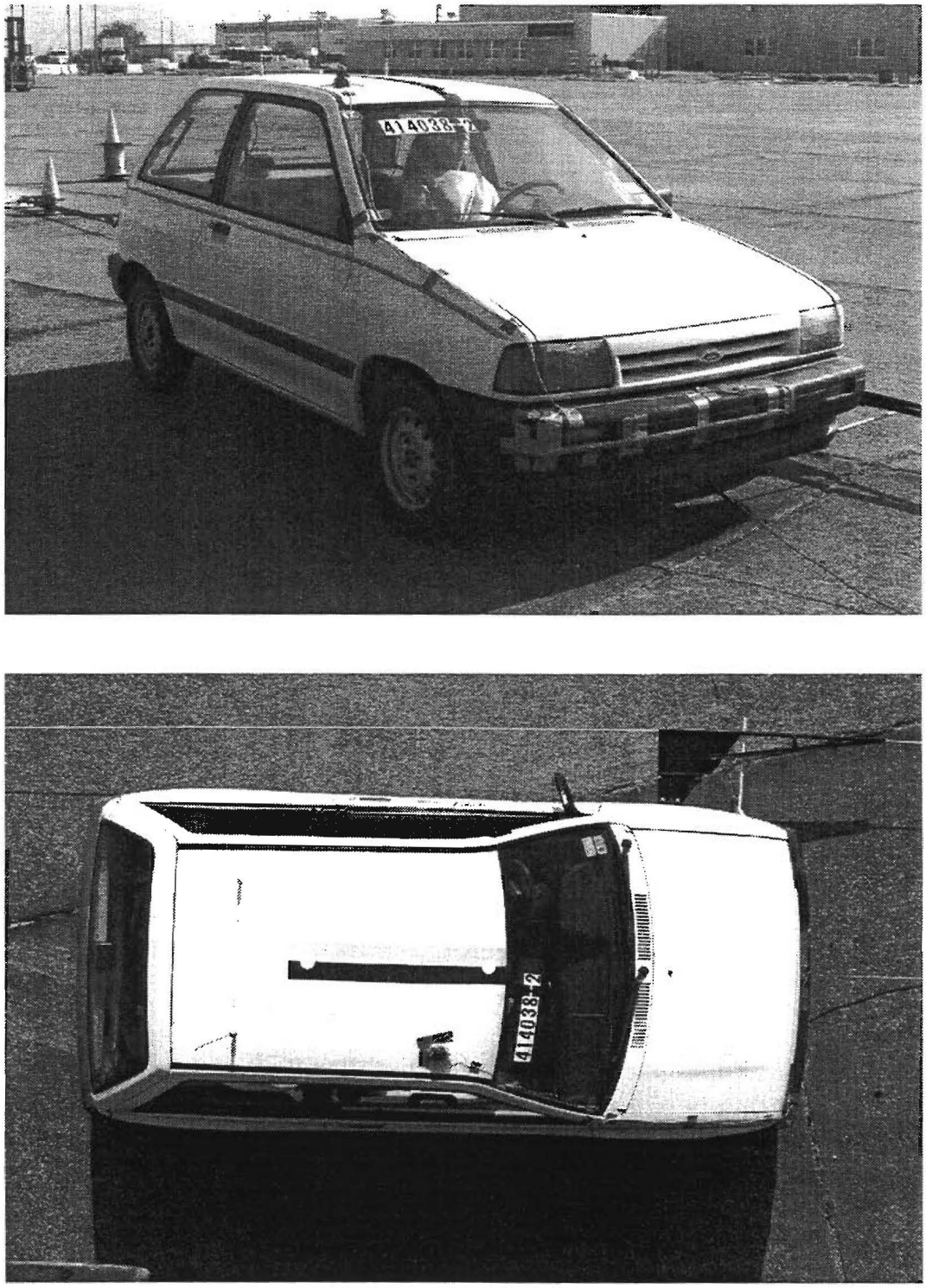


Figure 20. Vehicle Before Test 414038-2

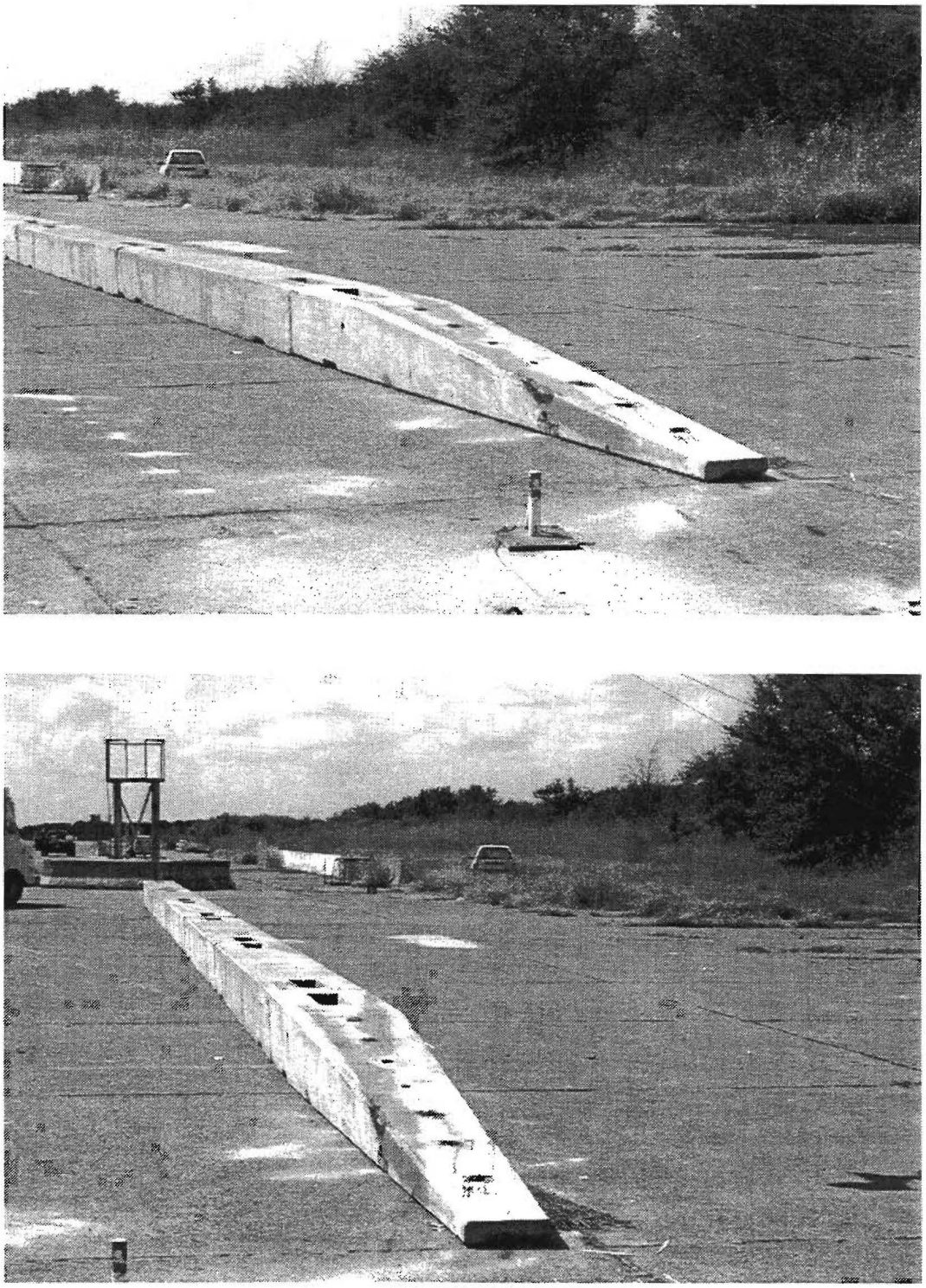


Figure 21. After Impact Trajectory for Test 414038-2

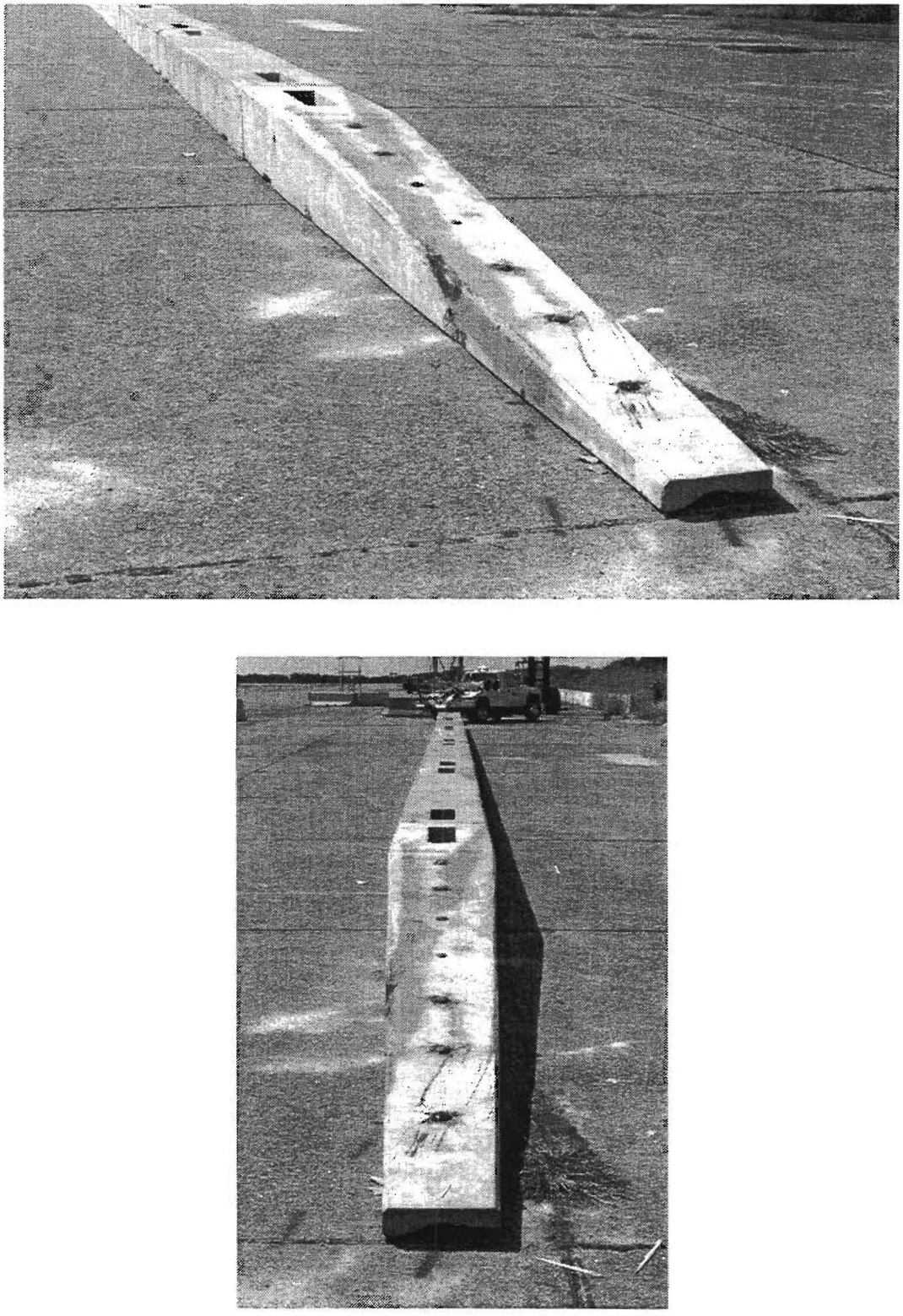


Figure 22. Installation After Test 414038-2

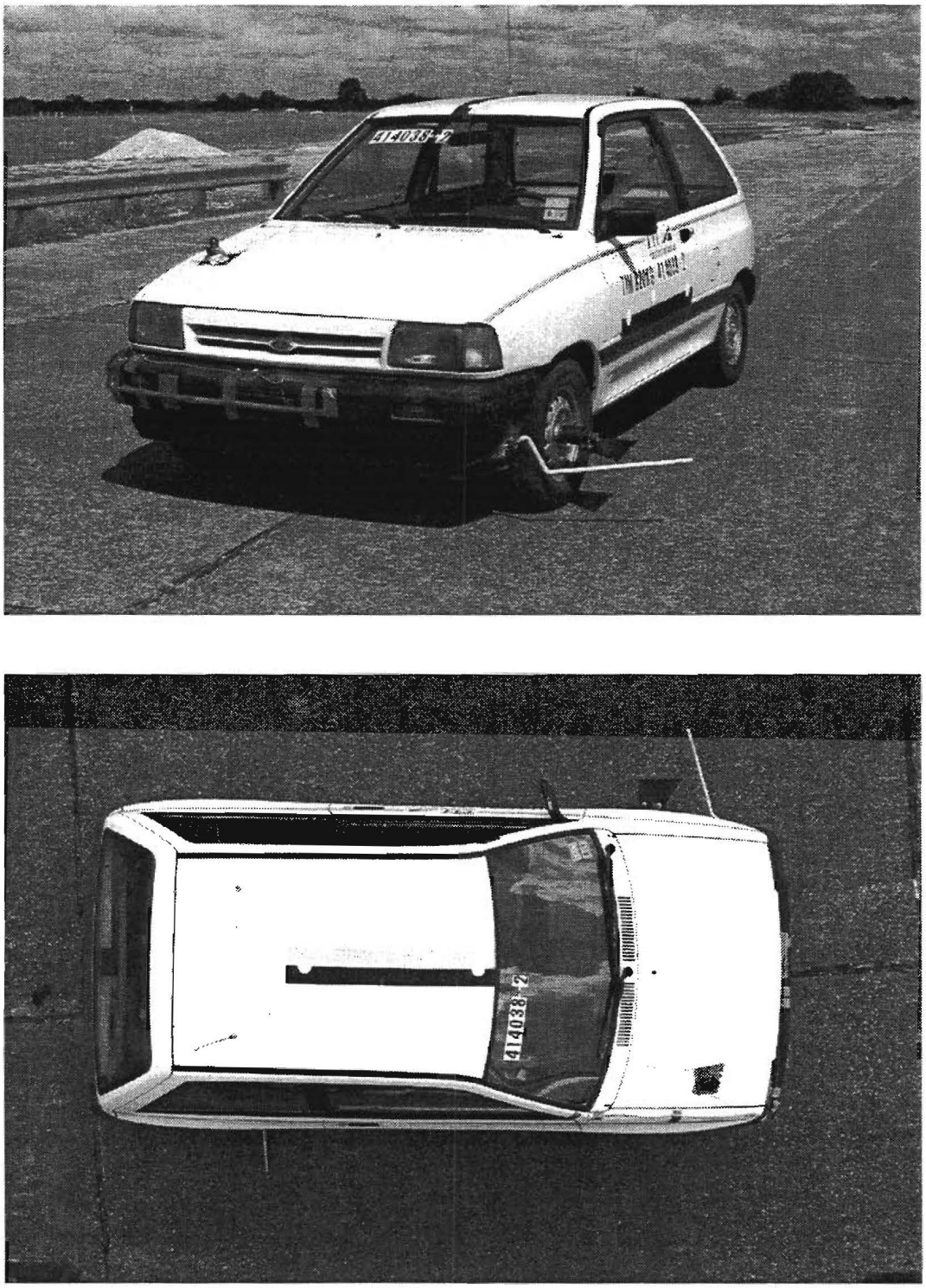


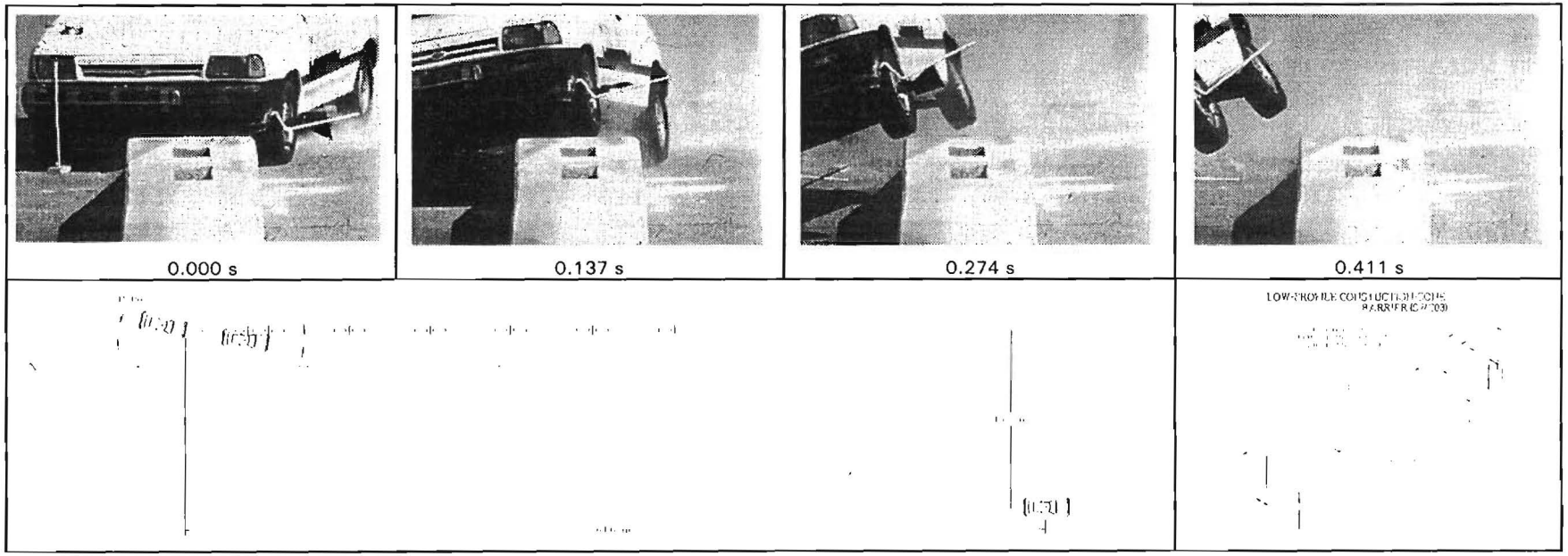
Figure 23. Vehicle After Test 414038-2

Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. There was no occupant impact in the longitudinal or lateral directions. The maximum 0.050-s average longitudinal acceleration was -0.73 g between 0.040 and 0.090, and the maximum 0.050-s average lateral acceleration was 1.33 g between 0.908 and 0.958 s. These data and other pertinent information from the test are summarized in Figure 24. Vehicle angular displacements are displayed in Figure 56 in Appendix D. Vehicular accelerations versus time traces are presented in Figures 57 through 59 in Appendix D.

Summary of NCHRP Report 350 test 2-32

After the impact, the low-profile end treatment allowed the vehicle to gate through the barrier. There were no detached elements or debris to penetrate or show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. There was no deformation or intrusion of the occupant compartment. The vehicle remained upright during and after the collision period. There was no occupant contact in the longitudinal or lateral direction. The vehicle did not intrude into adjacent traffic lanes. The vehicle came to rest behind the installation. The results of this test should be considered in bracketing the critical impact point required in NCHRP Report 350 test designation 2-34.



General Information
- Test Agency . . . . . Texas Transportation Institute
- Test No. 414038-2
- Date 09/18/97

Test Article
- Type . . . . . End Treatment
- Name . . . . . Low-Profile Barrier
- Installation Length (m) 36.58
- Size and/or dimension and material of key elements . . . . . 102-mm to 510 mm-High Constant Slope Concrete End Treatment, 6.1-m Long
- Soil Type and Condition . . . . . Concrete Pavement, Dry

Test Vehicle
- Type . . . . . Production
- Designation 820C
- Model . . . . . 1990 Ford Festiva
- Mass (kg) Curb 810
  - Test Inertial 820
  - Dummy 76
  - Gross Static 896

Impact Conditions
- Speed (km/h) 68.91
- Angle (deg) 15.06

Exit Conditions
- Speed (km/h) 63.15
- Angle (deg) 7.72

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction . . . . . No contact
  - y-direction . . . . . No contact
- Ridedown Accelerations (g's)
  - x-direction . . . . . N/A
  - y-direction . . . . . N/A
- Max. 0.050-s Average (g's)
  - x-direction . . . . . -0.73
  - y-direction 1.33
  - z-direction . . . . . -2.54

Test Article Deflections (m)
- Dynamic . . . . . nil
- Permanent . . . . . nil

Vehicle Damage
- Exterior
  - VDS 01RFQ0
  - CDC 01FRLU0
- Maximum Exterior Vehicle Crush (mm) . . . . nil
- Interior
  - OCDI RF0000000
- Max. Occ. Compart. Deformation (mm) 0

Post-Impact Behavior (during 1.0 s after impact)
- Max. Roll Angle (deg) . . . . . -17.4
- Max. Pitch Angle (deg) 8.2
- Max. Yaw Angle (deg) . . . . -7.3

Figure 24. Summary of Results for Test 414038-2

NCHRP REPORT 350 TEST DESIGNATION 2-34 (TEST 1949A-1)

In this test, a 1986 Yugo was directed into the low-profile end treatment. Figure 25 presents a view of the barrier prior to impact. The vehicle prior to impact is shown in Figures 26 and 27. Test inertial weight of the vehicle was 817 kg and its gross static weight was 893 kg. The height to the top of the bumper was 330 mm and it was 470 mm to the top of the bumper. Additional dimensions and information pertaining to the test vehicle are given in Figure 71 in Appendix E. The vehicle was directed into the end treatment using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact.

Test Description

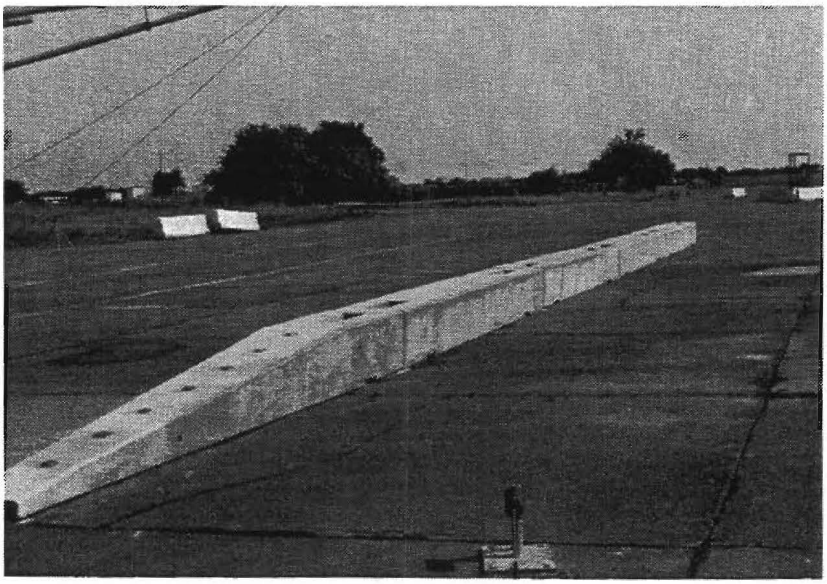
The vehicle impacted the end treatment 2.0 m from the end at a speed of 71.9 km/h. The angle of impact was 16.3 degrees. At 0.027 s after impact, the left wheel turned under and at 0.032 s the roof began to deform just over the door post location. The vehicle began to redirect at 0.050 s after impact and at 0.084 s, the dummy shattered the driver's side window. By 0.161 s, the vehicle was traveling parallel to the end treatment at a speed of 62.3 km/h, and at 0.188 s the rear of the vehicle impacted the end treatment. The vehicle became airborne at 0.253 s and remained airborne as the vehicle lost contact with the end treatment at 0.389 s traveling at a speed of 60.2 km/h and with an exit angle of 6.1 degrees. The brakes were applied at 2.5 s after impact, the vehicle yawed counterclockwise and came to rest facing the installation 39 m downstream of the point of impact. Sequential photographs for this test are shown in Figures 44 and 45 in Appendix C.

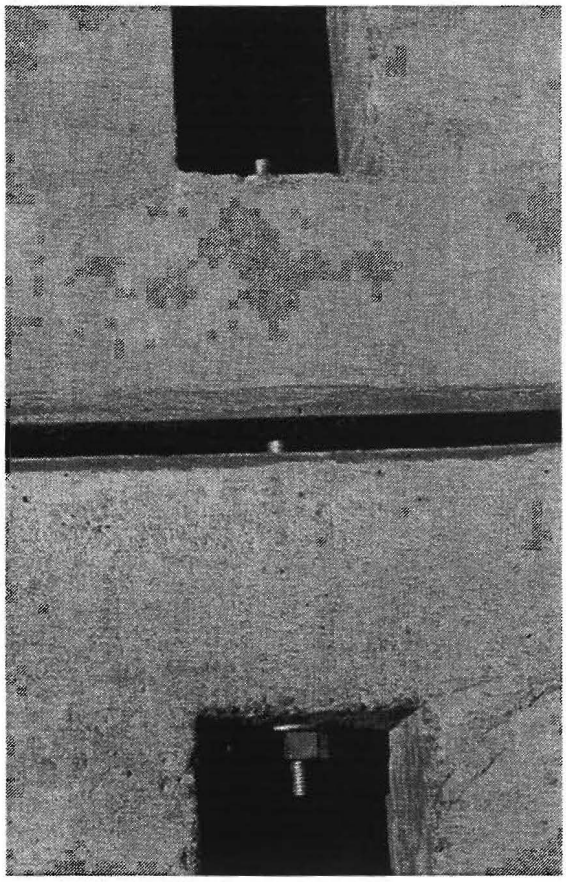
Damage to Test Installation

As can be seen in Figure 28, the end treatment received minimal damage. There was cosmetic damage (i.e., tire marks) along the 3.0 m of end treatment where the vehicle was in contact. In addition, the edge of the end treatment was chipped. There was no movement of the end treatment.

Vehicle Damage

The vehicle sustained damage to the left side as shown in Figure 29. Maximum crush at the left front corner at bumper height was 127 mm. The driver's door was deformed outward, the driver's side window was broken out, and the door was jammed. There was a 25 mm dent in the roof just above the door caused by the twisting motion of the vehicle as it was redirected. Also, damage was done to the front bumper, grill, the left front strut, left front quarter panel, left rear panel, and left front tire and rim.





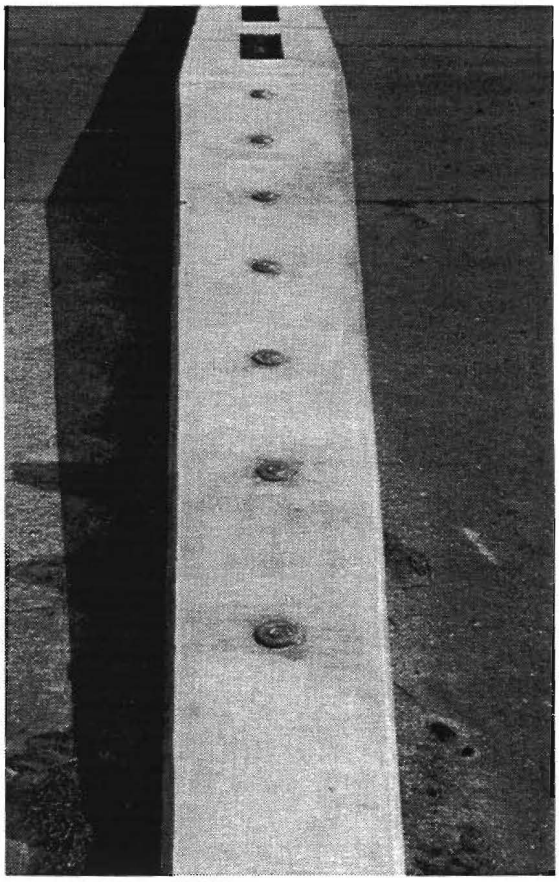


Figure 25. Low-Profile End Treatment Before Test 1949A-1

Figure 26. Vehicle/Installation Geometrics for Test 1949A-1

Figure 27. Vehicle Before Test 1949A-1

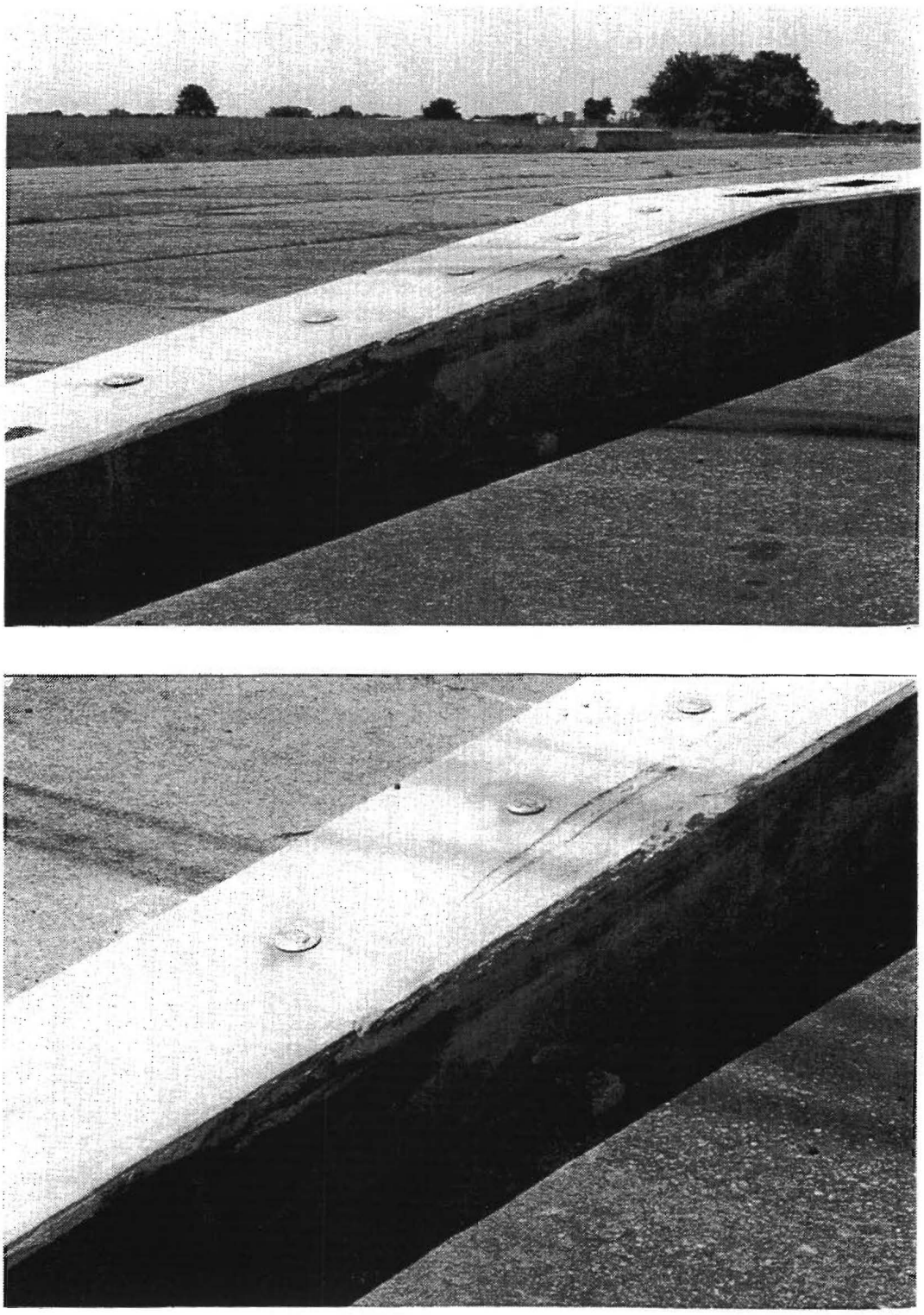


Figure 28. Low-Profile End Treatment After Test 1949A-1

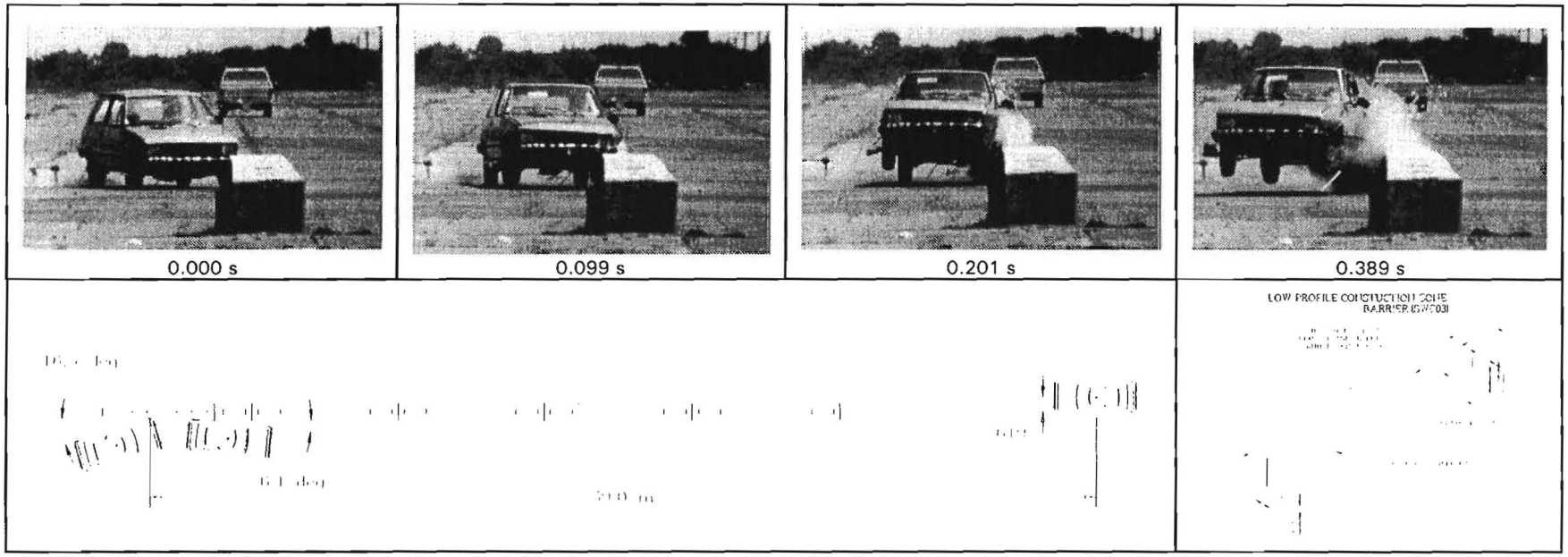
Figure 29. Vehicle After Test 1949A-1

Occupant Risk Values

Data from the accelerometer that was located near the center of gravity of the vehicle were digitized for evaluation and occupant risk factors were computed as follows. In the longitudinal direction, the occupant impact velocity was 4.1 m/s and the highest 0.010-s average ridedown was -1.9 g. In the lateral direction, the occupant impact velocity was 5.5 m/s and the ridedown was -4.5 g. The maximum 0.050-s average accelerations were -5.7 g (longitudinal) and -8.3 g (lateral). These and other pertinent data from this test are presented in Figure 30. Vehicular angular displacements for this test are presented in Figure 60 in Appendix D, and vehicular accelerations versus time traces filtered at Class 180 are presented in Figures 61 through 63 in Appendix D.

Summary of NCHRP Report 350 test 2-34

After impact, the vehicle redirected and did not penetrate, vault, or roll over the barrier. There was no measurable movement of the barrier. There were no detached elements or debris to show potential for penetration of the occupant compartment or to present undue hazard to other traffic. The vehicle remained upright and stable during the impact with the barrier and after exiting the test installation. There was no deformation or intrusion into the occupant compartment. The vehicle trajectory at loss of contact indicated minimum intrusion into the adjacent traffic lanes.



General Information
- Test Agency . . . . . Texas Transportation Institute
- Test No. 1949A-1
- Date 06/24/92

Test Article
- Type . . . . . End Treatment
- Name . . . . . Low-Profile End Treatment
- Installation Length (m) 30.5
- Size and/or dimension and material of key elements . . . . . 102-mm to 510-mm High Constant Slope Concrete End Treatment, 6.1-m Long
- Soil Type and Condition . . . . . Concrete Pavement, Dry

Test Vehicle
- Type . . . . . Production
- Designation 820C
- Model . . . . . 1986 Yugo GVL
- Mass (kg) Curb 824
  - Test Inertial 817
  - Dummy 76
  - Gross Static 893

Impact Conditions
- Speed (km/h) 71.9
- Angle (deg) 16.3

Exit Conditions
- Speed (km/h) 60.2
- Angle (deg) 6.1

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 4.1
  - y-direction 5.5
- Ridedown Accelerations (g's)
  - x-direction . . . . . -1.9
  - y-direction . . . . . -4.5
- Max. 0.050-s Average (g's)
  - x-direction . . . . . -5.7
  - y-direction . . . . . -8.3
  - z-direction 3.9

Test Article Deflections (m)
- Dynamic . . . . . nil
- Permanent . . . . . nil

Vehicle Damage
- Exterior
  - VDS 11LFQ1
  - CDC 11LFEW2
- Maximum Exterior Vehicle Crush (mm) 127
- Interior
  - OCDI LF0000000
- Max. Occ. Compart. Deformation (mm) 0

Post-Impact Behavior (during 1.0 s after impact)
- Max. Roll Angle (deg) . . . . . -3
- Max. Pitch Angle (deg) . . . . -8
- Max. Yaw Angle (deg) . . . . -34

Figure 30. Summary of Results for Test 1949A-1

NCHRP REPORT 350 TEST DESIGNATION 2-34 (TEST 414038-1)

A 1990 Ford Festiva, shown in Figures 31 and 32, was used for the crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 895 kg. The height to the lower edge of the vehicle bumper was 410 mm and it was 560 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Appendix E, Figure 72. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Test Description

The vehicle, traveling at 70.91 km/h, impacted the end treatment for the low-profile barrier 0.91 m from the end at 15.78 degrees. The vehicle began to redirect at 0.029 s after impact and the right front tire deflated at 0.034 s. At 0.058 s, the left front wheel began to steer to the left (toward traffic) and by 0.144 s the right rear tire contacted the end treatment and rolled up on top. The vehicle began traveling parallel with the barrier at 0.186 s while traveling at a speed of 59.61 km/h. As the vehicle continued forward, the rear of the vehicle began to yaw counterclockwise. The vehicle lost contact with the low-profile barrier at 0.842 s and then contacted the top of the barrier again with the rear wheels 10.7 m from the end. The vehicle continued to yaw counterclockwise, rolled off the barrier, and subsequently came to rest with the rear of the vehicle against the barrier 1.8 m from end of the installation. Brakes on the vehicle were not applied during this test. Sequential photographs of the test period are shown in Appendix C, Figures 46 and 47.

Damage to Test Installation

There was minimal damage to the end treatment as shown in Figures 33 and 34. The vehicle was in contact with the end treatment and low-profile barrier for 8.3 m during the first contact and 2.4 m during the second contact. There was no sign of movement in the end treatment or the barrier. The last joints crumbled when the vehicle came to rest at the end of the installation.

Vehicle Damage

The vehicle received damage to the right front corner, as shown in Figure 35, with most of the damage to the undercarriage. The right strut, sway bar and right side axle were deformed. Also damaged were the front bumper, grill, both right side tire and wheel assembly, and the right door was jammed. There was no measurable exterior crush to the vehicle. Maximum deformation into the occupant compartment was 35 mm in the firewall/floorpan area.

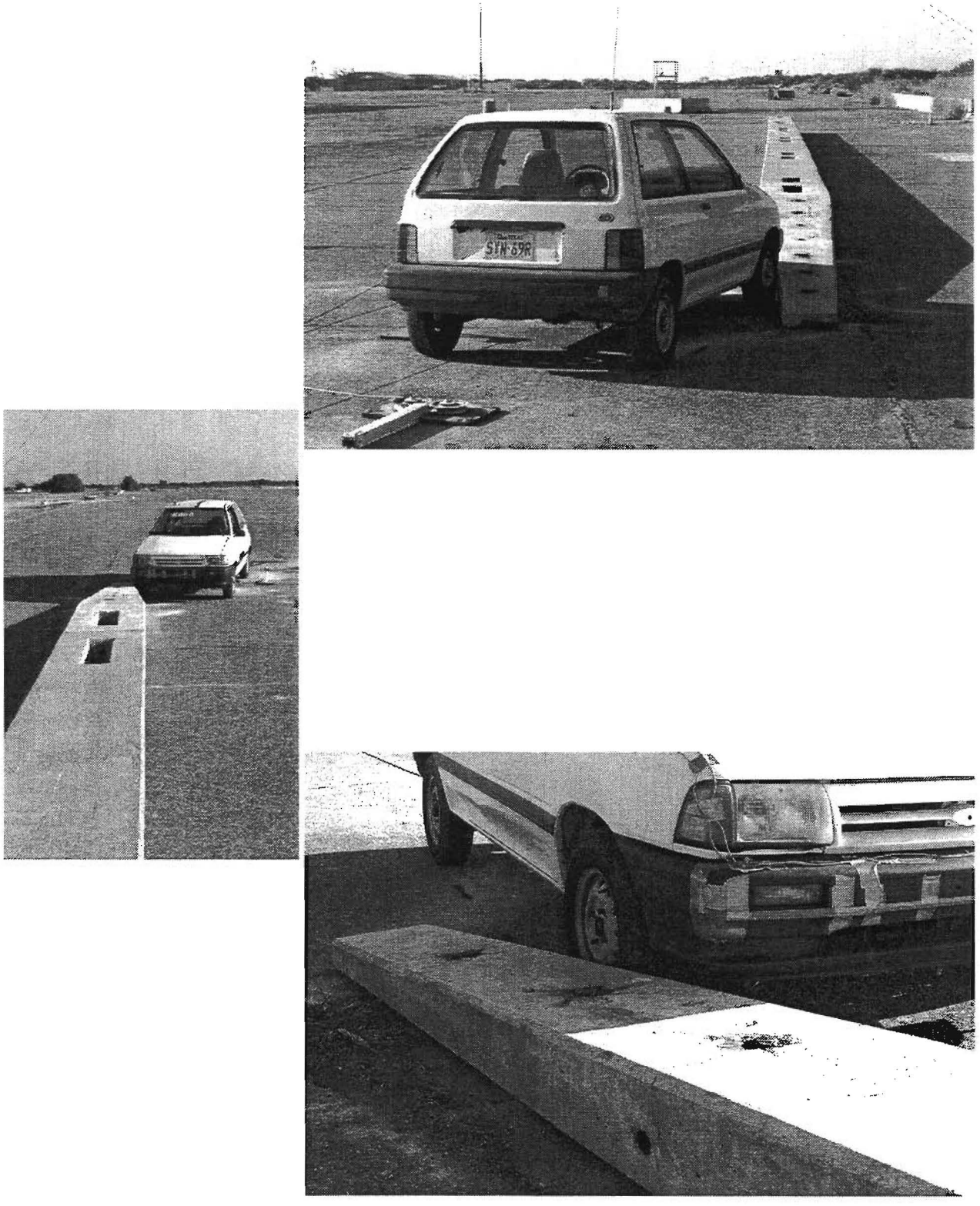


Figure 31. Vehicle/Installation Geometrics for Test 414038-1

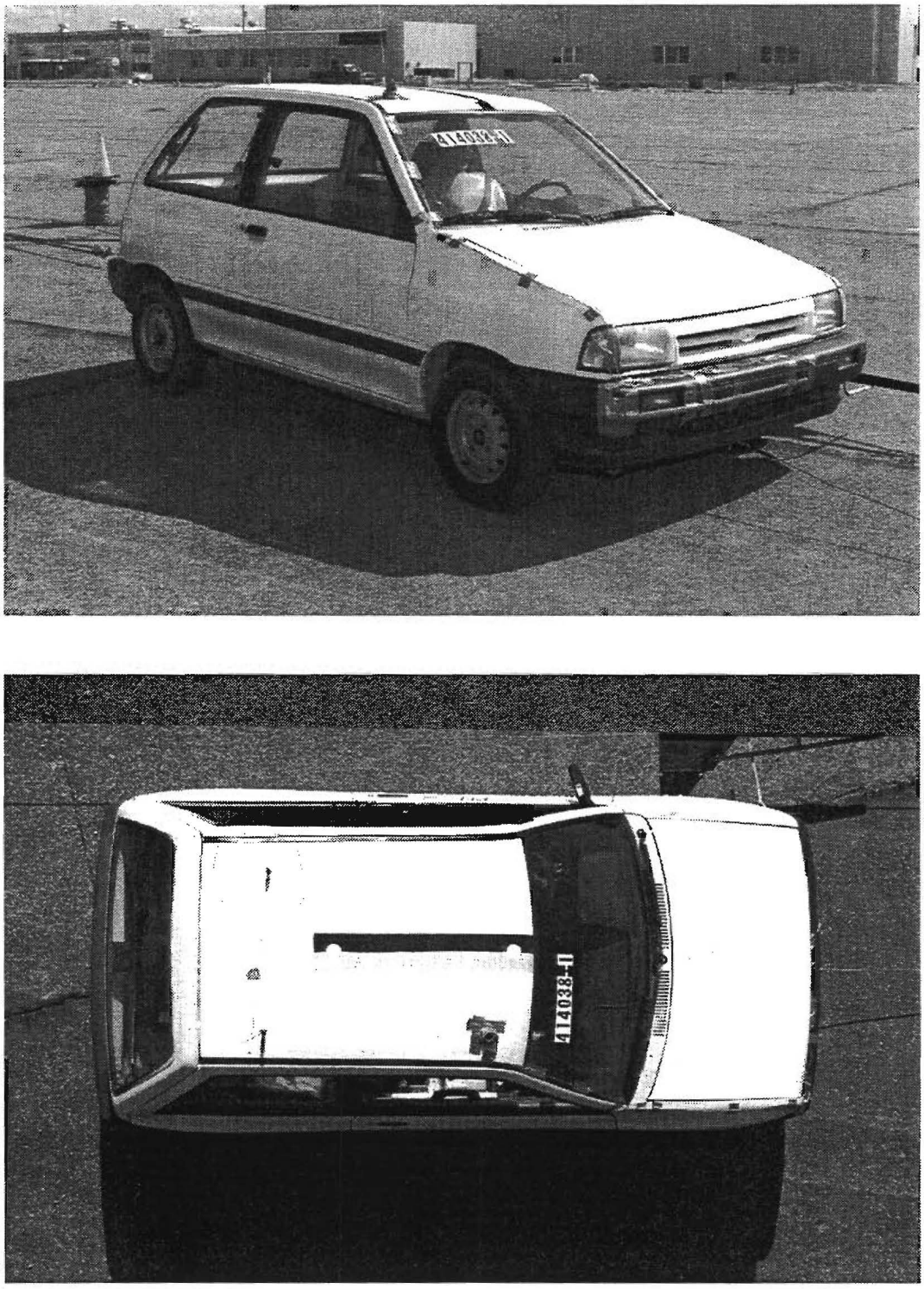


Figure 32. Vehicle Before Test 414038-1

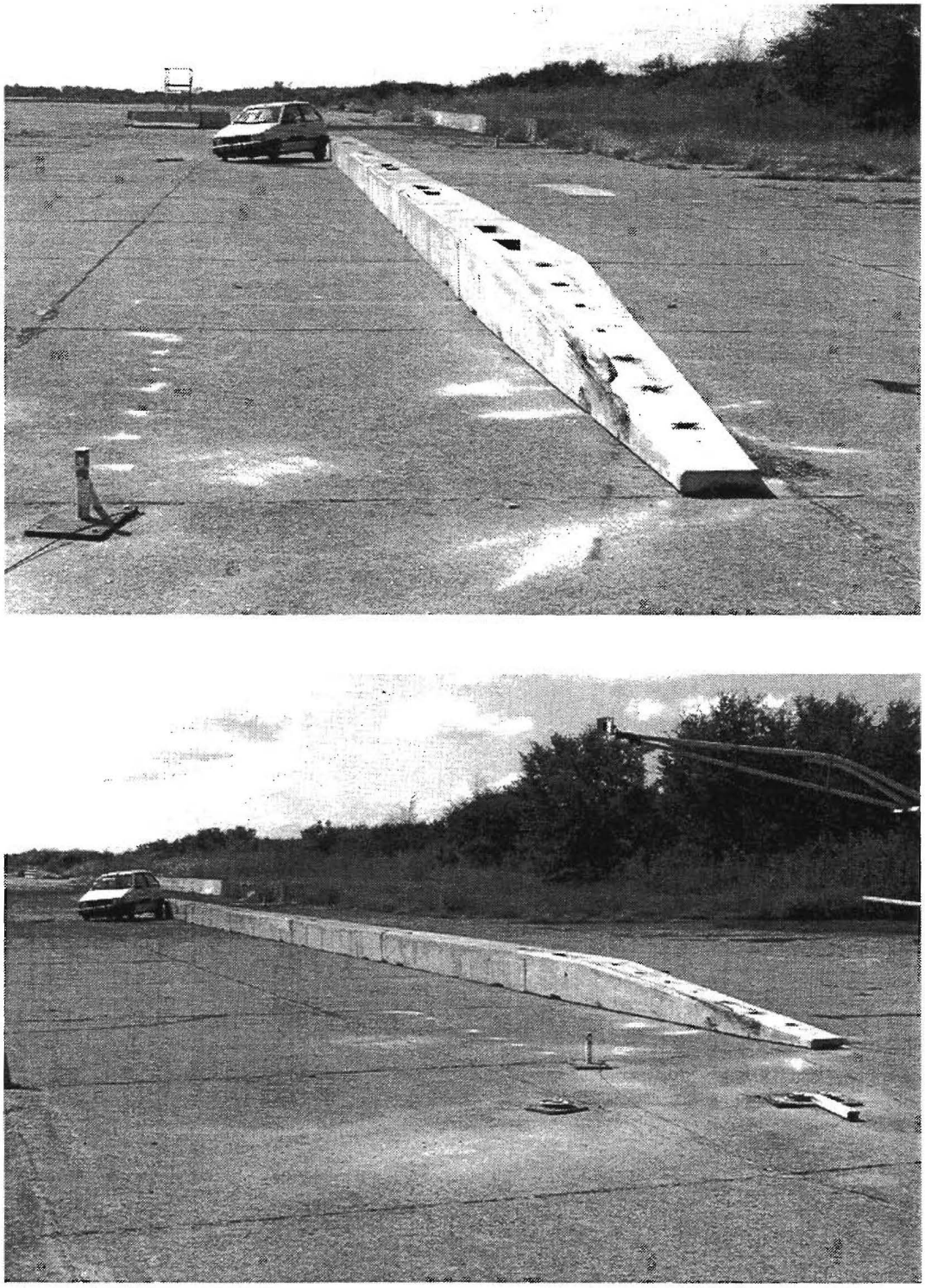
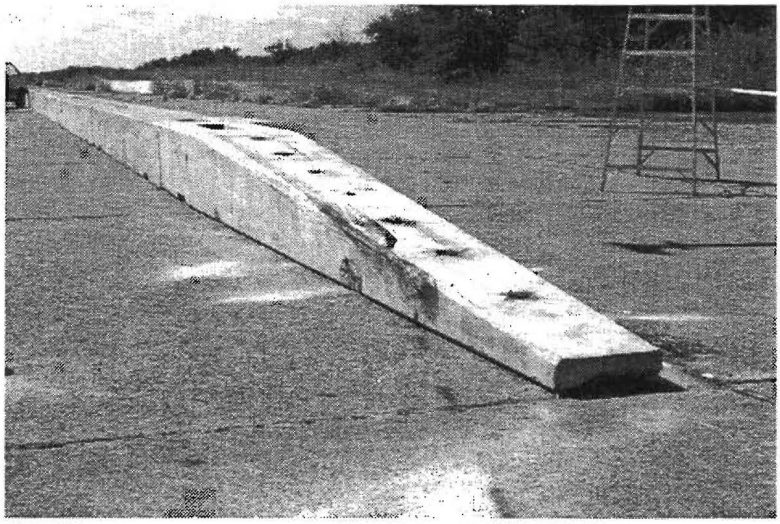
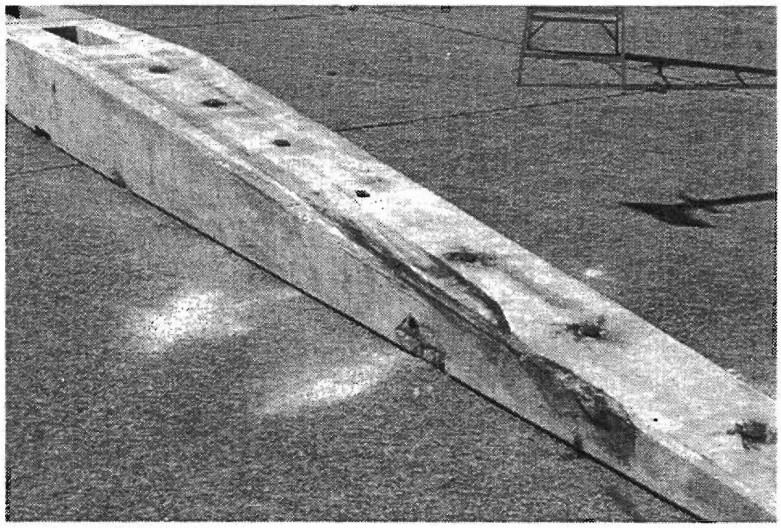


Figure 33. After Impact Trajectory for Test 414038-1





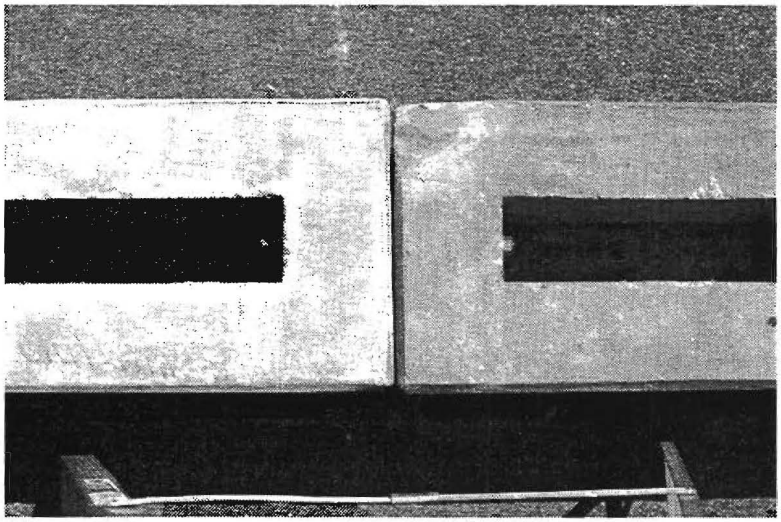


Figure 34. Installation After Test 414038-1

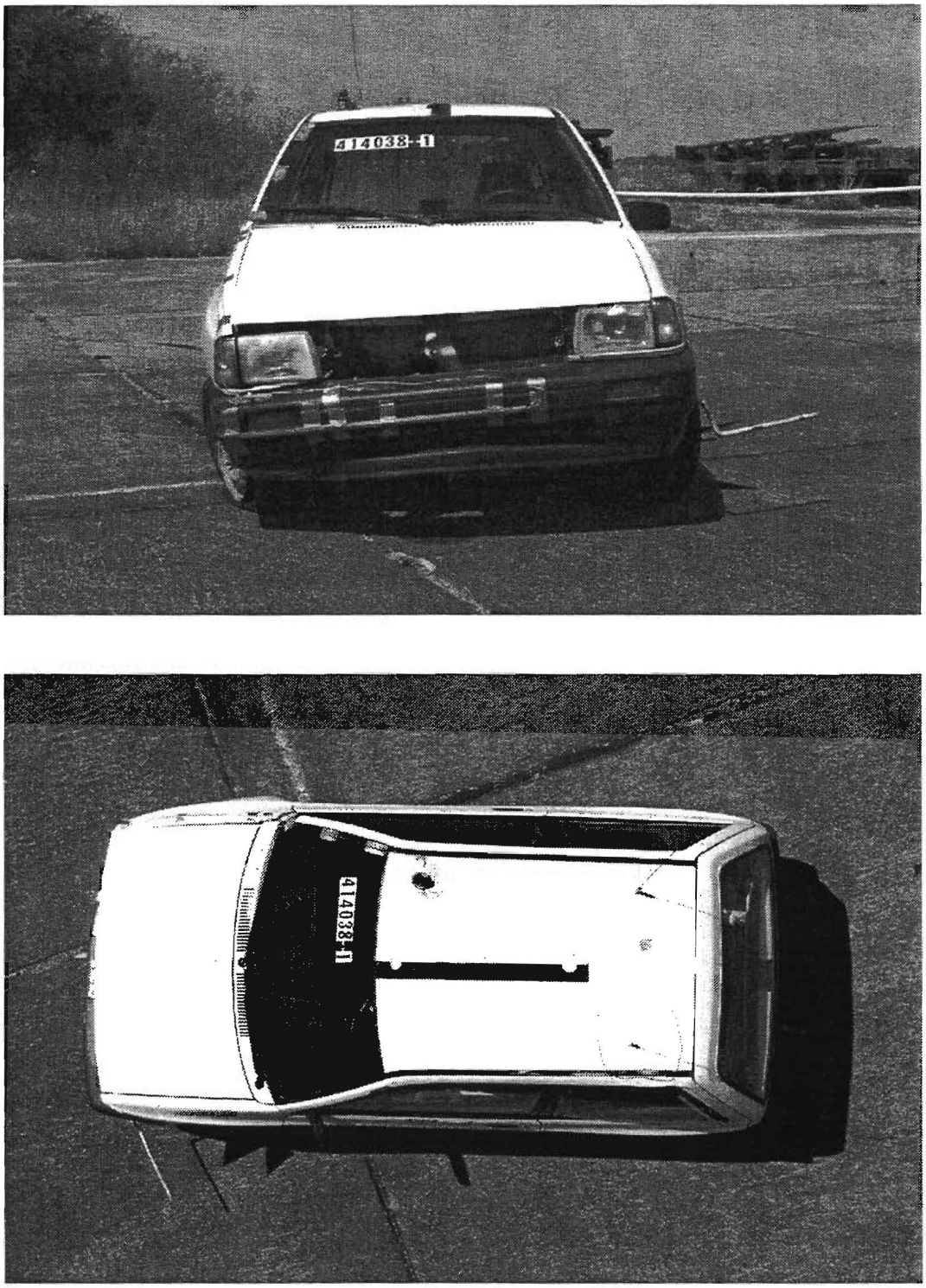


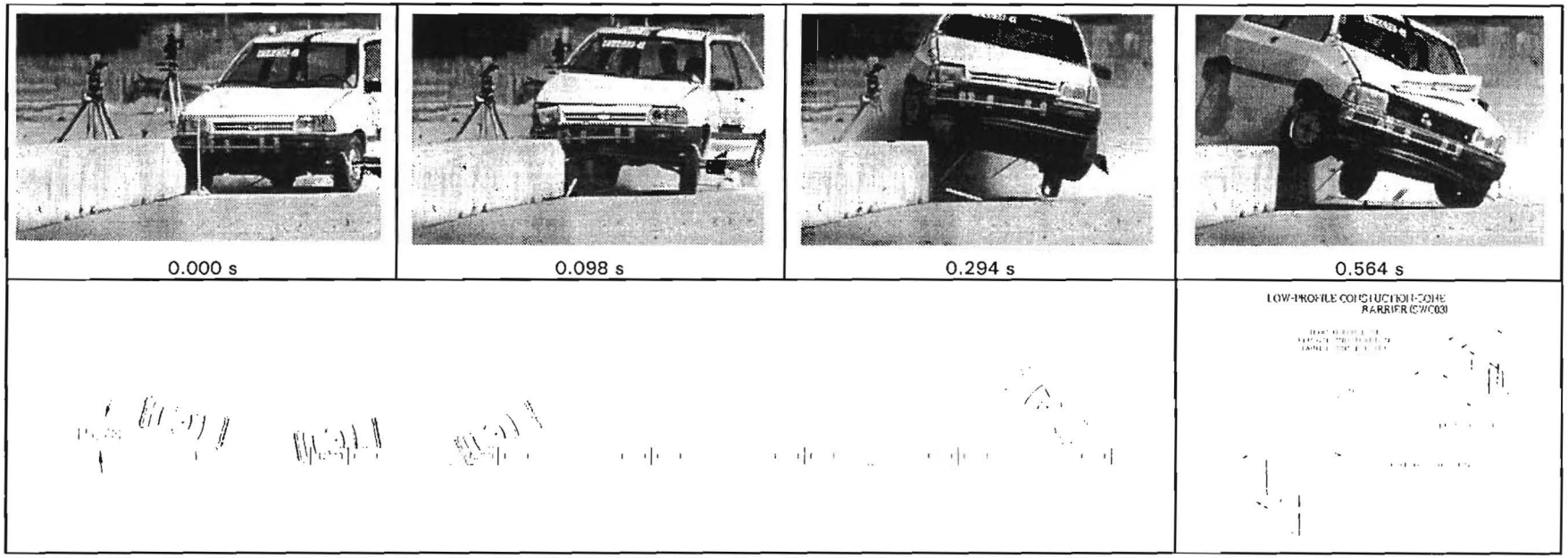
Figure 35. Vehicle After Test 414038-1

Occupant Risk Values

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, the occupant impact velocity was 2.94 m/s at 0.275 s, the highest 0.010-s occupant ridedown acceleration was -2.83 g from 0.704 to 0.714 s, and the maximum 0.050-s average acceleration -3.64 g between 0.029 and 0.079 s. In the lateral direction, the occupant impact velocity was 3.87 m/s at 0.138 s, the highest 0.010-s occupant ridedown acceleration was -3.06 g from 0.138 to 0.148 s, and the maximum 0.050-s average was -5.84 g between 0.045 and 0.095 s. These data and other pertinent information from the test are summarized in Figure 36. Vehicle angular displacements are displayed in Figure 64 of Appendix D. Vehicular accelerations versus time traces are presented in Figures 65 through 67 of Appendix D.

Summary of NCHRP Report 350 test 2-34

The end treatment for the low-profile barrier redirected the vehicle. There were no detached elements or debris to penetrate or show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. There was minimal deformation of the occupant compartment (35 mm in the firewall/floorpan area) and no intrusion. The vehicle remained upright during and after the collision period. Occupant risk factors were well within the limits specified in NCHRP Report 350. The vehicle did not intrude into adjacent traffic lanes. The vehicle came to rest against the traffic side of the barrier.



General Information
- Test Agency . . . . . Texas Transportation Institute
- Test No. 414038-1
- Date 09/16/97

Test Article
- Type . . . . . End Treatment
- Name . . . . . Low-Profile Barrier
- Installation Length (m) 36.58
- Size and/or dimension and material of key elements . . . . . 102-mm to 510-mm High Constant Slope Concrete End Treatment, 6.1-m Long

Soil Type and Condition . . . . . Concrete Pavement, Dry

Test Vehicle
- Type . . . . . Production
- Designation 820C
- Model . . . . . 1990 Ford Festiva
- Mass (kg) Curb 828
  - Test Inertial 820
  - Dummy 75
  - Gross Static 895

Impact Conditions
- Speed (km/h) 70.91
- Angle (deg) 15.78

Exit Conditions
- Speed (km/h) . . . . . N/A
- Angle (deg) . . . . . N/A

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 2.94
  - y-direction 3.87
- Ridedown Accelerations (g's)
  - x-direction . . . . . -2.83
  - y-direction . . . . . -3.06
- Max. 0.050-s Average (g's)
  - x-direction . . . . . -3.64
  - y-direction . . . . . -5.85
  - z-direction . . . . . -3.37

Test Article Deflections (m)
- Dynamic . . . . . nil
- Permanent . . . . . nil

Vehicle Damage
- Exterior
  - VDS 01RFQ1
  - CDC 01UDCW1
- Maximum Exterior Vehicle Crush (mm) . . . . nil
- Interior
  - OCDI RF0000000
- Max. Occ. Compart. Deformation (mm) 35

Post-Impact Behavior (during 1.0 s after impact)
- Max. Roll Angle (deg) . . . . . -22.8
- Max. Pitch Angle (deg) . . . . -16.9
- Max. Yaw Angle (deg) . . . . -68.5

Figure 36. Summary of Results for Test 414038-1

V. CONCLUSIONS

A low-profile PCB system, including a longitudinal barrier and a sloped end treatment, was previously developed at TTI.[1,2] Since its introduction, the low-profile PCB has gained widespread popularity throughout the state of Texas. The primary advantage of the low-profile PCB system is the increased visibility associated with the relatively low height of the system. This new barrier system has gained widespread acceptance in work zone situations throughout Texas.

The low-profile PCB was subjected to a reasonable set of crash tests prior to its introduction in 1992. However, the crash tests used to evaluate the low-profile PCB system were not fully consistent with the more recently released impact criteria presented in NCHRP Report 350.[3] Therefore, it was necessary to subject the low-profile PCB system to additional testing to assure that its performance is consistent with the impact criteria presented in NCHRP Report 350 so that it can continue to be used.

The initial testing conducted on the low-profile PCB system was consistent with the test level 2 conditions as defined in NCHRP Report 350. Initial tests conducted on the length of need of the longitudinal low-profile barrier were sufficient to show that the barrier meets the test level 2 conditions set forth in NCHRP Report 350. However, additional tests had to be conducted on the low-profile end treatment to assure that it meets the NCHRP Report 350 test level 2 conditions. This report presents logical justifications and full-scale crash test results to show that the low-profile PCB system meets the test level 2 conditions. This includes full descriptions of all crash tests conducted on the low-profile end treatment including a review of previous tests and new tests. It is thus shown that the low-profile PCB meets the NCHRP Report 350 test level 2 conditions, as shown in Tables 2 through 6.

When the low-profile PCB system was originally introduced, it was suggested that use of the system be limited to low-speed situations. This recommendation was made because there was no controlling testing authority that provided appropriate guidelines for the use of barriers in work zones and lower level performance situations. However, the test conditions presented in NCHRP Report 350 for longitudinal barriers and end treatments are referenced to three different test levels (there are six different test level conditions for the longitudinal barriers, but only three different test levels for end treatments). These different test levels are intended to represent different levels of impact performance and are not necessarily indicative of posted speed limits in a particular area of application. According to NCHRP Report 350:

> "It is the responsibility of the user agency(s) to determine which of the test levels is most appropriate for a feature's intended application. Agencies should develop objective guidelines for use of roadway safety features, considering factors such as traffic conditions, site conditions, traffic volume and mix, and the cost effectiveness of candidate safety alternatives. However, it is anticipated that safety features qualified for test level 3 will remain acceptable for a wide range of high-speed arterial highways. Test level 2 qualified features are expected to be

deemed acceptable for most local and collector roads and many work zones. Test level 1 qualified features are expected to be deemed acceptable for some work zones and very low-volume, low-speed local streets and highways."

Therefore, the researchers recommend the previously published low-speed limitations are rescinded. It is recommended that the low-profile PCB system is ready for use on most local and collector roads and many work zones as defined in NCHRP Report 350 subject to final judgments issued by the user agency(s) and subject to the concurrence of FHWA.

Table 2. Performance Evaluation Summary for Ttest 1949A-2, NCHRP Report 350 Test 2-30.

Test Agency: Texas Transportation Institute | Test No.: 1949A-2 | Test Date: 06/26/92

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The low-profile end treatment prevented the vehicle from penetrating or going over the barrier.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to penetrate or show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. There was no deformation or intrusion of the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component: Longitudinal and lateral — Preferred: 9 — Maximum: 12	Longitudinal occupant impact velocity = 1.9 m/s No contact in the lateral direction.	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component: Longitudinal and lateral — Preferred: 15 — Maximum: 20	Longitudinal ridedown acceleration = -0.6 g's There was no contact in the lateral direction.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal intrusion into adjacent traffic lanes.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle came to rest aligned with the barrier.	Pass

Table 3. Performance Evaluation Summary for Test 1949A-3, NCHRP Report 350 Test 2-31.

Test Agency: Texas Transportation Institute | Test No.: 1949A-3 | Test Date: 06/30/92

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The low-profile end treatment prevented the vehicle from penetrating or going over the barrier.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to penetrate or show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. There was no deformation or intrusion of the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
H. Occupant impact velocities should satisfy the following:	Longitudinal occupant impact velocity = 1.9 m/s Lateral occupant impact velocity = 0.4 m/s	Pass
I. Occupant ridedown accelerations should satisfy the following:	Longitudinal ridedown acceleration = 4.1 g's Lateral ridedown acceleration = 2.1 g's	Pass
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal intrusion into adjacent traffic lanes.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle came to rest aligned with the barrier.	Pass

Occupant Velocity Limits (m/s)

Component	Preferred	Maximum
Longitudinal and lateral	9	12

Occupant Ridedown Acceleration Limits (g's)

Component	Preferred	Maximum
Longitudinal and lateral	15	20

Table 4. Performance Evaluation Summary for Test 414038-2, NCHRP Report 350 Test 2-32.

Test Agency: Texas Transportation Institute | Test No.: 414038-2 | Test Date: 09/18/97

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The low-profile end treatment allowed the vehicle to gate through the barrier.	Pass or Fail?
Occupant Risk D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to penetrate or show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. There was no deformation or intrusion of the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component: Longitudinal and lateral — Preferred: 9 — Maximum: 12	There was no occupant contact in the longitudinal or lateral direction.	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component: Longitudinal and lateral — Preferred: 15 — Maximum: 20	N/A	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle came to rest behind the installation.	Pass

Table 5. Performance Evaluation Summary for Test 1949A-1, NCHRP Report 350 Test 2-34.

Test Agency: Texas Transportation Institute | Test No.: 1949A-1 | Test Date: 06/24/92

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The end treatment for the low-profile barrier redirected the vehicle.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to penetrate or show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. There was no deformation of the occupant compartment or intrusion.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component: Longitudinal and lateral — Preferred: 9 — Maximum: 12	Longitudinal occupant impact velocity = 4.1 m/s Lateral occupant impact velocity = 5.5 m/s	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component: Longitudinal and lateral — Preferred: 15 — Maximum: 20	Longitudinal ridedown acceleration = -1.9 g's Lateral ridedown acceleration = -4.5 g's	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle came to rest downstream and aligned with the barrier.	N/A

Table 6. Performance Evaluation Summary for Test 414038-1, NCHRP Report 350 Test 2-34.

Test Agency: Texas Transportation Institute | Test No.: 414038-1 | Test Date: 09/16/97

NCHRP Report 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The end treatment for the low-profile barrier redirected the vehicle.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to penetrate or show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. There was minimal deformation of the occupant compartment (35 mm in the firewall/floorpan area) and no intrusion.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
H. Occupant impact velocities should satisfy the following:	Longitudinal occupant impact velocity = 2.94 m/s Lateral occupant impact velocity = 3.87 m/s	Pass
I. Occupant ridedown accelerations should satisfy the following:	Longitudinal ridedown acceleration = -2.83 g's Lateral ridedown acceleration = -3.06 g's	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle came to rest against the traffic side of the barrier.	N/A

Occupant Velocity Limits (m/s)

Component	Preferred	Maximum
Longitudinal and lateral	9	12

Occupant Ridedown Acceleration Limits (g's)

Component	Preferred	Maximum
Longitudinal and lateral	15	20

APPENDIX A. FABRICATION DETAILS FOR THE LOW-PROFILE END TREATMENT

This section contains detailed drawings of the low-profile end treatment used for the crash tests performed under this study.

Figure 37. Fabrication Details for the Low-Profile End Treatment

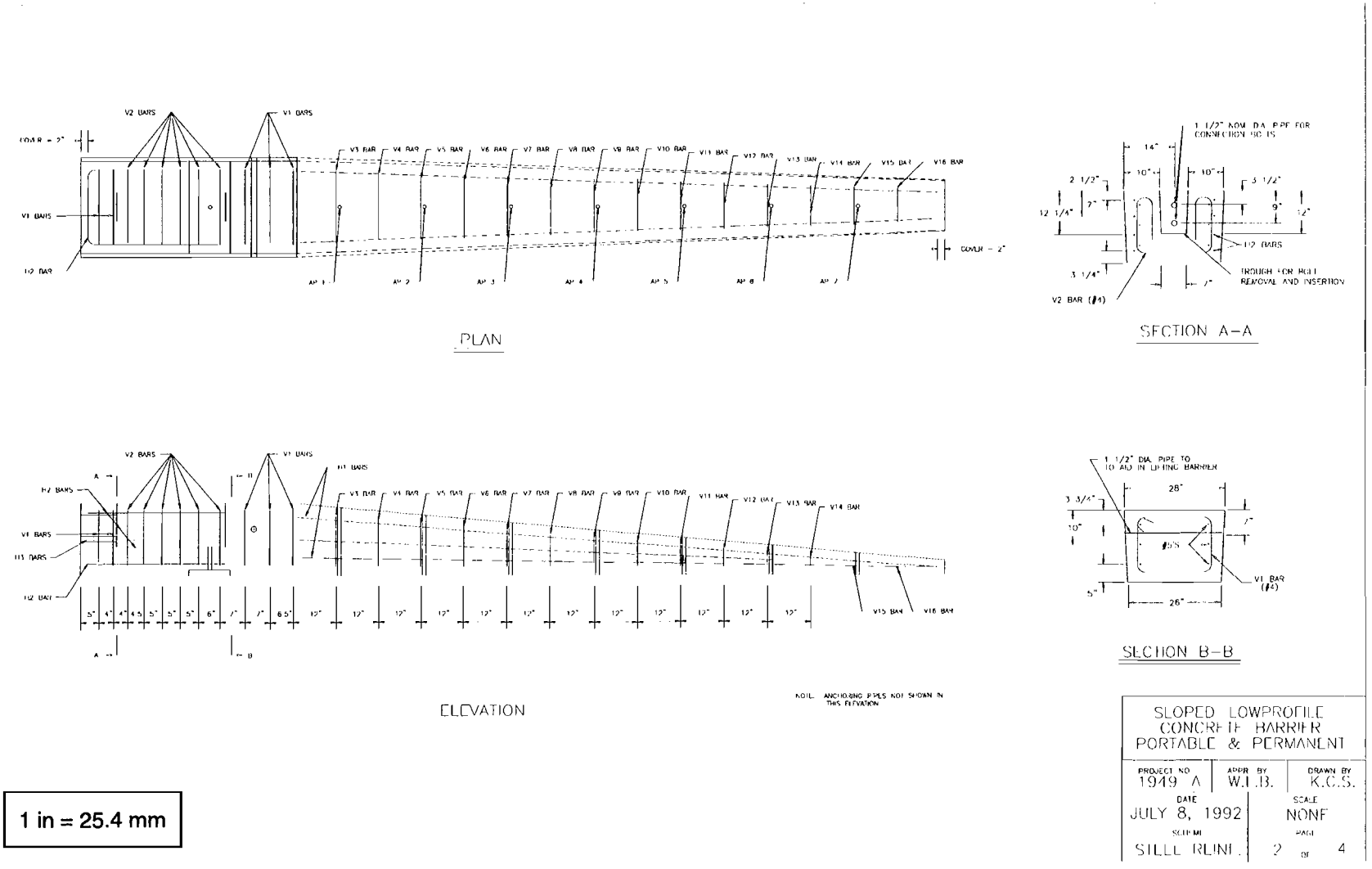
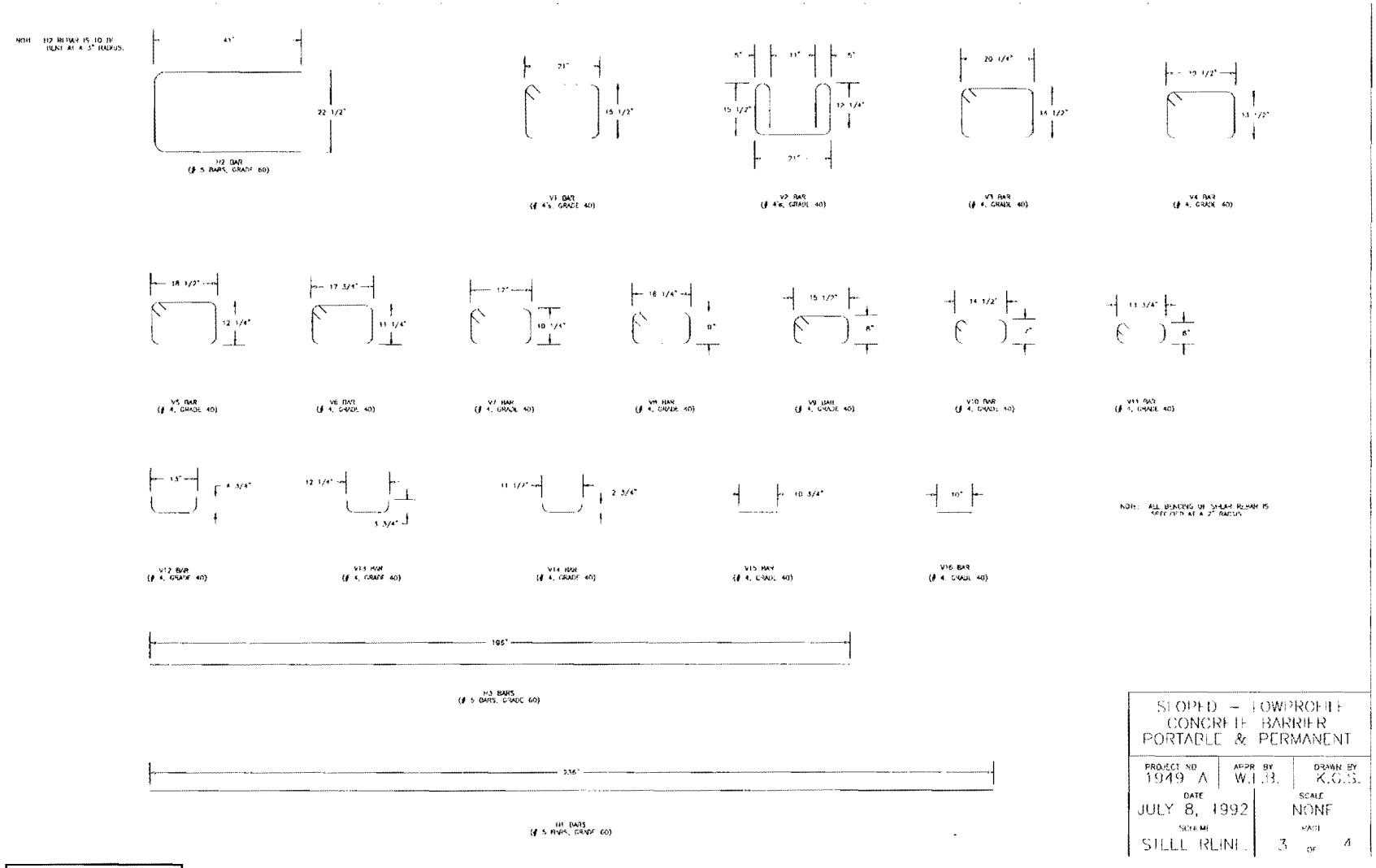


Figure 37. Fabrication Details for the Low-Profile End Treatment (continued)



1 in = 25.4 mm

Figure 37. Fabrication Details for the Low-Profile End Treatment (continued).

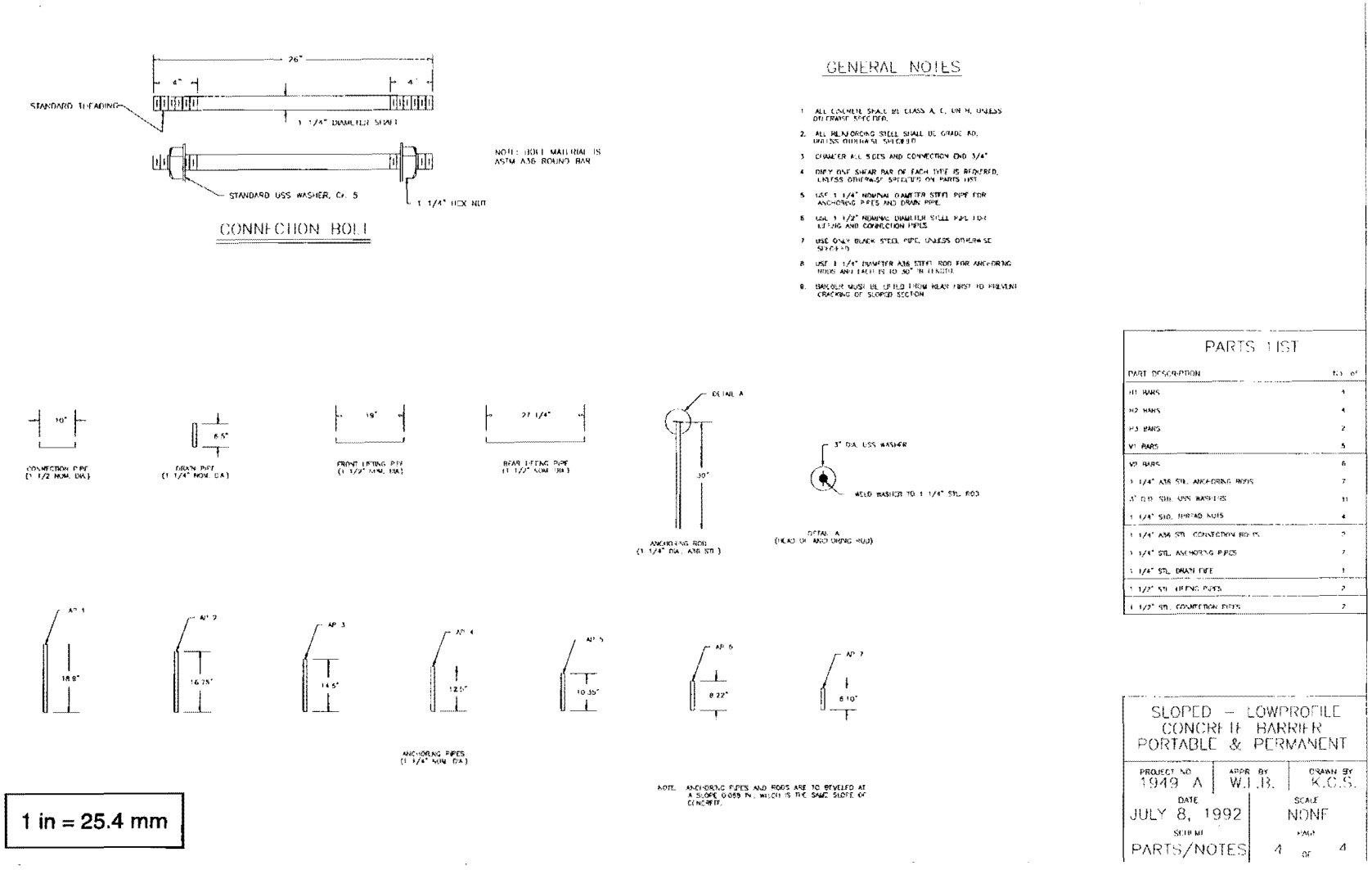


Figure 37. Fabrication Details for the Low-Profile End Treatment (continued)

APPENDIX B. CRASH TESTS AND DATA ANALYSIS PROCEDURES

The crash test and data analysis procedures were in accordance with guidelines presented in NCHRP Report 350. Brief descriptions of these procedures are presented as follows.

Electronic Instrumentation and Data Processing

The test vehicles were instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer near the vehicle center of gravity to measure longitudinal, lateral, and vertical acceleration levels, and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. The accelerometers were strain-gauge type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals were recorded before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Pressure sensitive switches on the bumper of the impacting vehicle were actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produced an "event" mark on the data record to establish the exact instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, was received at the data acquisition station, and demultiplexed into separate tracks of Inter-Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data were played back from the tape machines, filtered with an SAE J211 filter, and digitized using a microcomputer, for analysis and evaluation of impact performance.

The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are provided as follows.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/ compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers were then filtered with a 60-Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions were plotted using a commercially available software package (EXCEL).

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.00067-s intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th-percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the 820C vehicle. The dummy was un-instrumented. Use of a dummy in the 2000P vehicle is optional according to NCHRP Report 350 and there was no dummy used in this test with the 2000P vehicle.

Photographic Instrumentation and Data Processing

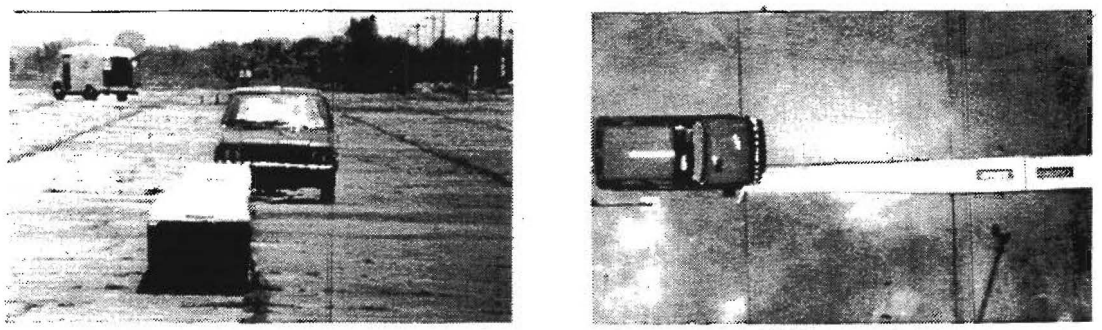
Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flash bulb activated by pressure sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement and angular data. A Betacam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

Test Vehicle Propulsion and Guidance

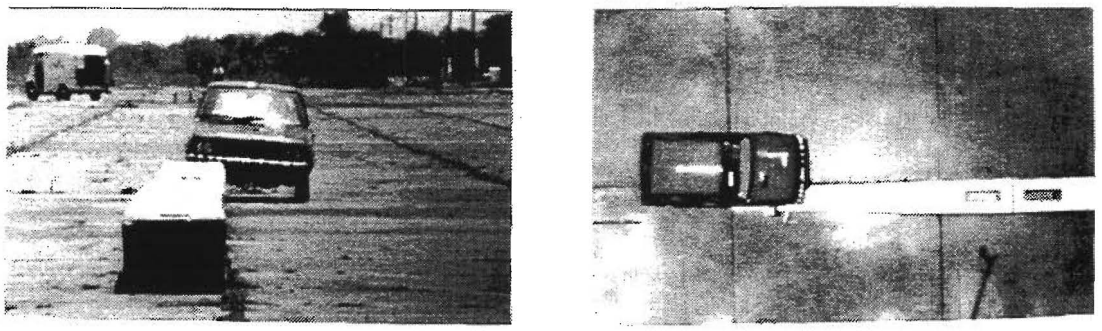
The test vehicles were towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2 to 1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring it to a safe and controlled stop, if necessary.

APPENDIX C. SEQUENTIAL PHOTOGRAPHS

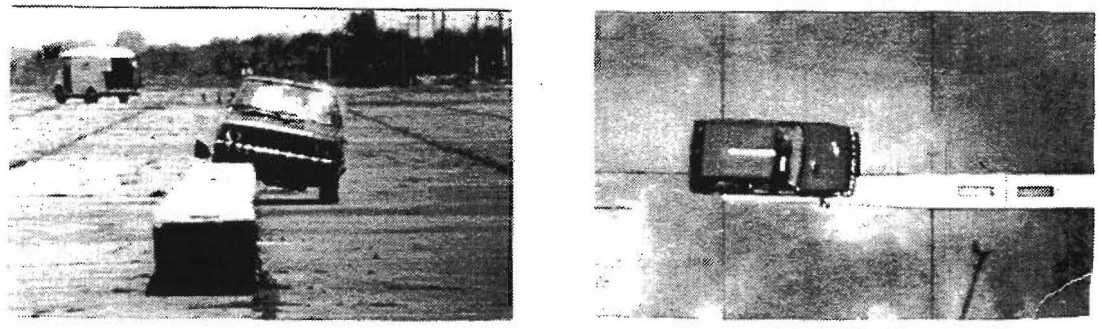
This section contains photographs taken from high speed film during the test sequence of the crash tests performed under this study.



0.000 s



0.062 s



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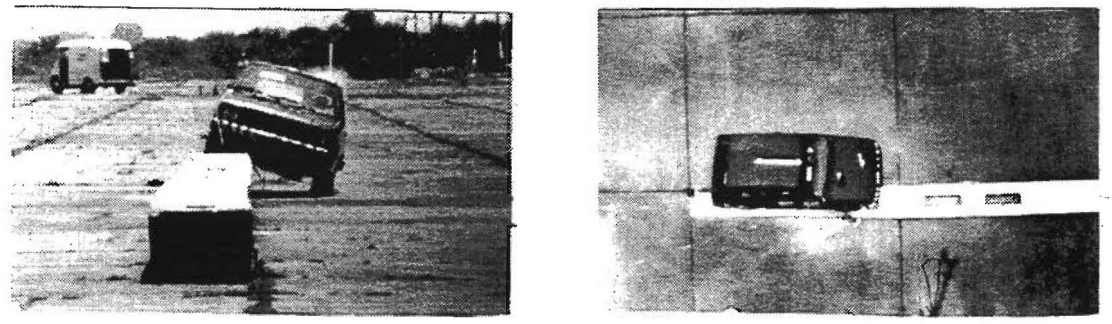
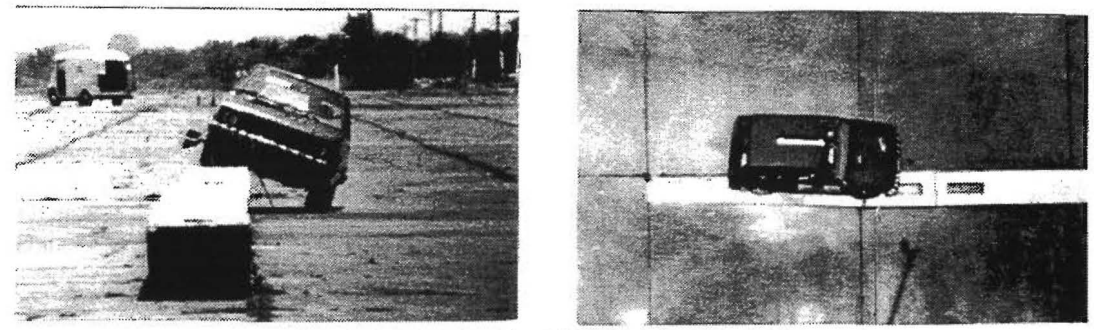


0.186 s

Figure 38. Sequential Photographs for Test 1949A-2 (Overhead and Frontal Views)



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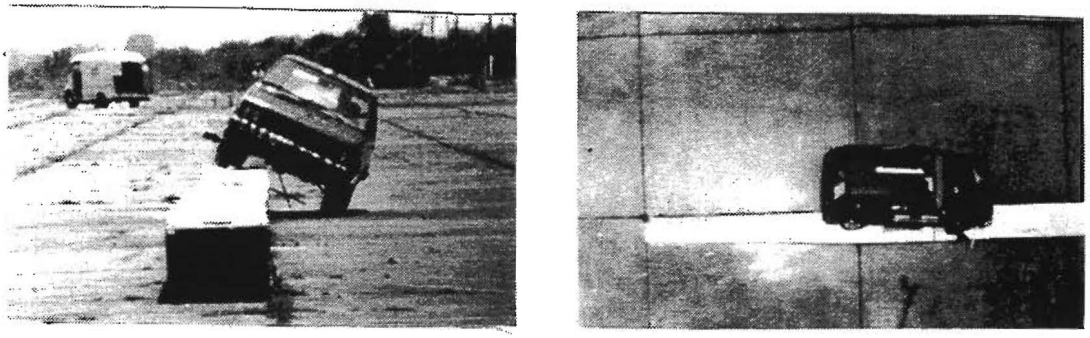
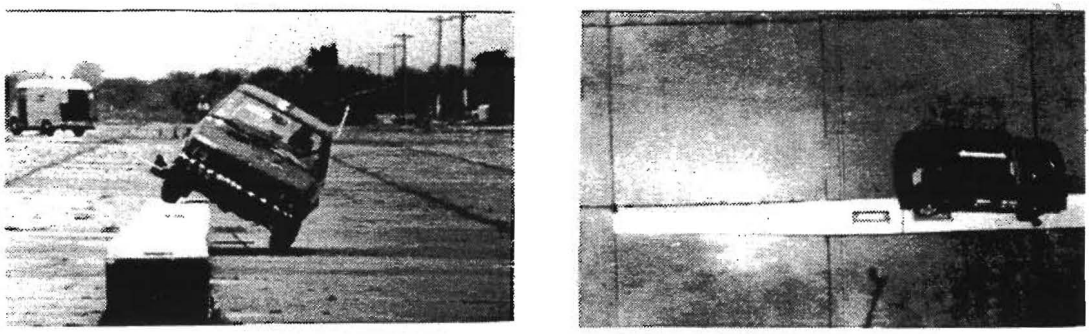
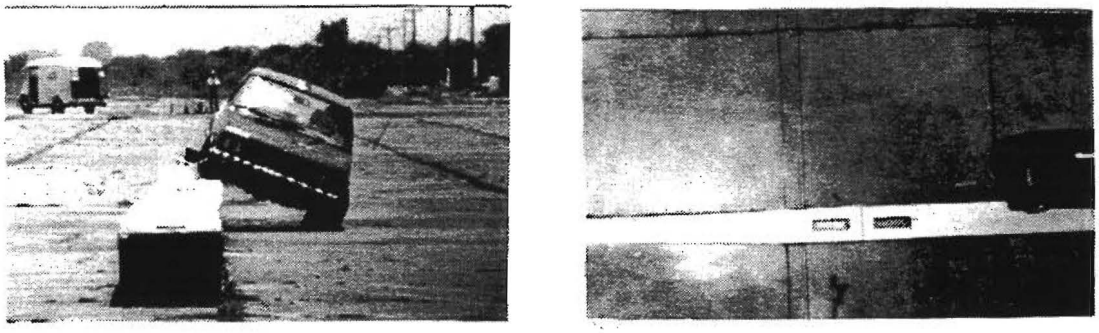


0.347 s

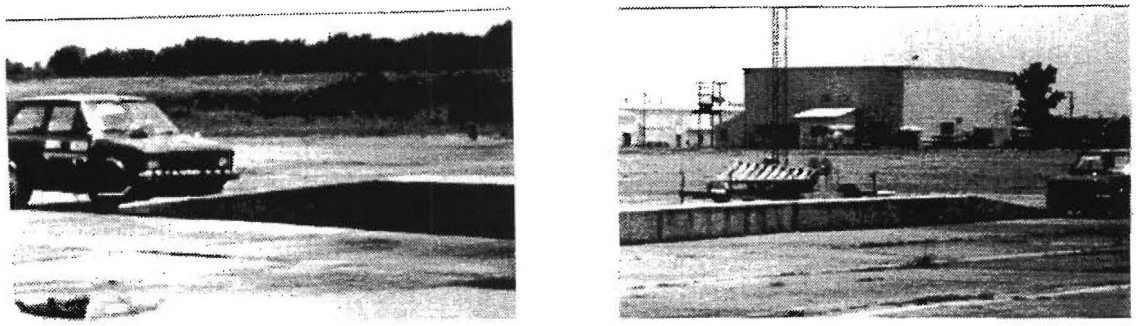


0.459 s

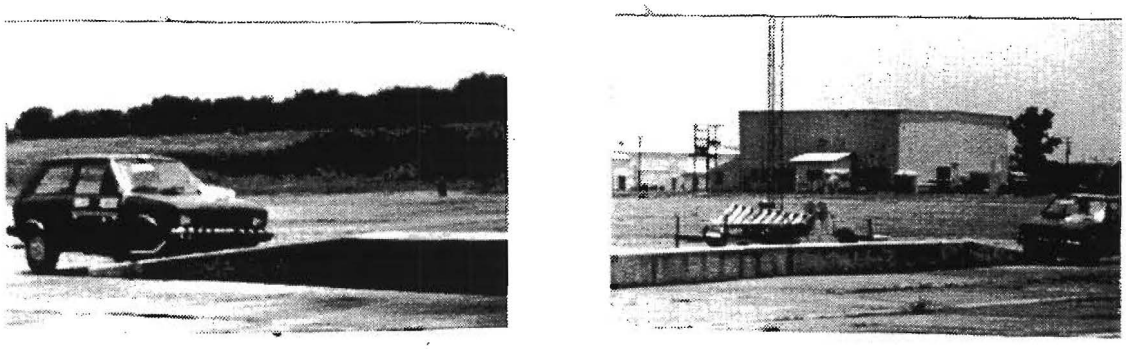


0.620 s

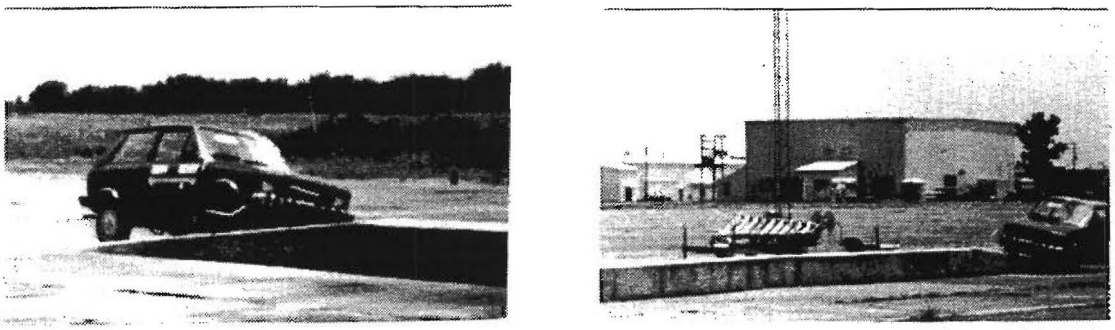
Figure 38. Sequential Photographs for Test 1949A-2 (Overhead and Frontal Views) (continued)



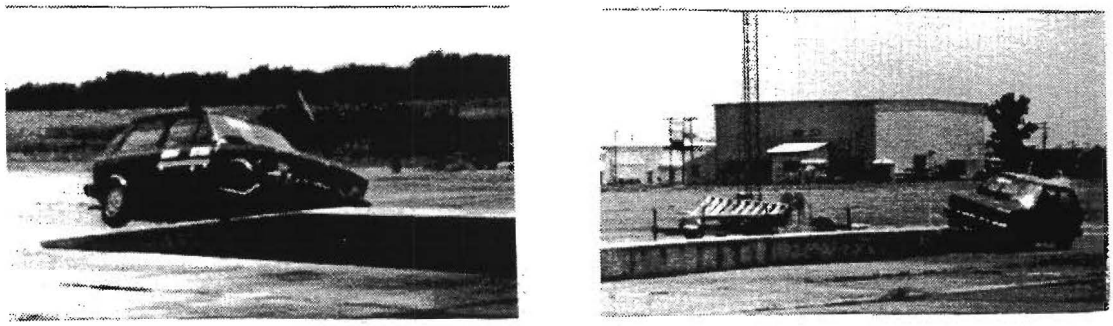
0.000 s



0.062 s

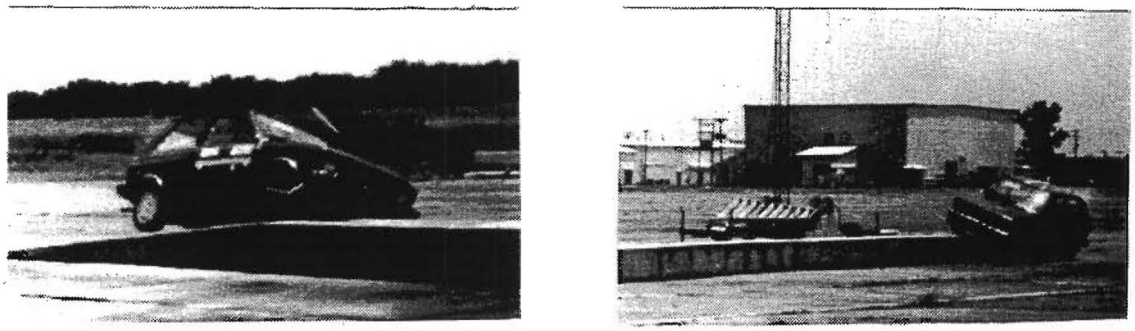


0.124 s

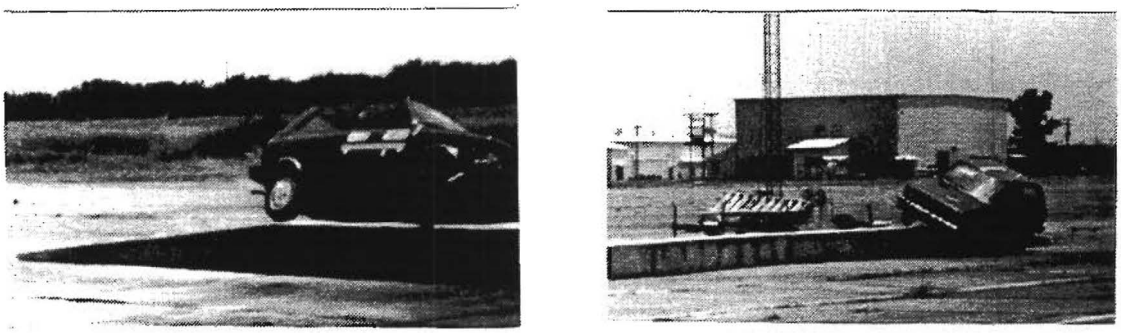


0.186 s

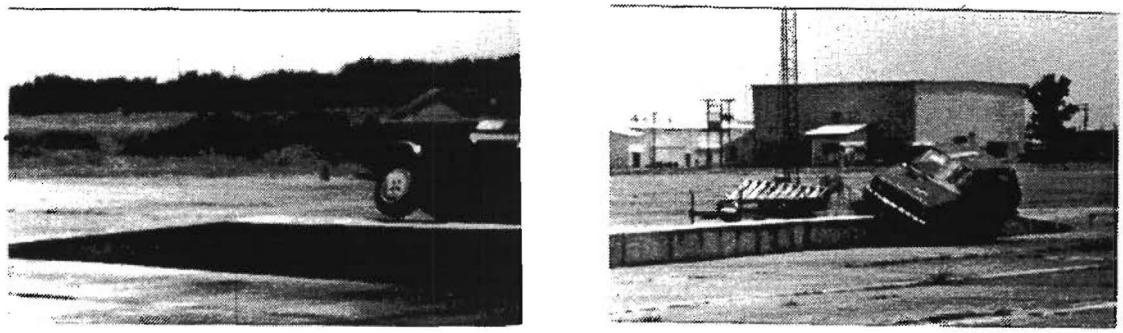
Figure 39. Sequential Photographs for Test 1949A-2 (Side Views)



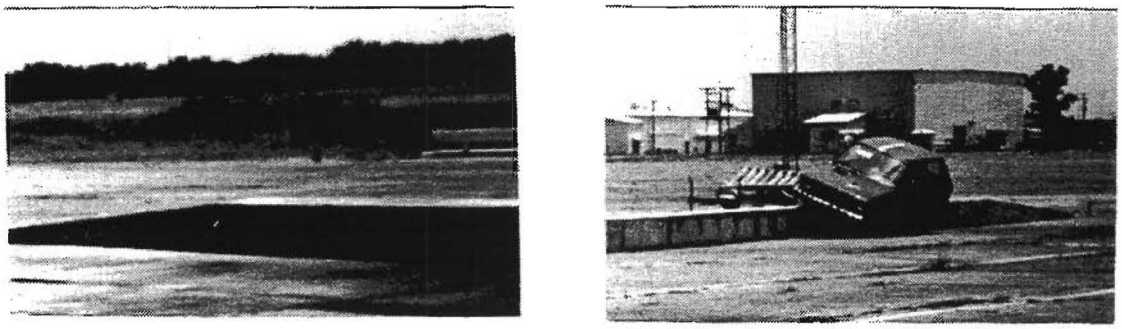
0.248 s



0.347 s



0.459 s



0.620 s

Figure 39. Sequential Photographs for Test 1949A-2 (Side Views) (continued)

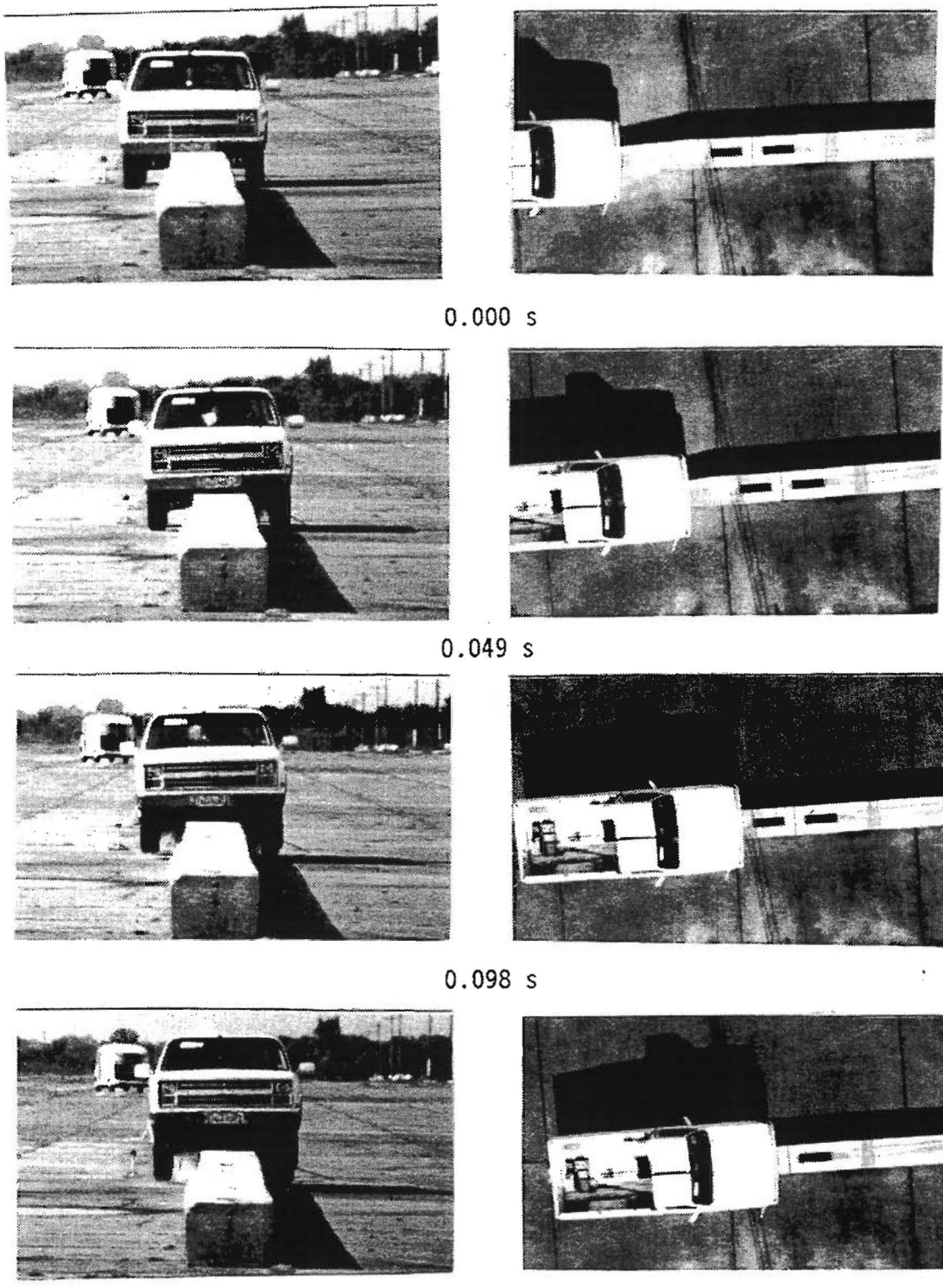
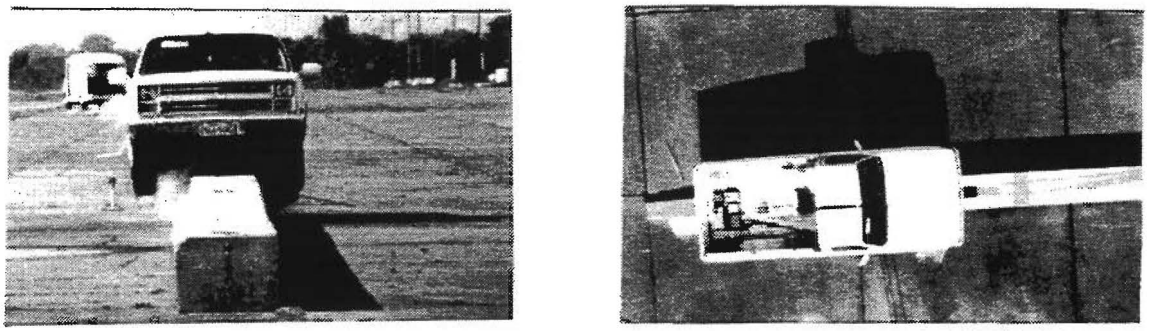
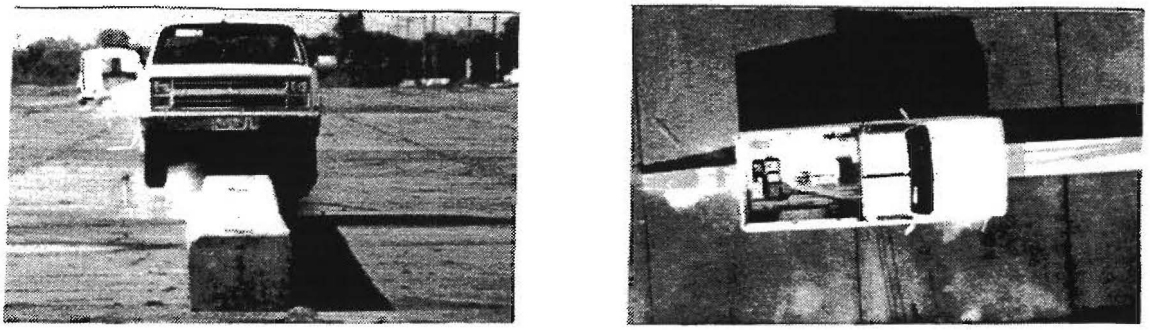


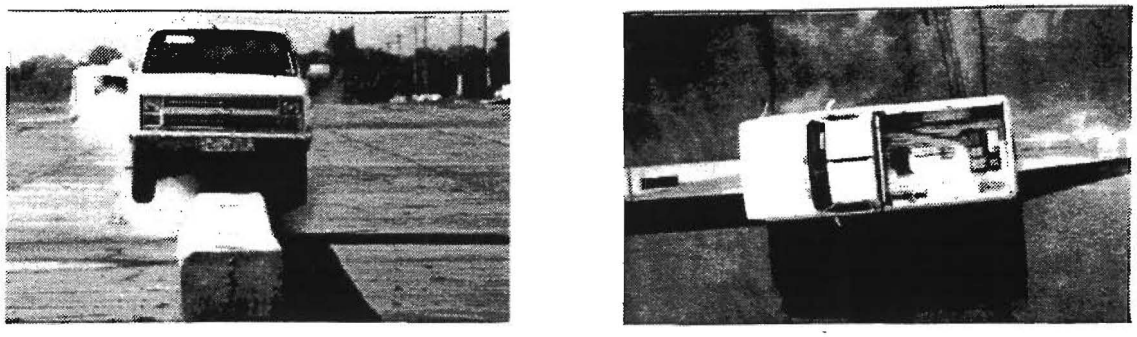
Figure 40. Sequential Photographs for Test 1949A-3 (Overhead and Frontal Views)



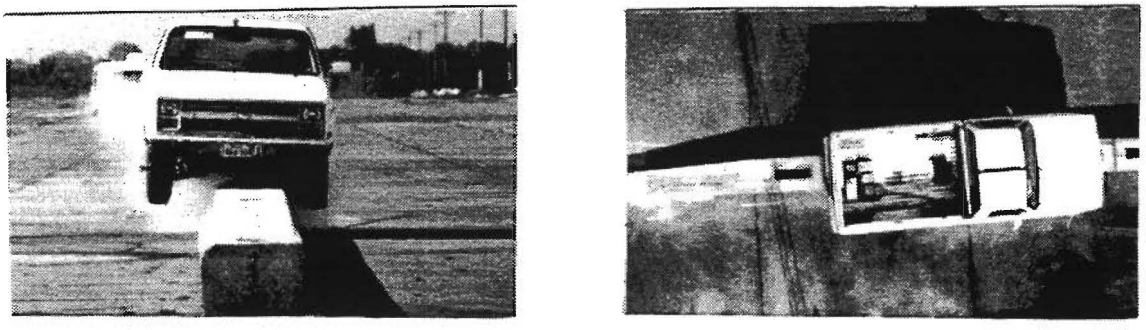
0.199 s



0.250 s

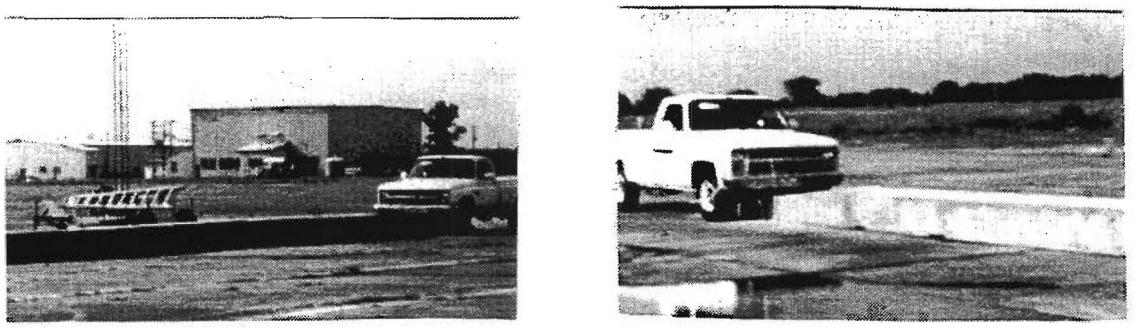


0.349 s

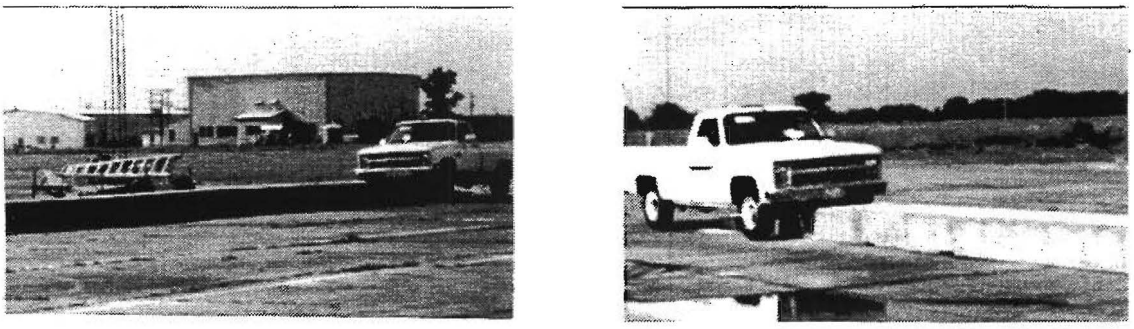


0.444 s

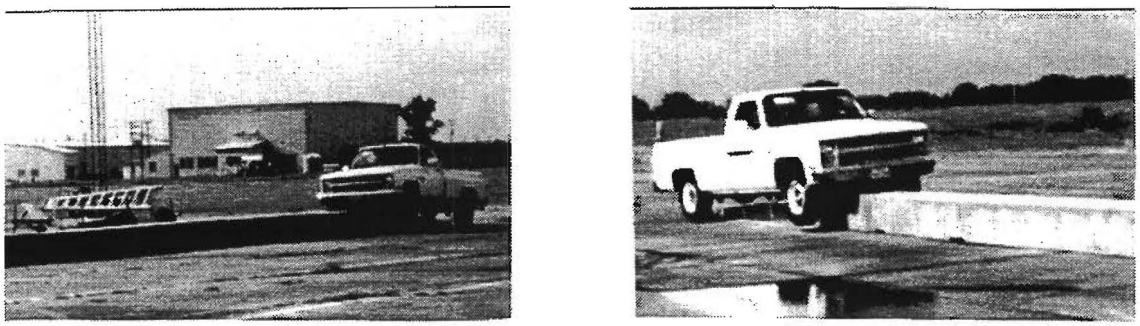
Figure 40. Sequential Photographs for Test 1949A-3 (Overhead and Frontal Views) (continued)



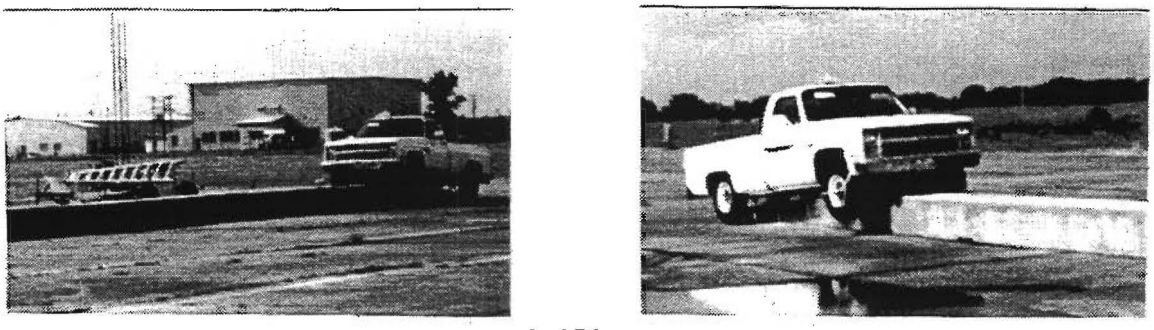
0.000 s



0.049 s

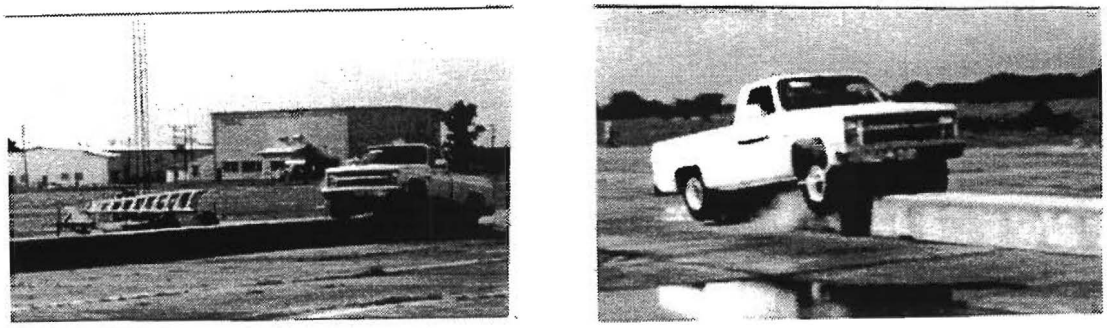


0.098 s

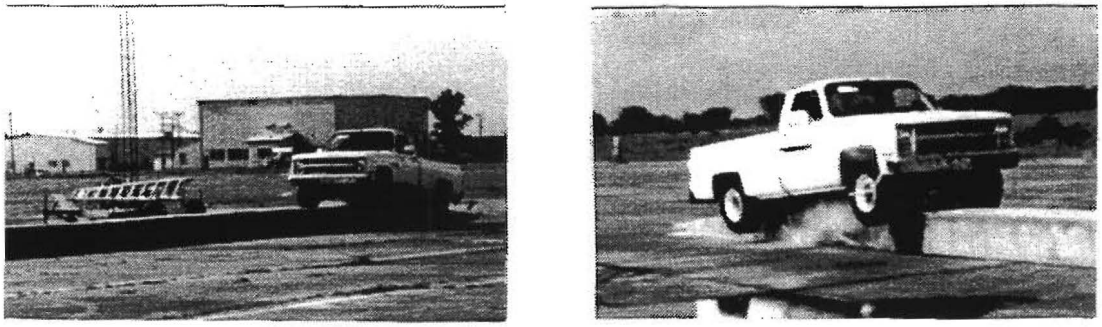


0.150 s

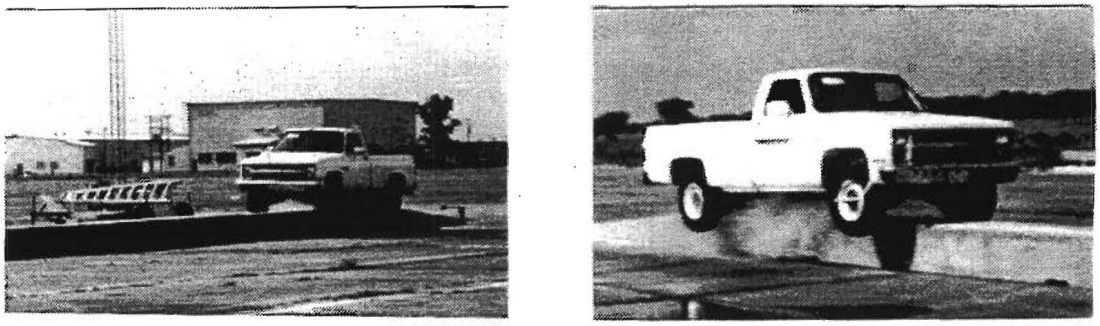
Figure 41. Sequential Photographs for Test 1949A-3 (Side Views)



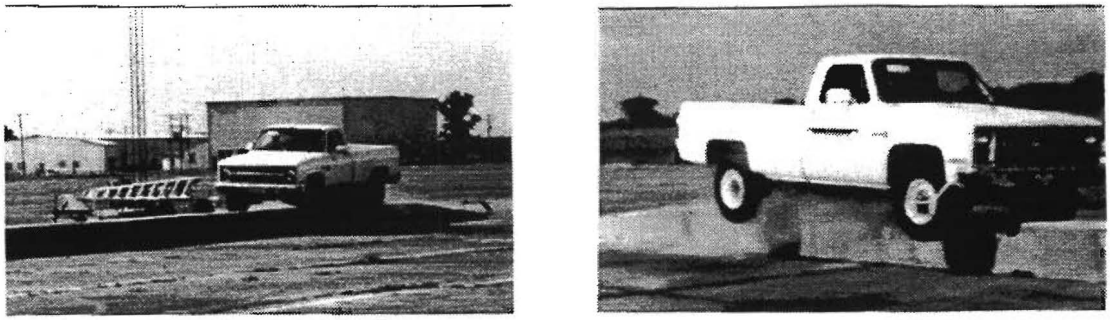
0.199 s



0.250 s

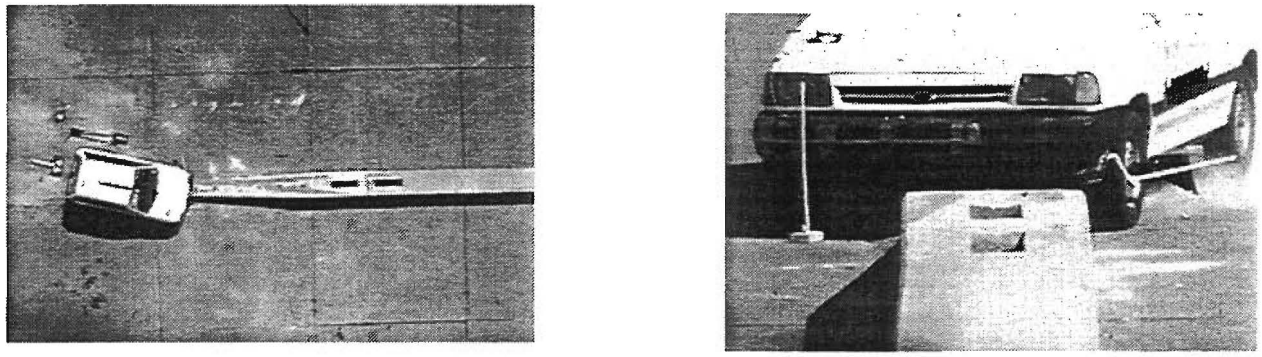


0.349 s

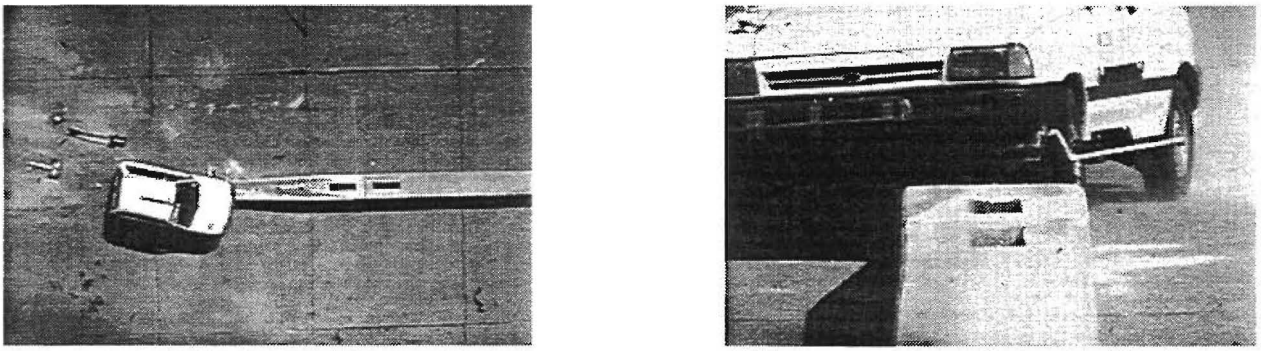


0.444 s

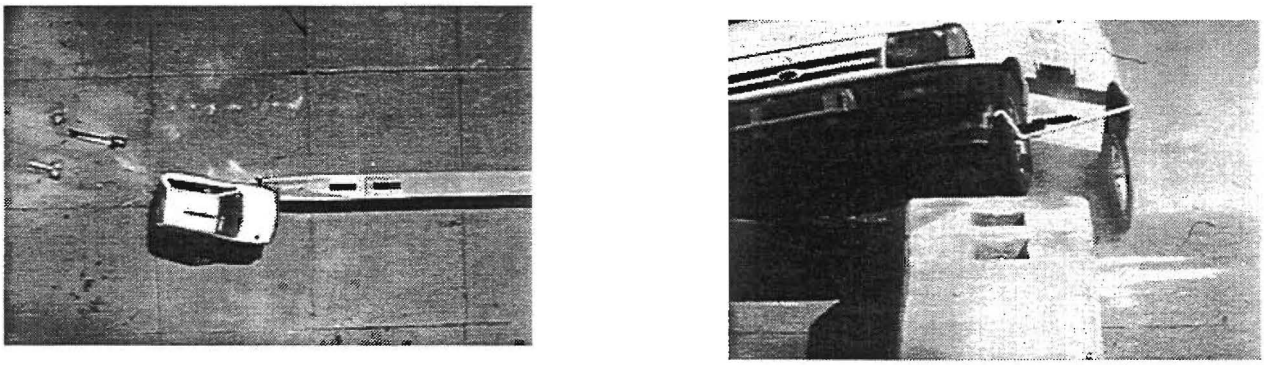
Figure 41. Sequential Photographs for Test 1949A-3 (Side Views) (continued)



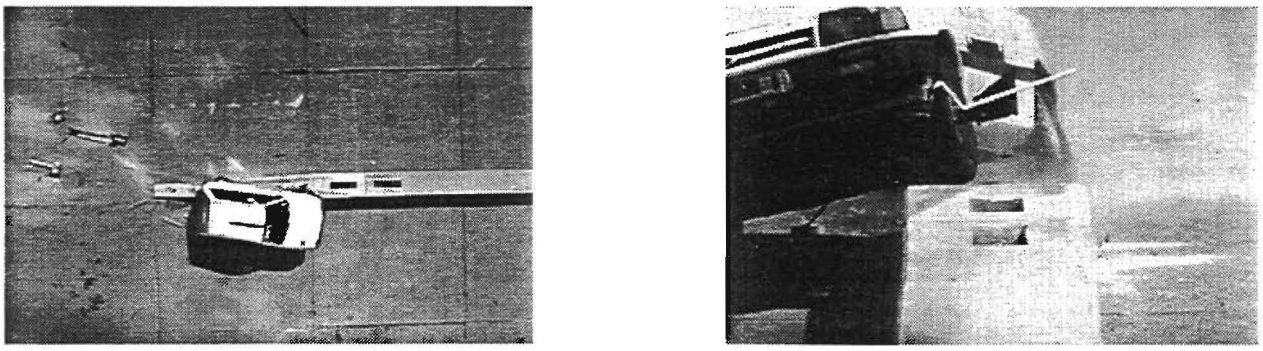
0.000 s



0.068 s

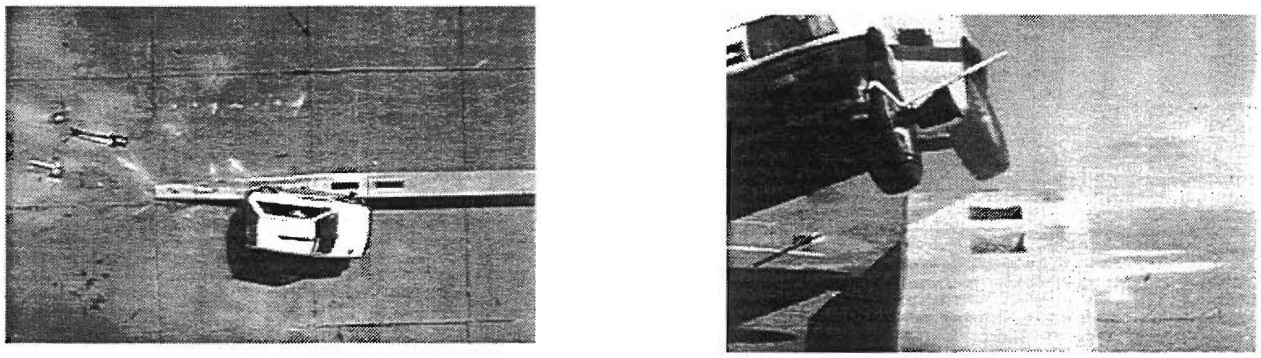


0.137 s

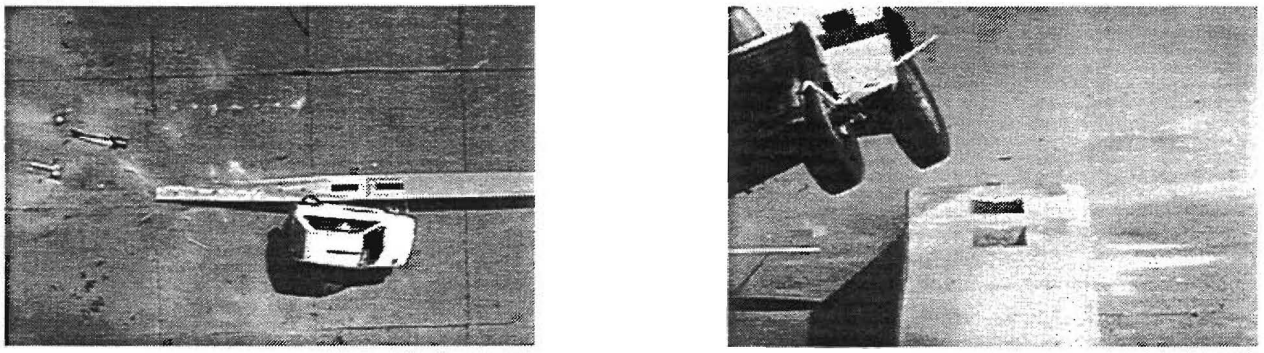


0.205 s

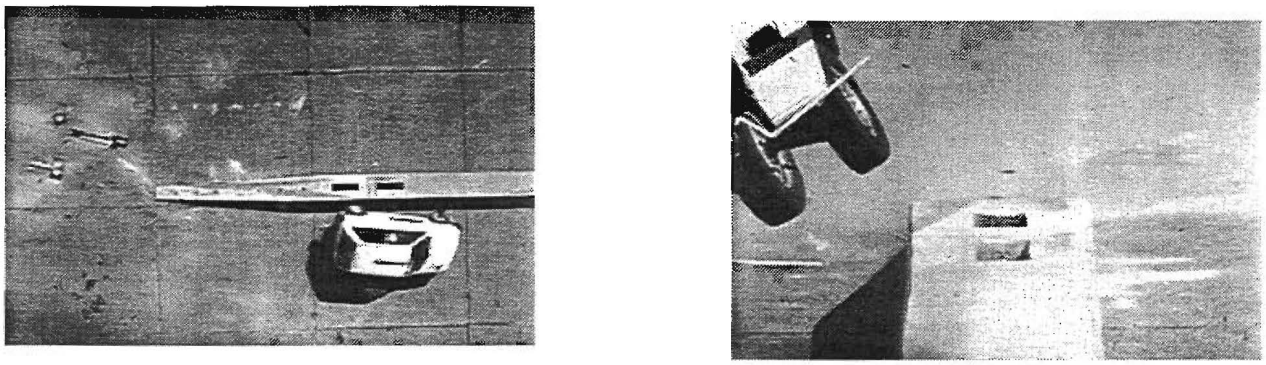
Figure 42. Sequential Photographs for Test 414038-2 (Overhead and Frontal Views)



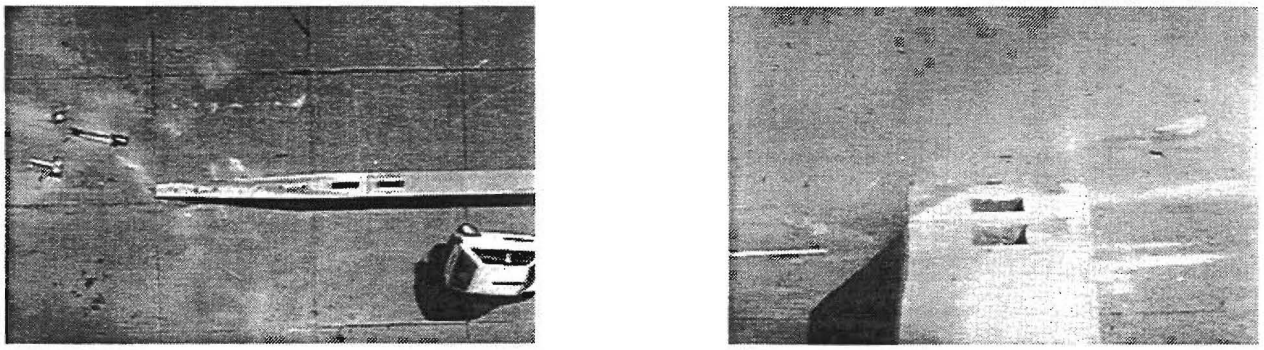
0.274 s



0.343 s



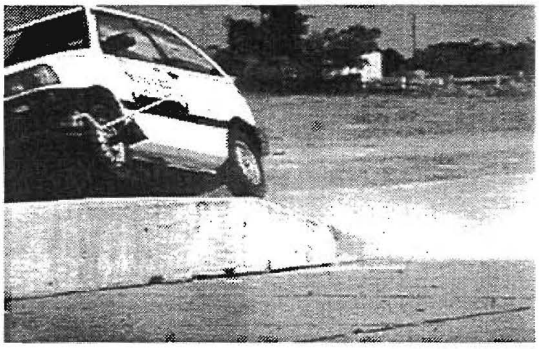
0.411 s



0.588 s

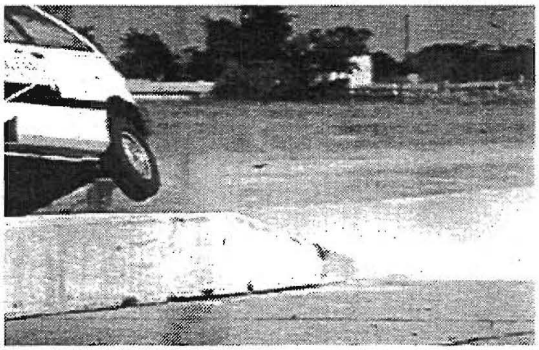
Figure 42. Sequential Photographs for Test 414038-2 (Overhead and Frontal Views) (continued)

0.000 s



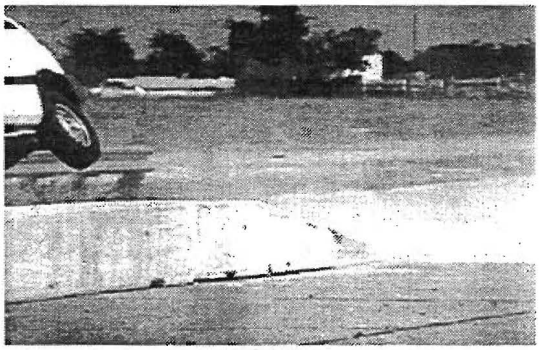
0.274 s

0.068 s



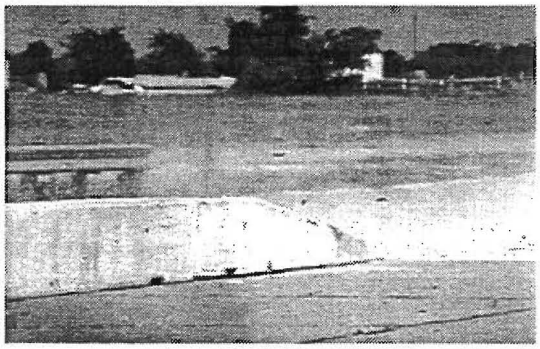
0.343 s

0.137 s



0.411 s

0.205 s



0.588 s

Figure 43. Sequential Photographs for Test 414038-2 (Oblique View)

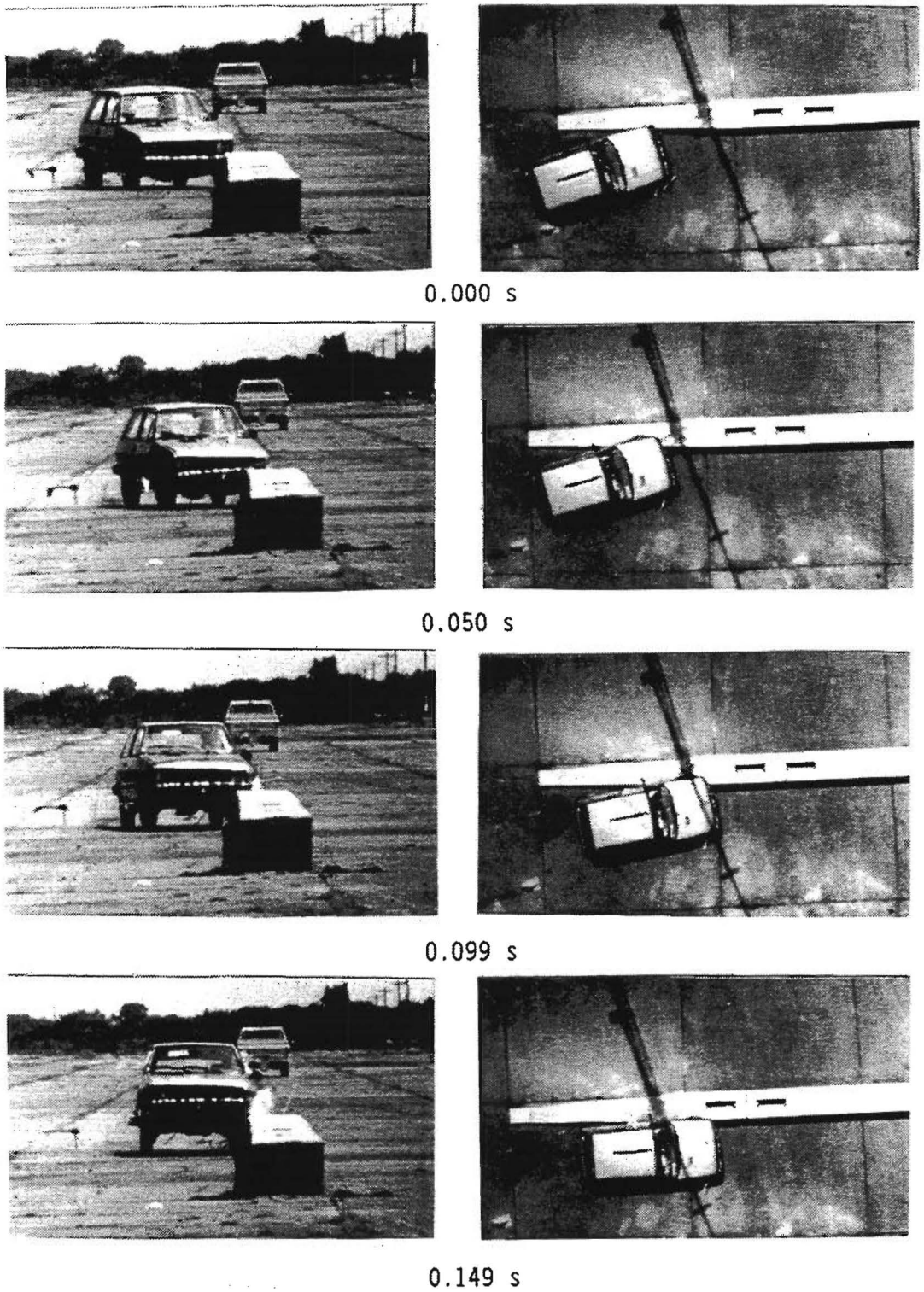
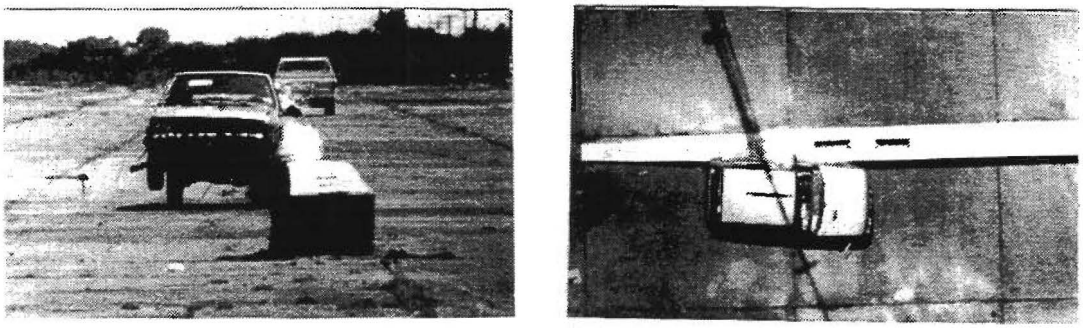
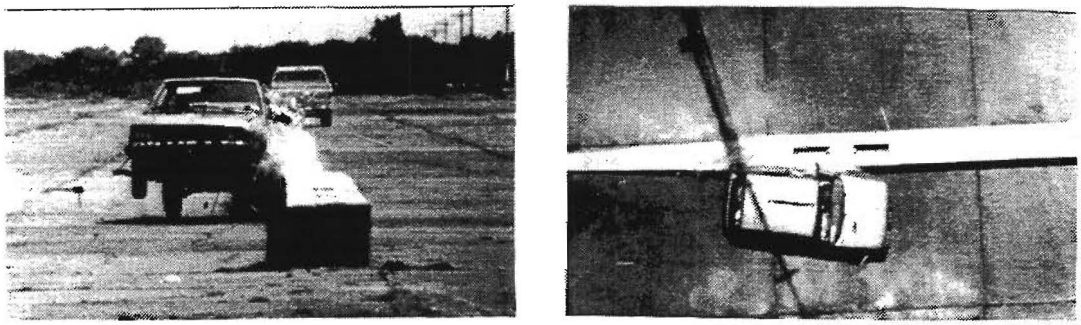


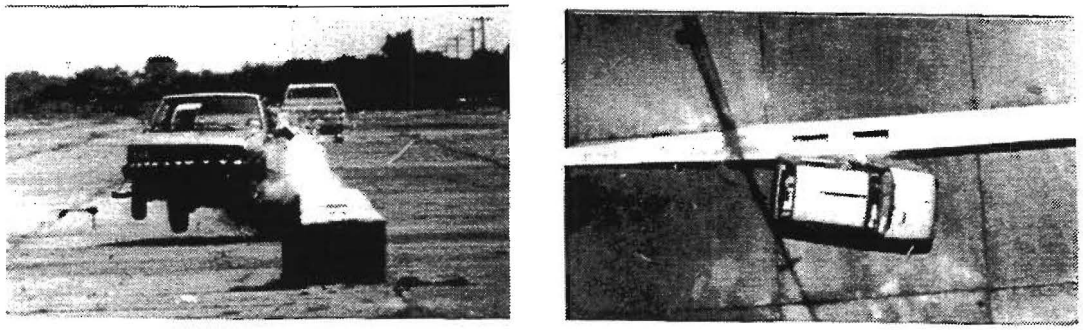
Figure 44. Sequential Photographs for Test 1949A-1 (Overhead and Frontal Views)



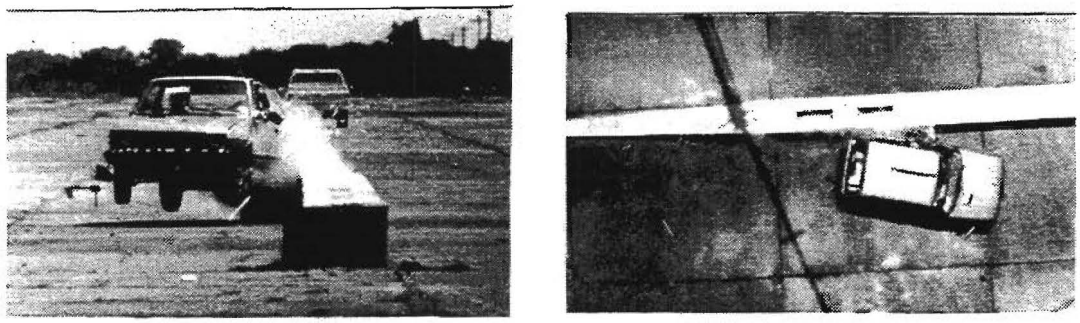
0.201 s



0.250 s

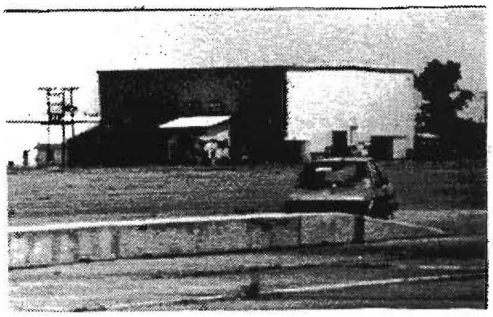


0.310 s

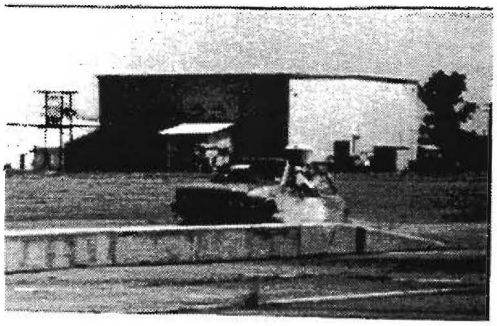


0.389 s

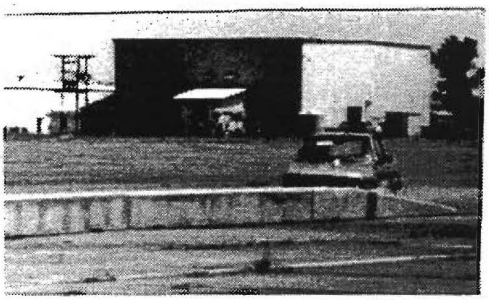
Figure 44. Sequential Photographs for Test 1949A-1 (Overhead and Frontal Views) (continued)



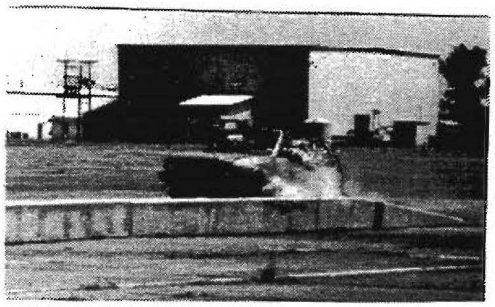
0.000 s



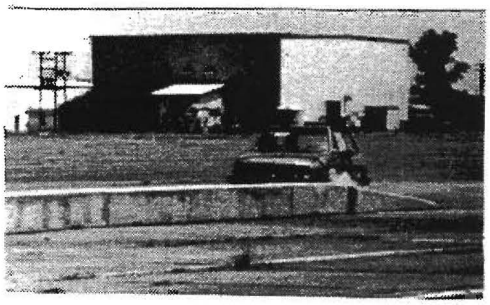
0.201 s



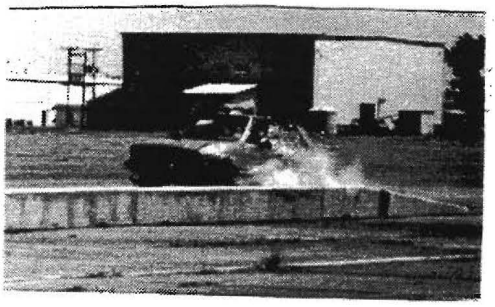
0.050 s



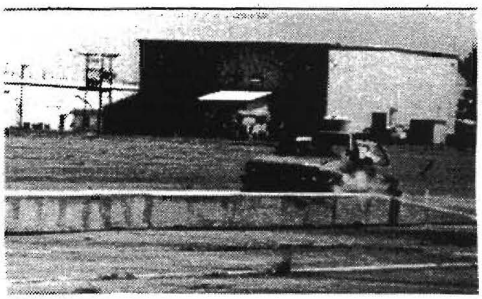
0.250 s



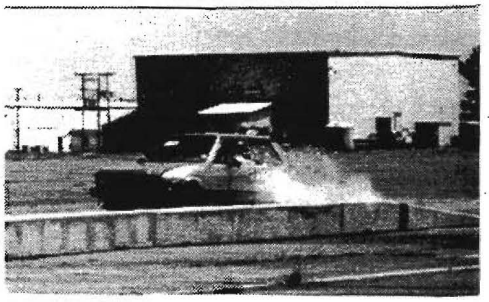
0.099 s



0.310 s

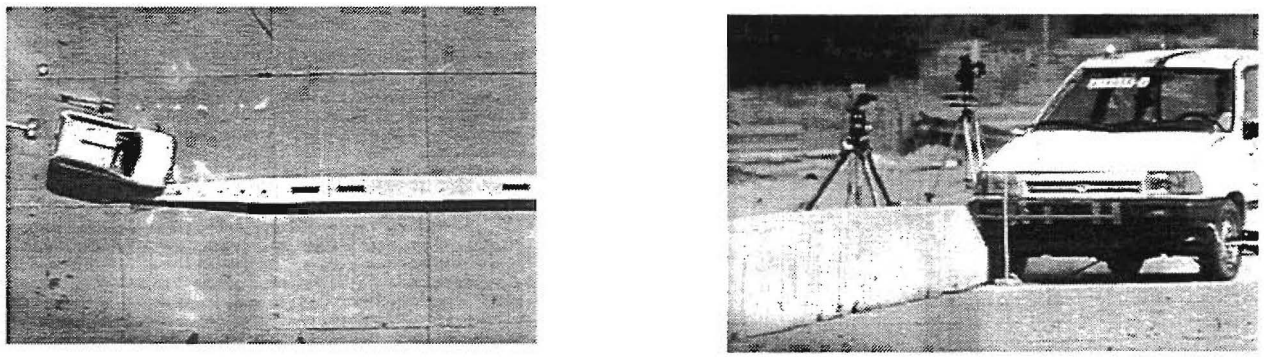


0.149 s

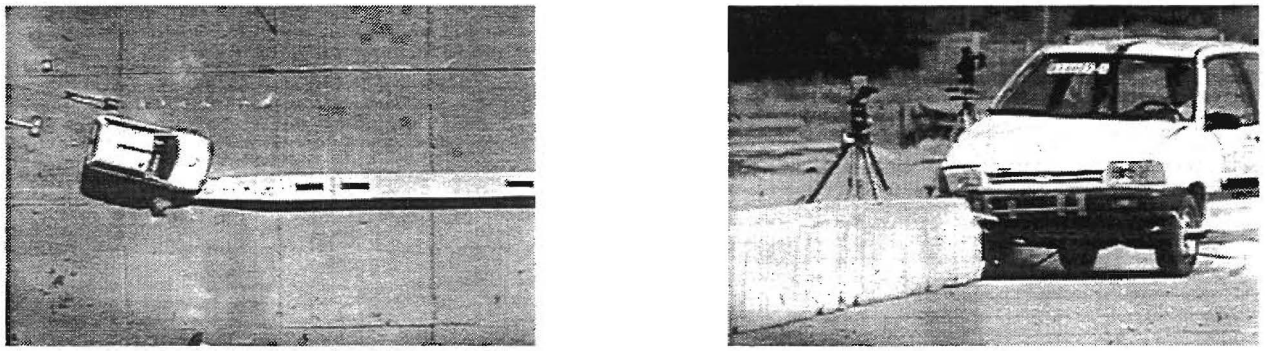


0.389 s

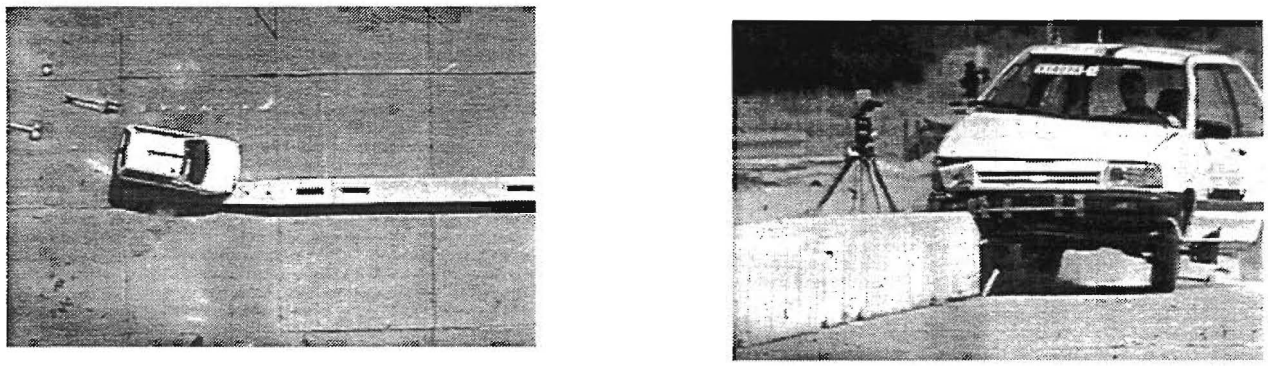
Figure 45. Sequential Photographs for Test 1949A-1 (Side View)



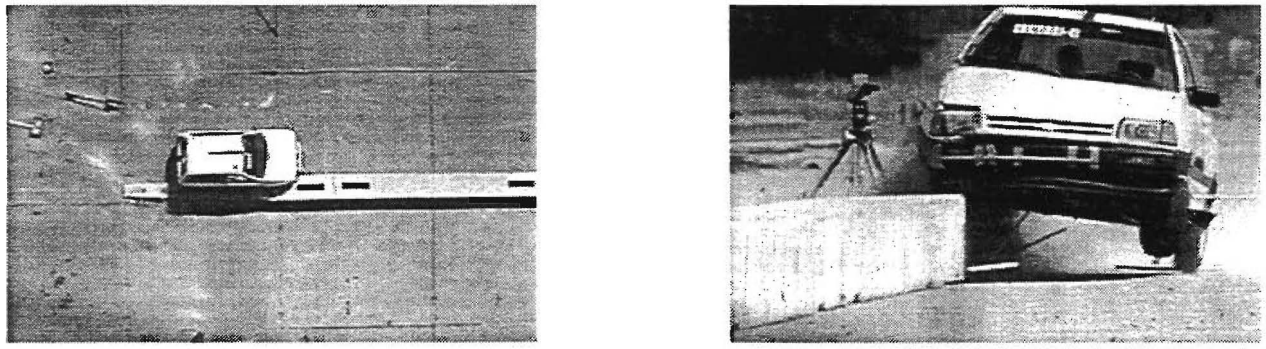
0.000 s



0.049 s

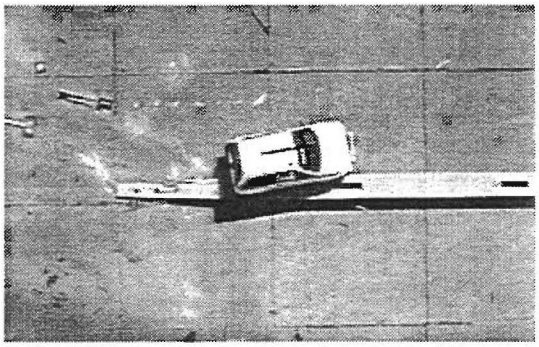


0.098 s

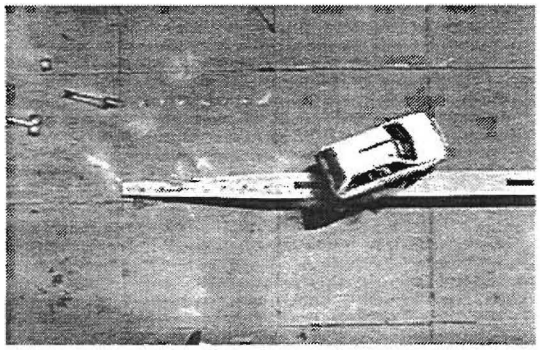


0.196 s

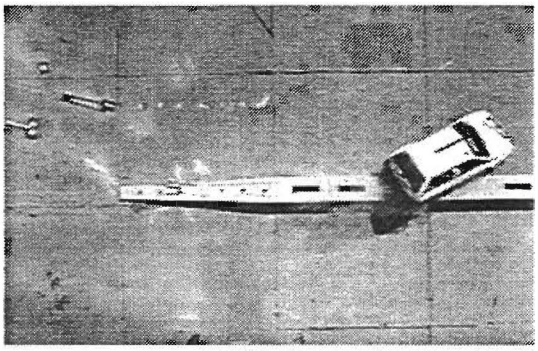
Figure 46. Sequential Photographs for Test 414038-1 (Overhead and Frontal Views)



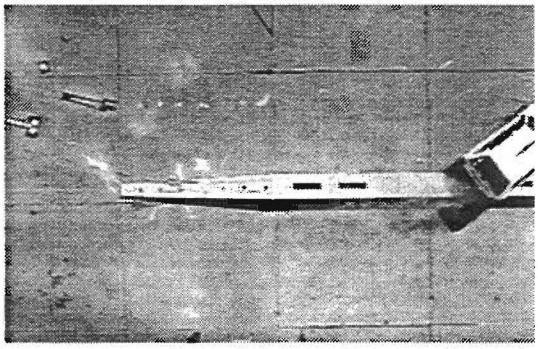
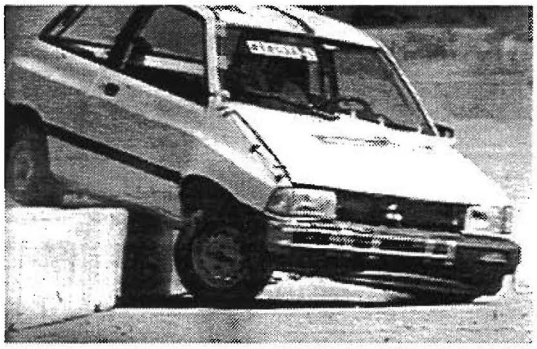

0.294 s




0.442 s

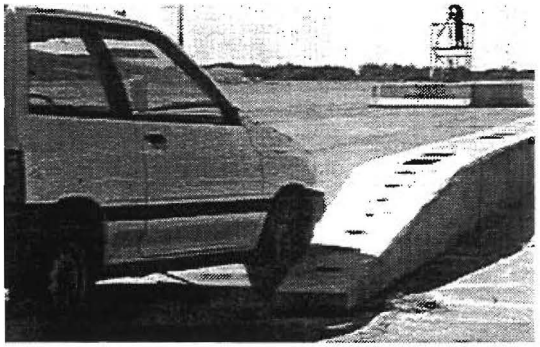



0.564 s

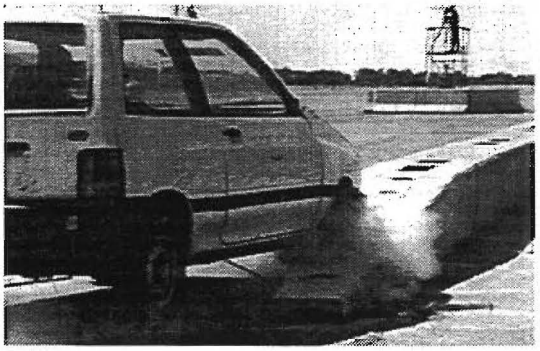
0.687 s

Figure 46. Sequential Photographs for Test 414038-1 (Overhead and Frontal Views) (continued)

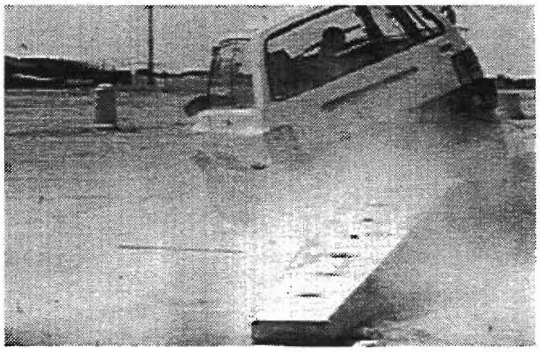


0.000 s

0.294 s

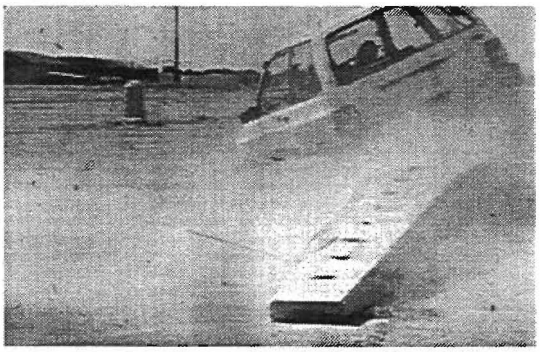


0.049 s



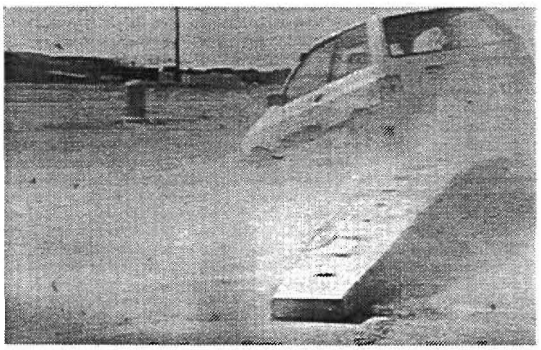
0.442 s

0.098 s



0.564 s

0.196 s



0.687 s

Figure 47. Sequential Photographs for Test 414038-1 (Rear View)

APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS AND VEHICLE ACCELEROMETER TRACES

This section contains plots of the vehicular angular displacements and vehicle accelerations exhibited by the vehicle in the crash tests performed under this study.

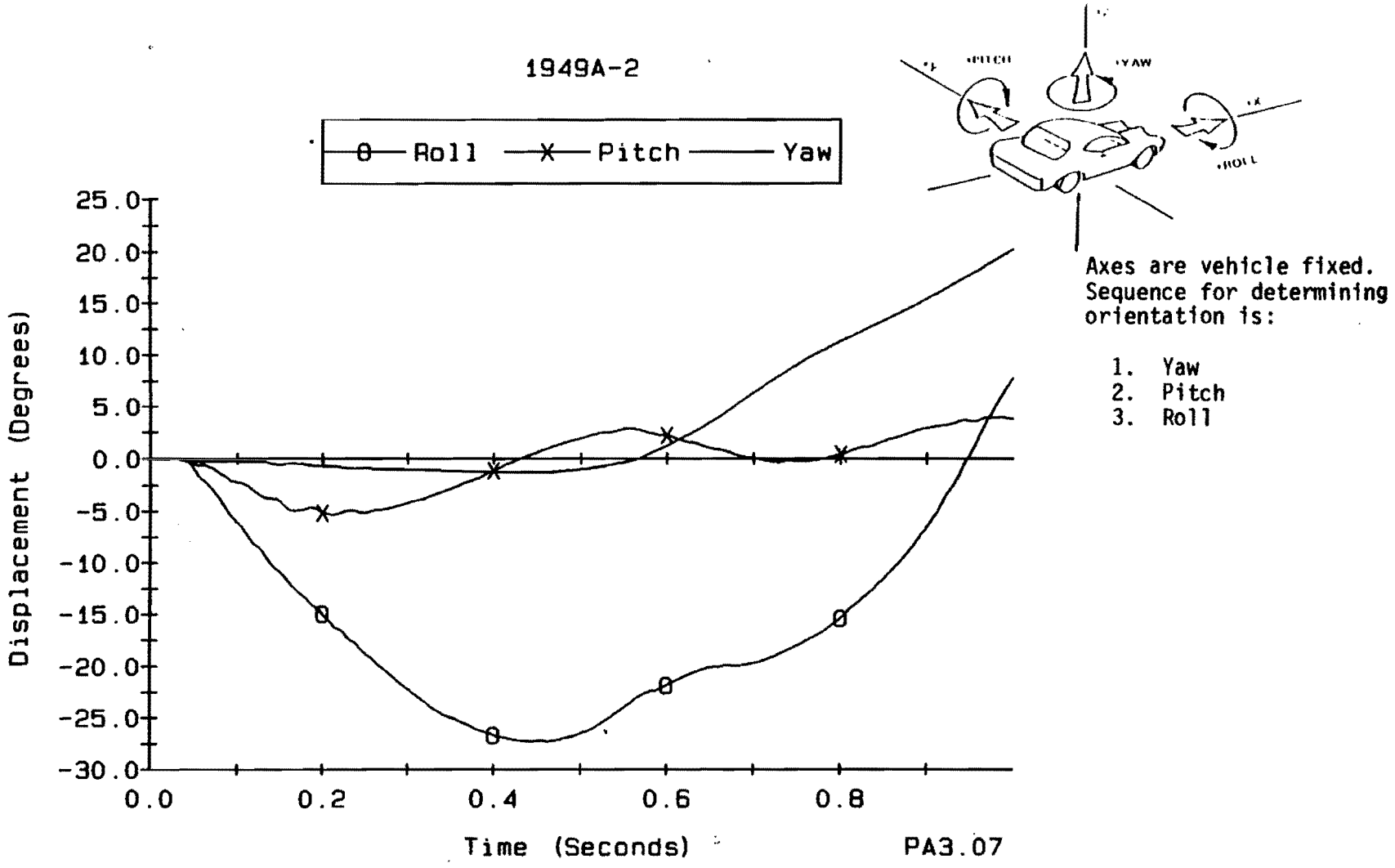


Figure 48. Vehicle Angular Displacements for Test 1949A-2

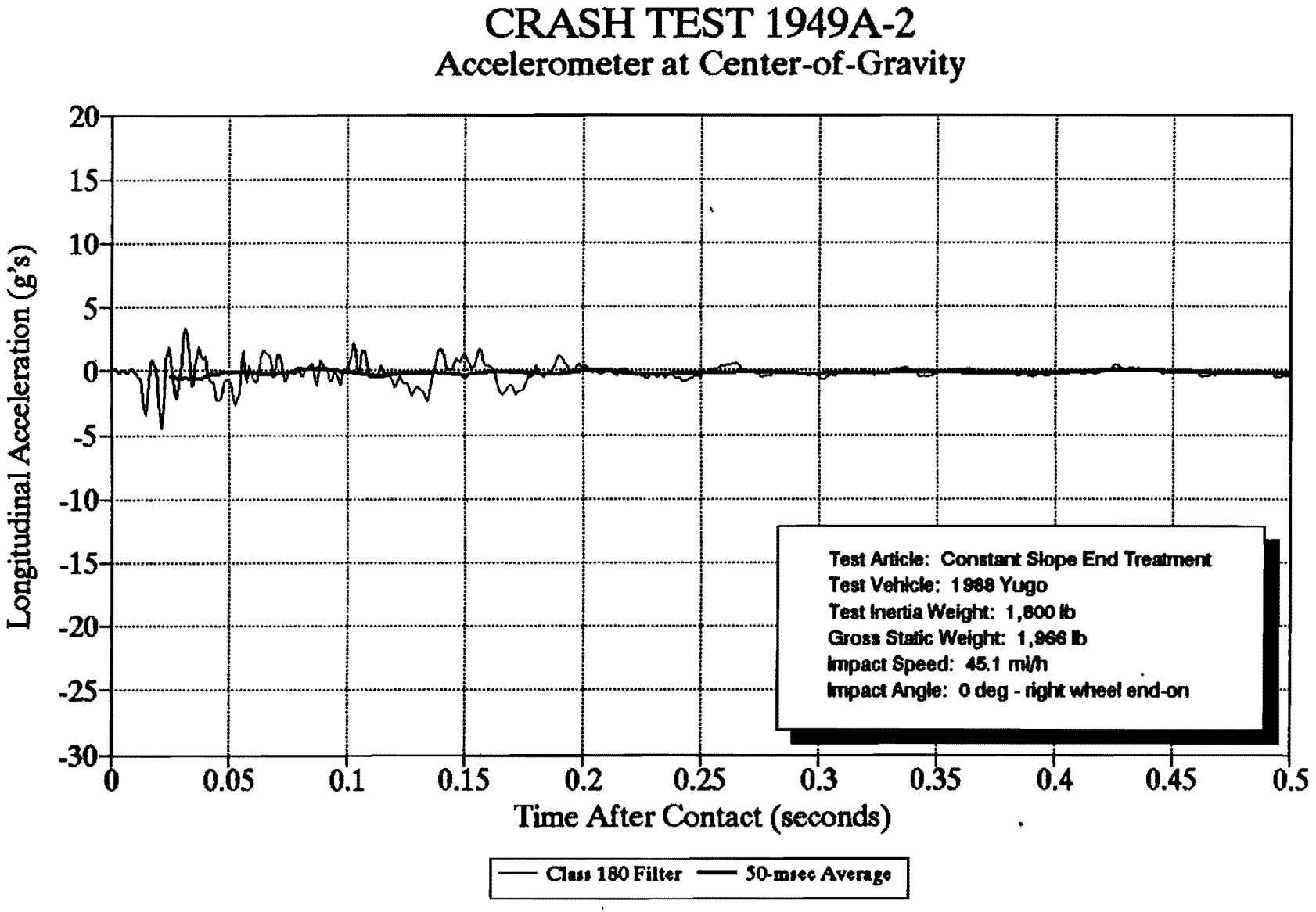


Figure 49. Vehicle Longitudinal Accelerometer Trace for Test 1949A-2

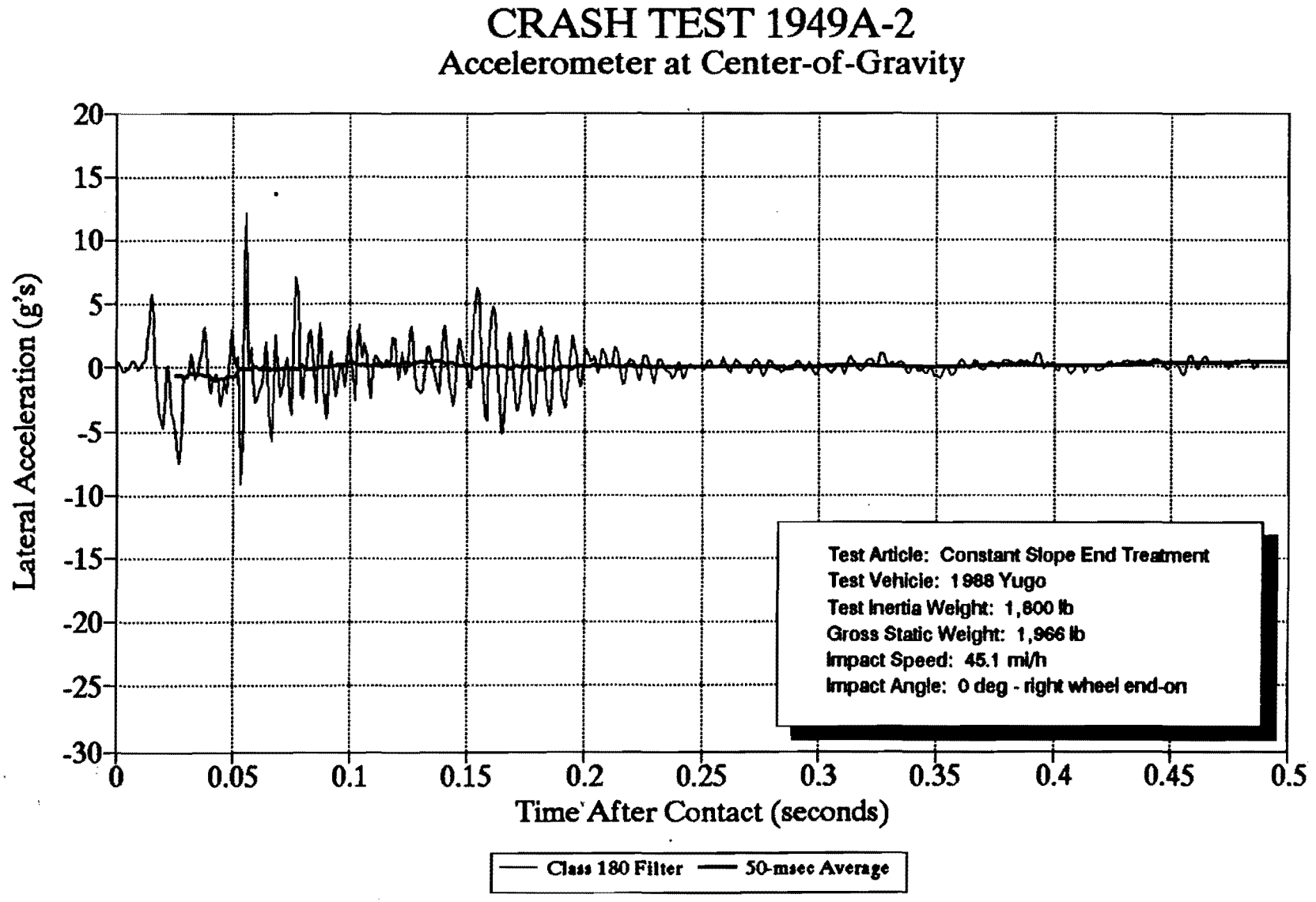


Figure 50. Vehicle Lateral Accelerometer Trace for Test 1949A-2

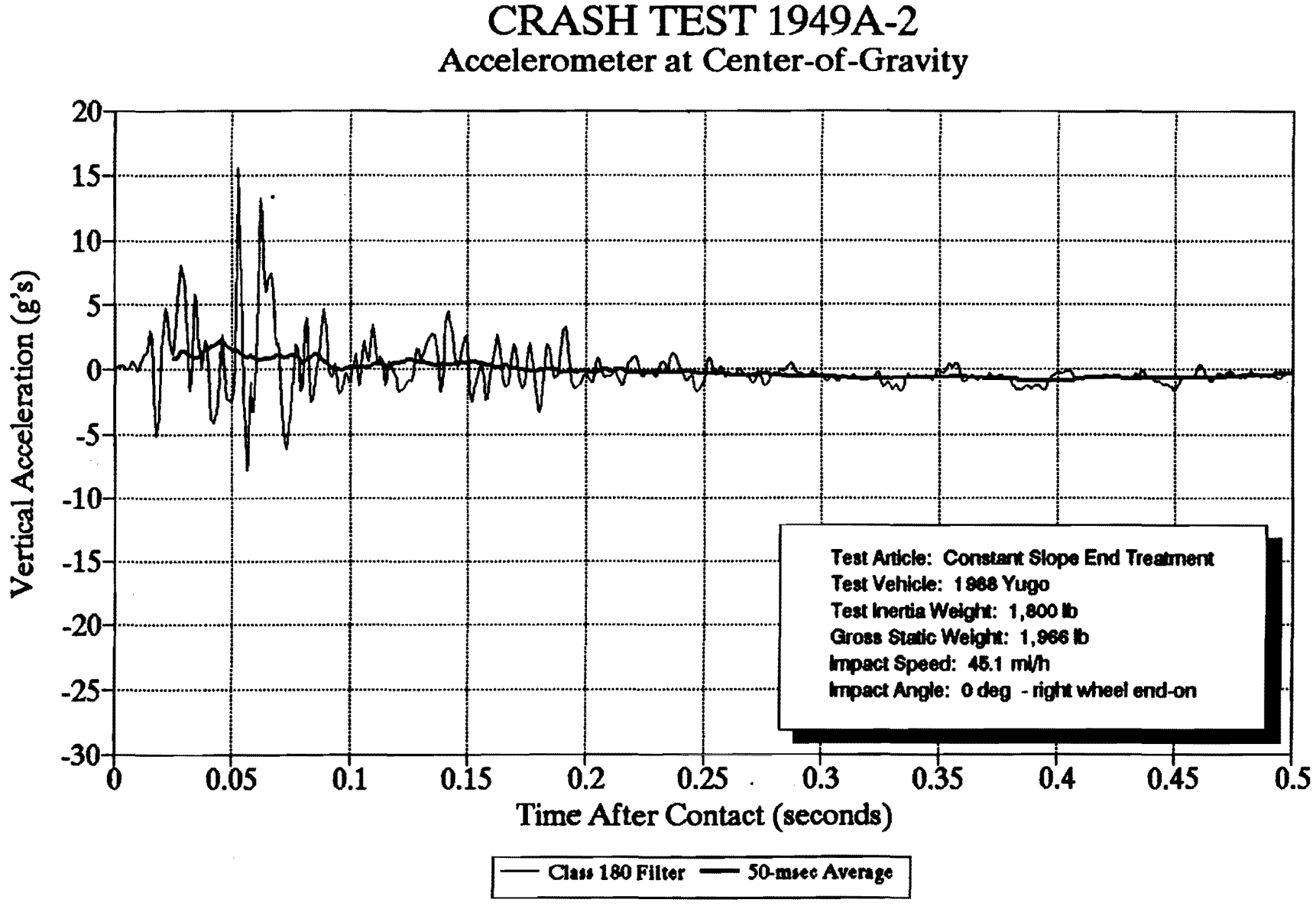


Figure 51. Vehicle Vertical Accelerometer Trace for Test 1949A-2

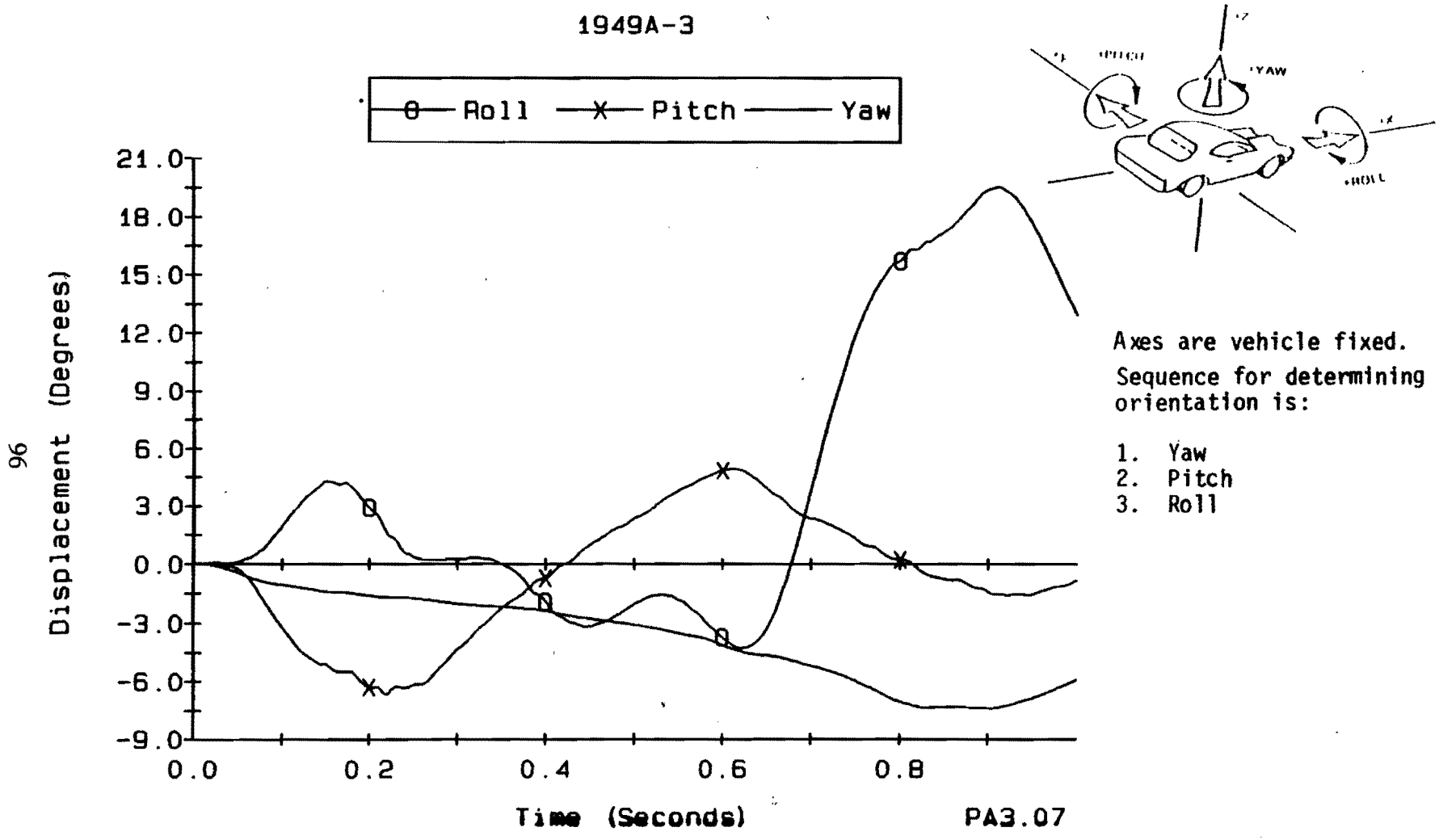


Figure 52. Vehicle Angular Displacements for Test 1949A-3

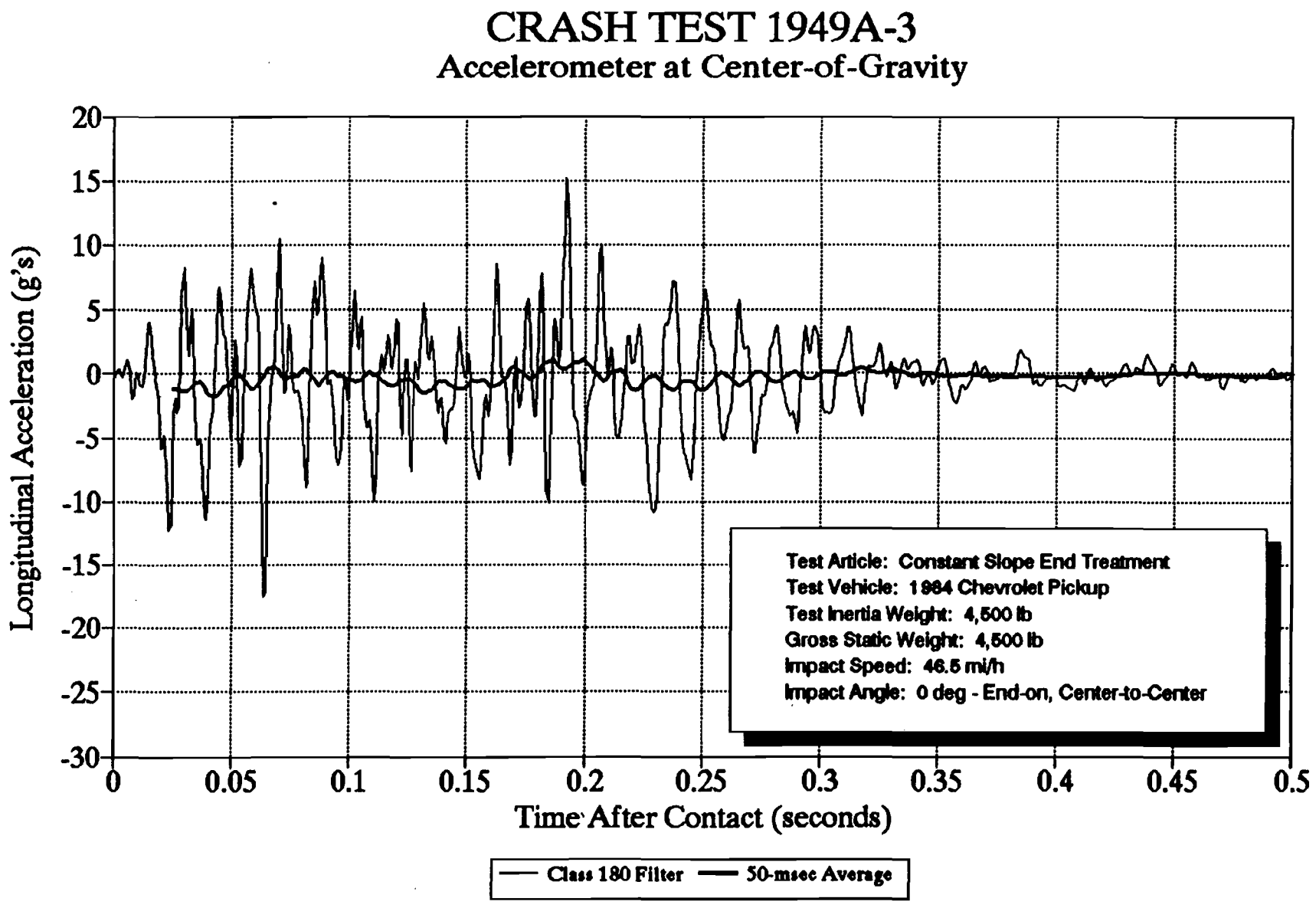


Figure 53. Vehicle Longitudinal Accelerometer Trace for Test 1949A-3

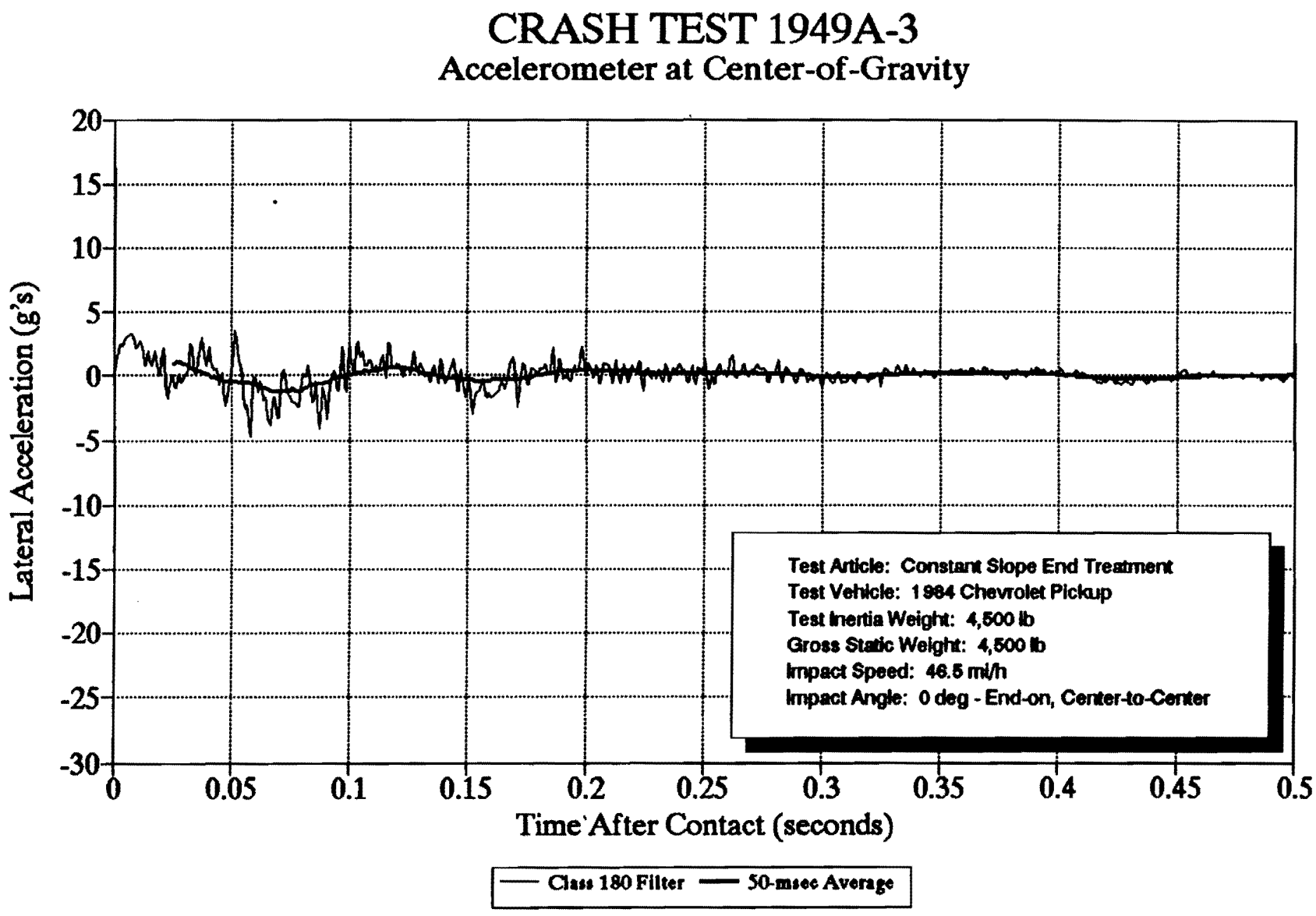


Figure 54. Vehicle Lateral Accelerometer Trace for Test 1949A-3

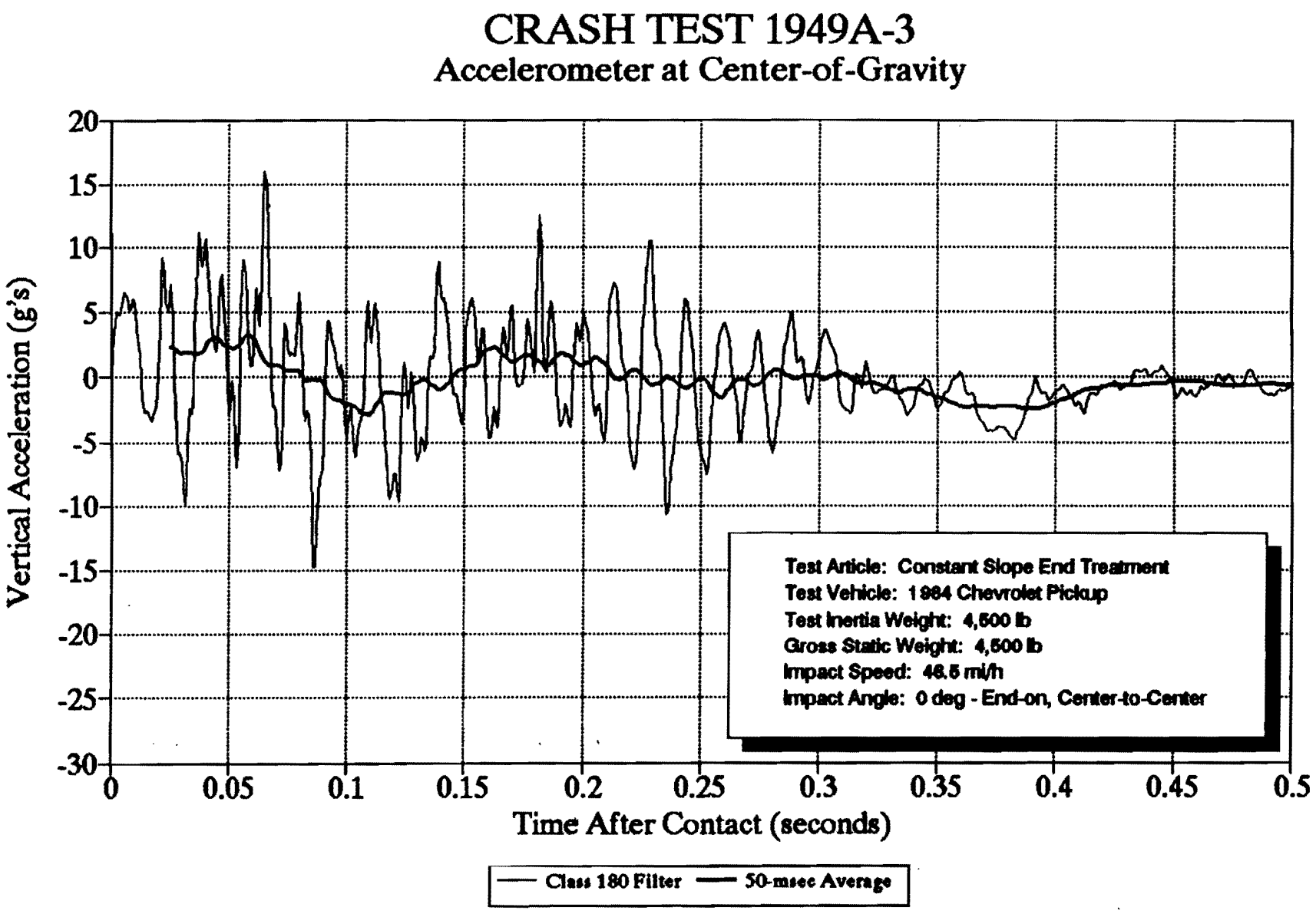


Figure 55. Vehicle Vertical Accelerometer Trace for Test 1949A-3

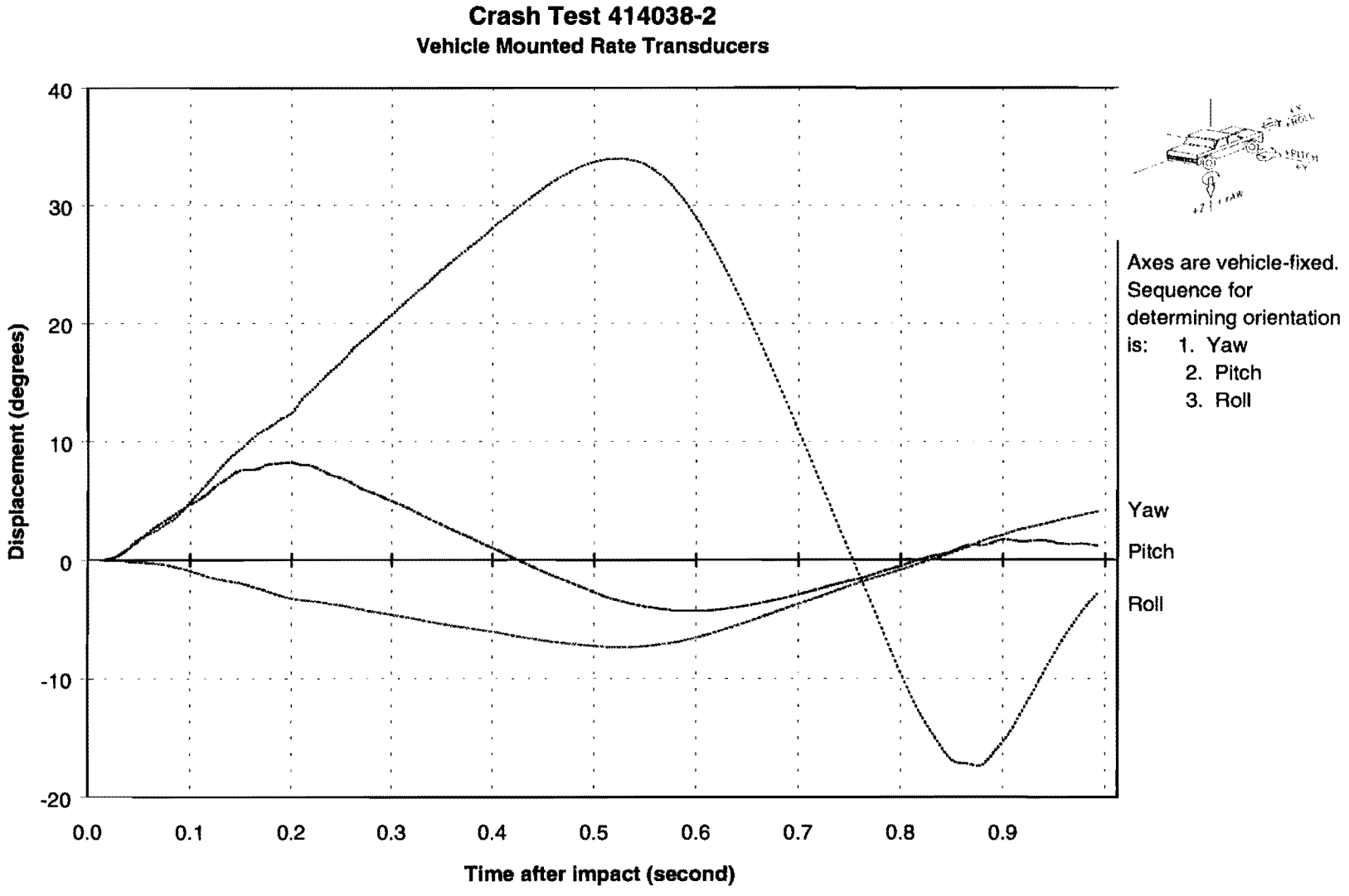


Figure 56. Vehicle Angular Displacements for Test 414038-2

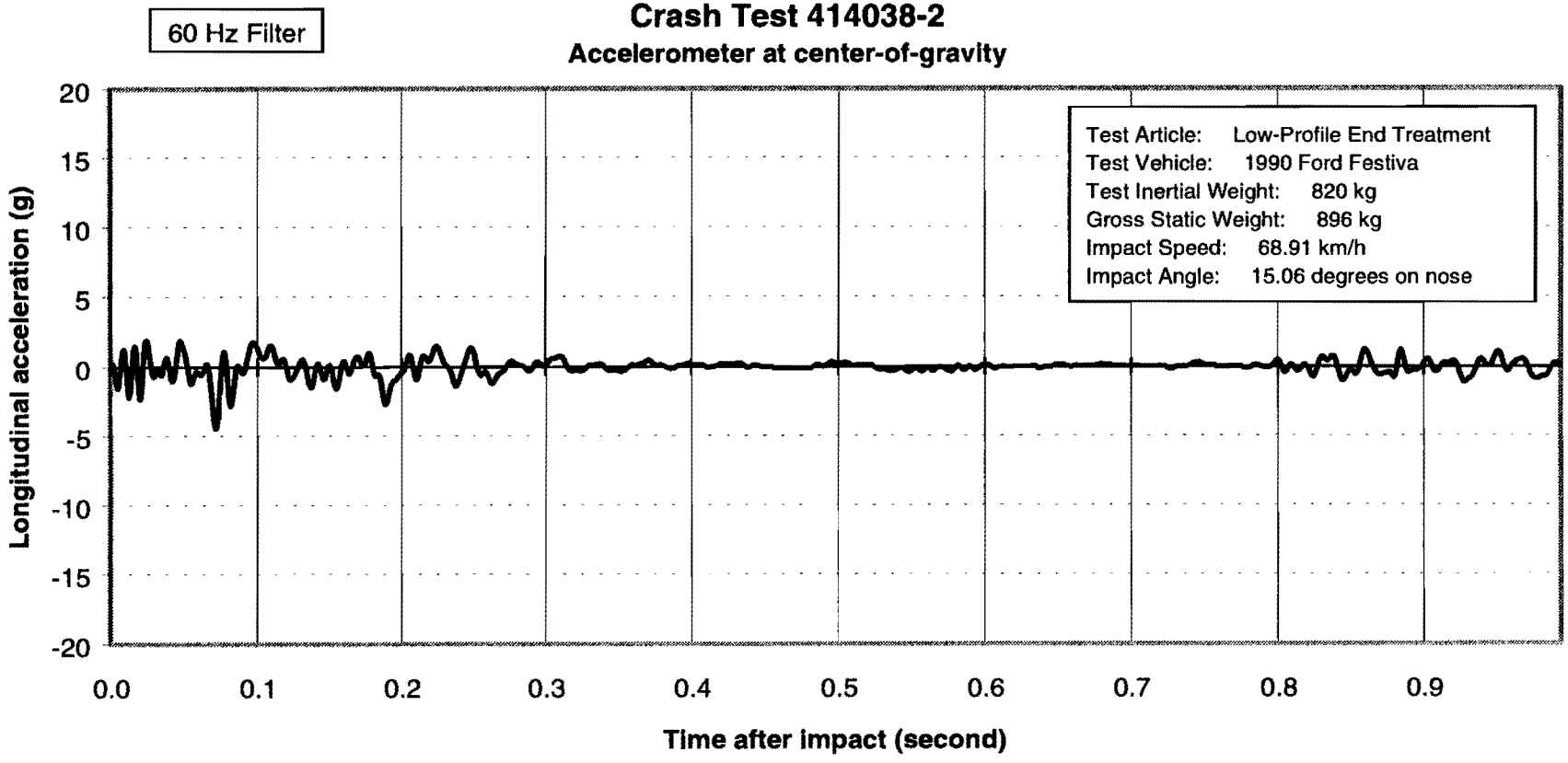


Figure 57. Vehicle Longitudinal Accelerometer Trace for Test 414038-2

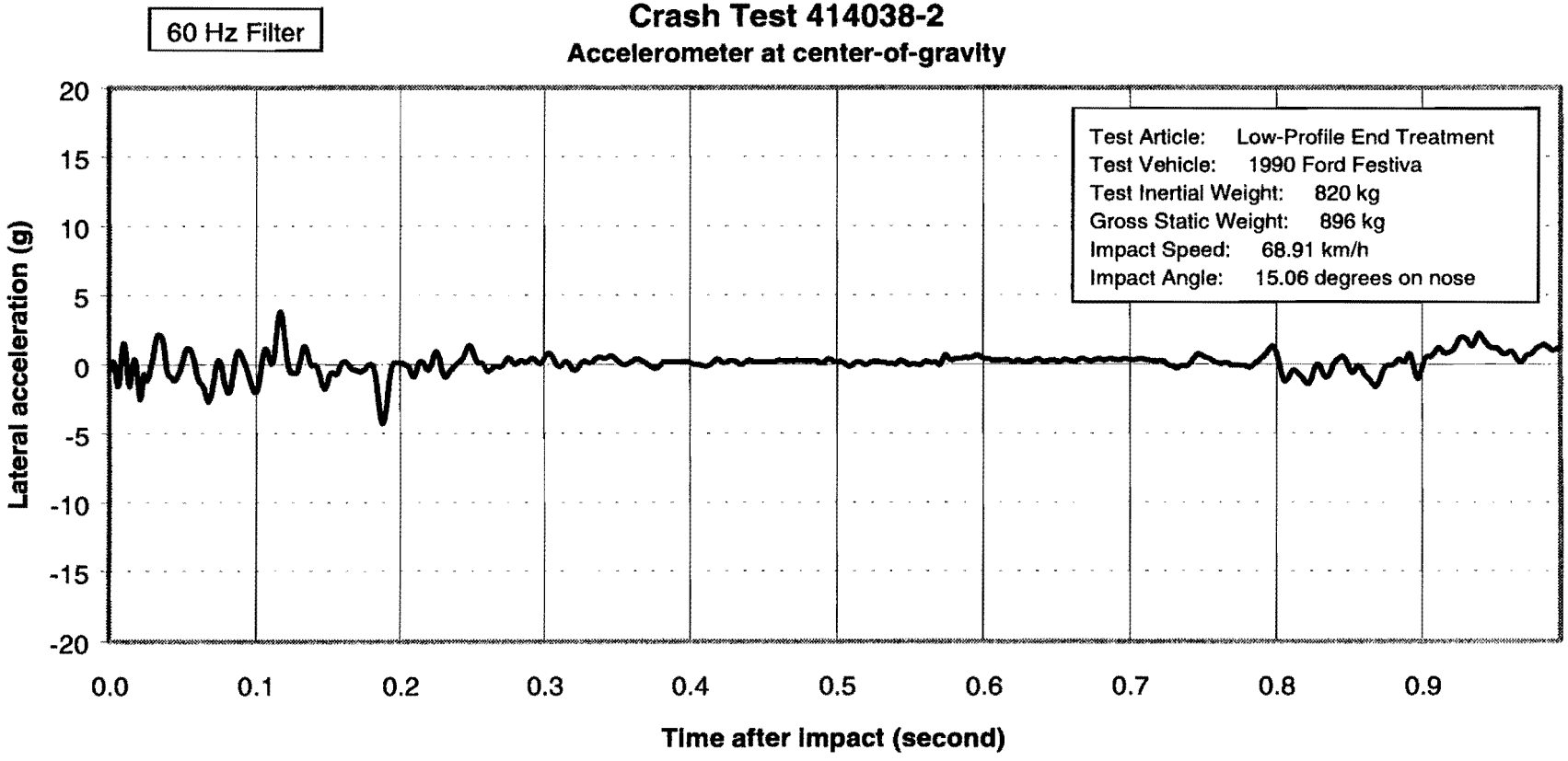


Figure 58. Vehicle Lateral Accelerometer Trace for Test 414038-2

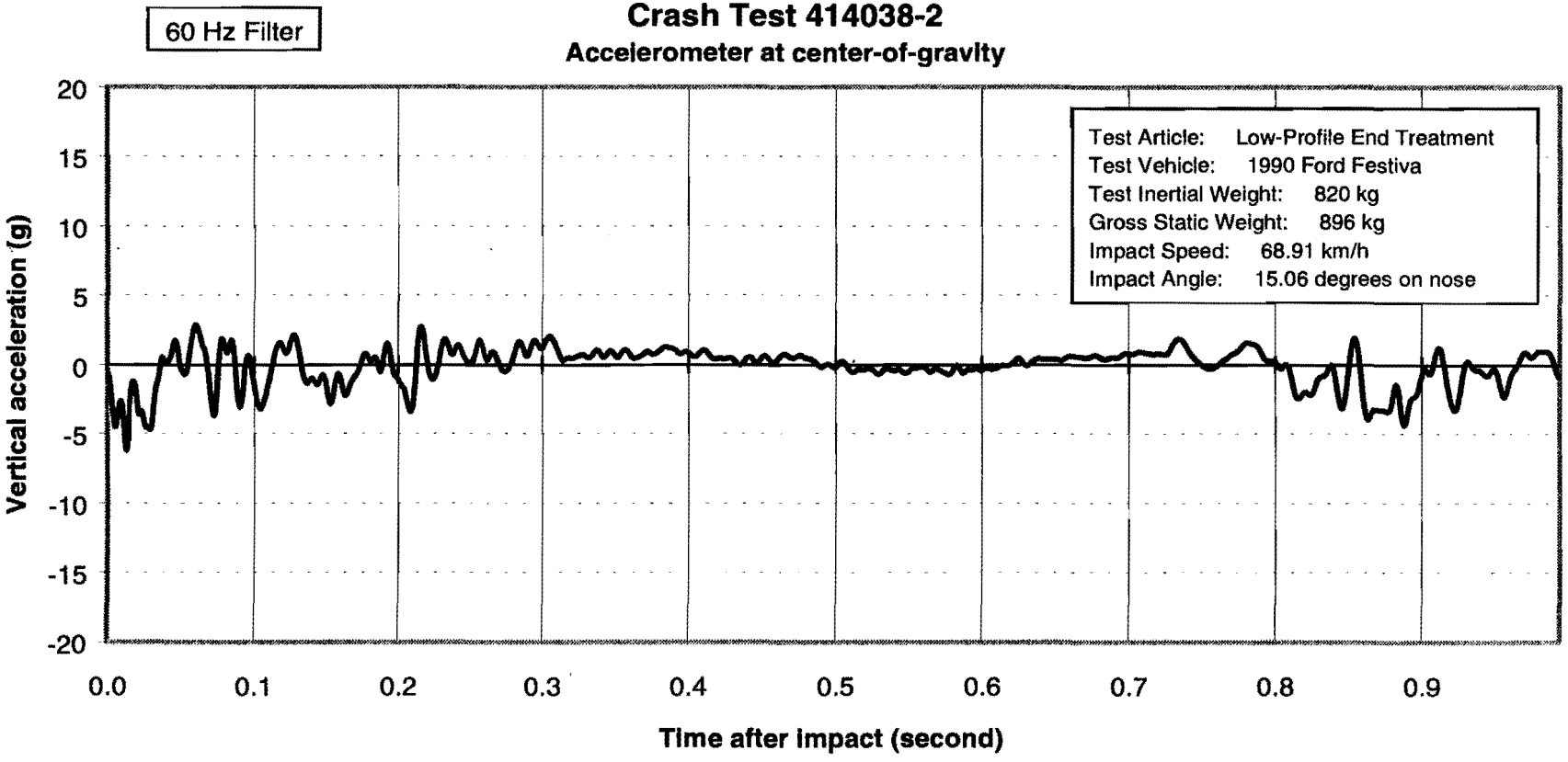


Figure 59. Vehicle Vertical Accelerometer Trace for Test 414038-2

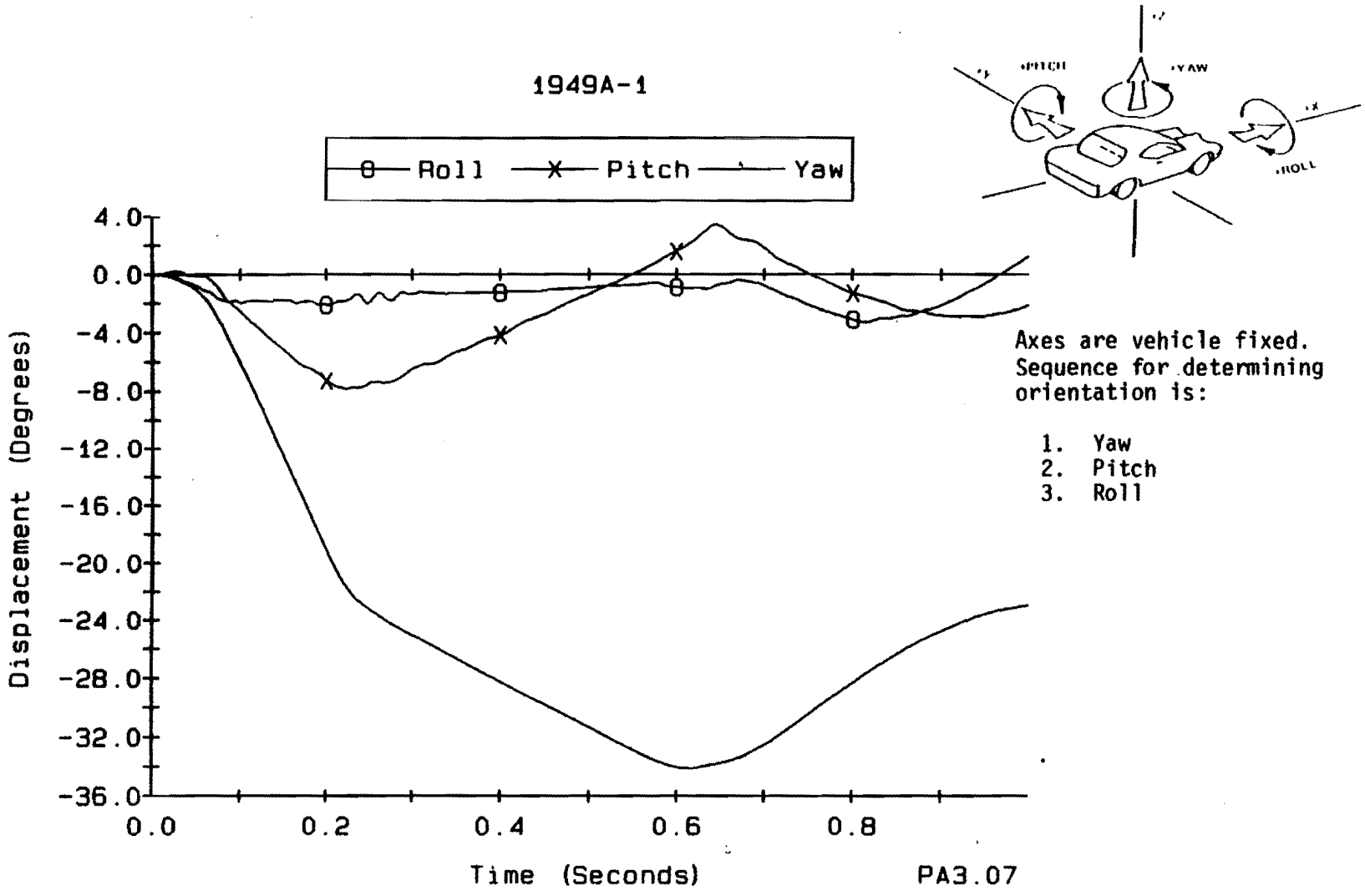


Figure 60. Vehicle Angular Displacements for Test 1949A-1

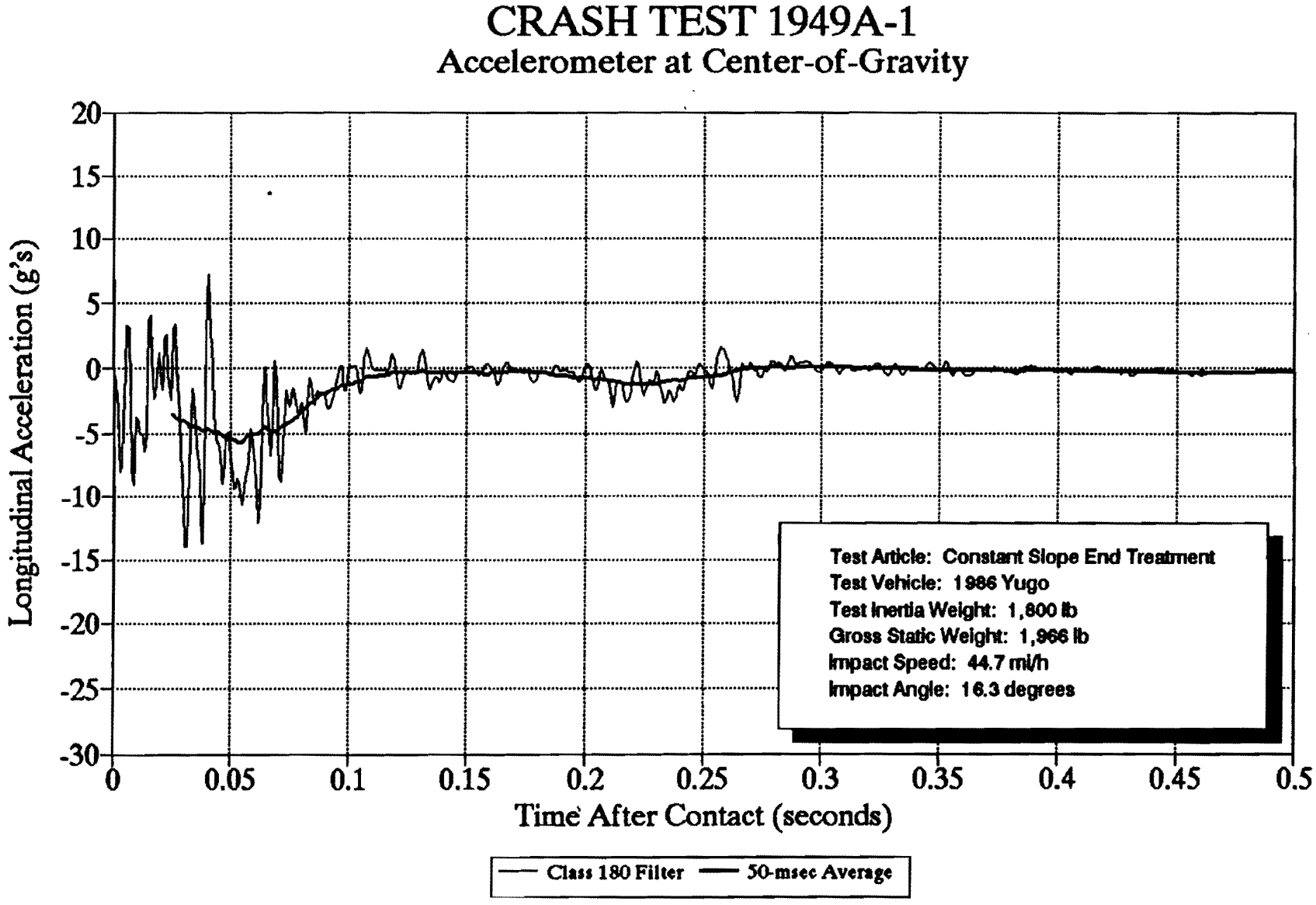


Figure 61. Vehicle Longitudinal Accelerometer Trace for Test 1949A-1

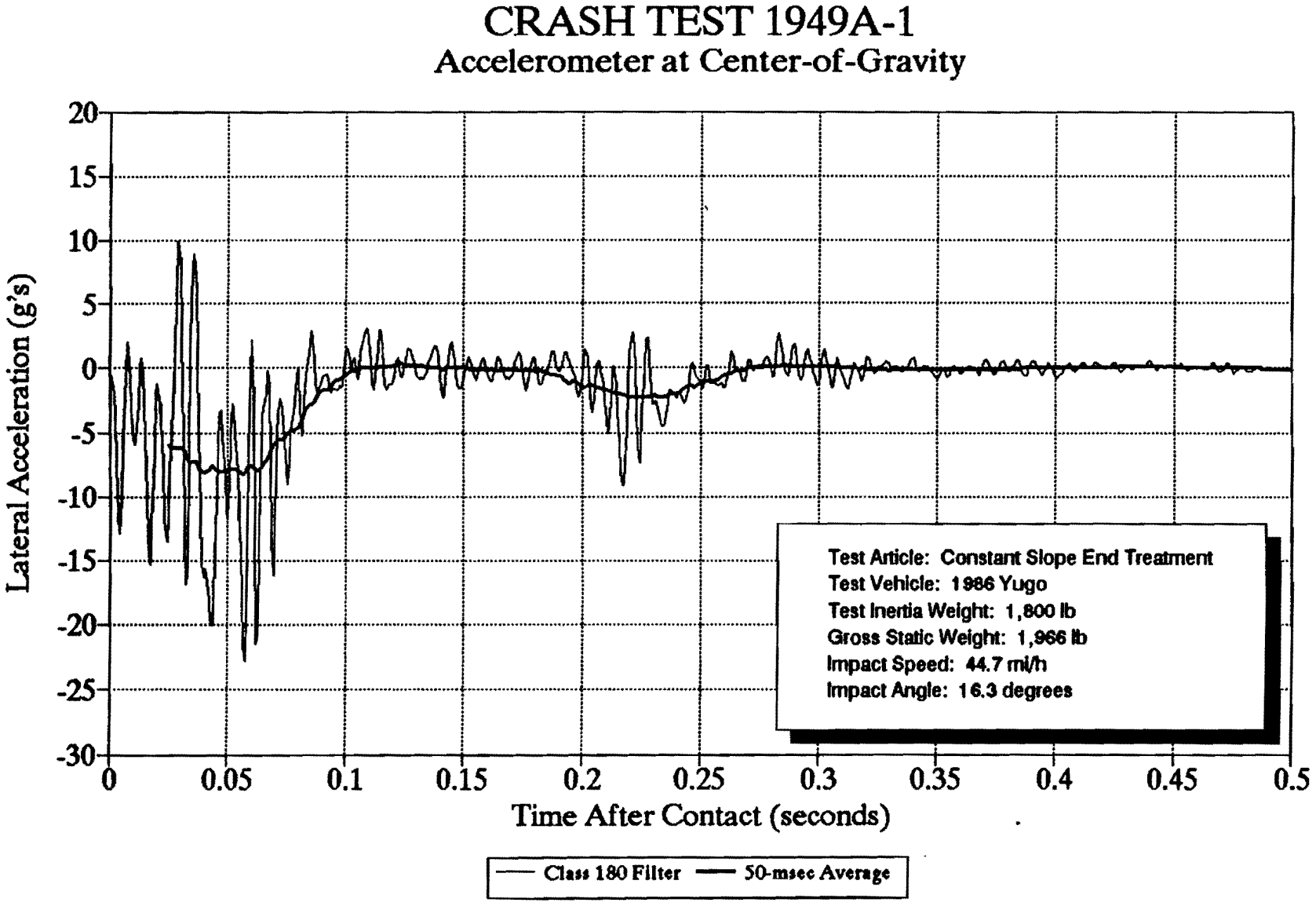


Figure 62. Vehicle Lateral Accelerometer Trace for Test 1949A-1

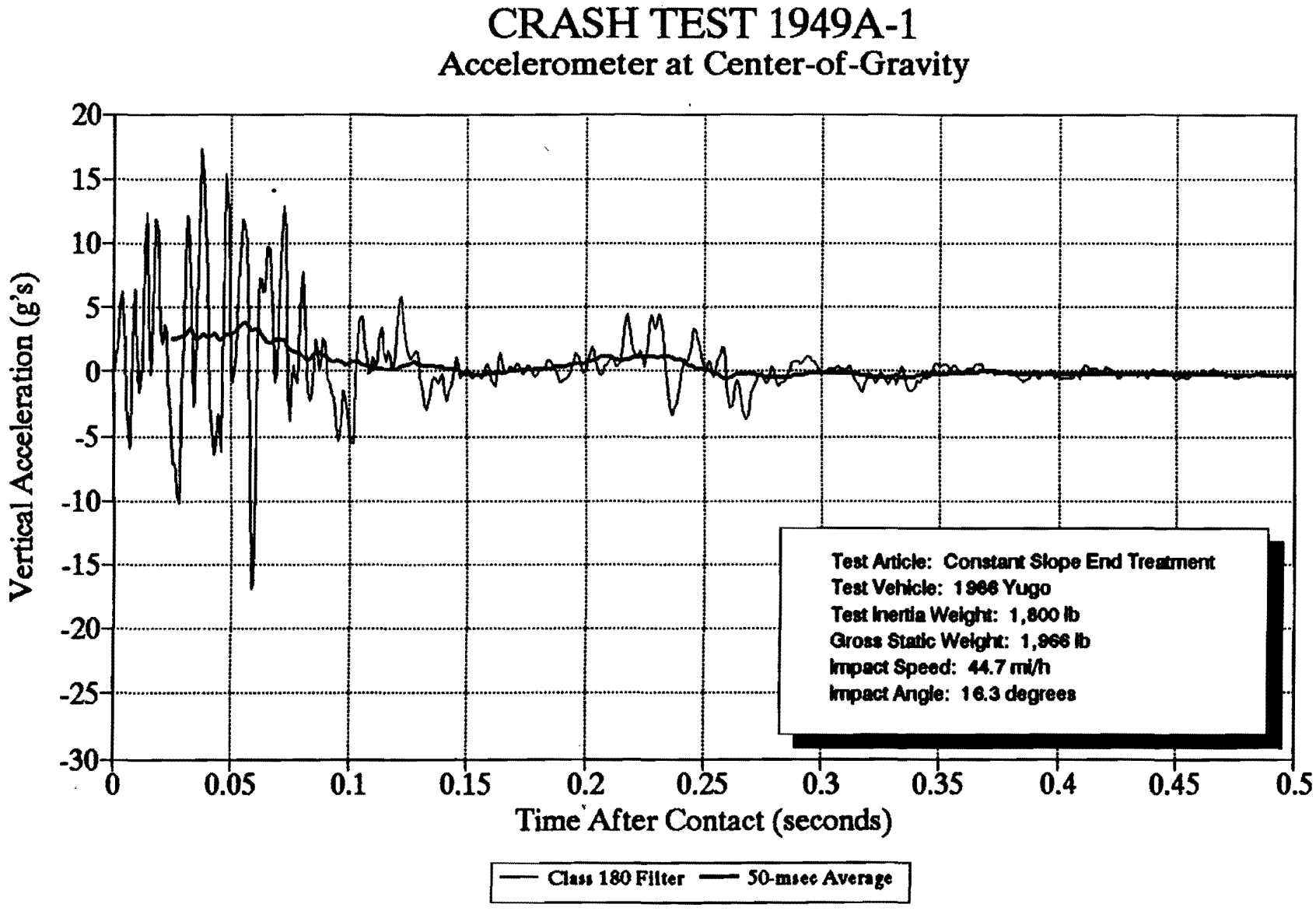


Figure 63. Vehicle Vertical Accelerometer Trace for Test 1949A-1

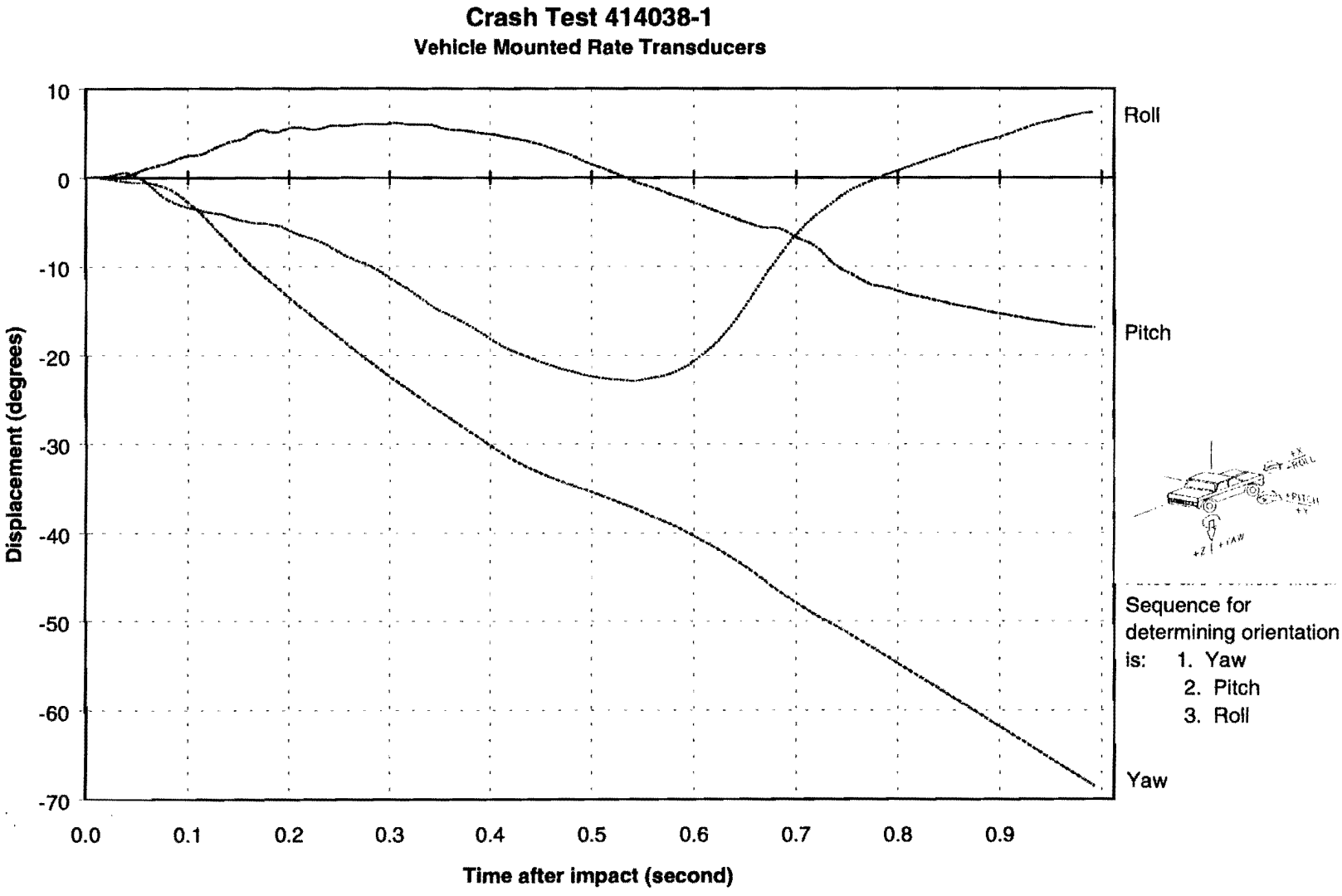


Figure 64. Vehicle Angular Displacements for Test 414038-1

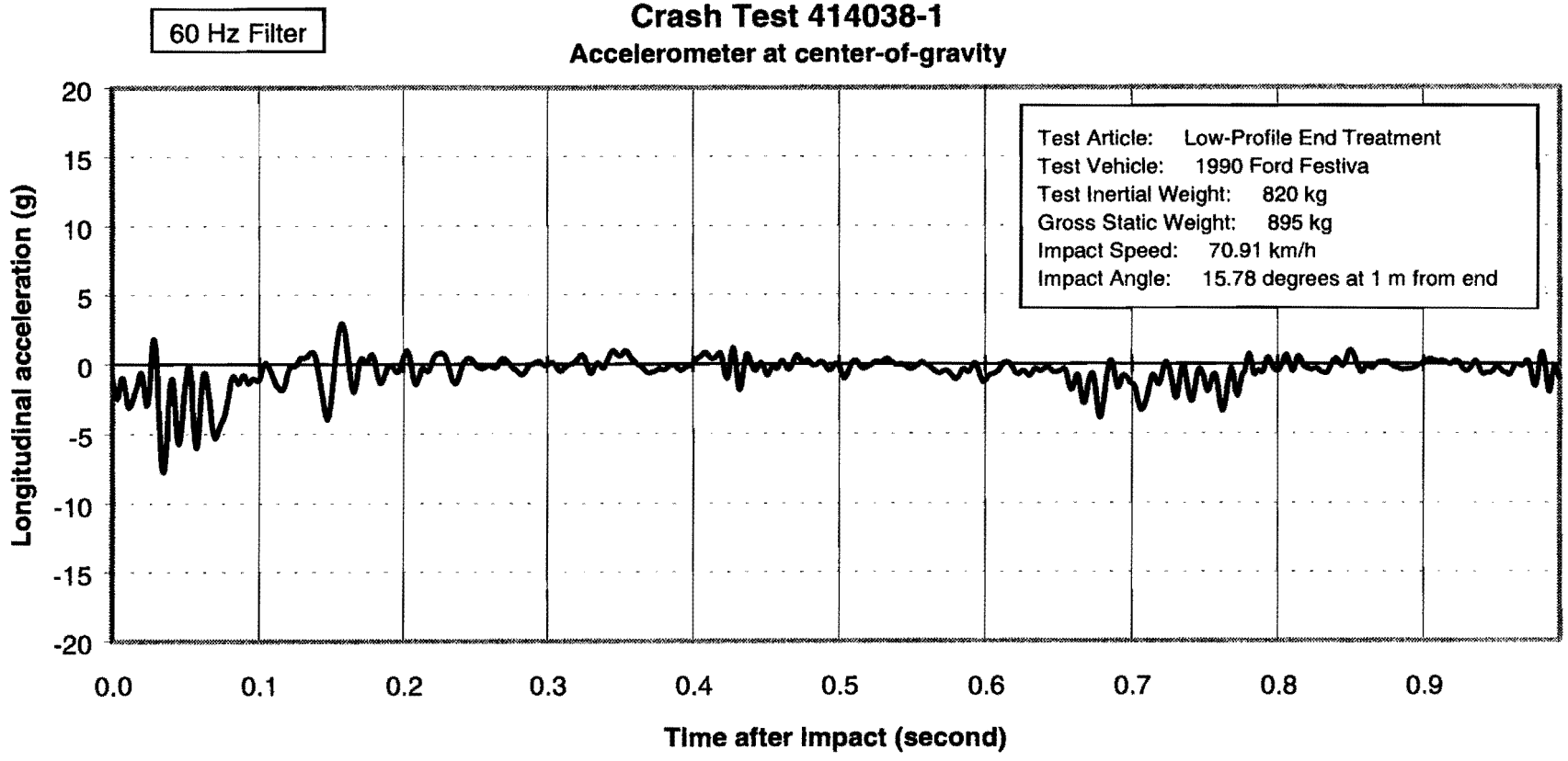


Figure 65. Vehicle Longitudinal Accelerometer Trace for Test 414038-1

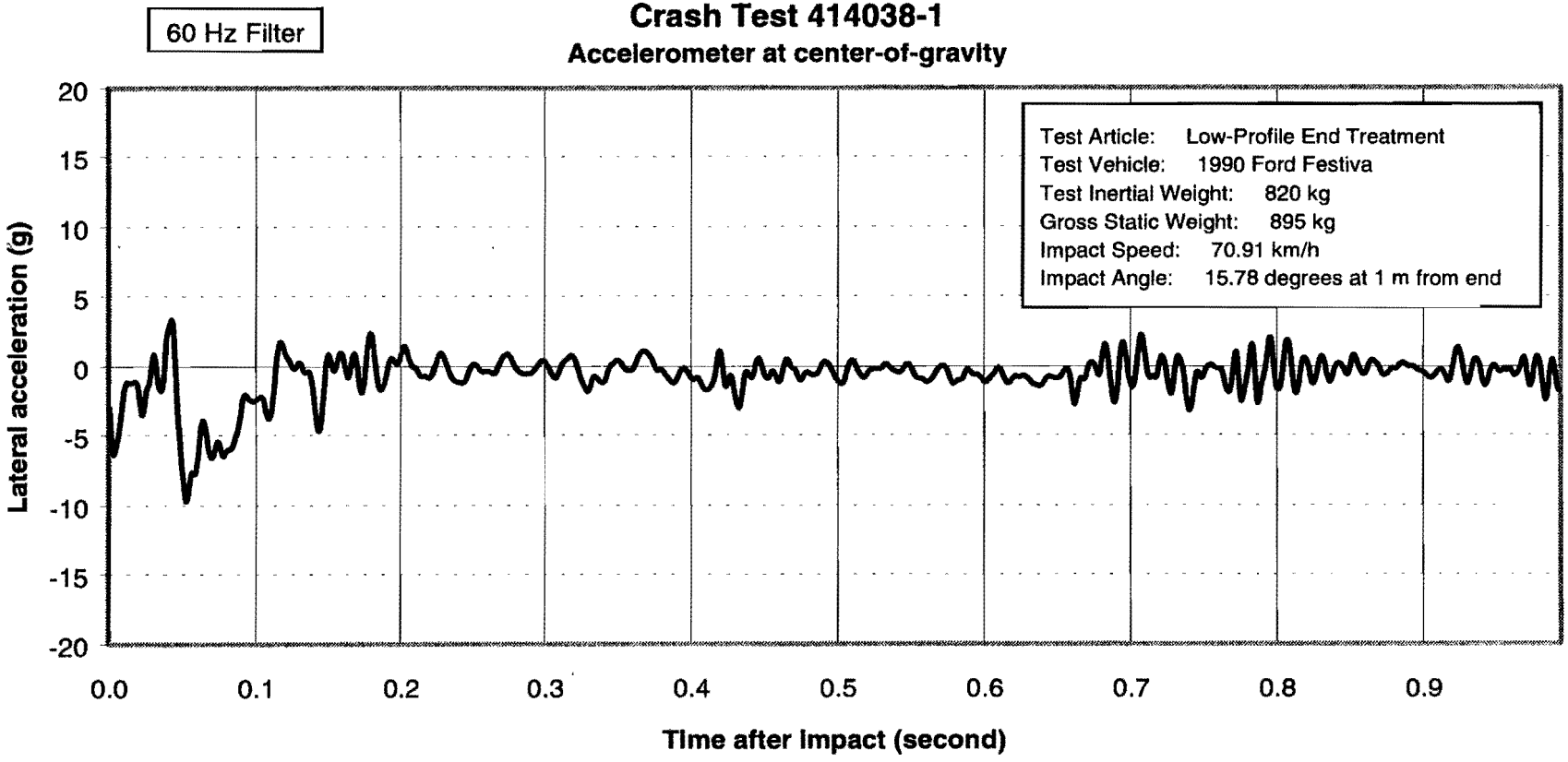


Figure 66. Vehicle Lateral Accelerometer Trace for Test 414038-1

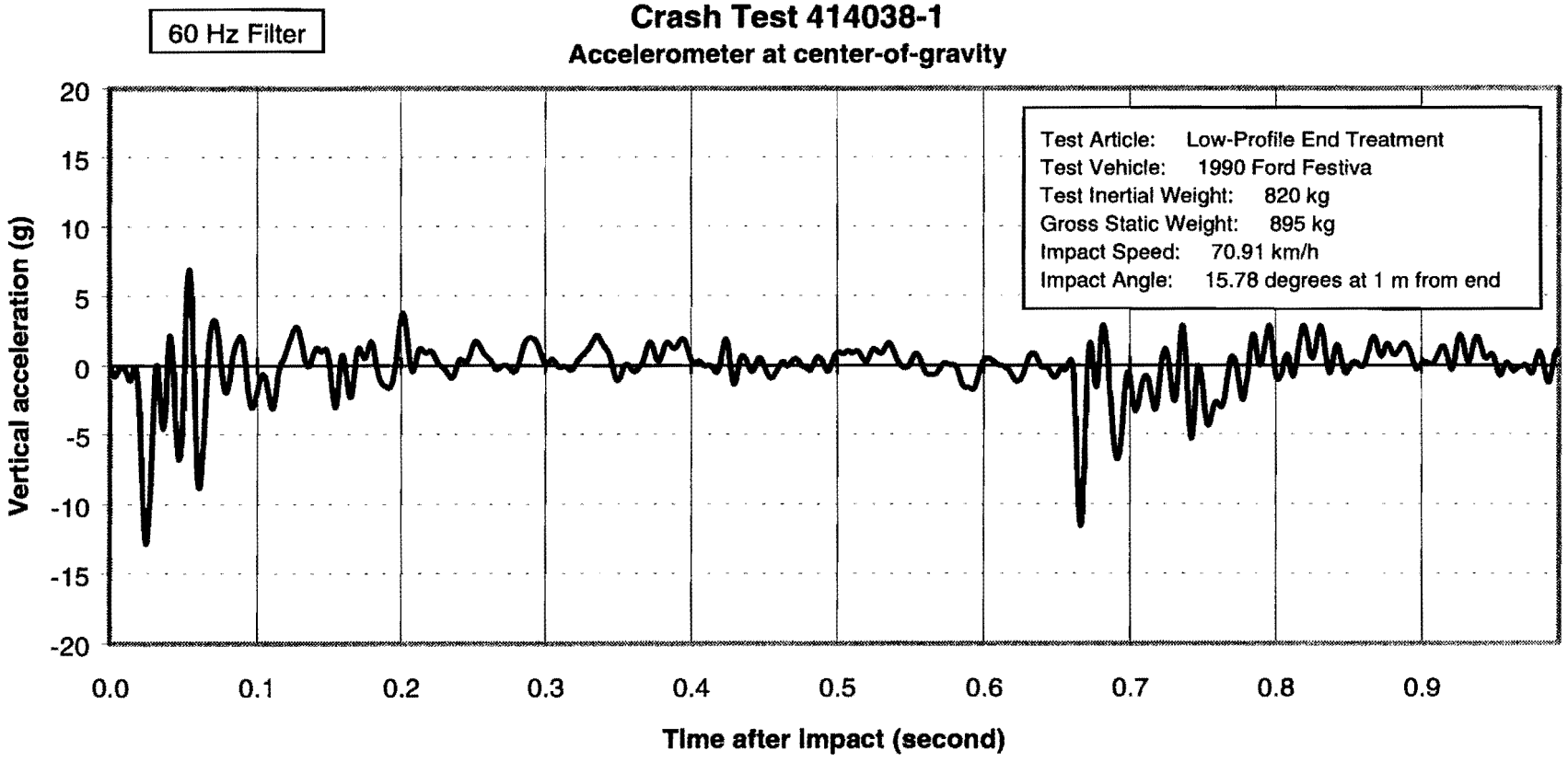


Figure 67. Vehicle Vertical Accelerometer Trace for Test 414038-1

APPENDIX E. VEHICLE PROPERTIES

This section provides additional dimensions and information on vehicles used for the crash tests performed under this study.

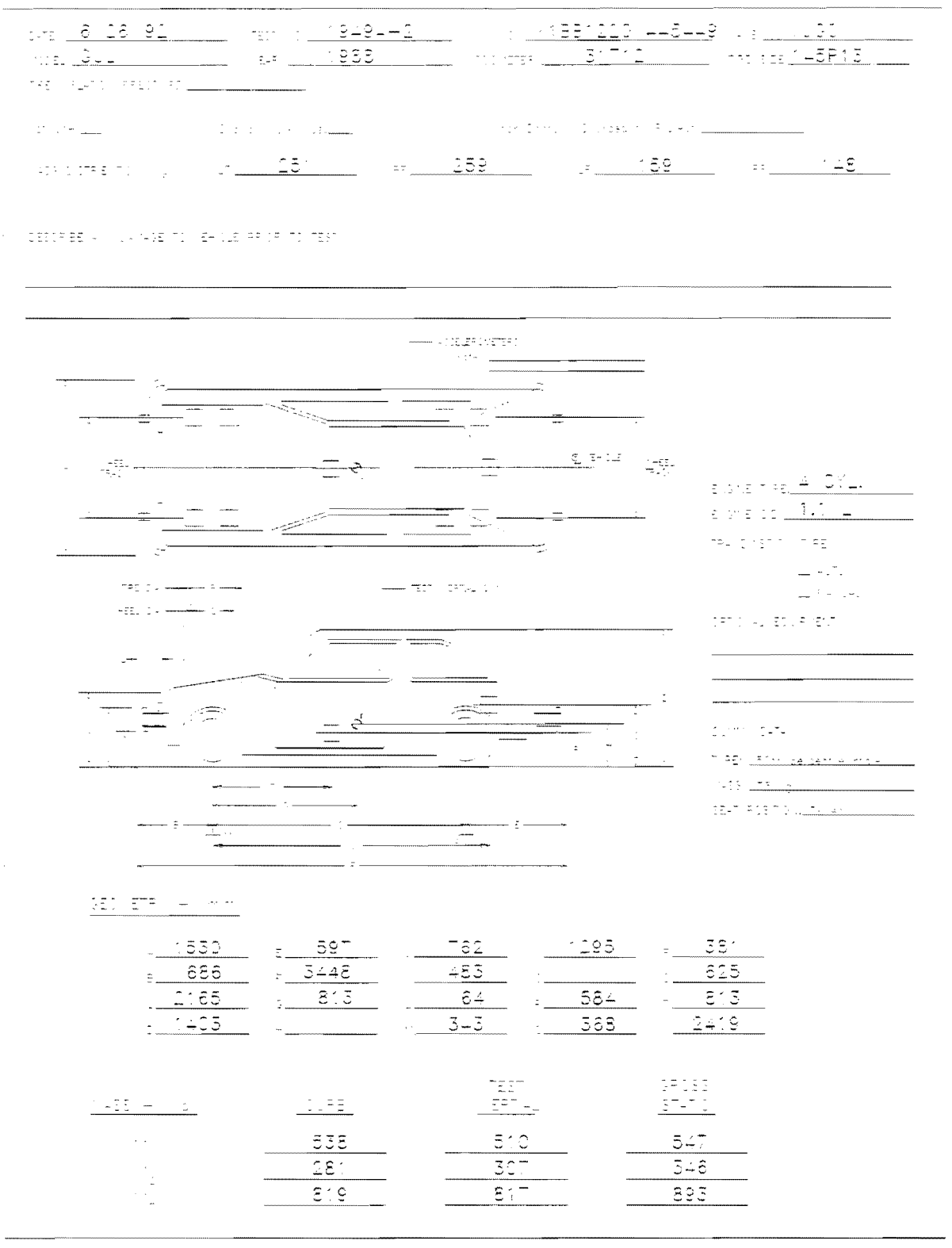


Figure 68. Vehicle Properties for Test 1949A-2

DATE: 7/1/92 TEST NO.: 1949A-3 VIN NO.: 1GCGC24MFS104060

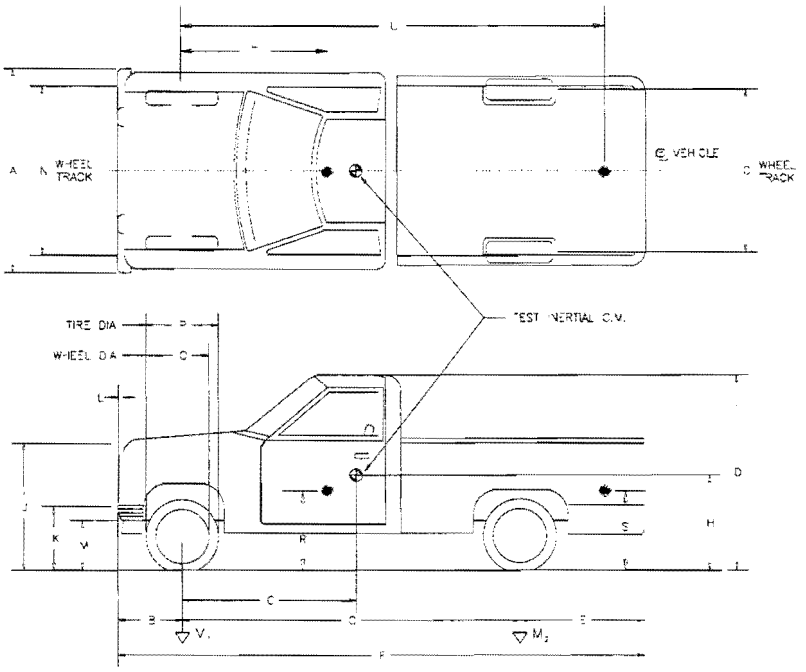
YEAR: 1984 MAKE: CHEVROLET MODEL: P/U CUSTOM DELUXE 20

TIRE INFLATION PRESSURE: _____ ODOMETER: 94706 TIRE SIZE: LT 235/85R16

MASS DISTRIBUTION (kg) LF 549 RF 555 LR 474 RR 464

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

CRACKED WINDSHIELD (MARKED)



● Denotes accelerometer location.

NOTES: _____

ENGINE TYPE: V8

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: _____

MASS: _____

SEAT POSITION: _____

GEOMETRY – (mm)

A	2013	E	1257	J	1181	N	1676	R	625
B	838	F	5436	K	679	O		S	1054
C	3340	G	1534	L	89	P	826	T	1524
D	1842	H		M	445	Q	437	U	

VASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
V_1	1176	1105	
V_2	945	938	
V_T	2121	2043	

Figure 69. Vehicle Properties for Test 1949A-3

DATE: 9/18/97 TEST NO.: 414038-2 VIN NO.: KNJPT05H4L6107118 MAKE: FORD

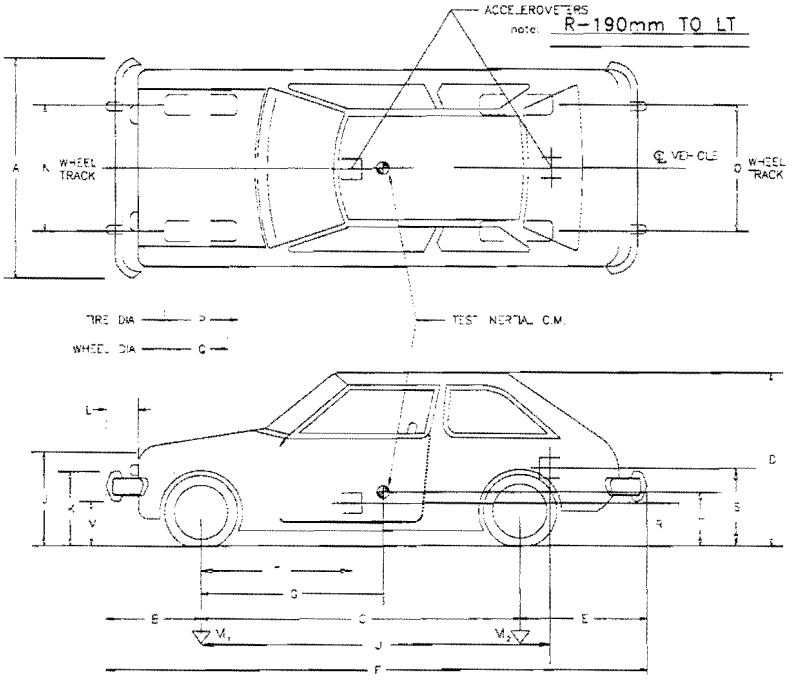
MODEL: FESTIVA YEAR: 1990 ODOMETER: 100125 TIRE SIZE: 155R12

TIRE INFLATION PRESSURE: _____

1st Use: X 2nd or More Use: ___ Minor Damage Changed to Project: _____

MASS DISTRIBUTION (kg) LF 264 RF 248 LR 157 RR 151

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 CYL.

ENGINE CID: 1.3L

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 76 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1500	E	560	V	750	N	1390	R	400
B	650	F	3510	K	530	O	1385	S	500
C	2300	G	863.9	-	120	P	520	T	900
D	1440	H		V	370	Q	330	U	2400

MASS – (kg)	CURB	TEST INERTIA	GROSS STATIC
M_1	525	512	550
M_2	285	308	346
M_T	810	820	896

Figure 70. Vehicle Properties for Test 414038-2

DATE: 6/24/92 TEST NO.: 1949A-1 VIN NO.: VX1BA1216GK324202 MAKE: YUGO

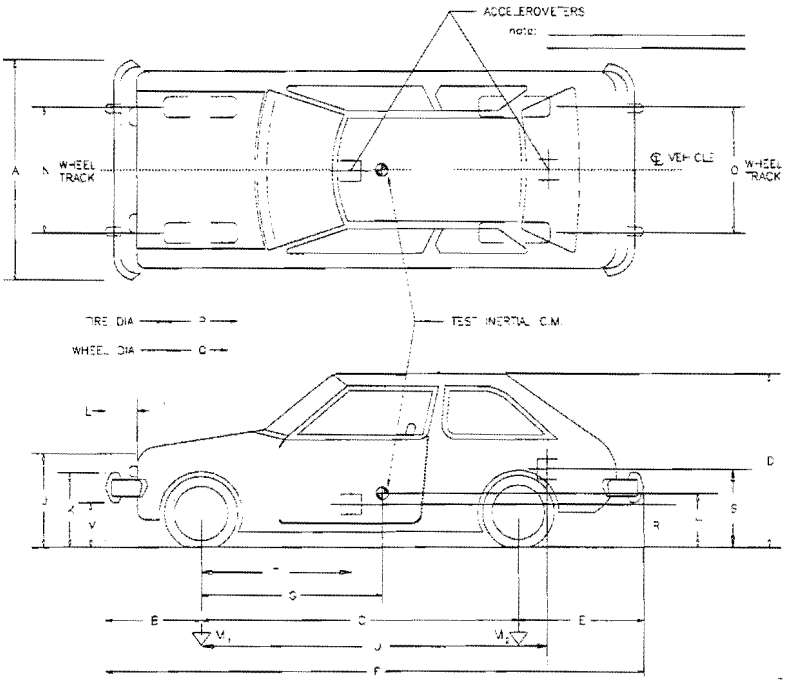
MODEL: GL YEAR: 1986 ODOMETER: 26331 TIRE SIZE: 145SR13

TIRE INFLATION PRESSURE: _____

1st Use: ___ 2nd or More Use: ___ Minor Damage Changed to Project: _____

MASS DISTRIBUTION (kg) LF 264 RF 252 LR 138 RR 163

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: V-4

ENGINE CID: 1100 CC

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 73 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	1530	E	610	L	762	N	1314	R	654
B	696	F	3348	K	470	O		S	381
C	2140	G	787		102	P	578	T	787
D	1403	H		V	330	Q	360	U	

MASS - (kg)	CURB	TEST INERTIA	GROSS STATIC
M_1	548	516	552
M_2	277	301	341
M_T	824	817	893

Figure 71. Vehicle Properties for Test 1949A-1

DATE: 9/16/97 TEST NO.: 414038-1 VIN NO.: KNJPT06H6L6151331 MAKE: FORD

MODEL: FEST VA YEAR: 1990 ODOMETER: 100730 TIRE SIZE: 155R12

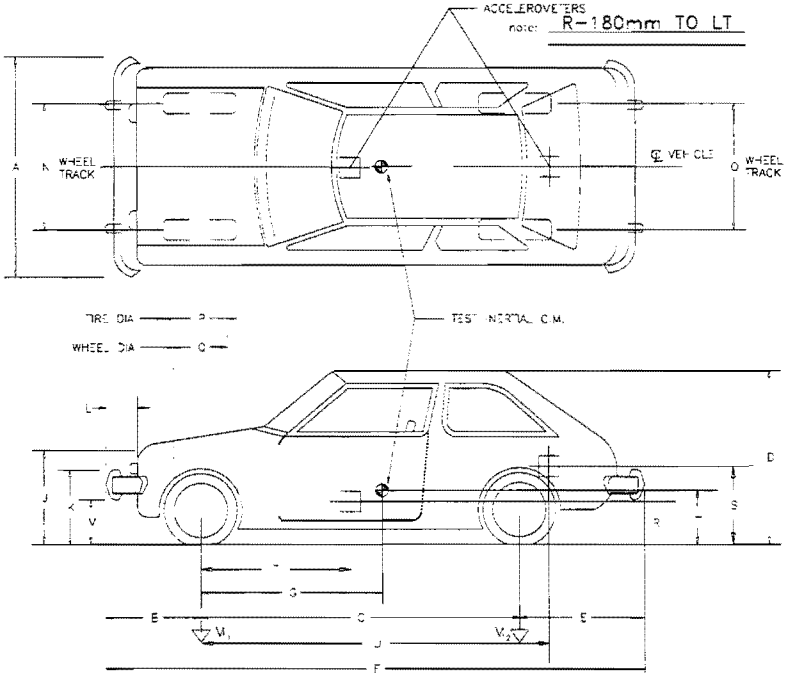
TIRE INFLATION PRESSURE: _____

1st Use: ___ 2nd or More Use: X Minor Damage Changed to Project: _____

MASS DISTRIBUTION (kg) LF: _____ RF: 251 LR: 169 RR: 131

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

DENT IN ROOF (MARKED)



ENGINE TYPE: 4 CYL.

ENGINE CID: 1.3L

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 75 kg

SEAT POSITION: Driver

GEOMETRY - (mm)

A	520	E	540	L	770	N	1380	R	400
B	640	F	3480	K	560	O	1395	S	500
C	2300	G	841.5	-	125	P	540	T	890
D	1400	H		V	410	Q	330	U	2400

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	539	520	561
M_2	289	300	334
M_-	828	820	895

Figure 72. Vehicle Properties for Test 414038-1

REFERENCES

1. T. R. Guidry and W. L. Beason, "Development of a Low-Profile Portable Concrete Barrier," Final Report No. 990-4F, Texas Department of Highways and Public Transportation, November 1991.

2. W. Lynn Beason, "Development of an End Treatment For a Low-Profile Concrete Barrier," Final Report No. 1949-2, Texas Department of Transportation, November 1992.

3. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer, and J. D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Features," NCHRP Report 350, Transportation Research Board, Washington, D.C., 1993.

4. American Association of State Highway and Transportation Officials (AASHTO), A Policy on Geometric Design of Highways and Streets, AASHTO, Washington, D.C., 1990.

5. J. D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230, Transportation Research Board, Washington, D.C., 1980.

6. Don L. Ivey, Dean C. Alberson, and Wanda L. Menges, "NCHRP Report 350 Compliance Tests of the ADIEM," Research Study 220517 and 220538, Texas Transportation Institute, The Texas A&M University System, College Station, Texas, December 1995.