Guardrail Testing Program II
Final Report

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16. Abstract

The Coordinated Federal Lands Highways Technology Improvement Program (CTIP) was developed with the purpose of serving the immediate needs of those who design and construct Federal Lands Highways. A wide assortment of guardrails, bridge rails, and transitions are being used on roads under the jurisdiction of the National Park Service and other Federal agencies. These guardrails, bridge rails, and transitions are intended to blend in with the roadside to preserve the visual integrity of the parks and parkways. However, many of them have never been crash tested. A testing program was developed to ensure that the safety hardware used in these areas is safe for the traveling public.

This report describes the safety evaluations which were included in the second Federal Highway Administration (FHWA) testing program - Guardrail Testing Program II. Systems tested under this program include the Steel-Backed Wood Rail to Bridge Rail Transition, the Foothills Parkway Memorial Bridge Rail, the Steel-Backed Log Guardrail, the Natchez Trace Parkway Bridge Rail, and the George Washington Memorial Parkway Bridge Rail.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
NOTE: Volumes greater than 1000 l shall be shown in m³.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m²	cd/m²
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	ac
ha	hectares	2.47	acres	mi²
km²	square kilometers	0.386	square miles	
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised August 1992)

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1. INTRODUCTION

BACKGROUND

The Coordinated Federal Lands Highways Technology Improvement Program (CTIP) was developed to serve the immediate needs of those who design and construct Federal Lands Highways, including Indian Reservation roads, National Park roads and parkways, and forest highways. A wide assortment of guardrails, bridge rails, and transitions are being used on roads under the jurisdiction of the National Park Service and other Federal agencies. These guardrails, bridge rails, and transitions are intended to blend in with the roadside to preserve the visual integrity of the parks and parkways. However, many of them have never been crash tested.(1,2) A testing program was developed to ensure that the safety hardware used in these areas are safe for the traveling public. The research reported herein describes the performance evaluations of the five systems tested under the second Federal Highway Administration (FHWA) testing program -- Guardrail Testing Program II. Systems tested under this program include the Steel-Backed Wood Rail to Bridge Rail Transition, the Foothills Parkway Bridge Rail, the Steel-Backed Log Guardrail, the Natchez Trace Bridge Rail, and the George Washington Memorial Parkway Steel Bridge Rail.

OBJECTIVE

The objective of this research project was to evaluate the safety performance of the five systems mentioned above. Any design modifications required throughout the course of these evaluations were made by engineers with FHWA's Eastern Federal Lands Highway Division.

2. TEST CONDITIONS

TEST FACILITY

The Midwest Roadside Safety Facility's (MwRSF) outdoor test site is located at the Lincoln Air-Park on the northwest end of the Lincoln Municipal Airport. The test facility is approximately 5 mi (8 km) northwest of the University of Nebraska-Lincoln. The site is surrounded and protected by an 8-ft (2.4-m) high chain-link security fence.

VEHICLE TOW AND GUIDANCE SYSTEM

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle are one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the appurtenance. A fifth wheel, built by Nucleus Corporation, was used in conjunction with a digital speedometer to increase the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch was used to steer the test vehicle.(3) The guide-flag, attached to the left-front wheel and the guide cable, was sheared off before impact. The ⅜-in (95-mm) diameter guide cable was tensioned to approximately 3,000 lb (13.3 kN) and supported laterally and vertically every 100 ft (30.5 m) by hinged stanchions.

TEST VEHICLE

All of the vehicles used in this testing program were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guidance cable. The details of the vehicles used for each test are presented in the individual test descriptions and appendix B.

Black and white checkered targets were placed on the test vehicle for use in the high-speed film analysis. Two targets were located on the center of gravity, one on the top and one on the driver's side of the test vehicle. Additional targets, visible from all external high-speed cameras, were located for reference. Two 5B flash bulbs, fired by a pressure tape switch on the front bumper, were mounted on the roof of each vehicle to establish the time of impact on the high-speed film.

DATA ACQUISITION SYSTEMS

Accelerometers

For the earlier tests in this program, two triaxial piezoresistive accelerometer systems with a range of ±200 g's (Endevco Model 7264) were used to measure vehicle accelerations. The accelerometers were rigidly attached to an aluminum block mounted near the vehicle's center of gravity. Accelerometer signals were received and conditioned by an onboard Series 300 Multiplexed FM Data System built by Metraplex Corporation. The multiplexed signal was then transmitted to a Honeywell 101 Analog Tape Recorder. Computer software EGAA and DADiSP were used to digitize, analyze, and plot the accelerometer data.

During this program, the MwRSF purchased a second triaxial piezoresistive accelerometer system with a range of ±200 g's to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 3,200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3, was configured with 256 Kb of RAM and a 1,120 Hz filter. Computer software DynaMax 1 (DM-1) and DADiSP were used to digitize, analyze, and plot the accelerometer data. This system was used in conjunction with the previous system for the majority of the tests in this program.

Rate Gyro

A Humphrey three-axis rate transducer with a range of 250 deg/sec in each of the three directions (pitch, roll, and yaw) was used to measure the rotational rates of the test vehicle.

High-Speed Photography

Four to six high-speed 16-mm cameras operating at 500 frames/sec were used to film the crash tests. A Red Lake Locam with a 12.5-mm lens was placed above the test installation to provide a field of view perpendicular to the ground. A Photec IV, with an 80-mm lens, was placed downstream from the impact point and had a field of view parallel to the barrier. A second Photec IV, with a 55-mm lens, was placed on the traffic side of the bridge rail and had a field of view perpendicular to the barrier. A Hi-G Red Lake Locam with a 5.7-mm lens was placed onboard the vehicle to record dummy motions during the test. Additional high-speed cameras were placed behind the rail in some tests to aid in evaluation of the vehicle/rail interaction. A white-colored 5-ft by 5-ft (1.52-m by 1.52-m) grid was painted on the concrete in front of the rail and in the view of the overhead camera. This grid provided a visible reference system to use in the analysis of the overhead high-speed film. The film was analyzed using a Vanguard Motion Analyzer.

Speed Trap

Seven pressure tape switches, spaced at 5-ft (1.52-m) intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light and sent an electronic timing mark to the data acquisition system as the left-front tire of the test vehicle passed over it. Test vehicle speeds were determined from electronic timing mark data recorded on EGAA software. Strobe lights and high-speed film analysis were used only as a backup in the event that vehicle speeds could not be determined from the electronic data.

3. STEEL-BACKED WOOD RAIL TO BRIDGE RAIL TRANSITION

TEST INSTALLATION

Photographs of the Steel-Backed Wood Rail to Bridge Rail Transition are shown in figure 1. Plan drawings of the original system, as well as the subsequently modified systems, are presented in appendix A. The approach rail consists of 6-in by 10-in by 9-ft 11-in (152-mm by 254-mm by 3.04-m) timber, backed with ⅜-in (10-mm) ASTM A588 steel plate. This plate is attached to the back of the timber rail with ⅝-in by 4-in (16-mm by 102-mm) ASTM A588 lag screws. The splice details vary as shown in the plan drawings. One of the major design changes throughout the evolution of this system was the stiffening of the first splice location. This splice originally consisted of one ⅜-in (10-mm) plate fastening the rails together and was eventually modified to include a 6-in by 4-in by ½-in (152-mm by 102-mm by 13-mm) structural tube.

The rail was blocked out and mounted on 10-in by 12-in by 7-ft (254-mm by 305-mm by 2.13-m) timber posts for the first test, but the length of the first three posts were increased to 8 ft (2.44 m) for the remaining tests. The rail was attached to the flared concrete abutment with four ¾-in by 2-ft (19-mm by 610-mm) A588 carriage bolts and a ⅜-in (10-mm) bearing plate.

TEST CRITERIA

The tests performed on this system were conducted, reported, and evaluated in accordance with requirements for guardrail to bridge rail transitions specified in the National Cooperative Highway Research Program (NCHRP) Report No. 230, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*.(4) This criteria requires that a 4,500-lb (2,043 kg) sedan impact the transition at 60 mi/h (96.6 km/h) and 25 degrees. Barrier VII computer simulation was used to determine the critical impact point (CIP), which was midway between the third and fourth posts from the concrete bridge abutment, or 17.5 ft (5.33 m) from the attachment point between the rail and the concrete abutment.(5) The vehicle damage was assessed by the traffic accident scale (TAD) and the vehicle damage index (VDI).(6,7)

TEST VEHICLES

The test vehicles used in the evaluation of this system are summarized in table 1. The pretest vehicle dimension and photos can be seen in appendix B.

Table 1. Test Vehicle Summary, SBT Series.

Test No.	Vehicle	Test Inertial Weight	
		(lb)	(kg)
SBT-1	1985 Ford LTD	4,300	1,950
SBT-2	1984 Buick LeSabre	4,456	2,021
SBT-3	1985 Ford LTD	4,496	2,039
SBT-4	1985 Mercury Grand Marquis	4,668	2,117
SBT-5	1985 Ford LTD	4,500	2,043

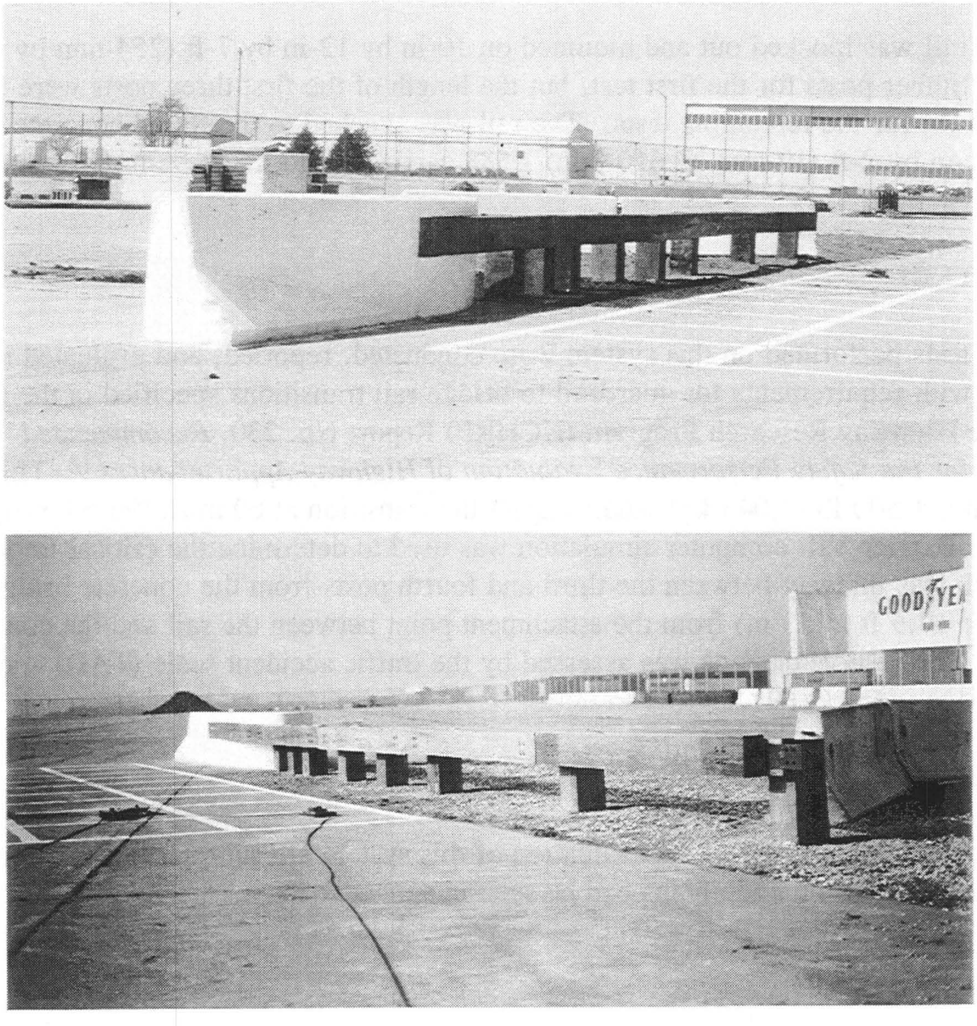
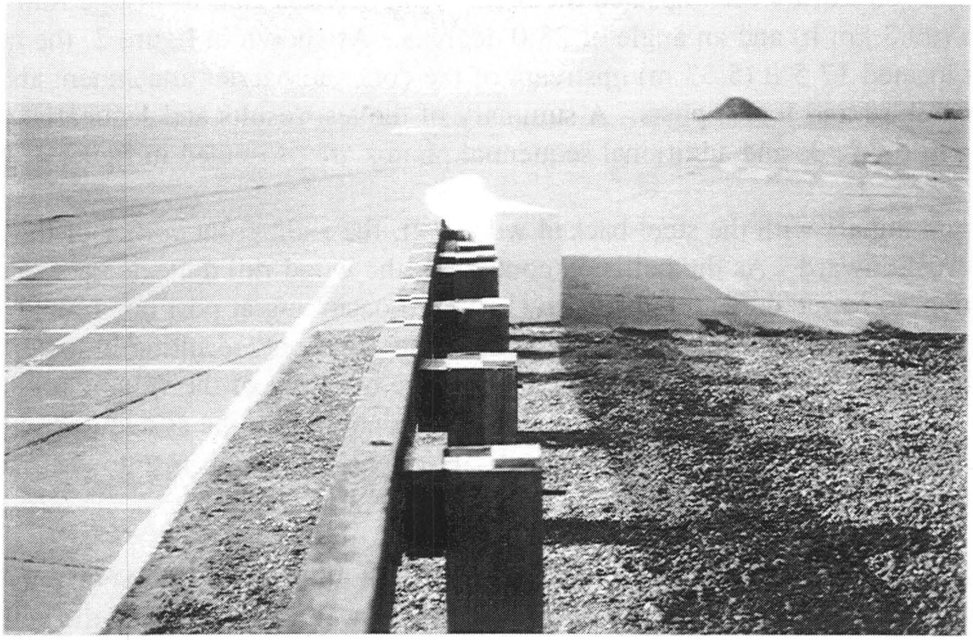


Figure 1. The Steel-Backed Wood Rail to Bridge Rail Transition.



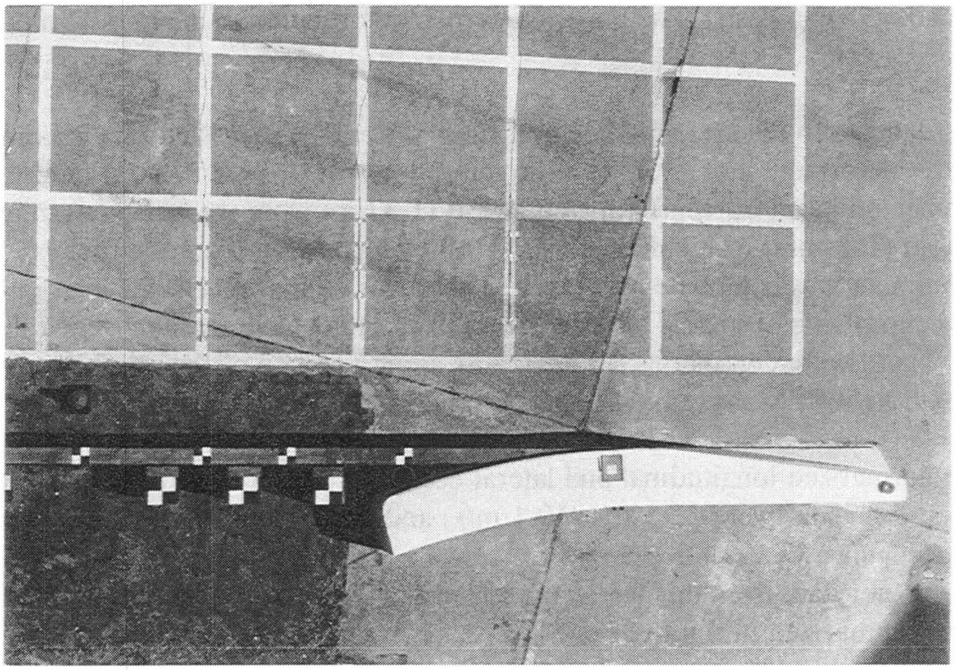


Figure 1. The Steel-Backed Wood Rail to Bridge Rail Transition (continued).

TEST RESULTS

Test SBT-1

The 1985 Ford LTD impacted the Steel-Backed Wood Rail to Bridge Rail Transition at 61.7 mi/h (99.3 km/h) and an angle of 25.0 degrees. As shown in figure 2, the target impact point was located 17.5 ft (5.33 m) upstream of the concrete barrier attachment and midway between the third and fourth posts. A summary of the test results and sequential photographs are shown in figure 3, and additional sequential photos are presented in figure 4.

Upon impact with the steel-backed wood rail, the right-front corner of the vehicle began to crush inward. As the collision continued, the wood rail deflected considerably, with the maximum dynamic deflection of 13 in (130 mm) occurring at post no. 1 at 130 ms. At 133 ms, the vehicle impacted the end of the concrete abutment, resulting in major damage to the vehicle. Approximately 167 ms after impact, the buckling of the vehicle roof became very evident. At 204 ms after impact, the vehicle became parallel to the system, and at 439 ms it exited the barrier at an angle of 17.5 degrees. The vehicle came to rest downstream and behind the rail, as shown in figure 5.

Damage to the vehicle, which can be seen in figure 6, included major crushing and deformation of the right-front corner of the vehicle, as well as buckling of the vehicle roof. The entire front half of the vehicle was bent slightly toward the driver's side. Interior occupant compartment damage included buckling of the floorboard on the passenger's side, as well as buckling of the dash. The maximum crush deformation of 17 in (492 mm) is shown in figure 7.

The damage to the system, shown in figures 8 and 9, consisted of a maximum permanent set deformation of 11.25 in (286 mm) at post no. 1. A flexural failure occurred in the first timber rail section, approximately 4.5 ft (1.37 m) from the downstream end of the rail. The 8-in (203-mm) inside diameter (I.D.) pipe located between the first rail and the concrete abutment was completely flattened. There was evidence of vehicle snagging at the splice between rails no. 1 and 2, as sheet metal from the vehicle was embedded in the end of rail no. 1. There were continuous scrape marks along the face of the rail from the point of impact to exit, as well as impact markings on the concrete abutment.

The normalized longitudinal and lateral occupant impact velocities, as determined from the accelerometer data, were 33.3 ft/s (10.1 m/s) and 20.4 ft/s (6.2 m/s), respectively. The maximum occupant ridedown decelerations were 13.8 g's (longitudinal), and 16.2 g's (lateral). The accelerometer data from this test is presented in appendix C, and the results of this analysis are summarized in figure 3.

The impact with the end of the concrete abutment caused excessive occupant compartment deformation, which resulted in the failure of this test. It was determined that the stiffness of the steel-backed wood rail was inadequate as it deflected considerably, allowing the vehicle to impact the end of the concrete abutment. The system was redesigned by Eastern Federal Lands Highway Division engineers for the next test by increasing the length of posts no. 1, 2, and 3 from 7 ft (2.13 m) to 8 ft (2.44 m). The 8-in (203-mm) I.D. pipe spacer between the rail and concrete abutment was replaced with an angled block of wood to restrict the deflection of the first rail. The splice between the first and second rails was stiffened by adding a second ⅜-in (10-mm) backup plate. The bolts at this splice were moved closer to the post and increased in number from 8 to 12. The details of these design changes are presented in the plan drawings in appendix A.

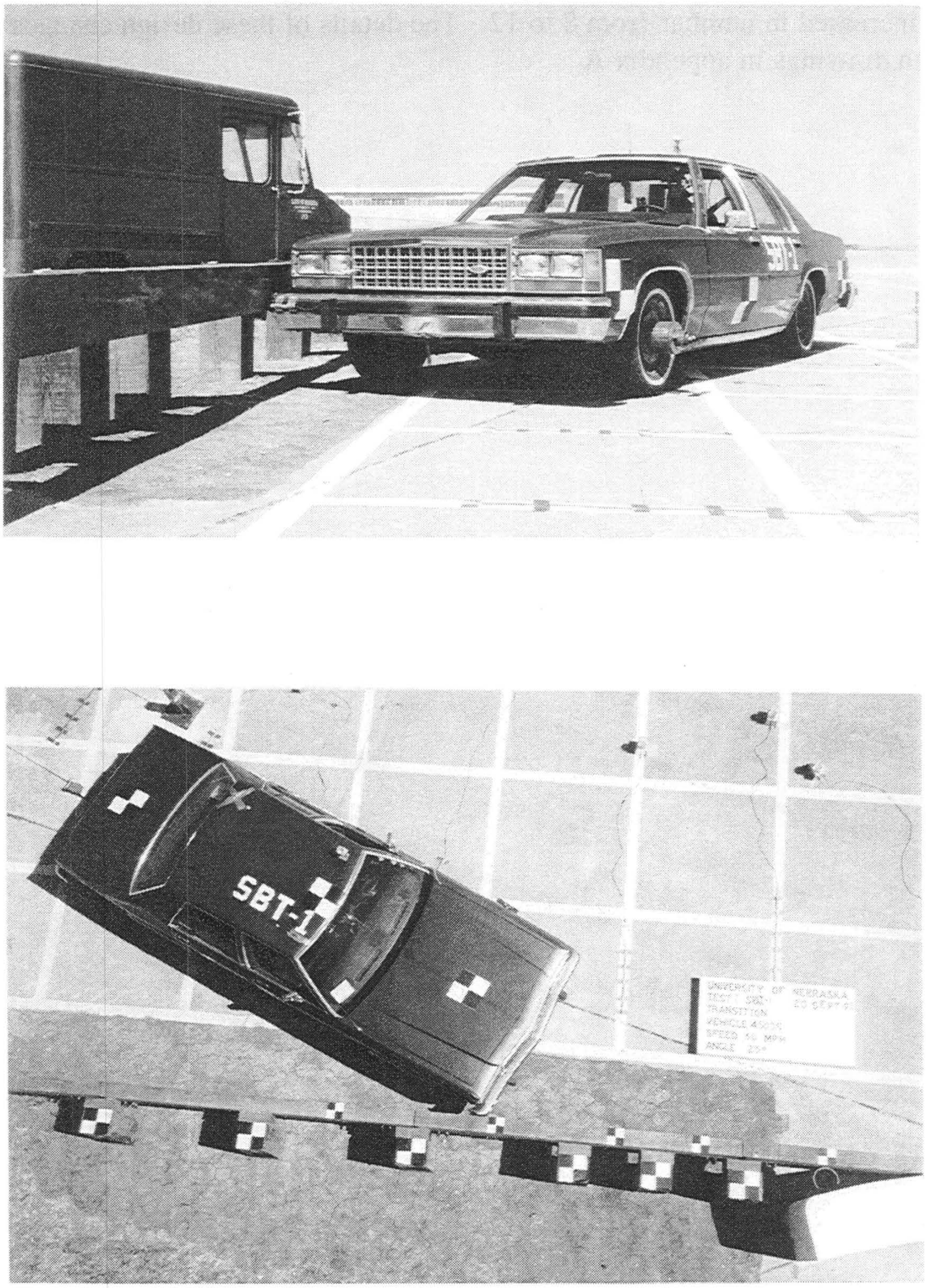
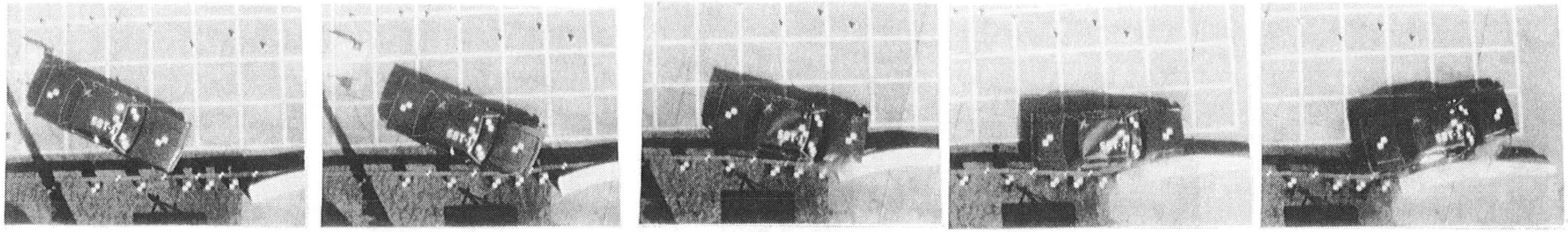
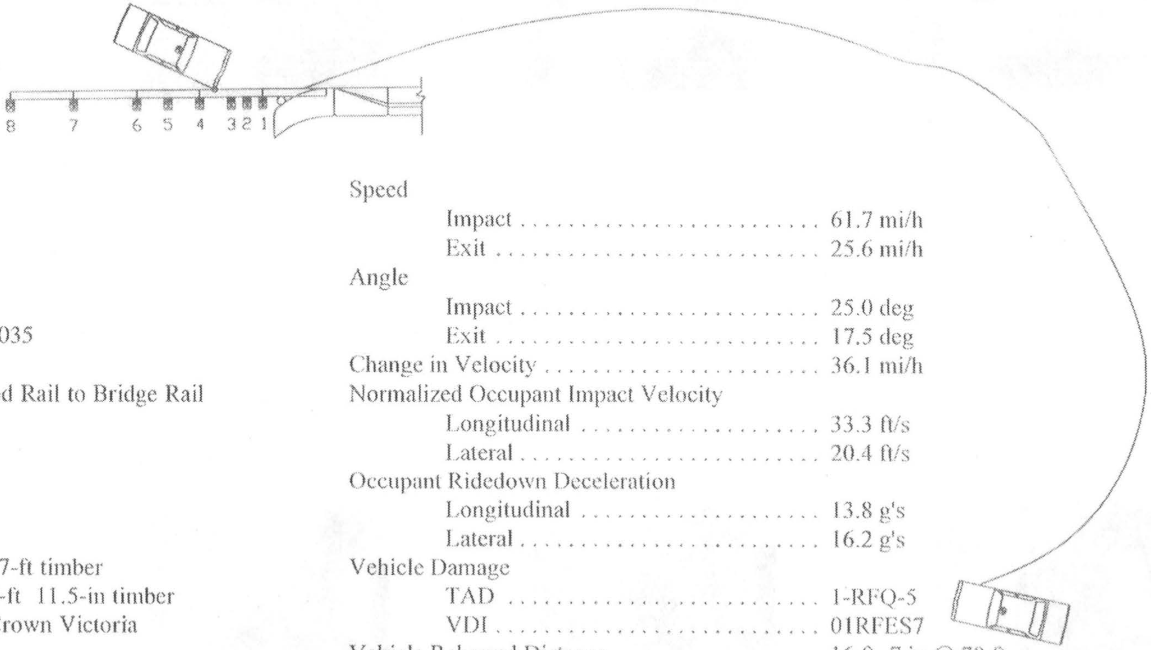


Figure 2. Impact Location, Test SBT-1.



Impact 61 ms 153 ms 204 ms 306 ms

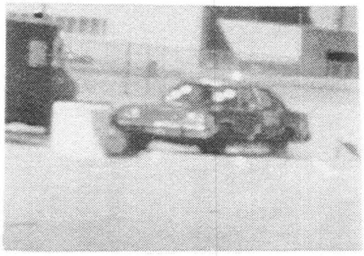


Test Number	SBT-1
Federal Contract No.	DTFH71-90-C-00035
Date	9/20/91
Installation	Steel-Backed Wood Rail to Bridge Rail Transition
Approach Guardrail	
Length	50 ft
Height	2 ft - 3 in
Material	
Post	10-in by 12-in by 7-ft timber
Rail	6-in by 10-in by 9-ft 11.5-in timber
Vehicle Model	1985 Ford LTD Crown Victoria
Vehicle Weight	
Curb	3,880 lbs
Test Inertia	4,460 lbs
Gross Static	4,300 lbs

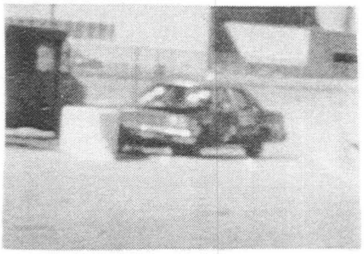
Speed	
Impact	61.7 mi/h
Exit	25.6 mi/h
Angle	
Impact	25.0 deg
Exit	17.5 deg
Change in Velocity	36.1 mi/h
Normalized Occupant Impact Velocity	
Longitudinal	33.3 ft/s
Lateral	20.4 ft/s
Occupant Ridedown Deceleration	
Longitudinal	13.8 g's
Lateral	16.2 g's
Vehicle Damage	
TAD	1-RFQ-5
VDI	01RFES7
Vehicle Rebound Distance	16 ft- 7 in @ 70 ft
Guardrail Damage	Minor
Maximum Deflections	
Permanent Set	11.25 in @ post No. 1
Dynamic	13 in @ post No. 1

Conversion Factors: 1 in= 2.54 cm; 1 lb= 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

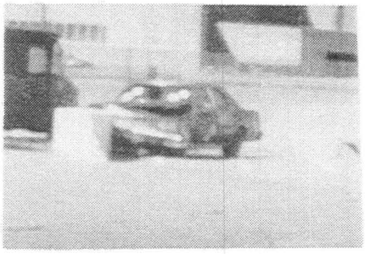
Figure 3. Summary of Test SBT-1.



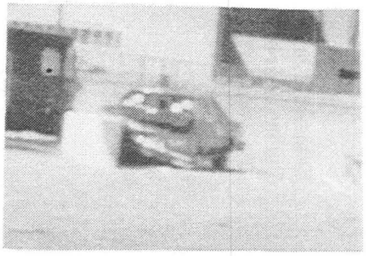
Impact



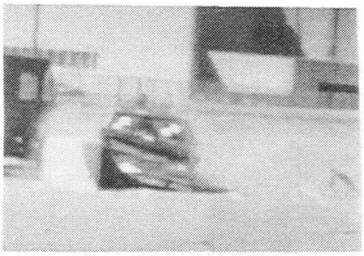
30 ms



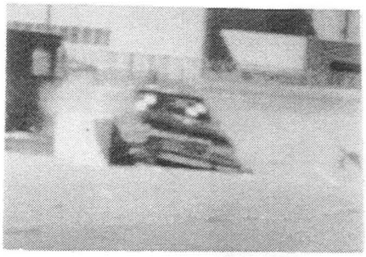
45 ms



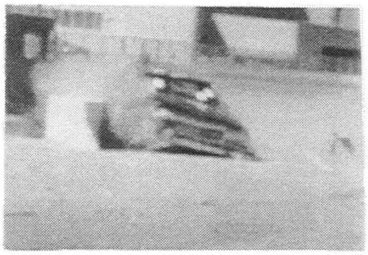
70 ms



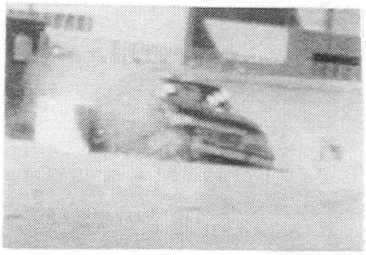
100 ms



130 ms



160 ms



200 ms

Figure 4. Downstream Sequential Photographs, Test SBT-1.

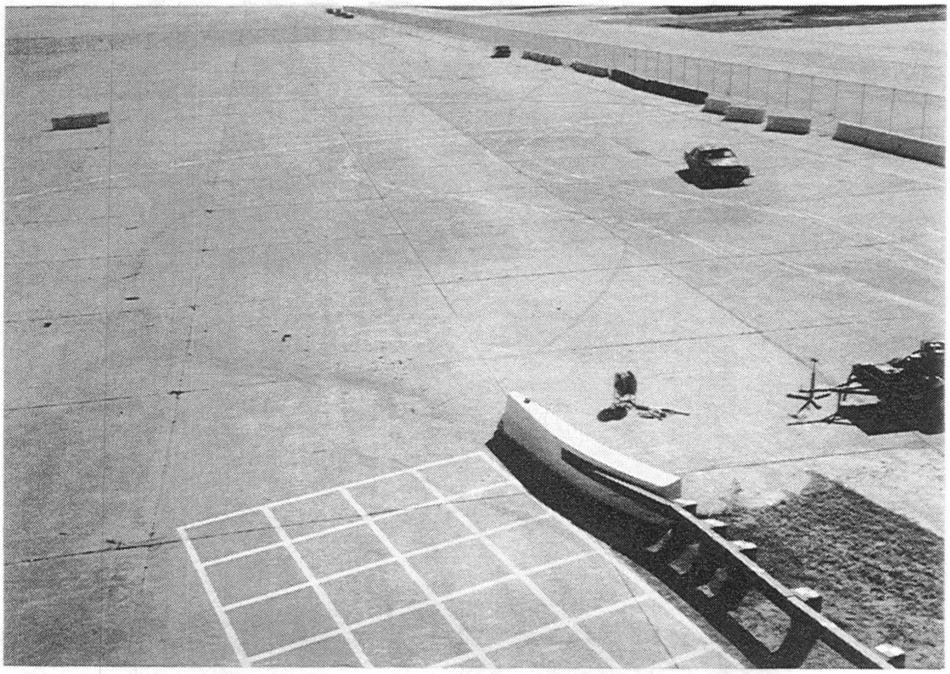


Figure 5. Vehicle Trajectory, Test SBT-1.

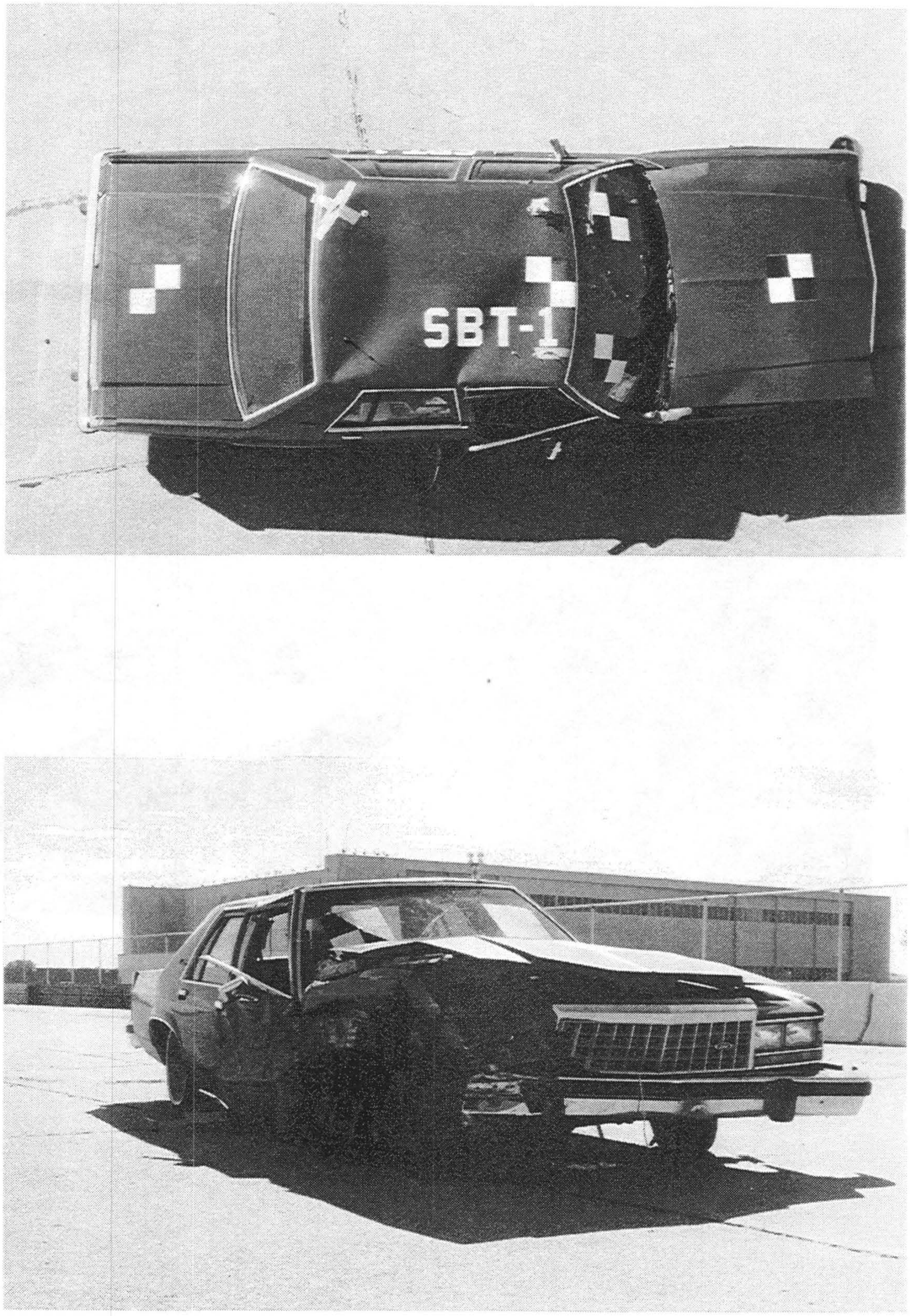
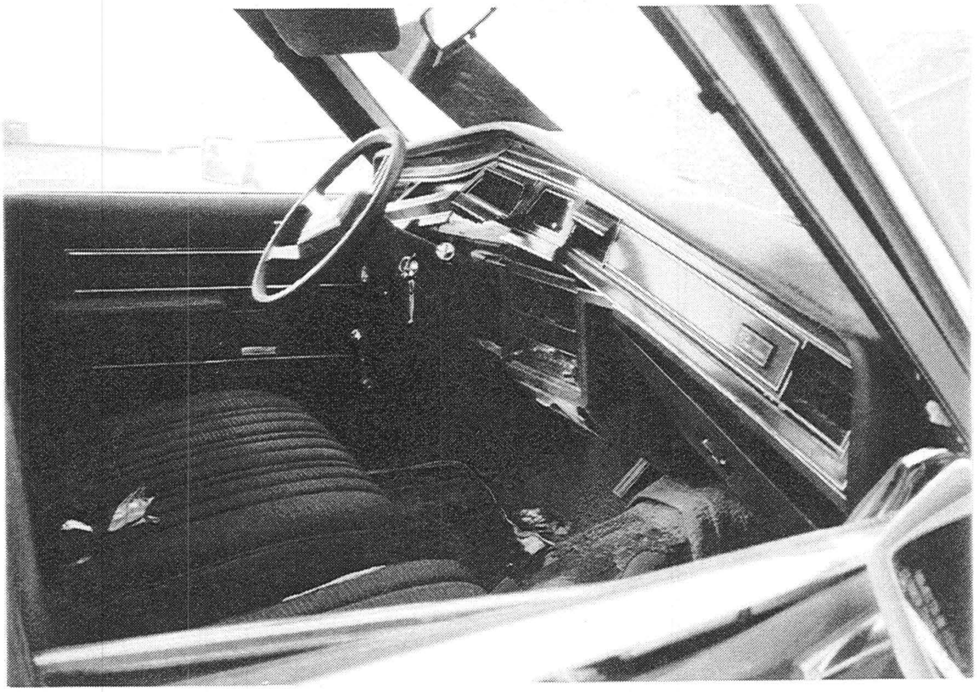


Figure 6. Vehicle Damage, Test SBT-1.



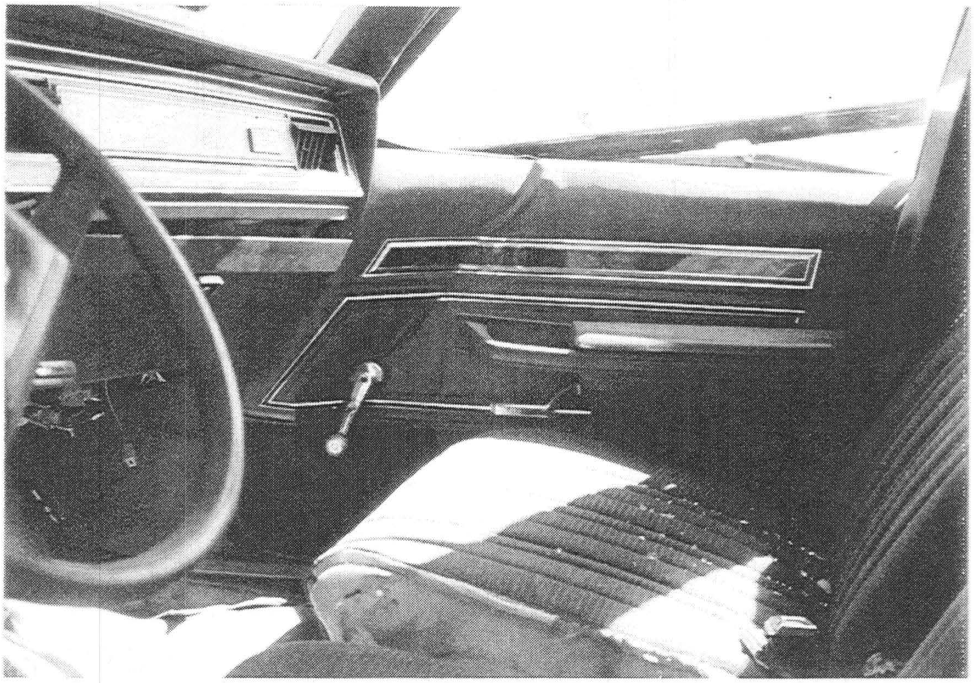


Figure 6. Vehicle Damage, Test SBT-1 (continued).

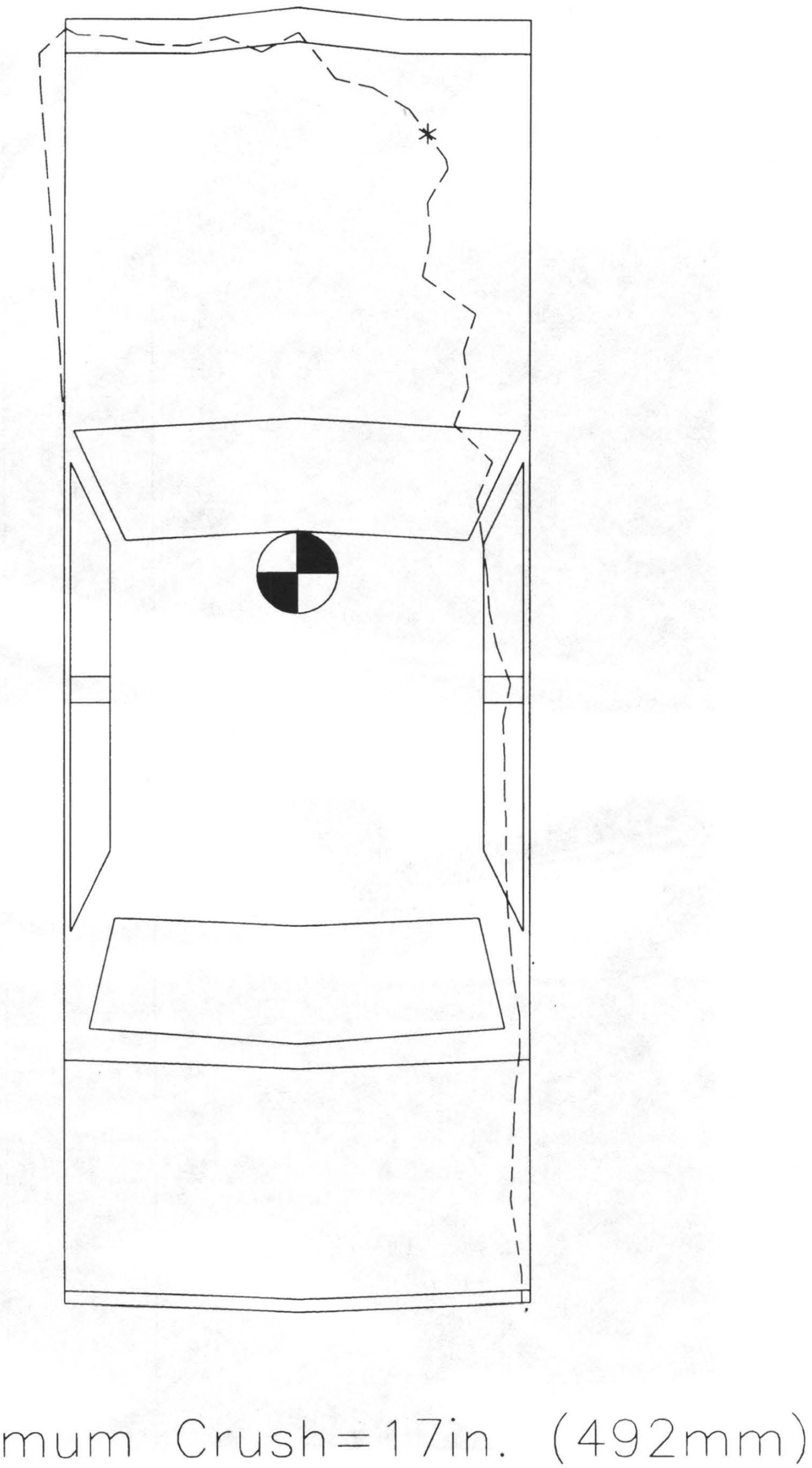


Figure 7. Crush Depth Diagram, Test SBT-1.

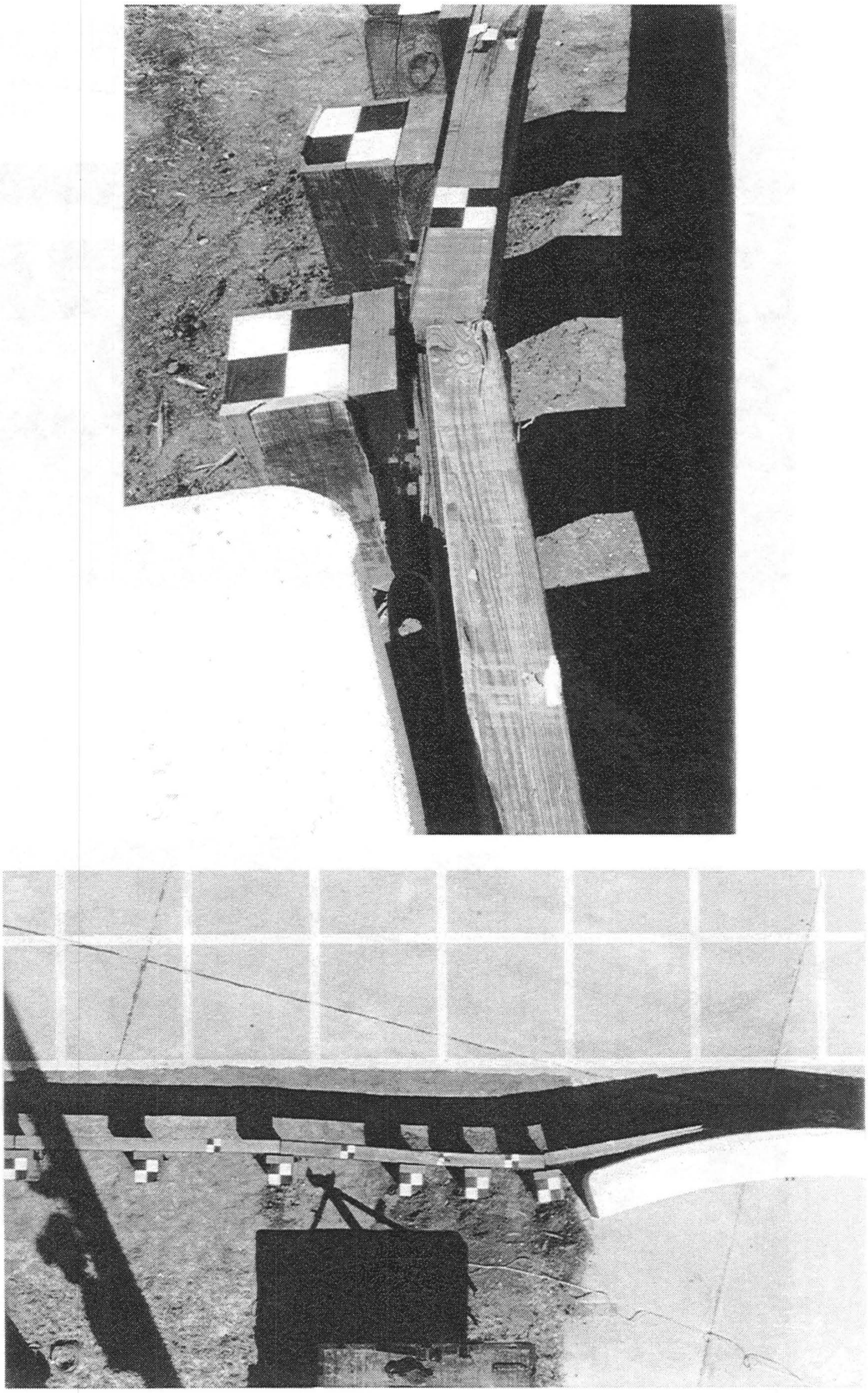


Figure 8. System Damage, Test SBT-1.

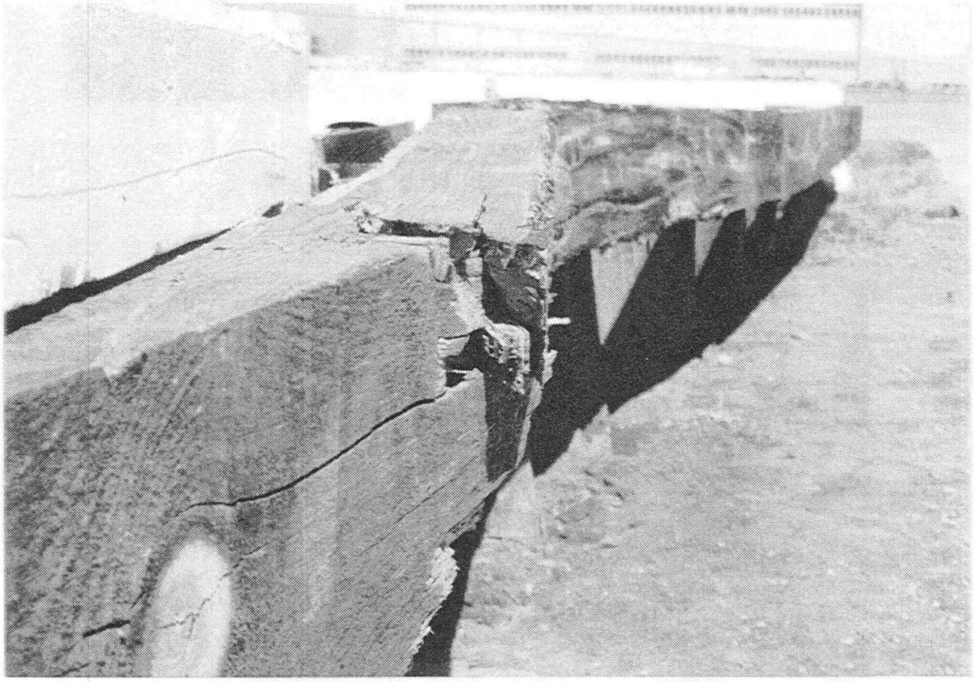


Figure 8. System Damage, Test SBT-1 (continued).

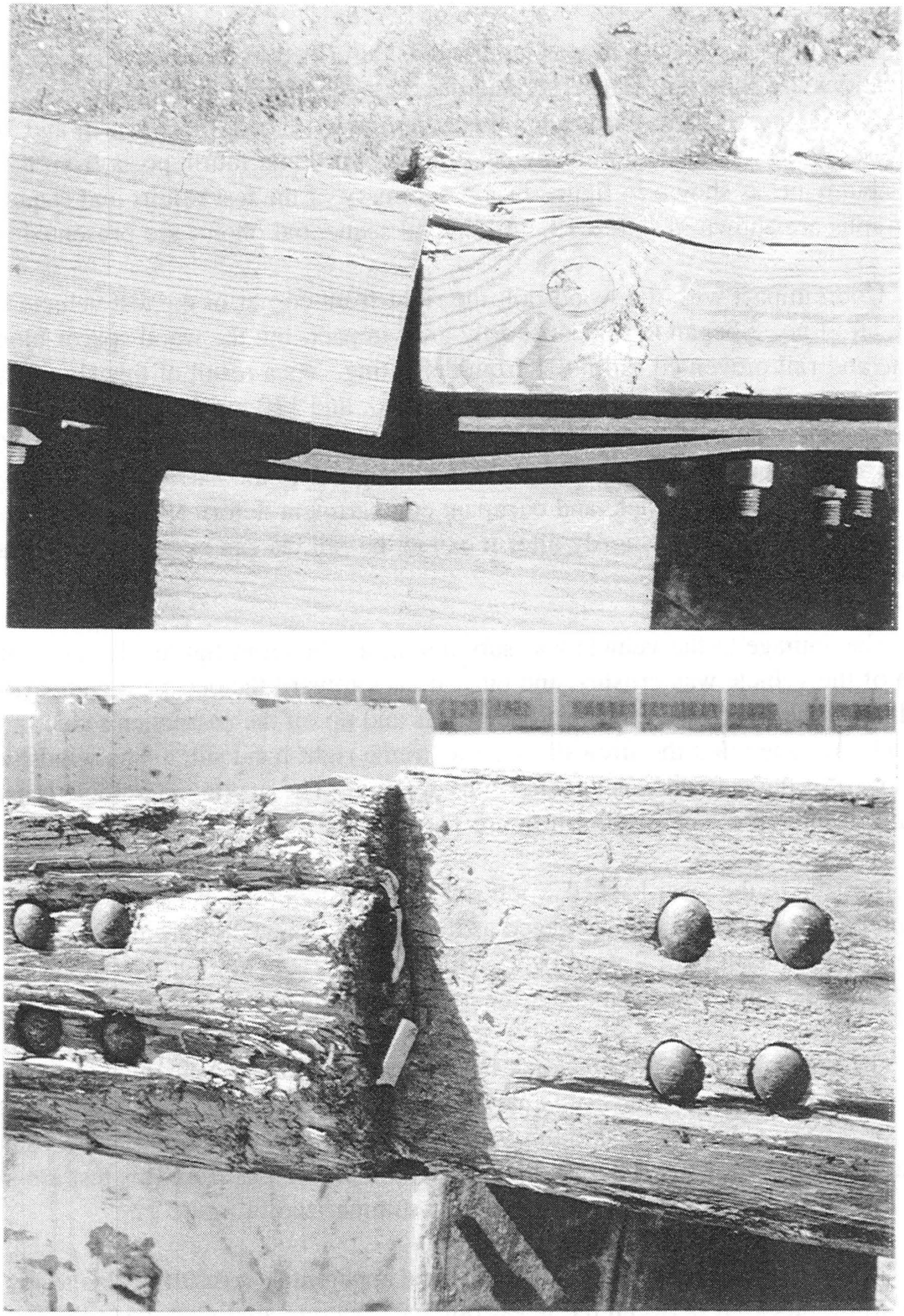


Figure 9. Damage at First Splice, Test SBT-1.

Test SBT-2

For this test, the system was modified as described in the previous section. These modifications are shown in figure 10, and details can be found in the plan drawings in appendix A. The 1984 Buick LeSabre impacted the system at 61.1 mi/h (98.3 km/h) and 26.5 degrees. The impact point was located midway between the third and fourth posts from the concrete bridge abutment, as shown in figure 11. A summary of the test results and sequential photographs are shown in figure 12. Additional sequential photos are presented in figure 13.

Upon impact with the wood rail, the right-front corner of the test vehicle began to crush inward. Rail no. 2 began to deflect shortly after impact, but the wood spacer block between the concrete and rail prevented rail no. 1 from deflecting. As a result of this significant difference in stiffness, the splice between these two rails yielded, and 110 ms after impact the first rail speared into the vehicle. The vehicle never became parallel to the rail, and it exited at 450 ms as its center of mass was traveling at an angle of 17.3 degrees to the barrier. The snagging at the first splice resulted in major vehicle and occupant compartment deformation, and the sedan was brought to a complete stop shortly after it exited the rail, as can be seen by its final resting position shown in figure 14.

The damage to the vehicle was substantial, as shown in figure 15. The entire right-front portion of the vehicle was crushed and pushed back toward the occupant compartment. The firewall and floorboard were pushed backwards and up on the passenger's side, and a section of the wood rail penetrated the firewall on the extreme right-hand side. The windshield was broken and the roof of the vehicle was buckled considerably. The maximum vehicle crush of 31.5 in (800 mm) is shown schematically in figure 16.

Damage to the steel-backed wood rail was considerable, as can be seen in figure 17. The upstream end of rail no. 1 was damaged as the vehicle snagged on it, and the splice plates between rails no. 1 and no. 2 were bent significantly. There were marks along the face of the rail and concrete abutment throughout the length of contact.

The normalized longitudinal and lateral occupant impact velocities for this test, as determined from accelerometer data analysis, were 35.1 ft/s (10.7 m/s) and 21.0 ft/s (6.4 m/s), respectively. The maximum occupant ridedown decelerations were 18.1 g's (longitudinal) and 22.1 g's (lateral). The accelerometer traces from this test are shown in appendix C, and the results of this analysis are summarized in figure 12.

Two of the system's design flaws became apparent as a result of this test. The first was that the wood blockout between the wood rail and concrete abutment made the first rail section much too stiff, resulting in the snagging problem at splice no. 1. The second observation was that the steel splice plates did not provide adequate strength for the splice between the first and second rail. Thus, two design changes were incorporated by FHWA engineers into the next design in an effort to alleviate these problems.

First, the angled wood blockout between the steel-backed rail and the concrete abutment was replaced with a 6-in (152-mm) diameter pipe. Second, the two ⅜-in (10-mm) splice plates at post no. 1 were replaced with a 3-ft (0.91-m) length of 6-in by 4-in by ½-in (152-mm by 102-mm by 13-mm) structural steel tube. The details of these design changes can be found in appendix A.

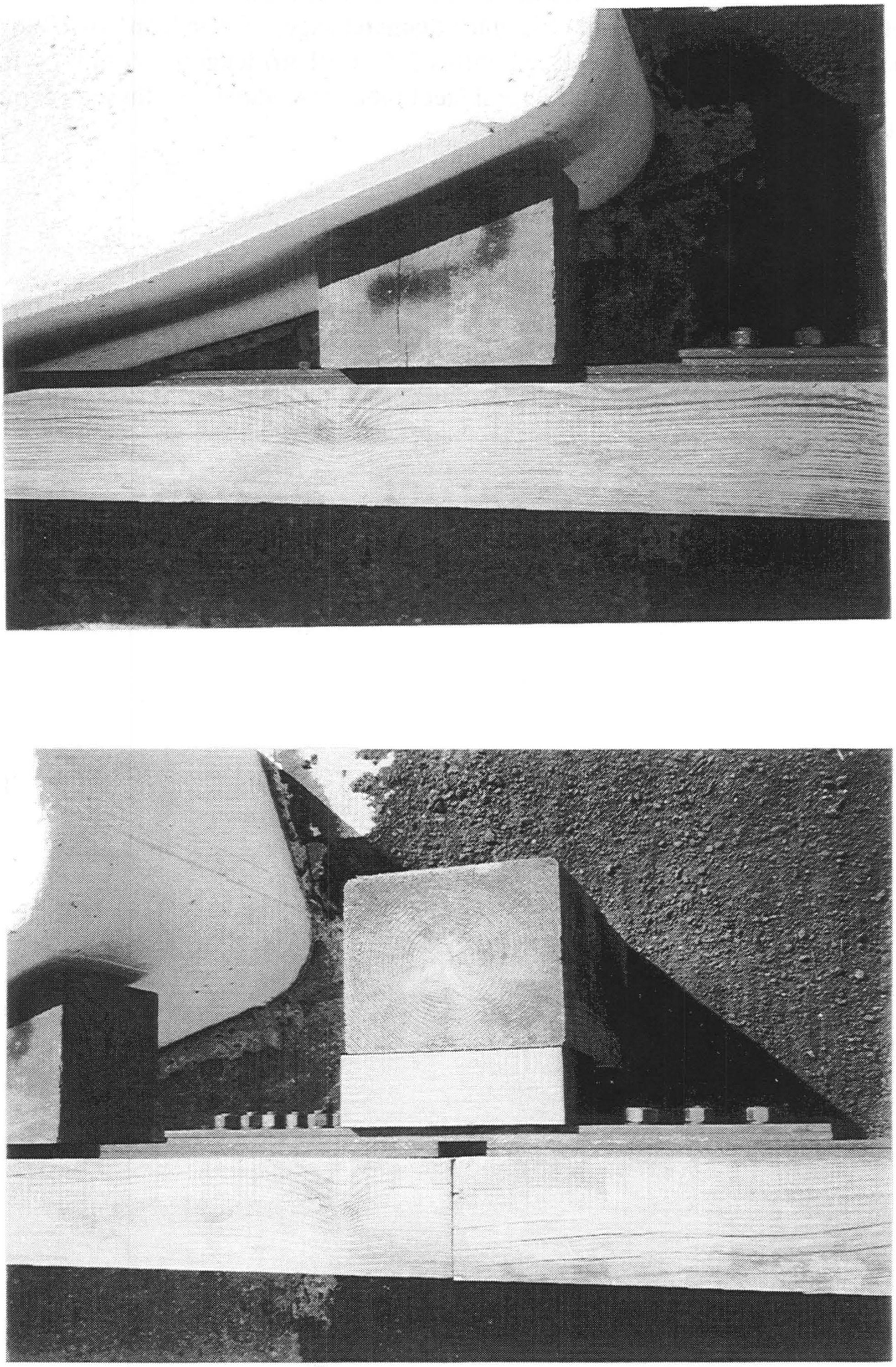


Figure 10. Design Modifications, Test SBT-2.

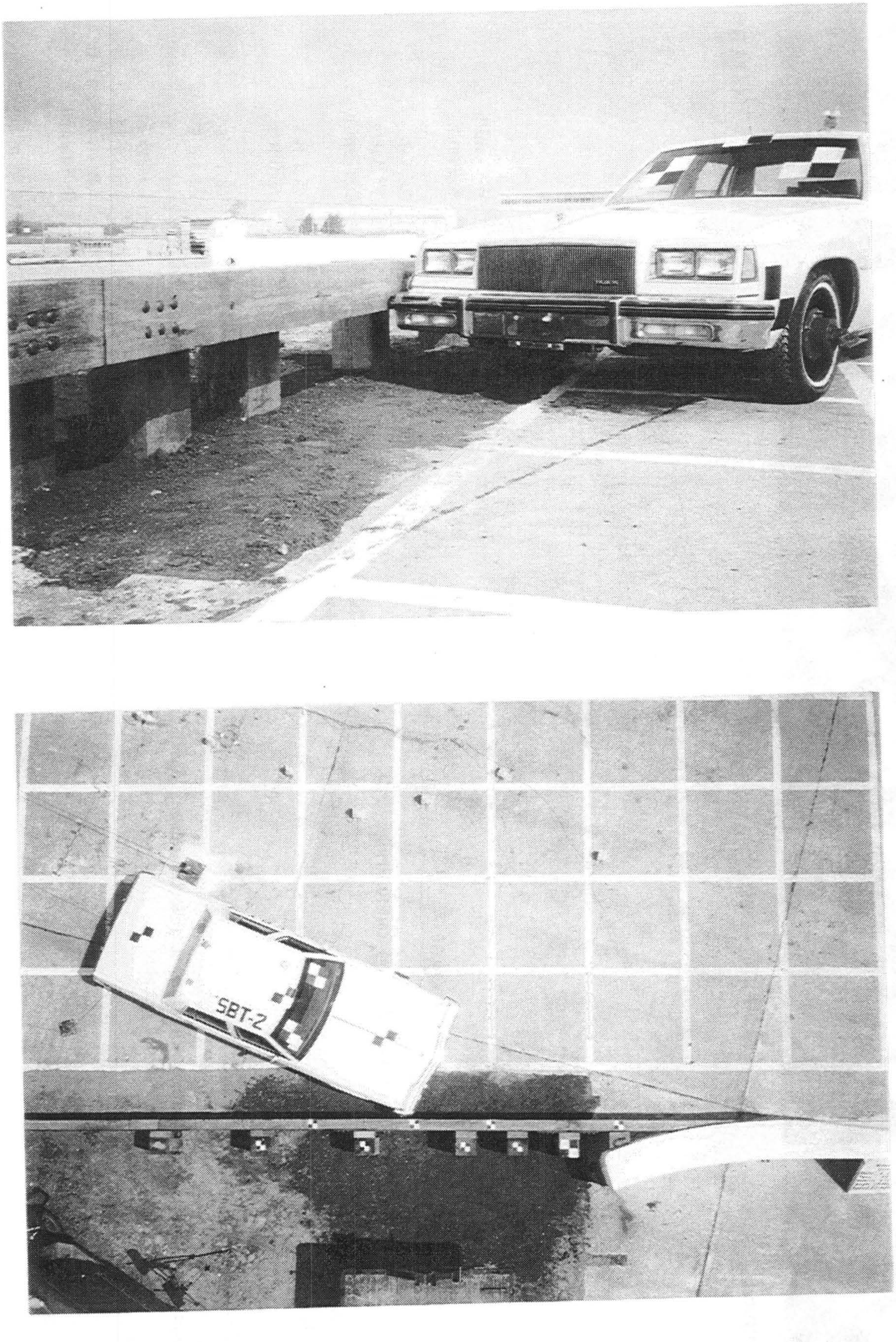
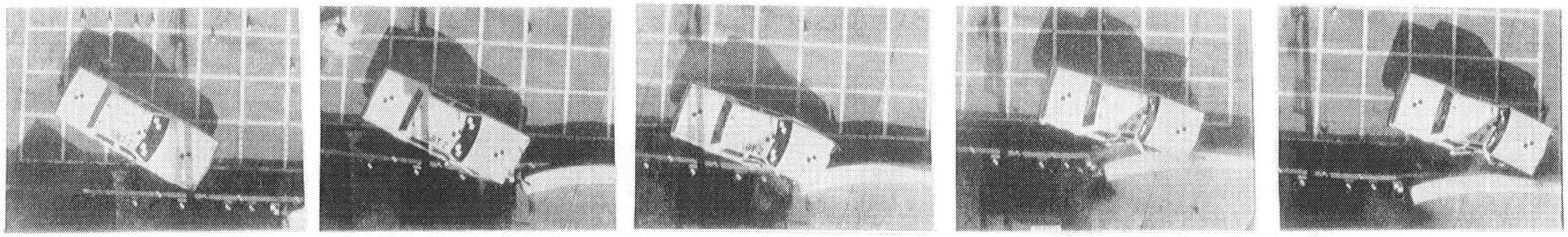
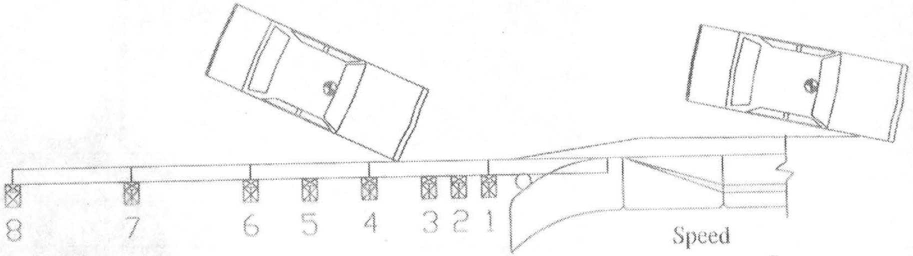


Figure 11. Impact Location, Test SBT-2.



Impact 110 ms 170 ms 400 ms 600 ms

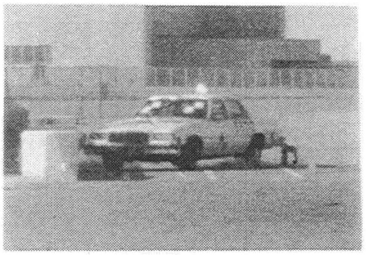


Test Number	SBT-2
Federal Contract No.	DTFH71-90-C-00035
Date	4/3/92
Installation	Steel-Backed Wood Rail to Bridge Rail
Transition	
Approach Guardrail	
Length	50 ft
Height	2 ft - 3 in
Material	
Posts 1-3	10-in by 2-in by 8-ft timber
Posts 4-8	10-in by 12-in by 7-ft timber
Rail	6-in by 10-in by 9 ft 11½-in timber
Vehicle Model	1984 Buick LeSabre
Vehicle Weight	
Curb	3,770 lbs
Test Inertia	4,616 lbs
Gross Static	4,456 lbs

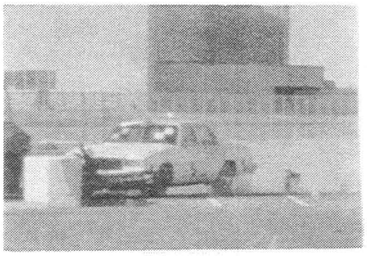
Speed	
Impact	61.1 mi/h
Exit	8.4 mi/h
Angle	
Impact	26.5 deg
Exit	17.3 deg
Change in Velocity	52.7 mi/h
Normalized Occupant Impact Velocity	
Longitudinal	35.1 ft/s
Lateral	21.0 ft/s
Occupant Ridedown Deceleration	
Longitudinal	18.1 g's
Lateral	22.1 g's
Vehicle Damage	
TAD	1-RFQ-7
VDI	01FZES5
Vehicle Rebound Distance	4 ft - 6 in @ 15 ft
Guardrail Damage	Substantial
Maximum Deflections	
Permanent Set	4.75 in between posts 2 & 3
Dynamic	10.4-in @ post No. 3

Conversion Factors: 1 in= 2.54 cm; 1 lb=0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

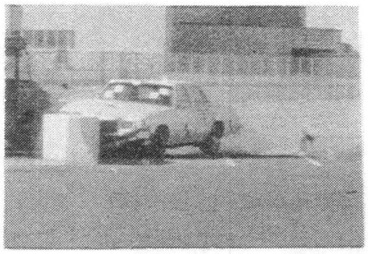
Figure 12. Summary of Test SBT-2.



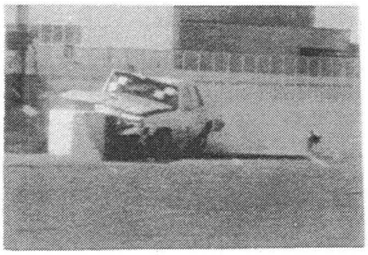
Impact



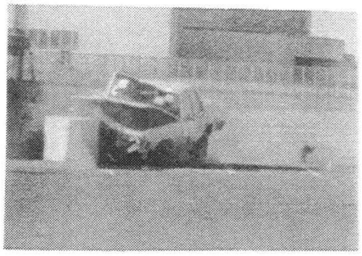
60 ms



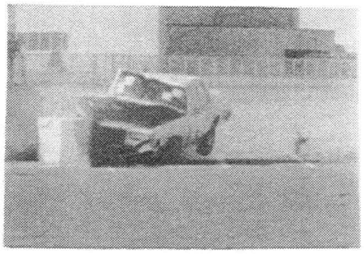
120 ms



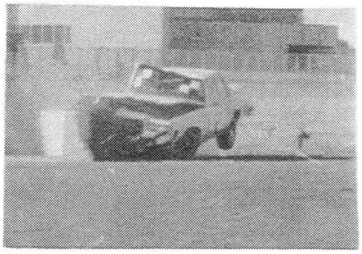
200 ms



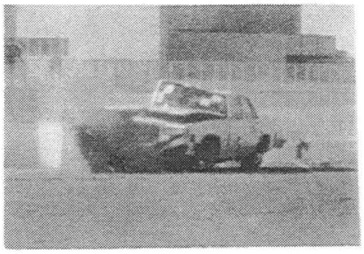
280 ms



380 ms



500 ms



700 ms

Figure 13. Downstream Sequential Photographs, Test SBT-2.

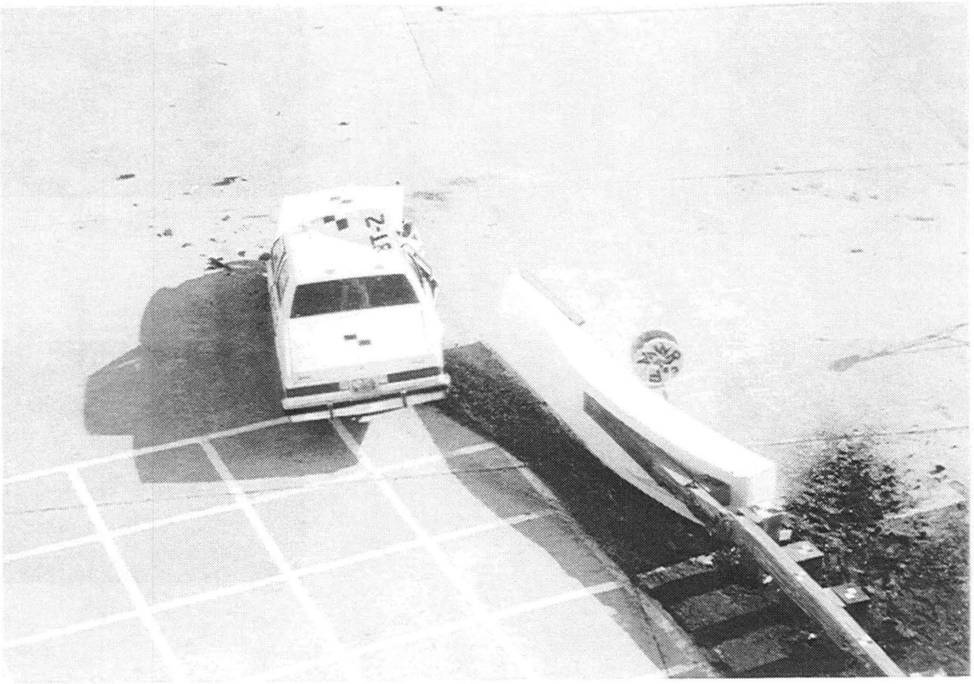


Figure 14. Vehicle Trajectory, Test SBT-2.

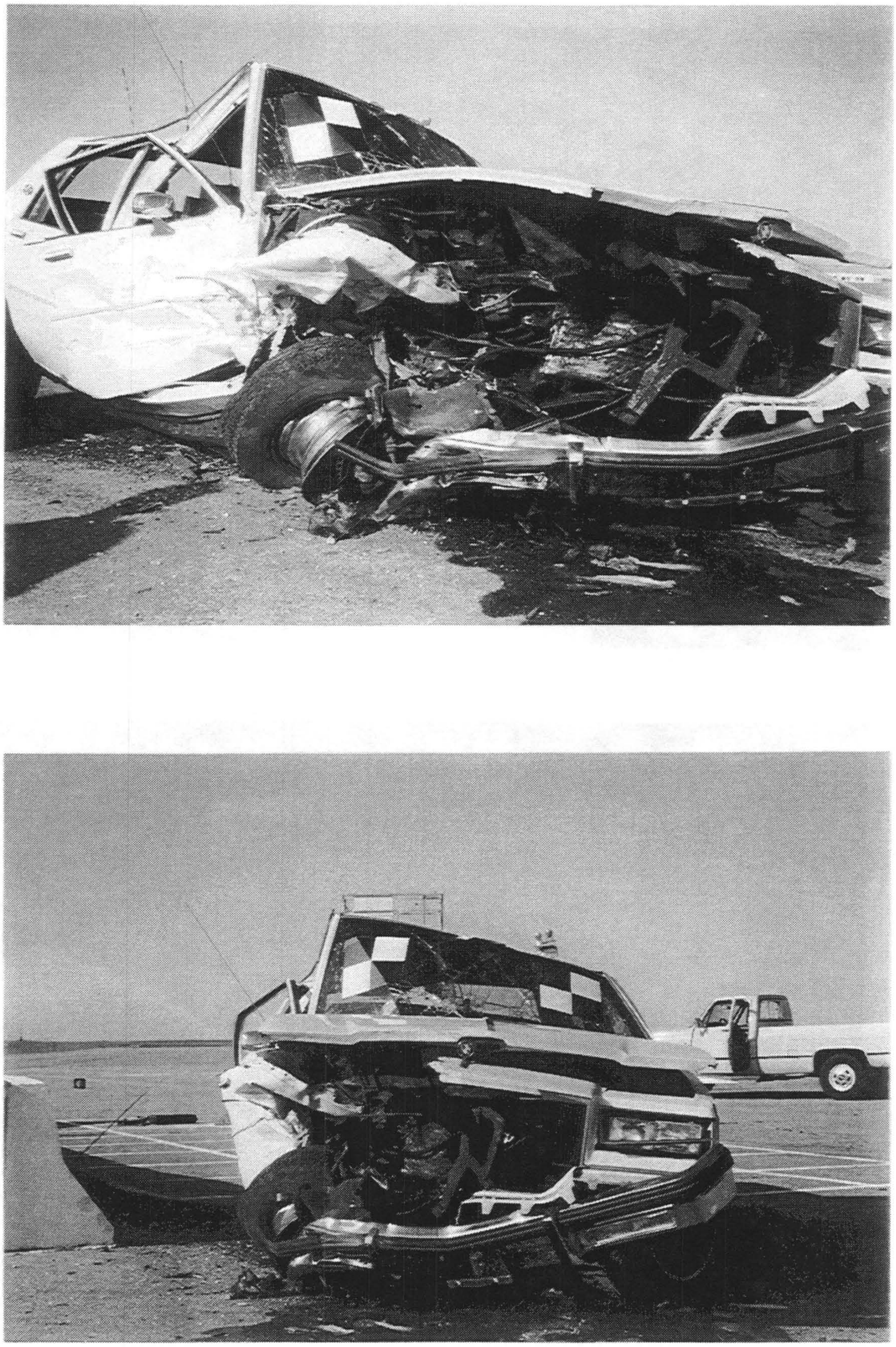


Figure 15. Vehicle Damage, Test SBT-2.

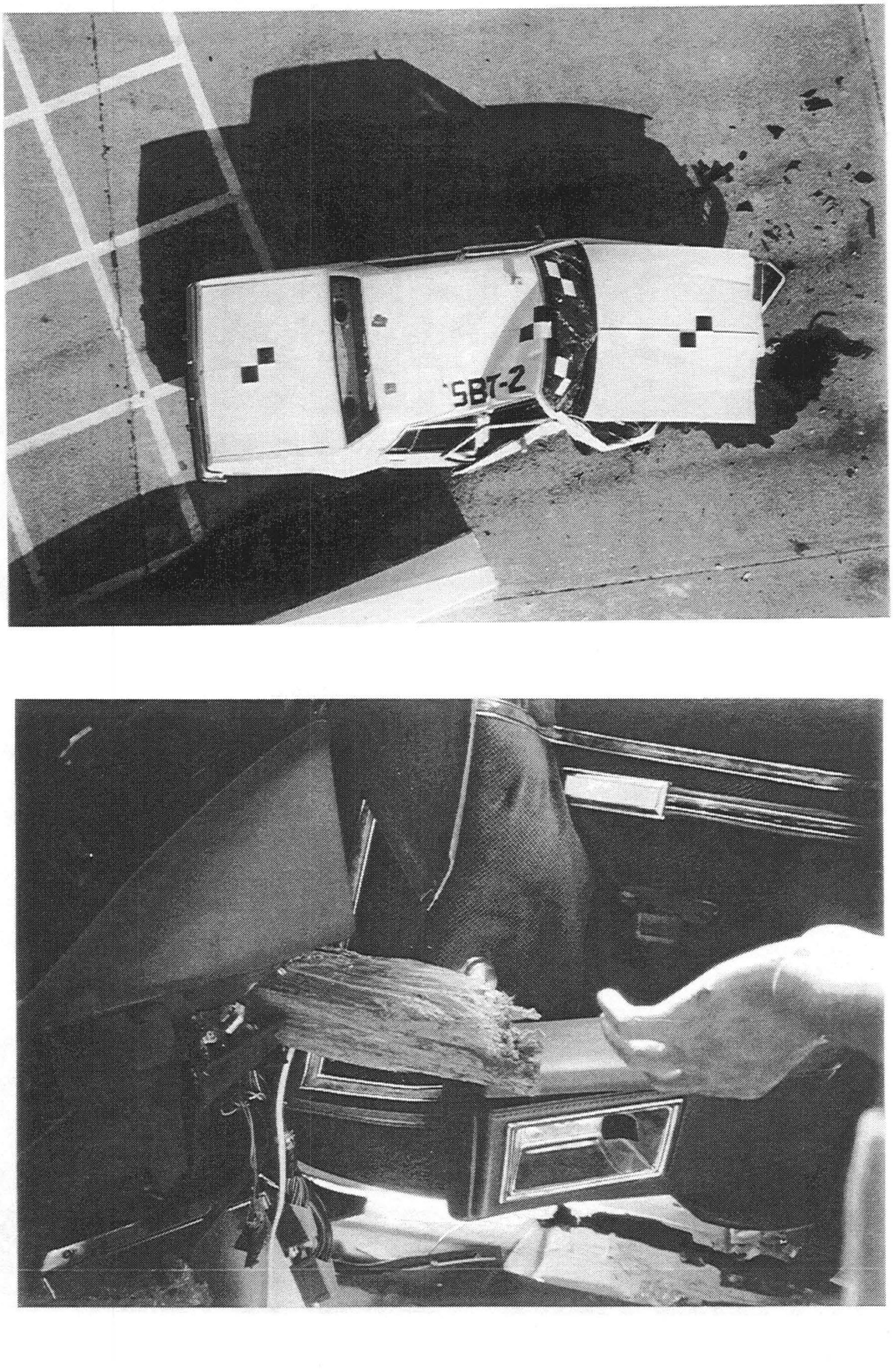


Figure 15. Vehicle Damage, Test SBT-2 (continued).

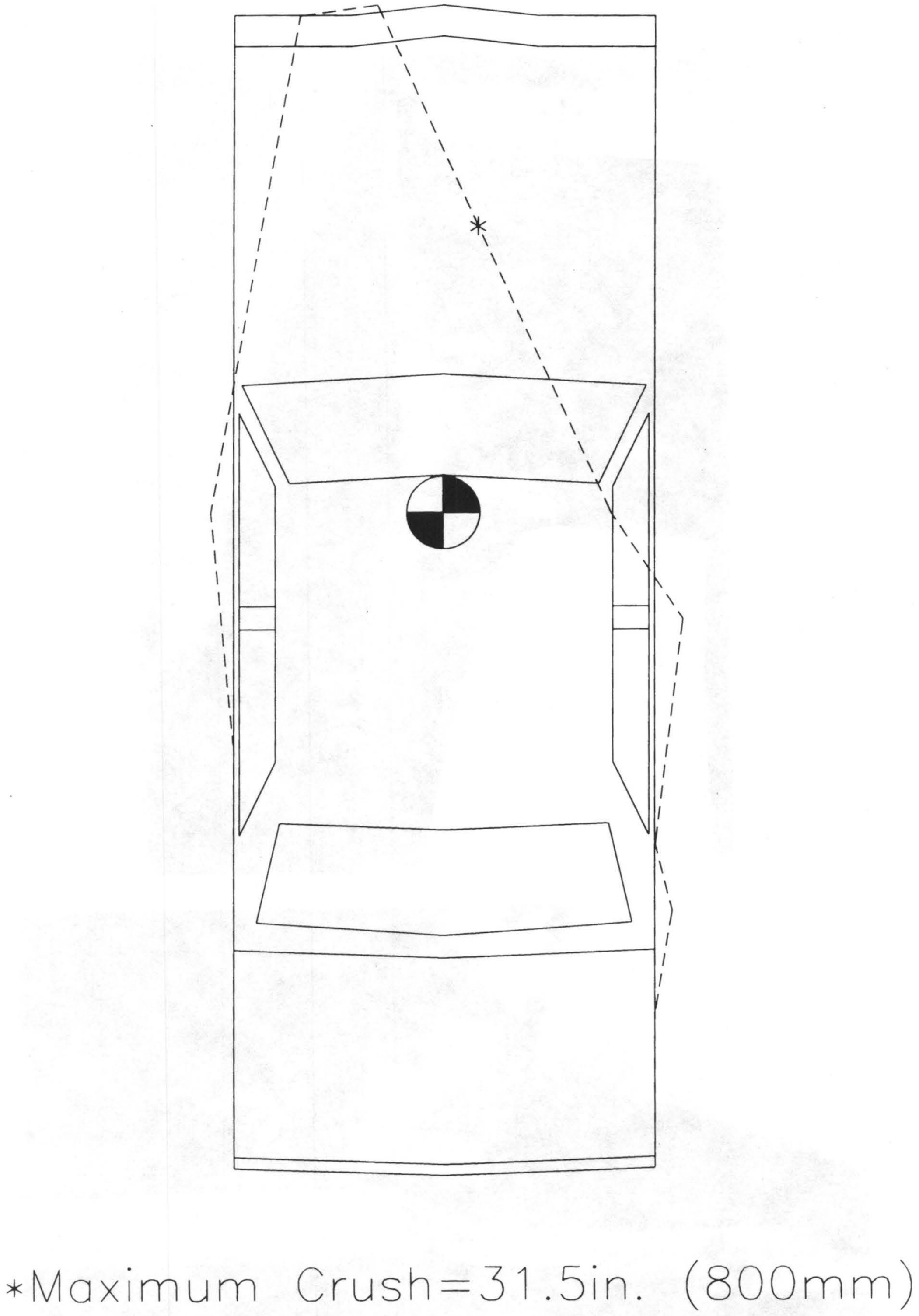


Figure 16. Crush Depth Diagram, Test SBT-2.

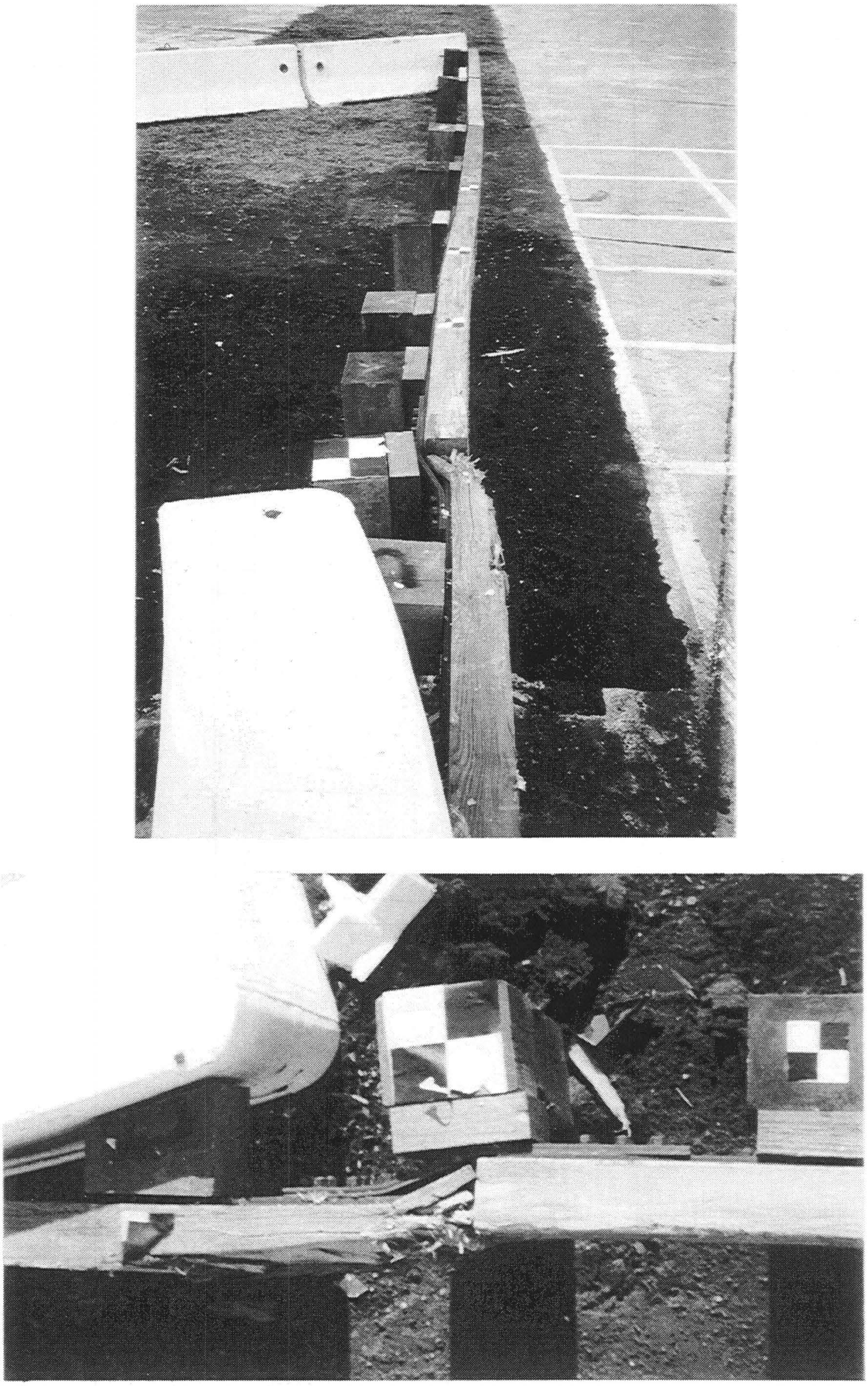


Figure 17. System Damage, Test SBT-2.

Figure 17. System Damage, Test SBT-2 (continued).

Test SBT-3

The design changes discussed in the previous section are shown in figure 18, and were implemented for this test. The design details for the system tested are shown in appendix A. For this test, a 1985 Ford LTD impacted the system at 62.0 mi/h (99.8 km/h) and 25.8 degrees. The impact point was located midway between the third and fourth posts from the concrete bridge abutment, as shown in figure 19. A summary of the test results and sequential photographs are shown in figure 20. Additional sequential photos are presented in figure 21.

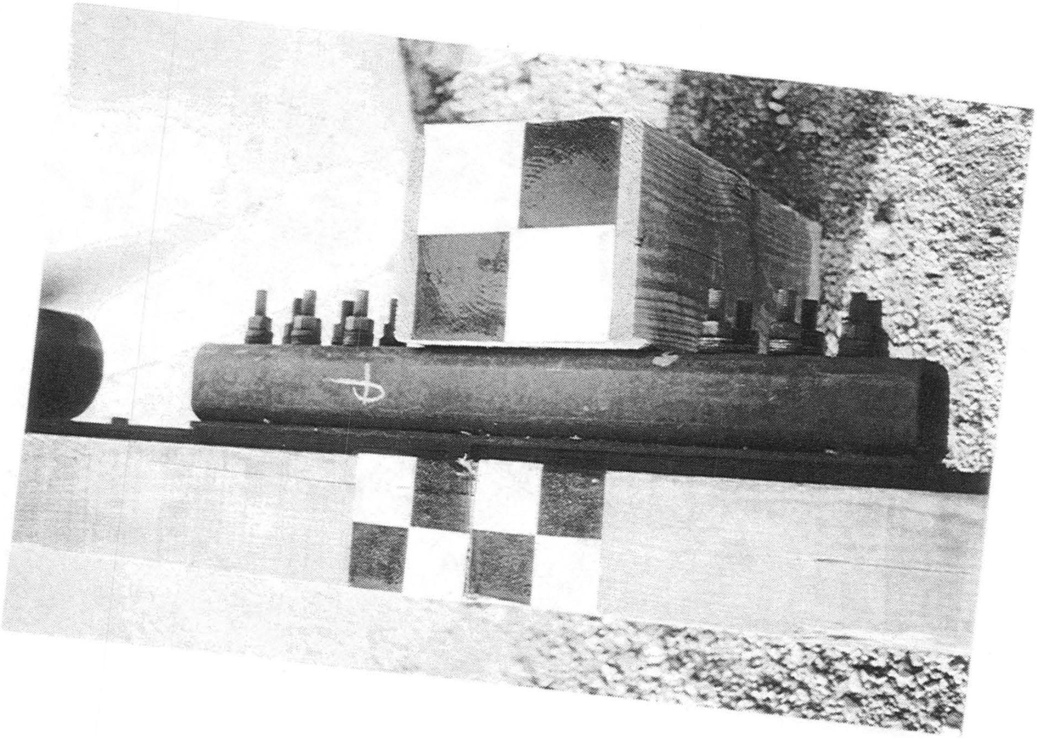
Upon impact with the wood rail, the right-front corner of the test vehicle was crushed inward, and the wheel was forced under the rail and back toward the post. This resulted in considerable tire snagging on posts no. 1 and 2, which pushed the wheel back against the firewall and resulted in significant deformation of the occupant compartment. The vehicle became parallel to the system at 212 ms and exited at 343 ms and 5.8 degrees. The maximum dynamic deflection of this system was limited to 6.4 in (163 mm) at post no. 3, and there was no problem with the vehicle impacting the end of the concrete abutment. The final resting position of the vehicle was downstream and behind the rail, as seen in figure 22.

The vehicle damage, shown in figure 23, consisted of the crushing of the right-front corner of the vehicle, as well as scrapes and dents continuing down the side to the rear wheel assembly. The tire was torn off the right-front wheel, and the rim was bent. Occupant compartment damage included buckling of the floor on the passenger's side of the vehicle, as well as buckling of the dashboard. The maximum crush deformation of 13.75 in (349 mm) is shown schematically in figure 24.

Damage to the system, shown in figure 25, consisted of minor scrapes along the face of the rail and significant gouges in posts no. 1 and 2. There were only minor tire marks evident on the concrete abutment. The maximum permanent set deflection of the rail was 2.5 in (64 mm), which occurred at post no. 2.

The normalized longitudinal and lateral occupant impact velocities, as determined from high-speed film analysis, were 23.1 ft/s (7.0 m/s) and 25.2 ft/s (7.7 m/s), respectively. The maximum occupant ridedown decelerations were 2.5 g's (longitudinal) and 15.0 g's (lateral). The results of this analysis are summarized in figure 20.

The change in the splice detail appears to have improved the performance of the system considerably, as the rail deflection was greatly reduced. This resolved the problem of impacting the end of the concrete abutment but produced a new problem where the front wheel was now forced under the rail and snagged on posts no. 1 and 2. Tire marks on the posts indicated that a maximum snag of 5.5 in (140 mm) occurred at post no. 2. To remedy this problem, a 4-in (102 mm) deep blockout was added to post no. 1, and the 4-in (102 mm) blockout at posts no. 2 and 3 were increased to a depth of 8 in (203 mm). The details of these design changes can be seen in appendix A.



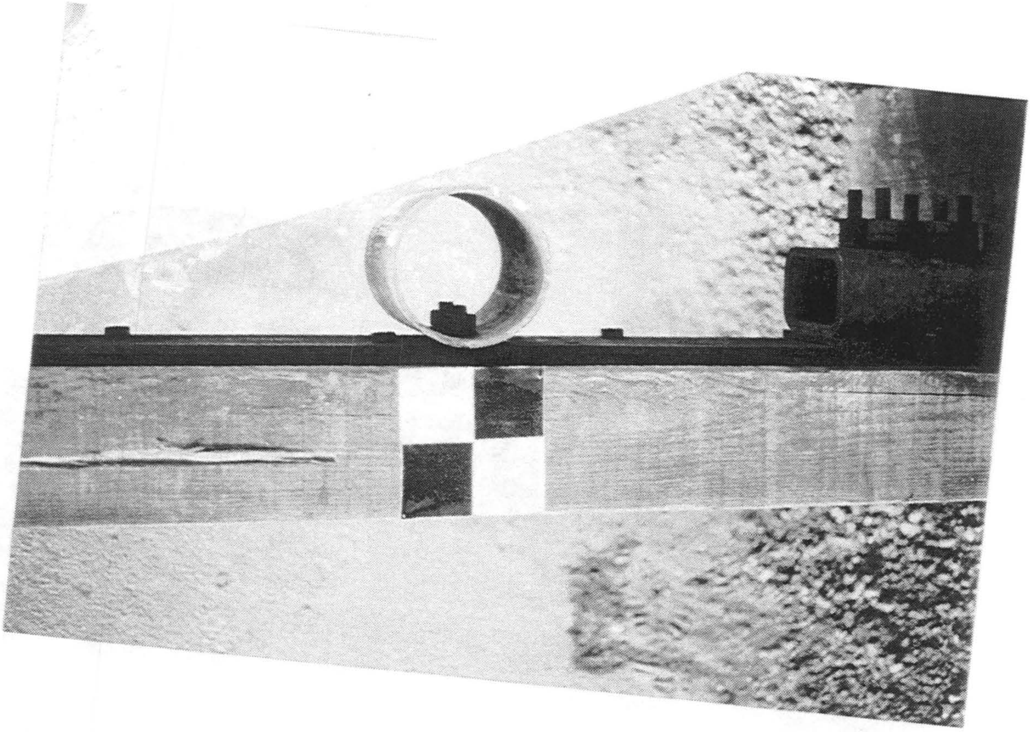
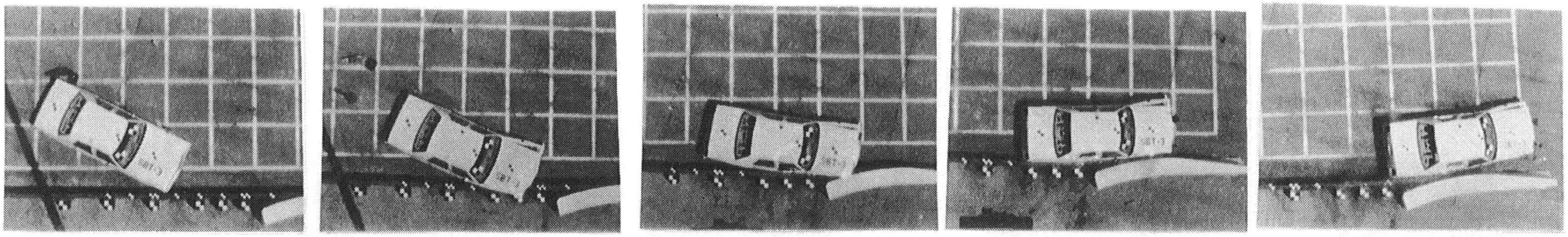
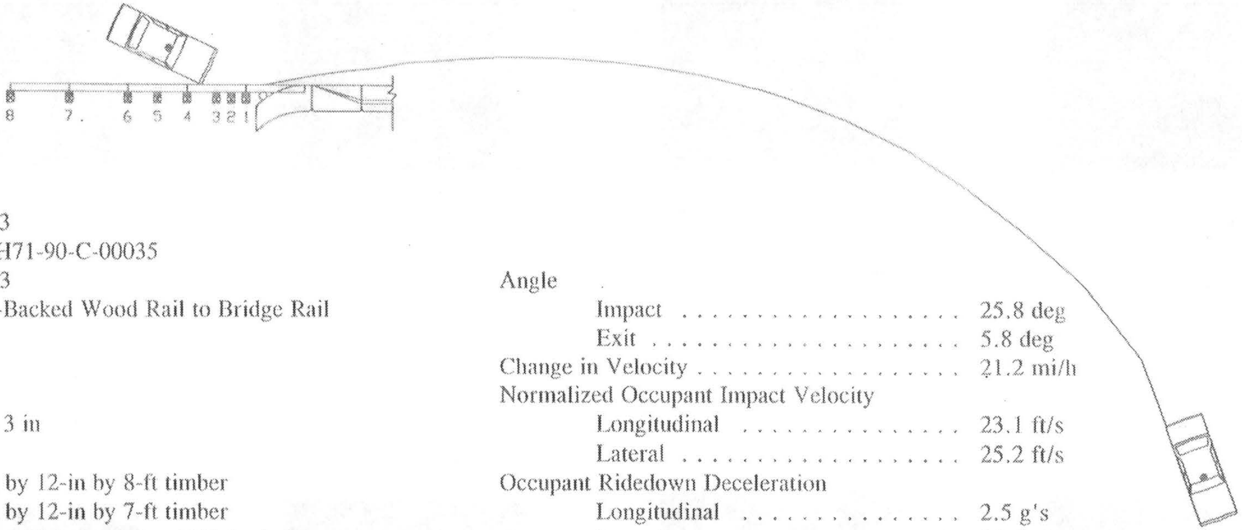


Figure 18. Design Modifications, Test SBT-3.

Figure 19. Impact Location, Test SBT-3.



Impact 80 ms 160 ms 240 ms 340 ms

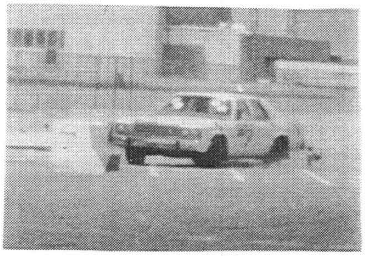


Test Number	SBT-3
Federal Contract No.	DTFH71-90-C-00035
Date	5/4/93
Installation	Steel-Backed Wood Rail to Bridge Rail
Transition	
Approach Guardrail	
Length	50 ft
Height	2 ft - 3 in
Material	
Posts 1-3	10-in by 12-in by 8-ft timber
Posts 4-8	10-in by 12-in by 7-ft timber
Rail	6-in by 10-in by 9-ft - 11½-in timber
Vehicle Model	1985 Ford LTD
Vehicle Weight	
Curb	3,940 lbs
Test Inertia	4,496 lbs
Gross Static	4,656 lbs
Speed	
Impact	62.0 mi/h
Exit	40.8 mi/h

Angle	
Impact	25.8 deg
Exit	5.8 deg
Change in Velocity	21.2 mi/h
Normalized Occupant Impact Velocity	
Longitudinal	23.1 ft/s
Lateral	25.2 ft/s
Occupant Ridedown Deceleration	
Longitudinal	2.5 g's
Lateral	15.0 g's
Vehicle Damage	
TAD	1-RFQ-5
VDI	01RYES2
Vehicle Rebound Distance	4 ft - 11 in @ 55 ft
Guardrail Damage	Minor
Maximum Deflections	
Permanent Set	2.5 in @ post No. 2
Dynamic	6.4 in @ post No. 3

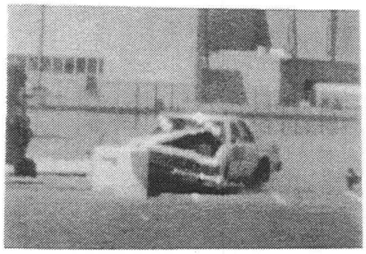
Conversion Factors: 1 in = 2.54 cm; 1 lb = 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

Figure 20. Summary of Test SBT-3.

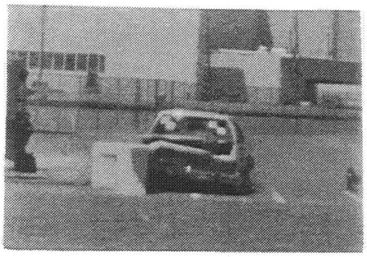


Impact

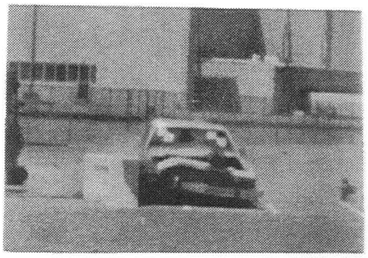
60 ms



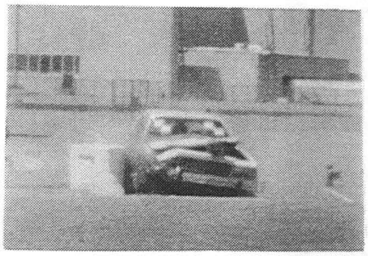
120 ms



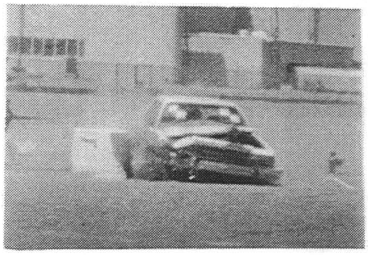
180 ms



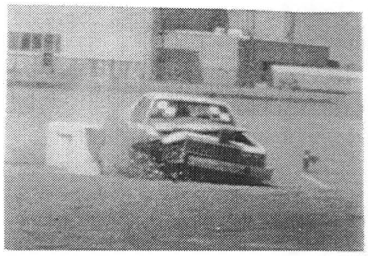
240 ms



300 ms



360 ms



440 ms

Figure 21. Downstream Sequential Photographs, Test SBT-3.

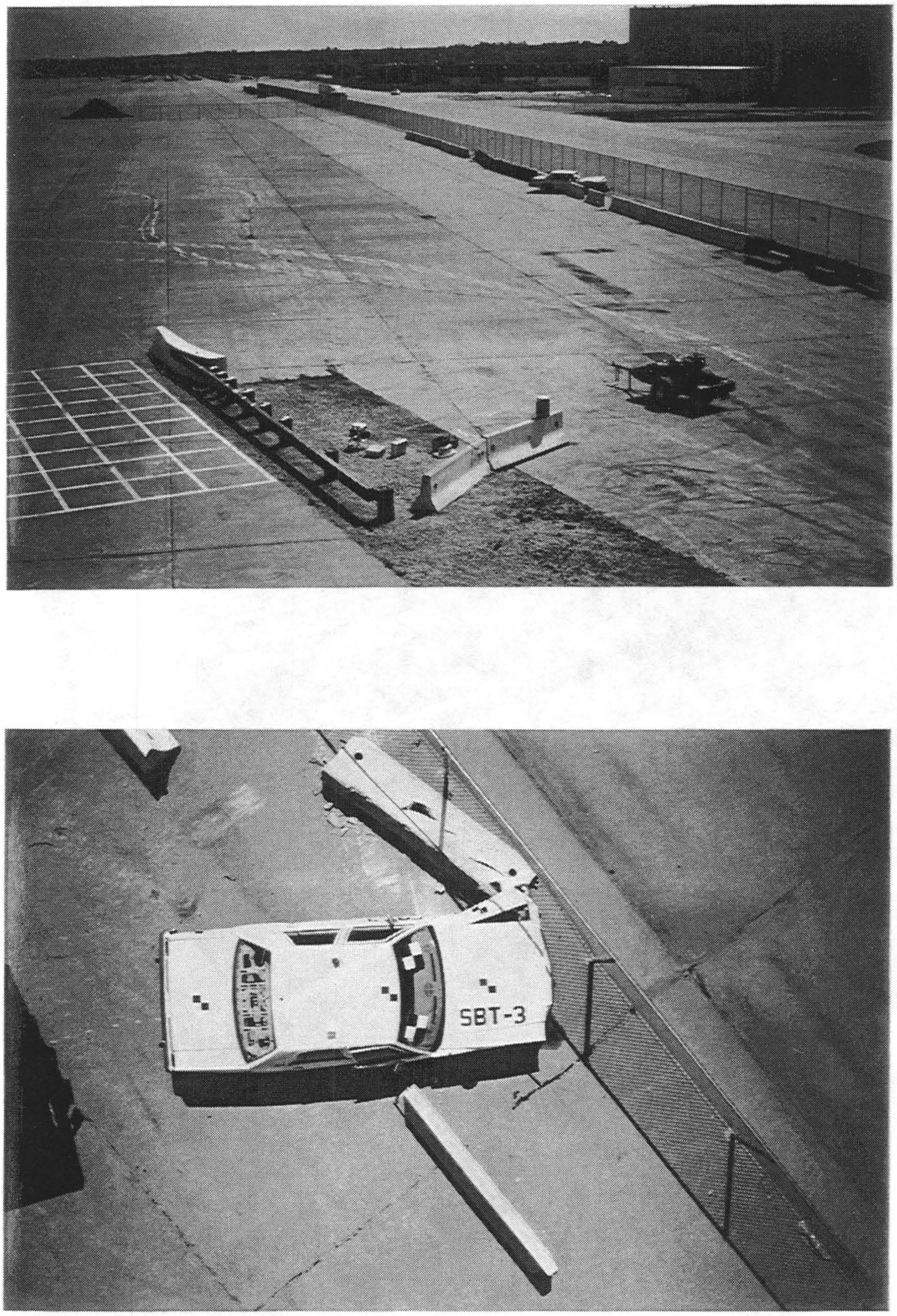


Figure 22. Vehicle Trajectory, Test SBT-3.

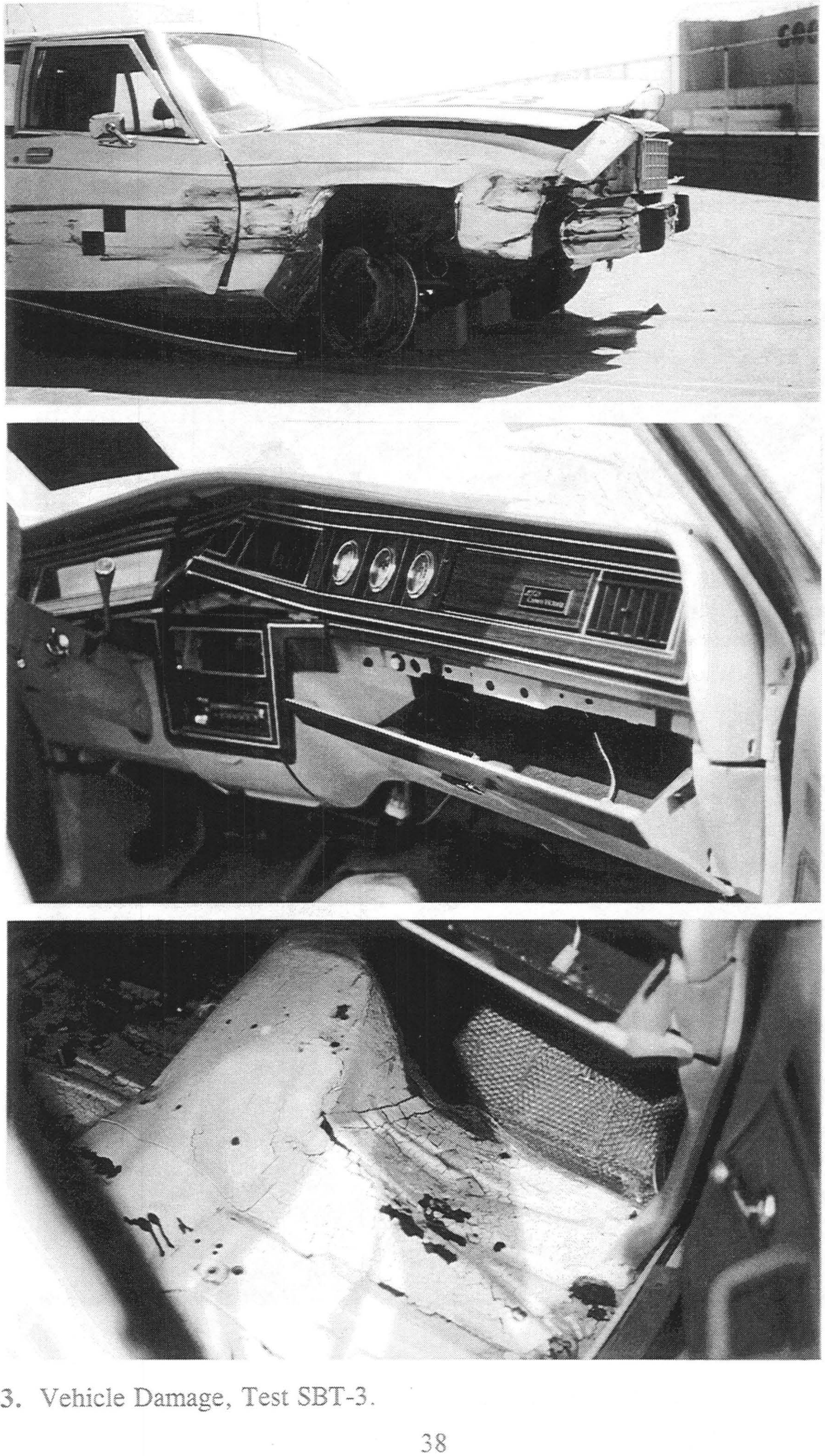


Figure 23. Vehicle Damage, Test SBT-3.

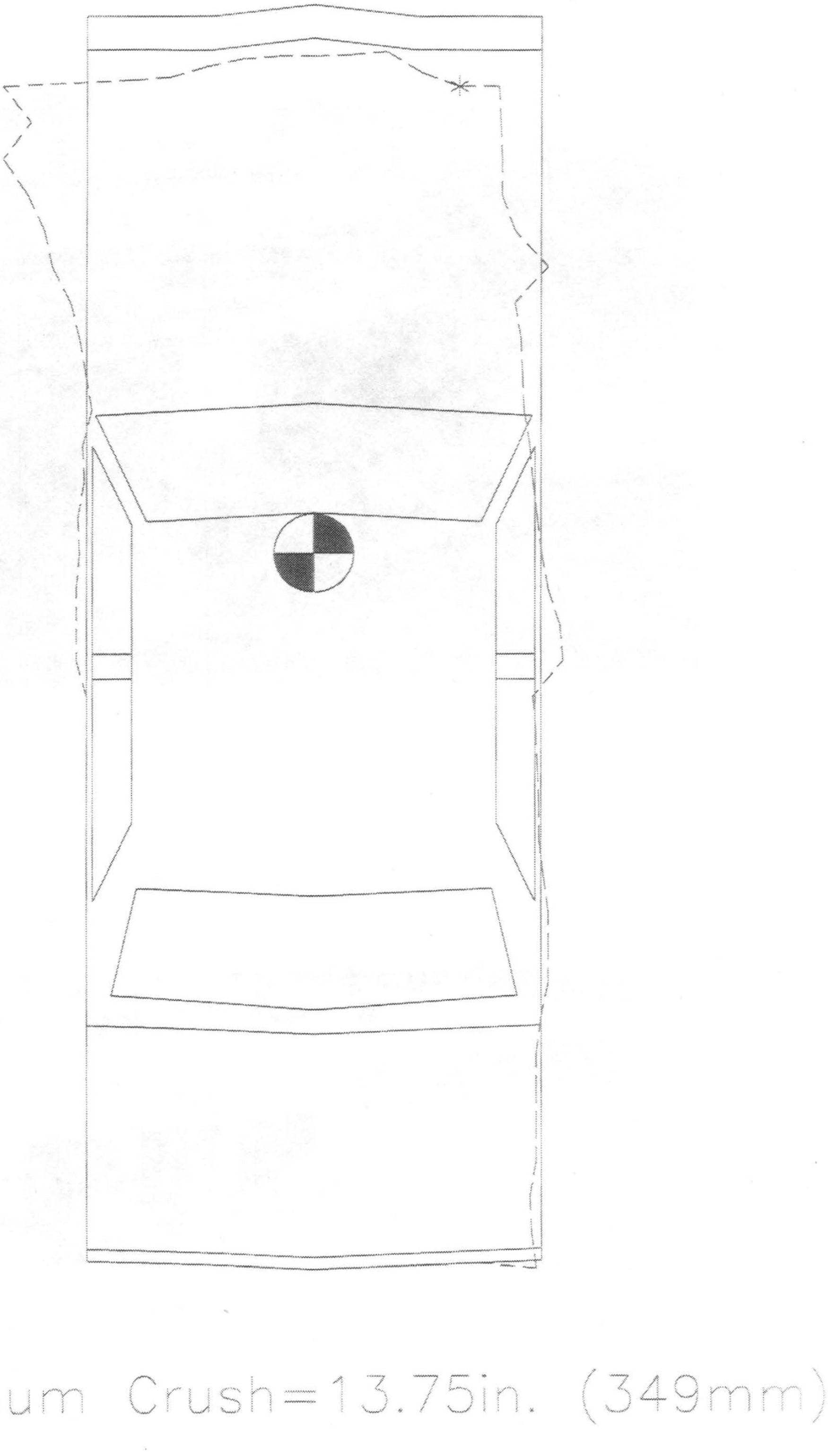


Figure 24. Crush Depth Diagram, Test SBT-3.

Figure 25. System Damage, Test SBT-3.

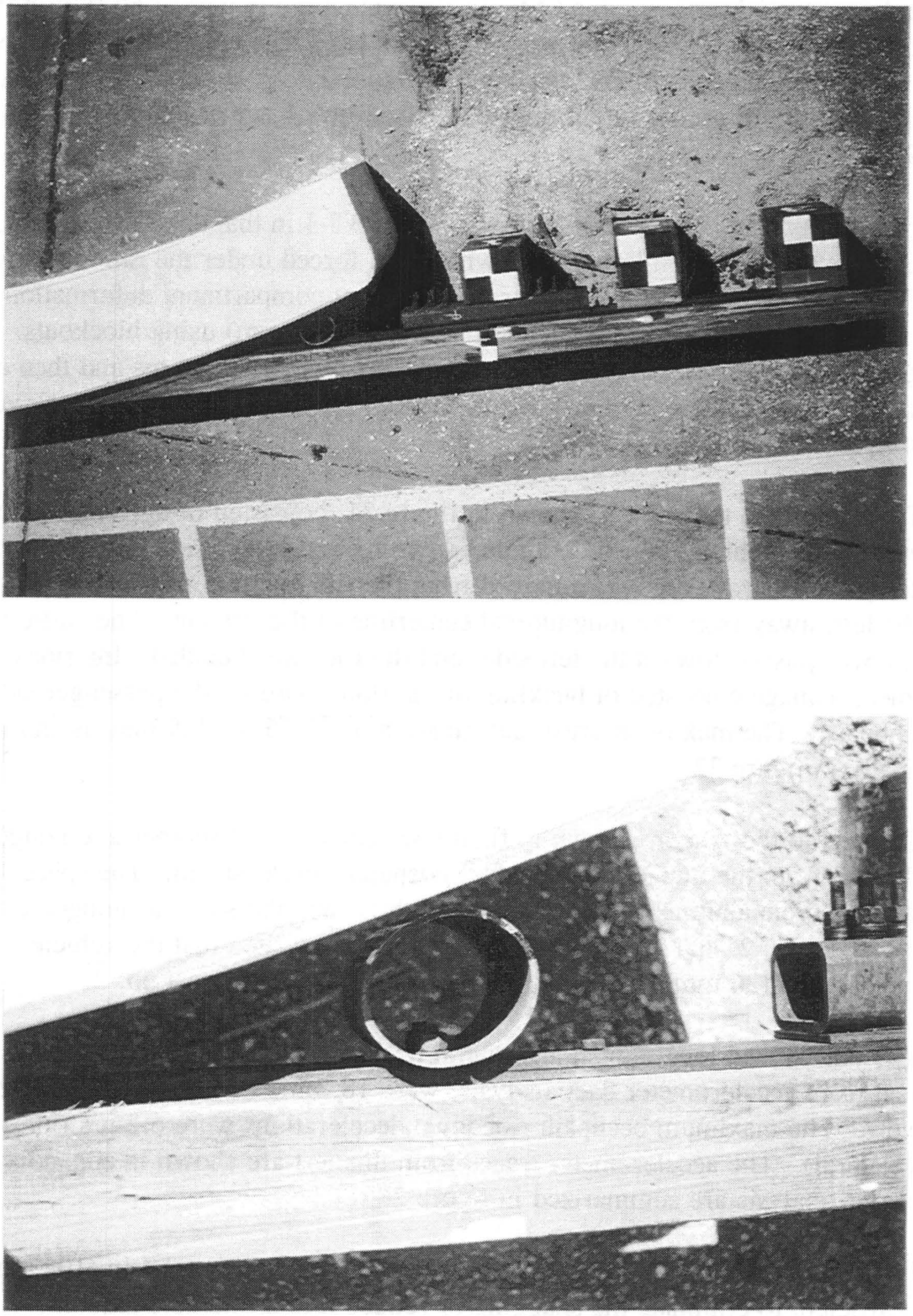


Figure 25. System Damage, Test SBT-3 (continued).

Test SBT-4

The design changes discussed in the previous section were incorporated into the system for this test. These changes can be seen in figure 26, and the design details are presented in appendix A. A 1984 Mercury Grand Marquis impacted the system at 60.0 mi/h (96.5 km/h) and 26.2 degrees. The impact point was located midway between the third and fourth posts from the concrete bridge abutment, as shown in figure 27. A summary of the test results and sequential photographs are shown in figure 28. Additional sequential photos are shown in figure 29.

The results of this test were similar to Test SBT-3 in that as the right-front corner of the vehicle was crushed upon impact, the wheel was forced under the rail and contacted the posts. This snagging resulted in considerable occupant compartment deformation, even though the first three posts had been offset an additional 4 in (102 mm) using blockouts. After this snagging occurred, the vehicle became parallel to the system at 246 ms and then exited the system at 357 ms and an angle of 4.0 degrees. The final resting position of the vehicle is shown in figure 30.

The damage to the vehicle, shown in figure 31, consisted of deformation of the right-front corner of the vehicle, which continued down the passenger side of the vehicle as scrapes and dents. The left-front tire was removed from the rim, and the front bumper was pushed toward the left, away from the longitudinal centerline of the vehicle. The entire front end of the vehicle was pushed toward the left side, and the roof was buckled. Interior occupant compartment damage consisted of buckling of the floorboard on the passenger side and the front dashboard. The maximum crush deformation of 13.75 in (349 mm) is shown schematically in figure 32.

Damage to the system, shown in figure 33, consisted of scrapes and gouges along the face of the rail from the impact point to the midspan of the first rail. The spacer pipe between the rail and concrete abutment was deformed slightly, and the soil was gouged considerably in front of posts no. 1, 2, and 3. Markings on the posts indicated that the vehicle snagged approximately 1 in (26 mm) on post no. 1 and 3 in (76 mm) on post no. 2.

The normalized longitudinal and lateral occupant impact velocities for this test, as determined from accelerometer data analysis, were 18.8 ft/s (5.7 m/s) and 23.9 ft/s (7.3 m/s), respectively. The maximum occupant ridedown decelerations were 6.2 g's (longitudinal) and 16.7 g's (lateral). The accelerometer traces from this test are shown in appendix C, and the results of this analysis are summarized in figure 28.

It was obvious from the results of this test that the additional 4 in (102 mm) of blockout was not sufficient to eliminate the snagging or reduce it to a tolerable amount. It was deemed impractical to extend the blockout beyond 8 in (203 mm), so it was decided to add a rub rail to the system to reduce the snag potential. A 4-in by 6-in by 11-ft 6-in (102-mm by 152-mm by

3.55-m) wood rub rail was attached to posts no. 1, 2, and 3 for the next test. The details of this design change can be found in appendix A.

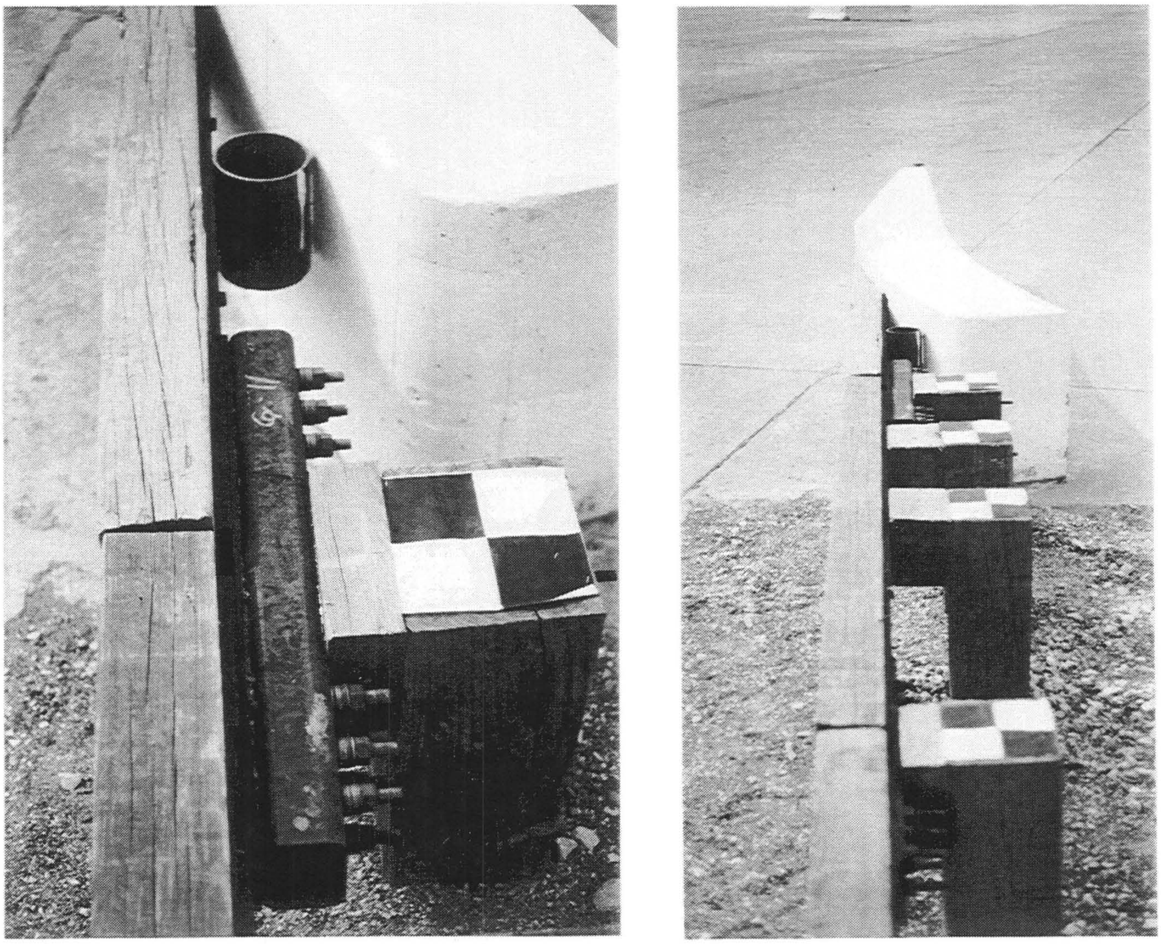


Figure 26. Design Modifications, Test SBT-4.

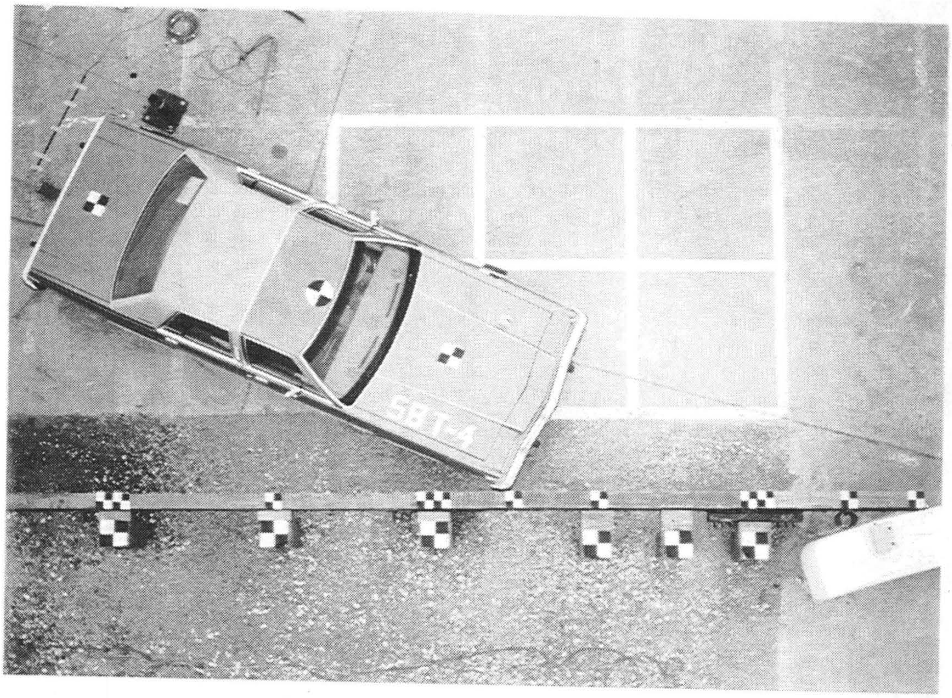
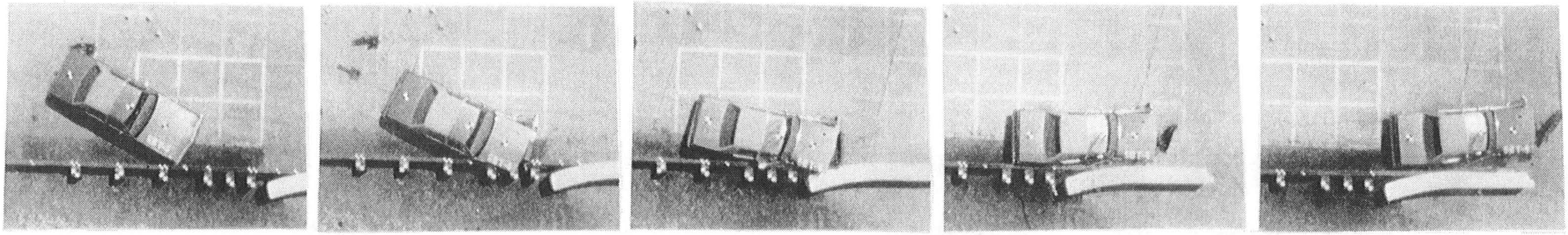
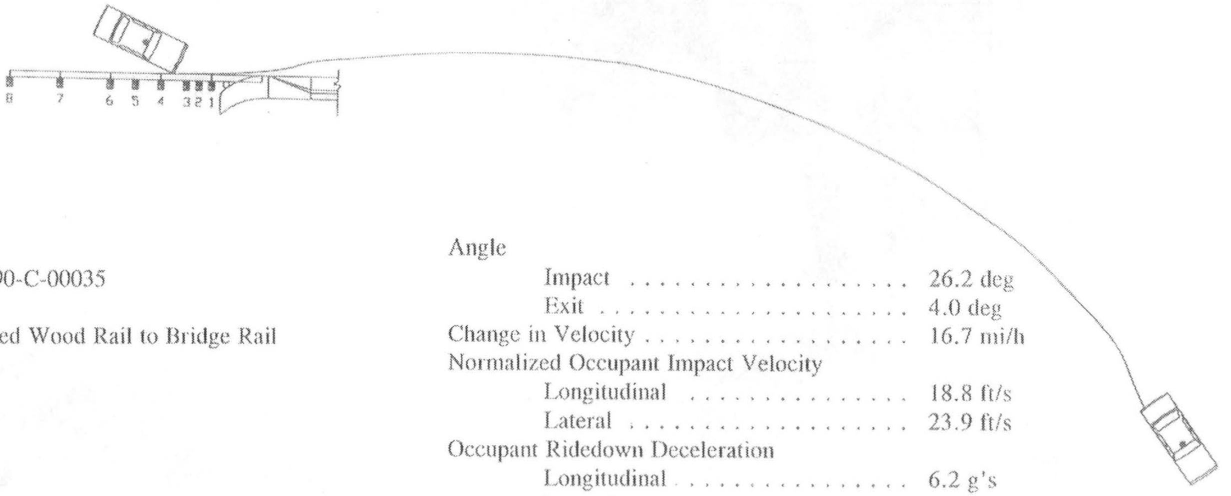


Figure 27. Impact Location, Test SBT-4.



Impact 80 ms 160 ms 280 ms 400 ms

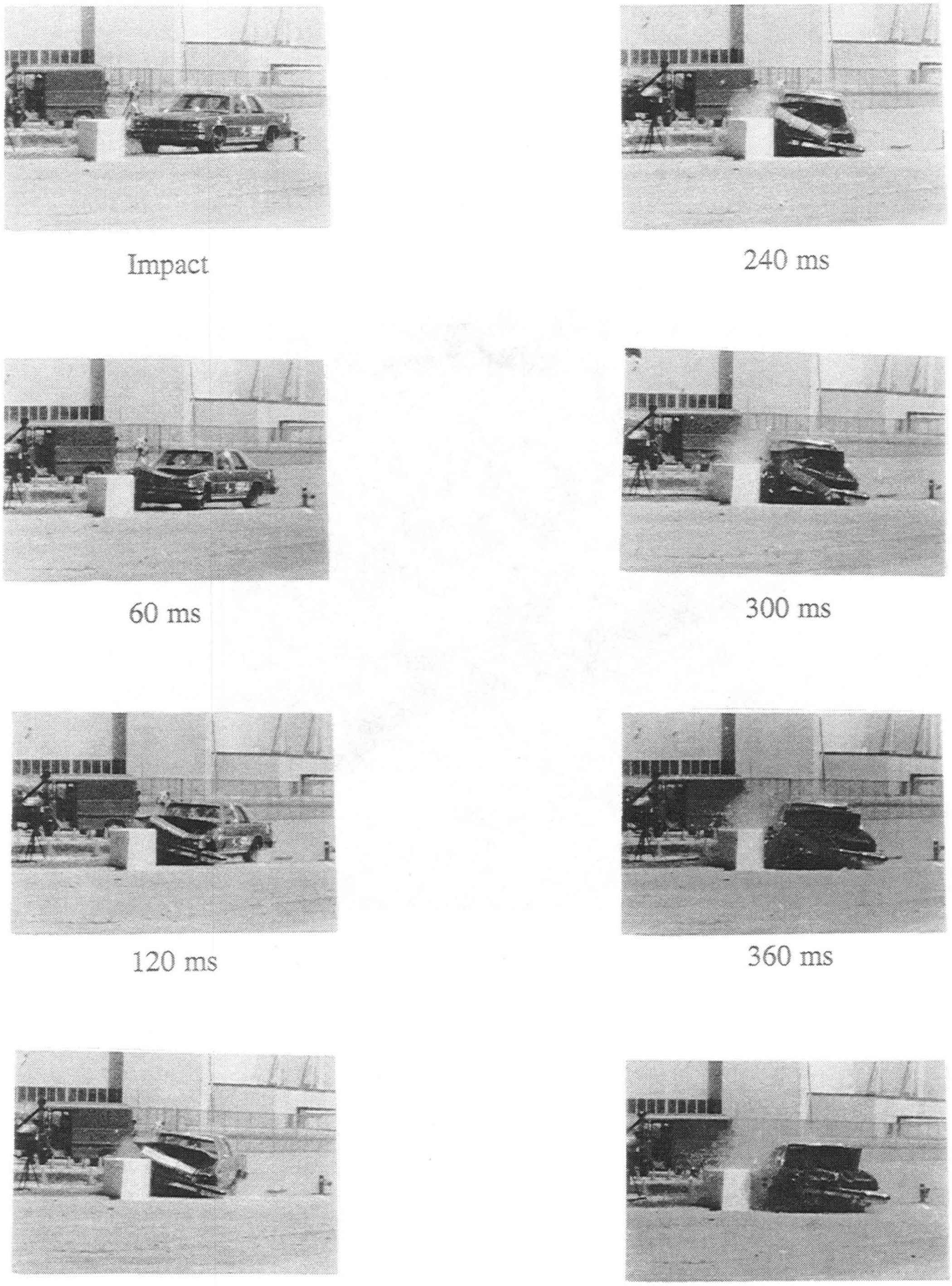


Test Number	SBT-4
Federal Contract No.	DTFH71-90-C-00035
Date	5/27/94
Installation	Steel-Backed Wood Rail to Bridge Rail Transition
Approach Guardrail	
Length	50 ft
Height	2 ft - 3 in
Material	
Posts 1-3	10-in by 12-in by 8-ft timber
Posts 4-8	10-in by 12-in by 7-ft timber
Rail	6-in by 10-in by 9 ft - 11½- in timber
Vehicle Model	1984 Mercury Grand Marquis
Vehicle Weight	
Curb	3,910 lbs
Test Inertia	4,668 lbs
Gross Static	4,508 lbs
Speed	
Impact	60.0 mi/h
Exit	43.3 mi/h

Angle	
Impact	26.2 deg
Exit	4.0 deg
Change in Velocity	16.7 mi/h
Normalized Occupant Impact Velocity	
Longitudinal	18.8 ft/s
Lateral	23.9 ft/s
Occupant Ridedown Deceleration	
Longitudinal	6.2 g's
Lateral	16.7 g's
Vehicle Damage	
TAD	1-RFQ-5
VDI	01RYES2
Vehicle Rebound Distance	5 ft - 7 in @ 55 ft
Guardrail Damage	Minor
Maximum Deflections	
Permanent Set	1.5 in @ post No. 3
Dynamic	8.9 in @ post No. 3

Conversion Factors: 1 in = 2.54 cm; 1 lb = 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

Figure 28. Summary of Test SBT-4.



Impact

60 ms

120 ms

180 ms

240 ms

300 ms

360 ms

420 ms

Figure 29. Downstream Sequential Photographs, Test SBT-4.

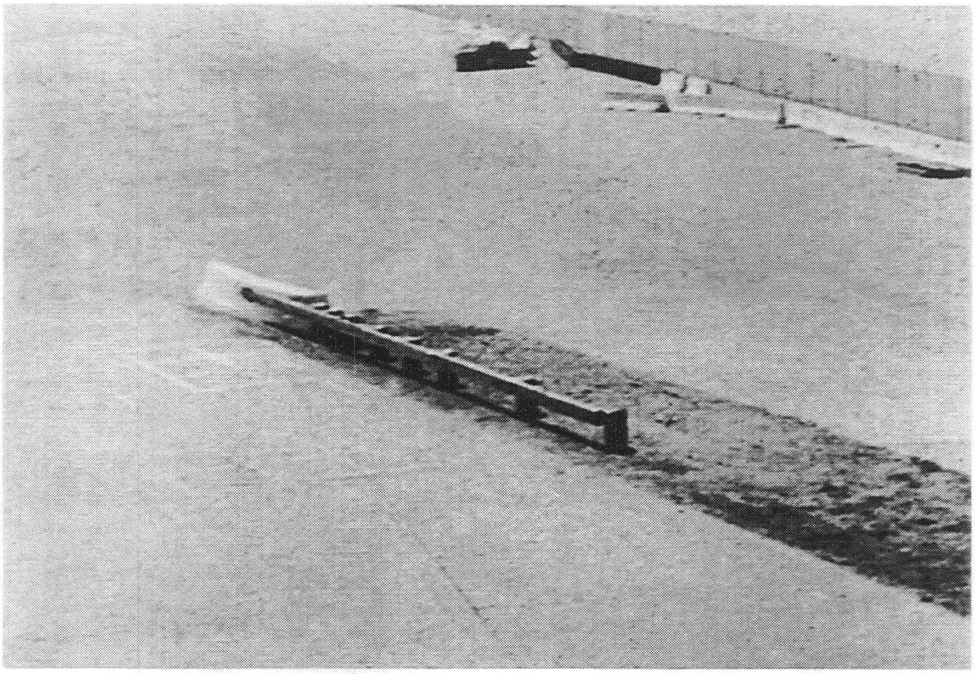


Figure 30. Vehicle Trajectory, Test SBT-4.

Figure 31. Vehicle Damage, Test SBT-4.

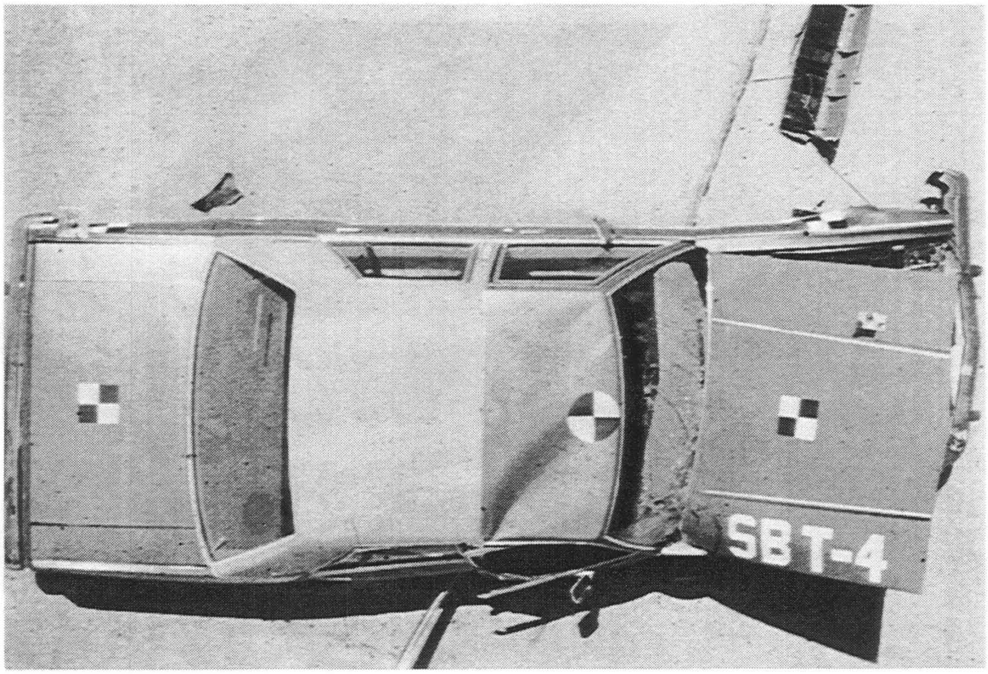
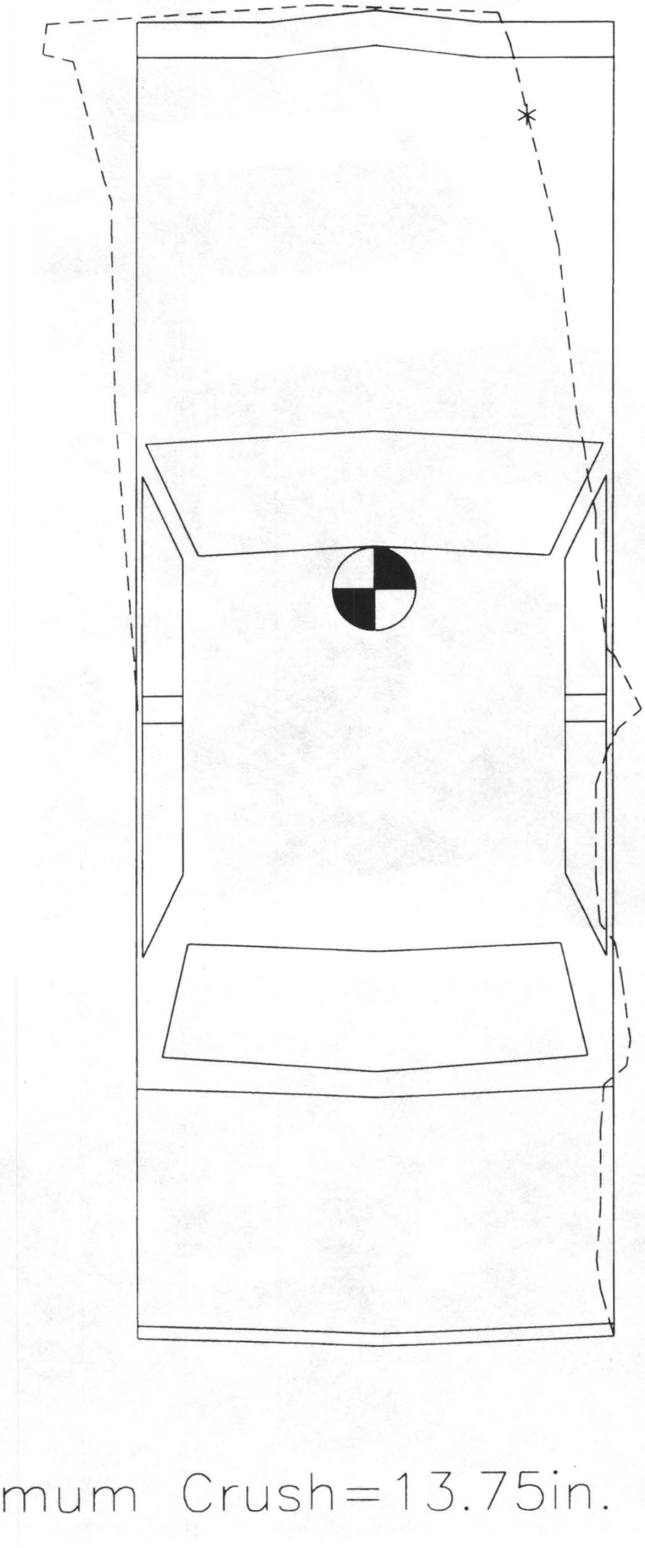


Figure 31. Vehicle Damage, Test SBT-4 (continued).



*Maximum Crush=13.75in. (349mm)

Figure 32. Crush Depth Diagram, Test SBT-4.

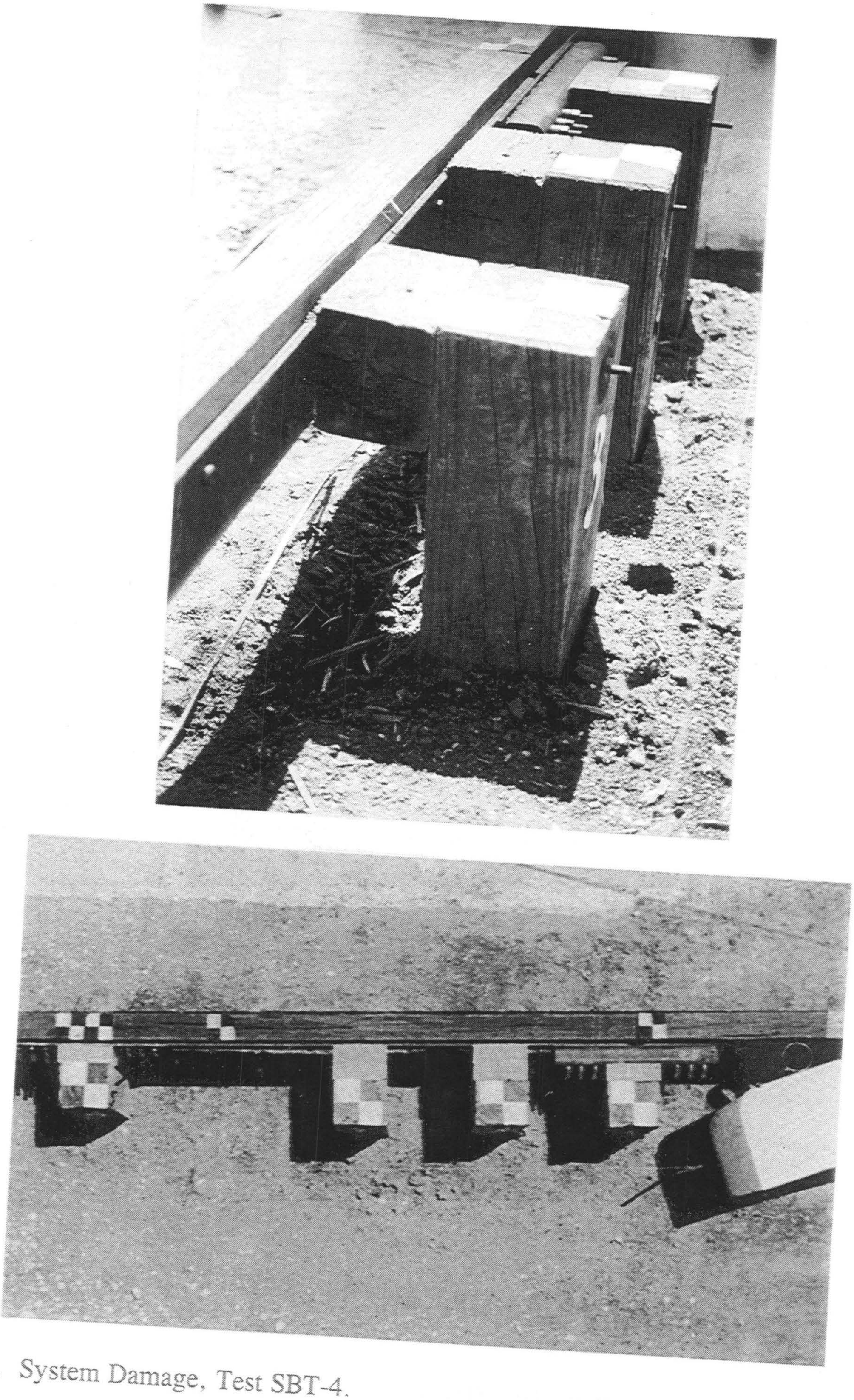


Figure 33. System Damage, Test SBT-4.

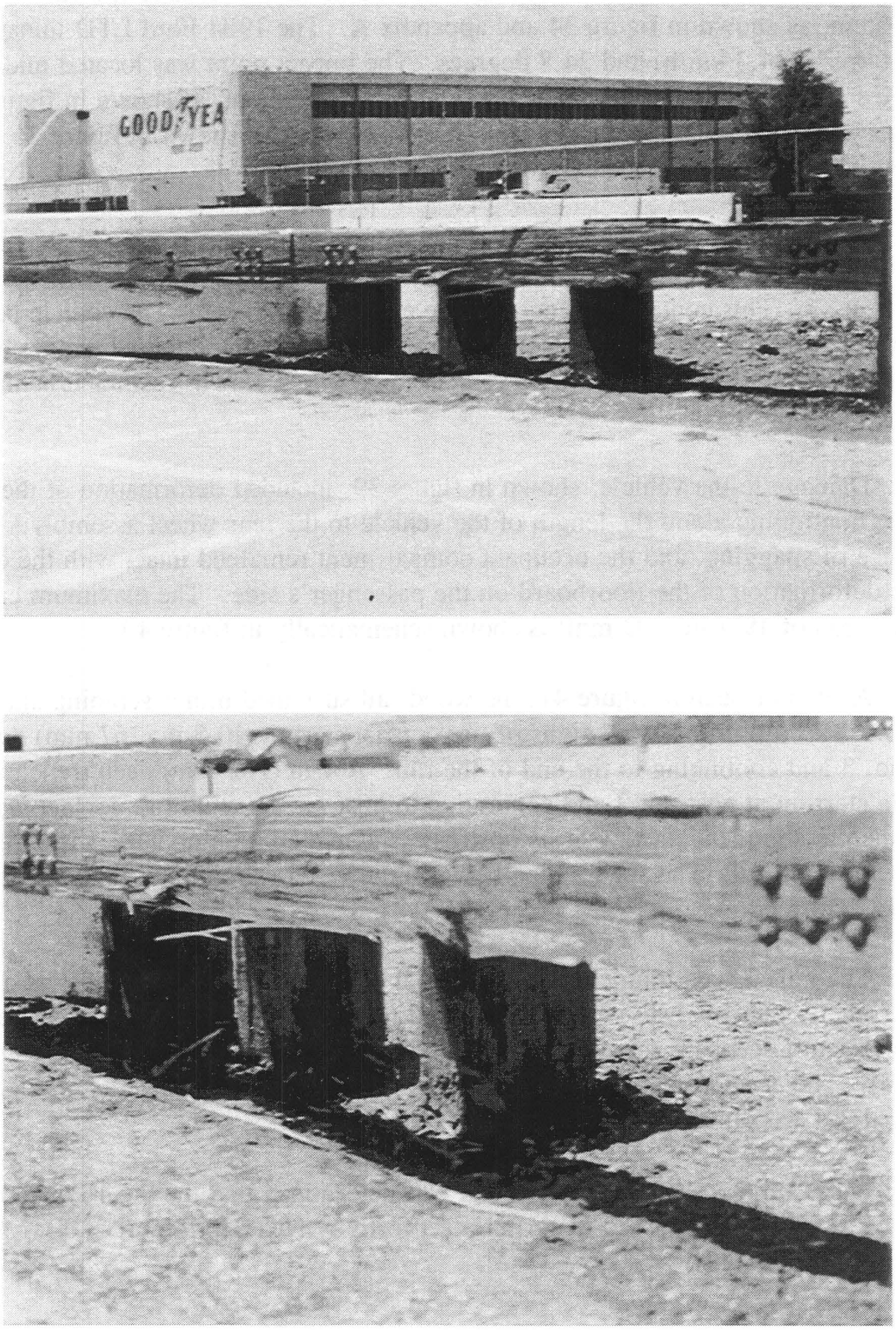


Figure 33. System Damage, Test SBT-4 (continued).

Test SBT-5

To eliminate the wheel snagging observed in the previous test, a rub rail was added to the system, as shown in figure 34 and appendix A. The 1984 Ford LTD impacted the system at 58.6 mi/h (94.3 km/h) and 24.8 degrees. The impact point was located midway between the third and fourth posts from the concrete bridge abutment, as shown in figure 35. A summary of the test results and sequential photographs are shown in figure 36. Additional sequential photographs are shown in figure 37.

Upon impact with the wood rail, the right-front corner of the vehicle was crushed inward, and the front tire contacted the rub rail approximately 10.5 in (267 mm) downstream of post no. 3. This contact continued to the end of the rub rail. The vehicle became parallel to the rail 206 ms after impact. It was smoothly redirected and exited the system at 367 ms and at an angle of 7.3 degrees. The vehicle came to rest downstream and behind the rail, as shown in figure 38.

Damage to the vehicle, shown in figure 39, included deformation of the right-front corner, continuing along the length of the vehicle to the rear wheel assembly. There was no evidence of snagging, and the occupant compartment remained intact with the exception of minor deformation of the floorboard on the passenger's side. The maximum crush deformation of 19.4 in (492 mm) is shown schematically in figure 40.

As can be seen in figure 41, the wood rail sustained minor scraping and gouging along its face. The rub rail showed signs of tire contact starting 10.5 in (267 mm) downstream of post no. 3 and continuing to the end of the rail. A 4-in (102-mm) deep trench was dug by the vehicle starting at post no. 3 and continuing to post no. 1. Full tire contact was evident on the concrete abutment starting at its upstream end and continuing until 3 in (76 mm) before the end of the first rail. The spacer pipe between the wood rail and the concrete abutment was slightly deformed.

The normalized longitudinal and lateral occupant impact velocities, as determined from accelerometer data analysis, were 21.5 ft/s (6.6 m/s) and 24.8 ft/s (7.6 m/s), respectively. The maximum occupant ridedown decelerations were 4.0 g's (longitudinal) and 17.8 g's (lateral). The accelerometer traces from this test are shown in appendix C, and the results of this analysis are summarized in figure 36.

Based on the results of this test, it was determined that the Steel-Backed Wood Rail to Bridge Rail Transition passed the criteria set forth by NCHRP Report 230 for guardrail to bridge rail transitions.(4)

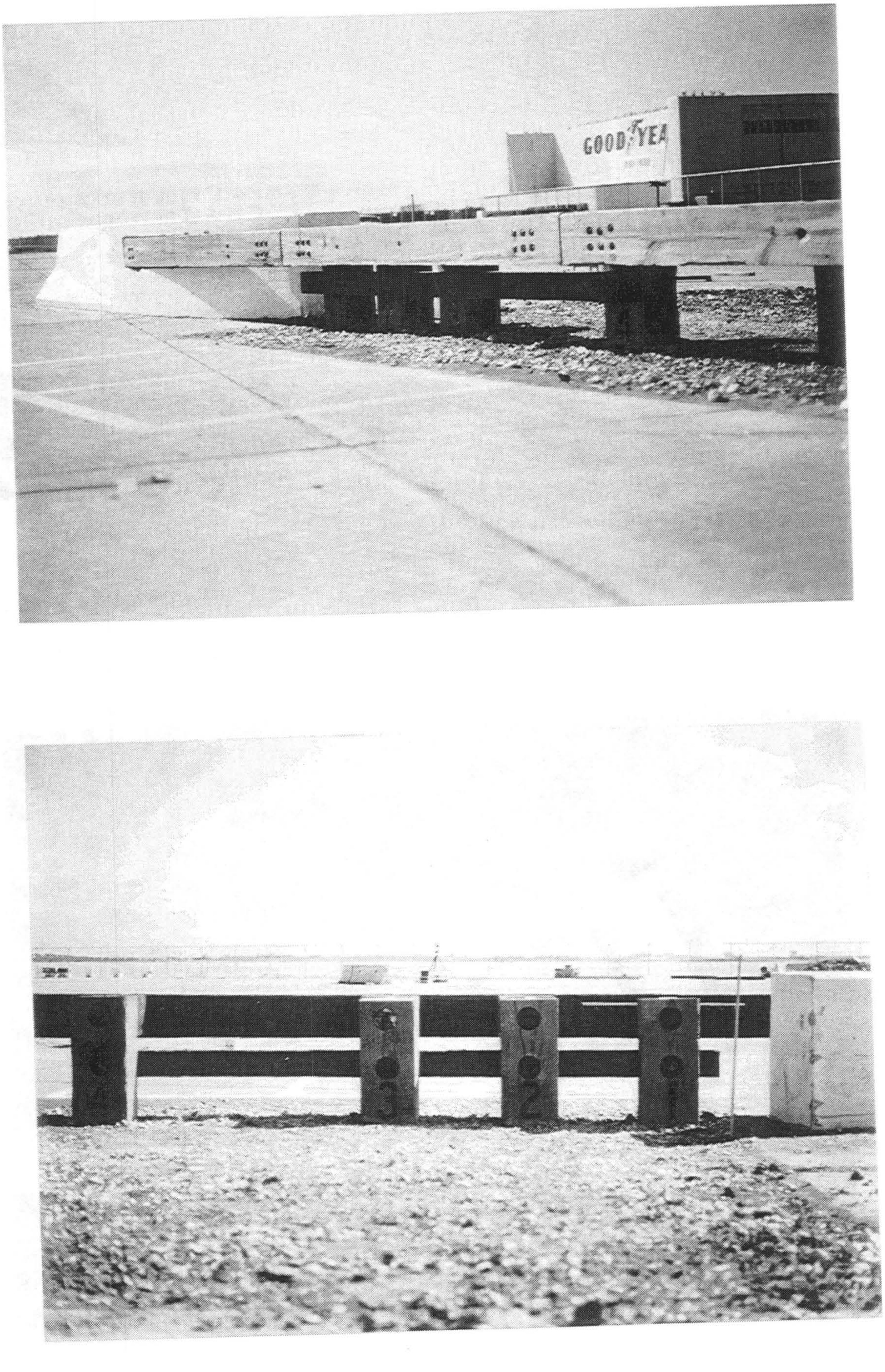


Figure 34. Design Modifications, Test SBT-5.

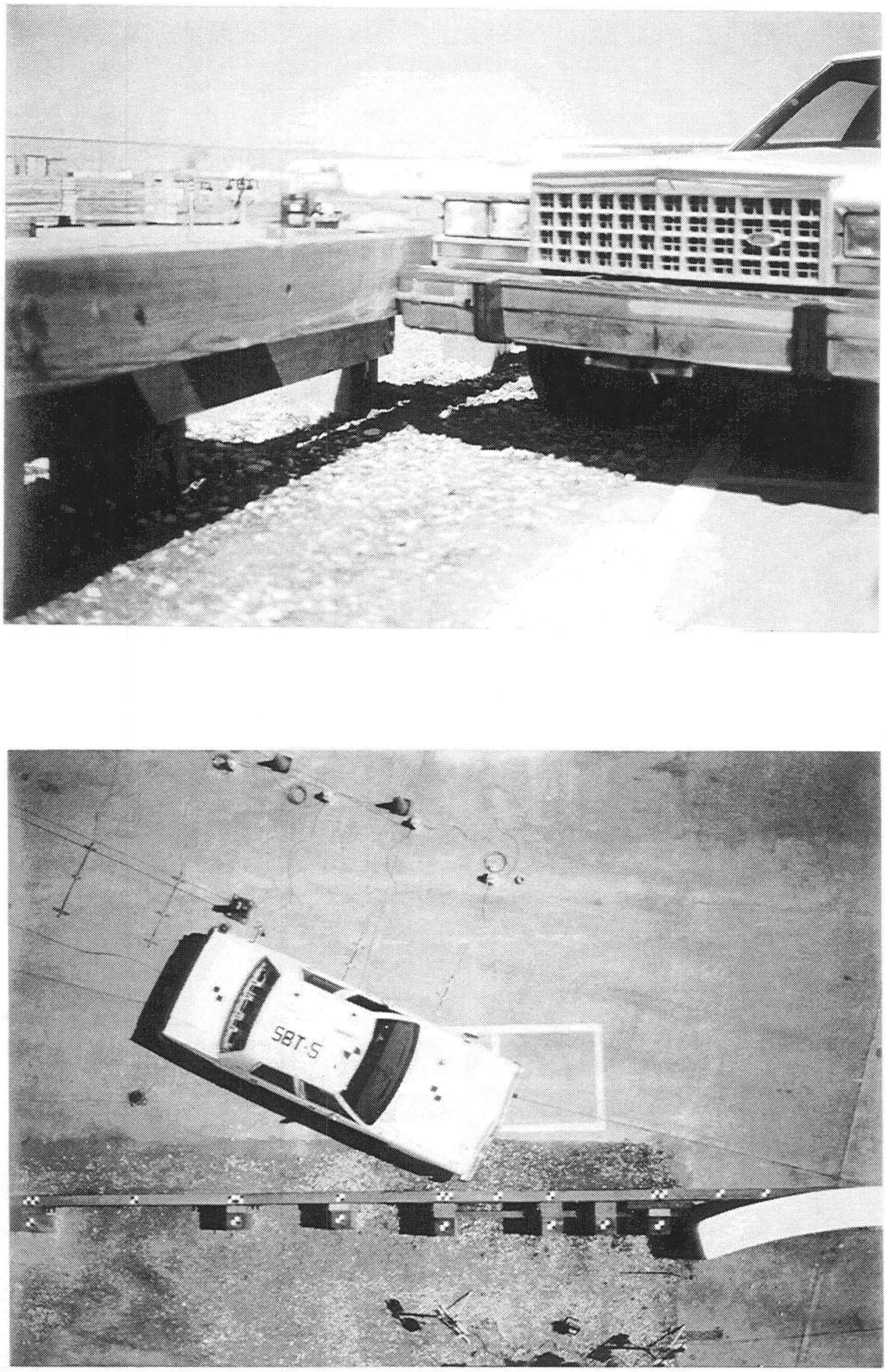
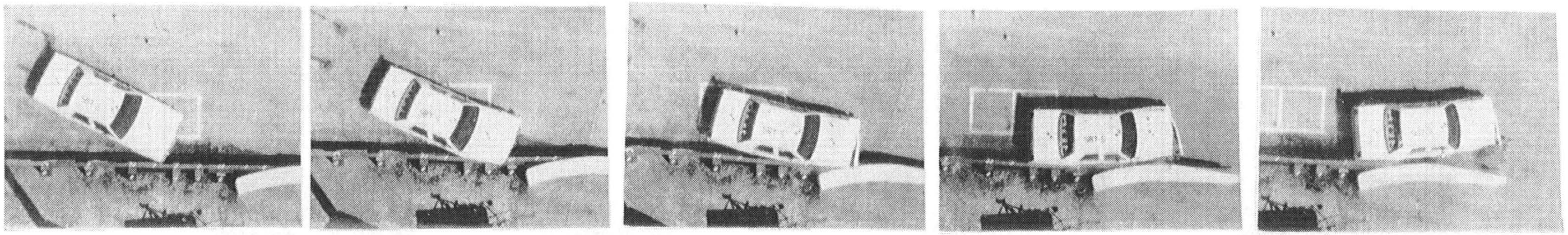
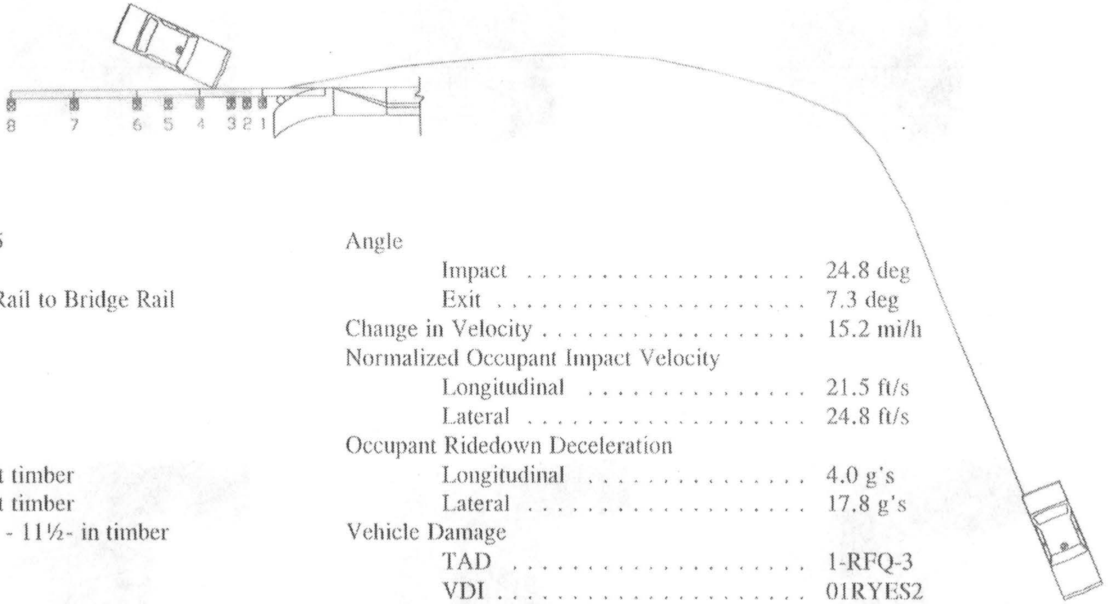


Figure 35. Impact Location, Test SBT-5.



Impact 70 ms 150 ms 240 ms 360 ms

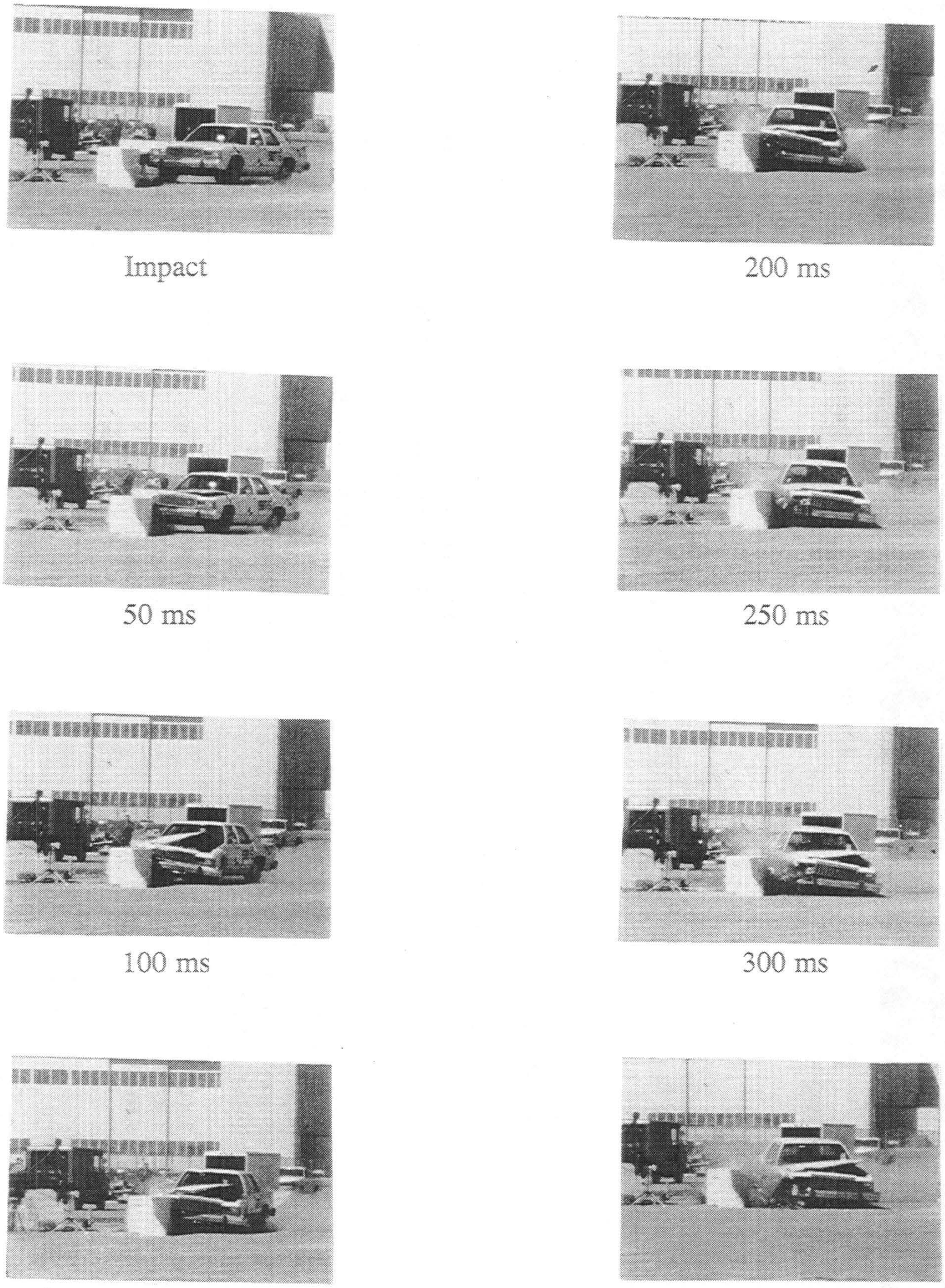


Test Number	SBT-5
Federal Contract No.	DTFH71-90-C-00035
Date	3/23/95
Installation	Steel-Backed Wood Rail to Bridge Rail
Transition	
Approach Guardrail	
Length	50 ft
Height	2 ft - 3 in
Material	
Posts 1-3	10-in by 12-in by 8-ft timber
Posts 4-8	10-in by 12-in by 7-ft timber
Rail	6-in by 10-in by 9 ft - 11½- in timber
Vehicle Model	1984 Ford LTD
Vehicle Weight	
Curb	3,860 lbs
Test Inertia	4,500 lbs
Gross Static	4,660 lbs
Speed	
Impact	58.6 mi/h
Exit	43.4 mi/h

Angle	
Impact	24.8 deg
Exit	7.3 deg
Change in Velocity	15.2 mi/h
Normalized Occupant Impact Velocity	
Longitudinal	21.5 ft/s
Lateral	24.8 ft/s
Occupant Ridedown Deceleration	
Longitudinal	4.0 g's
Lateral	17.8 g's
Vehicle Damage	
TAD	1-RFQ-3
VDI	01RYES2
Vehicle Rebound Distance	5 ft @ 60 ft
Guardrail Damage	Minor
Maximum Deflections	
Permanent Set	1.3 in @ post No. 2
Dynamic	6.25 in @ post No. 2

Conversion Factors: 1 in = 2.54 cm; 1 lb = 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

Figure 36. Summary of Test SBT-5.



Impact

50 ms

100 ms

150 ms

200 ms

250 ms

300 ms

400 ms

Figure 37. Downstream Sequential Photographs, Test SBT-5.

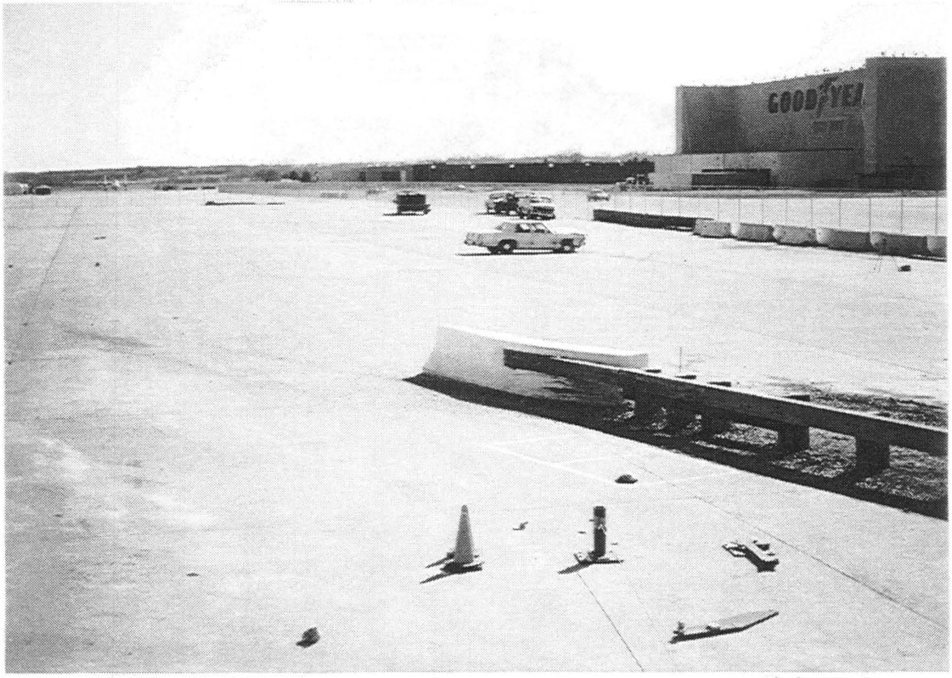


Figure 38. Vehicle Trajectory, Test SBT-5.

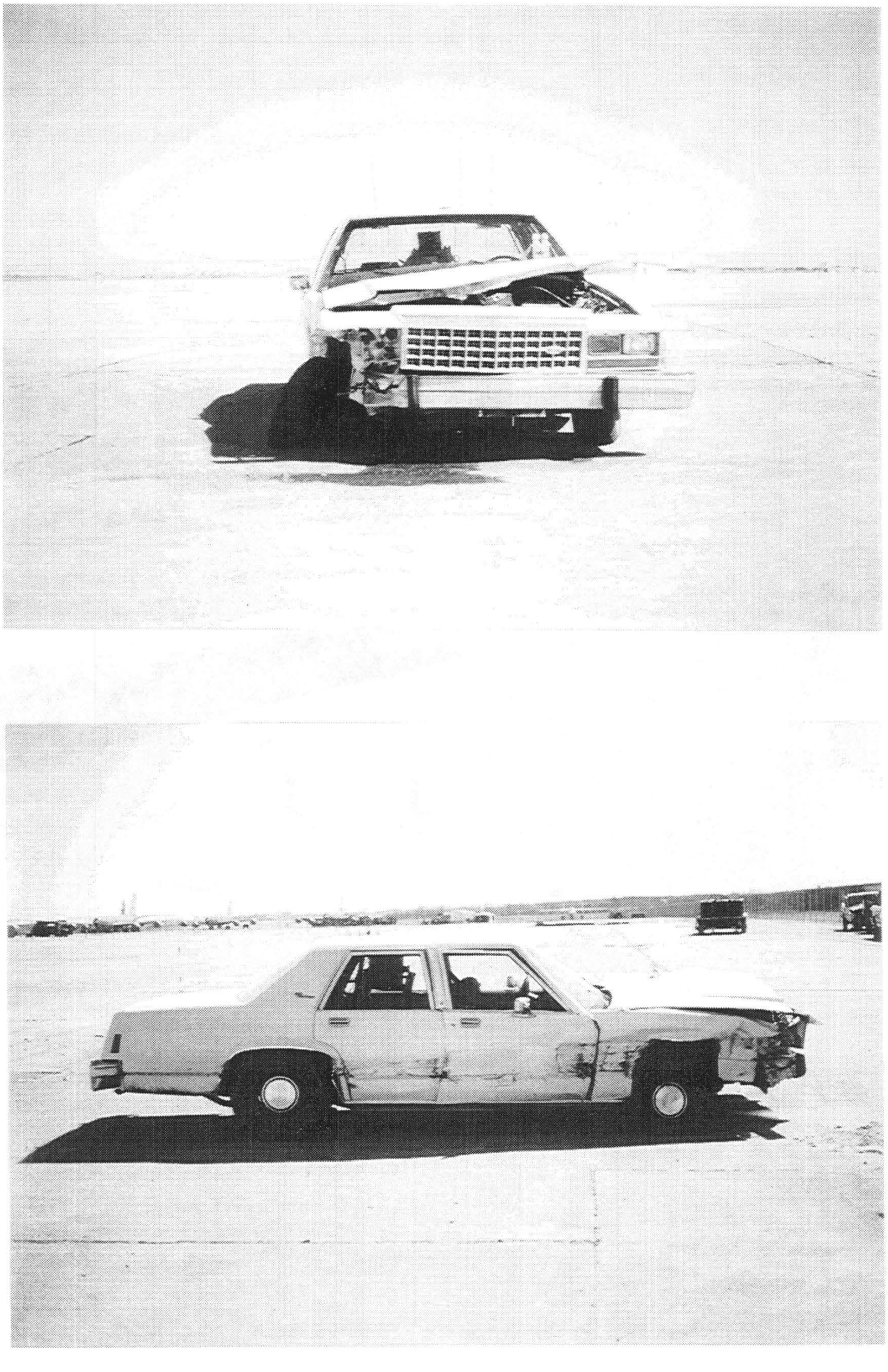
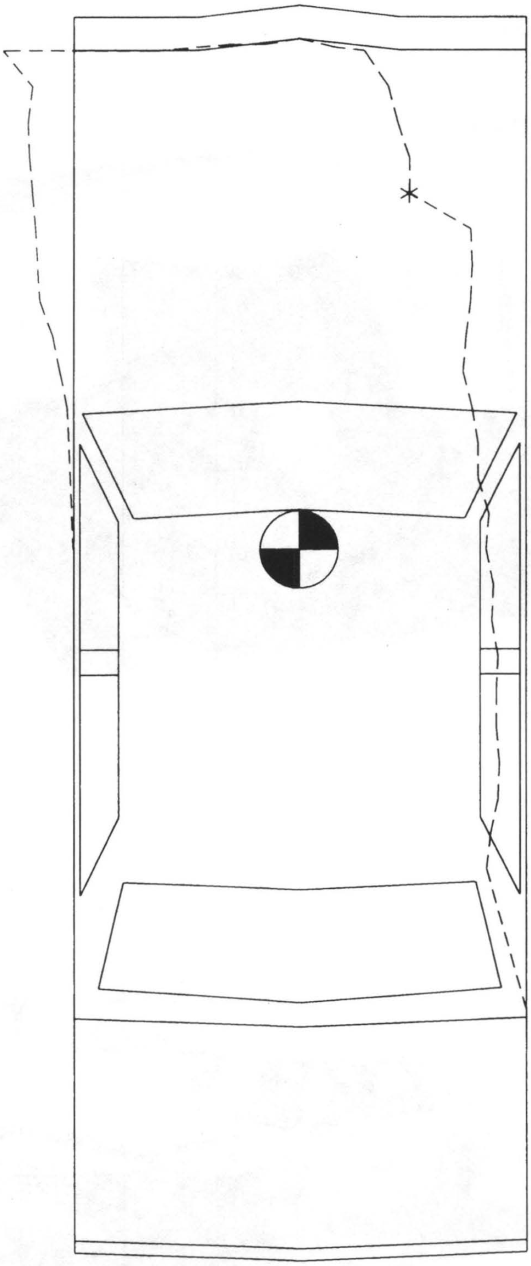


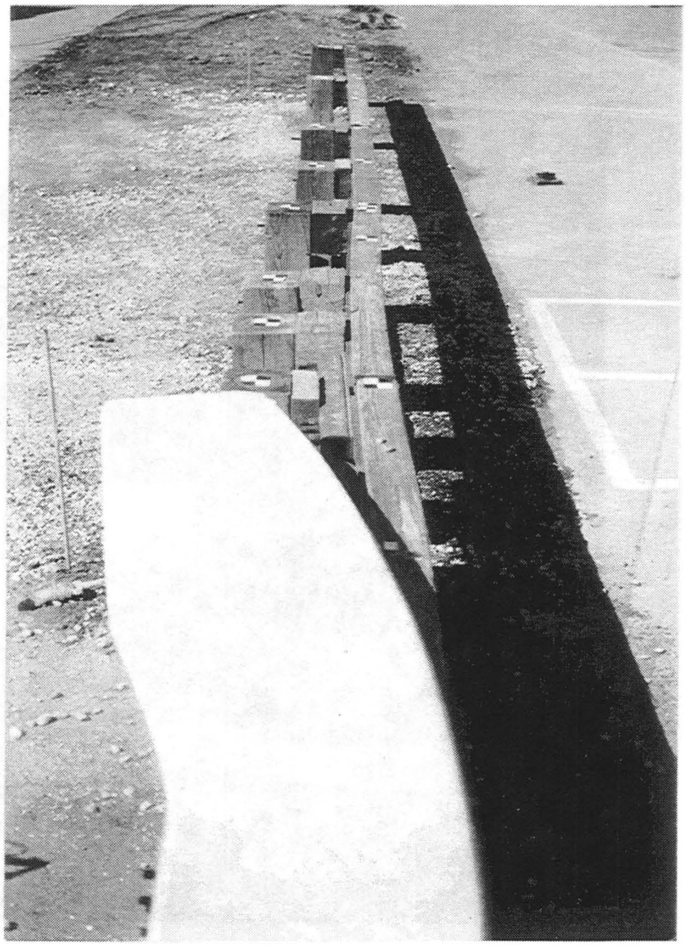
Figure 39. Vehicle Damage, Test SBT-5.

Figure 39. Vehicle Damage, Test SBT-5 (continued).



∗Maximum Crush=19.4in. (492mm)

Figure 40. Crush Depth Diagram, Test SBT-5.



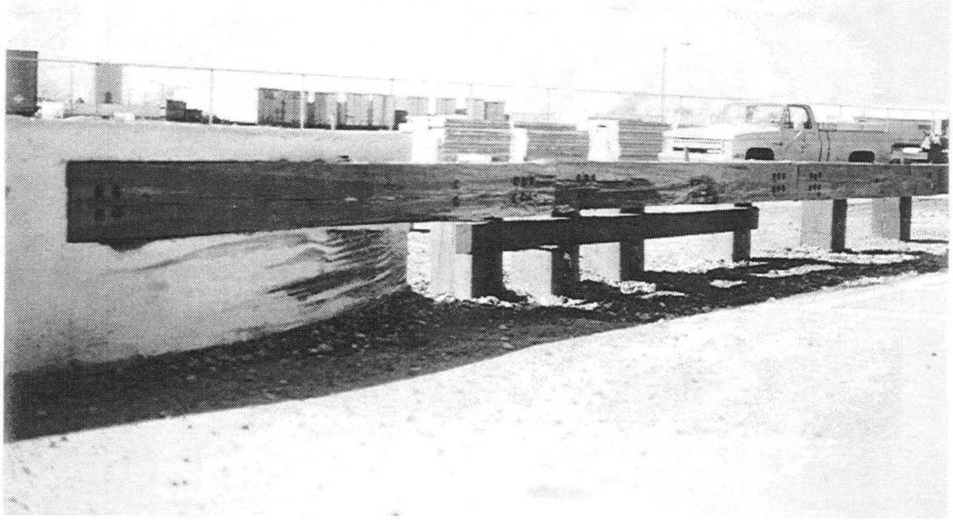
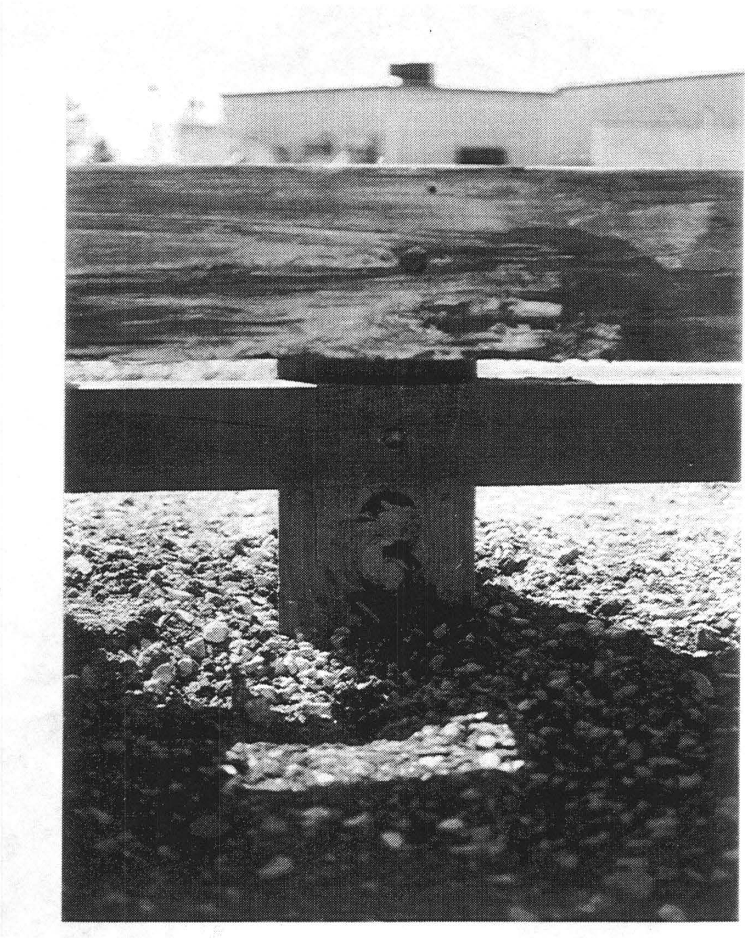


Figure 41. System Damage, Test SBT-5.



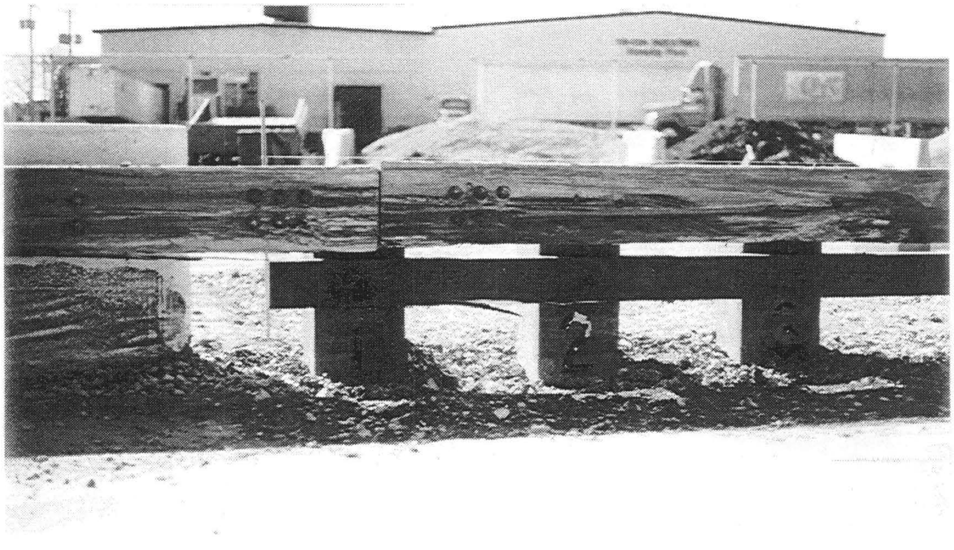


Figure 41. System Damage, Test SBT-5 (continued).

EVALUATION SUMMARY

Five full-scale vehicle crash tests were performed on the Steel-Backed Wood Rail to Bridge Rail Transition. These tests were evaluated, conducted, and reported in accordance with the criteria and requirements for guardrail to bridge rail transitions stated in NCHRP Report 230.(4) Table 2 summarizes the relevant evaluation criteria, as well as the findings from the five tests reported. As shown in this table, the final design of the Steel-Backed Wood Rail to Bridge Rail Transition successfully passed all of the requirements for guardrail to bridge rail transitions.

Table 2. Summary of Safety Performance Results, SBT Series.

Evaluation Factors	**Evaluation Criteria**	**Test SBT-1**	**Test SBT-2**	**Test SBT-3**	**Test SBT-4**	**Test SBT-5**
Structural Adequacy	A. The test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	U	U	U	U	S
	D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	S	U	S	S	S
Occupant Risk	E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	U	U	U	U	S
Vehicle Trajectory	H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	S	S	S	S	S
	I. In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mi/h and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	U	U	U	U	S

S Satisfactory
U Unsatisfactory

4. GEORGE WASHINGTON MEMORIAL PARKWAY BRIDGE RAIL

TEST INSTALLATION

Photographs of the George Washington Memorial Parkway Bridge Rail are shown in figure 42, and design plans can be found in appendix A. This system consists of ASTM A588 steel posts mounted on an 8-in (20.3-cm) curb, supporting three ASTM A53, Grade B extra strong steel pipe rails. Throughout the course of the safety evaluation of this system, the design was modified once. The original design was evaluated during Test GWMP-1, where it was determined that the system needed to be modified for Tests GWMP-2 and 3 by changing the pipe rails from 4.5 in to 5.0 in (114-mm to 127-mm) outside diameter (O.D.), and placing them further away from the post. The reasons for these design changes are presented in the discussion of Test GWMP-1.

The 75-ft (22.9-m) long bridge rail was constructed with a simulated bridge deck to test the adequacy of the post-to-deck connection in addition to testing the bridge rail itself. A cross section of the 80-ft (24.4-m) long simulated bridge deck is shown in figure 43. Grade 60 epoxy coated reinforcement was used in the deck.

TEST CRITERIA

This bridge rail system was evaluated according to the performance level 1 (PL-1) criteria for bridge railings presented in the American Association of State Highway and Transportation Officials' (AASHTO) *Guide Specifications for Bridge Railings*.(8) The vehicle damage was assessed by the TAD and VDI.(6,7) The full-scale vehicle crash tests were conducted and reported in accordance with requirements specified in NCHRP Report 230.(4)

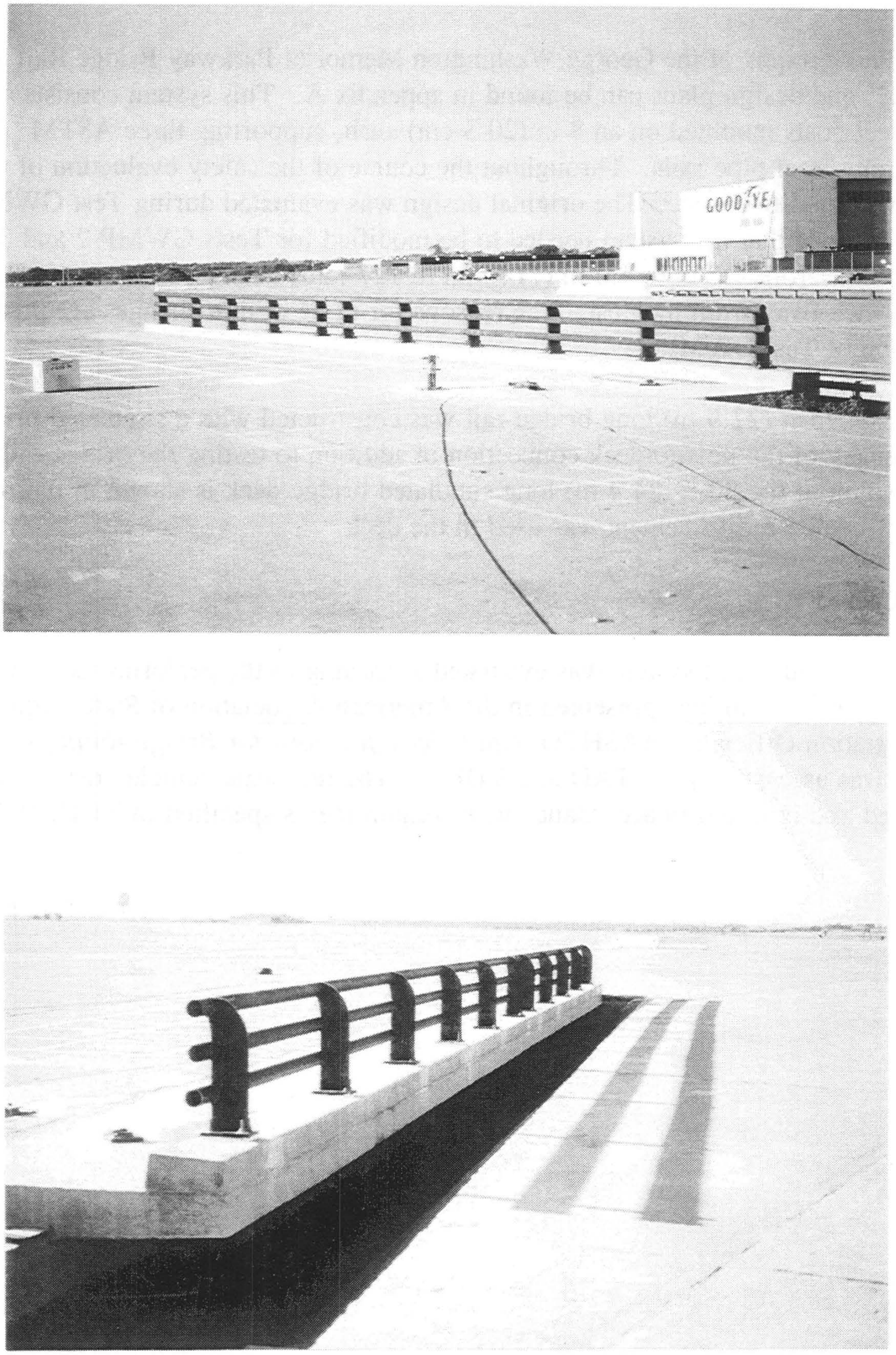


Figure 42. The George Washington Memorial Parkway Bridge Rail.

Figure 42. The George Washington Memorial Parkway Bridge Rail (continued).

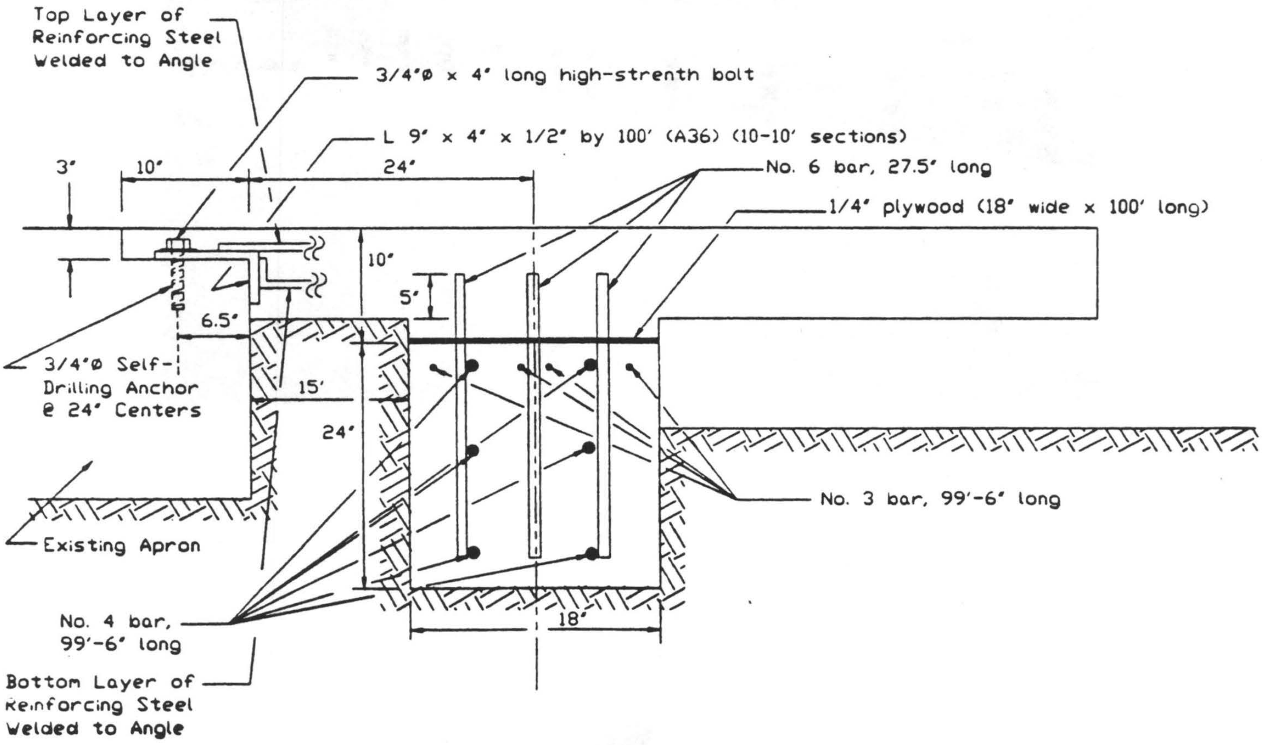


Figure 43. Cross Section of Simulated Concrete Deck.

TEST VEHICLES

The test vehicles used in the evaluation of this system are summarized in table 3. The pretest vehicle dimensions and photos can be seen in appendix B.

Table 3. Test Vehicle Summary, GWMP Series.

Test No.	Vehicle	Test Inertial Weight	
		(lb)	(kg)
GWMP-1	1984 Dodge Colt	1,850	839
GWMP-2	1984 Dodge Colt	1,750	794
GWMP-3	1985 Chevrolet ¾-ton pickup	5,400	2,452

TEST RESULTS

Test GWMP-1

The 1984 Dodge Colt impacted the system at 54.4 mi/h (87.5 km/h) and 21.0 degrees. As shown in figure 44, the impact point was located midway between the third and fourth posts from the upstream end of the installation (3 ft - 10¾ in (1.2 m) downstream of post no. 3). A summary of the test results and sequential photographs are shown in figure 45. Additional sequential photographs are shown in figure 46.

Upon impact with the steel bridge rail, the right-front quarter panel was crushed inward and the bumper was pulled to the right and pushed back, causing the front end of the vehicle to bend toward the right, away from the longitudinal centerline of the vehicle. Approximately 42 ms after impact, the bumper began to contact post no. 4 and was crushed into the right-front tire. With the bumper pushing the tire into the firewall, the vehicle began to buckle at the door post, also causing the windshield frame and roof to buckle. At 116 ms, the car lost contact with post no. 4 and continued down the rail with no additional snagging. There was no rolling motion detected throughout the collision, and the vehicle was redirected, coming to rest 170 ft (51.8 m) downstream and 90 ft (27.4 m) behind a line parallel to the rail face, as shown in figure 47.

The vehicle damage, shown in figure 48, included the crushing of the right-front corner of the vehicle, twisting of the car to the right of its longitudinal centerline, and buckling of the hood, roof, windshield frame, firewall, passenger compartment floor, and the passenger side door. The right-front tire was deflated, and the rim was deformed. The maximum crush deformation of 21 in (53.3 cm) is shown in figure 49.

The damage to the bridge rail was minor, with superficial scrapes on the curb, rail, and posts, as shown in figure 50. There was no permanent set deflection in the bridge rail. The contact marks on the curb started at impact, 4 ft - 5 in (1.35 m) before post no. 4, and continued for 11 ft - 8 in (3.56 m). Contact with the lower rail began 4 ft - 0 in (1.2 m) before post no. 4 and continued for 19 ft - 6 in (5.94 m). Contact with the middle rail began 3 ft - 8 in (1.12 m) before post no. 4 and continued for 17 ft - 0 in (5.18 m).

As a result of technical problems, the accelerometer data was not acquired for this test. It was therefore necessary to analyze the high-speed film to determine the values of the occupant risk criteria. The longitudinal and lateral occupant impact velocities, as determined from this high-speed film analysis, were 24.6 and 8.2 ft/s (7.5 and 2.5 m/s), respectively. The maximum occupant ridedown decelerations were 12.0 g's (longitudinal) and 22.4 g's (lateral). The results of this analysis are summarized in figure 45 and table 4.

As evident in the vehicle damage, shown in figure 48, there was significant occupant compartment damage to the test vehicle. This damage was caused by the snagging of the vehicle on posts no. 4 and 5. This occupant compartment deformation, accompanied by excessive lateral ridedown decelerations, caused the system to fail this compliance test. To alleviate this snagging problem, the rail size was increased from 4.5 in O.D. to 5.0 in O.D. (114 mm to 127 mm), and it was moved further out from the post, effectively moving the face of the rail 1 in (26 mm) further from the post. The design details of this change can be seen in appendix A.

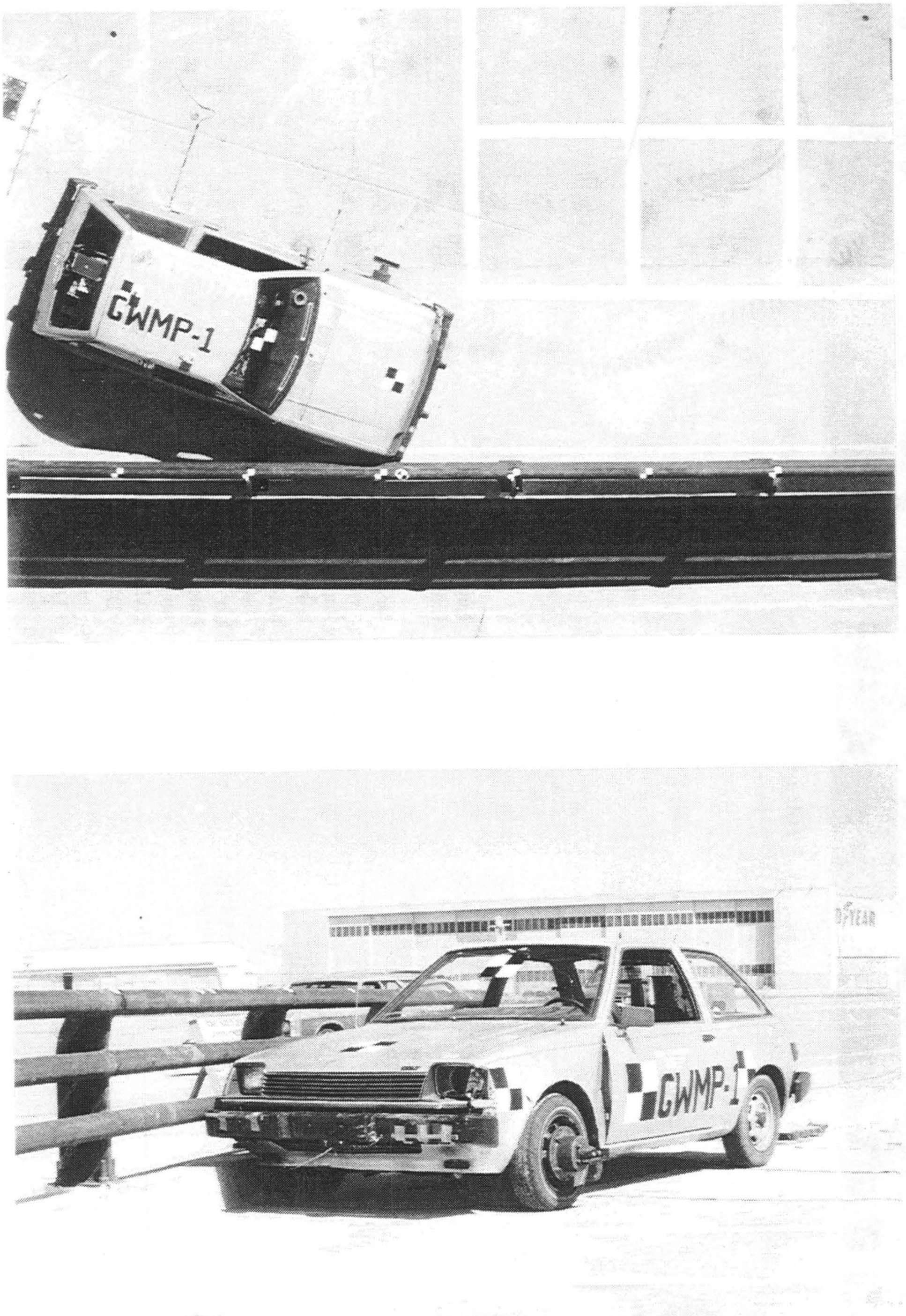
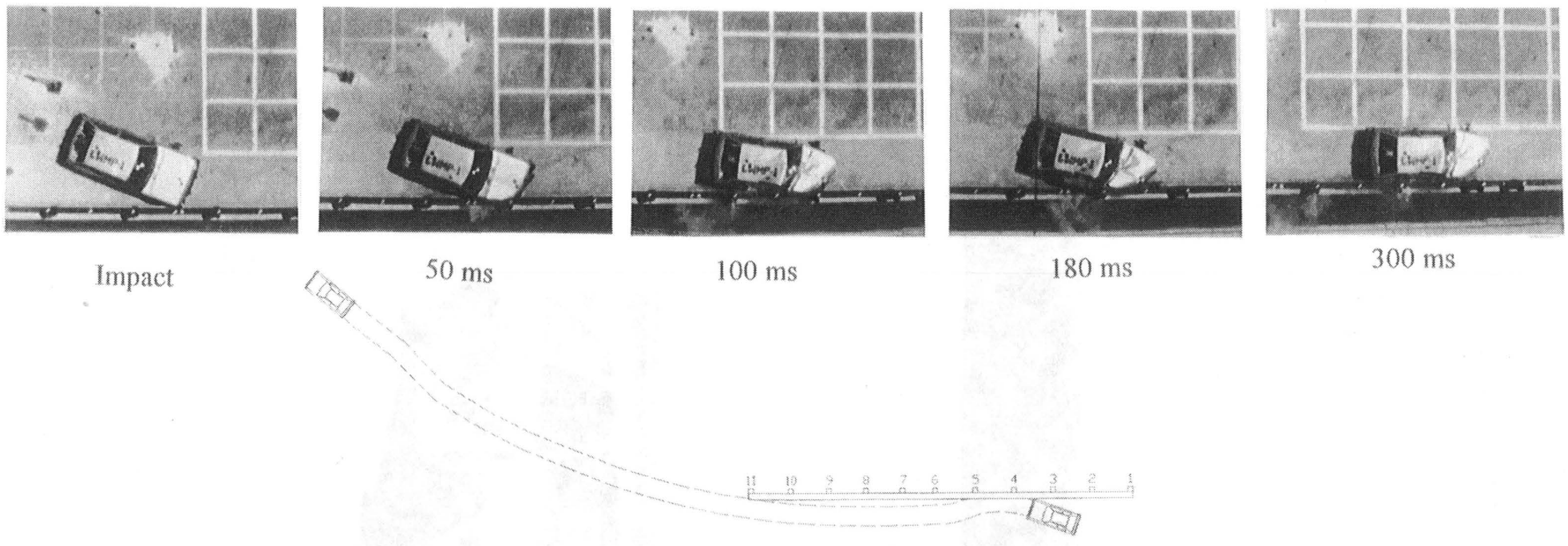


Figure 44. Impact Location, Test GWMP-1.



Test Number	GWMP-1
Federal Contract No.	DTFH71-90-C-00035
Date	8/04/93
Installation	George Washington Memorial Parkway Bridge Rail
Length	75 ft
Height from curb	2 ft - 10-in
Post spacing	7 ft - 9.5 in
Material	
Post	ASTM - A588
Rail	ASTM - A53, Grade B ESSP, 4.5 O.D.
Curb	
Height	8 in
Top width	1 ft - 4.5 in
Bottom width	1 ft - 6 in
Vehicle Model	1984 Dodge Colt
Vehicle Weight	
Curb	1,700 lbs
Test Inertia	1,850 lbs
Gross Static	2,010 lbs

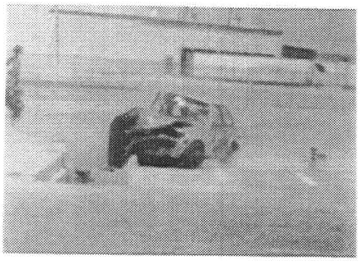
Speed	
Impact	54.4 mi/h
Exit	38.9 mi/h
Angle	
Impact	21.0 deg
Exit	3.8 deg
Occupant Impact Velocity	
Longitudinal	24.6 ft/s
Lateral	8.2 ft/s
Occupant Ridedown Deceleration	
Longitudinal	12.0 g's
Lateral	22.4 g's
Vehicle Damage	
TAD	1-RFQ-6
VDI	01RFES3
Vehicle Rebound Distance	22 in @ 40 ft
Bridge Rail Damage	Superficial
Maximum Permanent Set Deflection	0 in

Conversion Factors: 1 in = 2.54 cm; 1 lb = 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

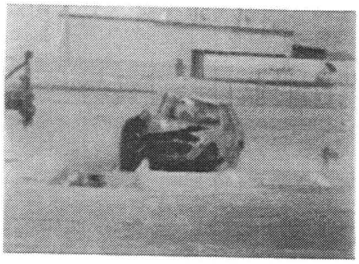
Figure 45. Summary of Test GWMP-1.

Impact

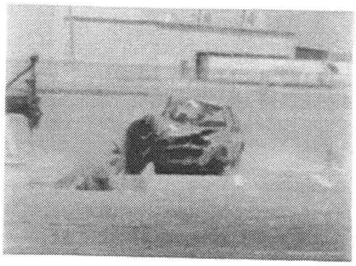
50 ms



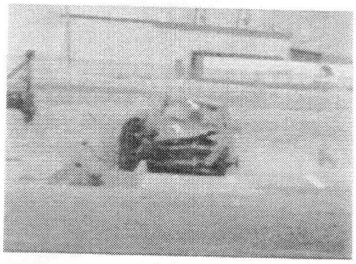
100 ms



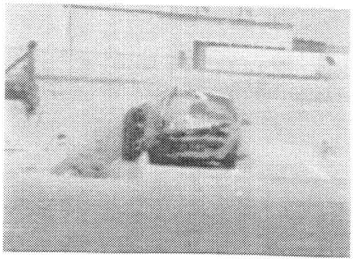
150 ms



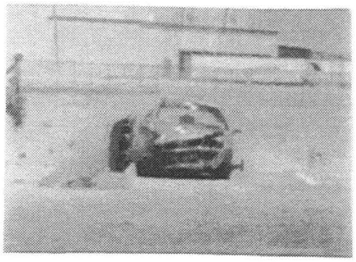
200 ms



300 ms



400 ms



500 ms

Figure 46. Downstream Sequential Photographs, Test GWMP-1.

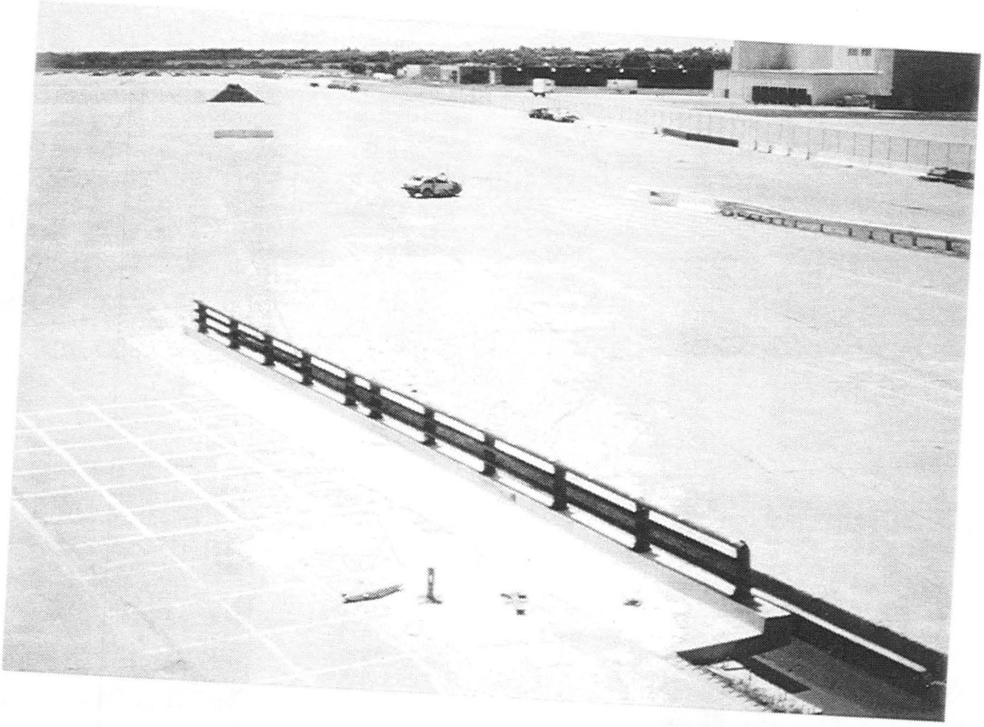


Figure 47. Vehicle Trajectory, Test GWMP-1.

Figure 48. Vehicle Damage, Test GWMP-1.

Figure 48. Vehicle Damage, Test GWMP-1 (continued).

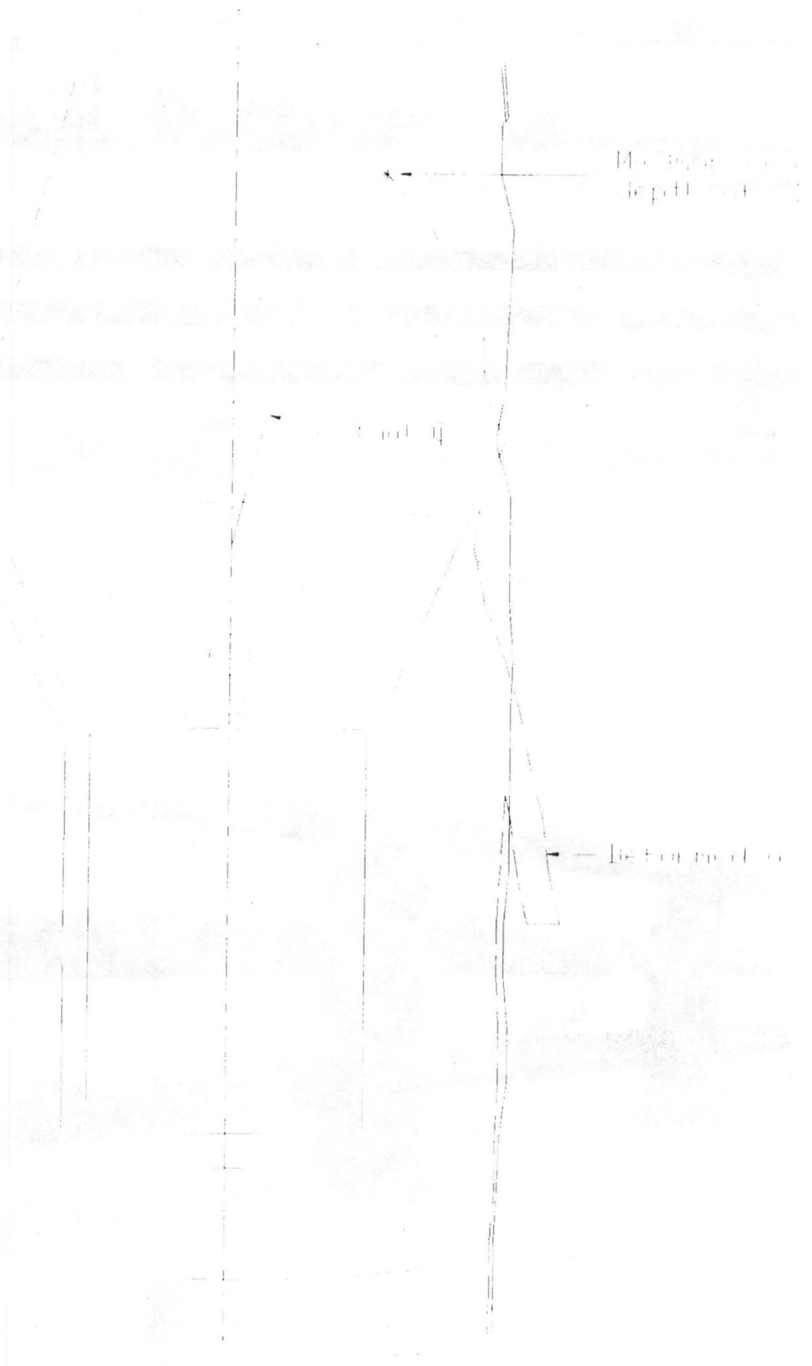


Figure 49. Crush Depth Diagram, Test GWMP-1.

Figure 50. Bridge Rail Damage, Test GWMP-1.

Test GWMP-2

The 1984 Dodge Colt impacted the George Washington Memorial Parkway Bridge Rail at 52.6 mi/h (84.65 km/h) and 22.6 degrees. The impact point was located midway between the third and fourth posts from the upstream end of the installation, as shown in figure 51. A summary of the test results and sequential photographs are shown in figure 52.

Upon impact with the bridge rail system, the right-front corner of the car was crushed inward. Approximately 68 ms after impact, the right-front corner of the hood contacted post no. 4, causing the hood to rotate 90 degrees clockwise about its right-front mount. The vehicle continued down the rail without the tire mounting the curb. When the vehicle approached post no. 5, 174 ms after impact, the left-front corner of the hood contacted post no. 5, separating it from the vehicle. The hood remained at post no. 5 between the upper and middle rails as the vehicle proceeded down the rail. The hood then made contact with right-front windshield support and the lower right corner of the windshield and was forced up and over the vehicle. The vehicle came to rest 120 ft (36.5 m) downstream of impact and 61 ft (18.6 m) in front of a line parallel with the front face of the bridge rail, as seen in figure 53.

The vehicle damage, shown in figure 54, included crushing of the right-front corner of the vehicle, minor scrapes and dents along the length of the passenger side, and separation of the hood. The windshield was not penetrated but did sustain localized cracking in the lower right corner. The right-front tire was blown out, and the rim was bent outward at the top. The occupant compartment floor sustained minor buckling in the front passenger side floor area. The maximum crush deformation of 12 in (30.5 cm) is shown in figure 55.

As shown in figure 56, the bridge rail and curb sustained minor scrapes in the area where the impact occurred. Contact with the middle and lower rail began at the midspan between posts no. 4 and 5, and continued to the midspan between posts no. 3 and 4.

The longitudinal and lateral occupant impact velocities were 17.0 ft/s and 25.7 ft/s, (5.2 m/s and 7.8 m/s) respectively. The maximum occupant ridedown decelerations were 5.2 g's (longitudinal) and 9.6 g's (lateral). The results of this analysis are summarized in figure 52 and table 4. Accelerometer traces are presented in appendix C. Criterion H requires that the railing side of the vehicle shall move no more than 20 ft from the line of the traffic face of the railing within 100 ft plus the length of the test vehicle from the point of impact with the railing. This criteria was not met, as the vehicle was 39 ft from the face of the railing at a distance of 115 ft downstream of impact. However, it was judged that failure of this criterion alone did not warrant failure of the entire test.

It was therefore determined that the overall performance of this test was acceptable according to the AASHTO PL-1 guidelines.(8)

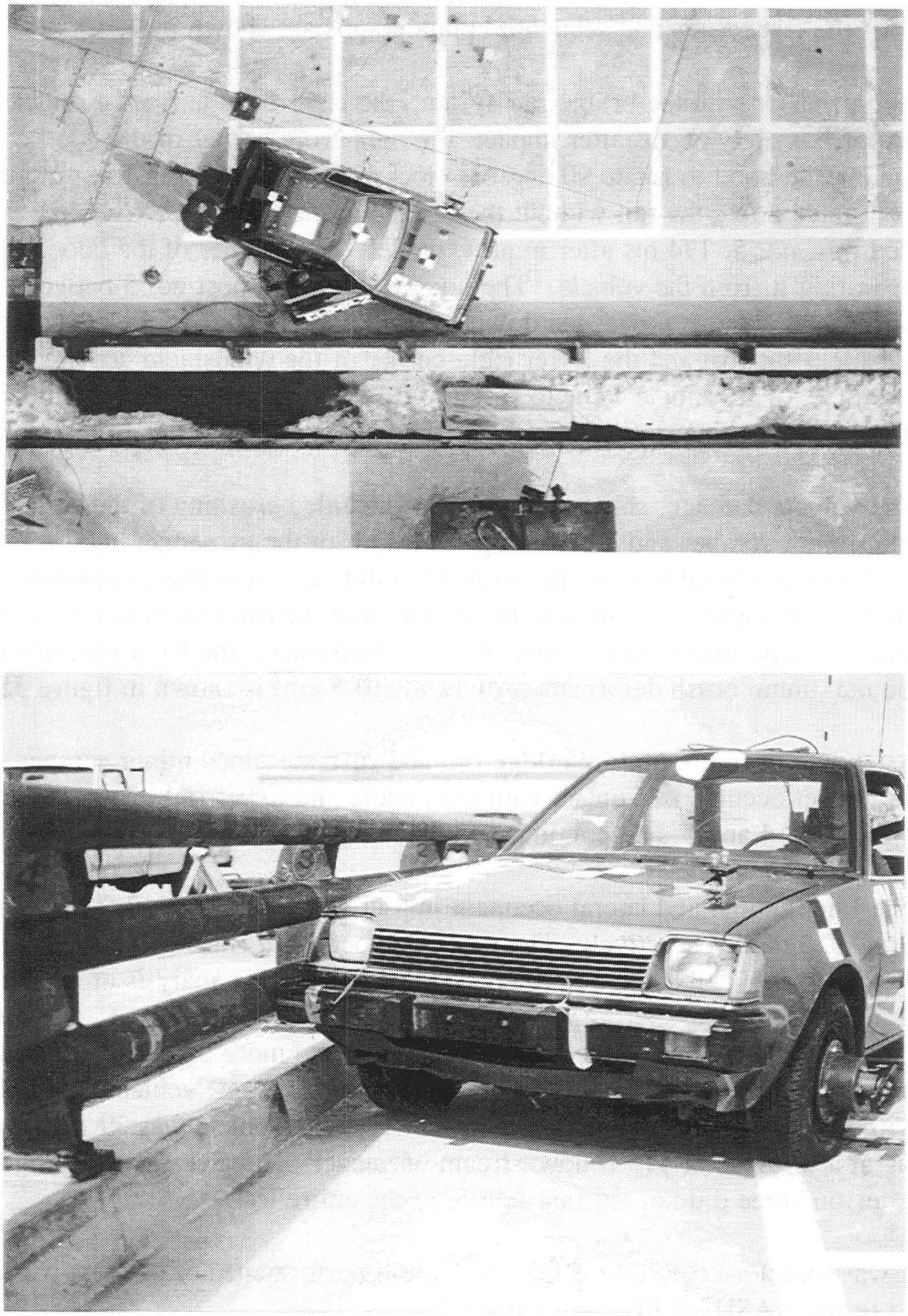
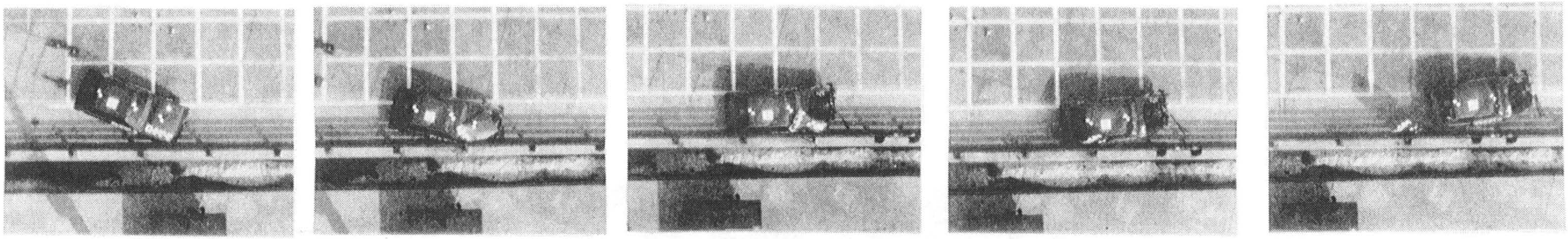
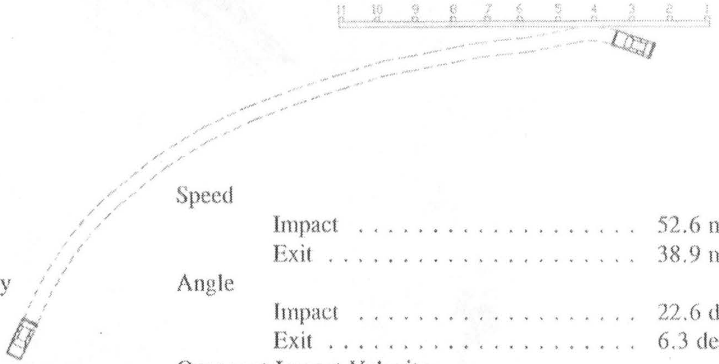


Figure 51. Impact Location, Test GWMP-2.



Impact 100 ms 200 ms 300 ms 400 ms



Test Number	GWMP-2
Federal Contract No.	DTFH71-90-C-00035
Date	3-08-94
Installation	George Washington Memorial Parkway Bridge Rail
Length	75 ft
Height from curb	2 ft - 10.5 in
Post spacing	7 ft - 9.5 in
Material	
Post	ASTM - A588
Rail	ASTM - A53, Grade B ESSP, 5 in O.D.
Curb	
Height	8 in
Top width	1 ft - 4.5 in
Bottom width	1 ft - 6 in
Vehicle Model	1984 Dodge Colt
Vehicle Weight	
Curb	1,800 lbs
Test Inertia	1,776 lbs
Gross Static	1,936 lbs

Speed	
Impact	52.6 mi/h
Exit	38.9 mi/h
Angle	
Impact	22.6 deg
Exit	6.3 deg
Occupant Impact Velocity	
Longitudinal	17.0 ft/s
Lateral	25.7 ft/s
Occupant Ridedown Deceleration	
Longitudinal	5.2 g's
Lateral	9.6 g's
Vehicle Damage	
TAD	1-RFQ-4
VDI	01FRES2
Vehicle Rebound Distance	39 ft @ 115 ft
Bridge Rail Damage	Minor
Maximum Permanent Set Deflection	0.125 in

Conversion Factors: 1 in= 2.54 cm; 1 lb= 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

Figure 52. Summary of Test GWMP-2.

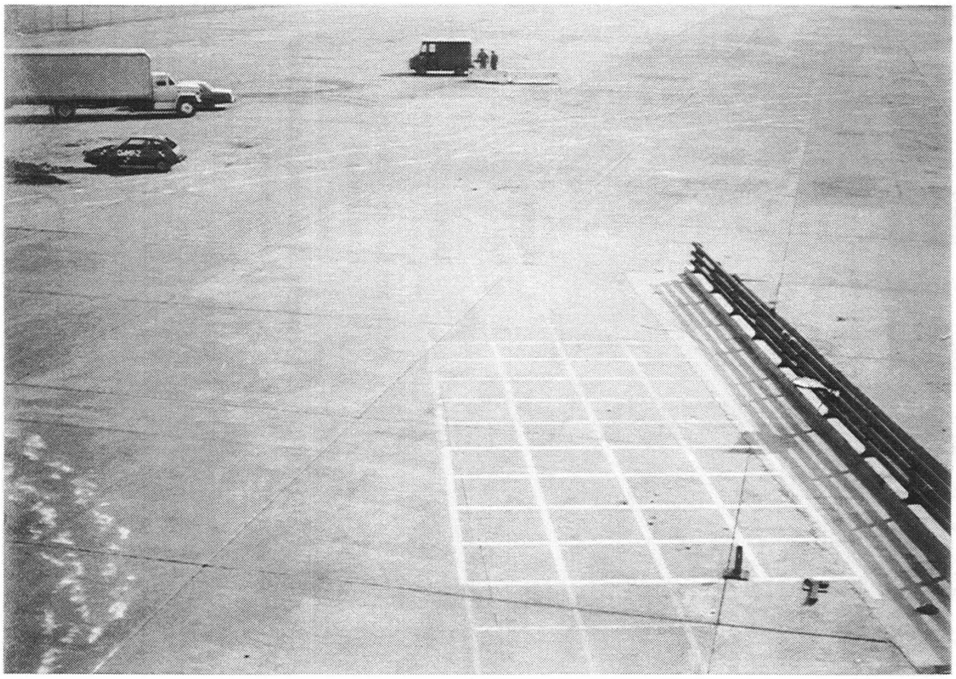


Figure 53. Vehicle Trajectory, Test GWMP-2.

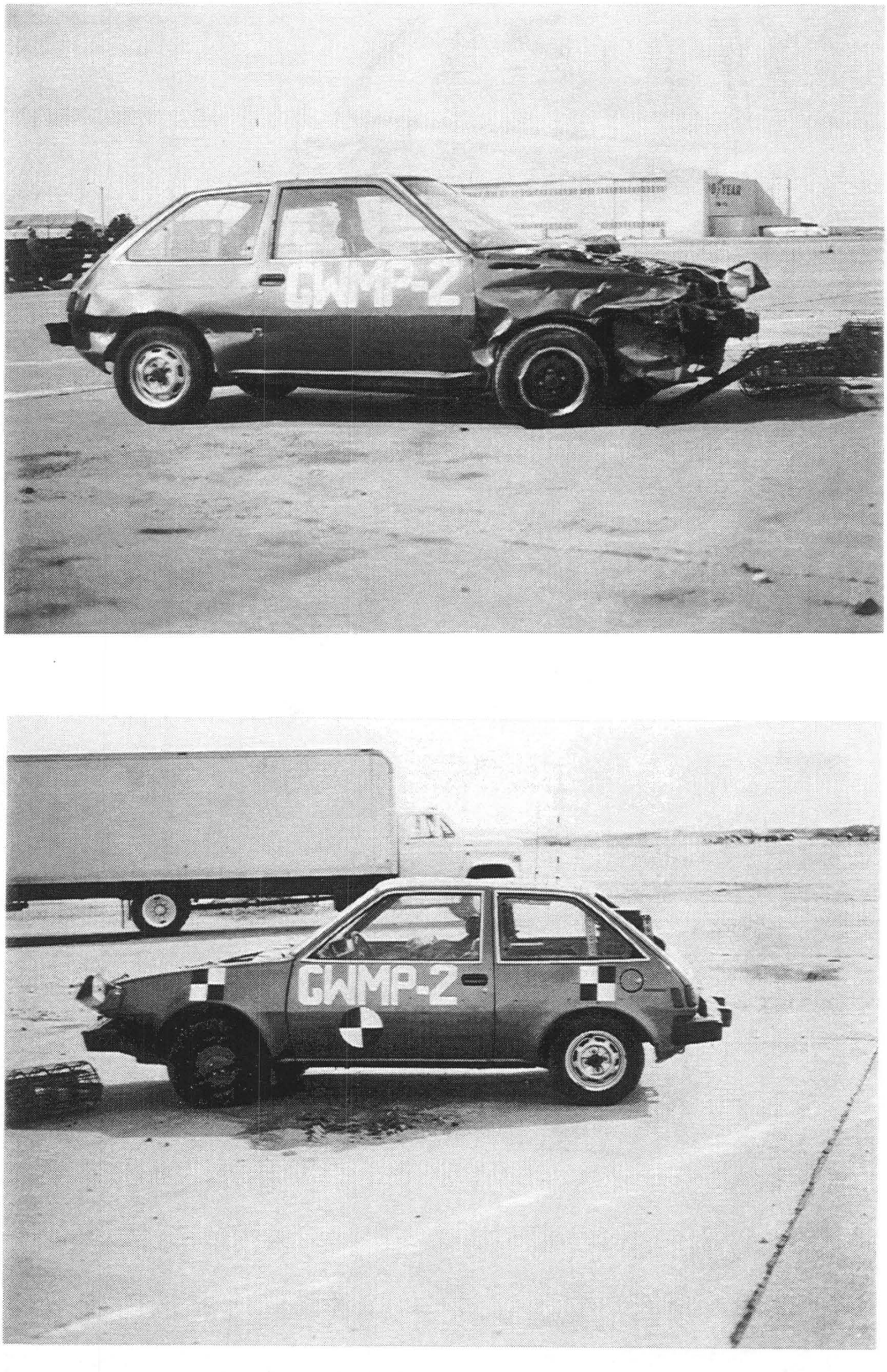


Figure 54. Vehicle Damage, Test GWMP-2.

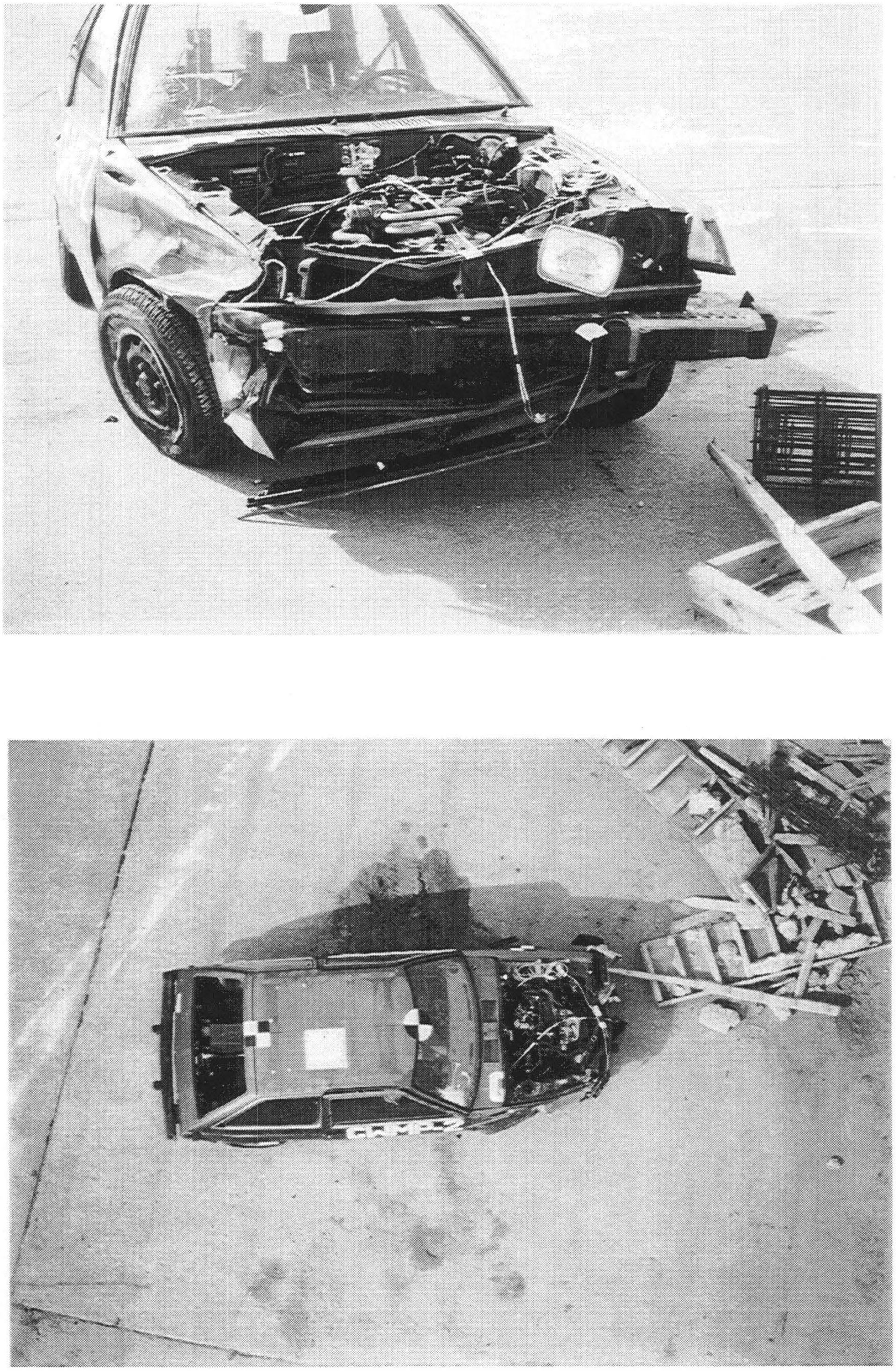


Figure 54. Vehicle Damage, Test GWMP-2 (continued).

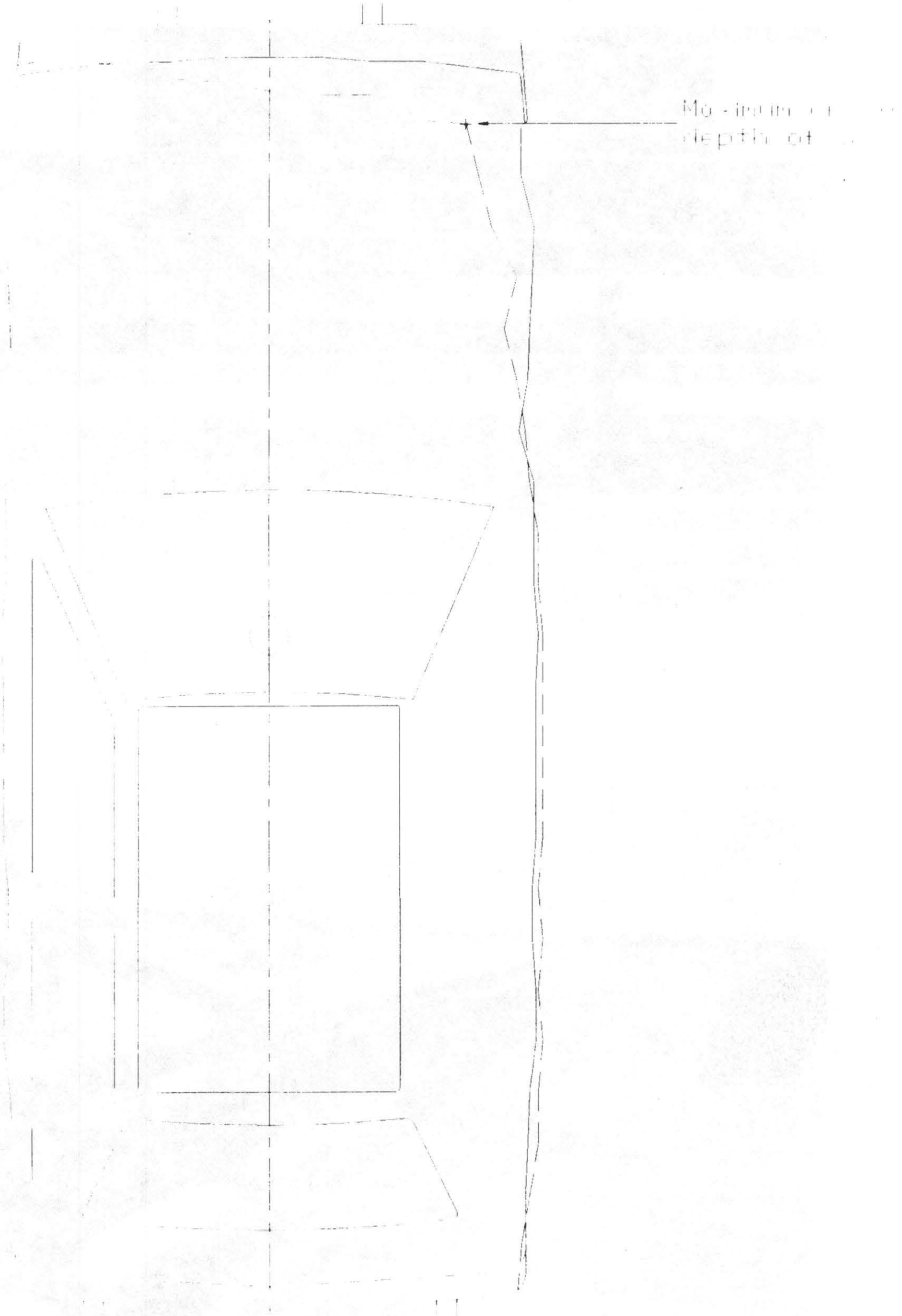


Figure 55. Crush Depth Diagram, Test GWMP-2.

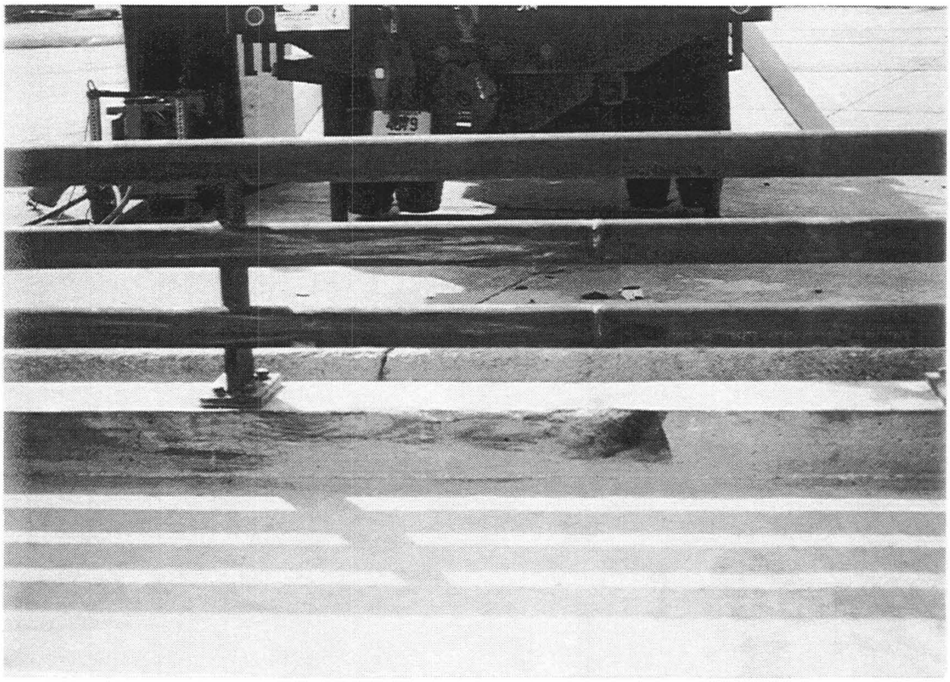


Figure 56. Bridge Rail Damage, Test GWMP-2.

Test GWMP-3

The 1985 Chevrolet ¾-ton pickup truck impacted the system at 46.6 mi/h (75.0 km/h) and 22.7 degrees. The impact point was located 3 ft-3.5 in (1.0 m) upstream of the expansion joint, or 1 ft-3.5 in (394 mm) upstream of post no. 6, as shown in figure 57. A summary of the test results and sequential photographs are shown in figure 58.

The vehicle was smoothly redirected by the bridge railing, with a relatively small amount of damage to the vehicle. At 140 ms, tail slap occurred between the passenger-side rear quarter panel of the vehicle and the rail, causing cracking of the curb and deck at post no. 6. There was no snagging of the vehicle. There was a maximum permanent set deflection of 0.125 in (3 mm) in the bridge rail. The vehicle came to rest 135 ft (41.1 m) downstream and 110 ft (33.5 m) to the back side of a line parallel with the front face of the bridge rail, as can be seen in figure 59.

The vehicle damage, shown in figure 60, included the crushing of the right-front corner of the vehicle and scrapes and dents along the length of the passenger side. The right-front tire was blown out, and the rim was deformed. The maximum crush deformation of 9.75 in (24.8 cm) is shown in figure 61. All damage to the vehicle on the driver's side of the longitudinal centerline occurred after impact with the bridge rail. Near the end of the vehicle's trajectory, the vehicle struck an obstacle on the testing grounds, resulting in damage to the left-front corner of the vehicle.

The bridge rail sustained only minor cosmetic damage on each of the three rails, as shown in figure 62. Contact with each of the rails began 3 ft-5 in (1.04 m) upstream of the expansion joint. The vehicle remained in contact with the rail for 8 ft (2.44 m) on the bottom rail, 8 ft-6 in (2.59 m) on the middle rail, and 8 ft-2 in (2.49 m) on the top rail.

Cracking occurred in the curb and bridge deck at post no. 6. On top of the curb, two cracks propagated outward from each of the rear post bolts, as shown in figure 63. The length of cracks upstream and downstream of post no. 6 were 10 in (25.4 cm) and 11 in (27.9 cm), respectively.

The longitudinal and lateral occupant impact velocities, as determined from accelerometer data analysis, were 9.6 ft/s (2.93 m/s) and 21.3 ft/s (6.49 m/s), respectively. The maximum occupant ridedown decelerations were 2.0 g's (longitudinal) and 8.0 g's (lateral). The results of this analysis are summarized in figure 58 and table 4. Accelerometer traces are presented in appendix C.

It was determined that the performance of this test was acceptable according to the AASHTO PL-1 guidelines.(8)

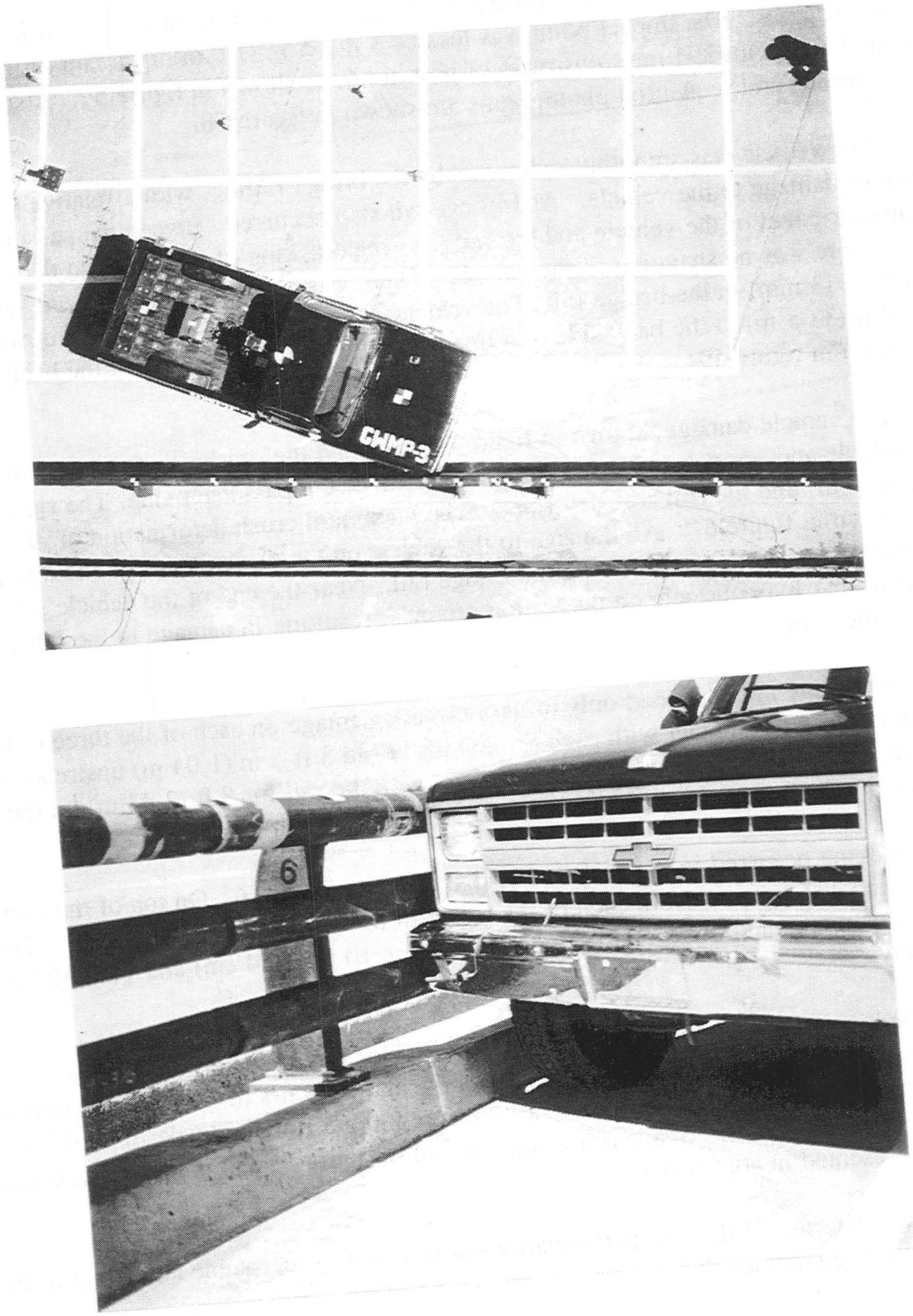
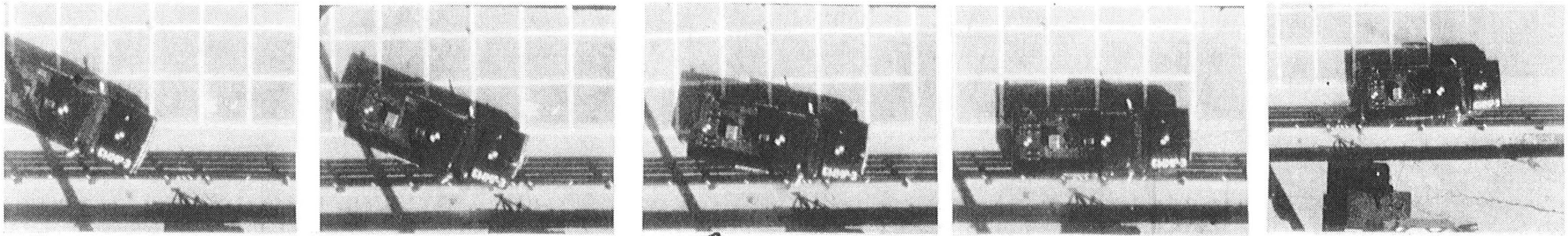
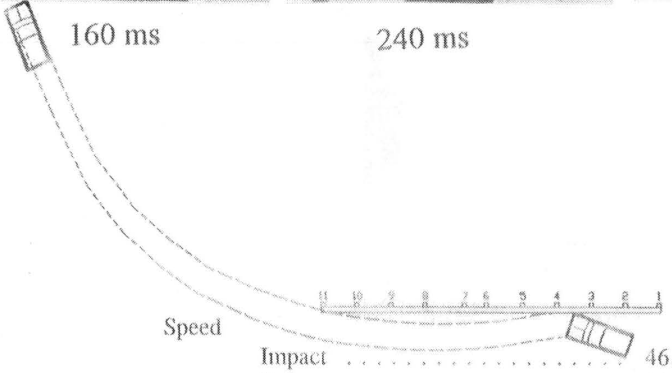


Figure 57. Impact Location, Test GWMP-3.



Impact 80 ms 160 ms 240 ms 410 ms



Test Number	GWMP-3
Federal Contract No.	DTFH71-90-C-00035
Date	3-24-94
Installation	George Washington Memorial Parkway Bridge Rail
Length	75 ft
Height from curb	2 ft - 10.5 in
Post spacing	7 ft - 9.5 in
Material	
Post	ASTM - A588
Rail	ASTM - A53, Grade B, 5 in O.D., ESSP
Curb	
Height	8 in
Top width	1 ft - 4.5 in
Bottom width	1 ft - 6 in
Vehicle Model	1985 Chevrolet ¾-ton pickup
Vehicle Weight	
Curb	4,440 lbs
Test Inertia	5,560 lbs
Gross Static	5,400 lbs

Speed	
Impact	46.6 mi/h
Exit	38.2 mi/h
Angle	
Impact	22.7 deg
Exit	3.1 deg
Occupant Impact Velocity	
Longitudinal	9.6 ft/s
Lateral	21.3 ft/s
Occupant Ridedown Deceleration	
Longitudinal	2.0 g's
Lateral	5.0 g's
Vehicle Damage	
TAD	1-RFQ-4
VDI	01RFES2
Vehicle Rebound Distance	3 ft @ 40 ft
Bridge Rail Damage	Minor
Maximum Permanent Set Deflection	0.125 in

Conversion Factors: 1 in= 2.54 cm; 1 lb= 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

Figure 58. Summary of Test GWMP-3.

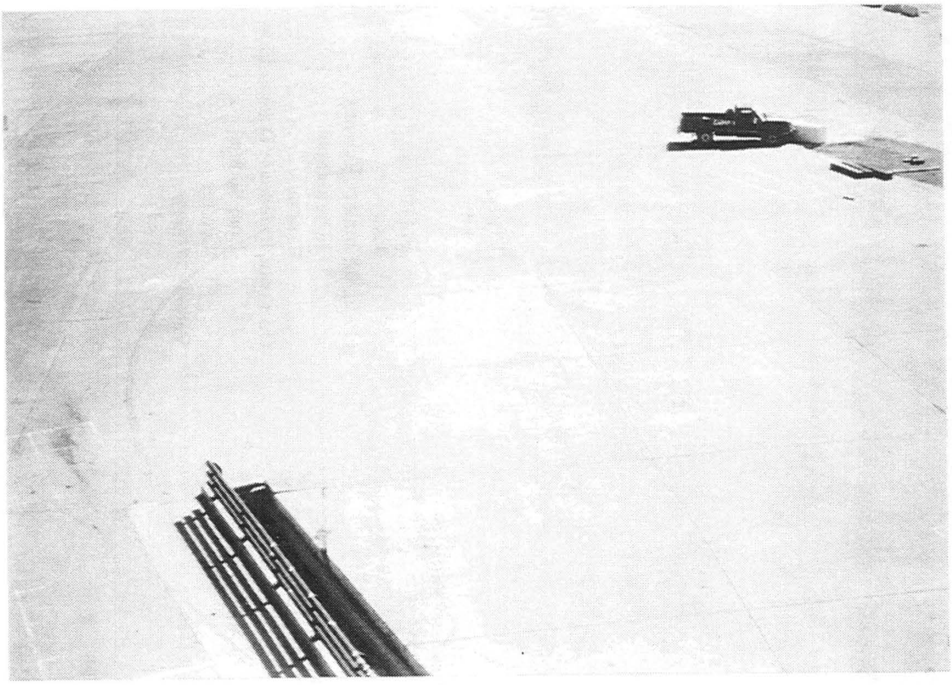


Figure 59. Vehicle Trajectory, Test GWMP-3.

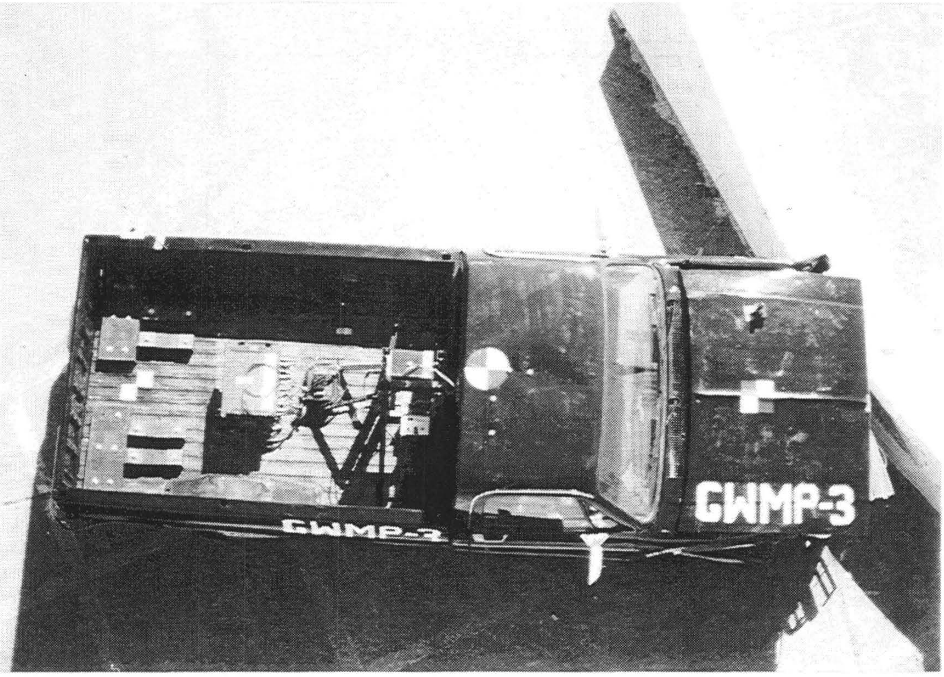


Figure 60. Vehicle Damage, Test GWMP-3.

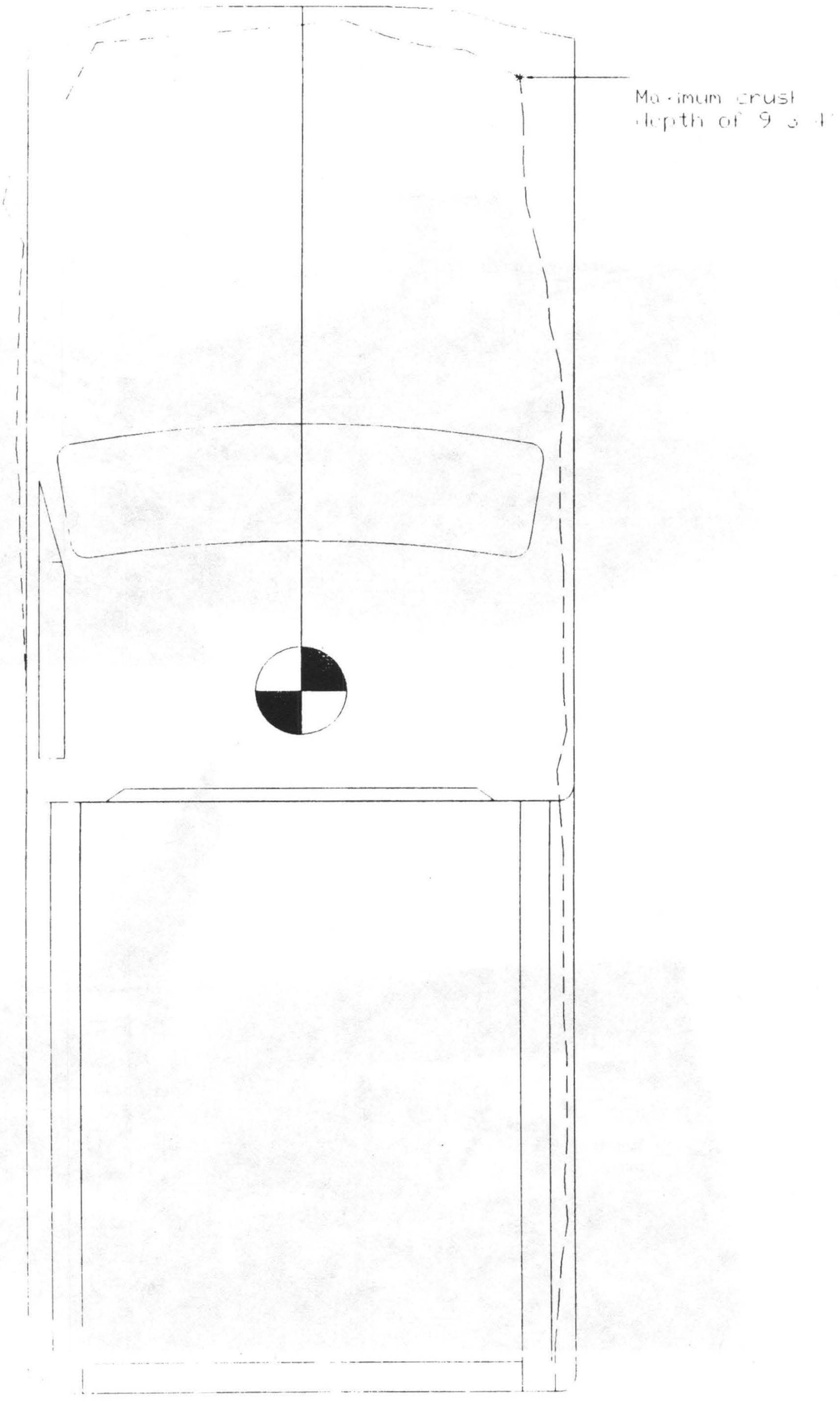


Figure 61. Crush Depth Diagram, Test GWMP-3.

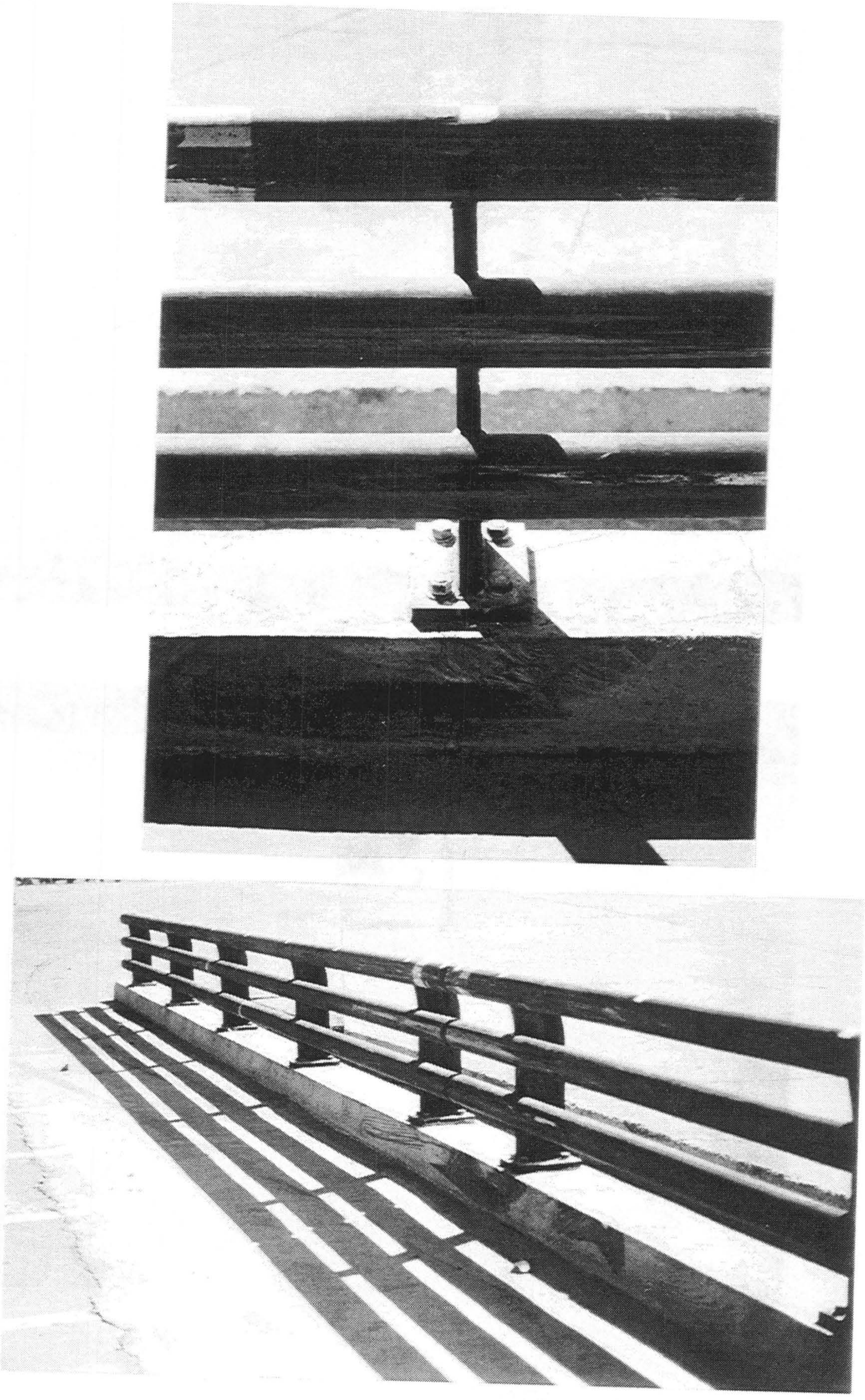


Figure 62. Bridge Rail Damage, Test GWMP-3.

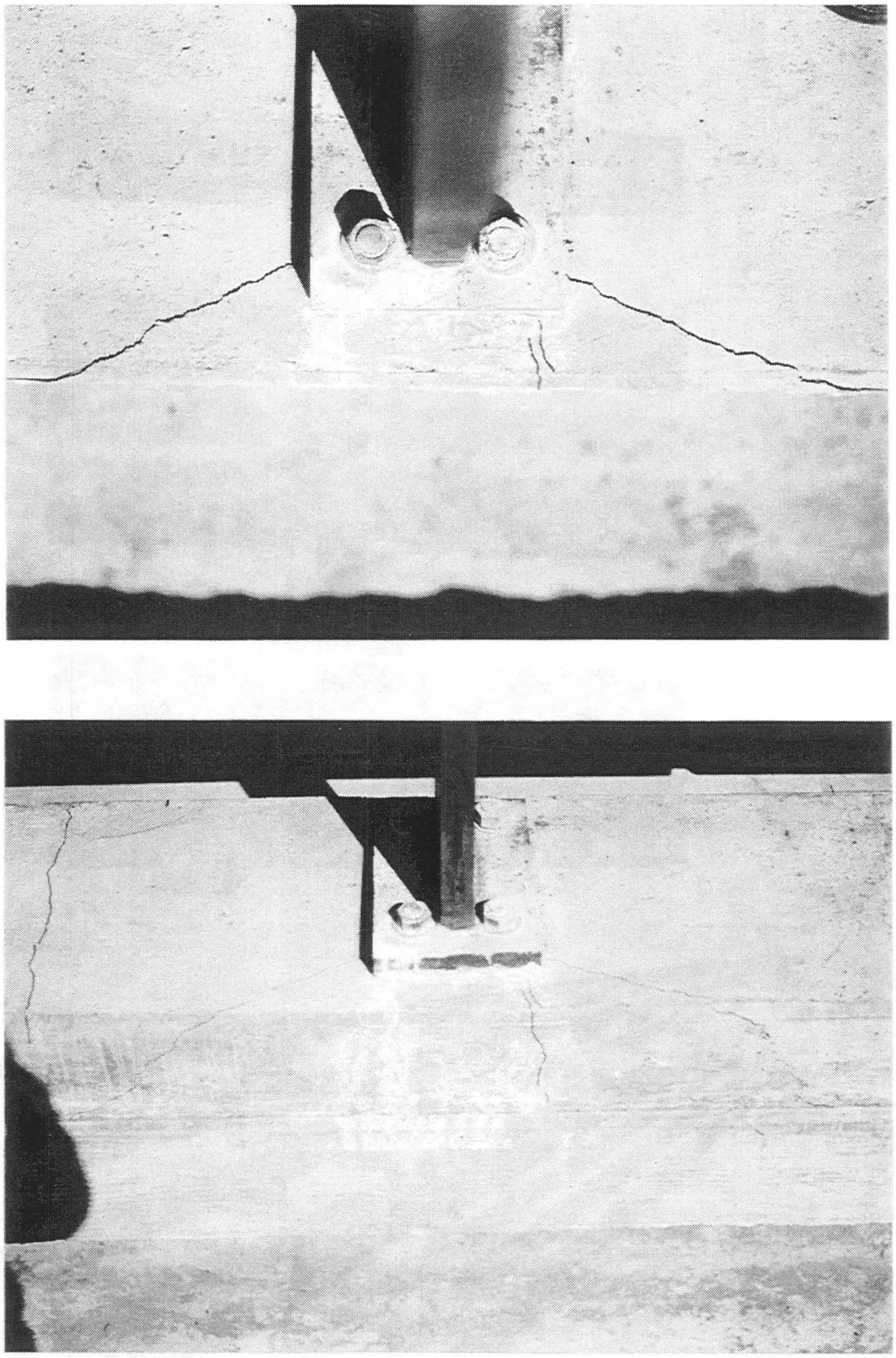


Figure 63. Curb Damage, Test GWMP-3.

EVALUATION SUMMARY

The performance of this system was evaluated according to criteria for PL-1 bridge rails presented in the *AASHTO Guide Specifications for Bridge Railings*.(8) The tests were conducted and reported in accordance with the requirements in NCHRP Report 230.(4) Table 4 summarizes all of the relevant evaluation criteria from AASHTO, as well as the findings from the three tests reported.(8) As shown in this table, the George Washington Memorial Parkway Bridge Rail successfully passed the PL-1 bridge rail criteria.

Table 4. Summary of Safety Performance Results, GWMP Series.

Evaluation Criteria	Results					
	GWMP-1		GWMP-2		GWMP-3	
3.a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	S		S		S	
3.b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	S		S		S	
3.c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	U		S		S	
3.d. The vehicle shall remain upright during and after collision.	S		S		S	
3.e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.	S		S		S	
3.f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ, where $\mu = (\cos\theta - V_p/V)/\sin\theta$. μ — Assessment 0.0 - 0.25 — Good 0.26 - 0.35 — Fair > 0.35 — Marginal	M (0.62)		F (0.30)		G (0.10)	
3.g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0 ft longitudinal and 1.0 ft lateral displacements, shall be less than: Occupant Impact Velocity - ft/s Longitudinal — Lateral 30 — 25 and for the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than: Occupant ridedown Accelerations - g's Longitudinal — Lateral 15 — 15	Occupant Impact Velocity (ft/s)					
	Long.	Lat.	Long.	Lat.	Long.	Lat.
	S (24.6)	S (8.2)	S (17.0)	S (25.7)	S (9.6)	S (21.3)
	Occupant Ridedown Accelerations (g's)					
	Long.	Lat.	Long.	Lat.	Long.	Lat.
	S (12.0)	U (22.4)	S (5.20)	S (9.6)	S (2.0)	S (5.0)
3.h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20 ft from the line of the traffic face of the railing.	S (3.8 deg)		S (6.3 deg)		S (5.0 deg)	
	S (22 in @ 40 ft)		U (39 ft @ 115 ft)		S (3 ft @ 40 ft)	

S = Satisfactory, M = Marginal, U = Unsatisfactory

Conversion Factor: 1 ft = 0.3048 m

5. FOOTHILLS PARKWAY MEMORIAL BRIDGE RAIL

TEST INSTALLATION

Photographs of the Foothills Parkway Memorial Bridge Rail are shown in figure 64. This system consists of cast aluminum posts mounted on a 6-in (15.2-cm) high curb, supporting two aluminum rails. Throughout the course of the safety evaluation of this system, the design was modified twice. The original design, shown in figure 65, was evaluated during Test FPAR-1. The system was modified for Test FPAR-2 by adding longitudinal steel reinforcement to the curb, as shown in figure 66. The final design, evaluated in Test FPAR-3, is shown in figure 67. The reasons for these design changes are discussed in the test results sections. The design details for this system are presented in appendix A.

The 75-ft (22.9-m) long bridge rail was constructed with a simulated bridge deck to test the adequacy of the post-to-deck connection in addition to testing the bridge rail itself. A cross section of the 80-ft (24.4-m) long simulated bridge deck is shown in figure 43. Grade 60 epoxy coated reinforcement was used in the deck.

TEST CRITERIA

This bridge rail system was evaluated according PL-1 criteria for bridge railings presented in AASHTO.(8) The full-scale vehicle crash tests were conducted and reported in accordance with requirements specified in NCHRP Report 230.(4) The vehicle damage was assessed by the TAD and VDI.(6,7)

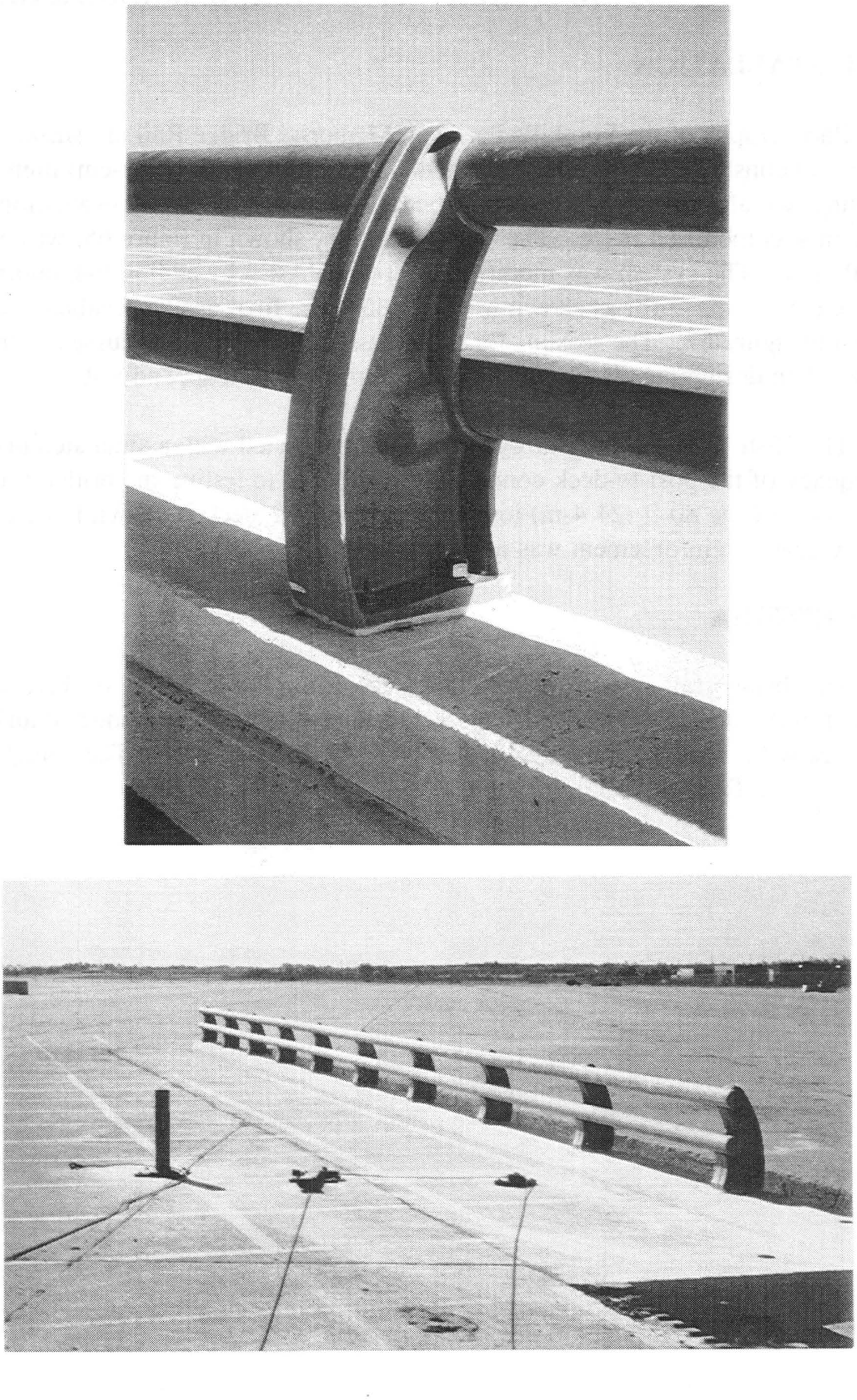


Figure 64. The Foothills Parkway Bridge Rail.

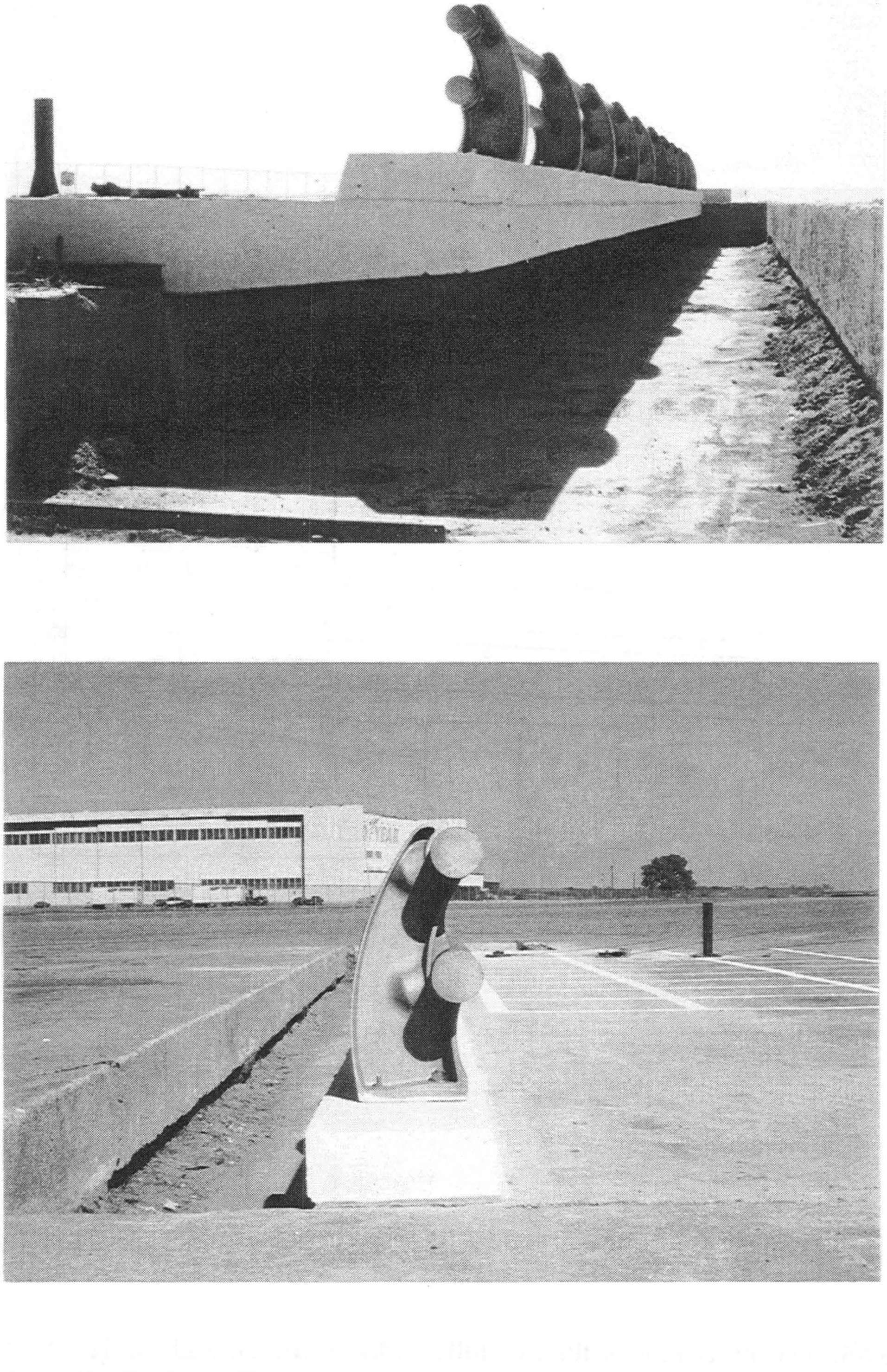


Figure 64. The Foothills Parkway Bridge Rail (continued).

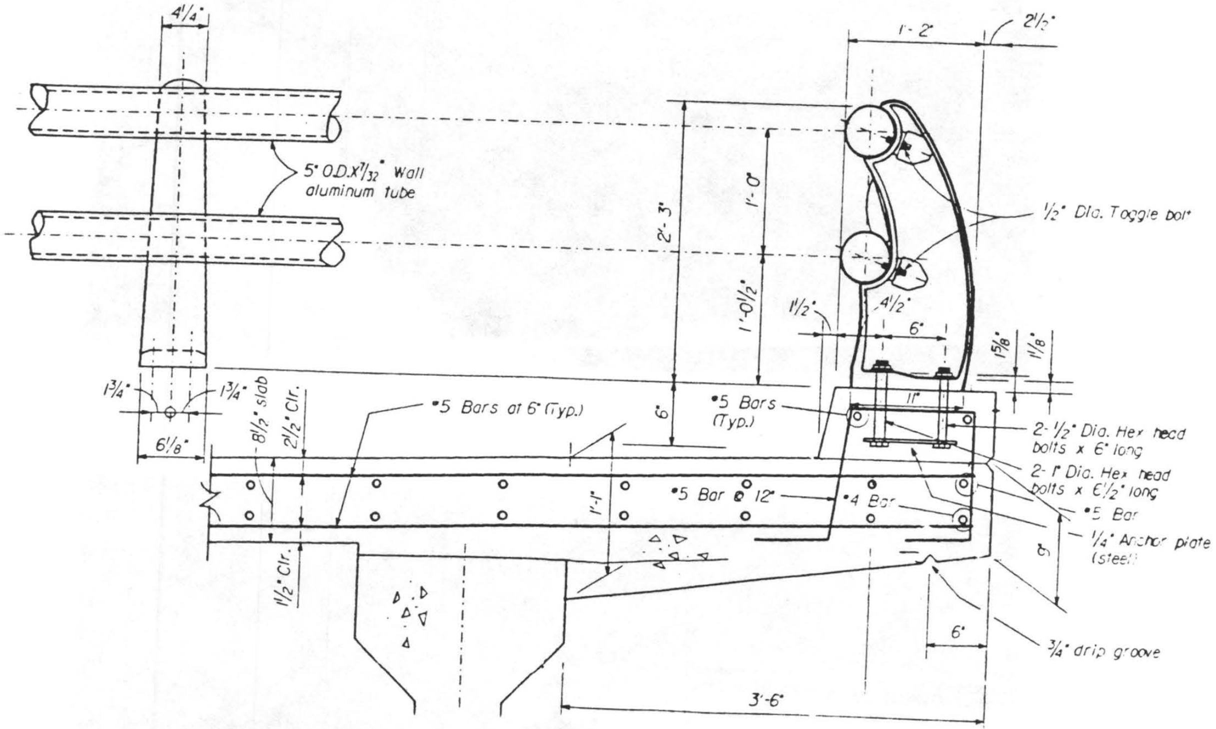


Figure 65. Design Details of the Foothills Parkway Bridge Rail for Test FPAR-1.

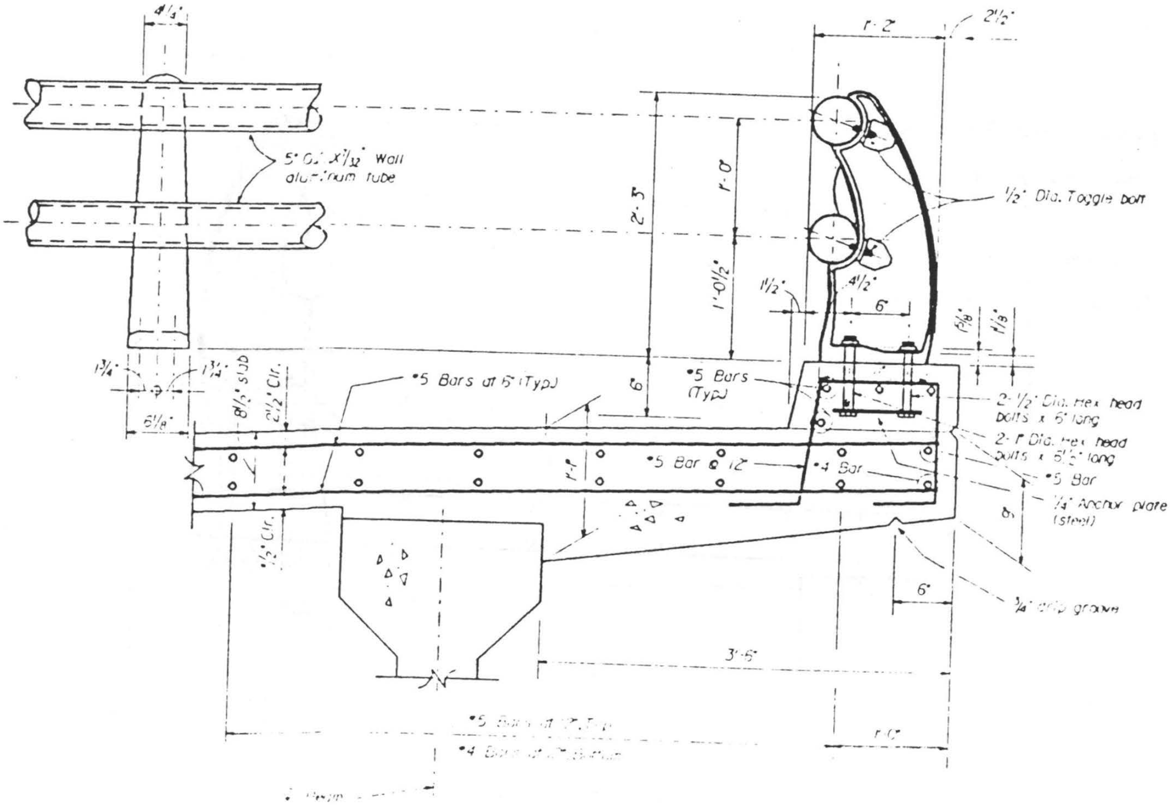


Figure 66. Design Details of the Foothills Parkway Bridge Rail for Test FPAR-2.

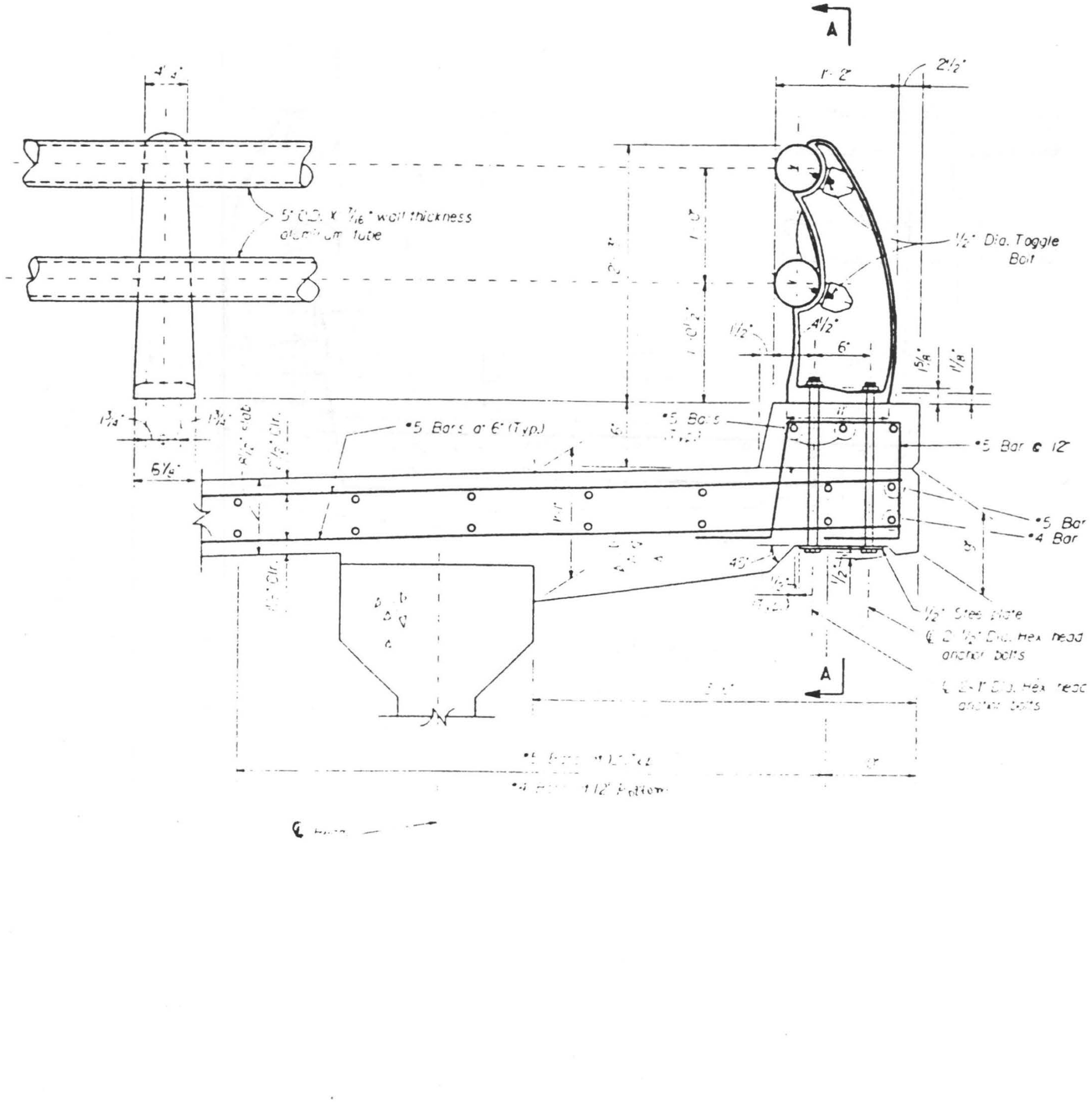


Figure 67. Design Details of the Foothills Parkway Bridge Rail for Test FPAR-3.

TEST VEHICLES

The test vehicles used in the evaluation of this system are summarized in table 5. The pretest vehicle dimensions and photographs can be seen in appendix B.

Table 5. Test Vehicle Summary, FPAR Series.

Test No.	Vehicle	Test Inertial Weight	
		(lb)	(kg)
FPAR-1	1984 Dodge Colt	1,904	864
FPAR-2	1984 Chevrolet ¾-ton pickup	5,300	2,300
FPAR-3	1985 Ford ¾-ton pickup	5,400	2,452

TEST RESULTS

Test FPAR-1

The 1984 Dodge Colt impacted the Foothills Parkway Bridge Rail at 52.0 mi/h (83.7 km/h) and 22.0 degrees. As shown in figure 68, the impact point was located midspan between the third and fourth posts from the upstream end of the installation (3 ft-11 in (1.2 m) downstream of post no. 3). A summary of the test results and sequential photographs are shown in figure 69. Additional sequential photographs are shown in figure 70.

Upon impact with the aluminum bridge rail, the right-front quarter panel of the vehicle was crushed inward, and the bumper was pushed to the left. Shortly after impact, the right-front tire blew out, and the wheel was crushed inward. The vehicle slid along the rail and became parallel to it at 19 ms, and then exited at approximately 30 ms. There was no rolling motion detected throughout the collision, and the vehicle was smoothly redirected, coming to rest 130 ft (39.6 m) downstream and 64 ft (19.5 m) to the left of a line parallel to the rail face, as shown in figure 71.

The vehicle damage, shown in figure 72, included the crushing of the right-front corner of the vehicle and minor scrapes and dents along the length of the passenger side. The right-front tire was blown out, and the rim was bent. The maximum crush deformation of 11.25 in (28.6 cm) is shown in figure 73.

The damage to the bridge rail was minor, with superficial scrapes on the curb and rail, as shown in figure 74. The maximum permanent set deflection of 1 in (2.54 cm) occurred approximately 2 ft (0.61 m) downstream from impact on the lower rail. There was evidence of minor tire and hub contact between the curb and the lower rail on the first post downstream from impact (post no. 4). There was also evidence of crushed vehicle body contact between the lower and upper rail at post no. 4. The contact marks on the railing started at impact and continued for 8 ft-6 in (2.59 m) on the upper rail, and 8 ft-8 in (2.64 m) on the lower rail.

The longitudinal and lateral occupant impact velocities, as determined from high-speed film analysis, were 9.6 ft/s (2.93 m/s) and 23.0 ft/s (7.01 m/s), respectively. The maximum occupant ridedown decelerations were 5.7 g's (longitudinal) and 4.3 g's (lateral). The results of this analysis are summarized in figure 69 and table 7.

The only notable damage to the curb was a set of microcracks which started at the 1-in (2.54-cm) anchor bolts and extended to the back face of the curb at an angle of approximately 45 degrees. These cracks (outlined for clarity) are shown in figure 75. This was interpreted as being the beginning of a classic shear failure, and it was anticipated that the curb would fracture during the next, more severe pickup truck crash test. Therefore, the reinforcement in the curb was redesigned by FHWA engineers and replaced before Test FPAR-2.

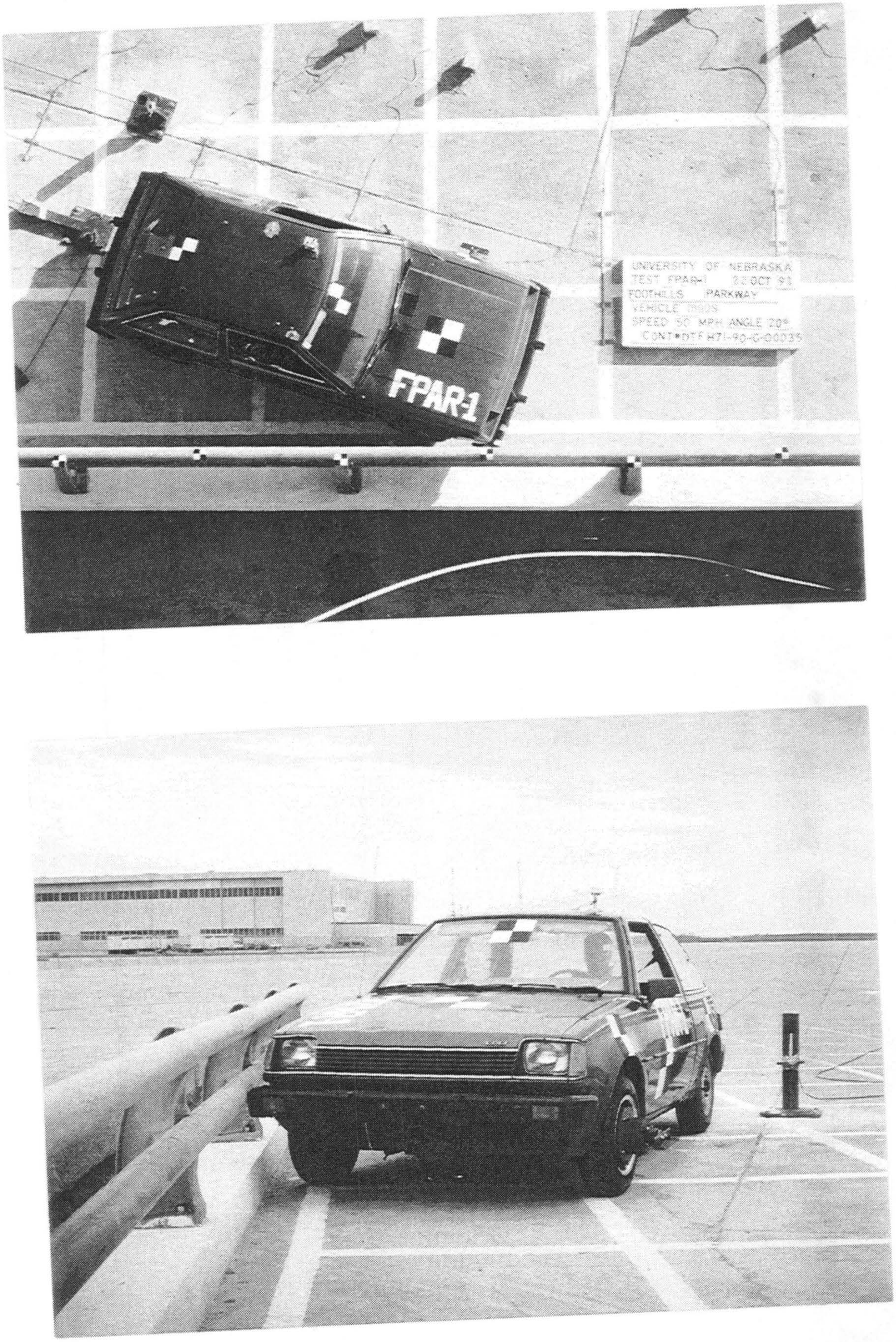
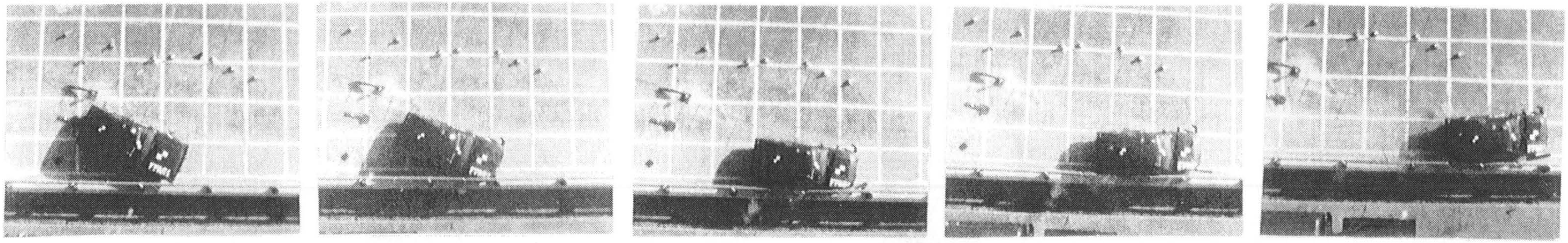
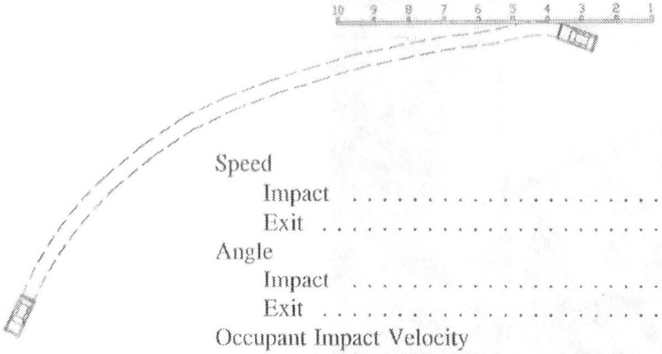


Figure 68. Impact Location, Test FPAR-1.



Impact 50 ms 140 ms 200 ms 300 ms

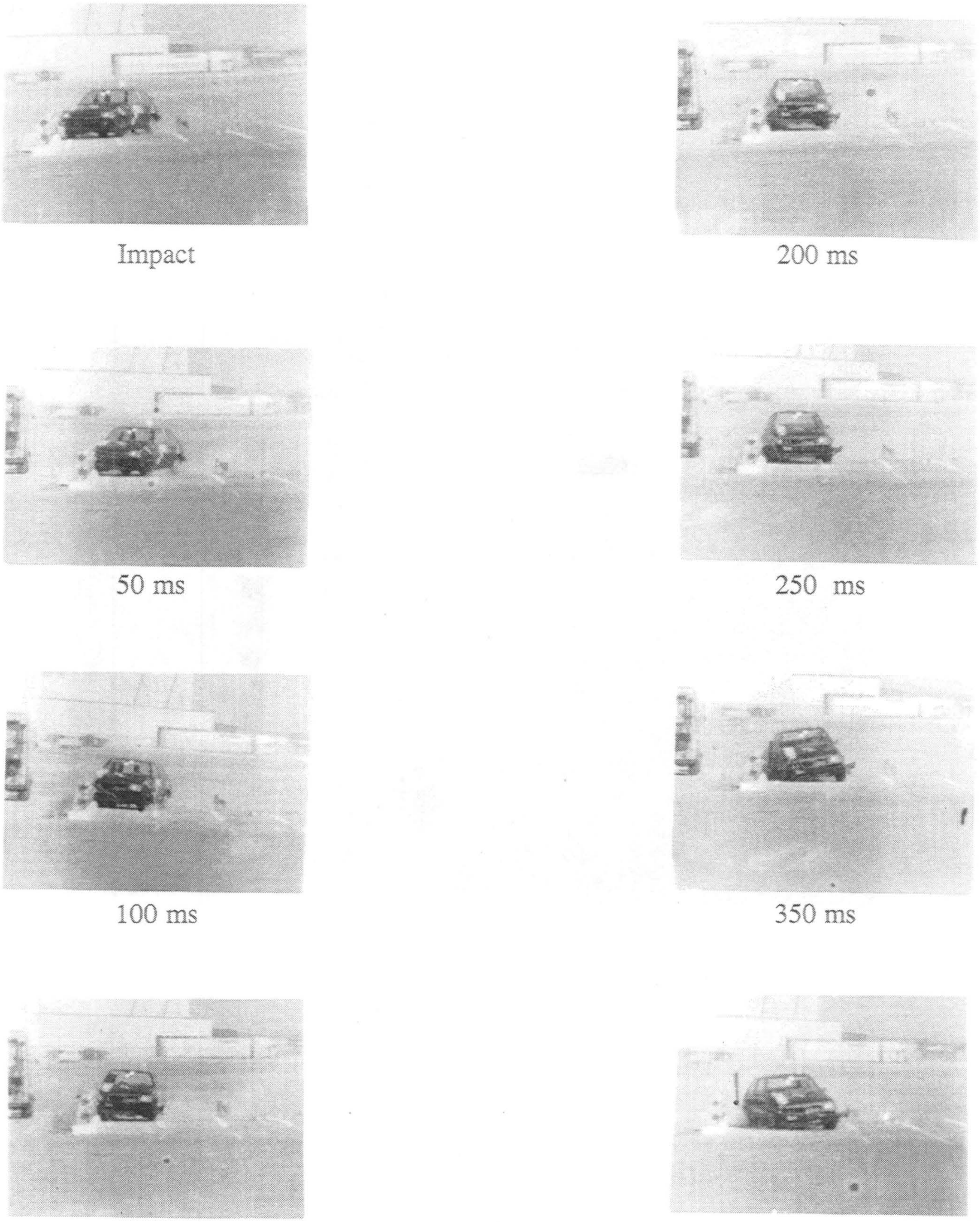


Test Number	FPAR-1
Federal Contract No.	DTFH71-90-C-00035
Date	10/22/91
Installation	Foothills Parkway Bridge Rail
Bridge Rail	
Length	75 ft
Height from curb	2 ft - 3 in
Post spacing	7 ft - 10-in
Material	Aluminum
Curb	
Height	6 in
Top width	1 ft - 4.5 in
Bottom width	1 ft - 6 in
Vehicle Model	1984 Dodge Colt
Vehicle Weight	
Curb	1,830 lbs
Test Inertia	1,904 lbs
Gross Static	2,069 lbs

Speed	
Impact	52.0 mi/h
Exit	41.8 mi/h
Angle	
Impact	22.0 deg
Exit	5.4 deg
Occupant Impact Velocity	
Longitudinal	9.6 ft/s
Lateral	23.0 ft/s
Occupant Ridedown Deceleration	
Longitudinal	5.7 g's
Lateral	4.3 g's
Vehicle Damage	
TAD	1-RFQ-4
VDI	01RFES2
Vehicle Rebound Distance	37 ft @ 113 ft
Bridge Rail Damage	Minor
Maximum Deflections	
Permanent Set	1.0 in
Dynamic	1.9 in

Conversion Factors: 1 in = 2.54 cm; 1 lb = 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

Figure 69. Summary of Test FPAR-1.



Impact

50 ms

100 ms

150 ms

200 ms

250 ms

350 ms

600 ms

Figure 70. Downstream Sequential Photographs, Test FPAR-1.

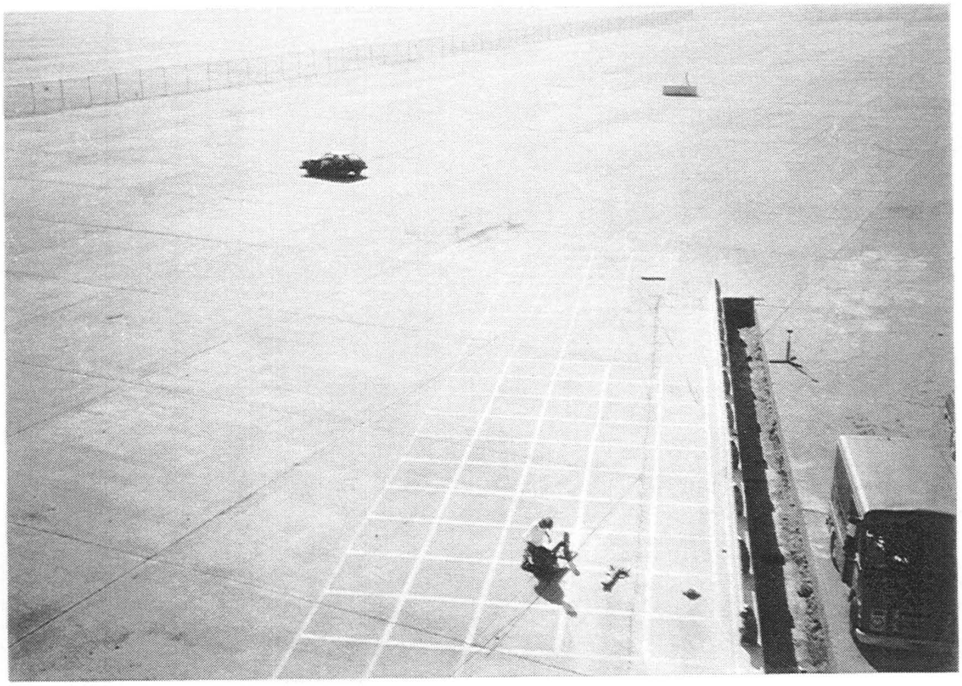
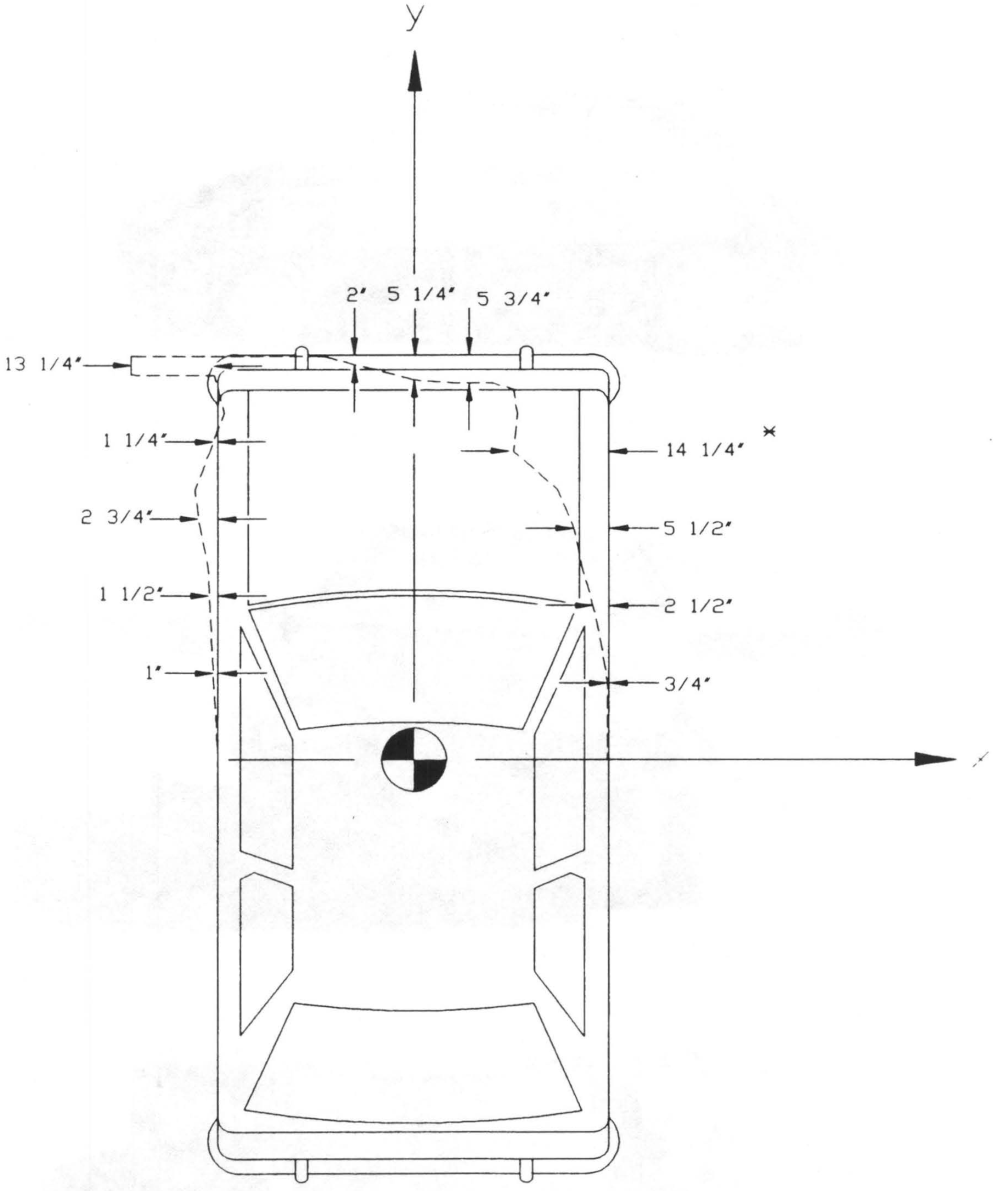


Figure 71. Vehicle Trajectory, Test FPAR-1.

Figure 72. Vehicle Damage, Test FPAR-1.



*-Maximum static crush distance of 14 1/4" occurred at (15 3/4",54")

Conversion factor: 1in.=2.54cm.

Figure 73. Crush Depth Diagram, Test FPAR-1.

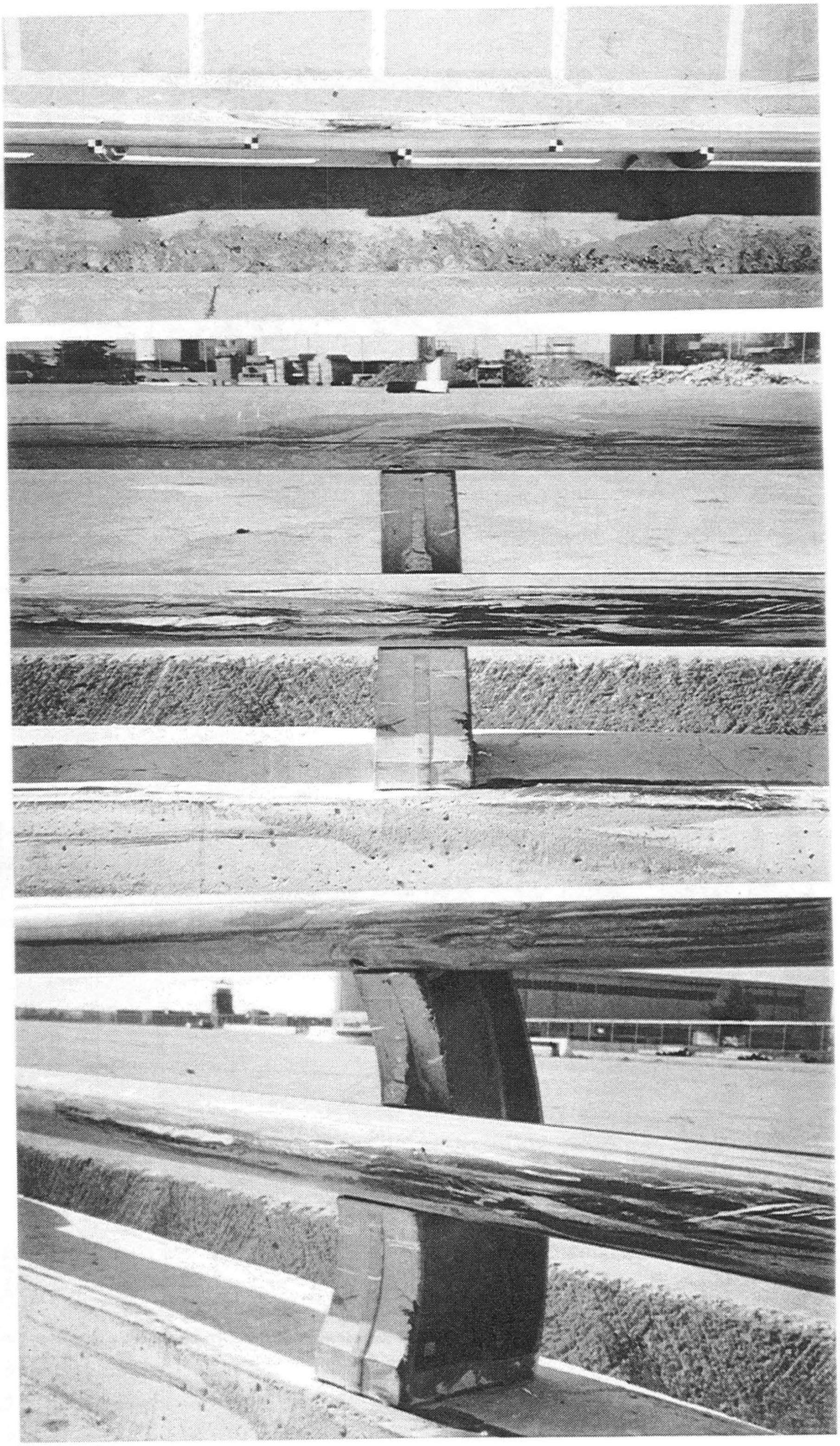


Figure 74. Bridge Rail Damage, Test FPAR-1.

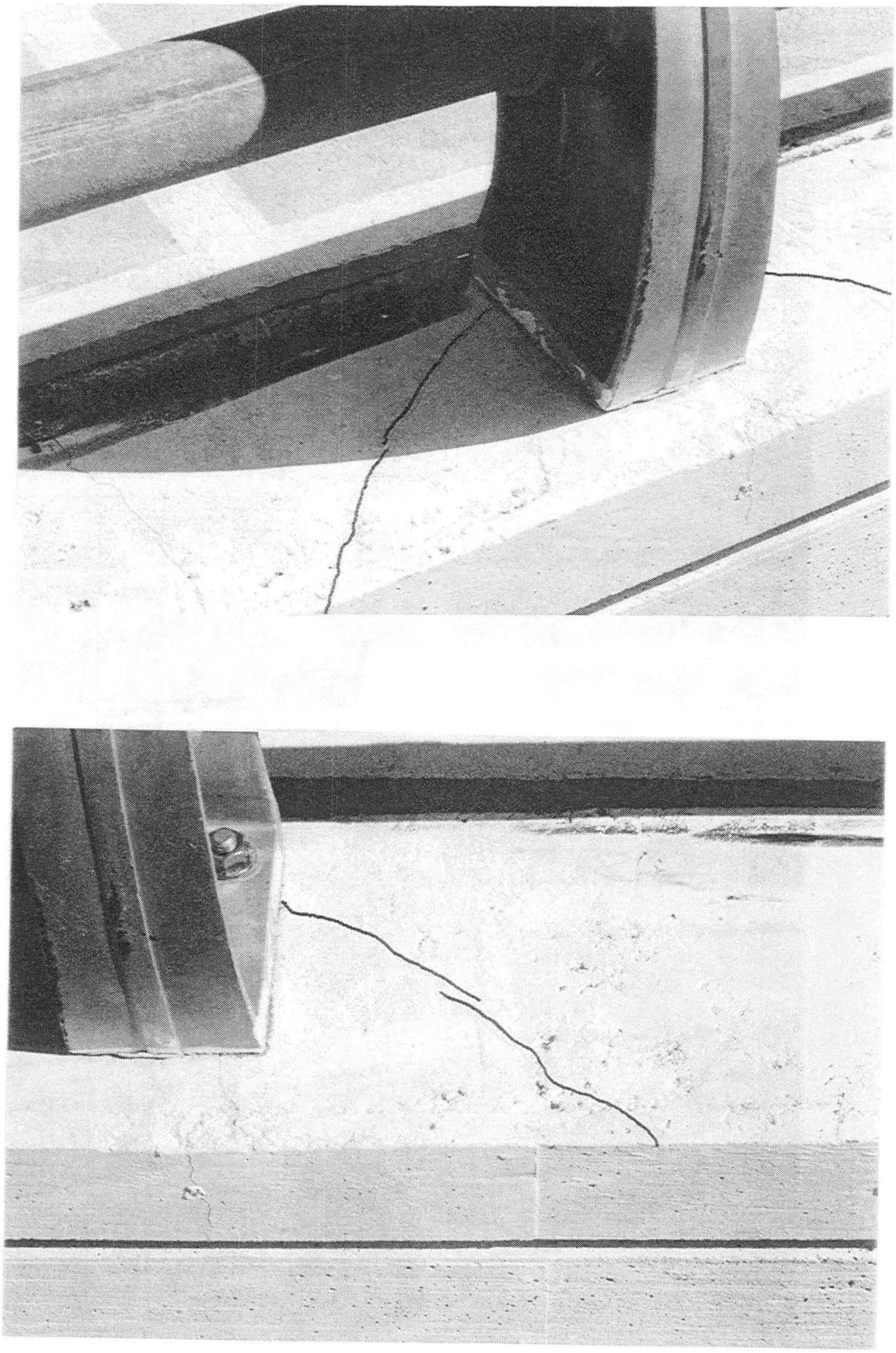


Figure 75. Cracking in Curb, Test FPAR-1 (outlined for clarity).

Test FPAR-2

The 1984 Chevrolet ¾-ton pickup impacted the Foothills Parkway Bridge Rail at 46.6 mi/h (75.0 km/h) and 20.7 degrees. The impact point was located midspan between the sixth and seventh posts from the upstream end of the installation, as shown in figure 76. A summary of the test results and sequential photographs are shown in figure 77. Additional sequential photographs are shown in figure 78.

Shortly after the impact with the bridge railing, both the top and bottom rail fractured completely through at post no. 7. In addition, the post and anchor assembly was uprooted from the concrete curb. After the vehicle had penetrated the bridge rail, it continued down the length of the system, knocking posts over until it came to a stop when the rear axle snagged on the last post.

The vehicle damage, shown in figure 79, included the crushing of the right-front corner of the vehicle and minor scrapes and dents along the length of the passenger side. The right-front tire was blown out, and the rim was bent. The maximum crush deformation of 26.5 in (67.3 cm) is shown in figure 80.

The longitudinal and lateral occupant impact velocities were 10.4 ft/s (3.2 m/s) and 16.0 ft/s (4.9 m/s), respectively. The maximum occupant ridedown decelerations were 6.0 g's (longitudinal) and 8.0 g's (lateral). The results of this analysis are summarized in figure 77 and table 7. Accelerometer traces are presented in appendix C.

As shown in figure 81, the bridge rail and curb were totally destroyed in the area where the impact occurred. It was evident from this test that both the post-to-deck connection and the aluminum rail itself needed to be redesigned. The FHWA engineers remedied the first of these problems, as shown in figure 67, by extending the anchor bolts through the entire deck instead of simply casting them into the 6-in (152-mm) curb. The aluminum rail was then redesigned by increasing the wall thickness from 7/32 in (5.6 mm) to 7/16 in (11.1 mm). This new design was evaluated in Test FPAR-3.

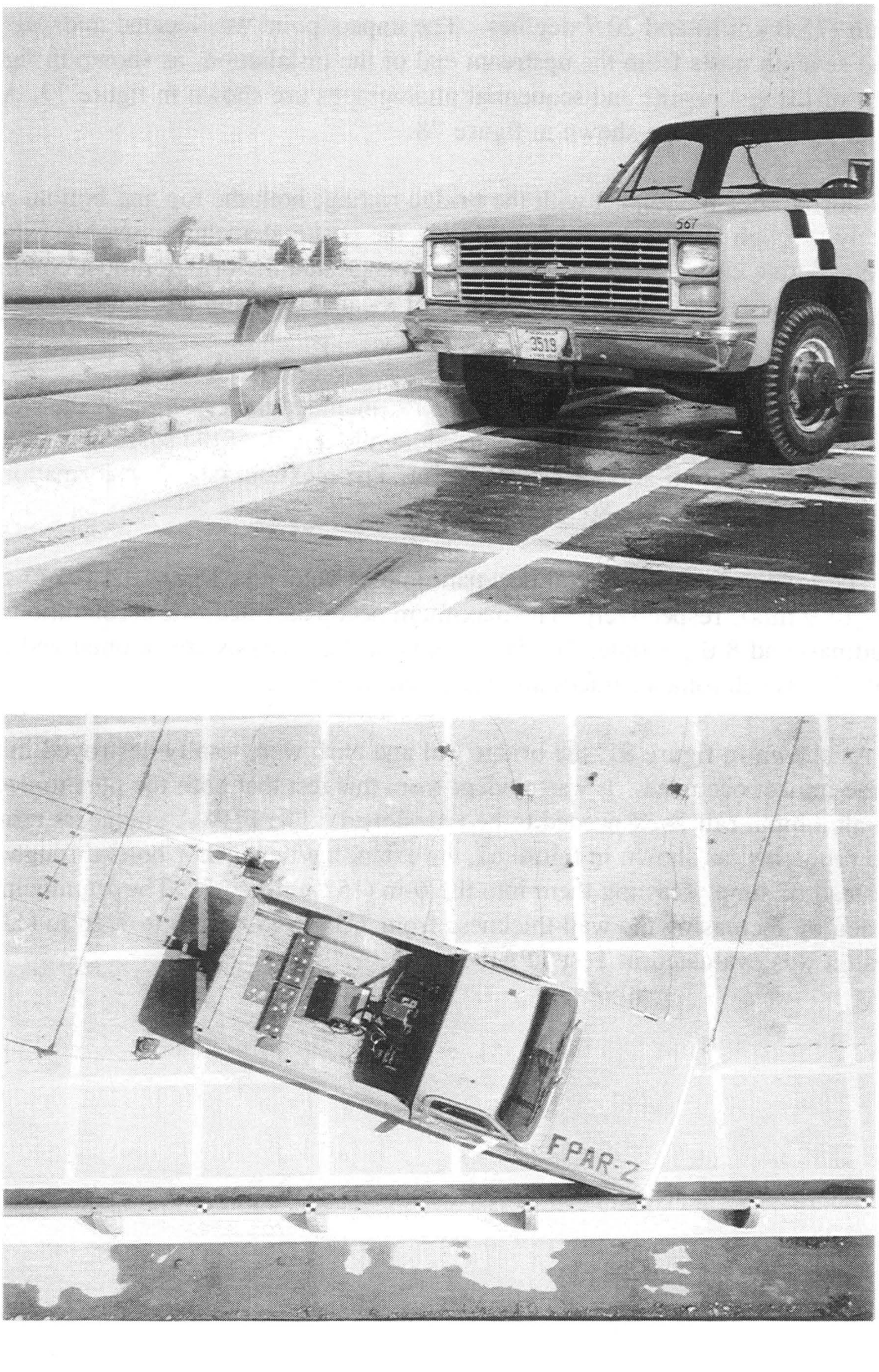
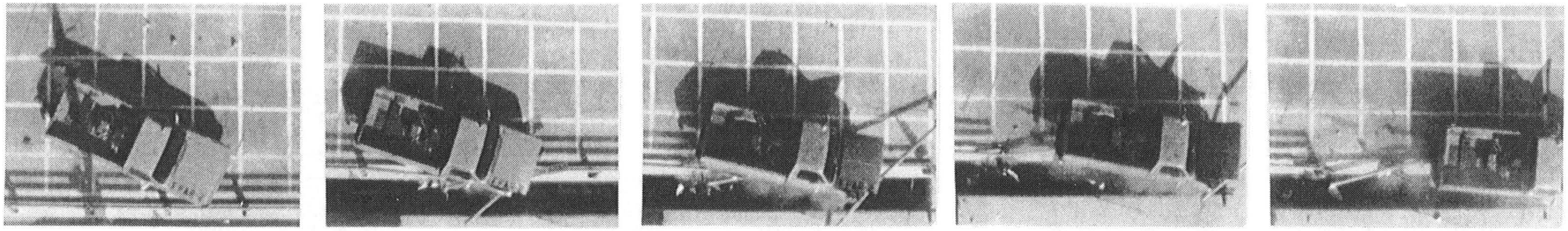
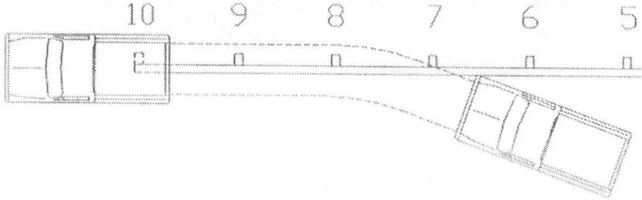


Figure 76. Impact Location, Test FPAR-2.


Impact 200 ms 400 ms 600 ms 800 ms

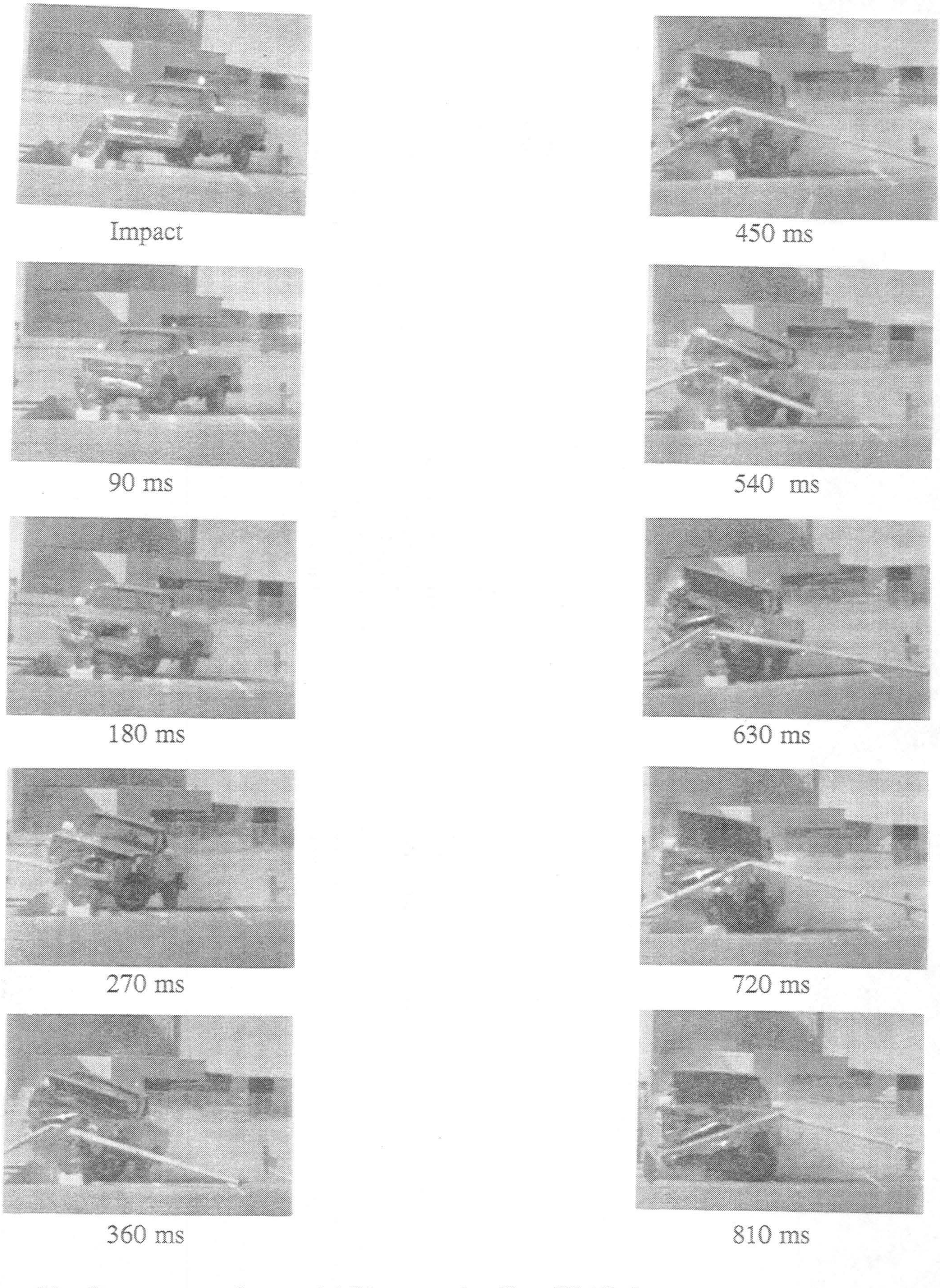


Test Number	FPAR-2
Federal Contract No.	DTFH71-90-C-00035
Date	3-13-92
Installation	Foothills Parkway Bridge Rail
Bridge Rail	
Length	75 ft
Height from curb	2 ft - 3 in
Post spacing	7 ft - 10-in
Material	Aluminum
Curb	
Height	6 in
Top width	1 ft - 4.5 in
Bottom width	1 ft - 6 in
Vehicle Model	1984 Chevy ¾-ton pickup
Vehicle Weight	
Curb	4,520 lbs
Test Inertia	5,300 lbs
Gross Static	5,465 lbs

Speed	
Impact	46.6 mi/h
Exit	0 mi/h
Angle	
Impact	20.7 deg
Exit	NA
Occupant Impact Velocity	
Longitudinal	10.4 ft/s
Lateral	16.0 ft/s
Occupant Ridedown Deceleration	
Longitudinal	6.0 g's
Lateral	8.0 g's
Vehicle Damage	
TAD	1-RFQ-4
VDI	01FRES2
Vehicle Rebound Distance	0 ft
Bridge Rail Damage	Destroyed
Maximum Deflections	
Permanent Set	NA
Dynamic	NA

Conversion Factors: 1 in = 2.54 cm; 1 lb = 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

Figure 77. Summary of Test FPAR-2.



Impact

90 ms

180 ms

270 ms

360 ms

450 ms

540 ms

630 ms

720 ms

810 ms

Figure 78. Downstream Sequential Photographs, Test FPAR-2.

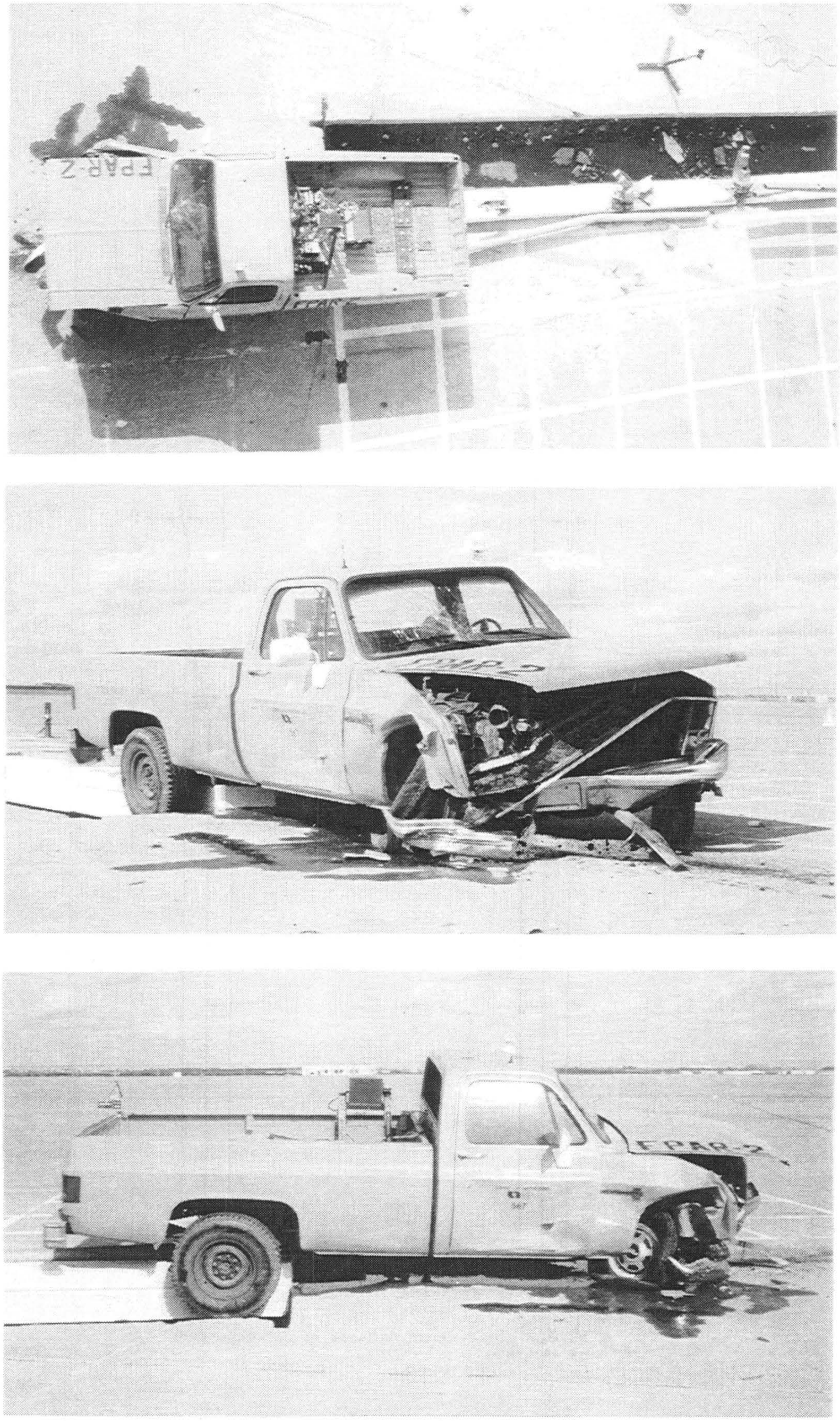
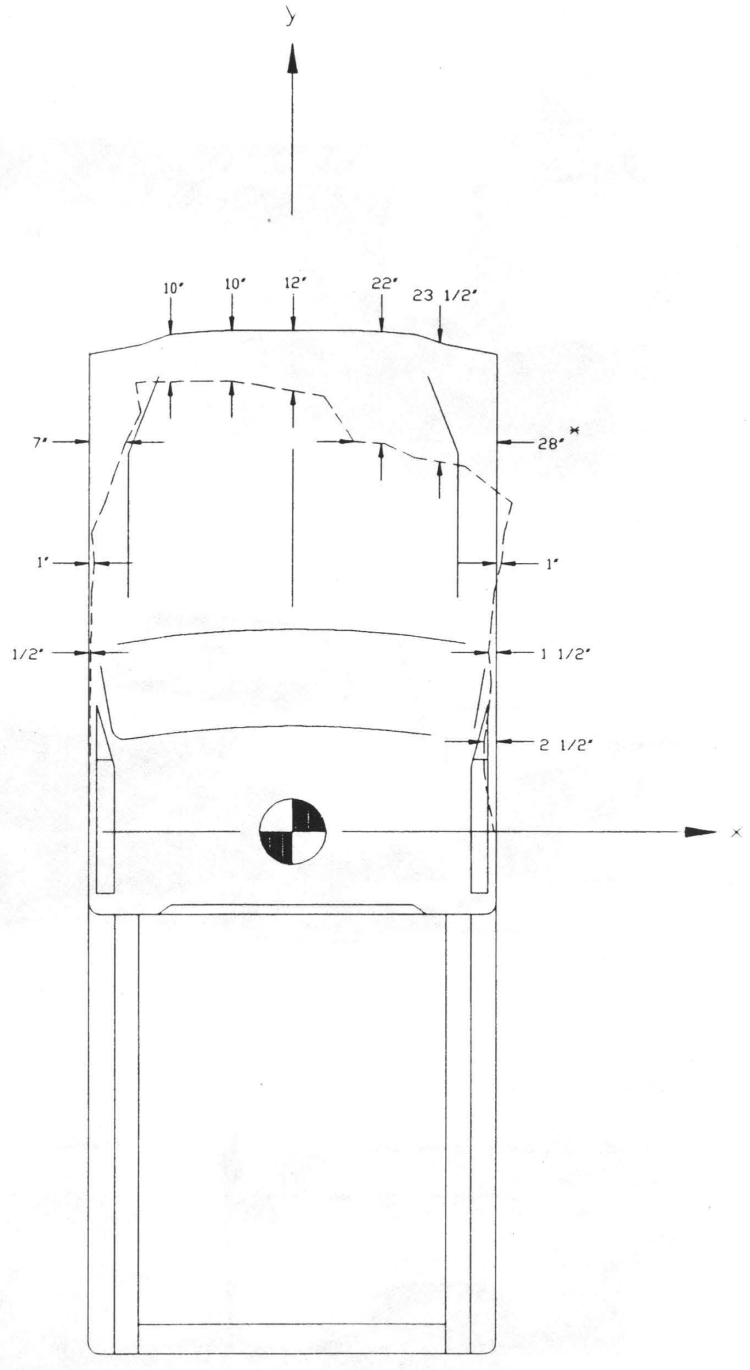


Figure 79. Vehicle Damage, Test FPAR-2.



* -Maximum static crush distance of 28" occurred at (40",78").

Conversion factor 1in=2.54cm

Figure 80. Crush Depth Diagram, Test FPAR-2.

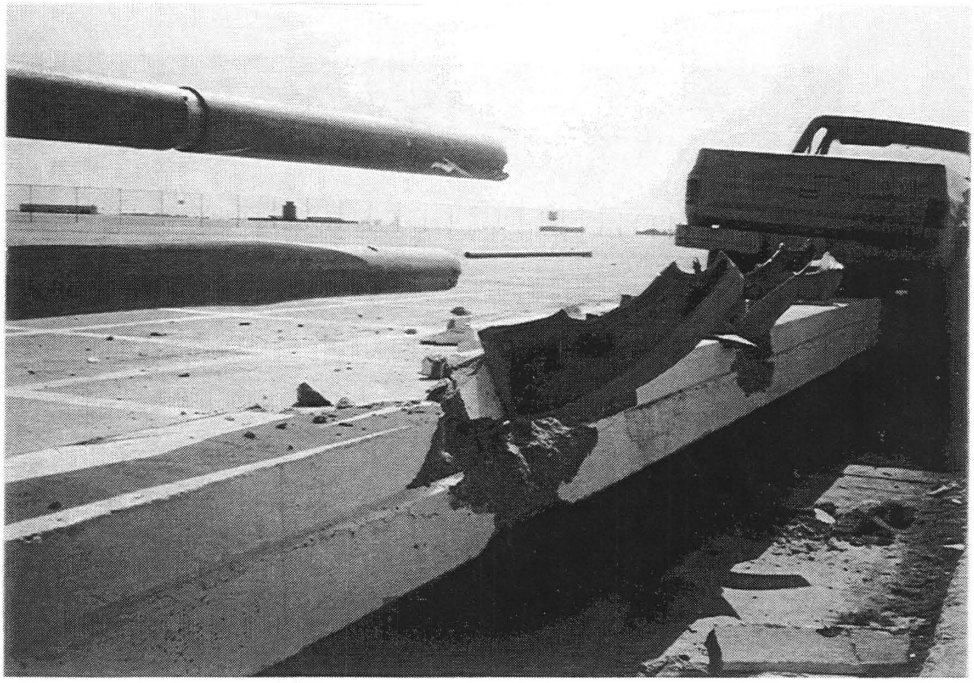


Figure 81. Bridge Rail Damage, Test FPAR-2.

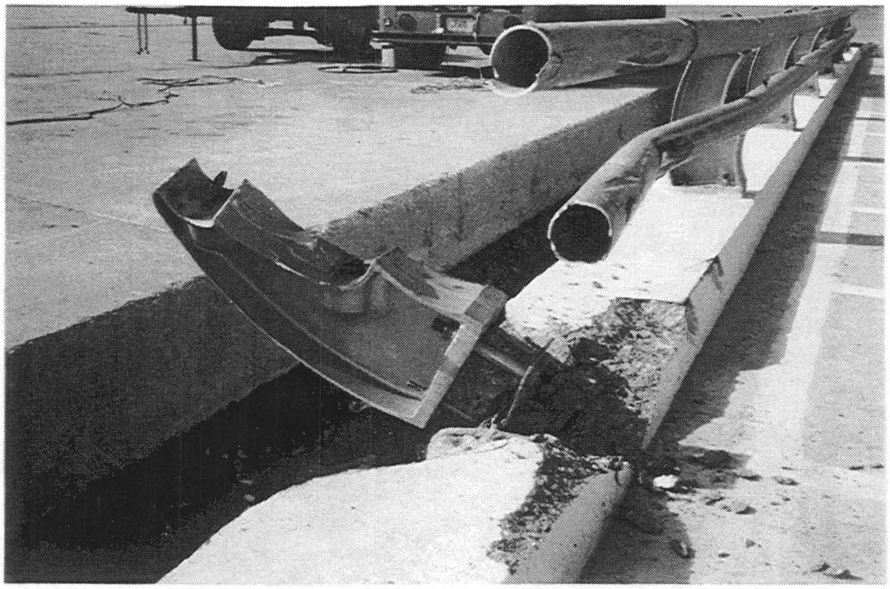


Figure 81. Bridge Rail Damage, Test FPAR-2 (continued).

Test FPAR-3

The 1985 Ford ¾-ton pickup impacted the Foothills Parkway Bridge Rail at 45.7 mi/h (73.5 km/h) and 22.7 degrees. The impact point was located midspan between the fifth and sixth posts from the upstream end of the installation, as shown in figure 82. A summary of the test results and sequential photographs are shown in figure 83. Additional sequential photographs are shown in figure 84.

The vehicle was smoothly redirected by the bridge railing, with a relatively small amount of damage to the rail and vehicle. There was no snagging of the vehicle or any evidence of cracking in the deck or curb. The maximum permanent set deflection of 1.9 in (4.8 cm) occurred midspan of posts no. 5 and 6. The damage to the bridge rail is shown in figure 85, and the vehicle trajectory is shown in figure 86.

The vehicle damage, shown in figure 87, included the crushing of the right-front corner of the vehicle and scrapes and dents along the length of the passenger side. The right-front tire was blown out, and the rim was bent. The maximum crush deformation of 10.75 in (27.3 cm) is shown in figure 88.

The longitudinal and lateral occupant impact velocities, as determined from high-speed film analysis, were 10.4 ft/s (3.17 m/s) and 16.0 ft/s (4.88 m/s), respectively. The maximum occupant ridedown decelerations were 6.0 g's (longitudinal) and 8.0 g's (lateral). The results of this analysis are summarized in figure 83 and table 7. Accelerometer traces are presented in appendix C.

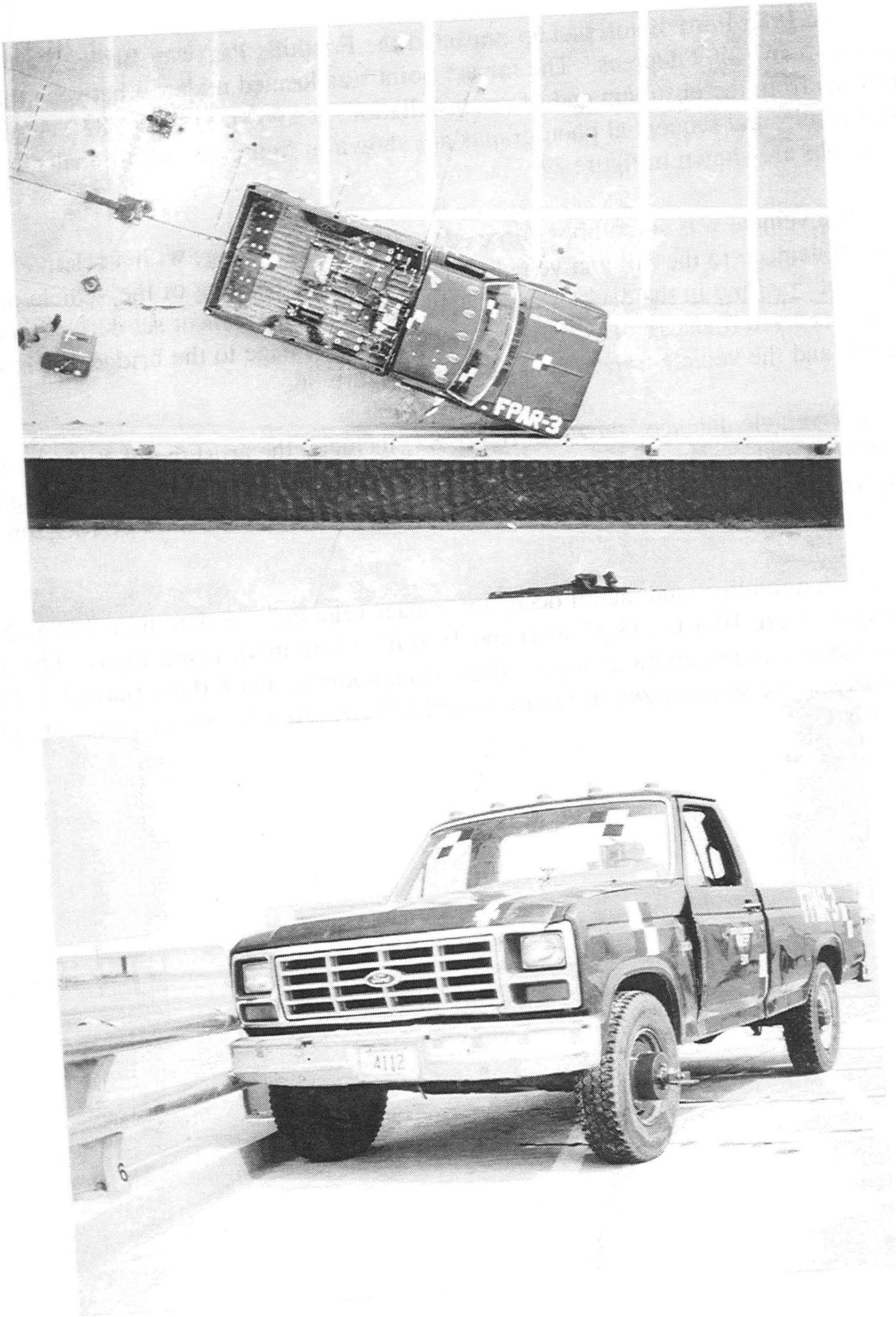
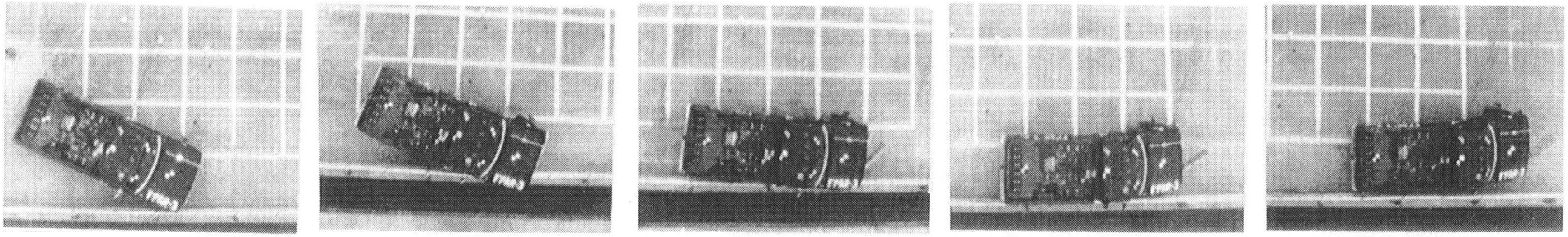


Figure 82. Impact Location, Test FPAR-3.



Impact 120 ms 240 ms 360 ms 480 ms

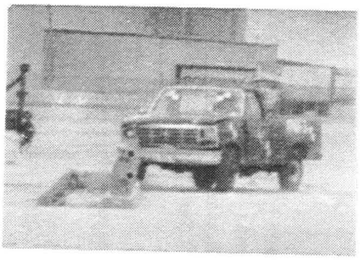
Test Number	FPAR-3
Federal Contract No.	DTFH71-90-C-00035
Date	6-7-93
Installation	Foothills Parkway Bridge Rail
Bridge Rail	
Length	75 ft
Height from curb	2 ft 3 in
Post spacing	7 f t 10-in
Material	Aluminum
Curb	
Height	6 in
Top width	1 ft 4.5 in
Bottom width	1 ft 6 in
Vehicle Model	1985 Ford ¾-ton pickup
Vehicle Weight	
Curb	4,060 lbs
Test Inertia	5,400 lbs
Gross Static	5,565 lbs

Speed	
Impact	45.7 mi/h
Exit	30.6 mi/h
Angle	
Impact	22.7 deg
Exit	5.0 deg
Occupant Impact Velocity	
Longitudinal	10.4 ft/s
Lateral	16.0 ft/s
Occupant Ridedown Deceleration	
Longitudinal	6.0 g's
Lateral	8.0 g's
Vehicle Damage	
TAD	1-RFQ-3
VDI	01RYES2
Vehicle Rebound Distance	24 ft
Bridge Rail Damage	Minor
Maximum Deflections	
Permanent Set	1.9 in
Dynamic	NA

Conversion Factors: 1 in= 2.54 cm; 1 lb= 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

Figure 83. Summary of Test FPAR-3.

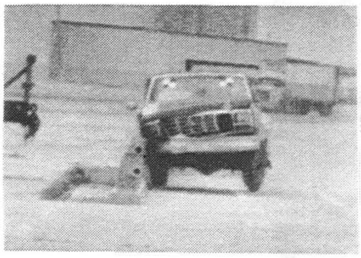
Impact



60 ms

120 ms

180 ms



240 ms

300 ms

360 ms

420 ms

Figure 84. Downstream Sequential Photographs, Test FPAR-3.

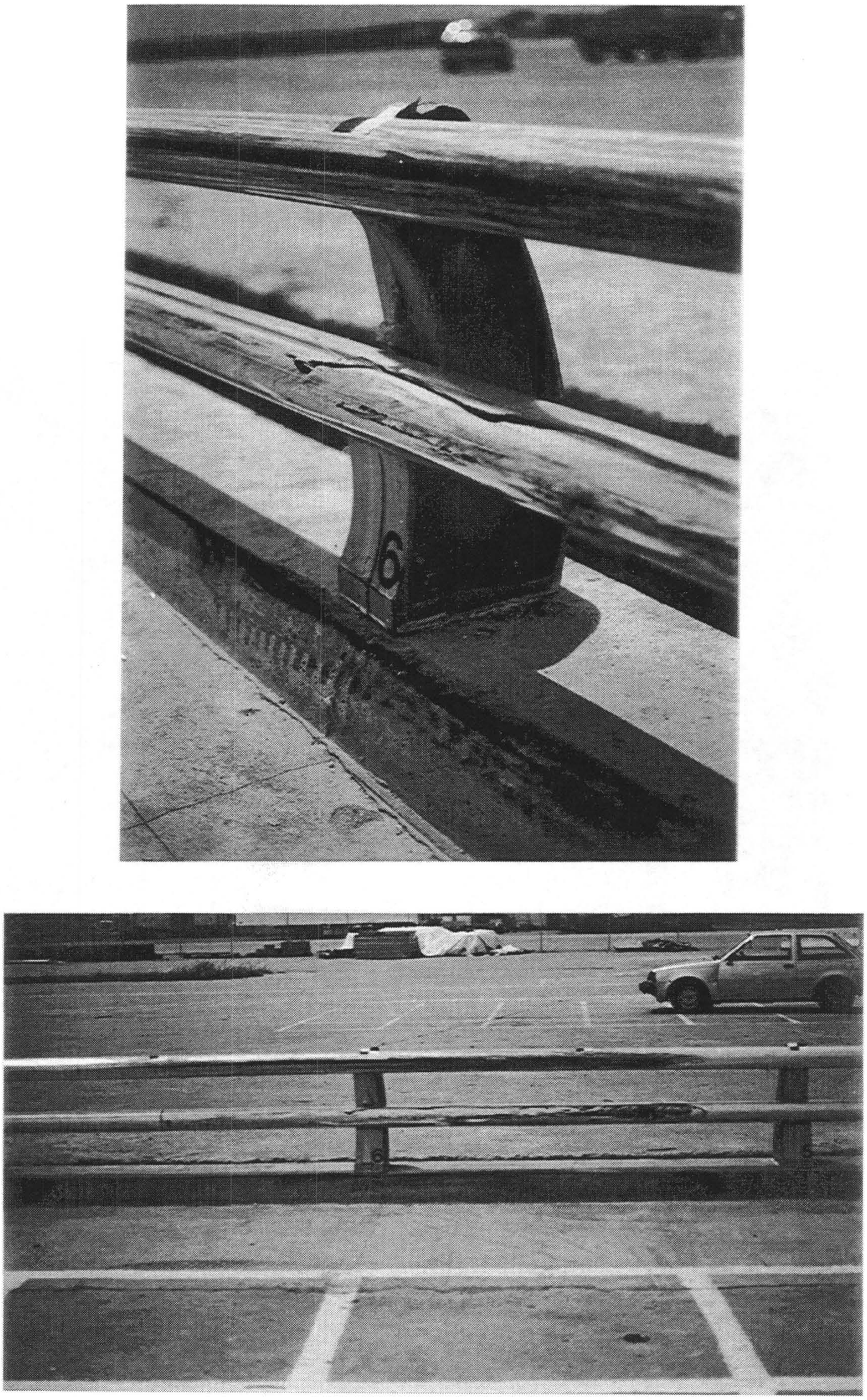


Figure 85. Bridge Rail Damage, Test FPAR-3.

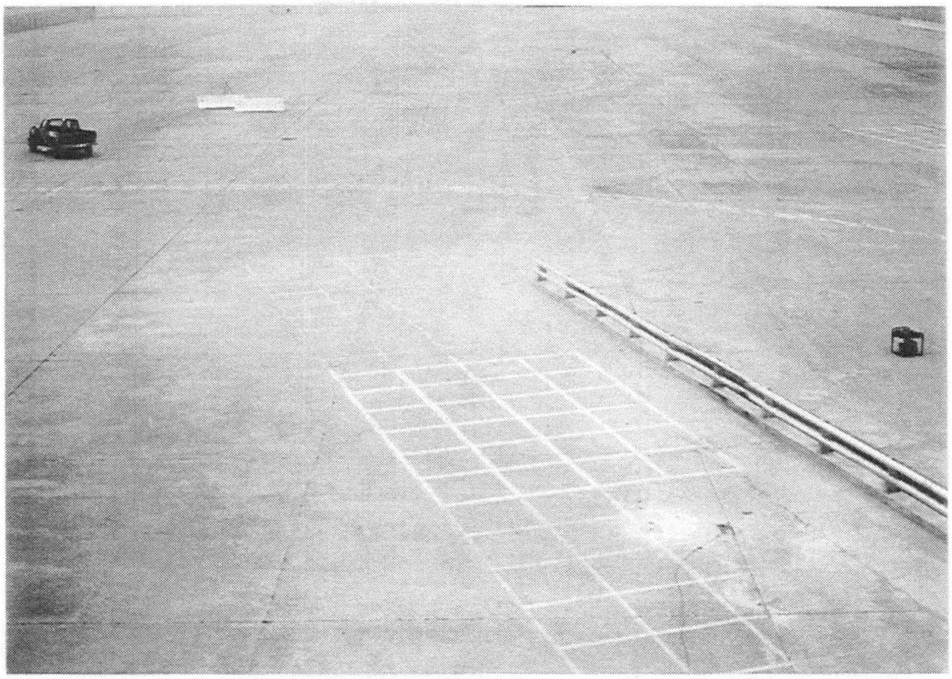


Figure 86. Vehicle Trajectory, Test FPAR-3.

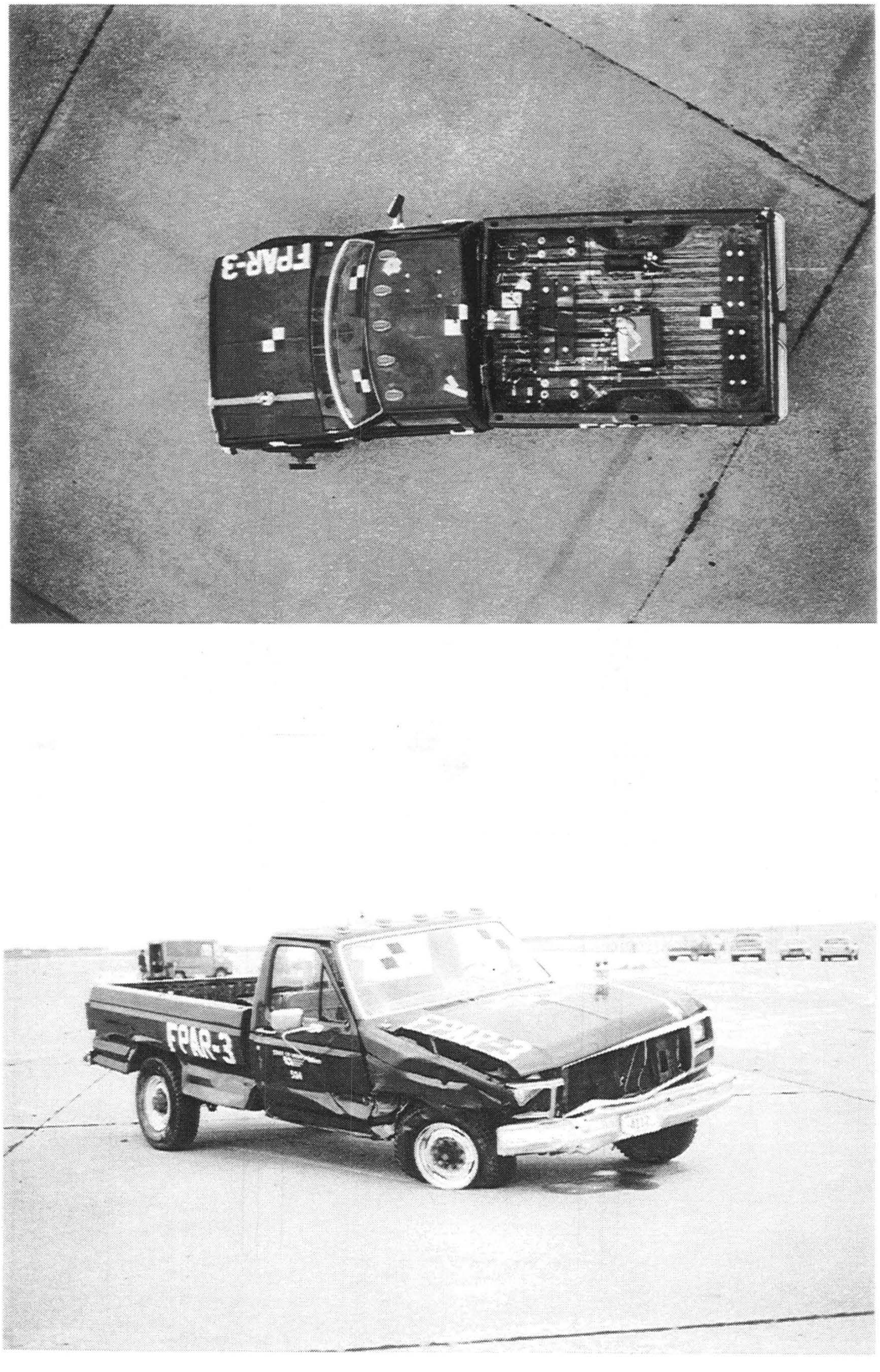
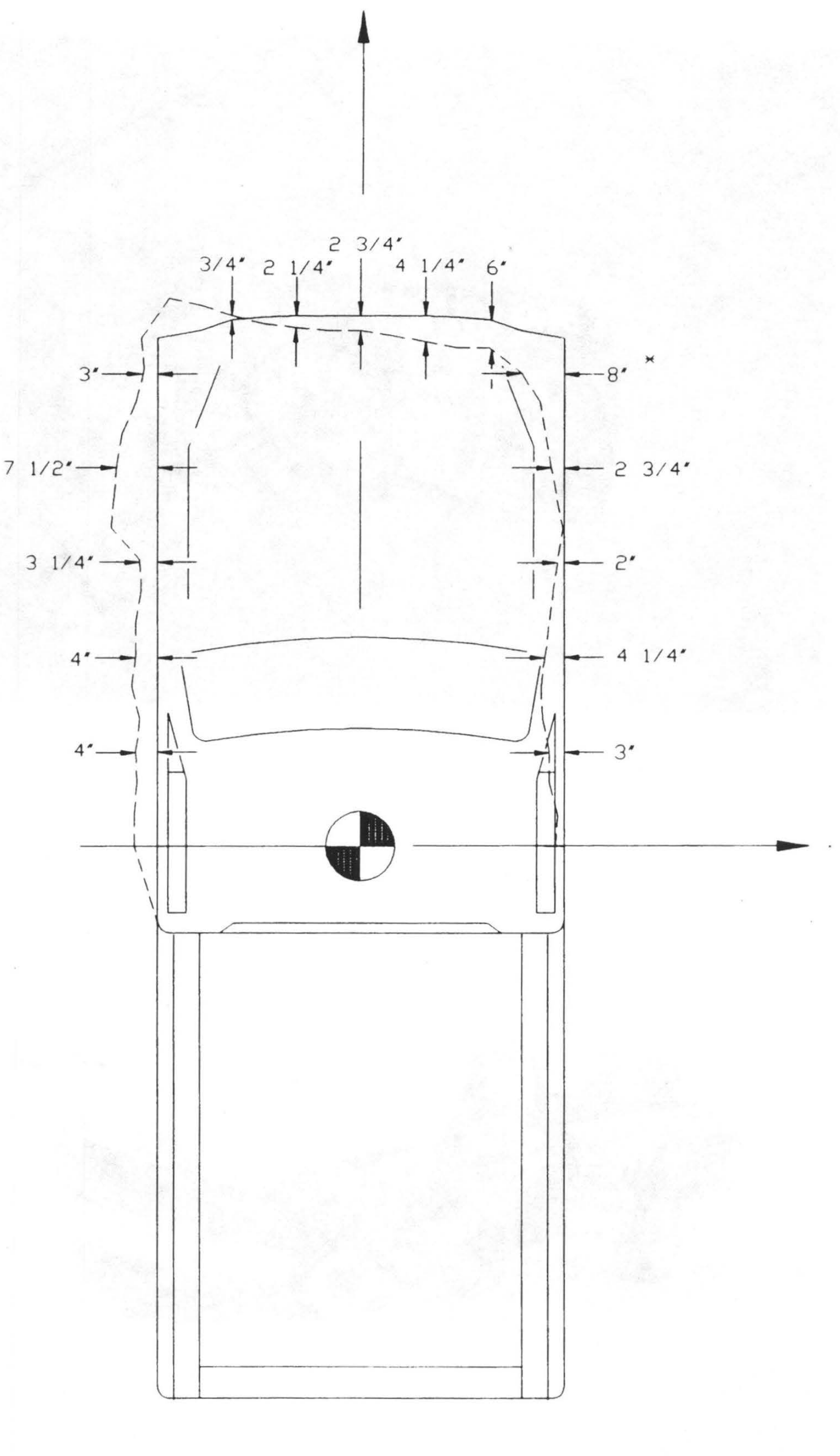


Figure 87. Vehicle Damage, Test FPAR-3.



* Maximum static crush distance of 8" occurs at (3",39 1/4")

Conversion factor 1in.=2.54cm.

Figure 88. Crush Depth Diagram, Test FPAR-3.

COMPONENT TESTING

Standard tensile samples were obtained from the two aluminum rails that were evaluated during this project. These samples were tested to verify that they met the specifications for aluminum extruded tube ASTM B-221, Alloy 6061-T6. The results of this testing are summarized in table 6.

Table 6. Results of Coupon Testing from Aluminum Rail Samples.

Material Property	Specification	FPAR-1, 2	FPAR-3
Yield Stress	35,000 lbf/in^2	41,500 lbf/in^2	43,800 lbf/in^2
Ultimate Stress	38,000 lbf/in^2	46,800 lbf/in^2	45,300 lbf/in^2
Percent Elongation	10 %	15.8 %	9.9 %

EVALUATION SUMMARY

The tests described herein were evaluated according to criteria for PL-1 bridge railings presented in *AASHTO Guide Specifications for Bridge Railings*.(8) They were conducted and reported in accordance with the requirements in NCHRP Report 230.(4) Table 7 summarizes all of the relevant evaluation criteria from AASHTO as well as the findings from the three tests reported herein.(8) As shown in this table, the Foothills Parkway Bridge Rail successfully passed all requirements for PL-1 bridge railings.

Table 7. Summary of Safety Performance Results, FPAR Series.

Evaluation Criteria	Results					
	FPAR-1		FPAR-2		FPAR-3	
3.a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	S		U		S	
3.b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	S		U		S	
3.c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	S		S		S	
3.d. The vehicle shall remain upright during and after collision.	S		S		S	
3.e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.	S		U		S	
3.f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ, where $\mu = (\cos\theta - V_p/V)/\sin\theta$. μ — Assessment 0.0 - 0.25 — Good 0.26 - 0.35 — Fair > 0.35 — Marginal	F (μ = 0.28)		NA		F (μ = 0.34)	
3.g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0 ft longitudinal and 1.0 ft lateral displacements, shall be less than:	Occupant Impact Velocity (ft/s)					
Occupant Impact Velocity - ft/s Longitudinal — Lateral 30 — 25	Long	Lat.	Long.	Lat.	Long.	Lat.
	S (9.6)	S (23)	S (10.4)	S (16)	S (10.4)	S (16)
and for the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than:	Occupant Ridedown Accelerations (g's)					
Occupant ridedown Accelerations - g's Longitudinal — Lateral 15 — 15	Long	Lat.	Long.	Lat.	Long.	Lat.
	S (5.7)	S (4.3)	S (8)	S (8)	S (8)	S (8)
3.h. Vehicle exit angle from the barrier shall not be more than 12 degrees.	S (5.4 deg)		NA		S (5.0 deg)	
Within 100 ft plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20 ft from the line of the traffic face of the railing.	U (37 ft @ 113 ft)		NA		M (24.0 ft @118 ft)	

S = Satisfactory
M = Marginal
U = Unsatisfactory

Conversion Factor: 1 ft = 0.3048 m

6. NATCHEZ TRACE PARKWAY BRIDGE RAIL

TEST INSTALLATION

The Natchez Trace Parkway Bridge Rail incorporates a 13-in (33-mm) deep concrete railing mounted at a height of 32.5 in (826 mm). Each railing element of the test installation was 37 ft-9 ¾ in (11.5 m) long and is supported by six concrete posts spaced at 7 ft-6 ¾ in (2.3 m) centers. Adjacent railings are not connected, and ½-in (13-mm) wide expansion joints are placed at the end of each rail element. The concrete posts are mounted on top of a 10-in (254-mm) high concrete curb. The face of the curb extends approximately 4 in (102 mm) out from the face of the concrete barrier railing. The wingwall section of the bridge rail is flared back away from the travelway and tapered down to a height of 16 in (406 mm). Photographs of the test installation are shown in figure 89. Cross section and profile drawings of the Natchez Trace Parkway Bridge Rail are shown in figure 90. The test installation was constructed on a simulated concrete bridge deck measuring 79.5 ft (24.2-m) long and 5 ft-9 in (1.75-m) wide. A typical cross section of the simulated bridge deck is shown in figure 43. Epoxy coated grade 60 reinforcement steel and class A air-entrained concrete were used throughout the installation. The 28-day compressive strength of the concrete rail and posts was measured to be approximately 5,700 lbf/in^2 (39,310 kPa). The 51-day compressive strength of the curb was approximately 6,500 lbf/in^2 (44,830 kPa).

TEST CRITERIA

This bridge rail system was evaluated according to the PL-1 criteria for bridge railings presented by AASHTO.(8) The full-scale vehicle crash tests were conducted and reported in accordance with requirements specified in NCHRP Report 230.(4) The vehicle damage was assessed by the TAD and VDI.(6,7)

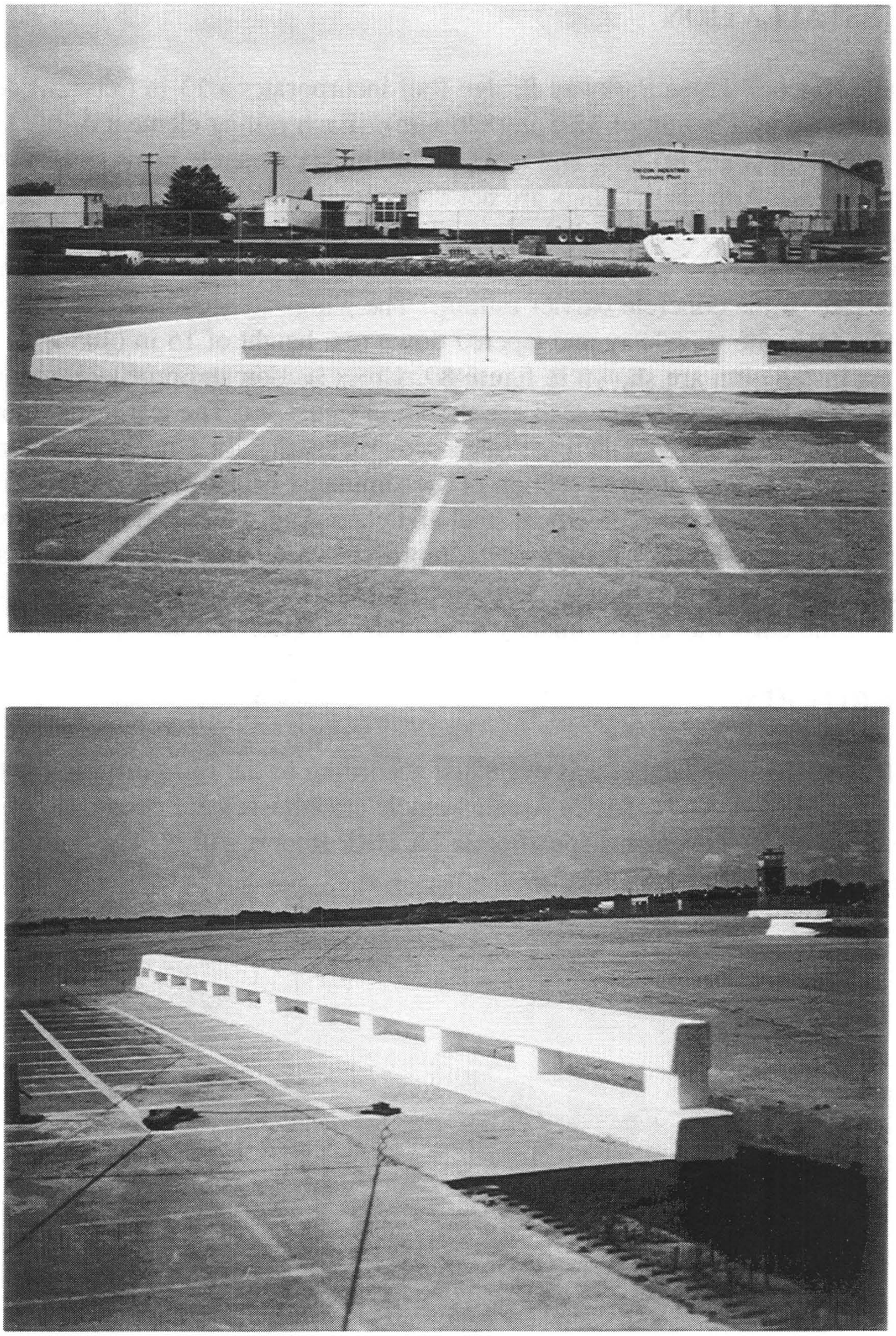
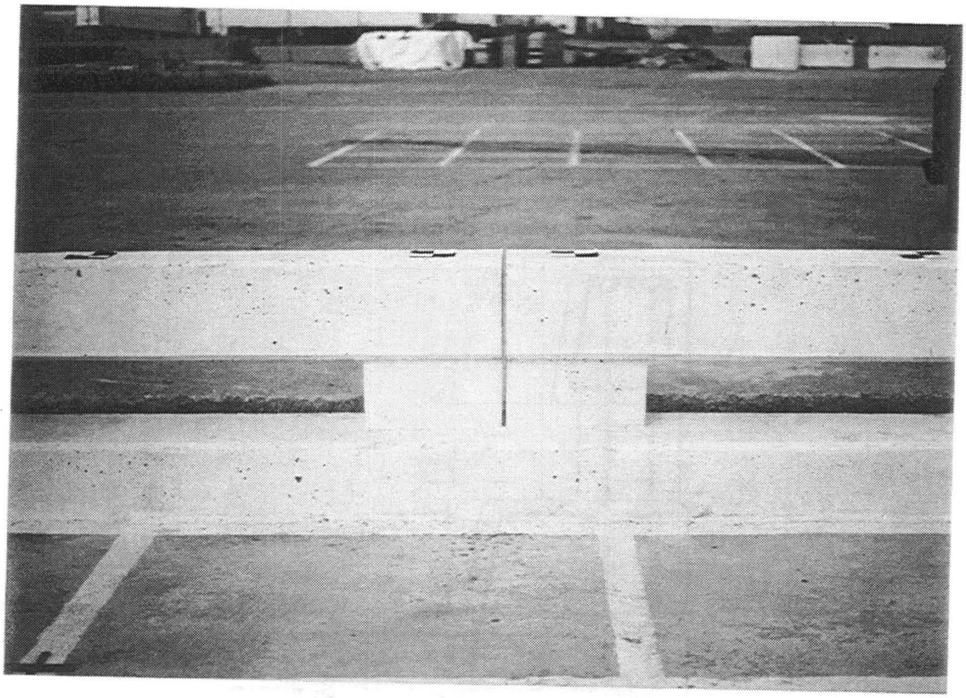


Figure 89. The Natchez Trace Parkway Bridge Rail.



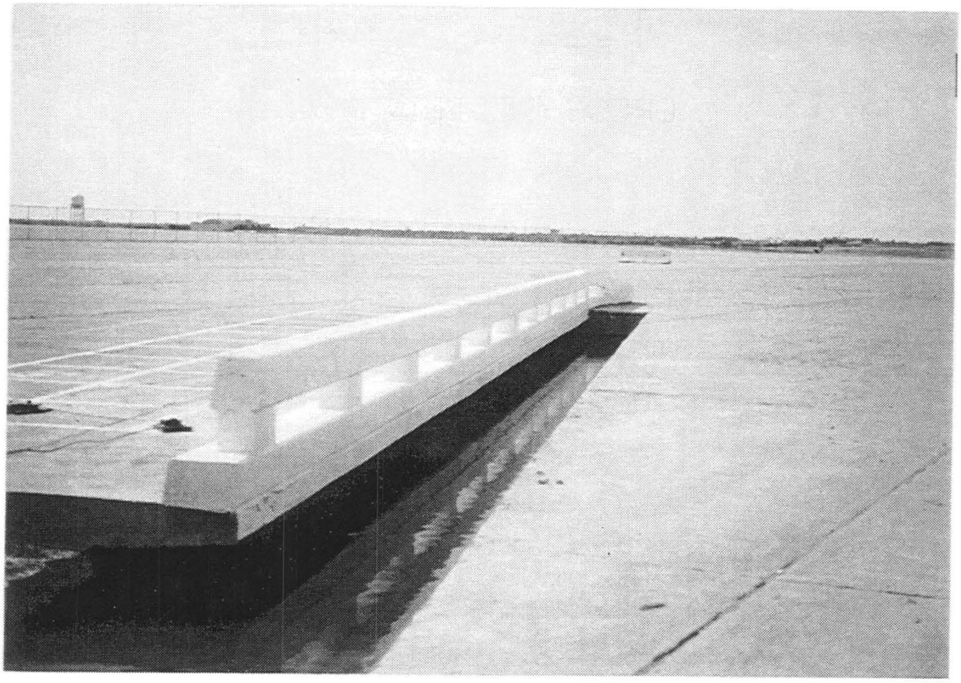
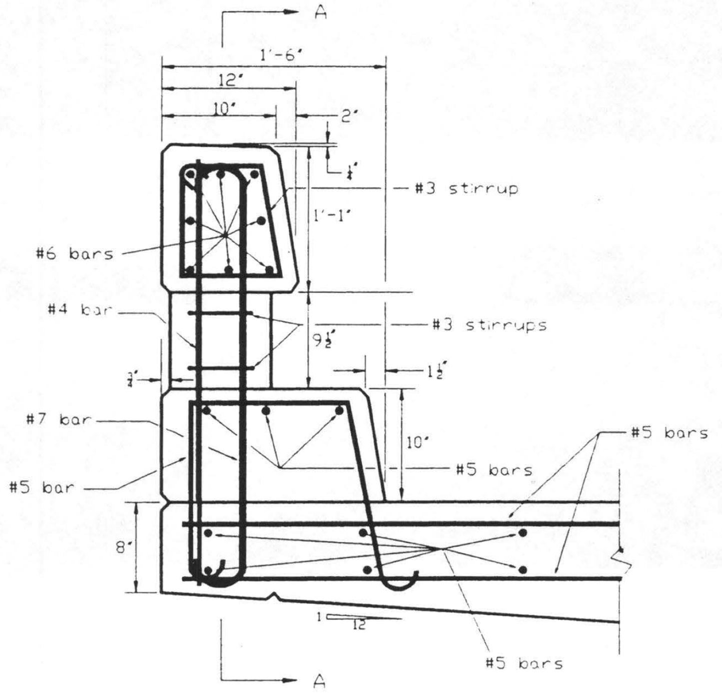
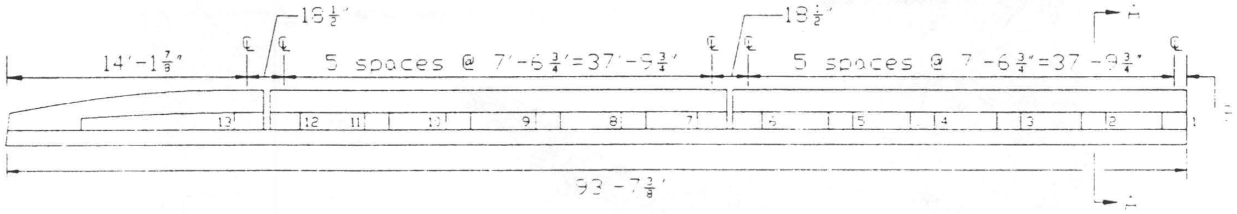


Figure 89. The Natchez Trace Parkway Bridge Rail (continued).



CROSS-SECTION A-A



PROFILE VIEW

Figure 90. Natchez Trace Parkway Bridge Rail Details.

TEST VEHICLES

The test vehicles used in the evaluation of this system are summarized in table 8. The pretest vehicle dimensions and photographs are presented in appendix B.

Table 8. Test Vehicle Summary, NTBR Series.

Test No.	Vehicle	Test Inertial Weight	
		(lb)	(kg)
NTBR-1	1984 Chevrolet ¾-ton pickup	5,400	2,451
NTBR-2	1984 Renault Encore	1,850	840

TEST RESULTS

Test NTBR-1

The 1984 Chevrolet Custom Deluxe 20 pickup impacted the bridge rail at 45.2 mi/h (72.7 km/h) and 22.4 degrees. The impact point, shown in figure 91, was located at midspan between posts no. 5 and 6, or 4 ft 6 ⅝ in (1.39 m) upstream from the center of the bridge rail expansion joint. A summary of the test results and sequential photographs are shown in figure 92. Additional sequential photographs are shown in figure 93.

Upon impact, the right-front corner of the test vehicle crushed inward and the right-front tire began climbing onto the curb. Approximately 32 ms after impact, the right-front tire became wedged under the concrete rail. The right-front corner of the vehicle began to move upward at 56 ms because of compression of the front suspension. At 75 ms, the right-front corner of the vehicle reached the bridge rail expansion joint. The vehicle became parallel with the bridge rail at approximately 250 ms at a velocity of 37 mi/h (59.5 km/h). The left-front tire lost contact with the roadway surface 255 ms after impact. The right-rear tire blew out when it contacted the expansion joint between the two railings at approximately 310 ms. The vehicle exited the bridge rail at approximately 335 ms with an angle of 1.6 degrees and at a speed of 37.0 mi/h (59.5 km/h). The left-front tire returned to the roadway surface at 474 ms. Damage to the suspension and tires caused the vehicle to steer back into the bridge rail, and a second impact occurred at the downstream end of the bridge rail and wingwall section. The vehicle came to a stop approximately 105 ft (32 m) downstream from impact, as shown in figure 94. The maximum perpendicular distance between the right side of the test vehicle and the barrier face was approximately 10 in (25 cm) at a point 30 ft (9.1 m) downstream from impact. The effective coefficient of friction was found to be 0.28 and would be classified as fair according to the *AASHTO Guide Specifications for Bridge Railings*.(8)

Test vehicle damage was relatively minor and was largely limited to the right-front quarter panel and front bumper, as shown in figure 95. Both right-side tires were blown out, and the rims were damaged during the impact. The right-rear bumper also received minor damage. There was no intrusion or deformation of the occupant compartment. Vehicle crush measurements are shown in figure 96. The bridge rail received superficial damage, as shown in figure 97. Heavy tire marks and deep scrapes on the rail indicating large contact forces were found over a 13-ft-11-in (4.2-m) length of the bridge rail. Lighter tire marks and small scrapes were observed over a 13-ft (4-m) length of the rail. Evidence of impact with the curb was limited to 4 ft-8 in (1.4 m) of tire marks.

As a result of technical problems incurred during this test, the accelerometer data were not available. As a result, the high-speed film was analyzed to obtain longitudinal and lateral occupant impact velocities of 10.8 ft/s (3.3 m/s) and 22.2 ft/s (6.8 m/s), respectively. The highest occupant ridedown decelerations in the longitudinal and lateral directions were 6.3 g's and 9.5 g's, respectively. The results of this analysis are summarized in figure 92 and table 9.

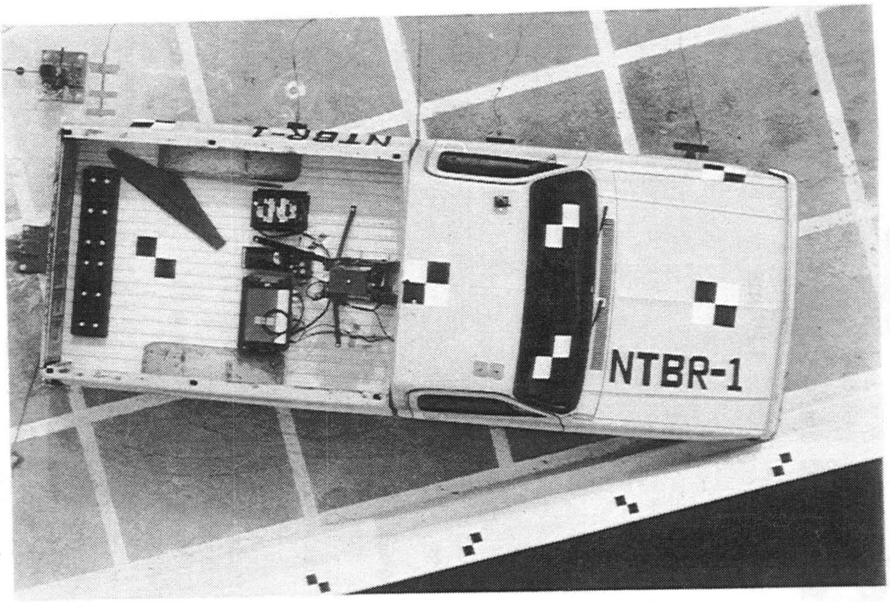
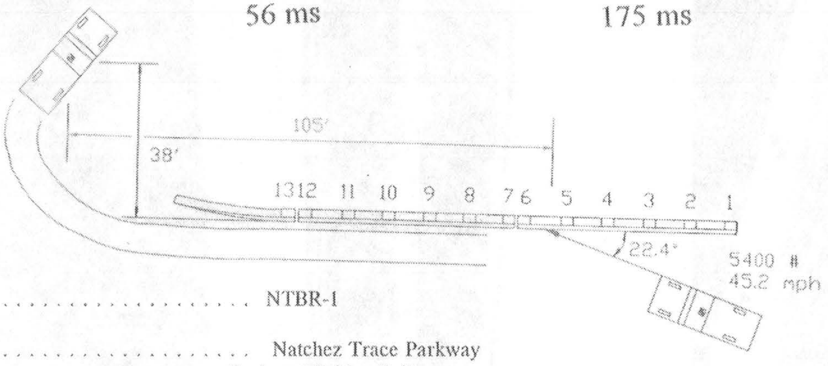
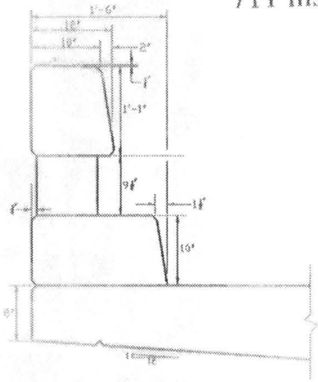


Figure 91. Vehicle Impact Location, Test NTBR-1.

Impact 56 ms 175 ms 319 ms 711 ms



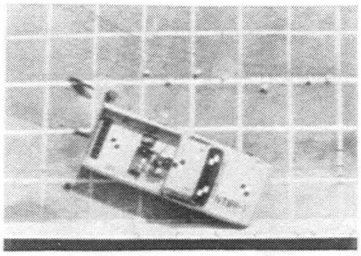


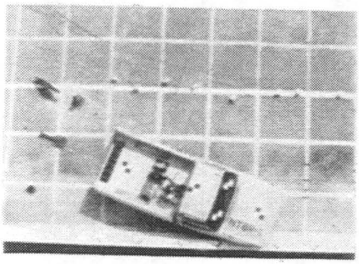
Test Number	NTBR-1
Date 7-9-92	
Bridge Rail Installation	Natchez Trace Parkway Curb and Bridge Rail
Total Length	93.6 ft
Material	
Concrete	Class A AE (4000 psi)
Reinforcing Steel	Grade 60 Epoxy Coated
Concrete Curb	
Length	93.6 ft
Bottom width	18 in
Top Width	16.5 in
Height	32.5 in
Concrete Posts	
Length	13 in
Width	18 in
Depth	9 in
Vehicle Model	1984 Chevrolet Custom Deluxe 20
Vehicle Weight	
Curb	4,610 lbs
Test Inertia	5,400 lbs
Gross Static	5,565 lbs

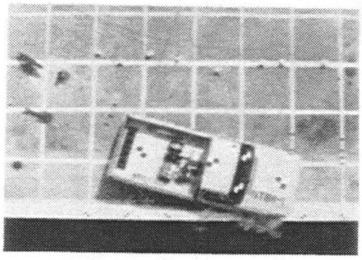
Vehicle Speed	
Impact	45.2 mi/h
Exit	37.0 mi/h
Vehicle Angle	
Impact)	22.4 degrees
Exit	1.6 degrees
Vehicle Snagging	None
Vehicle Stability	Satisfactory
Effective Coefficient of Friction (μ)	0.28 (Fair)
Occupant Impact Velocity	
Longitudinal	10.8 ft/s
Lateral	22.2 ft/s
Occupant Ridedown Deceleration	
Longitudinal	6.3 g's
Lateral	9.5 g's
Vehicle Damage	Minor
TAD	1-RFQ-3
VDI	01RFEW2
Bridge Rail Damage	Minor
Maximum Vehicle Rebound Distance	0.83 ft

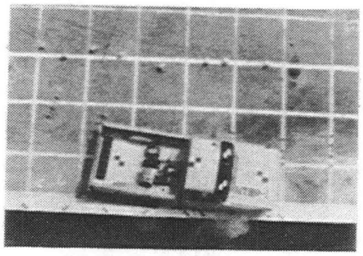
Conversion Factors: 1 in= 2.54 cm; 1 lb= 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

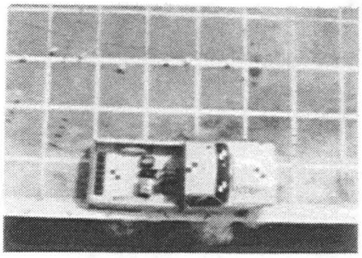
Figure 92. Summary of Test NTBR-1.

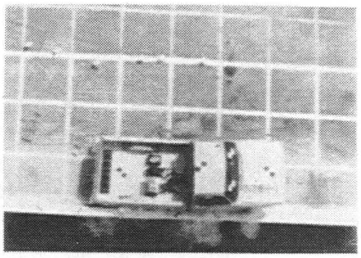

Impact

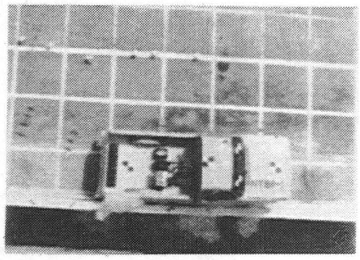

75 ms

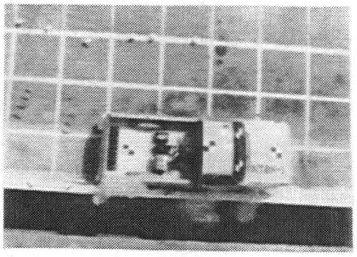

126 ms

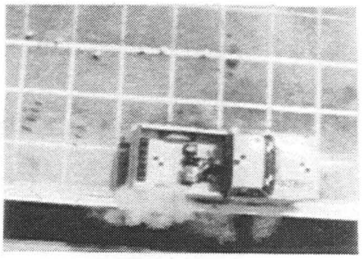

193 ms


250 ms


310 ms


335 ms


341 ms


375 ms

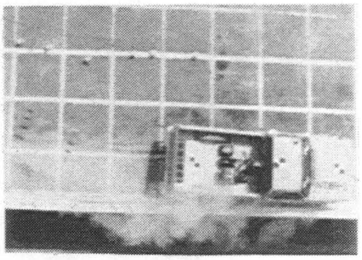
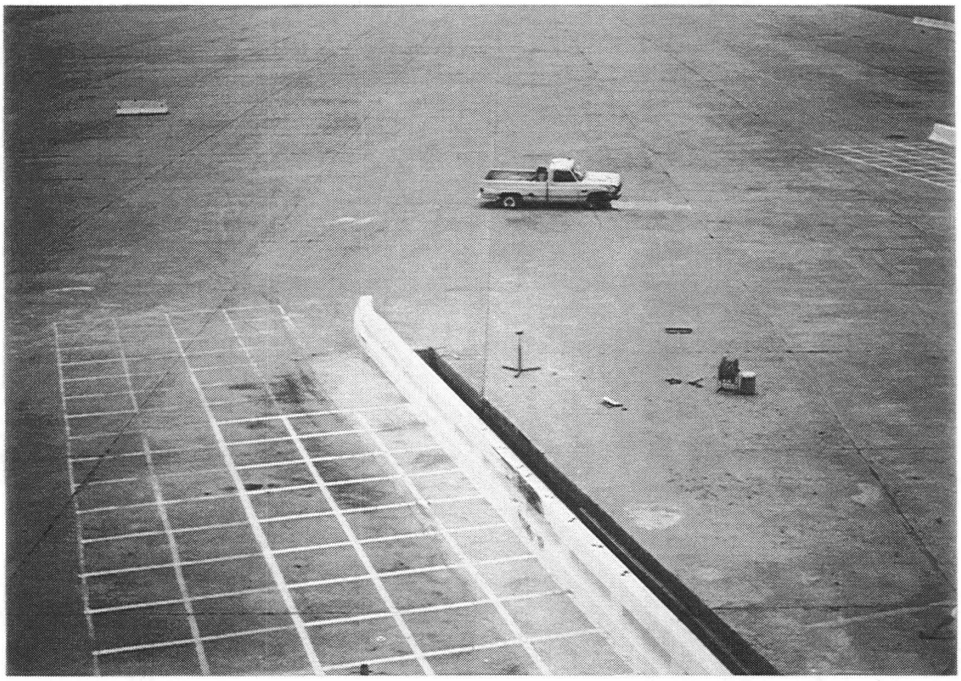

452 ms

Figure 93. Overhead Sequential Photographs, Test NTBR-1.



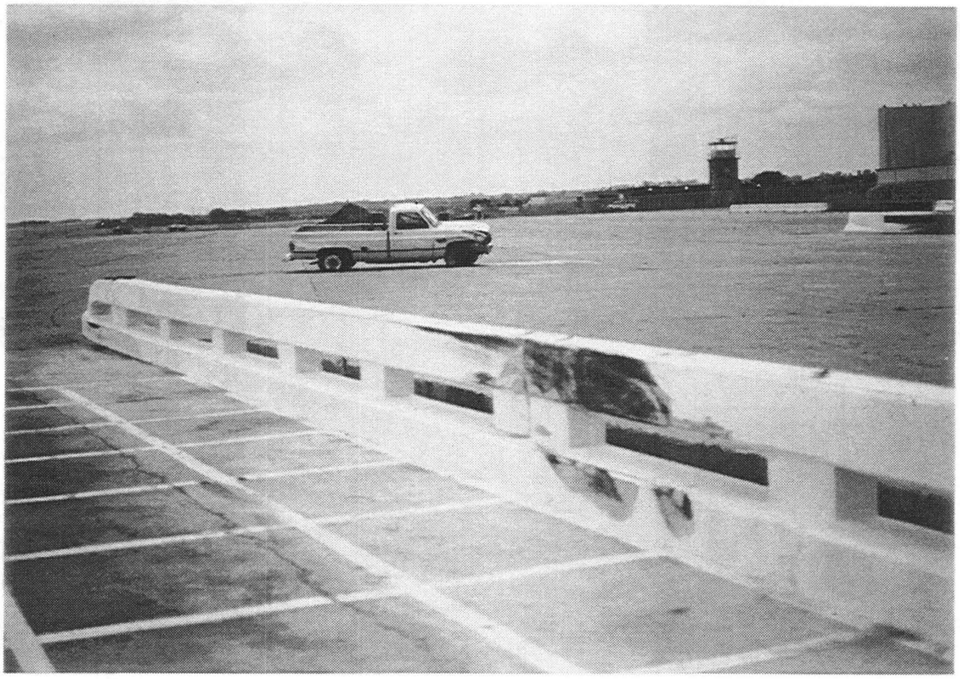
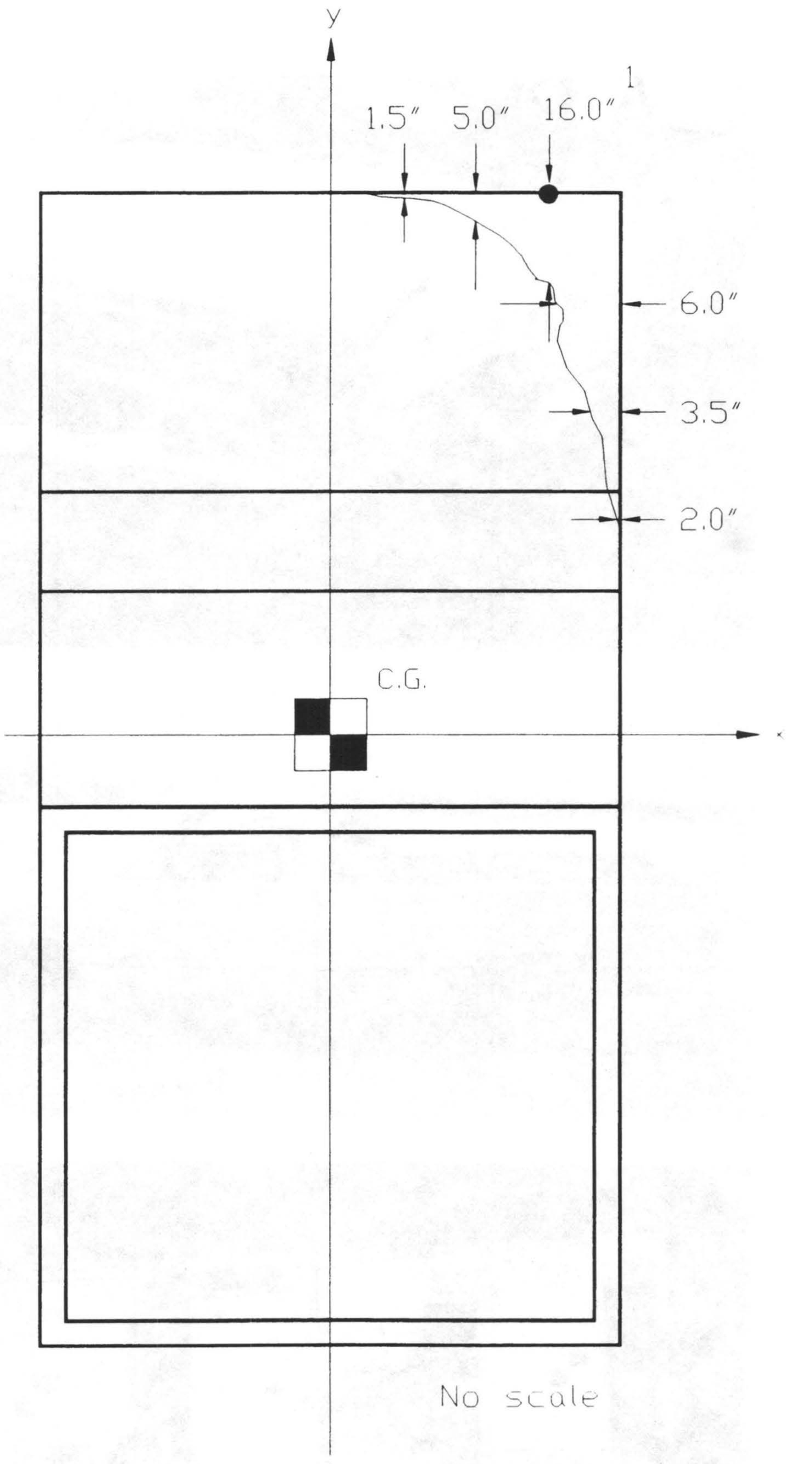


Figure 94. Vehicle Trajectory, Test NTBR-1.

Figure 95. Vehicle Damage, Test NTBR-1.



Maximum static crush distance of 16″ occurred [illegible] marked by the point

Figure 96. Crush Depth Diagram, Test NTBR-1.

Figure 97. Bridge Rail Damage, Test NTBR-1.

Test NTBR-2

The 1984 Renault Encore impacted the bridge rail at 51.5 mi/h (82.9 km/h) and 19.5 degrees. The impact point, shown in figure 98, was located at midspan between posts no. 4 and 5. A summary of the test results and sequential photographs are shown in figure 99. Additional sequential photographs are shown in figure 100.

After the initial impact with the bridge rail, the right-front corner of the vehicle crushed inward, causing the bumper to penetrate between the curb and the rail. Simultaneously, the right-front tire was deformed against the face of the curb. This interaction of the curb and the wheel caused the tire to blow out. The vehicle became parallel with the bridge rail at approximately 164 ms with a velocity of 38.3 mi/h (61.6 km/h). During redirection, the left-rear tire began to uplift, causing the vehicle to roll clockwise toward the rail. The vehicle exited the rail at approximately 345 ms with an angle of 8.5 degrees and a speed of 32.4 mi/h (52.1 km/h). Both left-side tires contacted the ground at 760 ms as the vehicle yawed away from the rail. The vehicle's trajectory is shown in figure 101. The maximum rebound distance was approximately 25.3 ft (7.7 m), which is higher than the desired value of 20 ft (6.1 m). The effective coefficient of friction was found to be 0.60 and would be classified as fair according to the *AASHTO Guide Specifications for Bridge Railings*.(8)

Test vehicle damage was relatively minor and was largely limited to the right-front quarter panel and wheel, and front bumper, as shown in figure 102. There was slight buckling of the right-front floorboard and roof. The vehicle remained upright both during and after the test, and there was no intrusion of the occupant compartment. Vehicle crush measurements are shown in figure 103.

Bridge rail damage is shown in figure 104. Tire marks and minor concrete spalling accounted for the majority of the damage. The length of the markings on the rail were approximately 7.5 ft (2.3 m), caused by the scraping of the bumper and the fender. The length of the markings on the curb were 8.5 ft (2.6 m), caused by the rubbing of the right-front tire, which blew out at impact.

The normalized longitudinal and lateral occupant impact velocities, as determined from accelerometer data, were 19.4 ft/s (5.9 m/s) and 26.2 ft/s (8.0 m/s), respectively. The highest 10-ms average occupant ridedown decelerations were 3.7 g's (longitudinal) and 7.8 g's (lateral). The results of this analysis are summarized in figure 99 and table 9. The accelerometer traces are shown in appendix C.

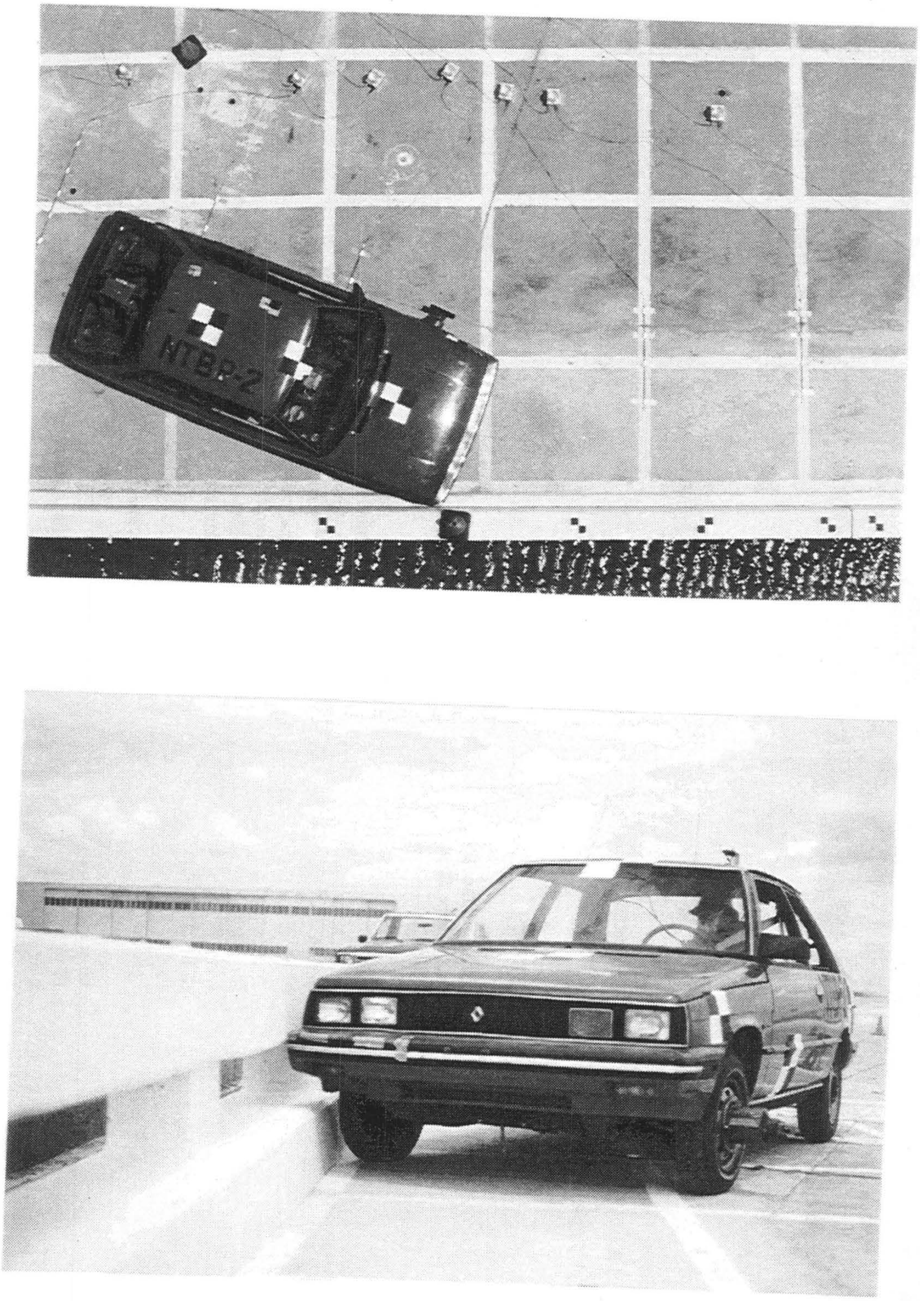
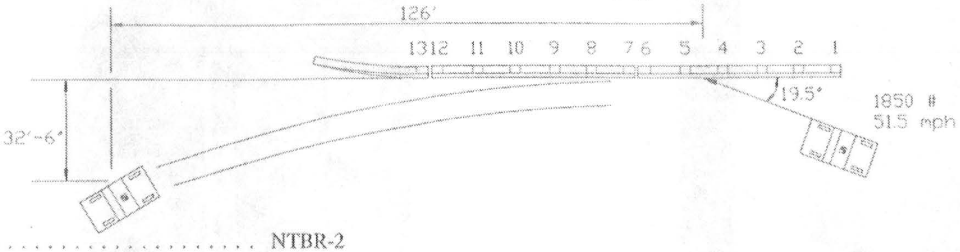
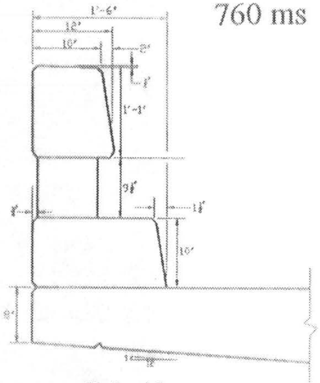


Figure 98. Vehicle Impact Location, Test NTBR-2.

Impact 162 ms 345 ms 404 ms 760 ms



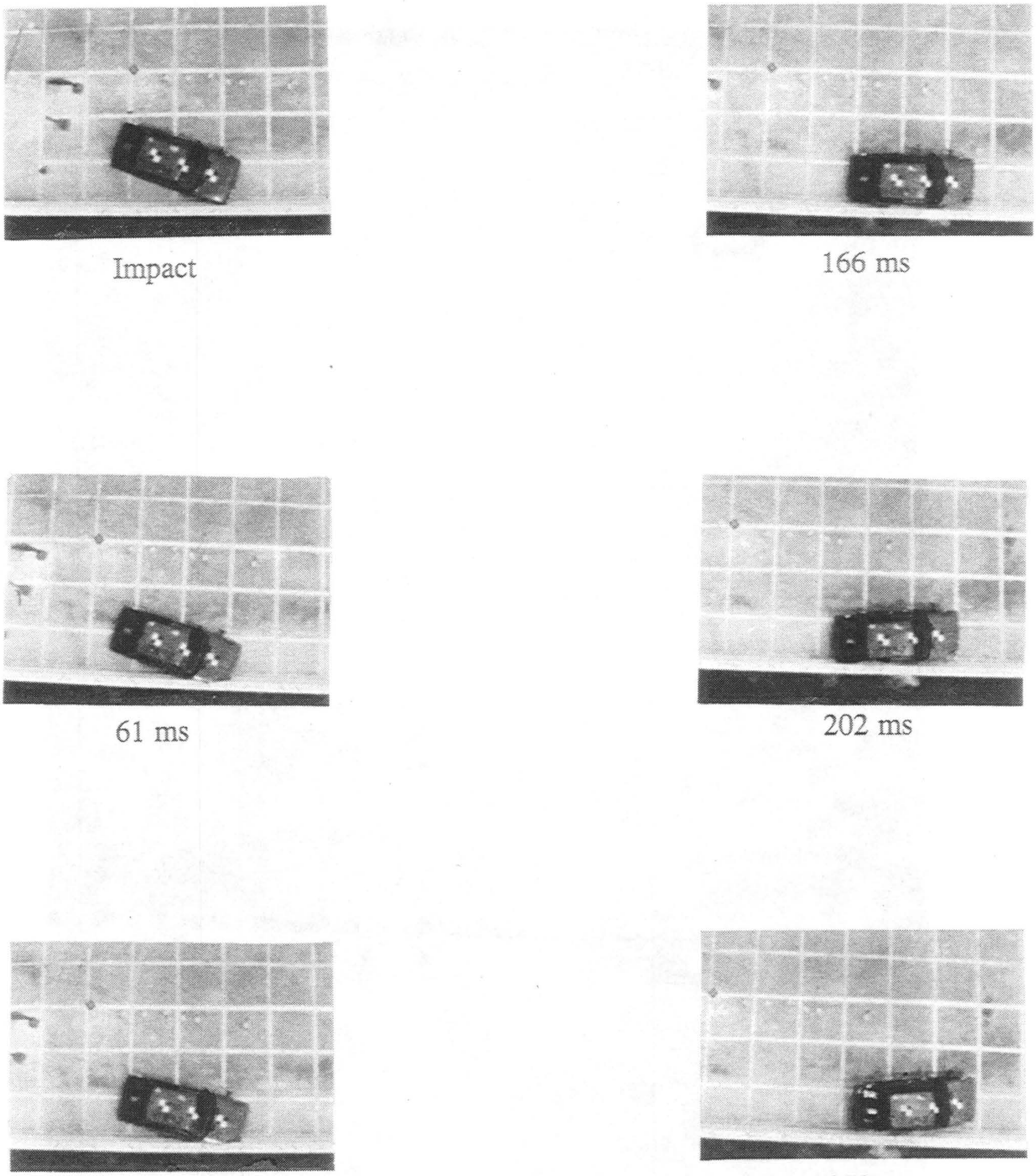


Test Number	NTBR-2
Date 7-21-92	
Bridge Rail Installation	Natchez Trace Parkway Curb and Bridge Rail
Total Length	93.6 ft
Concrete Curb	
Length	93.6 ft
Bottom width	18 in
Top Width	16.5 in
Height	10 in
Concrete Rail	
Length	78.7 ft
Bottom Width	12 in
Top Width	10 in
Bottom Height	19.5 in
Top Height	32.5 in
Concrete Posts	
Length	13 in
Width	18 in
Depth	9 in
Vehicle Model	1984 Renault Encore
Vehicle Weight	
Curb	2,070 lbs
Test Inertia	1,850 lbs
Gross Static	2,015 lbs

Vehicle Speed	
Impact	51.5 mi/h
Exit	47.7 mi/h
Vehicle Angle	
Impact	19.5 degrees
Exit	8.5 degrees
Vehicle Snagging	None
Vehicle Stability	Satisfactory
Effective Coefficient of Friction (μ)	0.60 (Marginal)
Occupant Impact Velocity	
Longitudinal	19.4 ft/s
Lateral	26.2 ft/s
Occupant Ridedown Deceleration	
Longitudinal	3.7 g's
Lateral	7.8 g's
Vehicle Damage	Minor
TAD	1-RFQ-3
VDI	01RFEW3
Bridge Rail Damage	Minor
Maximum Vehicle Rebound Distance	25.3 ft

Conversion Factors: 1 in= 2.54 cm; 1 lb= 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

Figure 99. Summary of Test NTBR-2.



Impact

61 ms

81 ms

166 ms

202 ms

273 ms

Figure 100. Overhead Sequential Photographs, Test NTBR-2.

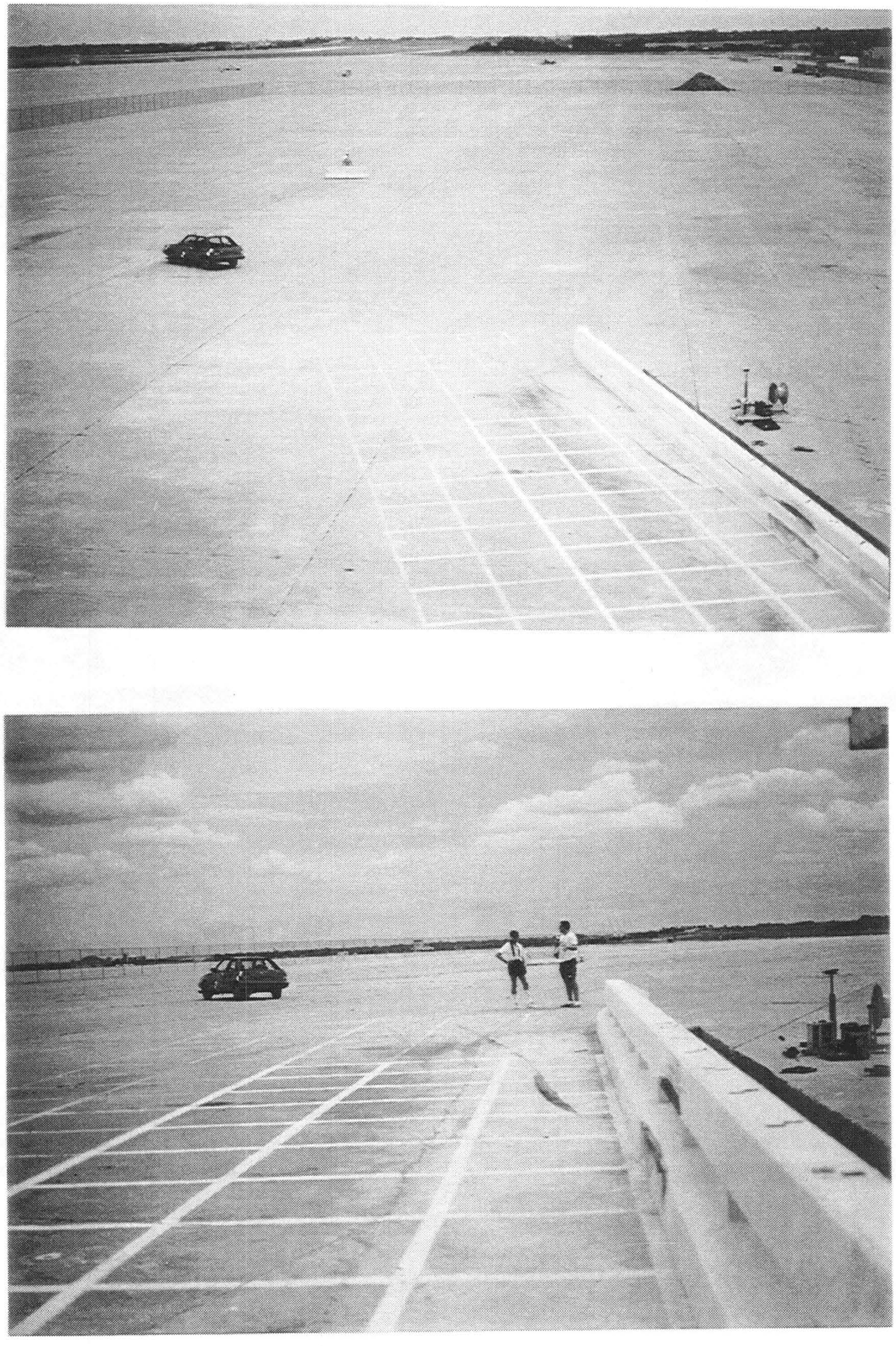


Figure 101. Vehicle Trajectory, Test NTBR-2.

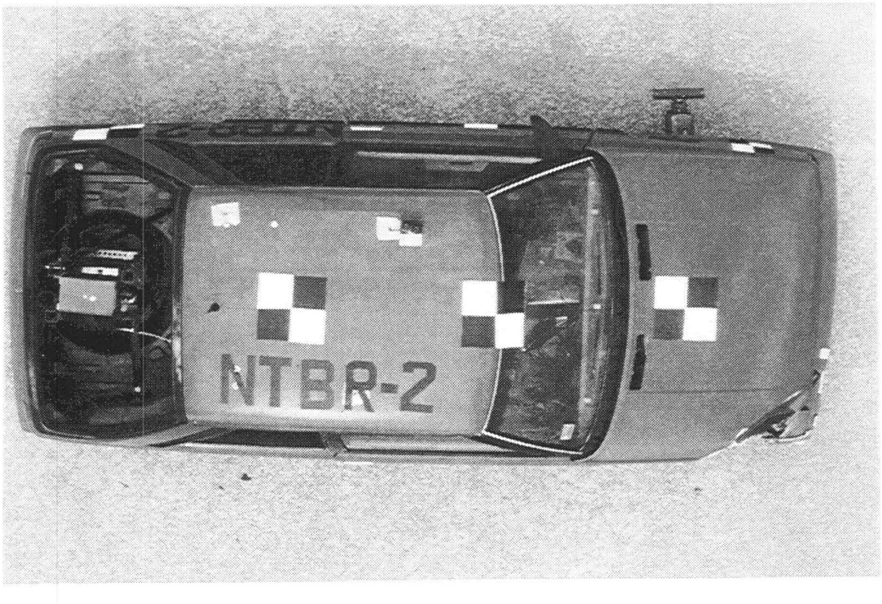


Figure 102. Vehicle Damage, Test NTBR-2.

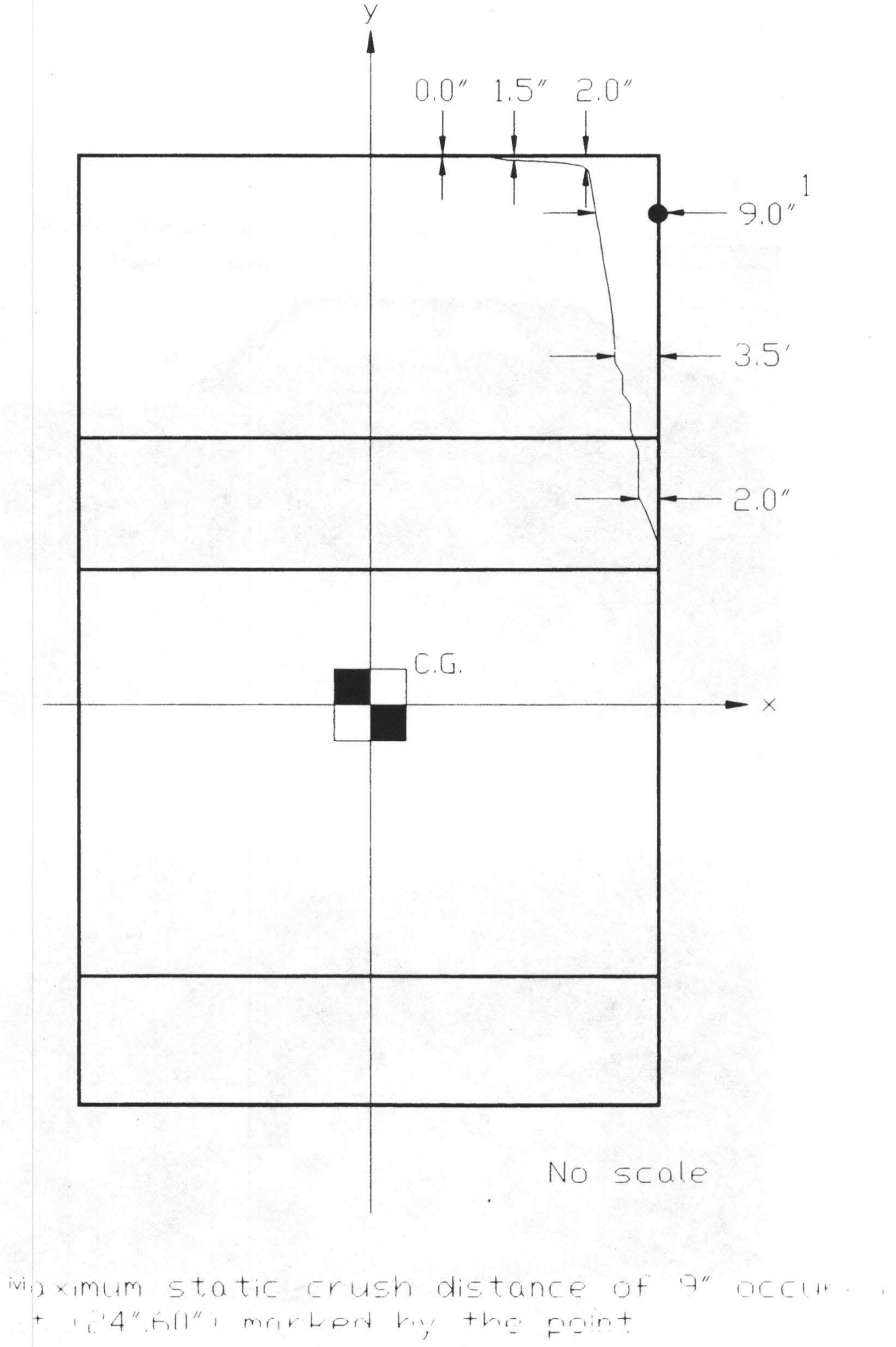


Figure 103. Crush Depth Diagram, Test NTBR-2.

Figure 104. Bridge Rail Damage, Test NTBR-2.

EVALUATION SUMMARY

The tests described here were evaluated according to criteria for PL-1 bridge rails presented in *AASHTO Guide Specifications for Bridge Railings*.(8) The tests were conducted and reported in accordance with the requirements in NCHRP Report 230.(4) Table 9 summarizes all of the relevant evaluation criteria from AASHTO, as well as the findings from the two tests reported here.(8) As shown in this table, the Natchez Trace Bridge Rail successfully passed all requirements for PL-1 bridge railings.

Table 9. Summary of Safety Performance Results, NTBR Series.

Evaluation Criteria	Results			
	NTBR-1		NTBR-2	
3.a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	S		S	
3.b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	S		S	
3.c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	S		S	
3.d. The vehicle shall remain upright during and after collision.	S		S	
3.e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.	S		S	
3.f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ, where $\mu = (\cos\theta - V_p/V)/\sin\theta$. μ — Assessment 0.0 - 0.25 — Good 0.26 - 0.35 — Fair $>$ 0.35 — Marginal	F (μ=0.28)		M (μ = 0.60)	
3.g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0-ft longitudinal and 1.0-ft lateral displacements, shall be less than:	Long.	Lateral	Long.	Lateral
Occupant Impact Velocity - ft/s Longitudinal — Lateral 30 — 25	S (10.8)	S (22.2)	S (19.4)	M (26.2)
	Occupant Ridedown Accelerations (g's)			
and for the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than:	Long.	Lateral	Long.	Lateral
Occupant ridedown Accelerations - g's Longitudinal — Lateral 15 — 15	S (6.3)	S (9.5)	S (3.7)	S (7.8)
3.h. Vehicle exit angle from the barrier shall not be more than 12 degrees.	S (1.6 deg)		S (8.5 deg)	
Within 100 ft plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20 ft from the line of the traffic face of the railing.	S (0.83 ft)		M (25.3 ft)	

S - Satisfactory
M - Marginal
U - Unsatisfactory

7. STEEL-BACKED LOG RAIL

TEST INSTALLATION

The Steel-Backed Log Rail was constructed from 10-in (254-mm) diameter timber logs backed by 6-in by ⅜-in (152-mm by 10-mm) ASTM A588 steel plates. Backup plates were attached to the log rails with ⅝-in by 4-in (16-mm by 102-mm) lag screws, and the 10-ft (3.05-m) long rail elements were connected with 6-in by ⅜-in (152-mm by 10-mm) steel splice plates. The railing was mounted on 12-in (305-mm) diameter round posts with cast steel blockouts placed at each splice joint. The center of the rail elements was placed at a height of 1 ft-9 in (0.53 m). Photographs of the Steel-Backed Log Rail are shown in figure 105. Design details are shown in appendix A.

TEST CRITERIA

This system was evaluated according to the PL-1 criteria presented in AASHTO.(8) This barrier system was being developed for use on park roads where the expected operating speeds were 45 mi/h (72.4 km/h) or less. At the time these tests were conducted, there were no recognized tests at low speeds except for the tests for PL-1. The full-scale vehicle crash tests were conducted and reported in accordance with requirements specified in NCHRP Report 230.(4) The vehicle damage was assessed by the TAD and VDI.(6,7)

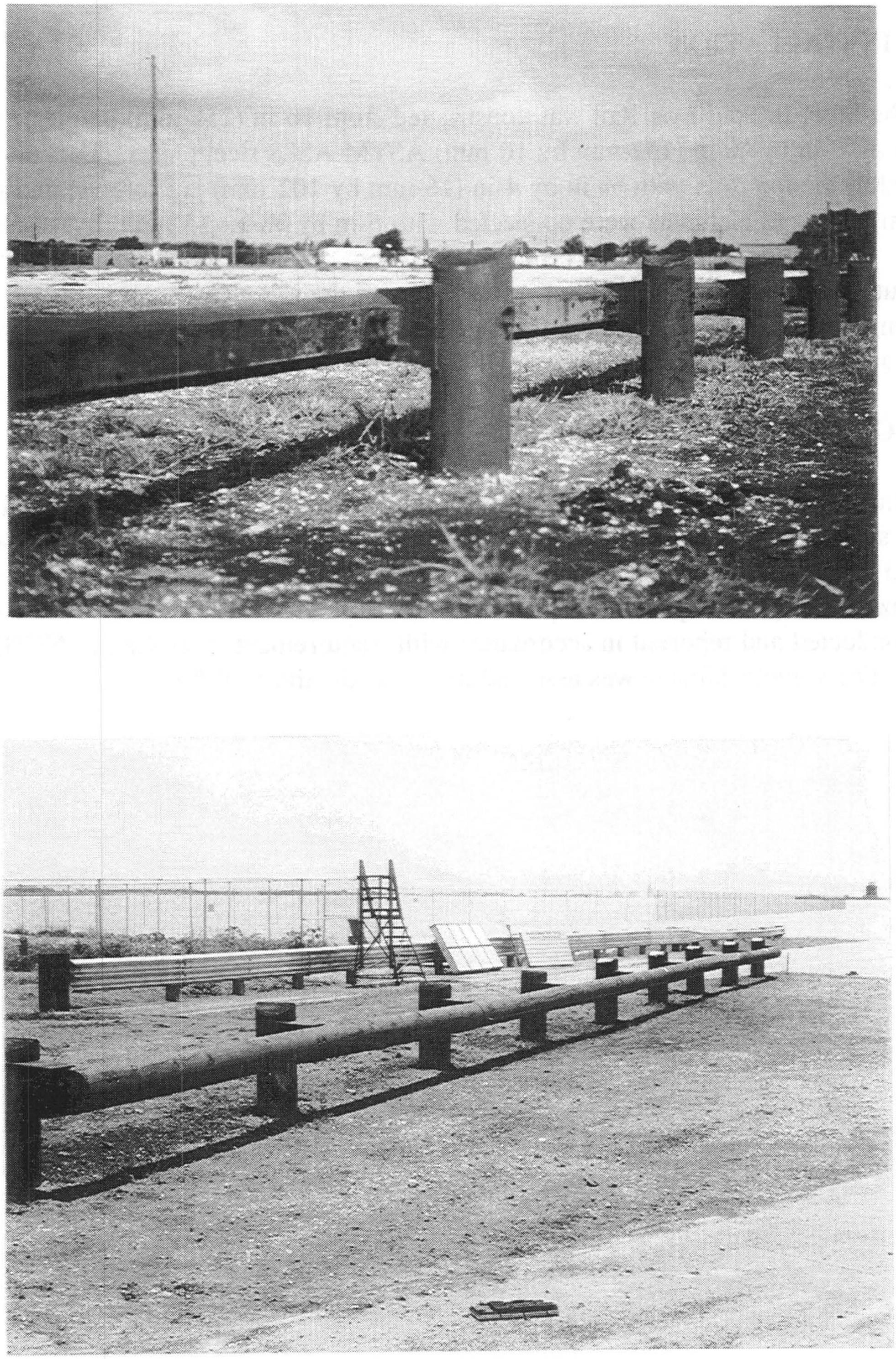


Figure 105. The Steel-Backed Log Rail

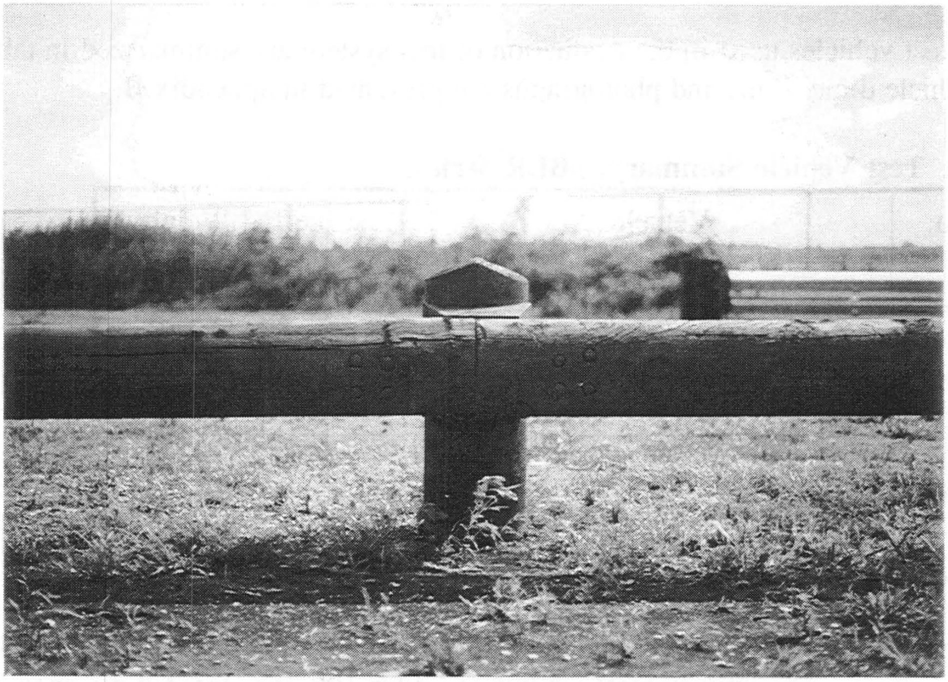


Figure 105. The Steel-Backed Log Rail (continued).

TEST VEHICLES

The test vehicles used in the evaluation of this system are summarized in table 10. The pretest vehicle dimensions and photographs are presented in appendix B.

Table 10. Test Vehicle Summary, SBLR Series.

Test No.	Vehicle	Test Inertial Weight	
		(lb)	(kg)
SBLR-1	1984 Dodge Colt	1,850	840
SBLR-2	1986 Chevrolet ¾-ton pickup	5,400	2,452

TEST RESULTS

Test SBLR-1

The 1984 Dodge Colt impacted the Steel-Backed Log Rail at 50.6 mi/h (81.4 km/h) and 19.2 degrees. The impact point, shown in figure 106, was located midspan between posts no. 2 and 3, or 15 ft (4.6 m) downstream from the upstream end of the installation. A summary of the test results and sequential photographs are shown in figure 107. Additional sequential photographs are shown in figure 108.

Upon impact with the log rail, the front bumper slipped under the rail, and the right-front corner of the vehicle began to crush inward. The vehicle slid along the log rail and reached post no. 3 at 64 ms after impact. The vehicle reached post no. 4 approximately 216 ms after impact and became parallel to the rail at approximately 352 ms. The vehicle exited the rail at an angle of 2 degrees approximately 503 ms after impact. After exiting the rail, the vehicle continued to travel downstream and to the left, coming to a rest 240 ft (73 m) downstream from impact and 153 ft (46.5 m) to the left of a line parallel to the railing face. This vehicle trajectory is shown in figure 109.

Test vehicle damage was relatively minor and was largely limited to the right-front quarter panel and passenger door, as shown in figure 110. There was no intrusion or deformation of the occupant compartment. Vehicle crush measurements are shown in figure 111.

Damage to the log rail consisted of minor scrapes on the surface of the rail and a maximum permanent deflection of 2 15/16 in (75 mm) at the first post after impact. This damage can be seen in figure 112. The effective coefficient of friction was found to be 1.18 and would be classified as marginal according to the *AASHTO Guide Specifications for Bridge Railings*.(8)

The longitudinal and lateral occupant impact velocities, as determined from accelerometer data, were 24.3 ft/s (7.4 m/s) and 21.1 ft/s (6.4 m/s), respectively. The highest 10-ms average occupant ridedown decelerations were 3.9 g's (longitudinal) and 4.8 g's (lateral). The results of this analysis are summarized in figure 107 and table 11. The accelerometer traces are shown in appendix C.

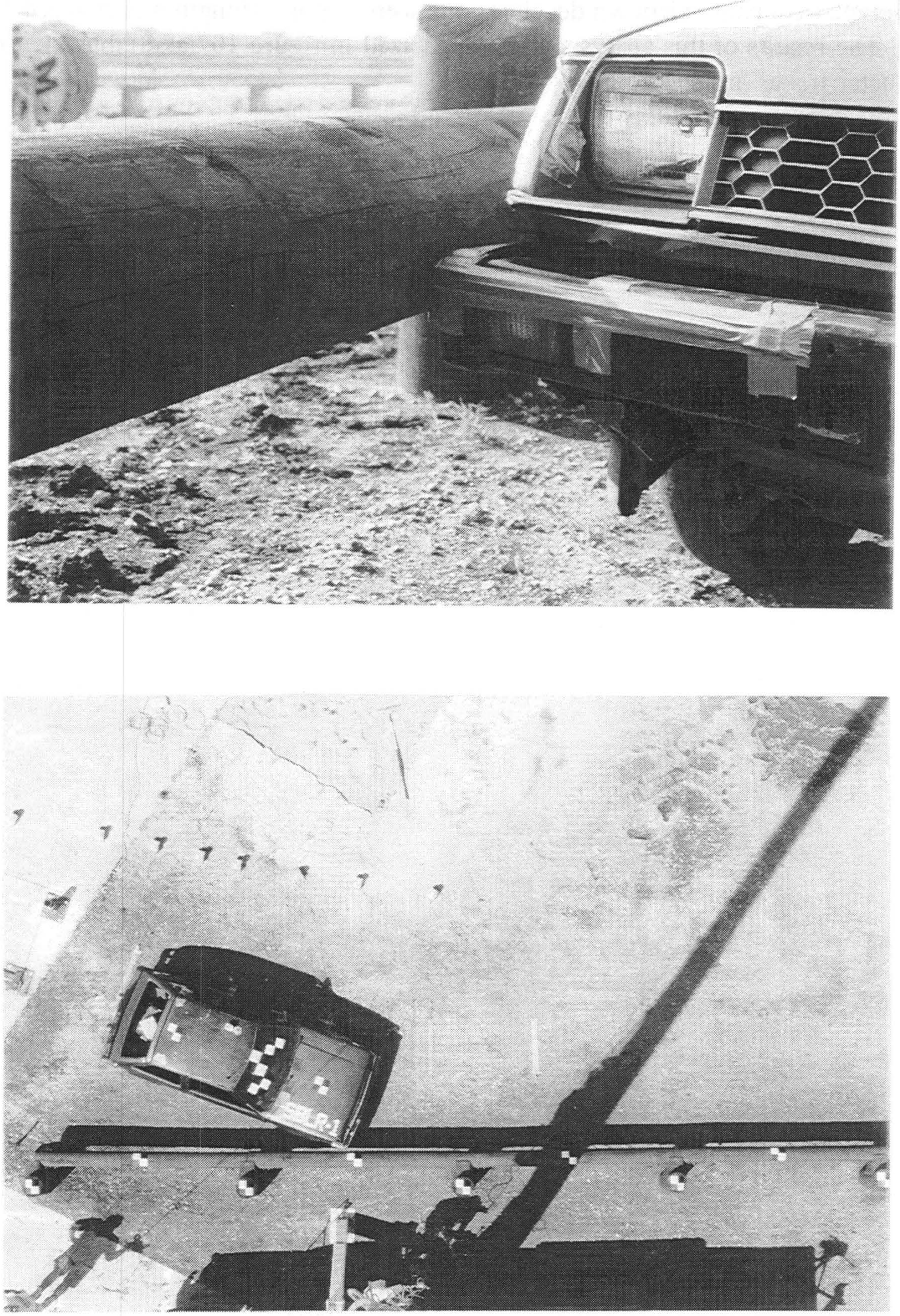
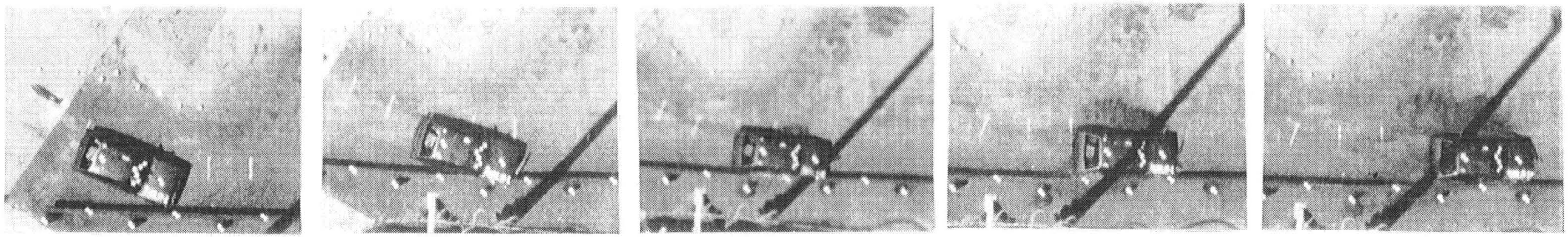
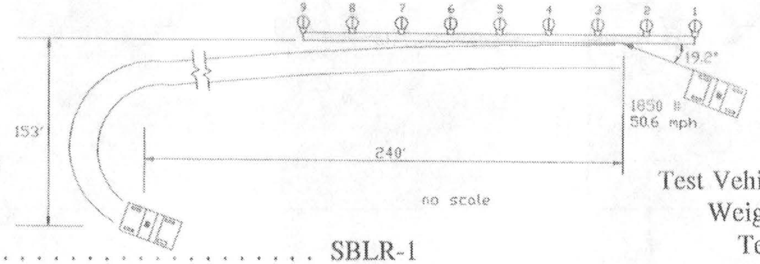


Figure 106. Vehicle Impact Location, Test SBLR-1.



Impact 105 ms 209 ms 314 ms 418 ms

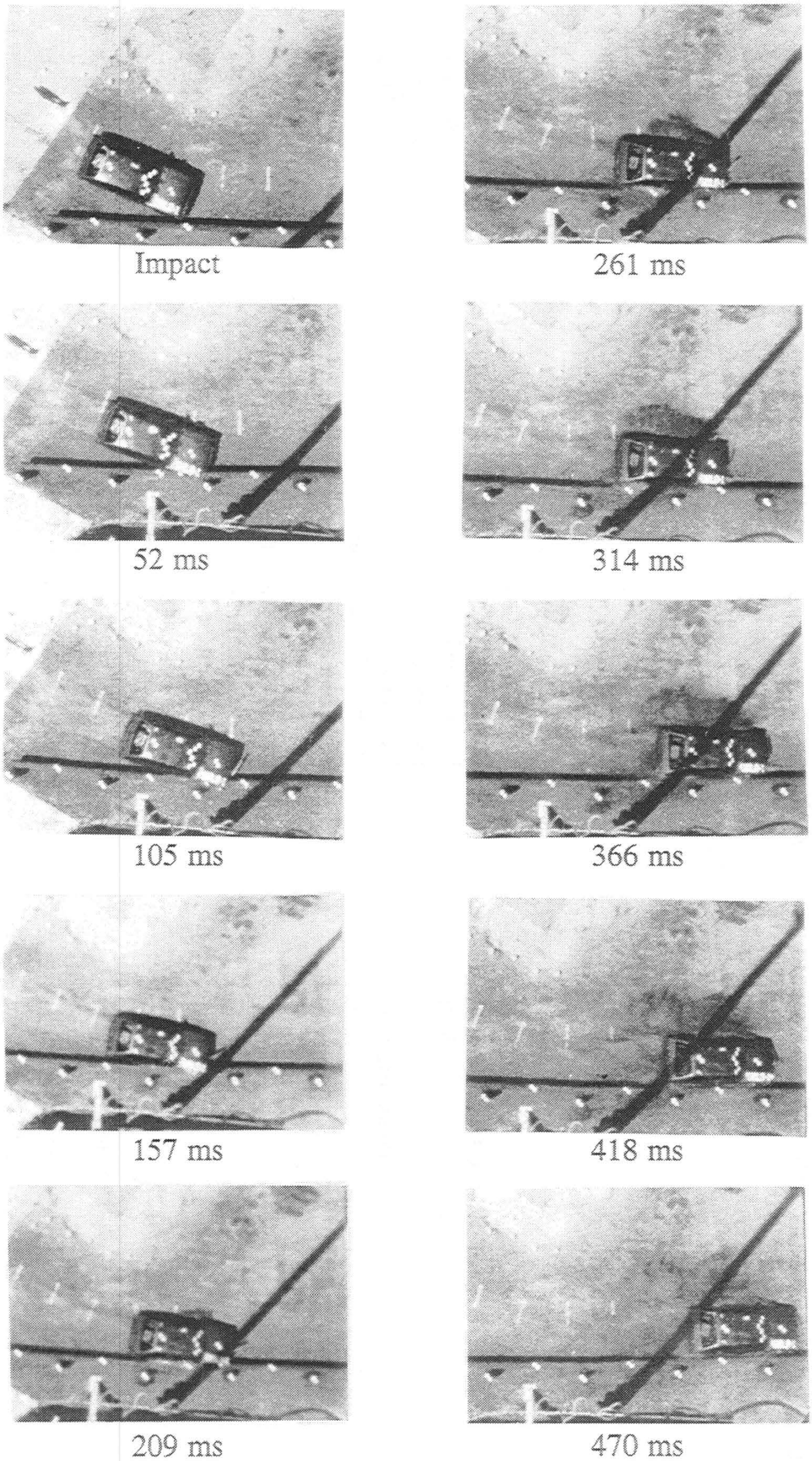


Test Number	SBLR-1
Date	6/18/92
Installation	Steel-Backed Log Guardrail
Installation Length	80 ft
Post	
Material	Ponderosa Pine
Diameter	12 in
Length	7 ft
Rail Sections	
Material	Ponderosa Pine
Diameter	10-in
Length	10 ft
Backup Plate	
Material	ASTM A588 Steel
Dimensions	6-in by ⅜-in by 9 ft -9 in
Splice Plate	
Material	ASTM A588 Steel
Dimensions	6-in by ⅜-in by 30-in
Cast Blockout	
Material	ASTM A588 Steel

Test Vehicle	1984 Dodge Colt
Weight	
Test Inertial	1,850 lbs
Gross Static	2,015 lbs
Impact Speed	50.6 mi/h
Impact Angle	19.2 deg
Exit Speed	28.2 mi/h
Exit Angle	2 deg
Occupant Impact Velocity	
Longitudinal	24.3 ft/s
Lateral	21.1 ft/s
Occupant Ridedown Deceleration	
Longitudinal	3.9 g's
Lateral	4.8 g's
Vehicle Damage	
TAD	1-RFQ-4
VDI	01RYES2
Vehicle Rebound Distance	6 ft-11 in @ 113 ft
Coefficient of Friction	1.18

Conversion Factors: 1 in = 2.54 cm; 1 lb = 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

Figure 107. Summary of Test SBLR-1.



Impact

52 ms

105 ms

157 ms

209 ms

261 ms

314 ms

366 ms

418 ms

470 ms

Figure 108. Overhead Sequential Photographs, Test SBLR-1.

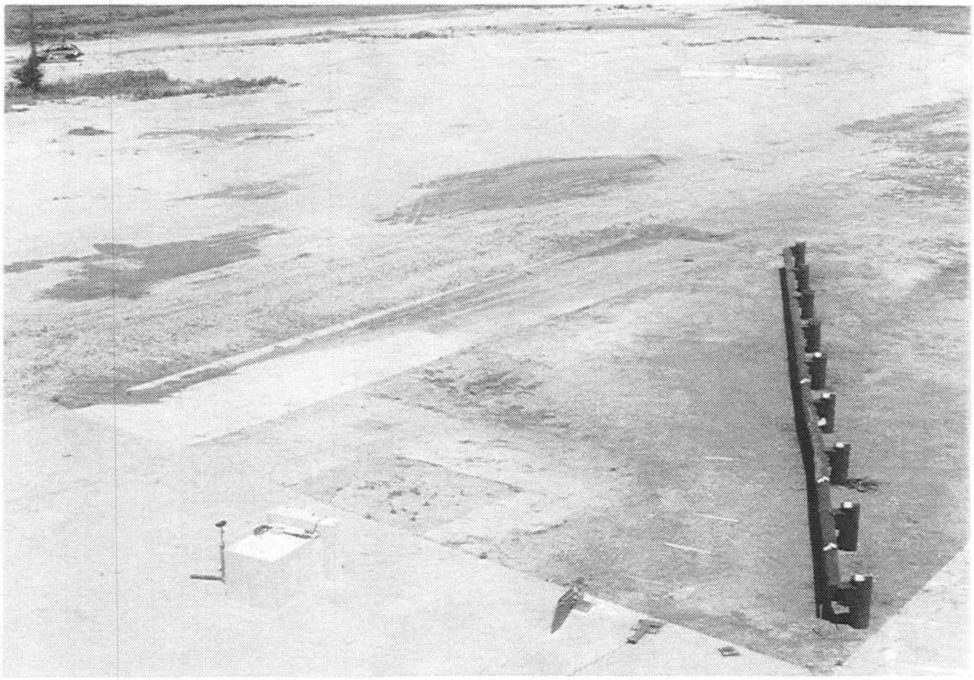
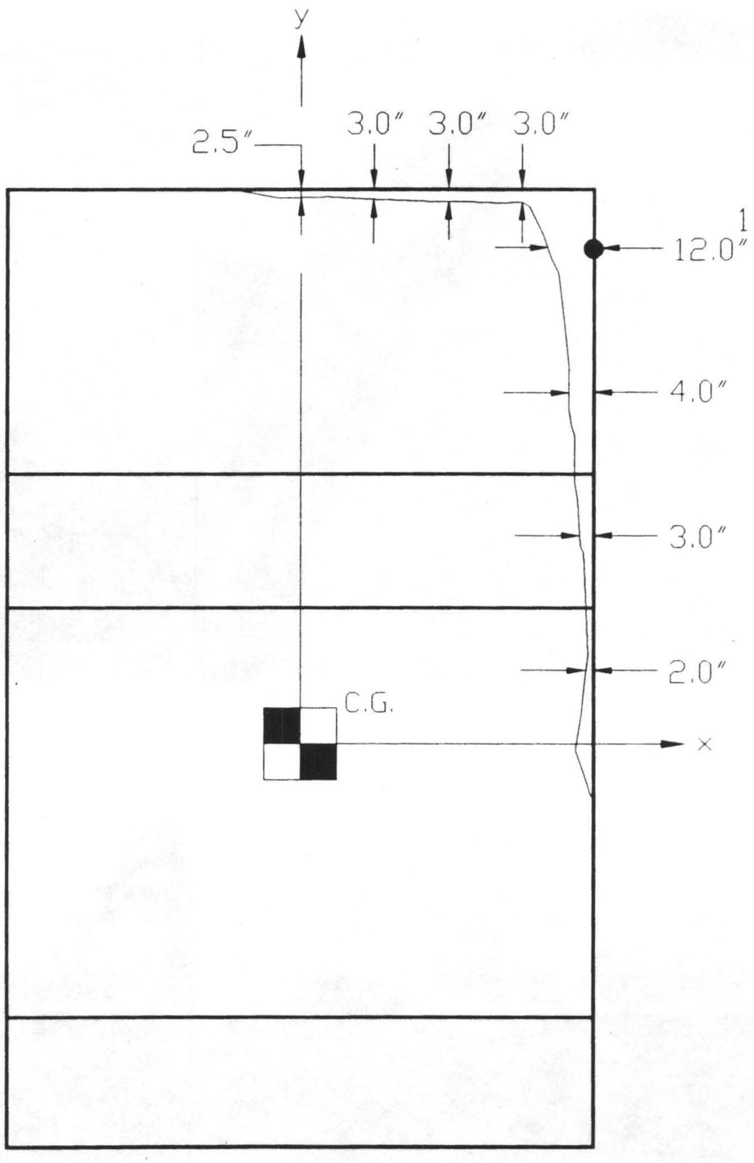


Figure 109. Vehicle Trajectory, Test SBLR-1.

Figure 110. Vehicle Damage, Test SBLR-1.



No scale

[1] Maximum static crush distance of 12" occurred at (24",54") marked by the point.

Figure 111. Crush Depth Diagram, Test SBLR-1.

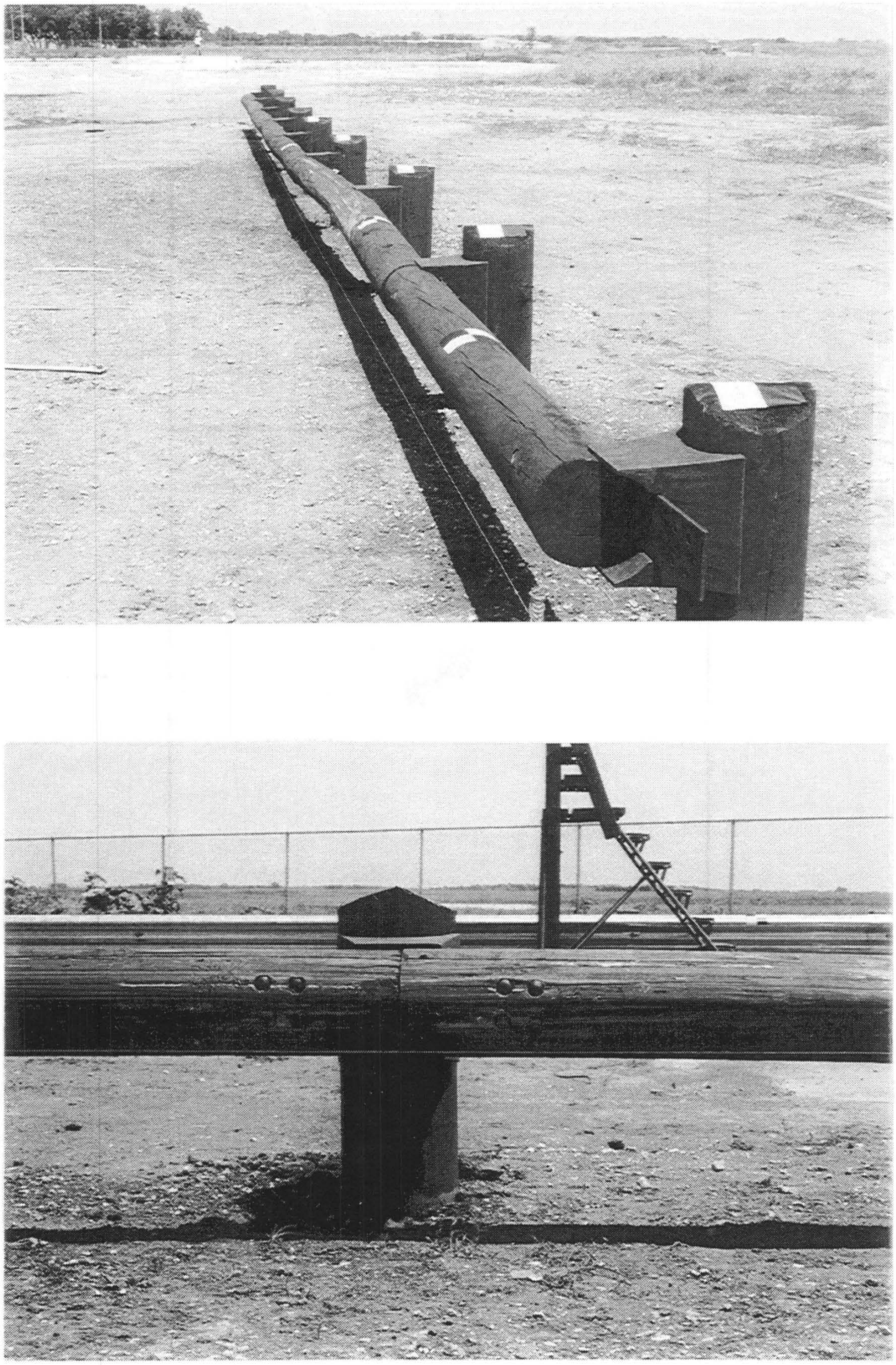


Figure 112. Log Rail Damage, Test SBLR-1.

Test SBLR-2

A 1986 Chevrolet ¾-ton pickup impacted the Steel-Backed Log Rail at 46.1 mi/h (74.2 km/h) and 20.9 degrees. The impact point, shown in figure 113, was located midspan between posts no. 2 and 3, or 15 ft (4.6 m) downstream from the upstream end of the rail. A summary of the test results and sequential photographs are shown in figure 114. Additional sequential photographs are shown in figure 115.

Upon impact, the bumper of the test vehicle began to ride up onto the log rail. The vehicle traveled along the top of the rail until it reached post no. 5, approximately 448 ms after impact. After impacting post no. 5, the vehicle began to rotate clockwise, coming to rest perpendicular to the rail 45 ft (13.7 m) downstream from impact. The vehicle trajectory is shown in figure 116.

Test vehicle damage, shown in figure 117, was limited to the undercarriage on the right-front corner and along the right side. Vehicle crush measurements are shown in figure 118. The vehicle remained upright both during and after the test, and there was no intrusion of the occupant compartment.

Damage to the log rail consisted of scrapes and gouges along the traffic face and at some of the posts. A maximum permanent deflection of 9⅛ in (232 mm) was measured at post no. 3. The damaged barrier is shown in figure 119.

As a result of technical problems incurred during this test, the accelerometer data was not available. Therefore, the high-speed film was analyzed to obtain longitudinal and lateral occupant impact velocities of 14.8 ft/s (4.5 m/s) and 12.8 ft/s (3.9 m/s), respectively. The highest occupant ridedown decelerations in the longitudinal and lateral directions were 13.1 g's and -13.4 g's, respectively. The results of this analysis are summarized in figure 114 and table 11.

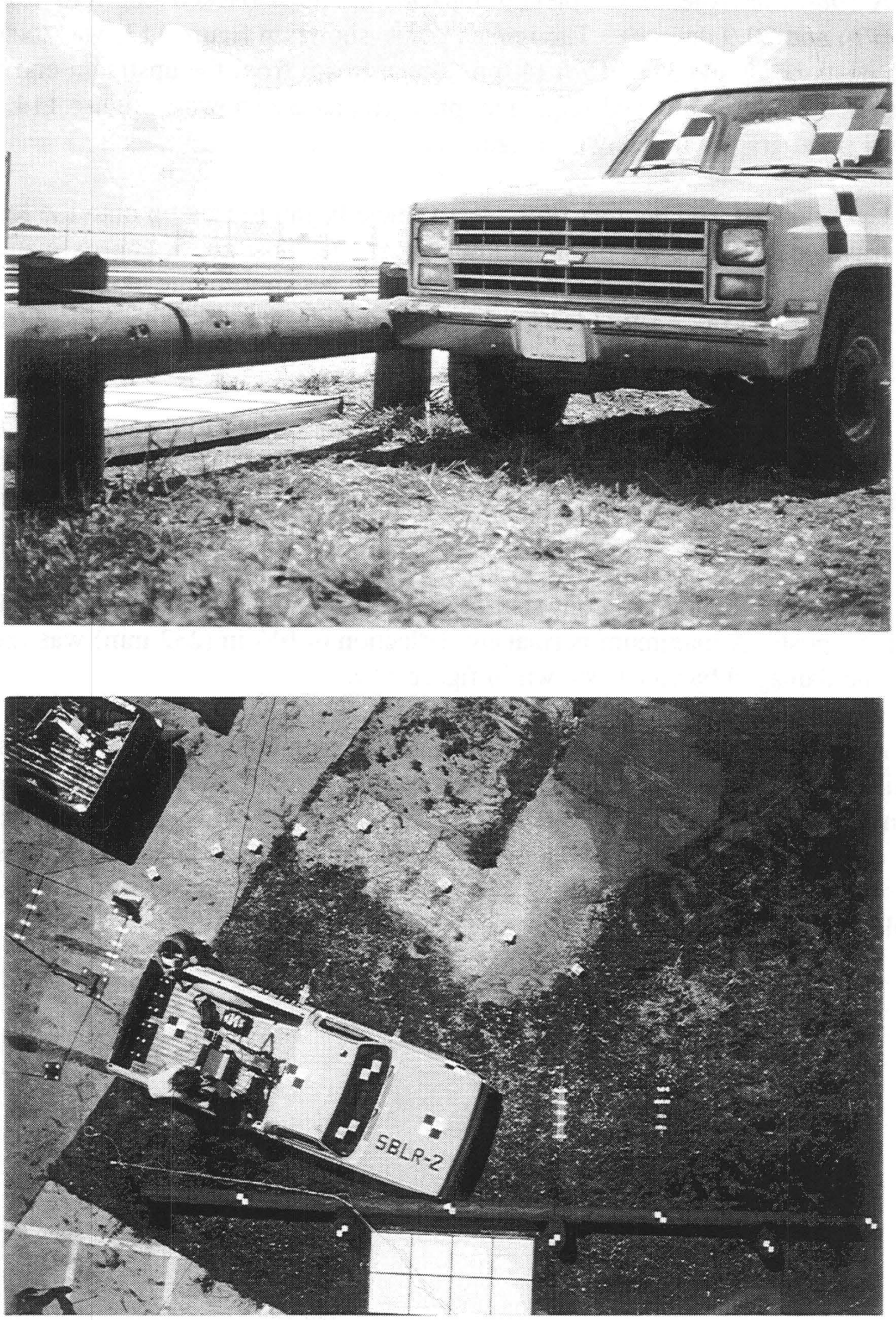
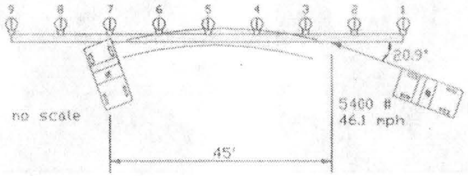


Figure 113. Vehicle Impact Location, Test SBLR-2.

Impact 183 ms 396 ms 711 ms 1137 ms

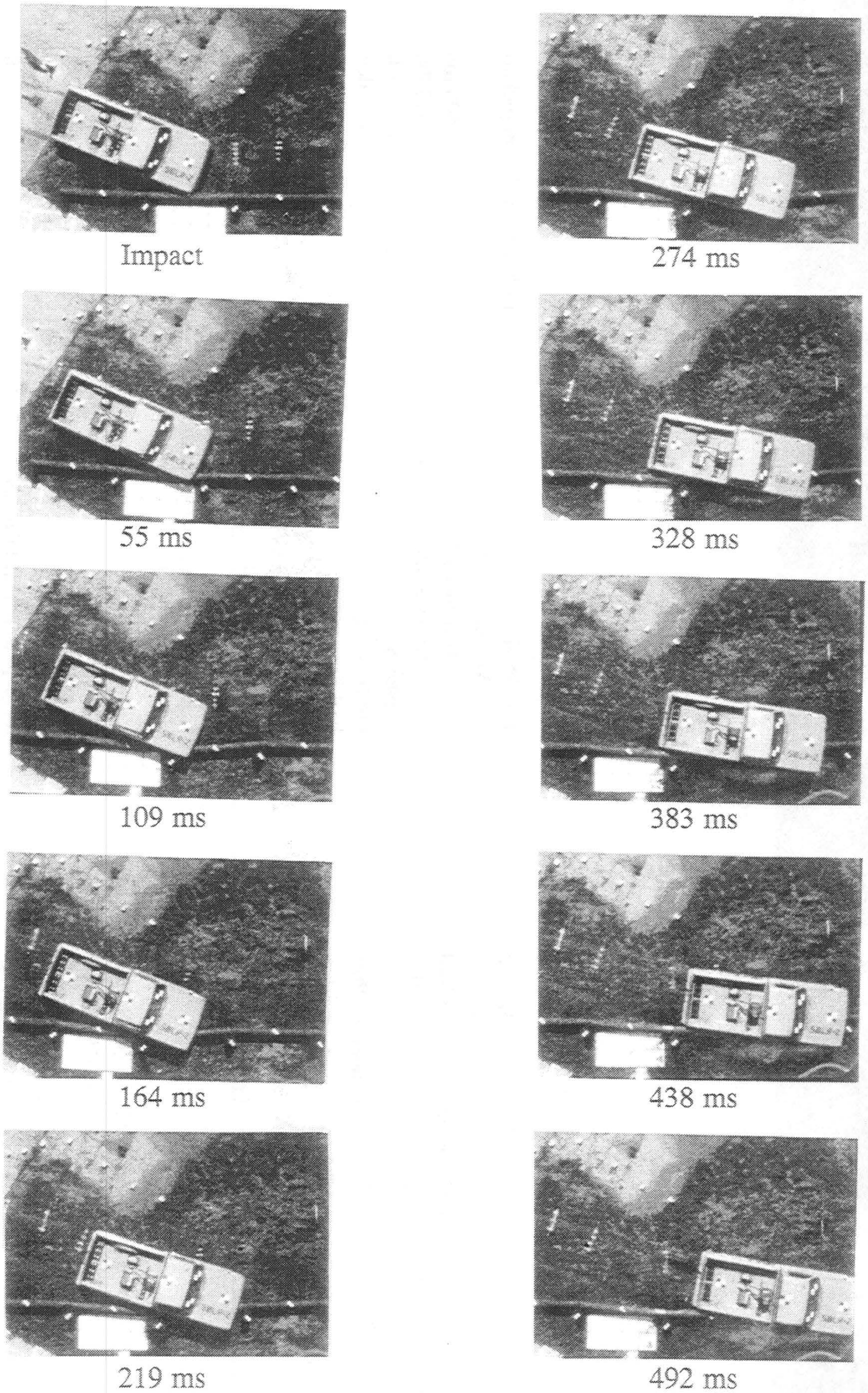


Test Number	SBLR-2
Date	7/29/92
Installation	Steel-Backed Log Guardrail
Installation Length	80 ft
Post	
Material	Ponderosa Pine
Diameter	12 in
Length	7 ft
Rail Sections	
Material	Ponderosa Pine
Diameter	10-in
Length	10 ft
Backup Plate	
Material	ASTM A588 Steel
Dimensions	6 in by ⅜ in by 9 ft-9 in
Splice Plate	
Material	ASTM A588 Steel
Dimensions	6 in by ⅜ in by 30 in
Cast Blockout	
Material	ASTM A588 Steel

Test Vehicle	1986 Chevy ¾ ton pickup
Weight	
Test Inertial	5,400 lbs
Gross Static	5,565 lbs
Impact Speed	46.1 mi/h
Impact Angle	20.9 deg
Exit Speed	NA
Exit Angle	NA
Occupant Impact Velocity	
Longitudinal	14.8 ft/s
Lateral	12.8 ft/s
Occupant Ridedown Deceleration	
Longitudinal	13.1 g's
Lateral	-13.4 g's
Vehicle Damage	
TAD	1-RD-5
VDI	01RDES2
Vehicle Rebound Distance	0 ft
Coefficient of Friction	NA

Conversion Factors: 1 in= 2.54 cm; 1 lb= 0.454 kg
1 ft/s = 0.3048 m/s
1 mi/h = 1.6095 km/h

Figure 114. Summary of Test SBLR-2.



Impact

55 ms

109 ms

164 ms

219 ms

274 ms

328 ms

383 ms

438 ms

492 ms

Figure 115. Overhead Sequential Photographs, Test SBLR-2.

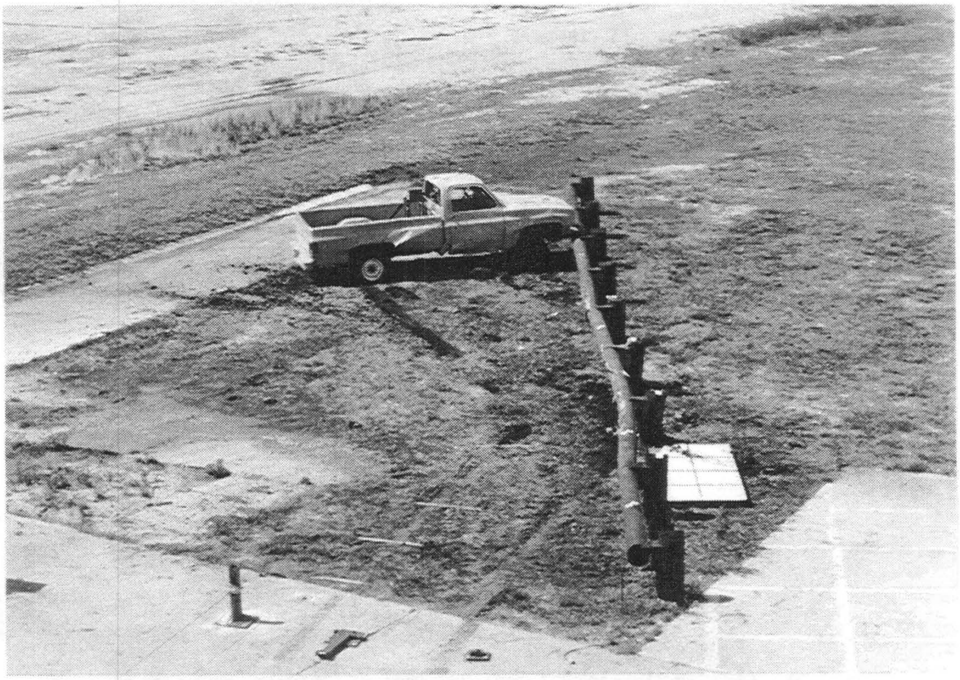


Figure 116. Vehicle Trajectory, Test SBLR-2.

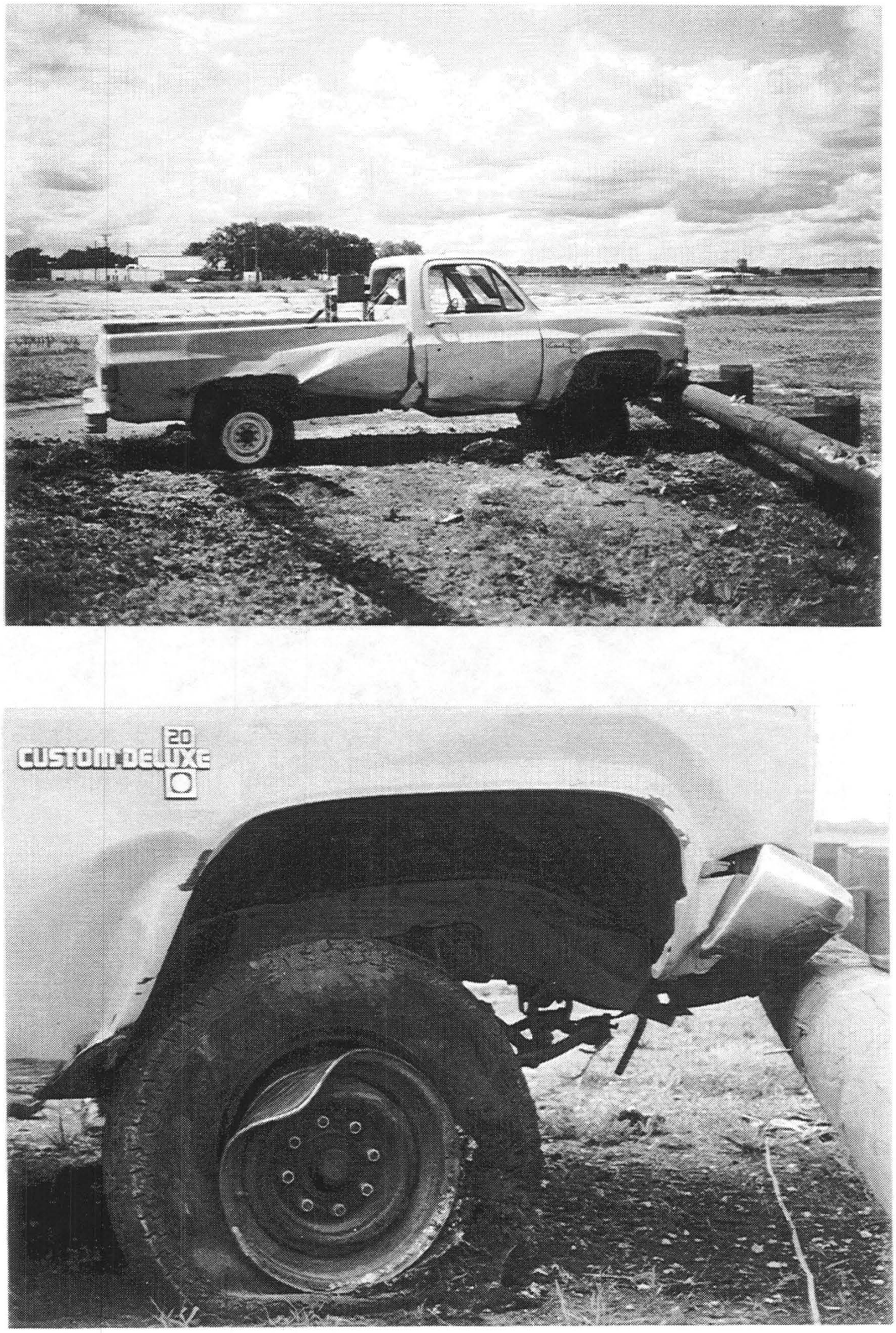
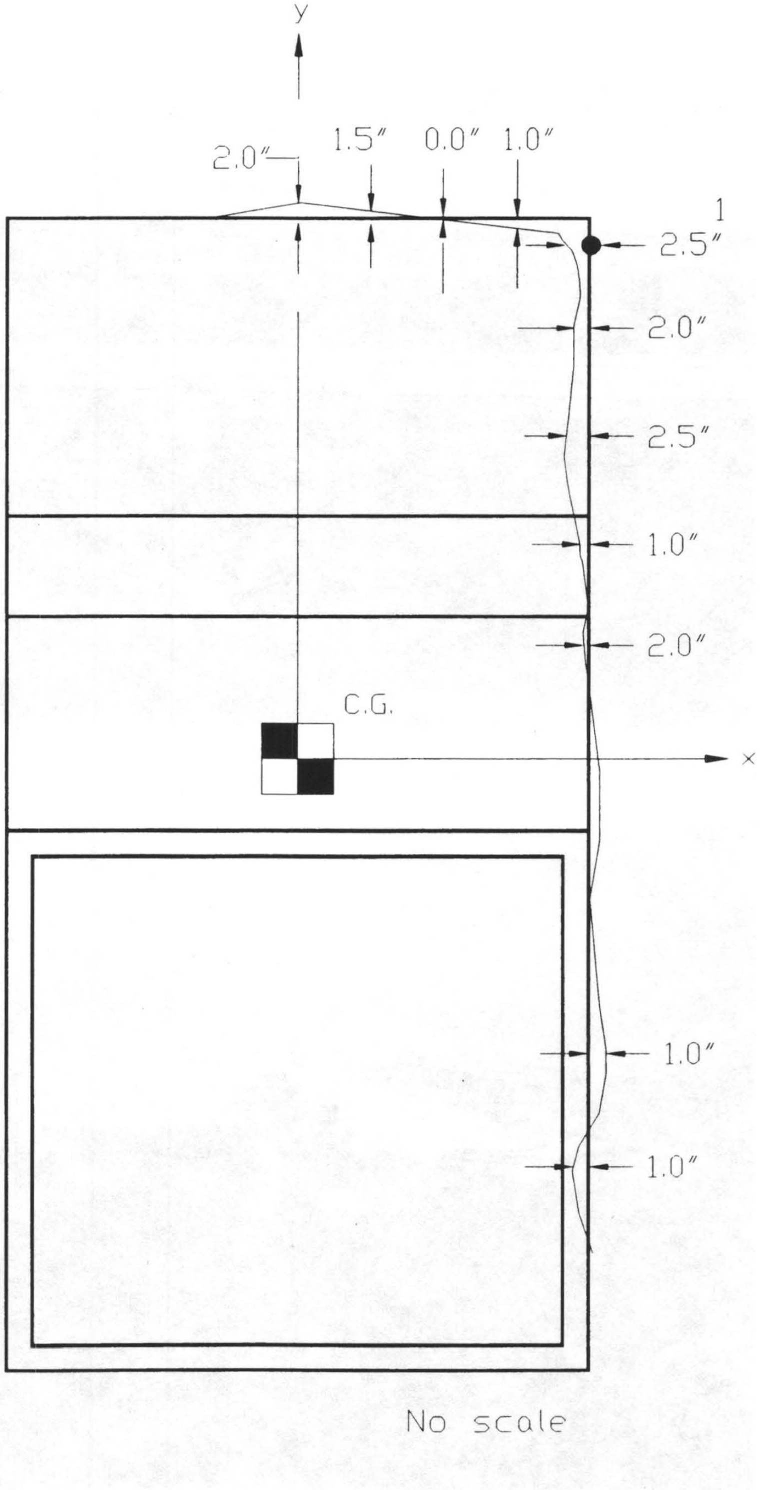


Figure 117. Vehicle Damage, Test SBLR-2.



1 Maximum static crush distance of 2.5″ occurred at (36″,96″) marked by the point.

Figure 118. Crush Depth Diagram, Test SBLR-2.

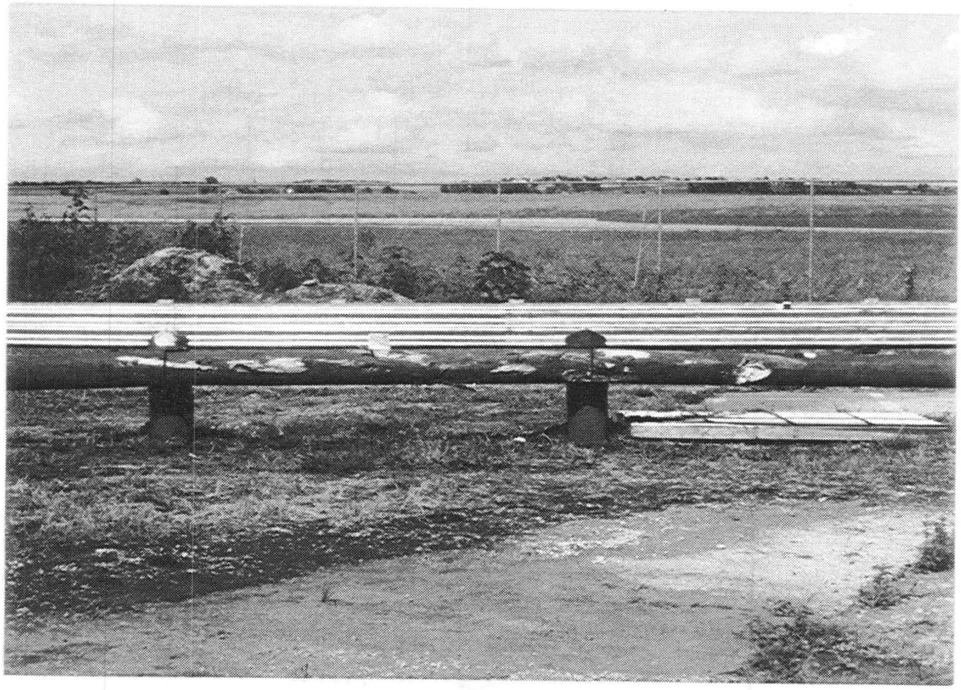


Figure 119. Log Rail Damage, Test SBLR-2.

EVALUATION SUMMARY

The tests described here were evaluated according to criteria for PL-1 bridge rails presented in *AASHTO Guide Specifications for Bridge Railings*.(8) They were conducted and reported in accordance with the requirements in NCHRP Report 230.(4) Table 11 summarizes all of the relevant evaluation criteria from AASHTO, as well as the findings from the two tests reported here.(8) As shown in this table, the Steel-Backed Log Rail successfully passed all requirements for PL-1 bridge railings. It should be noted that the pickup truck climbed on top of the barrier after impacting it at 46.1 mi/h (74.2 km/h). When a bumper impacts the round face of the log rail, it tends to slide either under the rail or over it. The barrier contained the test vehicle, but it was close to its performance limit. Therefore, this barrier is not recommended for park roads where the operating speed would be expected to exceed 45 mi/h (72.4 km/h).

Table 11. Summary of Safety Performance Results, SBLR Series.

<table>
<tr><th rowspan="2">Evaluation Criteria</th><th colspan="4">Results</th></tr>
<tr><th colspan="2">SBLR-1</th><th colspan="2">SBLR-2</th></tr>
<tr><td>3.a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.d. The vehicle shall remain upright during and after collision.</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ, where
$\mu = (\cos\theta - V_p/V)/\sin\theta$.

μ Assessment
0.0 - 0.25 Good
0.26 - 0.35 Fair
> 0.35 Marginal</td><td colspan="2">M
(μ=1.18)</td><td colspan="2">NA</td></tr>
<tr><td rowspan="6">3.g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0-ft longitudinal and 1.0-ft lateral displacements, shall be less than:

Occupant Impact Velocity - ft/s
Longitudinal Lateral
30 25

and for the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than:

Occupant ridedown Accelerations - g's
Longitudinal Lateral
15 15</td><td>Long.</td><td>Lateral</td><td>Long.</td><td>Lateral</td></tr>
<tr><td>S
(24.3)</td><td>S
(21.1)</td><td>S
(14.8)</td><td>S
(12.8)</td></tr>
<tr><td colspan="4">Occupant Ridedown Accelerations (g's)</td></tr>
<tr><td>Long.</td><td>Lateral</td><td>Long.</td><td>Lateral</td></tr>
<tr><td>S
(3.9)</td><td>S
(4.8)</td><td>S
(13.1)</td><td>S
(-13.4)</td></tr>
<tr></tr>
<tr><td rowspan="2">3.h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20 ft from the line of the traffic face of the railing.</td><td colspan="2">S
(2.0 deg)</td><td colspan="2">NA</td></tr>
<tr><td colspan="2">U</td><td colspan="2">S</td></tr>
</table>

S - Satisfactory U - Unsatisfactory
M - Marginal NA - Not Available

8. SUMMARY AND CONCLUSIONS

The safety of each of the five systems described here was evaluated according to criteria in AASHTO and NCHRP Report 230.(8,4) Several of the systems required design changes throughout the evaluation, but the final design of each system was found to pass the required safety criteria.

9. REFERENCES

1. Hancock, K.L., Hansen, A.G., Mayer, J.B., *Aesthetic Bridge Rails, Transitions, and Terminals for Park Roads and Parkways*, Federal Highway Administration, Report No. FHWA-RD-90-052, May 1990.

2. Stout, D., Hinch, J., Sawyer, D., *Guardrail Testing Program*, Federal Highway Administration, Report No. FHWA-RD-90-087, June 1990.

3. Hinch, J., Yang, T-L, and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, VA, 1986.

4. *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program Report No. 230, Transportation Research Board, Washington, DC, March 1981.

5. Powell, G.H., *BARRIER VII: A Computer Program For Evaluation of Automobile Barrier Systems*, Federal Highway Administration, Report No. FHWA-RD-73-51, April 1973.

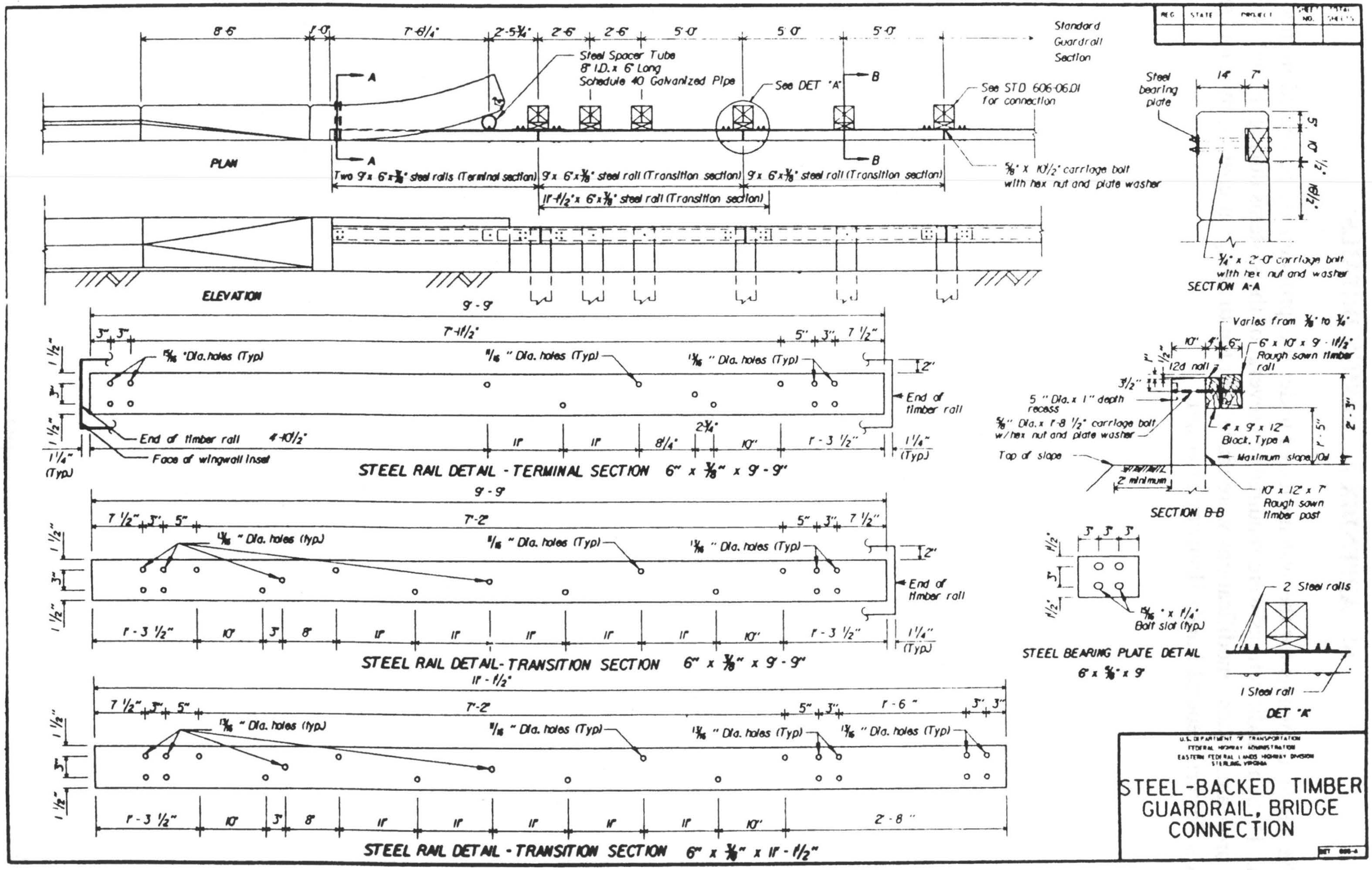
6. Vehicle Damage Scale for Traffic Investigators, Traffic Accident Data Project Technical Bulletin No. 1, National Safety Council, Chicago, IL, 1971.

7. Collision Deformation Classification, Recommended Practice J224, March 1980, SAE Handbook Vol. 4, Society of Automotive Engineers, Warrendale, PA, 1985.

8. *Guide Specifications for Bridge Railings*, American Association of State Highway and Transportation Officials, Washington, DC, 1989.

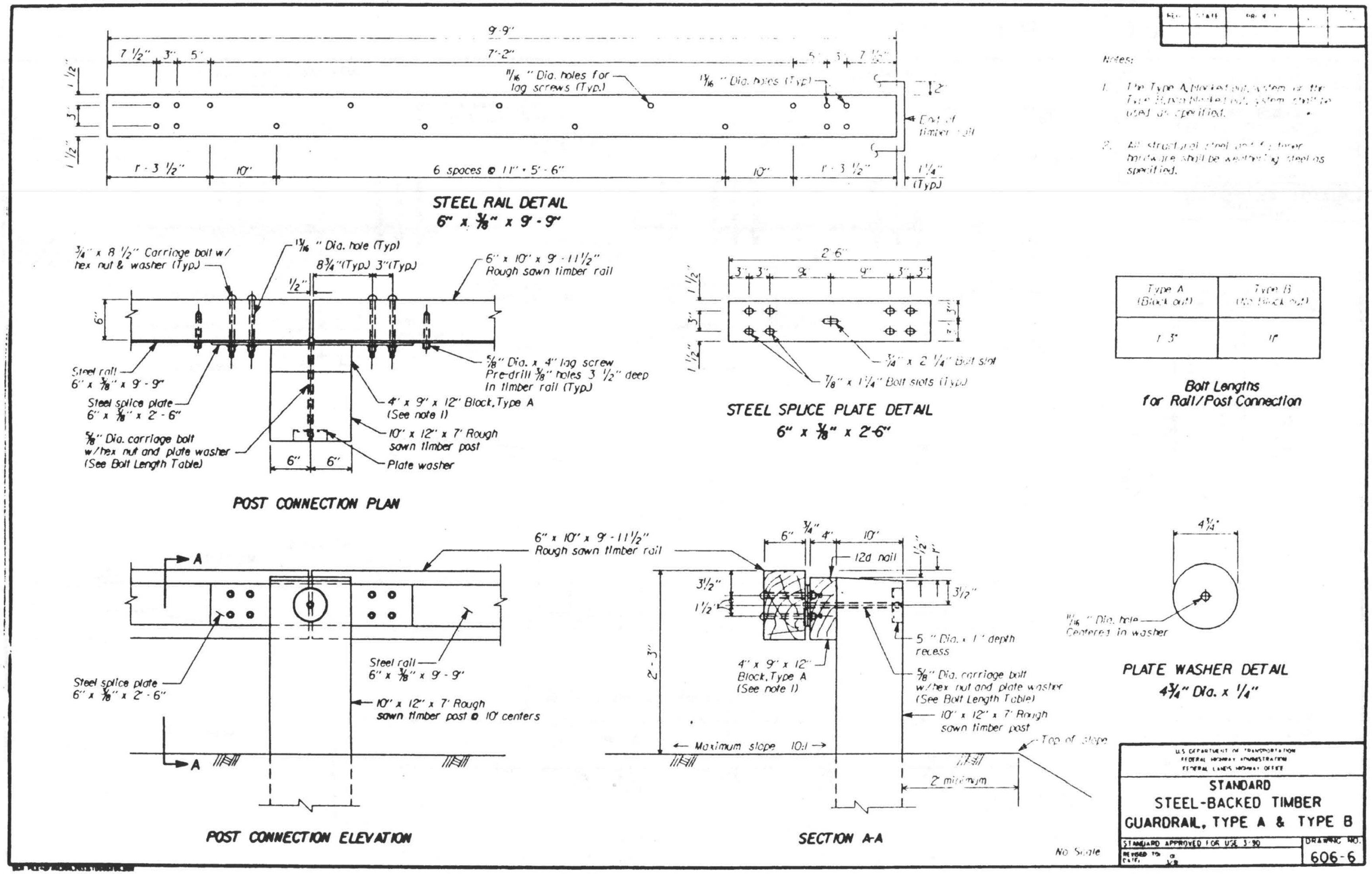
10. APPENDIX A - DESIGN DETAILS

The design drawings for the systems tested under this program are presented in this section. Design modifications were required for several of the systems during the full-scale testing program. These modifications were made, and the drawings prepared, by engineers at FHWA's Eastern Federal Lands Highway Division.



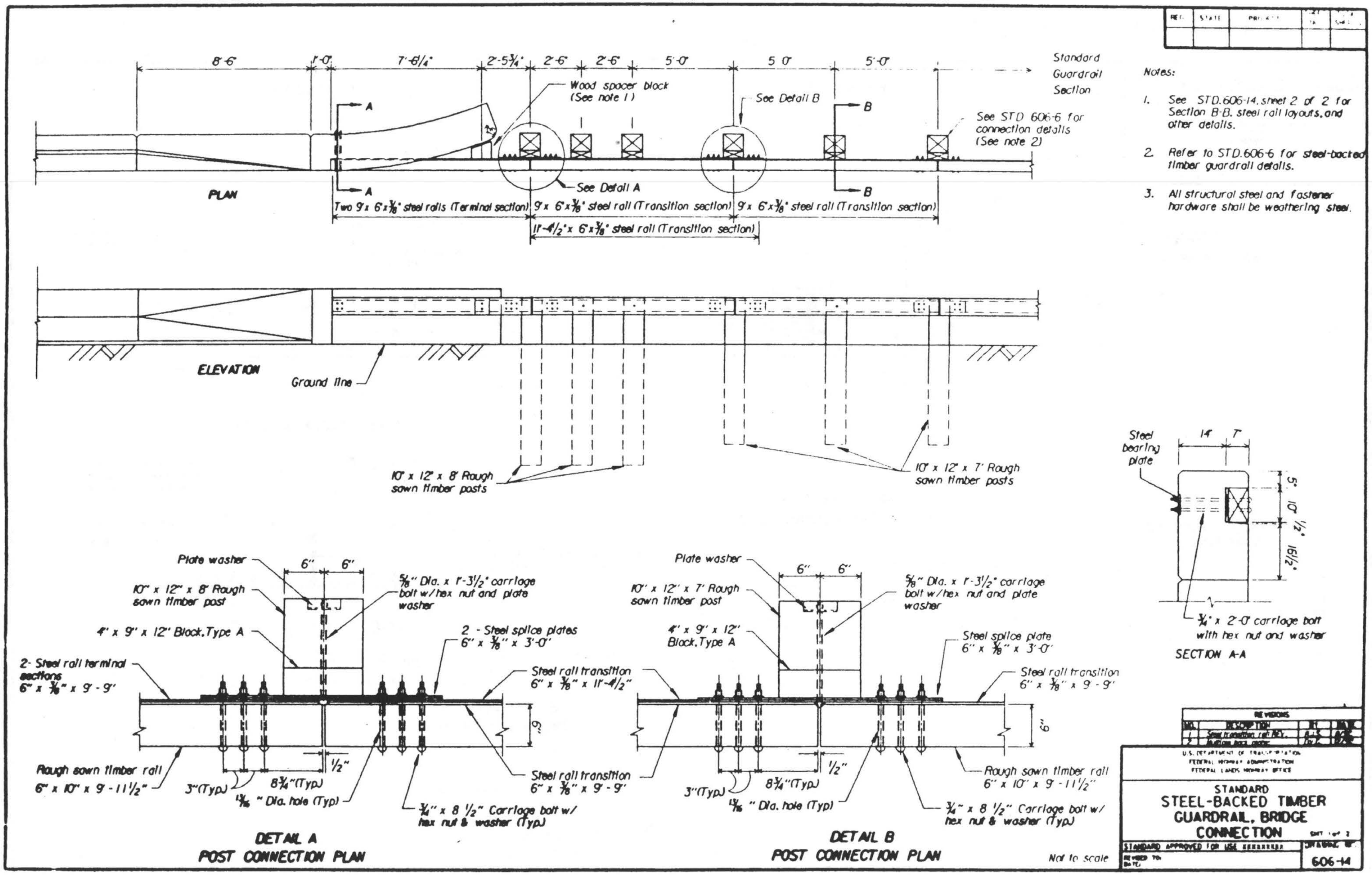
1 in = 25.4 mm 1 ft = 0.3048 m

Figure 120. Design Details of the SBT for Test SBT-1.



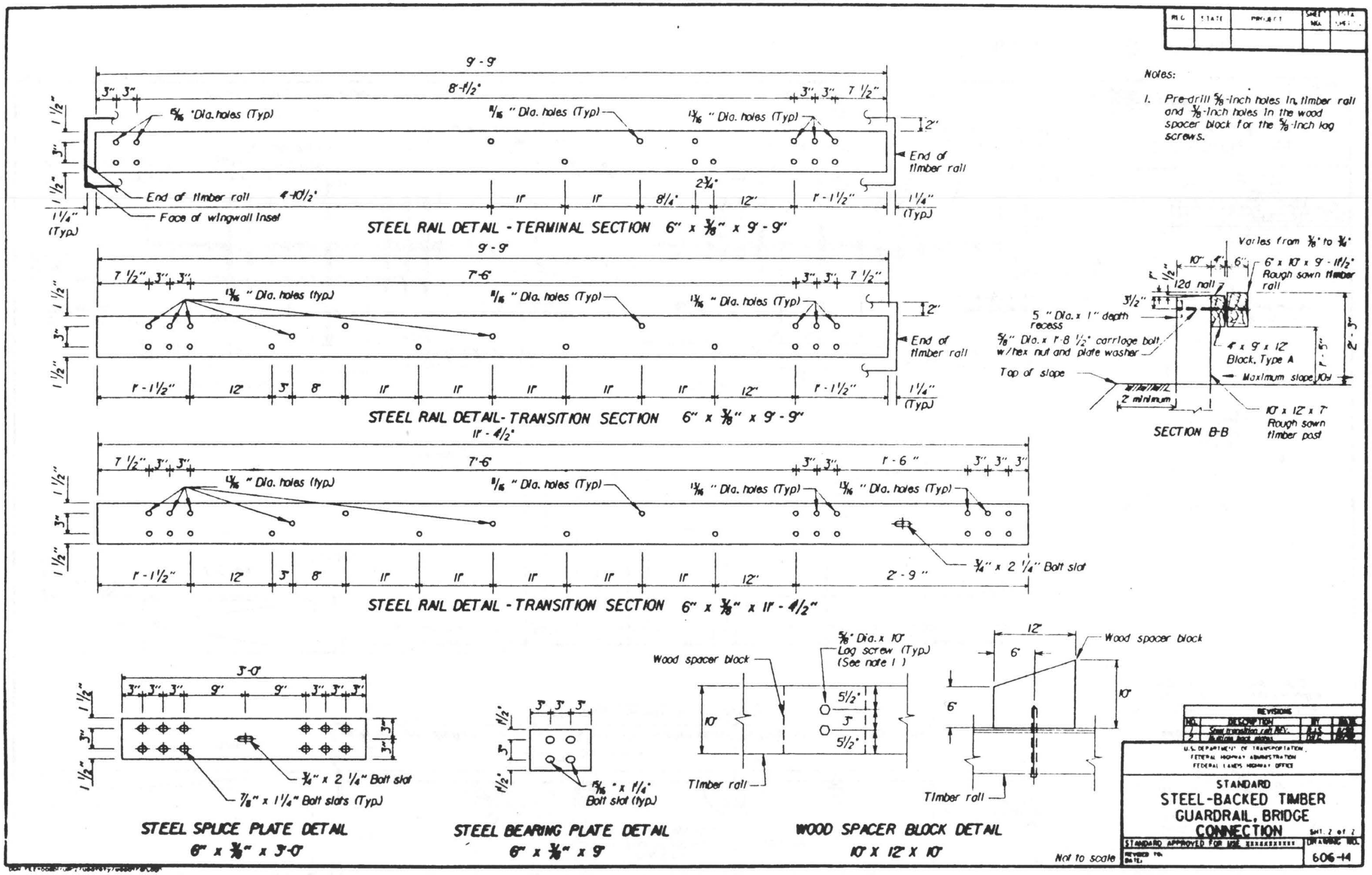
1 in = 25.4 mm 1 ft = 0.3048 m

Figure 120. Design Details of the SBT for Test SBT-1 (continued).



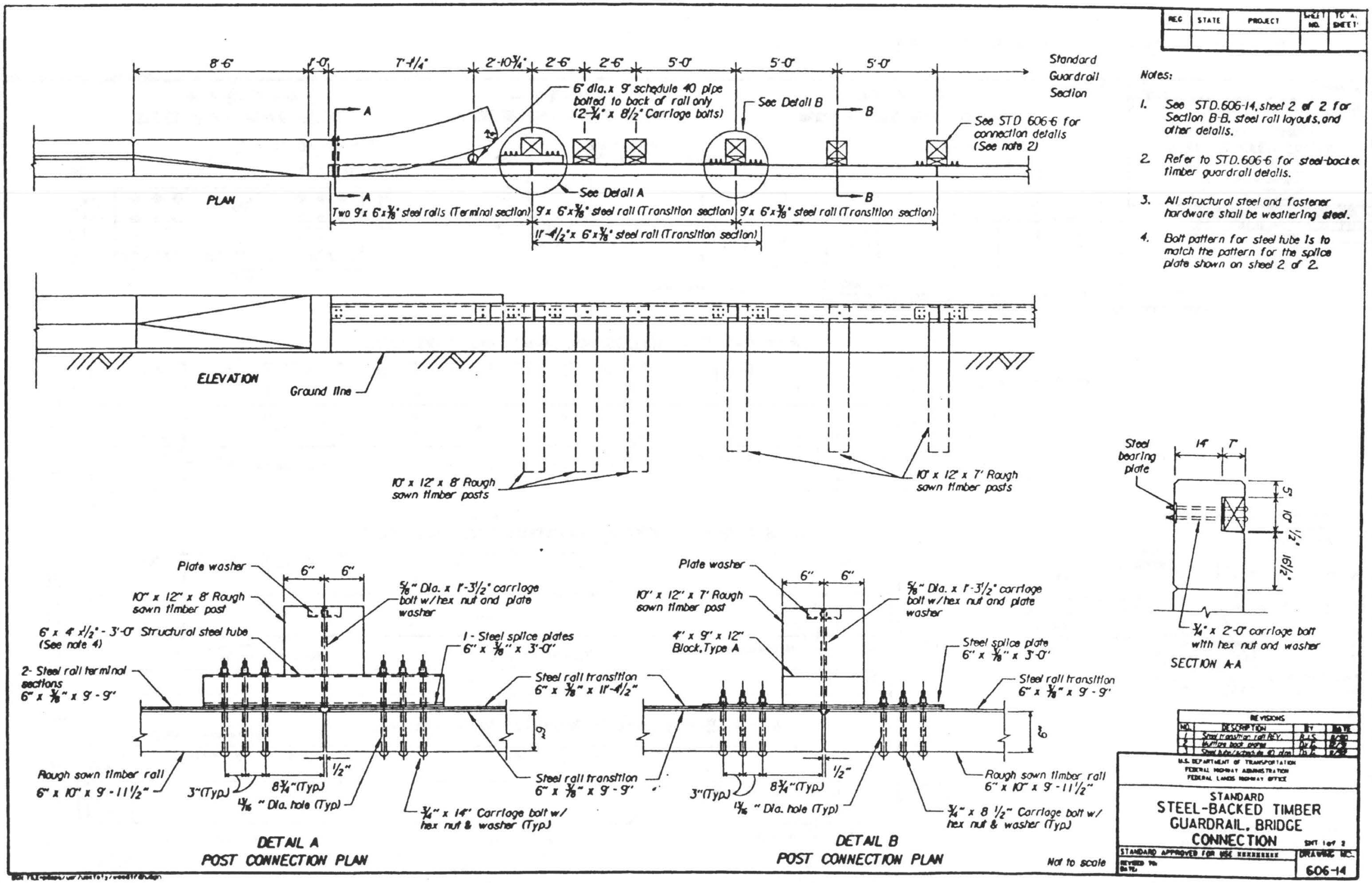
1 in = 25.4 mm 1 ft = 0.3048 m

Figure 121. Design Details of the SBT for Test SBT-2.



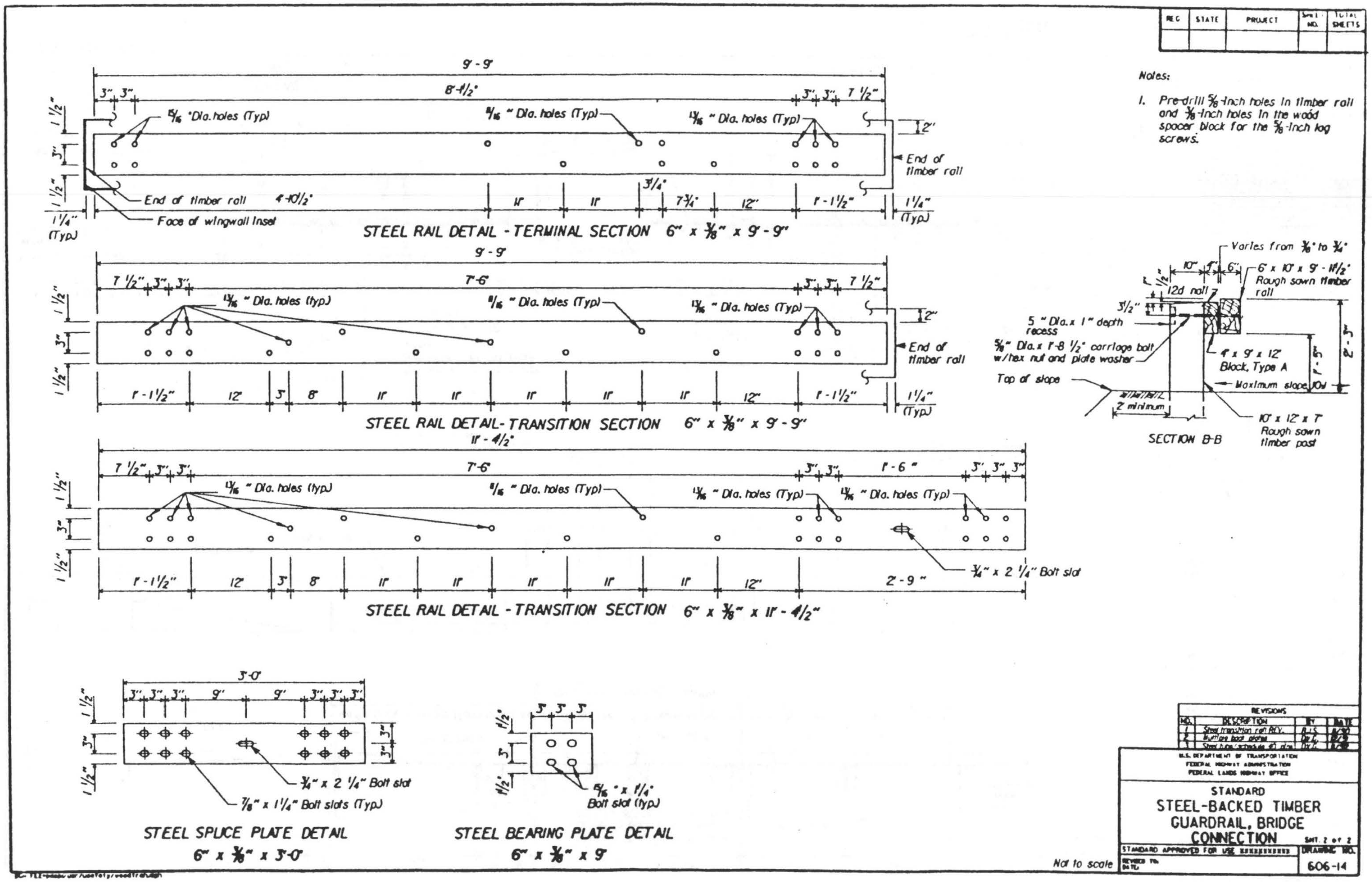
1 in = 25.4 mm 1 ft = 0.3048 m

Figure 121. Design Details of the SBT for Test SBT-2 (continued).



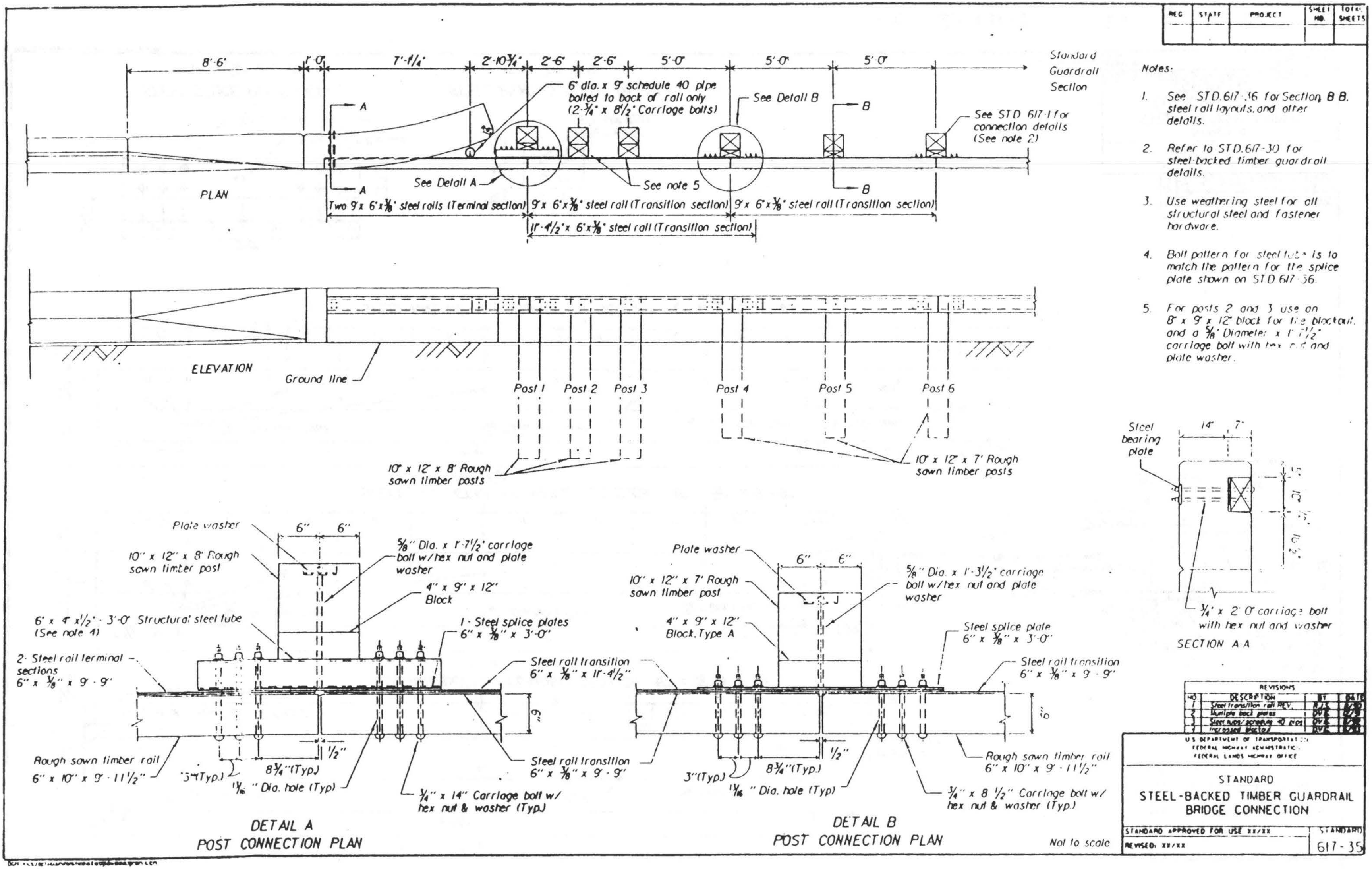
1 in = 25.4 mm 1 ft = 0.3048 m

Figure 122. Design Details of the SBT for Test SBT-3.



1 in = 25.4 mm 1 ft = 0.3048 m

Figure 122. Design Details of the SBT for Test SBT-3 (continued).

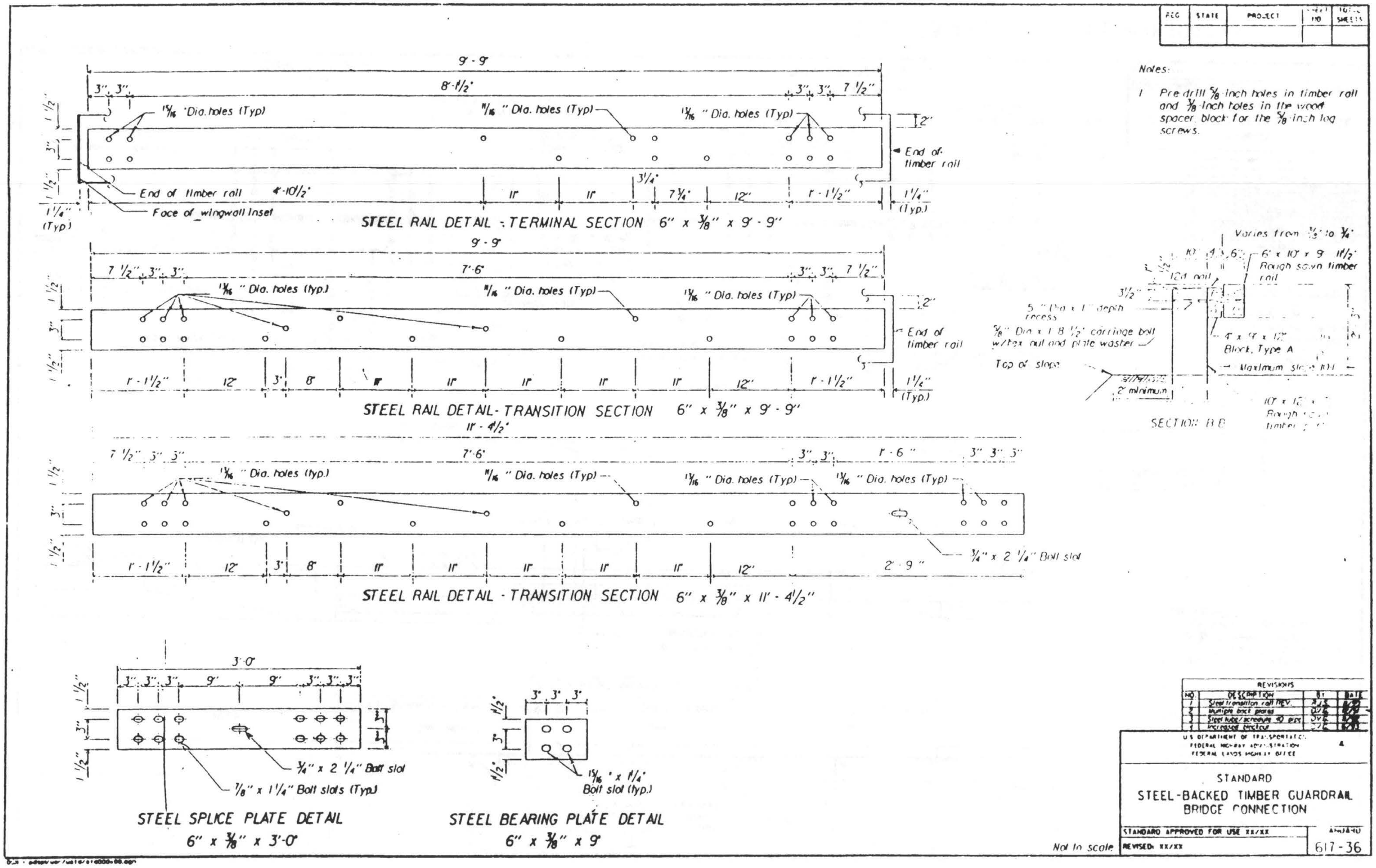


Notes:

1. See STD.617-36 for Section B-B, steel rail layouts, and other details.
2. Refer to STD.617-30 for steel-backed timber guardrail details.
3. Use weathering steel for all structural steel and fastener hardware.
4. Bolt pattern for steel tube is to match the pattern for the splice plate shown on STD 617-36.
5. For posts 2 and 3 use an 8" x 9" x 12" block for the blockout, and a ⅝" Diameter x 1' 7½" carriage bolt with hex nut and plate washer.

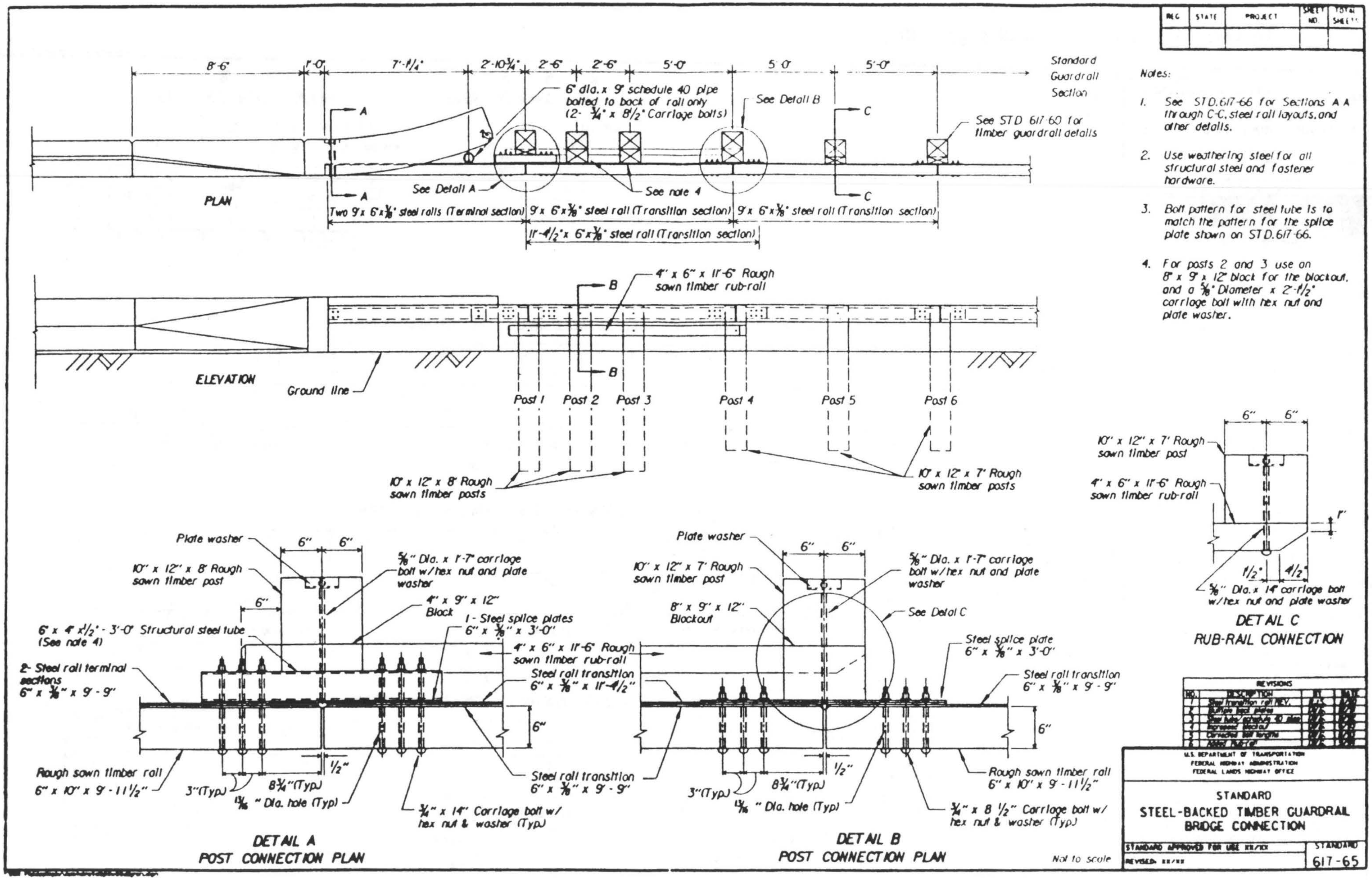
1 in = 25.4 mm 1 ft = 0.3048 m

Figure 123. Design Details of the SBT for Test SBT-4.



1 in = 25.4 mm 1 ft = 0.3048 m

Figure 123. Design Details of the SBT for Test SBT-4 (continued).

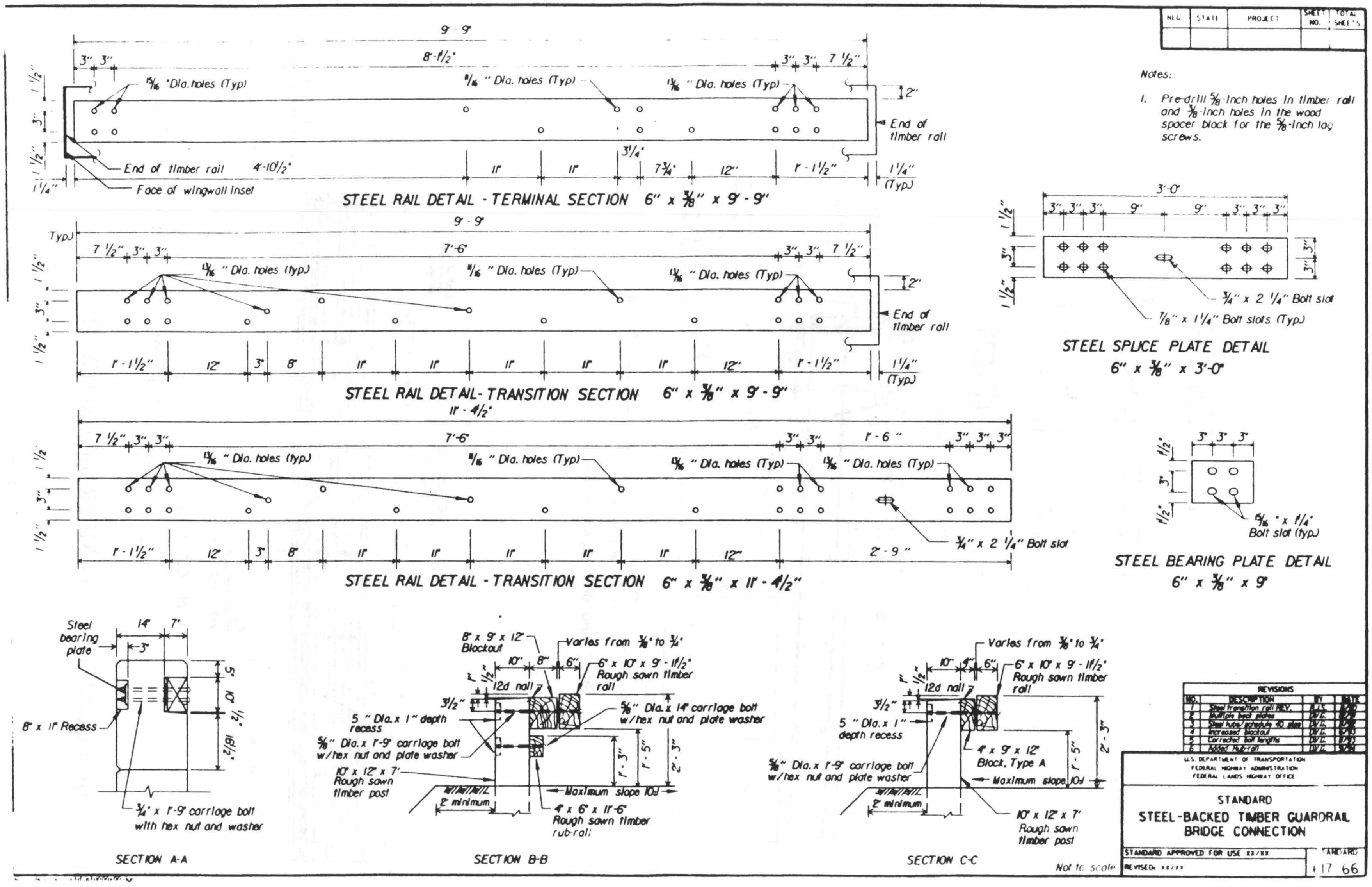


Notes:

1. See STD.617-66 for Sections A-A through C-C, steel rail layouts, and other details.
2. Use weathering steel for all structural steel and fastener hardware.
3. Bolt pattern for steel tube is to match the pattern for the splice plate shown on STD.617-66.
4. For posts 2 and 3 use an 8" x 9" x 12" block for the blockout, and a ⅝" Diameter x 2'-1½" carriage bolt with hex nut and plate washer.

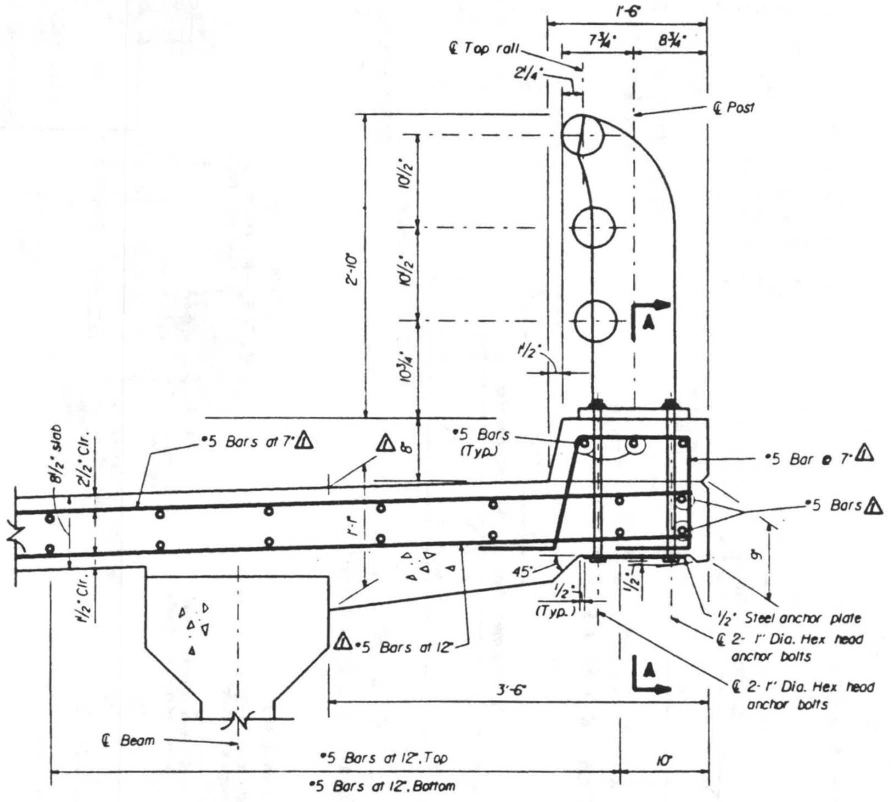
1 in = 25.4 mm 1 ft = 0.3048 m

Figure 124. Design Details of the SBT for Test SBT-5.

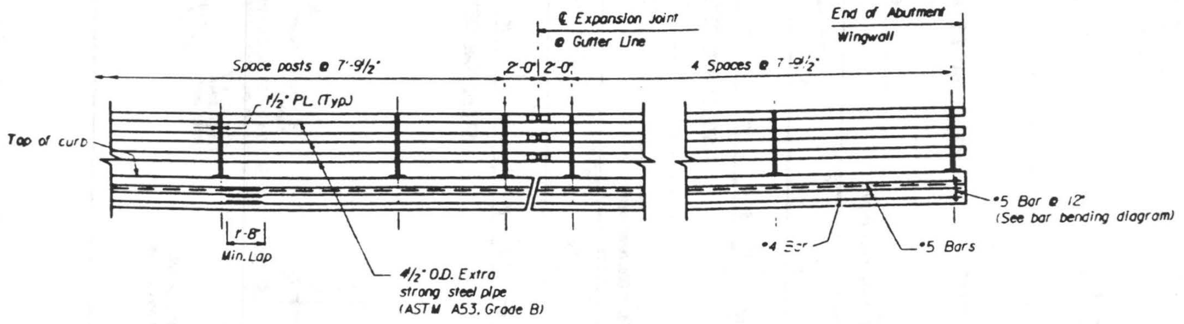


1 in = 25.4 mm 1 ft = 0.3048 m

Figure 124. Design Details of the SBT for Test SBT-5 (continued).



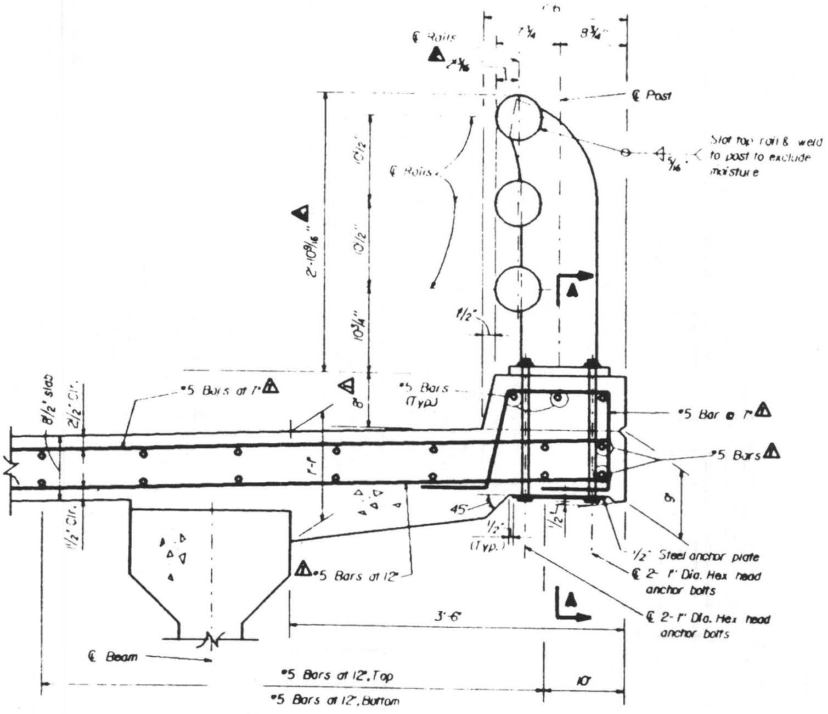
POST AND DECK SLAB DETAILS



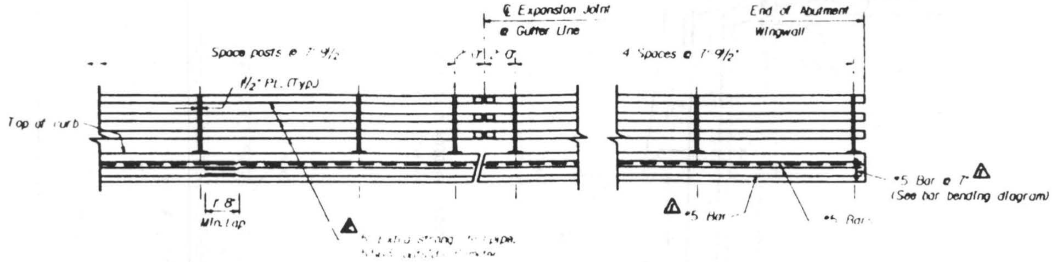
RAILING ELEVATION

1 in = 25.4 mm 1 ft = 0.3048 m

Figure 125. Design Details of the GWMPBR for Test GWMP-1.



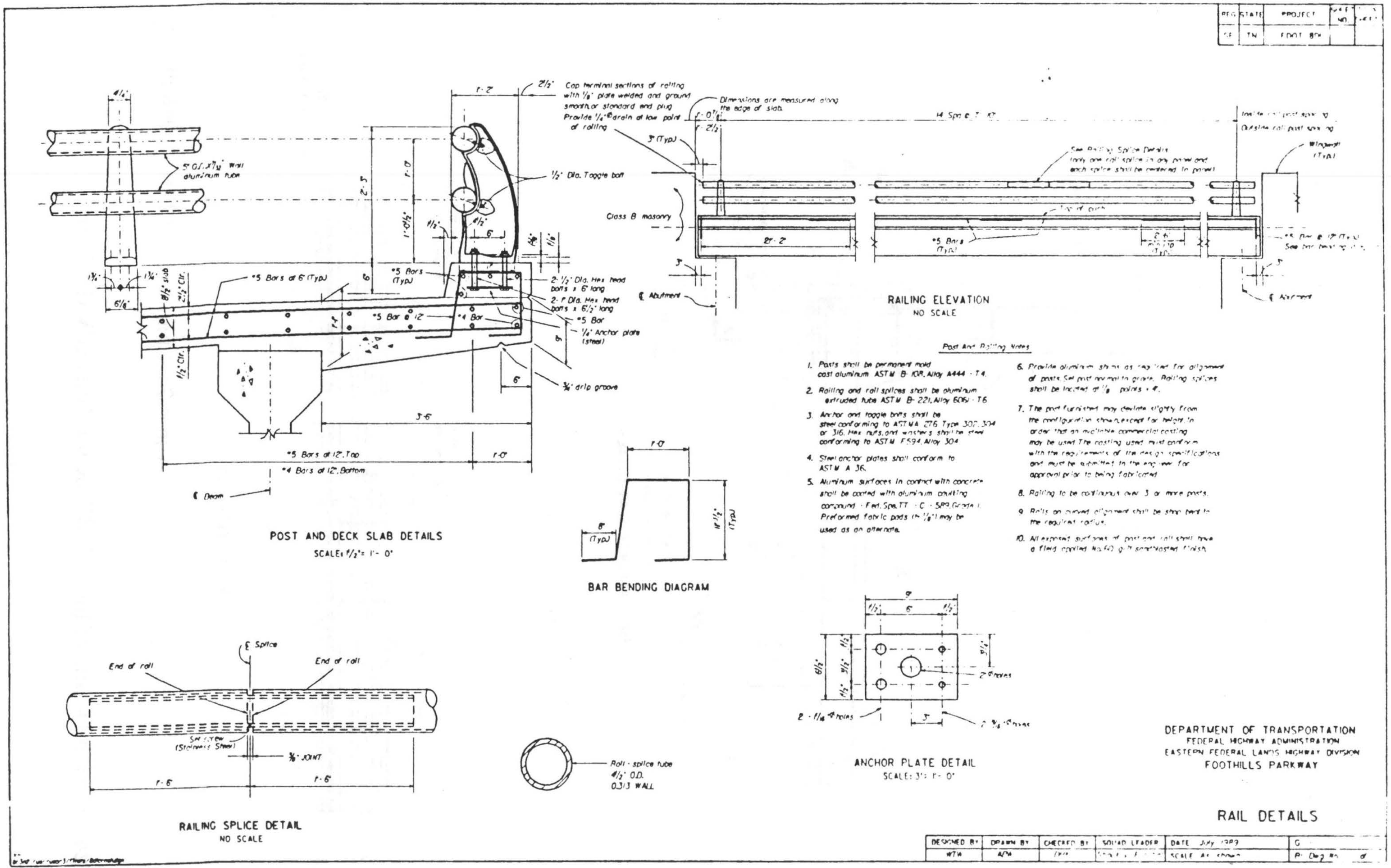
POST AND DECK SLAB DETAILS



RAILING ELEVATION

1 in = 25.4 mm 1 ft = 0.3048 m

Figure 126. Design Details of the GWMPBR for Tests GWMP-2 and 3.

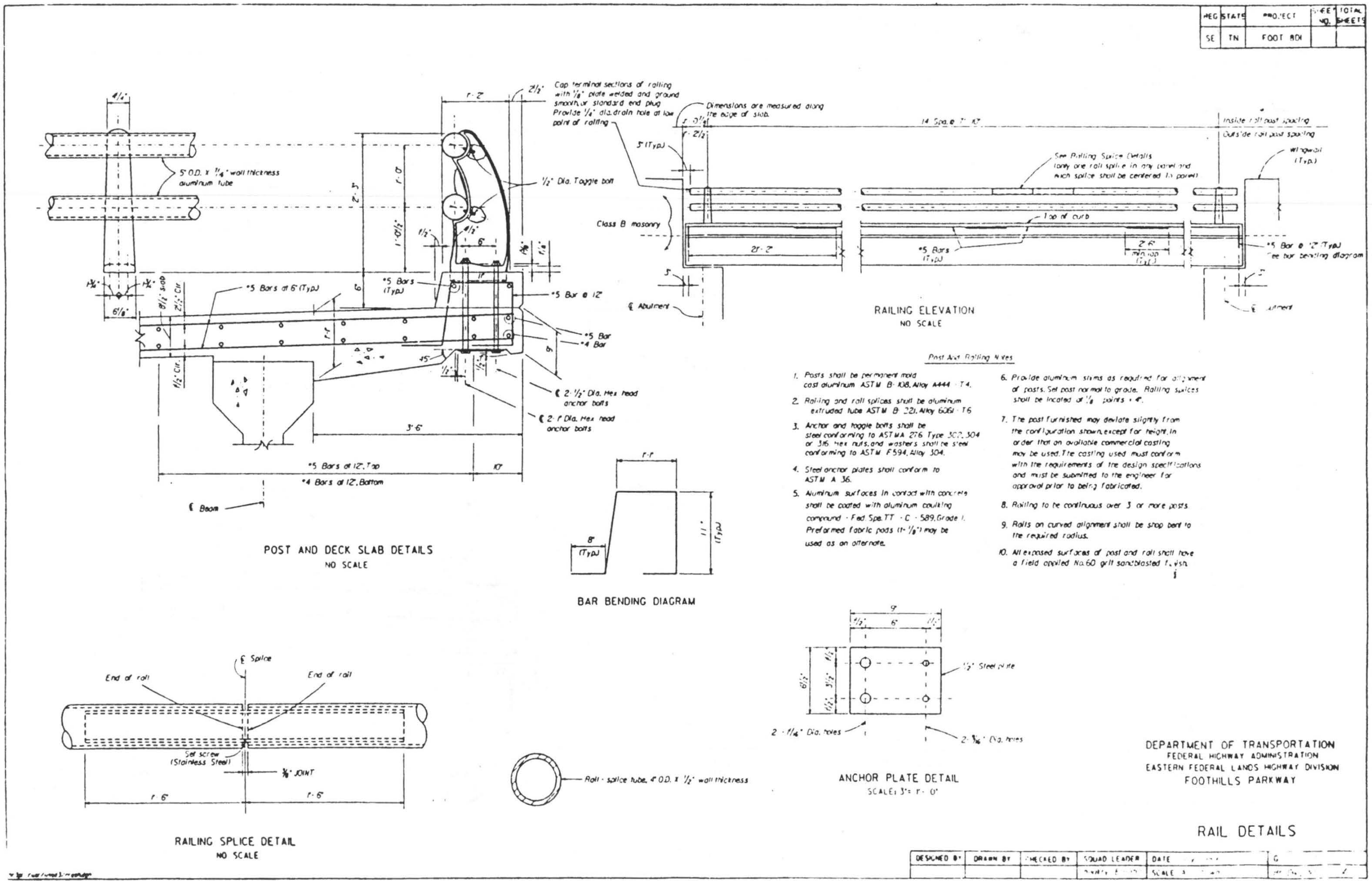


Post And Railing Notes

1. Posts shall be permanent mold cast aluminum ASTM B-108, Alloy A444 - T4.
2. Railing and rail splices shall be aluminum extruded tube ASTM B-221, Alloy 6061 - T6
3. Anchor and toggle bolts shall be steel conforming to ASTM A 276 Type 302, 304 or 316. Hex nuts, and washers shall be steel conforming to ASTM F594, Alloy 304
4. Steel anchor plates shall conform to ASTM A 36.
5. Aluminum surfaces in contact with concrete shall be coated with aluminum caulking compound - Fed. Spec. TT - C - 598, Grade I. Preformed fabric pads (⅛") may be used as an alternate.
6. Provide aluminum shims as required for alignment of posts. Set post normal to grade. Railing splices shall be located at ⅛ points ± 4'.
7. The post furnished may deviate slightly from the configuration shown, except for height, in order that an available commercial casting may be used. The casting used must conform with the requirements of the design specifications and must be submitted to the engineer for approval prior to being fabricated.
8. Railing to be continuous over 3 or more posts.
9. Rails on curved alignment shall be shop bent to the required radius.
10. All exposed surfaces of post and rail shall have a field applied No. 60 grit sandblasted finish.

1 in = 25.4 mm 1 ft = 0.3048 m

Figure 127. Design details of the Foothills Parkway Bridge Rail for Test FPAR-1.

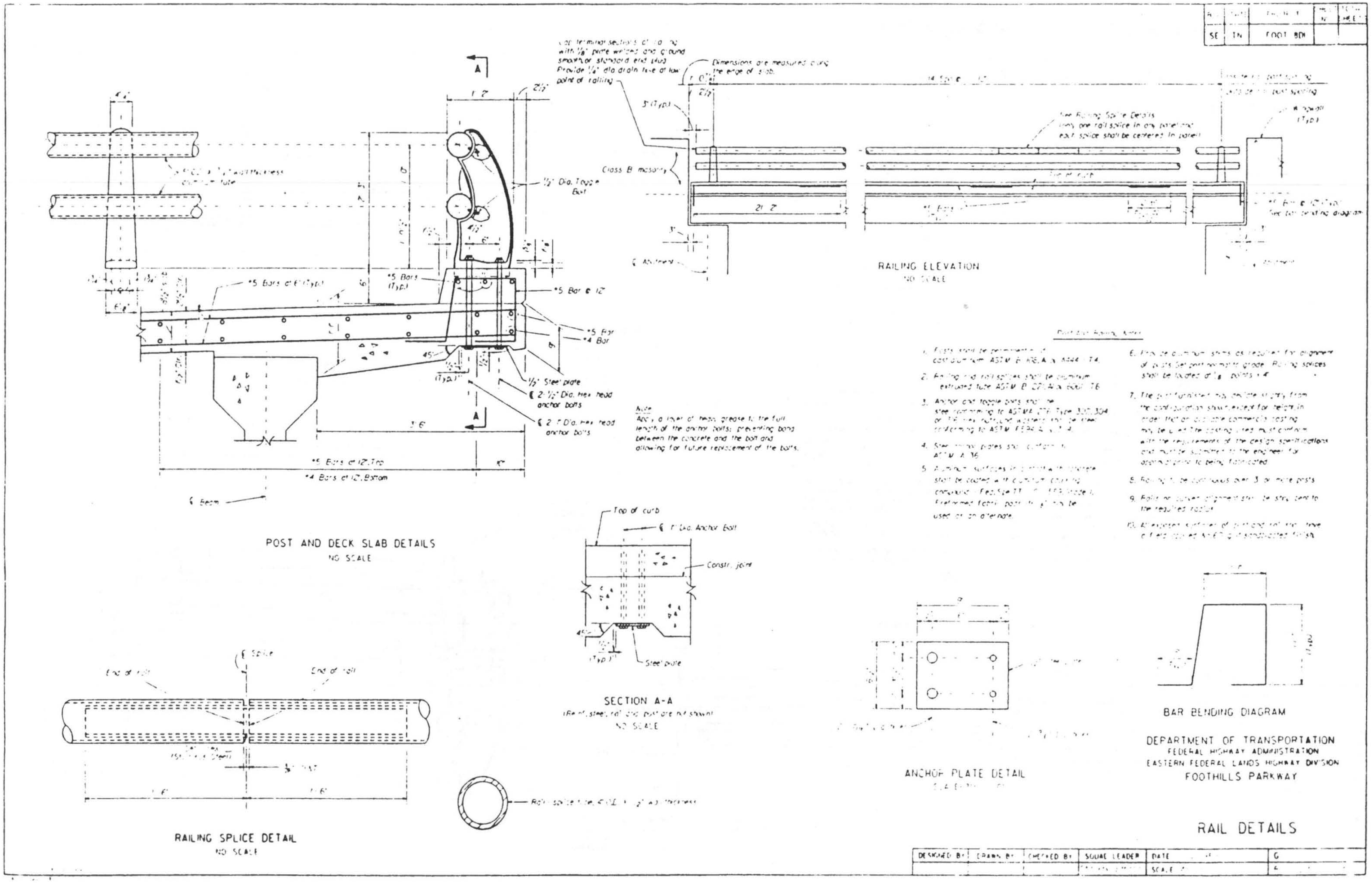


Post And Railing Notes

1. Posts shall be permanent mold cast aluminum ASTM B-108, Alloy A444-T4.
2. Railing and rail splices shall be aluminum extruded tube ASTM B-221, Alloy 6061-T6
3. Anchor and toggle bolts shall be steel conforming to ASTM A 276 Type 302, 304 or 316. Hex nuts, and washers shall be steel conforming to ASTM F594, Alloy 304.
4. Steel anchor plates shall conform to ASTM A 36.
5. Aluminum surfaces in contact with concrete shall be coated with aluminum caulking compound - Fed. Spe. TT-C-589, Grade I. Preformed fabric pads (1-⅛") may be used as an alternate.
6. Provide aluminum shims as required for alignment of posts. Set post normal to grade. Railing splices shall be located at ⅛ points ± 4".
7. The post furnished may deviate slightly from the configuration shown, except for height, in order that an available commercial casting may be used. The casting used must conform with the requirements of the design specifications and must be submitted to the engineer for approval prior to being fabricated.
8. Railing to be continuous over 3 or more posts.
9. Rails on curved alignment shall be shop bent to the required radius.
10. All exposed surfaces of post and rail shall have a field applied No. 60 grit sandblasted finish.

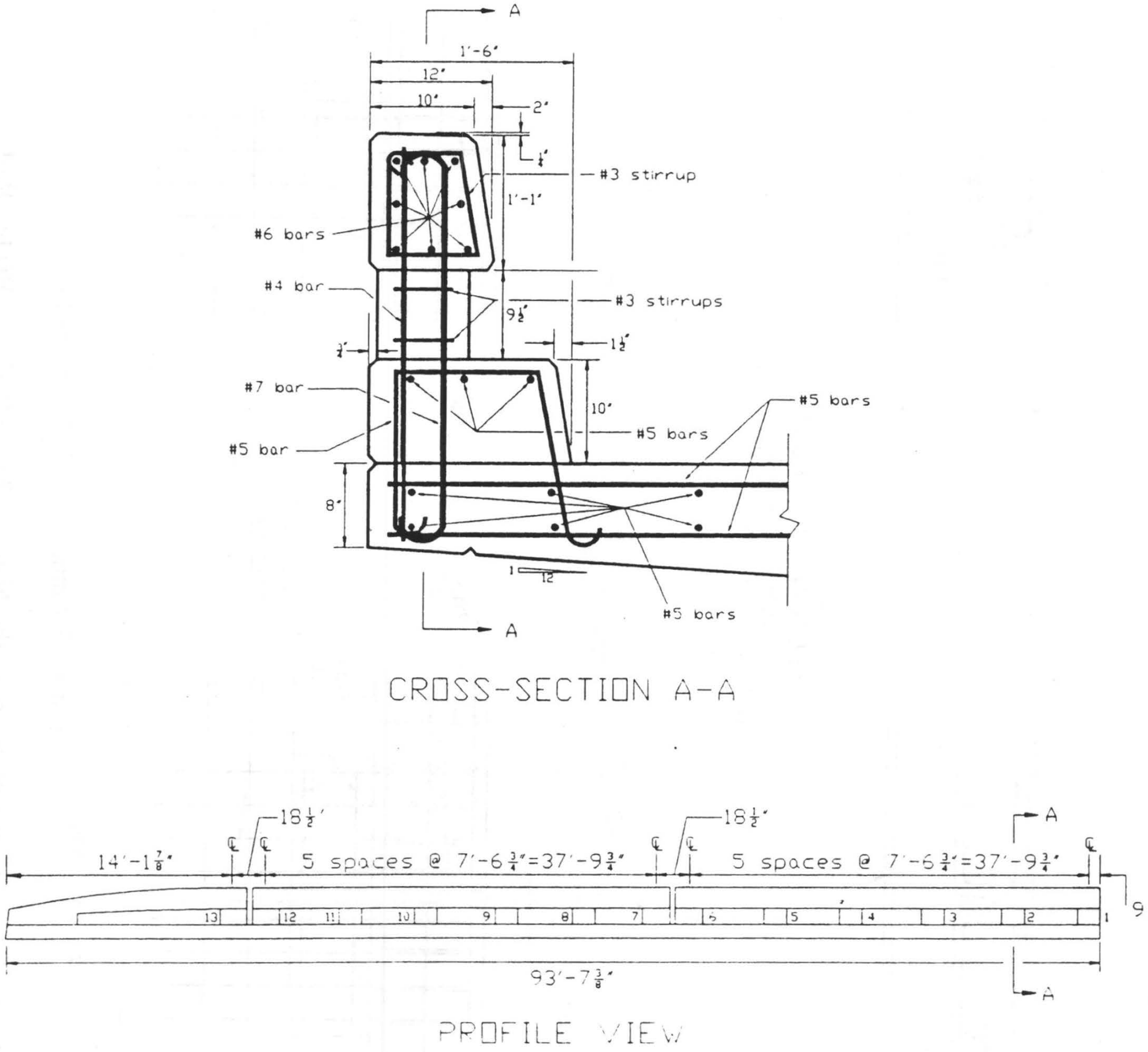
1 in = 25.4 mm   1 ft = 0.3048 m

Figure 128. Design details of the Foothills Parkway Bridge Rail for Test FPAR-2.



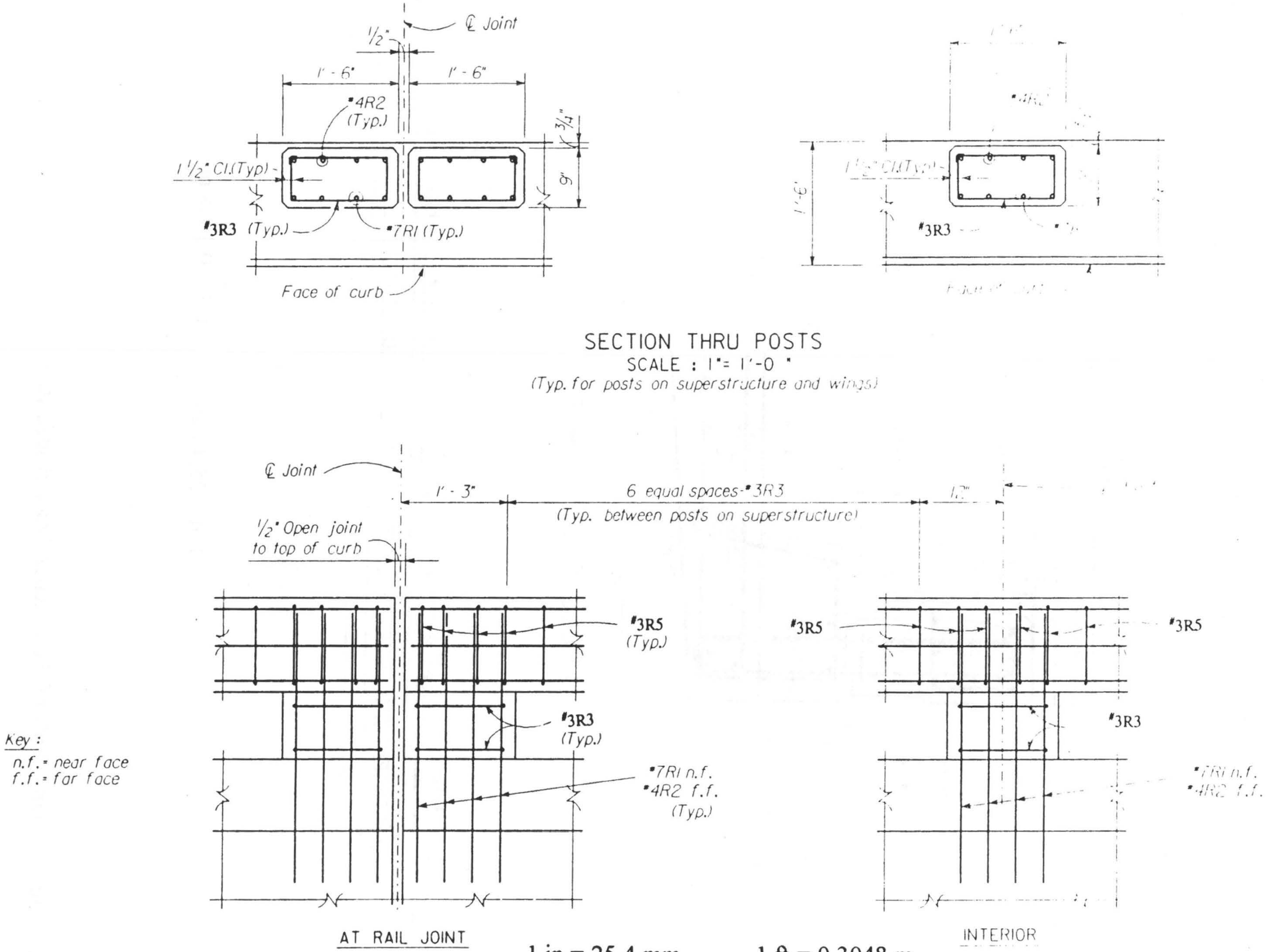
1 in = 25.4 mm 1 ft = 0.3048 m

Figure 129. Design details of the Foothills Parkway Bridge Rail for Test FPAR-3.



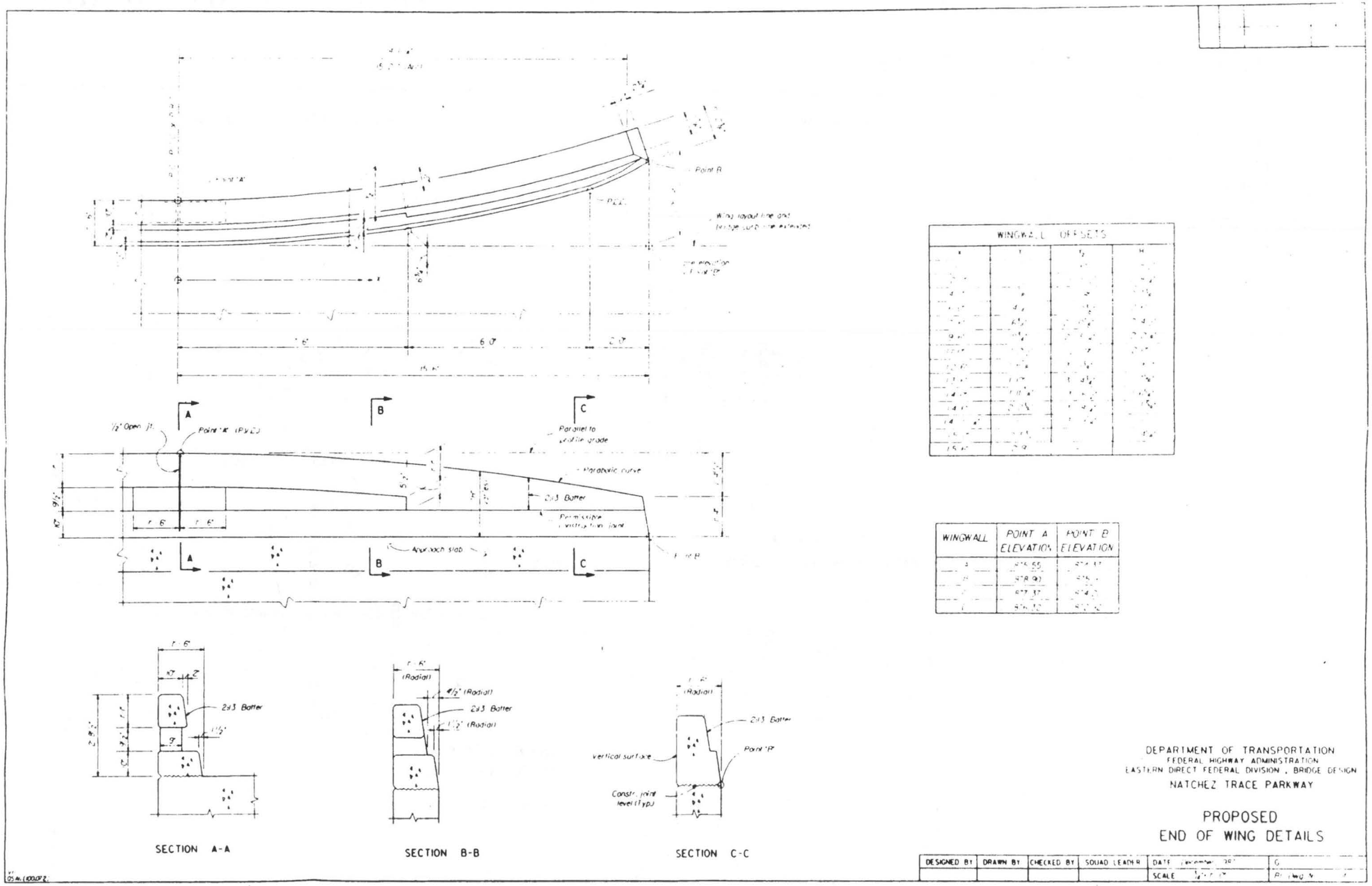
1 in = 25.4 mm 1 ft = 0.3048 m

Figure 130. Design details of the Natchez Trace Bridge Rail.



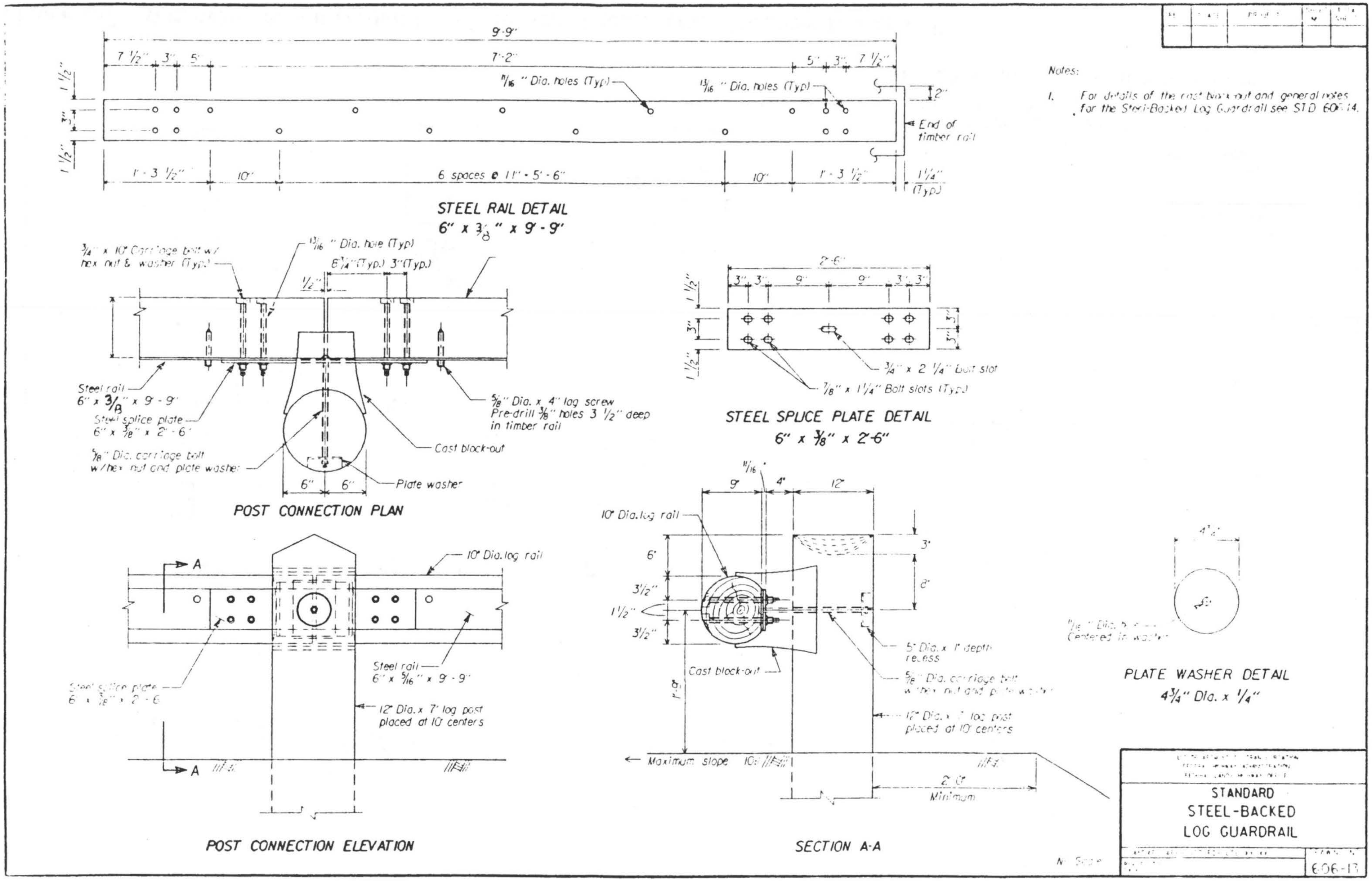
1 in = 25.4 mm 1 ft = 0.3048 m

Figure 131. Reinforcement Details for the Concrete Posts in the Natchez Trace Parkway Bridge Rail.



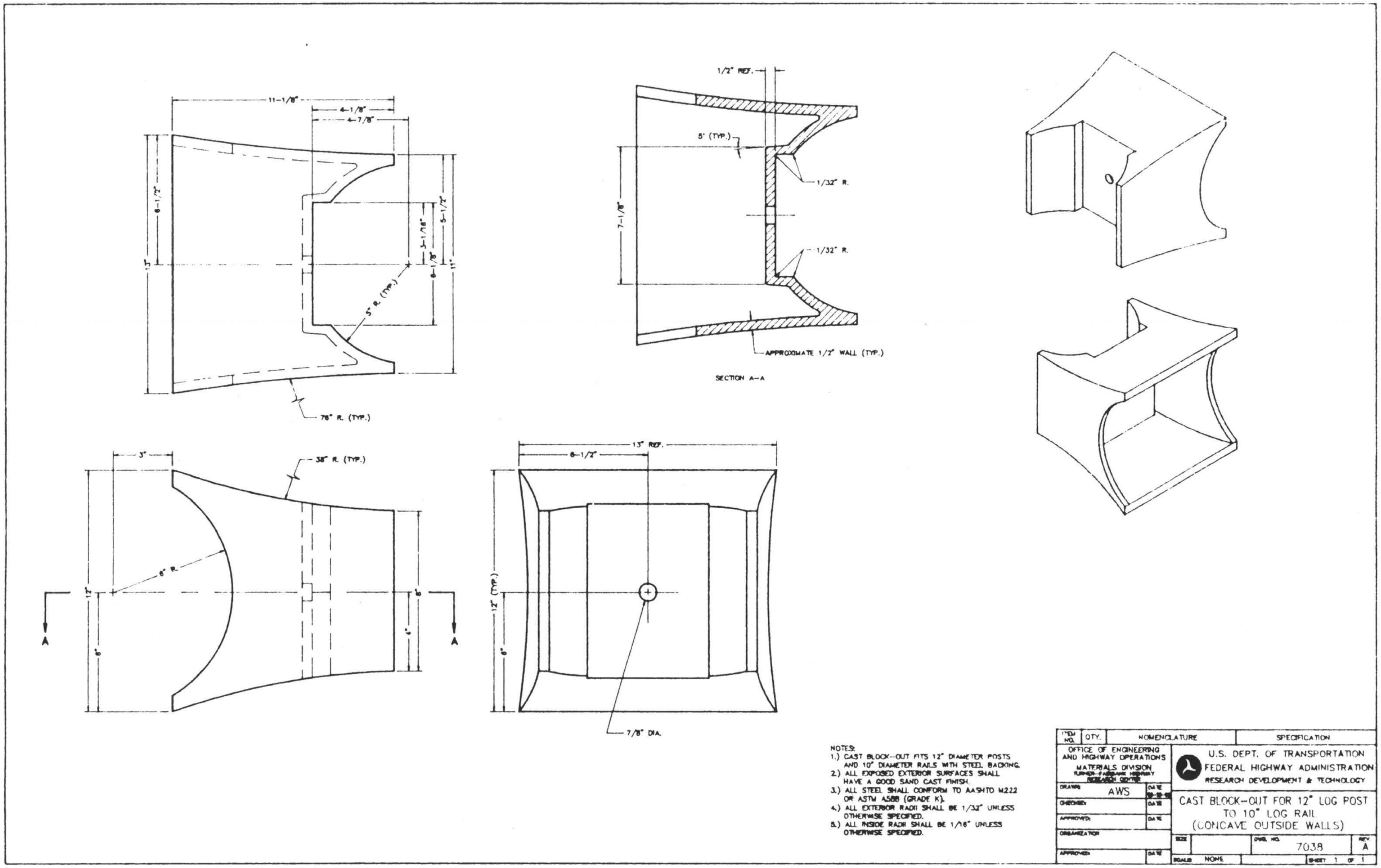
1 in = 25.4 mm 1 ft = 0.3048 m

Figure 132. Wingwall Section Design Details for the Natchez Trace Parkway Bridge Rail.



1 in = 25.4 mm . 1 ft = 0.3048 m

Figure 133. Design Details of the Steel-Backed Log Rail.



NOTES:
1.) CAST BLOCK-OUT FITS 12" DIAMETER POSTS AND 10" DIAMETER RAILS WITH STEEL BACKING.
2.) ALL EXPOSED EXTERIOR SURFACES SHALL HAVE A GOOD SAND CAST FINISH.
3.) ALL STEEL SHALL CONFORM TO AASHTO M222 OR ASTM A588 (GRADE K).
4.) ALL EXTERIOR RADII SHALL BE 1/32" UNLESS OTHERWISE SPECIFIED.
5.) ALL INSIDE RADII SHALL BE 1/16" UNLESS OTHERWISE SPECIFIED.

1 in = 25.4 mm 1 ft = 0.3048 m

Figure 134. Details of the Cast Steel Blockout Used in the Steel-Backed Log Rail System.

11. APPENDIX B - TEST VEHICLES

Photographs and relevant dimensions and weights of the test vehicles used in this testing program are presented in this section. The test vehicles utilized in this program included large sedans, small cars, and ¾-ton pickups. The instrumentation of these vehicles is described in Chapter 2 of this report.

Figure 135. Test Vehicle, Test SBT-1.

Make: Ford

Model: LTD Crown Victoria

Year: 1985

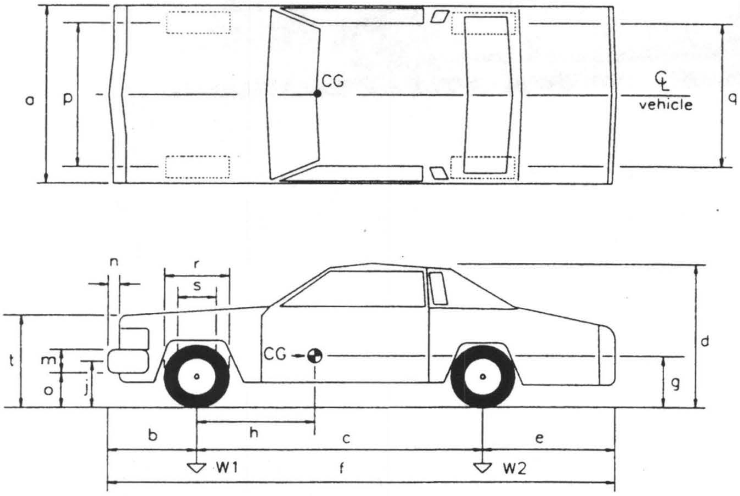
Test No.: SBT-1

Tire Size: P205-75R15

VIN: 1FABP43F6FZ109889

Vehicle Geometry
Inches

a — 76.75
b — 39.0
c — 114.0
d — 57.0
e — 55.5
f — 208.5
g — 20.5
h — 52.6
j — 18.5
m — 8.0
n — 4.5
o — 14.5
p — 62.25
q — NA
r — 27.0
s — 16.25
t — NA



Engine Size: 5.0 liter

Transmission: Automatic

Weight (lbs)	Curb	Test Inertial	Gross Static
W1	2190	2400	2315
W2	1690	2060	1985
Wtotal	3880	4460	4300

Damage prior to test: None

1 in = 25.4 mm **1 lb = 0.454 kg**

Figure 136. Test Vehicle Dimensions, Test SBT-1.

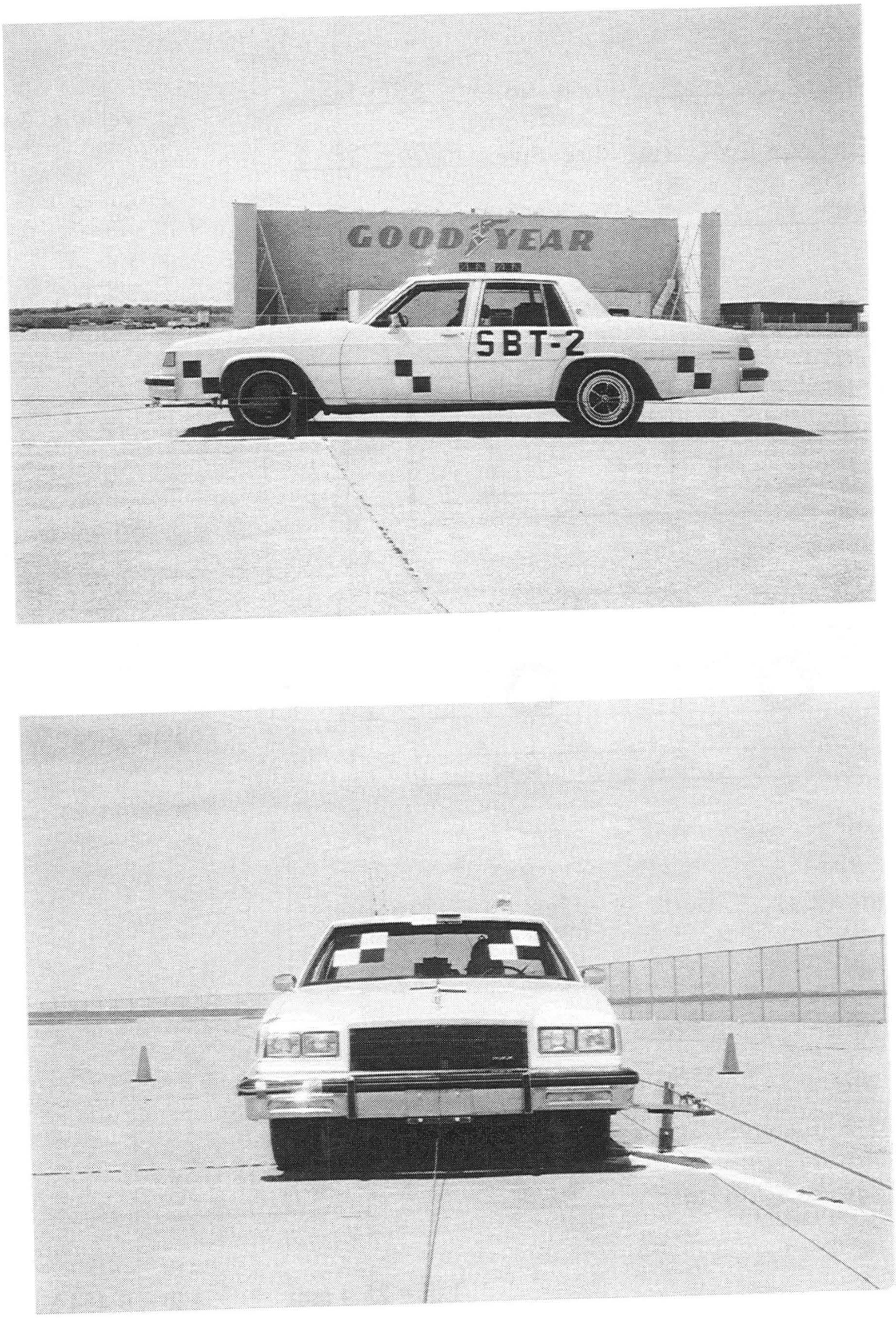


Figure 137. Test Vehicle, Test SBT-2.

Make: Buick

Model: LeSabre

Year: 1984

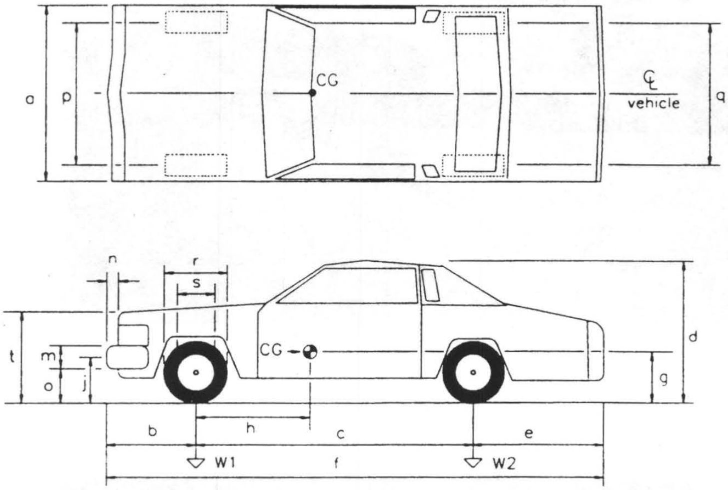
Test No.: SBT-2

Tire Size: P215-75R15

VIN: 1G4AN6948EX424358

Vehicle Geometry
Inches

a — 77.0
b — 41.5
c — 116.0
d — NA
e — 56.5
f — 214.0
g — 22.0
h — 51.0
j — 18.0
m — 8.0
n — 5.0
o — 14.0
p — 61.5
q — 63.0
r — 26.5
s — 16.25
t — NA



Engine Size: 5.0 liter

Transmission: Automatic

Weight (lbs)	Curb	Test Inertial	Gross Static
W1	2210	2683	2598
W2	1560	1933	1858
Wtotal	3770	4616	4456

Damage prior to test: None

1 in = 25.4 mm 1 lb = 0.454 kg

Figure 138. Test Vehicle Dimensions, Test SBT-2.

Figure 139. Test Vehicle, Test SBT-3.

Make: Ford

Model: LTD Crown Victoria

Year: 1985

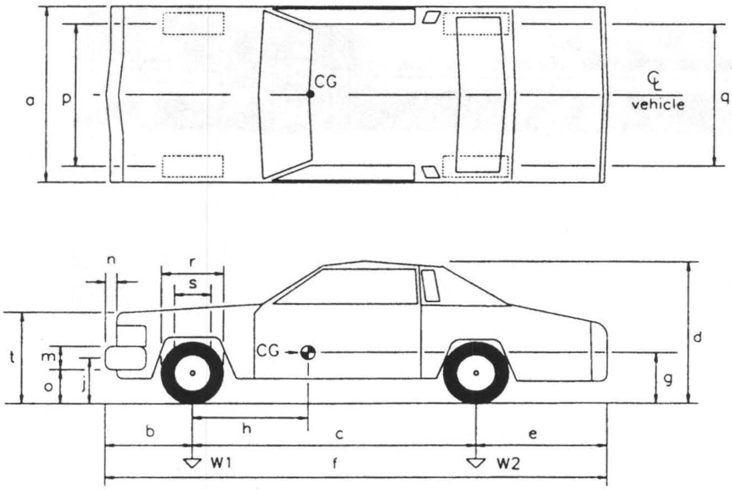
Test No.: SBT-3

Tire Size: P205-75R15

VIN: 2FABP43GXFX207998

Vehicle Geometry
Inches

a — 77.0
b — 37.0
c — 114.0
d — 55.5
e — 52.5
f — 205.0
g — 22.0
h — 50.0
j — 18.0
m — 8.25
n — 4.0
o — 12.5
p — 62.5
q — NA
r — 27.0
s — 16.25
t — NA



Engine Size: 351 cu. in.

Transmission: Automatic

Weight (lbs)	Curb	Test Inertial	Gross Static
W1	2310	2524	2609
W2	1630	1972	2047
Wtotal	3940	4496	4656

Damage prior to test: None

1 in = 25.4 mm 1 lb = 0.454 kg

Figure 140. Test Vehicle Dimensions, Test SBT-3..

Figure 141. Test Vehicle, Test SBT-4.

Make: Mercury

Model: Grand Marquis

Year: 1984

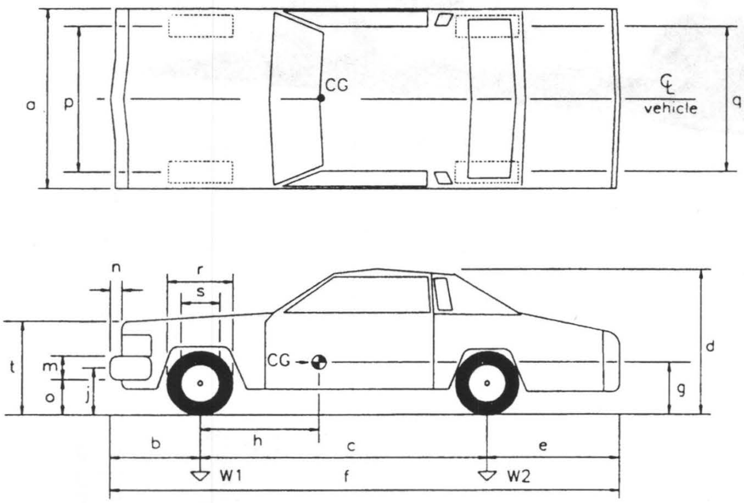
Test No.: SBT-4

Tire Size: P215-75R15

VIN: 1MEBP95F1EZ623182

Vehicle Geometry
Inches

a —	76.0	b —	40.0
c —	114.0	d —	56.0
e —	55.0	f —	210.0
g —	20.0	h —	51.0
j —	20.0	m —	8.0
n —	5.0	o —	14.0
p —	63.0	q —	63.0
r —	26.5	s —	16.5
t —	33.5		



Engine Size: 5.0 liter

Transmission: Automatic

Weight (lbs)	Curb	Test Inertial	Gross Static
W1	2250	2661	2576
W2	1660	2007	1932
Wtotal	3910	4668	4508

Damage prior to test: None

1 in = 25.4 mm 1 lb = 0.454 kg

Figure 142. Test Vehicle Dimensions, Test SBT-4.

Figure 143. Test Vehicle, Test SBT-5.

Make: Ford

Test No.: SBT-5

Model: LTD

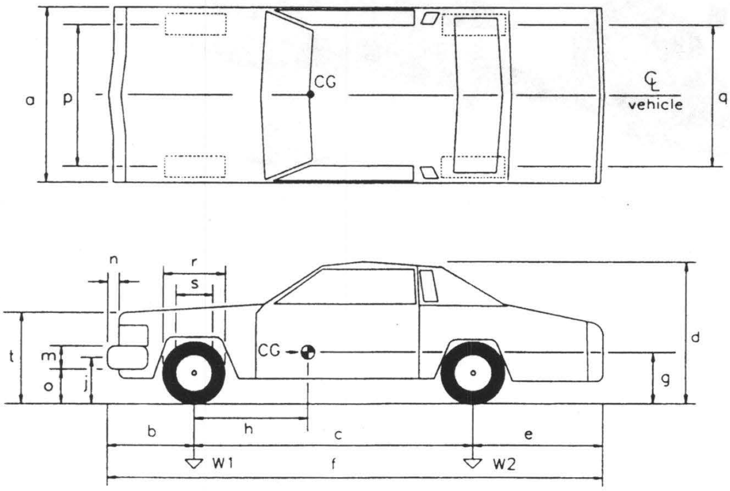
Tire Size: P235-75R15

Year: 1984

VIN: 1FABP43G3EZ2182161

Vehicle Geometry
Inches

a — 76.5
b — 41.0
c — 114.5
d — 57.5
e — 56.0
f — 211.0
g — 27.0
h — 49.8
j — 18.75
m — 22.5
n — 4.0
o — 15.0
p — 63.0
q — 63.0
r — 28.0
s — 16.0
t — 34.5



Engine Size: 351 V8

Transmission: Automatic

Weight (lbs)	Curb	Test Inertial	Gross Static
W1	2310	2627	2542
W2	1550	2033	1958
Wtotal	3860	4660	4500

Damage prior to test: None

1 in = 25.4 mm **1 lb = 0.454 kg**

Figure 144. Test Vehicle Dimensions, Test SBT-5.

Figure 145. Test Vehicle, Test GWMP-1.

Make: Dodge

Test No.: GWMP-1

Model: Colt

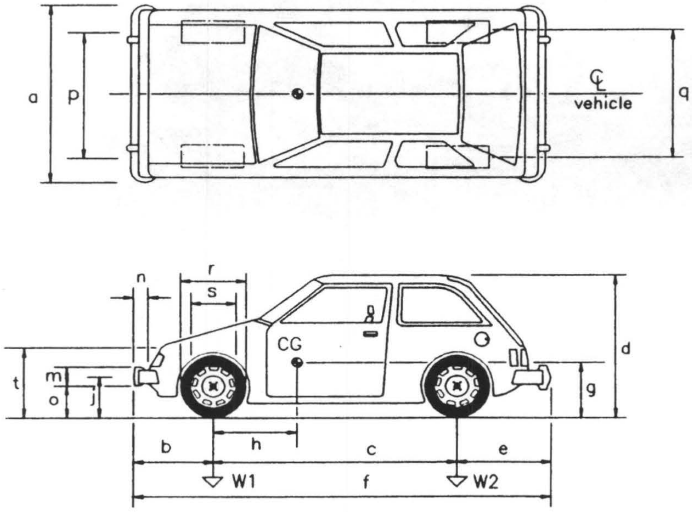
Tire Size: P155/80R13

Year: 1984

VIN: JB3BE24A9EU104612

Vehicle Geometry
Inches

a — 58.0	b — 32.5
c — 90.5	d — 53.0
e — 31.5	f — 154.5
g — 19.5	h — 30.5
j — 17.0	m — 4.5
n — 6.0	o — 15.0
p — 54.0	q — 53.5
r — 22.5	s — 14.25
t — 31.0	



Engine Size: 4 cyl.

Transmission: manual

Weight (lbs)	Curb	Test Inertial	Gross Static
W1	1175	1225	1305
W2	625	625	705
Wtotal	1800	1850	2010

Moment of Inertia $(\text{lb-sec}^2\text{-in})$ - Gross Static

Roll (Ix)	1299.0
Pitch (Iy)	5628.0
Yaw (Iz)	9119.0

1 in = 25.4 mm   1 lb = 0.454 kg

Damage prior to test: SEE PHOTOS

Figure 146. Test Vehicle Dimensions, Test GWMP-1.

Figure 147. Test Vehicle, Test GWMP-2.

Make: Dodge

Test No.: GWMP-2

Model: Colt

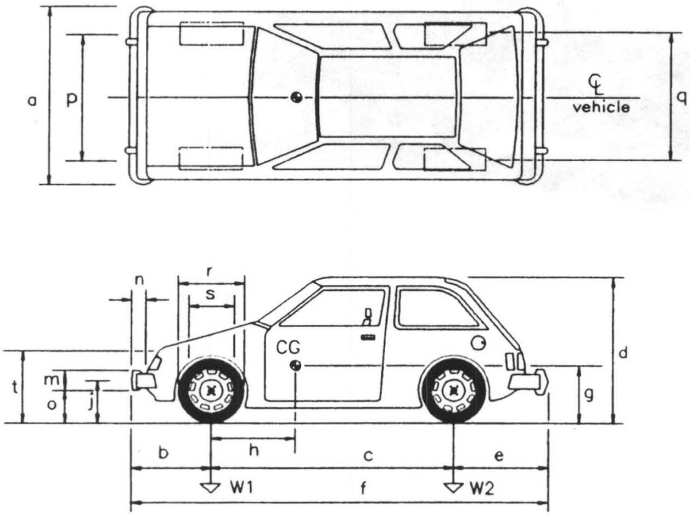
Tire Size: P155/80R13

Year: 1984

VIN: JB3BE24AXEU119411

Vehicle Geometry
Inches

a —	60.0	b —	29.9
c —	91.5	d —	52.5
e —	28.5	f —	149.5
g —	19.5	h —	38.0
j —	19.4	m —	5.0
n —	3.5	o —	16.9
p —	53.6	q —	53.0
r —	22.5	s —	14.5
t —	30.25		



Engine Size: 4 cyl.

Transmission: manual

Weight (lbs)	Curb	Test Inertial	Gross Static
W1	1175	1068	1162
W2	625	708	774
Wtotal	1800	1776	1936

Moment of Inertia (lb-sec^2-in) - Gross Static

Roll (Ix) NA

Pitch (Iy) NA

Yaw (Iz) NA

1 in = 25.4 mm **1 lb = 0.454 kg**

Damage prior to test: SEE PHOTOS

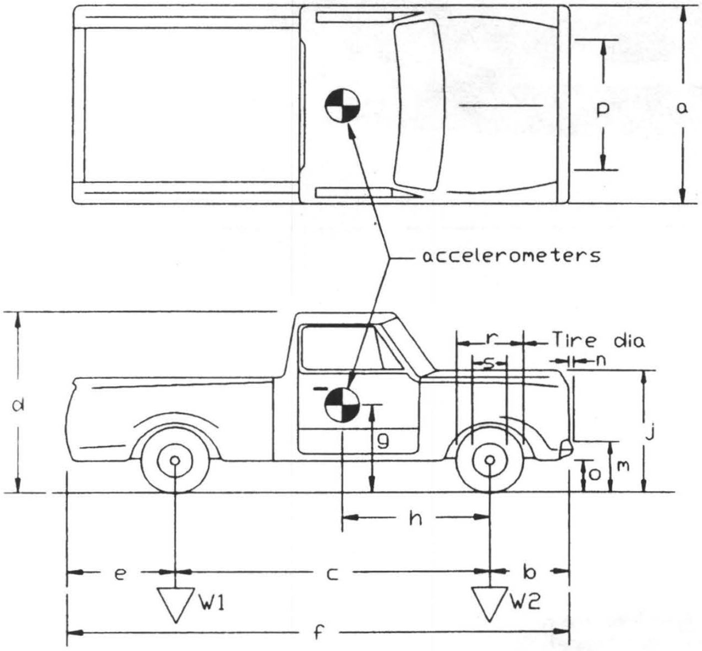
Figure 148. Test Vehicle Dimensions, Test GWMP-2.

Figure 149. Test Vehicle, Test GWMP-3.

Date: 3/24/94 Test No.: GWMP-3 Vehicle I.D. #: 1GBGC24M6FJ170210

Make: Chevrolet Model: C-20 3/4 ton Pickup

Tire Size: 235/85R16 Year: 1985 Odometer: Exceeds Mech. Limits



Vehicle Geometry - inches

a	77	b	32
c	131.5	d	71.5
e	52.0	f	215.5
g	—	h	67.5
i	—	j	44.5
k	—	l	—
m	25.5	n	4.0
o	16.5	p	65.75
r	30.5	s	17.5

Engine Type: 8 cyl.

Engine Size: 350 cu. in.

Transmission Type:

[✓ Automatic] or Manual

FWD or [✓ RWD] or 4WD

Weight - pounds	Curb	Test Inertial	Gross Static
W1	1950	2610	2528
W2	2490	2950	2872
Wtotal	4440	5560	5400

Note any damage prior to test: none

1 in = 25.4 mm 1 lb = 0.454 kg

Figure 150. Test Vehicle Dimensions, Test GWMP-3.

Figure 151. Test Vehicle, Test FPAR-1.

Make: Dodge Test No.: FPAR-1

Model: Colt Tire Size: P155/80R13

Year: 1984

Vehicle Geometry
Inches

a — 60.0 b — 34.5

c — 90.0 d — 52.0

e — 32.0 f — 156.5

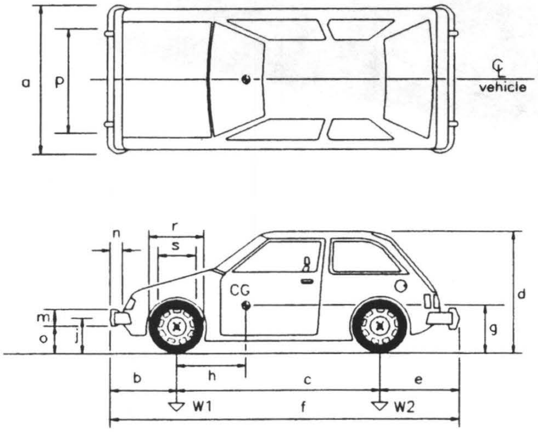
g — 21.0 h — 34.9

j — 17.5 m — 4.5

n — 6.5 o — 15.25

p — 51.5 r — 22.5

s — 15



Engine Size: 4 cyl.

Transmission: manual

Weight (lbs)	Curb	Test Inertial	Gross Static
W1	735	1166	1265
W2	1095	738	804
Wtotal	1850	1904	2069

Damage prior to test: NONE

Conversion Factors: 1in.=2.54cm. 1lb.=0.454kg.

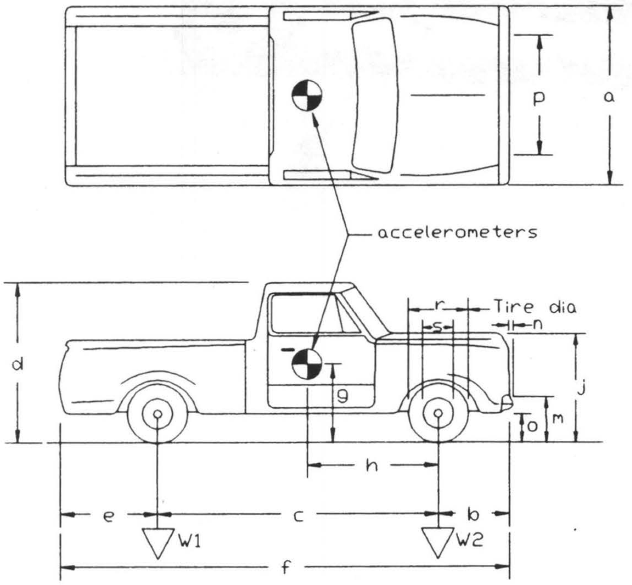
Figure 152. Test Vehicle Dimensions, Test FPAR-1.

Figure 153. Test Vehicle, Test FPAR-2.

Date: 3/13/92   Test No.: FPAR-2   Vehicle I.D. #: 1GCGC24MXE11/1709

Make: Chevrolet   Model: 3/4 ton Custom Deluxe C-20

Tire Size: LT235/85R16   Year: 1984   Odometer: 106270



Vehicle Geometry - inches

a 79   b 33

c 132   d 71.5

e 53.5   f 218.5

g 26   h 69

i ——   j 44.5

k ——   l ——

m 26   n 4

o 17   p 66

r 31.5   s 17.5

Engine Type: 8cyl.

Engine Size: 350cu./in.

4 - wheel weight: lf____ rf____ lr____ rr____

Transmission Type:

Automatic or [✓ Manual]

FWD or [✓ RWD] or 4WD

Weight - pounds	Curb	Test Inertial	Gross Static
W1	1990	2770	2843
W2	2530	2530	2622
Wtotal	4520	5300	5465

Note any damage prior to test: none

Conversion Factors: 1in.=2.54cm.   1lb.=0.454kg.

Figure 154. Test Vehicle Dimensions, Test FPAR-2.

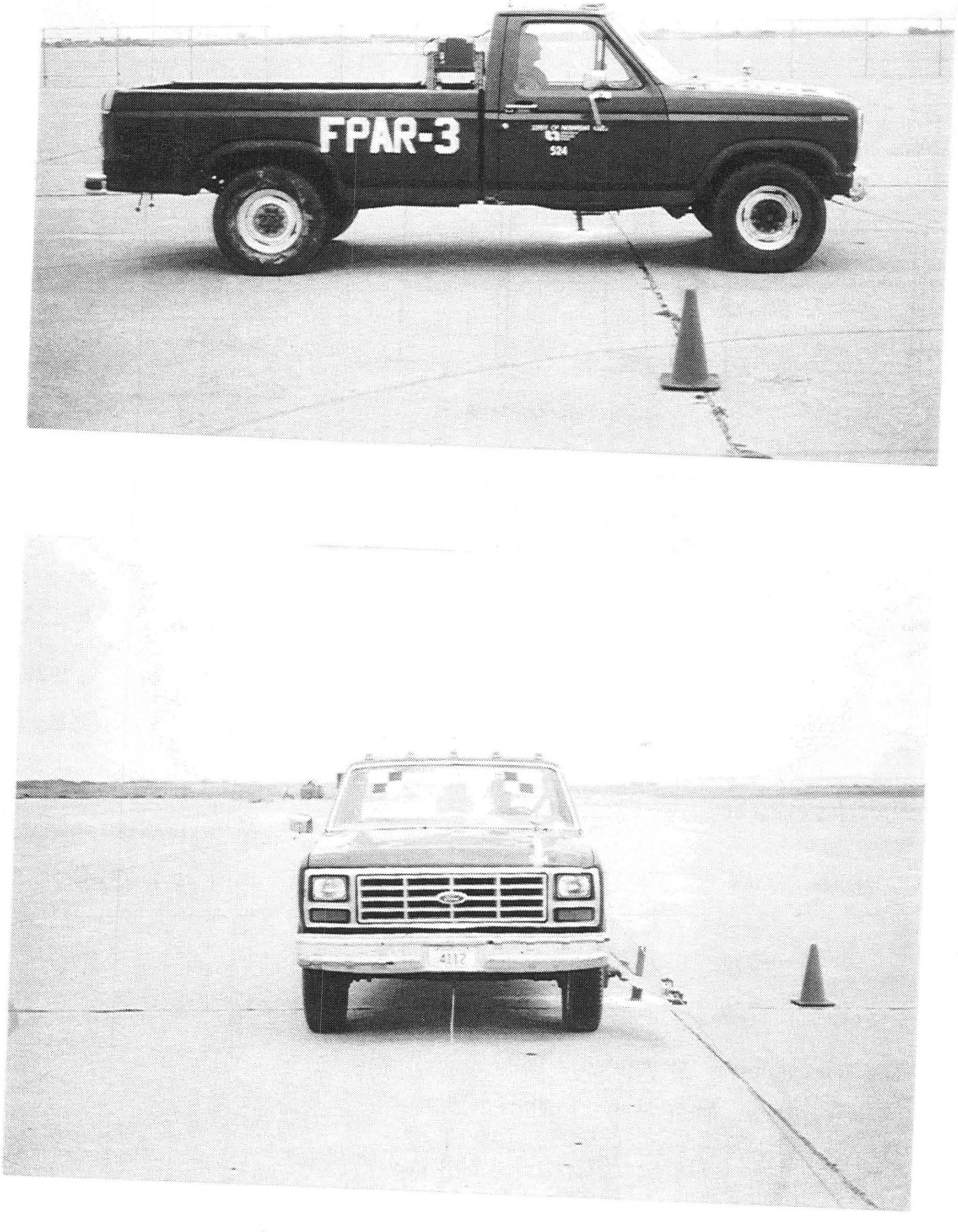
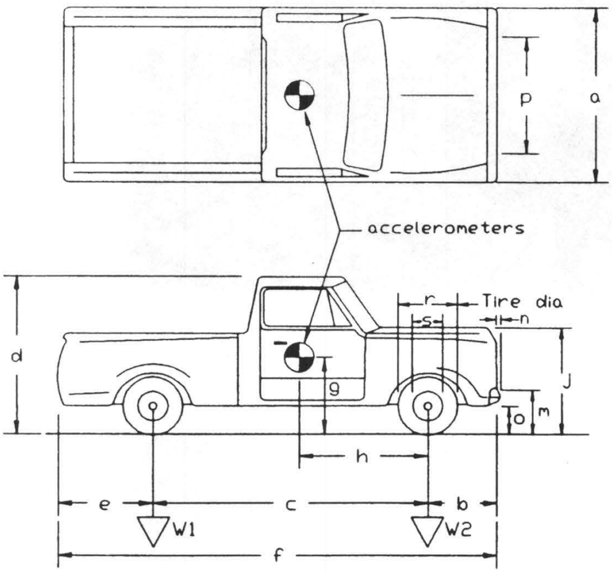


Figure 155. Test Vehicle, Test FPAR-3.

Date: 6/7/93   Test No.: FPAR 3   Vehicle I.D. #: 1FTHF25Y6FPA62188

Make: FORD   Model: F-250

Tire Size: P235/85R16   Year: 1985   Odometer: 110,257



Vehicle Geometry - inches

a 75   b 29

c 133   d 72.5

e 50.75   f 212.75

g 26   h 69

i ——   j 49.5

k ——   l ——

m 27.5   n 3.0

o 19.25   p F 65.75/ R 64.5

r 31   s 17.5

Engine Type: 6cyl.

Engine Size: 300cu./in.

Transmission Type:

Automatic or [✓ Manual]

FWD or [✓ RWD] or 4WD

Weight - pounds	Curb	Test Inertial	Gross Static
W1	1760	2912	2997
W2	2300	2488	2568
Wtotal	4060	5400	5565

Note any damage prior to test: Minor body damage on passenger side--see photographs

Conversion Factors: 1in.=2.54cm.   1lb.=0.454kg.

Figure 156. Test Vehicle Dimensions, Test FPAR-3.

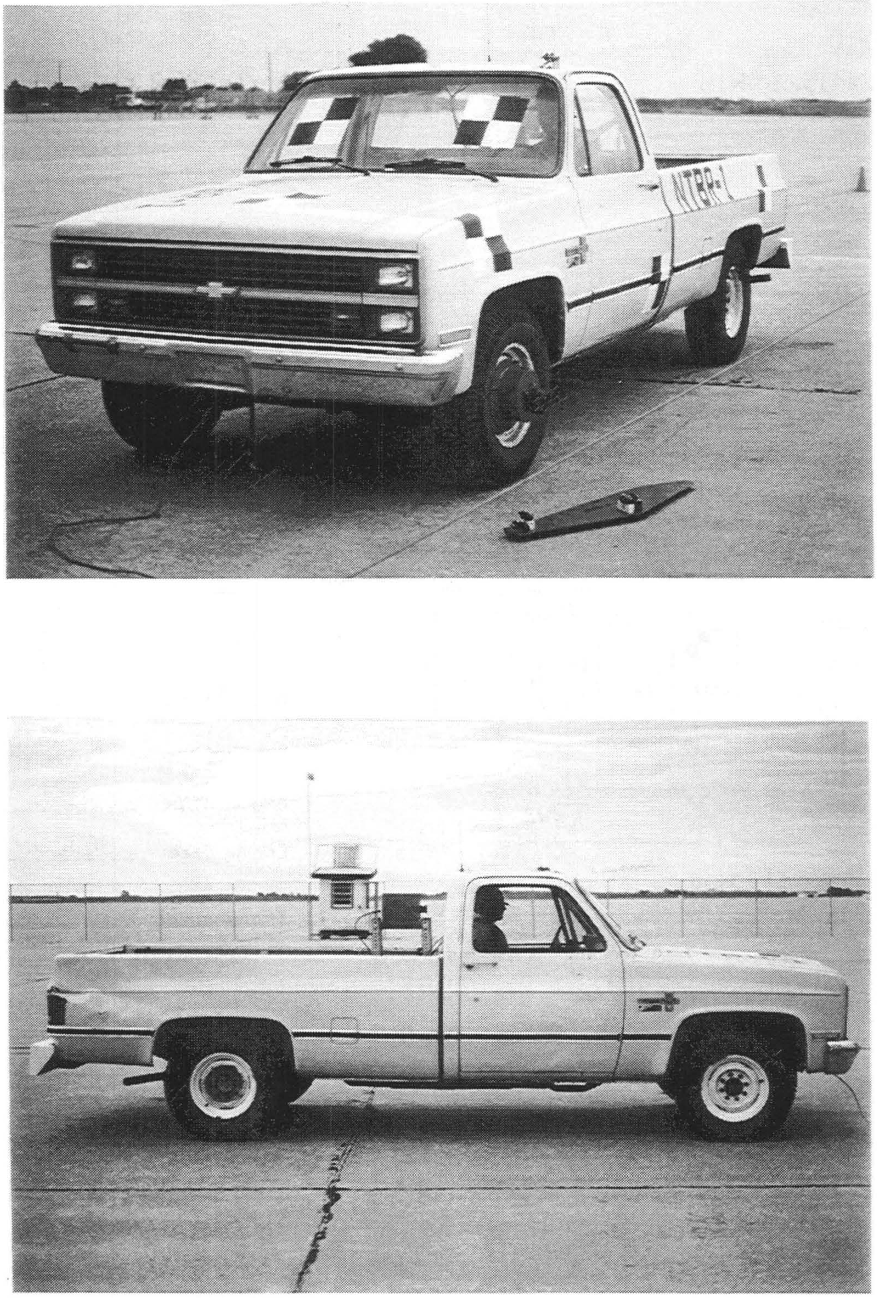
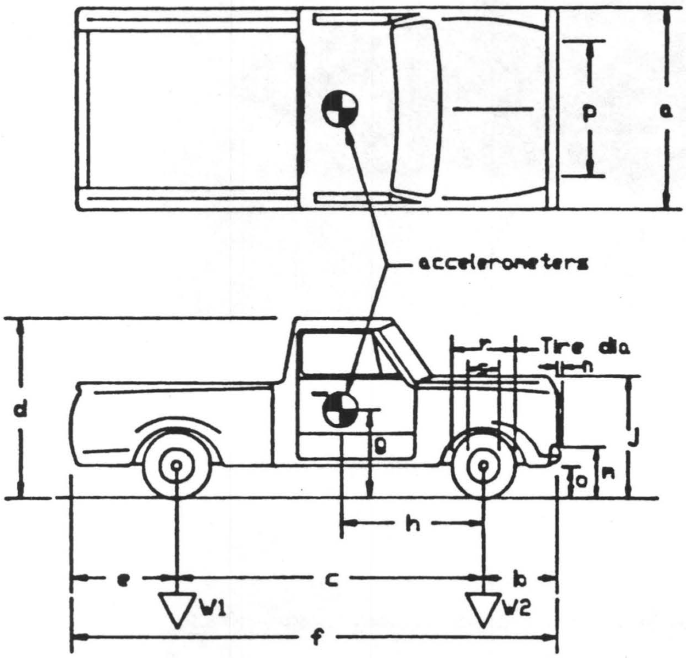


Figure 157. Test Vehicle, Test NTBR-1.

Date: 7/9/92 **Test No.:** NTBR-1 **Vehicle I.D. #:** GCGC24M6EJ132168

Make: Chevrolet **Model:** Custom Deluxe 20 **Year:** 1984 **Odometer:** 125,903

Tire Size: LT/235/85R16



Vehicle Geometry - inches

a 77.5
b 32
c 132
d 71
e 51
f 215
g 27
h 67
i ------
j 47.5
k ------
l -------
m 26.5
n 3.5
o 17
p 66.5
r 30
s 17.5

Engine Type: V8

Engine Size: 350 cu. in.

Transmission Type:

[✓ Automatic] or Manual

FWD or [✓ RWD] or 4WD

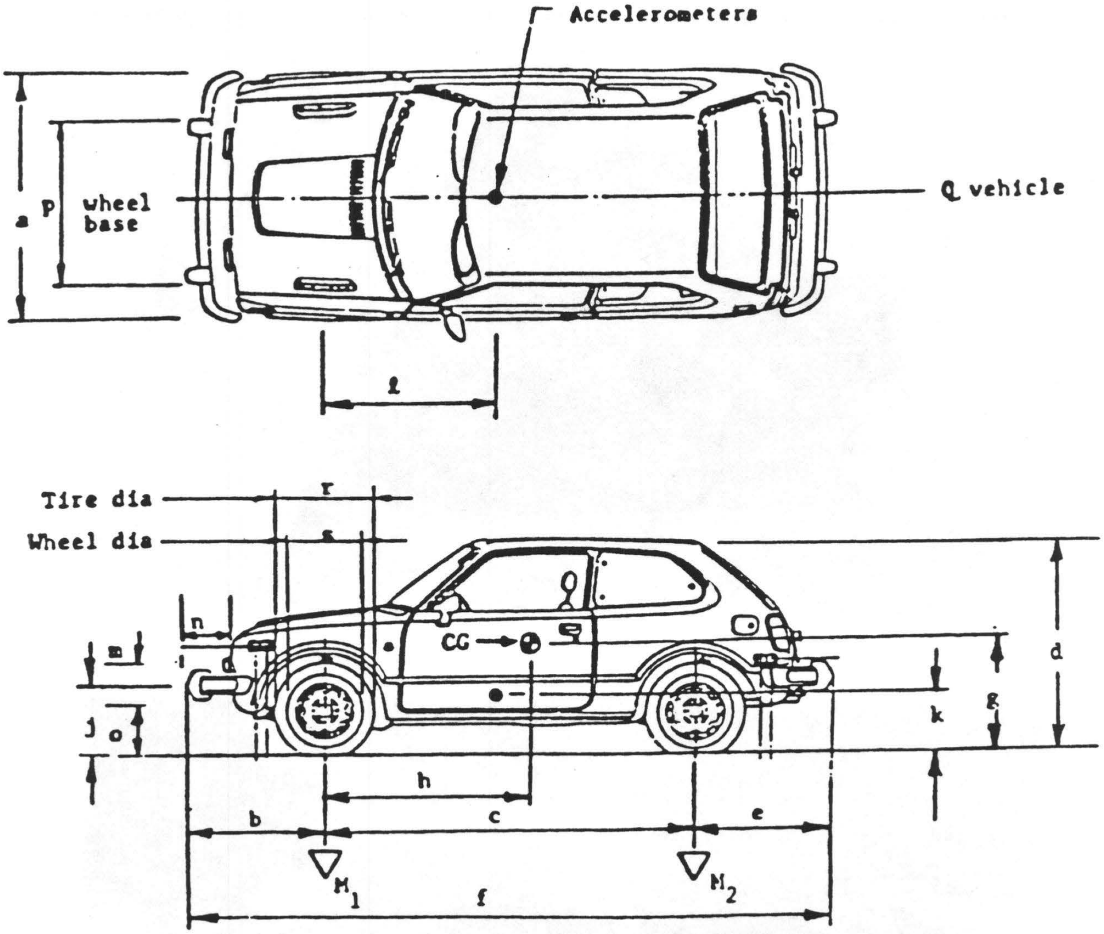
Weight - pounds	Curb	Test Inertial	Gross Static
W1	2030	2771	2836
W2	2580	2629	2729
Wtotal	4610	5400	5565

Note any damage prior to test: None

1 in = 25.4 mm 1 lb = 0.454 kg

Figure 158. Test Vehicle Dimensions, Test NTBR-1.

Figure 159. Test Vehicle, Test NTBR-2.



Geometry - in.

a	58.5	d	56	j	20.75	m	6.5	p	53.5
b	30	e	32	k	17	n	4.5	r	22
c	97	f	159	l	36	o	17	s	14

Mass - lb	Curb	Test Inertial	Gross Static
M_1	1310	1150	1245
M_2	760	700	770
M_T	2070	1850	2015
h - in.	35.5	36	36
g - in.	17	19	19

Vehicle Type: 1984 Renault Encore

1 in = 25.4 mm 1 lb = 0.454 kg

Figure 160. Test Vehicle Dimensions, Test NTBR-2.

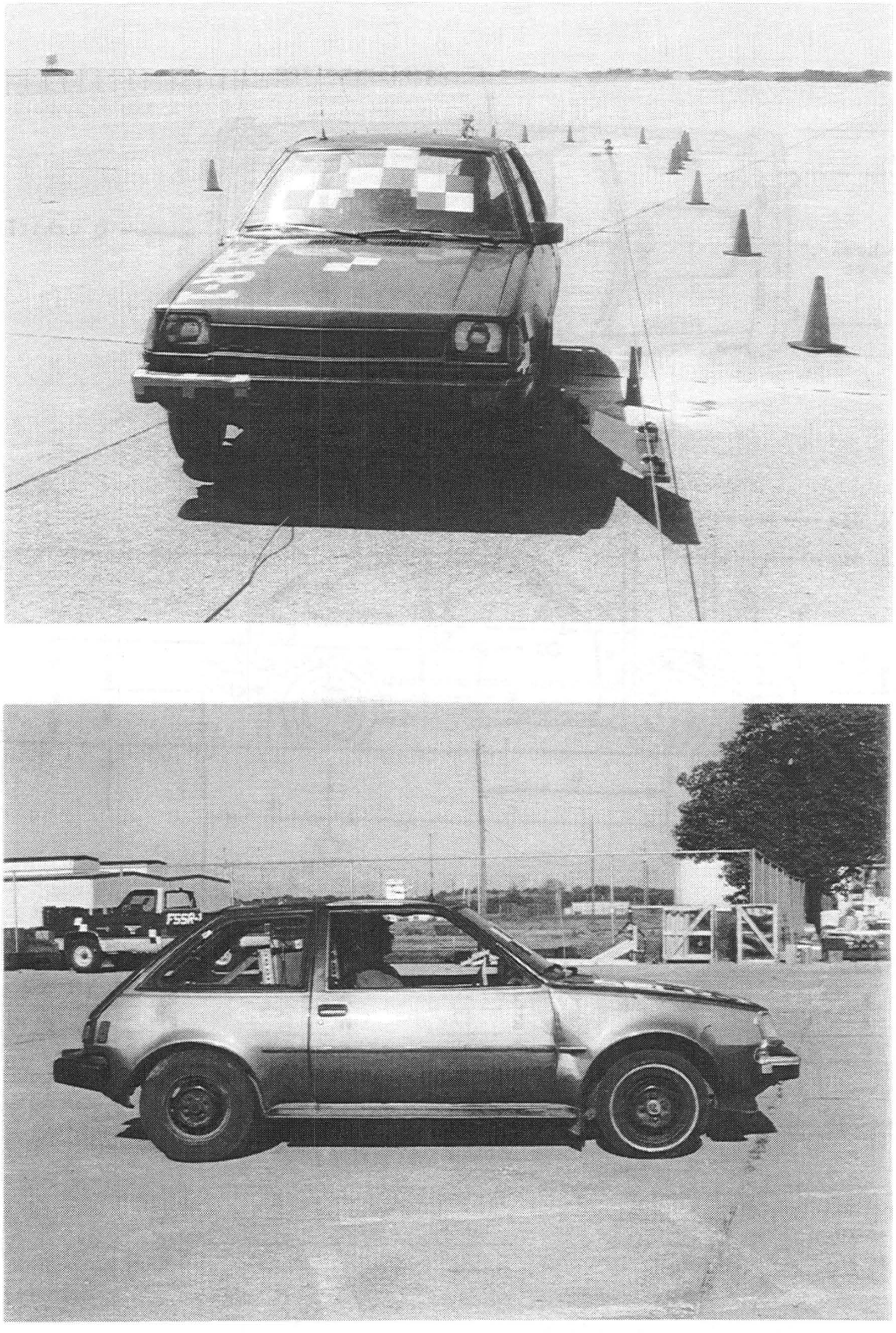
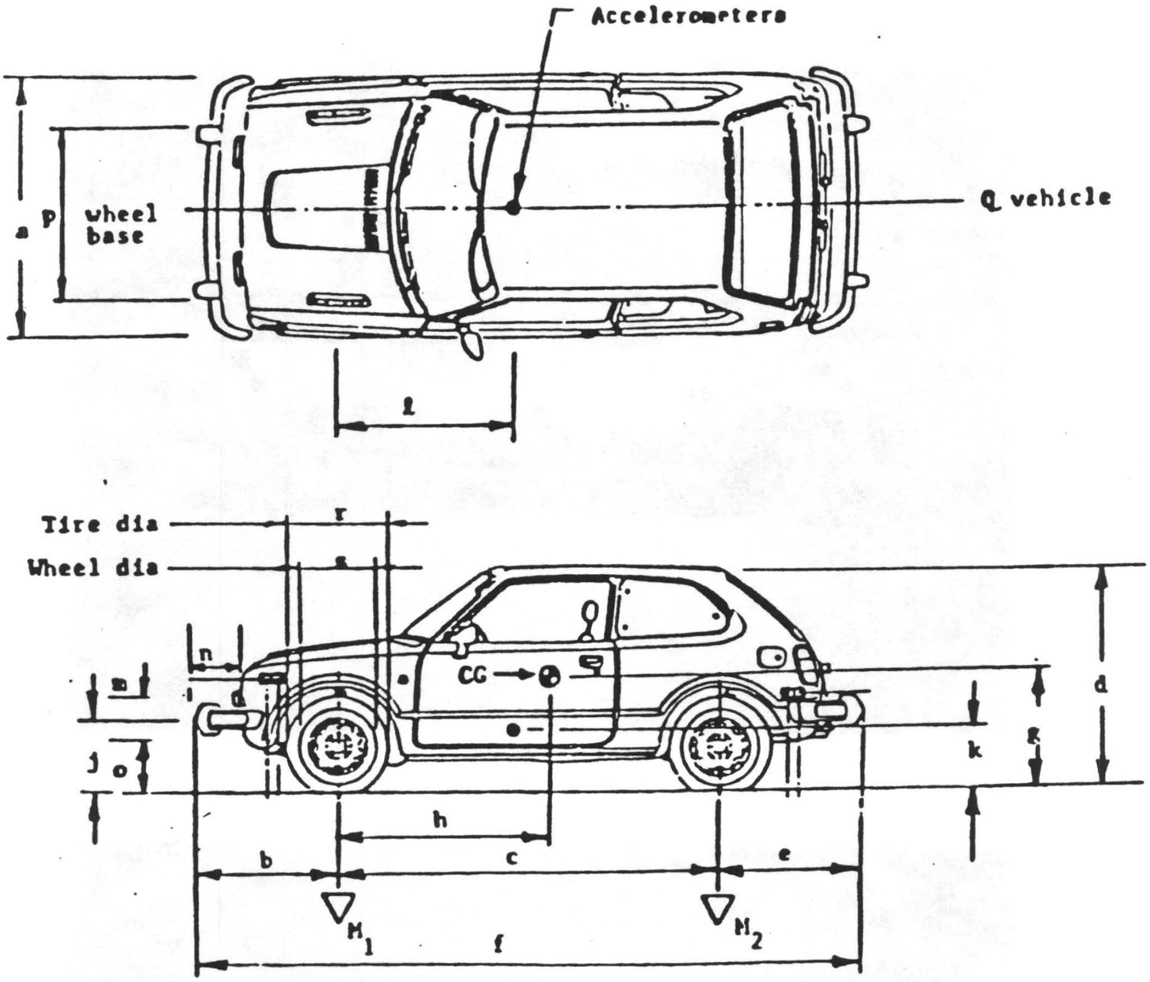


Figure 161. Test Vehicle, Test SBLR-1.



Geometry - in.

a	62.0	d	52.0	j	18.0	m	5.0	p	54.0
b	33.5	e	32.0	k	17.0	n	6.25	r	22.5
c	90.0	f	155.5	ℓ	46.5	o	15.5	s	14.0

Mass - lb	Curb	Test Inertial*	Gross Static**
M_1	1107	1205	1290
M_2	552	645	725
M_T	1659	1850	2015
h - in. (m)	31.75	31.75	31.75
g - in. (m)	21.0	21.0	21.0

Vehicle Type
1984 Dodge Colt

1 in = 25.4 mm

1 lb = 0.454 kg

* Ready for test but excludes passenger/cargo payload
** Gross ready for test including passenger/cargo payload

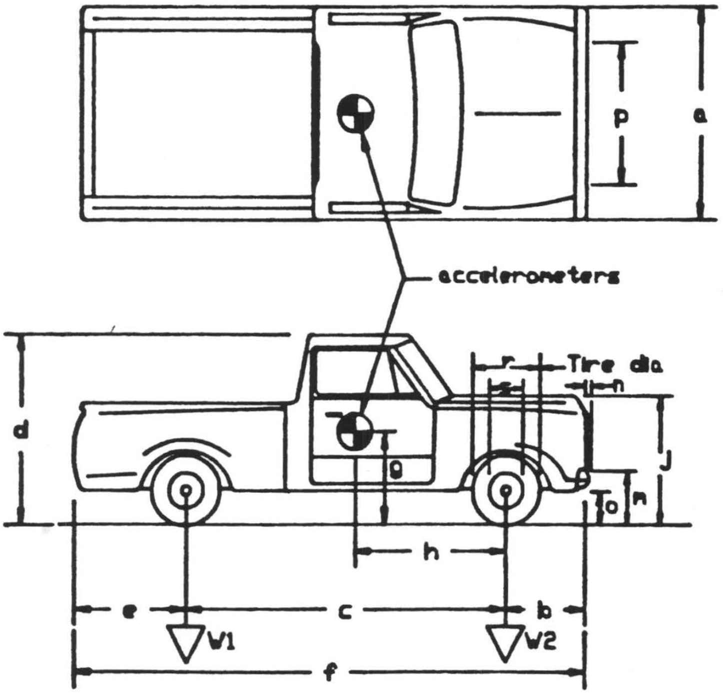
Figure 162. Test Vehicle Dimensions, Test SBLR-1.

Figure 163. Test Vehicle, Test SBLR-2.

Date: 7/29/92 **Test No.:** SBLR-2 **Vehicle I.D. #:** 1GC6C24M31116120

Make: Chevrolet **Model:** Custom Deluxe 20 **Year:** 1986 **Odometer:** ____

Tire Size: 7.5 16LT



Vehicle Geometry - inches

a	78	b	31.5
c	132	d	72
e	52	f	215.5
g	27	h	67
i	--	j	45
k	--	l	--
m	27	n	3
o	18.5	p	66
r	30.5	s	17

Engine Type: V8

Engine Size: 350 cu. in.

4 - wheel weight: lf____ rf____ lr____ rr____

Transmission Type:

Automatic or Manual

FWD or [✓ RWD] or 4WD

Weight - pounds	Curb	Test Inertial	Gross Static
W1	2600	2760	2840
W2	2000	2640	2725
Wtotal	4600	5400	5565

Note any damage prior to test: None

1 in = 25.4 mm 1 lb = 0.454 kg

Figure 164. Test Vehicle Dimensions, Test SBLR-2.

12. APPENDIX C - ACCELEROMETER DATA

This section contains the accelerometer data from all of the tests conducted under this program. It should be noted that technical problems were encountered during tests no. SBT-3, GWMP-1, FPAR-1, FPAR-3 and NTBR-1 which resulted in the loss of accelerometer data. The high-speed film was analyzed for these tests to obtain change in velocity and acceleration data, but there are no accelerometer traces to report in this appendix.

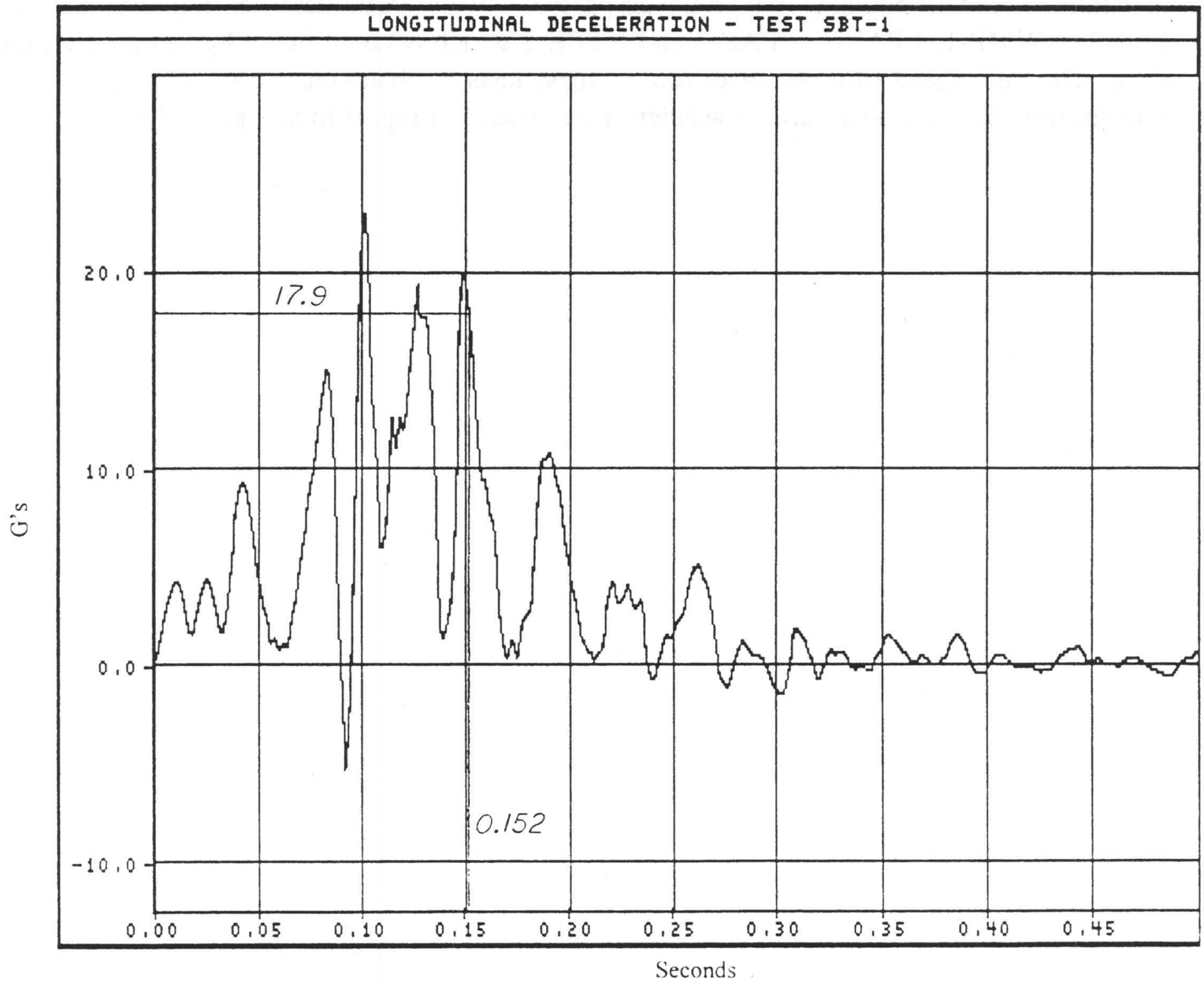


Figure 165. Graph of Longitudinal Deceleration, Test SBT-1.

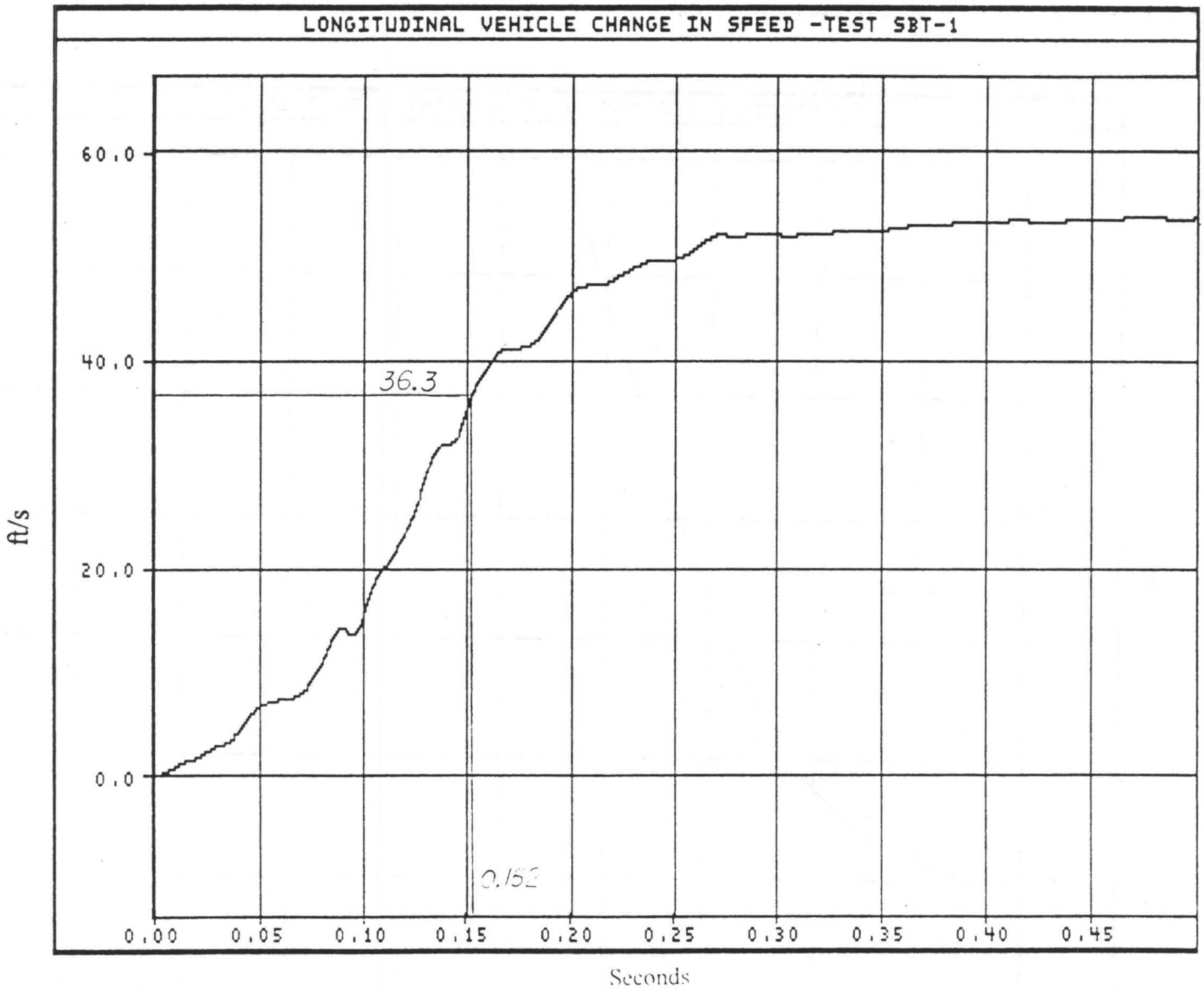


Figure 166. Graph of Longitudinal Change in Velocity, Test SBT-1.

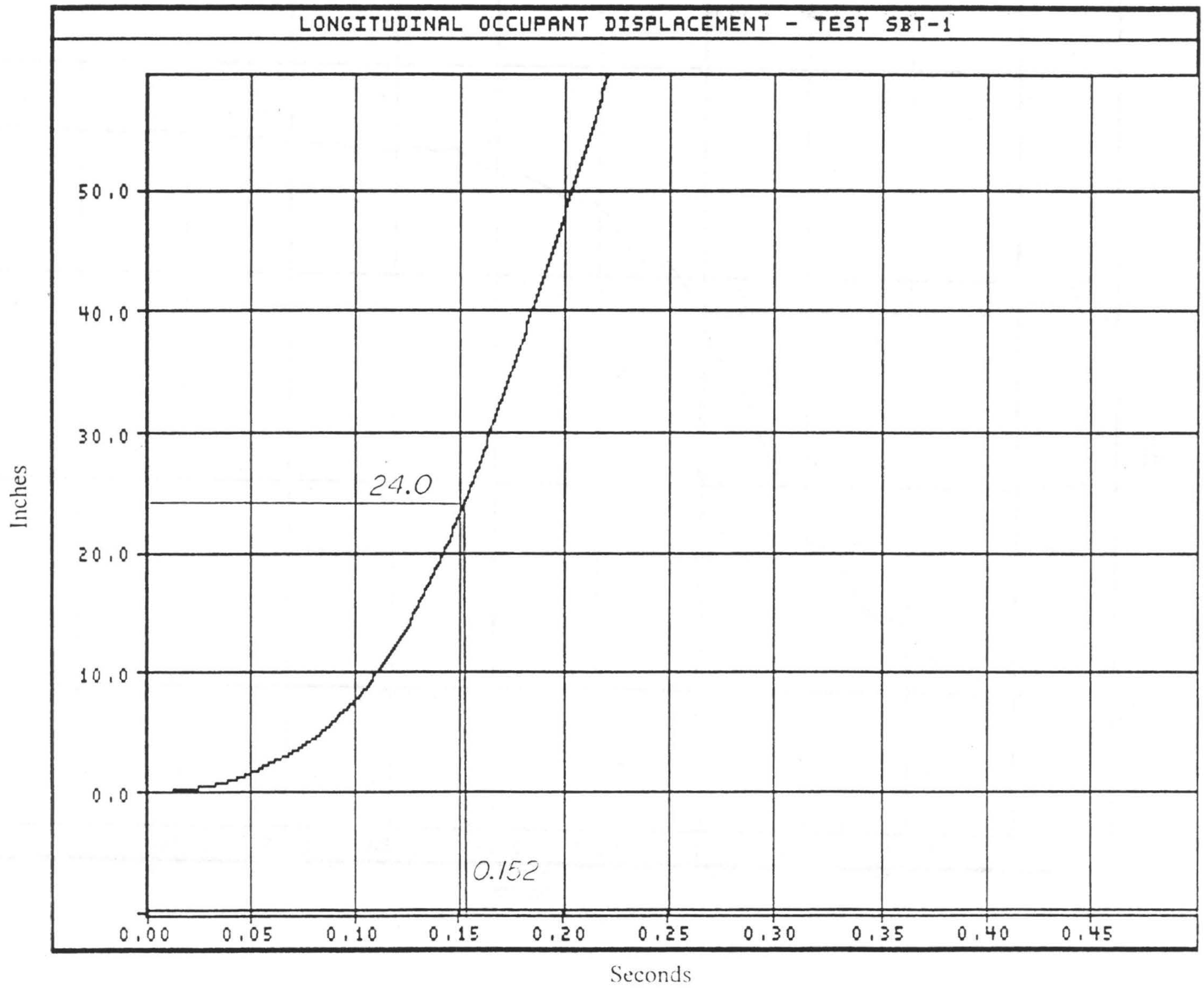


Figure 167. Graph of Longitudinal Occupant Displacement, Test SBT-1.

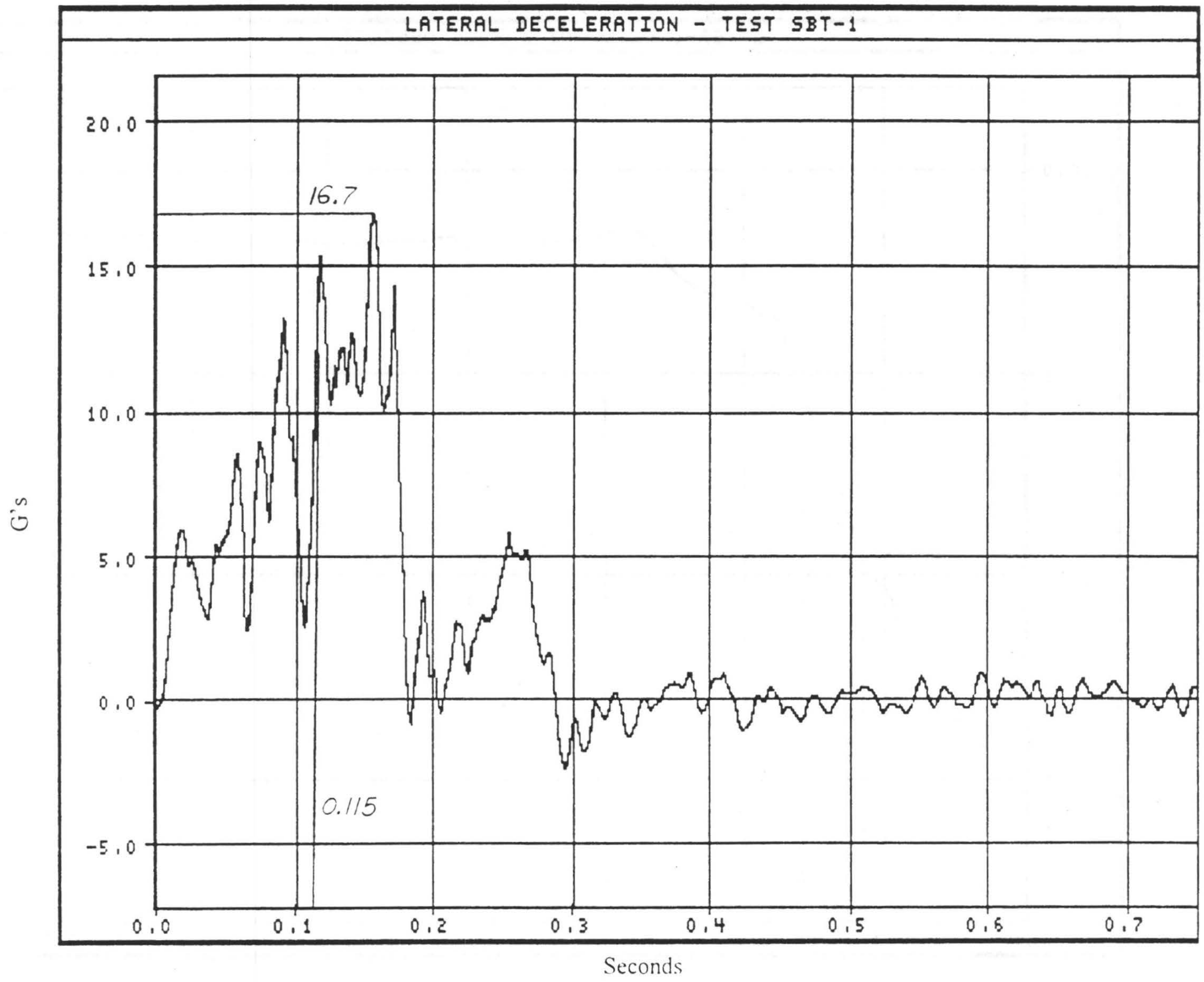


Figure 168. Graph of Lateral Deceleration, Test SBT-1.

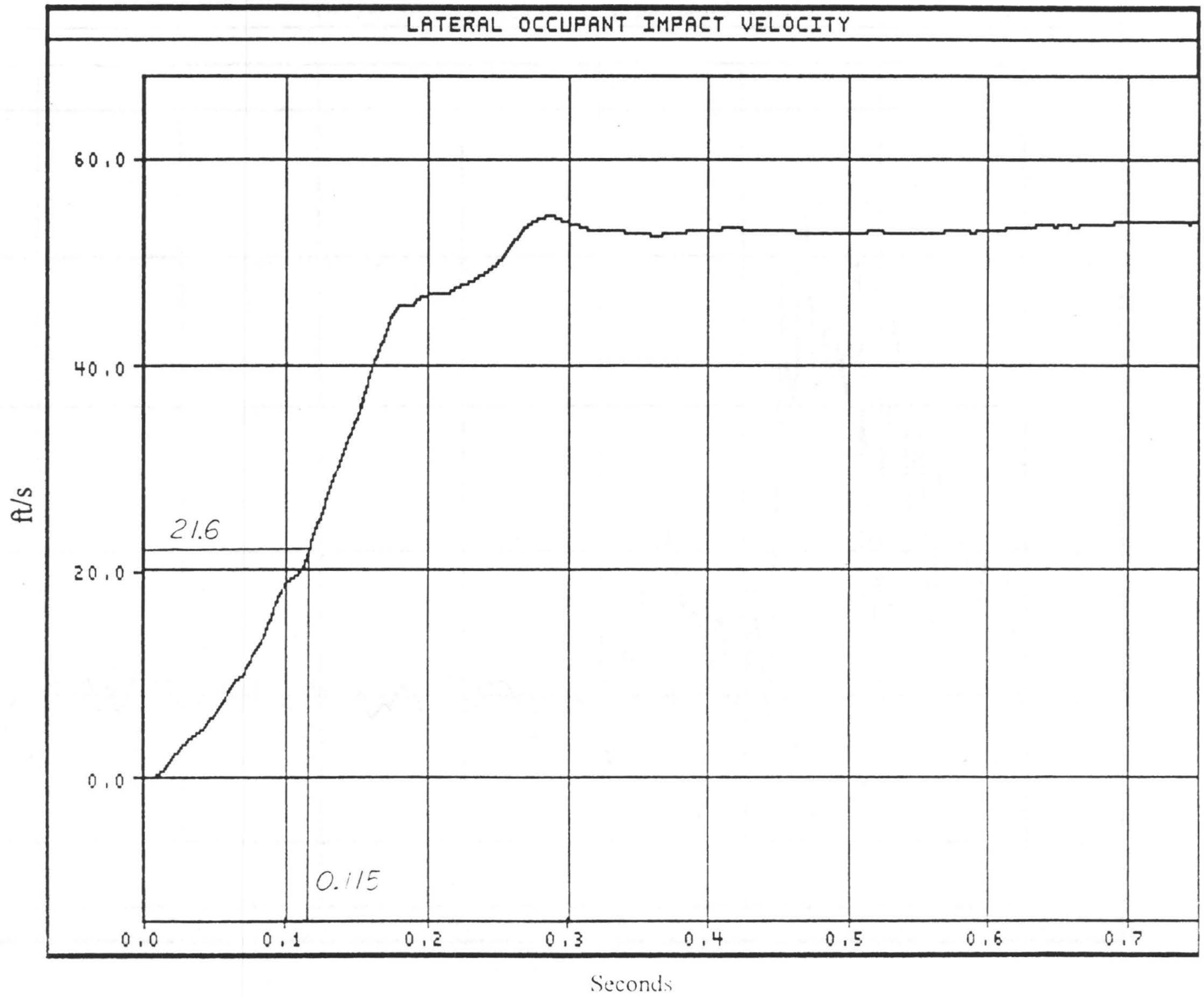


Figure 169. Graph of Lateral Change in Velocity, Test SBT-1.

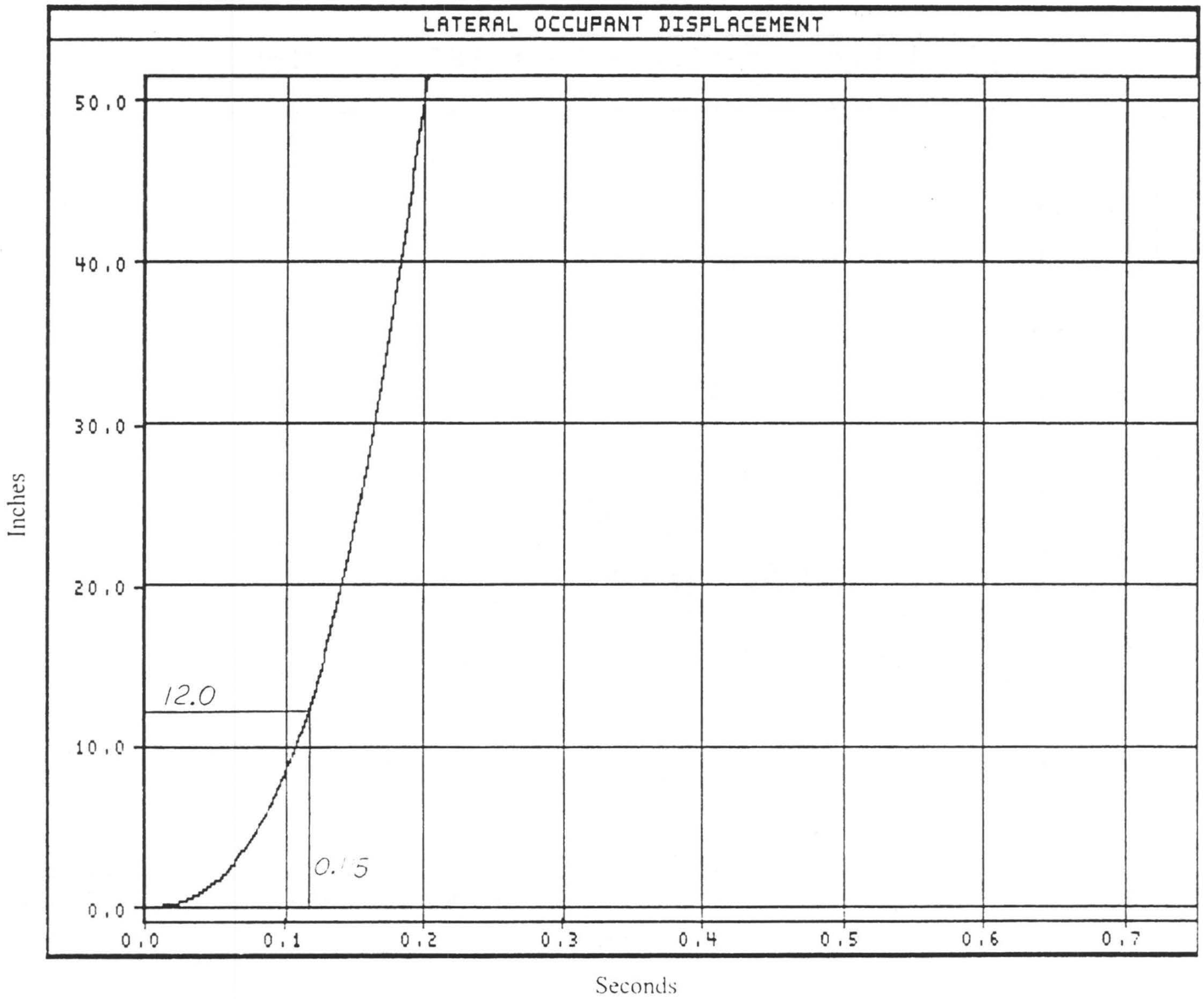


Figure 170. Graph of Lateral Occupant Displacement, Test SBT-1.

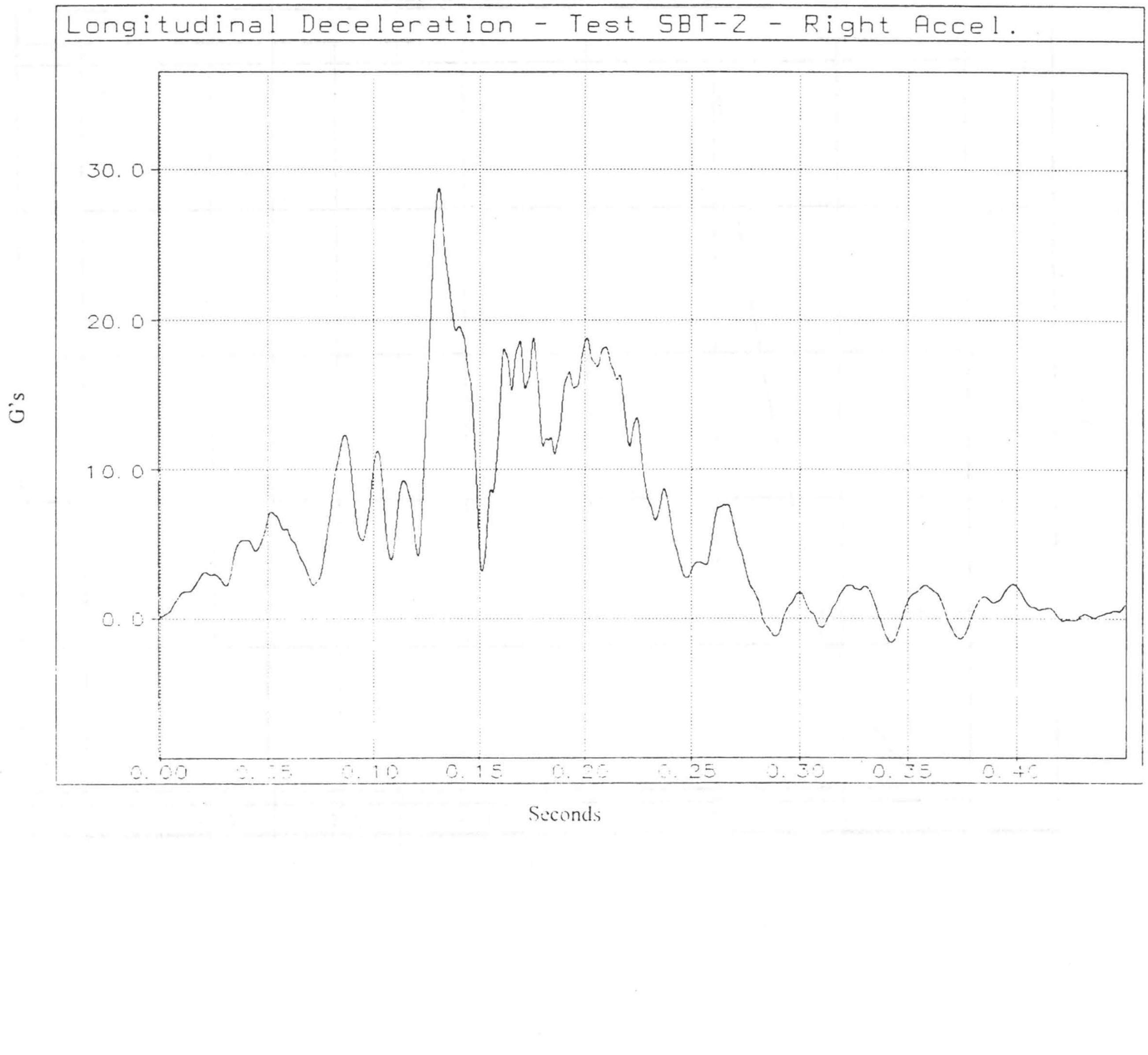


Figure 171. Graph of Longitudinal Deceleration, Test SBT-2.

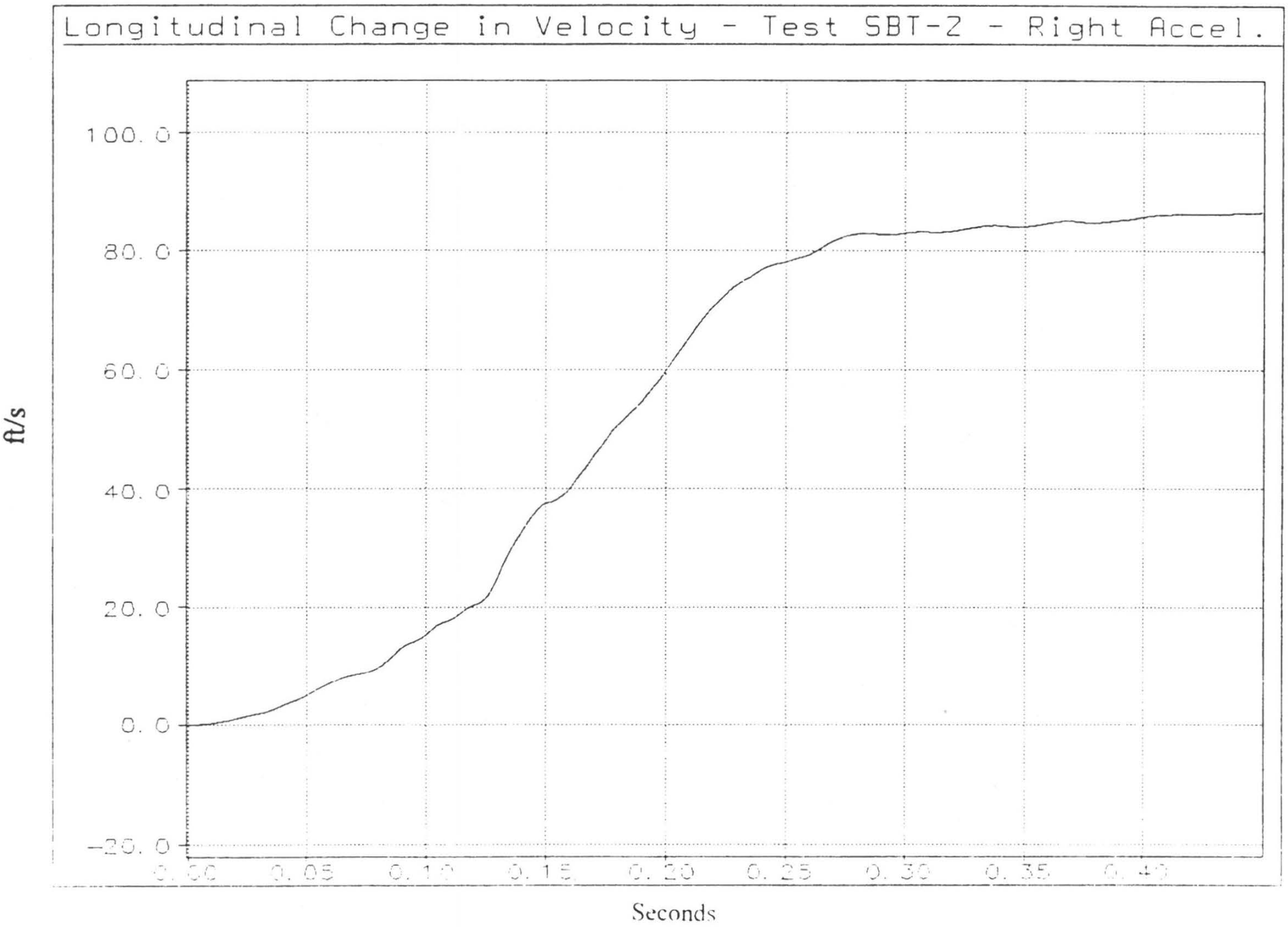


Figure 172. Graph of Longitudinal Change in Velocity, Test SBT-2.

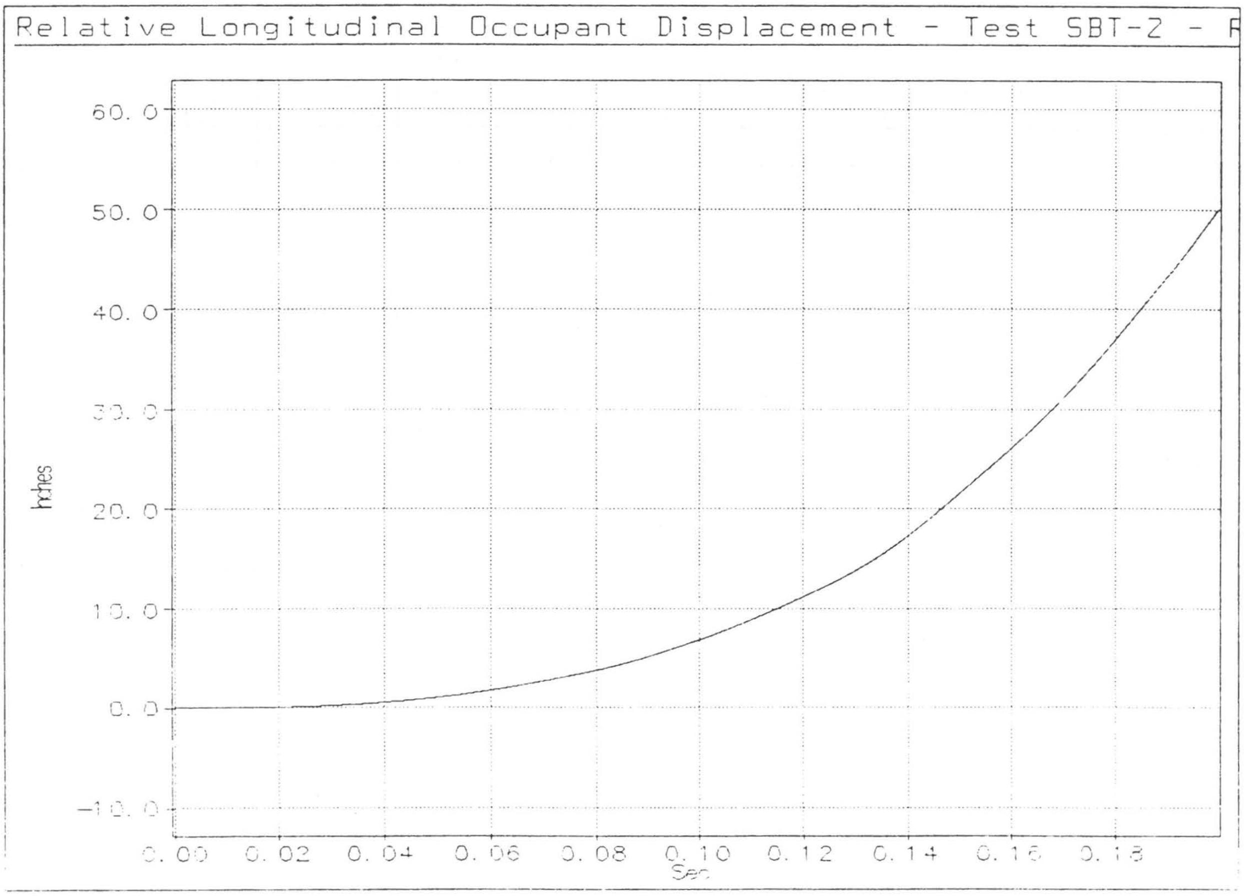


Figure 173. Graph of Longitudinal Occupant Displacement, Test SBT-2.

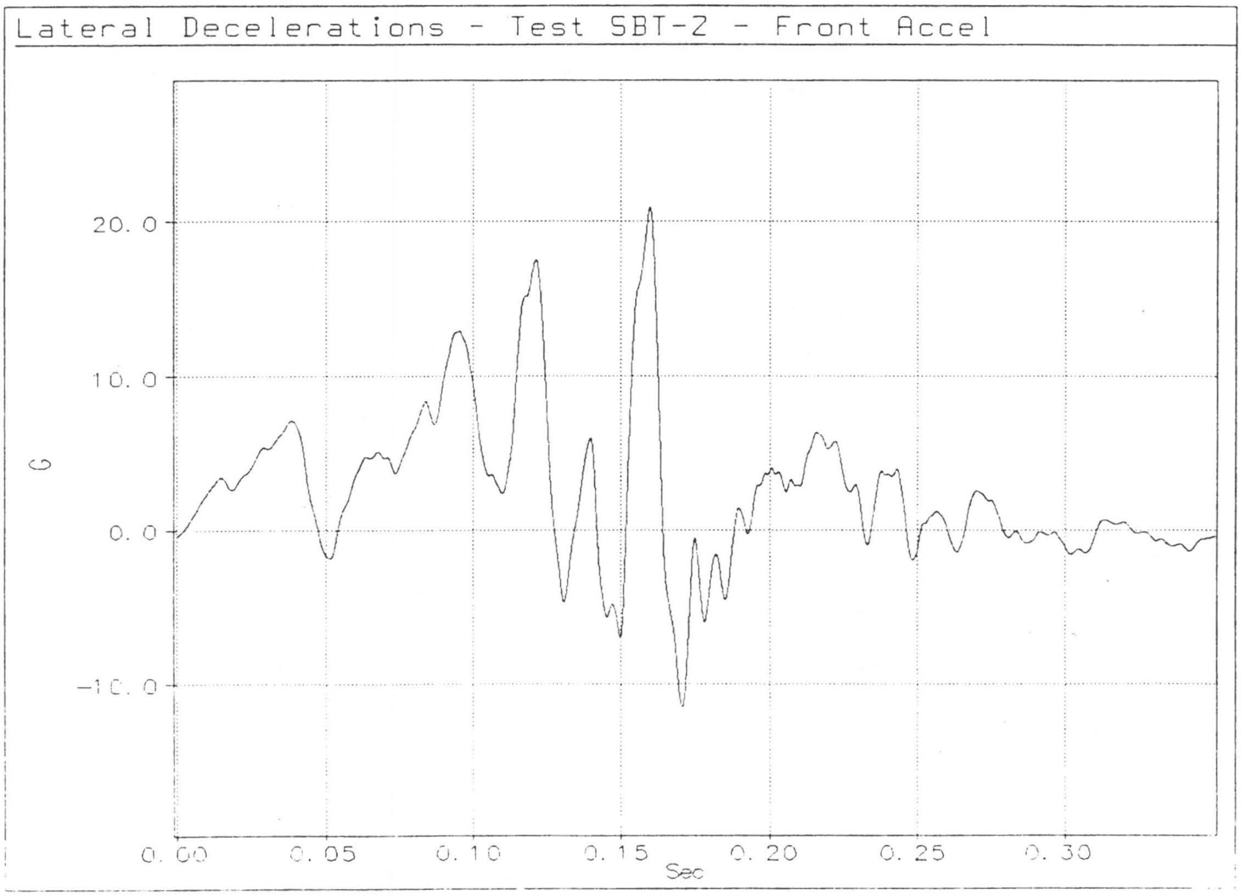


Figure 174. Graph of Lateral Deceleration, Test SBT-2.

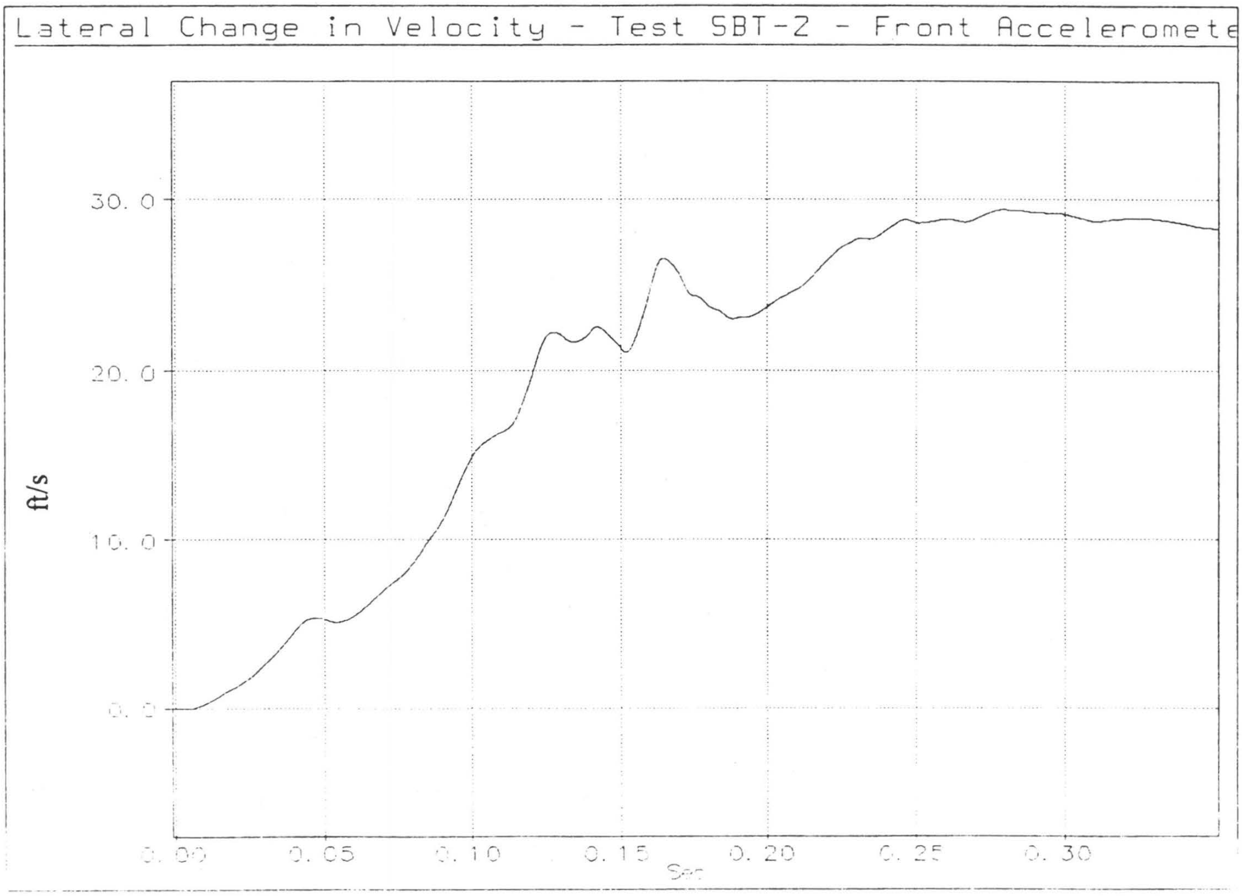


Figure 175. Graph of Lateral Change in Velocity, Test SBT-2.

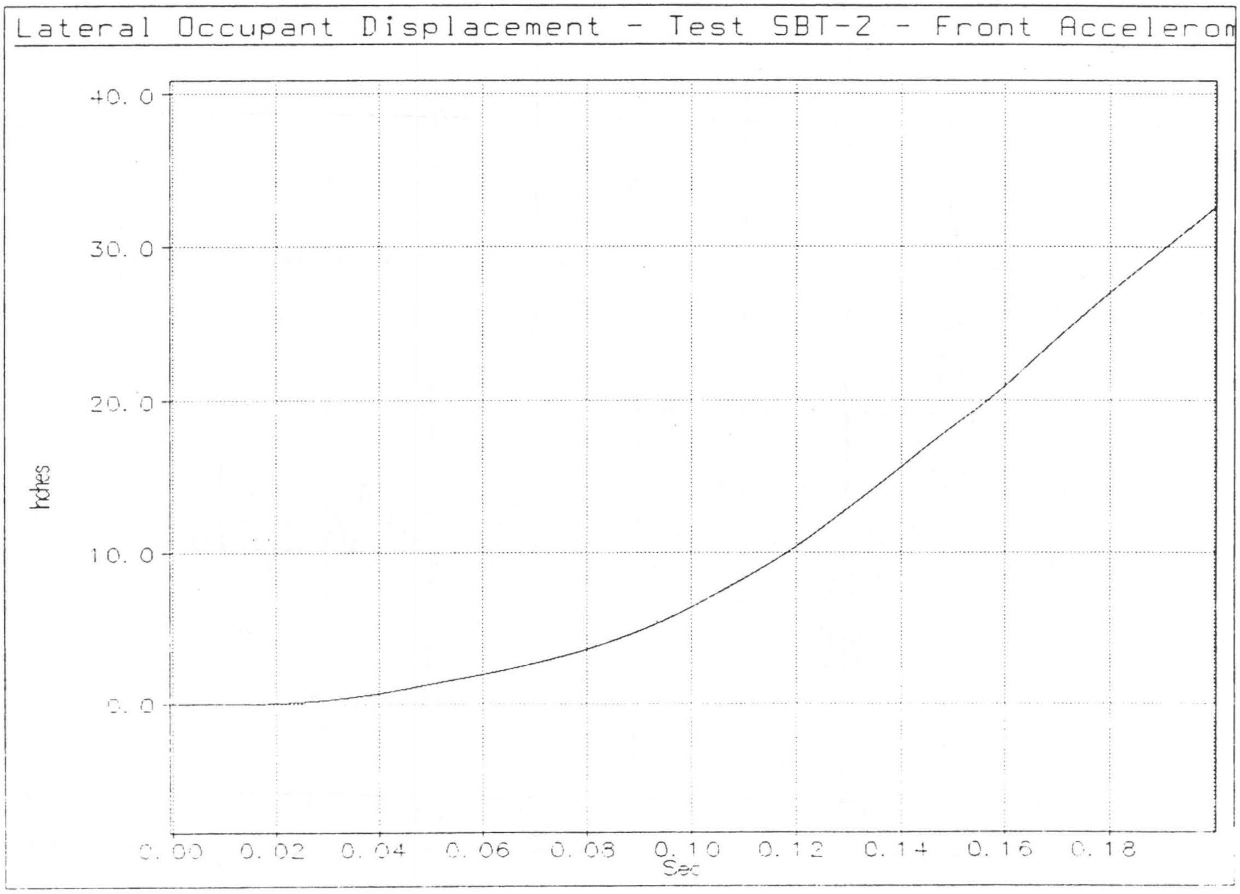


Figure 176. Graph of Lateral Occupant Displacement, Test SBT-2.

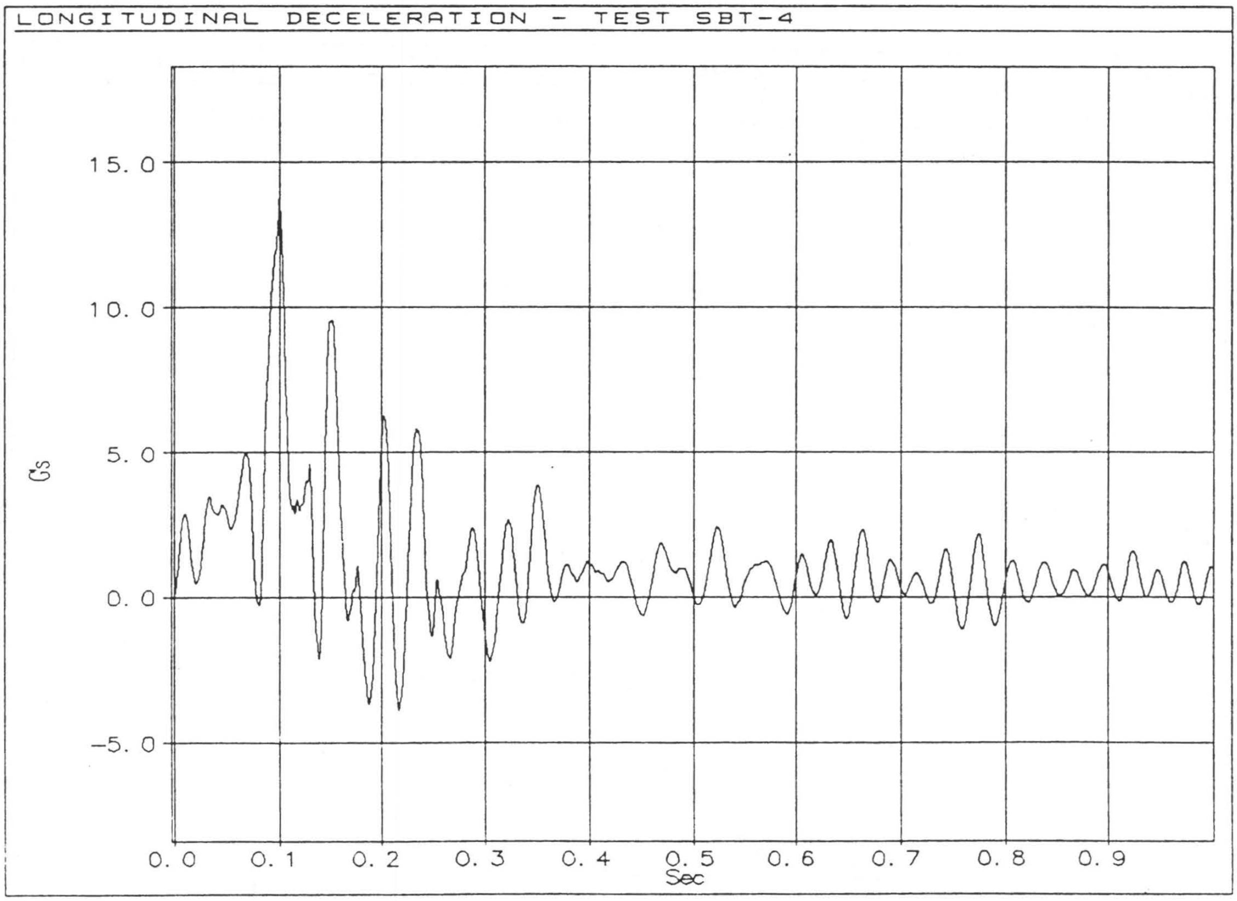


Figure 177. Graph of Longitudinal Deceleration, Test SBT-4.

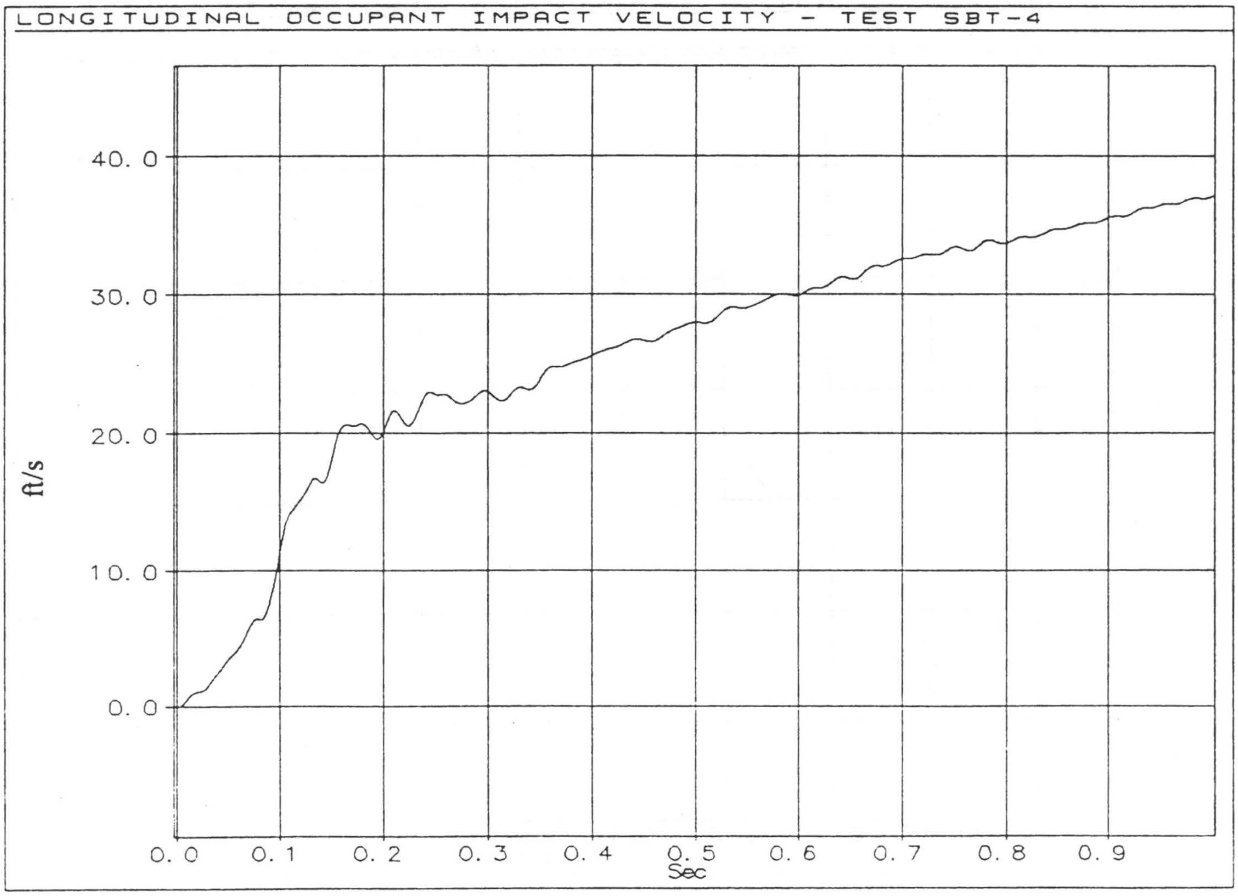


Figure 178. Graph of Longitudinal Change in Velocity, Test SBT-4.

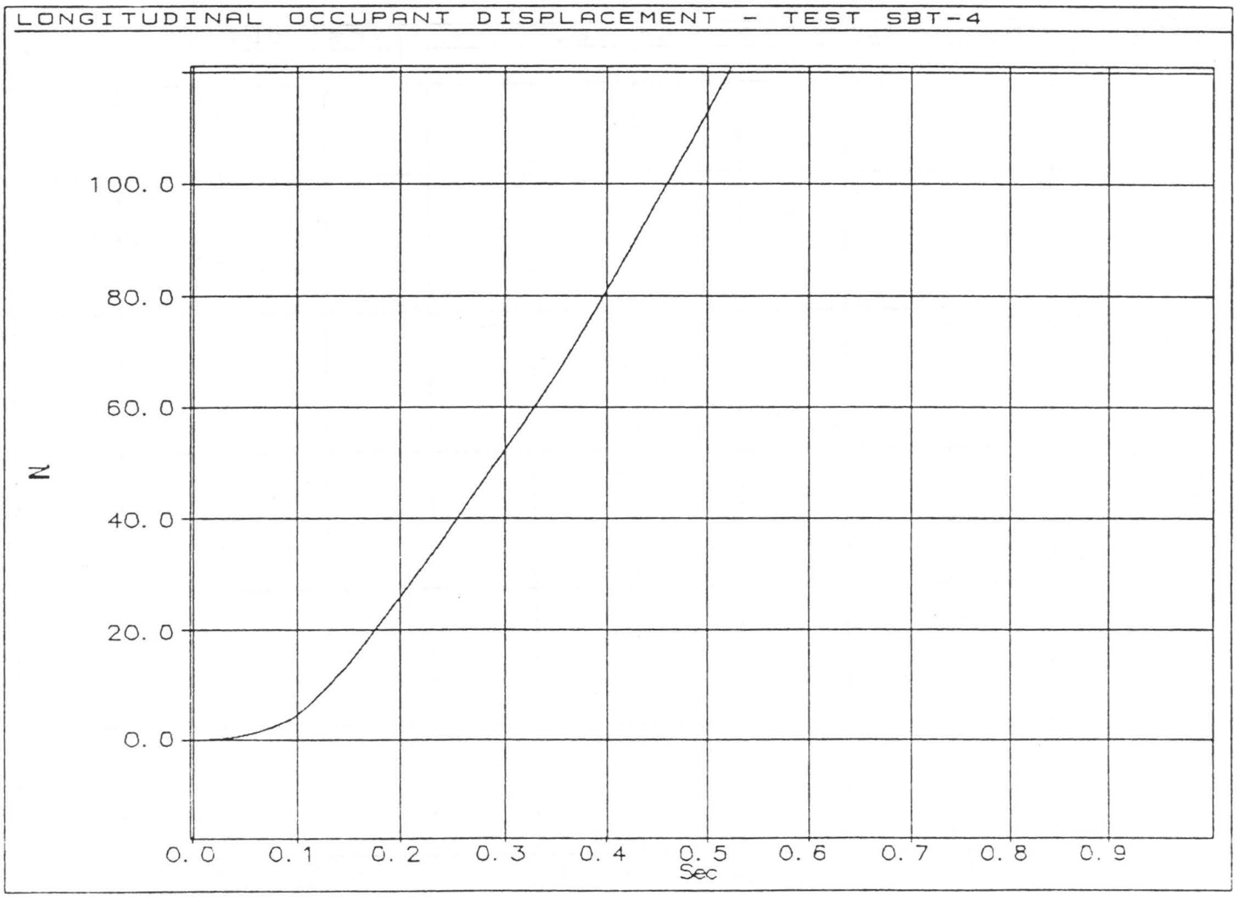


Figure 179. Graph of Longitudinal Occupant Displacement, Test SBT-4.

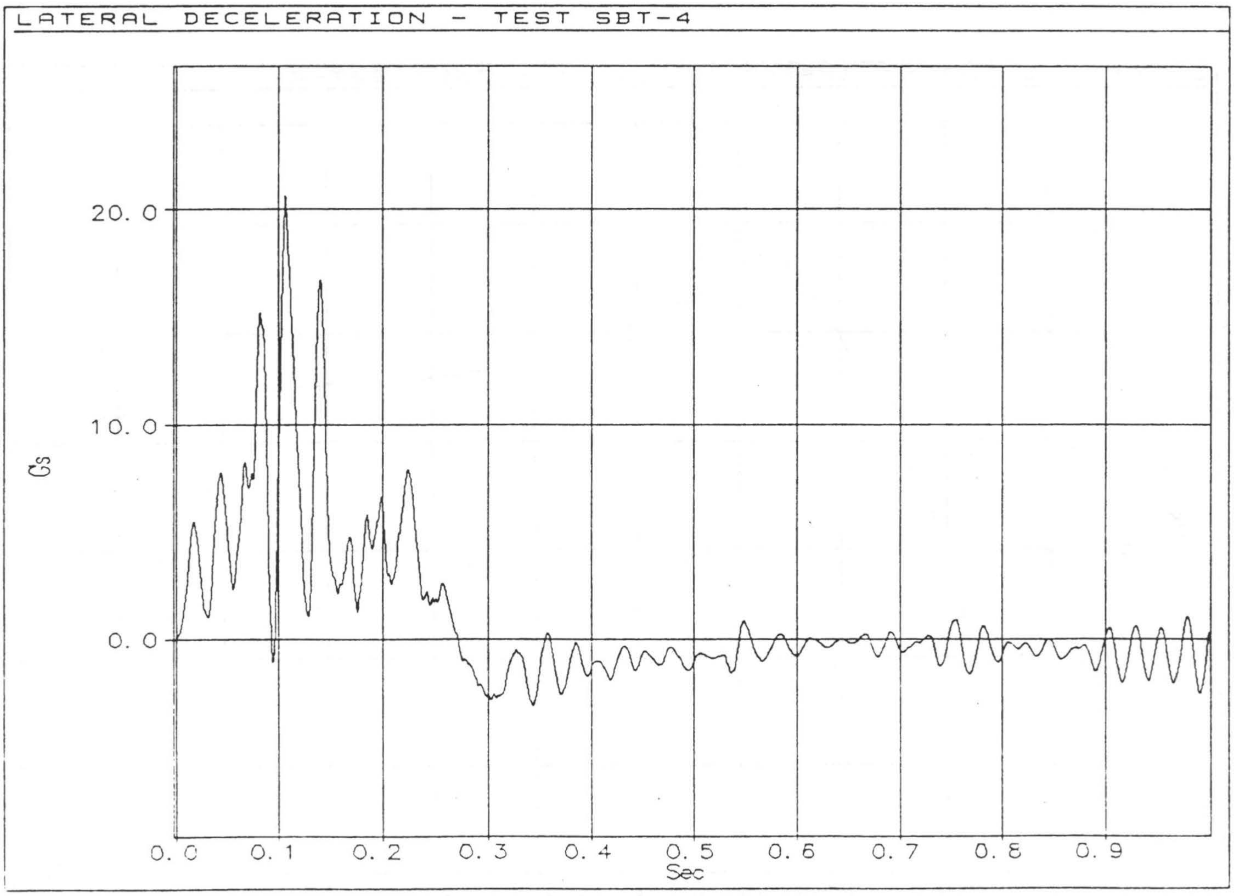


Figure 180. Graph of Lateral Deceleration, Test SBT-4.

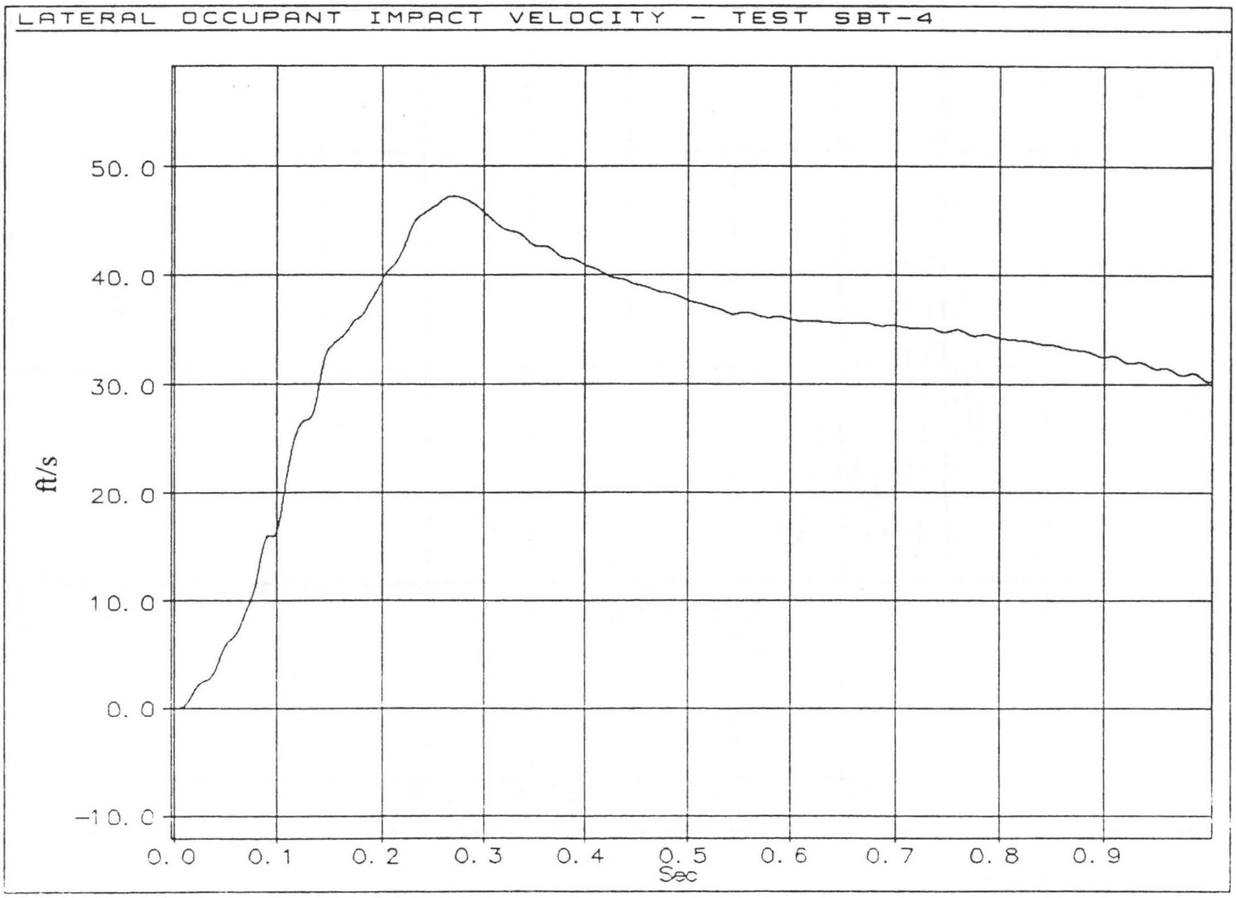


Figure 181. Graph of Lateral Change in Velocity, Test SBT-4.

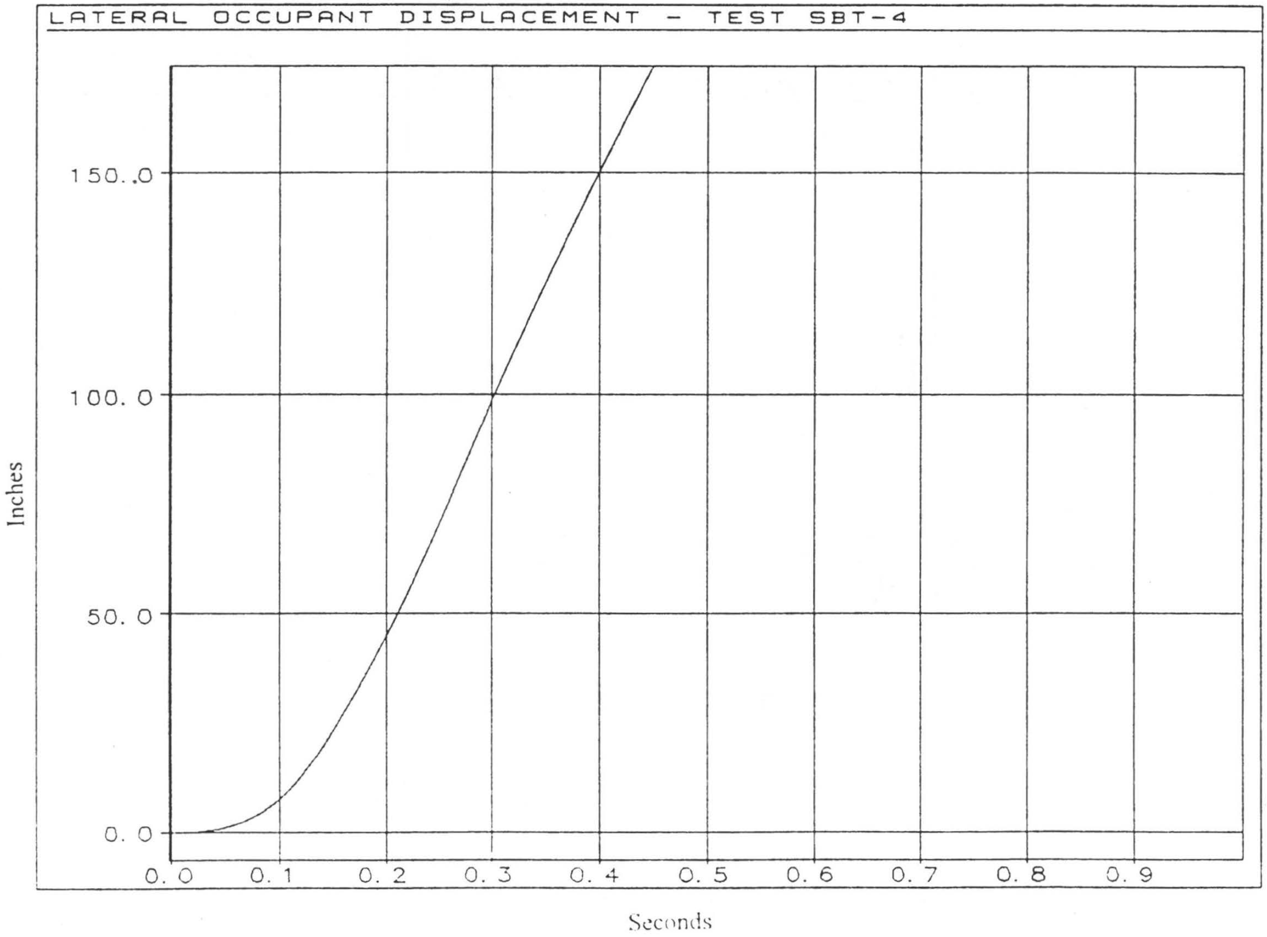


Figure 182. Graph of Lateral Occupant Displacement, Test SBT-4.

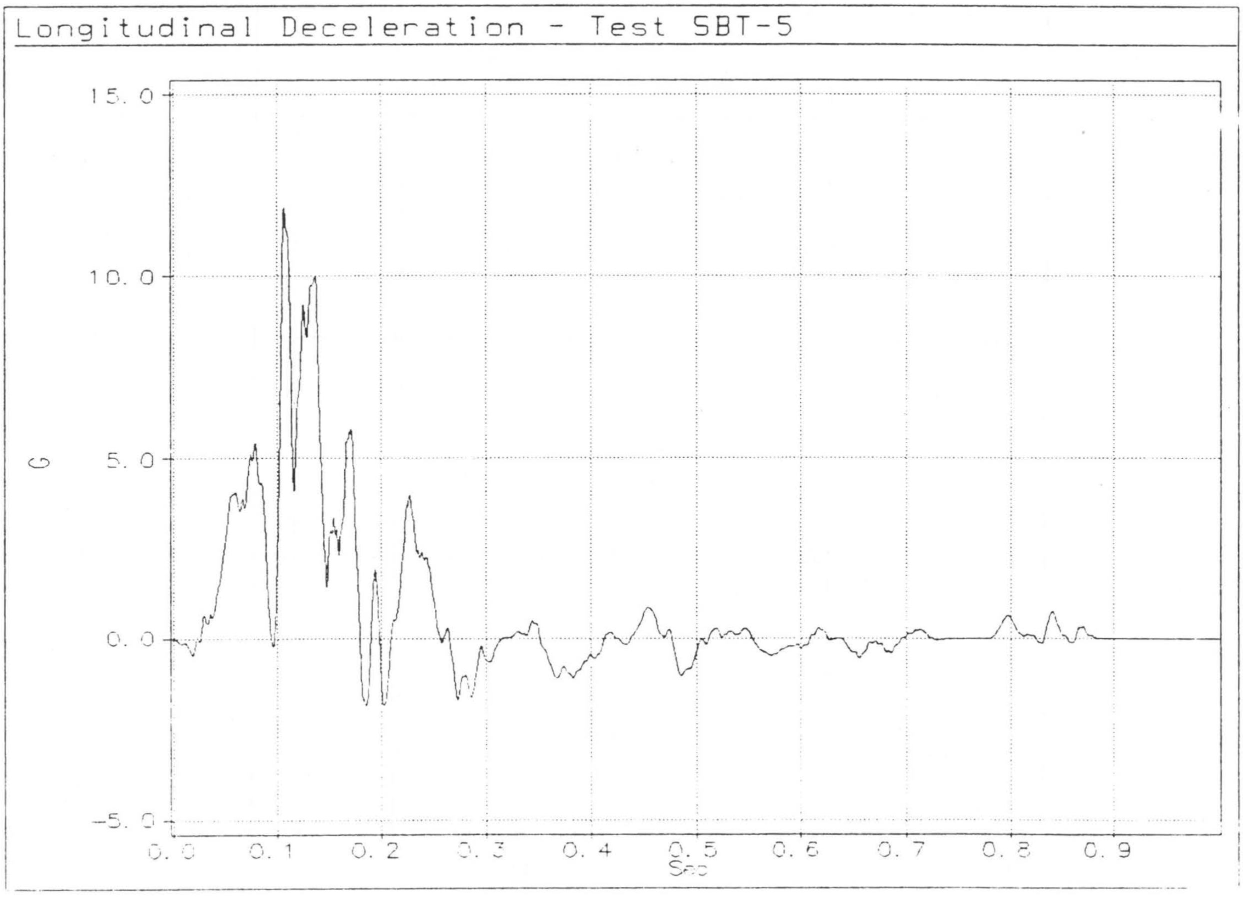


Figure 183. Graph of Longitudinal Deceleration, Test SBT-5.

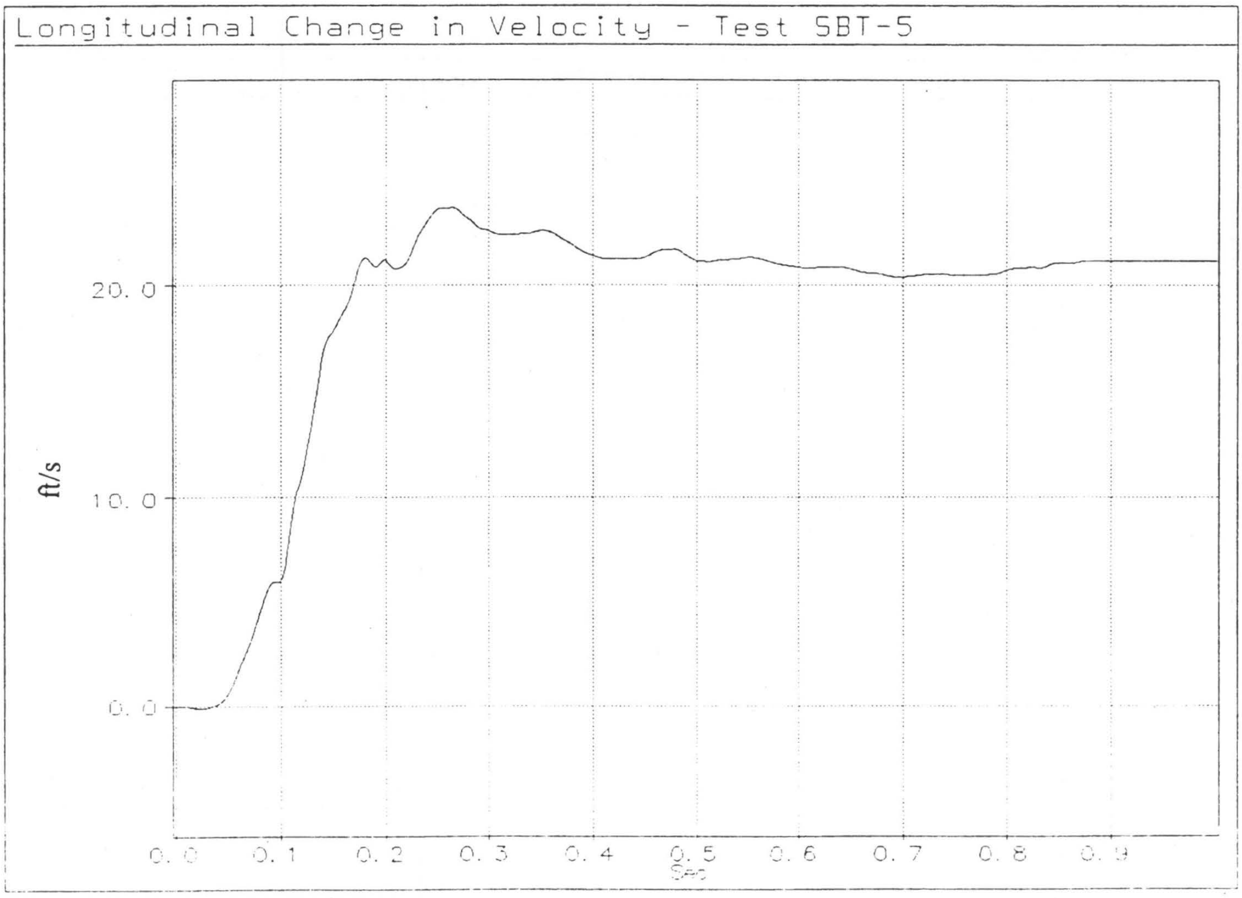


Figure 184. Graph of Longitudinal Change in Velocity, Test SBT-5.

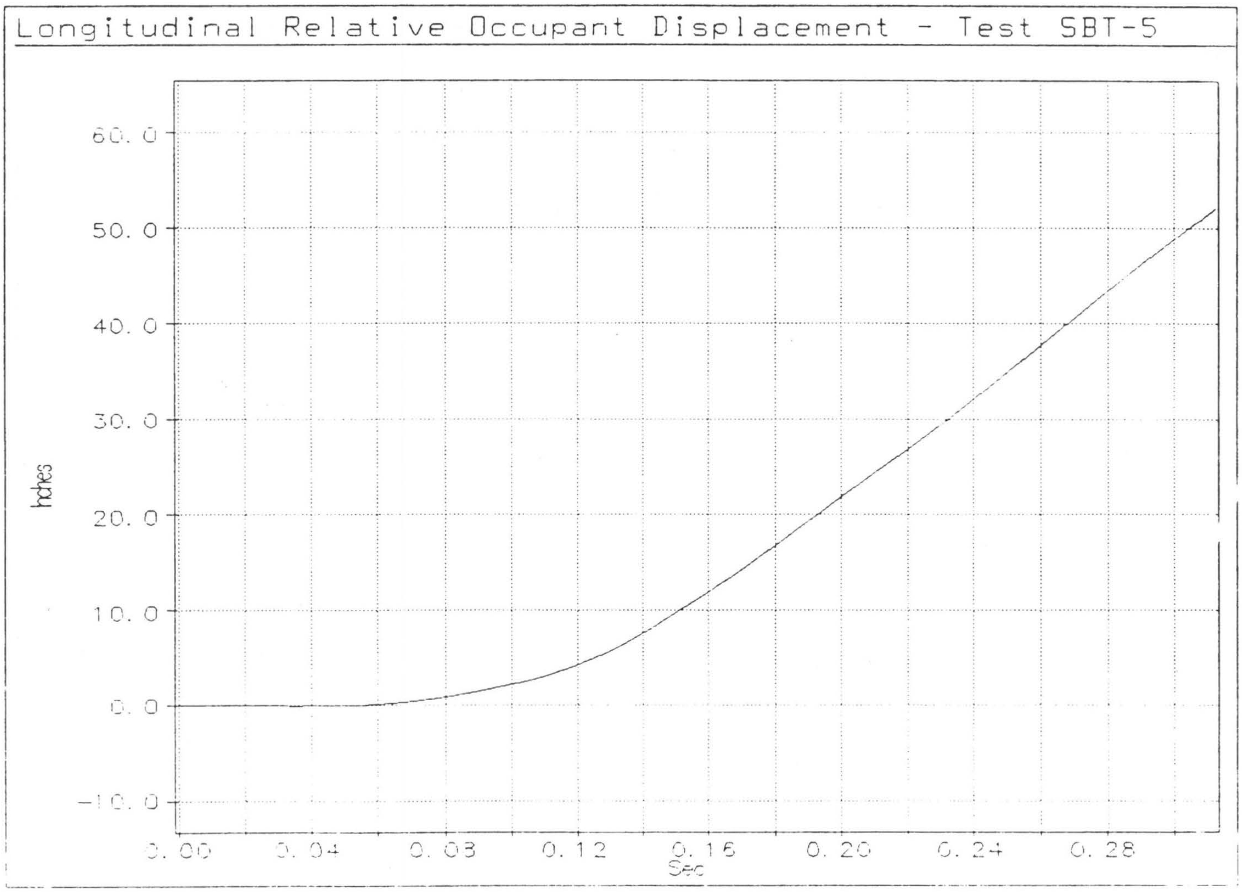


Figure 185. Graph of Longitudinal Occupant Displacement, Test SBT-5.

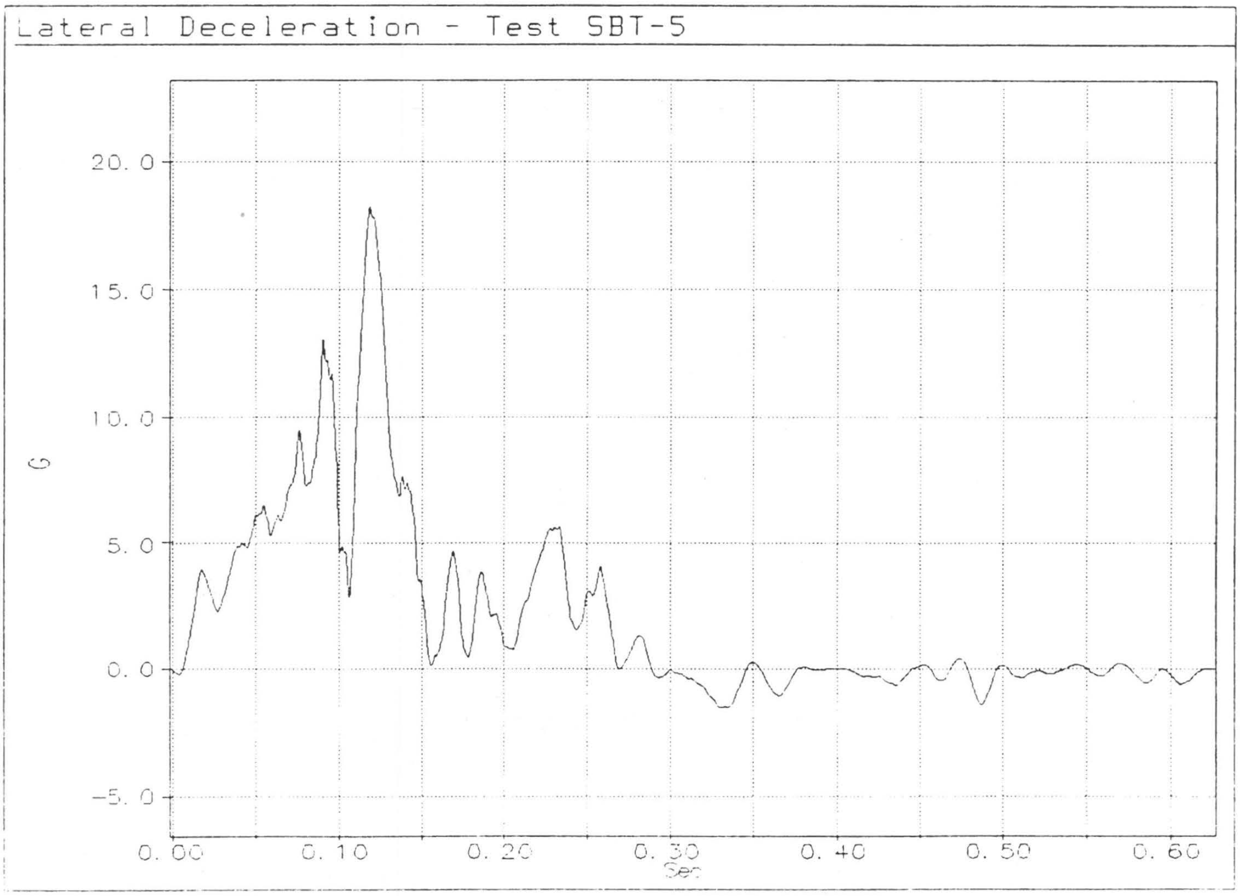


Figure 186. Graph of Lateral Deceleration, Test SBT-5.

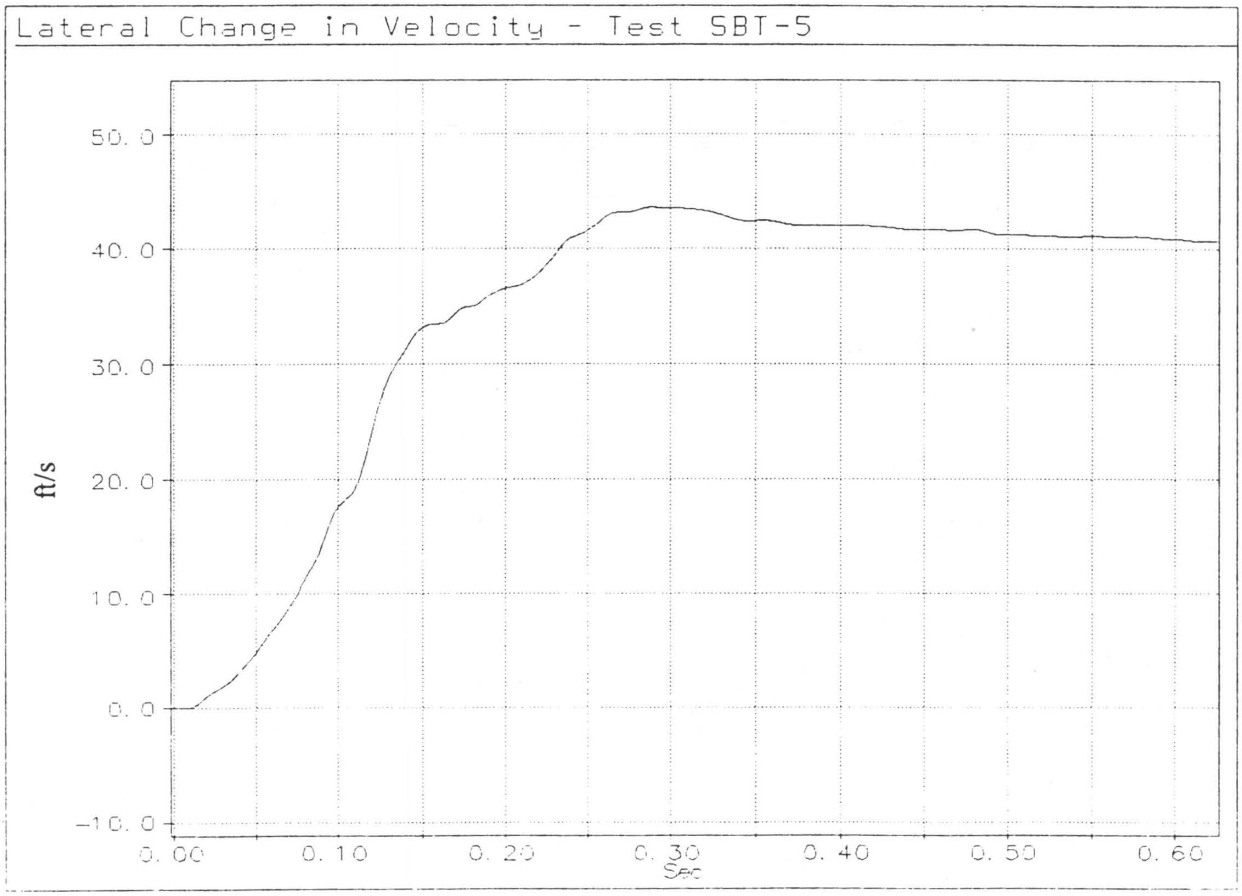


Figure 187. Graph of Lateral Change in Velocity, Test SBT-5.

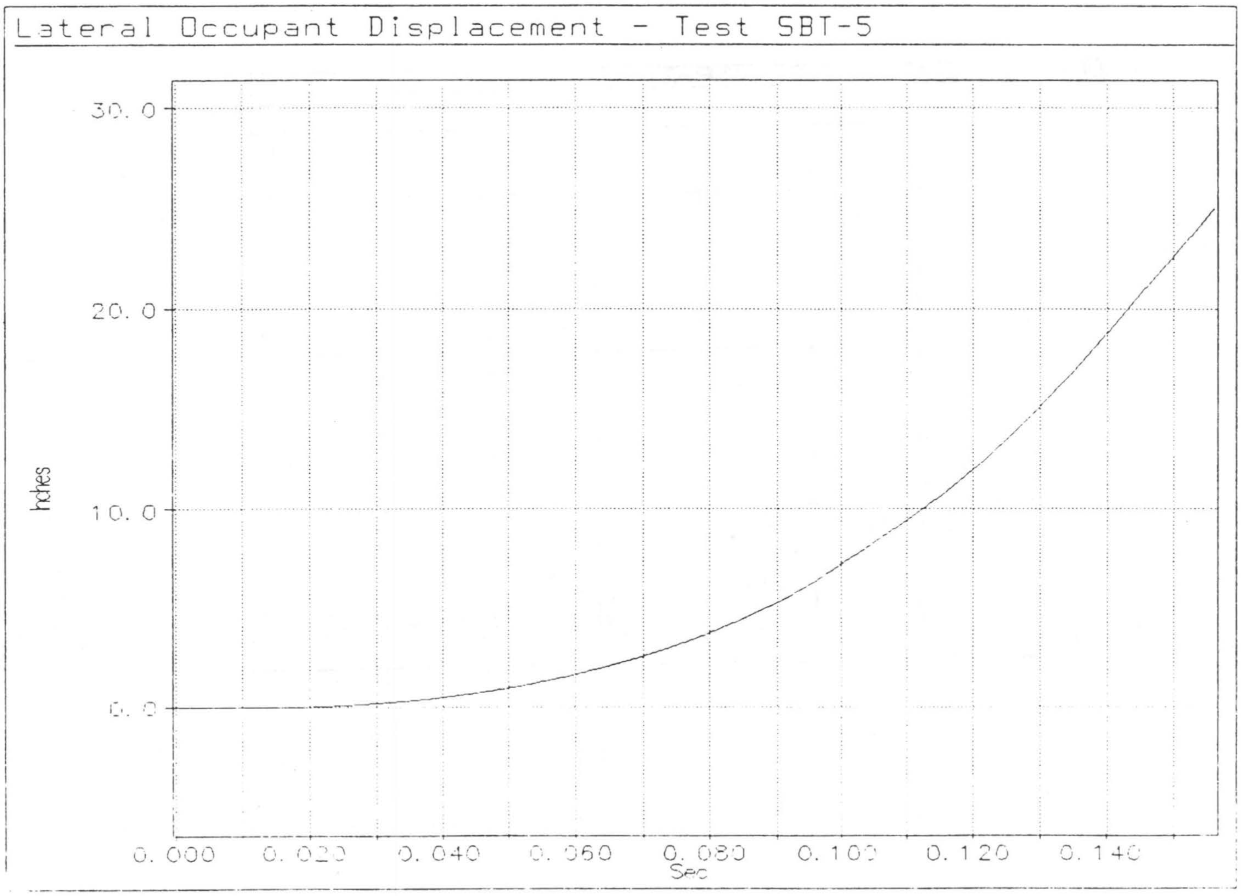


Figure 188. Graph of Lateral Occupant Displacement, Test SBT-5.

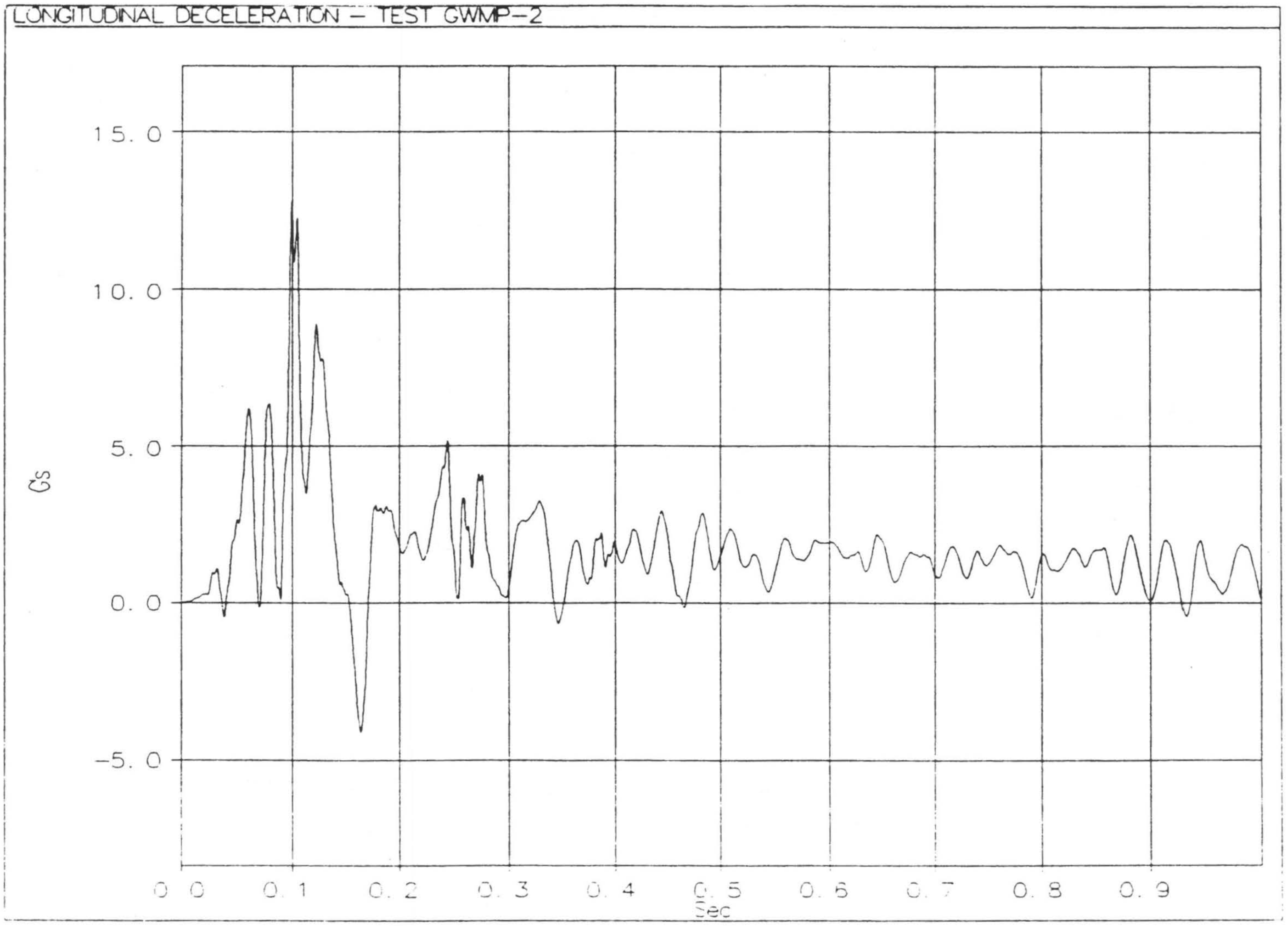


Figure 189. Graph of Longitudinal Deceleration, Test GWMP-2.

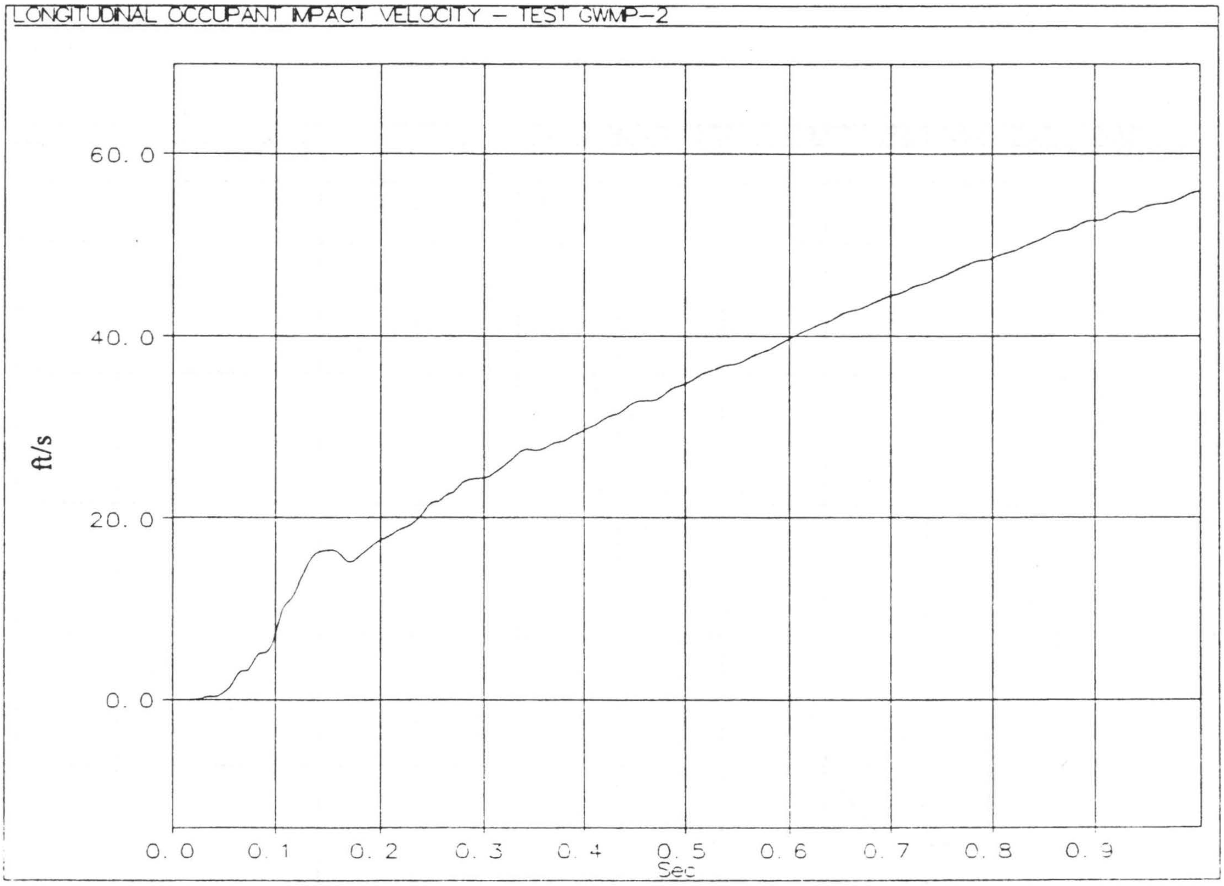


Figure 190. Graph of Longitudinal Change in Velocity, Test GWMP-2.

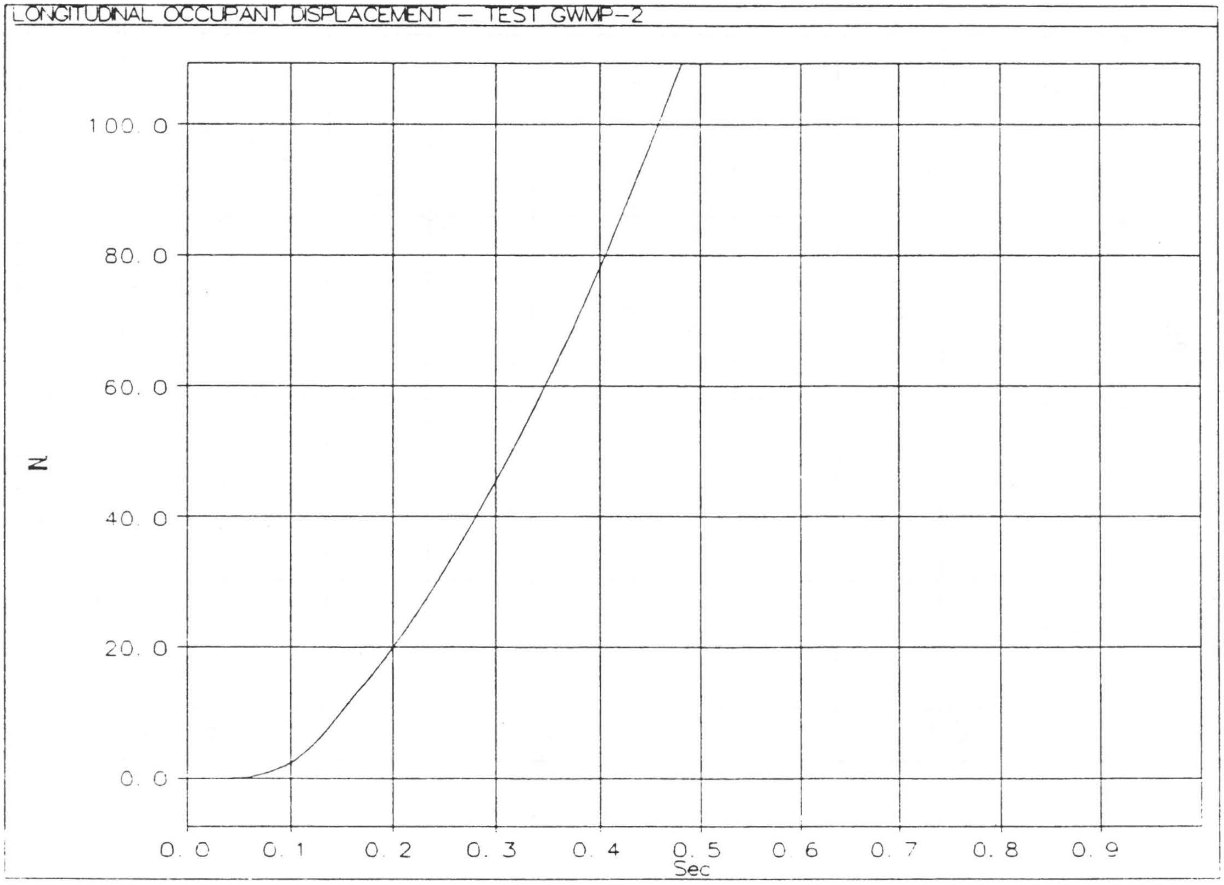


Figure 191. Graph of Longitudinal Occupant Displacement, Test GWMP-2.

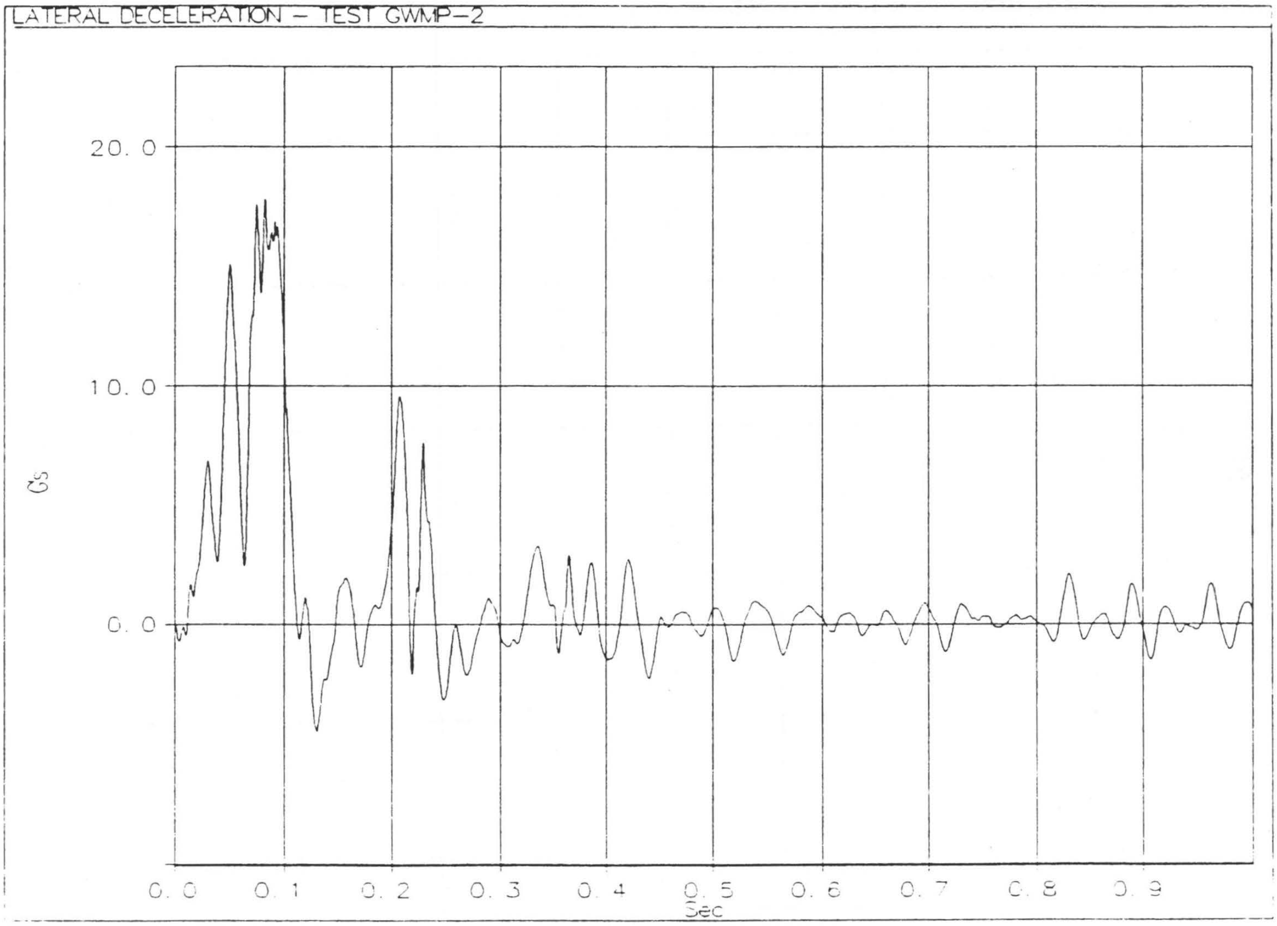


Figure 192. Graph of Lateral Deceleration, Test GWMP-2.

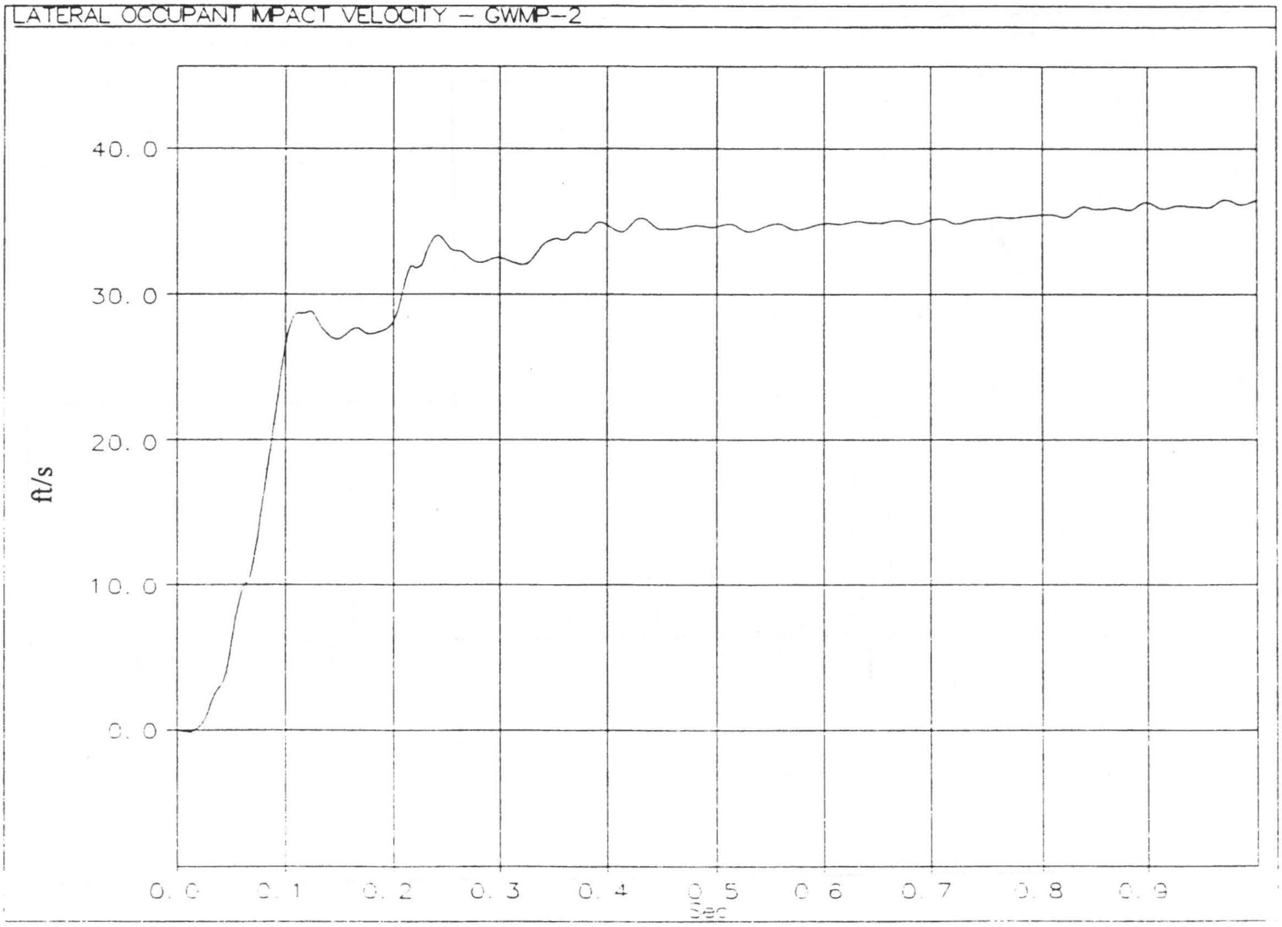


Figure 193. Graph of Lateral Change in Velocity, Test GWMP-2.

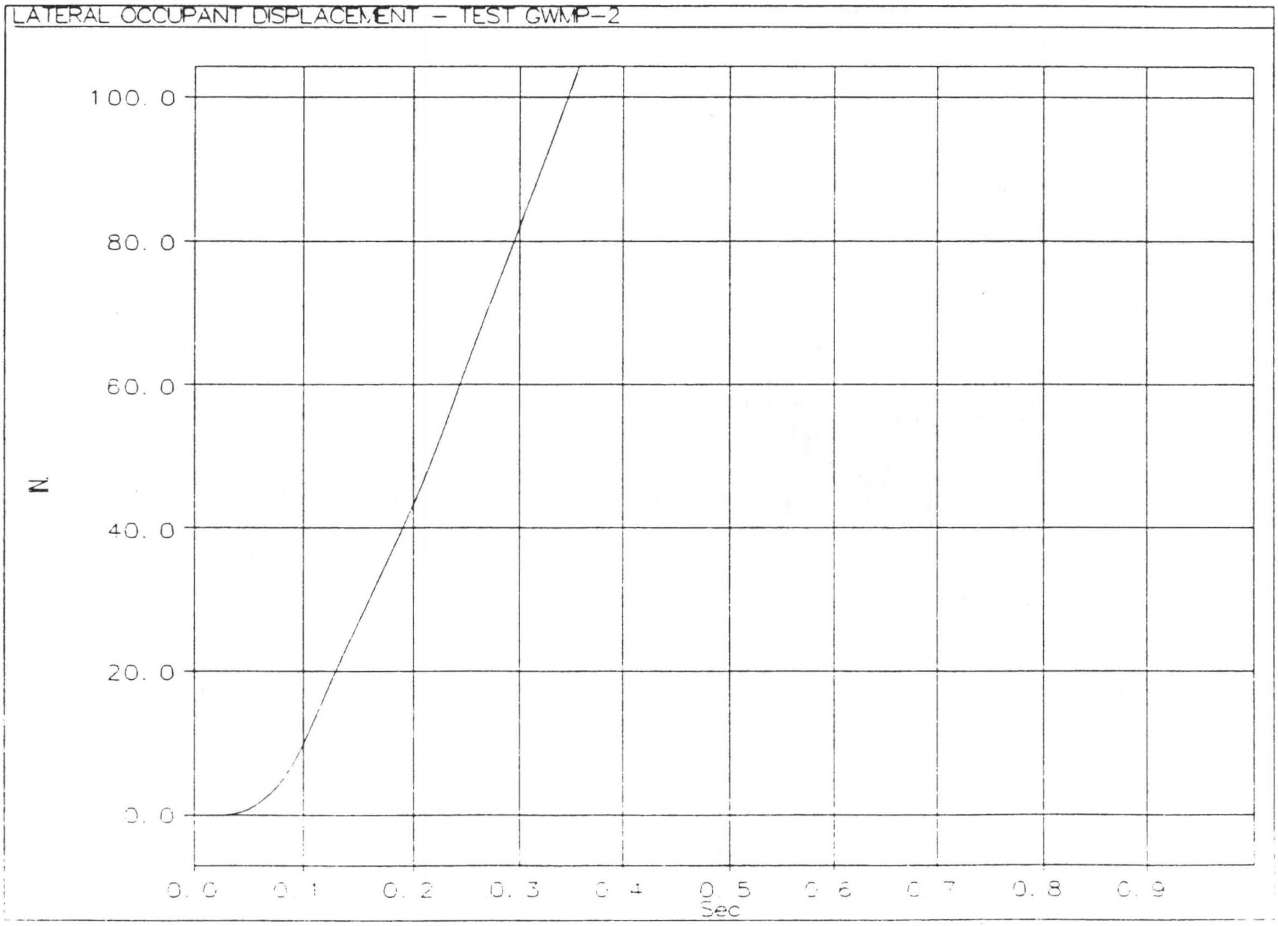


Figure 194. Graph of Lateral Occupant Displacement, Test GWMP-2.

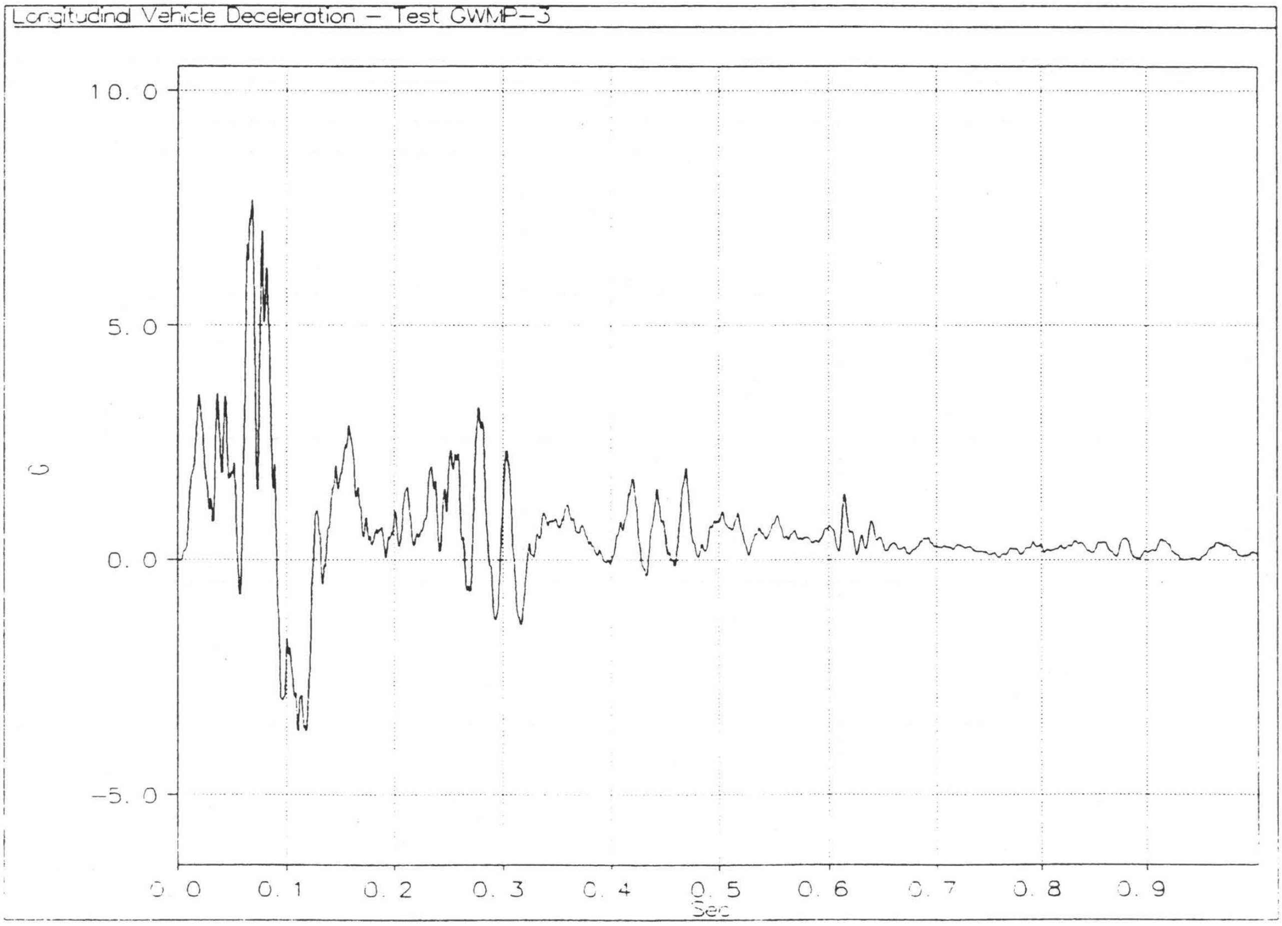


Figure 195. Graph of Longitudinal Deceleration, Test GWMP-3.

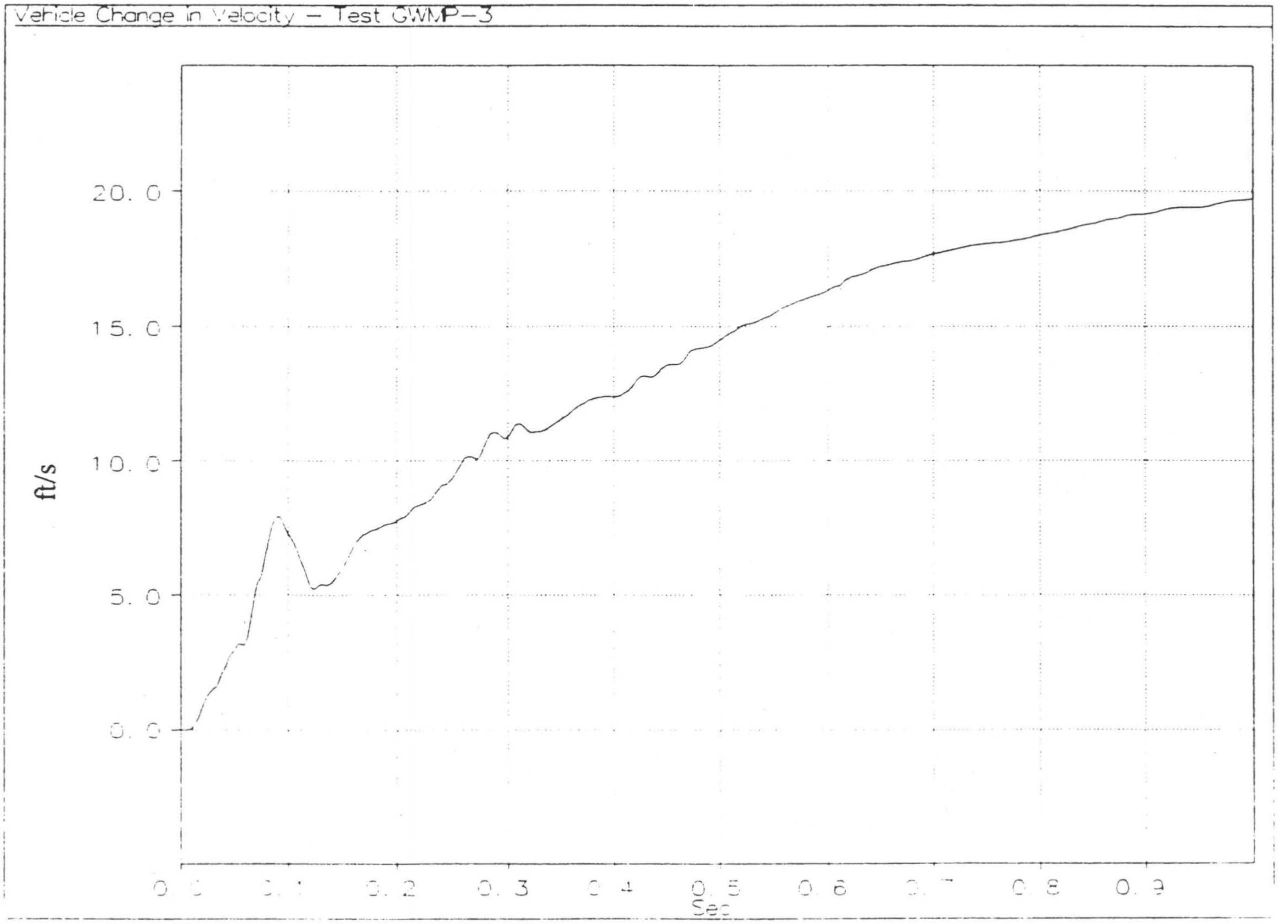


Figure 196. Graph of Longitudinal Change in Velocity, Test GWMP-3.

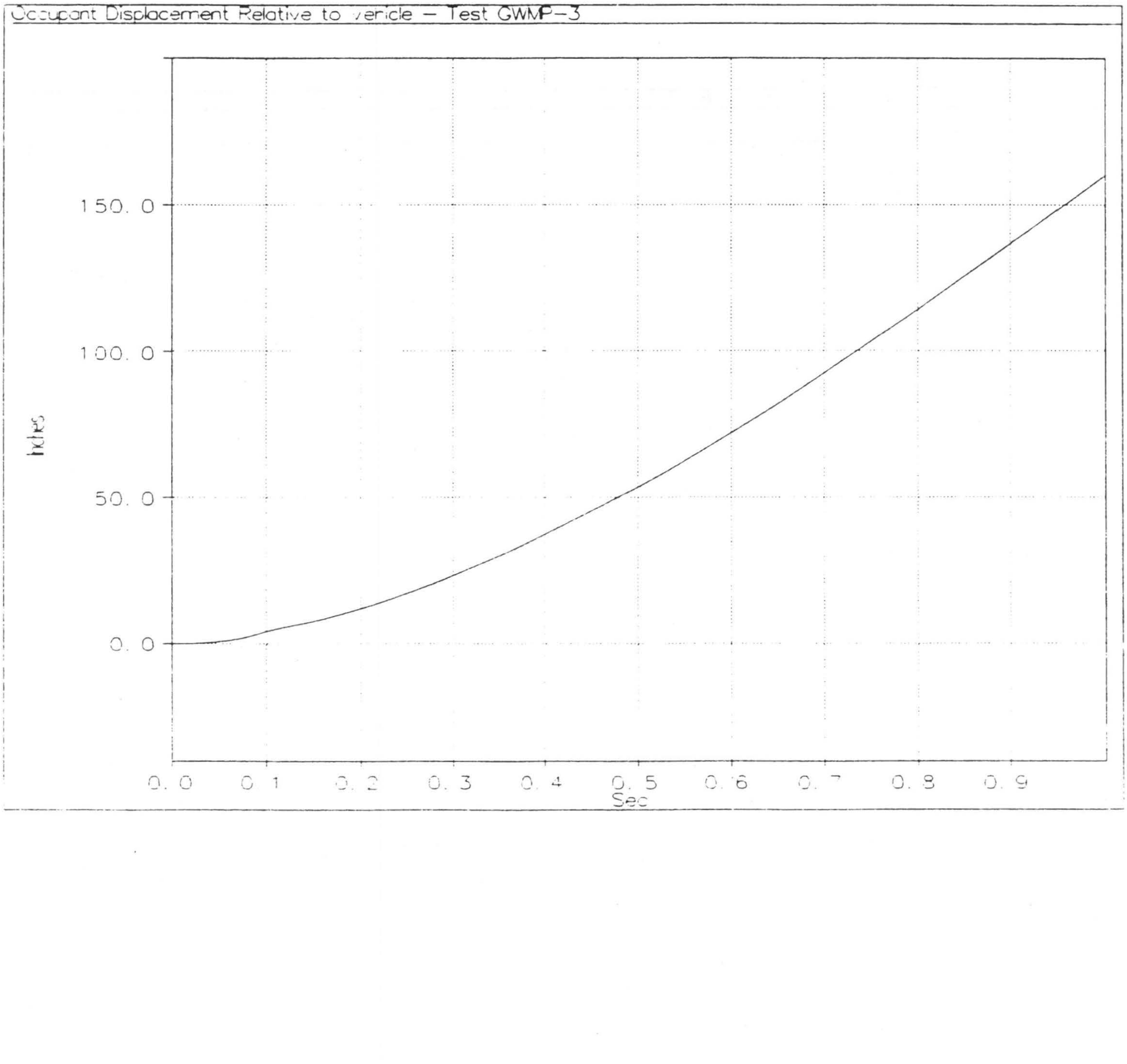


Figure 197. Graph of Longitudinal Occupant Displacement, Test GWMP-3.

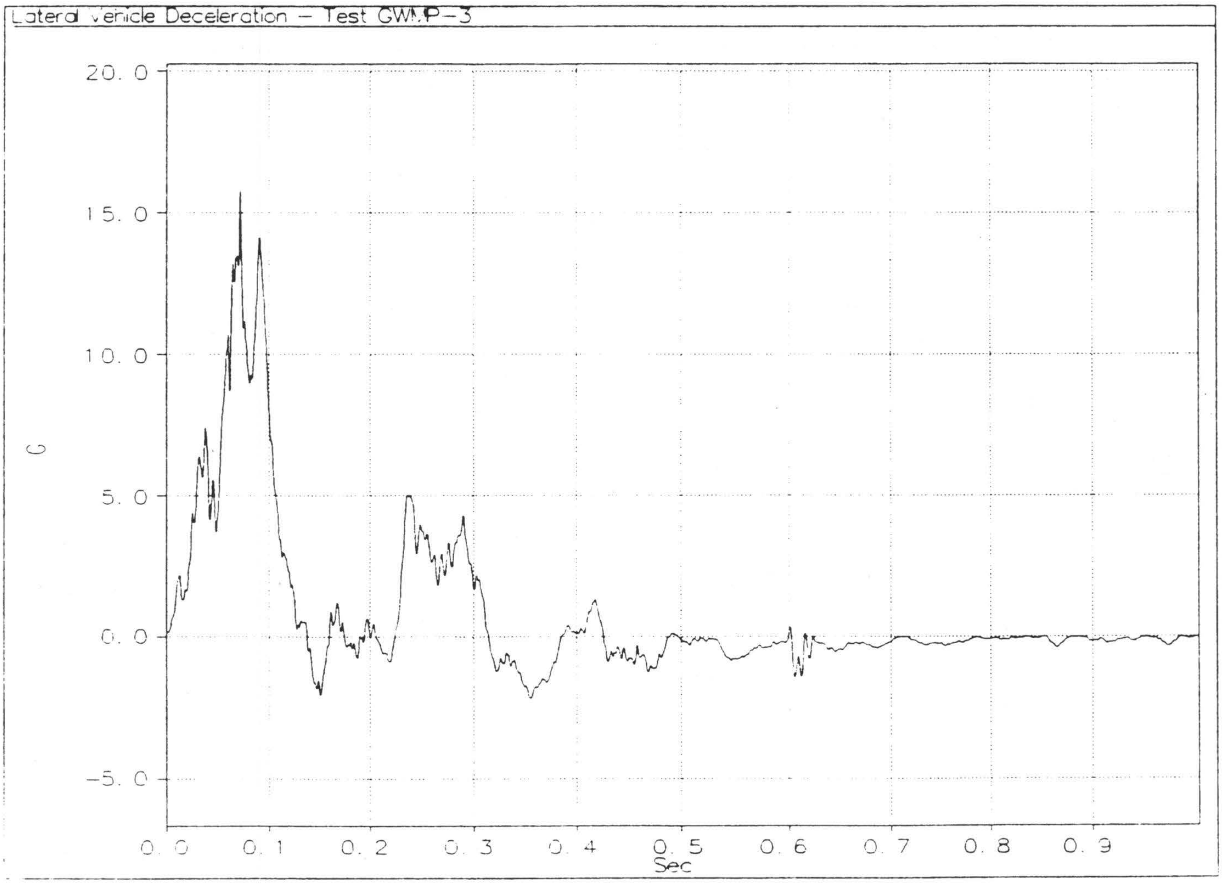


Figure 198. Graph of Lateral Deceleration, Test GWMP-3.

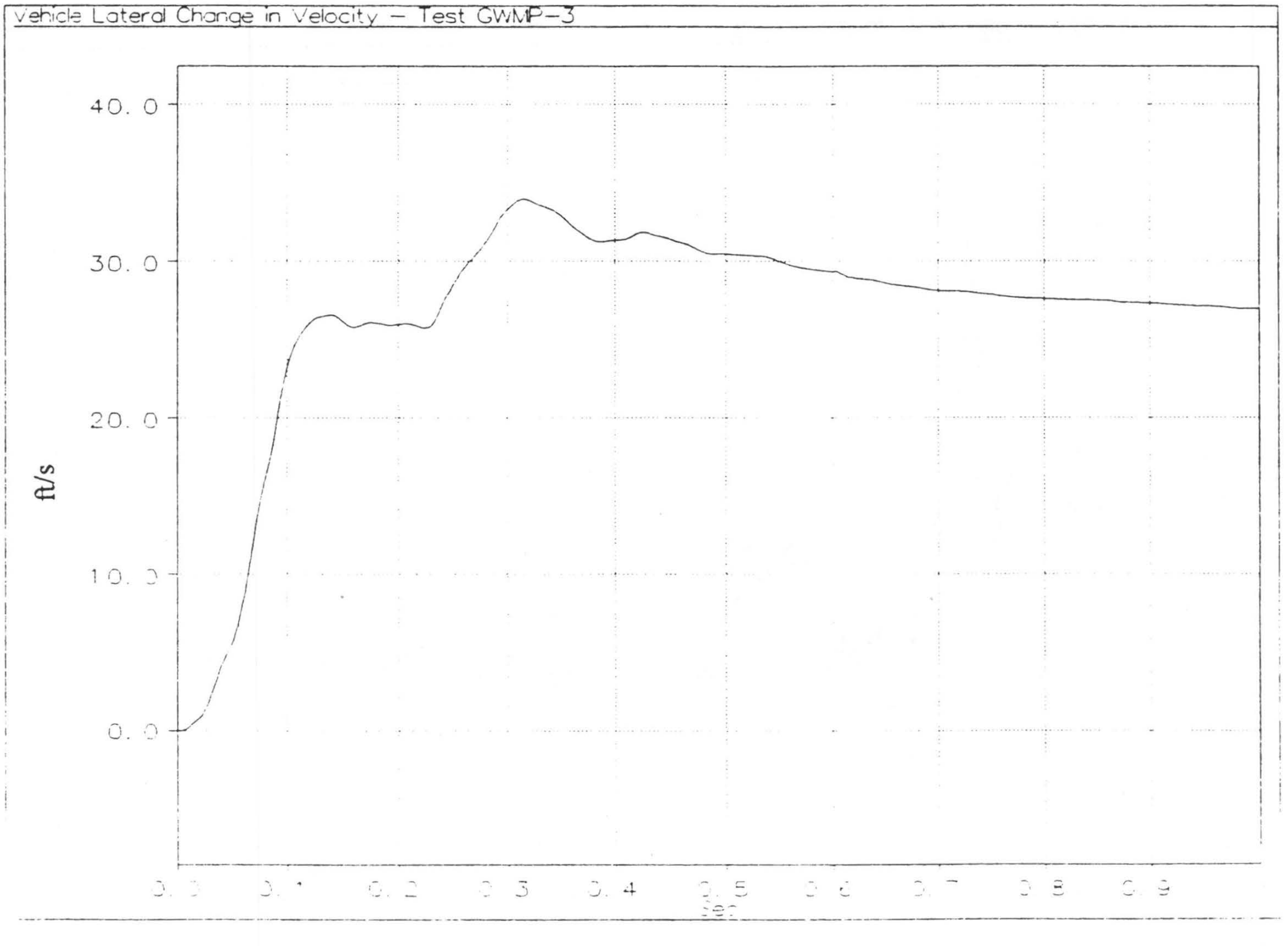


Figure 199. Graph of Lateral Change in Velocity, Test GWMP-3.

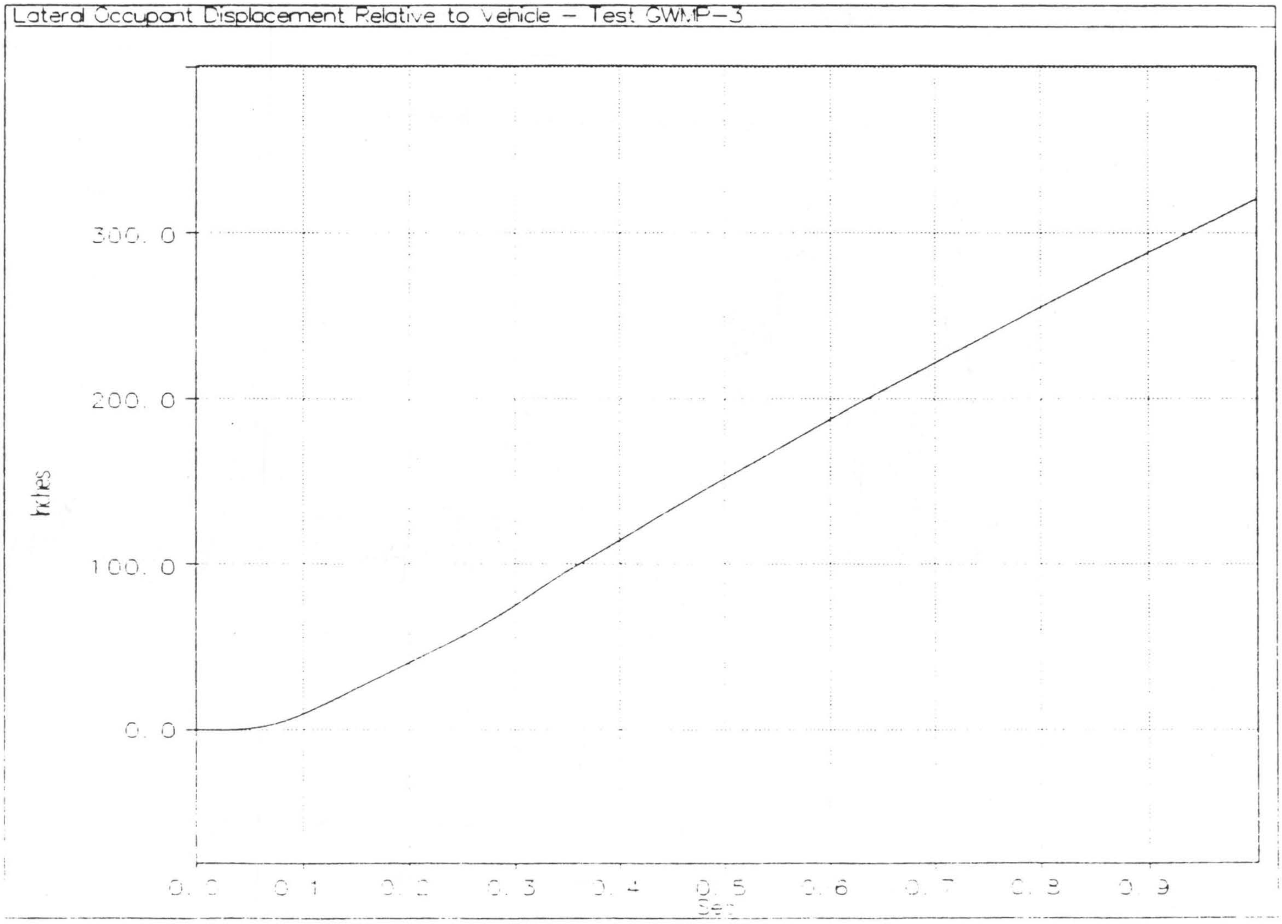


Figure 200. Graph of Lateral Occupant Displacement, Test GWMP-3.

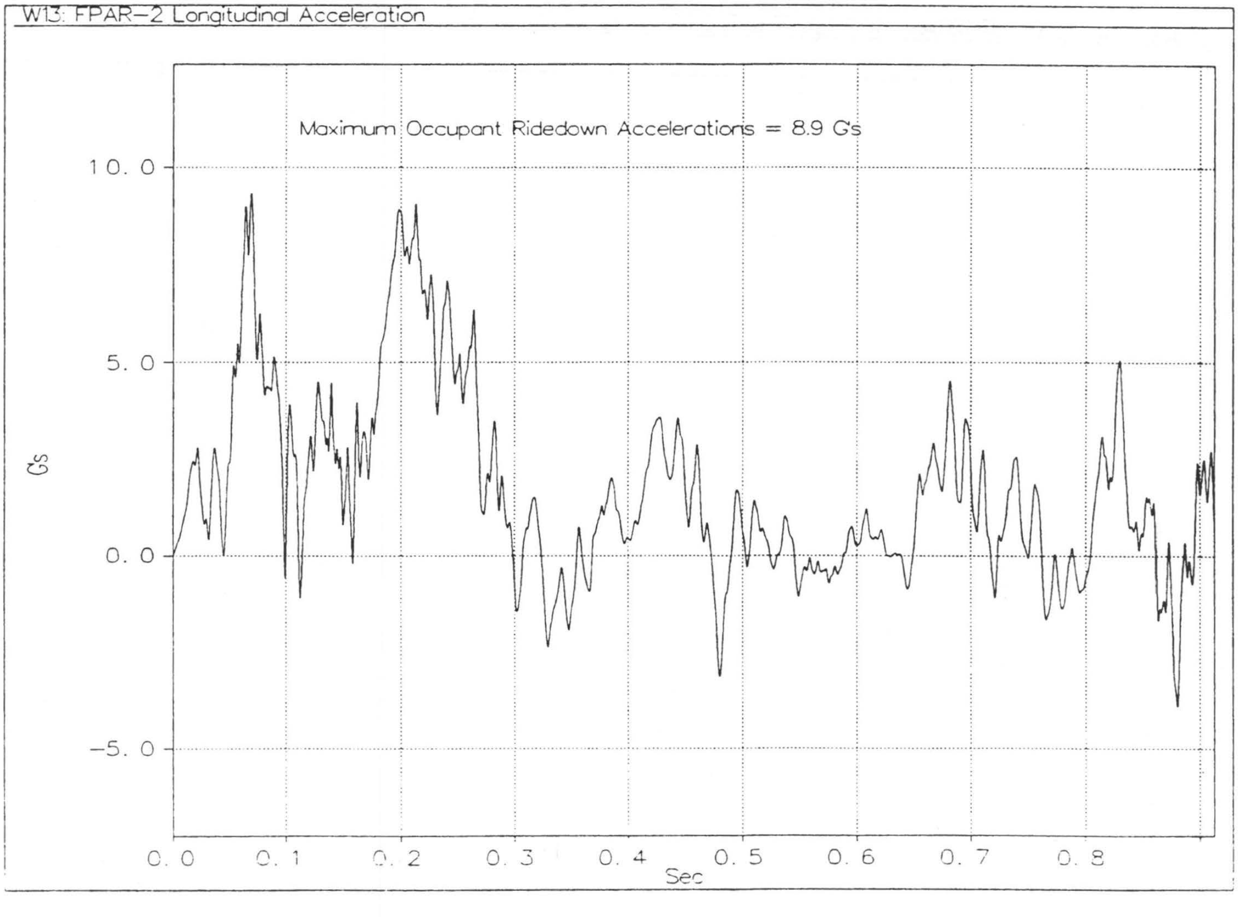


Figure 201. Graph of Longitudinal Deceleration, Test FPAR-2.

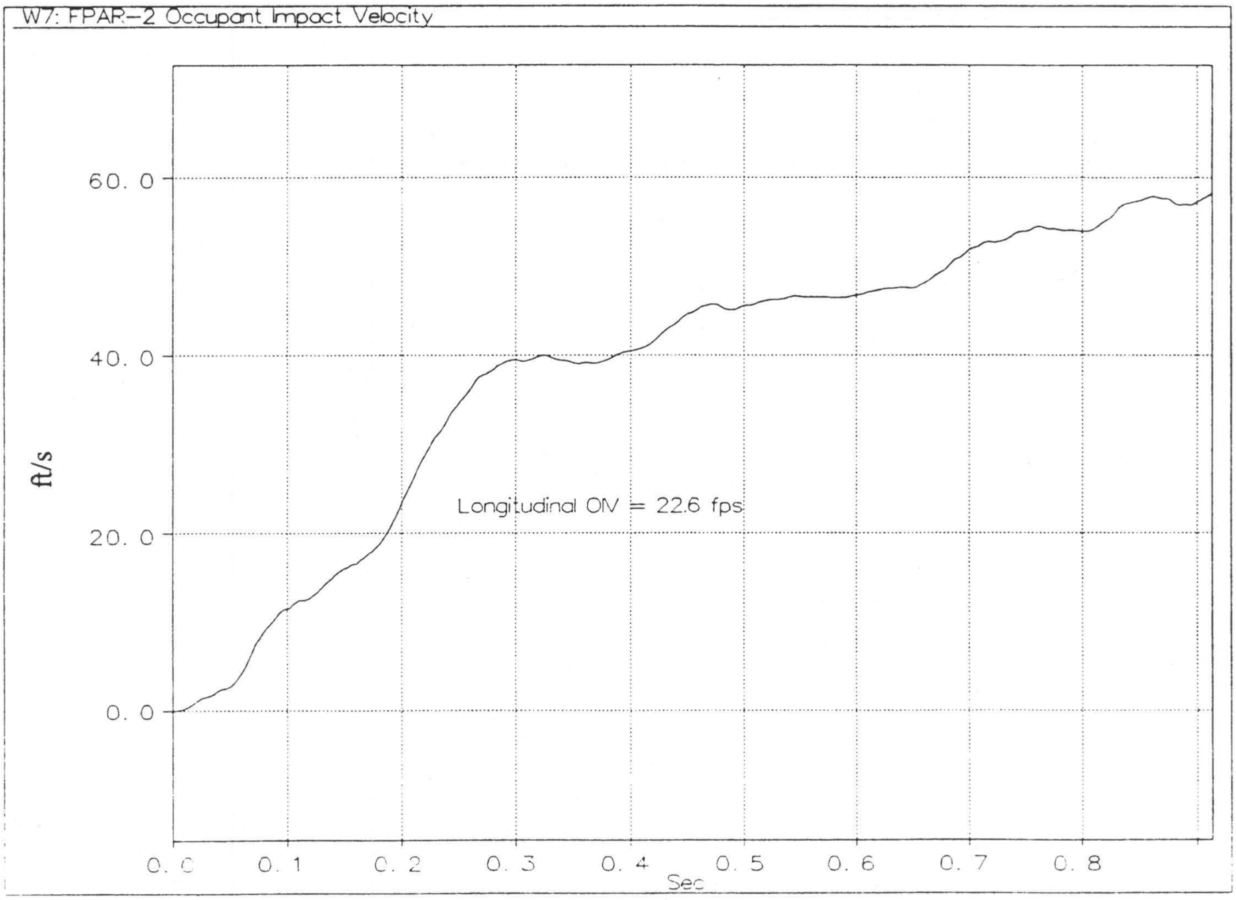


Figure 202. Graph of Longitudinal Change in Velocity, Test FPAR-2.

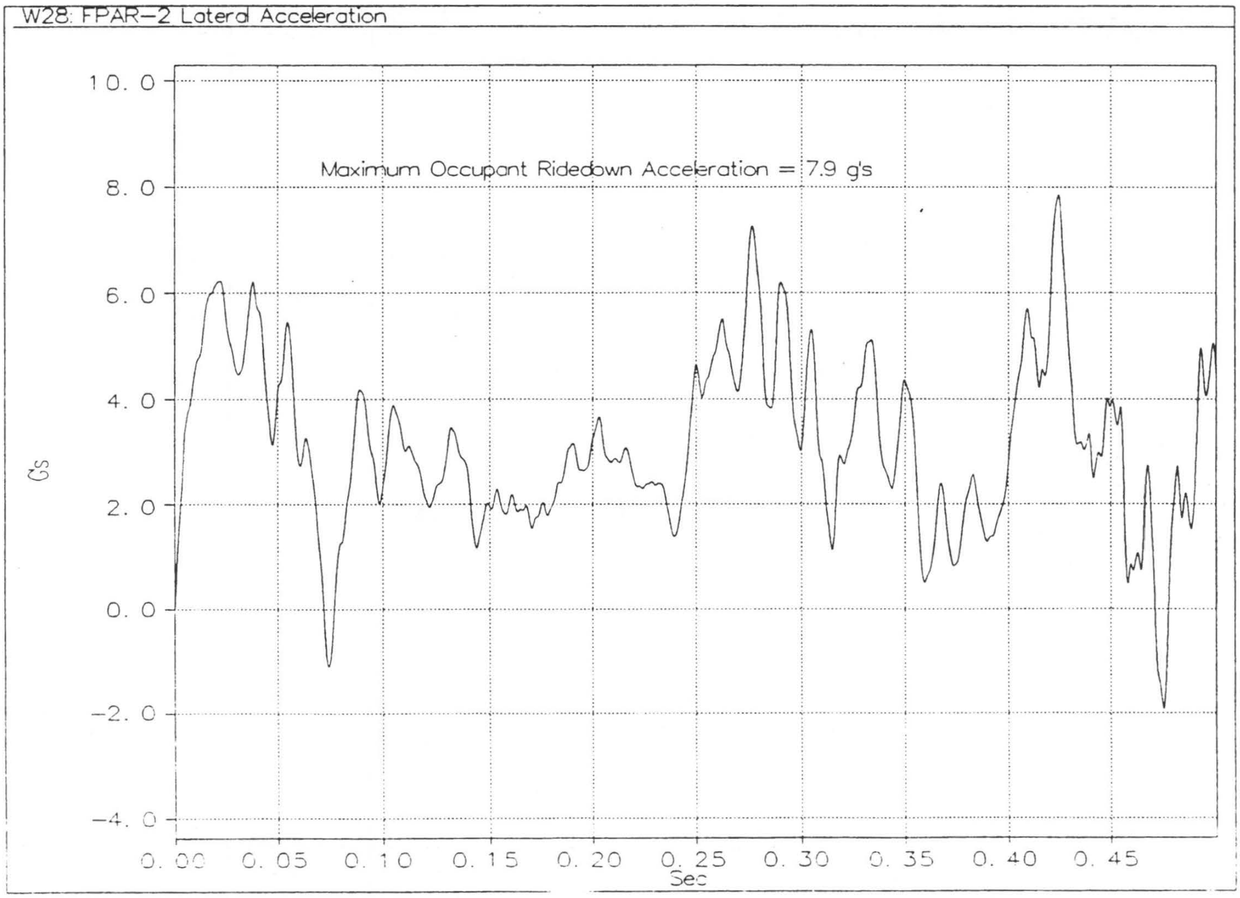


Figure 203. Graph of Lateral Deceleration, Test FPAR-2.

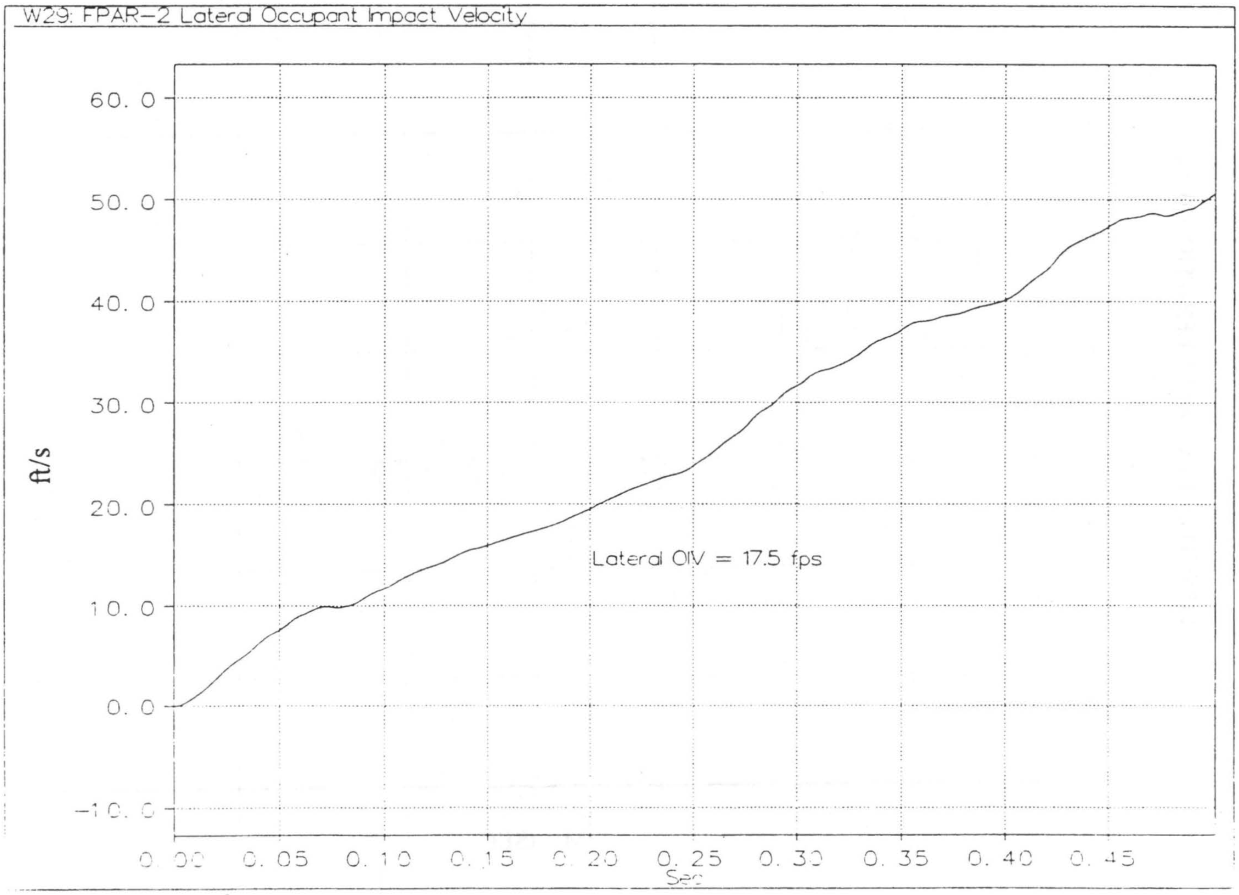


Figure 204. Graph of Lateral Change in Velocity, Test FPAR-2.

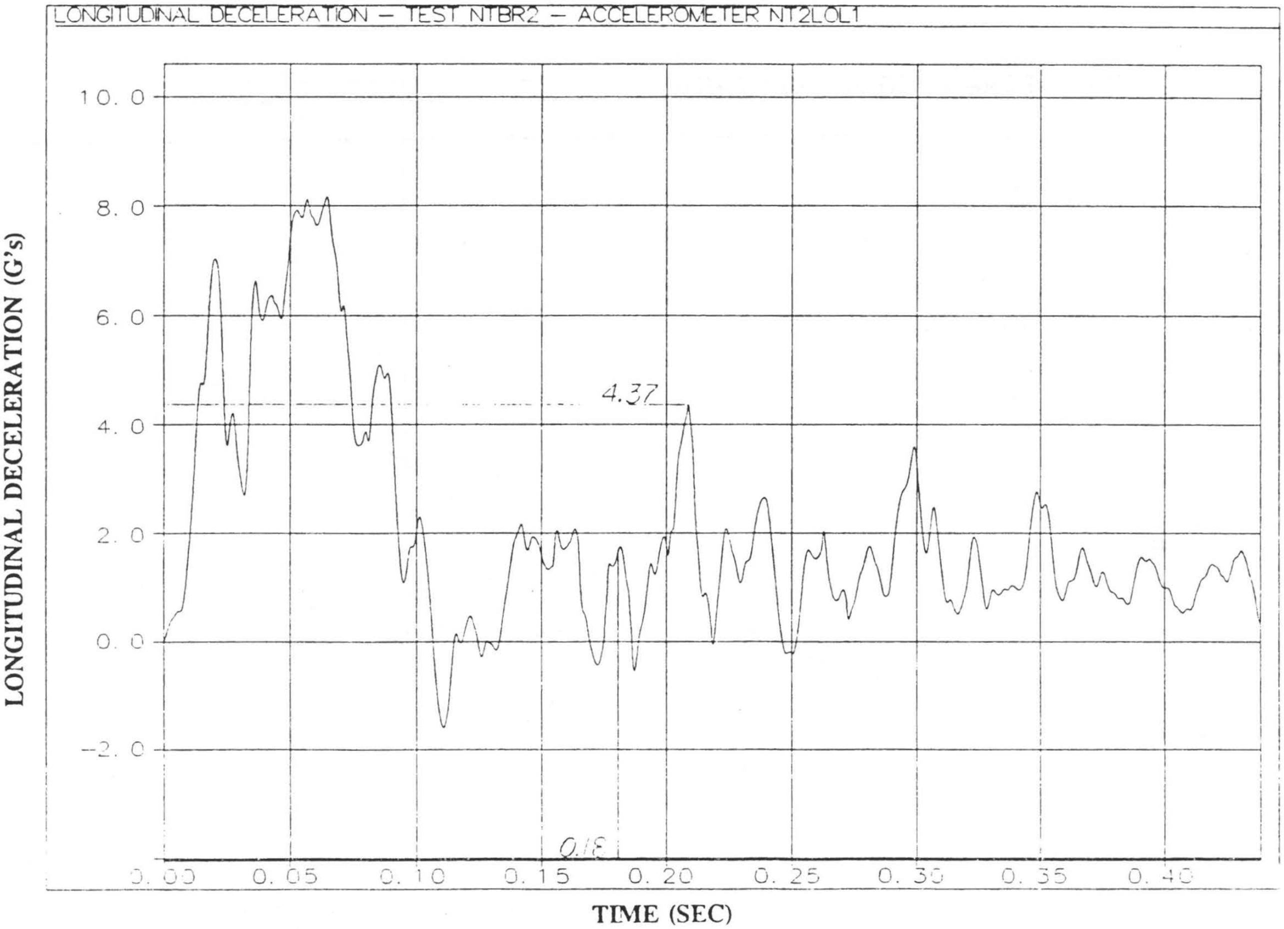


Figure 205. Graph of Longitudinal Deceleration, Test NTBR-2.

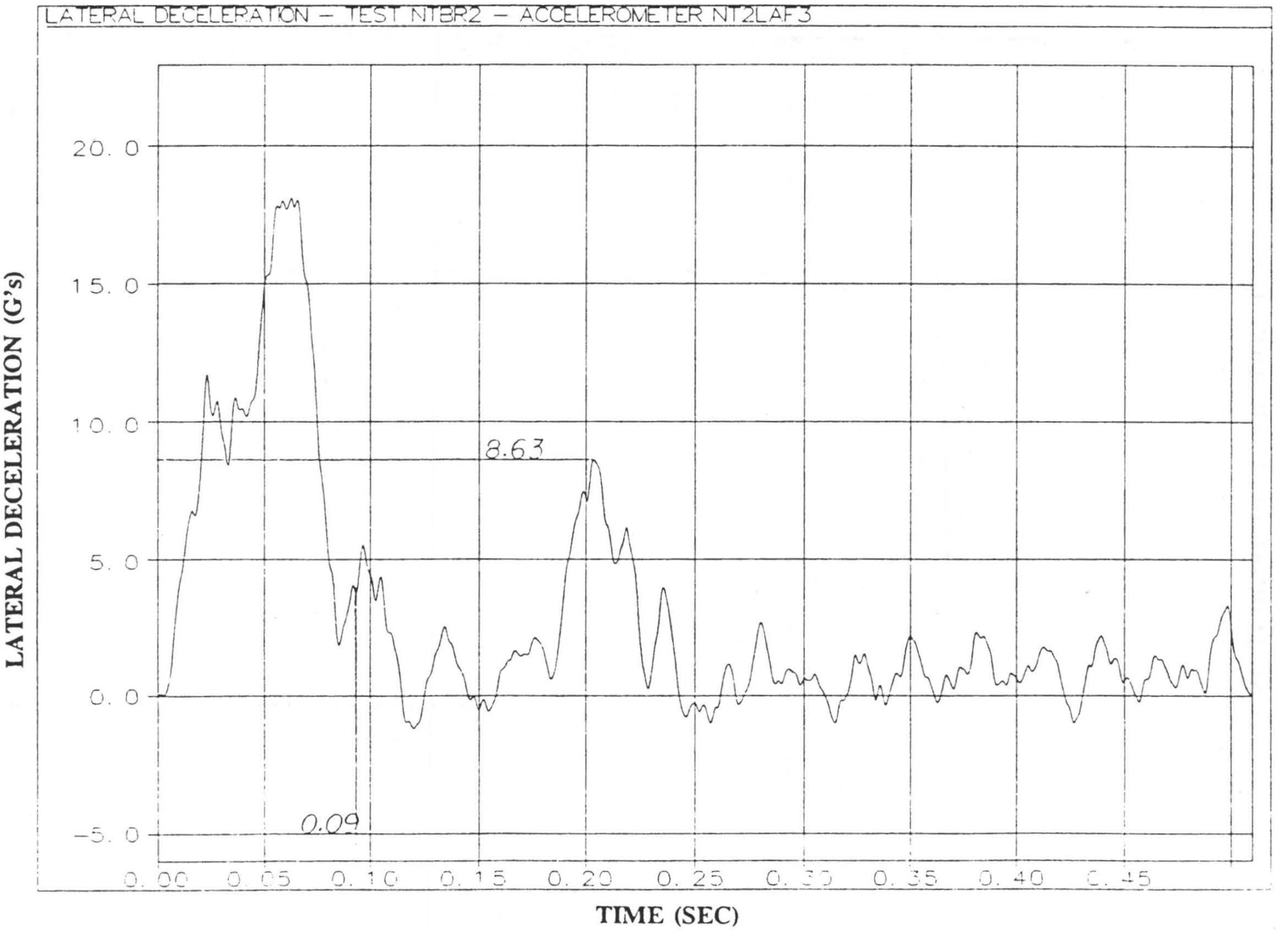


Figure 206. Graph of Lateral Deceleration, Test NTBR-2.

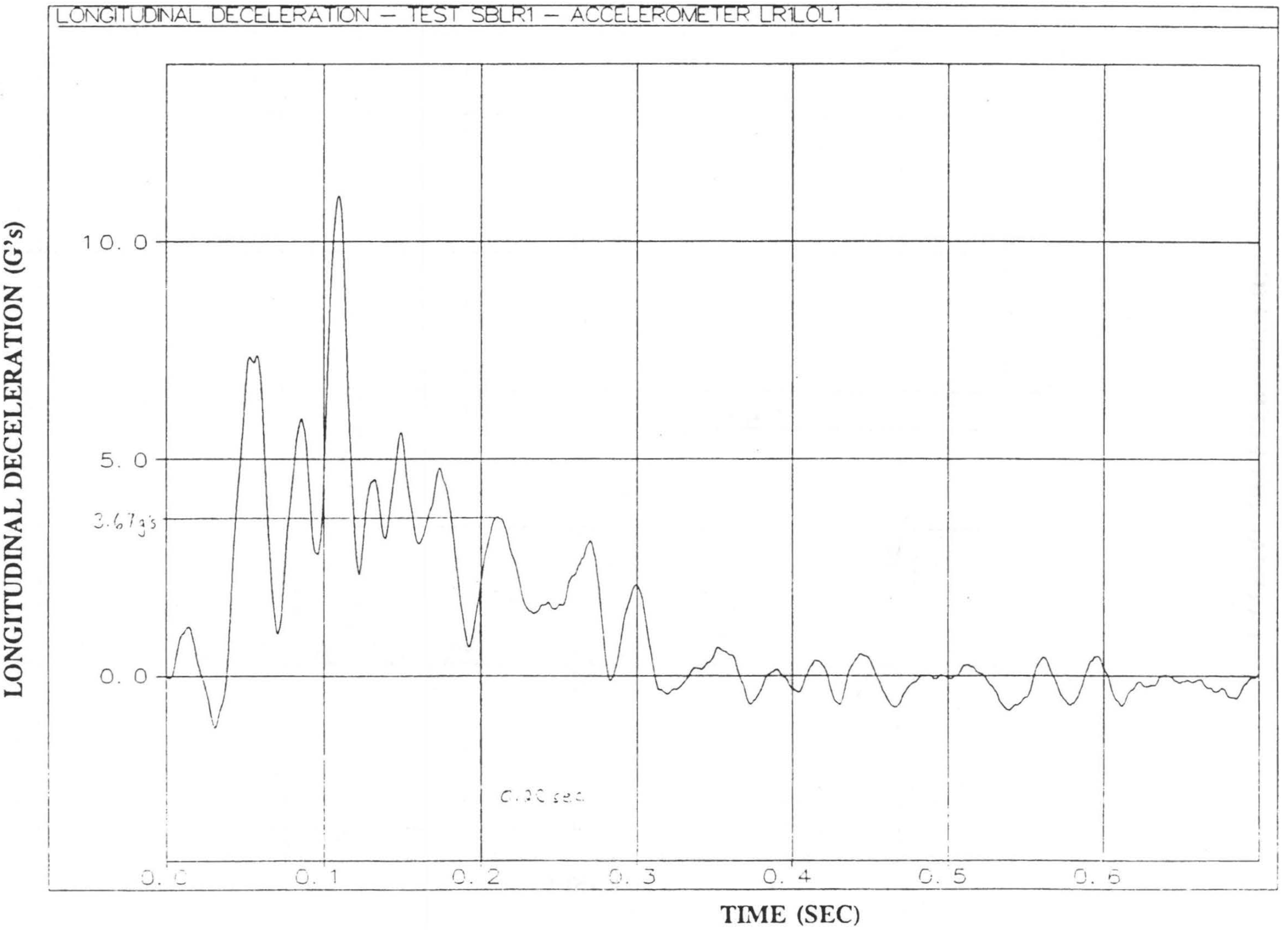


Figure 207. Graph of Longitudinal Deceleration, Test SBLR-1.

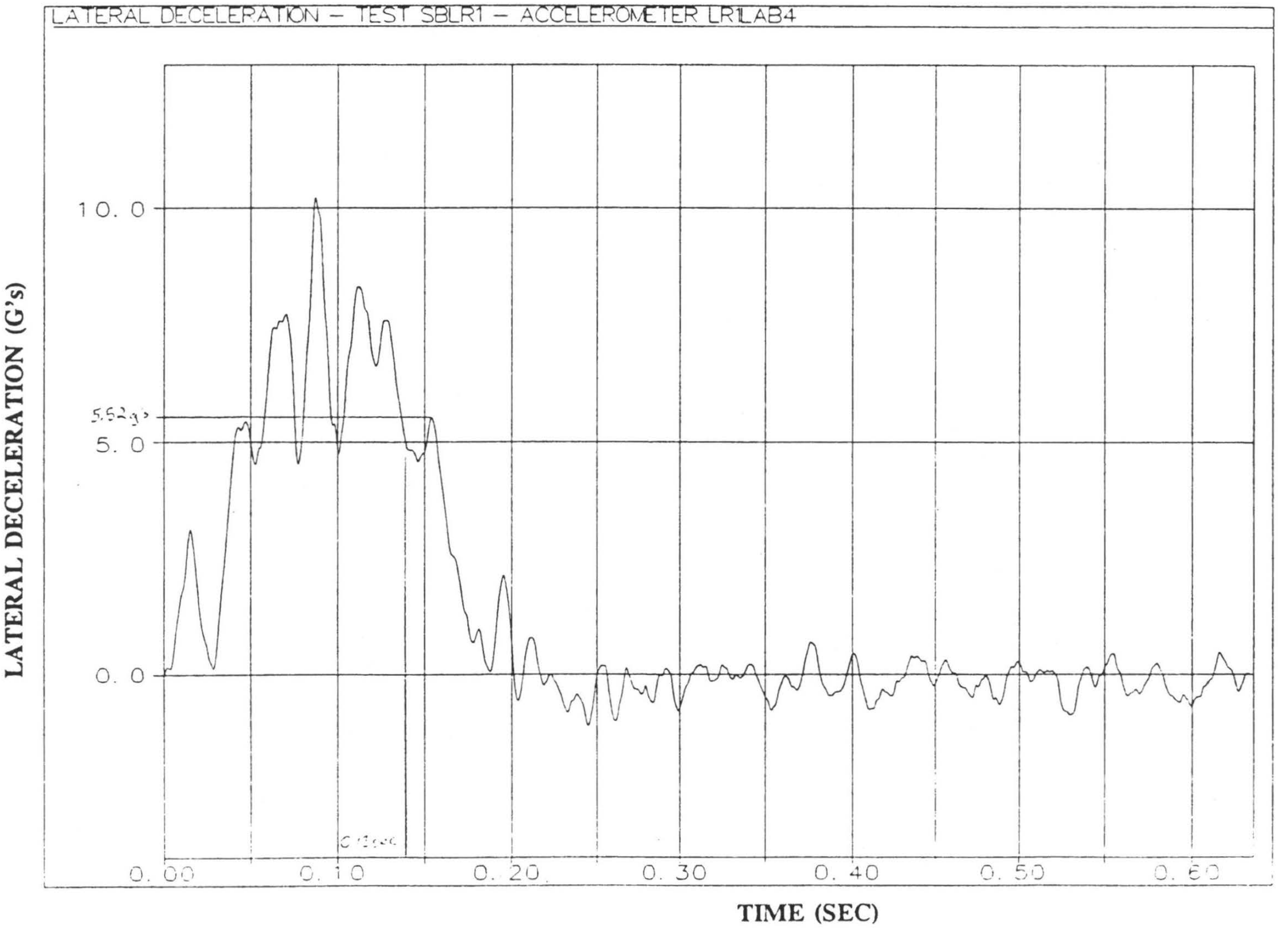


Figure 208. Graph of Lateral Deceleration, Test SBLR-2.