FULL-SCALE VEHICLE CRASH TEST ON THE IOWA TEMPORARY CONCRETE BARRIER RAIL HALF-SECTION

by

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DISCLAIMER STATEMENT

TABLE OF CONTENTS

ABSTRACT

One full-scale vehicle crash test was conducted on the Iowa Temporary Concrete Barrier Rail Half-Section. Test I3-1 was conducted with a 5,386 lb. vehicle at 20 deg. and 60 mph.

The installation consisted of ten (10) longitudinally placed Temporary Concrete Barrier Rail Half-Sections, which rested directly on the airport's concrete apron surface. Each section was 10 ft. long. The front face of the barrier resembled the New Jersey Face Shape. The barriers were connected with a 1-in., L-shaped, A-36 steel rod which fit into two sets of cable or wire rope loops embedded into both ends of the concrete barriers. The 1/2-in. wire rope or cable had a minimum breaking strength of 20,000 lbs. One No. 8 rebar was used for reinforcement and was placed 3-in. from the back face and 5-in. above the concrete pavement surface.

The point of impact was at the midpoint of the 100 ft. installation between barriers No. 5 and No. 6.

The test was evaluated according to the safety criteria in NCHRP 230 and also in the AASHTO guide specifications. The safety performance of the Iowa Temporary Concrete Barrier Rail Half-Section was determined to be unsatisfactory.

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

The authors wish to express their appreciation and thanks to the following people who made a contribution to the outcome of this research project.

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1. INTRODUCTION

1.1. Problem Statement

The Iowa Department of Transportation (IDOT) and the Federal Highway Administration (FHWA) 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 sucessfully crash tested before its use on Federal Aid Projects is approved.

Space limitations for work such as repair or rehabilitation on bridge decks sometimes prevents the use of a full-section New Jersey barrier between the work area and the traveled roadway. Thus, full-scale vehicle crash testing was performed to evaluate the half-section New Jersey barrier for the possibility of overturning, deflection, and the strength of the connections.

The results of this study will be used to help guide the IDOT in the use of temporary barriers in the work zone.

1.2. Objective of Study

The objective of the research study was to evaluate the safety performance of the Iowa Temporary Concrete Barrier Rail Half-Section by conducting a full-scale vehicle crash test in accordance with the "Recommended Procedures for the Safety

Performance Evaluation of Highway Appurtenances," NCHRP 230 (1) and 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 18 ft. before impact with the Temporary Concrete Barrier Rail Half-Section. 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

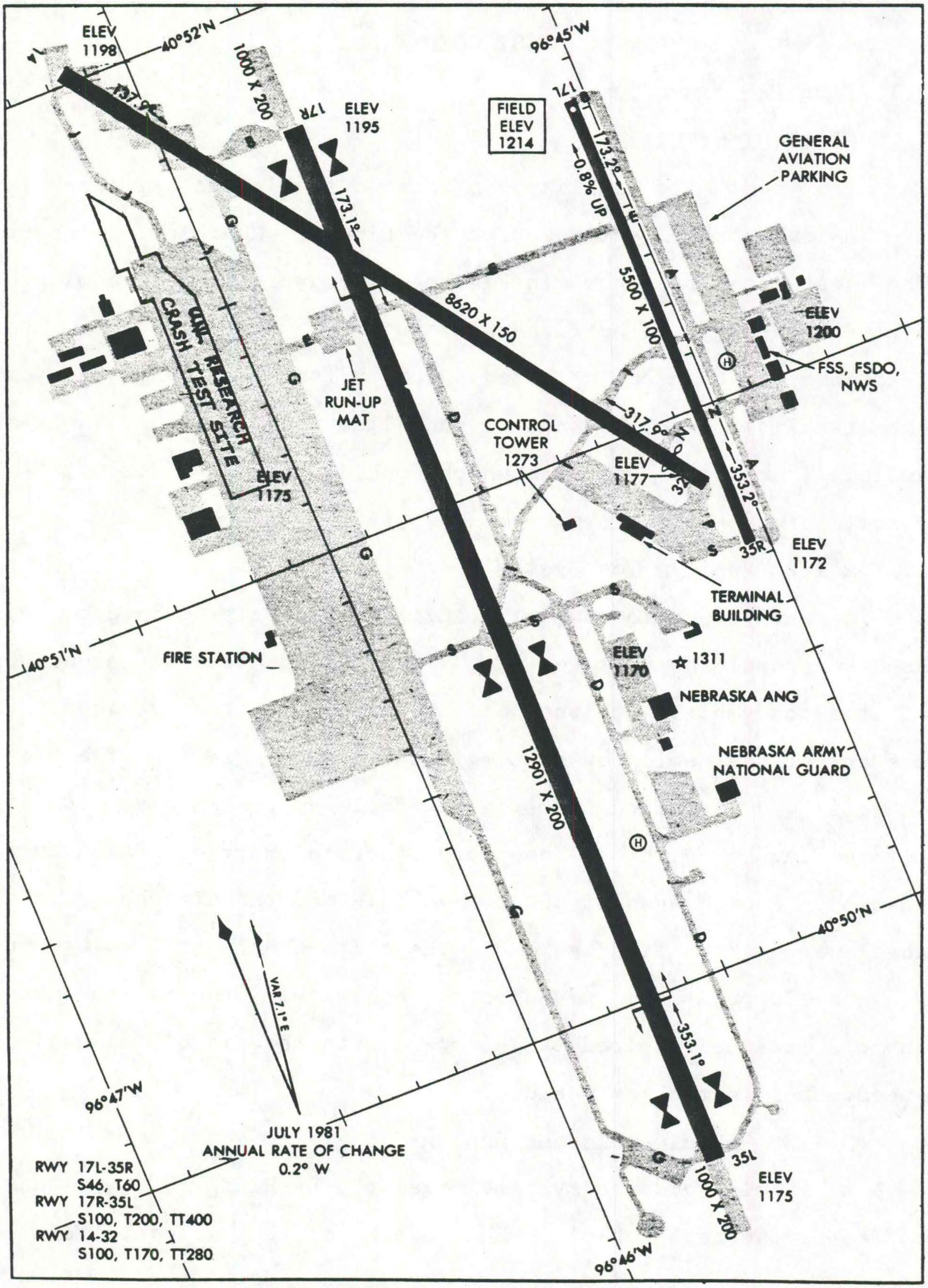


FIGURE 1. FULL-SCALE VEHICLE CRASH TEST FACILITY

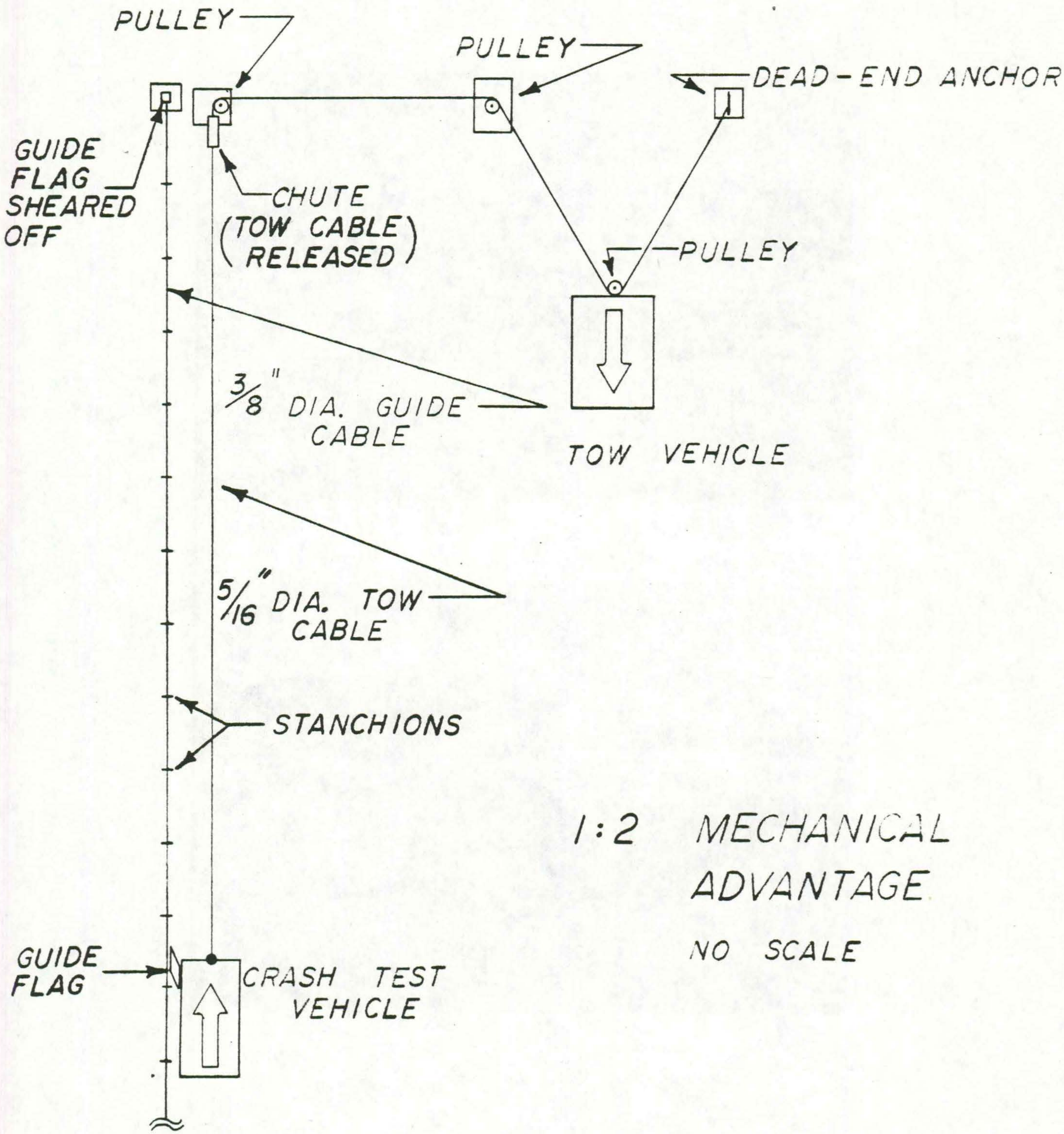


FIGURE 2. SKETCH OF CABLE TOW AND GUIDANCE SYSTEMS

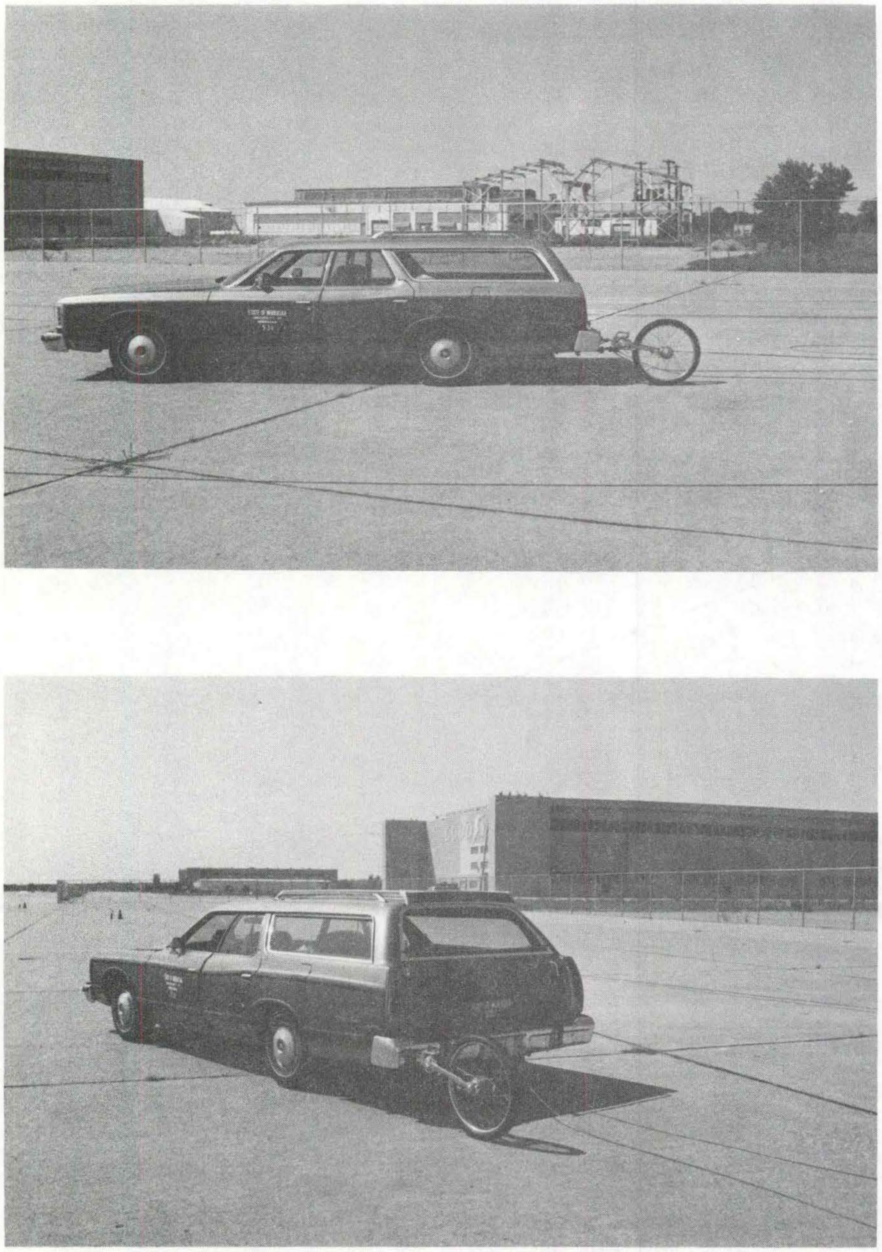


FIGURE 3. PHOTOGRAPHS OF TOW VEHICLE AND FIFTH WHEEL

are shown in Figure 4, and a sketch of the guidance system is shown in Figure 2. The guide-flag, attached to the vehicle's front-left wheel and the guide cable, was sheared off (at the distances stated above) before impact with the Temporary Concrete Barrier Rail Half-Section. 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 Temporary Barrier Design Details

An overall view of the Iowa Temporary Concrete Barrier Rail Half-Section is shown in the photographs in Figure 4, and a detailed drawing is shown in Figure 5.

The installation consisted of ten (10) longitudinally placed Temporary Concrete Barrier Rail Half-Sections. The barriers were placed directly on the airport's concrete apron surface. Each section was 10 ft. in length with the gap between the attached barriers ranging between 2.4-in. and 3.6-in. The total installation length was 101.1 ft. in length. A diagram of the barrier layout is shown in Figure 6.

The front face of the temporary barrier is the Standard New Jersey Shape while the rear face was vertical. The vertical height, top lateral width, and bottom lateral width were 2 ft.-8 in., 6-in., and 1 ft.-3in., respectively. One No. 8 rebar was

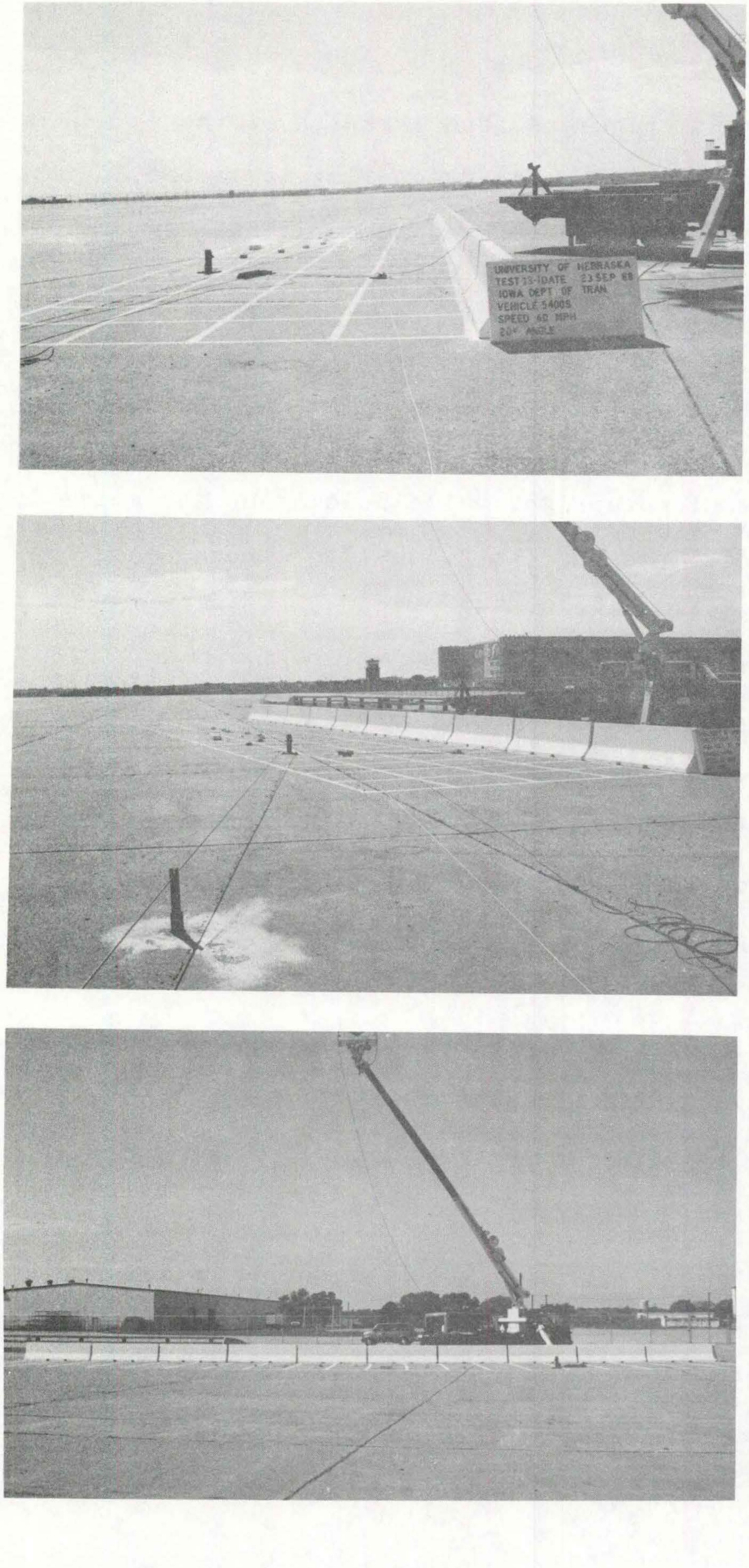
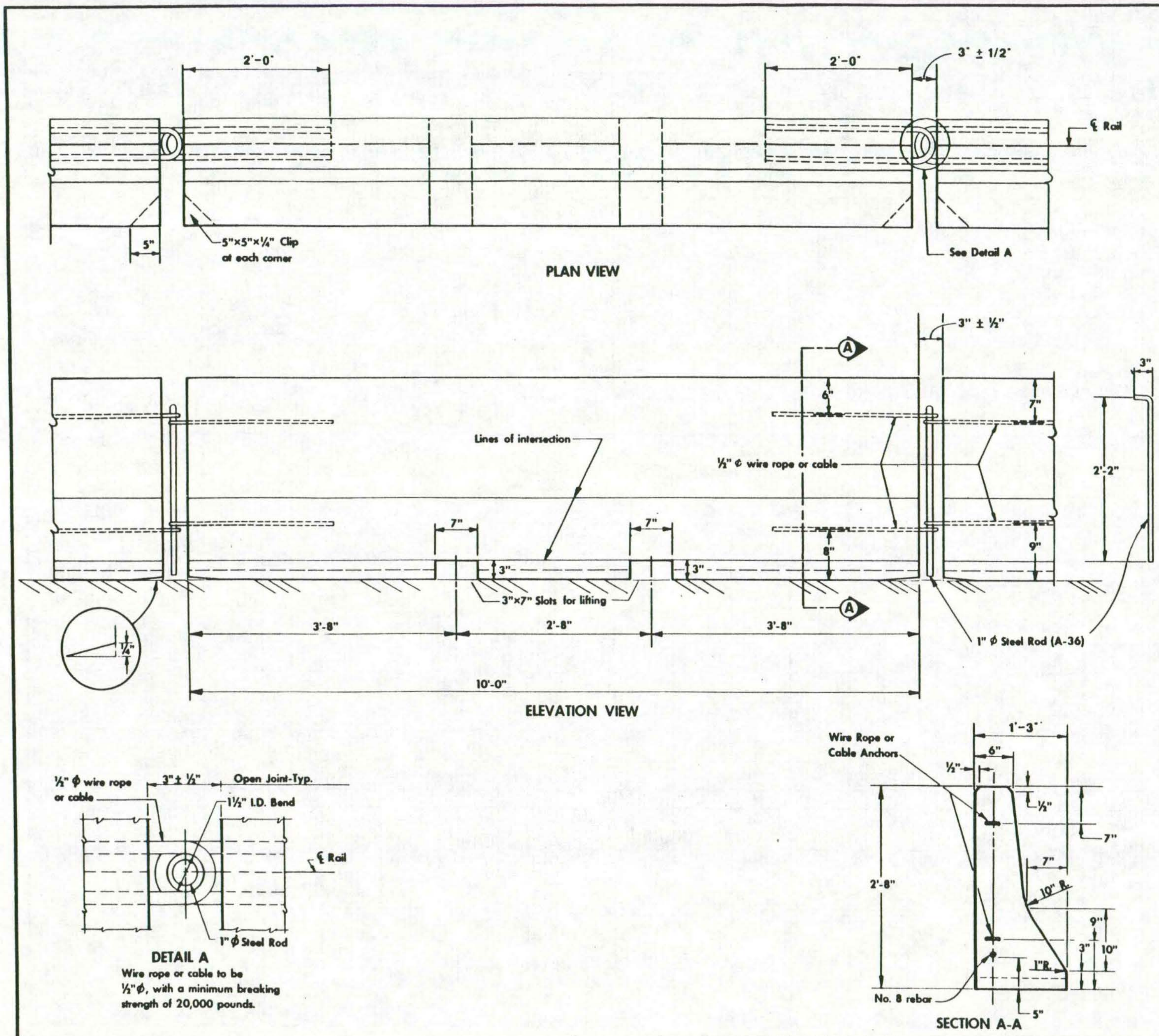


FIGURE 4. PHOTOGRAPHS OF VEHICLE GUIDANCE SYSTEM



GENERAL NOTES:

The details hereon are for the fabrication and installation of temporary concrete barrier rail. The barrier shall be Class "D" structural concrete and finished in conformance with current specifications.

Details shown are typical. Alternate design details may be submitted to the engineer for approval.

The contractor shall provide for an approved schedule of surveillance with a person on call and available 24 hours a day, each day of the week, to realign barrier rail which has been struck. Initiation of service shall be within one hour of notification of need.

Markers shall be furnished and installed by the contractor. Marker shall be placed on the barrier as recommended by the manufacturer, and as shown in the Marker Placement Detail or as directed by the engineer. The markers shall be installed at 10 ft. spacing on both sides of barrier. Refer to Details of Barrier Placement. The contractor shall maintain the markers and promptly repair or replace any damaged or missing units. All costs for furnishing, installing and maintaining markers shall be included in the price bid for the temporary barrier rail.

The barrier rail sections shall remain the property of the contractor and at the completion of the work shall be removed from the site by him.

When Temporary Barrier Rail is installed adjacent to a drop-off, tie downs as described and shown on Detail Sheet 540-10 shall be required.

The method of measurement for "Temporary Barrier Rail, Furnish Only" will be the maximum length furnishd and in use on the project at any one time based on the nominal length times the number of units.

The price bid for "Temporary Barrier Rails Furnish Only" in linear feet shall be full compensation for furnishing temporary barrier rail as detailed and measured on this sheet.

The method of measurement for "Temporary Barrier Rail, Place Only" will be the length initially installed, and the length reinstalled in new position, as required by the plans based on the nominal length times the number of units.

The price bid for "Temporary Barrier Rails, Place Only" in linear feet of Barrier Rail shall be full compensation for placing temporary barrier rail as detailed on this sheet and elsewhere in the plan.

CRASH TEST
PROJECT BRF-000S(2)-38-00
TASK No.
APPENDIX A
Project Sheet of

DETAIL SHEET

Revision Date

DETAILS OF TEMPORARY CONCRETE BARRIER RAIL HALF SECTION

COUNTY

FIGURE 5. SKETCH OF THE IOWA TEMPORARY CONCRETE BARRIER RAIL HALF-SECTION

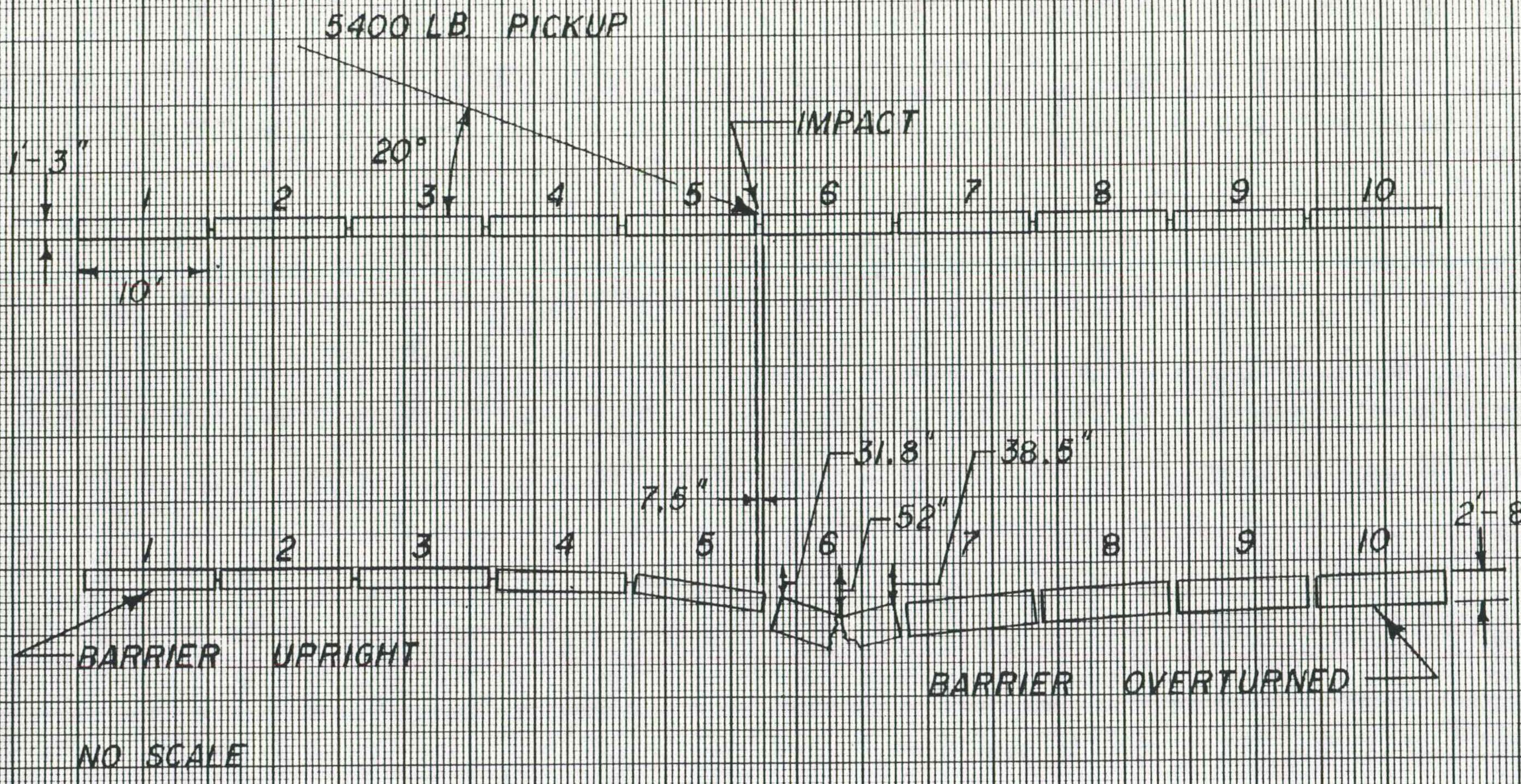


FIGURE 6. SCHEMATIC OF TEMPORARY CONCRETE BARRIER RAIL HALF-SECTION

used for reinforcement. The rebar was located 3-in. from the back face and 5-in. above the bottom barrier surface. The barriers were fabricated with Iowa Class "D" structural concrete by Wilson Concrete of Omaha, Nebraska.

The barriers were connected with a pin and wire rope (cable) attachment system. The pin consisted of a 1-in. diameter, L-shaped, A-36 steel rod. The dimensions of the short and long legs of the rod were 3-in. and 2 ft.-2in., respectively. The 1/2-in. diameter wire rope was embedded 2 ft. into both ends of each barrier at two different elevation schemes. The wire rope protruding out of the barrier formed the loop through which the pin was placed to connect the barriers, as shown in Figure 5. The wire rope had a minimum breaking strength of 20,000 lbs.

A recent report completed for the Federal Highway Administration (FHWA) titled, "Portable Concrete Barrier Connectors," describes various methods for connecting barriers currently used by the states (4). It was stated that at the time of the completion of the report that no crash tests had been performed on the pin and wire rope connector. Some of the relevant discussion on the pin and wire rope connector from the FHWA report (4) is included in Appendix A.

2.3. Test Vehicles

One test vehicle was used to evaluate the Iowa Temporary Concrete Barrier Rail Half-Section. The barrier was intended to be evaluated according to the AASHTO performance level PL-2 (2), which has three different test vehicles under that performance level category. It was determined that a good indication of barrier performance would be obtained with the 5,400 lb. pickup truck rather than the 1,800 lb. small automobile.

For Test I3-1, a 1985 Chevrolet Scottsdale 3/4-ton pickup weighing approximately 5,386 lbs. was used as the crash test vehicle. Photographs of the test vehicle are shown in Figure 7. Dimensions of the test vehicle are shown in Figure 8.

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 vehicle. The middle target was placed over the center of mass. The front and rear targets were placed 5 ft. ahead and 6 ft. behind, the center of mass, respectively. The targets were used 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.

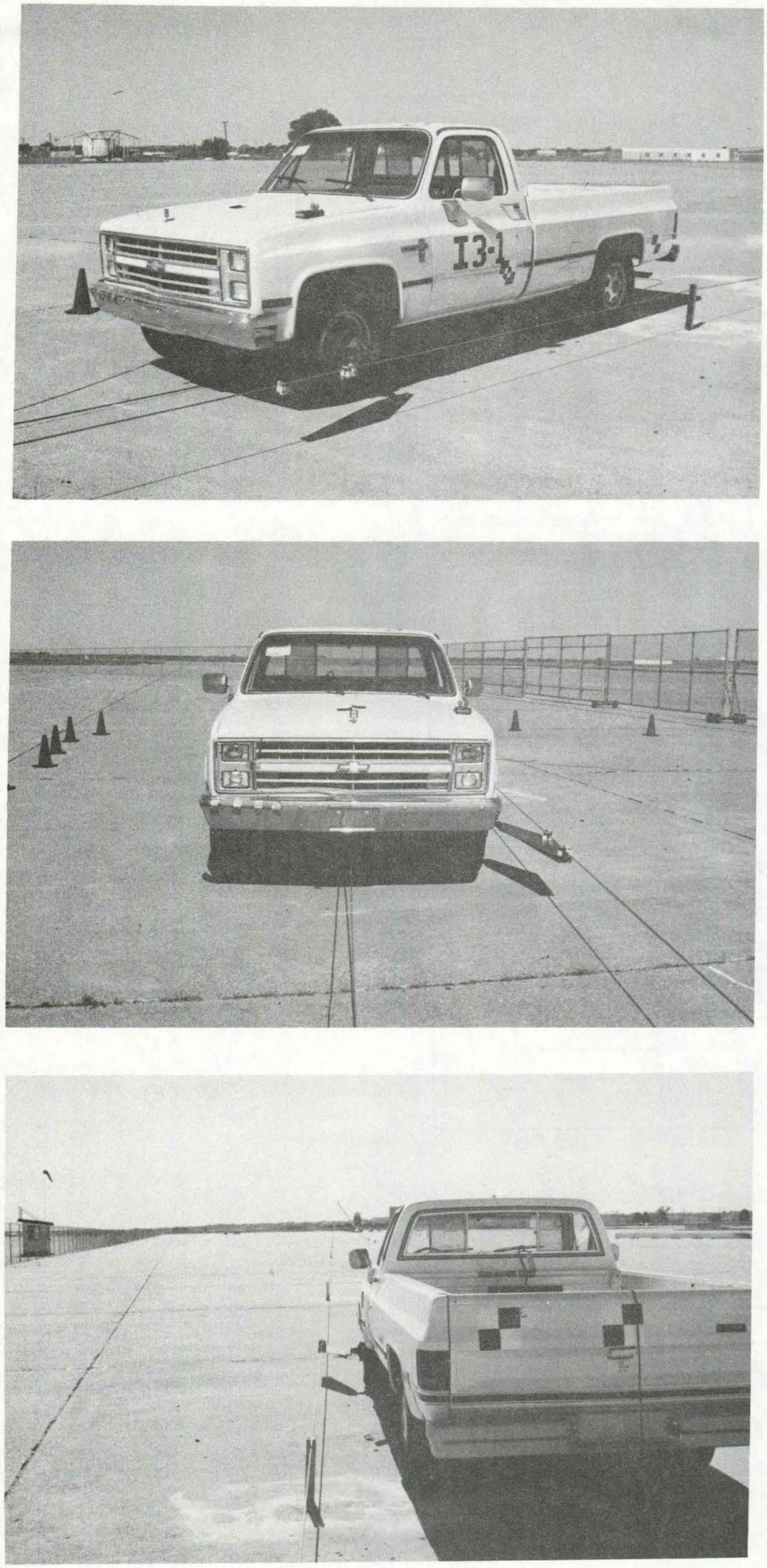
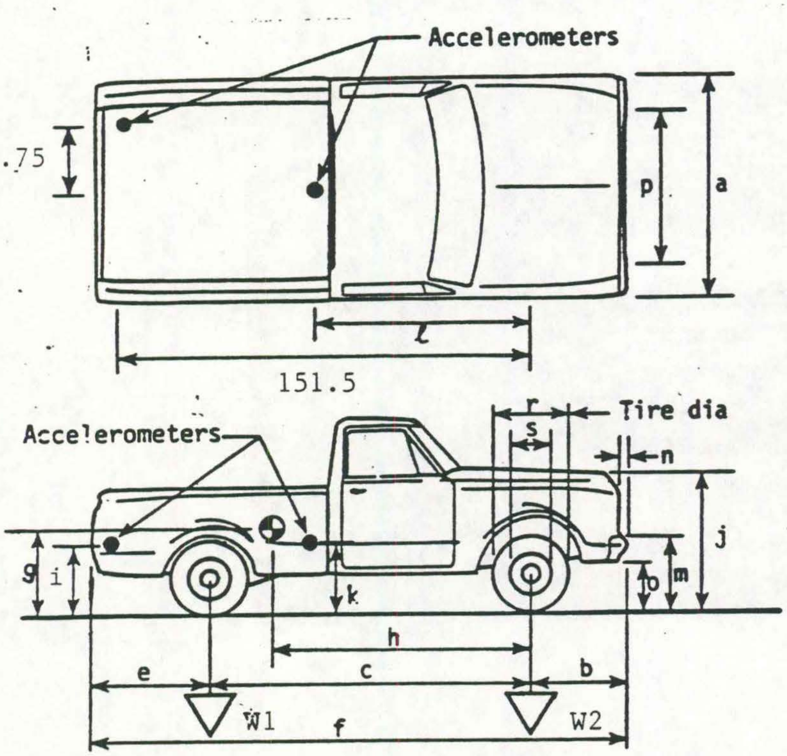


FIGURE 7. PHOTOGRAPHS OF TEST VEHICLE

Date: 9/23/88 Test No.: I3-1 Vehicle I.D. #: 6CCC24J1FJ117500

Make: Chevrolet Model: Scottsdale 3/4 ton Year: 1985 Odometer: 19392

Tire Size: 7.50R16LT



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	
W2	2820	2795	
Wtotal	4760	5386	

Note any damage prior to test: None

FIGURE 8. VEHICLE DIMENSIONS FOR CHEVROLET PICKUP TRUCK

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 9. 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 Analog Tape Recorder (Model 101) in the central control van. A flowchart of the accelerometer data acquisition system is shown in Figure 10, and photographs of the system located in the test vehicle and the centrally controlled step van are shown in Figures 9 and 11. The latest state-of-the-art computer software, "Computerscope and DSP," was used to analyze and plot 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 test. The cameras ran 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 51 ft. above the concrete apron. The perpendicular camera was a Photec IV with a 55 mm

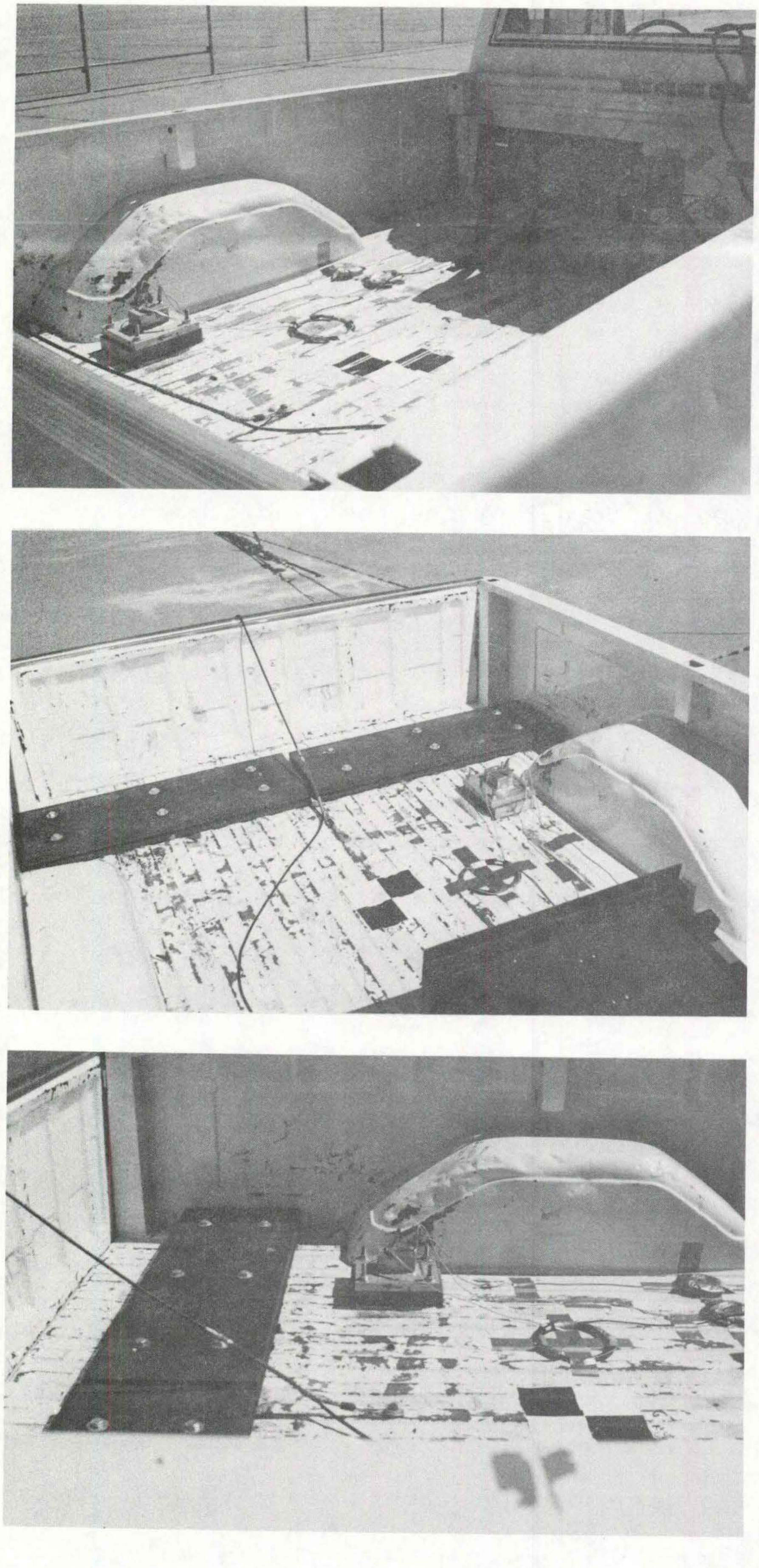


FIGURE 9. PHOTOGRAPHS OF THE ONBOARD DATA ACQUISITION SYSTEM

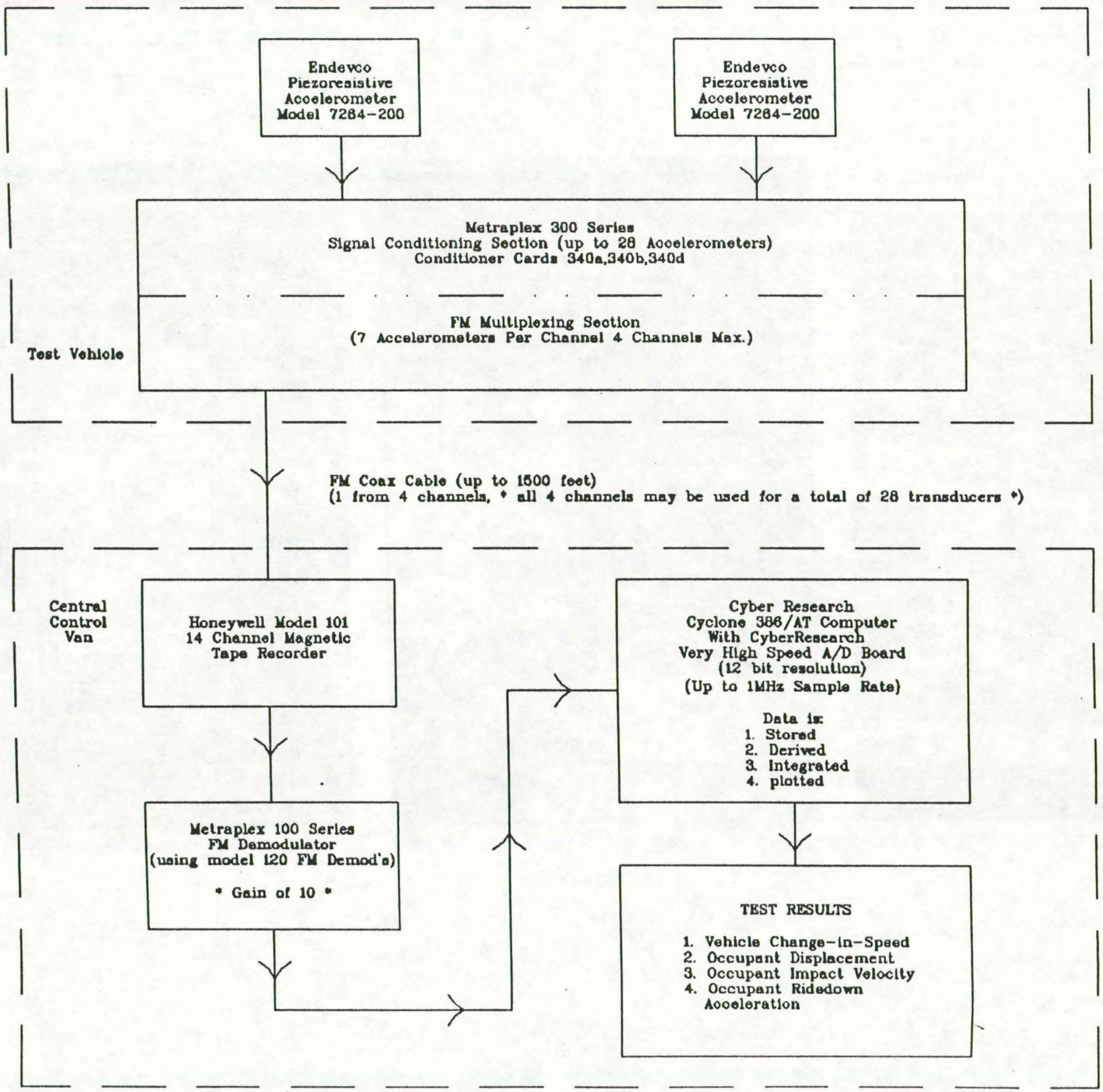


FIGURE 10. FLOWCHART OF ACCELEROMETER DATA ACQUISITION SYSTEM

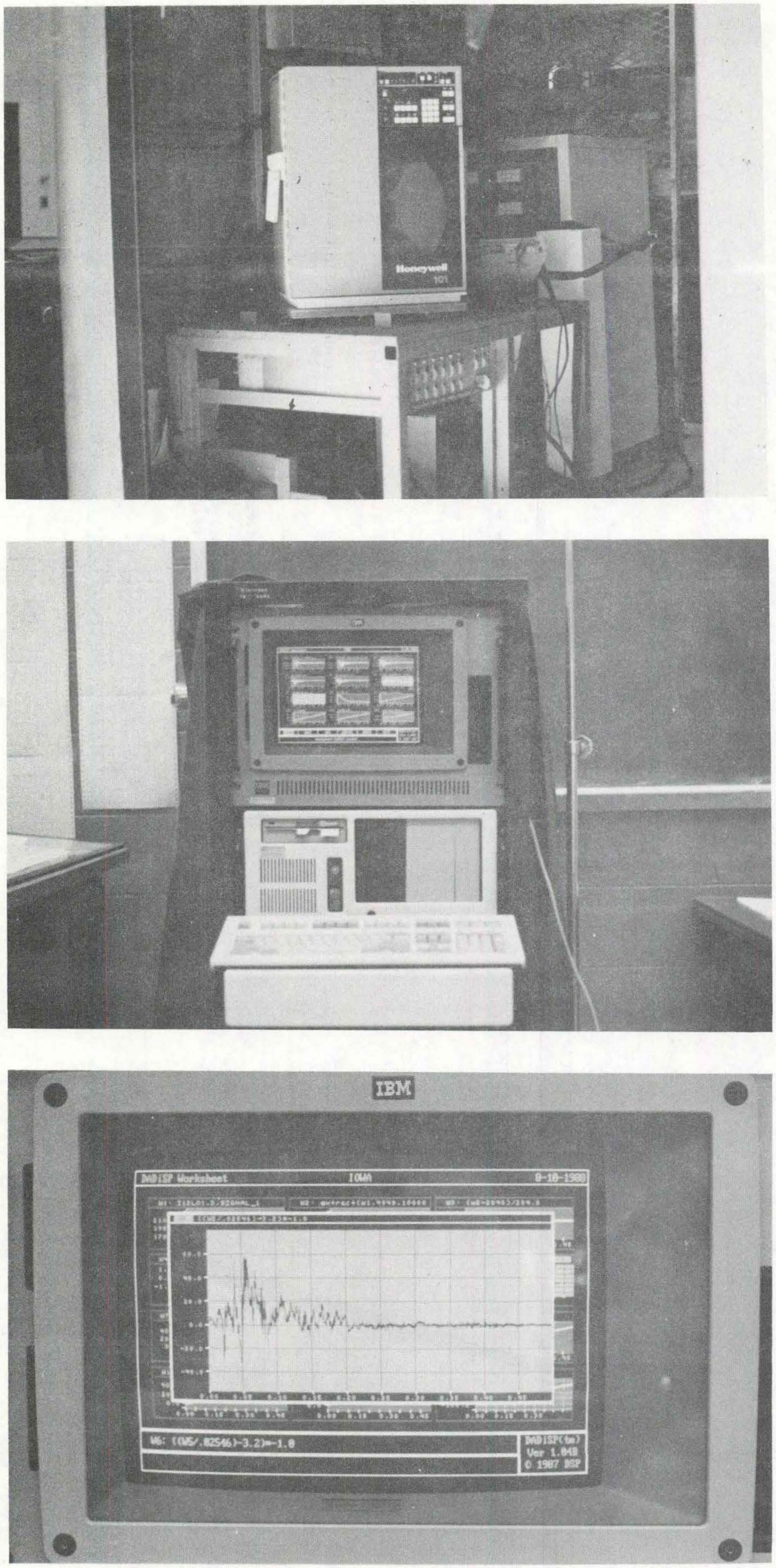


FIGURE 11. DATA RECORDER AND 386/AT
COMPUTER

lens. It was placed 165 ft. from the vehicle point of impact. The parallel upstream camera was also a Photec IV with an 80 mm lens. It was placed 185 ft. upstream and offset 3.3 ft. from a line parallel to the barrier rail. A schematic of the camera locations are shown in Figure 12.

A 20 ft. wide by 100 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 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.

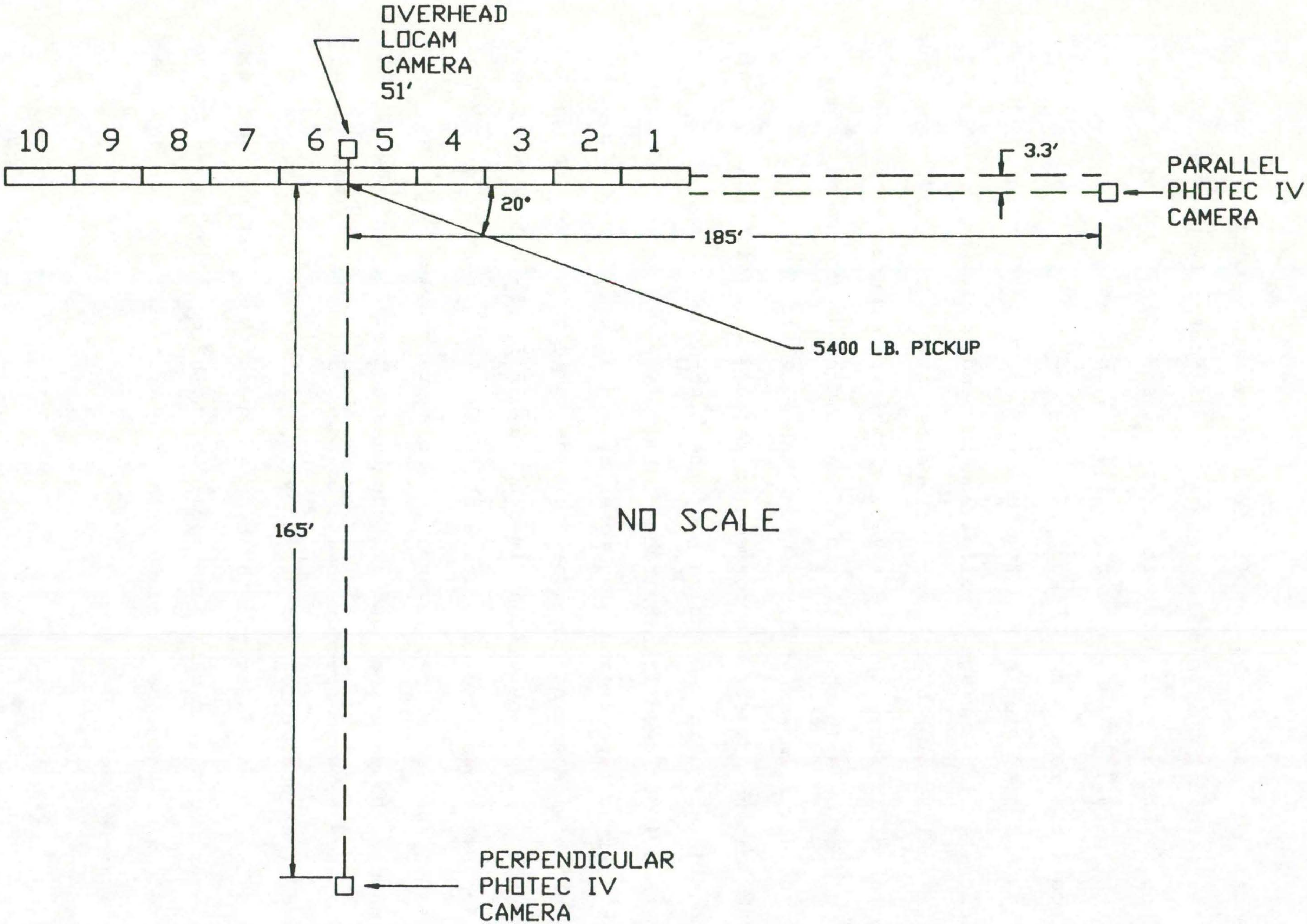


FIGURE 12. SCHEMATIC OF CAMERA LOCATIONS

2.5. Test Parameters

One full-scale vehicle crash test was conducted on the Iowa Temporary Concrete Barrier Rail Half-Section as shown in Figures 4 and 5.

Test I3-1 was conducted at a target impact speed of 60 mph with an impact angle of 20 degrees. A 1985 Scottsdale pickup weighing 5,386 lb. was used as the crash test vehicle. The location of impact was at the joint between section No. 5 and No. 6 as shown in Figure 6.

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 (Temporary Concrete Barrier Rail Half-Section) 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								
Temporary Concrete Barrier Rail Half-Section	PL-2	5400 lb. ±100	60	20	Barrier connector between two barrier sections and at the midpoint of the entire installation	NCHRP 230:	A,D,E,H,I	F
						AASHTO:	A,B,C,D	E,F,G,H

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

4. TEST RESULTS

4.1. TEST NO. I3-1

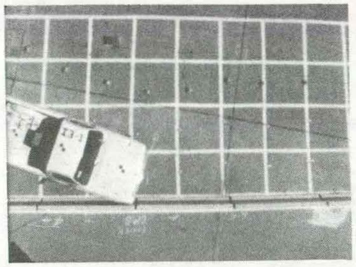
Test I3-1 was conducted with a 5,386 lb. pickup under the impact conditions of 62.3 mph and 20 degrees. A summary of the test results is shown in Figure 13. The sequential photographs are shown in Figures 14(a) and (b).

Upon impact with the temporary concrete barrier rail, the right front corner of the vehicle began to crush inward at approximately 0.042 sec. At this time, it was also evident that the crack in barrier No. 6 began to form. At about 0.063 sec, the right front wheel started to climb over the barrier rail.

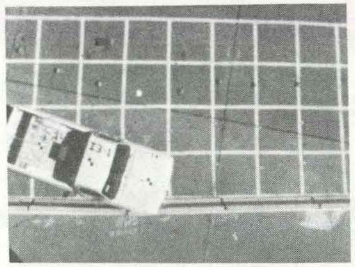
As the vehicle continued on its straight-line path over the barrier rail, it was evident at 0.084 sec. that barrier No. 6 began to rotate and overturn. Between 0.084 and 0.115 sec., large differences between the roll motions of the cab and box sections of the pickup were evident and are presented graphically in Appendix B along with graphs of the pitch and yaw motions.

The fracture of the concrete on the end of barrier No. 7 occurred when the front bumper impacted the concrete section corner as the vehicle passed over the top. The time-sequence was between 0.115 and 0.130 sec. The vehicle bumper damage due to the corner of barrier No. 7 is shown in Figure 15(a) and (b).

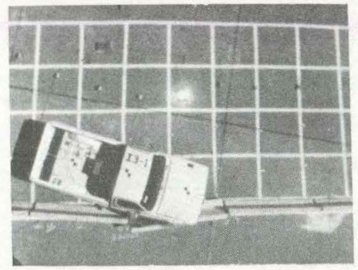
From 0.168 to 0.304sec., the vehicle was launched over the top of barrier No. 7, and then became totally airborne. Photographs of the airborne vehicle between 0.450 and 0.490 sec. are shown in Figure 14(b).



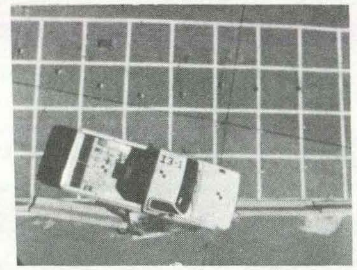
Impact



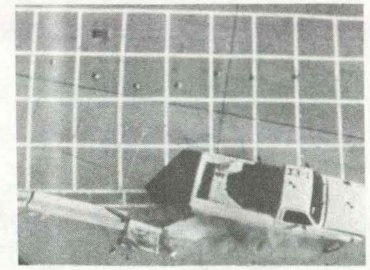
0.042 sec



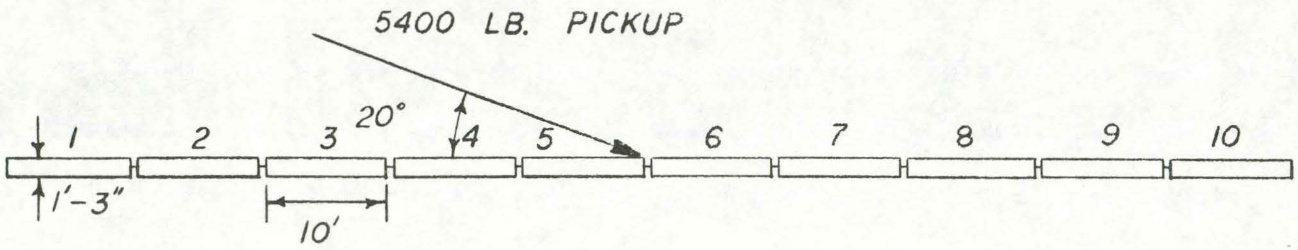
0.084 sec



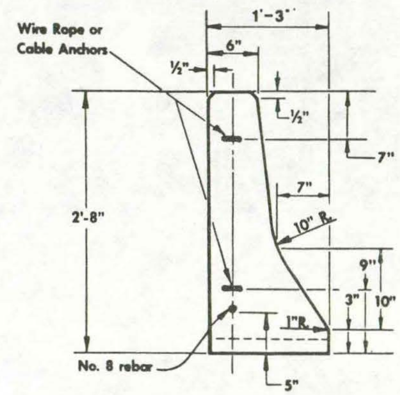
0.124 sec



0.304 sec



PLAN VIEW



TYPICAL SECTION

Test No.	I3-1
Date	9/23/88
Installation	Temporary Concrete Barrier Rail Half-Section
Drawing No.	BRF-000S(2)-38-00
Length (ft)	101.1
Concrete Barrier	
Member	New Jersey Face
Length - One Section (ft). .	10
Maximum Deflections - Permanent Set	
Lateral (in)	52
Longitudinal (in)	7.5
Material	Iowa Class "D" Structural Concrete
Dimensions	
Height (ft)	2.67
Width (ft)	1.25
Weight (lb/ft)	304.4
Vehicle	
Model	1985 Chevrolet Scottsdale 3/4-Ton

Weight	
Test Inertia (lb)	5,386
Gross Static (lb)	5,386
Vehicle Speed	
Impact (mph)	62.3
Exit (mph)	47.5
Vehicle Angle	
Impact (deg)	20
Exit (deg)	Not Redirected
Vehicle Snagging	Marginal
Vehicle Stability	Marginal
Occupant Impact Velocity	
Longitudinal (fps)	21.8
Lateral (fps)	6.0 (est.)
Occupant Ridedown Decelerations	
Longitudinal (g's)	2.1
Lateral (g's)	1.0 (est.)
Vehicle Damage	Marginal
TAD	1-FR-4, 1-RFQ-4
VDI	01RFEN2
Vehicle Rebound Distance (ft) . . .	Not Redirected
Barrier Rail Damage	Extensive

FIGURE 13. TEST I3-1 SUMMARY AND SEQUENTIAL PHOTOS

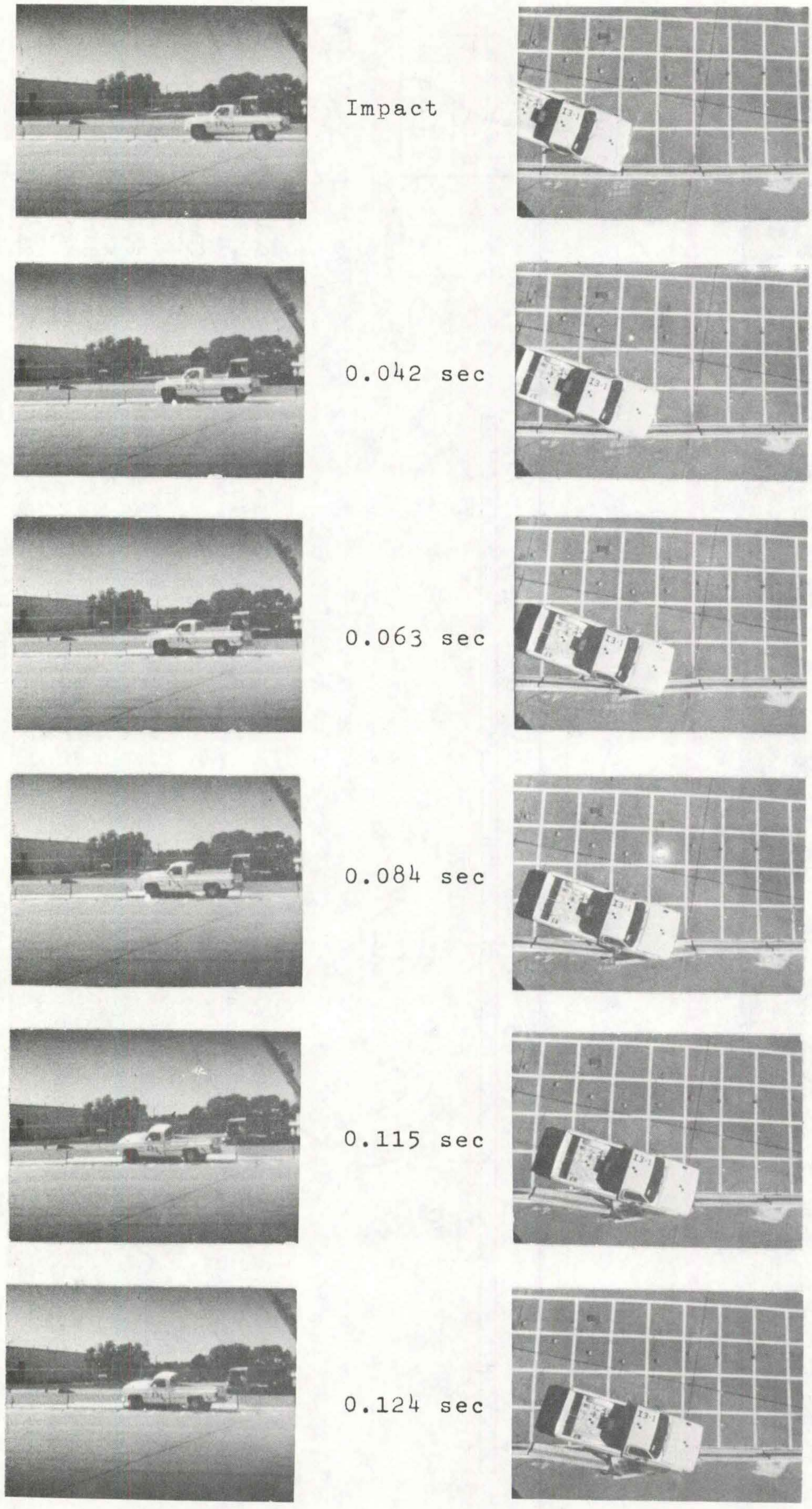


FIGURE 14(a). TIME-SEQUENTIAL PHOTOGRAPHS

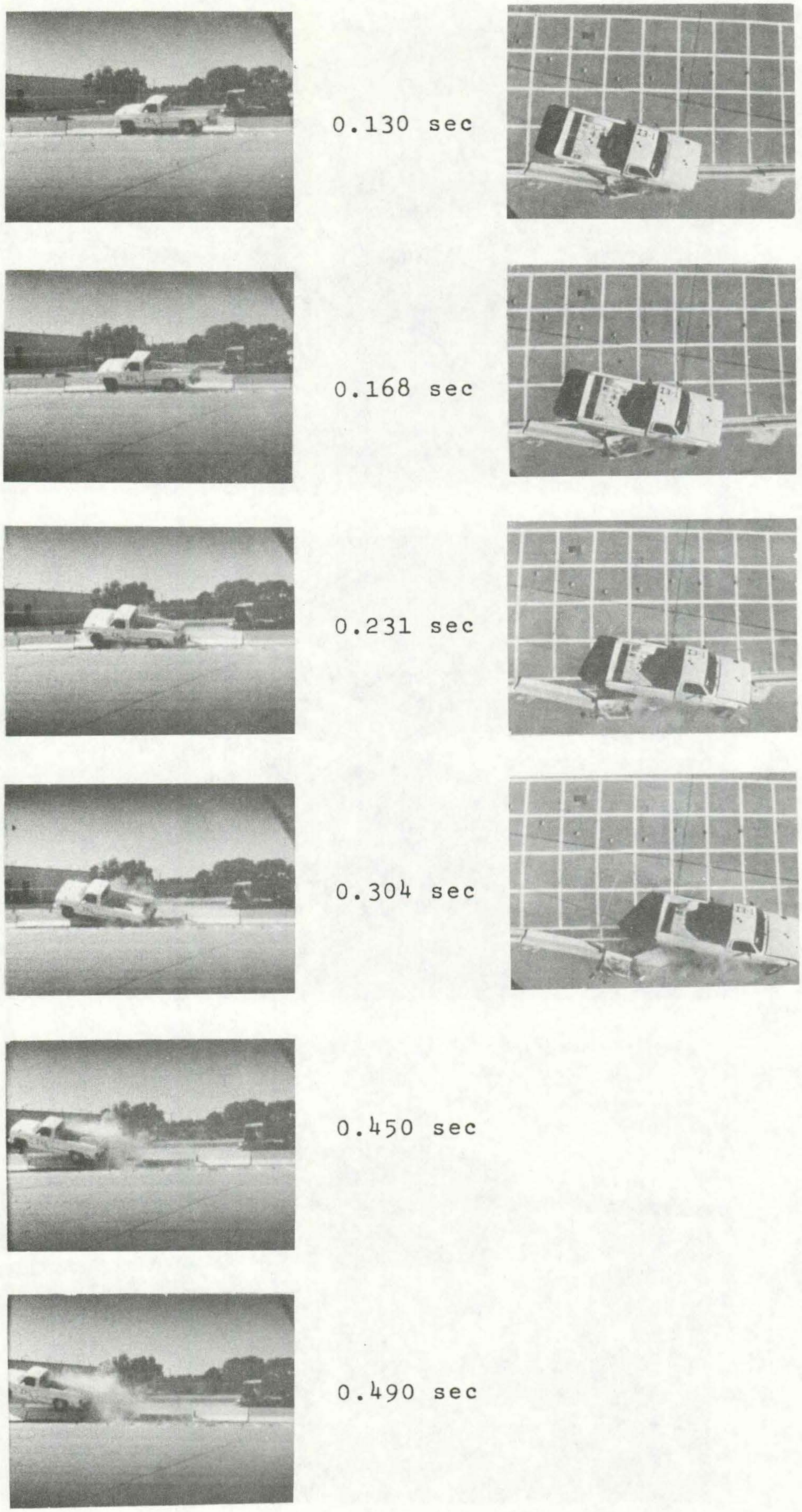
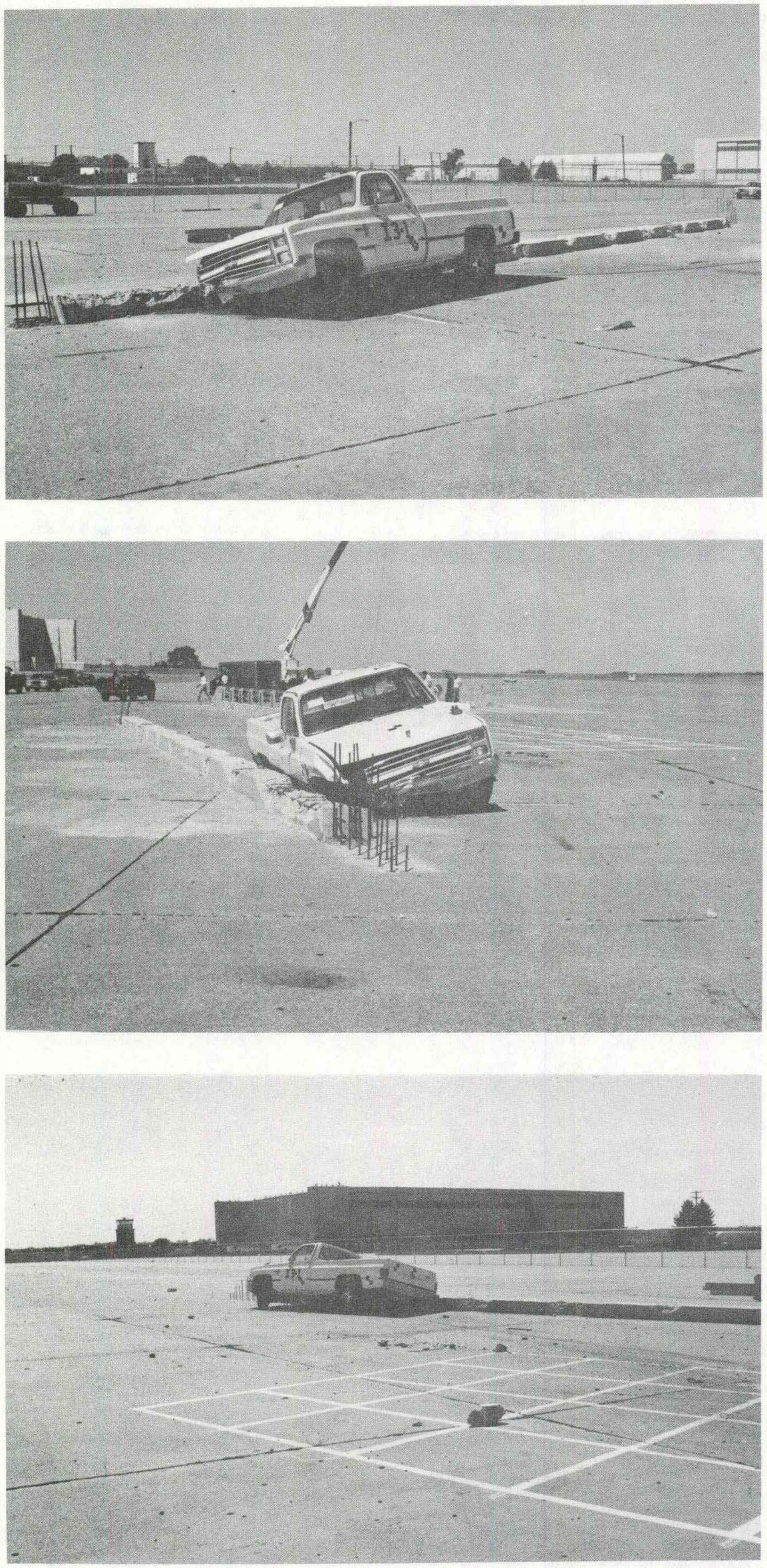


FIGURE 14(b). TIME-SEQUENTIAL PHOTOGRAPHS (CONT'D)



(a)

(b)

(c)

FIGURE 15. VEHICLE DAMAGE, TEST I3-1

Photographs of the vehicle damage are shown in Figure 15. As evident, the vehicle damage was marginal. The TAD and VDI damage classifications are shown in Figure 13. Photographs of the extensive damage to the barrier rail are shown in Figures 16 and 17. During the crash test, medium-size pieces of concrete were thrown away from the barrier.

After impact, the excessive barrier rotation caused the steel rod between barriers No. 5 and No. 6 to bend. This allowed the steel rod to pull out of the cable loops. This was evident in the photographs in Figure 17. The top embedded cable in barrier No. 7, at the joint between barriers No. 6 and No. 7, pulled out of the concrete barrier. This may have occurred when the front undercarriage of the vehicle snagged at the top of barrier No. 7 as it climbed over the end of the section.

Maximum permanent set displacements measured after the test are shown in Figure 13 and on the barrier rail schematic in Figure 6.

During impact with the barrier rail, the power cables on the battery became dislodged. Thus, it caused the data aquisition system to malfunction after impact due to a power cutoff. In order to analyze the results of the test, the overhead high-speed camera was used to determine the occupant risk values which are presented in Appendix C. The graphs of the cutoff accelerometer traces are presented in Appendix D.

The accelerometer mounting schematics are given in Appendix E.

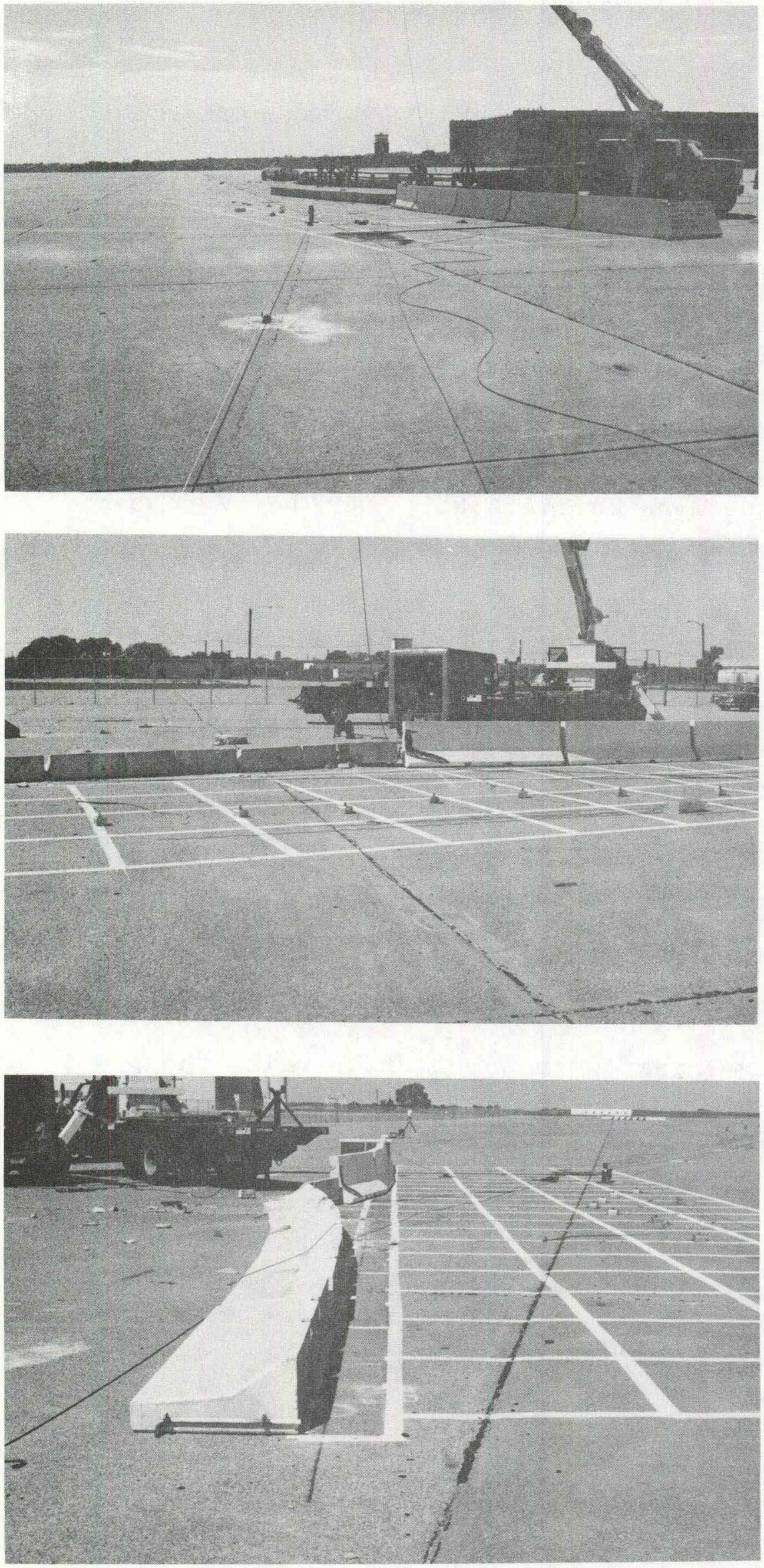
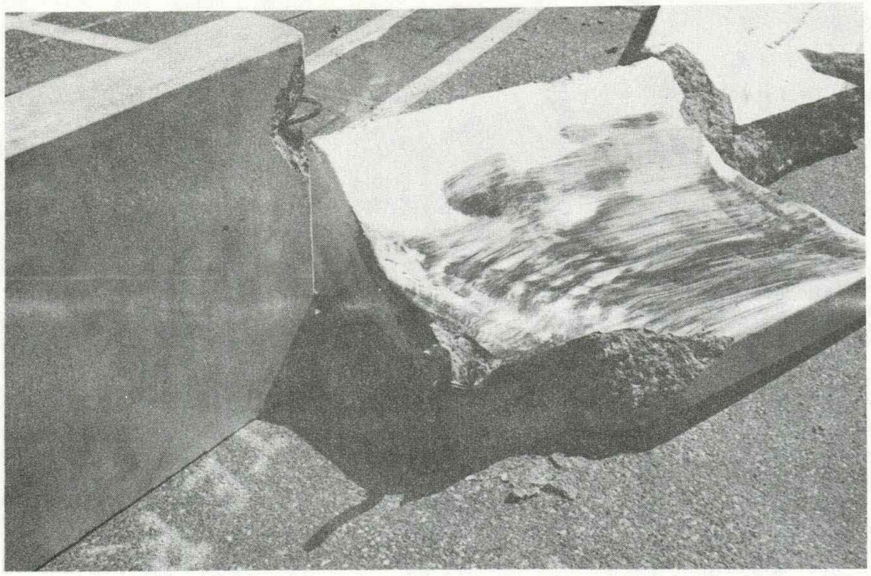
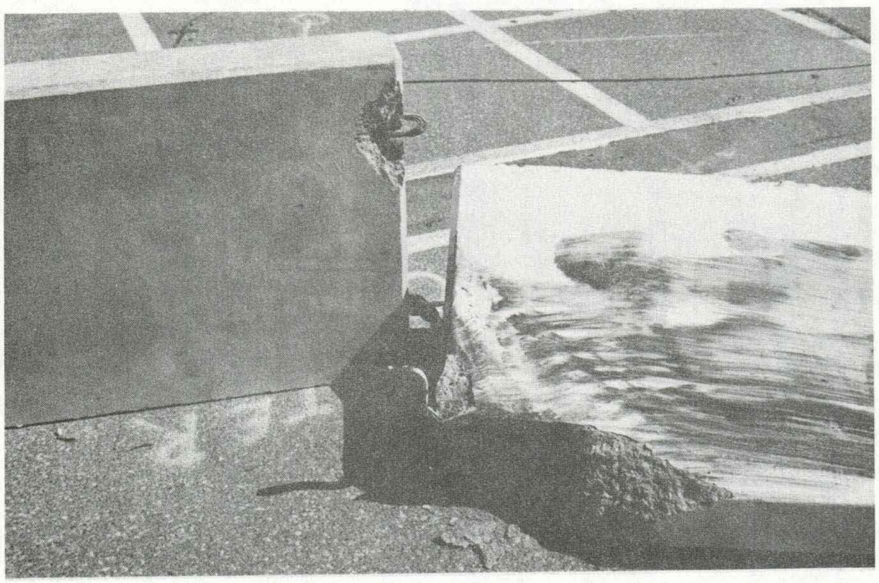


FIGURE 16. TEMPORARY CONCRETE BARRIER RAIL DAMAGE





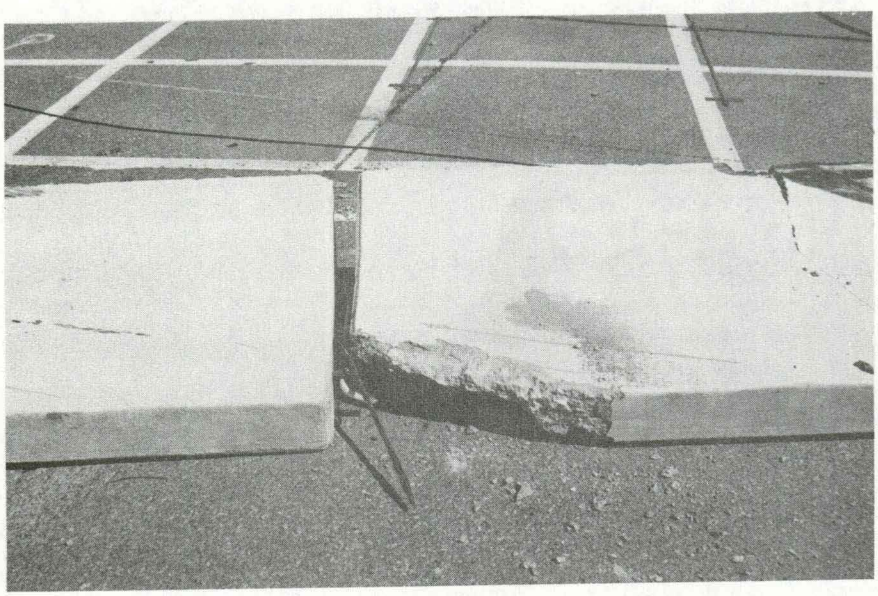


FIGURE 17. TEMPORARY CONCRETE BARRIER RAIL CONNECTOR DAMAGE

5. CONCLUSIONS

One full-scale vehicle crash test was conducted to evaluate the safety performance of the Iowa Temporary Concrete Barrier Rail Half-Section.

Test I3-1 was 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 analysis of the crash test revealed the following:

1. The temporary barrier did not smoothly redirect the vehicle.
2. The vehicle penetrated and was launched over the temporary barrier.
3. Medium-sized concrete fragments were thrown from the impact location.
4. The integrity of the passenger compartment was maintained.
5. Although the vehicle remained upright, excessive pitch and roll motions occurred due to the vehicle climbing over the top of the temporary barrier. A second impact between the test vehicle and the concrete apron surface occurred when the vehicle returned to the ground after being launched and airborne.
6. The occupant risk values for impact velocity and ridedown decelerations were acceptable during impact.
7. The vehicle trajectory could not be evaluated according

Evaluation Criteria		Test I3-1
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.	U
	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.	U
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
	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 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	(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.	Not Applicable
	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.	Not Applicable

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

TABLE 2. NCHRP 230 EVALUATION CRITERIA

Evaluation Criteria	Test I3-1
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.	U[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.	U[1]
C: Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	S[1]
D: The vehicle shall remain upright during and after collision.	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.	U[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	Not Applicable[2]
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 — Lateral 30 — 25 and for the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than: Occupant Ridedown Accelerations - g's Longitudnal — Lateral 15 — 15	Satisfactory[2]
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.	Not Applicable[2]

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

TABLE 3. AASHTO EVALUATION CRITERIA

to exit angle and rebound distance due to the vehicle traveling over the temporary barrier.

Based upon the above listed items, the results of the test are not acceptable according to the NCHRP 230 (1) and AASHTO (2) guidelines.

6. RECOMMENDATIONS

In the designs plans for the concrete temporary barrier, currently only one No. 8 reinforcing bar was specified. It was evident that one bar was not structurally adequate. Thus, it would be beneficial to add more reinforcement steel to reduce the chances of the concrete section failing by fracture.

The cable or wire rope connector faired reasonably well. The only major problem occurred at the point of impact. The steel rod bent and pulled through the wire loops. It is not known if this would still occur if the barrier (section No. 6) would not have fractured at midspan due to inadequate reinforcement. Thus, if proper reinforcement was located, it is in our opinion that the connector assembly at impact may have performed in a more predictable manner.

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. "Portable Concrete Barrier Connectors," Federal Highway Administration, Publication No. FHWA-TS-88-006, November, 1987.

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.

RELEVANT PORTABLE CONCRETE BARRIER CONNECTOR INFORMATION

U.S. Department
of Transportation
**Federal Highway
Administration**

Portable Concrete Barrier Connectors

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

Publication No. FHWA-TS-88-0()
November 1987

the PCB is used from coast to coast, its design features vary from State to State.... It is in the method of joining these segments that the widest design variation takes place". (5)

For the PCB system to perform properly and redirect vehicles it must be capable of withstanding the kinetic energy exerted by a vehicle striking it. The weakest point in the PCB system is its connectors, which include the physical connection and mating faces of adjoining barriers.

Figure 1 also shows a number of methods of connecting barrier segments. Although the strength of these connectors varies widely, published research has shown that barriers with the tongue and groove connector, one of the weakest, had 49 vehicle contacts for every reported accident in which the barrier was involved. (2)

B. Present Use of Portable Concrete Barrier Connectors

The wide variety of connector types is reflected in the results (table 1) of a survey of PCB use. In a 1985 telephone survey, the Federal Highway Administration (FHWA) asked the States what type of connectors they were using. The results of this earlier survey were sent to the principal construction engineer of each State highway agency, including Puerto Rico and the District of Columbia with a letter asking each engineer to verify the type of connector used in his/her State, send copies of the State's standard plan(s) on portable concrete barriers, and designate a contact person in the event that interviews would be sought.

Forty-eight of the fifty-two agencies responded to the survey and confirmed the type of PCB connector used. For each State, the primary connector type and approved alternates are listed in the table. Some States specified a number of acceptable connectors with no preference. For these States all the connectors are listed under Primary Connector. Other States allowed more than one type of connector but preferred one or more types. In these States the preferred types(s) are listed under Primary Connector and the others are listed under Alternate Connector. The length of the barrier segments used in each State is also given.

The most commonly used connector is the pin and loop connector. It consists of steel loops cast in each end of the barrier segment. The barriers are connected by inserting a pin through the loops of two adjacent barrier segments. (Detailed descriptions of each connector type are given in chapter II.) Forty-six of the agencies use some variation of the pin and loop connector.

The pin and loop connector category can be subdivided by the types of material used to form the loops. Loops are commonly formed from reinforcing steel bars (rebar), wire rope, eye bolts, or steel plates. Twenty-seven agencies specify the pin and rebar connections, fourteen agencies specify the pin and wire rope, two agencies specify the eye bolt, and one agency specifies the pin and plate connector. (Two agencies using pin and loop connectors did not respond to the survey and, therefore, could not be categorized.)

After the pin and loop category, the next most commonly used connector is the tongue and groove connector. It consists of a vertical protrusion, or tongue, cast into the end of a barrier segment that is inserted into the groove of an adjacent segment. Eight agencies specify the tongue and groove connector as their primary or alternate connector.

The plate insert connector consists of a steel plate inserted in a vertical slot located in the lower center of each barrier end. This connector is specified by five agencies.

Eight agencies specify connectors other than the three types mentioned. The channel splice, I-beam, grid slot, side plates, top T lock, Welsbach, lapped joint and bolt and continuous cable connectors are each specified by one agency. The dowel connector is specified by two agencies. (See chapter II for descriptions of these connectors.)

The review of each State's standard plans for portable concrete barriers reveals even greater variability in connector types than the survey results shown in table 1. Even though twenty-seven agencies use the pin and rebar connector, their specifications for pin diameter, loop diameter, depth of loop embedment in the barrier end, and gap width between barrier segments differ. Virtually no two States have identical specifications for PCB connectors.

C. Problems Observed in FHWA Field Reviews

A 1985 memorandum [6] covering portable concrete barrier connectors was sent to FHWA Regional Administrators from the Directors of the Offices of Highway Operations and Traffic Operations. This memorandum stated that in field reviews by FHWA headquarters personnel, recurring problems involving PCB connectors had been observed. These problems were serious enough to make the barriers ineffective in protecting both workers and motorists.

Some of the most serious recurring problems observed were as follows:

- In pin and loop connections, contractors often failed to install the vertical steel pin. The pin also was prone to removal by vandals. The loops were structurally inadequate because of design deficiencies or previous damage.

- Tongue and groove systems were not adequately interlocked. At times the barrier sections were not butted flush against each other. The tongue or groove was damaged to the point of being ineffective.

- Some systems, such as the plate insert connector, might not have enough connection slack to be installed on sharp curves or flares.

- A number of systems were difficult to realign if they shifted as a result of a vehicular impact.

3. Pin and Twin Double Rebar

The pin and twin double rebar connector (see figure 4), a variety of the pin and loop connector, has four rebar loops cast into each barrier end rather than the usual two. Only South Dakota uses this connector at this time. The advantage of this configuration is the decreased probability of connector failure due to loop rupture or rebar loops coming out of the barrier ends. It has a segment length of 10 ft, a rebar diameter of 5/8 in, a pin diameter of 1 3/8 in, and no specification of gap width. To date, no crash tests have been performed on this connector.

4. Pin and Wire Rope

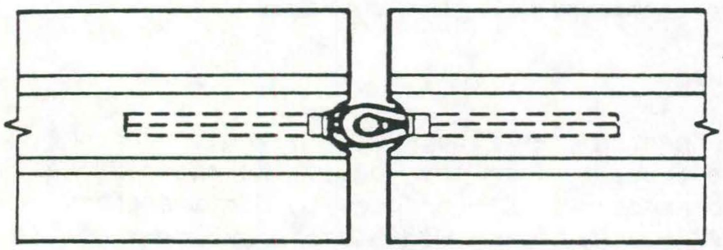
The pin and wire rope connector (see figure 5), a variety of the pin and loop connector, uses wire ropes to form the loops. Fourteen States now use the pin and wire rope connector. Differences in pin diameters vary from 7/8 in to 1 1/4 in. Differences in gap width are anywhere from 1/4 in to 3 1/2 in; however, most users do not specify the gap width for this connector. Also, segment lengths vary from 10 ft to 25 ft, with several intermediate lengths between. There is little difference, however, in wire rope diameters, the dimensions being either 1/2 in or 5/8 in. To date, no crash tests have been performed on the pin and wire rope connector.

5. Pin and Eye Bolt

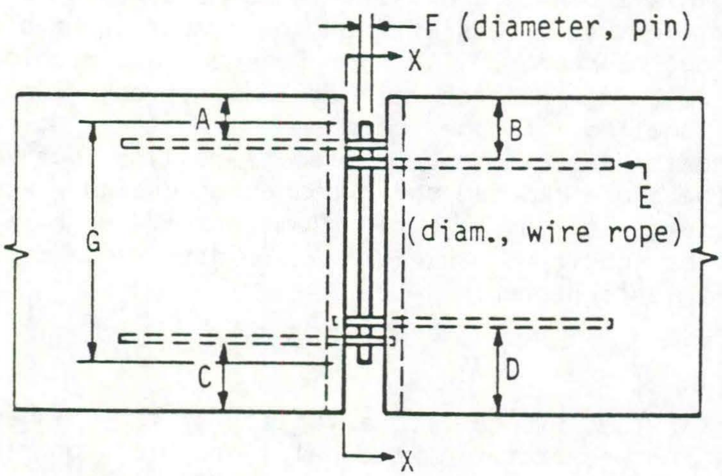
The pin and eye bolt connector (see figure 6), a variety of the pin and loop connector, consists of two eye bolts cast into each barrier end to form the loops. West Virginia and Michigan use this connector at this time, although Michigan is in the process of changing their connector design to the pin and wire rope connector. A major reason for Michigan changing from the pin and eye bolt connector is that the eye-bolt would break off in shear during handling of the barriers. Another State, Minnesota, in the past had the experience of eye-bolts pulling out of barrier ends on impact, and therefore changed their connector design. West Virginia specifies a segment length of 10 ft, a pin diameter of 7/8 in, and a 3/4-in-eye bolt, but does not specify a gap width. To date, no crash tests have been performed on this connector.

6. Pin and Plate

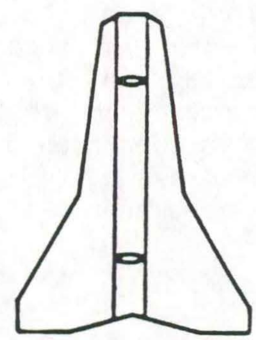
The pin and plate connector (see figure 7), a variety of the pin and loop connector, uses steel tongues cast longitudinally into the barrier ends to form the loops. Holes are cut into the tongues to form the loops through which the pin goes. Utah is the only State which uses this connector at this time. The connector has the same basic performance characteristics as the pin and rebar connector. It has segment lengths of 10 ft, 12 1/2 ft, and 20 ft; a pin diameter of 1 in; and a plate thickness of 1/2 in. No gap width is specified. To date, no crash tests have been performed on this connector.



TYPICAL PANEL PLAN WITH A VIEW
OF CONNECTION DETAIL



TYPICAL PANEL ELEVATION WITH A
VIEW OF CONNECTION DETAIL



VIEW X-X

(see page 90 for values of lettered dimensions)

Figure 5. Pin and wire rope

Connector Type

Pin and Wire
Rope
(Figure 5)

No.	A(in)	B(in)	C(in)	D(in)	E(in)	F(in)	G(in)	State or Agency	Crash Tests	Segment Length(ft-in)	Gap Width(in)	Notes
1	8	6	7	9	1/2	1	29	Arizona		12-6 or 20	NS	
2	8-1/4	7-1/4	9-1/4	10-1/4	5/8	1-1/4	21	Arkansas		10	2 max.	
3	8	6	6	8	1/2	1 1/4	30	Florida		12 min	NS	Type 4
4	specifications not available							Idaho				
5	8	6	6	8	1/2	7/8	32	Illinois		10	NS	
6	7	6	9	8	1/2	1	26	Iowa		10	3 ± 1/2	
7	7-1/2	6	7-1/2	6	1/2	1	29	Louisiana		15	1/4	
8	10	8	6	8	1/2	1-1/4	24	Minnesota		10	NS	
9	10	8-1/2	10	11-1/2	1/2	1	26	Montana		10	NS	
10	10	8	6	8	NS	1 1/4	24	North Dakota		10	NS	
11	8	6	5	7	5/8	7/8	25-1/2	Oregon		12 6, 25	1	
12	9	6-1/2	7	9-1/2	1/2	1	29	Utah		10, 12 6, 20	NS	alternate
13	7-1/2	6	7-1/2	6	5/8	1	26	Washington		10, 12-6	NS	
14	8	6	6	8	1/2 5/8	7/8	26	Wyoming		10	0 to 1 (Taper)	

Connector Type

Pin and Eye Bolt
(Figure 6)

No.	A(in)	B(in)	C(in)	D(in)	E(in)	F(in)	G(in)	State or Agency	Crash Tests	Segment Length(ft-in)	Gap Width(in)	Notes
1	10	8	6	8	3/4	3/4	32	Michigan		10	NS	
2	8	6	8	10	3/4	7/8	30	W. Virginia		10	NS	alternate

NS - Not Specified

The connector detail plan for Illinois does not specify a gap, but the loops are set so that when the connection is made there is about a 1 1/2 in gap between the segments. Illinois specifies not more than 1 in of offset between the barrier segments to prevent any snagging of vehicles.

One of the problems of application in Illinois arises on two-lane bridges. In these narrow situations, contractors often leave connectors out of some segments of the barrier in order to furnish access to the work area. Illinois has developed a detail using barrels and attenuators that will furnish some contractor access to their sites, but still feels they have a problem keeping these barriers connected.

Across bridge decks, Illinois uses a 3-in-by-12-in tube. A connection detail ties this tube barrier into the PCB. In this detail, a W-beam coming from the end of the tube is blocked out from the barrier to prevent snagging and then is bolted into the side of the barrier.

Sometimes, smaller rebars are substituted for the usual 7/8 in pin. The design engineer who was interviewed had heard of substitutions as small as #4 rebars where additional space was needed.

Barriers are often replaced in the field after impacts or when they are damaged by handling. When these replacements are necessary, it is not difficult with the pin connectors to replace a segment in the middle of a barrier run.

Illinois does not have specific criteria relating to maintenance of the barrier. It would replace barrier if chunks are missing or realign barrier if there is an offset of more than 1 in from segment to segment.

Illinois barriers are reinforced with rebar and also wire mesh. Part of the reason for this type of reinforcement is that it prevents large chunks of concrete from becoming flying missiles if the barrier is impacted by a heavy vehicle.

Illinois has used its connector detail since 1978 without major modifications. From field experience, personnel believe that their barrier and the connector are withstanding vehicle impacts, even in the Chicago area, and have no plans at this time for further modifications to their PCB connector.

4. <u>Iowa Department of Transportation</u>

Connector Type: Pin and wire rope
Type of Visit: Office
Date of Visit: January 22, 1987
Personnel Interviewed: Construction Section

No site visits were made in Iowa because of lack of work zones during the winter season.

Iowa has used the pin and wire rope connector for portable concrete barrier for about 7 years. Before 1978, it used timber barricades and various other types of barrier, but only the pin and wire rope connector has been used for portable concrete barrier.

Iowa specifies a gap width between its PCB of 3 in, plus or minus 1/2 in. They believe they need this width for the fabrication of the portable barriers. They believe in this compromise of the gap width between having a tighter segment and the workability or constructability of the barriers.

For placing barriers in curves, Iowa standards allow for corners to be clipped somewhat for placement in especially tight curves. Since these corners must be cast already clipped for placement in curves, there is not a lot of use of them in the field.

Iowa personnel do not believe there is a problem in the field of a lack of connectors in their portable concrete barriers. They encourage inspectors to make sure that the segments are connected at all times. The only time they do not have this connection is when opening up a gap to allow contractor access into a work area. Normally these areas are on two-lane roads around bridge construction where the barrier takes up room and is run across the shoulder causing the contractors difficulty in getting their equipment in and out of the work area.

Neither are there problems with the pin connectors in moving for access or to replace a damaged segment in the middle of a barrier run.

Iowa normally uses standard 10-ft segment but they are allowing up to 20-ft segment believing these may be used more in the future. Normally their PCB is the standard New Jersey size and cross-section. In order to reduce glare for opposing traffic, they are building some permanent barrier that is up to 42 in high. Also, they have gone to wider tops (up to 9 in.)

Iowa uses an anchoring strap. This strap, anchored into the surface below, runs to just above the bottom set of loops in the connector and connects with the loops in the pin into the barrier to prevent overturning. They rely on the anchoring system at a bridge structure where they are using one lane at a time and when they have little deflection distance (less than 2 ft behind the barrier).

Iowa has problems with leveling segments when it runs the barrier out across an earth shoulder. Sometimes they have to hollow out some of the shoulder to make the segment level. There is a small amount of play for differences in vertical alignment, but they would normally level the barrier on a shoulder.

Most of the impacts that Iowa sees on its barrier system deflect the barrier only a few inches, and then the barrier can be realigned using skid loaders. They have limited experience in having to replace a segment due to an accident. They believe that most of their impacts are at a angle much flatter than 15 or 25 degrees.

Iowa has a specification for connecting PCB to a steel barrier rail that is used on bridges. The barrier cross-section is made vertical and then tapered into the normal safety shape. PCB is used on the approach and the steel rail is used across the bridge.

Overall, Iowa personnel are very satisfied and confident with their pin and wire rope connectors. They believe the gap of 3 in plus or minus 1/2 in is the best compromise for ease of fabrication and workability in the field, and believe the barriers are performing well.

5. Kansas Department of Transportation

Connector Type: Tongue and groove with dowels; with side plates
Type of Visit: Resident office and one field site
Date of Visit: May 28, 1987
Personnel Interviewed: Resident construction engineer

Kansas uses the tongue and groove connector with the single dowel bar, a 1-in-diameter bar 2 ft 2 in long. As an alternate connector, they use the tongue and groove with side plates when a segment has to be replaced and the dowels cannot be put back in the barrier run. Barrier segments are 10 ft long.

Kansas contractors use a hydraulic system to lift barrier segments, using two rubber pads around the upper portion of the barrier.

A major construction project was visited. There had been many impacts on the barrier system in this project. The configuration of the barrier was two or three parallel runs forming an S curve through the project. In viewing barrier in the field, there was evidence of many impacts, some near the top of the barrier. The resident engineer believes small cars overturn with the barrier because of their narrow wheel width. He believes also that gas tanks are subject to rupture when cars go up on the barriers.

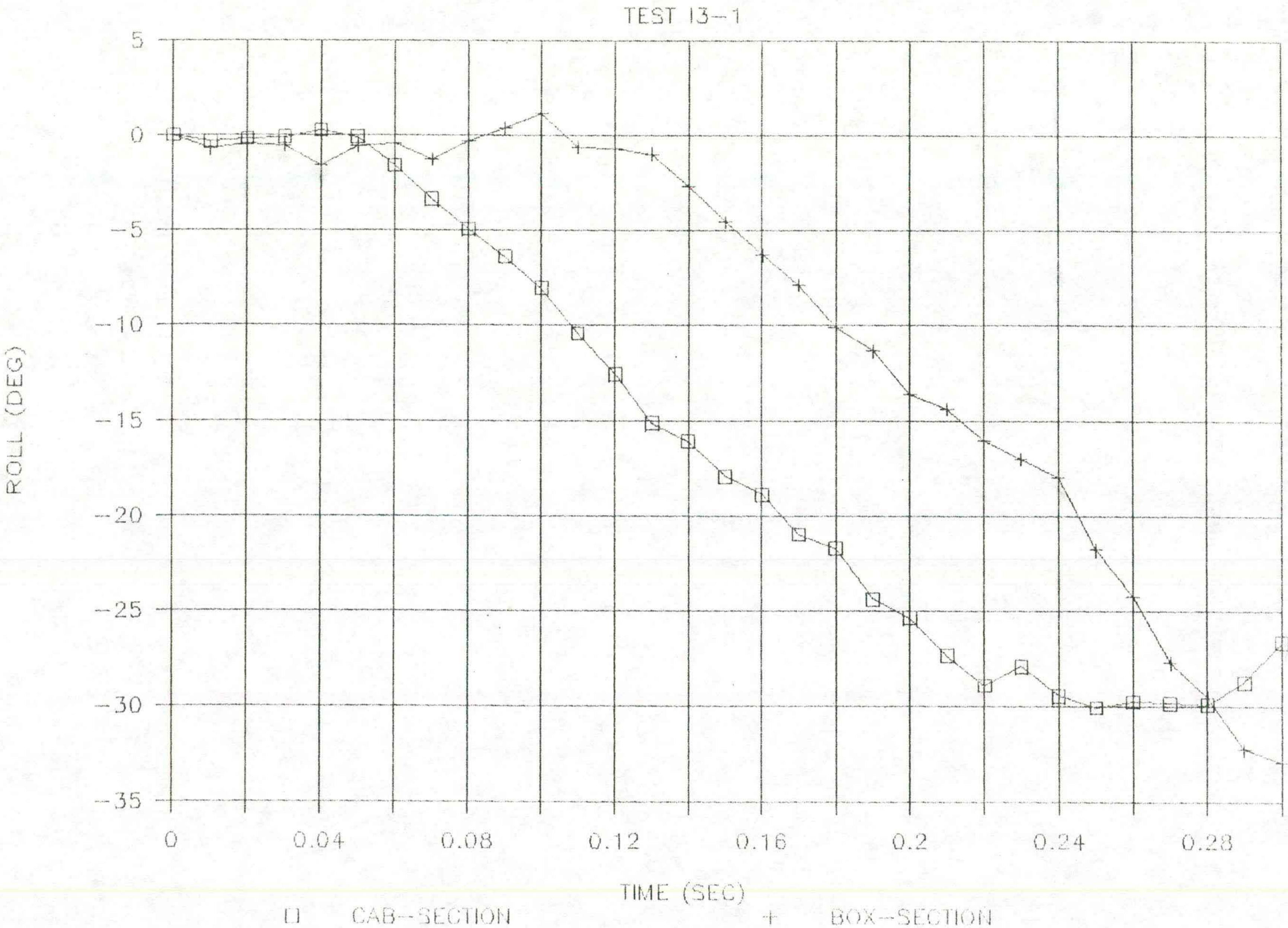
At the resident engineer's office, 11 accident reports were obtained that involved vehicle contacts with the barrier. A summary of these accidents is given in table 10. It is quite evident from looking at the accidents that barriers are being pushed out of line and overturned. One vehicle hit the barrier segment, overturned the segment, and entered the opposing lane of travel. A diagram of this accident (No.11) is shown in figure 44. Also, in accident No. 1, two vehicles hit the barrier and pushed segments of the barrier into opposing lanes, causing two cars in the opposing direction to become involved in the accident. The diagram of this accident is shown as figure 45.

While at the site, the barrier near the start of the taper was inspected. Twenty-five connections were observed. Of these 25 connectors, 5 did not have a gap, so whether the dowel bar had been installed could not be determined; 19 had been installed with the dowel bar as specified; and 1 had not had the dowel installed. The one connection where the dowel bar had not been installed was a segment that appeared to have been replaced after the barrier run had been installed.

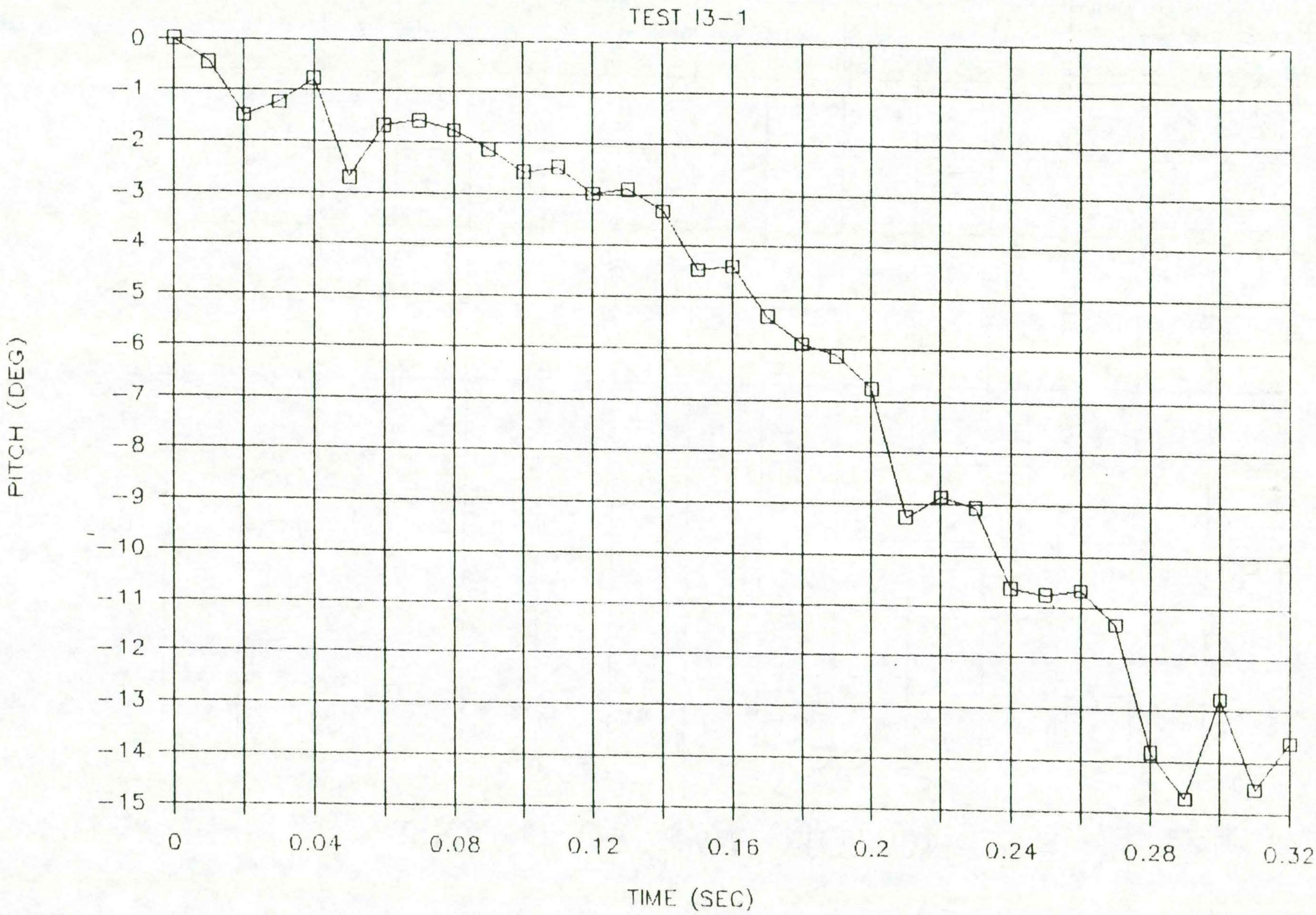
APPENDIX B.

GRAPHS OF ROLL, PITCH, AND YAW MOTIONS

GRAPH OF PICKUP ROLL MOTION

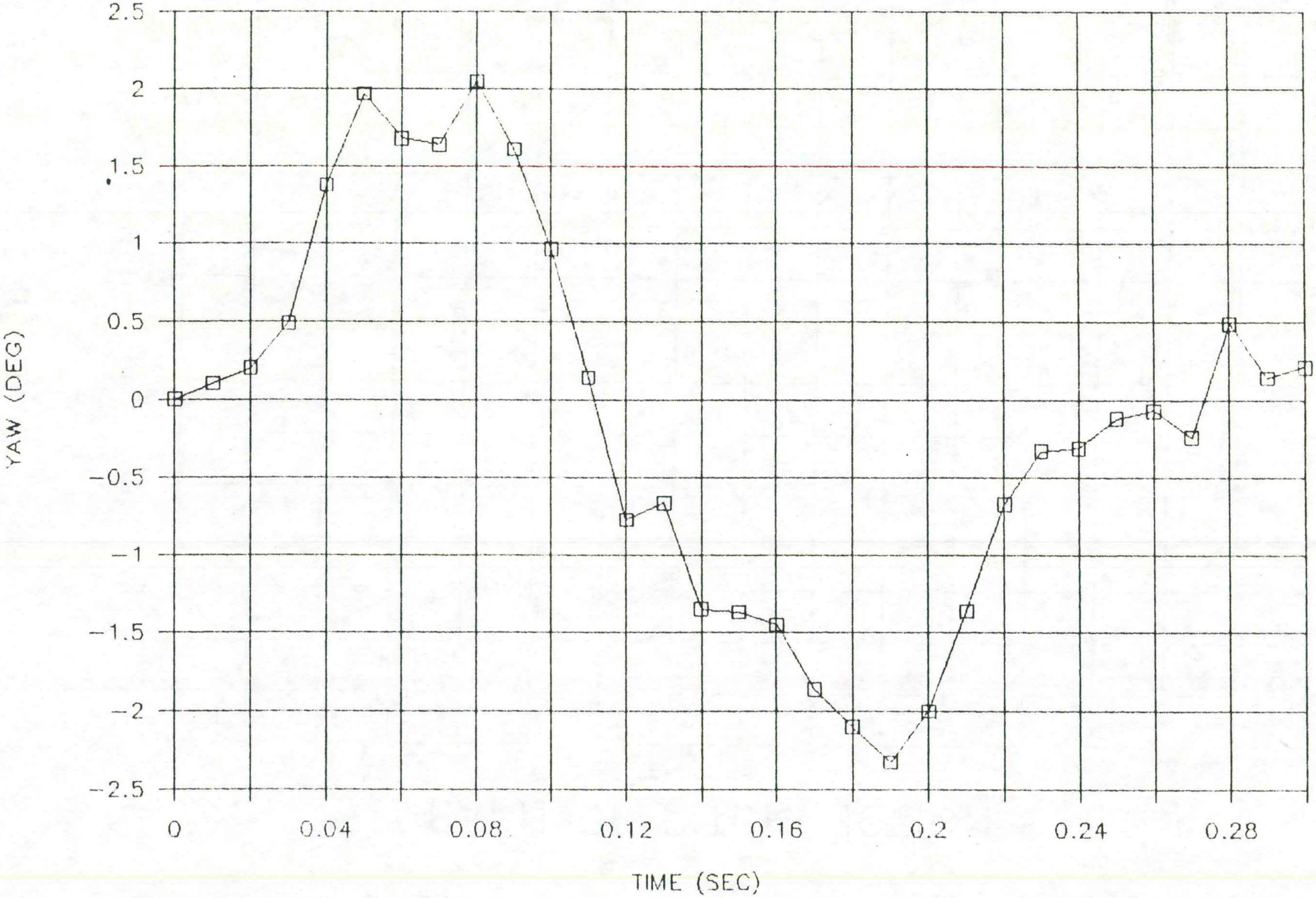


GRAPH OF PITCH MOTION



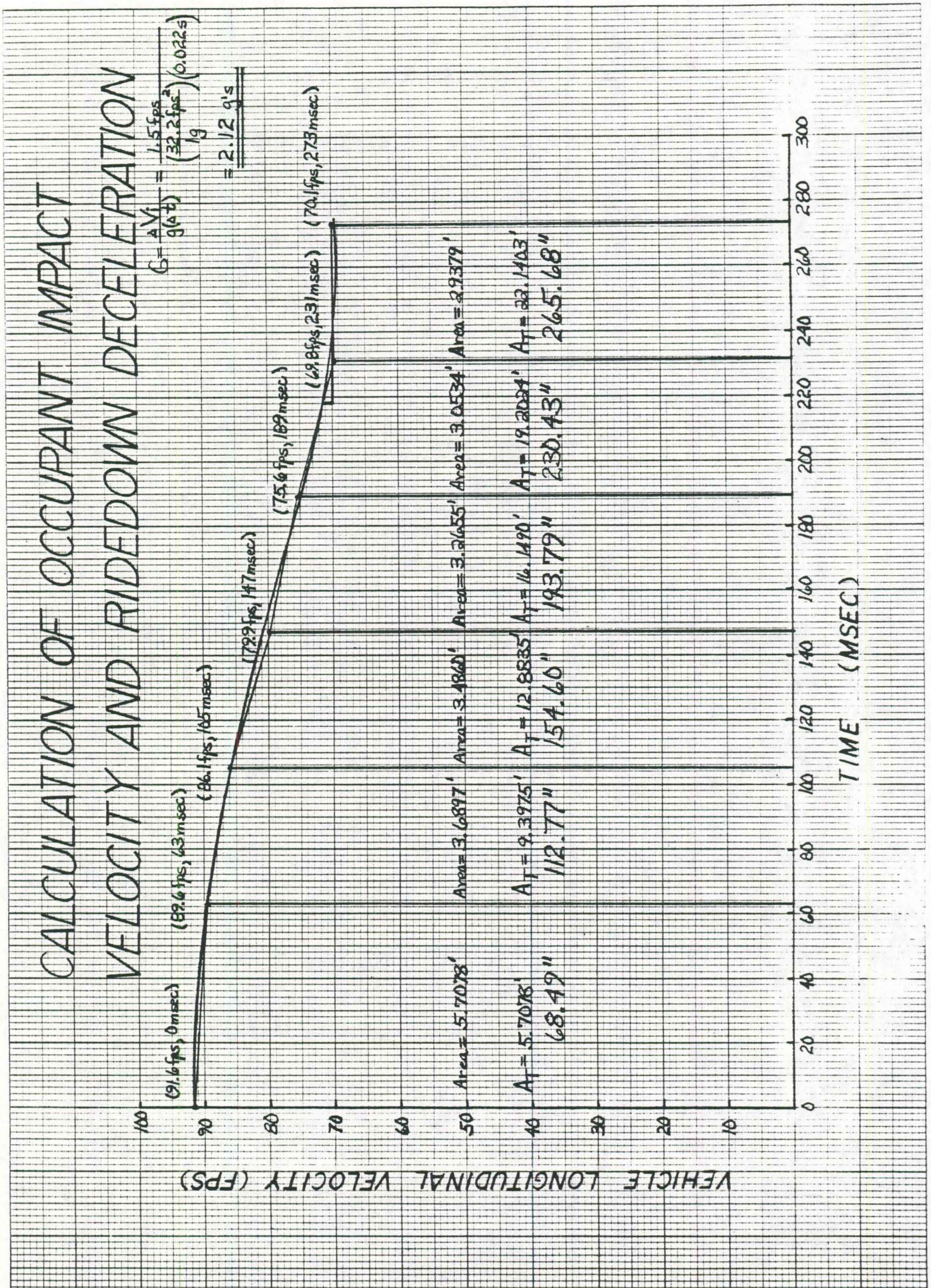
GRAPH OF YAW MOTION

TEST 13-1



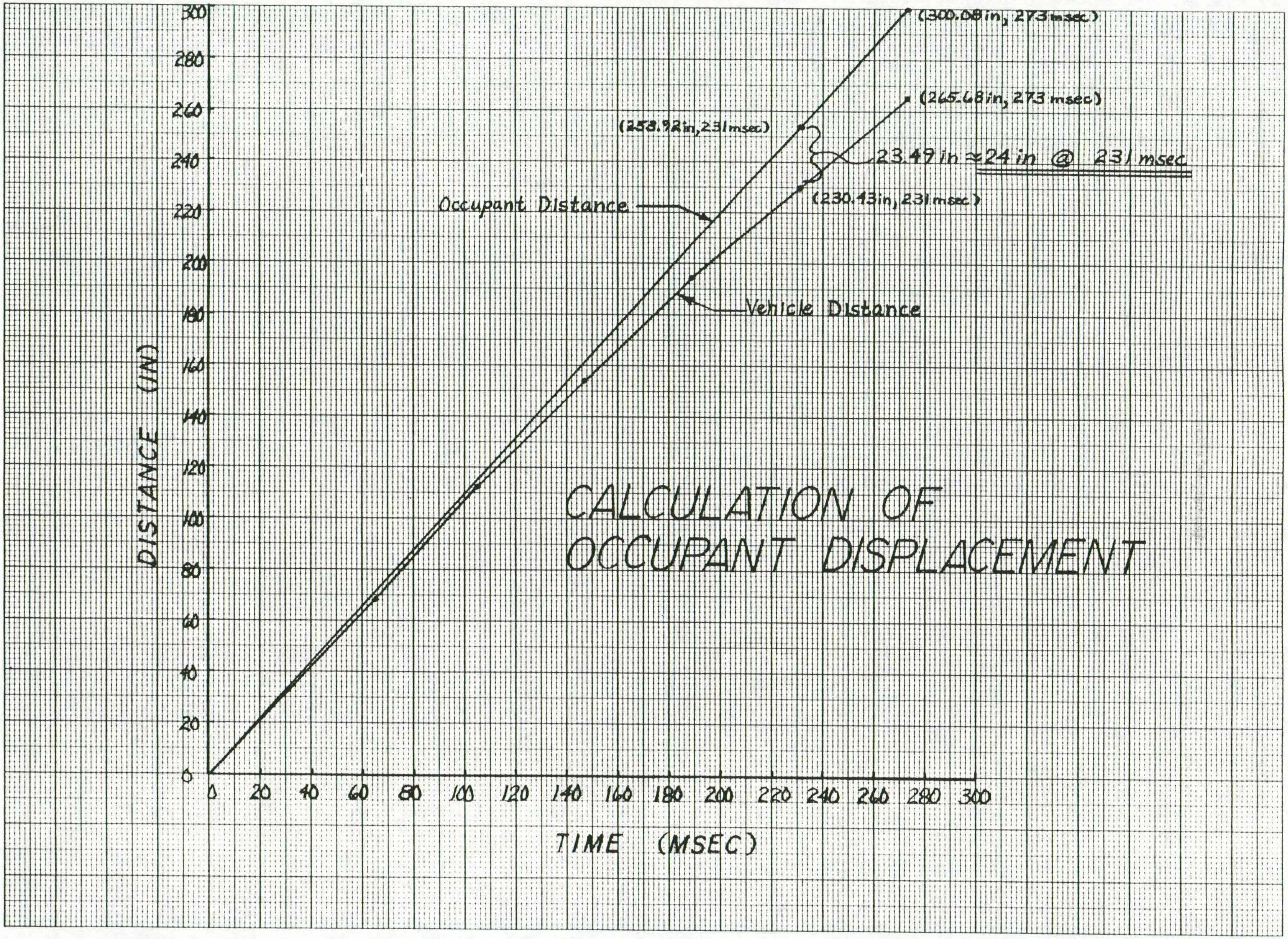
APPENDIX C.

OCCUPANT RISK DETERMINATION



20 Squares to the Inch

K·E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1513



APPENDIX D.

ACCELEROMETER DATA ANALYSIS

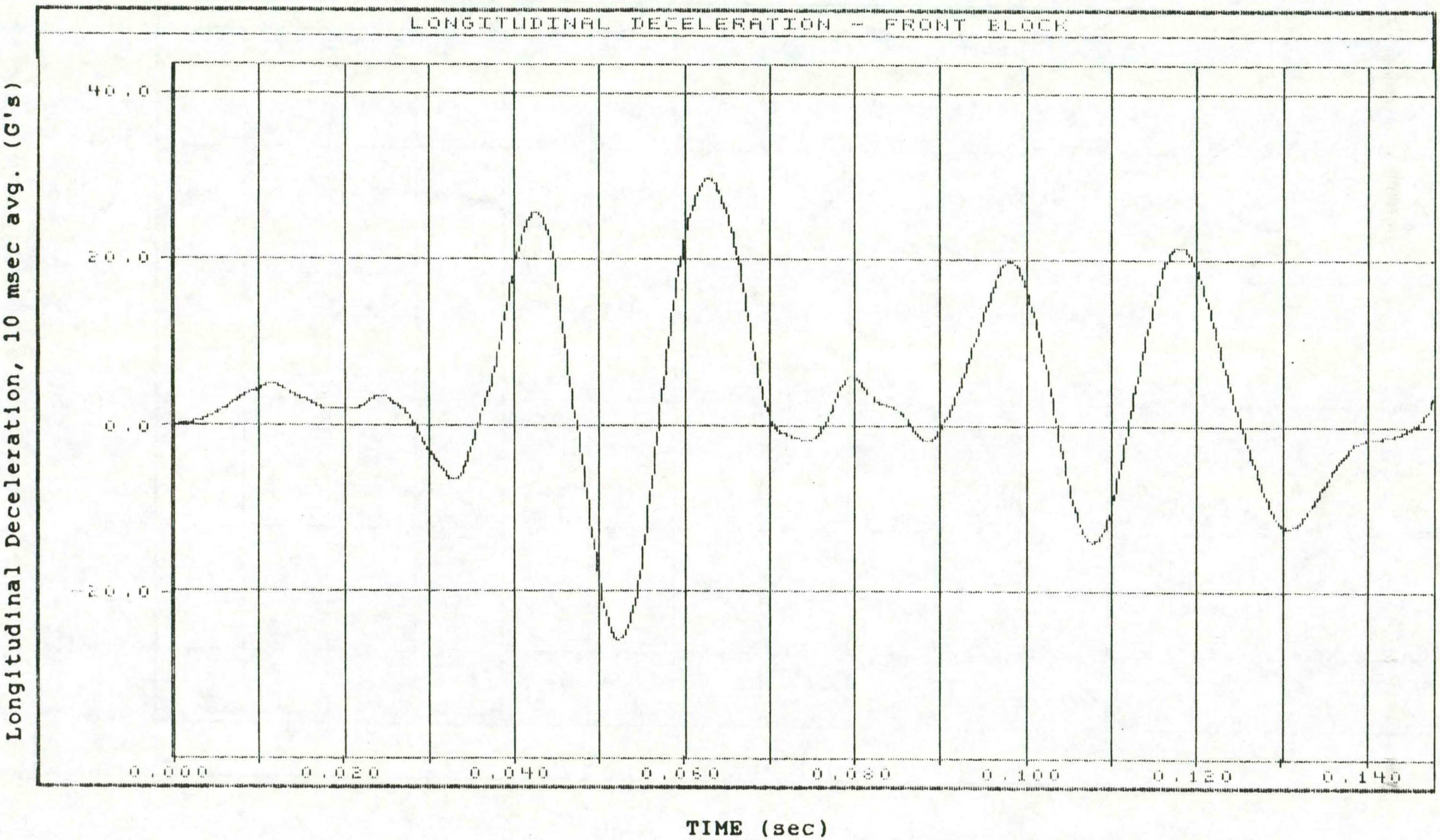


FIGURE D-1. Graph of Longitudinal Deceleration, Front Block, Test I3-1

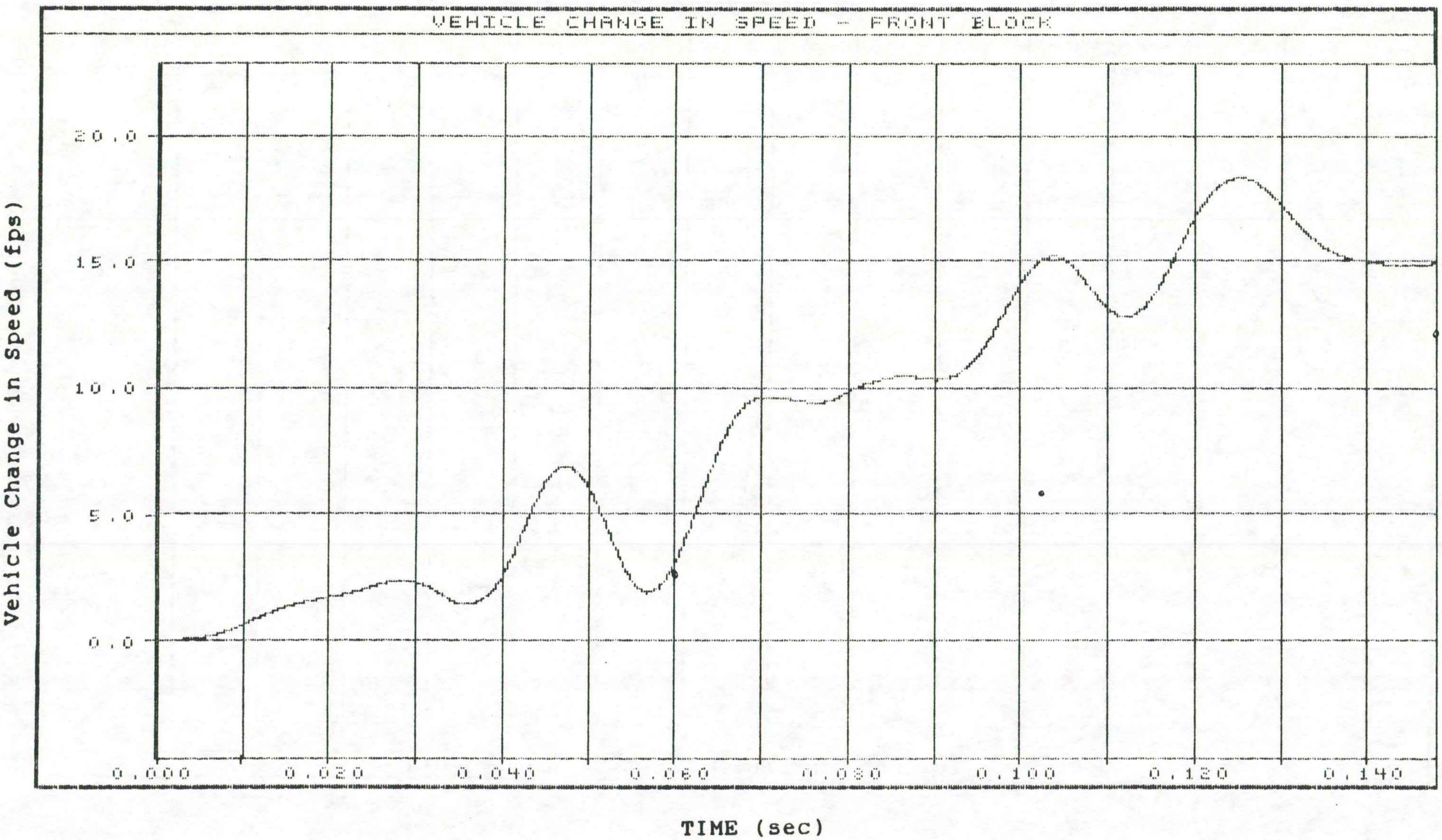


FIGURE D-2. Graph of Vehicle Change in Speed, Front Block, Test I3-1

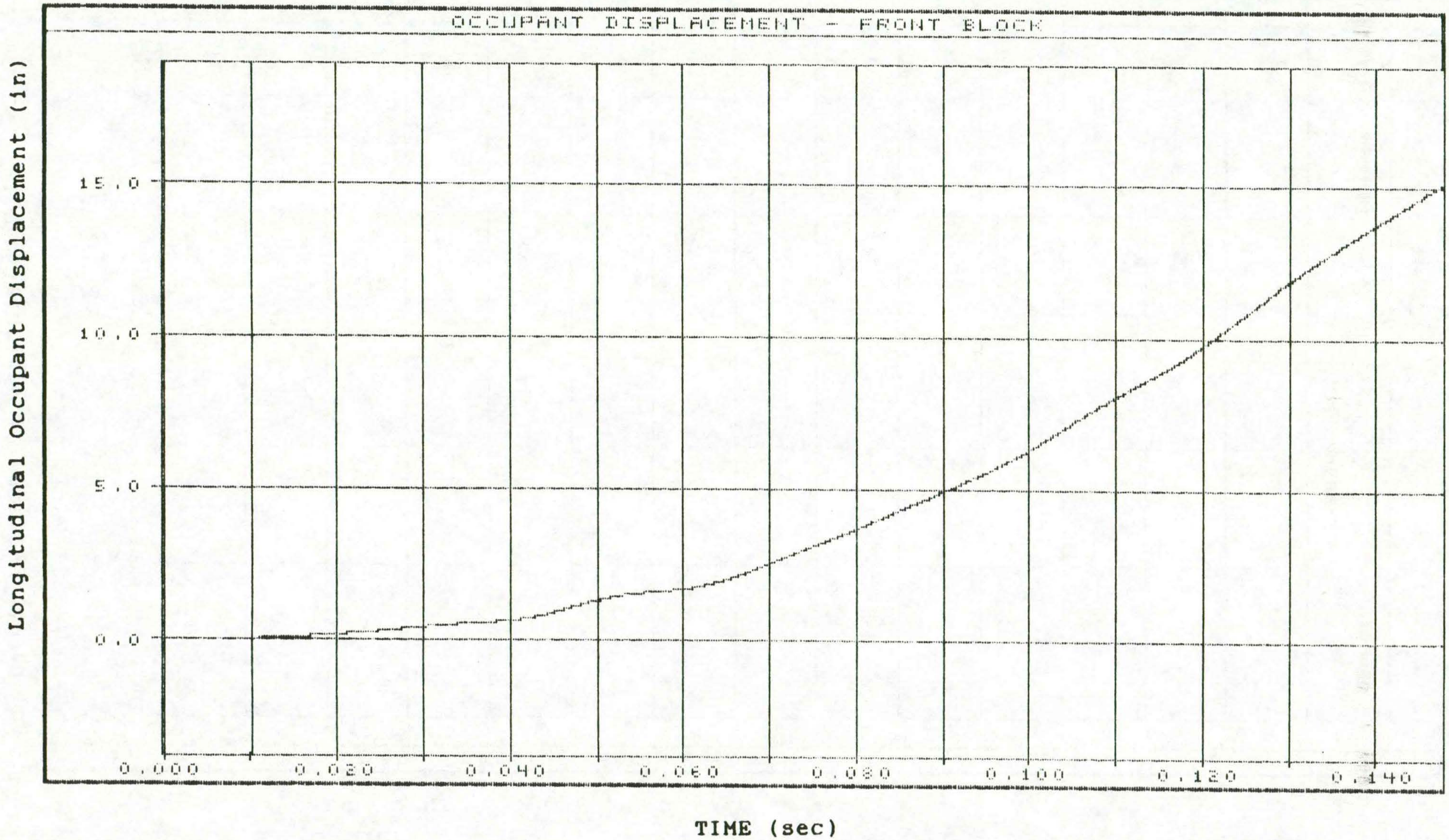


FIGURE D-3. Graph of Longitudinal Occupant Displacement, Front Block, Test I3-1

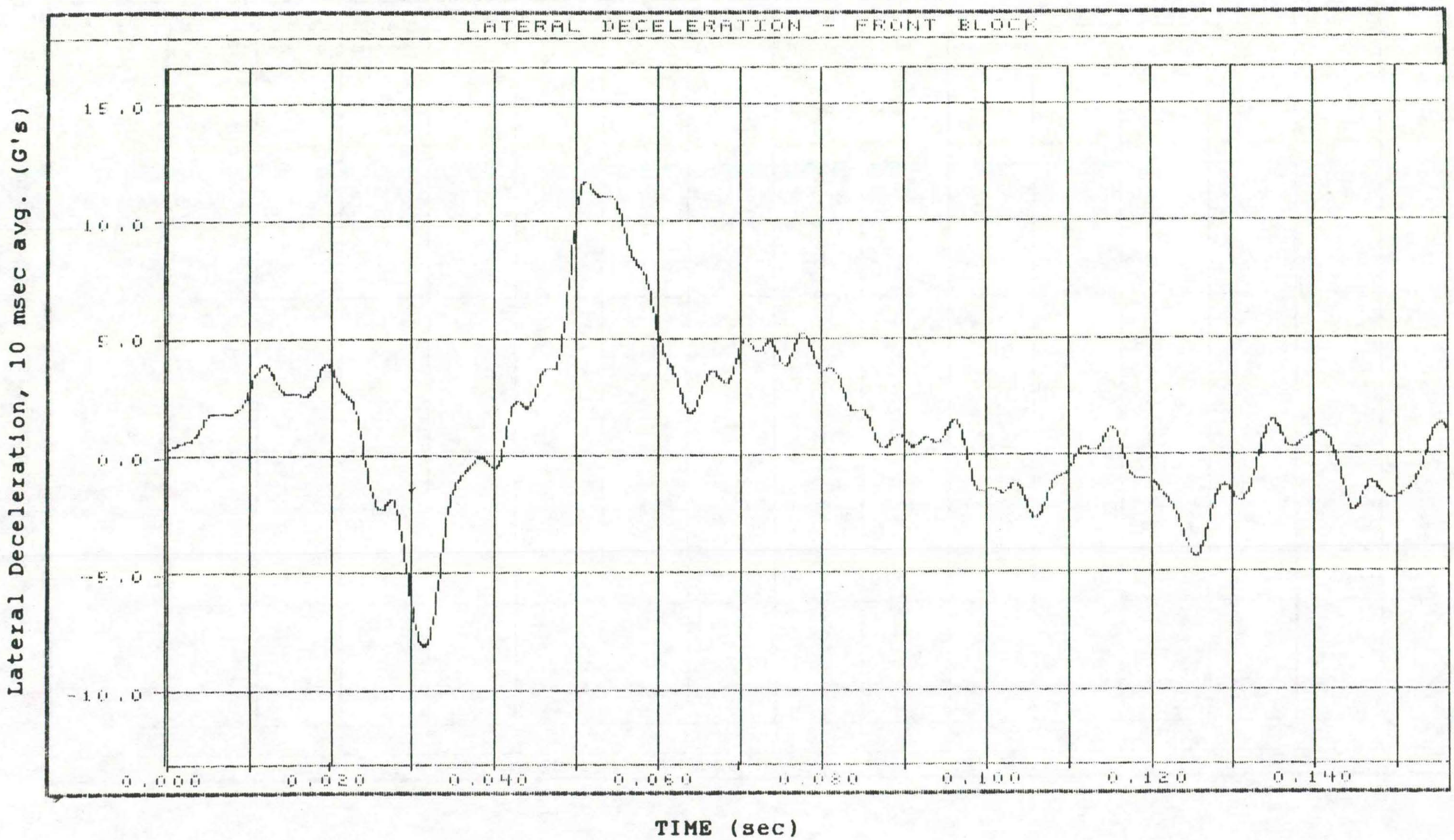


FIGURE D-4. Graph of Lateral Deceleration, Front Block, Test I3-1

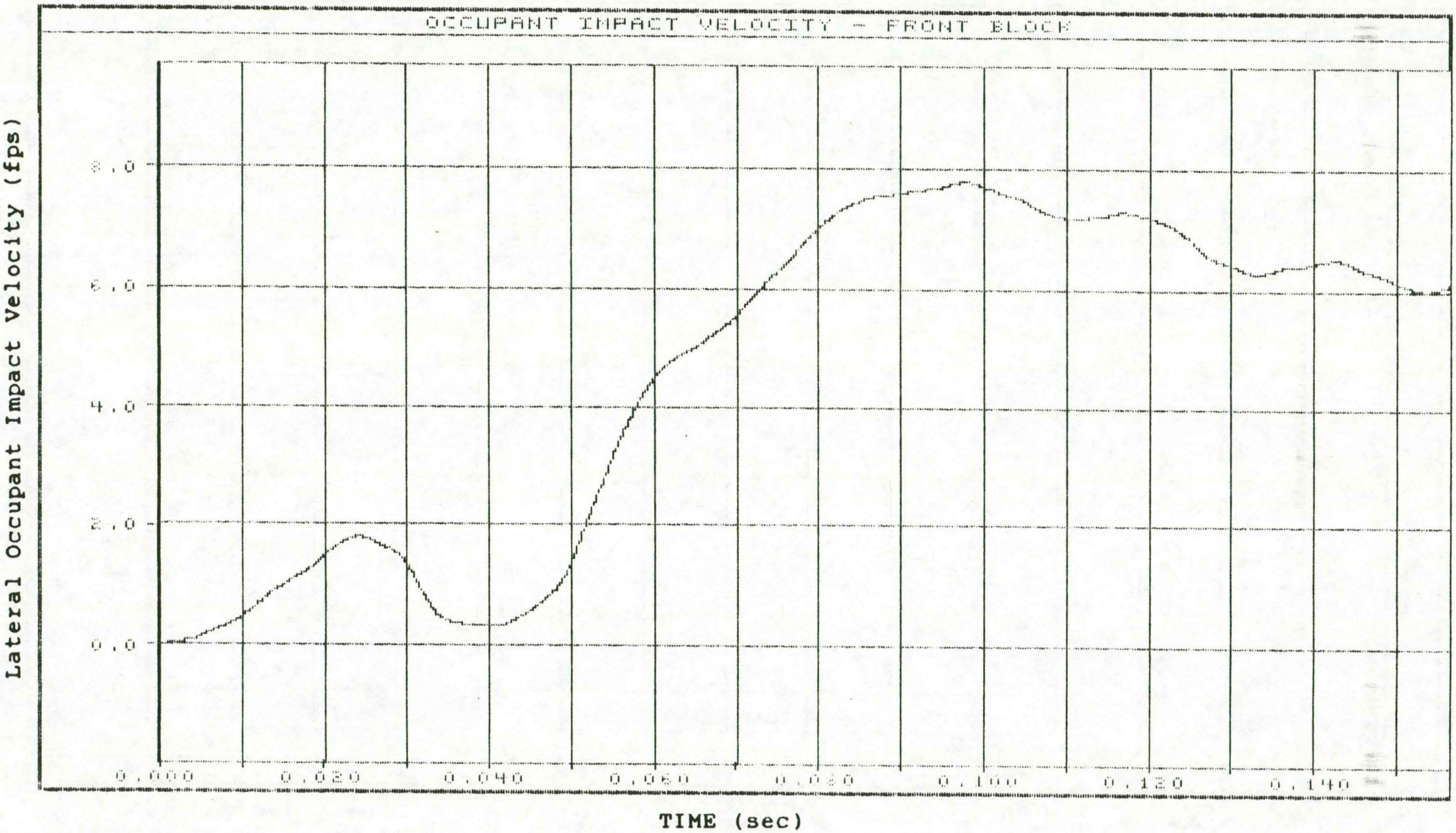


FIGURE D-5. Graph of Lateral Occupant Impact Velocity, Front Block, Test I3-1

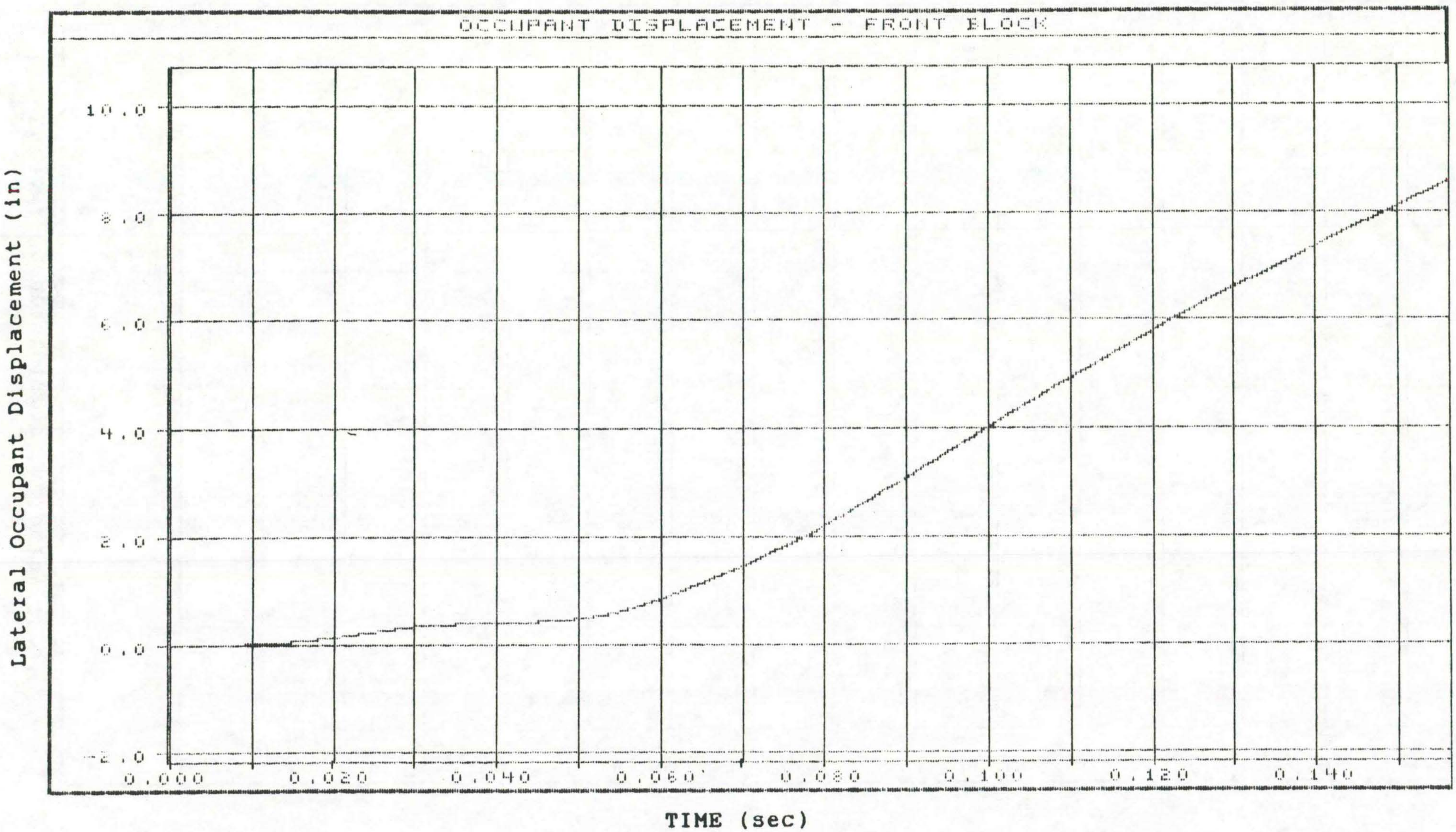


FIGURE D-6. Graph of Lateral Occupant Displacement, Front Block, Test I3-1

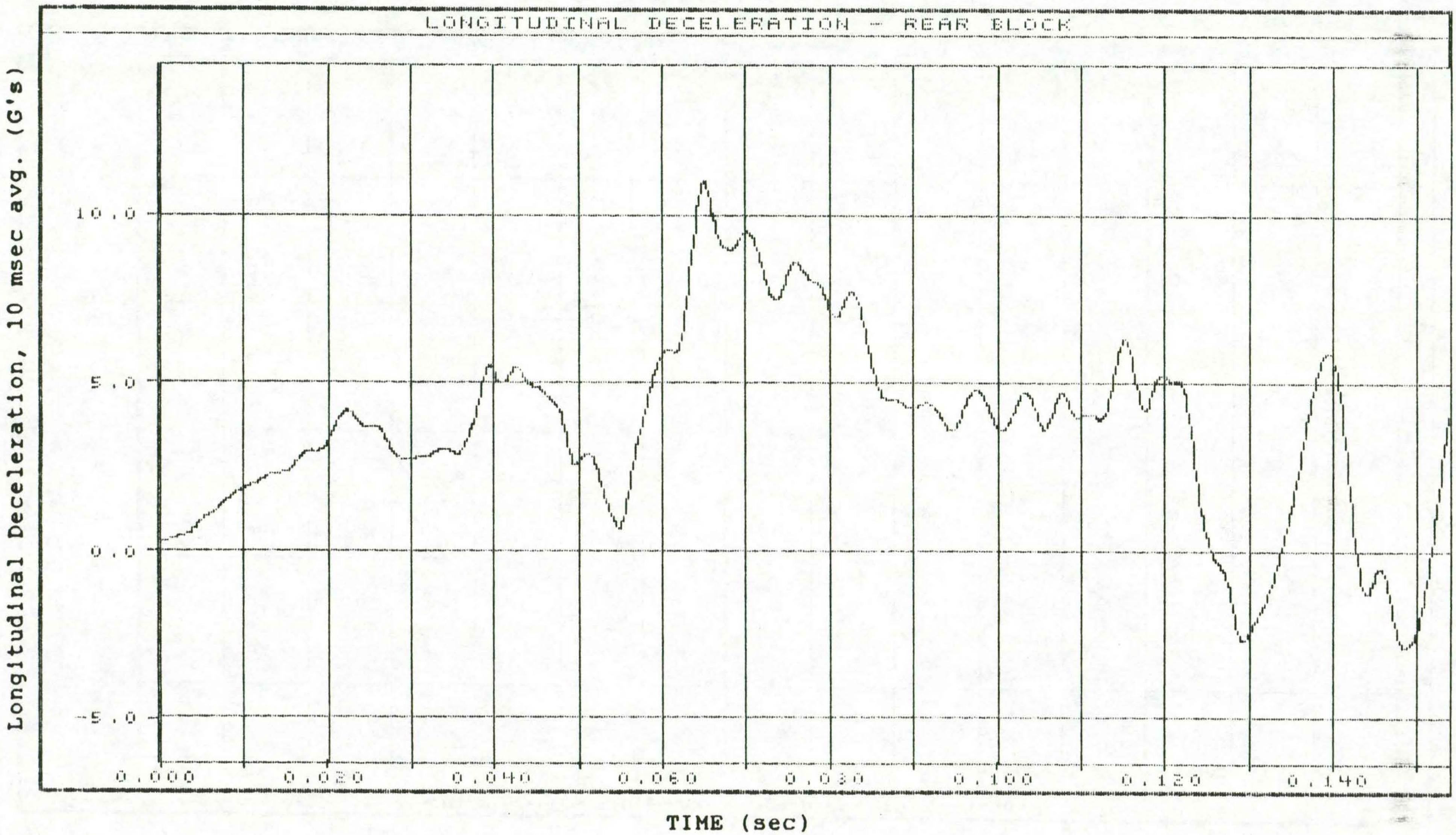


FIGURE D-7. Graph of Longitudinal Deceleration, Rear Block, Test I3-1

64

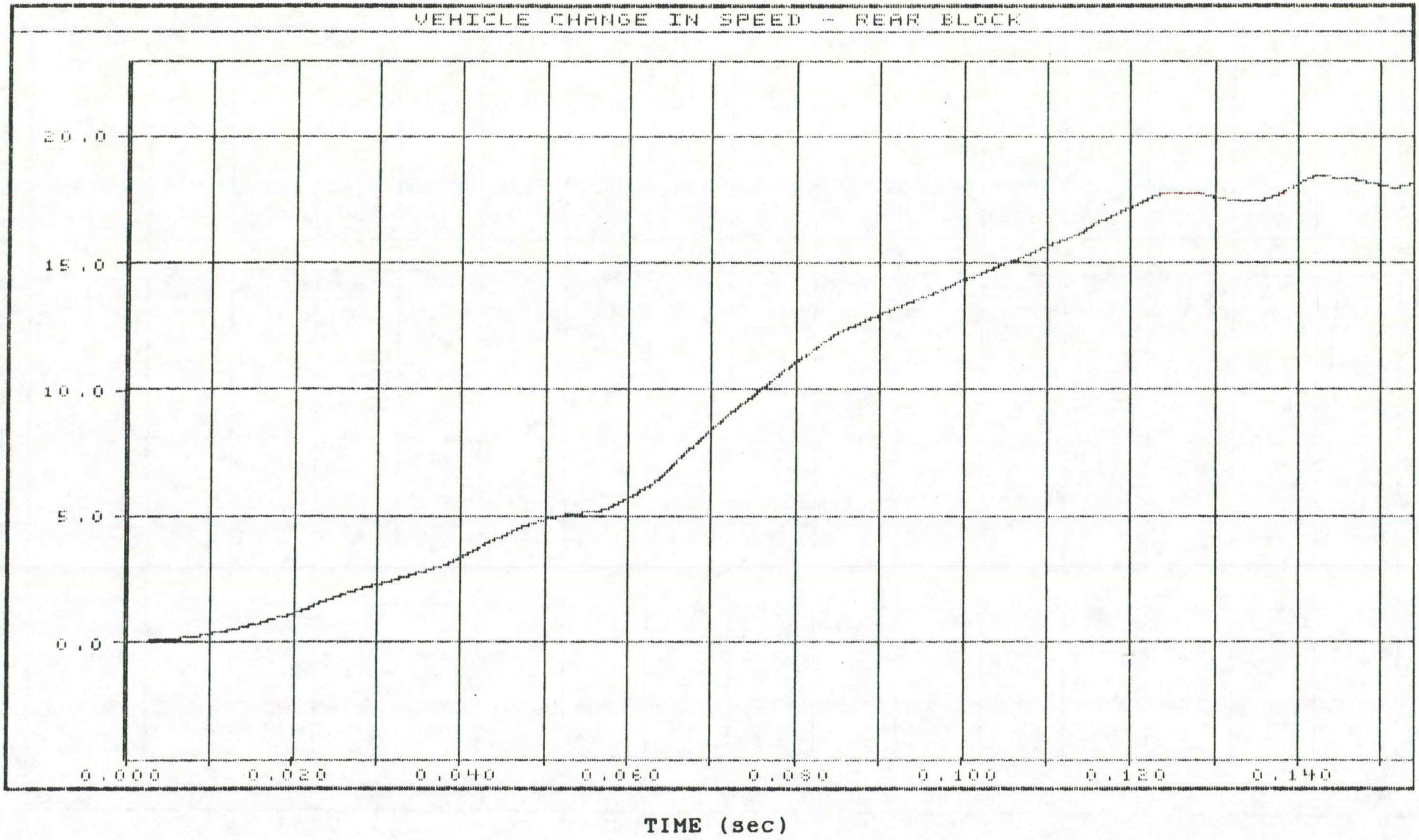


FIGURE D-8. Graph of Vehicle Change in Speed, Rear Block, Test I3-1

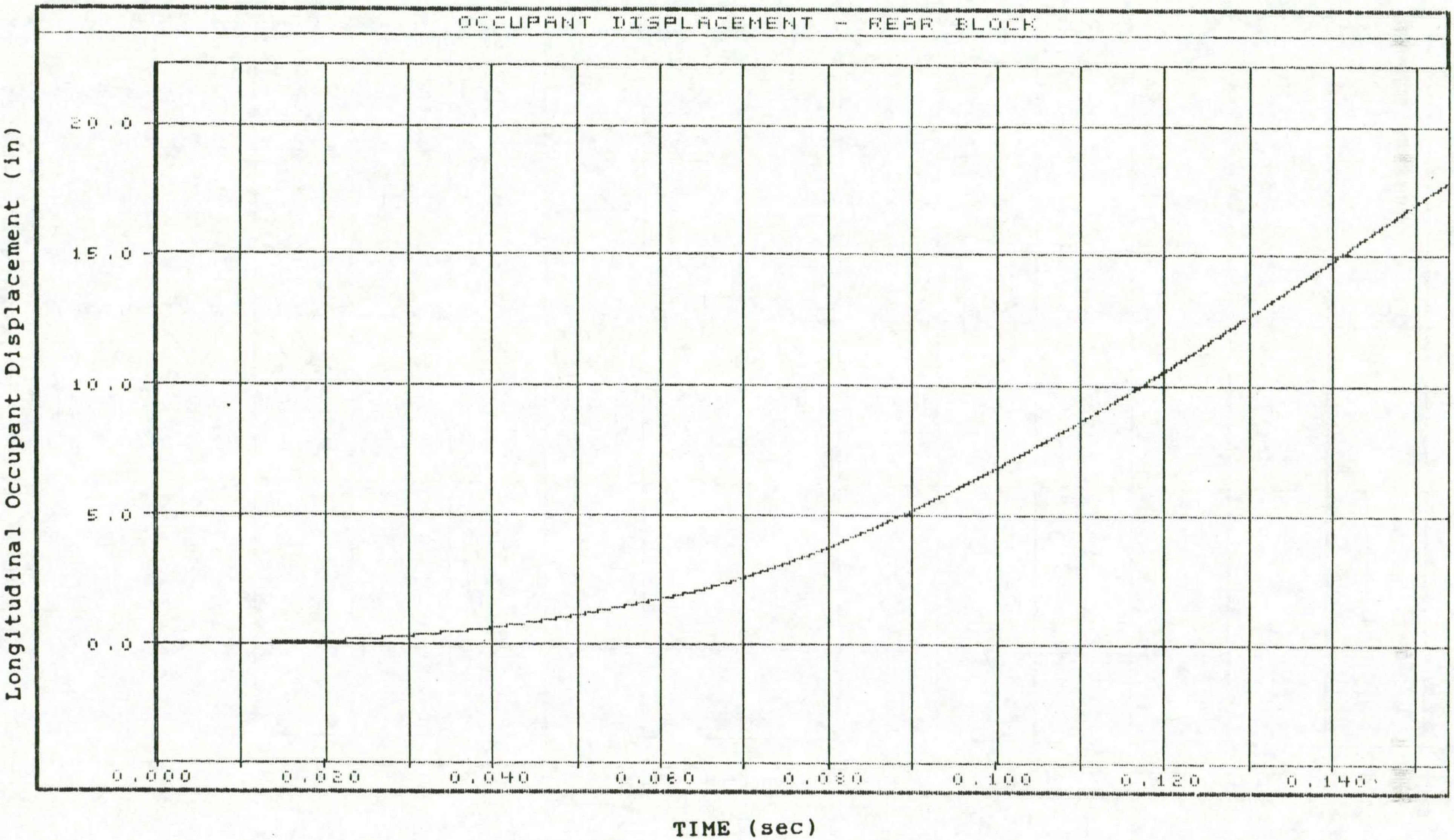


FIGURE D-9. Graph of Longitudinal Occupant Displacement, Rear Block, Test I3-1

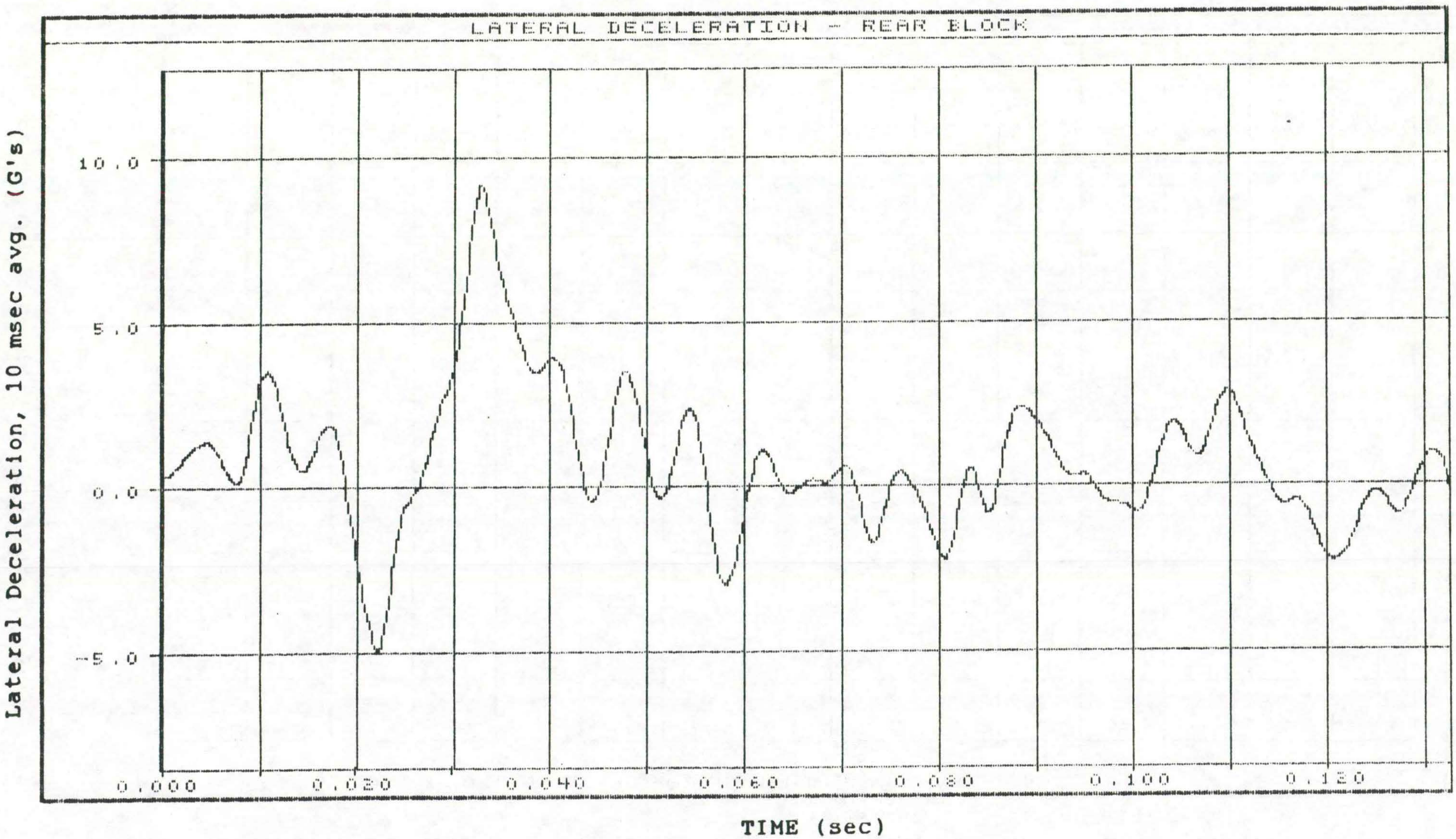


FIGURE D-10. Graph of Lateral Deceleration, Rear Block, Test I3-1

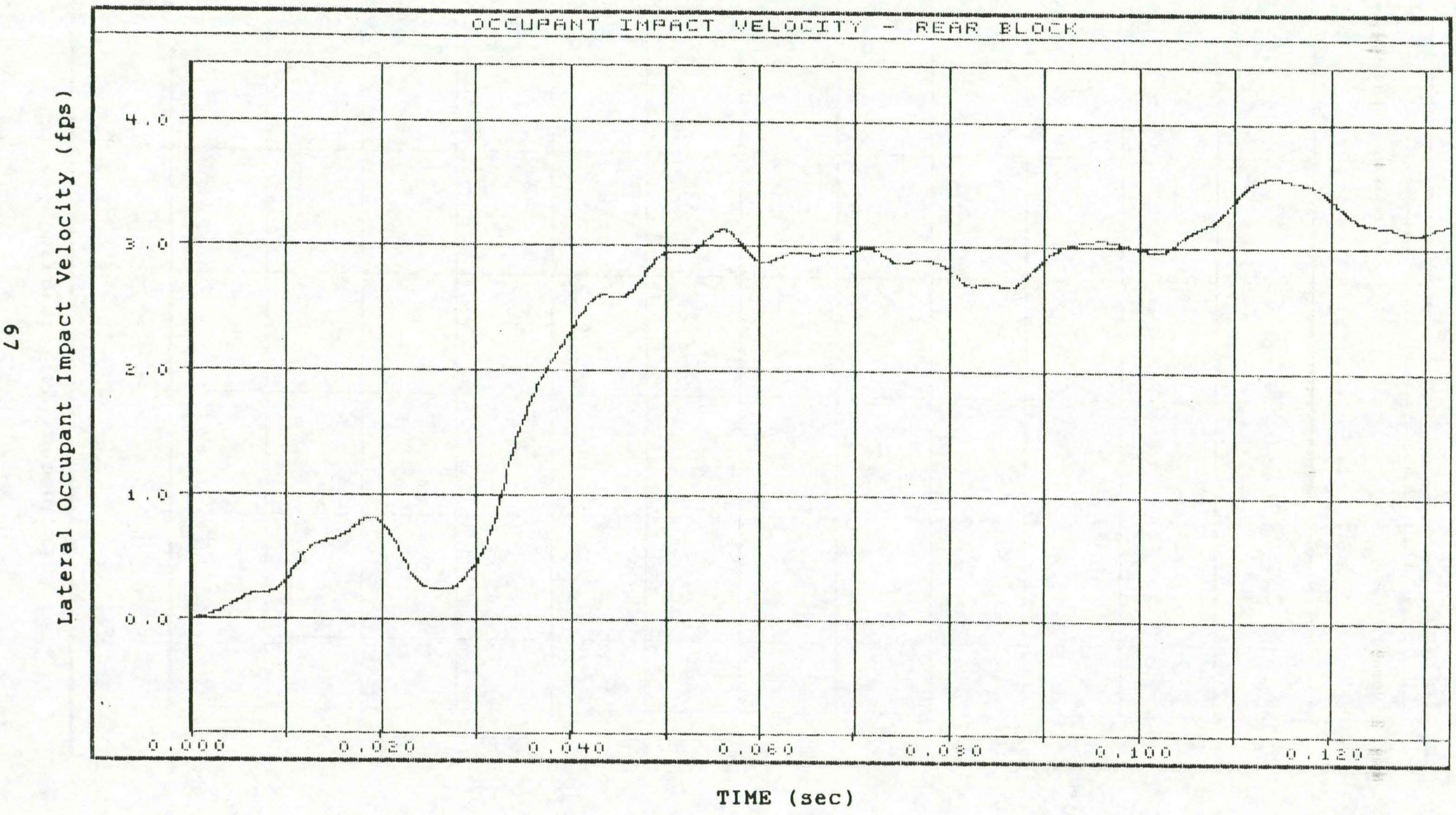


FIGURE D-11. Graph of Lateral Occupant Impact Velocity, Rear Block,Test I3-1

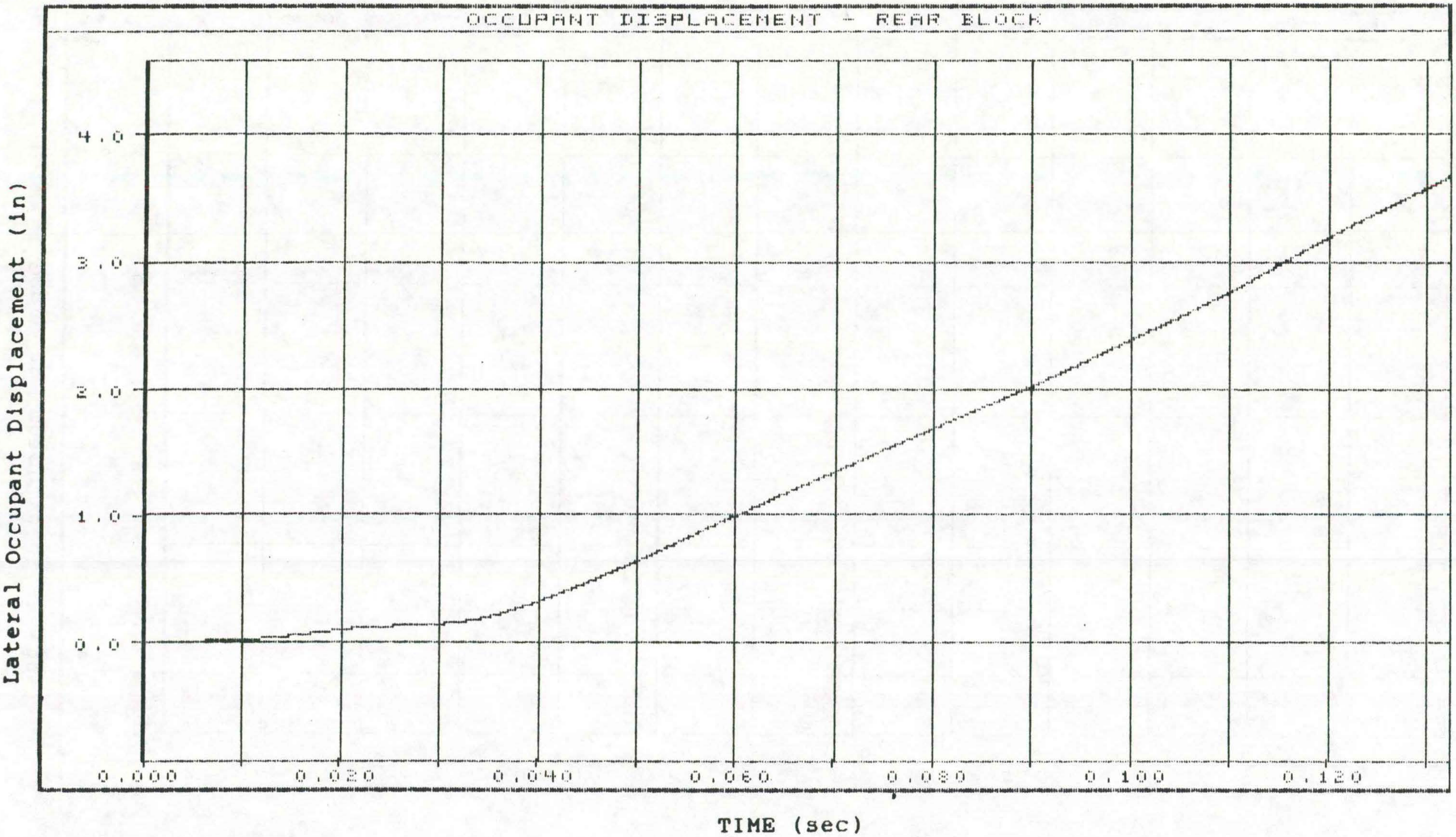
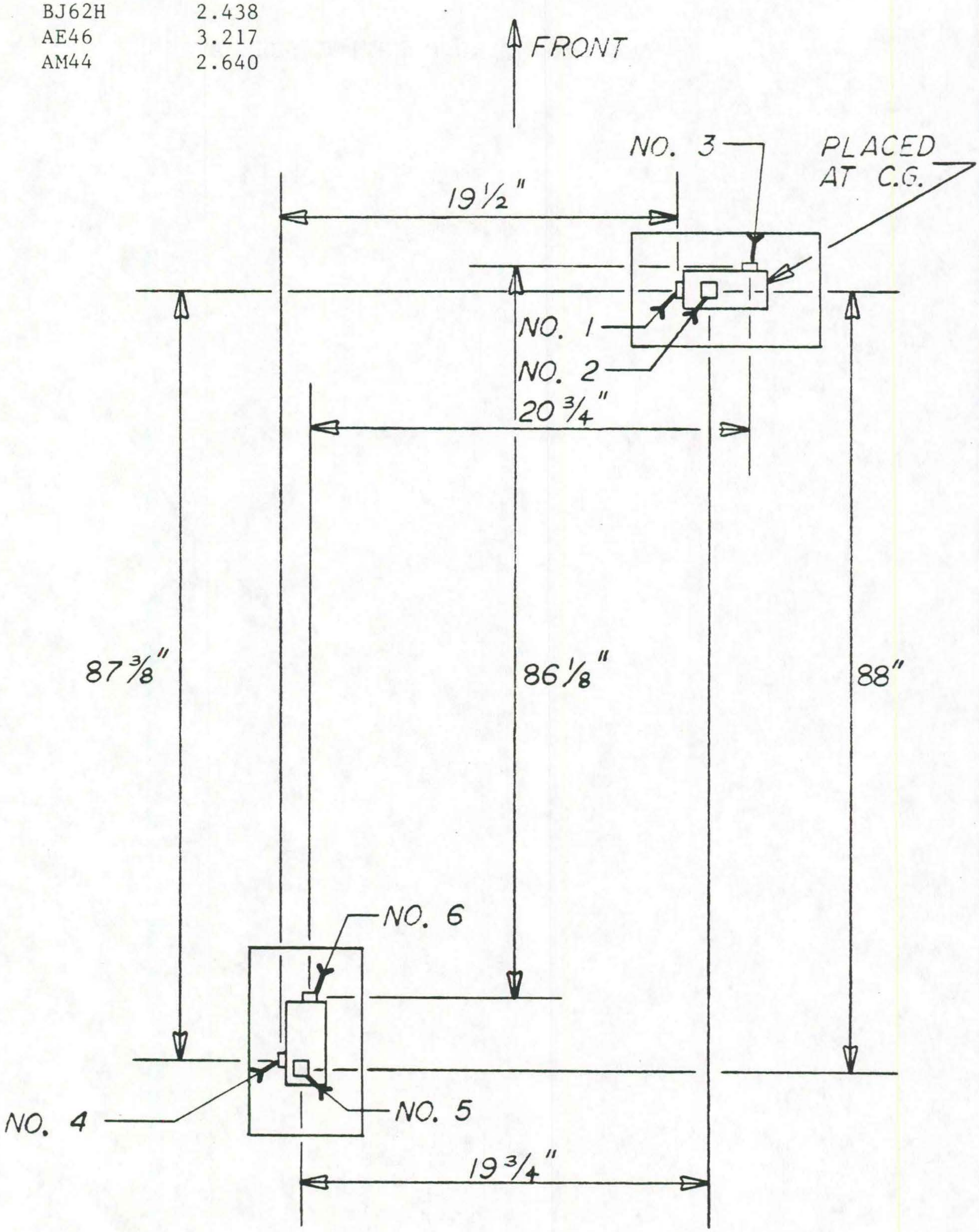


FIGURE D-12. Graph of Lateral Occupant Displacement, Rear Block, Test I3-1

APPENDIX E.

ACCELEROMETER MOUNTING SCHEMATICS

Accel. No.	Serial No.	Calibr. Factor
No. 1	BR47H	2.224
No. 2	BP24H	2.125
No. 3	BF57H	2.546
No. 4	BJ62H	2.438
No. 5	AE46	3.217
No. 6	AM44	2.640



FIGURE

ACCELEROMETER PLAN VIEW
TEST NO. I3-1

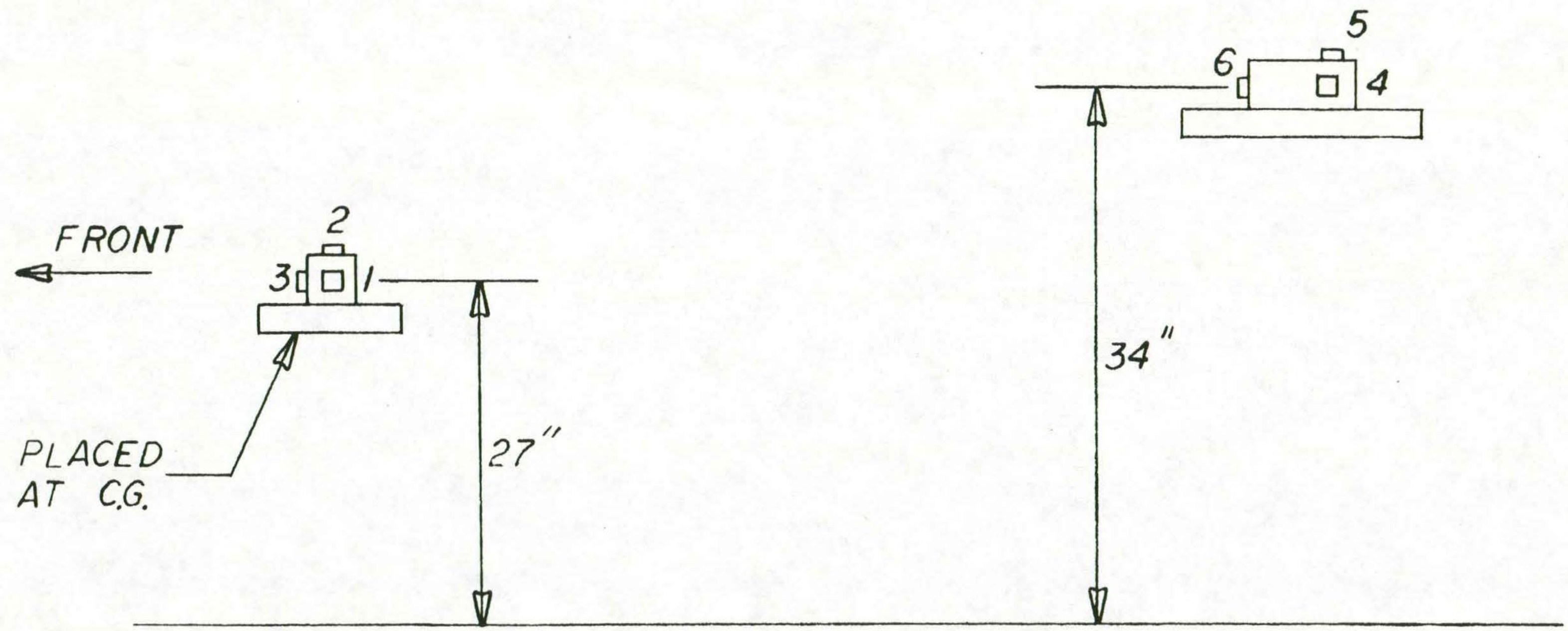


FIGURE
ACCELEROMETER PROFILE VIEW
TEST NO. I3-1