FULL-SCALE VEHICLE CRASH TESTS ON THE IOWA RETROFIT CONCRETE BARRIER RAIL

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DISCLAIMER STATEMENT

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ABSTRACT

Three full-scale vehicle crash tests were conducted on the Iowa Retrofit Concrete Barrier Rail. Test I2-1 was conducted with a 1,849 lb. vehicle at 20 deg. and 56.8 mph. Test I2-2 was conducted with a 5,386 lb. vehicle at 20 deg. and 62.3 mph. Test I2-3 was conducted with an 1,849 lb. vehicle at 20 deg. and 62.5 mph.

The total length of the installation was 100 ft. It consisted of 86 ft. of standard retrofit concrete barrier rail section and 7 ft. of concrete endwall section on each end of the standard retrofit section. Two construction joints were located 35 ft. inward from both ends of the installation.

The bride rail consisted of three major components: the existing concrete curb, the rectangular (retrofit) concrete wall-section, and the concrete endwalls. The overall height of the barrier was 32-in. above the roadway surface. The 86 ft. long, retrofit concrete barrier rail was doweled into the existing concrete curb and setback 3-in. from the curb face.

The location of the vehicle impacts were set at 18-in. from both of the construction joints.

The tests were evaluated according to the safety criteria in NCHRP 230 and also in the AASHTO guide specifications. The safety performance of the Iowa Retrofit Concrete Barrier Rail was determined to be satisfactory.

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ACKNOWLEDGMENTS

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1. INTRODUCTION

1.1. Problem Statement

The Iowa Department of Transportation and the Federal Highway Administration are concerned with the safety and structural adequacy of highway and bridge railing systems installed on Iowa highways. The performance of certain Iowa railing systems, now in service, cannot be predicted nor verified by conventional analysis.

Current AASHTO Standard Specifications for Highway Bridges permits the qualification of railing systems by full-scale vehicle crash testing. The Federal Highway Administration has directed that bridge railing systems be successfully crash tested before its use on Federal Aid Projects is approved.

The Iowa Retrofit Concrete Barrier Rail is currently constructed as a replacement bridge rail for bridges on the Iowa Primary and Interstate Systems. Thus, full-scale vehicle crash testing was to be performed to evaluate the structural adequacy, occupant risk, and redirectional characteristics.

The results of this study will be used to help guide the IDOT in the identification and evaluation of current procedures in which to improve the safety of the roadway environment.

1.2. Objective of Study

The objective of the research study was to evaluate the safety performances of the Iowa Retrofit Concrete Barrier Rail by conducting full-scale vehicle crash tests in accordance with the "Recommended Procedures for the Safety Performance Evaluation of

Highway Appurtenances," NCHRP 230 (1) and also in the "Guide Specifications for Bridge Railings, An Alternative to Bridge Railing Specifications," AASHTO (2).

2. TEST CONDITIONS

2.1. Test Facility

2.1.1. Test Site

The test site facility was located at Lincoln Air-Park on the NW end of the west apron of the Lincoln Municipal Airport. The test facility, shown in Figure 1, is approximately 5 mi. NW of the University of Nebraska-Lincoln.

An 8 ft. high chain-linked security fence surrounds the test site facility to ensure that no vandalism would occur to the test articles or test vehicles which could possibly disrupt the results of the tests.

2.1.2. Vehicle Tow System

A reverse cable tow, with a 1:2 mechanical advantage, was used to propel the test vehicle. The distance traveled and speed of the tow vehicle are one-half of that of the test vehicle. A sketch of the cable tow system is shown in Figure 2. The test vehicle was released from the tow cable approximately 10 ft. for Tests I2-1 and I2-3 and 18 ft. for Test I2-2 before impact with the Retrofit Concrete Barrier Rail. Photographs of the tow vehicle and the attached fifth-wheel are shown in Figure 3. The fifth-wheel, built by the Nucleus Corporation, was used for accurately towing the test vehicle at the required target speed with the aid of a digital speedometer in the tow vehicle.

2.1.3. Vehicle Guidance System

A vehicle guidance system, developed by Hinch (3), was used to steer the test vehicle. Photographs of the guidance system

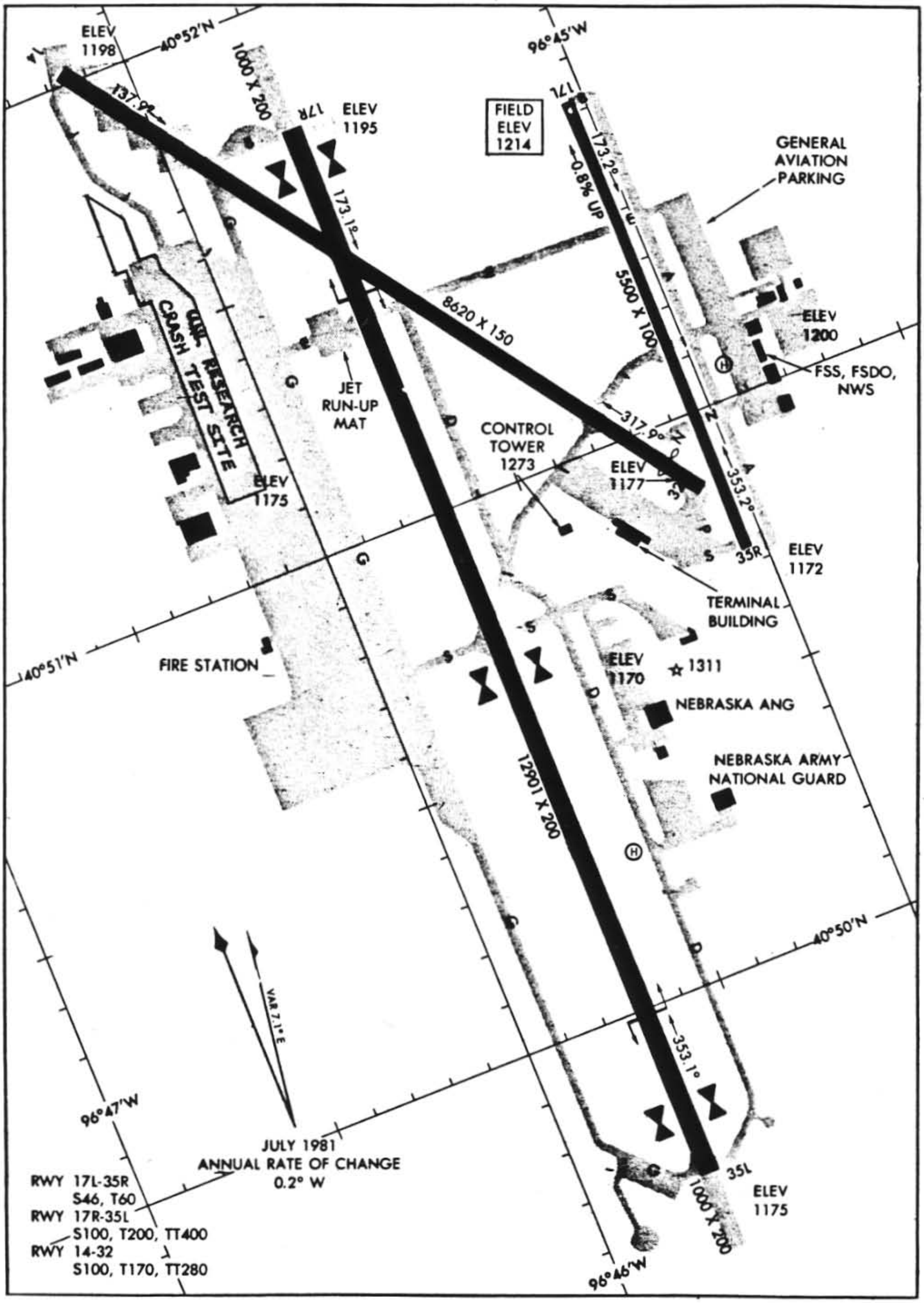


FIGURE 1. FULL-SCALE VEHICLE CRASH TEST FACILITY

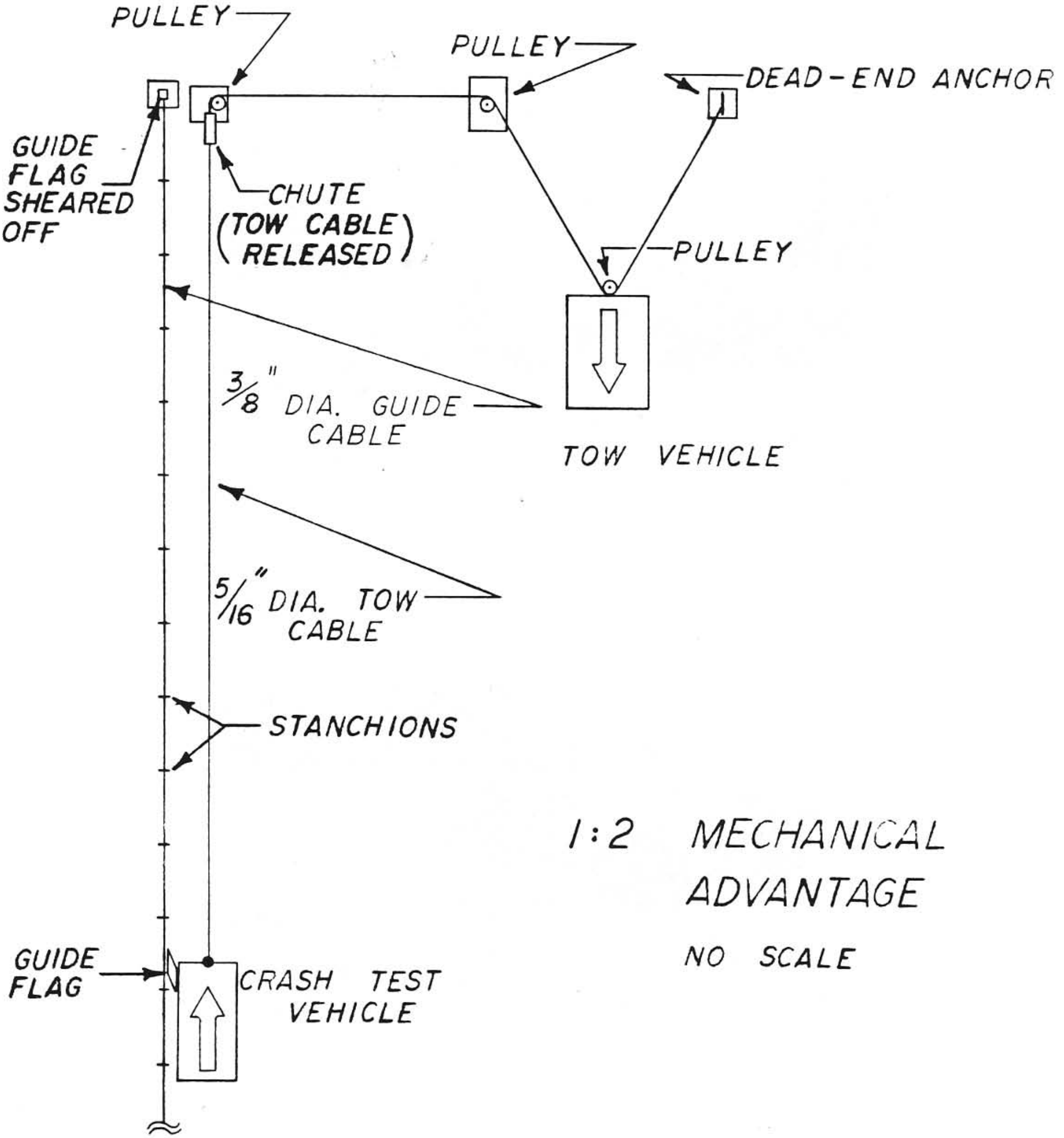


FIGURE 2. SKETCH OF CABLE TOW AND GUIDANCE SYSTEMS

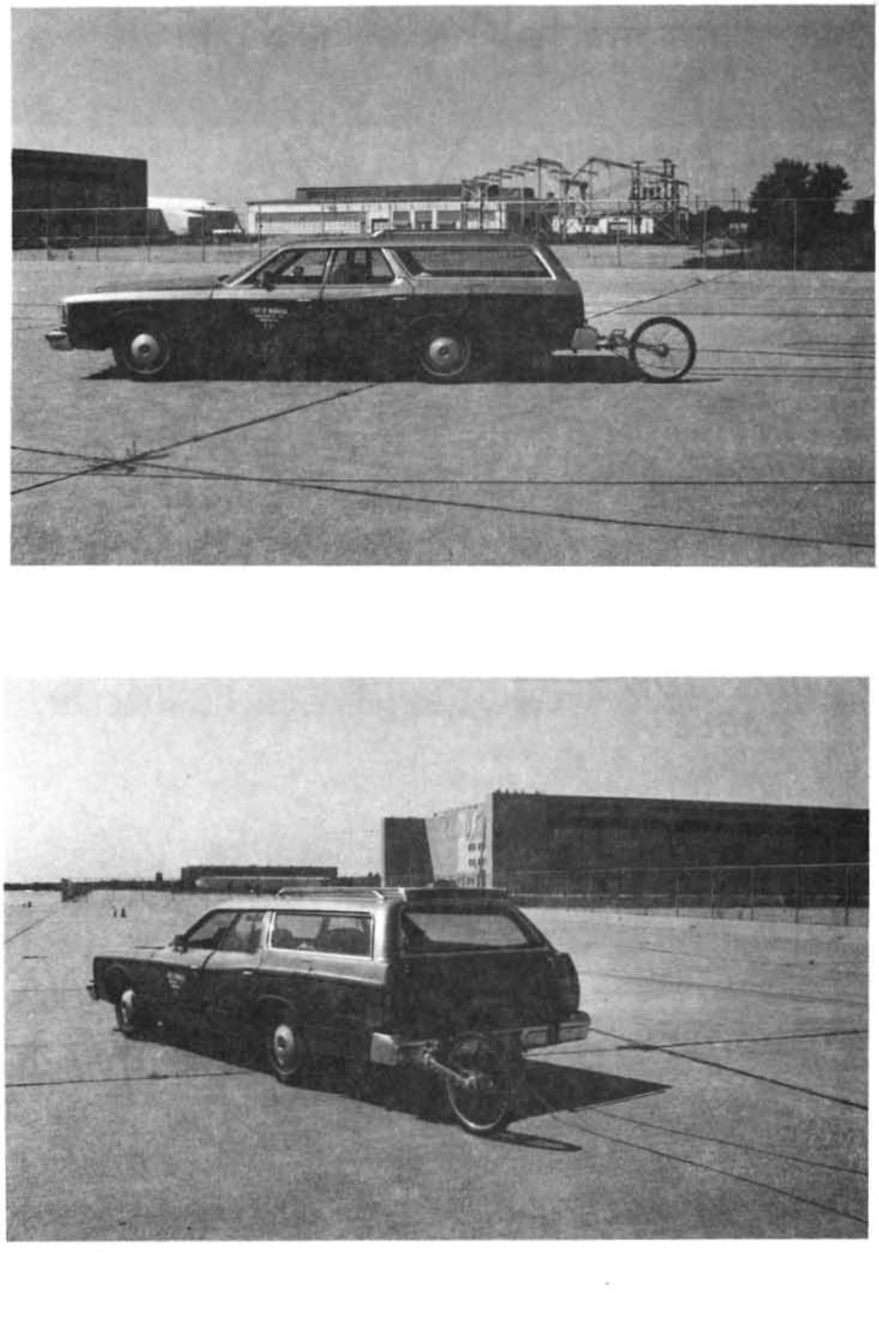


FIGURE 3. PHOTOGRAPHS OF TOW VEHICLE AND FIFTH WHEEL

are shown in Figure 4, and a sketch of the guidance system is shown in Figure 2. The guide-flag, attached to the front left wheel and the guide cable, was sheared off (at the distances stated above) before impact with the Retrofit Concrete Barrier Rail. The 3/8-in. diameter guide cable was tensioned to 3,000 lbs., and it was supported laterally and vertically every 100 ft. by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable. When the vehicle passed, the guide-flag struck each stanchion and knocked it to the ground. The vehicle guidance system was approximately 1,500 ft. in length.

2.2 <u>Retrofit Concrete Barrier Design Details</u>

An overall view of the Iowa Retrofit Concrete Barrier Rail is shown in the photographs in Figure 4, and a detailed drawing is shown in Figure 5. The total length of the installation was 100 ft. It consisted of 86 ft. of standard retrofit concrete barrier rail section and 7 ft. of concrete endwall section on each end of the standard retrofit section. The bridge rail consisted of three major components: the existing concrete curb, the rectangular (retrofit) concrete wall-section, and the concrete endwalls. The overall height of the barrier was 32-in. above the roadway surface, and the barrier was setback 3-in. from the curb face.

The existing concrete curb remained from the full-scale vehicle crash tests performed on the Iowa Box-Aluminum Bridge Rail (4). The 12-in. high concrete curb was constructed with a Nebraska Class "47-B-PHE" design mix. The concrete compressive

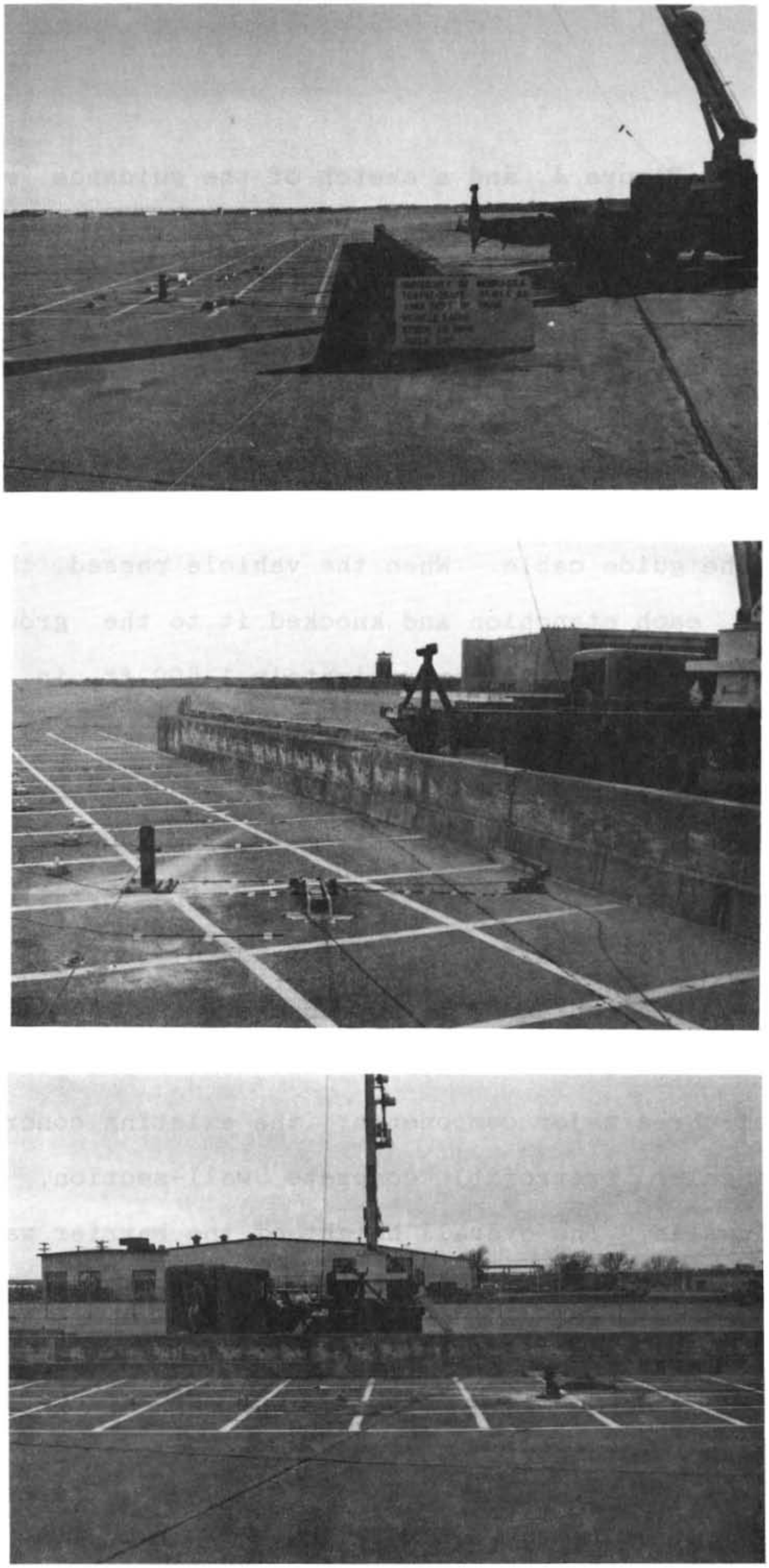
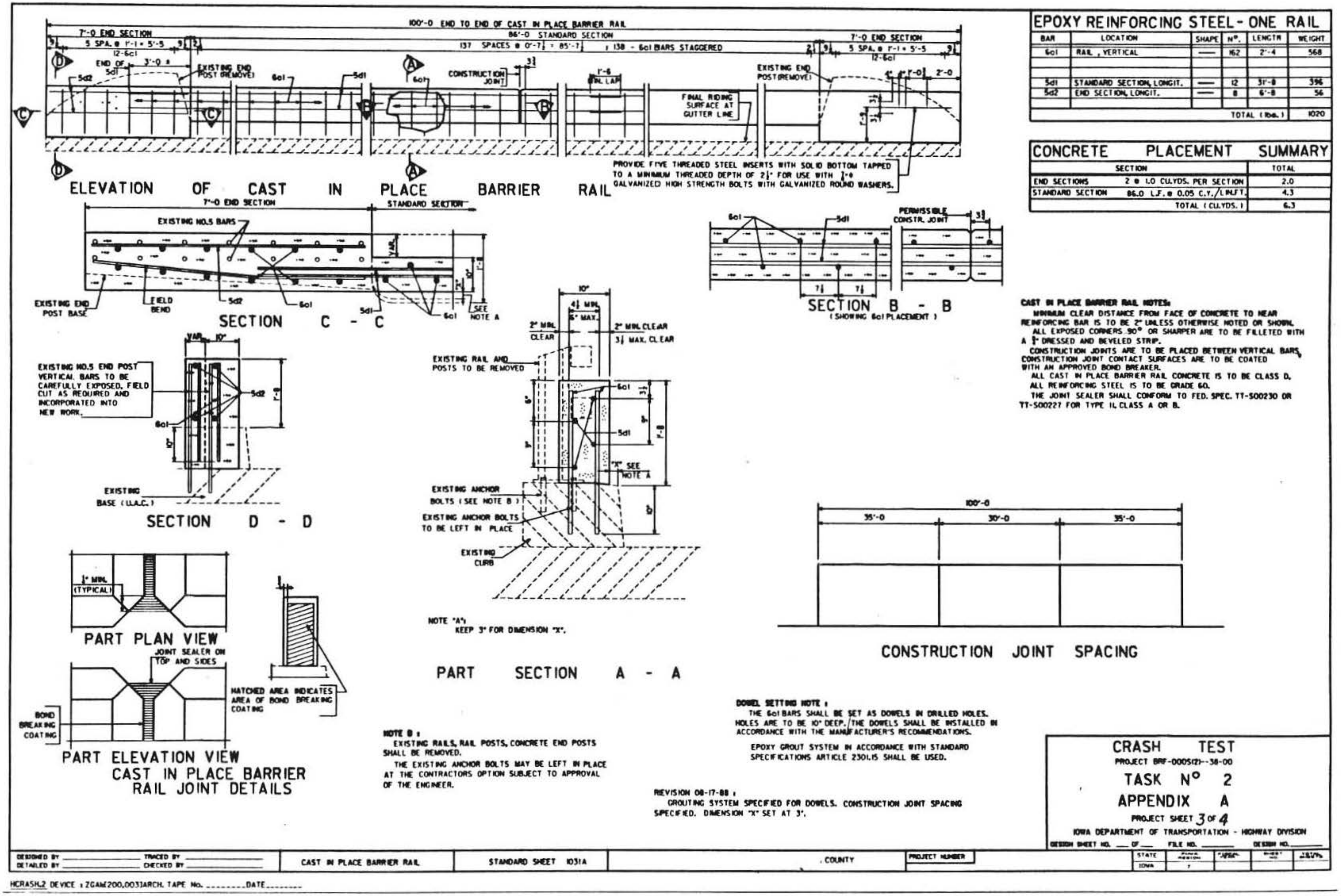


FIGURE 4. PHOTOGRAPHS OF VEHICLE GUIDANCE SYSTEM



EPOXY REINFORCING STEEL - ONE RAIL

BAR	LOCATION	SHAPE	N°.	LENGTH	WEIGHT
6a1	RAIL, VERTICAL	—	162	2'-4	568
5d1	STANDARD SECTION, LONGIT.	—	12	31'-8	396
5d2	END SECTION, LONGIT.	—	8	6'-8	56
				TOTAL (lbs.)	1020

CONCRETE PLACEMENT SUMMARY

	SECTION	TOTAL
END SECTIONS	2 @ 1.0 CU.YDS. PER SECTION	2.0
STANDARD SECTION	86.0 L.F. @ 0.05 C.Y./LIN.FT.	4.3
	TOTAL (CU.YDS.)	6.3

FIGURE 5. SKETCH OF THE IOWA RETROFIT CONCRETE BARRIER RAIL

strength at the time of the crash tests (for the Box-Aluminum Bridge Rail) averaged about 6,000 psi (see Appendix A). The curb was 20-in. wide and 86 ft. in length. The curb was anchored 8-in. into the existing airport concrete apron by two L-shaped No. 5 rebar dowels, spaced at 14-in. on centers over the length of the curb. An epoxy grout material was used as the bonding agent for the dowels.

The 86 ft. rectangular (retrofit) concrete wall-section was rigidly attached to the top of the existing 12-in. high concrete curb. The wall was also constructed with a Nebraska Class "47-B-PHE" design mix. The concrete compressive strength at the time of the crash tests averaged above 6,000 psi (see Appendix A). The rectangular concrete wall-section was 10-in. wide and 20-in. high. The front face was located 3-in. back from the top-front edge of the existing concrete curb. This dimension may vary 1-in. to 3-in. on existing installations. The rectangular concrete wall-section was anchored 10-in. into the existing concrete curb by two vertical No. 6 rebar dowels, staggered at 15-in. on centers over the length of the wall-section. An epoxy grout material was used as the bonding agent for the dowels. The rectangular concrete wall-section was constructed with two construction joints located 28 ft. from each end of the 86 ft. section.

The 7 ft. concrete endwalls were also constructed with the Nebraska concrete design mix and had the same concrete compressive strengths as the wall-section (see Appendix A). The endwalls were rigidly anchored to the existing airport concrete apron by the existing, two No. 5 vertical dowels spaced at 13-in. on centers over the length of the endwall. An epoxy grout material was used as the bonding agent for dowels.

Photographs of the construction process are shown in Figures 6 and 7.

2.3. Test Vehicles

Three different test vehicles were used to evaluate the Iowa Retrofit Concrete Barrier Rail.

For Test I2-1 and I2-3, 1984 Honda Civics weighing approximately 1,849 lbs. were used as the crash test vehicles. For Test I2-2, a 1983 Chevrolet Scottsdale 3/4-ton pickup weighing approximately 5,386 lbs. was used as the crash test vehicle. Photographs of the test vehicles are shown in Figures 8, 9, and 10. Dimensions of the test vehicles are shown in Figures 11 and 12.

The front wheels of the vehicle were aligned to a toe-in value of zero-zero so that the vehicle would track properly along the guide cable.

Three 8-in. square, black and white checkered targets were placed on the centerline of the top of the test vehicles. The middle targets were placed over the center of mass. For Tests I2-1 and I2-3, the front and rear targets were placed 3 ft. ahead and 4 ft. behind the center of mass, respectively. For Test I2-2, the front and rear targets were placed 5 ft. ahead and 7 ft. behind the center of mass, respectively. The targets were used

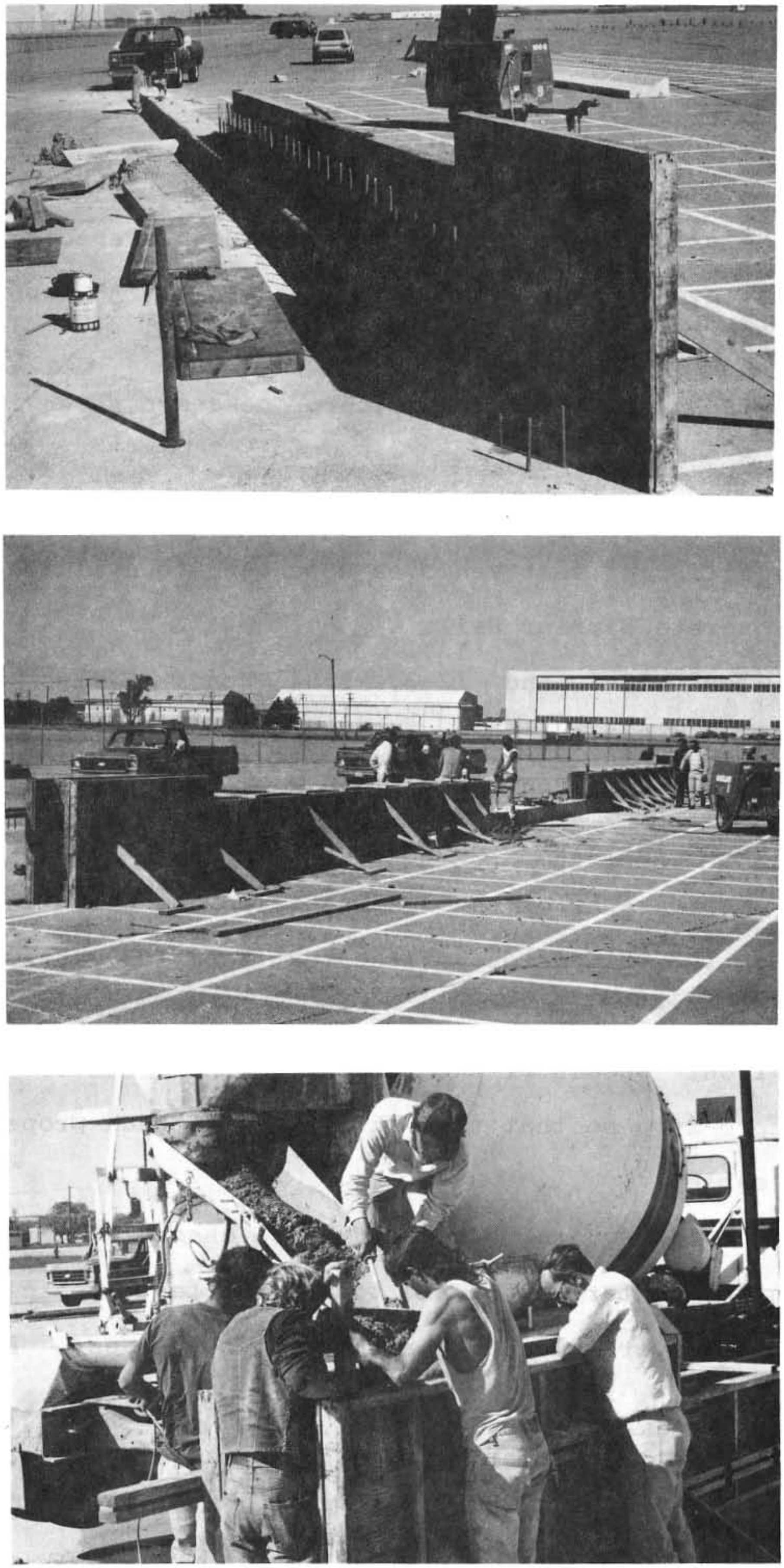
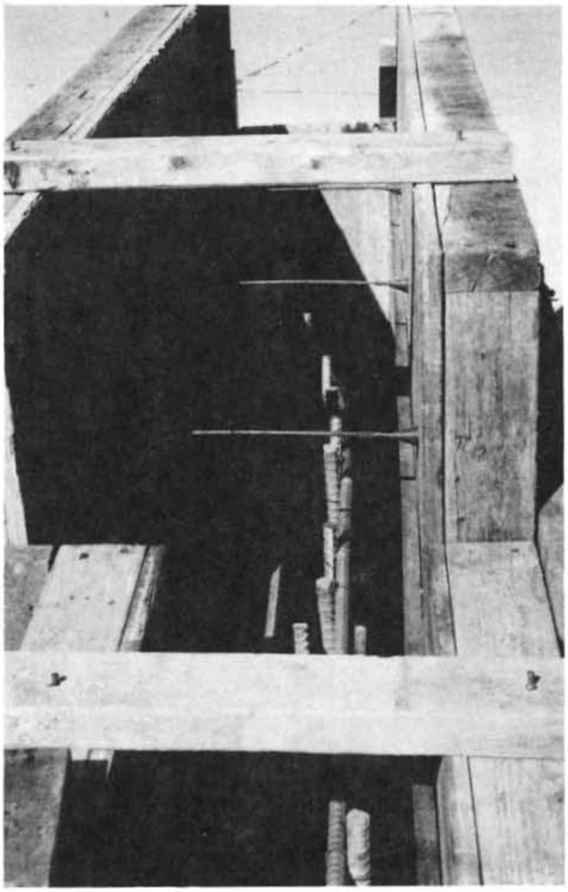


FIGURE 6. PHOTOGRAPHS OF CONSTRUCTION



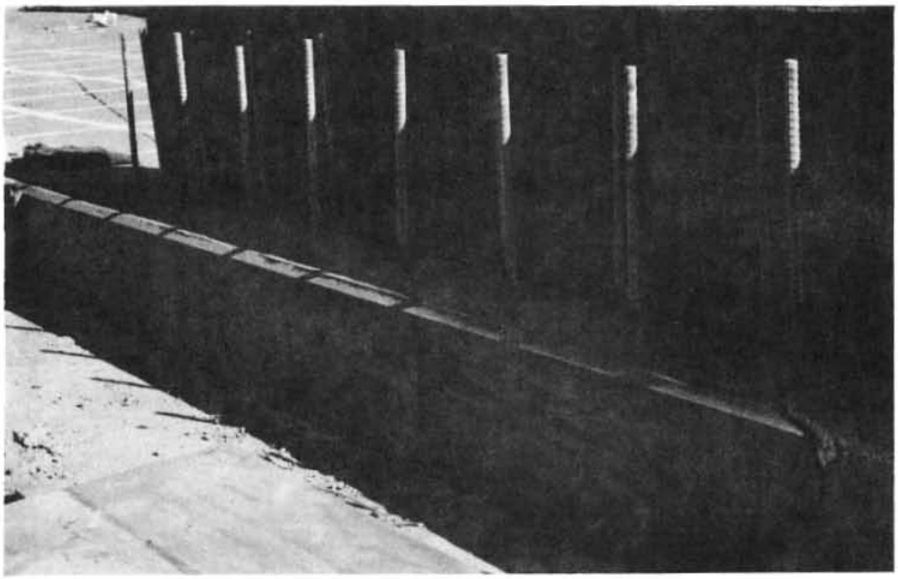


FIGURE 7. PHOTOGRAPHS OF CONSTRUCTION

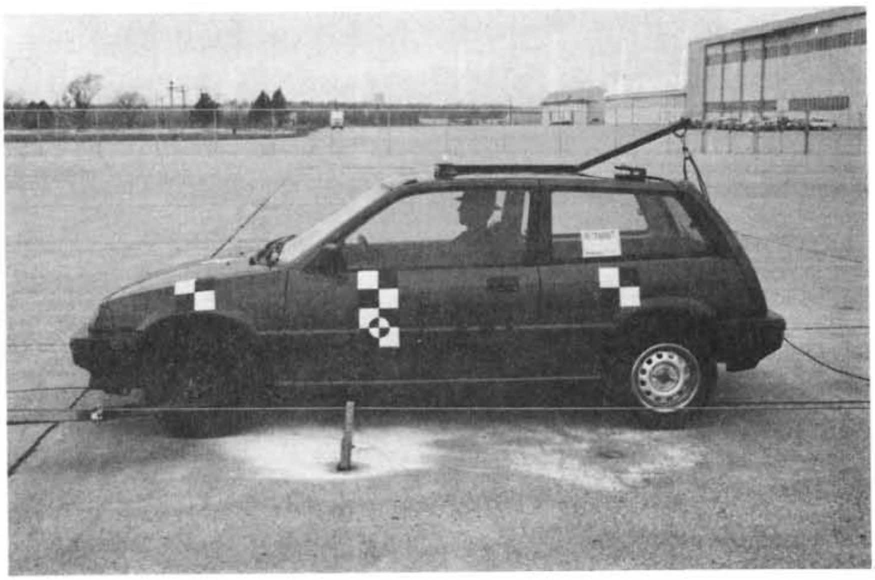


FIGURE 8. PHOTOGRAPHS OF TEST VEHICLE, TEST I2-1

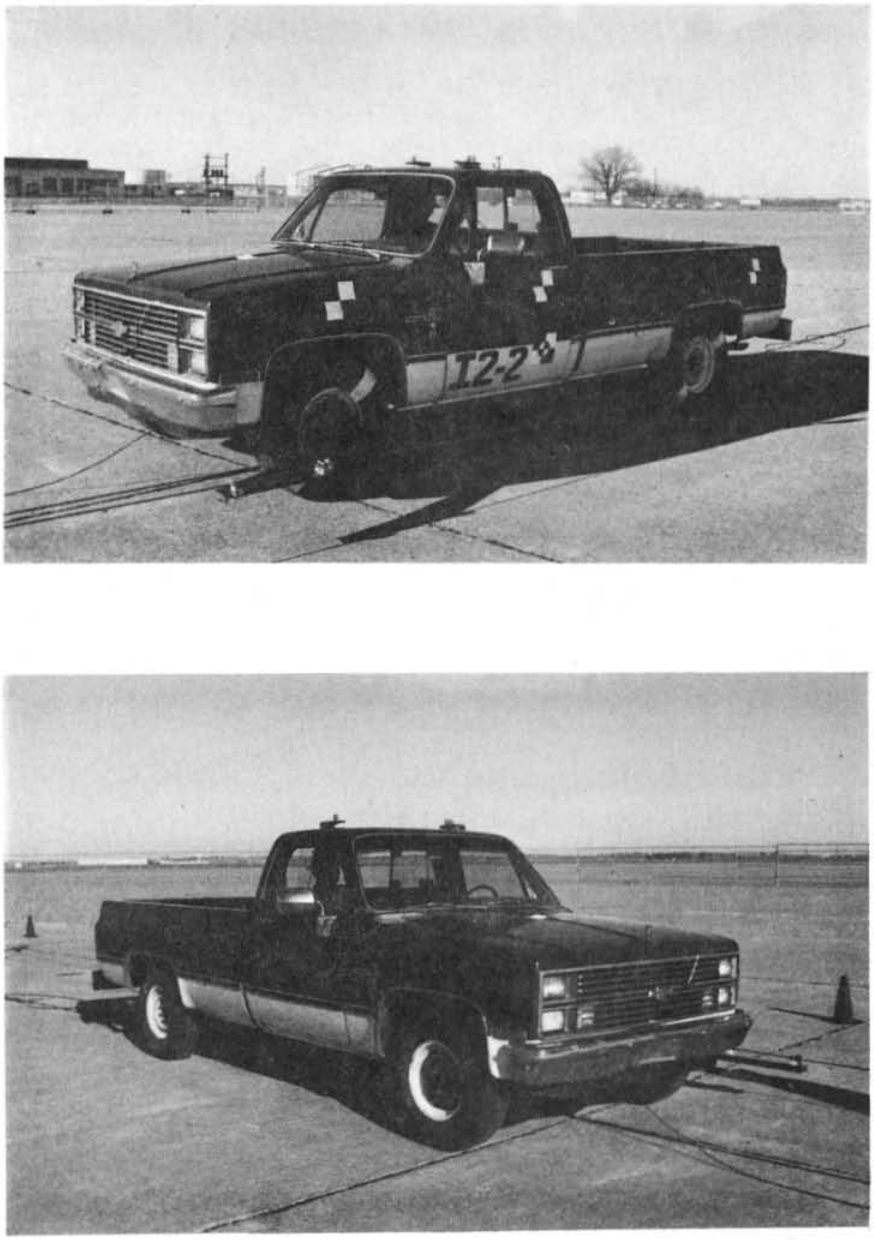


FIGURE 9. PHOTOGRAPHS OF TEST VEHICLE, TEST I2-2

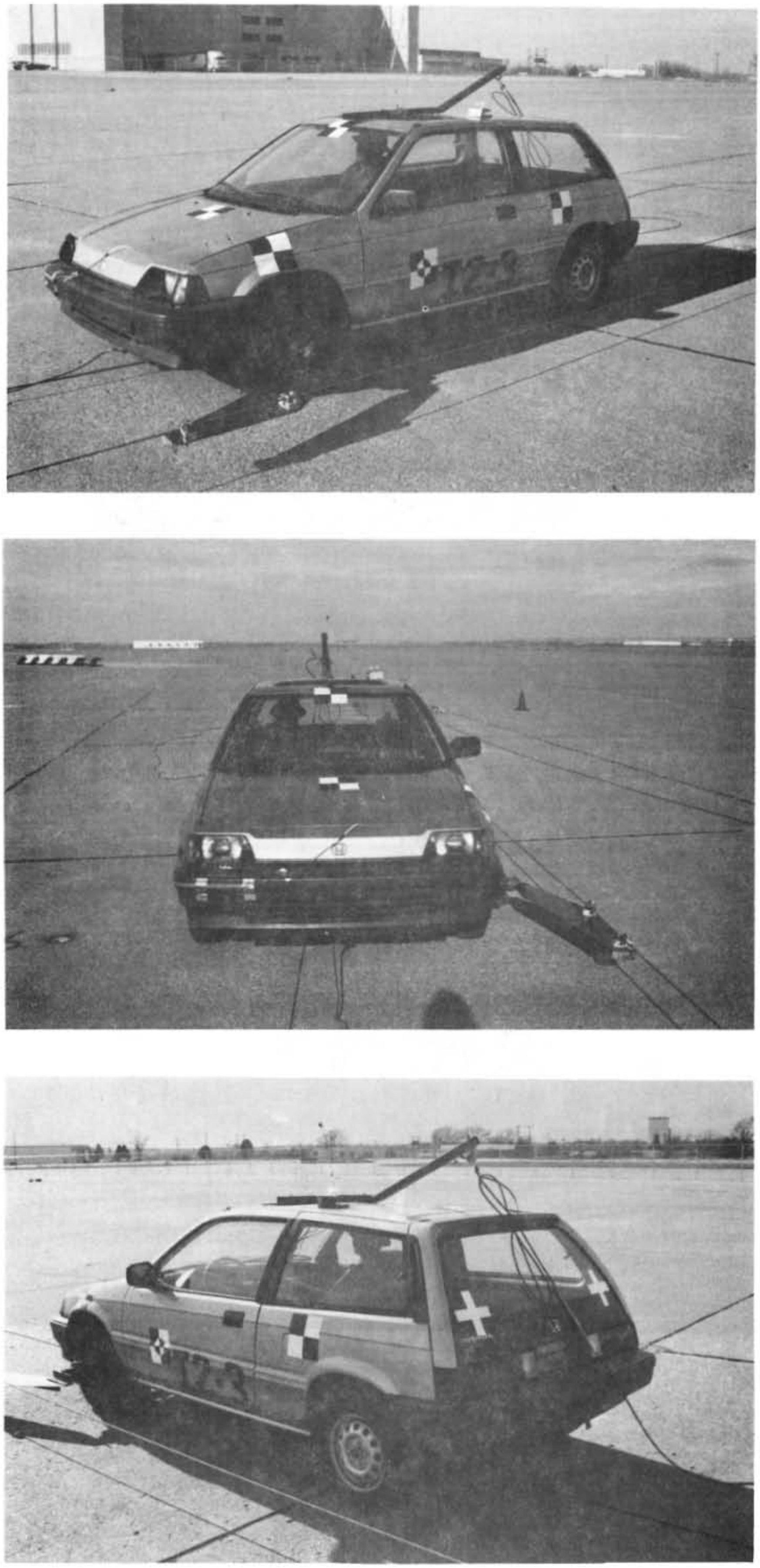
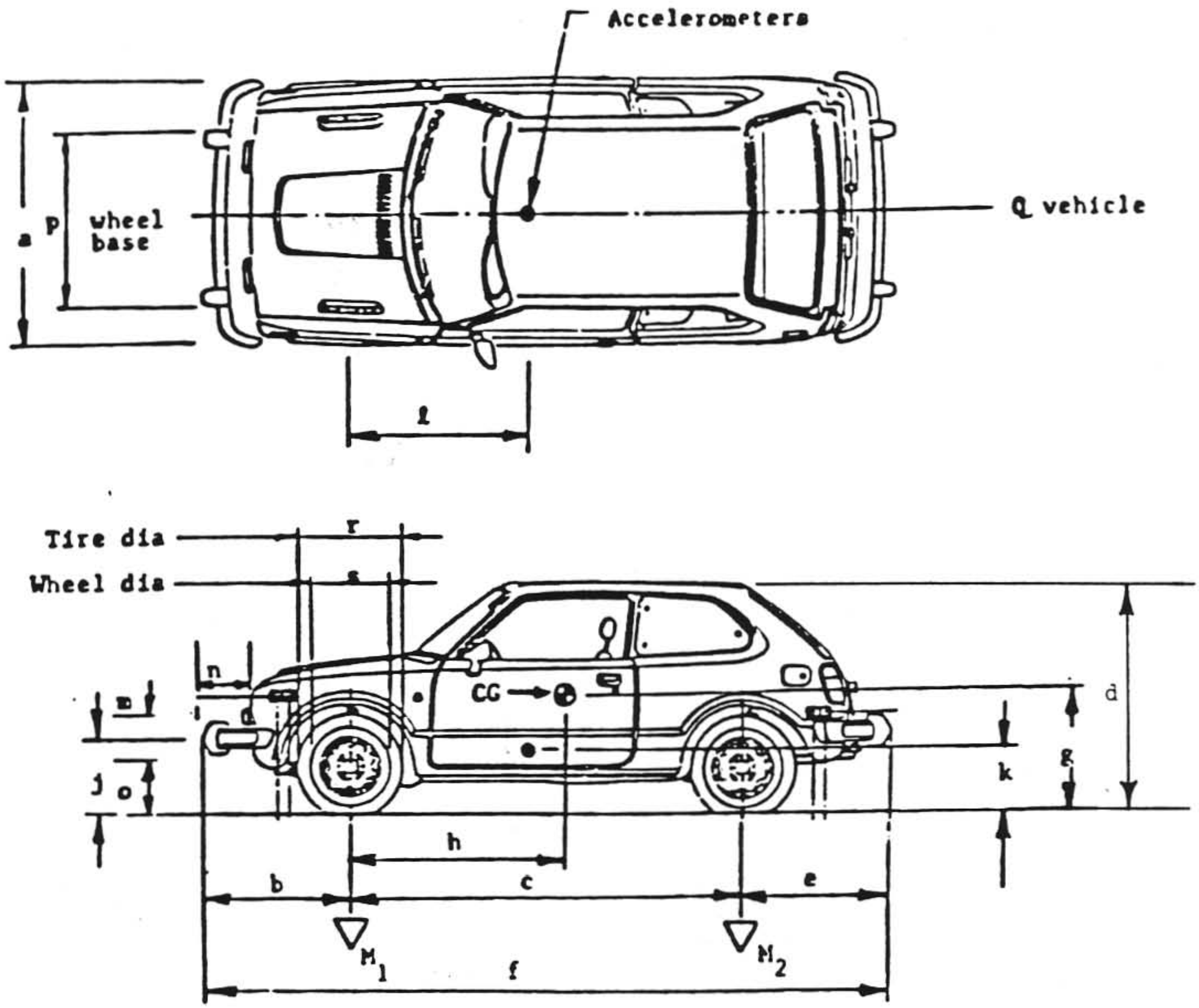


FIGURE 10. PHOTOGRAPHS OF TEST VEHICLE, TEST I2-3



Geometry - in. (in.)

a	62.5"	d	51"	j	17.4"	m	4.2"	p	55.5"
b	29"	e	27"	k	22.2"	n	3.8"	r	22.5"
c	93"	f	149"	ℓ	36"	o	14.5"	s	14.5"

Mass - lb (kg)		Curb	Test Inertial*	Gross Static**
M_1		1297 lb	1230 lb	
M_2		653 lb	619 lb	
M_T		1950 lb	1849 lb	2014 lb
h - in. (m)	36"			
g - in. (m)	21.5"			

Moments of Inertia (lb-ft-sec^2)

Roll		
Yaw		
Pitch		

*Ready for test but excludes passenger/cargo payload

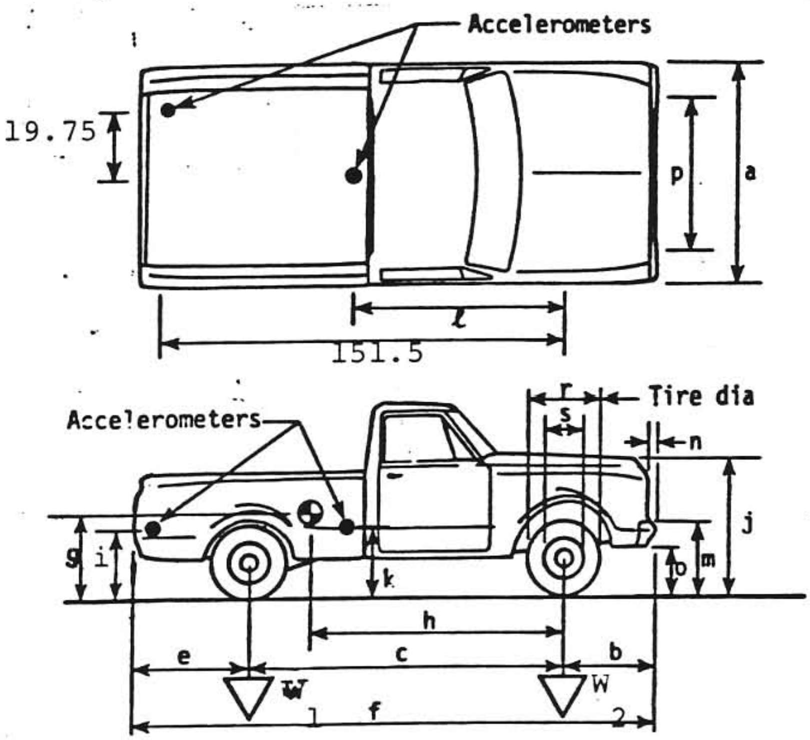
**Gross ready for test including passenger/cargo payload

FIGURE 11. VEHICLE DIMENSIONS FOR HONDA CIVICS

Date: 12/1/89 Test No.: I2-2 Vehicle I.D. #: ______

Make: Chevrolet Model: Scottsdale 3/4 ton Year: 1983 Odometer: ______

Tire Size: 7.50T16LT



d* - Overall height of vehicle

Vehicle Geometry - inches

a	78.7	b	32.5
c	132	d*	71.6
e	51	f	215.5
g	26.9	h	63.5
i	34	j	44.2
k	27	l	63.5
m	27	n	3
o	18	p	66.3
r	29	s	16

Engine Type: V8 Diesel

Engine Size: 6.2 Liter

Transmission Type:

[Automatic] or Manual

FWD or [RWD] or 4WD

4 - wheel weight: lf ____ rf ____ lr ____ rr ____

Weight - pounds	Curb	Test Inertial	Gross Static
W1	1940	2591	2670
W2	2820	2795	2881
Wtotal	4760	5386	5551

Note any damage prior to test: None

FIGURE 12. VEHICLE DIMENSIONS FOR CHEVROLET SCOTTSDALE PICKUP

in the analysis of the high-speed film. In addition to the roof targets, side and rear targets were also placed at known distances to aid in the evaluation process.

Two 5B flash-bulbs were mounted on the front hood of the test vehicle to record the time of impact with the temporary concrete barrier rail on the high-speed film. The flash bulbs were fired by a pressure tape switch mounted on the front face of the bumper.

2.4. Data Acquisition Systems

2.4.1. Accelerometers

Endevco triaxial piezoresistive accelerometers (Model 7264) with a range of 200 g's were used to measure the accelerations in the longitudinal, lateral, and vertical directions of the test vehicle. The accelerometers were rigidly attached to a metal block mounted at both the center-of-mass and at a known location in the left-rear corner of the test vehicle. Photographs of the accelerometers mounted in the test vehicle are shown in Figure 13. The signals from the accelerometers were received and conditioned by an onboard vehicle Metraplex Unit. The multiplexed signal was then sent through a single coaxial cable to the Honeywell 101 Analog Tape Recorder in the central control van. A flowchart of the accelerometer data acquisition system is shown in Figure 14, and photographs of the system located in the test vehicle and the centrally controlled step van are shown in Figures 13 and 15. The latest state-of-the-art computer software, "Computerscope and DSP," was used to analyze and plot

FIGURE 13. PHOTOGRAPHS OF THE ONBOARD DATA ACQUISITION SYSTEM

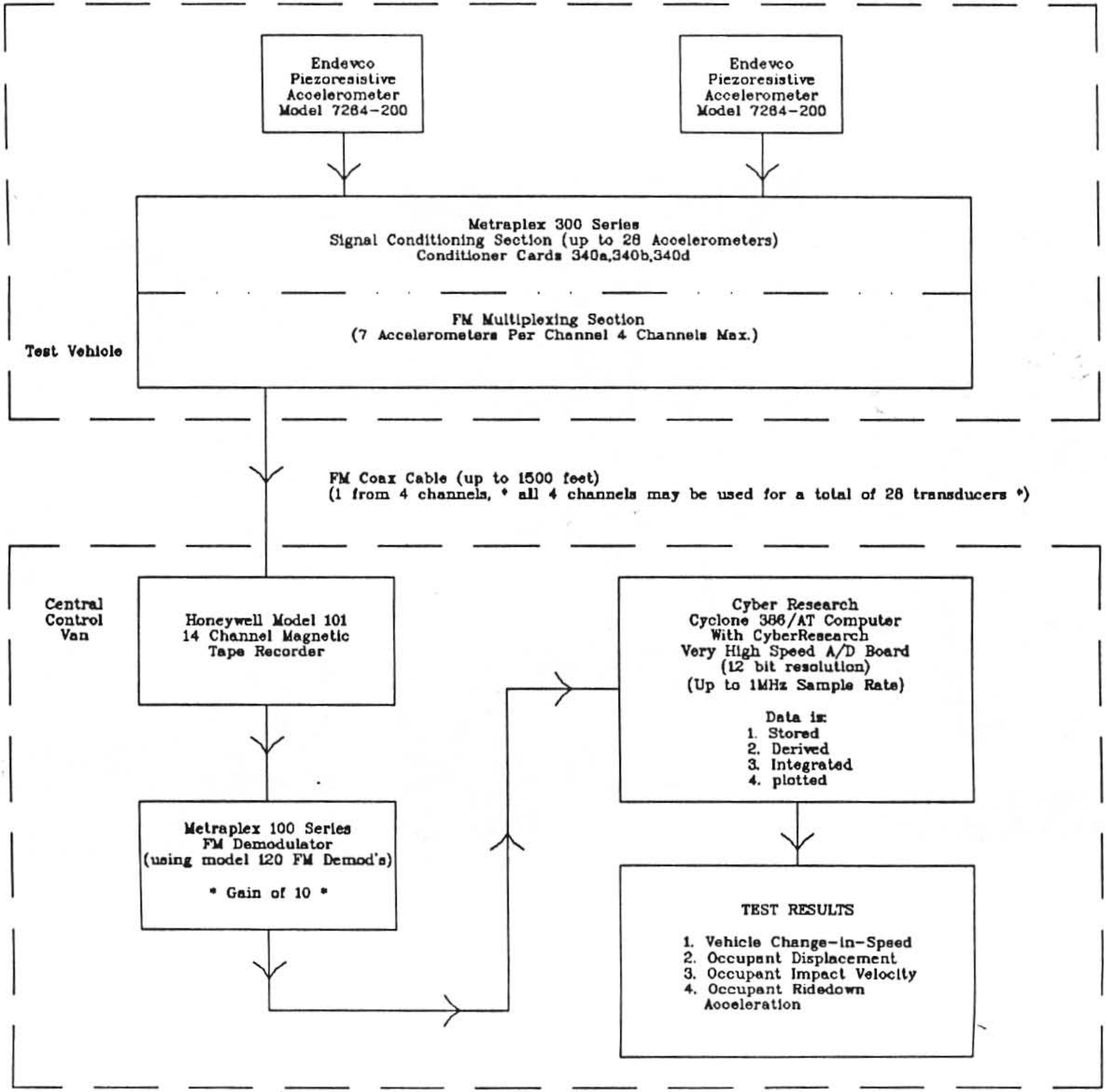


FIGURE 14. FLOWCHART OF ACCELEROMETER DATA ACQUISITION SYSTEM

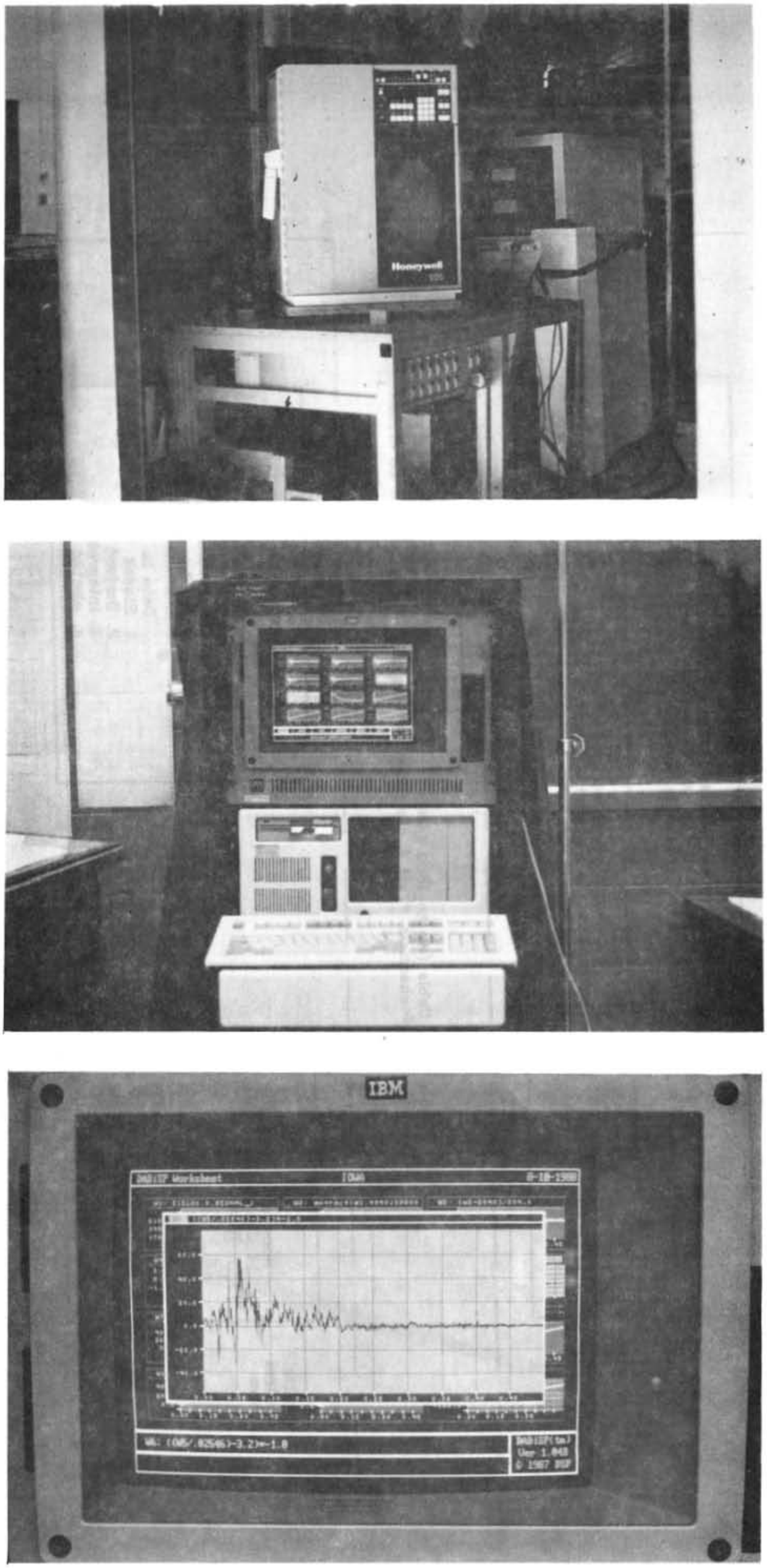


FIGURE 15. DATA RECORDER AND 386/AT COMPUTER

the accelerometer data on a Cyclone 386/AT, which uses a very high-speed data acquisition board.

2.4.2. High-Speed Photography

Three high-speed 16 mm cameras were used to film the crash tests. The cameras operated at approximately 500 frames/sec. The overhead camera was a Red Lake Locam with a wide angle 12.5 mm lens. It was placed approximately 64 ft. above the concrete apron. The parallel camera was a Photec IV with a 80 mm lens. It was placed 213 ft. upstream and offset 3 ft. from a line parallel to the barrier rail for Tests I2-1 and I2-3. For Test I2-2, it was placed 183 ft. upstream and offset 3.3 ft. from a line parallel to the barrier rail. The perpendicular camera was a Photec IV with a 55 mm lens. It was placed 165 ft. from the vehicle point of impact. A schematic of the camera locations is shown in Figure 16.

A 20 ft. wide by 115 ft. long grid layout was painted on the concrete slab surface parallel and perpendicular to the barrier. The white-colored grid was incremented with 5 ft. divisions in both directions to give a very visible reference system which could be used in the analysis of the overhead high-speed film.

The film was analyzed using the Vanguard Motion Analyzer. The camera divergence correction factors were also taken into consideration in the analysis of the high-speed film.

2.4.3. Speed Trap Switches

Eight tape pressure switches spaced at 5 ft. intervals were used to determine the speed of the vehicle before and after

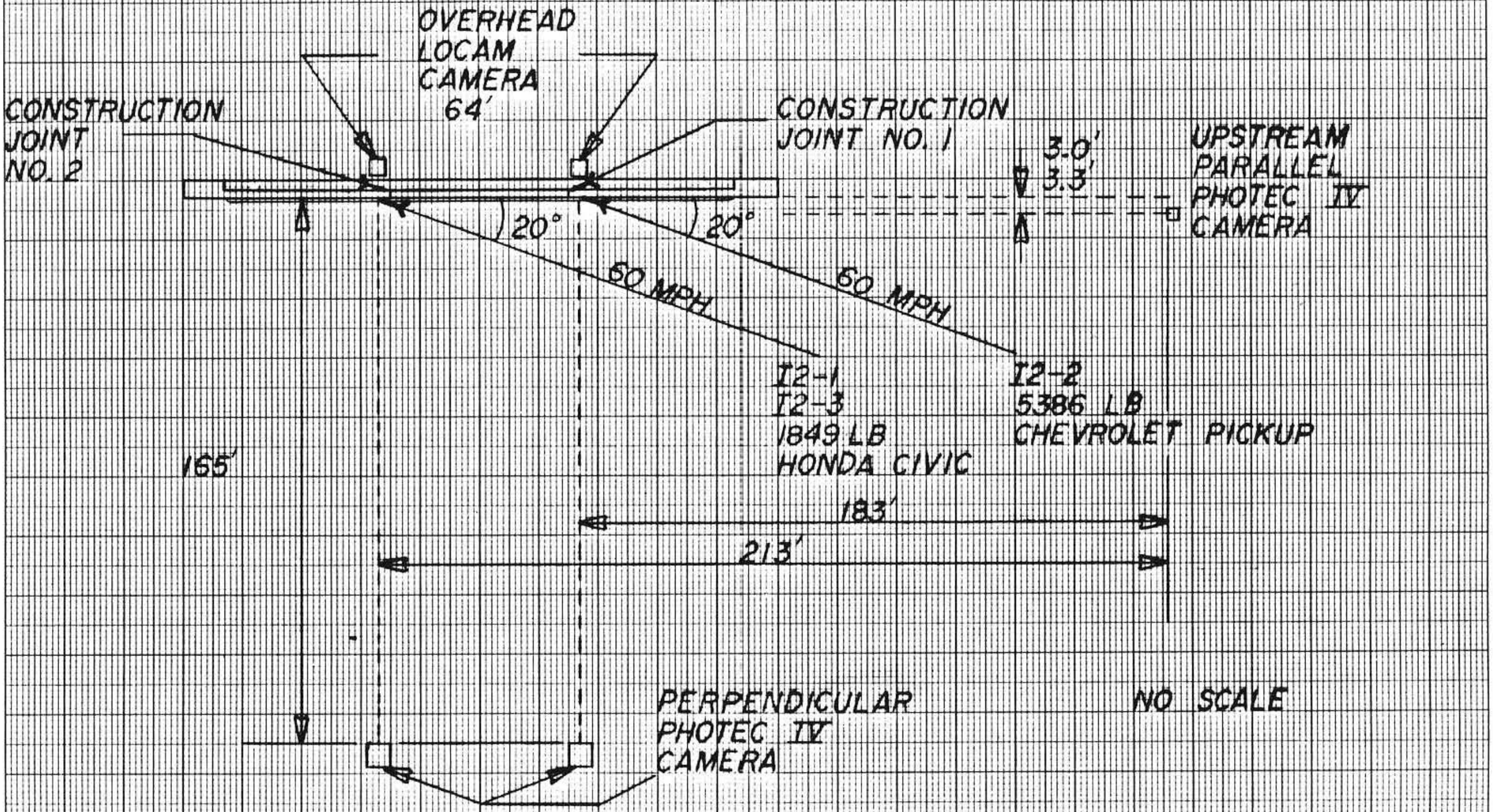


FIGURE 16. SCHEMATIC OF CAMERA LOCATIONS

impact. Each tape switch fired a blue 5B flash-bulb located near each switch on the concrete slab as the left front tire of the test vehicle passed over it. The average speed of the test vehicle between the tape switches was determined by knowing the distance between pressure switches, the calibrated camera speed, and the number of frames from the high-speed film between flashes. In addition, the average speed was determined from electronic timing mark data recorded on the oscilloscope software used with the 386/AT computer as the test vehicle passed over each tape switch.

2.5. Test Parameters

Three full-scale vehicle crash tests were conducted on the Iowa Retrofit Concrete Barrier Rail as shown in Figure 5.

Tests I2-1 and I2-3 were conducted at a target impact speed of 60 mph with an impact angle of 20 degrees. A 1984 Honda Civic weighing 1,849 lbs. was used as the crash test vehicle. The location of impact was 18-in. downstream from construction joint No. 2 as shown in Figure 16.

Test I2-2 was conducted at a target impact speed of 60 mph with an impact angle of 20 degrees. A 1983 Chevrolet Scottsdale 3/4-ton pickup weighing 5,386 lbs. was used as the crash test vehicle. The location of impact was 18-in. upstream from construction joint No. 1 as shown in Figure 16.

3. PERFORMANCE EVALUATION CRITERIA

The safety performance objective of a highway appurtenance is to minimize the consequences of a vehicle leaving the roadway to create an off-road incident. The safety goal is met when the appurtenance (Retrofit Concrete Barrier Rail) smoothly redirects the vehicle away from a hazard zone without subjecting the vehicle occupants to major injury producing forces.

Safety performance of a highway appurtenance cannot be measured directly, but it can be evaluated according to three major factors: (1) structural adequacy, (2) occupant risk, and (3) vehicle trajectory after collision. These three factors are defined and explained in NCHRP 230 (1). Similar criteria is presented in the new AASHTO criteria (2).

The test conditions for the matrix are shown in Table 1. Also, the specific evaluation criteria used to determine the adequacy of the barrier are listed and will be explained later in Tables 2 and 3.

After each test, the vehicle damage was assessed by the traffic accident data scale (TAD) (5) and the vehicle damage index (VDI) (6).

TABLE 1.

CRASH TEST CONDITIONS
AND EVALUATION CRITERIA

Appurtenance	Test Designation	Vehicle Type	Target Impact Speed (mph)	Target Impact Angle (deg)	Impact Point	Evaluation Criteria*	
						Required	Desirable
Longitudinal Barrier							
Retrofit Concrete Barrier Rail Test No. I2-1	PL-2	±50 1800 lb	60	20	18" downstream from the second of two construction joints	NCHRP 230: A,D,E,F,H,I AASHTO: A,B,C,D,G	 E,F,H
Retrofit Concrete Barrier Rail Test No. I2-2	PL-2	±100 5400 lb	60	20	18" upstream from the first of two construction joints	NCHRP 230: A,D,E,H,I AASHTO: A,B,C,D	 E,F,G,H
Retrofit Concrete Barrier Rail Test No. I2-3	PL-2	±50 1800 lb	60	20	18" downstream from the second of two construction joints	NCHRP 230: A,D,E,F,H,I AASHTO: A,B,C,D,G	 E,F,H

* The evaluation criteria are explained in Tables 2 and 3 in the conclusions.

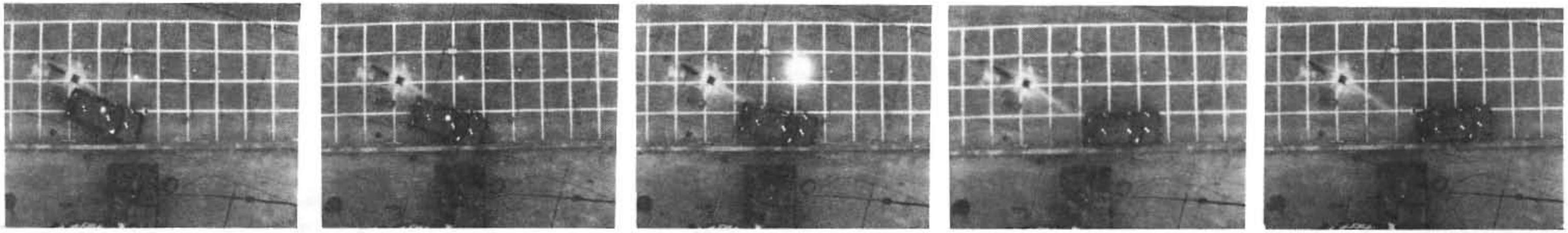
4. TEST RESULTS

4.1. Test No. I2-1

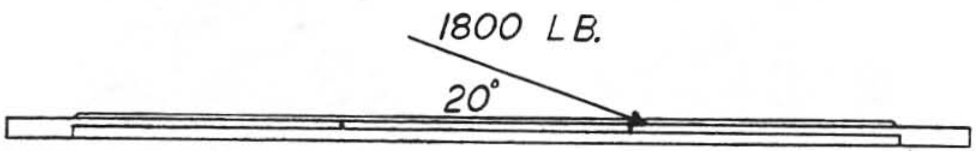
Test I2-1 was conducted with an 1,849 lb. Honda Civic under the impact conditions of 56.8 mph and 20 degrees. A summary of the test results is shown in Figure 17. The sequential photographs are also shown in Figure 17.

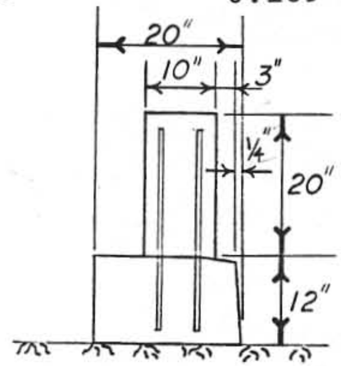
Upon impact with the retrofit concrete barrier rail, the frght front corner of the vehicle began to crush inward at approximately 0.040 sec. At 0.082 sec, the passenger-side window began to break due to the impact of the dummy's head. The vehicle was parallel to the barrier at approximately 0.151 sec. At this time, the dummy's head was protruding out of the window. As the vehicle became parallel to the barrier, the vehicle began to roll clockwise toward the barrier until contact was made between the upper portion of the vehicle and the top portion of the concrete wall. At this time, the left-side tires of the vehicle began to lose contact with the concrete ground surface. The rear right-side of the vehicle impacted the concrete barrier between 0.189 and 0.212 sec. The vehicle exited the concrete barrier at approximately 0.294 sec. The vehicle was in contact with the barrier rail for approximately 8 ft.

Photographs of the vehicle damage are shown in Figure 18. As evident, the vehicle damage was marginal. The TAD and VDI damage classifications are shown in Figure 17. Photographs of the minimal damage to the retrofit concrete barrier rail are shown in Figure 19. Only paint and tire marks were evident.



Impact | 0.040 sec | 0.082 sec | 0.151 sec | 0.189 sec





Test No.	I2-1
Date	11/22/88
Installation	Retrofit Concrete Barrier Rail
Drawing No.	BRF-000S(2)-38-00
Length (ft)	100
Concrete Barrier	
Material.	Nebraska Class "47-B-PHE" Mix
Member.	Rectangular Concrete Wall-Section
Length (ft).	86
Dimensions	
Width (in).	10
Height (in)	20
Member.	Existing Concrete Curb-Section
Length (ft).	86
Dimensions	
Width (in).	20
Height (in)	12
Member.	Concrete Endwalls
Length (ft).	7 (each end)
Dimensions	
Width (in).	20
Height (in)	32

Vehicle	
Model	1984 Honda Civic
Weight	
Test Inertia (lb).	1849
Dummy (lb)	165
Gross Static (lb).	2014
Vehicle Speed	
Impact (mph).	56.8
Exit (mph).	45.0
Vehicle Angle	
Impact (deg).	20
Exit (deg).	8.7
Vehicle Snagging	None
Vehicle Stability.	Satisfactory
Occupant Impact Velocity	
Longitudinal (fps).	17.9
Lateral (fps)	14.8
Occupant Ridedown Decelerations	
Longitudinal (g's).	+8.6,-11.9
Lateral (g's)	+27.5,-24.2
Vehicle Damage	Marginal
TAD	1-RFQ-4,1-RBQ-2
VDI	01RDAK2
Vehicle Rebound Distance (ft).	22.3 @ 112 ft.(AASHTO)
Bridge Rail Damage	Minimal

FIGURE 17. TEST I2-1 SUMMARY AND SEQUENTIAL PHOTOS

FIGURE 18. PHOTOGRAPHS OF VEHICLE DAMAGE, TEST I2-1

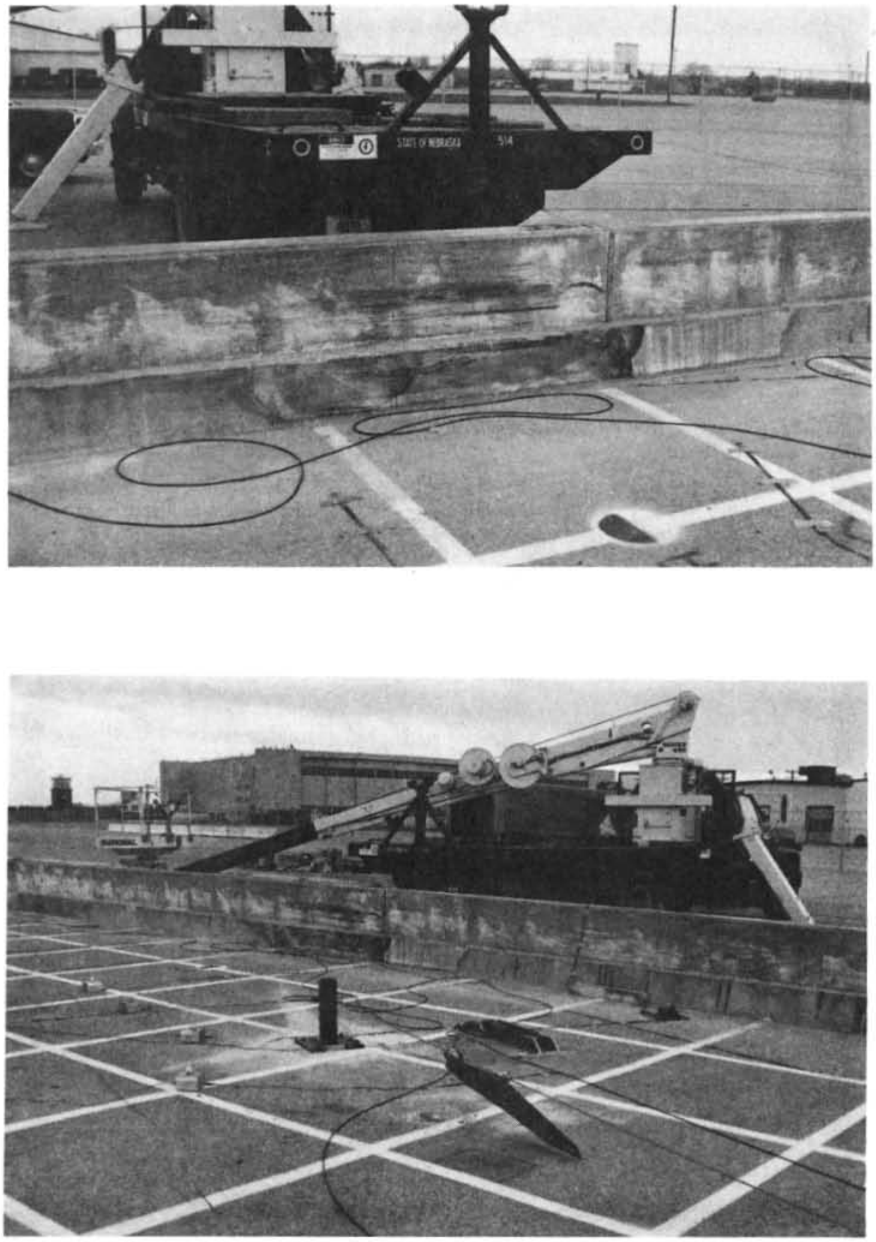


FIGURE 19. RETROFIT CONCRETE BARRIER RAIL DAMAGE, TEST I2-1

Graphs of the longitudinal and lateral deceleration, vehicle change in speed, lateral occupant impact velocity, and longitudinal and lateral occupant displacement versus time are given in Appendix C.

It was noted that high occupant values occurred for the lateral 0.010 sec. average ridedown deceleration. This occurred from a second impact between the rear portion of the vehicle and the concrete barrier. After discussions with both Mr. Charles F. McDevitt with the Federal Highway Administration and Mr. Jarvis D. Michie with Dynatech Engineering (formerly with Southwest Research Institute and developer of the flail space model), the high lateral ridedown decelerations should not be of great concern. This was due to the fact that the flail space model was not developed to handle the case of a second impact. The model would not be accurate, because it does not take into consideration the location of the occupant due to bouncing around when the second impact occurred.

4.2. Test No. I2-2

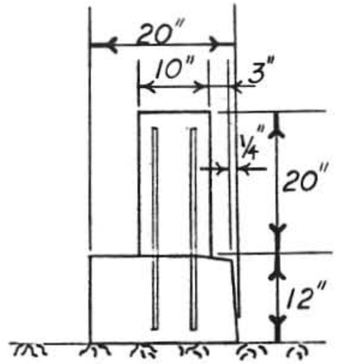
Test I2-2 was conducted with a 5,386 lb. Chevrolet Scottsdale 3/4-ton pickup under the impact conditions of 62.3 mph and 20 degrees. A summary of the test results is shown in Figure 20. The sequential photographs are also shown in Figure 20.

Upon impact with the retrofit concrete barrier rail, the right front corner of the vehicle began to crush inward between 0.044 and 0.054 sec. At 0.094 sec., the passenger-side door began to open due to the impact. Subsequently between 0.129 and 0.136 sec., the dummy's head impacted the side window causing it to shatter. At 0.173 sec., the dummy's head was protruding out of the window. The vehicle became parallel to the concrete barrier at approximately 0.219 sec. At this point, the dummy was hanging out of the window. The vehicle exited the concrete barrier at approximately 0.256 sec. The vehicle was in contact with the barrier rail for approximately 12 ft.

Photographs of the vehicle damage are shown in Figure 21. As evident, the vehicle damage was marginal. The TAD and VDI damage classifications are shown in Figure 20. Photographs of the minimal damage to the retrofit concrete barrier rail are shown in Figure 22. Minor concrete spalling and paint and tire marks were evident.

Graphs of the longitudinal and lateral deceleration, vehicle change in speed, lateral occupant impact velocity, and longitudinal and lateral occupant displacement versus time are given in Appendix C.

Impact | 0.094 sec | 0.136 sec | 0.176 sec | 0.296 sec

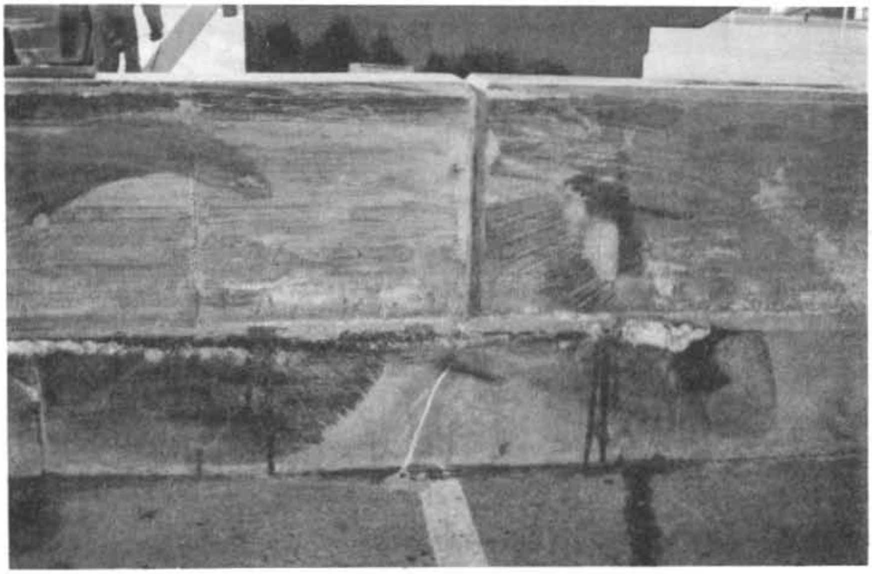


Test No.	I2-2
Date	12/01/88
Installation	Retrofit Concrete Barrier Rail
Drawing No.	BRF-000S(2)-38-00
Length (ft)	100
Concrete Barrier	
Material	Nebraska Class "47-B-PHE" Mix
Member	Rectangular Concrete Wall-Section
Length (ft)	86
Dimensions	
Width (in)	10
Height (in)	20
Member	Existing Concrete Curb-Section
Length (ft)	86
Dimensions	
Width (in)	20
Height (in)	12
Member	Concrete Endwalls
Length (ft)	7 (each end)
Dimensions	
Width (in)	20
Height (in)	32

Vehicle	
Model	1983 Chevrolet Scottsdale 3/4-Ton
Weight	
Test Inertia (lb)	5386
Dummy (lb)	165
Gross Static (lb)	5551
Vehicle Speed	
Impact (mph)	62.3
Exit (mph)	47.0
Vehicle Angle	
Impact (deg)	20
Exit (deg)	5.2
Vehicle Snagging	None
Vehicle Stability	Satisfactory
Occupant Impact Velocity	
Longitudinal (fps)	14.4
Lateral (fps)	27.9(accel.),24.0(film)
Occupant Ridedown Decelerations	
Longitudinal (g's)	10.0
Lateral (g's)	+8.0(accel.),+7.1(film)
Vehicle Damage	Marginal
TAD	1-FR-4,1-RBQ-5
VDI	01RYEK2
Vehicle Rebound Distance (ft)	7.5 @ 118 ft.(AASHTO)
Bridge Rail Damage	Minimal

FIGURE 20. TEST I2-2 SUMMARY AND SEQUENTIAL PHOTOS

FIGURE 21. PHOTOGRAPHS OF VEHICLE DAMAGE, TEST I2-2



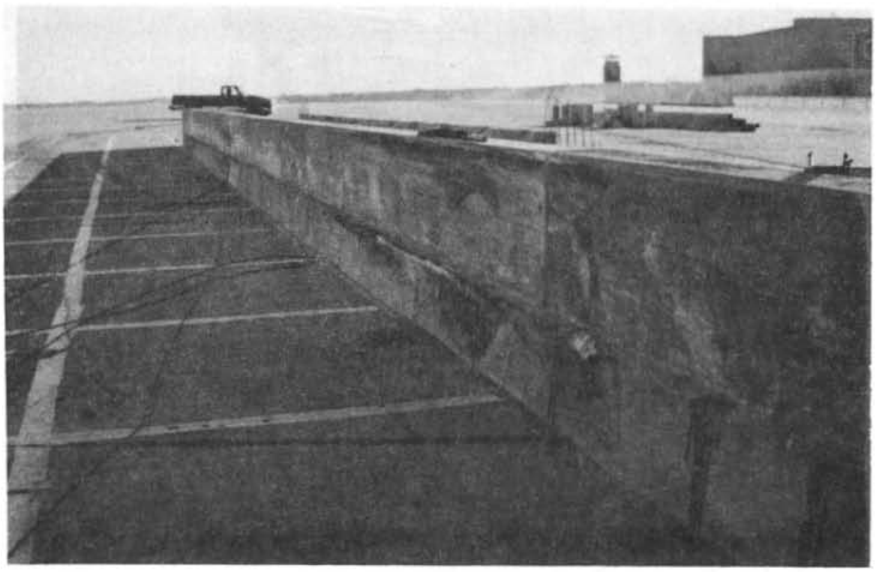


FIGURE 22. RETROFIT CONCRETE BARRIER RAIL DAMAGE, TEST I2-2

4.3. Test No. I2-3

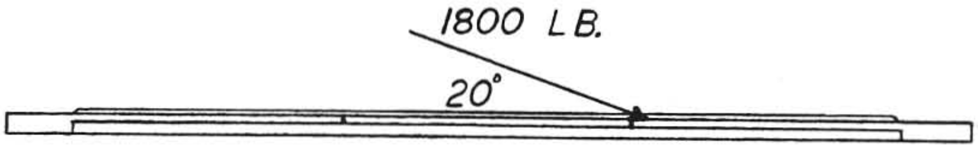
Test I2-3 was conducted with an 1,849 lb. Honda Civic under the impact conditions of 62.5 mph and 20 degrees. A summary of the test results is shown in Figure 23. The sequential photographs are also shown in Figure 23.

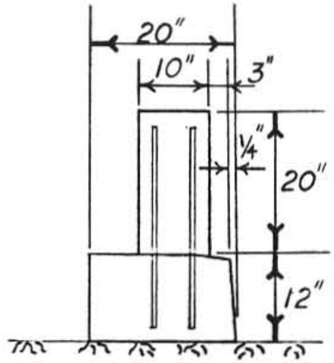
Upon impact with the retrofit concrete barrier rail, the right front corner of the vehicle began to crush inward at approximately 0.029 sec. At 0.098 sec., the passenger-side window began to break due to the impact of the dummy's head. The vehicle was parallel to the barrier at approximately 0.140 sec. As the vehicle became parallel to the barrier, the vehicle began to roll clockwise toward the barrier until contact was made between the upper portion of the vehicle and the top portion of the wall. At this time the left-side tires of the vehicle began to lose contact with the concrete ground surface. The rear right-side of the vehicle impacted the concrete barrier between 0.171 and 0.194 sec. The vehicle exited the concrete barrier between 0.290 and 0.302 sec. The vehicle was in contact with the barrier rail for approximately 10 ft.

Photographs of the vehicle damage are shown in Figure 24. As evident, the vehicle damage was marginal. The TAD and VDI damage classifications are shown in Figure 23. Photographs of the minimal damage to the retrofit concrete barrier rail are shown in Figure 25. Only paint and tire marks were evident.

Graphs of longitudinal deceleration, vehicle change in speed, and longitudinal occupant displacement versus time are

Impact — 0.052 sec — 0.098 sec — 0.146 sec — 0.250 sec





Test No.	I2-3
Date	12/19/88
Installation	Retrofit Concrete Barrier Rail
Drawing No.	BRF-000S(2)-38-00
Length (ft)	100
Concrete Barrier	
Material	Nebraska Class "47-B-PHE" Mix
Member	Rectangular Concrete Wall-Section
Length (ft)	86
Dimensions	
Width (in)	10
Height (in)	20
Member	Existing Concrete Curb-Section
Length (ft)	86
Dimensions	
Width (in)	20
Height (in)	12
Member	Concrete Endwalls
Length (ft)	7 (each end)
Dimensions	
Width (in)	20
Height (in)	32

Vehicle	
Model	1984 Honda Civic
Weight	
Test Inertia (lb)	1849
Dummy (lb)	165
Gross Static (lb)	2014
Vehicle Speed	
Impact (mph)	62.5
Exit (mph)	45.6
Vehicle Angle	
Impact (deg)	20
Exit (deg)	6.3
Vehicle Snagging	None
Vehicle Stability	Satisfactory
Occupant Impact Velocity	
Longitudinal (fps)	20.9
Lateral (fps)	Not Available
Occupant Ridedown Decelerations	
Longitudinal (g's)	5.9
Lateral (g's)	Not Available
Vehicle Damage	Marginal
TAD	1-RFQ-4,1-RBQ-2
VDI	01RDAK2
Vehicle Rebound Distance (ft)	15.3 @ 112 ft.(AASHTO)
Bridge Rail Damage	Minimal

FIGURE 23. TEST I2-3 SUMMARY AND SEQUENTIAL PHOTOS

FIGURE 24. PHOTOGRAPHS OF VEHICLE DAMAGE, TEST I2-3

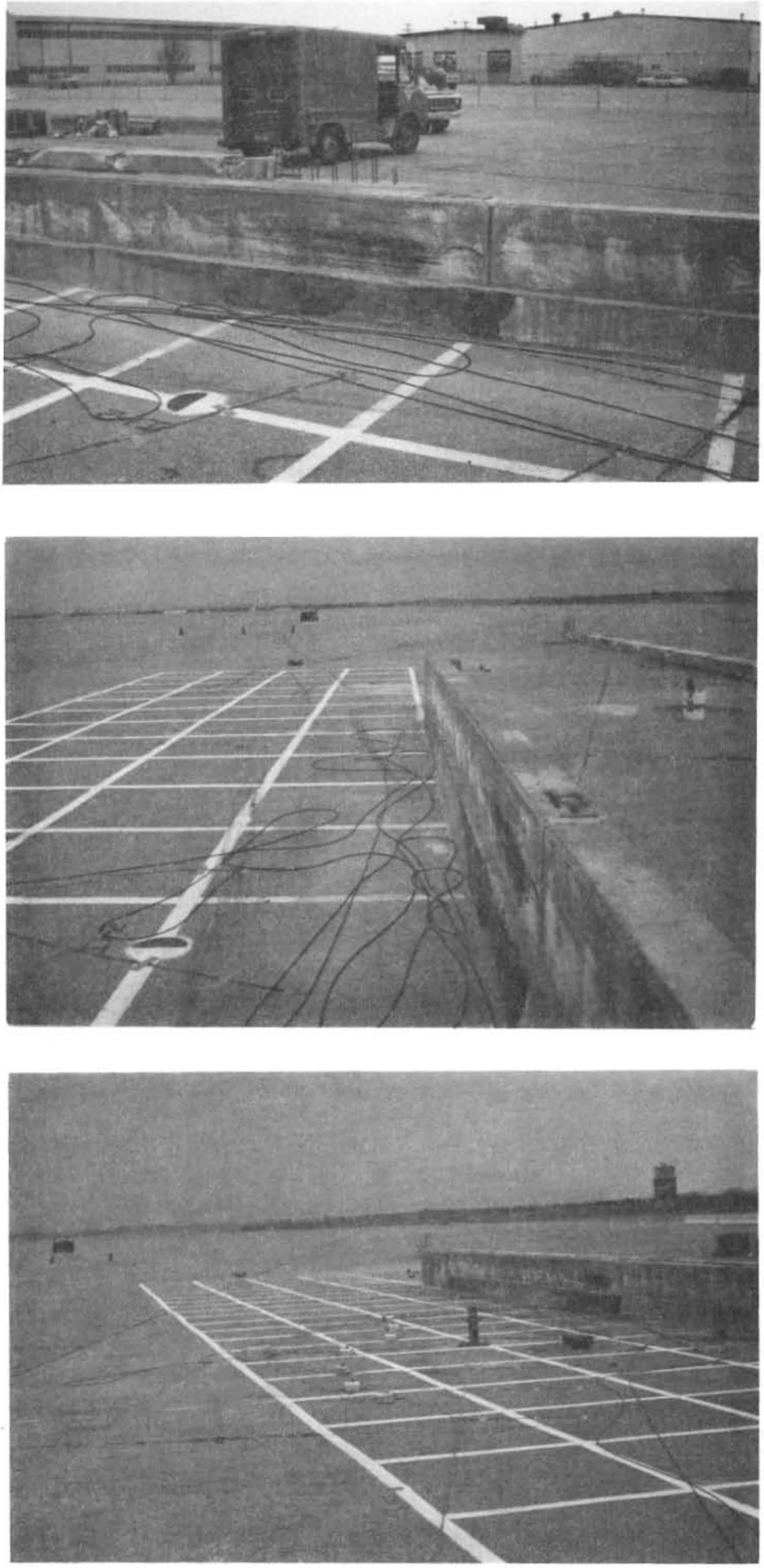


FIGURE 25. RETROFIT CONCRETE BARRIER RAIL DAMAGE, TEST I2-3

given in Appendix C.

Before vehicle impact with the barrier rail, the coaxial data cable broke when it snagged on the cable guidance stanchions. Also, the overhead Locam camera malfunctioned during the test. Thus, the longitudinal occupant risk values were determined from the perpendicular Photec IV camera.

Test I2-3 was conducted as a rerun of Test I2-1 because the impact speed did not meet the AASHTO impact speed criteria (2)

5. CONCLUSIONS

Three full-scale vehicle crash tests were conducted to evaluate the safety performance of the Iowa Retrofit Concrete Barrier Rail. Tests I2-1 and I2-3 were conducted with the impact location at 18-in. downstream from construction joint No. 2 as shown in Figure 16. Test I2-2 was conducted with the impact location at 18-in. upstream from construction joint No. 1 as shown in Figure 16.

The three tests were evaluated according to the safety performance criteria given in NCHRP 230 (1) and AASHTO (2). The safety evaluation summaries using both sets of criteria are presented in Tables 2 and 3. The results of the three tests are summarized in Table 4.

The analysis of the three crash tests revealed the following:

Test No. I2-1: 1,849 lb. vehicle

1. The retrofit concrete barrier did smoothly redirect the vehicle.
2. No detached elements or fragments penetrated the passenger compartment.
3. Integrity of the passenger compartment was maintained.
4. Vehicle remained upright.
5. Effective coefficient of friction was marginal.
6. Occupant risk values were considered acceptable even though high values for lateral occupant ridedown deceleration occurred from a second impact.

Evaluation Criteria		Test		
		I2-1	I2-2	I2-3
Structural Adequacy	A: Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	S	S	S
	D: Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	S	S	S
Occupant Risk	E: The vehicle shall remain upright during and after collision although moderate roll, pitching, and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	S	S	S
	F: Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 24 in. forward and 12 in. lateral displacement, shall be less than: Occupant Impact Velocity - fps Longitudnal Lateral 30 20	S	U (NR)	S
	and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than: Occupant Ridedown Accelerations - g's Longitudnal Lateral 15 15	S	S (NR)	S
Vehicle Trajectory	H: After collision, vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	YES	YES	YES
	I: In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	S	M	M

NR - Not Required
S - Satisfactory
M - Marginal
U - Unsatisfactory

TABLE 2. NCHRP 230 EVALUATION CRITERIA

Evaluation Criteria	Test		
	I2-1	I2-2	I2-3
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^1	S^1	S^1
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^1	S^1	S^1
C: Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	S^1	S^1	S^1
D: The vehicle shall remain upright during and after collision.	S^1	S^1	S^1
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^2	S^2	S^2
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^2 (0.35)	M^2 (0.67)	M^2 (0.49)
G: The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0 ft. longitudnal and 1.0 ft. lateral displacements, shall be less than: Occupant Impact Velocity - fps Longitudnal: 30 — Lateral: 25	S^1	M^2	S^1
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 Longitudnal: 15 — Lateral: 15	S^1	S^2	S^1
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.	M^2	S^2	S^2

1 Required
2 Desirable
S - Satisfactory
M - Marginal
U - Unsatisfactory

TABLE 3. AASHTO EVALUATION CRITERIA

Test Item		Test No.		
		I2-1	I2-2	I2-3
Vehicle Weight (lb)		1849	5386	1849
Vehicle Speed (mph)	Impact	53.86	62.30	62.47
	Exit	44.97	46.99	45.64
Vehicle Angle (deg)	Impact	20	20	20
	Exit	8.7	5.2	6.3
Vehicle Rebound Distance (ft) (AASHTO)		22.3 @ 112 ft.	7.5 @ 118 ft.	15.3 @ 112 ft.
Vehicle Damage	TAD	1-RFQ-4 1-RBQ-2	1-FR-4 1-RBQ-5	1-RFQ-4 1-RBQ-2
	VDI	01RDAK2	01RYEK2	01RDAK2
Occupant Impact Velocity (fps)	Longitudinal	17.9	14.4	20.9
	Lateral	14.8	27.9 (accel.) 24.0 (film)	NA
Occupant Ridedown Deceleration (g's)	Longitudinal	+8.6 -11.9	+10.0	+5.9
	Lateral	+27.5 -24.2	+8.0 (accel.) +7.1 (film)	NA
Did Snagging Occur?		No	No	No
Did Vehicle Rollover Occur?		No	No	No

NA - Not Available: Loss of accelerometer data and overhead Locam camera.

TABLE 4. SUMMARY OF TEST RESULTS

7. The vehicle's speed change and exit angle were less than 15 mph and 12 degrees, respectively.
8. The vehicle's final resting place was marginal.

Test No. I2-2: 5,386 lb. vehicle

1. The retrofit concrete barrier did smoothly redirect the vehicle.
2. No detached elements or fragments penetrated the passenger compartment.
3. Integrity of the passenger compartment was maintained.
4. Vehicle remained upright.
5. Effective coefficient of friction was marginal.
6. Occupant risk values were considered marginal due to high values of lateral occupant impact velocity.
7. The vehicle's speed change was marginal (15.31 mph > 15 mph).
8. The vehicle's final resting place was satisfactory.

Test No. I2-3: 1,849 lb. vehicle

1. The retrofit concrete barrier did smoothly redirect the vehicle.
2. No detached elements or fragments penetrated the passenger compartment.
3. Integrity of the passenger compartment was maintained.
4. Vehicle remained upright.
5. Effective coefficient of friction was marginal.
6. Longitudinal occupant risk values were considered acceptable.

7. The vehicle's speed change was marginal (16.83 mph > 15 mph).

8. The vehicle's final resting place was satisfactory.

Based upon the above listed items, the results of Tests I2-1, I2-2, and I2-3 are acceptable according to the NCHRP 230 (1) and AASHTO (2) guidelines.

6. RECOMMENDATIONS

The Iowa Retrofit Concrete Barrier Rail has met two vehicle classifications of the PL-2 performance level in the AASHTO guide specifications (2), the 1,800 lb. and 5,400 lb. vehicles. Thus, the concrete barrier can now be full-scale vehicle crash tested with the 18,000 lb. vehicle in order to fully satisfy the PL-2 performance level.

7. REFERENCES

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

2. "Guide Specifications for Bridge Railings, An Alternative to Bridge Railing Specifications in the AASHTO Standard Specifications for Highway Bridges," American Association of State Highways and Transportation Officials, Proposed March 7, 1988.

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

4. Faller, R.K., Magdaleno, J.A., Post, E.R., "Full-Scale Vehicle Crash Tests on the Iowa Box-Aluminum Bridge Rail," Final Report to Iowa Department of Transportation, Report No. TRP-03-013-88, Civil Engineering Department, University of Nebraska-Lincoln, November, 1988.

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

6. "Collision Deformation Classification, Recommended Practice J224 Mar 80," SAE Handbook Vol. 4, Society of Automotive Engineers, Warrendale, Penn., 1985.

8. APPENDICES

APPENDIX A.

CONCRETE COMPRESSIVE STRENGTHS

STATE OF NEBRASKA
DEPARTMENT OF ROADS

KAY A. ORR
GOVERNOR

G. C. STROBEL
DIRECTOR-STATE ENGINEER

Dr. Edward R. Post
University of Nebraska
Department of Civil Engineering
W348 Nebraska Hall
Lincoln, NE 68588-0531

November 3, 1988

Reference: Project No. BRF-0005(2)--38--00

Dear Dr. Post:

Final inspection on phase 2 of the above referenced project has been made. It is our opinion that the work is in reasonable conformity to the plans and specifications and is acceptable.

Compressive strengths of concrete cylinders fabricated during this phase are as follows:

ITEM	DATE PLACED	AGE (days)	COMPRESSIVE STRENGTH
Curb Repair	10/11/88	7	5090 psi
		14	5620 psi
Barrier rail (35' sec's.) and both end sections	10/14/88	7	5450 psi
		10	4880 psi
		14	5090 psi
Barrier rail-center section	10/17/88	7	4530 psi
		14	5940 psi

Results of the 28 day breaks will be forwarded when completed. Cylinders were cured under field conditions so compressive strengths should be representative of the material in the structure.

Best Regards,

D. Ronnau

Dalyce Ronnau
Assistant Engineer
Materials & Tests Division

DR/bb

P.O. BOX 94759, LINCOLN, NEBRASKA 68509-4759, PHONE (402) 471-4567

STATE OF NEBRASKA

DEPARTMENT OF ROADS

KAY A. ORR
GOVERNOR

G. C. STROBEL
DIRECTOR-STATE ENGINEER

Dr. Edward R. Post
University of Nebraska
Department of Civil Engineering
W348 Nebraska Hall
Lincoln, NE 68588-0531

November 22, 1988

Reference: Project No. BRF-0005(2)--38--00

Dear Dr. Post:

Compressive strengths of concrete cylinders fabricated during Phase 2 of the above referenced project are as follows:

ITEM	DATE PLACED	AGE (days)	Compressive Strength
Curb Repair	10/11/88	7	5090 psi
		14	5620 psi
		28	5620 psi
Barrier rail (35' sec's.) and both end sections	10/14/88	7	5450 psi
		10	4880 psi
		14	5090 psi
		28	6050 psi
Barrier rail-center section	10/17/88	7	4530 psi
		14	5940 psi
		35	6440 psi

Please advise should further information on the concrete placements be needed.

Best Regards,

D. Ronnau

Dalyce Ronnau
Assistant Engineer
Materials & Tests Division

DR/bb

P.O. BOX 94759, LINCOLN, NEBRASKA 68509-4759, PHONE (402) 471-4567

APPENDIX B.

IDOT CORRESPONDENCE

Iowa Department of Transportation

800 Lincoln Way, Ames, Iowa 50010 515/239-1206

August 31, 1988

Ref. No. Statewide Safety
BRF-000S(2)--38-00

Dr. Edward R. Post
Civil Engineering Department
University of Nebraska
W348 Nebraska Hall
Lincoln, Nebraska 68588-0531

Dear Dr. Post:

In order to more accurately represent existing installations as they are actually constructed, we will require certain changes or restrictions to the details for the Retrofit Concrete Barrier Rail to be tested. Project Sheet 3 of 4, showing the installation for task No. 2 of our testing contract, shall be changed as follows:

1. For dowel setting, the epoxy grout system shall be used.

2. Provide two construction joints within the length of rail. Vehicle impact should be just behind a construction joint. As shown by the project sheet, longitudinal reinforcing shall extend through the construction joint.

3. Vertical bars are to be spaced transversely as shown by the project sheet. The dimensions as shown are clear dimensions.

4. The front vertical face of the retrofit barrier shall be a constant 3 inches from the top front edge of the curb i.e. keep dimension "x" at 3 inches.

Please notify the Nebraska Department of Roads and your subcontractor, M. E. Collins Contracting Co., of these revisions. Three copies of the revised project sheet are enclosed for your use.

Sincerely,

William A. Lundquist
William A. Lundquist
Bridge Engineer

WAL:WCE/dlt
enclosure
cc: R. Humphrey, G. Anderson
B. Brown, B. Brakke, FHWA

Iowa Department of Transportation
800 Lincoln Way, Ames, Iowa 50010 515/239-1206

September 9, 1988 Ref. No. 521.5

Dr. Edward R. Post
Civil Engineering Department
University of Nebraska
W348 Nebraska Hall
Lincoln, Nebraska 68588-0531

Dear Dr. Post:

This memo is to advise you that, based on the tests run previously, no further testing of the box-aluminum rail system (Task I) is required. You may proceed to remove that rail system and construct the concrete retrofit wall in preparation for the testing required for Task II.

The Iowa Department of Transportation and FHWA have agreed that the vehicles used in Task II be as follows:

Vehicle (lb)	Speed (mph)	Impact Angle (degrees)
1800	60	20
5400 (pickup)	60	20

Also, construction details shall be as listed in my memo of August 31, 1988.

Inspection of the damage to the rail and curb section due to Task I testing indicated that all of the reinforcing bars for the curb were not placed in accordance with the plan. Although this apparent misplacement probably did not affect that testing it is imperative that the rebars be placed correctly for Task II testing. I would request that this requirement be brought to the attention of the Contractor and Inspector.

Sincerely,

William A. Lundquist
William A. Lundquist
Bridge Engineer

WAL:dlt
cc: R. Humphrey, G. Anderson
B. Brown, G. Sisson
B. Brakke, FHWA

APPENDIX C.

ACCELEROMETER DATA ANALYSIS

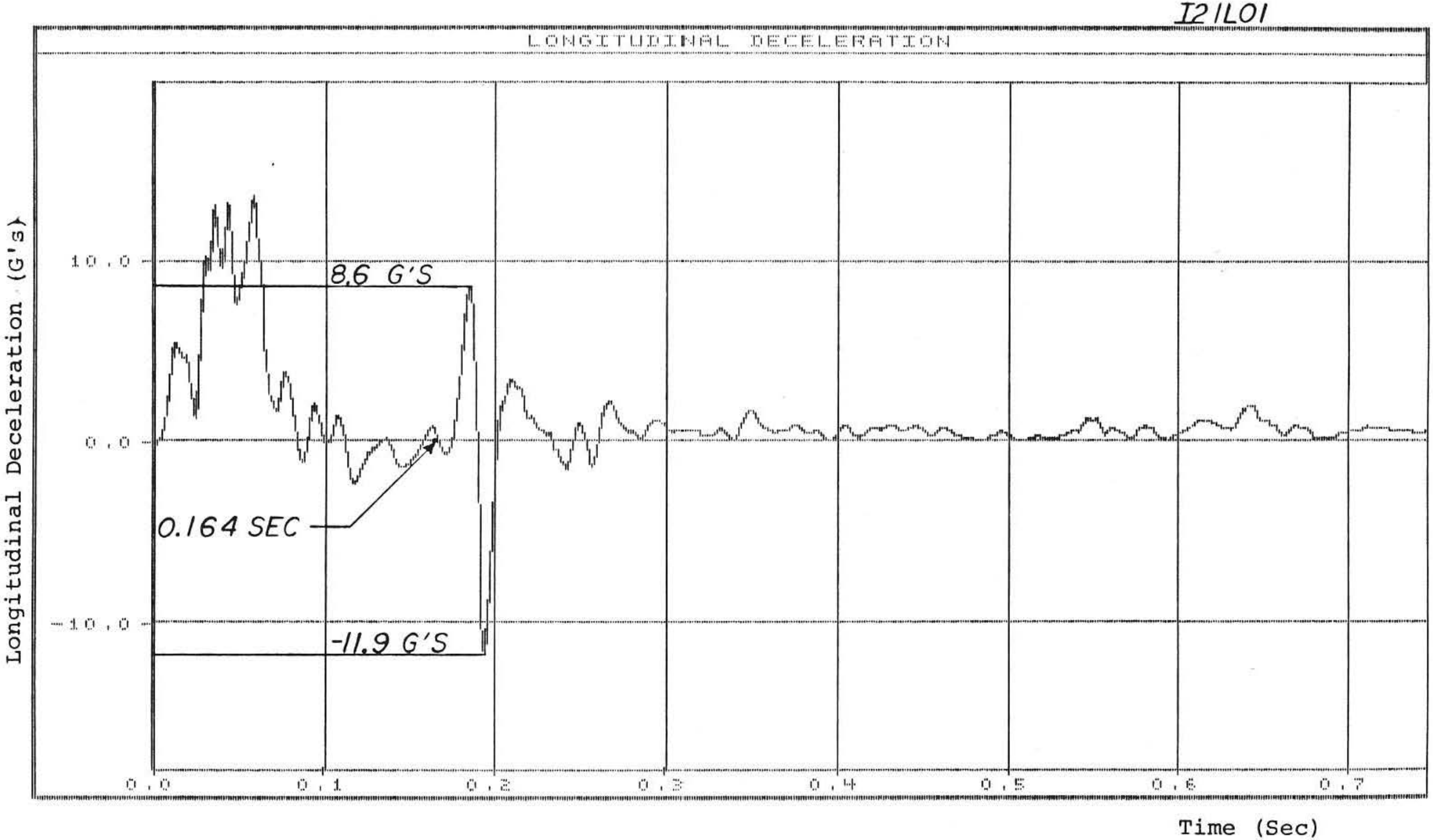
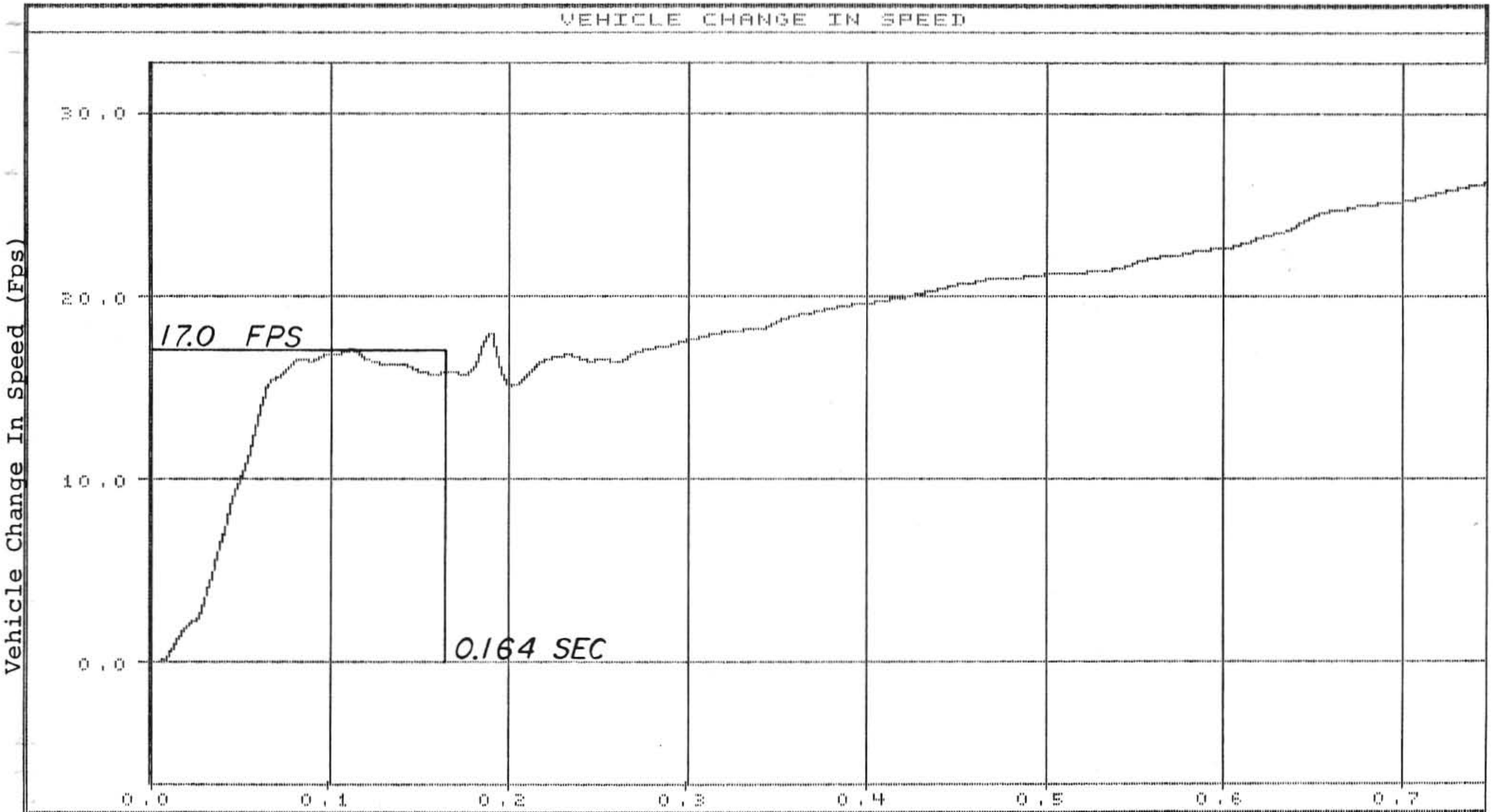


FIGURE C-1. GRAPH OF LONGITUDINAL DECELERATION, TEST I2-1



Normalized Occupant Impact Velocity $(\Delta V)^* = \frac{(\Delta V)(V \sin \theta)\ target}{(V \sin \theta)\ actual} = \frac{17.0\ fps\ (88.2)}{(83.54)} = 17.9\ fps$

FIGURE C-2. GRAPH OF VEHICLE CHANGE IN SPEED, TEST I2-1

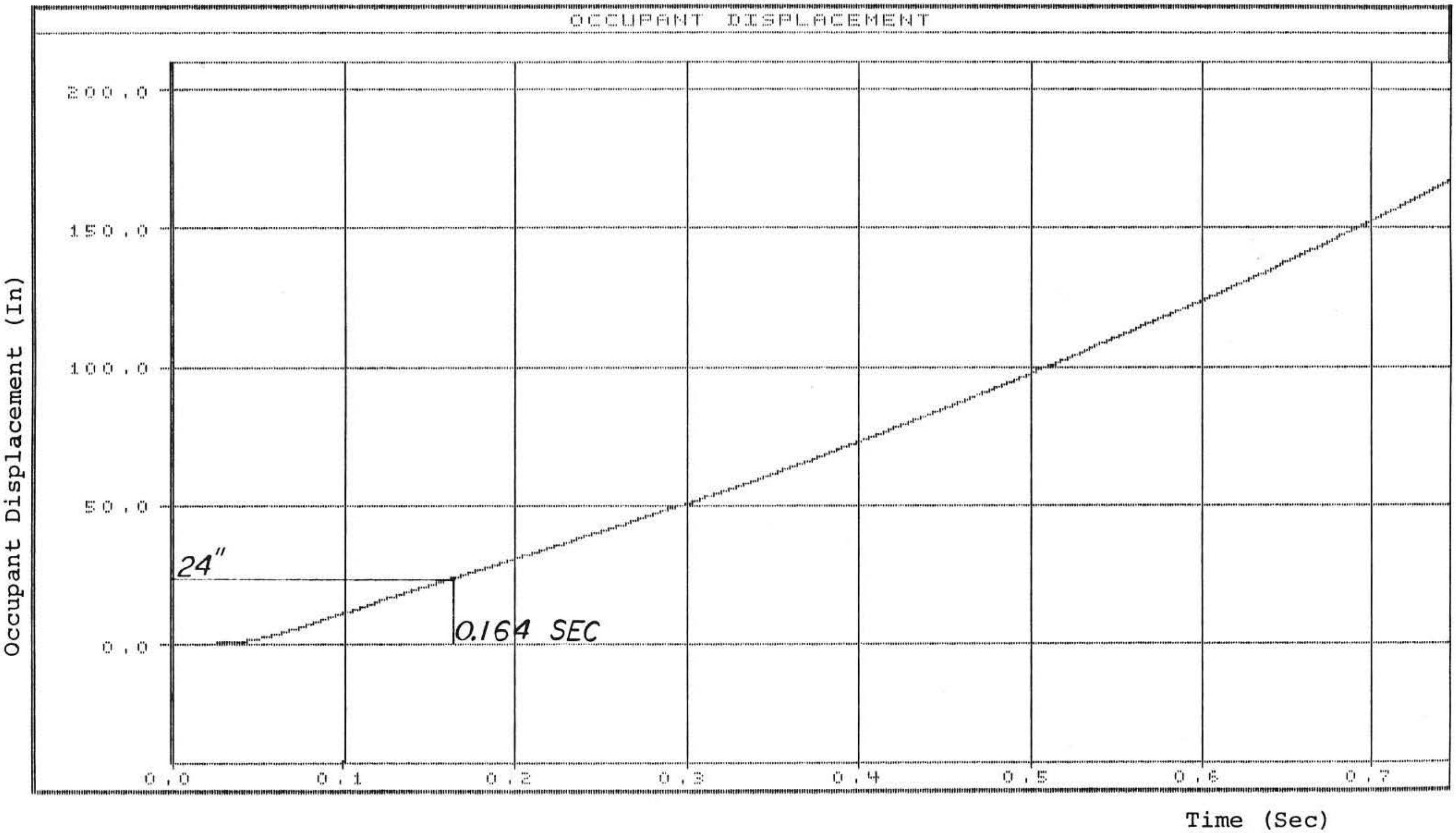


FIGURE C-3. GRAPH OF LONGITUDINAL OCCUPANT DISPLACEMENT, TEST I2-1

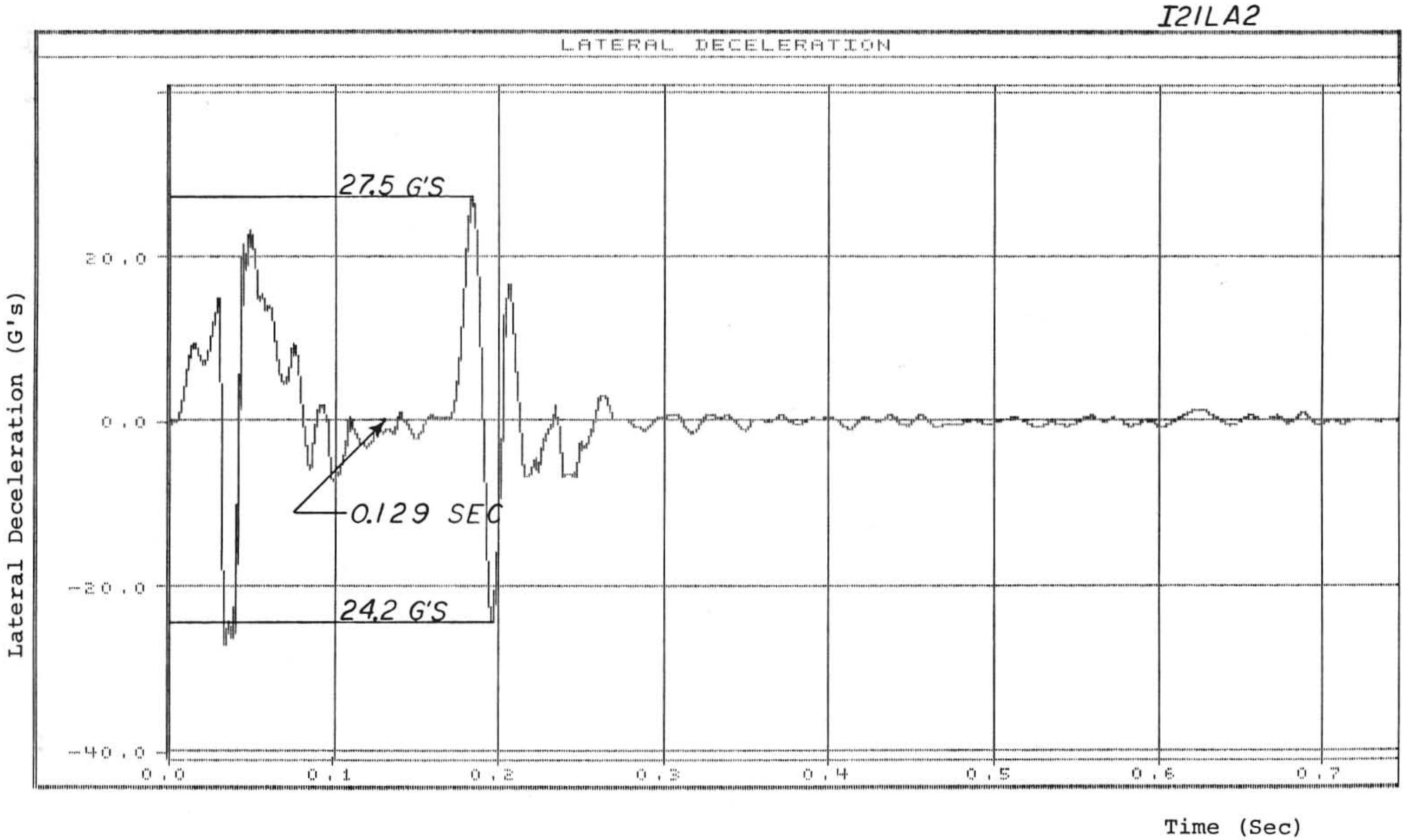
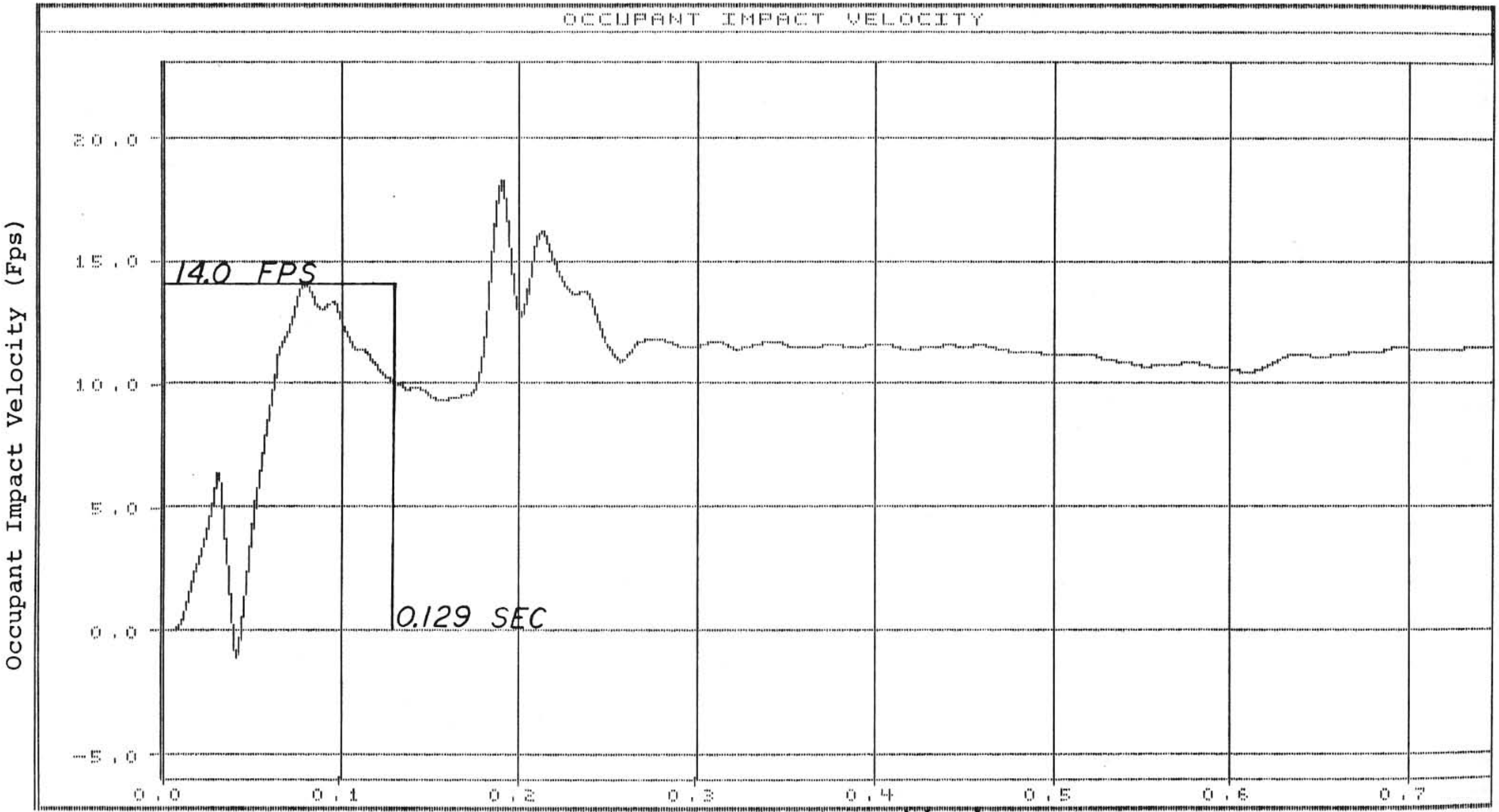


FIGURE C-4. GRAPH OF LATERAL DECELERATION, TEST I2-1



Normalized Occupant Impact Velocity $(\Delta V)^* = \frac{(14.0 \text{ fps})(88.2)}{(83.54)} = 14.8$ fps

Time (Sec)

FIGURE C-5. GRAPH OF LATERAL OCCUPANT IMPACT VELOCITY, TEST I2-1

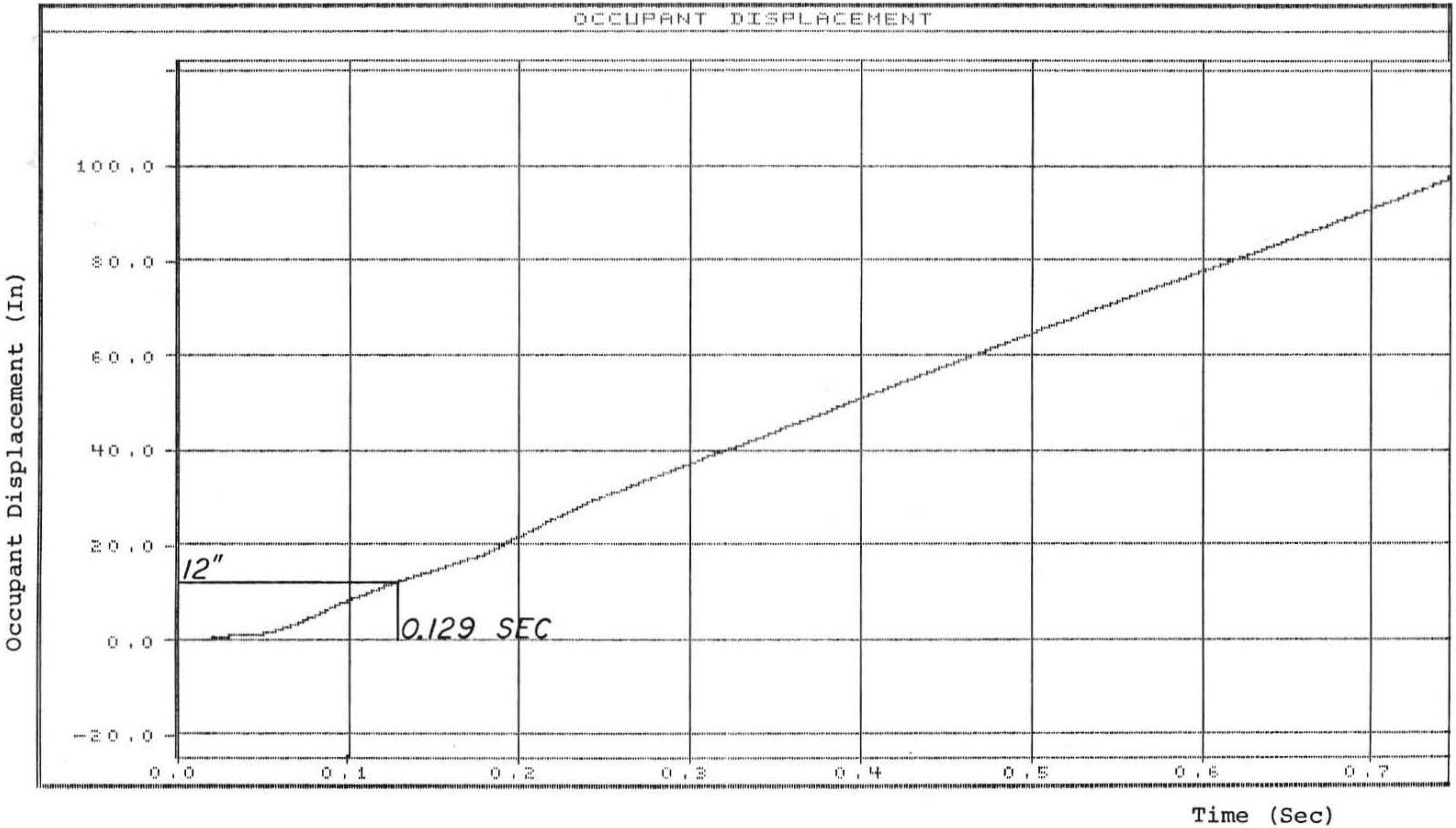


FIGURE C-6. GRAPH OF LATERAL OCCUPANT DISPLACEMENT, TEST I2-1

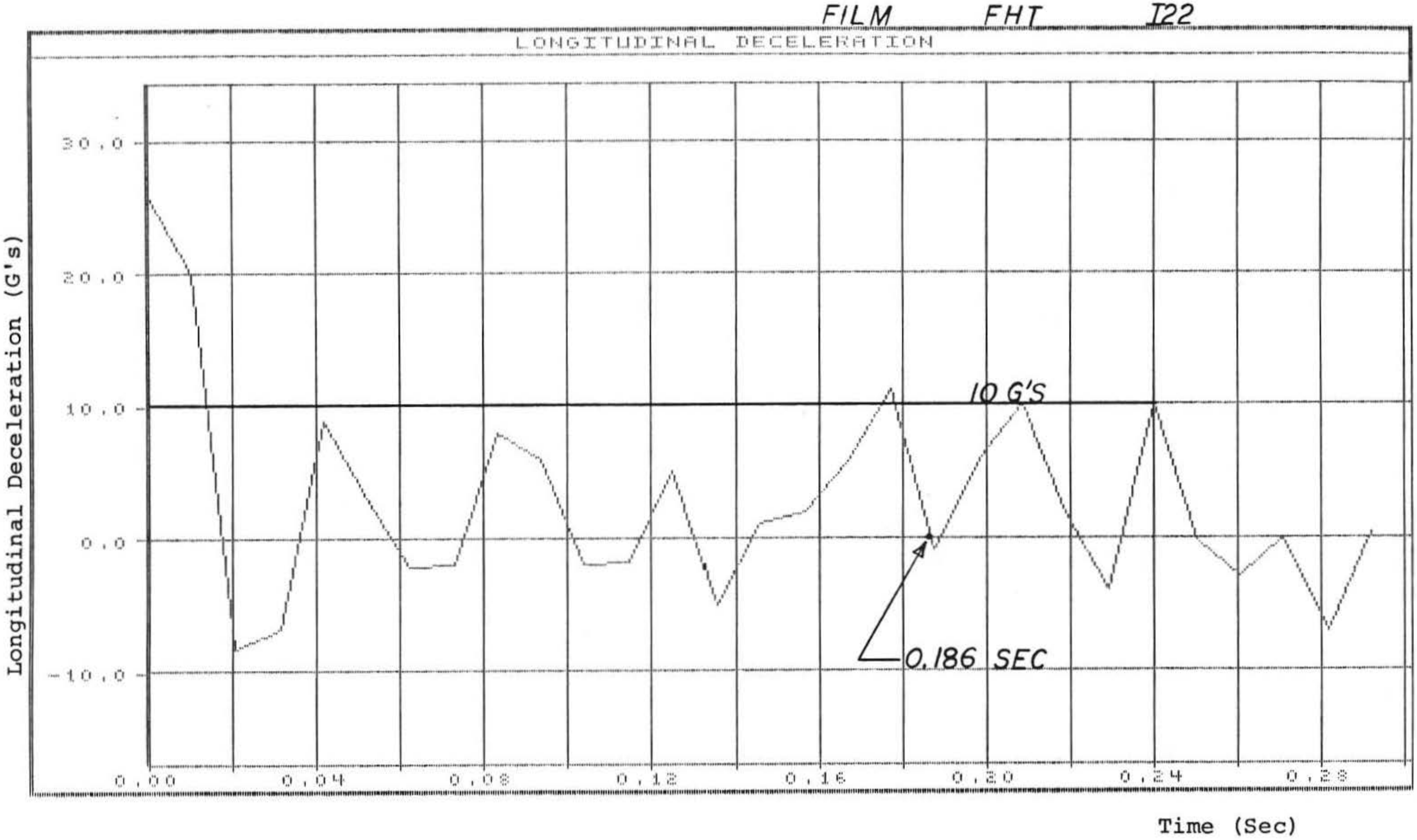
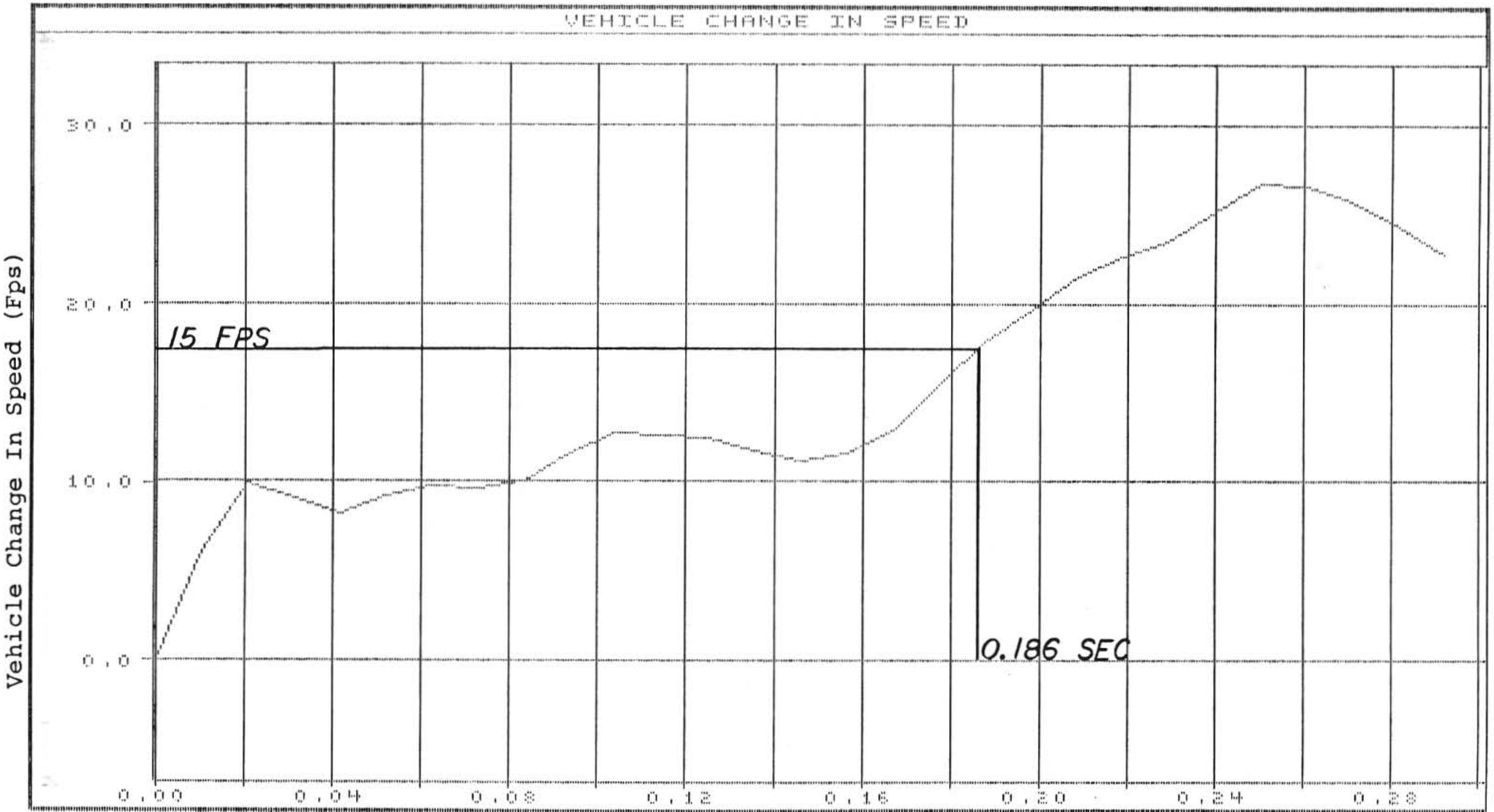


FIGURE C-7. GRAPH OF LONGITUDINAL DECELERATION, TEST I2-2



Normalized Occupant Impact Velocity $(\Delta V)^* = \frac{(15.0\ fps)(88.2)}{(91.58)} = 14.4\ fps$

FIGURE C-8. GRAPH OF VEHICLE CHANGE IN SPEED, TEST I2-2

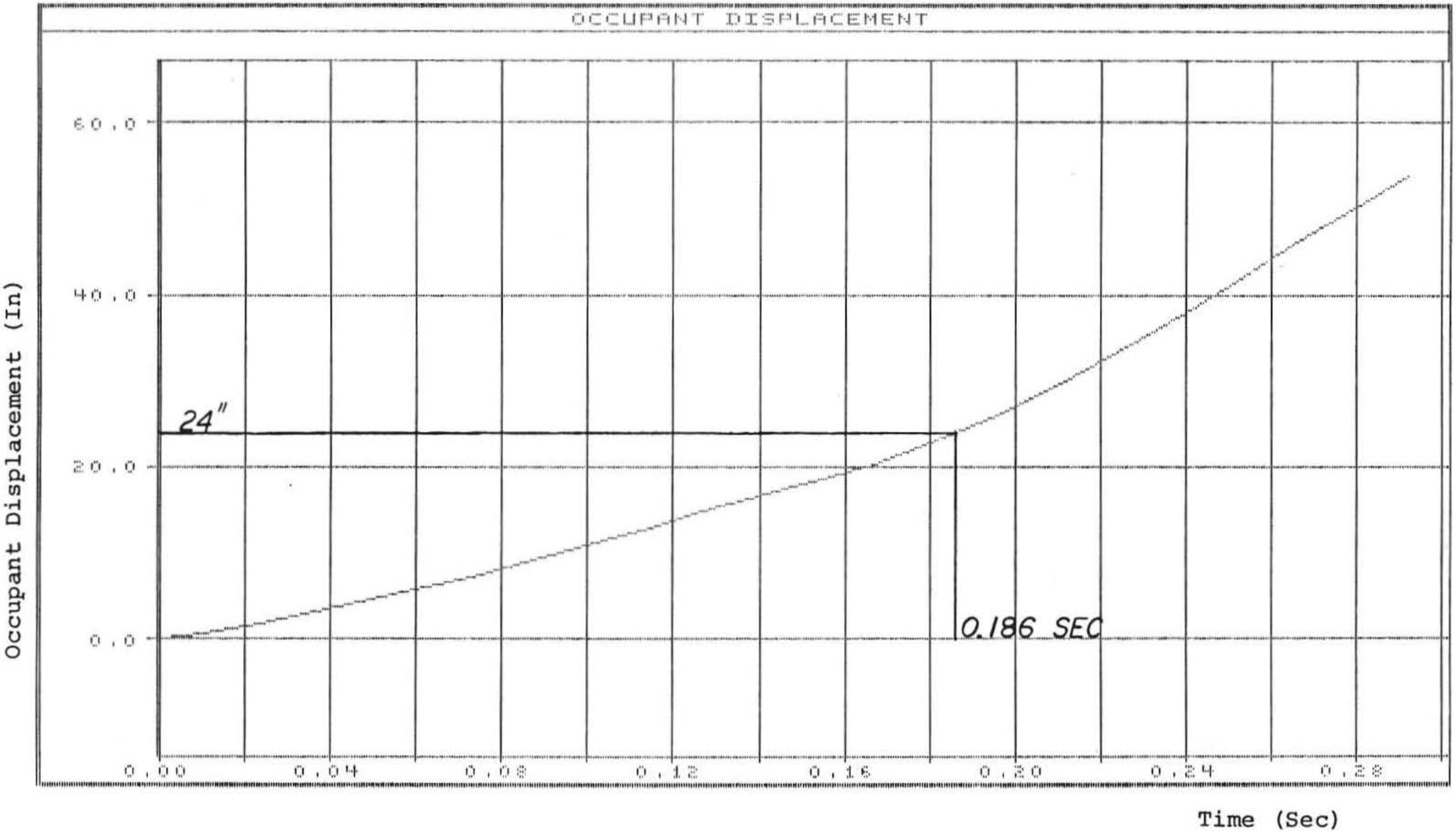


FIGURE C-9. GRAPH OF LONGITUDINAL OCCUPANT DISPLACEMENT, TEST I2-2

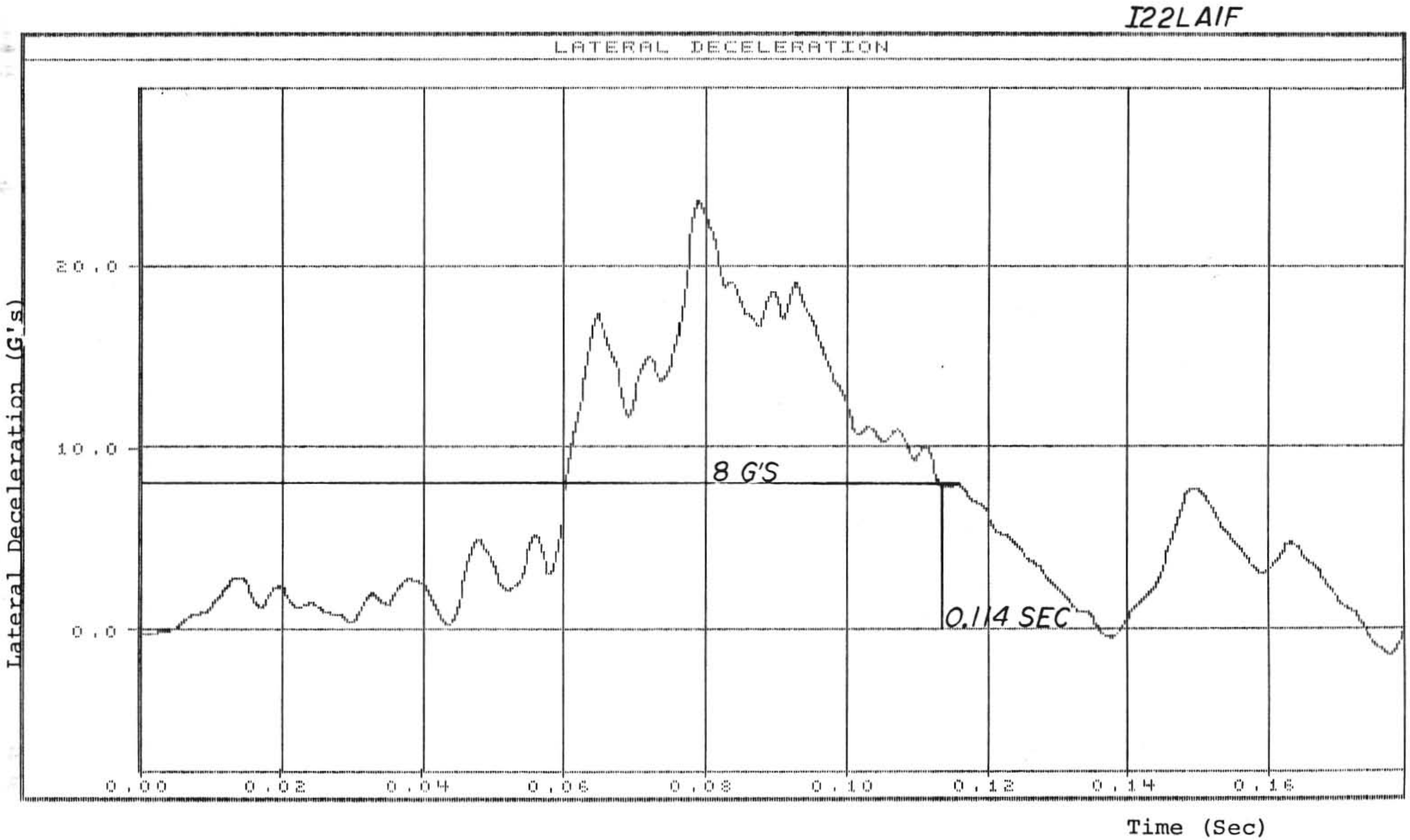
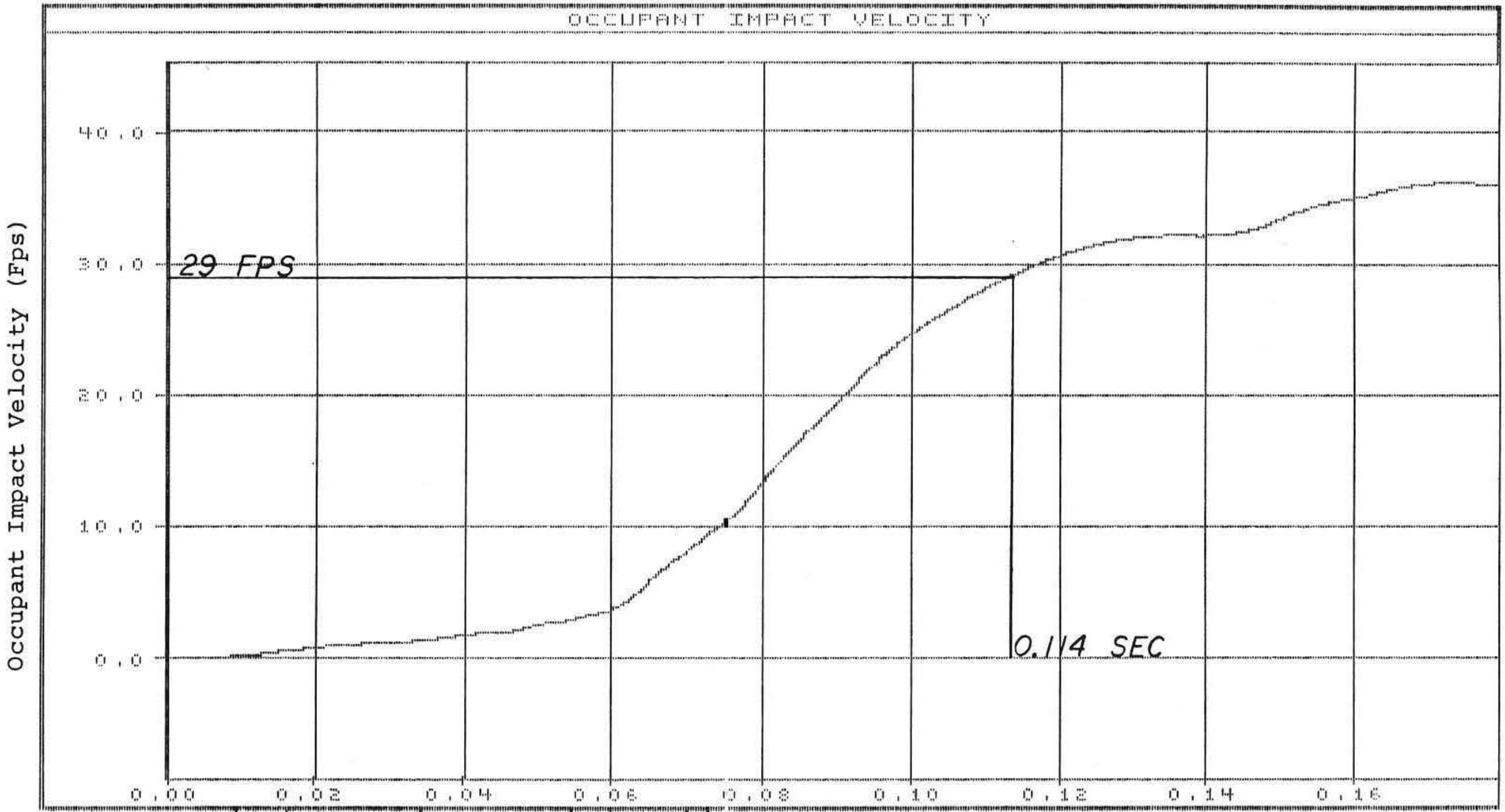


FIGURE C-10. GRAPH OF LATERAL DECELERATION, TEST I2-2



Normalized Occupant Impact Velocity (ΔV)* $= \frac{(29.0 \text{ fps})(88.2)}{(91.58)} = 27.9$ fps

FIGURE C-11. GRAPH OF LATERAL OCCUPANT IMPACT VELOCITY, TEST I2-2

FIGURE C-12. GRAPH OF LATERAL OCCUPANT DISPLACEMENT, TEST I2-2

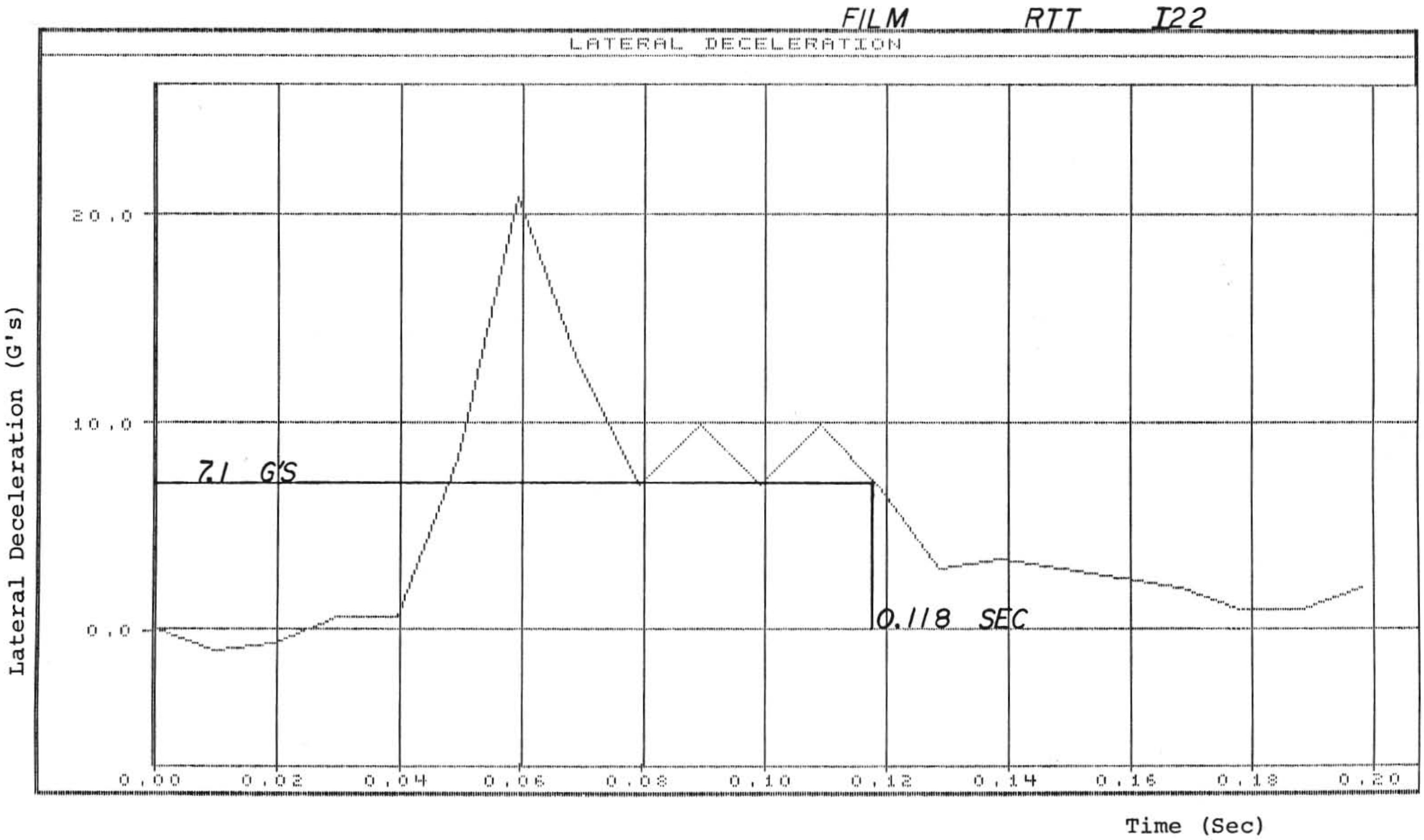
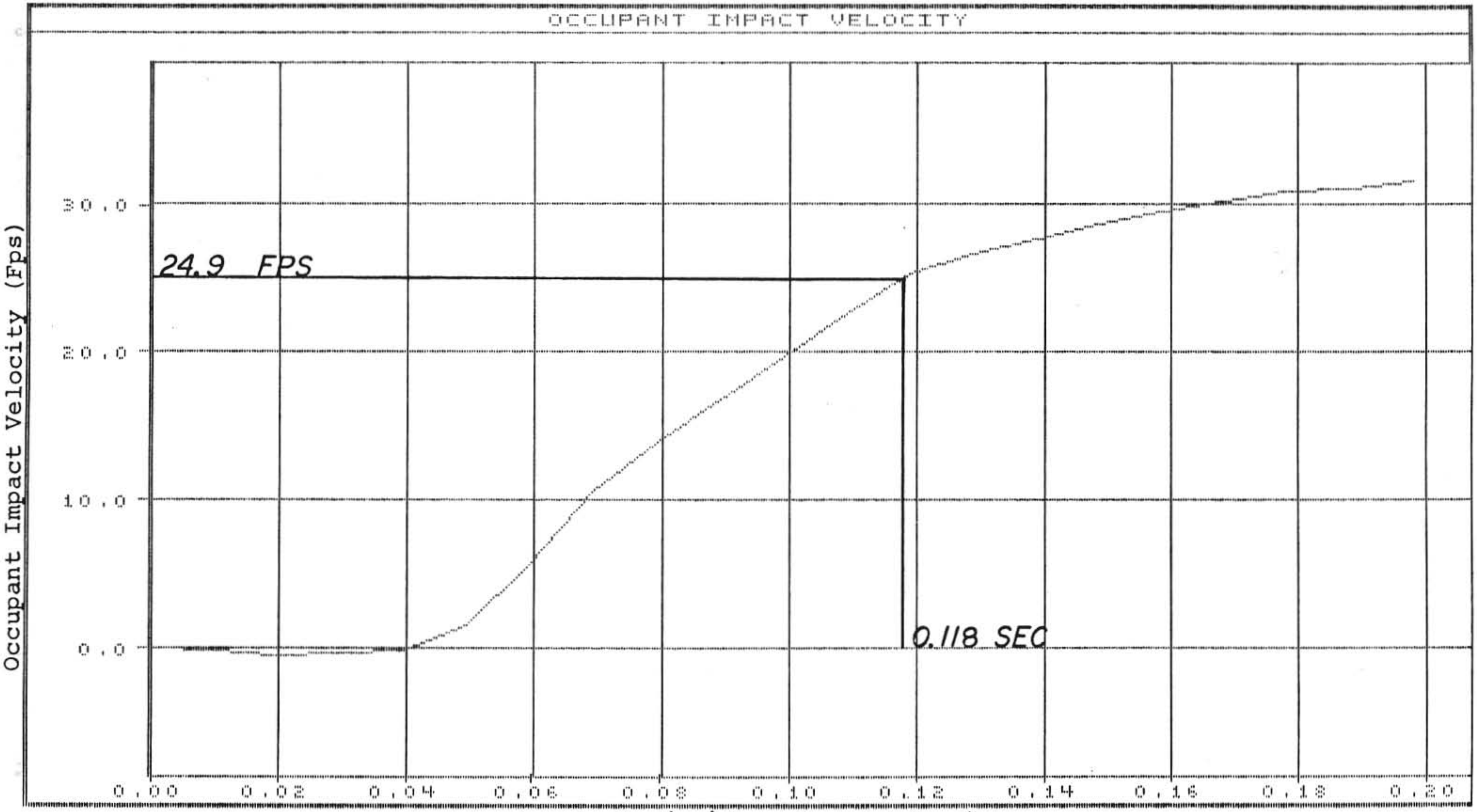


FIGURE C-13. GRAPH OF LATERAL DECELERATION, TEST I2-2



Normalized Occupant Impact Velocity $(\Delta V)^* = \frac{(24.9 \text{ fps})(88.2)}{(91.58)} = 24.0 \text{ fps}$

FIGURE C-14. GRAPH OF LATERAL OCCUPANT IMPACT VELOCITY, TEST I2-2

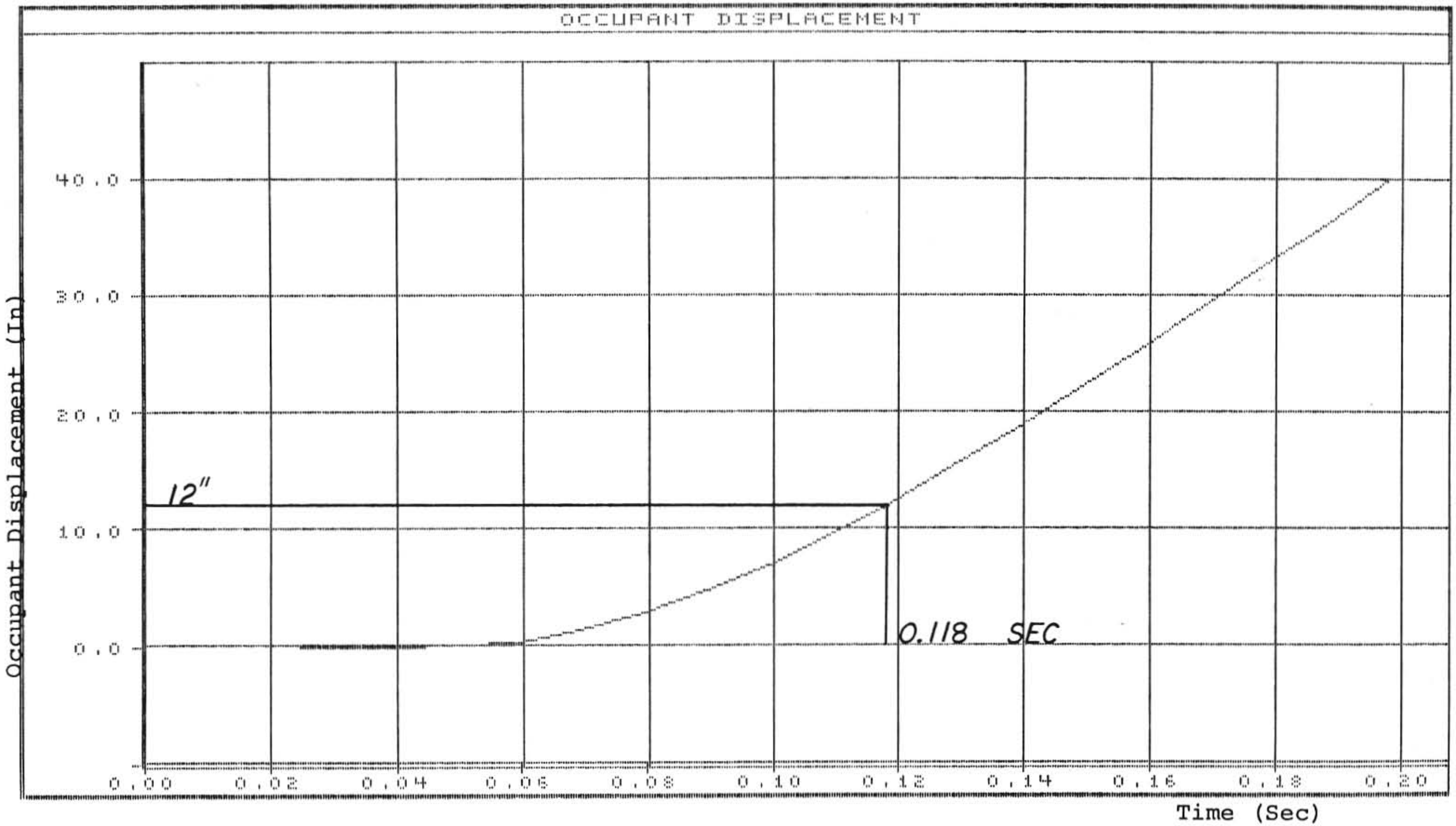


FIGURE C-15. GRAPH OF LATERAL OCCUPANT DISPLACEMENT, TEST I2-2

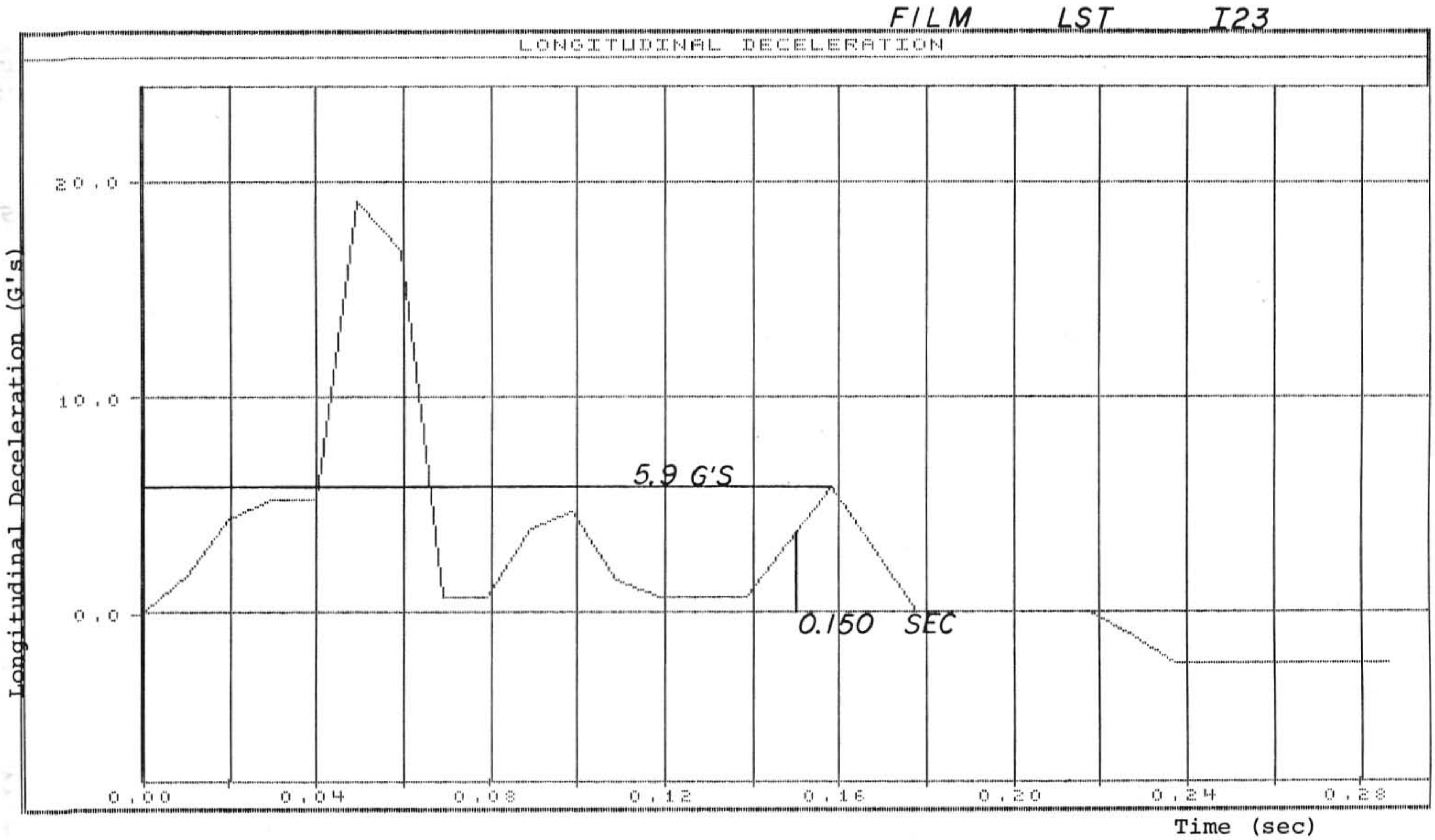
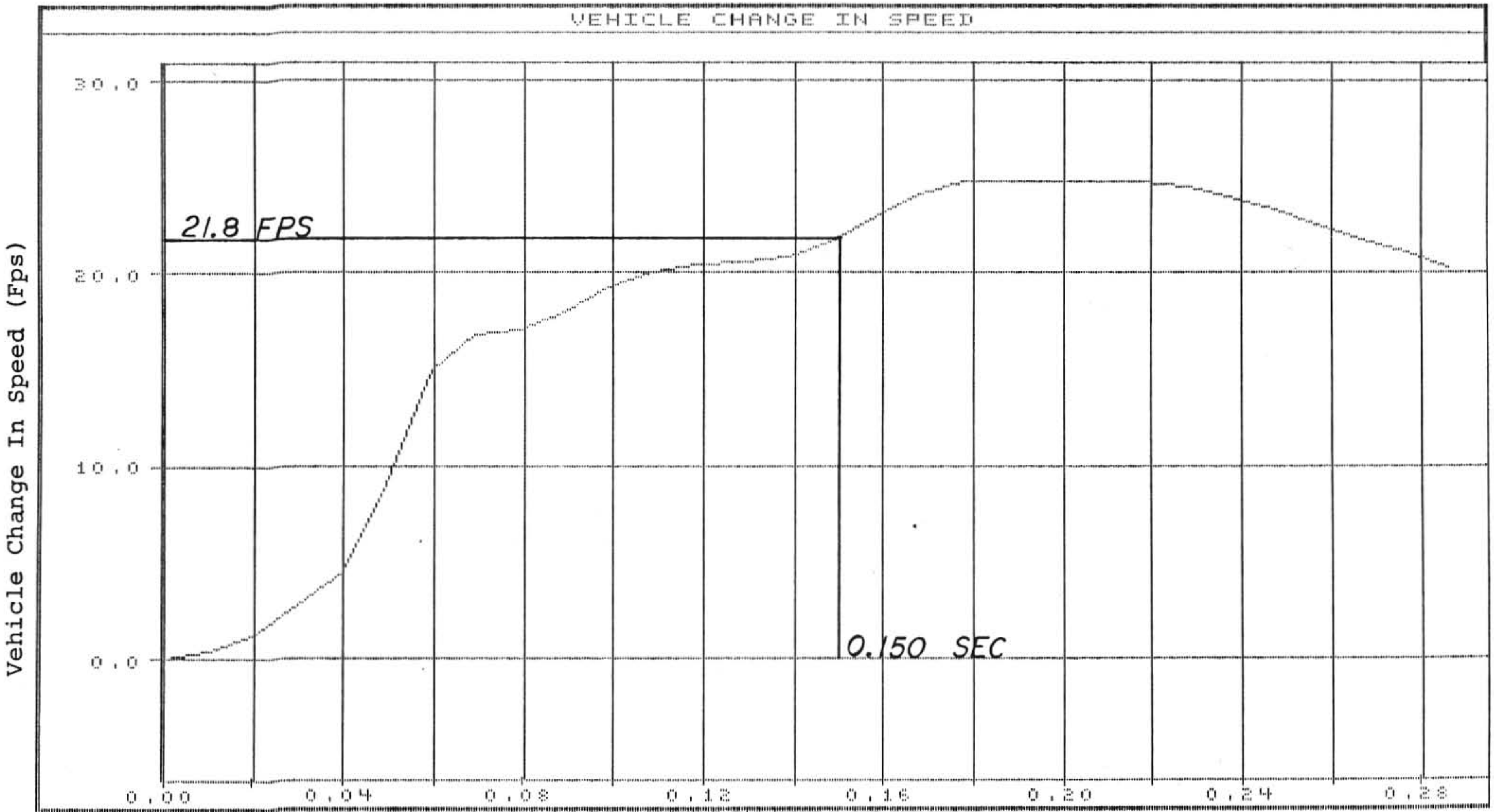


FIGURE C-16. GRAPH OF LONGITUDINAL DECELERATION, TEST I2-3



Normalized Occupant Impact Velocity $(\Delta V)^* = \frac{(21.8 fps)(88.2)}{(91.83)} = 20.9 fps$ Time (Sec)

FIGURE C-17. GRAPH OF VEHICLE CHANGE IN SPEED, TEST I2-3

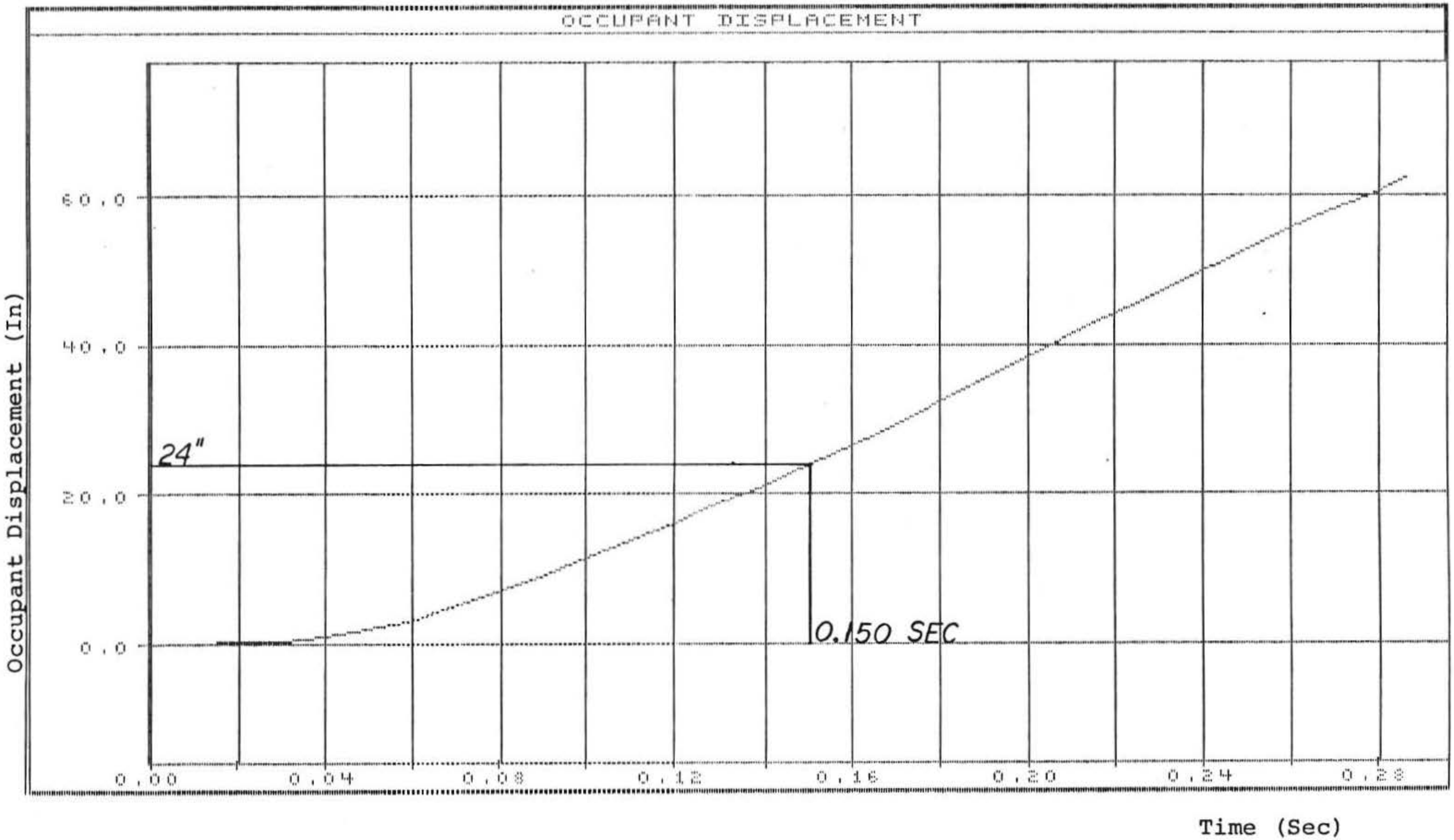


FIGURE C-18. GRAPH OF LONGITUDINAL OCCUPANT DISPLACEMENT, TEST I2-3