BARRIERS IN CONSTRUCTION ZONES
VOLUME 4

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Federal Highway Administration

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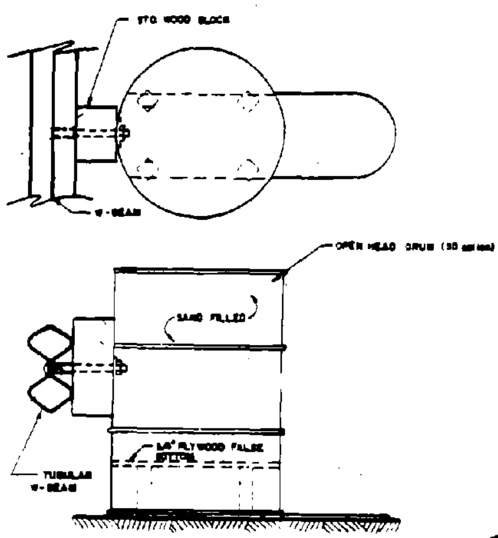
April 1985



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16. Abstract

Eight crash tests of utility vehicles, pickup trucks and one straight truck were conducted to determine the response of these atypical vehicles during collisions with concrete median barriers. In order for these tests to be compared with GUARD simulations of similar collisions, vehicle geometrics, suspension and inertial properties were determined and are reported. The utility vehicle and pickup responses in these tests resulted, in most cases, in responses similar to those of full-sized automobiles. Some exceptions are noted and discussed. Straight trucks with relatively high load locations are susceptible to rolling over concrete median barriers.

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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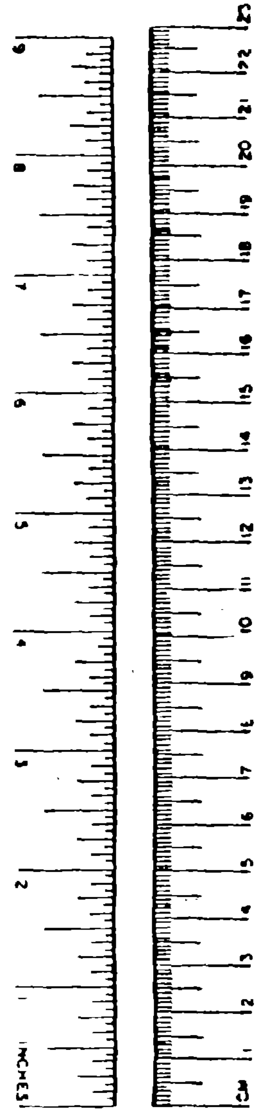
METRIC CONVERSION FACTORS

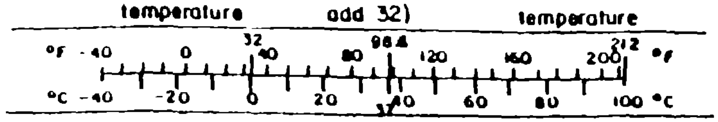
APPROXIMATE CONVERSIONS FROM METRIC MEASURES

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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I. INTRODUCTION

Highway barriers, including concrete median barriers (CMB's) have primarily been designed for automobiles. Since automobiles are the largest segment of the highway vehicle population, engineers have considered the welfare of their occupants of primary importance, all the time realizing that longitudinal barriers such as CMB's would not always be effective for all segments of that population.

Efforts are now being made to extend the safety improvements offered by longitudinal barriers to vehicles other than conventional automobiles. Efforts to contend with the growing numbers of small automobiles are indications of this, as are several new designs of barriers to accommodate tractor semitrailers.

Other segments of the population are utility vehicles, pickups and straight trucks. Perhaps because CMB's produce a more obvious three dimensional response of a vehicle than do many other longitudinal barriers and because utility vehicles, pickups and straight trucks have an atypical center of gravity height to wheel base ratio, it was hypothesized that these vehicles might be more susceptible to rolling during a CMB collision than are automobiles. This hypothesis is being studied analytically (using the GUARD code), but full-scale crash tests are needed to validate the analytical studies. In response to this need, the crash tests and vehicle parametric measurements presented here were conducted.

II. DOCUMENTATION OF TESTS

General

The purpose of these tests was to develop full-scale crash test data for comparison with computer simulations and to provide data for determining the performance of concrete median barriers in tests with special vehicles other than standard passenger automobiles.

After study of the characteristics of utility vehicles reported by Snyder et al, and consideration of the different sizes and suspension conditions of pickups and straight trucks, the vehicles and test conditions shown by table 1 were selected.[1]

When considering the roll stability of vehicles, the term T/2H is often used. This is the ratio of half the vehicle track width to the center of gravity. This ratio is numerically equivalent to the lateral acceleration in g's required to roll the vehicle, if the vehicle is considered a rigid body.[2] Although suspension and dynamic response characteristics render the ratio T/2H a rough estimate at best, it appears to be useful as a qualitative estimate of relative roll stability. Note all the vehicles tested here have values of T/2H less than 1.4 (see table 1). The value 1.4 is common for automobiles. As a further indication of the way these static stability ratios compare with a large spectrum of vehicles figure 1 is shown. The stability ratios of the utility vehicles and pickups tested are somewhat toward the upper end of the spectrum. Even so, all these vehicles would be judged less stable in the roll mode than the average automobile.

Discussion of the tests described in subsequent sections will focus on roll stability.

Test Barrier Installation

A segmented concrete median barrier was installed such that the base would not move laterally and the entire barrier would function similar to a permanent rigid barrier for Tests 3825-10 through 3825-17. The test installation consisted of 12.0-ft (3.7-m) reinforced concrete median barrier (CMB) sections joined by a steel T-Lock at the base of each joint. Details of the T-Lock are shown in figure 2. Ten CMB sections were combined to form an installation 120.0 ft (36.7 m) in length. The barrier

Table 1. Test Matrix

TEST DESIGNATION	TEST VEHICLE	IMPACT CONDITIONS			WHEEL BASE (in)	HEIGHT OF CG, (H, in)	VEHICLE TRACK, (T, in)	STATIC STABILITY RATIO (T/2H)
		wt (lb)	speed (mph)	angle (deg.)				
3825-10	1966 Ford Bronco	3598	60	7	92.5	23.9	59.5	1.24
3825-11	1966 Ford Bronco	3598	60	15	92.5	23.9	59.5	1.24
3825-12	1974 Datsun Pickup	2434	60	15	100.4	22.6	50.5	1.12
3825-13	1977 Ford Pickup	4490	60	7	133	25.0	65	1.30
3825-14	1977 Ford Pickup	4490	60	15	133	25.0	65	1.30
3825-15	1974 Ford Pickup	4540	60	22	133	25.0	65	1.30
3825-16	1972 Chev. Pickup	4760	60	15	122	26.4	66.5	1.26
3825-17	1973 Ford Straight Truck	18,240	60	15	202	58.2	77.8	0.67

STATIC STABILITY RATIOS FOR SELECTED VEHICLES

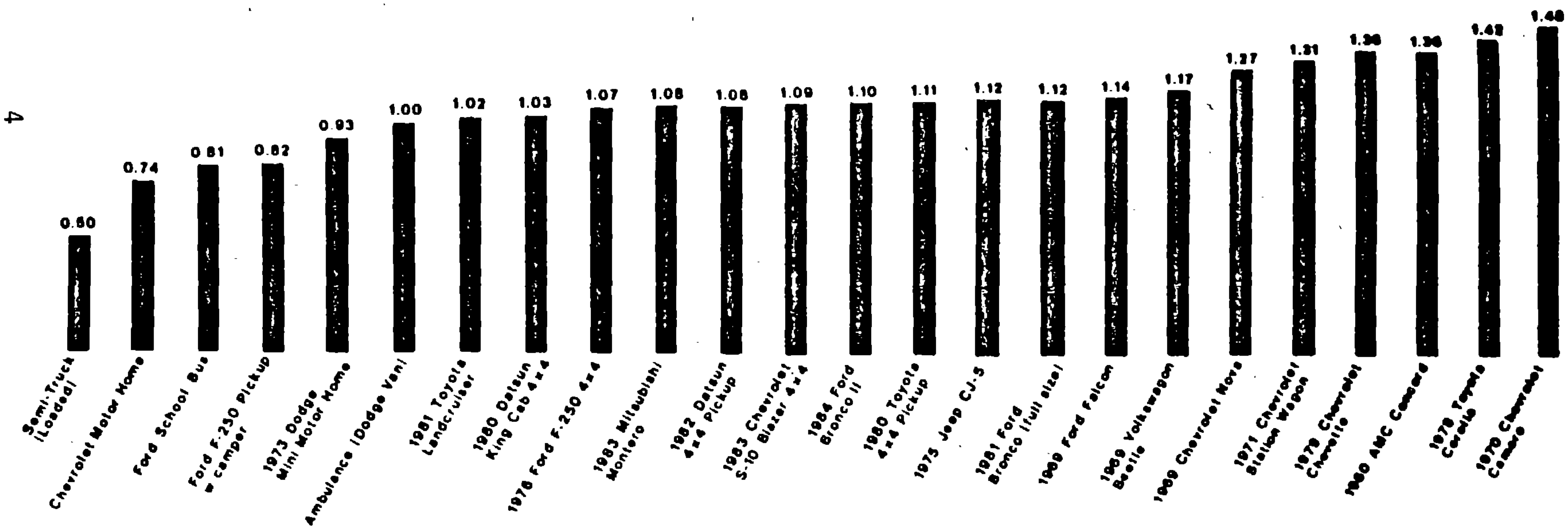


Figure 1. Static stability ratios for selected vehicles.

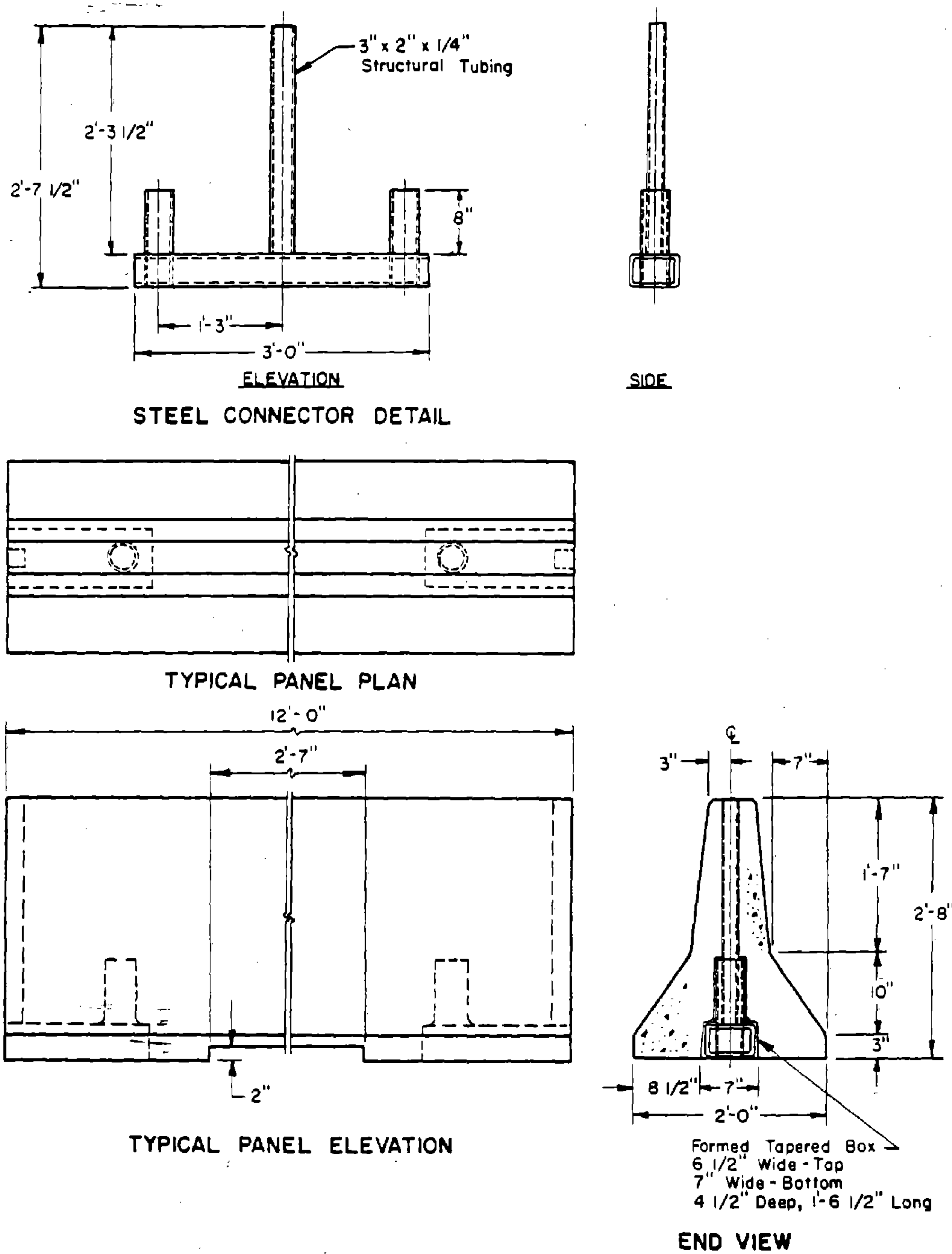


Figure 2. Details of T-Lock.

system was placed on hot-mix asphalt surface with a 2-in (5.1-cm) asphalt back-up on the rear of the barrier (see figures 3 and 4).

Instrumentation and Data Analysis

Test vehicles were equipped with triaxial accelerometers mounted near the center of gravity. Yaw, pitch and roll were measured by on-board 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.

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

Data from the electronic transducers were digitized, using a microcomputer, for analyses and evaluation of performance. Several computer programs on the Amdhal 470/V6/V8 mainframe computer were used to process various types of data from the test vehicle.

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 maximum resultant 0.050-sec average vehicle acceleration was also computed by the VEHICLE program. Several methods exist for computing this resultant value. The one used for the data presented here may be described as follows: Resultant 0.050-sec average accelerations are computed by taking the vector resultant of 0.050-sec average accelerations at corresponding times in each of the three directions with the 0.050-sec interval beginning at impact. The process is repeated with the time interval shifted 0.001 sec until the duration of impact is covered. The maximum value from these computations is sought and reported as the maximum resultant 0.050-sec average vehicle acceleration. The VEHICLE program also plots acceleration versus time curves for the longitudinal, lateral,

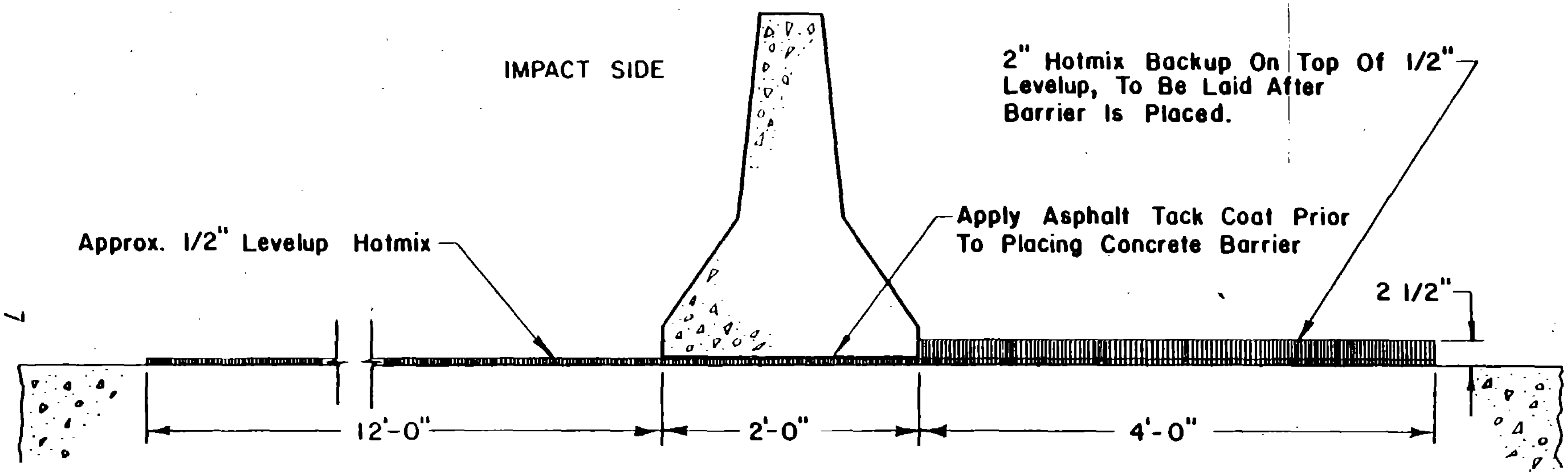
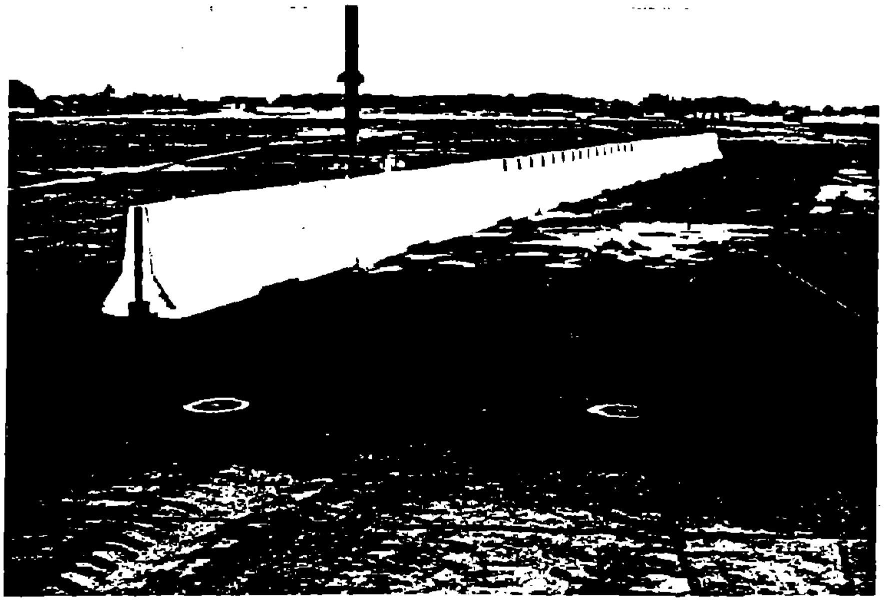


Figure 3. Cross section of Installation Site. (This "Installation Site" was used for tests 3825-10 through 3825-16. In test 3825-17 a steel back up structure was added to prevent significant barrier deflection in the case of an 18,000 lb straight truck. See figures 77 and 78.)



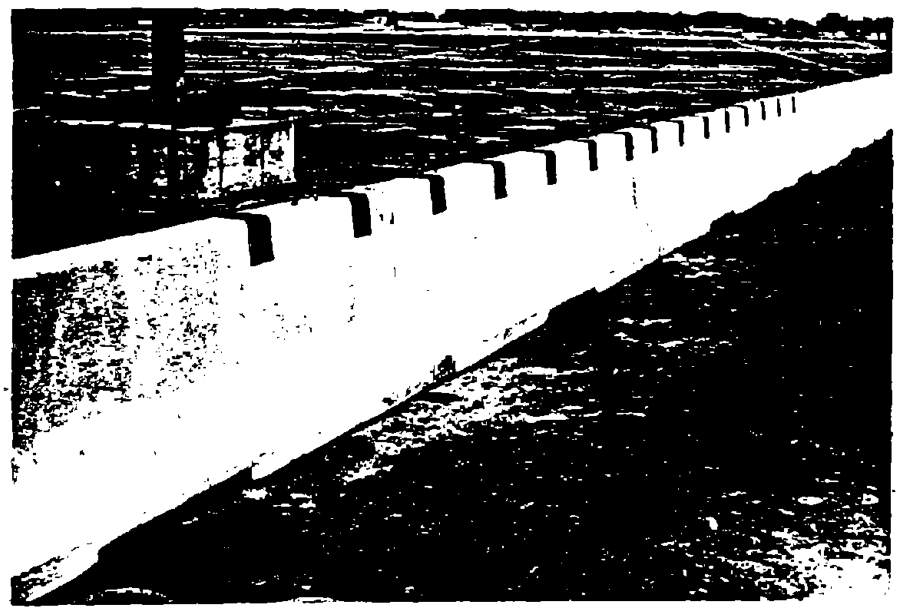


Figure 4. Barrier before tests 10 through 16.

and vertical directions.

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate data to compute angular displacement (degrees) at 0.001 sec and then instructs the Versatec Plotter (Model 1200 Electrostatic Plotter) to produce a reproducible plot: yaw, pitch, 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 test installation before and after the test. Motion photography was used to record the collision event. Typical camera positions for the tests are shown in figure 5.

Camera	Position and Coverage
1	High Speed Camera Overhead: -10' +40'
2	High Speed Camera Perpendicular to Barrier -10' +40'
3	High Speed Camera Perpendicular to Vehicle Approach Path: ±15'
4	High Speed Camera Longitudinal ±10' at Impact
5	Documentary Camera

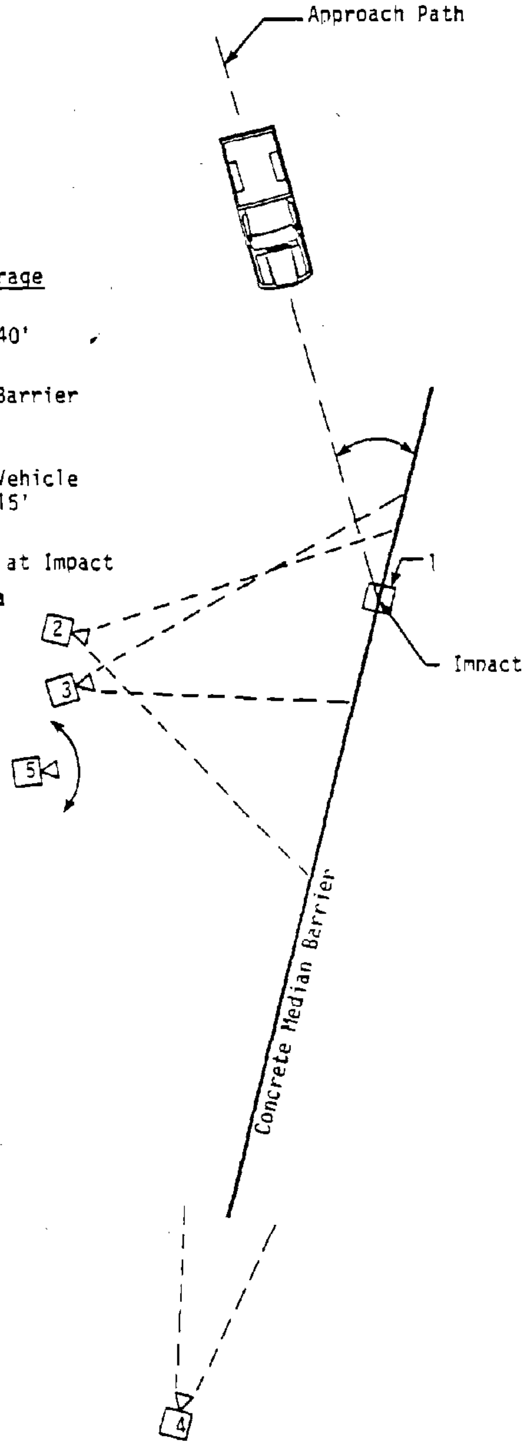


Figure 5. Typical camera positions.

Details of Individual Tests

TEST REPORT NO. 3825-10

Vehicle: 1966 Ford Bronco, Vehicle Weight 3,598 lbs

Barrier: 32 in high Concrete Median Barrier

Impact Conditions: 7 degrees, along length of need.
60 mph

Test Description

A 1966 Ford Bronco (shown in figure 6) was directed into the barrier at 60.6 mph (97.5 kph) and 6.5 degrees. Test inertia mass of the vehicle was 3,598 lb (1,633 kg). The vehicle was free-wheeling and unrestrained at impact.

The vehicle impacted the barrier 1.0 ft (0.3 m) upstream of the joint between segments 3 and 4. The tire path moved up the side of the CMB reaching a maximum height of 2.1 ft (0.6 m) approximately 12.0 ft (3.7 m) from impact. Total length of contact was approximately 24.0 ft (7.3 m). The vehicle was redirected and exited the barrier at 0.305 sec with exit angle of 0 degrees. Subsequently, the vehicle impacted the barrier again at 0.727 sec, rode off the end of the barrier and spun around.

As shown in figure 7, the vehicle sustained slight damage to the left front quarter. The left end of the bumper was bent back slightly.

The barrier received minor cosmetic damage to segments 3 and 4 as shown in figure 8. The tire path of the initial impact is plotted in figure 9. There were also tire marks on segments 9 and 10 where the vehicle impacted the barrier a second time. The top of the barrier moved 0.05 ft (0.02 m) during the test but retained a set of only 0.02 ft (0.01 m).

Test Results

A summary of test data is presented in figure 10. Figure 11 consists of sequential photographs. Vehicle accelerometer traces are displayed in figures 12 through 14, and vehicle angular displacements in figure 15.

The maximum 50-msec average accelerations were -1.8 g longitudinal and -2.6 g lateral. Maximum 50-msec average vector resultant acceleration was 3.2 g.

NCHRP Report 230 describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted with standard passenger automobiles at 15-degree impact angles.(3) These acceptance limits do not apply to the test reported herein but were computed and reported for information only. The normalized occupant/compartment impact velocity in the longitudinal direction was 6.7 fps (2.0 m/s) and 11.3 fps (3.4 m/s) in the lateral direction. The maximum 10-msec average longitudinal occupant ridedown acceleration was -2.3 g, and -2.2 g for the lateral direction.

The barrier redirected the vehicle and detached elements did not penetrate the occupant compartment. The vehicle remained upright during and after impact. Exit angle was 0.0 degrees and vehicle change in speed at loss of contact was 8.0 mph (12.9 kph).

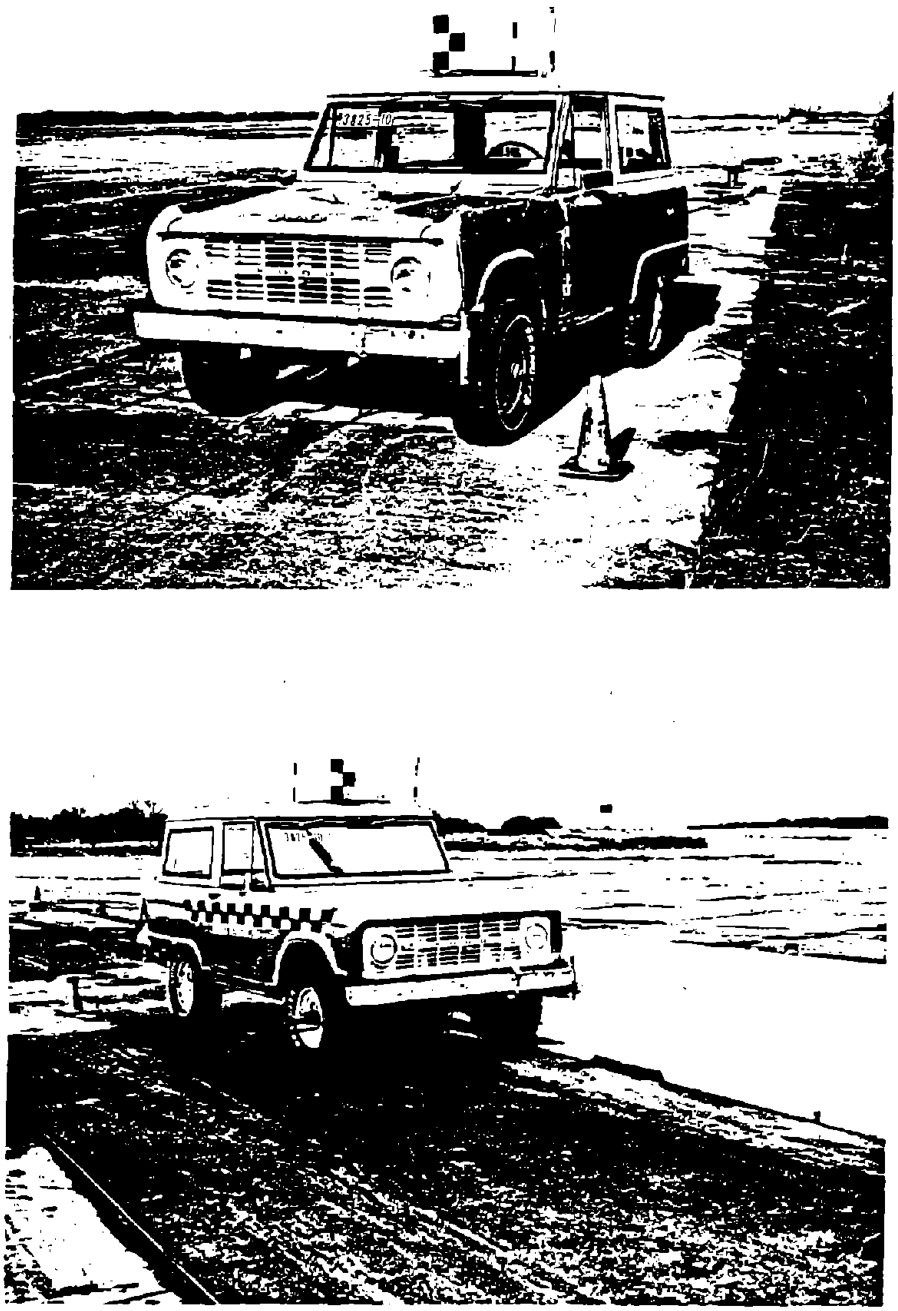


Figure 6. Vehicle before test 3825-10.

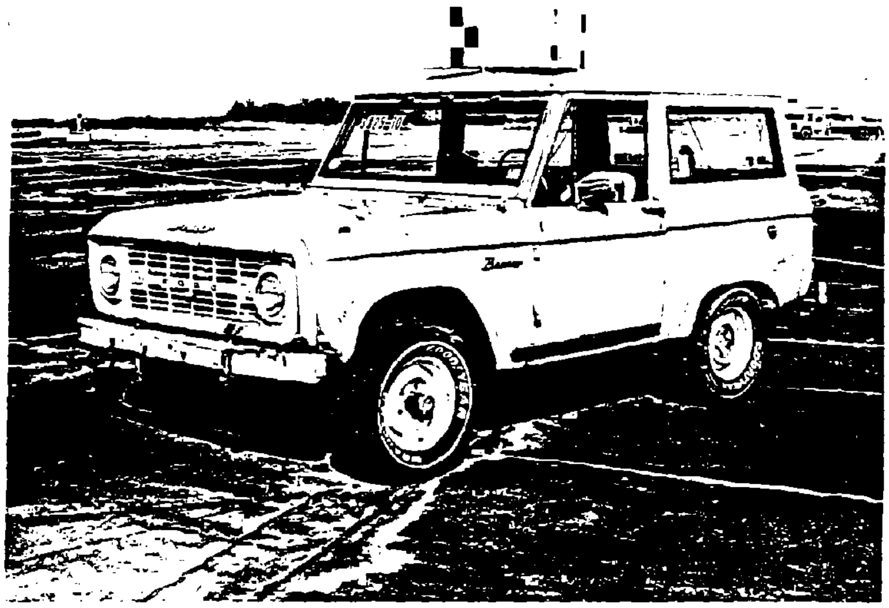


Figure 7. Vehicle after test 3825-10.

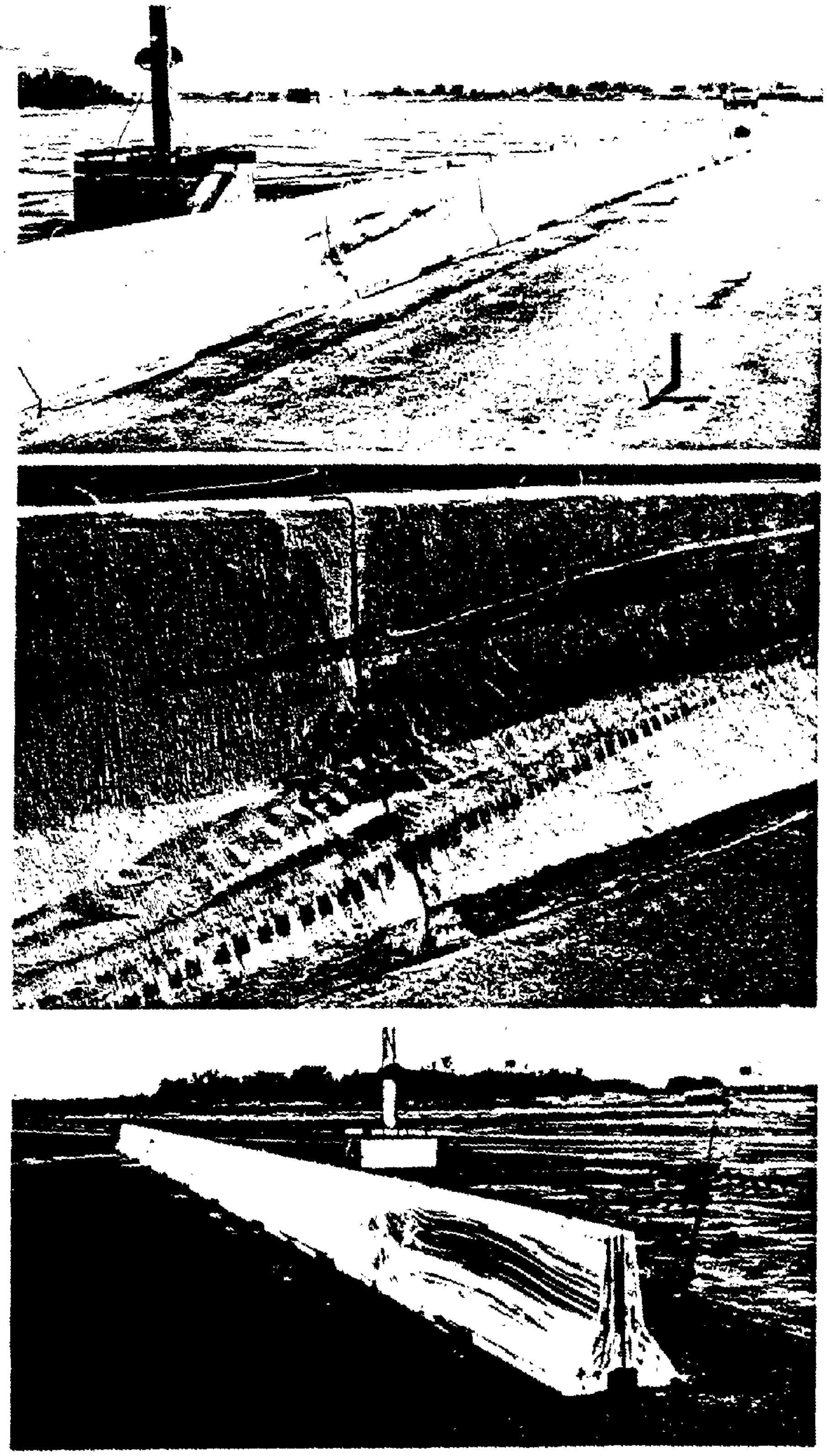


Figure 3. Barrier after test 3825-10.

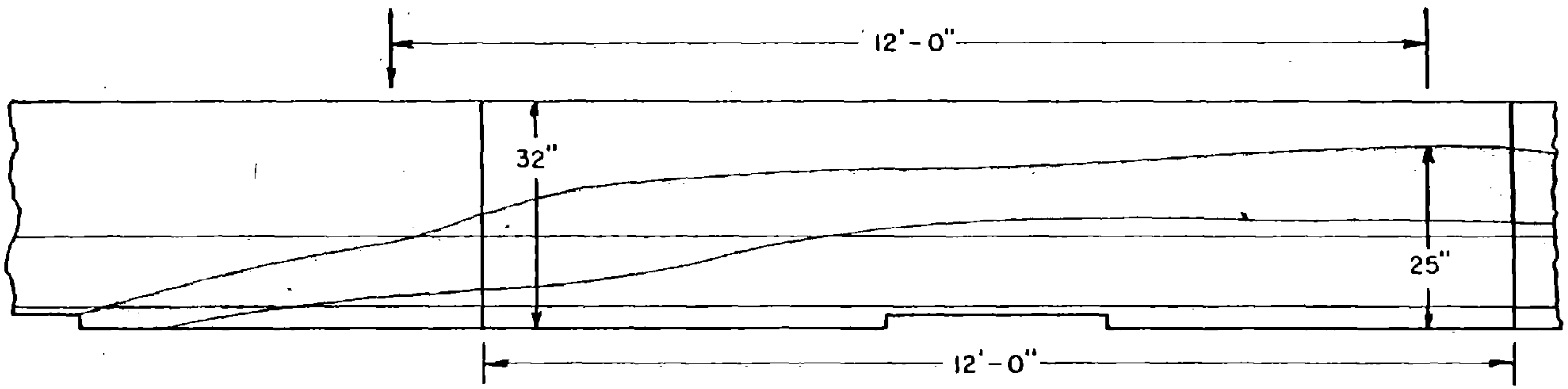
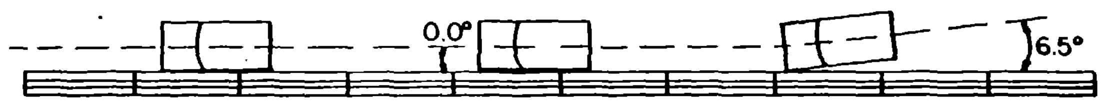
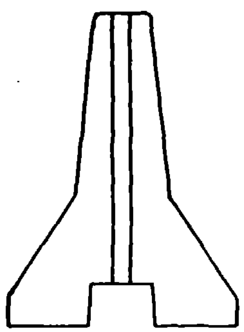


Figure 9. Tire path for test 3825-10.





Test No.	3825-10
Date	1/11/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.02 ft (0.01 m)
Maximum	0.05 ft (0.02 m)
Vehicle	1966 Ford Bronco
Vehicle Weight	3598 lbs (1633 kg)
Vehicle Damage Classification	
TAD	11LFQ1
SAE	11FLEN1

Impact Speed	60.6 mph (97.5 kph)
Impact Angle	6.5 deg
Exit Speed	52.6 mph (84.6 kph)
Exit Angle	0.0 deg
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-1.8 g
Lateral	-2.6 g
Vertical	-0.3 g
Vector Resultant	3.2 g
Occupant Impact Velocity	
Longitudinal	6.7 fps (2.0 m/s)
Lateral	11.3 fps (3.4 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-2.3 g
Lateral	-2.2 g

Figure 10. Data summary for test 3825-10.

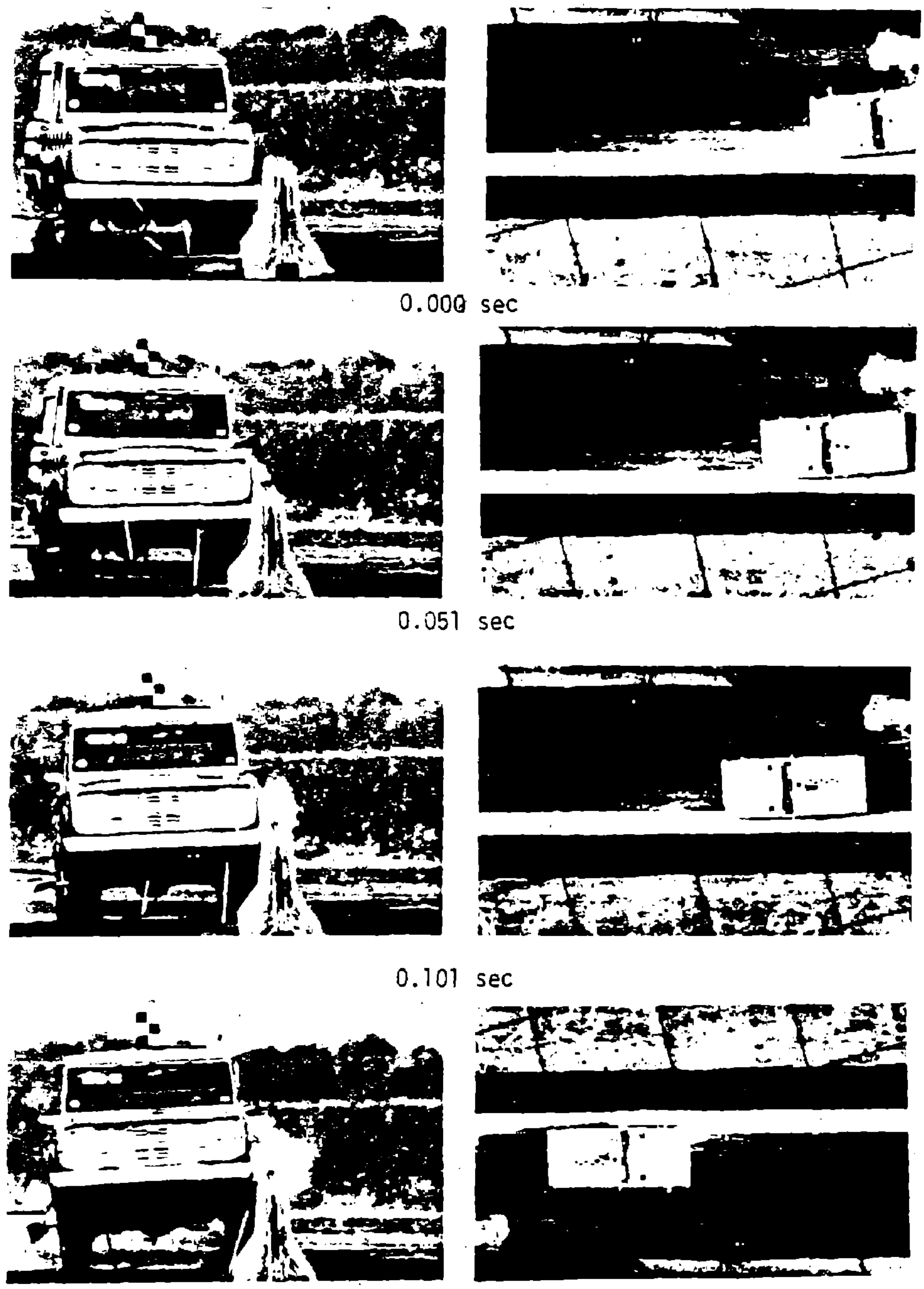
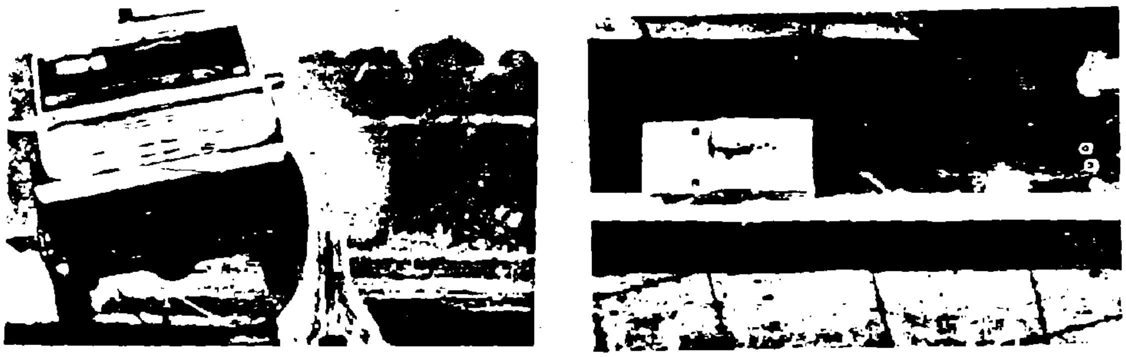


Figure 11. Sequential photographs for test 3825-10.

0.202 sec

0.253 sec

0.303 sec



0.359 sec

Figure 11. Sequential photographs for test 3825-10 (continued).

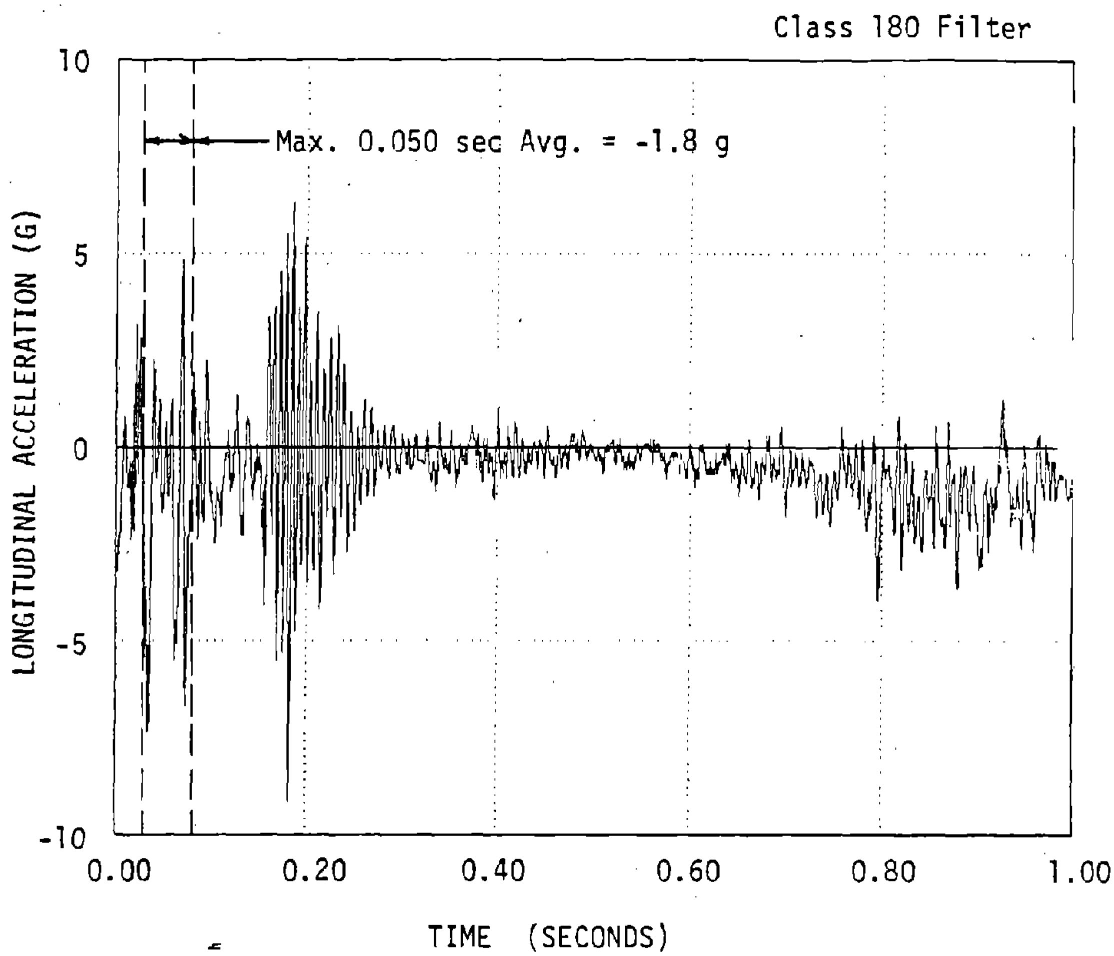


Figure 12. Vehicle longitudinal accelerometer trace for test 3825-10.

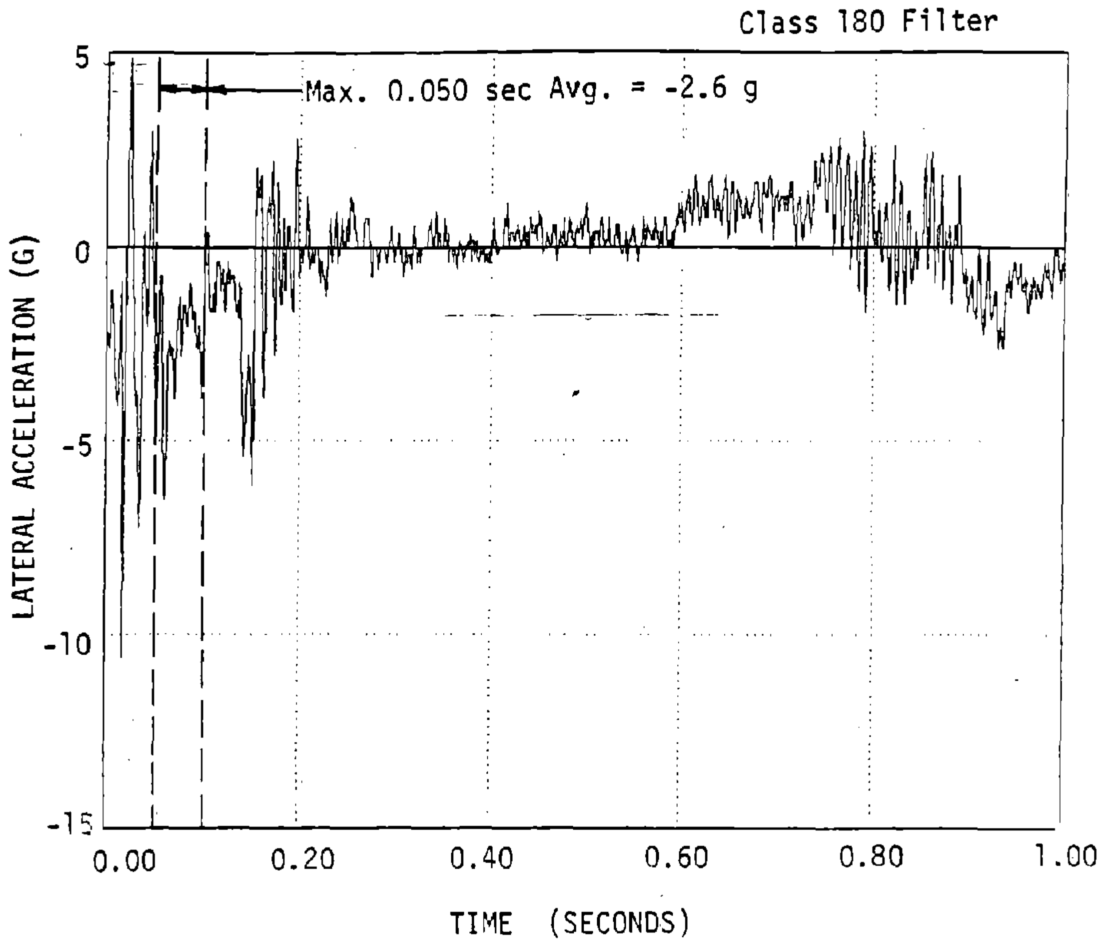


Figure 13. Vehicle lateral accelerometer trace for test 3825-10.

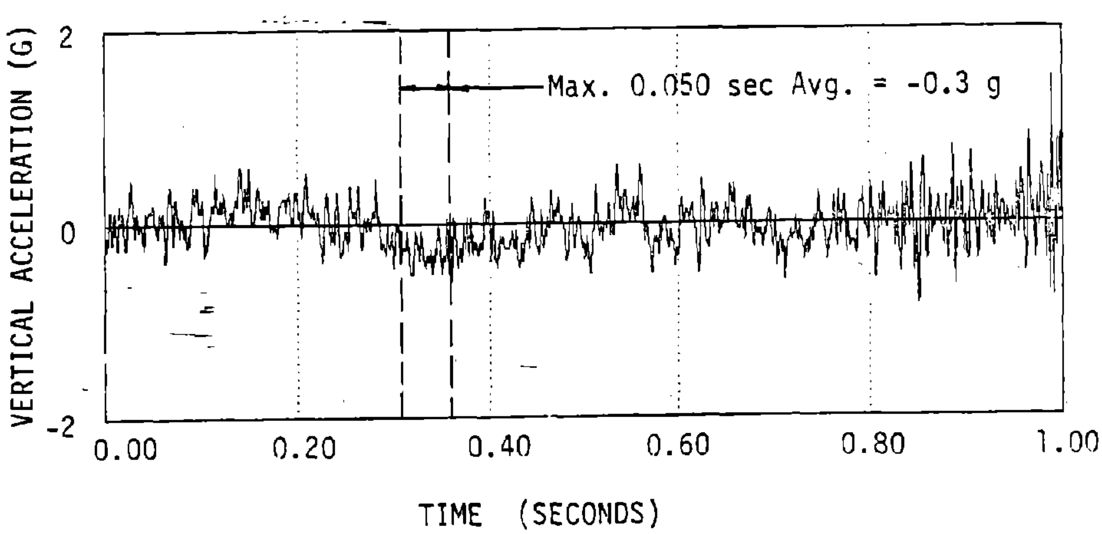
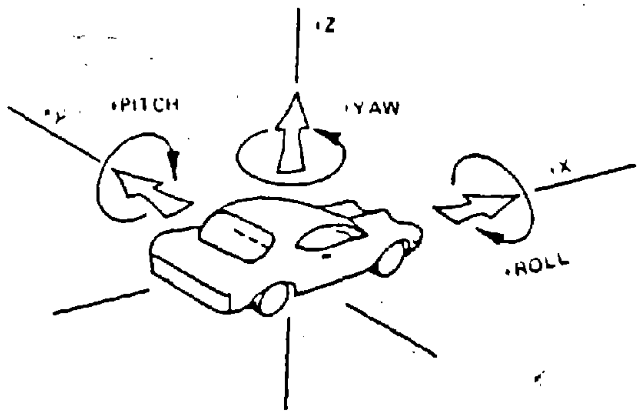


Figure 14. Vehicle vertical accelerometer trace for test 3825-10.



Axes are vehicle fixed.
Sequence for determining orientation is:
1. Yaw
2. Pitch
3. Roll

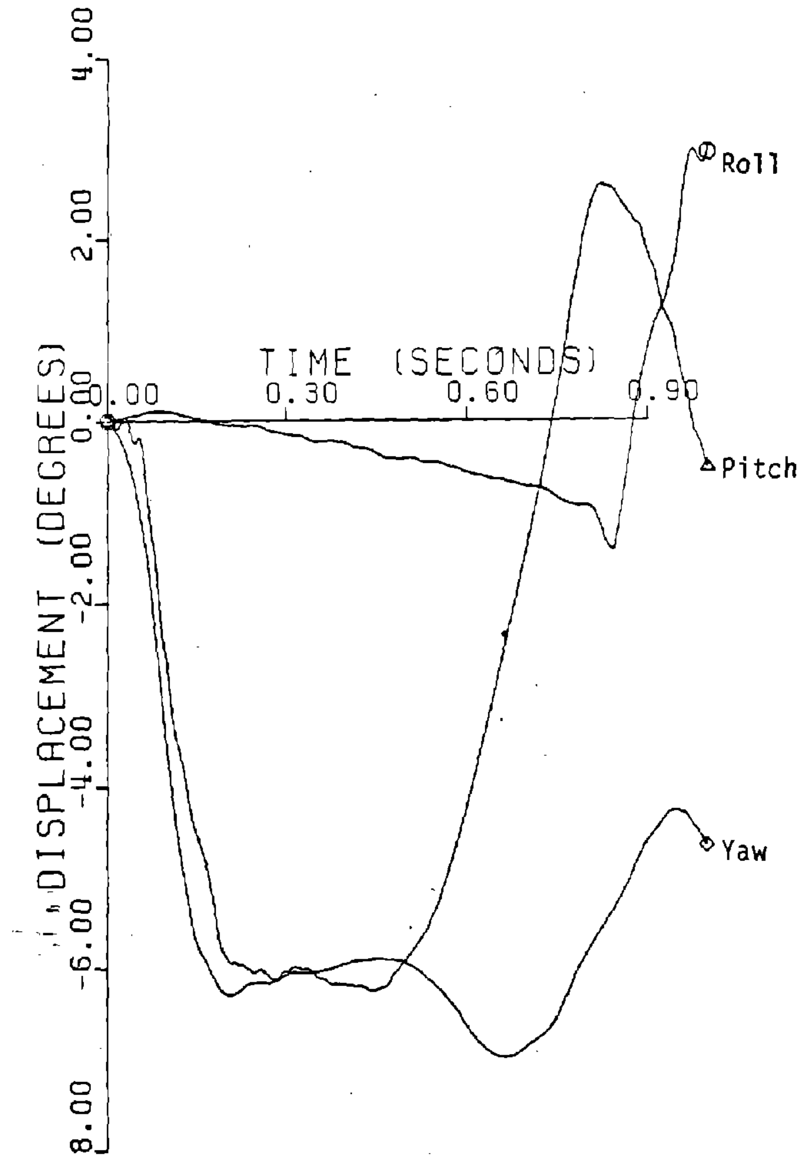


Figure 15. Vehicle angular displacements for test 3825-10.

TEST REPORT NO. 3825-11

Vehicle: 1966 Ford Bronco, Vehicle Weight 3,598 lbs

Barrier: 32 in high Concrete Median Barrier

Impact Conditions: 15 degrees, along length of need.
60 mph

Test Description

The 1966 Ford Bronco used in Test 3825-10 (see figure 16) was directed into the barrier at 60.7 mph (97.7 kph) and 14.5 degrees. Test inertia mass of the vehicle was 3,598 lb (1,633 kg). The vehicle was free-wheeling and unrestrained at impact.

The vehicle impacted the barrier approximately 2.0 ft (0.6 m) downstream of the joint between segments 3 and 4. The tire path on the barrier face is shown in figure 17. The top of the path reached the top of the barrier approximately 2.0 ft (0.6 m) downstream of the impact point. Tire marks extended to the upper edge of the barrier for a distance of about 7.0 ft (2.1 m) and the bottom of the tire marks formed a curved path as shown in figures 17 and 18. Total length of contact was approximately 13.8 ft (4.2 m). The vehicle was redirected and exited the barrier at 0.286 sec with exit angle of 1.2 degrees. The speed of the vehicle at loss of contact was 52.0 mph (83.7 kph).

The barrier received damage to segment 4 as shown in figure 18. The upper corners of joints 3-4 and 4-5 were cracked and broken. The top of the barrier moved 0.11 ft (0.03 m) during the test but returned to its original position afterwards.

As shown in figure 19, the vehicle sustained minimal damage to the left front quarter. The left front tire was deflated and the rim bent. The left corner of the rear bumper was also pulled back.

Test Results

A summary of test data is presented in figure 20. Figure 21 consists of sequential photographs. Vehicle accelerometer traces are displayed in figures 22 through 24, and vehicle angular displacements in figure 25.

The maximum 50-msec average accelerations were -4.9 g longitudinal and -7.2 g lateral. Maximum-50 msec average vector resultant acceleration was 8.9 g.

NCHRP Report 230 describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted with standard passenger automobiles at 15-degree impact angles.(3) These acceptance limits do not apply to the test reported herein but were computed and reported for information only. The normalized occupant/compartment impact velocity in the longitudinal direction was 14.1 fps (4.3 m/s) and 16.6 fps (5.1 m/s) in the lateral direction. The maximum 10-msec average longitudinal occupant ridedown acceleration was -5.7 g, and -8.2 g for the lateral direction.

The barrier redirected the vehicle and detached elements did not penetrate the occupant compartment. The vehicle remained upright during and after impact. Exit angle was 1.2 degrees and vehicle change in speed at loss of contact was 8.7 mph (14.0 kph).

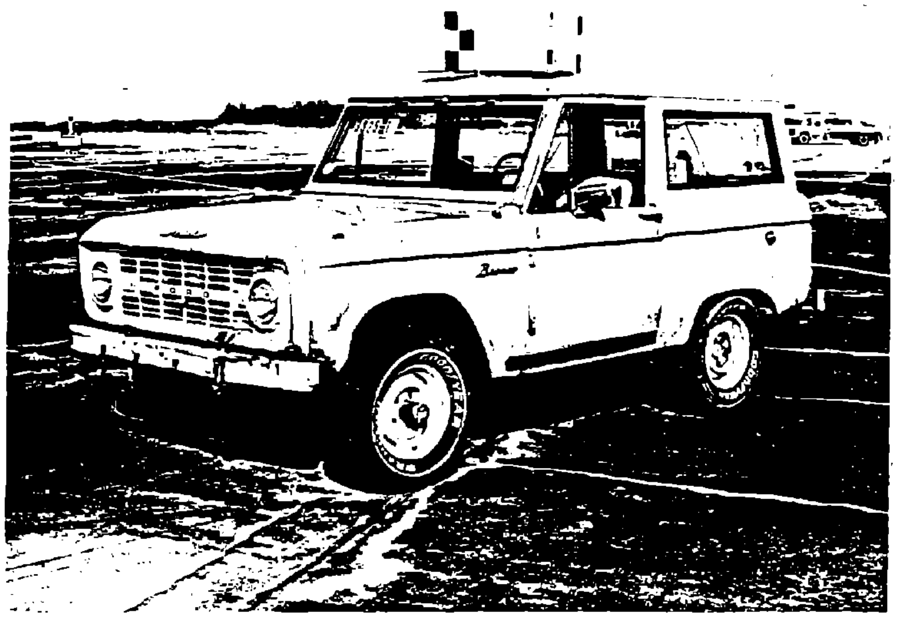


Figure 16. Vehicle before test 3825-11.

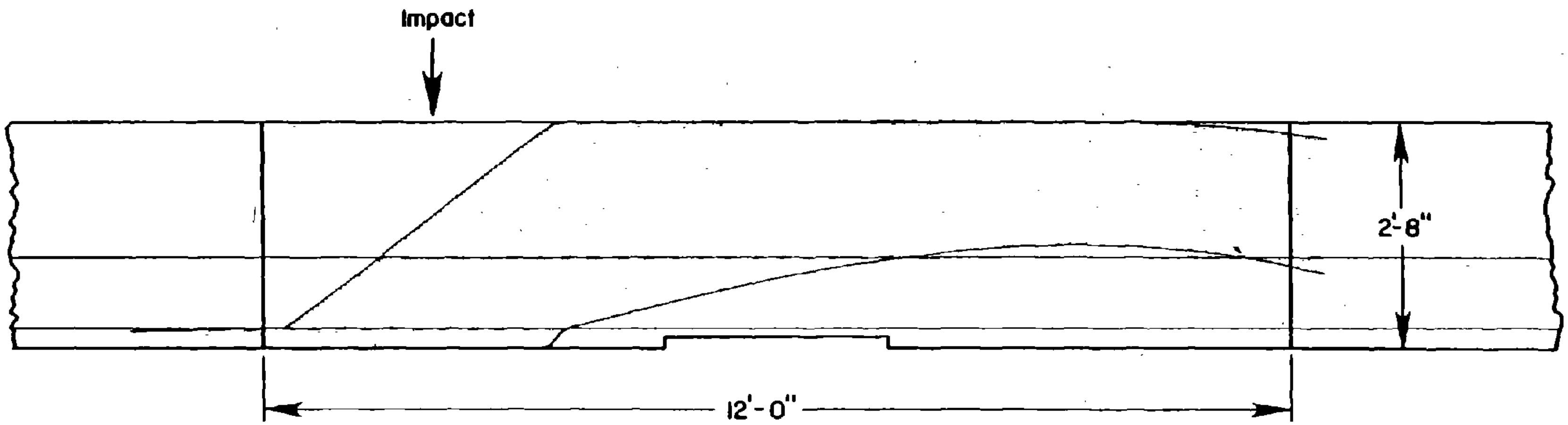


Figure 17. Tire path for test 3825-11.

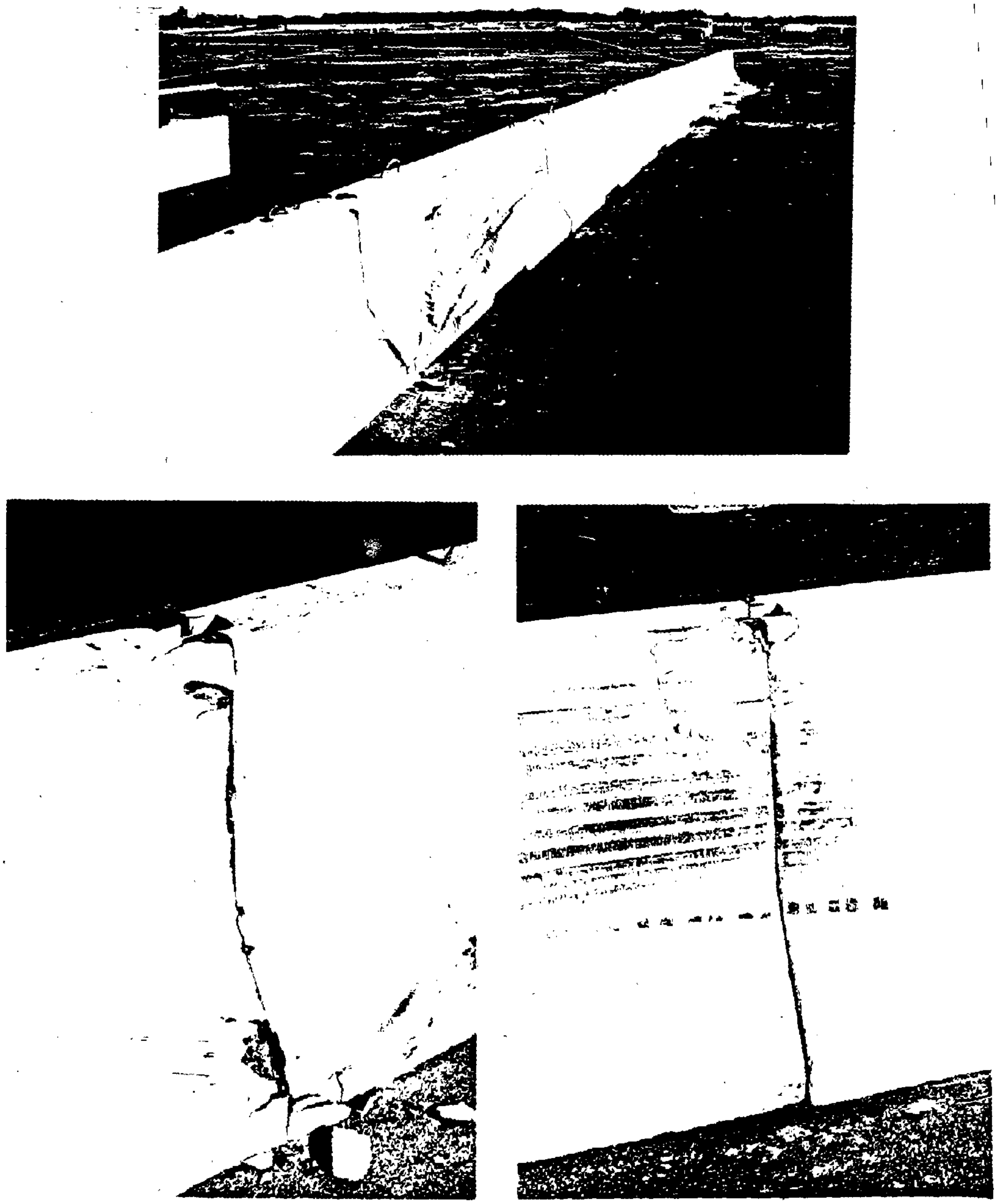


Figure 18. Barrier after test 3825-11.

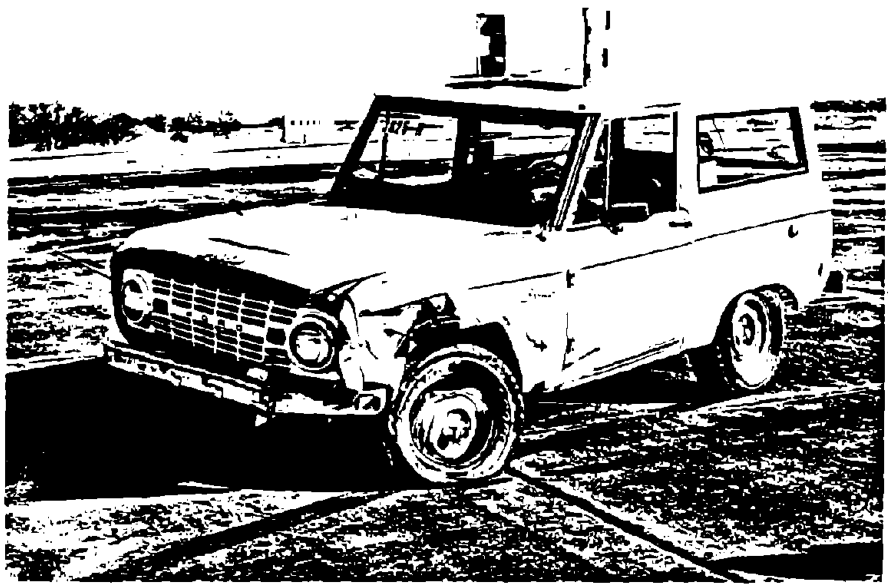
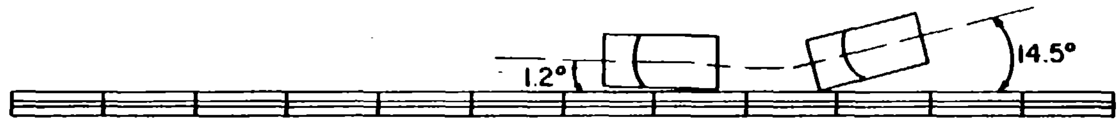
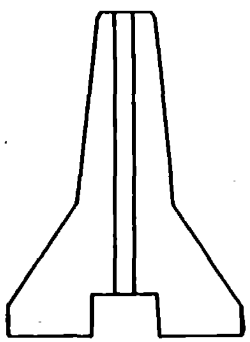


Figure 19 . Vehicle after test 3825-11.

0.000 sec	0.114 sec	0.228 sec	0.345 sec





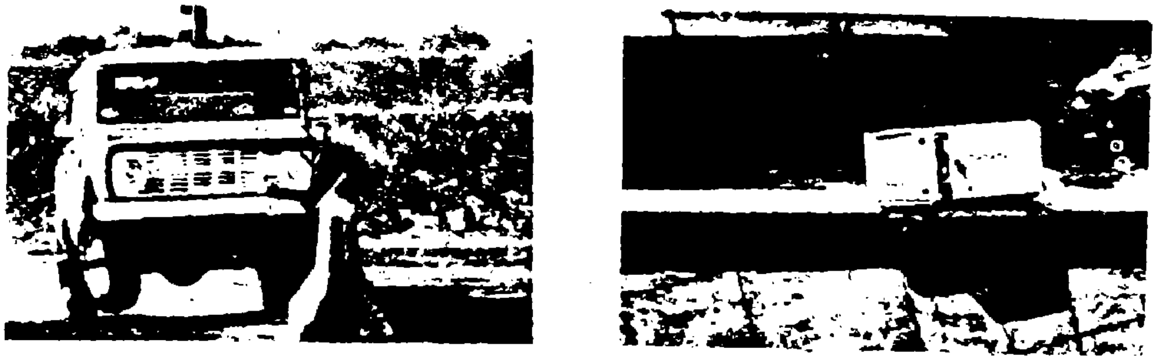
Concrete Median Barrier

Test No.	3825-11	Impact Speed	60.7 mph (97.7 kph)
Date	1/11/84	Impact Angle	14.5 deg
Barrier	Concrete Median Barrier	Exit Speed	52.0 mph (83.7 kph)
Joint Connection	Bottom T-Lock	Exit Angle	1.2 deg
Segment Length	12.0 ft (3.7 m)	Vehicle Accelerations (Max. 0.050 sec Avg)	
Length of Installation	120.0 ft (36.7 m)	Longitudinal	-4.9 g
Barrier Movement		Lateral	-7.2 g
Permanent	0.00 ft (0.00 m)	Vertical	-3.8 g
Maximum	0.11 ft (0.03 m)	Vector Resultant	8.9 g
Vehicle	1966 Ford Bronco	Occupant Impact Velocity	
Vehicle Weight	3598 lbs (1633 kg)	Longitudinal	14.1 fps (4.3 m/s)
Vehicle Damage Classification		Lateral	16.6 fps (5.1 m/s)
TAD	11LFQ3	Occupant Ridedown Accelerations	
SAE	11FLEK2 11LFES2	Longitudinal	-5.7 g
		Lateral	-8.2 g

Figure 20. Data summary for test 3825-11.

0.000 sec

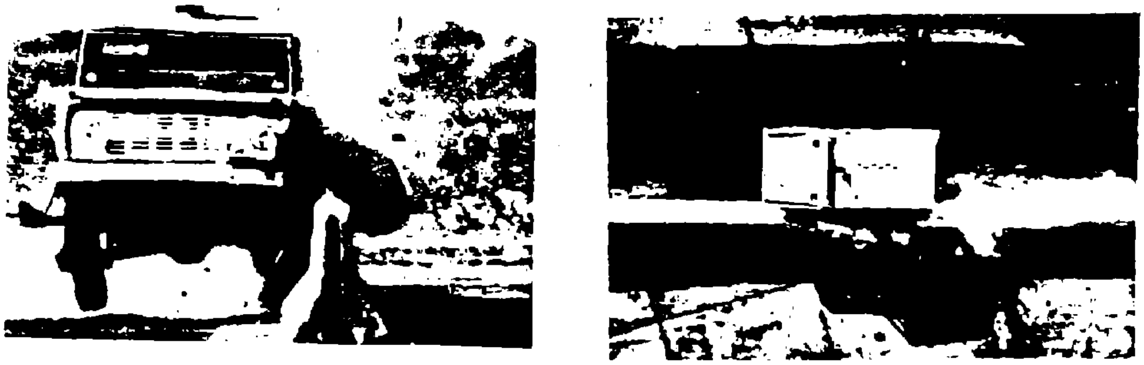
0.058 sec



0.114 sec

0.172 sec

Figure 21. Sequential photographs for test 3825-11.



0.228 sec

0.286 sec

0.345 sec

0.400 sec

Figure 21. Sequential photographs for test 3825-11 (continued).

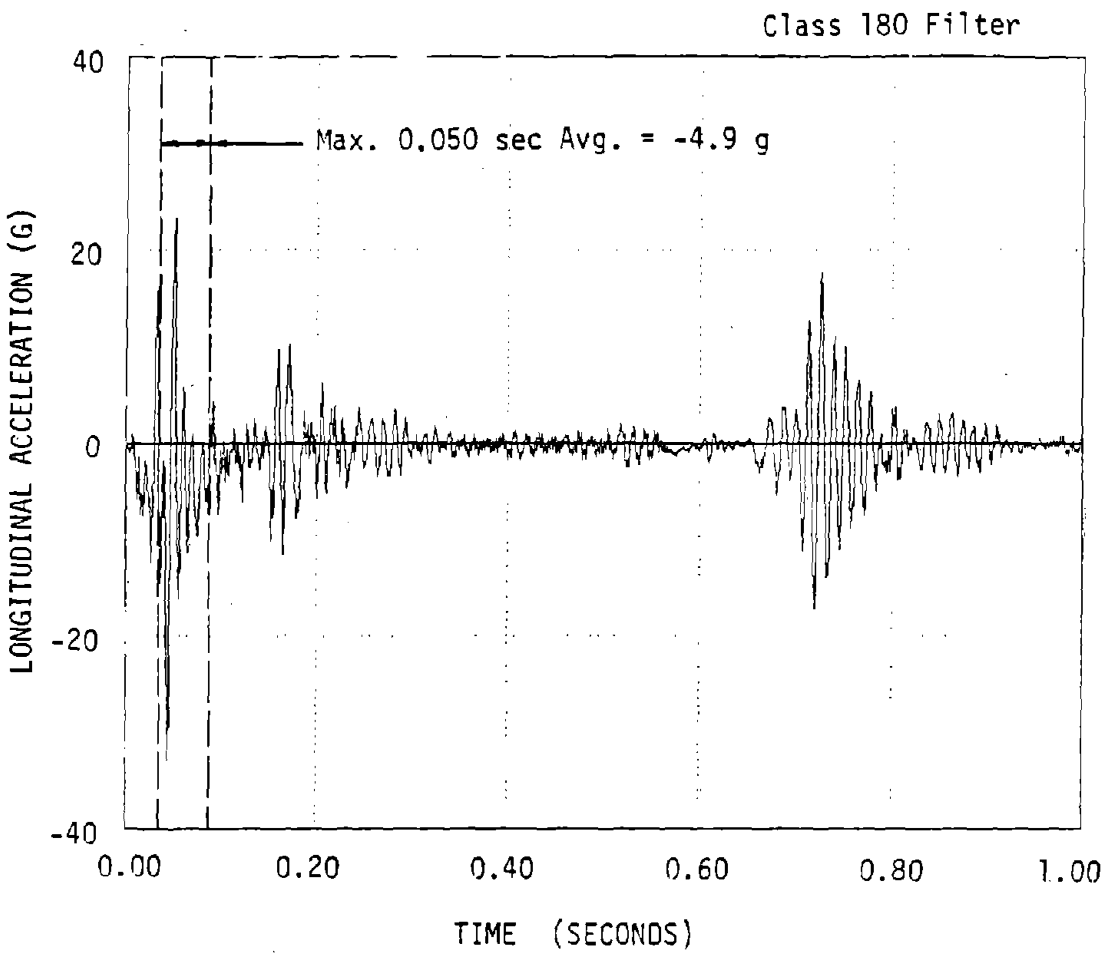


Figure 22. Vehicle longitudinal accelerometer trace for test 3825-11.

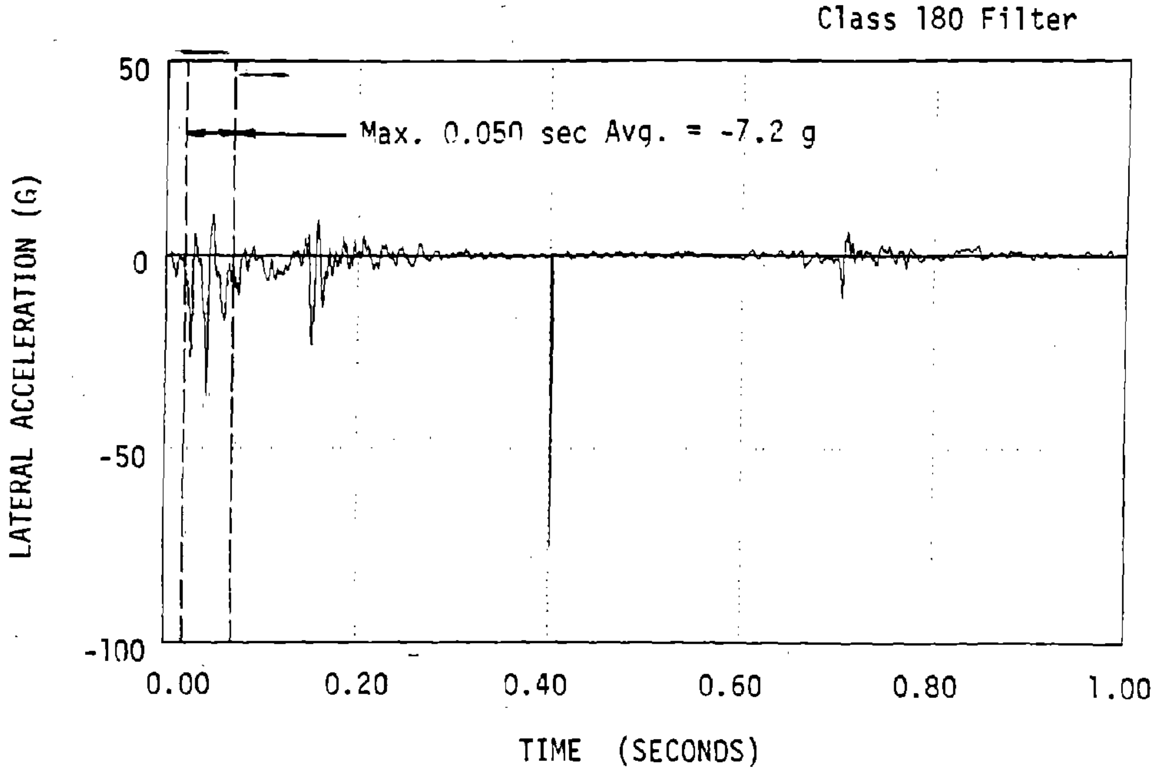


Figure 23. Vehicle lateral accelerometer trace for test 3825-11.

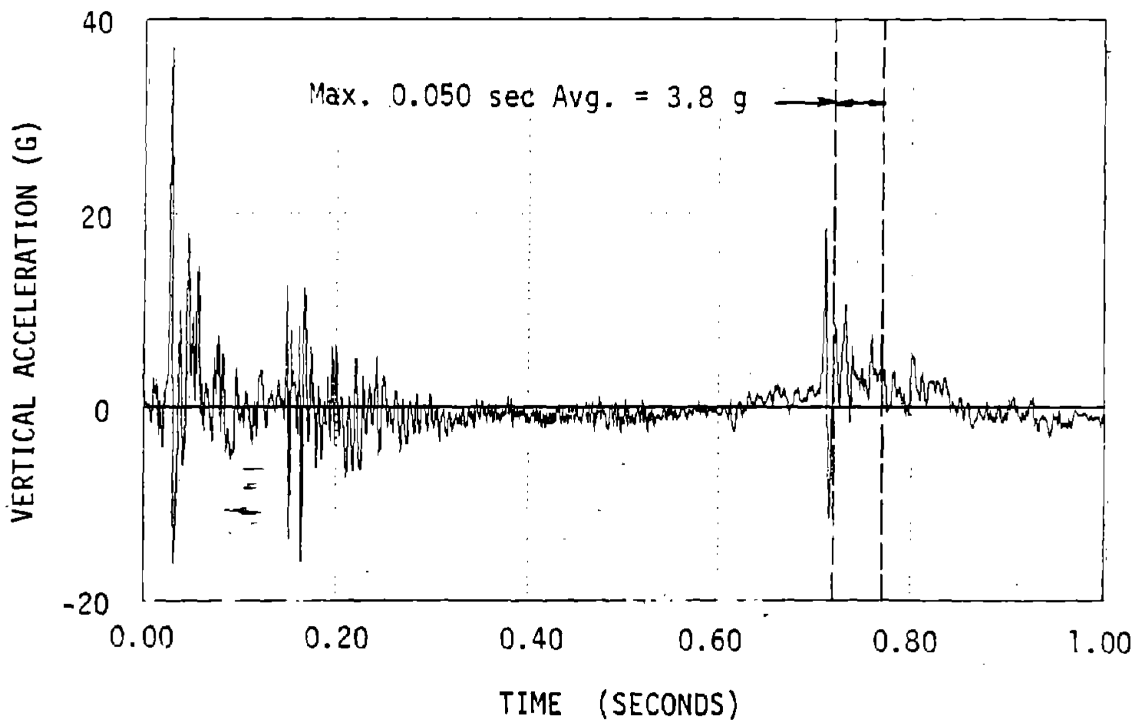


Figure 24. Vehicle vertical accelerometer trace for test 3825-11.

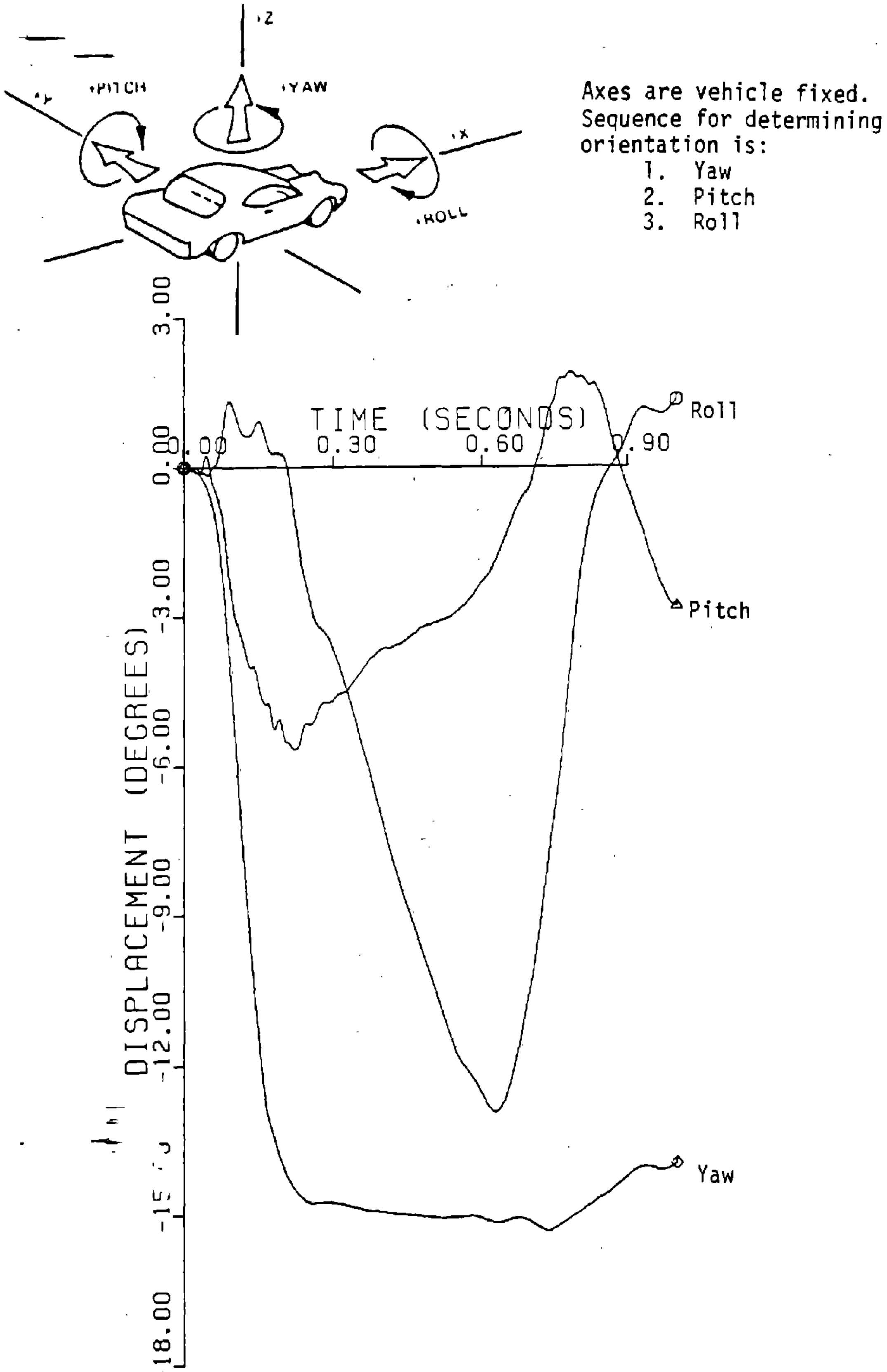


Figure 25. Vehicle angular displacements for test 3825-11.

TEST REPORT NO. 3825-12

Vehicle: 1974 Datsun Pickup, Vehicle Weight 2,434 lbs

Barrier: 32 in high Concrete Median Barrier

Impact Conditions: 15 degrees, along length of need.
60 mph

Test Description

A 1974 Datsun Pickup (shown in figure 26) was directed into the barrier at 61.0 mph (98.2 kph) and 15.0 degrees. Test inertia mass of the vehicle was 2,434 lb (1,105 kg). The vehicle was free-wheeling and unrestrained at impact.

The vehicle impacted the barrier approximately 3.0 ft (0.9 m) downstream of the joint between segments 3 and 4. The tire path on the barrier face is shown in figure 27. The top of the path reached the top of the barrier approximately 0.5 ft (0.2 m) downstream of the impact point. Tire marks extended to the upper edge of the barrier for a distance of about 7.5 ft (2.3 m) before fading out as shown in figures 27 and 28. Total length of contact was approximately 10.5 ft (3.2 m). The vehicle was redirected and exited the barrier at 0.284 sec with exit angle of 2.0 degrees. The speed of the vehicle at loss of contact was 54.0 mph (86.9 kph).

The barrier received damage to segments 3 and 4 with minimal cracking at joints 3-4 and 4-5. Damage to the barrier is shown in figure 28. The barrier showed no measurable movement during the test.

As shown in figure 29, the vehicle sustained minimal damage to the left front quarter. The left front tire was deflated and the rim bent slightly.

Test Results

A summary of test data is presented in figure 30. Figure 31 consists of sequential photographs. Vehicle accelerometer traces are displayed in figures 32 through 34, and vehicle angular displacements in figure 35.

The maximum 50-msec average accelerations were -4.1 g longitudinal and -10.1 g lateral. Maximum 50-msec average vector resultant acceleration was 11.2 g.

NCHRP Report 230 describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted with standard passenger automobiles at 15-degree impact angles.(3) These acceptance limits do not apply to the test reported herein but were computed and reported for information only. The normalized occupant/compartment impact velocity in the longitudinal direction was 13.1 fps (4.0 m/s) and 19.9 fps (6.1 m/s) in the lateral direction. The maximum 10-msec average longitudinal occupant ridedown acceleration was 0.9 g, and -4.9 g for the lateral direction.

The barrier redirected the vehicle and detached elements did not penetrate the occupant compartment. The vehicle remained upright during and after impact. Exit angle was 2.0 degrees and vehicle change in speed at loss of contact was 7.0 mph (11.3 kph).

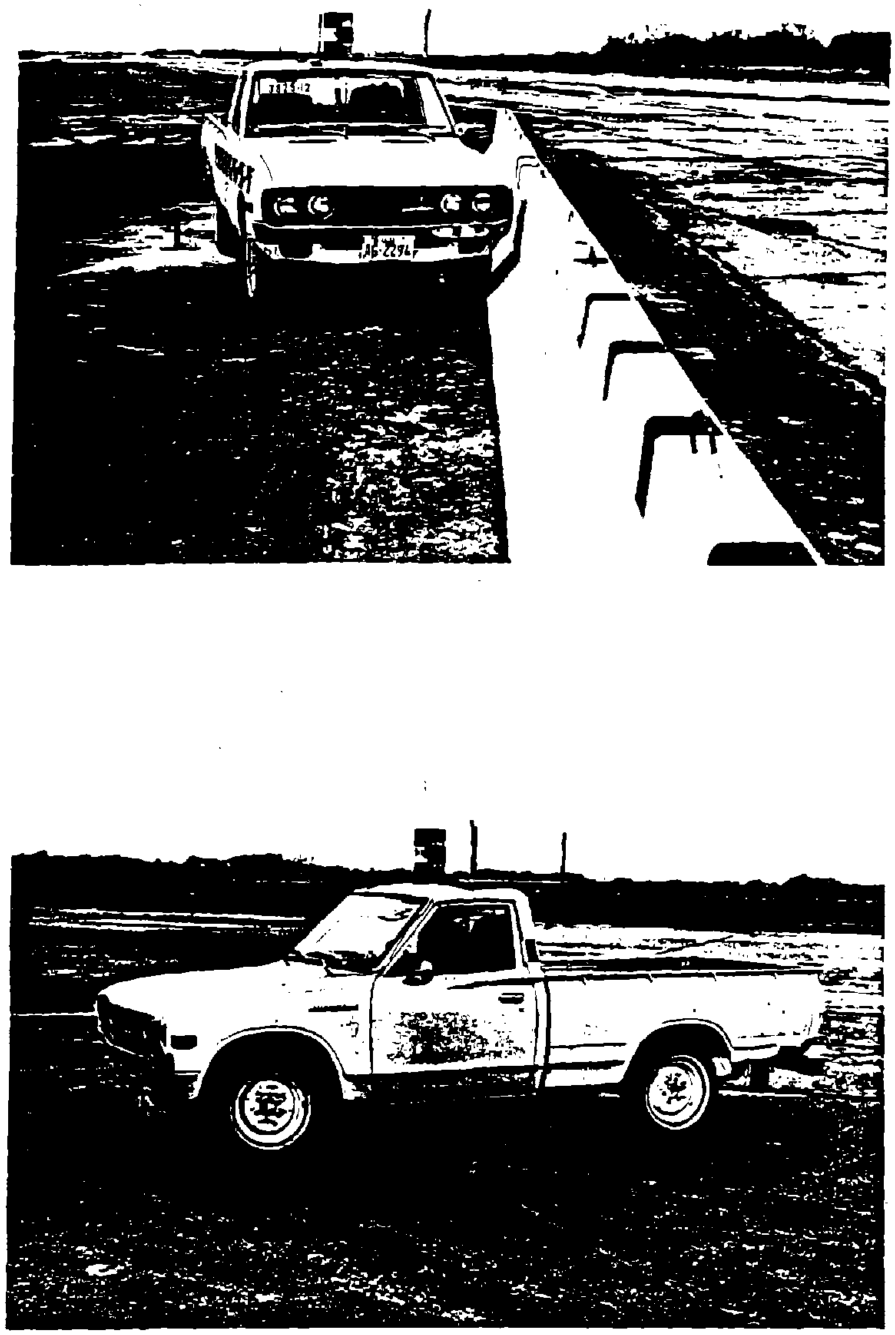


Figure 26. Vehicle before test 3825-12.

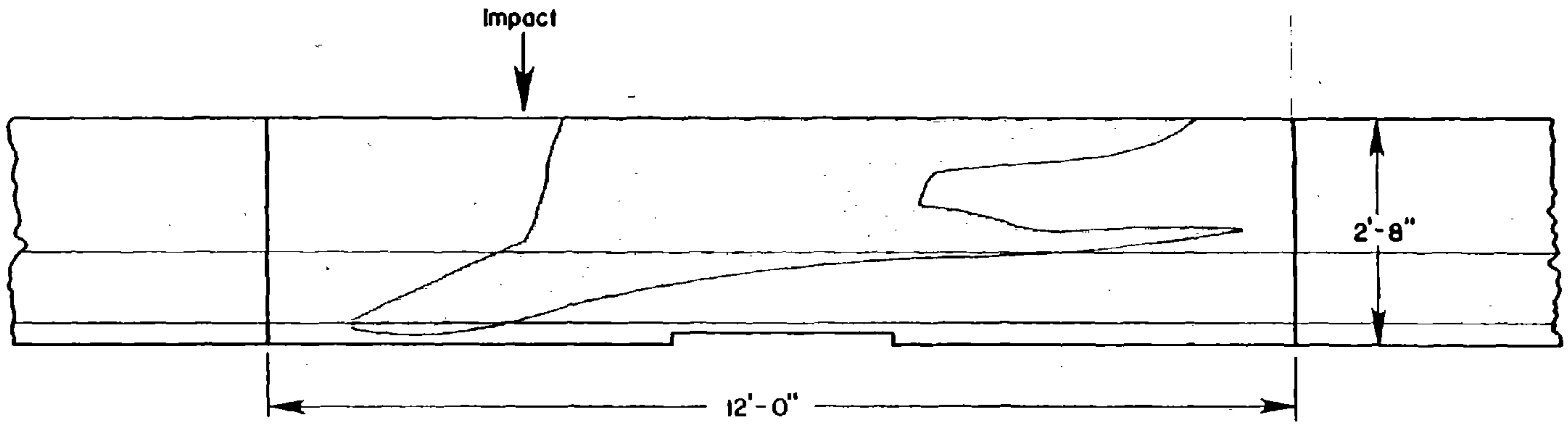


Figure 27. Tire path for test 3825-12.

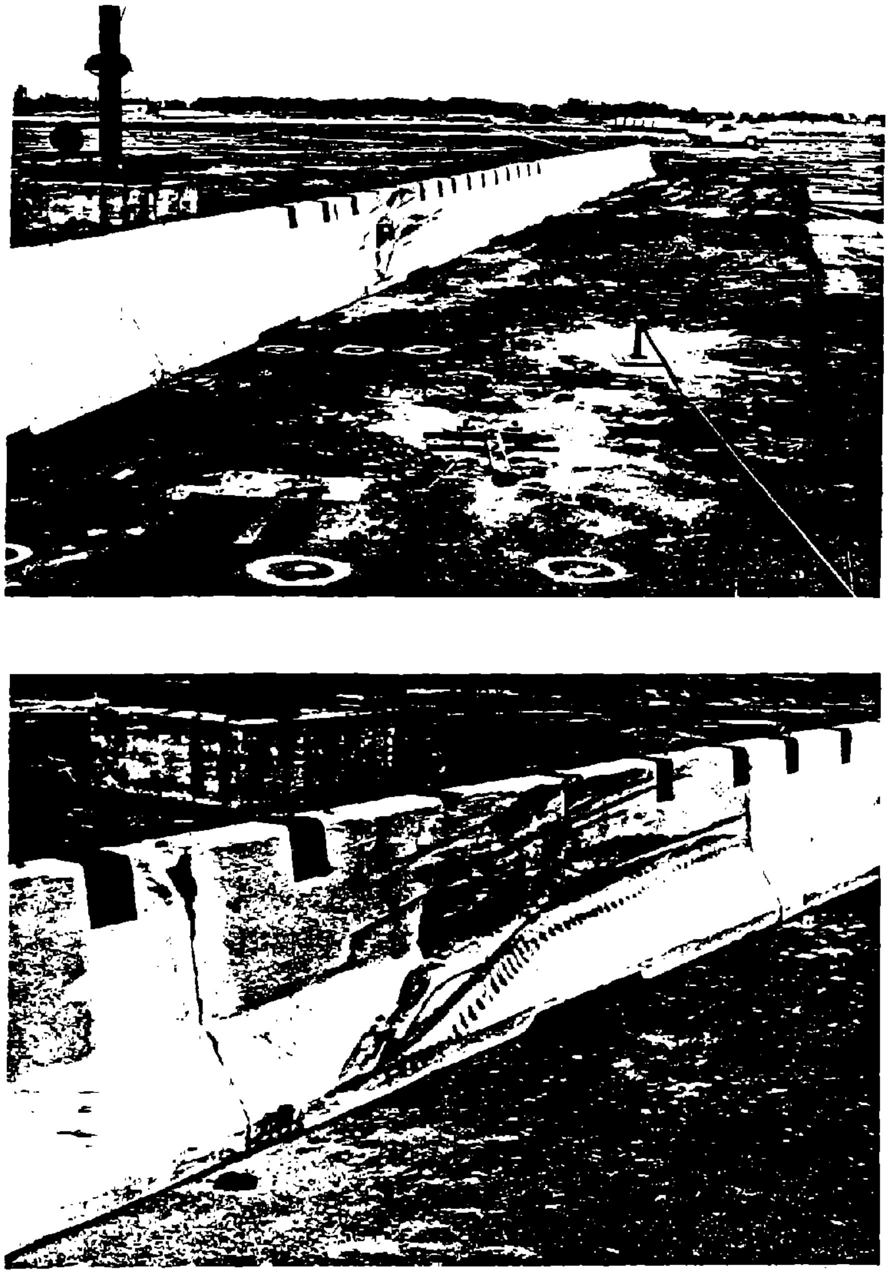


Figure 28. Barrier after test 3825-12.

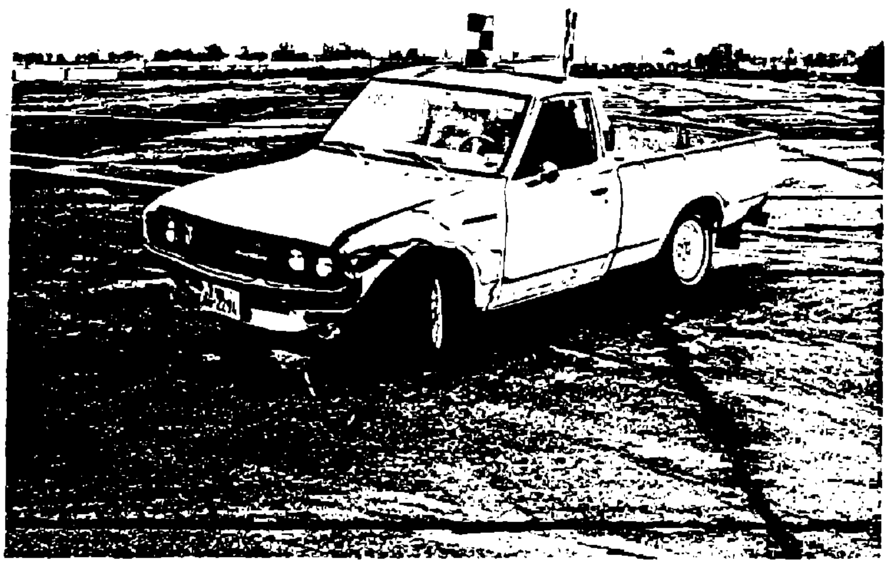
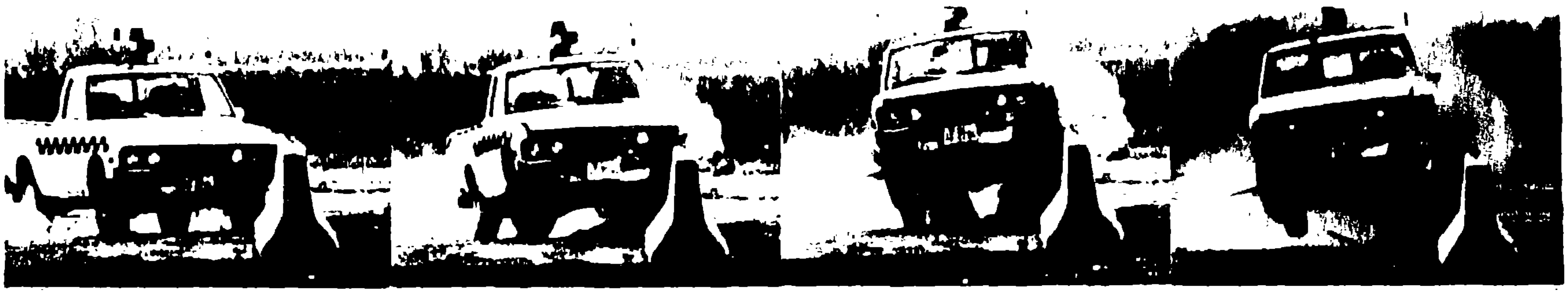
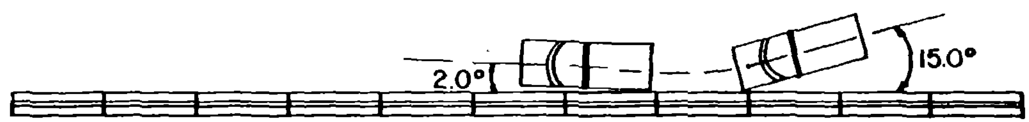
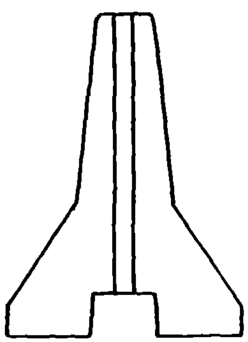


Figure 29. Vehicle after test 3825-12.







Test No. 3825-12
Date 1/17/84
Barrier. . . . . Concrete Median Barrier
Joint Connection . . . . . . Bottom T-Lock
Segment Length . . . . 12.0 ft (3.7 m)
Length of Installation . . . 120.0 ft (36.7 m)
Barrier Movement
  Permanent . . . . 0.00 ft (0.00 m)
  Maximum . . . . 0.00 ft (0.00 m)
Vehicle. . . . . 1974 Datsun Pickup
Vehicle Weight . . . . 2434 lbs (1105 kg)
Vehicle Damage Classification
  TAD 11LFQ3
  SAE 11FLEK2
  11LFES2

Impact Speed . . . . 61.0 mph (98.2 kph)
Impact Angle . . . . 15.0 deg
Exit Speed . . . . 54.0 mph (86.9 kph)
Exit Angle . . . . 2.0 deg
Vehicle Accelerations
  (Max. 0.050 sec Avg)
    Longitudinal . . . . -4.1 g
    Lateral. . . . . -10.1 g
    Vertical . . . . 4.5 g
    Vector Resultant . . . . 11.2 g
Occupant Impact Velocity
  Longitudinal . . . . 13.1 fps (4.0 m/s)
  Lateral. . . . . 19.9 fps (6.1 m/s)
Occupant Ridedown Accelerations
  Longitudinal . . . . 0.9 g
  Lateral. . . . . -4.9 g

Figure 30. Data summary for test 3825-12.

0.000 sec

0.045 sec

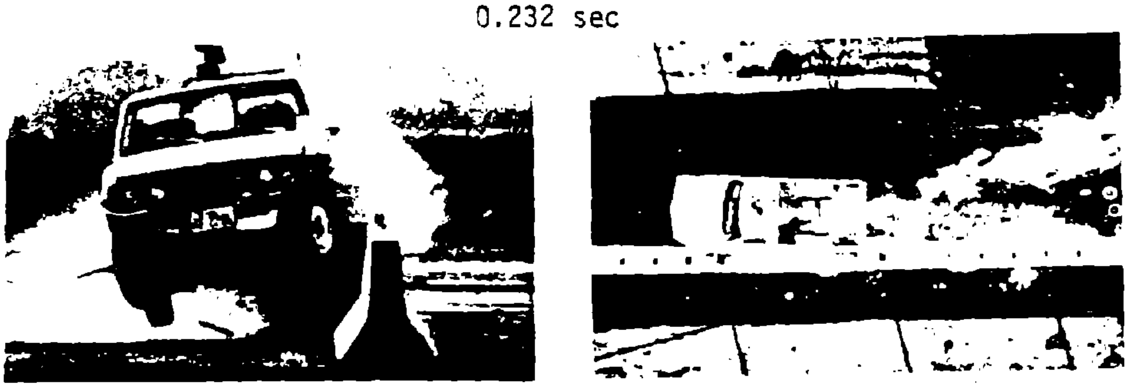
0.091 sec

0.136 sec

Figure 31. Sequential photographs for test 3825-12.

0.182 sec

0.232 sec



0.283 sec

0.338 sec

Figure 31. Sequential photographs for test 3825-12 (continued).

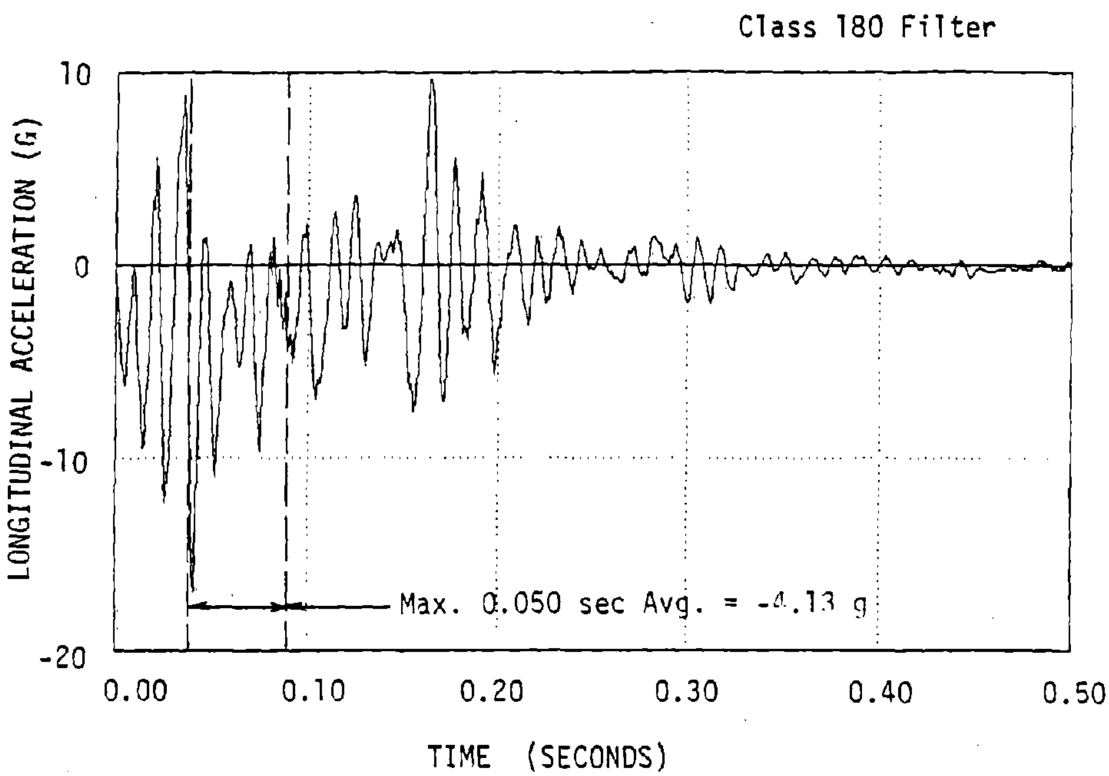


Figure 32. Vehicle longitudinal accelerometer trace for test 3825-12.

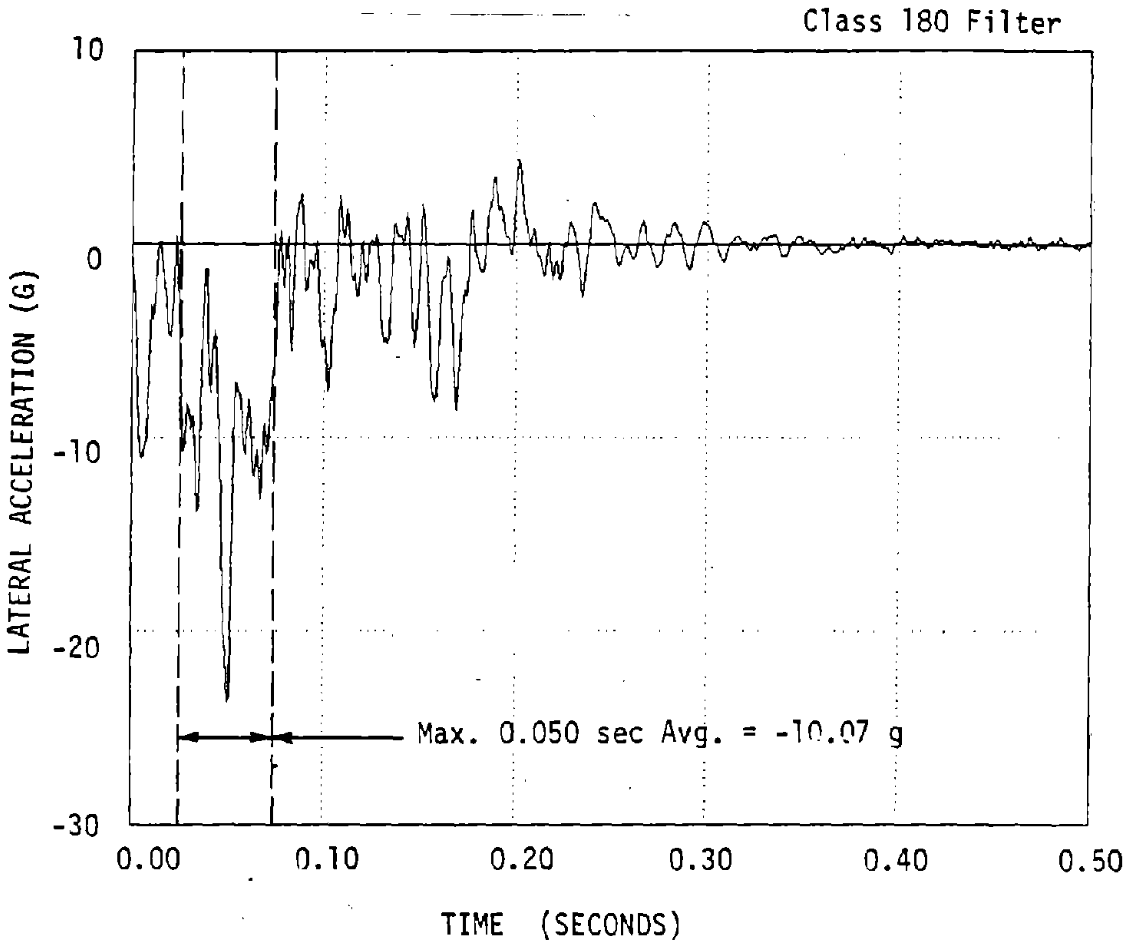


Figure 33. Vehicle lateral accelerometer trace for test 3825-12.

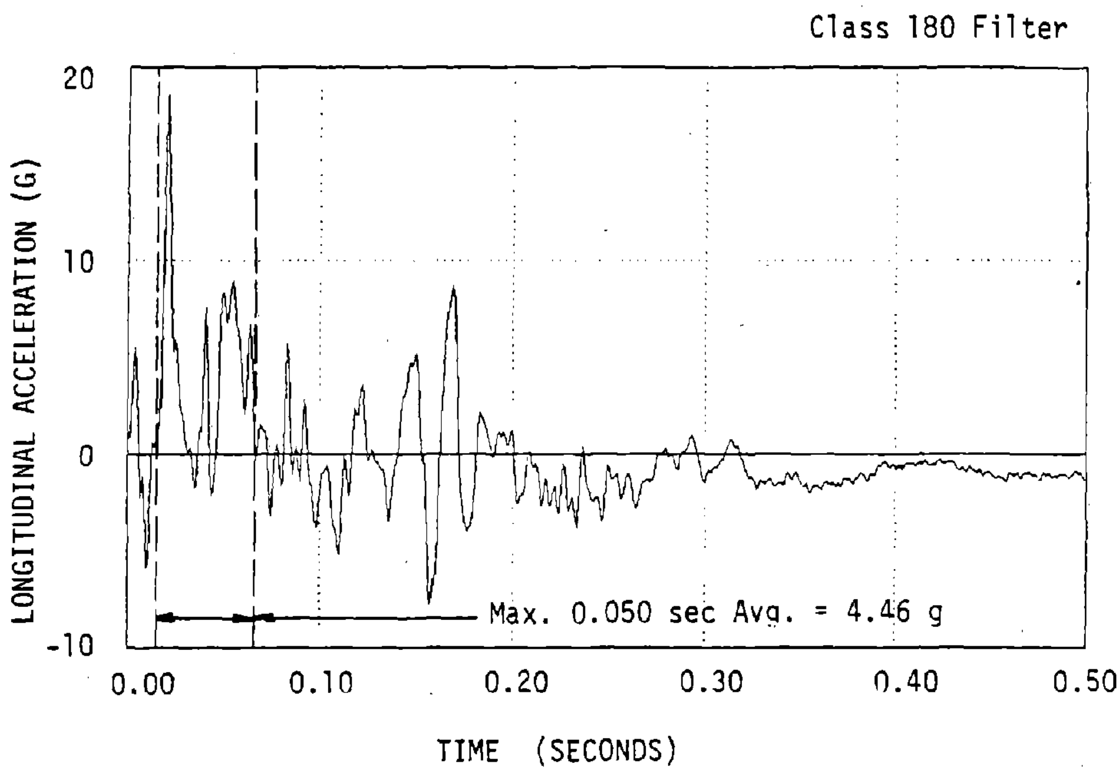
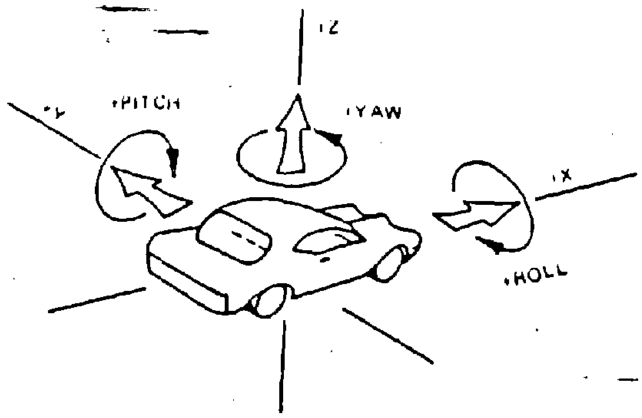


Figure 34. Vehicle longitudinal accelerometer trace for test 3825-12.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

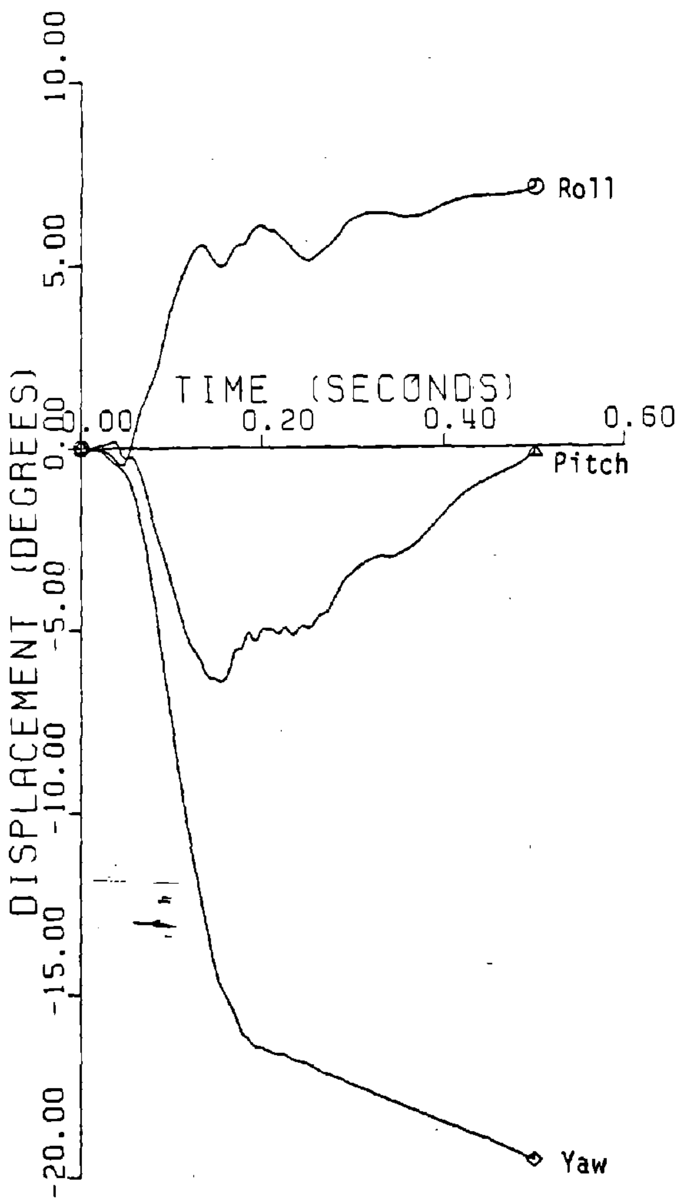


Figure 35. Vehicle angular displacements for test 3825-12.

TEST REPORT NO. 3825-13

Vehicle: 1977 Ford F250 Pickup, Vehicle Weight 4,490 lbs

Barrier: 32 in high Concrete Median Barrier

Impact Conditions: 7 degrees, along length of need.
60 mph

Test Description

A 1977 Ford F250 Pickup (see figure 36) was directed into the barrier at 57.3 mph (92.2 kph) and 6.5 degrees. Test inertia mass of the vehicle was 4,490 lb (2,038 kg). The vehicle was free-wheeling and unrestrained at impact.

The vehicle impacted the barrier approximately 2.0 ft (0.6 m) downstream of the joint between segments 3 and 4. The tire path on the barrier face is shown in figure 37. The top of the path reached a maximum height of 2.2 ft (0.7 m) approximately 11.6 ft (3.5 m) downstream of the impact point. Total length of contact was approximately 16.8 ft (5.1 m). The vehicle was redirected and exited the barrier at 0.363 sec with exit angle of 4.0 degrees. The speed of the vehicle at loss of contact was 50.6 mph (81.3 kph).

The barrier received damage to segments 3 through 5 as shown in figure 38. The upper corners of joints 3-4 and 4-5 were cracked and broken. The top of the barrier moved 0.11 ft (0.03 m) during the test but returned to its original position afterwards.

As shown in figure 39, the vehicle sustained minimal damage to the left front quarter. The left front corner of the bumper was pushed back.

Test Results

A summary of test data is presented in figure 40. Figure 41 consists of sequential photographs. Vehicle accelerometer traces are displayed in figures 42 through 44, and vehicle angular displacements in figure 45.

The maximum 50-msec average accelerations were -1.5 g longitudinal and -3.1 g lateral. Maximum 50-msec average vector resultant acceleration was 8.3 g.

NCHRP Report 230 describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted with standard passenger automobiles at 15-degree impact angles.[3] These acceptance limits do not apply to the test reported herein but were computed and reported for information only. The normalized occupant/compartment impact velocity in the longitudinal direction was 7.4 fps (2.3 m/s) and 10.8 fps (3.3 m/s) in the lateral direction. The maximum 10-msec average longitudinal occupant ridedown acceleration was -0.4 g, and -5.3 g for the lateral direction.

The barrier redirected the vehicle and detached elements did not penetrate the occupant compartment. The vehicle remained upright during and after impact. Exit angle was 4.0 degrees and vehicle change in speed at loss of contact was 6.7 mph (10.8 kph).

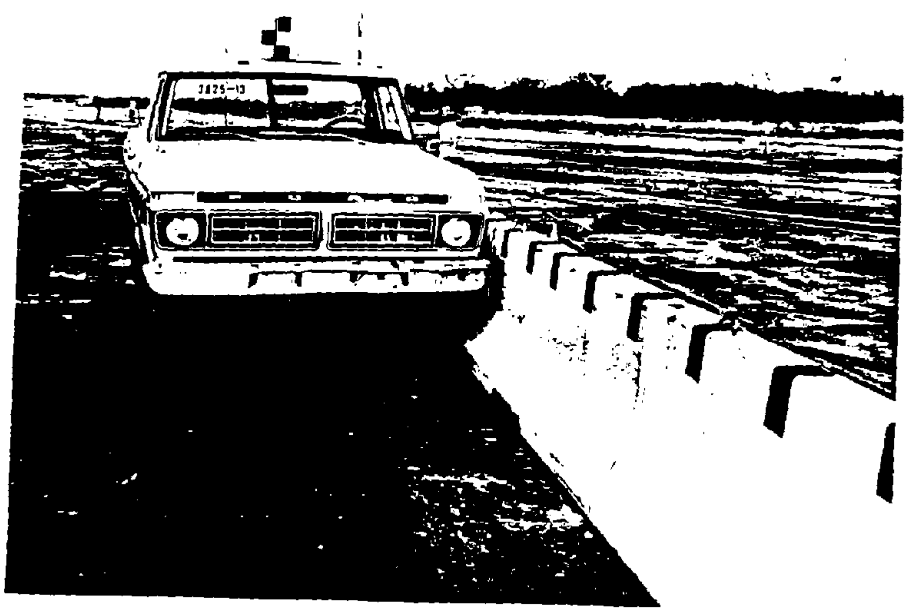


Figure 36. Vehicle before test 3825-13.

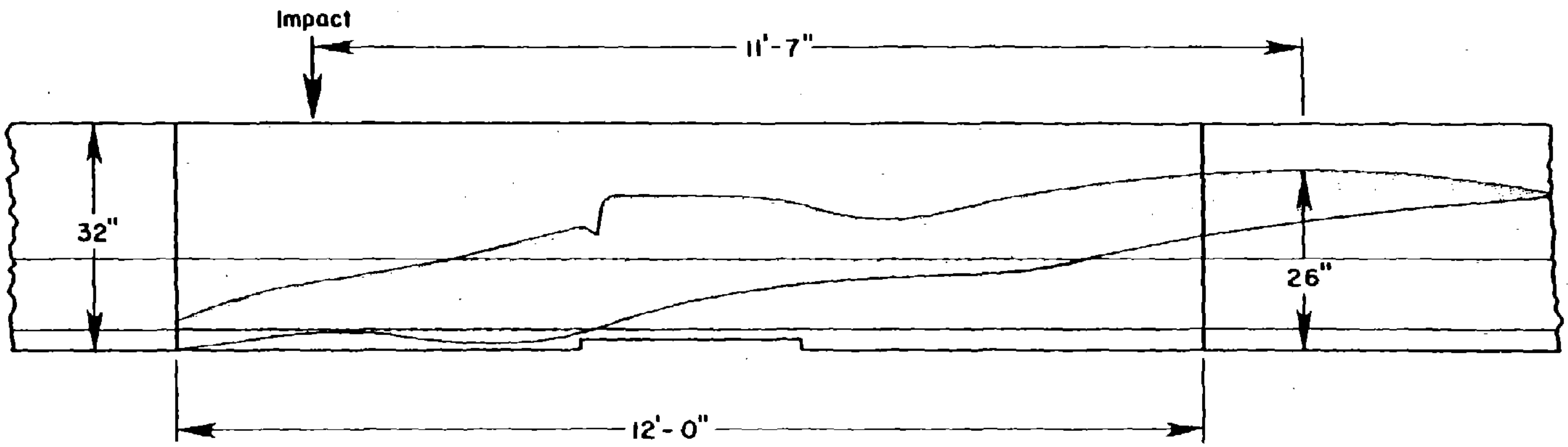


Figure 37. Tire path for test 3825-13.

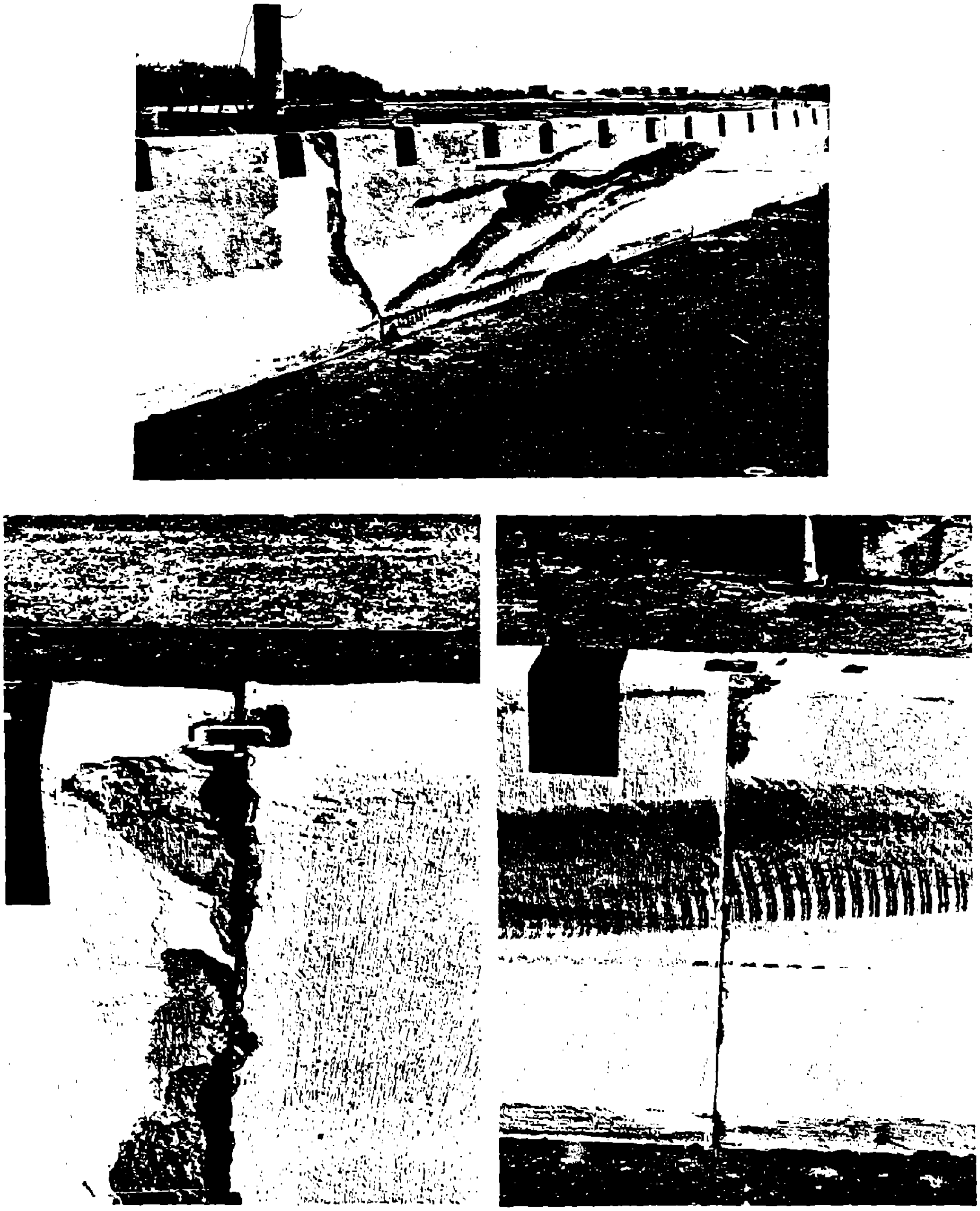


Figure 38. Barrier after test 3825-13.

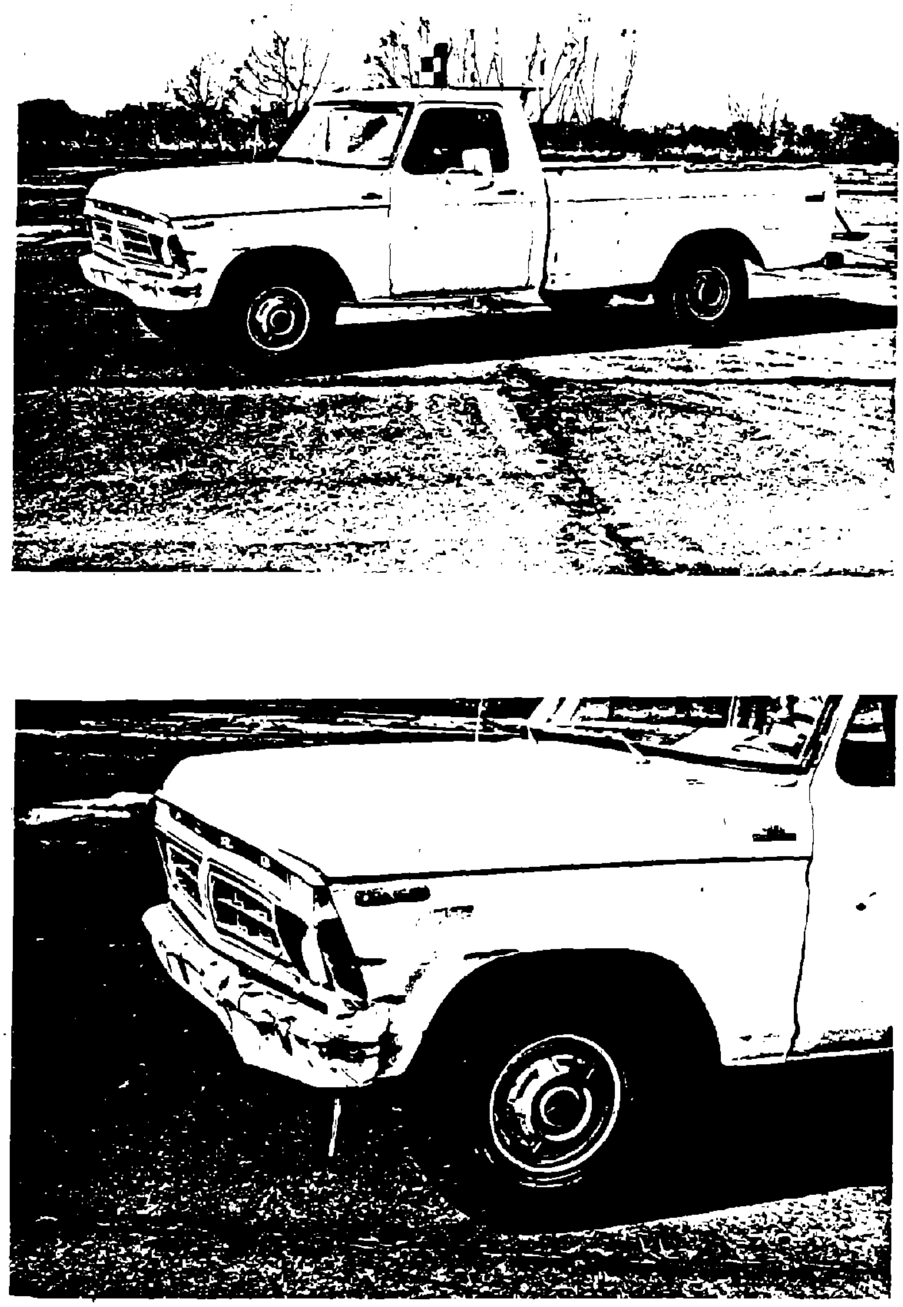
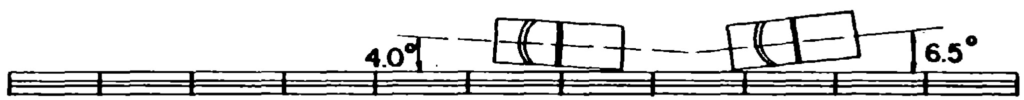
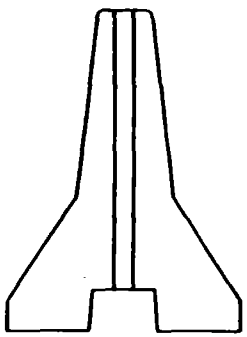


Figure 39. Vehicle after test 3825-13.

0.000 sec 0.120 sec 0.240 sec 0.363 sec



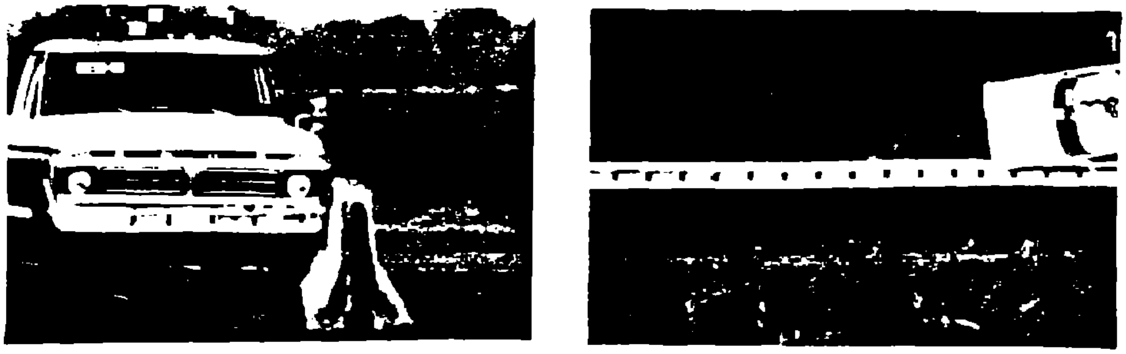


Concrete Median Barrier

Test No.	3825-13
Date	1/13/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.00 ft (0.00 m)
Maximum	0.11 ft (0.03 m)
Vehicle	1977 Ford F250 Pickup
Vehicle Weight	4490 lbs (2038 kg)
Vehicle Damage Classification	
TAD	11LFQ1
SAE	11FLEM1

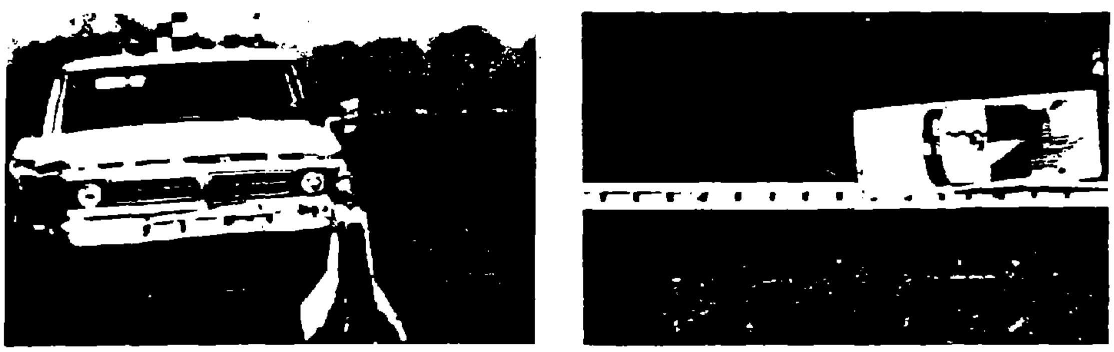
Impact Speed	57.3 mph (92.2 kph)
Impact Angle	6.5 deg
Exit Speed	50.6 mph (81.3 kph)
Exit Angle	4.0 deg
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-1.5 g
Lateral	-3.1 g
Vertical	1.4 g
Vector Resultant	8.3 g
Occupant Impact Velocity	
Longitudinal	7.4 fps (2.3 m/s)
Lateral	10.8 fps (3.3 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-0.4 g
Lateral	-5.3 g

Figure 40. Data summary for test 3825-13.



0.000 sec

0.060 sec

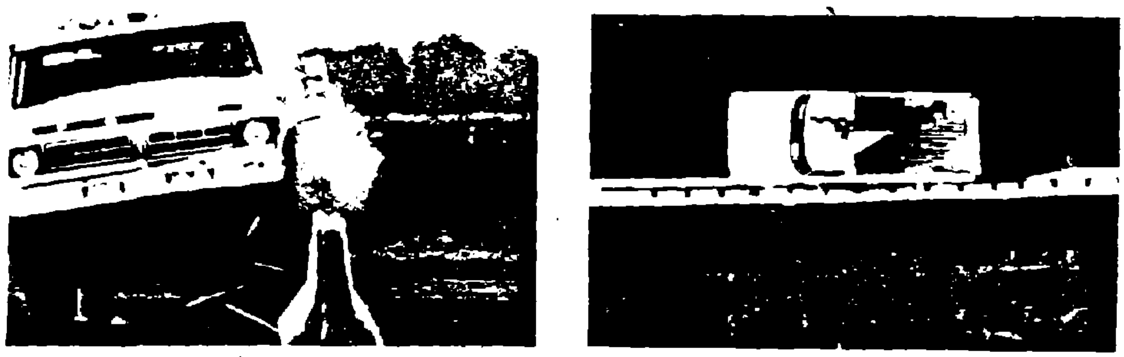


0.120 sec

0.180 sec

Figure 41. Sequential photographs for Test 3825-13.

0.240 sec



0.300 sec

0.363 sec

0.425 sec

Figure 41. Sequential photographs for test 3825-13 (continued).

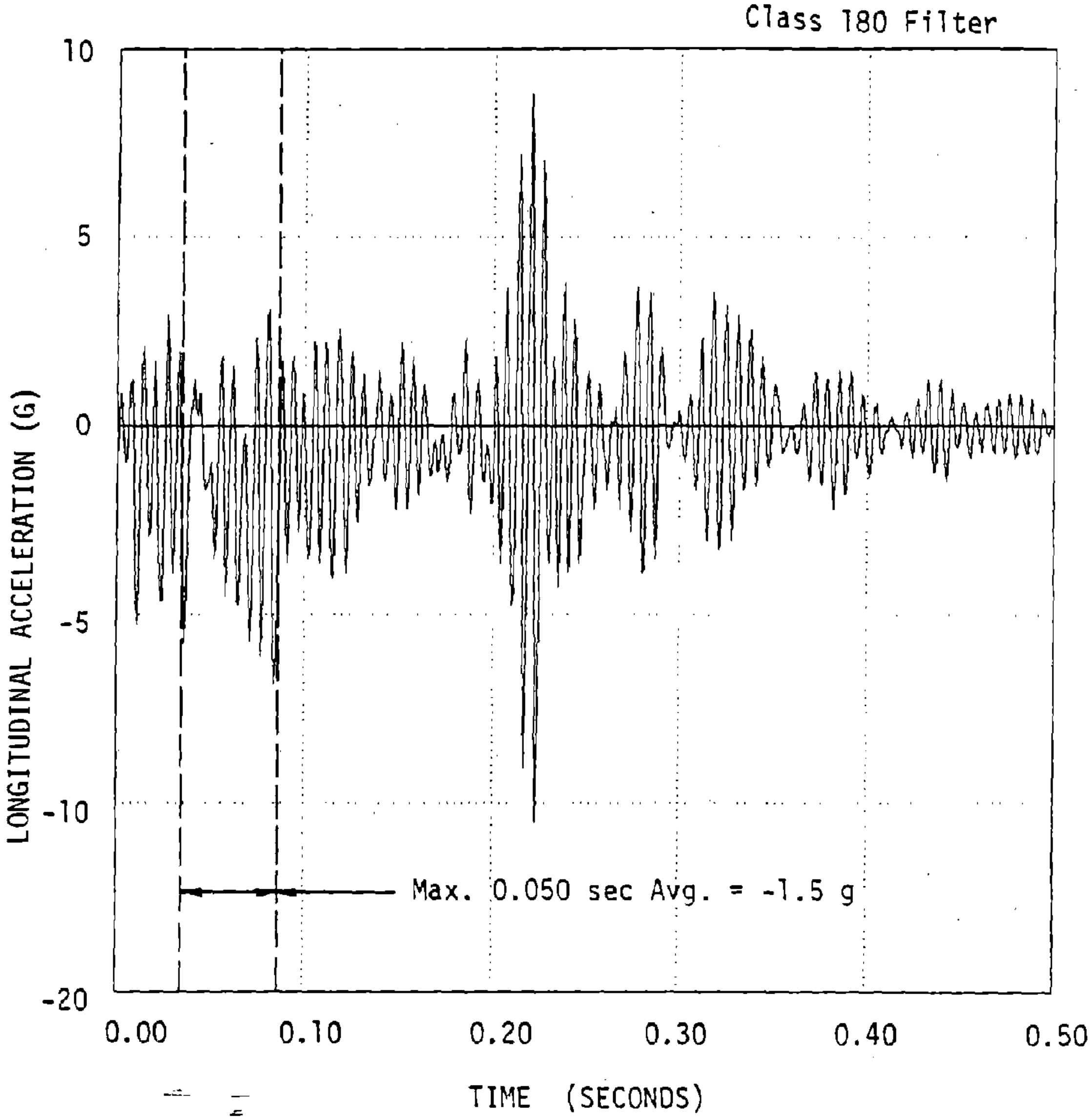


Figure 42. Vehicle longitudinal accelerometer trace for test 3825-13.

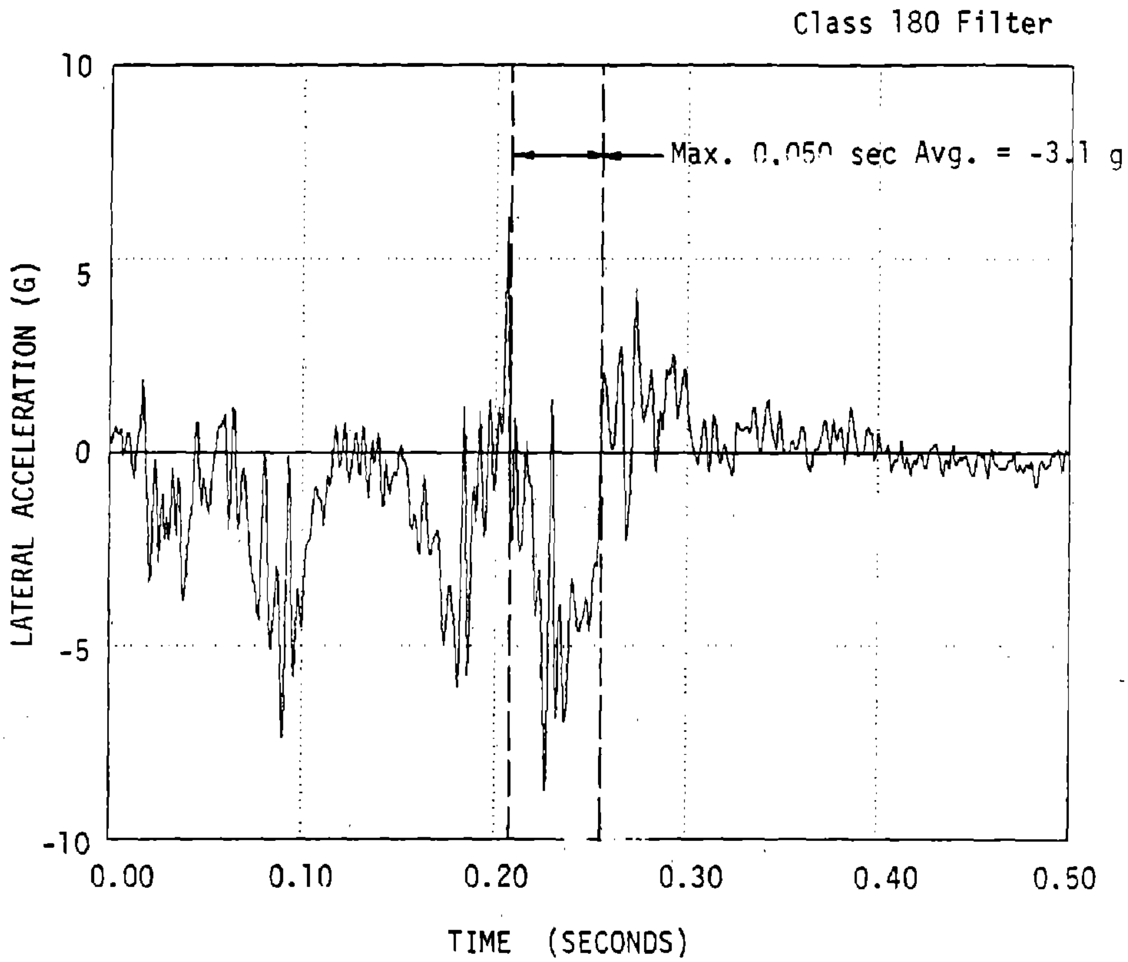


Figure 43. Vehicle lateral accelerometer trace for test 3825-13.

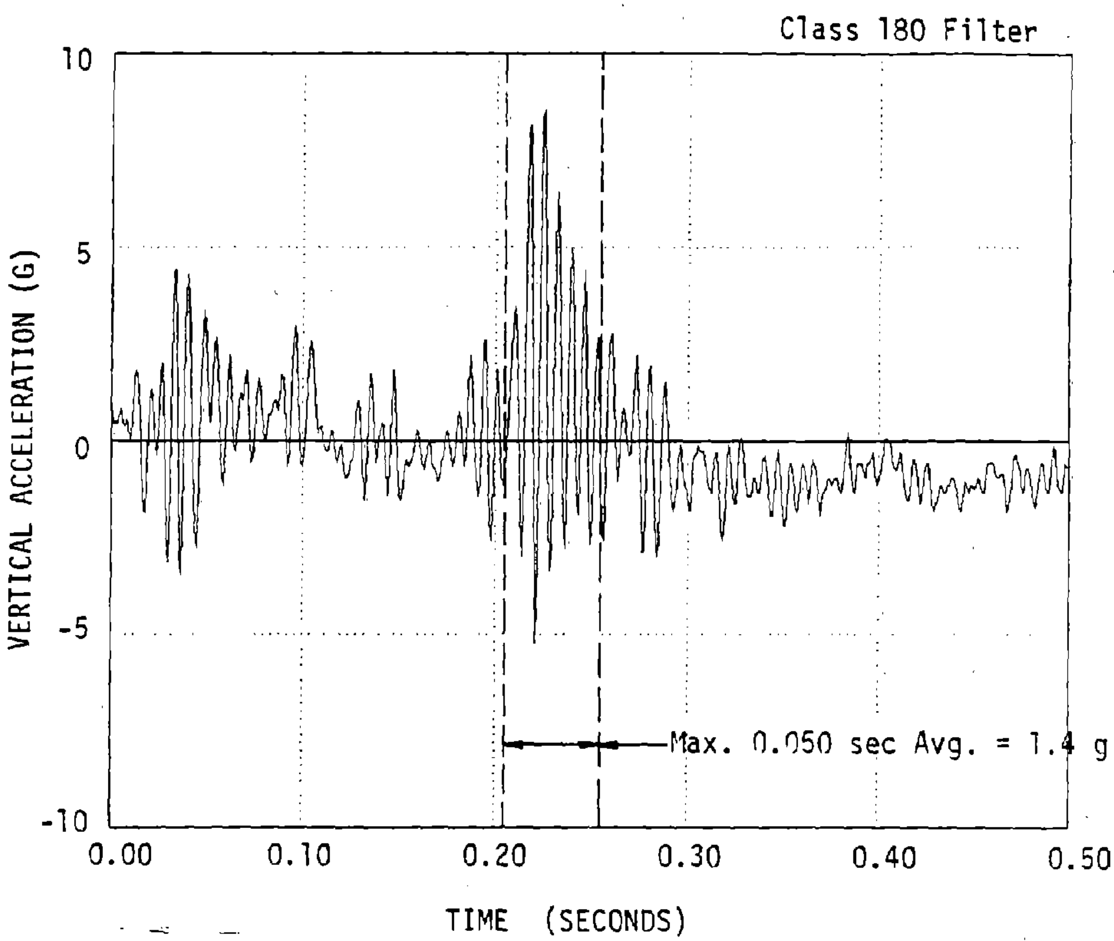


Figure 44. Vehicle vertical accelerometer trace for test 3825-13.

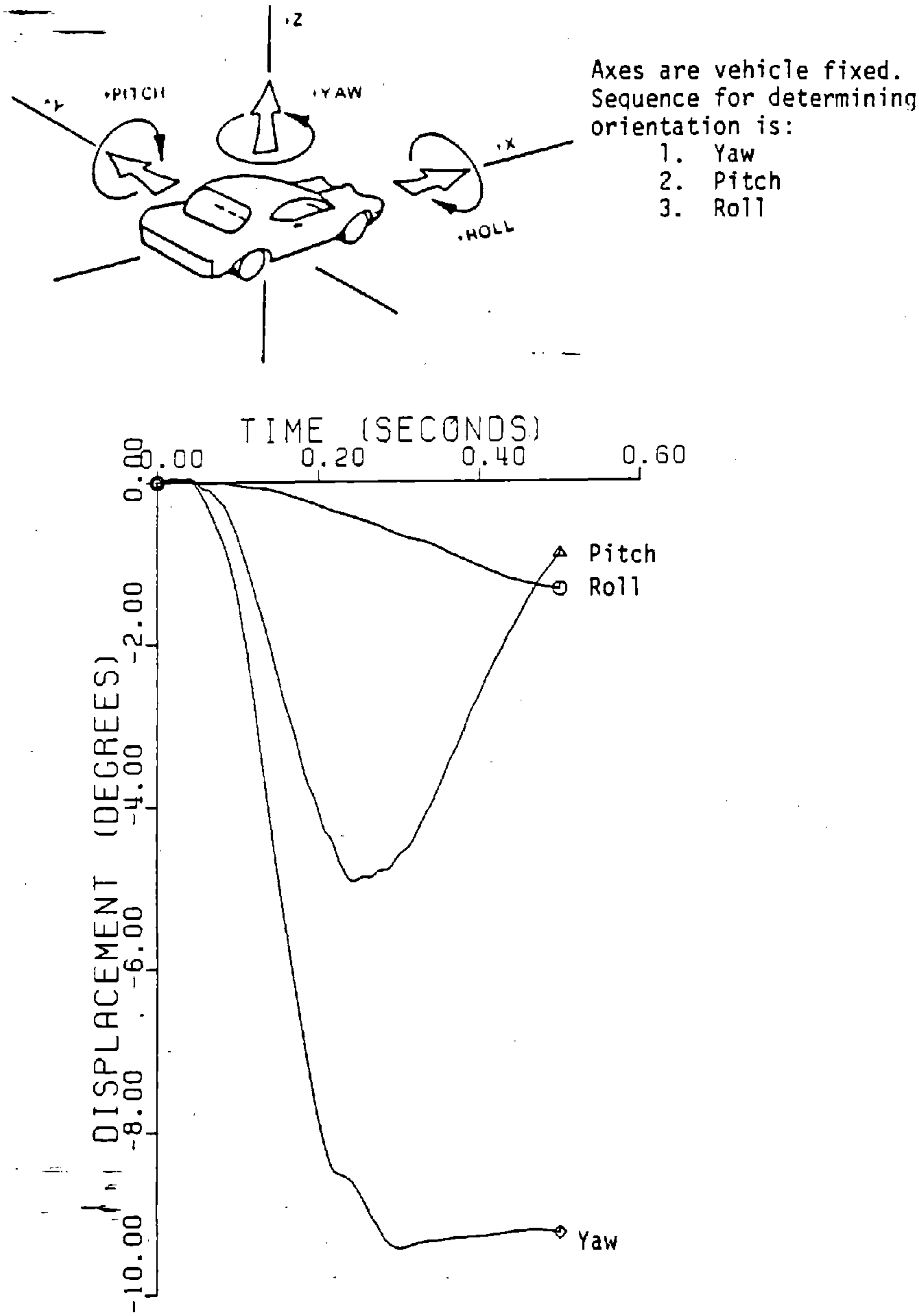


Figure 45. Vehicle angular displacements for test 3825-13.

TEST REPORT NO. 3825-14

Vehicle: 1977 Ford F250 Pickup, Vehicle Weight 4,490 lbs

Barrier: 32 in high Concrete Median Barrier

Impact Conditions: 15 degrees, along length of need.
60 mph

Test Description

The 1977 Ford F250 Pickup used in Test 3825-13 (see figure 46) was directed into the barrier at 58.1 mph (93.5 kph) and 14.0 degrees. Test inertia mass of the vehicle was 4,490 lb (2,038 kg). The vehicle was free-wheeling and unrestrained at impact.

The vehicle impacted the barrier approximately 4.0 ft (1.2 m) downstream of the joint between segments 3 and 4. The tire path on the barrier face is shown in figure 47. The top of the path reached the top of the barrier approximately 6.5 ft (2.0 m) downstream of the impact point. Tire marks extended to or near the upper edge of the barrier for a distance of about 6.0 ft (1.8 m) as shown in figures 47 and 48. Total length of contact was approximately 17.0 ft (5.2 m). The vehicle was redirected and exited the barrier at 0.418 sec with exit angle of 4.0 degrees. The speed of the vehicle at loss of contact was 46.8 mph (75.3 kph).

The barrier received damage to segments 3 through 5 as shown in figure 48. The upper corners of joints 3-4 and 4-5 were cracked and broken. The top of the barrier moved 0.12 ft (0.04 m) during the test but returned to its original position afterwards.

As shown in figure 49, the vehicle sustained damage to the left side. The left front and left rear tires were deflated and the rims bent.

Test Results

A summary of test data is presented in figure 50. Figure 51 consists of sequential photographs. Vehicle accelerometer traces are displayed in figures 52 through 54, and vehicle angular displacements in figure 55.

The maximum 50-msec average accelerations were -5.3 g longitudinal and -6.3 g lateral. Maximum 50-msec average vector resultant acceleration was 8.3 g.

NCHRP Report 230 describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted with standard passenger automobiles at 15-degree impact angles.(3) These acceptance limits do not apply to the test reported herein but were computed and reported for information only. The normalized occupant/compartment impact velocity in the longitudinal direction was 15.1 fps (4.6 m/s) and 14.7 fps (4.5 m/s) in the lateral direction. The maximum 10-msec average longitudinal occupant ridedown acceleration was 5.4 g, and -12.4 g for the lateral direction.

The barrier redirected the vehicle and detached elements did not penetrate the occupant compartment. The vehicle remained upright during and after impact. Exit angle was 4.0 degrees and vehicle change in speed at loss of contact was 11.3 mph (18.2 kph).

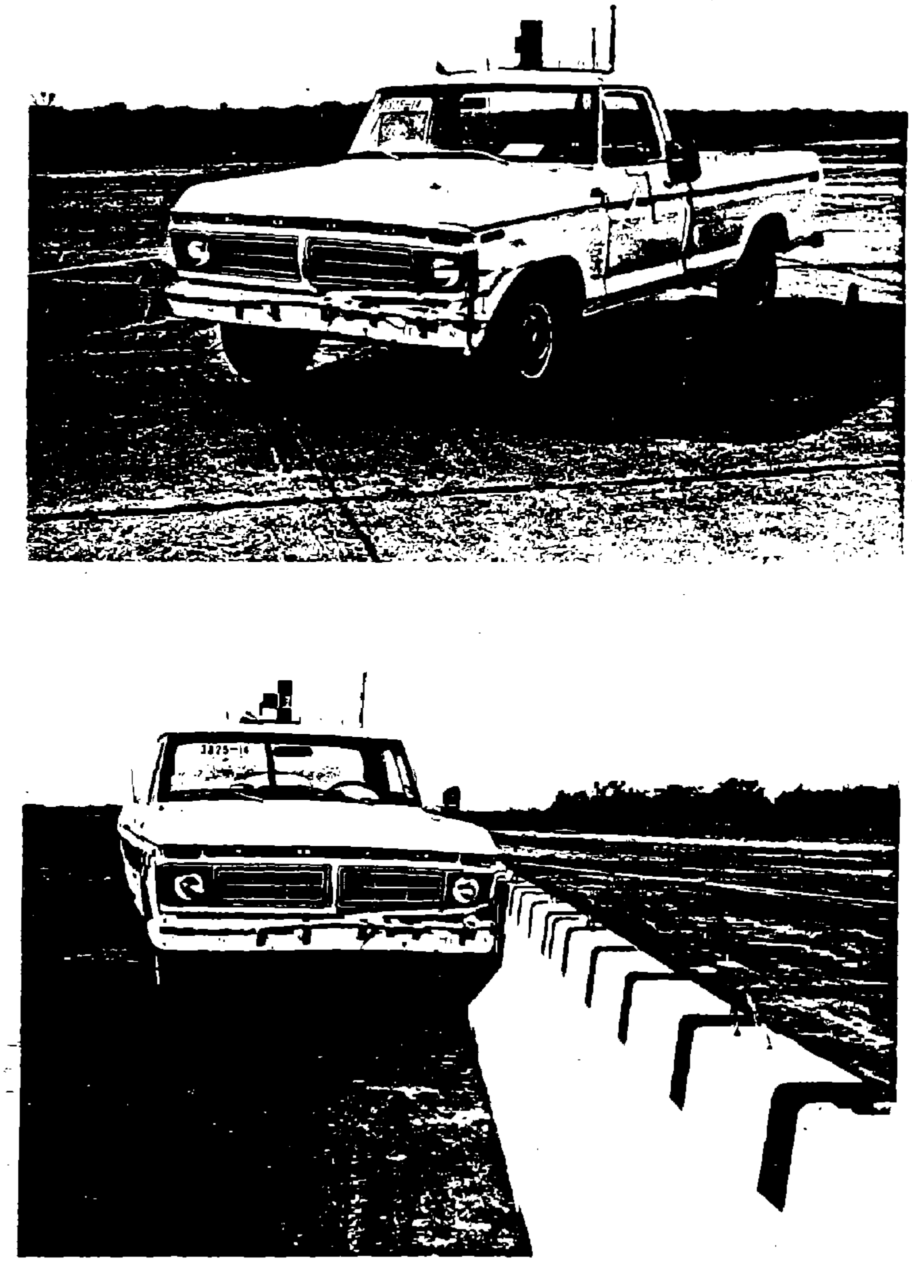


Figure 46. Vehicle before test 3825-14.

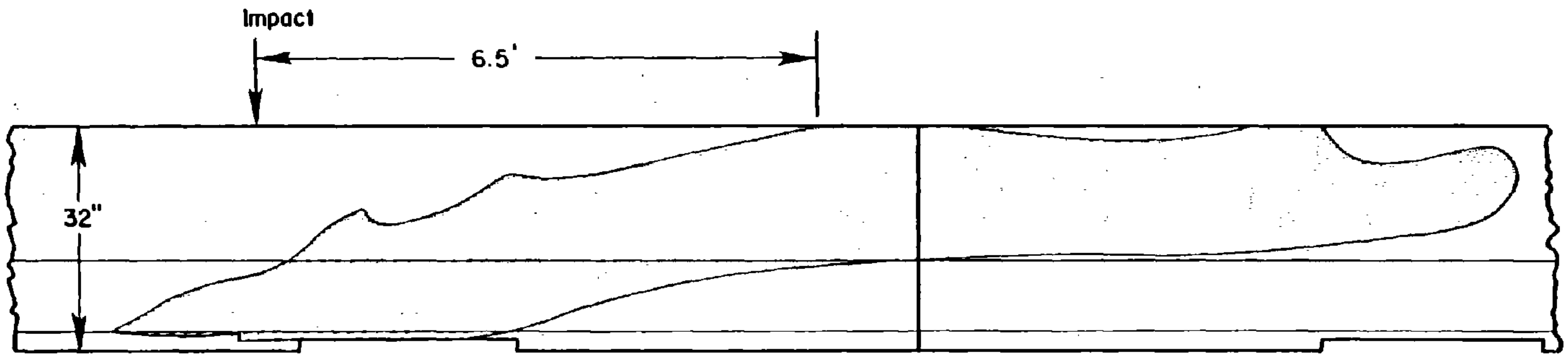
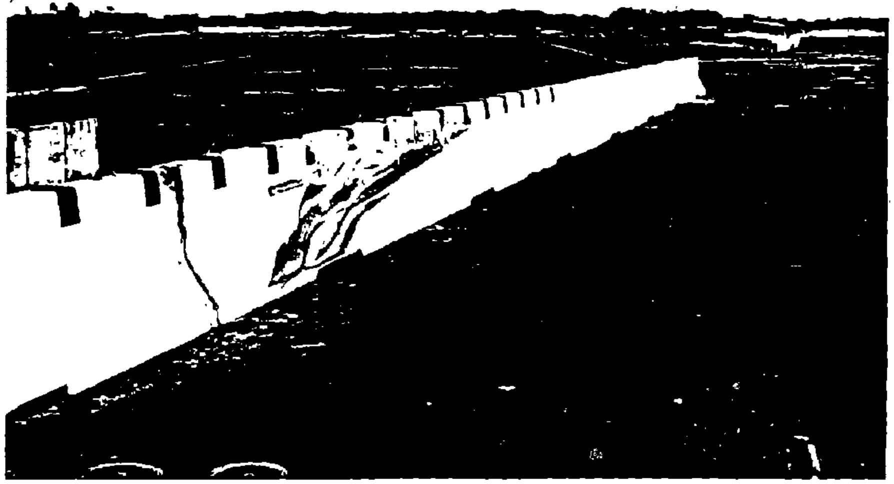


Figure 47. Tire path for test 3825-14.



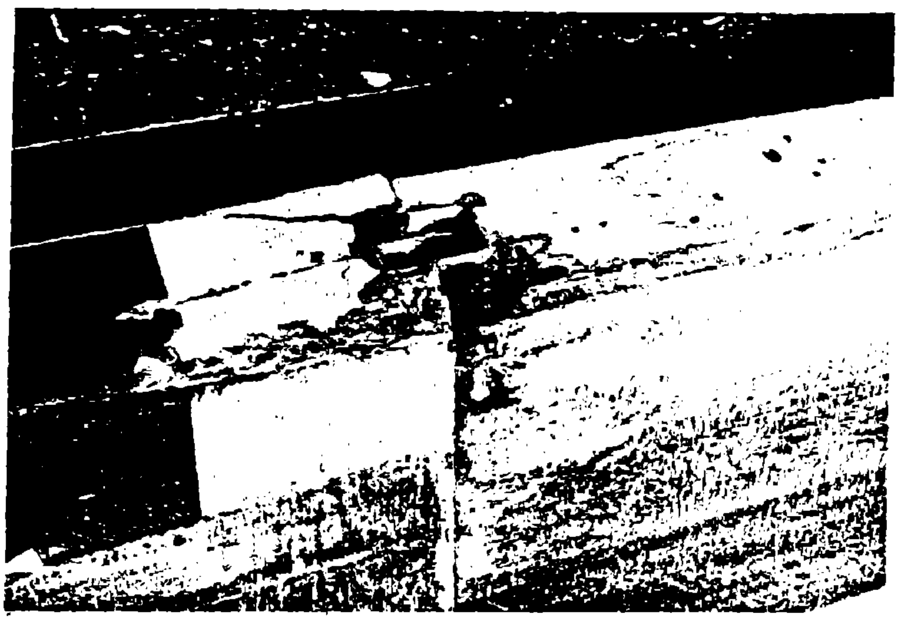


Figure 48. Barrier after test 3825-14.

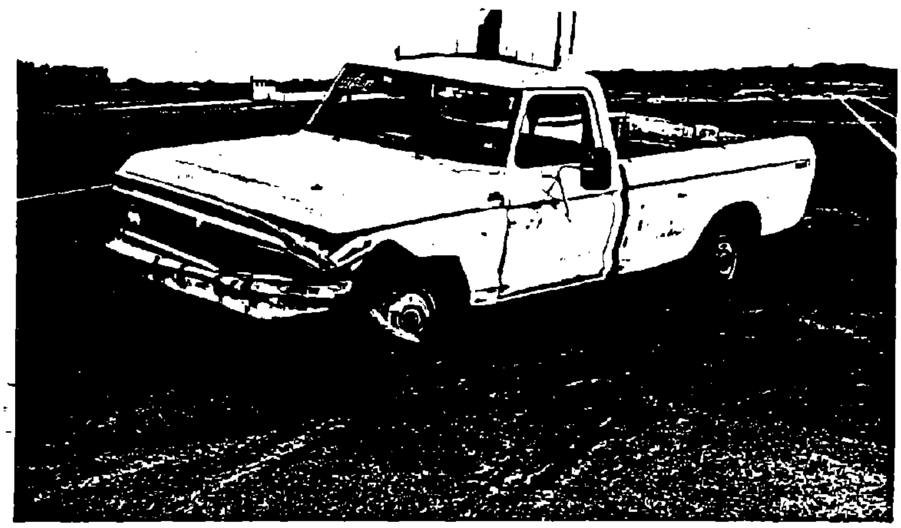
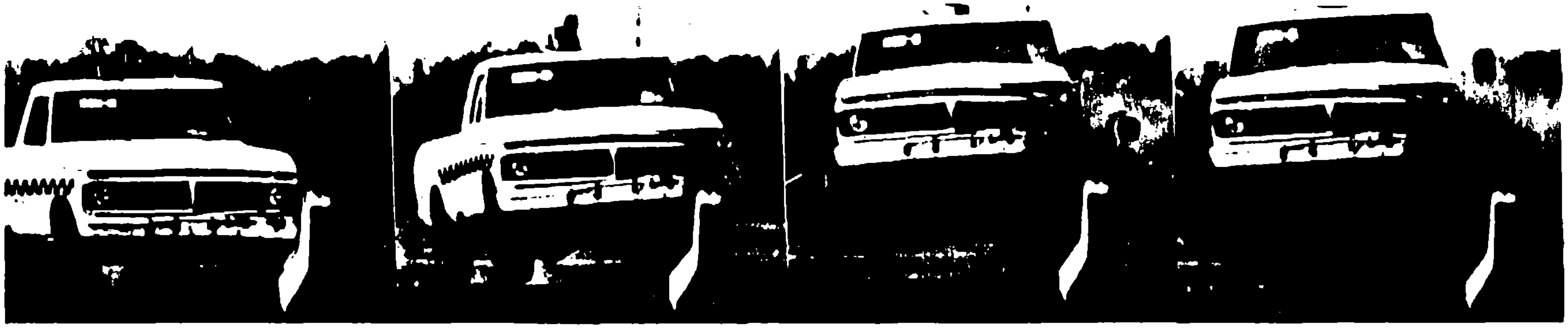
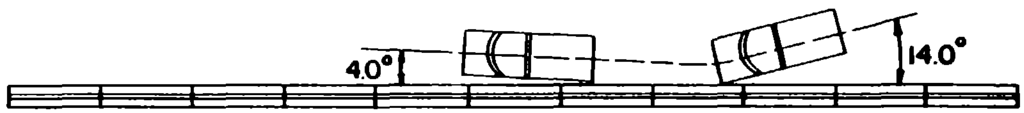
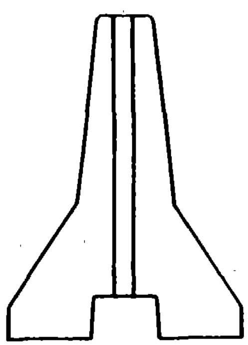


Figure 49. Vehicle after test 3825-14.



0.000 sec　0.139 sec　0.278 sec　0.418 sec





Concrete
Median Barrier

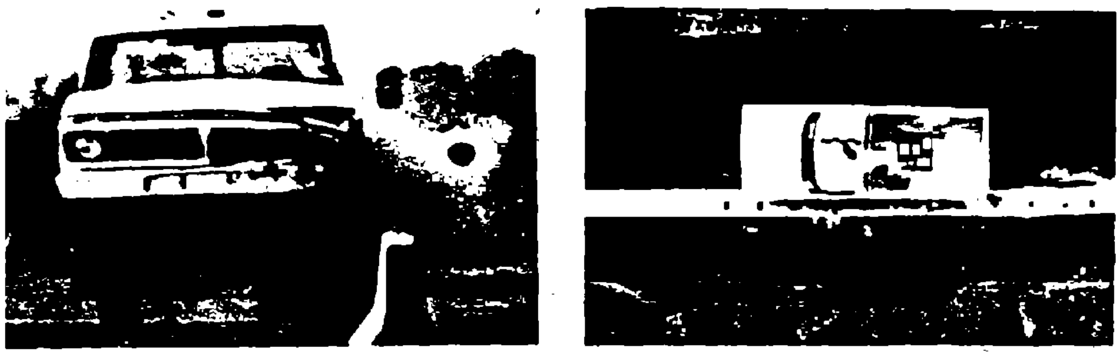
Test No.	3825-14
Date	1/13/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.00 ft (0.00 m)
Maximum	0.12 ft (0.04 m)
Vehicle	1977 Ford F250 Pickup
Vehicle Weight	4490 lbs (2038 kg)
Vehicle Damage Classification	
TAD	11LFQ4
SAE	11FLEK1 11LFES3

Impact Speed	58.1 mph (93.5 kph)
Impact Angle	14.0 deg
Exit Speed	46.8 mph (75.3 kph)
Exit Angle	4.0 deg
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-5.3 g
Lateral	-6.3 g
Vertical	2.9 g
Vector Resultant	8.3 g
Occupant Impact Velocity	
Longitudinal	15.1 fps (4.6 m/s)
Lateral	14.7 fps (4.5 m/s)
Occupant Ridedown Accelerations	
Longitudinal	5.4 g
Lateral	-12.4 g

Figure 50. Data summary for test 3825-14.

Figure 51. Sequential photographs for test 3825-14.

0.278 sec



0.349 sec

0.418 sec

0.491 sec

Figure 51. Sequential Photographs for test 3825-14 (continued).

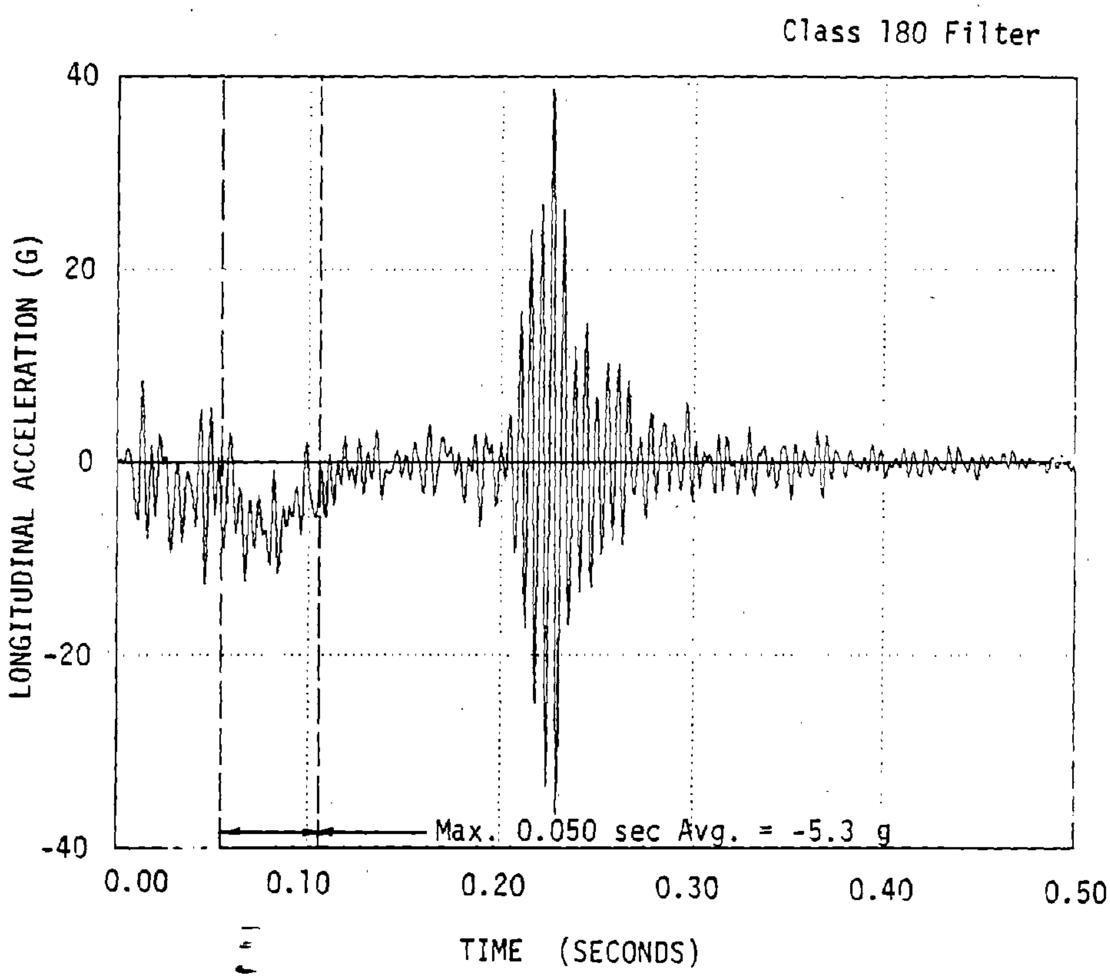


Figure 52. Vehicle longitudinal accelerometer trace for test 3825-14.

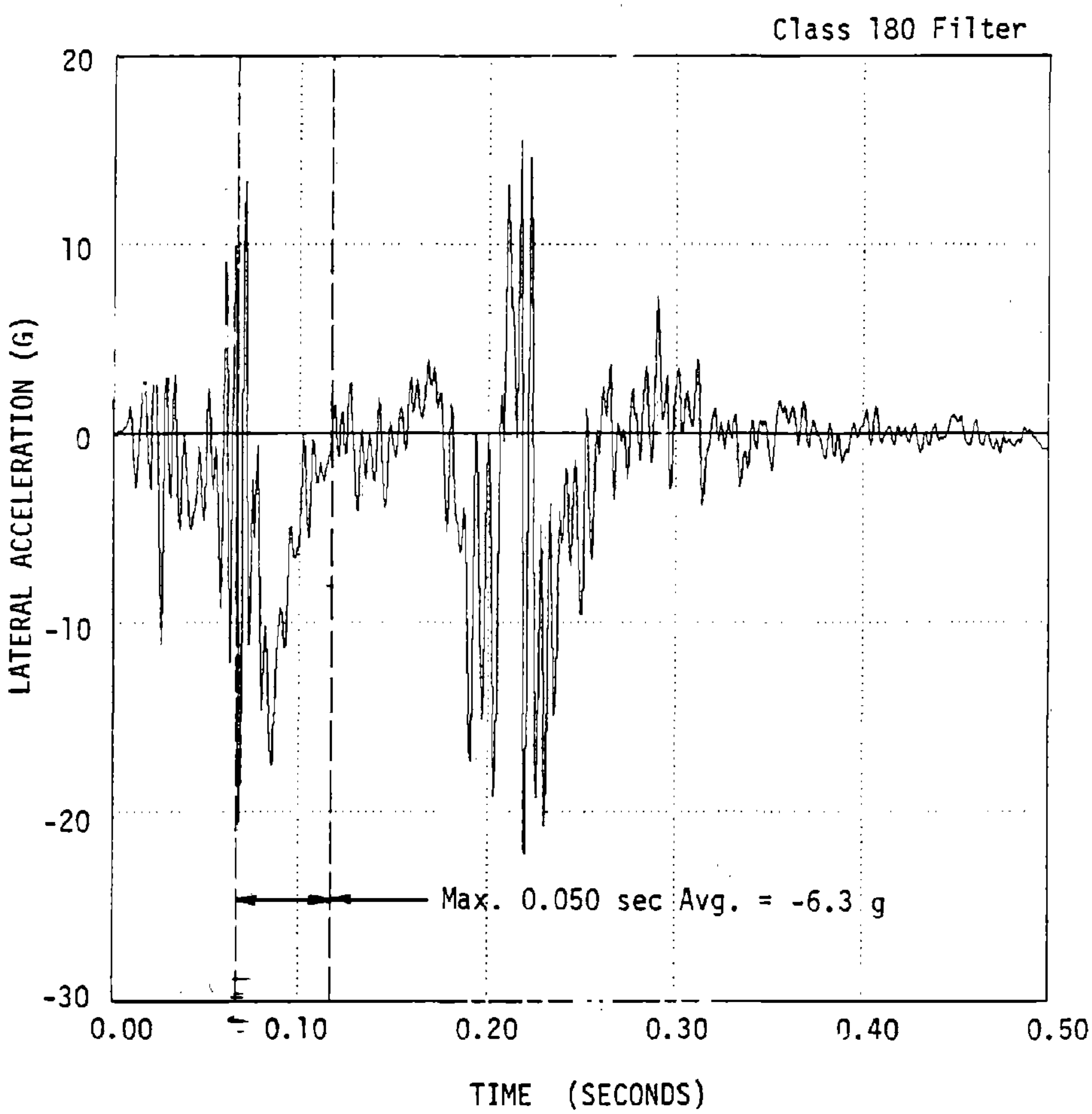


Figure 53. Vehicle lateral accelerometer trace for test 3825-14.

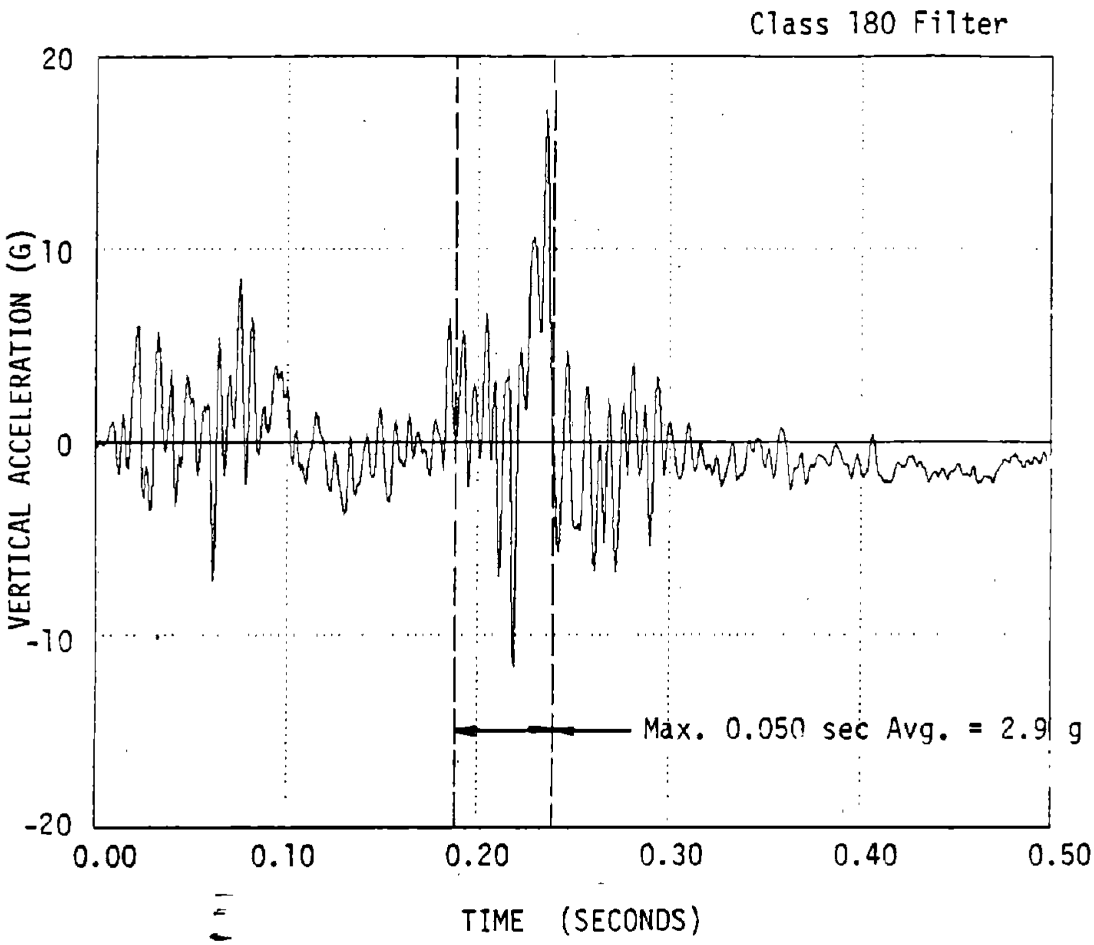
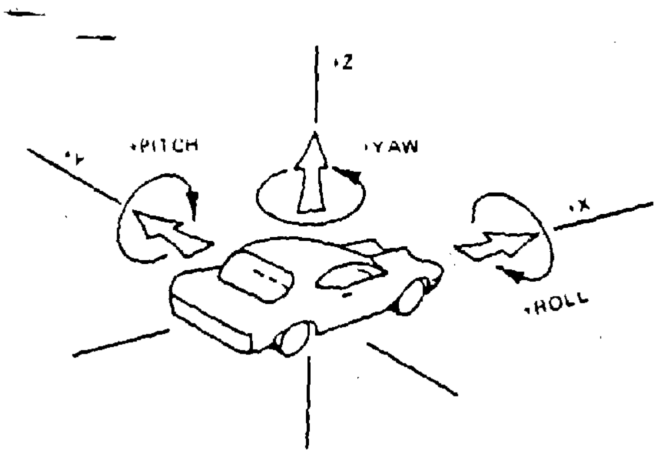


Figure 54. Vehicle vertical accelerometer trace for test 3825-14.



Axes are vehicle fixed.
Sequence for determining orientation is:
1. Yaw
2. Pitch
3. Roll

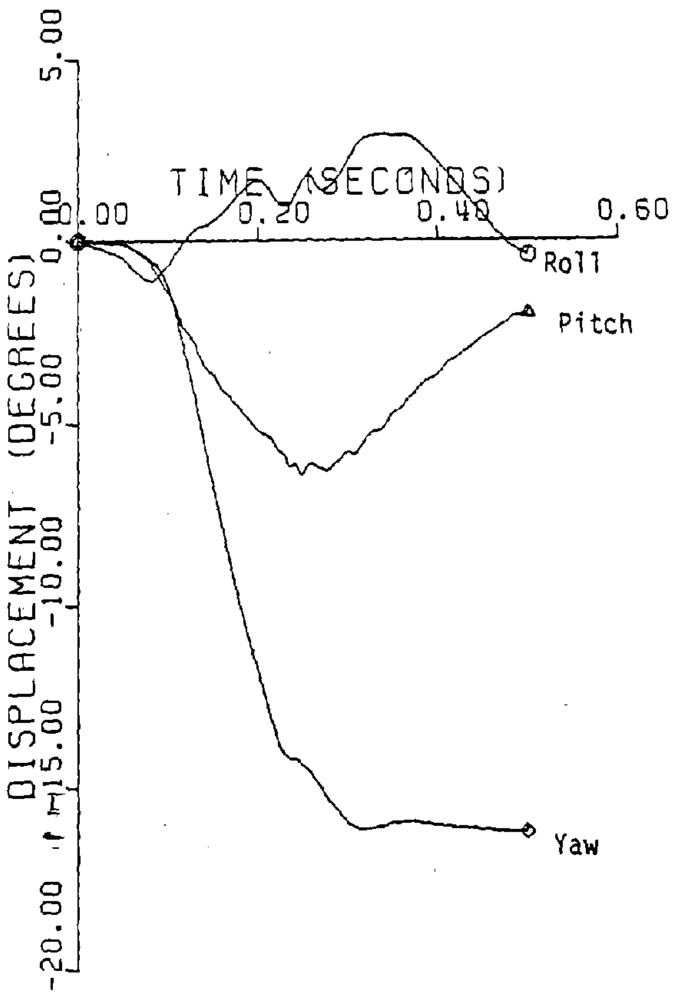


Figure 55. Vehicle angular displacements for test 3825-14.

TEST REPORT NO. 3825-15

Vehicle: 1974 Ford F250 Pickup, Vehicle Weight 4,540 lbs

Barrier: 32 in high Concrete Median Barrier

Impact Conditions: 22 degrees, along length of need.
60 mph

Test Description

A 1974 Ford F250 Pickup (see figure 56) was directed into the barrier at 60.2 mph (96.9 kph) and 21.5 degrees. Test inertia mass of the vehicle was 4,540 lb (2,061 kg). The vehicle was free-wheeling and unrestrained at impact.

The vehicle impacted the barrier approximately 3.5 ft (1.1 m) downstream of the joint between segments 3 and 4. The vehicle rode up the face of the CMB and started rolling away from the barrier. The vehicle left the barrier at about 0.370 sec after impact and had rolled approximately 30 degrees. As the vehicle left the barrier it continued to roll and subsequently touched ground on its right side and slid approximately 150.0 ft (45.7 m).

The tire path on the barrier face is shown in figure 57. The top of the path reached the top of the barrier approximately 3.0 ft (0.9 m) downstream of the impact point. Tire marks extended to the upper edge of the barrier for a distance of over 12.0 ft (3.7 m). Total length of contact was approximately 16.0 ft (4.9 m).

Segment 4 had tilted back during impact causing the concrete at the joints on each end to break off, exposing the channel in the T-lock as shown in figure 58. The segment came to rest on some of these pieces of concrete elevating it approximately 2 in (5.1 cm). The T-lock was also exposed at joint 5-6. The top of the barrier (segment 4) moved 0.63 ft (0.19 m) during impact and retained a permanent deflection of 0.08 ft (0.02 m).

As shown in figure 59, the vehicle sustained damage to the undercarriage. The left I-beam (axle) was bent back, the left strut attachment bracket was sheared from the frame and both mainframe rails were bent. The left front tire was deflated and the rim bent (shown in figure 60).

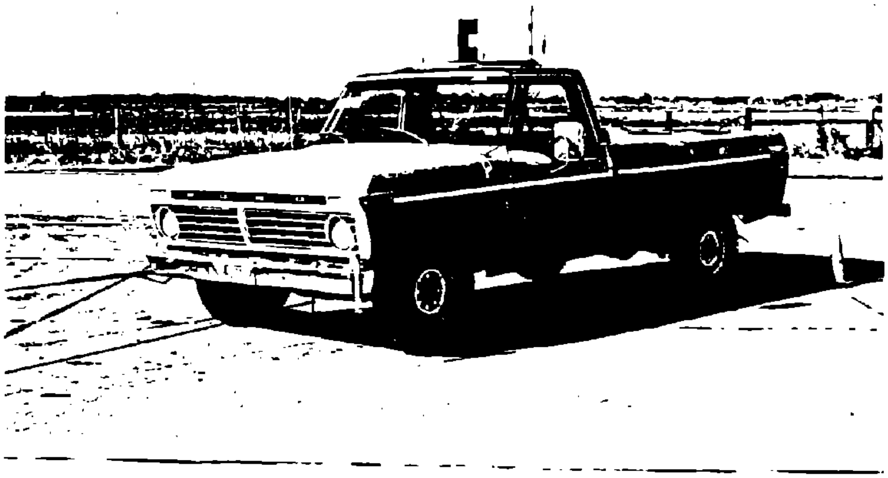
Test Results

A summary of test data is presented in figure 61. Figure 62 consists of sequential photographs. Vehicle accelerometer traces are displayed in figures 63 through 65, and vehicle angular displacements in figure 66.

The maximum 50-msec average accelerations were -7.0 g longitudinal and -8.7 g lateral. Maximum 50-msec average vector resultant acceleration was 11.4 g.

NCHRP Report 230 describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted with standard passenger automobiles at 15-degree impact angles.[3] These acceptance limits do not apply to the test reported herein but were computed and reported for information only. The normalized occupant/compartment impact velocity in the longitudinal direction was 24.2 fps (7.4 m/s), and 19.3 fps (5.9 m/s) in the lateral direction. The maximum 10-msec average longitudinal occupant ridedown acceleration was -3.0 g, and -11.1 g for the lateral direction.

The barrier redirected the vehicle and detached elements did not penetrate the occupant compartment; however, the vehicle rolled as it exited the barrier and came to rest on its right side.



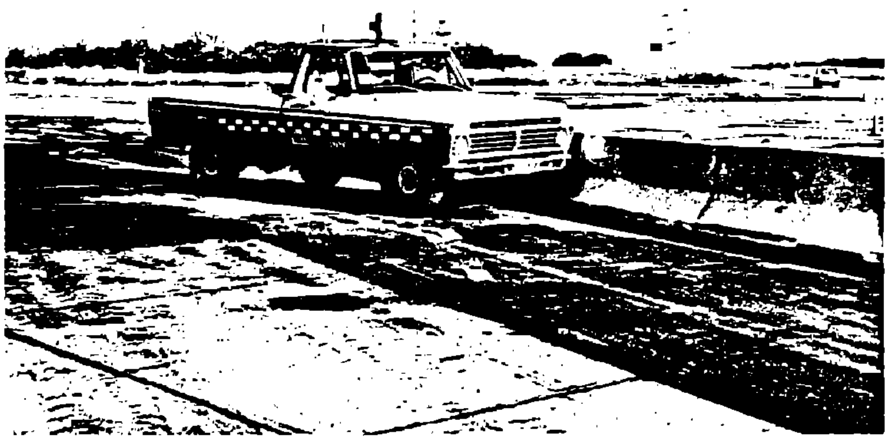


Figure 56. Vehicle before test 3825-15.

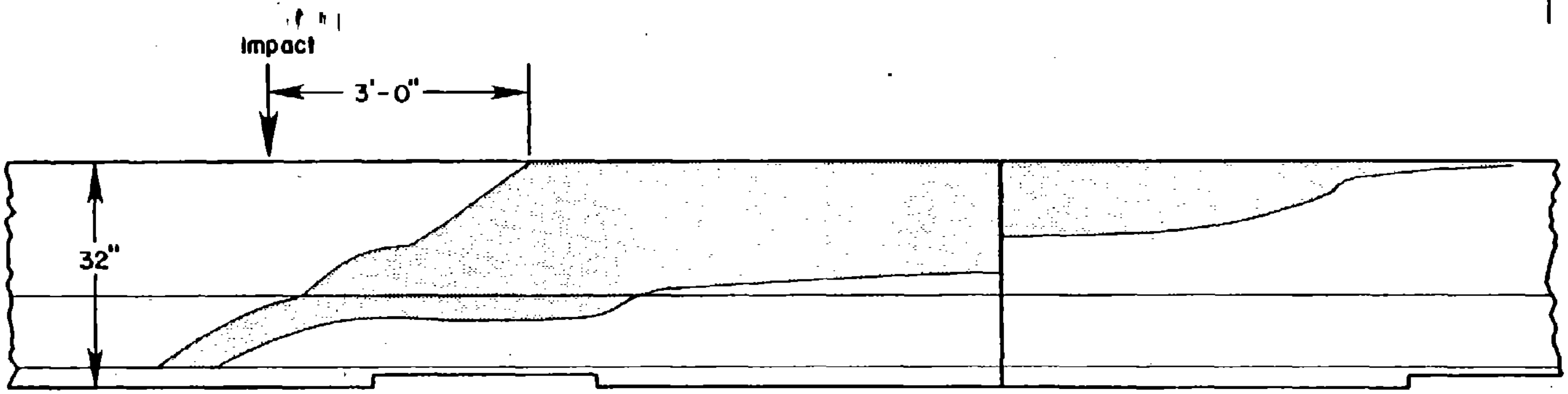
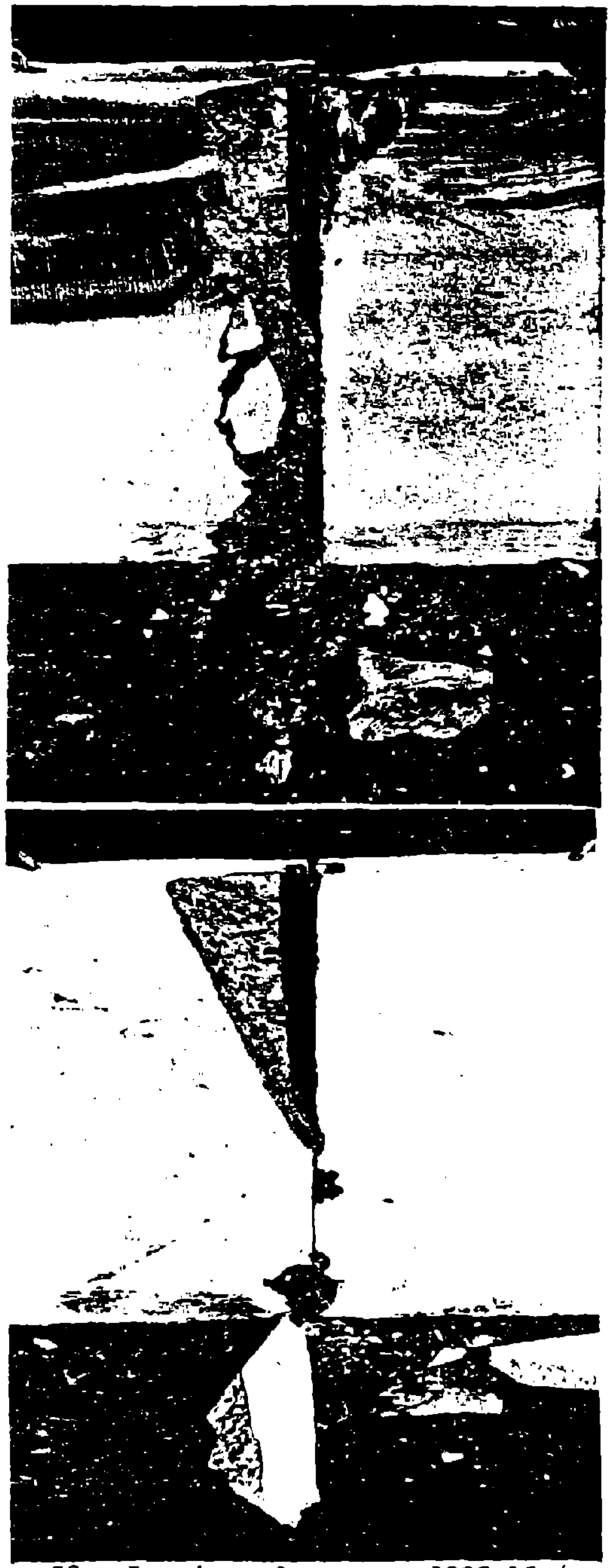


Figure 57. Tire path for test 3825-15.

Joint between segments 3 and 4.

Figure 58. Barrier after test 3825-15.



Joint between segments 4 and 5.

Joint between segments 5 and 6.

Figure 58. Barrier after test 3825-15 (continued).

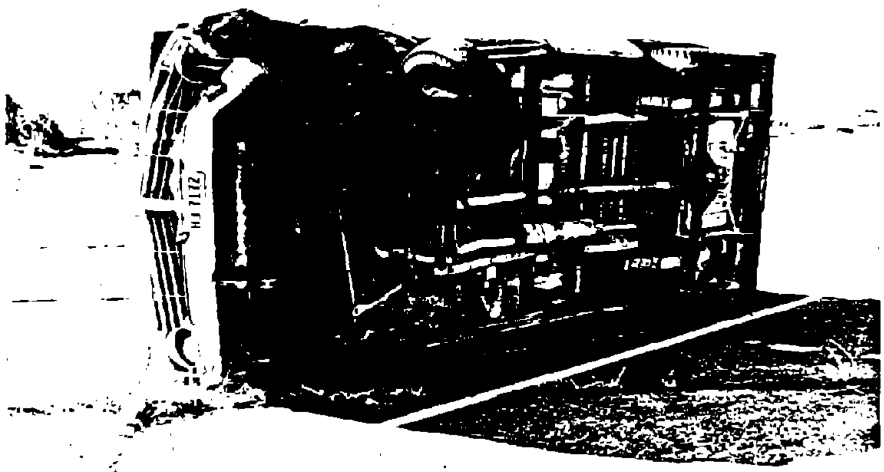


Figure 59. Vehicle after test 3825-15.
(Showing damage to undercarriage)

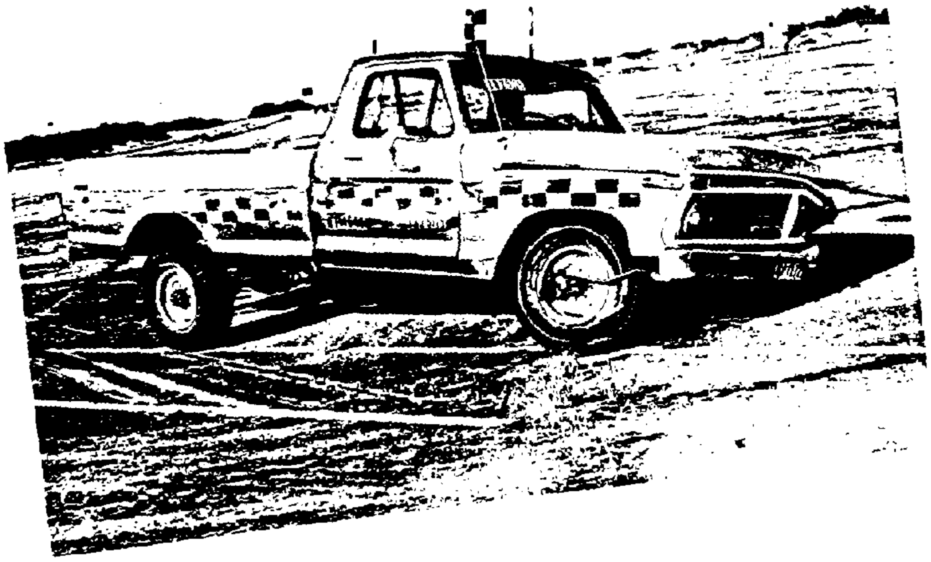
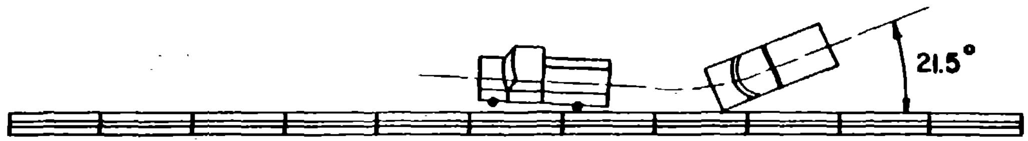
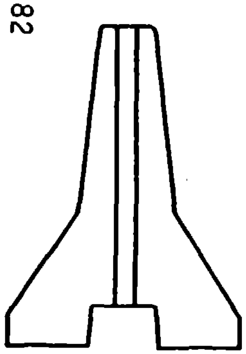


Figure 60. Vehicle after test 3825-15.
(After being turned upright)

0.000 sec 0.123 sec 0.249 sec 0.371 sec





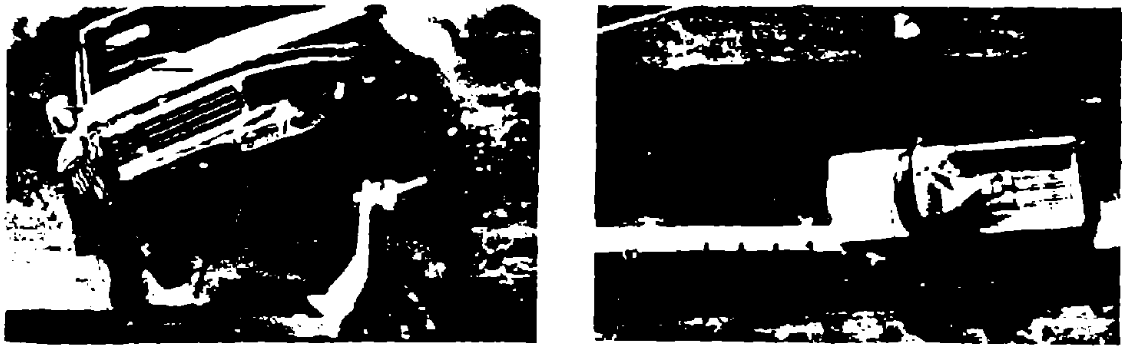
Concrete
Median Barrier

Test No.	3825-15
Date	1/26/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.08 ft (0.02 m)
Maximum	0.63 ft (0.19 m)
Vehicle	1974 Ford F250
Vehicle Weight	4540 lbs (2061 kg)
Vehicle Damage Classification	
TAD	11LFQ5
SAE	11FLEK2 11LFES3

Impact Speed	60.2 mph (96.9 kph)
Impact Angle	21.5 deg
Exit	Vehicle subsequently came to rest on side
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-7.0 g
Lateral	-8.7 g
Vertical	3.1 g
Vector Resultant	11.4 g
Occupant Impact Velocity	
Longitudinal	24.2 fps (7.4 m/s)
Lateral	19.3 fps (5.9 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-3.0 g
Lateral	-11.1 g

Figure 61. Data summary for test 3825-15.

Figure 62. Sequential photographs for test 3825-15.



0.249 sec

0.310 sec

0.371 sec

0.436 sec

Figure 62. Sequential photographs for test 3825-15 (continued).

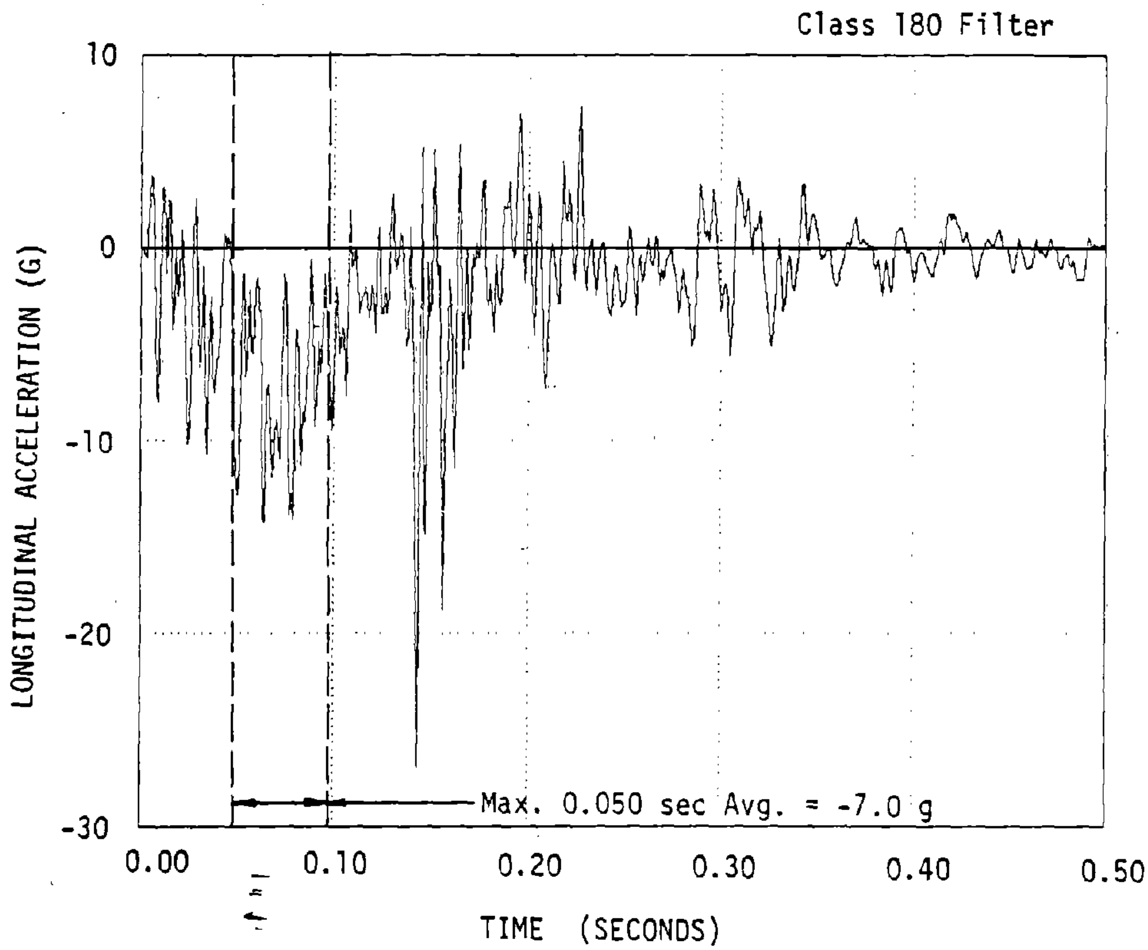


Figure 63. Vehicle longitudinal accelerometer trace for test 3825-15.

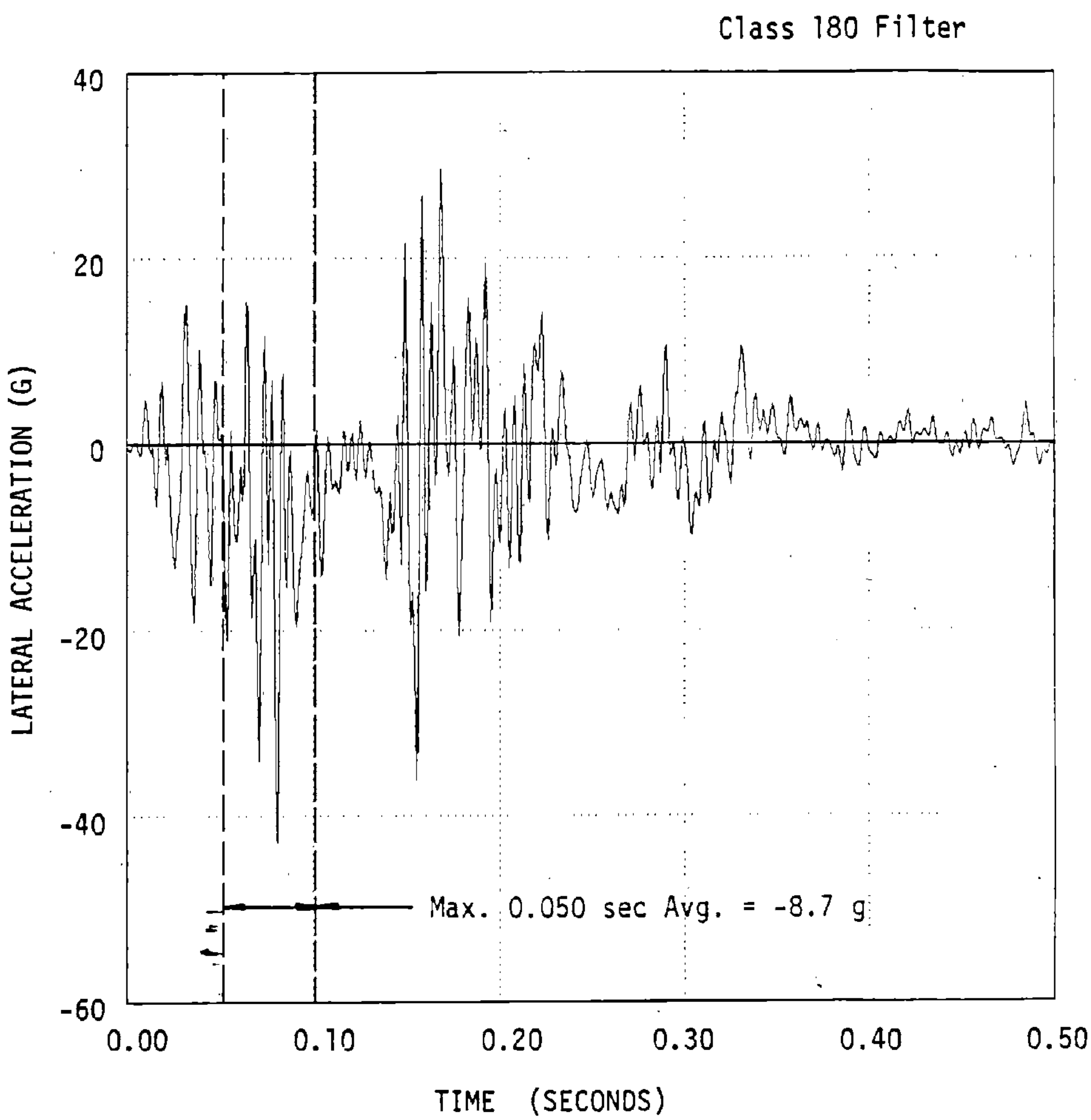


Figure 64. Vehicle lateral accelerometer trace for test 3825-15.

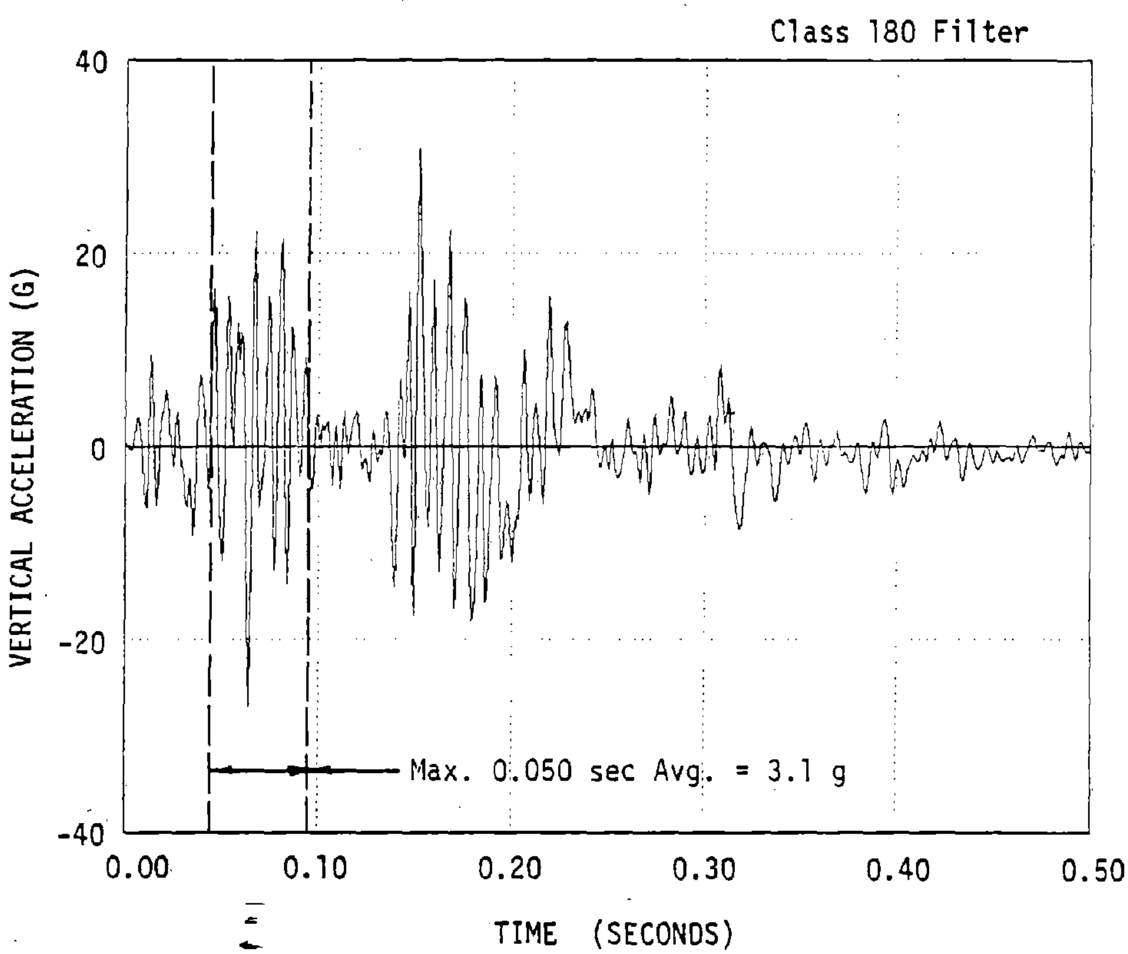


Figure 65. Vehicle vertical accelerometer trace for test 3825-15.

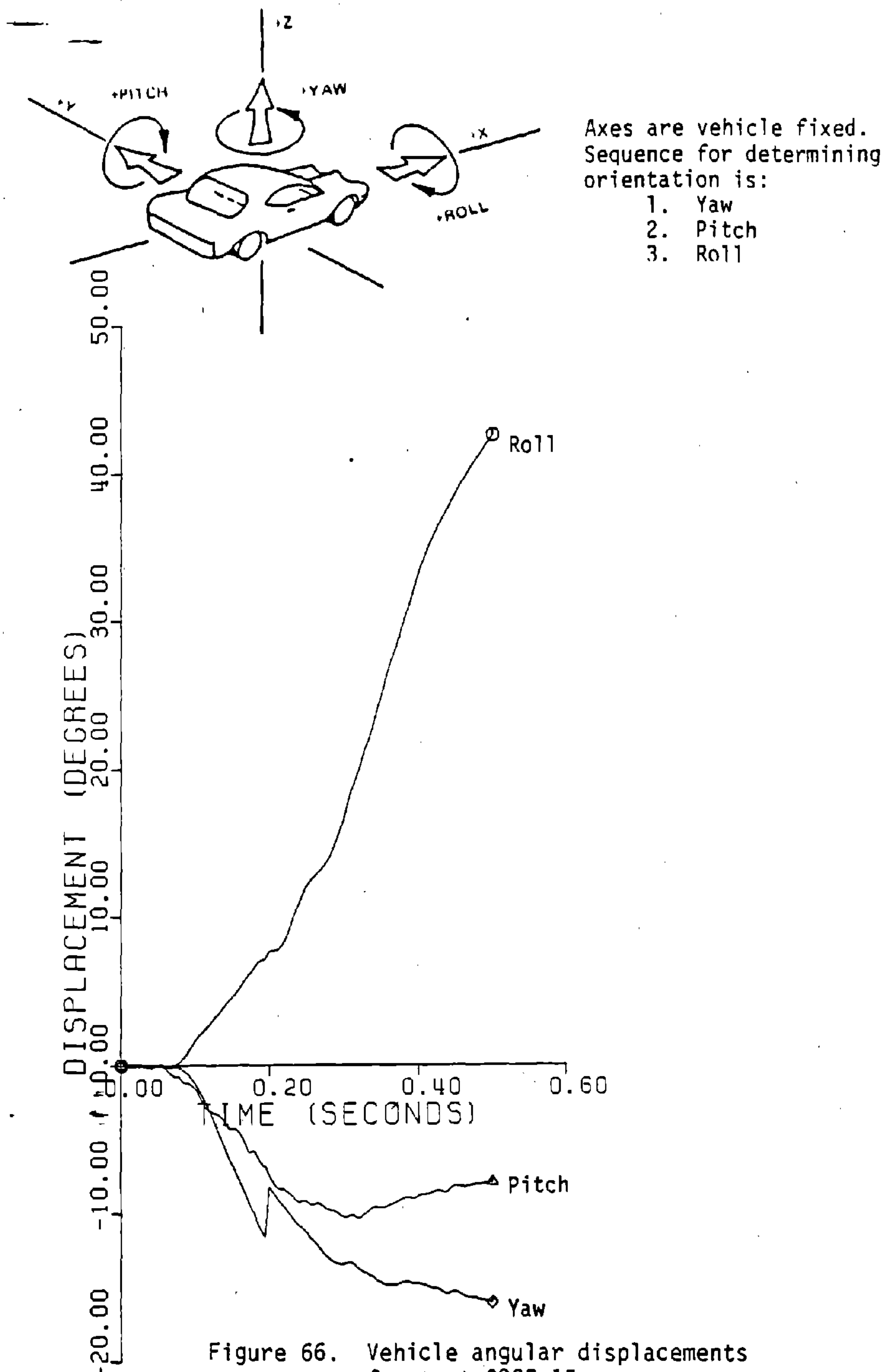


Figure 66. Vehicle angular displacements for test 3825-15.

TEST REPORT NO. 3825-16

Vehicle: 1972 Chevrolet 4-Wheel Drive Pickup,
Vehicle Weight 4,760 lbs

Barrier: 32 in high Concrete Median Barrier

Impact Conditions: 15 degrees, along length of need.
60 mph

Test Description

A 1972 Chevrolet Cheyenne 4-wheel drive pickup (see figure 67) was directed into the barrier at 59.7 mph (96.1 kph) and 14.5 degrees. Test inertia mass of the vehicle was 4,760 lb (2,161 kg). The vehicle was free-wheeling and unrestrained at impact.

The vehicle impacted the barrier approximately 3.0 ft (0.9 m) downstream of the joint between segments 3 and 4. The tire path on the barrier face is shown in figure 68. The top of the path reached the top of the barrier approximately 2.0 ft (0.6 m) downstream of the impact point. Tire marks extended to the upper edge of the barrier for a distance of over 14.0 ft (4.3 m) and the bottom of the tire marks formed a curved path as shown in figures 68 and 69. Total length of contact was approximately 18.0 ft (5.5 m). The vehicle was redirected and exited the barrier at 0.405 sec with exit angle of 0.5 degrees toward the barrier. The speed of the vehicle at loss of contact was 51.7 mph (83.2 kph).

The barrier received damage to segment 4 as shown in figure 69. Joints 3-4 and 4-5 were chipped and broken. The top of the barrier moved 0.14 ft (0.04 m) during the test and retained a permanent set of 0.03 ft (0.01 m).

As shown in figure 70, the vehicle sustained damage to the left front quarter. The left front tire was deflated and the rim bent. The front axle and wheel assembly were also damaged.

Test Results

A summary of test data is presented in figure 71. Figure 72 consists of sequential photographs. Vehicle accelerometer traces are displayed in figures 73 through 75, and vehicle angular displacements in figure 76.

The maximum 50-msec average accelerations were -4.4 g longitudinal and -8.9 g lateral. Maximum 50-msec average vector resultant acceleration was 10.4 g.

NCHRP Report 230 describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted with standard passenger automobiles at 15-degree impact angles.(3) These acceptance limits do not apply to the test reported herein but were computed and reported for information only. The normalized occupant/compartment impact velocity in the longitudinal direction was 12.7 fps (3.9 m/s), and 17.5 fps (5.3 m/s) in the lateral direction. The maximum 10-msec average longitudinal occupant ridedown acceleration was -1.2 g, and -6.7 g for the lateral direction.

The barrier redirected the vehicle and detached elements did not penetrate the occupant compartment. The vehicle remained upright during and after impact. Exit angle was 0.5 degrees toward the barrier and vehicle change in speed at loss of contact was 8.0 mph (12.9 kph).

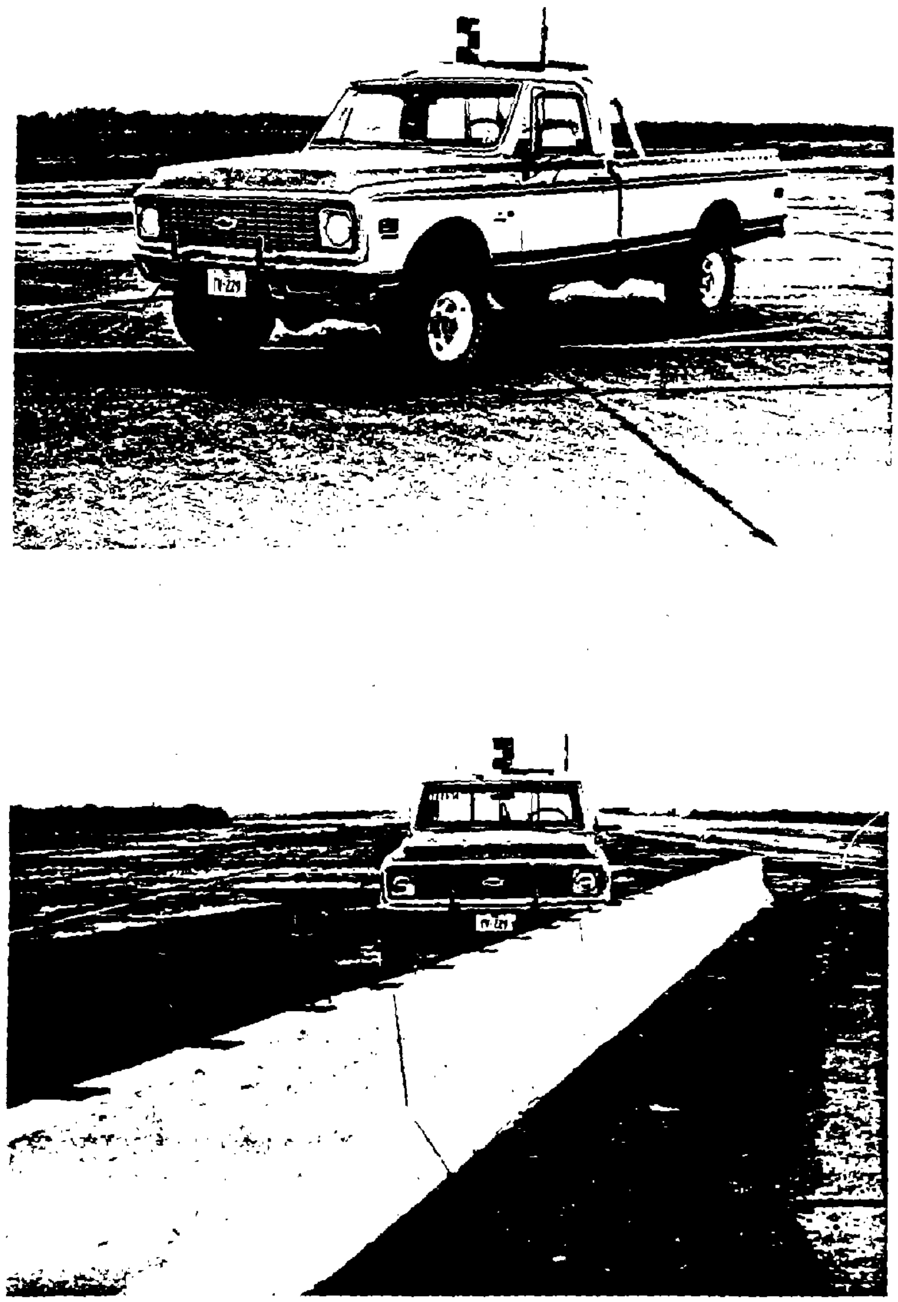


Figure 67. Vehicle before test 3825-16.

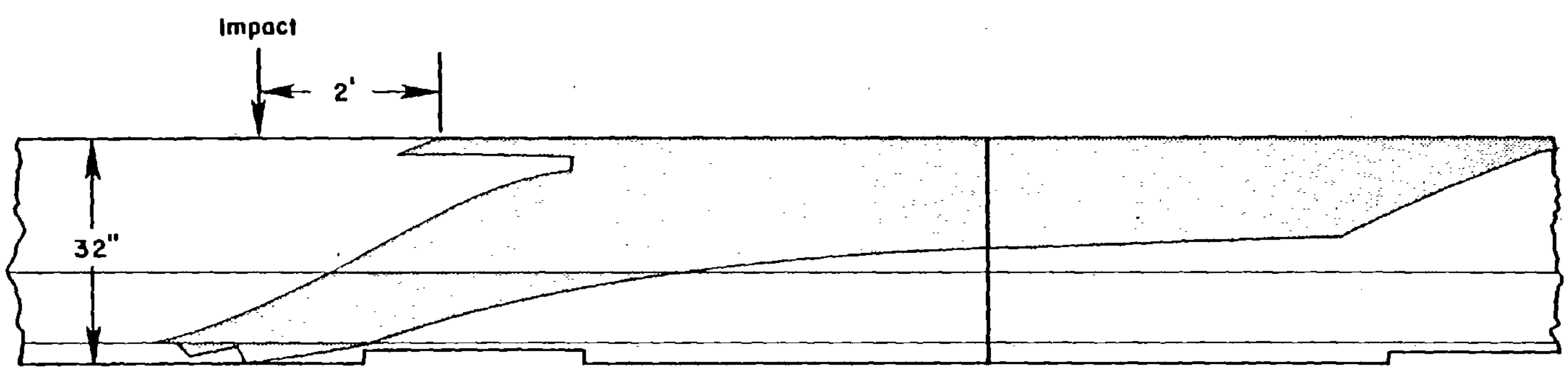


Figure 68. Tire path for test 3825-16.

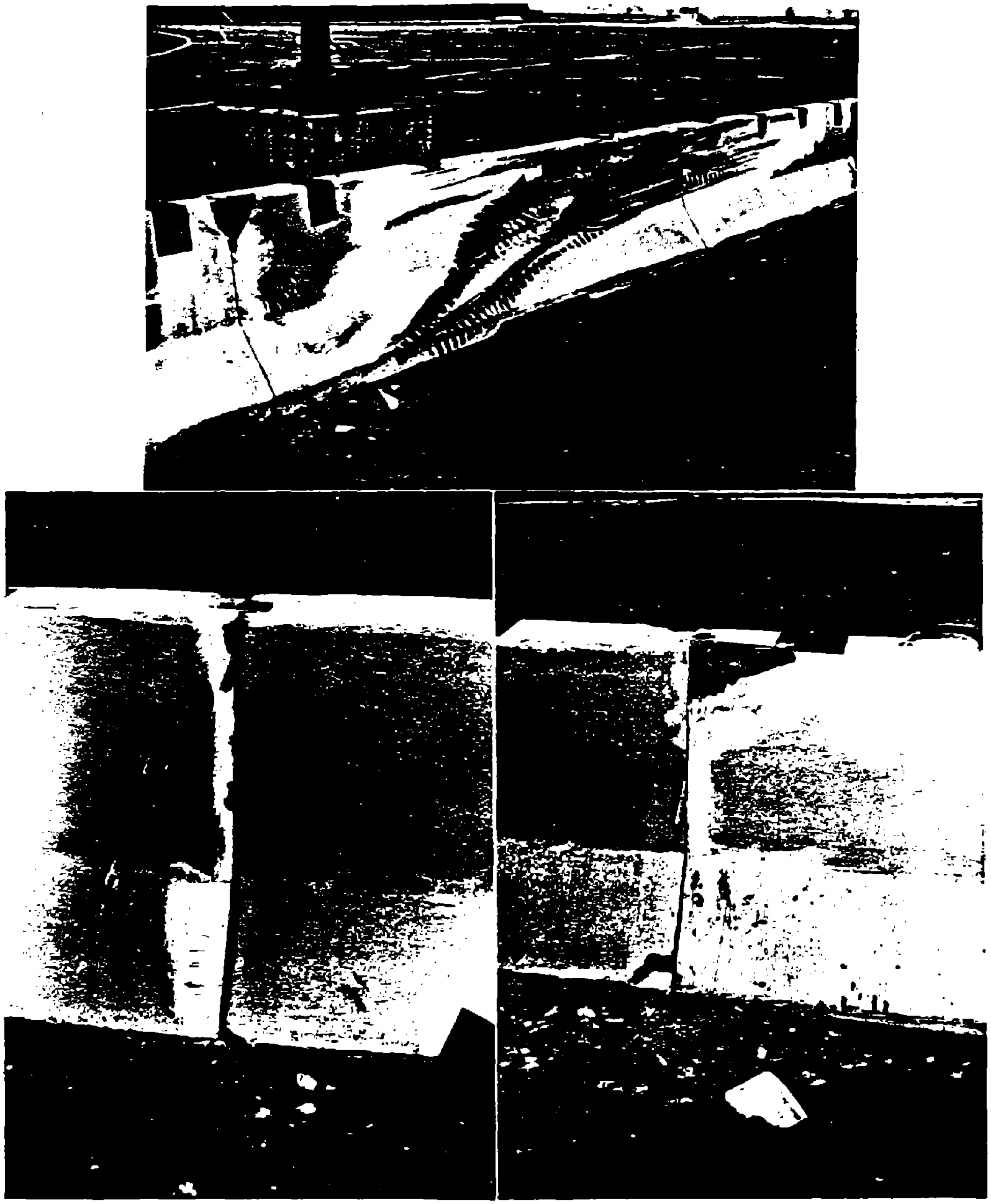


Figure 69. Barrier after test 3825-16.

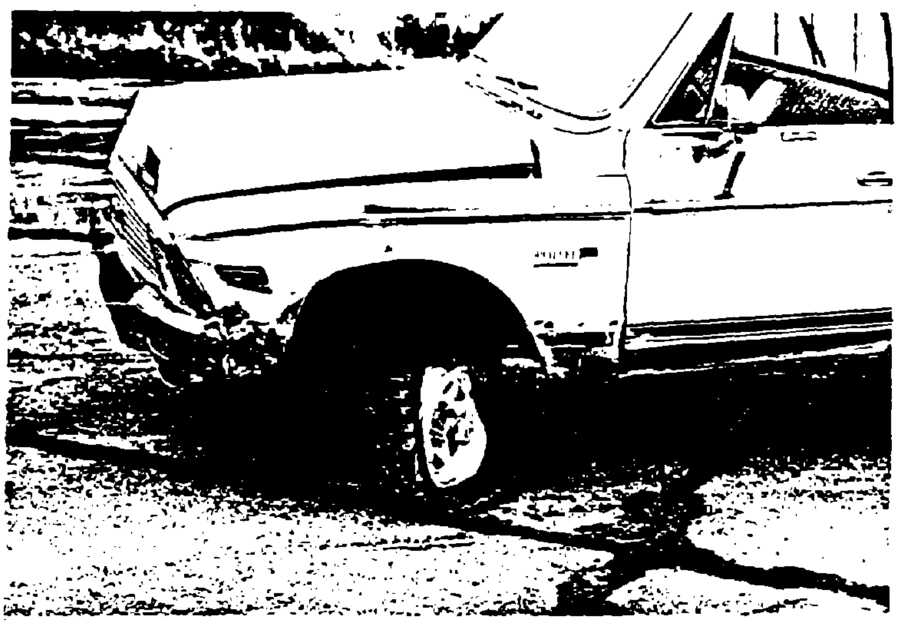
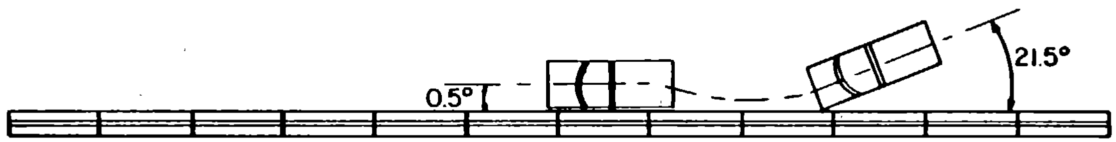
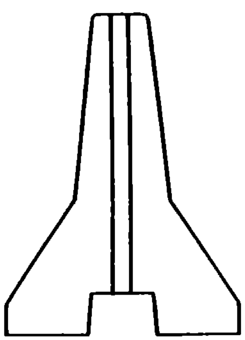


Figure 70. Vehicle after test 3825-16.

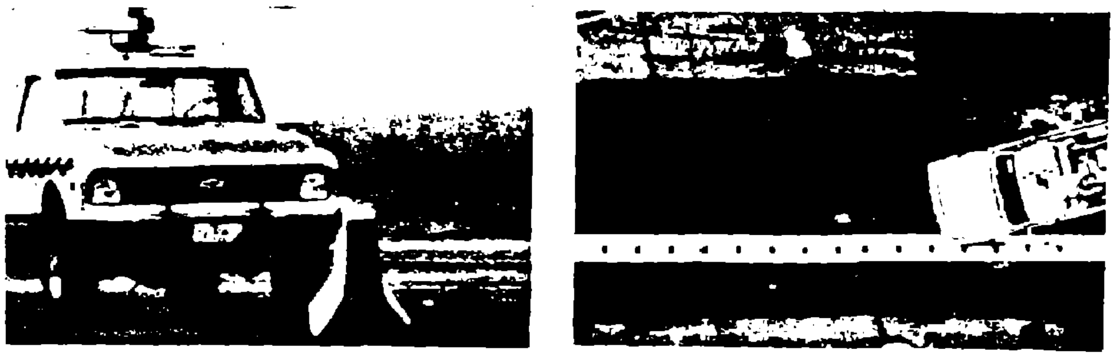




Test No.	3825-16
Date	1/24/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.03 ft (0.01 m)
Maximum	0.14 ft (0.04 m)
Vehicle	1972 Chev. 4-wheel drive pickup
Vehicle Weight	4760 lbs (2161 kg)
Vehicle Damage Classification	
TAD	11LFQ3
SAE	11FLEK1 11LFES3

Impact Speed	59.7 mph (96.1 kph)
Impact Angle	14.5 deg
Exit Speed	51.7 mph (83.2 kph)
Exit Angle	0.5 deg
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-4.4 g
Lateral	-8.9 g
Vertical	3.3 g
Vector Resultant	10.4 g
Occupant Impact Velocity	
Longitudinal	12.7 fps (3.9 m/s)
Lateral	17.5 fps (5.3 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-1.2 g
Lateral	-6.7 g

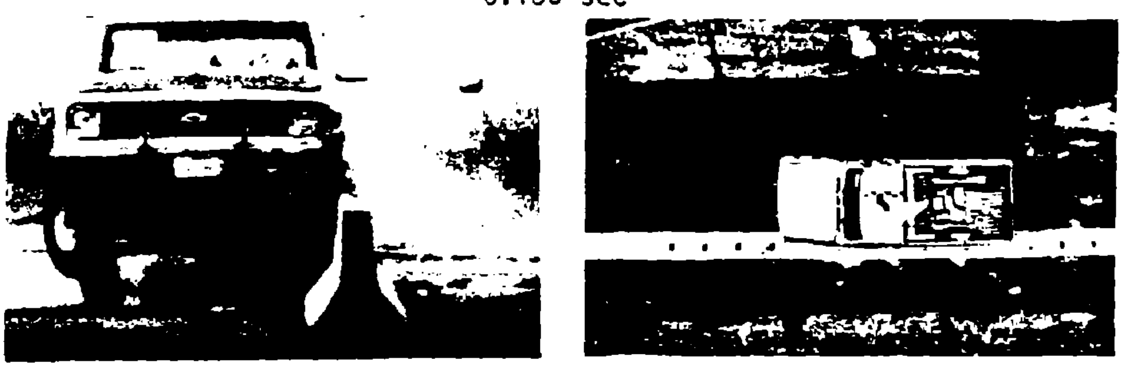
Figure 71. Data summary for test 3825-16.



0.000 sec

0.070 sec

0.135 sec

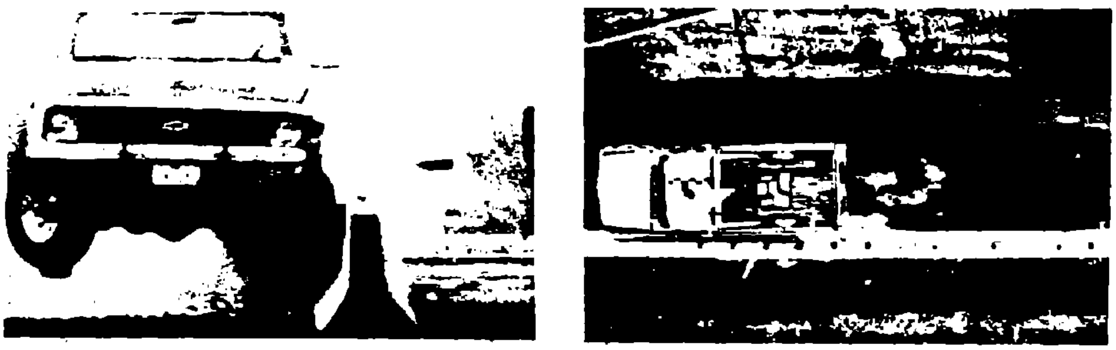


0.205 sec

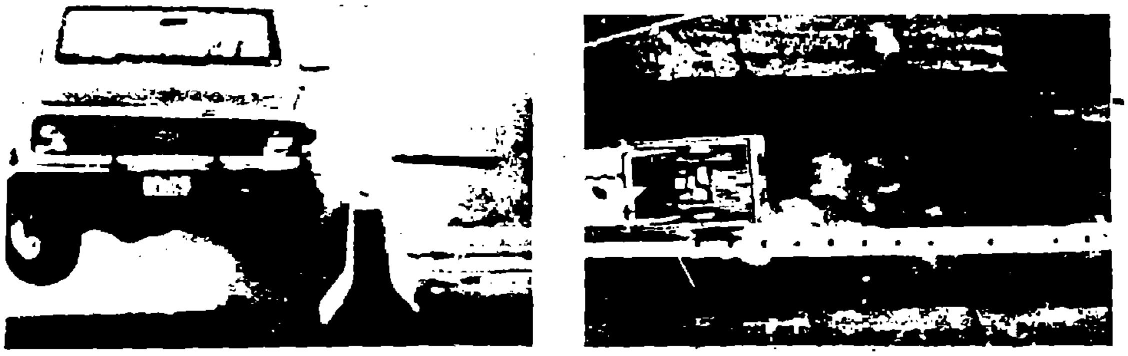
Figure 72. Sequential photographs for test 3825-16.

0.275 sec

0.340 sec



0.405 sec



0.480 sec

Figure 72. Sequential photographs for test 3825 (continued).

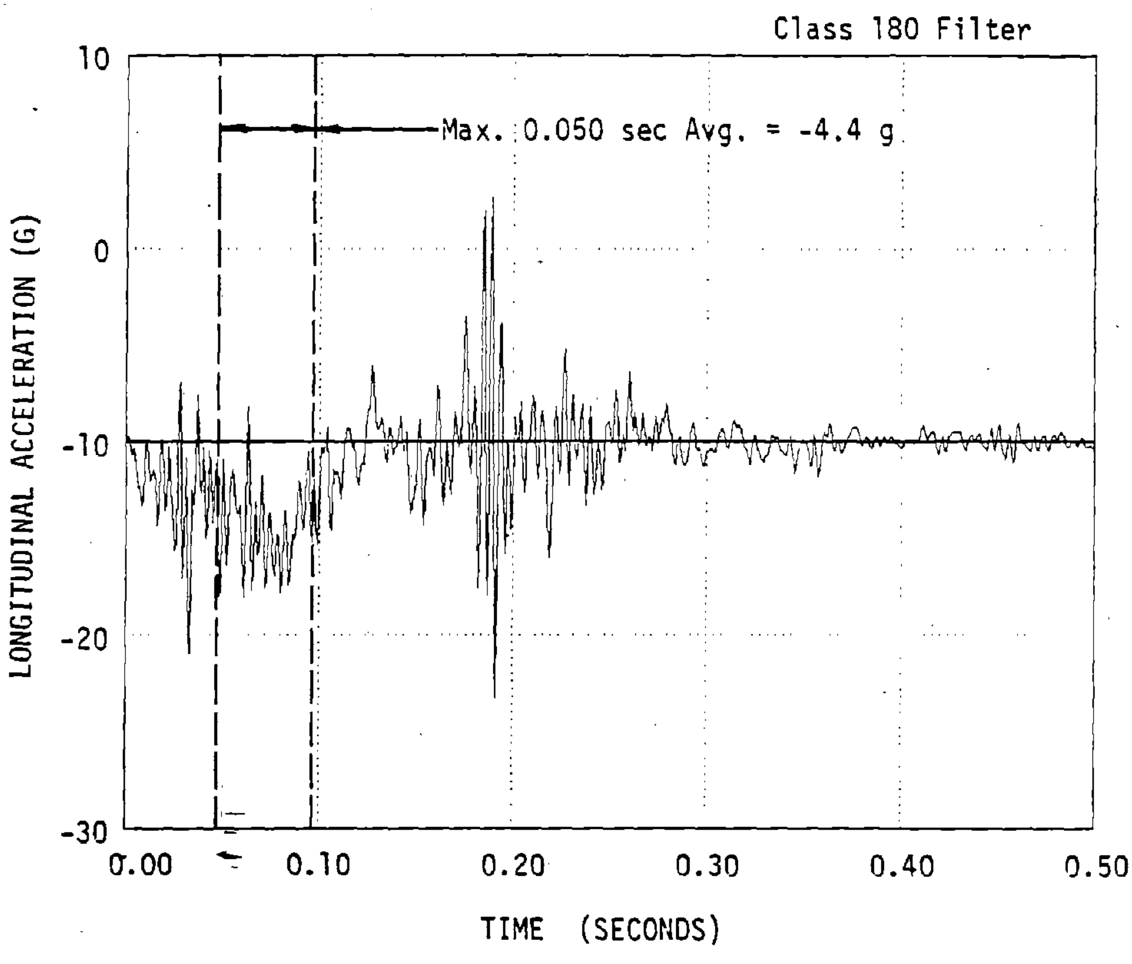


Figure 73. Vehicle longitudinal accelerometer trace for test 3825-16.

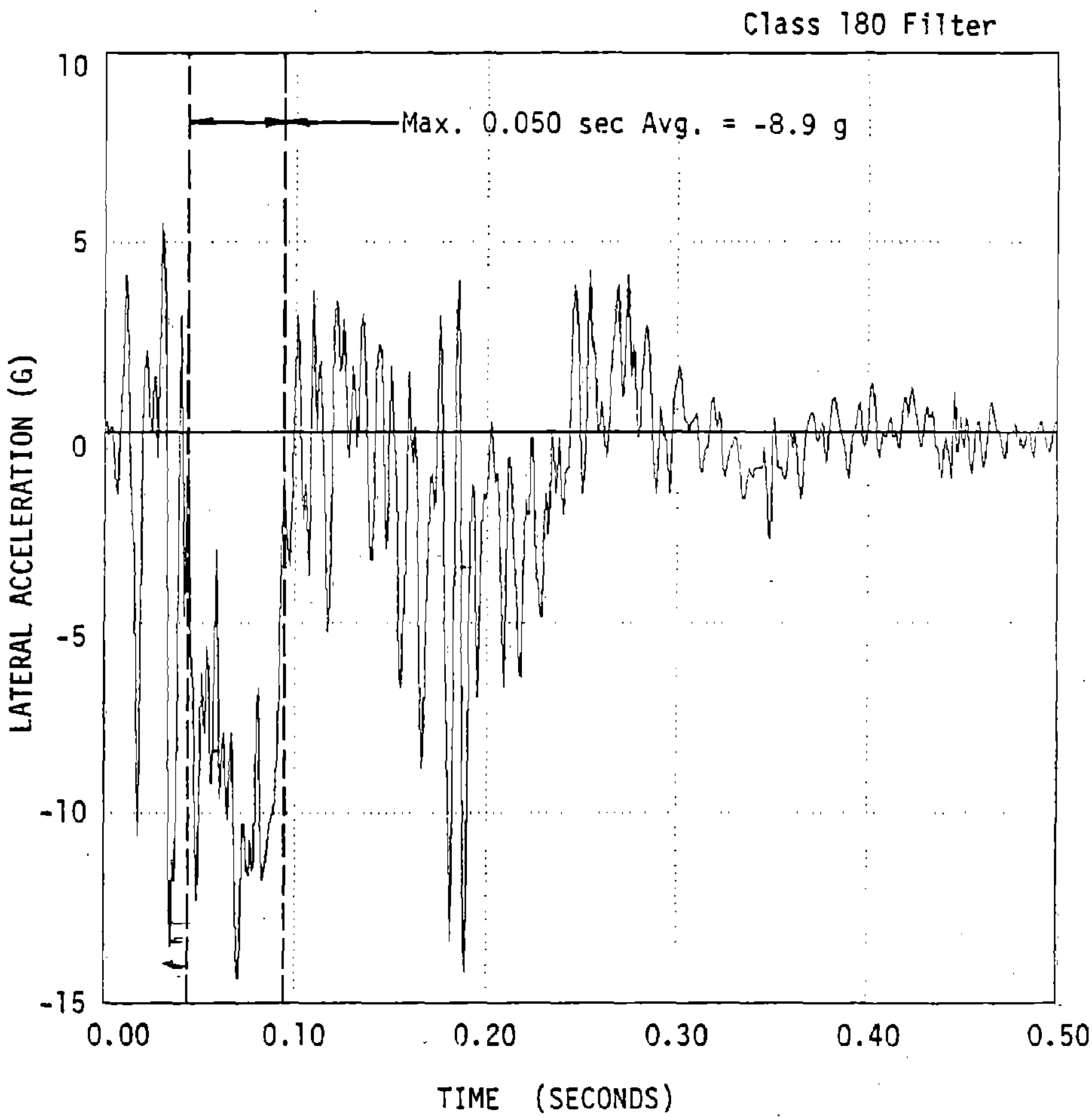


Figure 74. Vehicle lateral accelerometer trace for test 3825-16.

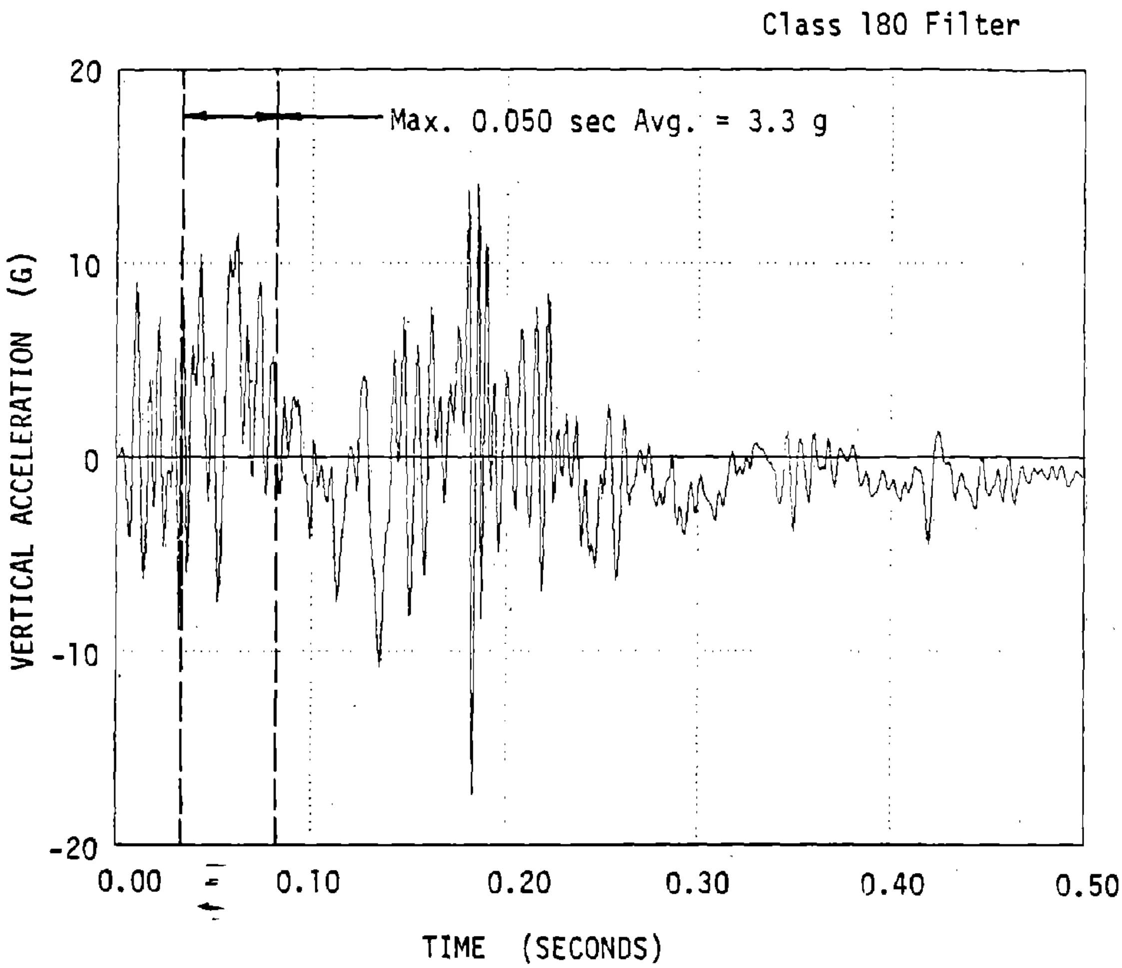
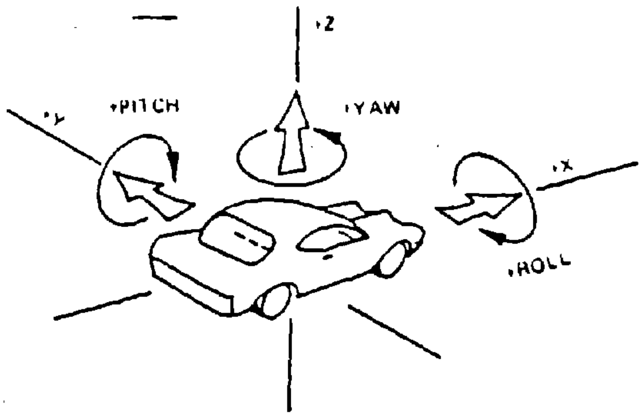


Figure 75. Vehicle vertical accelerometer trace for test 3825-16.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

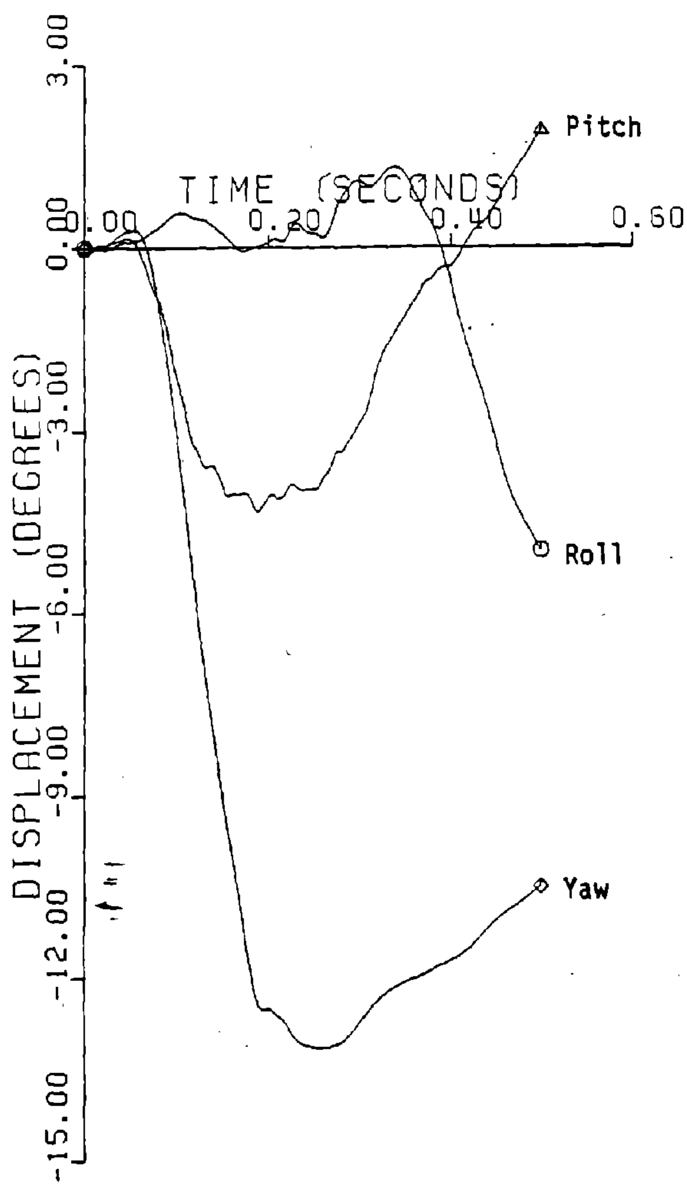


Figure 76. Vehicle angular displacements for test 3825-16.

TEST REPORT NO. 3825-17

Vehicle: 1973 Ford 2-1/2-ton Truck

Barrier: 32 in high Concrete Median Barrier

Impact Conditions: 15 degrees, along length of need.
60 mph

Test Description

For this test a steel back up structure was added to the rear side of the barrier as shown in figure 77. This was added to prevent significant deflection of the barrier when impacted by the heavy vehicle. A 1973 Ford 2-1/2-ton truck (see figure 78 and 79) was directed into the barrier at 60.1 mph (96.7 kph) and 15.0 degrees. Empty weight of the vehicle was 9,770 lbs (4,436 kg) and the gross static mass was 18,240 lb (8,281 kg). The vehicle was free-wheeling and unrestrained at impact.

The vehicle impacted the barrier approximately 1.0 ft (0.3 m) downstream of the joint between segments 3 and 4. The tire path on the barrier face is shown in figure 80. The top of the path reached the top of the barrier approximately 5.0 ft (1.5 m) downstream of the impact point. Tire marks extended to the upper edge of the barrier for a distance of over 60.0 ft (18.3 m) as shown in figure 81. Marks were also made on the rear of the barrier. Total length of contact was approximately 86.0 ft (26.2 m). The vehicle was redirected; however, it rolled onto the barrier and slid off the end at about 1.224 sec. Maximum roll was approximately 94 degrees. The speed of the vehicle at 1.000 sec (end of data processing) was 54.1 mph (87.0 kph).

The barrier received damage extending from the downstream end of segment 3 to the downstream end of the barrier (approximately 86.0 ft (26.2 m)). Joints 3-4, 4-5, 5-6 and 6-7 were chipped and cracked. Damage to the front of barrier is shown in figure 81. The top rear of segment 6 and the steel framework were scraped. Tire marks started on the top rear of segment 7, moved along the rear of segment 8 and ended near the ground 1.8 ft (0.6 m) upstream of joint 9-10. The rear of segment 10 was scraped. The barrier showed no measurable sign of movement.

The vehicle was severely damaged. The U-bolts attaching the axle to the frame were broken and the frame was bent. The motor mounts, springs and shack~~les~~ were severly damaged. The vehicle is shown in figures 82 and 83.

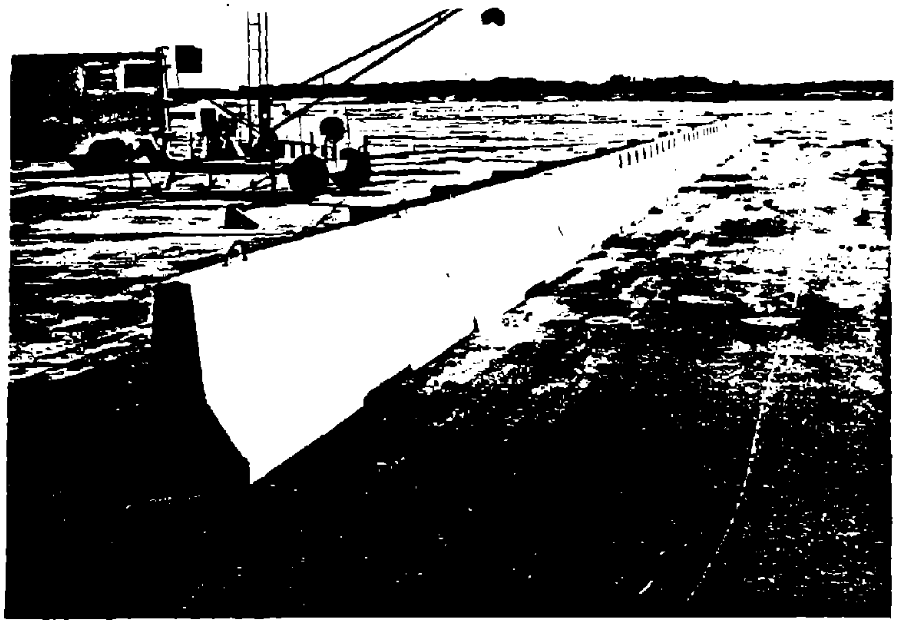
Test Results

A summary of test data is presented in figure 84. Figure 85 consists of sequential photographs. Vehicle accelerometer traces are displayed in figures 86 through 88, and vehicle angular displacement in figure 89.

The maximum 50-msec average accelerations were -1.7 g longitudinal and -8.4 g lateral. Maximum 50-msec average vector resultant acceleration was 8.6 g.

NCHRP Report 230 describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted with standard passenger automobiles at 15-degree impact angles.(3) These acceptance limits do not apply to the test reported herein, but were computed and reported for information only. The normalized occupant/compartment impact velocity in the longitudinal direction was 7.3 fps (2.2 m/s), and 10.0 fps (3.1 m/s) in the lateral direction. The maximum 10 msec average longitudinal occupant ridedown acceleration was -2.9 g, and -15.9 g for the lateral direction.

The barrier redirected the vehicle and detached elements did not penetrate the occupant compartment. However, the vehicle rolled onto the barrier and subsequently slid off the end of the barrier and came to rest on its left side. Vehicle change in speed at 1.000 sec after impact was 6.0 mph (9.7 kph).



Barrier Front

Rear View of Barrier

Figure 77. Barrier before test 3825-17.

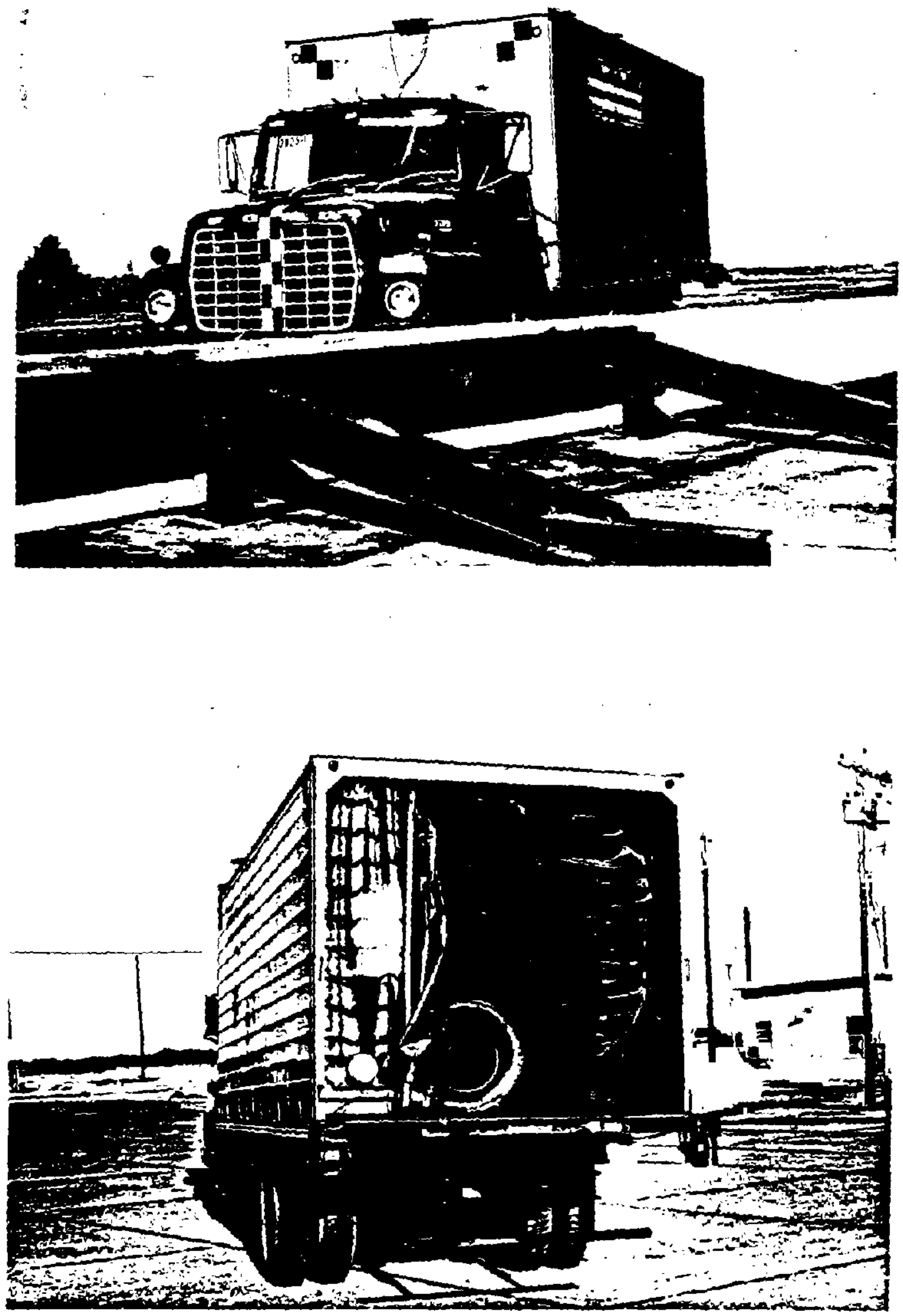


Figure 78. Vehicle before test 3825-17.

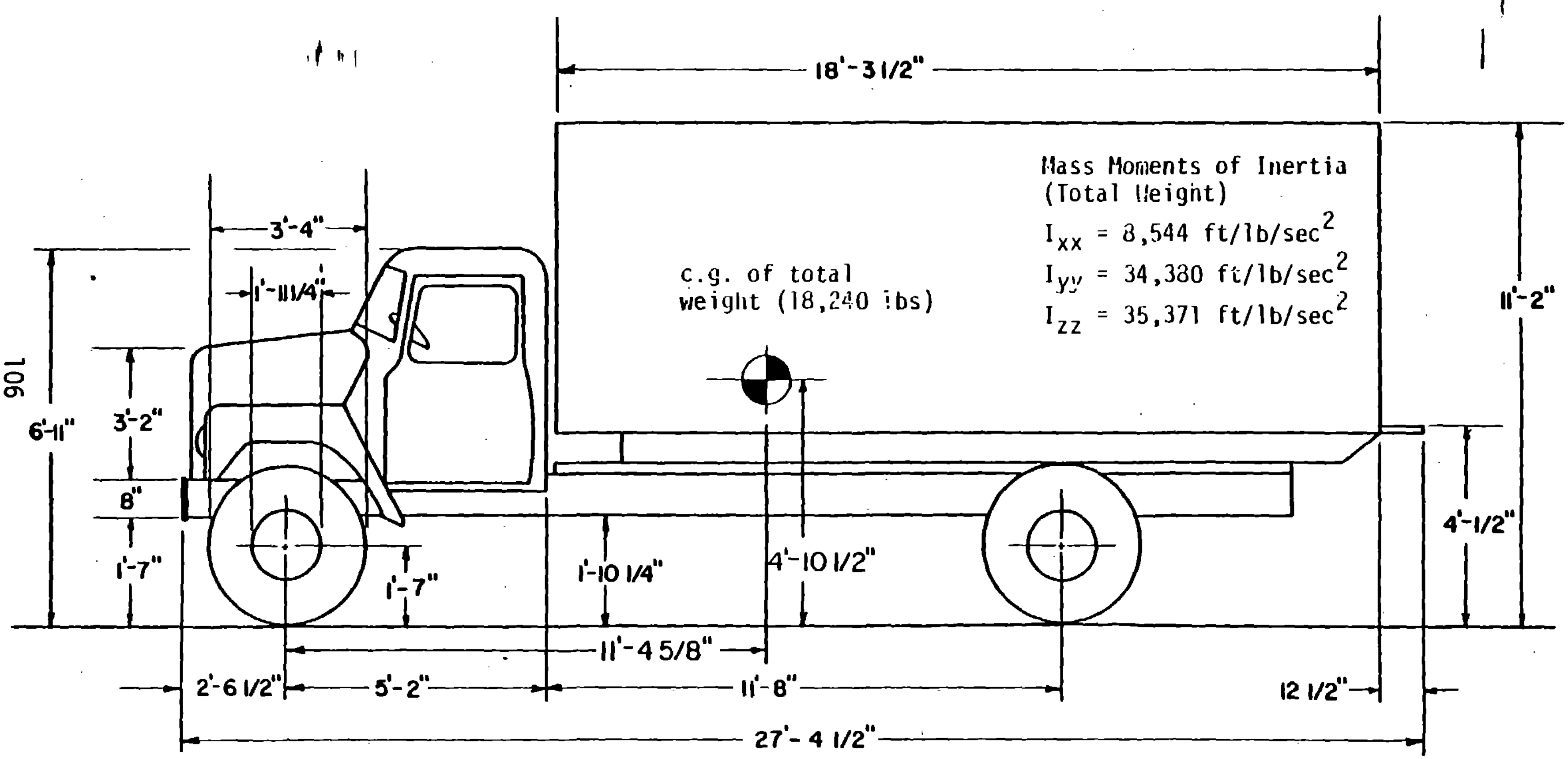


Figure 79. Test vehicle dimensions.

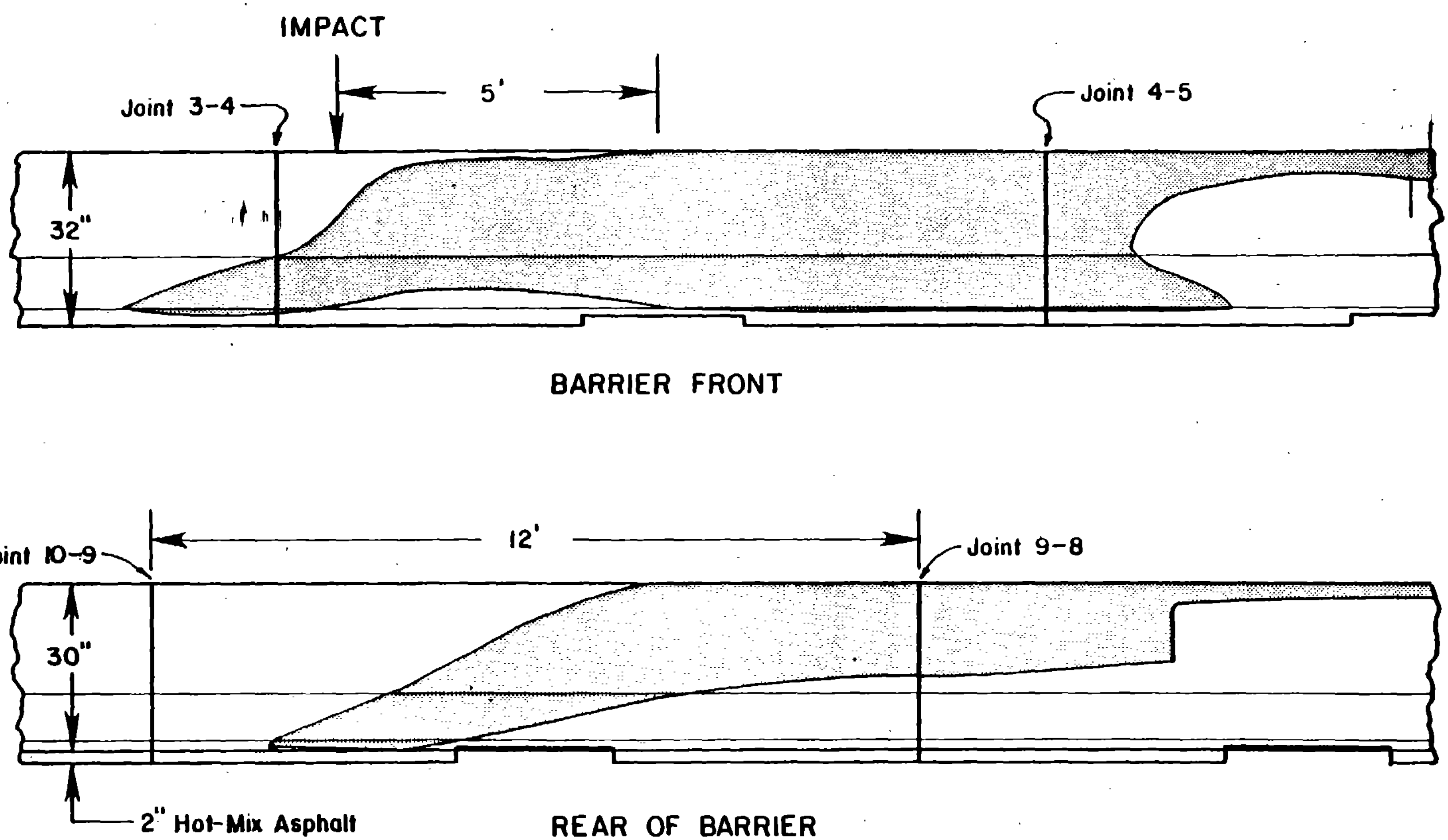
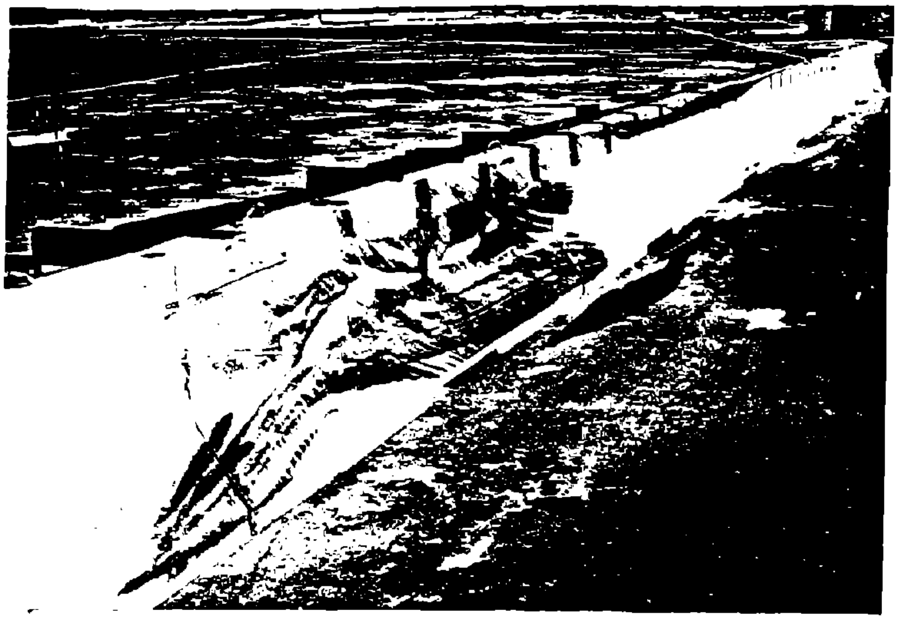
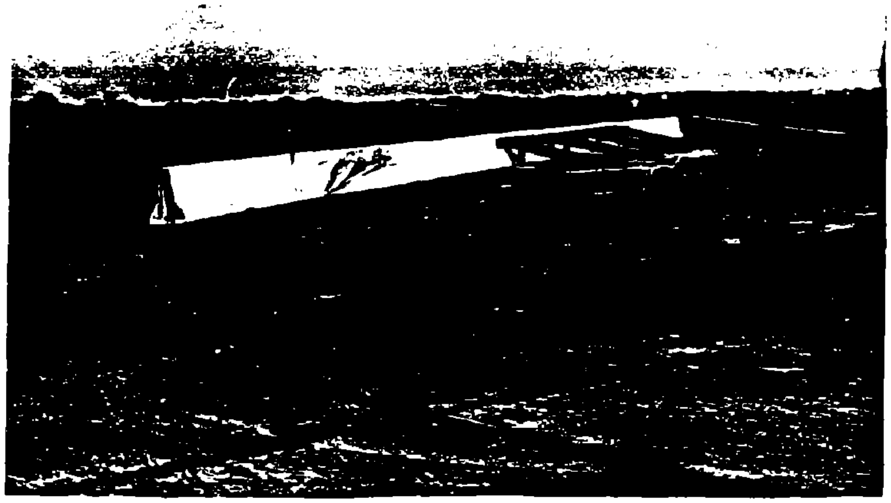


Figure 80. Tire path for test 3825-17.

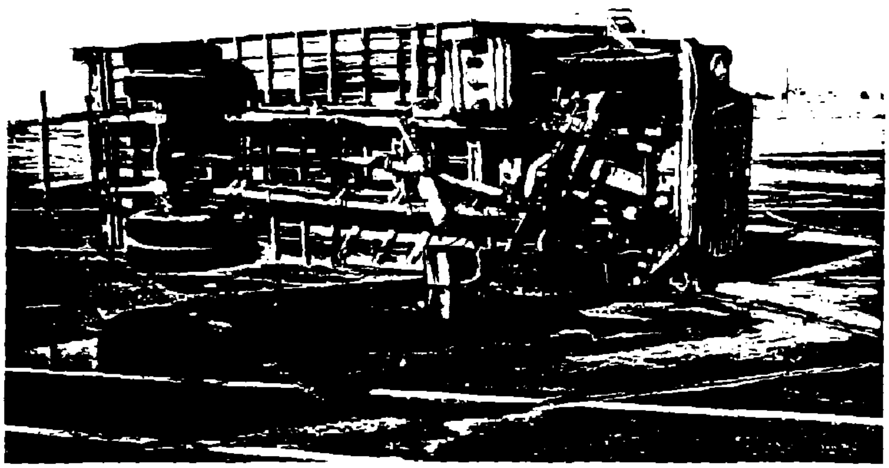


Front of Barrier



Rear Side of Barrier

Figure 81. Barrier after test 3825-17.



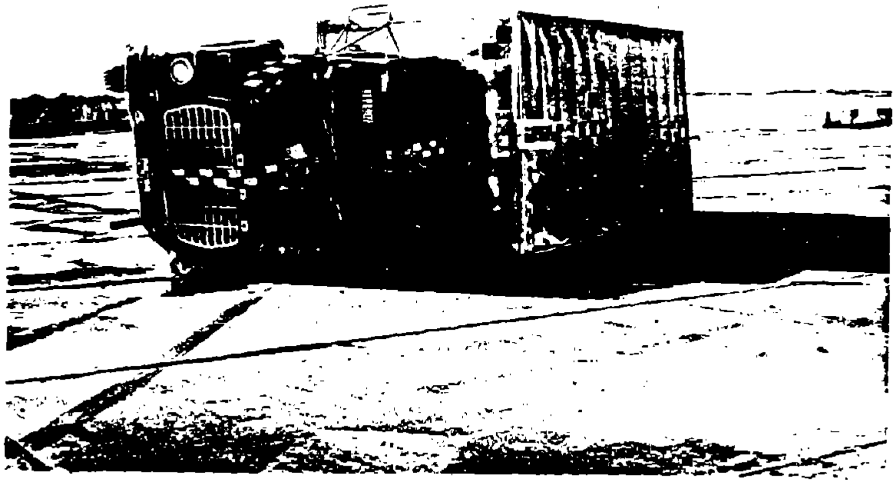


Figure 82. Vehicle after test 3825-17.

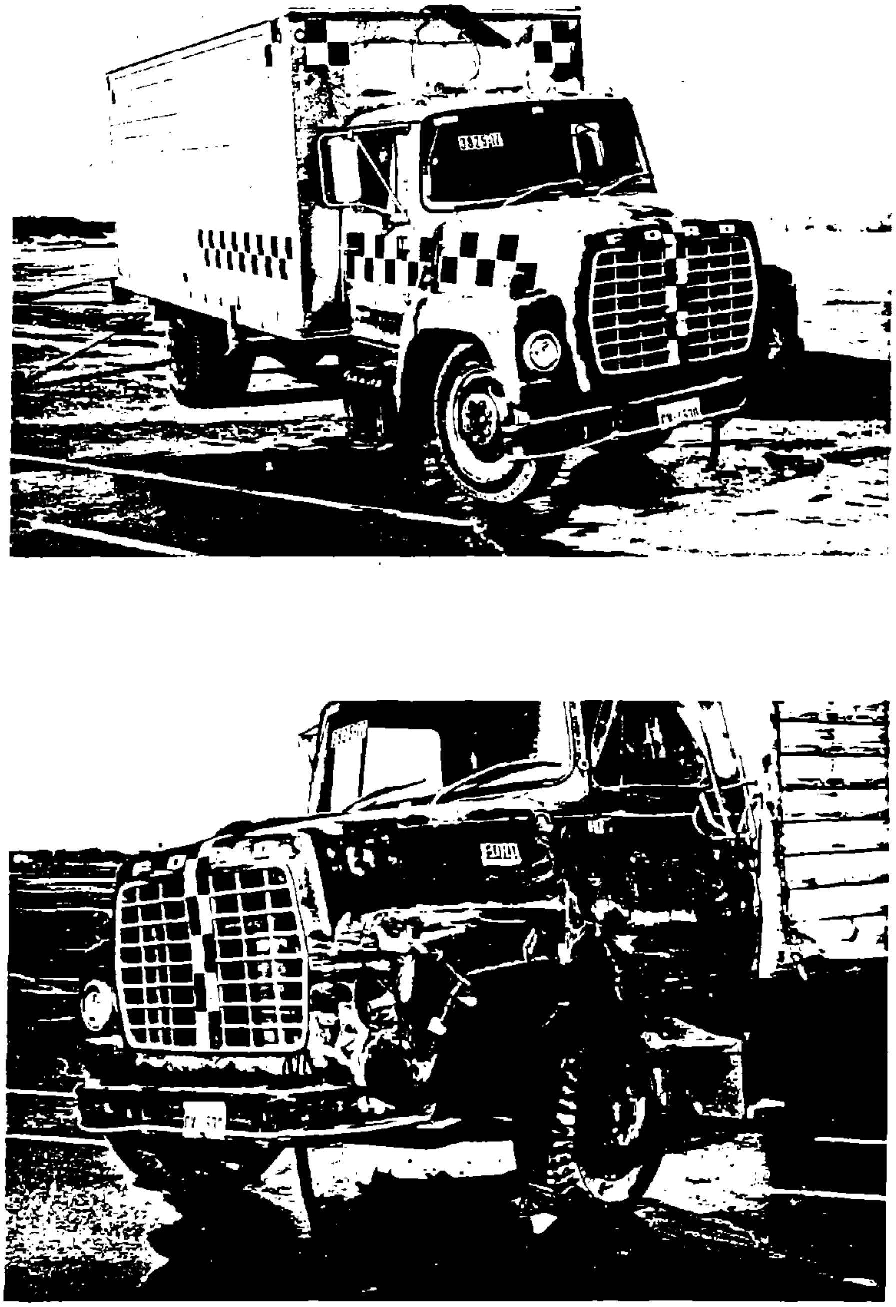
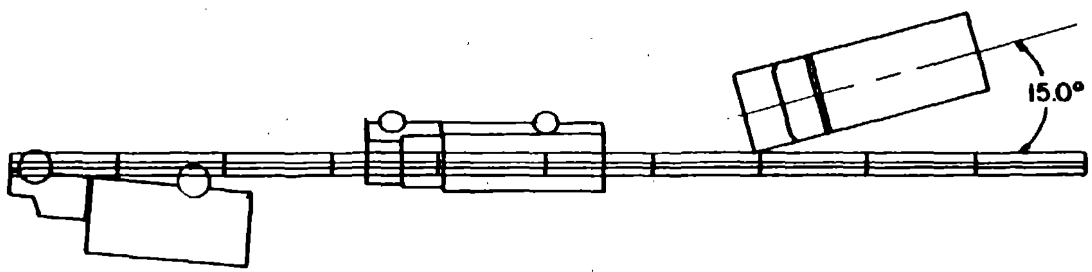
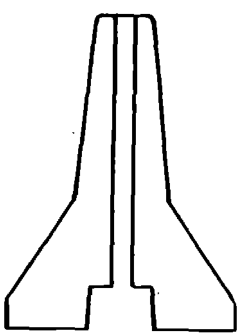


Figure 83. Vehicle after being uprighted
(After test 3825-17)

0.000 sec   0.171 sec   0.343 sec   0.514 sec





Concrete
Median Barrier

Test No.	3825-17
Date	2/24/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.00 ft (0.00 m)
Maximum	0.00 ft (0.00 m)
Vehicle	1973 Ford 2 1/2 ton truck
Vehicle Weight	
Empty Weight	9,770 lbs (4,436 kg)
Gross Static	18,240 lbs (8,281 kg)

Impact Speed	60.1 mph (96.7 kph)
Impact Angle	15.0 deg
Speed at 1.000 sec	54.1 mph (87.0 kph)
Exit	Truck slid off end of barrier and came to rest on left side
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-1.7 g
Lateral	-8.4 g
Vertical	2.7 g
Vector Resultant	8.6 g
Occupant Impact Velocity	
Longitudinal	7.3 fps (2.2 m/s)
Lateral	10.0 fps (3.1 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-2.9 g
Lateral	-15.9 g

Figure 84. Data summary for test 3825-17.

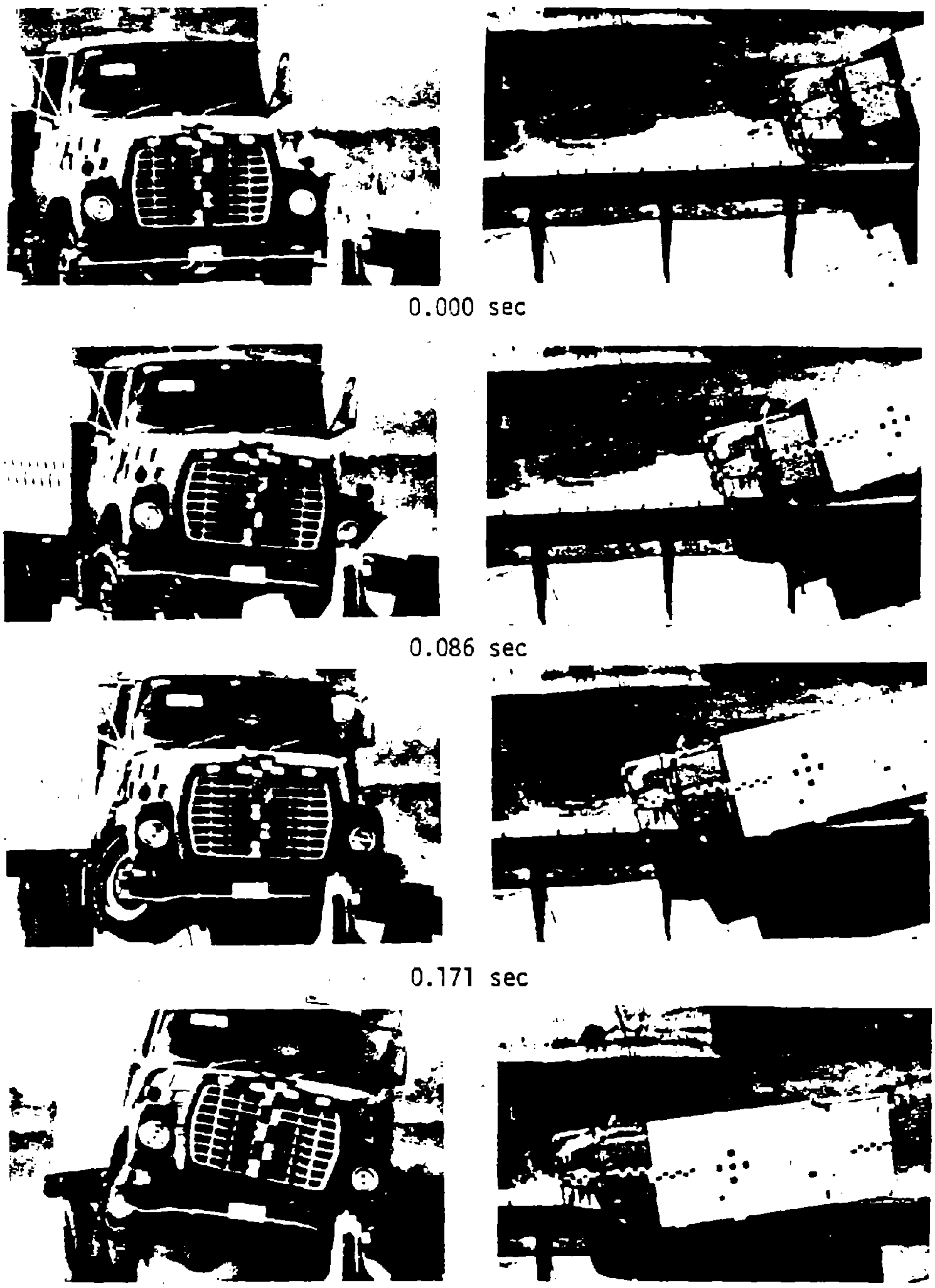


Figure 85. Sequential photographs for test 3825-17.

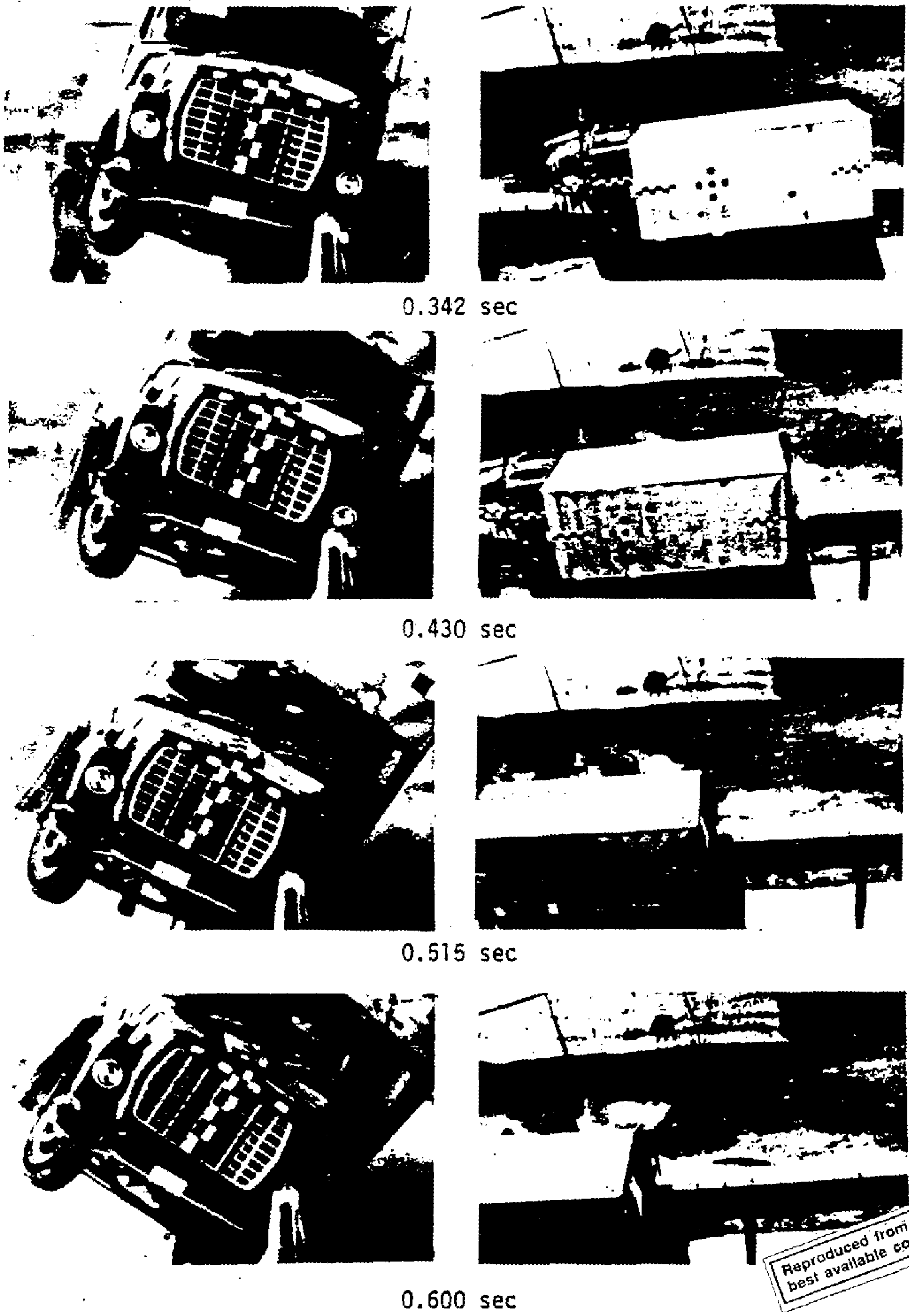


Figure 85. Sequential photographs for test 3825-17 (continued).

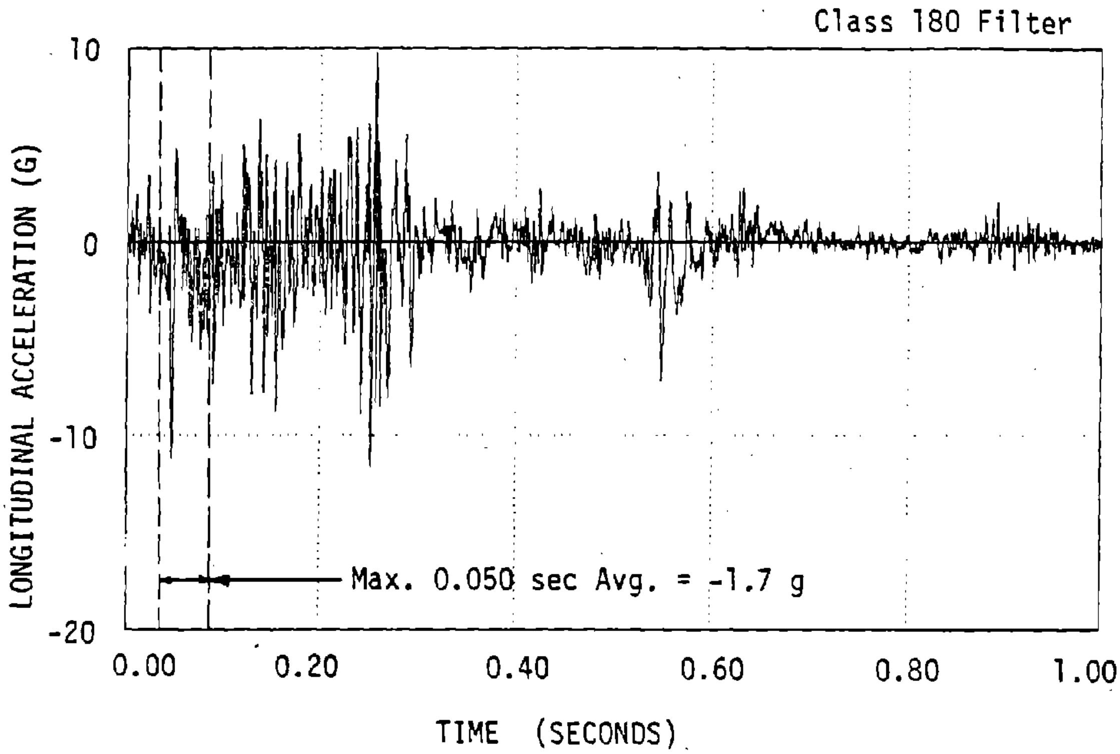


Figure 86. Vehicle longitudinal accelerometer trace for test 3825-17.

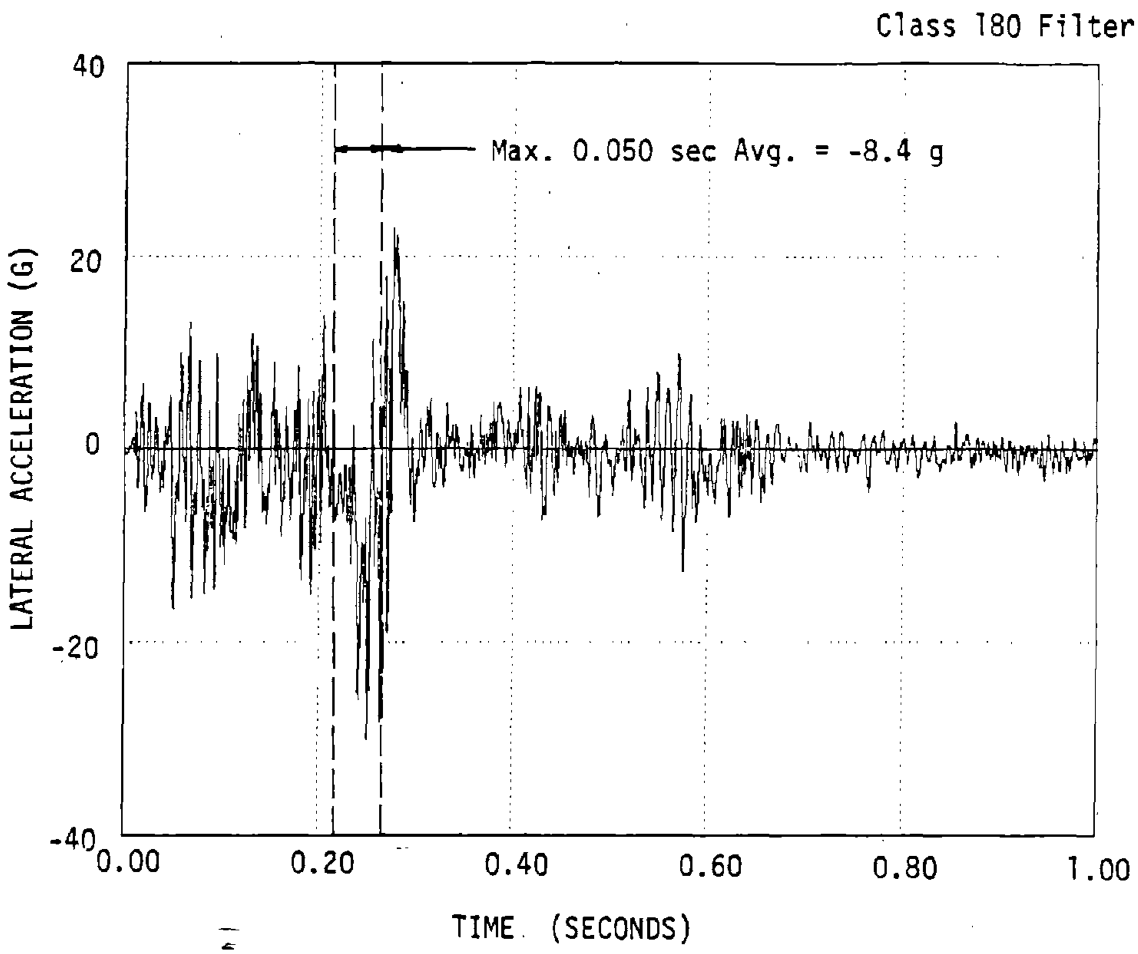


Figure 87. Vehicle lateral accelerometer trace for test 3825-17.

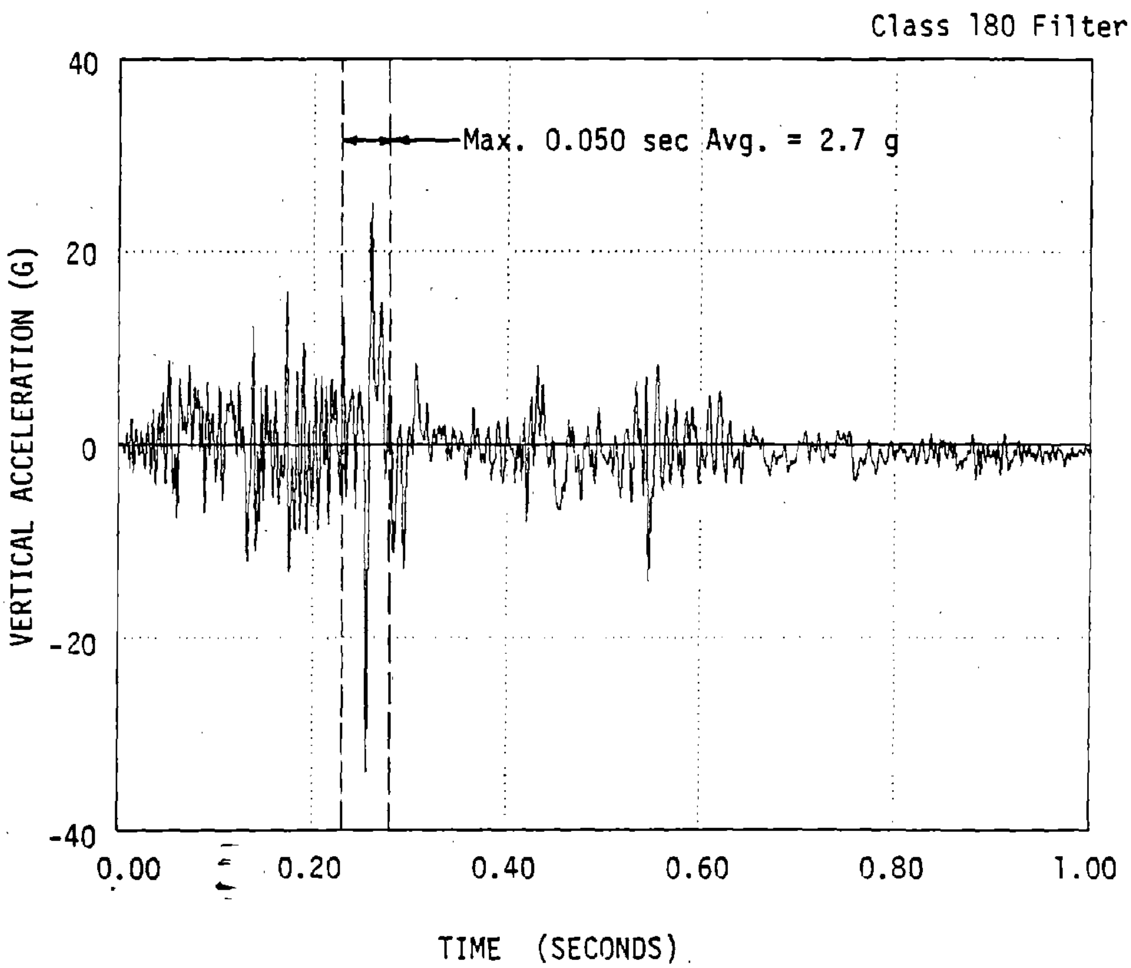
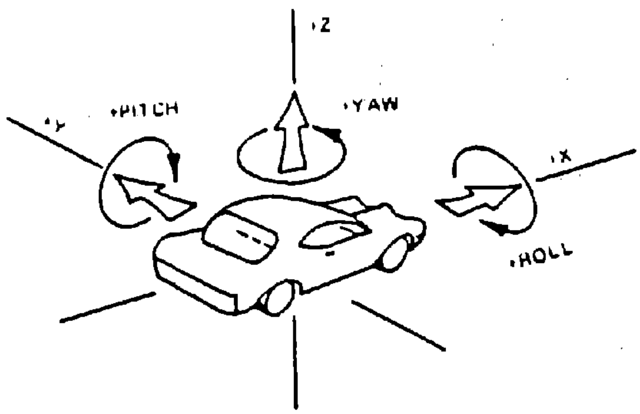


Figure 88. Vehicle vertical accelerometer trace for test 3825-17.



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

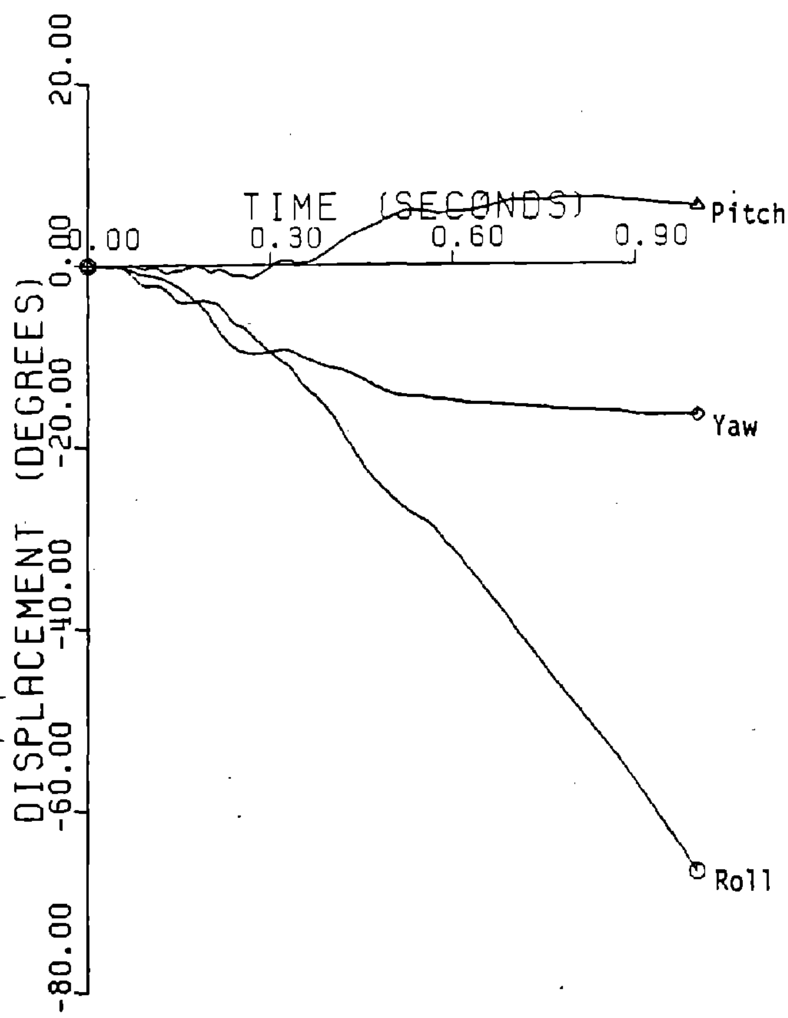


Figure 89. Vehicle angular displacements for test 3825-17.

III. DISCUSSION OF TESTS

The results of all tests with regard to roll stability are given by table 2. Examination of table 2 and the Data Summary sheets, figures 90 through 97, show that the test vehicles remained stable, subject to only small roll angles in all tests except 3825-15 and 3825-17. The tests where the vehicle remained stable included 7-degree and 15-degree tests of the Ford Bronco, a 15-degree test of the Datsun pickup, 7-degree and 15-degree tests of the 1977 Ford pickup and a 15-degree test of the Chevrolet pickup. In all these tests barrier deflection was very small, varying from 0.05 to 0.14 ft (0.02 to 0.04 m) laterally at the extreme top of the barrier.

Study of the test films reveals in tests conducted at the 7-degree impact angle the vehicle would never completely lose contact with the road or shoulder surface plane. The left (contact) side of the vehicle would ride up on the barrier less than two ft (0.6 m), the right front wheel would usually come slightly off the shoulder plane but the right rear wheel would maintain contact throughout the event. See the high speed photo sequence in figure 90.

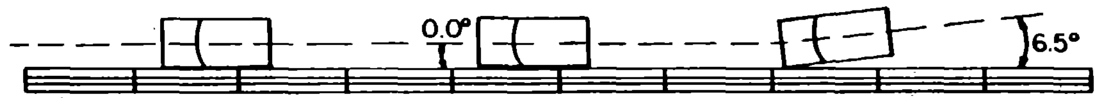
This was not true for the 15-degree tests. In these the vehicle would completely lose contact with the shoulder plane, as shown in figure 96, but would remain in a low roll angle condition and be stable on returning to the surface. The following occurs: during the time the left front (contact side) and left rear wheel are receiving an upward thrust from the barrier, the right rear wheel is still in contact with the ground plane. A major vertical thrust is generated on this wheel by the roll motion of the vehicle. This thrust counteracts the rolling impulse. The vehicle springs on the right rear are first compressed and then rebound as the vehicle becomes airborne. The net result of the cycle of destabilizing and stabilizing vertical forces is a vehicle with a small net roll angle and roll velocity. Assuming vehicle yaw and pitch are not large, the vehicle should be relatively stable.

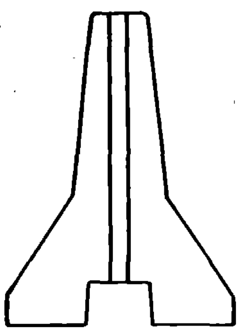
In two tests, the vehicle was not stable. The first, 3825-15, the 1974 Ford pickup at a 22-degree impact angle, may not be typical of an impact with a rigid CMB. The reason for this is that the adapted

Table 2. Summary of Test Results.

TEST DESIGNATION	TEST VEHICLE	IMPACT CONDITIONS (lb/mph/deg.)	VEHICLE REACTION TO IMPACT
3825-10	1966 Ford Bronco	3598/60.6/6.5	Struck barrier twice with good stability then spun out, due to brake lock, after departing barrier end. Maximum barrier movement = 0.05 ft.
3825-11	1966 Ford Bronco	3598/60.7/14.5	Vehicle goes completely off ground but maintains stable attitude. Maximum barrier movement = 0.11 ft.
3825-12	1974 Datsun Pickup	2434/61.0/15.0	Vehicle goes completely off ground but maintains stable attitude. No measurable movement of barrier.
3825-13	1977 Ford Pickup	4490/57.3/6.5	Maintains stable attitude. Maximum barrier movement = 0.11 ft.
3825-14	1977 Ford Pickup	4490/58.1/14.0	Vehicle goes off ground but maintains stable attitude. Maximum barrier movement = 0.12 ft.
3825-15	1974 Ford Pickup	4540/60.2/21.5	Too much barrier deflection (maximum barrier movement = 0.63 ft). Vehicle rolls away from barrier 90 deg and slides to stop on side.
3825-16	1972 Chev. Pickup	4760/59.7/14.5	Vehicle goes off ground but maintains stable attitude. Maximum barrier movement = 0.14 ft.
3825-17	1973 Ford Straight Truck	18,240/60.1/15	Vehicle rolls toward and over barrier and slides to stop on side. No measurable movement of barrier.

0.000 sec | 0.101 sec | 0.201 sec | 0.307 sec

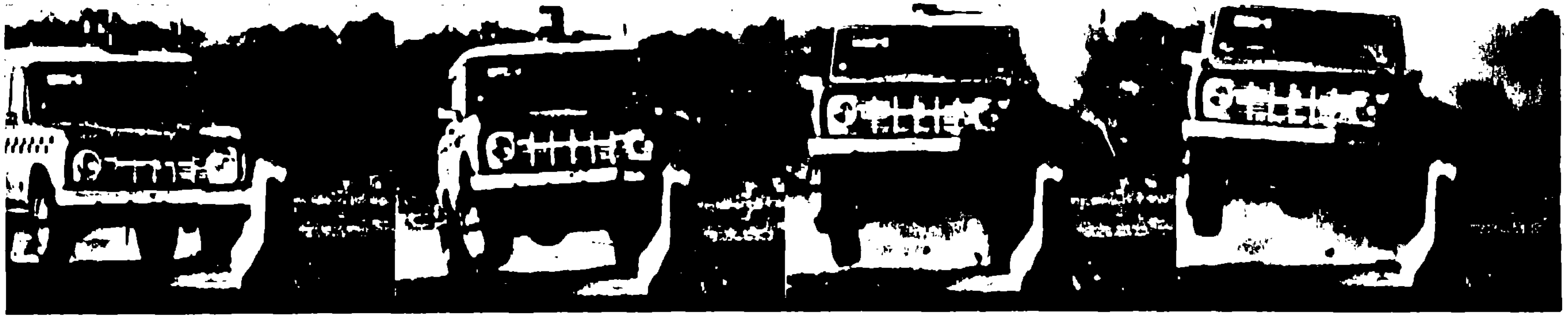




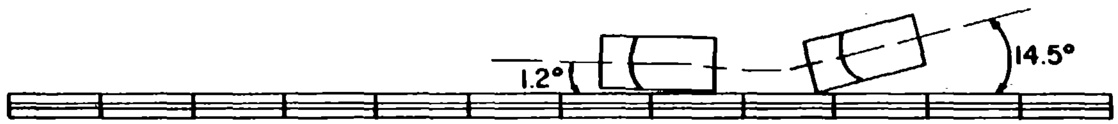
Test No.	3825-10
Date	1/11/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.02 ft (0.01 m)
Maximum	0.05 ft (0.02 m)
Vehicle	1966 Ford Bronco
Vehicle Weight	3598 lbs (1633 kg)
Vehicle Damage Classification	
TAD	11LFQ1
SAE	11FLEN1

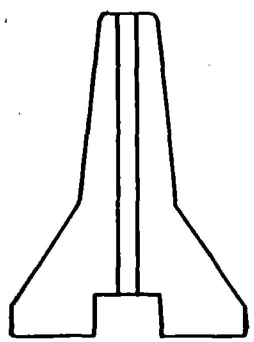
Impact Speed	60.6 mph (97.5 kph)
Impact Angle	6.5 deg
Exit Speed	52.6 mph (84.6 kph)
Exit Angle	0.0 deg
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-1.8 g
Lateral	-2.6 g
Vertical	-0.3 g
Vector Resultant	3.2 g
Occupant Impact Velocity	
Longitudinal	6.7 fps (2.0 m/s)
Lateral	11.3 fps (3.4 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-2.3 g
Lateral	-2.2 g

Figure 90. Data summary for test 3825-10.



0.000 sec 0.114 sec 0.228 sec 0.345 sec

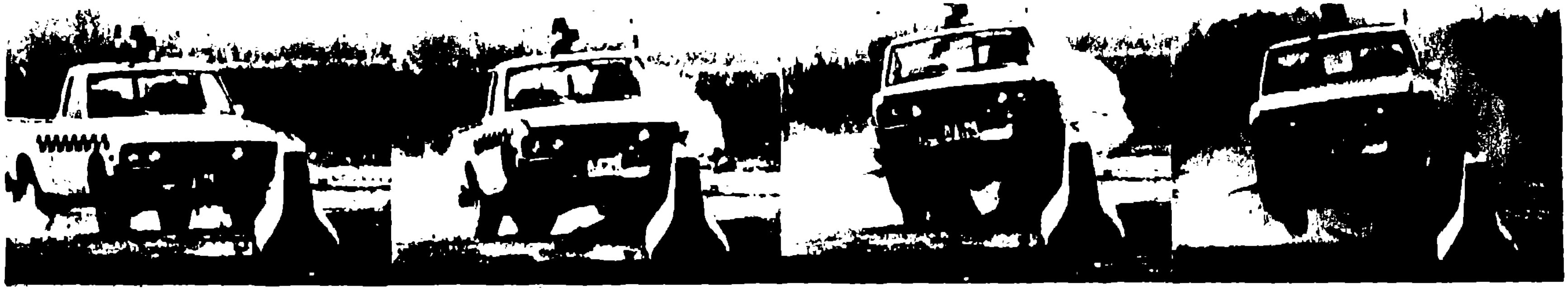




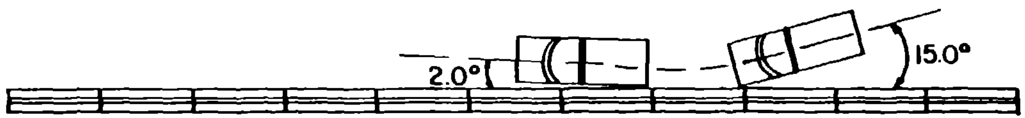
Test No.	3825-11
Date	1/11/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.00 ft (0.00 m)
Maximum	0.11 ft (0.03 m)
Vehicle	1966 Ford Bronco
Vehicle Weight	3598 lbs (1633 kg)
Vehicle Damage Classification	
TAD	11LFQ3
SAE	11FLEK2 11LFES2

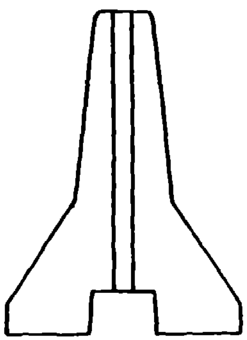
Impact Speed	60.7 mph (97.7 kph)
Impact Angle	14.5 deg
Exit Speed	52.0 mph (83.7 kph)
Exit Angle	1.2 deg
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-4.9 g
Lateral	-7.2 g
Vertical	-3.8 g
Vector Resultant	8.9 g
Occupant Impact Velocity	
Longitudinal	14.1 fps (4.3 m/s)
Lateral	16.6 fps (5.1 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-5.7 g
Lateral	-8.2 g

Figure 91. Data summary for test 3825-11.



0.000 sec | 0.091 sec | 0.182 sec | 0.283 sec





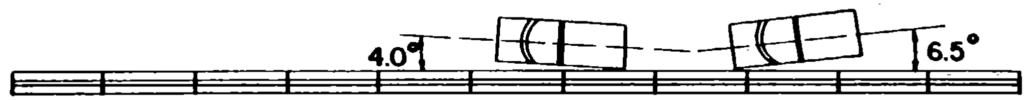
Concrete
Median Barrier

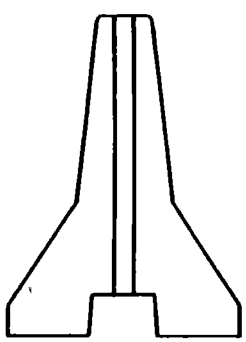
Test No.	3825-12
Date	1/17/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.00 ft (0.00 m)
Maximum	0.00 ft (0.00 m)
Vehicle	1974 Datsun Pickup
Vehicle Weight	2434 lbs (1105 kg)
Vehicle Damage Classification	
TAD	11LFQ3
SAE	11FLEK2
	11LFES2

Impact Speed	61.0 mph (98.2 kph)
Impact Angle	15.0 deg
Exit Speed	54.0 mph (86.9 kph)
Exit Angle	2.0 deg
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-4.1 g
Lateral	-10.1 g
Vertical	4.5 g
Vector Resultant	11.2 g
Occupant Impact Velocity	
Longitudinal	13.1 fps (4.0 m/s)
Lateral	19.9 fps (6.1 m/s)
Occupant Ridedown Accelerations	
Longitudinal	0.9 g
Lateral	-4.9 g

Figure 92. Data summary for test 3825-12.

0.000 sec　0.120 sec　0.240 sec　0.363 sec





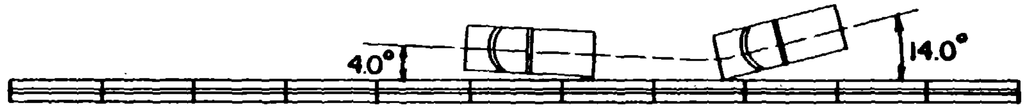
Concrete
Median Barrier

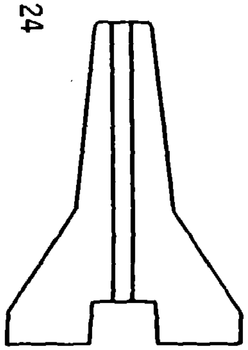
Test No.	3825-13
Date	1/13/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.00 ft (0.00 m)
Maximum	0.11 ft (0.03 m)
Vehicle	1977 Ford F250 Pickup
Vehicle Weight	4490 lbs (2038 kg)
Vehicle Damage Classification	
TAD	11LFQ1
SAE	11FLEN1

Impact Speed	57.3 mph (92.2 kph)
Impact Angle	6.5 deg
Exit Speed	50.6 mph (81.3 kph)
Exit Angle	4.0 deg
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-1.5 g
Lateral	-3.1 g
Vertical	1.4 g
Vector Resultant	8.3 g
Occupant Impact Velocity	
Longitudinal	7.4 fps (2.3 m/s)
Lateral	10.8 fps (3.3 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-0.4 g
Lateral	-5.3 g

Figure 93. Data summary for test 3825-13.

0.000 sec | 0.139 sec | 0.278 sec | 0.418 sec



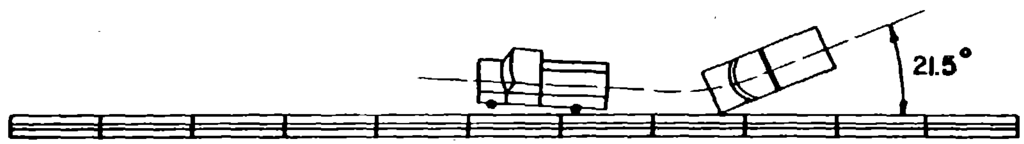


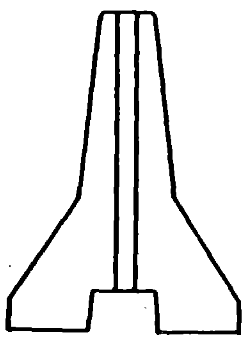
Concrete Median Barrier

Test No.	3825-14
Date	1/13/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.00 ft (0.00 m)
Maximum	0.12 ft (0.04 m)
Vehicle	1977 Ford F250 Pickup
Vehicle Weight	4490 lbs (2038 kg)
Vehicle Damage Classification	
TAD	11LFQ4
SAE	11FLEK1 11LFES3

Impact Speed	58.1 mph (93.5 kph)
Impact Angle	14.0 deg
Exit Speed	46.8 mph (75.3 kph)
Exit Angle	4.0 deg
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-5.3 g
Lateral	-6.3 g
Vertical	2.9 g
Vector Resultant	8.3 g
Occupant Impact Velocity	
Longitudinal	15.1 fps (4.6 m/s)
Lateral	14.7 fps (4.5 m/s)
Occupant Ridedown Accelerations	
Longitudinal	5.4 g
Lateral	-12.4 g

Figure 94. Data summary for test 3825-14.



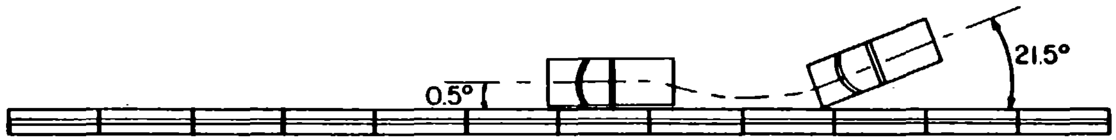


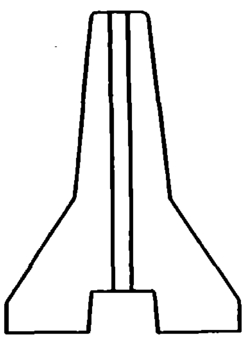
Concrete
Median Barrier

Test No.	3825-15
Date	1/26/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.08 ft (0.02 m)
Maximum	0.63 ft (0.19 m)
Vehicle	1974 Ford F250
Vehicle Weight	4540 lbs (2061 kg)
Vehicle Damage Classification	
TAD	11LFQ5
SAE	11FLEK2 11LFES3

Impact Speed	60.2 mph (96.9 kph)
Impact Angle	21.5 deg
Exit	Vehicle subsequently came to rest on side
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-7.0 g
Lateral	-8.7 g
Vertical	3.1 g
Vector Resultant	11.4 g
Occupant Impact Velocity	
Longitudinal	24.2 fps (7.4 m/s)
Lateral	19.3 fps (5.9 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-3.0 g
Lateral	-11.1 g

Figure 95. Data summary for test 3825-15.



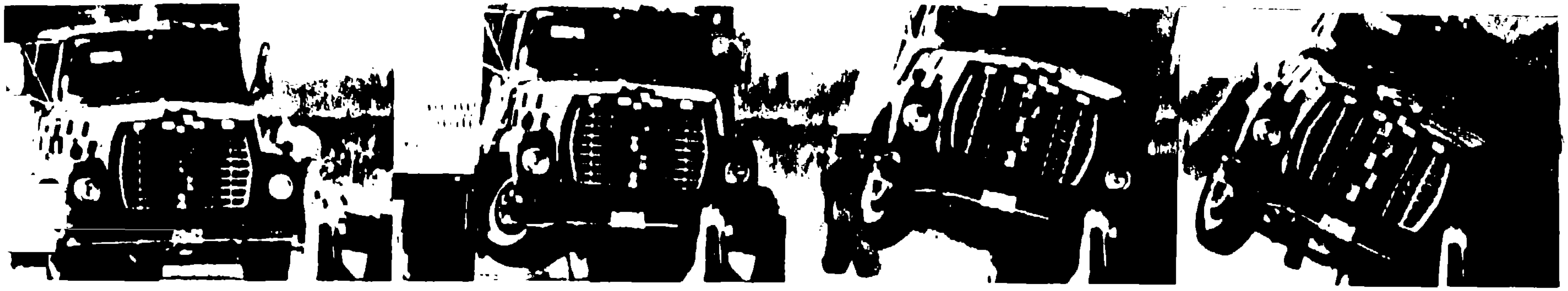


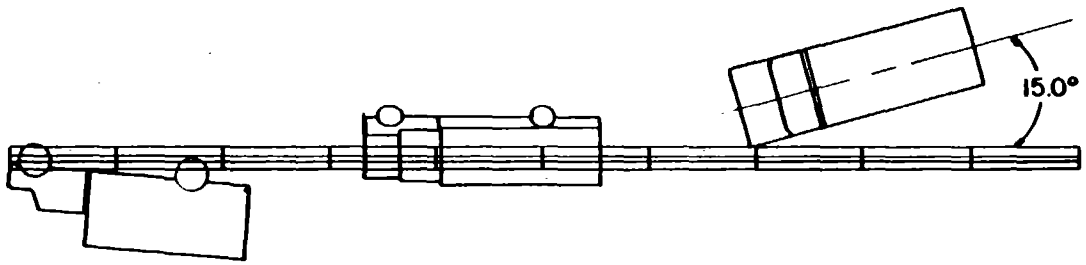
Concrete
Median Barrier

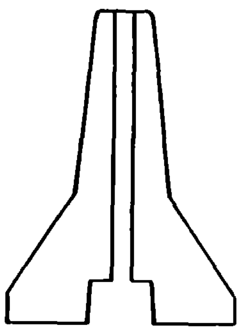
Test No.	3825-16
Date	1/24/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.03 ft (0.01 m)
Maximum	0.14 ft (0.04 m)
Vehicle	1972 Chev. 4-wheel drive pickup
Vehicle Weight	4760 lbs (2161 kg)
Vehicle Damage Classification	
TAD	11LFQ3
SAE	11FLEK1 11LFES3

Impact Speed	59.7 mph (96.1 kph)
Impact Angle	14.5 deg
Exit Speed	51.7 mph (83.2 kph)
Exit Angle	0.5 deg
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-4.4 g
Lateral	-8.9 g
Vertical	3.3 g
Vector Resultant	10.4 g
Occupant Impact Velocity	
Longitudinal	12.7 fps (3.9 m/s)
Lateral	17.5 fps (5.3 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-1.2 g
Lateral	-6.7 g

Figure 96. Data summary for test 3825-16.







Test No.	3825-17
Date	2/24/84
Barrier	Concrete Median Barrier
Joint Connection	Bottom T-Lock
Segment Length	12.0 ft (3.7 m)
Length of Installation	120.0 ft (36.7 m)
Barrier Movement	
Permanent	0.00 ft (0.00 m)
Maximum	0.00 ft (0.00 m)
Vehicle	1973 Ford 2 1/2 ton truck
Vehicle Weight	
Empty Weight	9,770 lbs (4,436 kg)
Gross Static	18,240 lbs (8,281 kg)

Impact Speed	60.1 mph (96.7 kph)
Impact Angle	15.0 deg
Speed at 1.000 sec	54.1 mph (87.0 kph)
Exit	Truck slid off end of barrier and came to rest on left side
Vehicle Accelerations (Max. 0.050 sec Avg)	
Longitudinal	-1.7 g
Lateral	-8.4 g
Vertical	2.7 g
Vector Resultant	8.6 g
Occupant Impact Velocity	
Longitudinal	7.3 fps (2.2 m/s)
Lateral	10.0 fps (3.1 m/s)
Occupant Ridedown Accelerations	
Longitudinal	-2.9 g
Lateral	-15.9 g

Figure 97. Data summary for test 3825-17.

temporary barrier was not rigid. The dynamic deflection of the top of the impacted barrier segment moved 0.63 ft (0.19 m). This means the slope of the upper plane of the CMB face increased from 6 degrees to 18 degrees, providing a plane that produced much more lift to the vehicle contact side than would occur had the barrier top not deflected laterally. Analysis of high speed films indicates this as one probable cause of the destabilizing force that produced a ninety degree vehicle roll away from the barrier. Another factor is the rotation of segment 4 with respect to segment 5, as shown in figure 58, which formed a discontinuity at the joint. This exposed corner appears to have caused an uplifting force as the wheel traversed it. The increase in impact angle from 15 degrees to 22 degrees, while producing the force necessary to deflect this barrier, is probably not a critically destabilizing factor during impact with a rigid CMB, as several stable 25-degree automobile tests have indicated.

The final test, an 18,240 lb (8,281 kg) straight truck at 60 mph (97 kph) and 20 degrees, was an obvious unstable condition. This was due to the fact the box-van body was loaded uniformly producing a resultant c.g. height of nearly five feet (58.2 in. (147.8 cm)). Since the barrier height is 32 in (81.3 cm), there is a destabilizing moment about the center of gravity developed by the barrier resisting force. As the truck rotates into the barrier, the moment arm would initially be almost five feet (1.5 m) when the wheels first contact the lower revealment of the CMB. As the interaction proceeded this arm would decrease to about two feet (0.6 m). In any case, box-van straight trucks loaded uniformly are distinctly unstable during a CMB impact. Many rental units loaded with household goods and furniture are in this load condition. This is also illustrated by the extremely low value of T/2H. Table 1 shows this ratio is 0.67, the lowest of all vehicles tested.

The sequential photographs of figure 95 (Test 3825-15) and figure 97 (Test 3825-17) illustrate the two modes of roll instability: 1) Roll away from the barrier, also a failure mode during some tests of very small cars, and 2) Roll into and over the barrier, also a failure mode of large trucks (80,000 lb (36,320 kg) tractor semitrailers) with relatively high trailer centers of gravity.

It appears that utility vehicles and pickups that do no exhibit excessive sprung mass elevation by special wheels and suspensions may not be unstable during many CMB collisions, although without conducting 25-degree impact angle tests this statement is not fully supported. In contrast, it seems apparent that straight trucks with high c.g. values have a critical capacity to roll.

IV. VEHICLE INERTIAL AND SUSPENSION PROPERTIES

The test vehicle inertial properties (mass moments of inertia, mass and center of gravity) were measured by TTI using the Mobile Parametric Measurement Device (MPMD). This device is a vehicle property measurement system contained on a flat-bed trailer and on loan to TTI by the NHTSA. Vehicle suspension rates (spring rates effective at wheel center) were also measured. Table 3 lists all measured values. The test methodology for these measurements is explained following this table, along with photographs of the testing being performed (figures 98 through 103).

Table 3. Vehicle Properties RF 3825

Vehicle	Wt(lb)	WB(in)	Track (in) F / R	CG Location (in) Long-X	Vert-Z	Suspension Rates (lb/in) F	R	Total Vehicle Mass Moments of Inertia (ft-lb-sec²) I_{xx} Roll	I_{yy} Pitch	I_{zz} Yaw
1976 Ford Bronco	3558	92.5	60 / 59	38.5	23.9	187	143	594	1823	1798
1974 Ford F250 PU	4547	133	65 / 65	54.5	25.0	247	230	799	4112	4463
1974 Datsun PU	2538	100.4	50 / 51	45.1	22.6	117	200	165	1260	1454
1972 Chevy 4WD PU	4742	122	68 / 65	53.4	26.4	640-C/ 278-E*	330	958	3943	4721
1979 Ford LN 700 S.T.	18240	202	74 / 81.5**	136.6	58.2	550	1875	8544	34380	35371

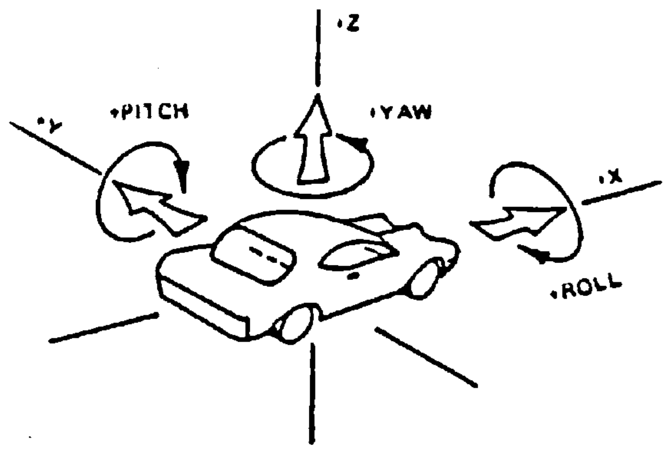
NOTES: WB - Wheel Base
CG Location: Long - X; From Front Spindle
Vert - Z; From Ground

* Chevy Front Susp. - Had coil-over shocks giving different rates in compression (C) and extension (E) from ride height

** Center of Outside Pair of Tires

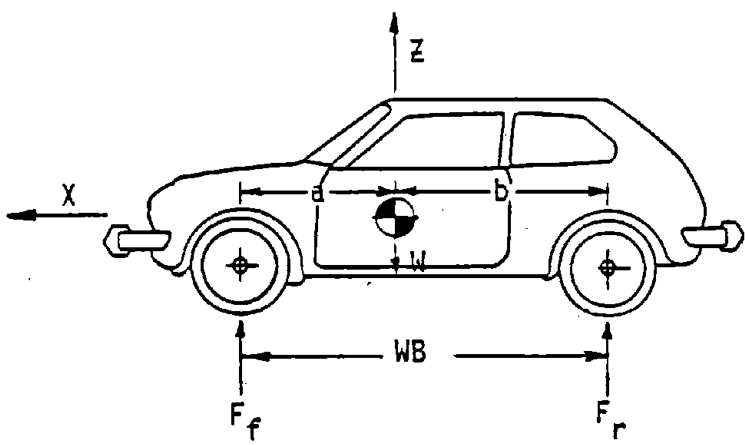
Test Methodology

Vehicle Sign Convention:



Longitudinal C.G.:

The vehicle was weighed on precision NBS traceable scales to determine the longitudinal C.G.



$$a = \frac{F_r}{W} WB$$

Where:

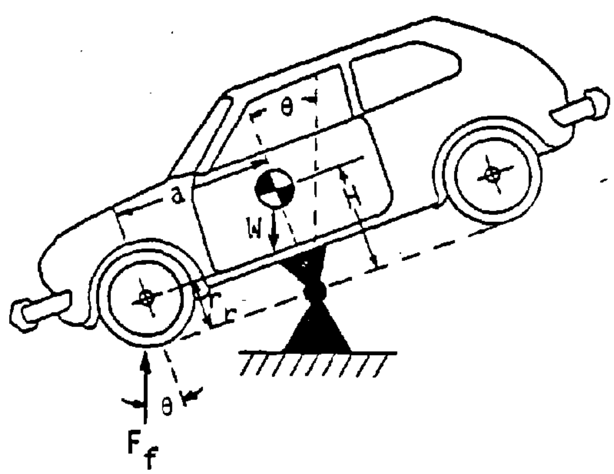
a	=	Longitudinal (x) distance from front axle to C.G.
F_r	=	Rear axle weight
W	=	Total vehicle weight
WB	=	Wheel Base

Lateral ~~G.~~G.:

The standard assumption that the lateral C.G. was located in the XY plane was made.

Vertical C.G.:

The vehicle was weighed on precision NBS traceable scales in a tilted position and the weight transfer used to determine the vertical height of the C.G.



$$H = \frac{(F_f)(\cos\theta)(a + r_r \sin\theta)}{W (\sin\theta)}$$

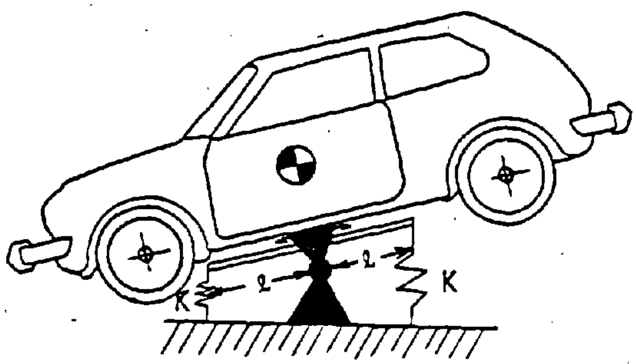
where: H = Vertical C.G. height above ground

θ = Angle of Tilt

r_r = Tire radius

Roll and Pitch Mass Moment of Inertia:

The vehicle was mounted on an inverted pendulum and was set into oscillation about a given fixed axis (longitudinal for roll, transverse for pitch). The restoring moment was provided by a matched pair of springs acting on opposed moment arms. The characteristic period of oscillation for the system was measured and the moments of inertia of the vehicle calculated.



(Pitch shown)

$$I = \frac{2K\ell^2 - M_c H - M_s H_s}{4\pi^2}\tau^2 - \frac{M_c H^2}{g} - \frac{M_s H_s^2}{g} - I_s$$

where:

I ≡ Mass Moment of Inertia About Vehicle C.G. Either I_{xx} = Roll or I_{yy} = Pitch

M_c ≡ Mass of vehicle

M_s ≡ Mass of support structure

H ≡ CG Heights of support structure above axis of rotation

τ ≡ Period of oscillation

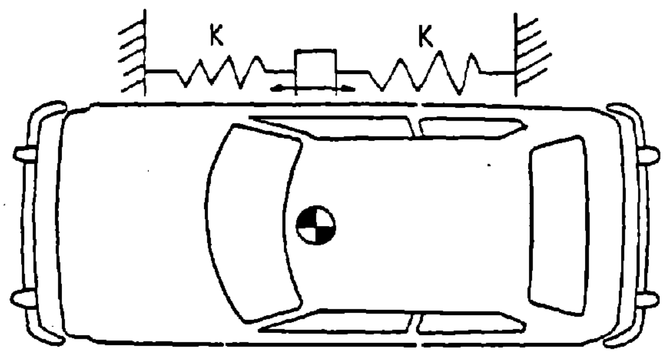
I_s ≡ Mass moment of inertia of support structure about it's C.G. (I_{s_x} = Roll; I_{s_y} = Pitch)

K ≡ Spring Rate

ℓ ≡ Moment arm length

Yaw Mass Moment of Inertia

The vehicle was mounted on a torsional pendulum and was set into oscillation about an axis passing through the vehicle C.G. The restoring moment was provided by a matched pair of springs acting on a moment arm. The characteristic period of oscillation for the system was measured and the moments of inertia of the vehicle calculated.



$$I_{zz} = \frac{k\ell^2\tau^2}{2\pi^2} - I_{s_z}$$

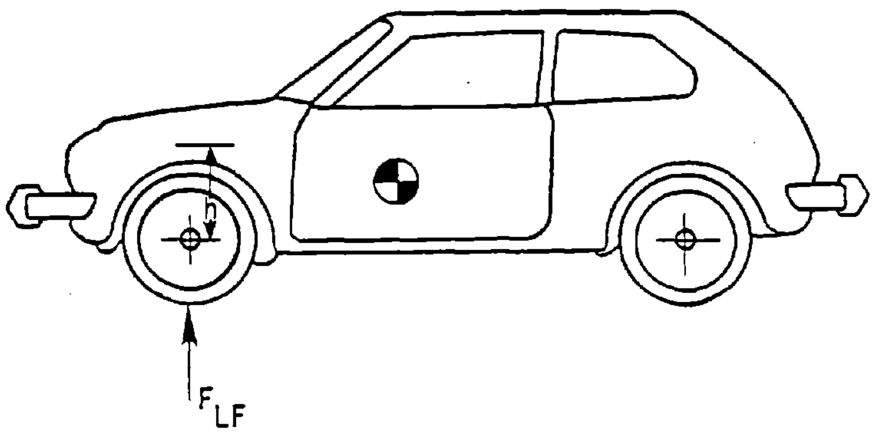
Where: I_{zz} ≡ Mass moment of inertia about vehicle CG in yaw

τ ≡ Period of oscillation

I_{s_z} ≡ Mass moment of inertia of support structure about it's C.G. in yaw

SUSPENSION RATES:

The vehicle was weighed on precision N.B.S. traceable scales and the distance from a fixed reference point on the body to the wheel center was measured. Ballast was added to the vehicle, and measurements repeated, until the suspension bumpers were encountered. Measurements were also taken while weight of the vehicle was progressively supported until full suspension extension was obtained. This was repeated for all wheels and values were averaged for assumed x - z plane symmetry (i.e.: LF & RF; LR & RR)



Effective suspension rate = $\frac{\Delta F}{\Delta h}$

where:

F_{LF} = Measured weights at wheel (i.e.: LF)

h = Distance to reference

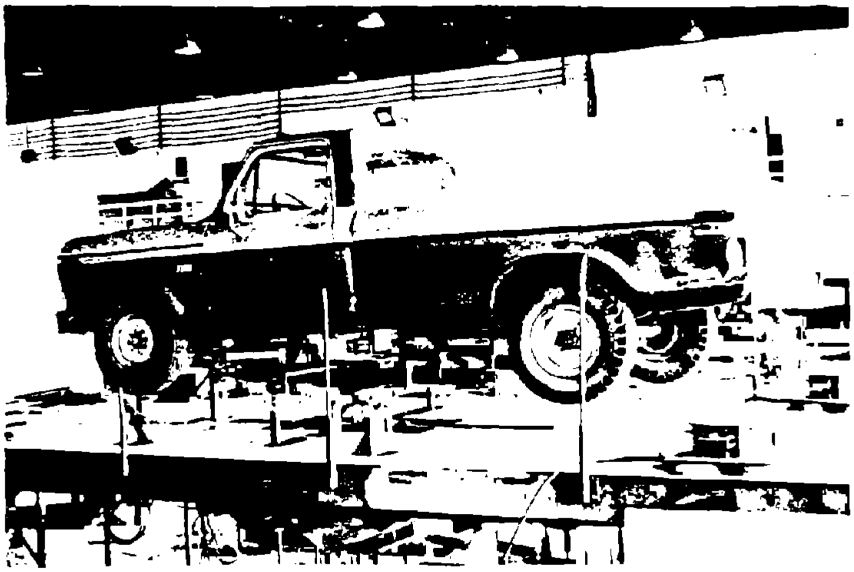


Figure 98. 1974 Ford F250 pickup setup for roll (I_{xx}) MMI measurement.

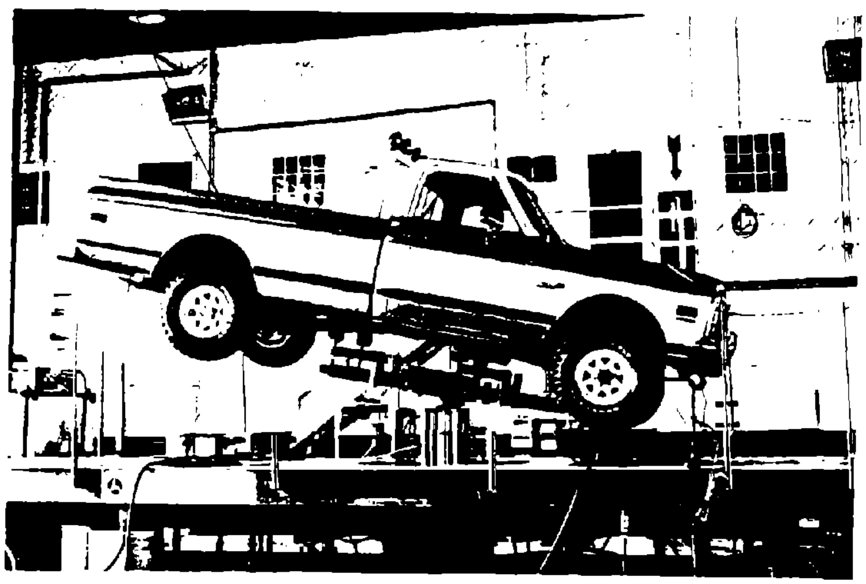


Figure 99. Vertical C.G. determination on 1972 Chevy 4WD pickup.

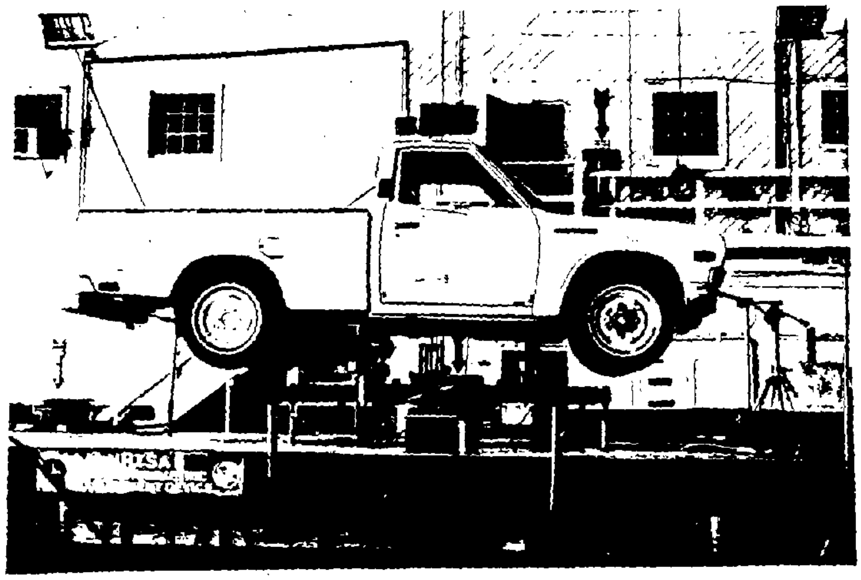


Figure 100. 1974 Datsun pickup setup for pitch (I_{yy}) MMI measurement.

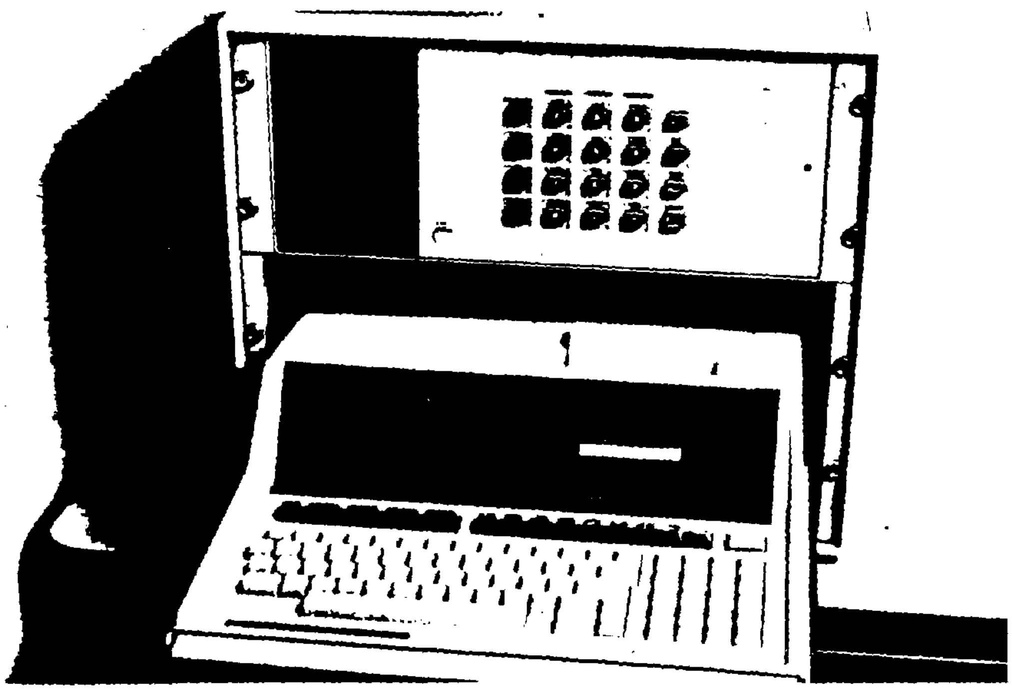


Figure 101. Data acquisition and reduction system.

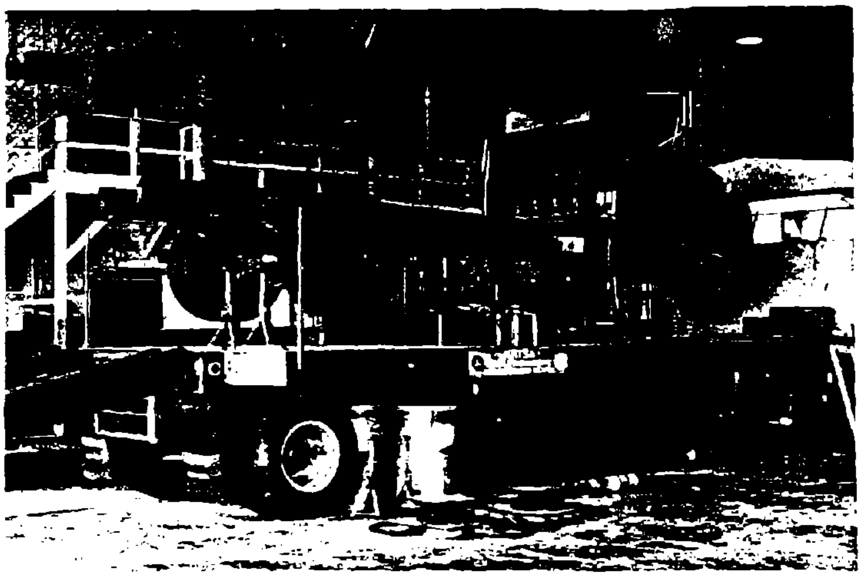


Figure 102. Measurement of 1979 Ford LN 700 straight truck.

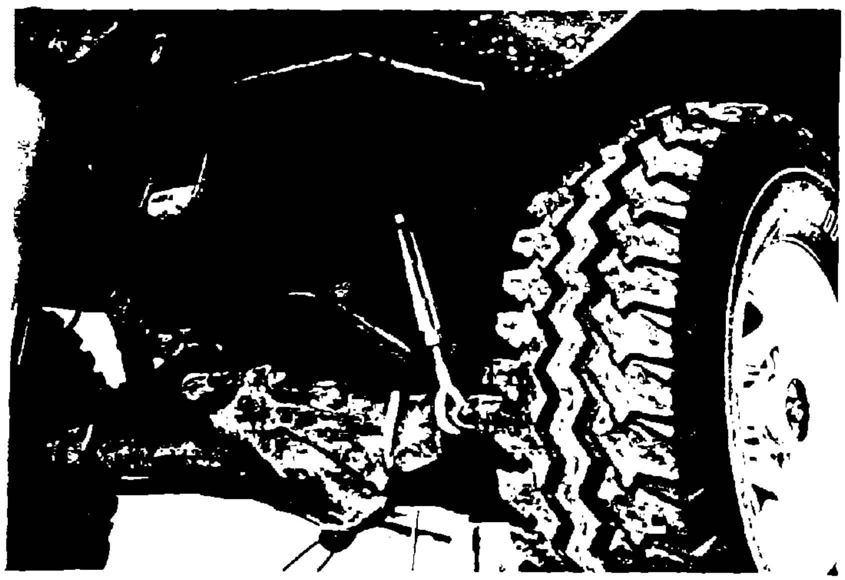


Figure 103. Method of immobilizing suspension during measurements.

V. ANALYSIS OF SUSPENSION DAMAGE

Damage Modes and Severity Levels

Damage to a vehicle's suspension system when it comes into contact with a barrier is of concern for three major reasons. The post-impact trajectory can be affected by suspension damage since the vehicle might not behave normally after leaving the barrier. Damage might also interfere with attempts by a driver to regain control of the vehicle after it leaves the barrier. Most importantly, sufficient damage might cause a rollover of the vehicle subsequent to barrier impact. The likelihood of each of these scenarios occurring depends to a great extent on the severity of damage.

Damage to various components of the suspension affect the vehicle differently. Damage to the tire usually results in an air-out. This lowers the ride-height of the vehicle and changes its attitude. The rolling resistance of the tire increases dramatically, resulting in an unsymmetrical force on the vehicle, while the ability of the tire to produce side force is extremely low. This results in a decrease in control for the driver. Problems may also arise if the vehicle is required to traverse soft terrain and/or terrain irregularities with a flat tire.

The next component to be damaged is usually the wheel rim/assembly. Effects of damage can range from difficulty in control for light damage to lack of control for heavy damage. Different wheels exhibit varying types of damage during barrier impacts. One piece wheels may sustain large amounts of deformation to the rim before the welds connecting the rim to the center section will fail. If sufficient deformation occurs a tire air-out will result. Other suspension members (axle, control arms) will usually fail before the center section. Multi-piece wheels have varying types of construction. Those found on medium duty trucks and buses may have a center-spoked section bolted to an outer rim. On barrier impacts, these bolts often contact the barrier face, causing them to shear. This permits the rim/tire assembly to break free from the wheel center section. This can lead to lock-up of the suspension and/or steering systems and creates a situation conducive to vehicle rollover.

An air-out of the tire does not necessarily occur in this case.

For very severe impacts the supporting suspension members such as control arms, steering links, springs or spring supports may be damaged. Damage to these parts may cause problems ranging from lack of control to a rollover situation, depending on their severity. Details of suspension systems vary widely, and analysis of a particular system is necessary to pin-point specific weaknesses.

The following section contains a description of the damage to each test vehicle, along with photographs of the damaged suspensions. After this, a listing correlating impact severity and damage classification is provided. Impact severity is as defined in NCHRP Report 230.(3) The damage classifications are four basic groups, subjectively defined as follows:

1. no significant damage, controllable
   - Damage to the vehicle suspension is slight, and not enough to prevent a driver from remaining in control.
2. significant damage, probably controllable
   - Damage to the vehicle suspension probably inhibits driver control to some degree. Possibility of vehicle rollover due to rim contact with the ground, if the tire airs out.
3. significant damage, probably uncontrollable
   - Damage to the vehicle suspension probably prevents driver from controlling vehicle. Increased probability of vehicle rollover.
4. major damage, definitely uncontrollable.
   - Damage to the vehicle suspension is severe, with no chance for driver control, and a high probability for vehicle rollover.

Also shown in the listing is a normalized impact severity, which is the impact severity divided by vehicle weight. Comparison plots of impact severity and damage class, and normalized impact severity and damage class are also provided.

Description of Suspension Damage to Test Vehicles

Test 3825-10

1966 Ford Bronco 60 mph 7-degree angle

There was no significant damage to the suspension of the vehicle.

Test 3825-11

1966 Ford Bronco 60 mph 15-degree angle

There was significant damage to the suspension of the vehicle on this test, as documented in figure 104. The left front control arm was bent out of line approximately 6 in (15 cm). This appears to be a column-buckling type failure due to the longitudinal loading from impact. This buckling allowed a rearward displacement of the left side of the solid axle of approximately 2 in (5 cm). There was no apparent damage to the frame. The left front wheel rim was damaged sufficiently to cause an air-out of the tire. The suspension damage was probably not severe enough to prevent a driver from regaining control after redirection.

Test 3825-12

1974 Datsun Pickup 60 mph 15-degree angle

There was significant damage to the suspension of the vehicle on this test, as documented in figure 105. The left front lower control arm was bent rearward approximately 3 in (8 cm) at its attachment to the spindle. The tie strut bracket on the lower control arm was severly deformed and partially separated from the arm. Both of these failures appear to be from the longitudinal loading from impact. There was a small amount of deformation to the left front wheel rim, however the tire was cut and punctured. This damage was probably not severe enough to prevent a driver from regaining control after redirection.

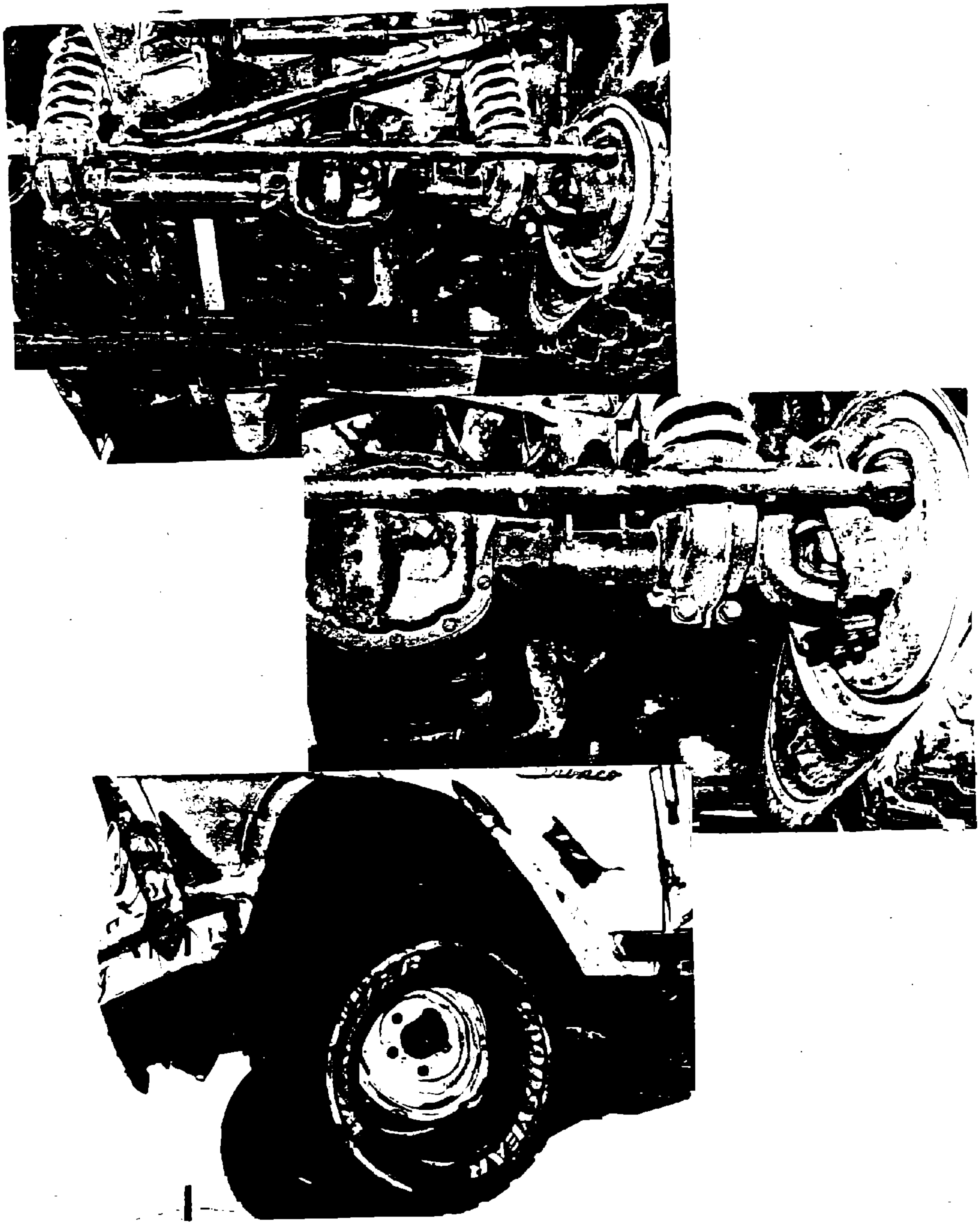


Figure 104. Damage to 1966 Ford Bronco suspension in test 3825-11.

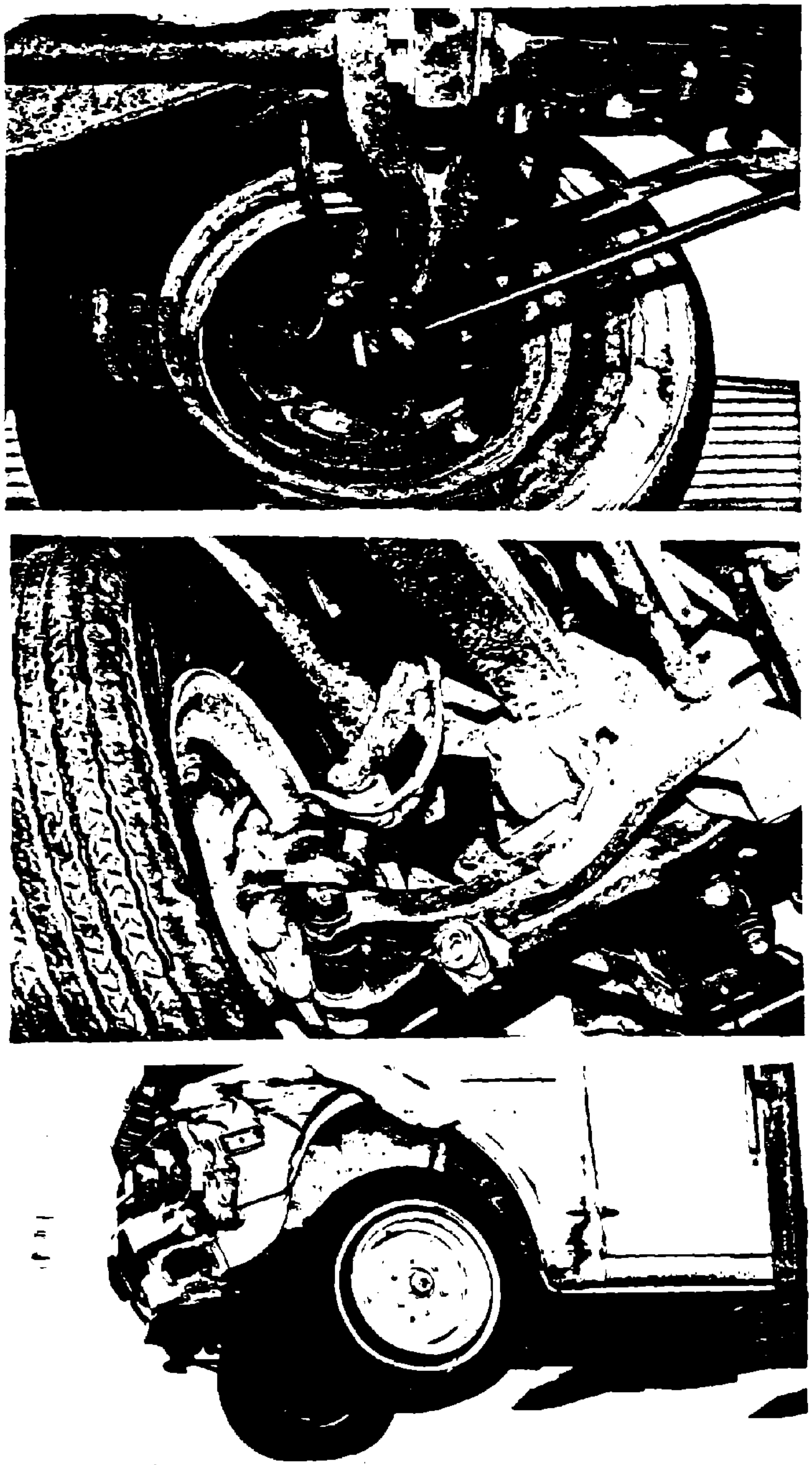


Figure 105. Damage to 1974 Datsun pickup suspension in test 3825-12.

Test 3825-13

1974 Ford F250 Pickup 60 mph 7-degree angle

There was no significant damage to the suspension of the vehicle.

Test 3825-14

1974 Ford F250 Pickup 60 mph 15-degree angle

There was significant damage to the suspension of the vehicle on this test, as documented in figure 106. The left side I-beam was severly bent rearward outside of the control arm attachment, and bowed downward inboard of the control arm. The maximum deviation from the original relatively straight shape was about 6 in (15 cm). The rearward force of impact caused the outward bend, while the sideward force caused the column buckling type failure (bowing). The control arm was relatively undamaged, showing only a slight compression deformation. The split ring detached on both front wheels allowing both tires to deflate. The deformation in the I-beam allowed the left front wheel to move rearward sufficiently to heavily contact the wheel well. This damage was probably sufficient to cause driver control problems after redirection.

Test 3825-15

1974 Ford F250 Pickup 60 mph 22-degree angle

There was major damage to the suspension of the vehicle on this test, documented in figure 107. The left front suspension was detached from the frame at all points except the inboard I-beam pickup point. The left I-beam suffered deformation similar to that in Test 3825-14, except to a greater degree. The left control arm suffered some compression deformation before its rear attachment bracket bolts (2) failed in shear. This permitted the shock to pull free and the spring to be pulled away from the top perch. The left front wheel rim and split ring was severly damaged, allowing an air out. The vehicle rolled after loss of contact with the barrier. The suspension damage was severe enough that a driver would not have been able to control the vehicle and prevent the roll from occurring.

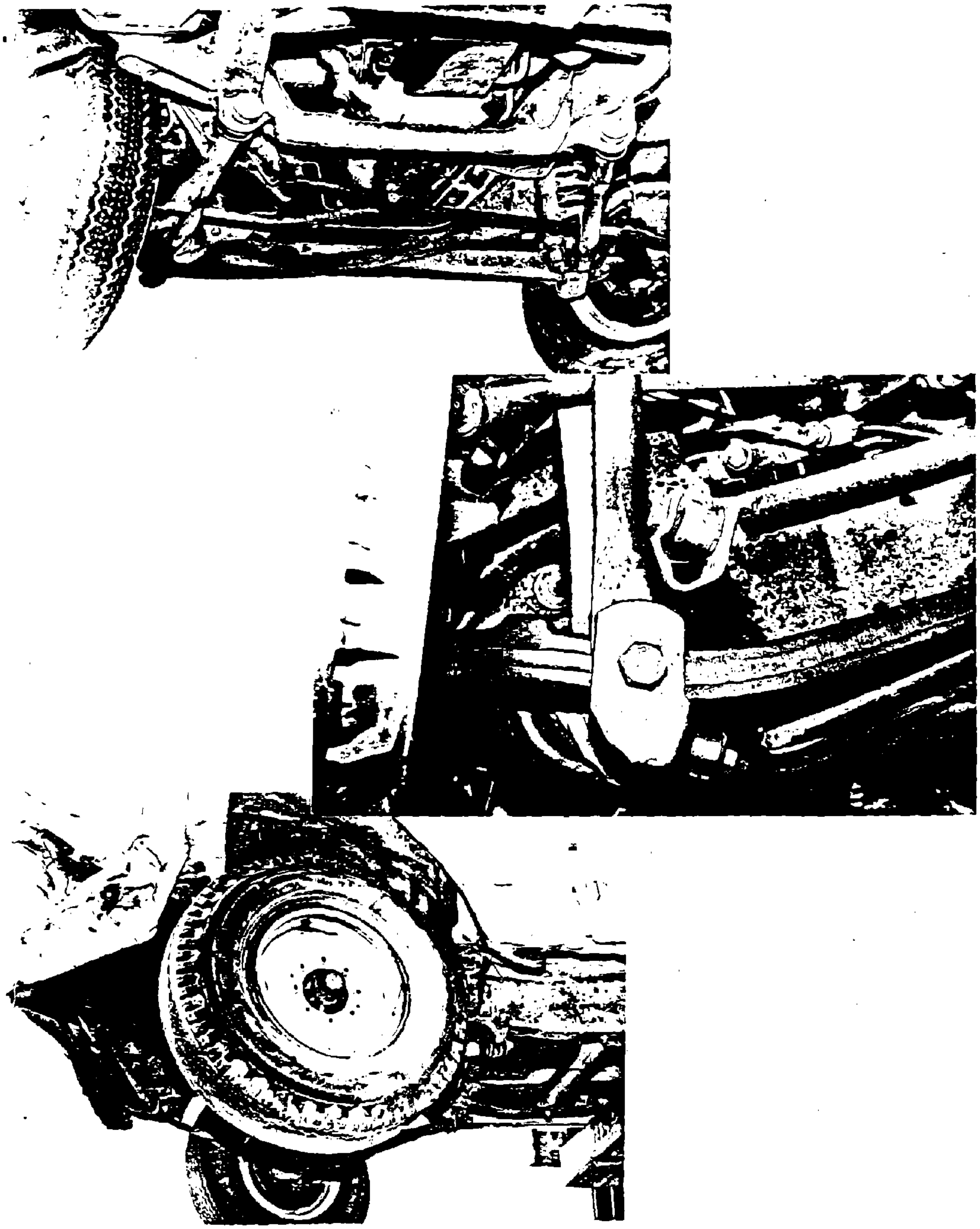
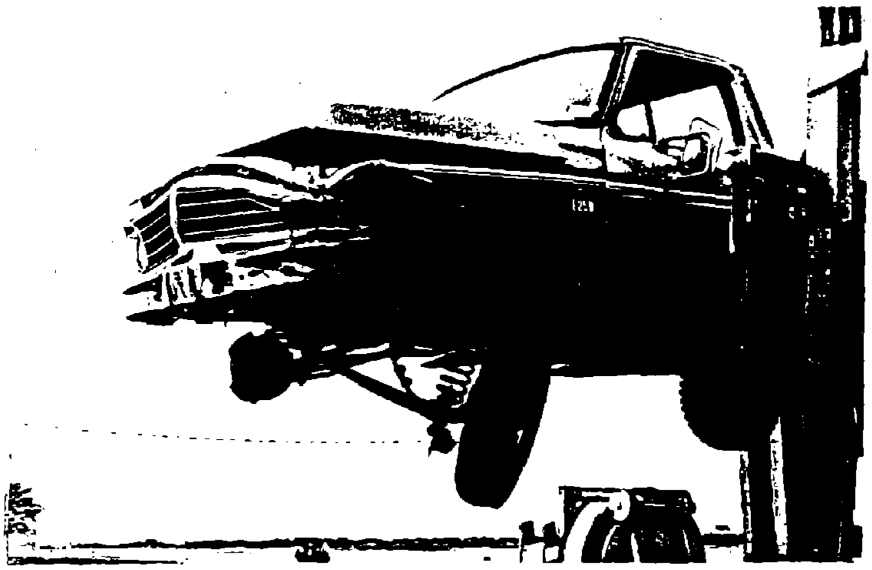


Figure 106. Damage to 1974 Ford F250 pickup suspension in test 3825-14.



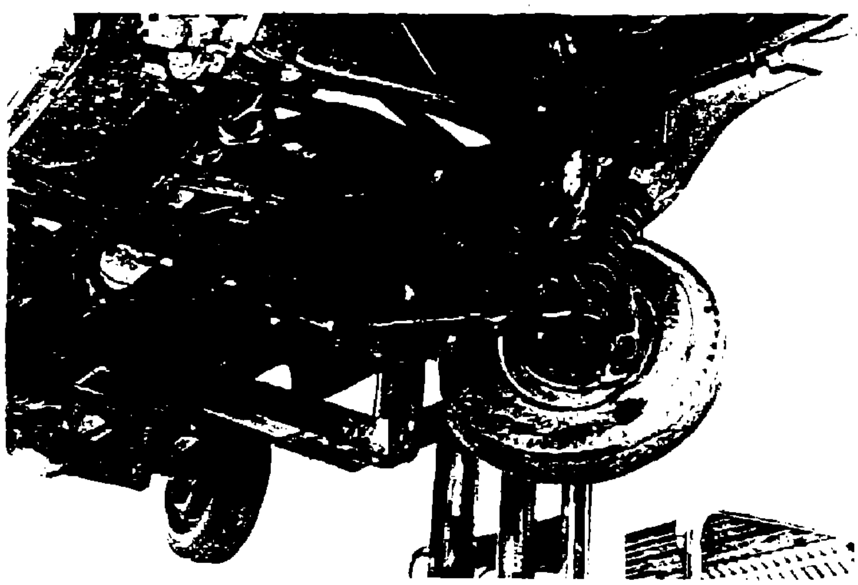


Figure 107. Damage to 1974 Ford F250 pickup suspension in test 3825-15.

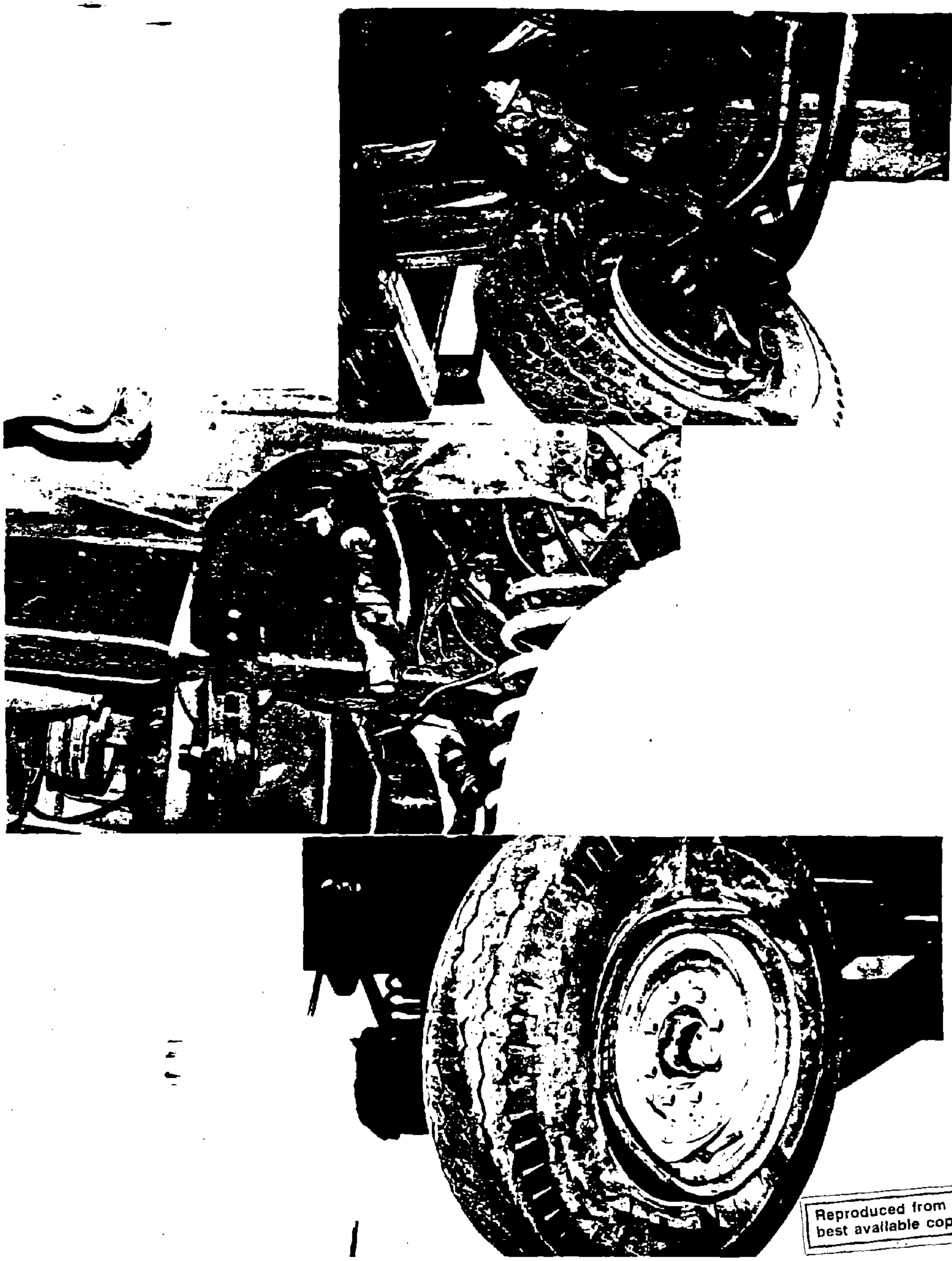


Figure 107. Damage to 1974 Ford F250 pickup suspension in test 3825-15 (continued).

Test 3825-16

1972 Chevrolet 4WD Pickup 60 mph 15-degree angle

There was significant damage to the suspension of the vehicle on this test, as documented in figure 108. The front of the left spring attaches to the frame through a shackle. This shackle was bent sideways toward the center of the vehicle by approximately 3/4 in (2 cm). The frame arch above the axle on the left front was buckled, with the front spring attachment approximately 2 in (5 cm) lower than originally. The combination of these two deformations caused the left front leaf spring leafs to separate horizontally and twist relative to their original position. The shock/booster spring failed at the upper eyelet connection to the shaft. The left front wheel was severely deformed and bent out of plane due to contact with the barrier. The tire side wall was cut and resulted in an air-out. The suspension damage was probably not severe enough to prevent a driver from regaining control after redirection.

Test 3825-17

1979 Ford LN 700 Straight Truck 60 mph 15-degree angle

There was major damage to the suspension of the vehicle in this test, as documented in figure 109. The left front leaf spring failed about 18 in (46 cm) behind the front mount. The upper leaf fractured allowing the front of the spring to become unattached to the frame. The inside element of the rear spring attachment bracket was broken. This indicates the spring was not pulled out, but forced sideways through the bracket. The rear end of the spring then pierced the transmission case. On the right front, one of the U-bolts securing the spring to the drop axle failed. The shackle that held the spring pack together failed, allowing the leafs to separate horizontally. The left side frame rail was warped and twisted. All the motor and transmission mounts were broken, permitting the engine to set on the frame cross-member. The steering arm (1-3/8 in (3.5 cm) diameter) was sheared off where the pittman arm connects. The left front wheel was not structurally damaged, and the tire held air. The suspension damage was severe enough that a driver would not have been able to control the vehicle after redirection.

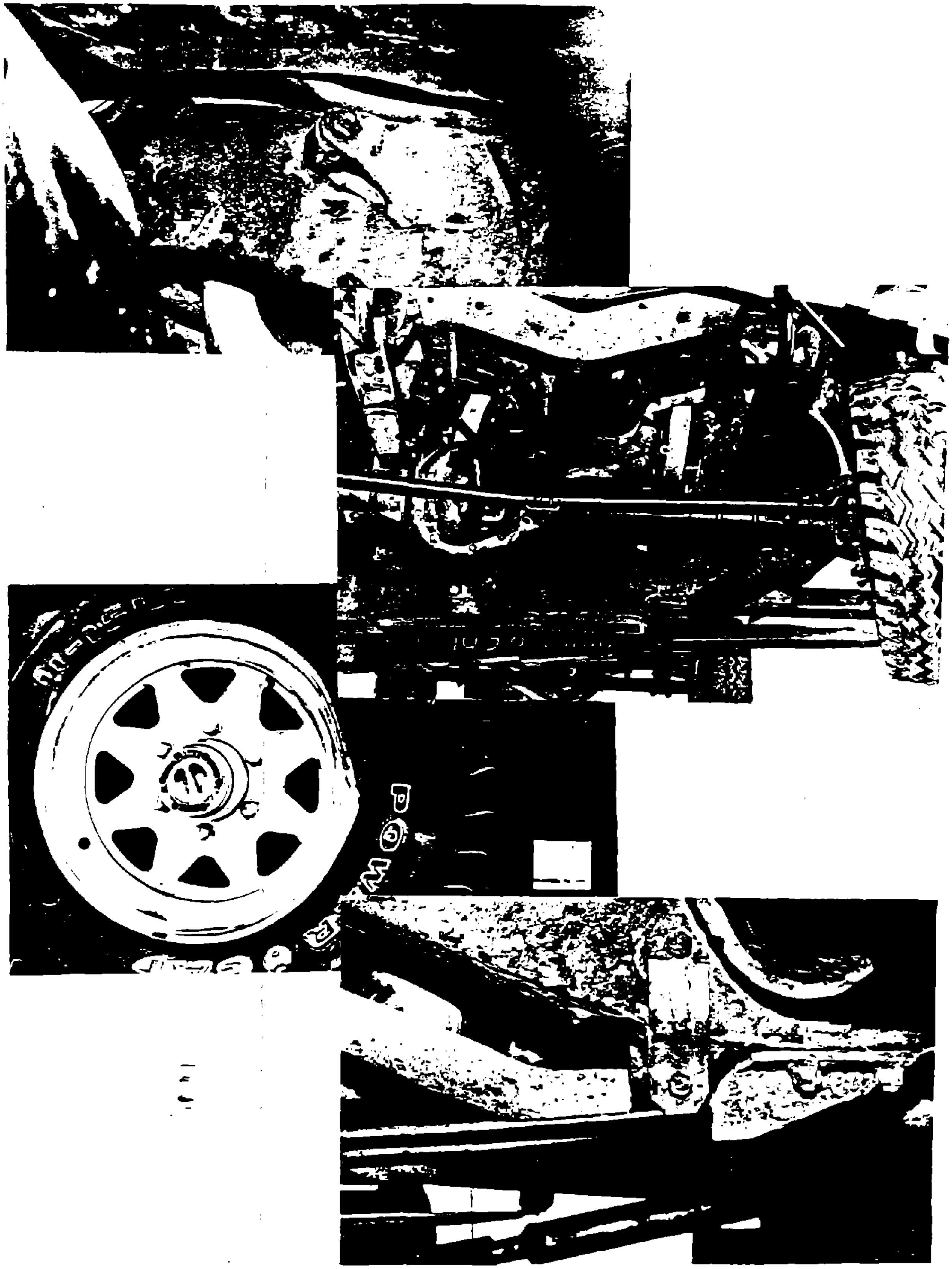
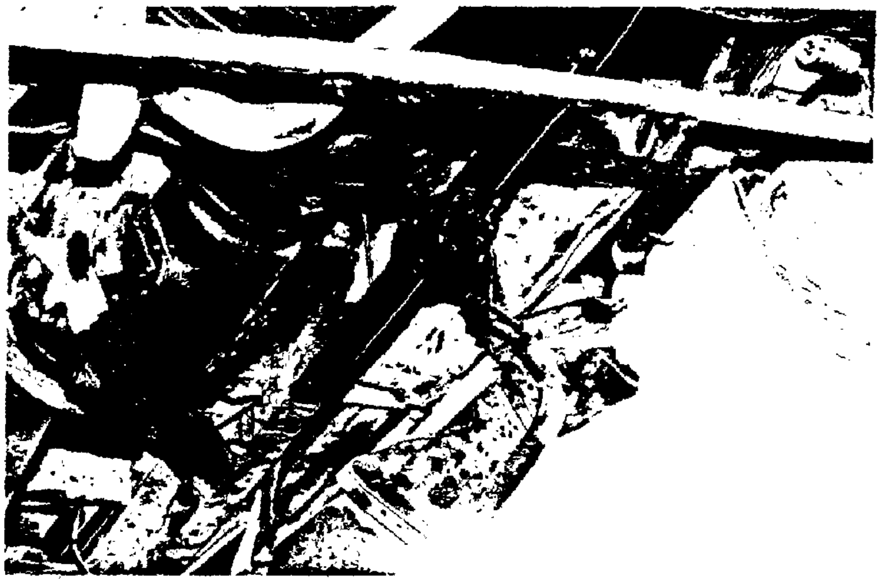


Figure 108. Damage to 1972 Chevrolet 4WD pickup suspension in test 3825-16.

Figure 109. Damage to 1979 Ford LN 700 straight truck suspension in test 3825-17.



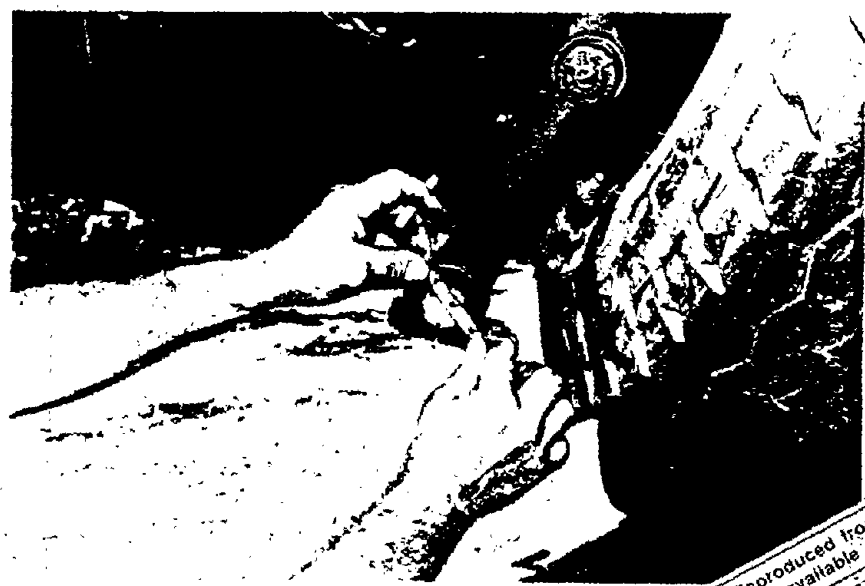


Figure 109. Damage to 1979 Ford LN 700 straight truck suspension in test 3825-17 (continued).

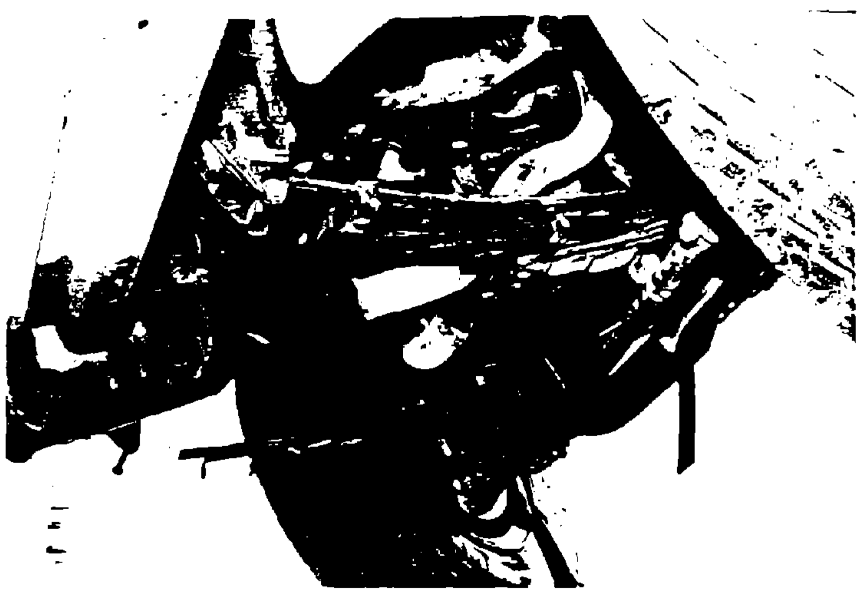


Figure 109. Damage to 1979 Ford LN 700 straight truck suspension in test 3825-17 (continued).

Predicting Suspension Damage

It was considered of value to be able to predict suspension damage as a function of impact conditions. In pursuit of this goal the damage classes (1 through 4) previously described were defined using damage class as the ordinate and two measures of impact severity as the abscissa. Figures 110 and 111 were plotted using the data given in table 4. Figure 110 uses Impact Severity as defined in NCHRP Report 230.[3]

$$\text{i.e.}\quad I.S. = \frac{W}{2g}(V \sin \theta)^2$$

As might be expected damage increases as I.S. increases. It appears, for vehicles weighing under 5,000 lbs (2,270 kg), a linear relationship between Damage Class and I.S. is a fair representation of the data. There is some indication that the line slope decreases radically or becomes curvilinear as vehicle weight increases.

It must be recognized that the elevated energy level attributed to the larger vehicles is simply due to their larger mass. Therefore it is no surprise that the values for large vehicles are so much higher than for the small. The question is whether the four suspension damage categories are satisfactorially discriminate to justify conclusions based on these figures. If they are, it might be possible to define a characteristic suspension damage versus Impact Severity curve for every different motor vehicle, given a great deal of test data.

Figure 111 provides what may be a significant insight to suspension damage among radically different sized vehicles. When the abscissa is normalized by dividing I.S. by the vehicle weight, the order of plotting the tests at Damage Class (or level) 4 is reversed. Now the largest vehicles (80,000 lb (36,320 kg) tractor semitrailers) are at the lowest normalized I.S. level while the smallest vehicles (F250 Pickup) are at the largest normalized level.

This phenomenon may be called "The Galileo Effect". In his book "Two New Sciences", English translation, p. 130 (see also ref 7), Galileo states:

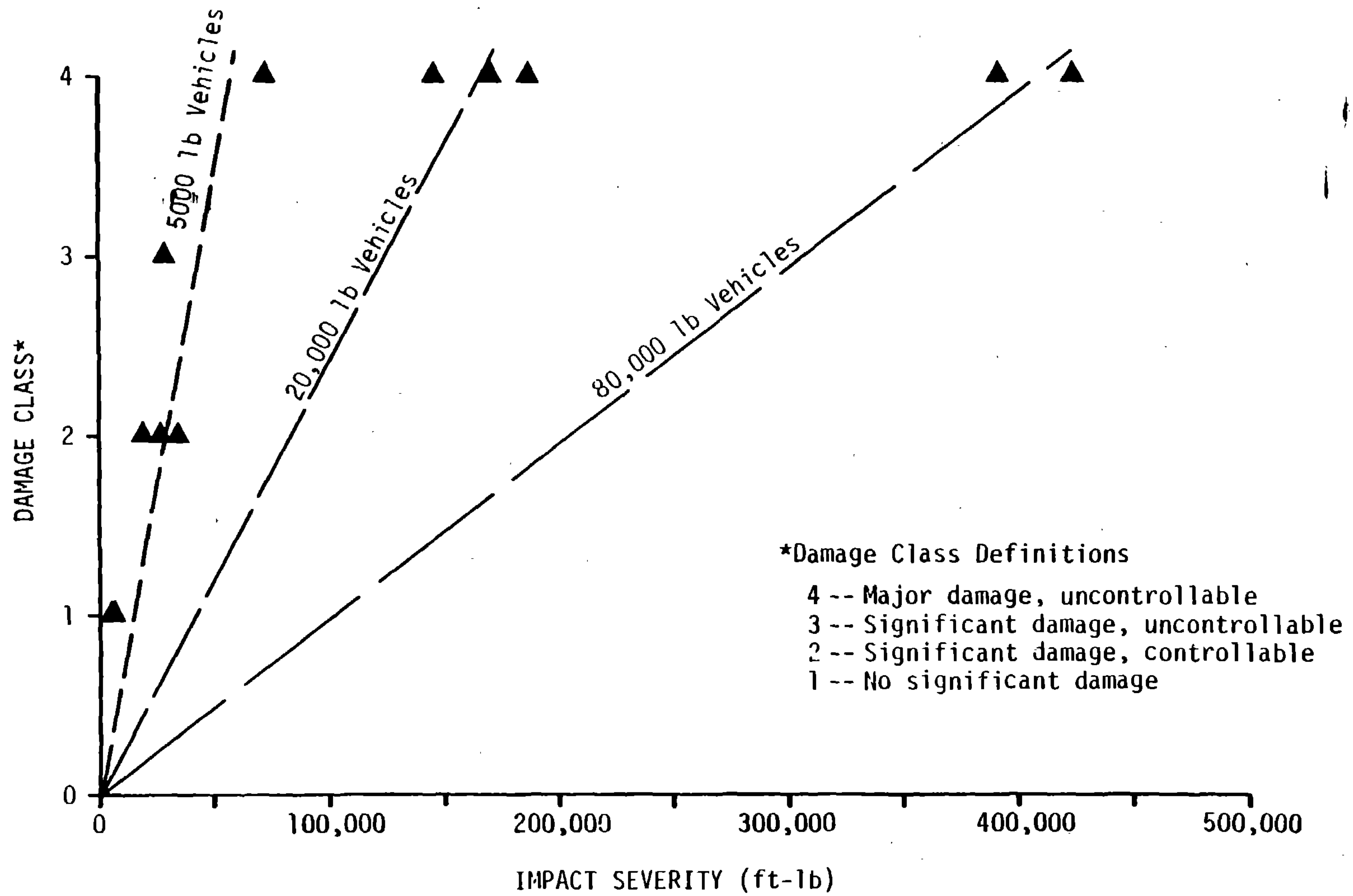


Figure 110. Comparison of impact severity and damage class.

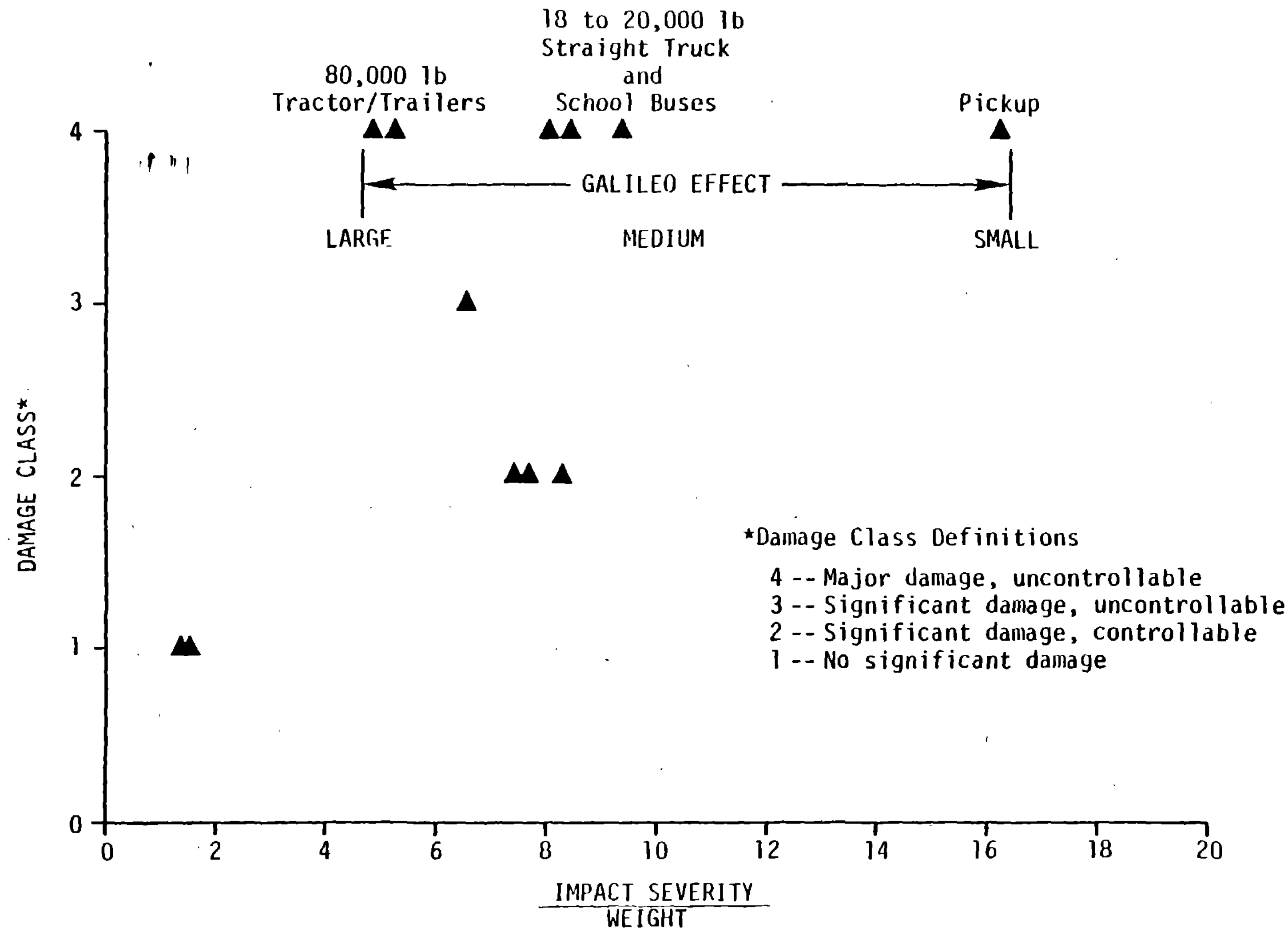


Figure 111. Comparison of normalized impact severity and damage class.

Table 4. Listing of Impact Severity and Damage Type

Vehicle	Test No.	Impact Severity IS = (1/2) (w/g) $(V\sin\theta)^2$ (ft lb)	$\frac{IS}{w}$ (ft)	Type of Suspension Damage
1966 Ford Bronco	3825-10	5,658	1.57	No significant damage Controllable
1966 Ford Bronco	3825-11	27,770	7.72	Significant damage Probably controllable
1974 Datsun Pickup	3825-12	20,270	8.33	Significant damage Probably controllable
1974 Ford F250 Pickup	3825-13	6,313	1.41	No significant damage
1974 Ford F250 Pickup	3825-14	29,640	6.60	Significant damage Probably uncontrollable
1974 Ford F250 Pickup	3825-15	73,850	16.30	Major damage Definitely uncontrollable
1972 Chevy 4WD Pickup	3825-16	35,540	7.47	Significant damage Probably controllable
1979 Ford Straight Truck	3825-17	147,500	8.09	Major damage Definitely uncontrollable
1970 Ford Wayne 66 P School Bus	DSI (4) 3080-I	172,180	8.49	Major damage Definitely uncontrollable
1970 GMC Wayne 66 P School Bus	DSI (4) 3115-I	188,234	9.42	Major Damage Definitely uncontrollable
1980 Kenworth C500 Tractor and Tank Trailer	TTI (5) 2911-I	425,660	5.30	Major damage Definitely uncontrollable
1981 Kenworth and Van-Type Trailer	TTI (6) 2416-I	392,996	4.90	Major damage Definitely uncontrollable

> —You can plainly see the impossibility of increasing the size of structures to vast dimensions either in art or in nature; likewise the impossibility of building ships, palaces, or temples of enormous size in such a way that their oars, yards, beams, iron-bolts, and, in short, all their other parts will hold together; nor can nature produce trees of extraordinary size because the branches would break down under their own weight; so also it would be impossible to build up the bony structures of men, horses, or other animals so as to hold together and perform their normal functions if these animals were to be increased enormously in height; for this increase in height can be accomplished only by employing a material which is harder and stronger than usual, or by enlarging the size of the bones, thus changing their shape until the form and appearance of the animals suggest a monstrosity . . . If the size of a body be diminished, the strength of that body is not diminished in the same proportion; indeed the smaller the body the greater its relative strength. Thus a small dog could probably carry on his back two or three dogs of his own size; but I believe that a horse could not carry even one of his own size.

What is true of animals seems also to be true of motor vehicle suspensions. Figure 111 indicates the probability that the larger the vehicle the more sensitive the suspension is to lateral impact forces.

Front Suspension Characteristics of School Buses

During the course of testing a number of school buses during the 1970's and 80's, primarily pre-1970 buses, researchers at Southwest Research Institute noted some major differences in the way the front suspensions of different bus makes were constructed. Figures 112, 113 and 114 show three ways leaf springs carrying the front or steering axle were attached to the frame. Figure 112 shows a common system of having a pin support at the front with slider to the rear. Figure 113 shows the reverse of 112, i.e. slider to the front, pin support at the rear. Figure 114 is somewhat similar to 112 except that it has a shackle to the rear in place of the slider.

Crash tests of buses into concrete median barriers (CMB's) as shown in figure 115 can produce loads on the impacting front wheel that will cause structural damage to both wheel and suspension. In some cases the front axle may be knocked completely out from under the bus. The main loads produced by this kind of an impact are shown in figure 116.

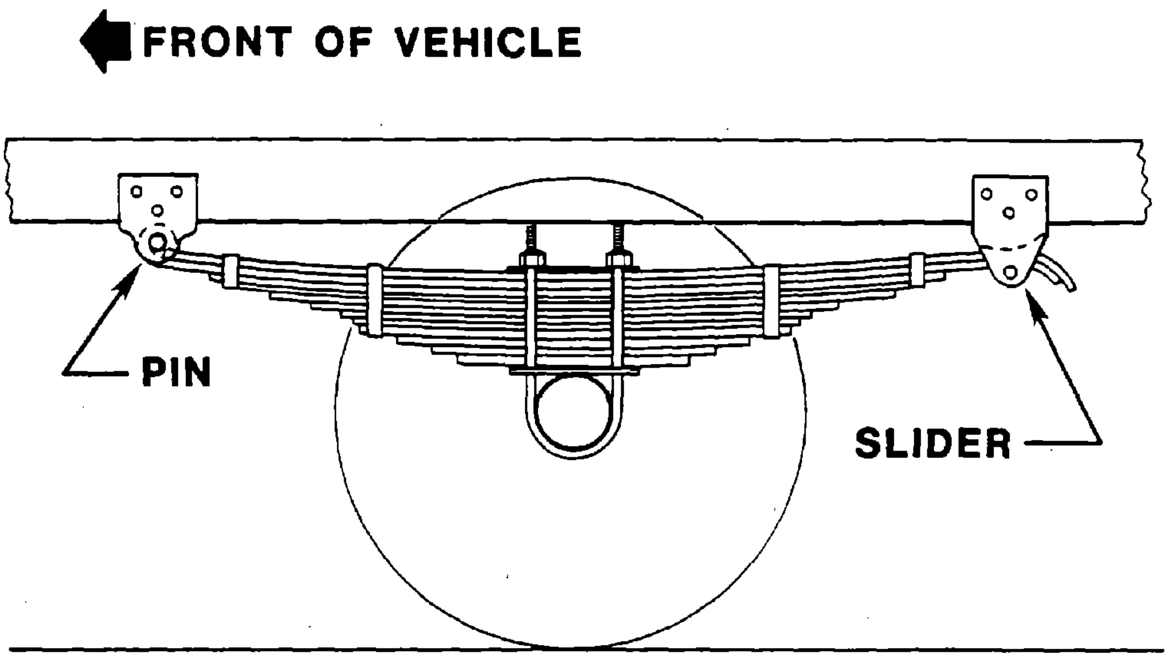


Figure 112. Leaf spring system (1): pin support at front with slider to rear.

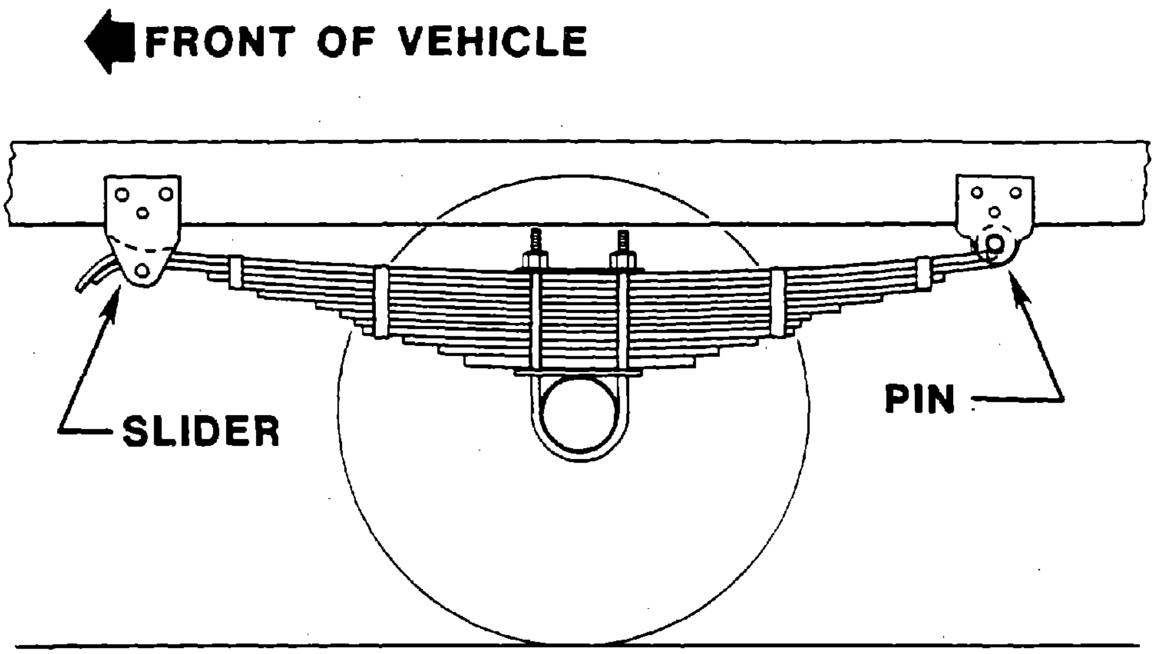


Figure 113. Leaf spring system (2): slider at front with pin support to rear.

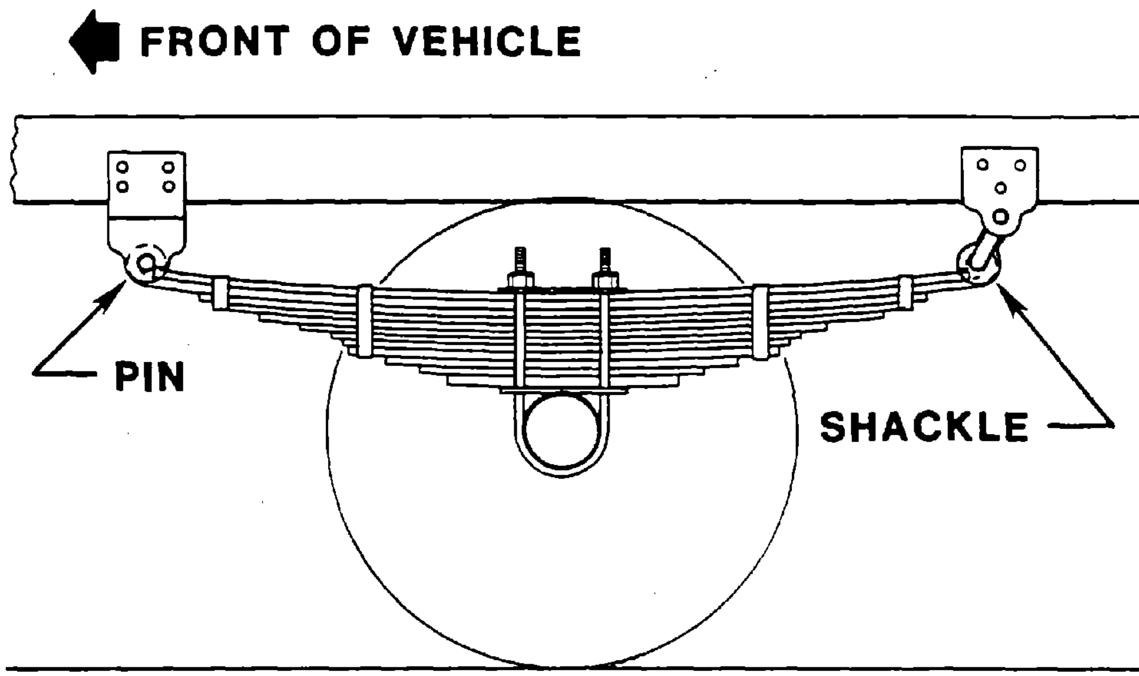


Figure 114. Leaf spring system (3): pin support at front with shackle to rear.

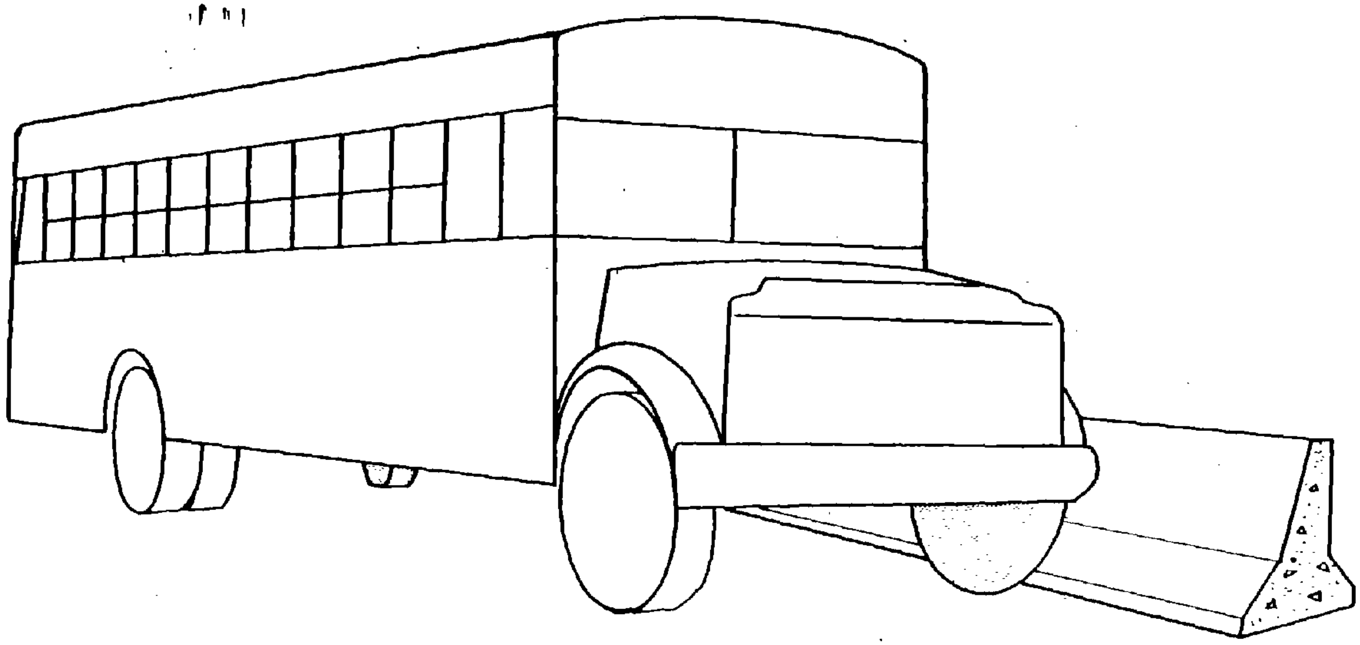


Figure 115. Impact on left front wheel.

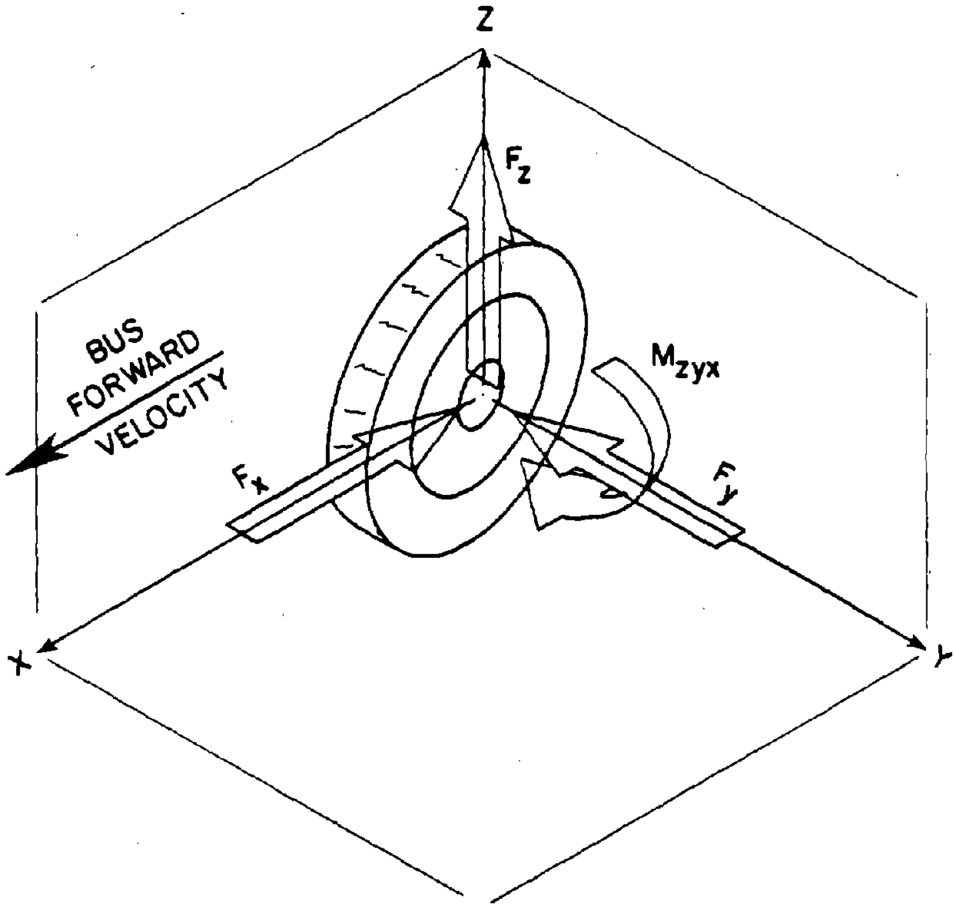


Figure 116. Main loads on the left front wheel impacting a CMB.

M_{zyx} is a moment about the x axis in the zy plane tending to make the wheel in contact with a CMB tuck under. Using the right hand rule this would be a negative rotation about the x axis. The freedom of the vehicle wheel to roll and the steering degree of freedom would preclude development of major moments about the y and z axes respectively.

F_y is a lateral force acting on the wheel in a horizontal direction (approximately in a direction perpendicular to the face of the barrier). It is the major redirecting force during the first part of the collision. F_x is a force in opposition to the movement of the wheel on the face. It is due to friction or gouging of the wheel elements on the face of the barrier. It acts primarily in the plane of the barrier face.

The major forces and moment acting on the left spring (Spring L of figure 117) are transmitted from the wheels through the axle to the spring. These forces and moment are in directions the same as those specified on the wheel and are caused primarily by the forces on the wheel. Figure 117 shows how these forces would be transmitted through the axle to the leaf springs.

These forces result in the following primary internal forces acting on Sections A and B.

1. Pin Forward, Slider to Rear.
   Section A. Torsion, Moment and <u>Tension</u>
   Section B. Moment and Torsion
2. Slider Forward, Pin to Rear
   Section A. Moment and Torsion
   Section B. Torsion, Moment and <u>Compression</u>
3. Pin Forward, Shackle to Rear
   Section A. Torsion, Moment and <u>Tension</u>
   Section B. Moment and Torsion

Comparison of these three cases indicate 1 and 3 are quite similar but both of these have a major difference from 2. In Case 2, a critical spring section (Section B) is placed in compression while in Cases 1 and 3 the critical section (Section A) is placed in tension. Considering the relatively small cross section, there is no doubt the compression situation is the most critical. A local buckling situation will be produced if the rearward force F_x' becomes large enough. This type of

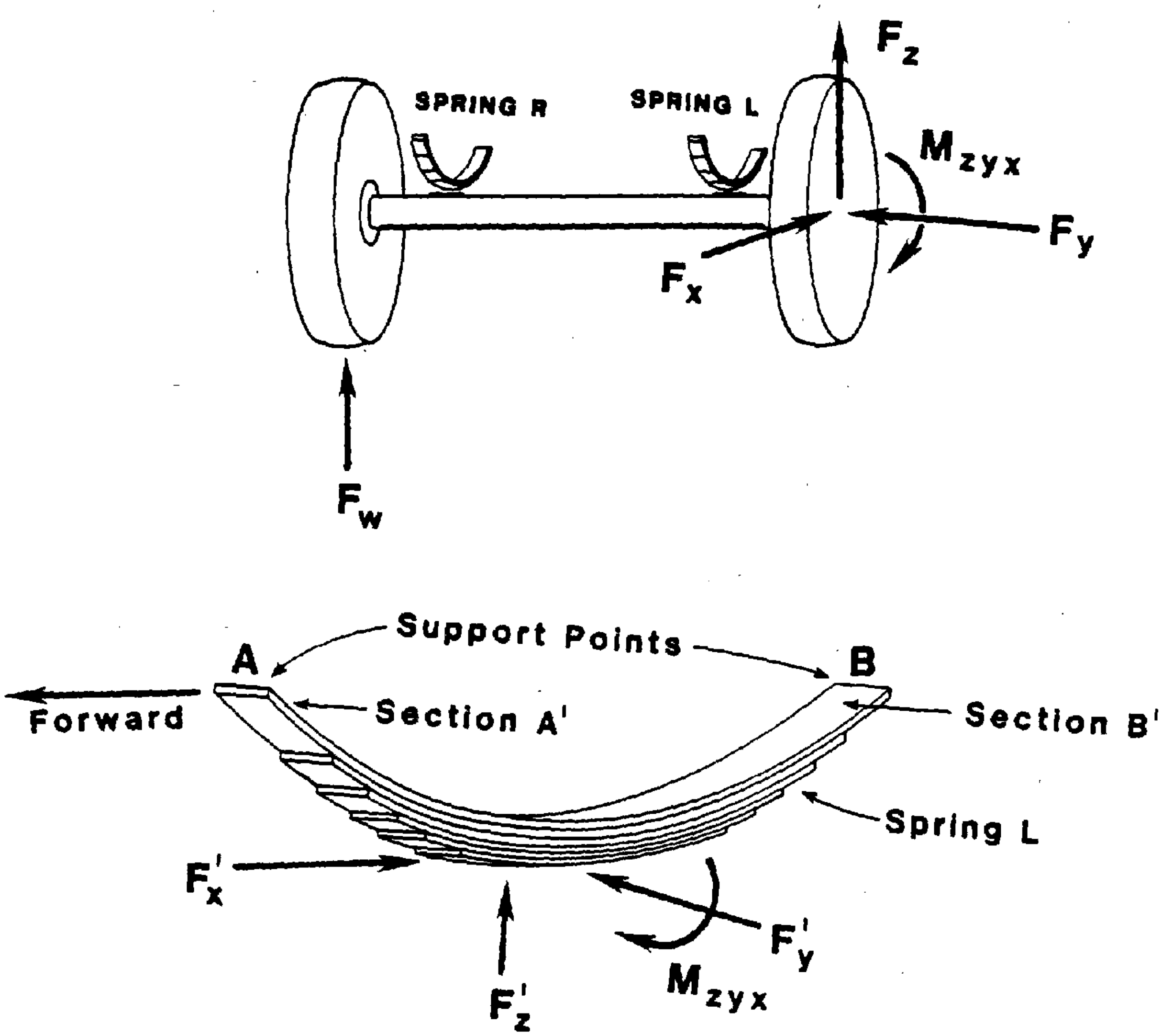


Figure 117. Forces transmitted to the impact side front leaf spring.

failure is illustrated by figure 118. Another disadvantage of Case 2 is that Case 2 (slider forward) is the only one which can produce disengagement of the spring from the forward support if the spring bends in compression due to the force, F_x' (figure 117). It may be equally important to consider what happens if the bolts holding a pin bracket to the frame are sheared. Such an occurrence is shown in figure 119. In this case, if the pin bracket is forward, some support of the spring and axle is still available from the rear slider or shackle (See figure 120). This may be enough to hold the axle under the vehicle following a collision. In contrast, if the pin bracket is to the rear its failure allows the spring to move rearward and disengage from the front axle. Neglecting support from steering linkage, the axle is then completely unsupported on one side. This can lead to a progressive failure of supports on the other end of the axle and complete loss of the steering axle. This situation may make a roll more likely.

Although there are many ways front suspensions can fail when subjected to the intense loads typical during impacts with CMB's, it does appear the slider to the front case, as shown in figure 113, is more sensitive to these loads, from the view point of structural geometry, than are Cases 1 and 3, which move the pin to the front. It is this simple - a leaf spring, when subjected to loads along its longitudinal axis can support more tensile load than it can compressive load.

During the course of this contract examples of this slider forward condition were sought for straight trucks. None were found. The only examples of this found to date have been in pre-1970 school buses. The writers feel strongly that this suspension configuration should be discouraged.

Figure 118. Break in spring adjacent to rear pin.
(Slider forward, pin to rear)

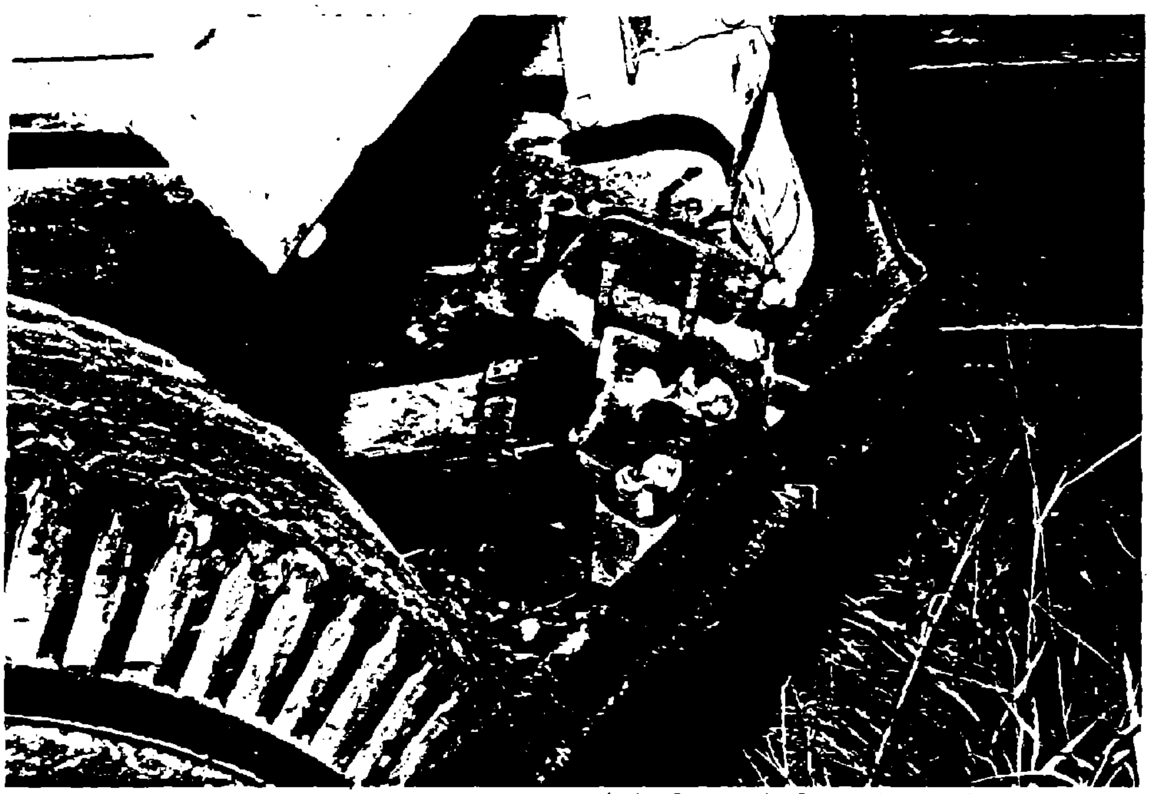


Figure 119. Pin bracket with frame bolts sheared.

Figure 120. Partial support from slider if spring is forced into slider.

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