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BARRIERS IN CONSTRUCTION ZONES
VOLUME 2

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**Federal Highway
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Turner-Fairbank Highway
Research Center
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McLean, Virginia 22101

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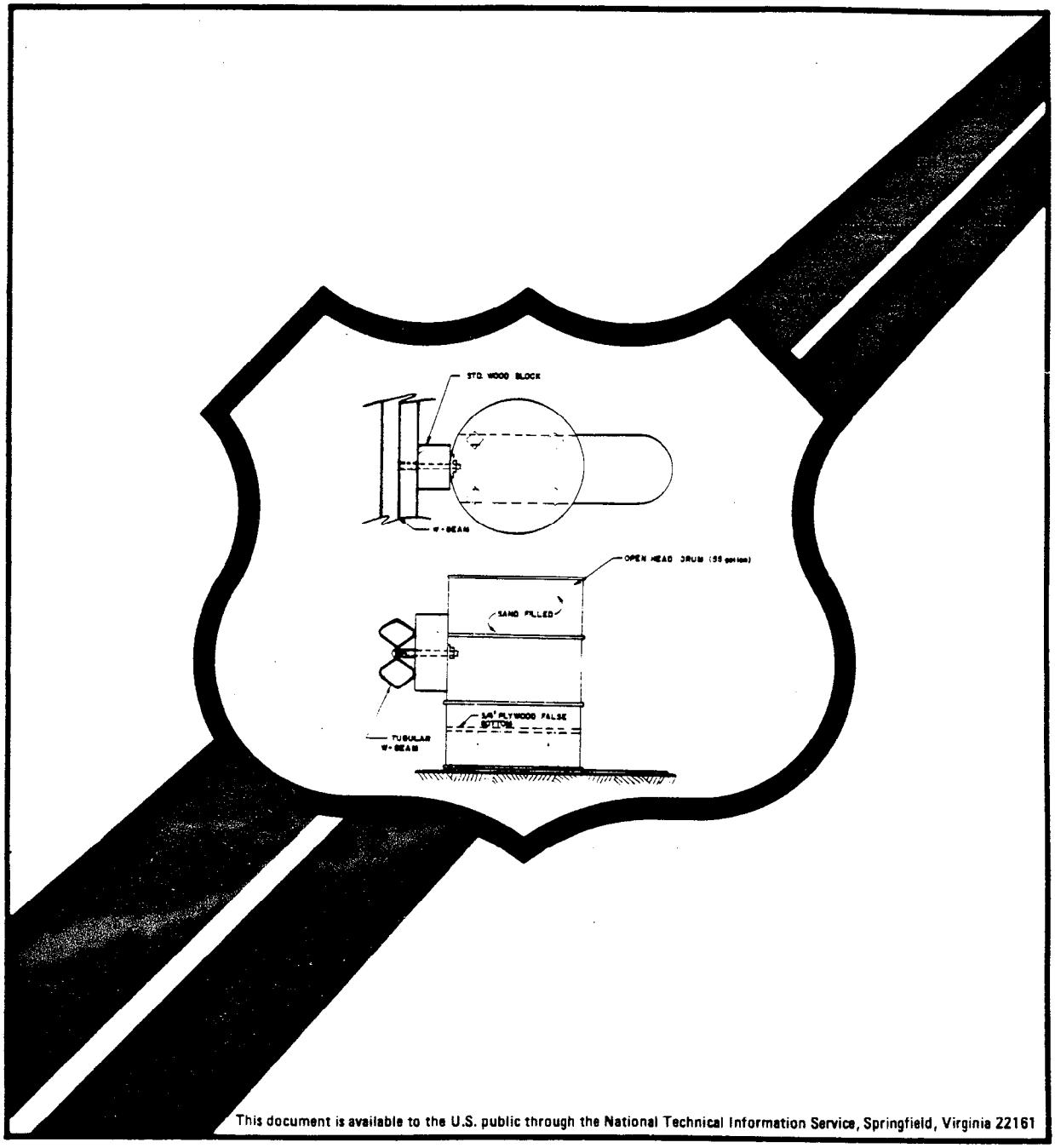
**Final Report
April 1985**



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16. Abstract

This study addressed the design and performance of longitudinal barriers for construction zones. The strengths of various connections for portable concrete median barriers (PCB) are analyzed and theoretical treatments of behavior of the PCB during a collision are presented. These analyses along with cost data and crash test information are used to develop a barrier performance rating and selection system. Crash tests on a non-deflecting PCB with various types and sizes of vehicles are reported.

This volume contains details of the crash tests performed on the PCB as well as tests on Stabilized Barrel/W-Section Barrier.

This report consists of four volumes:

Volume 1: Summary Report

Volume 2: Appendix A - Documentation of Crash Tests

Volume 3: Appendix B, C, D, E and F - Theoretical and Economic Analysis

Volume 4: The Response Of Atypical Vehicles During Collisions With Median Barriers

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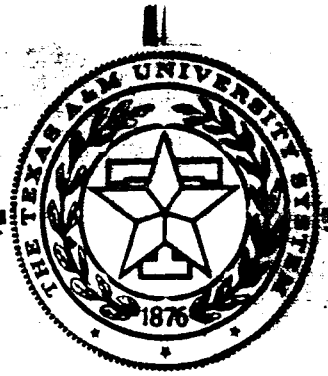

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BARRIERS IN CONSTRUCTION ZONES

VOLUME 2: Appendix A
Full-Scale Crash Tests

Prepared for
Contract DOT-FH-11-9458
Office of Research

Federal Highway Administration

U. S. Department of Transportation

by

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Texas A&M Research Foundation

Texas Transportation Institute

The Texas A&M University System

April 1985

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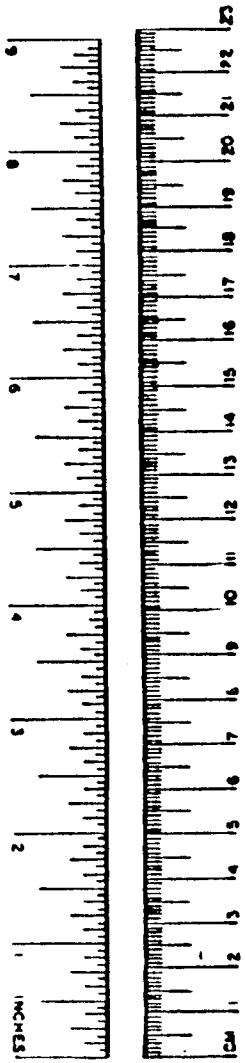
METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

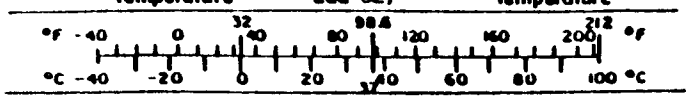


APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Full-Scale Crash Tests

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INSTRUMENTATION AND DATA ANALYSIS

The vehicles used in Tests 1 through 7 and Test 9 were towed toward the barrier using a cable reverse tow and guidance system to achieve the desired impact speed and angle. The vehicle was released from the tow and guide cables immediately prior to impact and was free-wheeling during the collision. The bus used in Test 8 was operated under its own power by remote control from a chase vehicle.

Each vehicle was equipped with triaxial accelerometers mounted near the center of gravity. Yaw, pitch, and roll rates were measured by on-board gyroscopic instruments. The electronic signals were telemetered to a base station for recording on magnetic tape and for display on a real-time strip chart. Provision was made for transmission of calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data.

Tape switches near the impact area were actuated by the vehicle to indicate the elapsed time over a known distance to provide measurement of impact speed. The initial contact also produced an "event" mark on the data record to establish the instant of impact.

Two anthropometric dummies (Alderson Hybrid II) were used in the bus test (Test 8). The Alpha dummy positioned in the driver's seat was restrained with original equipment lap belt, while the Beta dummy positioned in the right front passenger seat was unrestrained. Both were equipped with triaxial accelerometers mounted in the head and chest. Signals from these accelerometers were also telemetered to the base station and recorded on magnetic tape.

Data from the electronic transducers were digitized, using a micro-computer, for analysis and evaluation of performance. Several computer programs were used to process various types of data from the test vehicles.

The VEHICLE computer program uses data from the three vehicle-mounted linear accelerometers to compute accelerations, areas enclosed by acceleration-time curves, changes in velocity, changes in momentum, instantaneous forces, average forces, and maximum average accelerations over 0.050 sec intervals in each of the three directions. The VEHICLE program also plots acceleration versus time curves for the longitudinal, transversal and vertical directions.

The PLOTANGL Program uses the digitized data from the yaw, pitch, and roll charts to compute angular displacement (deg) at 0.001 sec and then instructs the Versatec Plotter (Model 1200 Electrostatic Plotter) to produce three reproducible plots: yaw versus time; pitch versus time; and roll versus time. It should be noted that these angular displacements are sequence dependent with the sequence being yaw - pitch - roll for the data presented herein. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

Still and motion photography were used to document the test, to obtain time-displacement data, and to observe phenomena occurring during the impact. Still photography was used to record conditions of the test vehicles and barrier before and after the test. Motion photography was used to record the collision event.

TEST REPORT 1

The test installation was 12 gauge tubular W-beam mounted on 55 gal (208 l) drums (barrels) with wooden blockout and skid plate as illustrated in Figure 1. The barrels were sand filled. A false bottom in each barrel was used to raise the center of gravity of the sand to coincide with the impact force. The tubular W-beam rail was in 25.0 ft (7.6 m) sections. The barrier was placed on unpaved level soil, similar to surfaces encountered in construction zones. The installation was 200.0 ft (61.0 m) long including a 25.0 ft (7.6 m) transition as shown in Figures 2 and 3.

Test 1 - 4,500 lb/44.3 mph/15 deg (2,041 kg/71.4 km/h/15 deg)

A 1975 Plymouth Grand Fury weighing 4,500 lb (2,041 kg) including instrumentation was used in this test. Initial impact occurred 1.5 ft (0.5 m) downstream from barrel 6. The rear of the vehicle contacted the rail near the point of initial impact. Contact was maintained through barrel 14. The vehicle was exceptionally stable during redirection and left the rail at a 3.5 deg exit angle. The maximum dynamic rail deflection was 2.1 ft (0.6 m). The rail rebounded 0.3 ft (0.1 m) leaving 1.8 ft (0.5 m) deflection after collision.

A summary of test results is presented in Figure 4. The maximum 0.050 sec average transverse acceleration was 4.0 g which is within the acceptable 5 g limit given in TRC 191 (1). The average acceleration on the vehicle, perpendicular to the barrier, from impact until the vehicle became parallel to the barrier was only 1.3 g. The longitudinal 0.050 sec average was a modest -1.4 g.

Before and after photographs of the test installation and vehicle are shown in Figure 5. Damage to both vehicle and barrier was negligible.

Sequential photographs of the collision are presented in Figure 6. A tabulation of time, displacement, and specific events is summarized in Table 1.

The linear accelerometer traces are presented in Figure 7 through 11. The angular displacements yaw, pitch and roll are presented in Figures 12, 13 and 14, respectively. The results are order related and must be evaluated in this sequence.

Restoration

The barrier was pushed to its original position in 30 minutes by two men with a forklift. The extent of the permanent deformation was isolated to one 25.0 ft (7.6 m) rail segment. The rail segment was between post 6 and post 10 with a 1/2 in. (1.3 cm) permanent set. The damage to the rail segment was so slight replacement was not considered necessary. Four barrels in the immediate area of impact were deformed slightly adjacent to the wooden block. The barrels were not replaced because the deformation would not effect performance.

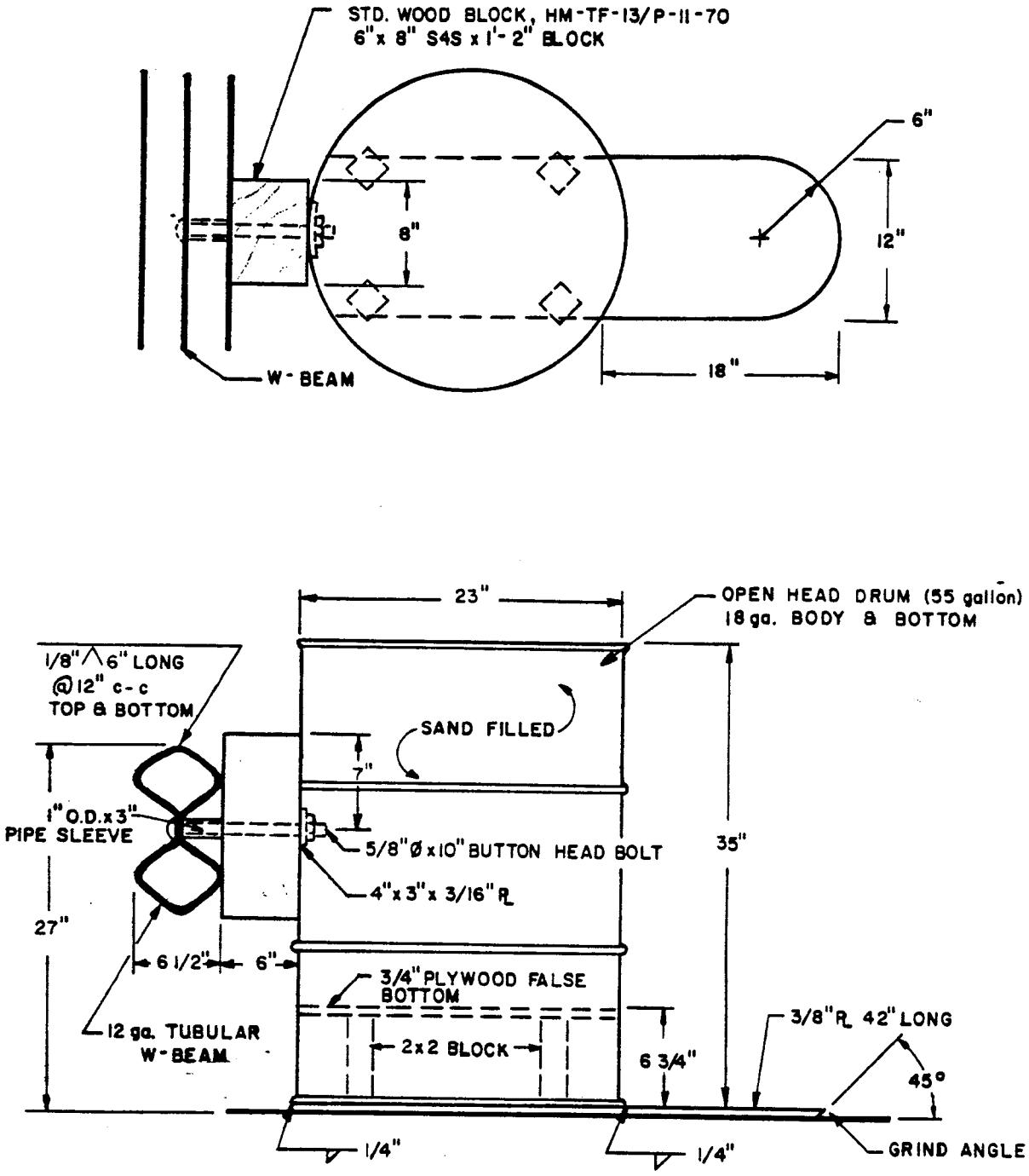


Figure 1. Stabilized Barrel System #3 Detail.

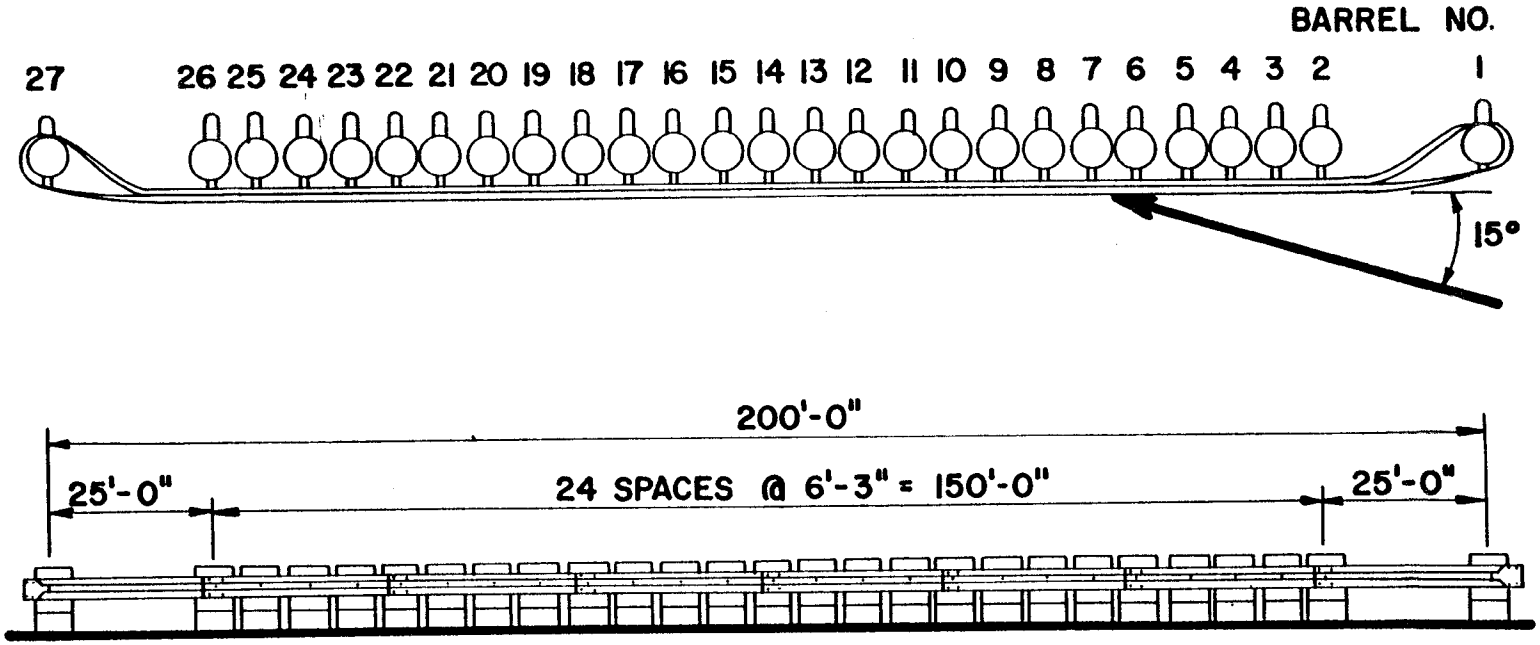


Figure 2. Test Installation For Test 3825-1.

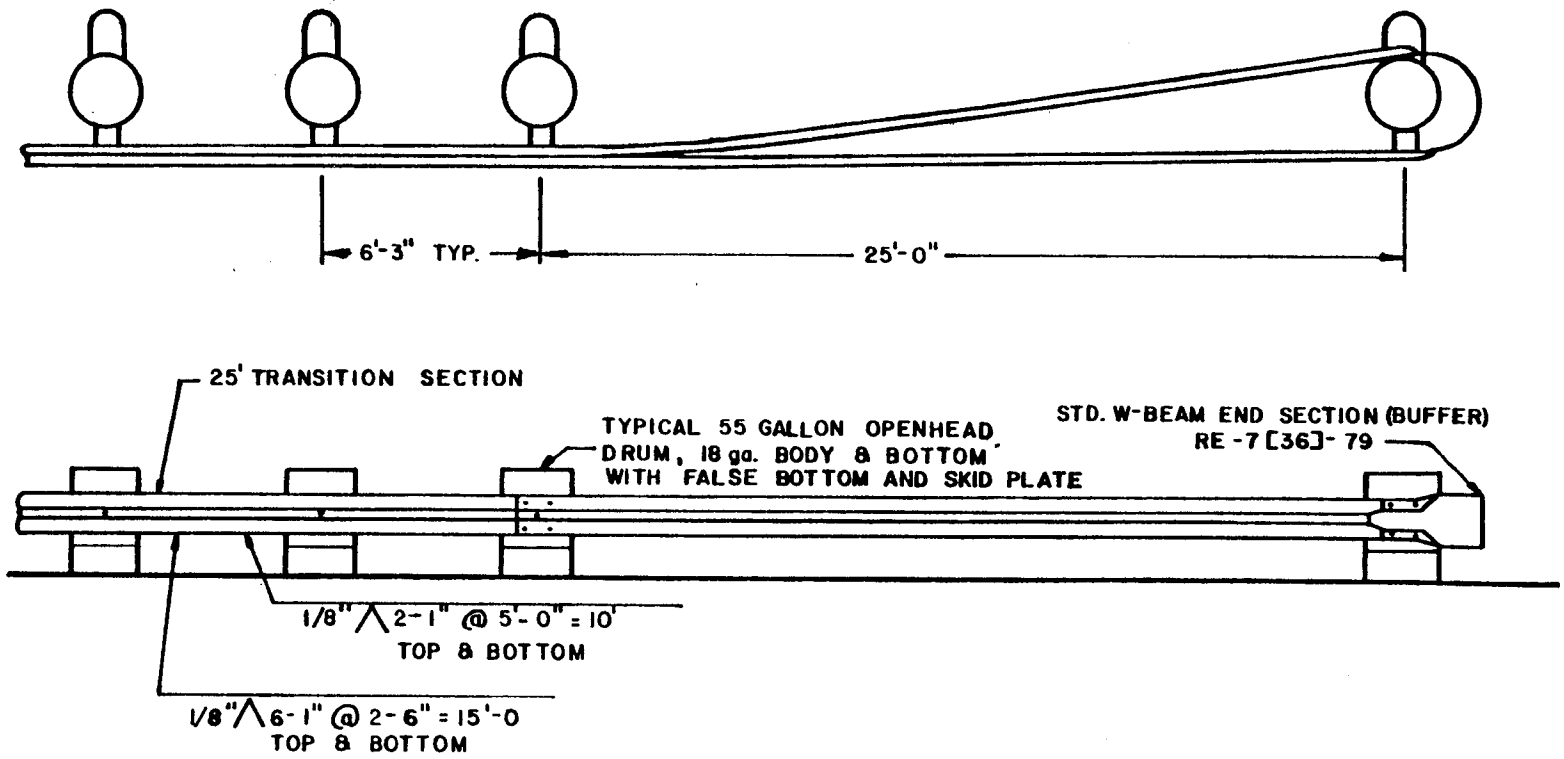
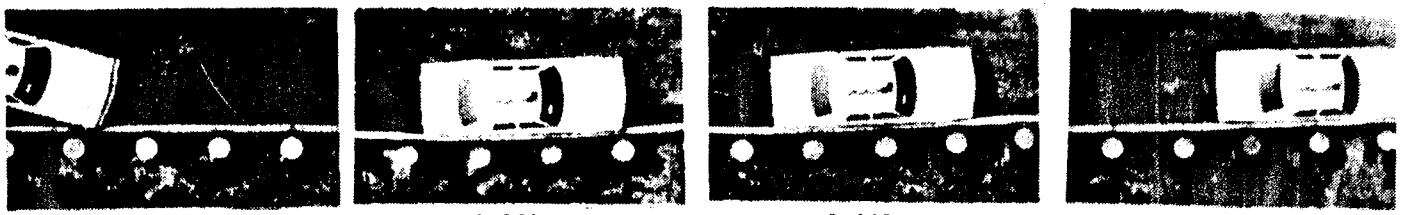
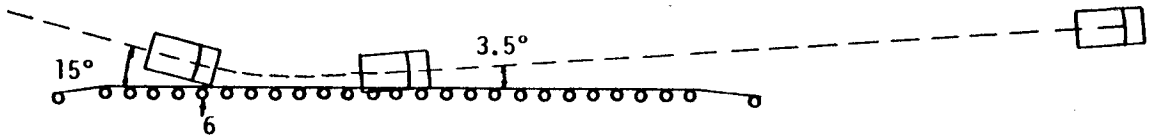
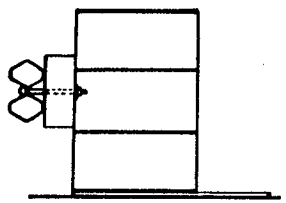


Figure 3. Terminal Detail For Test 3825-1.







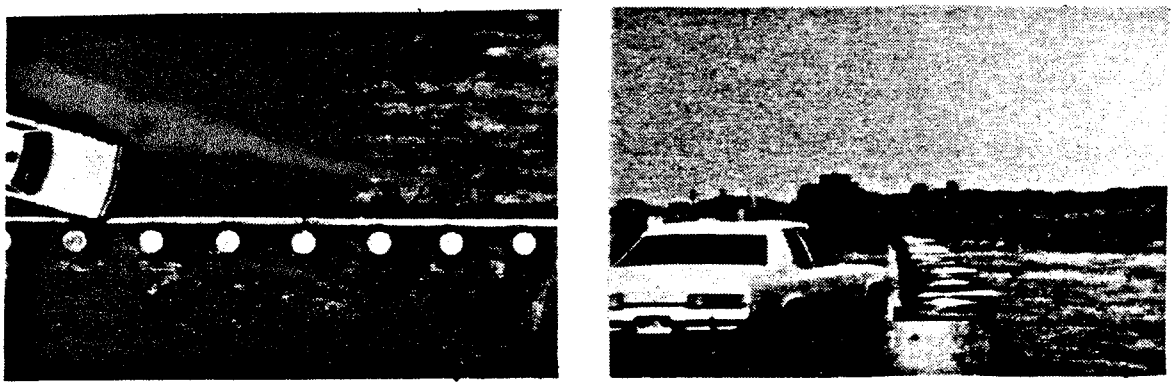
Stablilized Barrel
Beam No. 3
Construction Barrier

Test No.	3825-1
Date	11/08/79
Rail	12 gauge Tubular W-beam
Post	55 gal (208 ℓ) Open Head Drum, 18 gal (68 ℓ) Bottom & Body w/False Bottom & Skid Plate
Post Spacing	6.2 ft (1.9 m)
Post to Anchor Spacing	25.0 ft (7.6 m)
Beam Rail Deflection	200.0 ft (61.0 m)
Max. Dynamic	2.1 ft (0.6 m)
Max Permanent	1.8 ft (0.5 m)

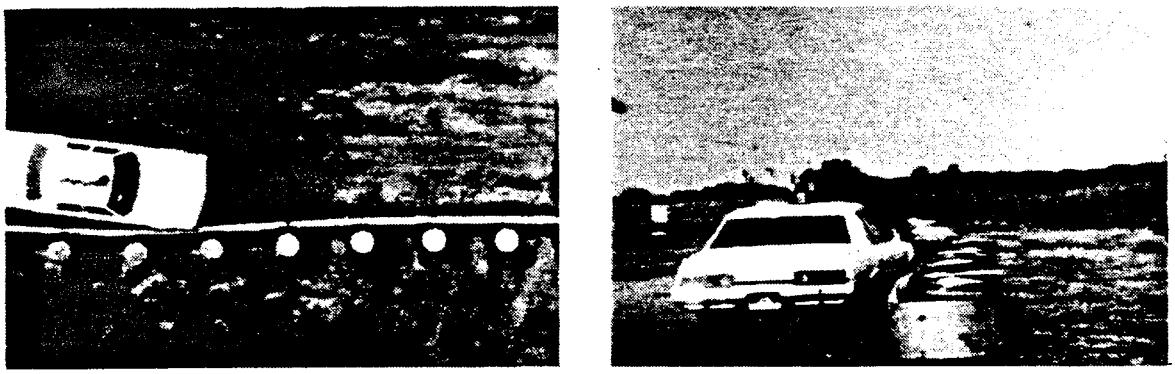
Vehicle	1975 Grand Fury
Vehicle Weight	4,500 lb (2,041 kg)
Impact Speed	44.3 mph (71.4 km/h)
Impact Angle	15 deg
Exit Speed	33.3 mph (53.6 km/h)
Exit Angle	3.5 deg
Vehicle Acceleration (Max. 0.050 sec avg.)	
Longitudinal (rt & lt avg)	-1.4 g
Transverse	4.0 g
Vertical	0.8 g
Vehicle Damage	
TAD	1-RFQ-1
SAE	01RFEW1

Figure 4. Summary of Results for Test 3825-1.

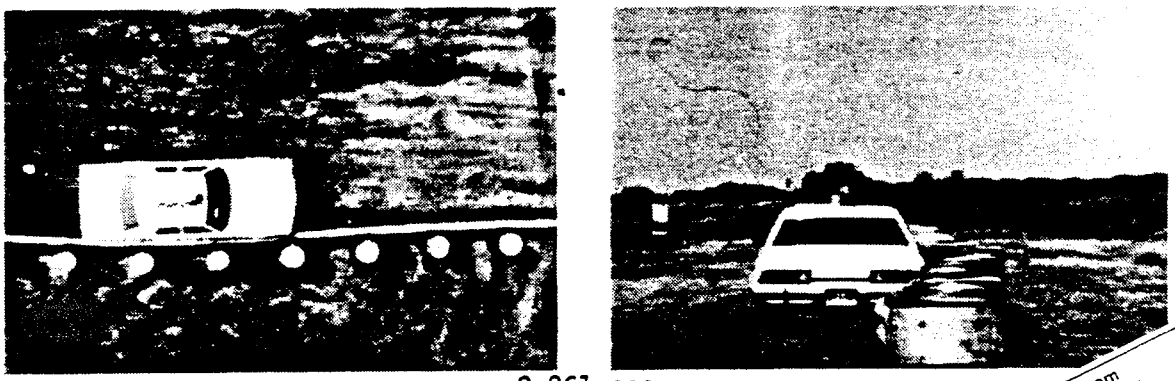
Figure 5. Vehicle and Rail Before and After Test 3825-1.



0.000 sec



0.140 sec



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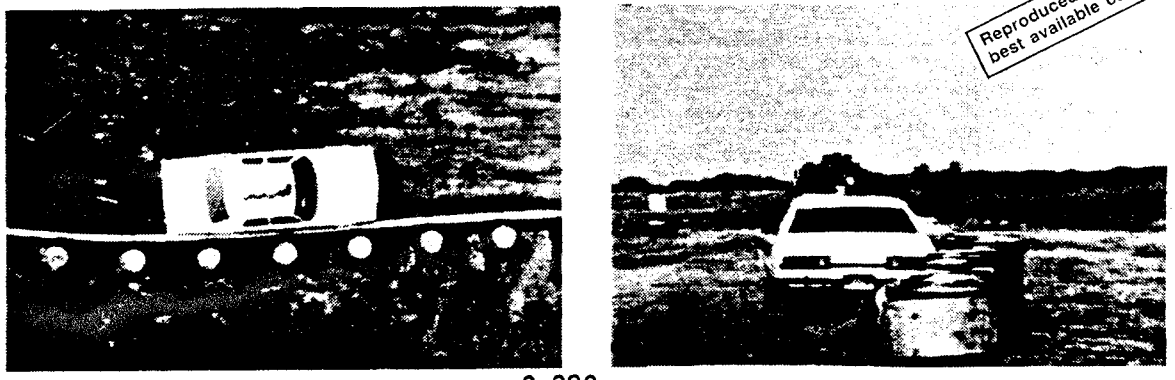
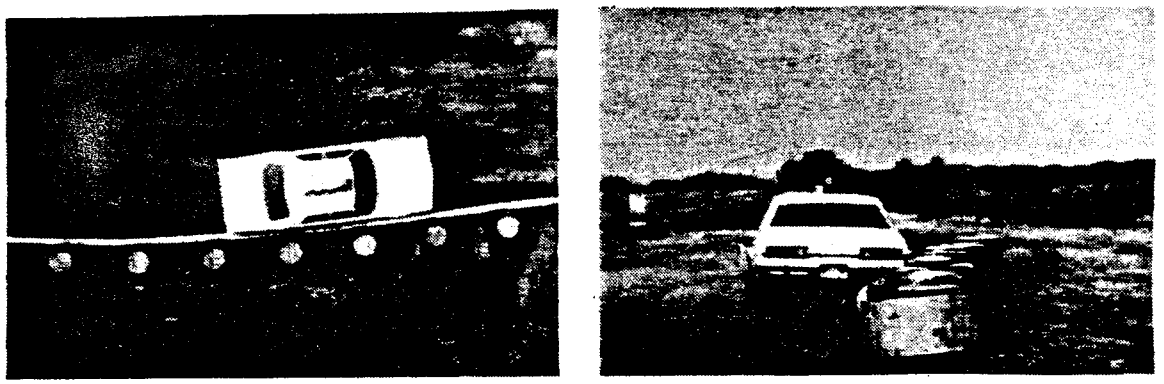
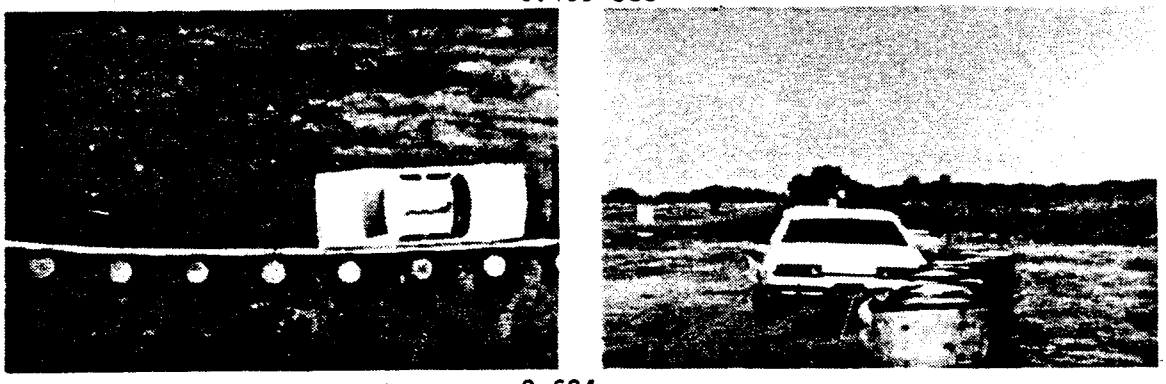


0.389 sec

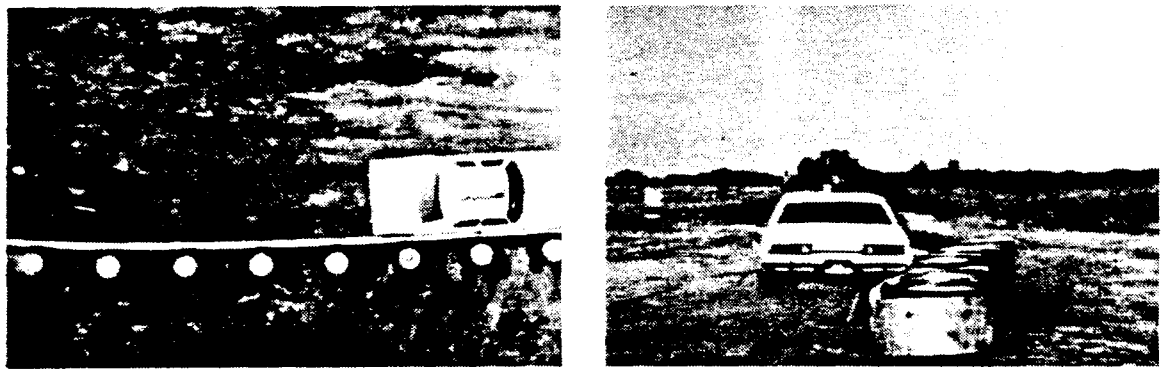
Figure 6. Sequential Photographs for Test 3825-1.



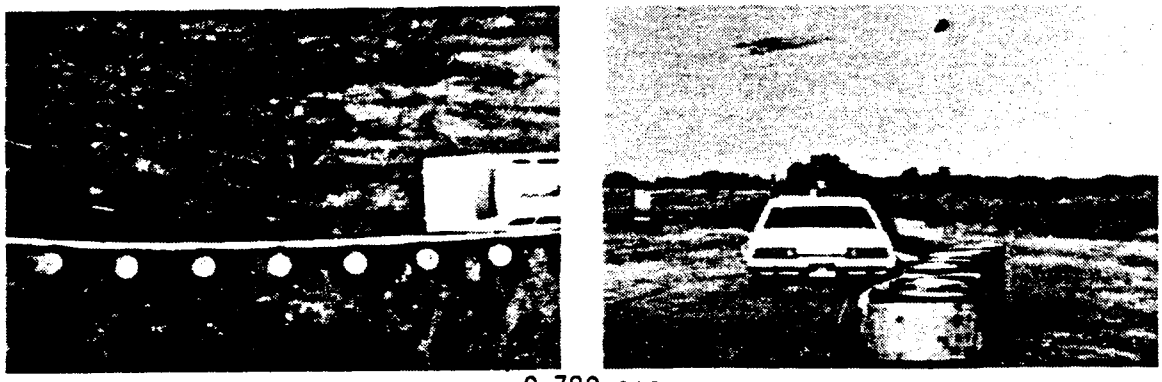
0.469 sec



0.624 sec



0.727 sec



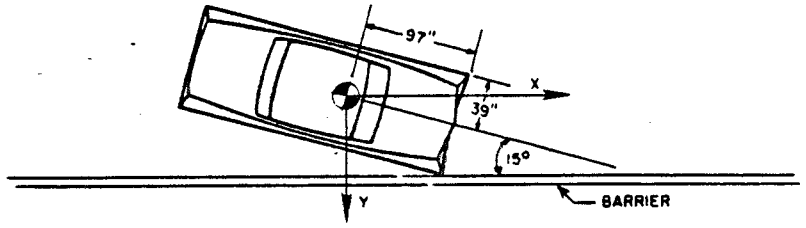
0.780 sec

Figure 6 (Continued). Sequential Photographs for Test 3825-1.

Table 1. Time, Displacement, Event Summary for Test 3825-1.

TIME (sec)	X-DISPLACEMENT (ft)	Y-DISPLACEMENT (ft)	EVENT
-0.016	-1.05	-0.27	
-0.008	-0.48	-0.13	
0.000	0.00*	0.00*	Impact
0.016	0.94	0.28	
0.031	1.93	0.62	
0.047	2.91	0.81	Lt. fender begins to ride rail
0.062	3.92	1.06	
0.078	4.82	1.29	
0.094	5.66	1.44	
0.109	6.64	1.63	
0.140	8.48	1.88	
0.179	10.77	2.18	
0.226	13.59	2.71	
0.260	15.79	2.97	Full side of car in contact with rail
0.299	18.09	3.24	Car beginning to redirect
0.351	21.03	3.17	
0.390	23.28	3.17	
0.429	25.60	3.24	
0.468	27.82	3.33	Maximum rail deflection
0.494	29.31	3.39	Car motion parallel to rail
0.546	32.30	3.14	Rail begins to rebound
0.598	35.27	3.14	
0.624	36.79	3.14	
0.676	39.74	2.92	Car leaving rail
0.728	42.65	2.74	
0.780	45.59	2.24	

*Location of vehicle c.g. at point of impact with barrier.



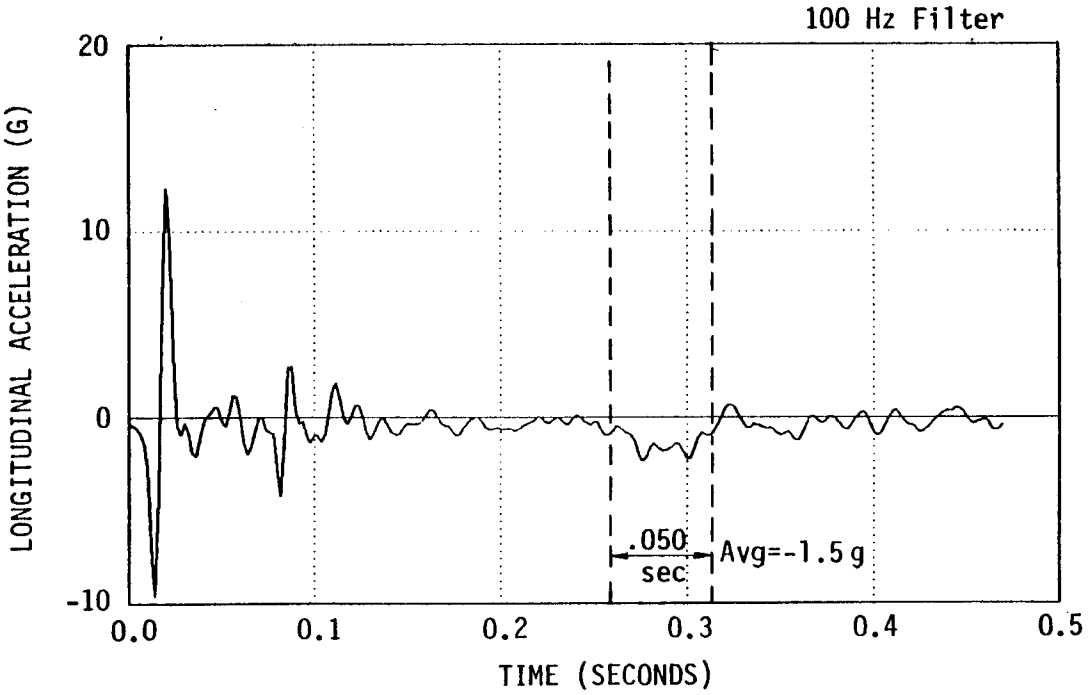


Figure 7. Vehicle Right Longitudinal Accelerometer Trace for Test 3825-1.

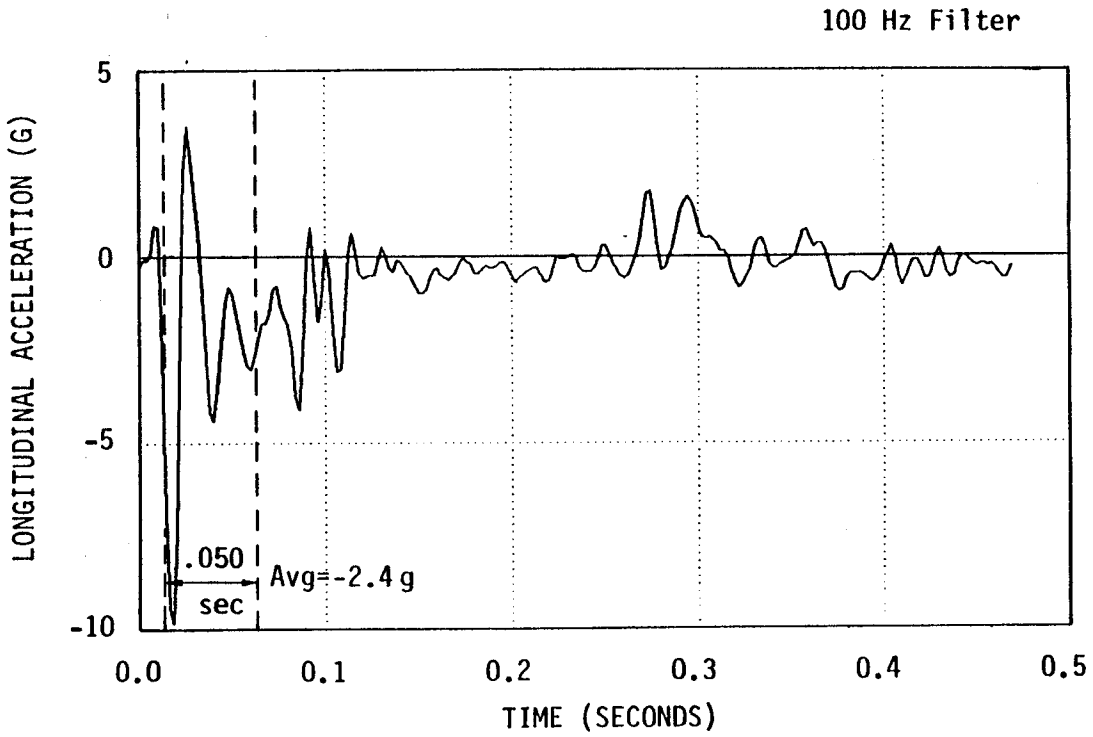


Figure 8. Vehicle Left Longitudinal Accelerometer Trace for Test 3825-1.

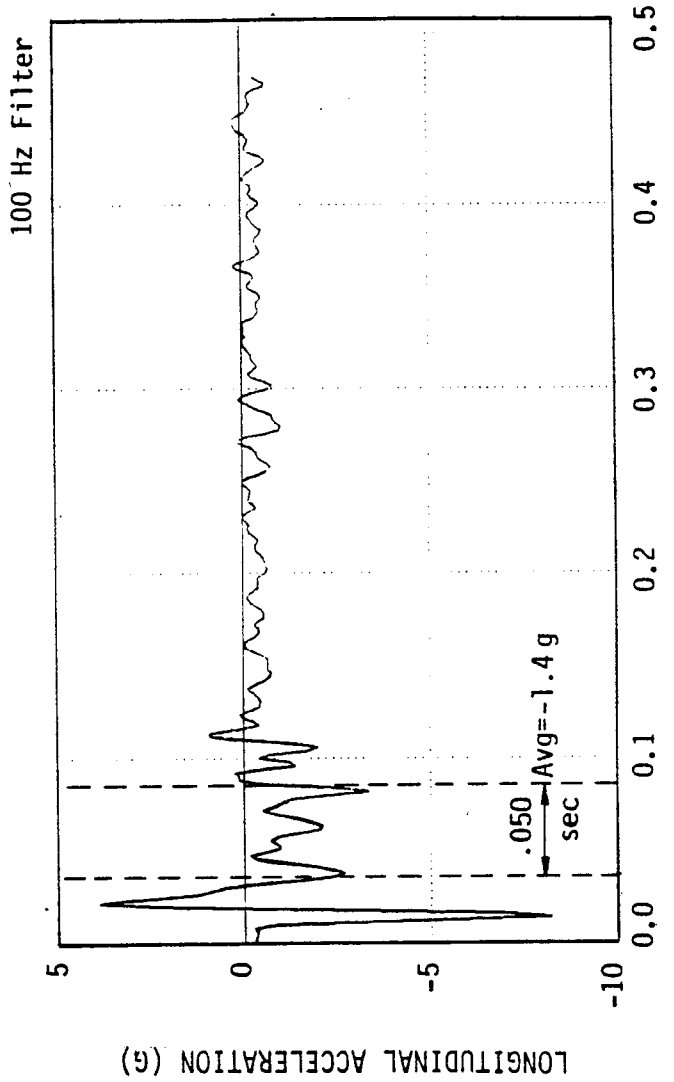


Figure 9. Vehicle Longitudinal Accelerometer Trace for Test 3825-1 (Averaged from Two Accelerometers).

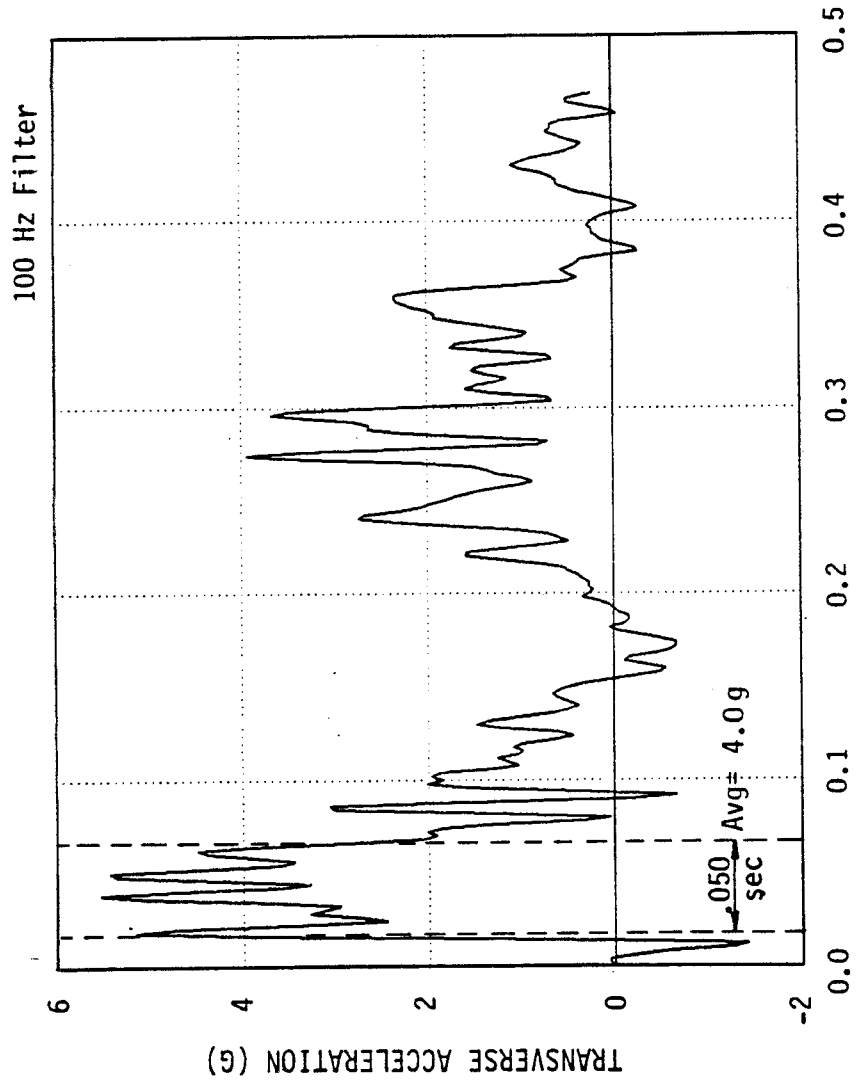


Figure 10. Vehicle Left Transverse Accelerometer Trace for Test 3825-1.

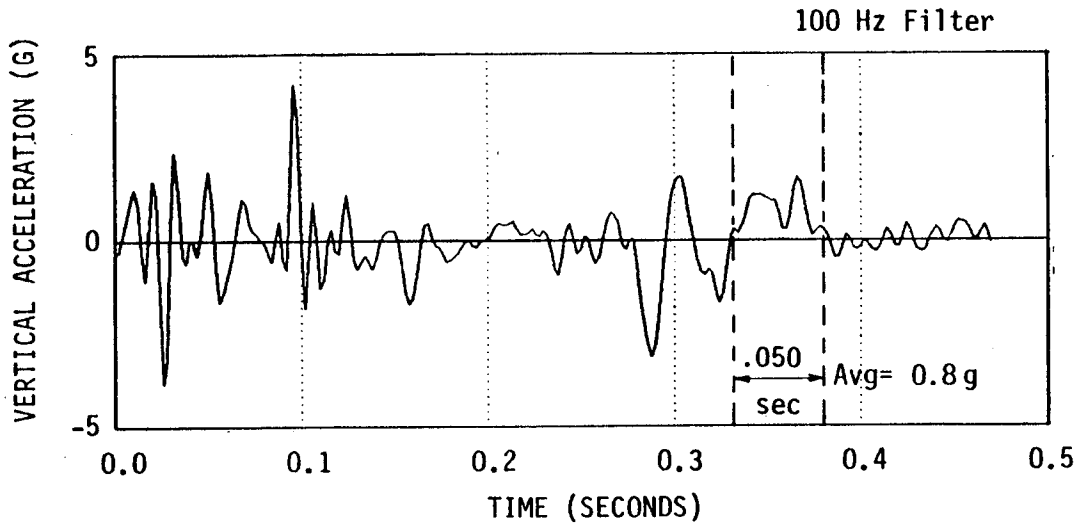
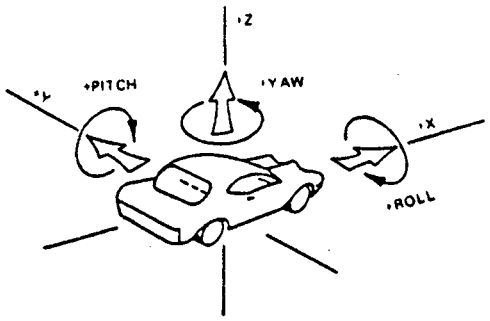


Figure 11. Vehicle Left Vertical Accelerometer Trace for Test 3825-1.



Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

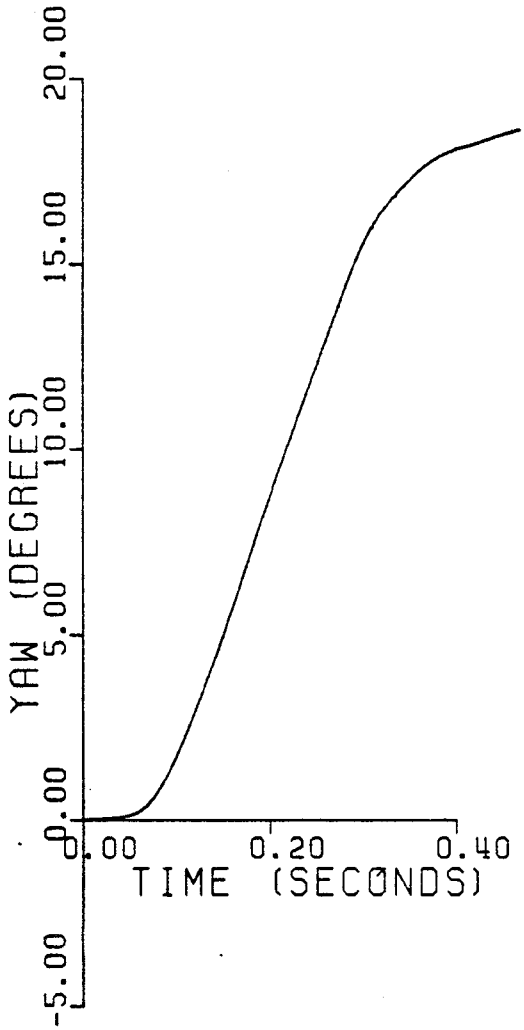
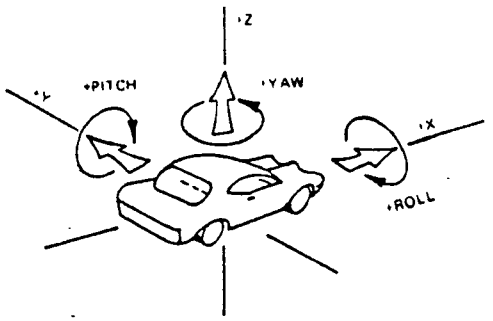


Figure 12. Vehicle Yaw Angle for Test 3825-1.



Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

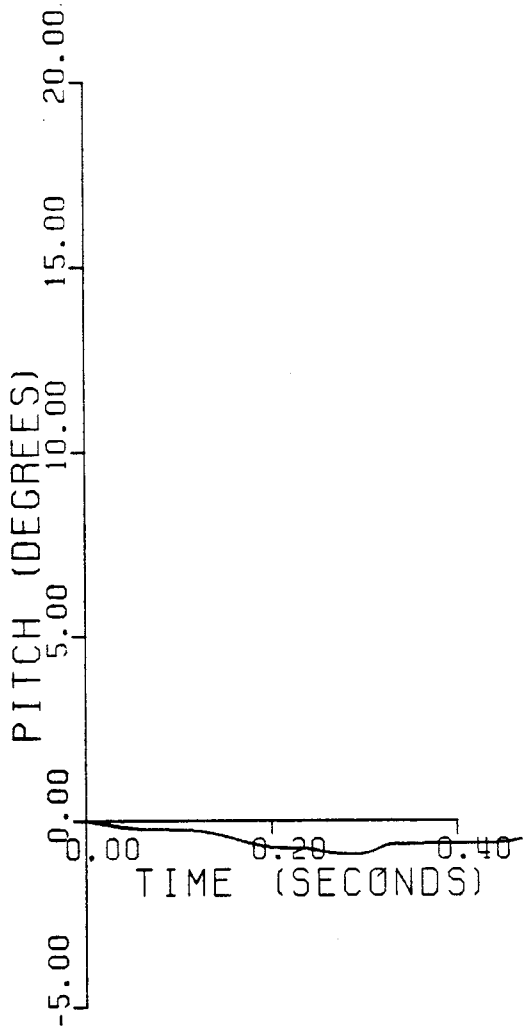
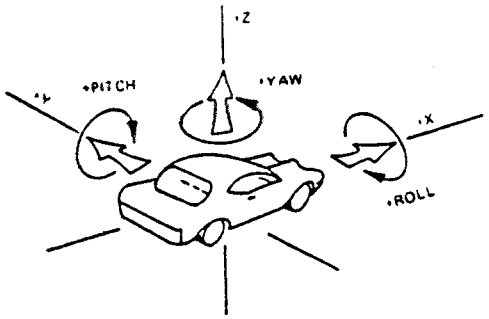


Figure 13. Vehicle Pitch Angle for Test 3825-1.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

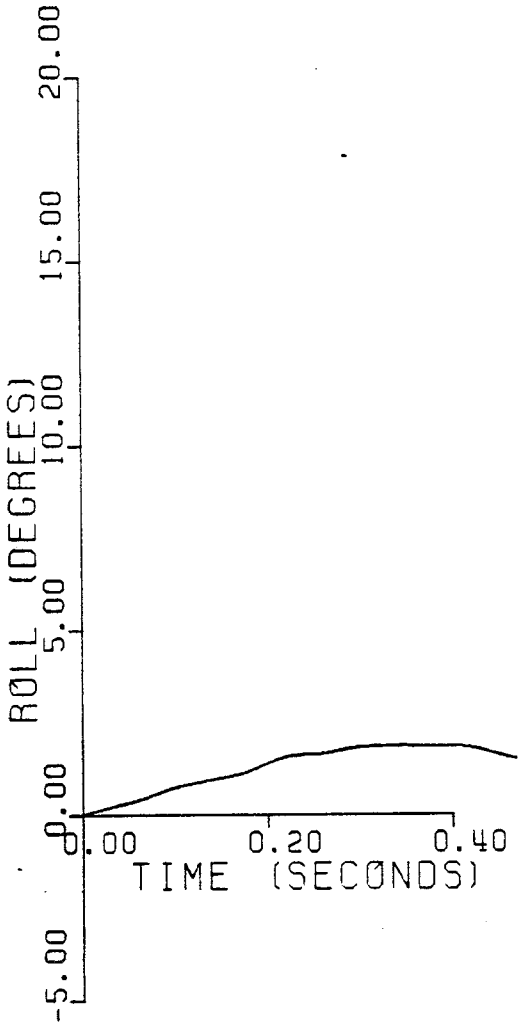


Figure 14. Vehicle Roll Angle for Test 3825-1.

TEST REPORT 2

The test installation was 12 gauge tubular W-beam mounted on 55 gal (208 l) drums (barrels) with wooden blockout and skid plate as illustrated in Figure 15. The barrels were sand filled. A false bottom in each barrel was used to raise the center of gravity of the sand to coincide with the impact force. The section of tubular W-beam was in 25.0 ft (7.6 m) lengths. The barrier was placed on unpaved level soil, similar to surfaces encountered in construction zones. The installation was 200.0 ft (61.0 m) long including a 25.0 ft (7.6 m) terminal and 25.0 ft (7.6 m) transition as shown in Figures 16 and 17. This test was performed immediately after Test 3825-1. The installation was only repositioned and no structural elements were replaced before testing.

Test 2 - 4,500 lb/61.7 mph/15.5 deg (2,041 kg/99.4 km/h/15.5 deg)

In Test 2, a 1975 Plymouth Grand Fury impacted the barrier at 15.5 deg and 61.7 mph (99.4 km/h). The vehicle weighed 4,500 lb (2,041 kg) including telemetry equipment. Photographs of the vehicle and barrier are shown in Figures 18 and 19. In Figure 18, the slight damage to the vehicle before Test 2 occurred in Test 1. Results of Test 2 are summarized in Figure 20.

Sequential photographs are presented in Figure 21. Table 2 is a summary of time and displacement related to specific events. Impact occurred approximately 3.0 ft (0.9 m) downstream of barrel 6. The rear of the vehicle contacted the rail 2.0 ft (0.6 m) downstream from point of impact. The vehicle remained quite stable during redirection. During the test no tendency on the part of the vehicle to mount the rail occurred. The vehicle exited the barrier at an angle of 12.3 deg at a speed of 51.9 mph (83.5 km/h). In Figure 19 the rotation of the first three barrels can be seen. This rotation is the result of the longitudinal thrust caused by friction of the vehicle and by deflection of the rail. The maximum 0.050 sec average transverse acceleration was 4.6 g. This compares favorably with the 5 g acceptance limit from TRC 191 (1). The longitudinal acceleration was -2.0 g, well within the 5 g preferred limit. The maximum rail deflection was 5.4 ft (1.6 m) but the vehicle only penetrated into the protected zone 4.7 ft (1.4 m).

The accelerometer traces are presented in Figures 22 through 26. The angular displacements yaw, pitch, and roll are presented in Figures 27, 28 and 29, respectively. These results are order related and must be evaluated in this sequence. The exceptionally low values of roll and pitch coupled with the smooth development of the yaw required for redirection illustrate the ideal nature of the vehicle-barrier interaction.

Restoration

Two men with a forklift were required to push the barrier back to its original position as shown by Figure 30. Restoration was completed in 60 minutes.

Significant permanent deformation was confined to the 25.0 ft (7.6 m) rail section between barrels 6 and 10. The maximum permanent set was 3.9 in. (9.9 cm) located 2.0 ft (0.6 m) downstream from barrel 7. This rail section and barrels 6 through 8 were replaced.

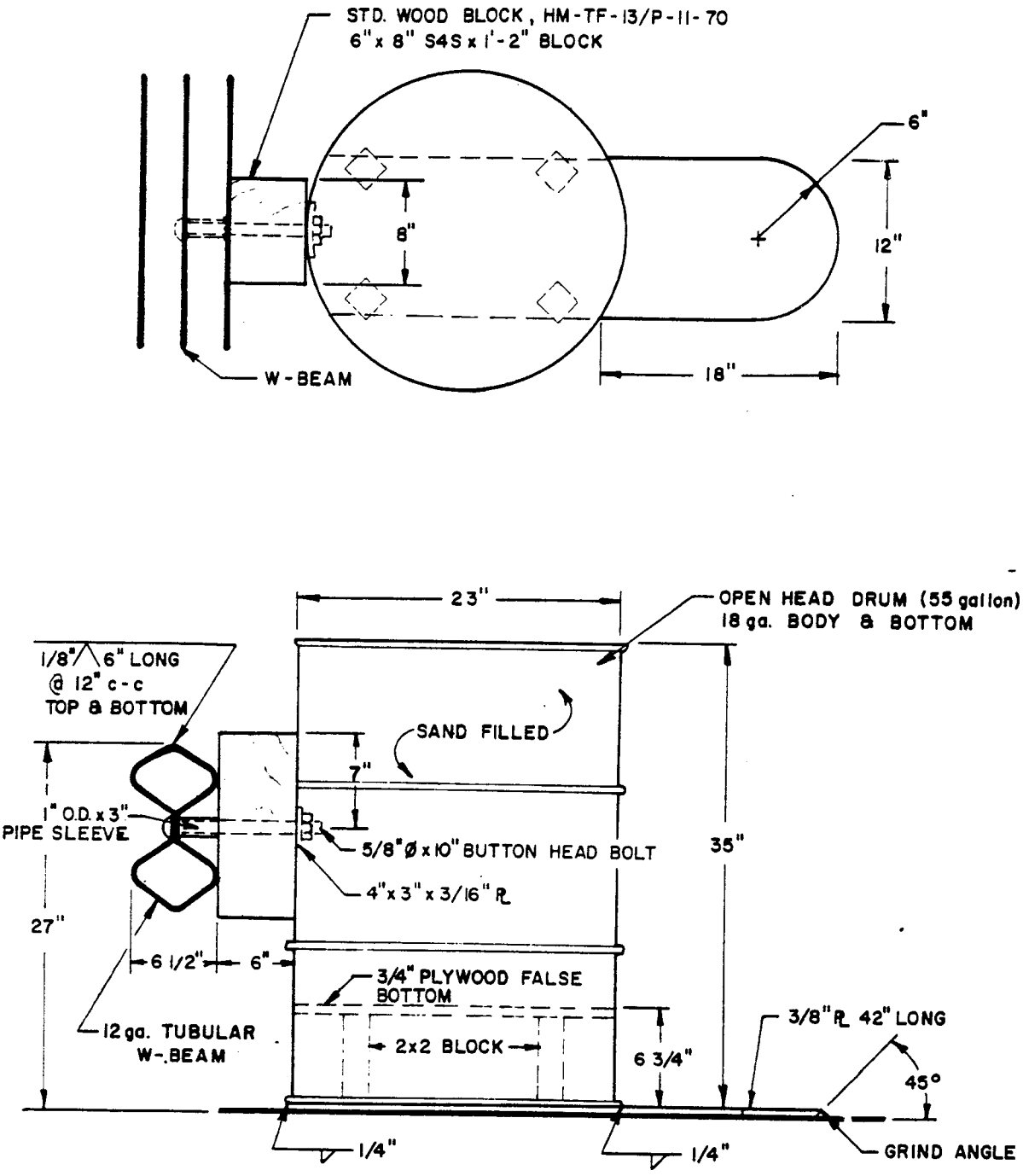


Figure 15. Stabilized Barrel System #3 Detail.

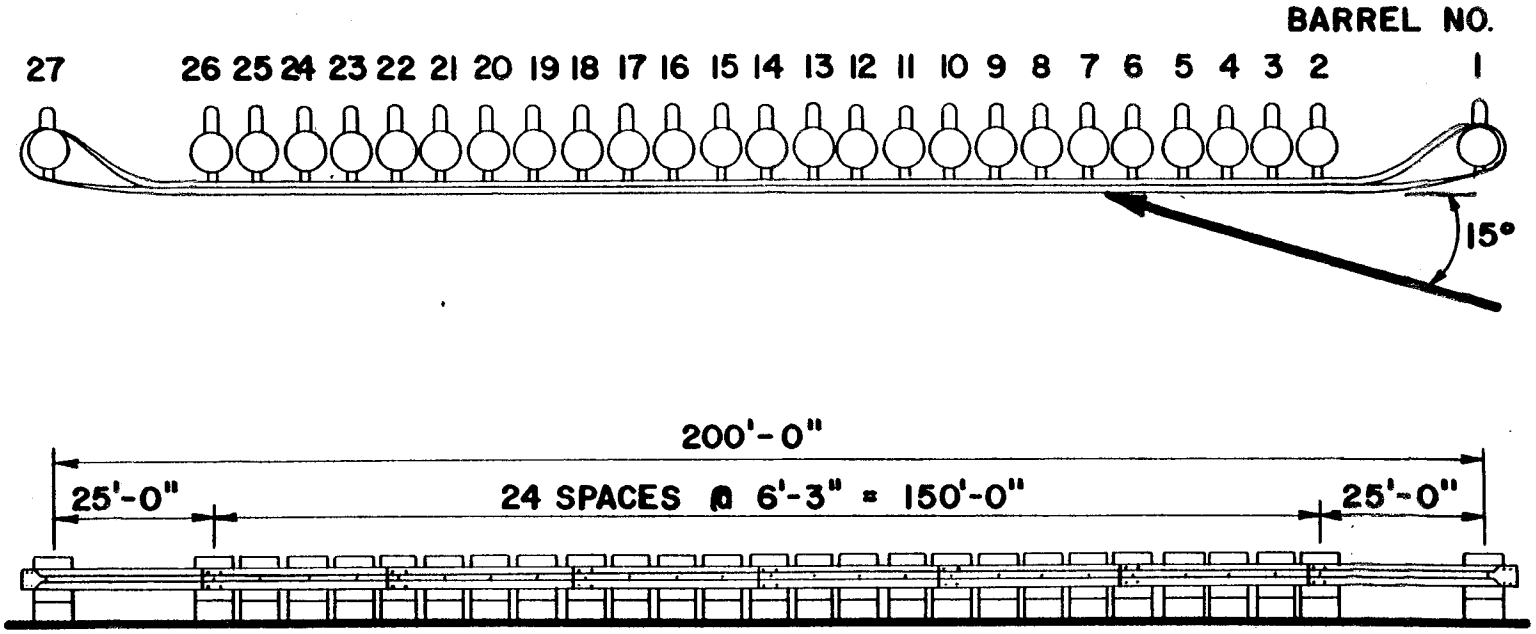


Figure 16. Test Installation 3825-2.

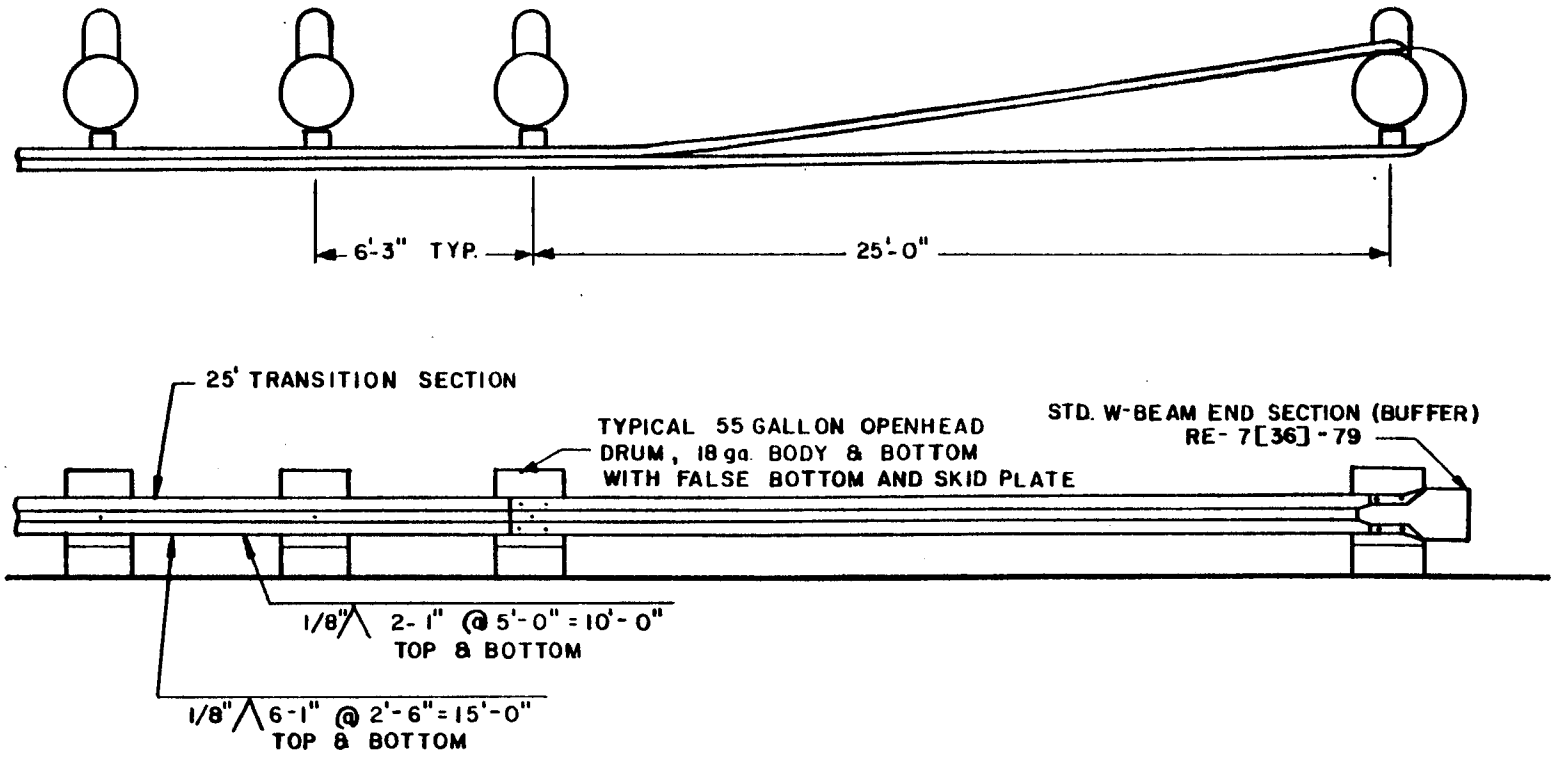


Figure 17. Terminal Detail For Test 3825-2.

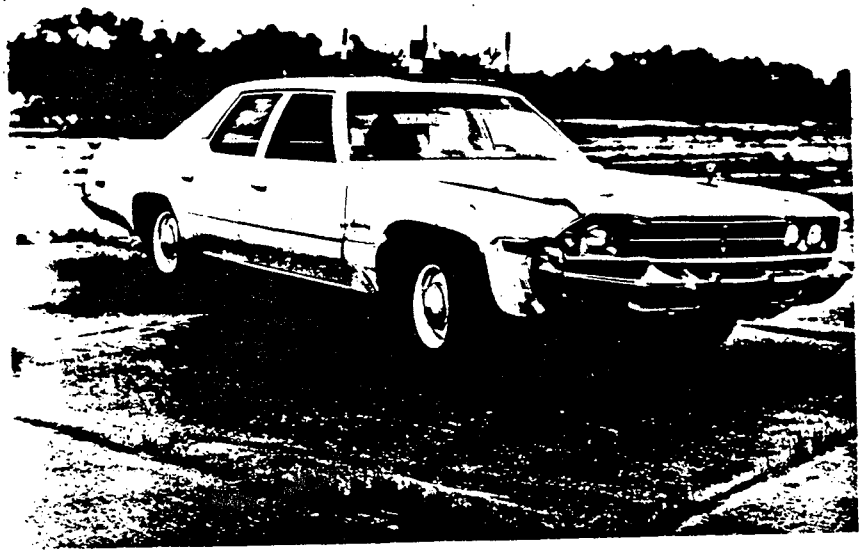
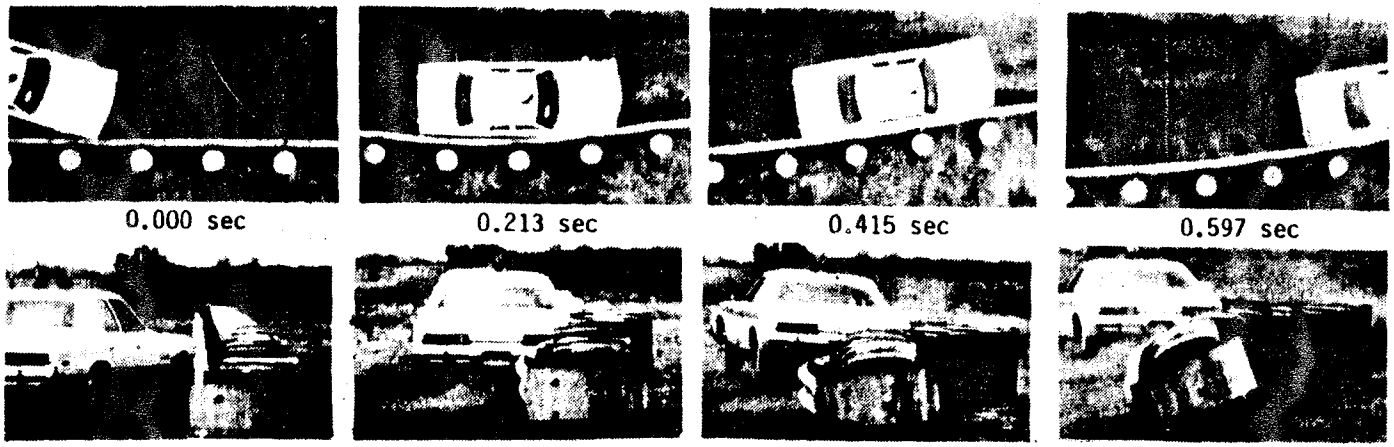
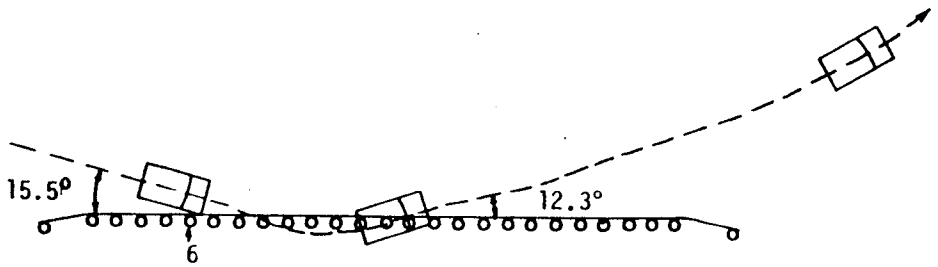
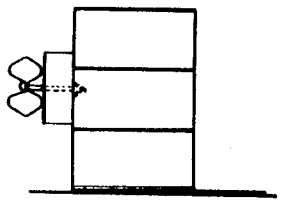


Figure 18. Vehicle Before and After Test 3825-2.

Figure 19. Rail Before and After Test 3825-2.



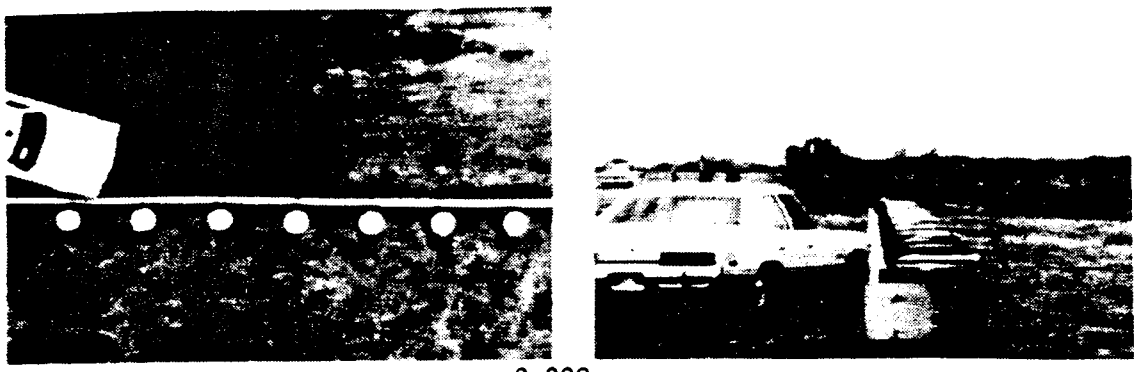




Stablilized Barrel
Beam No. 3
Construction Barrier

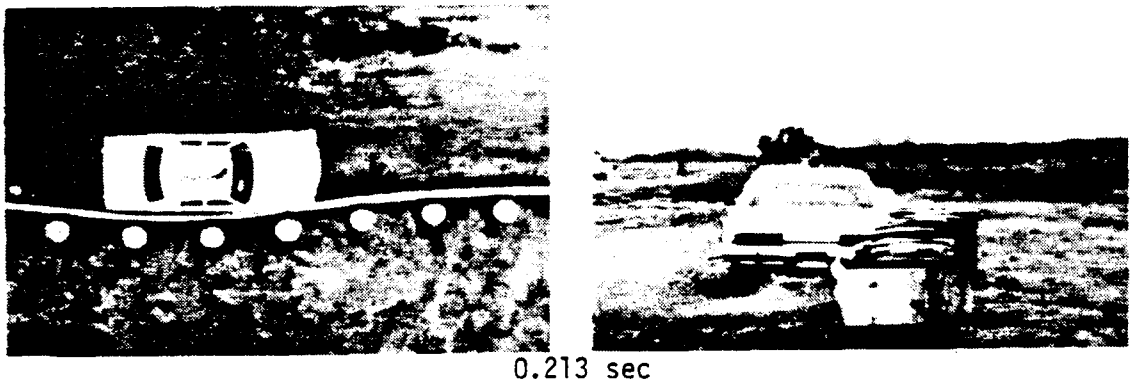
Test No.	3825-2	Vehicle	1975 Grand Fury
Date	11/08/79	Vehicle Weight.	4,500 lb (2,041 kg)
Rail	12 gauge tubular W-beam	Impact Speed.	61.7 mph (99.4 km/h)
Post	55 gal (208 ℓ) Open Head Drum, 18 gal (68 ℓ) Bottom and Body w/False Bottom & Skid Plate	Impact Angle.	15.5 deg
		Exit Speed.	51.9 mph (83.5 km/h)
		Exit Angle.	-12.3 deg
		Vehicle Acceleration (Max. 0.050 sec avg)	
		Longitudinal (ft & lt avg).	-2.0 g
		Transverse.	4.6 g
		Vertical.	1.6 g
Post Spacing	6.2 ft (1.9 m)	Vehicle Damage	
Post to Anchor Spacing	25.0 ft (7.6 m)	TAD	1-RFQ-2
Length of Installation	200.0 ft (61.0 m)	SAE	01RFEW2
Beam Rail Deflection			
Max. Dynamic	5.4 ft (1.6 m)		
Max. Permanent	5.0 ft (1.5 m)		

Figure 20. Summary of Results for Test 3825-2.

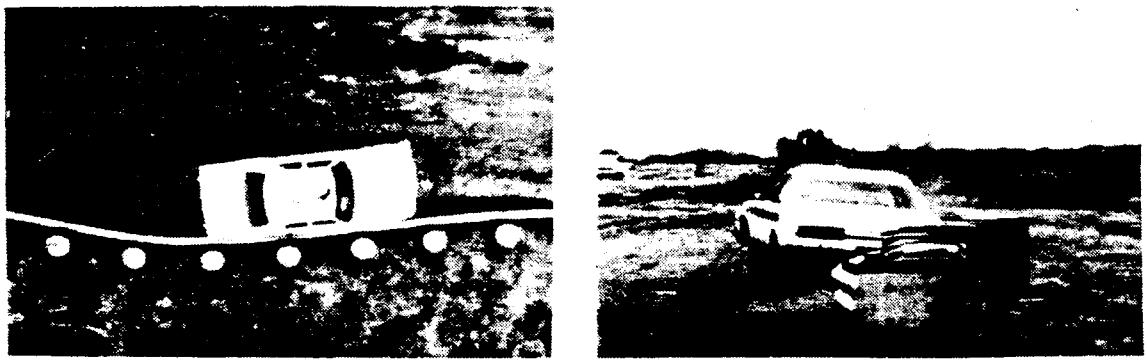


0.000 sec

0.104 sec

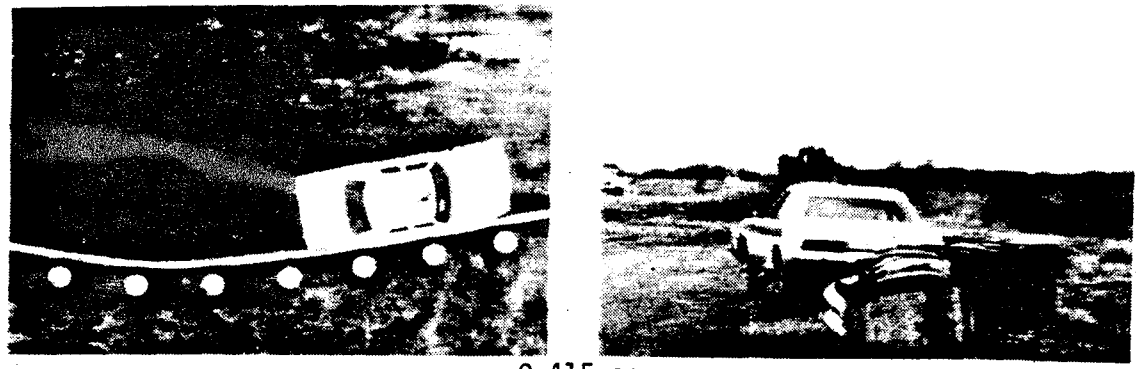


0.213 sec



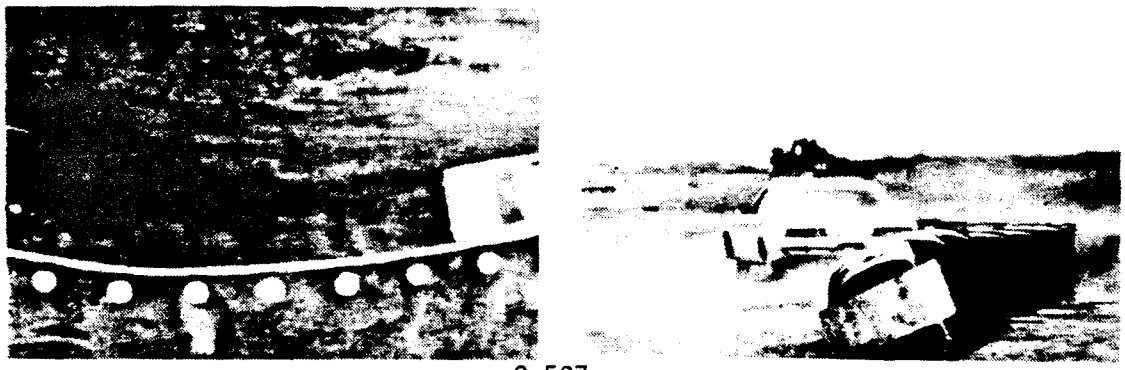
0.312 sec

Figure 21. Sequential Photographs for Test 3825-2.

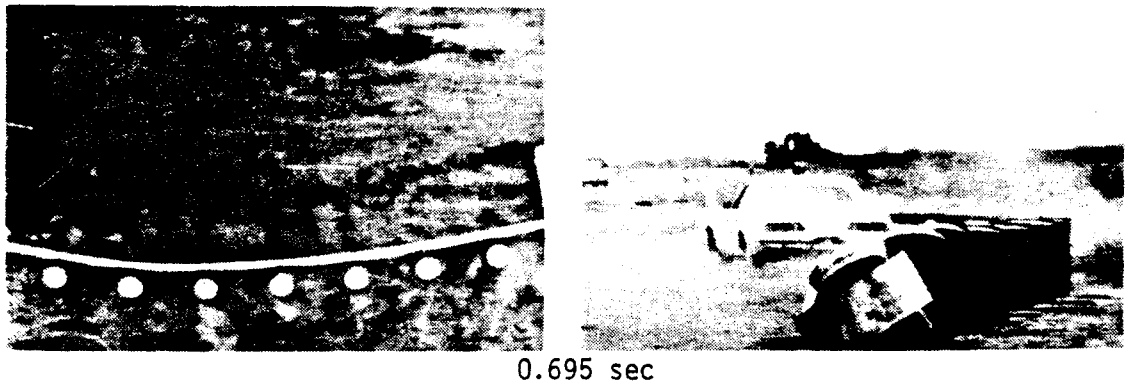


0.415 sec

0.519 sec



0.597 sec



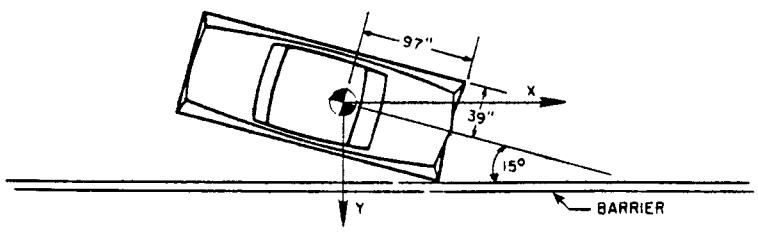
0.695 sec

Figure 21 (Continued). Sequential Photographs for Test 3825-2.

Table 2. Time, Displacement, Event Summary for Test 3825-2.

TIME (sec)	X-DISPLACEMENT (ft)	Y-DISPLACEMENT (ft)	EVENT
-0.029	-2.580	0.738	
-0.018	-1.613	0.496	
-0.008	-0.666	0.189	
0.000	0.000*	0.000*	Impact
0.026	2.246	-0.731	
0.052	4.519	-1.300	
0.078	6.753	-1.796	
0.104	8.875	-2.188	
0.114	9.776	-2.377	Front wheels begin veer
0.130	11.017	-2.619	
0.156	13.166	-3.117	
0.182	15.415	-3.465	
0.216	18.281	-4.004	Full side contact
0.234	19.807	-4.241	
0.260	22.051	-4.544	
0.288	24.369	-4.703	Car motion parallel
0.312	26.317	-4.657	
0.338	28.443	-4.677	
0.364	30.543	-4.657	
0.390	32.716	-4.571	
0.415	34.696	-4.484	
0.467	38.834	-4.349	
0.519	42.870	-3.950	
0.579	47.427	-3.612	Car exits rail

*Location of vehicle c.g. at point of impact with barrier.



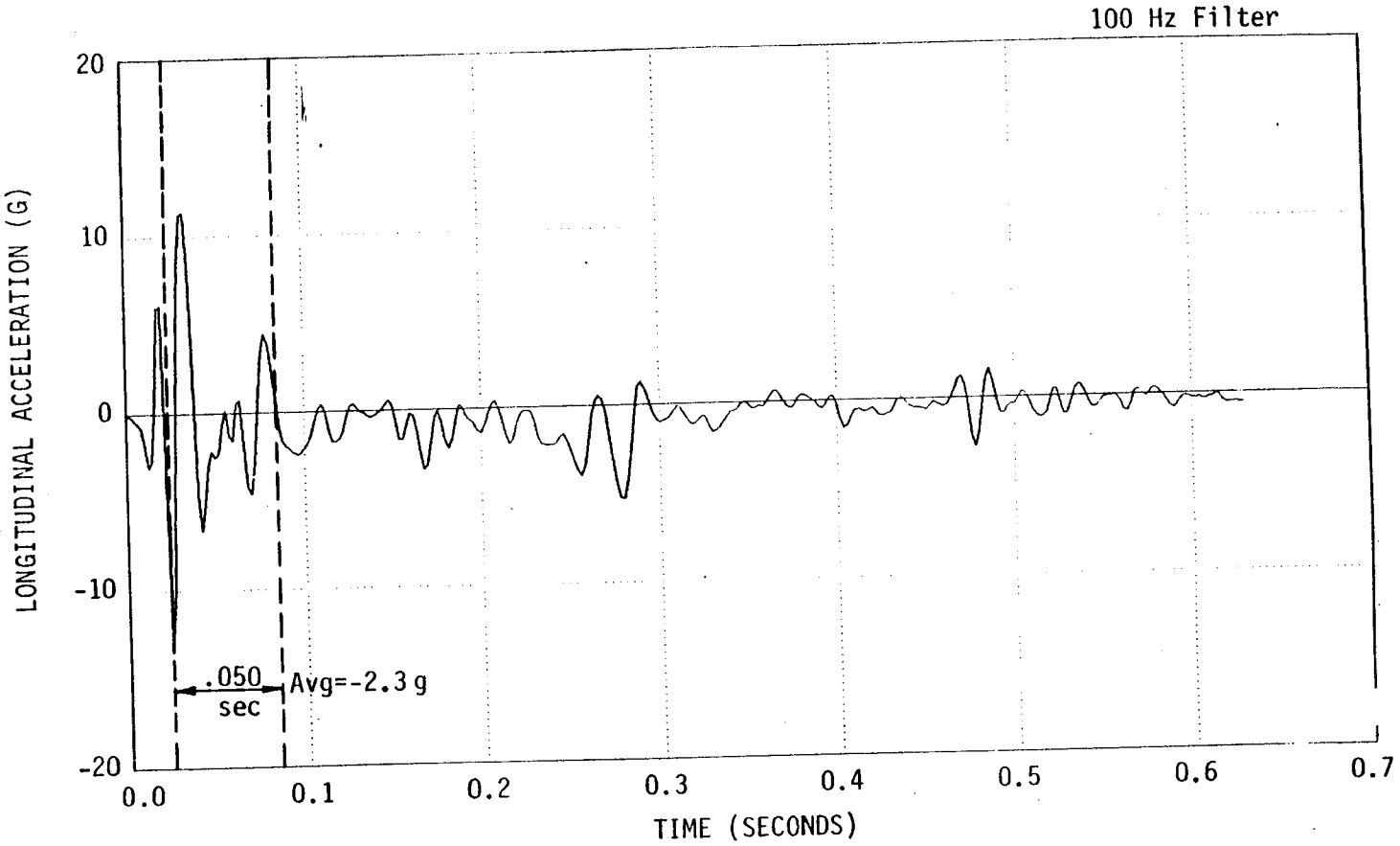


Figure 22 . Vehicle Right Longitudinal Accelerometer Trace for Test 3825-2.

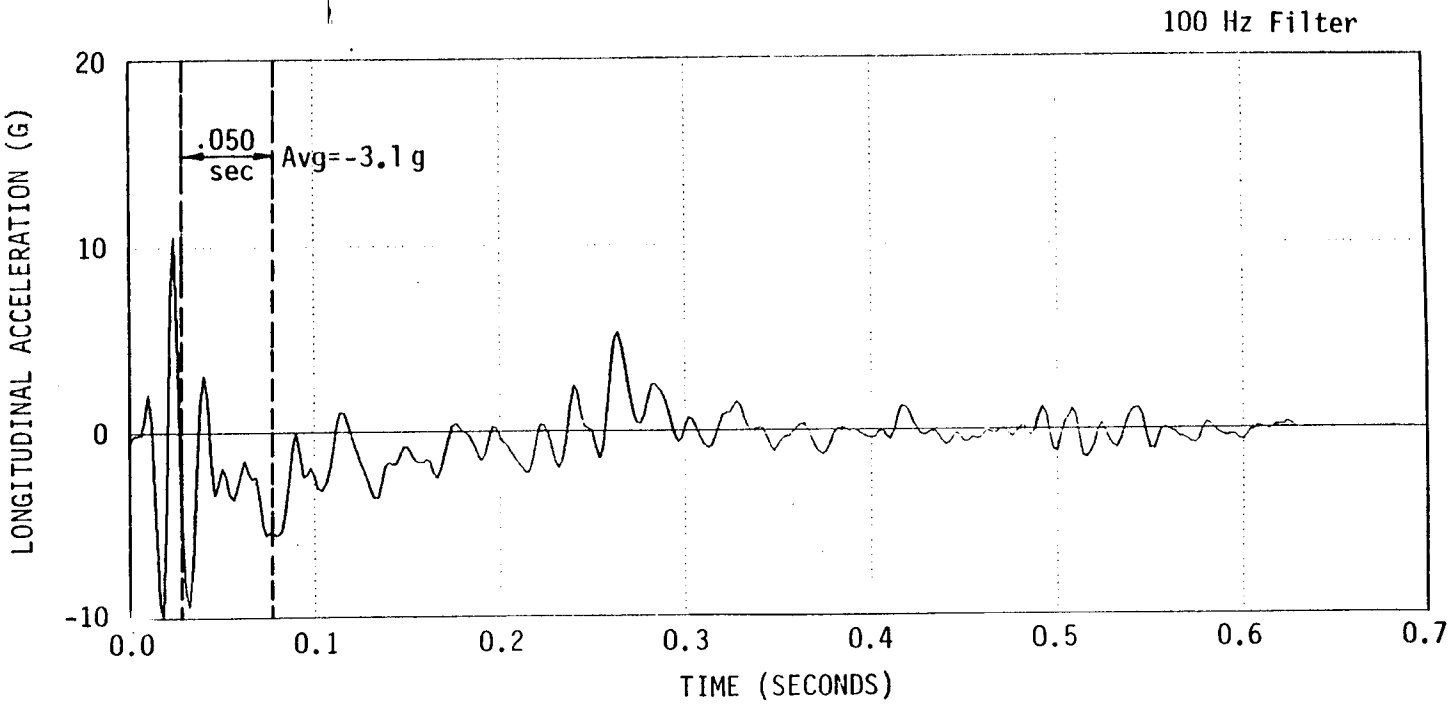


Figure 23. Vehicle Left Longitudinal Accelerometer Trace for Test 3825-2.

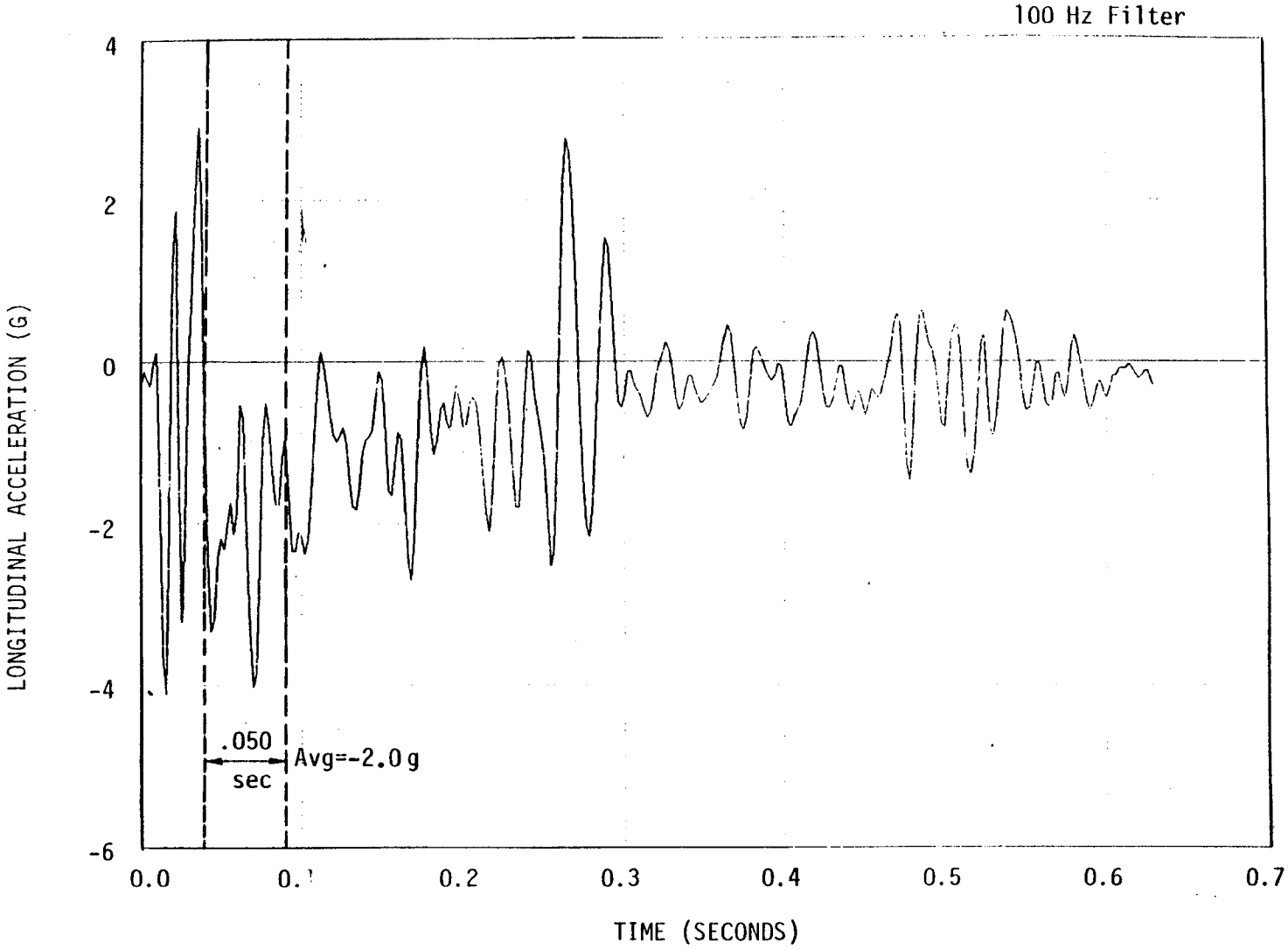


Figure 24. Vehicle Longitudinal Accelerometer Trace for Test 3825-2. (Averaged from Two Accelerometers).

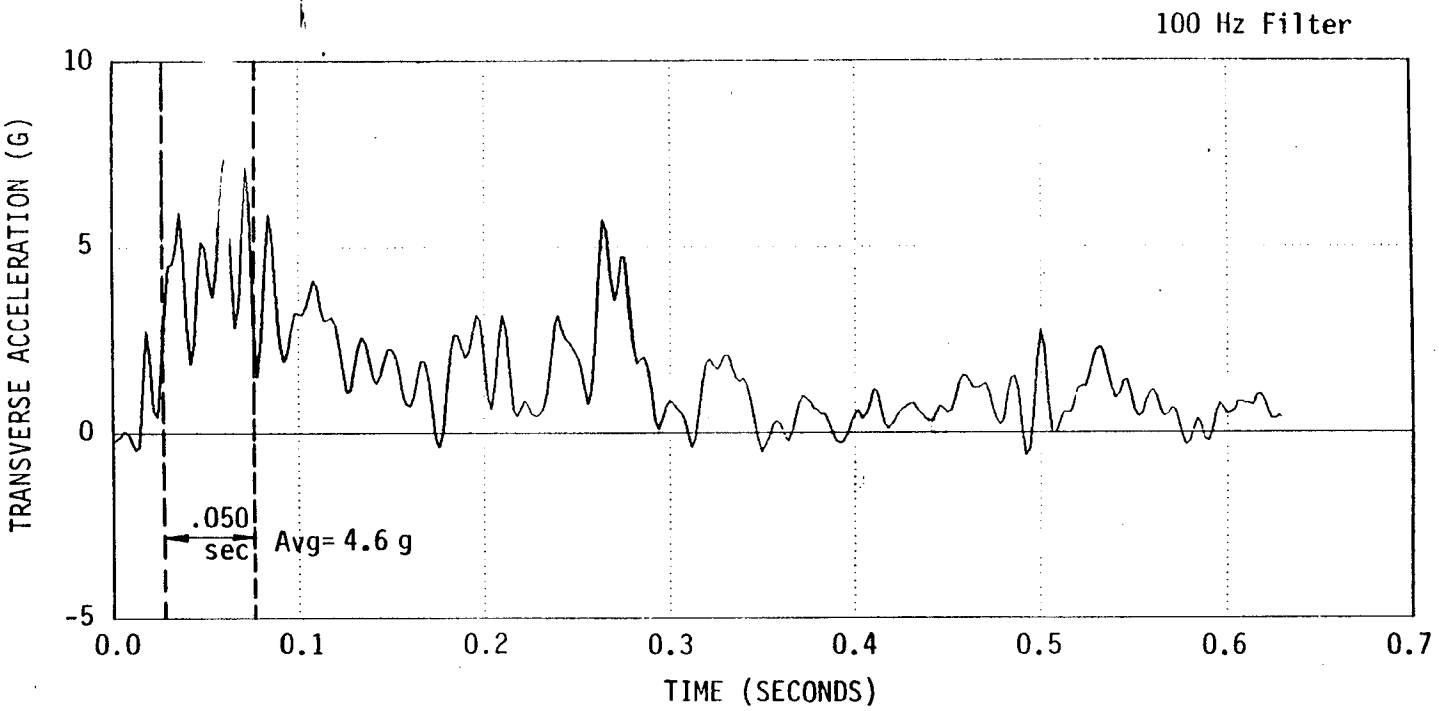


Figure 25. Vehicle Left Transverse Accelerometer Trace for Test 3825-2.

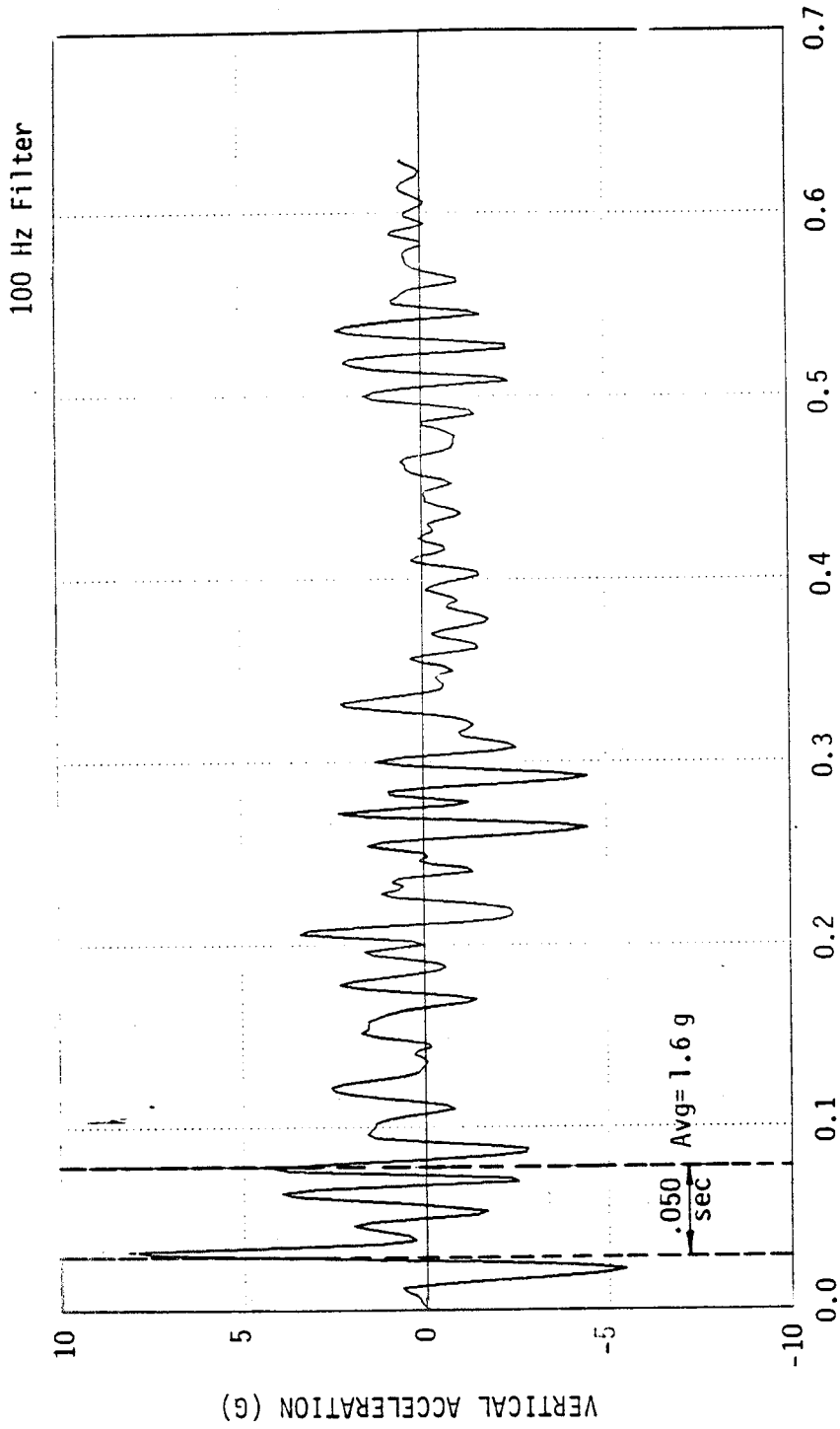


Figure 26. Vehicle Left Vertical Accelerometer Trace for Test 3825-2.

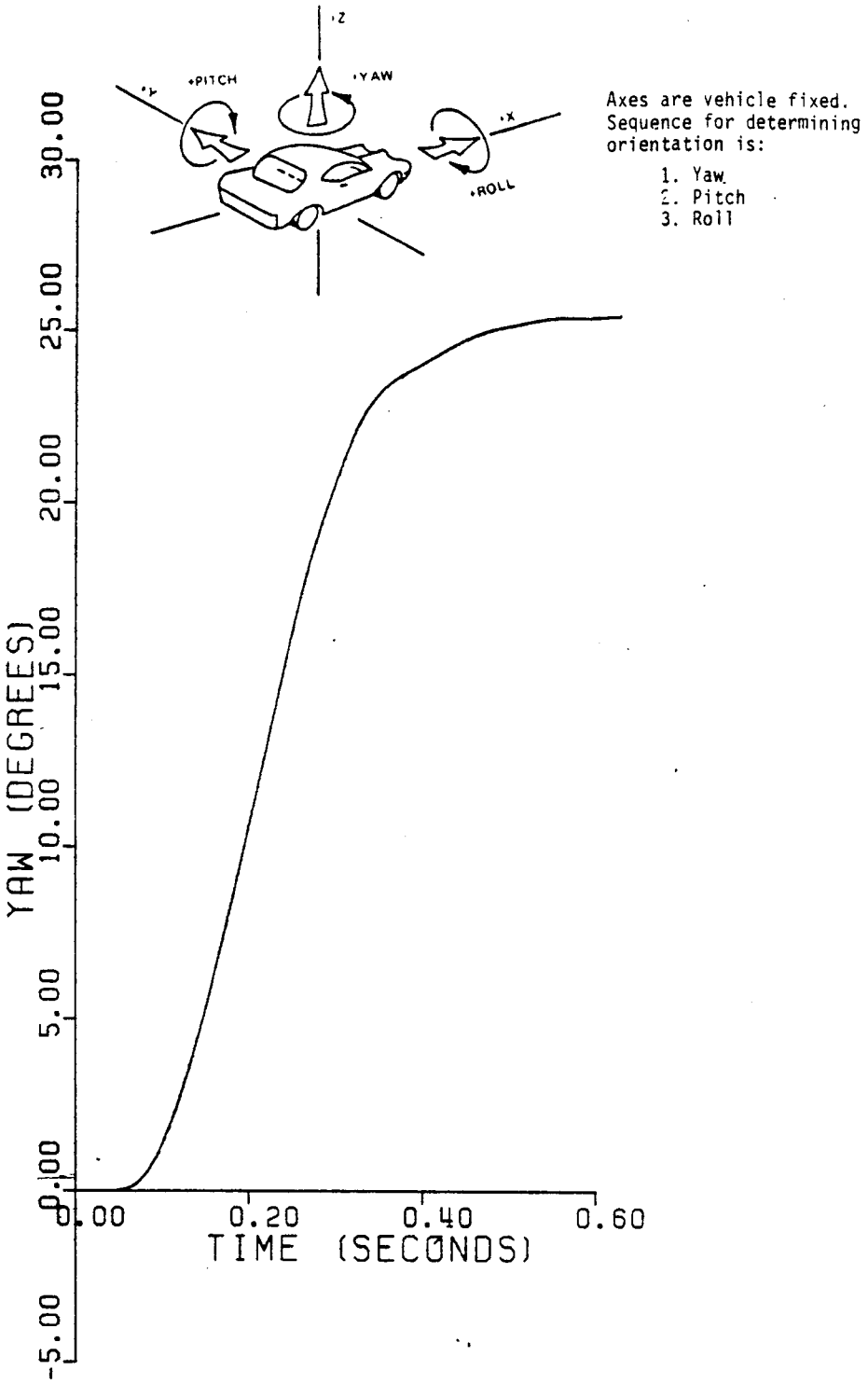


Figure 27. Vehicle Yaw Angle for Test 3825-2.

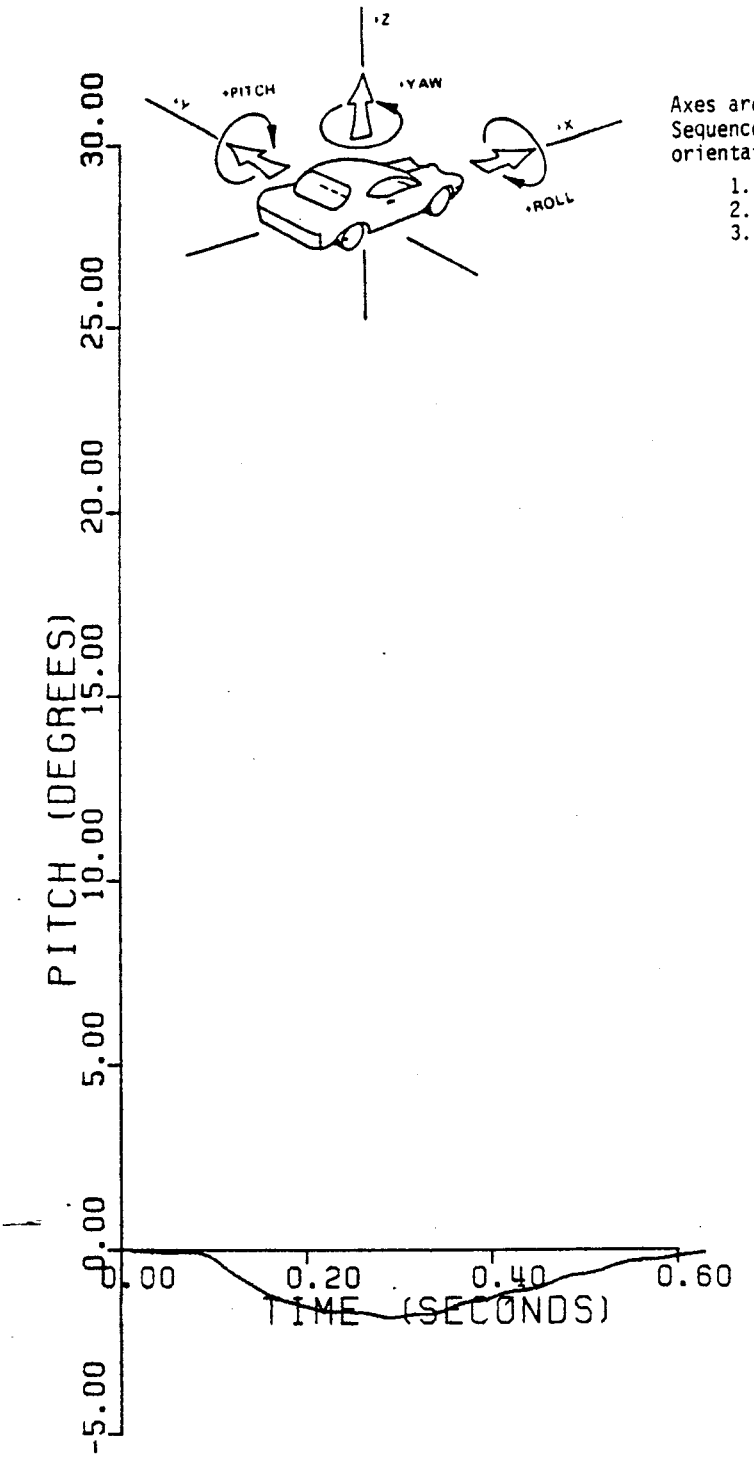


Figure 28. Vehicle Pitch Angle for Test 3825-2.

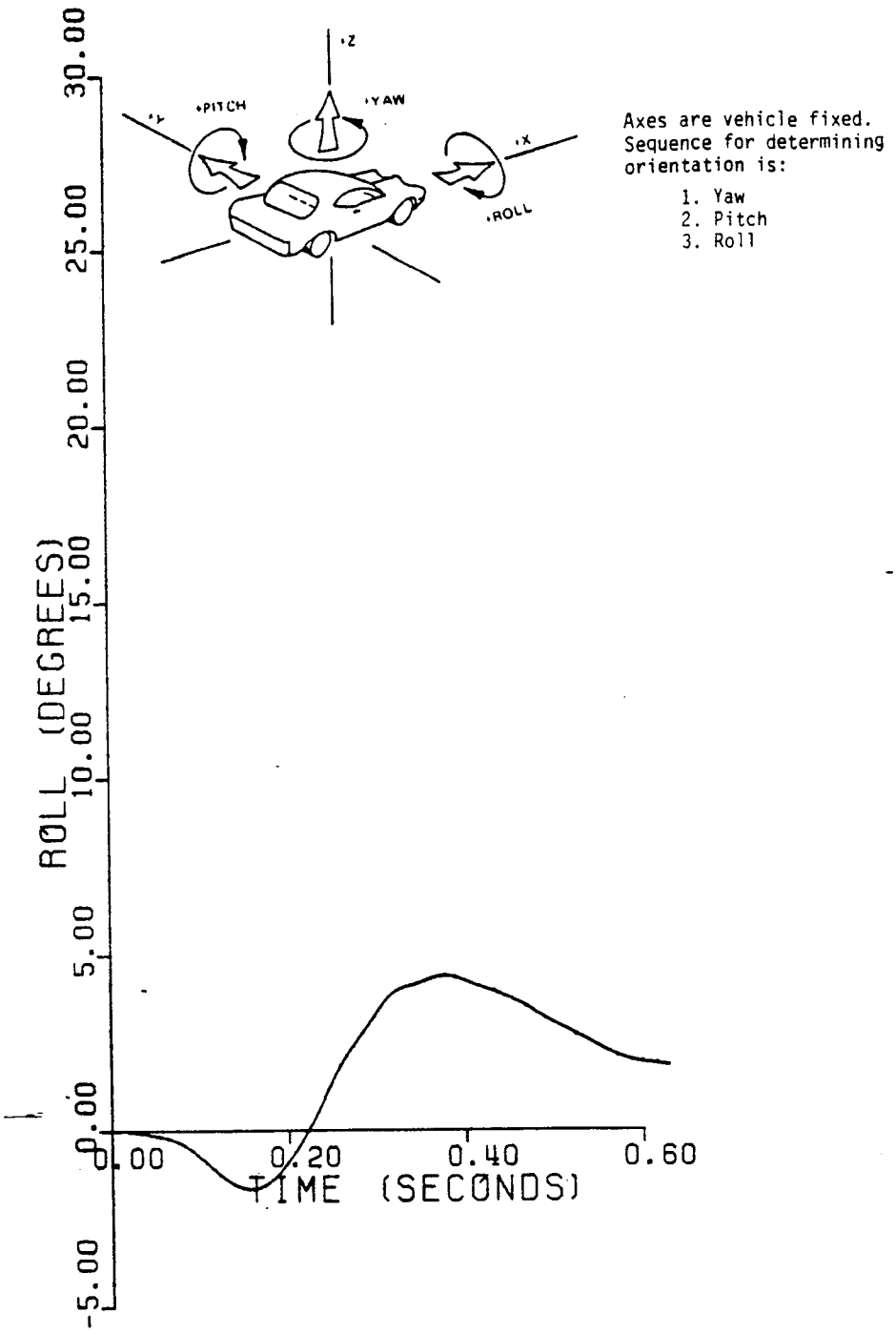


Figure 29. Vehicle Roll Angle for Test 3825-2.

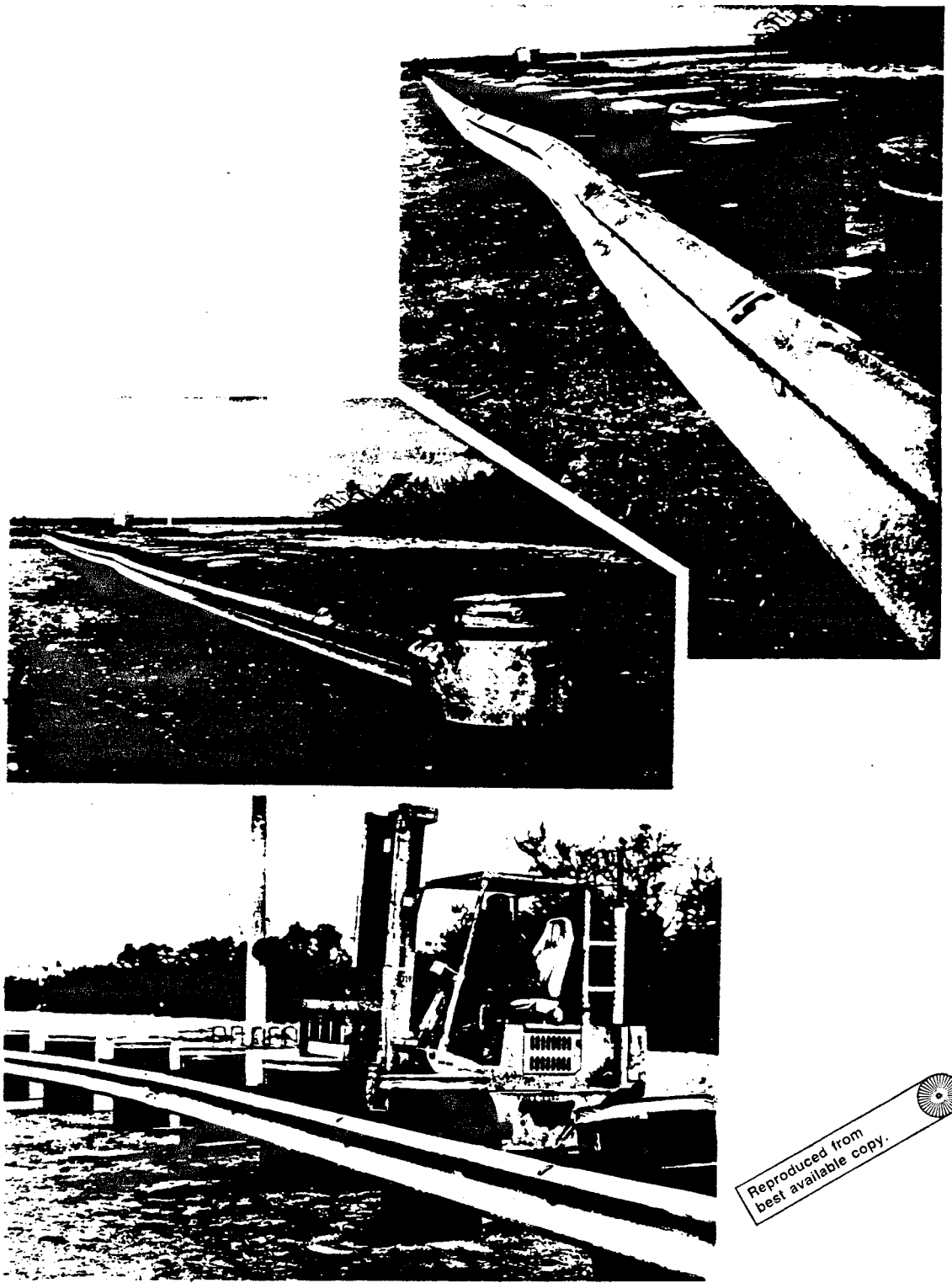


Figure 30. Rail Restoration After Test 3825-2.

TEST REPORT 3

The test installation consisted of a 12 gauge tubular W-beam mounted on a 55 gal (208 l) drums (barrels) with a wooden blockout and skid plate as illustrated in Figure 31. The barrels were sand filled. A false bottom in each barrel was used to raise the center of gravity of the sand to coincide with the impact force. The tubular W-beam was in 25.0 ft (7.6 m) lengths. The barrier was placed on unpaved level soil similar to surfaces found in construction zones. The barrier was lengthened after Test 1 and 2 to nearly 250.0 ft (76.2 m) including the 25.0 ft (7.6 m) terminal and 25.0 ft (7.6 m) transition sections at each end; see Figure 32. The terminal was modified after Tests 1 and 2 by flaring the end of the terminal with a 3 ft-4 in. (1.0 m) offset as illustrated in Figure 33. It should be noted that the displacement of the terminal did not require a physical bend in the tubular W-section but was simply pushed into position by a forklift.

In preparation for Test 3, the barrier required the replacement of one 25.0 ft (7.6 m) section of rail and three barrels which were damaged in Tests 1 and 2.

Test 3 - 4,500 lb/62.4 mph/22.5 deg (2,041 kg/100.4 km/h/22.5 deg)

The test vehicle, a 1974 Plymouth Fury, impacted the barrier at 22.5 deg with a velocity of 62.4 mph (100.4 km/h). The vehicle weighed a total of 4,500 lb (2,041 kg) including the telemetry equipment. Photographs of the vehicle and the barrier before and after the test are shown in Figure 34. In Figure 35 a summary of test results are presented.

Sequential photographs of Test 3 are in Figure 36. Time, displacement, and events are summarized in Table 3. Point of impact occurred 3.0 ft (0.9 m) downstream of barrel 14. At approximately 0.210 sec the vehicle became parallel to the barrier, after which the rear of the vehicle swung into the rail 2.5 ft (0.8 m) downstream of barrel 15. By 0.236 sec the upstream barrels were beginning to rotate. By 0.641 sec, the first of the upstream barrels fell over and succeeding downstream barrels began to fall. But in the vicinity of the vehicle, the barrels remained upright and resisting throughout the test. The vehicle exited

the rail at an angle of 18 deg and a velocity of 45.4 mph (73.0 km/h). The vehicle yawed to the right and came to rest behind the barrier.

The linear accelerometer traces are presented in Figures 37 through 41. Yaw, pitch and roll are presented in Figures 42, 43 and 44, respectively. These results are order related and must be evaluated in this sequence. During the test the vehicle remained exceptionally level and stable as illustrated by the maximum roll and pitch of only 2.5 deg and 0.8 deg, respectively. The maximum 0.050 sec average longitudinal and transverse accelerations were -1.4 g and 5.4 g. The maximum dynamic deflection of the barrier was 11.0 ft (3.4 m); this returned to 10.7 ft (3.3 m) after the test.

Restoration

The barrier was returned to its original position by three men with two forklifts in 90 minutes; see Figure 45. The extent of the permanent deformation after repositioning was between barrels 13 through 20. The maximum deformation occurred at barrel 16 of magnitude 5.7 in. (14.5 cm). The restored barrier is shown in Figure 46. The 25.0 ft (7.6 m) rail section between barrels 13 and 17 was replaced along with barrels 14 through 18 before testing continued.

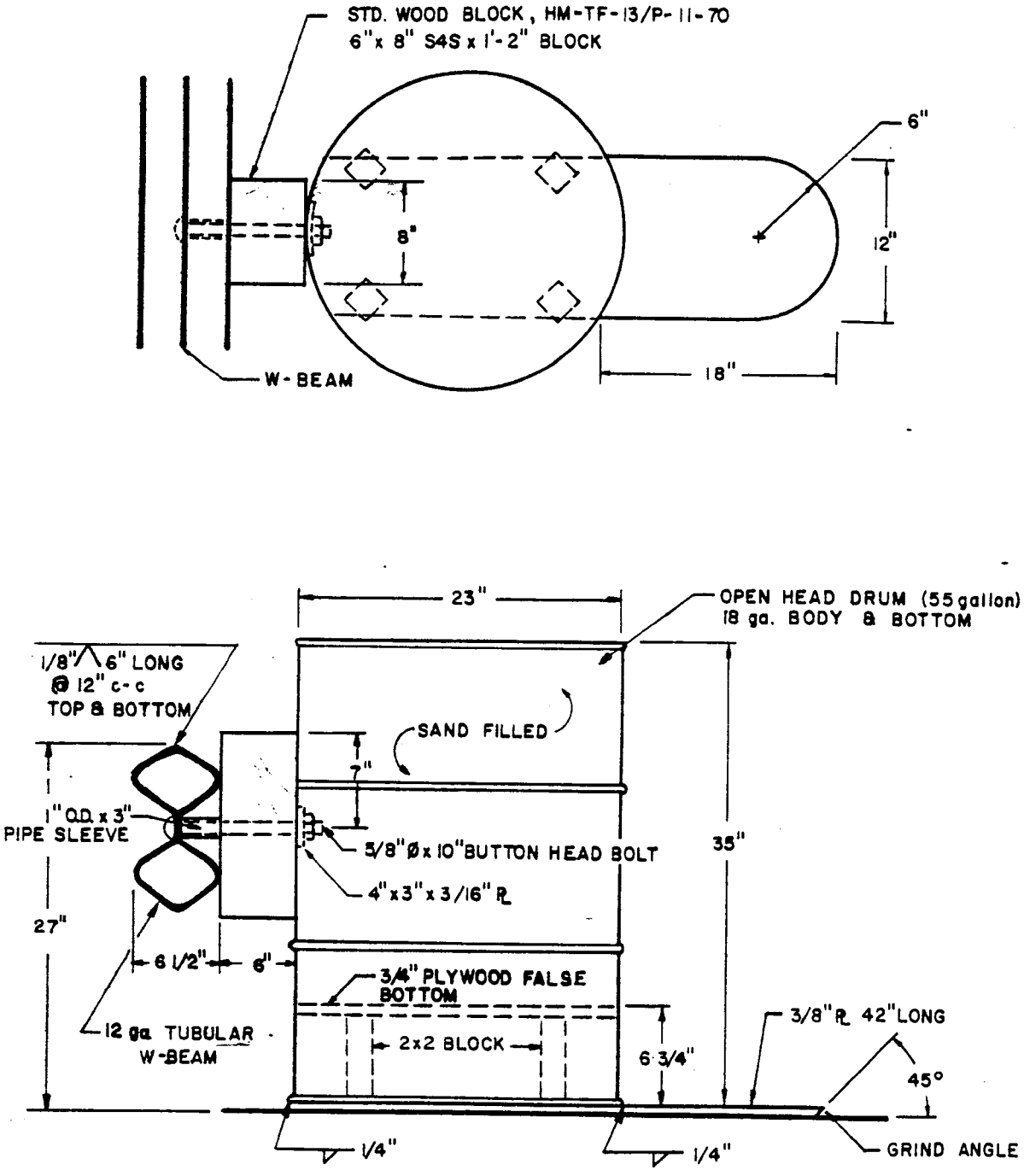


Figure 31. Stabilized Barrel System #3 Detail.

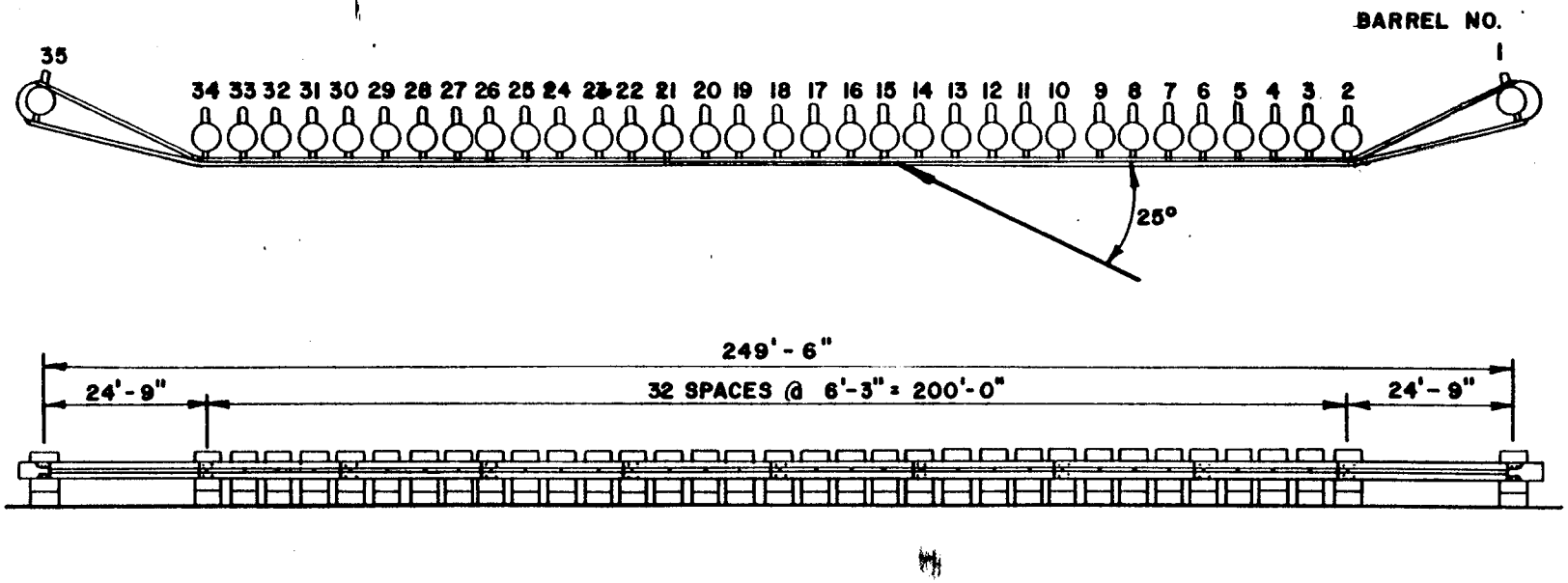


Figure 32 . Test Installation 3825-3.

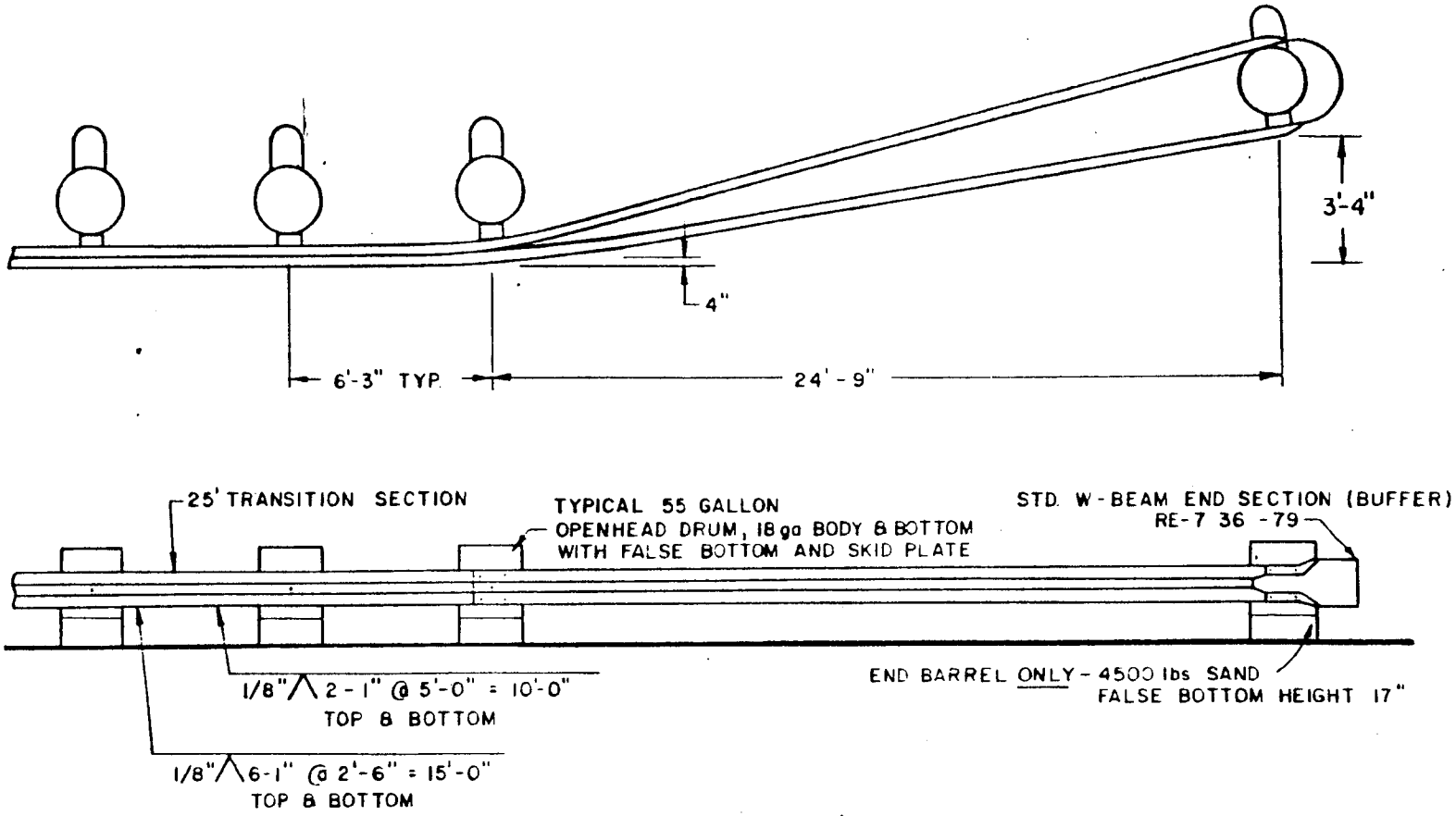


Figure 33. Terminal Detail Test 3825-3.

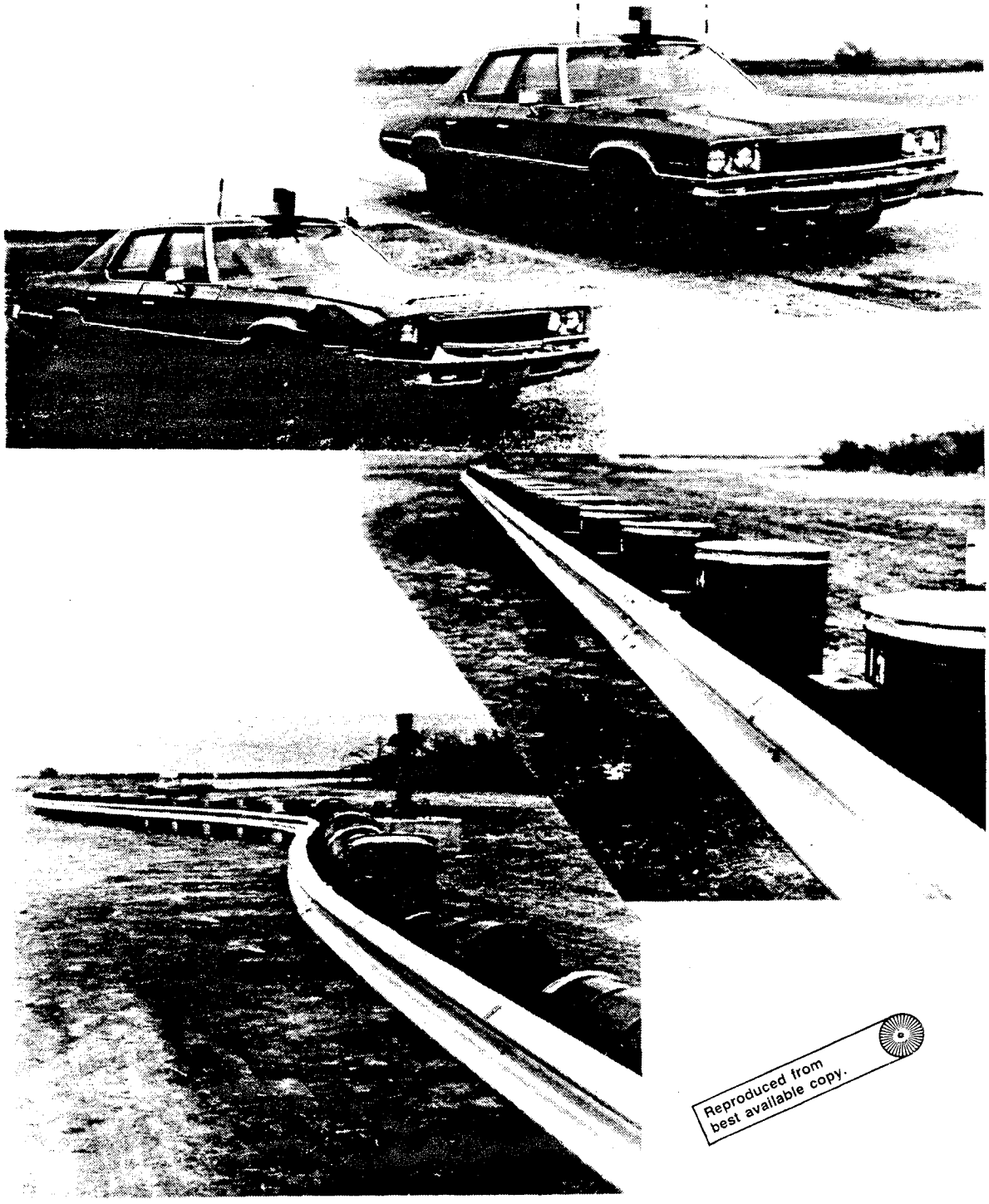
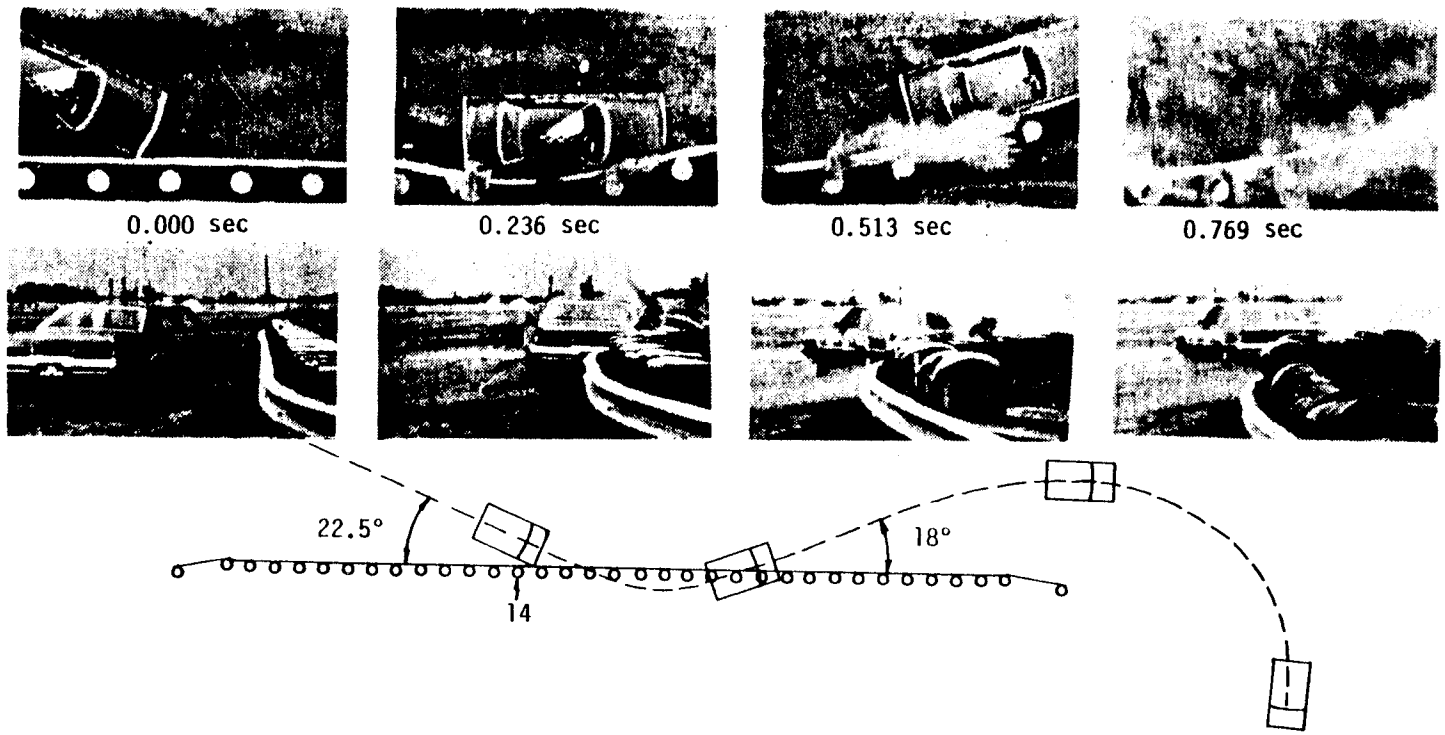
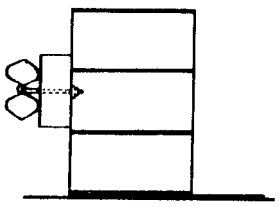


Figure 34. Vehicle and Rail Before and After Test 3825-3.



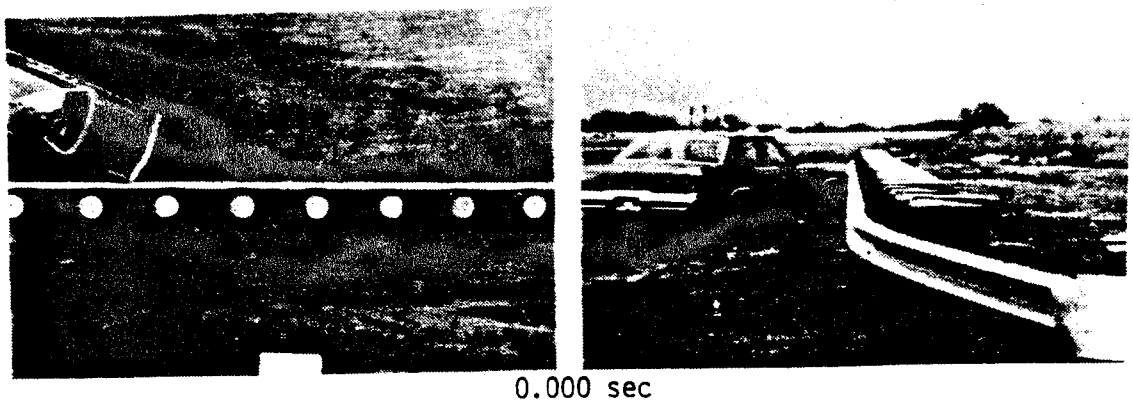


Stablilized Barrel
Beam No. 3
Construction Barrier

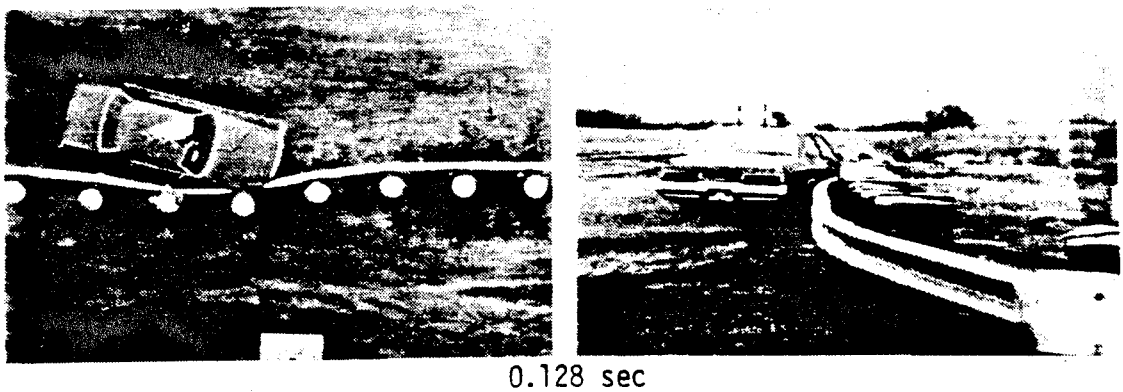
Test No.	3825-3
Date	12/11/79
Rail	12 ga. tubular W-beam
Post	55 gal (208 ℓ) Open Head Drum, 18 gal (68 ℓ) Bottom & Body w/False Bottom & Skid Plate
Post Spacing	6.25 ft (1.9 m)
Post to Anchor Spacing	24.8 ft (7.6 m)
Length of Installation	250.0 ft (76.2 m)
Beam Rail Deflection	
Max. Dynamic	11.0 ft (3.4 m)
Max. Permanent	10.7 ft (3.3 m)

Vehicle	1974 Fury III
Vehicle Weight	4,500 lb (2,041 kg)
Impact Speed	62.4 mph (100.4 km/h)
Impact Angle	22.5 deg
Exit Speed	45.4 mph (73.0 km/h)
Exit Angle	18 deg
Vehicle Acceleration (Max. 0.050 sec avg)	
Longitudinal (rt & lt avg)	-1.4 g
Transverse	5.4 g
Vertical	-1.2 g
Vehicle Damage	
TAD	1-RFQ-3
SAE	01RFEW2

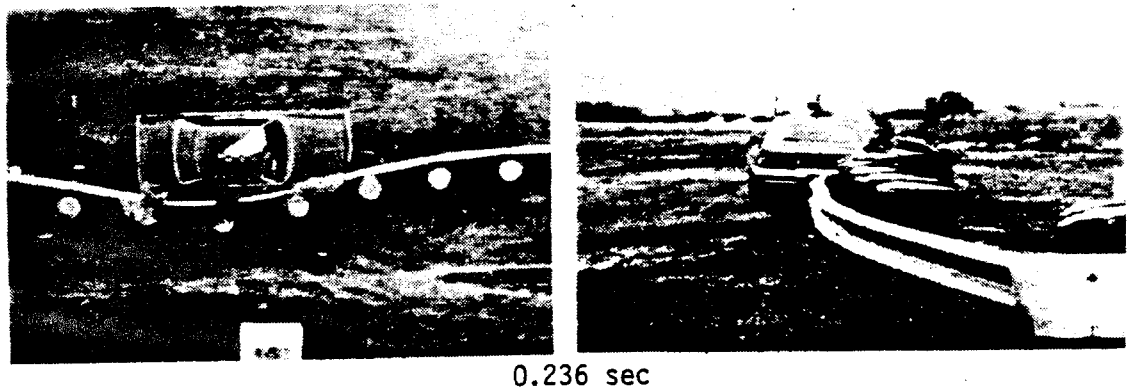
Figure 35. Summary of Results for Test 3825-3.



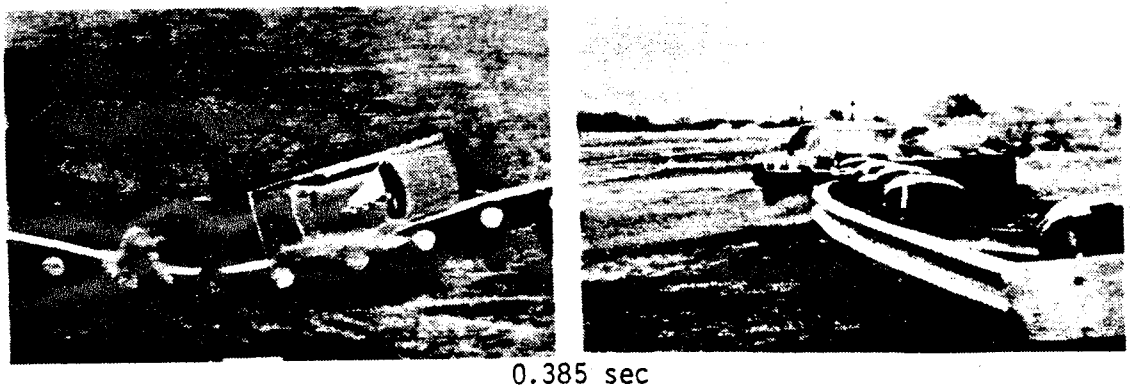
0.000 sec



0.128 sec

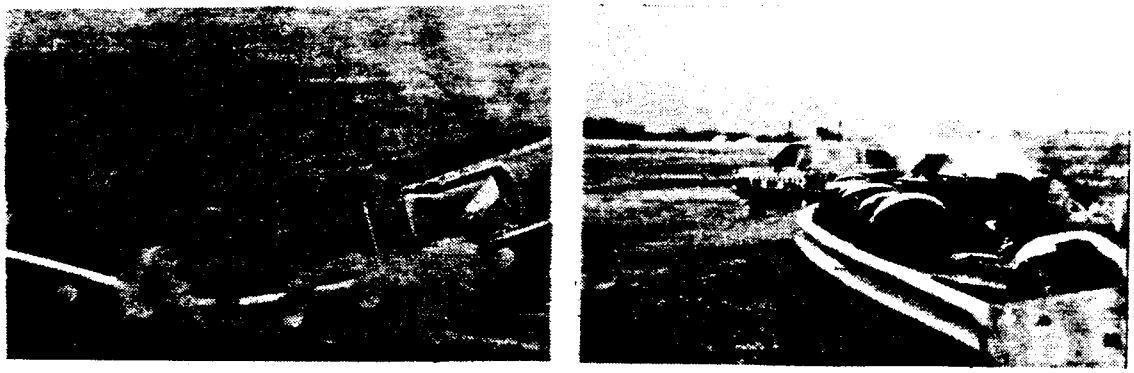


0.236 sec

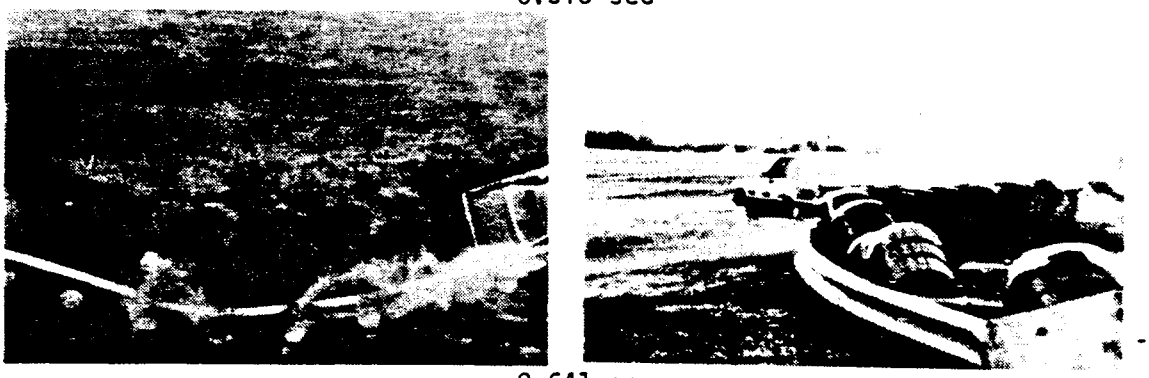


0.385 sec

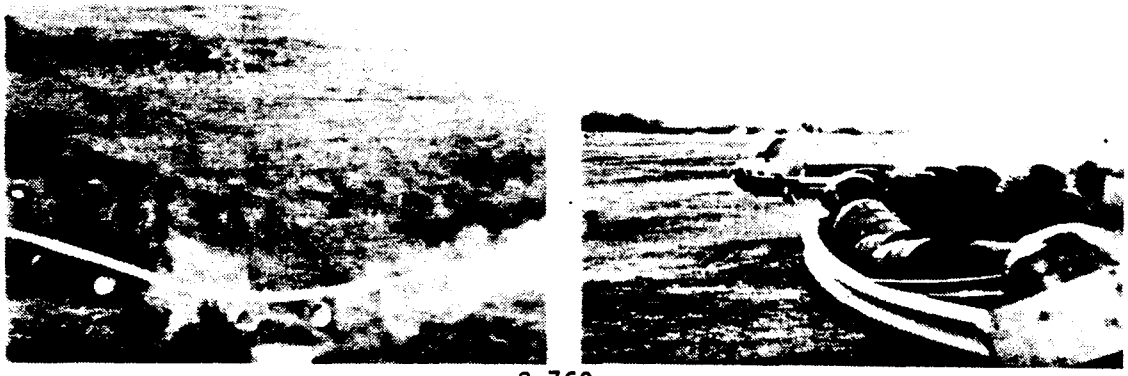
Figure 36. Sequential Photographs for Test 3825-3.



0.513 sec



0.641 sec



0.769 sec

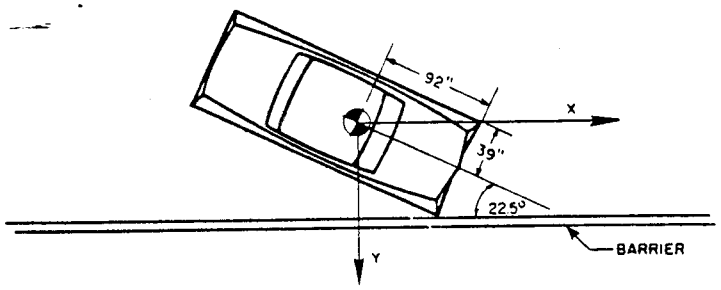
1.036 sec

Figure 36 (Continued). Sequential Photographs for Test 3825-3.

Table 3. Time, Displacement, Event Summary for Test 3825-3.

TIME (sec)	X-DISPLACEMENT (ft)	Y-DISPLACEMENT (ft)	EVENT
-0.026	-2.172	-0.964	
-0.015	-1.302	-0.604	
-0.005	-0.468	-0.252	
0.000	0.000*	0.000*	Impact
0.015	1.194	0.518	
0.051	4.114	1.626	
0.097	7.790	2.942	
0.103	8.241	3.068	
0.154	12.348	4.274	
0.205	16.447	5.221	
0.220	17.667	5.487	Full side contact
0.256	20.508	6.016	
0.308	24.408	6.611	Upstream barrels begin to tip
0.359	28.133	6.807	
0.369	28.845	6.822	Car motion parallel to rail
0.410	31.636	6.695	
0.461	35.299	6.484	
0.513	38.706	6.219	
0.564	42.060	5.789	
0.615	45.361	5.373	Tilted barrels begin to fall down

*Location of vehicle c.g. at point of impact with barrier.



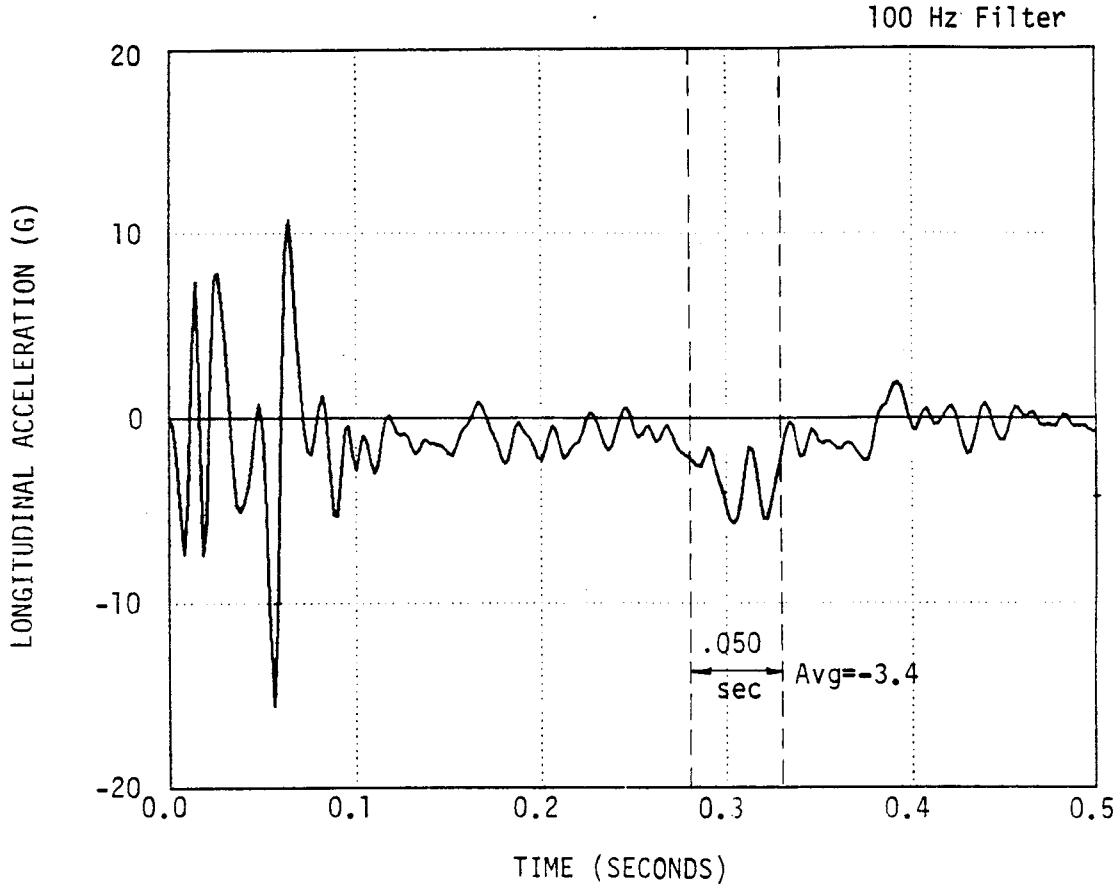


Figure 37. Vehicle Right Longitudinal Accelerometer Trace for Test 3825-3.

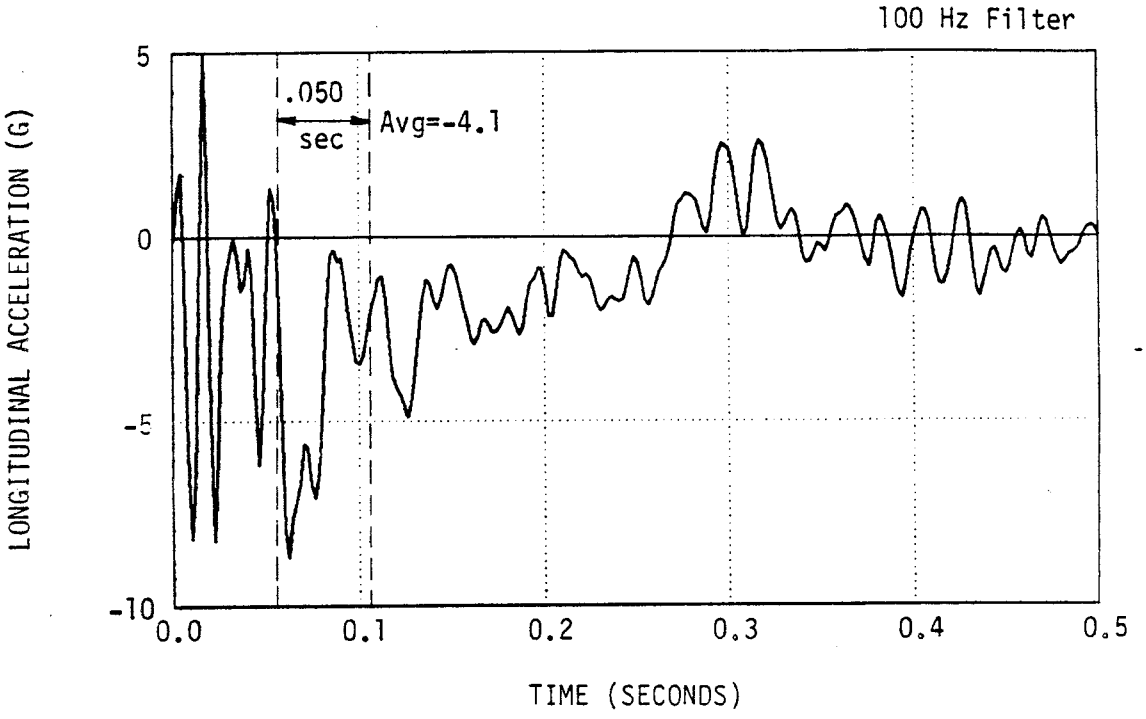


Figure 38. Vehicle Left Longitudinal Accelerometer Trace for Test 3825-3.

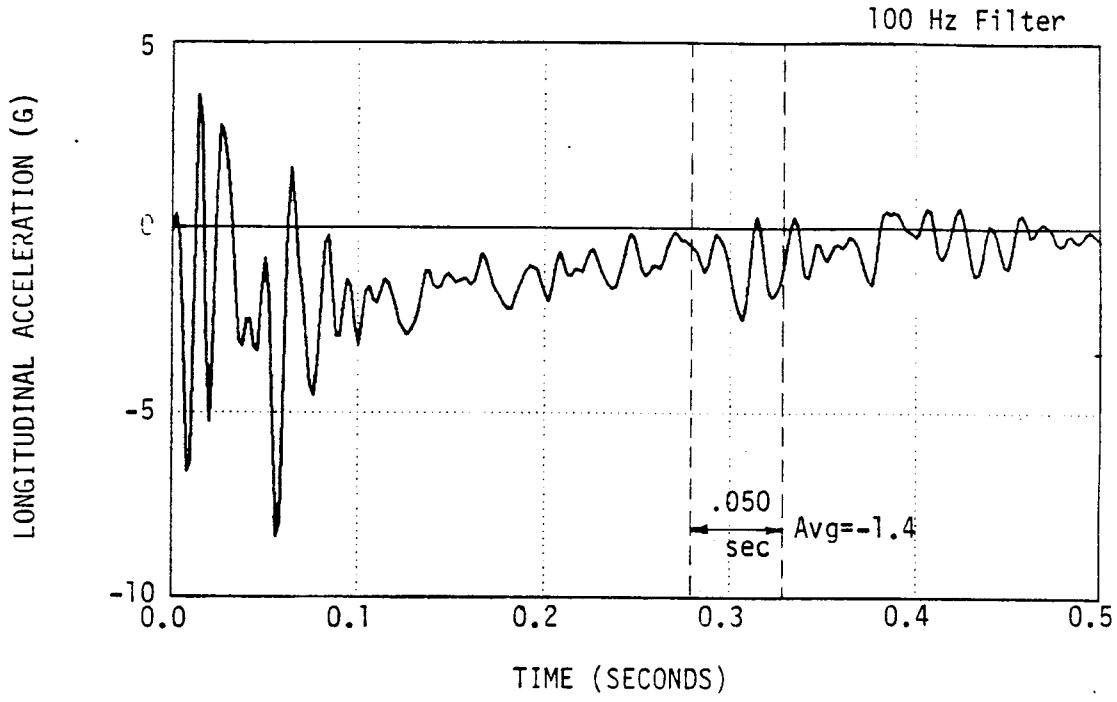


Figure 39. Vehicle Longitudinal Accelerometer Trace for Test 3825-3. (Averaged from Left and Right Accelerometers).

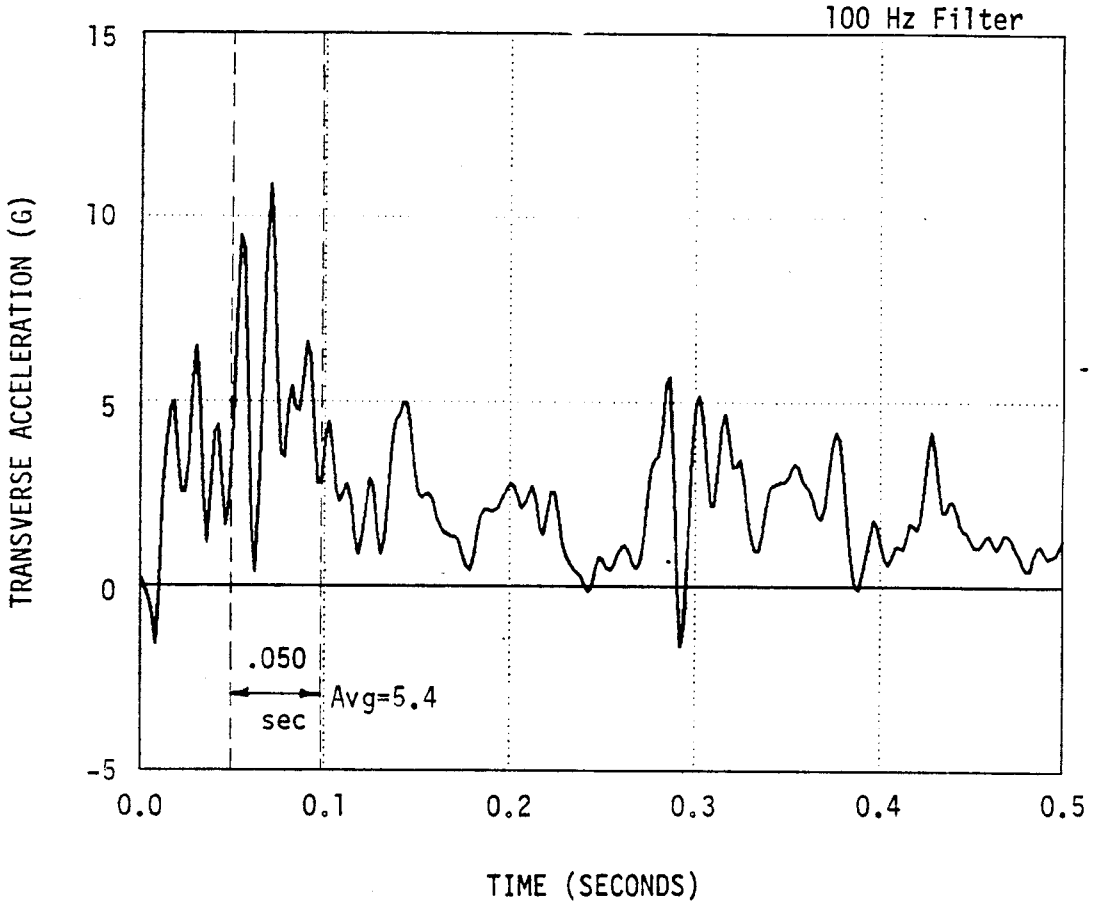


Figure 40. Vehicle Left Transverse Accelerometer Trace for Test 3825-3.

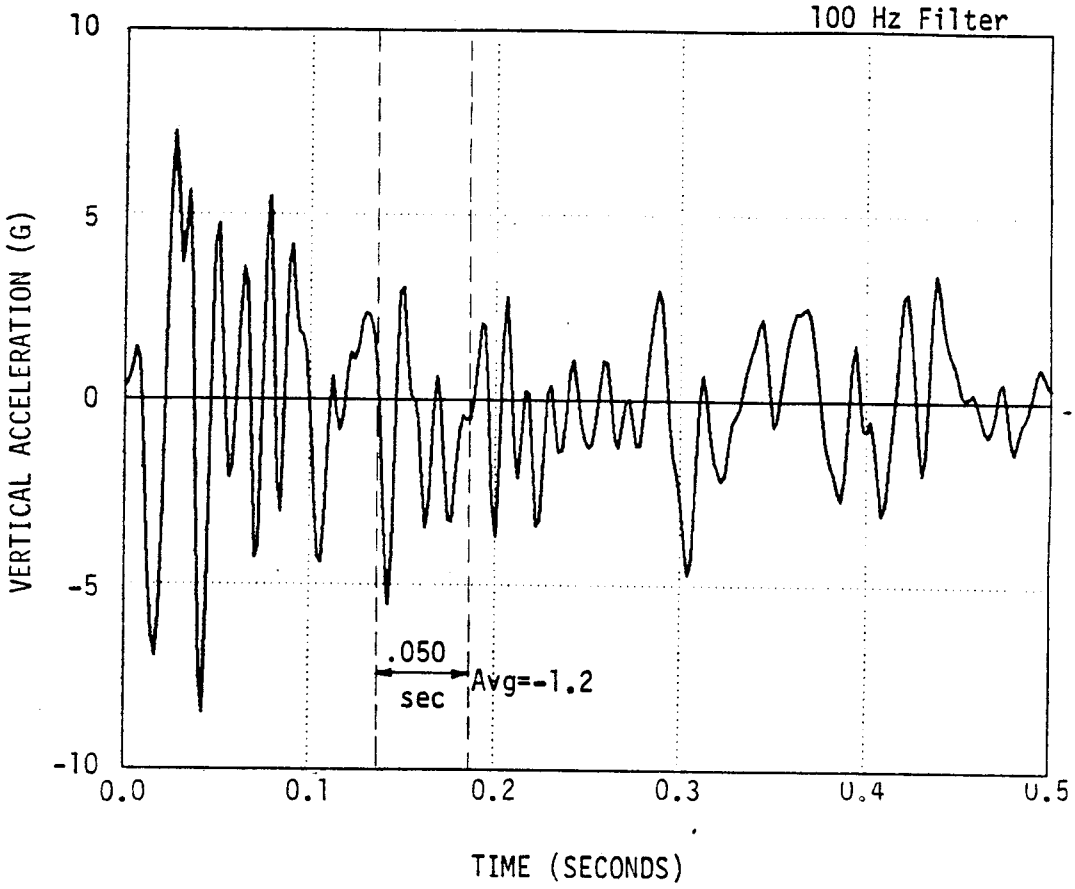
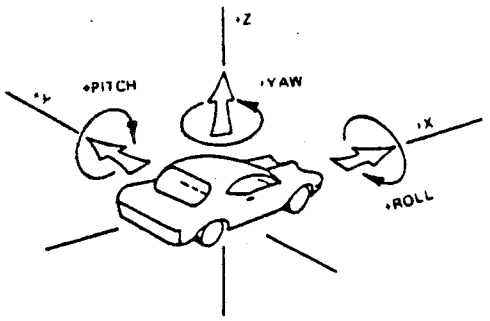


Figure 41. Vehicle Left Vertical Accelerometer Trace for Test 3825-3.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

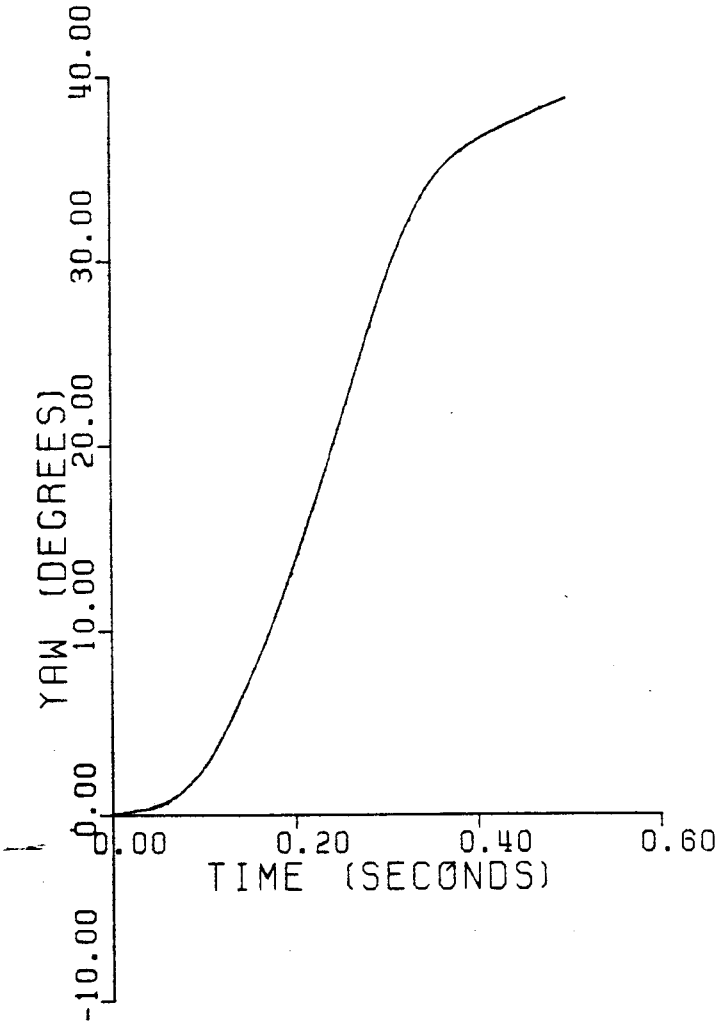


Figure 42. Vehicle Yaw Angle for Test 3825-3.

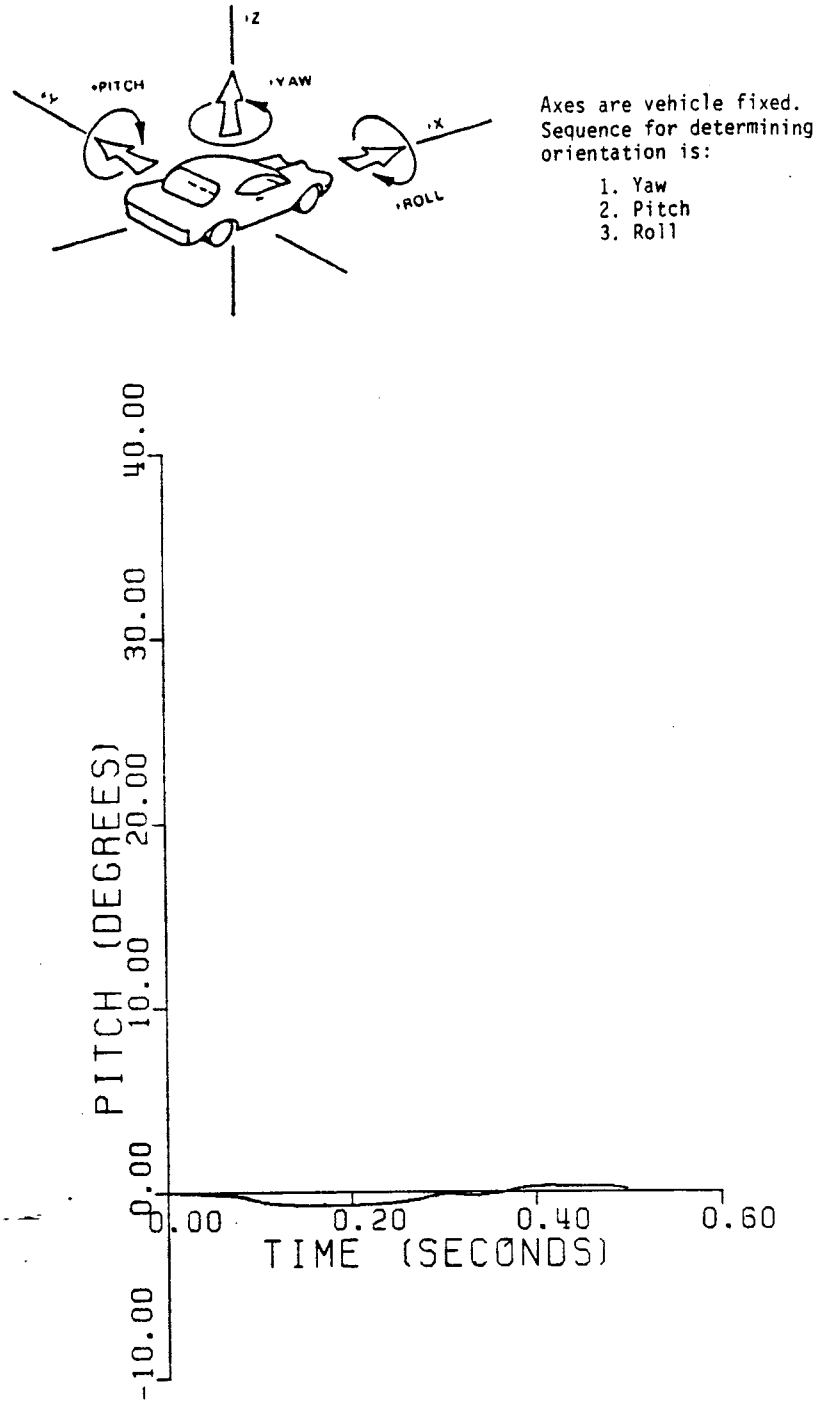


Figure 43. Vehicle Pitch Angle for Test 3825-3.

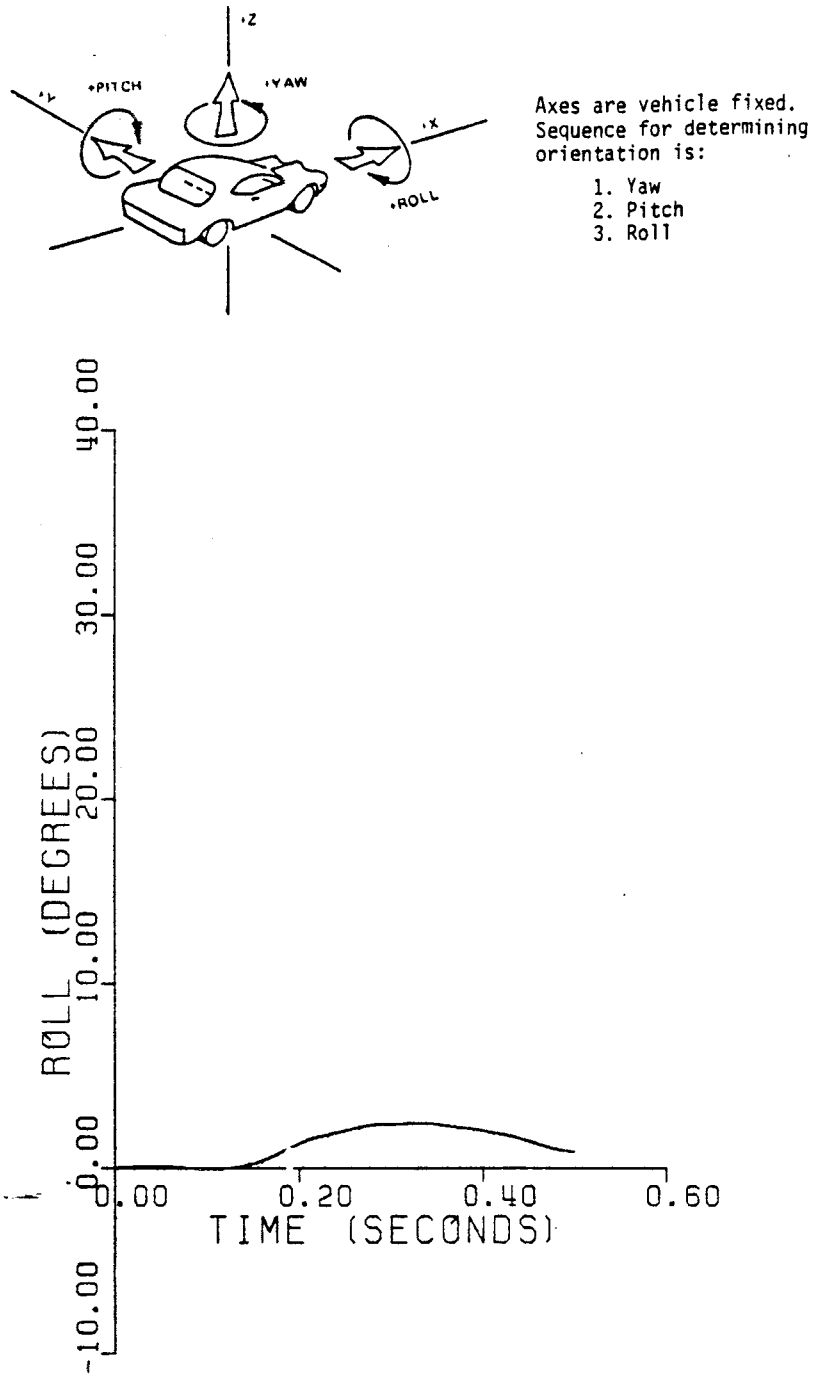


Figure 44. Vehicle Roll Angle for Test 3825-3.

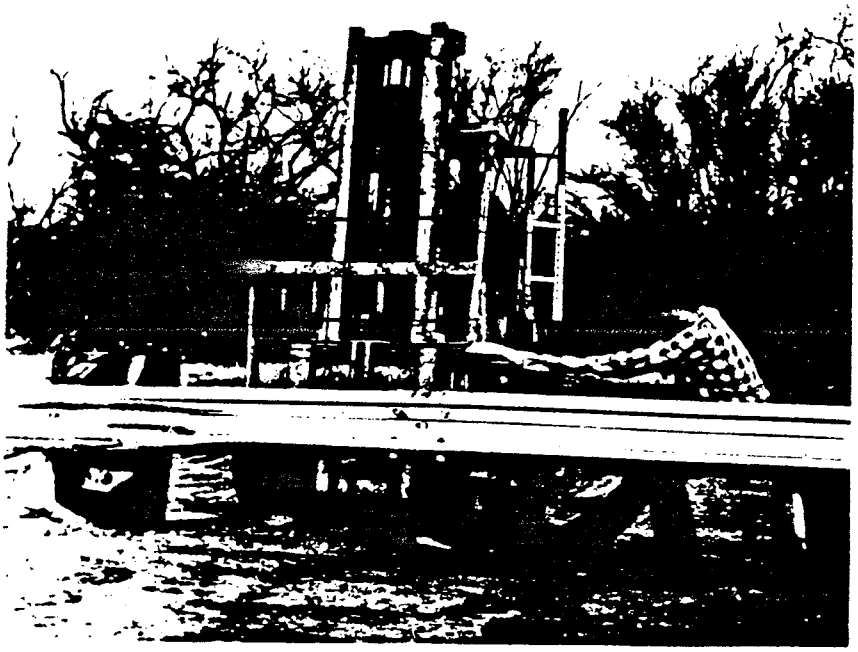


Figure 45. Repositioning of Barrier After Test 3825-3.

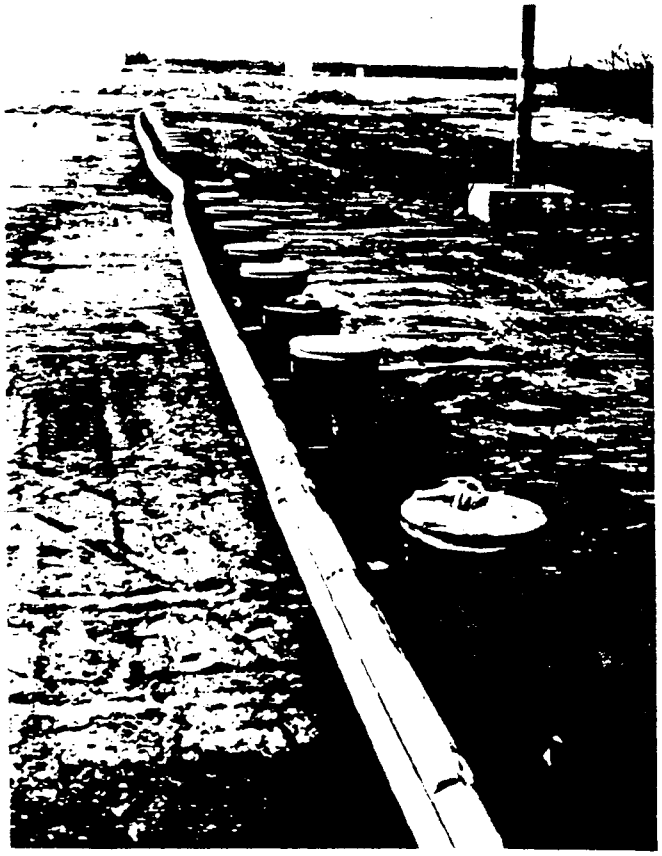


Figure 46. Barrier Repositioned After Test 3825-3.

TEST REPORT 4

The test installation was a 12 gauge tubular W-beam mounted on 55 gal (208 l) drums (barrels) with wooden blockout and skid plate as illustrated in Figure 47. The barrels were sand filled. A false bottom in each barrel was used to raise the center of gravity of the sand to coincide with the impact force. The section of tubular W-beam was in 25.0 ft (7.6 m) lengths. The barrier was placed on unpaved level soil, similar to surfaces encountered in construction zones. The installation was 250.0 ft (76.2 m) long including a 25.0 ft (7.6 m) terminal and 25.0 ft (7.6 m) transition as shown in Figures 48 and 49. The installation was repaired by the replacement of barrels 14 through 18 as well as the rail sections between barrels 13 and 17 following Test 3825-3.

Test 4 - End Treatment - 4,500 lb/61.4 mph/0 deg (2,041 kg/98.8 km/h/0 deg)

In Test 4, a 1974 Plymouth Grand Fury impacted the end of the barrier at 0 deg and 61.4 mph (98.8 km/h). The vehicle weighed 4,500 lb (2,041 kg) including telemetry equipment. Photographs of the vehicle and barrier before and after the test are shown in Figures 50 and 52. Figure 51 illustrates the impact point. Figure 53 summarizes the results of Test 4. Sequential photographs are presented in Figure 54. Table 4 is a summary of time and displacement as related to specific events.

As shown in Figure 51, impact occurred at the end of the terminal. The W-beam began to buckle upstream of barrel 2 and folded inward toward the back side of the barrier causing the vehicle to ride up and over it. Outward buckling occurred at barrels 2 and 3. The vehicle yawed to the left and came to rest behind the barrier. Damage to the front of the vehicle was extensive.

The accelerometer traces are presented in Figures 55 through 57. The maximum 0.050 sec averages were -15.8 g and 3.1 g for longitudinal and transverse acceleration, respectively. Yaw, pitch and roll are shown in Figures 58 through 60. These test results are order dependent and must be evaluated in this sequence.

Restoration

Although the barrier was not repaired following Test 4, the barrier was severely damaged upstream of barrel 3. Repairs that would have been required to restore the barrier included the replacement of the first two sections of W-beam and the first three barrels. Barrels 4 through 8 would also need to have been repositioned.

Summary

The peak longitudinal acceleration was high. It would have been much too high on a small vehicle. The writers, therefore, propose to reduce the sand ballast in the end barrel to roughly 200 lb (91 kg) and to elevate the center of gravity of this sand to prevent the vehicle from ramping to the end barrel.

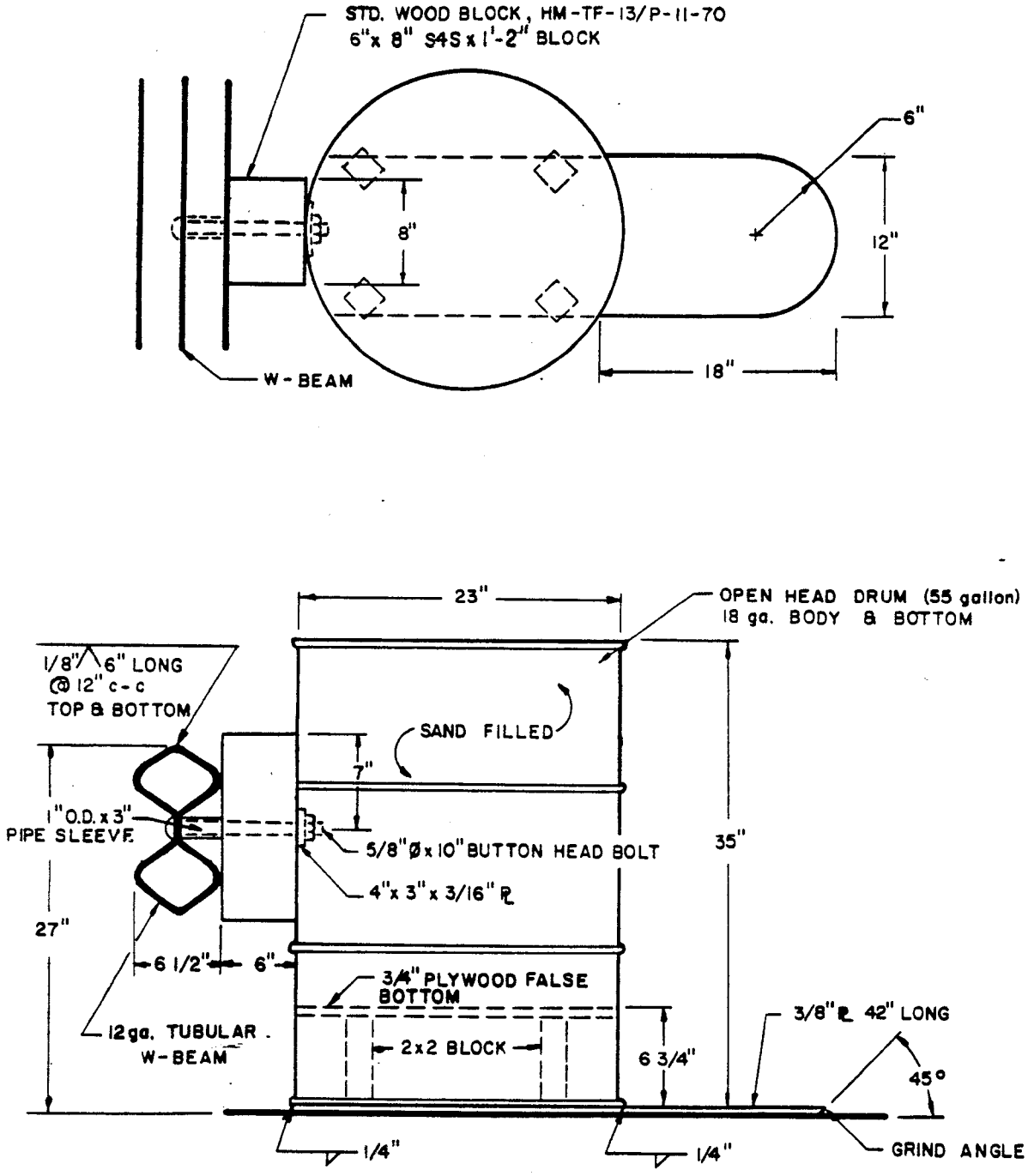


Figure 47. Stabilized Barrel System #3.

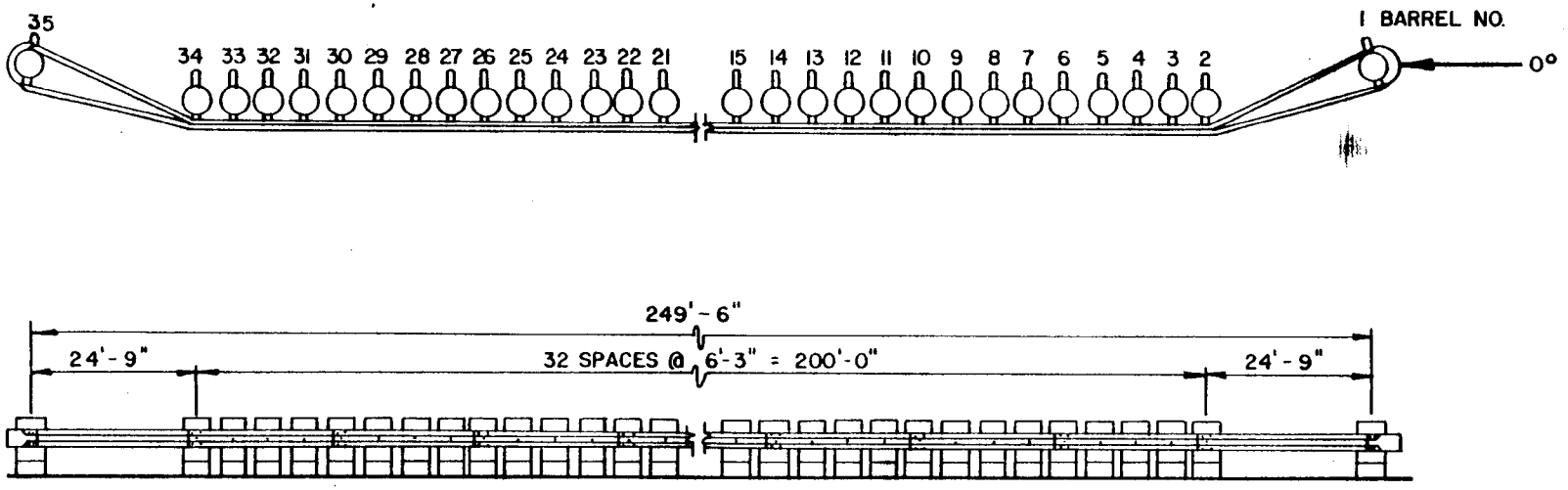


Figure 48. Test Installation 3825-4.

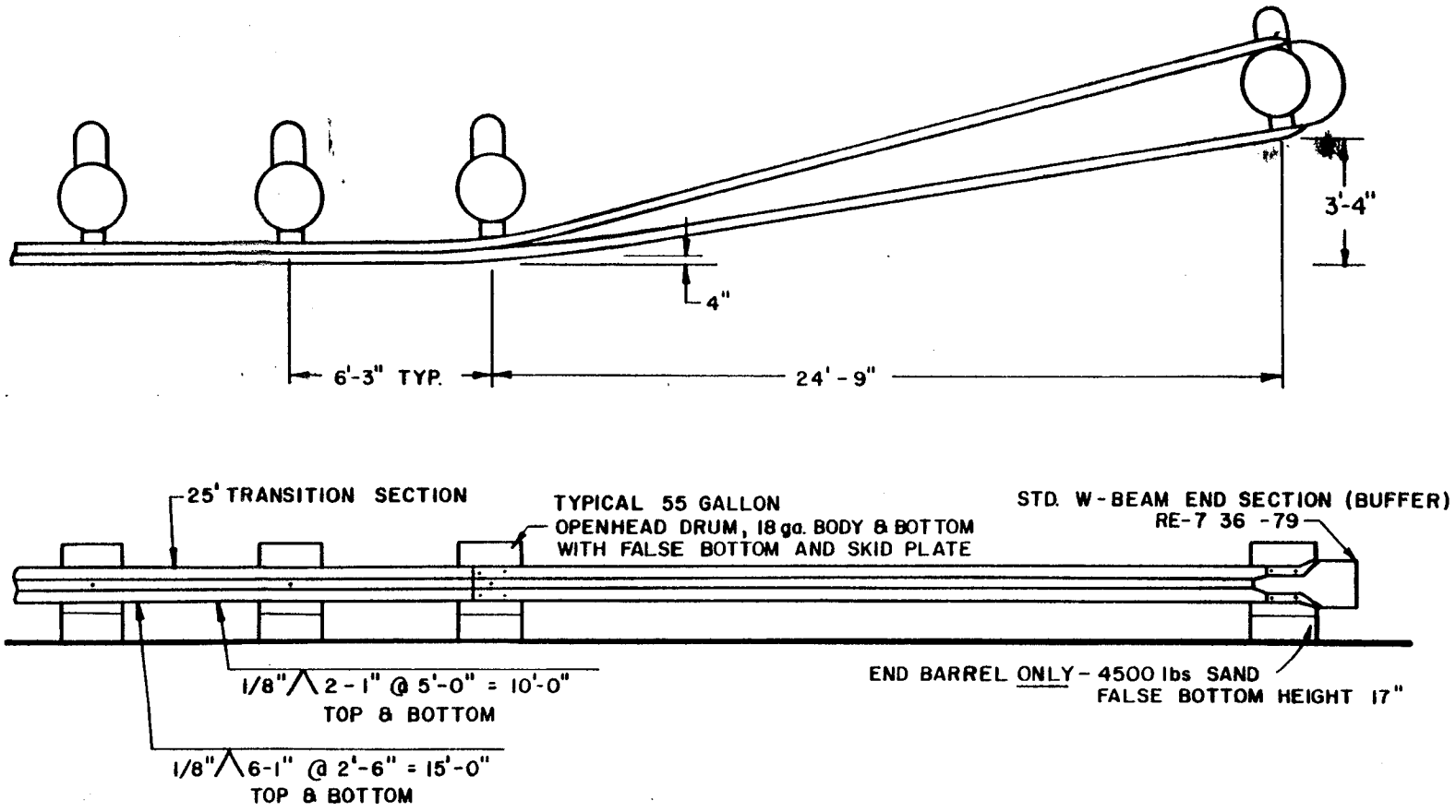


Figure 49. Terminal Detail Test 3825-4.

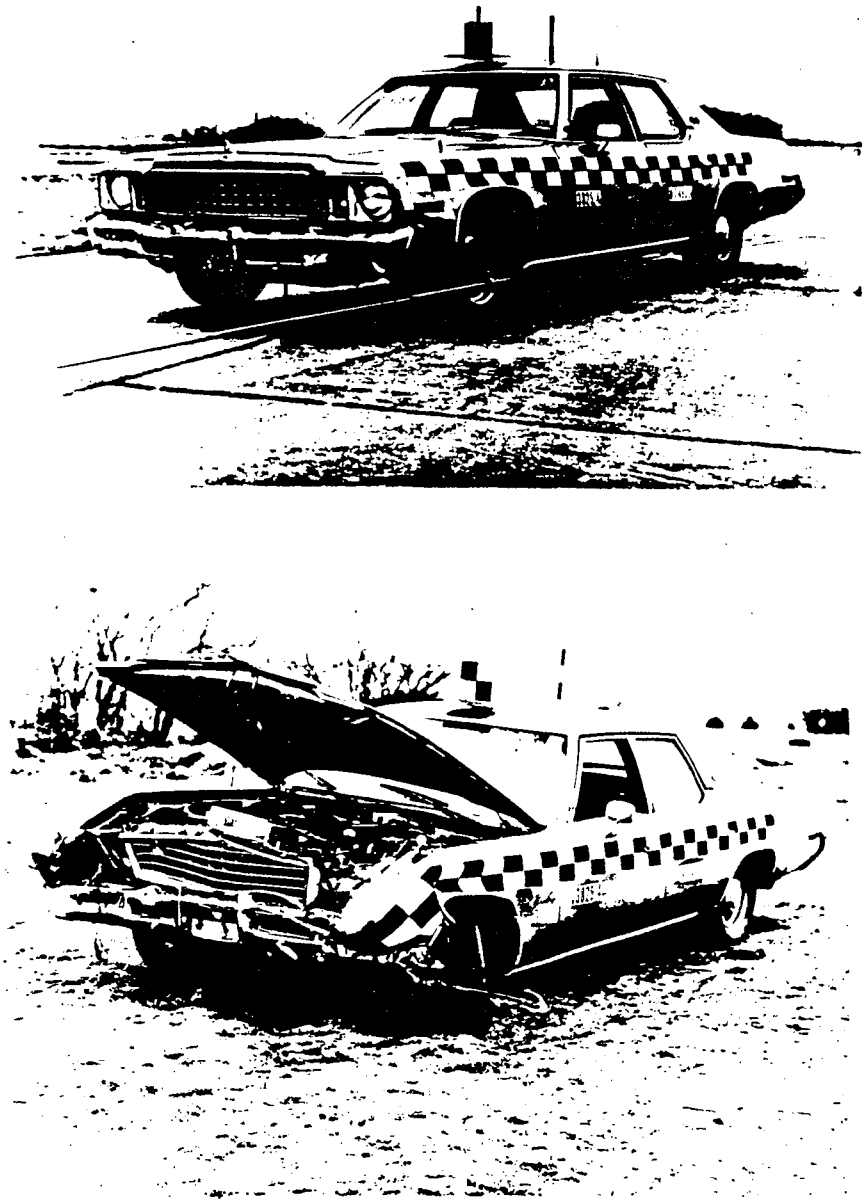


Figure 50. Vehicle Before and After Test 3825-4.

Figure 51. Impact Point for Test 3825-4.

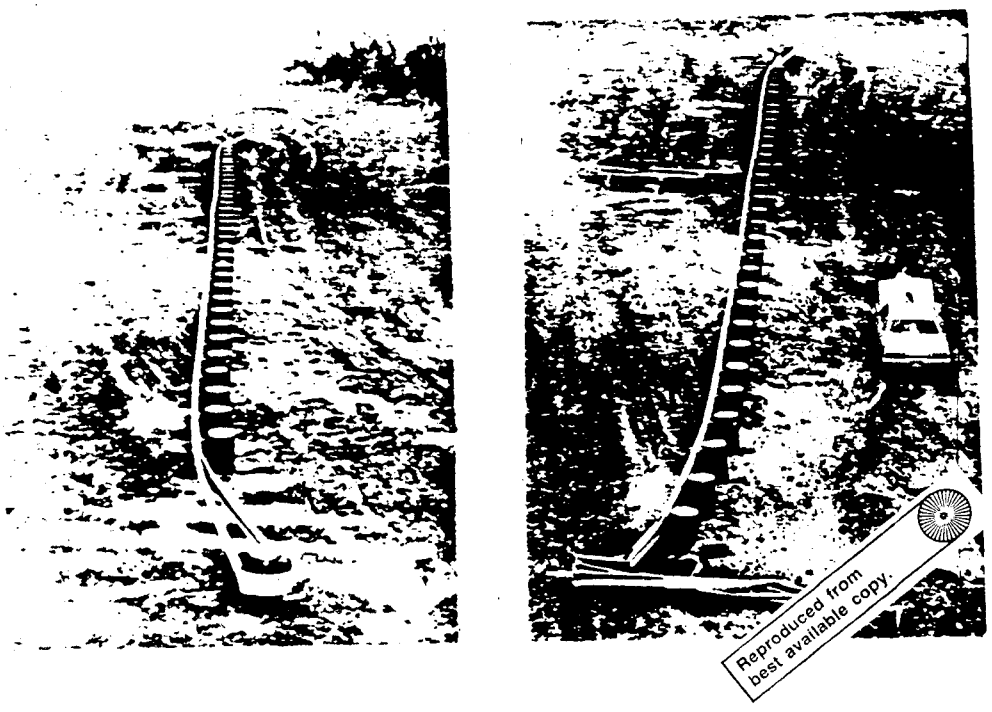
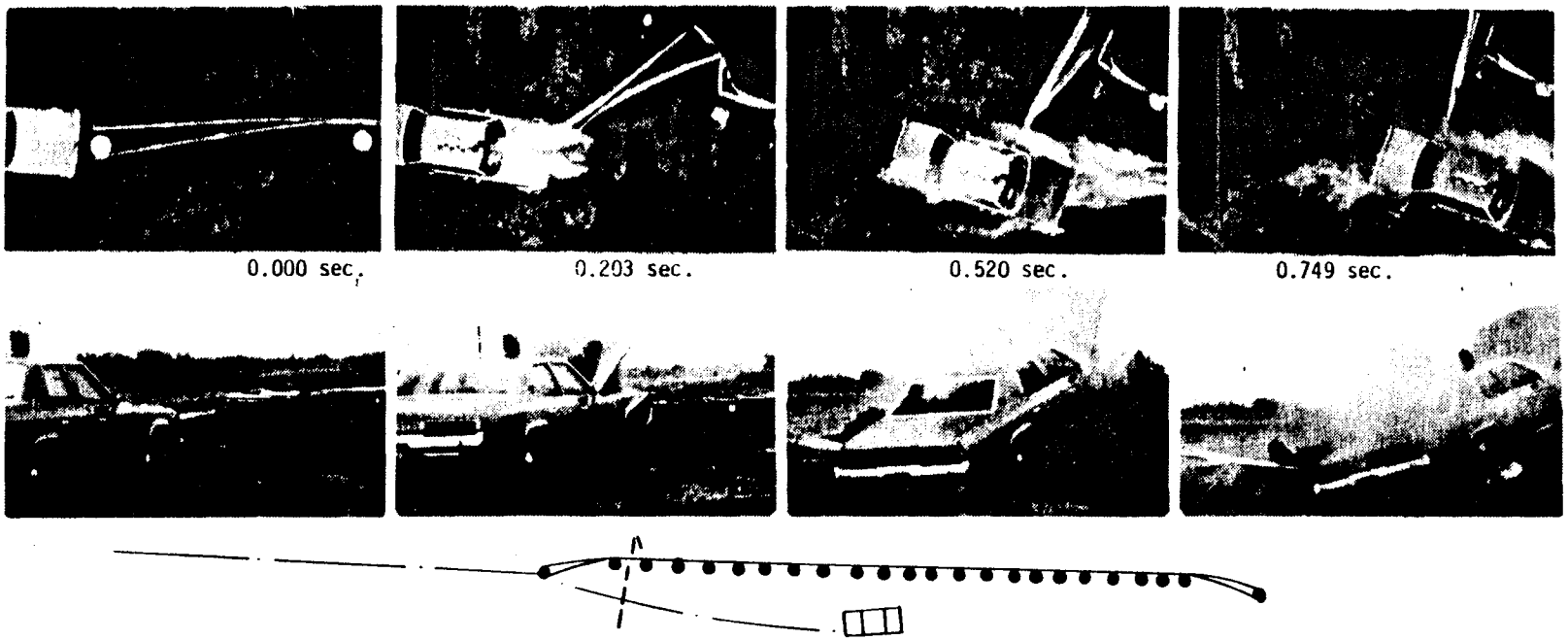
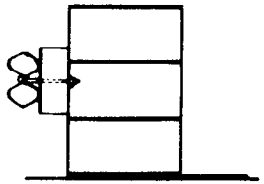


Figure 52. Rail Before and After Test 3825-4.



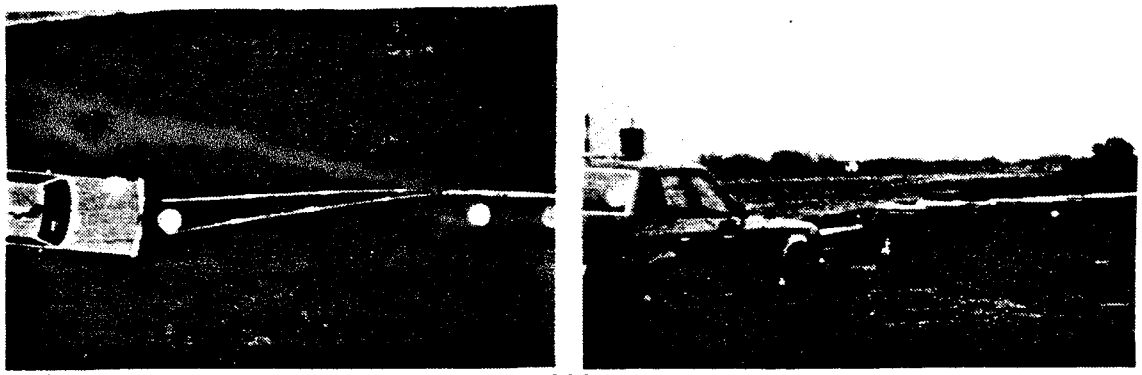


Stablilized Barrel
Beam No. 3
Construction Barrier

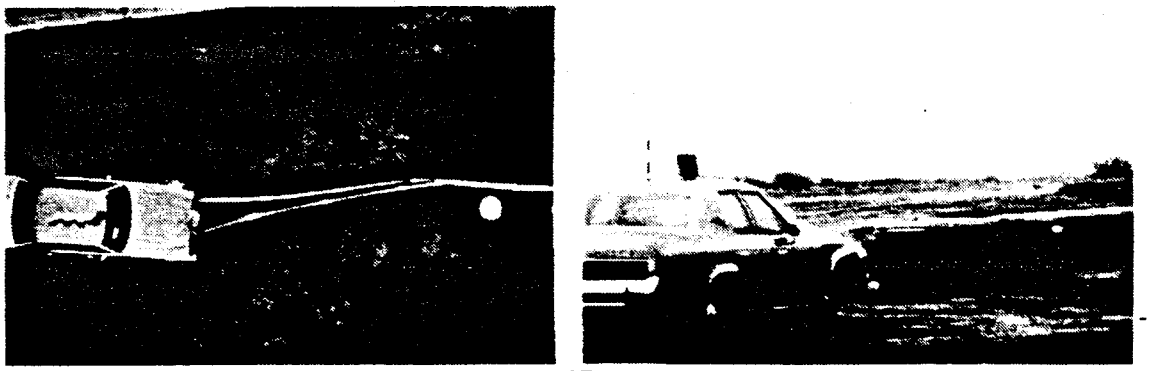
Test No.	3825-4
Date	3/8/80
Rail	12 gauge Tubular W-beam
Post	55 gal (208 ℓ) Open Head Drum, 18 gal (68 ℓ) Bottom and Body w/False Bottom & Skid Plate
Post Spacing	6.3 ft (1.9 m)
Post to Anchor Spacing	24.8 ft (7.6 m)
Length of Installation	250.0 ft (76.2 m)

Vehicle	Plymouth
Vehicle Weight	4,500 lb (2,041 kg)
Impact Velocity	61.4 mph (98.8 km/h)
Impact Angle	0 deg
Vehicle Acceleration (Max. 0.050 sec avg.)	
Longitudinal	15.8 g
Transverse	-3.1 g
Vertical	6.8 g
Vehicle Damage	
TAD	12-FD-3
SAE	12FDEW1

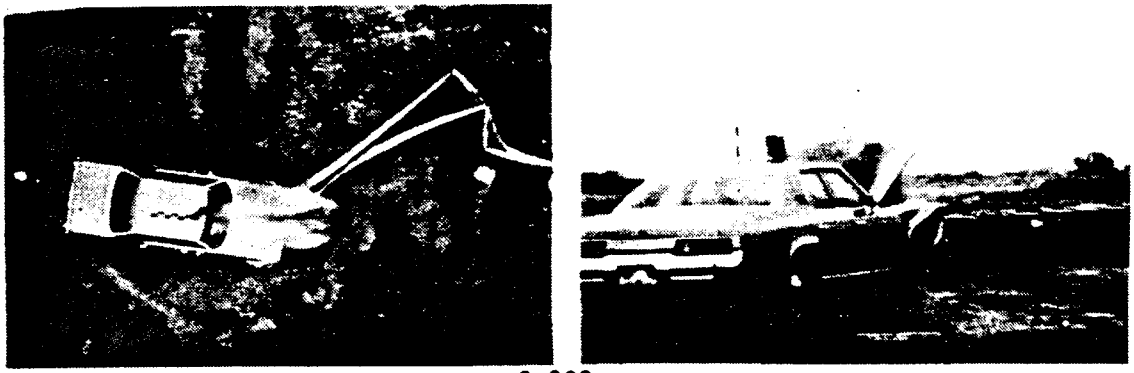
Figure 53. Summary of Results for Test 3825-4.



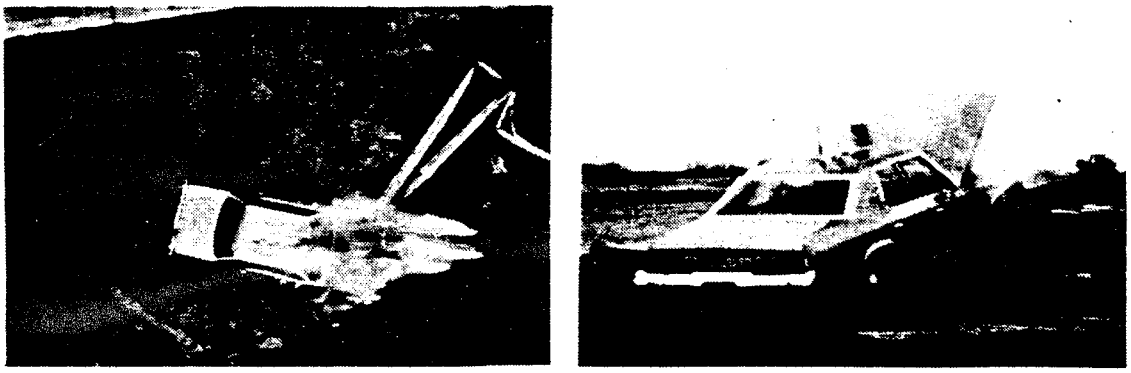
0.000 sec



0.047 sec

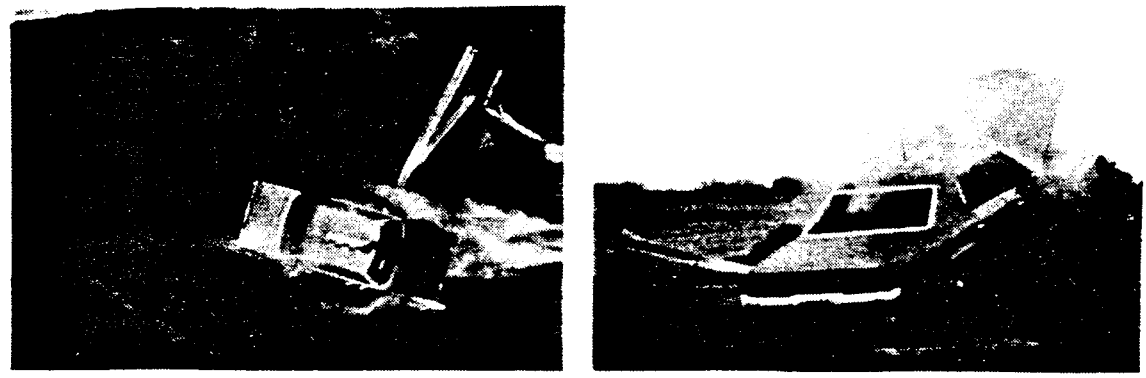


0.203 sec

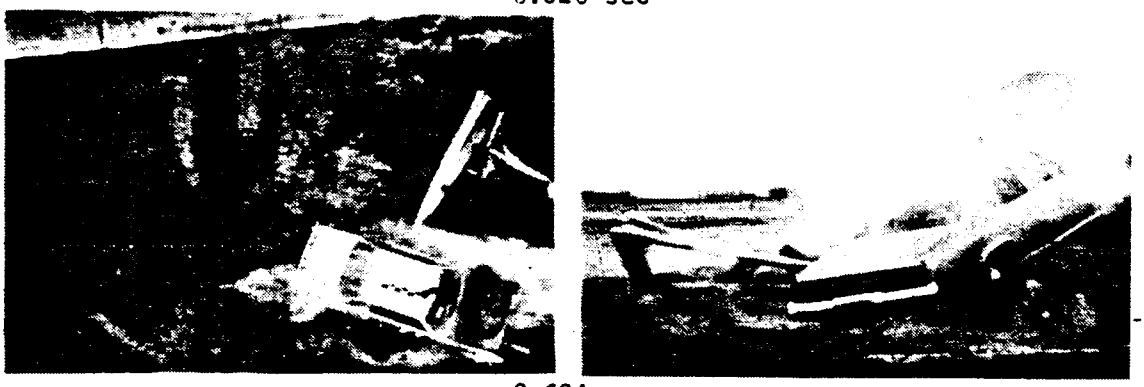


0.364 sec

Figure 54. Sequential Photographs for Test 3825-4.

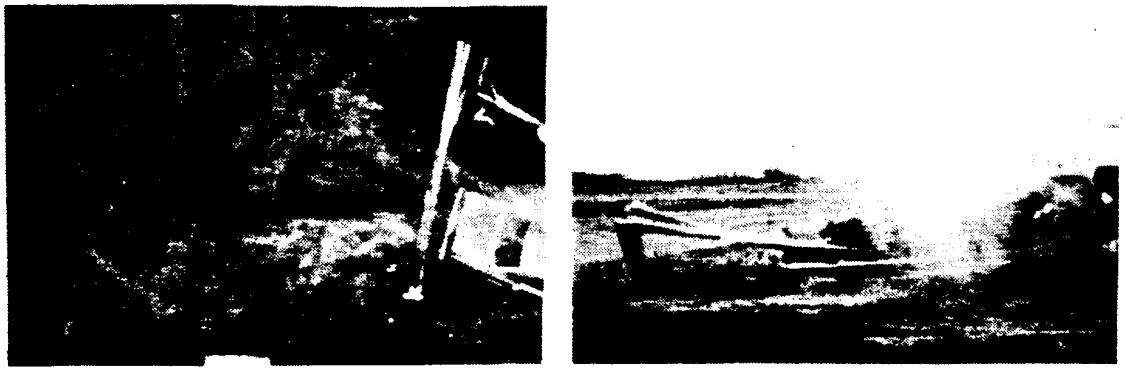


0.520 sec



0.624 sec

0.749 sec



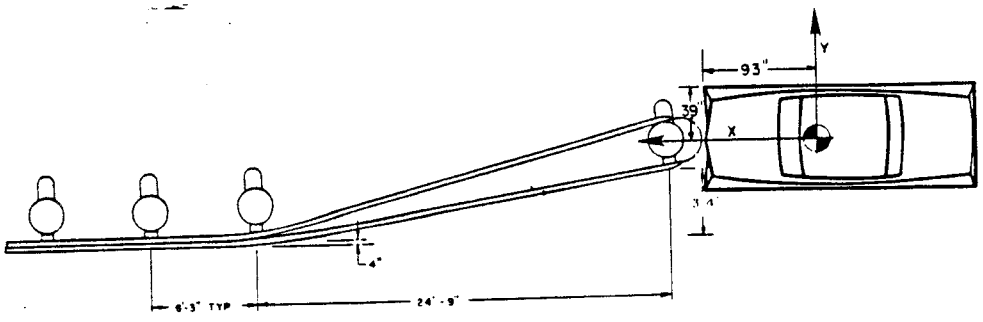
0.967 sec

Figure 54 (Continued). Sequential Photographs for Test 3825-4.

Table 4. Time, Displacement, Event Summary for Test 3825-4.

TIME (SEC)	X-DISPLACEMENT (FT)	Y-DISPLACEMENT (FT)	EVENT
-0.052	-4.591	-0.341	
-0.042	-3.666	-0.308	
-0.031	-2.735	-0.295	
-0.021	-1.810	-0.197	
-0.010	-0.912	-0.085	
0.000	0.000*	0.000*	Impact
0.016	1.351	0.079	Car hits 1st barrel
0.026	2.289	0.118	
0.047	3.935	0.282	Rail begins to bend
0.078	6.032	0.451	
0.130	8.822	0.750	
0.182	11.217	0.969	
0.203	12.188	1.131	Rail breaks from 2nd barrel
0.260	14.808	1.374	
0.312	17.163	1.671	
0.364	19.412	1.843	2nd barrel falls
0.416	21.629	2.008	
0.468	23.733	2.582	
0.520	25.870	2.832	
0.572	28.011	3.118	
0.624	30.167	3.430	
0.728	34.368	4.022	
0.832	38.461	4.790	
0.936	42.302	5.490	Car leaves rail
0.988	44.097	5.878	Car leaves view

*Location of vehicle c.g. at point of impact with barrier.



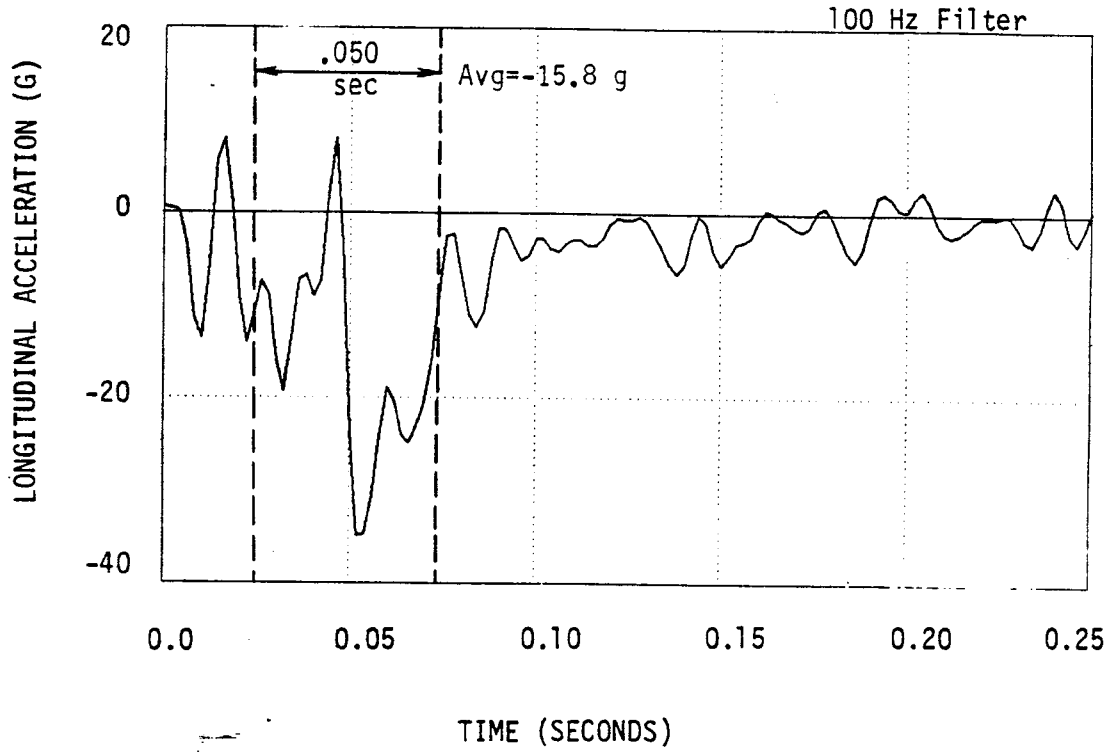


Figure 55. Vehicle Longitudinal Accelerometer Trace for Test 3825-4.

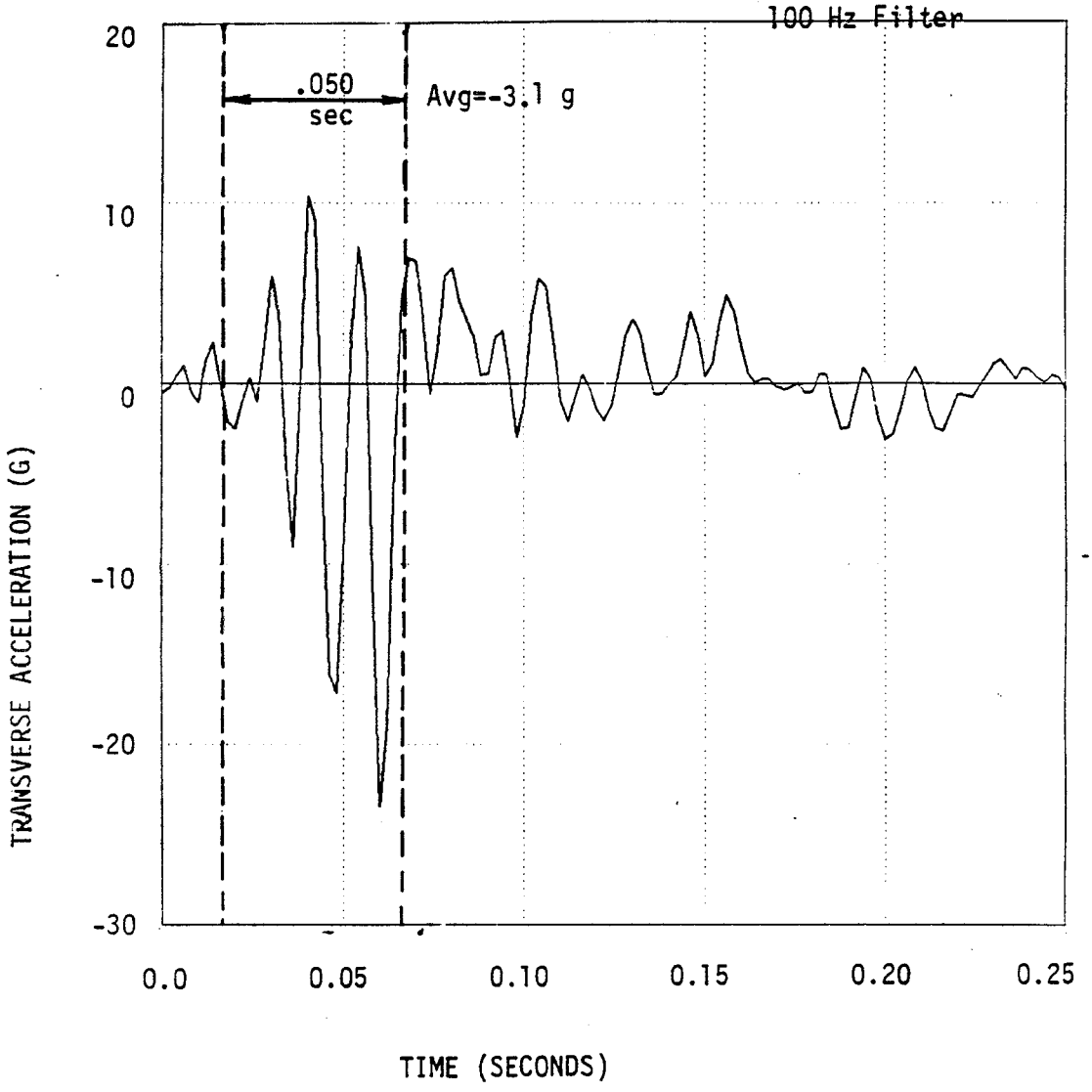


Figure 56. Vehicle Transverse Accelerometer Trace for Test 3825-4.

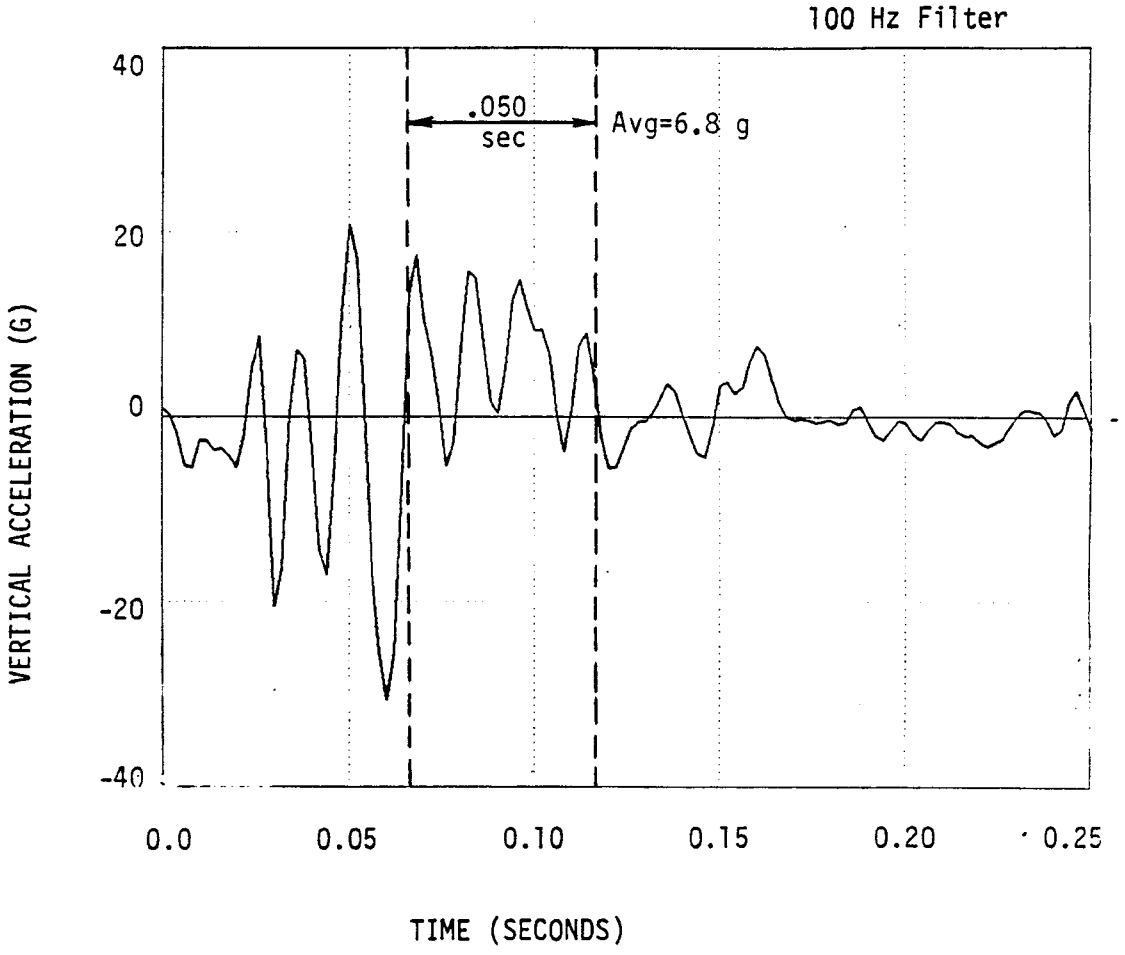


Figure 57. Vehicle Vertical Accelerometer Trace for Test 3825-4.

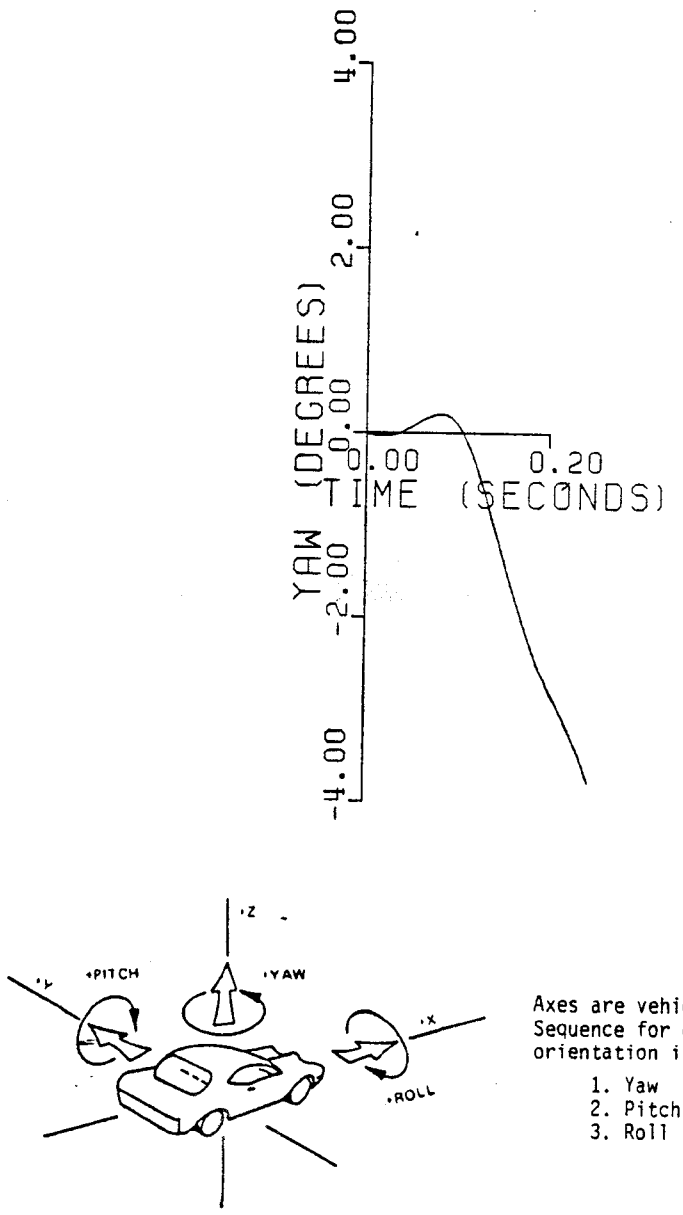


Figure 58. Vehicle Yaw for Test 3825-4.

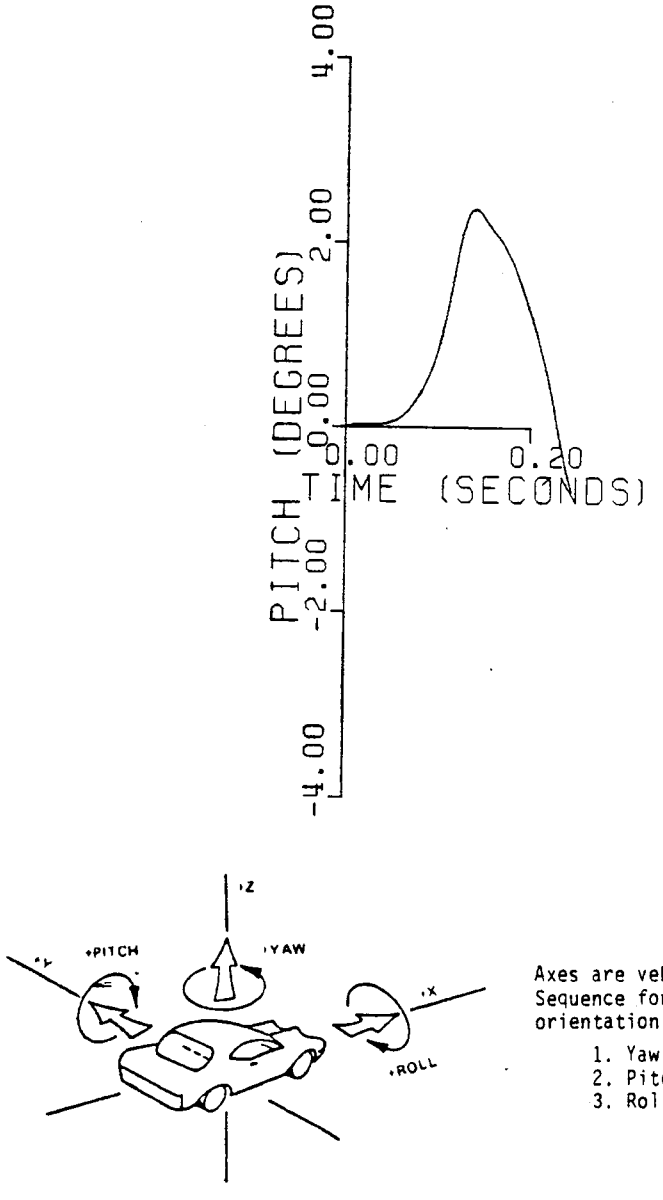


Figure 59. Vehicle Pitch for Test 3825-4.

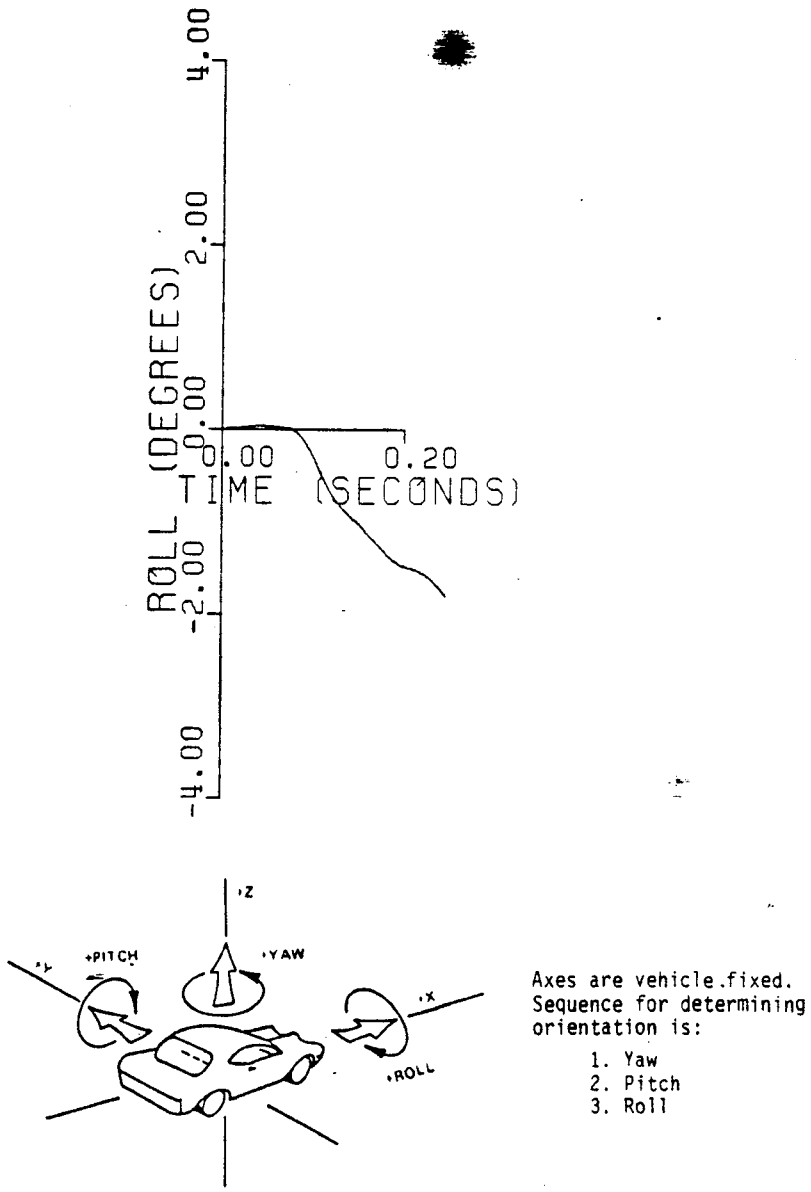


Figure 60. Vehicle Roll for Test 3825-4.

TEST REPORT 5

The test installation was made up of 12.0 ft (3.7 m) portable concrete median barrier (CMB) sections joined by a built-in male-female vertical "tongue and groove" coupling and 0.25 in. (0.64 cm) thick side plates bolted horizontally to the base of the CMB sections at the joints as illustrated in Figure 61. The barrier system consisted of ten CMB sections combined to form an installation 120.0 ft (36.7 m) long with a projected impact point at the center of section 4 as shown in Figure 62. This installation was placed on a dry, level concrete surface similar to PCC road surfaces.

Test 5 - 4,500 lb/60.7 mph/25 deg (2,041 kg/97.7 km/h/25 deg)

In Test 5, a 1974 Plymouth Fury, weighing 4,500 lb (2,041 kg) including telemetry equipment, impacted the test installation at a speed of 60.7 mph (97.7 km/h) and an angle of 25 deg. Photographs of the vehicle and barrier system before and after Test 5 are presented in Figure 63, while a summary of test results is shown in Figure 64. Sequential photographs of Test 6 are presented in Figure 65 and Table 5 lists time and displacements as related to specific events.

The vehicle impacted the barrier initially at the center of CMB section 4. The force of the impact disengaged the hood causing it to fly up and eventually be folded back against the windshield. The left front wheel contacted the barrier 1.2 ft (0.4 m) downstream from impact and began to ramp causing the vehicle to roll and yaw to the right and the barrier to deflect. By 0.331 sec the left front wheel was up and over the barrier with the vehicle continuing to roll and yaw. As this yaw continued, the left rear tire swung into the barrier 4.8 ft (1.5 m) downstream from joint 3-4 and also cleared the barrier. The motion of the vehicle came parallel to the barrier by 0.264 sec as the vehicle skidded along the top of the barrier and continued to yaw to the right. The vehicle exited when it slid off the end of the barrier and skidded sideways to a stop 253.0 ft (77.1 m) downstream from the initial impact point. During the test the vehicle penetrated a maximum 4.6 ft (1.4 m) into the construction zone as measured from the initial centerline of the barrier. This occurred when the rear of the vehicle went over the top of

the barrier. The maximum dynamic deflection of the barrier was 1.6 ft (0.5 m) and maximum permanent deflection was also 1.6 ft (0.5 m) both occurring at joint 4-5. The linear accelerometer traces for Test 5 are presented in Figures 66 through 70. The maximum 0.050 sec average longitudinal acceleration was -6.2 g while the maximum 0.050 sec average transverse and vertical accelerations were -7.5 g and 8.2 g, respectively.

The permanent barrier deflections are shown in Figure 71 while flexural cracking due to Test 5 is detailed in Figure 72. Figures 73 through 77 show specific damage to the CMB sections. Minor damage occurred due to flexural cracking and concrete spalling at the base of the joints near the impact area. Major spalling occurred at some of the joints due to interaction of the "tongue and groove" coupling when undergoing large deflections. Figure 77 specifically illustrates this type of damage.

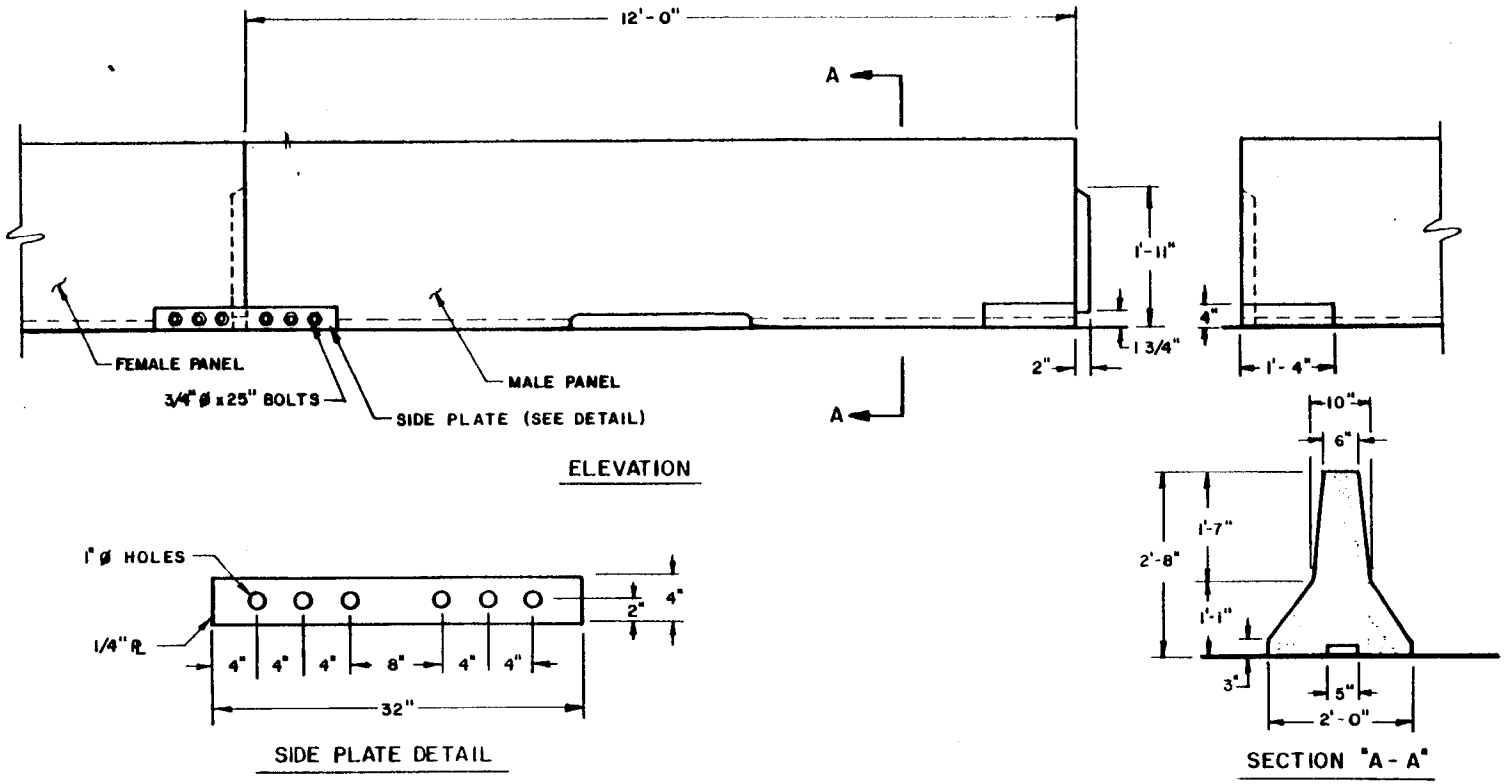


Figure 61. Portable Concrete Median Barrier Details for Test 3825-5.

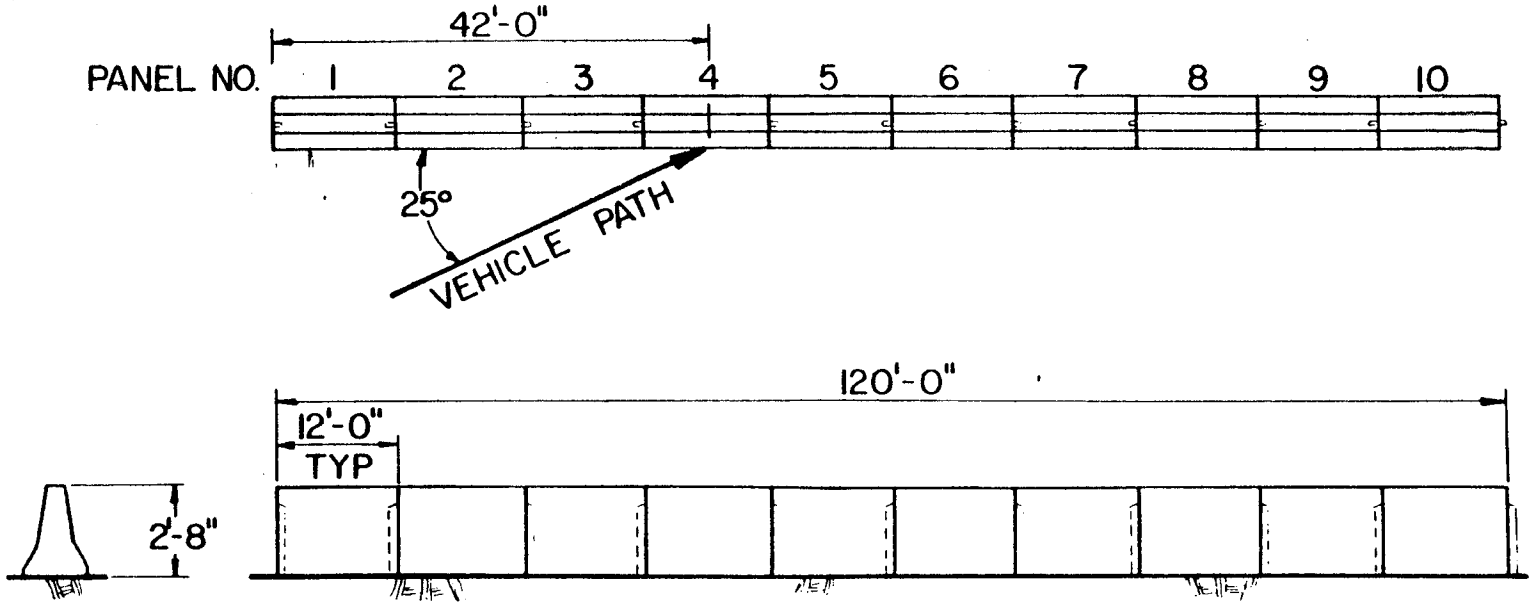


Figure 62. CMB Installation for Test 3825-5.

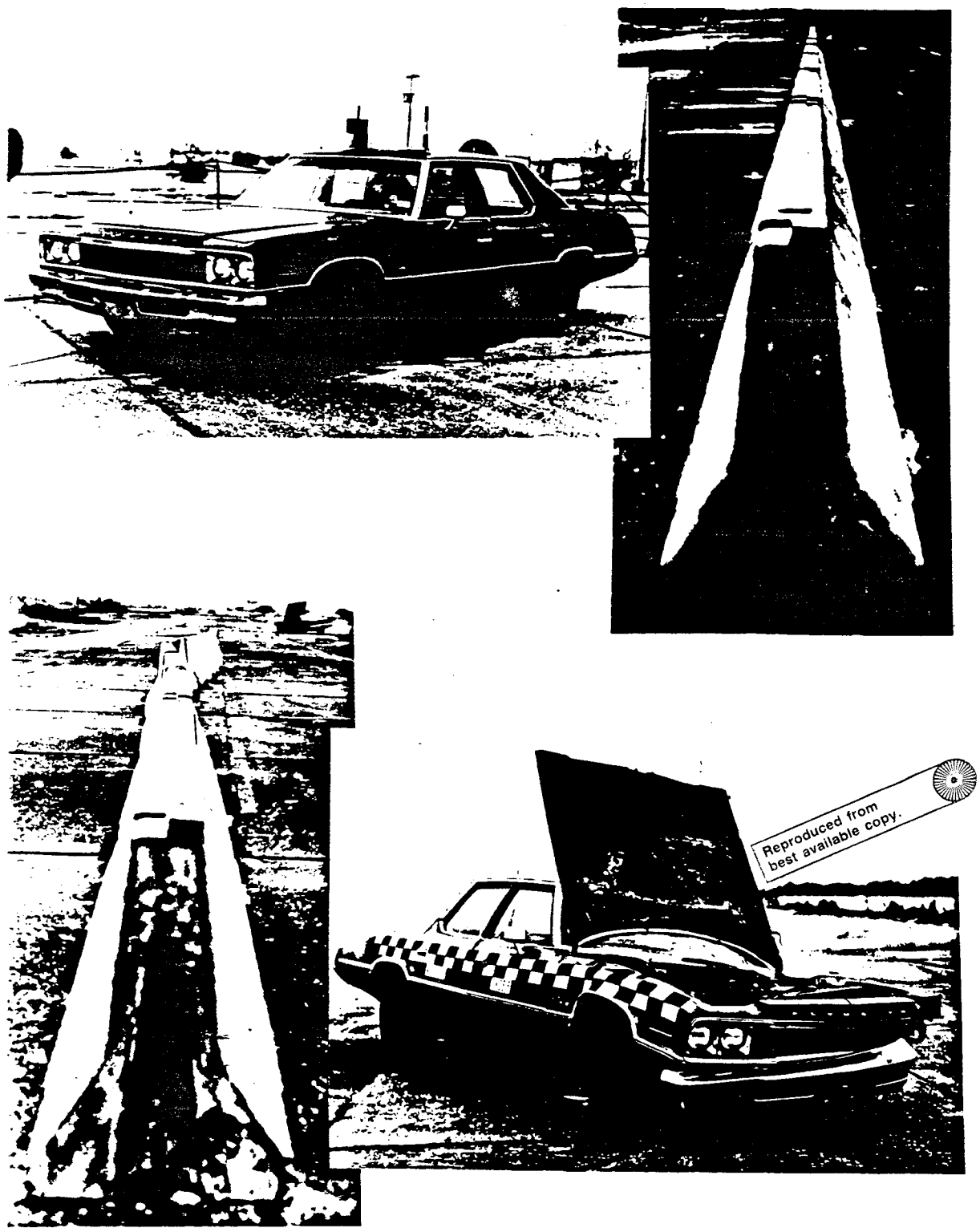
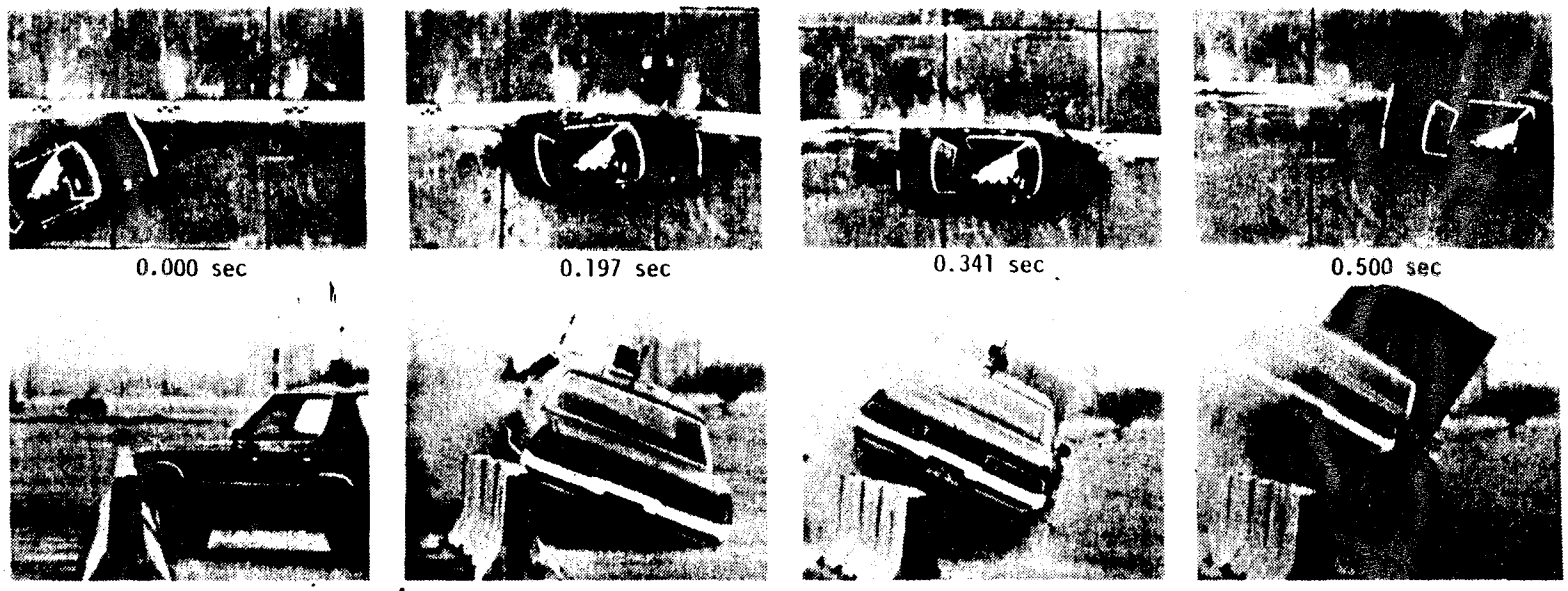
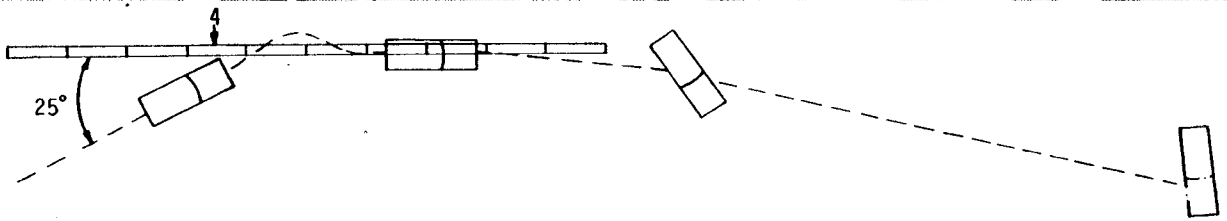
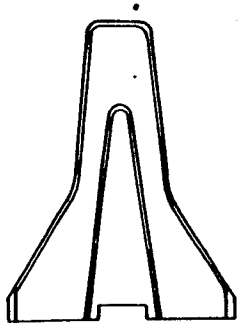


Figure 63 . Vehicle and Barrier Before and After Test 3825-5.







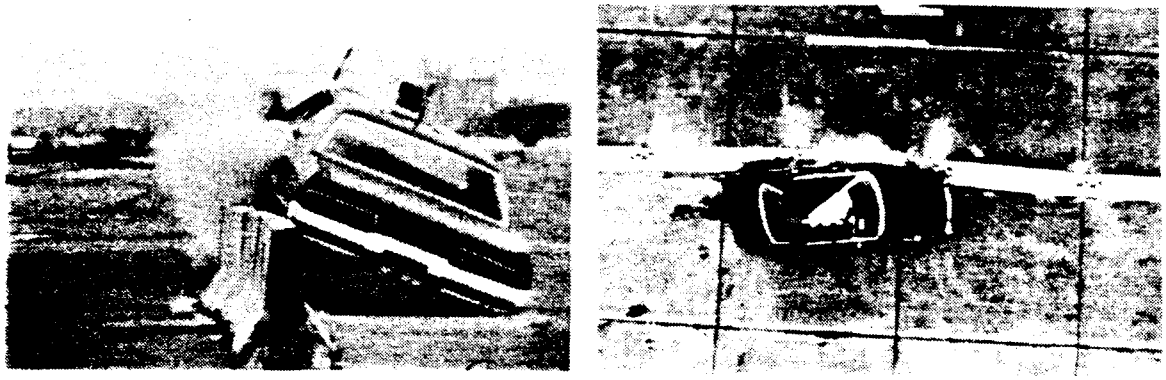
Portable Concrete
Median Barrier

Test No.	3825-5
Date	1/10/80
Barrier	Portable Concrete Median Barrier
Segment	Vertical Tongue & Groove w/ 1/4 in.(.64 cm) Steel Side Plates
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Deflection	
Max. Dynamic	1.6 ft (0.5 m)
Max. Permanent	1.6 ft (0.5 m)

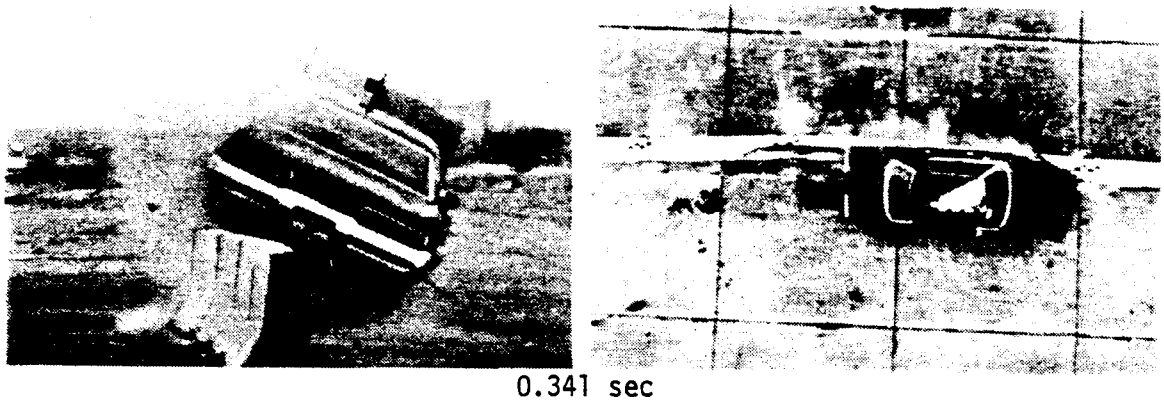
Vehicle	1974 Plymouth Fury
Vehicle Weight	4,500 lb (2,041 kg)
Impact Speed	60.7 mph (97.7 km/h)
Impact Angle	25 deg
Exit Speed	Not Applicable
Exit Angle	Not Applicable
Vehicle Acceleration (Max. 0.050 sec avg.)	
Longitudinal (rt & lt avg)	-6.2 g
Transverse	-7.5 g
Vertical	8.2 g
Vehicle Damage	
TAD	11FL4
SAE	11FLME1

Figure 64. Summary of Results for Test 3825-5.

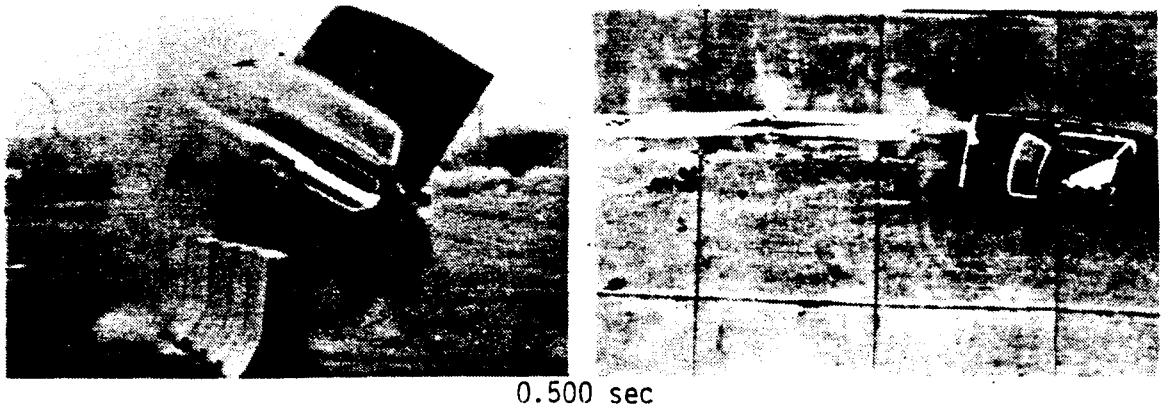
0.000 sec



0.197 sec



0.341 sec



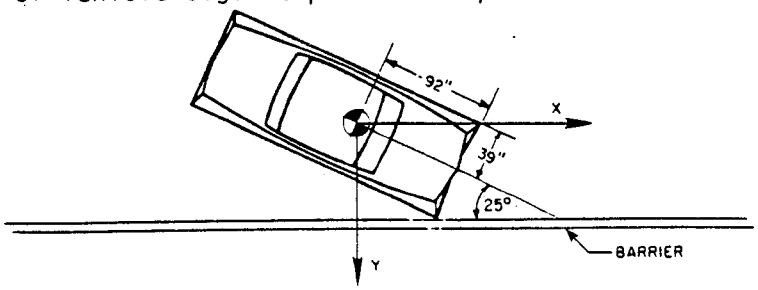
0.500 sec

Figure 65. Sequential Photographs for Test 3825-5.

Table 5. Time, Displacement, Event Summary for Test 3825-5.

TIME (sec)	X-DISPLACMENT (ft)	Y-DISPLACEMENT (ft)	EVENT
0.000	0.000*	0.000*	Impact
0.018	1.295	0.581	
0.035	2.671	1.189	
0.053	3.993	1.636	Car Hood Pops Up
0.070	5.362	2.043	
0.088	6.584	2.190	
0.106	7.793	2.290	Barrier Begins to Deflect
0.123	8.980	2.263	Car Begins to Roll
0.141	10.281	2.351	
0.158	11.448	2.378	
0.176	12.650	2.455	
0.194	13.859	2.559	Car Slides on Barrier
0.211	14.946	2.507	
0.229	16.163	2.683	
0.246	17.362	2.854	Rear Bumper Hits Barrier
0.264	18.371	2.930	Car Motion Parallel
0.282	19.684	2.855	Car Rolls and Slides Along Barrier
0.299	20.780	2.886	
0.317	22.025	2.886	
0.334	23.273	2.867	
0.352	24.515	2.924	
0.370	25.756	2.880	
0.387	27.040	2.828	
0.405	28.264	2.847	
0.422	29.652	2.762	
0.440	30.925	2.836	Hood Folded Back Against Windshield
0.458	32.144	2.863	
0.475	33.504	2.816	
0.493	34.872	2.870	
0.510	36.144	2.802	
0.528	37.303	2.749	
0.546	38.603	2.627	
0.563	39.768	2.600	
0.581	41.223	2.479	
0.595	41.916	1.610	C.G. Leaves View

*Location of vehicle c.g. at point of impact.



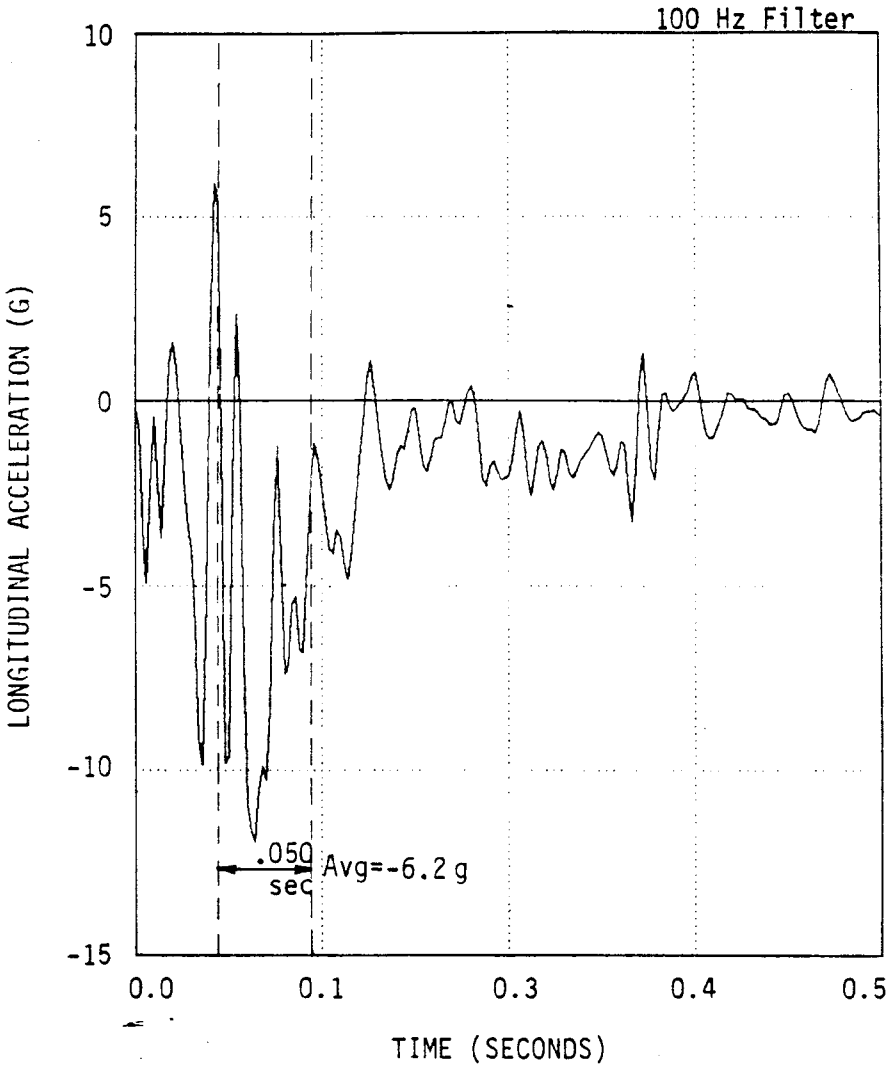


Figure 66. Vehicle Longitudinal Accelerometer Trace for Test 3825-5 (Averaged from Two Accelerometers).

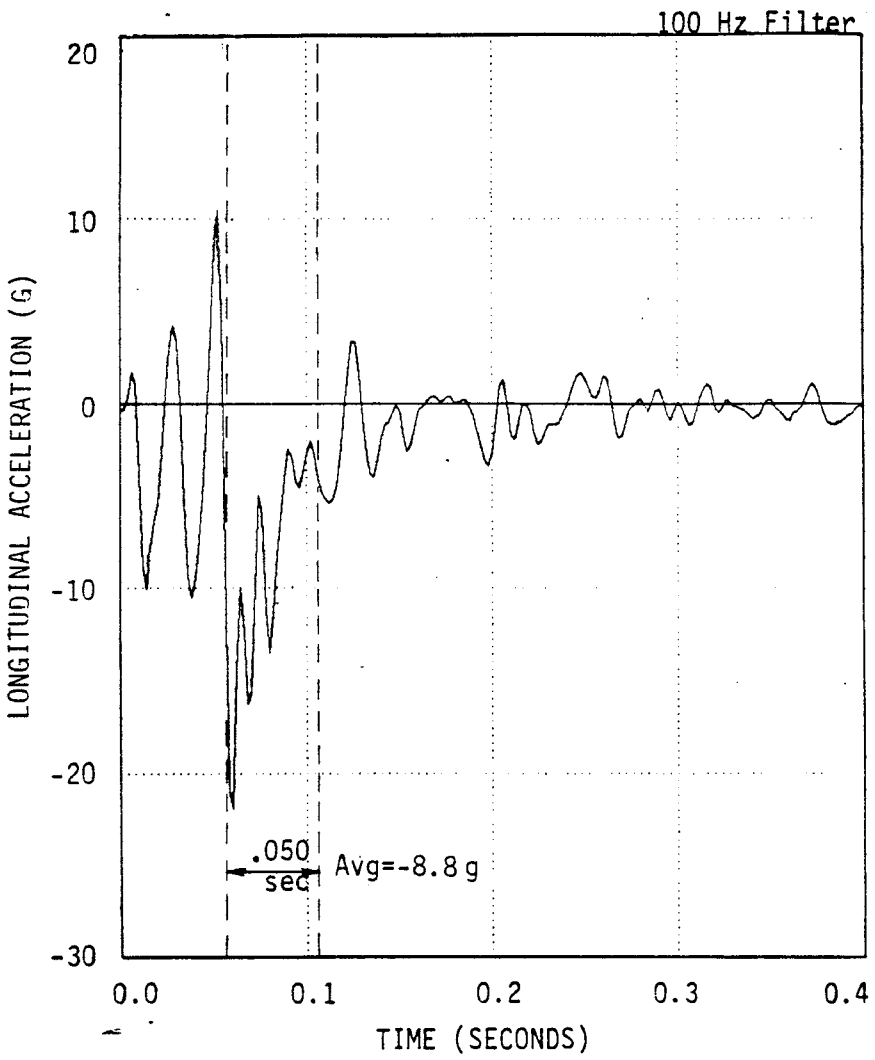


Figure 67. Vehicle Right Longitudinal Accelerometer Trace for Test 3825-5.

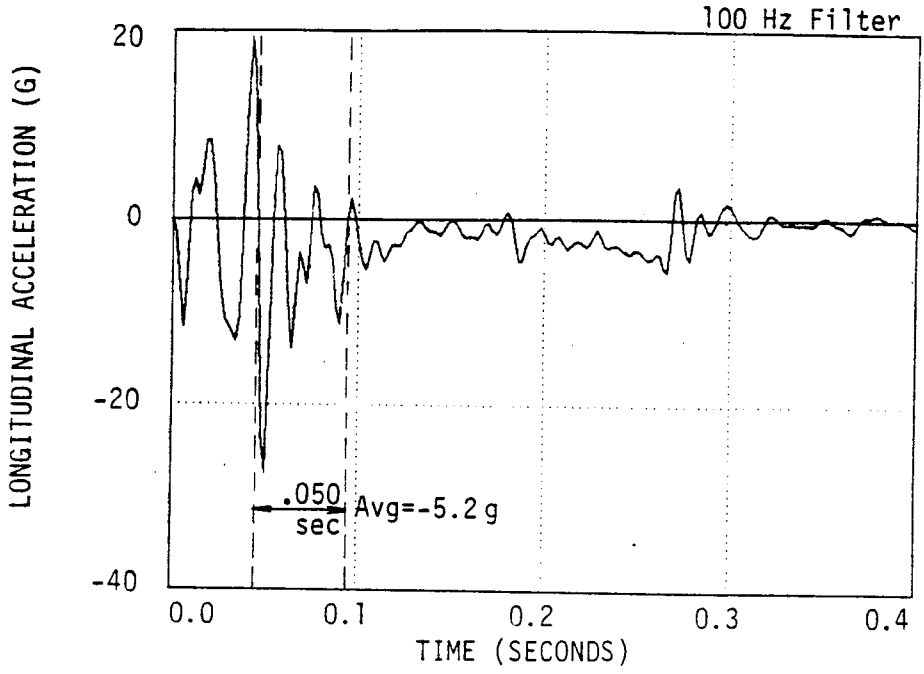


Figure 68. Vehicle Left Longitudinal Accelerometer Trace for Test 3825-5.

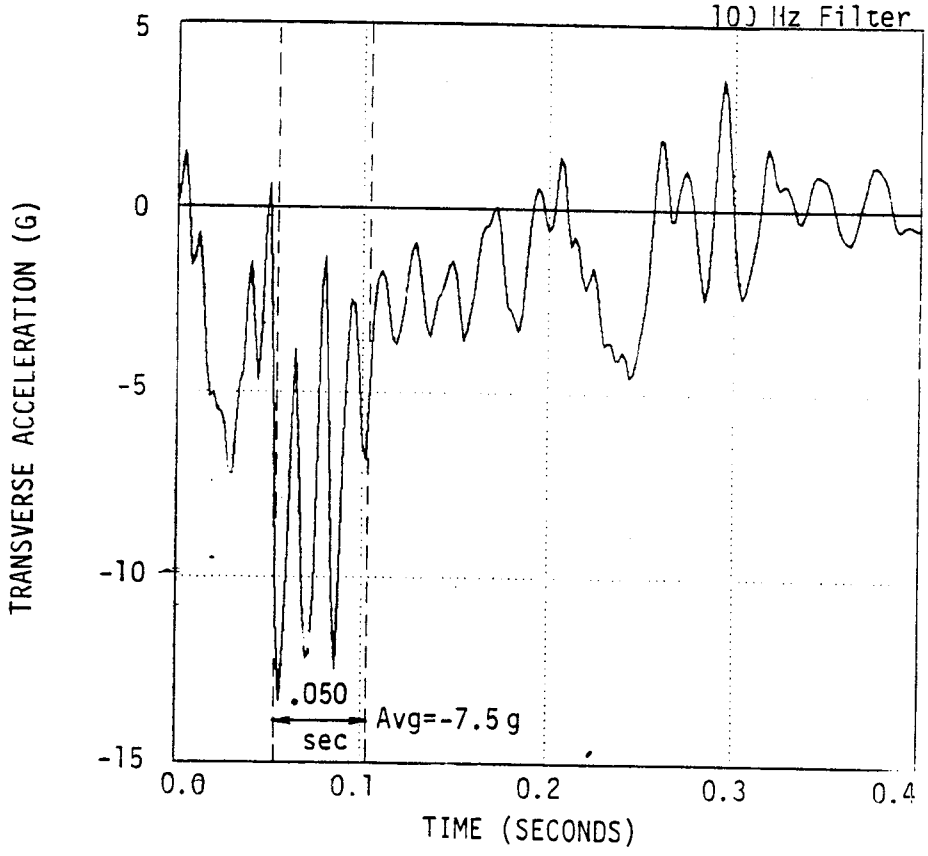


Figure 69. Vehicle Left Transverse Accelerometer Trace for Test 3825-5.

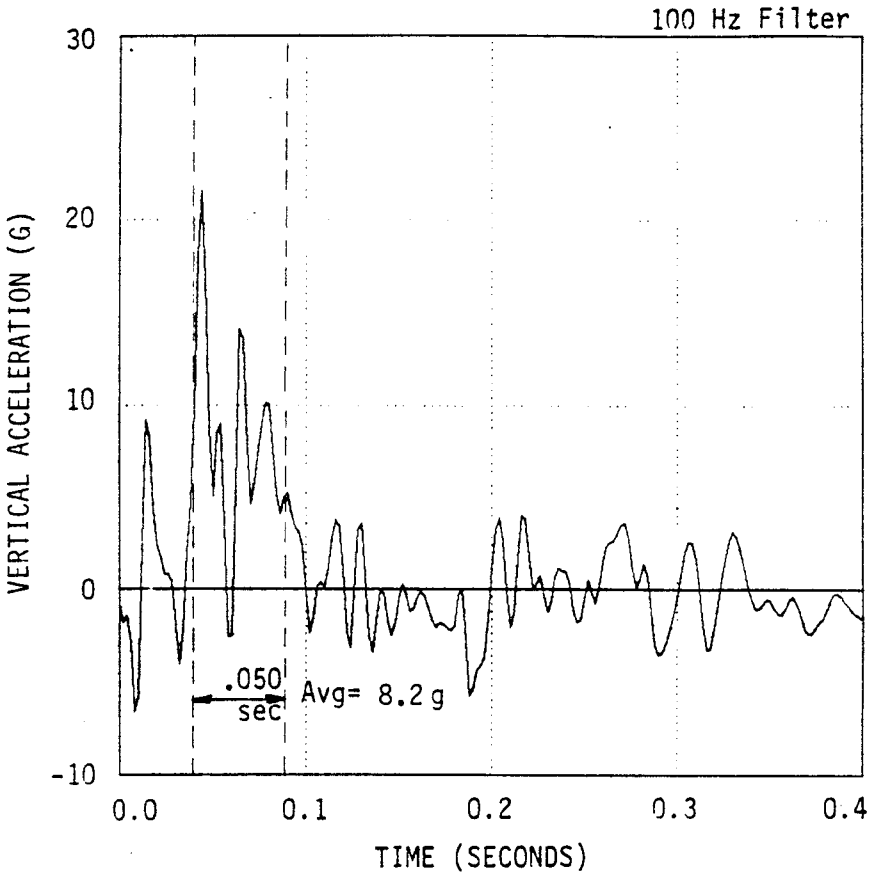


Figure 70. Vehicle Left Vertical Accelerometer Trace for Test 3825-5.

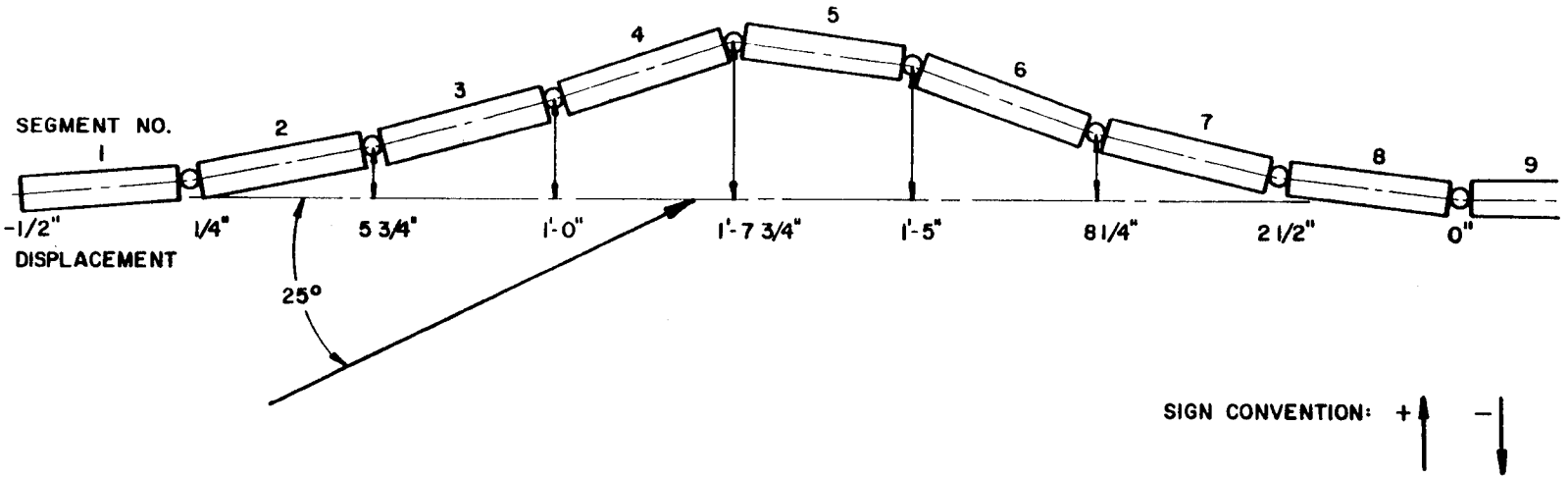
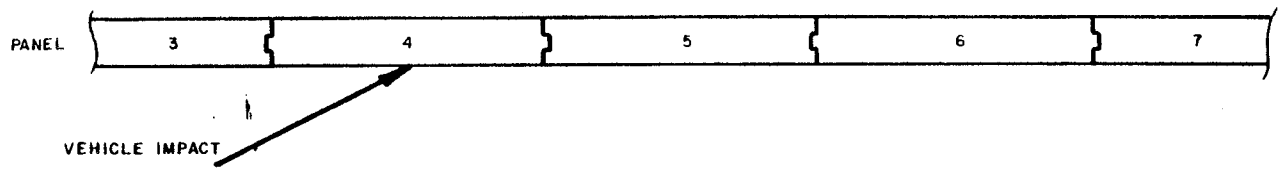


Figure 71. Permanent Barrier Deflection Test 3825-5.



NOTE: IMPACT FACE OF PANEL IS SHOWN, CRACKS ARE ON BACK FACE.

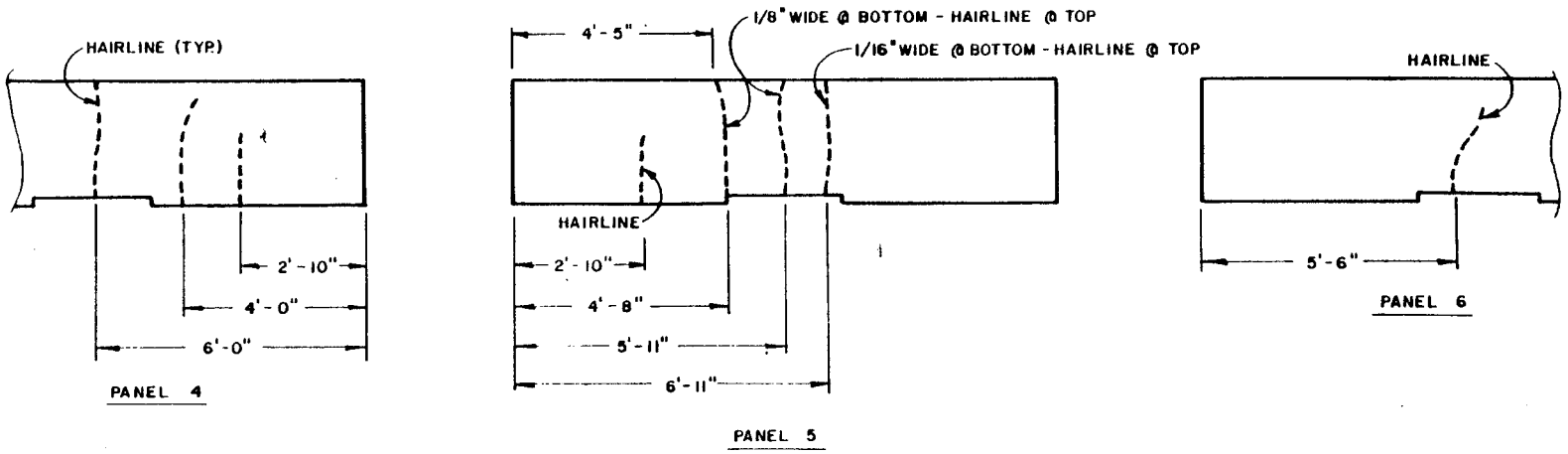
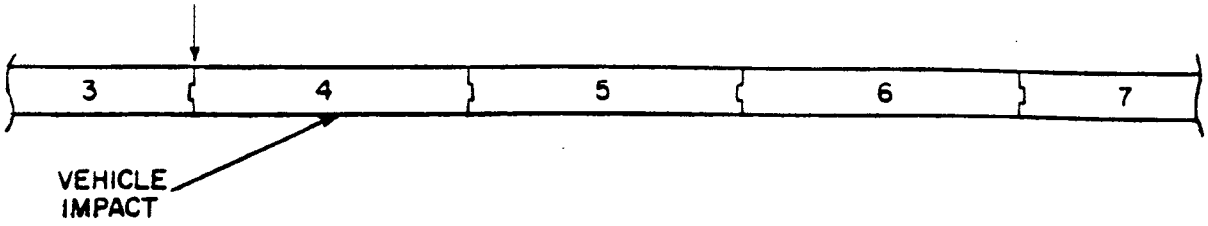
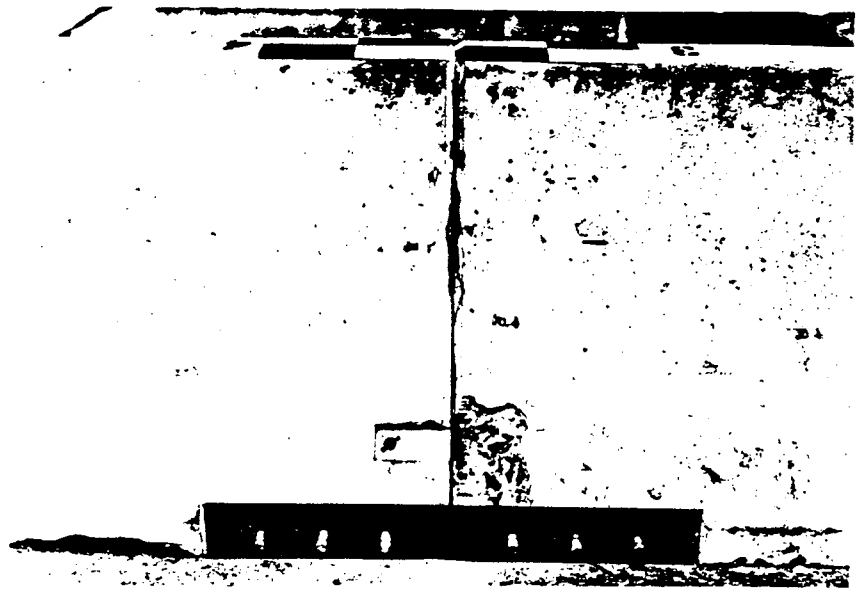


Figure 72. Flexural Cracking From Test 3825-5.





Before

After

Figure 73. Joint 3-4 Back Before and After Test 3825-5.

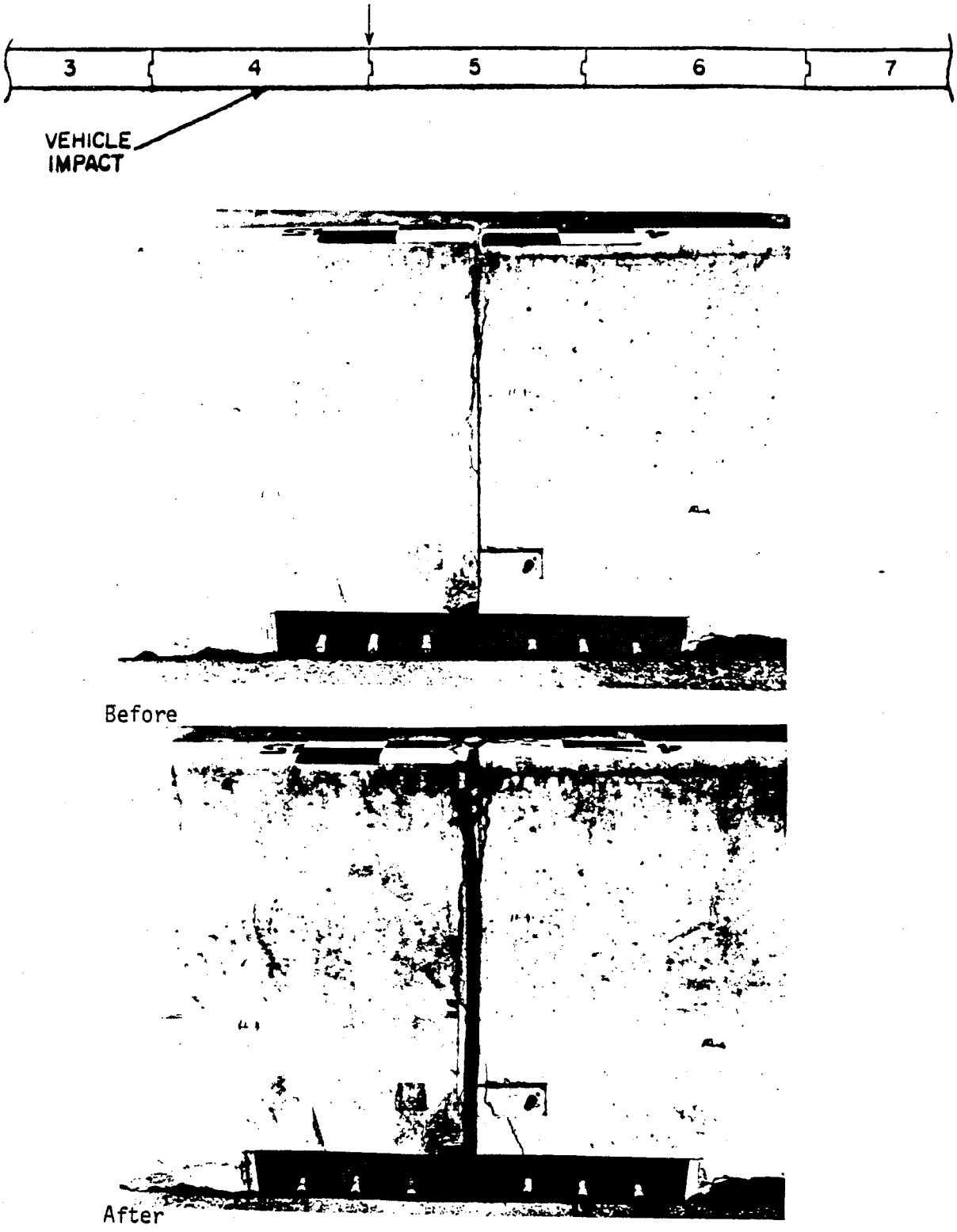
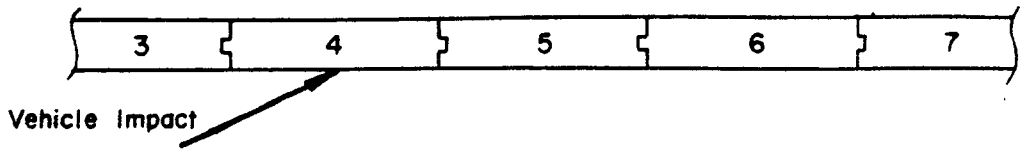


Figure 74. Joint 4-5 Back Before and After Test 3825-5.



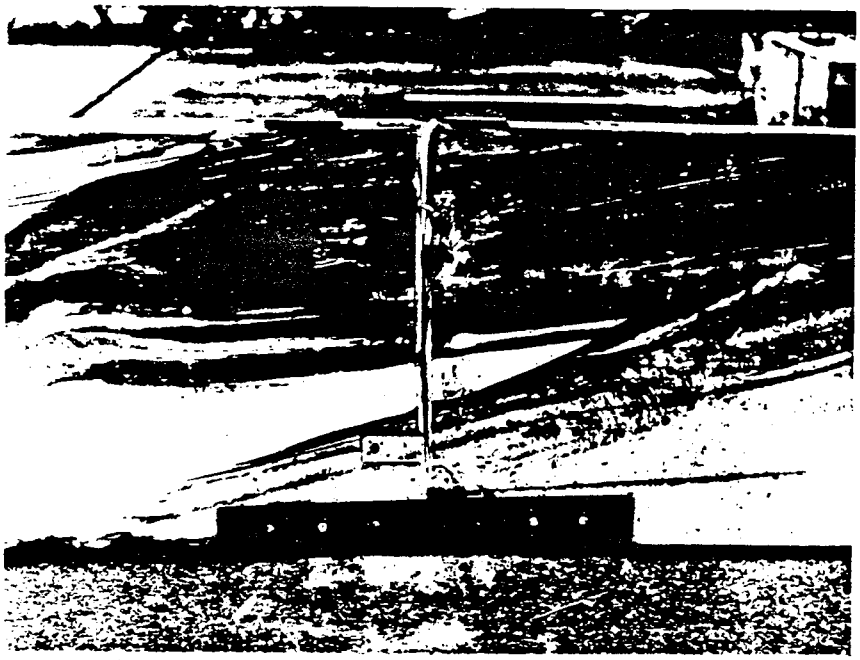
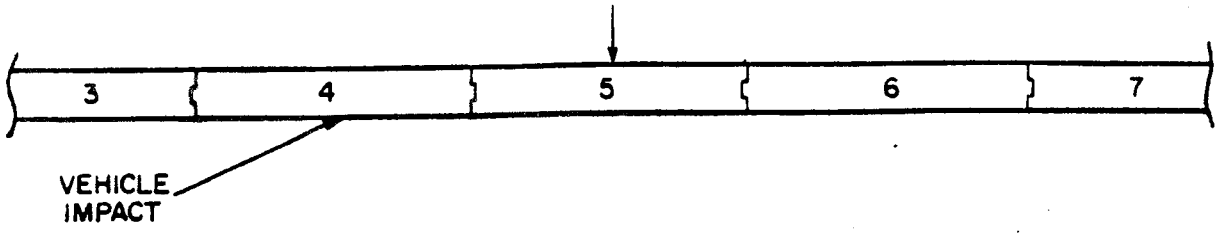


Figure 75 . Joint 4-5 Front After Test 3825-5.



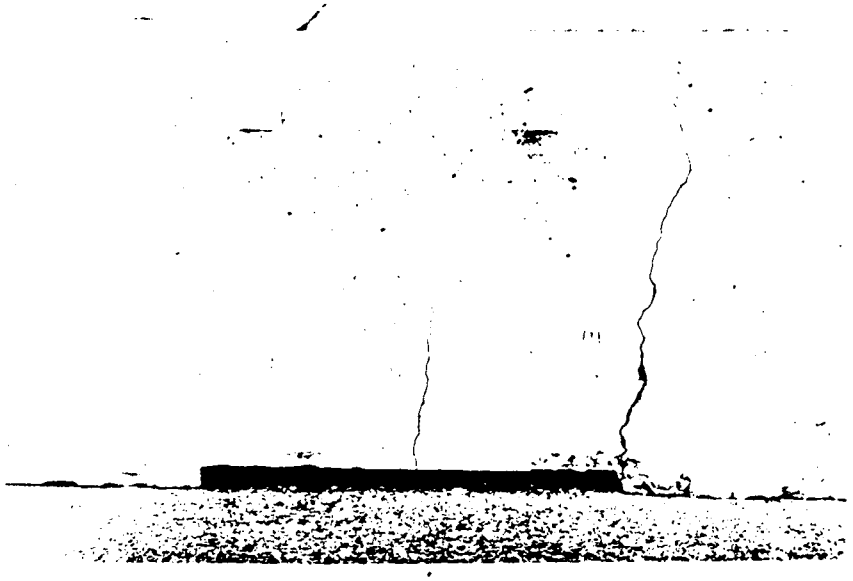
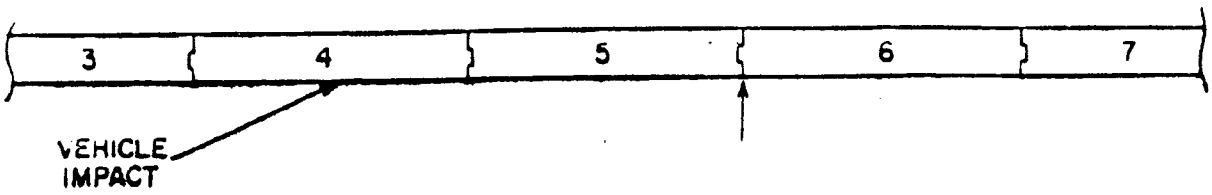


Figure 76. Section 5 Back After Test 3825-5.



Before

After

Figure 77. Joint 5-6 Front Before and After Test 3825-5.

TEST REPORT 6

The test installation consisted of 12.0 ft (3.7 m) portable concrete median barrier CMB sections. These CMB sections were joined by a built-in vertical male-female "tongue and groove" coupling and 0.375 in. (0.95 cm) thick side plates bolted horizontally to the base of the CMB sections as illustrated in Figure 78. The barrier system consisted of ten CMB sections combined to form an installation 120.0 ft (36.7 m) long with a projected impact point near the center of section 4 as shown in Figure 79. This installation was placed on a dry, level concrete surface similar to a typical PCC highway surface.

Test 6 - 4,500 lb/60.1 mph/24 deg (2,041 kg/96.7 km/h/24 deg)

In Test 6, a 1974 Plymouth Fury, weighing 4,500 lb (2,041 kg) including all telemetry equipment, impacted the barrier at a speed of 60.1 mph (96.7 km/h) and an angle of 24 deg. Photographs of the vehicle and barrier system before and after Test 6 are presented in Figure 80. A summary of test results is presented in Figure 81 and sequential photographs are shown in Figure 82. Table 6 lists time and displacement as related to specific events.

The vehicle impacted the barrier initially at a distance of 5.9 ft (1.8 m) downstream from joint 3-4 on barrier section 4. The force of the impact buckled the hood and crushed the left front fender back to the wheel. The left front wheel ramped on the barrier and by 0.225 sec was over the CMB section. During this time the barrier was deflecting laterally and rotating while the vehicle began to yaw to the right and redirect. As this yaw continued the rear of the vehicle swung into the barrier 5.7 ft (1.7 m) downstream from joint 3-4 and also moved over the barrier. The motion of the vehicle became parallel to the barrier 0.243 sec after impact as the vehicle settled on the barrier, with both the left front and rear wheels over the barrier, and skidded along the top. The vehicle exited when it slid off the end of the system at approximately 6 deg to the barrier and continued to yaw to the right. After sliding off, the vehicle then rolled one and a half times, eventually ending upside down 178.0 ft (54.3 m) downstream from the initial impact point. Although the vehicle did roll subsequent to losing contact with the barrier, and

that would not be an appropriate result to qualify the barrier system as a whole, the fact that barrier length played a part in the ultimate vehicle reaction and the knowledge that whether or not a vehicle ultimately rolls is subject to wide testing variation leads one to conclude that this test alone should not be used to disqualify a particular connection design. The way the connection functioned was reasonable from a structural integrity viewpoint. During the test, the vehicle penetrated a maximum 2.9 ft (0.9 m) into the simulated construction zone. The maximum dynamic deflection of the barrier system was 2.0 ft (0.6 m) occurring 12.3 ft (3.8 m) downstream from the impact at joint 4-5 and the maximum permanent deflection was 1.8 ft (0.5 m) also at joint 4-5. The linear accelerometer traces for Test 6 are presented in Figures 83 through 87. The maximum 0.050 sec average longitudinal acceleration was -5.6 g while the maximum 0.050 sec transverse and vertical acceleration were -7.9 g and 7.8 g, respectively. These accelerations were observed during the vehicle-barrier primary impact. Accelerations generated during subsequent vehicle rolling were not considered.

The deflected barrier shape is shown in Figure 88 and the location of flexural cracks due to Test 6 are shown in Figure 89. Figures 90 through 94 show detailed pictures of damage to the barrier system. Minor damage to the CMB sections occurred due to flexural cracking and concrete spalling near the base of the joints in the vicinity of the impact point. Most damage occurred at the joints that underwent the largest rotations due to the "tongue and groove" coupling interaction. Damage of this type is shown specifically in Figures 90, 92 and 94.

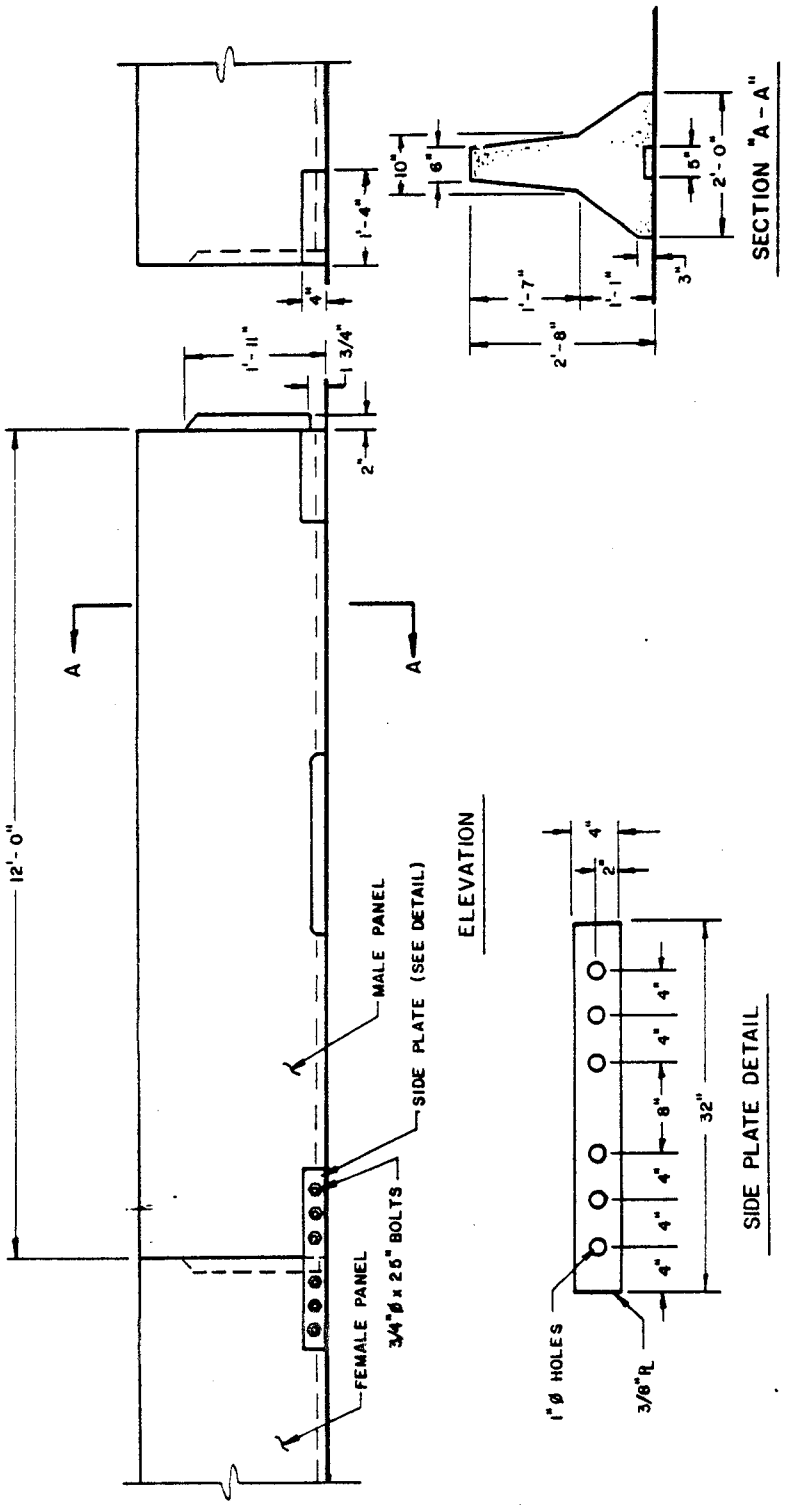


Figure 78. Portable Concrete Median Barrier Detail for Test 3825-6.

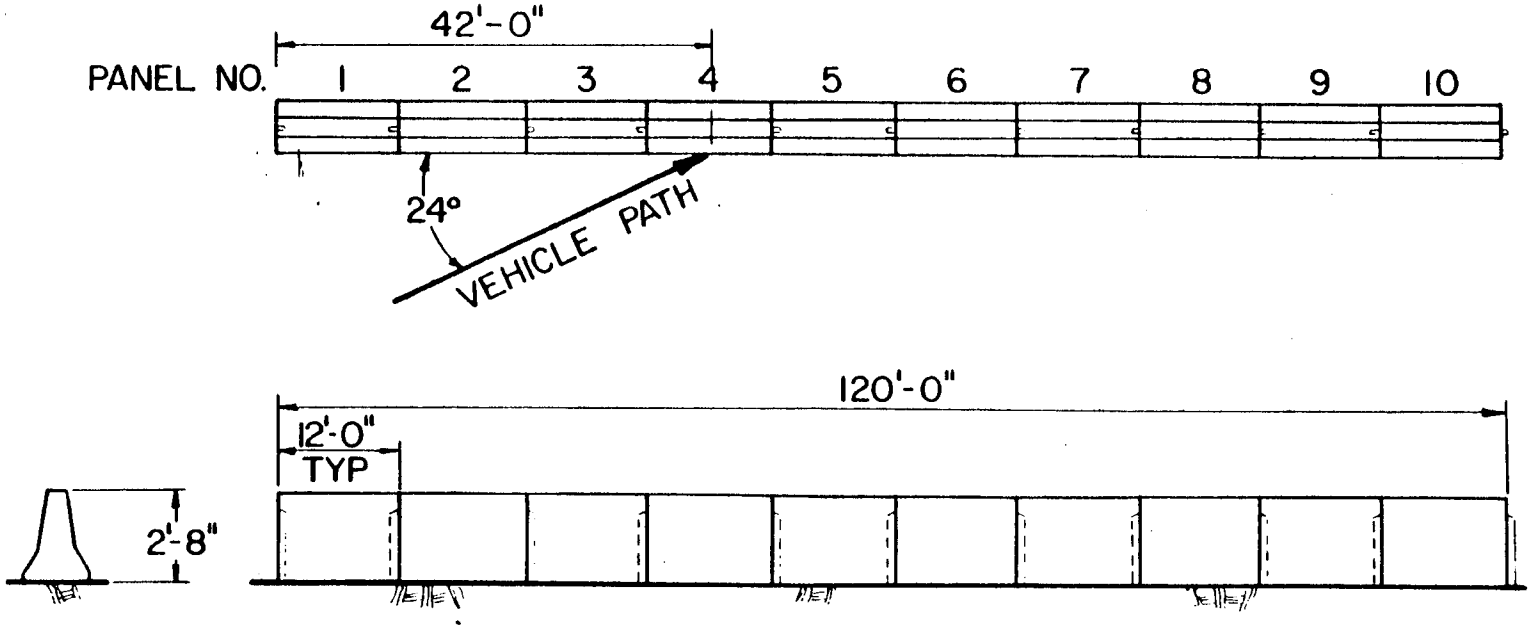


Figure 79. Barrier Installation for Test 3825-6.

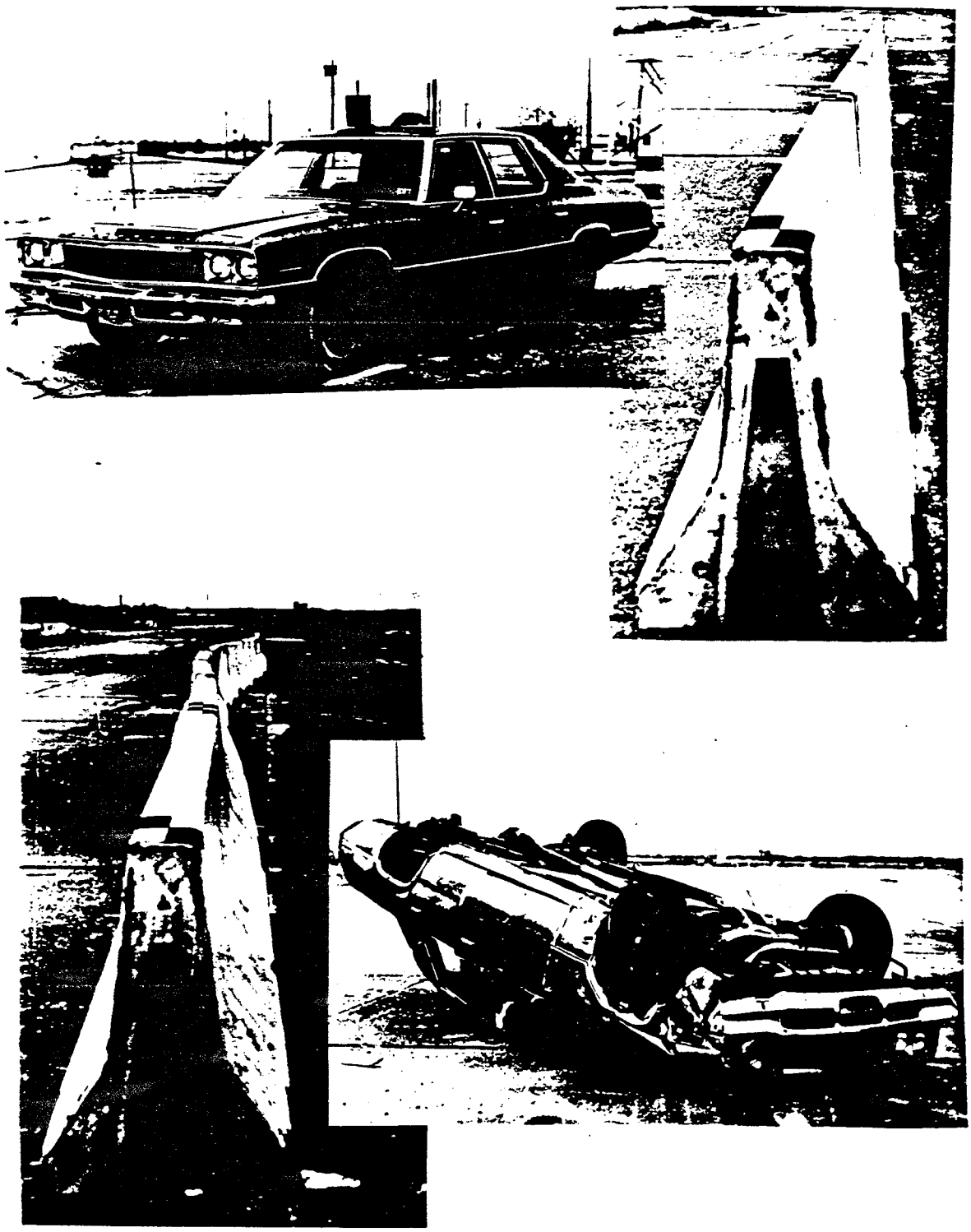
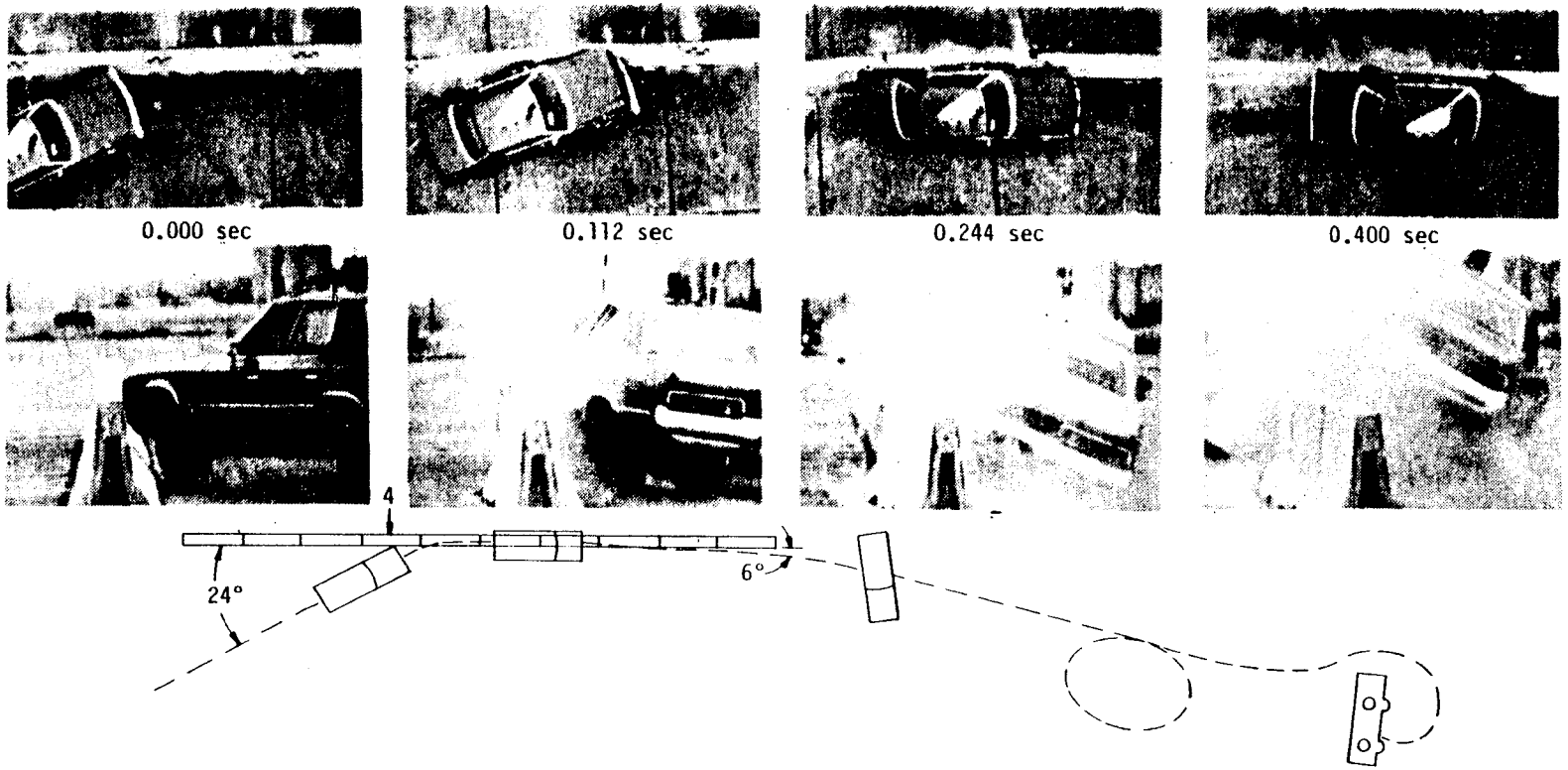
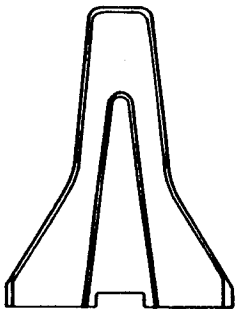


Figure 80. Vehicle and Barrier Before and After Test 3825-6.



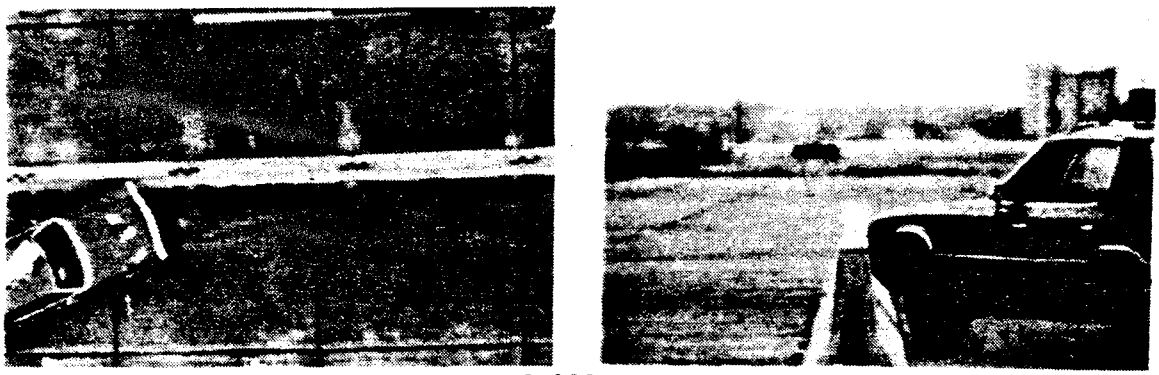


Portable Concrete
Median Barrier

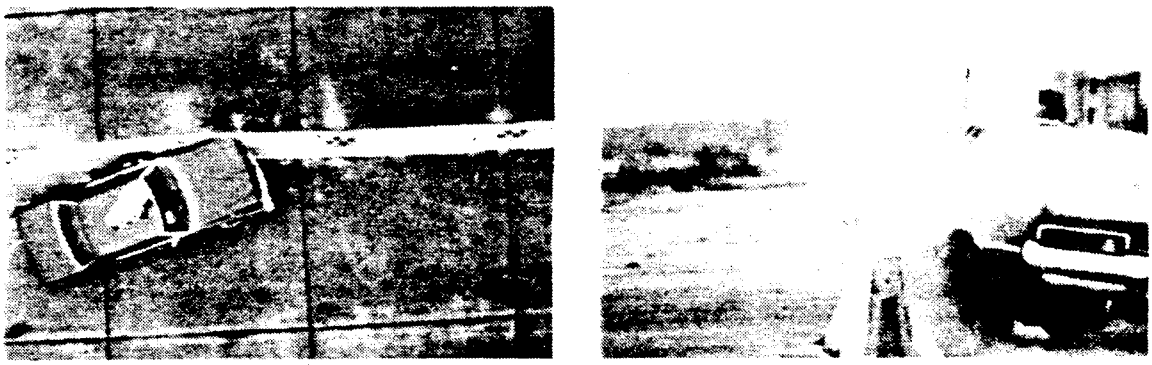
Test No.	3825-6
Date	1/9/80
Barrier	Portable Concrete Median Barrier
Segment	Vertical Tongue & Groove w/ 3/8in. (.95 cm) Steel Side Plates
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Deflection	
Max. Dynamic	2.0 ft (0.6 m)
Max. Permanent	1.8 ft (0.5 m)

Vehicle	1974 Plymouth Fury
Vehicle Weight	4,500 lb (2,041 kg)
Impact Speed	60.1 mph (96.8 km/h)
Impact Angle	24 deg
Exit Speed	Not Applicable
Exit Angle	∿6 deg
Vehicle Acceleration (Max. 0.050 sec avg.)	
Longitudinal (ft & lt avg).	-5.6 g
Transverse	-7.9 g
Vertical	7.8 g
Vehicle Damage	
TAD	10L&T5
SAE	10FLEW2 10LDES1 00ULXW1

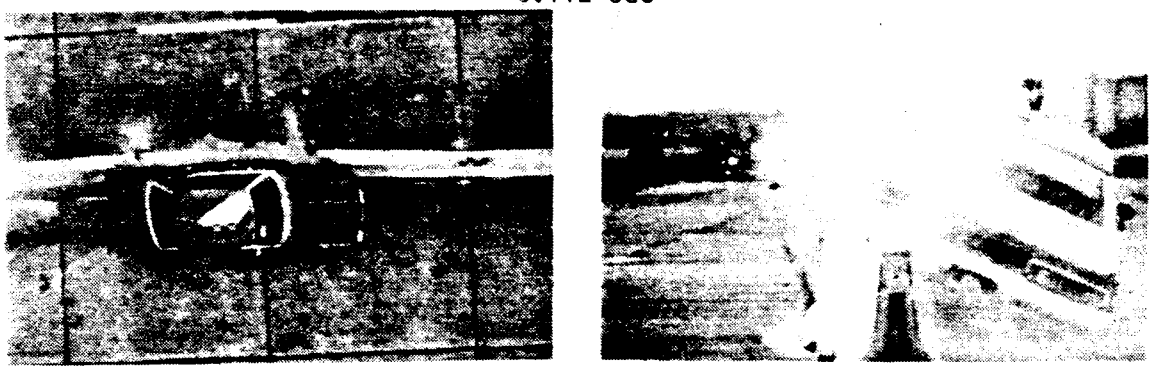
Figure 81. Summary of Results for Test 3825-6.



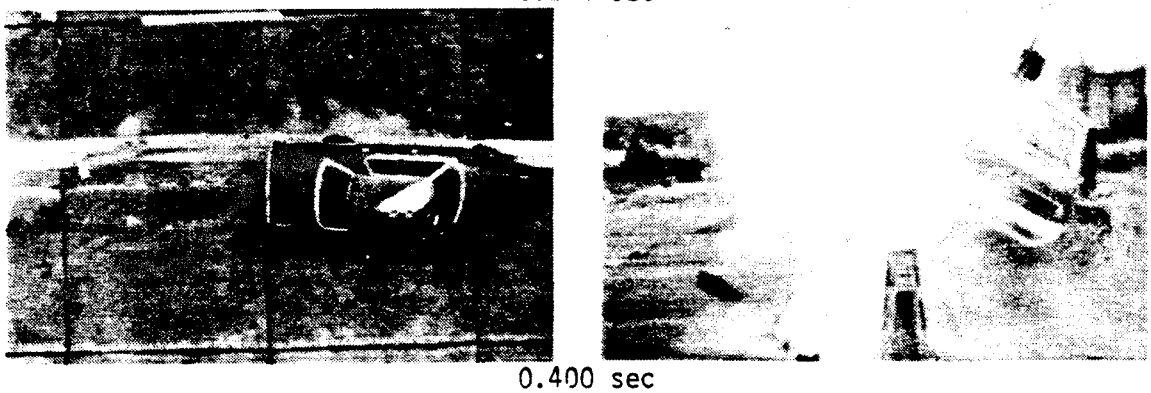
0.000 sec



0.112 sec



0.244 sec



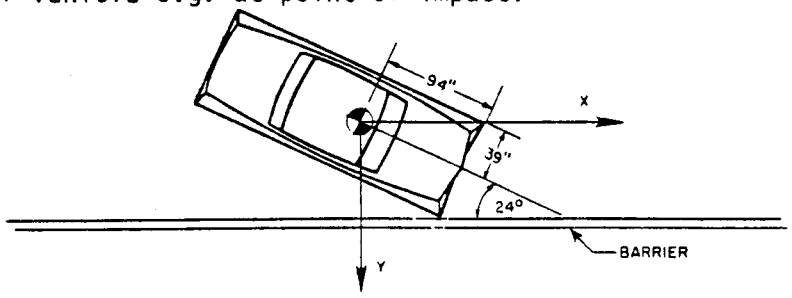
0.400 sec

Figure 82. Sequential Photographs for Test 3825-6.

Table 6. Time, Displacement, Event Summary for Test 3825-6.

TIME (sec)	X-DISPLACEMENT (ft)	Y-DISPLACEMENT (ft)	EVENT
0.000	0.000*	0.000*	Impact
0.017	1.318	-0.562	L. F. wheel hits barrier
0.035	2.669	-1.231	
0.052	3.993	-1.699	Hood pops up
0.069	5.301	-1.989	
0.087	6.494	-2.292	
0.104	7.728	-2.380	Barrier begins to deflect
0.121	9.036	-2.488	
0.139	10.262	-2.455	
0.156	11.461	-2.456	
0.173	12.634	-2.461	Headlight shatters
0.191	13.847	-2.567	
0.208	15.054	-2.670	Rear bumper hits barrier
0.225	16.313	-2.735	L. F. wheel clears barrier
0.243	17.481	-2.780	Car motion parallel
0.260	18.708	-2.912	
0.277	19.884	-2.937	Car slides along barrier
0.295	21.116	-2.918	
0.312	22.336	-2.843	
0.329	23.548	-2.755	L. R. wheel clears barrier
0.347	24.772	-2.762	
0.364	26.052	-2.768	Maximum barrier dynamic deflection
0.382	27.276	-2.680	
0.399	28.511	-2.655	
0.416	29.771	-2.510	
0.434	30.980	-2.460	L. R. wheel over barrier
0.451	32.257	-2.383	
0.468	33.521	-2.441	
0.486	34.650	-2.364	L. F. wheel over barrier
0.503	36.016	-2.332	
0.520	37.262	-2.312	
0.538	38.501	-2.299	
0.555	39.721	-2.285	
0.572	41.039	-2.233	
0.579	41.645	-2.154	C. G. leaves view

*Location of vehicle c.g. at point of impact.



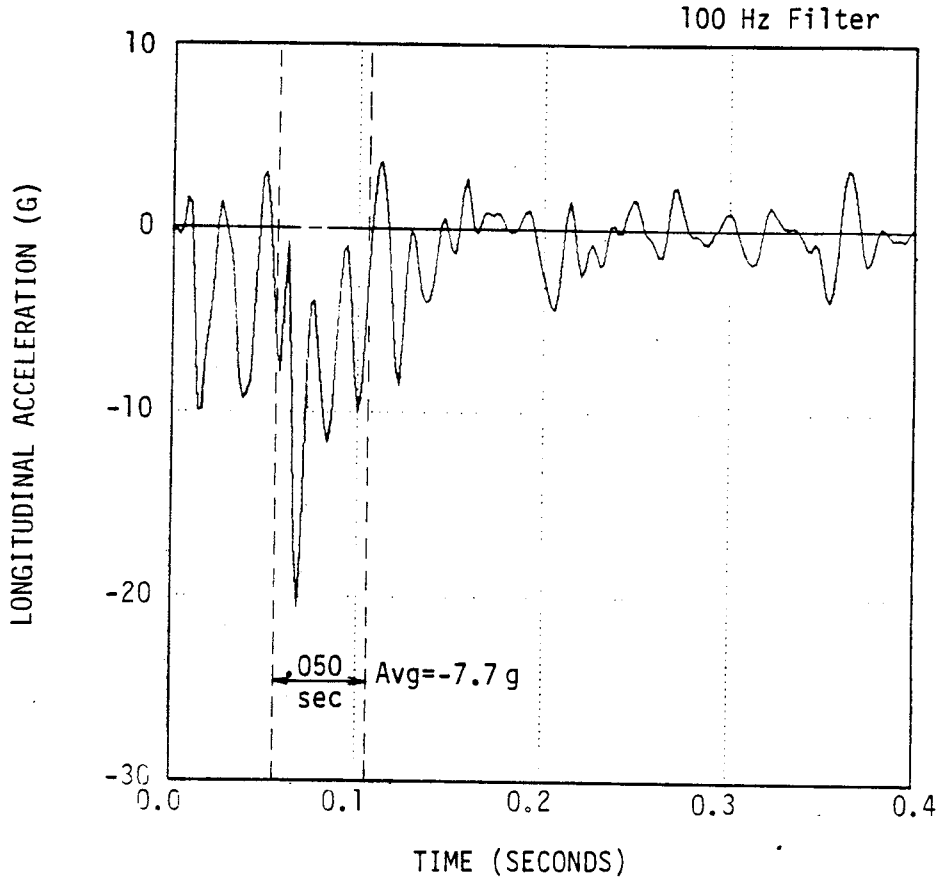


Figure 83. Vehicle Right Longitudinal Accelerometer Trace for Test 3825-6.

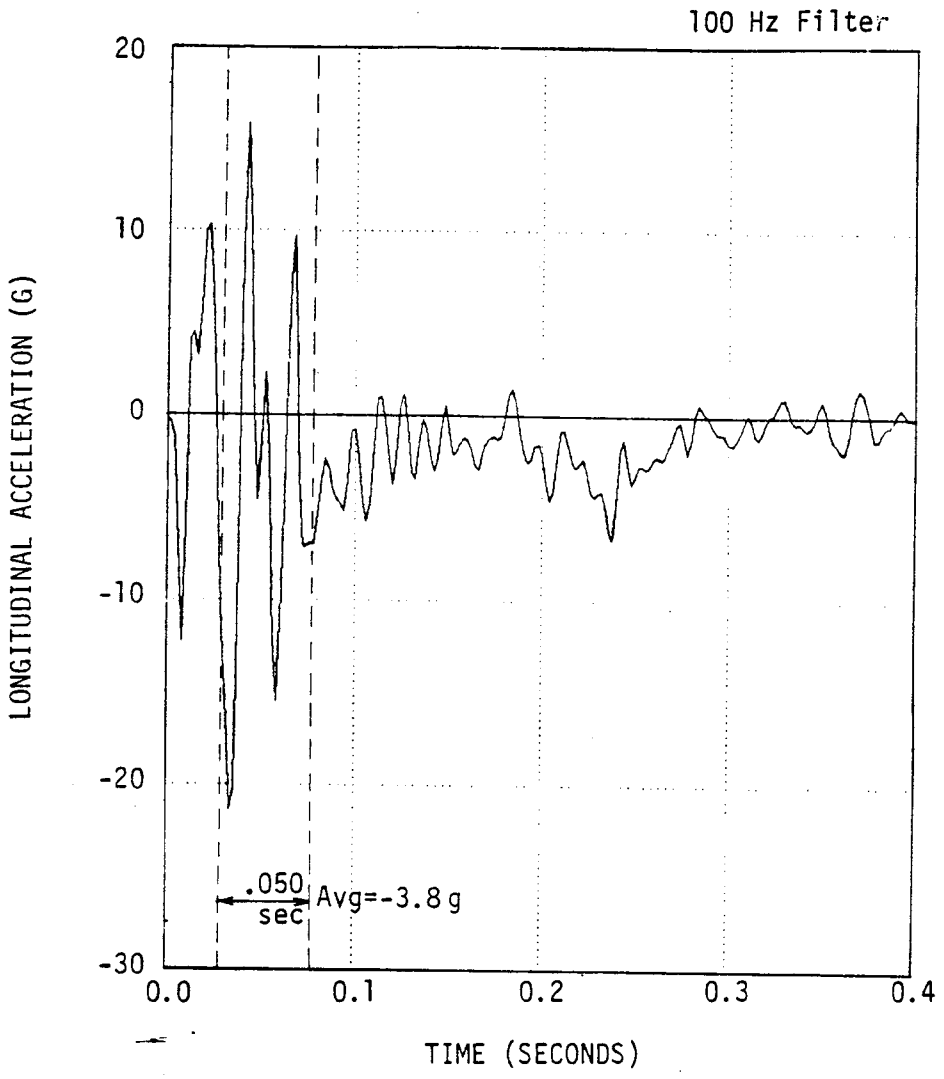


Figure 84. Vehicle Left Longitudinal Accelerometer Trace for Test 3825-6.

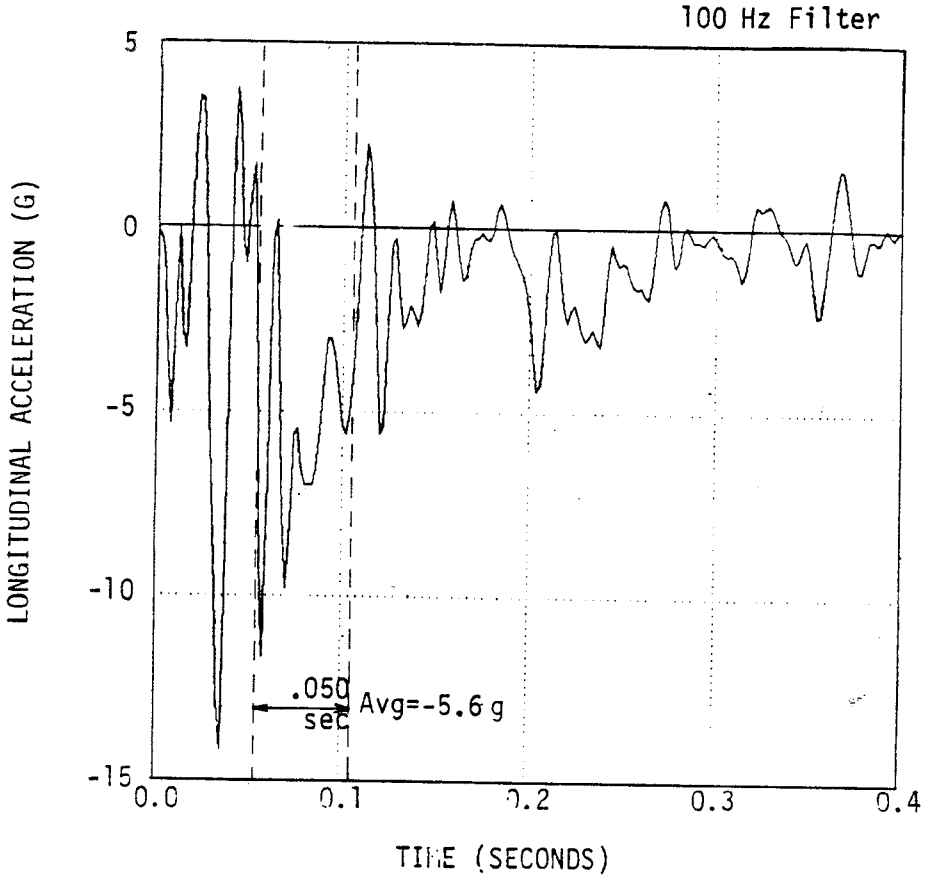


Figure 85. Vehicle Longitudinal Accelerometer Trace for Test 3825-6. (Averaged from Two Accelerometers)

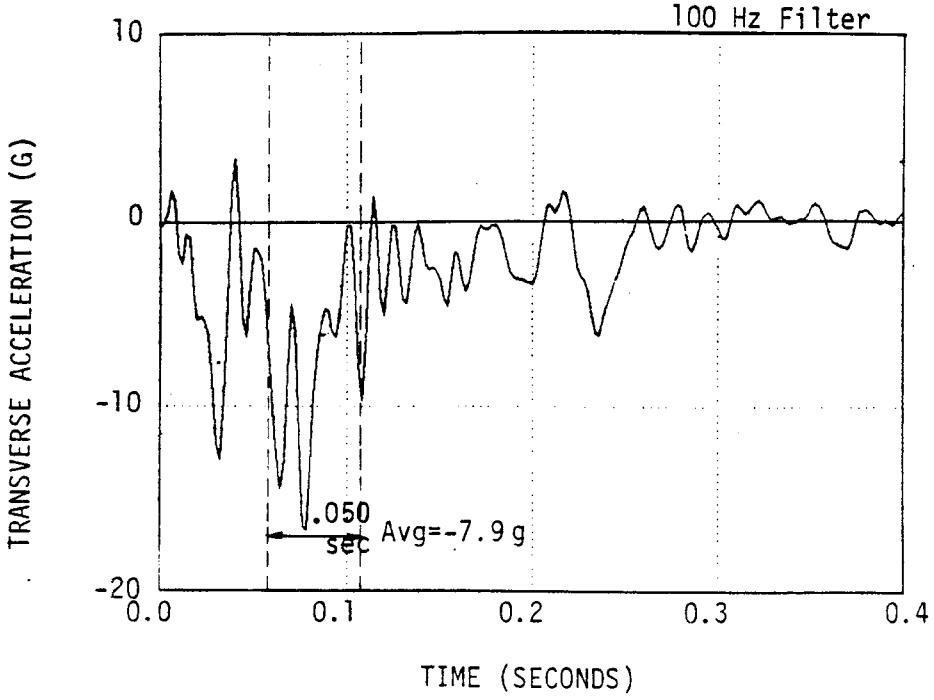


Figure 86. Vehicle Left Transverse Accelerometer Trace for Test 3825-6.

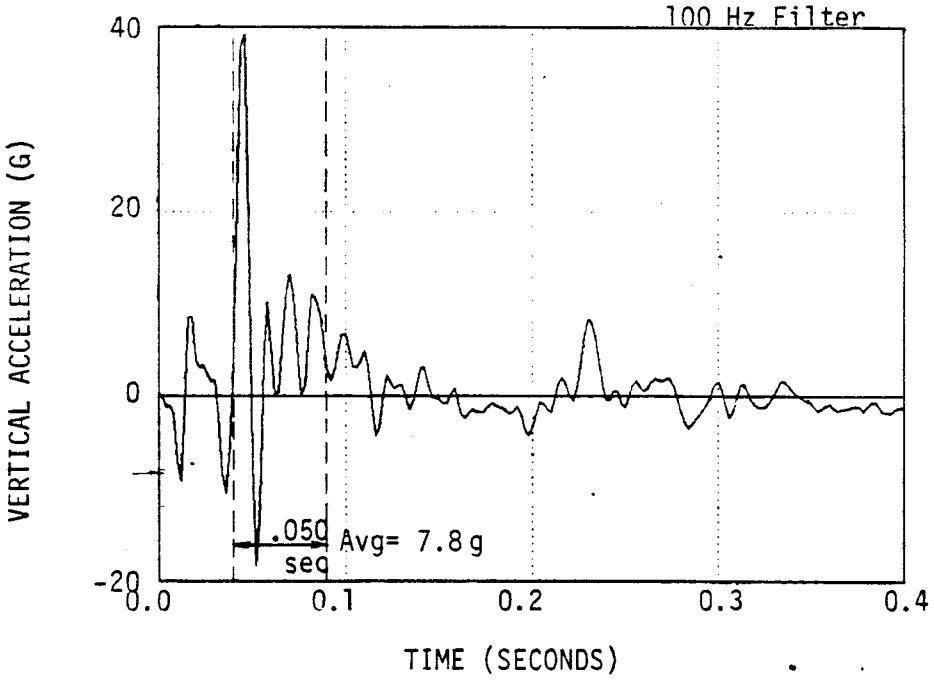


Figure 87. Vehicle Left Vertical Accelerometer Trace for Test 3825-6.

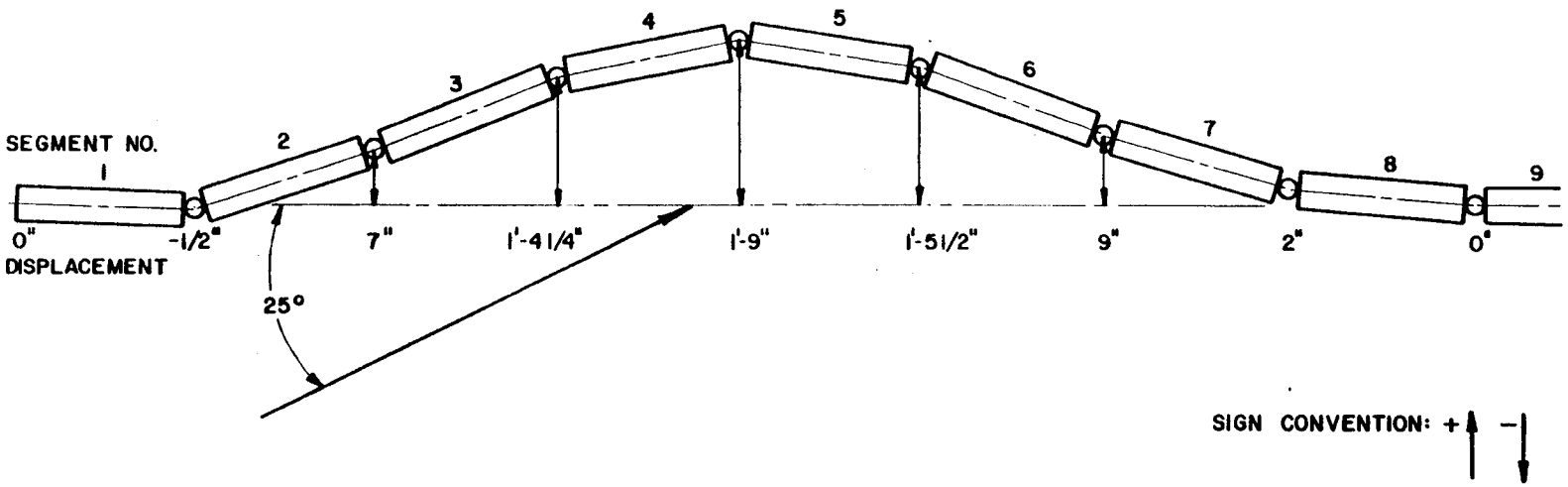
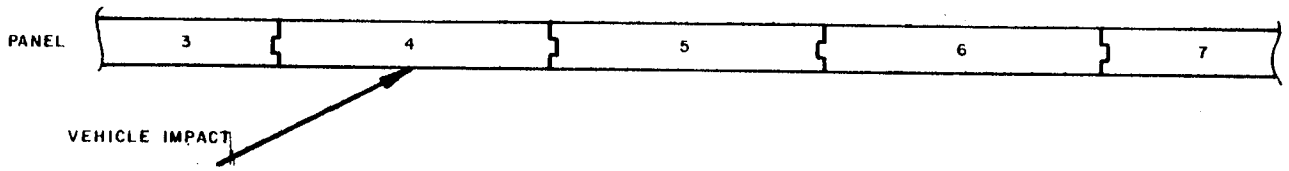
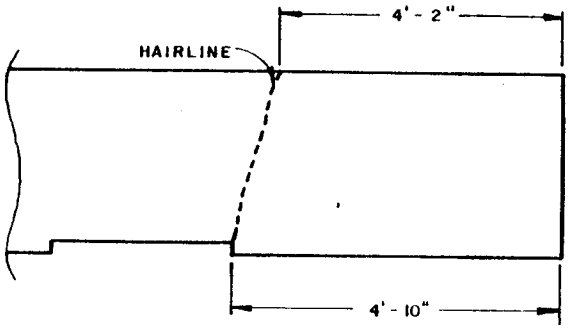


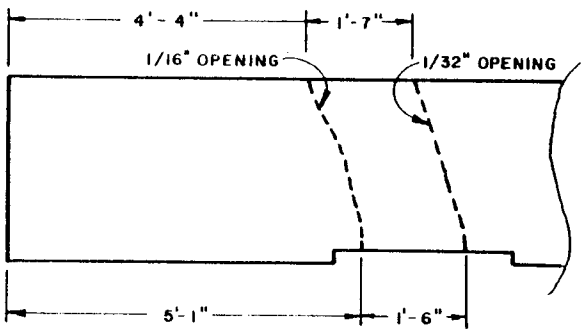
Figure 88. Permanent Barrier Deflection After Test 3825-6.



NOTE: IMPACT FACE OF PANEL IS SHOWN, CRACKS ARE ON BACK FACE.

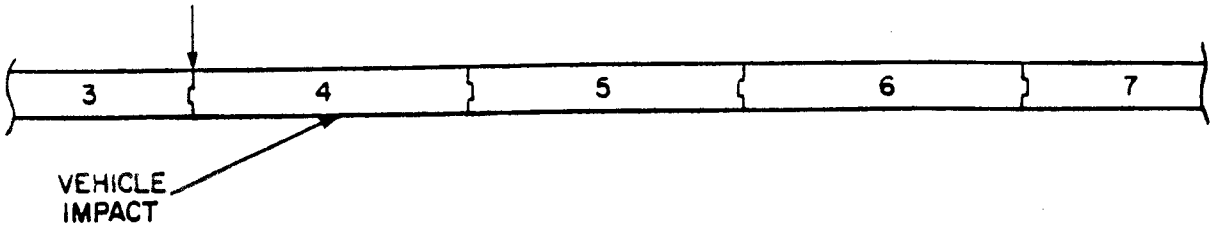


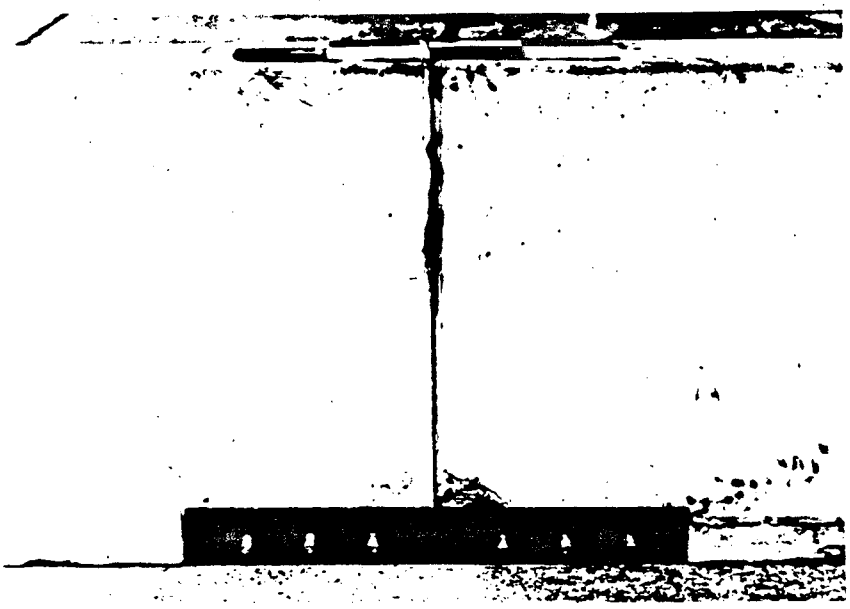
PANEL 4



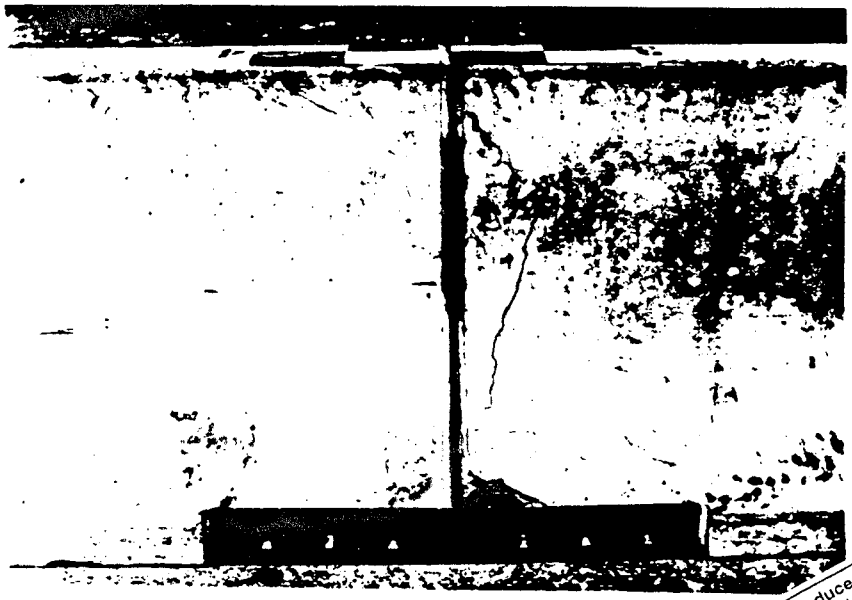
PANEL 5

Figure 89. Flexural Cracking From Test 3825-6.





Before



After

Figure 90: Joint 3-4 Back Before and After Test 3825-6.

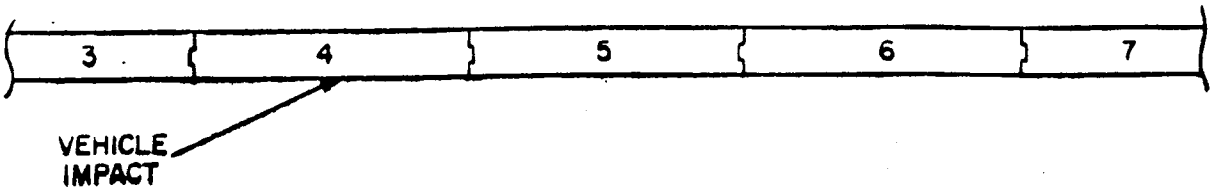
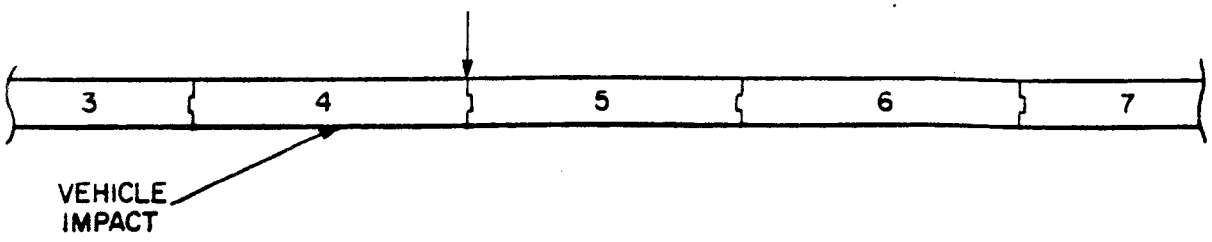
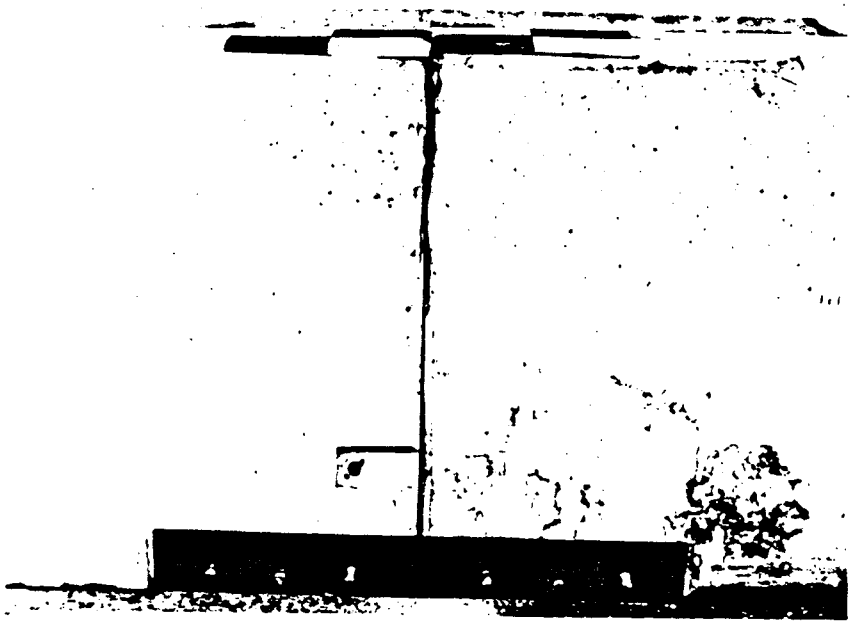
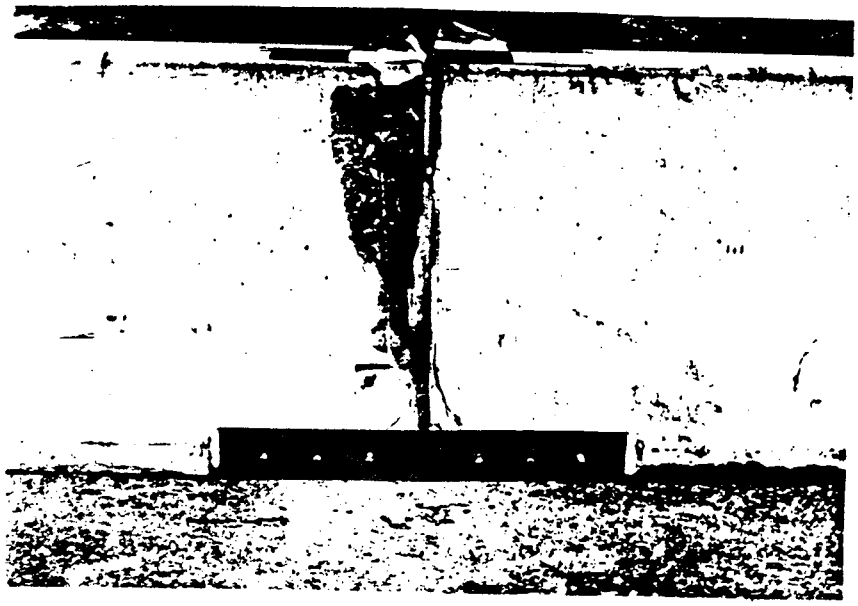


Figure 91. Joint 4-5 Front After Test 3825-6.





Before



After

Figure 92. Joint 4-5 Back Before and After Test 3825-6.

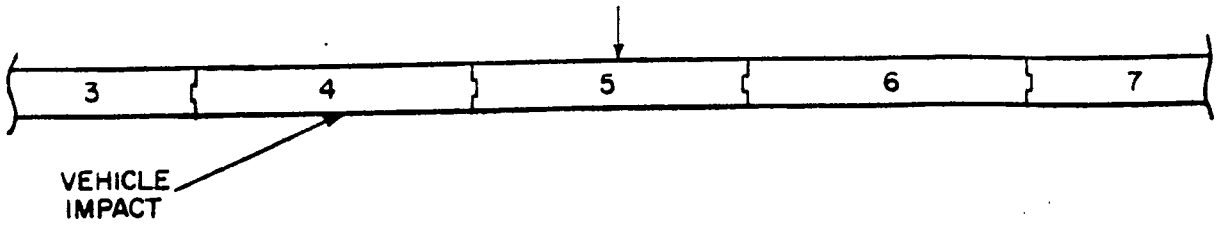
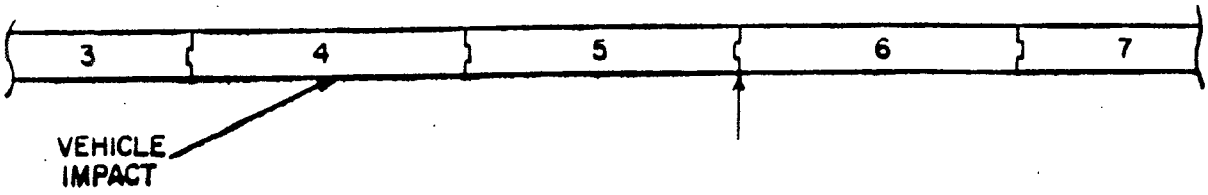


Figure 93. Section 5 Back After Test 3825-6.



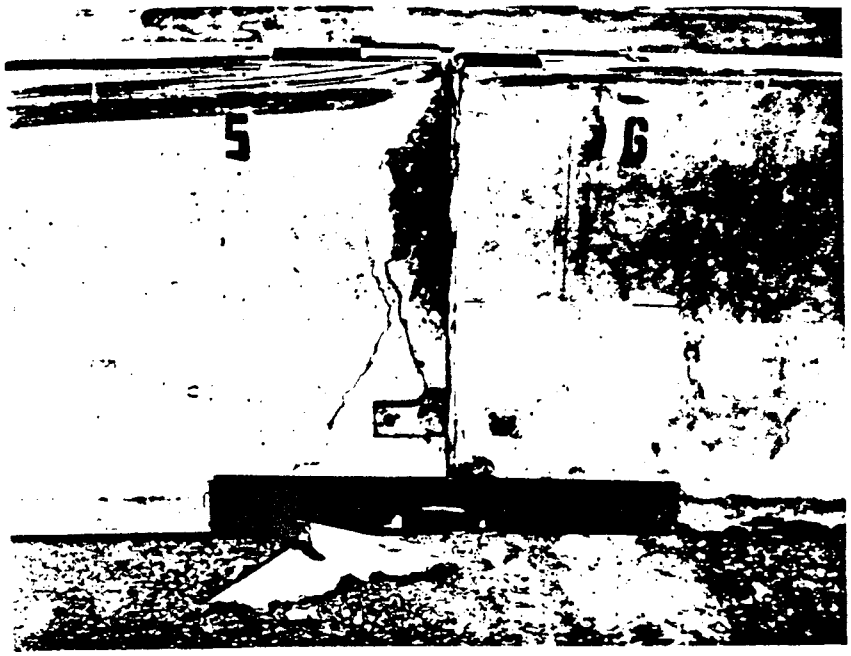


Figure 94. Joint 5-6 Front After Test 3825-6.

TEST REPORT 7

The barrier system consisted of 12.0 ft (3.7 m) portable concrete median barrier (CMB) sections. These sections were jointed by a vertical male-female tongue and groove coupling and 0.5 in. (1.3 cm) thick side plates bolted to the base of the CMB section at the joints as illustrated in Figure 95. The barrier system consisted of ten CMB sections combined to form an installation 120.0 ft (36.7 m) long shown in Figure 96. This system was installed on a level concrete surface similar to a typical PCC road surface.

Test 7 - 4,500 lb/59.2 mph/25 deg (2,041 kg/95.3 km/h/25 deg)

In Test 7, a 1974 Plymouth Fury, weighing 4,500 lb (2,041 kg) including all telemetry equipment impacted the barrier at a speed of 59.2 mph (95.3 km/h) and an angle of 25 deg to the barrier. Photographs of the vehicle and barrier before and after the test are shown in Figure 97. Results are summarized in Figure 98 and sequential photographs are presented in Figure 99. Table 7 lists time and displacements as related to specific events.

The vehicle first contacted the barrier at a distance 5.8 ft (1.8 m) downstream from joint 3-4 on barrier section 4. The force of the impact caused the hood to disengage and begin to open and eventually folding back against the windshield. The left front tire rode up the barrier and by 0.172 sec was over the top of the CMB section. During this time the vehicle was yawing to the right eventually to become parallel to the barrier system at 0.240 seconds. As this yaw continued the rear of the vehicle swung into the barrier 8.3 ft (2.5 m) downstream from joint 3-4 causing the left rear tire to be sheared off and the entire car to undergo moderate counterclockwise roll. The loose tire continued on a course behind the barrier roughly parallel to it and penetrating 5.4 ft (1.6 m) into the construction zone while the vehicle settled and skidded along the top of the barrier and continued to yaw to the right. The vehicle exited at approximately 13 degree to the barrier system. The maximum dynamic deflection of the barrier system was 2.3 ft (0.7 m) occurring 11.9 ft (3.6 m) downstream from the impact point at joint 4-5 while the maximum permanent deflection remaining in the barrier was 1.8 ft (0.6 m) at joint

4-5. However, the vehicle penetrated a maximum of 5.6 ft (1.7 m) into the construction zone when the rear of the vehicle went over the top of the barrier. The linear accelerometer traces are shown in Figure 100 through 104. The maximum 0.050 sec average longitudinal acceleration was -5.7 g while the maximum 0.050 sec average transverse acceleration was -7.1 g.

The final permanent barrier deflected shape is shown in Figure 105 and the flexural cracks due to Test 7 in the CMB sections are shown in Figure 106. Damage to the barrier was slight due to the smooth deflection of the barrier section acting as a unit. The major portion of the damage that occurred was due to the tongue and groove interaction at the joints. Detailed pictures of the damage are shown in Figures 107 through 112. Minor cracking and spalling occurred near the initial impact point at the base of the joints where the side plates were bolted. The side plates were all intact with no tensile yielding apparent.

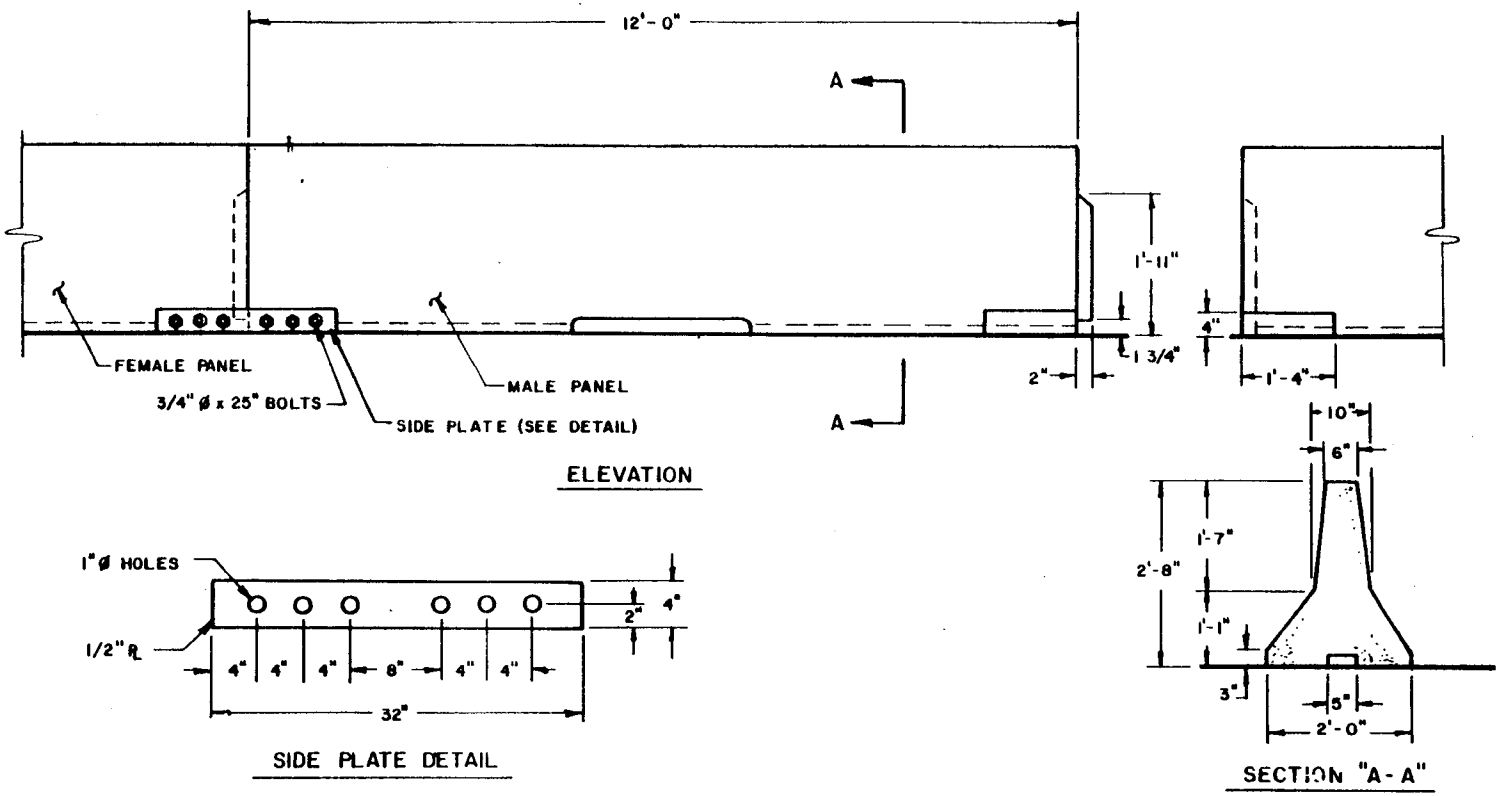


Figure 95. Concrete Median Barrier Detail for Test 3825-7.

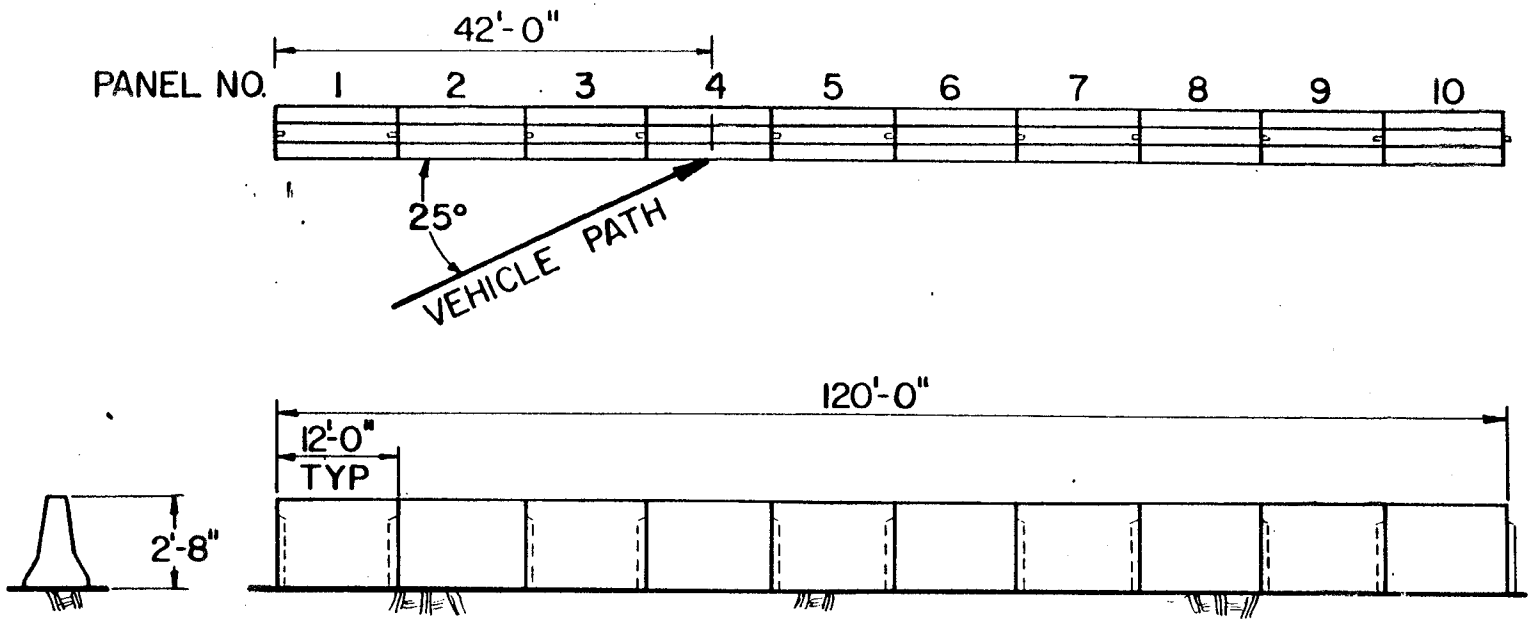


Figure 96. Barrier Installation for Test 3825-7.

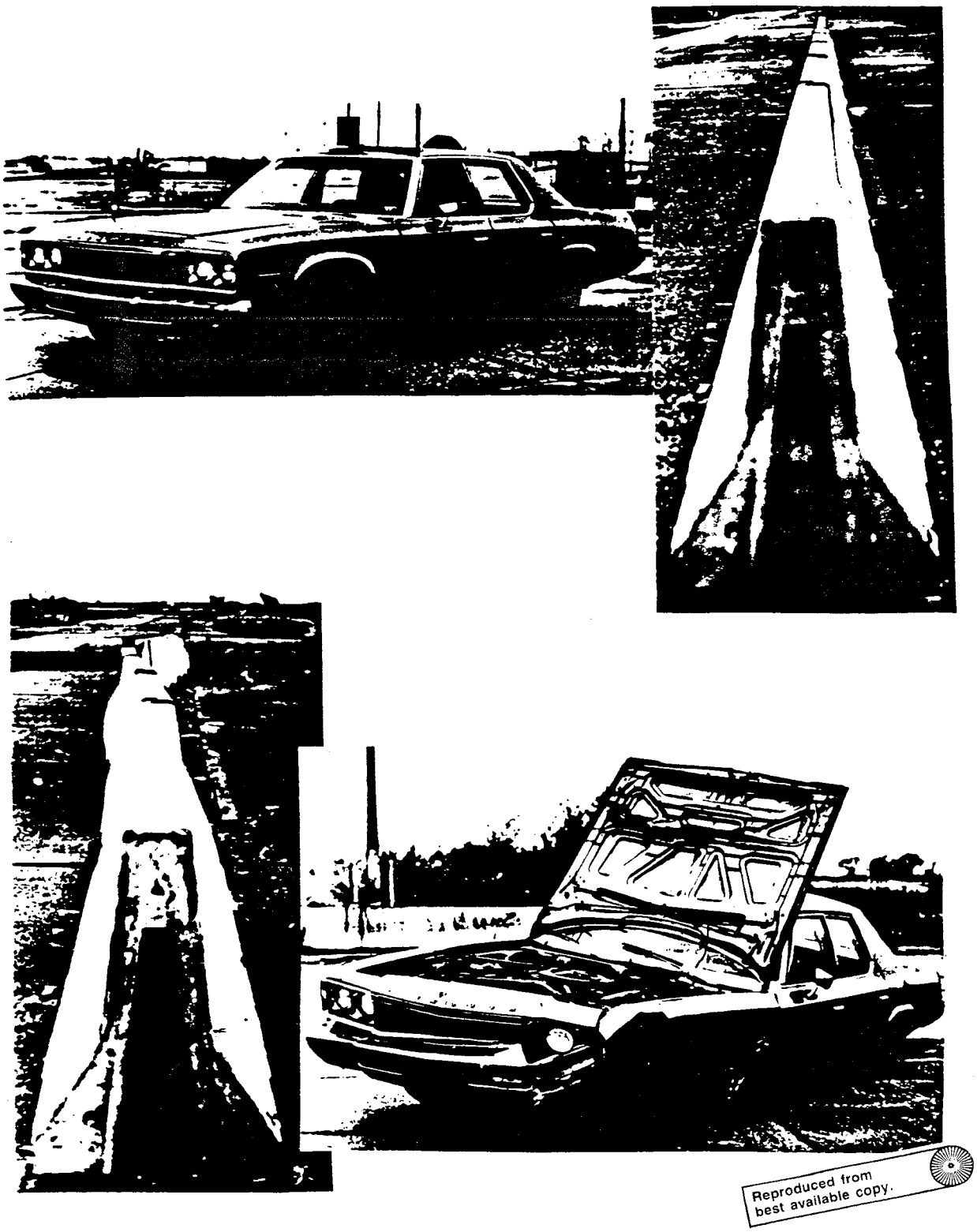
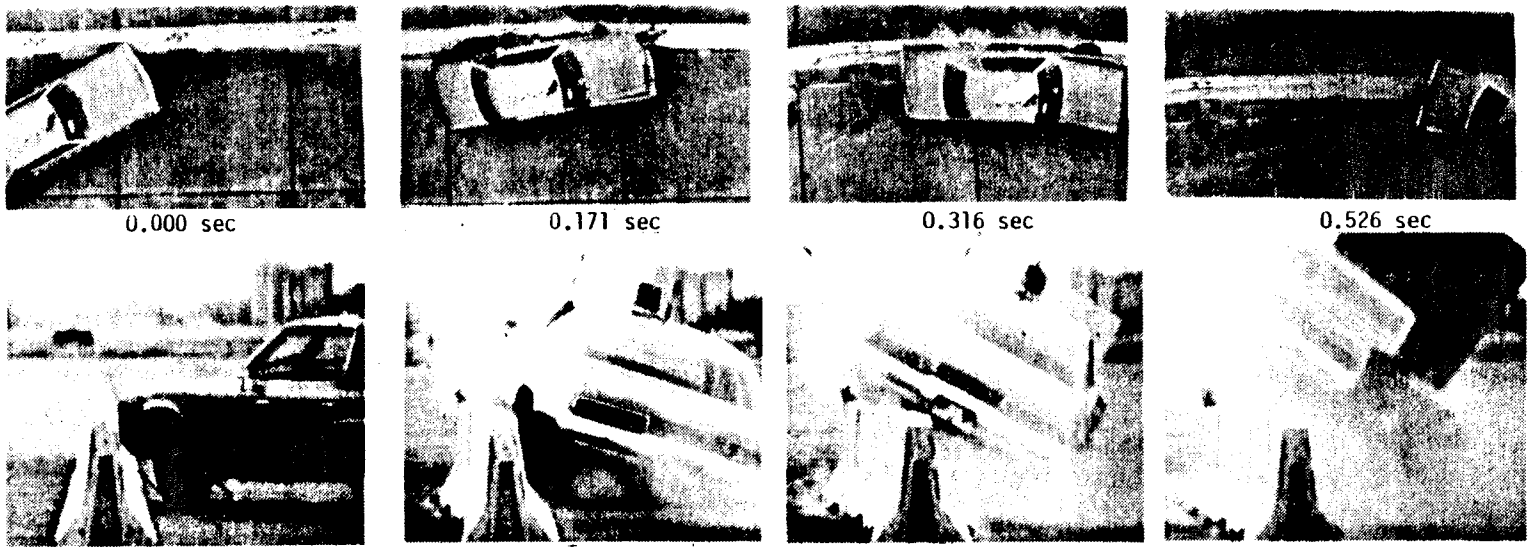
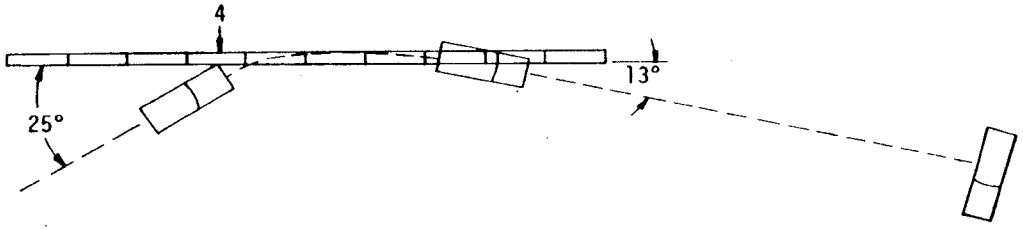
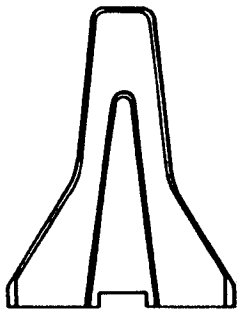


Figure 97. Vehicle and Barrier Before and After Test 3825-7.





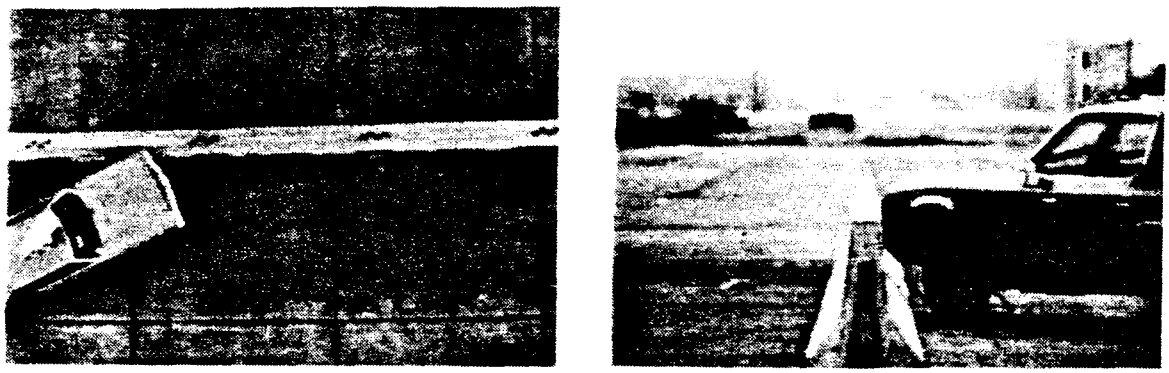


Portable Concrete
Median Barrier

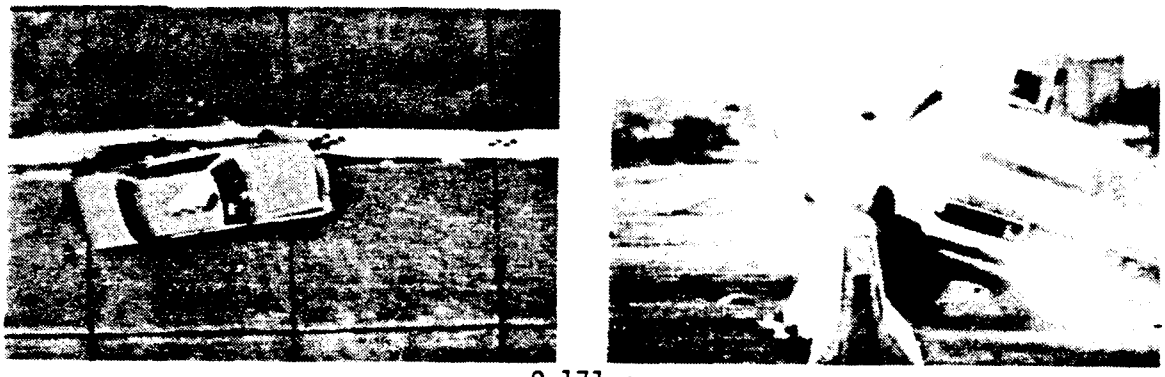
Test No.	3825-7
Date	1/8/80
Barrier	Portable Concrete Median Barrier
Segment	Vertical Tongue & Groove w/ 1/2 in. (1.3 cm) Steel Side Plates
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Deflection	
Max. Dynamic	2.3 ft (0.7 m)
Max. Permanent	1.8 ft (0.6 m)

Vehicle	1974 Plymouth Fury
Vehicle Weight	4,500 lb (2,041 kg)
Impact Speed	59.2 mph (95.3 km/h)
Impact Angle	25 deg
Exit Speed	
Exit Angle	∿13°
Vehicle Acceleration (Max. 0.050 sec avg.)	
Longitudinal (rt & lt avg)	-5.7 g
Transverse	-7.1 g
Vertical	-7.6 g
Vehicle Damage	
TAD	10FL3
SAE	10FLEW2 10LDES1

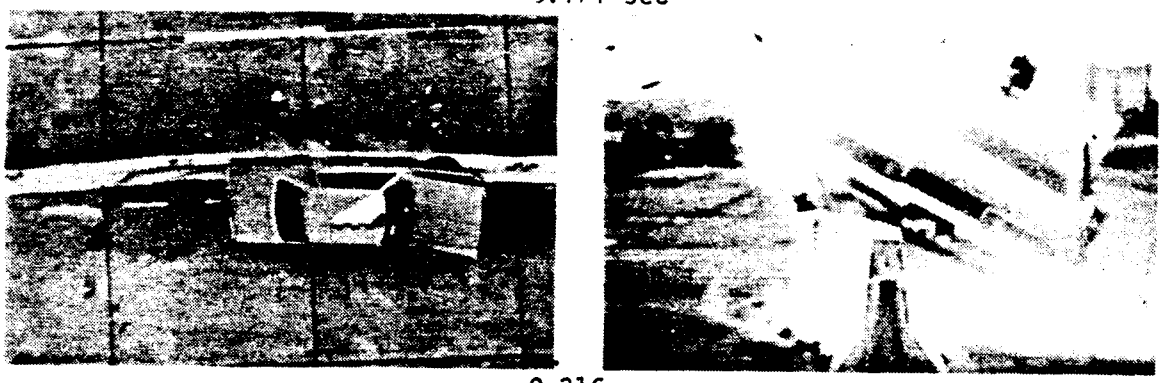
Figure 98. Summary of Results for Test 3825-7.



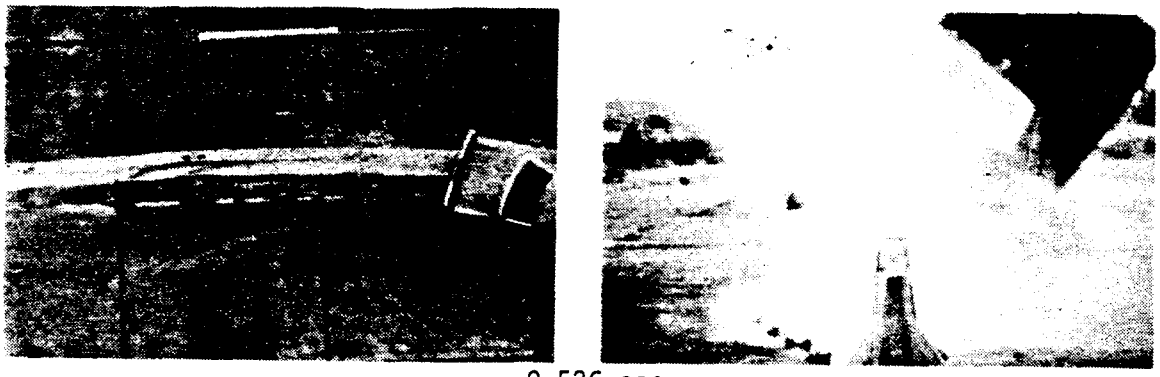
0.000 sec



0.171 sec



0.316 sec



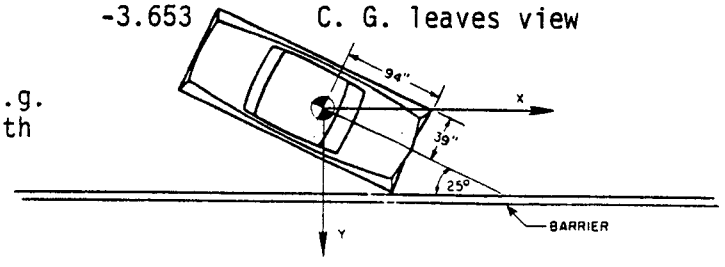
0.526 sec

Figure 99. Sequential Photographs for Test 3825-7.

Table 7. Time, Displacement, Event Summary for Test 3825-7.

TIME (sec)	X-DISPLACEMENT (ft)	Y-DISPLACEMENT (ft)	EVENT
0.000	0.000*	0.000*	Impact
0.017	1.290	-0.069	
0.034	2.601	-1.290	Hood pops up
0.051	3.954	-1.870	Fender crushed
0.069	5.175	-2.286	Headlight shatters
0.086	6.465	-2.614	Wall begins to deflect
0.103	7.707	-2.900	
0.120	8.929	-3.030	
0.137	10.171	-3.129	
0.154	11.366	-3.103	
0.172	12.549	-3.248	Car begins to roll-L.F. tire rides up barrier
0.189	13.730	-3.334	
0.206	14.720	-3.367	
0.223	16.120	-3.611	Rear bumper hits barrier
0.240	17.110	-3.690	Car motion parallel
0.257	18.359	-3.832	
0.275	19.498	-3.935	Car slides along barrier
0.292	20.663	-3.883	
0.309	21.950	-3.832	
0.326	23.107	-3.878	
0.343	24.389	-3.898	
0.360	25.704	-3.917	L. F. tire over barrier
0.378	26.842	-3.878	Max. barrier dynamic deflection
0.395	28.107	-3.846	Left rear tire shears off
0.412	29.308	-3.891	
0.429	30.382	-3.916	
0.446	32.455	-3.936	
0.463	33.496	-3.810	
0.481	34.803	-3.857	
0.498	35.964	-3.857	
0.515	37.086	-3.790	
0.532	38.355	-3.810	
0.549	39.478	-3.744	
0.566	40.687	-3.843	
0.584	41.928	-3.850	Hood folded back against windshield
0.601	43.312	-3.653	C. G. leaves view

*Location of vehicle c.g. at point of impact with barrier.



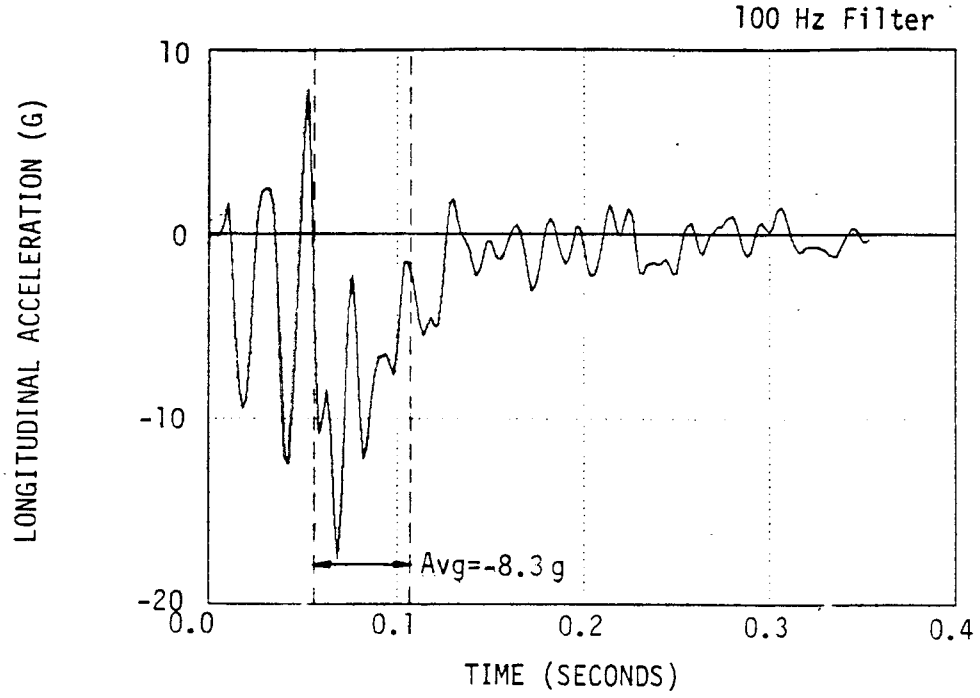


Figure 100. Vehicle Right Longitudinal Accelerometer Trace for Test 3825-7.

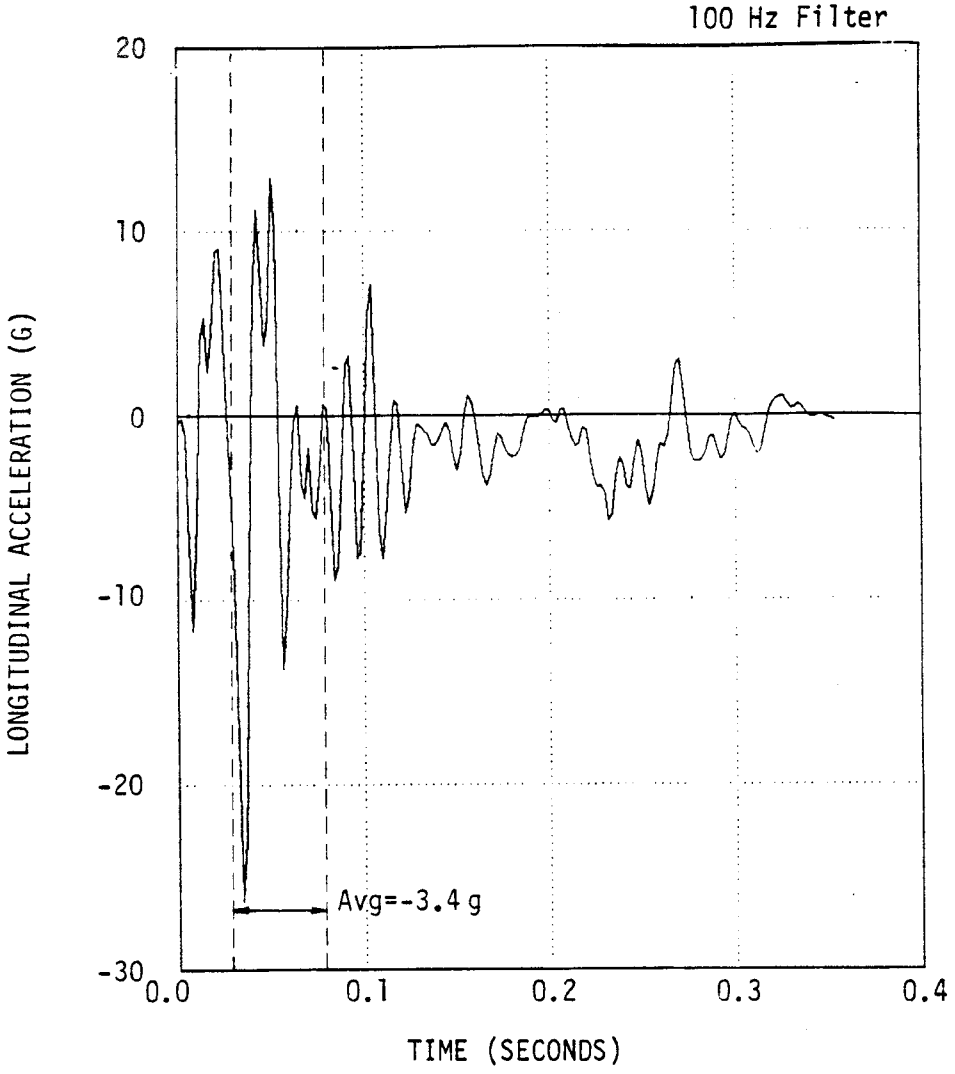


Figure 101. Vehicle Left Longitudinal Accelerometer Trace for Test 3825-7.

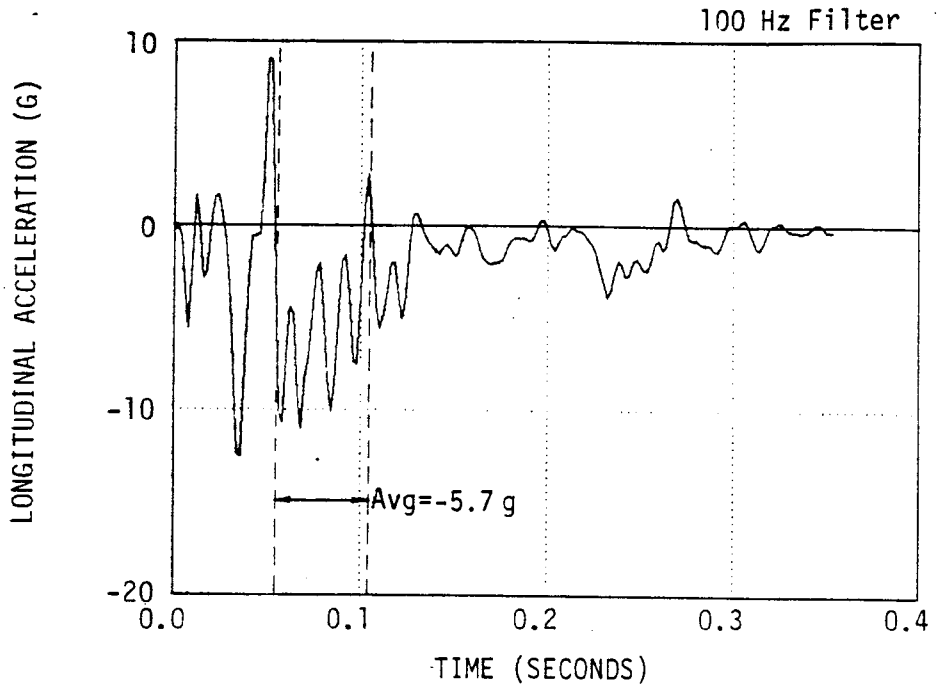


Figure 102. Vehicle Longitudinal Accelerometer Trace for Test 3825-7. (Averaged from Two Accelerometers).

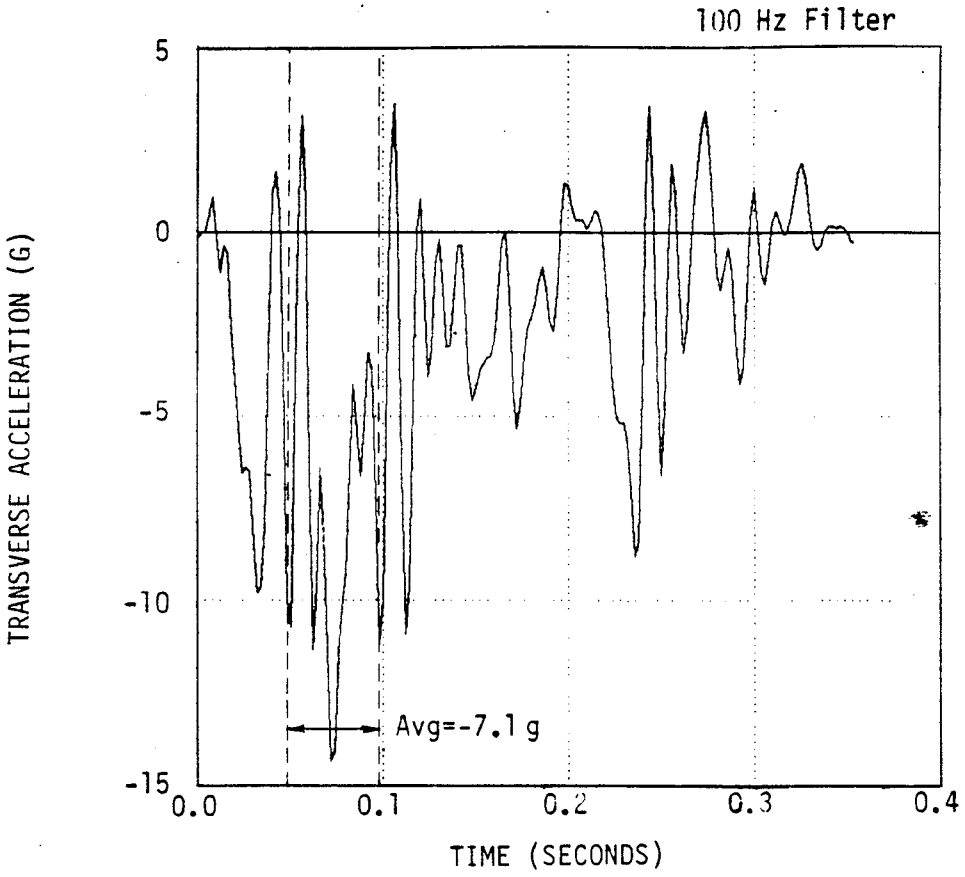


Figure 103. Vehicle Left Transverse Accelerometer Trace for Test 3825-7.

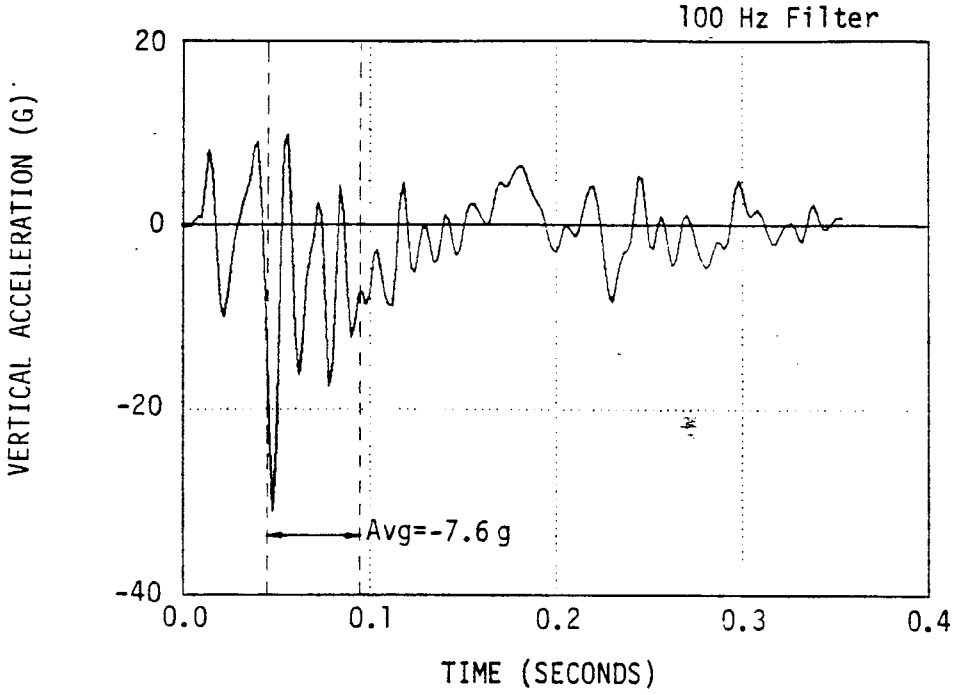


Figure 104. Vehicle Left Vertical Accelerometer Trace for Test 3825-7.

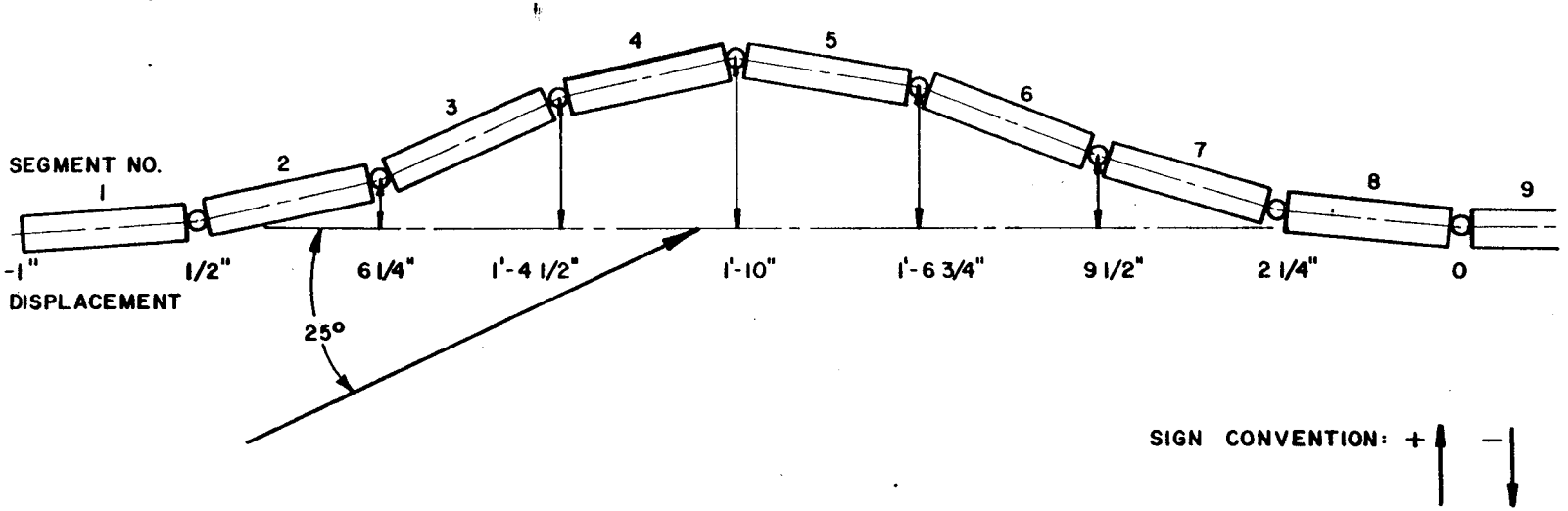
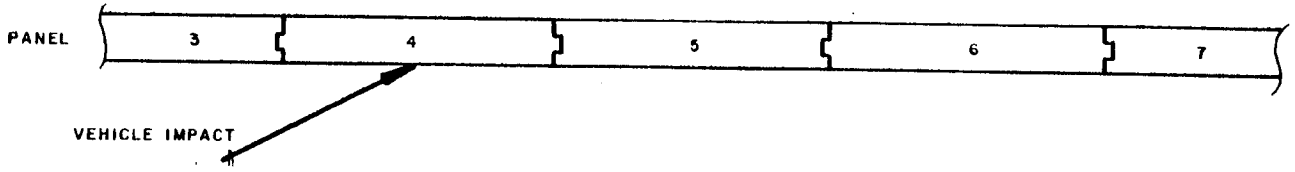


Figure 105. Permanent Barrier Deflection From Test 3825-7.



NOTE: IMPACT FACE OF PANEL IS SHOWN, CRACKS ARE ON BACK FACE.

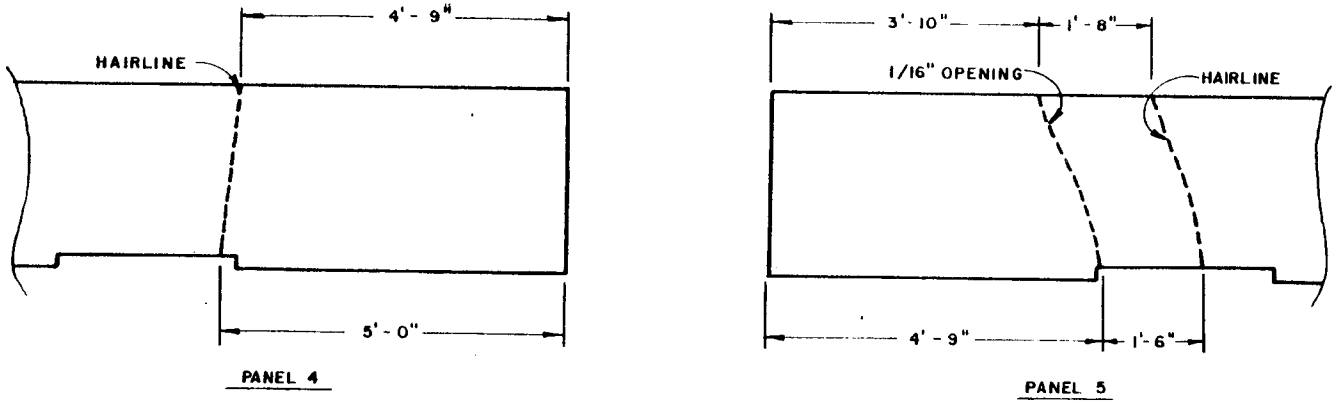
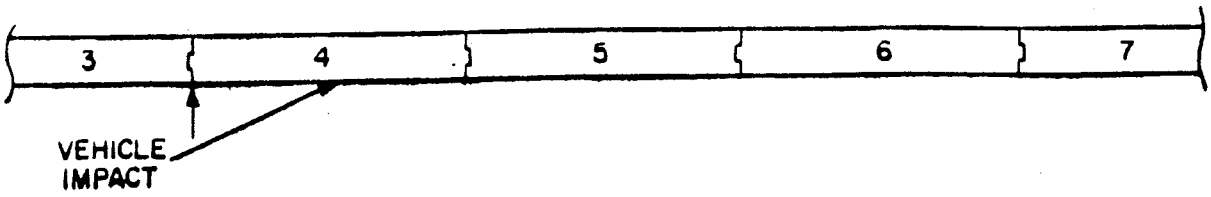


Figure 106. Flexural Cracks From Test 3825-7.



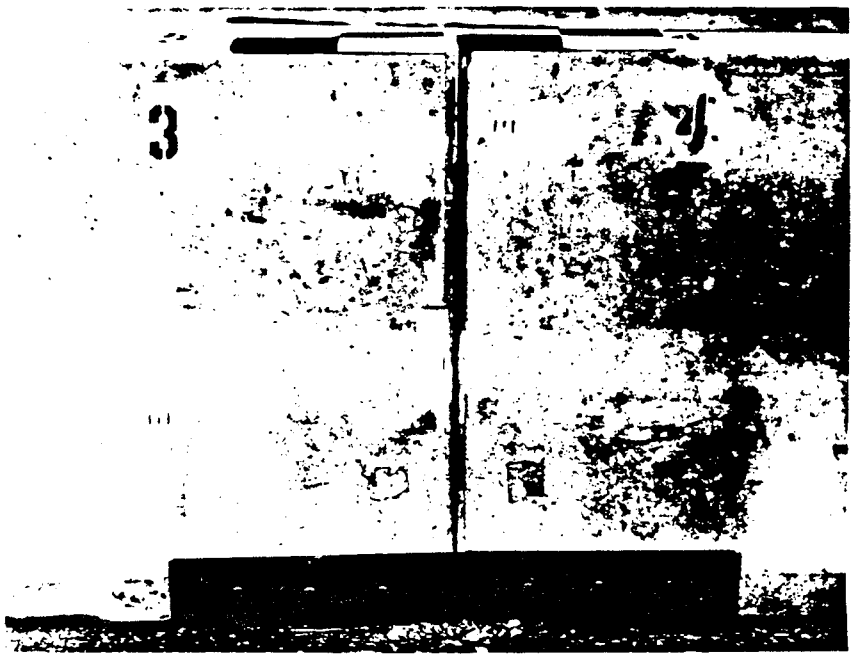


Figure 107. Joint 3-4 Front After Test 3825-7.

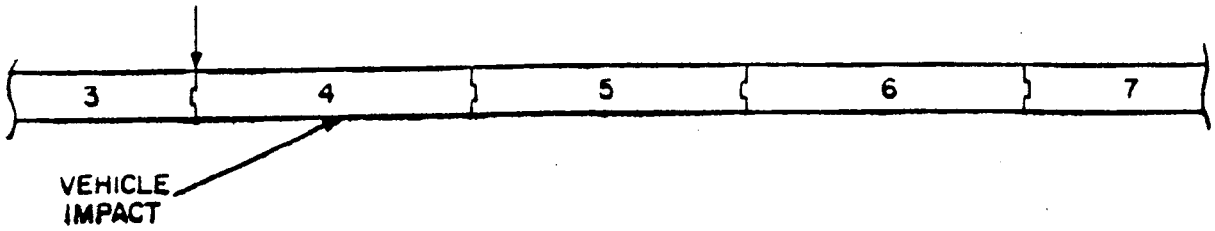


Figure 108 . Joint 3-4 Back After Test 3825-7.

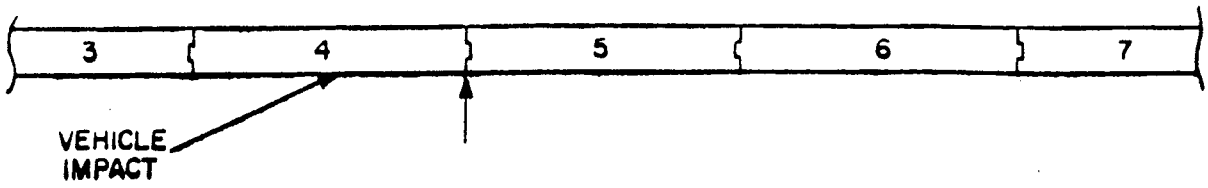
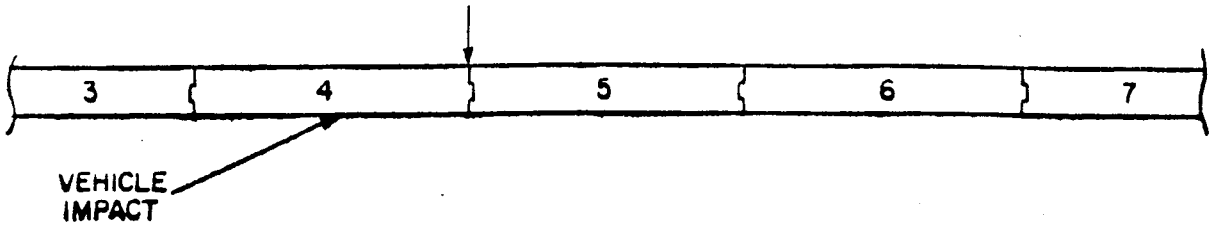


Figure 109. Joint 4-5 Front After Test 3825-7.



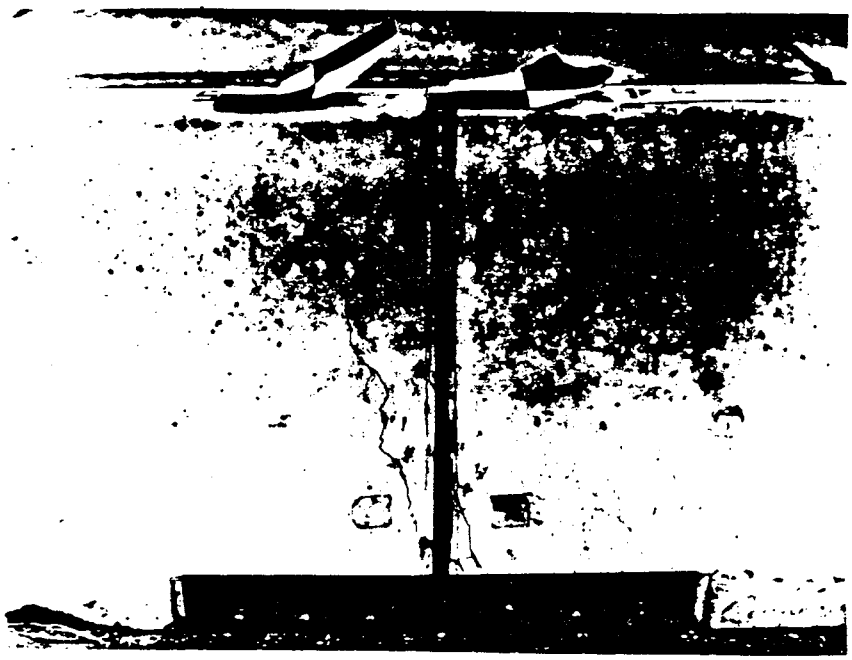


Figure 110. Joint 4-5 Back After Test 3825-7.

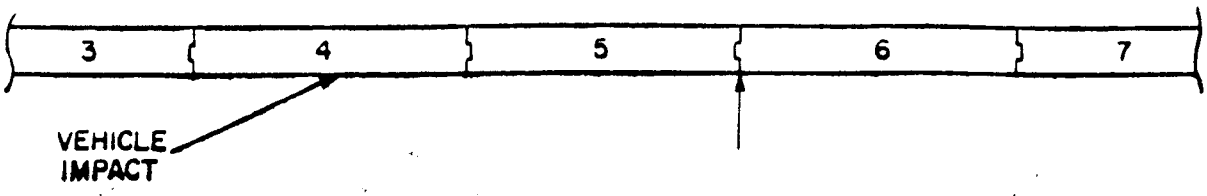
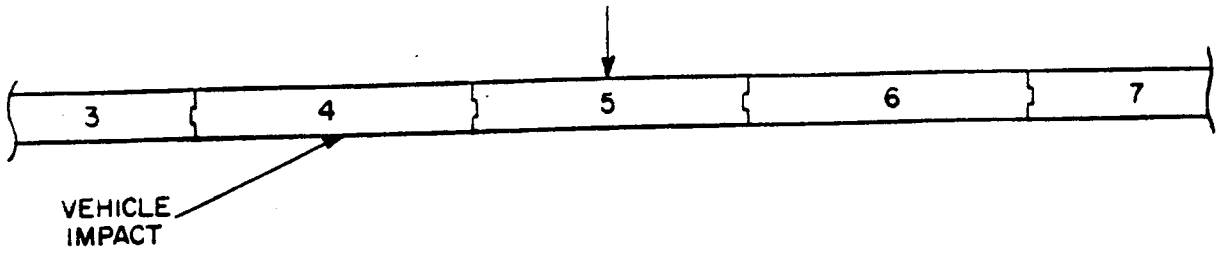


Figure 111. Joint 5-6 Front After Test 3825-7.



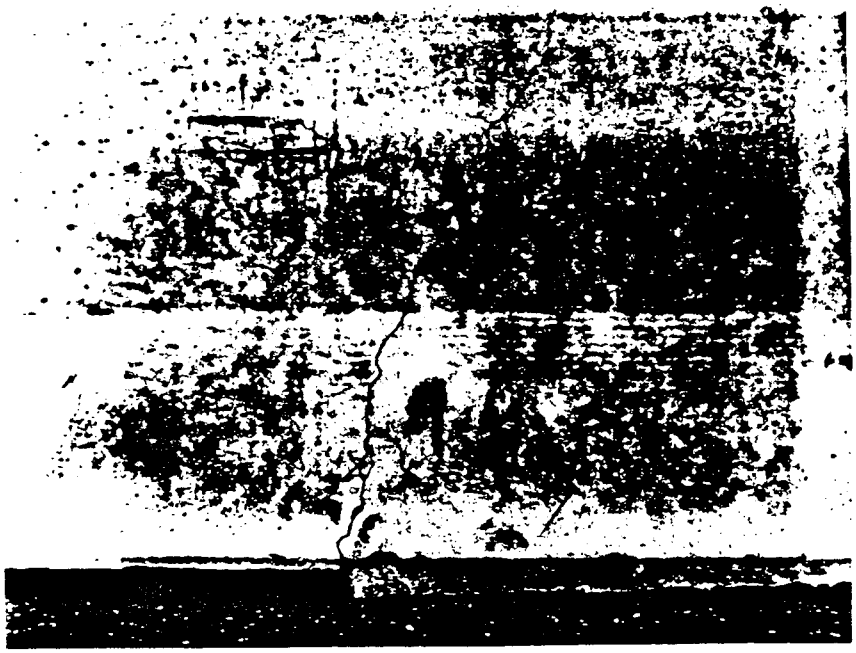


Figure 112. Section 5 Back After Test 3825-7.

TEST REPORT 8

A new concrete median barrier (CMB) system was installed for Test 3825-8. Although the cross section configuration was different from the last test (narrower base with a slightly wider top), the major difference was in segment length, 15.0 ft (4.6 m), and the manner in which they were connected. Figure 113 shows the barrier details. Note that instead of the tongue and groove with flat steel splice plates employed in previous tests, the barriers are joined with smooth steel dowels and channel splice plates (Figure 114). This arrangement seemed to increase the lateral stiffness of the barrier system. Figure 115 shows the test installation, consisting of twelve CMB sections joined on a level, concrete surface similar to what would be found on a highway installation.

Test 8 - 20,000 lb/57.7 mph/15 deg (9,072 kg/92.8 km/h/15 deg)

In Test 8, a 1970 International Harvestor school bus weighing 20,000 lb (9,072 kg) including telemetry equipment, anthropomorphic dummies, and sandbags impacted the barrier at an angle of 15 deg and a speed of 57.7 mph (92.8 km/h). Fully instrumented anthropomorphic dummies were positioned in the driver's seat (Alpha, restrained with a lap belt) and in the right front passenger seat (Beta, unrestrained). Before and after photographs of the barrier, vehicle, and dummies are shown in Figures 116 through 120. Figure 121 summarizes the test results.

The test is illustrated by interior and exterior sequential photographs in Figures 122 and 123, respectively. Impact occurred 1.2 ft (0.4 m) downstream of joint 4-5 on section 5. The right front wheel impacted initially, and the right fender rode up onto the barrier. The vehicle began to roll while the rear of the vehicle impacted the barrier. The vehicle continued to roll as it slid off of the barrier and came to rest on its side 168.0 ft (51.2 m) beyond the downstream end of the test installation. A time-displacement-event-summary for the vehicle is shown in Table 8, while Table 9 shows one for the dummies.

Linear accelerometer traces for the vehicle are presented in Figures 124 through 126. The maximum 0.050 sec average lateral acceleration of 5.3 g compares favorably with the 5 g acceptable limit published in TRC 191 (1). Yaw, pitch and roll are shown in Figures 127 through 129.

These results are order dependent and must be evaluated in this sequence. Accelerometer traces for both dummies are given in Figures 130 through 133.

The maximum permanent deflection of the barrier was 1.8 ft (0.6 m) and occurred in section 5 adjacent to joint 5-6. Figure 134 illustrates the position of the barrier sections after the test. Damage to the CMB sections principally consisted of flexural cracking on the back faces. Some spalling occurred on the top end of panel 5 adjacent to panel 6. A crack from the top of the dowel in panel 4 (joint 4-5) also formed. Figure 135 shows the damage. Figure 136 through 138 show the joints between panels 3 and 6 before and after the test.

This test illustrates the structural capacity of portable CMB's to redirect vehicles as large as school buses. The reaction of the bus was not ideal, but this relates to the geometry of the barrier rather than to structural capacity. Modification of barrier geometry will improve the reaction of large vehicles during redirection.

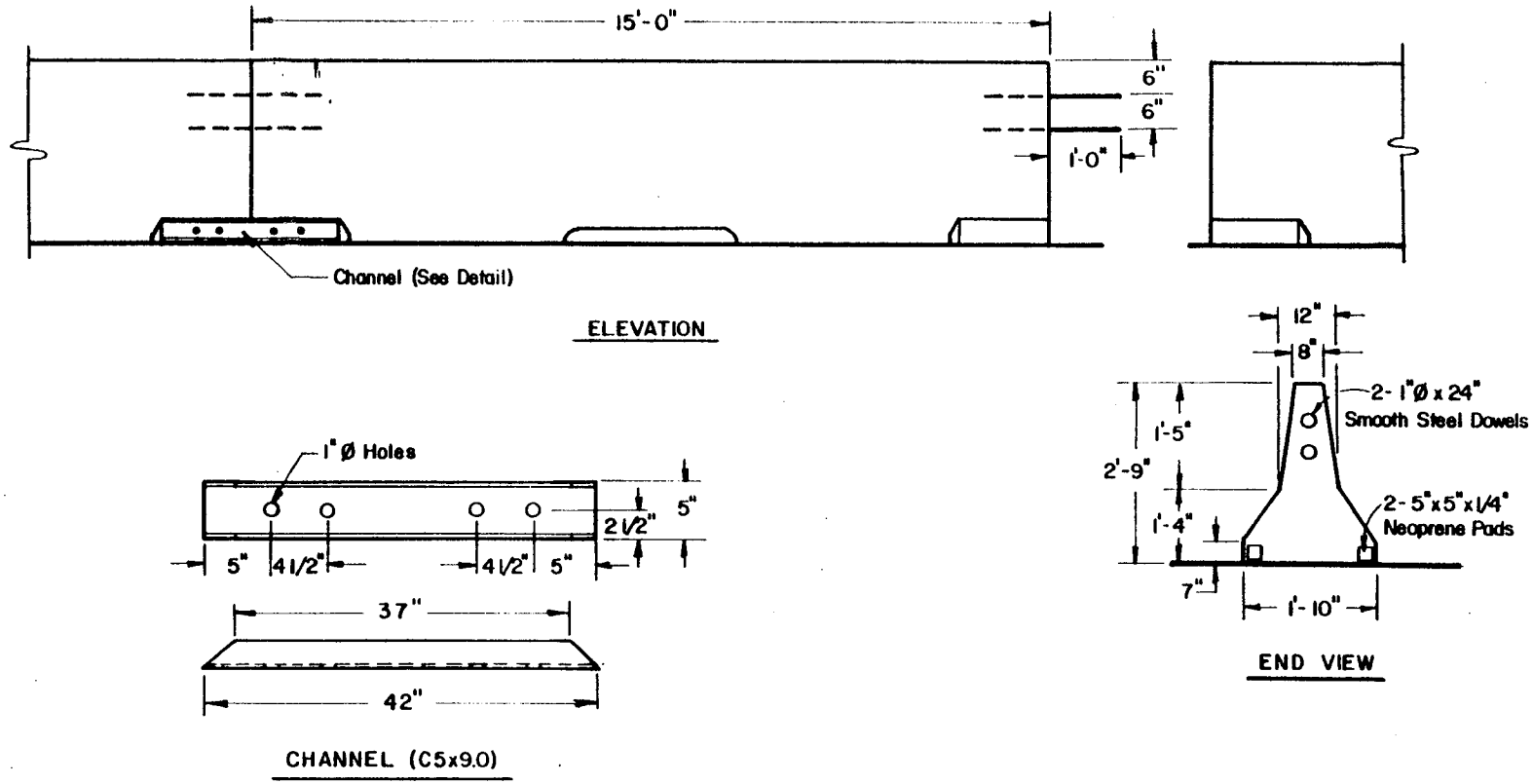


Figure 113. Concrete Median Barrier Detail for Test 3825-8.

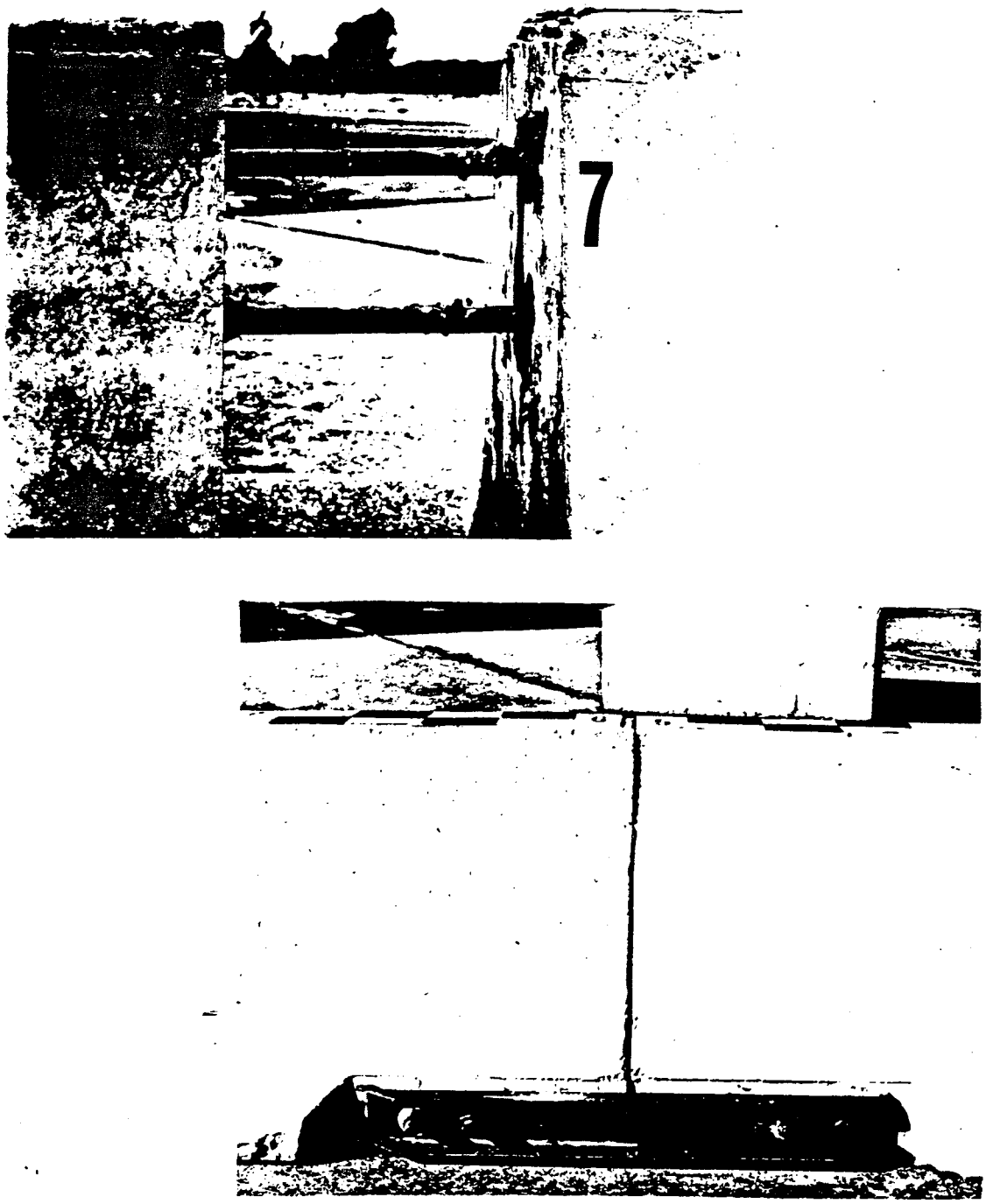


Figure 114. Fastener Details of CMB Sections for Test 3825-8.

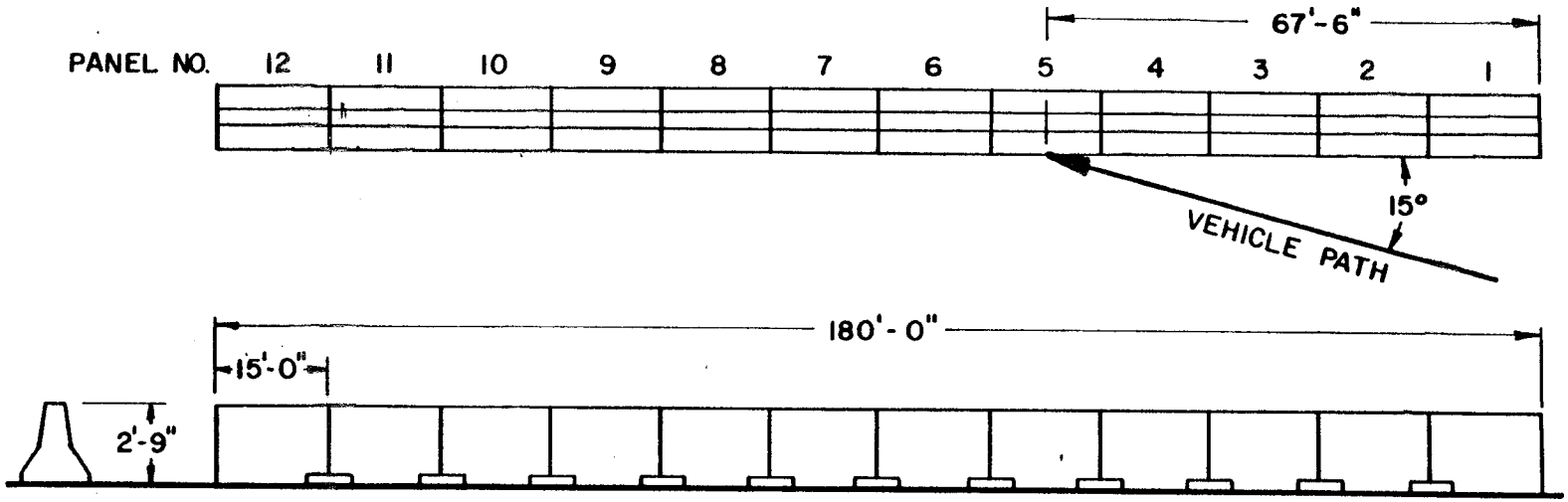


Figure 115. Barrier Installation for Test 3825-8.

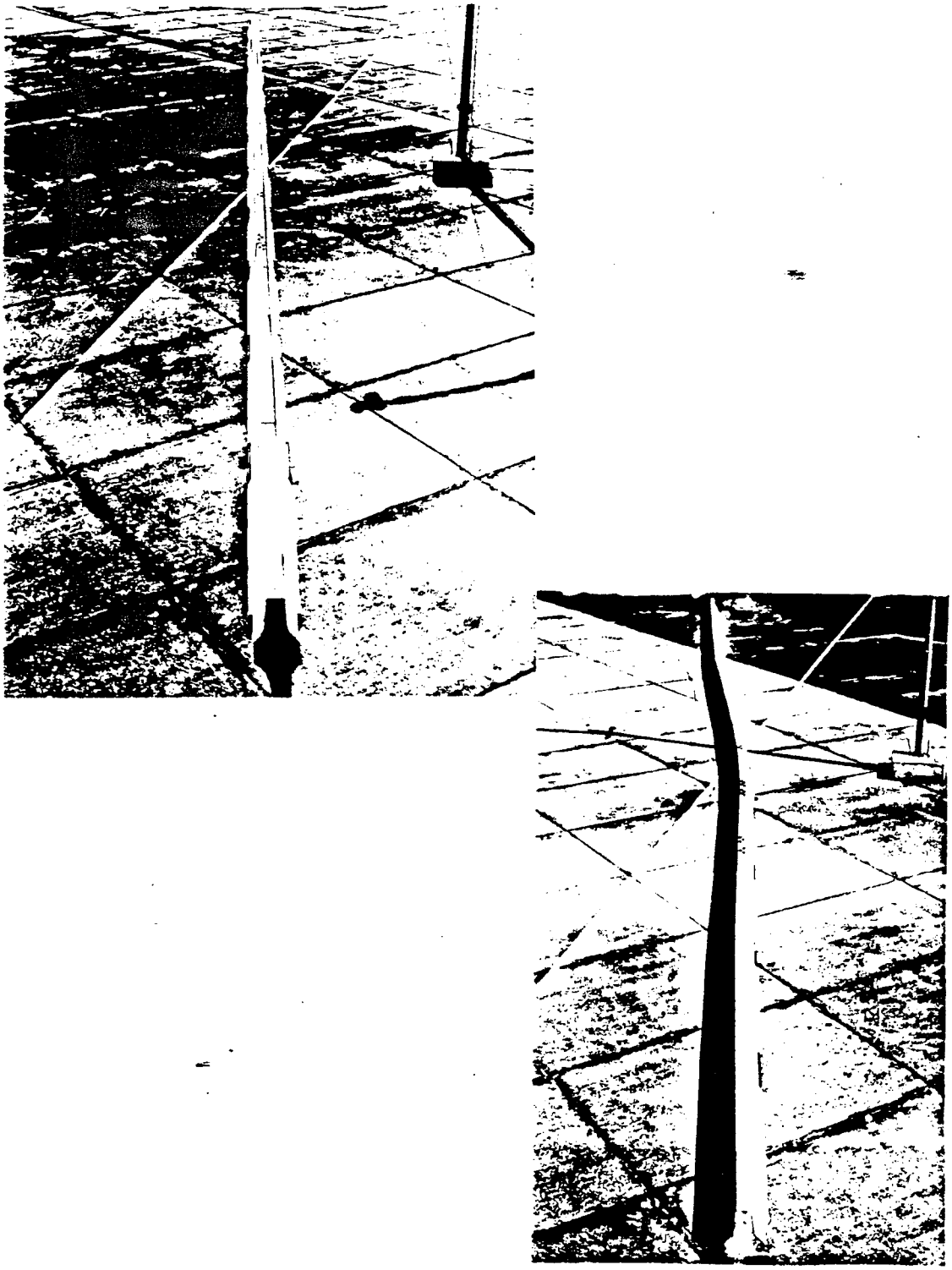


Figure 116. Barrier Before and After Test 3825-8.

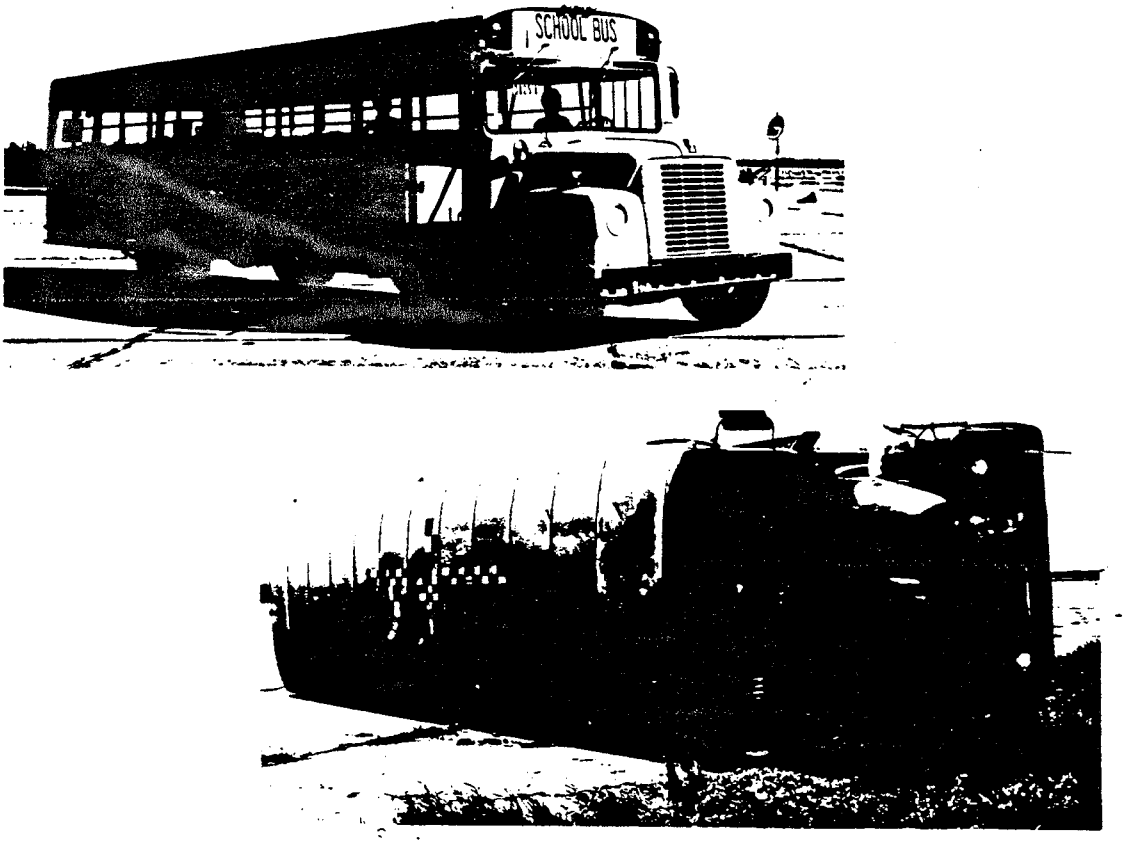


Figure 117. Vehicle Before and After Test 3825-8.

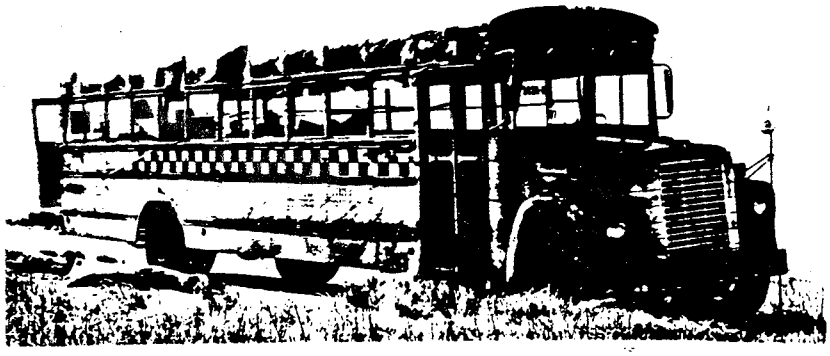


Figure 118. Vehicle After Being Righted.

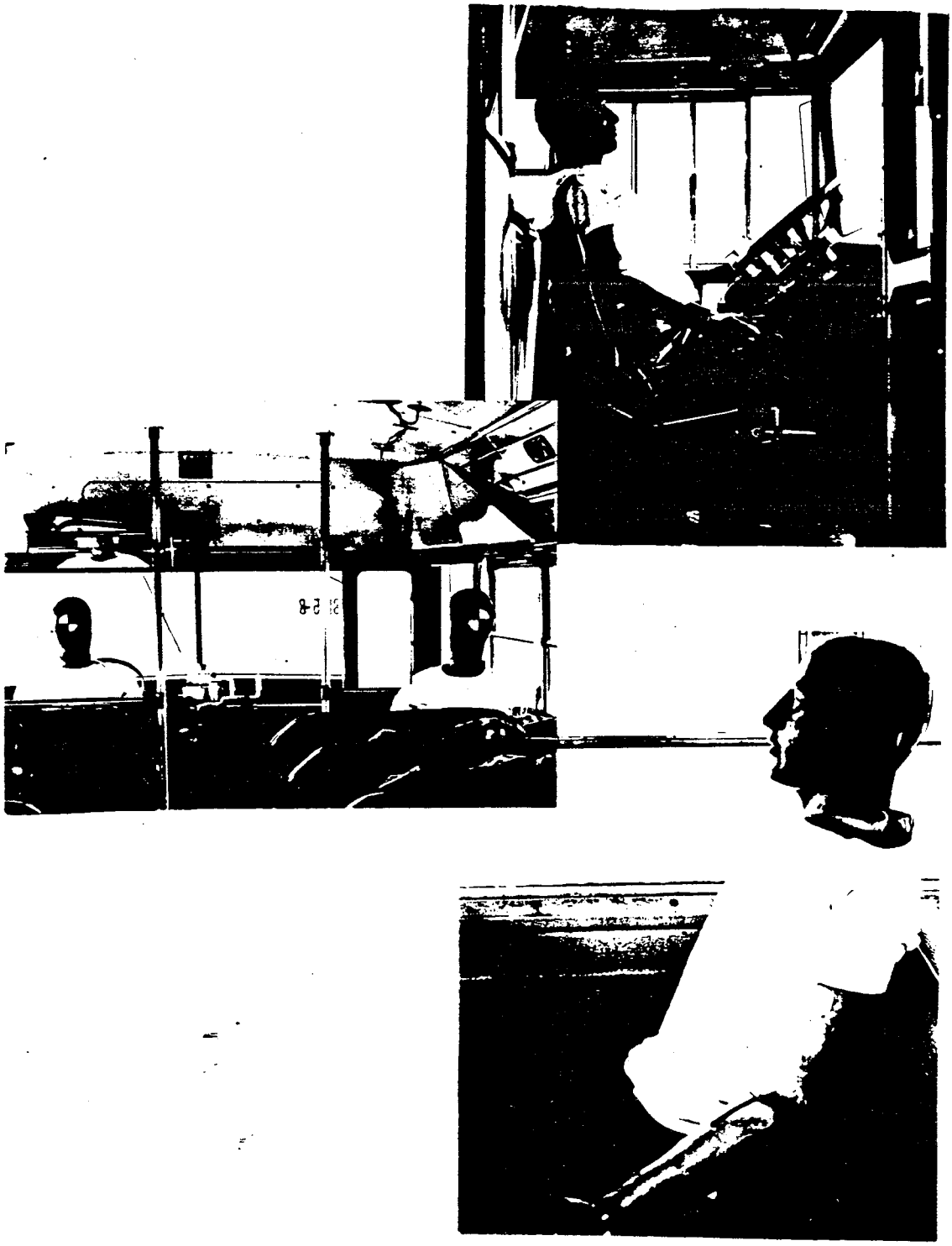


Figure 119. Vehicle Interior and Anthropomorphic Dummy Positions Before Test 3825-8.

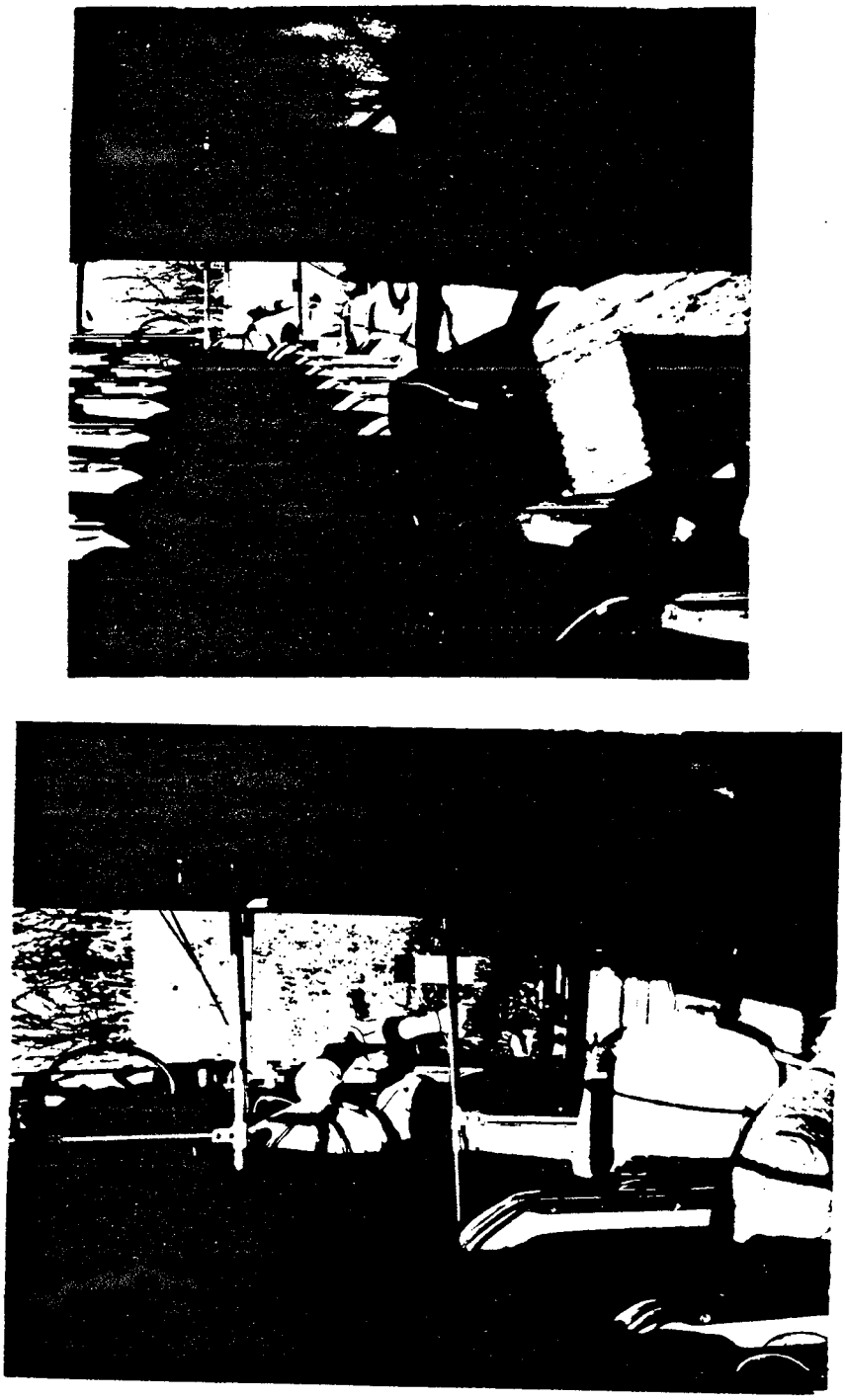
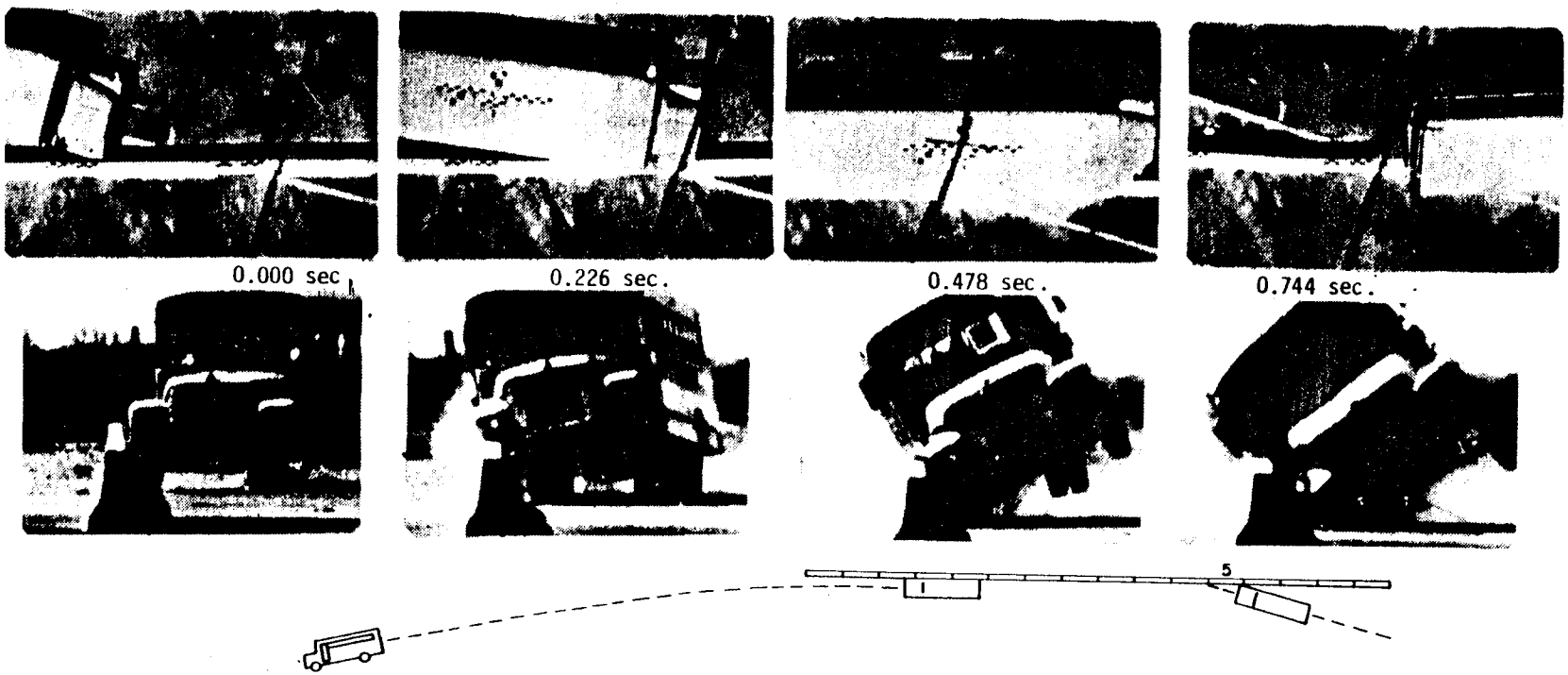
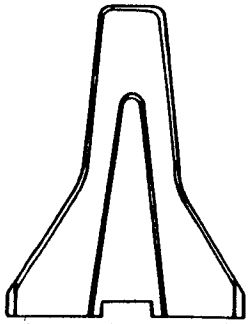


Figure 120. Vehicle Interior and Anthropomorphic Dummy Positions After Test 3825-8.





PORTABLE CONCRETE
MEDIAN BARRIER

Test No.	3825-8
Date	4/3/80
Barrier	Portable Concrete Median Barrier
Segment	Vertical tongue & groove w/C5x9.0 & 1 in. dia. (2.5 cm) steel dowels
Segment Length	15 ft (4.6 m)
Length of Installation	180 ft (54.9 m)
Beam Rail Deflection	
Max. Dynamic	
Max. Permanent	1.8 ft (0.6 m)

Vehicle	School Bus
Vehicle Weight (w/ dummies & instrumentation)	20,000 lb (9,072 kg)
Dummy Restraints	
Alpha (driver)	Lap Belt
Beta (passenger)	No Restraint
Impact Velocity	57.7 mph (92.8 km/h)
Impact Angle	15 deg
Exit Angle	Bus Rolled
Vehicle Acceleration (Max. 0.050 sec avg.)	
Longitudinal	-1.1 g
Transverse	5.3 g
Vertical	-1.9 g

Figure 121. Summary of Results for Test 3825-8.

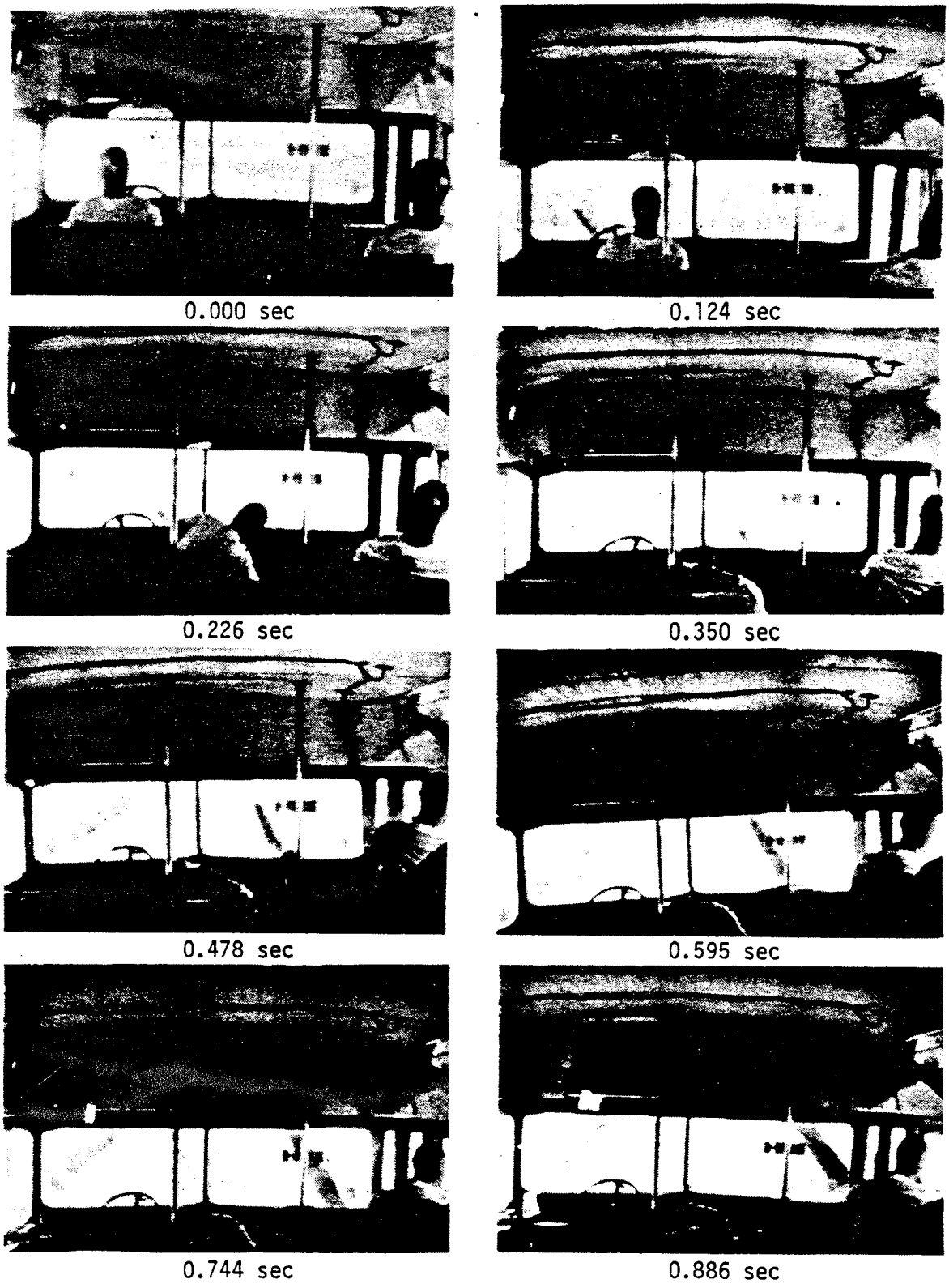
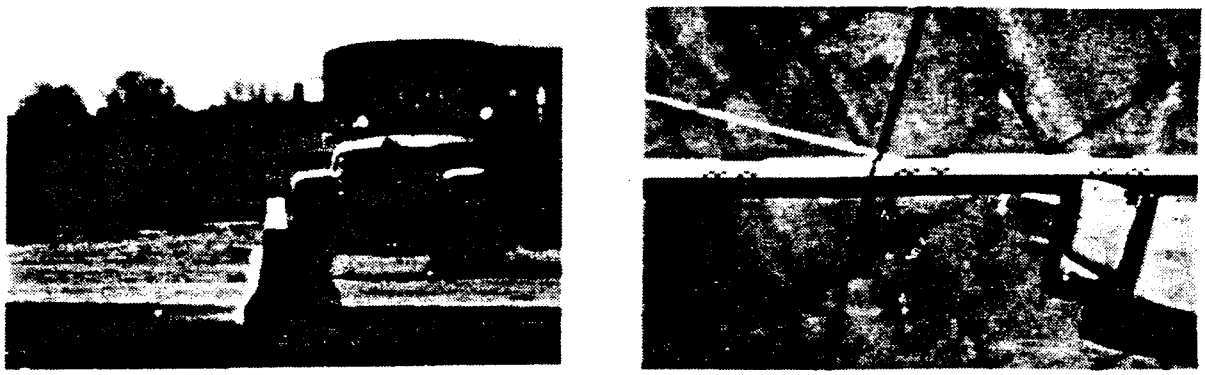
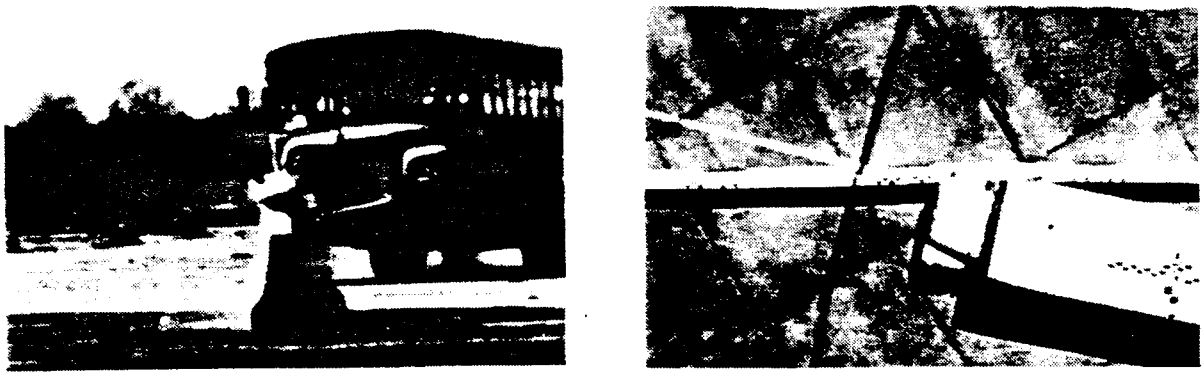


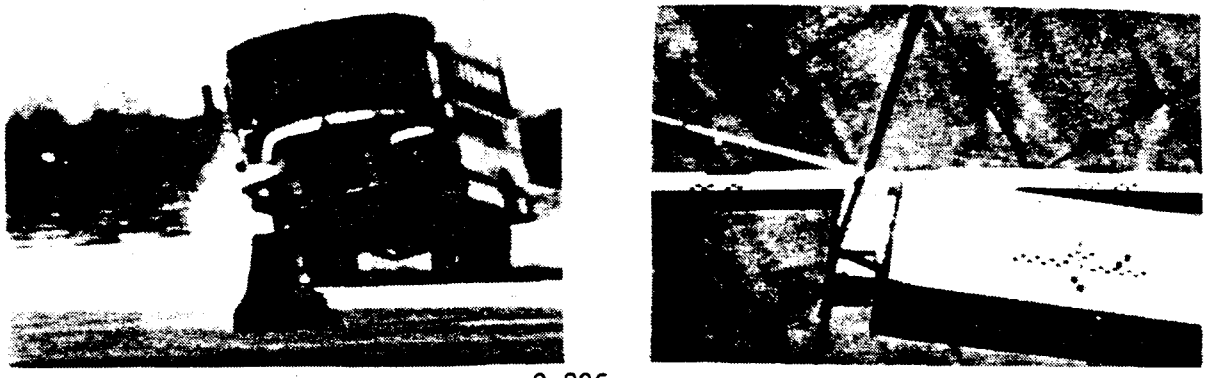
Figure 122. Interior Sequential Photographs for Test 3825-8.



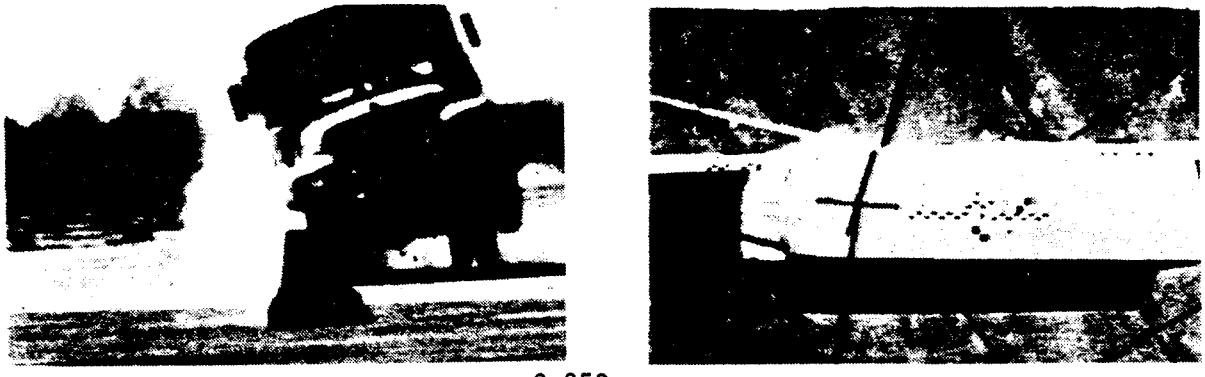
0.000 sec



0.124 sec

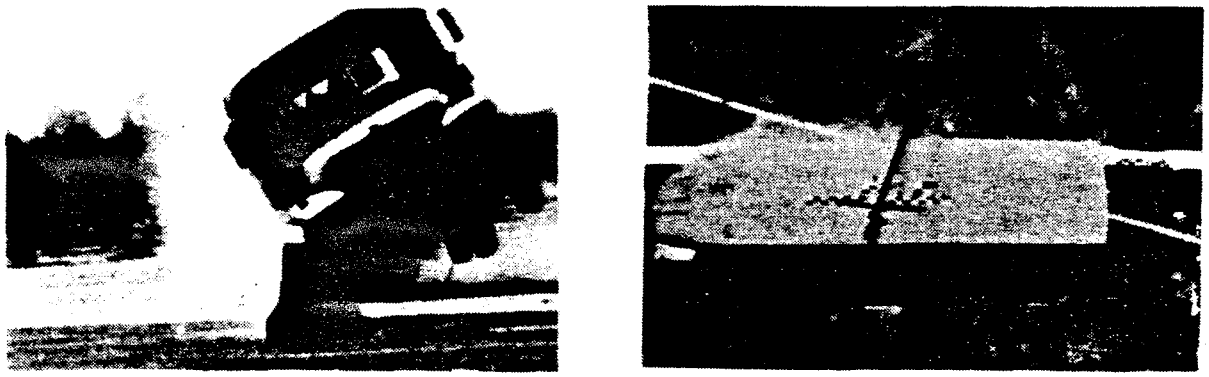


0.226 sec



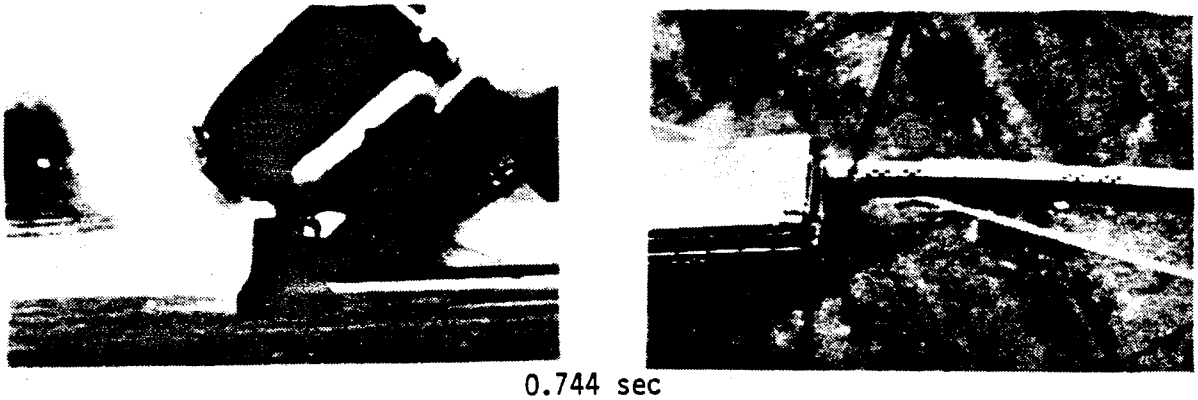
0.350 sec

Figure 123. Sequential Photographs for Test 3825-8.



0.478 sec

0.595 sec



0.744 sec

0.886 sec

Figure 123 (Continued). Sequential Photographs for Test 3825-8.

Table 8. Time, Displacement, Event Summary for Test 3825-8.

TIME (sec)	X-DISPLACEMENT (ft)	Y-DISPLACEMENT (ft)	EVENT
0.000	0.000*	0.000*	Impact
0.013	1.120	0.400	
0.026	2.167	0.714	
0.039	3.275	0.930	L. F. Fender
0.053	4.395	1.059	Bends under
0.066	5.497	1.391	
0.079	6.507	1.662	
0.092	7.683	1.951	
0.105	8.709	2.189	
0.118	9.854	2.333	
0.131	10.899	2.565	
0.145	11.994	2.828	
0.158	13.082	2.985	
0.171	14.158	3.166	
0.184	15.155	3.396	
0.197	16.286	3.662	
0.210	17.265	3.843	
0.223	18.313	4.190	
0.237	19.361	4.440	
0.250	20.440	4.684	
0.263	21.476	4.830	
0.276	22.576	4.963	
0.289	23.610	5.114	
0.302	24.662	5.187	
0.315	25.659	5.392	Rear of bus hits rail
0.329	26.712	5.525	
0.342	27.722	5.693	
0.355	28.799	5.946	Bus rolls approx. 5 deg

*Location of vehicle c.g. at point of impact.

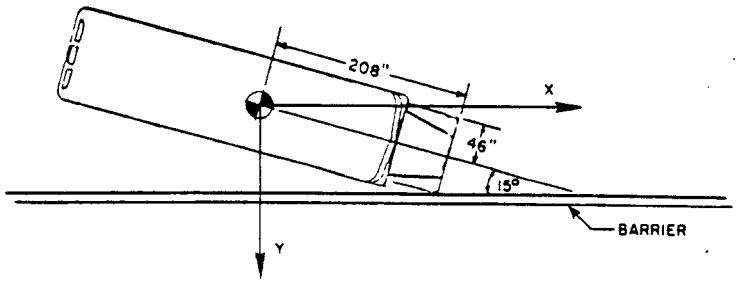


Table 9. Time/Event Summary for Test 3825-8.

TIME (sec)	EVENT
0.000	Impact
0.057	Alpha begins to slide sideways toward left side of bus
0.067	Beta begins to move side ways toward left side of bus
0.124	Beta begins to lose contact with bus seat
0.200	Alpha hits left shoulder and top left side of head on window directly left of drivers seat
0.277	Alpha still in contact with window, Beta is completely out of seat
0.286	Alpha begins to travel back to original driver position
0.429	Beta's left shoulder hits 1st window behind driver
0.487	Beta's posterior hits 1st window behind driver

NOTE: Alpha dummy positioned in driver's seat.
Beta dummy positioned in right front passenger seat.

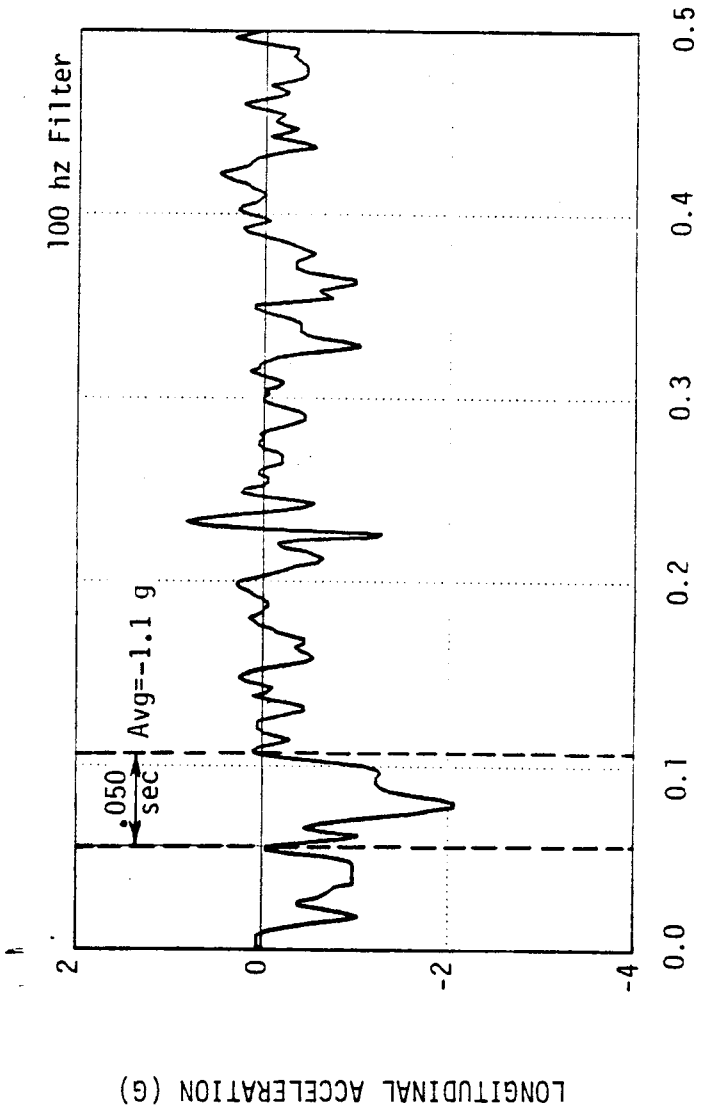


Figure 124. Vehicle Longitudinal Accelerometer Trace for Test 3825-8.

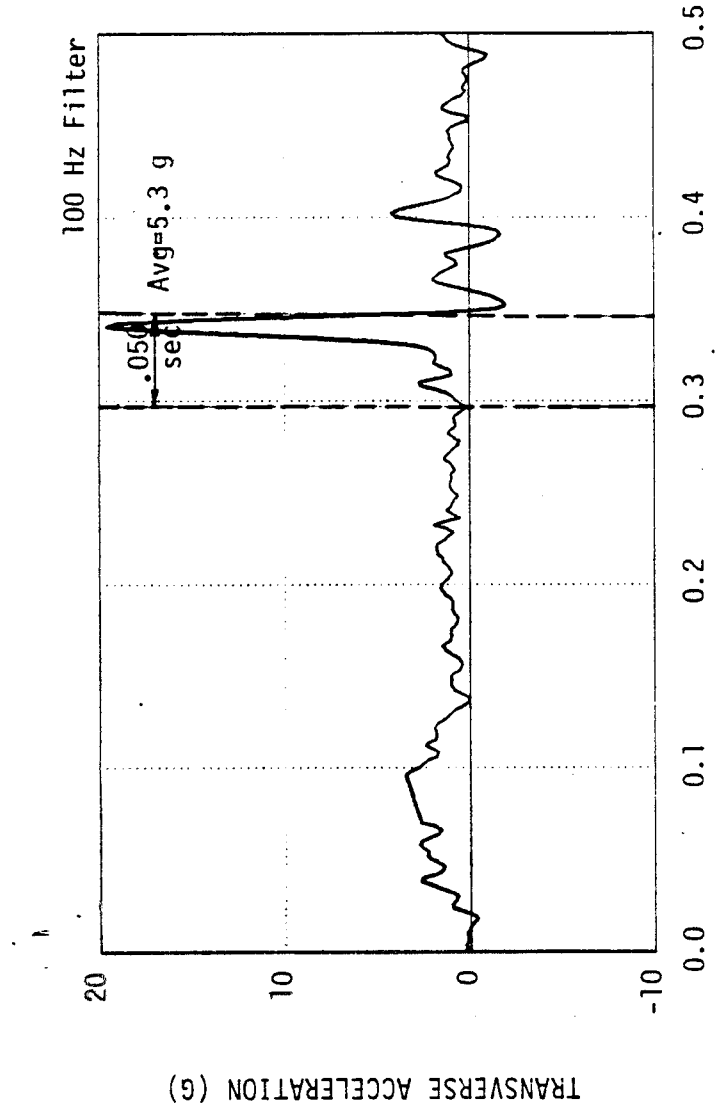


Figure 125. Vehicle Transverse Accelerometer Trace for Test 3825-8.

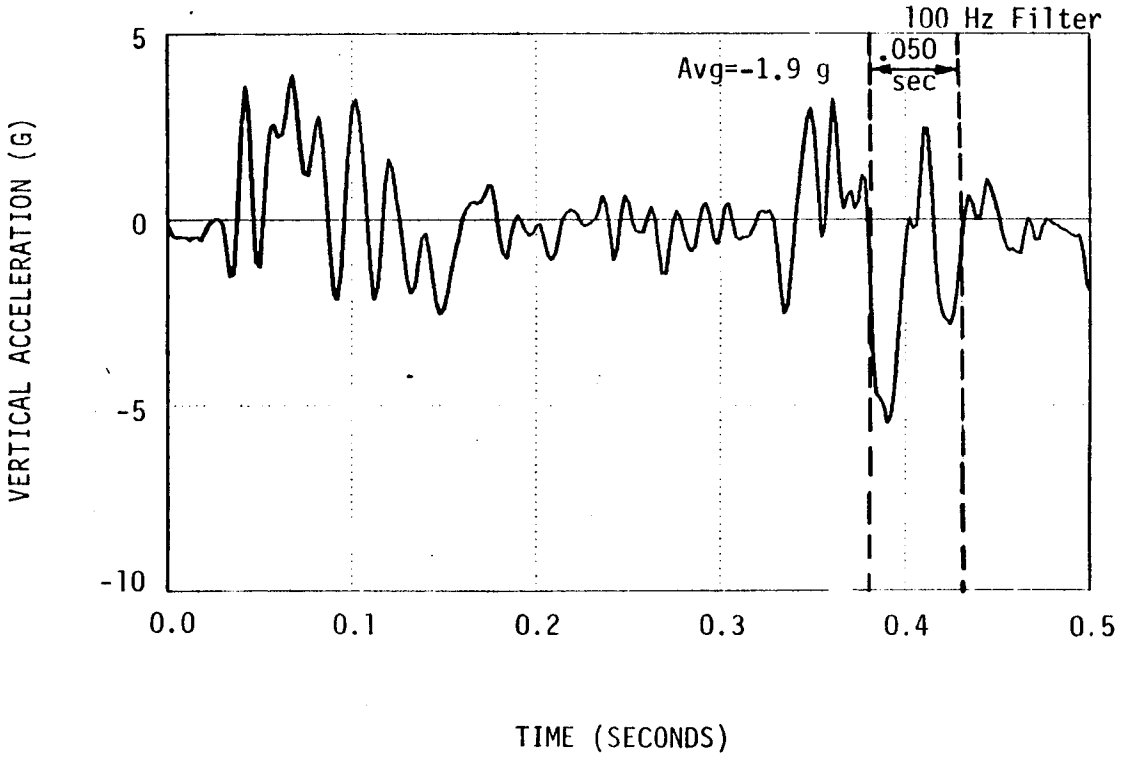


Figure 126. Vehicle Vertical Accelerometer Trace for Test 3825-8.

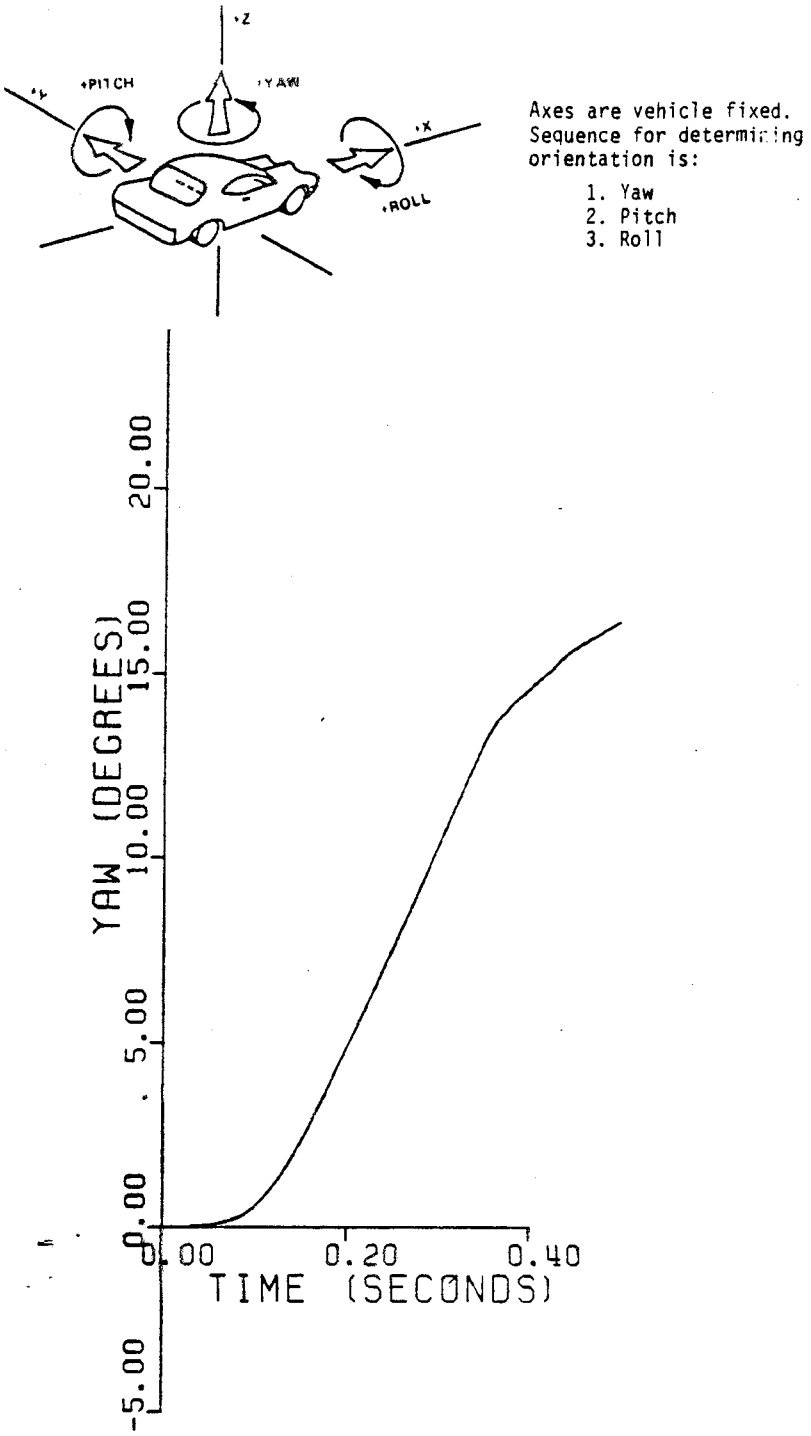


Figure 127. Yaw Verses Time for Test 3825-8.

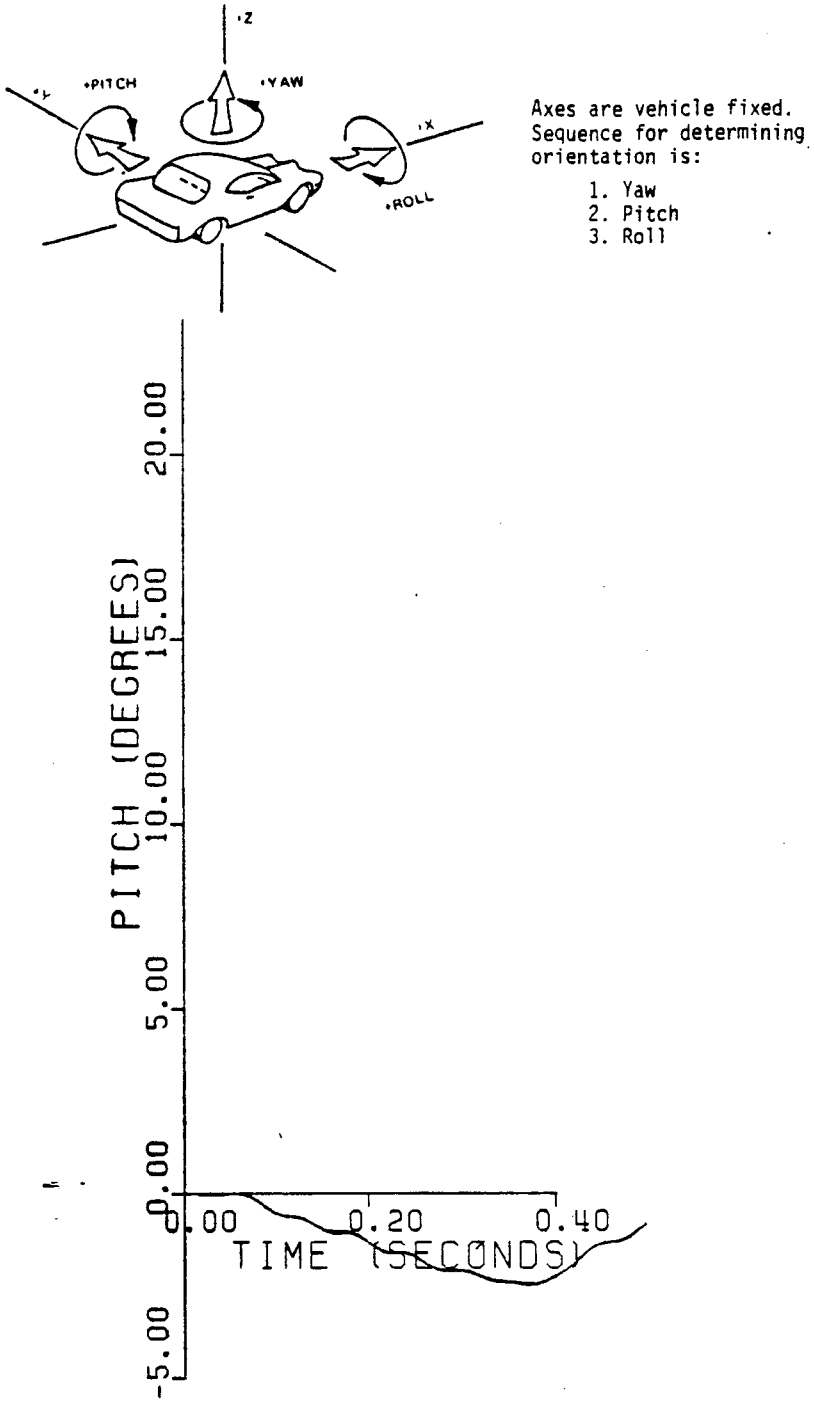


Figure 128. Pitch Verses Time for Test 3825-8.

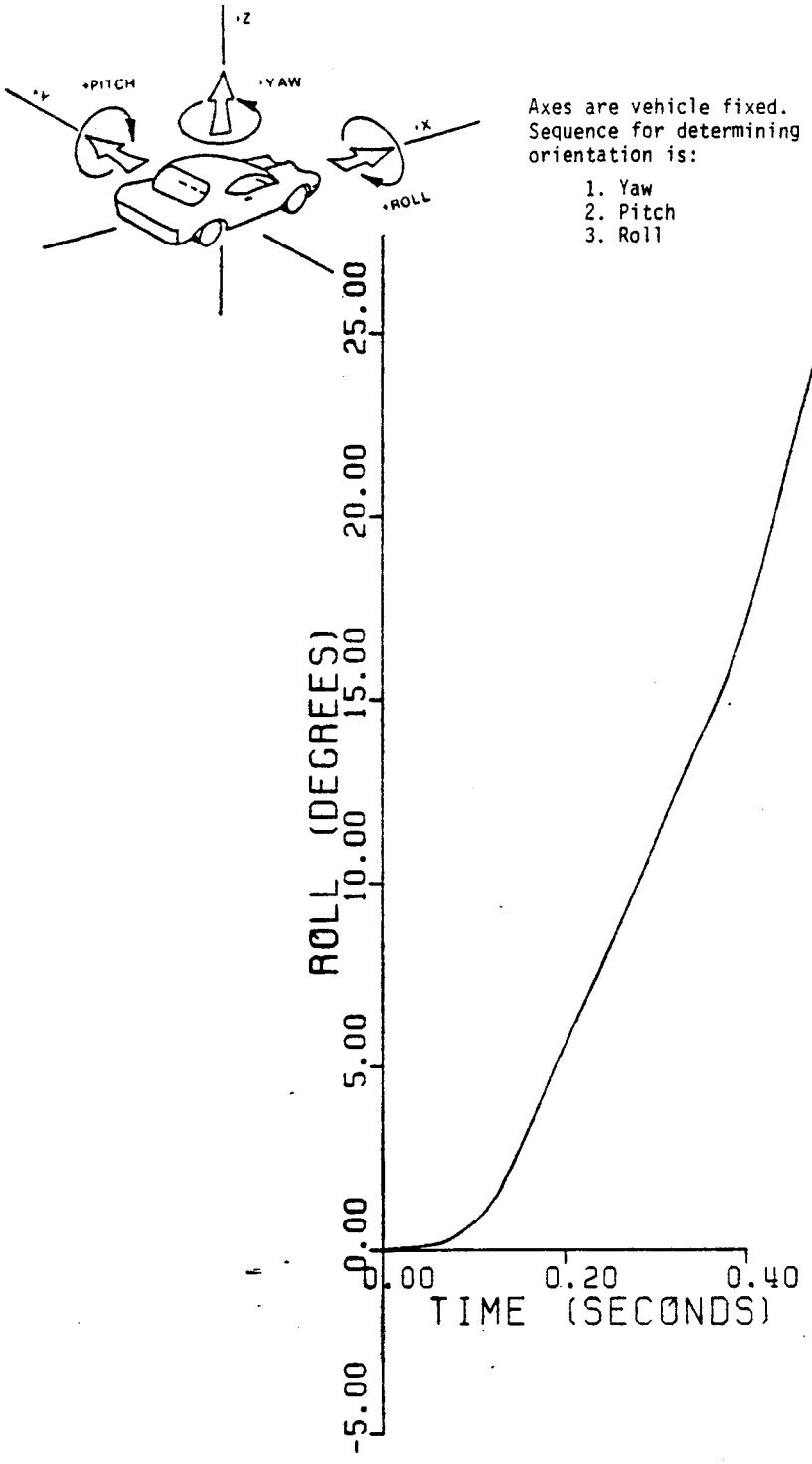


Figure 129. Roll Verses Time for Test 3825-8.

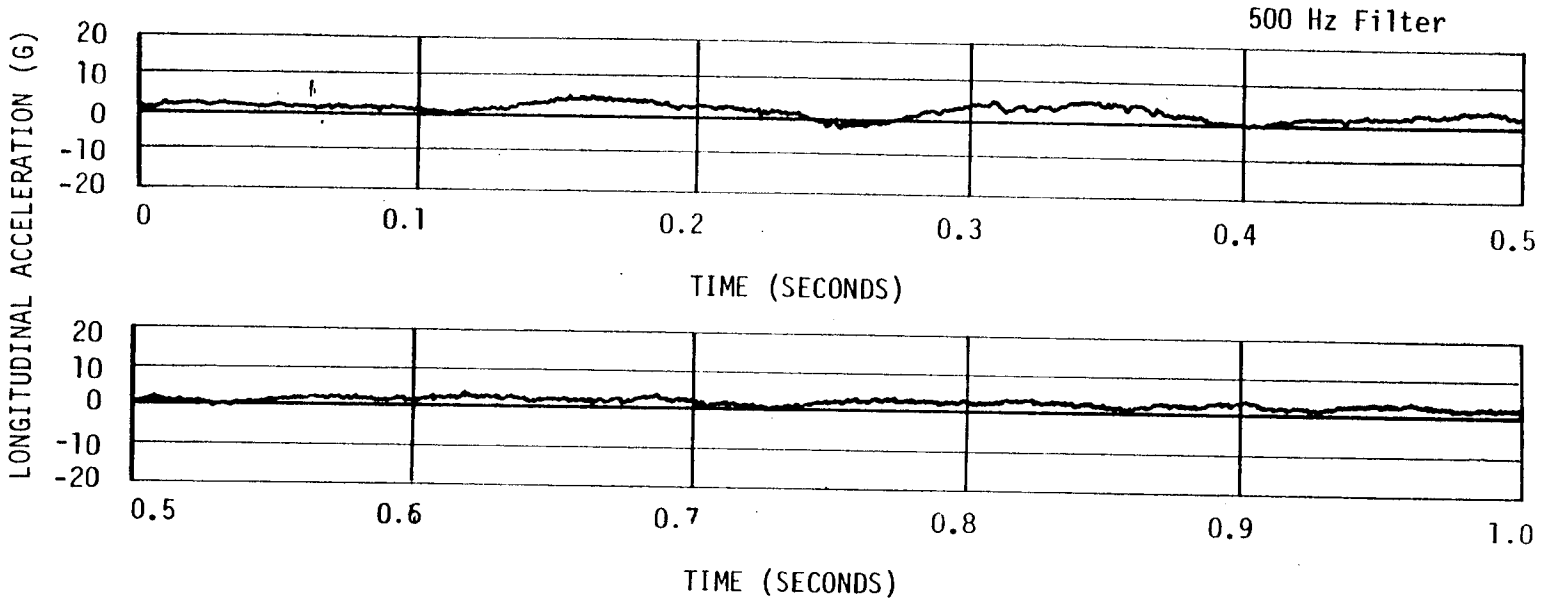


Figure 130. Alpha Head Accelerometer Traces for Test 3825-8. (driver position)

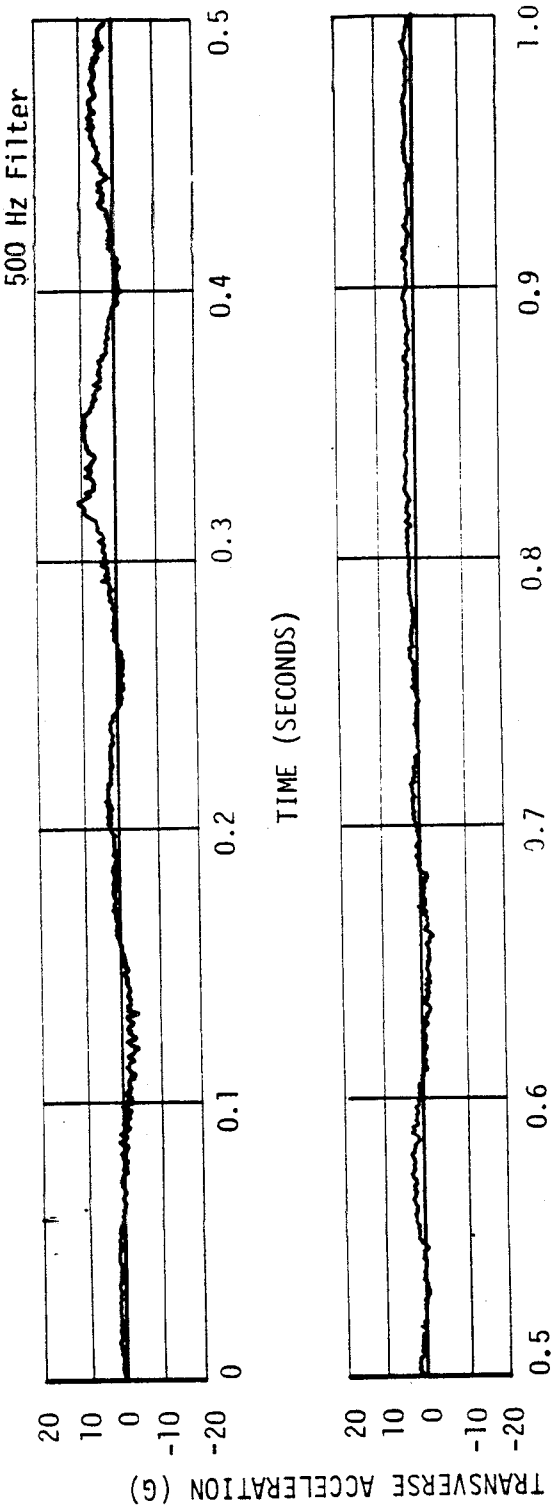


Figure 130. (Continued). Alpha Head Accelerometer Traces for Test 3825-8. (driver position)

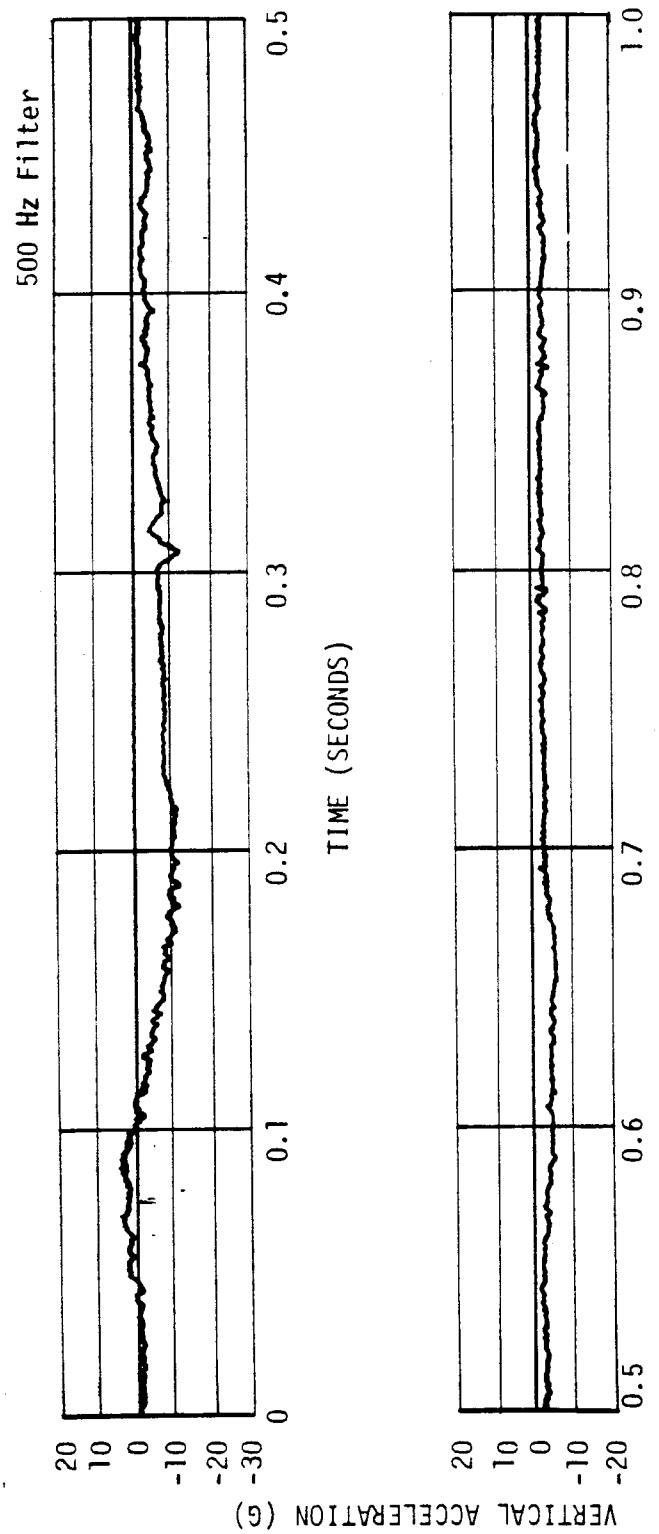


Figure 130. (Continued). Alpha Head Accelerometer Traces for Test 3825-8. (driver position)

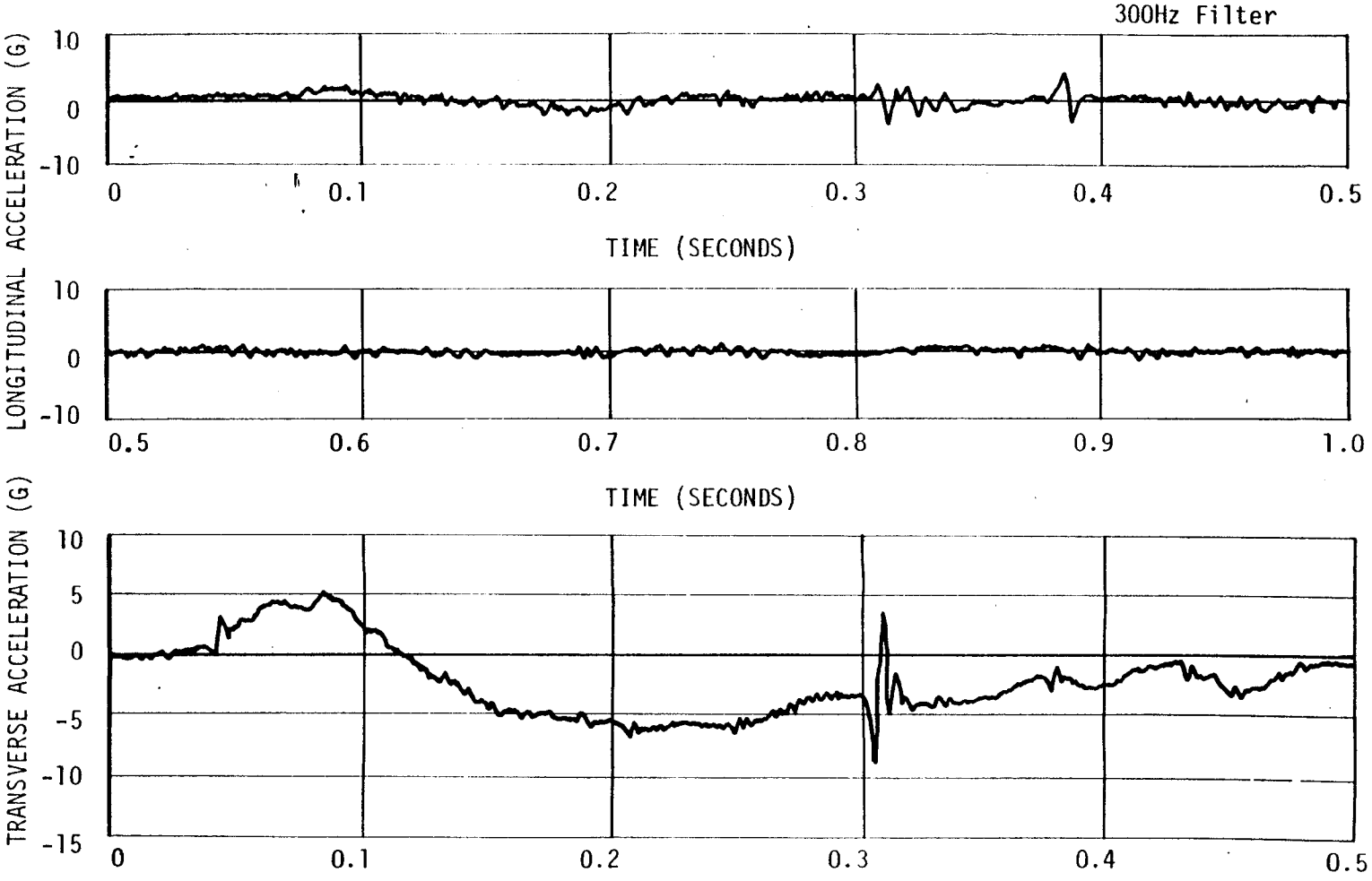


Figure 131. Alpha Chest Accelerometer Traces for Test 3825-8. (driver position)

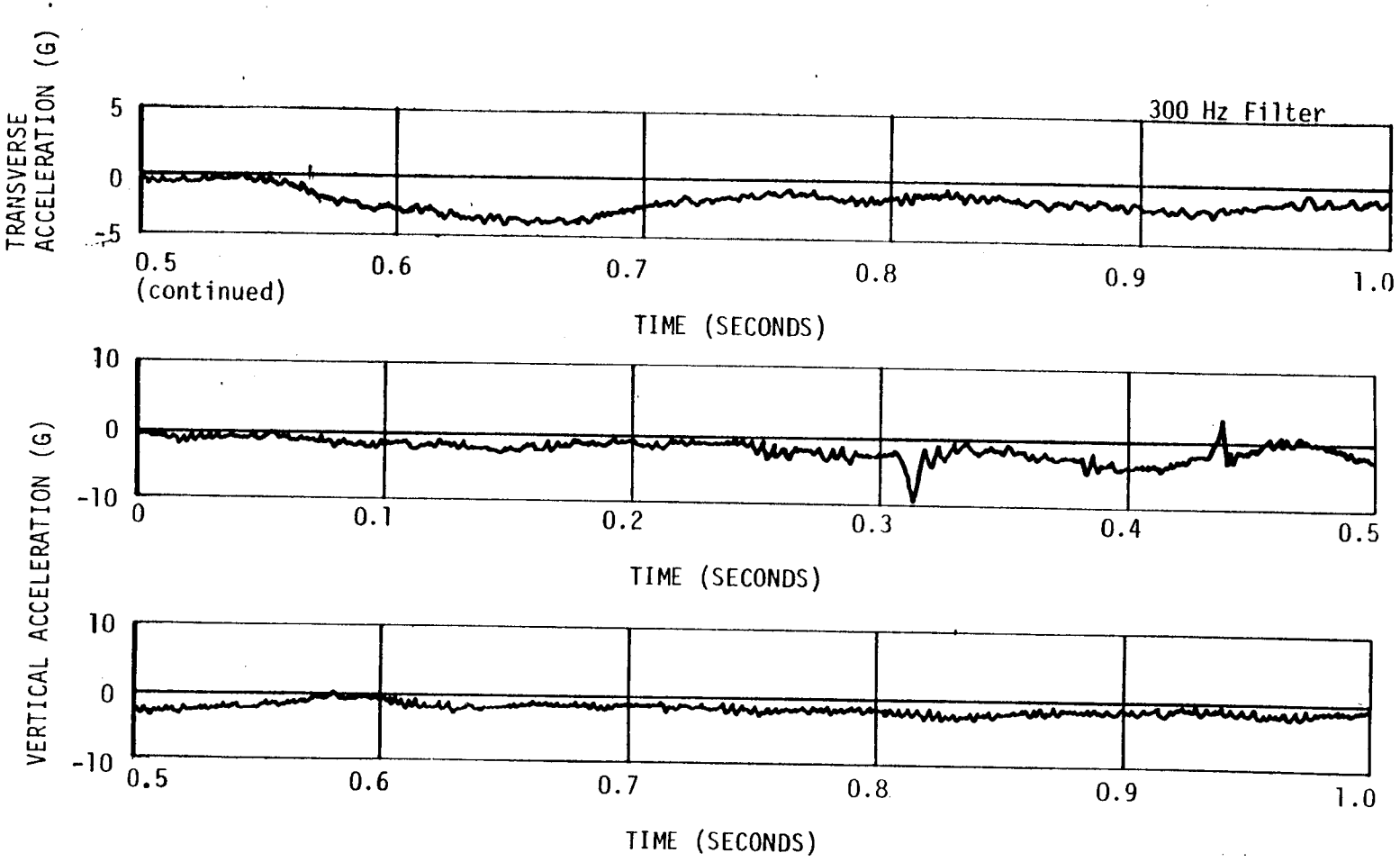


Figure 131. (Continued). Alpha Chest Accelerometer Traces for Test 3825-8. (driver position)

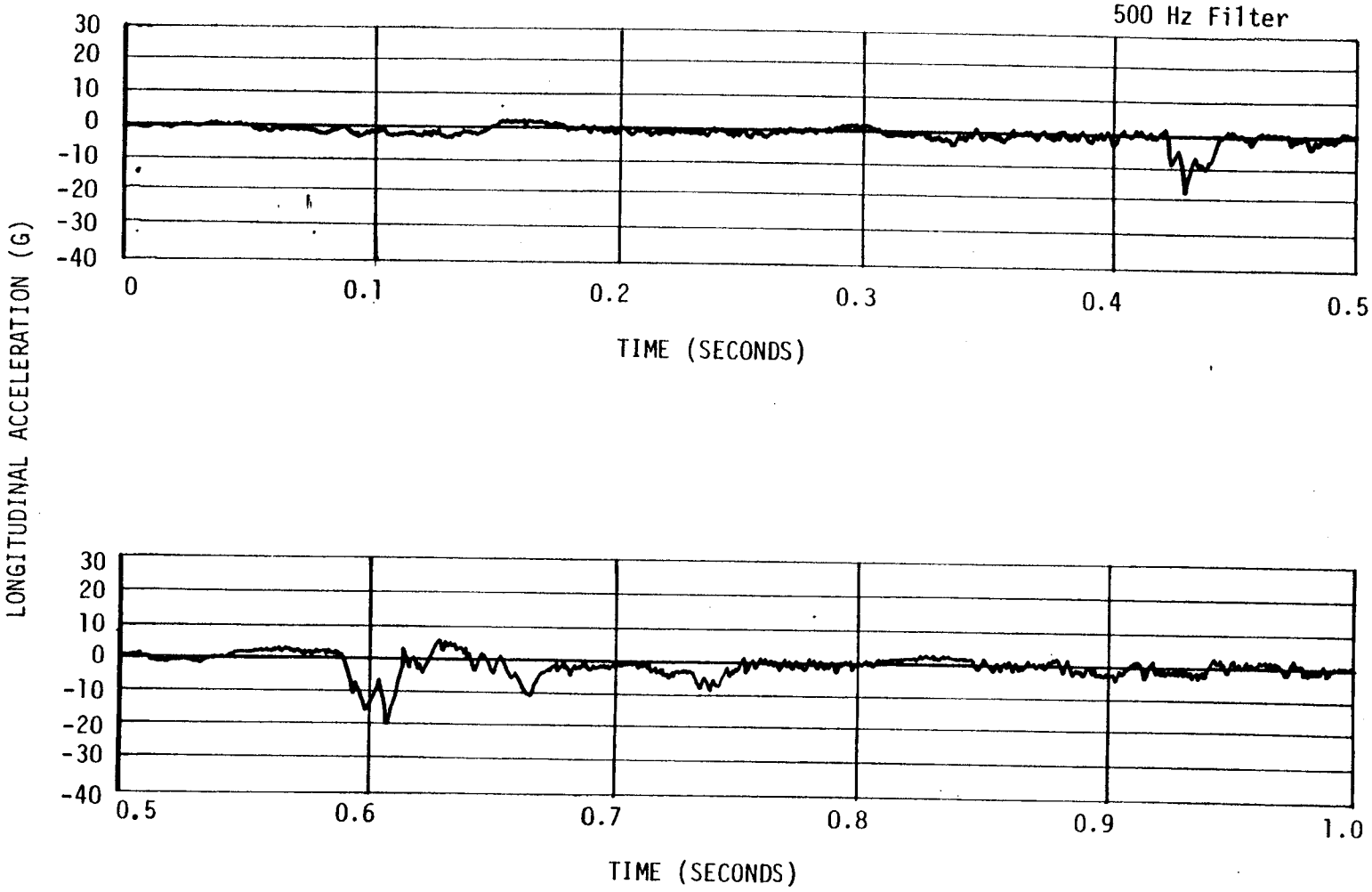


Figure 132. Beta Head Accelerometer Traces for Test 3825-8. (right front passenger position)

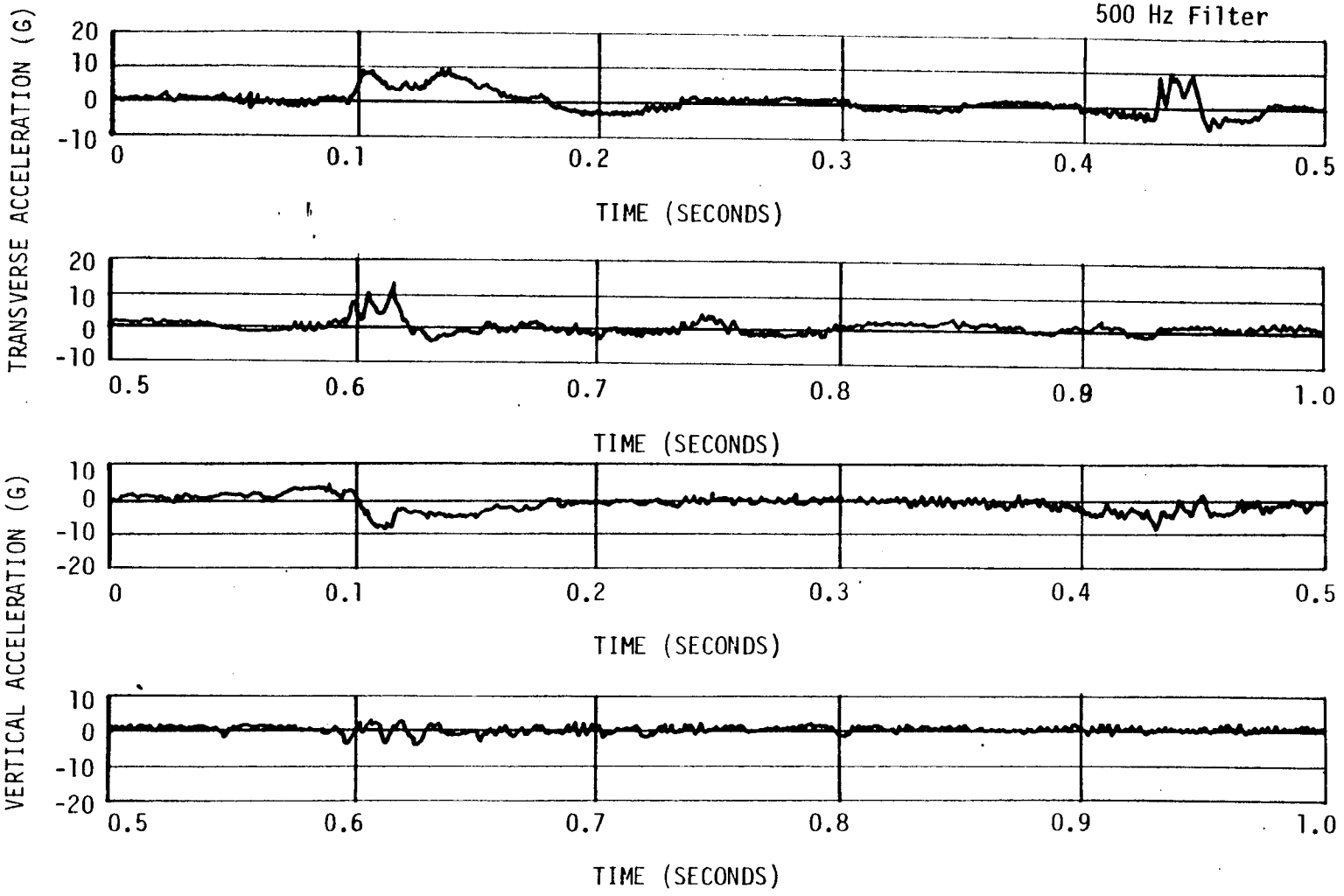


Figure 132. (Continued). Beta Head Accelerometer Traces for Test 3825-8. (right front passenger position)

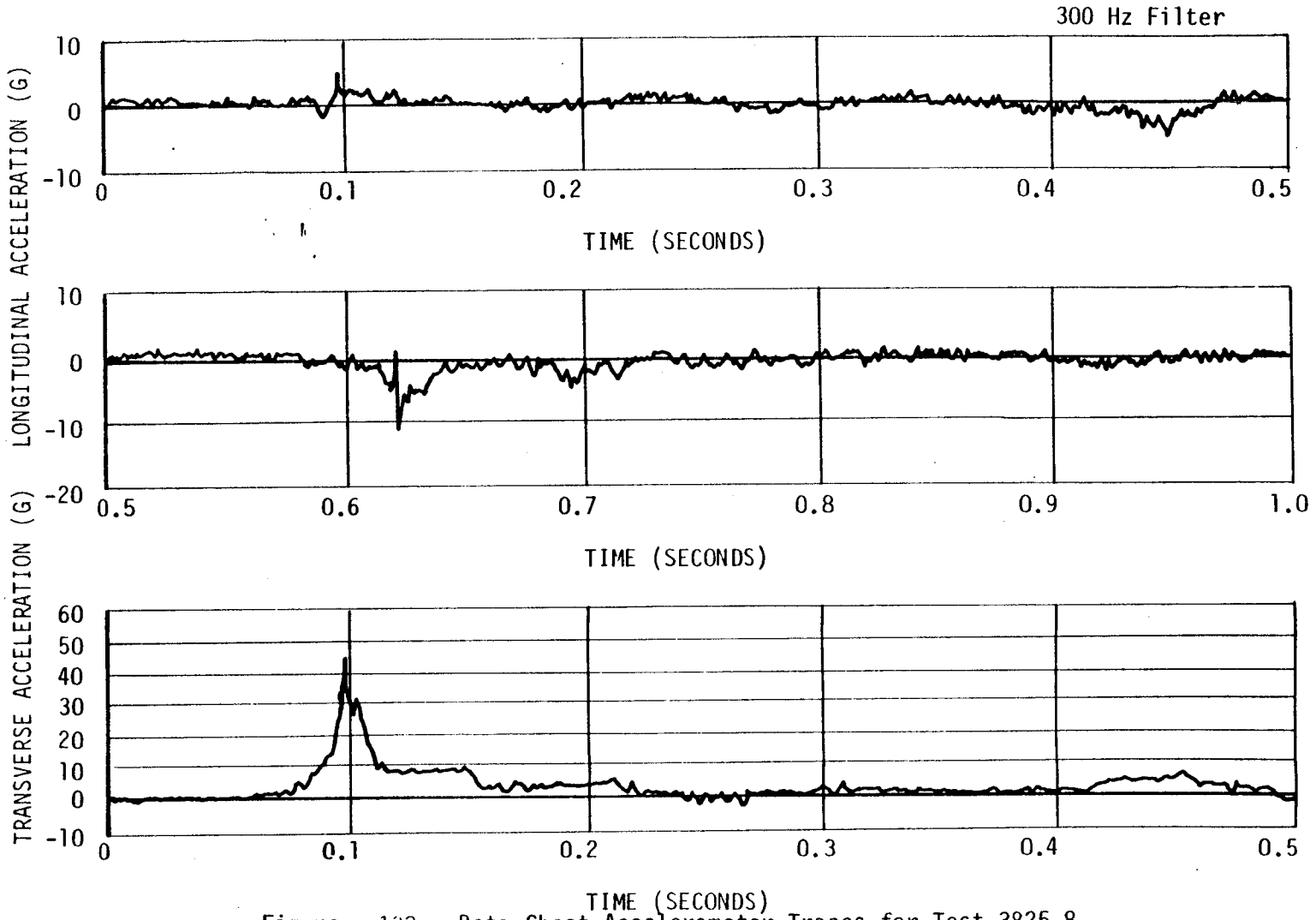


Figure 133. Beta Chest Accelerometer Traces for Test 3825-8. (right front passenger position)

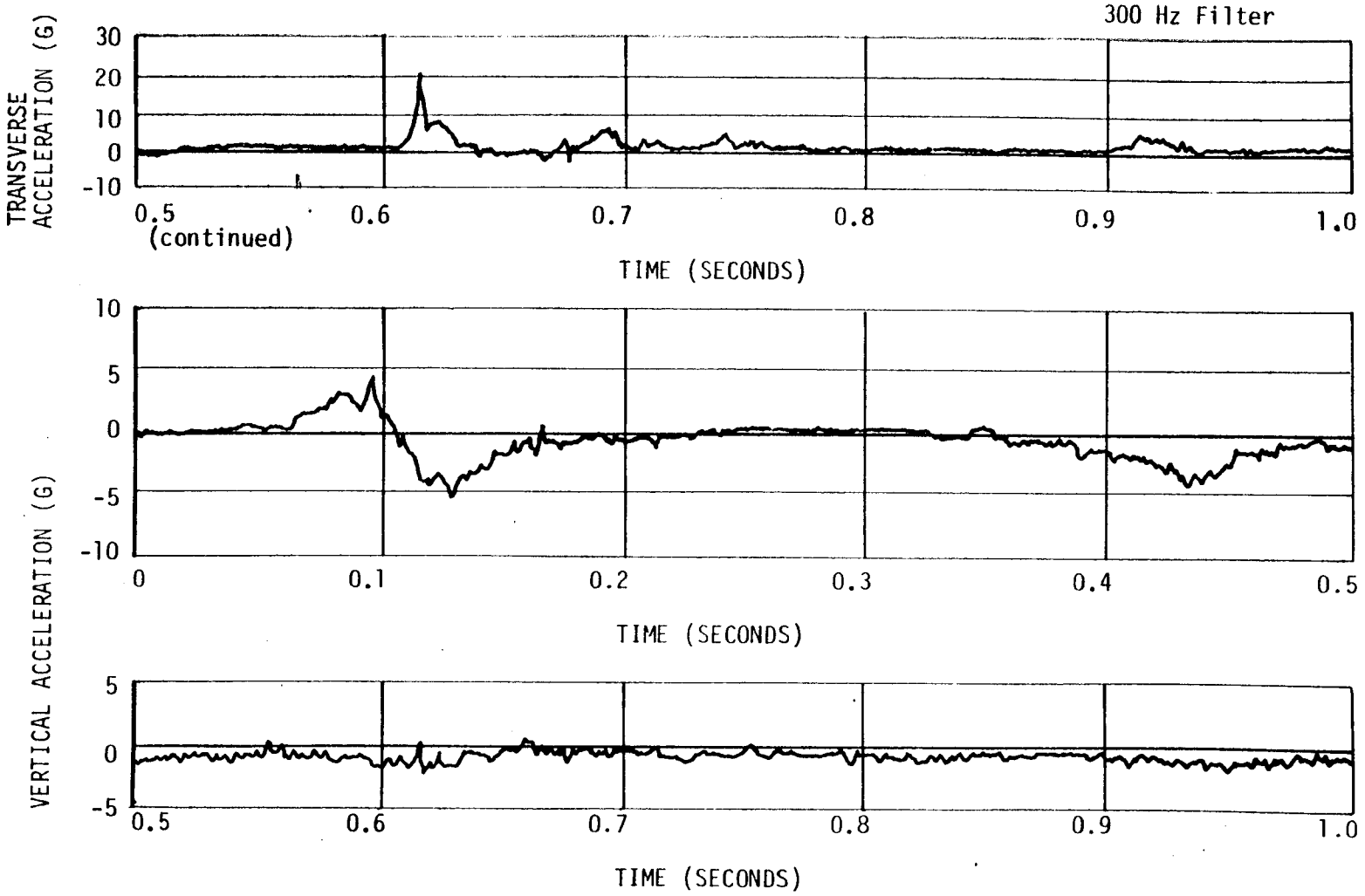


Figure 133. (Continued). Beta Chest Accelerometer Traces for Test 3825-8. (right front passenger position)

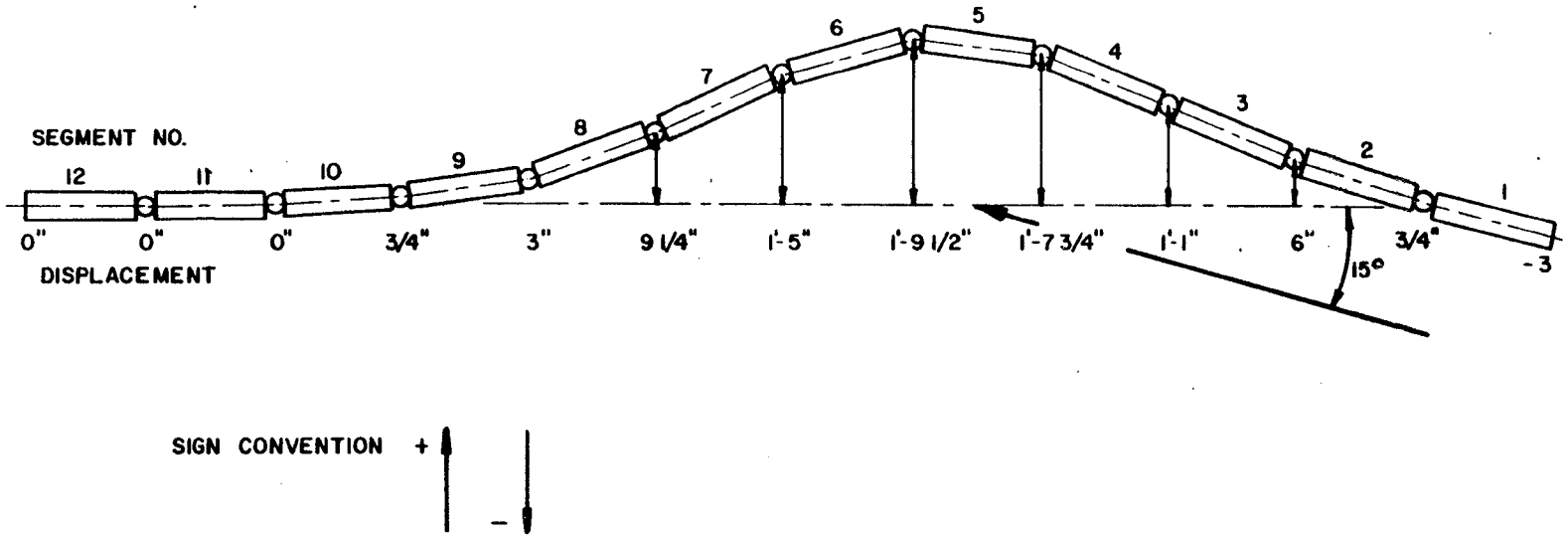
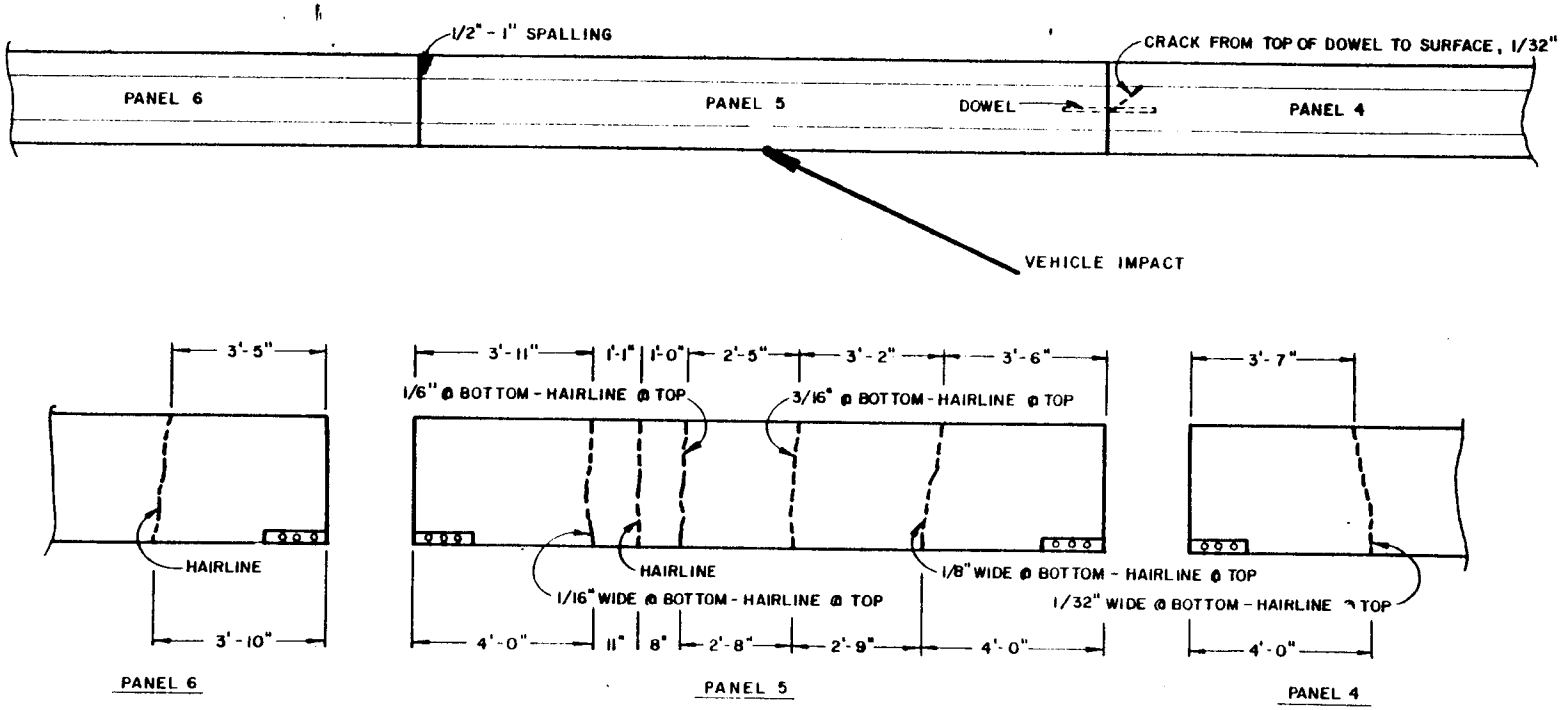


Figure 134. Permanent Barrier Displacement After Test 3825-8.



NOTE: IMPACT FACE OF PANEL IS SHOWN, CRACKS ARE ON BACK FACE

Figure 135. Flexural Cracks After Test 3825-8.

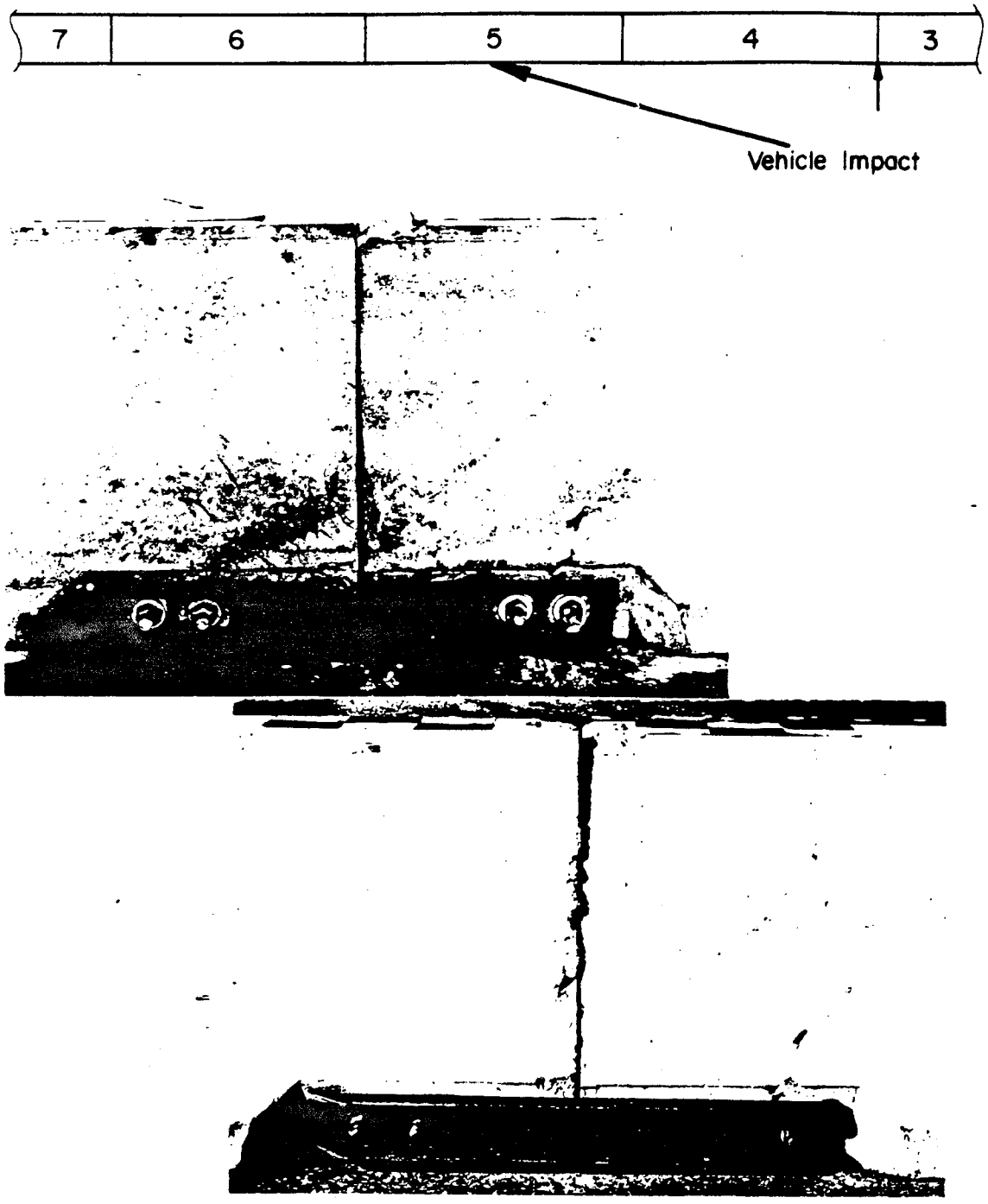


Figure 136. Joint 3-4 Before and After Test 3825-8.

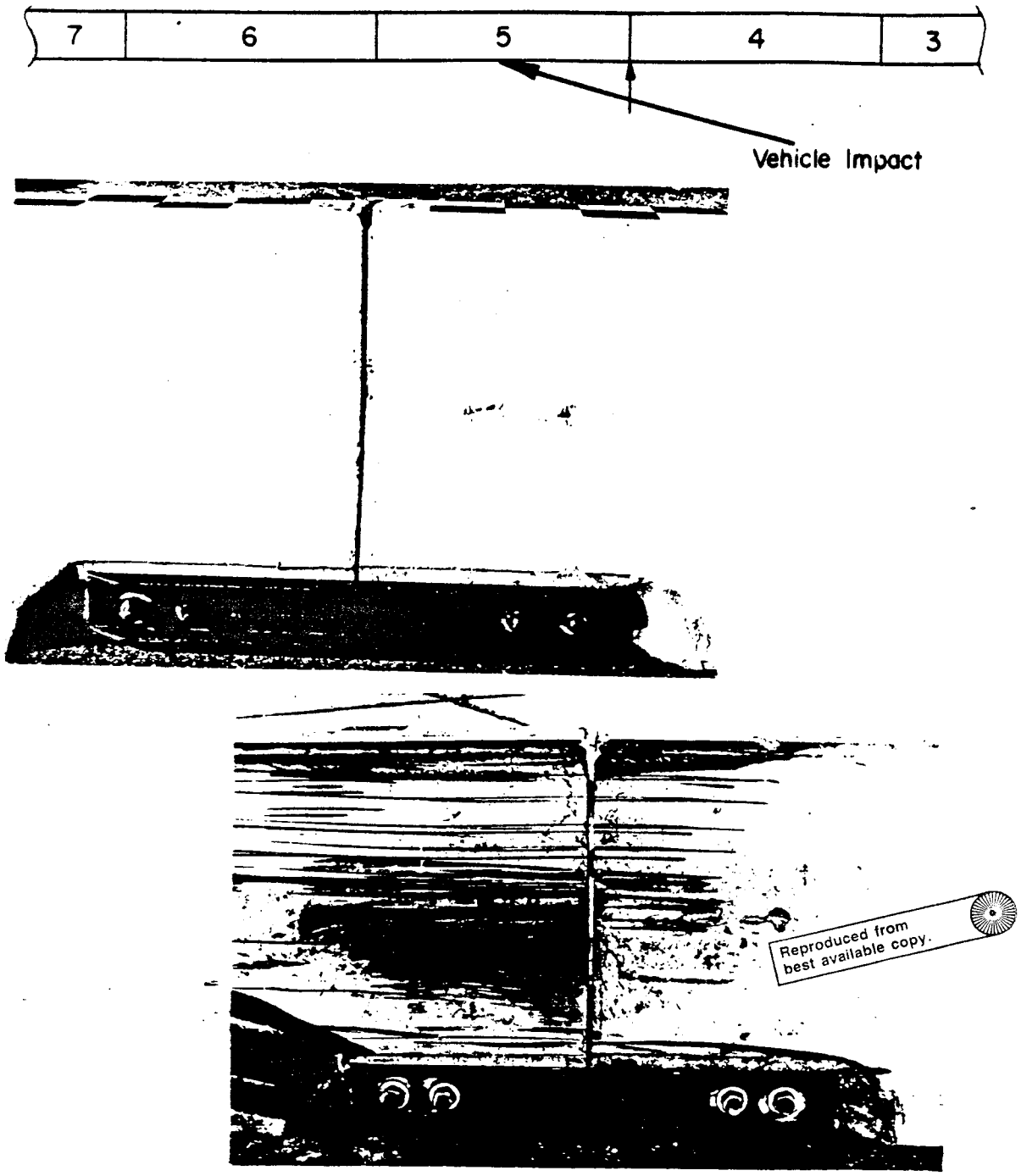


Figure 137. Joint 4-5 Before and After Test 3825-8.

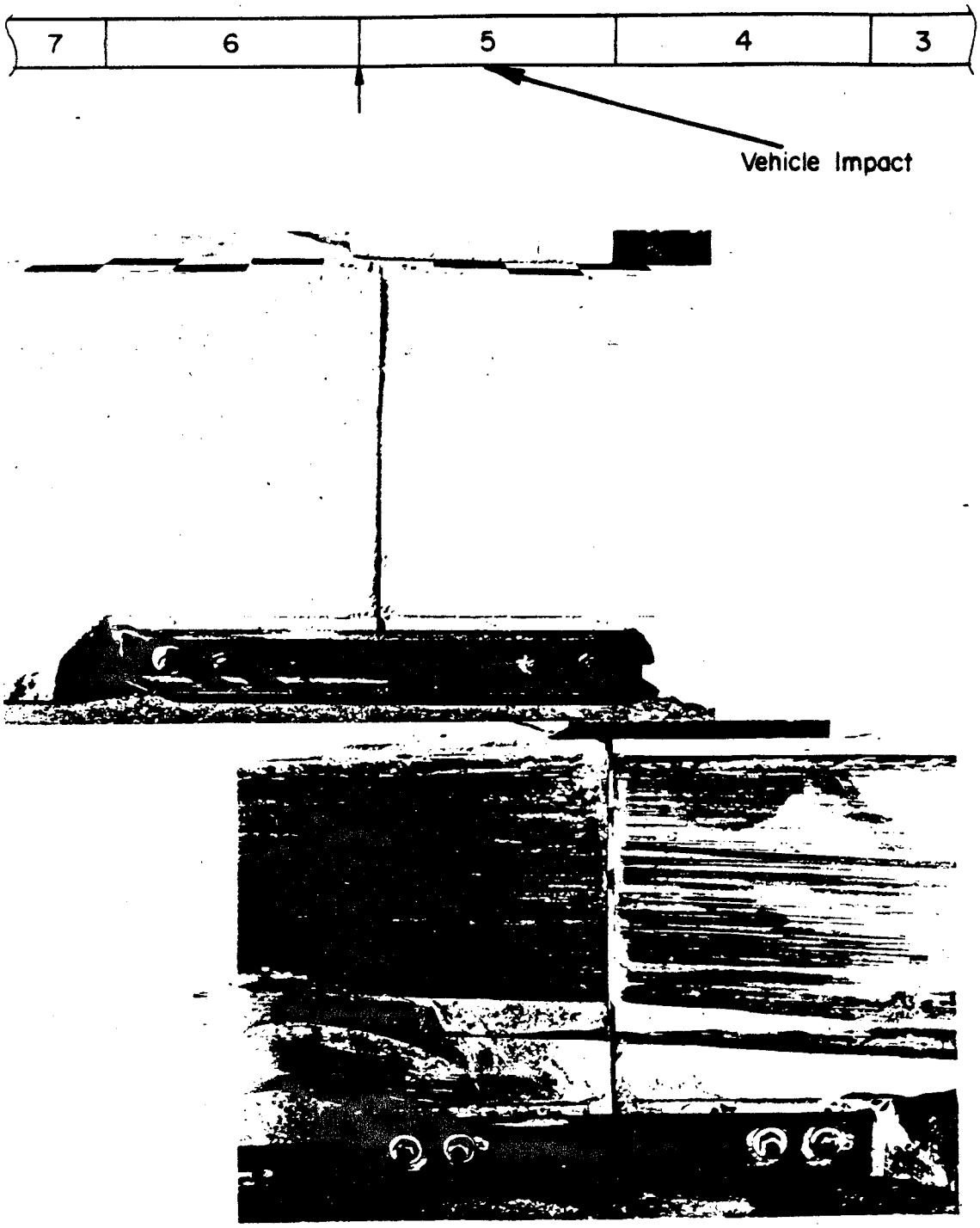


Figure 138. Joint 5-6 Before and After Test 3825-8.

TEST REPORT 9

The test installation was made up of 12.0 ft (3.7 m) portable concrete median barrier (CMB) sections joined by a built-in vertical male/female tongue and groove couplings and 1/8 in. (0.32 cm) thick side plates bolted horizontally to the base of the CMB sections. In addition, a blockout W-beam rail was installed on the simulated traffic face of the CMB sections as shown in Figure 139. The total barrier system was 120.0 ft (36.7 m) long. Ten CMB sections were used with the projected impact point near the midpoint of section 4 as illustrated in Figure 140. The installation was placed on a dry level concrete surface similar to a typical PCC highway surface.

Test 9 - 4,510 lb/63.4 mph/25 deg (2,046 kg/102.0 km/h/25 deg)

In Test 9, a 1976 Plymouth Fury, weighing 4,510 lb (2,046 kg) including all telemetry equipment, impacted the barrier at a speed of 63.4 mph (102.0 km/h) and an angle of 25 deg. Photographs of the vehicle and barrier before and after Test 9 are shown in Figures 141 and 142, respectively. A summary of test results is presented in Figure 143 and sequential photographs are shown in Figure 144. Table 10 lists time and displacement as related to specific events.

The vehicle impacted the barrier initially 6.8 ft (2.1 m) downstream from joint 3-4 on barrier section 4. The force of the impact crushed the right front fender back to the wheel and caused the hood to begin to fly up. Due to the W-section rail blockout attached to the CMB's there was no tendency for the vehicle to ramp on the barrier. As the vehicle yawed and redirected, the motion of the vehicle became parallel to the rail 0.247 sec after impact. The vehicle exited the barrier system at approximately 8 deg. Due to severe damage to the right part of the vehicle, it skidded and yawed 180 deg ending up 138.0 ft (42.1 m) downstream from the initial impact point. The maximum vehicle penetration into the simulated construction zone was 2.0 ft (0.6 m). The maximum dynamic deflection of the barrier was 6.5 ft (2.0 m).

Linear accelerometer traces are shown in Figures 145 through 147. The maximum 0.050 sec average longitudinal and transverse accelerations were -8.8 g and 9.9 g, respectively. The permanent barrier deflection is

shown in Figure 148. Damage to the CMB sections was significant with the most severe damage occurring at joint 4-5 (see Figure 149). This was due to the large deflection causing large rotation of the tongue and groove joints. The 1/8 in. (0.32 cm) base plates were broken at joints 4-5, 5-6 and 6-7.

The test illustrates the inadequacy of the 1/8 in. (0.32 cm) base plates due to the large deflections and failure of several joints. The concept of mounting the W-beam on the CMB section was shown to be quite effective in preventing the vehicle from ramping on the CMB sections.

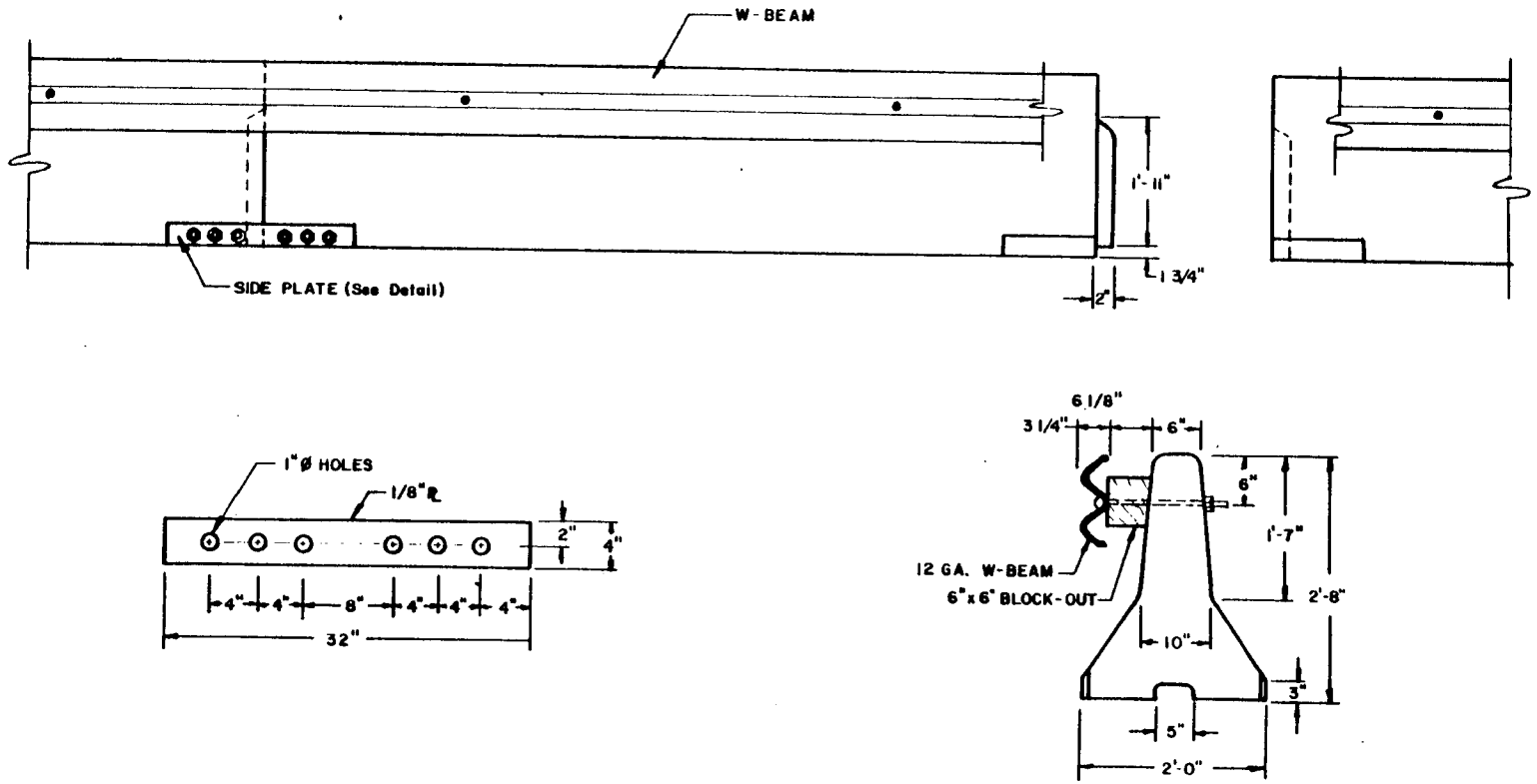


Figure 139. Modified Portable Concrete Median Barrier Details Test 3825-9.

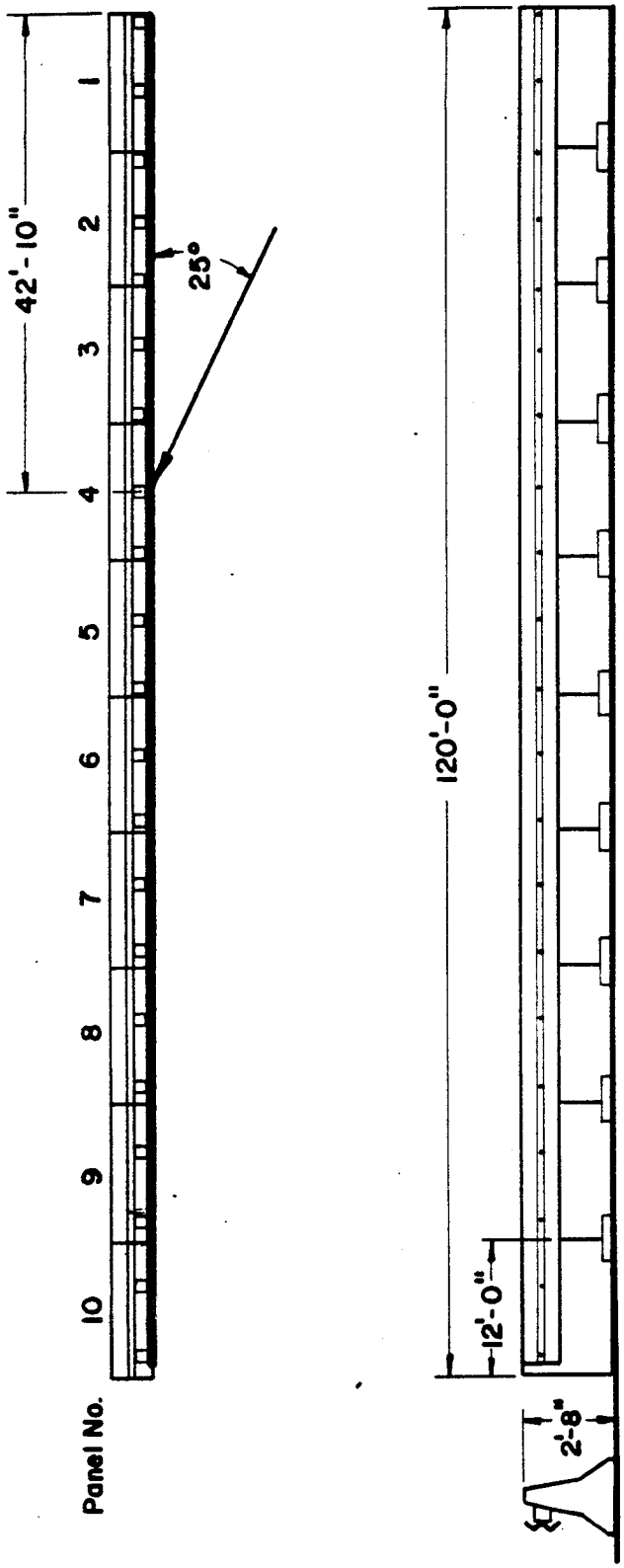


Figure 140 . Barrier Installation Test 3285-9.

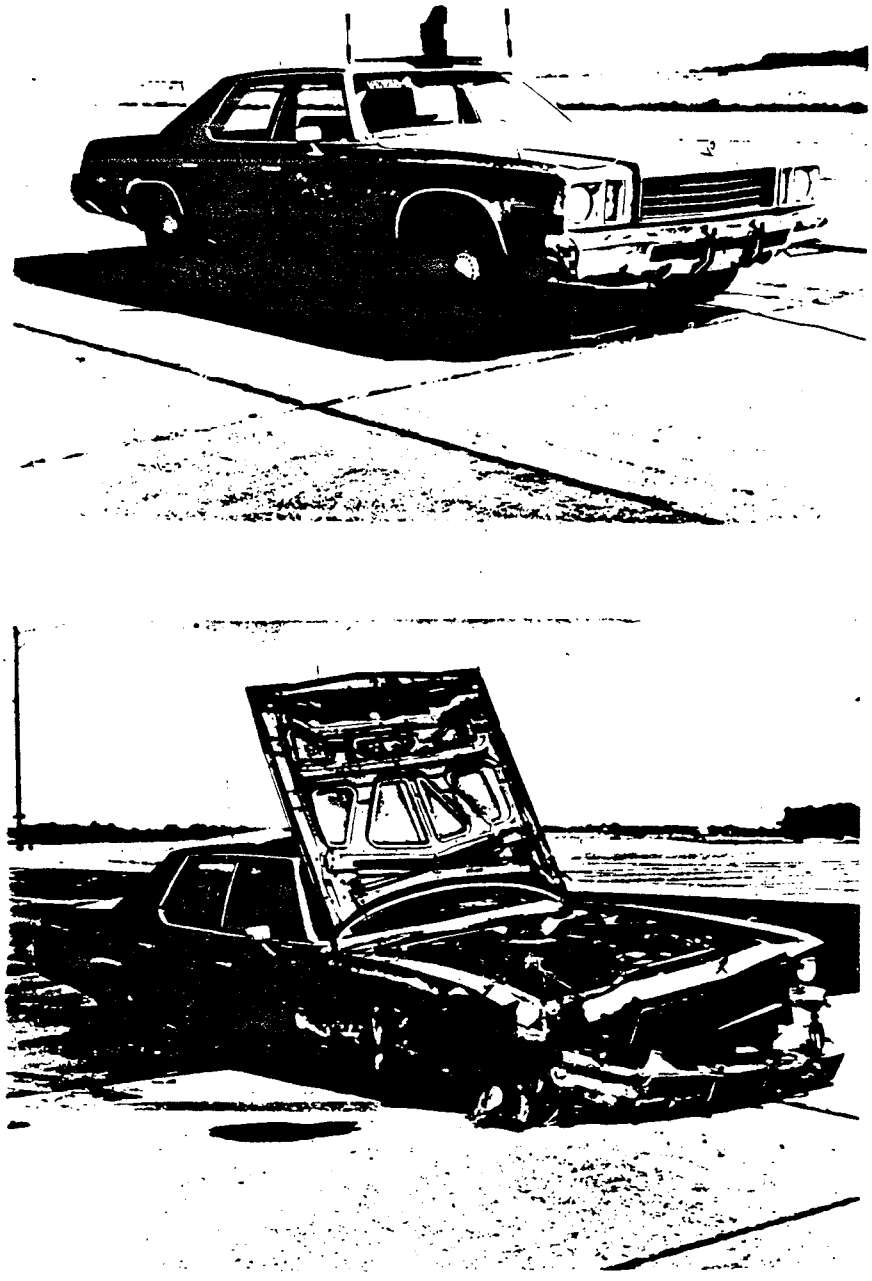


Figure 141. Vehicle Before and After Test 3825-9.

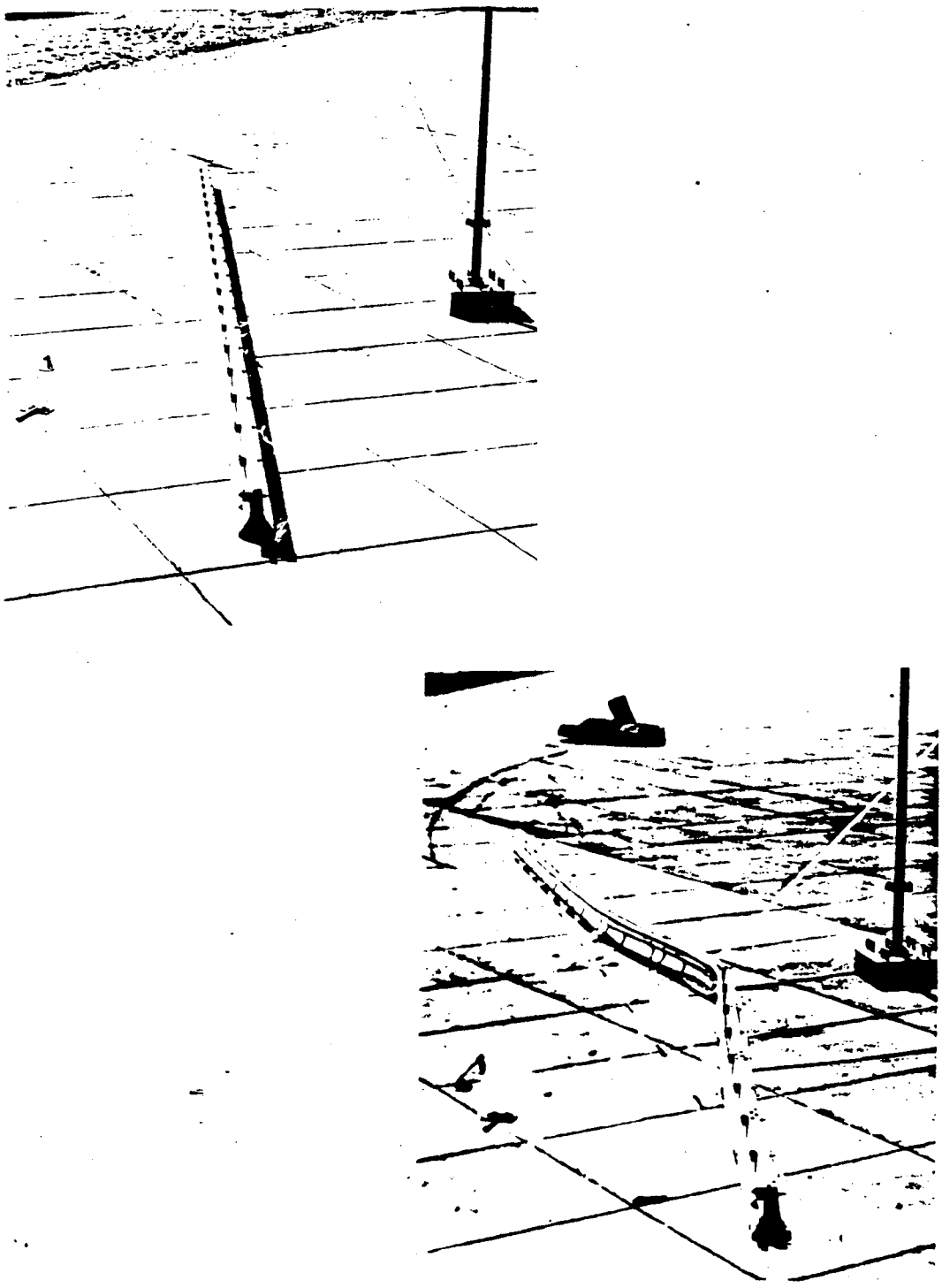
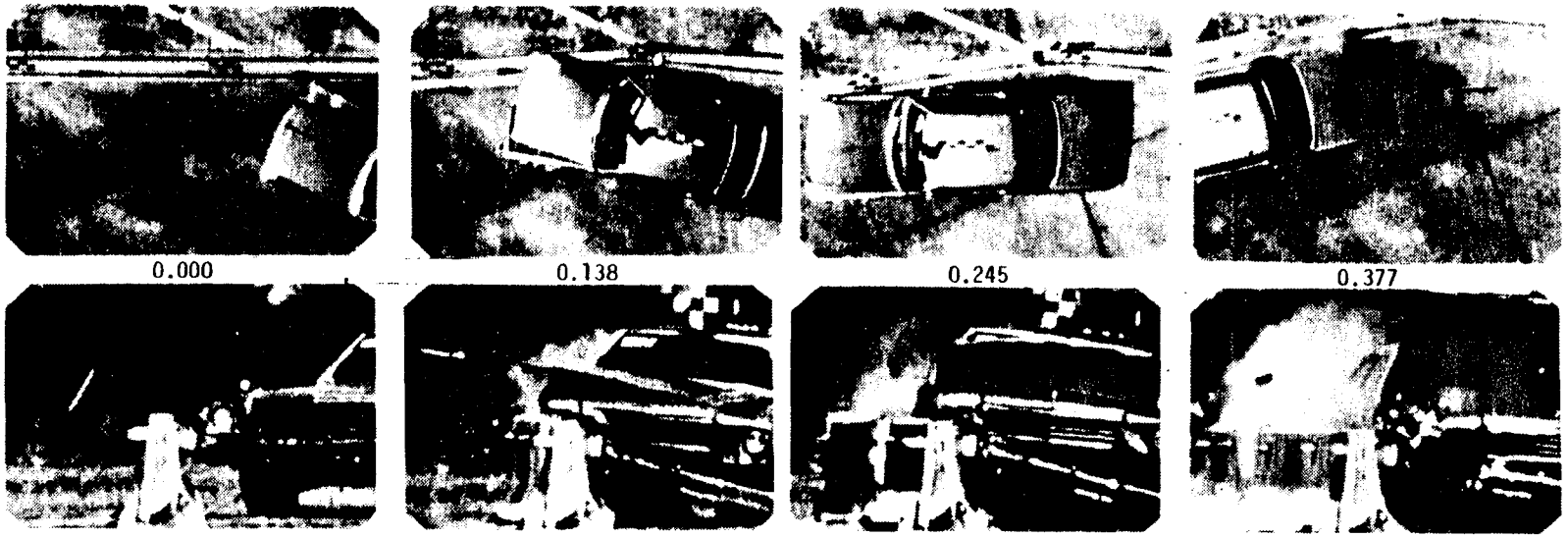
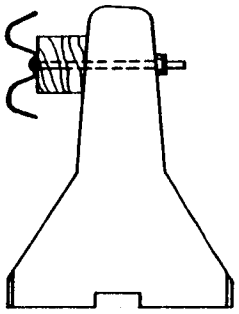
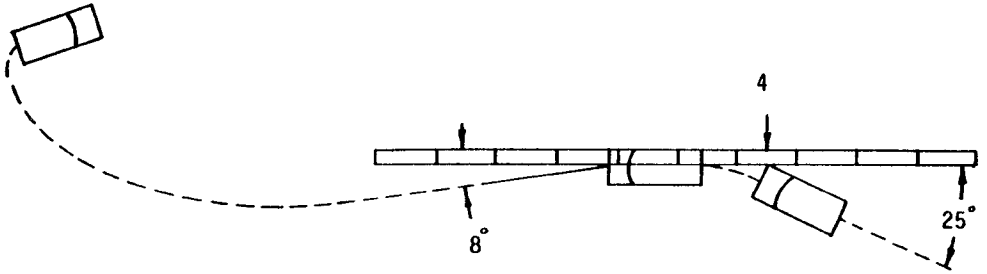


Figure 142. Barrier System Before and After Test 3825-9.





Portable Concrete
Median Barrier
W/ Guard Rail



Test No.	3825-9
Date	7/17/80
Barrier	Portable Concrete Median w/ Rail
Segment	Vertical Tongue & Groove w/ .32 cm thick side plates
Segment Length	12 ft (3.7 m)
Length of Installation	120 ft (36.7 m)
Barrier Deflection	
Max. Dynamic	6.5 ft (2.0 m)
Max. Permanent	6.5 ft (2.0 m)

Vehicle	1976 Plymouth Fury
Vehicle Weight	4,510 lb (2,046 kg)
Impact Speed	63.4 mph (102.0 km/h)
Impact Angle	25 deg
Exit Angle	8 deg
Vehicle Acceleration (Max. 0.050 sec avg.)	
Longitudinal (rt & lt avg.)	-8.8 g
Transverse	9.9 g
Vertical	-2.2 g
Vehicle Damage	
TAD	01RFQ6
SAE	01FREW9

Figure 143. Summary of Results for Test 3825-9.

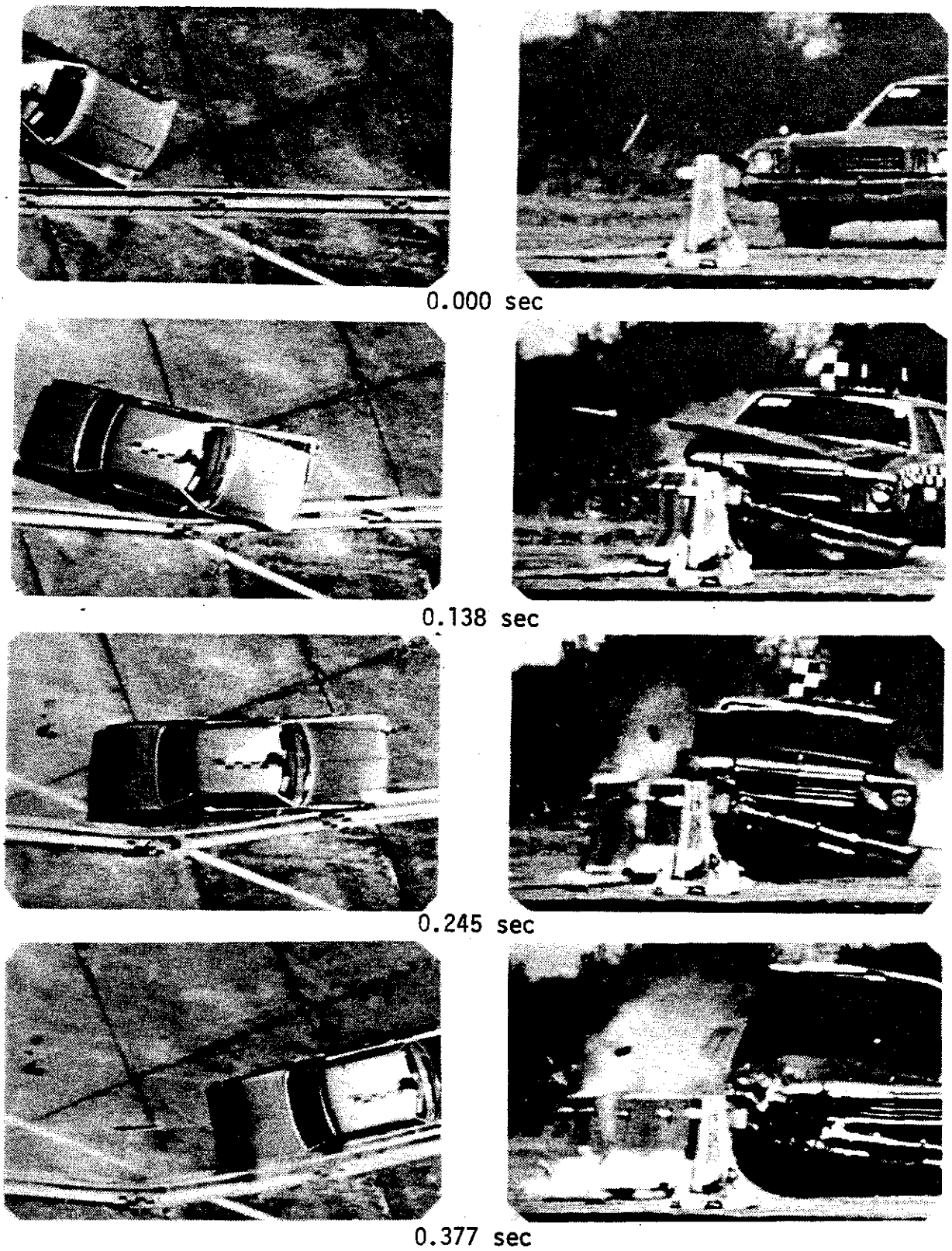
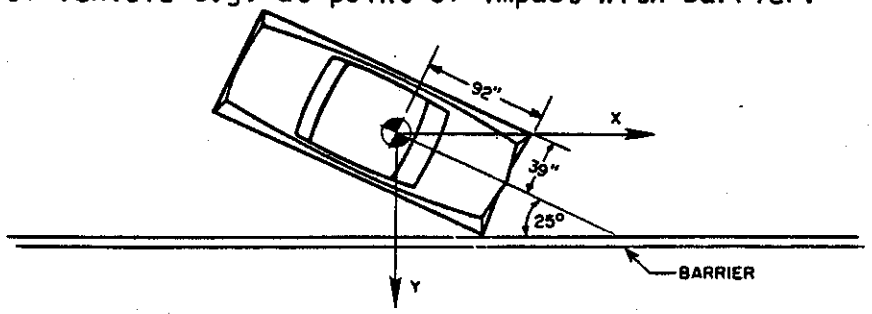


Figure 144. Sequential Photographs for Test 3825-9.

Table 10. Time, Displacement, Event Summary for Test 3825-9.

TIME (sec)	X-DISPLACEMENT (ft)	Y-DISPLACEMENT (ft)	EVENT
0.000	0.000*	0.000*	Impact
0.013	1.049	0.527	Front corner bumper crushed
0.026	2.089	1.069	
0.039	3.144	1.522	
0.052	4.238	2.049	
0.065	5.238	2.477	
0.078	6.297	2.795	Barrier begins to deflect
0.091	7.296	3.108	
0.104	8.339	3.381	
0.117	9.337	3.486	
0.130	10.370	3.630	
0.143	11.309	3.708	
0.156	12.259	3.771	
0.169	13.110	3.902	
0.182	14.069	4.024	
0.195	14.935	4.077	
0.208	15.857	4.161	
0.221	16.735	4.220	
0.234	17.700	4.259	
0.247	18.534	4.259	Vehicle Motion Parallel
0.260	19.441	4.126	
0.273	20.286	4.332	
0.286	21.253	4.402	Rear of vehicle hits barrier
0.299	22.043	4.537	
0.312	23.004	4.617	
0.325	23.844	4.546	
0.338	24.710	4.607	
0.351	25.550	4.612	
0.364	26.451	4.658	
0.377	27.286	4.612	
0.390	28.167	4.530	
0.403	28.981	4.460	
0.416	29.862	4.369	
0.429	30.702	4.318	C. G. leaves view

*Location of vehicle c.g. at point of impact with barrier.



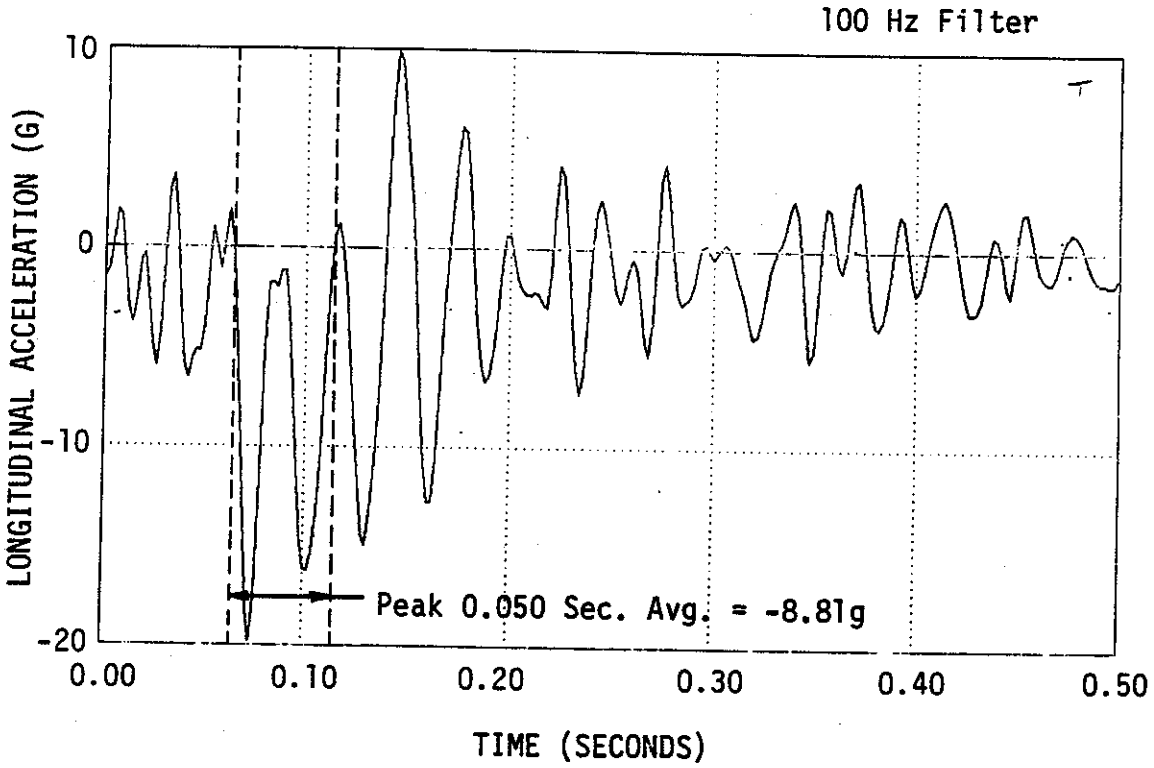


Figure 145. Vehicle Longitudinal Accelerometer Trace for Test 3825-9.

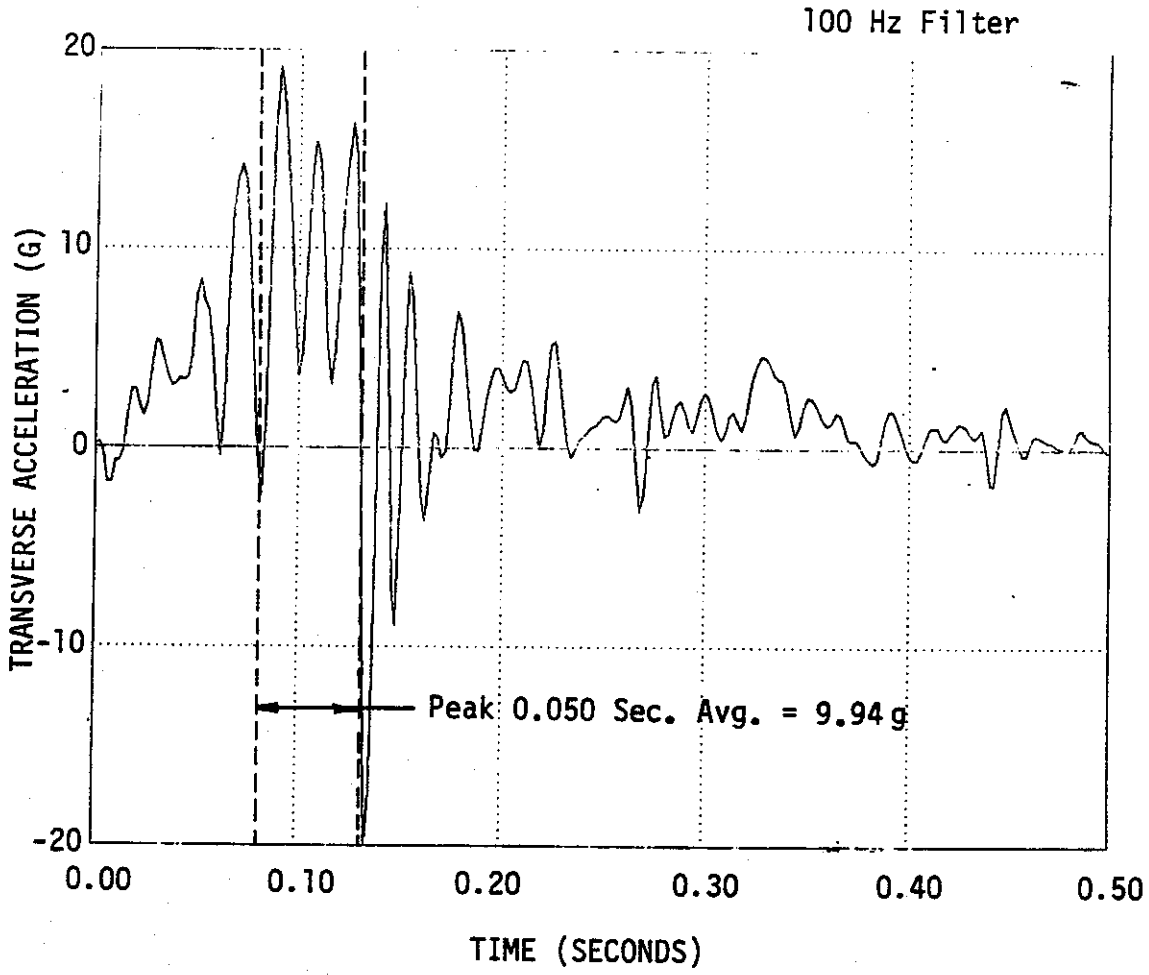


Figure 146. Vehicle Transverse Accelerometer Trace for Test 3825-9.

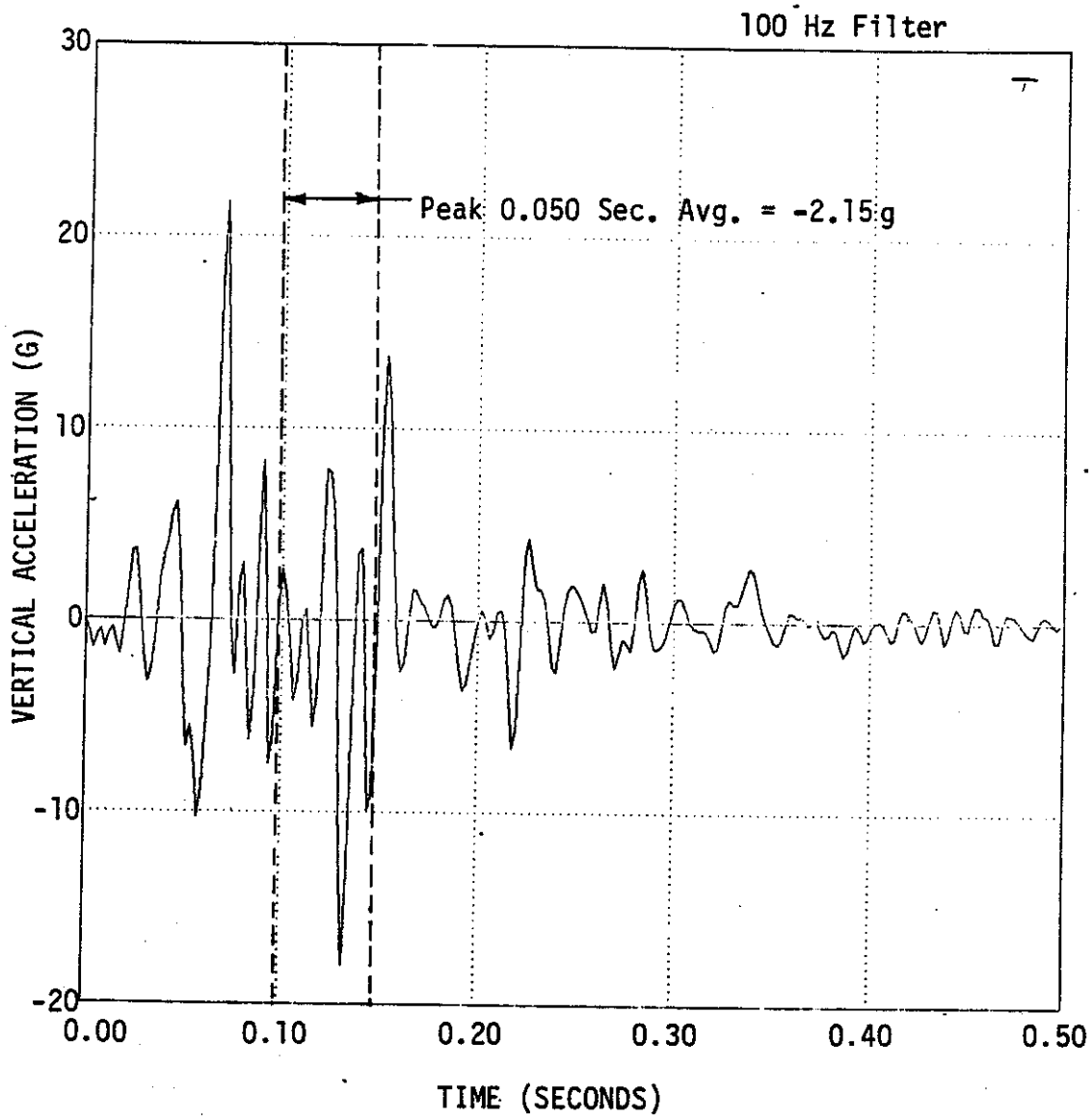


Figure 147. Vehicle Vertical Accelerometer Trace for Test 3825-9.

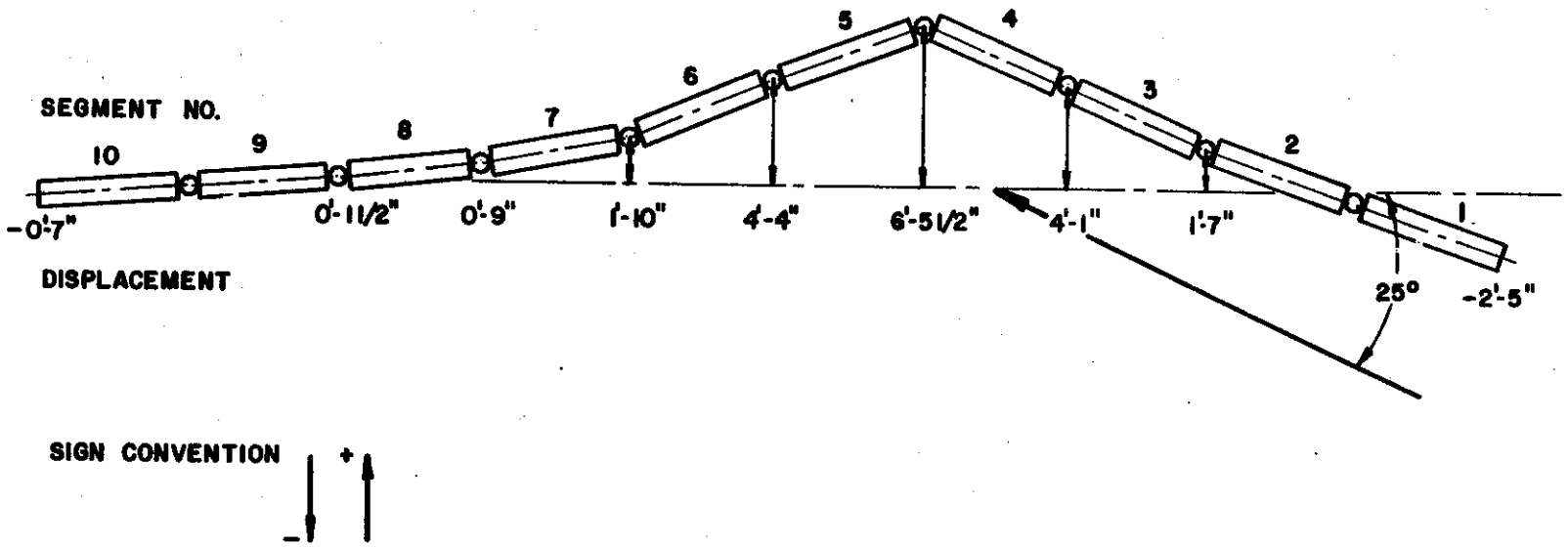


Figure 148. Permanent Barrier Deflection After Test 3825-9.

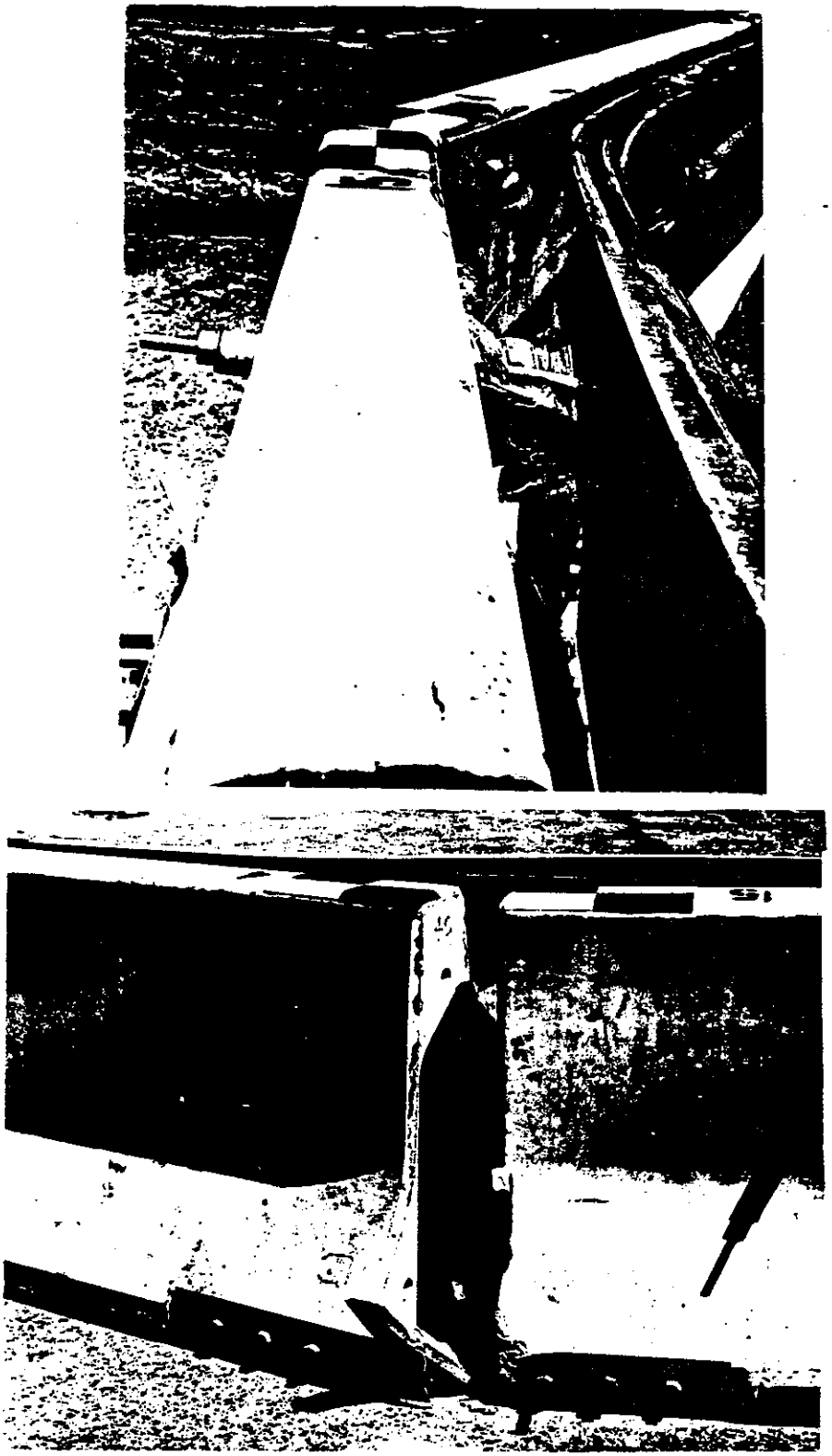


Figure 149. Damage to Joint 4-5 After Test 3825-9.

REFERENCES

1. "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", Transportation Research Circular Number 191, Transportation Research Board, Washington, D.C., February 1978.

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