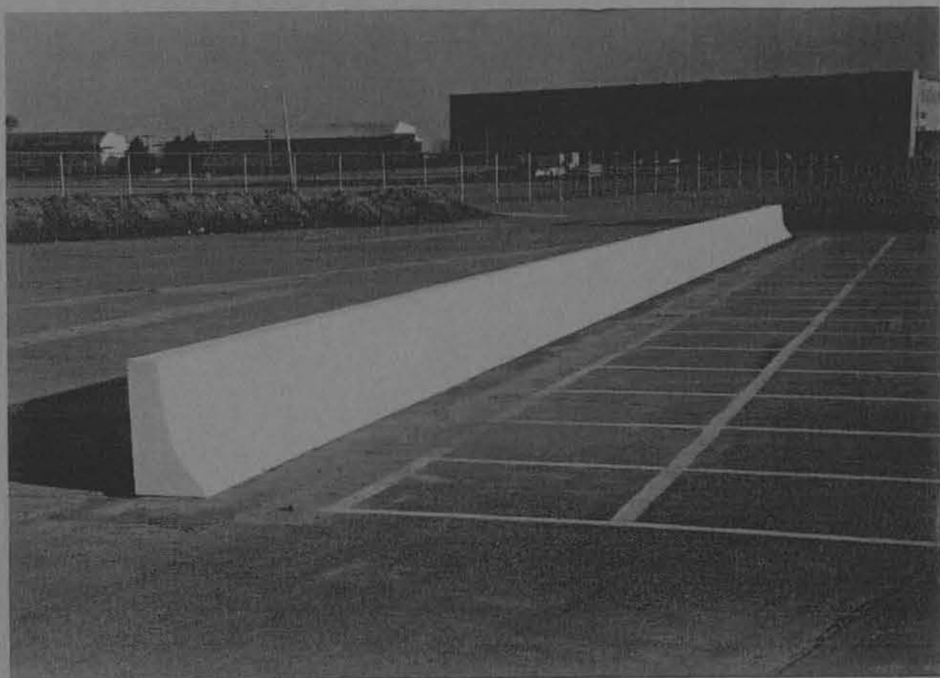
PERFORMANCE LEVEL 2 TESTS ON THE MISSOURI 30 IN. NEW JERSEY SAFETY SHAPE BRIDGE RAIL



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DISCLAIMER STATEMENT

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ABSTRACT

The Federal Highway Administration (FHWA) currently considers a concrete safety shape bridge rail substandard for the AASHTO PL-2 performance level if it does not conform with the 32 in. minimum vertical height. This situation occurs when an existing bridge deck, with an attached 32 in. bridge rail, requires an overlay. As a result of this overlay, the bridge rail must be modified or subjected to a safety performance evaluation.

The Missouri Highway and Transportation Department (MHTD) has existing 32 in. standard New Jersey safety shape bridge rails on decks which need to be resurfaced with a 2 in. concrete overlay. This would reduce the vertical height above the roadway surface from the standard 32 in. to 30 in. and would also lower the vertical face of the bridge rail from 3 in. to 1 in. To evaluate the performance of this bridge rail, the Midwest Roadside Safety Facility (MwRSF) conducted three full-scale vehicle crash tests on the Missouri 30 in. standard New Jersey safety shape bridge rail.

Test MS30-1 was conducted with an 18,011 lb single unit straight truck at 16.1 deg and 52.5 mph. Test MS30-2 was conducted with a 1,759 lb small automobile at 20.0 deg and 62.5 mph. Test MS30-3 was conducted with a 5,460 lb pickup truck at 20.0 deg and 63.5 mph.

The test procedures were conducted and reported in accordance with the requirements in the National Cooperative Highway Research Program (NCHRP) Report 230. The tests were evaluated in accordance with the safety criteria in the American Association of State Highway and Transportation Officials (AASHTO) "Guide Specifications for Bridge Railings," 1989. The safety performance of the Missouri 30 in. New Jersey safety shape bridge rail was found to be satisfactory according to the AASHTO safety criteria.

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1 INTRODUCTION

1.1 Problem Statement

The Federal Highway Administration (FHWA) currently considers a concrete safety shape bridge rail substandard for the PL-2 performance level if it does not conform to a 32 in. minimum vertical height as stated in Appendix A of the AASHTO "Guide Specifications For Bridge Railings"(1). Section 2.7.1.2.2 of the AASHTO "Standard Specifications for Highway Bridges"(2) states that, "concrete parapets designed with sloping faces intended to allow vehicles to ride up them under low angle contacts shall be at least 2 feet 8 inches in height." Therefore, a problem would be encountered when bridge decks with an attached 32 in. bridge rail required a 2 in. overlay.

In the past when an overlay was to be constructed on the roadway surface of a bridge rail, the FHWA required that the bridge rail be modified so that it would remain in compliance with current specifications i.e., increase the height of the bridge rail by retrofitting. Although the use of the unmodified bridge rail may remain in operation if the bridge rail is subjected to a safety performance evaluation by full-scale crash testing.

1.2 Objective of Study

The Missouri Highway and Transportation Department (MHTD) and other highway departments across the midwest have encountered this problem. Therefore, Nebraska and Kansas pooled their efforts with Missouri to evaluate this unmodified bridge rail. The purpose of the effort was to determine if a 32 in. New Jersey safety shape bridge rail could have a 2 in. overlay placed on the adjacent bridge deck and still provide a satisfactory safety performance.

A safety performance evaluation was conducted on a 30 in. New Jersey safety shape bridge rail according to test procedures in NCHRP 230 (3) and the PL-2 performance level evaluation criteria in AASHTO (1).

2 TEST CONDITIONS

2.1 Test Facility

2.1.1 Test Site

The test site facility is located at the Lincoln Air-Park on the NW end of the Lincoln Municipal Airport. The test facility is approximately 5 mi. NW of the University of Nebraska-Lincoln.

An 8 ft high chain-link security fence surrounds the test site facility to ensure that no vandalism occurs 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 the speed of the tow vehicle are one-half that of the test vehicle. A sketch of the cable tow system is shown in Figure 1. The test vehicle is released from the tow cable before impact with the bridge rail. The tow vehicle and the attached fifth-wheel are shown in Figure 2. The fifth wheel was used in conjunction with a digital speedometer to increase the accuracy of the test vehicle impact speed.

2.1.3 Vehicle Guidance System

A vehicle guidance system, developed by Hinch(4), was used to steer the test vehicle. The guidance system is shown in Figure 1. The guide flag, attached to the front left wheel and the guide cable, was sheared off before impact. The 3/8 in. diameter guide cable was tensioned to 3000 lbs, and supported laterally and vertically every 100 ft by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable. As the vehicle was towed down the line, the guide-flag struck each stanchion and knocked it to the ground. The vehicle guidance system varied in length according to which test vehicle was used.

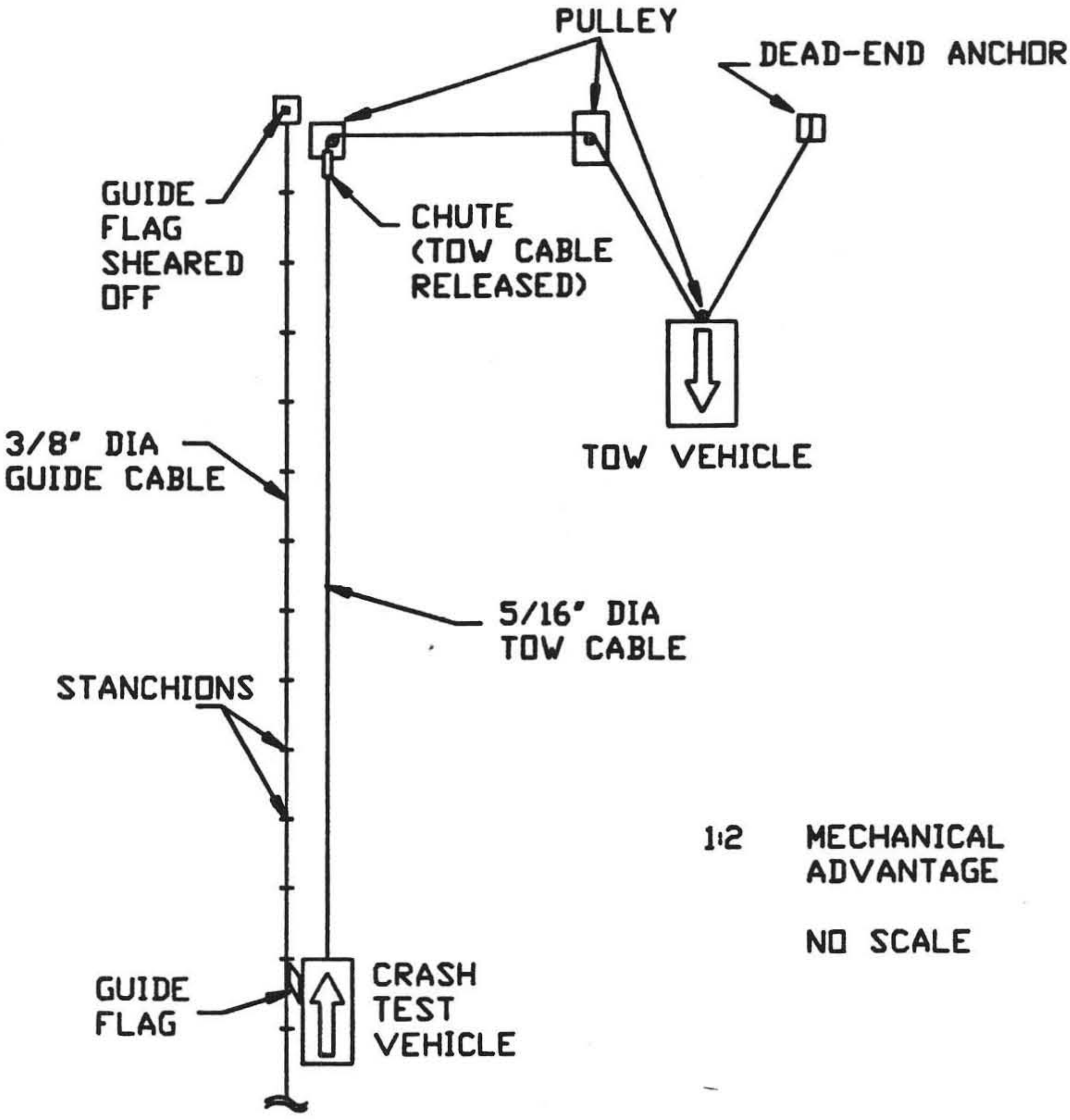


FIGURE 1. Cable Tow and Guidance System.

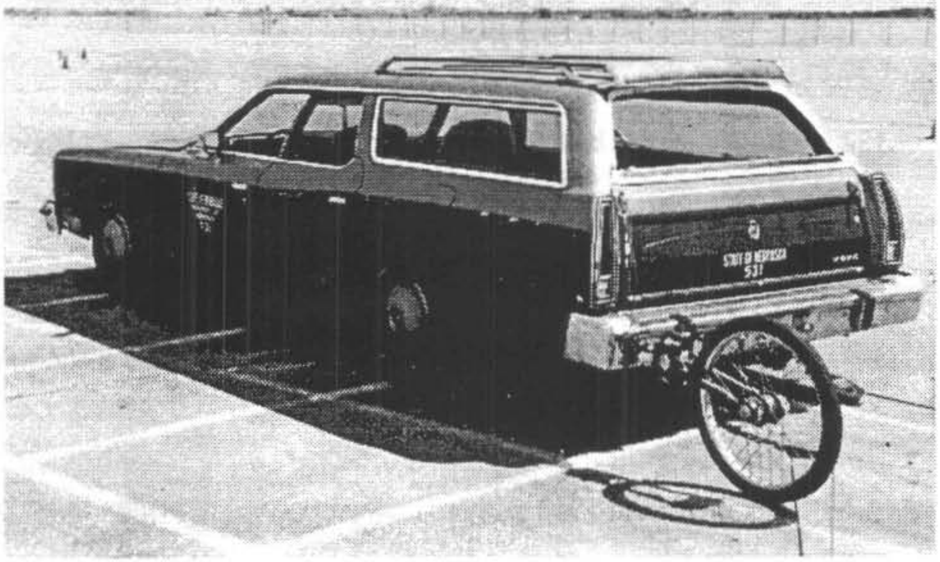


FIGURE 2. Tow Vehicles and Fifth Wheel

2.2 Bridge Rail Design Details

The installation consisted of a concrete New Jersey safety shape bridge rail with an overall height of 30 in., and an overall length of 100 ft. The bridge rail design details are shown in Figure 3, and photographs of the installation before impact are shown in Figure 4. The 30 in. bridge rail was constructed by reducing the lower vertical face from 3 in. to 1 in. This construction procedure was accomplished by recessing standard 32 in. steel forms 2 in. below the existing concrete surface, as shown in Figure 5. The base width of the installation was 16.0 in. and the top width was 7.0 in.

The bridge rail was not constructed with a simulated concrete bridge deck because only the change in geometry caused by the reduced height was in question. Therefore, the bridge rail was attached to the existing concrete apron with two rows of No. 5 bent rebar spaced at 12 in. centers. The bars were rigidly attached to the apron with an epoxy grout adhesive material. These bars were embedded 8 in. into the concrete apron surface. The reinforcement details are shown in Figure 3. Grade 60 reinforcing bars were used in all locations. The concrete compressive strength was approximately 6,000 psi. The results of the concrete compressive tests are shown in Appendix A.

2.3 Test Vehicles

Three different test vehicles were used to evaluate the safety performance of the 30 in New Jersey safety shape bridge rail. These vehicles were used to satisfy the required test matrix which consisted of a 1800 lb small car, a 5400 lb pickup, and a 18,000 lb single unit truck.

<u>Test MS30-1</u>

The test vehicle used for Test MS30-1 was a 1986 Ford F-700 Series single unit truck. The test vehicle had a test inertial and a gross static weight of 18,011 lbs. The test vehicle is shown in Figure 6, and the vehicle dimensions are shown in Figure 7.

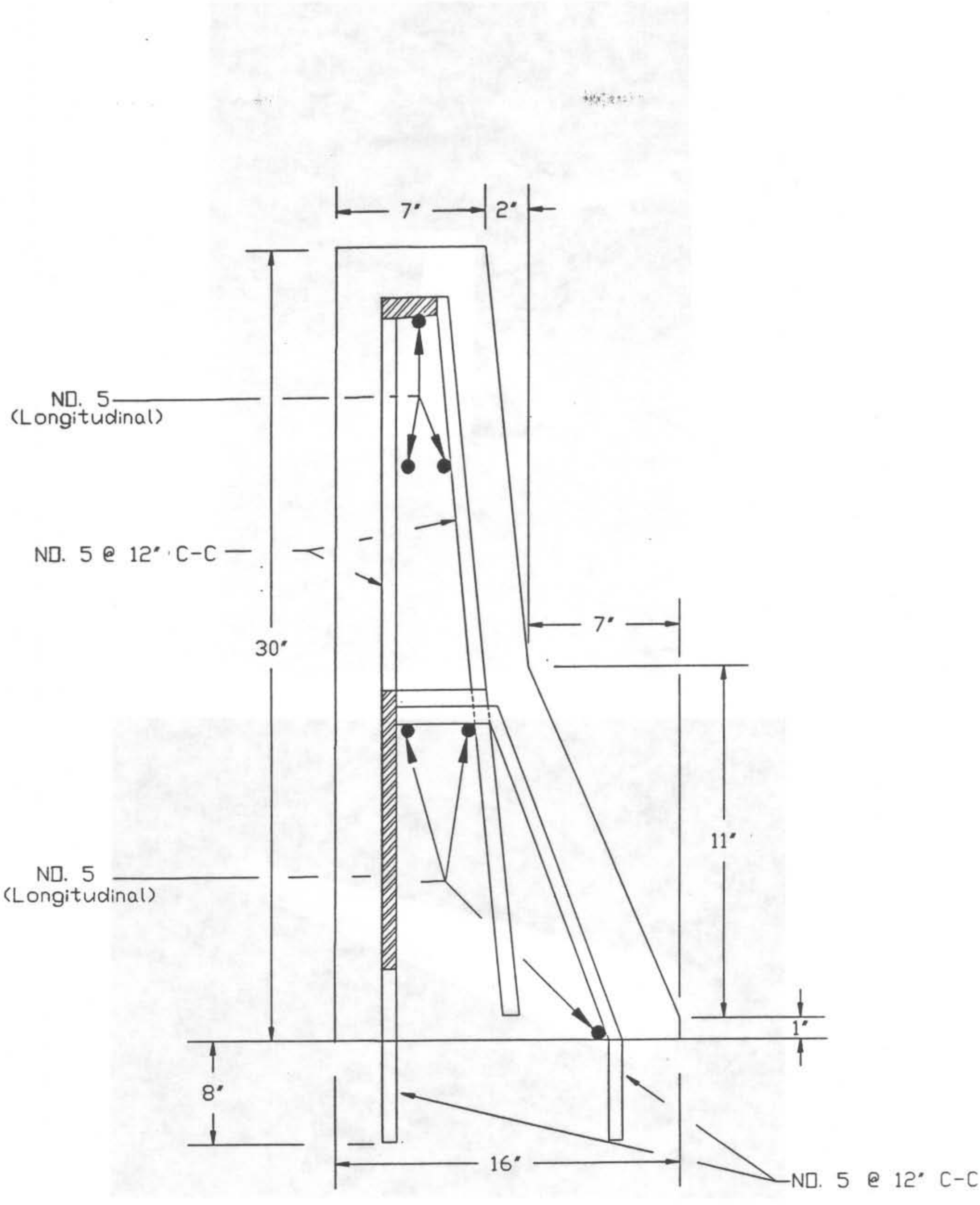


FIGURE 3. Bridge Rail Design Details

FIGURE 4. Missouri 30 in. New Jersey Safety Shape Bridge Rail

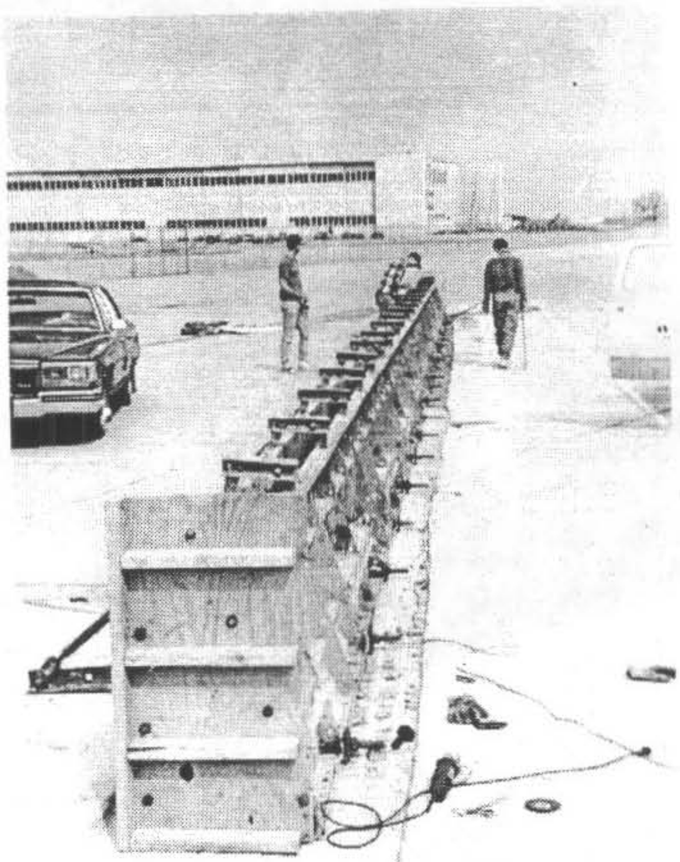
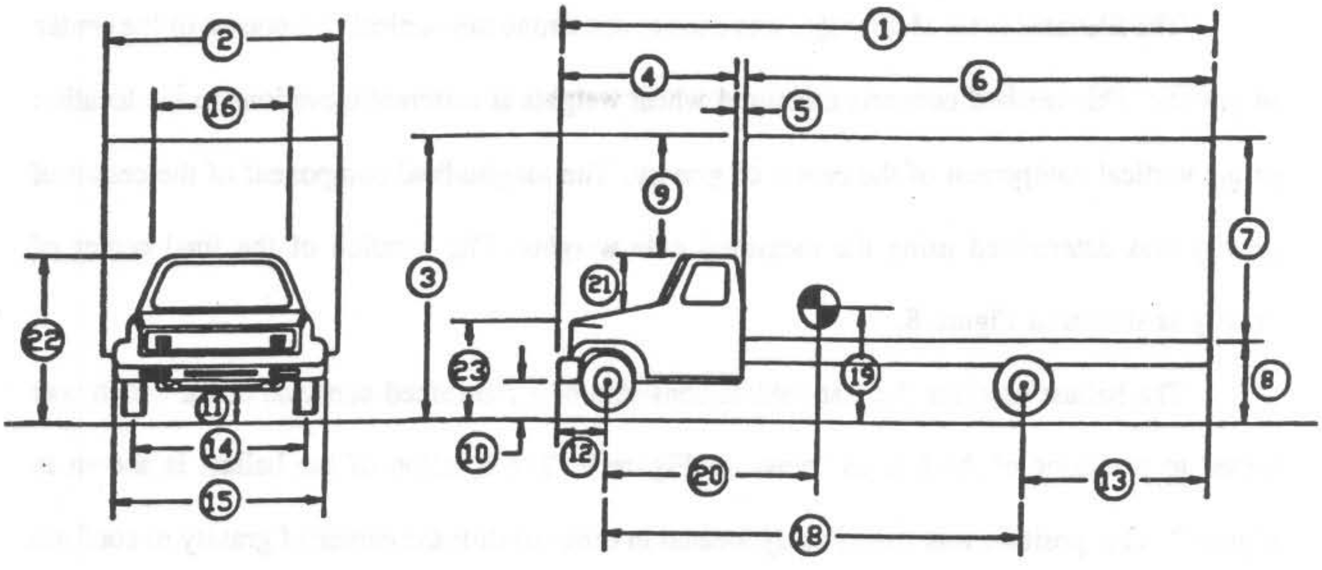


FIGURE 5. Bridge Rail Construction

FIGURE 6. Test Vehicle, MS30-1



Model FORD F-700

Total Weight 18,011

Front Weight 4549

Rear Axle Weight 6062

Ballast 7400

1. Overall Length 325.0
2. Overall Width 96.0
3. Overall Front Height 133.0
4. Cab Length 101.0
5. Gap Length 3.0
6. Trailer/Box Length 221.0
7. Rear Body Height 91.0
8. Rear Ground Clearance 45.0
9. Roof Height Differential 48.0
10. Front Ground Clearance 20.0
11. Minimum Ground Clearance 11.5
12. Front Overhang 33.0
13. Rear Overhang 87.0
14. Front Track Width 79.5
15. Front Bumper Width 93.0
16. Roof Width 61.0
17. Typical Tire Size and Diameter 39.5
18. Wheel Base 208.0
19. C.G. Height 49.0
20. C.G. Longitudinal Distance 120.6
21. Roof-Hood Distance 19.0
22. Roof Height 86.0
23. Hood Height 64.0

Note: All measurements are in inches.

FIGURE 7. Test Vehicle Dimensions, MS30-1

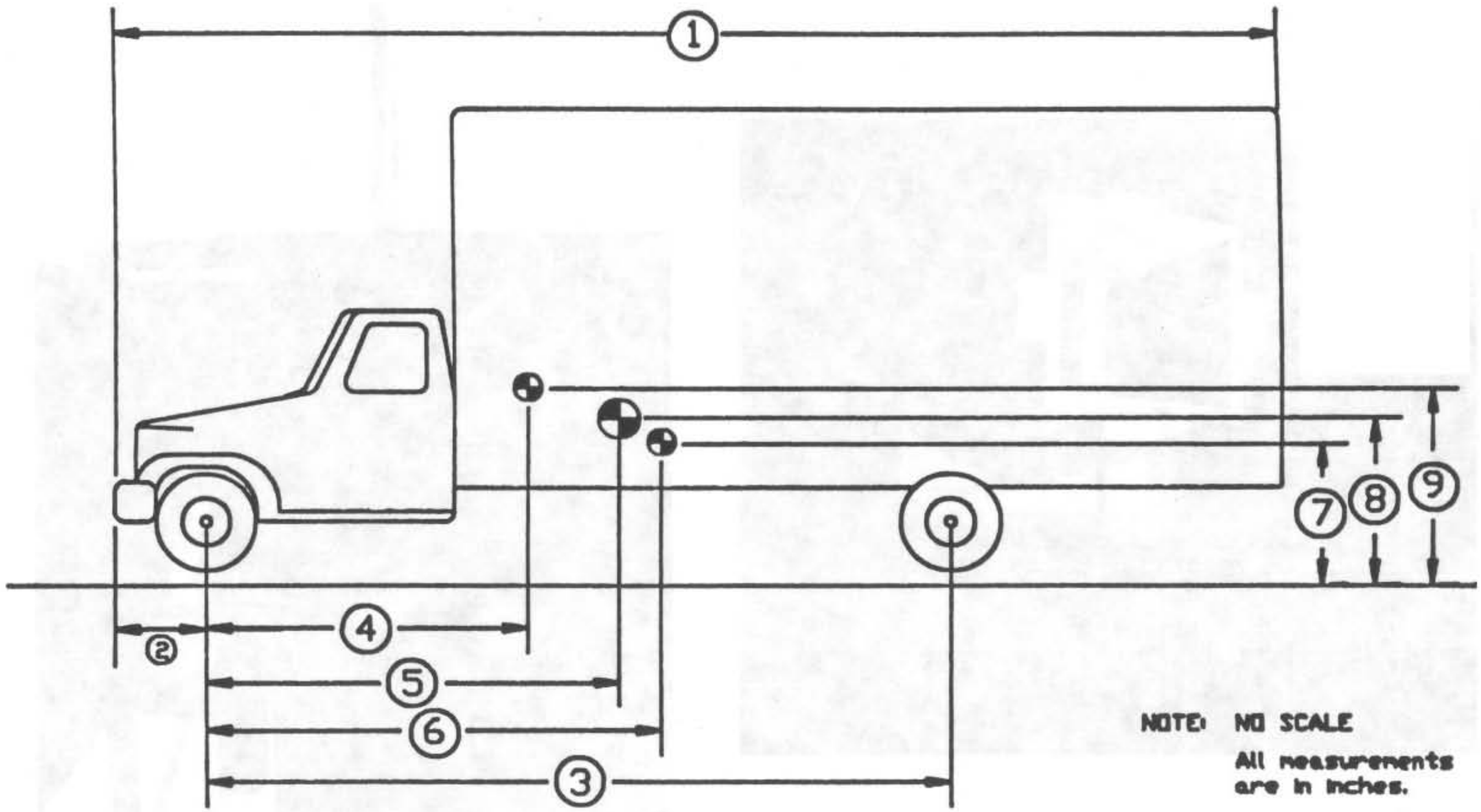
The Elevated Axle Method(5), was used to determine the vertical component of the center of gravity. This method converts measured wheel weights at different elevations to the location of the vertical component of the center of gravity. The longitudinal component of the center of gravity was determined using the measured axle weights. The location of the final center of gravity is shown in Figure 8.

The ballast used for the test vehicle consisted of a reinforced concrete block which was bolted to the floor of the box as shown in Figure 9. The location of the ballast is shown in Figure 8. This position was strategically located in order to shift the center of gravity to conform with the recommended values given in AASHTO (1). The vertical reinforcement used was 5/8 in. ASTM A325 all-thread rod and the longitudinal reinforcement was Grade 60 No. 6 reinforcing bars. The reinforcement design was capable of sustaining loads equivalent to 20 times the mass of the concrete block. The reinforcement arrangement and the concrete block is shown in Figure 9.

Test MS30-2

The test vehicle used for Test MS30-2 was a 1984 Dodge Colt. The test vehicle had a test inertial and gross static weight of 1,759 lbs. The Suspension Method (6), was used to determine the vertical component of the center of gravity. The longitudinal component of the center of gravity was determined using the measured axle weights. The curb weight matched the recommended values for the test inertial weight given in AASHTO (1), and therefore did not require ballasting. The test vehicle is shown in Figure 10, and the vehicle dimensions are shown in Figure 11.

DETERMINATION OF MASS CENTER



1. Overall Length 325.0
2. Front Overhang 33.0
3. Wheel Base 208.0
4. Ballast C.G. Longitudinal Distance 123.2
5. Total Weight C.G. Longitudinal Distance 120.6
6. Unballasted C.G. Longitudinal Distance 118.8
7. Unballasted C.G. Height 43.2
8. Total Weight C.G. Height 49.0
9. Ballast C.G. Height 57.3

FIGURE 8. Location of Center of Gravity, MS30-1

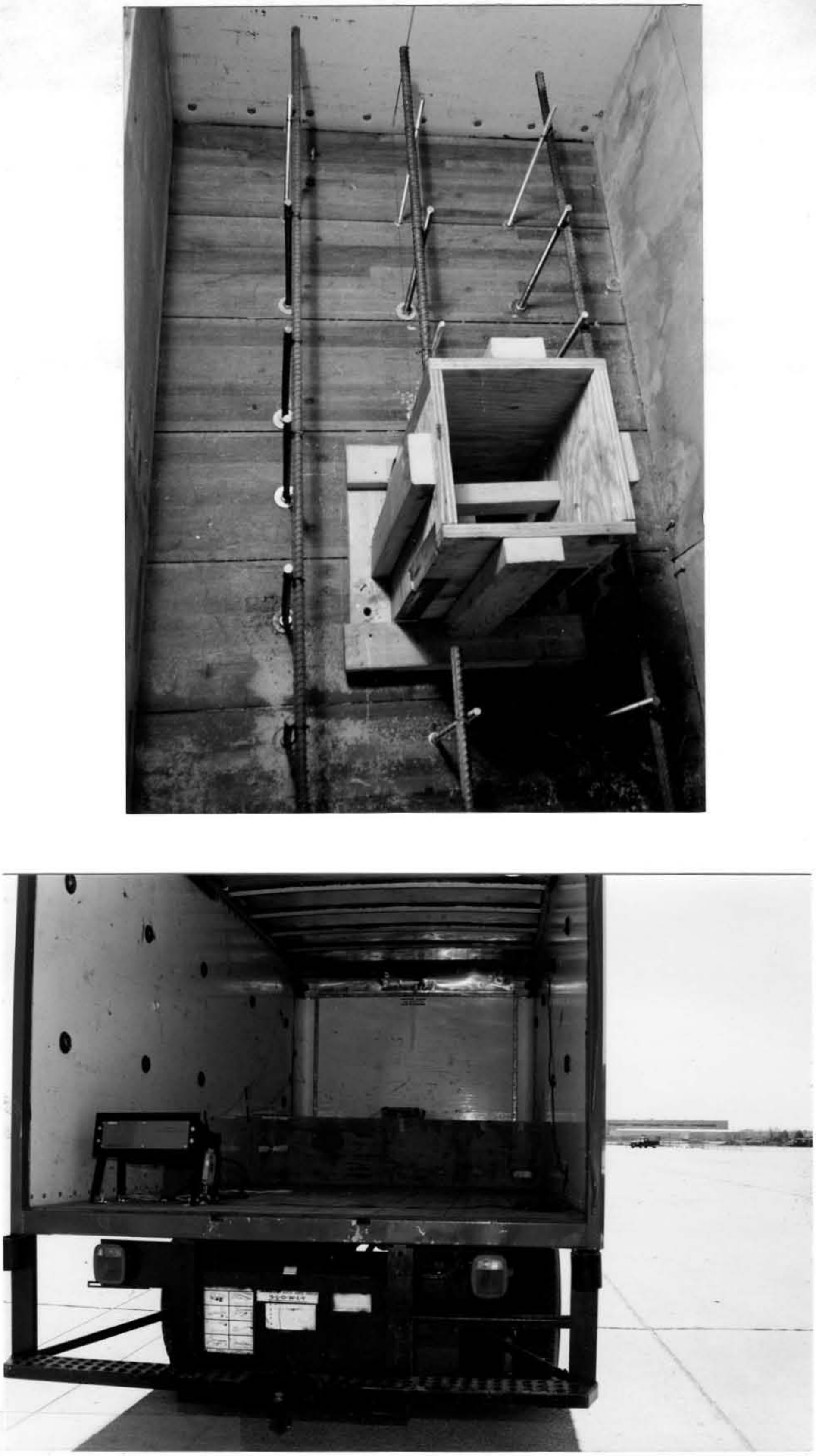
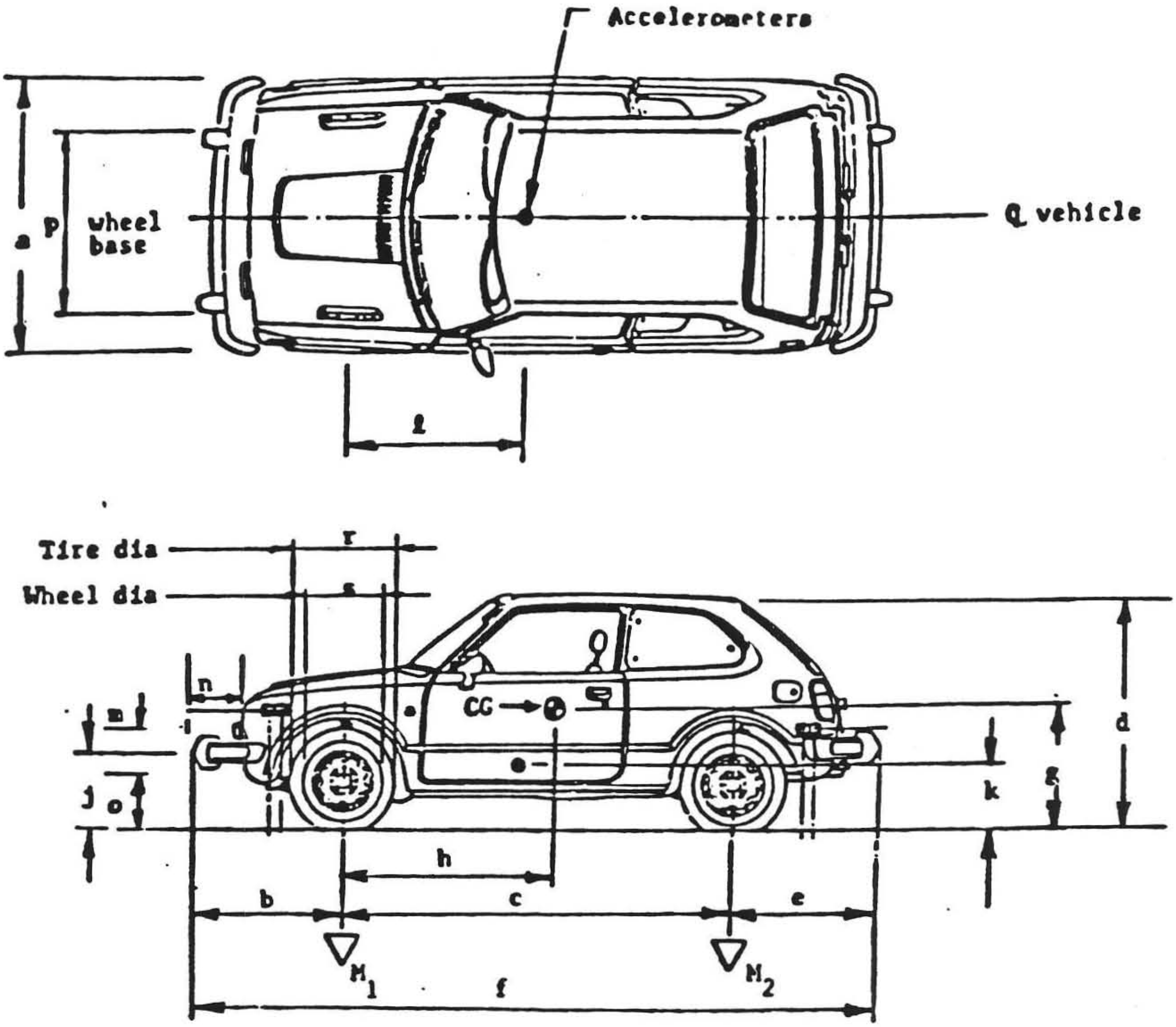


FIGURE 9. Concrete Block used for Ballast, MS30-1

FIGURE 10. Test Vehicle, MS30-2



Geometry - in. (in.)

a	62.0	d	52.0	j	18.0	m	5.0	p	54.0
b	33.5	e	32.0	k	17.0	n	6.25	r	22.5
c	90.0	f	155.5	ℓ	46.5	o	15.5	s	14.0

Mass - lb (kg)	Curb	Test Inertial*	Gross Static**
M_1	1107	1157	1157
M_2	552	602	602
M_T	1659	1759	1759
h - in. (m)	46.5	46.5	46.5
g - in. (m)	22.2	22.2	22.2

FIGURE 11. Test Vehicle Dimensions, MS30-2

Test MS30-3

The test vehicle used for Test MS30-3 was a 1984 Chevrolet Silverado pickup. This test vehicle had a test inertial and a gross static weight of 5,460 lbs.The test vehicle is shown in Figure 12, and the vehicle dimensions are shown in Figure 13.

The Elevated Axle Method (5), was used to determine the vertical component of the center of gravity. The longitudinal component of the center of gravity was determined using the measured axle weights. The ballast used for this test vehicle consisted of steel plates bolted to the floor of the pickup box. The mass of this ballast was 312 lb, and the attachment design was capable of withstanding 20 times this mass of the steel plates. The position of the ballast was strategically located in order to shift the center of gravity to conform with the recommended values given in AASHTO (1).

Targets were placed on the vehicles to aid in the high speed film analysis. Two targets were located on the center of gravity, one on the top and one on the driver's side of the vehicle. The remaining targets were located such that they could be viewed from all three cameras.

The front wheels of the test vehicles were aligned for camber, caster, and toe-in values of zero so that they would track properly along the guide cable. Two 5B flash bulbs were mounted on the roof of each test vehicle to pinpoint the time of impact with the bridge 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

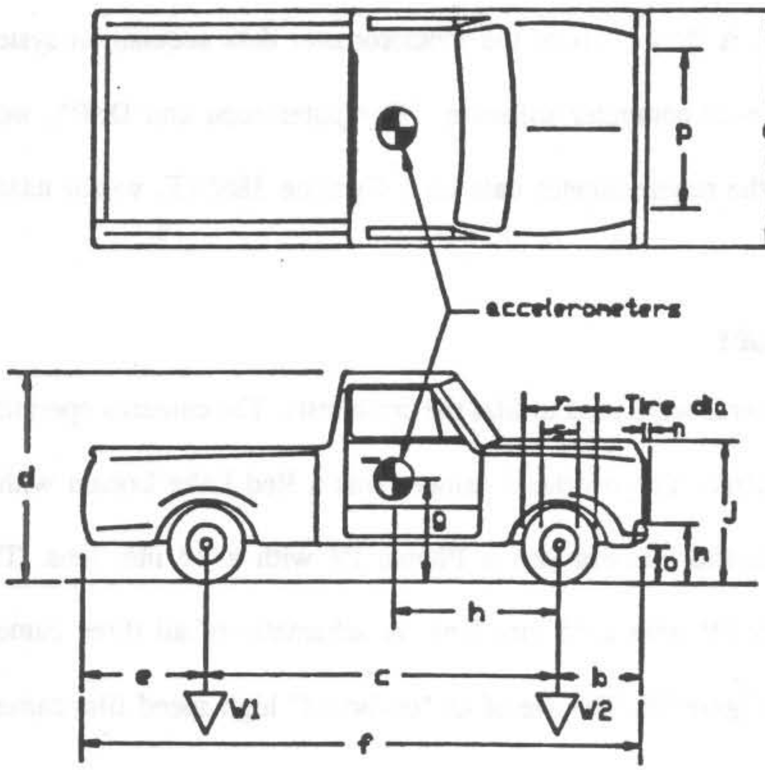
Four Endevco triaxial piezoresistive accelerometers (Model 7264) with a range of $\pm$ 200 g's were used to measure the acceleration in the longitudinal and the lateral directions of the test vehicle. Two accelerometers were mounted in each of these directions in order to validate results.

FIGURE 12. Test Vehicle, MS30-3

Date: 6-14-91 **Test No.:** MS30-3 **Vehicle I.D. #:** GCGC24W4ES104524

Make: CHEVROLET **Model:** SILVERADO **Year:** 1984 **Odometer:** 56,015

Tire Size: LT245-7.5R16



Vehicle Geometry - inches

a	79.25	b	34.0
c	131.75	d	71.0
e	50.5	f	216.25
g	28.0	h	63.5
i	–	j	44.5
k	–	l	–
m	27.0	n	3.5
o	7.5	p	69.5
r	29.5	s	17.5

Engine Type: GASOLINE

Engine Size: 454 V8

4 - wheel weight: lf____ rf____ lr____ rr____

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Weight - pounds	Curb	Test Inertial	Gross Static
W1	2153	2389	2389
W2	2835	3071	3071
Wtotal	4988	5460	5460

Note any damage prior to test: Cracked windshield on passenger side

FIGURE 13. Test Vehicle Dimensions, MS30-3

The accelerometers were rigidly attached to a metal block mounted at the center of gravity. The accelerometer locations for each test vehicle are shown in Figure 14. The accelerometers were rigidly attached to a metal block mounted at the center of gravity. The accelerometer locations for each test vehicle are shown in Figure 14.

The signals from the accelerometers were received and conditioned by an onboard vehicle metraplex unit. The multiplexed signal was then transmitted to the Honeywell 101 analog tape recorder in the central control van. A flow chart of the accelerometer data acquisition system is shown in Figure 15. State-of-the-art computer software, "Computerscope and DSP", were used to collect, analyze, and plot the accelerometer data on a Cyclone 386/AT, which uses a high-speed data acquisition board.

2.4.2 High Speed Photography

Three high speed 16mm cameras were used to film the crash tests. The cameras operating speed is approximately 500 frames/sec. The overhead camera was a Red Lake Locam with a wide angle 12.5 mm lens. The parallel camera was a Photec IV with a 80 mm lens. The perpendicular camera was a Photec IV with a 55 mm lens. A schematic of all three camera locations for each test is shown in Figure 16. The use of an "on-board" high speed film camera was used in Test MS30-3.

A 20 ft wide by 100 ft long grid was painted on the concrete surface parallel and perpendicular to the barrier. The white colored grid was incremented with 5 ft divisions in both directions to give a 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 actual camera speed and the camera divergence factors were taken into consideration in the analysis of the high speed film.

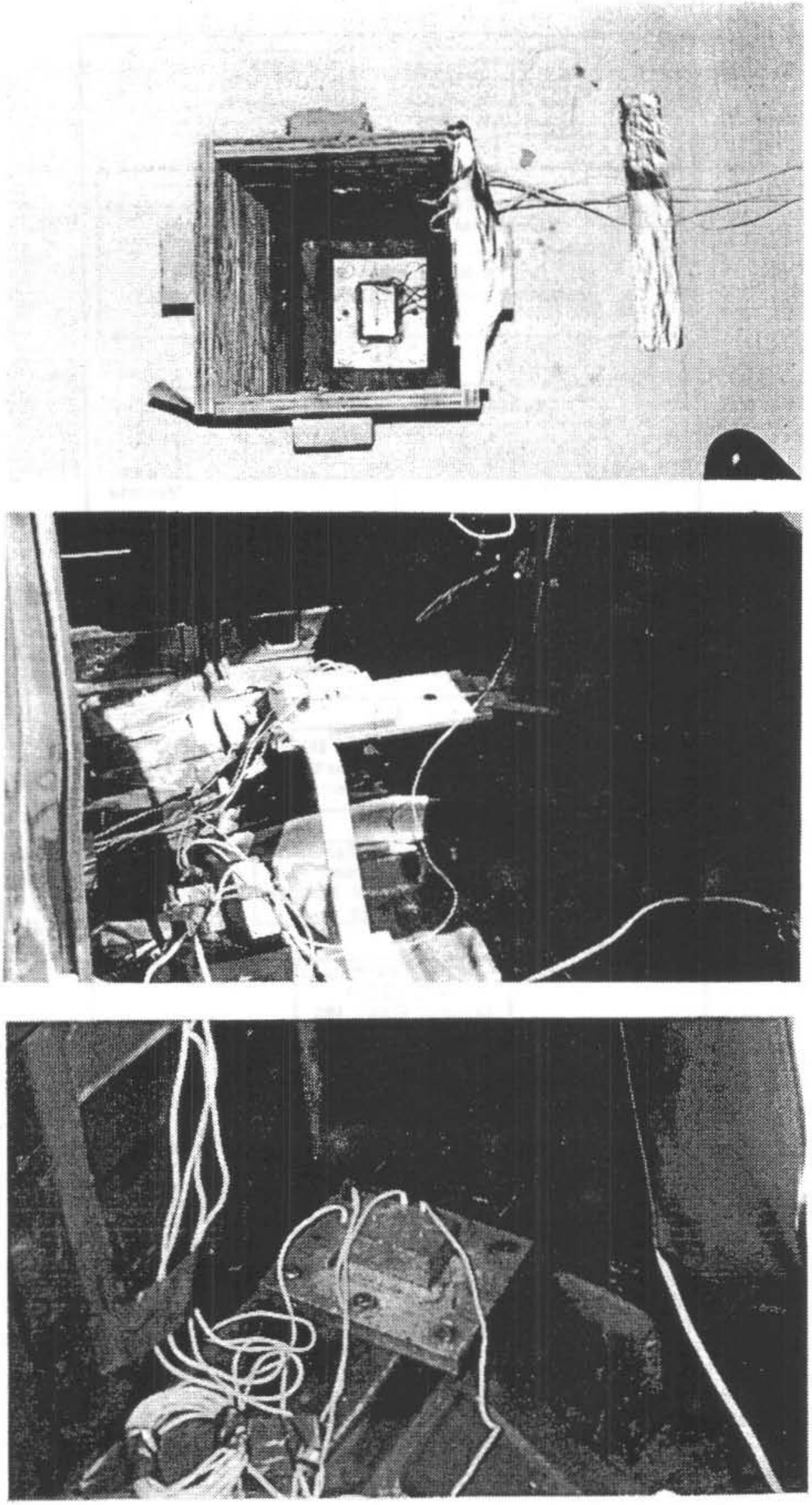


FIGURE 14. Accelerometer Locations, Tests MS30-1,2,3

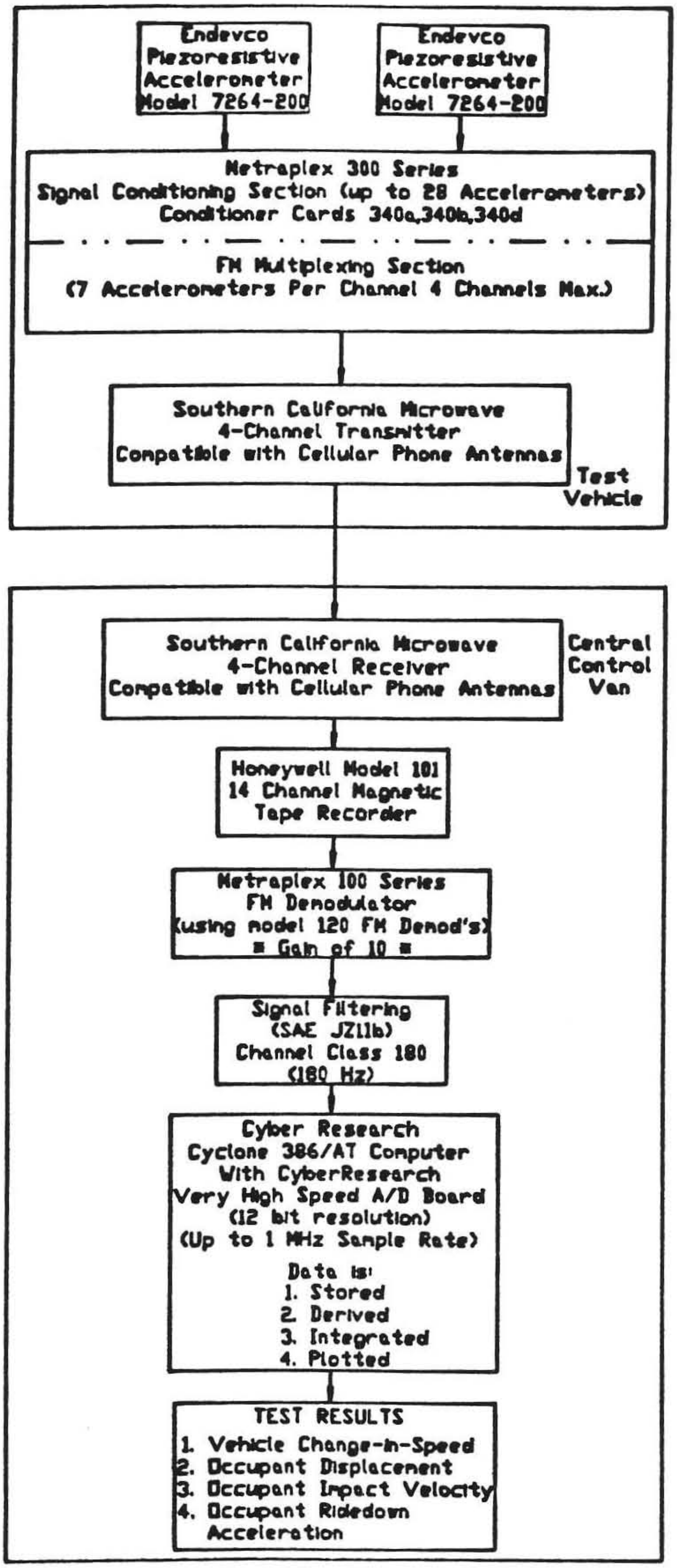


FIGURE 15. Flow Chart of Accelerometer Data Acquisition System

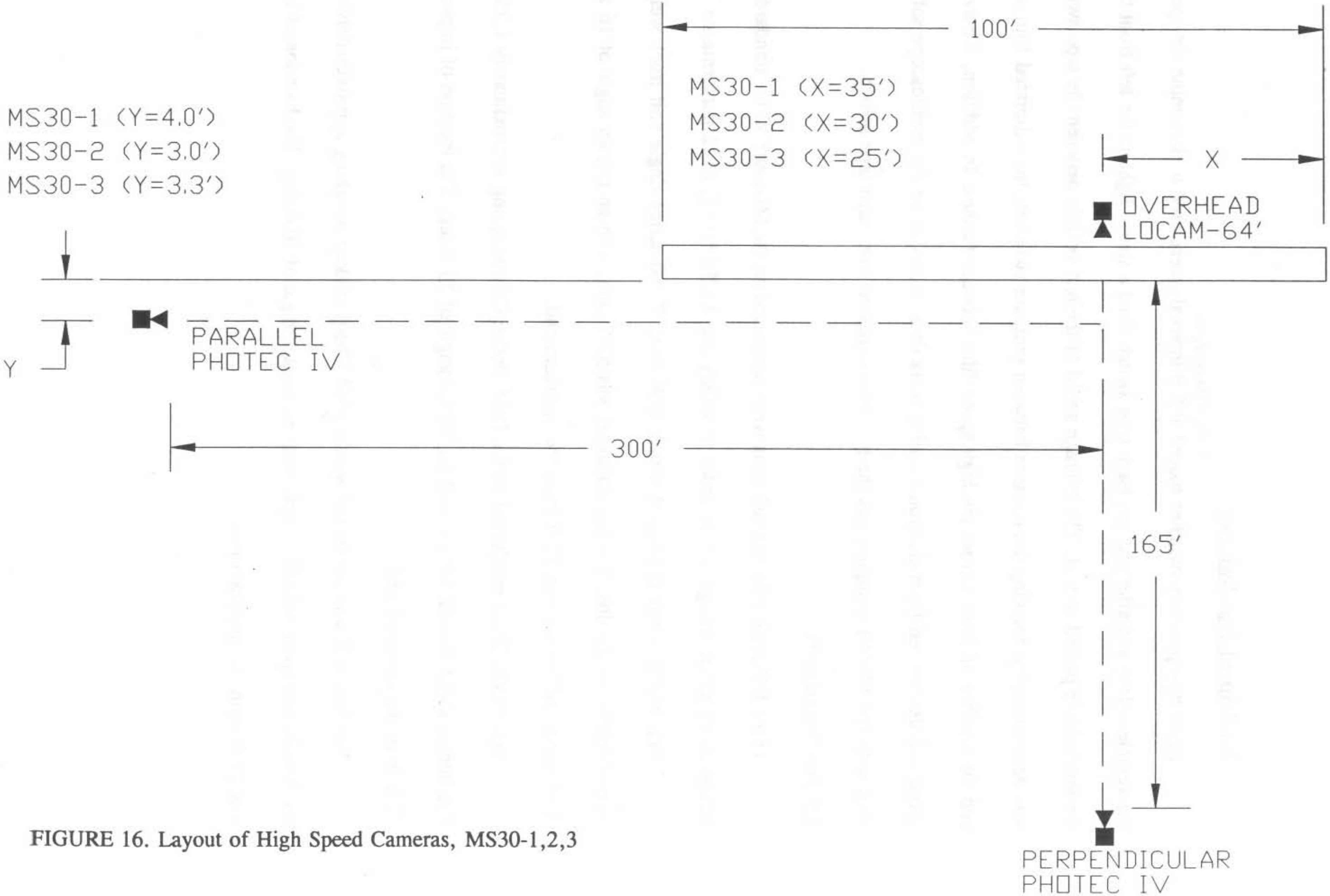


FIGURE 16. Layout of High Speed Cameras, MS30-1,2,3

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 strobe light 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 film 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 Missouri 30 in. standard New Jersey safety shape bridge rail in order to satisfy the AASHTO (1) PL-2 performance level.

Test MS30-1 was conducted with a 1986 Ford F-700 series single unit truck weighing approximately 18,011 lbs. The impact speed was 52.5 mph, with an impact angle of 16.1 deg. The location of impact was 35 ft from the upstream end.

Test MS30-2 was conducted with a 1984 Dodge Colt weighing approximately 1,759 lbs. The impact speed was 62.5 mph, with an impact angle of 20.0 deg. The location of impact was 30 ft from the upstream end.

Test MS30-3 was conducted with a 1984 Chevy pickup weighing approximately 5,460 lbs. The impact speed was 63.5 mph, with an impact angle of 20.0 deg. The location of impact was 25 ft from the upstream end.

3 PERFORMANCE EVALUATION CRITERIA

The safety performance objective of a bridge rail is to reduce death and injury to the occupants of errant vehicles and to protect lives and property on, adjacent to, or below a bridge (1). In order to prevent or reduce the severity of such accidents, special attention should be given to four major bridge rail characteristics. These characteristics are: (1) railing strength to resist impact forces; (2) effective railing height; (3) shape of the face of the railing; and (4) deflection characteristics of the railing (7). When careful consideration is given to these areas, the likelihood of a successful safety performance is increased.

The major concern of this installation was the reduced height of the bridge rail. The rail must have adequate height in order to prevent vehicles from rolling over the railing. In the case of the small car and the pickup truck it must also prevent the vehicle from rolling onto its side away from the railing after redirection.

The performance evaluation criteria used to evaluate the three crash tests were taken from AASHTO (1). The test conditions for the required test matrix are shown in Table 1. The specific evaluation criteria are shown in Table 2. The safety performance of the bridge rail was evaluated according to three major factors: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. These three evaluation criteria are defined and explained in NCHRP 230. The vehicle damage was assessed by the traffic accident scale (TAD) (8) and the vehicle damage index (VDI) (9).

Table 1. Crash Test Conditions and Evaluation Criteria

Guidelines	Performance Level	Appurtenance	Test Vehicle	Impact Conditions		Evaluation Criteria[1]	
				Speed (mph)	Angle (deg)	Required	Desirable
AASHTO	PL-2	Bridge Rail	Small Automobile	60	20	3. a,b,c, d,g	3. e,f,h
AASHTO	PL-2	Bridge Rail	Pickup Truck	60	20	3. a,b,c,d	3. e,f,g,h
AASHTO	PL-2	Bridge Rail	Medium Single Unit Truck	50	15	3. a,b,c	3. d,e,f,h

[1] - Evaluation criteria explained in Table 2.

Table 2. AASHTO Evaluation Criteria

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.
3.b.	Detached elements, fragments, or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.
3.c.	Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.
3.d.	The vehicle shall remain upright during and after collision.
3.e.	The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.
3.f.	The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ, where $\mu = (\cos\theta - V_p/V)/\sin\theta$. μ — Assessment 0.0 - 0.25 — Good 0.26 - 0.35 — Fair > 0.35 — Marginal
3.g.	The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0 ft longitudinal and 1.0 ft lateral displacements, shall be less than: Occupant Impact Velocity - fps Longitudinal: 30 — Lateral: 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 Longitudinal: 15 — Lateral: 15
3.h.	Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20 ft from the line of the traffic face of the railing.

4 TEST RESULTS

4.1 Test MS30-1 (18,011 lb, 52.5 mph, 20.0 deg)

After the initial impact with the bridge rail (35 ft from the upstream end), the right front corner crushed inward causing the right front fender to ride along the top of the rail. At 0.15 sec after impact, the cab began to ride up the rail, rolling in a counterclockwise direction. At 0.30 sec, the front axle broke away from the frame on the right side and rotated inward underneath the truck. At this time, the cab had a roll angle of approximately 30 deg counterclockwise, and the box remained level with the bridge rail. The front of the truck extended over the top as it travelled longitudinally along the bridge rail, leaving the axle assembly on the traffic side of the rail.

At 0.42 sec, the cab began to rotate in an opposite manner (clockwise), with a clockwise yaw motion occurring simultaneously. The box began its clockwise roll motion at this time. The combined effects of both the clockwise roll and yaw motions caused the rear end to uplift. This yaw motion continued for the remaining length of the rail. During the clockwise roll motion, the cab became level at 0.54 sec, and continued in a clockwise roll motion. At 0.66 sec, the cab and box were rolling in the same direction (clockwise).

The front of the vehicle reached the end of the rail at approximately 0.9 sec. At this time, a significant portion of the vehicle was extended over the top of the bridge rail. Although there was no physical evidence that the right front corner of the truck touched down behind the bridge railing. The front axle assembly connection broke away from the truck at this time. The cab began a redirection (counterclockwise) as it exited the end of the bridge rail. At 1.09 sec, the entire vehicle was free of the bridge rail and was rolling counterclockwise back away from the bridge rail. The vehicle came to rest, approximately 183 ft downstream from impact. The vehicle remained upright both during and after the collision. The vehicle trajectory after impact indicated no intrusion into the adjacent traffic lanes.

Bridge rail damage is shown in Figure 17. Concrete spalling occurred at the point of impact due to the right front wheel crushing into the bridge rail. Spalling also occurred along the top of the rail due to the undercarriage of the vehicle sliding along the top of the rail. No visible lateral movement of the rail occurred as a result of the collision. Tire marks were visible on the face of the rail for a length of about 17 ft after impact.

Vehicle damage is shown in Figure 18. Most of the vehicle damage occurred to the undercarriage. The front axle assembly was disengaged from its original position. The right rear wheels were damaged and the drive shaft was separated from the transmission. There was no intrusion or deformation of the occupant compartment.

The longitudinal occupant impact velocity was determined to be 11.1 fps and the lateral occupant impact velocity was 9.7 fps. The highest 0.010-sec average occupant ridedown decelerations were 2.1 g's (longitudinal) and 3.0 g's (lateral). The results of the occupant risk, determined from accelerometer data, are summarized in Figure 19. The results are shown graphically in Appendix B.

A summary of the test and sequential photographs are shown in Figure 19. Additional sequential photographs are shown in Figures 20, 21, and 22. The performance of the bridge rail was determined to be satisfactory for this test.

4.2 Test MS30-2 (1,759 lb, 62.5 mph, 20.0 deg)

After the initial impact with the bridge rail (30 ft from the upstream end), the right front corner crushed inward causing the corner of the hood to extend over the top of the rail. Following the initial impact, a counterclockwise rolling motion away from the bridge rail occurred. The vehicle became parallel with the bridge rail 0.15 sec after impact, and exited at 0.28 sec, which was approximately 20 ft from impact. The continued counterclockwise rolling

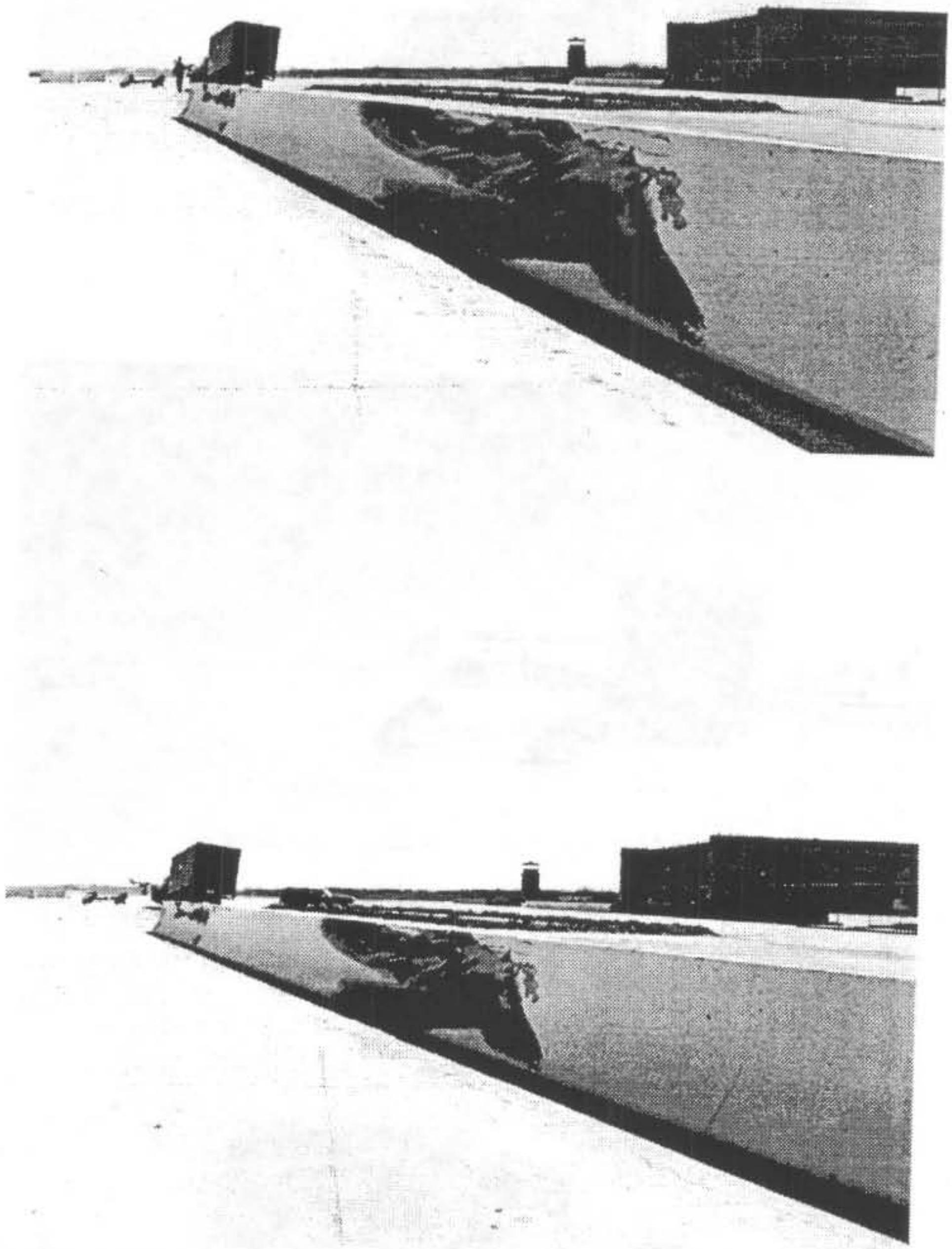
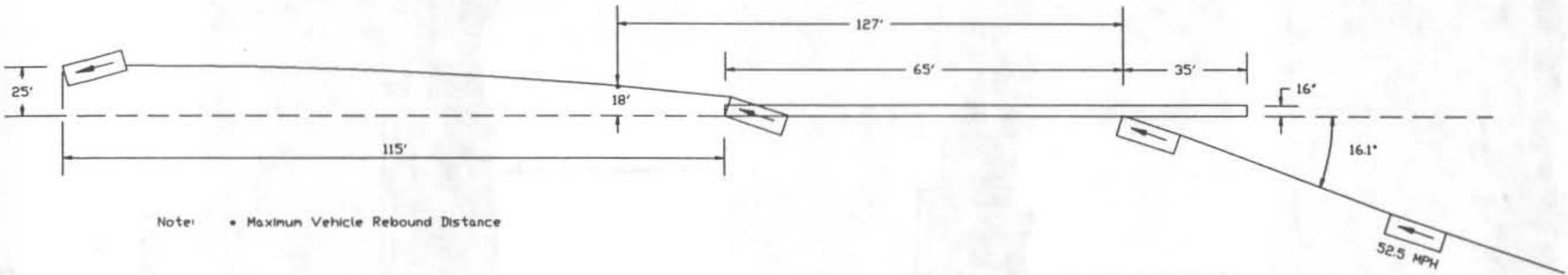


FIGURE 17. Bridge Rail Damage, MS30-1

FIGURE 18. Test Vehicle Damage, MS30-1

Impact | 0.55 sec | 1.09 sec | 1.64 sec | 2.19 sec



· Test Number	MS30-1
· Date	4/15/91
· Installation	30 in. N.J. Safety Shape
· Total Length	100 ft
· Concrete Bridge Rail	
Material	Ne.Special Mix (47-B)
Length	100 ft
Weight	340 lb/ft
Area	2.27 ft^2
Height	30 in.
Lower Vertical Face	1 in.
Middle Inclined Surface	
Length	10 in.
Inclination	55 deg
Upper Inclined Surface	
Length	19 in.
Inclination	84 deg
Base Width	16 in.
Top Width	7 in.

· Vehicle Model	1986 Ford F-700
· Vehicle Weight	
Test Inertia	18,011 lb
Gross Static	18,011 lb
· Vehicle Impact Speed	52.5 mph
· Vehicle Exit Speed	NA
· Vehicle Impact Angle	16.1 deg
· Vehicle Exit Angle	NA
· Vehicle Snagging	None
· Effective Coef. of Friction	NA
· Vehicle Stability	Marginal
· Occupant Impact Velocity	
Longitudinal	11.1 fps
Lateral	9.7 fps
· Occupant Ridedown Deceleration	
Longitudinal	2.1 g's
Lateral	3.0 g's
· Vehicle Damage	
TAD	1-RFQ-3
VDI	01RFWS1
· Vehicle Rebound Distance	18 ft
Bridge Rail Damage	Minor Spalling

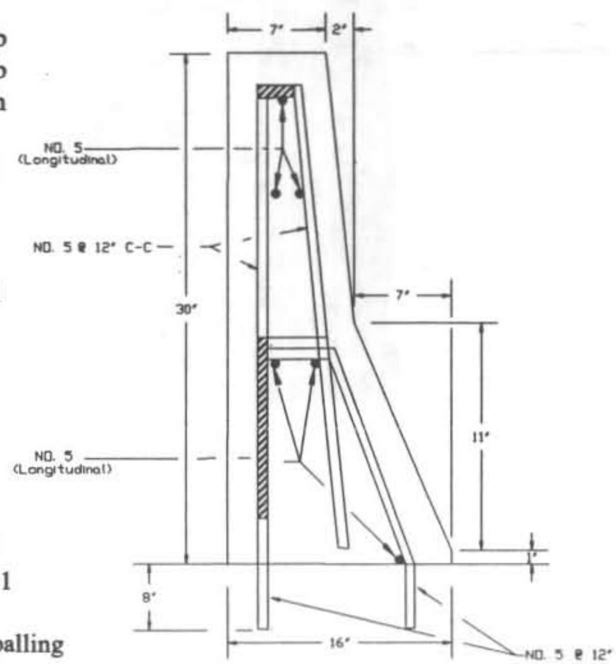


FIGURE 19. Summary and Sequential Photographs, MS30-1

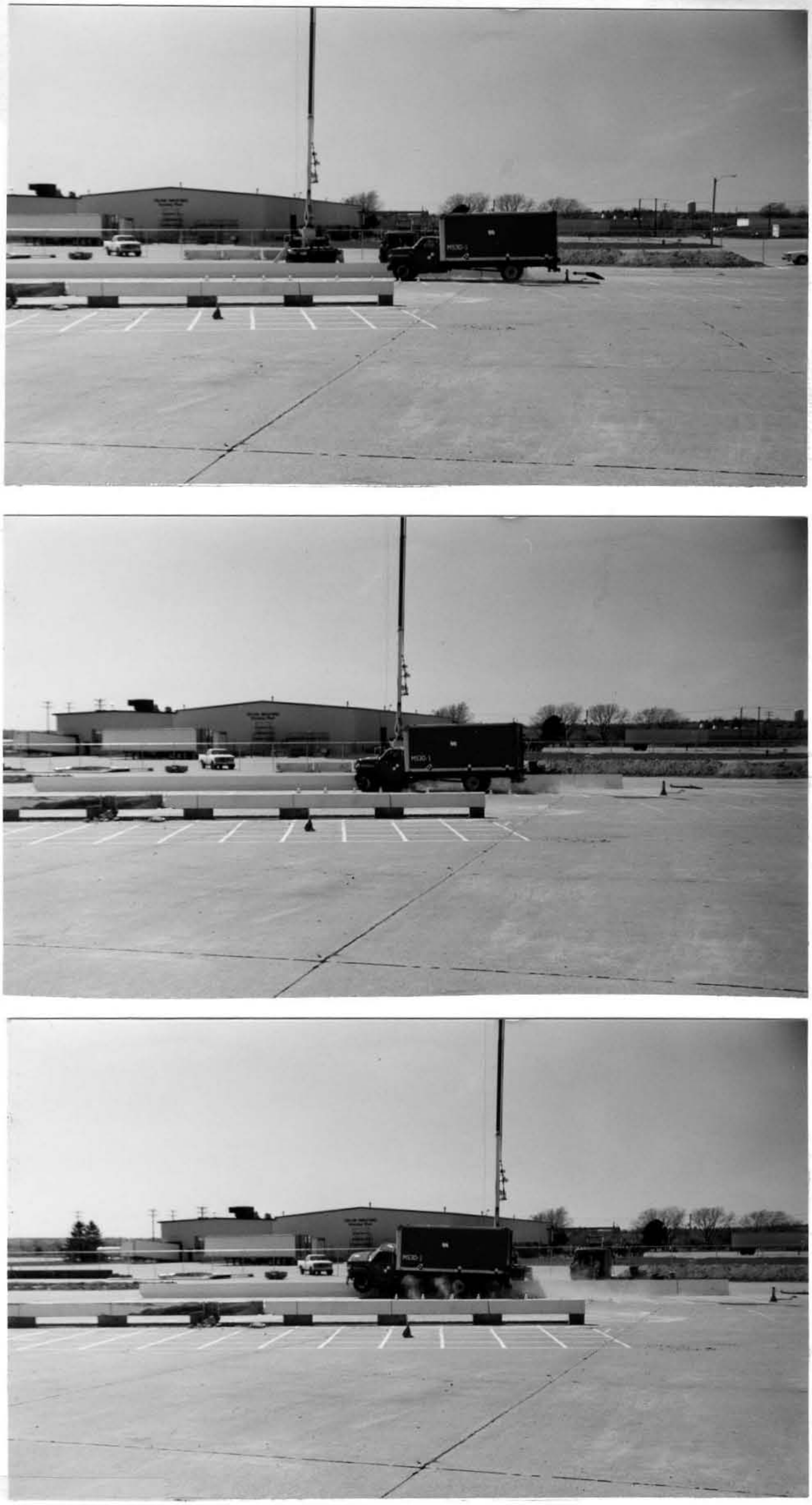


FIGURE 20. Full-Scale Vehicle Crash Test, MS30-1

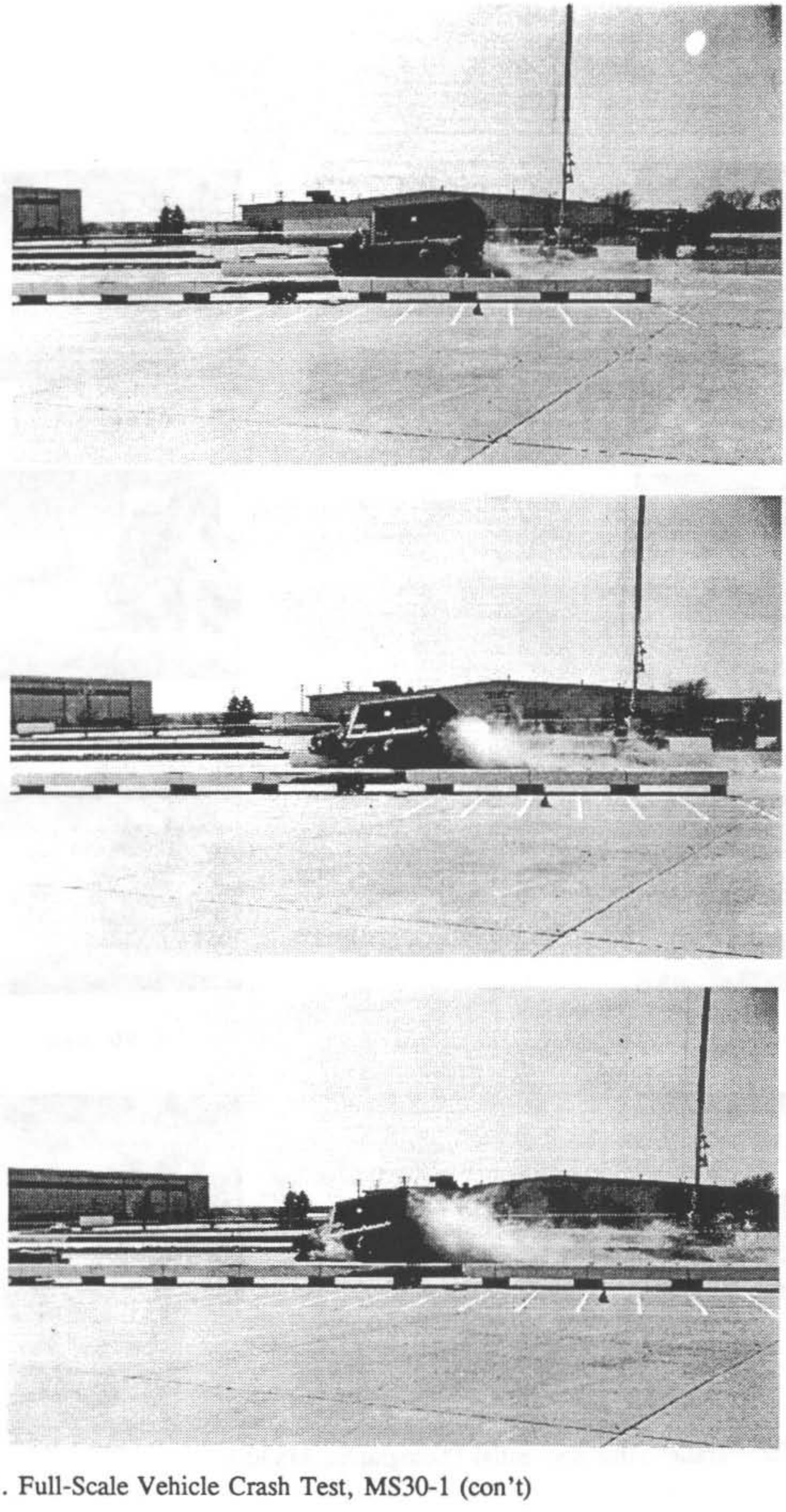
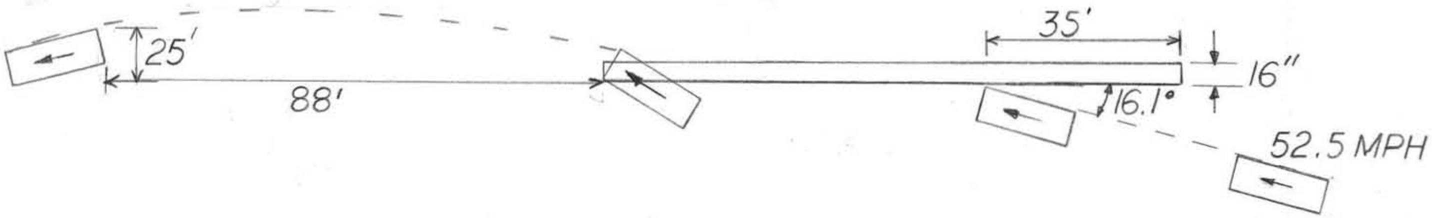


FIGURE 21. Full-Scale Vehicle Crash Test, MS30-1 (con't)

Impact | 0.55 sec | 1.09 sec | 1.64 sec | 2.19 sec



· Test Number	MS30-1
· Date	4/15/91
· Installation	30 in. high Bridge Rail
· Total Length	100 ft
· Concrete Bridge Rail	
Material	Nebraska Class 47-B-Special Mix
Length	100 ft
Weight	340 lb./ft
Area	2.27 ft^2
Height	30 in.
Lower Vertical Face	1 in.
Middle Inclined Surface	
Length	10 in.
Inclination	55 deg
Upper Inclined Surface	
Length	19 in.
Inclination	84 deg
Base Width	16 in.
Top Width	7 in.

· Vehicle Model	1986 Ford F-700
· Vehicle Weight	
Test Inertia	18,111 lbs.
Gross Static	18,111 lbs.
· Vehicle Impact Speed	52.5 mph
· Vehicle Exit Speed	32.8 mph
· Vehicle Impact Angle	16.1 deg
· Vehicle Exit Angle	0.0 deg
· Vehicle Snagging	None
· Vehicle Stability	Marginal
· Occupant Impact Velocity	
Longitudinal	11.07 fps
Lateral	9.70 fps
· Occupant Ridedown Deceleration	
Longitudinal	2.11 g's
Lateral	3.00 g's
· Vehicle Damage	
TAD	1-RFQ-3
VDI	01RFWS1
· Vehicle Rebound Distance	18 ft
· Bridge Rail Damage	Minor Spalling

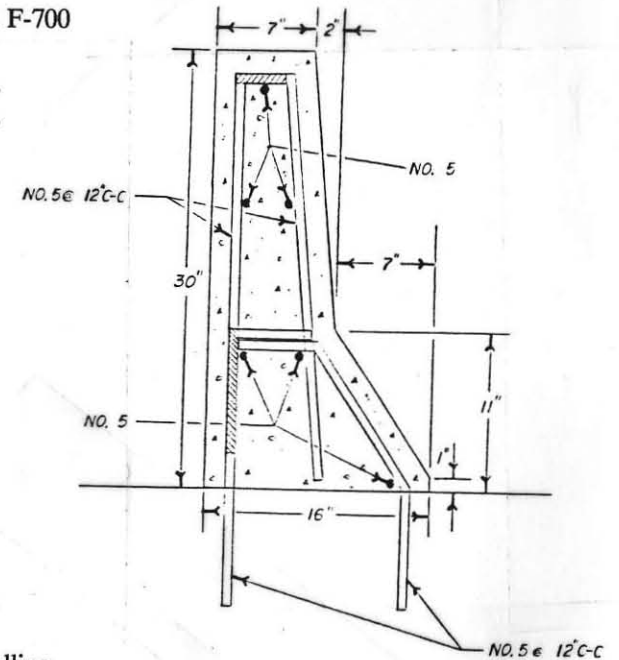


FIGURE 19. Summary and Sequential Photographs, MS30-1

motion caused the vehicle to become completely airborne at 0.31 sec. It was airborne until the left front wheel touched down at 0.60 sec.

The touchdown signified the maximum roll angle; although this angle could not be measured. The touchdown also caused the vehicle to roll clockwise towards the rail. The vehicle became level at 0.94 sec. Continuing the clockwise roll motion, the left side began to uplift. The vehicle then began a final rolling motion counterclockwise which returned the vehicle to its level position at 3.34 sec. The vehicle came to a rest, approximately 230 ft downstream of impact. The vehicle remained upright both during and after the collision; although excessive roll motion occurred during the test. Vehicle trajectory after impact indicated minimal intrusion into the adjacent traffic lanes.

Bridge rail damage is shown in Figure 23. This damage was minimal. Tire and paint marks, along with scrapes, accounted for the majority of the damage. The marks on the bridge rail indicated that the vehicle was in contact for approximately 12 ft. No visible lateral movement of the bridge rail occurred as a result of the collision.

Vehicle damage is shown in Figure 24. The damage was mainly to the right front corner, consisting of wheel, bumper, fender, and axle damage. Slight buckling of the roof was also apparent. There was no intrusion or deformation of the occupant compartment.

The longitudinal occupant impact velocity was determined to be 11.9 fps and the lateral occupant impact velocity was 26.5 fps. The highest 0.010-sec average occupant ridedown decelerations were 5.5 g's (longitudinal) and 9.0 g's (lateral). The results of the occupant risk, determined from film analysis, are summarized in Figure 25. The results are shown graphically in Appendix C.

FIGURE 23. Bridge Rail Damage, MS30-2

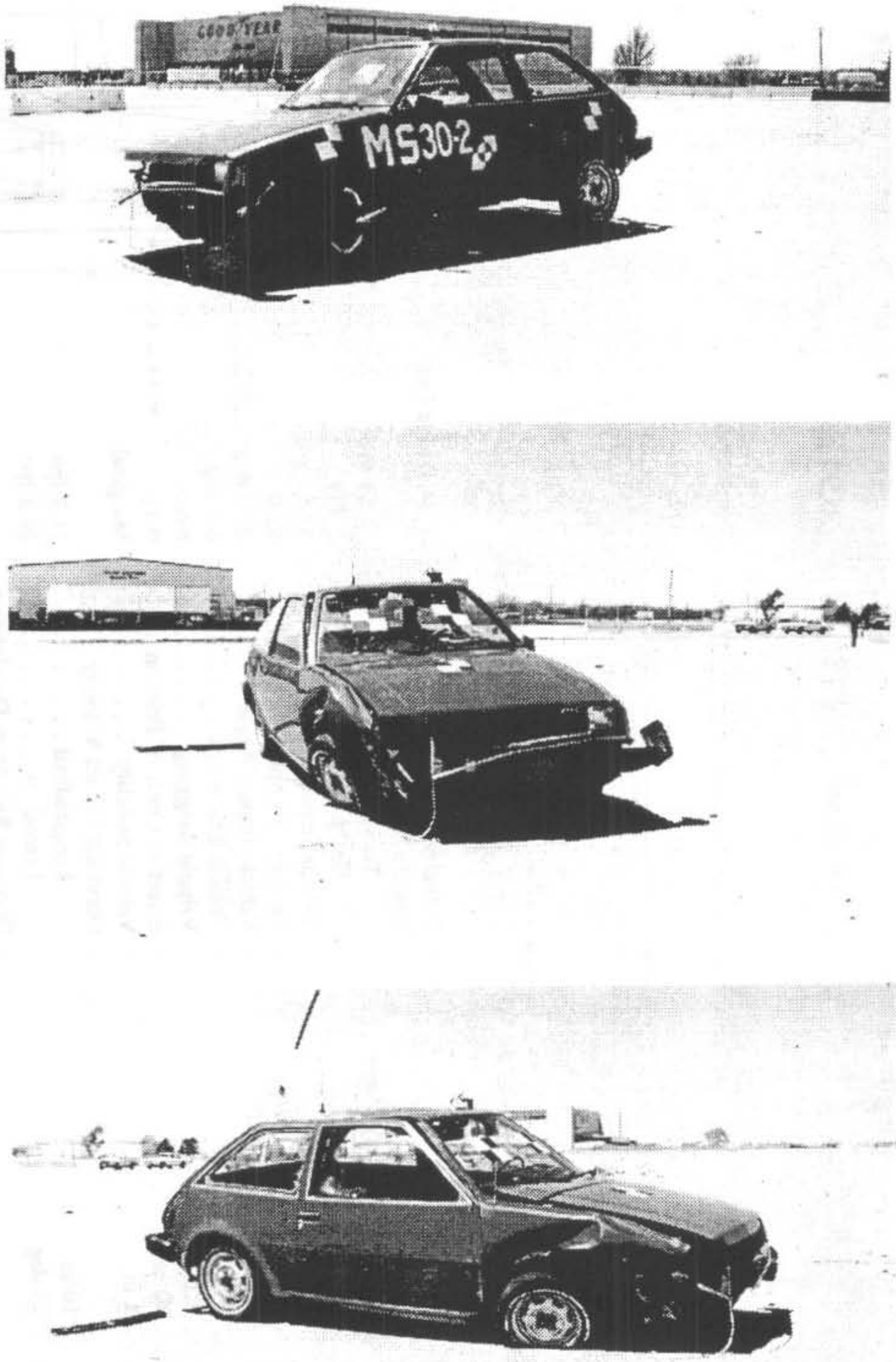
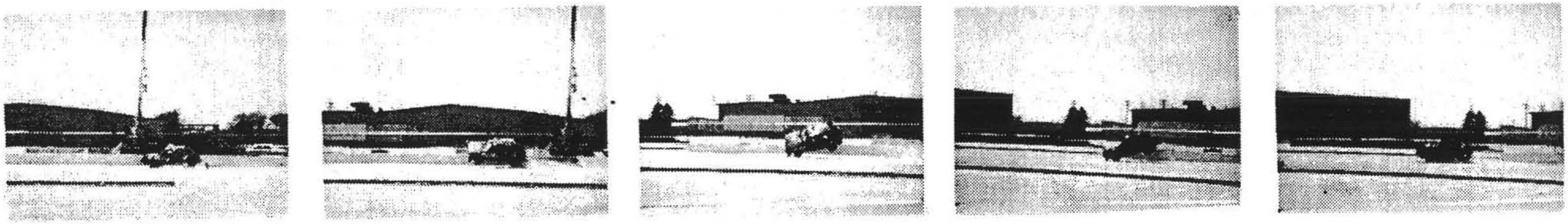
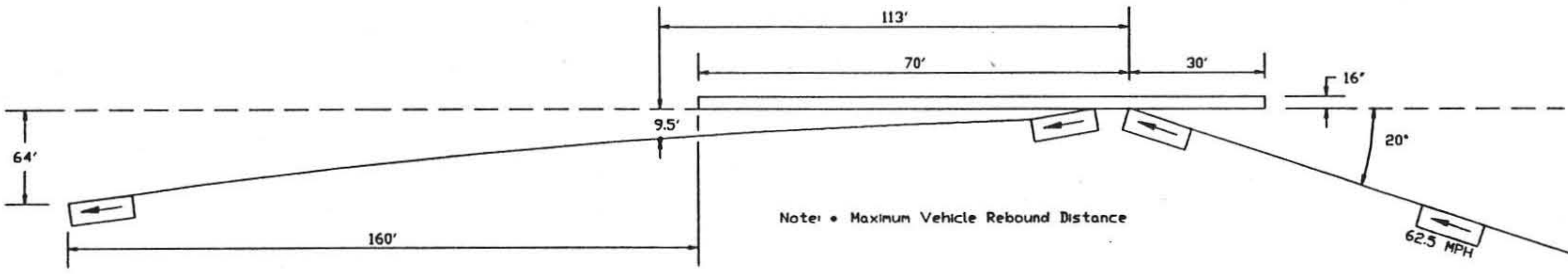


FIGURE 24. Test Vehicle Damage, MS30-2



Impact — 0.31 sec — 0.63 sec — 0.94 sec — 1.25 sec



· Test Number	MS30-2
· Date	5/1/91
· Installation	30 in. N.J. Safety Shape
· Total Length	100 ft
· Concrete Bridge Rail	
Material	Ne.Special Mix (47-B)
Length	100 ft
Weight	340 lb/ft
Area	2.27 ft^2
Height	30 in.
Lower Vertical Face	1 in.
Middle Inclined Surface	
Length	10 in.
Inclination	55 deg
Upper Inclined Surface	
Length	19 in.
Inclination	84 deg
Base Width	16 in.
Top Width	7 in.

· Vehicle Model	1984 Dodge Colt
· Vehicle Weight	
Test Inertia	1,759 lb
Gross Static	1,759 lb
· Vehicle Impact Speed	62.5 mph
· Vehicle Exit Speed	55.0
· Vehicle Impact Angle	20.0 deg
· Vehicle Exit Angle	6.6 deg
· Vehicle Snagging	None
· Effective Coef. of Friction	0.11
· Vehicle Stability	Marginal
· Occupant Impact Velocity	
Longitudinal	11.9 fps
Lateral	26.5 fps
· Occupant Ridedown Deceleration	
Longitudinal	5.5 g's
Lateral	9.0 g's
· Vehicle Damage	
TAD	1-RFQ-4
VDI	01RFES1
· Vehicle Rebound Distance	9.5 ft
· Bridge Rail Damage	Minor Spalling

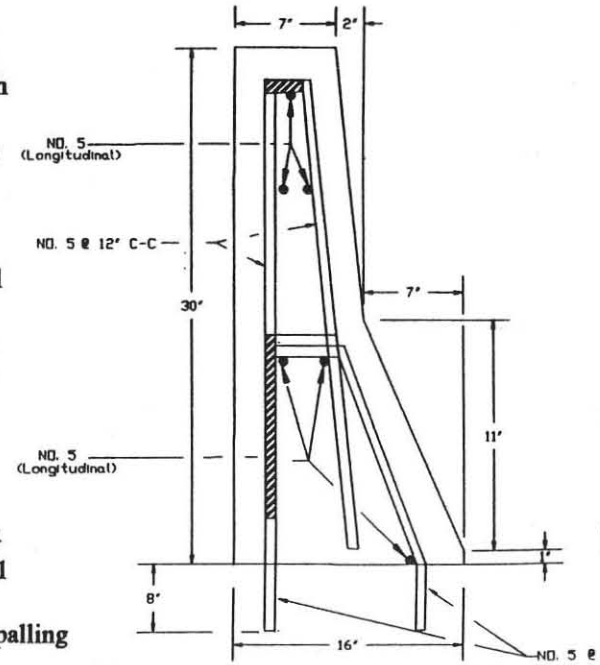


FIGURE 25. Summary and Sequential Photographs, MS30-2

A summary of the test and sequential photographs are shown in Figure 10. Additional sequential photographs are shown in Figures 26, 27, and 28. The performance of the bridge rail was determined to be satisfactory for this test.

4.3 Test MS30-3 (5,460 lb, 63.5 mph, 20.0 deg)

After the initial impact with the bridge rail (25 ft from the upstream end), the right front corner of the truck was crushed inward. This maximum crushing distance was approximately 2 ft. At 0.13 sec after impact, the right front wheel began to climb up the rail. A parallel position with the bridge rail was obtained at 0.19 sec.

As the vehicle came out of the parallel position with the rail, the front wheels became airborne. At 0.49 sec, the left front wheel touched down causing the vehicle to skid away from the rail. At 0.91 sec, the vehicle regained a parallel position with the bridge rail, having a lateral offset of approximately 5 ft. The vehicle came to rest approximately 203 ft downstream of the of impact. The vehicle remained upright both during and after the collision. The vehicle trajectory after impact indicated minimal intrusion into the adjacent traffic lanes.

Bridge rail damage is shown in Figure 29. The damage was minimal. Tire marks and scrapes accounted for the majority of the damage. The marks on the rail were approximately 12 ft long. No visible lateral movement of the bridge rail occurred as a result of the collision.

Vehicle damage is shown in Figure 30. The damage was mainly to the right front corner of the vehicle. The passenger side door and rear wheel was also slightly damaged. The lower right corner of the windshield was also broken. There was no intrusion or deformation of the occupant compartment.

The longitudinal occupant impact velocity was determined to be 16.6 fps and the lateral occupant impact velocity was 14.2 fps. The highest 0.010-sec average occupant ridedown decelerations were 6.0 g's (longitudinal) and 6.6 g's (lateral).

FIGURE 26. Full-Scale Vehicle Crash Test, MS30-2

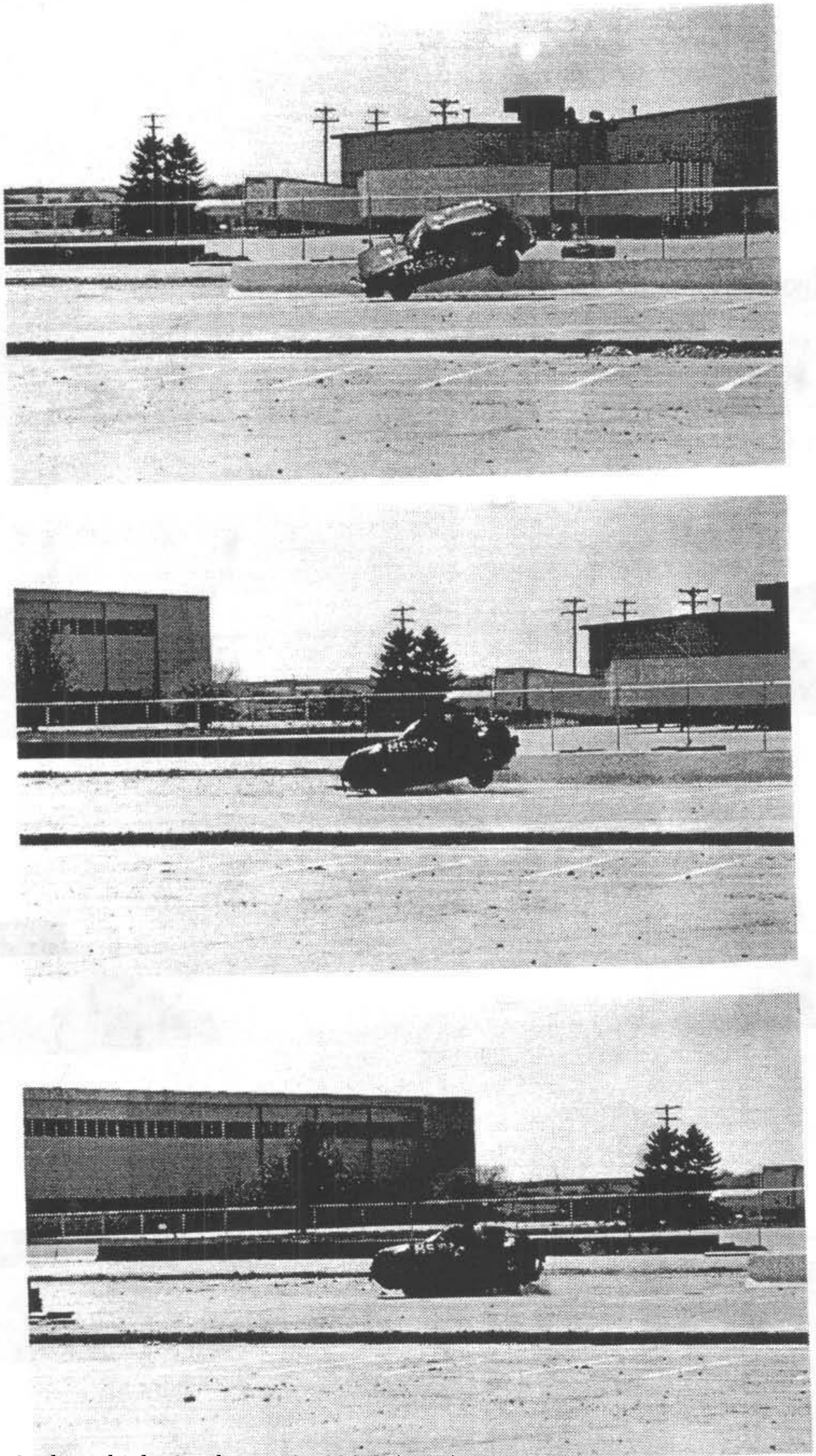
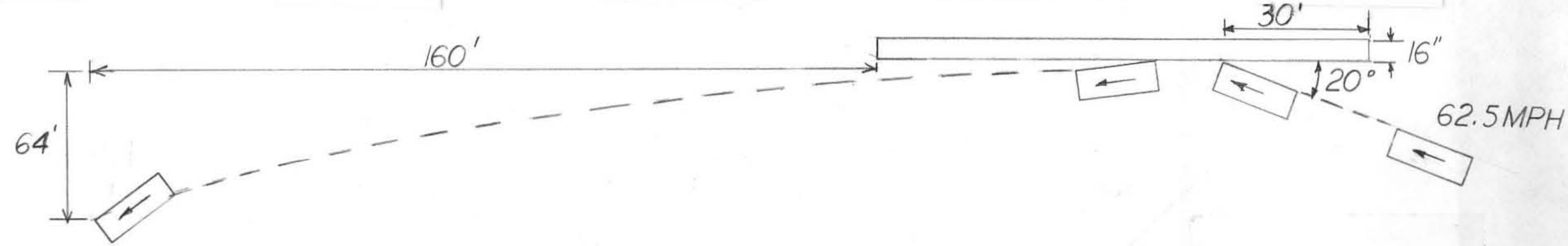


FIGURE 27. Full-Scale Vehicle Crash Test, MS30-2 (con't)

Impact | 0.31 sec | 0.63 sec | 0.94 sec | 1.25 sec



- Test Number MS30-2
- Date 5/11/91
- Installation .... 30 in. high Bridge Rail
- Total Length .... 100 ft
- Concrete Bridge Rail
  - Material .... Nebraska Class 47-B-Special Mix
  - Length .... 100 ft
  - Weight .... 340 lb./ft
  - Area .... 2.27 ft^2
  - Height .... 30 in.
  - Lower Vertical Face .... 1 in.
  - Middle Inclined Surface
    - Length .... 10 in.
    - Inclination .... 55 deg
  - Upper Inclined Surface
    - Length .... 19 in.
    - Inclination .... 84 deg
  - Base Width .... 16 in.
  - Top Width .... 7 in.

- Vehicle Model .... 1984 Dodge Colt
- Vehicle Weight
  - Test Inertia .... 1,759 lbs.
  - Gross Static .... 1,759 lbs.
- Vehicle Impact Speed .... 62.5 mph
- Vehicle Exit Speed .... 40.8 mph
- Vehicle Impact Angle .... 20.0 deg
- Vehicle Exit Angle .... 6.6 deg
- Vehicle Snagging .... None
- Vehicle Stability .... Marginal
- Occupant Impact Velocity
  - Longitudinal .... 11.90 fps
  - Lateral .... 26.50 fps
- Occupant Ridedown Deceleration
  - Longitudinal .... 5.49 g's
  - Lateral .... 9.04 g's
- Vehicle Damage
  - TAD 1-RFQ-4
  - VDI 01RFES1
- Vehicle Rebound Distance ..... 9.5 ft
- Bridge Rail Damage .... Minor Spalling

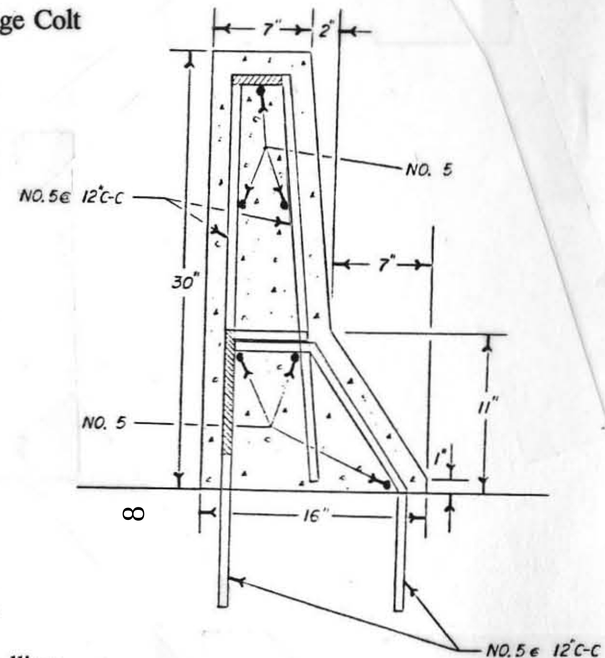


FIGURE 2 . Summary and Sequential Photographs, MS30-2

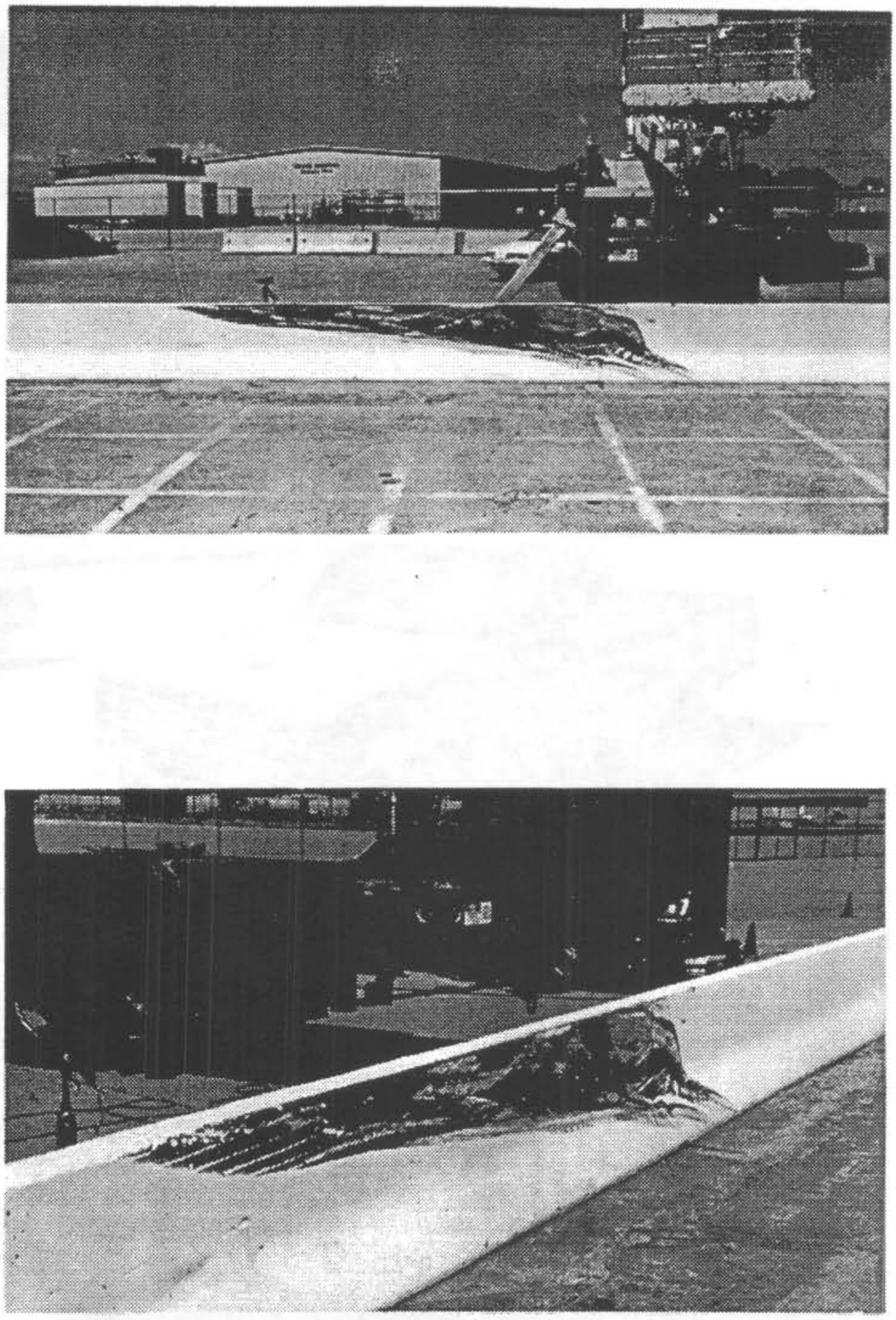
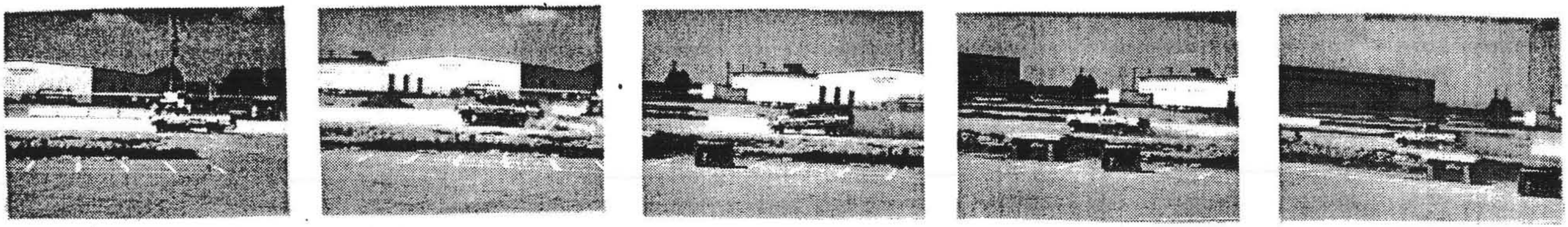


FIGURE 29. Bridge Rail Damage, MS30-3

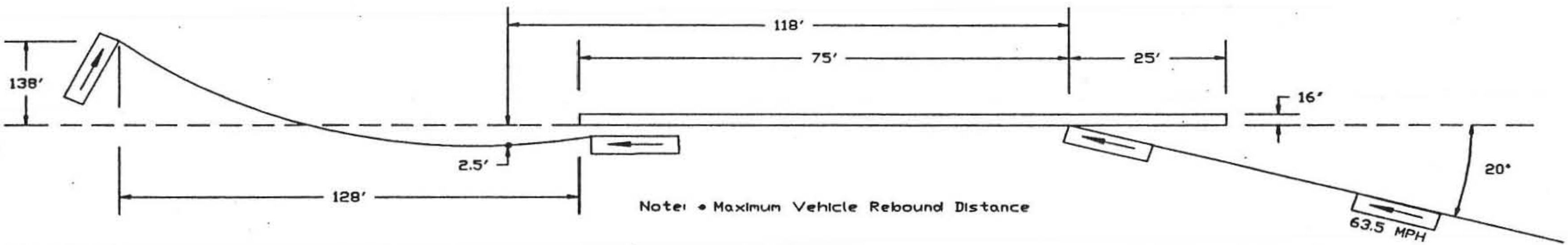
FIGURE 30. Test Vehicle Damage, MS30-3

The results of the occupant risk, determined from accelerometer data, are summarized in Figure 31. The results are shown graphically in Appendix D.

A summary of the test and sequential photographs are shown in Figure 31. Additional sequential photographs are shown in Figures 32, 33, and 34. The performance of the bridge rail was determined to be satisfactory for this test.



Impact | 0.40 sec | 0.78 sec | 1.17 sec | 1.52 sec



- Test Number MS30-3
- Date 6/14/91
- Installation . . . . 30 in. N.J. Safety Shape
- Total Length . . . . 100 ft
- Concrete Bridge Rail
  - Material . . . . Ne.Special Mix (47-B)
  - Length . . . . 100 ft
  - Weight . . . . 340 lb/ft
  - Area . . . . $2.27\ ft^2$
  - Height . . . . 30 in.
  - Lower Vertical Face . . . . 1 in.
  - Middle Inclined Surface
    - Length . . . . 10 in.
    - Inclination . . . . 55 deg
  - Upper Inclined Surface
    - Length . . . . 19 in.
    - Inclination . . . . 84 deg
  - Base Width . . . . 16 in.
  - Top Width . . . . 7 in.

- Vehicle Model . . . . 1984 Chevy Silverado
- Vehicle Weight
  - Test Inertia . . . . 5,460 lb
  - Gross Static . . . . 5,460 lb
- Vehicle Impact Speed . . . . 63.5 mph
- Vehicle Exit Speed . . . . 49.1 mph
- Vehicle Impact Angle . . . . 20.0 deg
- Vehicle Exit Angle . . . . 6.0 deg
- Vehicle Snagging . . . . None
- Effective Coef. of Friction 0.37
- Vehicle Stability . . . . Satisfactory
- Occupant Impact Velocity
  - Longitudinal . . . . 16.6 fps
  - Lateral . . . . 14.2 fps
- Occupant Ridedown Deceleration
  - Longitudinal . . . . 6.0 g's
  - Lateral . . . . 6.6 g's
- Vehicle Damage
  - TAD 1-RFQ-4
  - VDI 01RFES2
- Vehicle Rebound Distance . . . . . 2.5 ft
- Bridge Rail Damage . . . . Minor Spalling

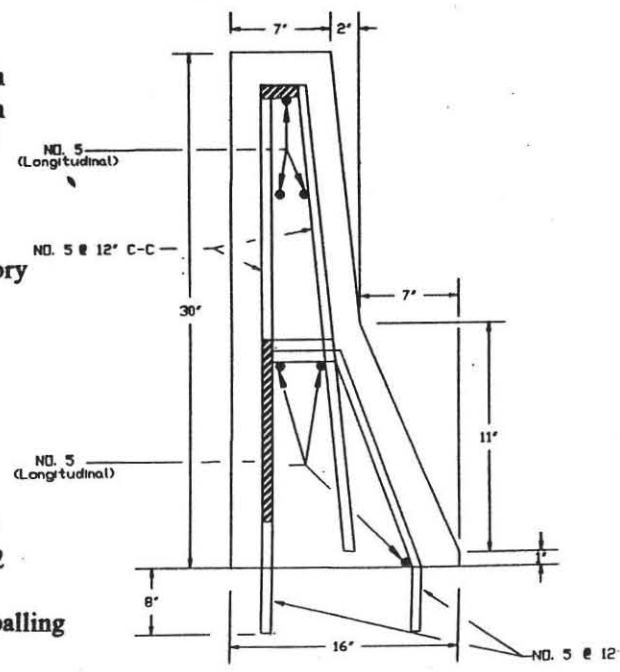


FIGURE 31. Summary and Sequential Photographs, MS30-3

FIGURE 32. Full-Scale Vehicle Crash Test, MS30-3

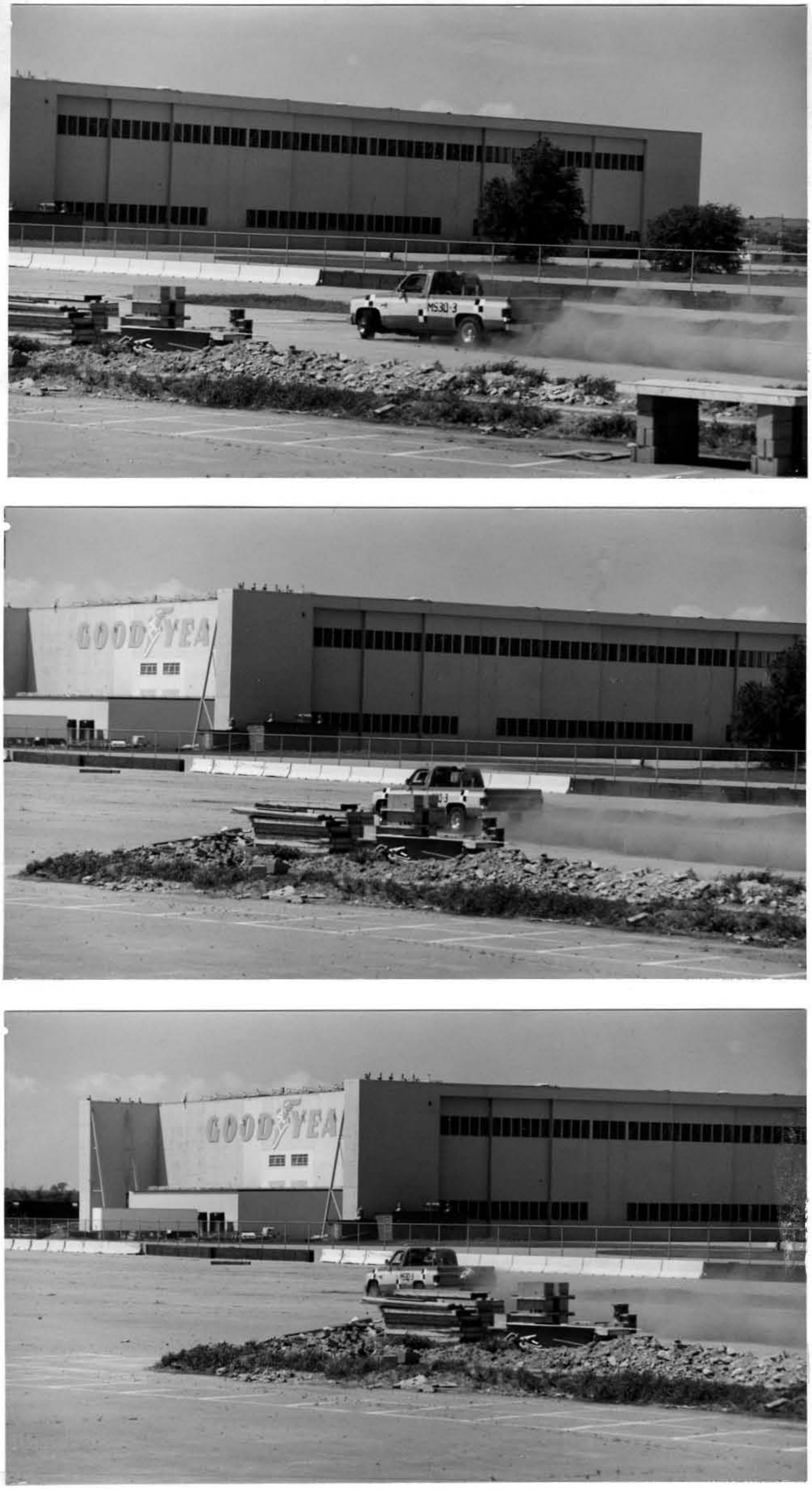


FIGURE 33. Full-Scale Vehicle Crash Test, MS30-3 (con't)

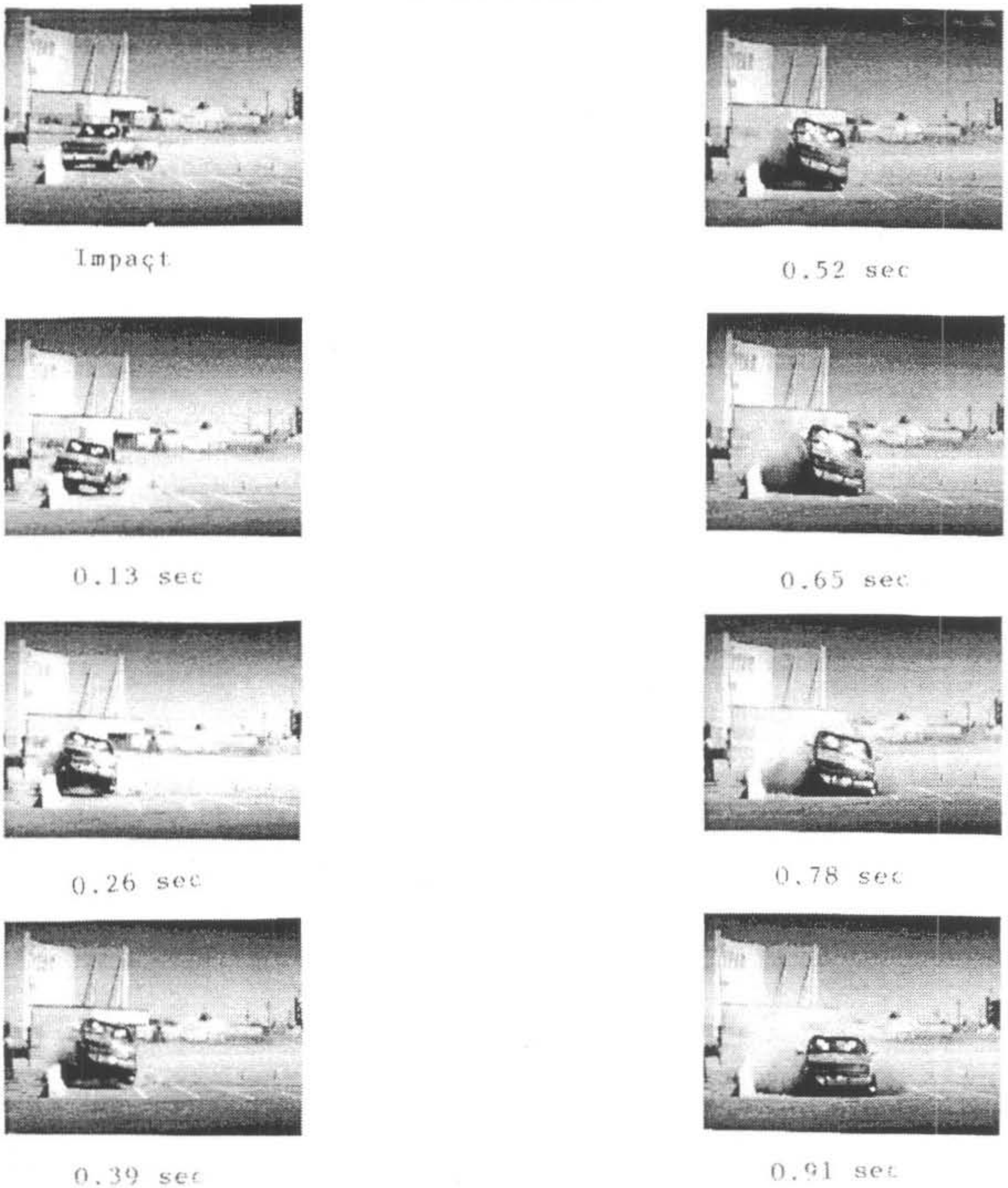


FIGURE 34. Parallel Time Sequential Photographs, MS30-3

5 CONCLUSIONS

The PL-2 performance level tests on the 30 in. New Jersey safety shape bridge rail proved to be satisfactory according to the safety performance criteria given in AASHTO (1). The safety evaluation summary using this set of criteria is presented in Table 3. The results of all three tests are summarized and presented in Table 4. The analysis of the tests revealed the following:

Test MS30-1 (18,011 lb, 52.5 mph, 16.1 deg)

1. The bridge rail did contain the vehicle without any visible lateral deflection, although a significant portion of the vehicle did extend over the top of the bridge rail without touching down behind the bridge rail.
2. No detached elements or fragments penetrated the occupant compartment.
3. The integrity of the occupant compartment was maintained.
4. The vehicle remained upright both during and after the collision.
5. The bridge rail's redirection capability was determined to be satisfactory although there was yawing of the rear end away from the rail.
6. The effective coefficient of friction was not available since the vehicle did not become parallel with the bridge rail.
7. The occupant ridedown decelerations were determined to be satisfactory.
8. The occupant impact velocity was determined to be satisfactory.
9. The vehicle's exit angle and rebound distance were determined to be satisfactory.

Test MS30-2 (1,759 lb, 62.5 mph, 20.0 deg)

1. The bridge rail did contain the vehicle without any visible lateral deflection.
2. No detached elements or fragments penetrated the occupant compartment.
3. The integrity of the occupant compartment was maintained.
4. The vehicle remained upright both during and after the collision.

5. The bridge rail smoothly redirected the vehicle.
6. The effective coefficient of friction was determined to be good (μ=0.11).
7. The occupant ridedown decelerations were determined to be satisfactory.
8. The lateral occupant impact velocity was determined to be marginal (26.5 fps), which is 5 % greater than the specified limit of 25 fps, but less than the threshold limit of 30 fps. The longitudinal impact velocity was satisfactory.
9. The vehicle's exit angle and rebound distance were determined to be satisfactory.

Test MS30-3 (5,460 lb, 53.5 mph, 20.0 deg)

1. The bridge rail did contain the vehicle without any visible lateral deflection.
2. No detached elements or fragments penetrated the occupant compartment.
3. The integrity of the occupant compartment was maintained.
4. The vehicle remained upright both during and after the collision.
5. The bridge rail smoothly redirected the vehicle.
6. The effective coefficient of friction was determined to be fair (μ=0.37).
7. The occupant ridedown decelerations were determined to be satisfactory.
8. The occupant impact velocity was determined to be satisfactory.
9. The vehicle's exit angle and rebound distance were determined to be satisfactory.

Table 3. Summary of AASHTO Safety Performance Results

<table>
<tr><th colspan="2" rowspan="2">Evaluation Criteria</th><th colspan="6">Results</th></tr>
<tr><th colspan="2">MS30-1</th><th colspan="2">MS30-2</th><th colspan="2">MS30-3</th></tr>
<tr><td>3.a.</td><td>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.</td><td colspan="2">S</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.b.</td><td>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.</td><td colspan="2">S</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.c.</td><td>Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.</td><td colspan="2">S</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.d.</td><td>The vehicle shall remain upright during and after collision.</td><td colspan="2">S</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.e.</td><td>The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle does no yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.</td><td colspan="2">S</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.f.</td><td>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</td><td colspan="2">NA</td><td colspan="2">G(μ=0.11)</td><td colspan="2">F(μ=0.37)</td></tr>
<tr><td rowspan="6">3.g.</td><td rowspan="3">The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0 ft. longitudinal and 1.0 ft. lateral displacements, shall be less than:

Occupant Impact Velocity - fps
Longitudinal: 30 — Lateral: 25</td><td colspan="6">Occupant Impact Velocity (fps)</td></tr>
<tr><td>Long.</td><td>Lateral</td><td>Long.</td><td>Lateral</td><td>Long.</td><td>Lateral</td></tr>
<tr><td>S (11.1)</td><td>S (9.7)</td><td>S (11.9)</td><td>M (26.5)</td><td>S (16.6)</td><td>S (14.2)</td></tr>
<tr><td rowspan="3">and for the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than:

Occupant ridedown Accelerations - g's
Longitudinal: 15 — Lateral: 15</td><td colspan="6">Occupant Ridedown Accelerations (g's)</td></tr>
<tr><td>Long.</td><td>Lateral</td><td>Long.</td><td>Lateral</td><td>Long.</td><td>Lateral</td></tr>
<tr><td>S (2.1)</td><td>G (3.0)</td><td>S (5.5)</td><td>S (9.0)</td><td>S (6.0)</td><td>S (6.6)</td></tr>
<tr><td rowspan="2">3.h.</td><td rowspan="2">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.</td><td colspan="2">S (0.0 deg.)</td><td colspan="2">S (6.6 deg.)</td><td colspan="2">S (6.0 deg.)</td></tr>
<tr><td colspan="2">S (18 ft.)</td><td colspan="2">S (9.5 ft.)</td><td colspan="2">S (7.5 ft.)</td></tr>
</table>

NA = Not Applicable S= Satisfactory M= Marginal U= Unsatisfactory

Table 4. Summary of Test Results

Test Item	Test MS30-1	Test MS30-2	Test MS30-3
Vehicle Impact (lb.)	18,011	1,759	5,460
Vehicle Impact Speed (mph)	52.5	62.5	63.5
Vehicle Exit Speed (mph)	NA	55.0	49.0
Vehicle Impact Angle (deg)	16.1	20.0	20.0
Vehicle Exit Angle (deg)	NA	6.6	6.0
Effective Coefficient of Friction	NA	0.11	0.37
Vehicle Rebound Distance (ft)	18.0	9.5	2.5
Vehicle Damage (TAD)	1-RFQ-4	1-RFQ-4	1-RFQ-4
Vehicle Damage (VDI)	01RFWS1	01RFES1	01RFES2
Occupant Impact Velocity (fps) Longitudinal Lateral	 11.1 9.7	 11.9 26.5	 16.6 14.2
Occupant Ridedown Decelerations (g's) Longitudinal Lateral	 2.1 3.0	 5.5 9.0	 6.0 6.6
Did Snagging Occur?	No	No	No

NA = Not Applicable

6 DISCUSSION

Current practice in state highway departments is to use concrete safety shape bridge rails with either the standard New Jersey safety shape or the F-shape. The standard New Jersey safety shape consists of a 32 in. concrete parapet with a 3 in. lower vertical face. The height above the roadway surface to the slope break point is 13 in. The F-shape consists of a 32 in. high concrete parapet with a 3 in. lower vertical face and a slope break point of 10 in. The Missouri 30 in. standard New Jersey safety shape consists of a concrete parapet with a 1 in. lower vertical face, and a slope break point of 11 in. These three bridge rails are shown in Figure 35.

Past research has shown that if the slope break point is higher than 13 in., the chances of vehicle rollover are increased, particularly for compact and subcompact automobiles. An example of this is the earlier General Motors (GM) shape, having a slope break point 15 in. above the roadway surface. This system is no longer recommended for use. By reducing the lower vertical face of the 30 in. bridge rail by 2 in., the slope break point was similar to that of the F-shape. This has been shown to reduce the magnitude of the vehicle roll angle.

To help establish the validity of the 30 in. safety shape bridge rail, a comparison of safety performance evaluations is presented against other AASHTO PL-2 safety shape bridge rails (10,11). The tests were conducted on the 32 in. New Jersey safety shape bridge rail and the 32 in. F-shape bridge rail. The comparison is shown in Table 5. It was evident that the safety performance results for these shapes and the 30 in. New Jersey safety shape provided similar results. One difference was that the 18,000 lb vehicle test on the 32 in. N.J. safety shape (Test 7069-12) (10) resulted in vehicle rollover, while the 18,000 lb tests on the F safety shape (Test 7069-4) (10) and the 30 in N.J. safety shape (Test MS30-1) did not result in vehicle rollovers. This may be explained due to the differences in the geometry of the bridge railings, the make and model of the trucks, or even the location of impact.

Some concern has been expressed concerning the length of the installation, and how this length affected the safety performance of the 18,000 lb vehicle test. This concern stems from the roll motion and the protrusion of the vehicle over the rail. It should be noted that the installation length (100 ft) and the location of impact (35 ft from the upstream end) are standard. There was no concern at the time of the test for justification of these values. There are no requirements set forth by AASHTO (1) or NCHRP 230 (3) for the impact location for the 18,000 lb vehicle test. The impact location and length of rail were similar to those used in Test 7069-12 (10).

The analysis of the high-speed film for the 18,000 lb test revealed that the behavior of the truck was altered as the end of the rail was encountered. As the truck approached the end of the rail, the clockwise roll motion was near a stable position. At this time, the cab appeared to be very close to contacting the ground behind the rail, but there was no physical evidence of this occurring. It was determined that the cab began a counterclockwise roll motion away from the rail at this time. The percentage of the vehicle which extended over the rail was unobtainable; although, it was obvious that most of the cab was over the top of the rail.

It is the authors opinion that the vehicle would have been contained had the installation length been increased. The clockwise yaw motion of the vehicle's rear end kept the vehicle from travelling over the rail. If the rail length was longer, the vehicle may have come to a rest on the top of the rail or may have fallen back onto the roadway on the traffic side of the rail.

From the four AASHTO PL-2 bridge railings reported in the Transportation Research Record No. 1258 (10), it was stated that test results indicate that a 32 in. vertical height would be a preferred minimum height. This statement was based upon the fact that only 32 in. bridge railings were tested. However, the authors did recognize that some innovative designs of a lesser height might function in a suitable manner, but must be subjected to full-scale crash testing to prove satisfactory performance. It is the author's opinion that additional full-scale crash testing be conducted on the New Jersey safety shape for reduction in height to 28 in., with an increased railing length.

The adequacy of the 30 in. bridge rail was verified by full-scale crash testing. It was the judgement of the authors that the 30 in. standard New Jersey shape bridge rail met the AASHTO PL-2 performance level evaluation criteria. However this does not justify the reduction of heights for other bridge railings. This can only be justified by full-scale crash testing.

Table 5. Comparison of PL-2 Bridge Rail Test Results.

TEST ITEMS	TEST INSTALLATION AND TESTING FACILITY								
	32 in. New Jersey Safety Shape (Texas Transportation Institute)(10)			32 in. F-Shape (Texas Transportation Institute)(10)			30 in. New Jersey Safety Shape (Midwest Roadside Safety Facility)		
	Tests Number and Dates			Test Numbers and Dates			Test Numbers and Dates		
	7069-12	3115-3[1]	7069-14	7069-11	7069-3	7069-4	MS30-1	MS30-2	MS30-3
	6/22/88	4/29/91	8/11/88	3/30/88	7/28/87	7/30/87	4/15/91	5/1/91	6/14/91
Vehicle (Year & Model)	1982 GMC SU Truck	1974 Honda	1981 Chevy PU	1982 Ford 7000 SUT	1980 Honda	1981 Chevy PU	1986 Ford F-700 SUT	1984 Dodge Colt	1984 Chevy PU
Vehicle Weight (Gross Static) lb.	18,000	1,968	5,724	18,000	1,966	5,780	18,011	1,759	5,460
Vehicle Impact Speed (mph)	51.6	61.3	57.7	52.1	60.1	65.4	52.5	62.5	63.5
Vehicle Impact Angle (deg)	15.5	20	20.6	14.8	21.4	20.4	16.1	20.0	20.0
Vehicle Exit Speed (mph)	NA	NA	35.8	NA	53.0	56.9	NA	55.0	49.0
Vehicle Exit Angle (deg)	2.0	7.0	.09	0.0	6.2	7.4	NA	6.6	6.0
Effective Coefficient of Friction	NA	NA	0.83	0.12	0.33	0.31	NA	0.11	0.37
Occupant Impact Velocity (fps)									
Longitudinal	13.4	NA	17.8	5.7	19.0	12.5	11.1	11.9	16.6
Lateral	10.2	NA	18.7	8.2	23.7	24.1	9.7	26.5	14.2
Occupant Ridedown Decelerations (g's)									
Longitudinal	3.0	4.4[2]	5.1	1.3	2.1	1.2	2.1	5.5	6.0
Lateral	4.9	10.6[2]	9.2	5.4	4.9	5.9	3.0	9.0	6.6

NA - Not Available
SUT - Single Unit Truck
PU - Pickup
[1] - Testing Performed at Dynamic Science, Inc. (11)
[2] - Maximum Deceleration (50 msec avg.)

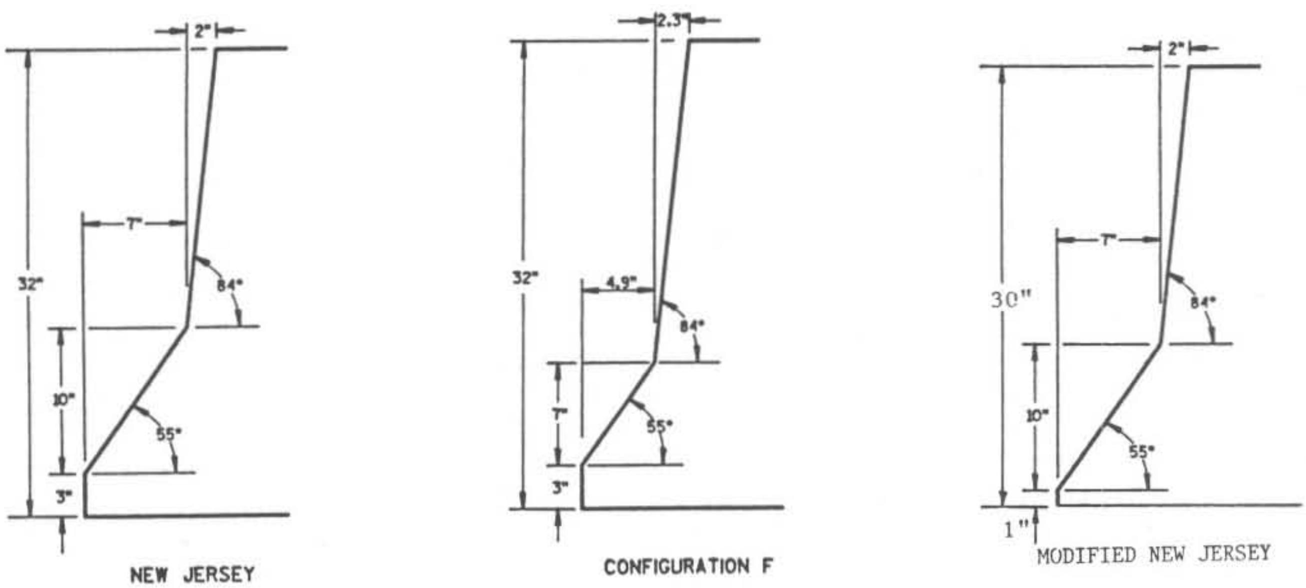


FIGURE 35. Geometric Properties of Safety Shape Bridge Rails

7 REFERENCES

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2. "Standard Specifications for Highway Bridges", American Association of State Highways and Transportation Officials, Washington D. C., Thirteenth Edition 1983.

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

10. Buth, C.E., Hirsch, T.J., McDevitt, C.F., "Performance Level 2 Bridge Railings, "Transportation Research Board No. 1258, Transportation Research Board, Washington D.C., 1990.

11. Davis, S., Baczynski, R., Garn, R., Bjork, R., "Test and Evaluation of Heavy Vehicle Barriere Concepts - Technical Report", Report No. 3115-81-023A/1839, Dynamic Sciences Inc., July 1981.

8 APPENDICES

APPENDIX A.
CONCRETE COMPRESSIVE STRENGTHS

REPORT OF CONCRETE CORES

UNIVERSITY OF NEBRASKA BARRIER TESTING

Project: Missouri Bridge Rail Crash Test

Examined For: Compressive Strength

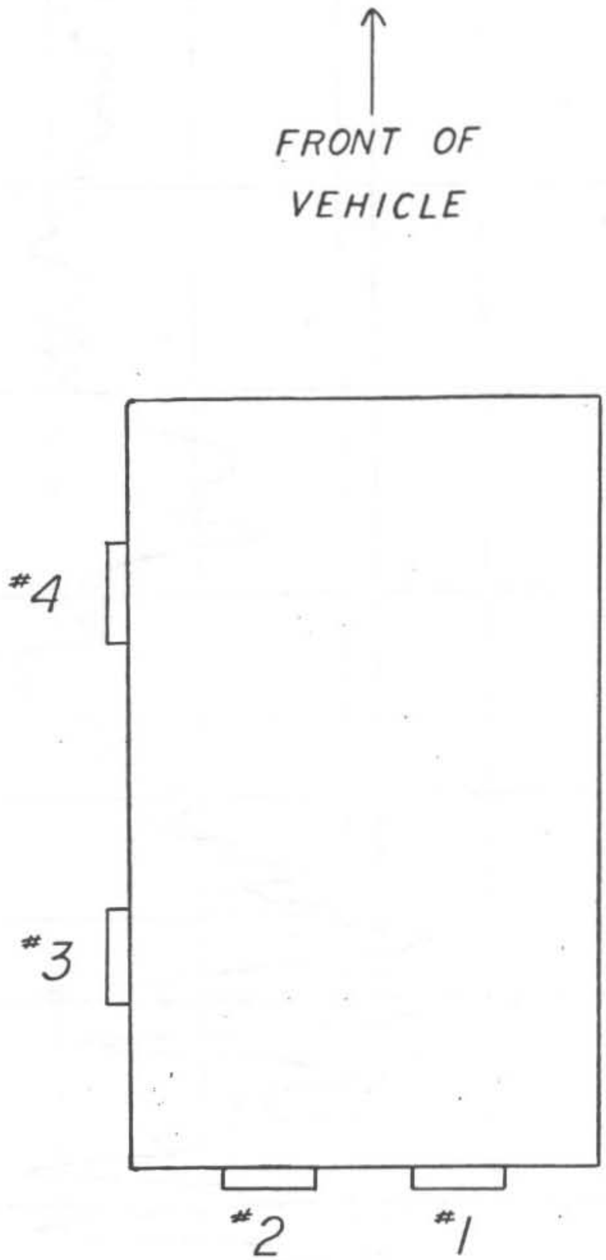
Date Placed	Date Tested	Location	Strength - PSI
3-25-91	4-4-91	Bridge Rail	5670
3-25-91	5-7-91	Bridge Rail	6920

Remarks:

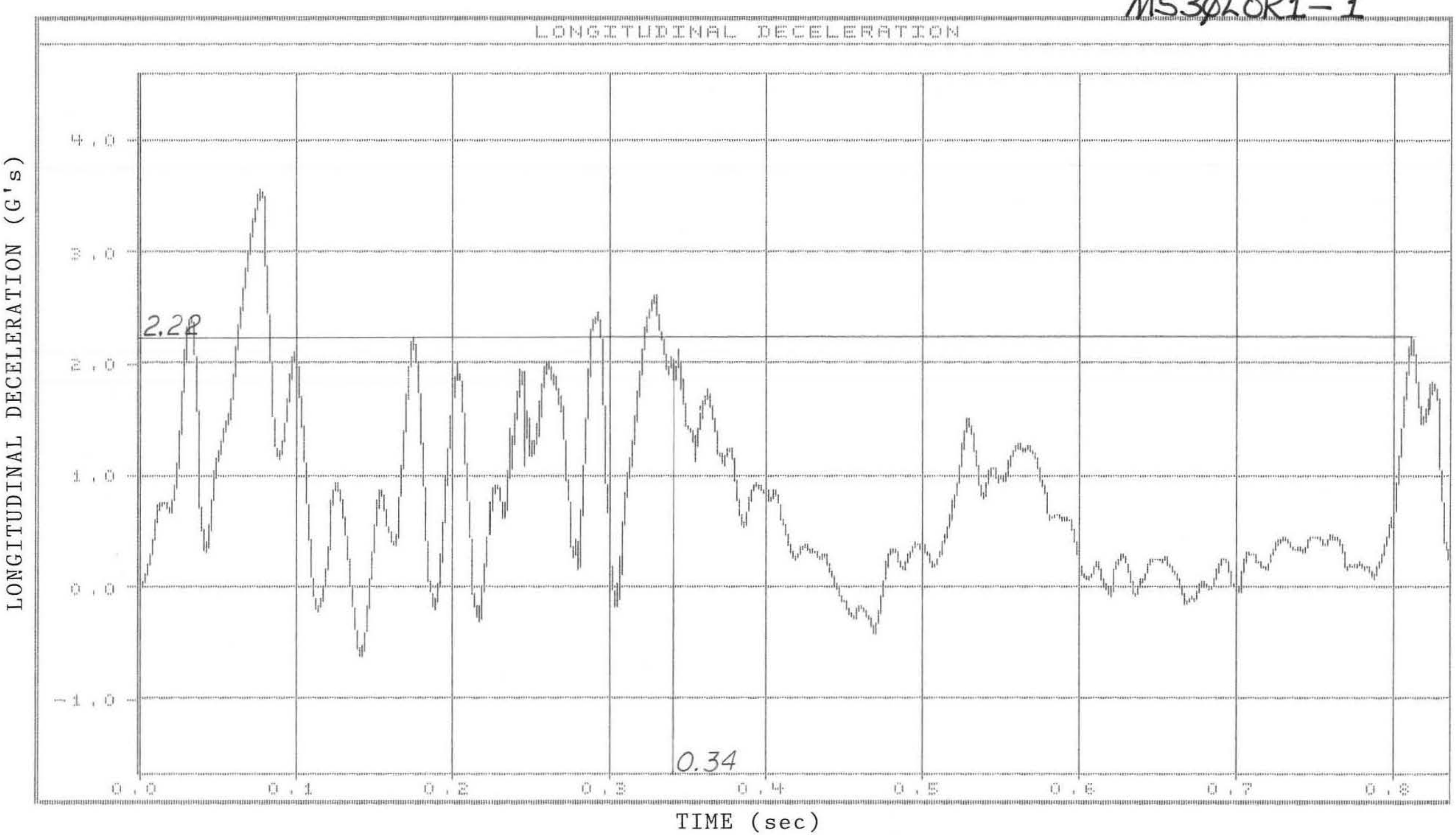
Daniel L. Mau

For NDOR Materials & Tests Division

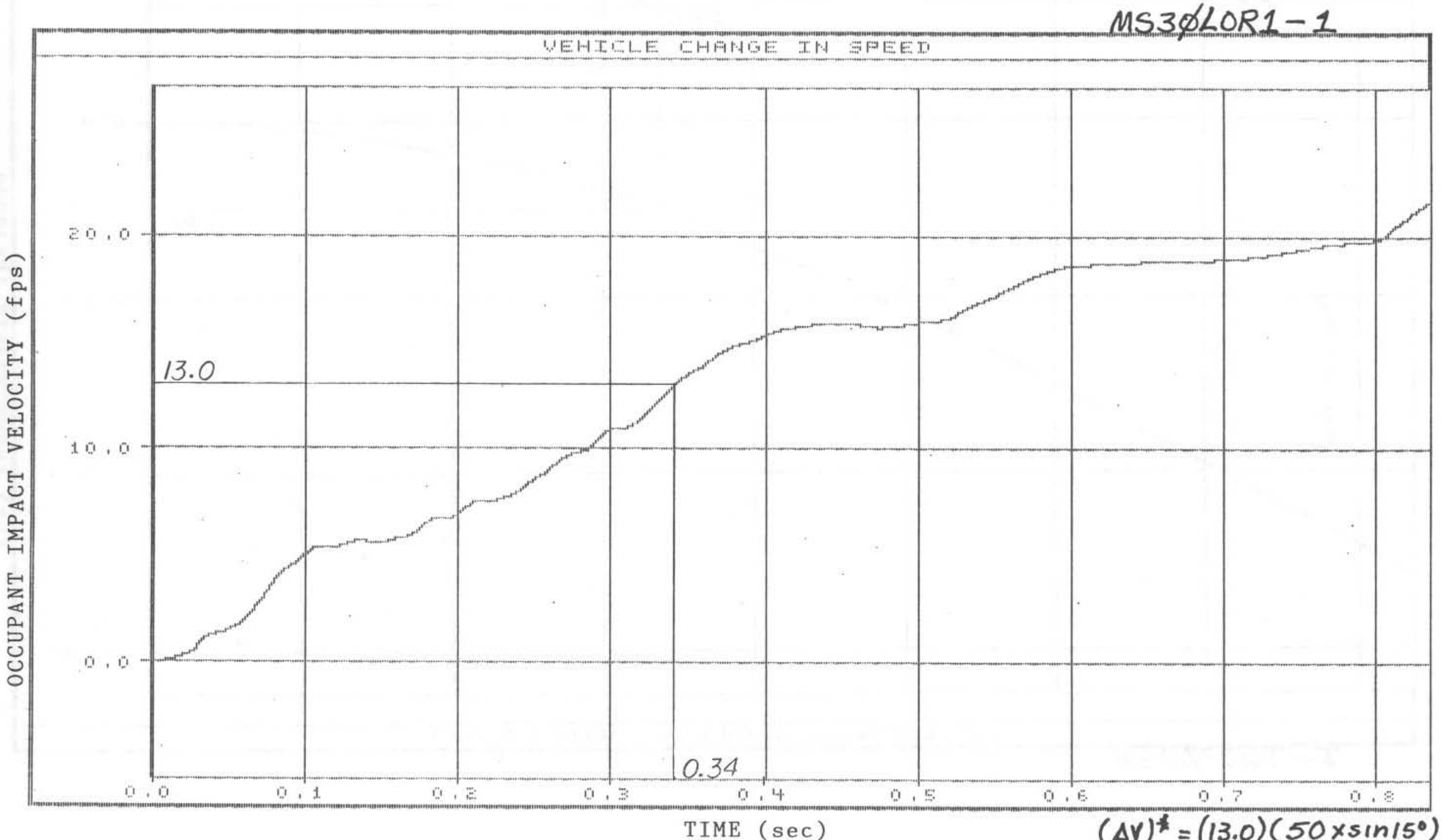
APPENDIX B.
ACCELEROMETER DATA ANALYSIS, MS30-1



APPENDIX B-1. SKETCH OF ACCELEROMETER LOCATIONS



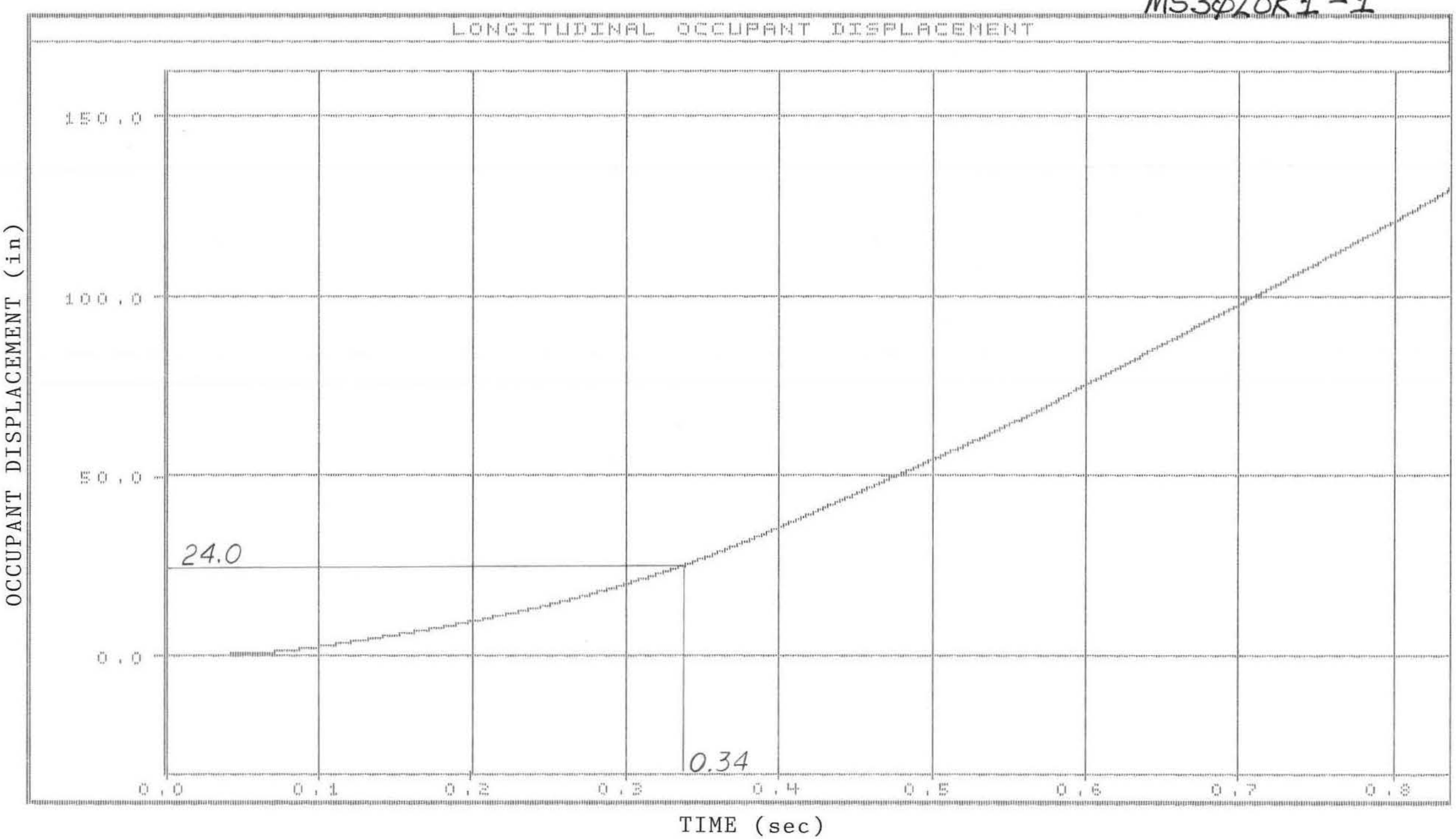
APPENDIX B-2. GRAPH OF LONGITUDINAL DECELERATION, Acc. #1



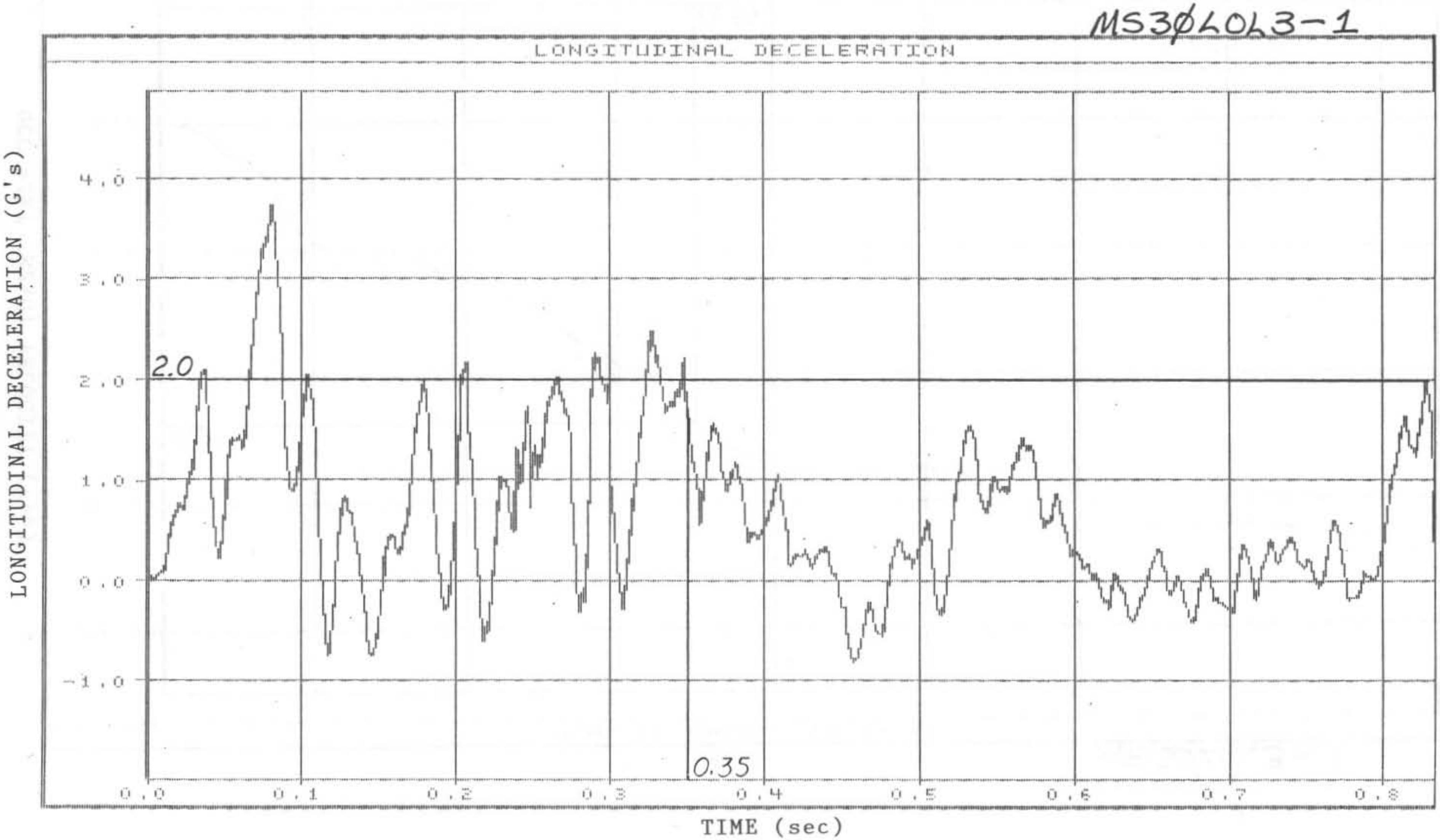
$(\Delta V)^* = \frac{(13.0)(50 \times \sin 15^\circ)}{(52.5 \times \sin 16.1^\circ)}$

$(\Delta V)^* = 11.56$ fps

APPENDIX B-3. GRAPH OF LONGITUDINAL OCCUPANT IMPACT VELOCITY, Acc. #1

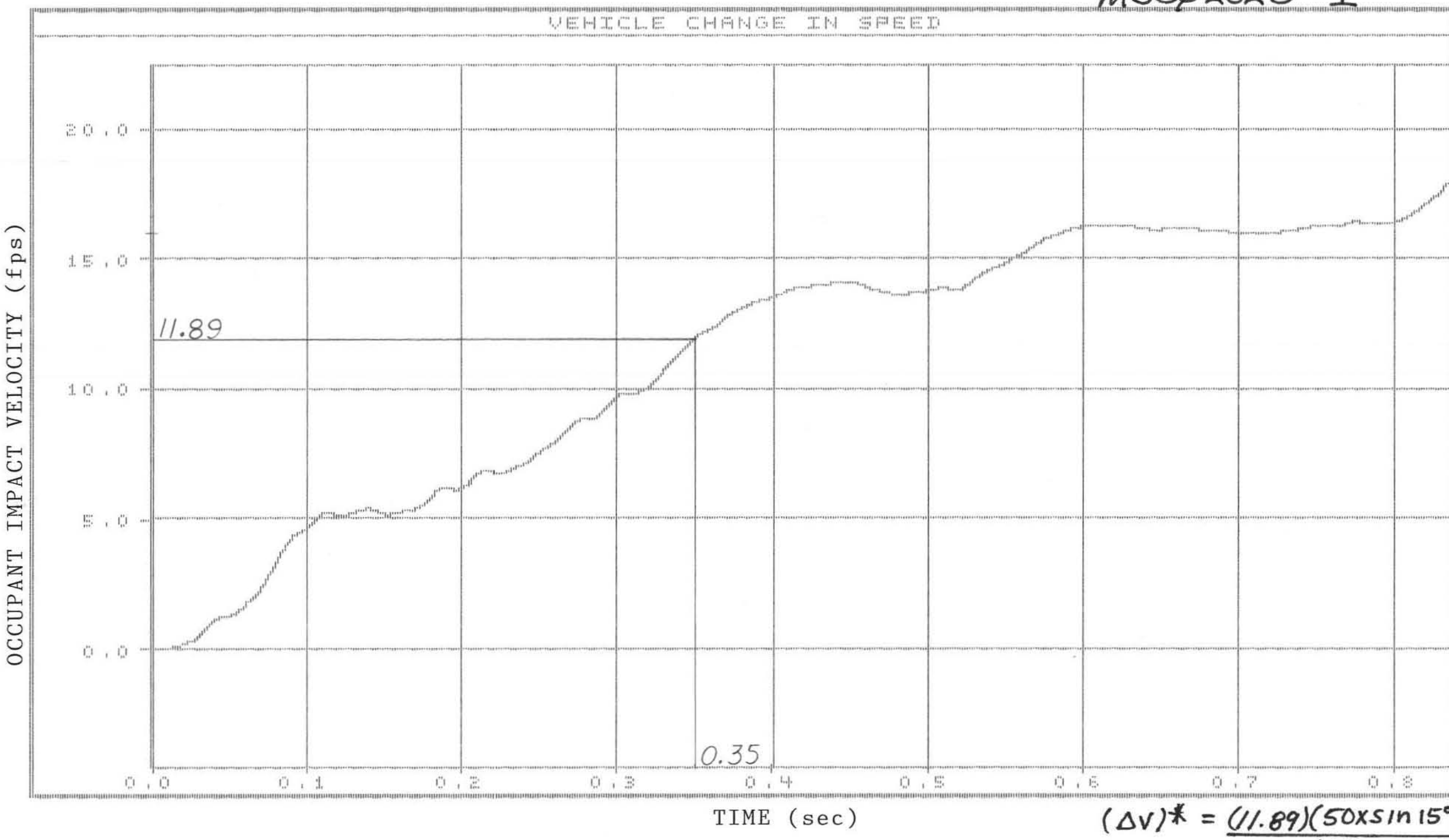


APPENDIX B-4. GRAPH OF LONGITUDINAL OCCUPANT DISPLACEMENT, Acc. #1



APPENDIX B-5. GRAPH OF LONGITUDINAL DECELERATION, Acc. #2

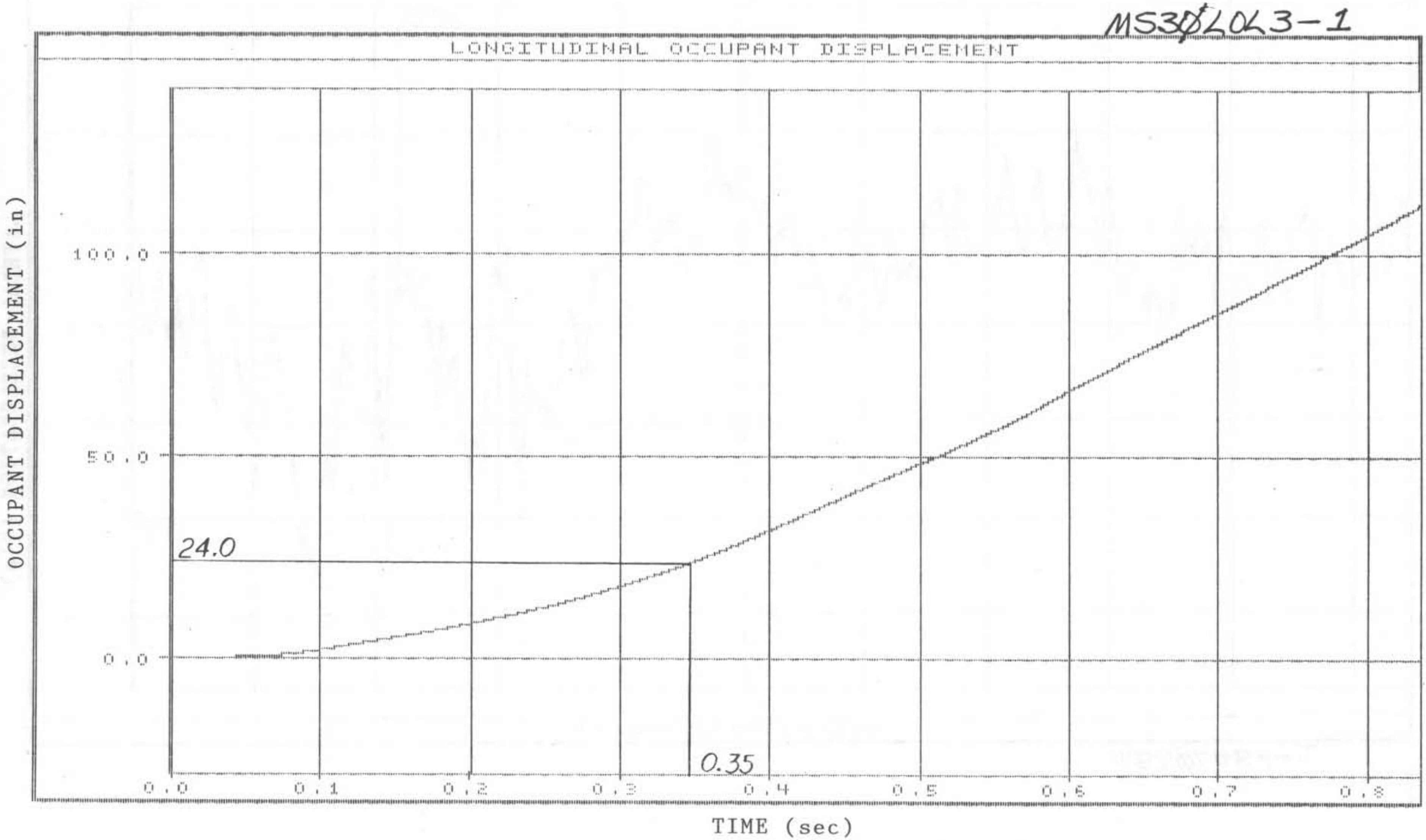
MS30LOL3-1



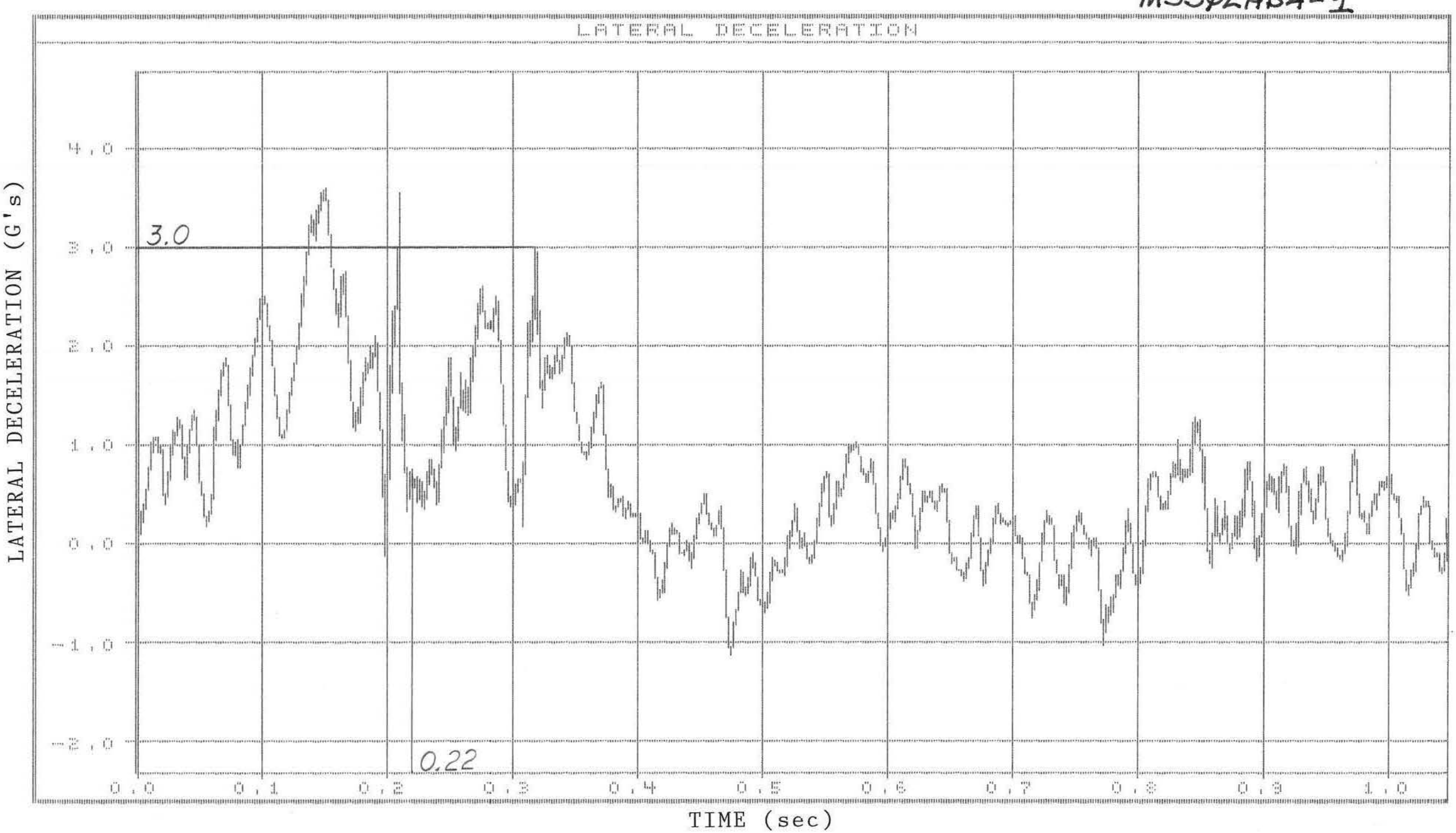
$(\Delta V)^* = \frac{(11.89)(50 \times \sin 15°)}{(52.5 \times \sin 16.1°)}$

$(\Delta V)^* = 10.57$ fps

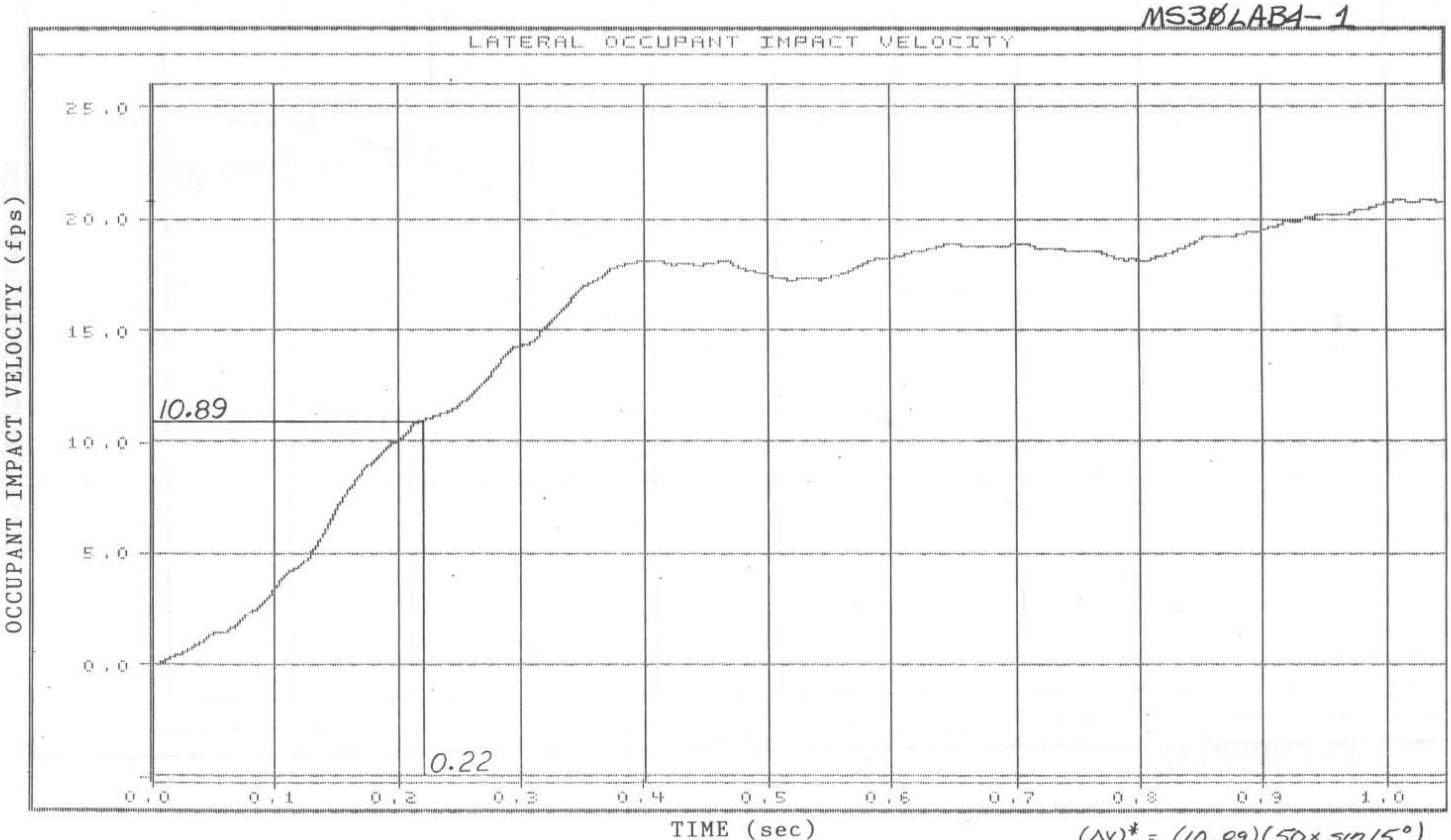
APPENDIX B-6. GRAPH OF LONGITUDINAL OCCUPANT IMPACT VELOCITY, Acc. #2



APPENDIX B-7. GRAPH OF LONGITUDINAL OCCUPANT DISPLACEMENT, Acc. #2



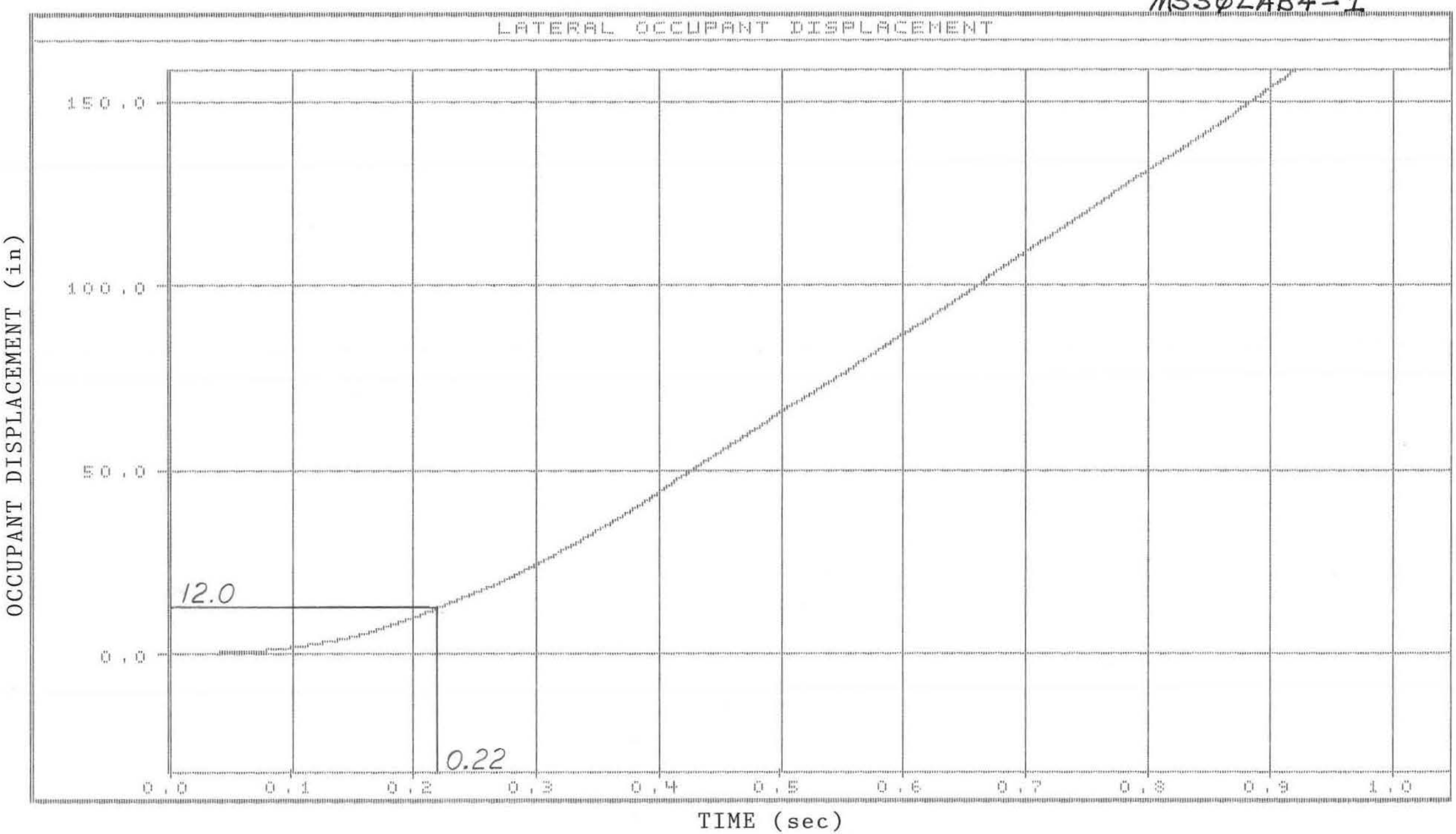
APPENDIX B-8. Graph of Lateral Deceleration, Acc. #4



APPENDIX B-9. GRAPH OF LATERAL OCCUPANT IMPACT VELOCITY, Acc.#4

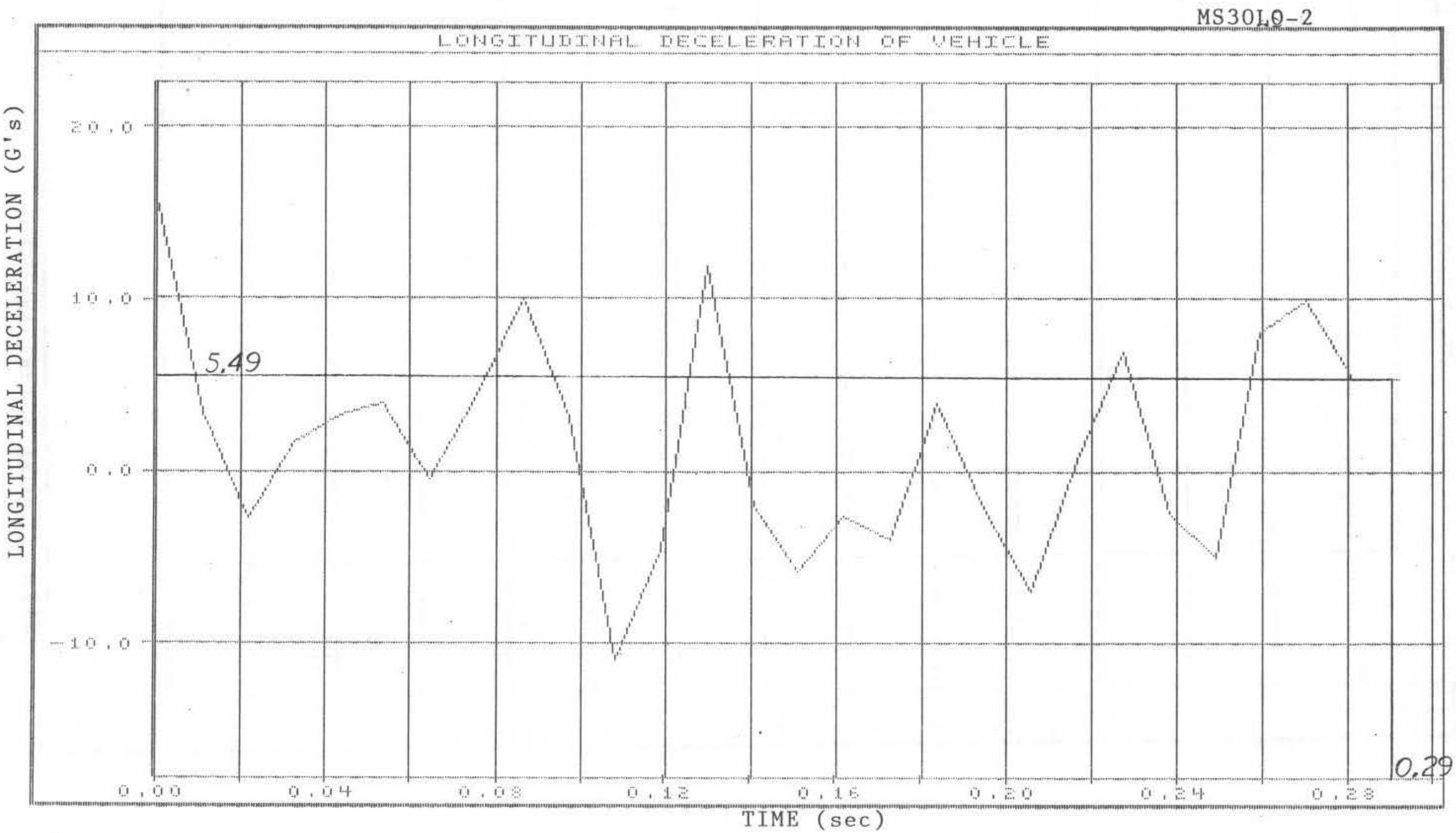
$(\Delta V)^* = (10.89)\dfrac{(50 \times \sin 15°)}{(52.5 \times \sin 16.1°)}$

$(\Delta V)^* = 9.70$ fps

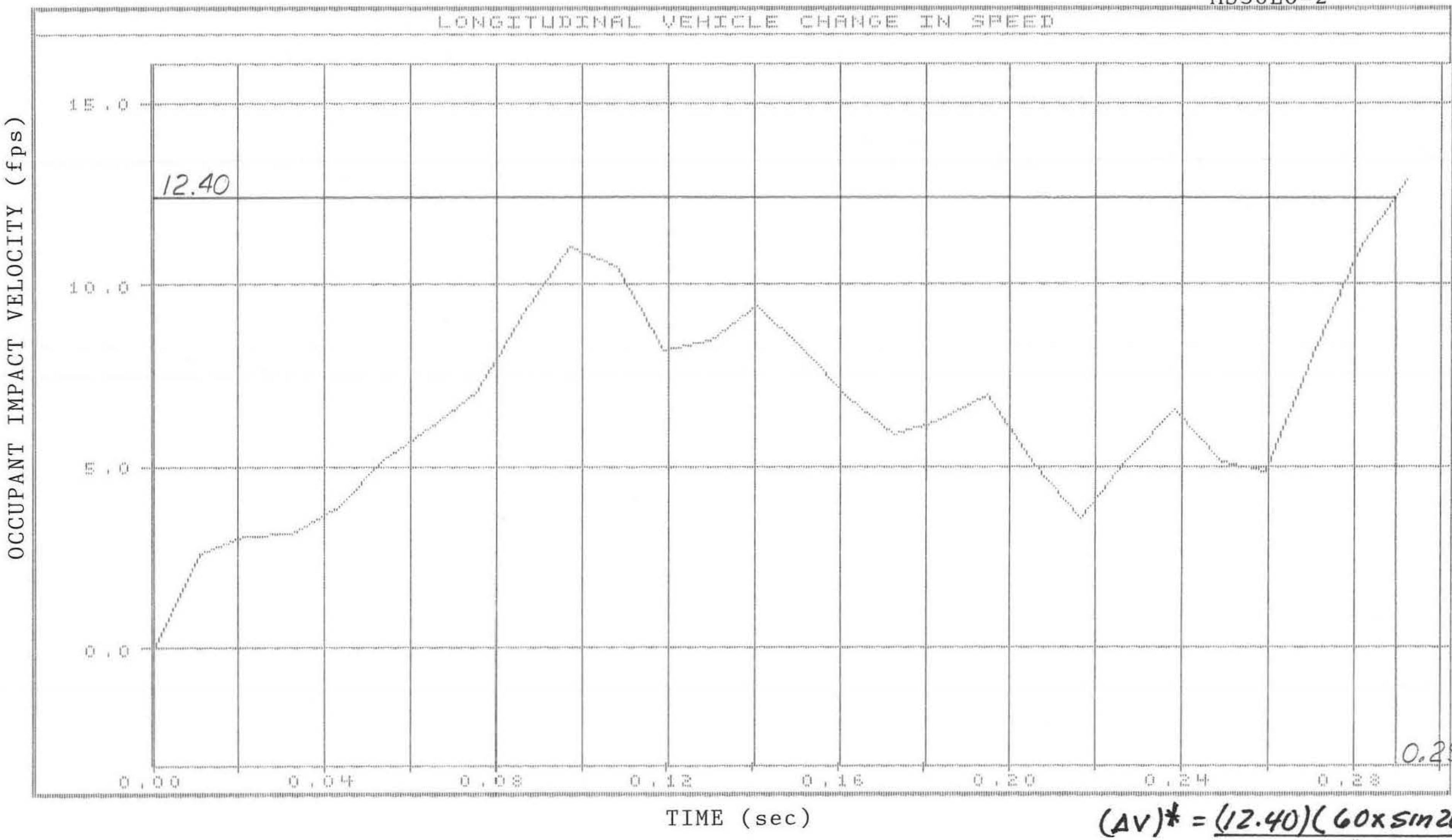


APPENDIX B-10 GRAPH OF LATERAL OCCUPANT DISPLACEMENT, Acc.#4

APPENDIX C.
HIGH SPEED FILM ANALYSIS, MS30-2



APPENDIX C-1. GRAPH OF LONGITUDINAL DECELERATION

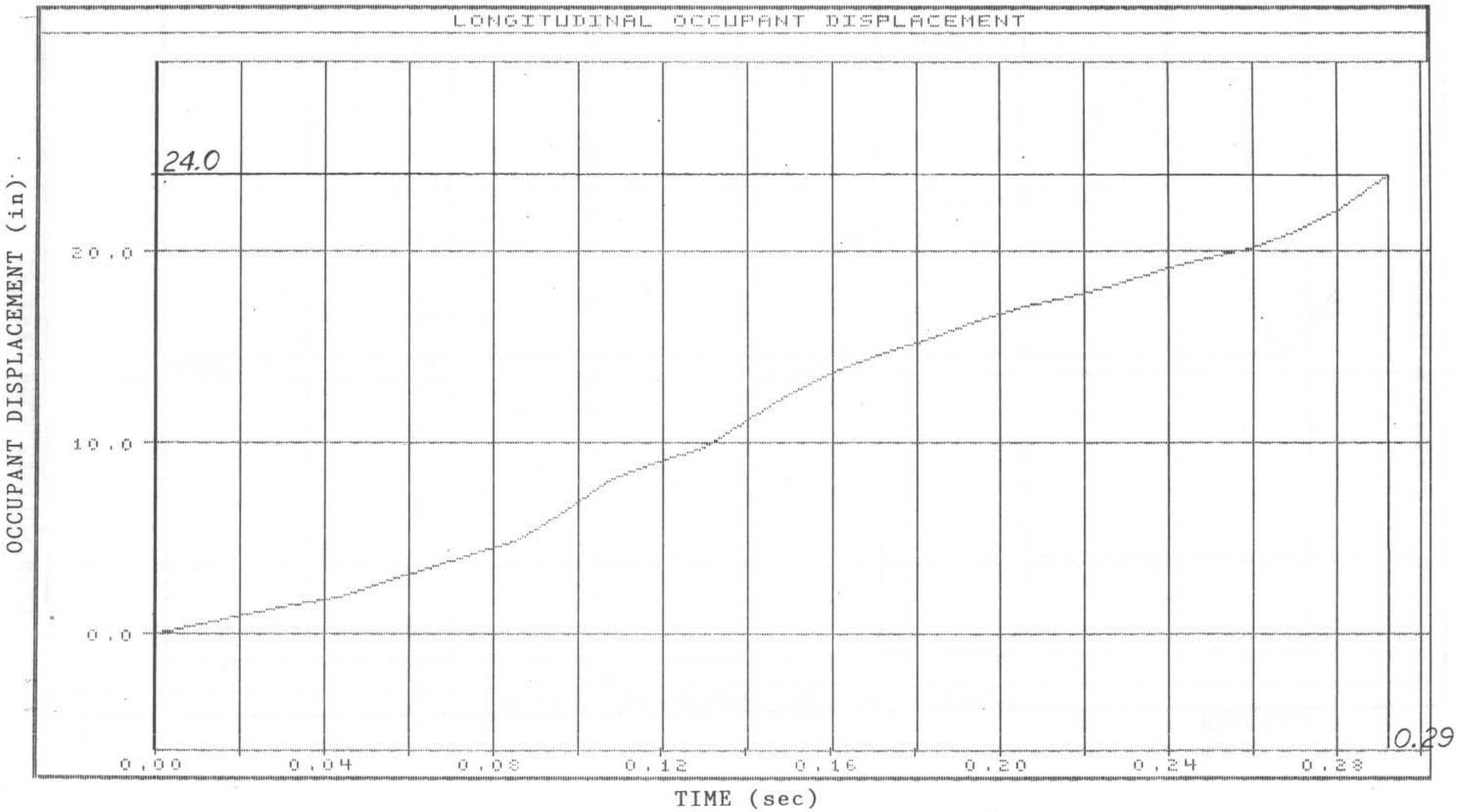


$$(\Delta V)^* = \frac{(12.40)(60 \times \sin 20^\circ)}{(62.5 \times \sin 20^\circ)}$$

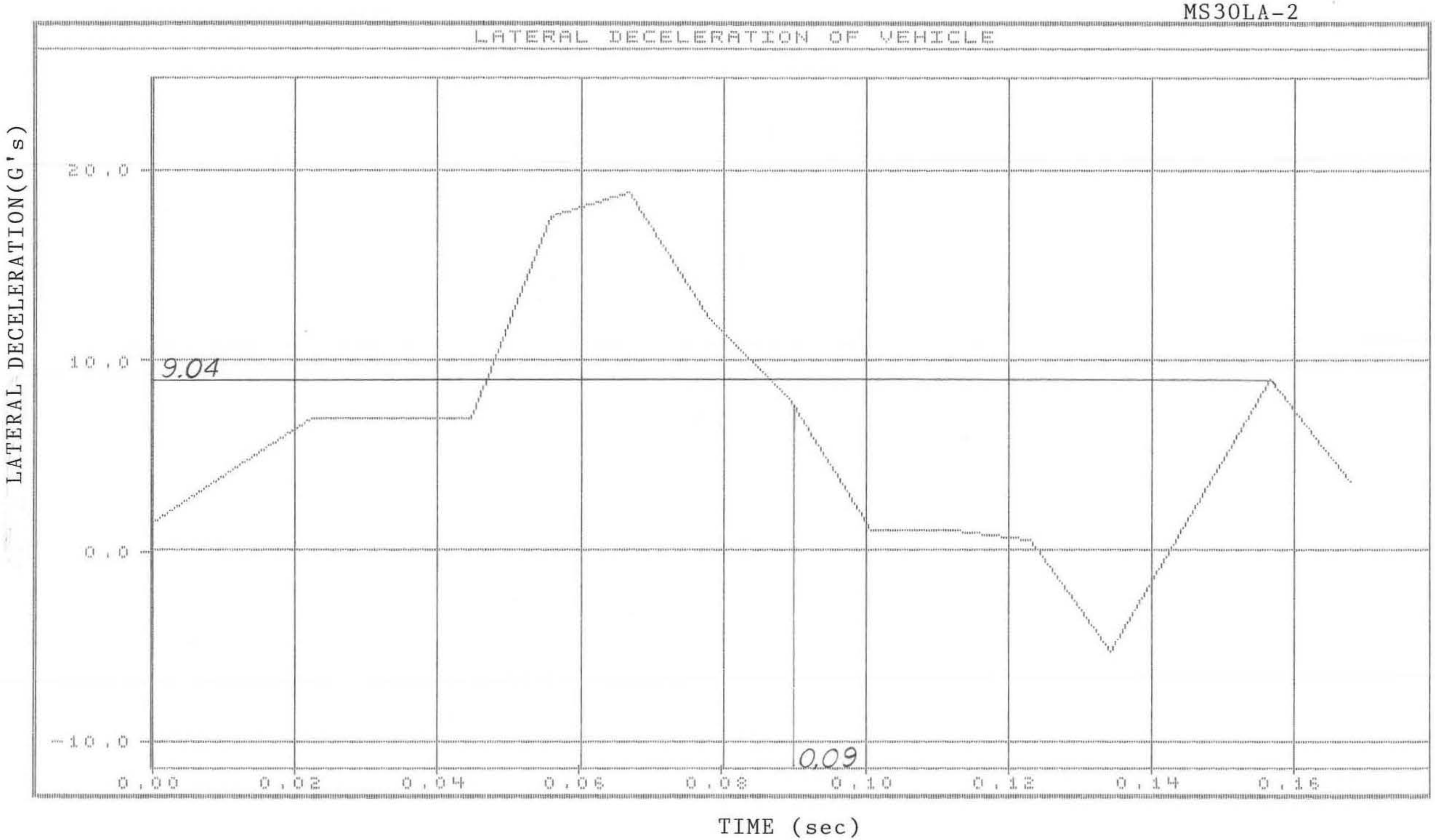
$$(\Delta V)^* = 11.90 \text{ fps}$$

APPENDIX C-2. GRAPH OF LONGITUDINAL OCCUPANT IMPACT VELOCITY

MS30LO-2

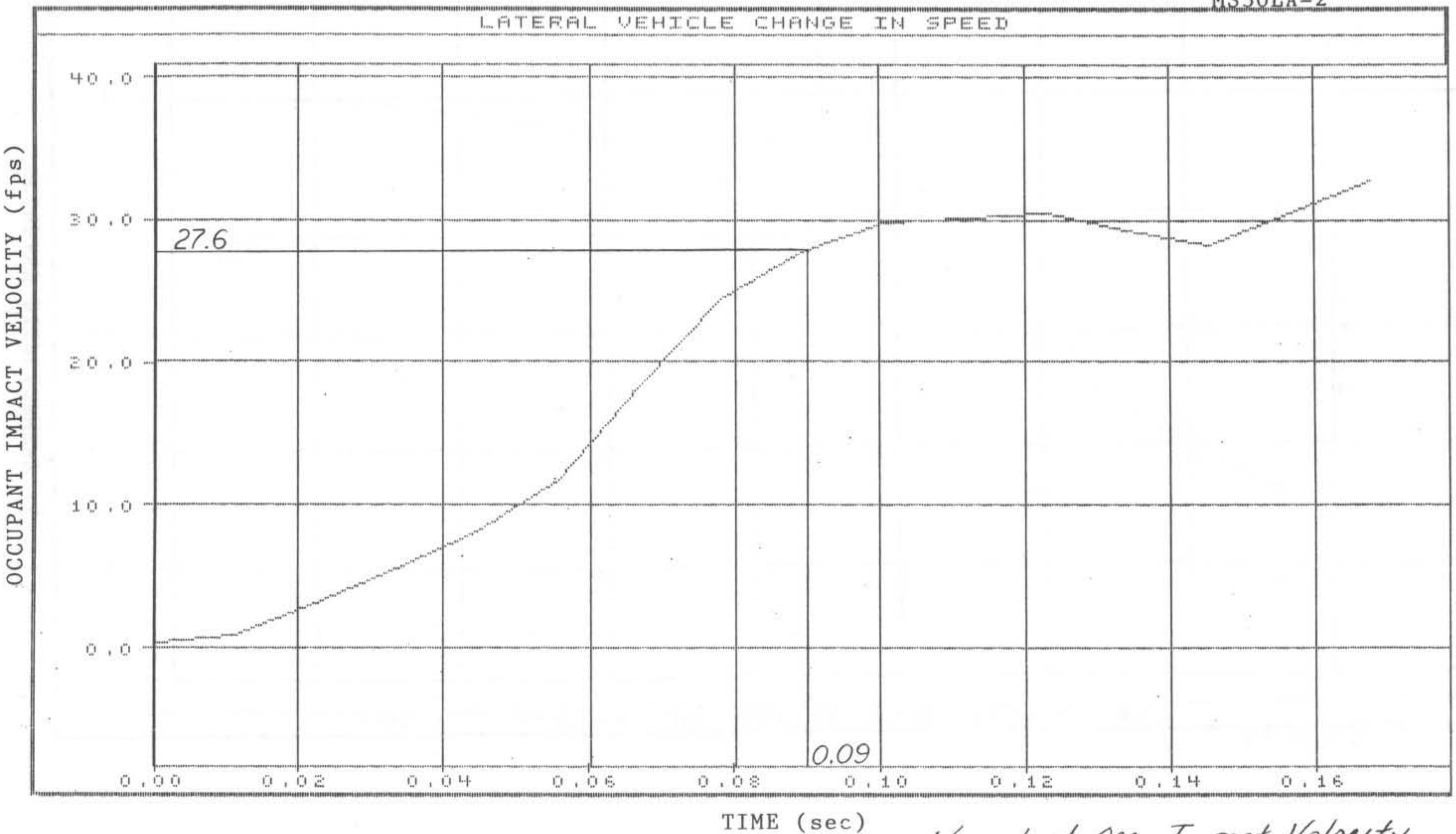


APPENDIX C-3. GRAPH OF LONGITUDINAL OCCUPANT DISPLACEMENT



APPENDIX C-4. GRAPH OF LATERAL DECELERATION

MS30LA-2

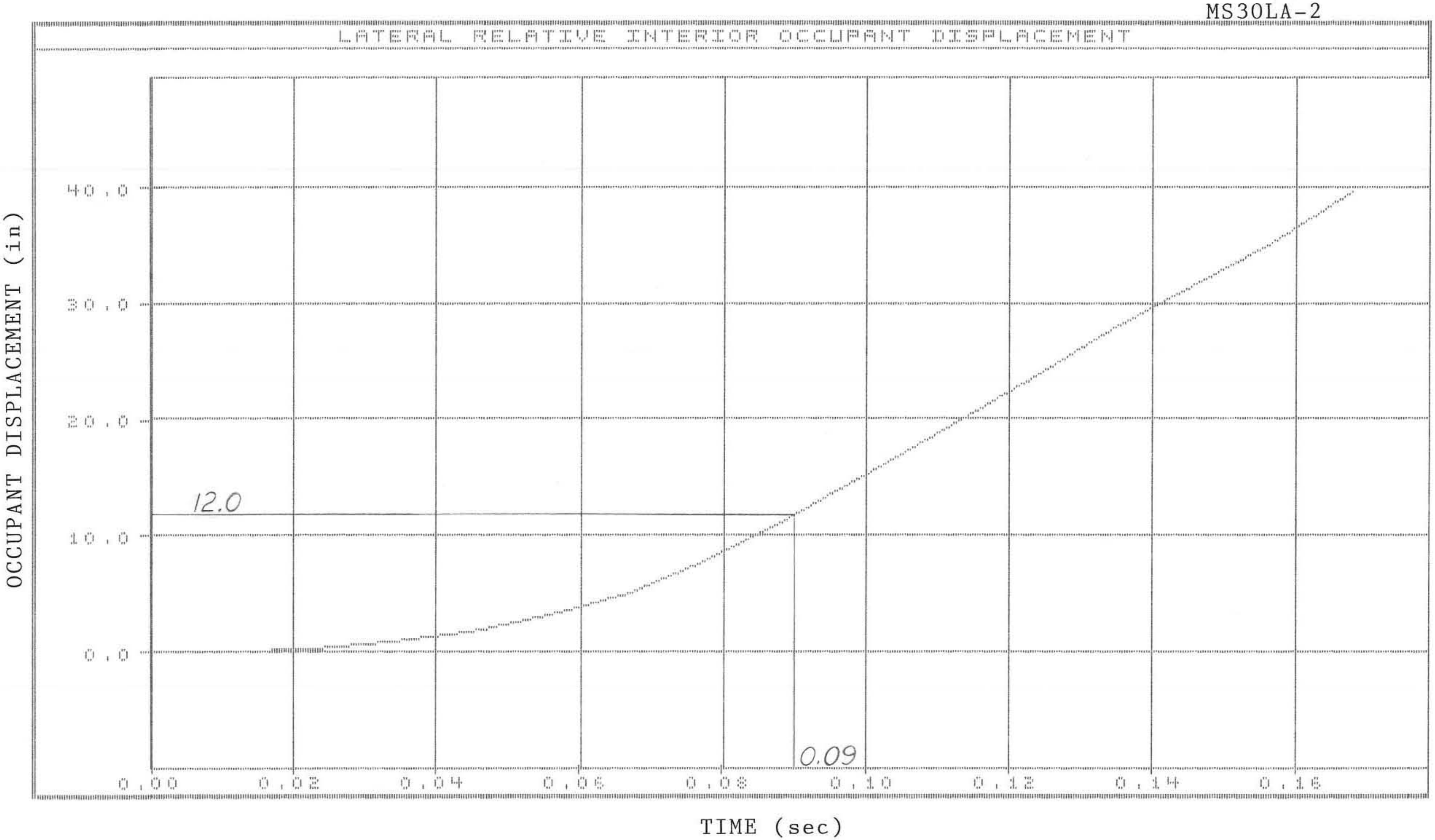


APPENDIX C-5. GRAPH OF LATERAL IMPACT VELOCITY

Normalized Occ. Impact Velocity

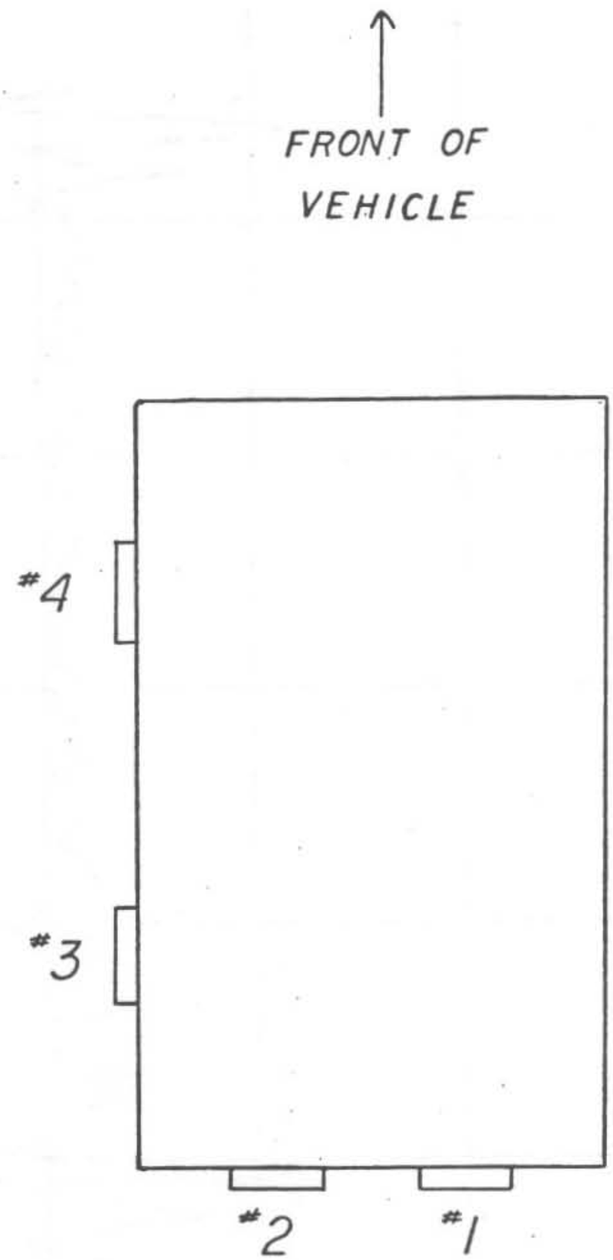
$$(\Delta V)^* = \frac{(60 mph) \sin 20°}{(62.5 mph) \sin 20°} \times 27.6 fps$$

$(\Delta V)^* = 26.5 fps$



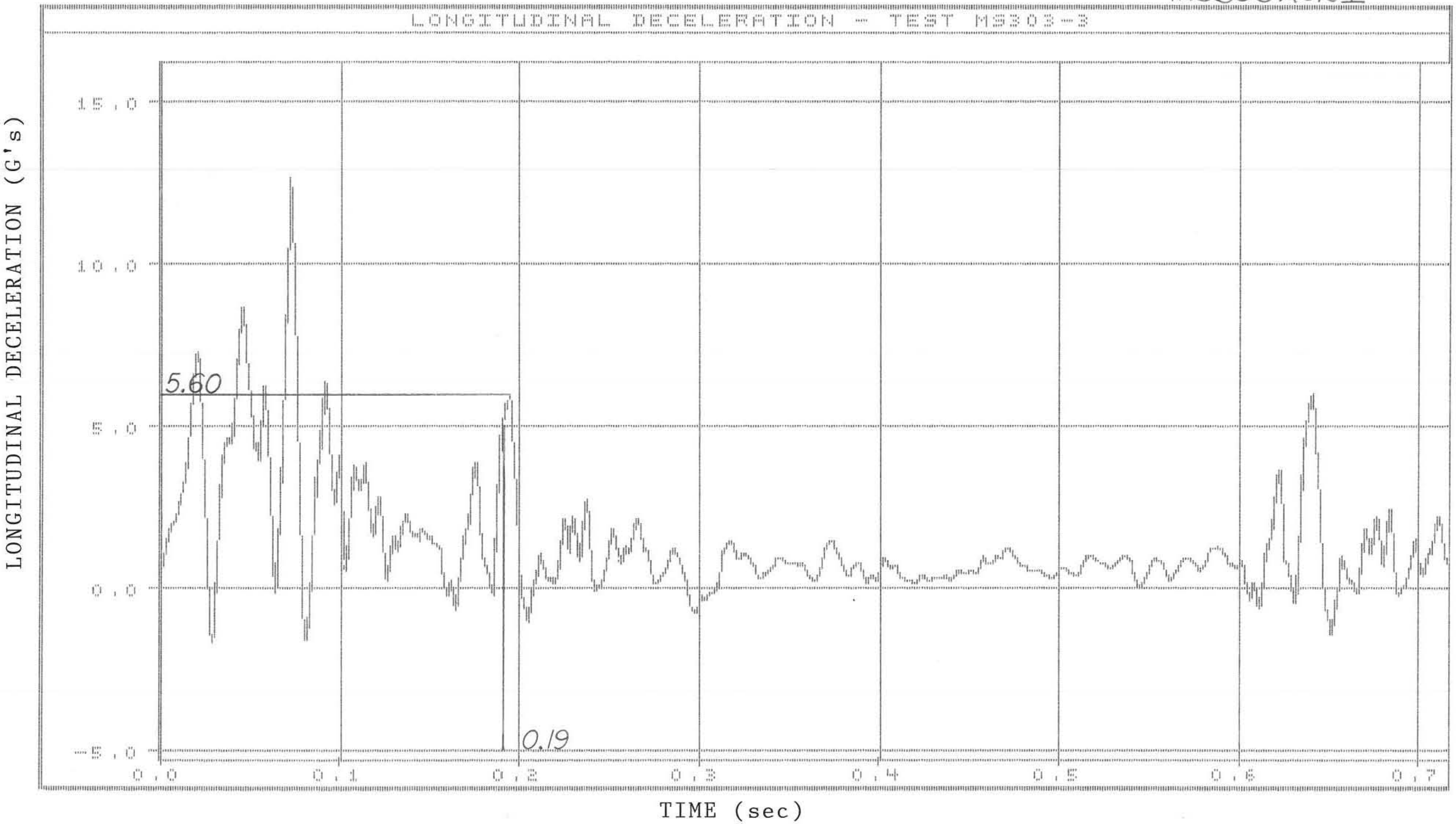
APPENDIX C-6. GRAPH OF LATERAL OCCUPANT DISPLACEMENT

APPENDIX D.
ACCELEROMETER DATA ANALYSIS, MS30-3

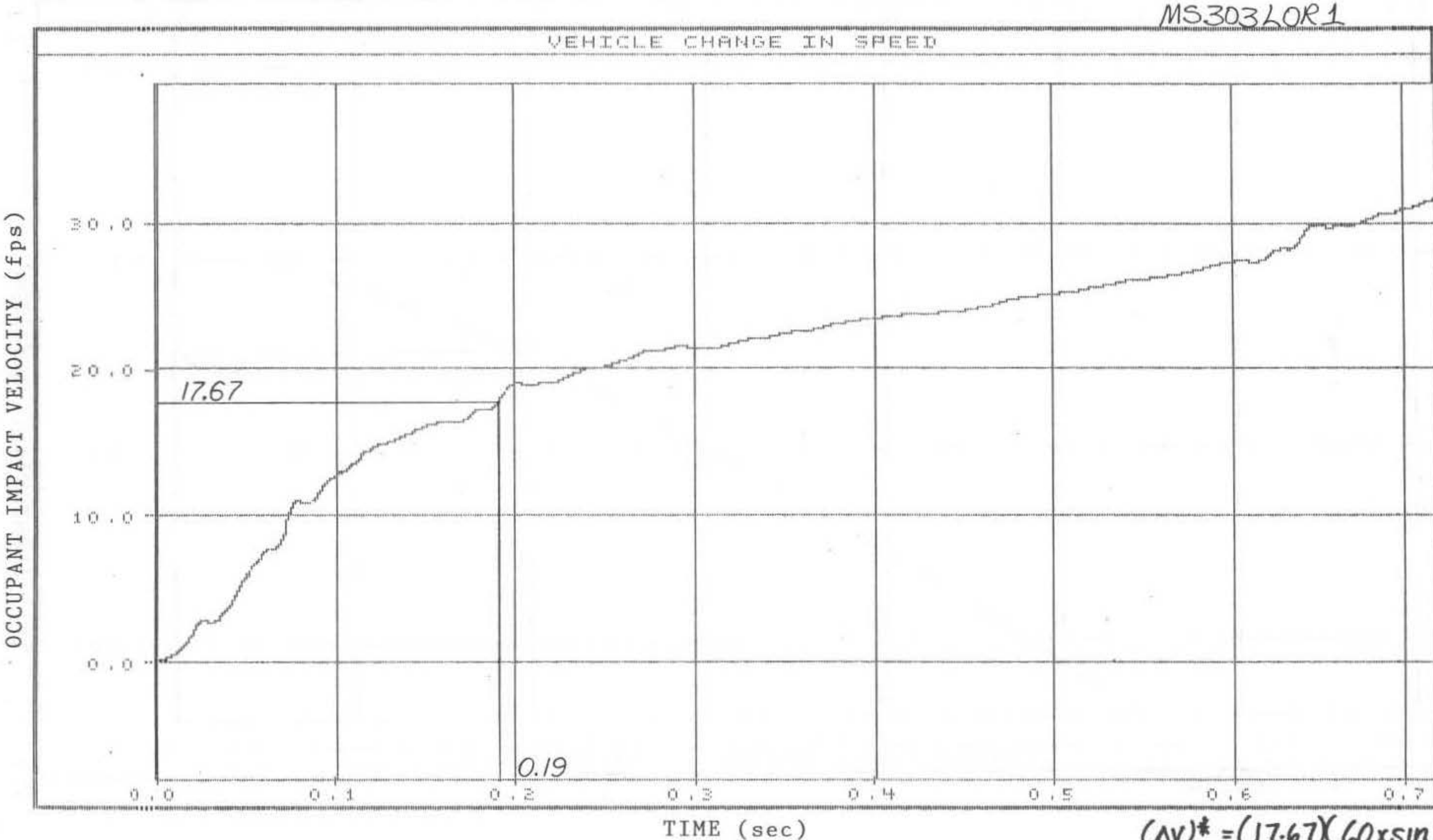


APPENDIX D-1. SKETCH OF ACCELEROMETER LOCATIONS

MS303LOR1



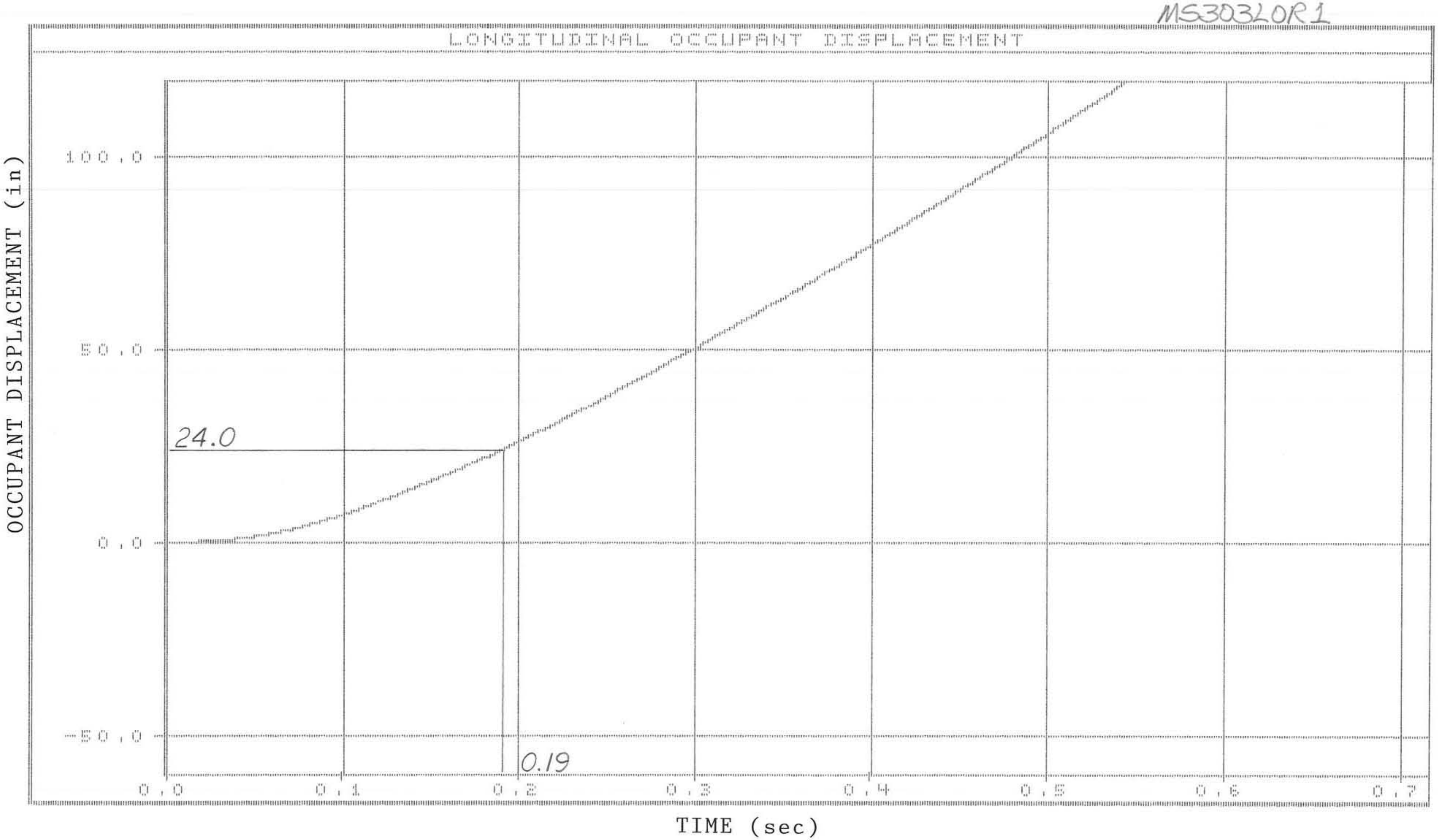
APPENDIX D-2. GRAPH OF LONGITUDINAL DECELERATION Acc. #1



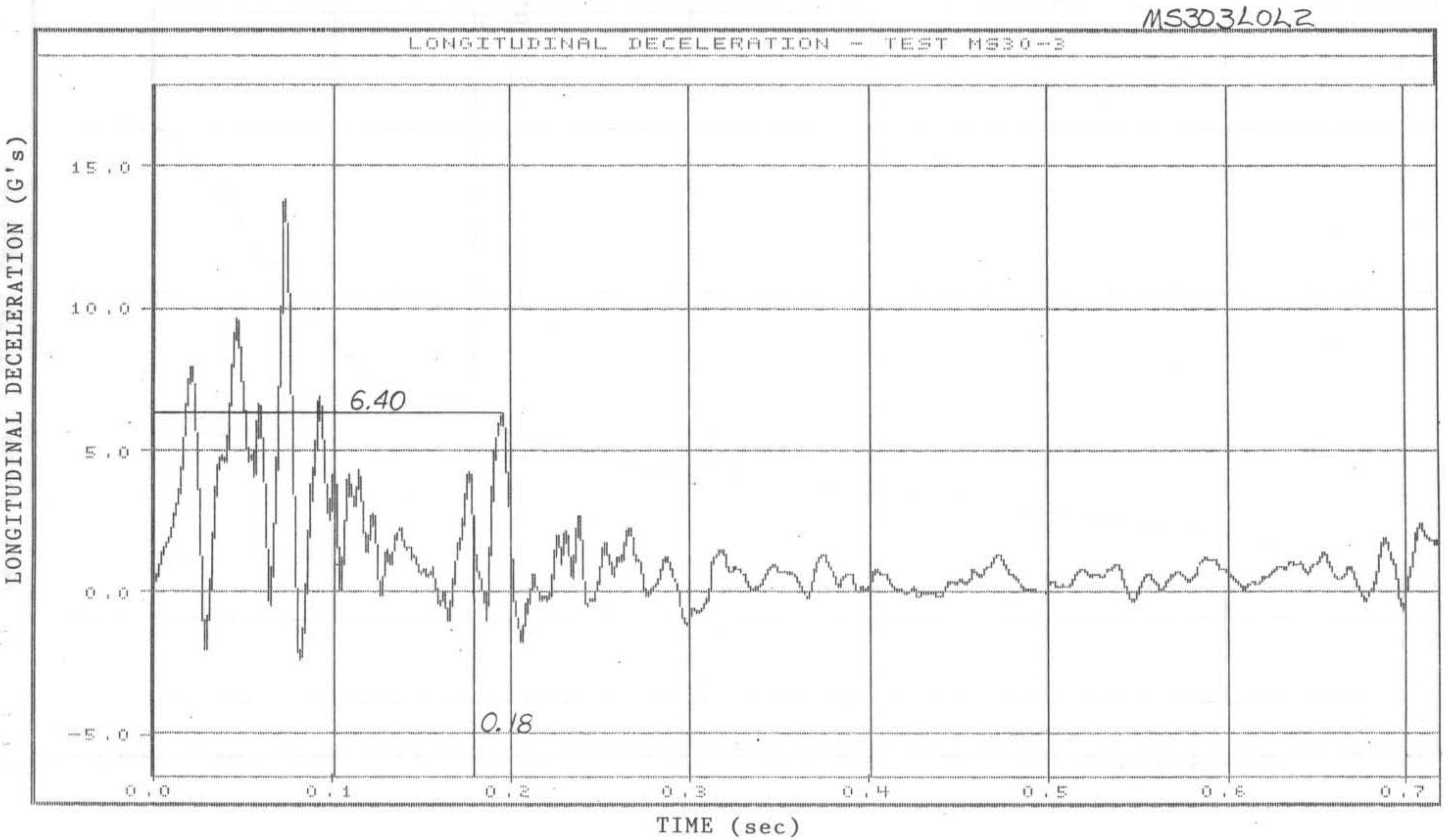
$(\Delta V)^{*} = \frac{(17.67)(60 \times \sin 20^{\circ})}{(63.5) \times \sin 20^{\circ}}$

$(\Delta V)^{*} = 16.62$

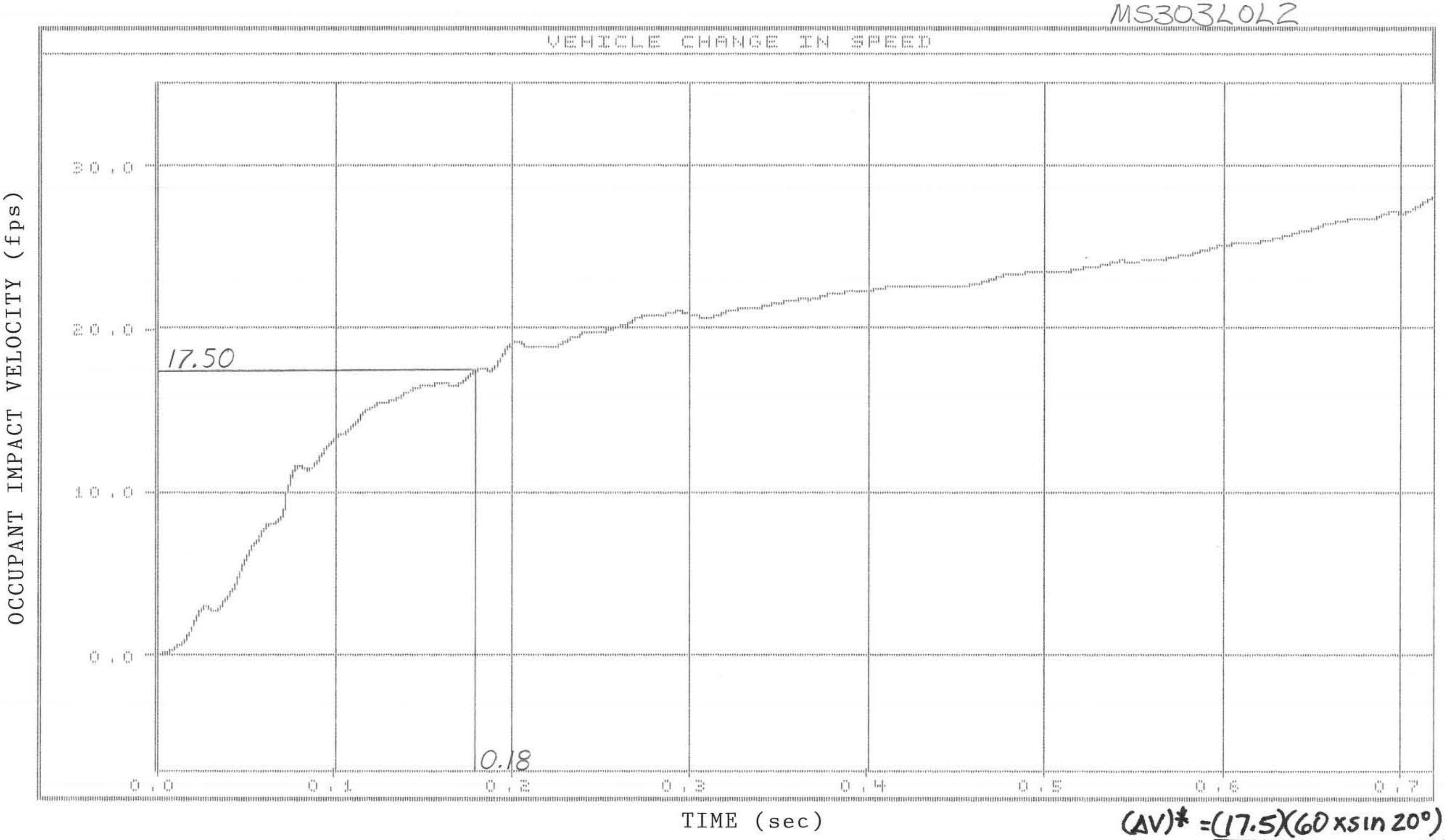
APPENDIX D-3. GRAPH OF LONGITUDINAL OCCUPANT IMPACT VELOCITY, Acc. #1



APPENDIX D-4. GRAPH OF LONGITUDINAL OCCUPANT DISPLACEMENT, Acc. #1



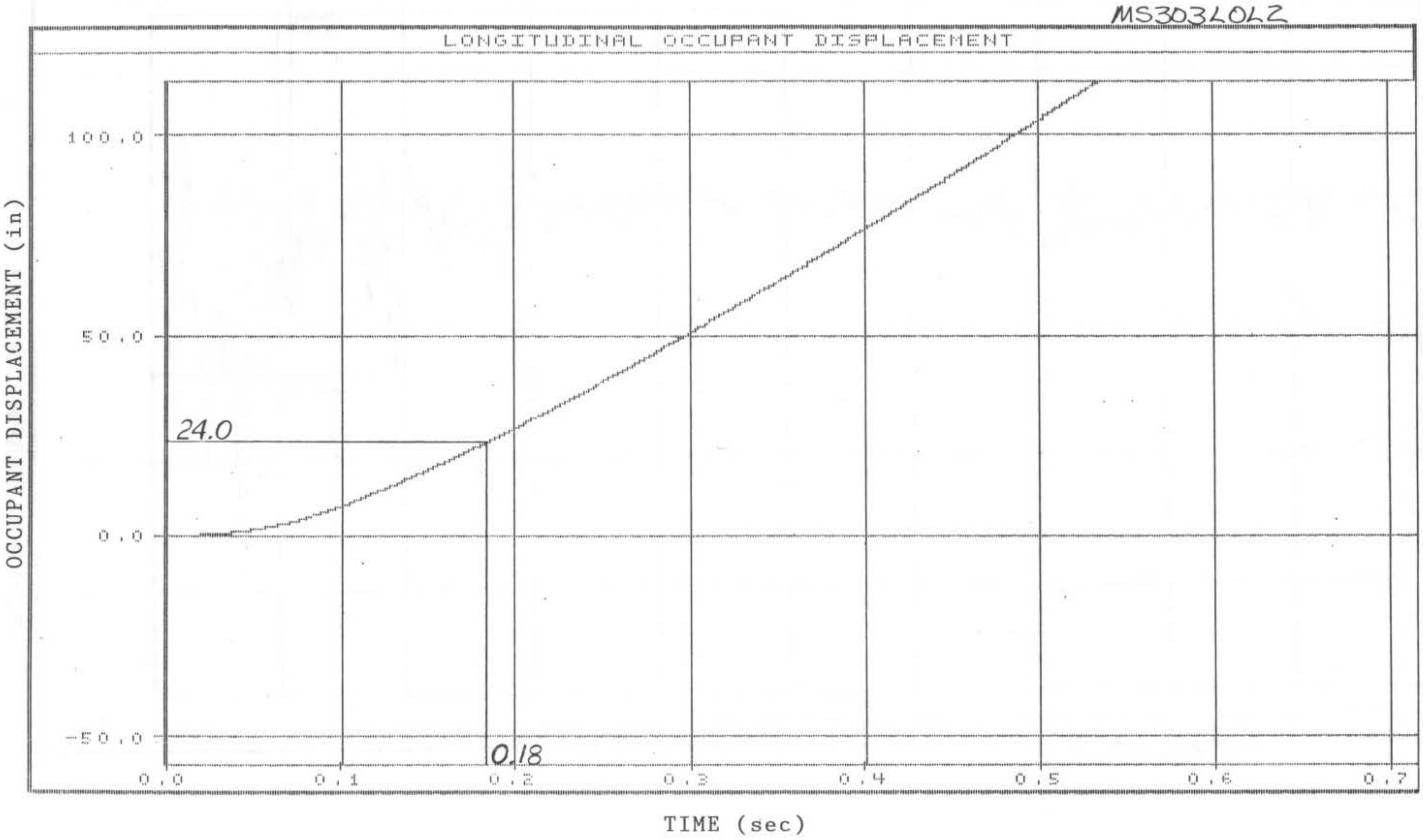
APPENDIX D-5. GRAPH OF LONGITUDINAL DECELERATION, Acc. #2



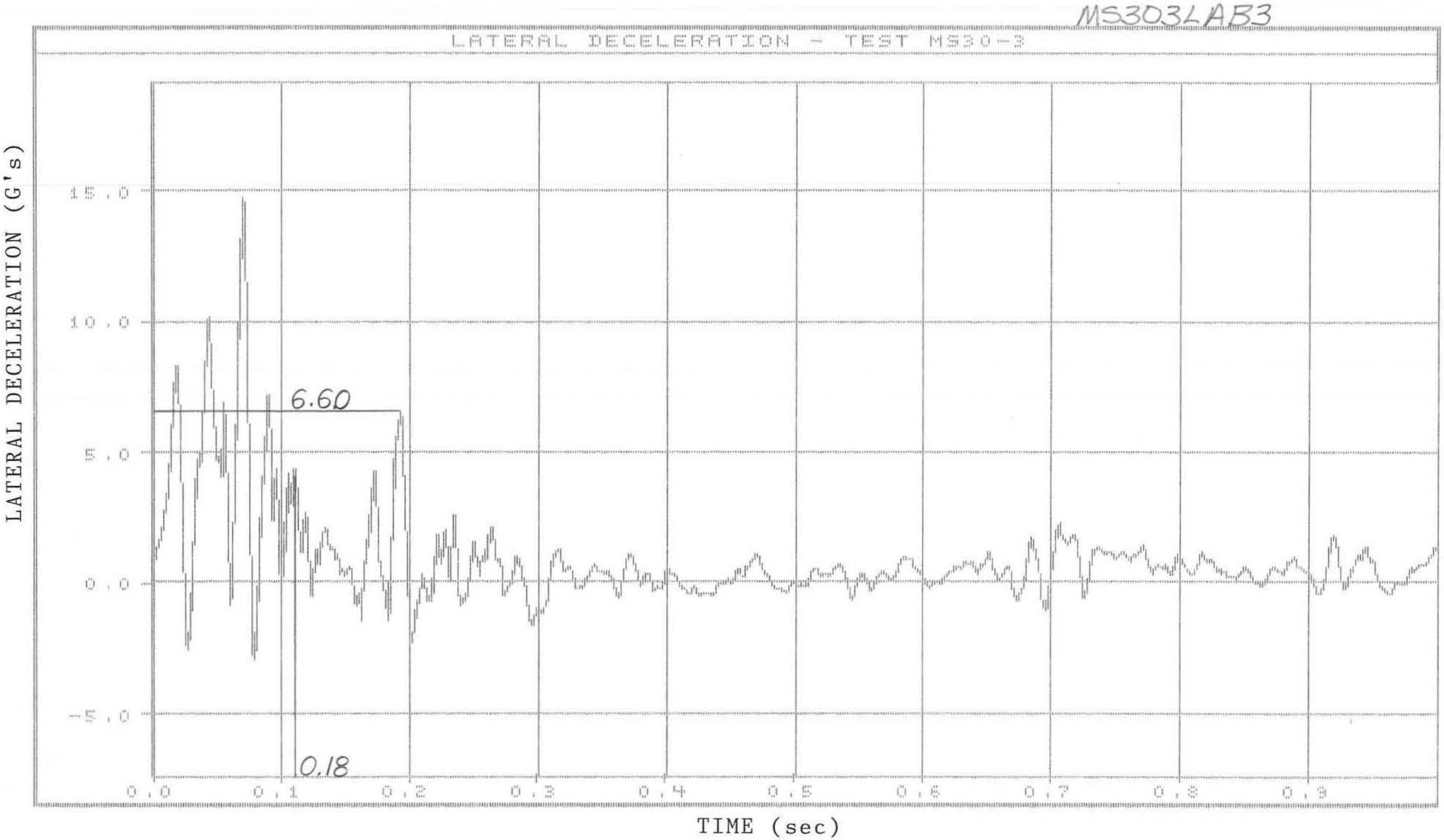
$(\Delta V)^* = \frac{(17.5)(60 \times \sin 20^\circ)}{(63.5) \times \sin 20^\circ}$

$(\Delta V)^* = 16.54$ fps

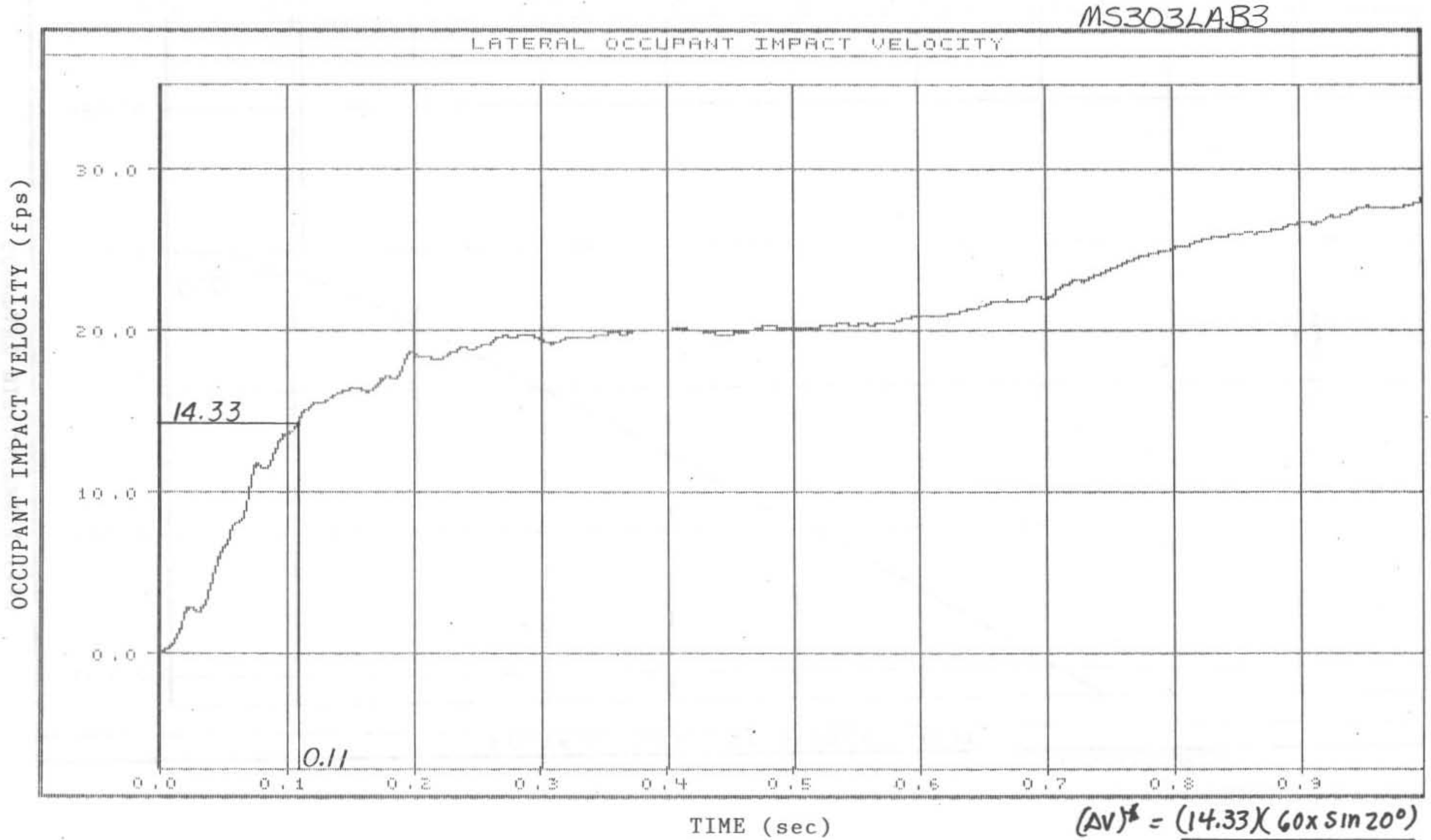
APPENDIX D-6. GRAPH OF LONGITUDINAL OCCUPANT IMPACT VELOCITY, Acc. #2



APPENDIX D-7. GRAPH OF LONGITUDINAL OCCUPANT DISPLACEMENT, Acc.#2



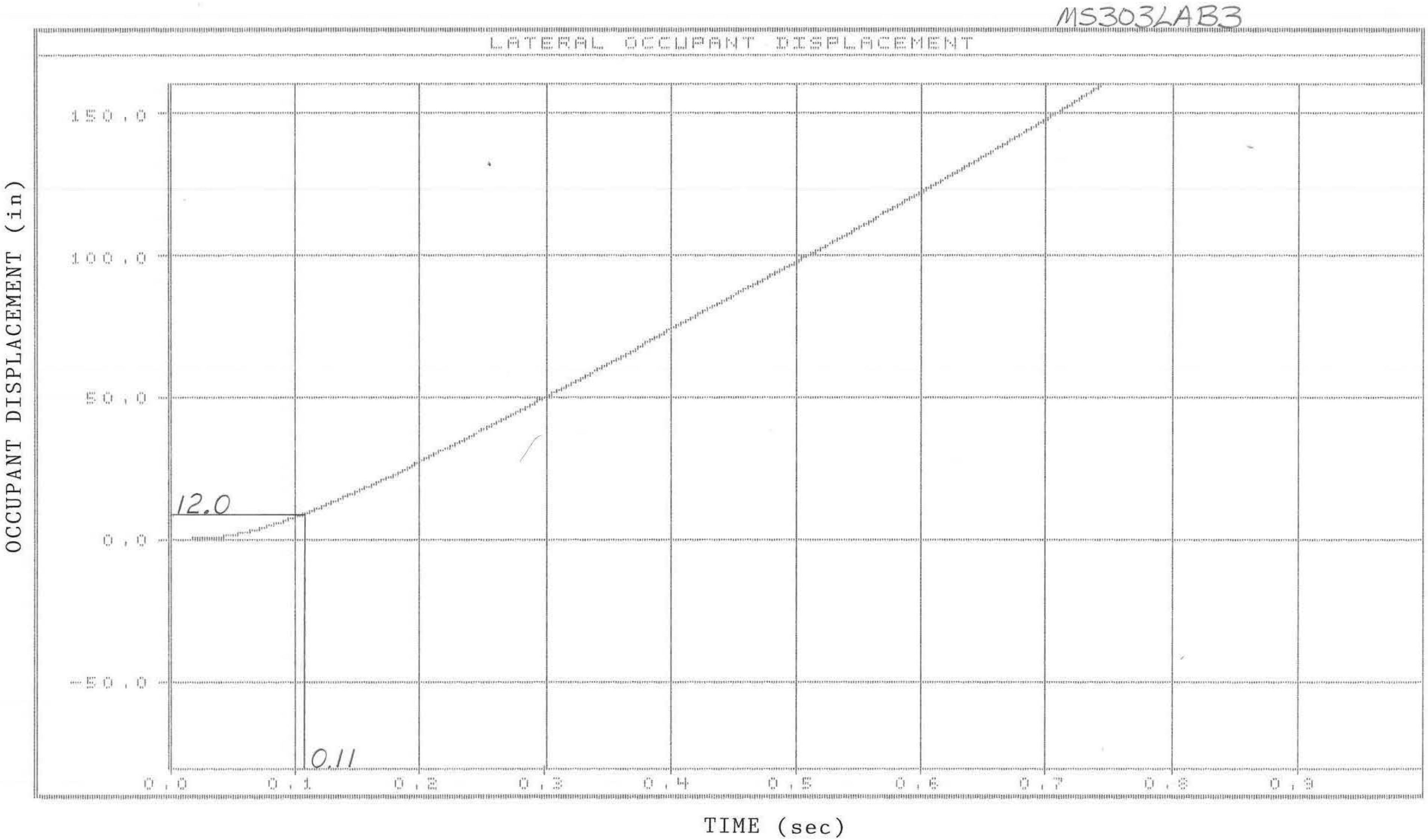
APPENDIX D-8. GRAPH OF LATERAL DECELERATION, Acc. #3



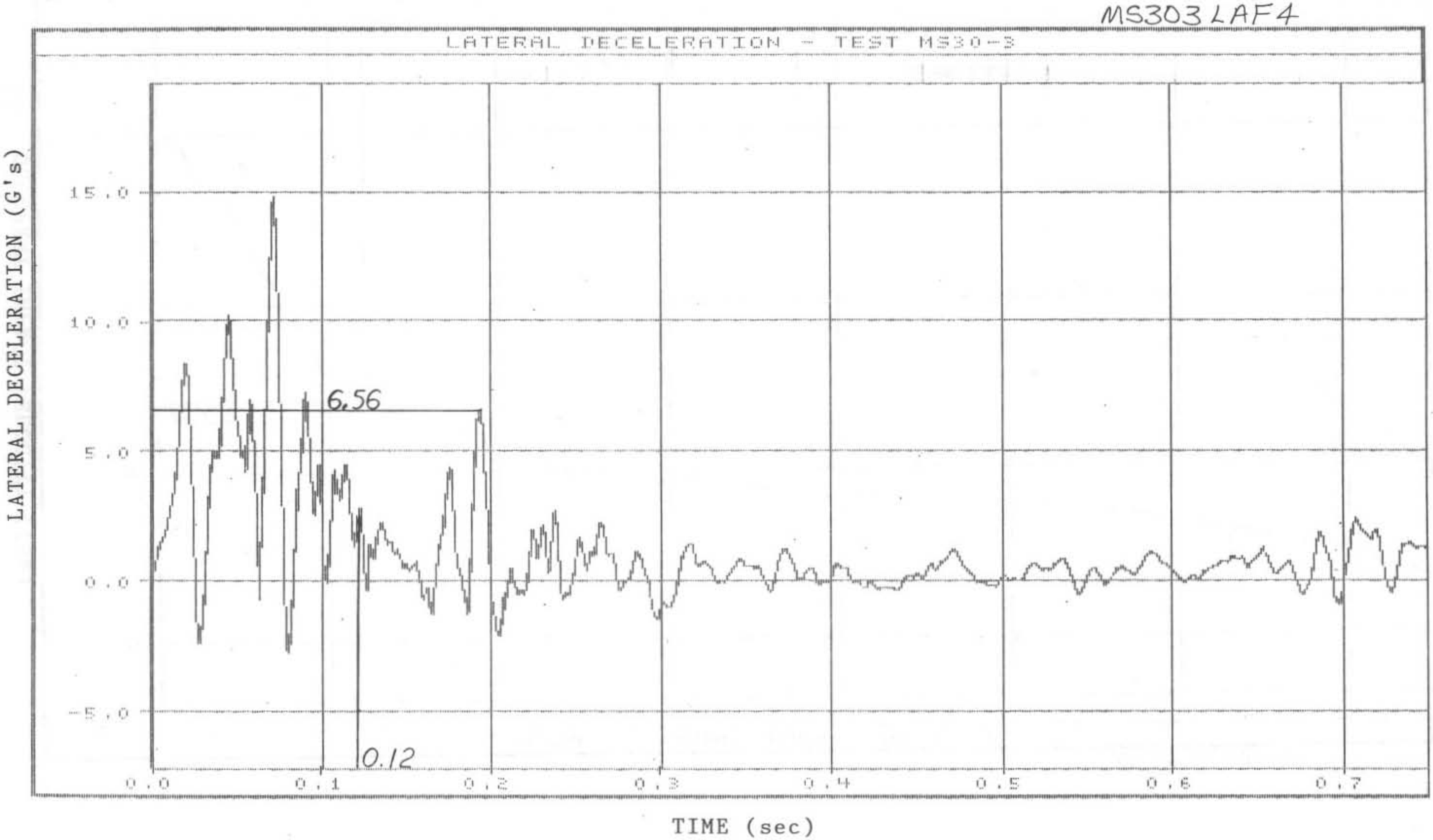
$(\Delta V)^* = \frac{(14.33)(60 \times \sin 20°)}{(63.5 \times \sin 20°)}$

APPENDIX D-9. GRAPH OF LATERAL OCCUPANT IMPACT VELOCITY, Acc. #3

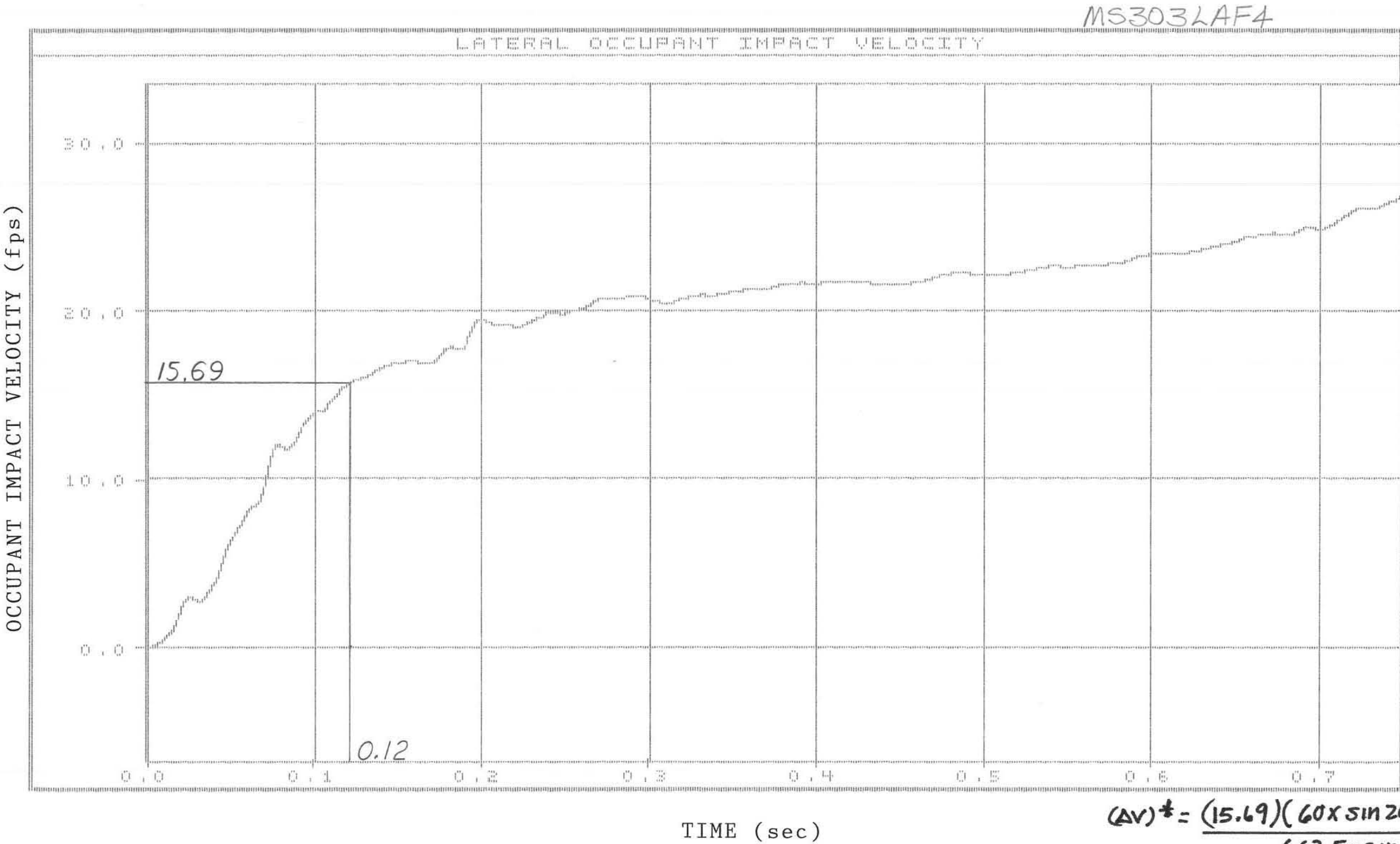
$(\Delta V)^* = 13.54$ fps



APPENDIX D-10. GRAPH OF LATERAL OCCUPANT DISPLACEMENT, Acc. #3



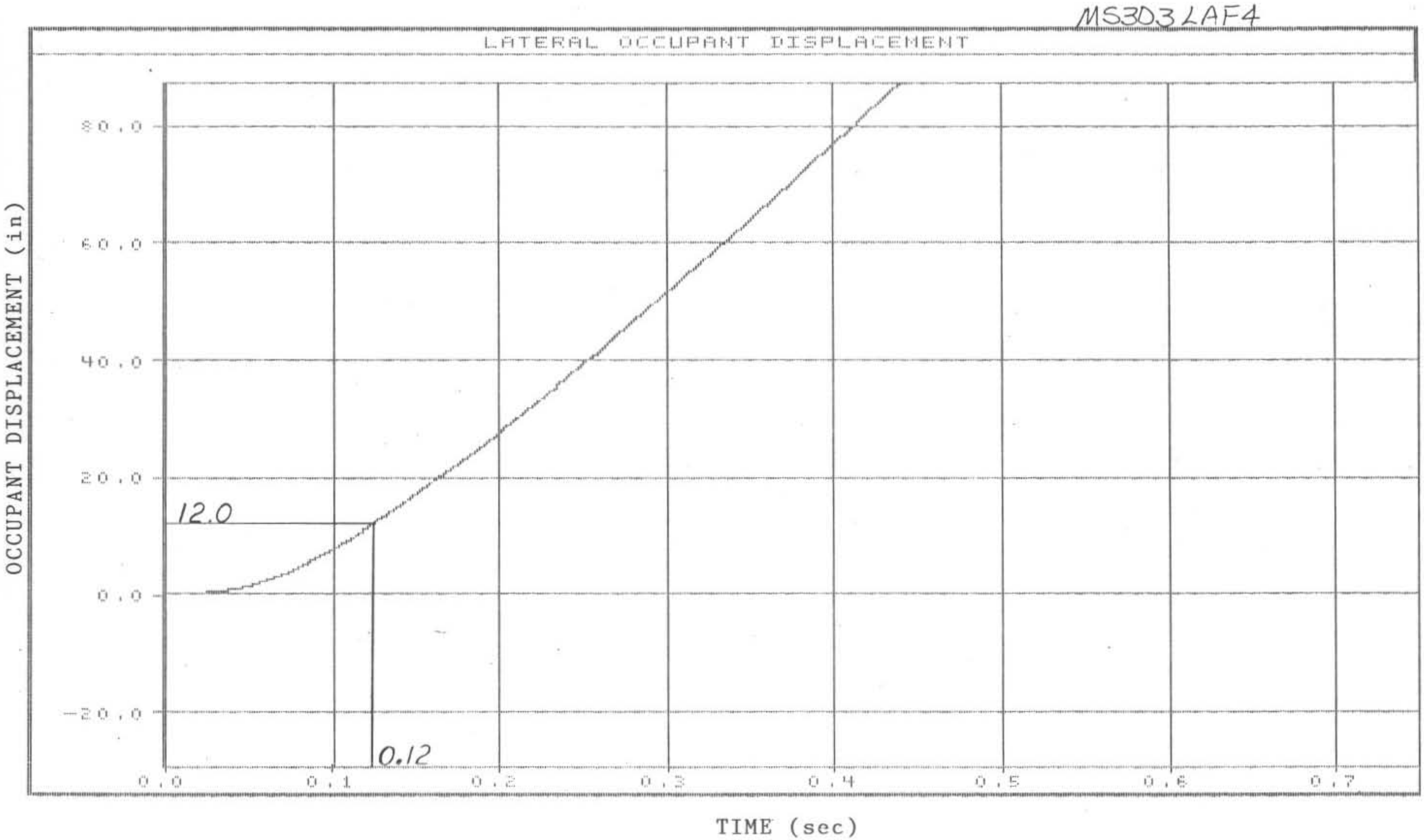
APPENDIX D-11. GRAPH OF LATERAL DECELERATION, Acc. #4



$$(\Delta V)^* = \frac{(15.69)(60 \times \sin 20^\circ)}{(63.5 \times \sin 20^\circ)}$$

$$\underline{(\Delta V)^* = 14.19 \text{ fps}}$$

APPENDIX D-12. GRAPH OF LATERAL OCCUPANT IMPACT VELOCITY, Acc. #4



APPENDIX D-13. GRAPH OF LATERAL OCCUPANT DISPLACEMENT, Acc. #4

APPENDIX E.
RELEVANT CORRESPONDENCE

University of Nebraska Lincoln

Department of
Civil Engineering
W348 Nebraska Hall
Lincoln, NE 68588-0531

August 15, 1990

TO: State Highway Departments of Nebraska, Kansas, and Missouri

FROM: Midwest Roadside Safety Facility, Civil Engineering Department, University of Nebraska-Lincoln

SUBJECT: Research Proposal For The Midwest Regional Pooled Fund Program (Year 1)

The Midwest Roadside Safety Facility (MwRSF) proposes to conduct six full-scale vehicle crash tests using three different concrete bridge rail systems for a total of $, as shown in Table 1. This includes two 18,000 lb., one 1,800 lb., and three 5,400lb. vehicle tests.

The three systems which will be constructed, removed, and disposed are as follows:

(1) the 30" high barrier rail (Missouri)
(2) the open concrete rail (Nebraska)
(3) the 32" high corral rail (Kansas)

The estimated construction, removal, etc., costs were determined from the preliminary provided plans. The preliminary work schedule is shown in Table 2.

MISSOURI

Three full-scale vehicle crash tests are required to satisfy the PL-2 Performance Level on the 30" high barrier rail.

NEBRASKA

The open concrete rail was previously tested under NCHRP 230 (FHWA/RD-89-119), but, a modification using less reinforcement would require the 5,400 lb. test at the expansion joint to satisfy the PL-1 Performance Level. An 1,800 lb. vehicle test would not be required. If a failed performance evaluation would occur, a redesign would follow, along with a 5,400 lb. test.

The previous testing was conducted at ENSCO consisting of a 29" high, open concrete rail. The results of the tests are as follows:

Test 1769-F-1-86: 4,669 lb. test vehicle
57.6 mph and 26 degrees
barrier contact - 11 ft.
impact velocity (fps) - (accelerometer)
longitudinal ...17.2 <30 ok
lateral ....31.2 >20 ?
ridedown acceleration (g's) - (accel.)
longitudinal ...-2.8 <15 ok
lateral ....-14.3 <15 ok

Test 1769-F-2-86: 1,971 lb. test vehicle
59.8 mph and 21 degrees
barrier contact - 12 ft.
impact velocity (fps) - (accelerometer)
longitudinal ...21.8 <30 ok
lateral ....24.1 >20 ?
ridedown acceleration (g's) - (accel.)
longitudinal ...-4.9 <15 ok
lateral ....-10.5 <15 ok

<u>KANSAS</u>

A 27" high corral rail was previously tested under NCHRP 230 (FHWA/RD-87-049) which was cited as a basis for not requiring the 1,800 lb. and 5,400 lb. vehicle tests. Thus, only an 18,000 lb. vehicle test is required to satisfy the PL-2 Performance Level.

The previous testing was conducted at Southwest Research Institute consisting of two designs, (1) the KBR Series and (2) the MKS Series. The KBR Series consisted of the 27" high, Kansas corral rail without curb. The MKS Series comes from a modification to the Kansas corral rail due to an addition of longitudinal beam steel and stirrups in both the beam and posts. The results of the MKS Series are as follows:

Test MKS-1: 1,850 lb. test vehicle
59.0 mph and 18.9 degrees
barrier contact - 7.8 ft.
impact velocity (fps) - (film/accelerometer)
longitudinal ... 9.2/14.0 <30 ok
lateral ....19.5/18.2 <20 ok
ridedown acceleration (g's) - (accelerometer)
longitudinal ... 1.4 <15 ok
lateral ....-14.8 <15 ok

Test MKS-2: 4,690 lb. test vehicle
59.2 mph and 24.9 degrees
barrier contact - 12.2 ft.
impact velocity (fps) - (film/accelerometer)
longitudinal ... 6.7/13.9 <30 ok
lateral ....19.3/24.9 <20 ok
ridedown acceleration (g's) - (accelerometer)
longitudinal ...-1.7 <15 ok
lateral ....-13.9 <15 ok

U.S. Department of Transportation
Federal Highway Administration

Region 7
Iowa, Kansas
Missouri, Nebraska

P.O. Box 419715
Kansas City, Missouri 64141-6715

October 23, 1991

In Reply Refer To
HEO-07

Mr. James C. Holloway
Research Associate Engineer
Midwest Roadside Safety Facility
Civil Engineering Department
University of Nebraska-Lincoln
W348 Nebraska Hall
Lincoln, Nebraska 68588-0531

Dear Jim:

Thank you for the opportunity to review the draft report titled "Performance Level 2 Tests on the Missouri 30 inch New Jersey Safety Shape Bridge Rail." I also appreciate your effort in preparing the video tape related to the MS30-1 test.

After reviewing the video of the test and reviewing other data, I agree with the findings of your report. I have no comments to offer on the draft report.

As a result of the review of this series of crash tests, I do recommend that at the earliest opportunity we crash test a 28 inch (71.1 cm) NJ Safety Shape Bridge Rail to help establish the PL-2 performance failure parameters for this system. I will discuss this at our 1993 crash test program technical committee meeting.

Sincerely yours,

Wm. H. Wendling
Technical Advisor
Midwest Crash Test Program

cc:
Mr. Milo Cress, Nebraska Division
Mr. Dan Davidson, MHTD