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16. ABSTRACT
The impact of a passenger vehicle, a 3600-lb four-door sedan, into a safety-shaped concrete median barrier, at a speed of 40 miles per hour and an angle of 45 degrees is described. The barrier, vehicle and occupant dynamics are discussed with respect to the standards presented in NCHRP Report 230. The behaviors of the two dummy occupants, one wearing a lap belt/shoulder strap, the other not, are compared.

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TRANSPORTATION LABORATORY

A SEAT BELT EFFICACY DEMONSTRATION: A LARGE ANGLE MODERATE SPEED IMPACT INTO A CONCRETE MEDIAN BARRIER

Caltrans

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF FACILITIES CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

87-06

A SEAT BELT EFFICACY DEMONSTRATION: A LARGE ANGLE MODERATE SPEED IMPACT INTO A CONCRETE MEDIAN BARRIER

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40	millimetres (mm)
		.02540	metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litre (1)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic years (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s	28.317	litres per second 1/s)
	gallons per minute (gal/min)	.06309	litres per second (1/s)
Mass	pounds (1b)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G) (ft/s^2)	9.807	metres per second squared (m/s^2)
Density	($1b/ft^3$)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (1bs)	4.448	newtons (N)
	(1000 1bs) kips	4448	newtons (N)
Thermal Energy	British termal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-1b)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (in-1bs)	.1130	newton-metres (Nm)
	foot-pounds (ft-1bs)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch ($ksi\sqrt{in}$)	1.0988	mega pascals$\sqrt{metre}$ ($MPa\sqrt{m}$)
	pounds per square inch square root inch ($psi\sqrt{in}$)	1.0988	kilo pascals$\sqrt{metre}$ ($KPa\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{+F - 32}{1.8} = +C$	degrees celsius (°C)

ACKNOWLEDGEMENTS

This work was accomplished with the assistance and cooperation of the following agencies and individuals outside of Caltrans: Craig Dill, Assistant Director of the Sacramento Mayor's Safety Belt and Safety Seat Project, initially proposed the project to Caltrans, coordinated with other outside agencies and publicized the impact test event. Lieutenant Ed Lafond of the California Highway Patrol Academy, coordinated the traffic direction and use of public address systems within the Academy grounds. Suburban Ford of Sacramento, California, donated the test vehicle.

Appreciation is due the Transportation Laboratory staff whose effort on the following tasks brought this project to fruition: Test barrier preparation, James Keesling and Suema Hawatky; test vehicle preparation, Connie J. Bennett and Eldon Wilson; electronic instrumentation, William Ng, Delmar Gans, Les Ballinger and Richard Johnson; photo-documentation, Don Tateishi, Robert Ratcliff and James Keesling; data reduction and analysis, Suema Hawatky; technical drawing for report, Leoncio Lopez; word processing for report, Lydia Burgin.

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1. INTRODUCTION

1.1 Problem

Some individuals do not understand the importance of wearing seat belts even when driving at moderate speeds typical of city traffic.

Although the safety-shaped concrete median barrier (CMB) has been proven effective for containing vehicles weighing 1800 to 4500 lbs that impact the barrier at speeds up to 60 mph and angles up to 25°, the barrier limits of performance are unknown. Defining these limits would assist designers when the CMB is placed where marginal performance might be expected.

1.2 Background

Craig Dill, Jr., Assistant Director of the Sacramento Mayor's Safety Belt and Safety Seat Project, organized a one-day seminar titled "Northern California Law Enforcement Occupant Protection Conference," held on September 16, 1986. The conference was co-sponsored by the Police Officer's Standard Training (P.O.S.T.) organization which coordinates and accredits this type of training. The importance of seat belts to law officers was to be emphasized.

Craig Dill requested that a crash test be conducted on the afternoon of September 15, 1986 when most attendees at the conference could be present. The test would not be officially part of the conference, but would be supplemental to it. Over 200 police officers were expected to attend. The purpose of the test was to show that severe vehicle damage can occur at moderate impact speeds, and to compare the effects of the impact on two dummies, one belted and one unbelted. The type of object to be impacted and the precise impact conditions were left up to the researchers.

Although the majority of accidents with CMB have impact angles less than 25°, the maximum angle used in standard crash tests, a few occur with much larger angles of impact. With no crash test experience at these larger angles, it is difficult to predict exactly how a passenger vehicle will react. The researchers expected that at an impact speed/angle of 45 mph/45° the deceleration values would be excessive, vehicle damage extensive, and risk to passengers high.

1.3 Objectives-Scope

The objectives of this research were to conduct a crash test that would:

1. Demonstrate to a large audience the effectiveness of wearing seat belts in a moderate speed impact into an immovable object.

2. Determine the vehicle behavior during and after impact with a safety-shaped barrier at a moderately large angle and moderate speed.

3. Determine the occupant behavior during an impact with a safety-shaped barrier at a moderately large angle and moderate speed.

2. CONCLUSIONS

Based on the results of this research, the following conclusions can be drawn:

1. Very severe to life threatening injury is likely for an unrestrained occupant during a 40 mph, 45° impact into a concrete median barrier and less severe injuries are likely for a restrained occupant in the same impact.

2. A safety-shaped concrete median barrier can successfully redirect a 3575-lb vehicle at a speed of 40 mph and angle of 45° without spalling or appreciable damage to the face of the barrier.

3. On dry pavement with good friction characteristics, a redirected vehicle will intrude into the traveled way a minimal amount while moving and probably come to rest next to the barrier.

4. Based on the cracking in the barrier opposite the impact area, impact by a larger and/or higher speed vehicle at such an angle would probably be detrimental to the structural integrity of a median barrier.

3. RECOMMENDATIONS

It is recommended that a short video tape be produced which demonstrates the effectiveness of seat belts on dummies in full scale crash tests.

4. IMPLEMENTATION

The Office of Transportation Laboratory (during preparation of this report) coordinated with Caltrans Graphic Services to produce an 8 1/2-minute seat belt safety videotape. This videotape will be distributed to approriate safety organizations that have expressed interest in such a film.

5. TECHNICAL DISCUSSION

5.1 Test Conditions

5.1.1 Test Facilities

This crash test was conducted at the Caltrans Dynamic Test Facility in Bryte, California, near Sacramento. The test area is a large flat asphalt concrete surface.

5.1.2 Test Barrier

The test barrier consisted of three 20-foot-long temporary concrete barrier segments linked together with a pin joint. They had a safety-shaped "New Jersey" profile. The barrier was backed up with several other barrier segments and concrete blocks to prevent lateral movement. Wood wedges were placed between the sloping back of the impacted barrier and some of the backup segments to prevent rotation upon impact. Thus, the test barrier simulated a standard cast-in-place, continuous median barrier. Figure 1 shows the test barrier layout.

5.1.3 Test Vehicle

The vehicle conformed with the requirements of NCHRP Report 230(1)* in the following respects: It was in good condition, had no major body damage and had no missing structural parts. The vehicle fuel tank was purged. The engine was front mounted (see Figure 2).

The vehicle varied from the requirements of NCHRP Report 230(1) in age and weight; it was eleven years old and weighed 3575 lbs without the dummies. Vehicle dimensions are shown in Appendix A.

TEST NO. 451

BARRIER INSTALLATION

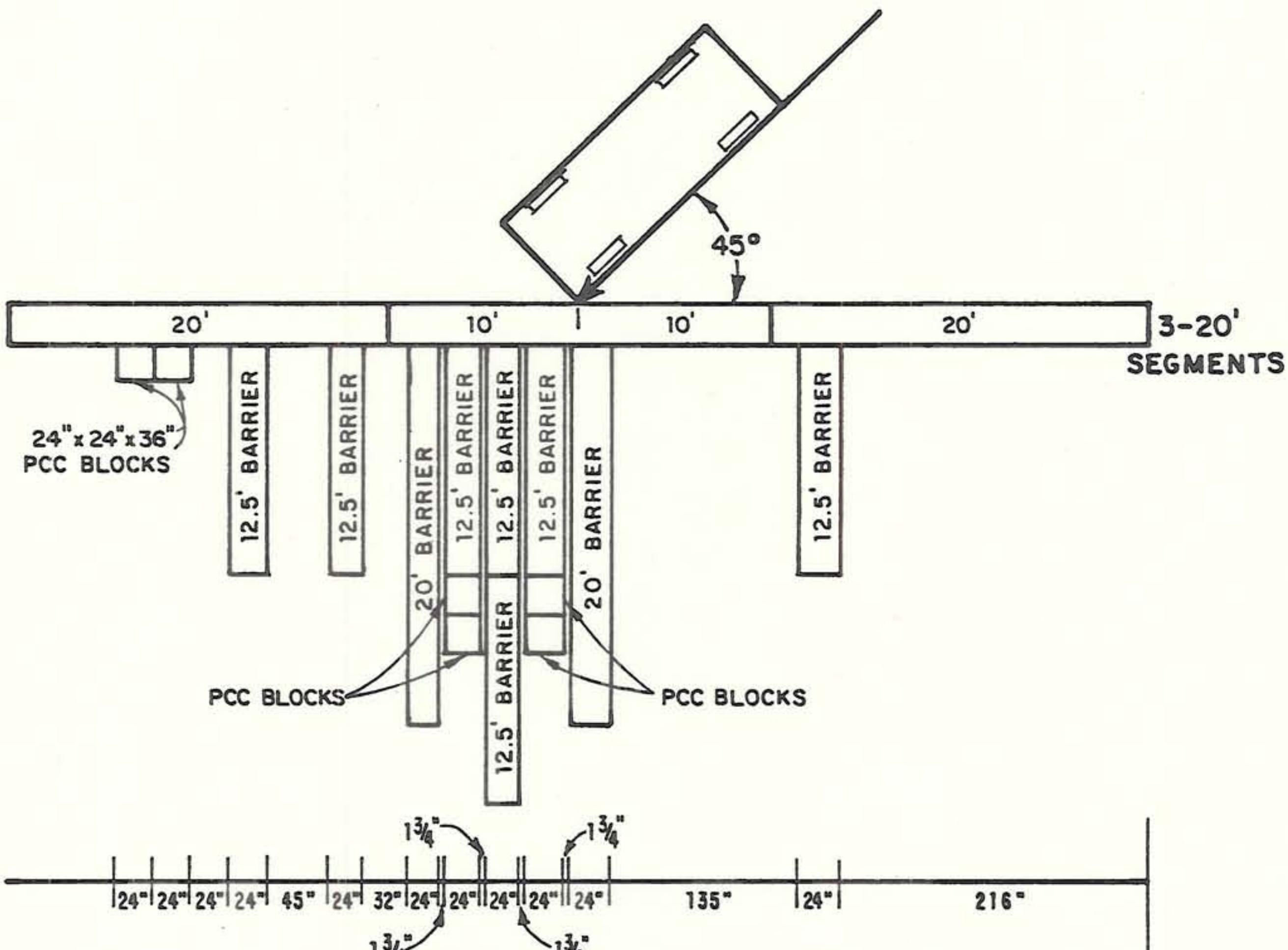


Figure 1. Barrier Installation

Figure 2. Test Vehicle - 1975 Ford Granada

5.1.4 Test Dummies

Two anthropomorphic test dummies were placed in the front seats. In the driver's seat was Rex Karrs, a Hybrid III 50th percentile male, 165 lbs, with the seat belt/shoulder strap worn. In the passenger seat was Willie Makit, a Part 572 50th percentile male, 165 lbs, with no seat belt restraint. A set of three mutually perpendicular accelerometers were installed in the head cavity of each of the dummies.

5.1.5 Data Acquisition Systems

The impact was recorded with several high speed movie cameras, one normal speed movie camera, one black and white sequence camera and one color slide sequence camera. All of these cameras were mounted on tripods except three high-speed cameras were mounted on a 35-foot high tower directly over the point of impact on the test barrier, one high speed camera was mounted on a scaffold in line with the approach of the vehicle, and one high speed camera was mounted in the car to record the dummies' motions. The test vehicle and test barrier were photographed before and after impact with a normal speed movie camera, a color still camera and a color slide camera. A film report of this project has been assembled using edited portions of the movie coverage.

Three accelerometers were attached to the floor of the vehicle at the center of gravity to measure acceleration in the longitudinal, lateral and vertical directions. The accelerometer data were used in calculating the occupant impact velocity to judge the risk to occupants.

To obtain occupant motion and head acceleration data, two anthropomorphic dummies were placed in the driver's seat and the passenger's seat of the test vehicle. Three accelerometers were mounted in each head cavity.

A sliding weight device, used to estimate "rattlespace" time, was attached to the roof of the vehicle (see Appendix B). A technical failure caused this device to not function during this test. The rattlespace time is the time required for an object to move two feet forward with respect to the passenger compartment after impact.

Houston deflection potentiometers were used to measure the dynamic deflections of the barrier during impact at several points on the barrier.

Appendices B and C contain a detailed description of the photographic and electronic equipment, the camera layout, data collection and reduction techniques, accelerometer records, and potentiometer records.

5.2 Test Results

The test vehicle, a 1975 Ford Granada weighing about 3575 lbs, excluding the dummies, impacted the barrier at an angle of 45° and a speed of 40.3 miles per hour. Figure 3 shows the vehicle in the impact position.

5.2.1 Impact Description

The car initially contacted the test barrier 7 inches downstream of the center of the middle segment. Crush of the left front bumper and fender began immediately. The left front tire contacted the barrier and the hood opened.

Redirection of the car began when the main structure of the front of the vehicle contacted the barrier. The front tire remained in contact with the barrier for 10 feet during redirection. Shortly after the front of the vehicle lost contact with the barrier, the rear tire side wall contacted the barrier for about 2 feet length and 0 to 6 inches above the pavement.

The vehicle continued away from the barrier at a speed of about 21 mph and exit angle of 9-1/2°. It then turned to the left (toward the barrier) and came to rest 11.8 feet downstream from the end of the barrier. The left rear tire was roughly centered on the centerline of the barrier and the longitudinal axis of the car was at an angle of 36-1/2° with respect to the barrier. The data summary sheet, Figure 4, and Figure 5, show the final position of the vehicle with respect to the barrier.

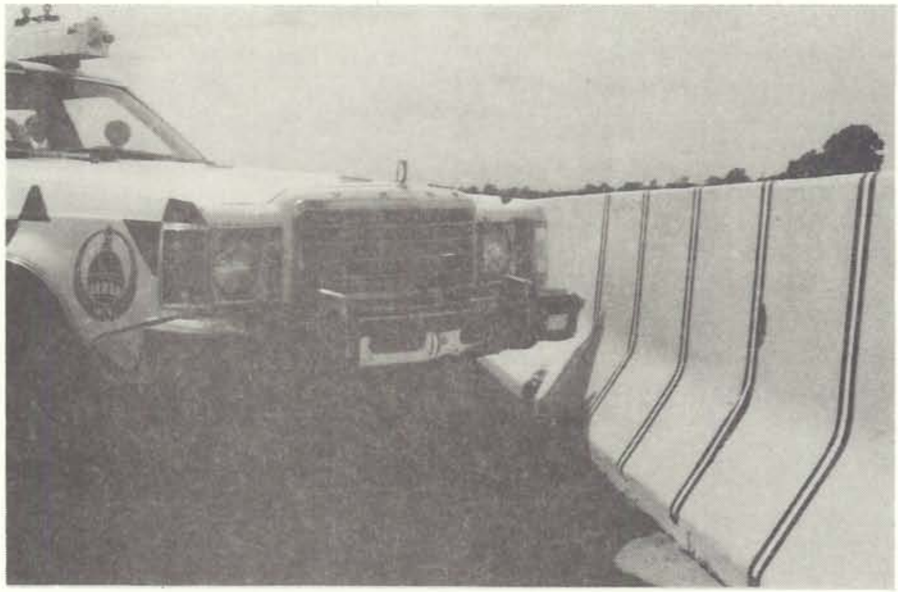


Figure 3. Test Vehicle at Impact Position

Impact + .007 sec.

I + .083 sec.

I + .236 sec.

I + .466 sec.

I + 1.230 sec.

Test Date:
September 15, 1986

Test Barrier:
Concrete Median Barrier

Test Vehicle:
1975 Ford Granada
Inertial Mass - 3575 lbs
Impact Speed - 40.3 mph
Impact Angle - 45°

Test Dummies:
1. Driver's seat - Hybrid III, 165 lbs
Lap & Shoulder Belts
2. Passenger's seat - Part 572, 165 lbs
Unrestrained

Test Results:
Occupant Impact Velocity
Longitudinal - 28.6 fps

Max 50 ms Avg Vehicle Acceleration
Longitudinal - 11.2 g
Lateral - 8.7 g

Exit Speed/Angle
21 mph/9-1/2°

Maximum Roll
7-1/2°

Dummy HIC
1 - 242
2 - 468

TAD/VDI
LFQ-7/10FYEW5

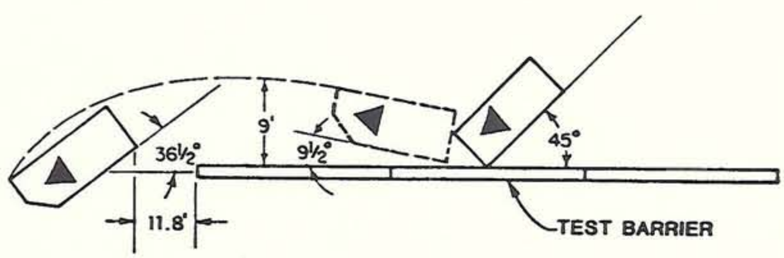


Figure 4. Data Summary Sheet - Test 451

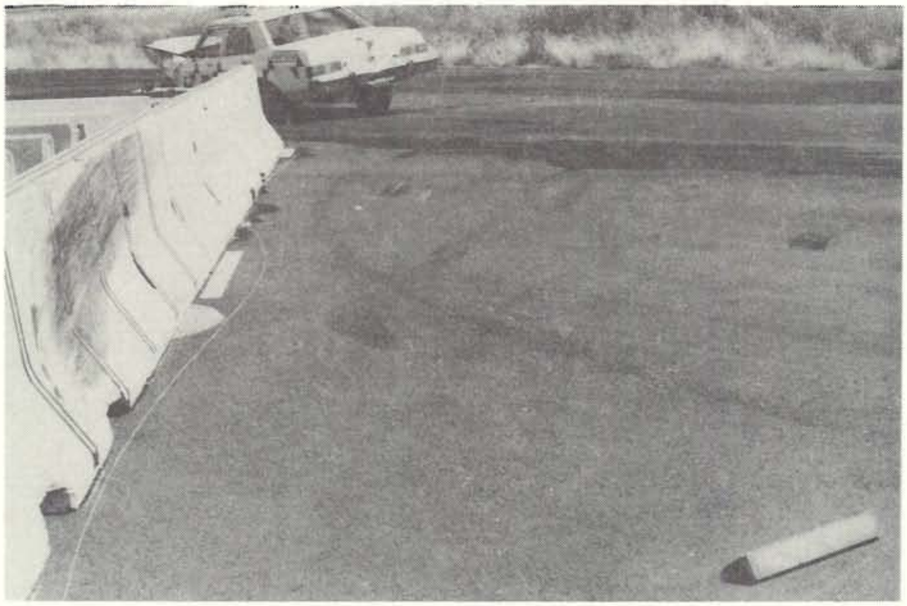


Figure 5. Postimpact Position of Vehicle

5.2.2 Vehicle Damage

The left front corner of the car made first contact with the barrier. This caused the entire left front corner of the vehicle to be crushed back to approximately the original position of the front tire. The left front wheel was deformed and the tire flattened (Figure 6). The fender was pushed back and contacted the front door so that it was very difficult to open. The left front corner of the hood was bent due to contact with the barrier. Crush of the front extended across about 3/4 of the width; the right head light was not broken (Figure 7). The radiator was pushed into the fan and bent the fan shaft. The engine was moved. The front bumper was pushed to the right 9 inches and the rear bumper was pushed to the right 2 inches.

Figure 6. Close-Up of Damaged Bumper, Fender and Wheel

Figure 7. Overall Front View of Damaged Vehicle

The vehicle interior and windshield were damaged by the two dummies. The passenger dummy's knees were forced into the lower dash fracturing the plastic in the area of the left side of the glove compartment and below the heater/air conditioner controls (Figure 8). The same dummy's head contacted and fractured the windshield. The driver dummy contacted the left front door bending a part of the interior door panel. The steering column was pushed down 1 inch and left 3/4 inch, measured at the dash board, by the passenger dummy.

Figure 8. Interior Damage Caused by Dummy

5.2.3 Barrier Damage

Vehicle contact with the barrier happened only on the center one of the three segments. That segment was permanently displaced 1/2, 1/2 and 3/8 inch as measured 10 feet upstream, at the center and 10 feet downstream from the center, respectively.

Potentiometers were placed near the top and bottom of the barrier 9 feet upstream and 9 feet downstream of the center of the middle segment, a total of four. The maximum dynamic deflection of each potentiometer is tabulated below:

Maximum Dynamic Deflection

	upstream	downstream
upper	.61 inch	.64 inch
lower	.25 inch	.34 inch

Traces of deflection vs time are included in Appendix C.

The face of the barrier received black tire marks, surface scraping from hood and front sheet metal and gouging from the frame of the car (see Figure 9). The tire marks started 3 inches upstream of the center of the barrier and extended to 10 feet downstream of the center. Surface scraping started 7 inches downstream from the center and extended to 5 feet downstream. Gouging was confined to an area 10 inches and 18 inches above the ground about 18 inches long 27 inches downstream from the center of the barrier.

The backside of the barrier in the region of impact developed 5 cracks spaced 16 inches to 18 inches apart over a length of 70 inches (Figure 10).

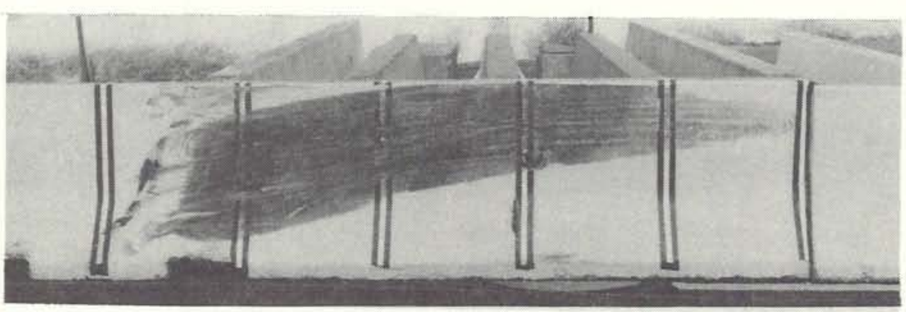
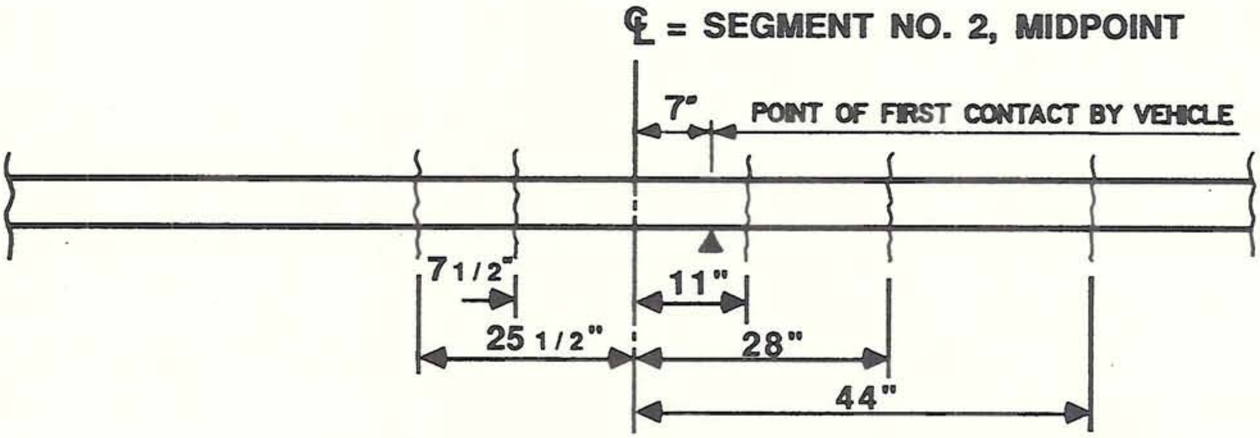
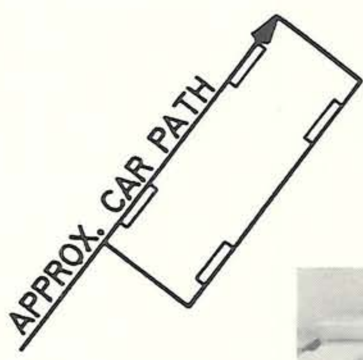


Figure 9. Tire Marks and Gouge Show Clearly on Face of Barrier

TEST NO. 451

LOCATION OF CRACKS ON BACK SIDE OF BARRIER





NOTE:

- NOT TO SCALE
- MEASUREMENTS WERE TAKEN FROM BARRIER'S ℄ AND NEAR THE TOP

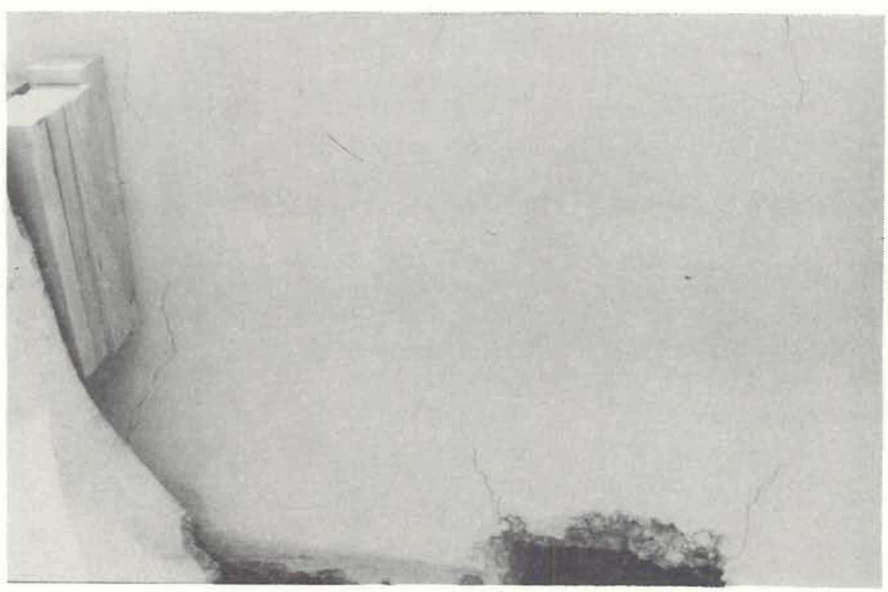


Figure 10. Location of Cracks on Back Side of Barrier
Cracks in photo enhanced for visibility

5.2.4 Dummy Response

Upon impact Rex Karrs, the restrained driver dummy, was thrust forward and caused the shoulder strap to extend about 10 inches, as evidenced by fraying of the edge due to the loop it passes through near the ceiling. This dummy was restrained from impacting the interior in the foward direction. As the vehicle was redirected the left door forcefully hit the dummy, causing slight indentation of the interior door panel (Figure 11) and caused the dummy to bend at the neck allowing its head to penetrate the plane of the (open) door window. Rex Karrs' final position was seated face forward with both feet on the left side of the foot well.

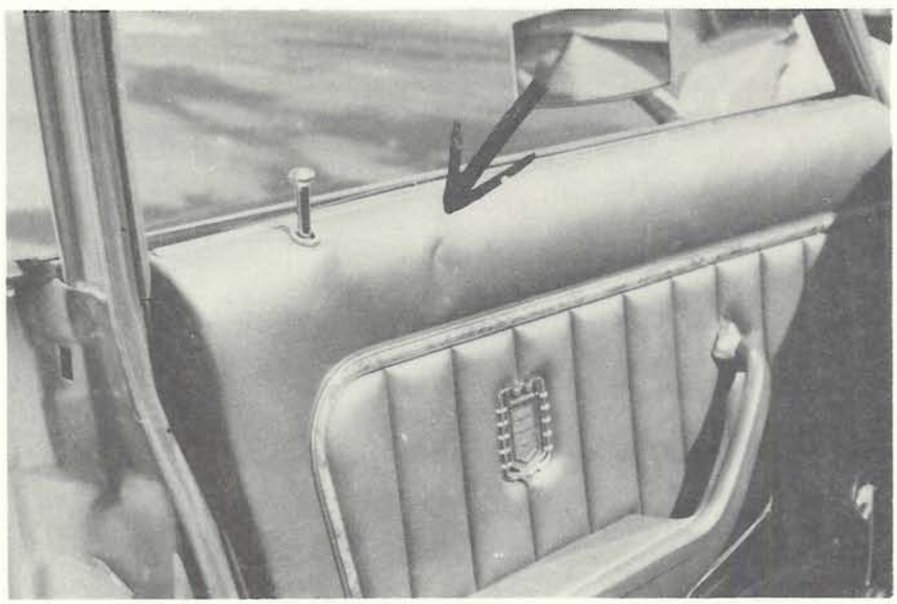


Figure 11. Dent in Left Front Door Panel from Dummy's Arm

Upon impact Willie Makit, the unrestrained passenger dummy, was thrust forward. Before its head hit the windshield, the vehicle began redirecting. The dummy's head hit the rearview mirror and knocked it off the windshield mount, cracking the window. Its head continued forward and toward the left of the car breaking the windshield, bulging it out a maximum of about 3 inches. The head was deflected downward and the chin hit and broke the top of the dashboard in front of the right side of the steering wheel. This dummy's knees firmly impacted the lower dash and fractured the plastic. The left side of the glove box and the area below the heater controls (center) were damaged. The upper torso of Willie Makit pushed hard against the steering wheel and shift lever causing a movement of the steering column downward and to the left. Willie Makit's final position was: feet in the passenger foot well, knees in the lower dash, upper torso leaning against the dash and shift lever and head wedged between the windshield and dash, chin imbedded in dash. The windshield continued to bulge out about 1 3/4 inch (Figure 12).

Figure 12. The Windshield Bulged 1-3/4 Inch After Vehicle Came to Rest

The Head Injury Criteria for Rex Karrs and Willie Makit were 242 and 468 respectively.

5.3 Discussion of Test Results

5.3.1 General - Safety Evaulation Guidelines

Although the impact conditions of this crash test were nonstandard and cannot be used to qualify or disqualify the impacted barrier for use on state highways, the results of this test will be compared to the three standard evaluation factors for a median barrier outlined in NCHRP Report 230(1). The standard factors are 1) structural adequacy, 2) occupant risk, and 3) vehicle trajectory. These comparisons only serve as a measure of impact severity. In addition, a comparison of the restrained and unrestrained occupants will be discussed.

It is worth noting that the barrier used in this test meets the NCHRP Report 230 evaluation criteria when tested under the required standard conditions.

5.3.2 Structural Adequacy

The Structural adequacy was evaluated by comparison of test results with the following criteria from Table 6 of NCHRP Report 230(1):

"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."

These criteria were essentially met in this test keeping in mind, of course, that when a vehicle is redirected through an angle of 54-1/2° in a distance of a few feet it can hardly be "smoothly redirected"; however, the redirection, in this case, was controlled and as smooth as can be expected for such a large impact angle.

In this test, the structural strength of the barrier was used to the limit. This was evidenced by several vertical cracks on the backside of the barrier in the region of impact as shown in Figure 10. These cracks are indicative of bending failure. Under more severe impact conditions, a more spectacular failure might be expected.

5.3.3 Occupant Risk

The occupant risk was evaluated by comparison of test results with the following critieria from Table 6 of NCHRP Report 230(1):

"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."

F. Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 24 in. forward and 12 in. lateral displacements, shall be less than:

Occupant Impact Velocity-fps	
Longitudinal	Lateral
$40/F_1$	$20/F_2$

and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than:

Occupant Ridedown Accelerations-g's	
Longitudinal	Lateral
$20/F_3$	$20/F_4$

where F_1, F_2, F_3, and F_4 are appropriate acceptance factors (see Table 8, Chapter 4 for suggested values)."

"G. (Supplementary) Anthropometric dummy responses should be less than those specified by FMVSS 208, i.e., resultant chest acceleration of 60g, Head Injury Criteria of 1000, and femur force of 2250 lb and by FMVSS 214, i.e., resultant chest acceleration of 60g, Head Injury Criteria of 1000 and occupant lateral impact velocity of 30 fps."

During and after impact the vehicle did not roll over. The maximum roll was 7-1/2° as measured from the high-speed film. There was no deformation or intrusion into the passenger compartment.

The calculated longitudinal Occupant Impact Velocity was 28.6 feet per second. The lateral impact velocity was not calculated, but can reasonably be assumed to be lower than the longitudinal in this impact. The ridedown acceleration was determined to be less than 10 g by visual inspection of the accelerometer traces. The Head Injury Criteria for each of the dummies was less than 1000, 242 for the restrained dummy and 468 for the unrestrained dummy. Other parameters in criterion G were not measured.

5.3.4 Vehicle Trajectory

The vehicle trajectory was evaluated by comparison of test results with the following criteria from Table 6 of NCHRP Report 230(1):

"H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.

I. In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device."

The vehicle trajectory would be considered acceptable when compared against the standards. The final stopping position was across the line of the barrier. If the barrier had extended farther downstream, the vehicle would have made secondary contact with it, and probably would have stopped adjacent to the barrier. After the redirection, the maximum distance the vehicle traveled away from the barrier was 9 feet at the right front corner, as evidenced by tire marks. Figure 13 shows the right front tire skid marks enhanced.

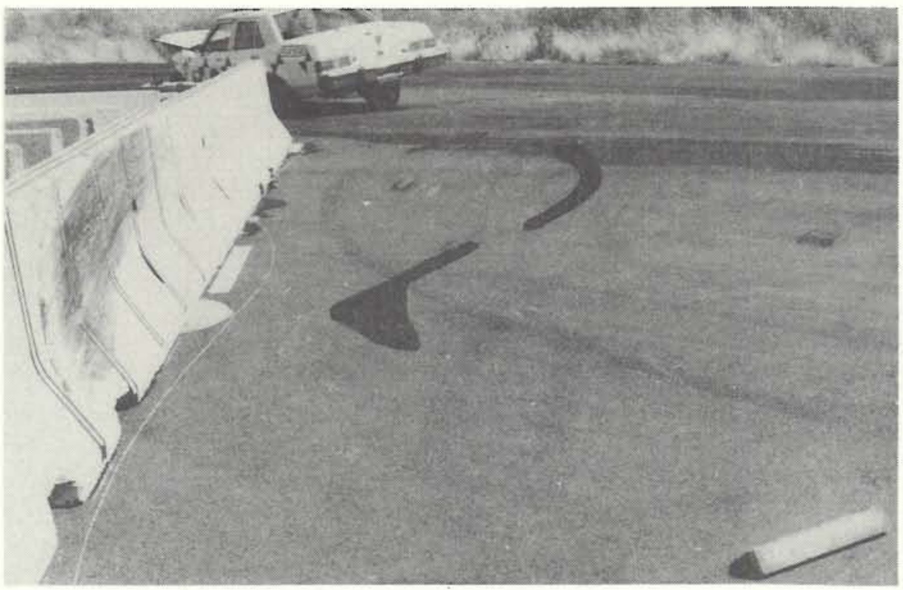


Figure 13. Skid Marks of Right Front Tire

The vehicle was not judged to have been redirected into the traffic lanes so the change in speed and the exit angle were not critical criteria. Nevertheless, they were calculated and the exit angle of 9-1/2° was less than 27° (60% of 45°) and the exit velocity of 21 mph represented a change of 19 mph which was greater than the 15 mph limit.

5.3.5 Restrained vs Unrestrained Occupant

The two anthropomorphic test dummies, Rex Karrs, the driver, a 50th percentile male, and Willie Makit, the passenger, a 50th percentile male, behaved quite differently after impact. The dominant factor affecting the diverse behavior of the two dummies was the use or nonuse of factory installed lap and shoulder belts. A less significant factor was the original position of each occupant.

The key difference in the behavior of the two dummies was the magnitude of forward motion. Rex Karrs, the driver dummy, was restrained by a lap belt/shoulder strap, while Willie Makit, the passenger dummy was not restrained. Rex Karrs' forward motion was halted by the lap belt/shoulder strap. The strap extended about 10 inches from the normal rest position allowing nominal forward motion while preventing any impact by the head, knee, or torso. Willie Makit's forward motion was halted when its head struck the windshield and its knees struck the lower dash. The windshield was broken by Willie's head and bulged out about 3 inches during redirection. Figure 14 shows the windshield bulging and glass spraying away in a sequence taken from one of the high-speed cameras. After the vehicle came to rest, the windshield still bulged 1 3/4 inches (Figure 12) while Willie's head was wedged between the dash and wind shield in Figure 15.

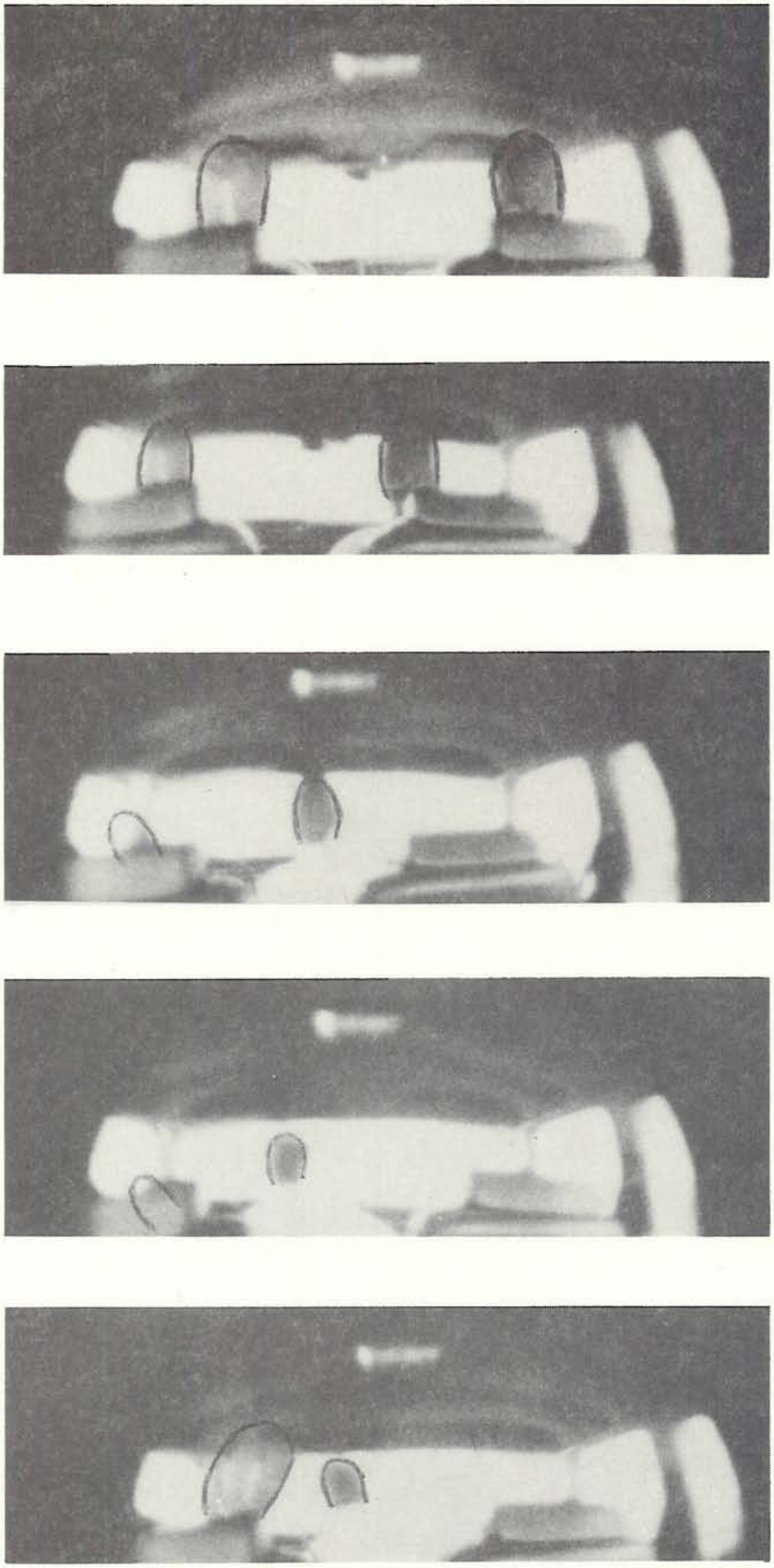
Willie's knees broke the plastic of the lower dash causing the glove compartment to be unusable.

The original position of each of the dummies had a small effect on the lateral motion, but the use or nonuse of restraint was still more significant. Since the impact was at an angle and not head-on , there was a lateral component of the dummies' movement relative to the vehicle, toward the left. Rex Karrs forcefully hit the inner door panel with the upper left arm, denting the panel. The dummy then bent sideways at the neck such that the plane of the front left window (which was open) was penetrated. Based on previous Caltrans crash tests a driver dummy has the potential of being

I+.162 sec.   I+.167 sec.   I+.217 sec.

Figure 14. Windshield Bulging During Impact

Figure 15. The Dummy's Head Wedged Between the Dash and Windshield



1. Shortly after impact the dummies have not yet begun to move.

2. Willie begins to move forward and to the left.

3. Rex's head bends forward due to torso restraint, Willie's head hits rearview mirror.

4. Willie's head penetrates the windshield, Rex's head bends to the left, not hitting anything.

5. Rex bounces back to an upright position while Willie continues to penetrate windshield.

Figure 16. Interior View of Dummy Motion

partially ejected through the side window in a 25° angle impact(2) or of hitting and denting the door post with its head in a 52° angle impact(3) when not wearing lap belt/shoulder strap. Willie Makit's lateral motion was stopped due to a combination of its upper torso impinging on the steering wheel, the shift lever and, to a lesser extent, its head wedging between the dash and windshield.

After forward and lateral movement relative to the car reached a maximum, Rex Karrs bounced back into the driver's seat, slightly to the right of the center of the seat, and then shook in the seat. Willie Makit remained in contact with the windshield, dash and steering wheel until the vehicle came to rest. The left shoulder and arm were stuck in front of the steering wheel. Figure 16 shows the dummies' motions as viewed by the interior high-speed camera. Figure 17 shows the final position of the two dummies.

Figure 17. Final Position of The Two Dummies

The dummies also experienced different head accelerations and Head Injury Criteria (HIC). The HIC for Rex Karrs and Willie Makit were 242 and 468 respectively. The difference can be attributed to the fact that Rex Karrs' head did not contact any of the vehicle structure whereas Willie Makit's head did. Figure 18 clearly shows the difference in head accelerations of the two dummies. Willie Makit's head experienced sharp spikes in acceleration due to contacts with the vehicle. Rex Karr's head experienced smooth increase and decrease in acceleration with a peak value of about one half of that of Willie Makit's head.

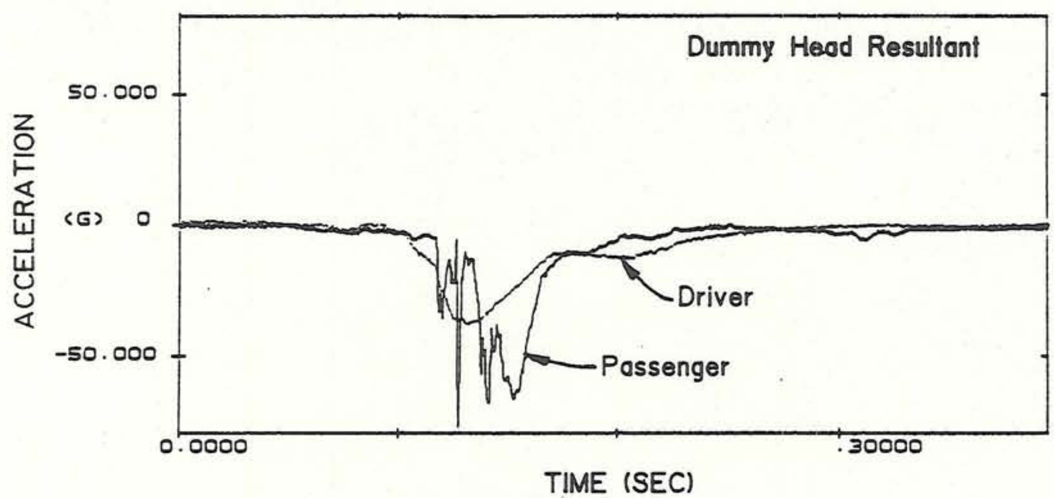


Figure 18. Comparison of Dummy Head Accelerations

Observation of dummy behavior during and after impact and the accelerometer data support the conclusions that: 1) Rex Karrs represented an occupant that may have suffered light to moderate, but not life threatening injuries. Had the front left window been closed, it is unknown how severe the dummy head impact with the window might have been. 2) Willie Makit represented an occupant that may have suffered severe and possibly life threatening injuries.

The only significant factor affecting the probable injury severity difference between the two test dummies appears to be the use or nonuse of lap belt/shoulder strap.

6. REFERENCES

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

2. "Vehicle Impact Tests of a See-Through, Collapsing Ring, Structural Steel Tube, Bridge Barrier Railing," Nagai, Stoker, Stoughton, California Department of Transportation, June 1983.

3. "Effects on a Vehicle Impacting a Concrete Safety Shape Barrier at a Low Speed and a Large Angle," Folsom, Stoughton, Hawatky, California Department of Transportation, July 1986.

APPENDIX A

TEST VEHICLE EQUIPMENT AND CABLE GUIDANCE SYSTEM

The test vehicle gas tank was disconnected from the fuel supply line and drained. Dry ice was placed in the empty tank to inhibit combustion. A one-gallon safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

The accelerator pedal was linked to a small cylinder with a piston which opened the throttle. The piston was activated by a manually thrown switch mounted on the rear fender of the test vehicle. The piston was connected to a CO_2 tube. A regulator was used to control the pressure. The car was placed in the drive position on the automatic transmission.

A speed control device, which was connected between the negative side of the ignition coil and the battery of the vehicle, regulated the speed of the test vehicle based on speedometer cable output. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap composed of two tape switches set a known distance apart and connected to a digital timer.

A cable guidance system was used to direct the vehicle into the barrier. The guidance cable, anchored at each end of the vehicle path to a threaded coupler embedded in a concrete footing, passed through a guide bracket bolted to the spindle of the front wheel of the vehicle on the side away from impact. A steel knockoff bracket anchored the end of the cable closest to barrier. It projected high enough to knock off the guide bracket, releasing the vehicle from the guidance cable prior to impact.

A micro switch was mounted below the front bumper and connected to the ignition system. A trip plate placed on the ground near the impact point triggered the switch when the car passed over it. This opened the ignition circuit and cut the vehicle engine prior to impact. The same switch also cut power to an electromagnet, releasing the sliding weight, so it was free to travel slightly before the instant of impact.

A solenoid-valve actuated CO_2 system was used for remote braking after impact or for emergency braking any other time. Part of this system was a cylinder with a piston which was attached to the brake petal. The pressure used to operate the piston was regulated based on braking test runs. This allowed the vehicle to stop without locking up the wheels.

The remote brakes were controlled at the console trailer through an instrumentation cable connected between the vehicle and the electronic instrumentation trailer and a cable from that trailer to the console trailer. Any loss of continuity in these cables caused an automatic activation of the brakes and ignition cut off. Remote activation of the brakes also would turn off the ignition.

APPENDIX B

PHOTO-INSTRUMENTATION AND DATA

Data film was obtained by using five high speed PhotoSonics Model 16mm 1B cameras, 200 or 400 frames per second (fps), and four high speed Redlake Locam cameras, 400 fps. These cameras were located around the impact area as shown in Figure B1. The cameras were remotely actuated from a central control console located adjacent to the impact area. Table B1 shows the camera types, approximate speeds, and lens size used for the test.

All high speed cameras were equipped with timing light generators which exposed reddish timing pips on the film at a rate of 1,000 per second. The pips were used to determine camera frame rates and to establish time/sequence relationships. Data from the high speed movies were reduced on a Vanguard Motion Analyzer. Some procedures used to facilitate data reduction for the test are listed as follows:

1. Butterfly targets were attached to the test car. Figure B2 shows the target locations.

2. Flashbulbs, mounted on the test vehicle, were electronically flashed to establish (a) initial vehicle/barrier contact and (b) application of the vehicle's brakes. The impact flashbulbs have a delay of several milliseconds before lighting up.

3. Five tape switches, placed at ten foot intervals, were attached to the ground perpendicular to the path of the impacting vehicle beginning about five feet from impact. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of most of the data cameras and made visible to the tower cameras through the use of mirrors. The flashing bulbs were used to correlate the cameras with the impact events and to calculate the impact speed independent of the electronic speed trap. The tape switch layout is shown in Figure B3.

Additional coverage of the impacts was obtained by a 70mm Hulcher sequence camera and a 35mm Hulcher sequence camera, each operating at 20 frames per second. Documentary coverage of the tests consisted of normal speed movies and still photographs taken before, during and after impact.

A sliding weight device was mounted on the test car to determine the rattlespace time as defined in Section 5.1.5. This device would only be used if accelerometer data failed. The weight contains ball bearings which roll along a smooth rod. The weight is held in place on the left end of the rod by an electromagnet before impact. The front bumper switch on the car which cuts the ignition about two feet before impact also cuts off the current to the electromagnet. The weight is then free to slide forward for a two foot distance on the rod after impact. The time it takes for the weight to travel two feet (rattlespace time) is determined from the high speed movie film. Flashbulbs mounted on the device are activated when the weight begins to move and also when it reaches the end of its travel. Due to a malfunction of the electromagnet, the sliding weight was not restrained during the run-in, so the flashbulbs had flashed long before impact.

TEST NO. 451

CAMERA LAYOUT

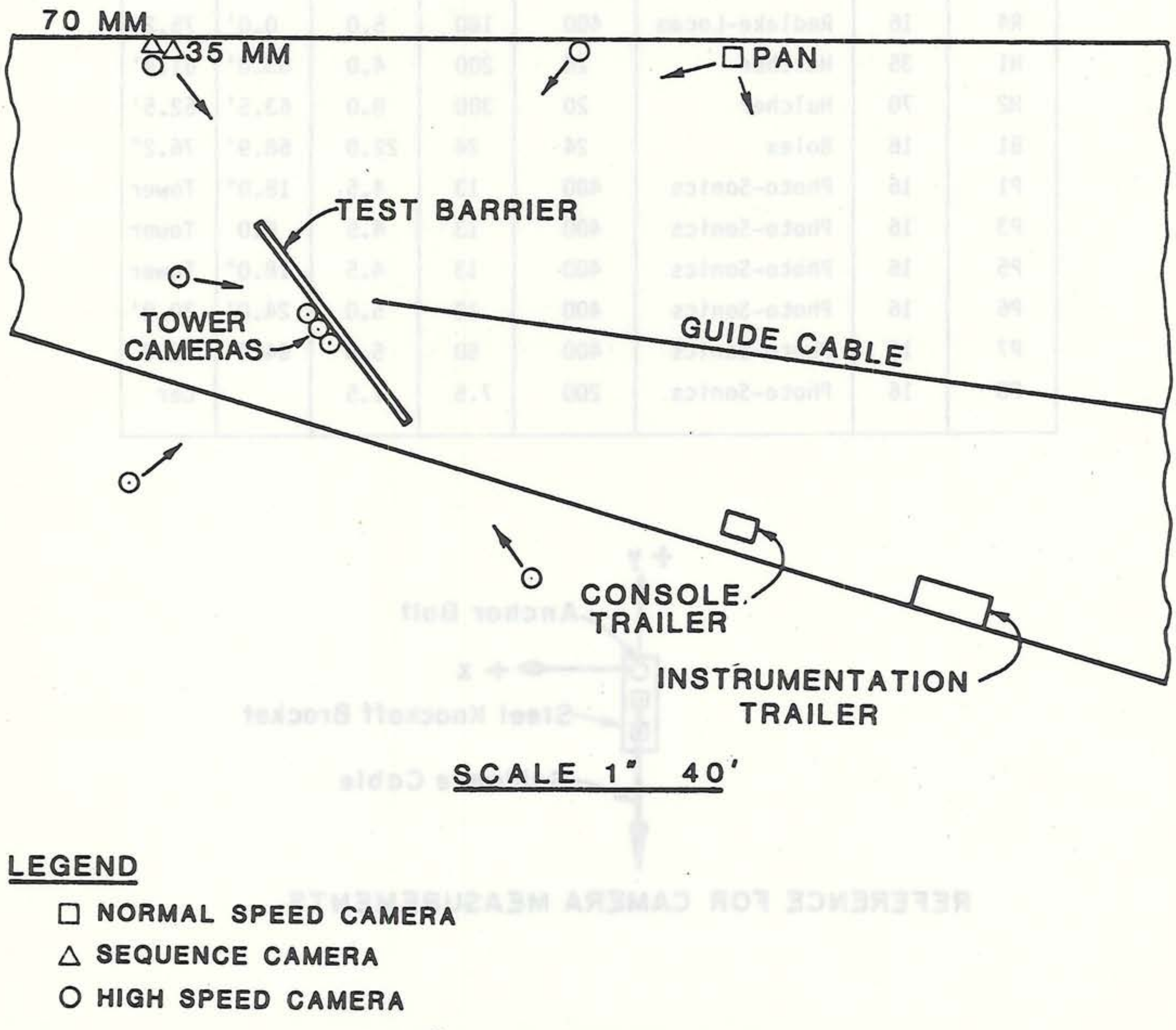
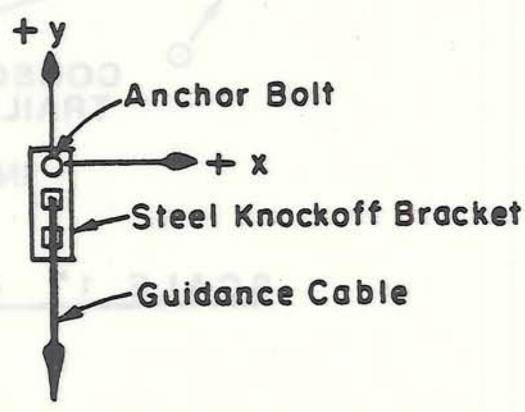


Figure B1. Camera Layout

TEST NO. 451

TABLE B1 CAMERA LAYOUT WORKSHEET

CAMERA				LENS		COORDINATES	
No.	Film Size (mm)	Type	Nom. Frame Rate (fr/sec)	Size (mm)	Opening	X (ft)	Y (ft)
R2	16	Redlake-Locam	400	50	5.6	65.2'	44.5'
R3	16	Redlake-Locam	400	25	5.6	63.0'	58.4'
R4	16	Redlake-Locam	400	180	5.0	0.0'	75.2'
H1	35	Hulcher	20	200	4.0	63.0'	61.4'
H2	70	Hulcher	20	300	8.0	63.5'	62.5'
B1	16	Bolex	24	24	22.0	68.9'	76.2"
P1	16	Photo-Sonics	400	13	4.5	18.0"	Tower
P3	16	Photo-Sonics	400	13	4.5	0.0	Tower
P5	16	Photo-Sonics	400	13	4.5	18.0"	Tower
P6	16	Photo-Sonics	400	13	5.0	24.0'	30.0'
P7	16	Photo-Sonics	400	50	5.0	64.0'	0.0
P8	16	Photo-Sonics	200	7.5	1.5		Car

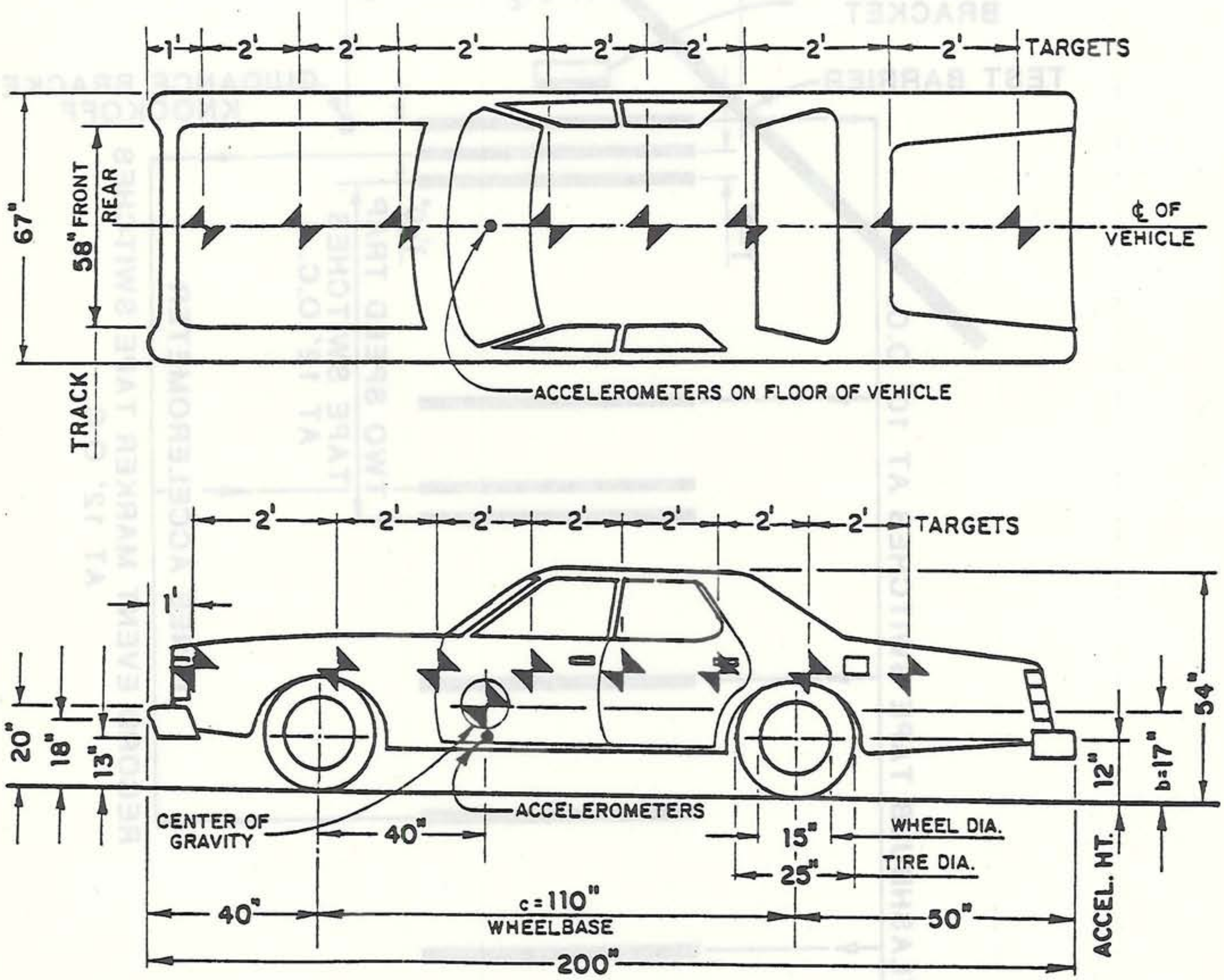


REFERENCE FOR CAMERA MEASUREMENTS

TEST NO. 451 TEST DATE - 9/15/86

VEHICLE - FORD GRANADA

CAR DIMENSIONS



WEIGHT-lb	TEST INERTIA	DUMMY	GROSS-STATIC
W_T	3575	2x165	3905

Figure B2. Car Dimensions

TEST NO. 451

TAPE SWITCH LAYOUT WORKSHEET

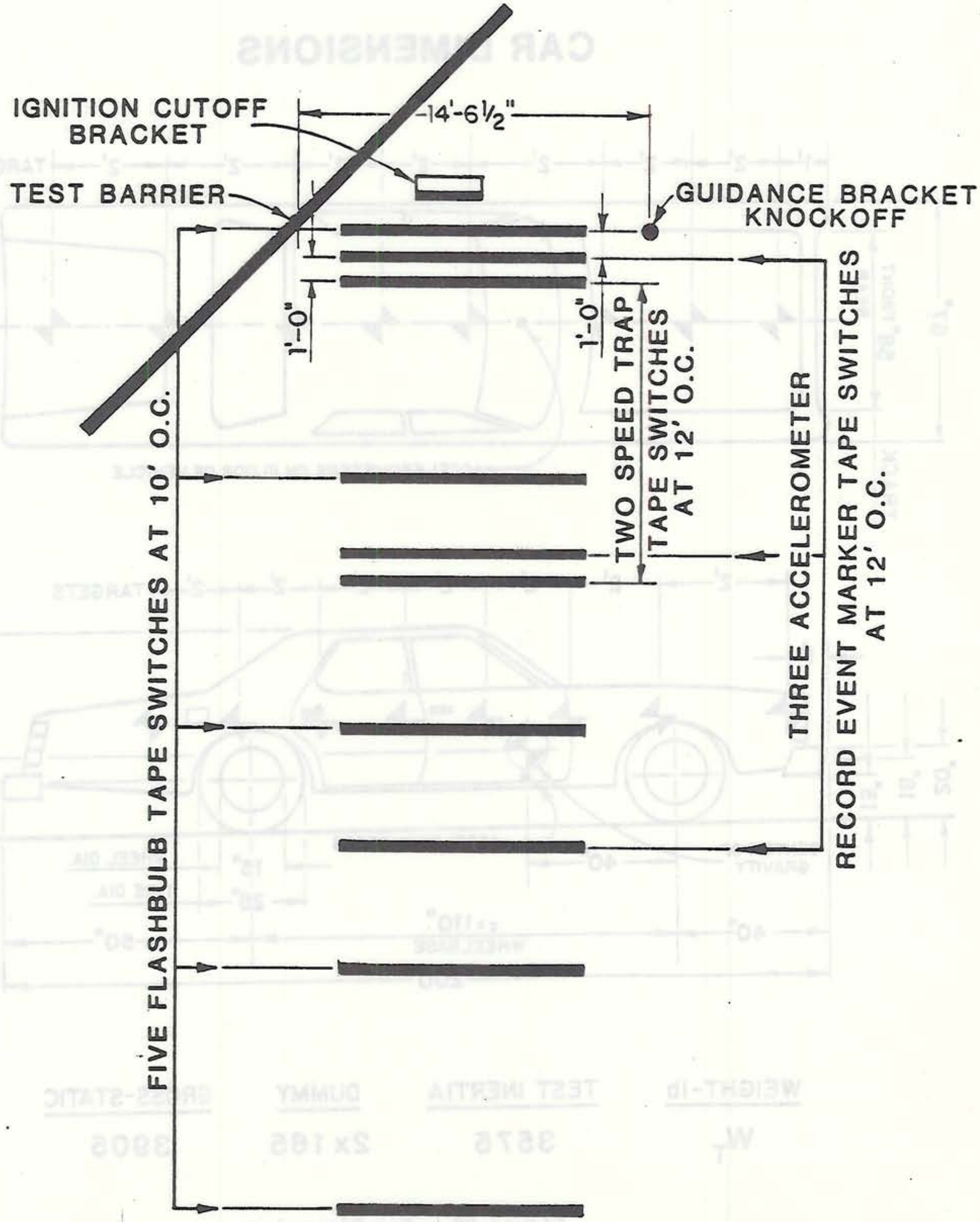


Figure B3. Tape Switch Layout

APPENDIX C

ELECTRONIC INSTRUMENTATION AND DATA

Three Endevco Model 2262-200 piezoresistive accelerometers were mounted in the head of the passenger dummy. Three Statham amplibridge accelerometers were mounted in the head cavity of the driver dummy. Those mounted in the car were close to the vehicle center of gravity.

Data from the accelerometers in the test vehicle were transmitted through a 1,000 foot Belden #8776 umbilical cable connecting the vehicle to a 14 channel Hewlett Packard 3924C magnetic tape recording system. This recording system was in an instrumentation trailer at the test control area.

Three pressure-activated tape switches were placed on the ground in the path of the vehicle near the barrier. They were spaced at carefully measured intervals of 12 feet. When the test vehicle tires passed over them, the switches produced sequential impulses or "event blips" which were recorded concurrently with the accelerometer signals on the tape recorder and served as "event markers". A tape switch on the front bumper of the car closed at the instant of impact and activated flash bulbs mounted on the car, and an "event marker" on the recording tape. A time cycle was recorded continuously on the tape with a frequency of 500 cycles per second. The impact velocity of the vehicle could be determined from the tape switch impulses and the timing cycles. Two other tape switches connected to digital readout equipment were placed 12 feet apart just upstream of the test barrier to indicate vehicle speed immediately after the test. The tape switch layouts are shown in Appendix B in Figure B3.

All accelerometer data were processed on a Norland Model 3001 waveform analyzer, the primary means of data reduction. The analyzer digitized and manipulated the raw data, printed test results, and plotted various curves. These data curves are shown in Figures C1 through C5.

The Occupant Impact Veloctiy is theoretical; however, on the plot of distance vs time in Figure C3, the curves can be visualized as representing the car windshield and the driver's head. It is assumed that the head starts out two feet behind the windshield. The point where the curves cross represents the impact between the head and the windshield because the windshield has slowed down from the impact velocity, but the head has not. The time when the windshield/head impact occurs (rattlespace time) is carried to the plot of velocity vs time. The Occupant Impact Velocity is the difference between the vehicle impact velocity and the vehicle velocity at the end of the rattlespace time. Only the vehicle accelerometers are used in determining the Occupant Impact Velocity, not the dummy accelerometers.

Four Huston potentiometers were attached to the back of the center barrier segment. Figure C6 shows the location where each of the potentiometers were attached to the barrier segment. The potentiometers recorded the dynamic deflection of the barrier during the impact event. Figures C7 through C10 show the traces of each of the four potentiometers.

TEST NUMBER
451.00

SAFETY SHAPE
40.3 M.P.H.
45 DEGREES
SEP. 15 1986

MAX. 50 MS
AVER. ACCEL.
FOR CAR (G)-

VERTICAL---
7.5438
FROM TIME(S)
9.0500E-02

LONGITUDINAL
-11.159
FROM TIME(S)
5.2500E-02

LATERAL
-8.6752
FROM TIME(S)
5.5000E-02

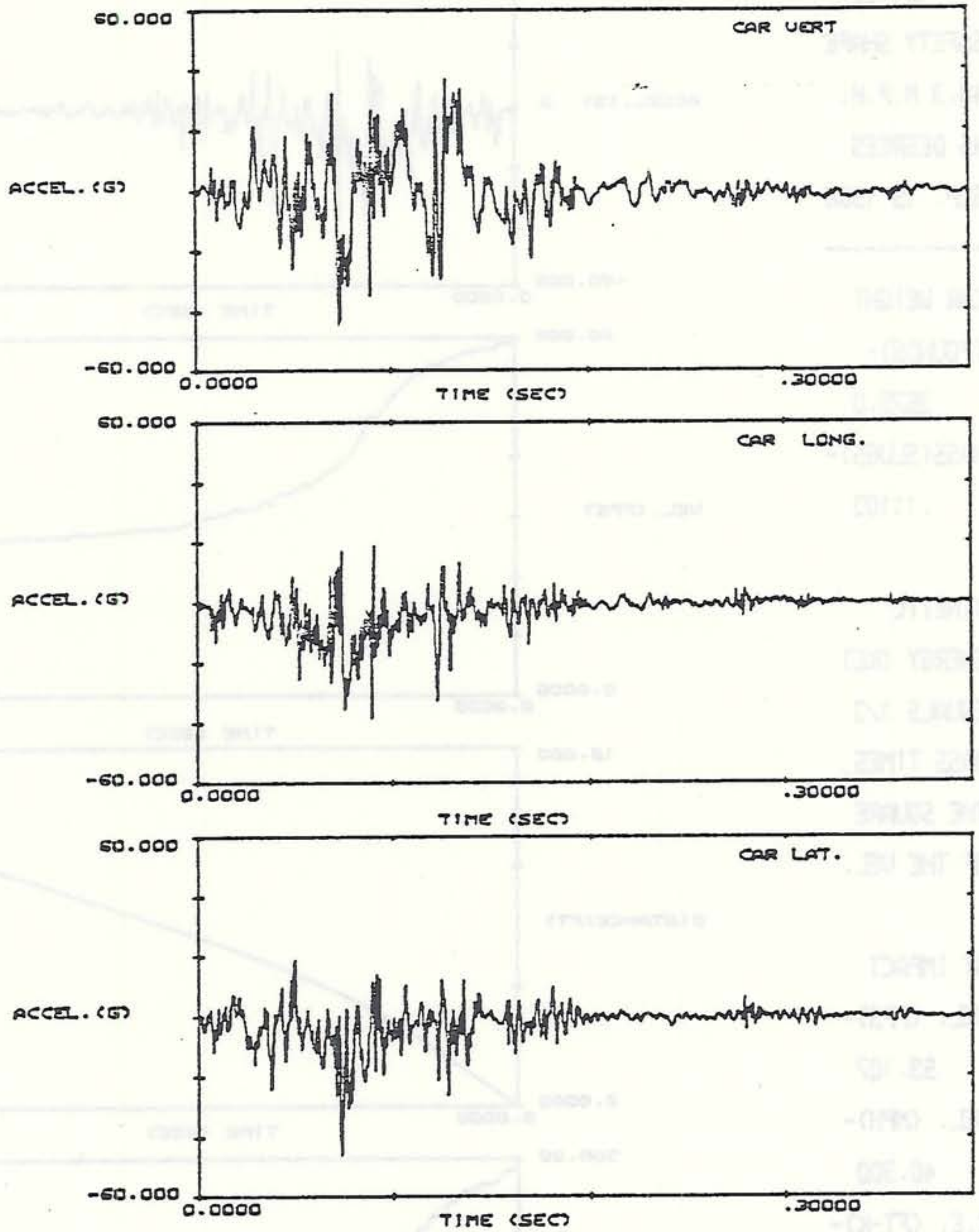


Figure C1. Vehicle Accelerometer Traces

TEST NUMBER
451.00
SAFETY SHAPE
40.3 M.P.H.
45 DEGREES
SEP. 15 1986

CAR WEIGHT
(POUNDS)-
3575.0
MASS(SLUGS)-
.11102

KINETIC
ENERGY (KE)
EQUALS 1/2
MASS TIMES
THE SQUARE
OF THE VEL.

AT IMPACT
VEL. (FPS)-
59.107
VEL. (MPH)-
40.300
K.E. (FT-K)-
193.94

DISSIPATED
KE (AT END
OF ANALYSIS)
156.98

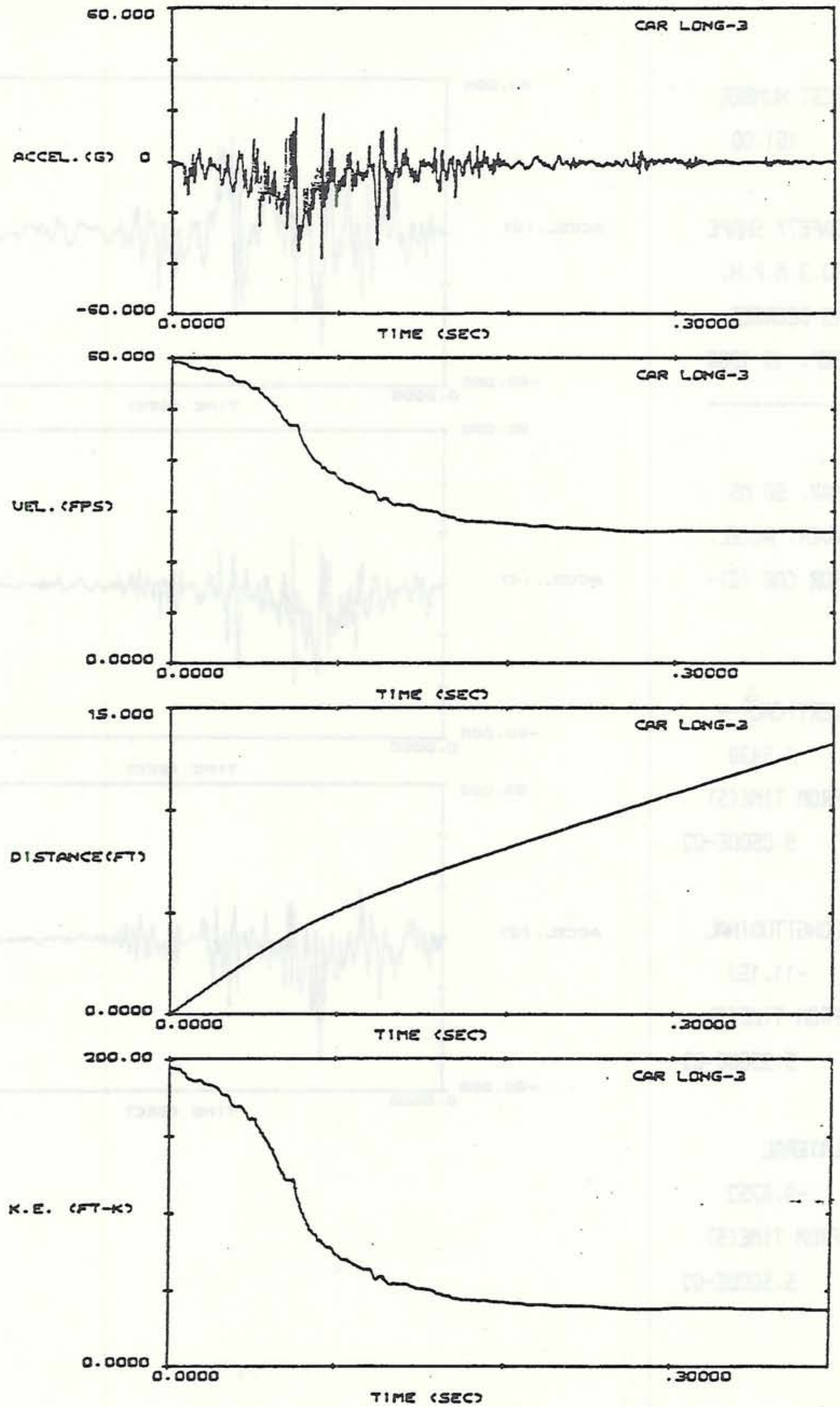


Figure C2. Reduced Vehicle Longitudinal Data

TEST NUMBER
451.00

SAFETY SHAPE
40.3 M.P.H.
45 DEGREES
SEP. 15 1986

CAR IMPACT
VELOCITY
(FPS)-
59.107

AT CAR
DISTANCE(FT)
6.6599
OCCUPANT
IMPACT
OCCURS

OCCUPANT
IMPACT
VELOCITY
(FPS)-
28.594
OCCURS AT
.14650
SEC. AFTER
CAR IMPACT

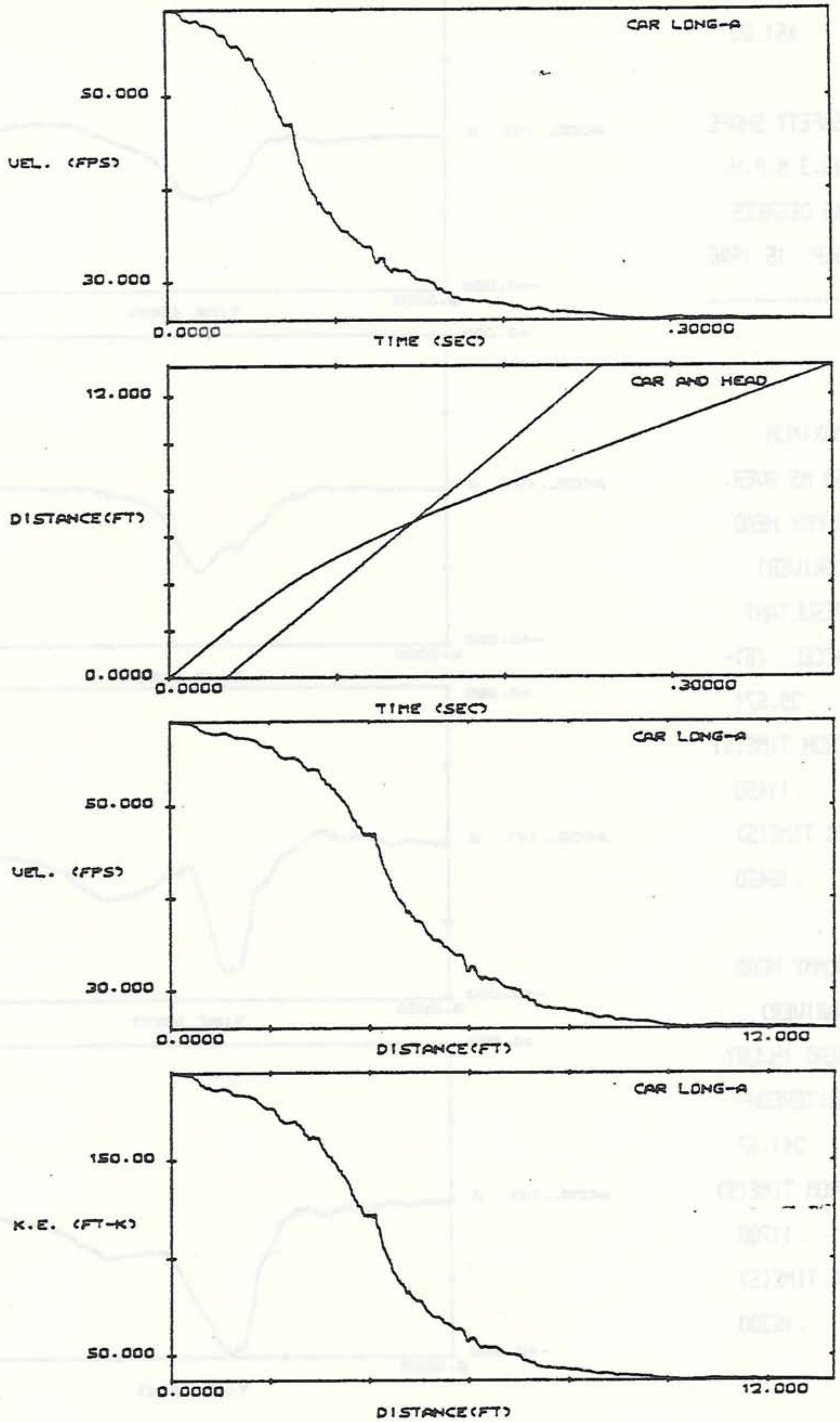


Figure C3. Reduced Vehicle Longitudinal Data With Theoretical Head Plot

TEST NUMBER
451.00

SAFETY SHAPE
40.3 M.P.H.
45 DEGREES
SEP. 15 1986

MAXIMUM
50 MS AVER.
DUMMY HEAD
(DRIVER)
RESULTANT
ACCEL. (G)-
29.674
FROM TIME(S)
.11450
TO TIME(S)
.16450

DUMMY HEAD
(DRIVER)
HEAD INJURY
CRITEREON-
241.87
FROM TIME(S)
.11700
TO TIME(S)
.16200

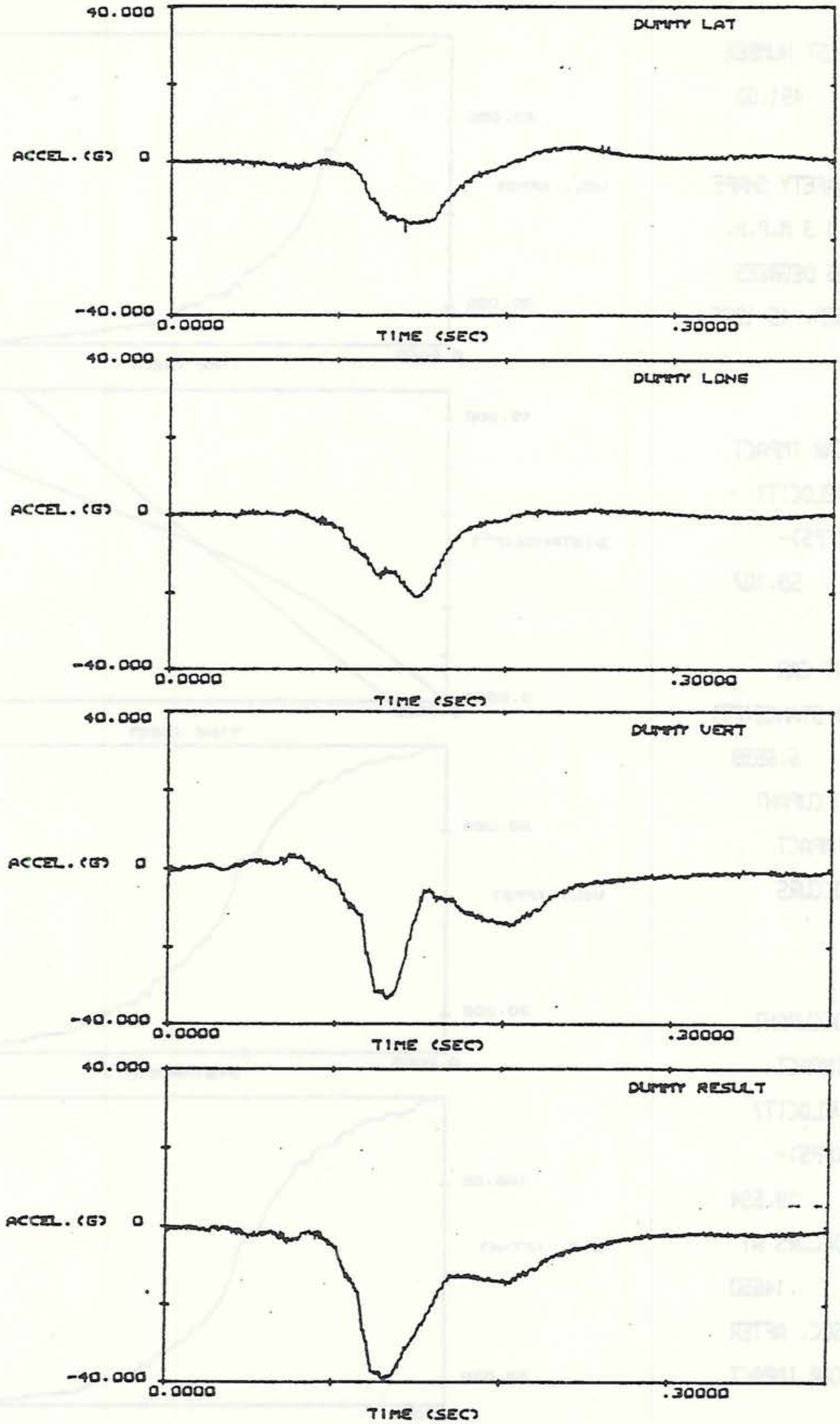


Figure C4. Driver Dummy Head Accelerometer Traces

TEST NUMBER
451.00

SAFETY SHAPE
40.3 M.P.H.
45 DEGREES
SEP. 15 1986

MAXIMUM
50 MS AVER.
DUMMY HEAD
(PASSENGER)
RESULTANT
ACCEL. (G)-
37.944
FROM TIME(S)
.11850
TO TIME(S)
.16850

DUMMY HEAD
(PASSENGER)
HEAD INJURY
CRITEREON-
468.31
FROM TIME(S)
.12750
TO TIME(S)
.16500

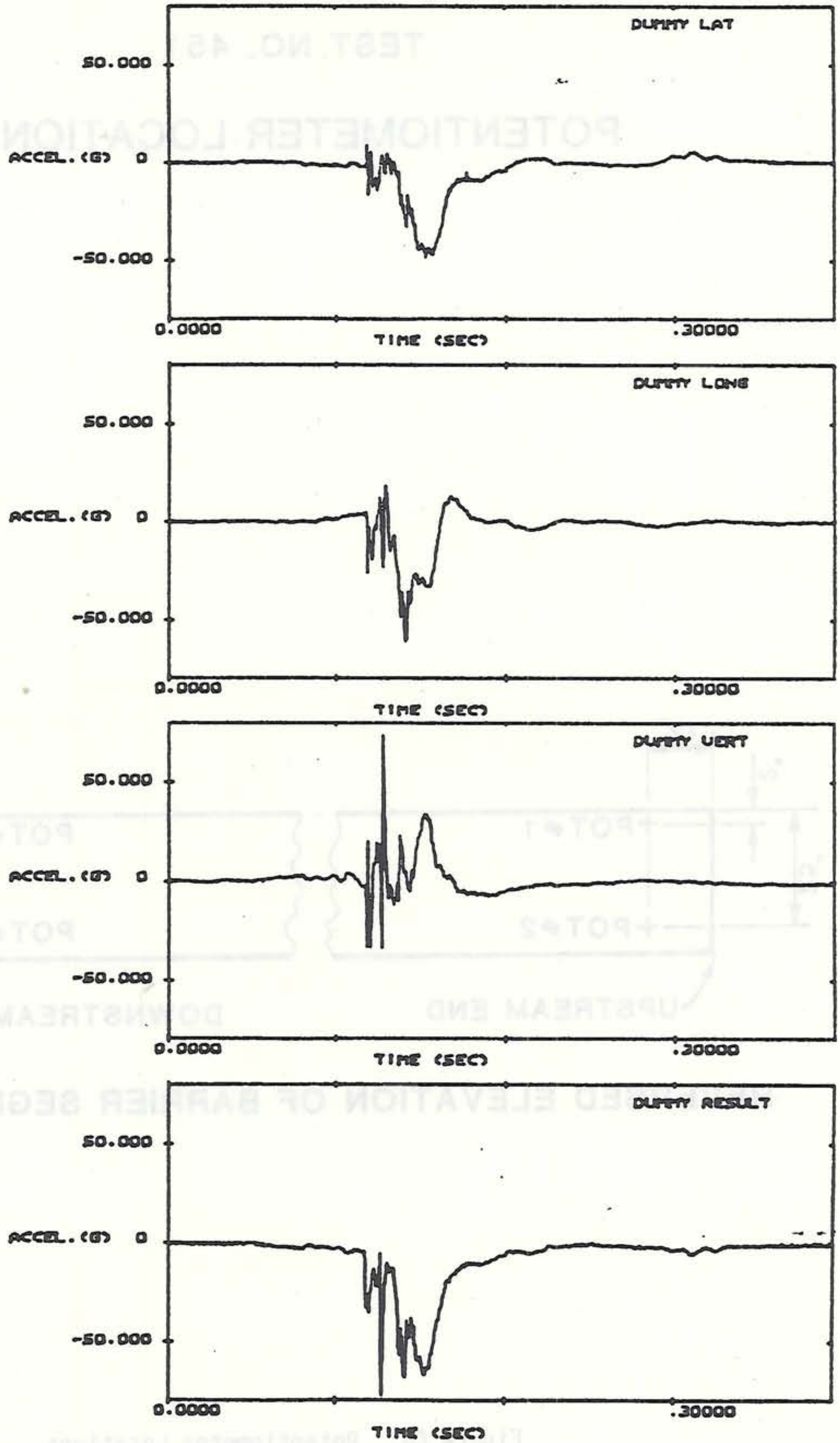
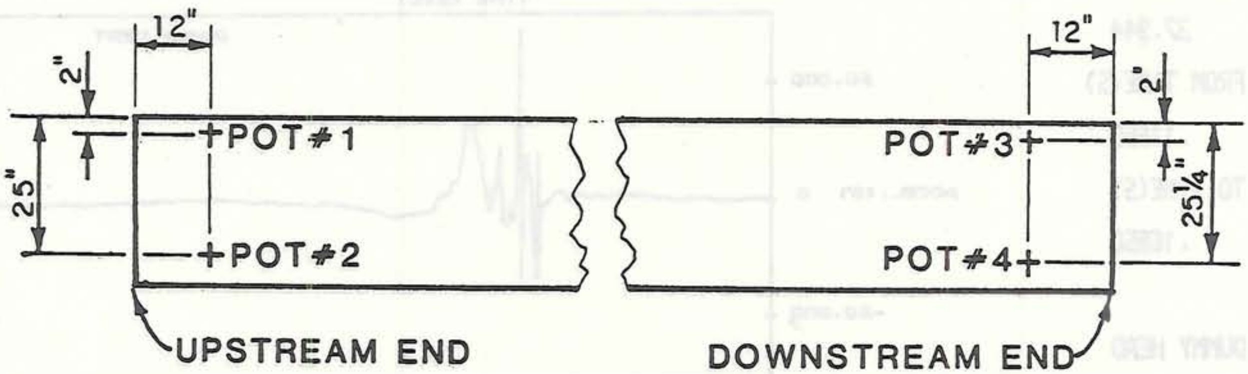


Figure C5. Passenger Dummy Head Accelerometer Traces

TEST NO. 451

POTENTIOMETER LOCATIONS



REVERSED ELEVATION OF BARRIER SEGMENT # 2

Figure C6. Potentiometer Locations

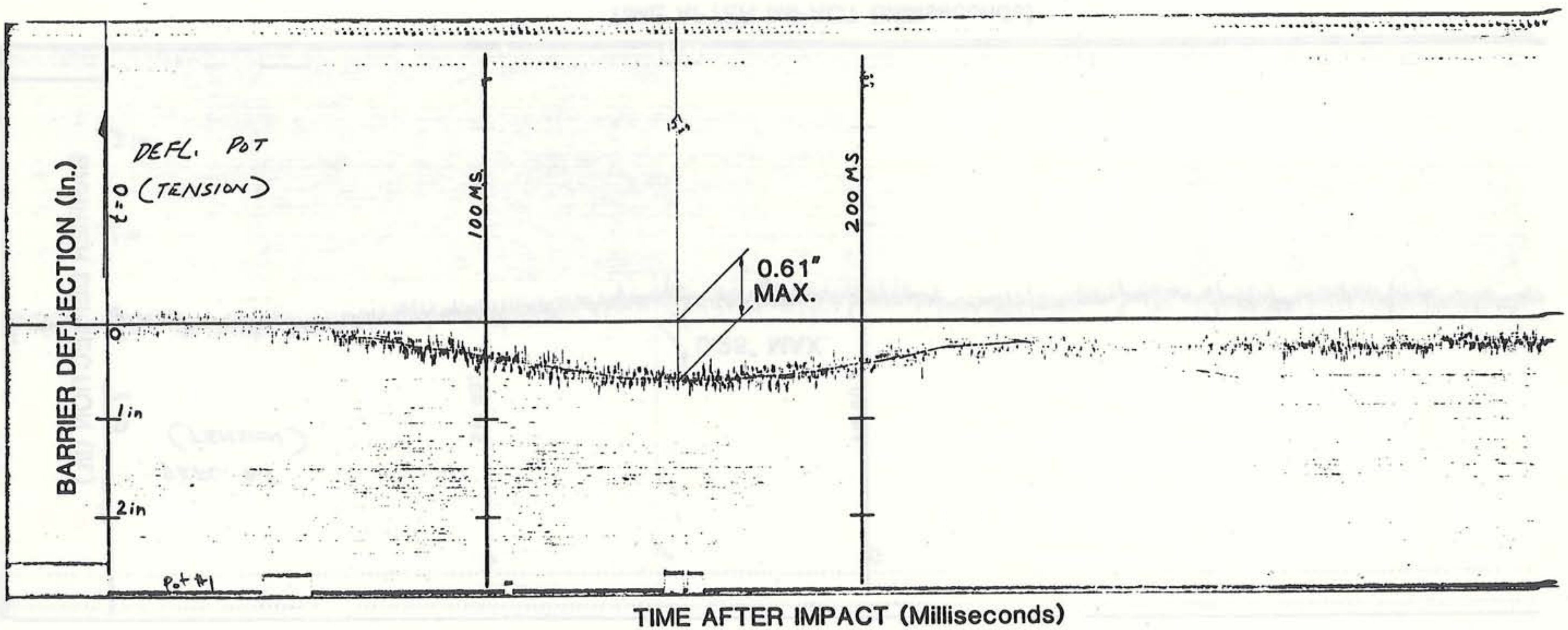


Fig. C7. DEFLECTION POTENTIOMETER TRACE – UPSTREAM, UPPER

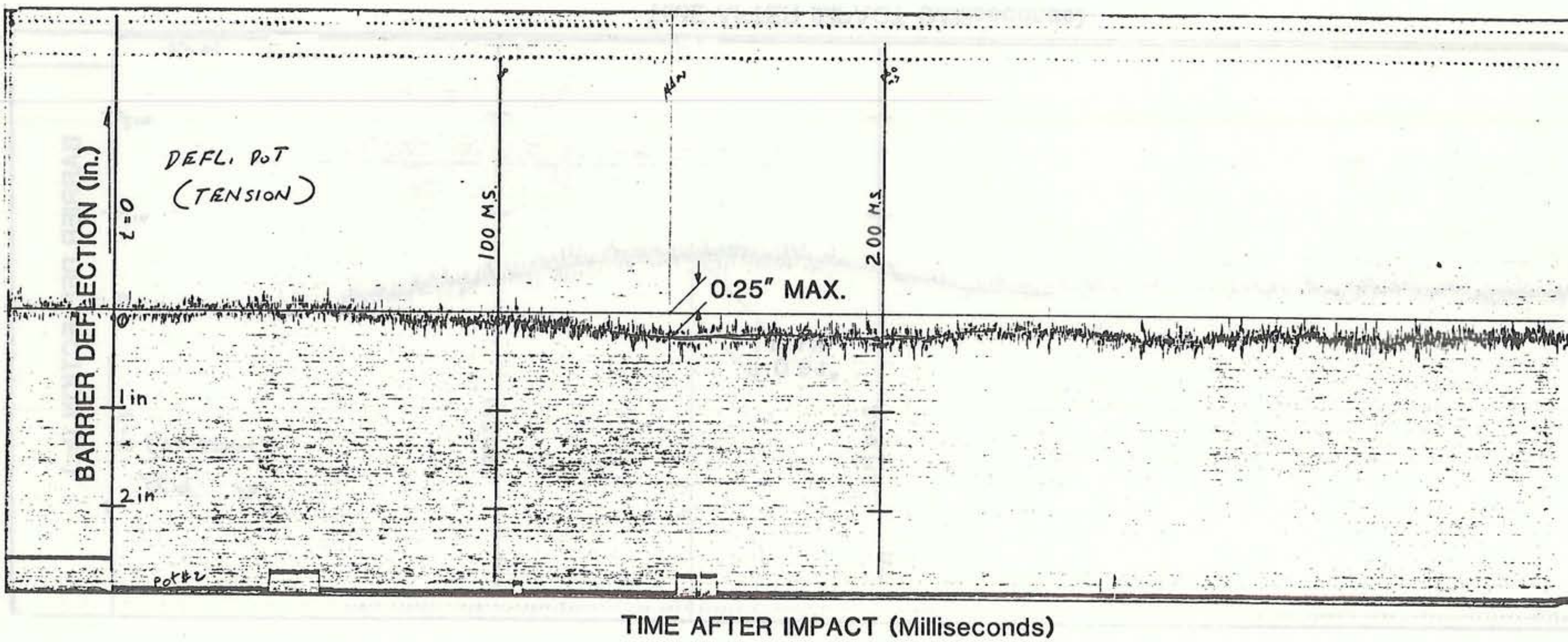
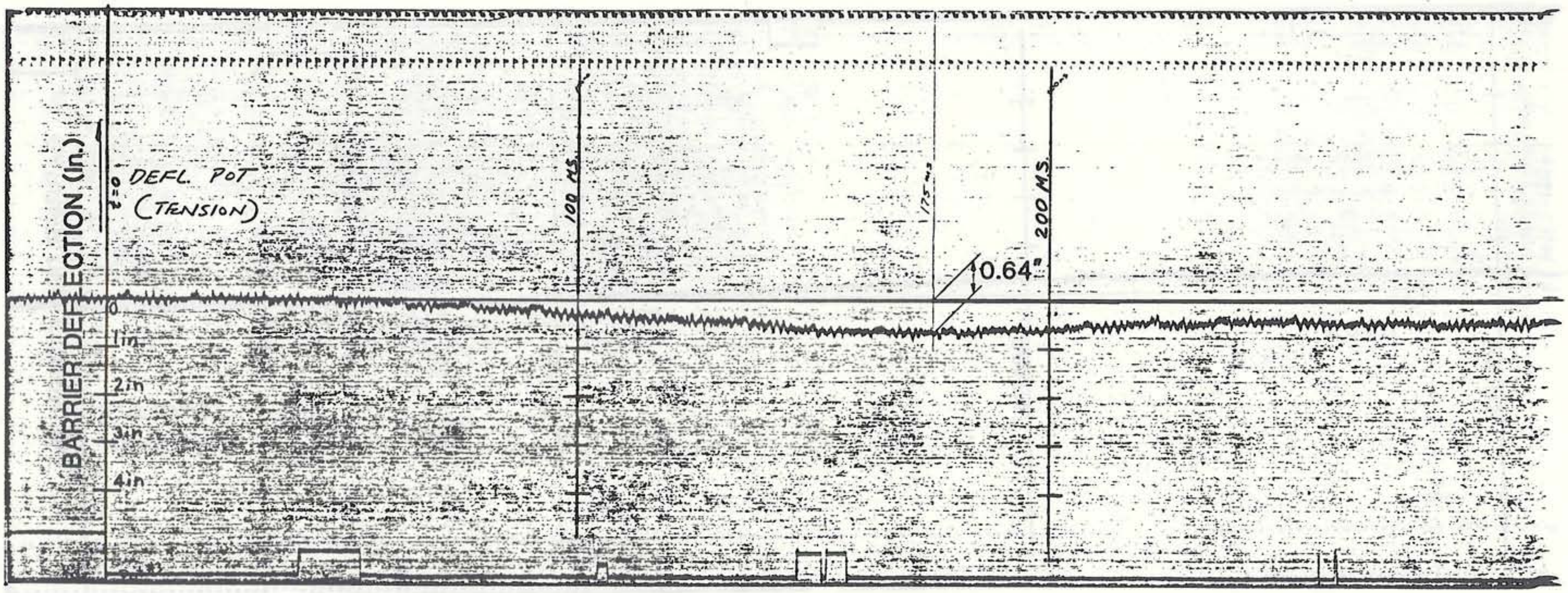


Fig. C8. DEFLECTION POTENTIOMETER TRACE – UPSTREAM, LOWER



TIME AFTER IMPACT (Milliseconds)

Fig. C9. DEFLECTION POTENTIOMETER TRACE – DOWNSTREAM, UPPER

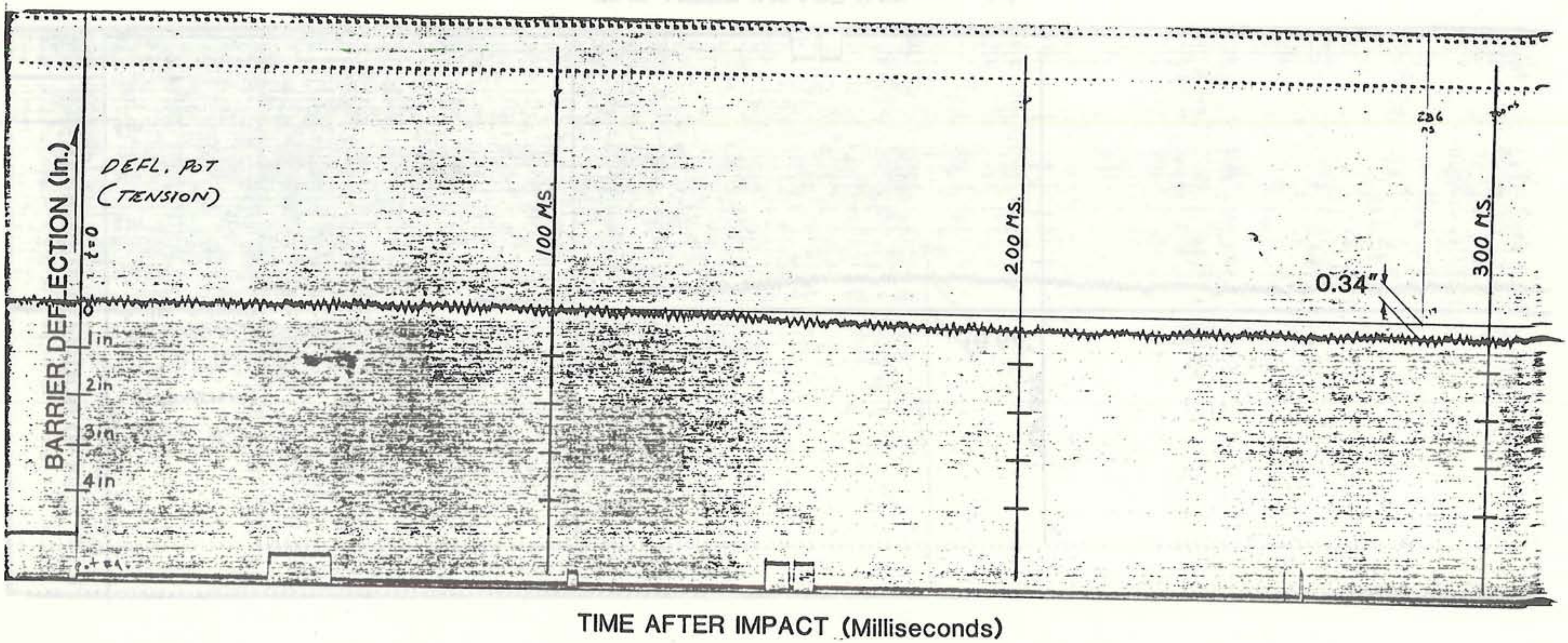


Fig. C10. DEFLECTION POTENTIOMETER TRACE – DOWNSTREAM, LOWER