AASHTO PL-1 PERFORMANCE LEVEL CRASH TESTS ON THE NATCHEZ TRACE PARKWAY BRIDGE RAIL

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DISCLAIMER STATEMENT

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Federal Highway Administration

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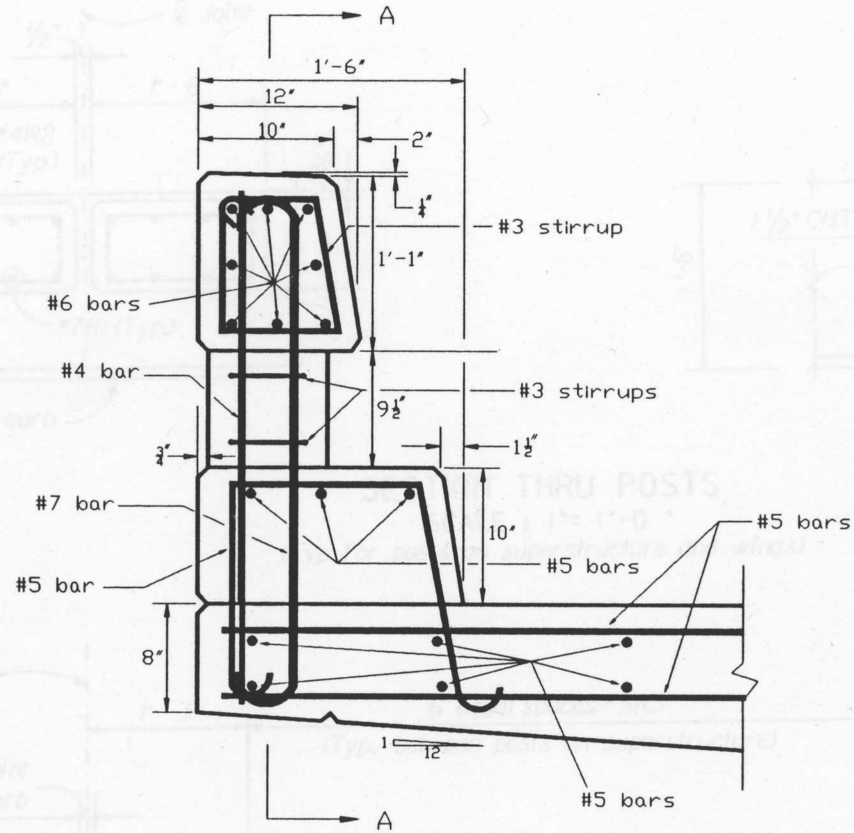
1 INTRODUCTION

1.1 Background

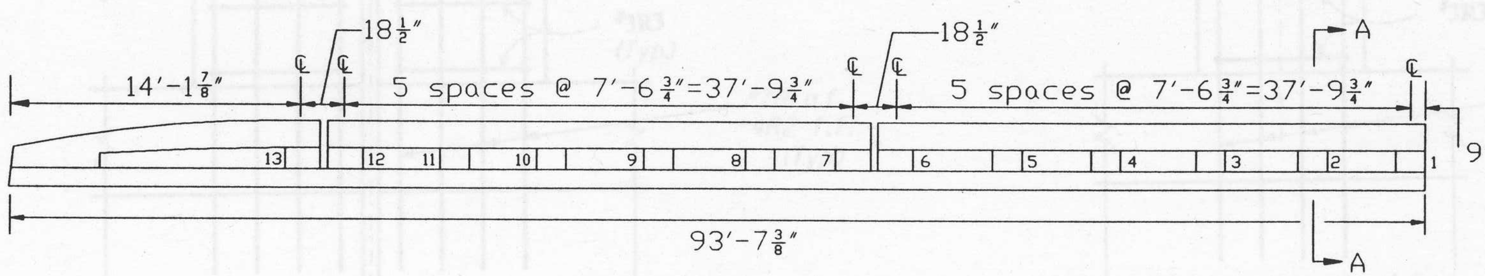
The Coordinated Federal Lands Highways Technology Improvement Program (CTIP) was developed with the purpose of serving the immediate needs of those who design and construct Federal Lands Highways, including Indian Reservation roads, National Park roads and parkways, and forest highways. A wide assortment of guardrails, bridge rails and transitions are being used on roads under the jurisdiction of the National Park Service and other Federal agencies. These guardrails, bridge rails and transitions are intended to blend in with the roadside in order to preserve the visual integrity of the parks and parkways. However, many of them have never been crash tested (1,2). A testing program was developed in order to ensure that the safety hardware used in these areas are safe for the traveling public. The Natchez Trace Parkway Bridge Rail was included in the second Federal Highway Administration (FHWA) testing program - Guardrail Testing Program II.

1.2 Test Installation

The Natchez Trace Parkway bridge rail incorporates a 13 in. deep concrete railing mounted at a height of 32.5 in. Each railing element of the test installation was 37 ft 9 3/4 in. long and is supported by 6 concrete posts spaced 7 ft 6-3/4 in. apart. Adjacent railings are not connected and 1/2 in. wide expansion joints are placed at the end of each rail element. The concrete posts are mounted at the back of a 10 in. high concrete curb. The face of the curb extends approximately 4 in. out from the face of the concrete barrier railing. Details of the Natchez Trace Parkway bridge rail are shown in Figures 1 through 3. The wingwall section of the bridge rail is flared back away from the travelway and tapered down to a height of 16 in., as shown in Figures 3 and 4. Photographs of the test installation are shown in Figures 4 through 6. The test installation was constructed on a simulated concrete bridge deck measuring 79.5 ft long and 5-ft 9-in. wide. A typical cross-section of the simulated bridge deck is shown in Figure 7. Epoxy coated, grade 60 reinforcement steel and class A, air-entrained concrete was used throughout the installation. The 28-day compressive strength of the concrete rail and posts was measured to be approximately 5700 psi. The 51-day compressive strength of the curb was approximately 6500 psi.



CROSS-SECTION A-A



PROFILE VIEW

FIGURE 1. Natchez Trace Parkway Bridge Rail Details

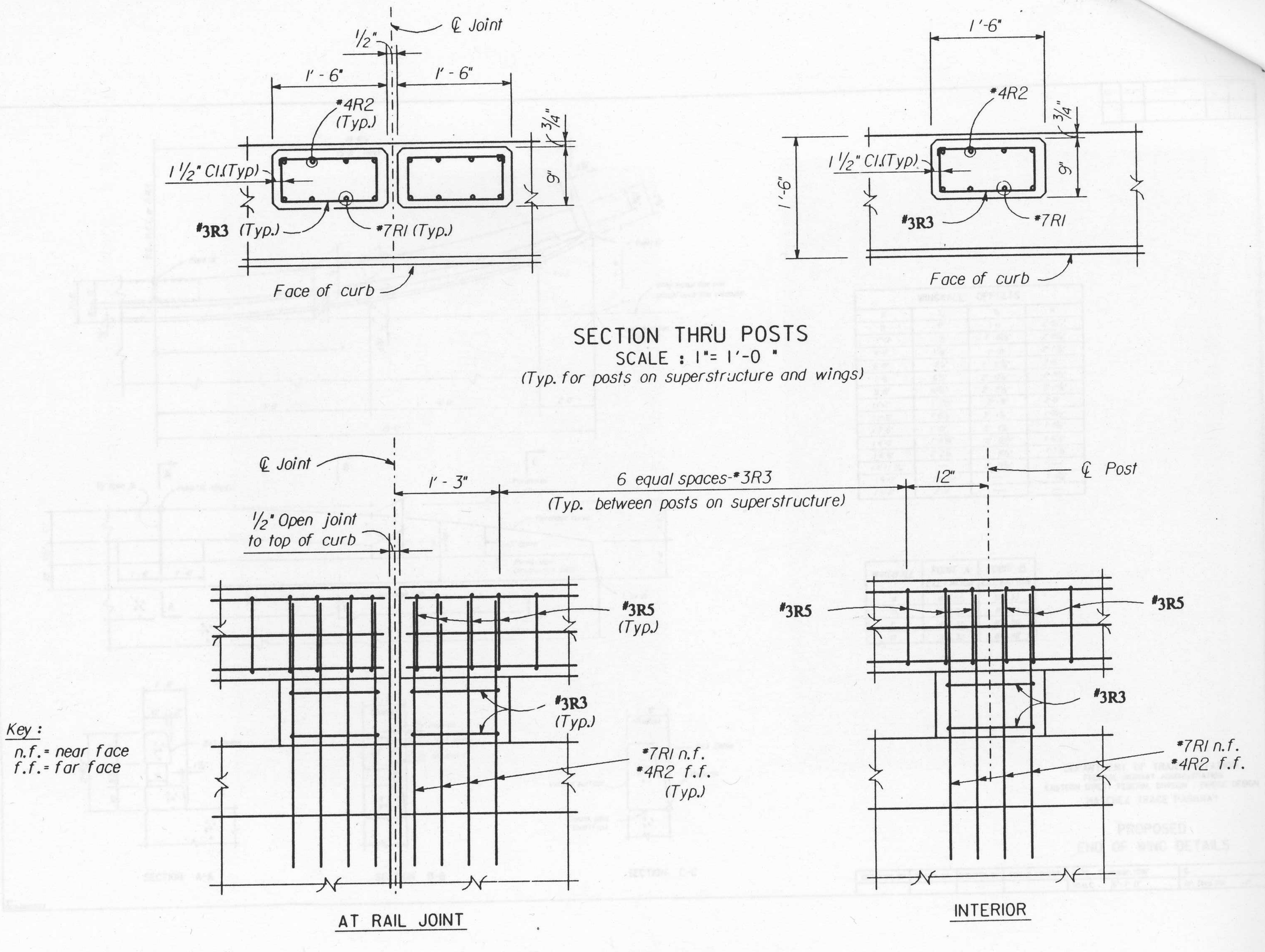
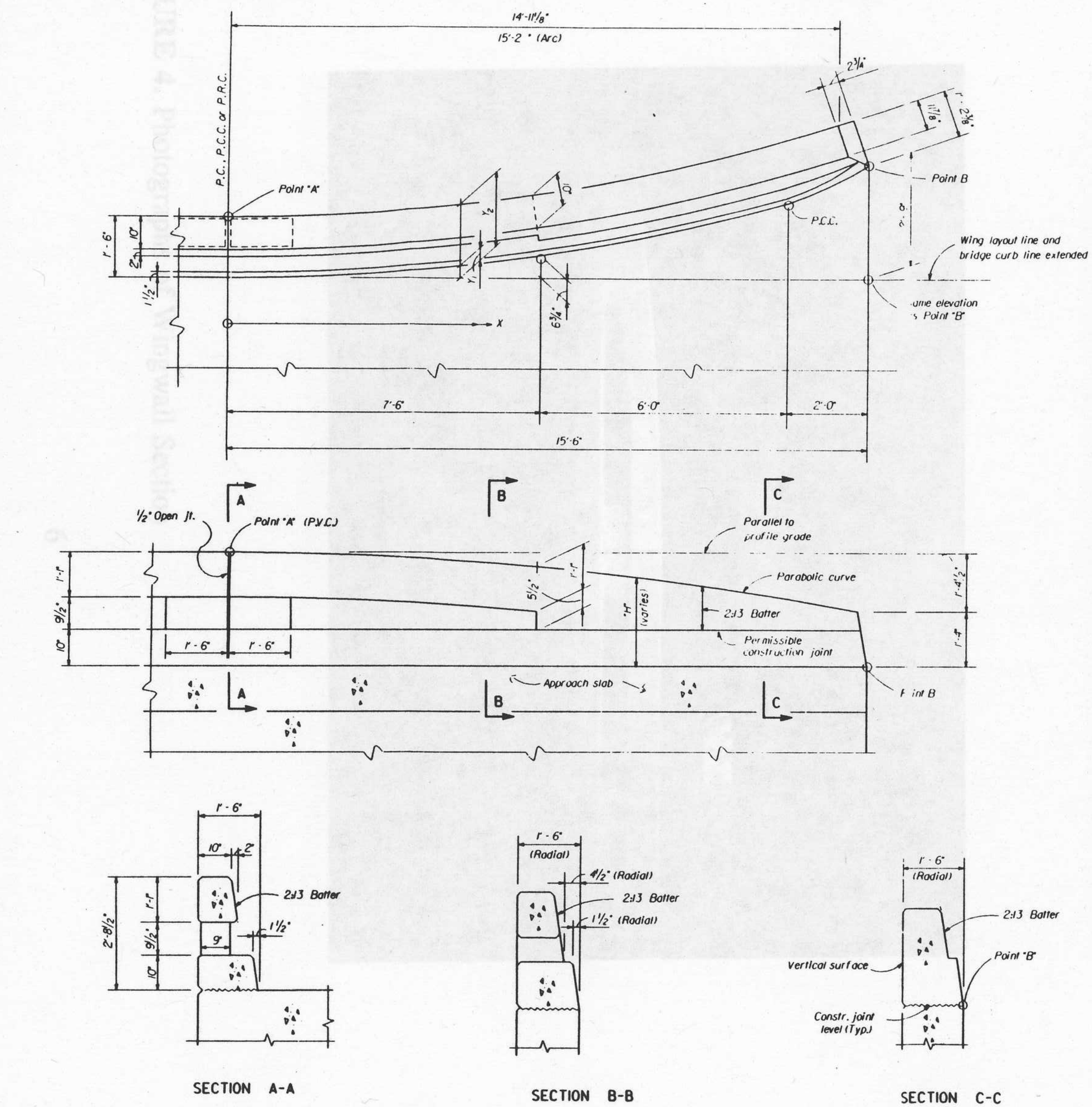


FIGURE 2. Reinforcement Details for Concrete Posts



WINGWALL OFFSETS			
X	Y_1	Y_2	H
0	0	1'-6"	2'-8½"
2'-0"	½"	1'-6½"	2'-8¼"
4'-0"	1⅞"	1'-8"	2'-7⅜"
6'-0"	4¼"	1'-10⅜"	2'-6"
7'-6"	6¾"	2'-0⅞"	2'-4½"
9'-6"	10¾"	2'-5⅛"	2'-2⅛"
11'-0"	1'-2½"	2'-9"	2'-0"
12'-6"	1'-6⅞"	3'-1⅜"	1'-9½"
13'-6"	1'-10"	3'-4¾"	1'-7⅝"
14'-0"	1'-11⅞"	3'-6½"	1'-6⅝"
14'-6"	2'-2⅜"	3'-8¼"	1'-5⅝"
14'-11⅛"	—	3'-9⅞"	—
15'-0"	2'-5⅜"	—	1'-4⅝"
15'-6"	2'-9"	—	—

WINGWALL	POINT A ELEVATION	POINT B ELEVATION
A	875.55	874.33
B	878.90	875.91
C	877.37	874.20
D	876.32	872.92

DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
EASTERN DIRECT FEDERAL DIVISION, BRIDGE DESIGN
NATCHEZ TRACE PARKWAY

PROPOSED
END OF WING DETAILS

DESIGNED BY	DRAWN BY	CHECKED BY	SQUAD LEADER	DATE December, 1987	G-
				SCALE ¾" = 1'-0"	Br. Dwg. No. of

VI-05A1(100D72)

FIGURE 3. Wingwall Section Design Details

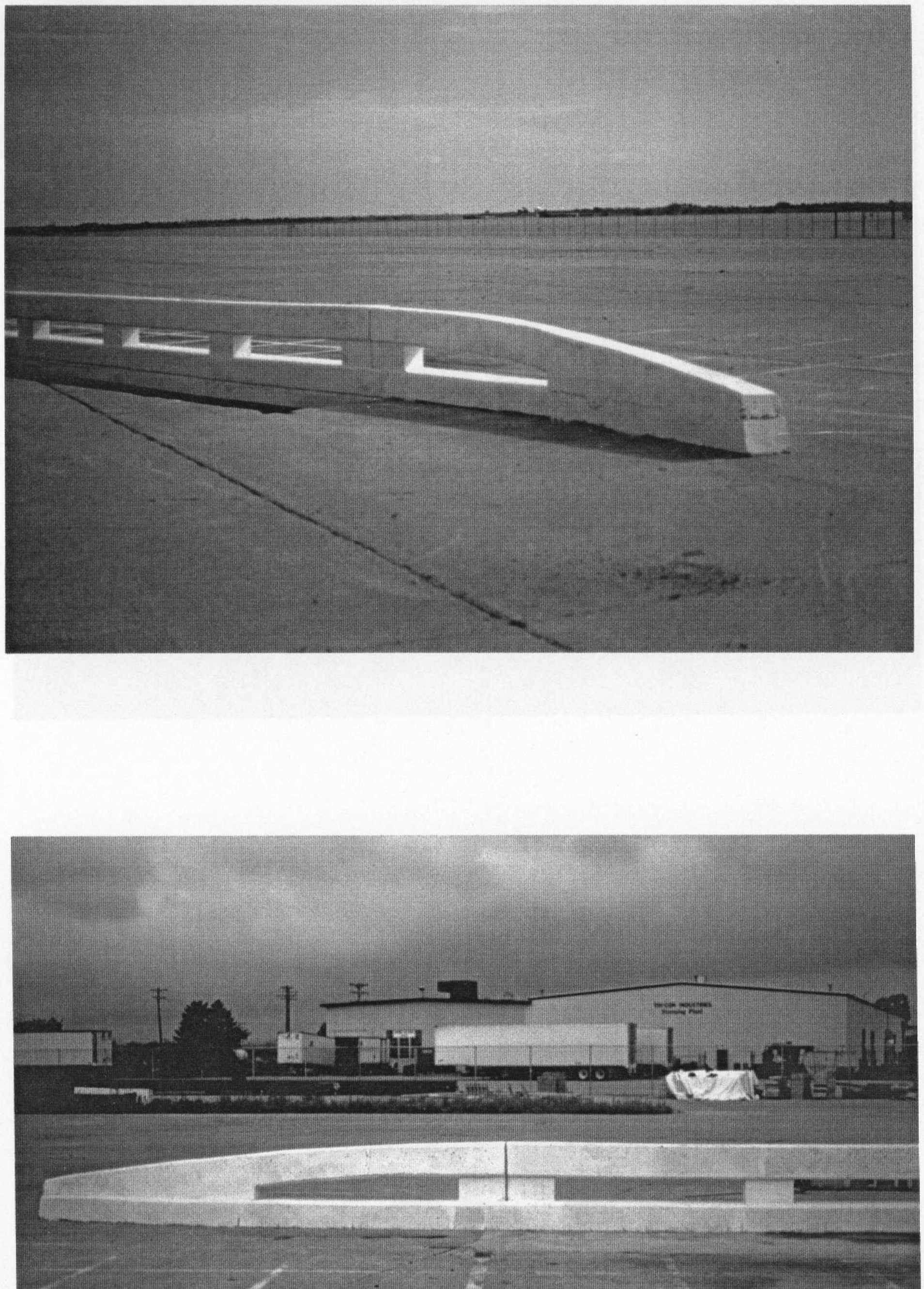


FIGURE 4. Photographs of Wingwall Section

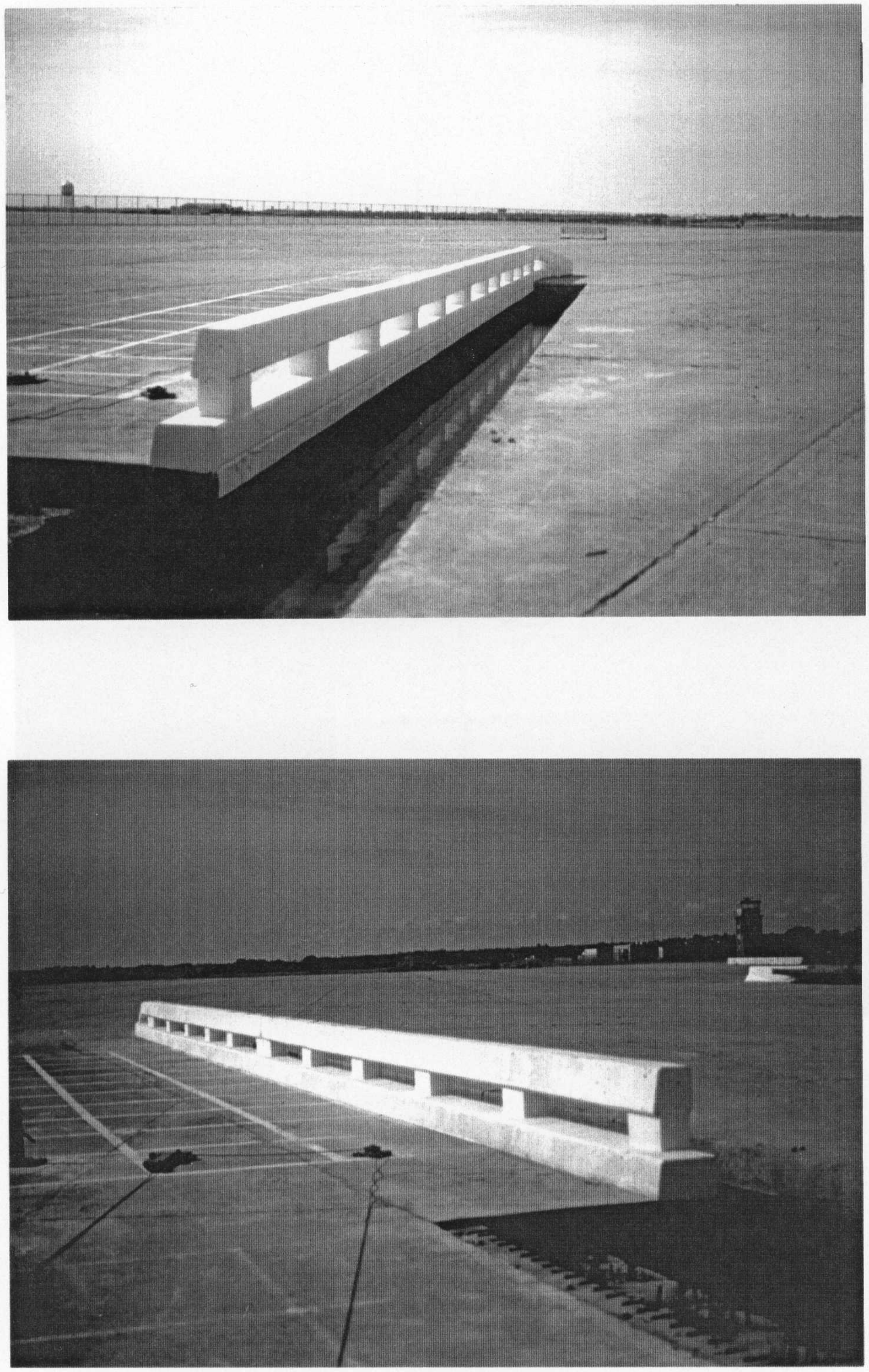


FIGURE 5. Photographs of the Natchez Trace Parkway Bridge Rail

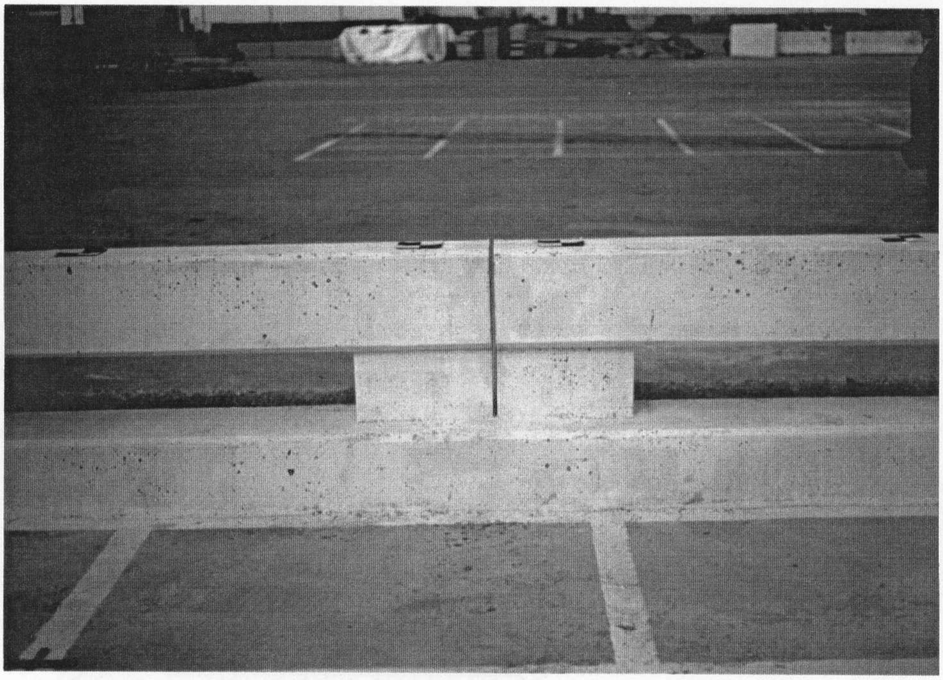


FIGURE 6. Bridge Rail Gap Between Post No.'s 6 and 7

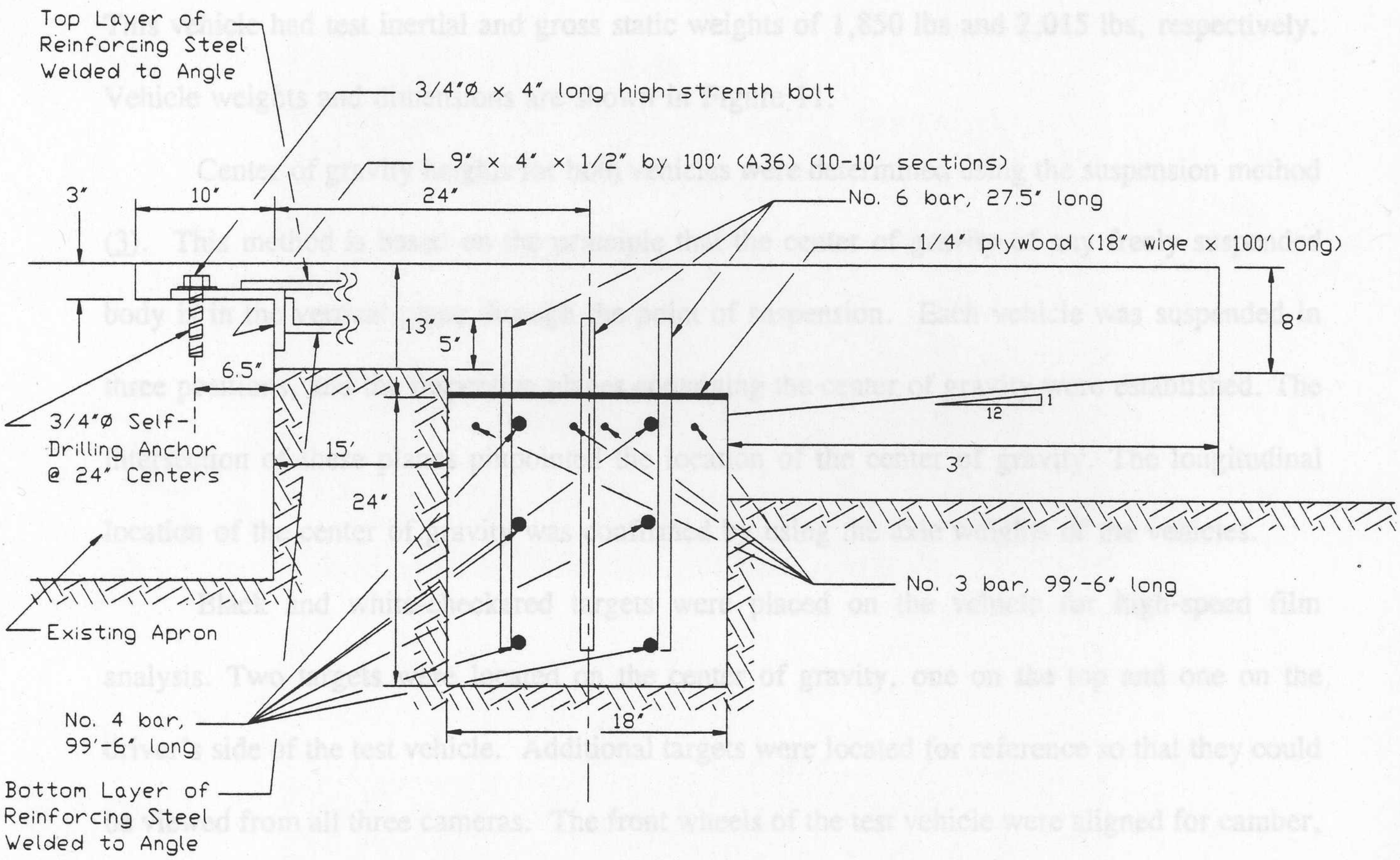


FIGURE 7. Simulated Concrete Bridge Deck

2 TEST CONDITIONS

2.1 Test Vehicles

A 1984 Chevrolet Custom Deluxe 20 pickup, shown in Figure 8, was used as a test vehicle in Test NTBR-1. As shown in Figure 9, the vehicle had a test inertial and a gross static weight of 5,400 lbs and 5,565 lbs, respectively.

A 1984 Renault Encore, shown in Figure 10, was used as a test vehicle in Test NTBR-2. This vehicle had test inertial and gross static weights of 1,850 lbs and 2,015 lbs, respectively. Vehicle weights and dimensions are shown in Figure 11.

Center of gravity heights for both vehicles were determined using the suspension method (3). This method is based on the principle that the center of gravity of any freely suspended body is in the vertical plane through the point of suspension. Each vehicle was suspended in three positions, and the respective planes containing the center of gravity were established. The intersection of these planes pinpointed the location of the center of gravity. The longitudinal location of the center of gravity was confirmed by using the axle weights of the vehicles.

Black and white-checkered targets were placed on the vehicle for high-speed film analysis. Two targets were located on the center of gravity, one on the top and one on the driver's side of the test vehicle. Additional targets were located for reference so that they could be viewed from all three cameras. The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. Two 5B flash bulbs, fired by a pressure tape switch on the front bumper, were mounted on the roof of each vehicle to establish the time of impact on the high-speed film.

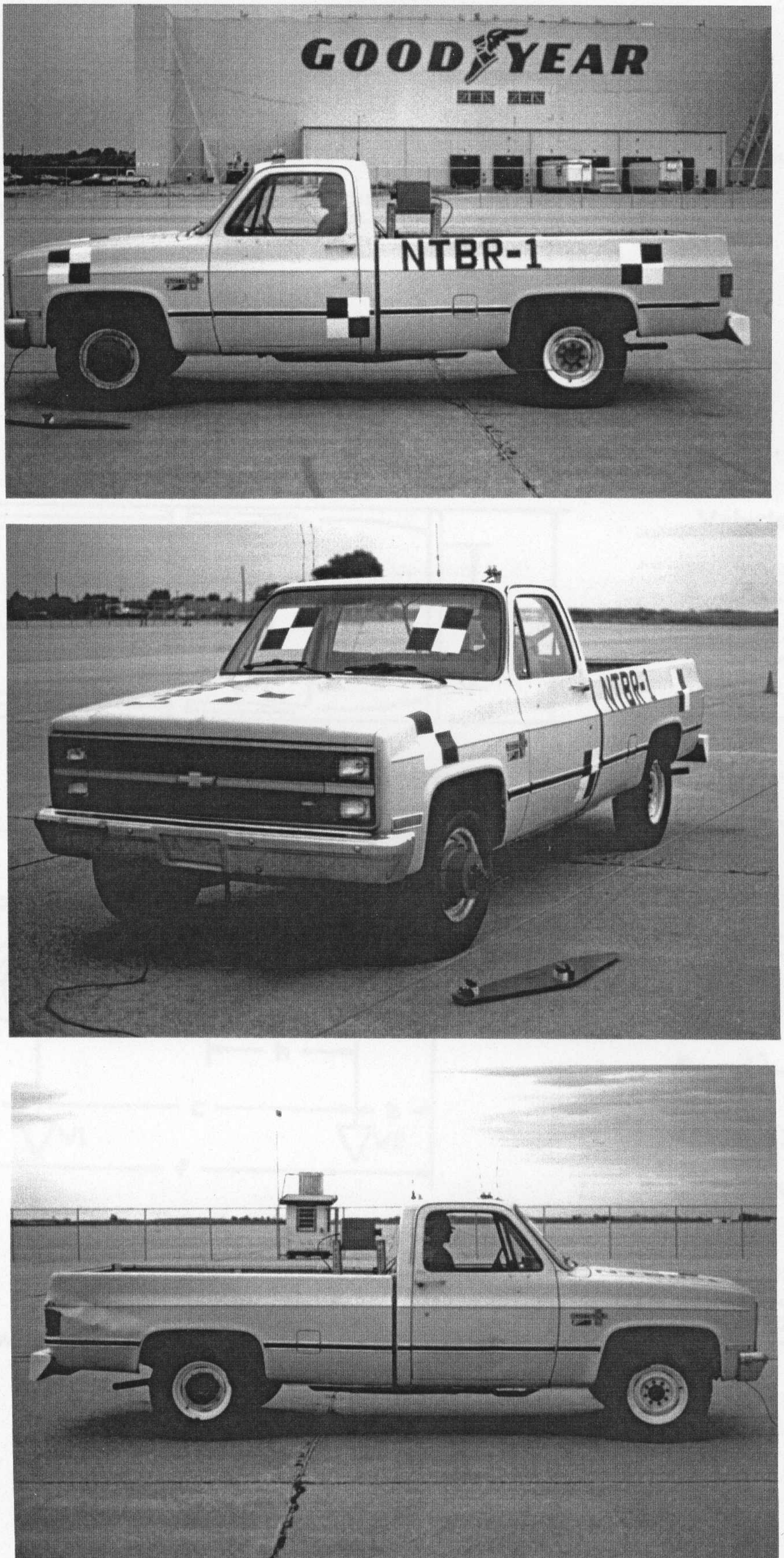
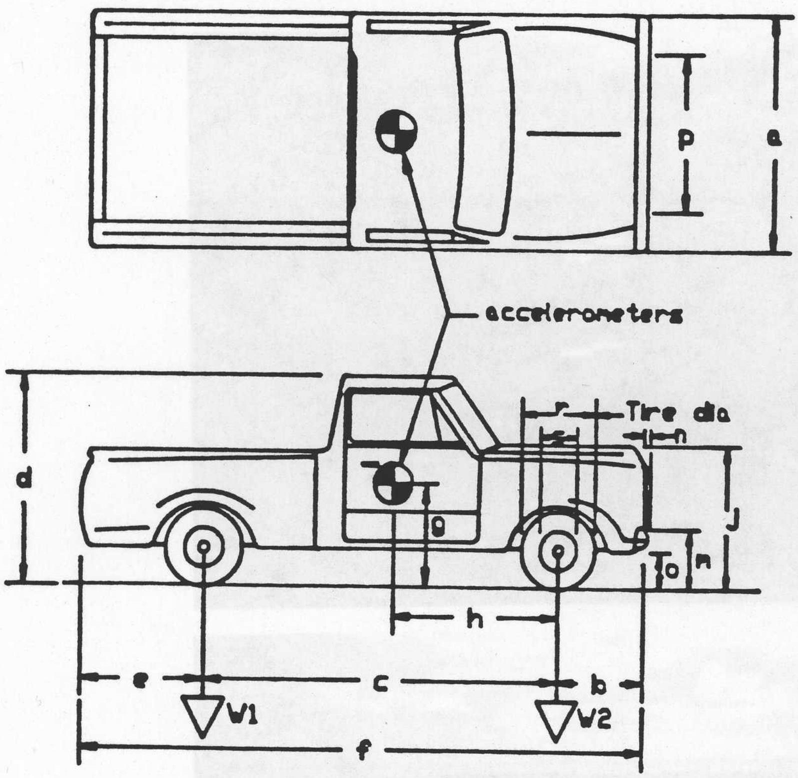


FIGURE 8. Test Vehicle, Test NTBR-1

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

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

Tire Size: LT/235/85R16



Vehicle Geometry - inches

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

Engine Type: V8

Engine Size: 350 cu. in.

Transmission Type:

[Automatic] or Manual

FWD or [RWD] or 4WD

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

Note any damage prior to test: None

FIGURE 9. Vehicle Dimensions, Test NTBR-1

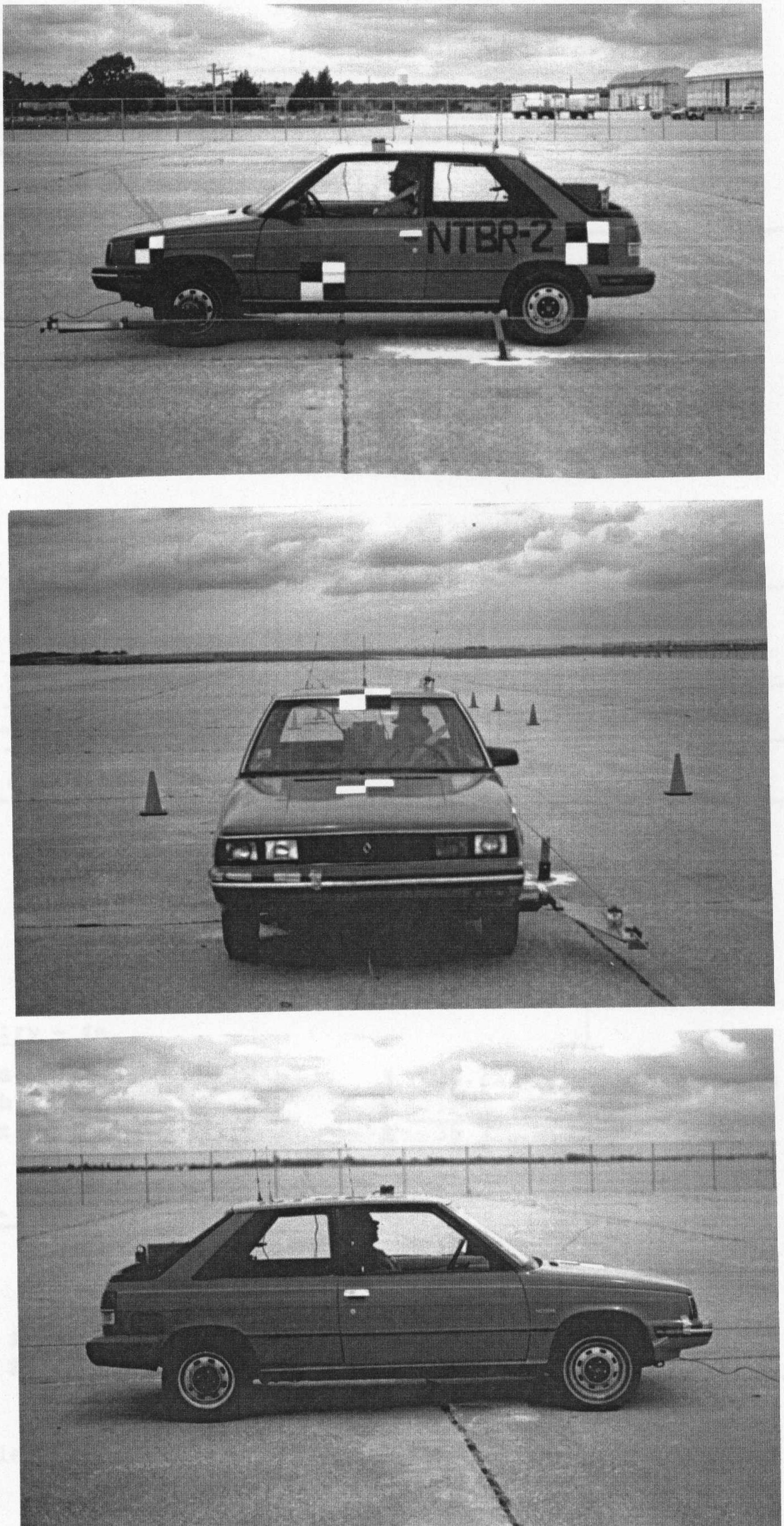
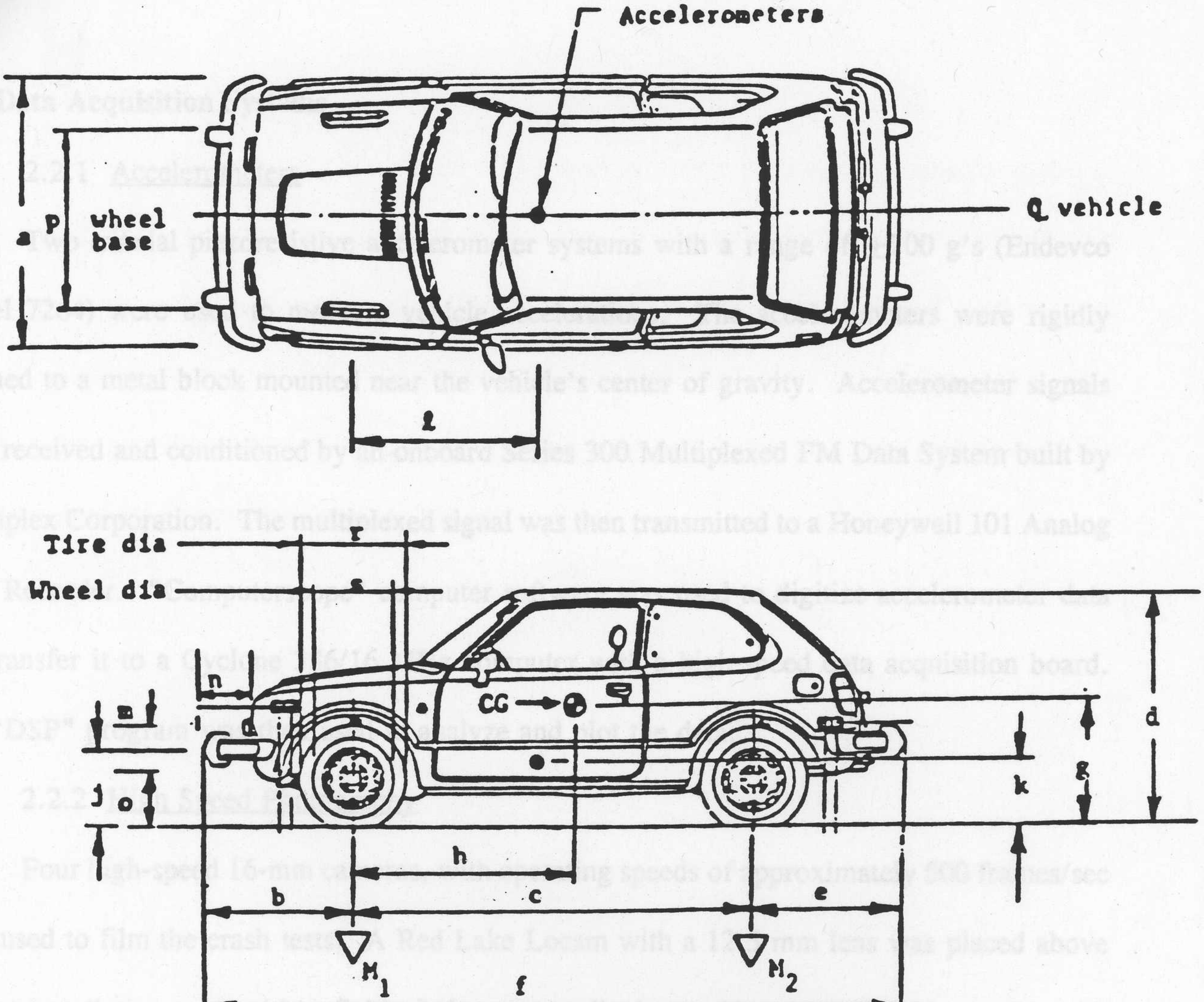


FIGURE 10. Test Vehicle, Test NTBR-2



Geometry - in.

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

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

Vehicle Type: 1984 Renault Encore

FIGURE 11. Vehicle Dimensions, Test NTBR-2

2.2 Data Acquisition Systems

2.2.1 Accelerometers

Two triaxial piezoresistive accelerometer systems with a range of ±200 g's (Endevco Model 7264) were used to measure vehicle accelerations. The accelerometers were rigidly attached to a metal block mounted near the vehicle's center of gravity. Accelerometer signals were received and conditioned by an onboard Series 300 Multiplexed FM Data System built by Metraplex Corporation. The multiplexed signal was then transmitted to a Honeywell 101 Analog Tape Recorder. "Computerscope" computer software was used to digitize accelerometer data and transfer it to a Cyclone 386/16 MHz computer with a high-speed data acquisition board. The "DSP" program was then used to analyze and plot the data.

2.2.2 High Speed Photography

Four high-speed 16-mm cameras, with operating speeds of approximately 500 frames/sec were used to film the crash tests. A Red Lake Locam with a 12.5 mm lens was placed above the test installation to provide a field of view perpendicular to the ground. A Photec IV, with an 80-mm lens, was placed downstream from the impact point and had a field of view parallel to the barrier. A second Photec IV, with a 55-mm lens, was placed on the traffic side of the bridge rail and had a field of view perpendicular to the barrier. Another Red Lake Locam with a 5.7-mm lens was placed onboard the vehicle to record dummy motions during the test. A schematic of the camera locations for each test is shown in Figure 12. A white-colored, 5-ft wide by 5-ft long grid was painted on the concrete surface to provide a visible reference system used in the analysis of the overhead high-speed film. The film was analyzed using a Vanguard Motion Analyzer.

2.2.3 Speed Trap

Eight tape pressure switches spaced at 5-ft intervals were used to determine the speed of the vehicle before and after impact. Each tape switch fired a strobe light and sent an electronic timing mark to the Metraplex unit as the left front tire of the test vehicle passed over it. Test vehicle speeds were determined from electronic timing mark data recorded on the analog tape. Strobe lights and high speed film analysis are used only as a backup in the event that vehicle speeds cannot be determined from the electronic data.

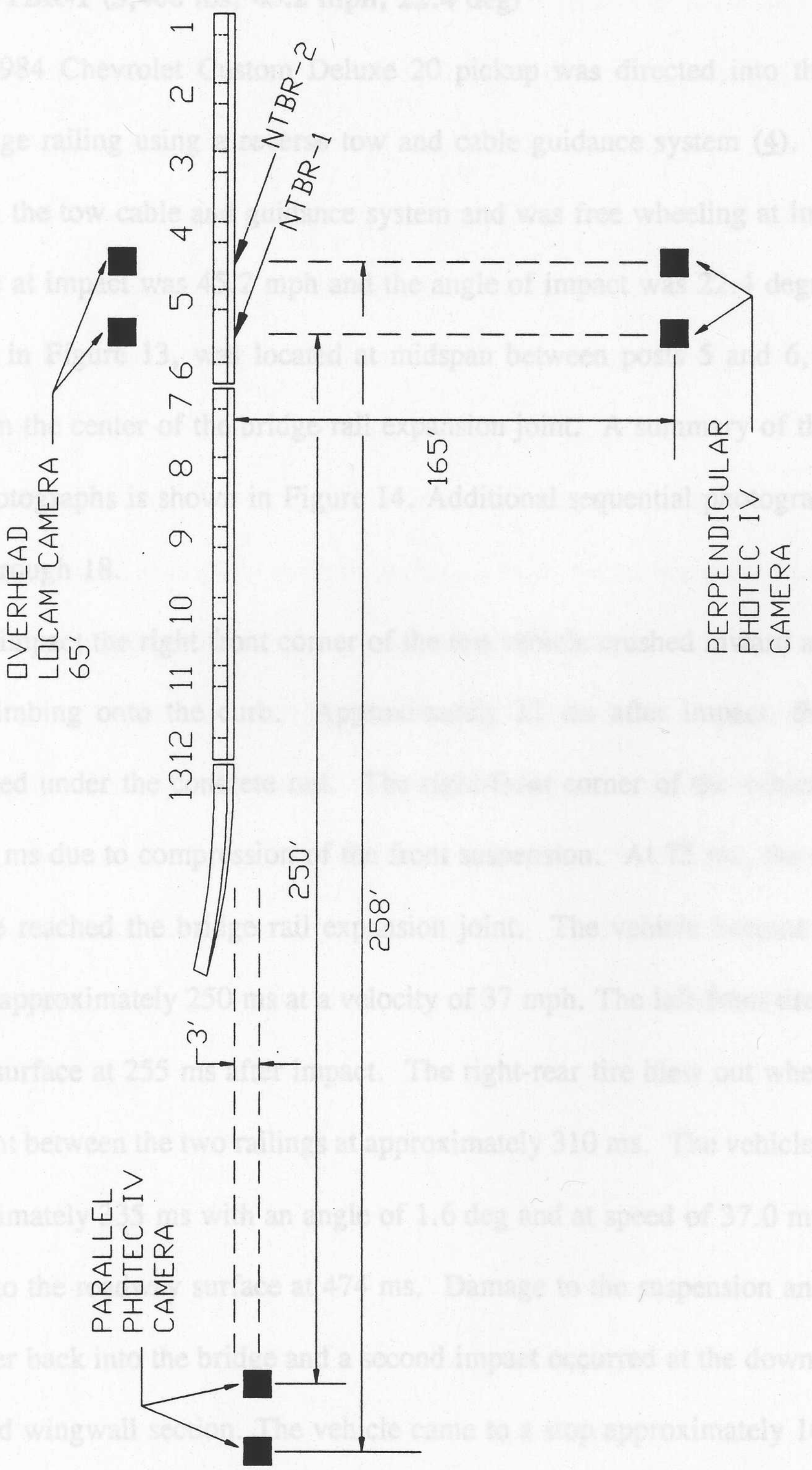


FIGURE 12. Layout of High-Speed Cameras

3 TEST RESULTS

3.1 TEST NTBR-1 (5,400 lbs, 45.2 mph, 22.4 deg)

The 1984 Chevrolet Custom Deluxe 20 pickup was directed into the Natchez Trace Parkway bridge railing using a reverse tow and cable guidance system (4). The vehicle was released from the tow cable and guidance system and was free wheeling at impact. The speed of the vehicle at impact was 45.2 mph and the angle of impact was 22.4 degrees. The impact point, shown in Figure 13, was located at midspan between posts 5 and 6, or 4-ft 6 5/8-in. upstream from the center of the bridge rail expansion joint. A summary of the test results and sequential photographs is shown in Figure 14. Additional sequential photographs are shown in Figures 15 through 18.

Upon impact the right front corner of the test vehicle crushed inward and the right-front tire began climbing onto the curb. Approximately 32 ms after impact, the right-front tire became wedged under the concrete rail. The right-front corner of the vehicle began to move upward at 56 ms due to compression of the front suspension. At 75 ms, the right-front corner of the vehicle reached the bridge rail expansion joint. The vehicle became parallel with the bridge rail at approximately 250 ms at a velocity of 37 mph. The left-front tire lost contact with the roadway surface at 255 ms after impact. The right-rear tire blew out when it contacted the expansion joint between the two railings at approximately 310 ms. The vehicle exited the bridge rail at approximately 335 ms with an angle of 1.6 deg and at speed of 37.0 mph. The left-front tire returned to the roadway surface at 474 ms. Damage to the suspension and tires caused the vehicle to steer back into the bridge and a second impact occurred at the downstream end of the bridge rail and wingwall section. The vehicle came to a stop approximately 105 ft downstream from impact as shown in Figure 19. The maximum perpendicular distance between the right-side of the test vehicle and the barrier face was approximately 0.83 ft at a point 30 ft downstream from impact. The effective coefficient of friction was found to be 0.28 and would be classified as "fair" according to the AASHTO Guide Specifications for Bridge Railings (5).

Test vehicle damage was relatively minor and was largely limited to the right-front quarter panel and front bumper, as shown in Figure 20. Both right-side tires were blown out and the rims were damaged during the impact. The right-rear bumper also received minor damage. There was no intrusion or deformation of the occupant compartment. TAD (6) and VDI (7) damage classifications are shown in Figure 14. Vehicle crush measurements are shown in Figure 21. The bridge rail received superficial damage, as shown in Figure 22. Heavy tire marks and deep scrapes on the rail indicating large contact forces were found over a 13-ft 11-in. length of the bridge rail. Lighter tire marks and small scrapes were observed over a 13 ft. length of the rail. Evidence of impact with the curb was limited to 4-ft 8-in. of tire marks.

As a result of technical problems incurred during this test, the accelerometer data was not available. As a result, the high speed film was analyzed to obtain longitudinal and lateral occupant impact velocities of 10.8 fps and 22.2 fps, respectively. The highest occupant ridedown decelerations in the longitudinal and lateral directions were 6.3 g's and 9.5 g's, respectively.

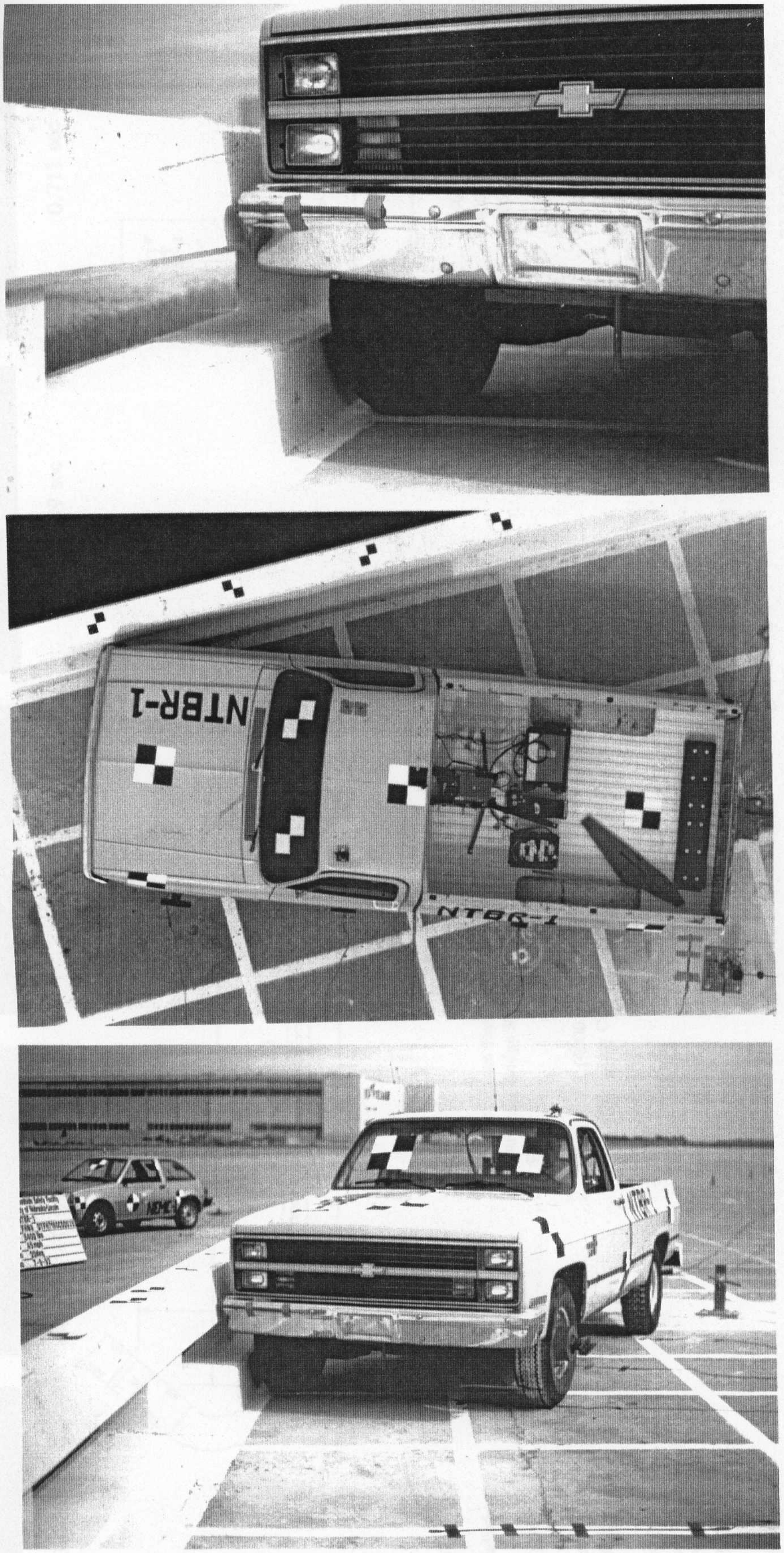
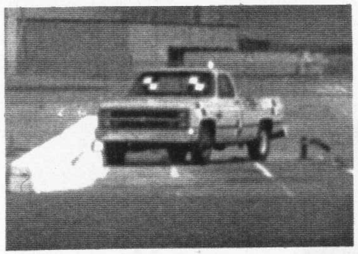


FIGURE 13. Vehicle Impact Location, Test NTBR-1



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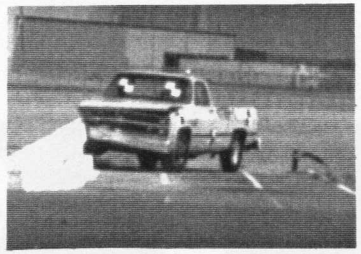

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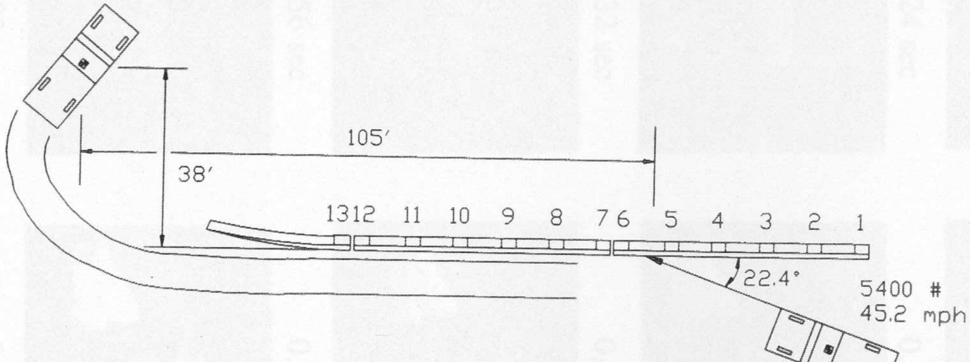
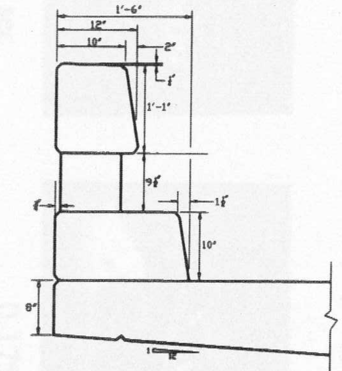




Test Number	NTBR-1
Date	7/9/92
Bridge Rail Installation	Natchez Trace Parkway Curb and Bridge Rail
Total Length (ft)	93.6
Material	
Concrete	Class A AE (4000 psi)
Reinforcing Steel	Grade 60 Epoxy Coated
Concrete Curb	
Length (ft)	93.6
Bottom Width (in.)	18
Top Width (in.)	16.5
Height (in.)	10
Concrete Rail	
Length (ft)	78.7
Bottom Width (in.)	12
Top Width (in.)	10
Bottom Height (in.)	19.5
Top Height (in.)	32.5
Concrete Posts	
Length (in.)	13
Width (in.)	18
Depth (in.)	9
Vehicle Model	1984 Chevrolet Custom Deluxe 20

Vehicle Weight	
Curb (lb)	4,610
Test Inertial (lb)	5,400
Gross Static (lb)	5,565
Vehicle Speed	
Impact (mph)	45.2
Exit (mph)	37.0
Vehicle Angle	
Impact (deg)	22.4
Exit (deg)	1.6
Vehicle Snagging	None
Vehicle Stability	Satisfactory
Effective Coefficient of Friction (μ)	0.28 (Fair)
Occupant Impact Velocity	
Longitudinal (fps)	10.8 (30)
Lateral (fps)	22.2 (25)
Occupant Ridedown Deceleration	
Longitudinal (g's)	6.3 (15)
Lateral (g's)	9.5 (15)
Vehicle Damage	Minor
TAD	1-RFQ-3
VDI	01RFEW2
Bridge Rail Damage	Tire marks and minor concrete spalling
Maximum Vehicle Rebound Distance (ft)	0.83

FIGURE 14. Test NTBR-1 Summary

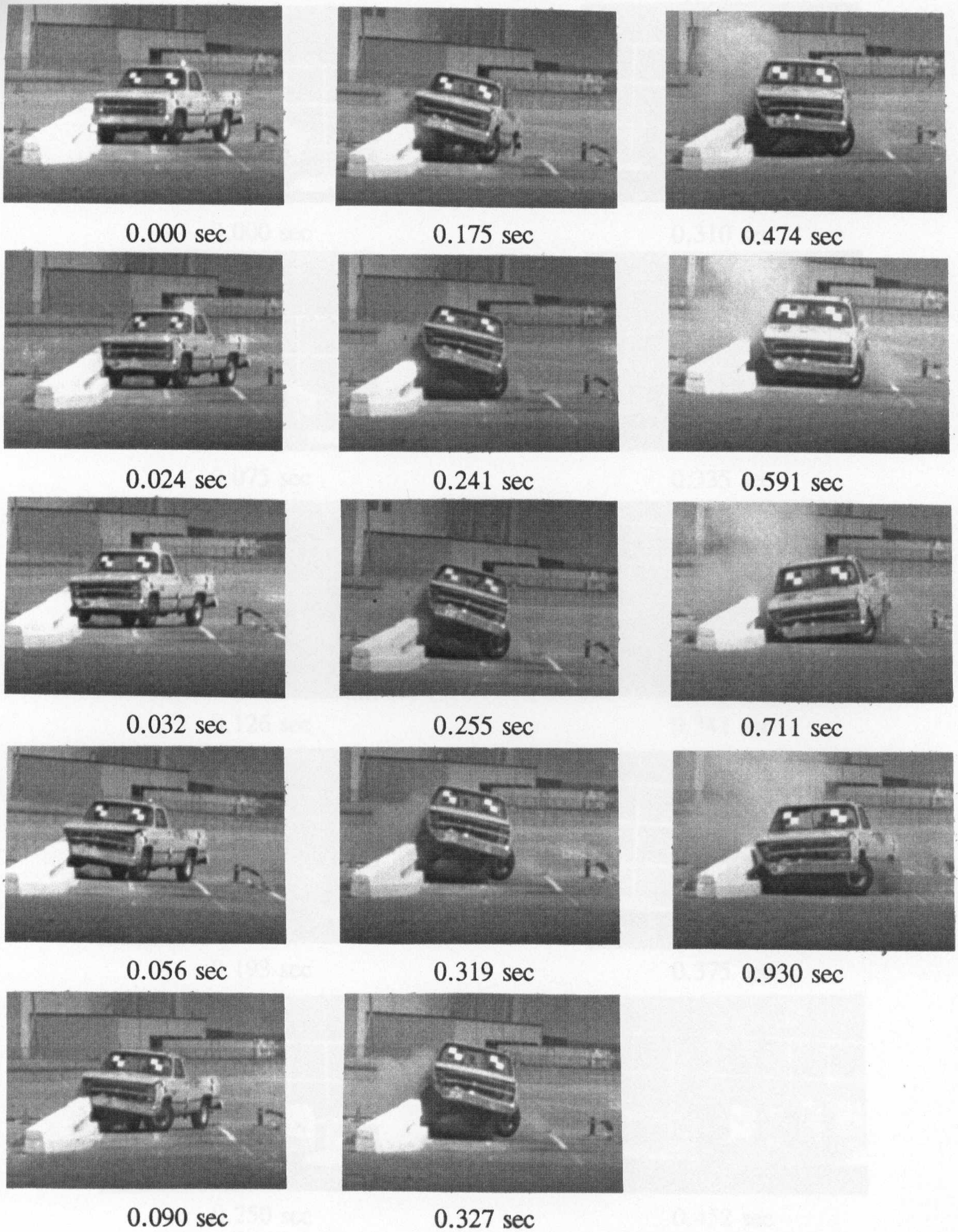
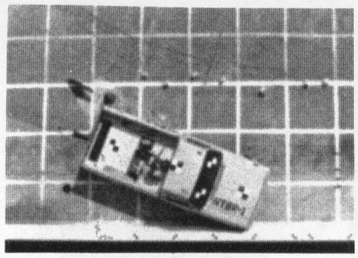


FIGURE 15. Downstream Sequential Photographs, Test NTBR-1



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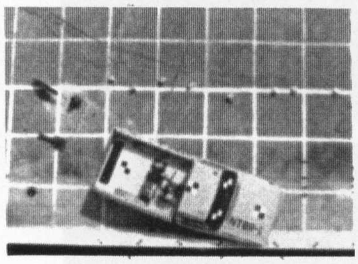

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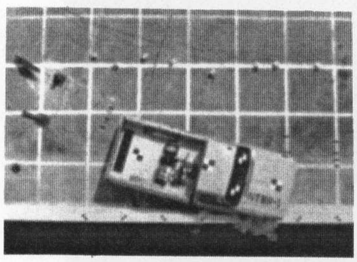

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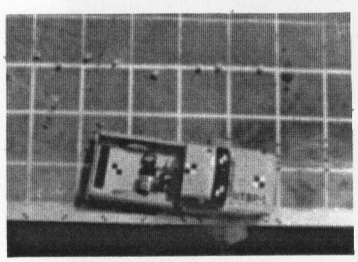

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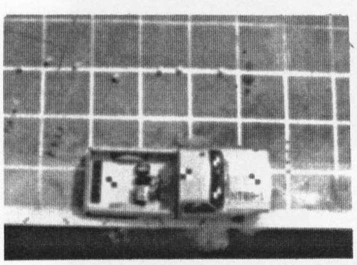

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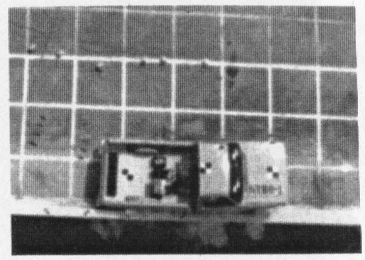

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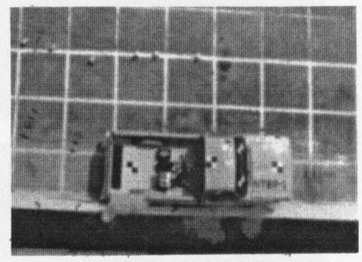

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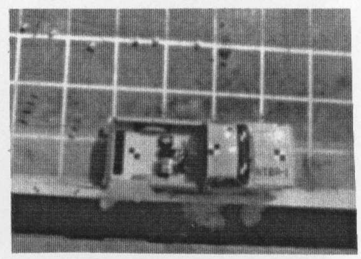

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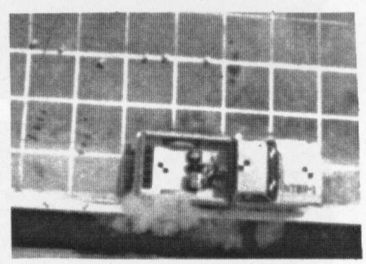

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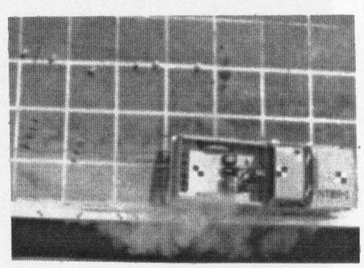

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FIGURE 16. Overhead Sequential Photographs, Test NTBR-1

FIGURE 17. Full-Scale Vehicle Crash Test, Test NTBR-1

FIGURE 18. Full-Scale Vehicle Crash Test, Test NTBR-1 (cont.)

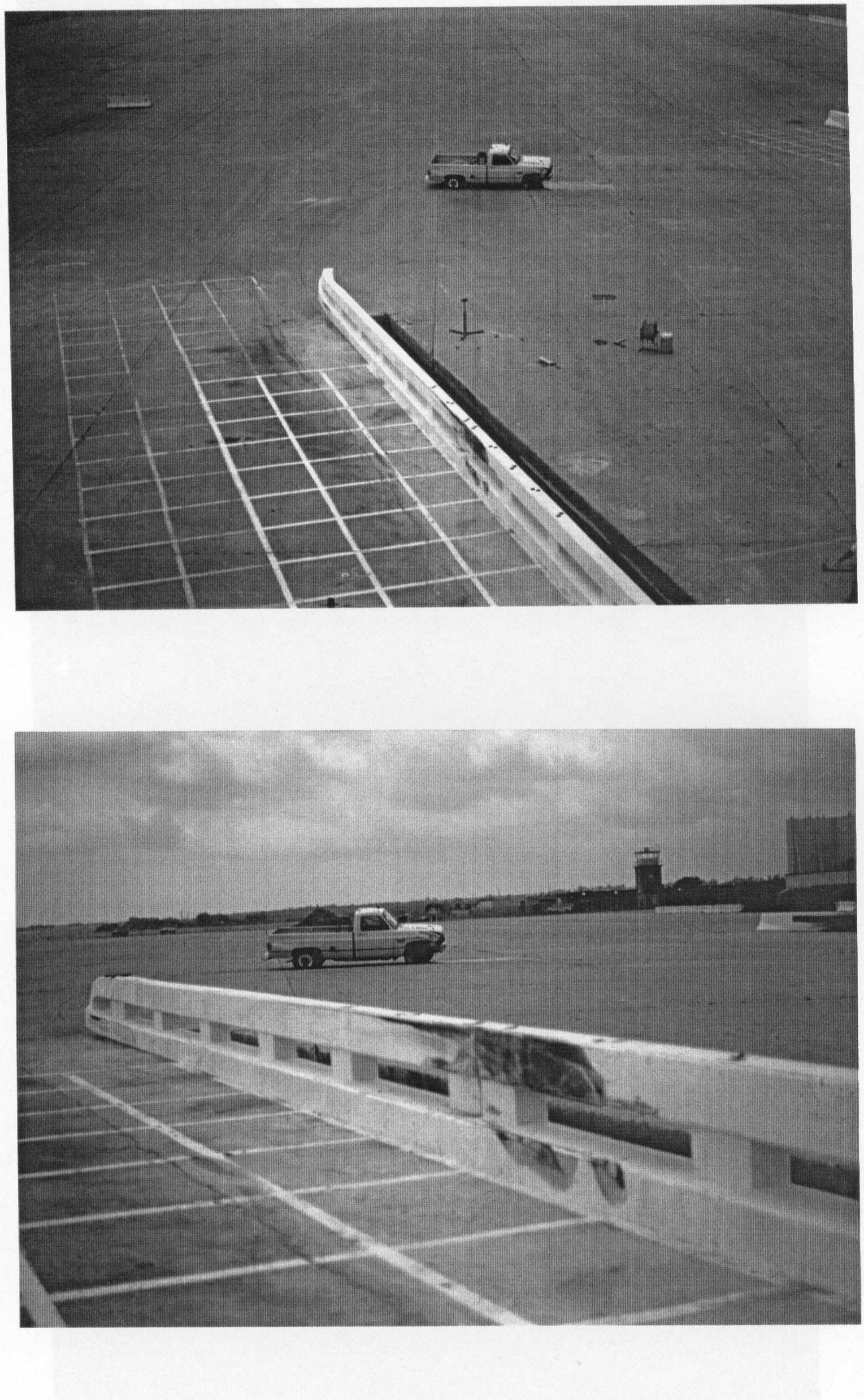


FIGURE 19. Vehicle Trajectory, Test NTBR-1

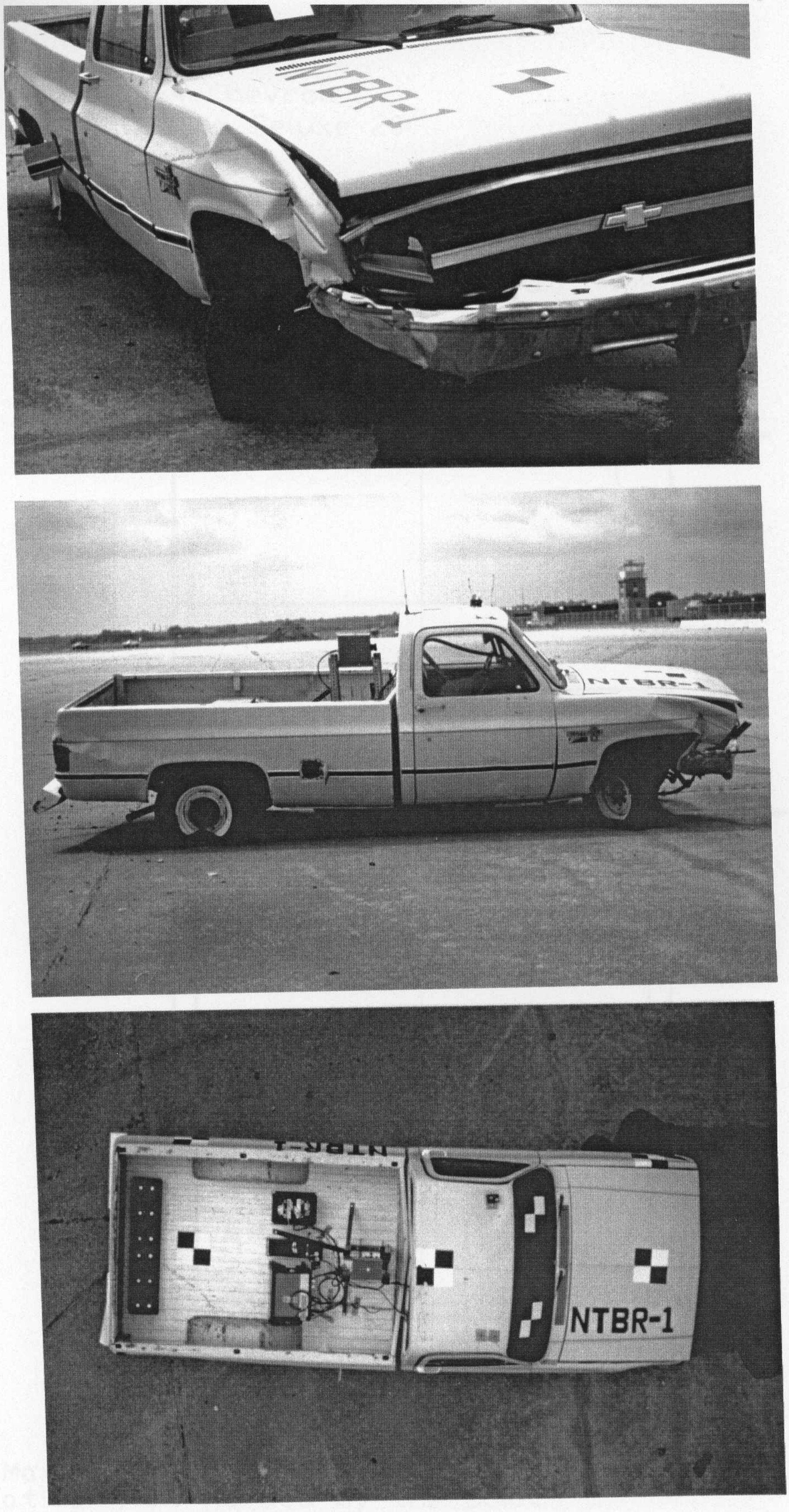


FIGURE 20. Vehicle Damage, Test NTBR-1

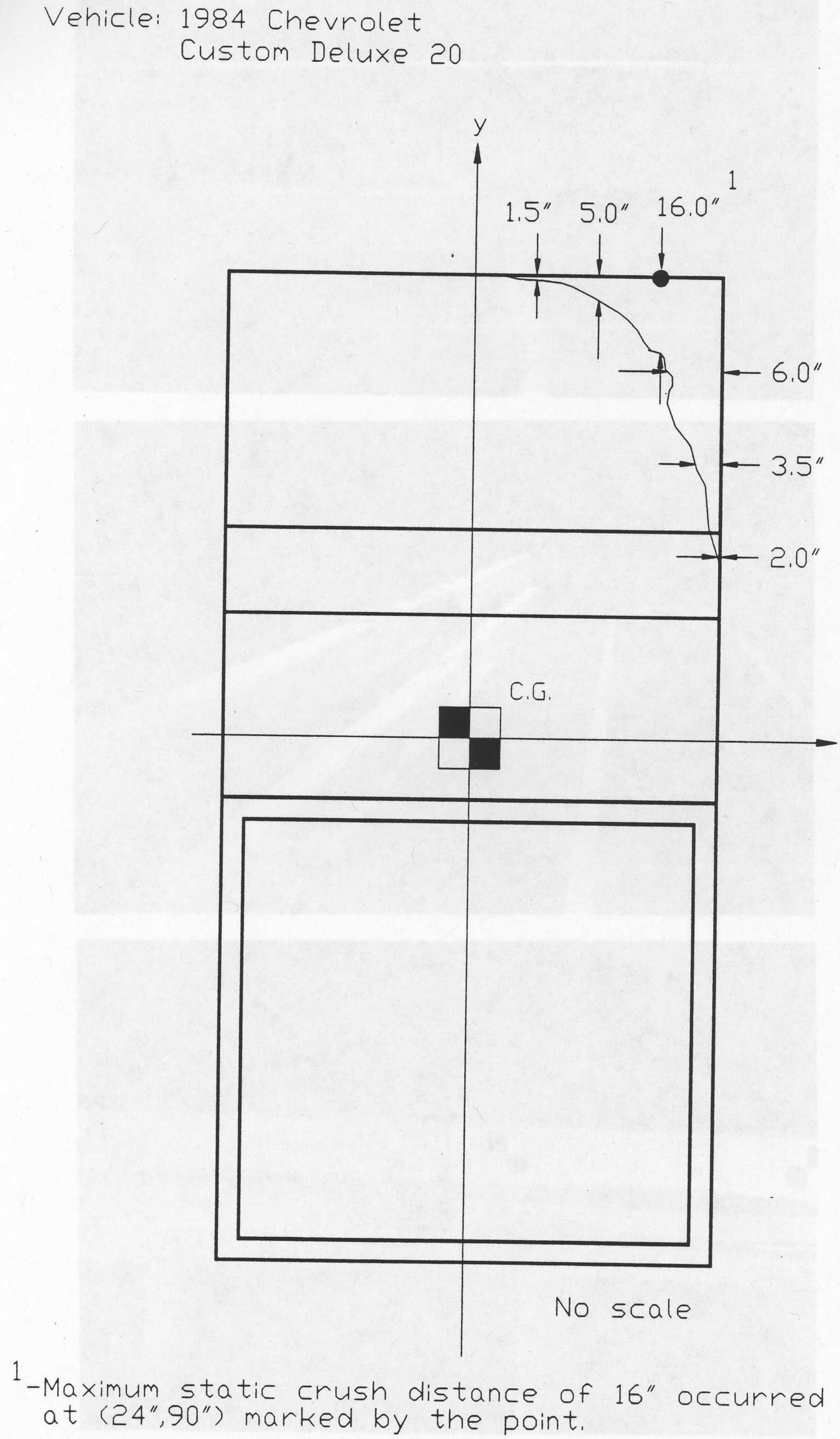


FIGURE 21. Vehicle Crush Measurements, Test NTBR-1

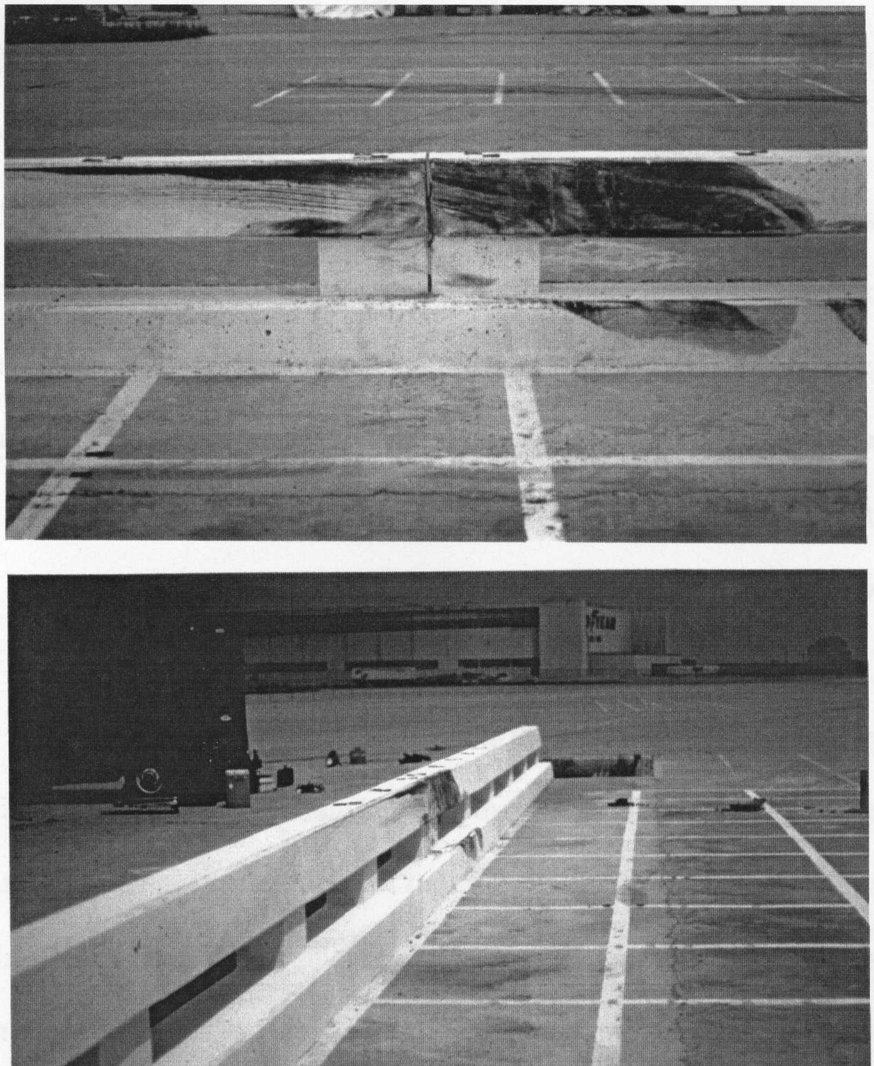


FIGURE 22. Bridge Rail Damage, Test NTBR-1

3.2 TEST NTBR-2 (1,850 lbs, 51.5 mph, 19.5 deg)

The 1984 Renault Encore was directed into the Natchez Trace Parkway bridge railing using a reverse tow and cable guidance system (4). The vehicle was released from the tow cable and guidance system and was free wheeling at impact. The speed of the vehicle at impact was 51.5 mph and the angle of impact was 19.5 degrees. The impact point, shown in Figure 23, was located at midspan between posts 4 and 5. A summary of the test results and sequential photographs is shown in Figure 24. Additional sequential photographs are shown in Figures 25 through 28.

After the initial impact with the bridge rail, the right-front corner of the vehicle crushed inward, causing the bumper to penetrate between the curb and the rail. Simultaneously, the right-front tire was deformed against the face of the curb. This interaction of the curb and the wheel caused the tire to blow out. The vehicle became parallel with the bridge rail at approximately 164 ms with a velocity of 38.3 mph. During redirection, the left-rear tire began to uplift, causing the vehicle to roll clockwise toward the rail. The vehicle exited the rail at approximately 345 ms with an angle of 8.5 degrees and an speed of 32.4 mph. Both left-side tires contacted the ground at 760 ms as the vehicle yawed away from the rail. The vehicle's trajectory is shown in Figure 29. The maximum rebound distance was approximately 25.3 ft which is higher than the desired value of 20 ft. The effective coefficient of friction was found to be 0.60, and would be classified as "fair" according to the AASHTO Guide Specifications for Bridge Railings (5).

Test vehicle damage was relatively minor and was largely limited to the right-front quarter panel and wheel, and front bumper, as shown in Figure 30. There was slight buckling of the right-front floorboard and roof due to the force of the impact. The vehicle remained upright both during and after the test, and there was no intrusion of the occupant compartment.

TAD (6) and VDI (7) classifications are shown in Figure 24. Vehicle crush measurements are shown in Figure 31.

Bridge rail damage is shown in Figure 32. Tire marks and minor concrete spalling accounted for the majority of the damage. The length of the markings on the rail were approximately 7.5 ft, caused by the scraping of the bumper and the fender. The length of the markings on the curb were 8.5 ft, caused by the rubbing of the right-front tire which blew out at impact.

The normalized longitudinal and lateral occupant impact velocities as determined from accelerometer data were 19.35 fps and 26.23 fps, respectively. The highest 10-ms average occupant ridedown decelerations were 3.69 g's (longitudinal) and 7.79 g's (lateral). The results of the occupant risk are summarized in Figure 24. The accelerometer traces are shown in Appendix A.

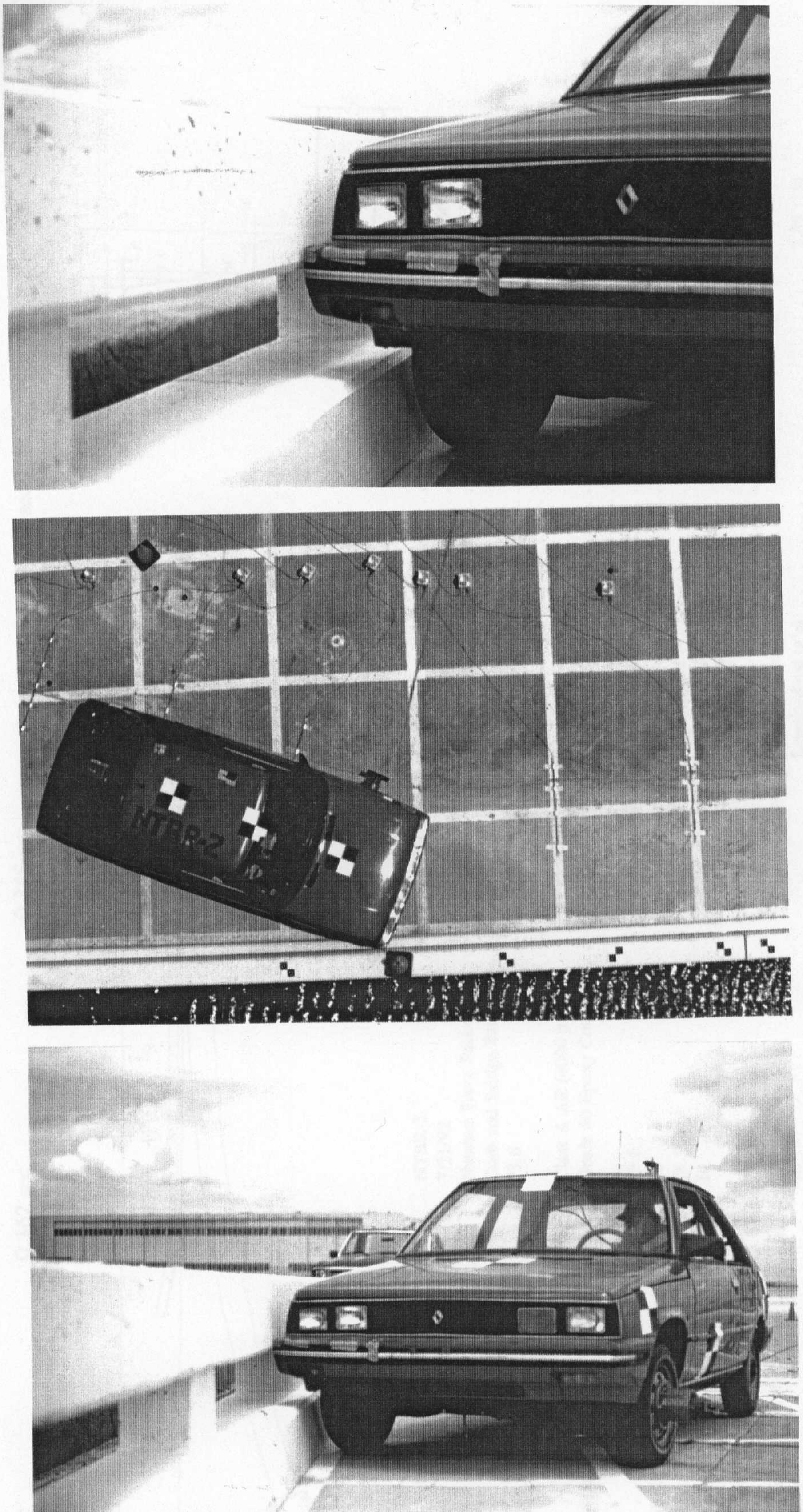
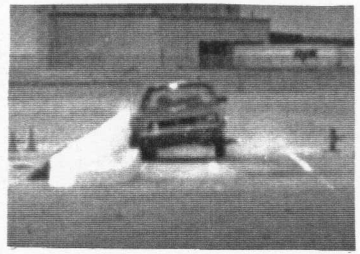


FIGURE 23. Vehicle Impact Location, Test NTBR-2

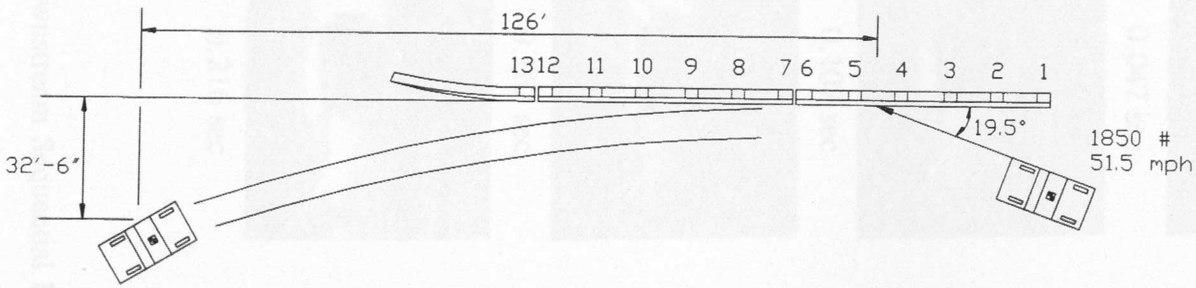

0.000 sec

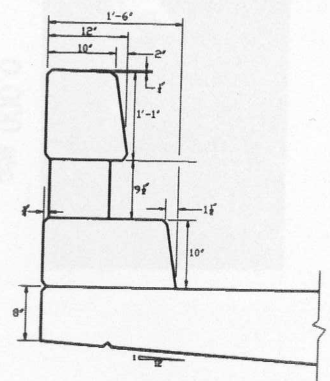

0.162 sec


0.345 sec


0.404 sec


0.760 sec





Test Number	NTBR-2
Date	7/21/92
Bridge Rail Installation	Natchez Trace Parkway Curb and Bridge Rail
Total Length (ft)	93.6
Material	
Concrete	Class A AE (4000 psi)
Reinforcing Steel	Grade 60 Epoxy Coated
Concrete Curb	
Length (ft)	93.6
Bottom Width (in.)	18
Top Width (in.)	16.5
Height (in.)	10
Concrete Rail	
Length (ft)	78.7
Bottom Width (in.)	12
Top Width (in.)	10
Bottom Height (in.)	19.5
Top Height (in.)	32.5
Concrete Posts	
Length (in.)	13
Width (in.)	18
Depth (in.)	9
Vehicle Model	1984 Renault Encore

Vehicle Weight	
Curb (lb)	2,070
Test Inertial (lb)	1,850
Gross Static (lb)	2,015
Vehicle Speed	
Impact (mph)	51.5
Exit (mph)	47.7
Vehicle Angle	
Impact (deg)	19.5
Exit (deg)	8.5
Vehicle Snagging	None
Vehicle Stability	Satisfactory
Effective Coefficient of Friction (μ)	0.60 (Marginal)
Occupant Impact Velocity	
Longitudinal (fps)	19.35 (30)
Lateral (fps)	26.23 (25)
Occupant Ridedown Deceleration	
Longitudinal (g's)	3.69 (15)
Lateral (g's)	7.79 (15)
Vehicle Damage	Minor
TAD	1-RFQ-3
VDI	01RFEW3
Bridge Rail Damage	Tire marks and minor concrete spalling
Maximum Vehicle Rebound Distance (ft)	25.3

FIGURE 24. Test NTBR-2 Summary

0.000 sec

0.047 sec

0.107 sec

0.162 sec

0.216 sec

0.345 sec

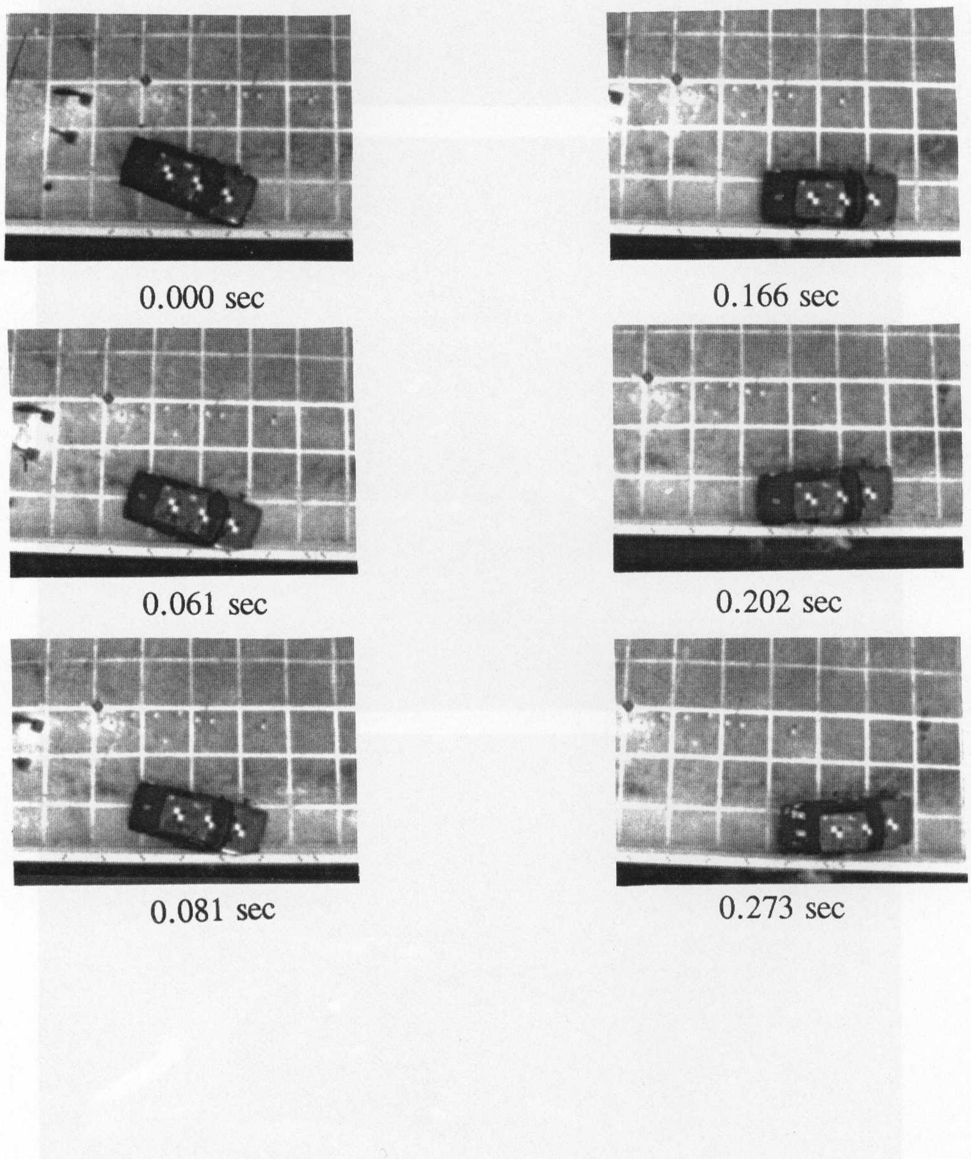
0.404 sec

0.483 sec

0.760 sec

0.958 sec

FIGURE 25. Downstream Sequential Photographs, Test NTBR-2



0.000 sec

0.166 sec

0.061 sec

0.202 sec

0.081 sec

0.273 sec

FIGURE 26. Overhead Sequential Photographs, Test NTBR-2

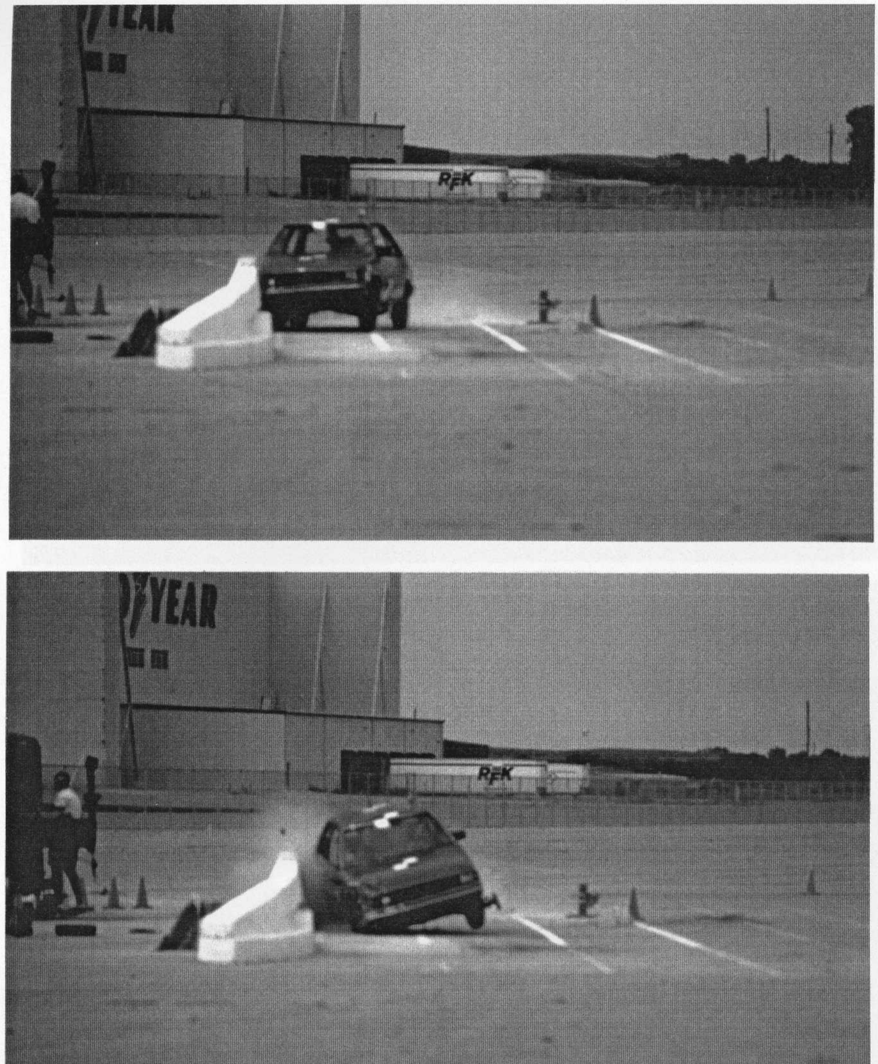


FIGURE 27. Full-Scale Vehicle Crash Test, Test NTBR-2

FIGURE 28. Full-Scale Vehicle Crash Test, Test NTBR-2 (cont.)

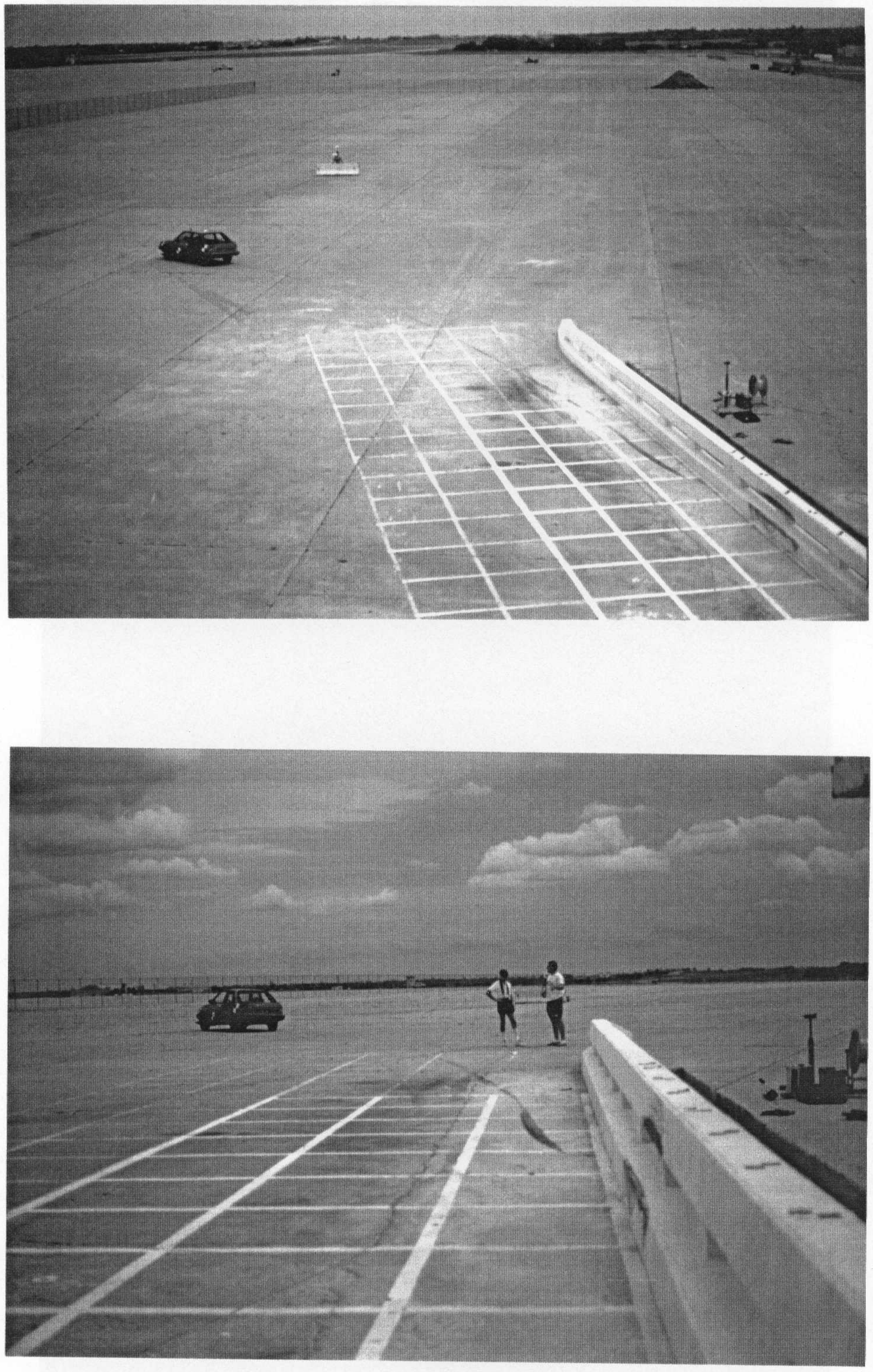


FIGURE 29. Vehicle Trajectory, Test NTBR-2

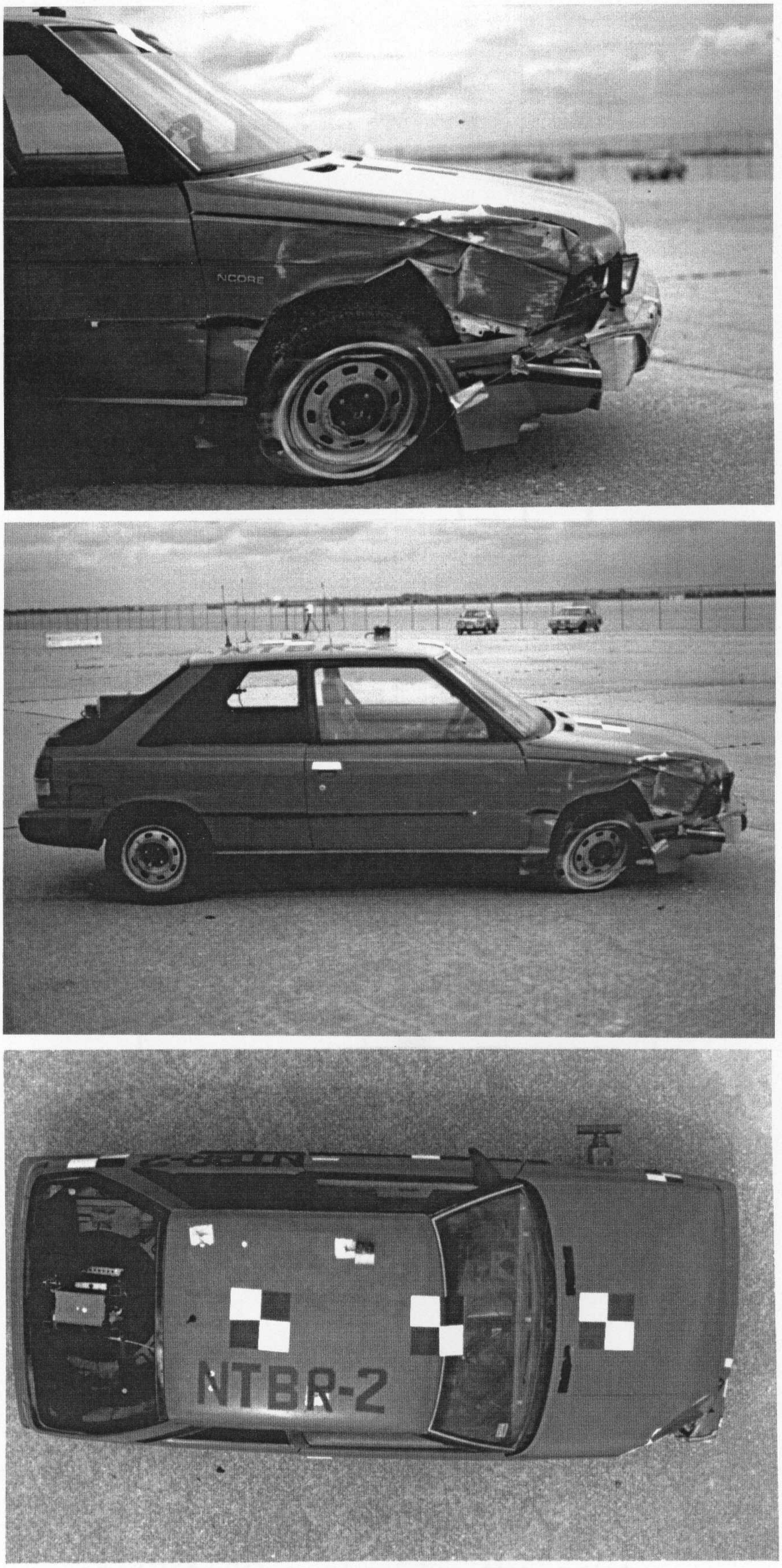
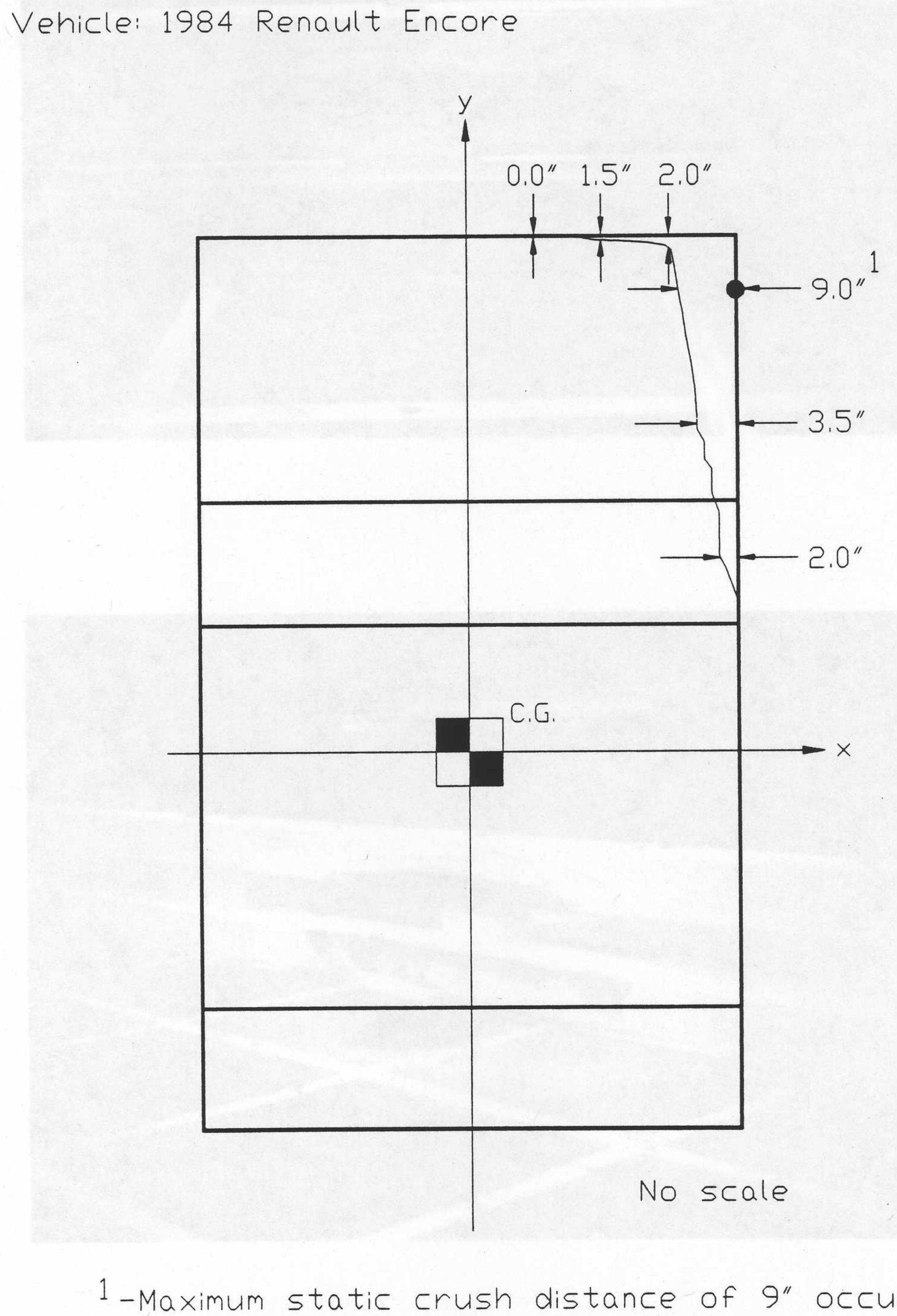


FIGURE 30. Vehicle Damage, Test NTBR-2



[1] -Maximum static crush distance of 9″ occured at (24″,60″) marked by the point.

FIGURE 31. Vehicle Crush Measurements, Test NTBR-2

FIGURE 32. Bridge Rail Damage, Test NTBR-2

4 CONCLUSIONS

Both the AASHTO Guide Specifications for Bridge Rails (5) and NCHRP Report 230 (8) provide specific criteria for evaluating the performance of PL-1 bridge rails. Table 3 summarizes all of the relevant evaluation criteria from these two reports, as well as the findings from the two tests reported herein. As shown in this table, the Natchez Trace Parkway Bridge Rail successfully passed the crash testing requirements for performance level 1 bridge rails.

Table 3. Summary of Safety Performance Results

Evaluation Criteria	Results	
	NTBR-1	NTBR-2
3.a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	S	S
3.b. Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	S	S
3.c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	S	S
3.d. The vehicle shall remain upright during and after collision.	S	S
3.e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.	S	S
3.f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ, where $\mu = (\cos\theta - V_p/V)/\sin\theta$. μ — Assessment 0.0 - 0.25 — Good 0.26 - 0.35 — Fair > 0.35 — Marginal	F(μ=0.28)	M(μ = 0.60)

Table 3. Summary of Safety Performance Results (continued)

Evaluation Criteria	Results			
	NTBR-1		NTBR-2	
3.g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0-ft longitudinal and 1.0-ft lateral displacements, shall be less than:	Occupant Impact Velocity (fps)			
	Longitudinal	Lateral	Longitudinal	Lateral
Occupant Impact Velocity - fps Longitudinal: 30 Lateral: 25	S (10.8)	S (22.2)	S (19.4)	M (26.2)
and for the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than:	Occupant Ridedown Accelerations (g's)			
	Longitudinal	Lateral	Longitudinal	Lateral
Occupant ridedown Accelerations - g's Longitudinal: 15 Lateral: 15	S (6.3)	S (9.5)	S (3.7)	S (7.8)
3.h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20 ft from the line of the traffic face of the railing.	S (1.6 deg)		S (8.5 deg)	
	S (0.83 ft)		M (25.3 ft)	

S - Satisfactory
M - Marginal
U - Unsatisfactory

5 REFERENCES

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

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

3. *Center of Gravity Test Code - SAE J874 March 1981*, SAE Handbook Vol. 4, Society of Automotive Engineers, Inc., Warrendale, Penn., 1986

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

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

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

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

APPENDIX A.

ACCELEROMETER TRACES, TEST NTBR-2

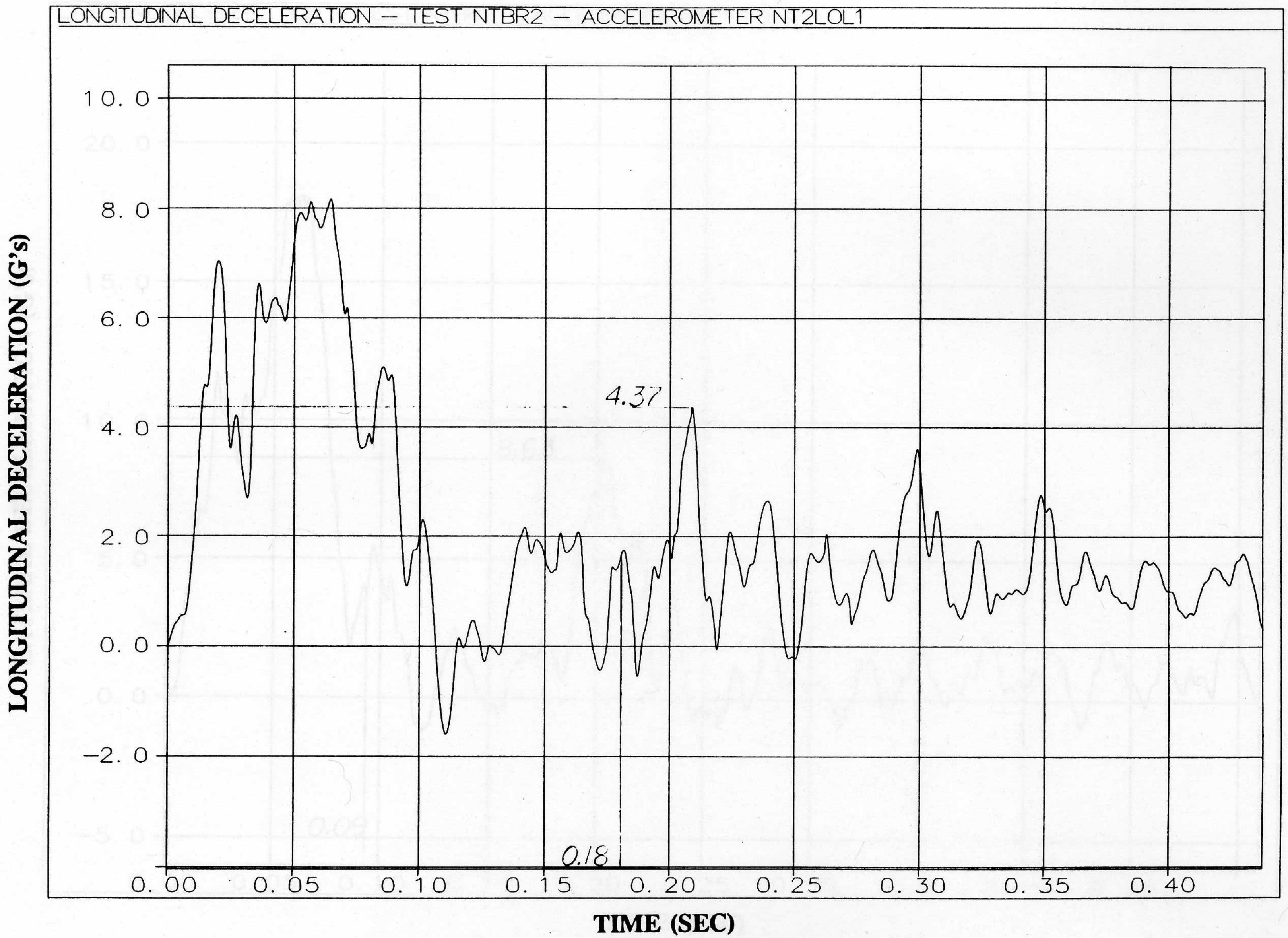

Figure A-1. Graph of Longitudinal Deceleration, Test NTBR-2

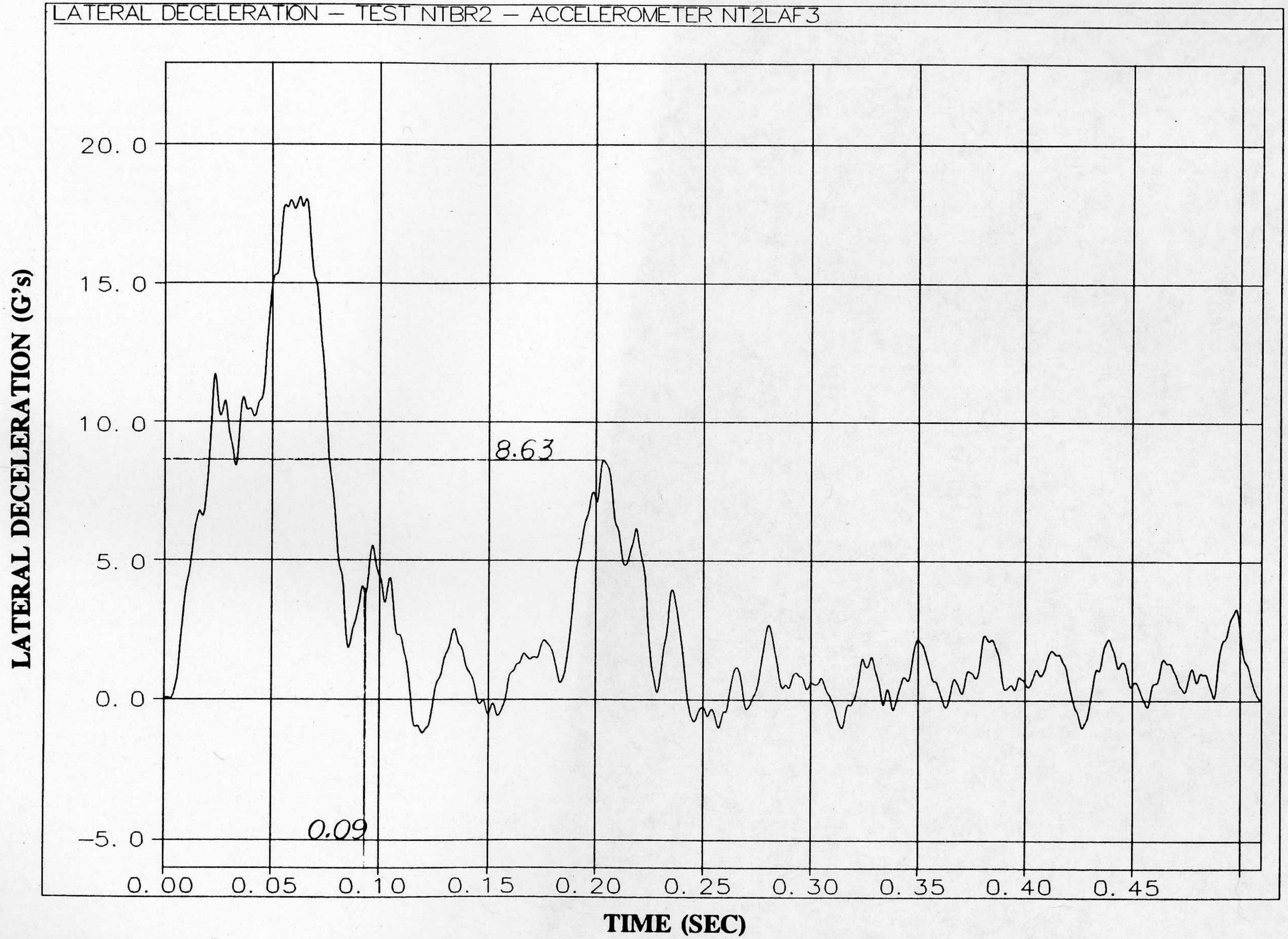

Figure A-2. Graph of Lateral Deceleration, Test NTBR-2