ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT NUMBER: FHWA-AZ92-329

EVALUATION OF BRIDGE APPROACH RAILS

Final Report

Prepared by:
Roger P. Bligh
Dean L. Sicking
Lance Bullard
Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

May 1992

Prepared for:
Arizona Department of Transportation
206 South 17th Avenue
Phoenix, Arizona 85007
in cooperation with
U.S. Department of Transportation
Federal Highway Administration

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-AZ92-329		

4. Title and Subtitle	5. Report Date
EVALUATION OF BRIDGE APPROACH RAILS	May 1992
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Roger P. Bligh, Dean L. Sicking, L. Bullard	Research Report 7155-1F
9. Performing Organization Name and Address	10. Work Unit No.
Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	11. Contract or Grant No. HPR-PL-1(37)329
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Arizona Department of Transportation 206 S. 17th Avenue Phoenix, Arizona 85007	Final: January 1990 to May 1992
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

A recent study on the performance of guardrail-to-bridge rail transitions revealed that many widely used designs do not meet current safety standards. As a result, the Federal Highway Administration (FHWA) requested that the Arizona Department of Transportation verify the safety performance of its standard transition designs. Three transition designs currently being used by ADOT were evaluated through a combined program of computer simulation and full-scale crash testing. The standard ADOT wood post transition, incorporating a channel rubrail and two different sizes of timber posts at a reduced post spacing near the bridge rail end, was found to be in compliance with National Cooperative Highway Research Program (NCHRP) Report 230 performance criteria. The standard ADOT steel post transition with channel rubrail was also found to be in compliance with NCHRP Report 230 requirements when impacted near the end of the bridge rail. However, the upstream end of the steel post transition required modification to eliminate deficiencies identified during testing. The modified design, which terminated the channel rubrail behind a W6x9 guardrail post, was successfully crash tested.

The third transition design evaluated was the standard ADOT steel post system with a 6 inch curb extending along the length of the transition. When tested, this system failed to meet NCHRP Report 230 test criteria. Significant modifications were made to the design including the addition of a rubrail section and tubular steel blockouts near the bridge end. This modified design was successfully tested in accordance with NCHRP Report 230 recommendations. In an effort to assess the risk posed by the current design, an additional test on the unmodified system was conducted using impact conditions of 60 mph and 20 degrees. The steel post system with curb successfully passed this crash test, indicating that there is no need to establish a retrofit program. It is recommended that the wood and steel post systems with curb, as well as the steel post system with rubrail and without curb, be retrofit or replaced as they are damaged and reconstructed.

17. Key Words	18. Distribution Statement	23. Registrant's Seal
approach rail, transition, guardrail, bridge rail/parapet, computer simulation, crash test, highway safety	No restrictions. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161	Registered Professional Engineer (Civil) CERTIFICATE NO. 24602 DEAN L. SICKING Date Signed 6-30-93 ARIZONA, U.S.A.

19. Security Classification	20. Security Classification	21. No. of Pages	22. Price
Unclassified	Unclassified	193	

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

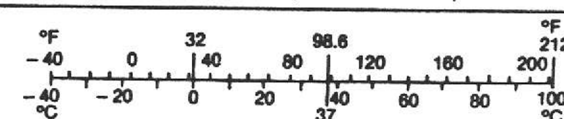
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	centimetres squared	cm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
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.

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

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
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		
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)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
		VOLUME		
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)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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

* SI is the symbol for the International System of Measurements

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

During the time when steel and aluminum bridge rails were common, numerous transition designs were implemented throughout the country. These relatively flexible bridge rails were not as demanding on transition designs as today's concrete barriers and, for this reason, little effort was directed at identifying the necessary stiffness or the critical impact conditions for these approach barriers. However, as rigid bridge rails such as the concrete safety-shaped barrier (CSSB) replaced metal designs, early transition standards were often retained.

In a recent study (1), a major crash test program was undertaken to evaluate the impact performance of guardrail-to-bridge rail transitions, many of the widely used designs were found to be inadequate. In an effort to eliminate this problem, the Federal Highway Administration (FHWA) issued Technical Advisory (TA) T5040.26 on the subject of guardrail transitions in January of 1988. Contained within this TA was a description of several transition systems which were successfully crash tested. The FHWA directed all state highway agencies to either adopt one of the tested designs or demonstrate the safety of their standard designs through full-scale crash testing. As a result, the Arizona Department of Transportation (ADOT) contracted with the Texas Transportation Institute (TTI) to analyze and test their standard designs.

Thus, the primary objective of this study was to evaluate the safety performance of ADOT's guardrail-to-bridge rail designs and to develop and test retrofit design modifications to alleviate the deficiencies of systems identified as substandard. The research approach, analysis procedures, and full-scale crash test results are presented in the sections which follow.

RESEARCH APPROACH

The basic configuration comprising the ADOT transitions incorporates a W-beam rail element mounted on posts with a reduced spacing of 3 ft.-1 1/2 in. The W-beam rail extends 12 ft.-6 in. onto the traffic face of the concrete bridge parapet at which point it is terminated with a standard 10 ga. terminal end shoe. Specially fabricated steel blocks spaced at 3 ft.-1 1/2 in. are used to block out the W-beam from the face of the concrete barrier. The steel spacers are connected to the concrete parapet using fabricated steel anchors embedded in the concrete. The concrete bridge rail is 32 inches in height and has a standard safety-shaped profile. Although the upper face of the barrier is maintained at a constant slope, the lower slope of the barrier transitions to a vertical wall over the last 12 ft.-6 in.

The ADOT transition systems which were evaluated in this study were essentially variations of this basic design. The variations include the use of either steel or wood guardrail posts in conjunction with either a lower rubrail or curb. The rubrail option incorporates a 25 ft. section of C6x8.2 rubrail mounted at a height of 12 inches. The rubrail is attached to every other post in the transition and is anchored to the concrete barrier. The curb option has a 6 inch curb which extends from the concrete barrier. The face of the curb aligns with the traffic face of the W-beam barrier. Both steel and wood guardrail posts can be used with these systems. The steel post systems utilize two W8x21 structural steel posts with an embedment depth of 68 inches adjacent to the concrete bridge rail to help transition the lateral of the guardrail. The other five posts in the transition are standard W6x9 posts with a 44 inch embedment. The W-beam rail is mounted at a height of 27 inches and is blocked out from the posts using standard W6x9 steel blockouts.

The first two posts adjacent to the concrete barrier in the wood post option are 10"x10"x6'-6" timbers with an embedment depth of 50 inches. The additional posts in the transition are 8"x8"x5'-4" with a standard embedment of 36 inches. The W-beam is blocked out from these posts using 6"x8"x14" wood blocks. It should be noted that, in order to accommodate the dimensions established by the rubrail and steel spacer blocks on the face of the concrete barrier, the blockouts are oriented sideways. Thus, both the steel and wood post systems provide a blockout distance of 6 inches.

These transition systems showed promise for meeting the test requirements of National Cooperative Highway Research Program (NCHRP) Report 230 (2). Use of a rubrail and blockouts minimizes the potential for wheel snagging on the guardrail posts or bridge rail end and the stronger posts immediately upstream from the bridge end help limit dynamic deflections and, thus, prevent vehicle pocketing. However, there were some concerns that warranted the analysis, testing, and evaluation of these designs. For instance, the single W-beam rail element had the potential for yielding locally and permitting structural components of the vehicle to snag on the fabricated steel blocks and/or the end of the concrete bridge rail. The ability of the concrete insert assemblies and rubrail anchorage to withstand a severe impact was also a concern. Additionally, it was uncertain to what extent the presence of the curb would degrade the performance of the transition.

The only way to definitively determine if a transition design can comply with current impact performance standards is through full-scale crash testing. However, in order to help establish a rational test matrix and eliminate the need for unnecessary full-scale tests, computer simulation techniques were used to augment the crash test program. Using computer simulation, a preliminary analysis of the transition systems was performed to identify potential weaknesses and to determine critical impact locations for each system. Additionally, when a system was found to be substandard, computer simulation was used to evaluate potential improvements and to help identify the limits of performance of the existing system.

The computer simulation model used in this study was the Barrier VII program (3). Barrier VII has been used very successfully for analyzing and designing a number of transitions from flexible to rigid barriers (1,4,5,6). The program has been proven to accurately predict maximum barrier deflections and degree of snagging, and to identify critical impact locations for various transition designs.

It should be noted that special considerations had to be taken into account when modeling the W-beam attachments on the face of the concrete barrier. Due to the presence of the fabricated steel blocks in the ADOT designs, the W-beam is initially free to deflect in the vicinity of the concrete barrier end. However, when the W-beam contacts the rigid barrier, a sudden high lateral resistance is developed. A series of pinned links and springs was used to model this behavior. Typical Barrier VII input used for the simulation of the ADOT transitions is shown in Appendix A.

After the transition designs had been modeled, the impact performance of each system was evaluated based on simulation results. The primary concern regarding the safety performance of a transition is that under severe impact conditions, the barrier will deflect sufficiently to allow pocketing or snagging on the end of the stiffer barrier. Vehicle pocketing is associated with excessive barrier deflections which permit the front of the vehicle to impact the end of the stiffer barrier. Snagging is a more common problem and can occur in two forms. A vehicle's wheel can contact a post or barrier end, or the stiff structural components of the vehicle can contact a barrier end, blockout, or post. Note that the point of impact can significantly affect the degree in which each of these events occurs. The critical impact point for a transition is defined as the location which maximizes wheel or frame snagging on the end of the stiffer system. Although NCHRP Report 230 recommends impacting a transition 15 feet upstream from the end of the second and more laterally stiff system, this number was not originally intended for transitions to rigid concrete barriers. Recent simulation and testing of transitions to rigid barriers has shown that the critical impact point for a transition to a rigid bridge rail is somewhat less than this value. In actuality, the critical impact location changes with the stiffness of the approach guardrail. Stiff approach barriers redirect impacting vehicles more quickly and, therefore, have a critical impact point nearer to the end of the rigid rail that do more flexible approach barriers.

Thus, the first step in the Barrier VII analysis was to determine the critical impact location for the ADOT transition designs. This was accomplished by simulating a number of impacts along the length of the barrier and determining which location maximized the potential for snagging on the exposed end of the bridge rail. The impact conditions used in these simulations corresponded to test designation 30 in NCHRP Report 230 which is the recommended test for evaluating the performance of a transition treatment. Test 30 is a structural adequacy test which involves a 4500 lb vehicle impacting the barrier at a speed of 60 mph and an angle of 25 degrees. These conditions examine the strength of the transition and its ability to contain and redirect an impacting vehicle.

Barrier VII indicated that the critical impact location for both the steel and wood post transition designs was approximately 6 ft. upstream from the end of the concrete barrier. This impact point was subsequently used for all simulation and testing of the ADOT transitions.

It should be noted that in most transition designs, a secondary transition exists at the point where the transition treatment begins and the standard guardrail ends. In the ADOT design, this point corresponds to the location where the rubrail begins. Barrier VII simulations of this upstream transition indicated that the critical impact location for a large car impact was approximately 10 ft. upstream from the beginning of the rubrail. These simulations evaluated the potential for wheel snagging on the end of the rubrail and on intermediate guardrail posts. The expected performance of this system, based on the simulation results, was poor due to the high probability of severe snagging on the end of the rubrail section and the post to which it was attached.

Test Matrix Selection

Based on the Barrier VII simulation runs, it was concluded that the basic transition configuration had a high probability of passing NCHRP Report 230 test requirements. Simulation results indicated that the W-beam rail would yield locally in bending and tension, thus permitting some vehicle snagging to occur on the first steel blockout mounted on the concrete parapet. However, the degree of frame and wheel snagging predicted was not significant enough to impart unsatisfactory decelerations to the vehicle. Furthermore, predicted strains for the yielded rail did not exceed the rated ductility of the W-beam, indicating that rupture of the rail was unlikely. Additionally, deflected barrier shapes showed no evidence of vehicle pocketing, and the predicted maximum dynamic rail deflection was only 10 inches.

However, potential problems related to some of the design variations were identified. For instance, there was concern about the propensity for the W6x9 blockouts used in the steel post system to collapse under the combined longitudinal and lateral loading experienced during a transition test. Such behavior would tend to increase the lateral barrier deflection, resulting in increased vehicle snagging. On the other hand, simulation results for the wood post system indicated that the shear capacity of one or more posts in the transition could be exceeded due to combined longitudinal loads from the W-beam and channel rail elements. Failure of this type would significantly increase barrier deflection and could result in vehicle pocketing, severe decelerations, or other unacceptable results. For this reason, the steel post system with channel rubrail was deemed to have the highest probability of passing NCHRP Report 230 test requirements and was, therefore, the first transition system tested. It was believed that this test would not only provide a good assessment of the impact performance of the basic transition configuration, but would additionally examine the integrity of the concrete insert anchors to which the fabricated steel blocks and rubrail were attached.

As mentioned previously, the simulation results indicated poor impact performance for the upstream transition point. Considerable wheel snagging on post 7 (i.e. the post at which the rubrail began) and other intermediate posts was predicted for both the wood and steel post systems. This was due to the fact that post 7 was restrained at the top by the W-beam and at the bottom by the rubrail, thus decreasing deflections at this point and causing a pocketing behavior to occur. Of the two post types, the steel post system was considered to be more critical. The blockouts on the standard G4(2W) guardrail upstream from the transition are 8 inches in depth, as opposed to the 6 inch blockout distance provided by the W6x9 blockouts used in the standard G4(1S) guardrail. Thus, the predicted degree of snagging on the intermediate guardrail posts upstream from the transition was less severe for the wood post system. Furthermore, the wood post system utilized 8"x8" timber posts in the transition region which tended to "shield" the exposed end of the rubrail. In the steel post design, however, the rubrail end extends slightly beyond the end of the flange of the W6x9 steel post and, therefore, represented a more severe hazard. Additionally, as mentioned above, the W6x9 steel blockouts have a tendency to collapse during impact, thus increasing the degree of snagging on the post and rubrail end.

There was also concern regarding the performance of the transition with a curb. Analysis indicated that the curb would impart a significant vertical motion to the test vehicle. This vertical motion had the potential for raising the effective barrier loading height and, as a result, increasing the bending moments at the base of the guardrail posts. Such behavior would tend to increase barrier deflections and lead to increased vehicle snagging on the end of the bridge rail and first fabricated steel blockout.

The potential problems identified above were discussed with ADOT personnel. These and other factors were taken into consideration when formulating the test matrix used in the crash testing phase of this study. As needed, the test matrix was modified to incorporate testing of retrofit designs when standard systems were found to be deficient. Crash test procedures and test results are presented in detail in the sections which follow.

CRASH TEST PROCEDURES

The crash test procedures used in this study were in accordance with guidelines outlined in NCHRP Report 230. The test vehicle was instrumented with three rate transducers to measure roll, pitch, and yaw rates and a triaxial accelerometer near the vehicle center of gravity to measure acceleration levels.

The electronic signals from the accelerometers and transducers were telemetered to a base station for recording on magnetic tape and for display on a real-time strip chart. Provision was made for transmission of calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Contact switches on the bumper were actuated just prior to impact by wooden dowels to determine an elapsed time over a known distance. This information provided a measurement of vehicular impact velocity. In addition, the initial contact produced an "event" mark on the data record to establish the exact instant of impact.

Photographic coverage of the tests included three high-speed cameras, one perpendicular to the installation, one behind the rail pointing downstream of the impact point and a third camera located overhead near the point of impact. The films from these high-speed cameras were used to observe phenomena occurring during collision and to obtain time-event, displacement and angular data. A 3/4-inch video recorder and 35-mm still cameras were also used for documentary purposes.

Data Analysis Procedures

The analog data from the accelerometers and transducers were digitized, using a microcomputer, for analysis and evaluation of performance. The digitized data were then analyzed using the computer programs DIGITIZE and PLOTANGLE. 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, final occupant displacement, and highest 0.010-second average accelerations. The DIGITIZE program also calculates vehicle impact velocity, change in vehicle velocity at the end of a given impulse period, and maximum average 0.050-second accelerations along each of three primary vehicle axes.

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate charts to compute and plot angular displacements versus time. It should be noted that these angular displacements are sequence dependent with the sequence being yaw-pitch-roll for the data presented in this report. Furthermore, the displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system corresponding to the conditions which existed at initial impact.

CRASH TEST RESULTS

Standards for testing barrier transitions are presented in NCHRP Report 230. This report requires that transitions be evaluated with a single test which involves a vehicle impacting the more flexible barrier upstream from its transition to the second and more laterally stiff system. The ADOT transitions were evaluated for impact performance in accordance with NCHRP Test Designation 30. Test 30 consists of a 4,500 lb vehicle impacting the transition system at 60 mph and an angle of 25 degrees. As mentioned previously, this test is considered primarily a strength test which examines the ability of the transition to contain and redirect the impacting vehicle. In addition, this test investigates the propensity for the more flexible barrier to deflect and allow the test vehicle to snag on or pocket behind the end of the stiffer barrier.

In total, nine full-scale crash tests were conducted during the course of this study. Results of these tests and descriptions of the test installations are presented below. It should be noted that the transition installations were impacted at critical impact locations as determined by computer simulation.

Test 7155-1

The purpose of Test 1 was to evaluate the performance of ADOT's standard steel post guardrail transition to a concrete bridge barrier. The basic transition installation consisted of a standard W-beam and channel rubrail mounted on steel posts. The first post in the transition (post 7) was spaced at the standard 6 ft.-3 in., with all other posts in the transition being spaced at 3 ft.-1 1/2 in. intervals. In addition, two different posts were used to help transition the lateral strength of the guardrail. The first two posts adjacent to the concrete bridge rail were W8x21 with an embedment depth of 68 inches. The other five posts in the transition were standard W6x9 with a 44 inch embedment. The W-beam was mounted at a height of 27 inches and was blocked out from the posts with W6x9 steel blockouts. The 25 ft. section of C6x8.2 rubrail was mounted at a height of 12 inches and was attached to the flange of every other post and anchored on the concrete rail. The concrete bridge rail was 32 inches in height and had a standard safety-shaped profile. Although the upper face of the concrete rail was maintained at a constant slope, the lower slope of the barrier was transitioned to a vertical wall over a distance of 12 ft.-3 in. The W-beam guardrail was extended onto the concrete barrier a distance of 12 ft.-6 in. and was blocked out from the rail with specially fabricated steel spacers. The steel spacers were connected to the concrete wall using fabricated steel anchors embedded in the concrete. Details of the overall transition design, as tested in this study, are shown in Figure 1. The completed test installation is shown in Figure 2.

Results

A 1983 Buick Electra (shown in Figure 3) impacted the transition 7.0 feet (2.1 m) upstream of the concrete bridge rail end at 62.1 miles per hour (99.9 km/h) and at an angle of 25.0 degrees using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 pounds (2,041 kg). The lower edge of the vehicle bumper was at a height 13.0 inches (33.0 cm) and the top of the bumper was at a height of 21.8 inches (54.6 cm). Other dimensions and pertinent information on the vehicle are given in Figure 4.

The vehicle was free wheeling and unrestrained just prior to impact. At approximately 0.087 seconds, the front of the vehicle came into contact with the end of the concrete bridge rail. After 0.181 seconds, the vehicle had been redirected and was traveling parallel to the transition. The vehicle lost contact with the rail approximately 0.358 seconds after impact, traveling at a speed of 40.9 miles per hour (65.7 km/h) and at an exit angle of 8.9 degrees. After the vehicle exited the installation, the brakes were applied and the vehicle came to rest approximately 150.0 feet (45.7 m) from the point of impact. Sequential photographs of the test are shown in Figure 5.

As shown in Figure 6, the transition and concrete bridge rail sustained only minor damage. The maximum permanent residual deformation in the rail was 5.3 in (13.3 cm) and the maximum lateral dynamic rail deflection was observed to be 8.5 inches (21.6 cm). The vehicle was in contact with the installation for a total length of 16.0 feet (4.9 m). The steel blockout on post number 1 collapsed during the impact allowing the vehicle's tires to scrub the end of the concrete barrier. However, the presence of the rubrail prevented any significant wheel snagging from occurring. There was evidence of some minor snagging on the first blockout on the concrete barrier, but no significant decelerations were experienced

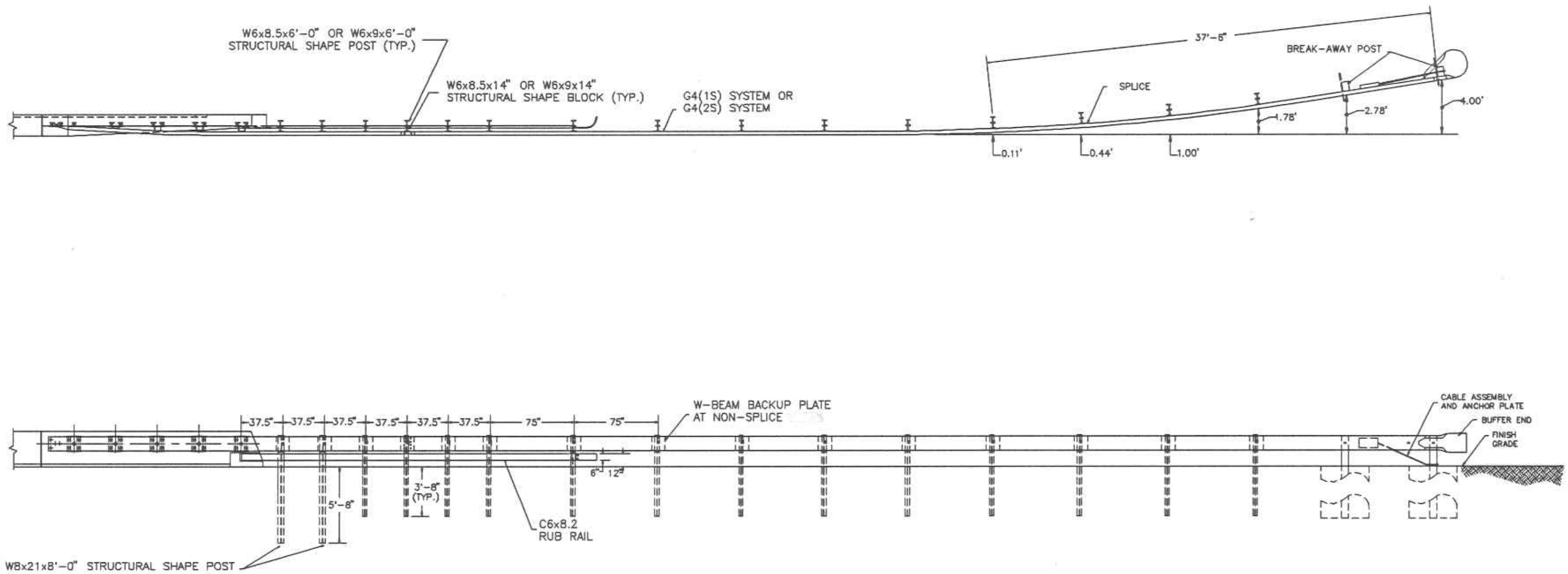


Figure 1. ADOT steel post transition without a curb

Figure 2. Arizona guardrail transition to concrete barriers before test 7155-1

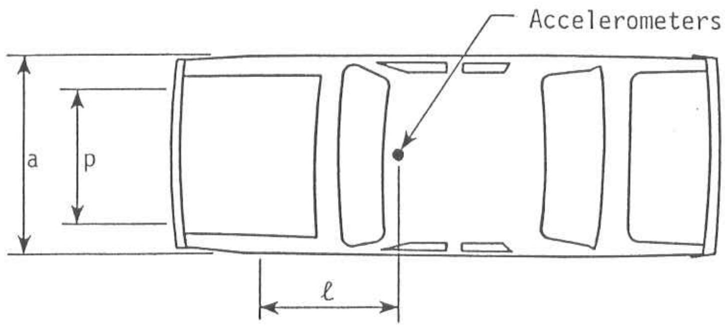
Figure 3. Vehicle before test 7155-1

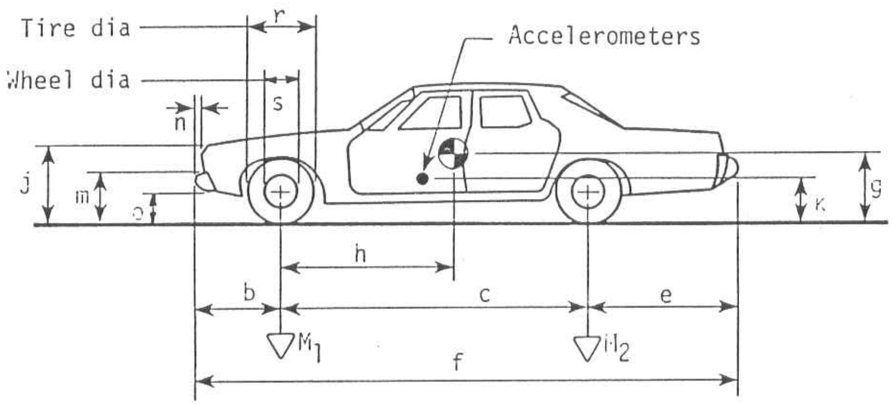
Date: ______ Test No.: 7155-1 VIN: 1G4AX69NDH410919

Make: Buick Model: Electra Year: 1983 Odometer: 28864.0

Tire Size: P225/75R15 Ply Rating: ______ Bias Ply: ___ Belted: ___ Radial: X

Tire Condition: good ___
fair ___
badly worn ___





Vehicle Geometry - inches

a	76	b	43 1/2
c	118 1/2	d*	57
e	56 1/2	f	218 1/2
g		h	52 1/2
i	----	j	33 1/2
k	19 1/2	ℓ	35
m	21 1/2	n	5
o	13	p	62
r	27 1/2	s	16 1/4

Engine Type: V-8

Engine CID: 350 Diesel

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

Body Type: 4-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

4-wheel weight for c.g. det. ℓf 1236 rf 1270 ℓr 980 rr 1014

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2410	2506	
M_2	1709	1994	
M_T	4119	4500	

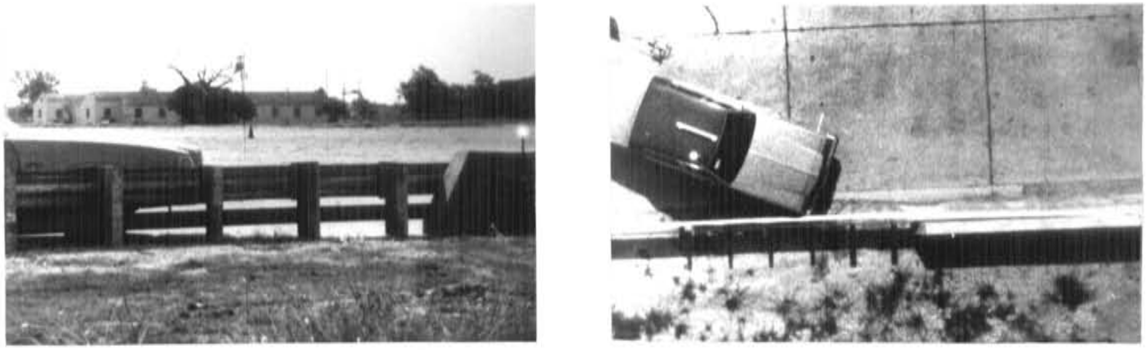
Note any damage to vehicle prior to test:

______

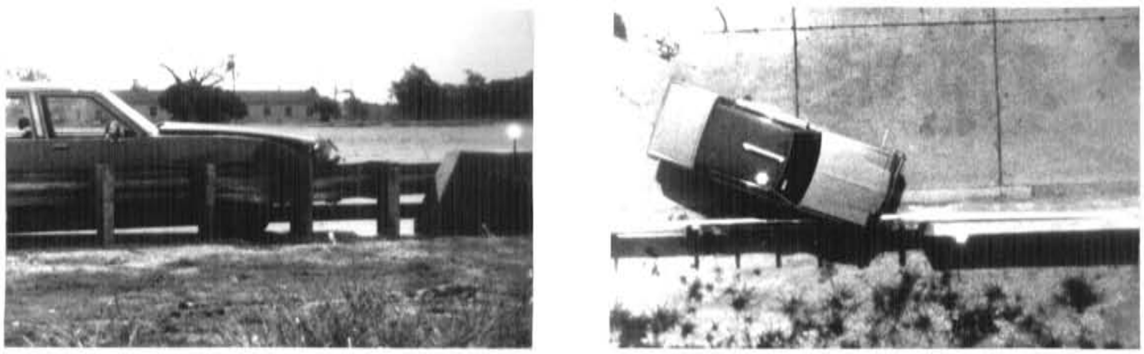
______

*d = overall height of vehicle

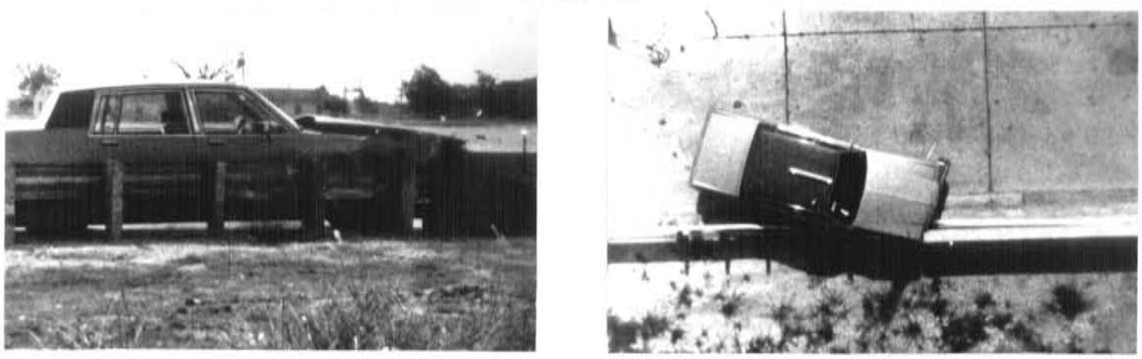
Figure 4. Vehicle properties (test 7155-1).



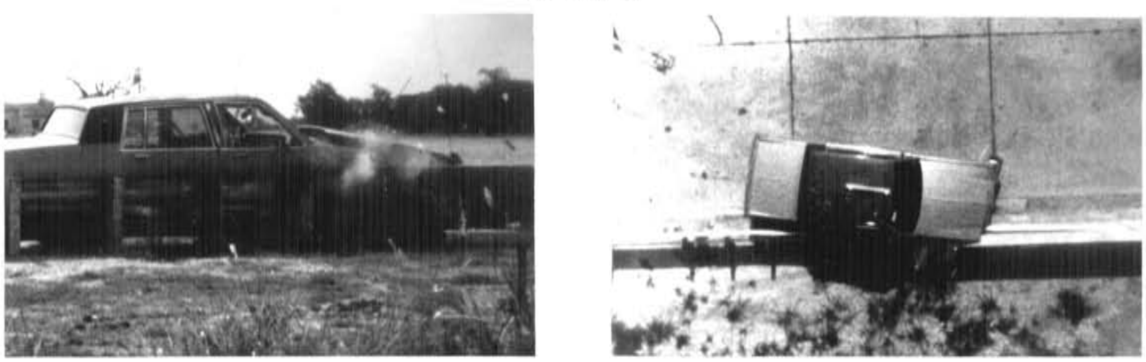
0.000 s



0.050 s

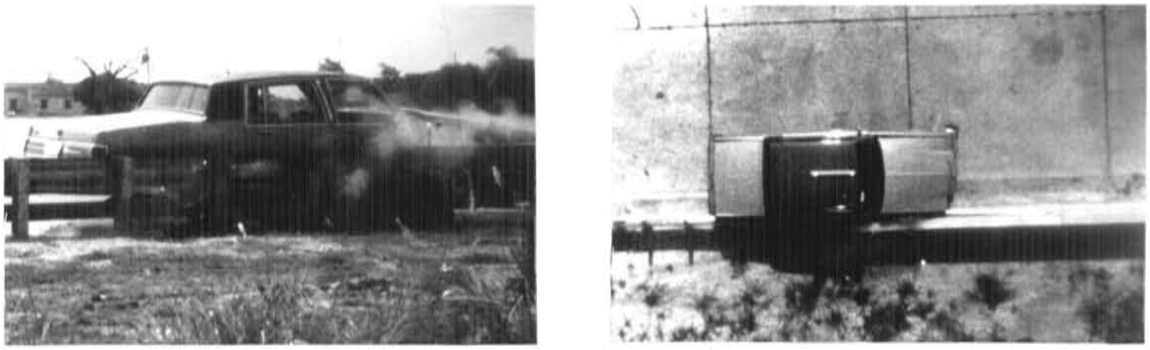


0.100 s

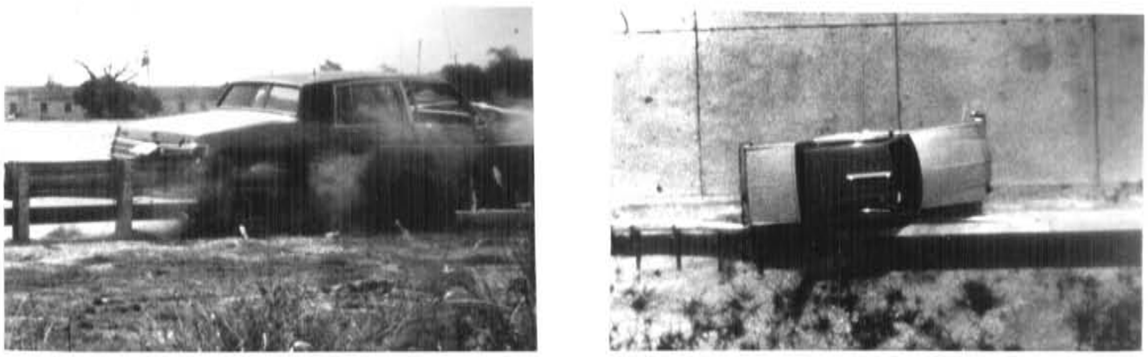


0.150 s

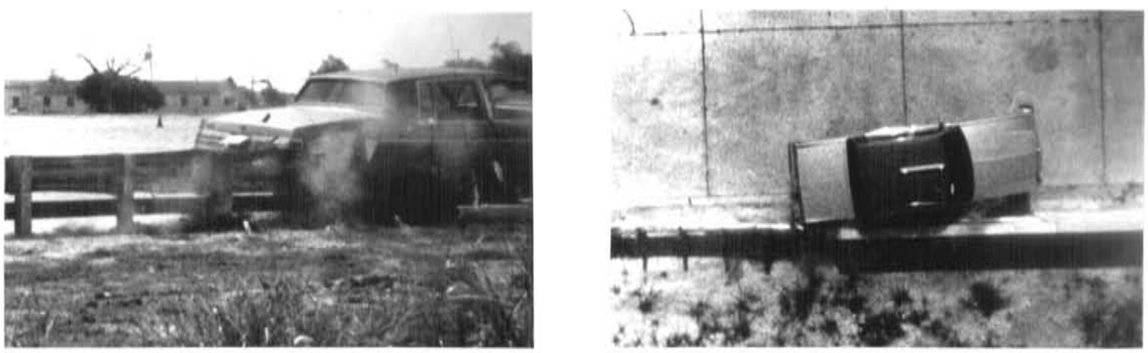
Figure 5. Sequential photographs for test 7155-1.



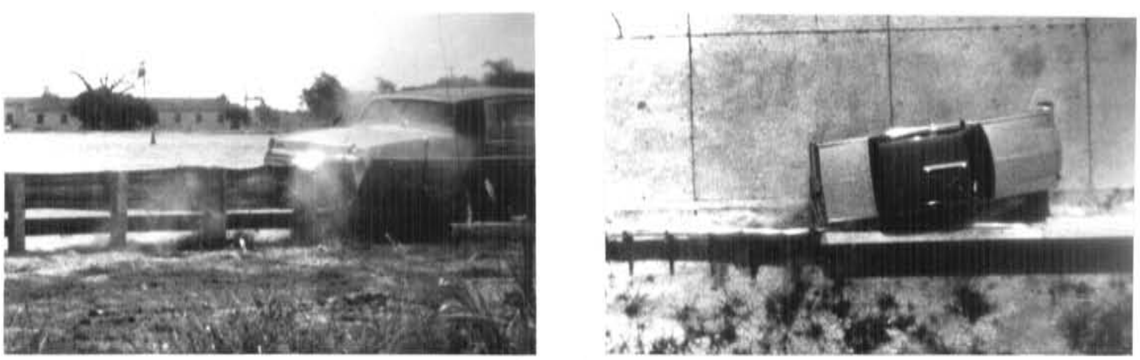
0.200 s



0.250 s



0.300 s



0.350 s

Figure 5. Sequential photographs for test 7155-1 (continued).

Figure 6. Arizona guardrail transition to concrete barrier after test 7155-1

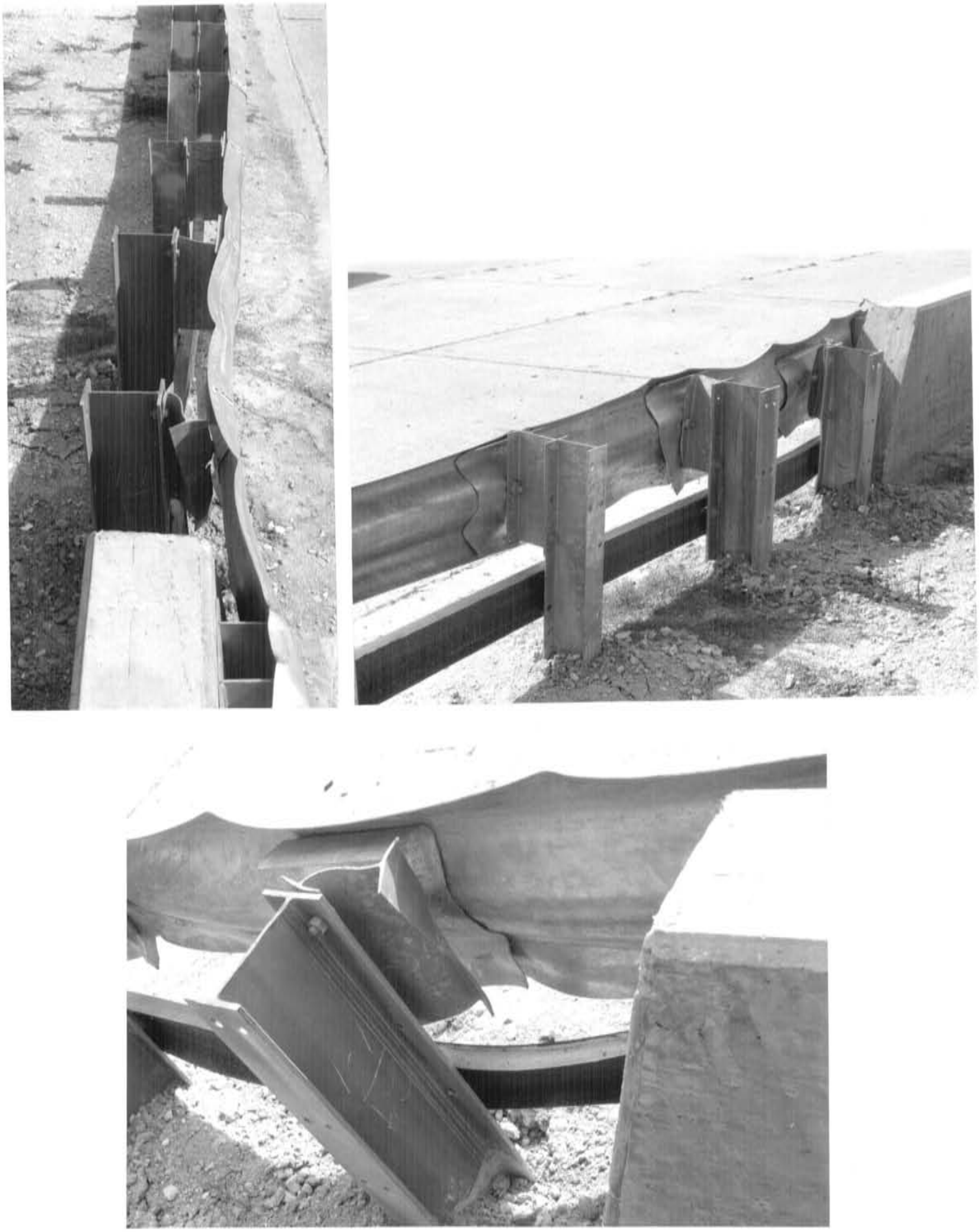


Figure 6. Arizona guardrail transition to concrete barrier after test 7155-1 (continued)

by the test vehicle. The concrete anchor inserts performed as designed with no visible signs of distress after the impact.

Damage to the vehicle is shown in Figure 7. The maximum crush was 18.0 inches (45.7 cm) at the right front corner of the vehicle. The right front wheel and control arm were bent and pushed rearward 13.0 inches (33.0 cm). The entire front end of the vehicle was shifted to the left 5.0 inches (12.7 cm).

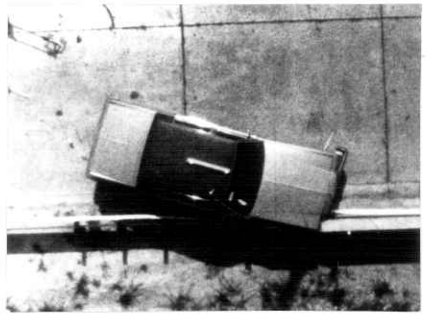
A summary of the test results and other information pertinent to this test are given in Figure 8. The maximum 0.050-second average accelerations experienced by the vehicle were -8.9 g in the longitudinal direction and 10.2 g in the lateral direction. Angular displacements of the vehicle are plotted in Figure 9, and accelerometer traces are displayed in Figures 10 - 12. Occupant impact velocity was 28.7 feet per second (8.8 m/s) in the longitudinal direction and -24.7 feet per second (7.5 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were -5.3 g (longitudinal) and 17.3 g (lateral). It should be noted that the occupant risk evaluation criteria reported above are not applicable in the performance assessment of this test and are reported for information purposes only. However, it is noteworthy to mention that all occupant risk criteria were below the maximum limit set forth in NCHRP Report 230.

In summary, the test was judged to be a success. The installation successfully contained and redirected the vehicle. The vehicle remained upright and stable during the initial test period and after leaving the installation. There was no debris or detached elements that would pose a hazard to other traffic, and deformation of the occupant compartment was minimal. Although the velocity change of 21.2 miles per hour (34.1 km/h) was higher than the recommended limit of 15 miles per hour established in NCHRP Report 230, this criterion is not applicable since the vehicle steered back into the barrier and was not redirected into adjacent traffic lanes. The exit angle of the vehicle was measured to be 8.9 degrees, which is less than 60 percent of the impact angle as recommended by NCHRP Report 230.

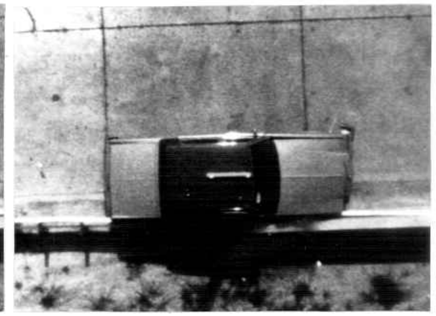
It should also be noted that the concrete anchor inserts for the fabricated steel blocks and rubrail terminal performed as designed with no signs of distress during this severe impact. Numerous tests have also been conducted using through bolt connections and this alternative would also be acceptable in the ADOT transition designs.

Figure 7. Vehicle after test 7155-1

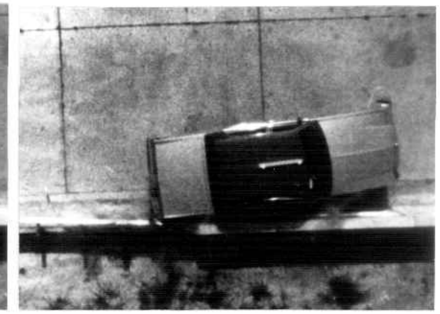
0.000 s



0.100 s



0.200 s



0.300 s

Test No. 7155-1
Date 07/26/90
Test Installation. . . . . .Arizona guardrail
transition to concrete half/barrier
Length of Installation . . .87.5 ft (26.7 m)
Vehicle. . . . . .1983 Buick Electra
Vehicle Weight
Test Inertia . . . . .4,500 lb (2041 kg)
Vehicle Damage Classification
TAD. 01RFQ-5
CDC. 81RFAW2
Maximum Vehicle Crush. . . .18.0 in (45.7 cm)
Max. Dyn. Rail Deflection. . 8.5 in (21.6 cm)
Max. Perm Rail Deformation . 5.3 in (13.3 cm)

Impact Speed . . . . 62.1 mi/h (99.9 km/h)
Impact Angle. . . . . 25.0 degrees
Exit Speed. . . . . 40.9 mi/h (65.8 km/h)
Exit Angle. . . . . 8.9 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . . . . . . -8.9 g
Lateral . . . . 10.2 g
Occupant Impact Velocity
Longitudinal. . . . . . . 28.7 ft/s (8.8 m/s)
Lateral . . . .-24.7 ft/s (7.5 m/s)
Occupant Ridedown Accelerations
Longitudinal. . . . . . . -5.3 g
Lateral . . . . 17.3 g

Figure 8. Summary of results for test 7155-1.

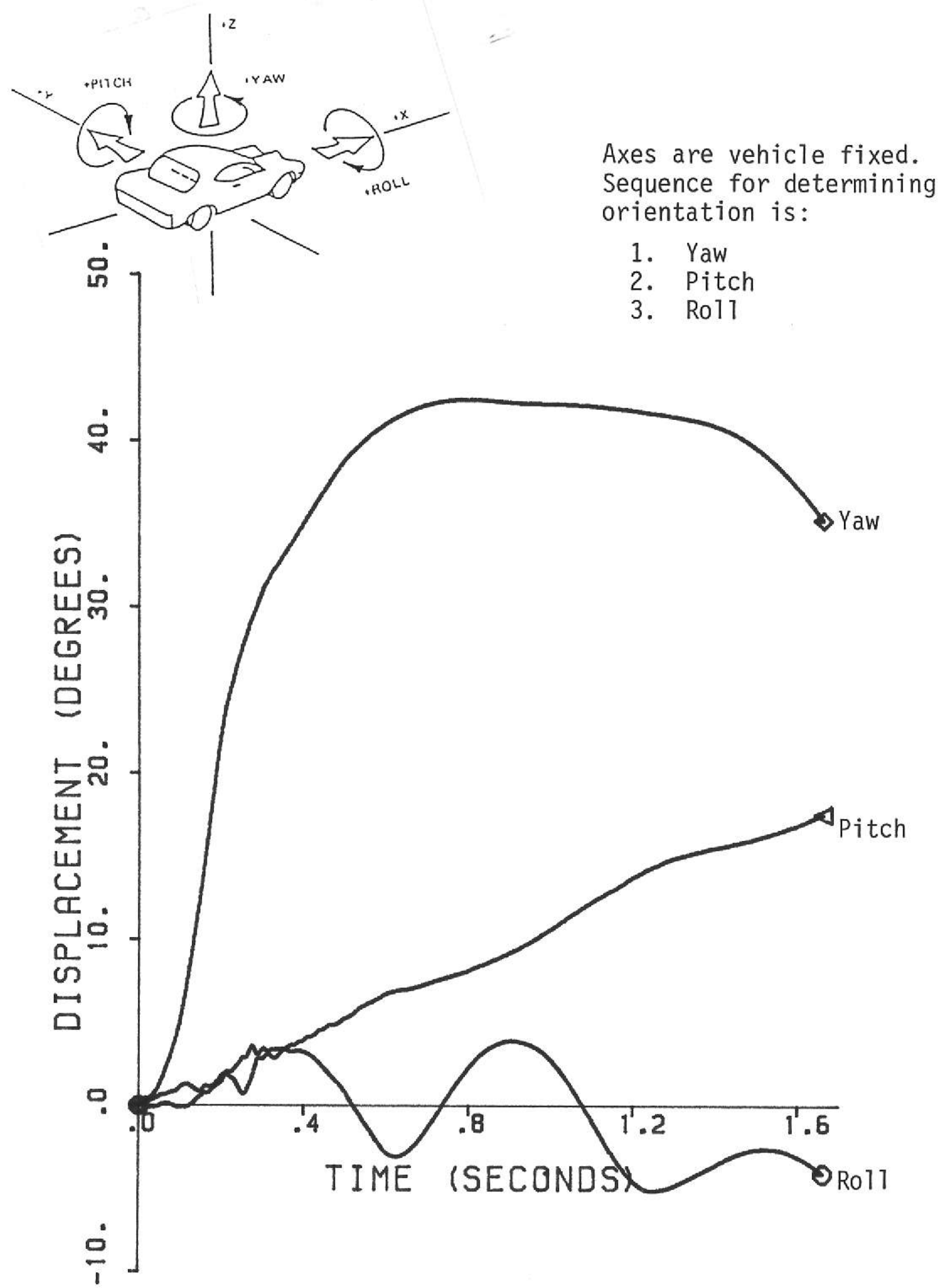


Figure 9. Vehicle angular displacements for test 7155-1

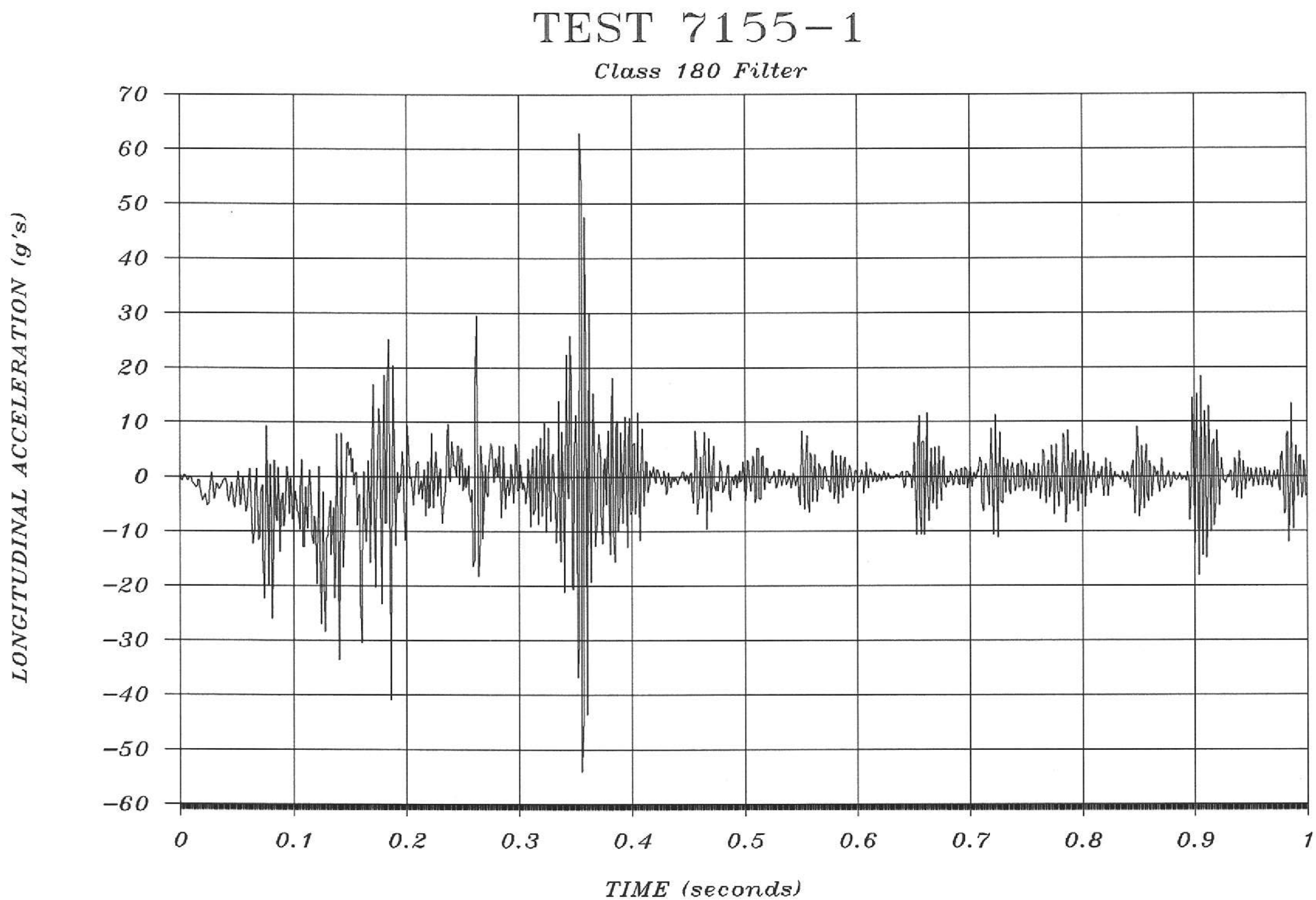


Figure 10. Longitudinal accelerometer trace for test 7155-1

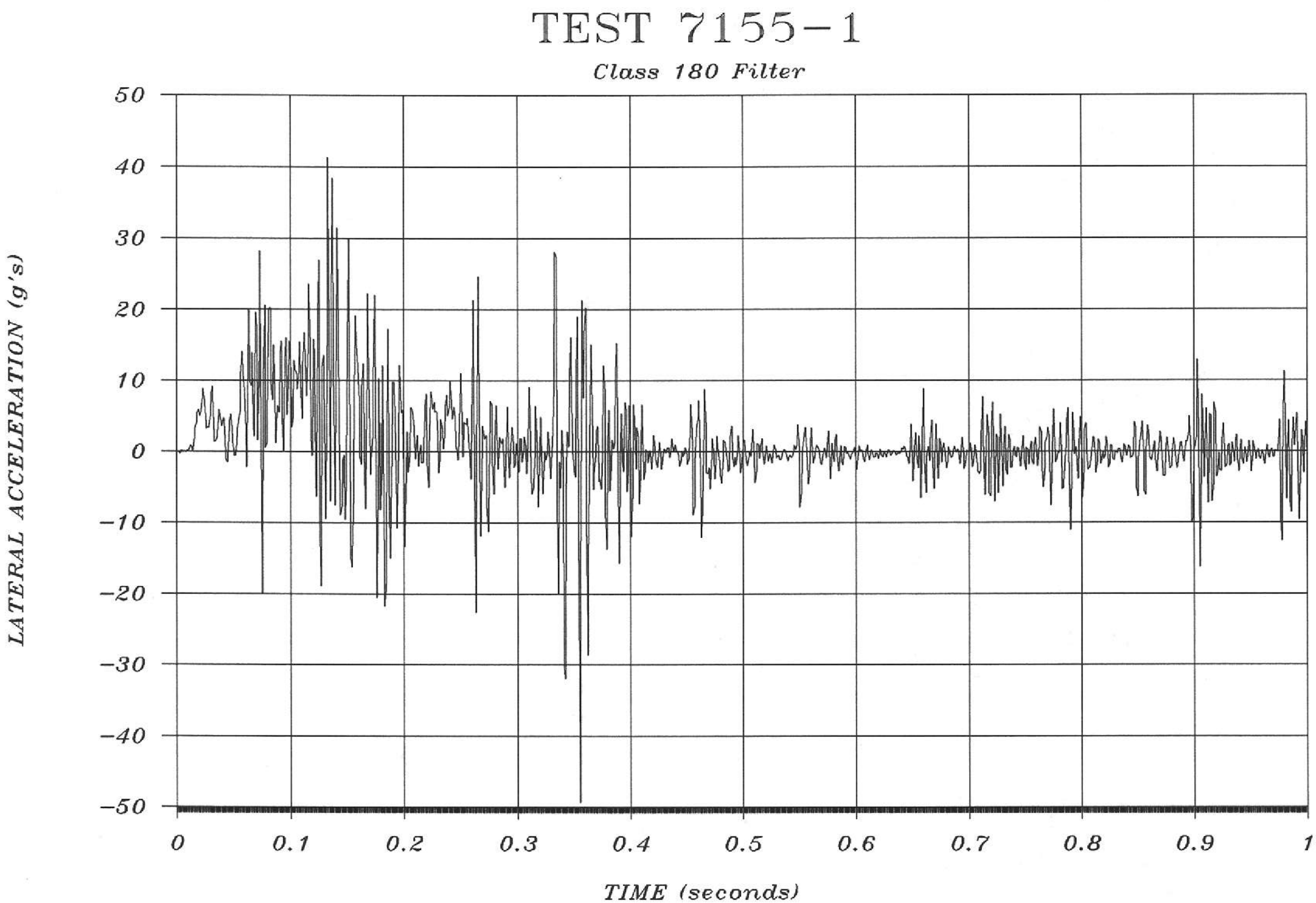


Figure 11. Lateral accelerometer trace for test 7155-1

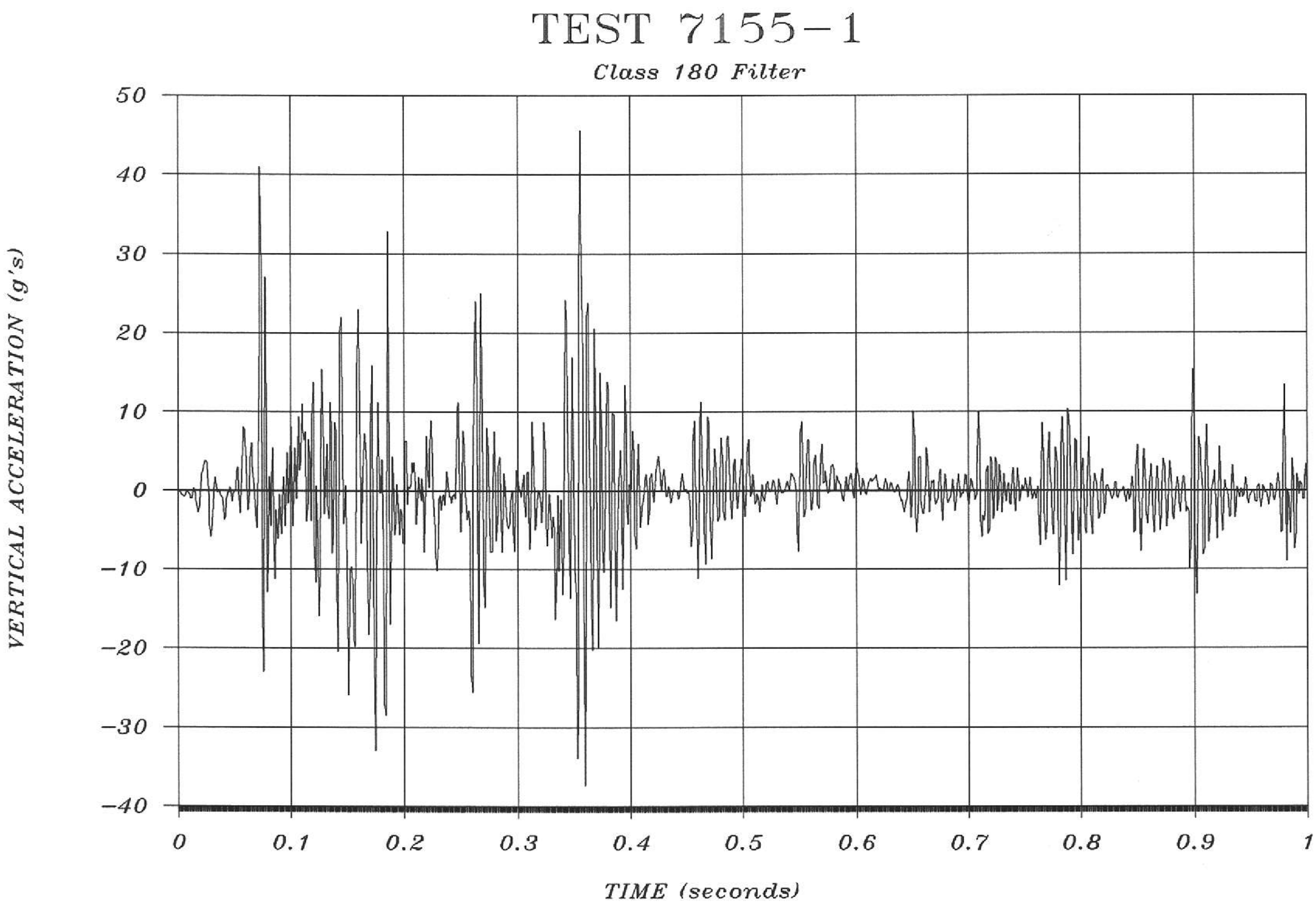


Figure 12. Vertical accelerometer trace for test 7155-1

Test 7155-2

In ADOT's guardrail-to-bridge rail transition design, as with most practical transition systems, the guardrail is first transitioned into an intermediate strength barrier which is then transitioned into the rigid bridge rail. This transition in lateral strength is accomplished by varying the post spacing and post size and through the addition of a rubrail. For proper evaluation of the transition system, the safety performance of the design must be evaluated at both transition points. The purpose of this test was to evaluate the upstream end of the transition at the point where the rubrail begins. The steel post transition was identical to the system tested in Test 1. Upstream of the transition was a standard G4(1S) guardrail. This guardrail consisted of a W-beam mounted on W6x9 steel posts spaced at 6 ft.-3 in. W-beam backup plates were used at all non-splice posts on both the guardrail and transition sections. As per ADOT specifications, rectangular plate washers were used on all posts in the transition region. These and other details of the design are shown in Figure 13. The complete test installation is shown in Figure 14.

Results

A 1981 Oldsmobile Ninety-Eight (shown in Figure 15) impacted 10.0 feet upstream from the beginning of the rub rail at 61.6 miles per hour (99.1 km/h) and at an angle of 26.0 degrees using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 pounds (2,041 kg). The lower edge of the vehicle bumper was at a height of 12.5 inches (31.8 cm) and the top edge of the bumper was at a height of 20.3 inches (51.4 cm). Other dimensions and information pertaining to the vehicle are given in Figure 16.

Just prior to impact, the vehicle was free wheeling and unrestrained. Due to the presence of the rectangular plate washer on the post 7, the W-beam could not disengage from the post. The post, being constrained at the top by the W-beam and at the bottom by the rubrail, did not deflect out of the test vehicle's path. This behavior allowed the vehicle to pocket in front of post 7, resulting in severe snagging on the end of the rubrail and the guardrail post. The vehicle was decelerated to an abrupt stop causing the rear tires to leave the pavement. Sequential photographs of the test are shown in Figure 17.

As shown in Figure 18, the guardrail and transition systems experienced considerable damage. There was residual deformation to the rail in the area of the first seventeen posts.

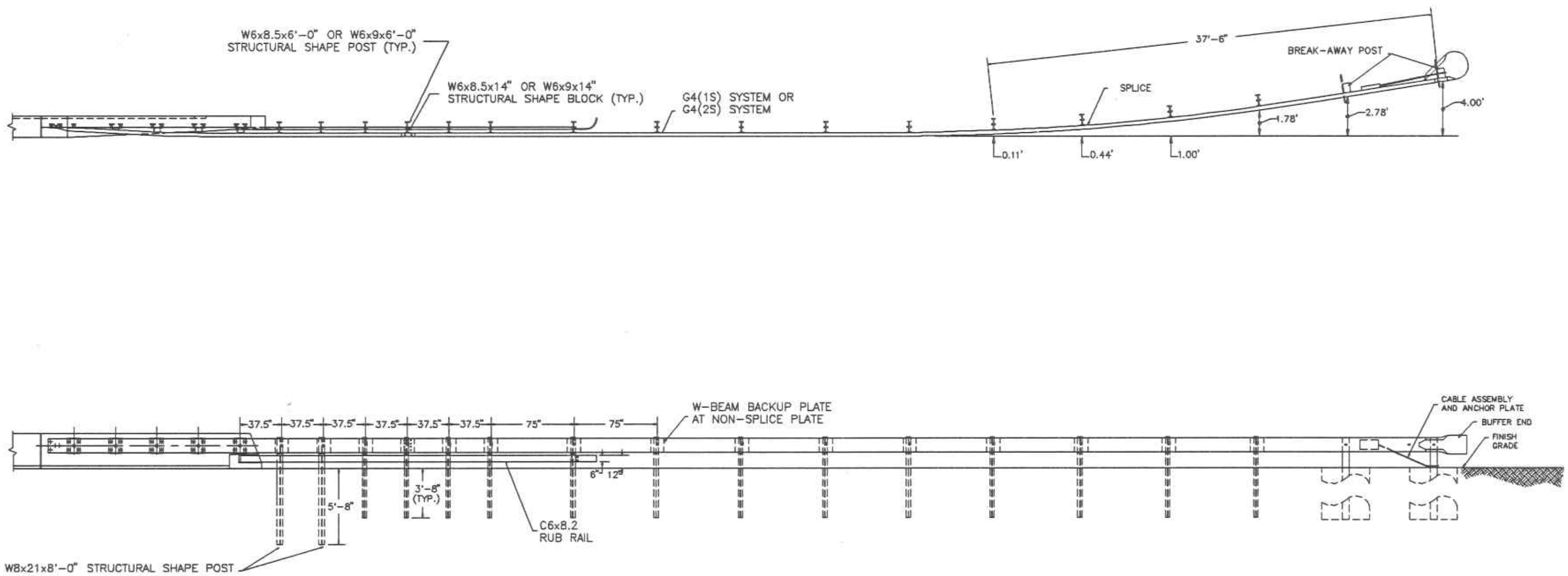


Figure 13. ADOT steel post transition without a curb

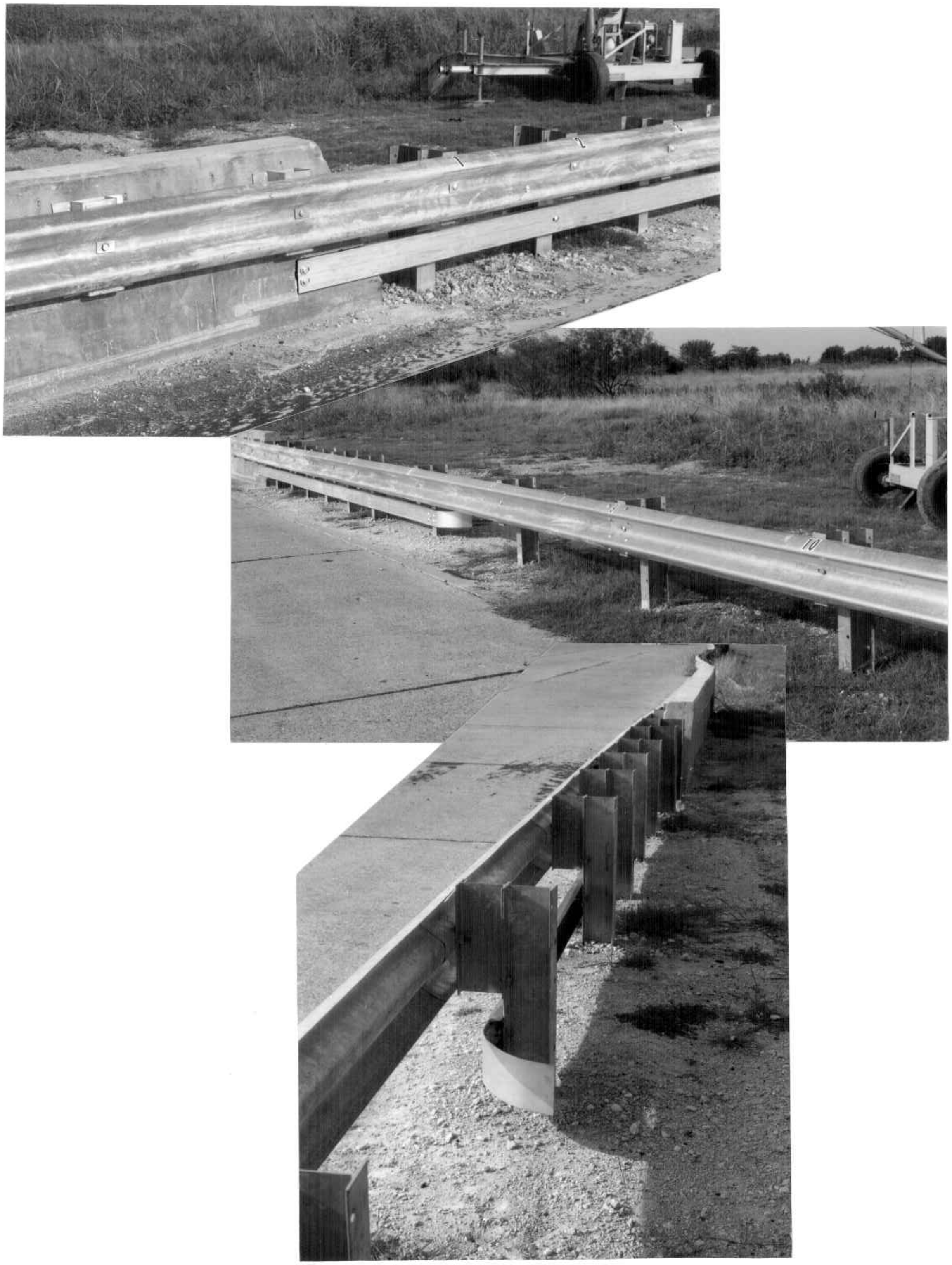


Figure 14. Arizona guardrail transition to concrete barrier before test 7155-2

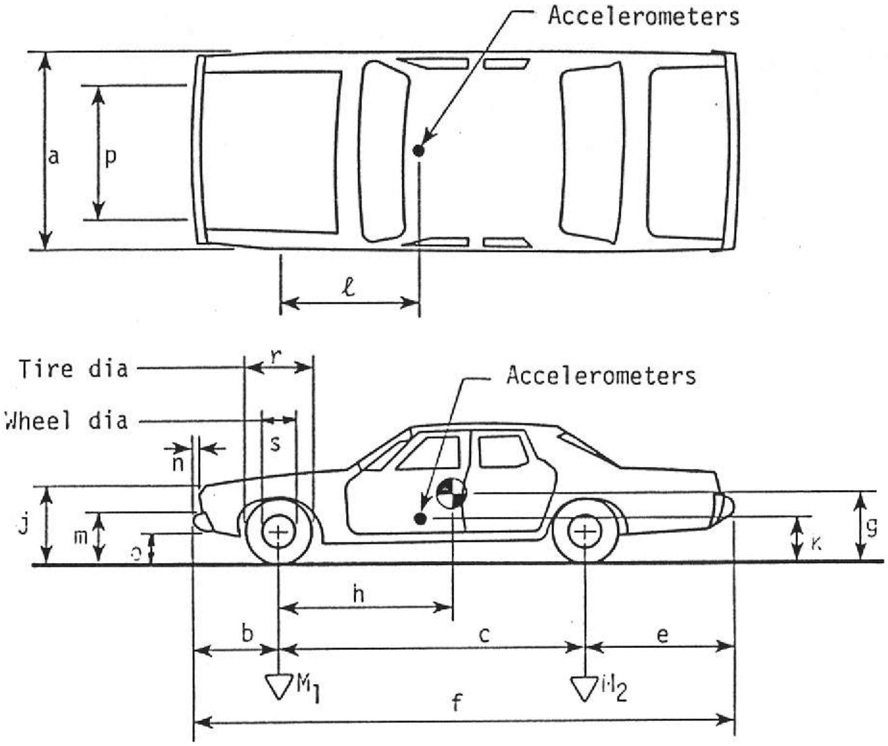
Figure 15. Vehicle before test 7155-2

Date: ______ Test No.: 7155-2 VIN: 163AX69N9BM227751

Make: Olds Model: 98 Regency Year: 1981 Odometer: 94004

Tire Size: P 225 Ply Rating: ______ Bias Ply: ___ Belted: ___ Radial: X

Tire Condition: good ___
fair X
badly worn ___



Vehicle Geometry - inches

a	75 3/4	b	44 1/2
c	119	d*	52 1/2
e	55	f	
g	20 1/2	h	51.9
i	----	j	32 1/2
k		ℓ	34 1/2
m	20 1/4	n	5
o	12 1/2	p	61 3/4
r	28 1/2	s	16 1/8

Engine Type: 350

Engine CID: Diesel

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

Body Type: 4-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

4-wheel weight for c.g. det. ℓf 1260 rf 1277 ℓr 973 rr 990

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2495	2537	
M_2	1596	1963	
M_T	4091	4500	

Note any damage to vehicle prior to test:

______

______

*d = overall height of vehicle

Figure 16. Vehicle properties (test 7155-2)

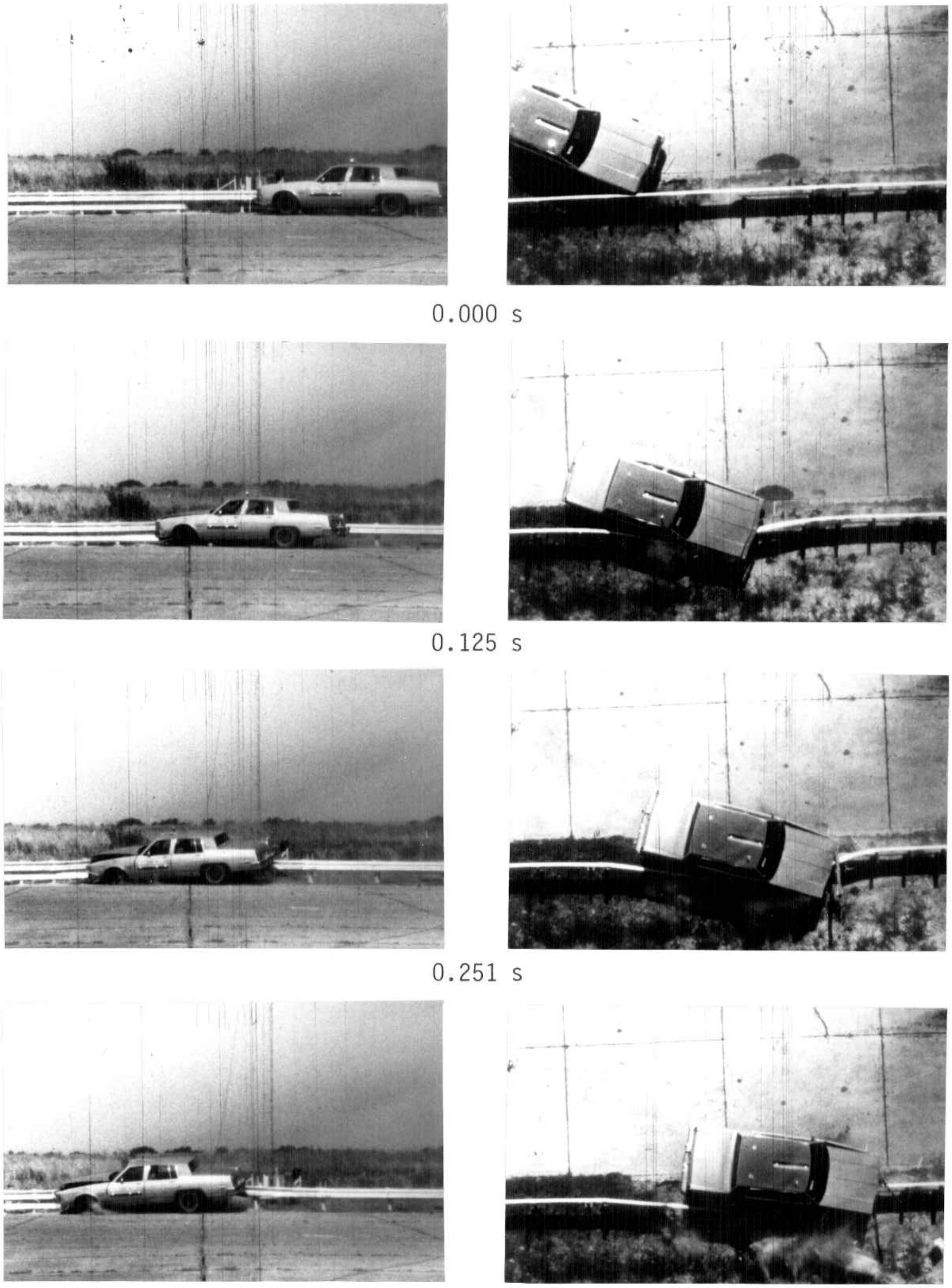
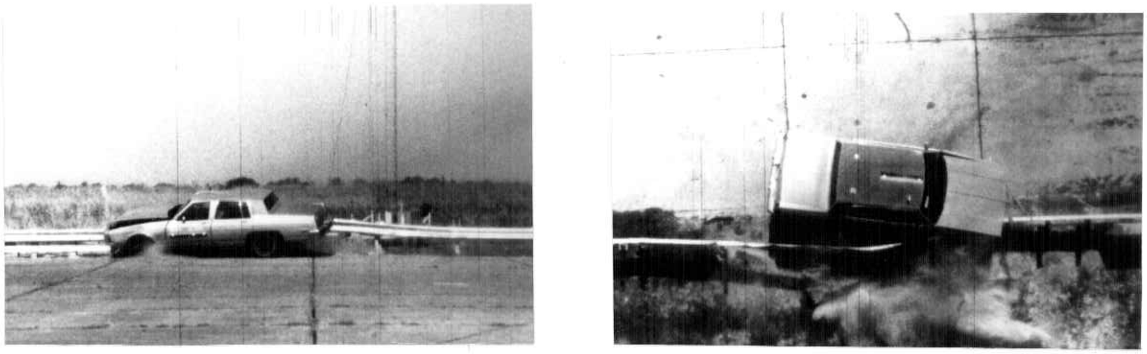
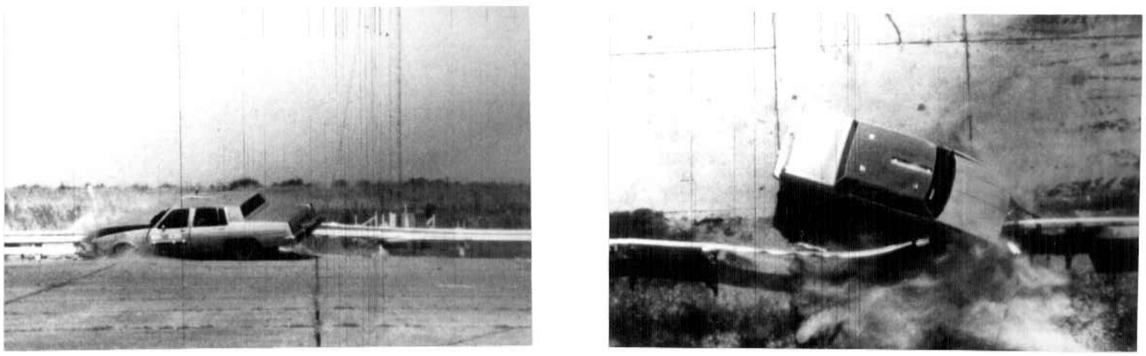


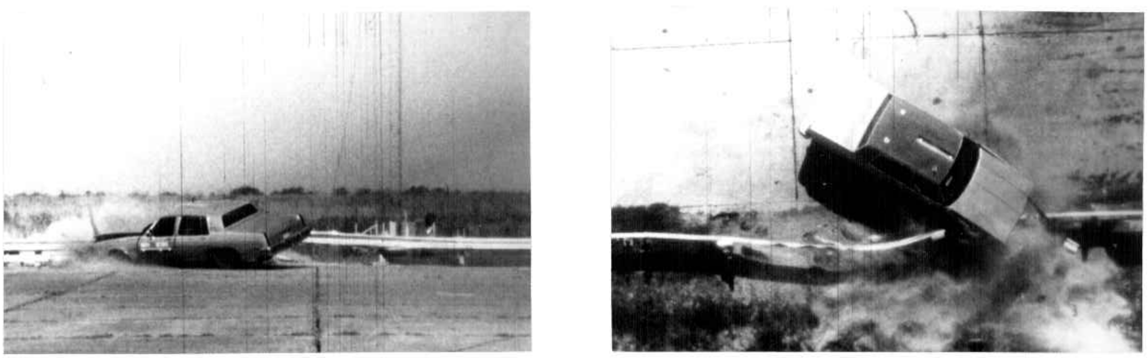
Figure 17. Sequential photographs for test 7155-2



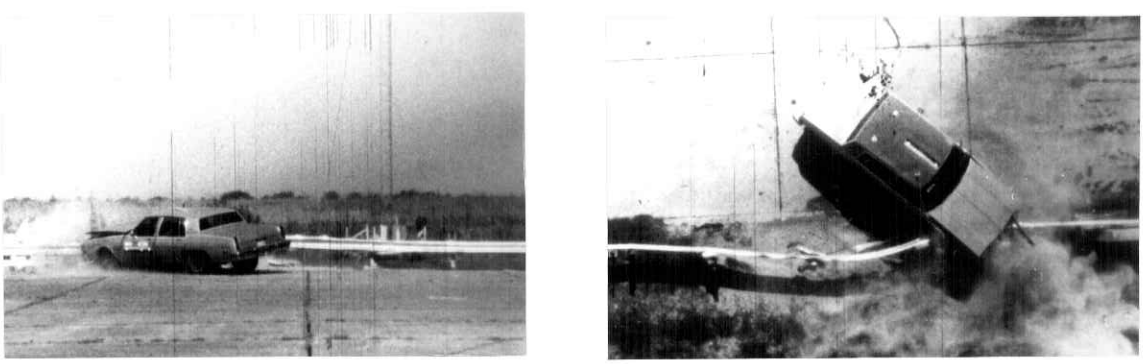
0.502 s



0.627 s



0.753 s



0.878 s

Figure 17. Sequential photographs for test 7155-2 (Continued)

Figure 18. Arizona guardrail transition to concrete half barrier after test 7155-2

The maximum permanent rail deformation was 22.0 inches (55.9 cm) and maximum lateral dynamic rail deflection was observed to be 34.9 in (88.7 cm).

Damage to the vehicle is shown in Figure 19. The maximum crush was 21.0 inches (53.3 cm) at the right front corner of the vehicle. The right front wheel and control arm were severely bent and pushed rearward 8.0 inches (20.3 cm). The entire front end of the vehicle was shifted to the left 2.0 inches (5.1 cm). Additionally, the right front tire was aired, the subframe was bent, and the windshield was broken.

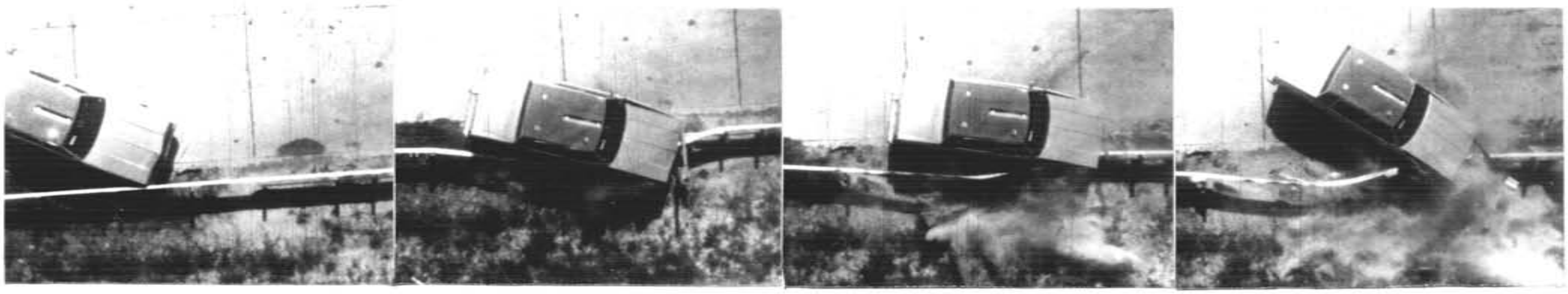
A summary of the test results and other information pertinent to this test are given in Figure 20. The maximum 0.050-second average accelerations experienced by the vehicle were -16.0 g in the longitudinal direction and 5.5 g in the lateral direction. Vehicle angular displacements are plotted in Figure 21 and accelerometer traces are displayed in Figures 22-24. Occupant impact velocities were 38.0 feet per second (11.6 m/s) and -13.7 feet per second (4.2 m/s) in the longitudinal and lateral directions respectively. The highest 0.010-second occupant ridedown accelerations were -11.9 g (longitudinal) and 12.2 g (lateral). It should be noted that occupant risk evaluation criterion are not applicable for this test and are reported for information purposes only.

In summary, this test was judged to be a failure. The installation contained but failed to redirect the impacting vehicle. The vehicle was brought to an abrupt stop after snagging on the rubrail end and first transition post (post 7).

Test 7155-3

In this test, the upstream end of the ADOT steel post transition was modified to eliminate the deficiencies identified in Test 2. The exposed end of the channel rubrail was removed from the traffic face of the barrier by extending it one post spacing (6 ft.-3 in.) and bending it behind the guardrail post. Furthermore, the high speed films from Test 2 indicated that an additional spacer block behind the post was warranted. Therefore, a W6x9 spacer block was placed between the rubrail and the back side of the post to provide additional blockout distance and further reduce the potential for wheel snagging on the rubrail end. The additional spacer block effectively placed the end of the rubrail 21 inches behind the traffic face of the rail which was a sufficient distance to prevent wheel contact based on the degree of snagging observed in Test 2.

Figure 19. Vehicle after test 7155-2



0.00 0.251 0.502 0.753

Test No.	7155-2
Date	08/06/90
Test Installation	Arizona guardrail transition to concrete half/barrier
Length of Transition	87.5 ft (26.7 m)
Vehicle	1981 Olds Ninety-Eight
Vehicle Weight	
Test Inertia	4,500 lb (2041 kg)
Vehicle Damage Classification	
TAD	01RFQ-6
CDC	01RFAW2
Maximum Vehicle Crush	21.0 in (53.3 cm)
Max. Dyn. Rail Deflection	34.9 in (88.7 cm)
Max. Perm Rail Deformation	22.0 in (55.9 cm)

Impact Speed	61.6 mi/h (99.1 km/h)
Impact Angle	26.0 degrees
Exit Speed	N.A.
Exit Angle	N.A.
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal	-16.0 g
Lateral	5.5 g
Occupant Impact Velocity	
Longitudinal	38.0 ft/s (11.6 m/s)
Lateral	-13.7 ft/s (4.2 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-11.9 g
Lateral	12.2 g

Figure 20. Summary of results for test 7155-2

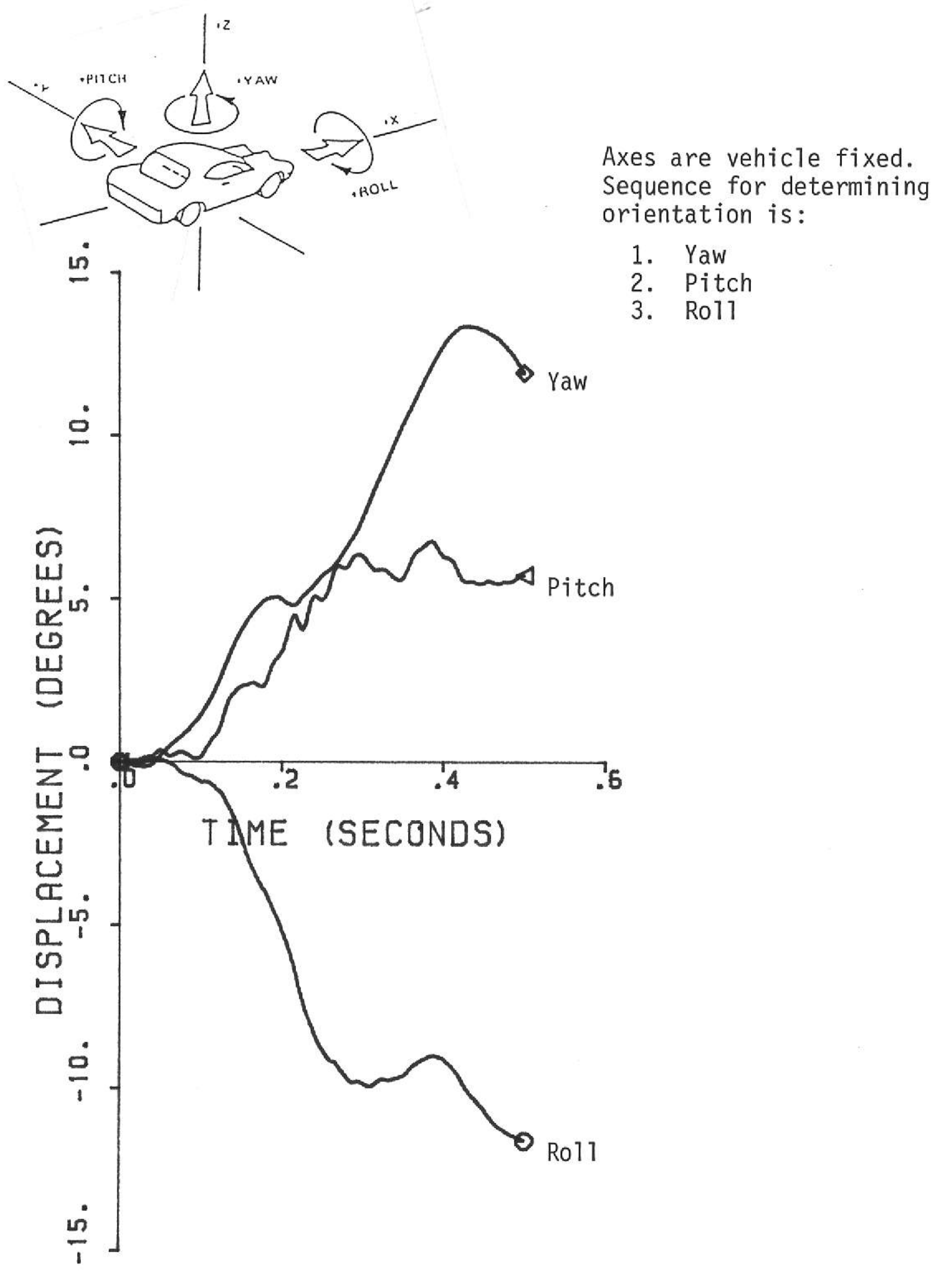


Figure 21. Vehicle angular displacements for test 7155-2

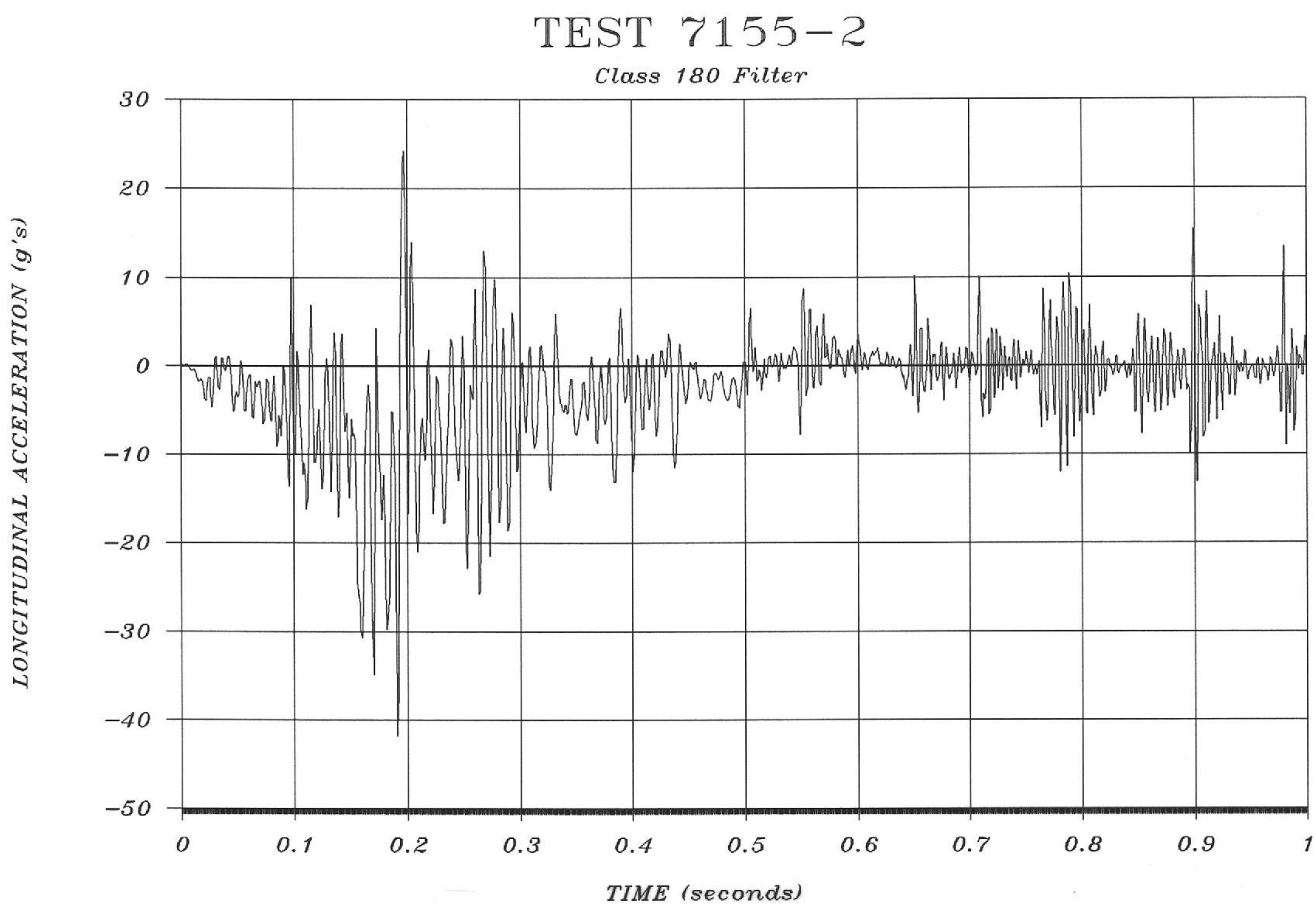


Figure 22. Longitudinal accelerometer trace for test 7155-2

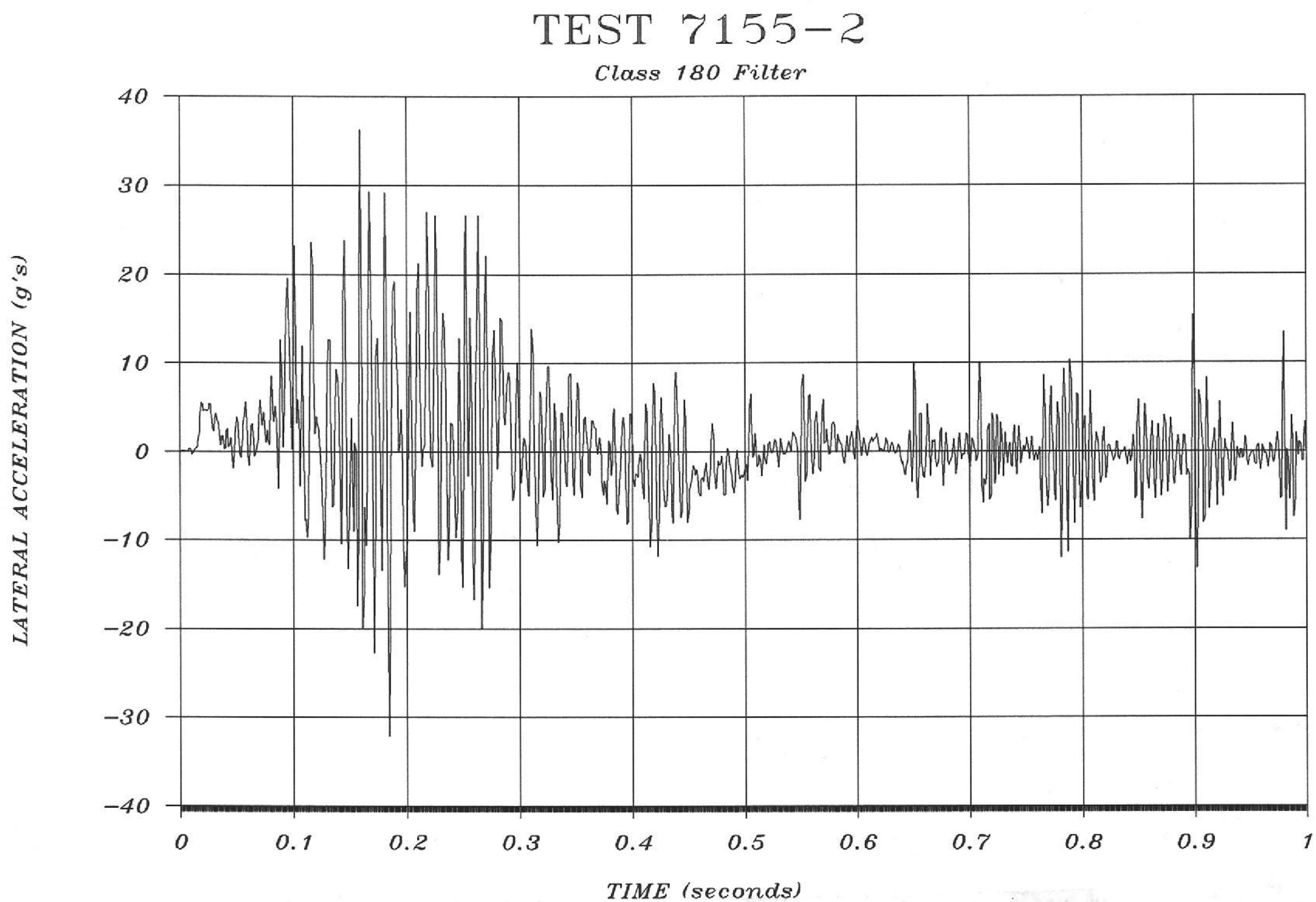


Figure 23. Lateral accelerometer trace for test 7155-1

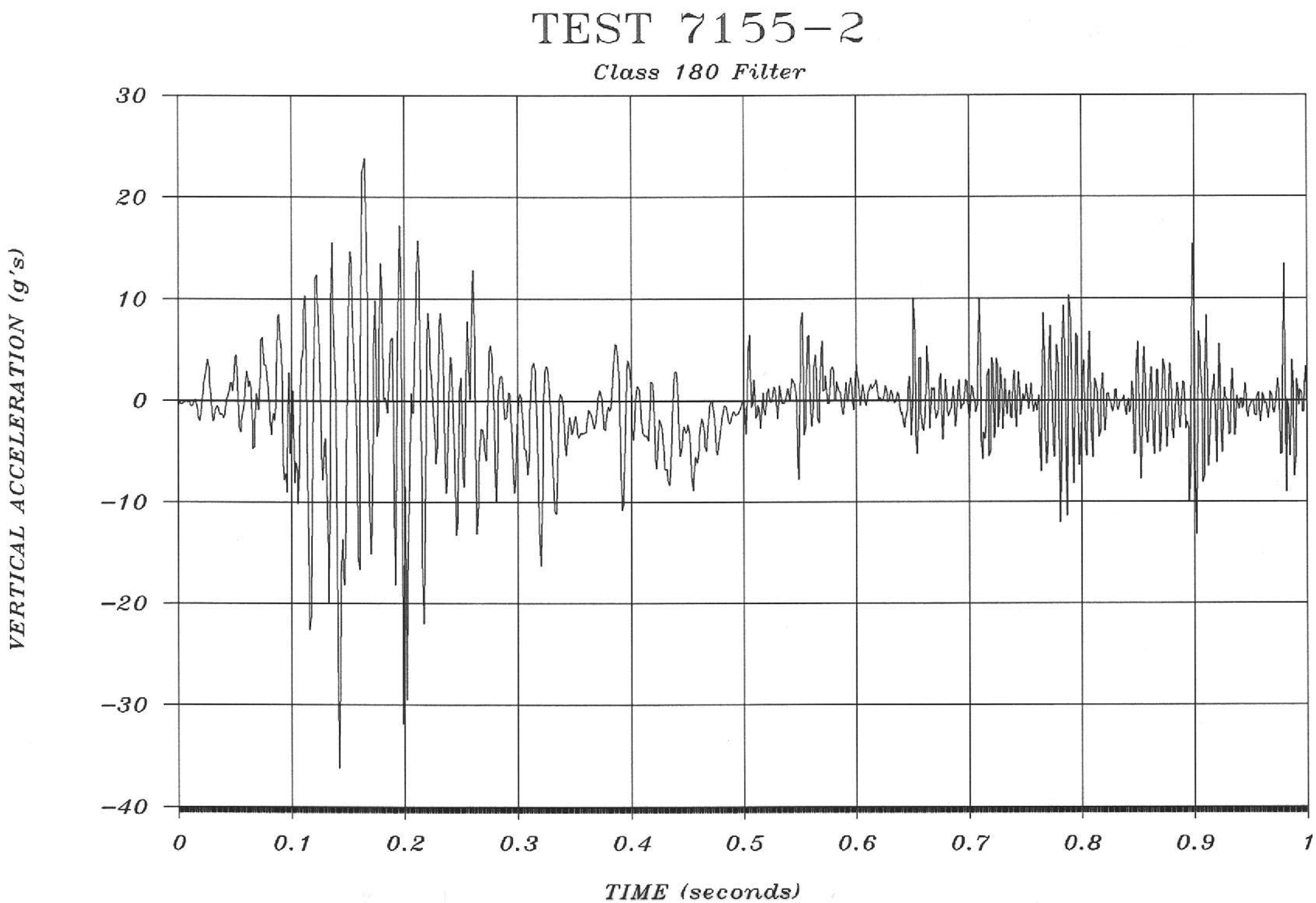


Figure 24. Vertical accelerometer trace for test 7155-2

The transition design was further modified by removing the rectangular plate washers on all but the two W8x21 posts adjacent to the concrete bridge rail. As observed in Test 2, the first post in the transition (post 7) was not able to deflect out of the path of the test vehicle due to being constrained from rotation at the top by the W-beam and at the bottom by the rubrail. In the absence of plate washers, the guardrail bolts are permitted to pull through the slot in the W-beam rail when sufficient lateral force is applied or post deflections become excessive. This effectively removes the upper constraint on the post and permits it to deflect more freely in front of the vehicle. This minor modification could therefore have significant affects on the performance of the transition since the propensity for pocketing behind and snagging on the transition posts will be reduced.

Since only the upstream end of the transition was modified, the results obtained from Test 1 at the downstream end of the transition adjacent to the concrete bridge rail remain valid. Details of the modified design are shown in Figure 25. The completed test installation for Test 3 is shown in Figure 26.

Results

A 1979 Cadillac Sedan (shown in Figure 27) impacted 10.0 feet upstream from the beginning of the rub rail at 61.9 miles per hour (99.6 km/h) and at an angle of 25.1 degrees using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 pounds (2,041 kg). The lower edge of the vehicle bumper was at a height of 13.0 inches (31.1 cm) and the height to the top edge of the bumper was 21.5 inches (54.6 cm). Other dimensions and information on the vehicle are given in Figure 28.

The vehicle was free wheeling and unrestrained just prior to impact. As the vehicle approached the post at which the rub rail was terminated (post 8), the post began to deflect out of its path. The post continued its lateral rotation until the end of the rubrail made contact with the ground surface. Although both the right front and rear tires aired out upon contacting post 8, the post deflection was sufficient enough to prevent any significant snagging and decelerations to the vehicle. At approximately 0.188 second, the rear of the vehicle was traveling parallel to the deformed rail at a speed of 48.6 miles per hour (78.2 km/h). When the vehicle lost contact with the installation, it was traveling 38.5 miles per hour (61.9 km/h) at an angle of 10.6 degrees. Shortly thereafter, the brakes were applied

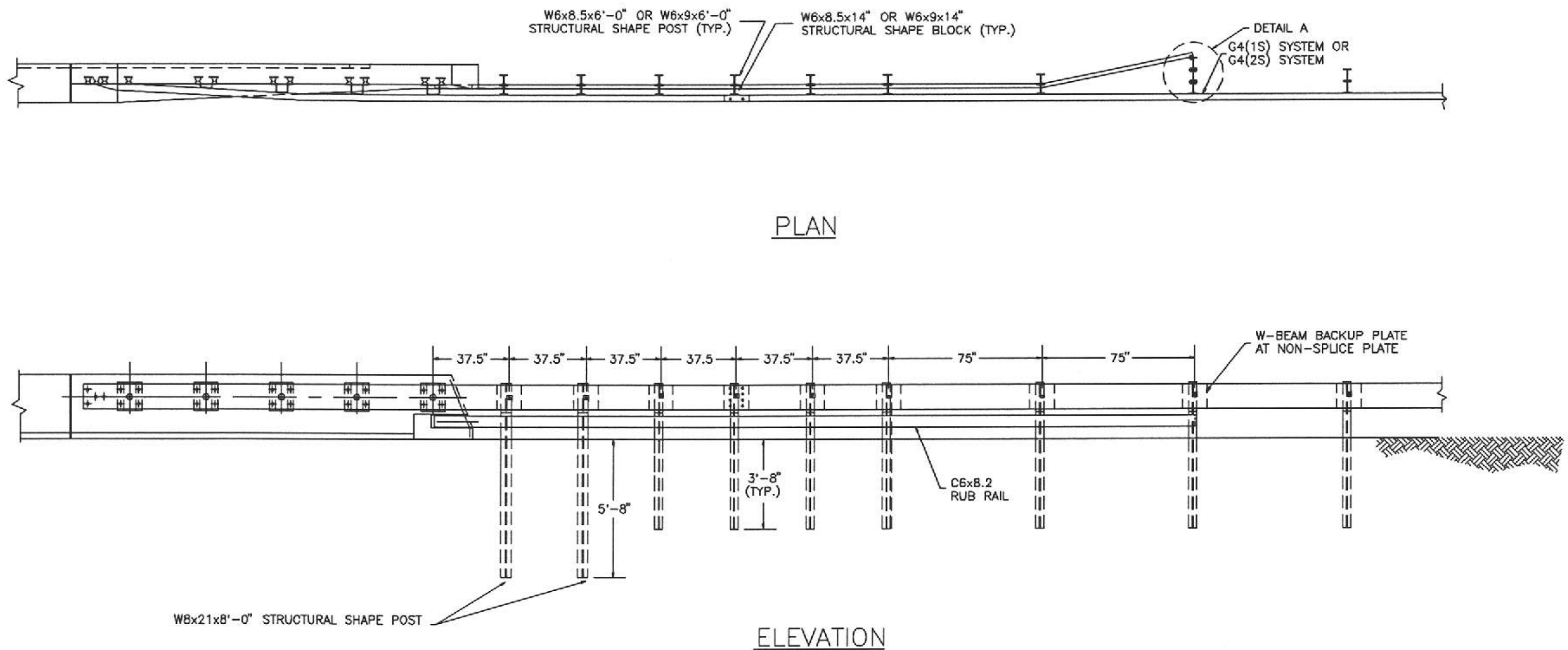


Figure 25. Modified ADOT steel post transition without curb.

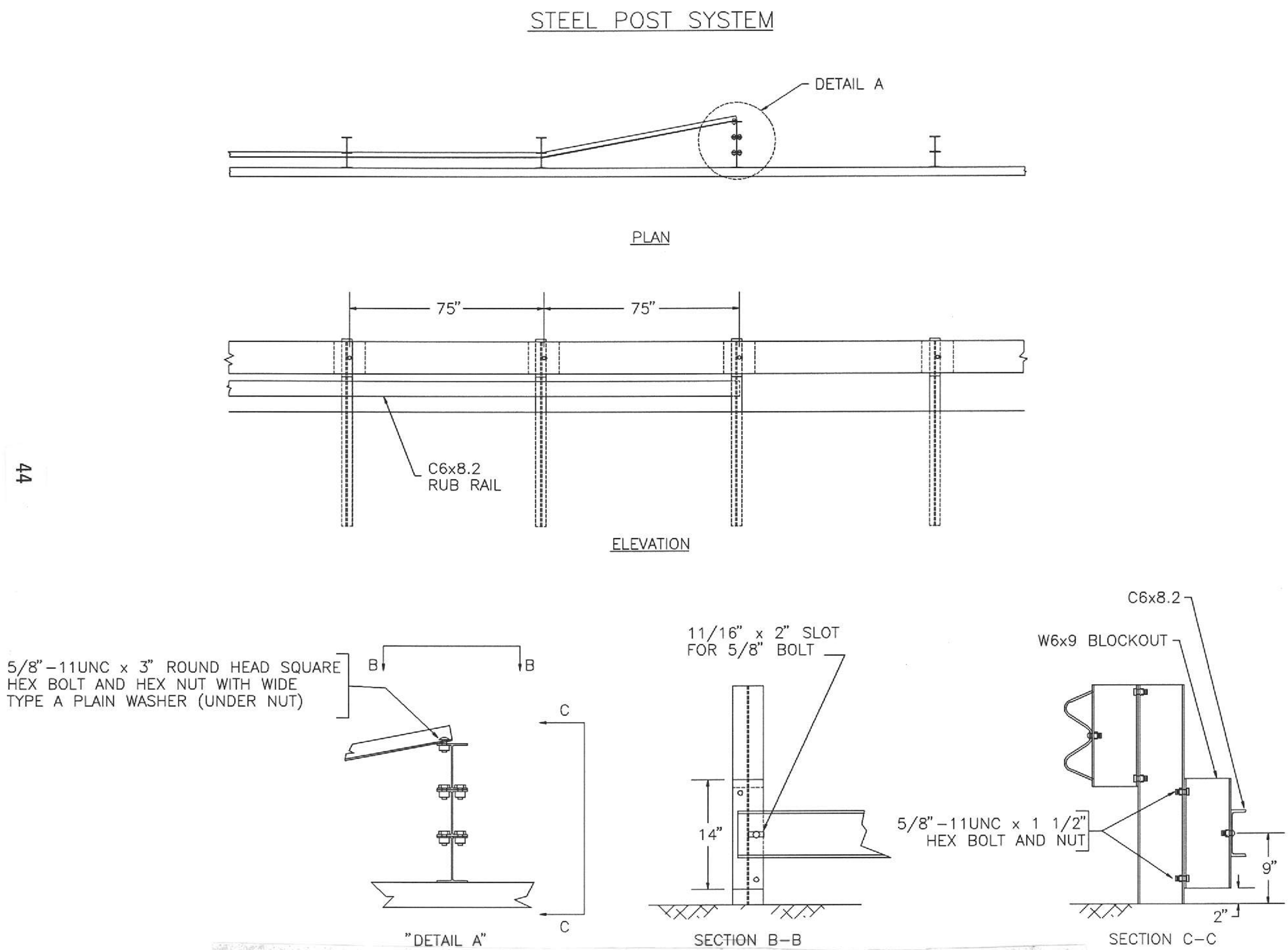


Figure 25. Modified ADOT steel post transition without curb (continued).

Figure 26. Arizona guardrail transition to concrete barrier before test 7155-3.

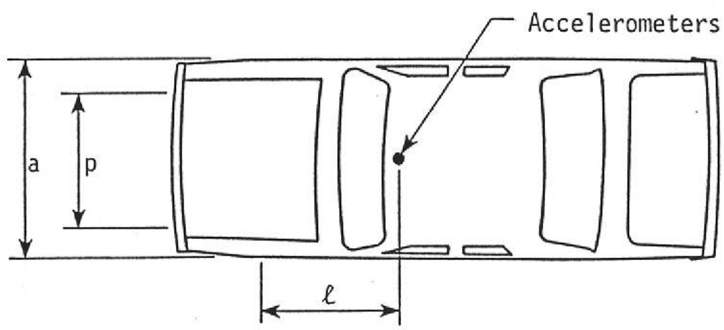
Figure 27. Vehicle before test 7155-3.

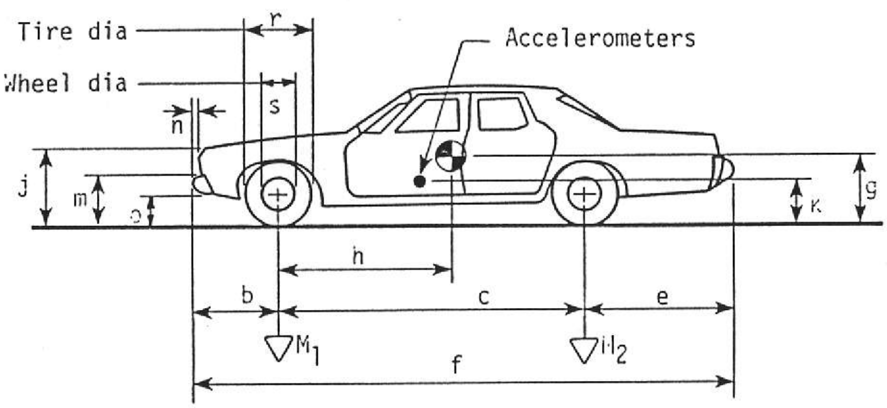
Date: ______ Test No.: 7155-3 VIN: 6D6959C384429

Make: Cadillac Model: Sedan Year: 1979 Odometer: 83235

Tire Size: P215/75R15 Ply Rating: ______ Bias Ply: ___ Belted: ___ Radial: X

Tire Condition: good ___ fair X badly worn ___





Vehicle Geometry - inches

a	76 3/4	b	47
c	122	d*	57
e	56	f	225
g		h	55.5
i	----	j	35
k	20	ℓ	35 1/4
m	21 1/2	n	5
o	12 1/4	p	62
r	27	s	16 1/4

Engine Type: V-8

Engine CID: 7.0

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Body Type: 4-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

4-wheel weight for c.g. det. ℓf 1200 rf 1253 ℓr 1028 rr 1019

Mass - pounds	Curb	Test Inertial	Gross Static
M_1		2453	
M_2		2047	
M_T		4500	

Note any damage to vehicle prior to test:

Crack in windshield

Dent in left front fender

*d = overall height of vehicle

Figure 28. Vehicle properties (test 7155-3).

and the vehicle came to rest 203 feet (61.9 m) from the point of impact. Sequential photographs of the test are shown in Figure 29.

Damage to the installation is shown in Figure 30. The maximum lateral dynamic rail deflection was observed to be 28.2 inches (71.6 cm), and the maximum permanent rail deformation was measured to be 27.0 inches (68.6 cm). As designed, several of the guardrail posts detached from the W-beam rail allowing the vehicle to push them over more readily. Although some wheel contact was observed on post 8, there was no significant snagging on the post or rubrail end. The vehicle was in contact with the installation for a total length of 31.0 feet (9.5 m).

As shown in Figure 31, damage to the vehicle was relatively minor. The damage was primarily confined to the right front fender area. The maximum crush was 15.0 inches (38.1 cm) at the lower right front corner of the vehicle. The right front wheel was pushed rearward only 0.5 inches (1.3 cm). The front end of the vehicle was shifted to the left 3.0 inches (7.6 cm). Additionally, the right side tires were aired and the wheels were bent.

A summary of the test results and other information pertinent to this test are given in Figure 32. The maximum 0.050-second average accelerations experienced by the vehicle were -4.3 g in the longitudinal direction and 5.6 g in the lateral direction. Angular displacements experienced by the vehicle are plotted in Figure 33 and accelerometer traces are displayed in Figures 34 - 36. Occupant impact velocities were 20.1 feet per second (6.1 m/s)in the longitudinal direction and -15.9 feet per second (4.8 m/s) in the lateral direction. The highest 0.010 second occupant ridedown accelerations were -4.3 g (longitudinal) and 9.2 g (lateral). Although not required for the transition test, it is noteworthy to mention that the occupant risk criteria stated above were all within the recommended limits set forth in NCHRP Report 230.

In summary, this test was a complete success. The modified installation smoothly contained and redirected the vehicle. There was only minor damage to the vehicle, and there was no debris or detached elements from the vehicle that could pose a hazard to other traffic. The vehicle remained upright and stable during the initial test period and after leaving the installation, and there was no deformation or intrusion into the occupant compartment of the vehicle. The velocity change of 23.4 miles per hour (37.7 km/h) was higher than the recommended limit of 15 miles per hour established in NCHRP Report 230.

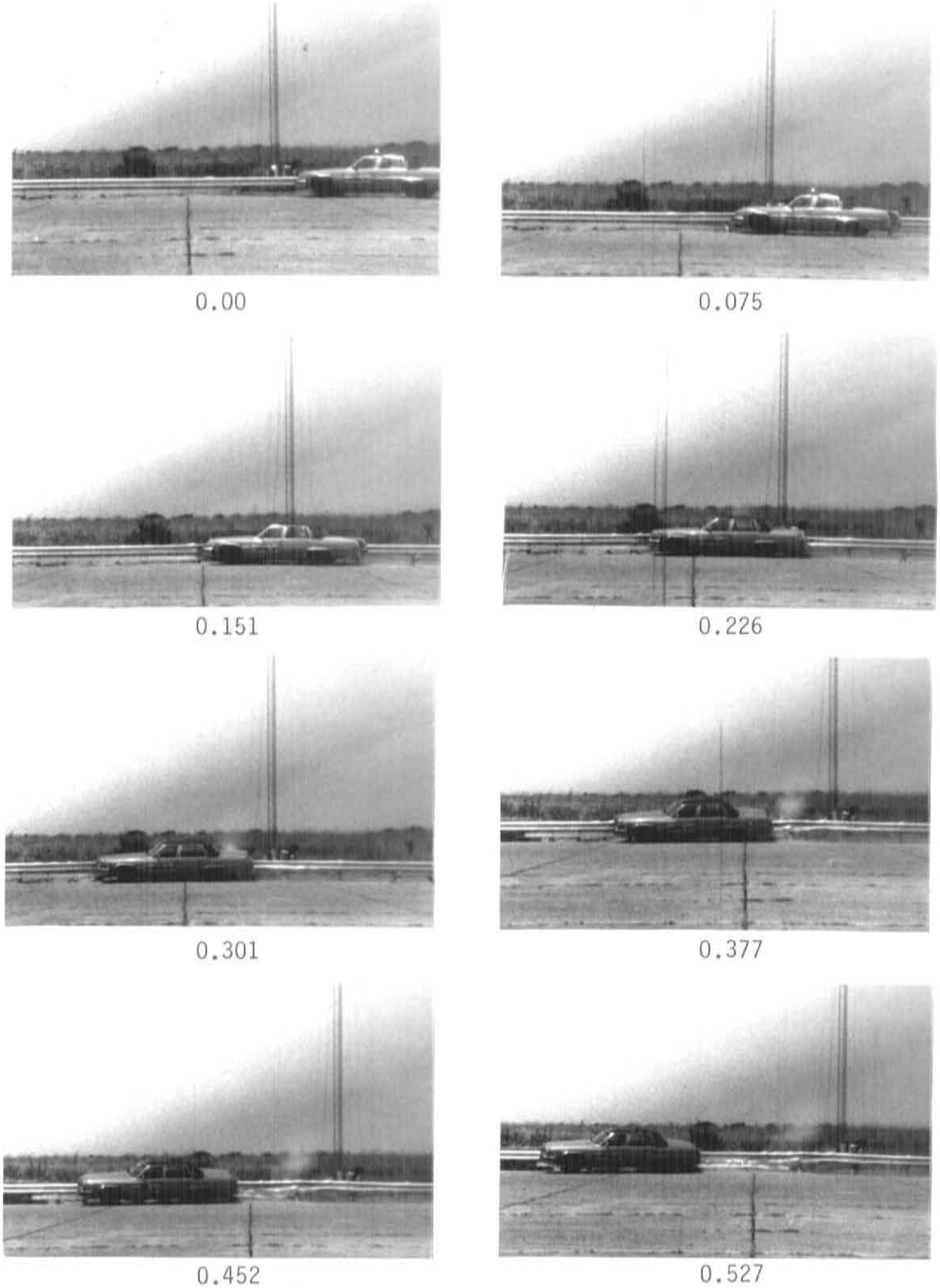


Figure 29. Sequential photographs of test 7155-3.

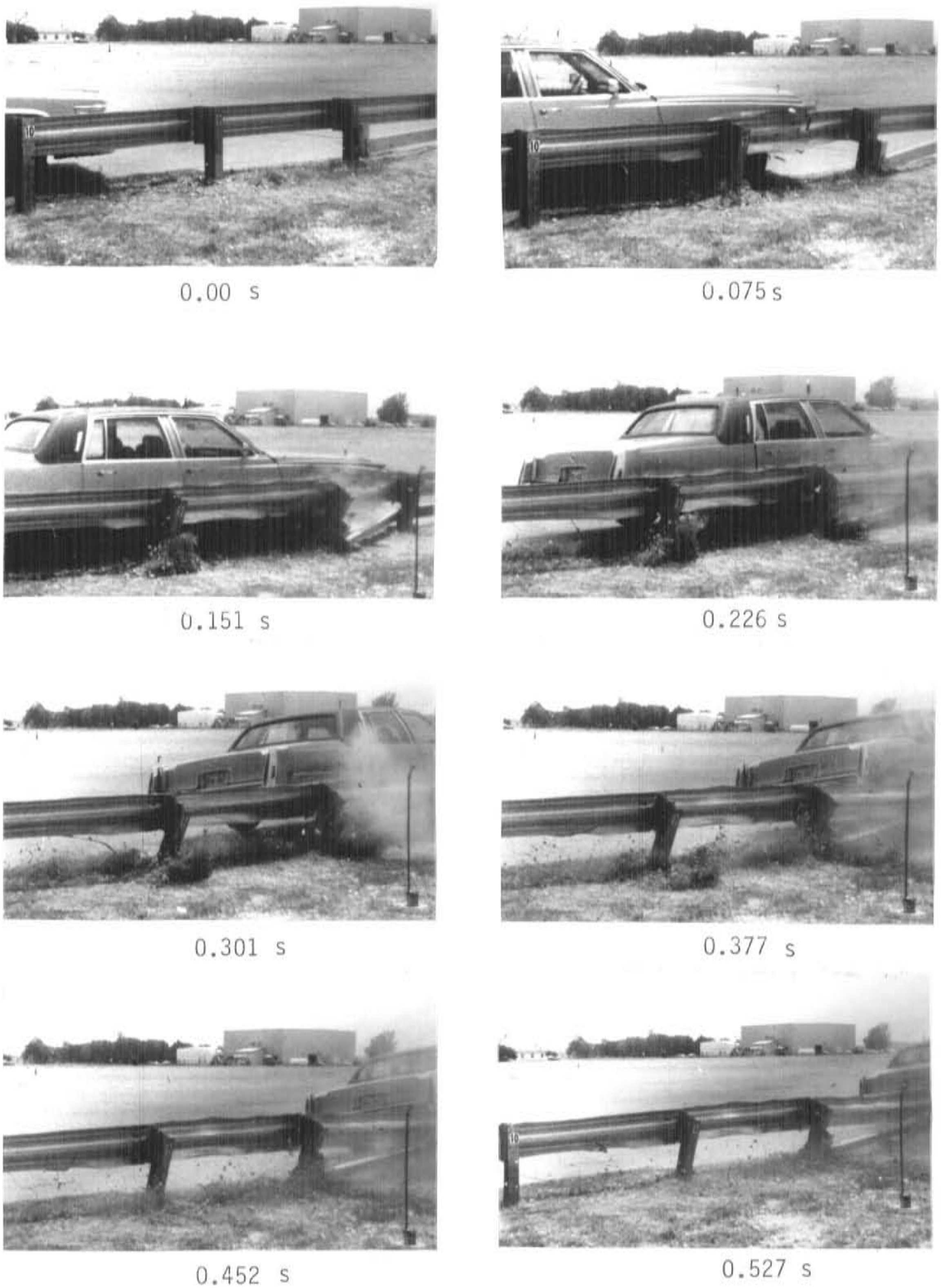
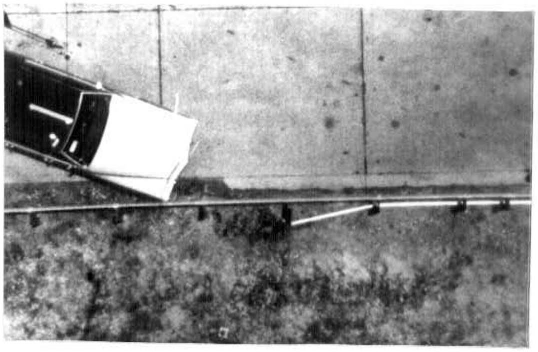
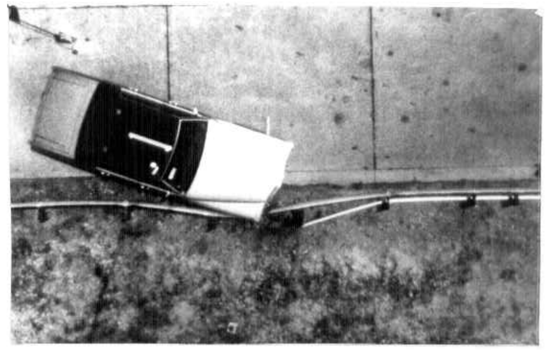


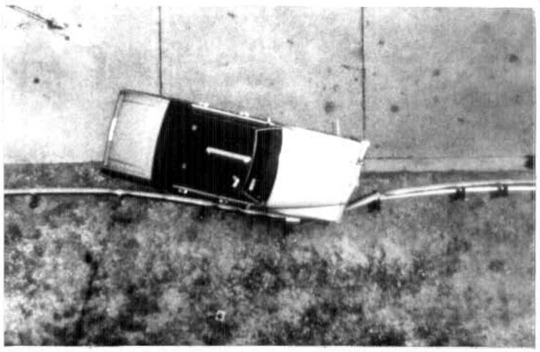
Figure 29. Sequential photographs of test 7155-3.
(continued)



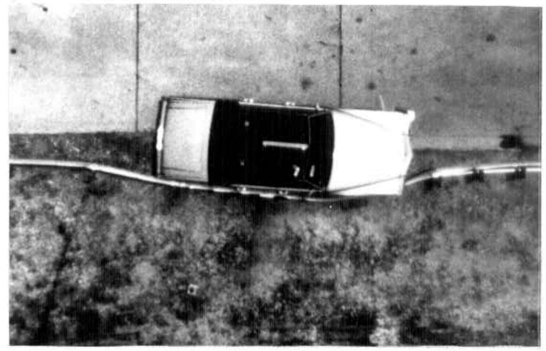
0.00



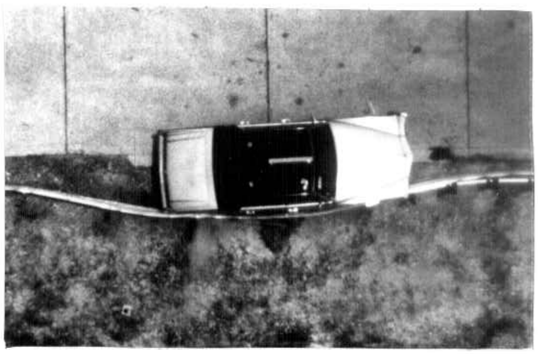
0.075



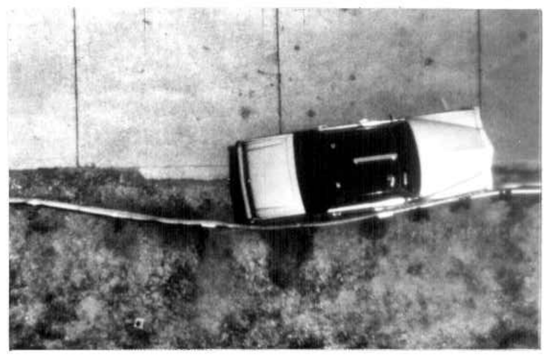
0.151



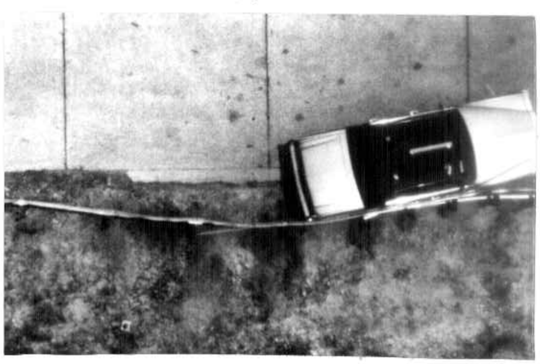
0.226



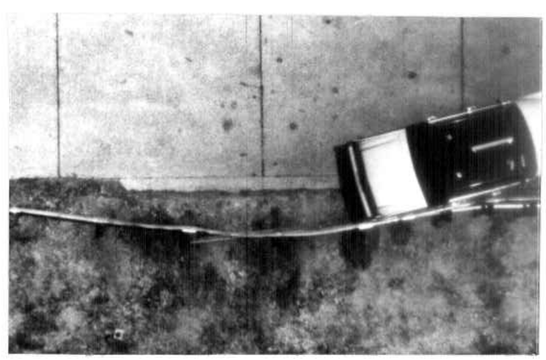
0.301



0.377



0.452



0.527

Figure 29. Sequential photographs of test 7155-3. (continued)

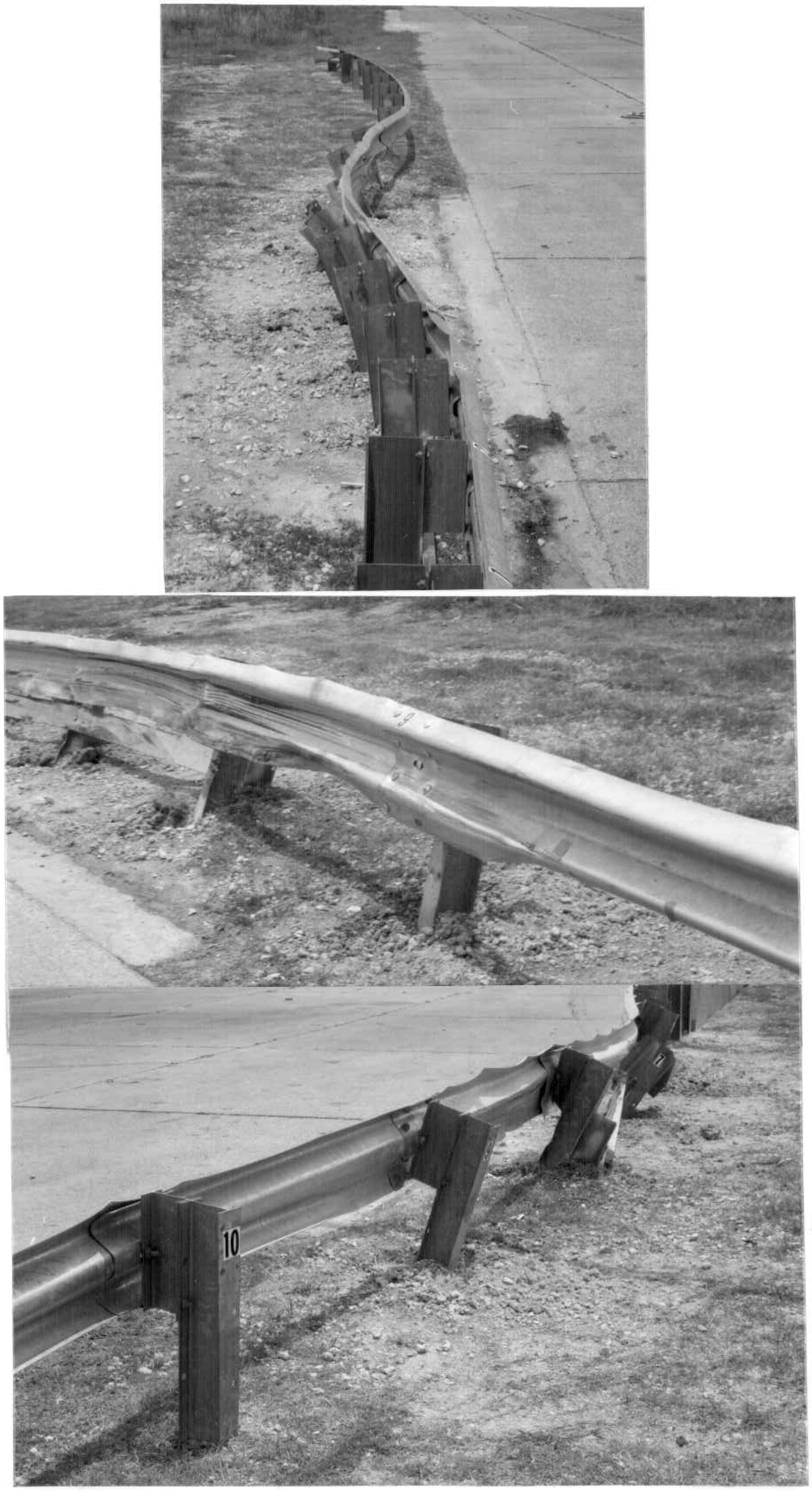
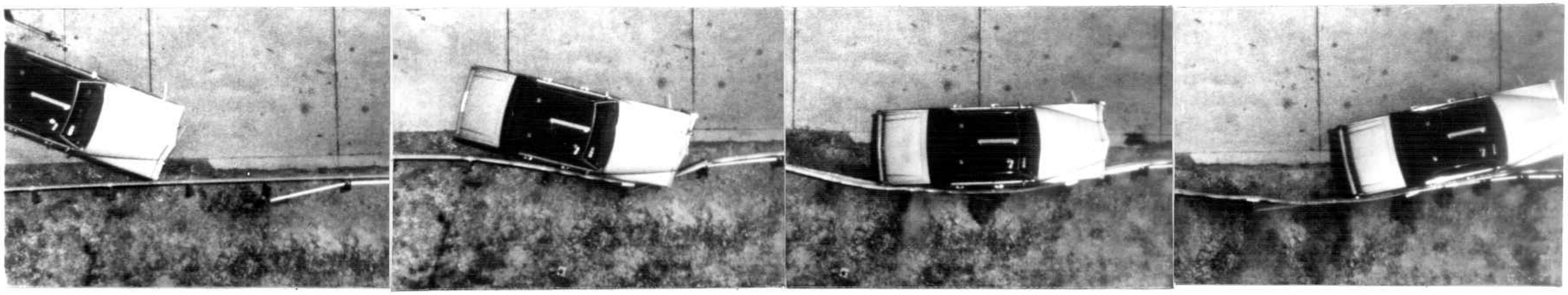


Figure 30. Arizona guardrail transition to concrete barrier after test 7155-3.

Figure 31. Vehicle after test 7155-3.



0.00 0.151 0.301 0.452

Test No.	7155-3
Date	08/14/90
Test Installation	Arizona Guardrail Transition to Concrete Half Barrier
Length of Transition	87.5 ft (26.7 m)
Vehicle	1979 Cadillac Sedan
Vehicle Weight	
Test Inertia	4500 lb (2041 kg)
Vehicle Damage Classification	
TAD	01RFQ-4
CDC	01RFAW3
Maximum Vehicle Crush . . .	15.0 in (38.1 cm)
Max. Dyn. Rail Deflection. .	28.2 in (71.6 cm)
Max. Perm. Rail Deflection .	27.0 in (68.6 cm)

Impact Speed	61.9 mi/h (99.6 km/h)
Impact Angle	25.1 deg
Exit Speed	38.5 mi/h (61.9 km/h)
Exit Angle	10.6 deg
Vehicle Accelerations	
(Max. 0.050-sec Avg)	
Longitudinal	-4.3 g
Lateral	5.6 g
Occupant Impact Velocity	
Longitudinal	20.1 ft/s (6.1 m/s)
Lateral	-15.9 ft/s (4.8 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-4.3 g
Lateral	9.2 g

Figure 32. Summary of results for test 7155-3.

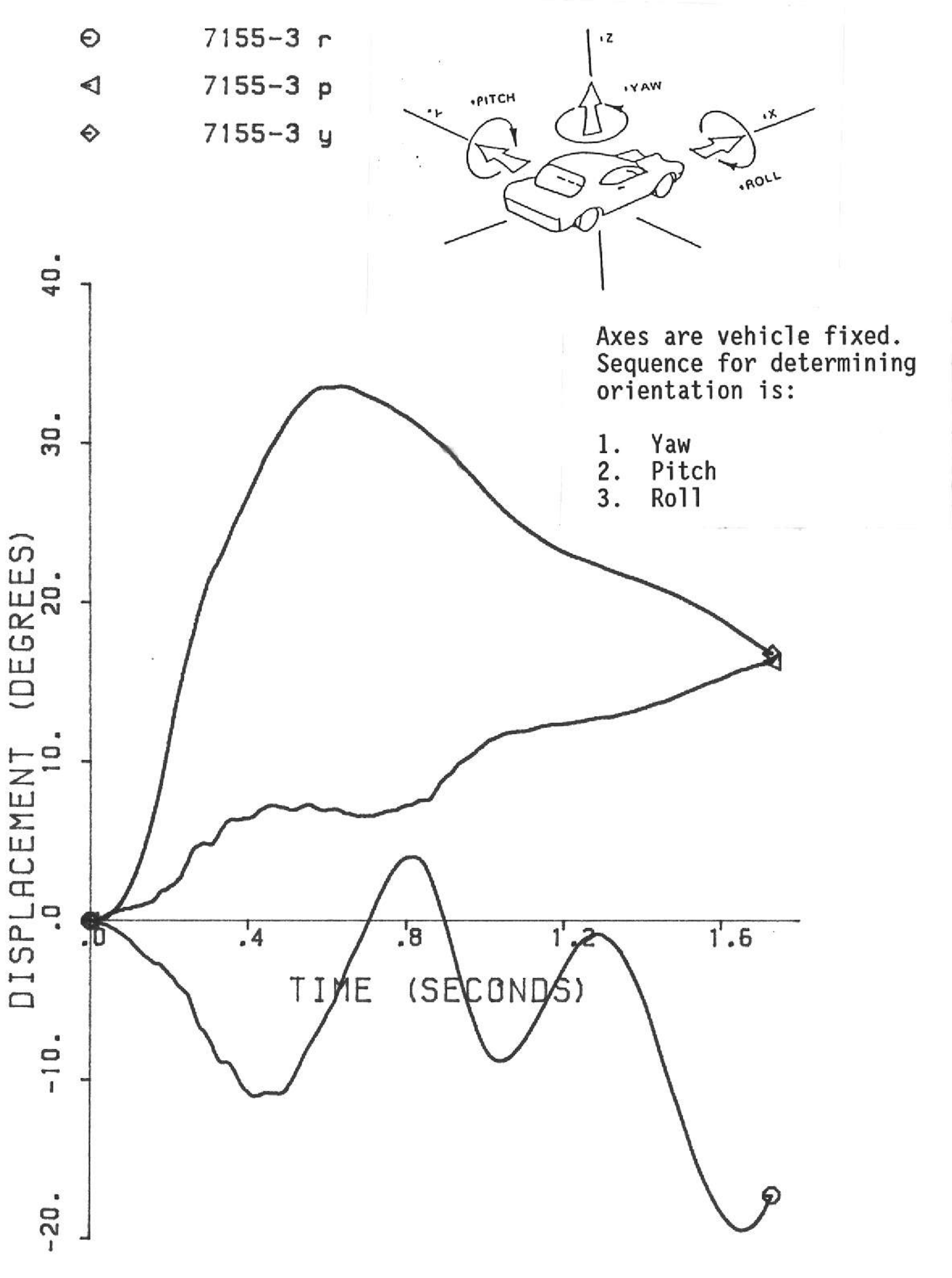


Figure 33. Vehicle angular displacement for test 7155-3.

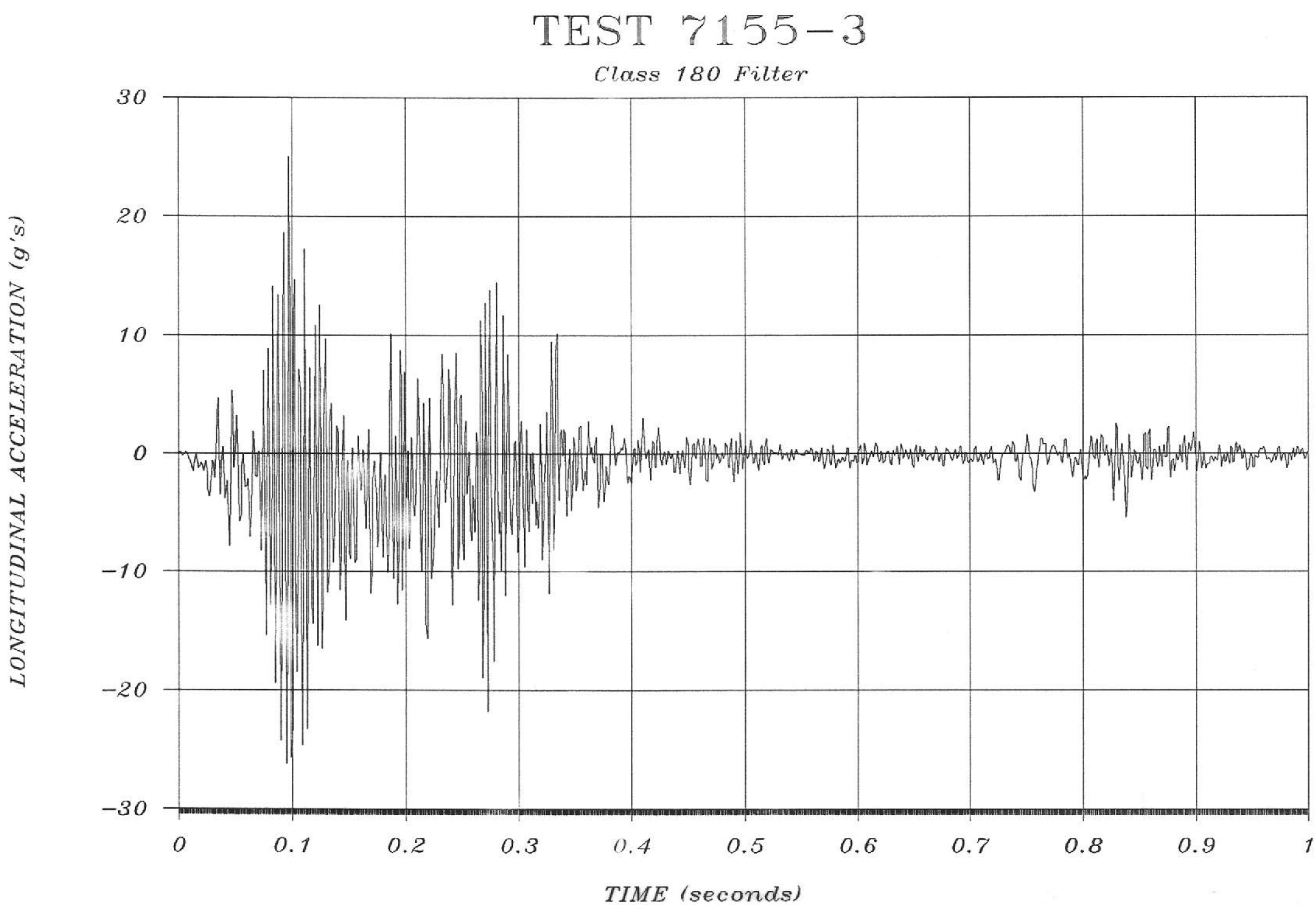


Figure 34. Longitudinal accelerometer trace for test 7155-3.

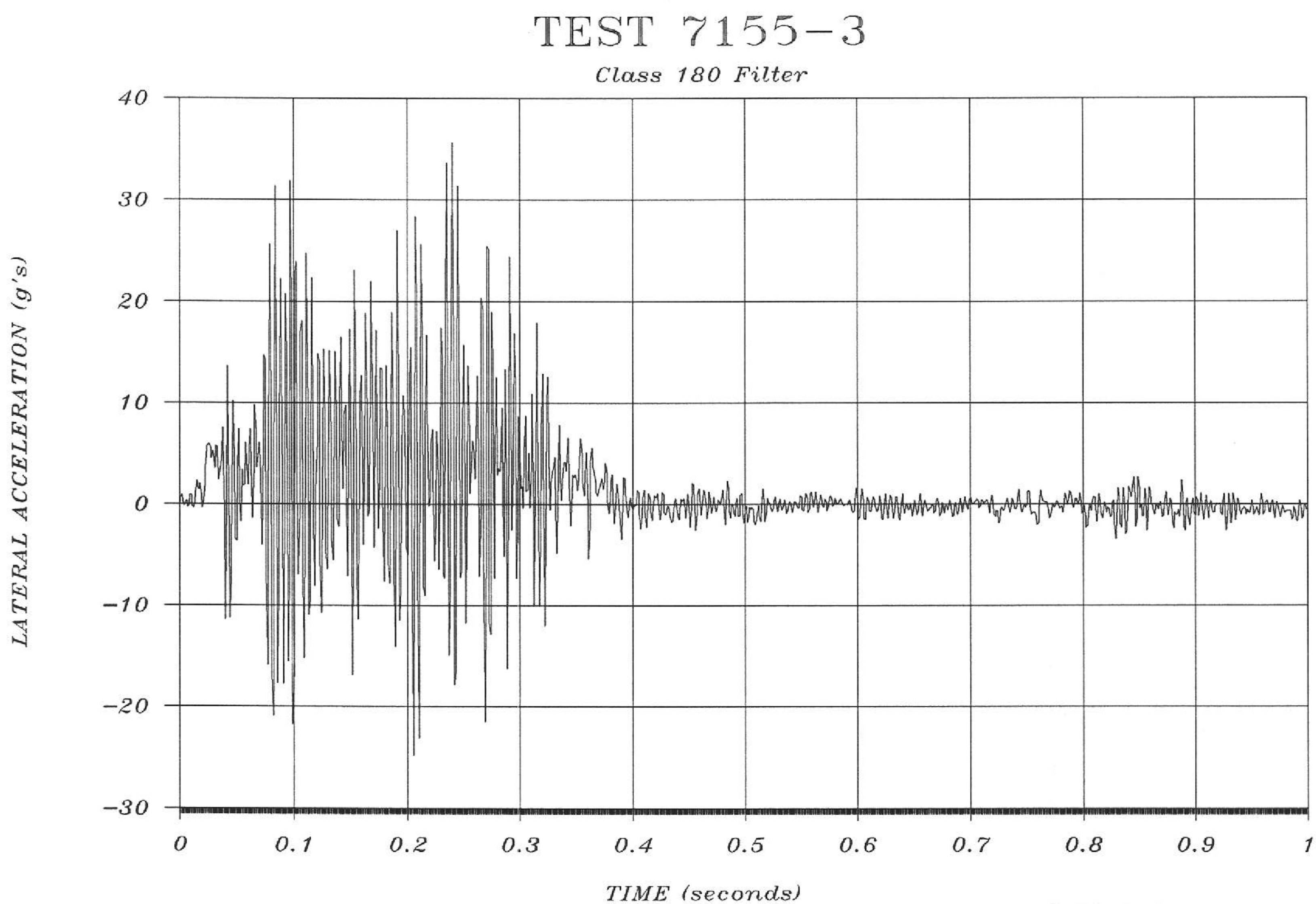


Figure 35. Lateral accelerometer trace for test 7155-3.

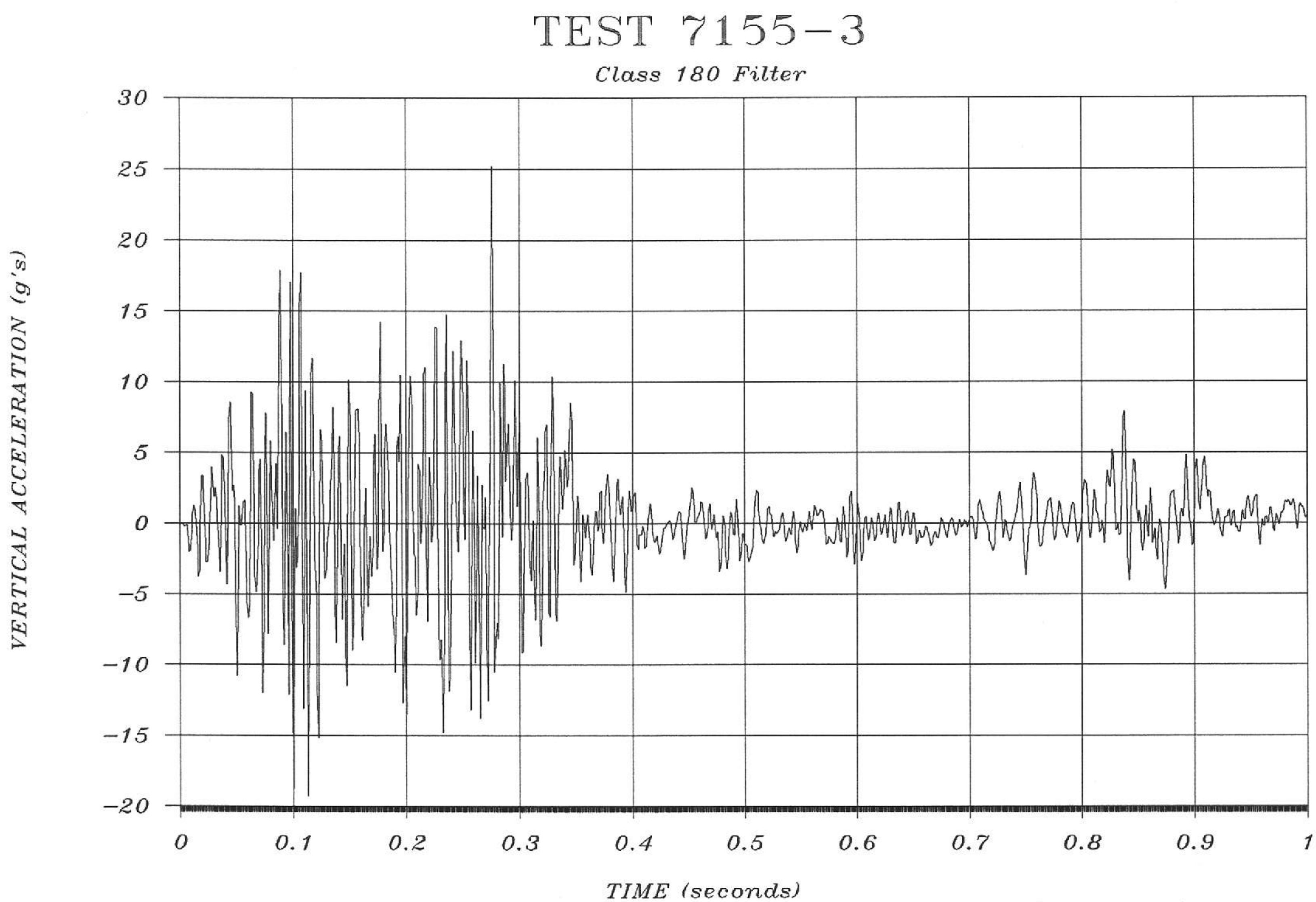


Figure 36. Vertical accelerometer trace for test 7155-3.

However, upon exiting the test installation, the vehicle steered back toward the barrier and would not have been redirected into adjacent traffic lanes. Therefore, the above criterion is not applicable to the evaluation of this test. The exit angle of 10.6 degrees was less than 60 percent of the impact angle as recommended in the evaluation of vehicle trajectory in NCHRP Report 230.

Test 7155-4

The purpose of this test was to evaluate the performance to ADOT's standard wood post transition to a rigid concrete bridge rail. With the exception of the type of posts, the wood post transition design is identical to the steel post design which was successfully tested in Tests 1 and 3. The first two posts adjacent to the concrete barrier were 10"x10"x6'-6" posts with an embedment of 50 inches. The other five posts in the transition region were 8"x8"x5'-4" with a standard 36 inch embedment depth. The W-beam guardrail was blocked out from these posts using 6"x8"x14" wood blocks. The blocks were oriented sideways, providing a 6 inch blockout depth, in order to accommodate the dimensions established by the rubrail and steel spacer blocks on the face of the concrete barrier. The guardrail upstream of the transition was a standard G4(2W) system. This design consists of a W-beam mounted on 6"x8"x5'-4" wood posts with 8" blockouts. Because of the increased blockout depth used on the standard guardrail design, the guardrail posts were offset 2 inches further from the roadway than the posts in the transition. It should be noted that in the ADOT design, as with most wood post systems, no W-beam backup plates were used in the transition or in the guardrail.

The rubrail was terminated in a fashion similar to that of the modified design which was evaluated in Test 3. The rubrail was extended beyond the transition and terminated behind the first standard guardrail post. An additional blockout behind the post was not used in the wood post design since the standard wood post and blockout provide nearly the same distance (16 inches) as the steel system with the additional spacer block. The high speed film from Test 3 indicated that a distance of 16 inches would be sufficient to prevent any vehicle contact with the end of the rubrail. Also, as in Test 3, the rectangular plate washers were removed from all but the 10"x10" posts adjacent to the concrete parapet.

Details of the wood post design are shown in Figure 37. The completed test installation is shown in Figure 38.

Results

A 1981 Cadillac Coupe Deville (shown in Figure 39) impacted 7.0 ft (2.1 m) upstream from the end of the concrete bridge rail at 61.5 miles per hour (98.9 km/h) and at an angle of 24.0 degrees using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 pounds (2,041 kg). The lower edge of the vehicle's bumper was at a height of 12.0 inches (30.5 cm) and the distance to the upper edge of the bumper was 20.0 inches (50.8 cm). Other dimensions and information pertaining to the test vehicle are given in Figure 40.

The vehicle was free wheeling and unrestrained just prior to impact. The performance of this system was very similar to the steel post system evaluated in Test 1. There was some evidence wheel contact with the first guardrail post adjacent to the concrete barrier and with the end of the concrete barrier itself. However, the presence of the rubrail prevented any significant vehicular decelerations from occurring. As seen in Test 1, the vehicle made contact with the first steel blockout on the face of the concrete barrier as the W-beam rail deformed around it. In spite of this contact, the vehicle was smoothly redirected without any abrupt ridedown decelerations. When the vehicle lost contact with the installation, it was traveling at a speed of 43.7 miles per hour (70.3 km/h) and at an angle of 8.2 degrees. Shortly thereafter, the brakes were applied, the vehicle yawed clockwise and came to rest 180.0 feet (54.9 m) from the point of impact. It should be noted that a secondary impact with an old test installation occurred downstream from the impact location. Sequential photographs of the test are shown in Figure 41.

As shown in Figure 42, the installation received only minor damage. The maximum permanent rail deformation was 7.5 inches (19.1 cm) and maximum lateral dynamic rail deflection was observed to be 8.3 inches (21.0 cm). Once again, the concrete insert anchors to which the steel blockouts were attached performed well and showed no visible signs of distress. The vehicle was in contact with the installation for a total length of 14.8 feet (4.5 m).

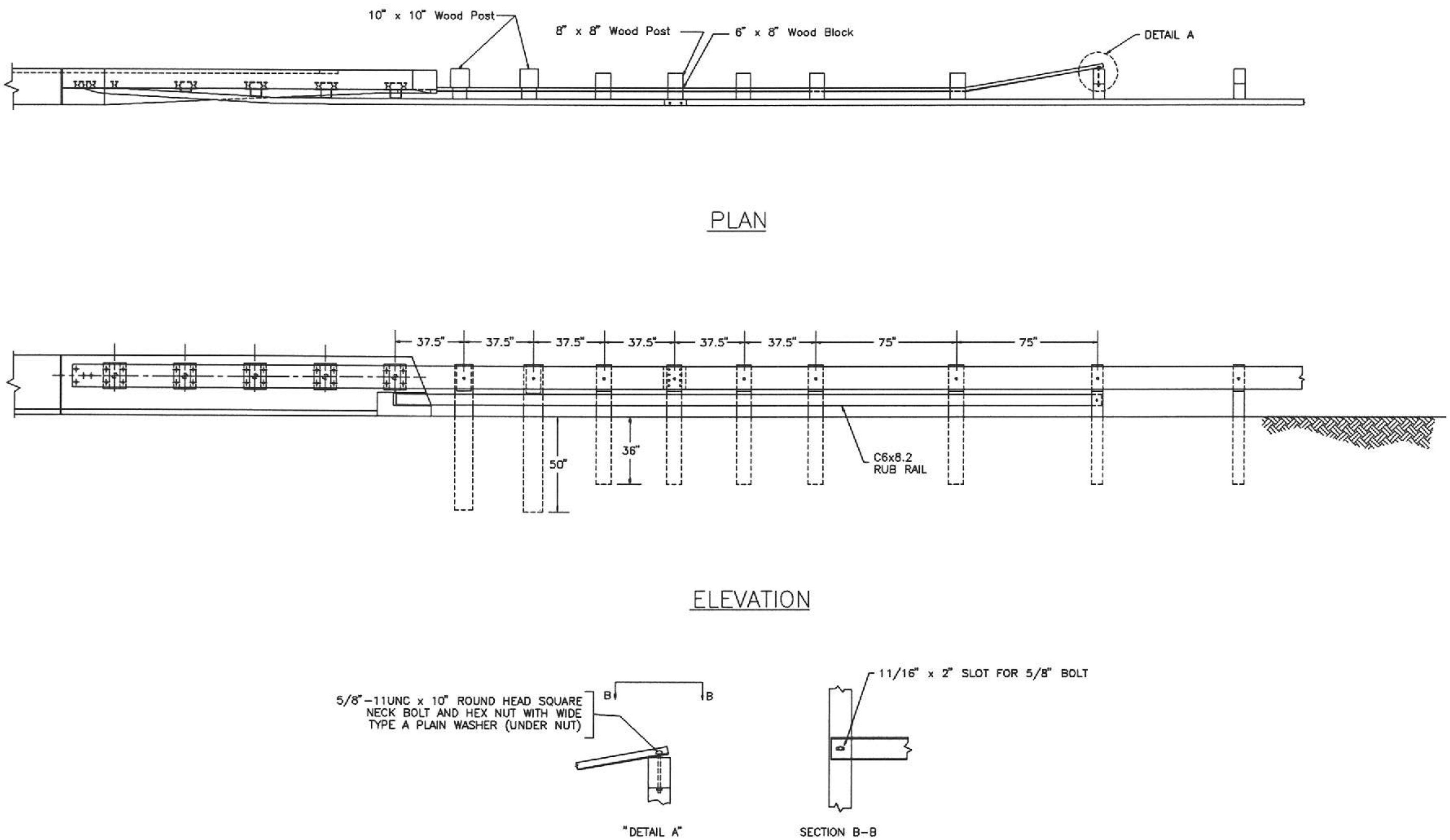


Figure 37. Modified ADOT wood post transition without curb

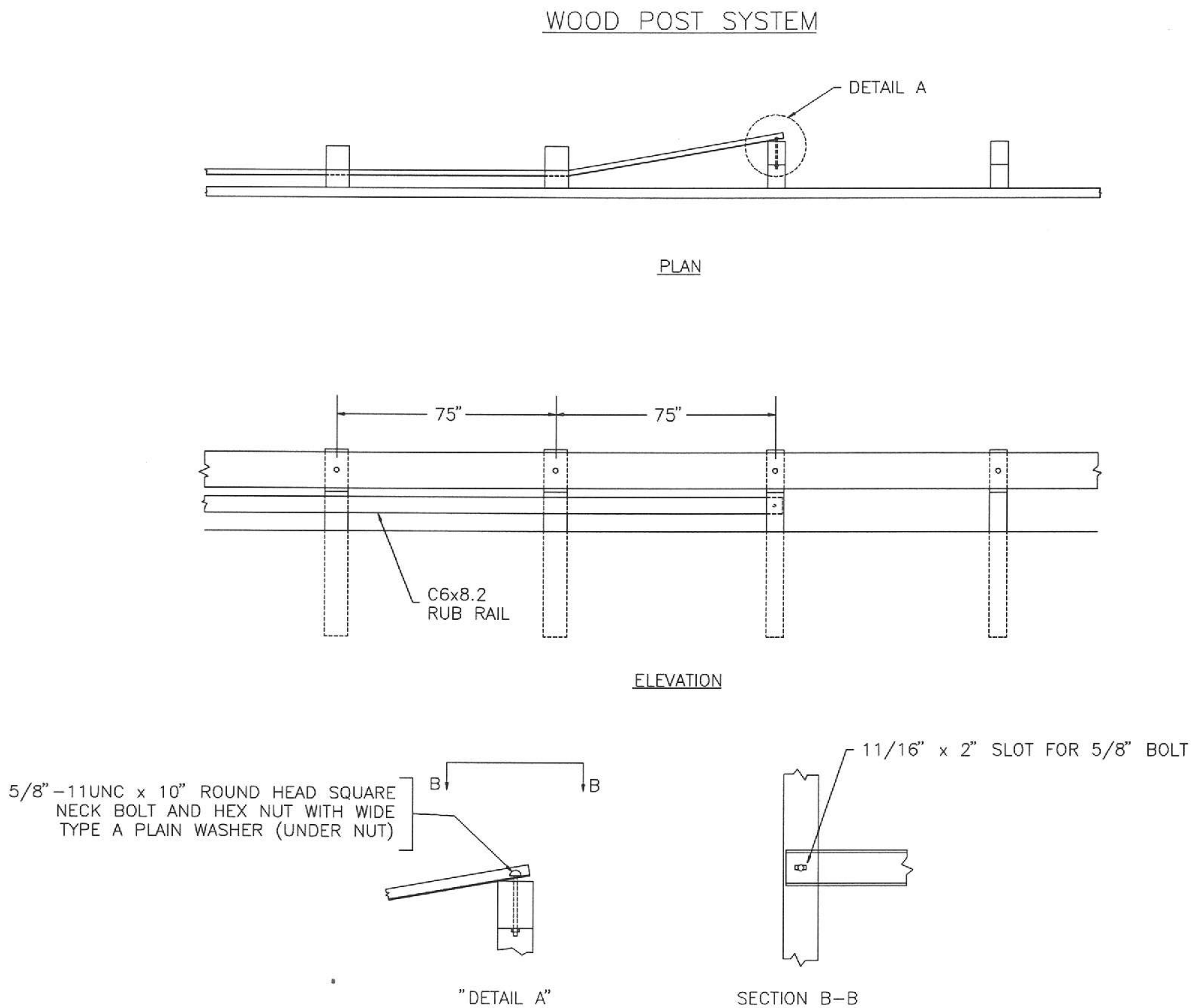


Figure **37.** Modified ADOT wood post transition without curb (Continue)

Figure 38. Arizona guardrail transition to concrete barrier before test 7155-4.

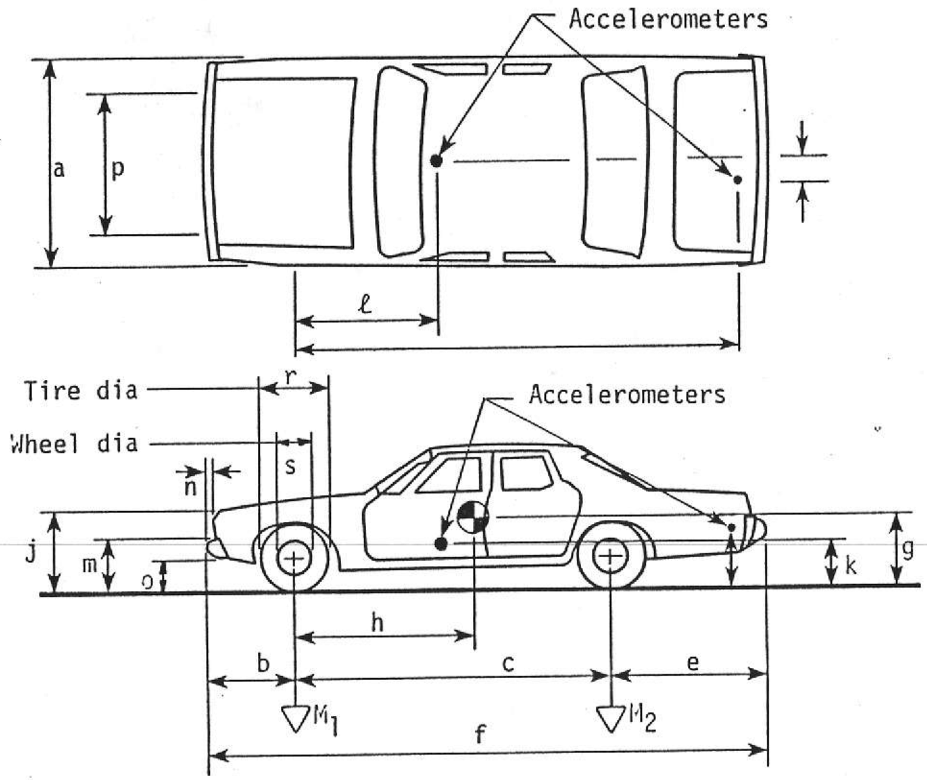
Figure 39. Vehicle before test 7155-4.

Date: ________ Test No.: 7155-4 VIN: IG6AD47N7B9179589

Make: Cadillac Model: Coupe DeVille Year: 1981 Odometer: 35689

Tire Size: P215 75R15 Ply Rating: 4 Bias Ply: __ Belted: __ Radial: X

Tire Condition: good __ fair X badly worn __



Vehicle Geometry - inches

a	77	b	42 1/4
c	121 1/2	d*	56
e	57	f	220 3/4
g		h	54.4
i	----	j	39 1/2
k	19 1/4	ℓ	38 1/2
m	20	n	4 1/2
o	12	p	62
r	27	s	16 1/4

Engine Type: Diesel V-8

Engine CID: 5.7

Transmission Type:

Automatic or Manual

FWD or (RWD) or 4WD

Body Type: Coupe

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 1268 rf 1219 ℓr 999 rr 1014

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2473	2487	
M_2	1712	2013	
M_T	4185	4500	

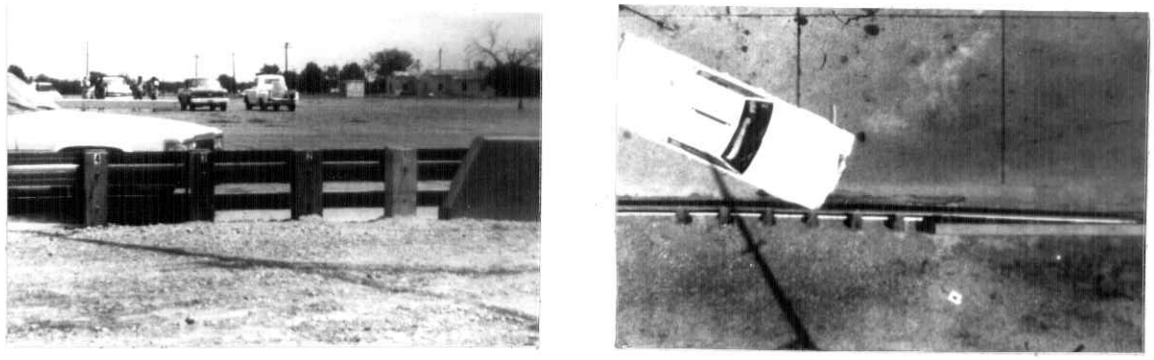
Note any damage to vehicle prior to test:

____

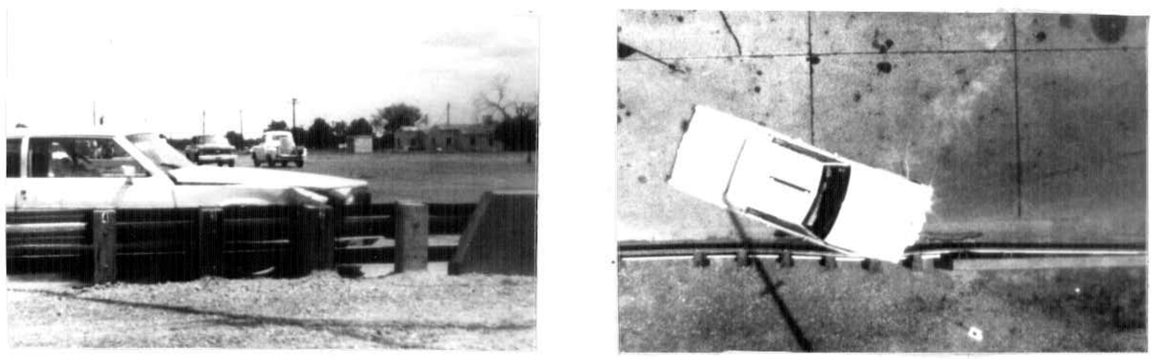
____

*d = overall height of vehicle

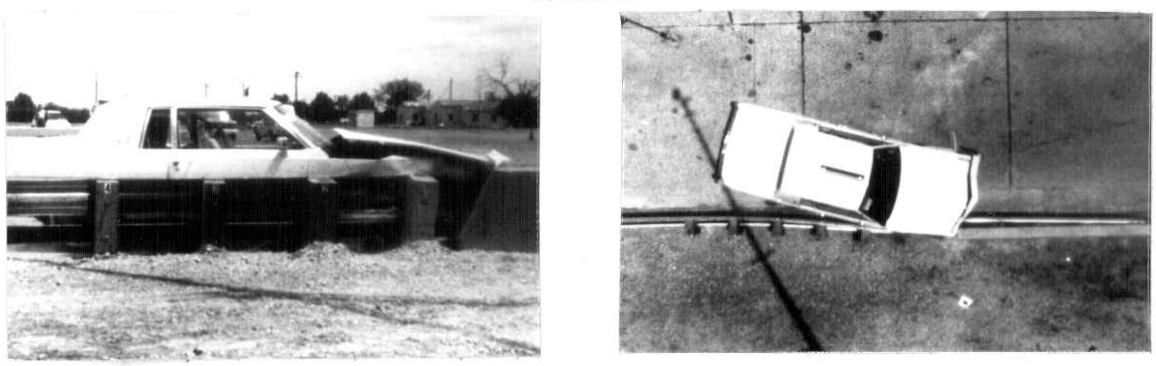
Figure 40. Vehicle properties (test 7155-4).



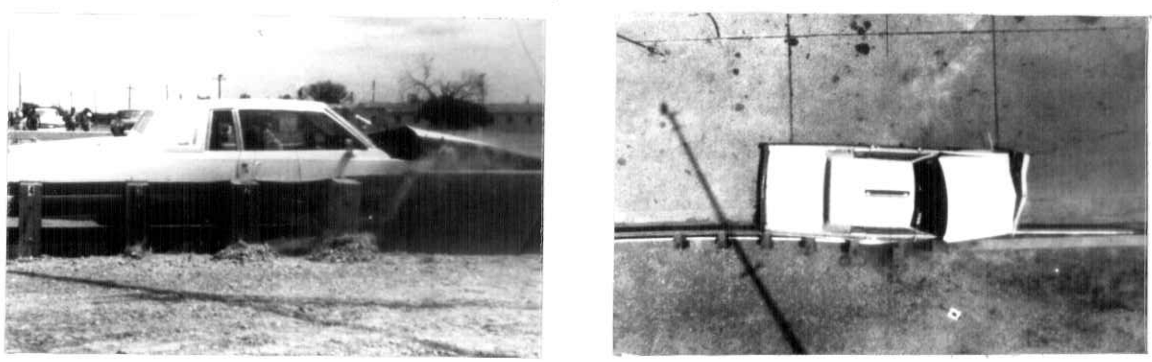
0.000 s



0.053 s

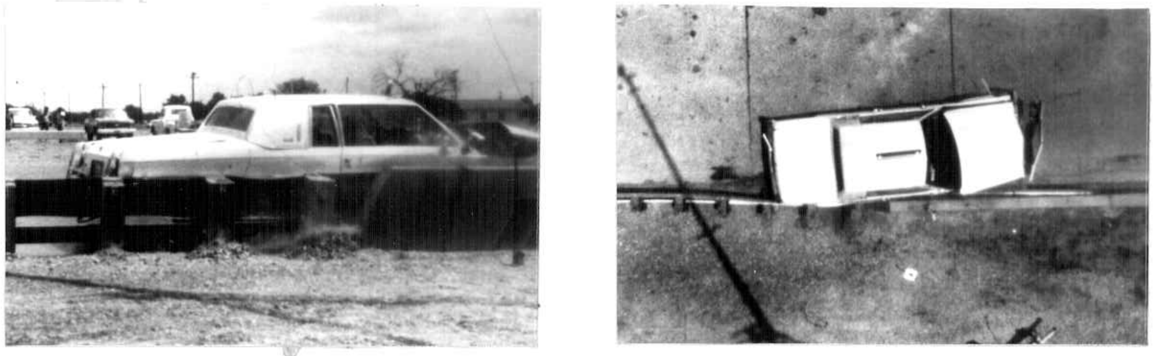


0.106 s

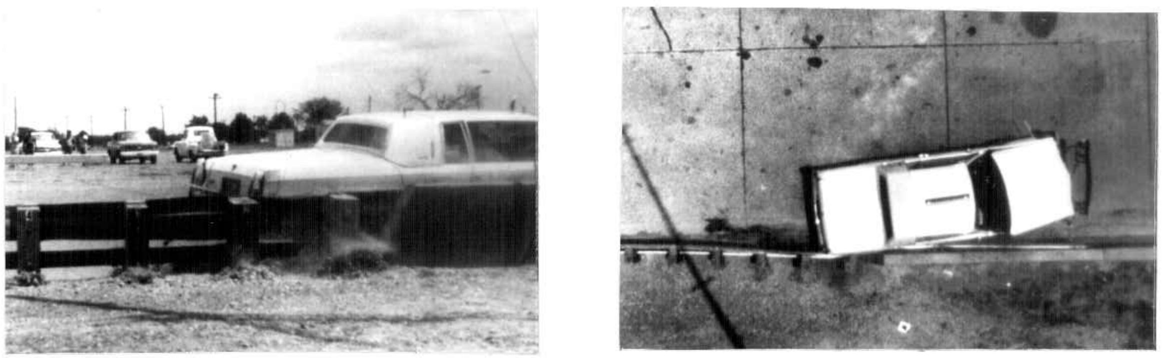


0.159 s

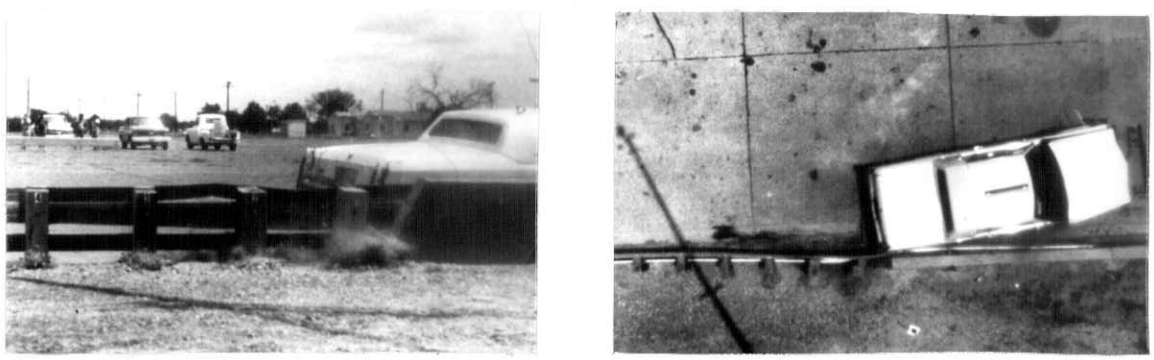
Figure 41. Sequential photographs of test 7155-4.



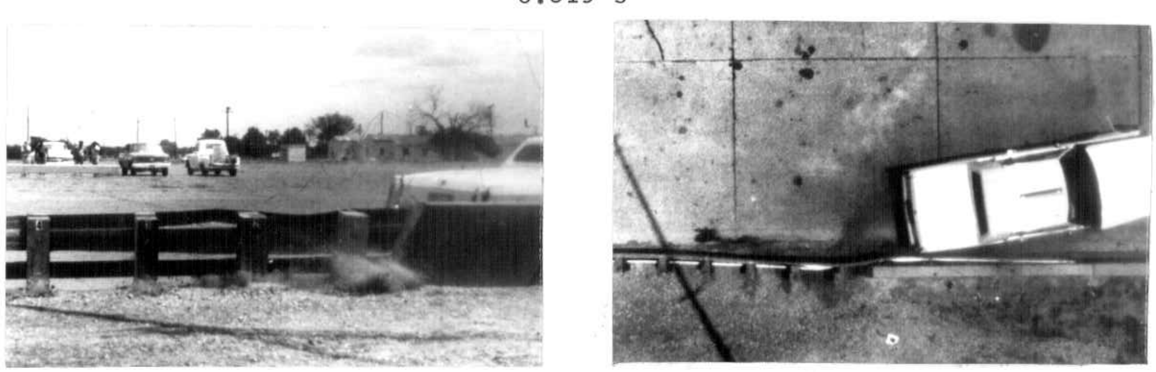
0.212 s



0.265 s

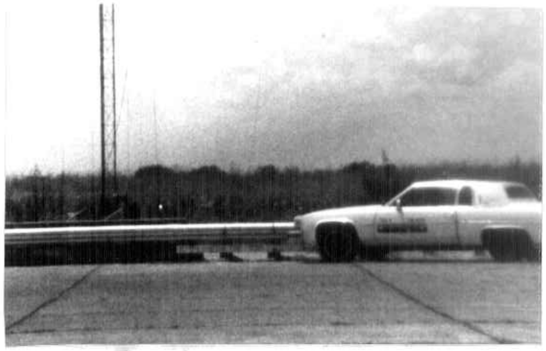


0.319 s



0.372 s

Figure 41. Sequential photographs of test 7155-4. (continued)



0.000 s

0.053 s

0.106 s

0.159 s

0.212 s

0.265 s

0.319 s

0.372 s

Figure 41. Sequential photographs of test 7155-4.
(continued)

Figure 42. Arizona guardrail transition to concrete barrier after test 7155-4.

Damage to the vehicle is shown in Figure 43. The damage was moderate for a test of this severity. The maximum crush was 17.0 inches (43.2 cm) at the right front corner of the vehicle. The right front wheel and control arm were pushed rearward 11.0 inches (27.9 cm), and the entire front end of the vehicle was shifted to the left a distance of 6.0 inches (15.2 cm).

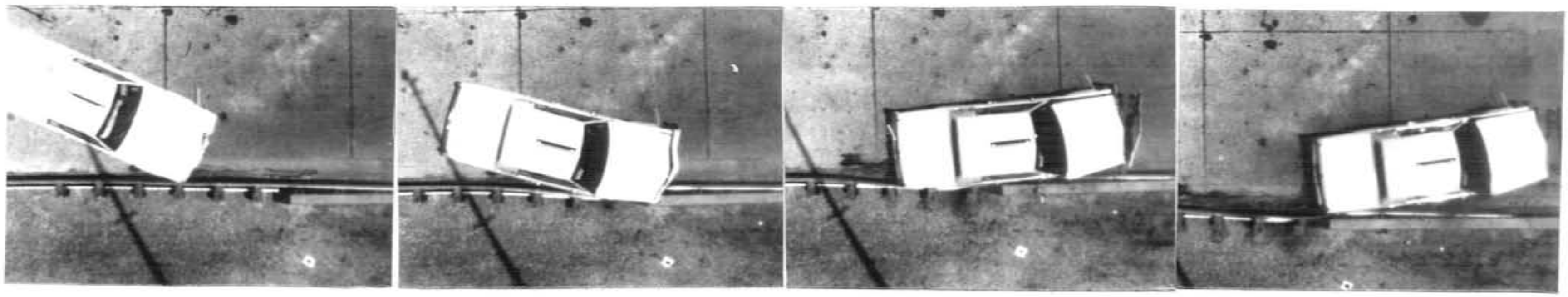
A summary of the test results and other information pertinent to this test are given in Figure 44. The maximum 0.050-second average accelerations experienced by the vehicle were -8.8 g in the longitudinal direction and 11.9 g in the lateral direction. Angular displacements of the vehicle during the impact event are plotted in Figure 45, and accelerometer traces are displayed in Figures 46 - 48. Occupant impact velocities were 27.4 feet per second (8.4 m/s) in the longitudinal direction and -25.4 feet per second (-7.7 m/s) in the lateral direction. The highest 0.010 second occupant ridedown accelerations were -4.2 g (longitudinal) and 20.5 g (lateral). It should be noted that the occupant risk evaluation criteria reported above are not required in the assessment of the performance of this test and are reported for information purposes only.

In summary, this test was judged to be a success. The installation successfully contained and redirected the impacting vehicle. The vehicle remained upright and stable during the initial test period and after leaving the installation. There was no debris or detached elements from the vehicle that would pose a hazard to other traffic, and there was only minor buckling of the floor board in the occupant compartment. The change in velocity of the vehicle was 17.8 miles per hour (28.6 km/h) which is slightly above the recommended limit of 15 miles per hour set forth in the guidelines of NCHRP Report 230. However, the vehicle would not have encroached into adjacent traffic lanes and, therefore, would not have posed a hazard to other traffic. The exit angle of the vehicle (8.2 degrees) was less than 60 percent of the impact angle as recommended by NCHRP Report 230.

Test 7155-5

This test evaluated the performance of ADOT's standard steel post transition with a curb. With the exception of the channel rubrail, the guardrail installation was identical to the design which was successfully tested in Tests 1 and 3. However, instead of a lower rubrail, the bottom face of the concrete barrier tapered into a 6 inch curb which continued

Figure 43. Vehicle after test 7155-4.

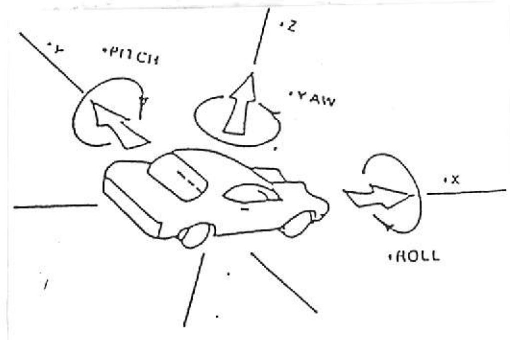


0.000 s   0.106 s   0.212 s   0.319 s

Test No.	7155-4
Date	08/16/90
Test Installation	Arizona Guardrail Transition to Concrete Half Barrier
Length of Transition	87.5 ft (26.7 m)
Vehicle	1981 Cadillac Coupe Deville
Vehicle Weight	
Test Inertia	4500 lb (2041 kg)
Vehicle Damage Classification	
TAD	11RFQ-5
CDC	81RFEW2
Maximum Vehicle Crush	17.0 in (43.2 cm)
Max. Dyn. Rail Deflection	8.3 in (21.0 cm)
Max. Perm. Rail Deflection	7.5 in (19.1 cm)

Impact Speed	61.5 mi/h (98.9 km/h)
Impact Angle	24.0 deg
Exit Speed	43.7 mi/h (70.3 km/h)
Exit Angle	8.2 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal	-8.8 g
Lateral	11.9 g
Occupant Impact Velocity	
Longitudinal	27.4 ft/s (8.4 m/s)
Lateral	-25.4 ft/s (-7.7 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-4.2 g
Lateral	20.5 g

Figure 44. Summary of results for test 7155-4.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

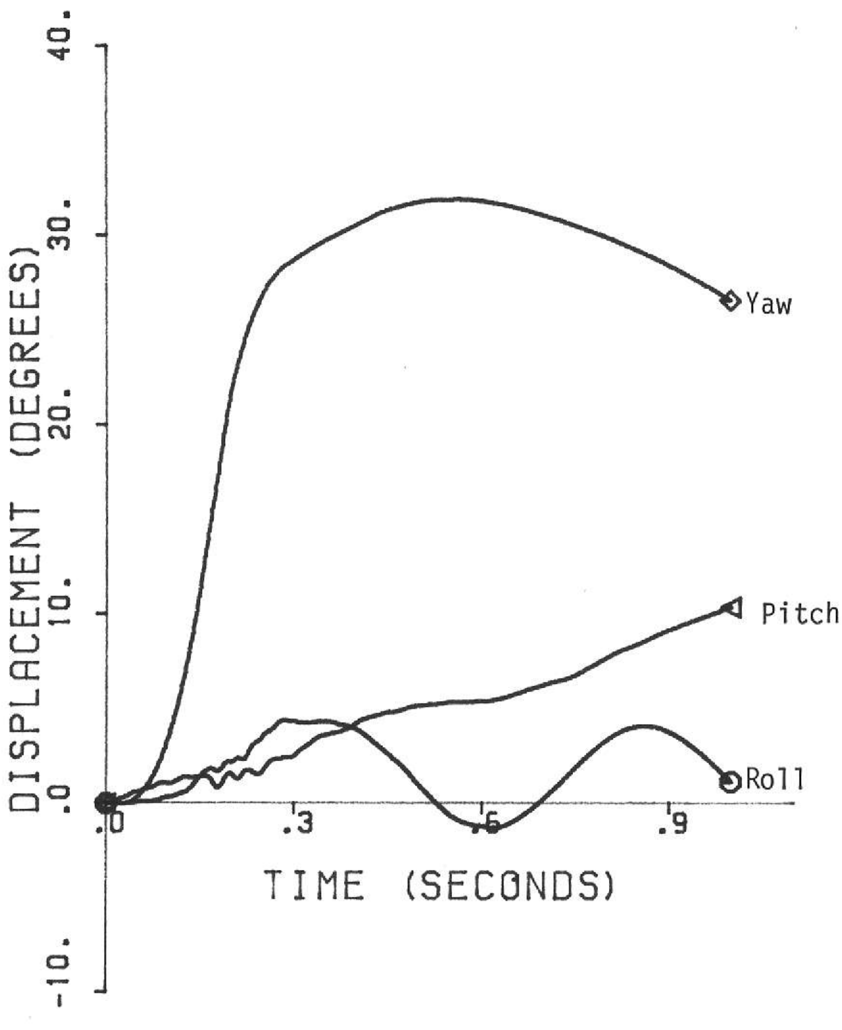


Figure 45. Vehicle angular displacements for test 7155-4.

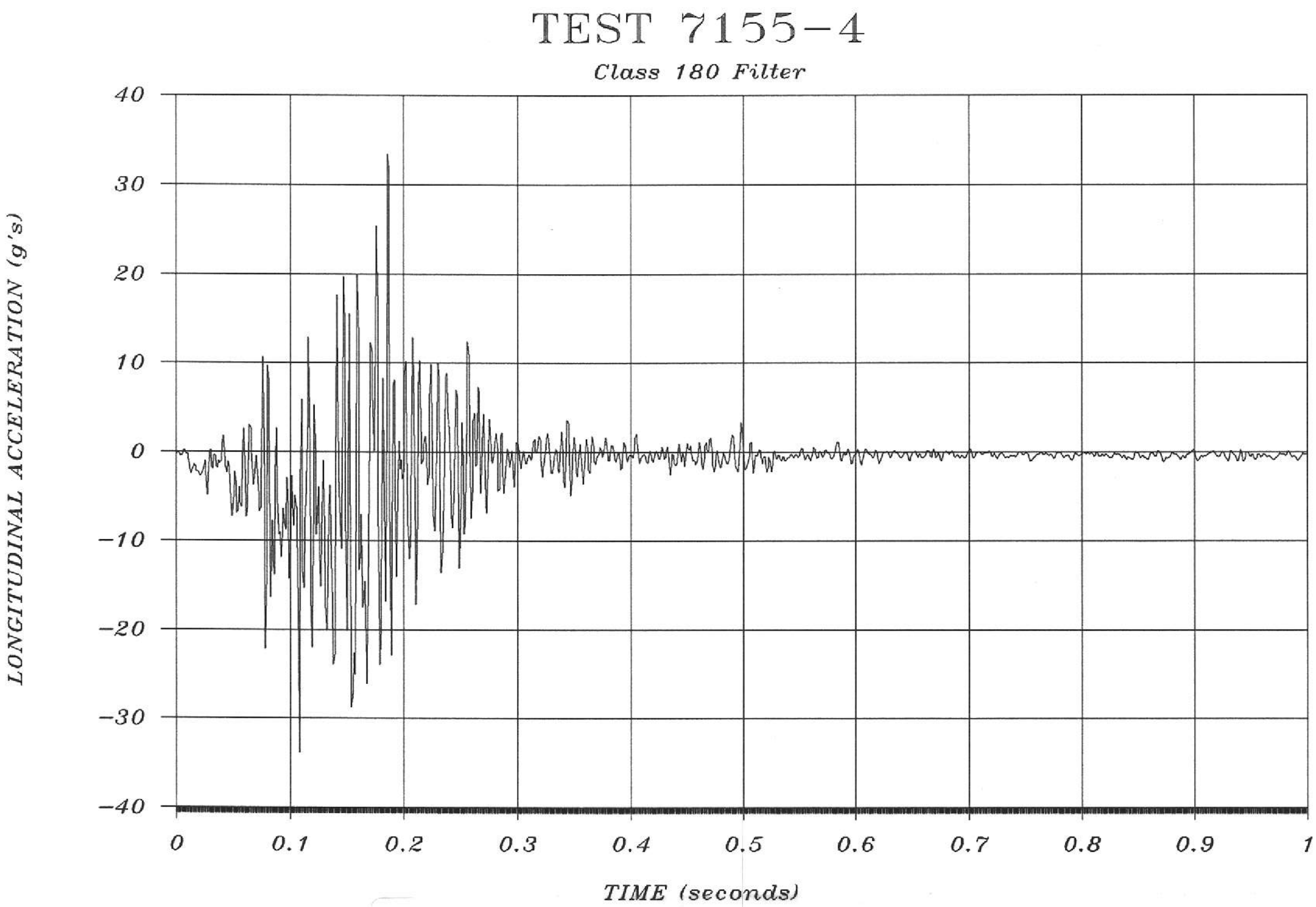


Figure 46. Longitudinal accelerometer trace for test 7155-4.

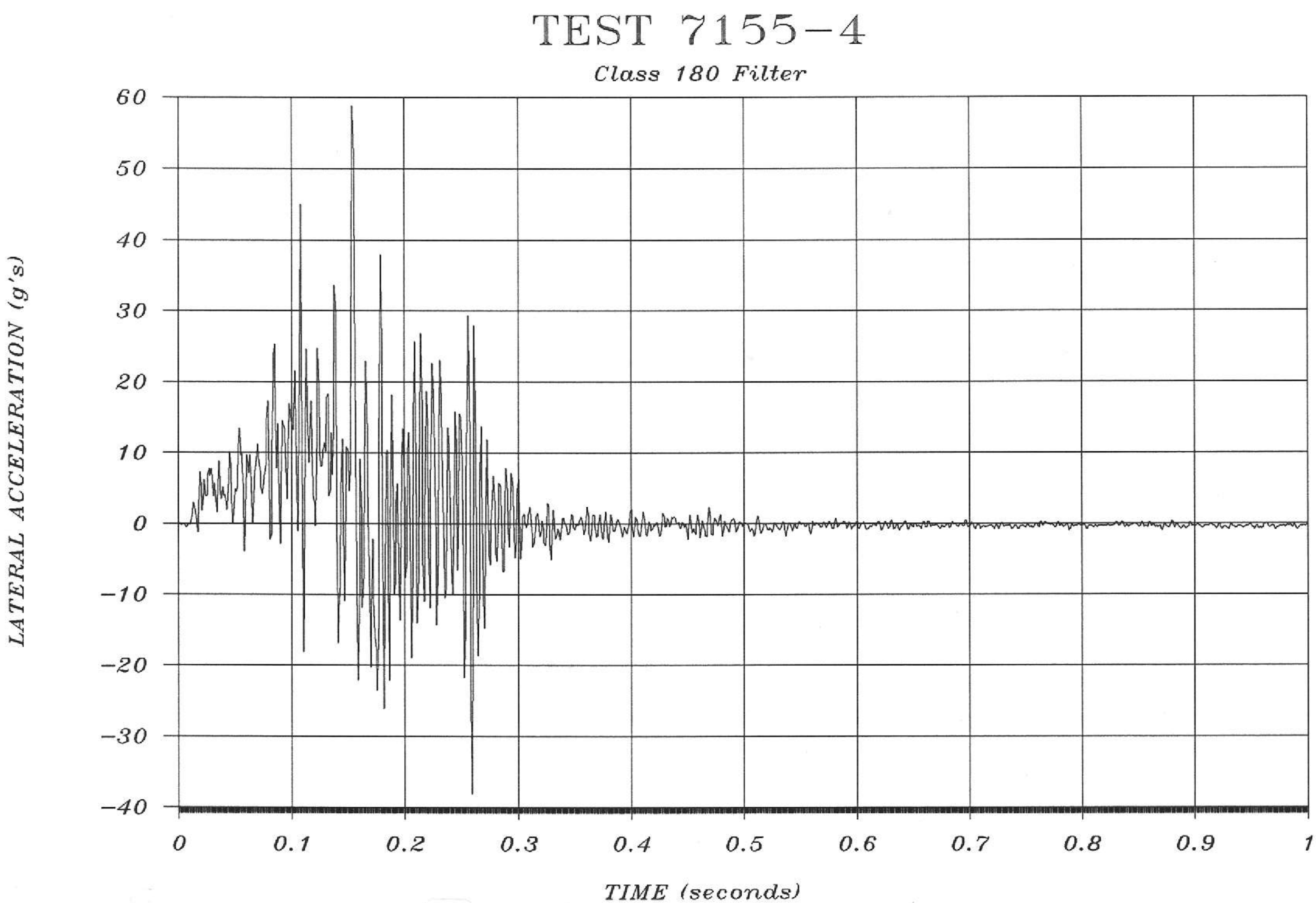


Figure 47. Lateral accelerometer trace for test 7155-4.

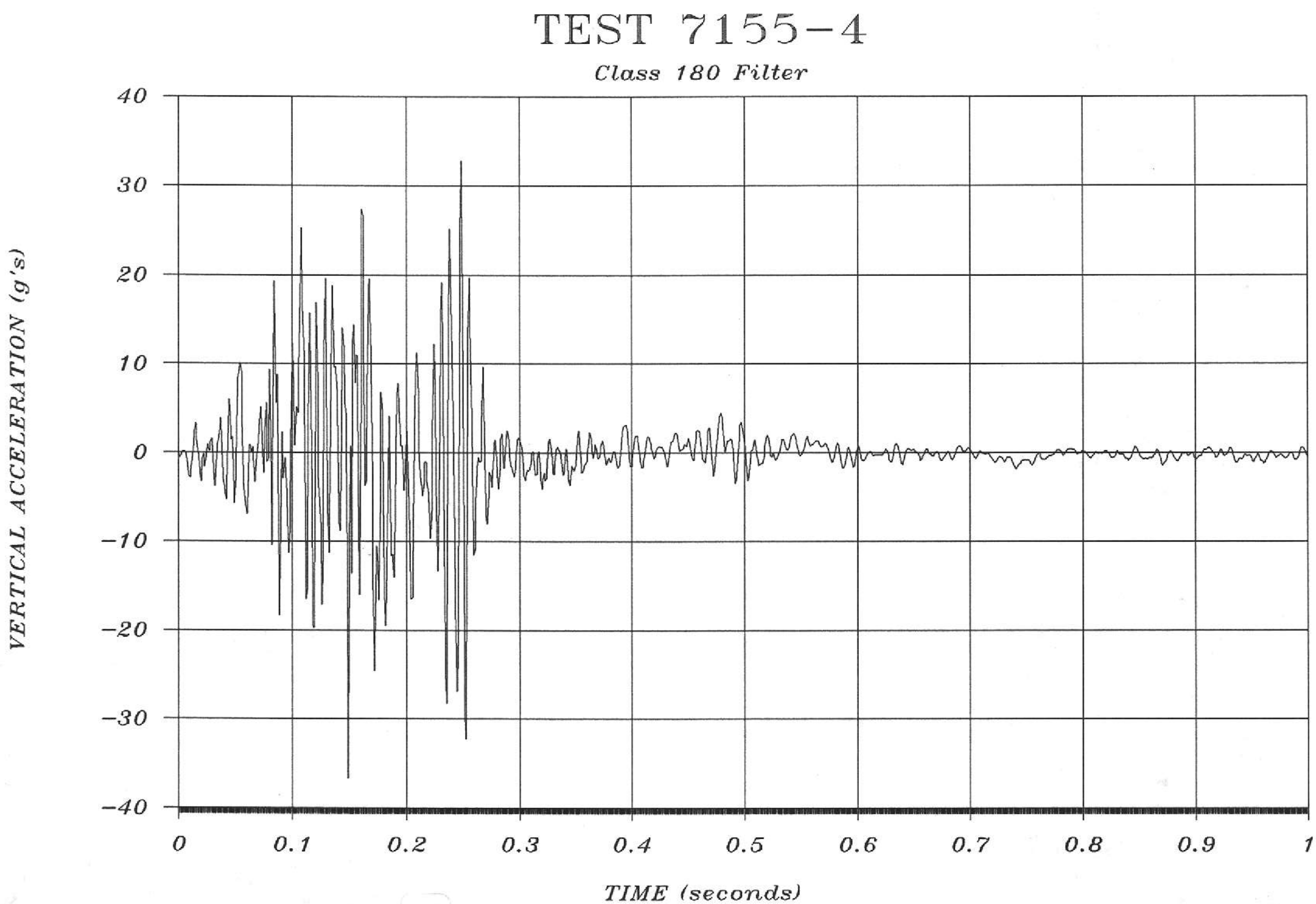


Figure 48. Vehicle accelerometer trace for test 7155-4.

from the end of the concrete rail along the transition. The face of the curb was aligned in a vertical plane with the traffic face of the W-beam guardrail. Post size, post spacing, and blockout depth were all the same as steel post designs previously tested in this study. As in Test 3, the rectangular plate washers were removed from all but the first two posts adjacent to the parapet.

Details of the curb transition are given in Figure 49, and the completed test installation before Test 5 is shown in Figure 50.

Results

A 1979 Cadillac Sedan Deville (shown in Figure 51) impacted 7.0 ft (2.1 m) upstream of the end of the concrete bridge rail at 62.8 miles per hour (101.0 km/h) and at an angle of 26.0 degrees using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 pounds (2,041 kg). The lower edge of the vehicle's bumper was at a height of 13.5 inches (34.3 cm) and the upper edge was at a height of 23.0 inches (58.4 cm). Other dimensions and pertinent information on the vehicle are given in Figure 52.

The vehicle was free wheeling and unrestrained just prior to impact. The vehicle immediately jumped the curb and thus had an upward trajectory as it impacted the W-beam guardrail. The guardrail was raised vertically allowing the bumper of the vehicle to ride underneath the guardrail and impact the W8x21 post adjacent to the concrete barrier. The blockout on this post partially collapsed and the W-beam yielded locally, wrapping itself around the end of the concrete rail. This allowed the front frame of the vehicle to impact the end of the bridge rail. Shortly thereafter, the left front wheel snagged on the end of the bridge rail causing the entire front end of the vehicle to nose down and shift toward the barrier. The vehicle experienced significant decelerations, but continued to move along the barrier. The vehicle finally lost contact with the installation at 0.444 second traveling 29.9 miles per hour at an angle of 4.9 degrees. Shortly thereafter, the brakes were applied, the vehicle yawed clockwise and came to rest 127.5 feet (38.9 m) from the point of impact. Sequential photographs of the test are shown in Figure 53.

As shown in Figure 54, the area of damage to the installation was limited to the first two guardrail posts and the end of the concrete bridge rail. The maximum permanent rail deformation was 11.8 inches (29.8 cm) and the maximum lateral dynamic rail deflection was

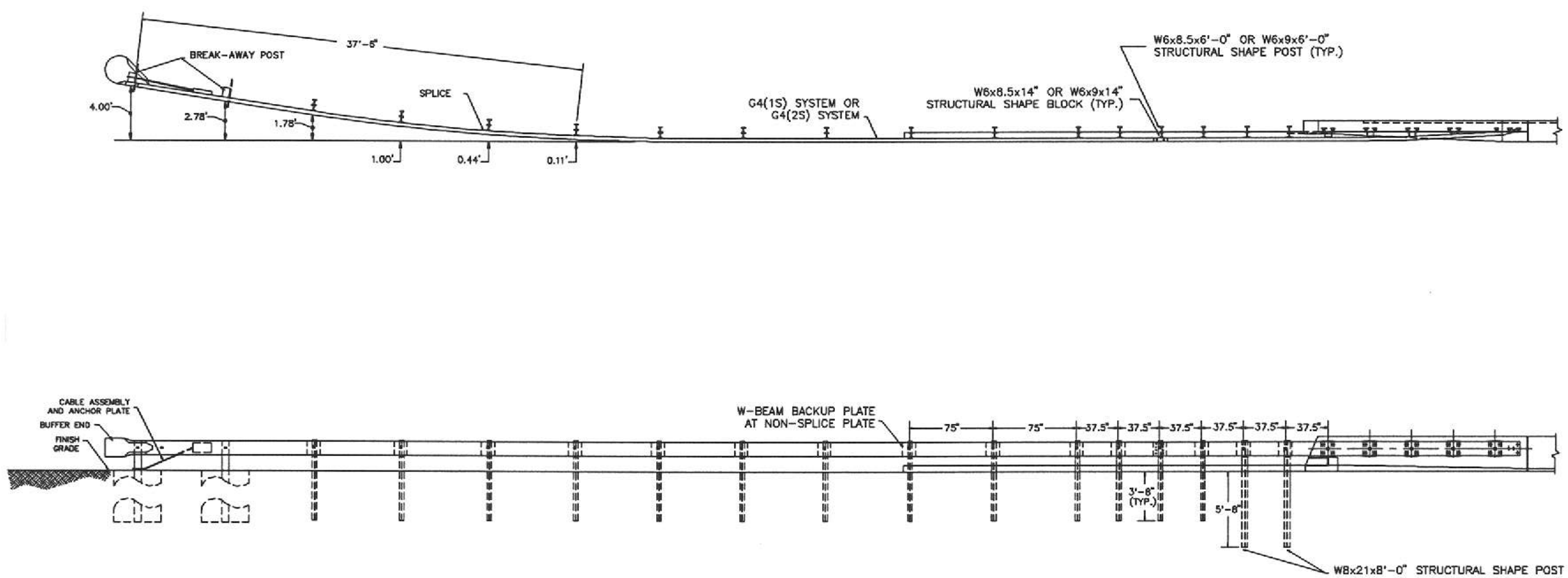


Figure 49. ADOT steel post transition with curb

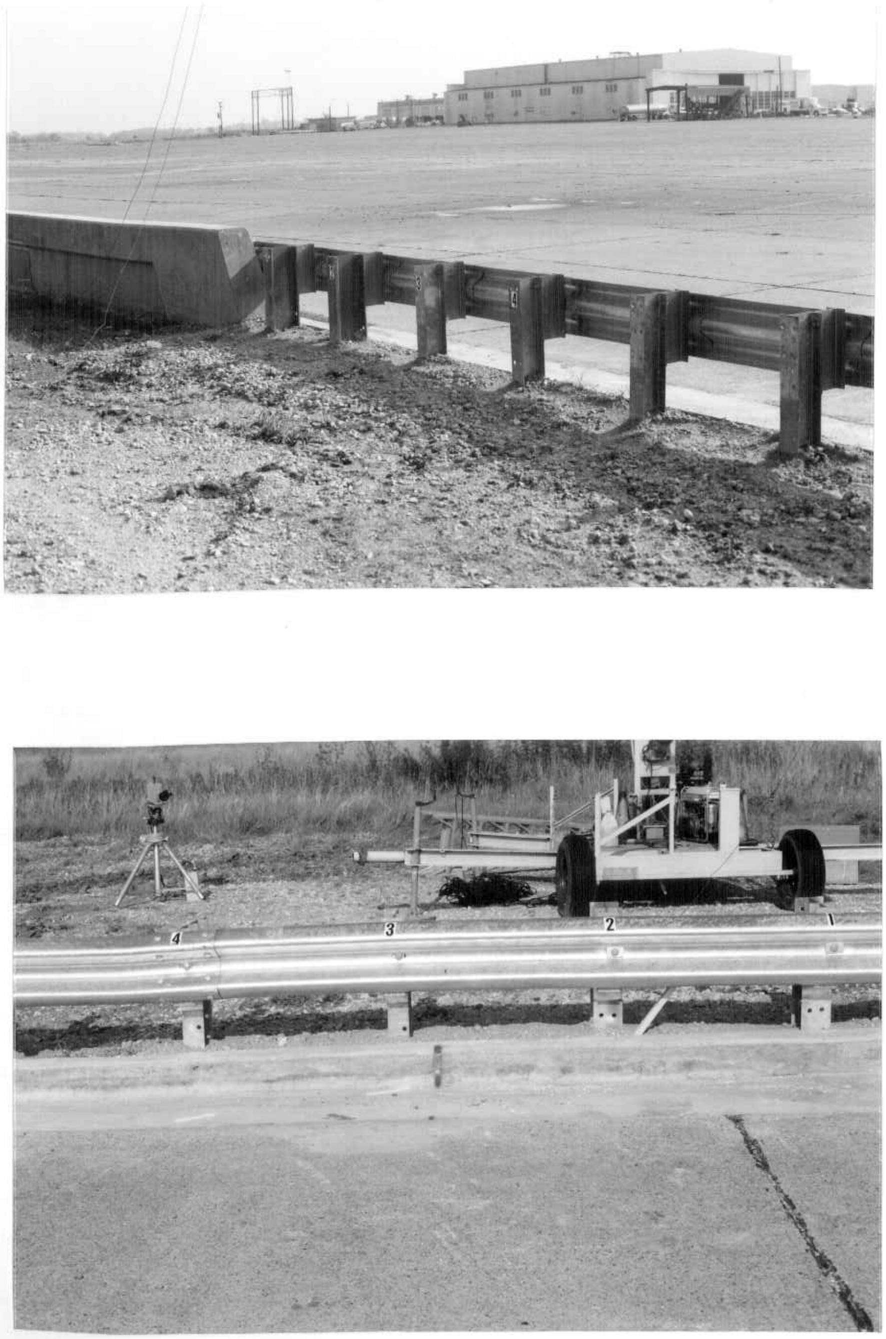


Figure 50. Arizona guardrail transition to concrete barrier before test 7155-5.

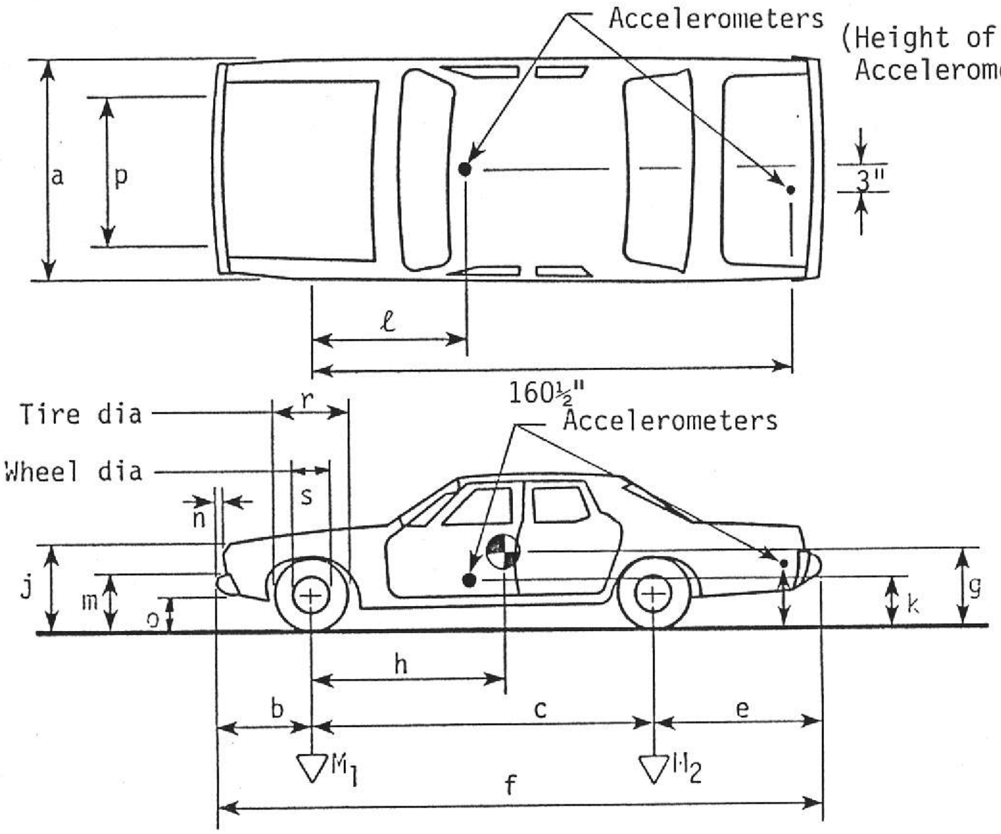
Figure 51. Vehicle before test 7155-5.

Date: ______ Test No.: 7155-5 VIN: 6D69599125049

Make: Cadillac Model: Sedan DeVille Year: 1979 Odometer: 48565

Tire Size: P215 75R15 Ply Rating: ______ Bias Ply: ___ Belted: ___ Radial: X

Tire Condition: good ___
fair X
badly worn ___



Vehicle Geometry - inches

a	76½"	b	41"
c	121½"	d*	56½"
e	56"	f	218½"
g		h	56½"
i	----	j	36"
k	19¼"	ℓ	38"
m	23"	n	4½"
o	13½"	p	61½"
r	27"	s	16¼"

Engine Type: V-8

Engine CID: 7.0 L

Transmission Type:

Automatic or ~~Manual~~

~~FWD~~ or RWD or ~~4WD~~

Body Type: 4 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

4-wheel weight for c.g. det. ℓf 1180 rf 1227 ℓr 1058 rr 1035

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2466	2407	
M_2	1724	2093	
M_T	4190	4500	

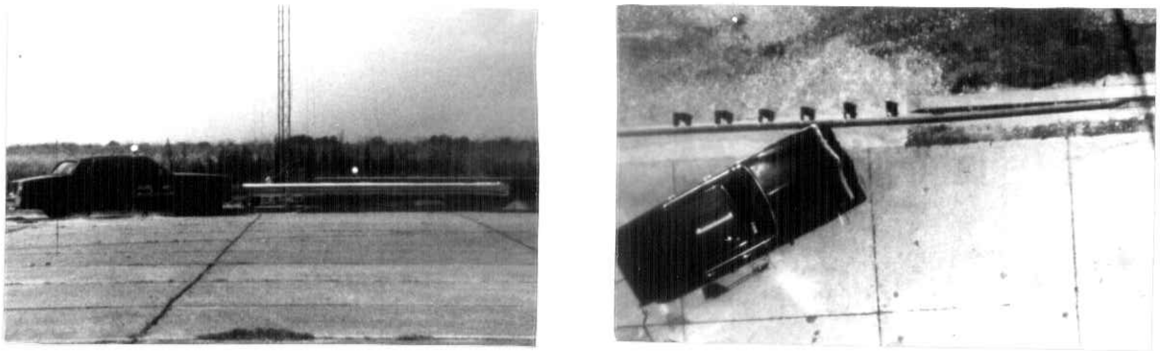
Note any damage to vehicle prior to test:

______

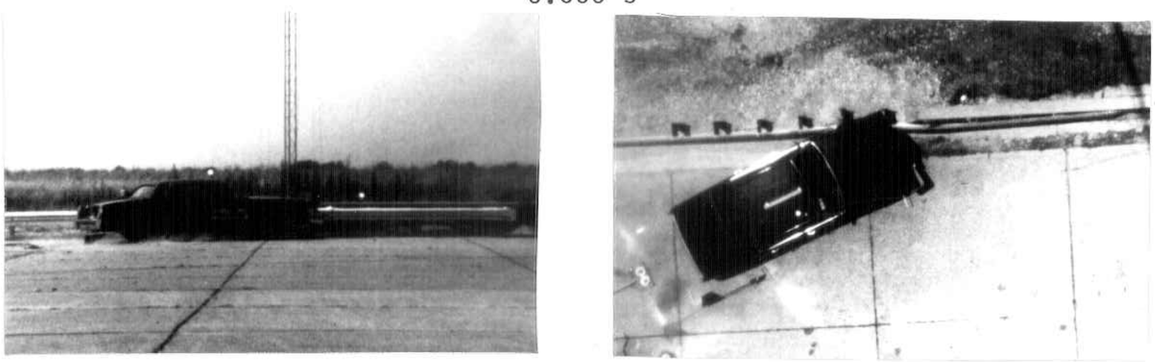
______

*d = overall height of vehicle

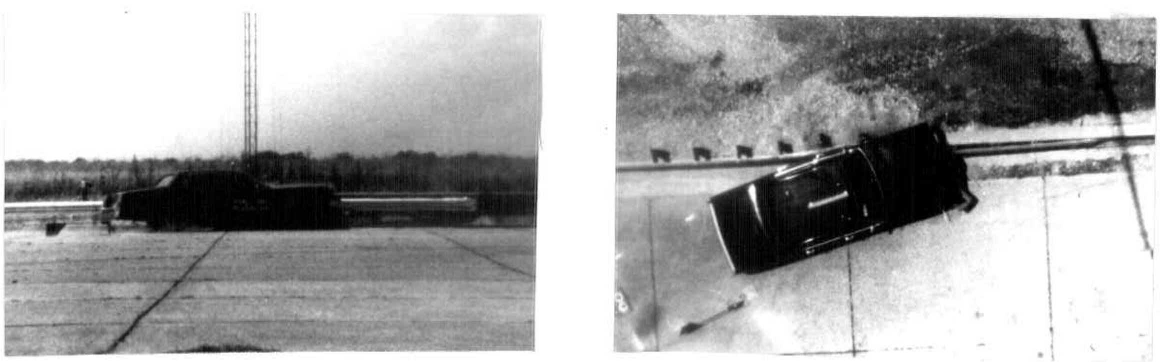
Figure 52. Vehicle properties (test 7155-5).



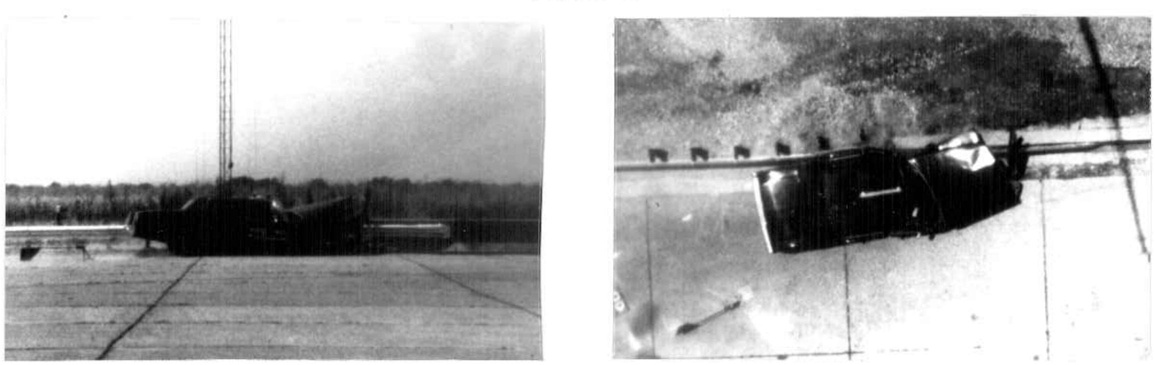
0.000 s



0.062 s



0.123 s



0.185 s

Figure 53. Sequential photographs of test 7155-5.

0.000 s

0.062 s

0.123 s

0.185 s

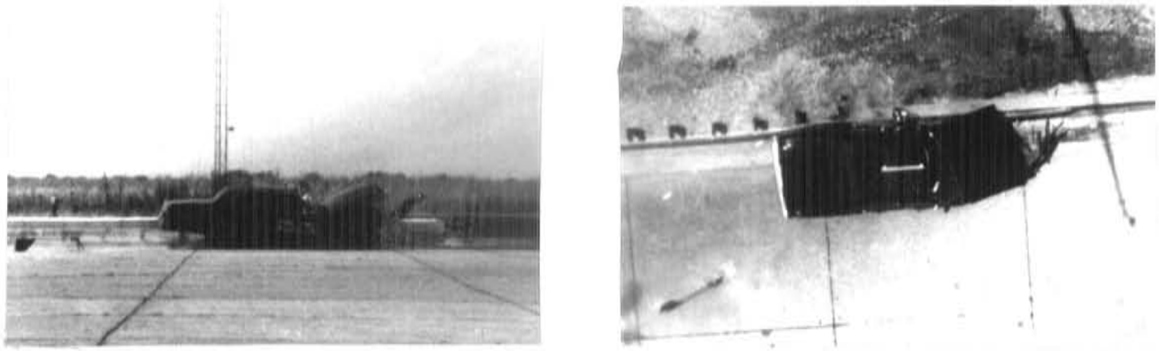
0.247 s

0.308 s

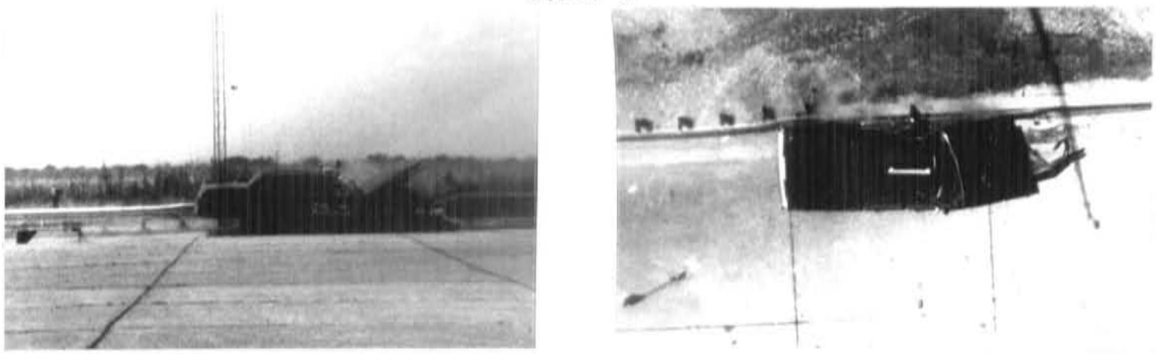
0.370 s

0.432 s

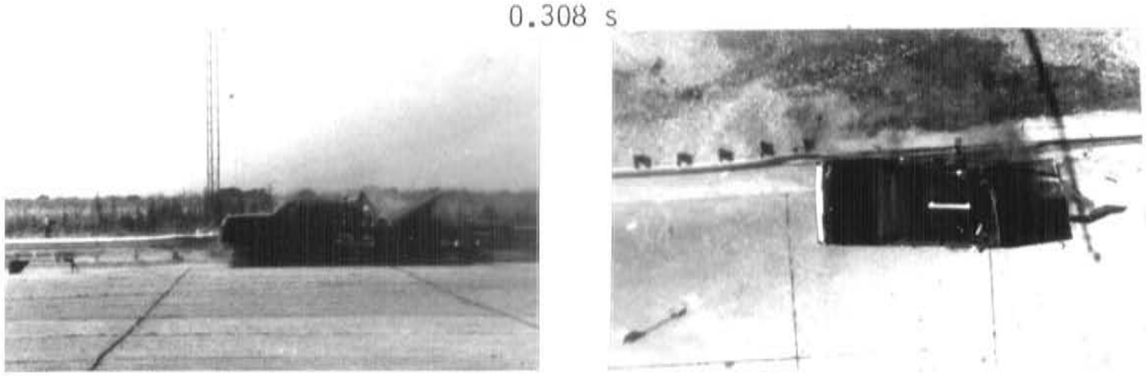
Figure 53. Sequential photographs of test 7155-5. (continued)



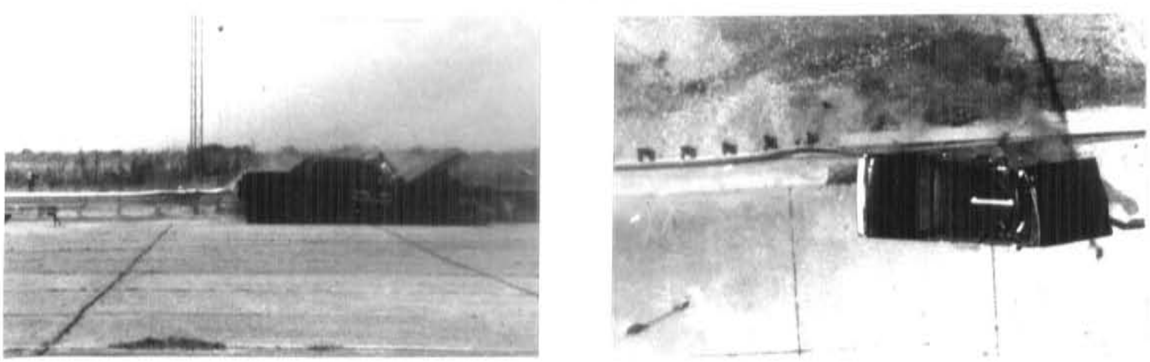
0.247 s



0.308 s



0.370 s



0.432 s

Figure 53. Sequential photographs of test 7155-5. (continued)

Figure 54. Arizona guardrail transition to concrete half barrier after test 7155-5.

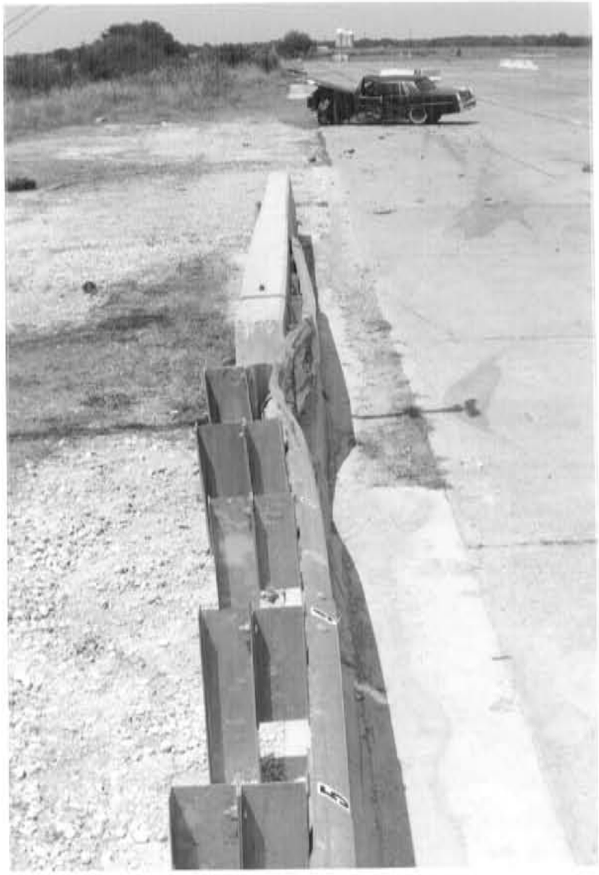


Figure 54. Arizona guardrail transition to concrete half barrier after test 7155-5. (continued)

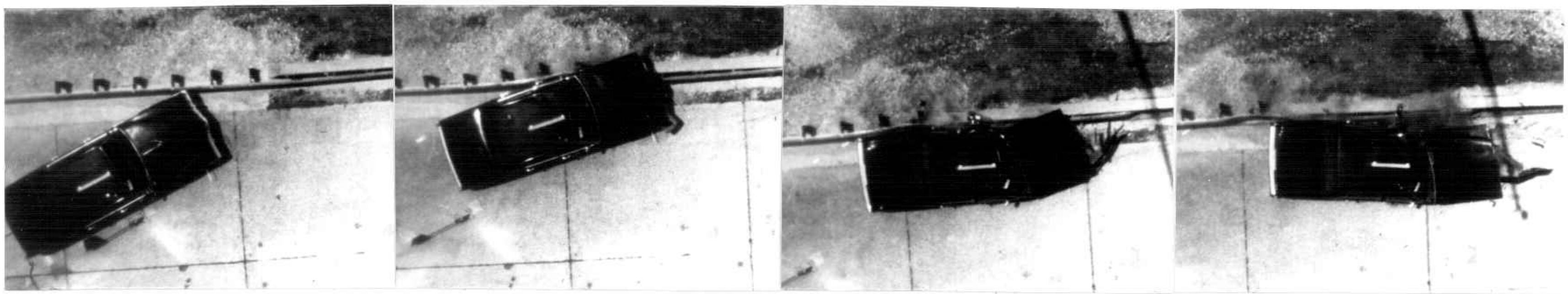
observed to be 12.7 inches (32.3 cm). The W-beam yielded around the end of the concrete rail and the first steel blockout on the face of the concrete barrier. Even under this severe impact, the concrete anchor inserts and blockouts were undamaged. In addition, the curb showed no visible signs of distress. The vehicle was in contact with the installation for a total length of 12.5 feet (3.8 m).

As shown in Figure 55, the vehicle was severely damaged. The maximum crush recorded on the vehicle was 22.0 inches (55.9 cm). The left front wheel and spindle assembly was separated from the vehicle at the ball joint attachment points on the control arm. The entire front end of the vehicle was shifted to the left 4.0 inches (10.2 cm). Additionally, the subframe was damaged and the roof and A-pillar were buckled. There was significant intrusion and deformation of the occupant compartment with the steering wheel nearly contacting the driver's seat.

A summary of the test results and other information pertinent to this test are given in Figure 56. The maximum 0.050-second average accelerations experienced by the vehicle were -17.4 g in the longitudinal direction and -13.3 g in the lateral direction. Angular displacements experienced by the vehicle during the impact event are plotted in Figure 57, and accelerometer traces for all three vehicle axes are displayed in Figures 58 - 60. Occupant impact velocities were 40.3 feet per second (12.3 m/s) in the longitudinal direction and 25.3 feet per second (-7.7 m/s) in the lateral direction. The highest 0.010 second occupant ridedown accelerations were -10.1 g (longitudinal) and -18.4 g (lateral). Although the occupant risk criteria of NCHRP Report 230 are not applicable to this test, the longitudinal occupant impact velocity gives an indication of the severity of this impact. The observed value of 40.3 feet per second (12.3 m/s) is just above the maximum allowable value of 40 feet per second.

In summary, this test was judged to be a failure. The installation failed to smoothly redirect the impacting vehicle. There was significant snagging of the vehicle frame and wheel on the end of the concrete barrier and the first steel blockout on the concrete bridge rail. There was also severe deformation and intrusion into the occupant compartment of the vehicle.

Figure 55. Vehicle after test 7155-5.



0.000 s   0.123 s   0.247 s   0.370 s

Test No.	7155-5
Date	08/23/90
Test Installation	Arizona Guardrail Transition to Concrete Half Barrier
Length of Transition	87.5 ft (26.7 m)
Vehicle	1979 Cadillac Sedan Deville
Vehicle Weight	
Test Inertia	4500 lb (2041 kg)
Vehicle Damage Classification	
TAD	11LFQ-7
CDC	11LFAW3
Maximum Vehicle Crush	22.0 in (55.9 cm)
Max. Dyn. Rail Deflection	12.7 in (32.3 cm)
Max. Perm. Rail Deflection	11.8 in (29.8 cm)

Impact Speed	62.8 mi/h (101.0 km/h)
Impact Angle	26.0 deg
Exit Speed	29.9 mi/h (48.1 km/h)
Exit Angle	4.9 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal	-17.4 g
Lateral	-13.3 g
Occupant Impact Velocity	
Longitudinal	40.3 ft/s (12.3 m/s)
Lateral	25.3 ft/s (7.7 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-10.1 g
Lateral	-18.4 g

Figure 56. Summary of results for test 7155-5.

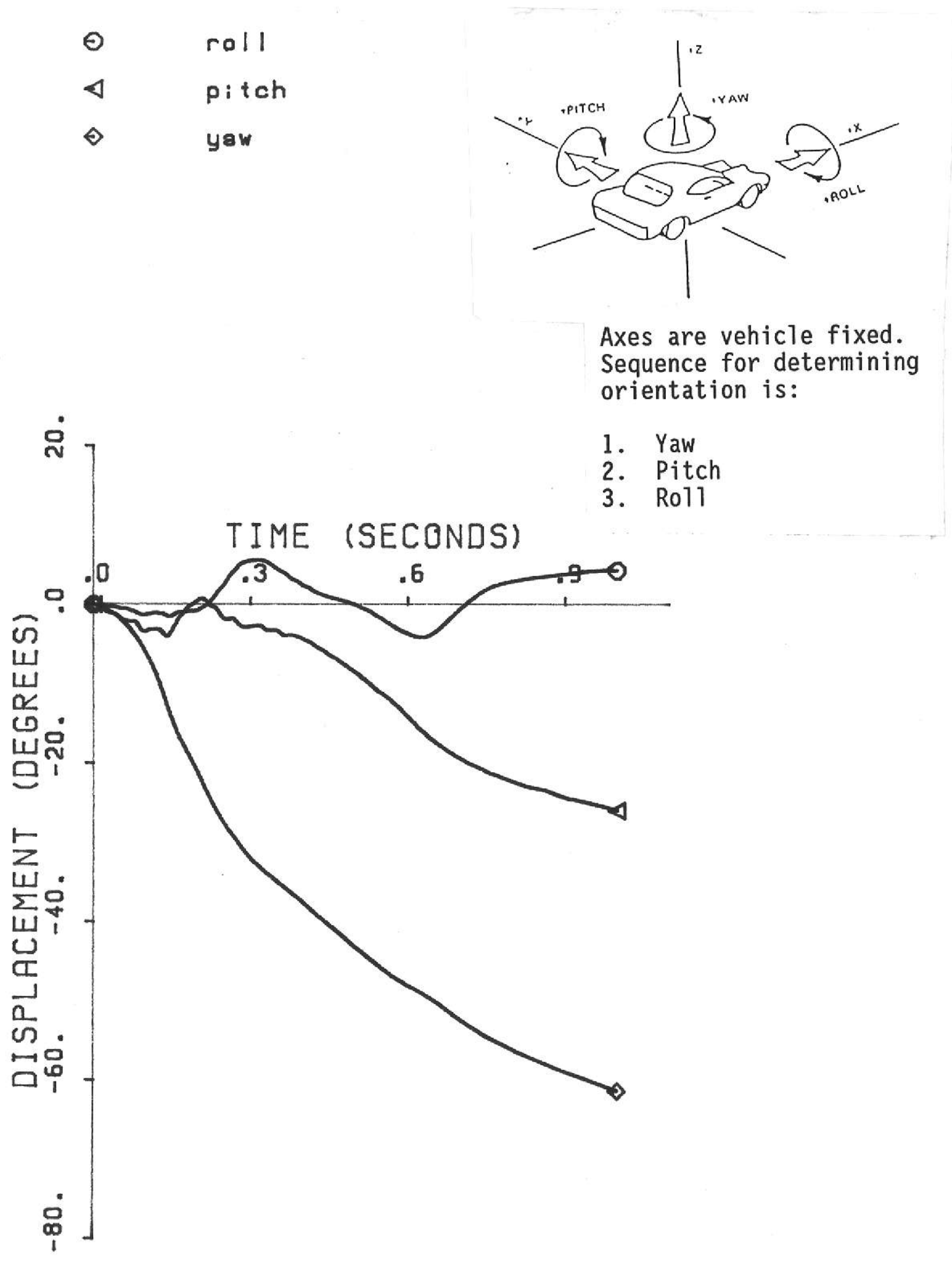


Figure 57. Vehicle angular displacements of test 7155-5.

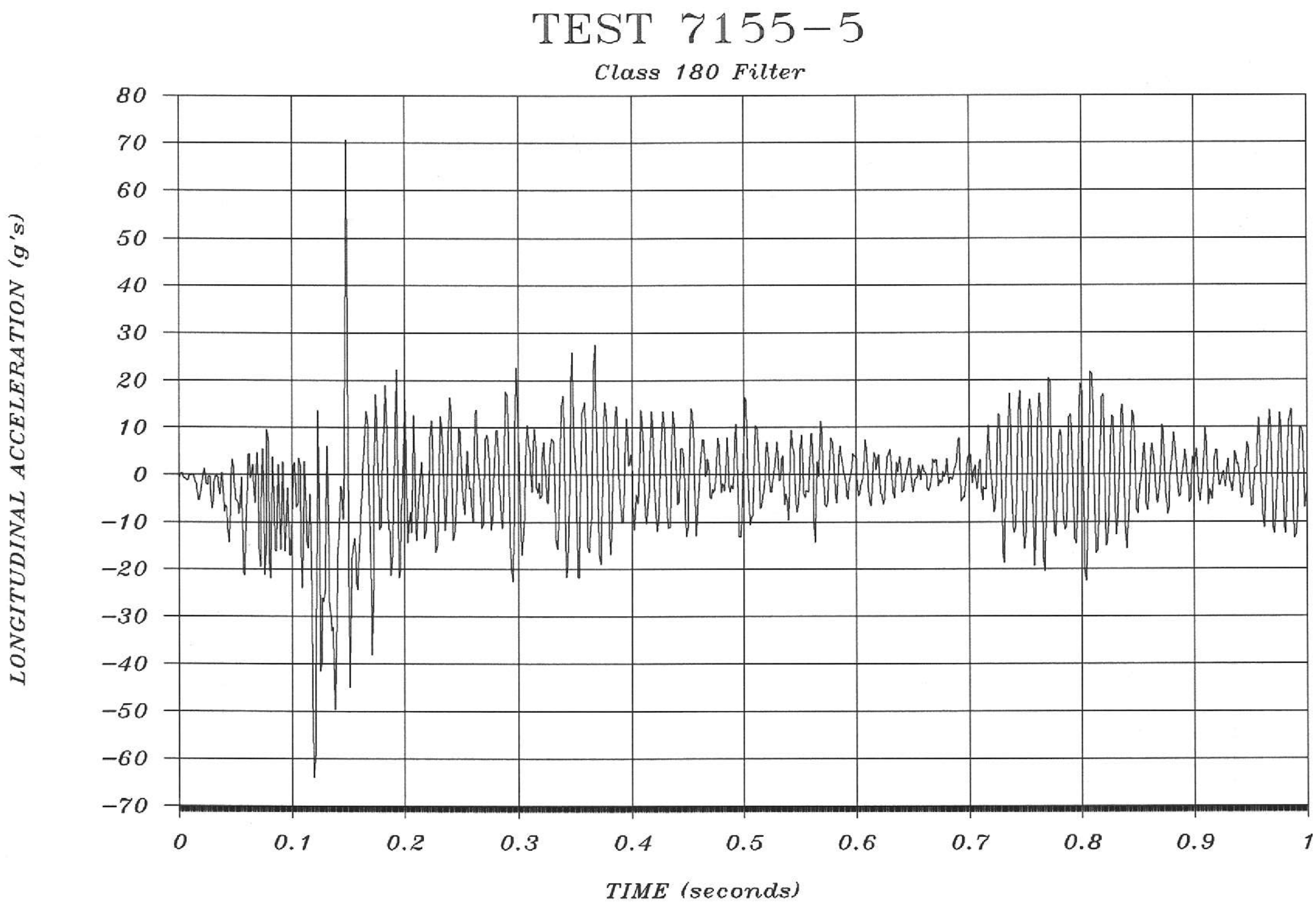


Figure 58. Longitudinal accelerometer trace of test 7155-5.

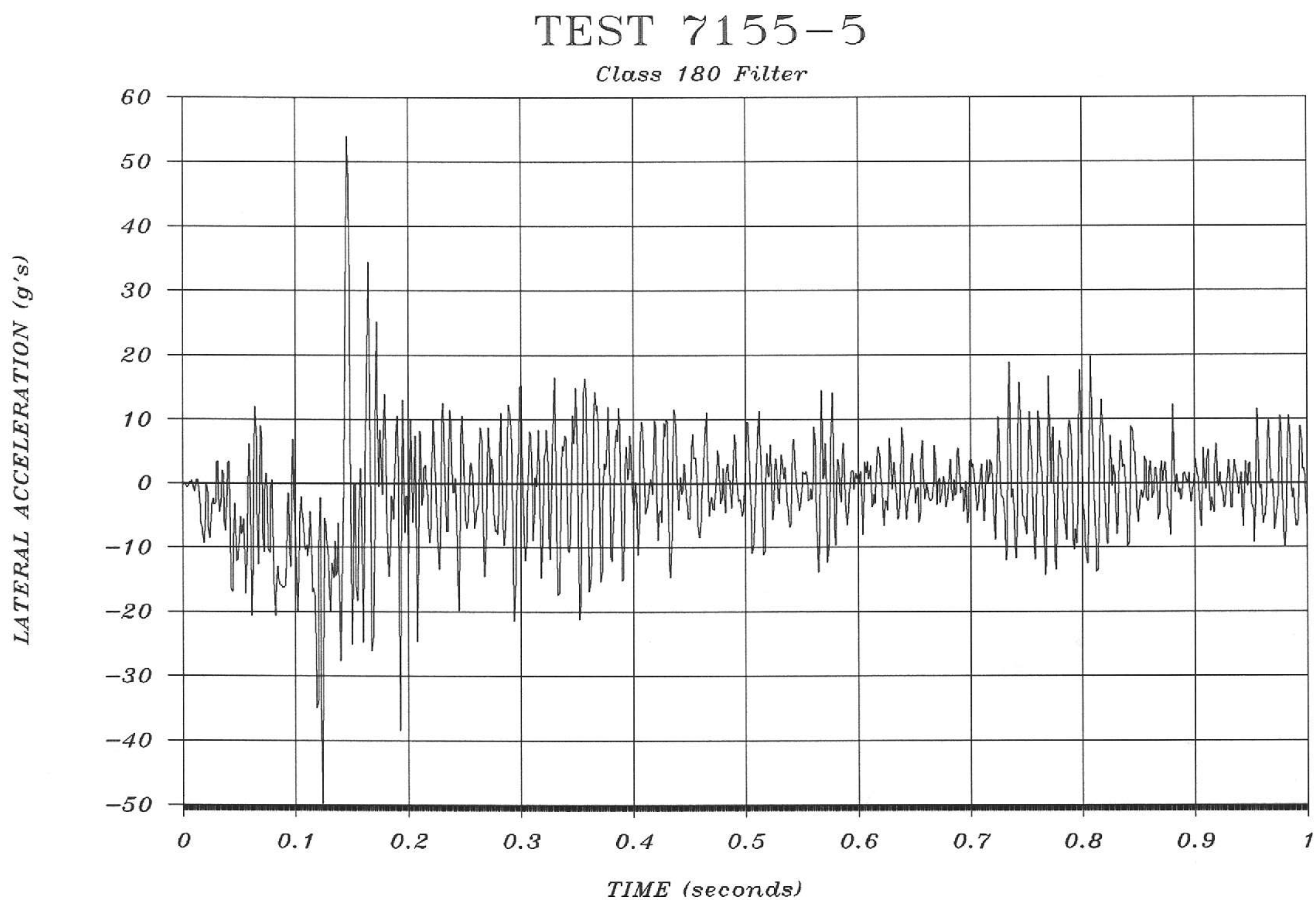


Figure 59. Lateral accelerometer trace of test 7155-5.

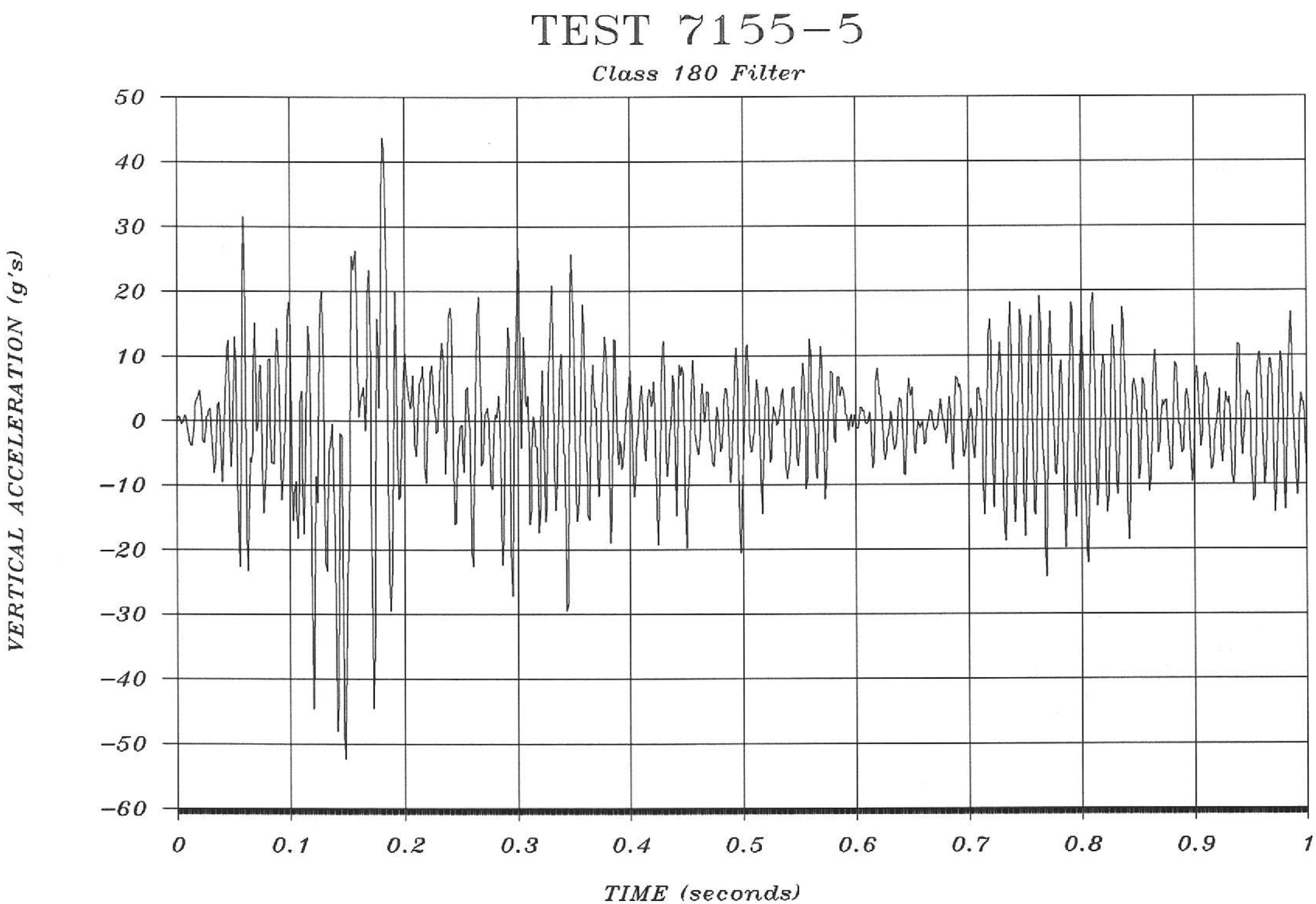


Figure 60. Vertical accelerometer trace of test 7155-5.

Test 7155-6

Due to the poor performance observed in Test 5, the curb transition design was modified. The retrofit modification included the addition of a channel rubrail similar in design to the previously tested steel post system. The rubrail was inset into a section cut out of the concrete rail in order to eliminate termination problems and allow the rubrail to be attached to the flanges of the steel posts in the transition. In lieu of the rubrail terminal anchor, the retrofit rubrail was through bolted to the concrete barrier. The purpose of the rubrail was to prevent the wheel of the vehicle from snagging on the end of the concrete barrier after it climbs the curb. In addition, W-beam backup plates were added behind the steel blockouts on the face of the concrete bridge rail to help reduce the localized yielding in these areas and thus reduce the potential for snagging of the vehicle frame. As in the previous test, rectangular plate washers were only used on the first two posts adjacent to the concrete parapet. Figure 61 shows details of the modified transition design, and the completed test installation is shown in Figure 62.

Results

A 1979 Cadillac Fleetwood (shown in Figure 63) impacted the transition 7.0 ft (2.1 m) upstream from the end of the concrete bridge rail at 59.5 miles per hour (95.8 km/h) and at an angle of 25.4 degrees using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 pounds (2,041 kg). The height to the lower edge of the vehicle's bumper was 12.0 inches (30.5 cm) and the height to the upper edge was 21.8 inches (55.2 cm). Other dimensions and information on the vehicle are given in Figure 64.

The vehicle was free wheeling and unrestrained just prior to impact. Upon impact, the vehicle climbed the curb and engaged the guardrail. The vertical motion imparted to the vehicle by the curb caused the wheel of the vehicle to ride up onto the rubrail, thus minimizing its effectiveness and raising the effective barrier loading height. Higher barrier loading increased bending moments at the base of the steel posts and increased barrier deflections. The combined lateral, longitudinal, and vertical loading transmitted to the posts caused total collapse of the W6x9 blockout on the first post adjacent to the end of the concrete wingwall. Thus, the effective blockout depth at this post was reduced to zero, resulting in a further increase in barrier rail deflection. This increase in deflection allowed

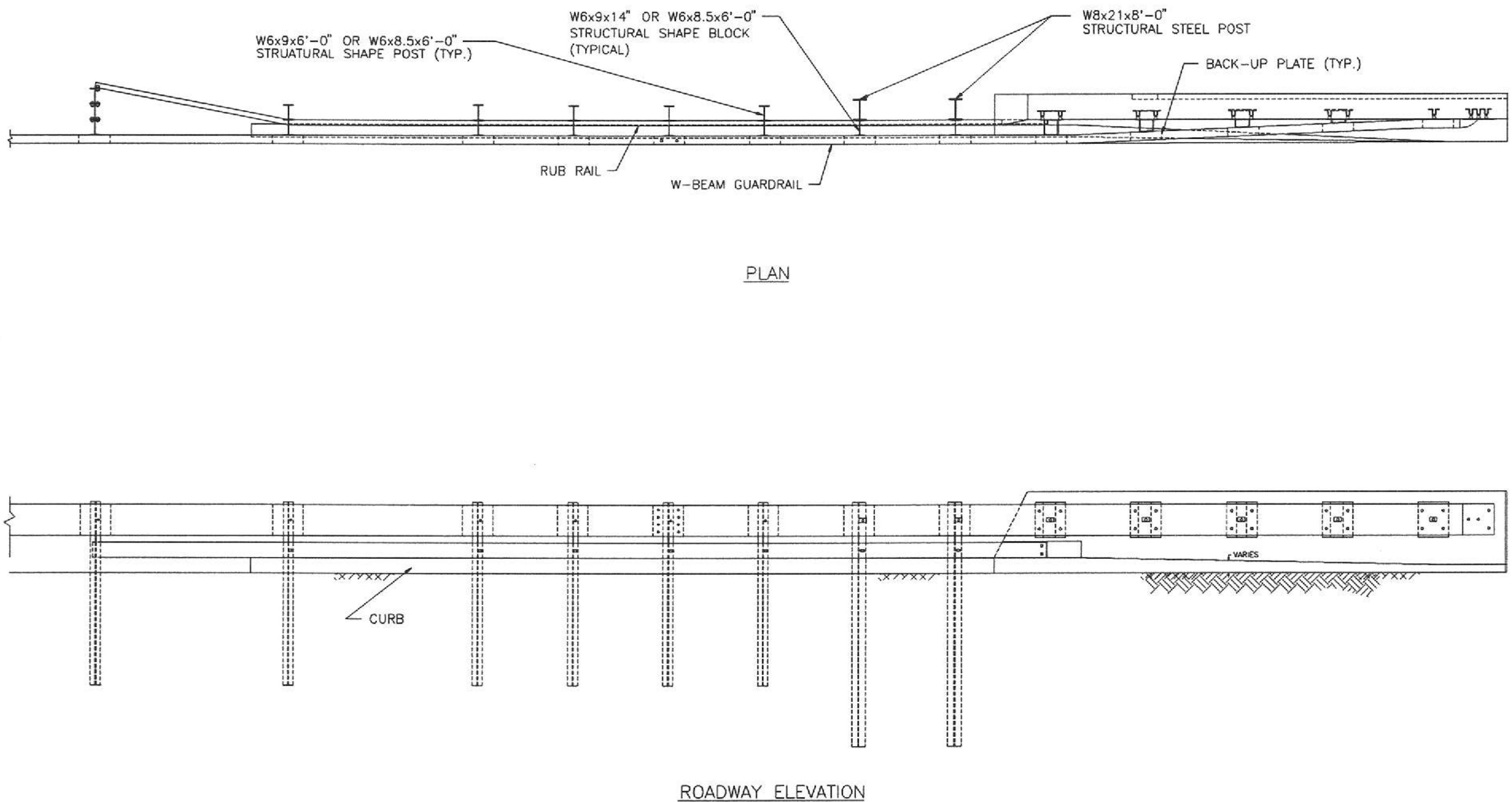


Figure 61. ADOT steel post transition with curb and rubrail

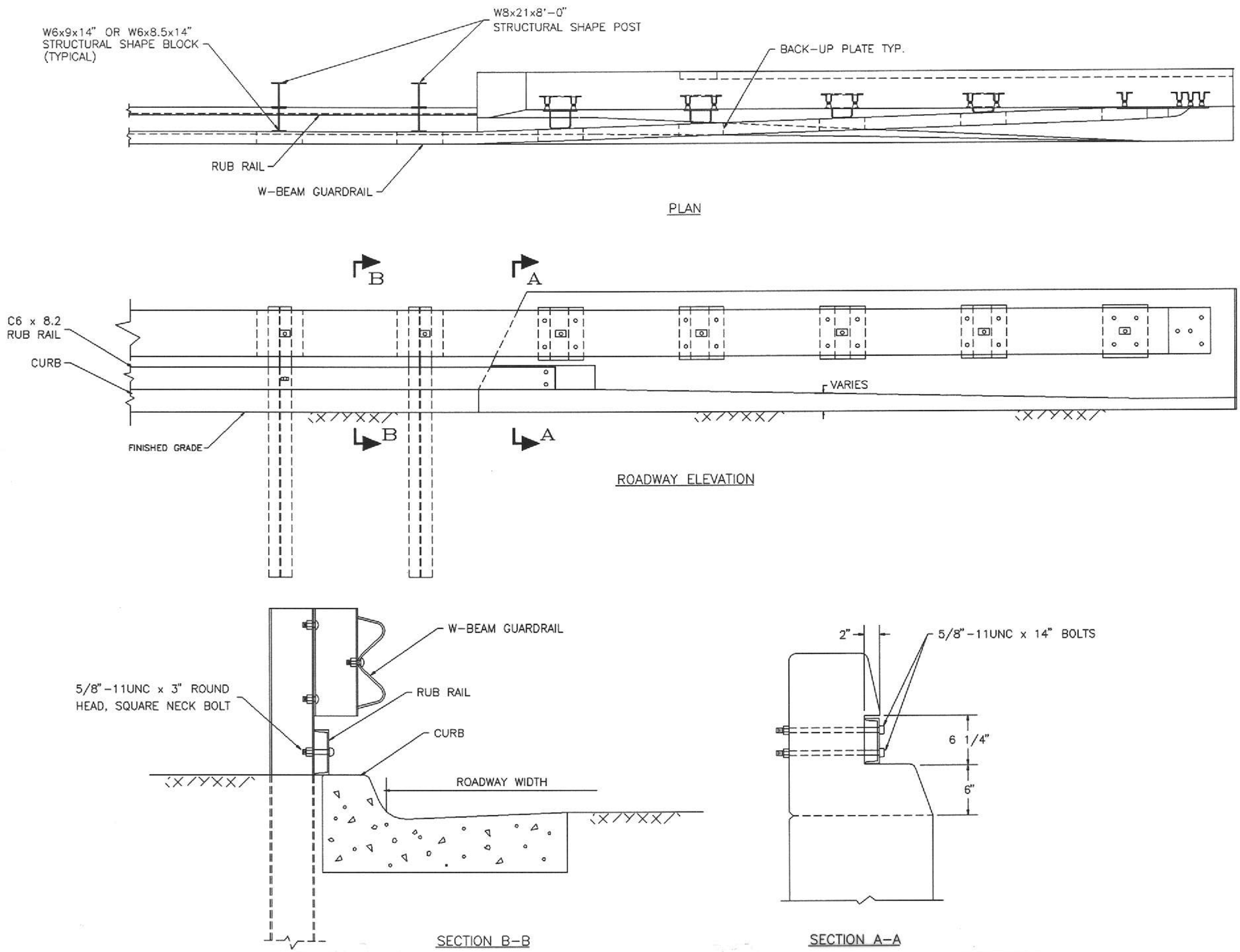


Figure 61. ADOT steel post transition with curb and rubrail. (Continue)

Figure 62. Arizona guardrail transition to concrete barrier before test 7155-6.

Figure 62. Arizona guardrail transition to concrete barrier before test 7155-6 (continued).

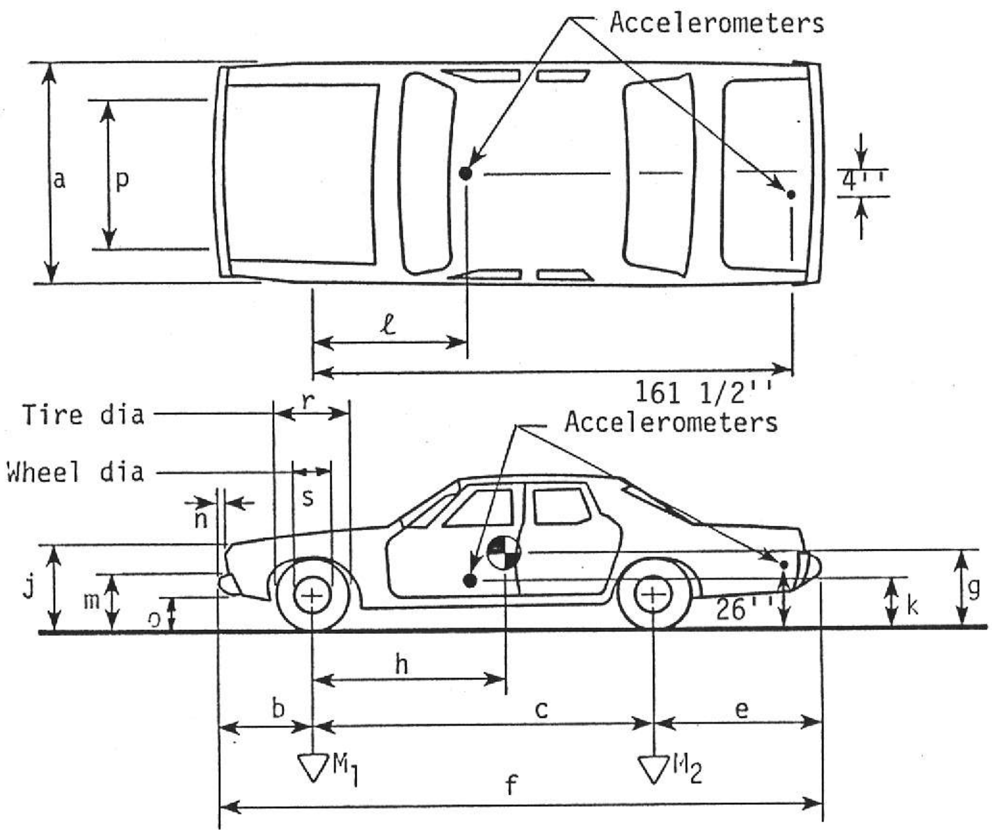
Figure 63. Vehicle before test 7155-6.

Date: ______ Test No.: 7155-6 VIN: 6B69599232504

Make: Cadillac Model: Fleetwood Year: 1979 Odometer: 49020

Tire Size: P235 75R15 Ply Rating: ______ Bias Ply: ___ Belted: ___ Radial: x

Tire Condition: good ___
fair x
badly worn ___



Vehicle Geometry - inches

a	76 1/2''	b	41''
c	121 1/2''	d*	57''
e	56 1/4''	f	
g		h	55.5''
i	----	j	34 3/4''
k	17 1/4''	ℓ	36 3/4''
m	21 3/4''	n	4 1/4''
o	12''	p	62''
r	29''	s	16 1/4''

4-wheel weight for c.g. det. ℓf 1194 rf 1251 ℓr 1048 rr 1007

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2503	2445	
M_2	1762	2055	
M_T	4265	4500	

Note any damage to vehicle prior to test:

______

______

*d = overall height of vehicle

Engine Type: V-8

Engine CID: 425

Transmission Type:

Automatic ~~Manual~~

~~FWD~~ RWD ~~4WD~~

Body Type: 4 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 64. **Vehicle properties (test 7155-6).**

the W-beam rail to wrap around the end of the concrete barrier and the first steel blockout on the concrete rail. Subsequently, the vehicle frame and wheel were permitted to snag on the end of the concrete bridge rail and the first blockout. The vehicle lost contact with the installation while traveling at 33.9 miles per hour and at an angle of 4.7 degrees. Shortly thereafter, the brakes were applied, the vehicle yawed clockwise and came to rest 113.0 feet (34.5 m) from the point of impact. Sequential photographs of the test are shown in Figure 65.

Damage to the transition installation is shown in Figure 66. The maximum permanent rail deformation was 10.4 inches (26.4 cm). As mentioned above, the lift imparted to the vehicle by the curb rendered the rubrail ineffective. The blockout on the first post adjacent to the end of the concrete barrier completely collapsed, allowing additional deflection to occur. The W-beam backup plate on the first steel blockout on the concrete barrier was not sufficient to prevent localized yielded in the rail from occurring. There were no signs of distress in the curb or around the concrete anchor inserts. The vehicle was in contact with the installation for a total length of 12.0 feet (3.7 m).

As shown in Figure 67, the vehicle sustained severe damage. The maximum crush recorded for the vehicle was 28.0 inches (71.1 cm). The left front wheel was pushed rearward 26.0 inches (66.0 cm), causing significant penetration of the occupant compartment. The entire front end of the vehicle was shifted to the left 3.0 inches (7.6 cm). Additionally, the A-pillar, roof, and door were all severely bent and buckled.

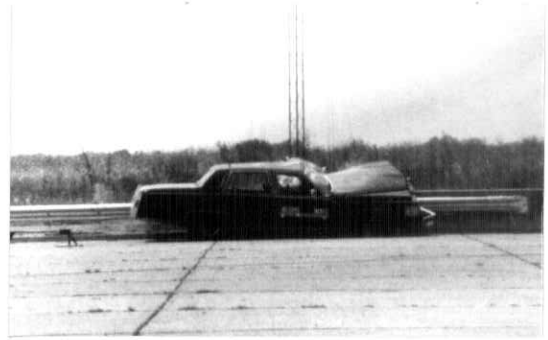
A summary of the test results and other information pertinent to this test are given in Figure 68. The maximum 0.050-second average accelerations experienced by the vehicle were -15.3 g in the longitudinal direction and -15.5 g in the lateral direction. Angular displacements of the vehicle are plotted in Figure 69 and accelerometer traces for each of the three vehicle axes are displayed in Figures 70 - 72. Occupant impact velocities were 39.2 feet per second (11.9 m/s) and 27.4 feet per second (8.4 m/s) in the longitudinal and lateral directions, respectively. The highest 0.010 second occupant ridedown accelerations were -18.1 g (longitudinal) and -8.3 g (lateral). These numbers are reported for information purposes only, since they are not required in the evaluation of the transition test.

In summary, this test was judged to be a failure. The installation failed to smoothly redirect the impacting vehicle. Significant snagging on the end of the concrete barrier was

000 msec

068 msec

136 msec



204 msec

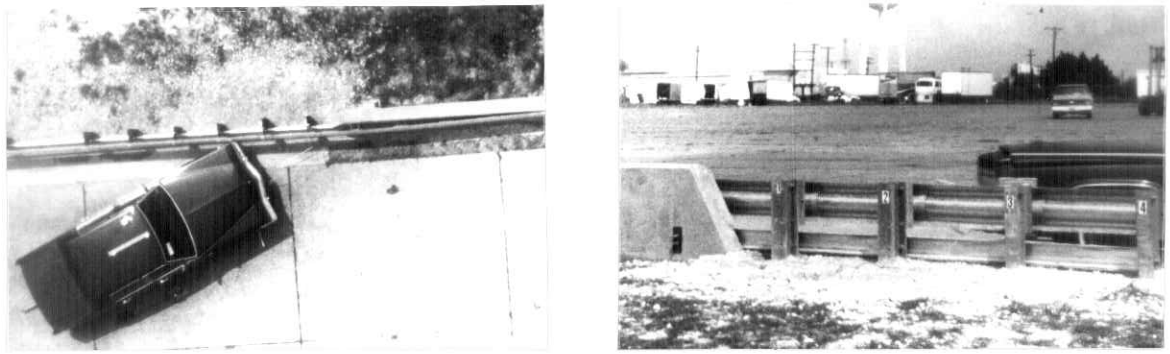
272 msec

340 msec

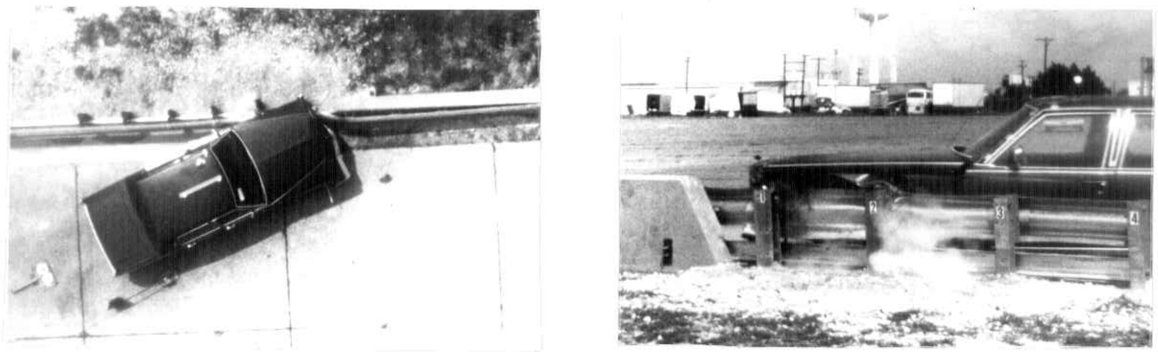
407 msec

475 msec

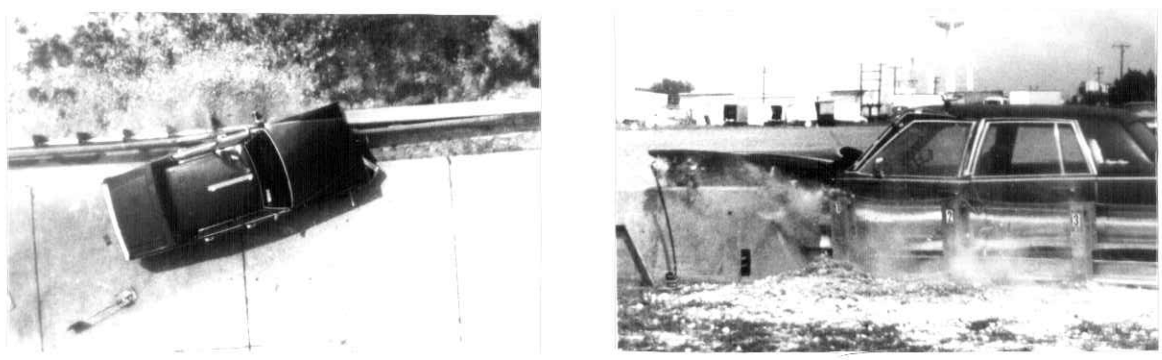
Figure 65. Sequential photographs for test 7155-6.



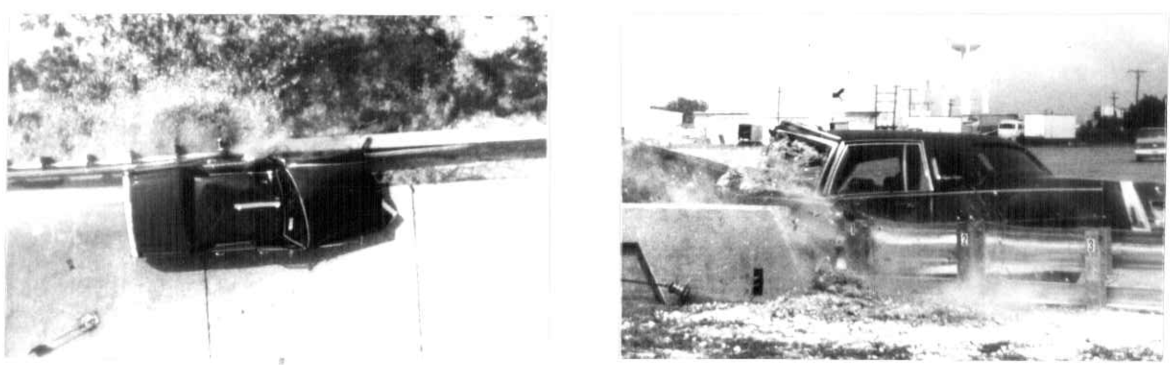
000 msec



068 msec

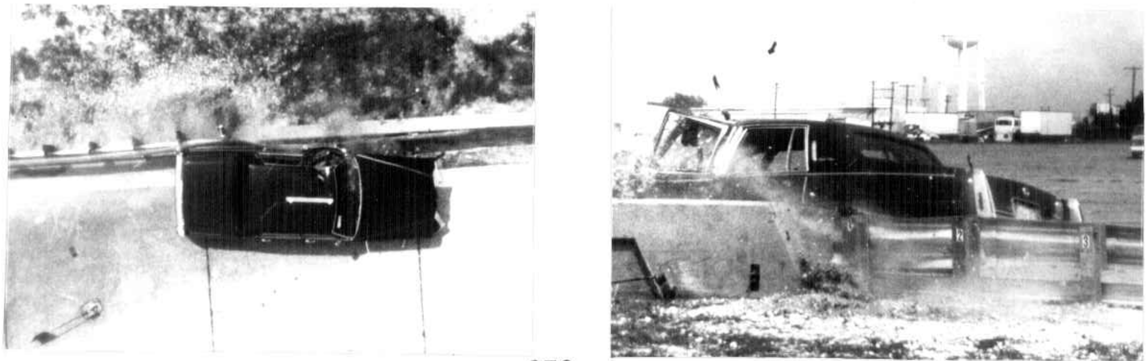


136 msec

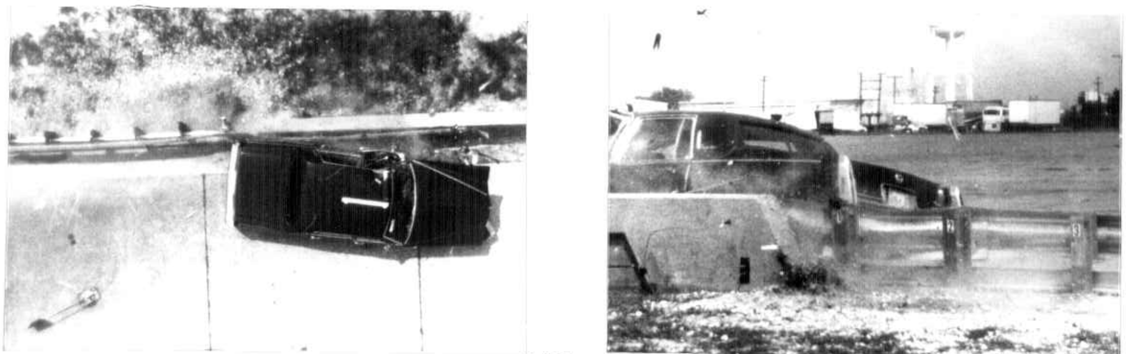


204 msec

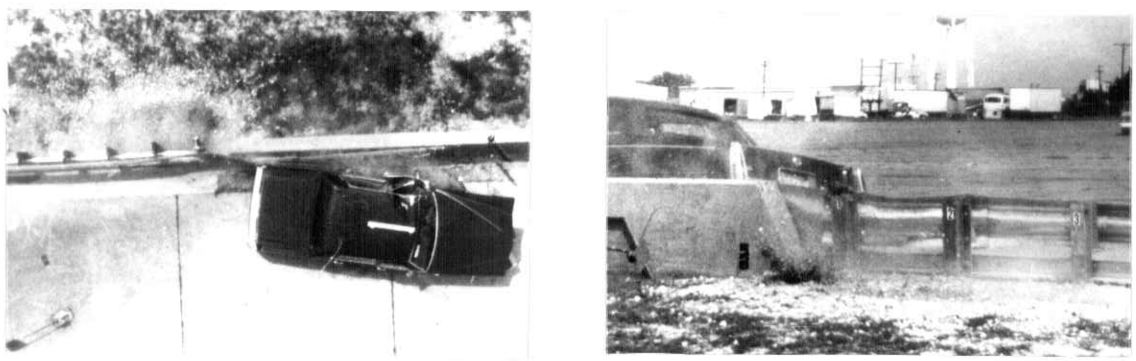
Figure 65. Sequential photographs of test 7155-6.
(Continued)



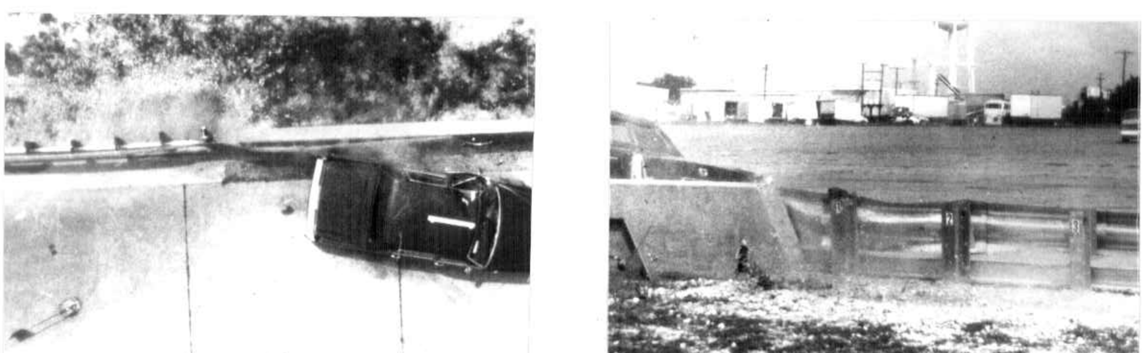
272 msec



340 msec



407 msec



475 msec

Figure 65. Sequential photographs for test 7155-6. (Continued)

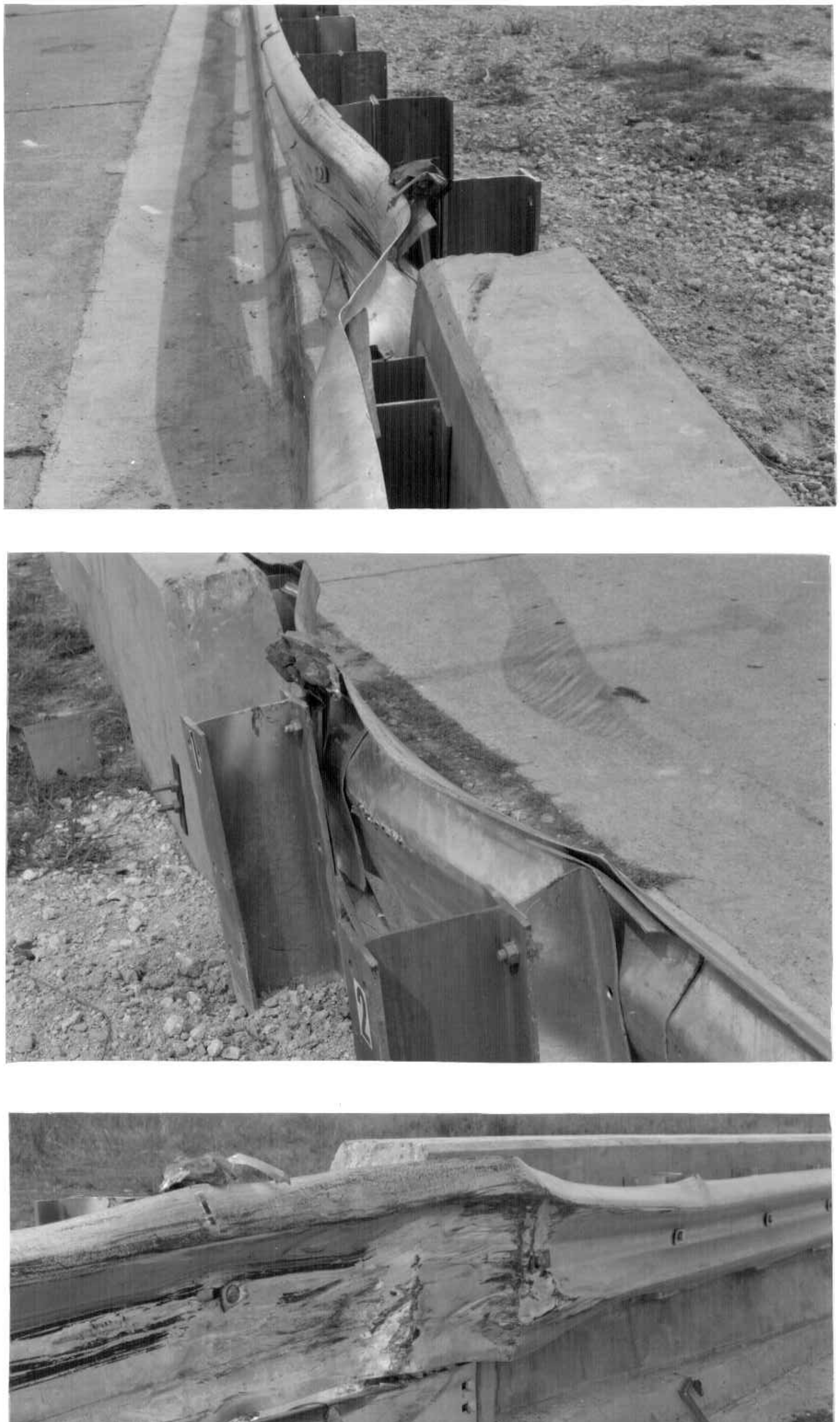
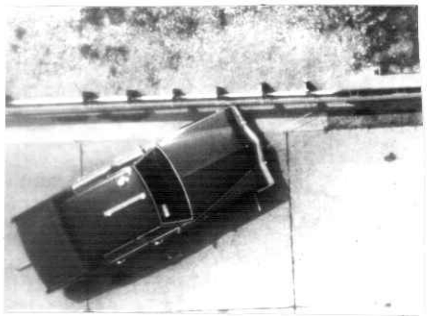
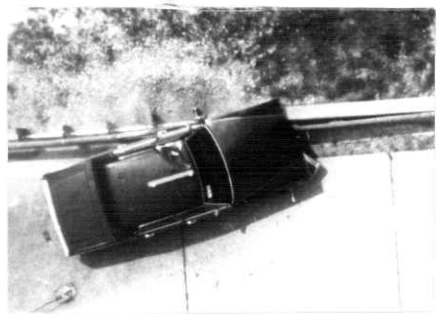


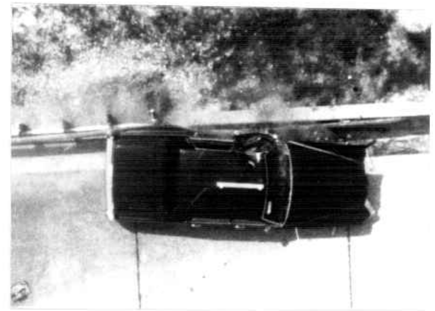
Figure 66. Arizona guardrail transition to concrete barrier after test 7155-6.

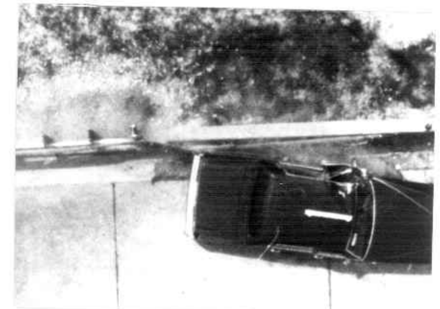
Figure 66. Arizona guardrail transition to concrete barrier after test 7155-6 (continued).

Figure 67. Vehicle after test 7155-6.









Test No. 7155-6
Date 9/14/90
Test Installation . . Arizona guardrail
transition to concrete half barrier.
Installation Length . 87.5 ft (26.7m)
Vehicle . . . . 1979 Cadillac
Fleetwood
Vehicle Weight
Test Inertia . . . . 4,500 lb (2,041 kg)
Vehicle Damage Classification
TAD 11FL-6
CDC 11LFAW3
Maximum Vehicle Crush . . . 28.0 in (71.1 cm)
Max. Perm. Rail Deformation . 10.4 in (26.4 cm)

Impact Speed. . . 59.5 mi/h (95.8 km/h)
Impact Angle. . . 25.4 deg
Exit Speed. . . . 33.9 mi/h (54.5 km/h)
Exit Trajectory . 4.7 deg
Vehicle Accelerations
(Max. 0.050-sec Avg)
Longitudinal. . -15.3 g
Lateral . . . . -15.5 g
Occupant Impact Velocity
Longitudinal. . 39.2 ft/s (11.9 m/s)
Lateral . . . . 27.4 ft/s (8.4 m/s)
Occupant Ridedown Accelerations
Longitudinal. . -18.1 g
Lateral . . . . -8.3 g

Figure 68. Summary of results for test 7155-6.

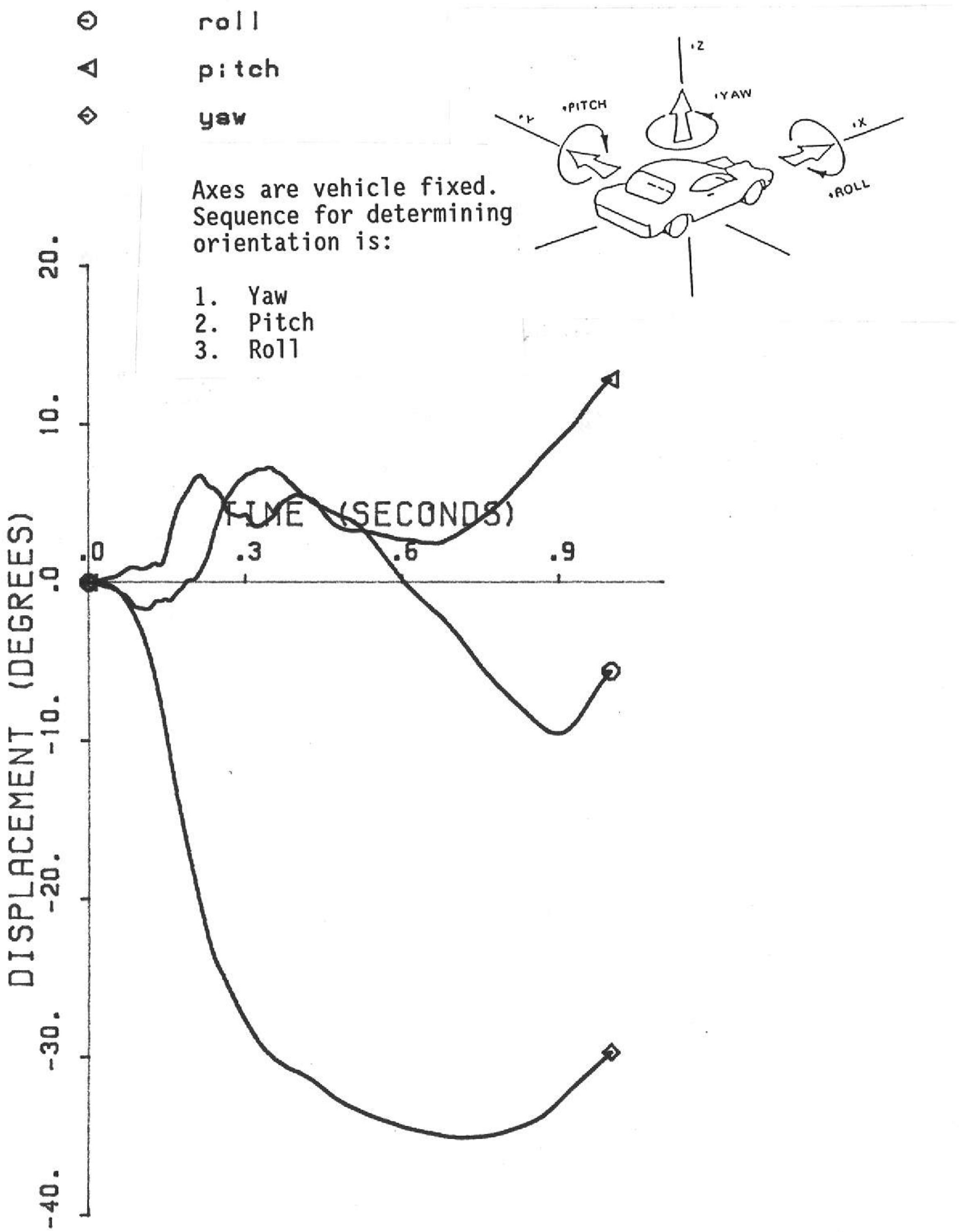


Figure 69. Vehicle angular displacements of test 7155-6.

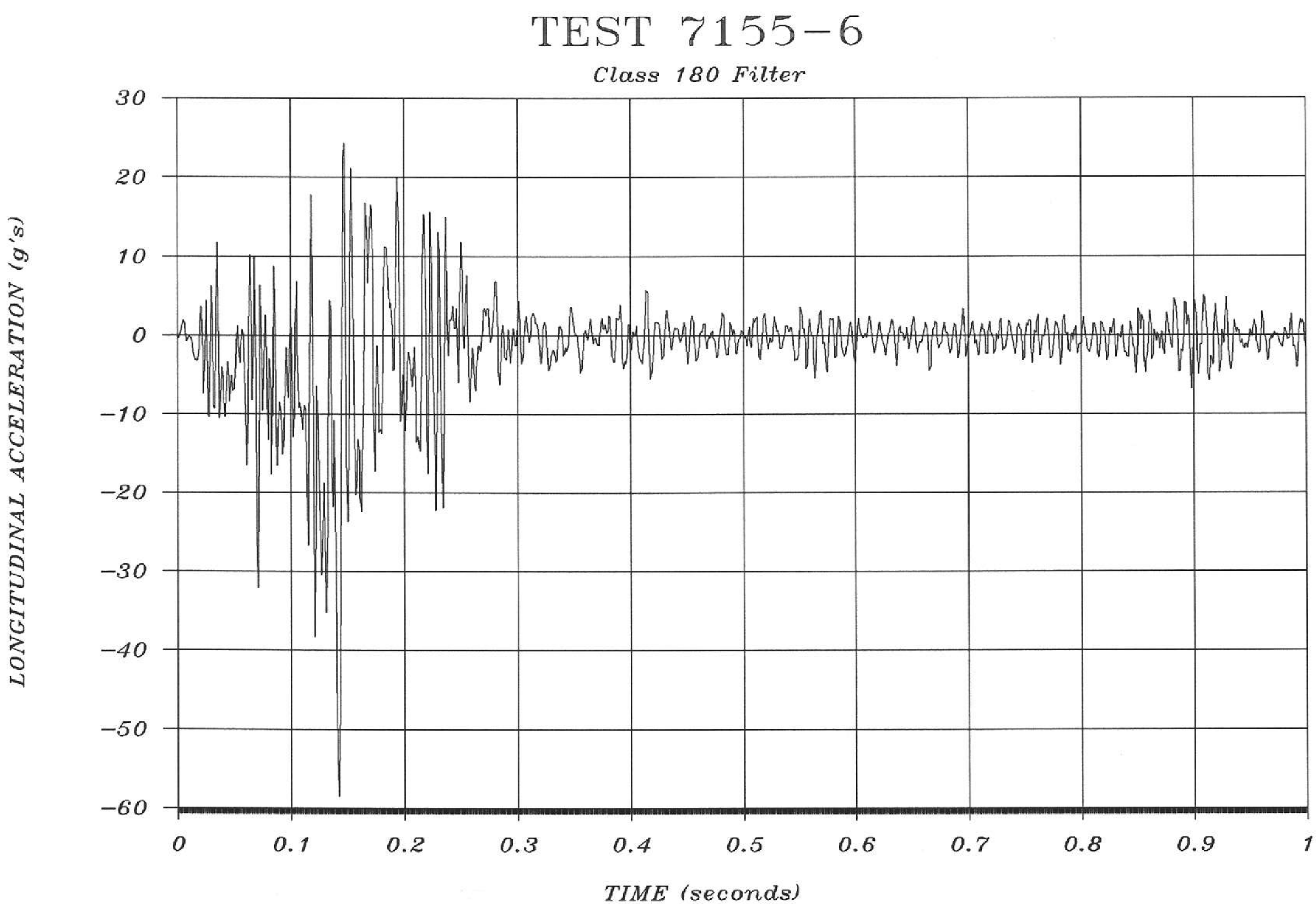


Figure 70. Longitudinal accelerometer trace of test 7155-6.

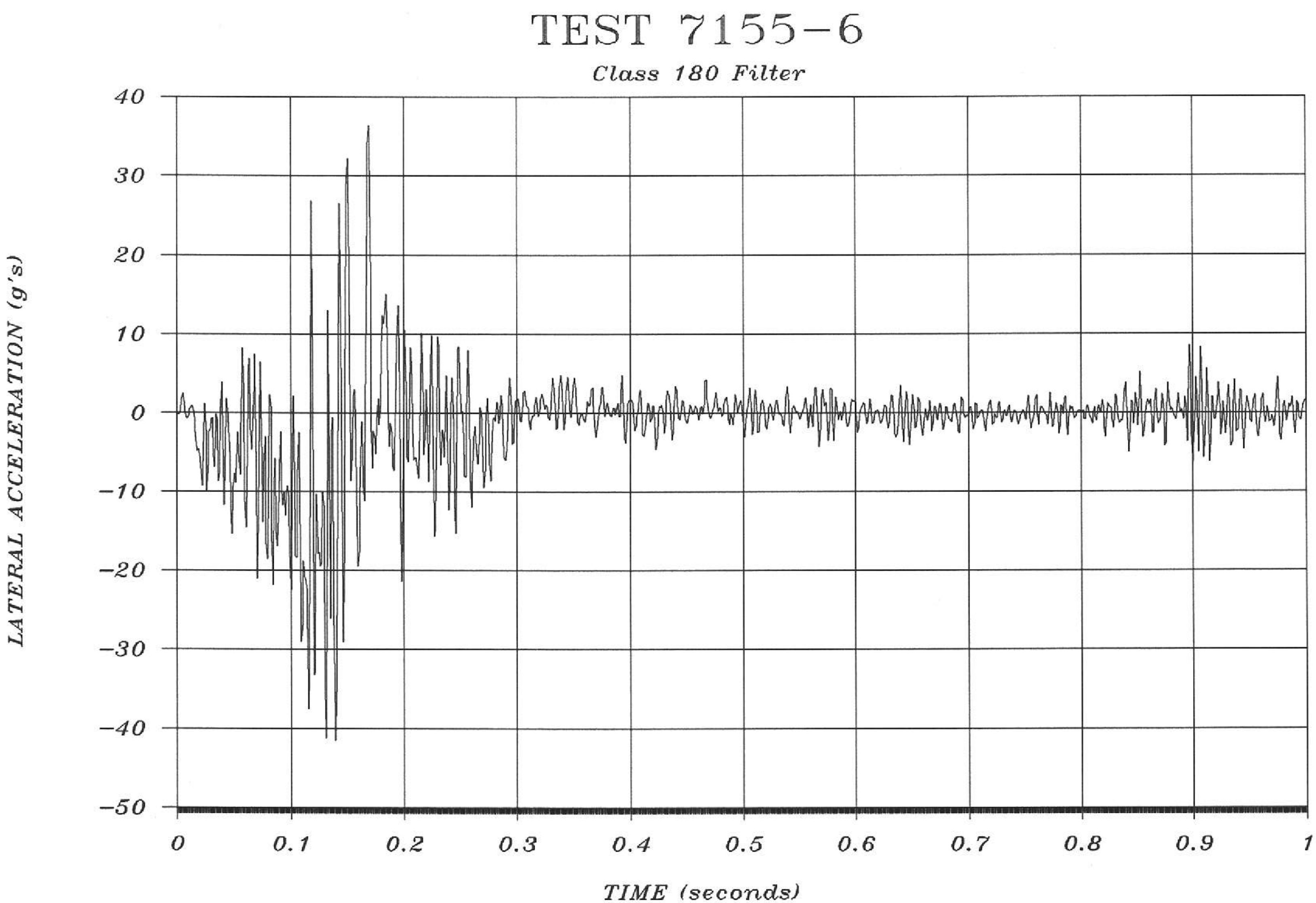


Figure 71. Lateral accelerometer trace of test 7155-6.

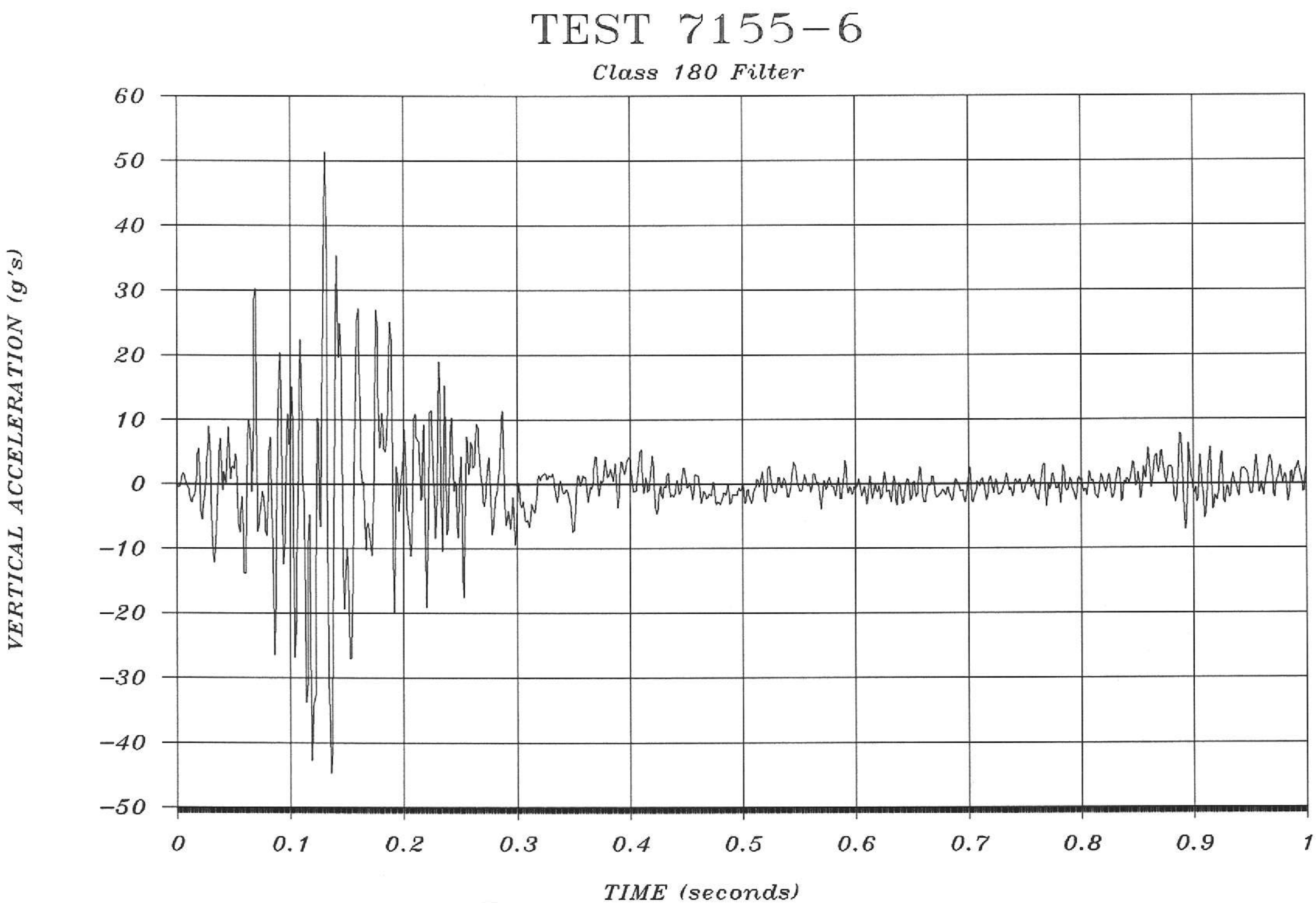


Figure 72. Vertical accelerometer trace of test 7155-6.

observed. This snagging caused severe damage to the vehicle as well as significant intrusion into the passenger compartment.

Test 7155-7

As indicated by the results of Test 6, a further increase in barrier stiffness was required in order to reduce snagging on the end of the concrete barrier. As shown in Table 1, several design modifications were evaluated using the Barrier VII program. The selected design provided additional barrier stiffness by incorporating a nested W-beam over the last 25 ft. of guardrail, utilizing tubular steel block outs on the first two guardrail posts, and attaching the rub rail to all posts in the transition. As shown in Table 1, the predicted degree of snagging for this installation was less than 1 inch. All other details were identical to those of Test 6. A drawing of the modified barrier transition design is shown in Figure 73. The completed test installation is shown in Figure 74.

Table 1. Predicted Snagging for Modified Curb Transition Designs

TRANSITION SYSTEM[a]	DEGREE OF SNAGGING[b] (in.)
Single W-beam with standard rubrail	2.5
Single W-beam with rubrail connected to all posts	1.9
Nested W-beam with standard rubrail	1.3
Nested W-beam with rubrail connected to all posts	0.7

(a) ADOT steel post system
(b) wheel snagging on end of concrete barrier

Results

A 1984 Oldsmobile Ninety-Eight (shown in Figure 75) impacted 7.0 ft (2.1 m) upstream of the end of the concrete bridge rail at 59.5 miles per hour (95.8 km/h) and at

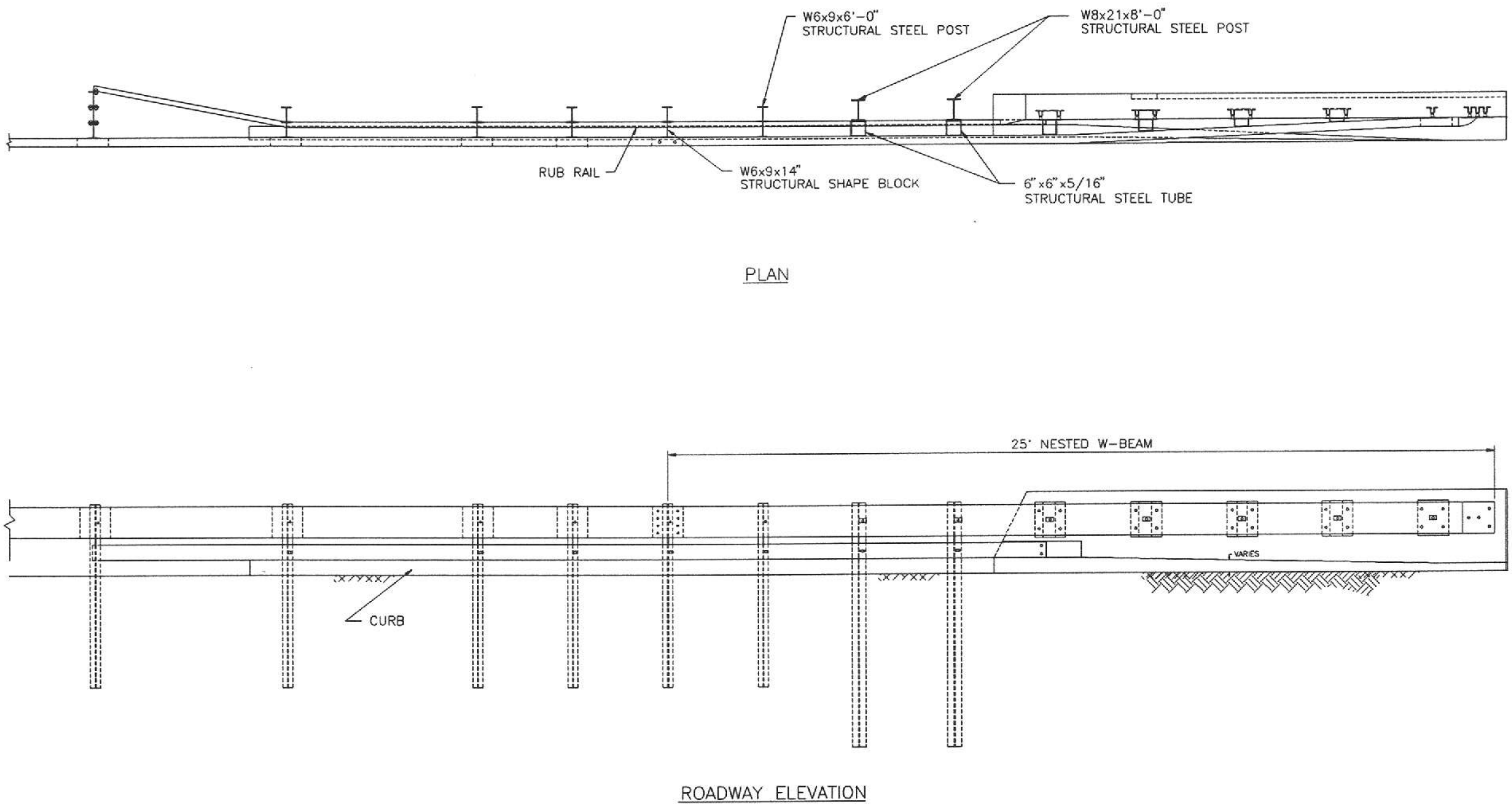


Figure 73. ADOT steel post transition with curb, rubrail, and nested W-beam.

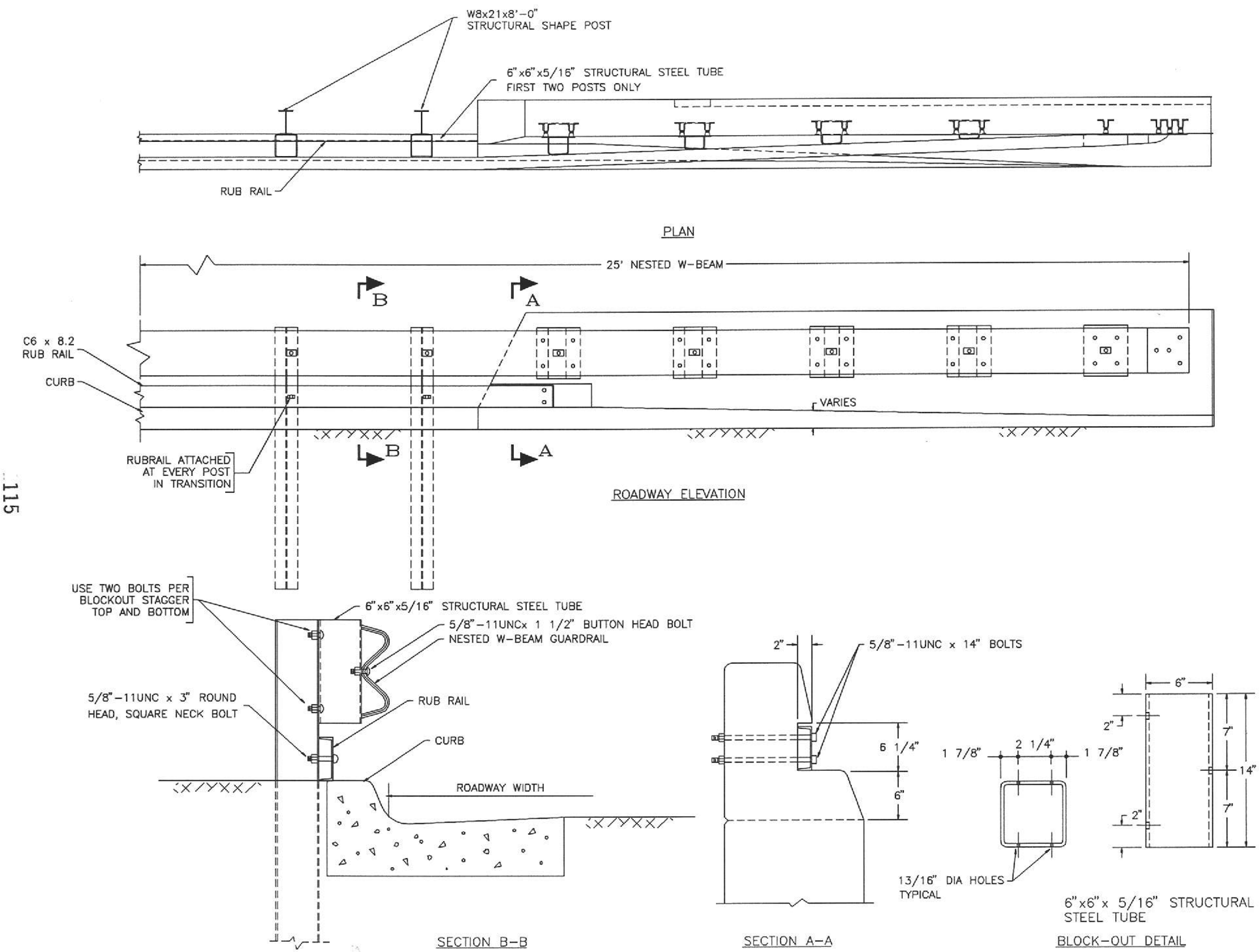


Figure 73. ADOT steel post transition with curb, rubrail, and nested W-beam.
(Continued)

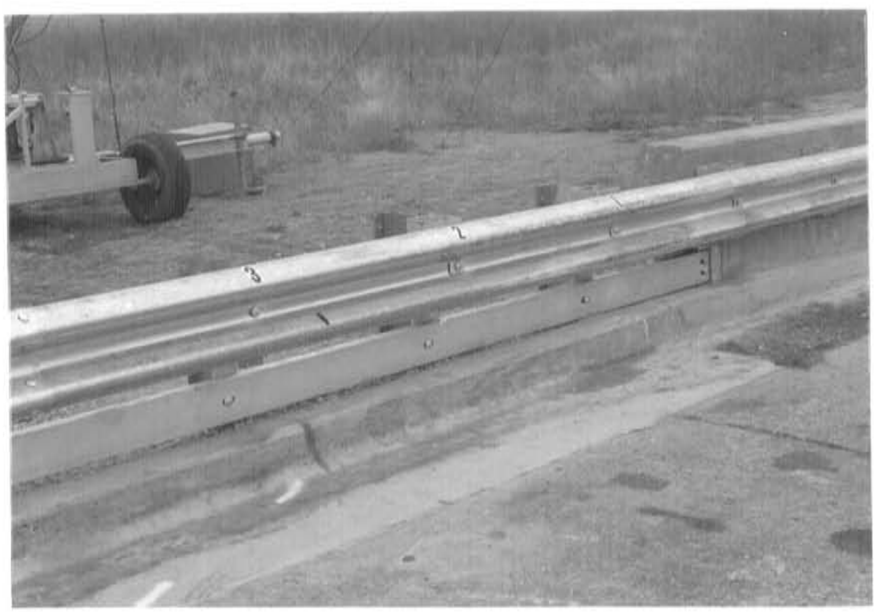


Figure 74. Arizona guardrail transition to concrete barrier before test 7155-7.

Figure 75. Vehicle before test 7155-7.

an angle of 25.9 degrees using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 pounds (2,041 kg). The lower edge of the vehicle bumper was at a height of 13.0 inches (33.0 cm) and the upper edge was at a height of 20.8 inches (52.7 cm). Other dimensions and information on the vehicle are given in Figure 76.

The vehicle was free wheeling and unrestrained just prior to impact. As in tests 5 and 6, the vehicle's left front tire quickly climbed the concrete curb. The vehicle was then smoothly redirected with only moderate deflection of the metal beam barrier. Although the amount of wheel snag on the barrier system was minor, the left front tire was blown-out. The test vehicle exited the barrier system at an angle of only 6.6 degrees and drag forces associated with the blown front tire caused the vehicle to quickly steer back to the roadside. Sequential photographs of the test are shown in Figure 77.

The installation received minor damage as shown in Figure 78. Permanent barrier deflection was limited to 4.5 in. (11.4 cm). The vehicle was in contact with the installation for a total length of 13.0 feet (4.0 m).

The vehicle received relatively minor damage for a test of this severity, as shown in Figure 79. Maximum vehicle crush was limited to 15.0 inches (38.1 cm) at the left front corner of the vehicle. The left front wheel was pushed rearward 7.0 inches (17.8 cm). The entire front end of the vehicle was shifted to the right 5.0 inches (12.7 cm). Additionally, the entire left side of the vehicle was scraped and dented. Damage to other areas included a bent roof, floor pan, hood, and a broken windshield.

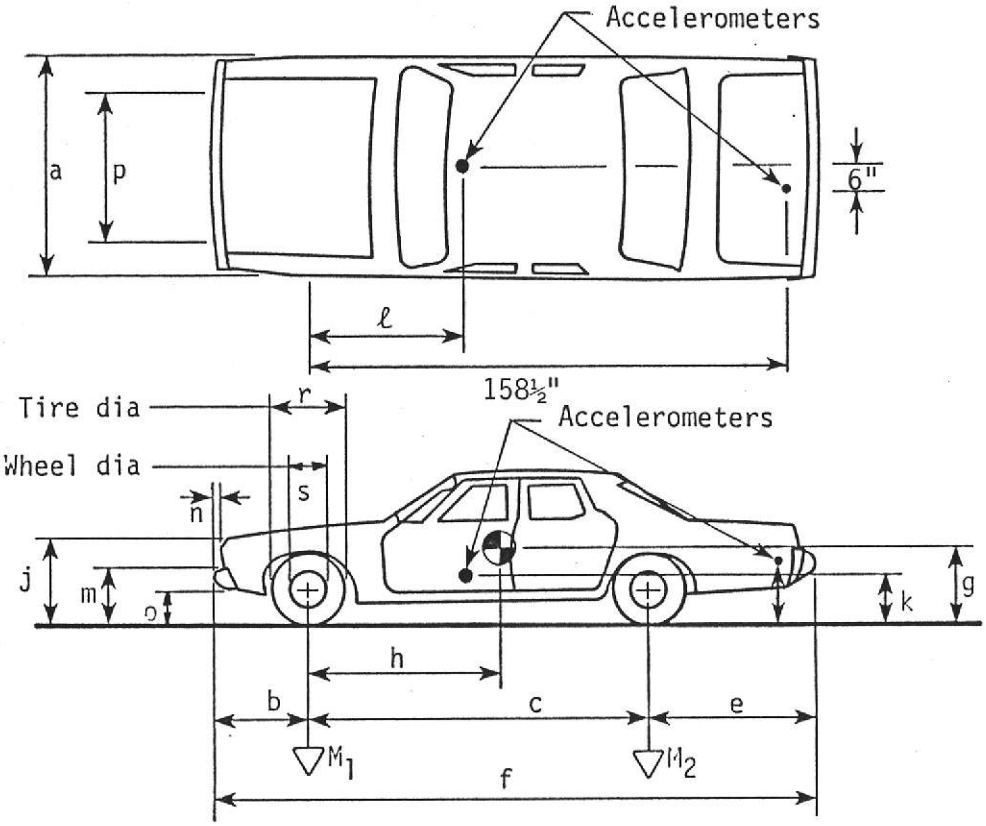
A summary of the test results and other information pertinent to this test are given in Figure 80. The maximum 0.050-second average acceleration experienced by the vehicle was -10.6 g in the longitudinal direction and -12.8 g in the lateral direction. Vehicle angular displacements are plotted in Figure 81 and vehicle accelerometer traces are displayed in Figures 82-84. Occupant impact velocity in the longitudinal direction was 30.3 feet per second (9.2 m/s) and 26.4 feet per second (8.0 m/s) in the lateral direction. The highest 0.10 second occupant ridedown accelerations were -5.6 g (longitudinal) and -16.7 g (lateral). Although the occupant impact velocities and lateral ridedown acceleration were higher than values recommended by NCHRP Report 230, the values were well below the maximum allowable values. All other measures of occupant risk were well below recommended limits.

Date: ______ Test No.: 7155-7 VIN: G3AX69N4CM103016

Make: Oldsmobile Model: Regency Year: 1984 Odometer: 03771

Tire Size: ______ Ply Rating: ______ Bias Ply: ___ Belted: ___ Radial: ___

Height of Rear Accelerometer 24"



Tire Condition: good ___
fair X
badly worn ___

Vehicle Geometry - inches

a	75½"	b	44"
c	118½"	d*	57¼"
e	55½"	f	
g		h	52.3
i	----	j	32½"
k	19½"	ℓ	34"
m	20-3/4"	n	5½"
o	13"	p	61-3/4"
r	27½"	s	16¼"

Engine Type: V-8

Engine CID: 350 Diesel

Transmission Type:

Automatic ~~Manual~~

FWD or RWD or 4WD

Body Type: 4 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

4-wheel weight for c.g. det. ℓf 1249 rf 1264 ℓr 995 rr 992

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2442	2513	
M_2	1567	1987	
M_T	4009	4500	

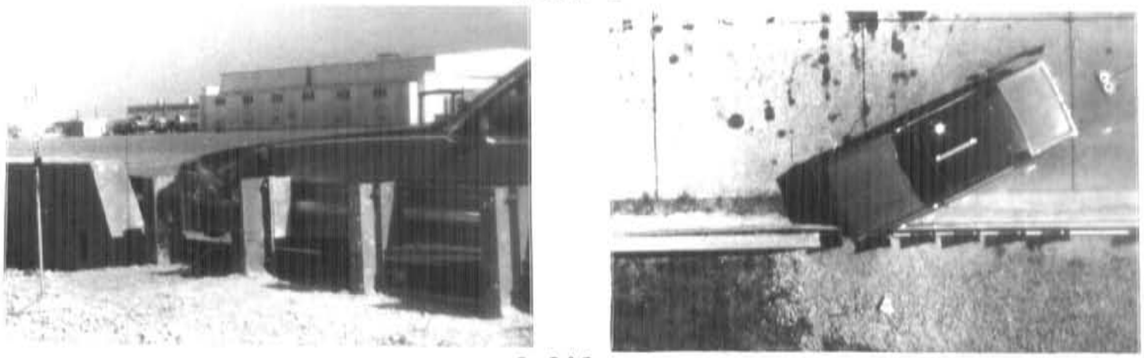
Note any damage to vehicle prior to test:

Dent in left rear fender

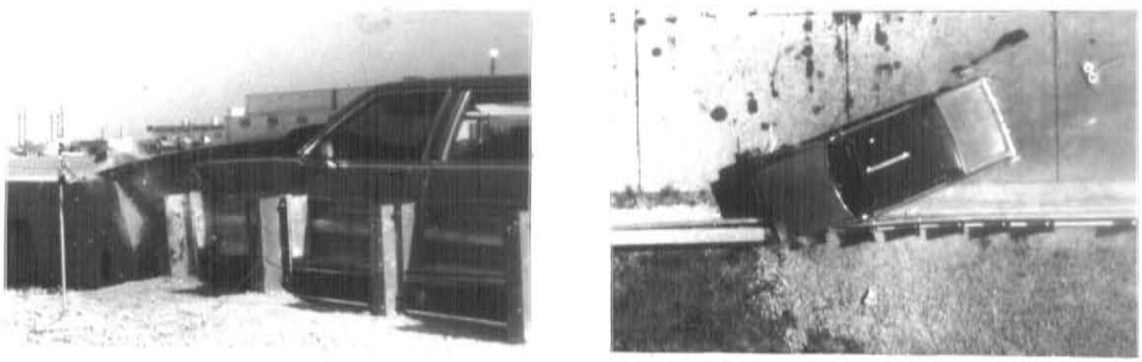
*d = overall height of vehicle

Figure 76. Vehicle properties (test 7155-7).

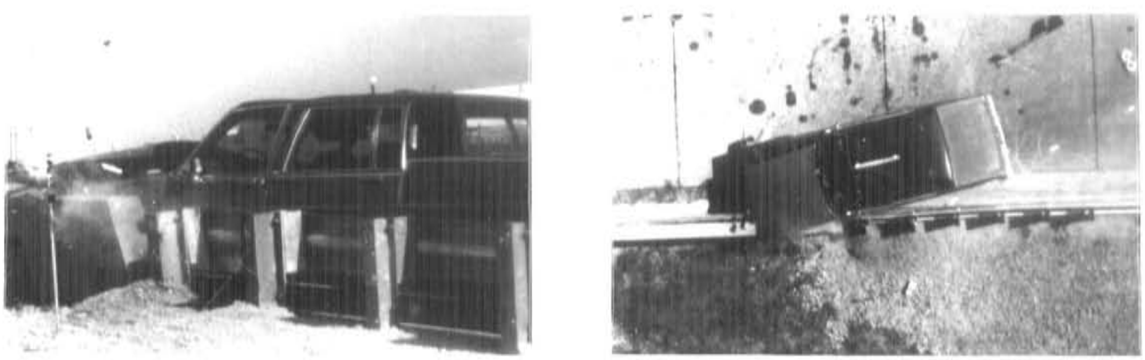
0.000 s



0.046 s

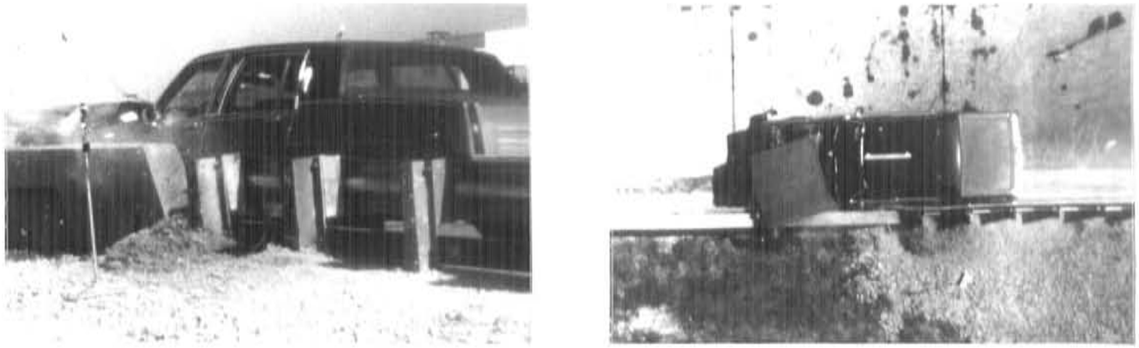


0.093 s

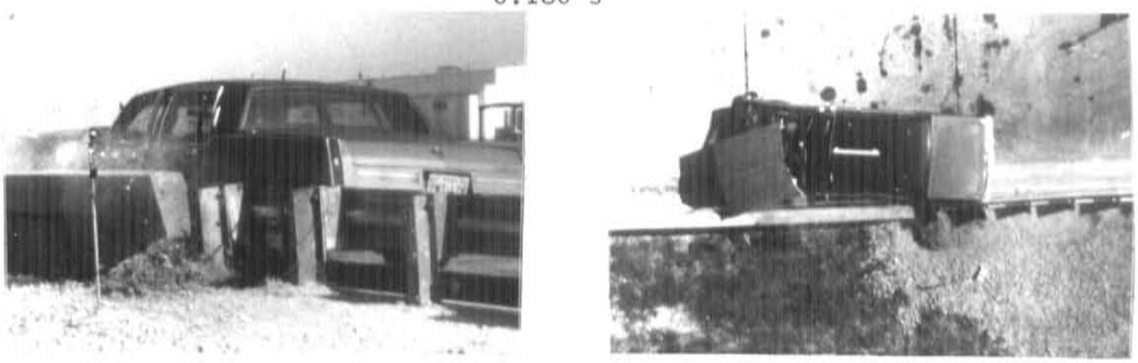


0.139 s

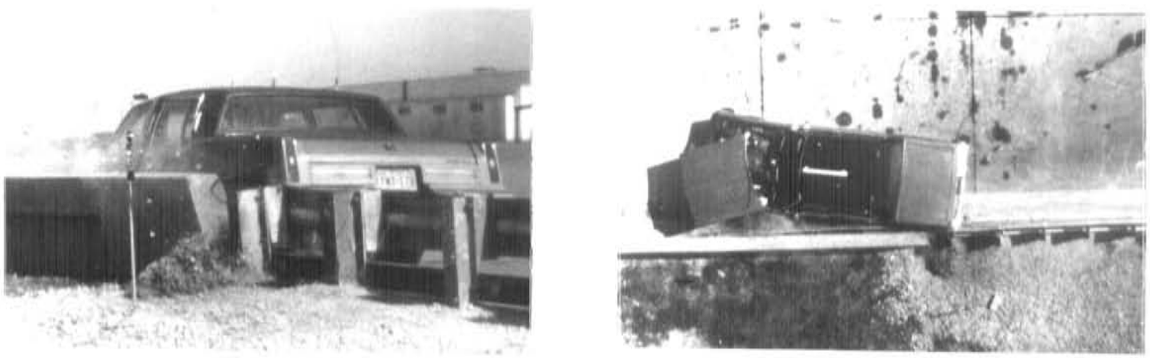
Figure 77. Sequential photographs for test 7155-7.



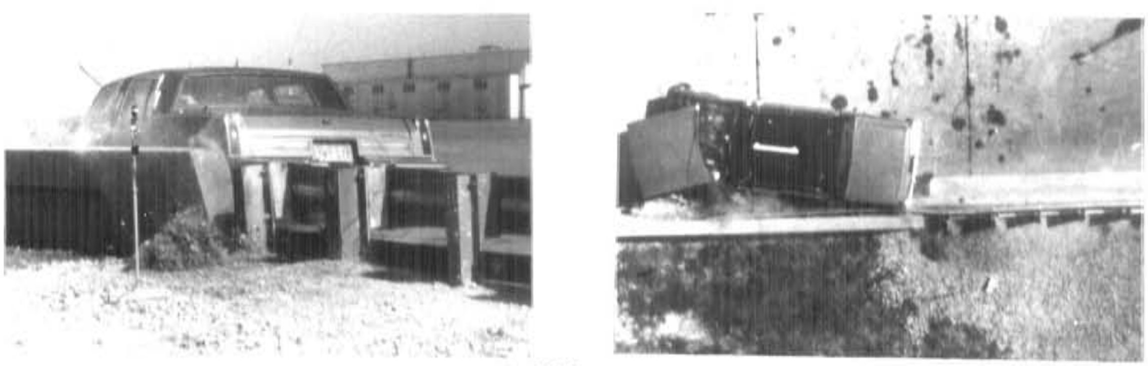
0.186 s



0.232 s



0.279 s



0.325 s

Figure 77. Sequential photographs for test 7155-7 (Continued).

0.000 s

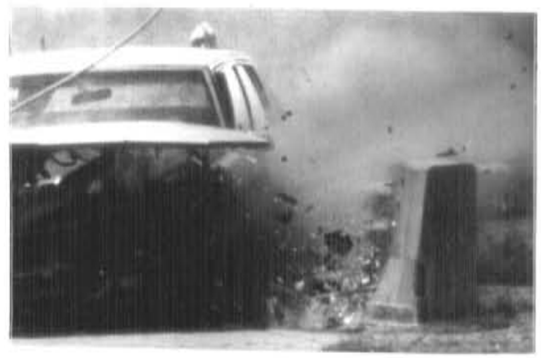
0.046 s

0.093 s

0.139 s

0.186 s

0.232 s



0.279 s

0.325 s

Figure 77. Sequential photographs for test 7155-7. (Continued)

Figure 78. Arizona guardrail transition to concrete half barriers after test 7155-7.

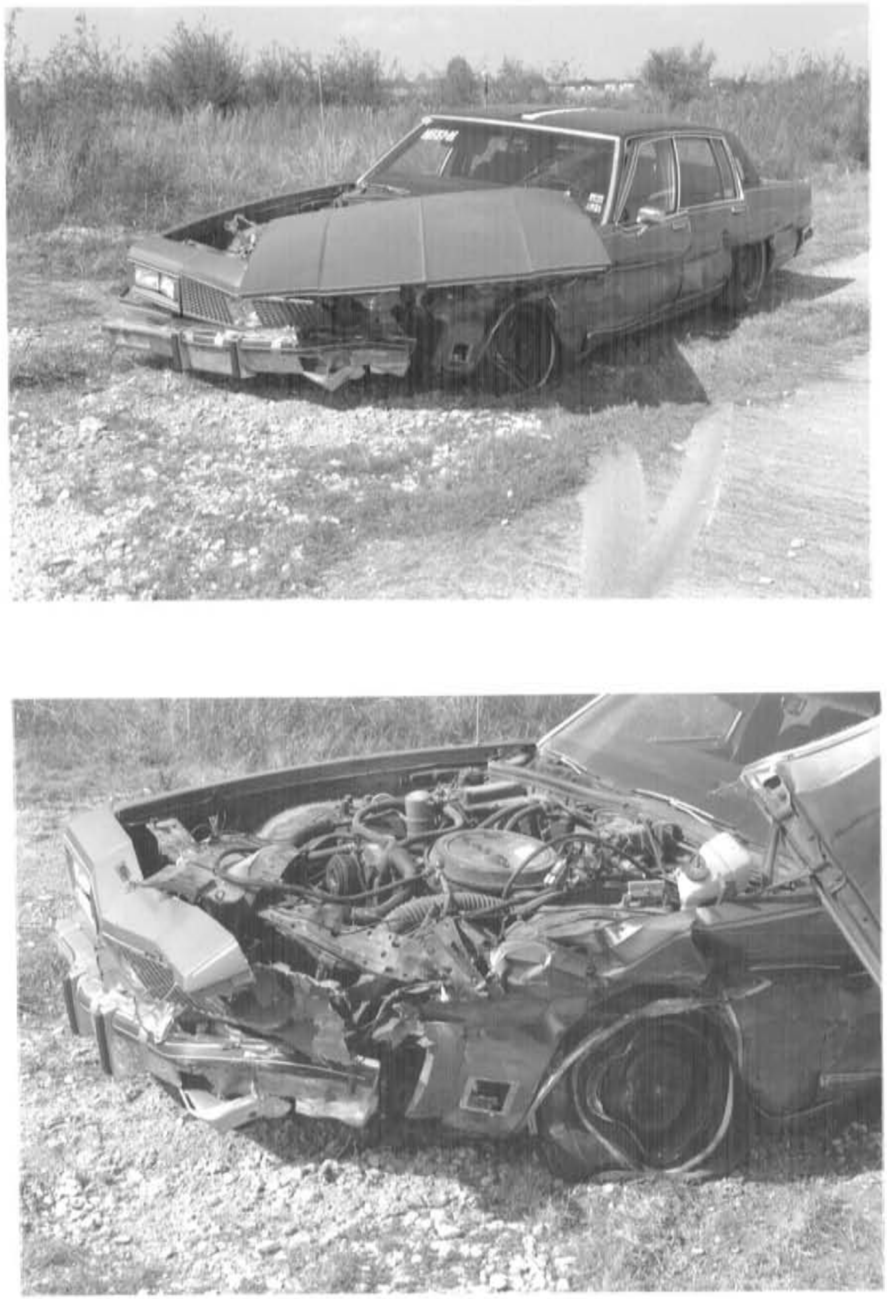
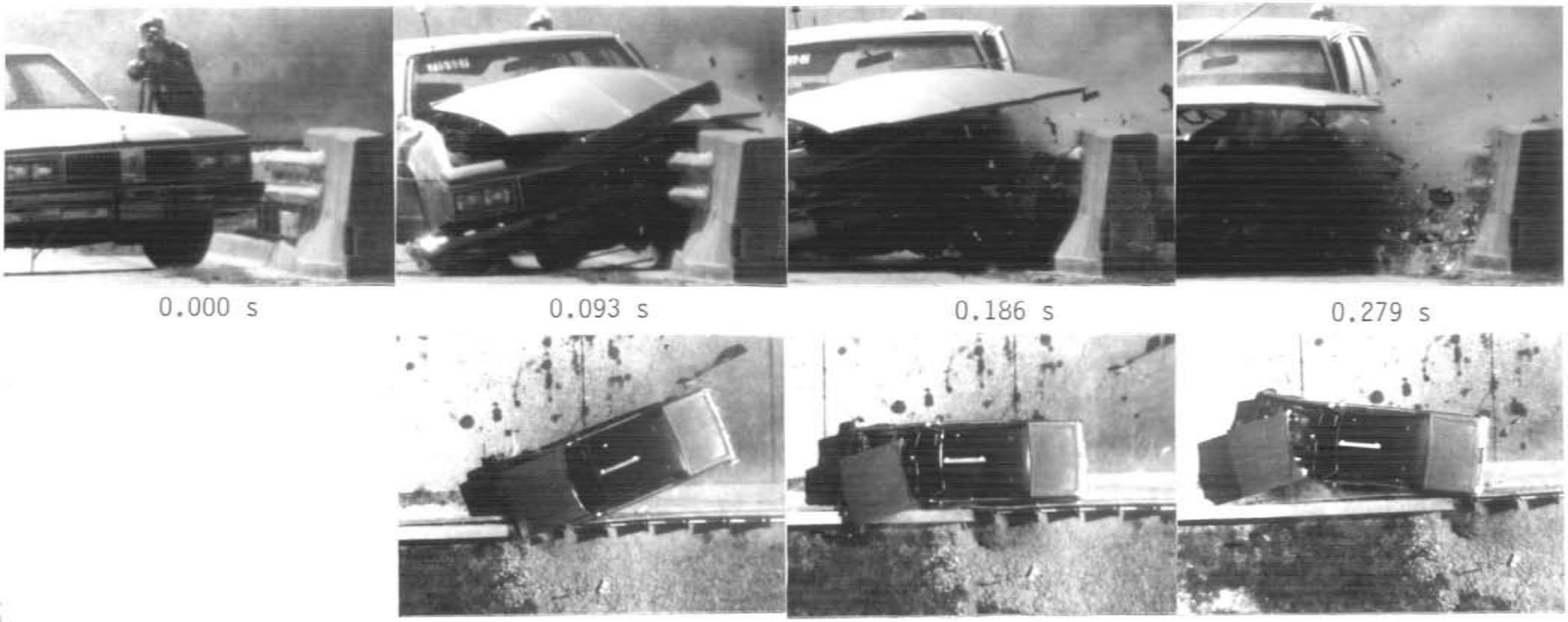


Figure 79. Vehicle after test 7155-7.

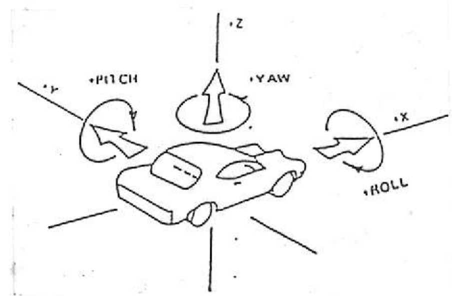


0.000 s 0.093 s 0.186 s 0.279 s

Test No.	7155-7
Date	11/15/90
Test Installation . . . . . . Arizona guardrail transition to concrete half barrier	
Installation Length	87.5 ft (26.7 m)
Vehicle	1984 Oldsmobile Ninety-Eight
Vehicle Weight	
Test Inertia	4,500 lb (2,041 kg)
Vehicle Damage Classification	
TAD	11LFQ-5
CDC	11LFEW2
Maximum Vehicle Crush	15.0 in (38.1 cm)
Max. Dyn. Rail Deflection. . .	N/A
Max. Perm. Rail Deformation.	4.5 in (11.4 cm)

Impact Speed.	59.5 mi/h (95.8 km/h)
Impact Angle.	25.9 deg
Exit Speed.	42.2 mi/h (67.9 km/h)
Exit Trajectory	6.6 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal.	-10.6 g
Lateral	-12.8 g
Occupant Impact Velocity	
Longitudinal.	30.3 ft/s (9.2 m/s)
Lateral	26.4 ft/s (8.0 m/s)
Occupant Ridedown Accelerations	
Longitudinal.	-5.6 g
Lateral	-16.7 g

Figure 80. Summary of results for test 7155-7.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

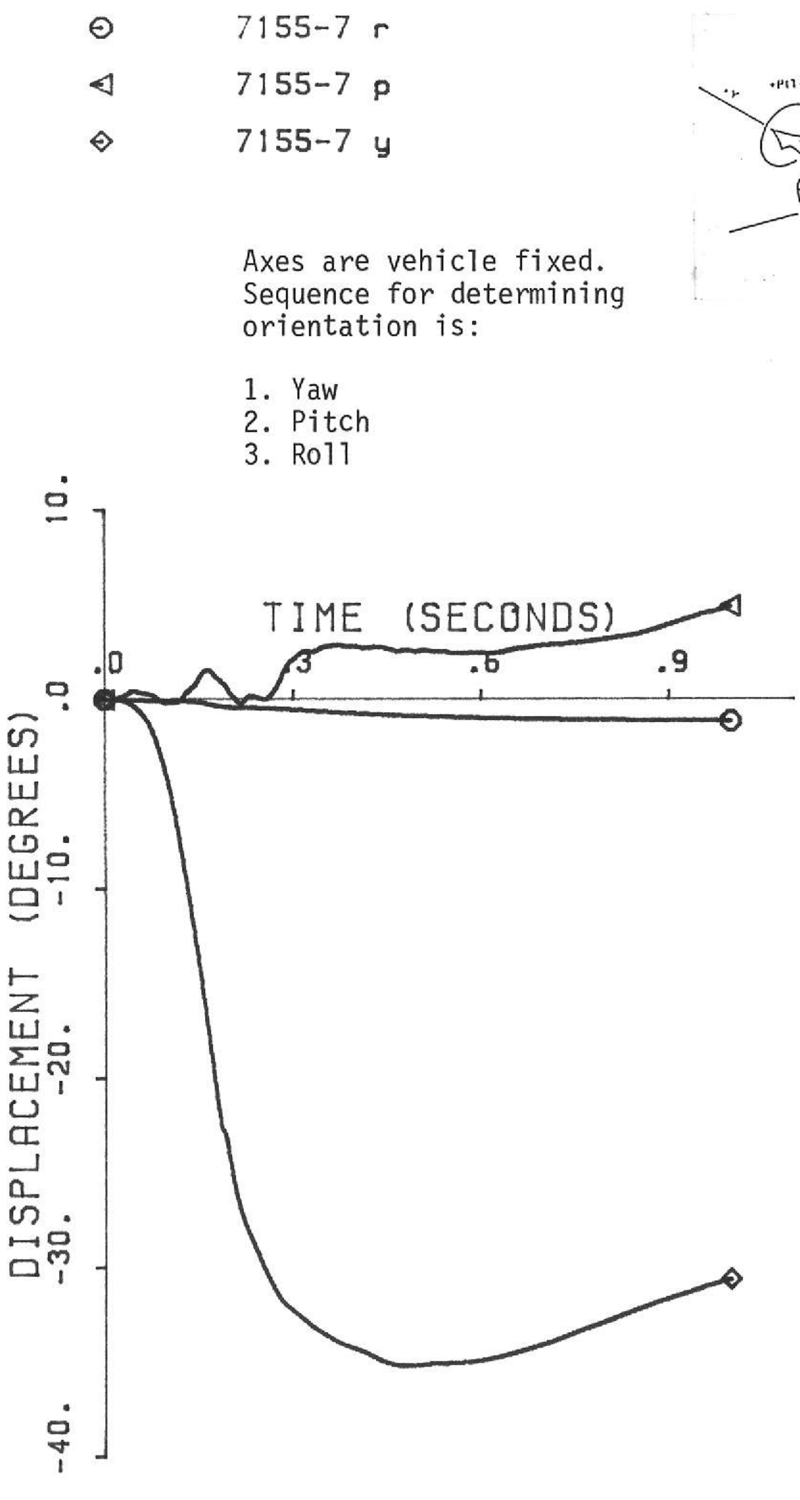


Figure 81. Vehicle angular displacements of test 7155-7.

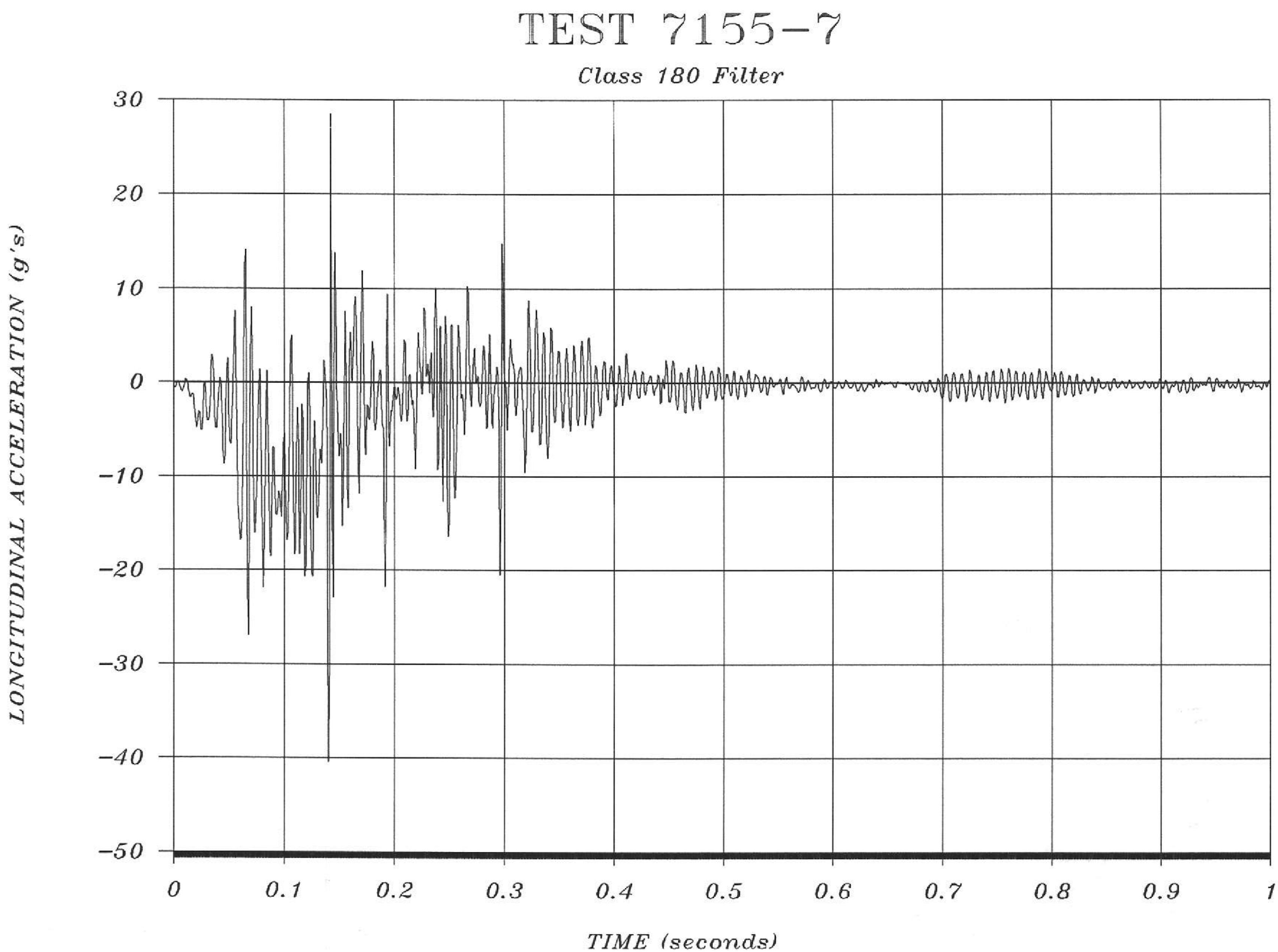


Figure 82. Longitudinal accelerometer trace of test 7155-7.

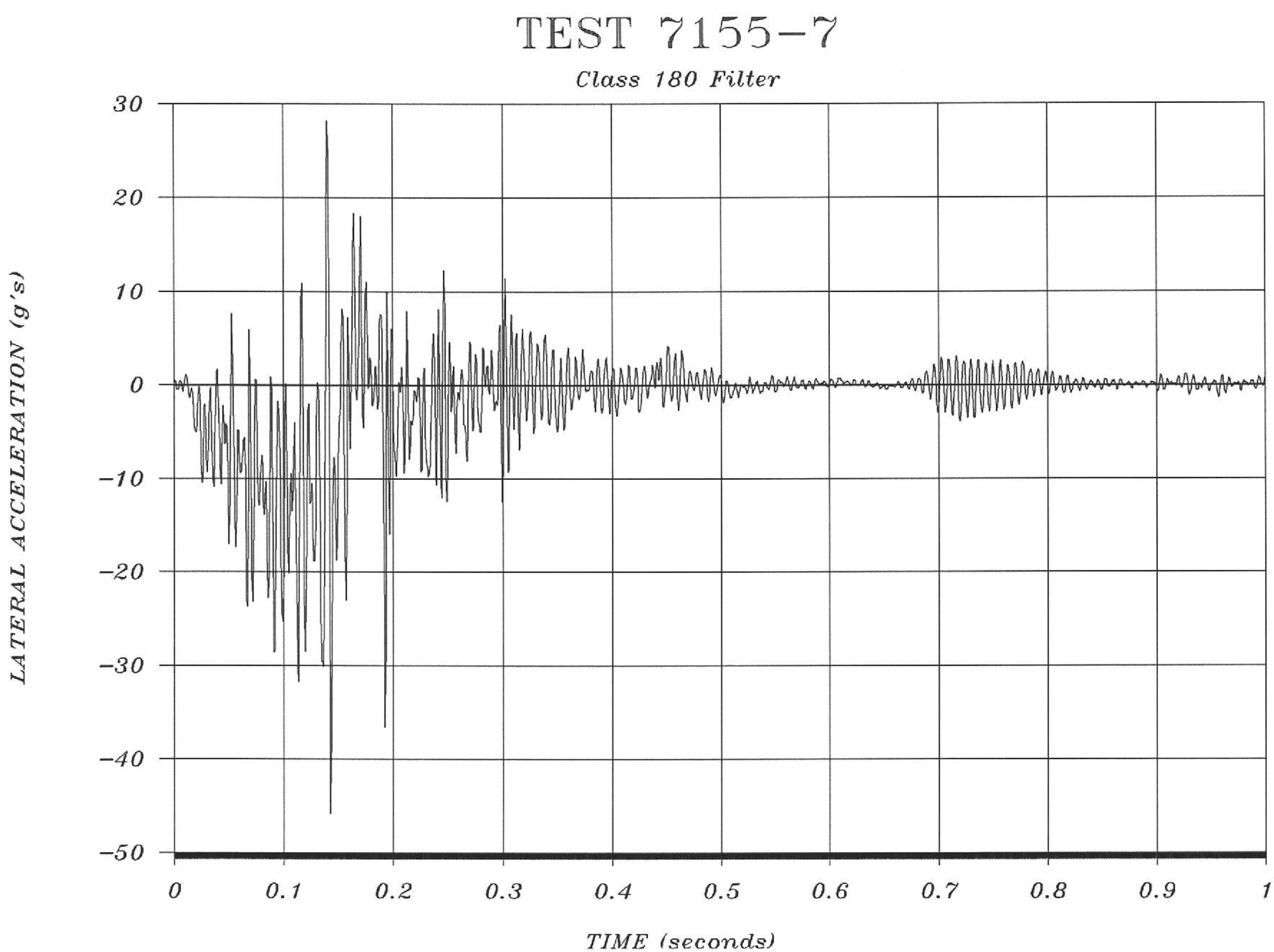


Figure 83. Lateral accelerometer trace of test 7155-7.

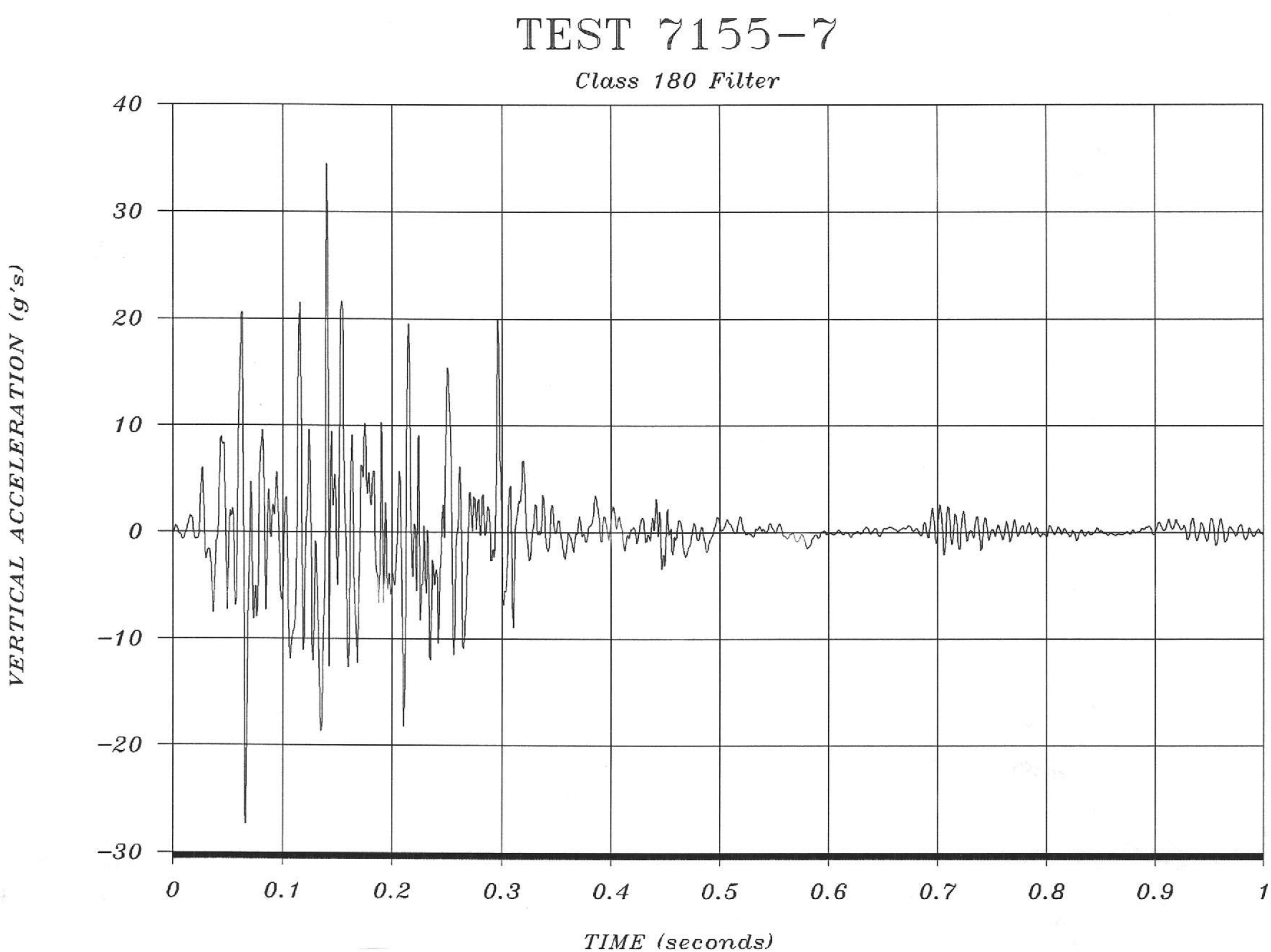


Figure 84. Vertical accelerometer trace of test 7155-7.

In summary, this test was judged to be a success. The installation contained and redirected the vehicle with only modest vehicle damage and minor damage to the transition. There was no debris or detached elements and little or no deformation of the occupant compartment. The vehicle remained upright and stable during the entire test. The velocity change of 17.3 miles per hour (27.8 km/h) was higher than the recommended limit of 15 miles per hour according to the guidelines presented in NCHRP Report 230. However, the vehicle would not have penetrated back onto the adjacent travel lanes and therefore would not have posed a hazard to other traffic.

Since the rubrail termination of this modified design utilized the same concept which was successfully crash tested in Test 3, it was determined that the upstream transition did not warrant another test.

Test 7155-8

The purpose of this test was to evaluate the upstream end of the unmodified wood post transition with channel rubrail. As discussed in an earlier section, the wood post system was predicted to have better impact performance than the steel post transition which failed in Test 2. The wider 8"x8" post to which the rubrail was attached had the potential for shielding the exposed end of the rubrail from vehicle contact. Therefore, although significant wheel snagging on the guardrail post was predicted, if the wheel was not allowed to spear on the end of the rubrail, the hazard would not be as severe and the test would have a chance to pass. In addition, the blockouts on the G4(2W) guardrail had a depth of 8 inches compared to the 6 inches provided by the steel post system. This increase in blockout distance reduces the degree of snagging on the intermediate guardrail posts and further improved the chances of this system performing satisfactorily. Details of the standard wood post transition are shown in Figure 85. The completed test installation is shown in Figure 86.

Results

A 1980 Cadillac Coupe DeVille (shown in Figure 87) impacted 10.0 ft (3.0 m) upstream from the end of the rub-rail at 59.6 miles per hour (95.8 km/h) and at an angle of 24.5 degrees using a cable reverse tow and guidance system. Test inertia mass of the

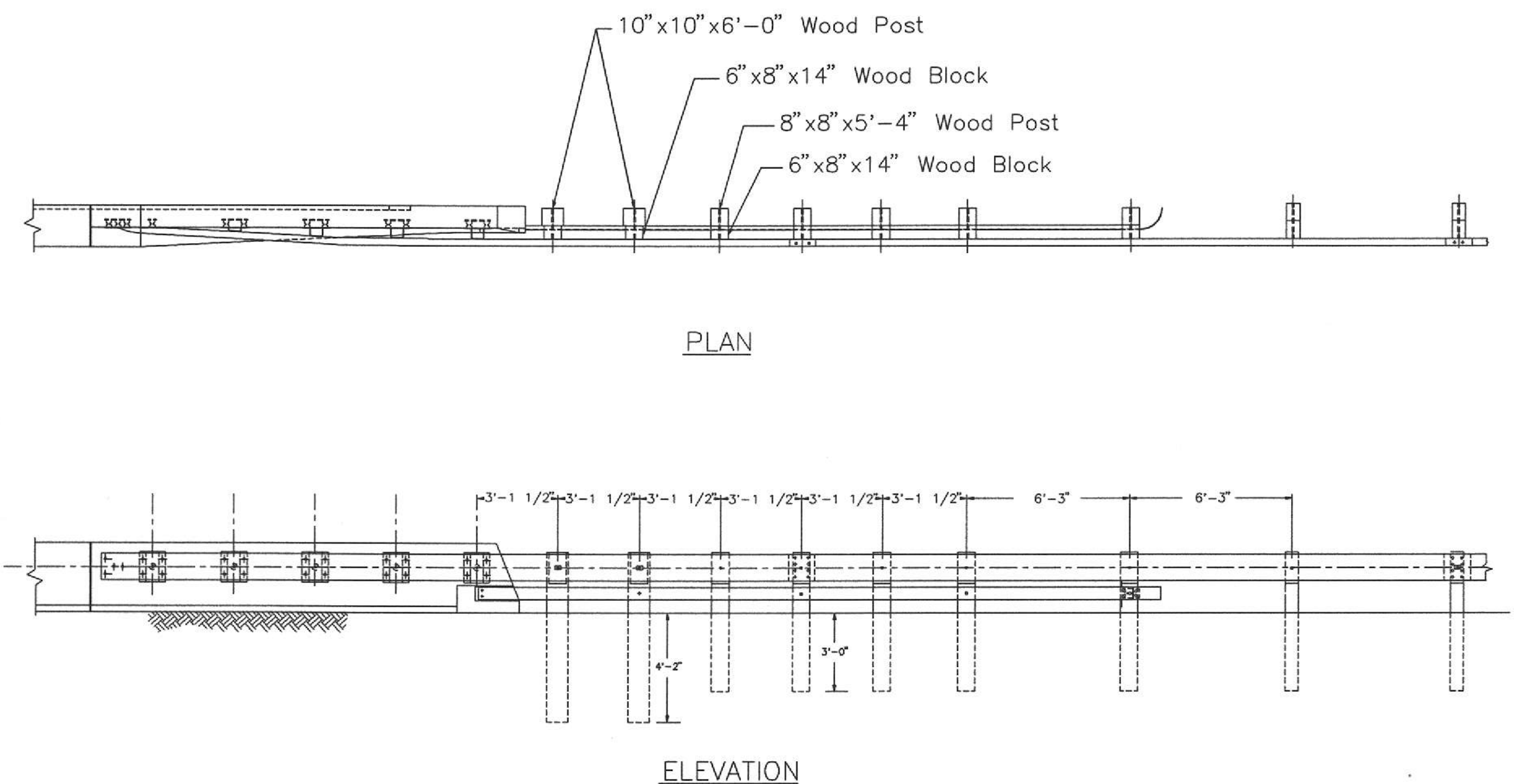


Figure 85. ADOT wood post transition without curb

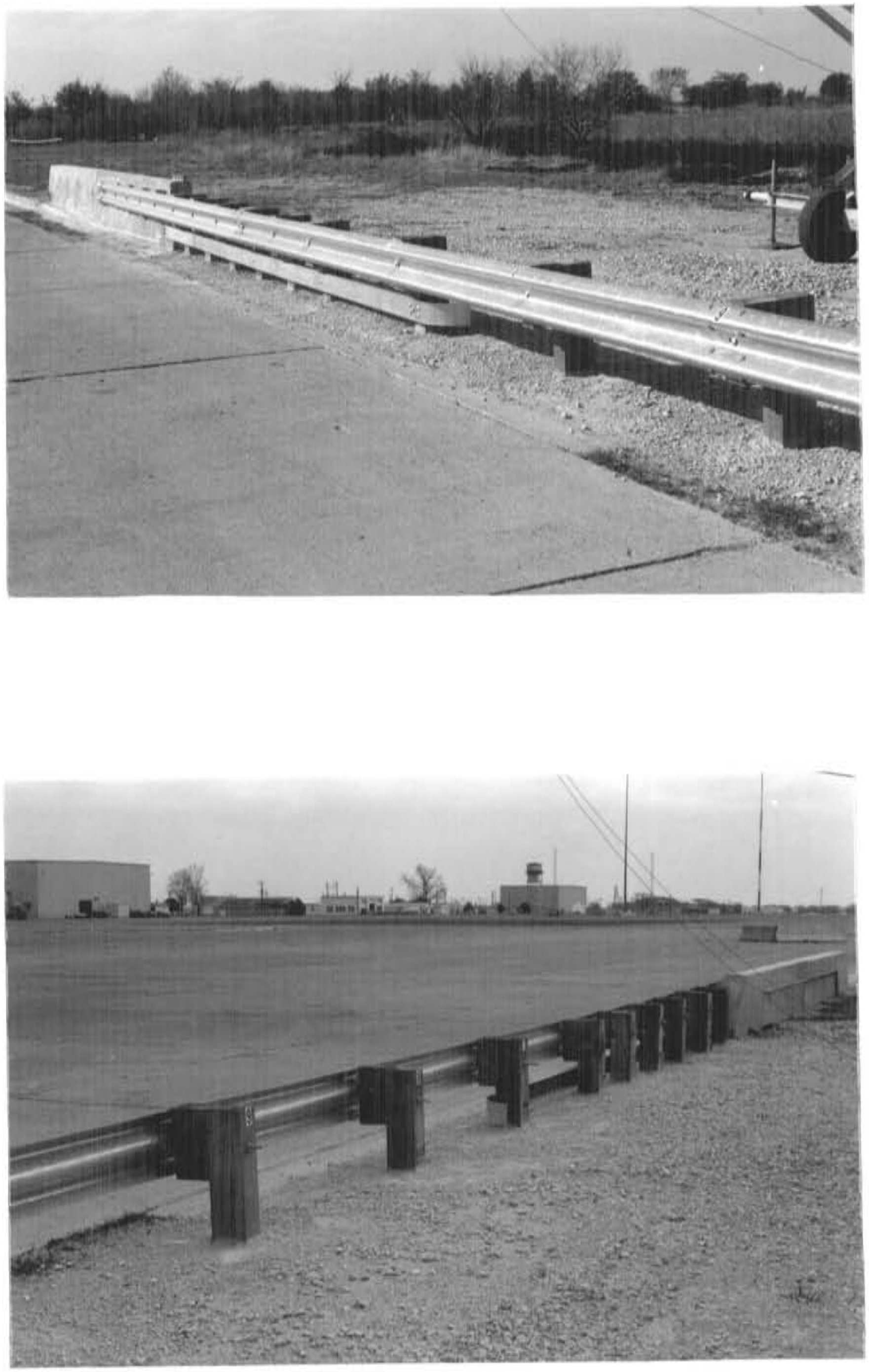


Figure 86. Arizona guardrail transition to concrete half barriers before test 7155-8.

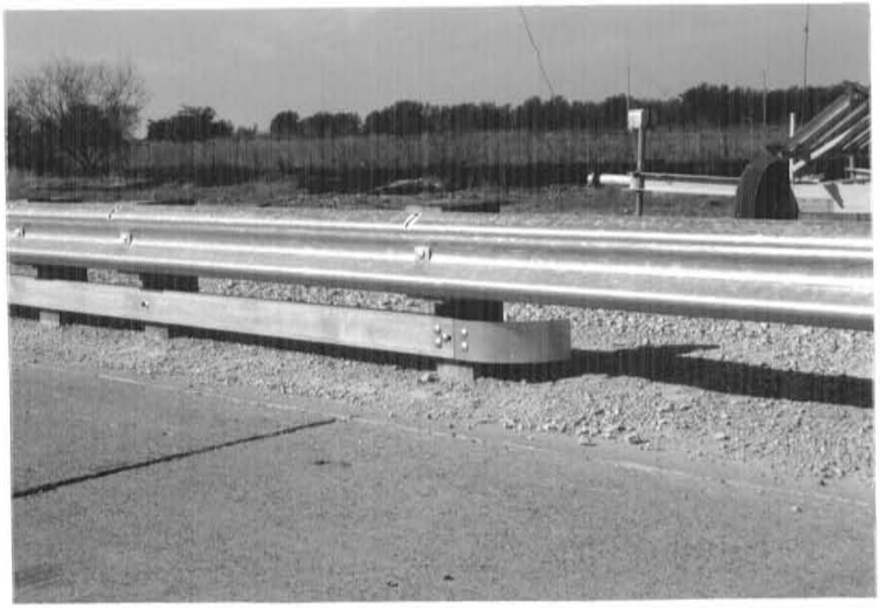


Figure 86. Arizona guardrail transition to concrete half barriers before test 7155-8. (Continued)

Figure 87. Vehicle before test 7155-8.

vehicle was 4,500 pounds (2,041 kg). The height to the lower edge of the vehicle bumper was 13.0 inches (33.0 cm) and the height to the upper edge was 21.0 inches (53.3 cm). Other dimensions and information pertaining to the vehicle are given in Figure 88.

The vehicle was free wheeling and unrestrained just prior to impact. Upon impact, the barrier began to deform in a manner similar to that observed in Test 2. There was some evidence of pocketing behind the first post of the transition (post 7). This was due to the fact that this post was restrained at the top by the W-beam and at the bottom by the rubrail and, thus, could not rotate as freely as the guardrail posts prior to the transition. However, the post was able to deflect an appreciable amount out of the path of the impacting vehicle and the pocketing was not as pronounced as that seen in Test 2. Although there was wheel contact on the first transition post (0.134 seconds after impact), the wheel did not engage the end of the rubrail. The vehicle became parallel to the installation at 0.199 seconds and lost contact with the installation at 0.600 second while traveling 37.6 miles per hour and at an angle of 18.0 degrees. Shortly thereafter, the brakes were applied, the vehicle yawed counterclockwise and came to rest 135.0 feet (41.2 m) from the point of impact. It should be noted that there was no evidence of wheel contact on the guardrail post immediately upstream of the transition, indicating that the 8 inch blockout was sufficient enough to prevent such behavior from occurring. The sequential photographs of the test are shown in Figure 89.

Damage to the barrier is shown in Figure 90. Maximum dynamic rail deflection during impact was 28.8 in (0.7 m), and the maximum permanent rail deformation was measured to be 25.3 inches (64.1 cm). The vehicle was in contact with the installation for a total length of 23.7 feet (7.2 m).

As shown in Figure 91, damage to the vehicle was minor for an impact of this severity. The maximum crush recorded on the vehicle was 10.0 inches (25.4 cm) at the right front corner. The right front wheel was pushed rearward 8.0 inches (20.3 cm) and the control arm was bent. Additionally, both the front and rear wheels were bent and the tires were aired out.

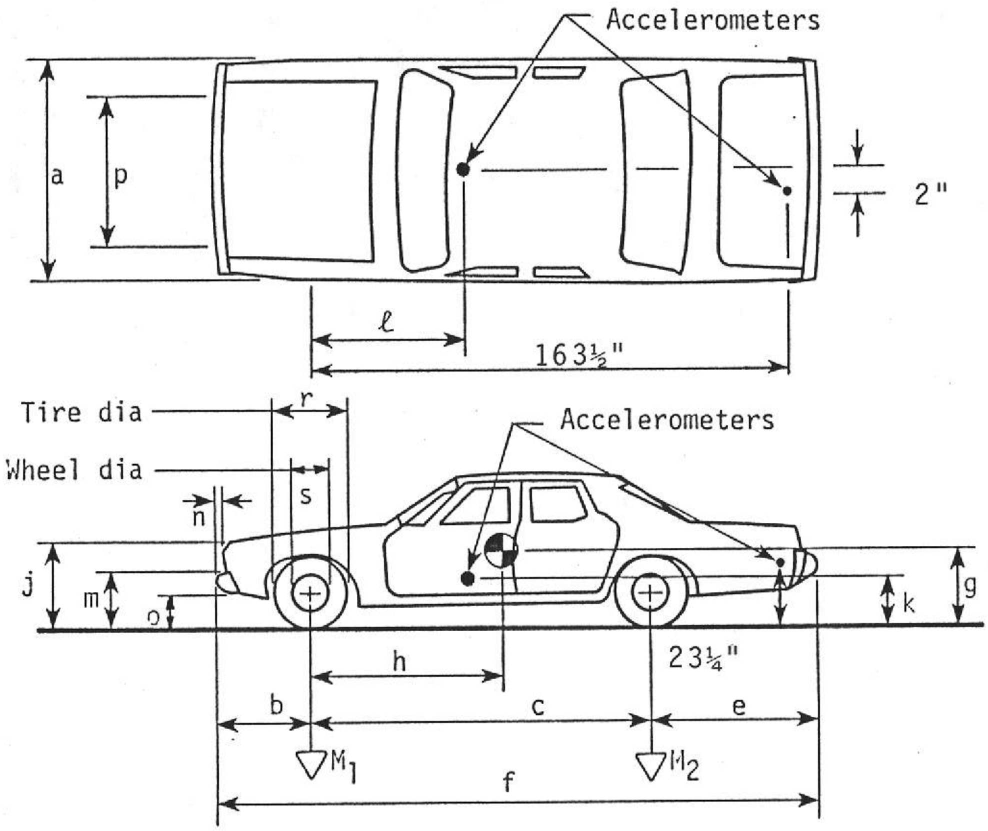
A summary of the test results and other information pertinent to this test are given in Figure 92. The maximum 0.050-second average accelerations experienced by the vehicle were -5.0 g in the longitudinal direction and 7.0 g in the lateral direction. Vehicle angular

Date: ______ Test No.: 7155-8 VIN: 6D47NA9223113

Make: Cad. Model: Coupe Deville Year: 1980 Odometer: 70001

Tire Size: P21575R15 Ply Rating: ______ Bias Ply: ___ Belted: ___ Radial: X

Tire Condition: good ___
fair X
badly worn ___



Vehicle Geometry - inches

a	77"	b	42"
c	121"	d*	55 ¼"
e	57½"	f	220.5"
g		h	54.9"
i	----	j	34¼"
k	16½"	ℓ	54"
m	21"	n	4 3/4"
o	13"	p	61½"
r	27¼"	s	16¼"

Engine Type: V-8

Engine CID: 350 Diesel

Transmission Type:

Automatic ~~or Manual~~

~~FWD or~~ RWD ~~or 4WD~~

Body Type: 2 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

4-wheel weight for c.g. det. ℓf 1246 rf 1212 ℓr 1025 rr 1017

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2454	2458	
M_2	1747	2042	
M_T	4201	4500	

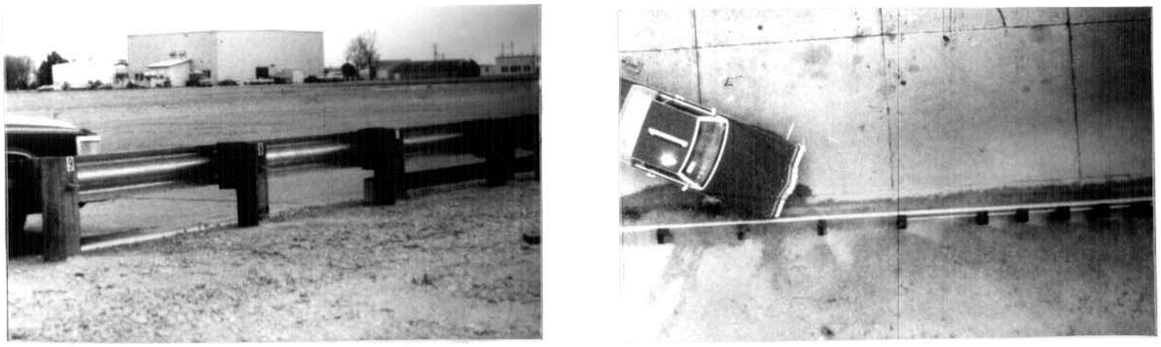
Note any damage to vehicle prior to test:

______

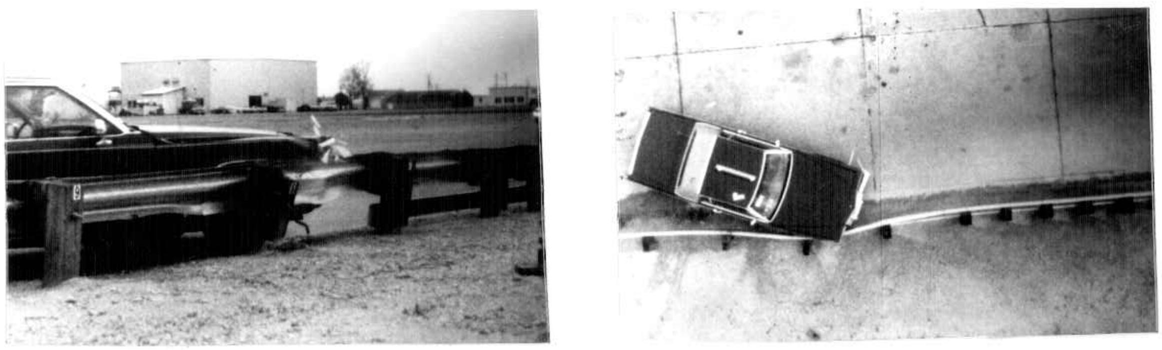
______

*d = overall height of vehicle

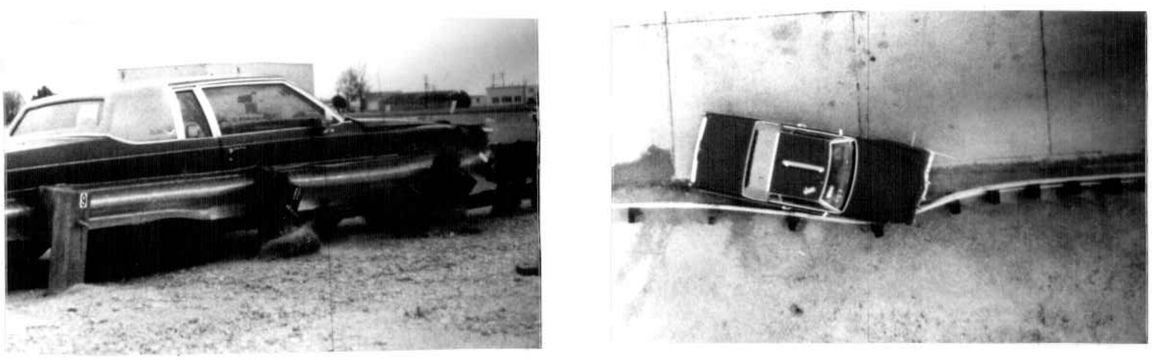
Figure 88. Vehicle properties (test 7155-8).



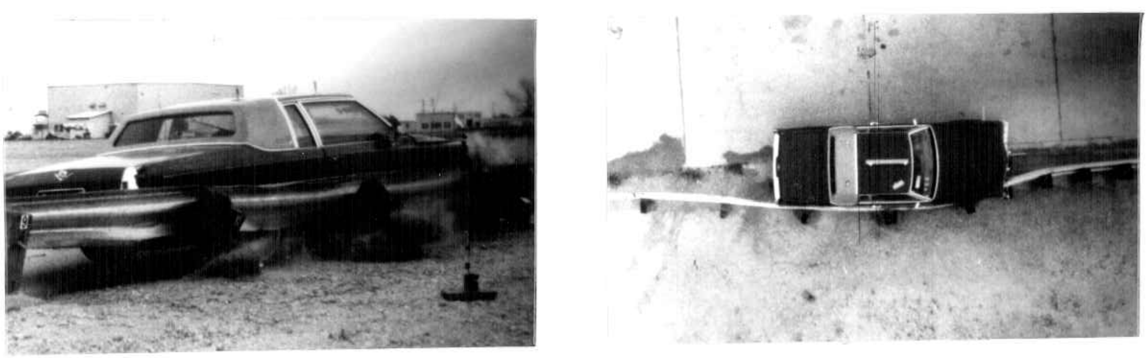
0.000 s



0.079 s



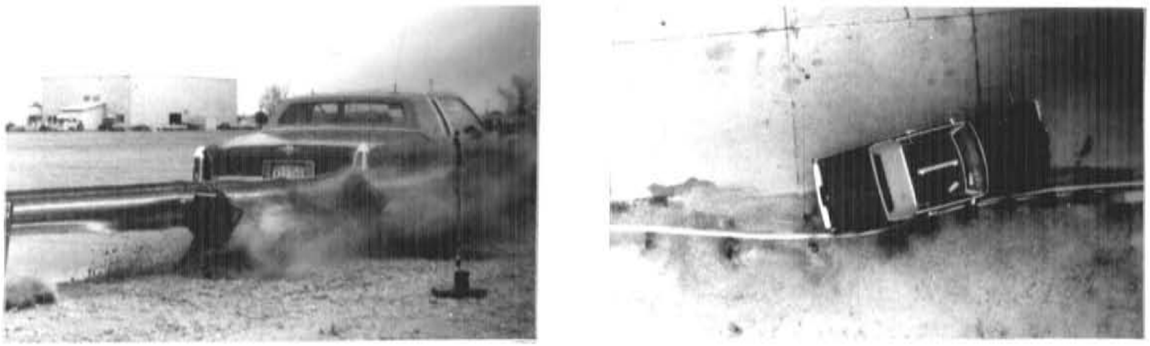
0.159 s



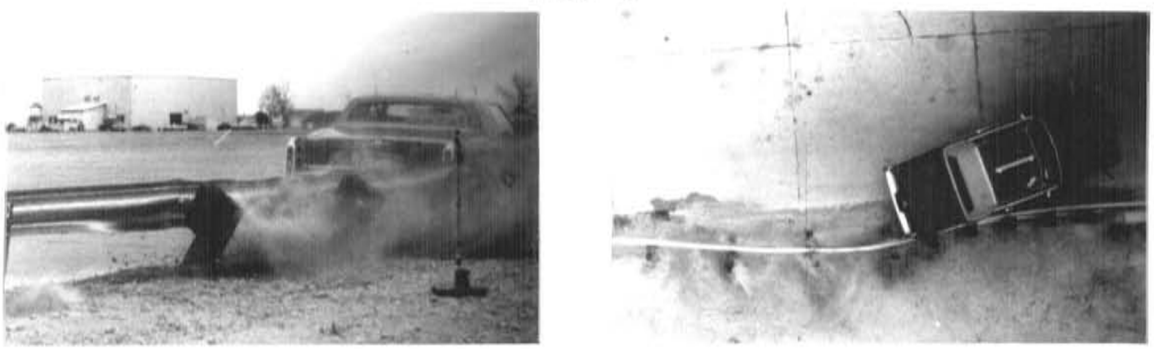
0.238 s

Figure 89. Sequential photographs of test 7155-8.

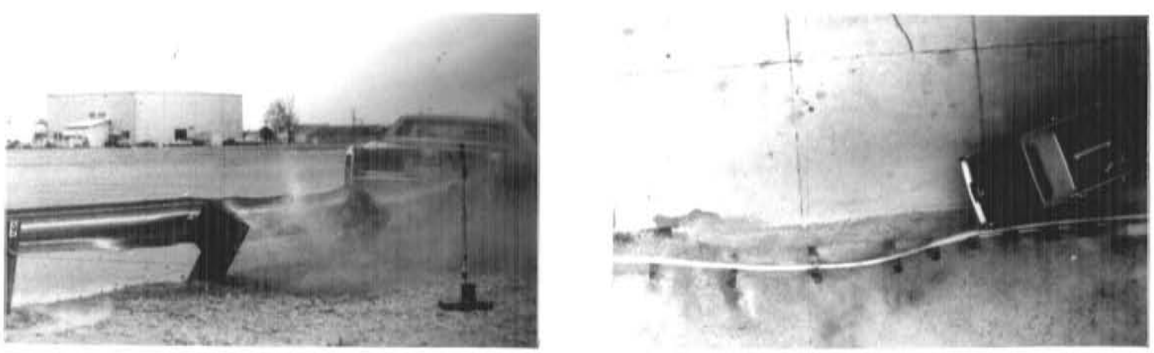
0.318 s



0.397 s



0.497 s



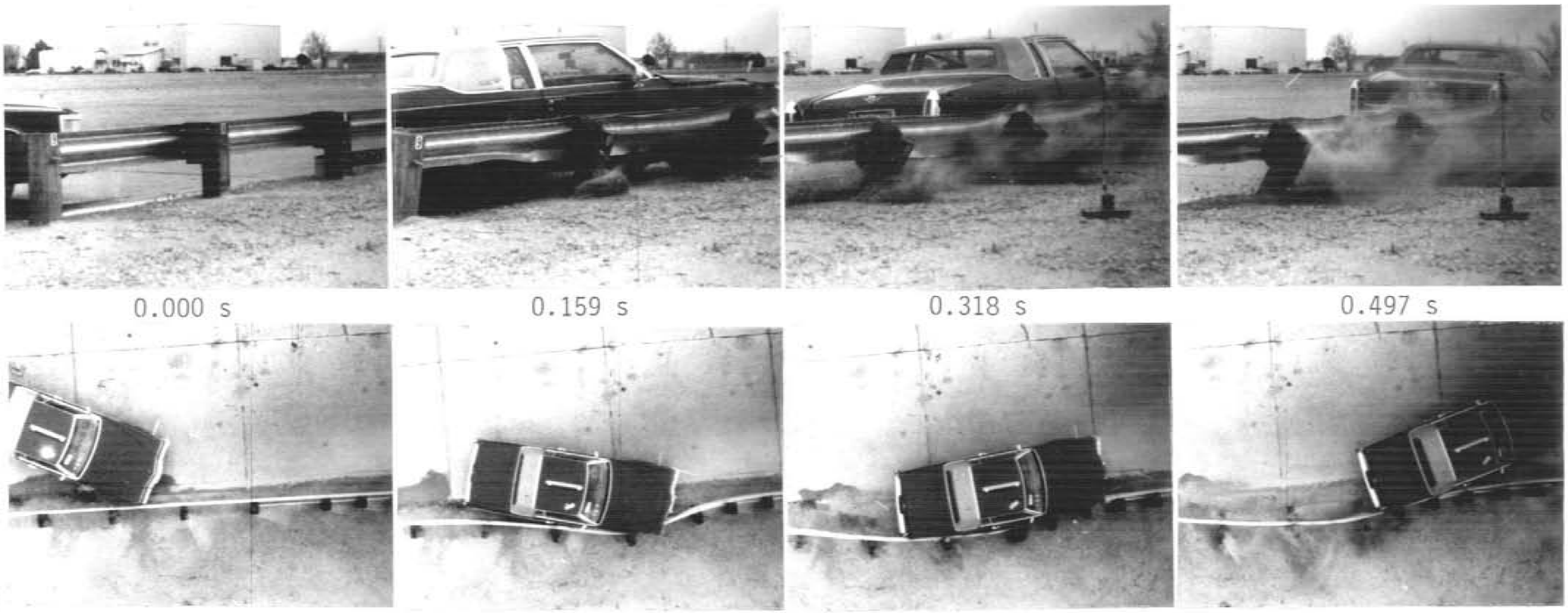
0.600 s

Figure 89. Sequential photographs of test 7155-8 (continued).

Figure 90. Arizona guardrail transition to concrete barrier after test 7155-8.

Figure 90. Arizona guardrail transition to concrete barrier after test 7155-8 (continued).

Figure 91. Vehicle after test 7155-8.



Test No.	7155-8
Date	03/07/91
Test Installation	Arizona guardrail transition to concrete half barrier
Installation Length	87.5 ft (26.7 m)
Vehicle	1980 Cadillac Coupe deVille
Vehicle Weight	
Test Inertia	4,500 lb (2,041 kg)
Vehicle Damage Classification	
TAD	01FR2
CDC	01FREW2
Maximum Vehicle Crush	10.0 in (25.4 cm)
Max. Dyn. Rail Deflection	28.8 in (0.7 m)
Max. Perm. Rail Deformation	25.3 in (64.1 cm)

Impact Speed	59.6 mi/h (95.8 km/h)
Impact Angle	24.5 deg
Exit Speed	37.6 mi/h (60.5 km/h)
Exit Trajectory	18.0 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal	-5.0 g
Lateral	7.0 g
Occupant Impact Velocity	
Longitudinal	22.6 ft/s (6.9 m/s)
Lateral	-15.4 ft/s (4.7 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-10.9 g
Lateral	9.6 g

Figure 92. Summary of results for test 7155-8.

displacements are plotted in Figure 93 and vehicle accelerometer traces are displayed in Figures 94 through 96. Occupant impact velocities were 22.6 feet per second (6.9 m/s) in the longitudinal direction and -15.4 feet per second (4.7 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were -10.9 g (longitudinal) and 9.6 g (lateral). Although not required for evaluation of the transition test, it is noteworthy to mention that all of the occupant risk criteria stated above are below the limits recommended in NCHRP Report 230.

In summary, this test was judged to be a success. The installation successfully contained and redirected the test vehicle. The test vehicle sustained only minor damage and there was no evidence of debris of detached elements from the vehicle which could pose a hazard to other traffic. Furthermore, the vehicle remained upright and stable during the initial test period and after leaving the installation, and there was no deformation or intrusion into the occupant compartment. Although not required for this test, the occupant impact criteria were all well below recommended limits. This indicates that, although wheel contact occurred on some of the guardrail posts, the vehicle was smoothly redirected without any severe decelerations. The vehicle speed change and vehicle exit angle were higher than allowable by criterion I in NCHRP Report No. 230, but this criterion is not applicable to this test because the vehicle was not redirected into or stopped while in adjacent traffic lanes. Damage to the wheel caused the test vehicle to steer back towards the barrier.

Test 7155-9

As indicated by the results of test 7155-5, the standard ADOT steel post transition with curb failed to meet NCHRP Report 230 impact criteria. In an effort to assess the risk posed by the current system and evaluate the need for a retrofit program, an additional crash test was conducted on the unmodified design. In consultation with FHWA, ADOT selected an impact speed of 60 mph and an impact angle of 20 degrees for this test. Studies have shown that less than 10% of all real-world, run-off-the-road accidents have an impact speed and angle that exceed both of these criteria (7). Simulation runs were made to determine the critical impact location for this new impact severity. Results indicated that the critical impact location was 5.5 ft upstream from the end of the concrete parapet.

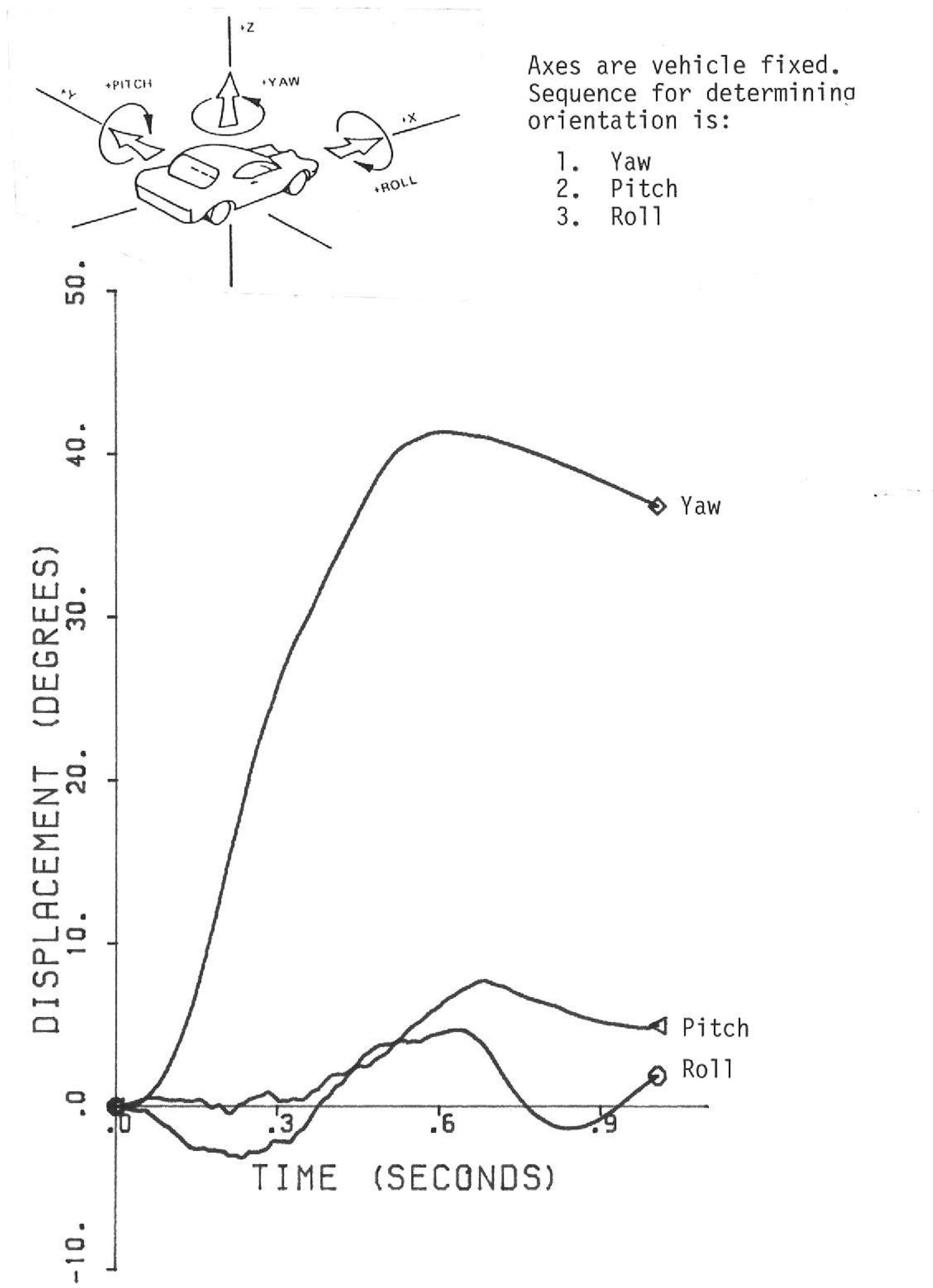


Figure 93. Vehicle angular displacements (test 7155-8).

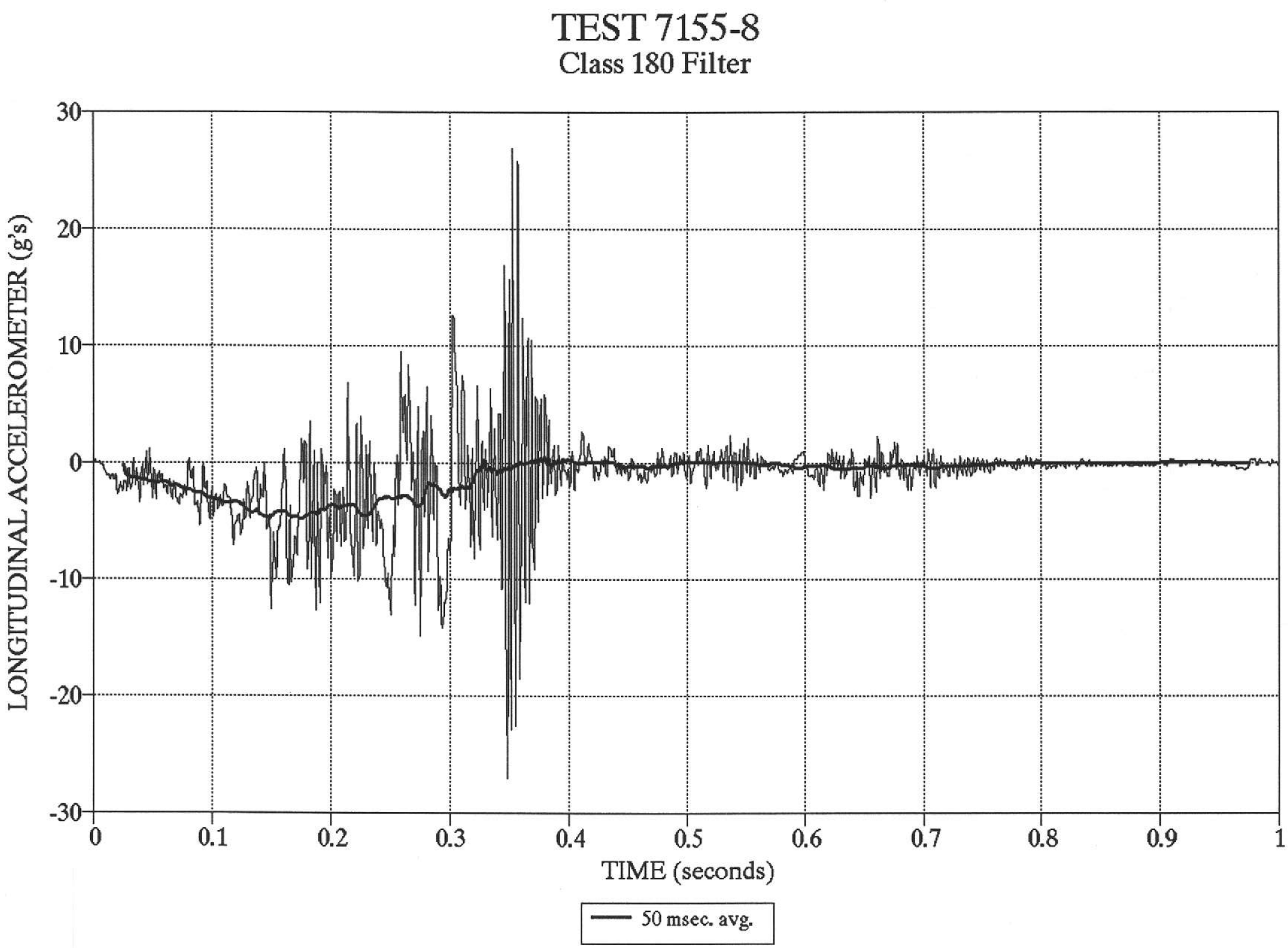


Figure 94. Longitudinal accelerometer trace of test 7155-8.

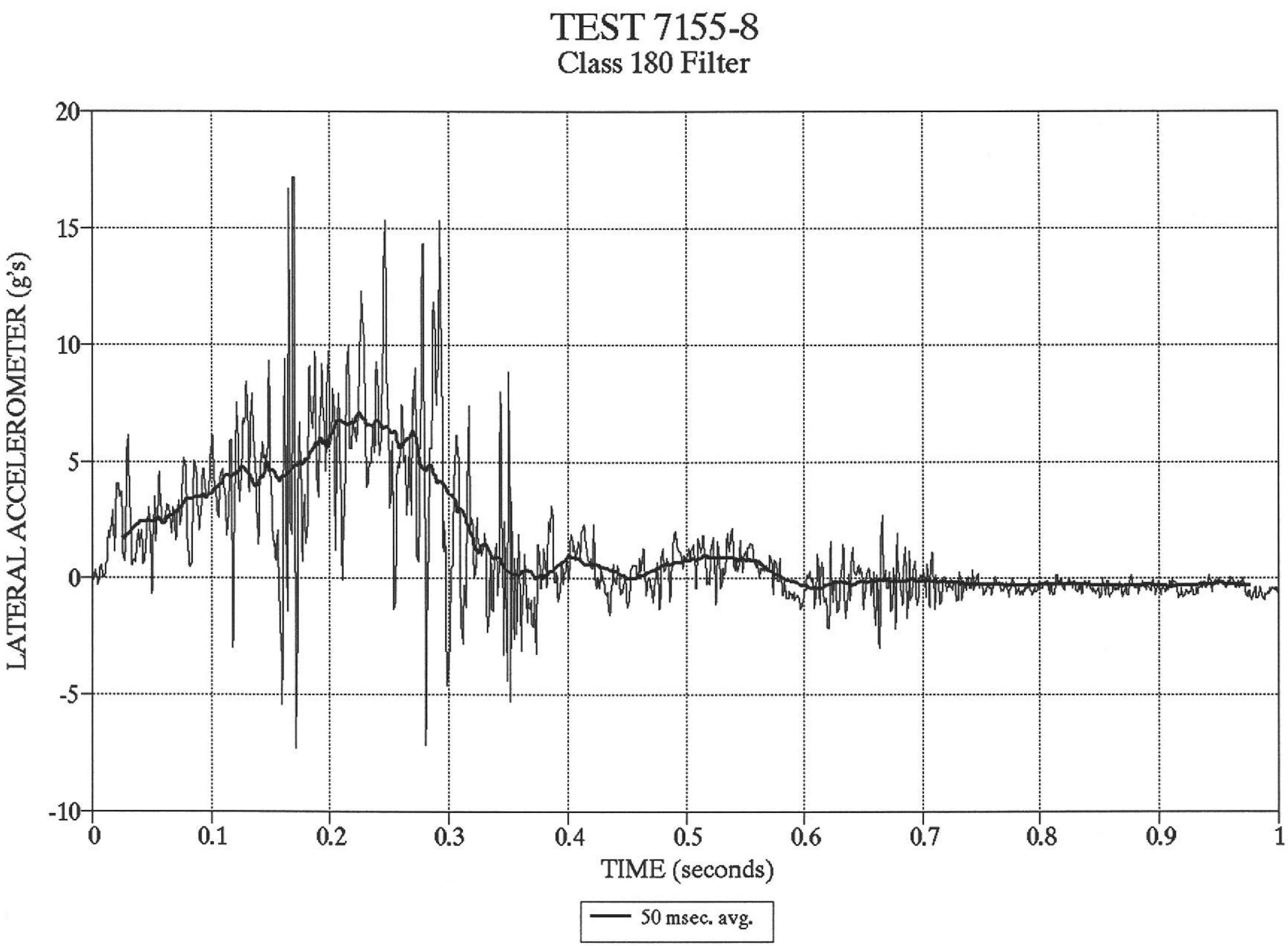


Figure 95. Lateral accelerometer trace of test 7155-8.

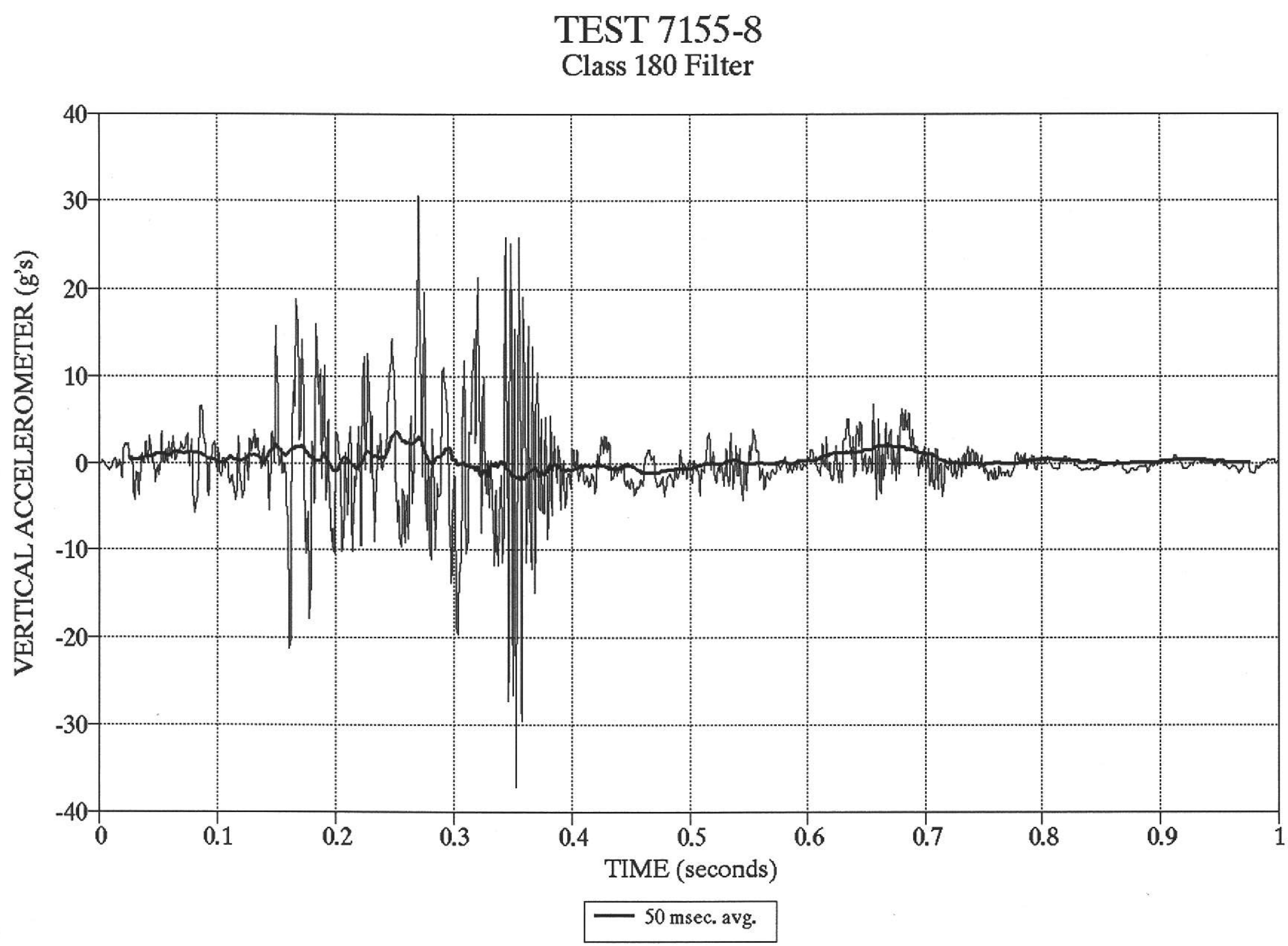


Figure 96. Vertical accelerometer trace of test 7155-8.

Details of the standard steel post transition with 6 inch curb are shown in Figure 49. The completed test installation for test 7155-9 is shown in Figure 97.

Results

A 1982 Cadillac Coupe DeVille (shown in Figure 98) impacted 5.5 ft (1.7 m) upstream of the concrete bridge parapet at 59.7 miles per hour (96.0 km/h) and at an angle of 21.5 degrees using a cable reverse tow and guidance system. Test inertia mass of the vehicle was 4,500 pounds (2,041 kg). Dimensions and other pertinent information on the vehicle are given in Figure 99.

The vehicle was free wheeling and unrestrained just prior to impact. The left front tire of the vehicle climbed the curb as the vehicle engaged the guardrail. Although yielding of the W-beam around the end of the concrete barrier and first steel blockout on the face of the barrier allowed some vehicle snagging to occur, the vehicle was smoothly redirected. The vehicle lost contact with the installation at 0.364 second traveling 41.2 miles per hour (66.3 km/h) at an angle of 3.7 degrees. After exiting the installation, the brakes were applied and the vehicle came to rest 160.0 feet (48.8 m) from the point of impact. Sequential photographs of the test are shown in Figure 100.

Residual damage to the installation is shown in Figure 101. The maximum permanent rail deformation was 3.5 inches (8.9 cm). The W-beam rail yielded locally around the end of the concrete parapet. The rail also yielded about the first steel blockout on the face of the parapet resulting in permanent deformation of the blockout as shown in Figure 101. The W6x9 steel blockouts on the first two posts from the end of the parapet retained their shape, and there was no observable damage or distress to the curb or the concrete anchor inserts. The vehicle was in contact with the installation for a total length of 12.7 feet (3.9 m).

Damage received by the vehicle is shown in Figure 102. The maximum recorded crush was 12.0 inches (30.5 cm) at the left front corner of the vehicle. The left front wheel was pushed rearward 3.5 inches (8.9 cm) causing some minor deformation of the floor pan. The left side of the vehicle was dented and scraped, and the windshield was broken. The left rear tire and wheel were undamaged.

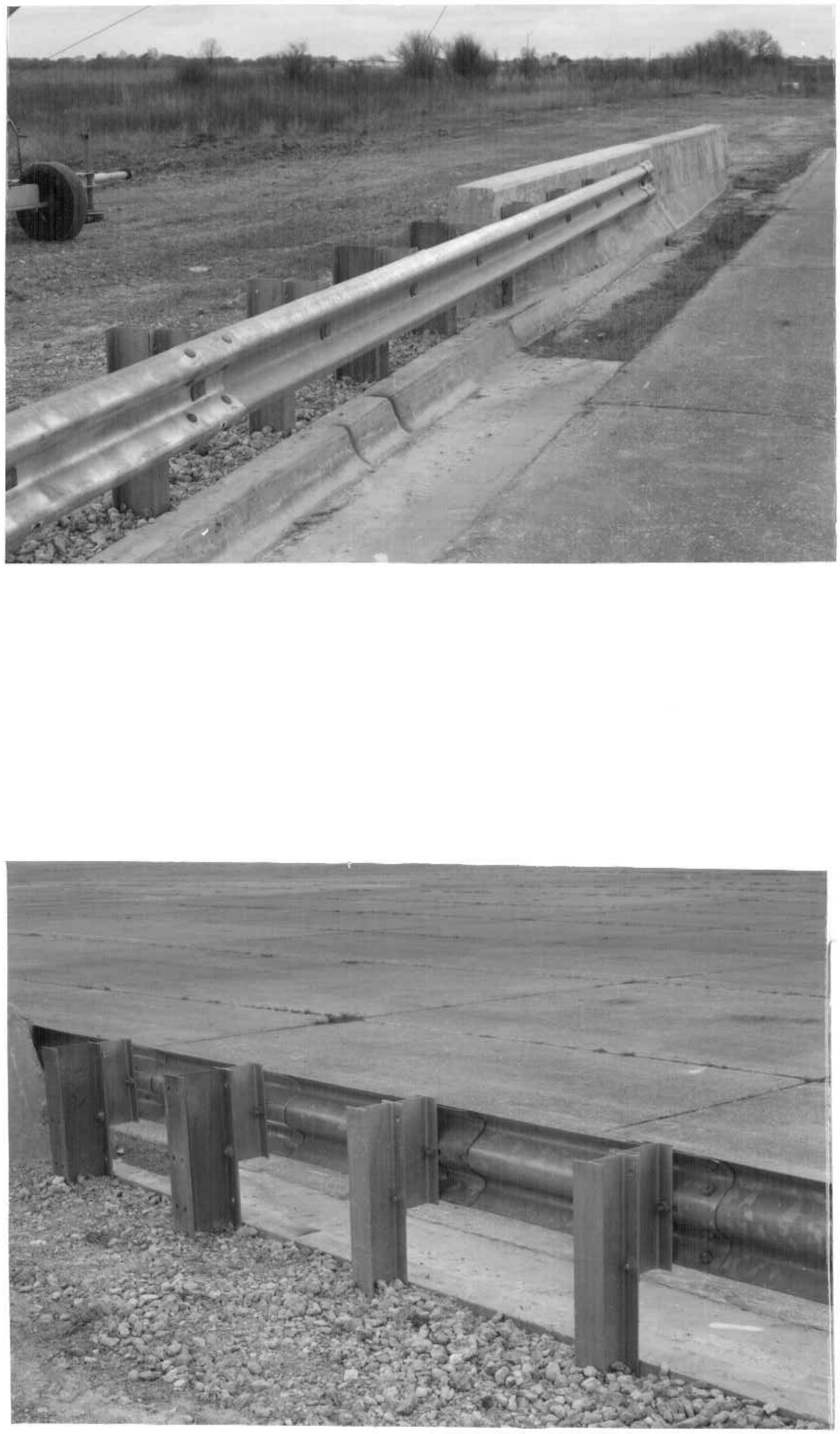


Figure 97. Arizona guardrail transition to concrete barrier before test 7155-9.

Figure 98. Vehicle before test 7155-9.

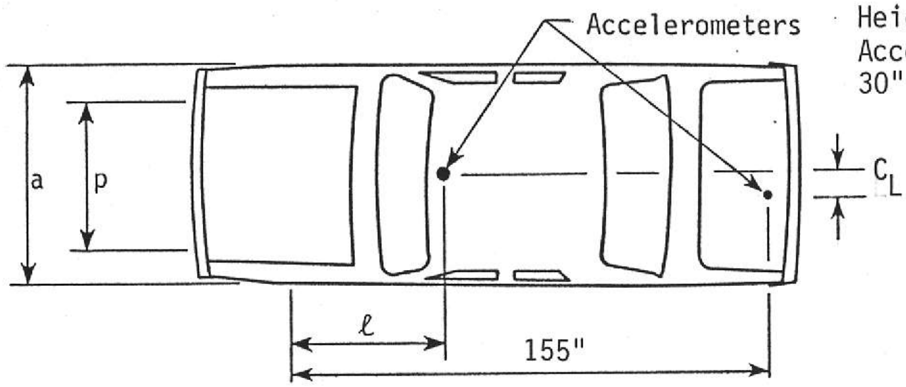
Date: 03-13-92 Test No.: 7155-9 VIN: 1G6AD4783C9171789

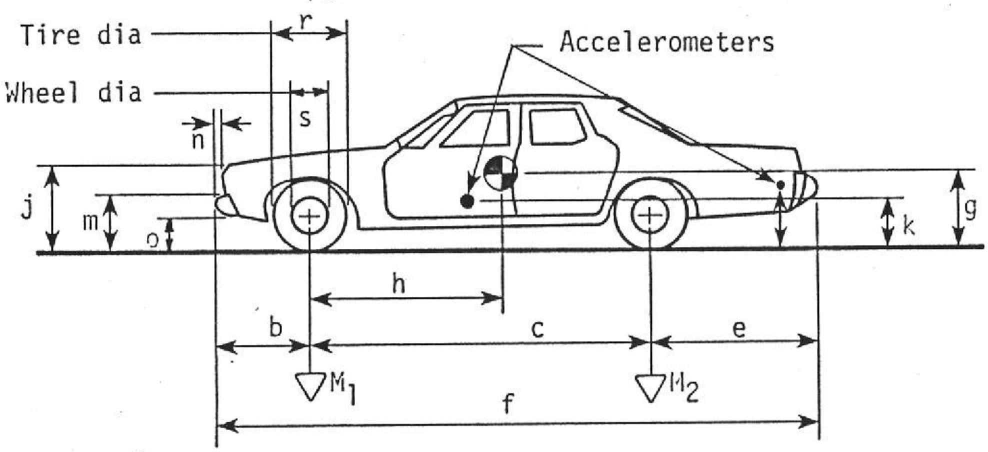
Make: Cadillac Model: Coupe DeVille Year: 1982 Odometer: 113732

Tire Size: P215 75R15 Ply Rating: 4 Bias Ply: ___ Belted: ___ Radial: X

Tire Condition: good ___ fair X badly worn ___

Height of Rear Accelerometer: 30"





Vehicle Geometry - inches

a	77"	b	43"
c	121"	d*	55"
e	56 1/2"	f	220 1/2"
g		h	57.6
i	----	j	33 3/4"
k	17"	ℓ	51 1/2"
m	20 1/2"	n	4 1/4"
o	11 1/2"	p	61 1/2"
r	27"	s	16 1/4"

Engine Type: V-8

Engine CID: 4.1 liter

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Body Type: 2 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

4-wheel weight for c.g. det. ℓf 1223 rf 1135 ℓr 1090 rr 1052

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	1111/2188/1077	2358	
M_2	823/1635/812	2142	
M_T	1934/3823/1889	4500	

Note any damage to vehicle prior to test:

crack in windshield (marked)

*d = overall height of vehicle

Figure 99. Vehicle properties (test 7155-9)

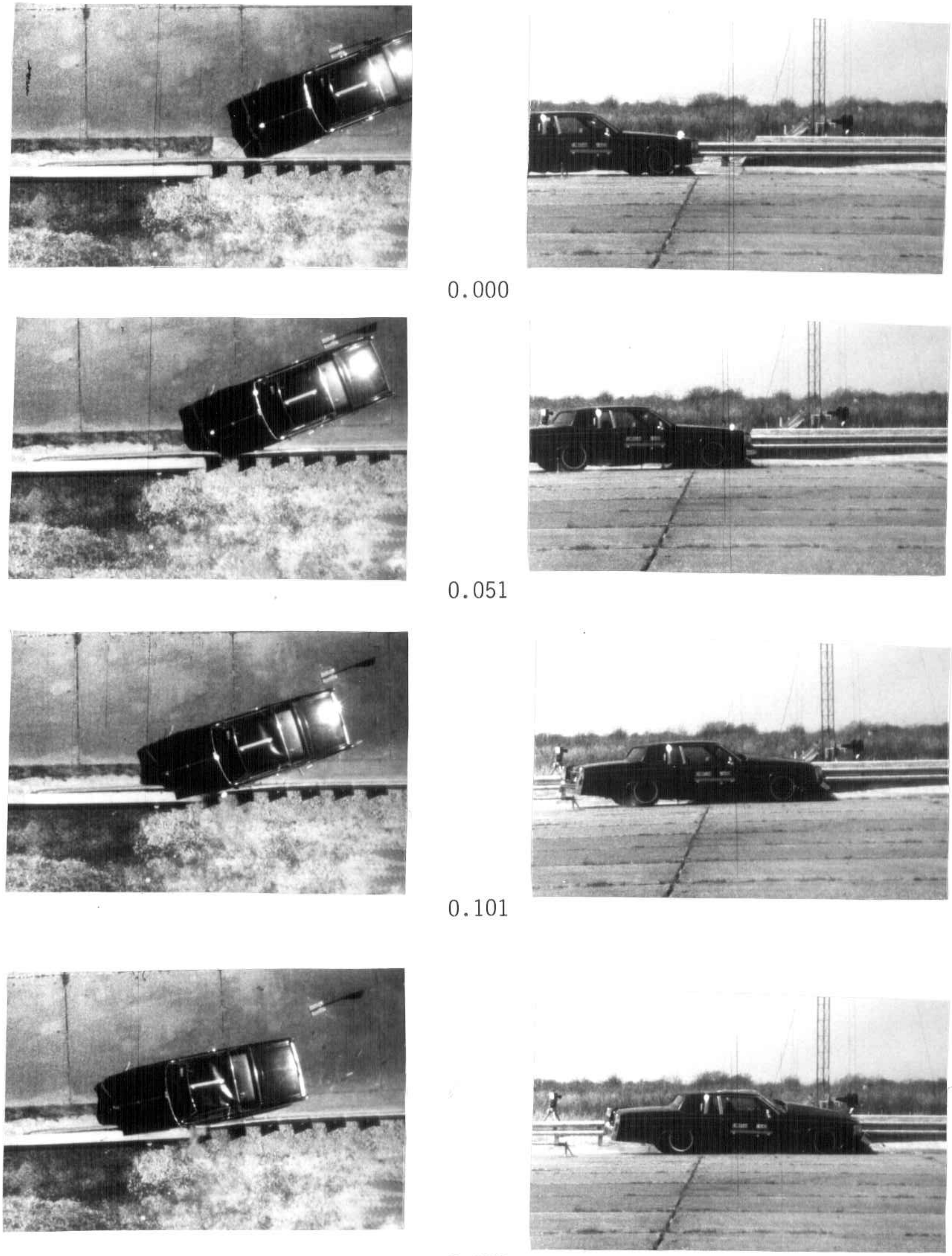
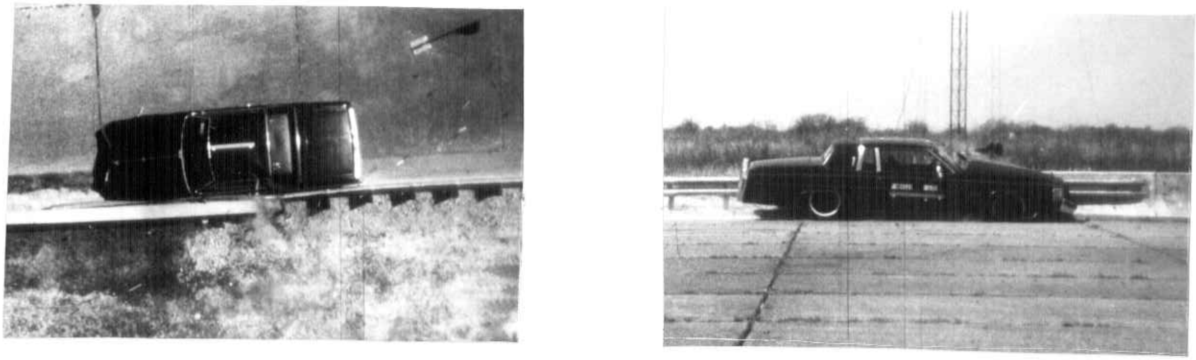
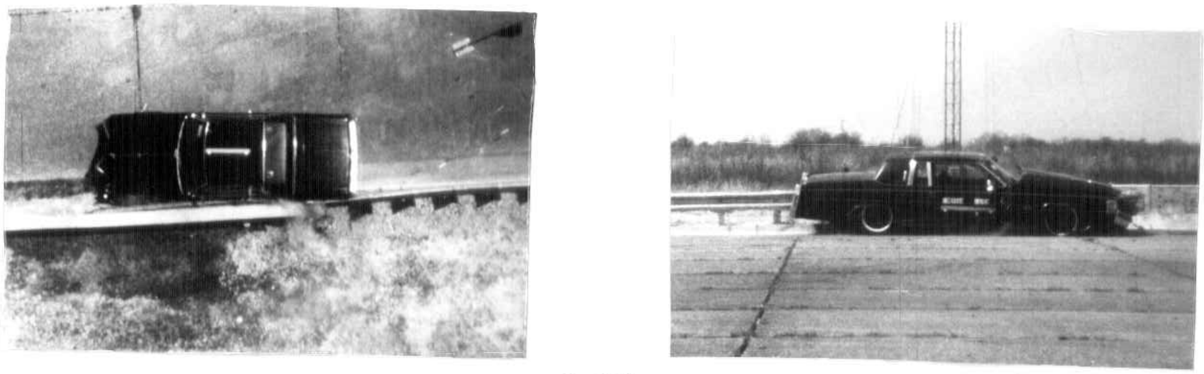


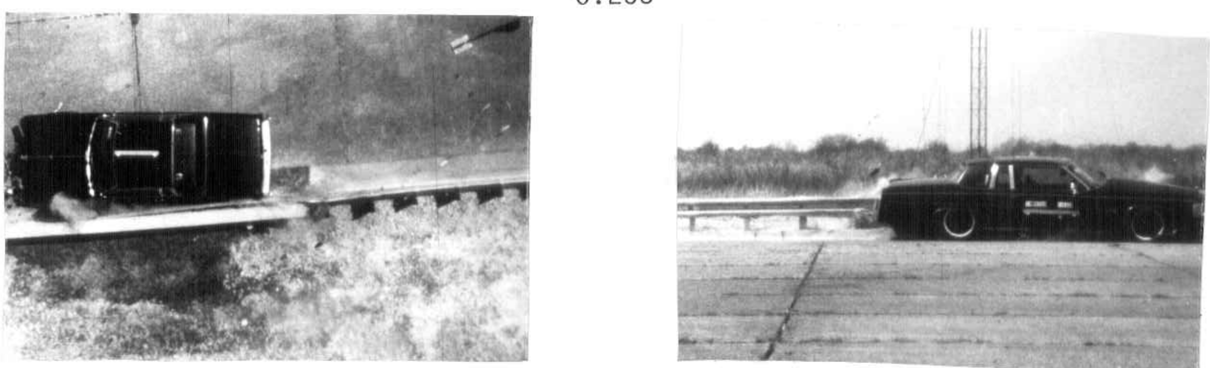
Figure 100. Sequential photographs of test 7155-9.



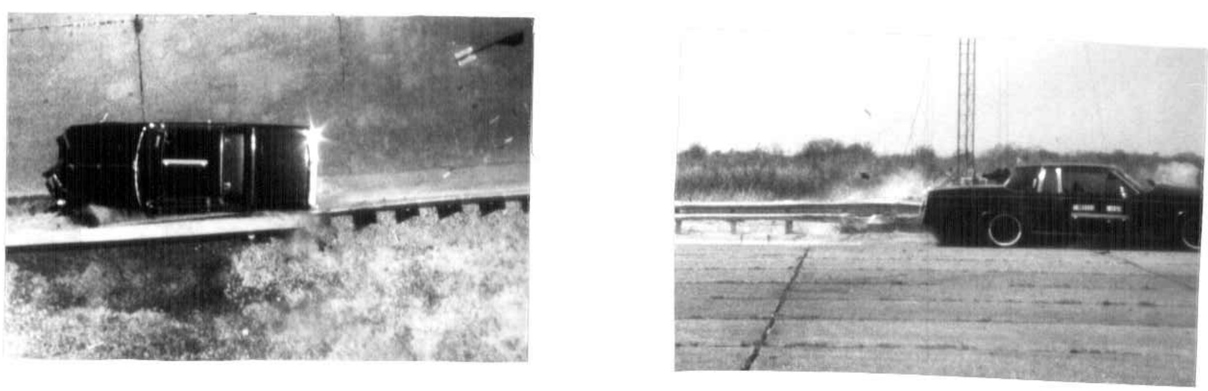
0.202



0.253



0.304



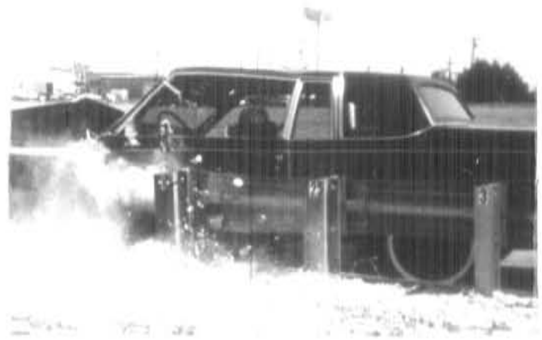
0.354

Figure 100. Sequential photographs of test 7155-9 (continued).

0.000

0.051

0.101



0.152

0.202

0.253

0.304

0.354

Figure 100. Sequential photographs of test 7155-9 (continued).

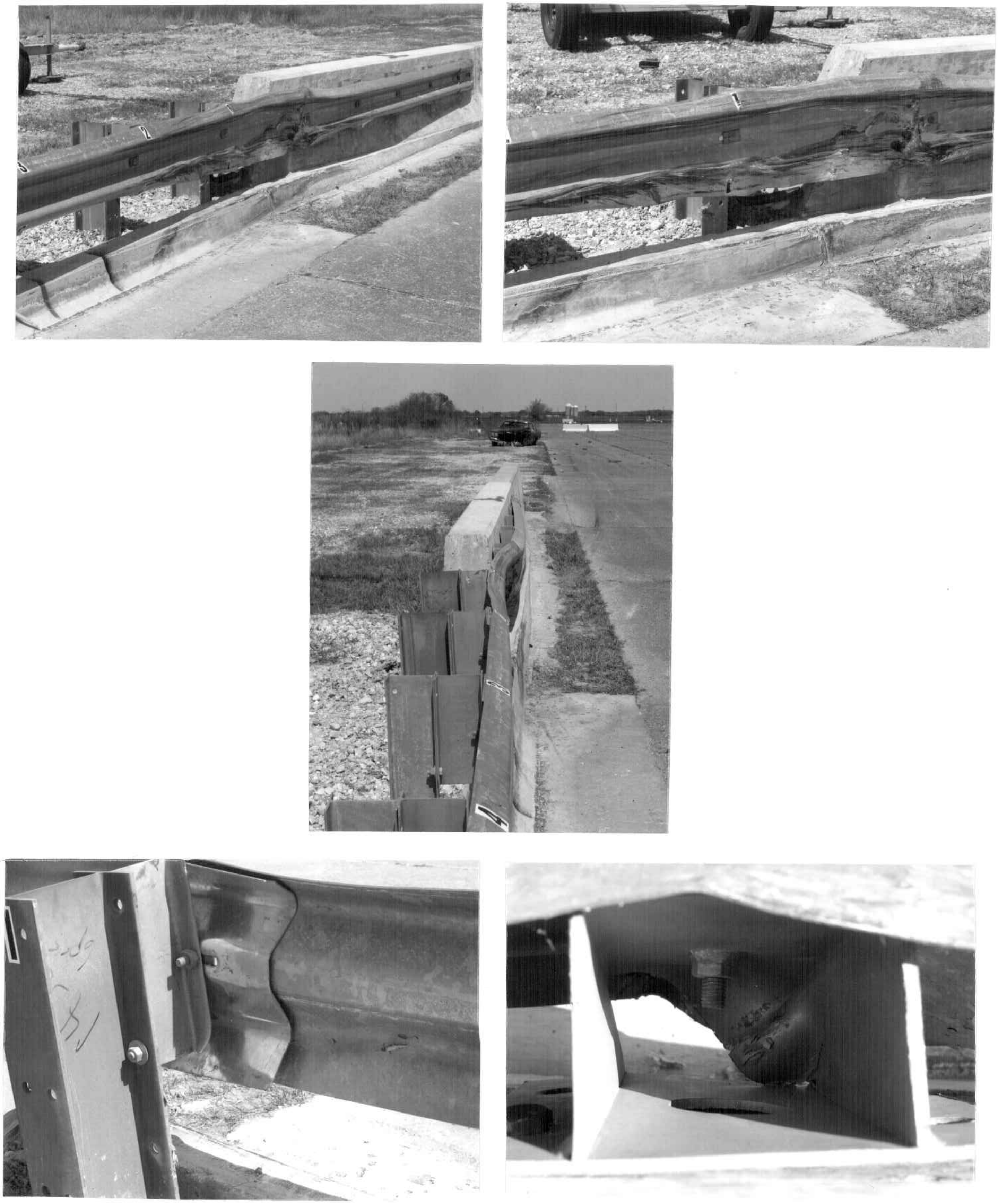
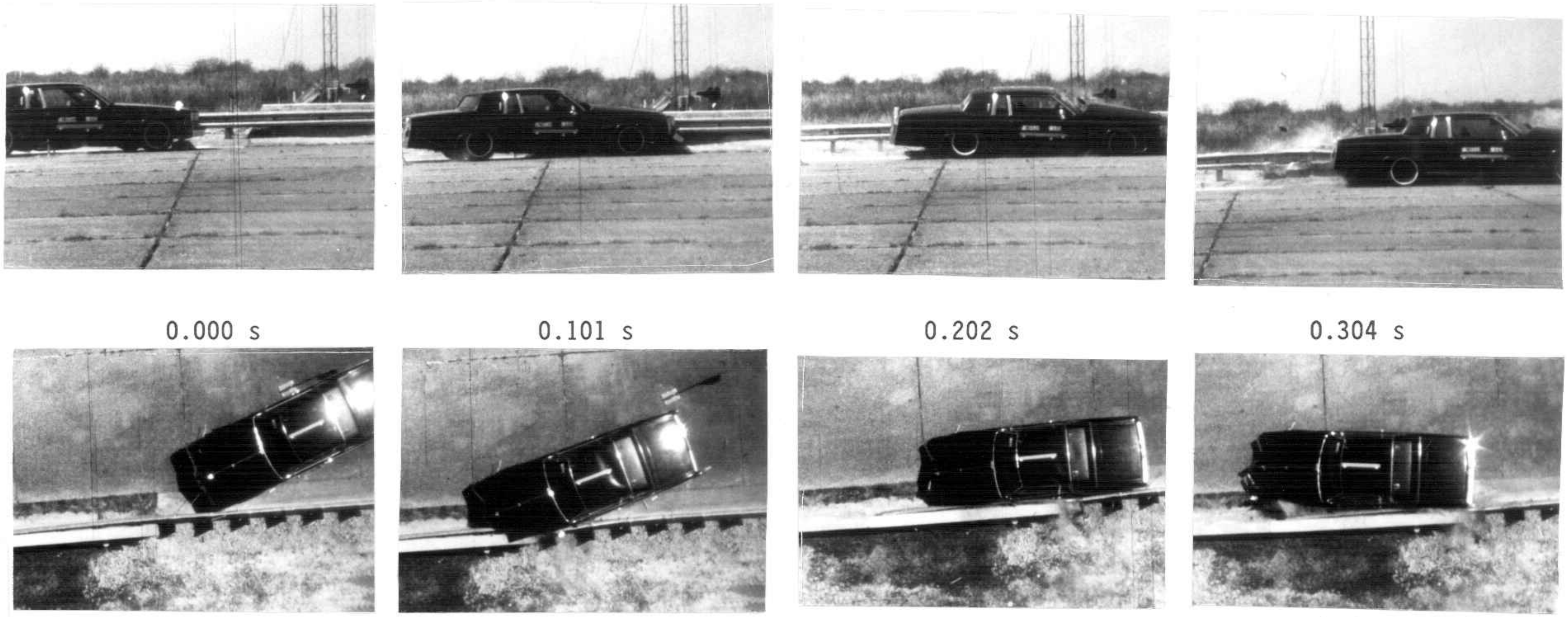


Figure 101. Arizona guardrail transition to concrete barrier after test 7155-9.

Figure 102. Vehicle after test 7155-9.



0.000 s   0.101 s   0.202 s   0.304 s

Test No.	7155-9	Impact Speed.	59.7 mi/h (96.0 km/h)
Date	03/03/92	Impact Angle.	21.5 deg
Test Installation	Arizona Bridge Rail Transition	Exit Speed.	41.2 mi/h (66.4 km/h)
Installation Length	87.5 ft (26.7 m)	Exit Trajectory	3.7 deg
Vehicle	1982 Cadillac	Vehicle Accelerations (Max. 0.050-sec Avg)	
Vehicle Weight		Longitudinal.	-8.0 g
Test Inertia	4,500 lb (2,041 kg)	Lateral	-8.8 g
Vehicle Damage Classification		Occupant Impact Velocity	
TAD	11FL5	Longitudinal.	24.3 ft/s (7.4 m/s)
CDC	11LFEW2	Lateral	20.7 ft/s (6.3 m/s)
Maximum Vehicle Crush . . .	12.0 in (30.5 cm)	Occupant Ridedown Accelerations	
Max. Dyn. Rail Deflection. .	N/A	Longitudinal.	-2.7 g
Max. Perm. Rail Deformation.	3.5 in (8.9 cm)	Lateral	-10.2 g

Figure 103. Summary of results for test 7155-9.

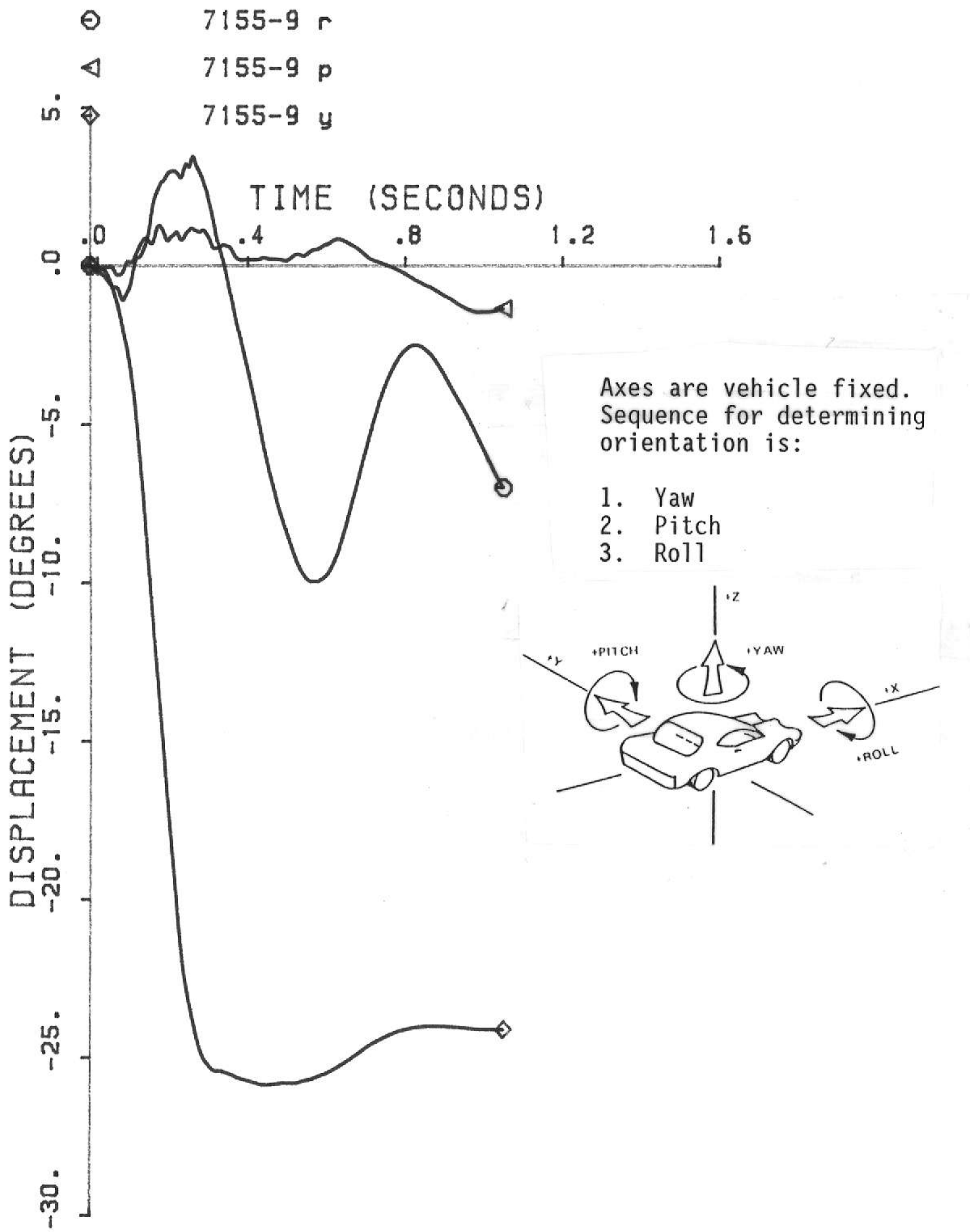


Figure 104. Vehicle angular displacements (test 7155-9).

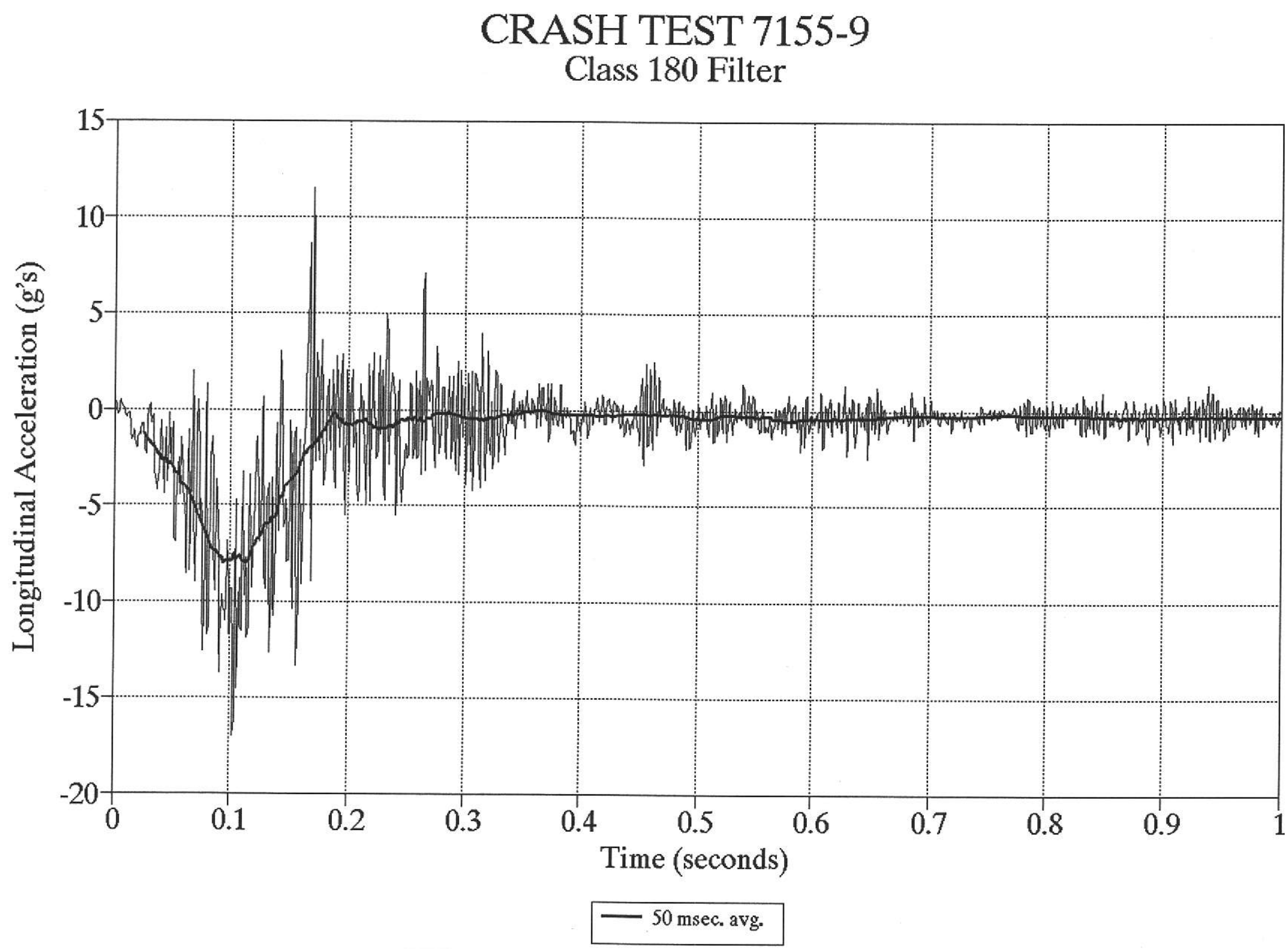


Figure 105. Longitudinal accelerometer trace (7155-9).

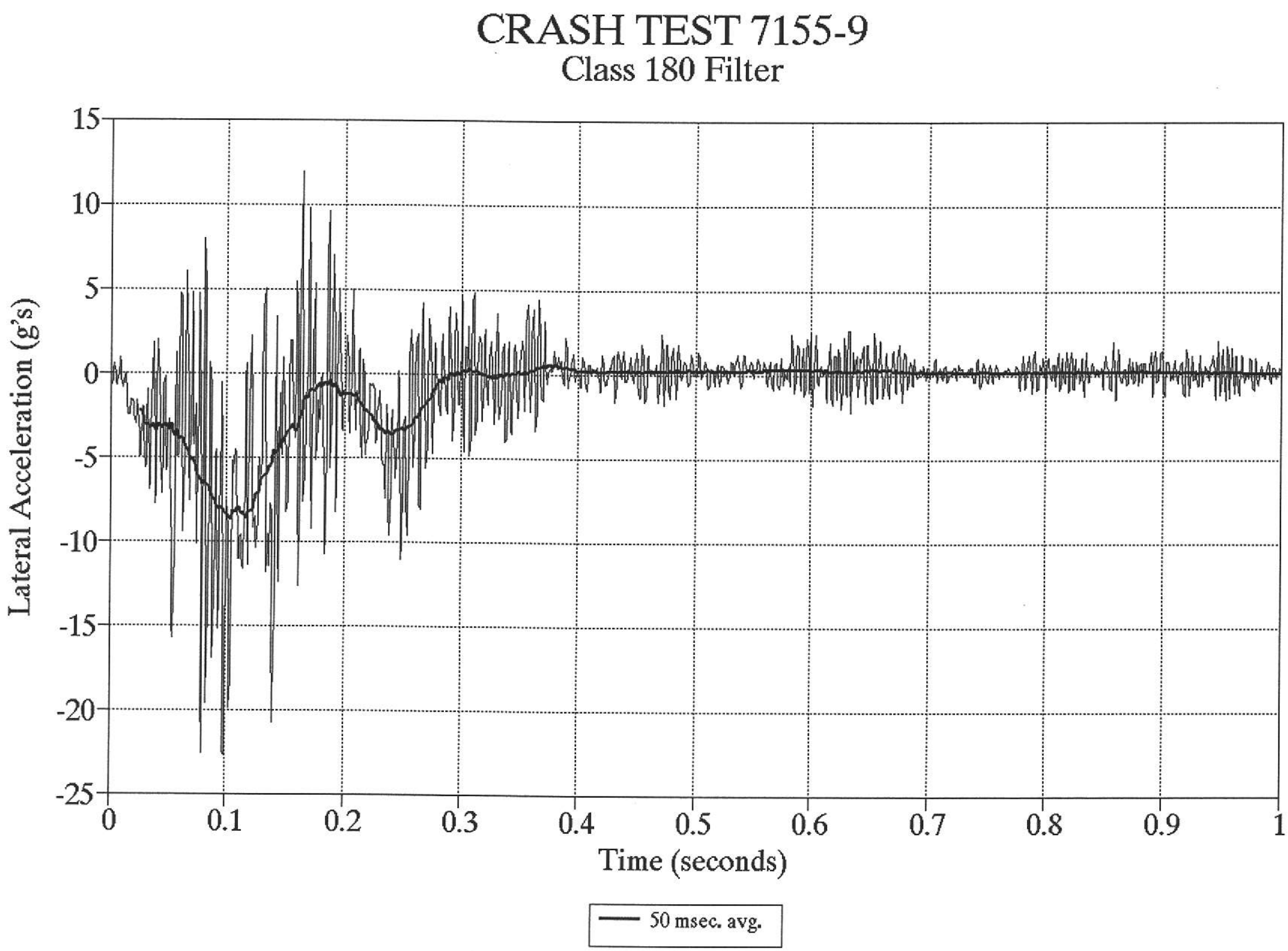


Figure 106. Lateral accelerometer trace (7155-9).

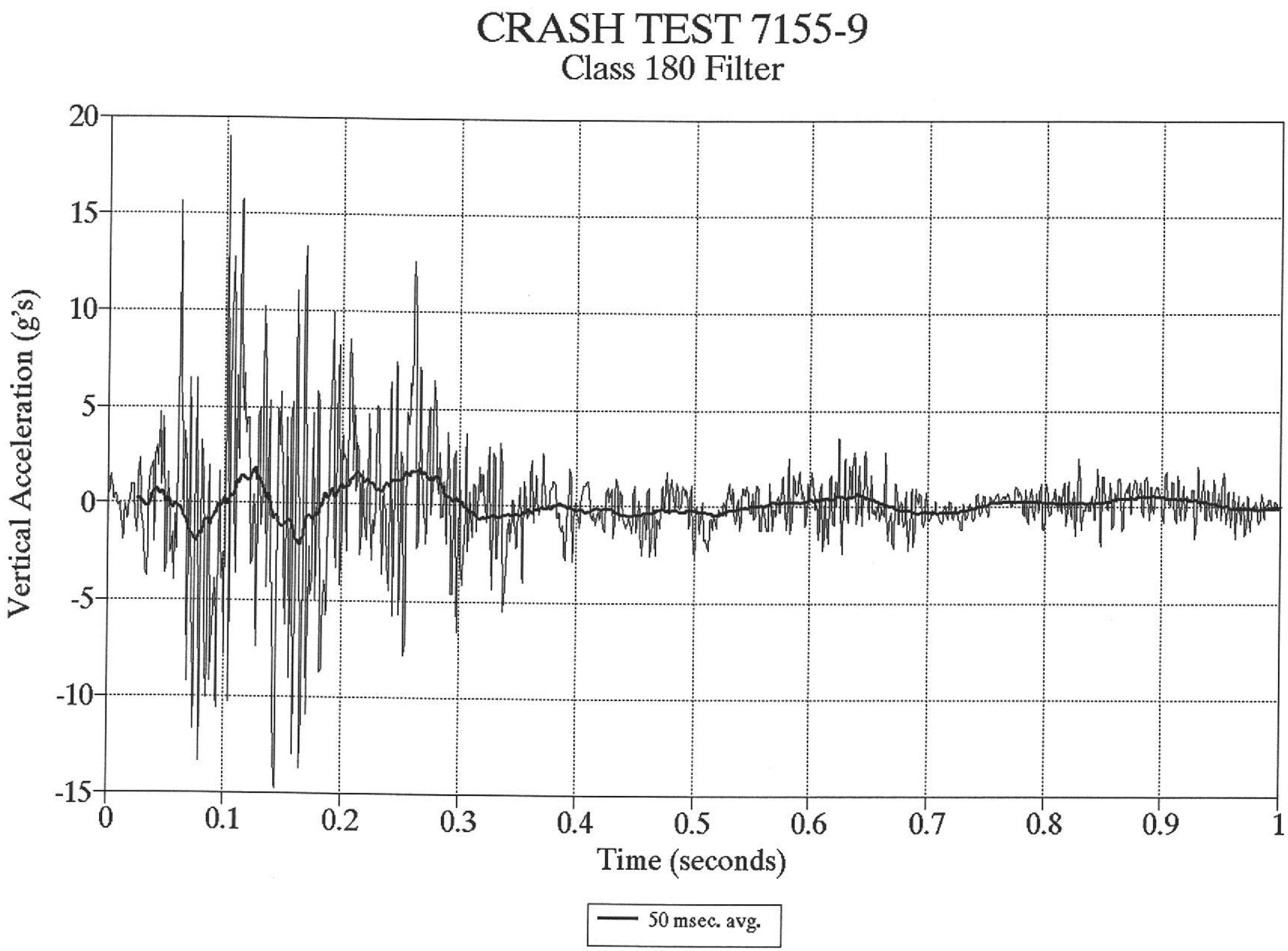


Figure 107. Vertical accelerometer trace (7155-9).

A summary of the test results and other information pertinent to this test are given in Figure 103. The maximum 0.050-second average accelerations experienced by the vehicle were -8.0 g in the longitudinal direction and -8.8 g in the lateral direction. Angular displacements of the vehicle are plotted in Figure 104 and the accelerometer traces are displayed in Figures 105 - 107. Occupant impact velocities were 24.3 feet per second (7.4 m/s) in the longitudinal direction and 20.7 feet per second (6.3 m/s) in the lateral direction. The highest 0.010-second occupant ridedown accelerations were -2.7 g and -10.2 g in the longitudinal and lateral directions respectively.

In summary, this test was judged to be a success. The installation successfully contained and redirected the impacting vehicle. The vehicle remained upright and stable during the initial test period and after leaving the installation. There was no debris or detached elements from the vehicle that would pose a hazard to other traffic, and there was only minor buckling of the floor board in the occupant compartment. Although not required for this test, the occupant impact criteria were all at or below the recommended limits of NCHRP Report 230. This tends to further indicate that, although the W-beam yielded around the end of the concrete parapet and the first steel blockout on the face of the parapet, the vehicle was redirected without experiencing any severe decelerations. The change in velocity of the vehicle was 18.5 miles per hour (29.7 km/h) is higher than the recommended limit of 15 miles per hour (24.1 km/h). However, the vehicle would not have encroached into adjacent traffic lanes and, therefore, would not have posed a hazard to other traffic. The exit angle of the vehicle (3.7 degrees) was considerably less than 60 percent of the impact angle as recommended by NCHRP Report 230.

An impact in the transition at the critical impact location with a heavy (4500 lb) vehicle travelling at 60 mph and 20 degrees to the rail is an extremely low probability event. In order for an accident in the transition to be of a serious nature, the impact conditions must meet or exceed all of these criteria. As mentioned above, less than 10% of all real-world, run-off-the-road accidents occur at an impact speed and angle greater than 60 mph and 20 degrees (7). The probability of an accident of this type occurring along the transition at its critical impact location is even further reduced. In addition, the majority of the existing vehicle population is small in relation to the 4500 lb passenger car, further reducing the likelihood of a severe accident. Therefore, based on the successful performance of this test, it can be concluded that the current transition system with curb does not pose a significant problem and there is no need to establish a retrofit program for the design. It is recommended that these installations be retrofit or replaced as they become damaged and need to be reconstructed.

CRASH TEST SUMMARY

The standard ADOT wood post transition with channel rubrail and no curb is shown in Figure 108. Both the parapet end and rubrail termination end were found to be in compliance with national test standards and no modifications to this design were necessary.

The standard ADOT steel post transition with channel rubrail and no curb is shown in Figure 109. This system was found to be in compliance NCHRP Report 230 test requirements when impacted near the end of the bridge rail. However, the rubrail termination at the upstream end of the steel post transition was found to be deficient. A subsequent test of a modified design in which the rubrail end was terminated behind a guardrail post was successful. Details of the modified rubrail terminal assembly, used in conjunction with the standard steel post transition with channel rubrail and no curb, is shown in Figure 110.

The standard ADOT steel post transition with a 6 inch curb, shown in Figure 111, was found to be substandard. However, a modified design, shown in Figure 112, was shown to be in compliance with NCHRP Report 230 test criteria. Although, as mentioned above, the current transition design with curb (see Figure 111) failed to meet national test standards, the system did successfully pass a subsequent test conducted at a lower impact severity. The implications of these results are discussed in the conclusions and recommendations below.

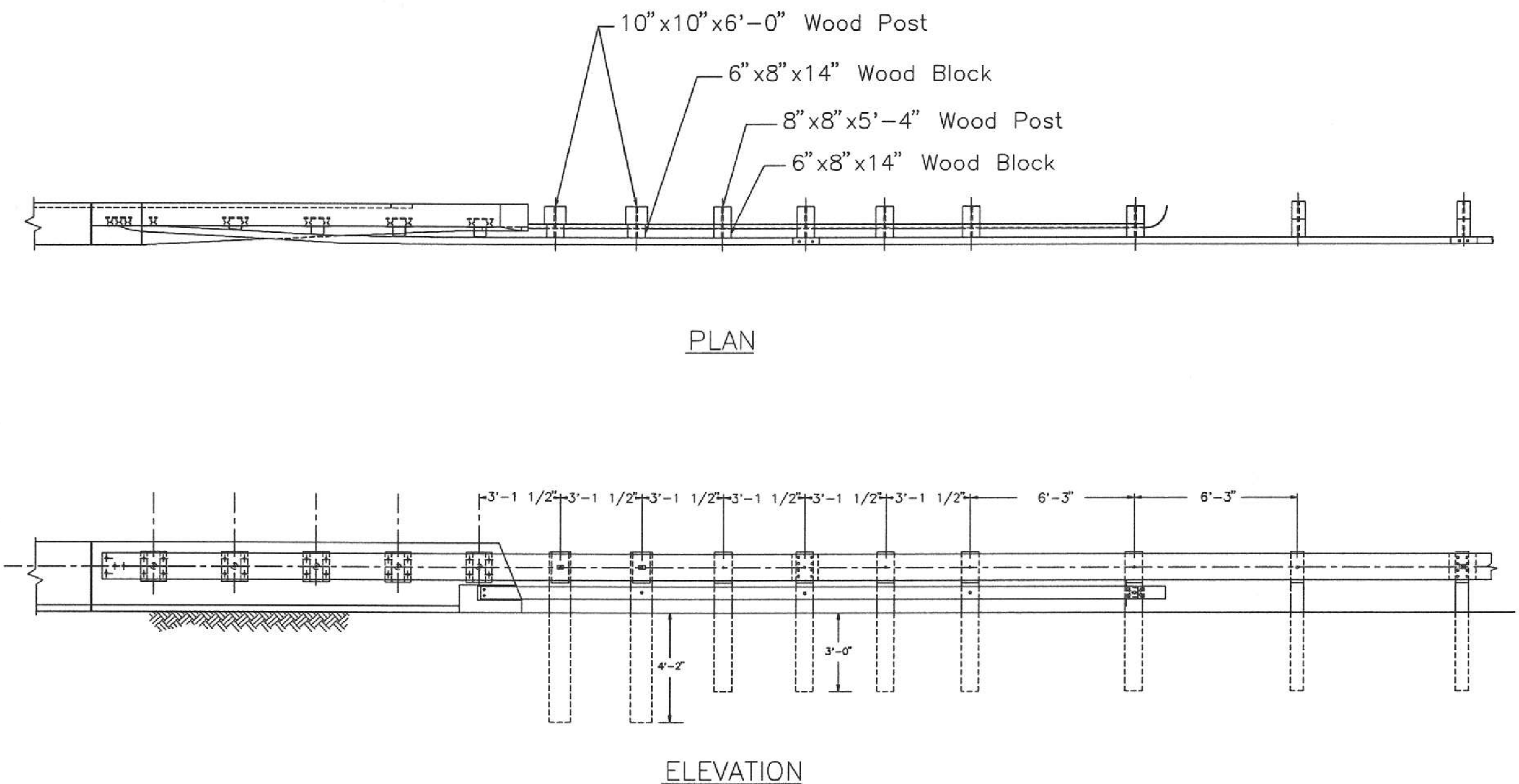


Figure 108. Standard ADOT wood post transition with rubrail, without curb

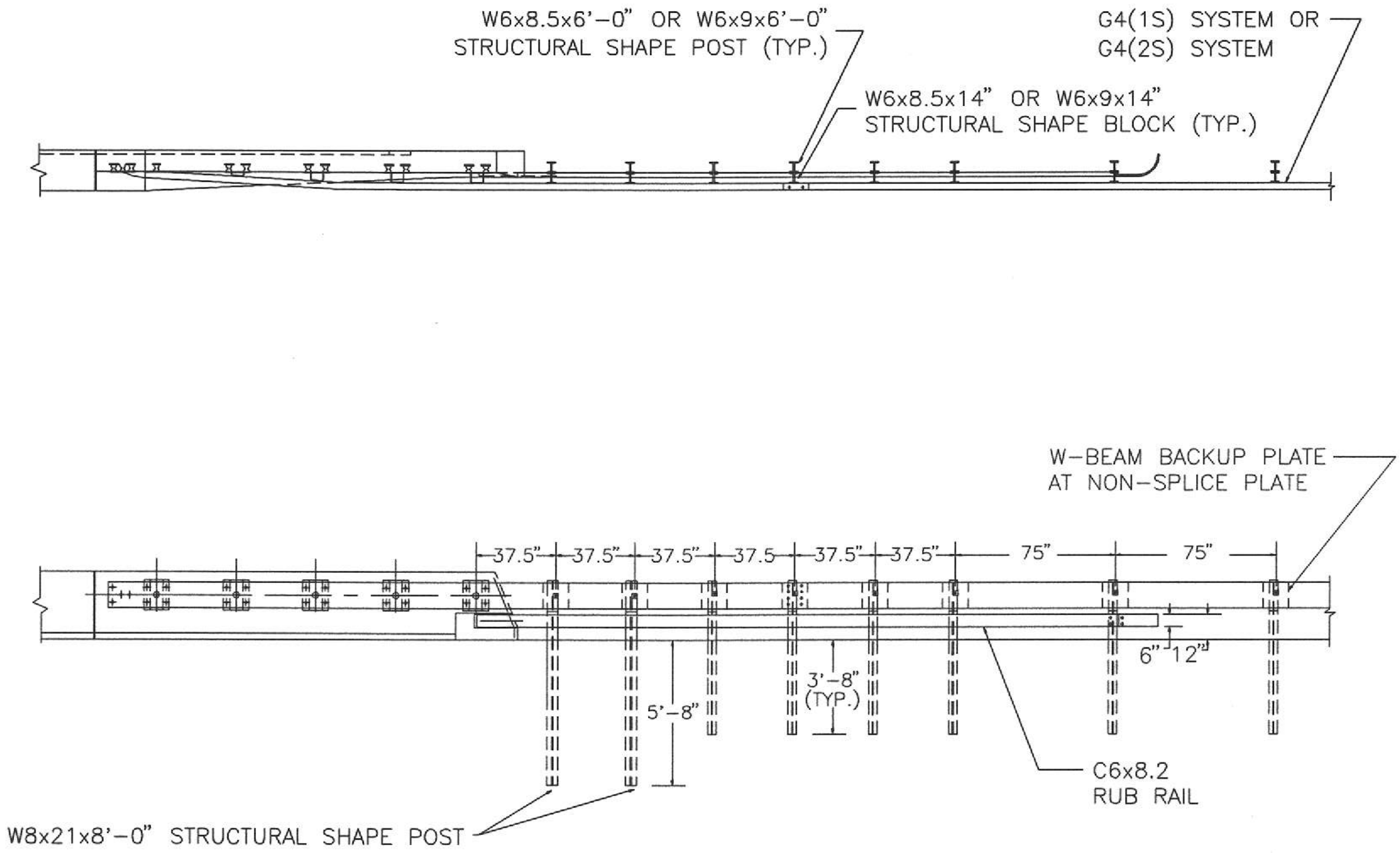


Figure 109. Standard ADOT steel post transition with rubrail, without curb

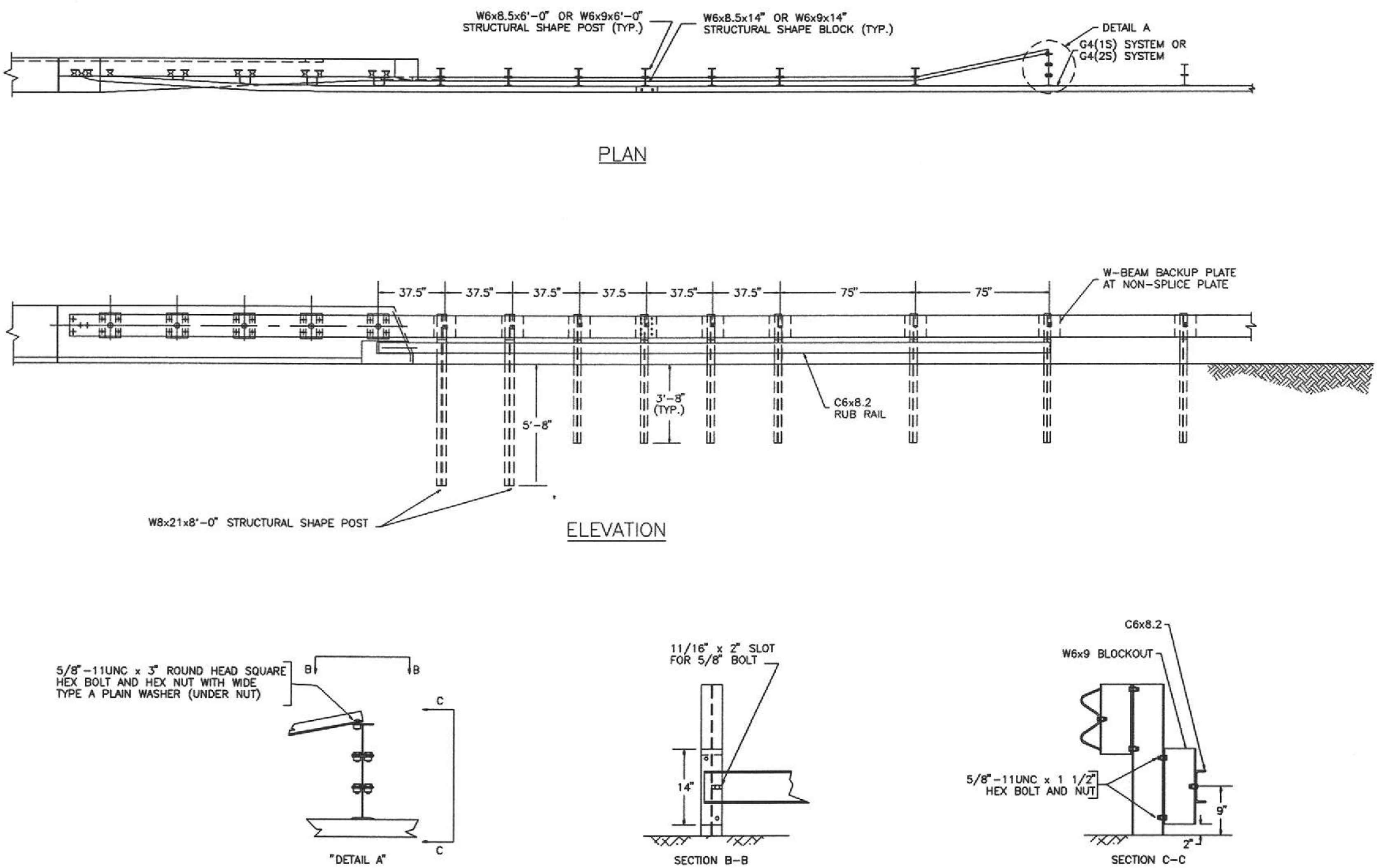


Figure 110. ADOT steel post transition with modified rubrail terminal assembly.

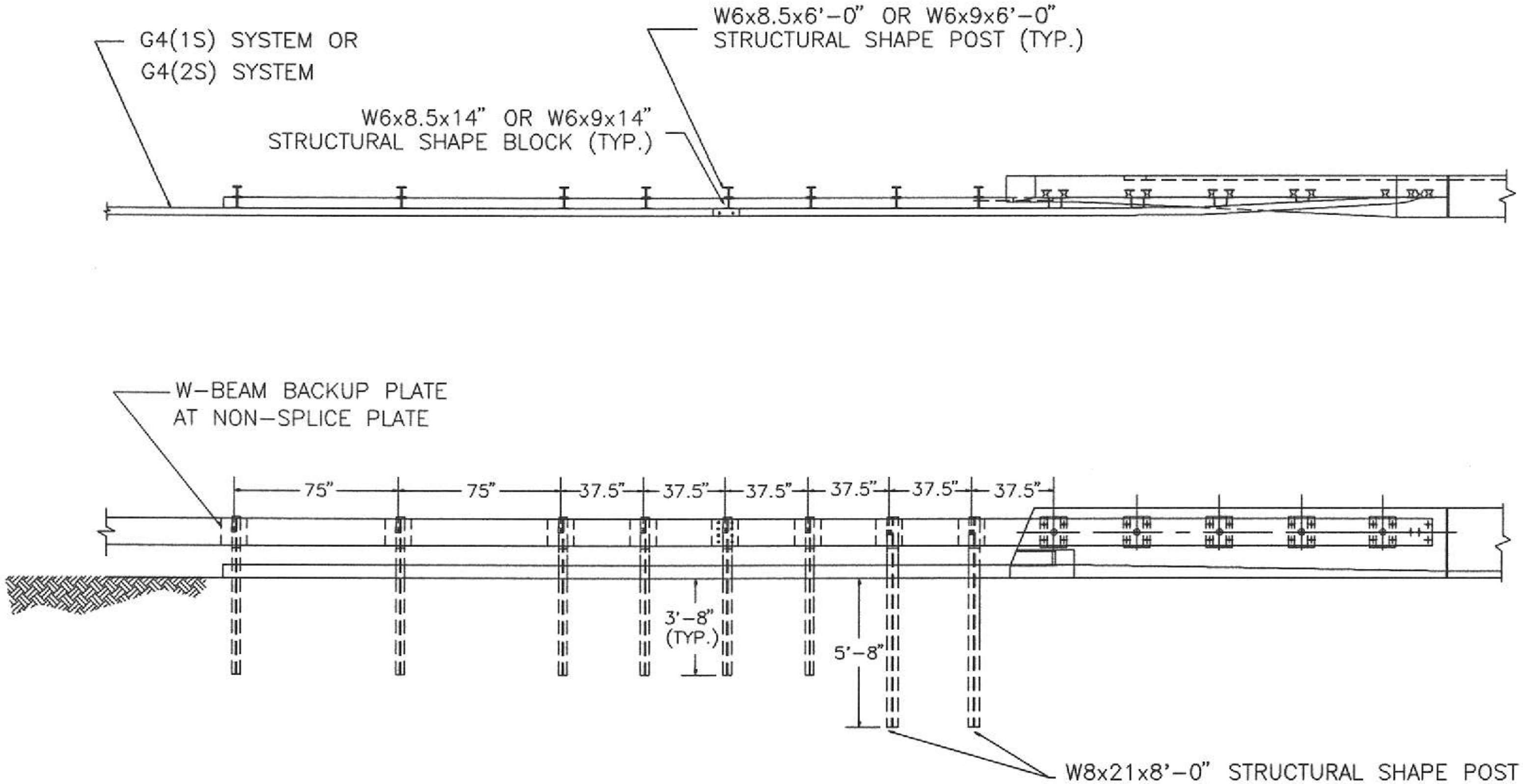


Figure 111. Standard ADOT steel post transition with 6 inch curb

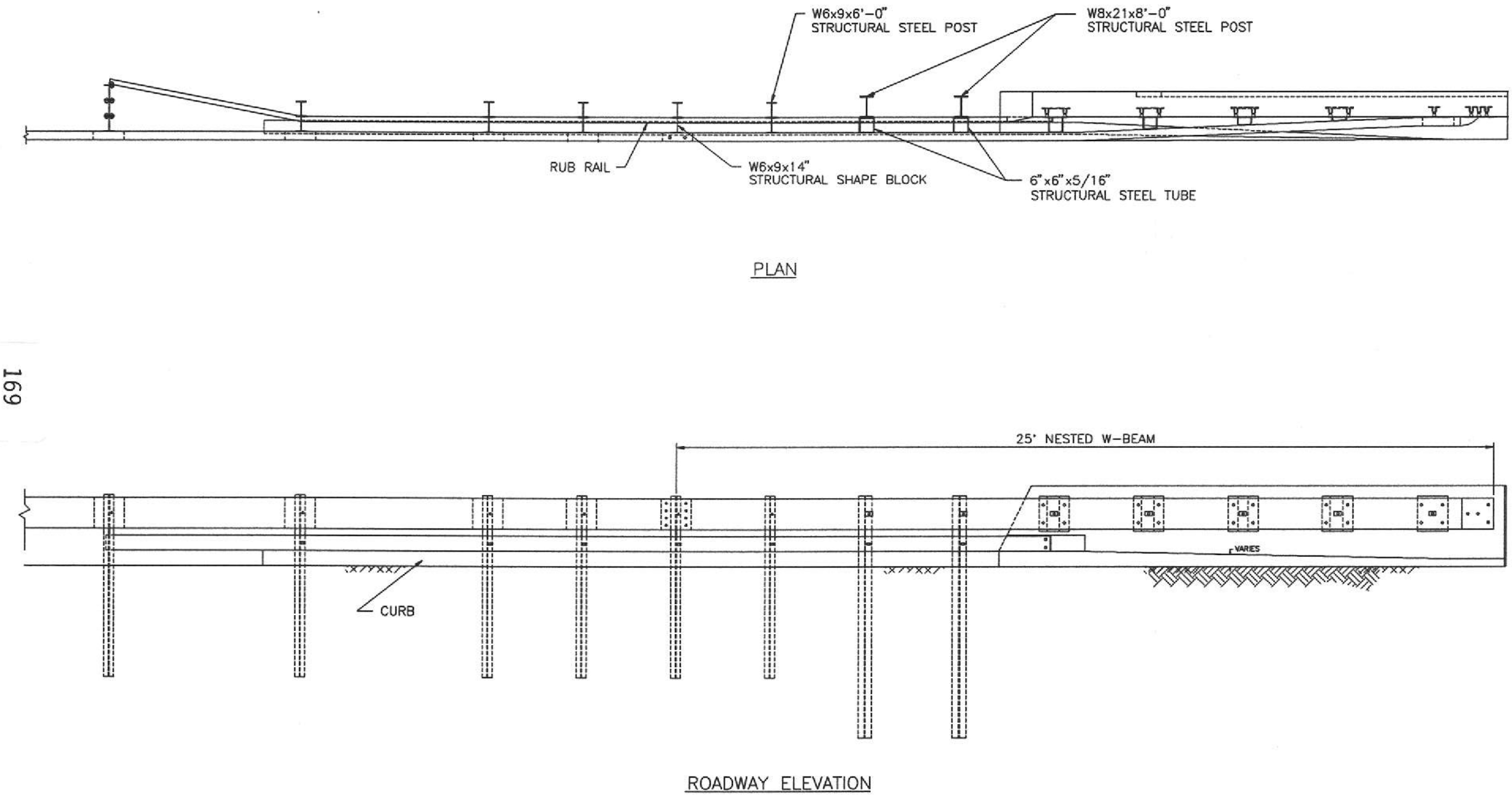


Figure 112. Modified ADOT steel post transition with 6 inch curb

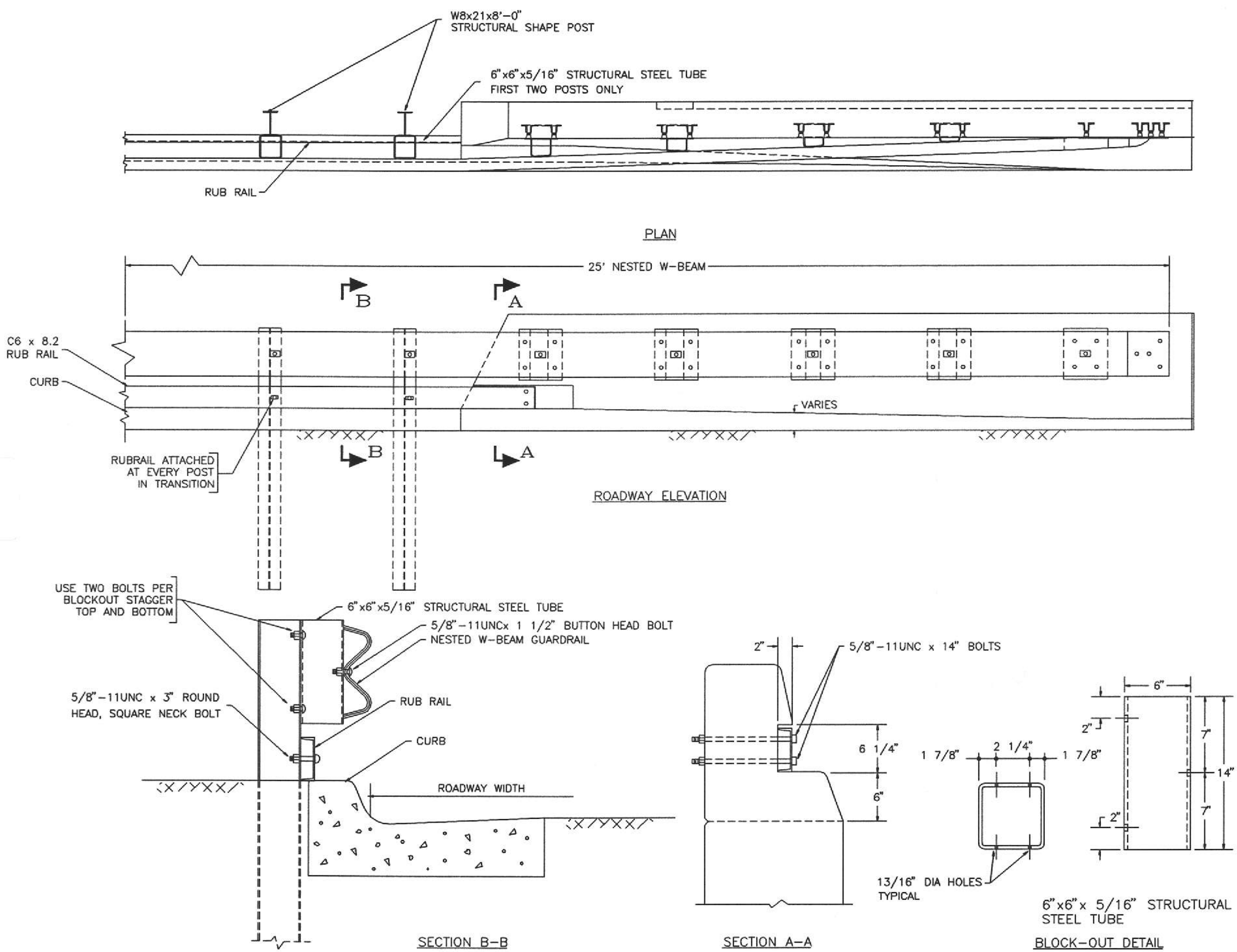


Figure 112. Modified ADOT steel post transition with 6 inch curb (continued)

CONCLUSIONS AND RECOMMENDATIONS

The standard ADOT bridge approach rails to rigid concrete bridge rails were evaluated through a combined program of computer simulation and full-scale crash testing. Crash test procedures, test instrumentation, documentation, and evaluation criteria were in accordance with guidelines presented in NCHRP Report 230. Based on full-scale testing and evaluation, the standard ADOT wood post transition with channel rubrail and no curb, shown in Figure 108, was found to be in compliance with national safety standards. This system incorporates a W-beam rail and C6x8.2 channel rubrail mounted on wood posts spaced at 3'-1 1/2". The first two posts adjacent to the concrete bridge rail were 10"x10"x6'-6" posts with an embedment of 50 inches. The other five posts in the transition region were 8"x8"x5'-4" and had a standard embedment of 36 inches. The W-beam was blocked out from these posts using 6"x8"x14" wood blocks. These wood blocks were oriented such that the 8 inch face was flush with the face of the posts, providing a blockout distance of 6 inches. Plate washers were used on all posts in the transition region and no W-beam backup plates were used. The rubrail was connected to every other post in the transition, and it was terminated on the traffic face of an 8"x8" wood post using a standard rubrail end terminal. The W-beam was blocked out from the face of the concrete parapet with fabricated steel blocks. It extended onto the concrete barrier a distance of 12'-6" and was terminated using a standard 10 ga. end shoe.

The standard ADOT steel post transition with channel rubrail and no curb (see Figure 109) also found to be in compliance NCHRP Report 230 test requirements when impacted near the end of the bridge rail. However, the upstream end of the steel post transition required modification to correct deficiencies identified during the testing program. The basic steel post design was similar to the wood post system except for the type of posts utilized. The steel system used two W8x21 posts with an embedment of 68 inches immediately adjacent to the concrete barrier. The other posts in the transition were standard W6x9 posts with an embedment of 44 inches. W6x9 steel blockouts were used to block out the W-beam rail 6 inches from the posts. W-beam backup plates were used at all non-splice post locations. The modification of the upstream end of the transition consisted of extending the channel rubrail one post spacing (6'-3") and bending it behind a guardrail post. To further minimize the potential for wheel snagging on the exposed end of the rubrail, an additional W6x9 spacer block was placed between the back side of the post and the rubrail. In addition, the rectangular plate washers were removed from all but the W8x21 posts adjacent to the bridge rail. This modified system (see Figure 110) was successfully tested in accordance with NCHRP guidelines.

It should be noted that although the test of the current upstream transition of the steel post system failed due to severe snagging on the rubrail end, the occupant risk criteria were all within the maximum acceptable limits established by NCHRP Report 230. Consequently, there does not appear to be any need to establish a retrofit program. However, procedures should be developed for maintenance crews to replace the rubrail with the modified design when barrier repair or reconstruction is performed.

A standard ADOT transition incorporating a 6 inch curb extending along the length of the transition, shown in Figure 111, was also evaluated and found to be substandard. Significant modifications were made to the design to bring it up to current national safety standards. The modified design incorporated a channel rubrail connected to every post in the transition. In addition, a 25 ft. section of nested W-beam rail was used in the transition and 6"x6"x5/16" tubular steel blockouts were used on the W8x21 steel posts adjacent to the concrete barrier. This modified design (see Figure 112) was shown to be in compliance with NCHRP Report 230 test standards.

Similar modifications are recommended for the wood post system with curb. The wood post system, being comparable in strength to the steel post system, requires a nested W-beam along the last 25 ft of rail and the addition of a C6x8.2 channel rubrail attached to every post in the transition. However, standard wood blockouts may be used in lieu of the tubular steel blockouts employed in the steel post system, since the wood blocks do not collapse during impact. Furthermore, as in the standard wood post transition with rubrail and no curb, a straight section of rubrail may be utilized rather than the flared design required for the steel post transition systems.

Although the current transition design with curb (see Figure 111) failed to meet NCHRP Report 230 test standards, the system did successfully pass a subsequent test conducted at 60 mph and 20 degrees. Based on the results of this test and the low probability of an impact of this severity occurring in the transition region at its critical impact location, it was concluded that there is no need to establish a comprehensive retrofit program for the transition designs with curbs. However, both the wood and steel post transitions with curb should be upgraded or replaced as the opportunity becomes available.

Review of the testing performed in this study reveals that the 6 inch curb did not contribute to the redirection of the test vehicles. It can therefore be concluded that although the current and modified designs were tested with ADOT's standard 6 inch curb, these systems will also work with curb heights less than 6 inches.

The concrete anchor inserts used in the ADOT transition designs to connect the W-beam to the fabricated steel blocks performed as designed with no signs of distress in any of the full-scale tests. These anchors are unquestionably adequate for use in any of the transition systems described above. An alternative to using the inserts is through bolted connections. Such connections have been tested in numerous transition studies with successful results. This alternative connection method provides an acceptable means of attaching the rubrail to the concrete parapet in the modified curb design.

It should be noted that the rectangular plate washers were removed from all but the first two posts adjacent to the concrete parapet in all of the modified systems (i.e. tests 7155-3 through 7). It is recommended that this practice be followed on all new construction and when upgrading existing transition systems.

APPENDIX -- TYPICAL BARRIER VII INPUT

```
1BARRIER VII  -  ANALYSIS OF AUTOMOBILE BARRIERS  -  U.C. BERKELEY,  1972

 ************************************************************************

0CONTROL INFORMATION

 NUMBER OF BARRIER NODES                =   113
 NUMBER OF CONTROL NODES                =    23
 NUMBER OF NODE GENERATIONS             =    12

 NUMBER OF INTERFACES                   =     3

 NUMBER OF MEMBERS                      =   146
 NUMBER OF MEMBER GENERATIONS           =    42
 NUMBER OF DIFFERENT MEMBER SERIES      =     4

 NUMBER  OF ADDITIONAL WEIGHT SETS      =     0

0BASIC TIME STEP (SEC)                  =    .00050
 LARGEST ALLOWABLE TIME STEP (SEC)      =    .00050
 MAXIMUM TIME SPECIFIED (SEC)           =    .12500
 MAX. NO. OF STEPS WITH NO CONTACT      =   200

 OVERSHOOT INDEX                        =     0
 ROTATIONAL DAMPING MULTIPLIER          =  1.00

 STEP-BY-STEP INTEGRATION TYPE          =     1



 OUTPUT FREQUENCIES

 AUTOMOBILE DATA      =  1
 BARRIER DEFLECTIONS  = 10
 BARRIER FORCES       = 10

 ENERGY BALANCE       =  0

 CONTACT INFORMATION  =  0

 PUNCHED JOINT DATA   =  0
 PUNCHED TRAJECTORY   =  0
1CONTROL NODE COORDINATES (IN)

 NODE        X-ORD          Y-ORD

    1          .00          48.00
    2        75.00          33.50
    3       150.00          21.50
    4       225.00          12.10
    5       300.00           5.40
    7       375.00           1.30
    9       450.00            .00
   13       525.00            .00
   31       750.00            .00
   32       750.00           6.00
   61       937.50            .00
   62       937.50           6.00
   77      1012.50            .00
```

78	1012.50	6.00
83	1028.00	.00
84	1028.00	6.00
85	1028.00	6.00
86	1039.00	6.00
87	1039.00	.50
88	1050.00	6.00
89	1050.00	1.00
112	1200.00	6.00
113	1237.50	6.00

COORDINATE GENERATION COMMANDS

FIRST NODE	LAST NODE	NO. OF NODES	NODE DIFF	DISTANCE
5	7	1	1	.00
7	9	1	1	.00
9	13	3	1	.00
13	31	17	1	.00
31	61	14	2	.00
32	62	14	2	.00
61	77	7	2	.00
62	78	7	2	.00
77	83	2	2	.00
78	84	2	2	.00
88	112	11	2	.00
89	112	11	2	.00

1NODE COORDINATES (IN)

NODE	X-ORD	Y-ORD
1	.00	48.00
2	75.00	33.50
3	150.00	21.50
4	225.00	12.10
5	300.00	5.40
6	337.50	3.35
7	375.00	1.30
8	412.50	.65
9	450.00	.00
10	468.75	.00
11	487.50	.00
12	506.25	.00
13	525.00	.00
14	537.50	.00
15	550.00	.00
16	562.50	.00
17	575.00	.00
18	587.50	.00
19	600.00	.00
20	612.50	.00
21	625.00	.00
22	637.50	.00
23	650.00	.00
24	662.50	.00
25	675.00	.00
26	687.50	.00
27	700.00	.00
28	712.50	.00
29	725.00	.00
30	737.50	.00
31	750.00	.00
32	750.00	6.00
33	762.50	.00
34	762.50	6.00

35	775.00	.00
36	775.00	6.00
37	787.50	.00
38	787.50	6.00
39	800.00	.00
40	800.00	6.00
41	812.50	.00
42	812.50	6.00
43	825.00	.00
44	825.00	6.00
45	837.50	.00
46	837.50	6.00
47	850.00	.00
48	850.00	6.00
49	862.50	.00
50	862.50	6.00
51	875.00	.00
52	875.00	6.00
53	887.50	.00
54	887.50	6.00
55	900.00	.00
56	900.00	6.00
57	912.50	.00
58	912.50	6.00
59	925.00	.00
60	925.00	6.00
61	937.50	.00
62	937.50	6.00
63	946.88	.00
64	946.88	6.00
65	956.25	.00
66	956.25	6.00
67	965.63	.00
68	965.63	6.00
69	975.00	.00
70	975.00	6.00
71	984.38	.00
72	984.38	6.00
73	993.75	.00
74	993.75	6.00
75	1003.13	.00
76	1003.13	6.00
77	1012.50	.00
78	1012.50	6.00
79	1017.67	.00
80	1017.67	6.00
81	1022.83	.00
82	1022.83	6.00
83	1028.00	.00
84	1028.00	6.00
85	1028.00	6.00
86	1039.00	6.00
87	1039.00	.50
88	1050.00	6.00
89	1050.00	1.00
90	1062.50	6.00
91	1062.50	1.42
92	1075.00	6.00
93	1075.00	1.83
94	1087.50	6.00
95	1087.50	2.25
96	1100.00	6.00
97	1100.00	2.67
98	1112.50	6.00
99	1112.50	3.08
100	1125.00	6.00
101	1125.00	3.50
102	1137.50	6.00

103	1137.50	3.92
104	1150.00	6.00
105	1150.00	4.33
106	1162.50	6.00
107	1162.50	4.75
108	1175.00	6.00
109	1175.00	5.17
110	1187.50	6.00
111	1187.50	5.58
112	1200.00	6.00
113	1237.50	6.00

1CONTACT INTERFACES

INTERFACE 1

NO. OF NODES = 38, FRICTION COEFF. = .300

LIST OF NODES

112	111	109	107	105	103	101	99	97	95
93	91	89	87	83	81	79	77	75	73
71	69	67	65	63	61	59	57	55	53
51	49	47	45	43	41	39	37		

INTERFACE 2

NO. OF NODES = 24, FRICTION COEFF. = .300

LIST OF NODES

84	82	80	78	76	74	72	70	68	66
64	62	60	58	56	54	52	50	48	46
44	42	40	38						

INTERFACE 3

NO. OF NODES = 16, FRICTION COEFF. = .300

LIST OF NODES

113	112	110	108	106	104	102	100	98	96
94	92	90	88	86	85				

1BEAM ELEMENTS, 100 SERIES

TYPE NUMBER	=	1	2	3	4	5	6	7	8
M. OF I. (IN4)	=	2.330E+00	2.330E+00	2.330E+00	2.330E+00	2.330E+00	2.330E+00	2.330E+00	6.930E-01
AREA (IN2)	=	1.990E+00	1.990E+00	1.990E+00	1.990E+00	1.990E+00	1.990E+00	1.990E+00	2.400E+00
LENGTH (IN)	=	7.500E+01	3.750E+01	1.875E+01	1.250E+01	9.375E+00	5.170E+00	1.100E+01	1.250E+01
YOUNGS MODULUS (KSI)	=	3.000E+04	3.000E+04	3.000E+04	3.000E+04	3.000E+04	3.000E+04	3.000E+04	3.000E+04
WEIGHT (LB/FT)	=	6.770E+00	6.770E+00	6.770E+00	6.770E+00	6.770E+00	6.770E+00	6.770E+00	8.200E+00
YIELD FORCE (K)	=	9.950E+01	9.950E+01	9.950E+01	9.950E+01	9.950E+01	9.950E+01	9.950E+01	8.640E+01
YIELD MOMENT (K.IN)	=	6.850E+01	6.850E+01	6.850E+01	6.850E+01	6.850E+01	6.850E+01	6.850E+01	1.770E+01
YIELD ACCURACY LIMIT	=	1.000E-01	1.000E-01	1.000E-01	1.000E-01	1.000E-01	1.000E-01	1.000E-01	1.000E-01

TYPE NUMBER	=	9	10	11	12
M. OF I. (IN4)	=	6.930E-01	6.930E-01	1.000E+04	1.000E+04
AREA (IN2)	=	2.400E+00	2.400E+00	1.000E+02	1.000E+02
LENGTH (IN)	=	9.375E+00	5.170E+00	1.250E+01	3.750E+01
YOUNGS MODULUS (KSI)	=	3.000E+04	3.000E+04	3.000E+05	3.000E+05
WEIGHT (LB/FT)	=	8.200E+00	8.200E+00	1.000E+02	1.000E+02
YIELD FORCE (K)	=	8.640E+01	8.640E+01	1.000E+04	1.000E+04
YIELD MOMENT (K.IN)	=	1.770E+01	1.770E+01	1.000E+04	1.000E+04
YIELD ACCURACY LIMIT	=	1.000E-01	1.000E-01	1.000E-01	1.000E-01

1POSTS, 300 SERIES

TYPE NUMBER	=	1	2	3	4	5	6	7
HEIGHT OF NODE I (IN)	=	2.100E+01	2.100E+01	2.100E+01	2.100E+01	2.100E+01	9.000E+00	2.100E+01
HEIGHT OF NODE J (IN)	=	.000E+00	.000E+00	9.000E+00	9.000E+00	.000E+00	.000E+00	.000E+00
A AXIS STIFFNESS (K/IN)	=	1.500E+02	1.150E+00	1.150E+00	2.340E+00	2.340E+00	1.200E+02	1.000E+04
B AXIS STIFFNESS (K/IN)	=	5.000E+01	2.460E+00	2.460E+00	2.440E+01	2.440E+01	1.000E+04	1.000E+04
EFFECTIVE WEIGHT (LB)	=	3.000E+01	3.000E+01	3.000E+01	8.000E+01	8.000E+01	1.000E+01	3.000E+02
B AXIS YIELD MOMENT (K.IN)	=	1.000E+04	9.660E+01	9.660E+01	1.000E+02	1.000E+02	1.000E+04	1.000E+04
A AXIS YIELD MOMENT (K.IN)	=	1.000E+04	2.310E+02	2.310E+02	1.034E+03	1.034E+03	1.000E+04	1.000E+04
YIELD ACCURACY LIMIT	=	1.000E-01	1.000E-01	1.000E-01	1.000E-01	1.000E-01	1.000E-01	1.000E-01
A SHEAR AT FAILURE (K)	=	1.000E+04	1.000E+04	1.000E+04	1.000E+04	1.000E+04	1.000E+04	1.000E+04
B SHEAR AT FAILURE (K)	=	1.000E+04	1.000E+04	1.000E+04	1.000E+04	1.000E+04	1.000E+04	1.000E+04
A DEFLN AT FAILURE (IN)	=	1.000E+04	1.600E+01	1.600E+01	2.000E+01	2.000E+01	1.000E+04	1.000E+04
B DEFLN AT FAILURE (IN)	=	1.000E+04	1.600E+01	1.600E+01	2.000E+01	2.000E+01	1.000E+04	1.000E+04

1 SPRINGS, 400 SERIES

TYPE NUMBER	=	1	2	3	4	5	6
BASIC STIFFNESS (K/IN)	=	1.000E-02	1.000E-02	1.000E-02	1.000E-02	1.000E-02	1.000E-02
COMP BOTTOMING DIST (IN)	=	6.000E+00	5.500E+00	4.580E+00	4.170E+00	3.330E+00	2.920E+00
BOTTOMING STIFF, COMP (K/IN)	=	1.000E+02	1.000E+02	1.000E+02	1.000E+02	1.000E+02	1.000E+02
TENS BOTTOMING DIST (IN)	=	1.000E+02	1.000E+02	1.000E+02	1.000E+02	1.000E+02	1.000E+02
BOTTOMING STIFF, TENS (K/IN)	=	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00
BOTTOMING ACCURACY LIMIT	=	2.000E-02	2.000E-02	2.000E-02	2.000E-02	2.000E-02	2.000E-02
WEIGHT (LB)	=	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00	.000E+00

1PINNED LINKS, 700 SERIES

TYPE NUMBER	=	1	2	3	4
AREA (IN2)	=	1.000E+00	1.000E+00	1.000E+00	1.000E+00
LENGTH (IN)	=	5.000E+00	3.750E+00	2.500E+00	1.250E+00
YOUNGS MODULUS (KSI)	=	3.000E+04	3.000E+04	3.000E+04	3.000E+04
WEIGHT (LB/FT)	=	8.000E+00	6.000E+00	4.000E+00	2.000E+00
YIELD FORCE (K)	=	1.000E+04	1.000E+04	1.000E+04	1.000E+04
BUCKLING FORCE	=	1.000E+04	1.000E+04	1.000E+04	1.000E+04
YIELD ACCURACY LIMIT	=	1.000E-01	1.000E-01	1.000E-01	1.000E-01

1MEMBER GENERATION COMMANDS

FIRST MEMBER	NODE I	NODE J	LAST MEMBER	NODE DIFF	TYPE NO.	PRESTRESS DATA 1	2	3	4	5
1	1	2	4	1	101	.000	.000	.000	.000	.000
5	5	6	8	1	102	.000	.000	.000	.000	.000
9	9	10	12	1	103	.000	.000	.000	.000	.000
13	13	14	30	1	104	.000	.000	.000	.000	.000
31	31	33	45	2	104	.000	.000	.000	.000	.000
46	61	63	53	2	105	.000	.000	.000	.000	.000
54	77	79	56	2	106	.000	.000	.000	.000	.000
57	83	87	0	0	107	.000	.000	.000	.000	.000
58	87	89	0	0	107	.000	.000	.000	.000	.000
59	89	91	69	2	104	.000	.000	.000	.000	.000
70	111	112	0	0	104	.000	.000	.000	.000	.000
71	32	34	85	2	108	.000	.000	.000	.000	.000
86	62	64	93	2	109	.000	.000	.000	.000	.000
94	78	80	96	2	110	.000	.000	.000	.000	.000
97	85	86	0	0	111	.000	.000	.000	.000	.000
98	86	88	0	0	111	.000	.000	.000	.000	.000
99	88	90	110	2	111	.000	.000	.000	.000	.000
111	112	113	0	0	112	.000	.000	.000	.000	.000
112	1	0	0	0	301	.000	.000	.000	.000	.000
113	2	0	116	1	302	.000	.000	.000	.000	.000
117	7	0	118	2	302	.000	.000	.000	.000	.000
119	13	0	121	6	302	.000	.000	.000	.000	.000
122	31	32	123	12	303	.000	.000	.000	.000	.000
124	49	0	0	0	302	.000	.000	.000	.000	.000
125	55	56	0	0	303	.000	.000	.000	.000	.000

126	61	0	0	0	302	.000	.000	.000	.000	.000
127	69	70	0	0	304	.000	.000	.000	.000	.000
128	77	0	0	0	305	.000	.000	.000	.000	.000
129	85	0	0	0	307	.000	.000	.000	.000	.000
130	88	0	134	6	307	.000	.000	.000	.000	.000
135	113	0	0	0	307	.000	.000	.000	.000	.000
136	88	89	0	0	701	.000	.000	.000	.000	.000
137	94	95	0	0	702	.000	.000	.000	.000	.000
138	100	101	0	0	703	.000	.000	.000	.000	.000
139	106	107	0	0	704	.000	.000	.000	.000	.000
140	83	85	0	0	401	.000	.000	.000	.000	.000
141	86	87	0	0	402	.000	.000	.000	.000	.000
142	90	91	0	0	403	.000	.000	.000	.000	.000
143	92	93	0	0	404	.000	.000	.000	.000	.000
144	96	97	0	0	405	.000	.000	.000	.000	.000
145	98	99	0	0	406	.000	.000	.000	.000	.000
146	84	0	0	0	306	.000	.000	.000	.000	.000

1COMPLETE MEMBER DATA

BEAMS, 100 SERIES

MEMBER	NODE I	NODE J	TYPE	FORCE	I-MOMENT	J-MOMENT
1	1	2	101	.00	.00	.00
2	2	3	101	.00	.00	.00
3	3	4	101	.00	.00	.00
4	4	5	101	.00	.00	.00
5	5	6	102	.00	.00	.00
6	6	7	102	.00	.00	.00
7	7	8	102	.00	.00	.00
8	8	9	102	.00	.00	.00
9	9	10	103	.00	.00	.00
10	10	11	103	.00	.00	.00
11	11	12	103	.00	.00	.00
12	12	13	103	.00	.00	.00
13	13	14	104	.00	.00	.00
14	14	15	104	.00	.00	.00
15	15	16	104	.00	.00	.00
16	16	17	104	.00	.00	.00
17	17	18	104	.00	.00	.00
18	18	19	104	.00	.00	.00
19	19	20	104	.00	.00	.00
20	20	21	104	.00	.00	.00
21	21	22	104	.00	.00	.00
22	22	23	104	.00	.00	.00
23	23	24	104	.00	.00	.00
24	24	25	104	.00	.00	.00
25	25	26	104	.00	.00	.00
26	26	27	104	.00	.00	.00
27	27	28	104	.00	.00	.00
28	28	29	104	.00	.00	.00
29	29	30	104	.00	.00	.00
30	30	31	104	.00	.00	.00
31	31	33	104	.00	.00	.00
32	33	35	104	.00	.00	.00
33	35	37	104	.00	.00	.00
34	37	39	104	.00	.00	.00
35	39	41	104	.00	.00	.00
36	41	43	104	.00	.00	.00
37	43	45	104	.00	.00	.00
38	45	47	104	.00	.00	.00
39	47	49	104	.00	.00	.00
40	49	51	104	.00	.00	.00
41	51	53	104	.00	.00	.00
42	53	55	104	.00	.00	.00
43	55	57	104	.00	.00	.00
44	57	59	104	.00	.00	.00

45	59	61	104	.00	.00	.00
46	61	63	105	.00	.00	.00
47	63	65	105	.00	.00	.00
48	65	67	105	.00	.00	.00
49	67	69	105	.00	.00	.00
50	69	71	105	.00	.00	.00
51	71	73	105	.00	.00	.00
52	73	75	105	.00	.00	.00
53	75	77	105	.00	.00	.00
54	77	79	106	.00	.00	.00
55	79	81	106	.00	.00	.00
56	81	83	106	.00	.00	.00
57	83	87	107	.00	.00	.00
58	87	89	107	.00	.00	.00
59	89	91	104	.00	.00	.00
60	91	93	104	.00	.00	.00
61	93	95	104	.00	.00	.00
62	95	97	104	.00	.00	.00
63	97	99	104	.00	.00	.00
64	99	101	104	.00	.00	.00
65	101	103	104	.00	.00	.00
66	103	105	104	.00	.00	.00
67	105	107	104	.00	.00	.00
68	107	109	104	.00	.00	.00
69	109	111	104	.00	.00	.00
70	111	112	104	.00	.00	.00
71	32	34	108	.00	.00	.00
72	34	36	108	.00	.00	.00
73	36	38	108	.00	.00	.00
74	38	40	108	.00	.00	.00
75	40	42	108	.00	.00	.00
76	42	44	108	.00	.00	.00
77	44	46	108	.00	.00	.00
78	46	48	108	.00	.00	.00
79	48	50	108	.00	.00	.00
80	50	52	108	.00	.00	.00
81	52	54	108	.00	.00	.00
82	54	56	108	.00	.00	.00
83	56	58	108	.00	.00	.00
84	58	60	108	.00	.00	.00
85	60	62	108	.00	.00	.00
86	62	64	109	.00	.00	.00
87	64	66	109	.00	.00	.00
88	66	68	109	.00	.00	.00
89	68	70	109	.00	.00	.00
90	70	72	109	.00	.00	.00
91	72	74	109	.00	.00	.00
92	74	76	109	.00	.00	.00
93	76	78	109	.00	.00	.00
94	78	80	110	.00	.00	.00
95	80	82	110	.00	.00	.00
96	82	84	110	.00	.00	.00
97	85	86	111	.00	.00	.00
98	86	88	111	.00	.00	.00
99	88	90	111	.00	.00	.00
100	90	92	111	.00	.00	.00
101	92	94	111	.00	.00	.00
102	94	96	111	.00	.00	.00
103	96	98	111	.00	.00	.00
104	98	100	111	.00	.00	.00
105	100	102	111	.00	.00	.00
106	102	104	111	.00	.00	.00
107	104	106	111	.00	.00	.00
108	106	108	111	.00	.00	.00
109	108	110	111	.00	.00	.00
110	110	112	111	.00	.00	.00
111	112	113	112	.00	.00	.00

POSTS, 300 SERIES

MEMBER	NODE I	NODE J	TYPE	A-SHEAR	B-SHEAR	B-MOMENT	A-MOMENT	ANGLE
112	1	0	301	.00	.00	.00	.00	.00
113	2	0	302	.00	.00	.00	.00	.00
114	3	0	302	.00	.00	.00	.00	.00
115	4	0	302	.00	.00	.00	.00	.00
116	5	0	302	.00	.00	.00	.00	.00
117	7	0	302	.00	.00	.00	.00	.00
118	9	0	302	.00	.00	.00	.00	.00
119	13	0	302	.00	.00	.00	.00	.00
120	19	0	302	.00	.00	.00	.00	.00
121	25	0	302	.00	.00	.00	.00	.00
122	31	32	303	.00	.00	.00	.00	.00
123	43	44	303	.00	.00	.00	.00	.00
124	49	0	302	.00	.00	.00	.00	.00
125	55	56	303	.00	.00	.00	.00	.00
126	61	0	302	.00	.00	.00	.00	.00
127	69	70	304	.00	.00	.00	.00	.00
128	77	0	305	.00	.00	.00	.00	.00
129	85	0	307	.00	.00	.00	.00	.00
130	88	0	307	.00	.00	.00	.00	.00
131	94	0	307	.00	.00	.00	.00	.00
132	100	0	307	.00	.00	.00	.00	.00
133	106	0	307	.00	.00	.00	.00	.00
134	112	0	307	.00	.00	.00	.00	.00
135	113	0	307	.00	.00	.00	.00	.00

PINNED LINKS, 700 SERIES

MEMBER	NODE I	NODE J	TYPE	FORCE	SLACK
136	88	89	701	.00	.000
137	94	95	702	.00	.000
138	100	101	703	.00	.000
139	106	107	704	.00	.000

SPRINGS, 400 SERIES

MEMBER	NODE I	NODE J	TYPE	FORCE
140	83	85	401	.00
141	86	87	402	.00
142	90	91	403	.00
143	92	93	404	.00
144	96	97	405	.00
145	98	99	406	.00

POSTS, 300 SERIES

MEMBER	NODE I	NODE J	TYPE	A-SHEAR	B-SHEAR	B-MOMENT	A-MOMENT	ANGLE
146	84	0	306	.00	.00	.00	.00	.00

STIFFNESS MATRIX STORAGE

REQUIRED = 5085
ALLOCATED = 6000
1AUTOMOBILE PROPERTIES

WEIGHT (LB)	=	4500.0
MOMENT OF INERTIA (LB.IN.SEC2)	=	47000.0
NO. OF CONTACT POINTS	=	15
NO. OF UNIT STIFFNESSES	=	1
NO. OF WHEELS	=	4
BRAKE CODE (1=ON, 0=OFF)	=	0
NO. OF OUTPUT POINTS	=	3

UNIT STIFFNESSES (K/IN/IN)

NO.	BEFORE BOTTOMING	AFTER BOTTOMING	UNLOADING	BOTTOMING DISTANCE
1	.040	.250	7.500	12.00

CONTACT POINT DATA

POINT	R COORD	S COORD	STIFFNESS NO.	TRIBUTARY LENGTH	INTERFACE CONTACTS			
1	-122.00	40.00	1	31.00	1	1	1	0
2	-91.00	40.00	1	31.00	1	1	1	0
3	-60.00	40.00	1	31.00	1	1	1	0
4	-30.00	40.00	1	30.00	1	1	1	0
5	.00	40.00	1	27.00	1	1	1	0
6	-67.00	31.00	1	1.00	0	0	0	0
7	23.00	40.00	1	23.00	1	1	1	0
8	46.00	40.00	1	23.00	1	1	1	0
9	69.00	40.00	1	23.00	1	1	1	0
10	93.00	40.00	1	22.00	1	1	1	0
11	93.00	20.00	1	20.00	1	1	1	0
12	93.00	.00	1	20.00	1	1	1	0
13	57.00	31.00	1	1.00	0	0	0	0
14	93.00	-40.00	1	1.00	0	0	0	0
15	-122.00	-40.00	1	1.00	0	0	0	0

OWHEEL COORDINATES (IN), STEER ANGLES (DEG), AND DRAG FORCES (LB)

POINT	R-ORD	S-ORD	STEER ANGLE	DRAG FORCE
1	57.00	31.00	.00	608.00
2	57.00	-31.00	.00	608.00
3	-67.00	31.00	.00	517.00
4	-67.00	-31.00	.00	517.00

OOUTPUT POINT COORDINATES (IN)

POINT	R-ORD	S-ORD
1	.00	.00
2	93.00	.00
3	57.00	31.00

1INITIAL POSITION AND VELOCITIES OF AUTO

SPECIFIED BOUNDARY POINT	=	10
X ORDINATE OF POINT	=	944.00
Y ORDINATE OF POINT	=	.00

ANGLE FROM X AXIS TO R AXIS (DEG)	=	25.00
VELOCITY IN R DIRECTION (M.P.H)	=	60.00
VELOCITY IN S DIRECTION (M.P.H)	=	.00
ANGULAR VELOCITY (RAD/SEC)	=	.000
MINIMUM RESULTANT VELOCITY (M.P.H)	=	.00
TRANSLATIONAL KINETIC ENERGY (K.IN)	=	6500.15
ROTATIONAL KINETIC ENERGY (K.IN)	=	.00
TOTAL INITIAL KINETIC ENERGY (K.IN)	=	6500.15

AUTO TRAJECTORY RESULTS

PT	X-ORD	Y-ORD	ANGLE	X-VEL	Y-VEL	R-VEL	S-VEL	T-VEL	ANGLE	X-ACC	Y-ACC	R-ACC	S-ACC	T-ACC	ANGLE
TIME = .0000 SECS															
1	876.6	-75.6	25.0	54.38	25.36	60.00	.00	60.00	25.0	.00	.00	.00	.00	.00	.0
2	960.9	-36.3	25.0	54.38	25.36	60.00	.00	60.00	25.0	.00	.00	.00	.00	.00	.0
3	915.2	-23.4	25.0	54.38	25.36	60.00	.00	60.00	25.0	.00	.00	.00	.00	.00	.0

REFERENCES

1. Bronstad, M. E., Calcote, M. H., Ray, M. H., and Mayer, J. B., "Guardrail-Bridge Rail Transition Designs -- Volume 1, Research Report," Report No. FHWA/RD-86/178, Federal Highway Administration, Washington, D. C., April 1988.

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

3. Powell, Graham H., "BARRIER VII: A Computer Program for Evaluation of Automobile Barrier Systems," Final Report FHWA No. CPR-11-6059, Federal Highway Administration, Washington, D. C., April 1973.

4. Bligh, R. P., Sicking, D. L., and Ross, H. E., Jr., "Development of a Strong Beam Guardrail to Bridge Rail Transition," Transportation Research Record 1198, Transportation Research Board, Washington, D. C., 1988.

5. Mak, K. K., Bligh, R. P., and Pope, D. H., "Wyoming Tube-Type Bridge Rail and Box-Beam Guardrail Transition," Transportation Research Record 1258, Transportation Research Board, Washington, D. C., 1990.

6. Tuan, C. Y., Post, E. R., Ataullah, S., and Brewer, J. O., "Development of Kansas Guardrail to Bridgerail Transition Designs Using Barrier VII," Transportation Research Record 1233, Transportation Research Board, Washington, D. C., 1989.

7. Mak, K. K., Sicking, D. L., and Ross, H. E., Jr., "Real-World Impact Conditions for Run-off-the-Road Accidents," Transportation Research Record 1065, Transportation Research Board, Washington, D. C., 1986.