FULL-SCALE 4,500 LB. VEHICLE CRASH TEST ON THE PERMANENT PRECAST CONCRETE MEDIAN BARRIER

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Project RES1 (0099) P451
TRANSPORTATION RESEARCH REPORT TRP-03-24-90

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March 1991

ACKNOWLEDGEMENTS

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

Kansas Department of Transportation

Ron Seitz, P.E., Road Design Squad Leader

Kansas Turnpike Authority

Ron Fogo, P.E., Chief Engineer Manager

Missouri Highway and Transportation Department

Wayne Muri, P.E.,Chief Engineer

Federal Highway Administration

Bill Wendling, P.E., Safety Program Engineer

Nebraska Department of Roads

Dalyce Ronnau, Materials and Test Division Research Engineer

University of Nebraska-Lincoln

Tom Grady (E.E. Technician)
Tom Hoffman (Instrument Maker III)

Midwest Roadside Safety Facility

Charles Lavaty (C.E. Graduate Student)
Virgil Oligmueller (C.E. Student)
Craig Rockwell (C.E. Student)
Jim Luedke (C.E. Student)
Greg Prang (M.E. Student)
Mike Plantenga (M.E. Student)

Private

Jim Dunlap (Dunlap Photography)
George Hendricks (General Excavating)

ABSTRACT

One full-scale crash test was conducted on the permanent precast concrete median barrier. Test KCB-1 was conducted with a 4,320 lb. test vehicle at 24.4 degrees and 59.3 mph. The point of impact was located 3-ft upstream of the center keyway or midpoint of installation. The installation had a total length of 100 ft, consisting of ten 10 ft precast barrier individual sections.

The test was evaluated according to the safety criteria in the National Cooperative Highway Research Program (NCHRP) Report 230. The safety performance of the precast concrete median barrier was determined to be marginal.

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1 INTRODUCTION

1.1 Problem Statement

The Kansas Department of Transportation (KDOT), the Kansas Turnpike Authority (KTA), and the Missouri Highway and Transportation Department are interested in subjecting a precast New Jersey shape concrete median barrier used in permanent installations to a safety performance evaluation. Although this installation has been in use in the state of Kansas for over a decade, there has not been sufficient accident data for which the Federal Highway Administration (FHWA) could evaluate the performance and approve its use on future Federal-aid projects.

1.2 Background

During 1990, the FHWA had been seeking information regarding the field performance history of precast concrete barriers used in permanent installations. Within that period, no state in Region VII had been able to provide that information. A large amount of accident data was available on the precast concrete barriers, but this data did not contain the right kinds of information to justify approval of its use without a full scale crash test.

Thus, the FHWA had stated that the use of 10 foot precast concrete barriers in permanent installations would be unacceptable for installation on Federal-aid projects unless they were subjected to full scale crash testing. The FHWA encourages full-scale crash testing of a standardized design for this type of installation because their is evidence of economic feasibility in the use of precast concrete barriers in permanent installations.

1.3 Objective of Study

The objective of the research study was to evaluate the safety performance of the permanent precast concrete median barrier 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).

1.4 Literature Review

Many foundation conditions are found in current barrier practice. Some of these conditions include barriers that have been (1) embedded in soil, (2) embedded in pavement, (3) placed on concrete pavements or on footings, with or without dowels, (4) placed on a grout bed (precast), or (5) placed with a combination of these methods (2).

When steel bars are used for restraint, they are placed in the concrete base during construction or anchored in holes drilled in the hardened concrete. Size and spacing of bars has varied. In the past they were generally spaced about 4 ft apart at staggered locations with respect to the centerline of the barrier. Bar diameter was usually 3/4 in. or 1 in. and length of embedment was 8 to 12 in. It has been determined that these bars are stressed primarily in tension, rather than in shear, so that they should be deformed tie bars rather than smooth round dowels (2).

Past research findings at Southwest Research Institute have established required size and spacing guidelines. With the development length of 5 in. or a total length of 10 in., for either the NJ or F-shape, No. 4 bars at 2 ft spacing or No. 8 bars at 4 ft are required for a barrier length up to 20 ft. With a 30 ft length or greater and the same embedment, requirements can be changed to No. 5 bars at 4 ft spacing.

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-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 2. The test vehicle was released from the tow cable approximately 20 ft before impact with the permanent precast CMB. 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 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 (3), was used to steer the test vehicle. A sketch of the guidance system is shown in Figure 2. The guide flag, attached to the front left wheel and the guide cable, was sheared off 20 ft before impact with the permanent precast CMB. 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. As the vehicle was towed down the line, 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 Permanent Precast CMB Design Details

The design drawing details of the permanent precast CMB are shown in Figure 4, and photographs of the barrier before impact are shown in Figure 5. The total length of the installation was 100 ft. It consisted of ten 10 ft sections of the precast concrete median barrier (CMB) used as a permanent installation.

The cross-sectional dimensions of the precast concrete median barrier were those of the New Jersey shape. The width of the barrier was 24 in. at the base and 6 in. at the top of the stem. The overall height was 32 in.

The barrier sections were anchored into the existing concrete apron with five No. 8 dowel bars. Three dowels were placed on the traffic side and two dowels were placed on the back side of each barrier section. The 10 in. long dowel bars extended 5 in. into the existing concrete apron and 5 in. into the barrier section. The No. 8 dowel bars were secured with a non-shrink grout material, Sika Grout 212, which is certified to meet the requirements of the Corps of Engineers CRD-C621.

The stem of the precast concrete median barrier was reinforced with two longitudinal No. 4 bars (fy = 60 ksi) located 4 in. and 10 in. from the top of the barrier. The 28 day compressive strength of the concrete was 4,000 psi.

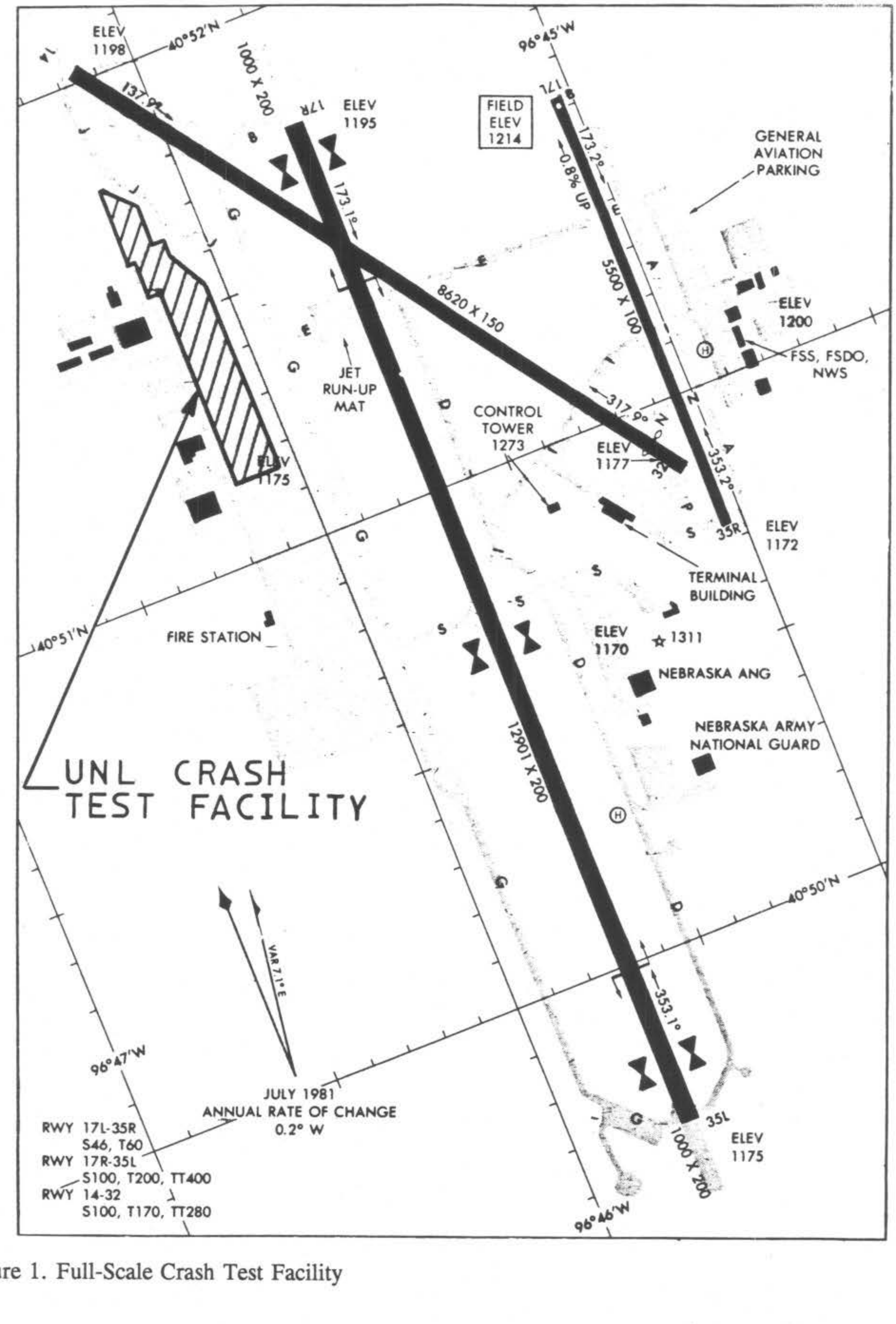


Figure 1. Full-Scale Crash Test Facility

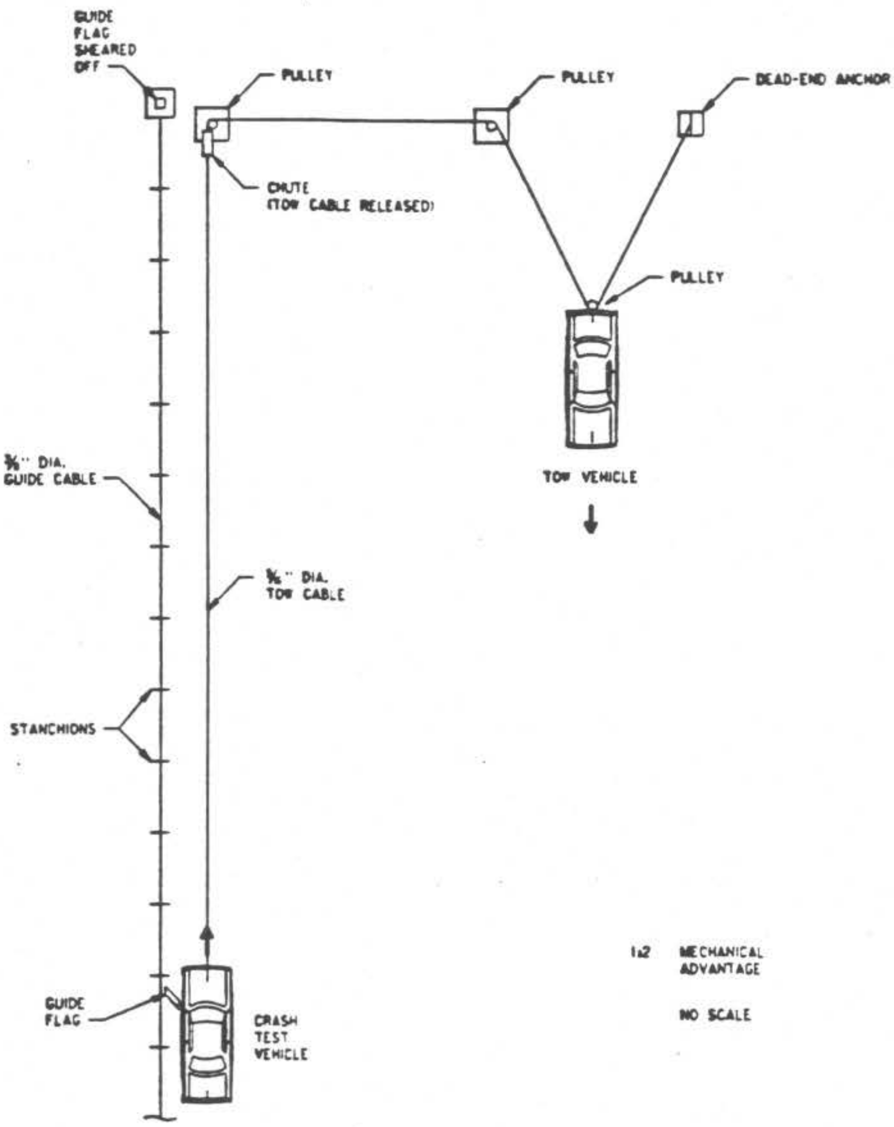


Figure 2. Sketch of Cable Tow and Guidance Systems

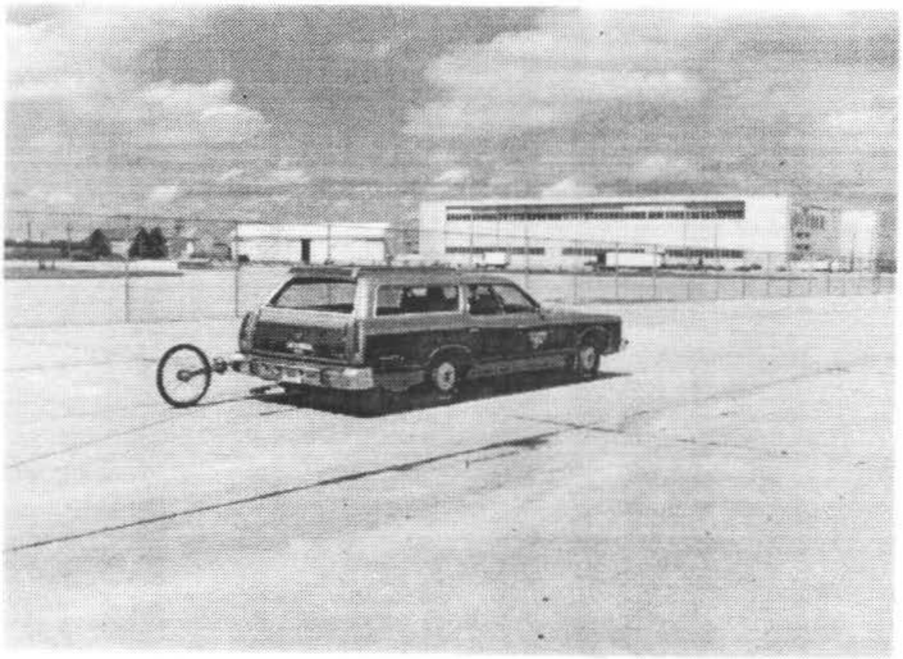


Figure 3. Photograph of Tow Vehicle and Fifth Wheel

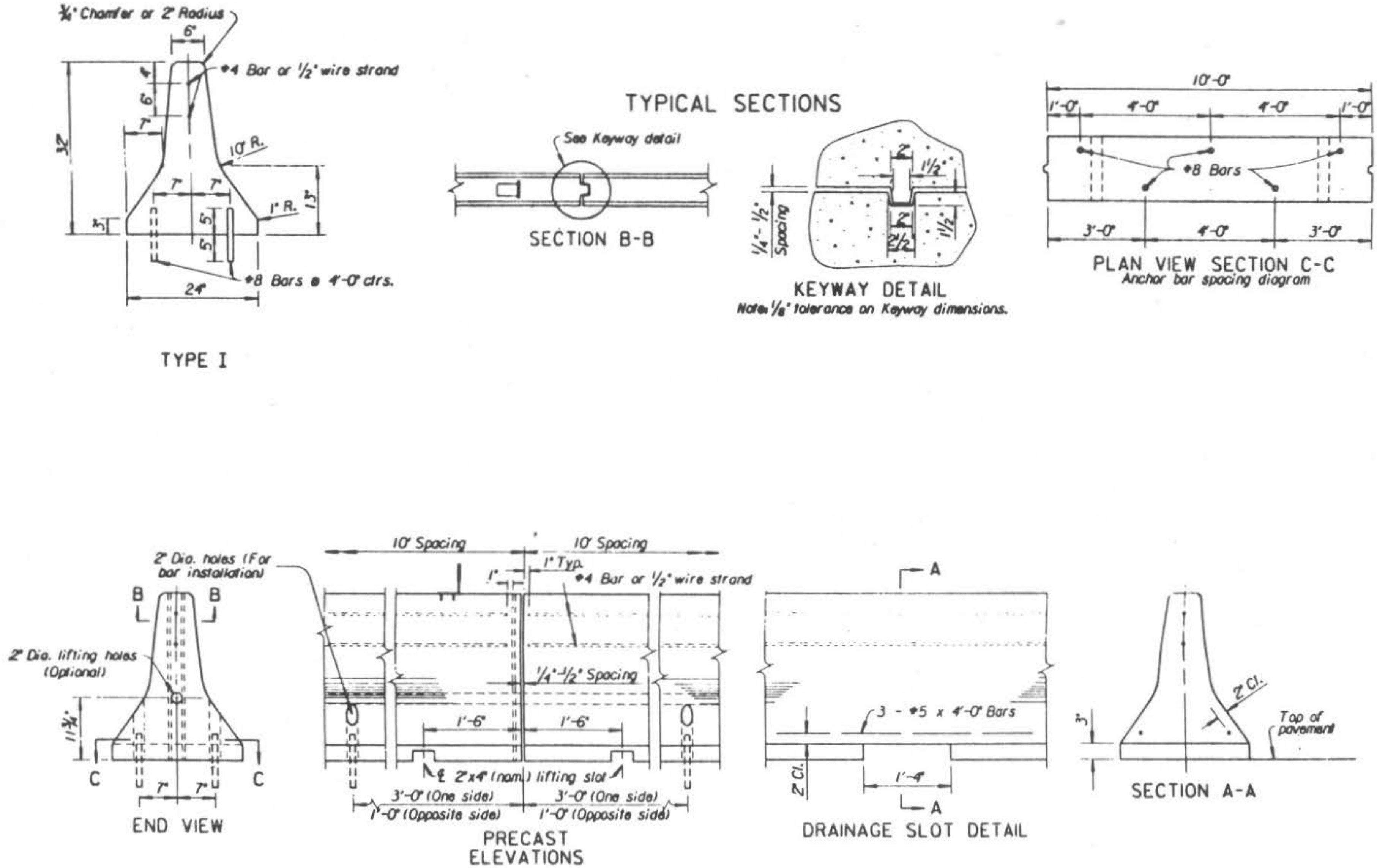


Figure 4. Details of the Permanent Precast CMB

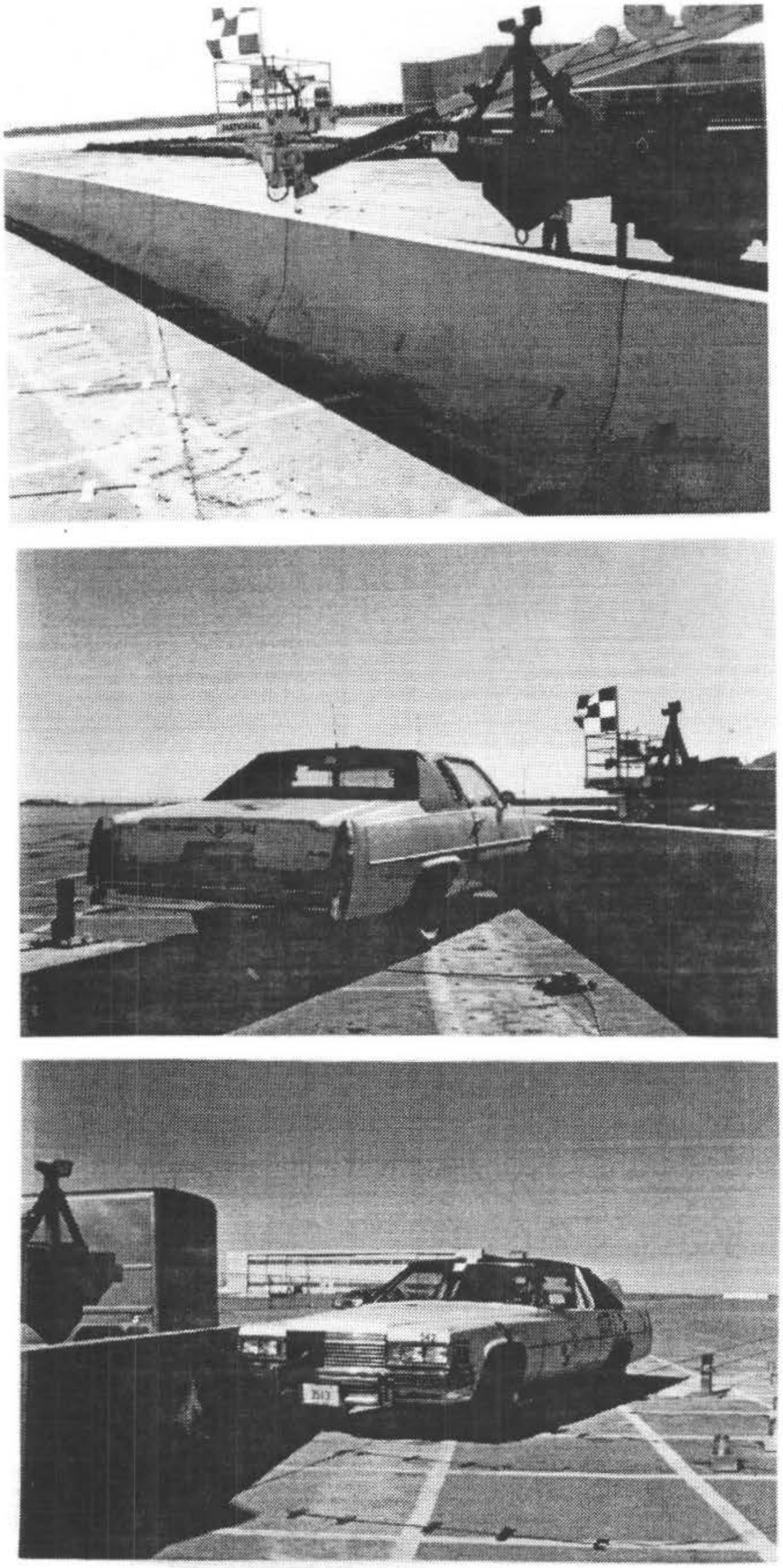


Figure 5. Pretest Photographs of the Permanent Precast CMB

The precast concrete median barriers were connected together with a concrete keyway located along the full height of the barrier as shown in Figure 4. The keyway was approximately 2 in. wide.

2.3 Test Vehicle

For Test KCB-1, a 1979 Cadillac Fleetwood Brougham weighing 4,320 lbs. was used as the crash test vehicle to evaluate the concrete median barrier. Photographs of the test vehicle are shown in Figure 6. Dimensions of the test vehicle are shown in Figure 7. A 4,500 lb. test vehicle older than 6 years was specified by William Wendling, FHWA, Region VII, Kansas City. The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable.

Five 8 in. square, black and white checkered targets were placed on the centerline of the top of the test vehicle. The second target from the front was placed over the center of mass of the vehicle. 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 positions to aid in the evaluation process.

Two 5B flash-bulbs were mounted on the roof of the test vehicle to record the time of impact with the permanent precast CMB on the high-speed film. The flash bulbs were fired by a pressure tape switch mounted on the front face of the bumper.

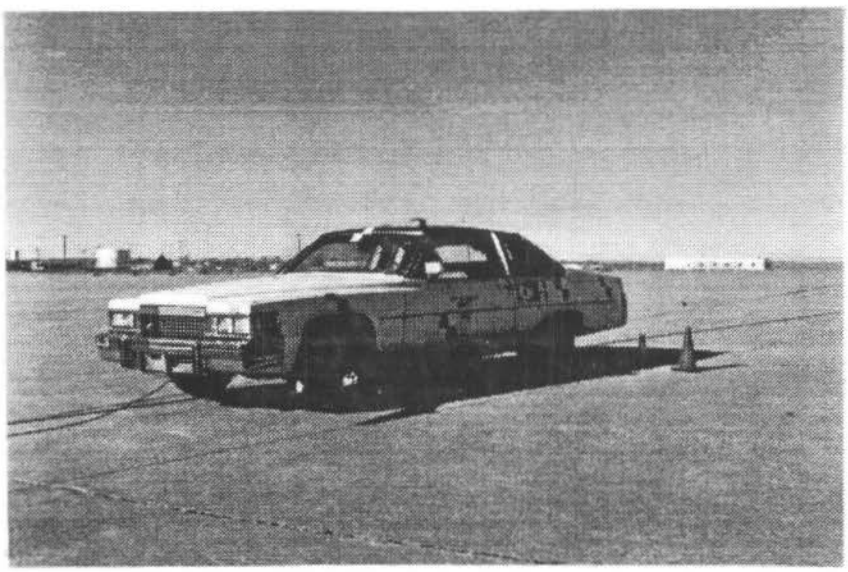
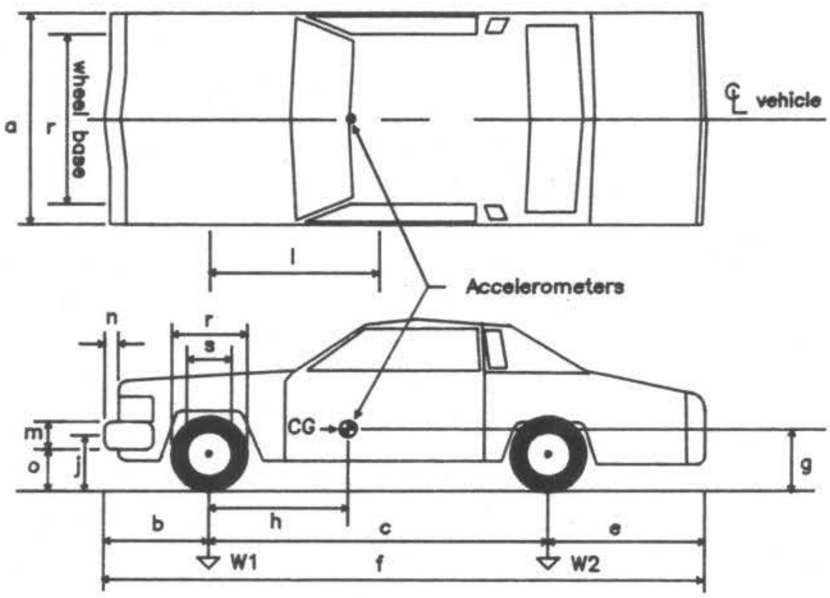


Figure 6. Pretest Photographs of Test Vehicle

Date: 11/21/90 | Test No.: KCB-1 | Vehicle I.D.#: 6D47S99152967

Make: Cadillac | Model: Fleetwood Brougham | Year: 1979

Tire Size; P225/75R15 | Odometer: 52619



Vehicle Geometry
Inches

a	76.0	b	37.5
c	121.0	d	N/A
e	56.0	f	214.5
g	22.6	h	49.5
j	20.0	l	49.5
m	10.0	n	5.0
o	15.0	p	61.0
r	27.0	s	16

Engine Type: Gasoline

Engine Size: 7.0 Liter

Transmission Type:
Automatic, RWD

Weight – pounds	Curb	Test Inertial	Gross Static
W1	2,490	2,490	2,490
W2	1,830	1,830	1,830
Wtotal	4,320	4,320	4,320

Damage prior to test: None

Figure 7. Test Vehicle Measurements

2.4 Data Acquisition Systems

2.4.1 Accelerometers

Six 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. Two accelerometers were mounted in each of the three directions so that there would be two accelerometer traces for validation of results. The accelerometers were rigidly attached to a metal block mounted at the center-of-mass. The signals from the accelerometers were received and conditioned by an onboard vehicle Metraplex Unit. The multiplexed signal was then radio 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 8, and photographs of the system located in the centrally controlled step van are shown in Figure 9. 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 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 operated at approximately 500 frames/sec. The overhead camera was a Red Lake Locam with a wide angle 12.5 mm lens. It was placed approximately 66 ft above the concrete apron. The parallel camera was a Photec IV with an 80 mm lens. It was placed 200 ft downstream from the point of impact and offset 3 ft from a line parallel to the barrier rail. The perpendicular camera was a Photec IV with a 55 mm lens. It was placed 165 ft from the vehicle point of impact. A schematic all three camera locations is shown in Figure 10.

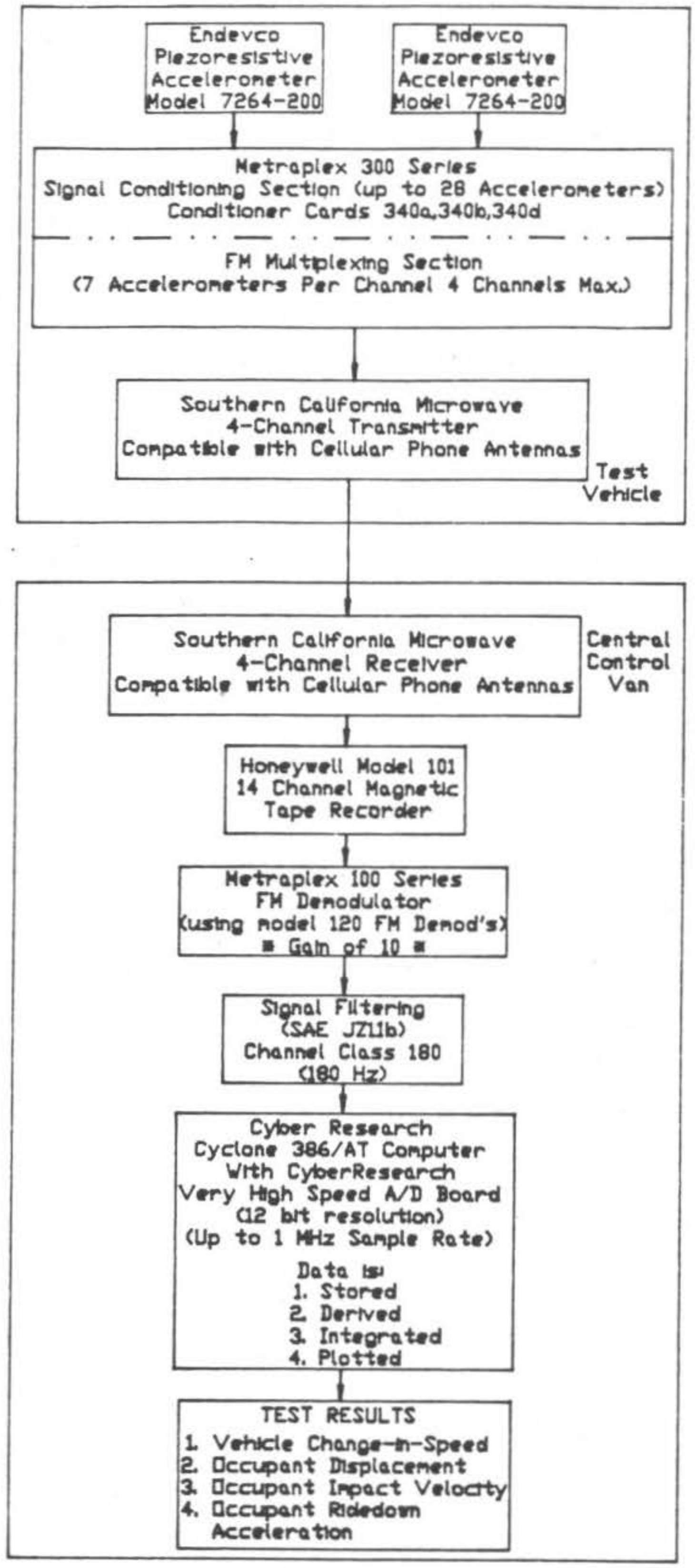


Figure 8. Flow Chart of Data Acquisition System

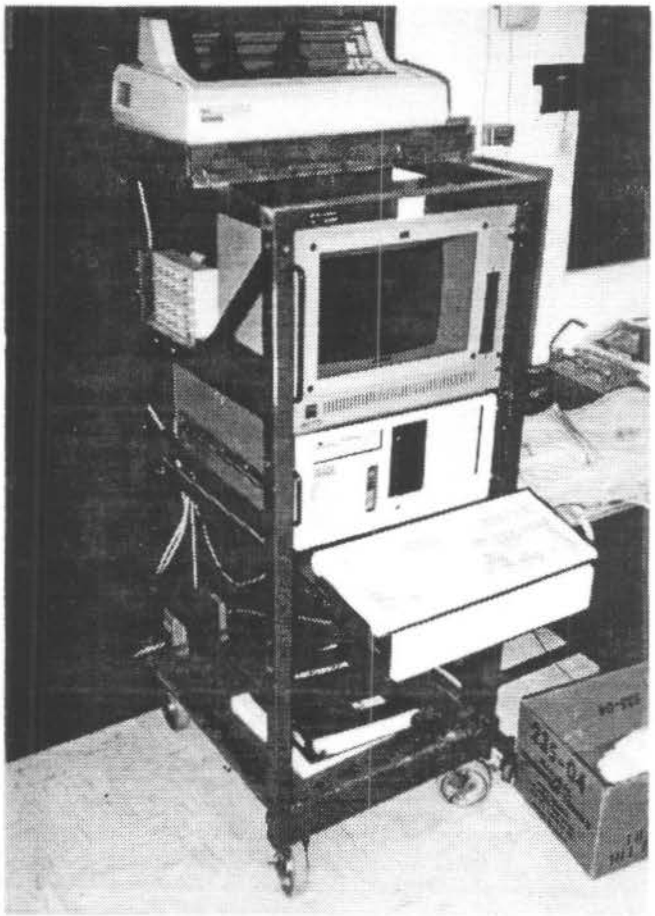


Figure 9. Photographs of Data Recorder and 386/AT Computer

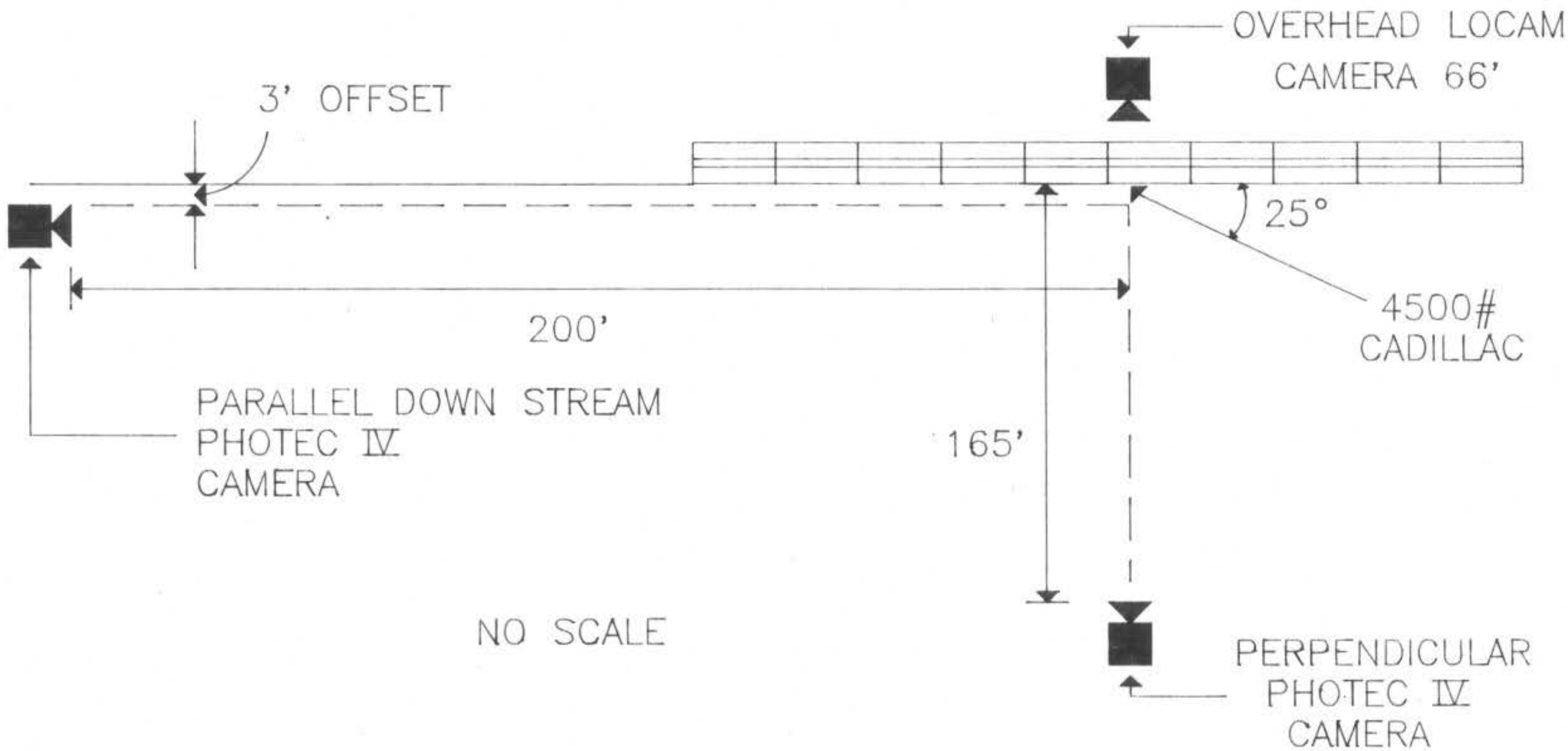


Figure 10 Layout of High-Speed Cameras

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

2.5 Test Parameters

One full-scale vehicle crash test was conducted on the permanent precast CMB. Test KCB-1 was conducted at an impact speed of 59.3 mph and at an angle of 24.4 degrees. The location of impact was 3 ft upstream of the centermost keyway. This position was determined to produce the maximum lateral load into the keyway.

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 (permanent precast CMB) 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 are presented in the new AASHTO criteria (4).

This test was evaluated according to criteria presented in NCHRP 230 (1). There is no criteria in AASHTO (4) for the 4,500 lb. vehicle in particular. 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 Table 2. After each test, the vehicle damage was assessed by the traffic accident scale (TAD) (5) and the vehicle damage index (VDI) (6).

Table 1. Crash Test Conditions and Evaluation Criteria for the Permanent Precast CMB

Test Agency	Test Designation	Appurtenance	Test Vehicle	Impact Conditions			Evaluation Criteria
				Speed (mph)	Angle (deg)	Location	
NCHRP 230 (1)	10	Longitudinal Barrier Length-of-need	4,500 lb. (sedan)	60	25	3 ft upstream of center joint	A,D,E,H,I

[a] Criteria described in Table 2.

Table 2. NCHRP 230 Evaluation Criteria

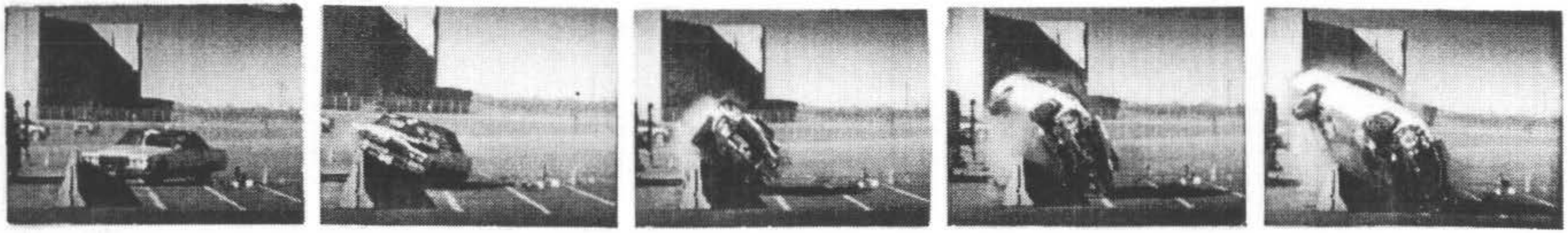
Structural Adequacy	A. Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.
	D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.
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.
Vehicle Trajectory	H. After collision, vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.
	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 the test impact angle, both measured at time of vehicle loss of contact with test device.

4 TEST RESULTS

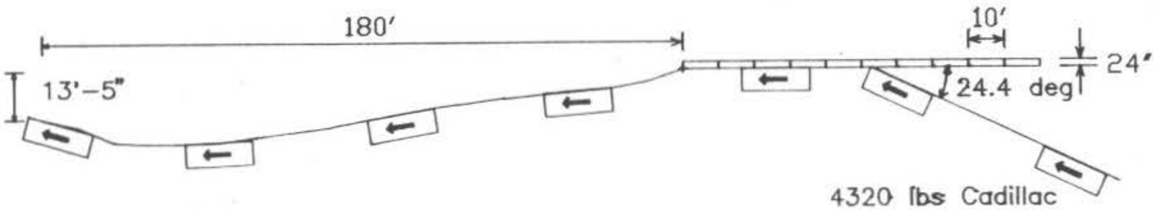
Test KCB-1 was conducted with a 4,320 lb. Cadillac Fleetwood Brougham under the impact conditions of 59.3 mph and 24.4 degrees. The location of impact was 3 ft upstream of the centermost keyway. A summary of the test results is shown in Figure 11. The sequential photographs are shown in Figures 12, 13, and 14.

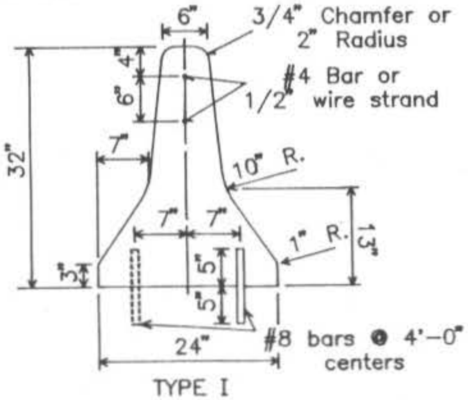
Upon impact with the permanent precast CMB, the right front corner of the vehicle began to crush inward. At 0.090 sec after impact the rotation of the barrier became noticeable and the vehicle began to ride up on the barrier. At 0.172 sec the barrier fractured after having rotated approximately 15 degrees. At 0.220 sec the vehicle was parallel to the barrier and the right side of the vehicle was completely above the barrier. At approximately 0.300 sec the vehicle was completely airborne and free from the barrier. At 0.500 sec the vehicle reached its maximum roll angle of approximately 75 degrees. At 0.570 sec the left front corner of the vehicle contacted the concrete apron and at 0.724 sec the right underside of the vehicle contacted the top of the barrier on its way down. At 1.070 sec the right tires of the car touched down and the vehicle slid across the concrete, coming to a stop 230 ft downstream from the barrier and offset a distance of 13 ft perpendicular to a line parallel to the barrier.

Photographs of the vehicle damage are shown in Figure 15. The vehicle damage was marginal, meaning that it was on the lower limit of acceptability. The TAD and VDI damage classifications are shown in Figure 11. Photographs of the damage to the permanent precast CMB are shown in Figures 16 through 21. As evident from the photographs, the barrier section rotated as a result of two different failure mechanisms: First, the concrete keyway fractured at multiple joint locations; second, the barrier was lifted off the grouted dowel bars located on the traffic side of the barrier. Portions of the concrete fractured off the lower edge near the grouted dowel bars. Appendix B contains graphs of longitudinal and lateral deceleration, occupant impact velocity, and occupant displacement versus time.



Impact	0.192 sec	0.384 sec	0.576 sec	0.768 sec





Test Number	KCB-1
Date	11/21/90
Installation	Permanent Precast Concrete Median Barrier
Length	100'
Concrete Barrier	
Member	New Jersey Barrier
Length One Section	10'
Dimensions	
Width, Top	6"
Width, Bottom	24"
Height	32"
Barrier Connection Type	Concrete Keyway
Rigid Connection Type	5 - #8 dowel bars
Grout Material	Sicka Grout 212 (CRD-C621)
Vehicle Model	1979 Cadillac Fleetwood Brougham
Weight, Test Inertia	4320 lbs.
Weight, Gross Static	4320 lbs.

Vehicle Speed	
Impact	59.3 mph
Exit	38.3 mph
Vehicle Angle	
Impact	24.4 degrees
Exit	0 degrees
Vehicle Snagging	Minor
Vehicle Stability	Excessive Roll Angle
Occupant Impact Velocity	
Longitudinal	18.4 fps (<30 fps)
Lateral	20.7 fps (>20 fps)
Occupant Ridedown Deceleration	
Longitudinal	11.7 g's (<15 g's)
Lateral	6.9 g's (<15 g's)
Vehicle Damage	Marginal
TAD	1-RFQ-4
VDI	01FZEW2
Vehicle Rebound Distance	10'-4" @ 120'
Barrier Damage	Marginal

Figure 11 Test KCB-1 Summary and Sequential Photographs

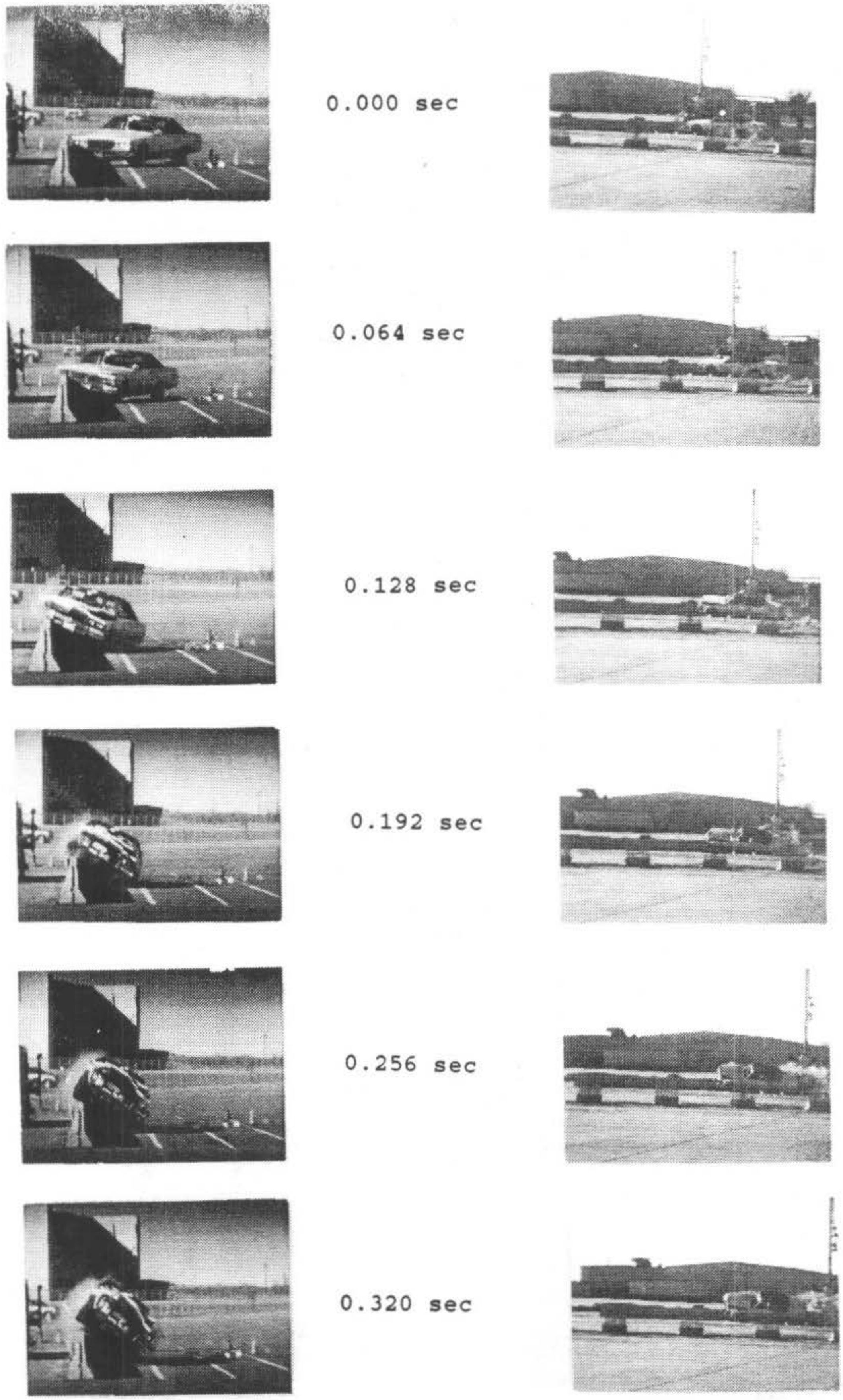


Figure 12. Time-Sequential Photographs

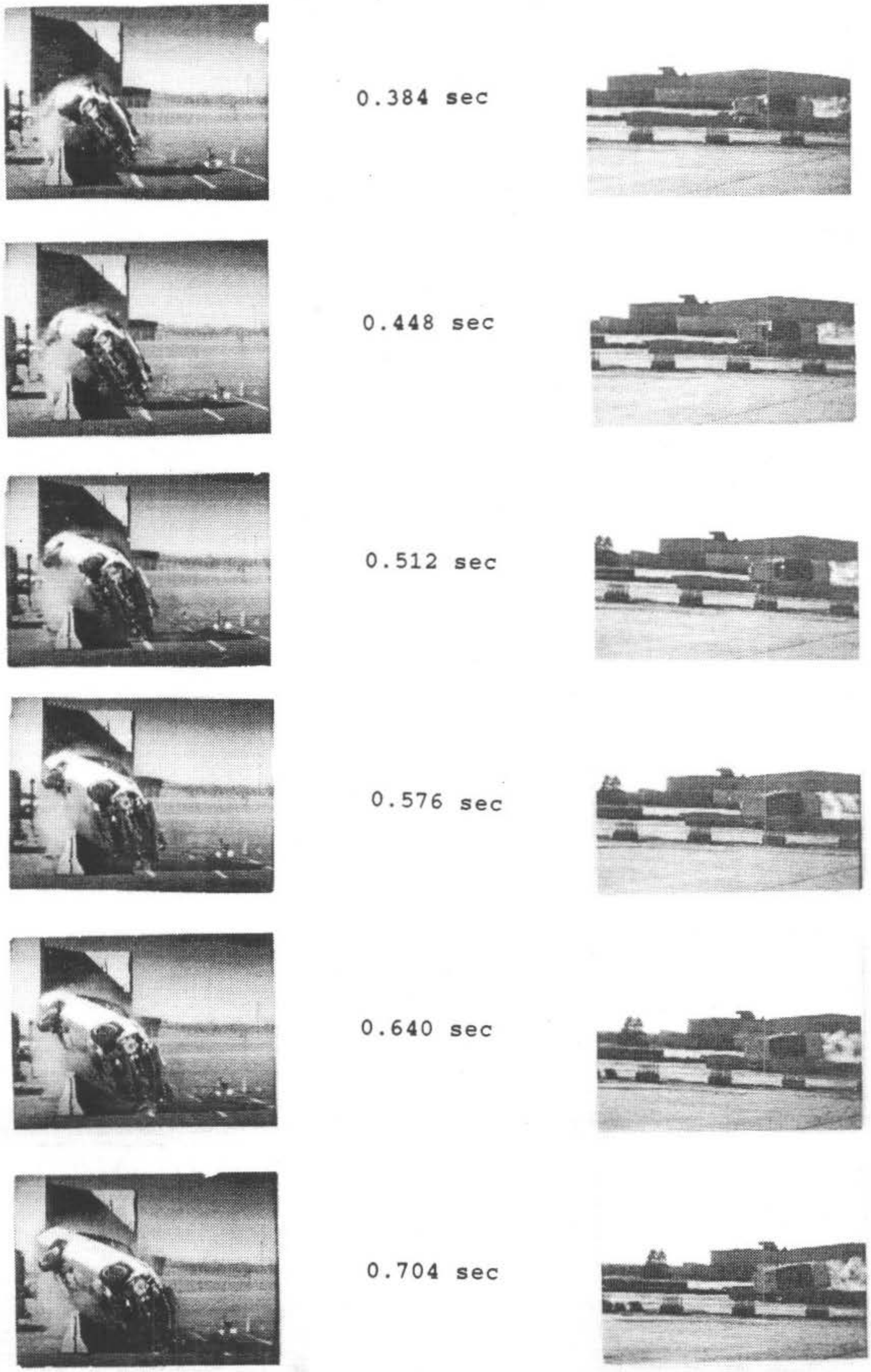


Figure 13. Time-Sequential Photographs (continued)

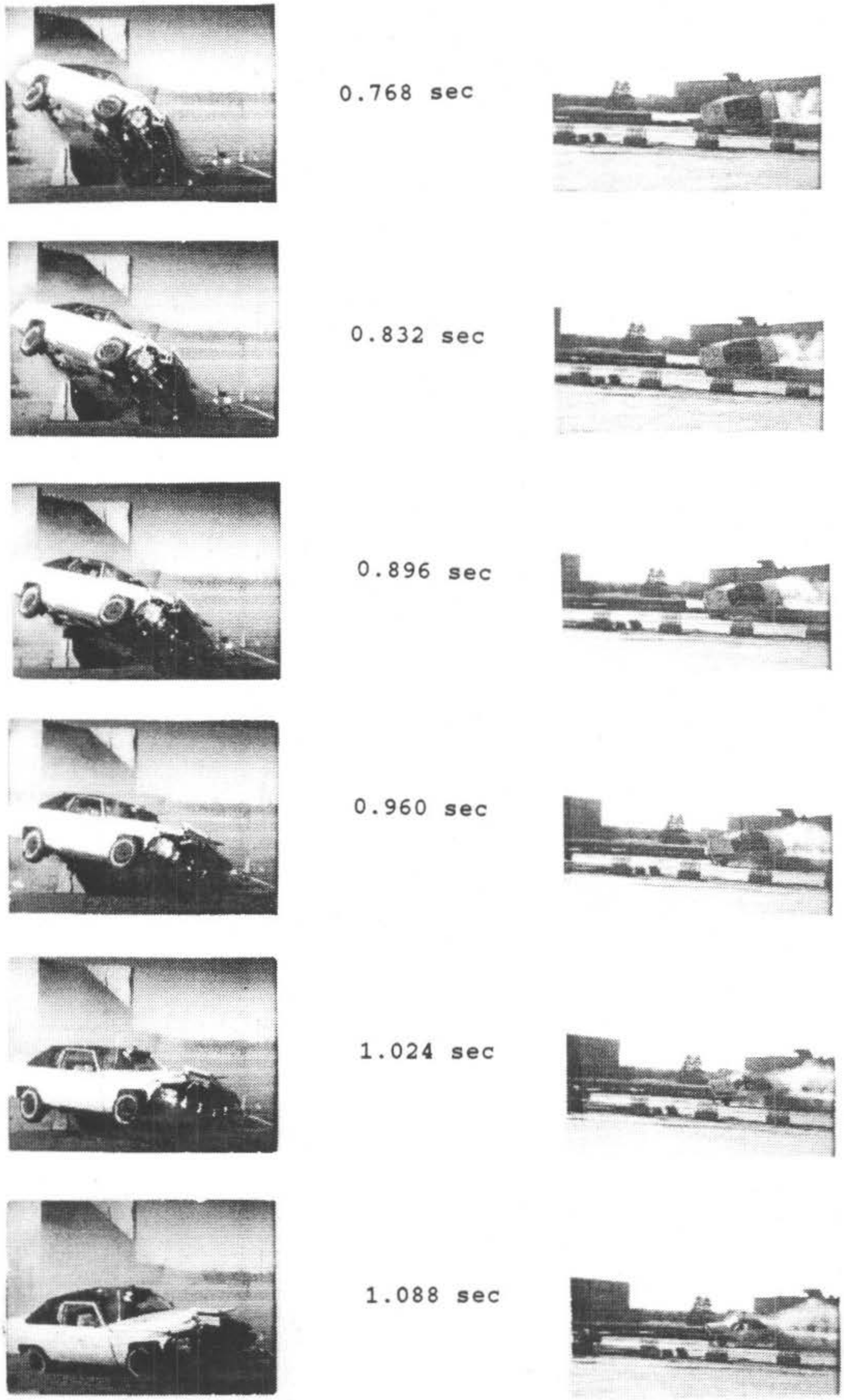


Figure 14. Time-Sequential Photographs (continued)

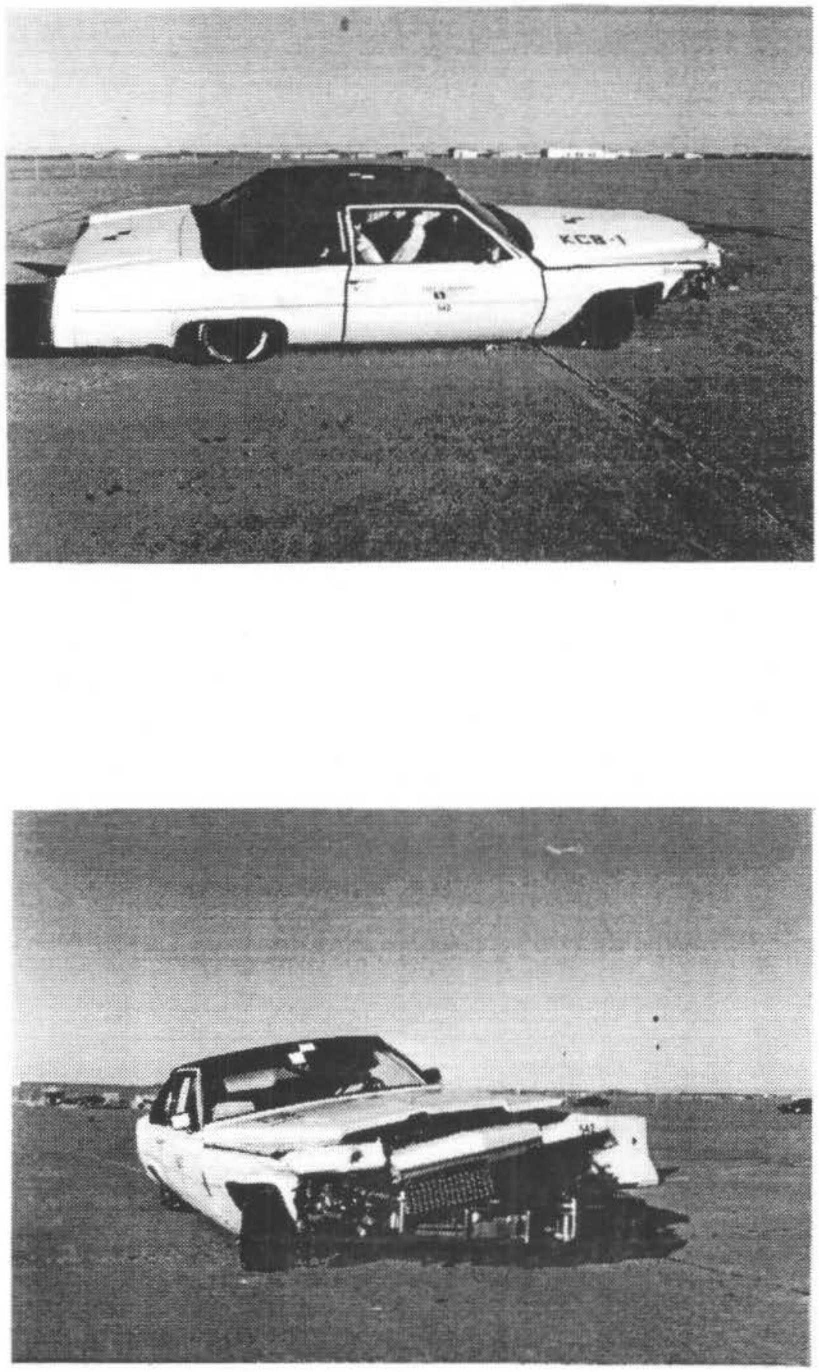


Figure 15. Photographs of Vehicle Damage

Figure 16. Photographs of the overall damage to the Permanent Precast CMB

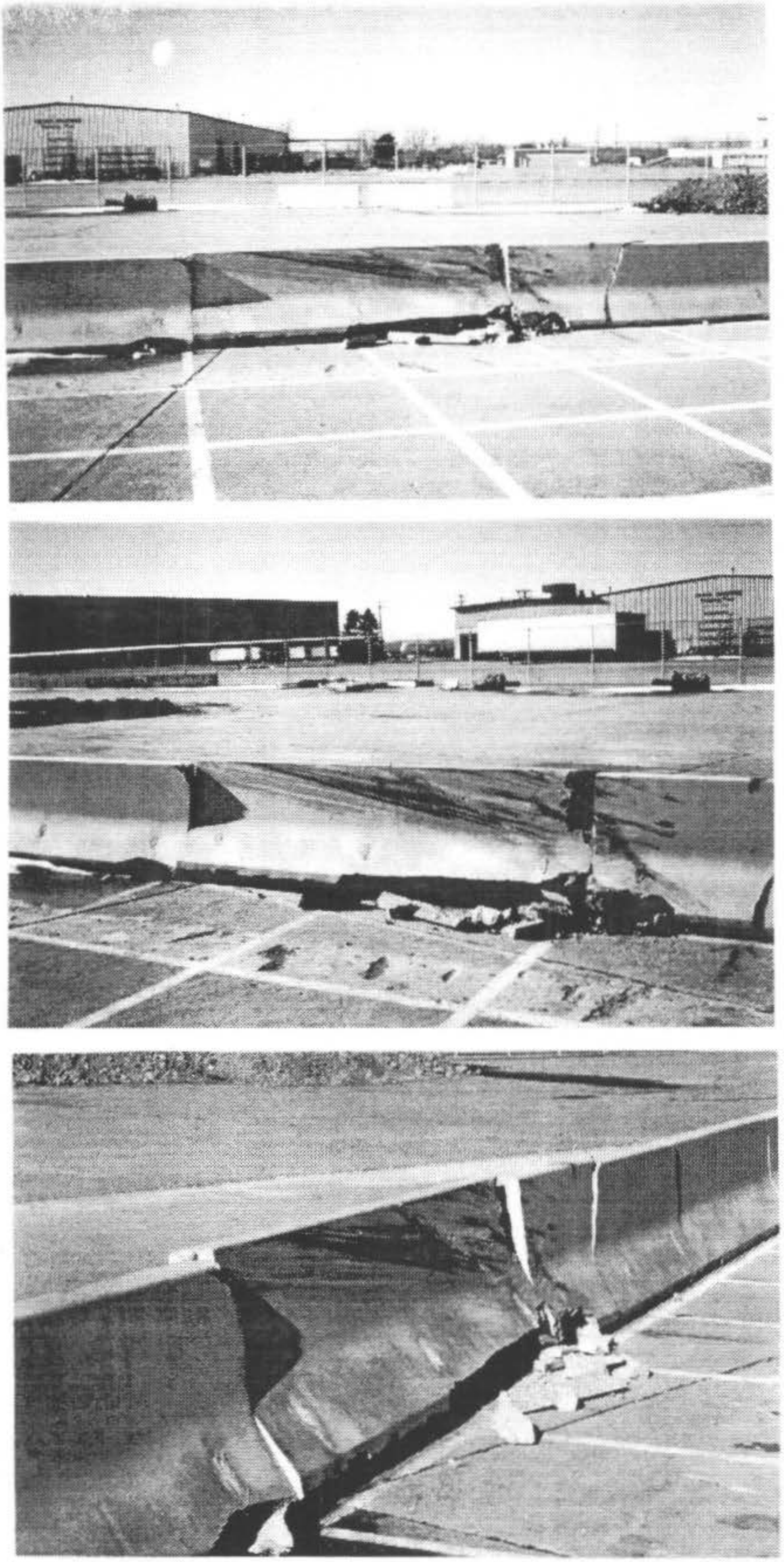


Figure 17. Photographs of the barrier damage at the location of impact (front side)

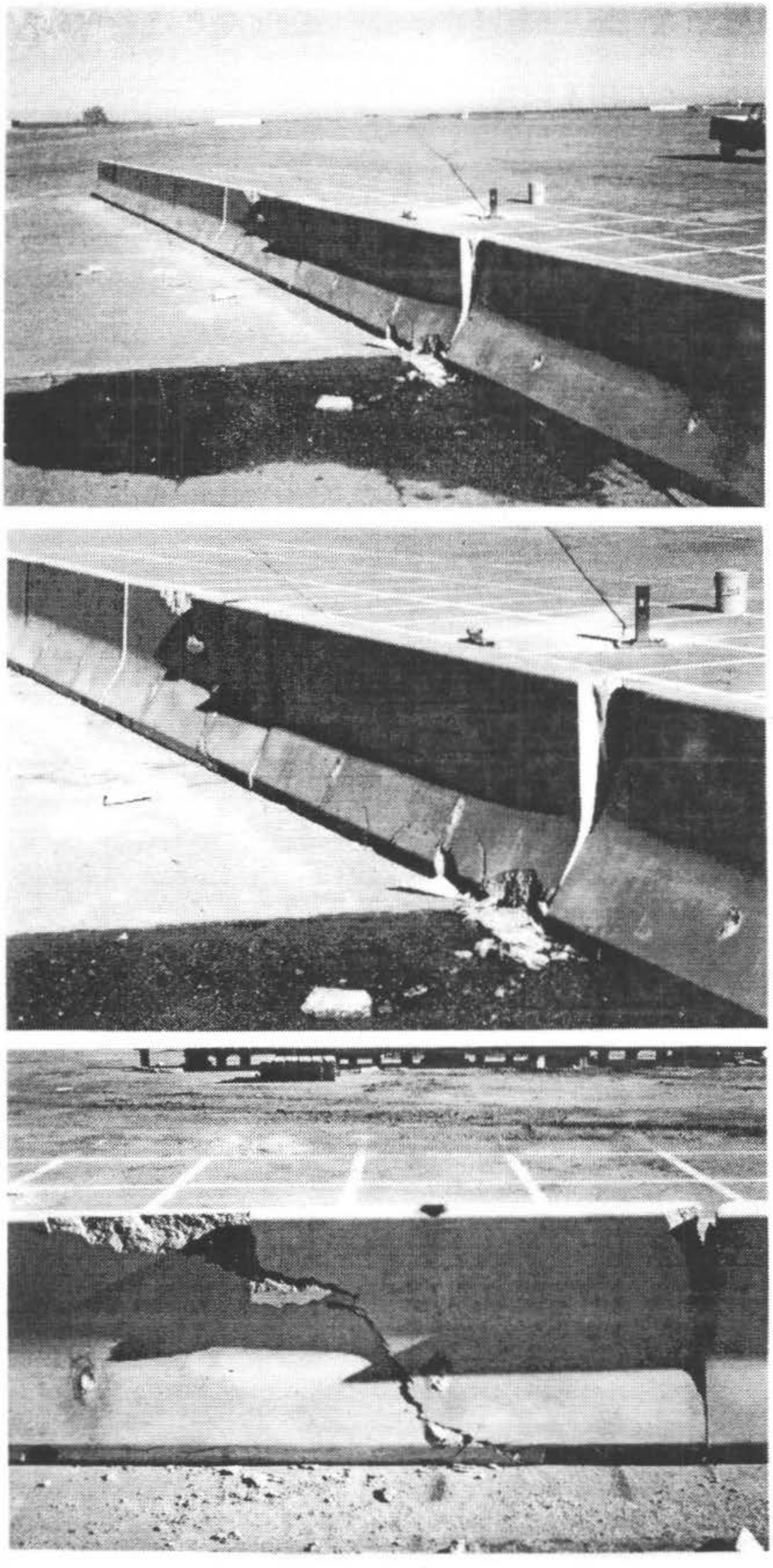
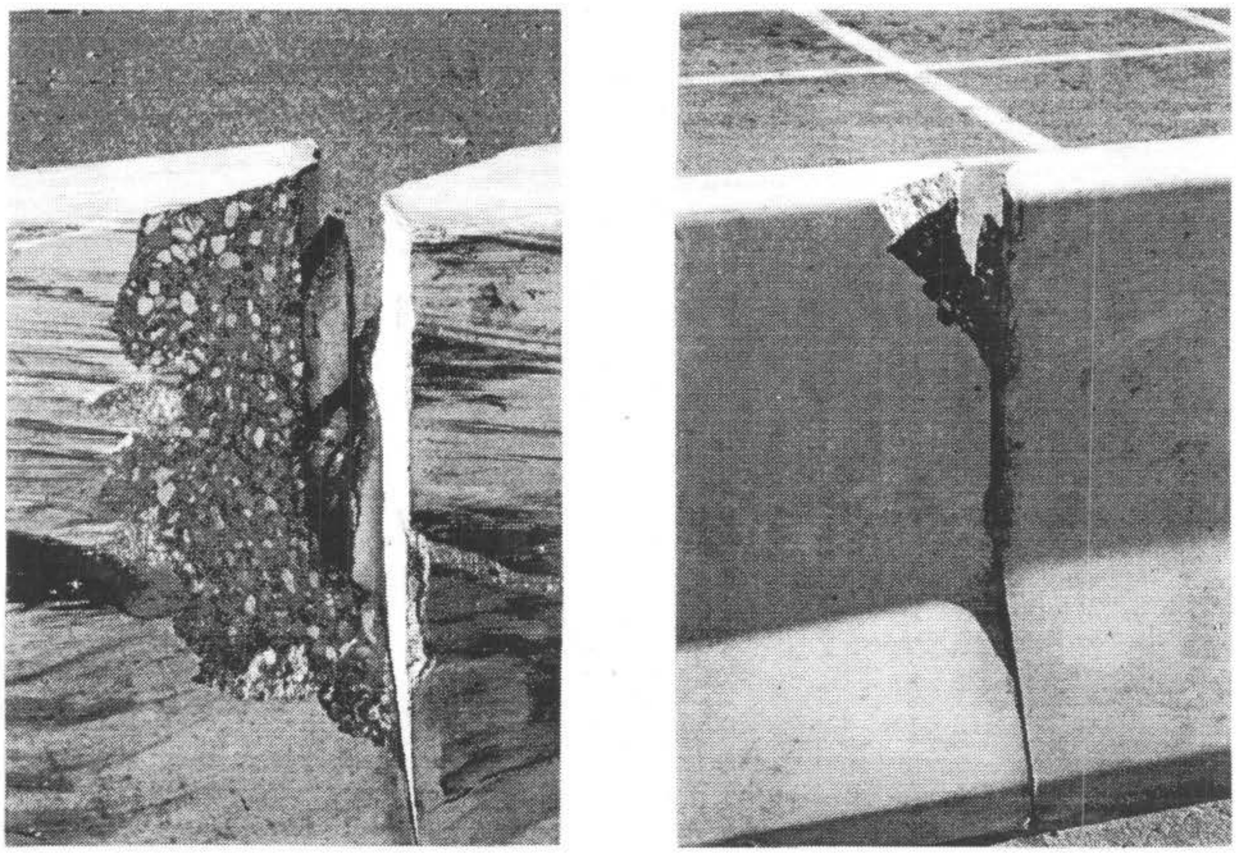


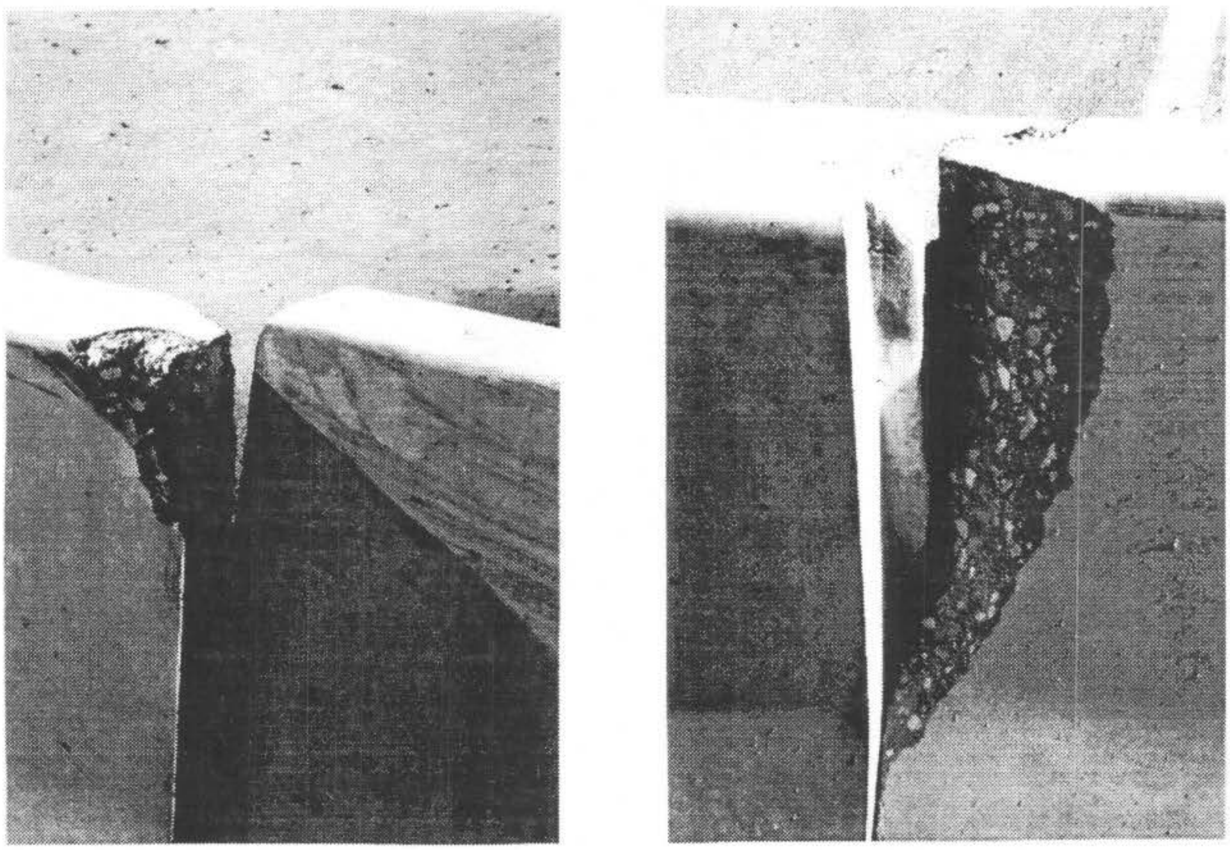
Figure 18. Photographs of the barrier damage at the location of impact (back side)



(a) Front Side

(b) Back Side

Figure 19. Photographs of damage to the key-way located 3 feet downstream from impact



(a) Front Side (b) Back Side

Figure 20. Photographs of damage to the key-way located 13 feet downstream from impact

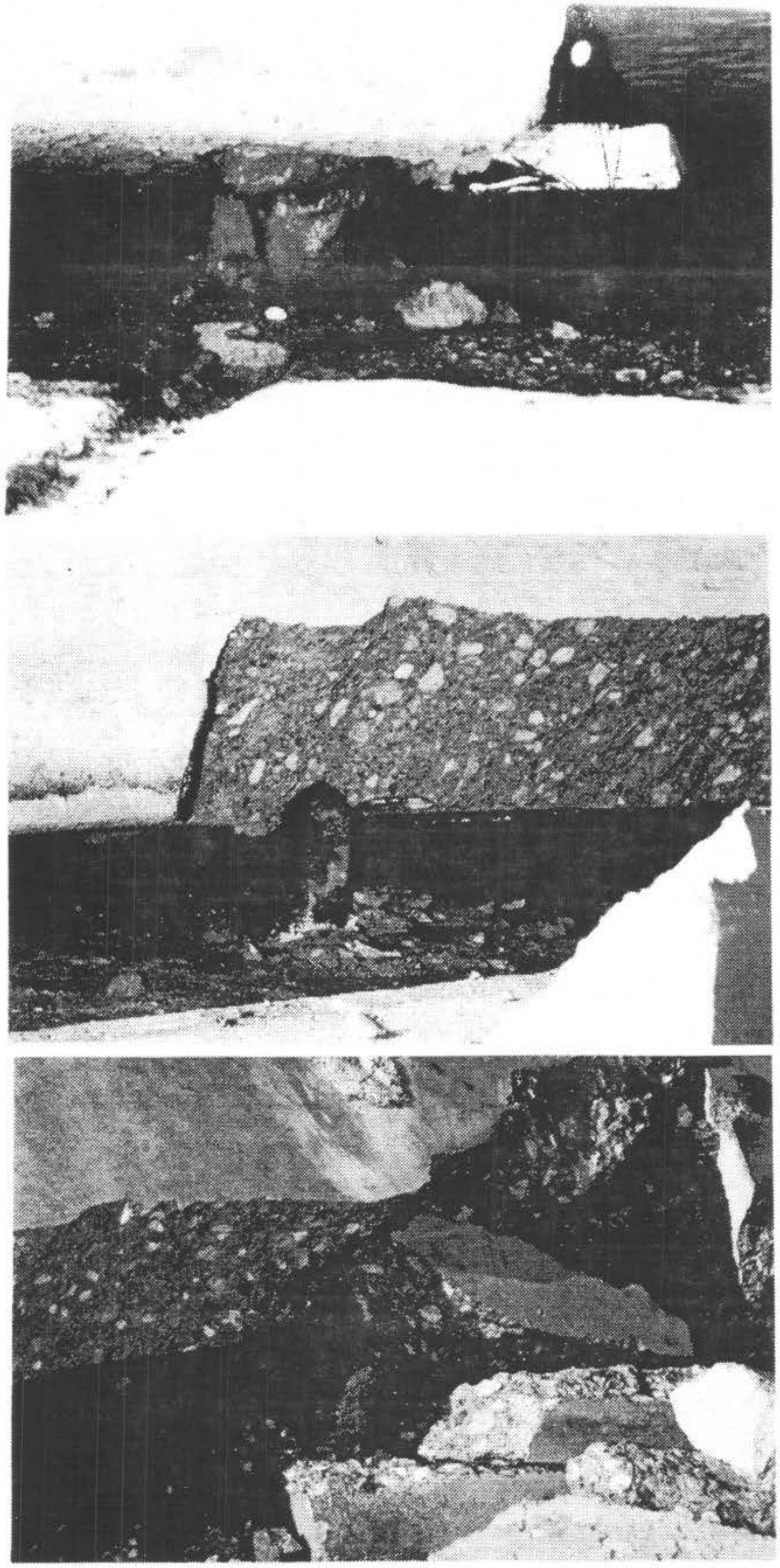


Figure 21. Photographs of barrier uplift and concrete fracture near grouted dowel bars

5 DISCUSSION

After the post-crash examination of the permanent barrier installation, it was evident that the structural integrity of the barrier had some known deficiencies. These are evident in the photographs shown in Figures 17 through 21 and will be discussed in the following section.

As shown in Figures 17 and 18, the concrete barrier section located immediately following the impact location showed the largest amount of permanent rotation. At the location of impact, a large crack had formed which projected through the entire cross-section of the barrier. This may be minimized by the addition of more longitudinal steel and shear pins located in an arrangement similar to that which is recommended in the article in the Portland Cement Association (2). This recommendation comes from the previous research which was conducted on permanent precast concrete median barriers by Southwest Research Institute (7,8).

The excessive rotation of the barrier section was due to a combination of two failure mechanisms. First, the concrete keyway fractured at multiple joint locations. Second, the barrier was lifted approximately 3 in. off the grouted dowel bars located on the traffic side of the barrier. Portions of the concrete fractured off the lower edge near the grouted dowel bars.

As can be seen in Figure 17, 1ft - 10 in. of the base of the impacted barrier was fractured near the downstream splice. The first 5 ft - 4 in. of the next barrier was also fractured at the base. A 1 ft - 6 in. length of concrete was broken from the second barrier downstream from impact. This fracture occurred in front of the upstream dowel at the base of the barrier.

As shown in Figures 19 and 20, the concrete keyway fractured at two locations, on both ends of the permanently rotated barrier, in two modes of failure. First, at the joint located 3 ft downstream of impact, the male end of the concrete keyway fractured off along with portions of the female end, as shown in Figure 19. Second, at the joint located 13 ft downstream from impact, the female end of the concrete keyway fractured off, as shown in Figure 20.

This physical evidence would suggest that additional reinforcement would be necessary in the location of the concrete keyways. Due to the small size of the male end of the concrete, it may be difficult to provide reinforcement at this location unless the dimensions are increased.

It should be noted that in 1983 the University of Nebraska completed a study for retrofitting concrete median barriers with an inverted concrete cap which provided a rigid connection between barrier sections while also providing a mechanism to prevent the roll motion (9).

As shown in Figure 21, the precast concrete median barrier located immediately after impact was lifted off the grouted dowel bars along the traffic face side of the installation. This physical evidence would suggest that the number of dowel bars available for tension reinforcement was inadequate as well as there being an insufficient amount of development length on the dowel bars.

The above discussion points out the structural inadequacies of the current design. Some additional suggestions are provided later, in the Recommendations section.

6 CONCLUSIONS

One full-scale crash test was conducted to evaluate the safety performance of the permanent precast concrete median barrier.

Test KCB-1 was evaluated according to the safety performance criteria given in NCHRP 230 (1). The safety evaluation summaries are presented in Table 3.

The analysis of the crash test revealed the following:

1. The permanent precast CMB contained the vehicle.
2. The test vehicle did not penetrate the installation, although it did ride up the side of the barrier considerably.
3. There were no detached elements or fragments from the test article which showed potential for undue hazard during and after the collision.
4. The integrity of the passenger compartment was maintained.
5. The test vehicle remained upright during and after the collision; it should be noted that the test vehicle underwent substantial rolling motion as it was vaulted into the air as a result of the barrier rotation.
6. The occupant risk value for the longitudinal impact velocity was satisfactory (18.4 fps < 30.0 fps). The occupant risk value for the lateral impact velocity was marginal [20.7 fps > 20.0 fps from NCHRP 230 (1)], [20.7 fps < 25.0 fps from AASHTO (4)].
7. The occupant risk values for ridedown decelerations were acceptable during impact.
8. The test vehicle's change in speed was excessive (21.0 mph > 15.0 mph). The speed change is a trajectory hazard factor only when the redirectional barrier is very near the traffic stream or when the vehicle is redirected abruptly back into the traffic stream.

9. The test vehicle's exit angle was satisfactory [0.0 degrees < 15.0 degrees (60% of the entrance angle)].

Based upon the above listed items, the results of Test KCB-1 are marginal (defined as being the lower limit of acceptability) according to the NCHRP 230 (1) guidelines. Changes which would possibly improve the performance of the permanent precast CMB are suggested in the next section.

Table 3. Safety Performance Results

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.	M
	D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	S
Occupant Risk	E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	M
	Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	S
Vehicle Trajectory	H. After collision, vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	S
	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 the test impact angle, both measured at time of vehicle loss of contact with test device.	M

S - Satisfactory
M - Marginal
U - Unsatisfactory

7 RECOMMENDATIONS

After careful analysis of this test, it is our recommendation that the following changes be considered before this installation is approved for use on Federal Aid Projects. Modifications to this design which may improve its safety performance include:

1. Increasing the number of No. 8 dowel bars to five on each side of the barrier while also increasing the length of the dowel bars to 12 in. This would provide 6 in. of development length, instead of the existing 5 in., in both the existing concrete apron and the precast concrete median barrier. This will help prevent the barrier from pulling off the dowel bars and decrease the chance of barrier rotation.
2. Implement a stronger connection than the concrete keyway system used in this design. A change in this area will greatly improve the stiffness of the barrier.

It is our recommendation that upon implementation of these modifications to the installation located on a concrete base, the Federal Highway Administration accept this installation so that its use on Federal Aid Projects can be approved.

8 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. "Concrete Safety Barriers," Concrete Information, Portland Cement Association, 1979.

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

4. "Guide Specifications for Bridge Railings," American Association of State Highways and Transportation Officials, Washington, D.C., 1989.

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

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

7. "Concrete Median Barrier Research", Vol. 1, Executive Summary, Report No. FHWA-RD-77-3, Federal Highway Administration, 1976.

8. "Concrete Median Barrier Research", Vol. 2, Research Report, Report No. FHWA-RD-77-4, Federal Highway Administration, 1976.

9. "Feasibility Study of Retrofitting Concrete Median Barriers," Report No. DOT/RSPA/DMA-50/83-33, U.S. Department of Transportation and Office of University Research, Washington, D.C., May 1983.

9 APPENDICES

APPENDIX A.

RELEVANT CORRESPONDENCE

U.S. Department
of Transportation

Federal Highway
Administration

Region 7
Iowa, Kansas
Missouri, Nebraska

Federal Building Room 487
100 Centennial Mall North
Lincoln, Nebraska 68508-3851

September 17, 1990

In Reply Refer To:
HEC-NE

Mr. G. C. Strobel
Director-State Engineer
Nebraska Department of Roads
Lincoln, Nebraska

Attention: Deputy Director - Engineering

Dear Mr. Strobel:

Precast Concrete Barrier in Permanent Installations
<u>Unacceptable for Federal-Aid Projects</u>

During 1990, the Federal Highway Administration has been seeking information regarding the performance history of precast concrete barrier used in permanent installations. No state in this region has been able to provide that information. Accident reports and records available do not have sufficient information to adequately evaluate the performance of such installations after the fact.

Since no state in this region has crash tested any of these designs and performance history is unavailable, the use of precast concrete barrier sections in permanent installations can no longer be approved for installation on Federal-aid projects.

This policy has no effect upon the use of precast barrier sections in temporary installations where the ultimate result is removal of the barrier upon completion of the work.

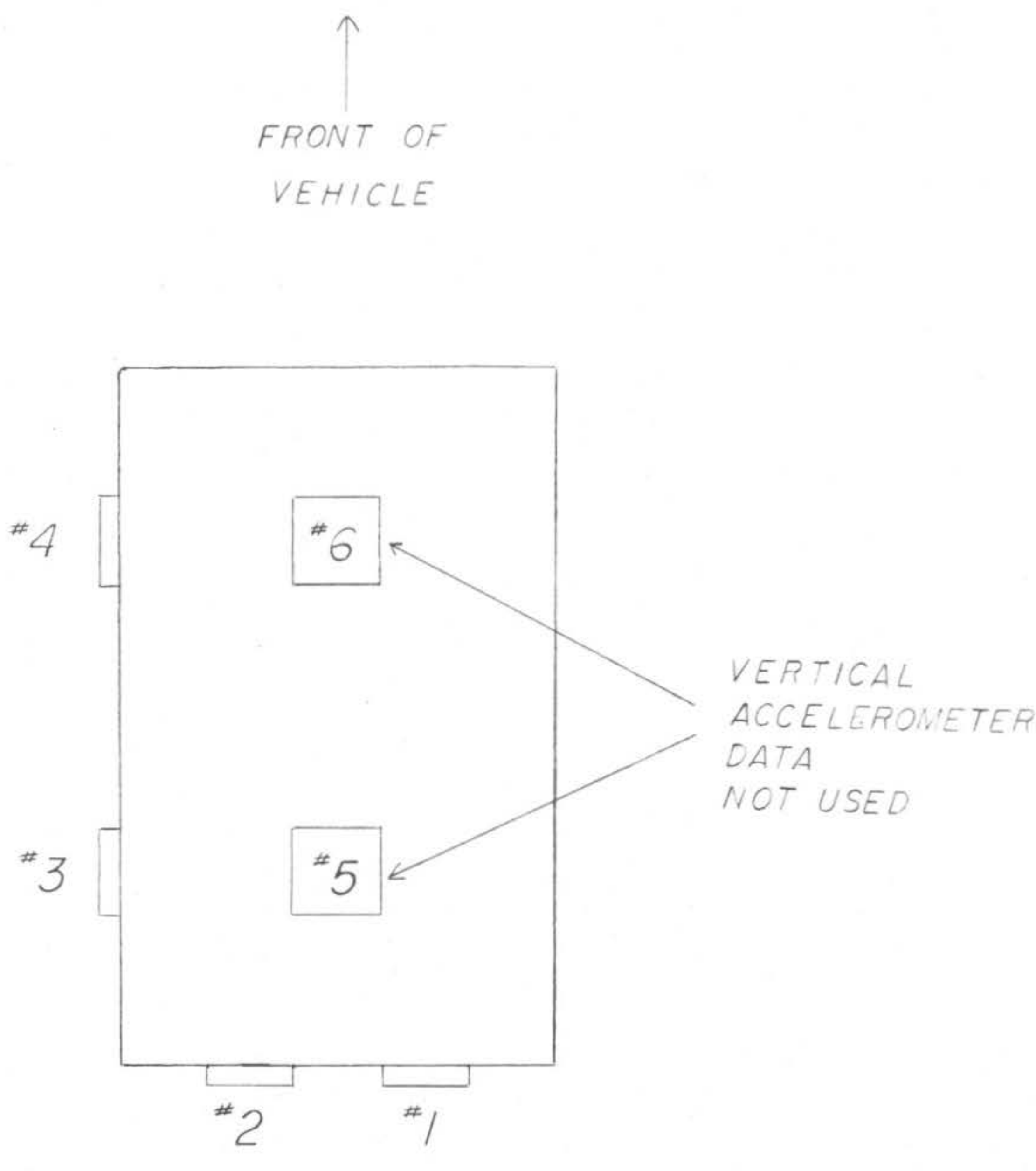
The Federal Highway Administration continues to encourage full scale crash testing of a standardized design for this type of installation. We still can see the possibility of economy resulting from use of precast barriers in permanent installations. Until they are crash tested, however, any design which uses precast barriers in a permanent installation are not to be installed on Federal-aid projects.

Sincerely yours,

for Charles A. Culp
Division Administrator

APPENDIX B.

ACCELEROMETER DATA ANALYSIS



B-1 Sketch of Accelerometer Locations

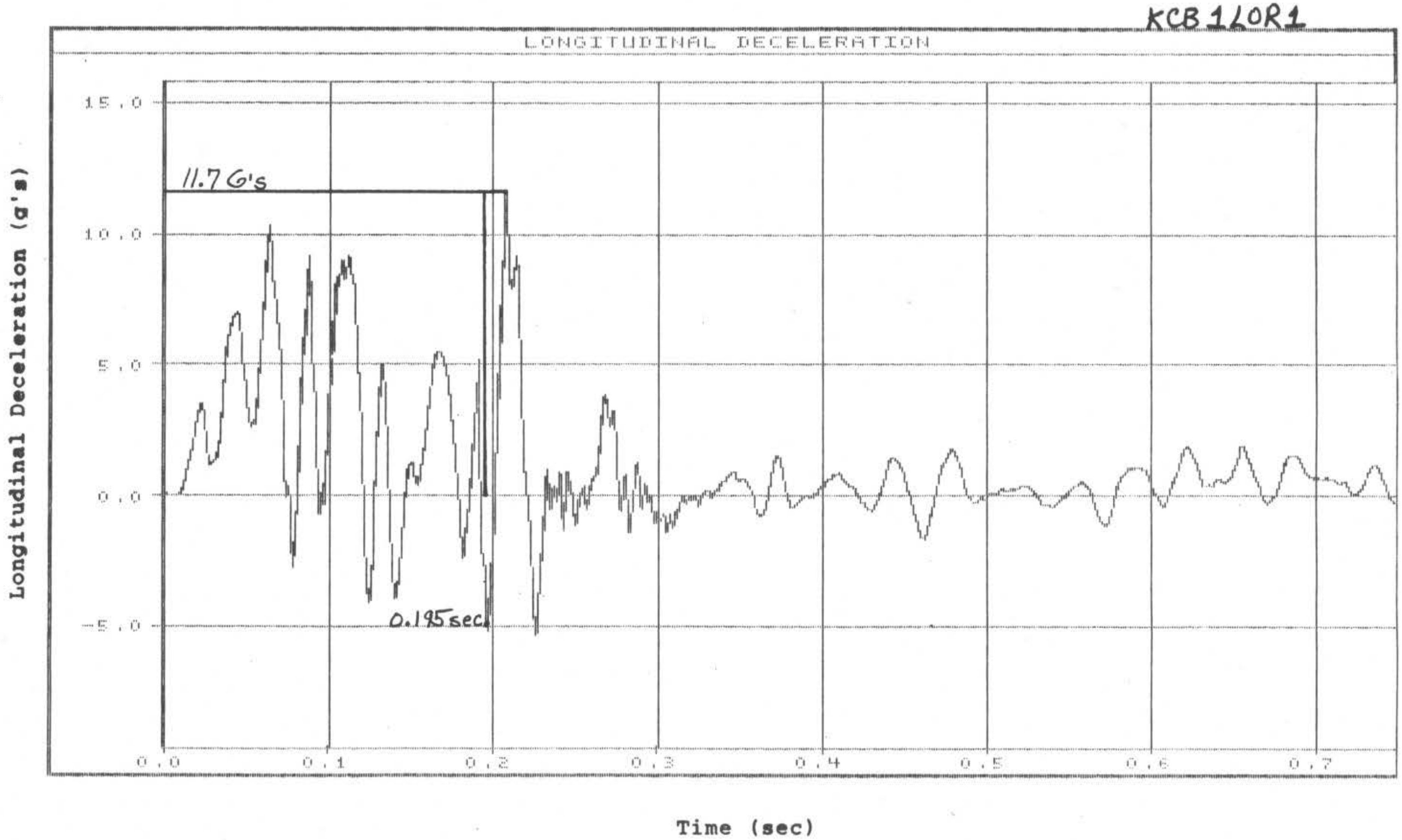
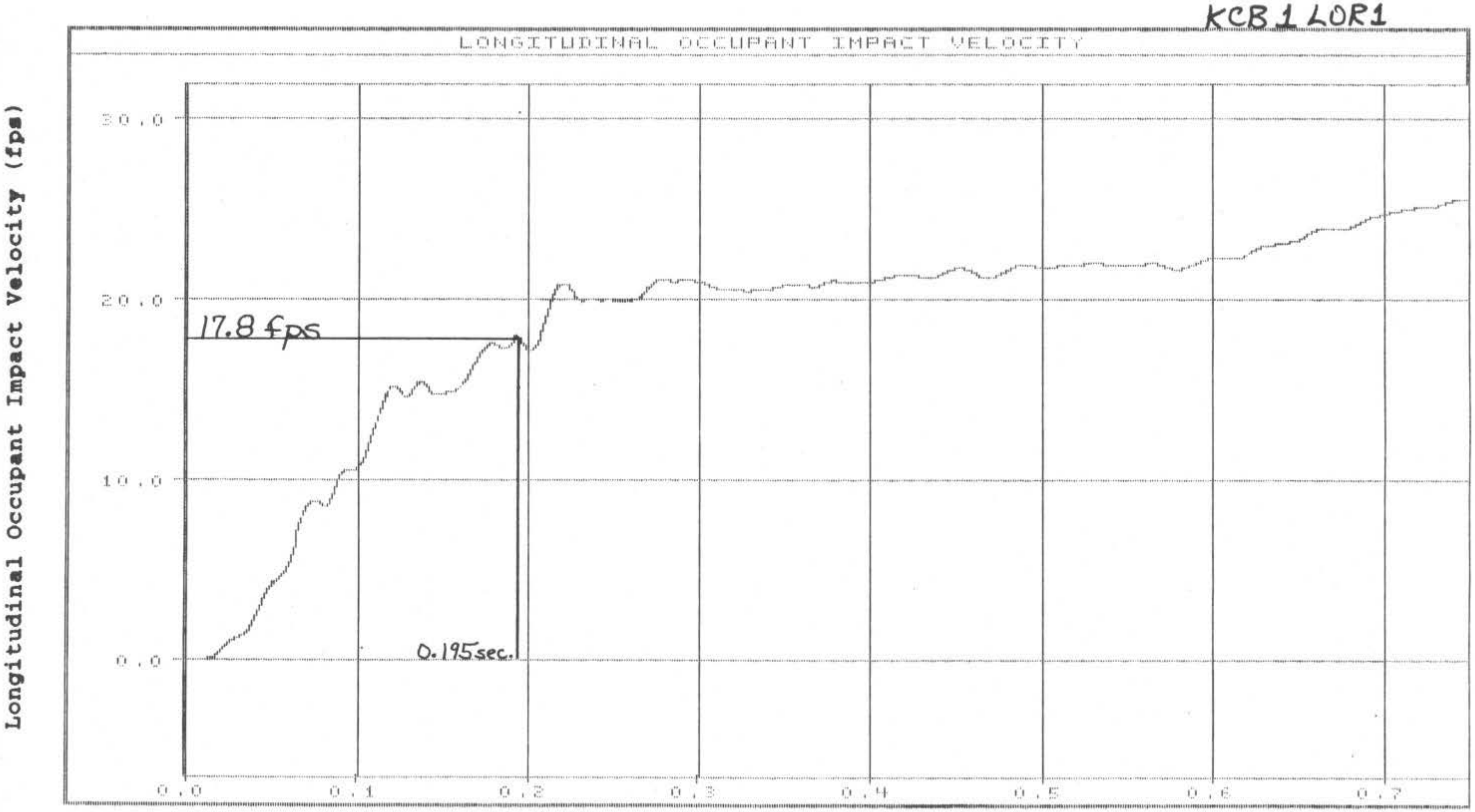


Figure B-2. Graph of Longitudinal Deceleration, Acc.#1



$$(\Delta V)^{*} = (17.8\ \text{fps})\,\frac{60 \sin 25^{\circ}}{59.3 \sin 24.4^{\circ}} = 18.42\ \text{fps}$$

Figure B-3. Graph of Longitudinal Occupant Impact Velocity, Acc. #1

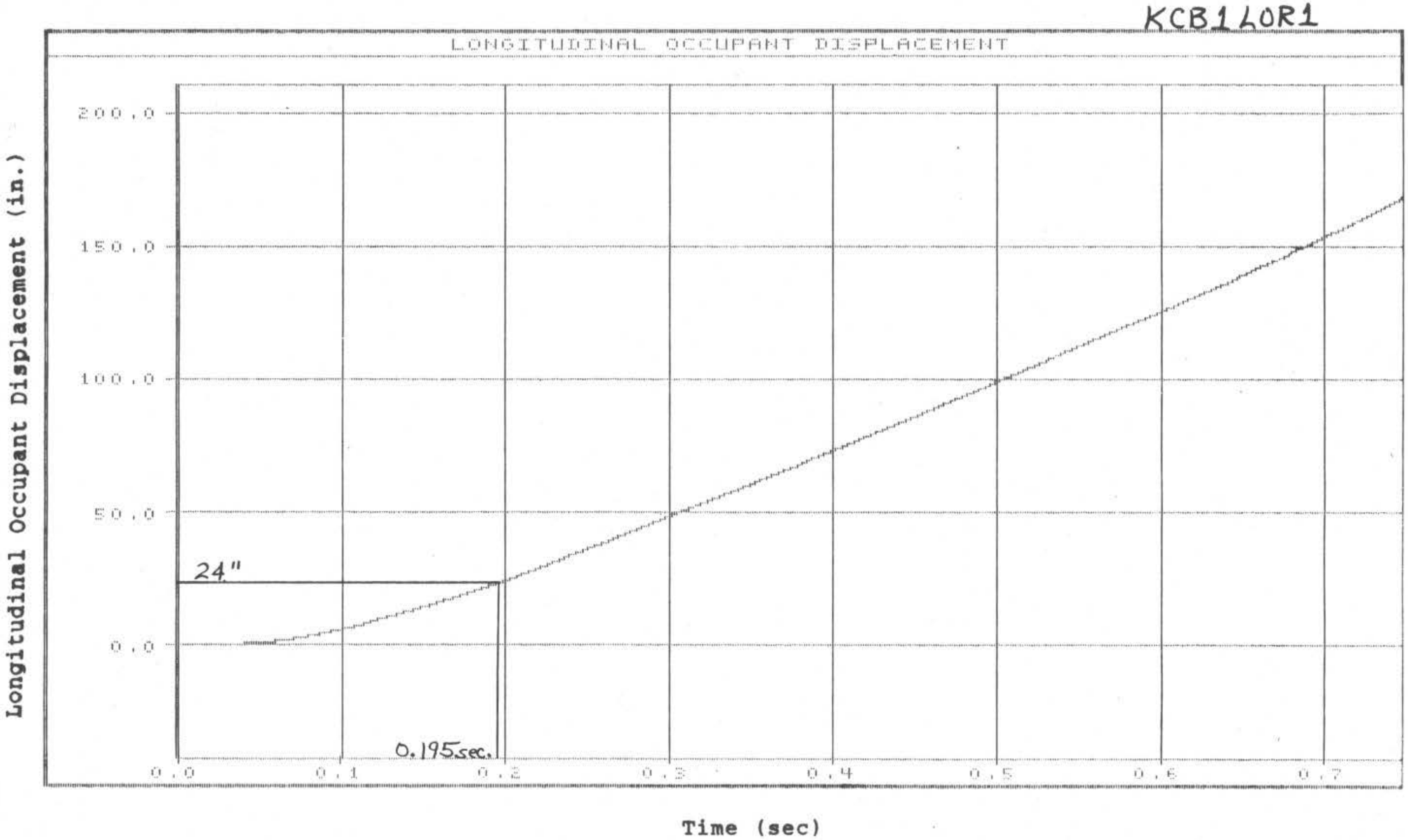


Figure B-4. Graph of Longitudinal Occupant Displacement, Acc.#1

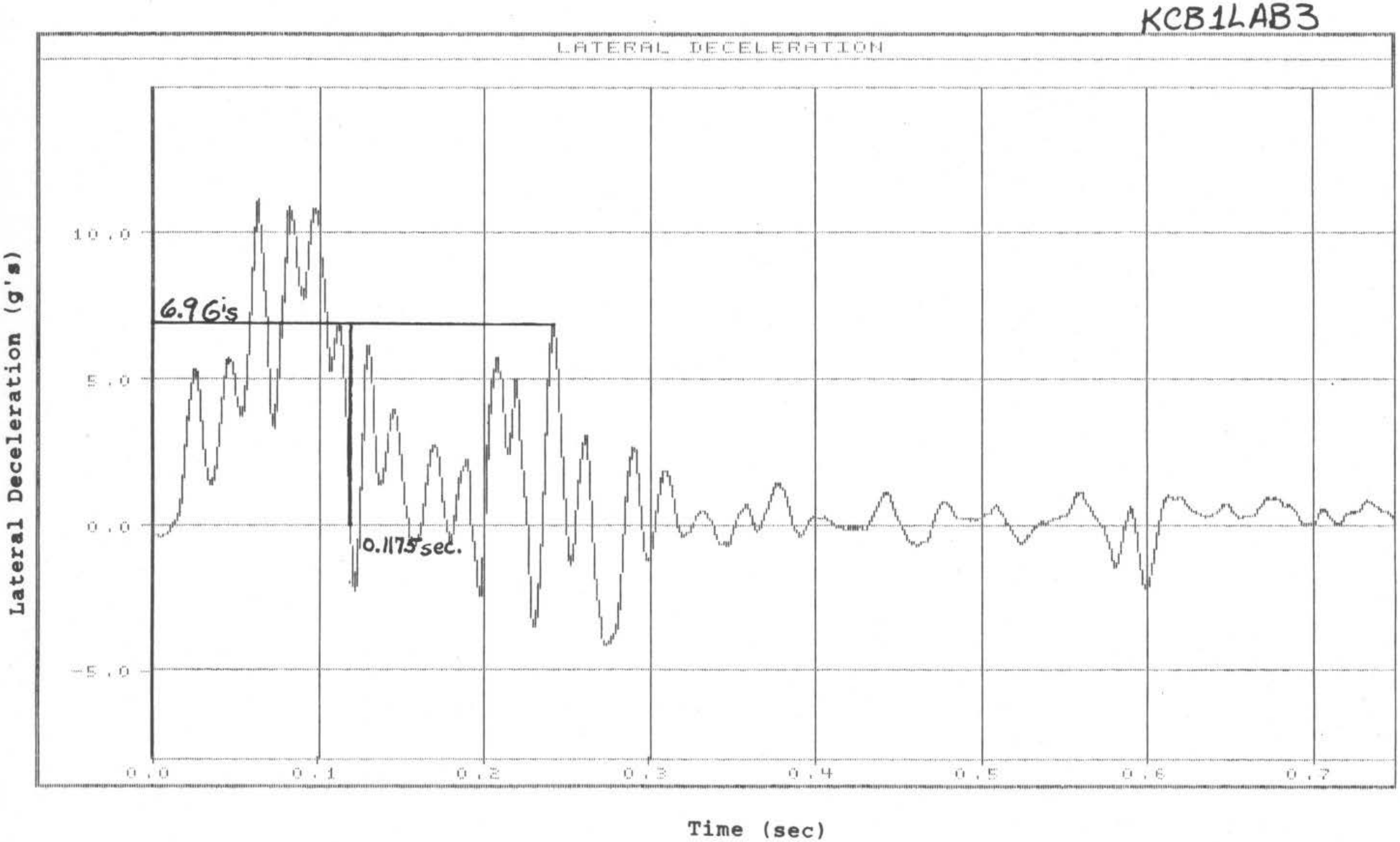
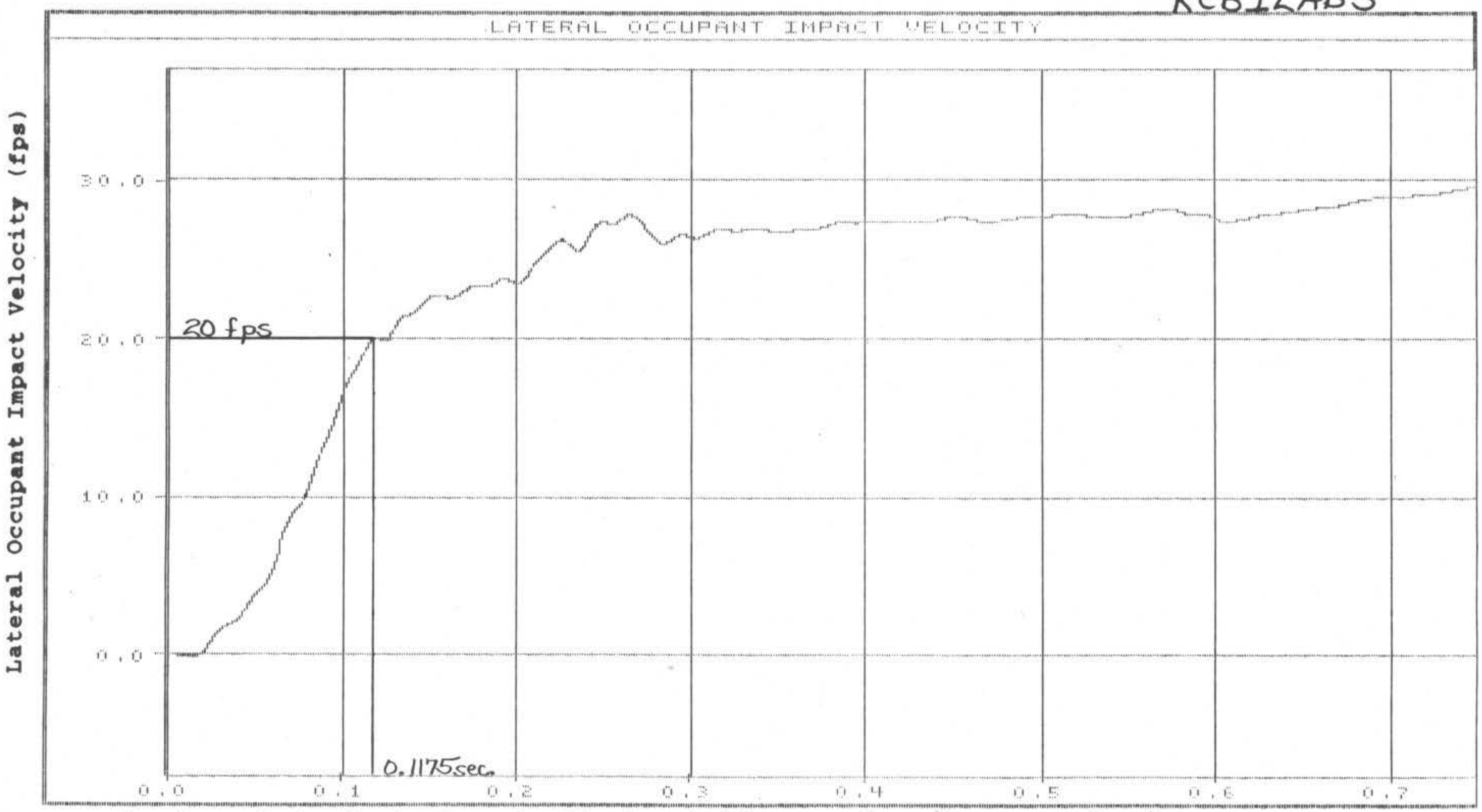


Figure B-5. Graph of Lateral Deceleration, Acc.#3

KCB1LAB3



Normalized Occupant Impact Velocity $(\Delta V)^* = (\Delta V)\frac{(V\sin\theta)_{target}}{(V\sin\theta)_{actual}} = \frac{(60\,mph)\sin 25^\circ}{(59.3\,mph)\sin 24.4^\circ}(20\,fps)$

$(\Delta V)^* = 20.7\ fps$

Figure B-6. Graph of Lateral Occupant Impact Velocity, Acc.#3

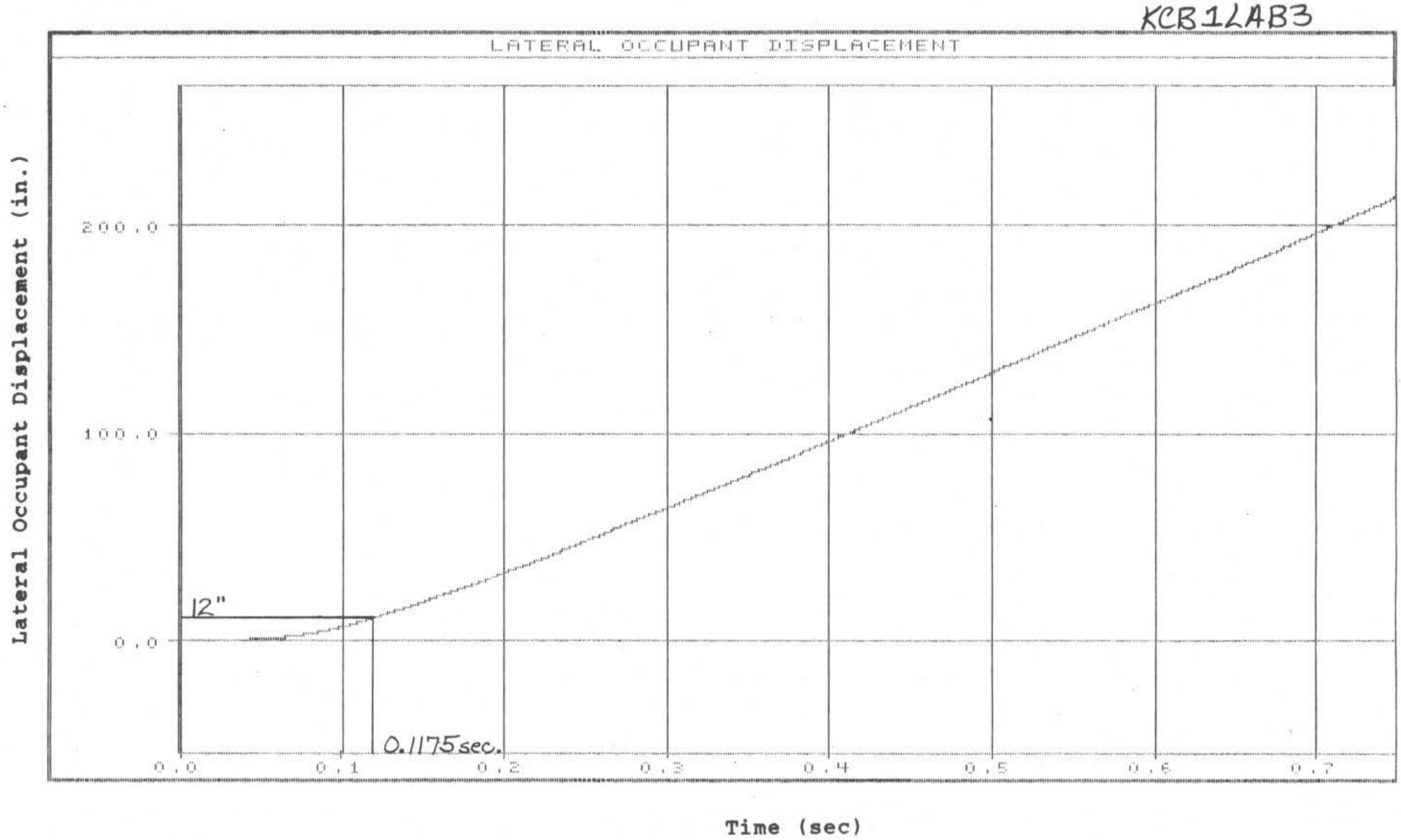


Figure B-7. Graph of Lateral Occupant Displacement, Acc.#3

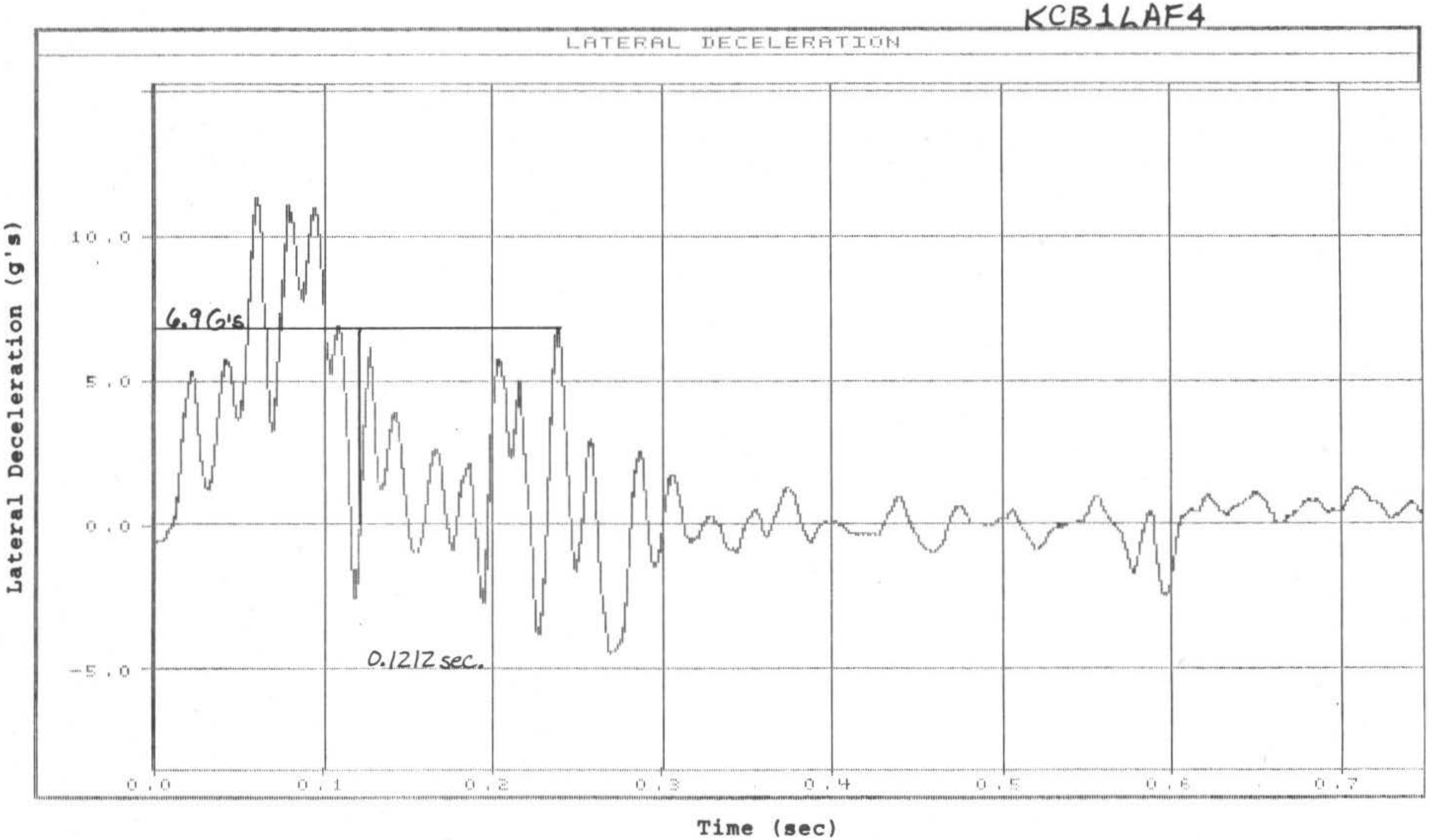
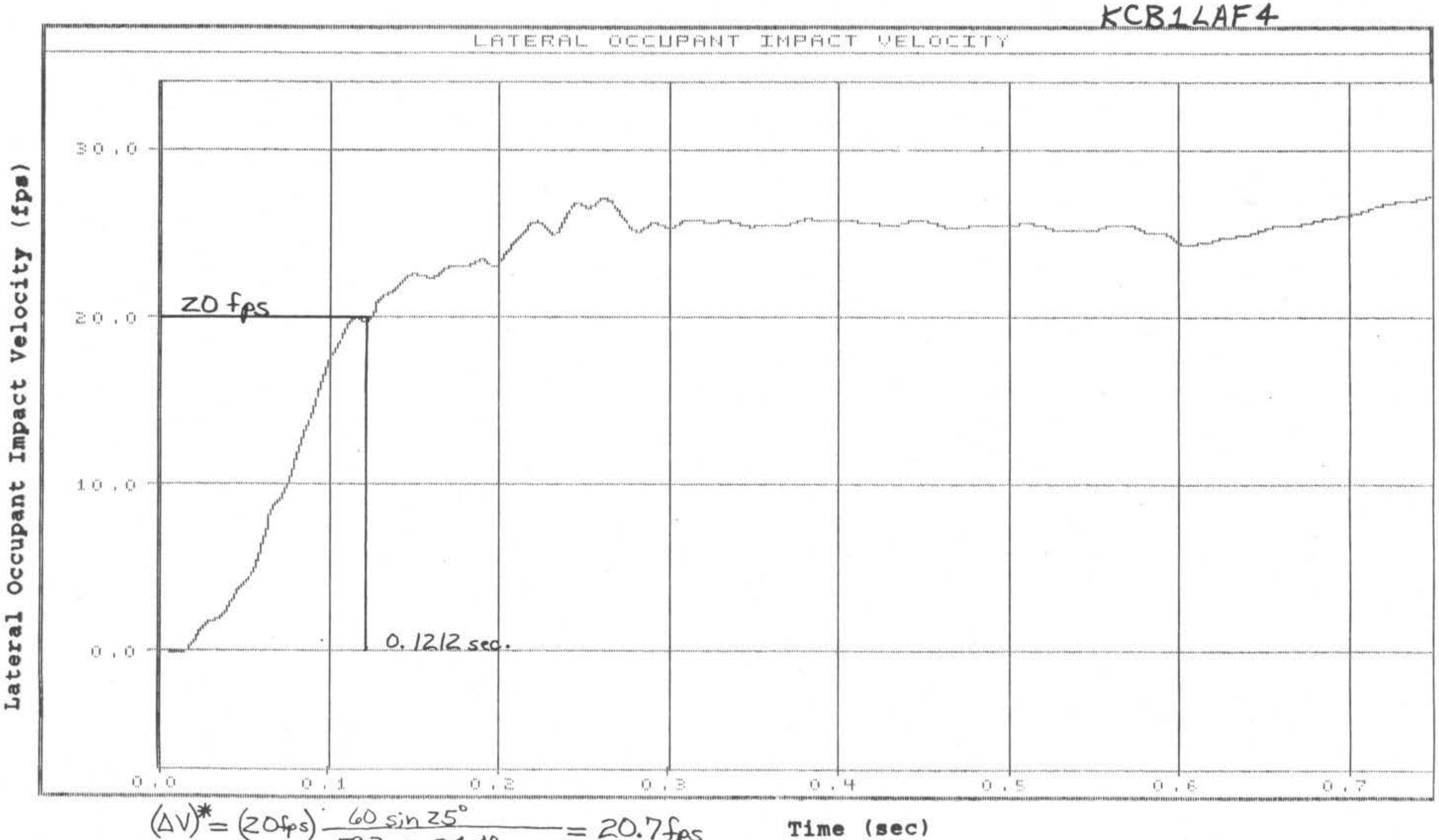


Figure B-8. Graph of Lateral Deceleration, Acc.#4



$$(\Delta V)^* = (20\,fps)\,\frac{60 \sin 25^\circ}{59.3 \sin 24.4^\circ} = 20.7\,fps$$

Figure B-9. Graph of Lateral Occupant Impact Velocity, Acc.#4

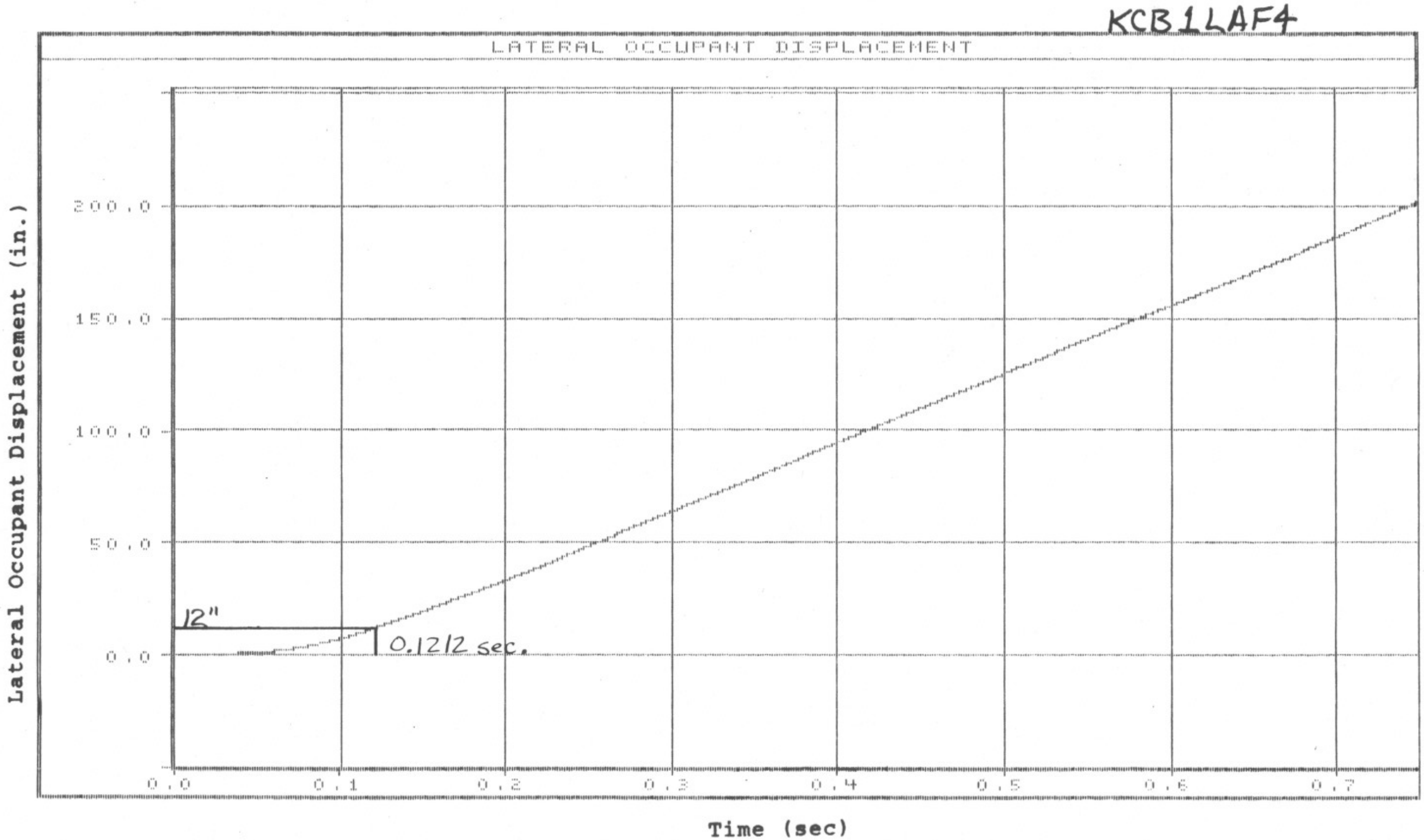


Figure B-10. Graph of Lateral Occupant Displacement, Acc.#4