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16. Abstract

An end treatment was developed in this project for a previously developed low-profile portable concrete median barrier. Together, the new end treatment and the low-profile barrier provide a new barrier system for use in low-speed (45 mph [73 km/h] or less) work zones. The end of the new end treatment has a minimum height of 4 in. (10.2 cm) which transitions into a maximum height of 20 in. (50.8 cm) in a distance of 20 ft (6.1 m). The 20 in. (50.8 cm) end of the end treatment connects to the previously developed 20 in (50.8 cm) low-profile barrier. The overall length of the new end treatment is 20 ft (6.1 m). The primary advantage of the new low-profile barrier system is that the 20 in (50.8 cm) height of the system is much less than the traditional concrete barrier height of 32 in. (81.3 cm). This reduced height of the new low-profile barrier system provides enhanced driver visibility. The enhanced visibility should provide drivers with safer conditions and should help to reduce the number of accidents in highway work zones. The performance of the new low-profile end treatment was demonstrated through a series of three 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 new end treatment is recommended for immediate implementation in low speed work zones.

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DEVELOPMENT OF AN END TREATMENT FOR A LOW-PROFILE CONCRETE BARRIER

by

W. Lynn Beason

with contributions by

M. L. Marek, H. E. Ross, Jr., D. L. Ivey, and W. L. Menges

Research Report No.

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Sponsored by
Texas Department of Transportation

November 1992

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in^2	square inches	645.2	centimetres squared	cm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

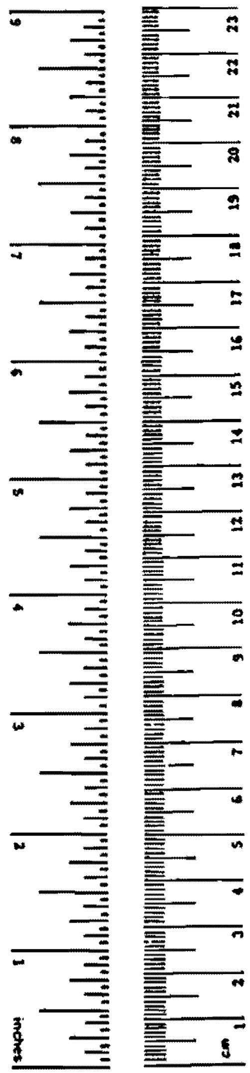
Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
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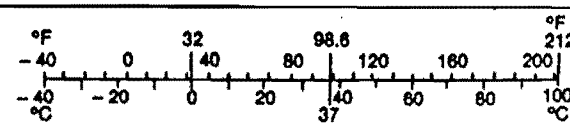

These factors conform to the requirement of FHWA Order 5190.1A.

SUMMARY

This report covers a six-month study to develop and test an end treatment for the recently developed low-profile portable concrete barrier. This study was conducted for the Texas Department of Transportation.

SUMMARY STATEMENT ON RESEARCH IMPLEMENTATION

A new low-profile end treatment has been developed and subjected to full-scale crash tests.

It is recommended that the low-profile barrier system which involves the previously developed low-profile portable concrete barrier and the newly developed low-profile end treatment be considered ready for immediate implementation in low-speed work zones.

DISCLAIMER

KEY WORDS

Concrete Median Barrier, End Treatment, Portable Concrete Barrier, Crash Test(s), Construction, Safety.

ACKNOWLEDGMENTS

This research study was conducted under the sponsorship of the Texas Department of Transportation. Messrs. Mark Marek and Gary Humes of TxDOT worked closely with the researchers. In addition, the efforts of Hayes E. Ross, Jr., Don L. Ivey, and Kenneth Scheffler helped to make this research possible. Their comments, suggestions, and cooperative spirits were appreciated.

DEVELOPMENT OF AN END TREATMENT FOR A LOW-PROFILE CONCRETE BARRIER

ABSTRACT

An end treatment was developed in this project for a previously developed low-profile portable concrete median barrier. Together, the new end treatment and the low-profile barrier provide a new barrier system for use in low-speed (45 mph [73 km/h] or less) work zones. The end of the new end treatment has a minimum height of 4 in. (10.2 cm) which transitions into a maximum height of 20 in. (50.8 cm) in a distance of 20 ft (6.1 m). The 20 in. (50.8 cm) end of the end treatment connects to the previously developed 20 in. (50.8 cm) low-profile barrier. The overall length of the new end treatment is 20 ft (6.1 m). The primary advantage of the new low-profile barrier system is that the 20 in (50.8 cm) height of the system is much less than the traditional concrete barrier height of 32 in. (81.3 cm). This reduced height of the new low-profile barrier system provides enhanced driver visibility. The enhanced visibility should provide drivers with safer conditions and should help to reduce the number of accidents in highway work zones. The performance of the new low-profile end treatment was demonstrated through a series of three 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 new end treatment is recommended for immediate implementation in low speed work zones.

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INTRODUCTION

A new low-profile portable concrete barrier (PCB) has been recently developed by researchers at the Texas Transportation Institute (TTI) in cooperation with engineers of the Texas Department of Transportation (TxDOT). The low-profile PCB is a 20 in. (51 cm) tall longitudinal barrier which is produced in 20 ft (6.1 m) segments. The primary advantage of the low-profile PCB is that it provides a reasonable amount of redirective capability for low speed applications while greatly enhancing work zone visibility when compared to 32 in. (81 cm) tall barriers (1).

The low-profile PCB has been shown to be an effective longitudinal barrier for low-speed work zone applications. This was demonstrated through the results of two full-scale crash tests. Based on these test results, the low-profile PCB was recommended for immediate use in low-speed (less than or equal to 45 mph [73 km/h]) applications (1).

The 20 in. (51 cm) high low-profile PCB provides a useful alternative to the 32 in. (81 cm) high New Jersey safety shape. However, the usefulness of the low-profile PCB has been limited by the lack of a low-profile end treatment. While there are several standard longitudinal barrier end treatments which could be adapted for use with the low-profile PCB, most of these end treatments were developed for use with 32 in. (81 cm) high barriers and are much taller than the low-profile barrier. Hence, the use of conventional end treatments would introduce visual obstructions which would defeat the purpose of the low-profile PCB. Therefore, there is a need for the development of a new low-profile end treatment.

The remainder of this report is divided into four major sections. The next section presents a brief review of the low-profile PCB. This is followed by a section which presents the development of the low-profile end treatment. The next section presents a discussion of the results of three full-scale crash tests which are used to document the performance of the new low-profile end treatment. The final section of this report presents a discussion of the results and major conclusions.

REVIEW OF LOW-PROFILE PCB

There are many urban and other low-speed work zones where the longitudinal barrier which 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 which incorporates such an interruption. The problem is that the height of the longitudinal barrier often obscures a clear view of oncoming vehicles from the driver of the cross-traffic vehicle. If this happens, the cross-traffic vehicle may enter the roadway and become involved in an accident with the oncoming vehicle. This is particularly a problem at night when the only visual cues apparent to the driver of the cross-traffic vehicle are those provided with by the headlights of the oncoming vehicle.

Examinations of vehicular geometrics show that the distance from the roadway to the center of the headlight height is at least 24 in. (61 cm) (1). This minimum headlight height is suggested by AASHTO (2) and its implementation has been confirmed by a limited survey conducted by TTI researchers (1).

If the cross-traffic driver is to have an unobstructed view of the oncoming vehicle headlights in a night-time situation, the barrier height cannot be greater than the headlight height. Therefore, the maximum height of the low-profile PCB is 24 in. (61 cm). If the low-profile PCB is located on a flat area, a constant slope, or a sagging vertical curve, it can be shown that a 24 in. (61 cm) barrier height provides unlimited visibility. However, if the low-profile PCB is located on a cresting vertical curve, the sight distance can be limited by even a 24 in. (61 cm) barrier. The degree of limitation depends upon the particular geometric conditions.

Based on the above discussion, it is clear that a normal barrier height of 32 in. (81 cm) will result in a significant visual obstruction for the cross-traffic vehicle driver. Further, it is clear that the maximum allowable barrier height is 24 in. (61 cm). Based on a detailed geometric analysis, it was concluded by TTI researchers and TxDOT engineers that a barrier height of 20 in. (51 cm) is reasonable for the low-profile PCB (1).

The low-profile PCB cross section developed in the previous project is shown in Figure 2. Figure 2 also incorporates the cross section of the popular 32 in. (81 cm) New Jersey safety shape for comparison purposes. The height of the low-profile PCB is 20 in. (51 cm). The width of the PCB at the top of the barrier is 28 in. (71 cm) and the width at the bottom is 26

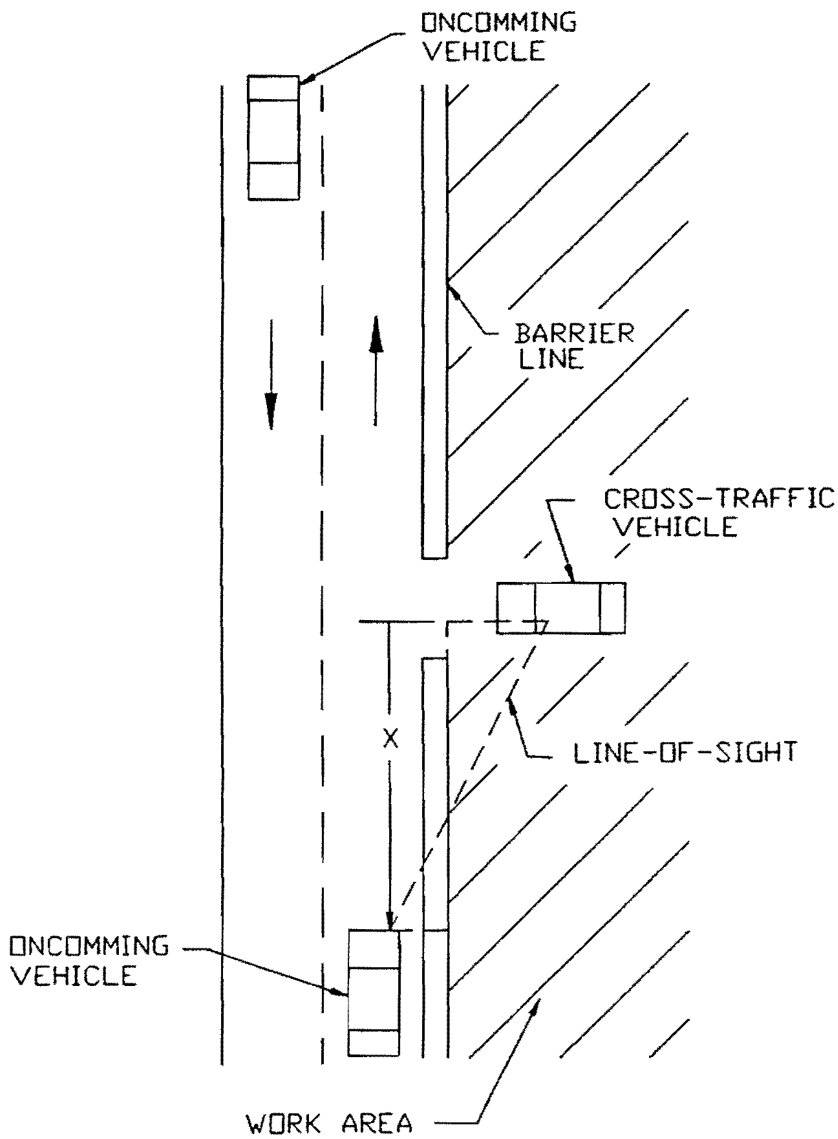


Figure 1. Geometry of sight-distance problem.

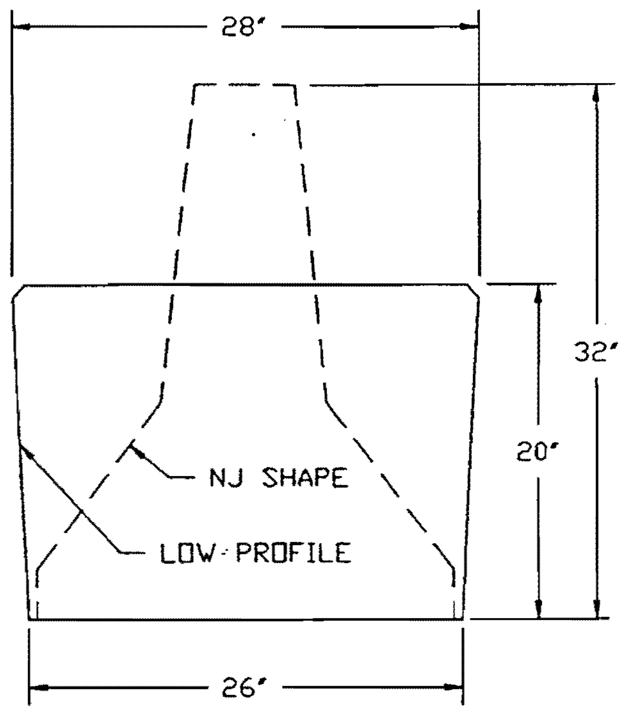


Figure 2. Cross-section of low-profile PCB.

in. (66 cm). 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 the vehicle to rise during an impact. Hence, the stability of the impacting vehicle is enhanced.

The low-profile PCB segments are fabricated in 20 ft (6.1 m) segments. Each segment weighs approximately 11,000 lb (5,000 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 holes. The trough is utilized to gain access to the connection holes. Then 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 force 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 barrier system which limits lateral displacements during impact.

The low-profile PCB was subjected to two full-scale crash tests to evaluate its performance. The first test involved a 4,500 lb (2043 kg) 3/4 ton pickup which impacted the low-profile PCB with a speed of 45 mph (73 km/h) and an angle of 25 degrees. The purpose of this test was to evaluate the ability of the system to redirect a full-size vehicle. The second test involved an 1,800 lb (817 kg) compact car which impacted the low-profile PCB with a speed of 45 mph (73 km/h) and an angle of 20 degrees. These conditions were selected to represent a relatively severe set of impact conditions for low-speed applications.

In both full-scale crash tests, the vehicles were smoothly redirected. The largest lateral deflection of the low-profile PCB was 5 in. (12.7 cm) resulting from the 3/4 ton pickup impact. There was no measurable deflection as a result of the compact car impact. All tests results fell within acceptable limits of occupant and vehicle accelerations according to NCHRP 230 (3). Based on these results, the low-profile PCB was recommended for immediate implementation. Complete details of the barrier fabrication and testing of the low-profile PCB are presented elsewhere (1).

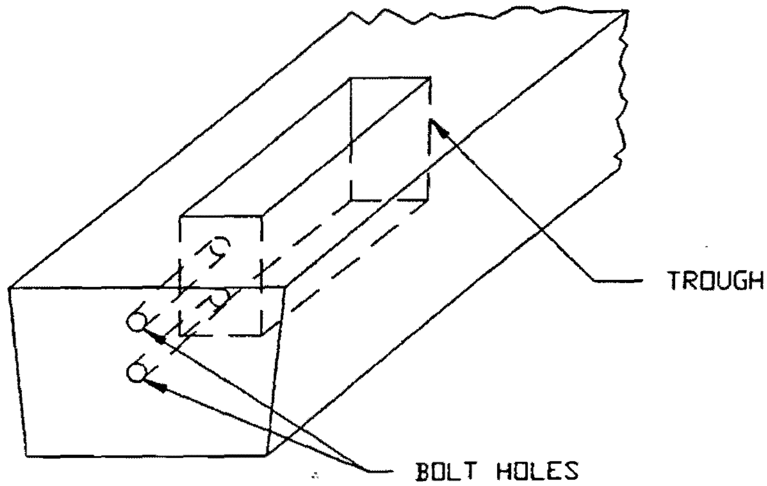


Figure 3. Low-profile PCB connection.

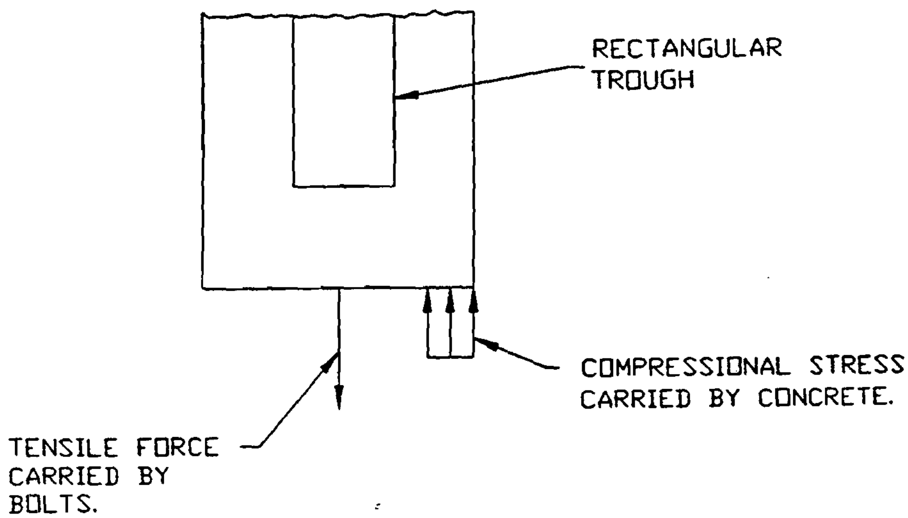


Figure 4. Loading on PCB connection.

LOW-PROFILE END TREATMENT

As stated in the previous section, a new low-profile PCB has been successfully developed for use in low-speed (45 mph [73 km/h] or less) work zones. The purpose of the research discussed in this report was to develop a low-profile end treatment which is compatible with the low-profile PCB. The new low-profile end treatment should be capable of redirecting a reasonable range of low-speed vehicles without reducing work zone visibility. This section presents the development of the low-profile end treatment. This section is divided into two parts. The first part presents general discussions relating to the various types of end treatments which were considered for development. The second part presents discussions relating to the final development of the low-profile end treatment.

A Review of Available End Treatments

There are three types of low-profile barrier end treatments which were given initial consideration: blunt end, sloped end, and energy-absorbing end treatments. Most conventional end treatments can be placed into one of these three categories.

A blunt end treatment would be formed by simply truncating the barrier system with a typical low-profile PCB segment. The primary advantage of the blunt end treatment is that the redirective capability of the system would remain uniform throughout its length, provided that the blunt end is properly anchored. In addition, the blunt end would minimize the logistics and costs associated with the use of the system because only one type of barrier segment would have to be manufactured and stockpiled.

The major problem associated with the use of the blunt end treatment is that an end-on impact would result in extreme vehicular accelerations. While this impact would be severe, it probably would not be as severe as an end-on impact with the blunt end of a 32 in. (81 cm) barrier because the low-profile PCB is much shorter. The only realistic use of the blunt end treatment probably involves a flaring of the blunt end treatment away from the roadway so that the probability of an end-on impact is greatly minimized. There may be some applications where flaring the low-profile PCB would provide a desirable end treatment.

The sloped low-profile end treatment is used extensively with 32 in. (81 cm) conventional barrier systems. While there are many variations of the sloped end treatment, the most direct application to the current problem would involve an end treatment with its height varying linearly from a minimum of 4 to 6 in. (10 to 15 cm) at the impact end to a full height of 20 in. (51 cm) where the low-profile end treatment connects with the low-profile PCB.

A sloped end treatment would be clearly superior to the blunt end treatment for end-on impacts because the vehicle would not be brought to a sudden stop. Instead, the vehicle would be allowed to skid down the top of the barrier until it came to rest or is bounced off of the barrier.

The major problem with a sloped end treatment is that it might cause an errant vehicle to be launched or rolled over. The tendency for a sloped end treatment to cause this problem depends upon the vehicle type, impact speed, and impact angle, as well as the geometry of the end treatment.

Simplified analyses of the constant slope low-profile end treatment suggest that it probably would not be as prone to the launch/roll problem as is the 32 in. (81 cm) conventional sloped end treatments. This is the case because the longitudinal slope of the low-profile end treatment should be less than the slope associated with conventional sloped end treatments because of the differences in height. This means that both the vertical accelerations and vertical velocities induced in the impacting vehicle will be less severe with a low-profile end treatment. Further, it is the opinion of the writer that the positive slope on the impact face of conventional sloped end treatments greatly enhances the propensity of an impacting vehicle to vault or be launched. However, as stated in the previous section, the impact surface of the low-profile PCB is negative. The negative slope on the low-profile PCB greatly reduces the tendency for impacting vehicles to vault or launch. Therefore, it is to be expected that a low-profile sloped end treatment, which incorporates a negative impact face slope, should perform better than conventional sloped end treatments.

The third type of end treatment that was considered is the energy-absorbing end treatment. The primary advantage of an energy-absorbing end treatment over a sloped end treatment is in its response to end-on impacts. A properly designed energy-absorbing end treatment will bring the vehicle to a controlled stop in a specified distance instead of allowing the vehicle to continue slide along the top of the barrier as it would with a sloped end treatment. The vehicle must be brought to a stop in a distance which is sufficient to result in acceptably low vehicle accelerations. It is anticipated that the performance of an energy-absorbing end treatment for impacts other than end-on impacts would be comparable to the performance of a sloped end treatment.

There are many different conventional energy-absorbing end treatments which could serve as models for the low-profile end treatment. Most of the available energy-absorbing end treatments could be modified for use with the low-profile PCB. However, in most cases the resulting end treatment would be more expensive than the sloped end treatment.

Development of Low-Profile End Treatment

The design constraints associated with the development of the new low-profile end treatment were as follows. First, it was determined that the maximum height of the low-profile end treatment should be less than or equal to the height of the low-profile PCB so that unnecessary visual restrictions would not be introduced by the end treatment. The second constraint was that the redirective capability of the low-profile end treatment should be consistent with the redirective capability of the existing low-profile PCB, i.e., the low-profile PCB was designed for 45 mph (73 km/h) impacts so the low-profile end treatment should be designed for 45 mph (73 km/h) impacts. As with the low-profile PCB, the impact conditions selected for the testing are based on fundamental criteria presented in NCHRP 230 (and projections of criteria for the update to NCHRP 230) with appropriate modifications to account for the low-speed work zone application (3). Finally, it was required that the low-profile end treatment should be as affordable as possible because it is anticipated that a relatively high percentage of end treatments will be required in most low-speed work zone applications. These design constraints were established by TTI researchers in coordination with TxDOT engineers.

As discussed above, three different types of end treatments were considered in this project: blunt ends, sloped ends, and energy-absorbing ends. Each of these types of end treatments was examined from a practical point of view as discussed in the previous section and a cost benefit analysis was conducted.

The vehicle barrier interaction was not studied using vehicle impact simulation programs because it is believed by the writer that the state-of-the-art in vehicle simulation technology is not adequate to critically model the subtle differences in the performance of the various concepts. Therefore, as with many advances in longitudinal barrier technology, engineering judgment and simplified analyses were used to evaluate the performance of the various concepts which were considered for development.

A panel was formed to evaluate the evidence relating to the selection of the best low-profile end treatment. This panel included both TTI researchers and TxDOT engineers. The combined judgment of the panel was that, with the exception of the blunt end, all of the concepts considered could developed into viable low-profile end treatments. Further, this panel determined that the primary difference between a sloped end treatment and an energy absorbing end treatment is that latter will bring an errant vehicle to a controlled stop in a relatively short distance while the former will allow the forward motion of an impacting vehicle to continue. It was the collective judgment of the panel that it is not necessary to bring the errant vehicle to controlled stop in a short distance. Therefore, either end treatment could be developed. The next criteria that was evaluated was cost. It is clear that a sloped end treatment presents the least costly option. Therefore, the panel decided that a constant slope low-profile end treatment would be developed for use with the low-profile PCB.

Once the decision was made to develop a constant slope low-profile end treatment, the basic geometrics followed from the physical constraints of the system. It was decided that the end treatment would be constructed with the same 20 ft (6.1 m) length as a typical low-profile PCB segment. Further, the panel decided to incorporate the same bolted connection as is used in the low-profile PCB to connect the low-profile end treatment to the rest of the low-profile PCB. Therefore, it was decided to make the details of the first 5 ft (1.5 m) of the end treatment identical to a typical low-profile PCB segment. The height of the end treatment was then reduced linearly to 4 in. (10 cm) at the impact end. In addition to reducing the height in the last 15 ft (4.6 m) of the end treatment, the widths of the barrier top and barrier bottom were tapered symmetrically to 14 3/8 in. (36.5 cm) and 14 in. (35.6 cm) respectively. The low-profile end treatment geometry is presented in Figure 5. The low-profile end treatment was reinforced appropriately so that the flexural capacity throughout the length of the end treatment would be sufficient to prevent major cracking during transport and handling. In addition, it was decided to preserve the constant negative slope of the impact face (1:20) throughout the length of the end treatment to help control the propensity of impacting vehicles to rise. The lateral deflections of the end treatment are controlled by anchoring the end treatment to the pavement with steel pins which are inserted through precast holes in the end treatment at 24 in. (61 cm) intervals from the end of the end treatment as shown in Figure 5. Complete fabrication details of the constant slope low-profile end treatment are presented in Appendix A.

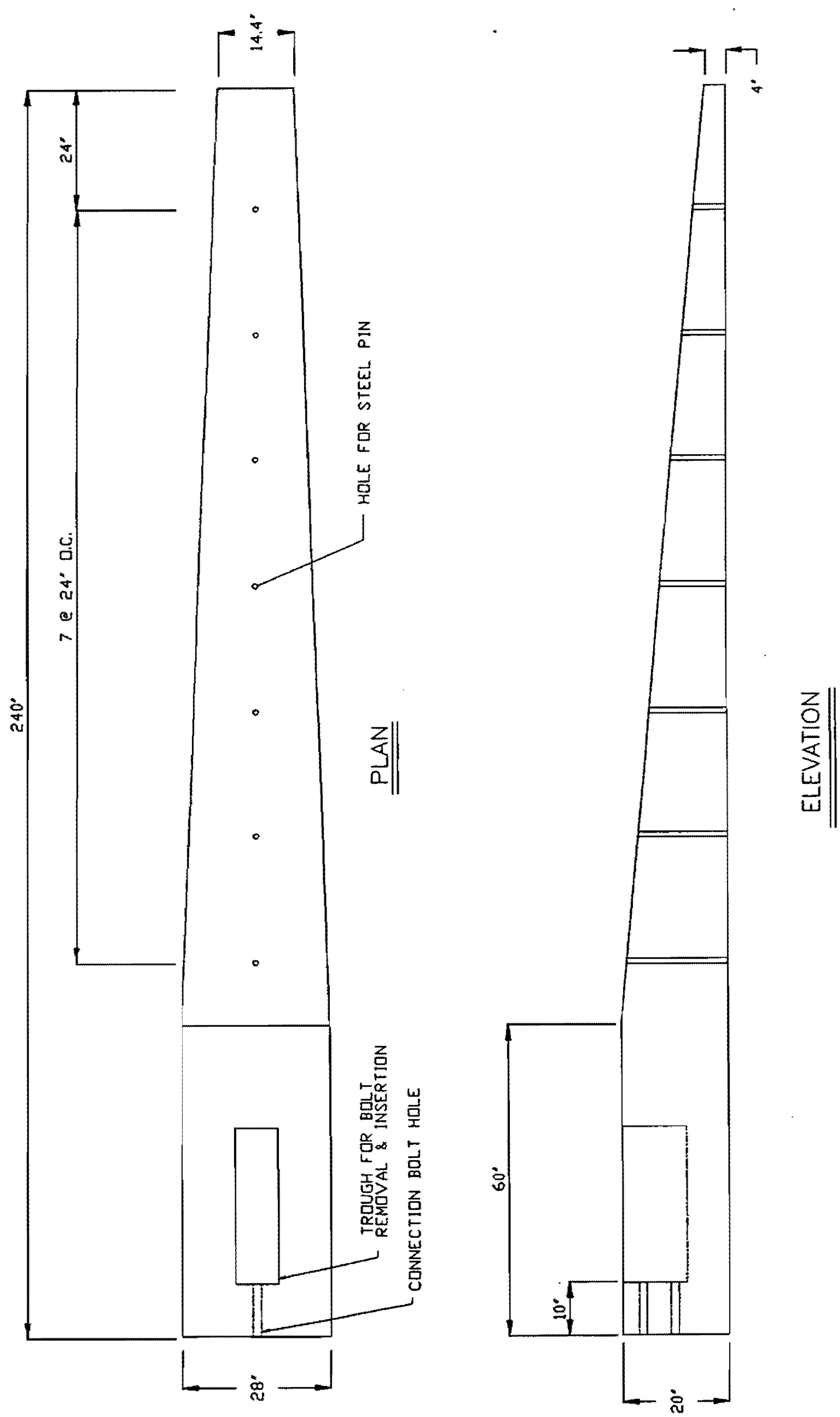


Figure 5. Geometry of low-profile end treatment.

FULL-SCALE CRASH TESTS

Three full-scale crash tests were conducted on the constant slope low-profile end treatment to evaluate its performance relative to structural adequacy, occupant risk, and vehicle exit trajectory. The first test involved an 1,800 lb (817 kg) compact automobile which impacted the end treatment at a point 6.5 ft (2.0 m) from the end of the end treatment with an angle of 15 degrees. The second test involved an 1,800 lb (817 kg) compact automobile which 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. The third and final test involved a 4,500 lb (2,043 kg) 3/4 ton pickup which impacted the end treatment with an end-on impact such that the centerline of the vehicle was lined up with the centerline of the end treatment. These test criteria are consistent with or they are more stringent than impact criteria contained within NCHRP 230 with the exception that all impact speeds were adjusted downward to 45 mph (73 km/h) to reflect the use of the end treatment in low-speed work zones.

The tests were conducted using one constant slope low-profile end treatment which was connected to a low-profile PCB installation which 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 1 1/4 in. (3.2 cm) steel pins as indicated in Appendix A. The steel pins were dropped into predrilled 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 it for the next test.

Test statistics for the three crash tests are summarized in Table 1. Sequential photographs of the tests are presented in Appendix B. Accelerometer traces and plots of roll, pitch, and yaw are presented in Appendix C. The remainder of this section is devoted to detailed discussions of the individual crash tests.

Results of Test 1949A-1

In this test, a 1986 Yugo was directed into the low-profile end treatment. Figure 6 presents a view of the barrier prior to the impact. The vehicle prior to impact is shown in Figure 7 and 8. Test inertia mass of the vehicle was 1,800 lb (817 kg) and its gross static mass

TABLE 1. SUMMARY OF CRASH TEST RESULTS

Test No.	1949A-1	1949A-2	1949A-3
Vehicle Weight, lb (kg)	1,800 (817)	1,800 (817)	4,500 (2,043)
Impact Speed, mph (km/hr)	44.7 (71.9)	45.1 (72.6)	46.5 (74.8)
Impact Angle, degrees	16.3	0	0
Exit Angle, degrees	6.1	2	0
Displacement, in. (cm)	0	0	0
Occupant Impact Velocity, ft/s (m/s)			
Longitudinal	13.3 (4.1)	6.3 (1.9)	6.3 (1.9)
Lateral	18.0 (5.5)	0	1.4 (.4)
Occupant Ridedown Acceleration, g's			
Longitudinal	-1.9	-.6	4.1
Lateral	-4.5	0	2.1
Vehicle Damage Classification			
TAD	11LFQ1	N/A	N/A
CPC	11LFEW2	12FRWU1	00UDCU1

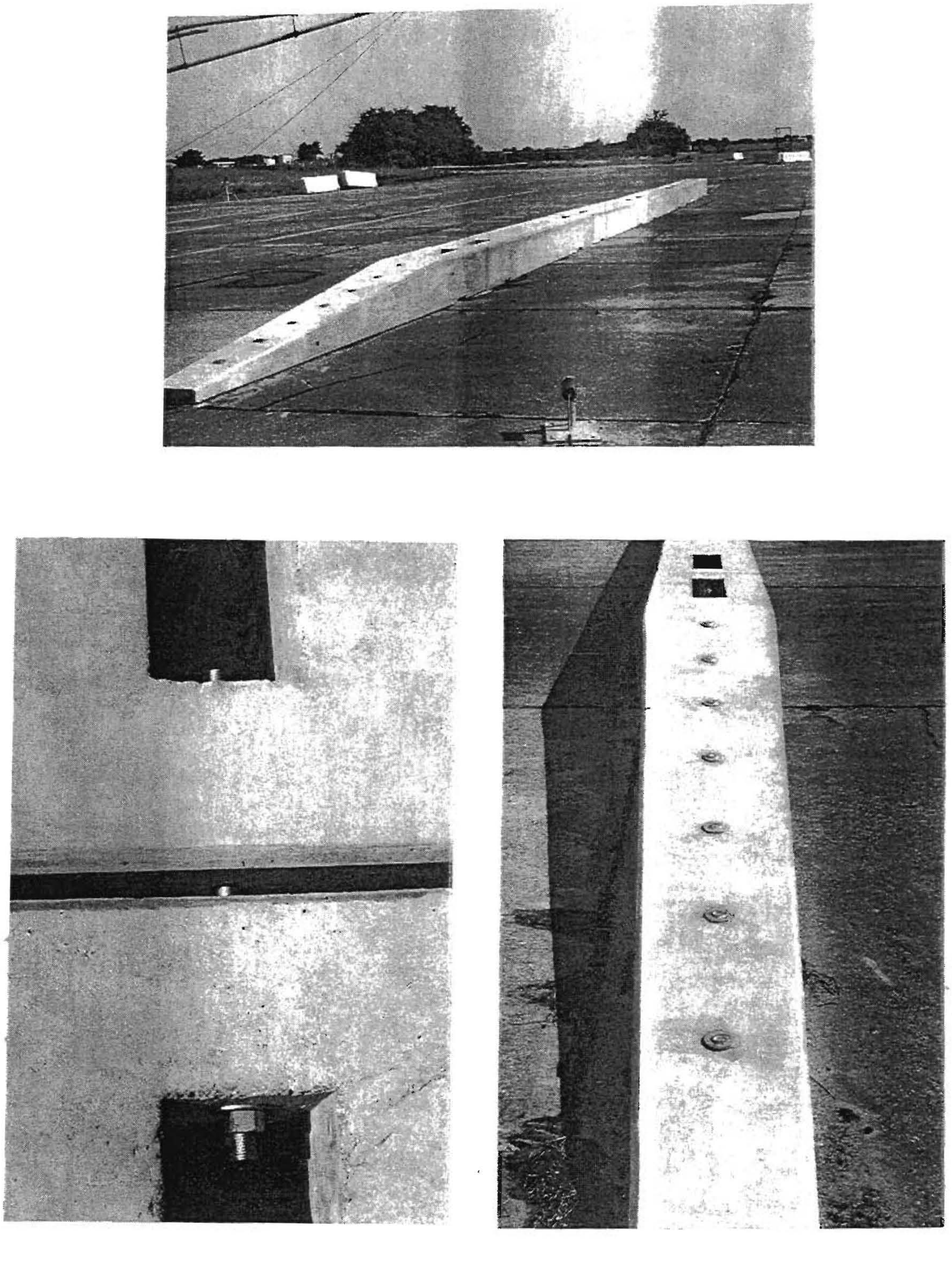


Figure 6. End treatment prior to Test 1949A-1.

Figure 7. Vehicle prior to Test 1949A-1.

Figure 8. Vehicle/end treatment geometrics for Test 1949A-1.

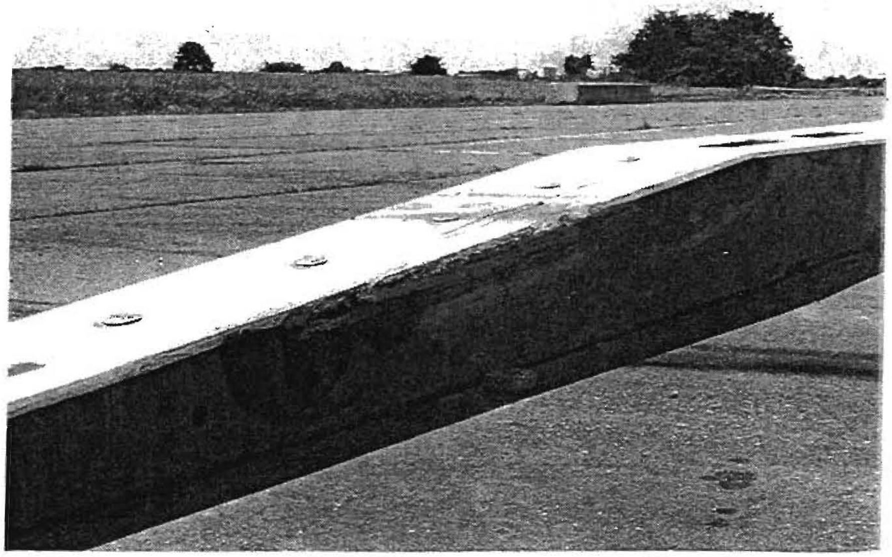
was 1,966 lb (893 kg). The height to the lower edge of the vehicle bumper was 13.0 in. (33.0 cm) and it was 18.5 in. (47.0 cm) to the top of the bumper. Additional dimensions and information pertaining to the test vehicle are given in Figure 43 in Appendix D. The vehicle was directed into the end treatment using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact.

The vehicle impacted the end treatment 6.5 ft (2.0 m) from the end at a speed of 44.7 mi/h (71.9 km/h). The angle of impact was 16.3 degrees. At 0.027 second after impact, the left wheel turned under and at 0.032 second the roof began to deform just over the door post location. The vehicle began to redirect at 0.050 second after impact and at 0.084 second, the dummy shattered the driver's side window. By 0.161 second, the vehicle was traveling parallel to the end treatment at a speed of 38.7 mi/h (62.3 km/h), and at 0.188 second the rear of the vehicle impacted the end treatment. The vehicle became airborne at 0.253 second and remained airborne as the vehicle lost contact with the end treatment at 0.389 second traveling at a speed of 37.4 mi/h (60.2 km/h) and with an exit angle of 6.1 degrees. The brakes were applied at 2.5 seconds after impact, the vehicle yawed counterclockwise and came to rest facing the installation 128 ft (39 m) downstream of the point of impact. Sequential photographs for this test are shown in Figures 25 and 26 in Appendix B.

As can be seen in Figure 9, the end treatment received minimal damage. There was cosmetic damage (i.e., tire marks) along the 9.8 ft (3.0 m) of the 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.

The vehicle sustained damage to the left side as shown in Figure 10. Maximum crush at the left front corner at bumper height was 5.0 in. (12.7 cm). The driver's door was deformed outward, the driver's side window was broken out, and the door was jammed. There was a 1.0 in. (2.5 cm) dent in the roof just above the door post 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 quarter panel, and the left front tire and rim.

Data from the accelerometer which was located near the center-of-gravity of the vehicle were digitized for evaluation and occupant risk factors were computed as follows. NCHRP 230 describes occupant risk evaluation criteria, and it places limits on these for acceptable performance for tests conducted with 1,800 lb (817 kg) vehicles (3). These limits do not apply



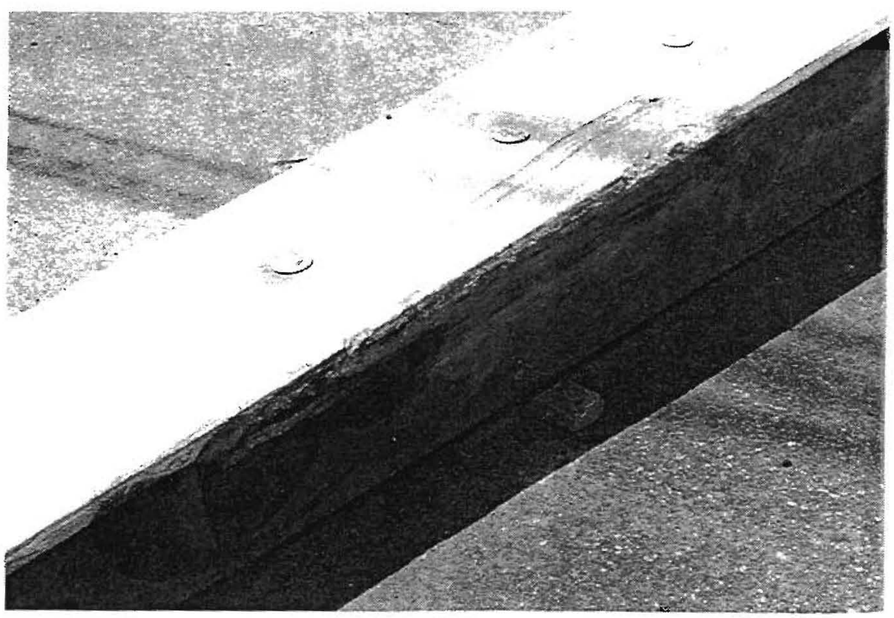
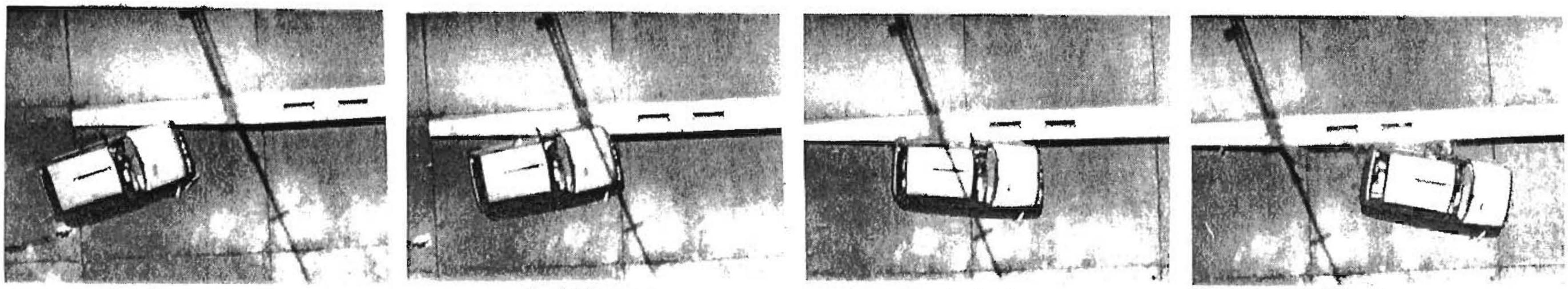


Figure 9. End treatment after Test 1949A-1.



Impact　　0.099 sec　　0.201 sec　　0.389 sec

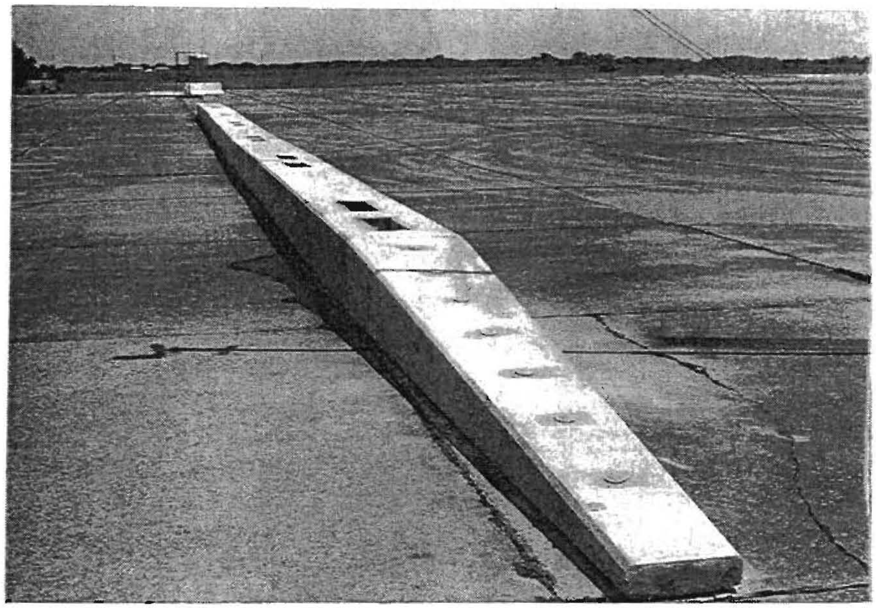
Test No. 1949A-1
Date 06/24/92

Test Article . . . . Constant Slope End Treatment

Test Vehicle . . . . 1986 Yugo
Vehicle Weight
  Test Inertia . . . . . . 1,800 lb (817 kg)
  Gross Static . . . . . . 1,966 lb (893 kg)
Vehicle Damage Classification
  TAD 11LFQ1
  CDC 11LFEW2
Maximum Vehicle Crush . . 5.0 in (12.7 cm)

Impact Speed . . . . 44.7 mi/h (71.9 km/h)
Impact Angle . . . . 16.3 degrees
Change in Velocity . . . 7.3 mi/h (11.7 km/h)
Change in Momentum . . . 599 lb-s (2,664 N-s)
Vehicle Accelerations
  (Max. 50 msec Average)
  Longitudinal . . . . . . -5.7 g
  Lateral . . . . -8.3 g
Occupant Impact Velocity
  Longitudinal . . . . . . 13.3 ft/s (4.1 m/s)
  Lateral . . . . 18.0 ft/s (5.5 m/s)
Occupant Ridedown Accelerations
  Longitudinal . . . . . . -1.9 g
  Lateral . . . . -4.5 g

Figure 11. Summary of results for Test 1949A-1.



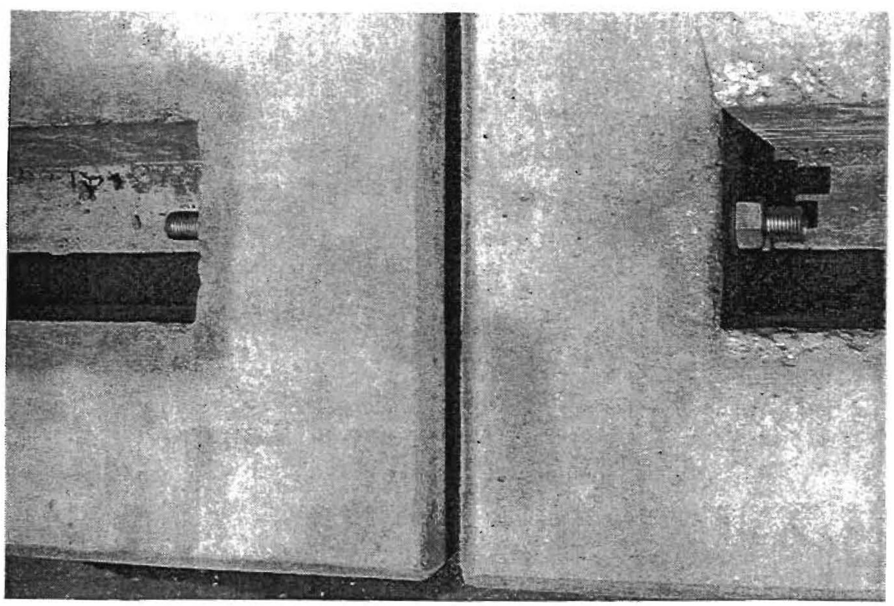


Figure 12. End treatment prior to Test 1949A-2.

Figure 13. Vehicle prior to Test 1949A-2.

Figure 14. Vehicle/end treatment geometrics for Test 1949A-2.

with the end treatment at 0.341 second. At 0.428 second, the vehicle reached a maximum roll angle of approximately 28 degrees. The tires touched down on top of the barrier at 0.457 second and immediately thereafter passed over the connection of the end treatment to the main body of the low-profile barrier traveling at a speed of 44.2 mi/h (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 second with the vehicle traveling at 40.6 mi/h (65.3 km/h). The exit angle was 2.0 degrees. The brakes were applied at 0.833 seconds after impact, the vehicle yawed clockwise and came to rest facing the end treatment 176 ft (54 m) downstream from the initial impact. Sequential photographs of the impact are shown in figures 27 and 28 in Appendix B.

As is shown in Figure 15, the end treatment received minimal damage. There was cosmetic damage (i.e., tire marks) and there was a hairline crack across the end treatment at the first bolt location on the end treatment (2.5 ft [0.8 m] from the end). There was no movement of the end treatment. The vehicle was in contact with the installation for 46.4 ft (14.1 m).

The vehicle sustained damage to the right front wheel as shown in Figure 16. 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 6 in. x 4 in. x 1/4 in. deep (15 cm x 10 cm x 0.6 cm) 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.

Data from the accelerometer located near the center-of-gravity were digitized for evaluation, and occupant risk factors were computed as follows. NCHRP 230 describes occupant risk evaluation criteria, and it places limits on these for acceptable performance for tests conducted with 1,800 lb (817 kg) vehicles (3). These limits do not apply to the set of impact conditions employed in this test but they were computed for information only. The occupant impact velocity was 6.3 ft/s (1.9 m/s) in the longitudinal direction and 0 ft/s (0 m/s) in the lateral direction because there was no occupant contact. The highest 0.010-second average ridedown accelerations were -0.6 g (longitudinal) and 0.0 g (lateral) because there was no occupant contact. These and other pertinent data from this test are presented in Figure 17.

Vehicular angular displacements are displayed in Figure 35 in Appendix C, and vehicular accelerations versus time traces filtered at SAE J211 (Class 180) are presented in Figures 36

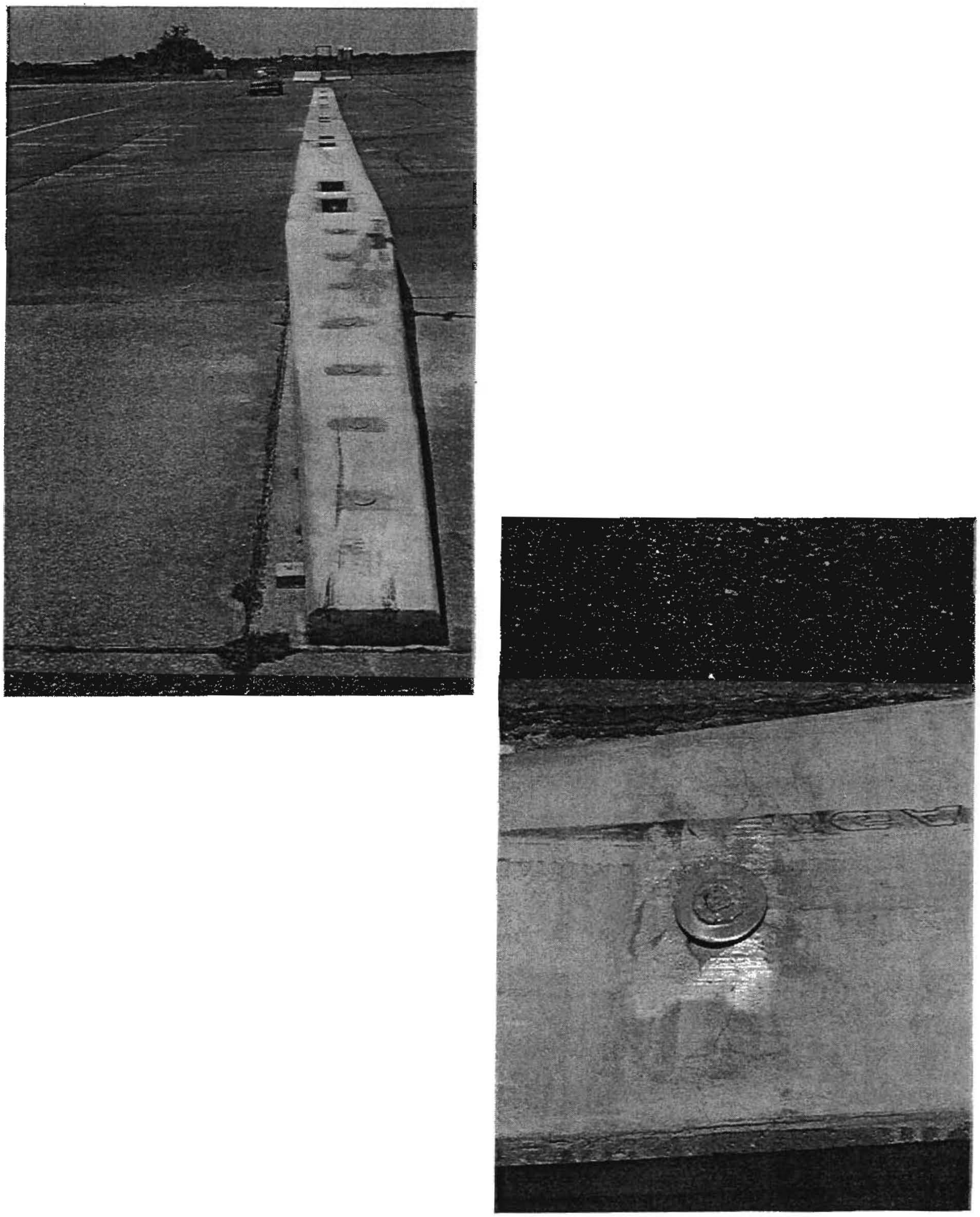


Figure 15. End treatment after Test 1949A-2.

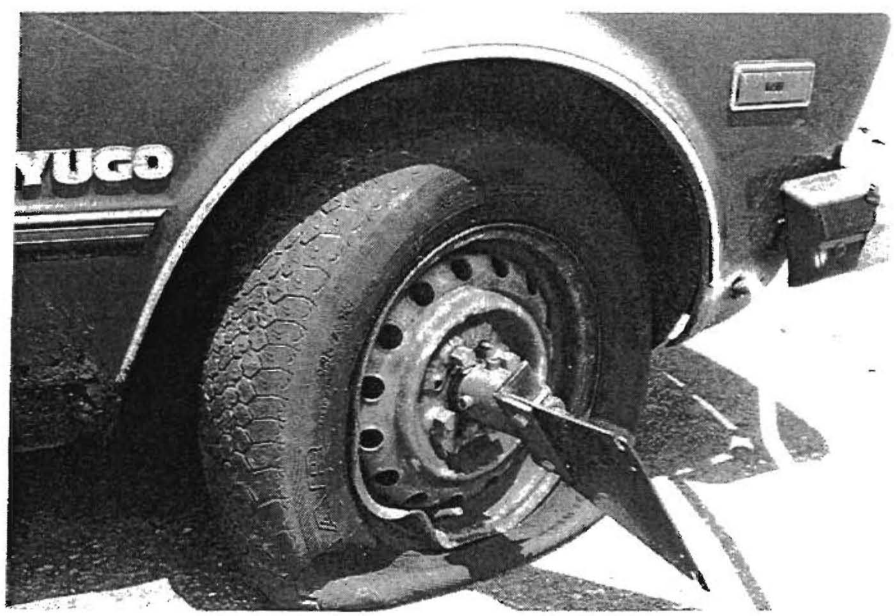
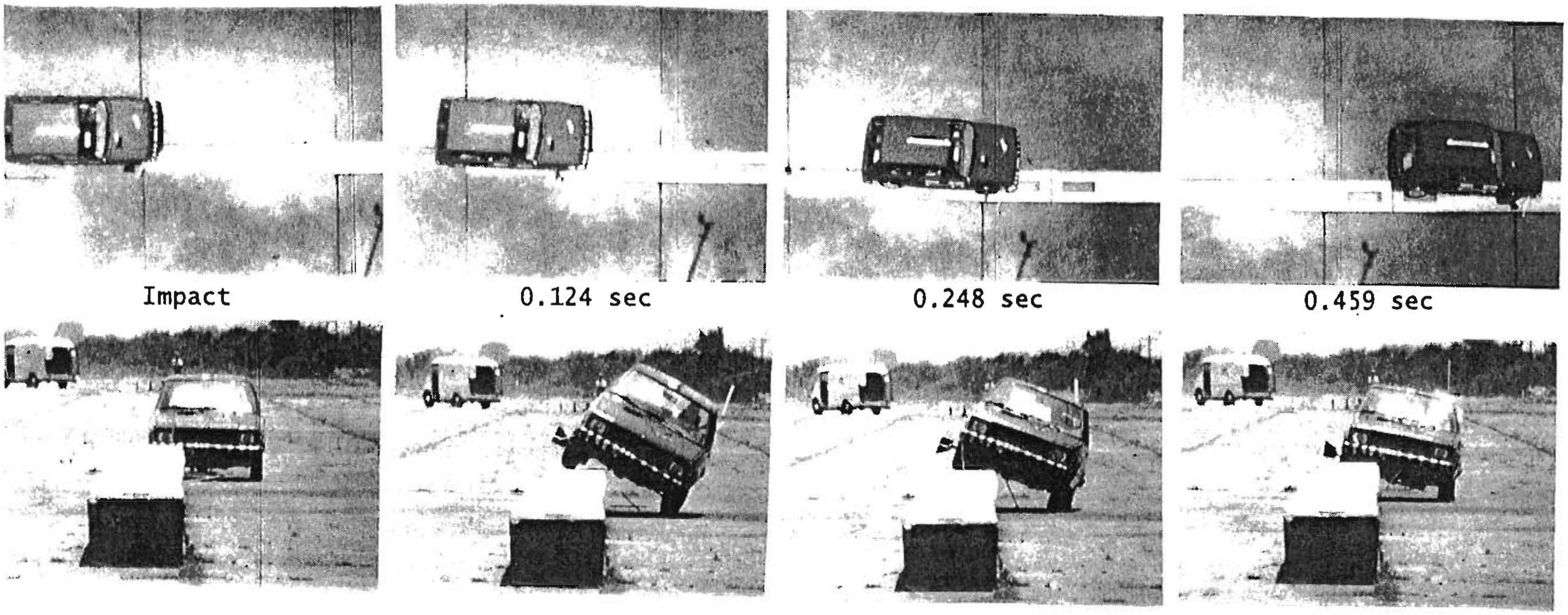


Figure 16. Vehicle after Test 1949A-2.



Test No. 1949A-2
Date 06/26/92

Test Article . . . . . . Constant Slope End Treatment

Test Vehicle . . . . . . 1988 Yugo GVL
Vehicle Weight
  Test Inertia . . . . . 1,800 lb (817 kg)
  Gross Static . . . . . 1,966 lb (893 kg)
Vehicle Damage Classification
  TAD . . . . N/A (wheel & tire)
  CDC 12FRWU1
Maximum Vehicle Crush . . 0.0 in (0.0 cm)

Impact Speed . . . . 45.1 mi/h (72.6 km/h)
Impact Angle . . . . 0 deg; right wheel end-on
Change in Velocity . . . 0.9 mi/h (1.4 km/h)
Change in Momentum . . . 74 lb-s (328 N-s)
Vehicle Accelerations
  (Max. 50 msec Average)
  Longitudinal . . . . . -0.6 g
  Lateral . . . . -1.0 g
Occupant Impact Velocity
  Longitudinal . . . . . 6.3 ft/s (1.9 m/s)
  Lateral . . . . No Occupant Contact
Occupant Ridedown Accelerations
  Longitudinal . . . . . -0.6 g
  Lateral . . . . No Contact

Figure 17. Summary of results for test 1949A-2.

Appendix A

FABRICATION DETAILS FOR THE LOW-PROFILE END TREATMENT

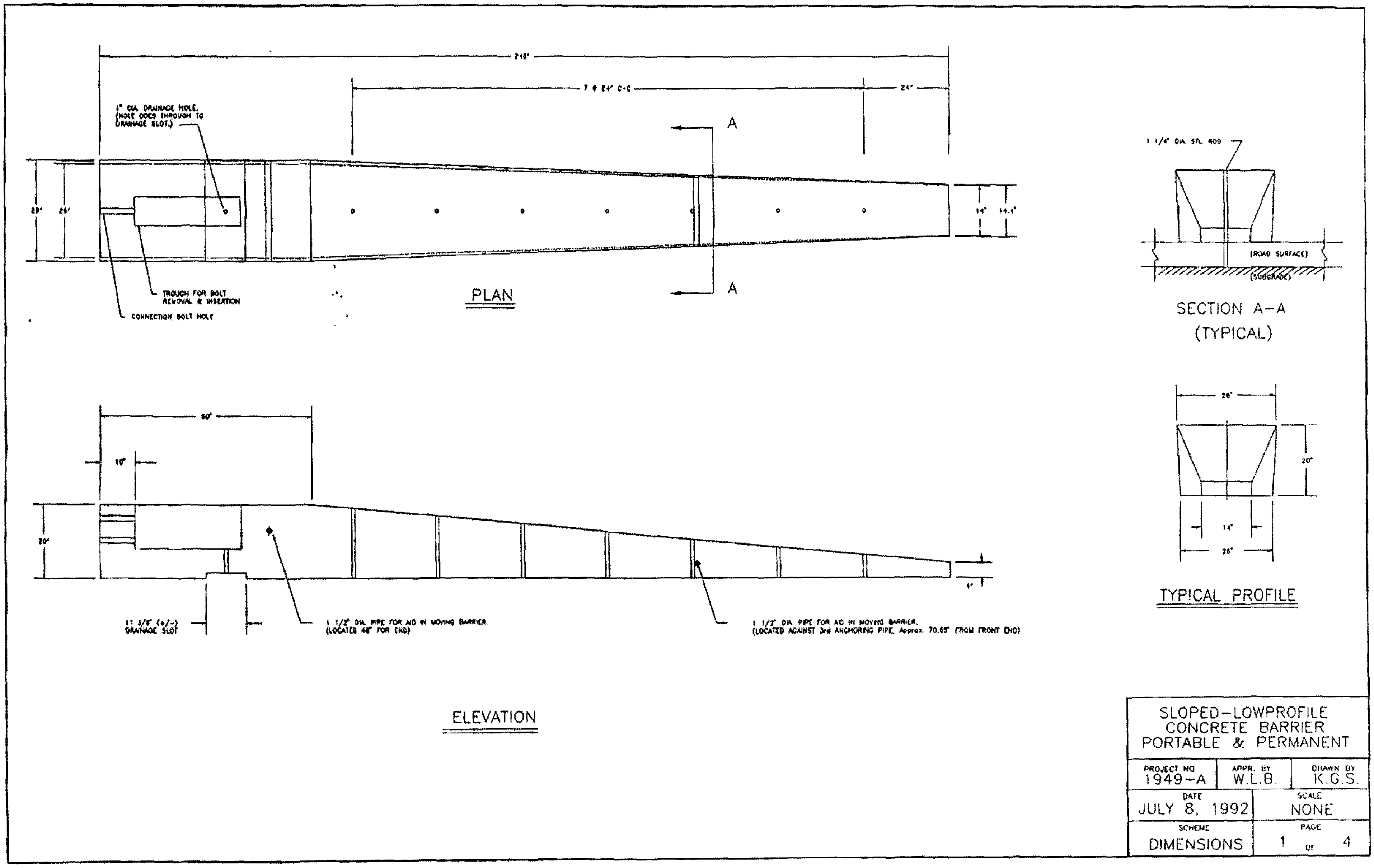


Figure 24. Fabrication details for low-profile end treatment.

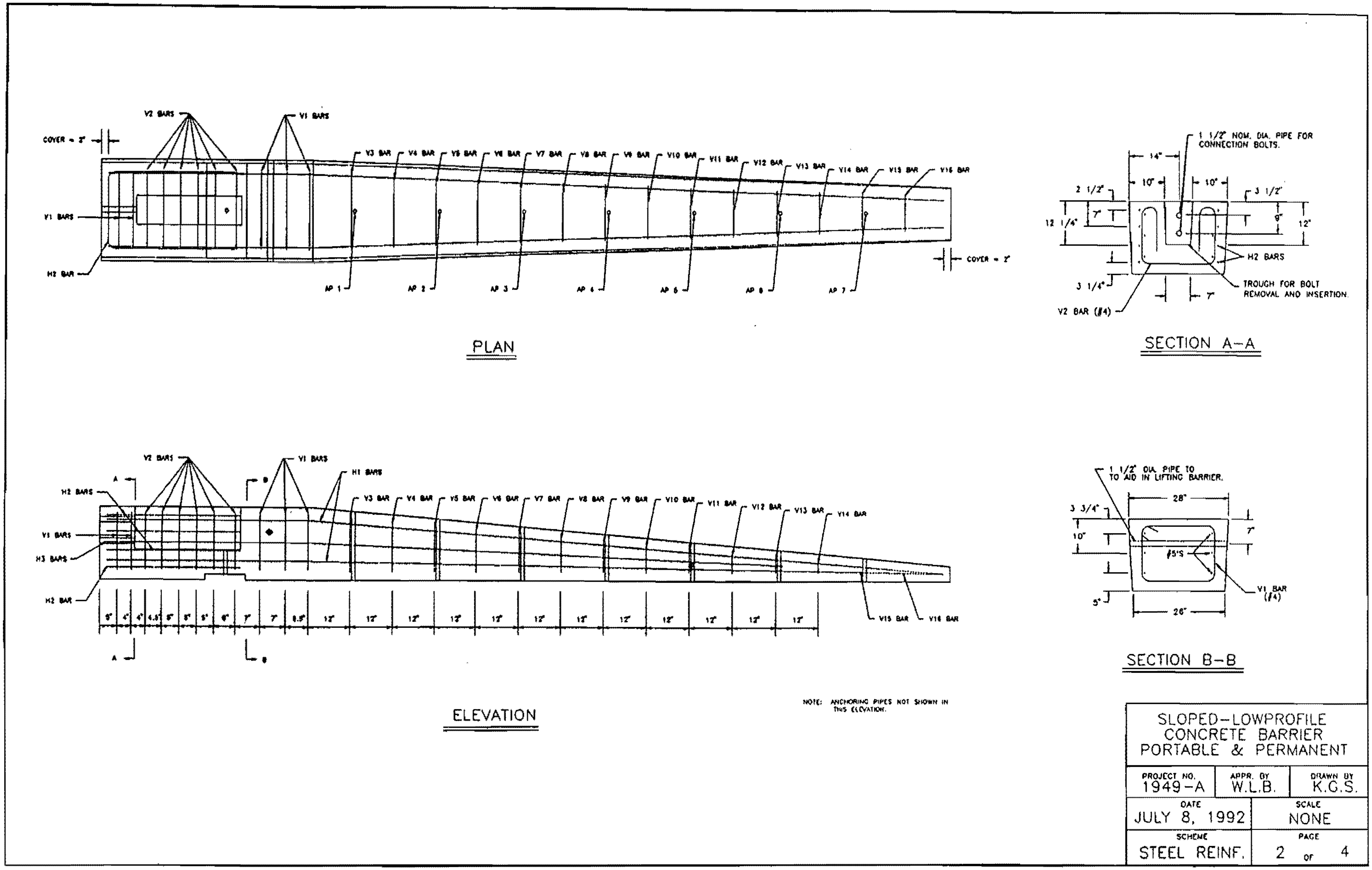


Figure 24. Fabrication details for low-profile end treatment (continued).

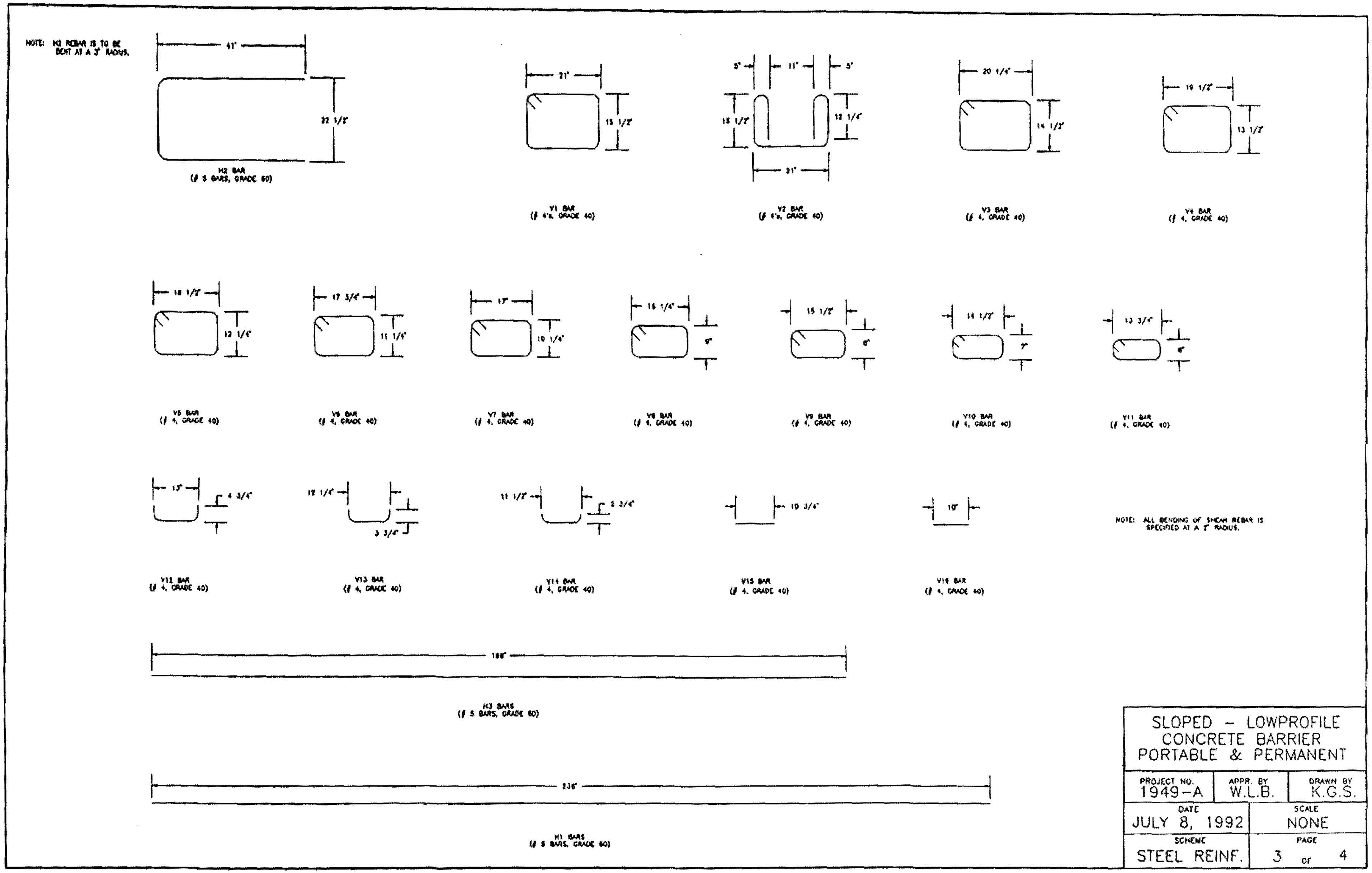


Figure 24. Fabrication details for low-profile end treatment (continued).

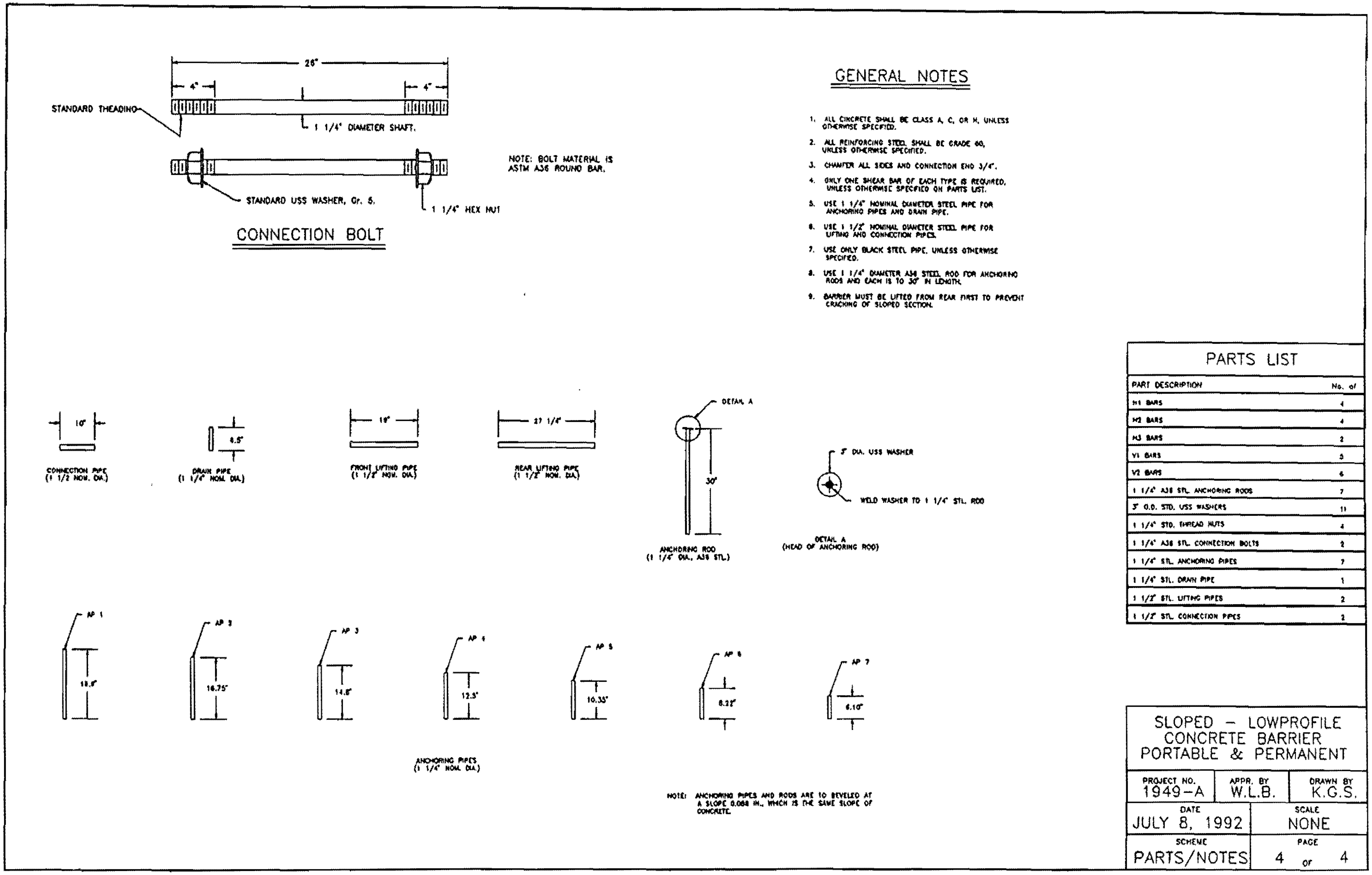
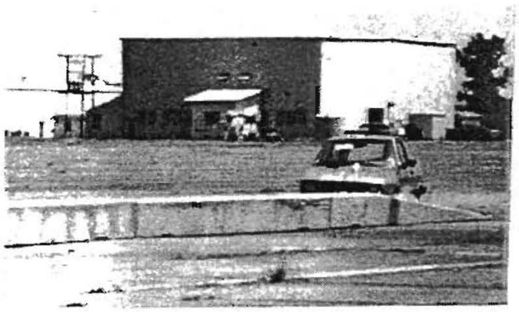


Figure 24. Fabrication details for low-profile end treatment (continued).

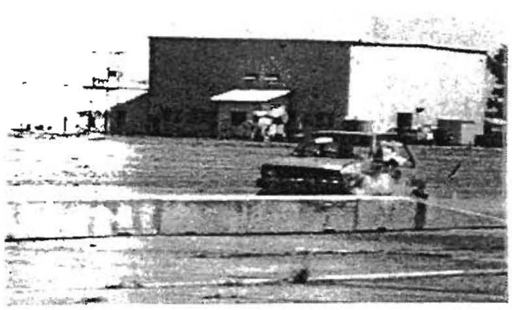
APPENDIX B
SEQUENTIAL PHOTOGRAPHS
OF CRASH TESTS

0.000 s

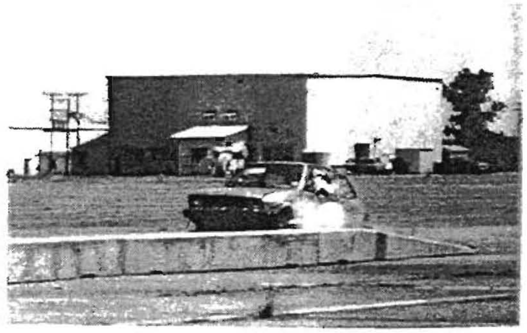


0.050 s

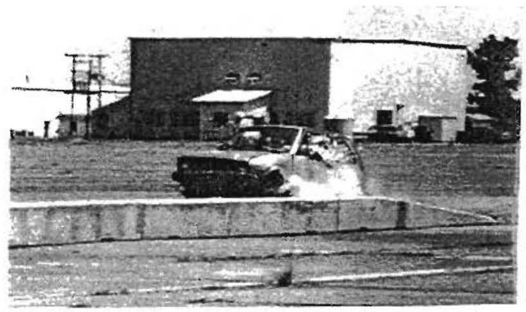
0.099 s



0.149 s



0.201 s



0.250 s

0.310 s

0.389 s

Figure 25. Sequential photographs for Test 1949A-1 (side view).

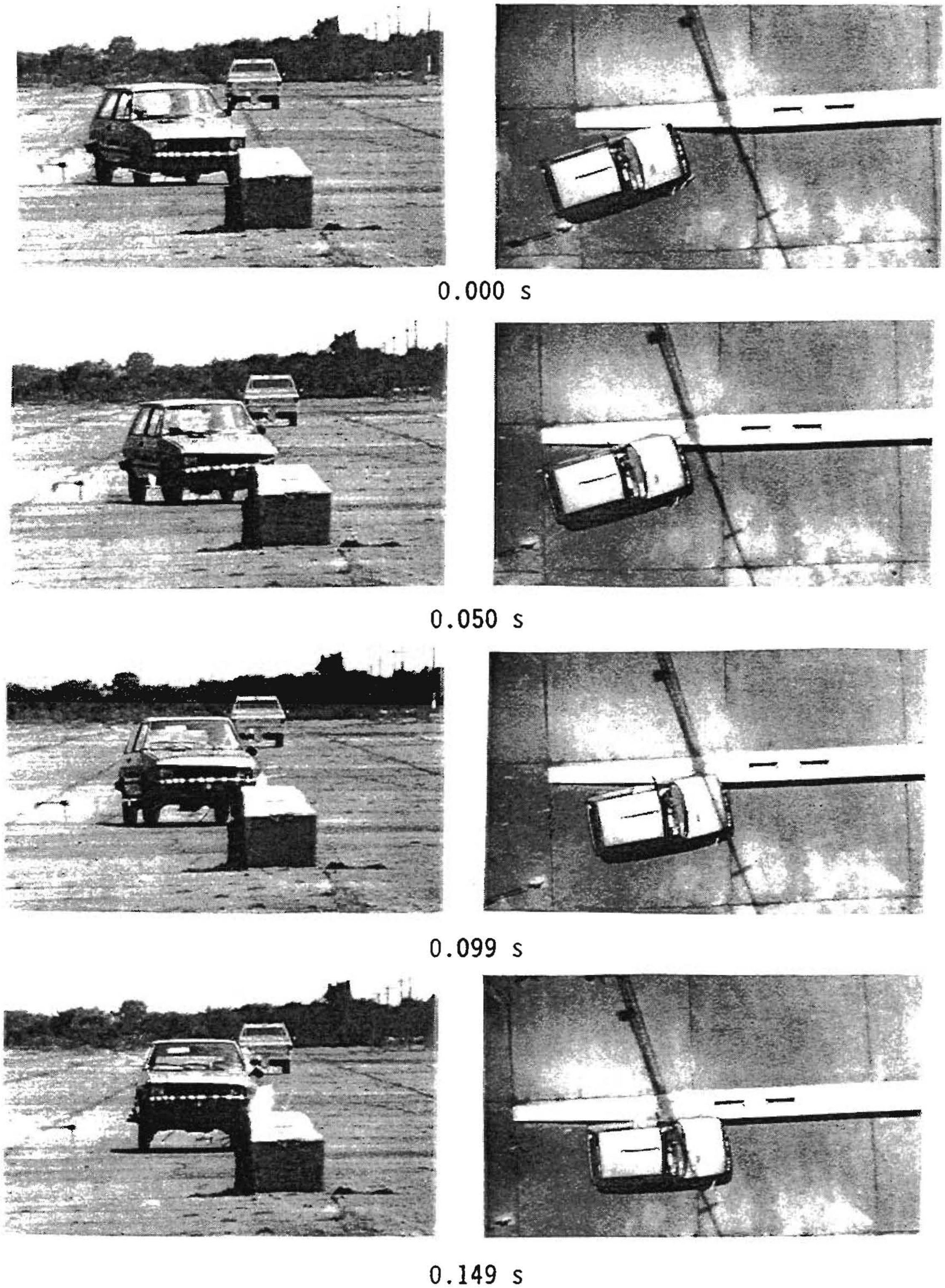
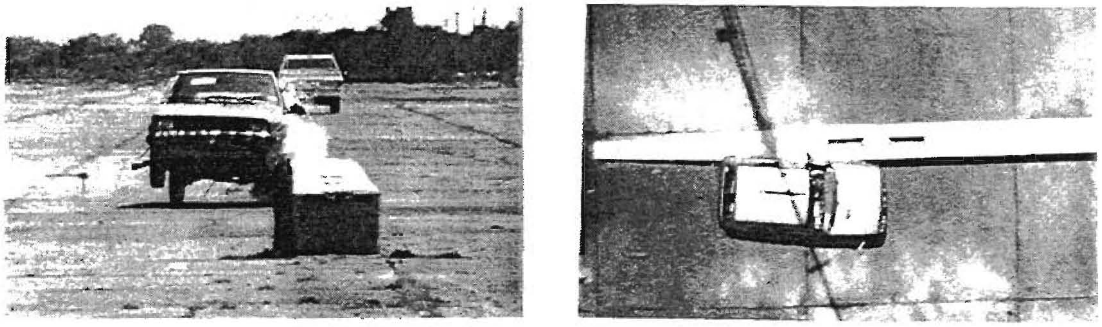
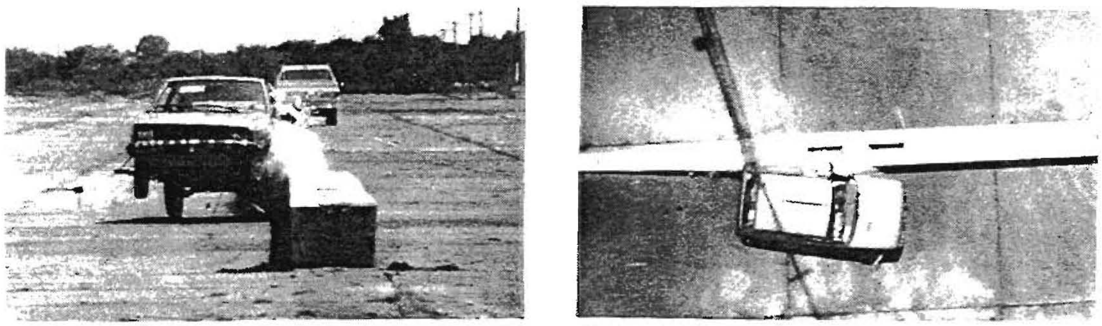


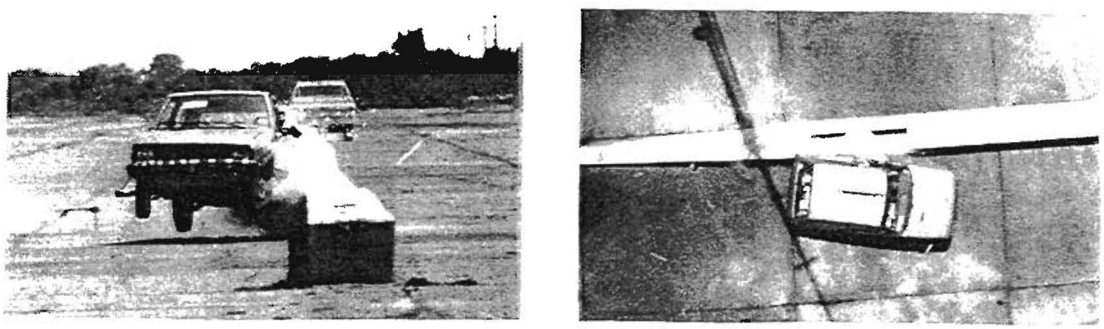
Figure 26. Sequential photographs for test 1949A-1.
(frontal and overhead views)



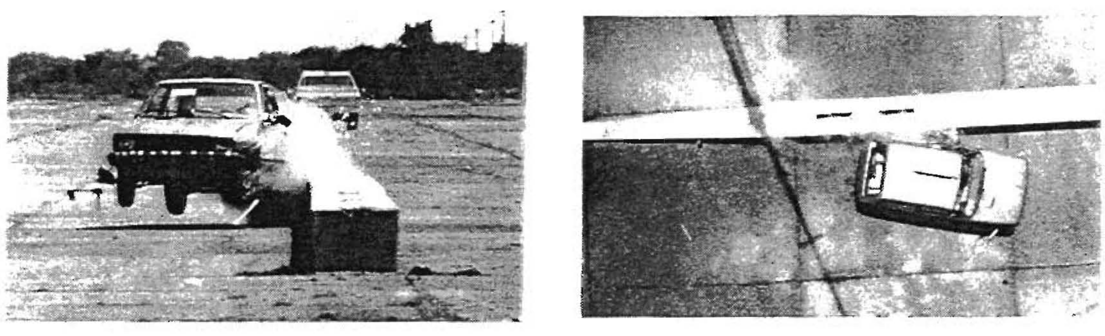
0.201 s



0.250 s

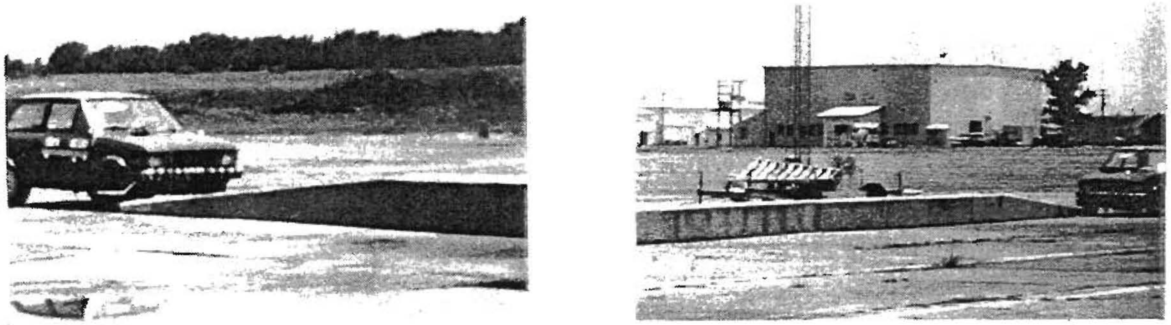


0.310 s



0.389 s

Figure 26. Sequential photographs for test 1949A-1.
(frontal and overhead views continued).



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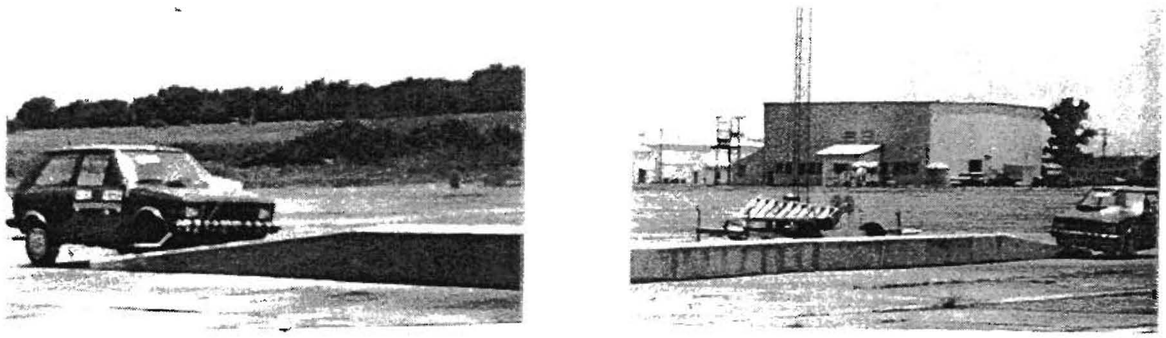

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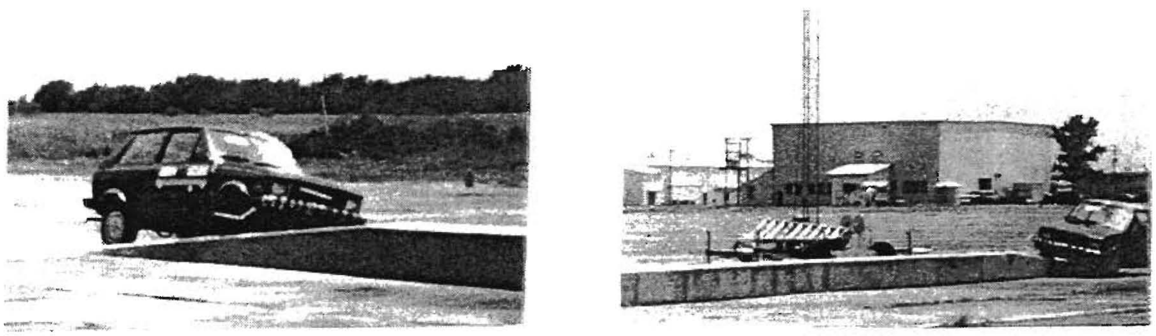
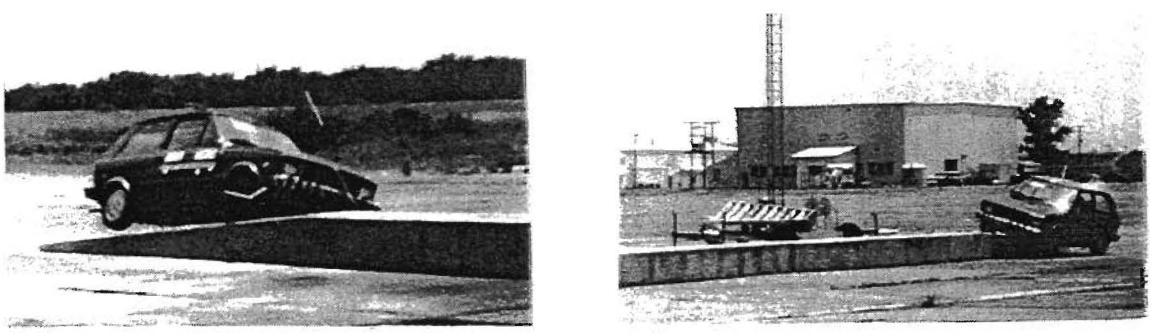
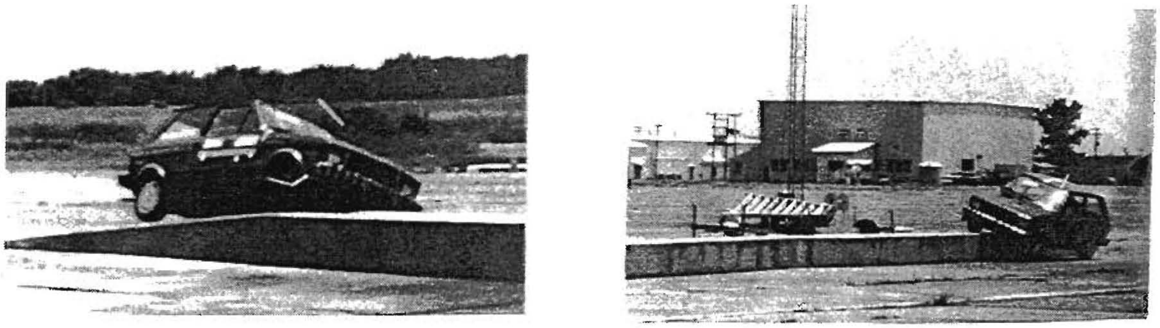


0.124 s

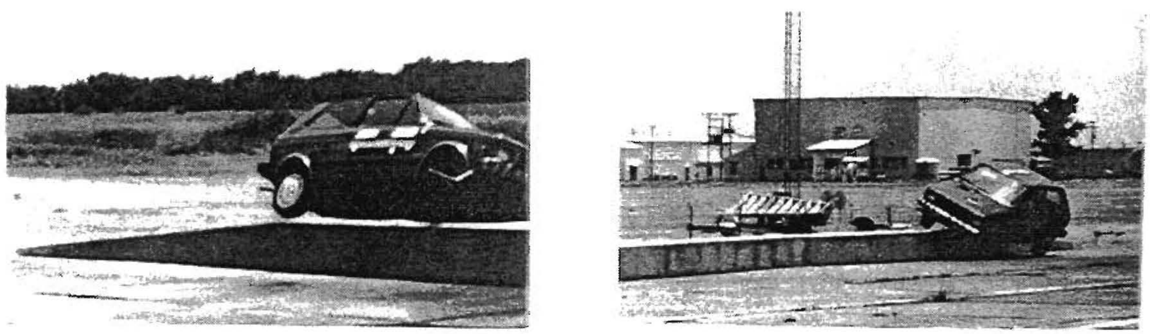


0.186 s

Figure 27. Sequential photographs for Test 1949A-2 (side views).



0.248 s



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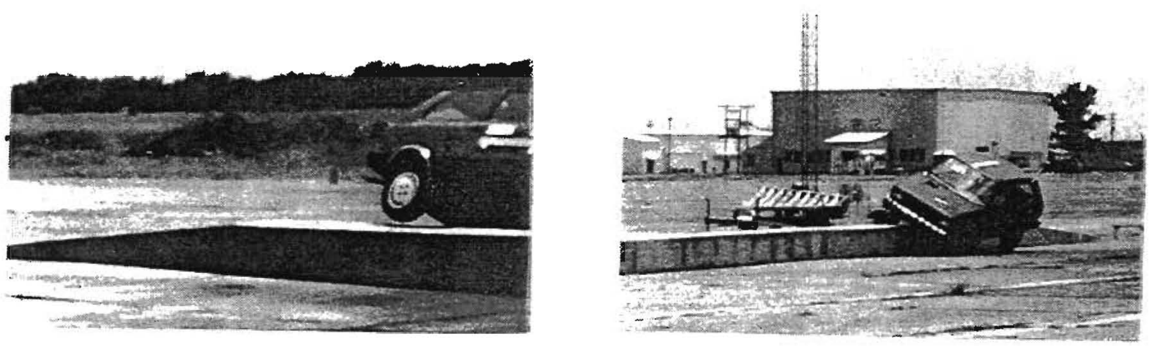
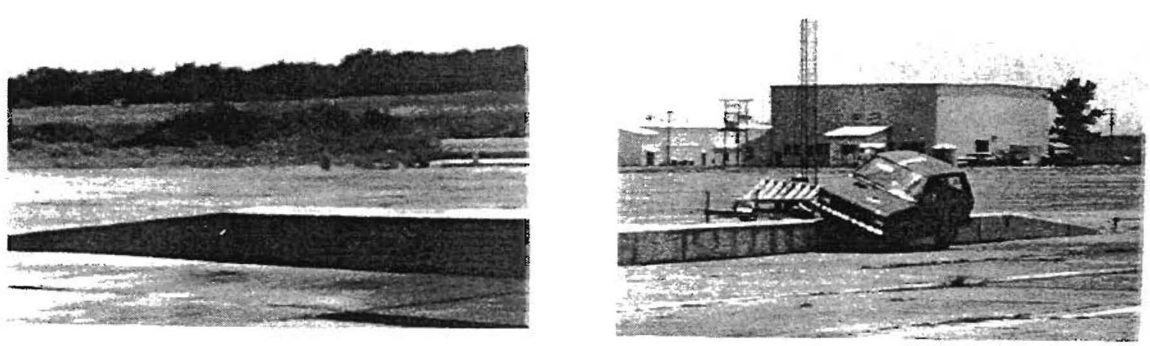


0.459 s



0.620 s

Figure 27. Sequential photographs for test 1949A-2 (side views continued).

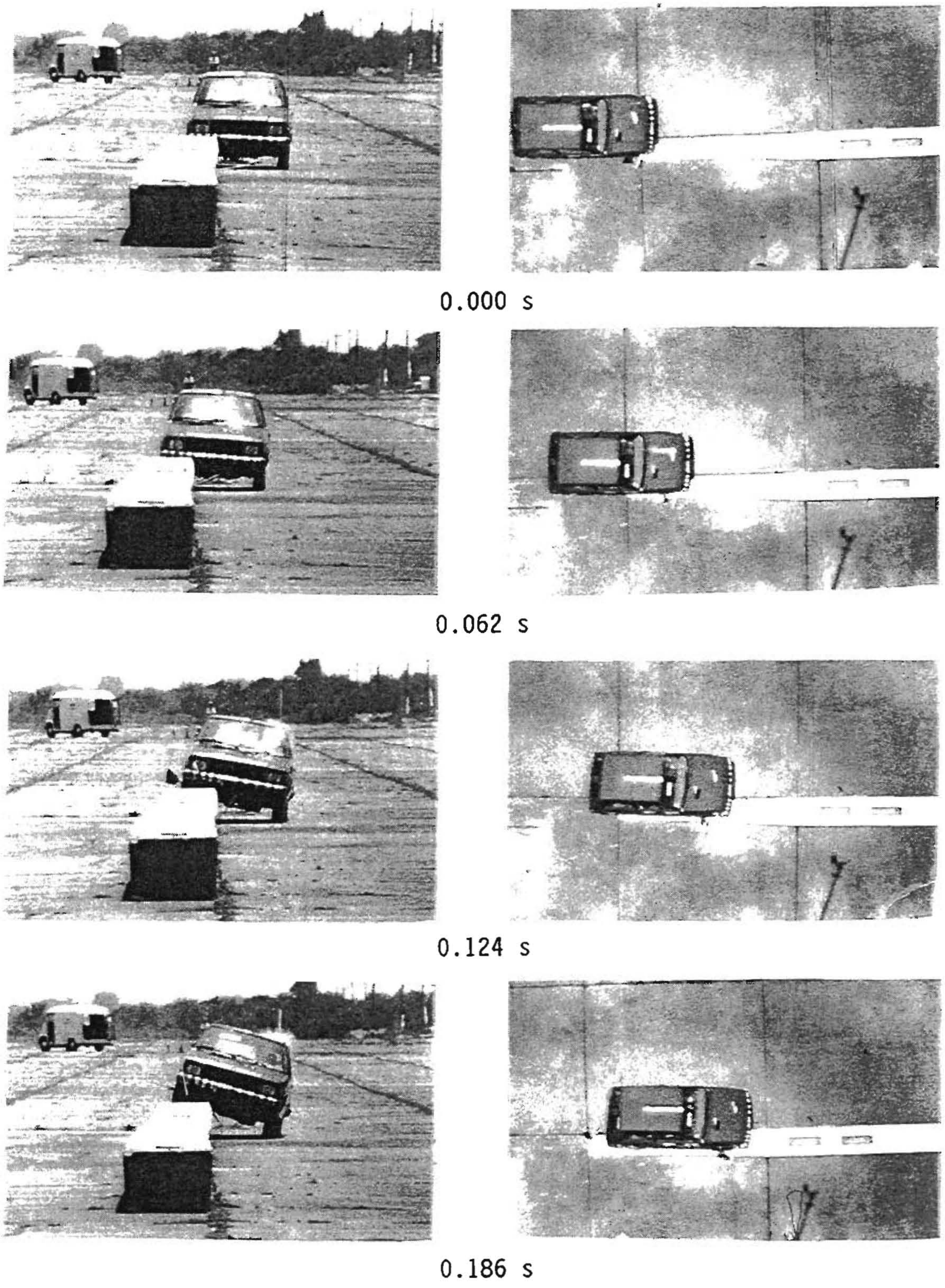
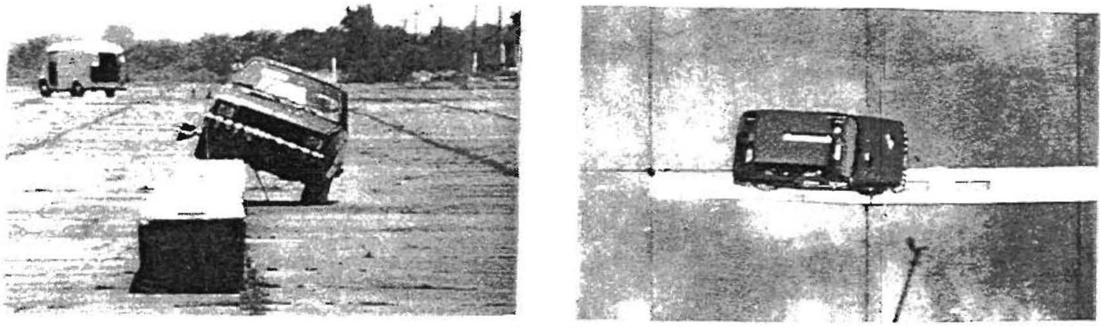
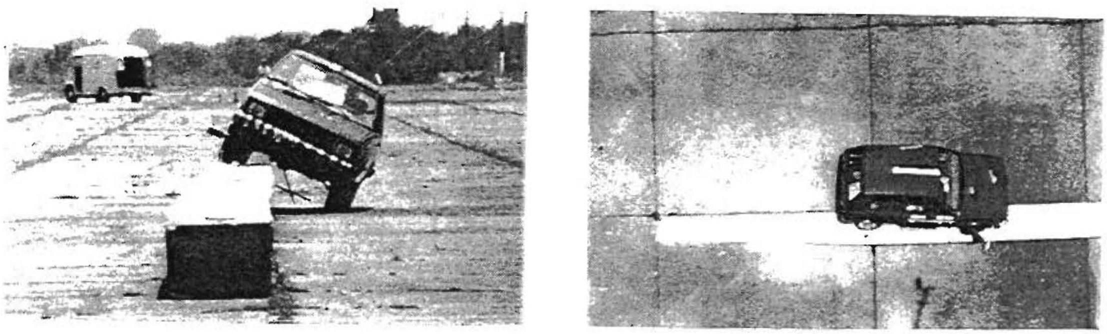


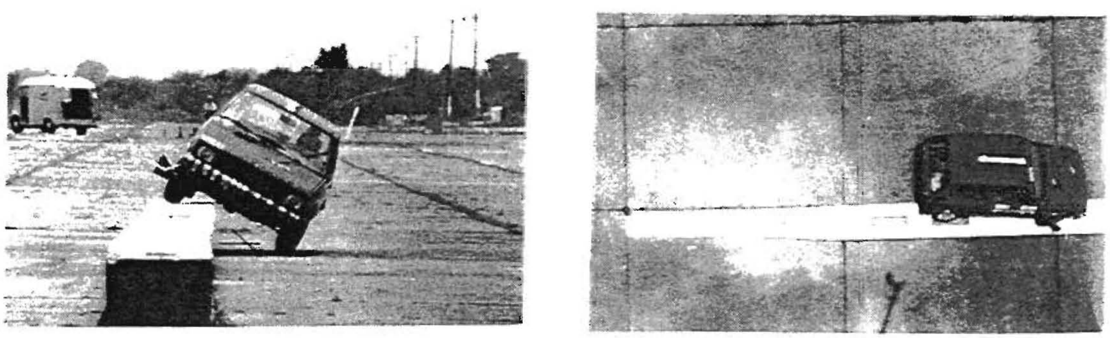
Figure 28. Sequential photographs for Test 1949A-2 (frontal and overhead views).



0.248 s



0.347 s



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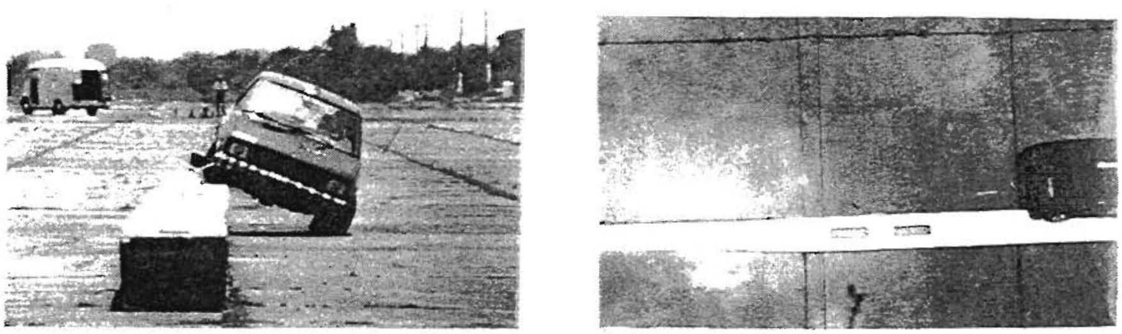
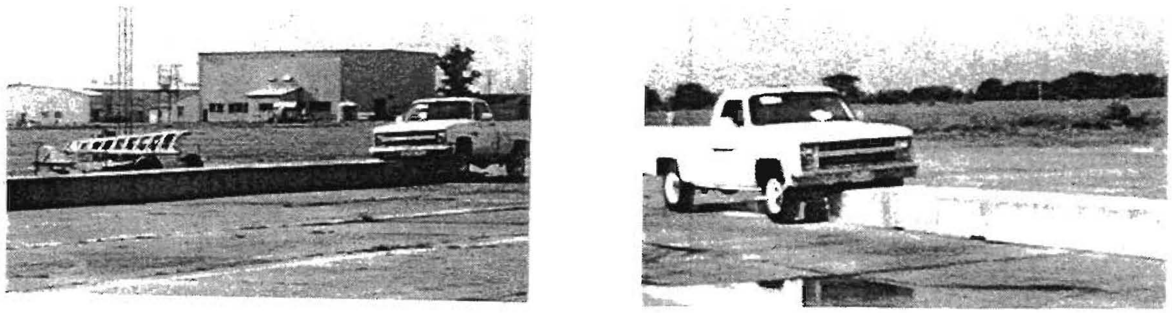


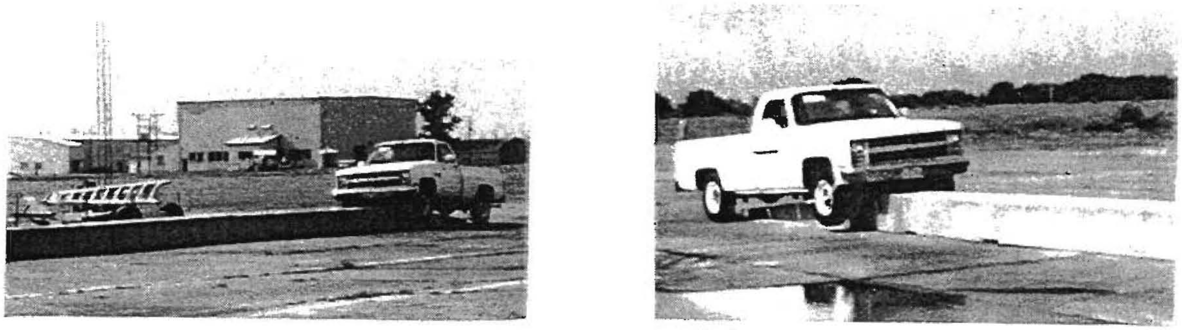
0.620 s

Figure 28. Sequential photographs for test 1949A-2 (frontal and overhead views continued).

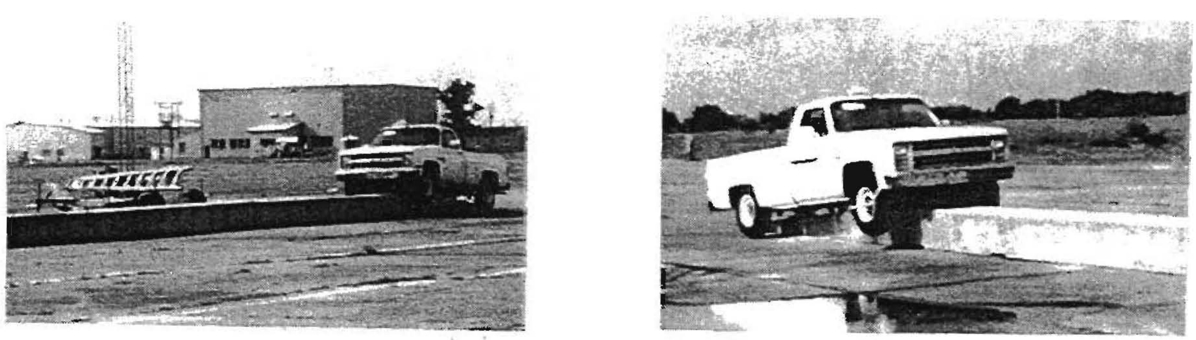
0.000 s



0.049 s

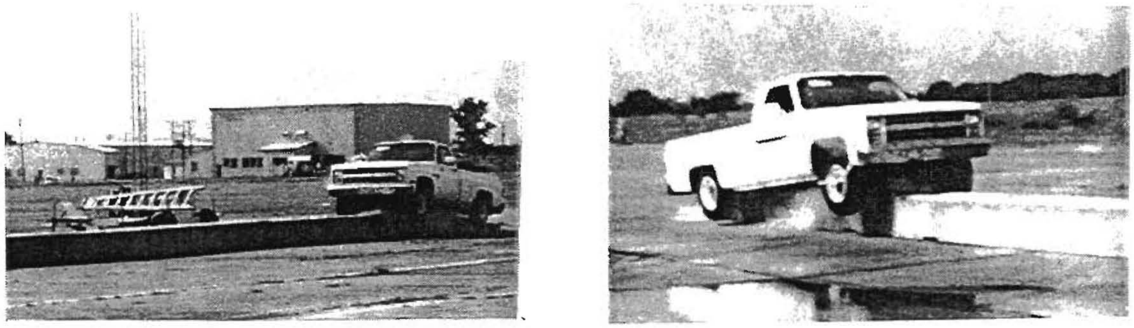


0.098 s

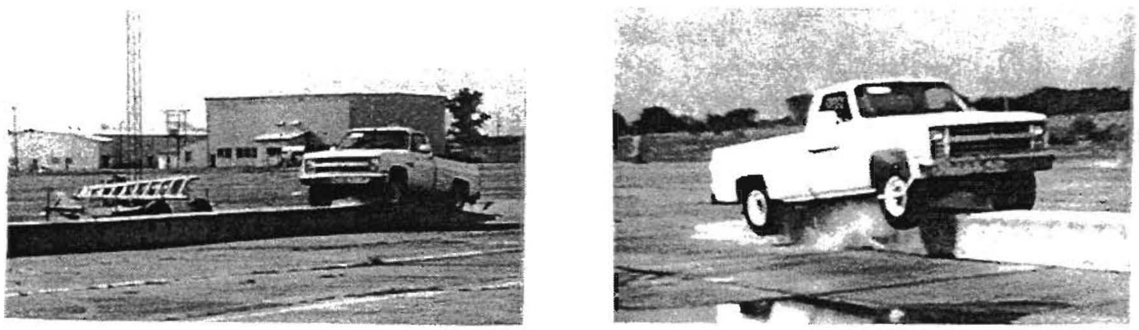


0.150 s

Figure 29. Sequential photographs for Test 1949A-3 (side views).



0.199 s



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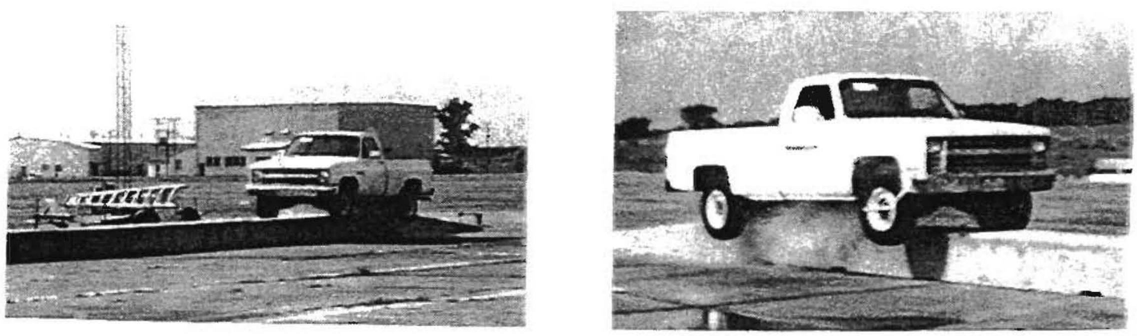
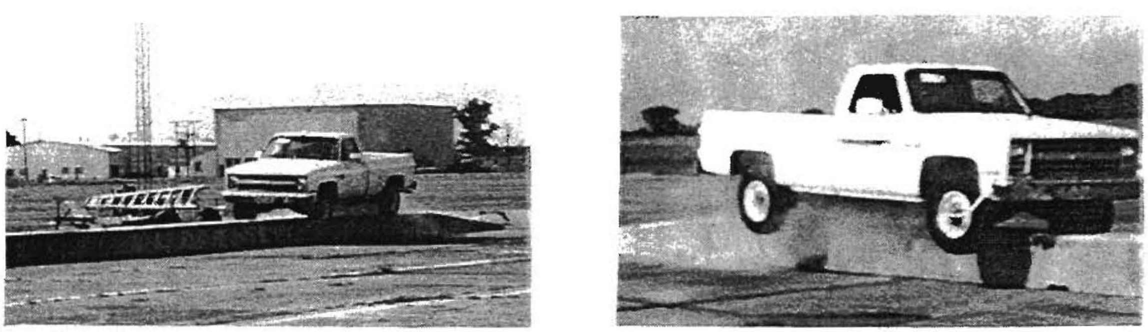
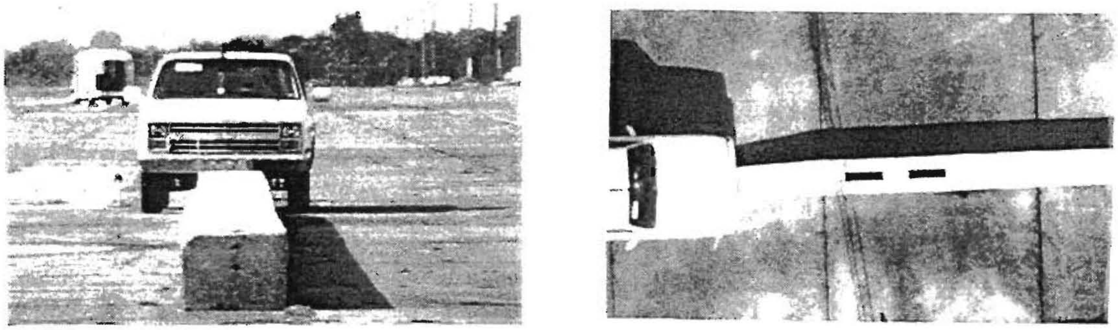


0.349 s



0.444 s

Figure 29. Sequential photographs for test 1949A-3 (side views continued).



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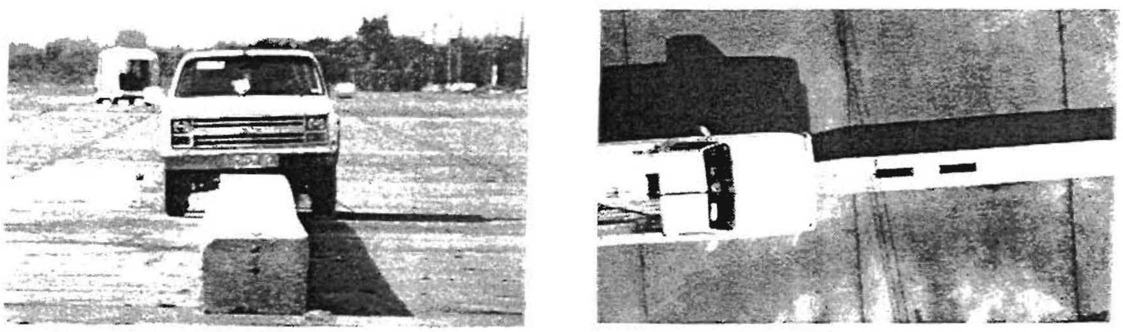
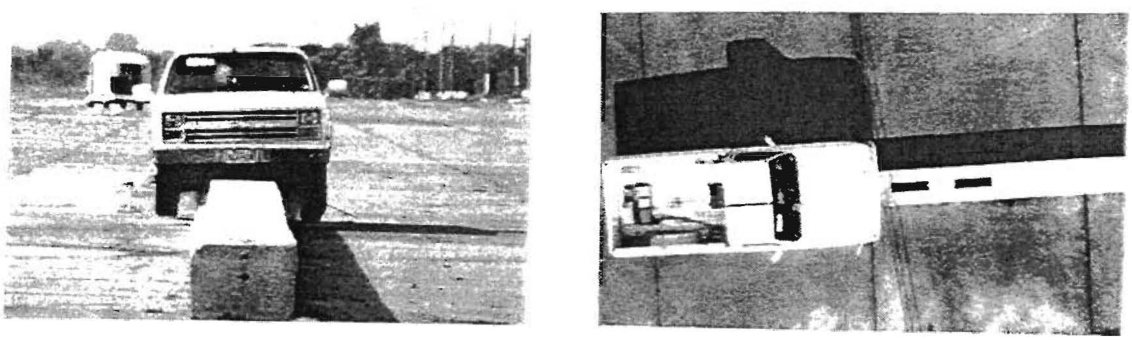
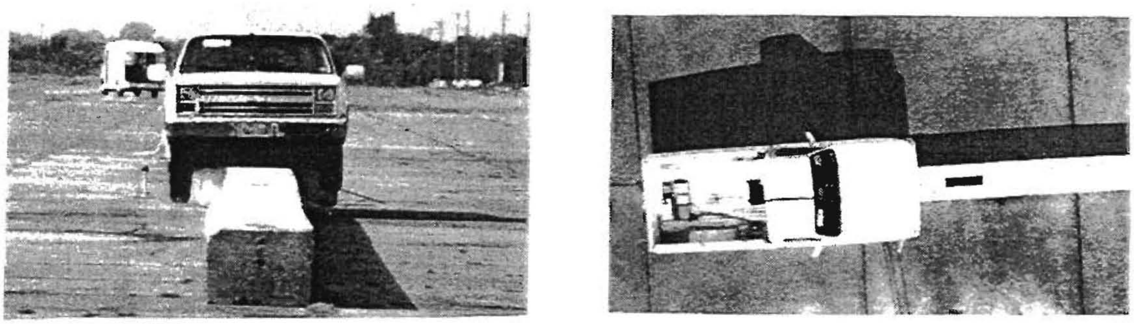


0.049 s

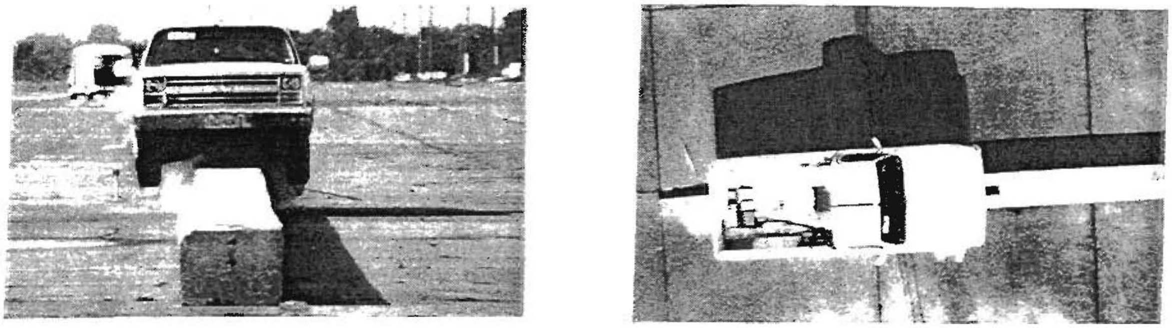


0.098 s



0.150 s

Figure 30. Sequential photographs for Test 1949A-3 (frontal and overhead views).



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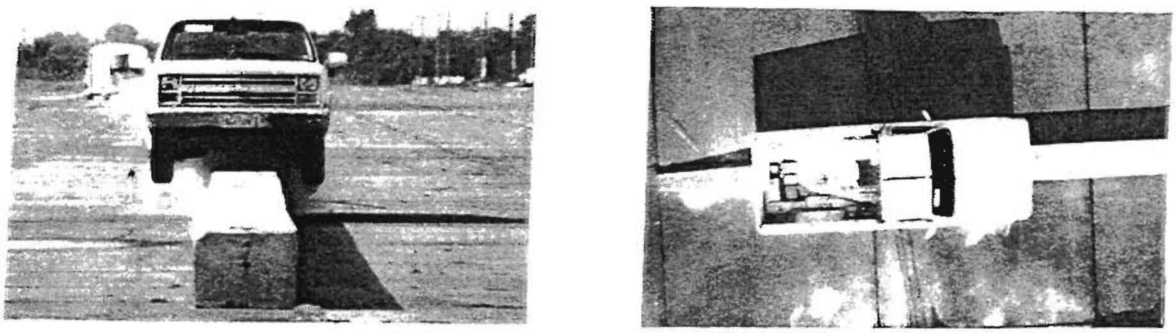

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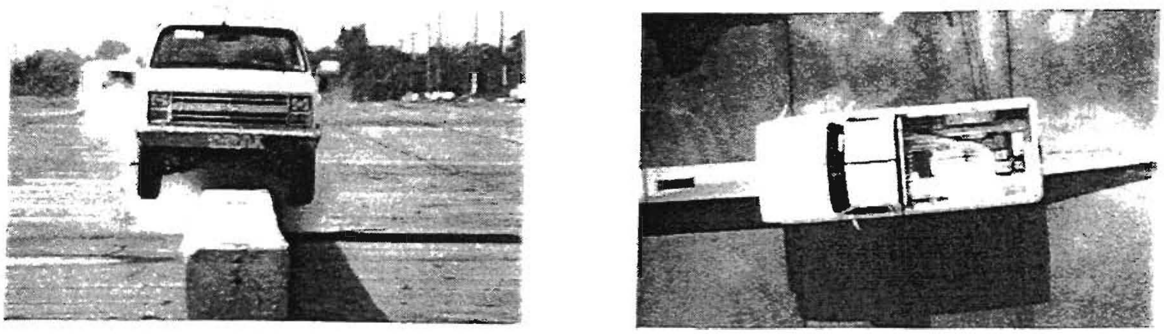
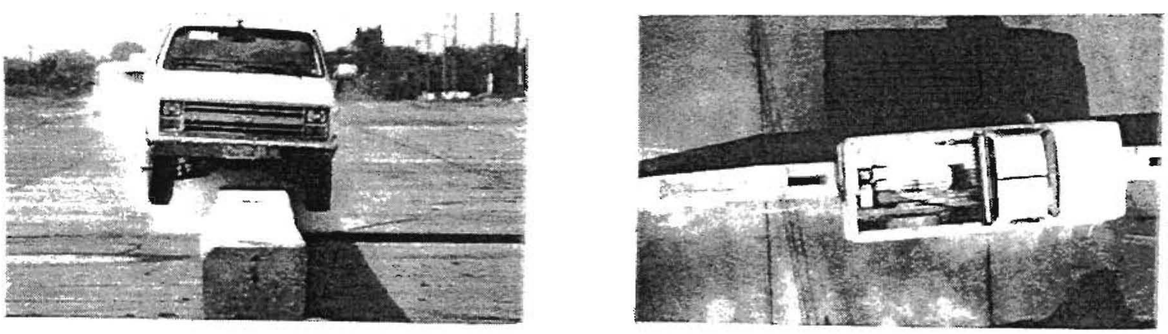


0.349 s



0.444 s

Figure 30. Sequential photographs for test 1949A-3 (frontal and overhead views continued).

APPENDIX C
ACCELEROMETER TRACES AND PLOTS OF ROLL, PITCH, AND YAW RATES

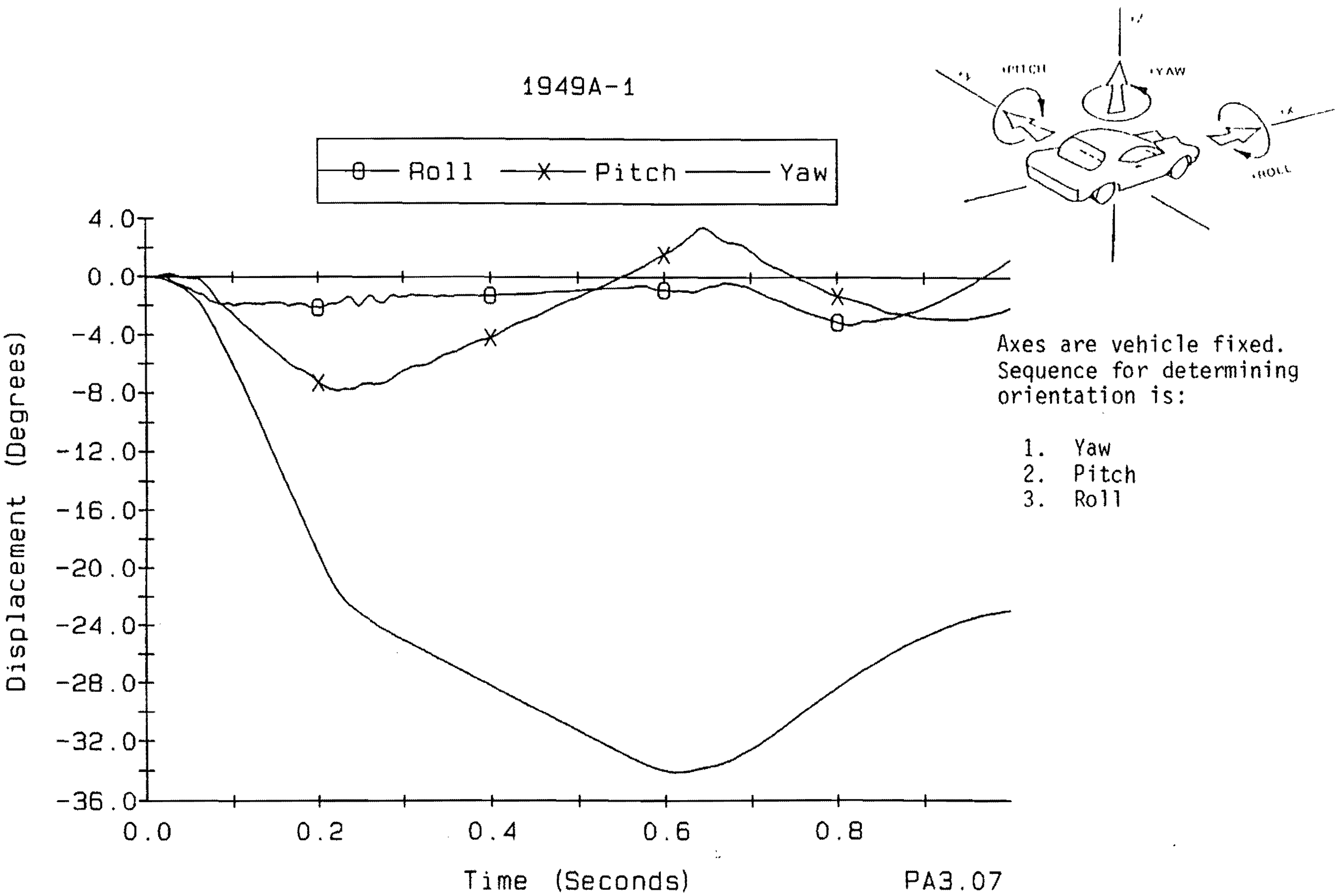


Figure 31. Vehicle angular displacements for Test 1949A-1.

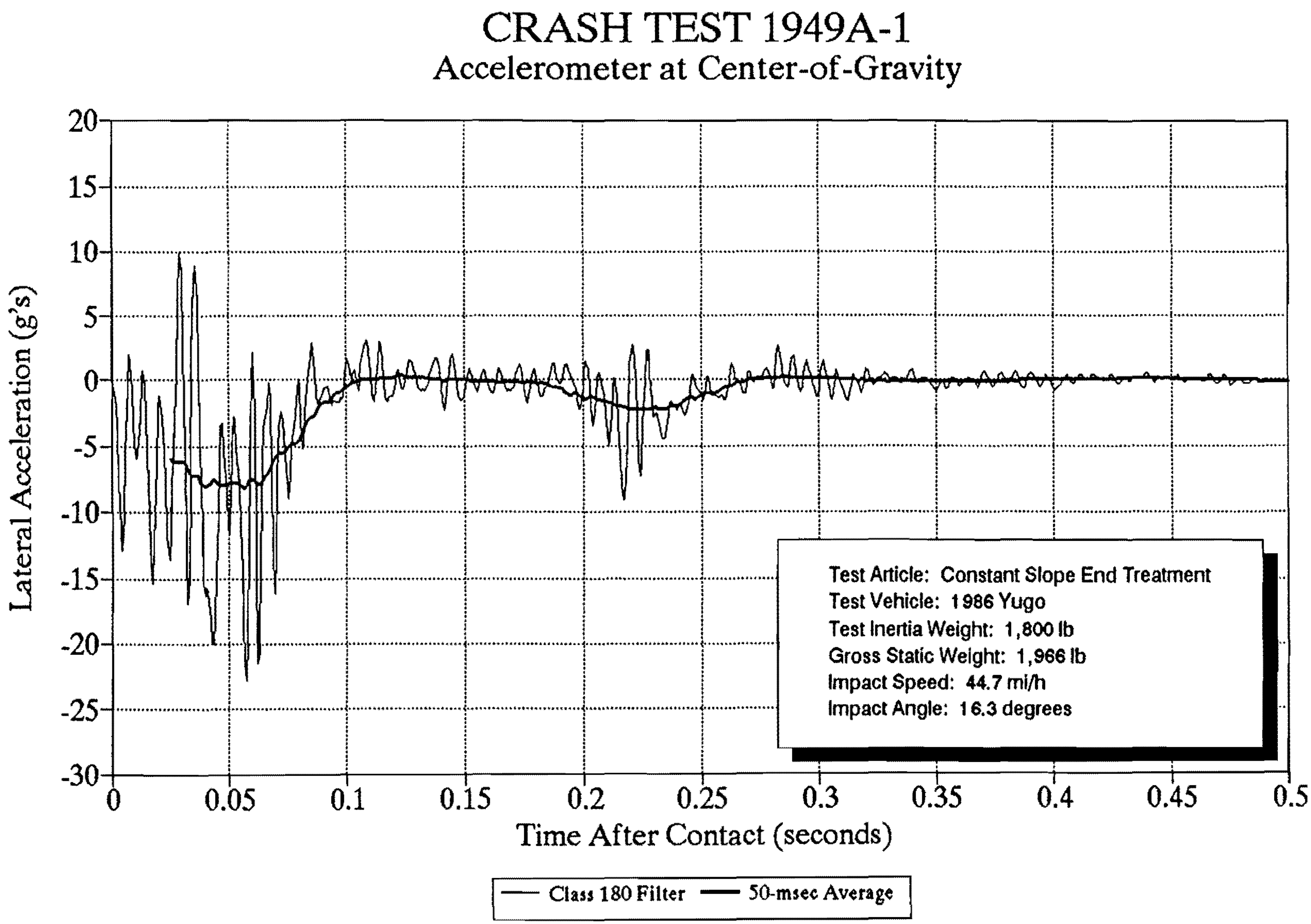


Figure 32. Lateral acceleration for Test 1949A-1.

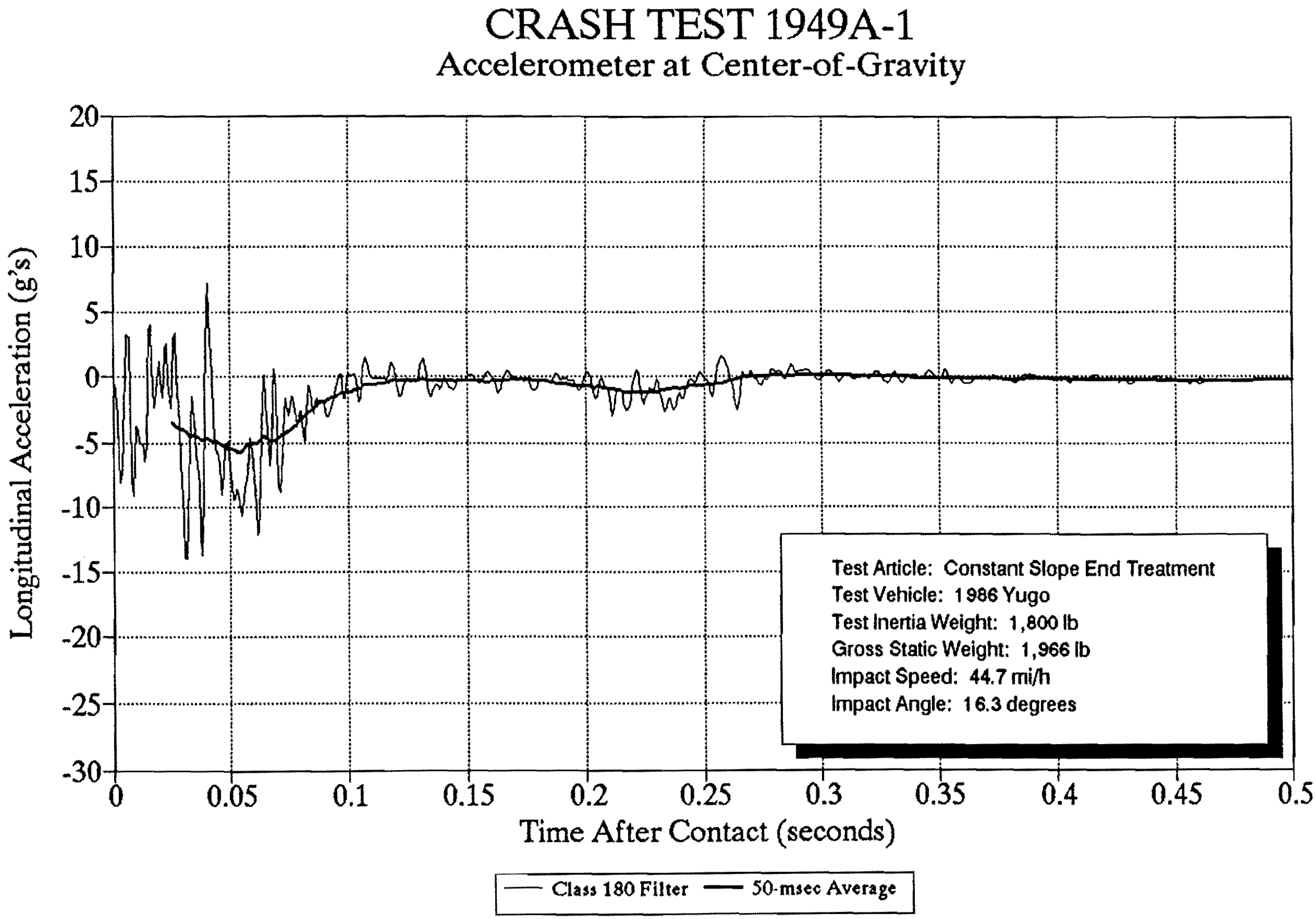


Figure 33. Longitudinal acceleration for Test 1949A-1.

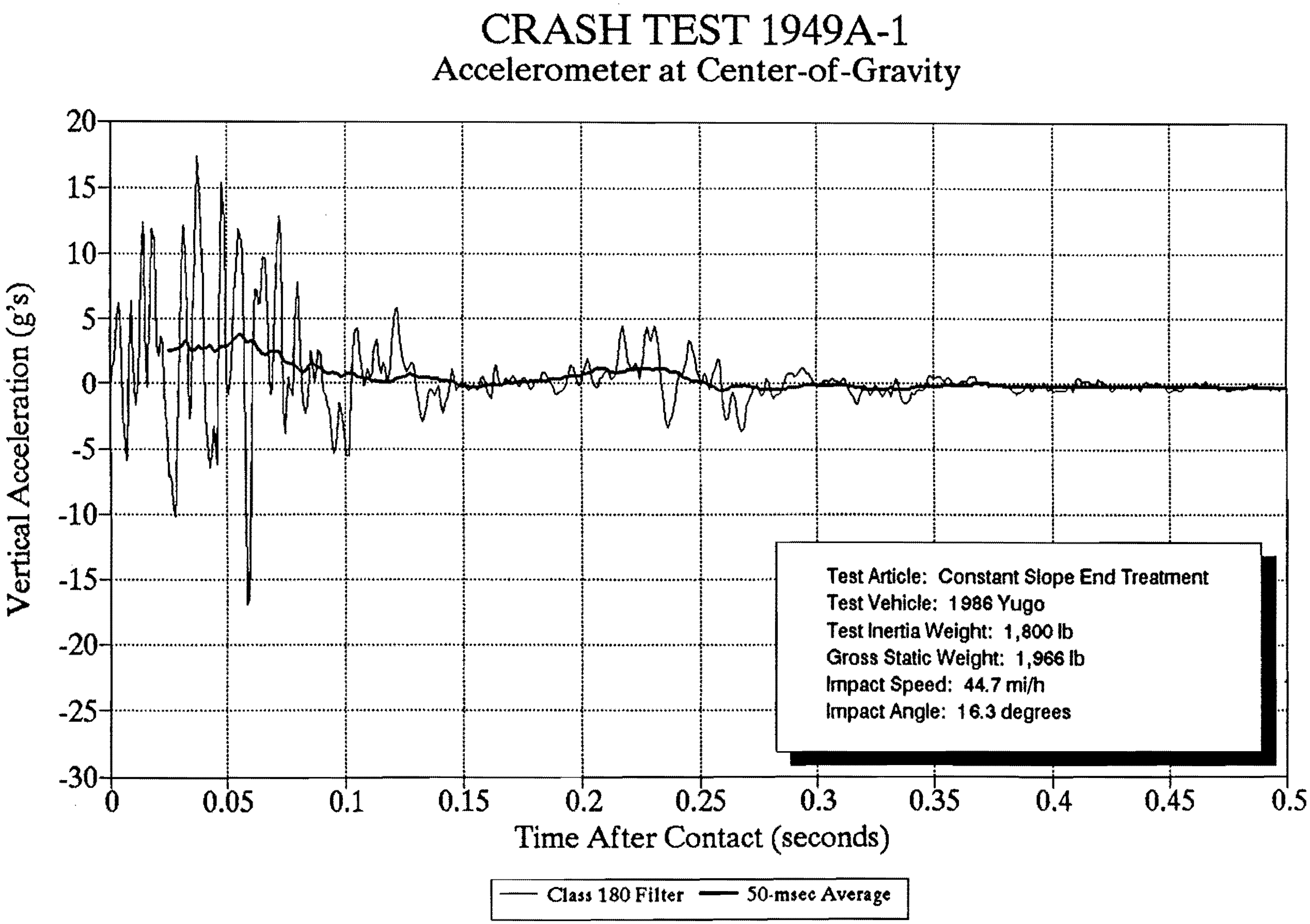


Figure 34. Vertical acceleration for Test 1949A-1.

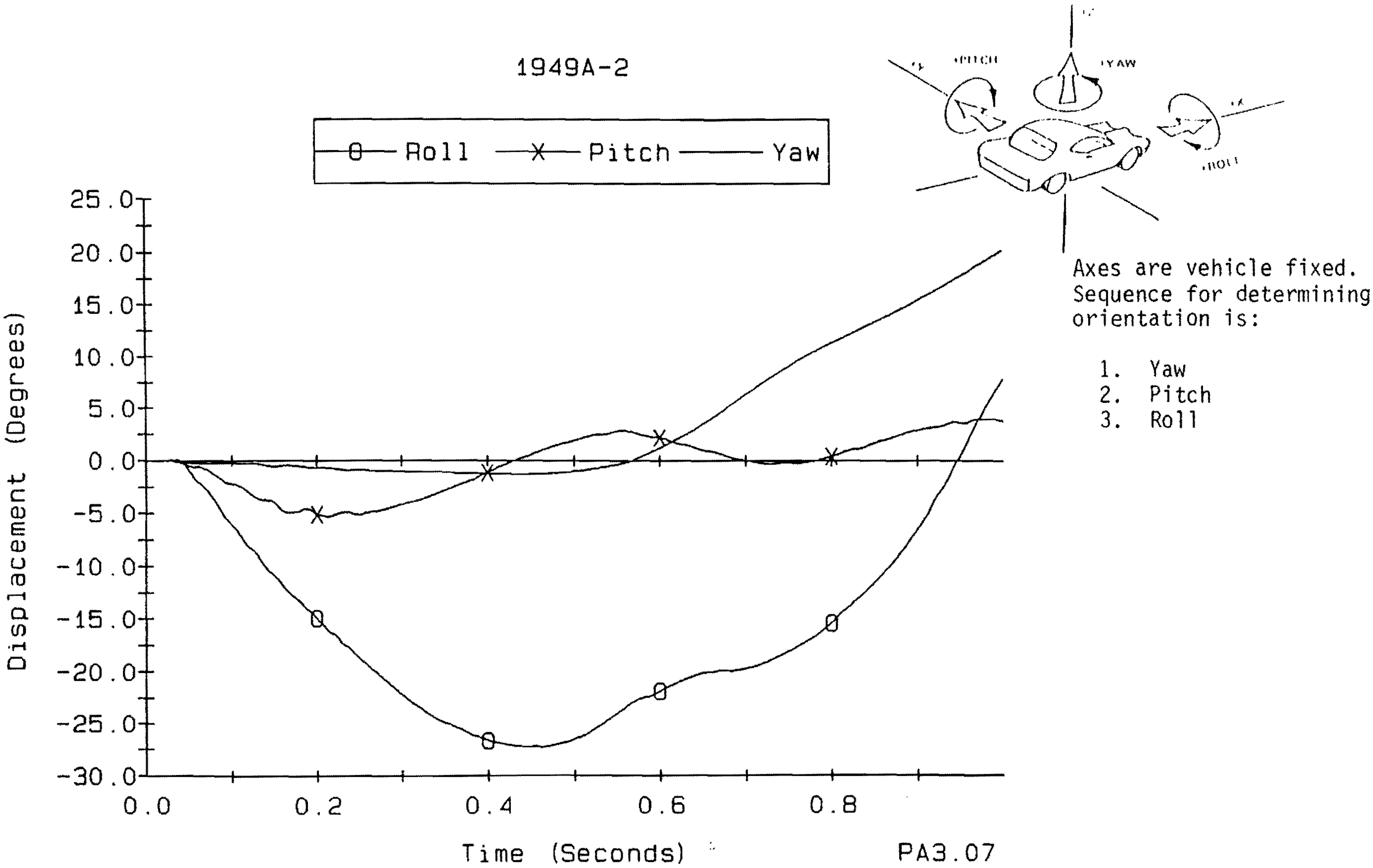


Figure 35. Vehicle angular displacements for Test 1949A-2.

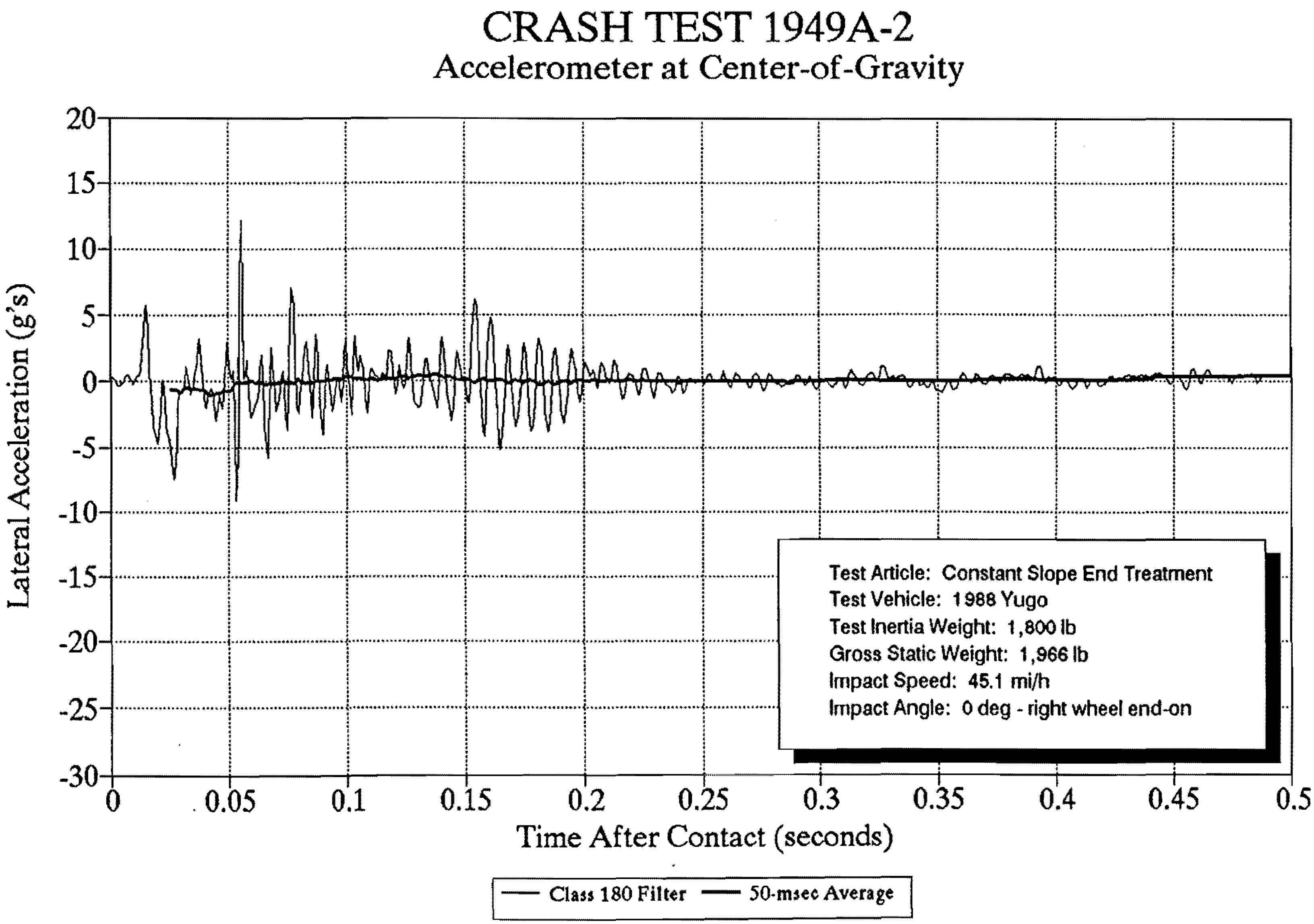


Figure 36. Lateral acceleration for Test 1949A-2.

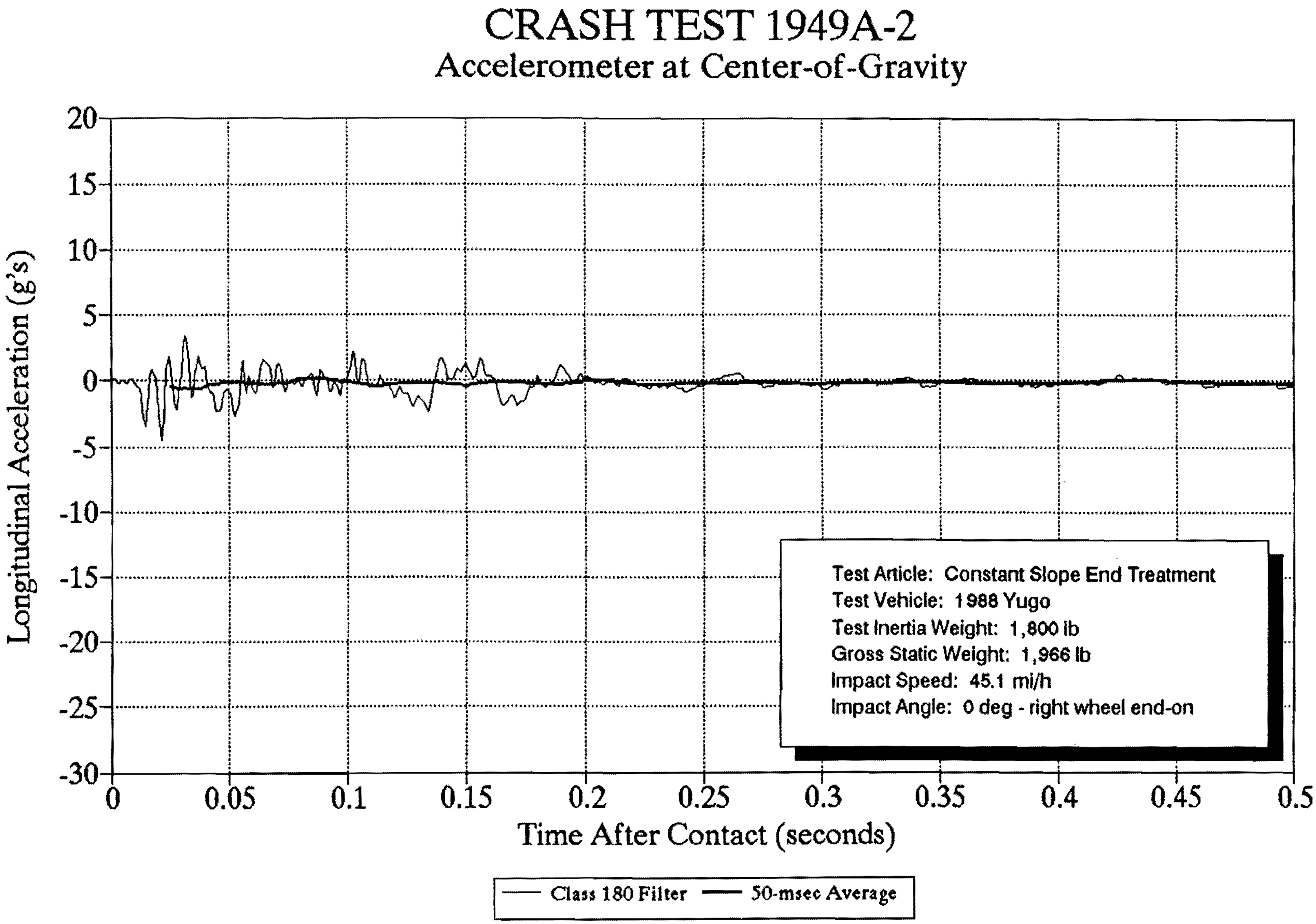


Figure 37. Longitudinal acceleration for Test 1949A-2.

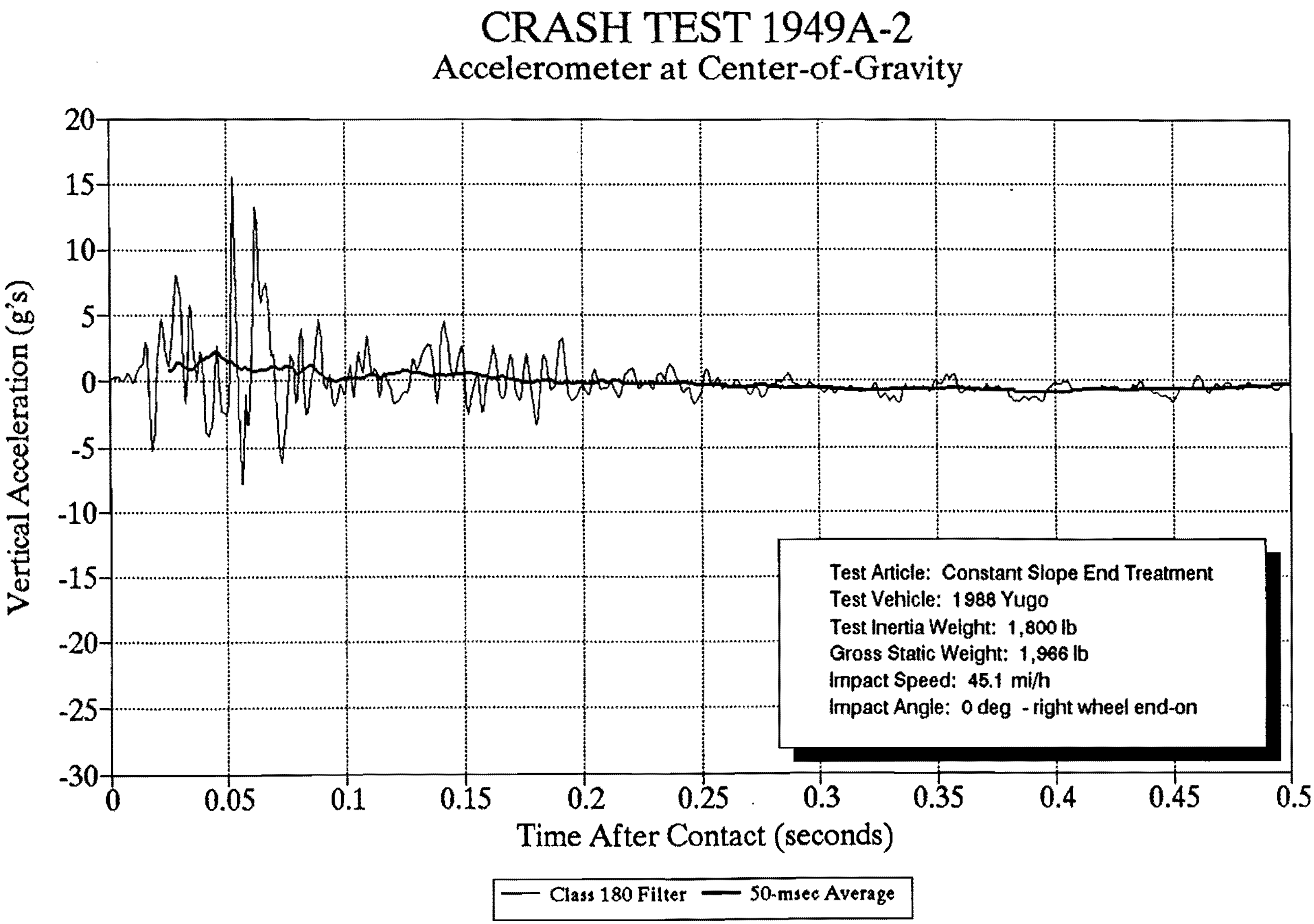


Figure 38. Vertical acceleration for Test 1949A-2.

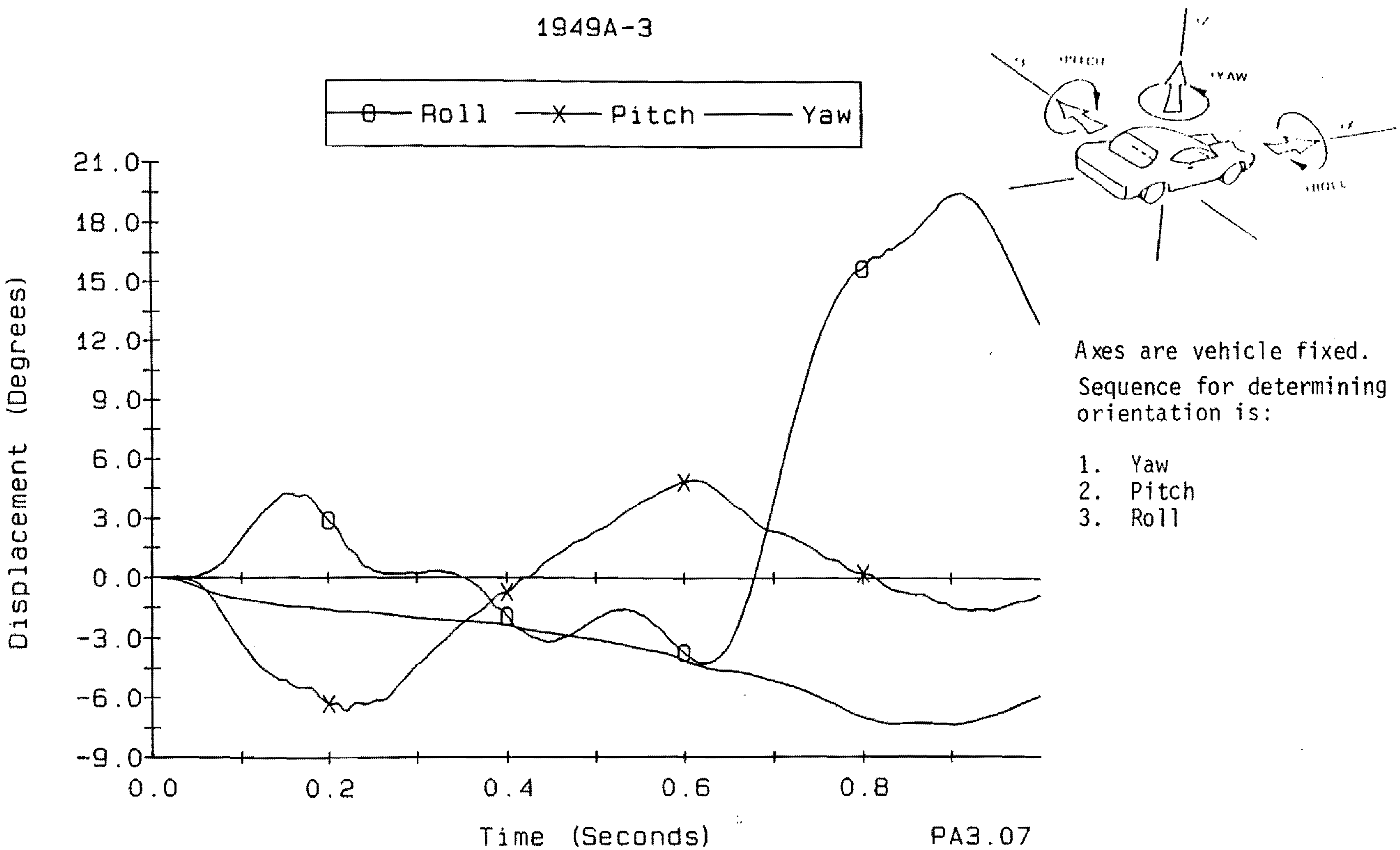


Figure 39. Vehicle angular displacements for Test 1949A-3.

CRASH TEST 1949A-3

Accelerometer at Center-of-Gravity

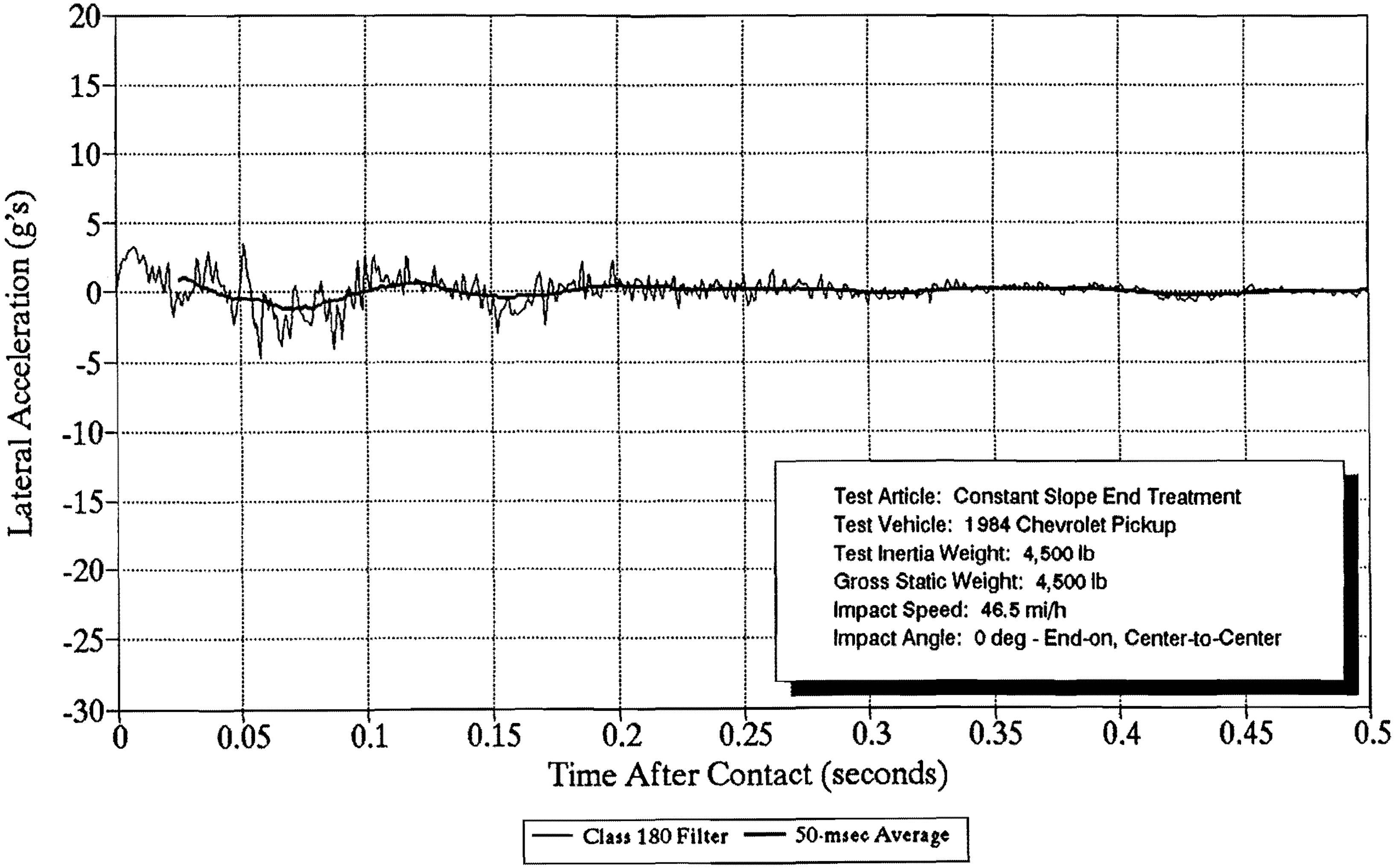


Figure 40. Lateral acceleration for Test 1949A-3.

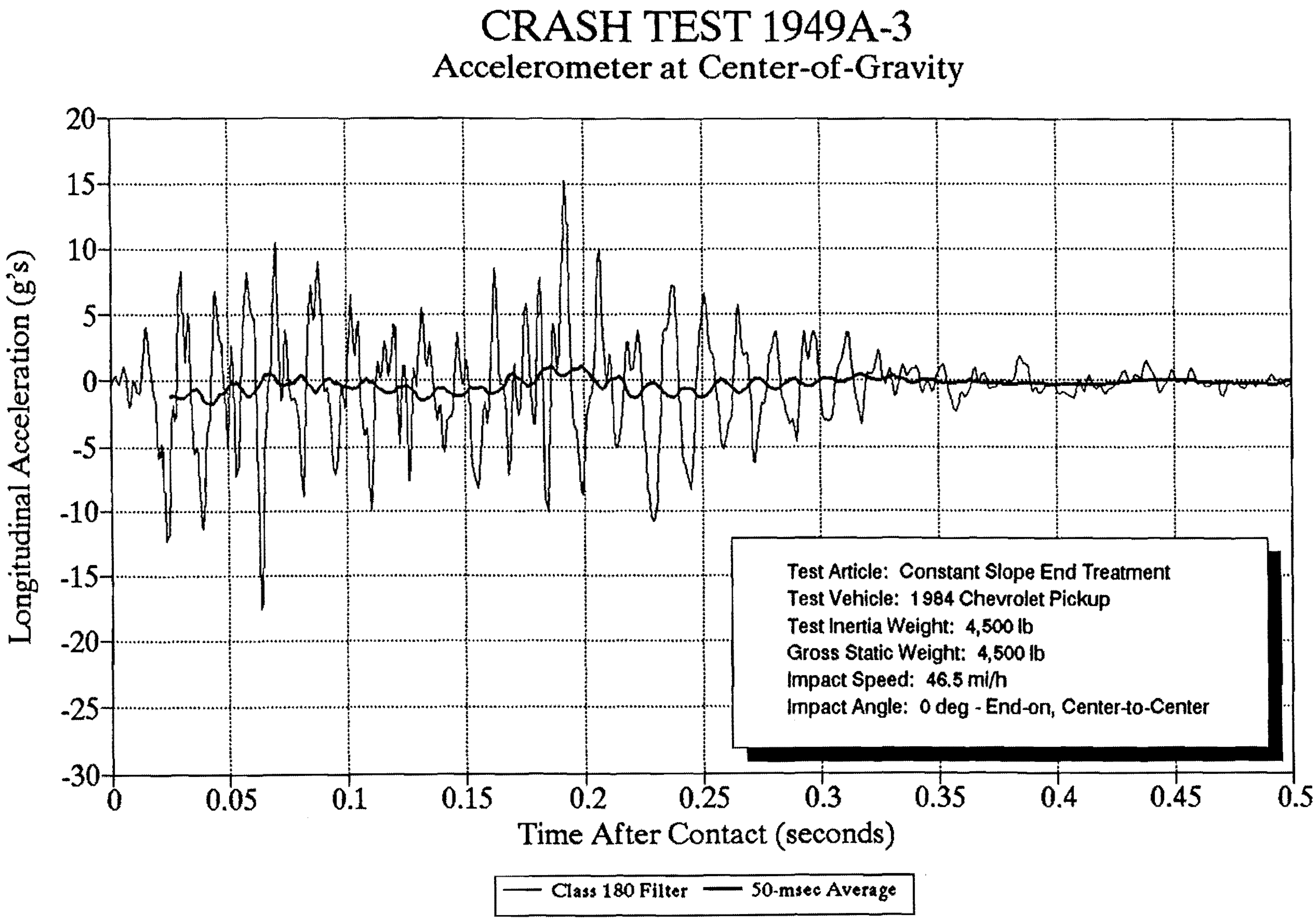


Figure 41. Longitudinal acceleration for Test 1949A-3.

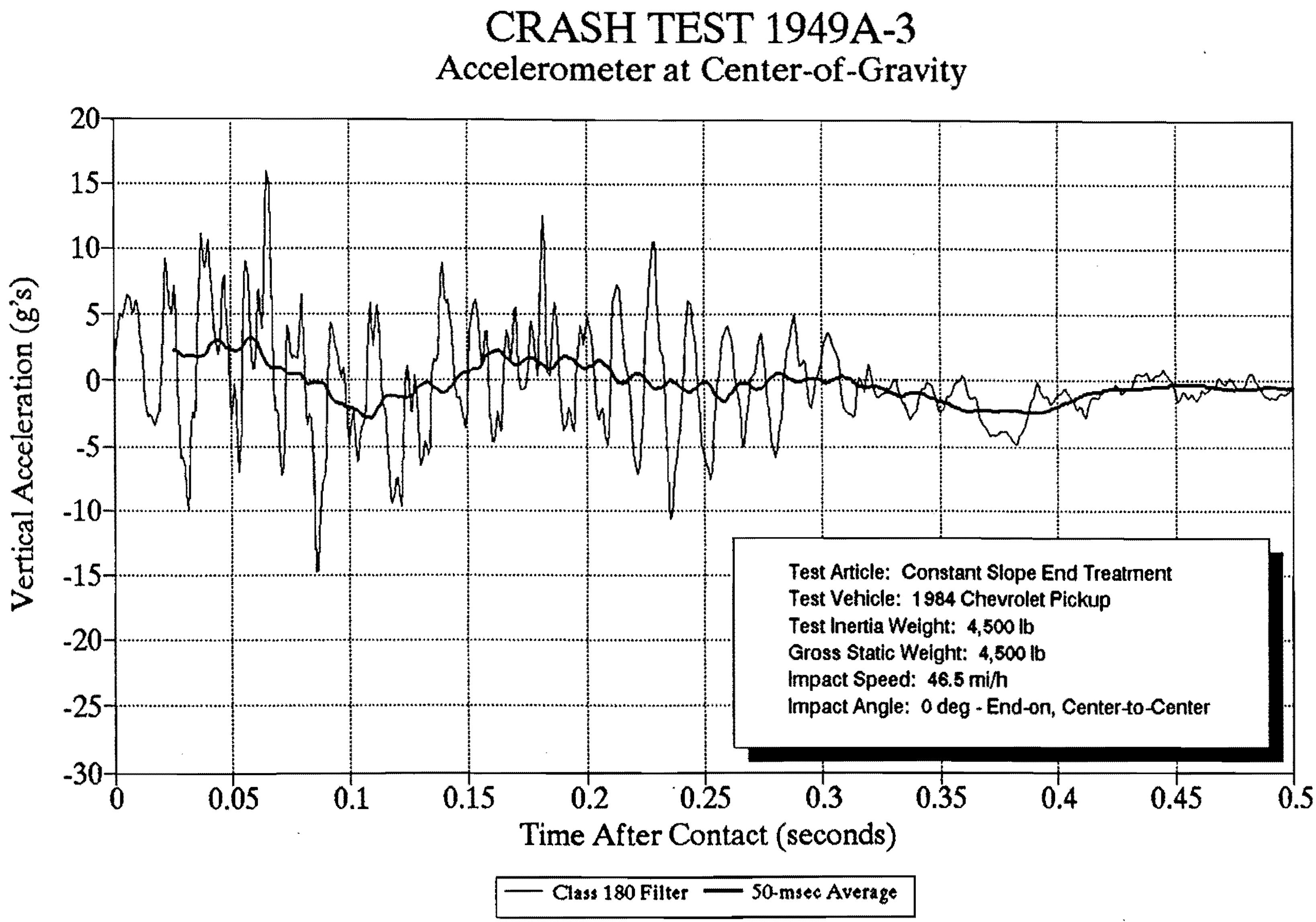


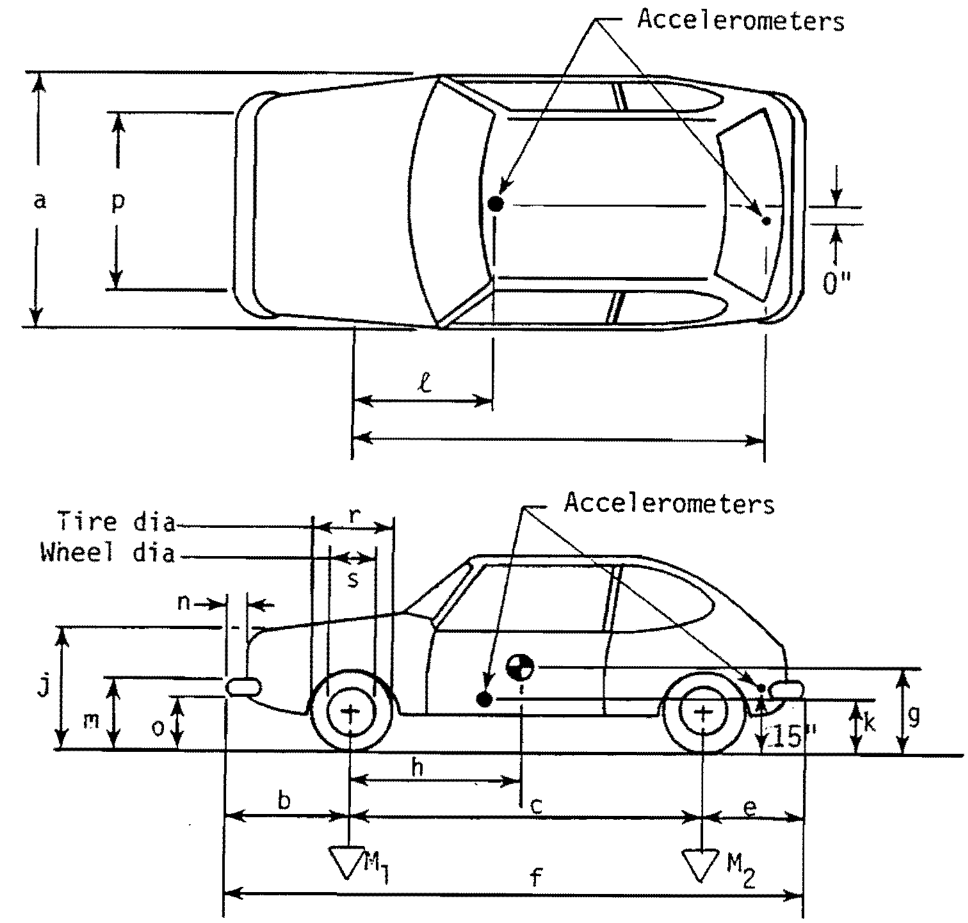
Figure 42. Vertical acceleration for Test 1949A-3.

APPENDIX D
TEST VEHICLE PROPERTIES

Date: 6-24-92 Test No.: 1949A-1 VIN: VX1BA1216GK324202

Make: Yugo Model: ______ Year: 1986 Odometer: 26331

Tire Size: 145SR13 Ply Rating: ______ Bias Ply: __ Belted: __ Radial: X



Tire Condition: good __
fair __
badly worn __

Vehicle Geometry - inches

a	60.25"	b	27.50"
c	84.25"	d*	55.25"
e	24.00"	f	135.75"
g		h	31.00"
i	----	j	30.00"
k	25.75"	ℓ	31.00"
m	18.50"	n	4.00"
o	13.00"	p	51.75"
r	22.75"	s	14.18"

4-wheel weight for c.g. det. ℓf 581 rf 556 ℓr 303 rr 360

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	1206	1137	1215
M_2	610	663	751
M_T	1816	1800	1966

Note any damage to vehicle prior to test:

______

______

*d = overall height of vehicle

Engine Type: V-4 Gas

Engine CID: 1100 cc

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Body Type: 3 door

Steering Column Collapse Mechanism:

__Behind wheel units
__Convoluted tube
__Cylindrical mesh units
__Embedded ball
__NOT collapsible
__Other energy absorption
__Unknown

Brakes:

Front: disc X drum __

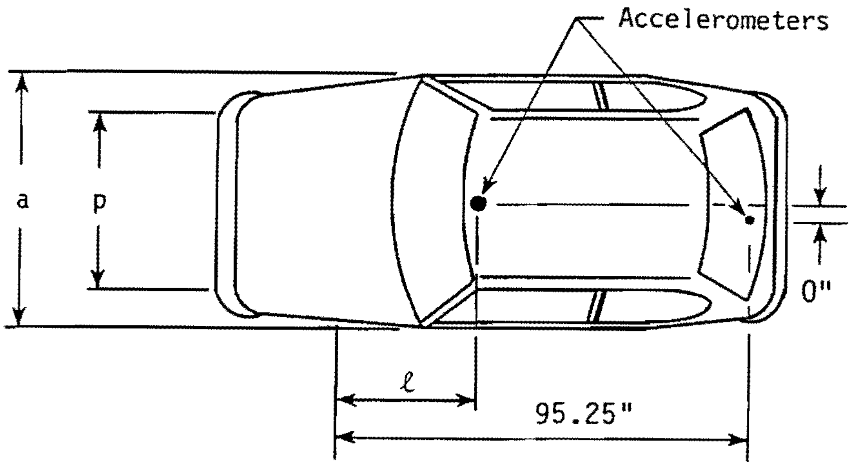
Rear: disc __ drum X

Figure 43. Test vehicle properties (Test 1949A-1).

Date: 6-26-92 Test No.: 1949A-2 VIN: VX1BB1220K445449

Make: Yugo Model: GVL Year: 1988 Odometer: 31712

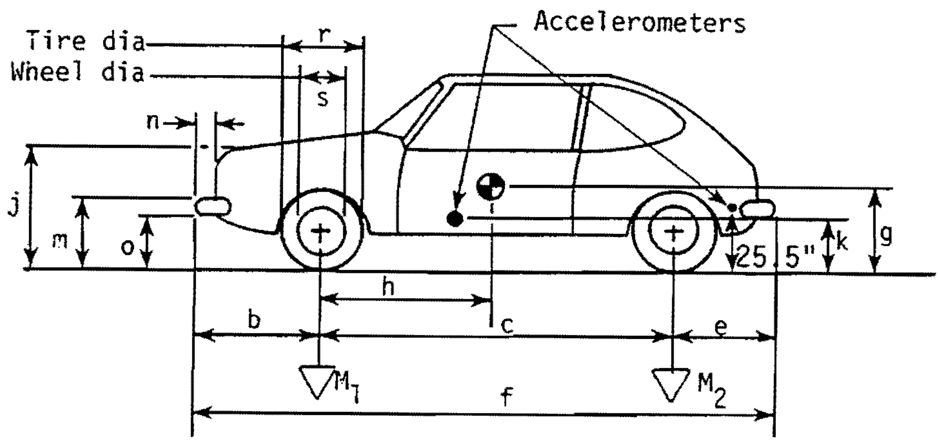
Tire Size: 145R13 Ply Rating: ____ Bias Ply: ___ Belted: ___ Radial: X



Tire Condition: good ___
fair X
badly worn ___

Vehicle Geometry - inches

a	60.25"	b	27.00"
c	85.25"	d*	55.25"
e	23.50"	f	135.75"
g		h	32.00"
i	----	j	30.00"
k	15.00"	ℓ	32.00"
m	19.00"	n	2.50"
o	13.50"	p	51.00"
r	23.00"	s	14.25"



4-wheel weight for c.g. det. ℓf 554 rf 570 ℓr 350 rr 326

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	1184	1124	1204
M_2	620	676	762
M_T	1804	1800	1966

Note any damage to vehicle prior to test:

Engine Type: 4 cyl. gas
Engine CID: 1.1 L.
Transmission Type:
Automatic or Manual
FWD or RWD or 4WD
Body Type: 3 door
Steering Column Collapse Mechanism:
__Behind wheel units
__Convoluted tube
__Cylindrical mesh units
__Embedded ball
__NOT collapsible
__Other energy absorption
__Unknown

Brakes:
Front: disc X drum ___
Rear: disc ___ drum X

*d = overall height of vehicle

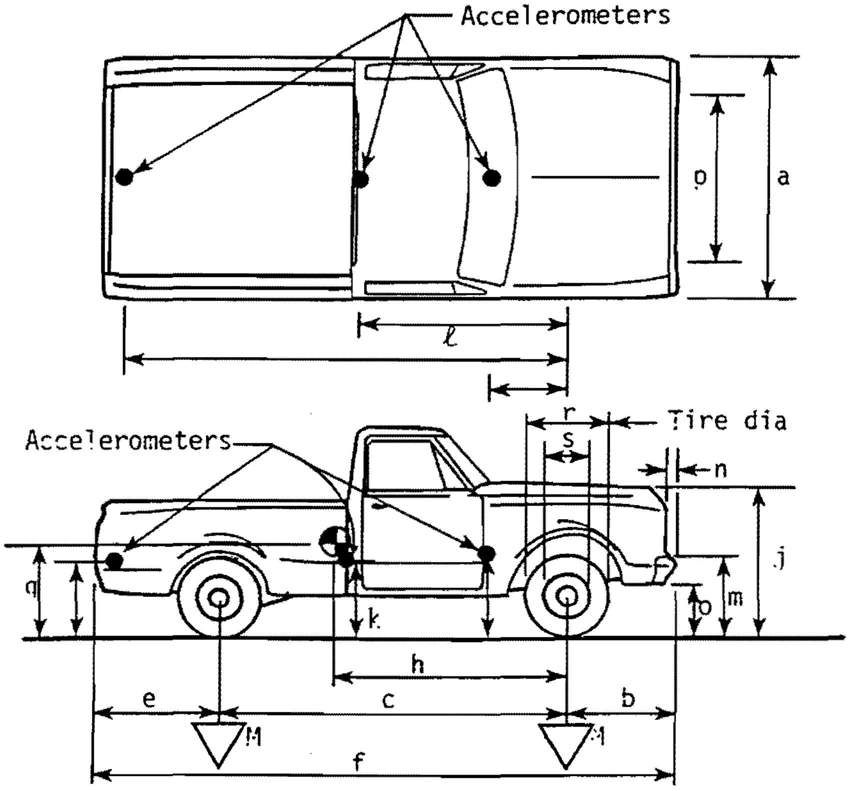
Figure 44. Test vehicle properties (Test 1949A-2).

Date: 7-1-92 Test No.: 1949A-3 VIN: 1GCGCZ4M5FS104060

Make: Chevy Model: PU Custom Deluxe 20 Year: 1984 Odometer: 94706

Tire Size: LT235/85R16 Ply Rating: ____ Bias Ply: __ Belted: __ Radial: X

Tire Condition: good X
fair __
badly worn __



Vehicle Geometry - inches

a	79.25"	b	33.00"
c	131.50"	d*	72.50"
e	49.50"	f	214.00"
g		h	60.40"
i	----	j	46.50"
k	25.50"	ℓ	60.00"
m	26.75"	n	3.50"
o	17.50"	p	66.00"
r	32.50"	s	17.18"

Engine Type: V8 Gas

Engine CID: 5.7 Litre

Transmission Type:
Automatic or (Manual)
FWD or (RWD) or 4WD

Body Type: P/U

Steering Column Collapse Mechanism:
__Behind wheel units
__Convoluted tube
__Cylindrical mesh units
__Embedded ball
__NOT collapsible
__Other energy absorption
__Unknown

Brakes:
Front: disc X drum __
Rear: disc __ drum X

4-wheel weight for c.g. det. ℓf 1210 rf 1223 ℓr 1045 rr 1022

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2590	2433	
M_2	2082	2067	
M_T	4672	4500	

Note any damage to vehicle prior to test:

Cracked windshield marked.

*d = overall height of vehicle

Figure 45. Test vehicle properties (Test 1949A-3).

REFERENCES

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

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

3. Michie, J.D., "Recommended Practices for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230, March 1981.