TEXAS TRANSPORTATION INSTITUTE

# CRASH TESTING A REUSABLE POLYETHYLENE NARROW IMPACT ATTENUATION SYSTEM

Project No. 472380
Polyethylene Cylinder Crash Cushion
Test 472380-6

Prepared for
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# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | ml |
| gal | gallons | 3.785 | liters | l |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| NOTE: Volumes greater than 1000 l shall be shown in $m^3$. | | | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5(F-32)/9 or (F-32)/1.8 | Celcius temperature | °C |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | l |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| psi | poundforce per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | ac |
| ha | hectares | 2.47 | acres | $mi^2$ |
| $km^2$ | square kilometers | 0.386 | square miles | |
| | | **VOLUME** | | |
| ml | milliliters | 0.034 | fluid ounces | fl oz |
| l | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.71 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg | megagrams | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact)** | | |
| °C | Celcius temperature | 1.8C + 32 | Fahrenheit temperature | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | psi |

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised August 1992)

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# INTRODUCTION

Most crash cushions have high maintenance costs associated with their use. Following a vehicular impact, the energy dissipating material and other system components must be discarded and replaced. Furthermore, because of this cost and the fact that the human resources of the State Departments of Transportation are usually spread rather thin, impacted safety devices sometimes remain unrefurbished for long periods of time. This unsafe situation represents a danger to the motoring public and an increased liability exposure to the State Department of Transportation involved.

The objective of this project is to develop an impact attenuation system composed of high molecular weight/high density polyethylene (HMW/HDPE) cylinders. Such a device can potentially dissipate large amounts of kinetic energy, undergo large deformations and strains without fracturing, and, most importantly, restore itself to 90% of its original size, shape, and energy dissipation potential when the forcing function is removed.

If this project is successful, crash cushion maintenance costs would be greatly reduced or eliminated. Tort liability exposure related to damage or collapsed hardware would be significantly decreased. Finally, the safety of the motoring public and the maintenance personnel involved in maintaining and repairing damaged hardware would be enhanced.

NCHRP Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features," outlines a series of tests for evaluating devices to be used as crash cushions. They are outlined as follows:

| NCHRP Test No. | Test Vehicle | Impact Speed | Impact Angle | Impact Point |
|---|---|---|---|---|
| 3-30 | 820-kg (1,808-lb) 1988 or later model sedan | 100 km/h (62.2 mi/h) | 0 deg. | Nose of device, width/4 offset |
| 3-31 | 2,000-kg (4,409-lb) 1988 or later model pickup truck | 100 km/h (62.2 mi/h) | 0 deg | Center nose of device |

| | | | | |
|---|---|---|---|---|
| 3-32 | 820-kg (1,808-lb) 1988 or later model sedan | 100 km/h (62.2 mi/h) | 15 deg. | Center nose of device |
| 3-33 | 2,000-kg (4,409-lb) 1988 or later model pickup truck | 100 km/h (62.2 mi/h) | 15 deg | Center nose of device |
| 3-36 | 820-kg (1,808-lb) 1988 or later model sedan | 100 km/h (62.2 mi/h) | 15 deg. | Beginning of length of need |
| 3-37 | 2,000-kg (4,409-lb) 1988 or later model pickup truck | 100 km/h (62.2 mi/h) | 20 deg | Beginning of length of need |
| 3-38 | 2,000-kg (4,409-lb) 1988 or later model pickup truck | 100 km/h (62.2 mi/h) | 20 deg | Critical impact point |
| 3-39 | 2,000-kg (4,409-lb) 1988 or later model pickup truck | 100 km/h (62.2 mi/h) | 20 deg | Reverse hit, mid-length |

This report includes test information pertaining to test 3-38 outlined above.

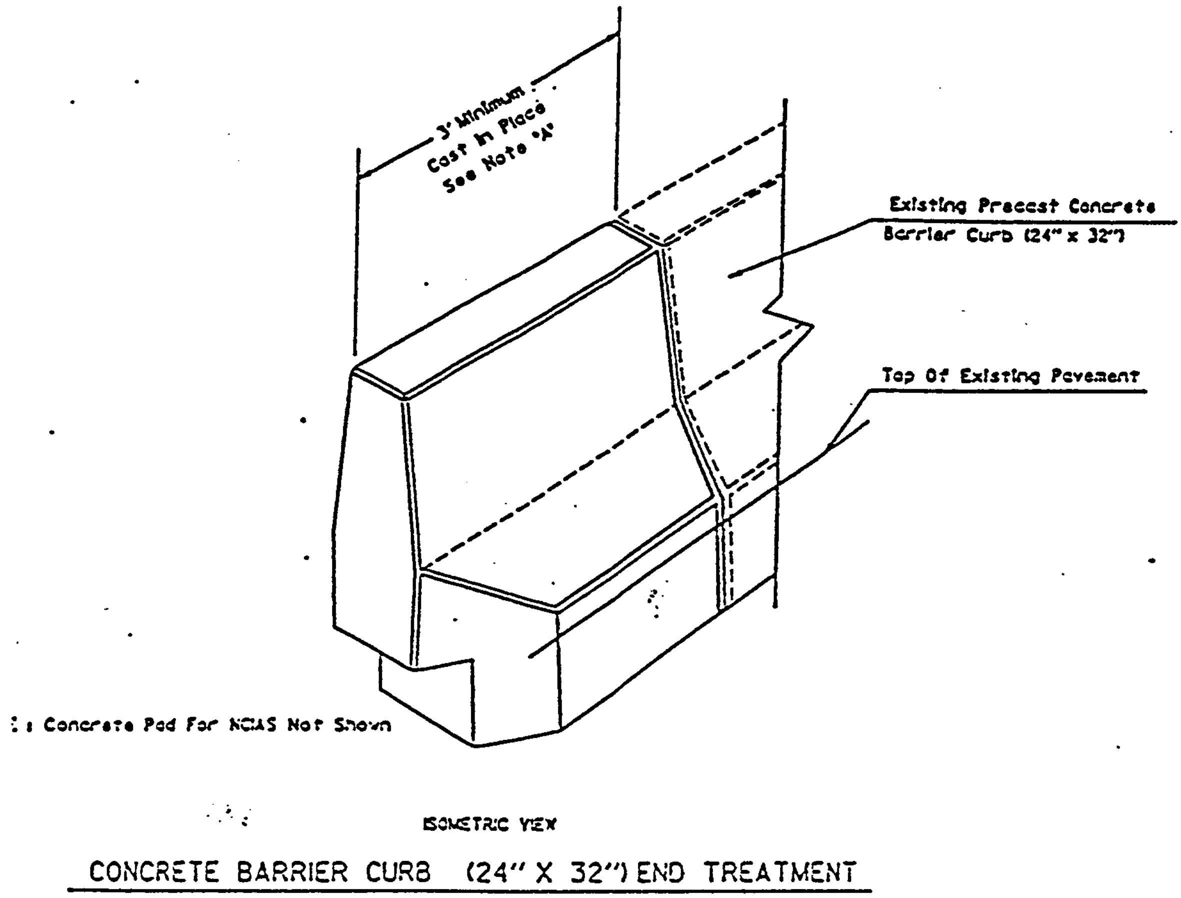
## TEST ARTICLE

Three 9.1 m (30 ft) Portable Concrete Barriers (PCB) were placed behind a 2.44 m (8 ft) long, "cast-in-place" concrete barrier curb shown in Figure 1. The PCB's were anchored to the concrete mat with 25 mm (1 in) dowels placed diagonally through the PCB into the concrete surface. Longitudinal #5 bars were placed in the top and bottom of the barrier curb and were held in place with #4 stirrups at 305 mm (12 in) on center. The overall height of the barrier curb was 813 mm (32 in).

The backup assembly, as shown in Figure 2, consisted of three pipes 787 mm (31 in) in length with respective diameters of 152 mm (6 in), 203 mm (8 in) and 254 mm (10 in) which were welded vertically to a 13 mm (0.5 in) x 711 mm (28 in) x 686 mm (27 in) base plate. Pipes 51 mm (2 in) in diameter were placed diagonally in the largest of the two vertical pipes for anchoring of the cable system. The vertical pipes were then filled with concrete and covered with another 13 mm (0.5 in) plate. Twenty anchor bolts were secured through the base plate into the existing concrete surface.

Nine polyethylene cylinders were placed in front of the backup assembly atop 76.2 mm (3.0 in) x 76.2 mm (3.0 in ) x 8.2 m (27.0 ft) steel angle skid rails. Steel rods, 38.1 mm (1.5 in) diameter, were welded to the angle skid rails adjacent to the interfaces between the cylinders. Chain was attached to plates at the cylinder interfaces and then slid on the steel rods with steel shackles. Figures 3 and 4 show the overall views of the installation. The polyethylene cylinders measured 0.91 m (3.0 ft) diameter by 1.22 m (4.0 ft) tall. Wall thicknesses increased from 20.3 mm (0.8 in) on the first two cylinders to 22.9 mm (0.9 in) on cylinders 3 and 4, 25.4 mm (1.0 in) on cylinders 5 and 6, 30.5 mm (1.2 in) on cylinder 7, and 35.2 mm (1.385 in) on cylinders 8 and 9. Eye bolts were located in cylinders 1 and 9 to hold the cable system in place. Additional U-bolts were located in cylinders 3, 5, and 7.

Steel core wire ropes, 25.4 mm diameter (1 in), with industrial type closed swage sockets on one end and threaded studs on the other end, were attached to front anchor plates, passed through the eye bolts and U-bolts, and secured to the backup assembly. The front anchor plates were 13 mm (0.5 in) x 330 mm (13 in) x 432 mm (17 in) steel plates with beveled fronts. Steel pins 153 mm (6 in) x 51 mm (2 in) were passed through vertical 13 mm (0.5 in) plates and the swage sockets to firmly attach the front end of the cable system.



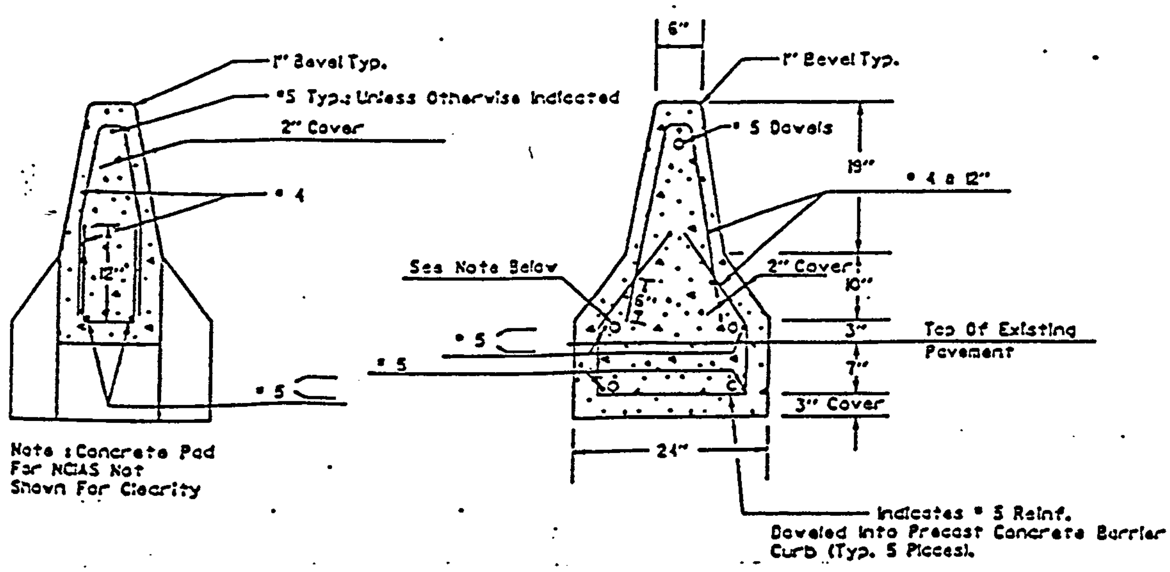




Figure 1. Drawings for concrete curb barrier.

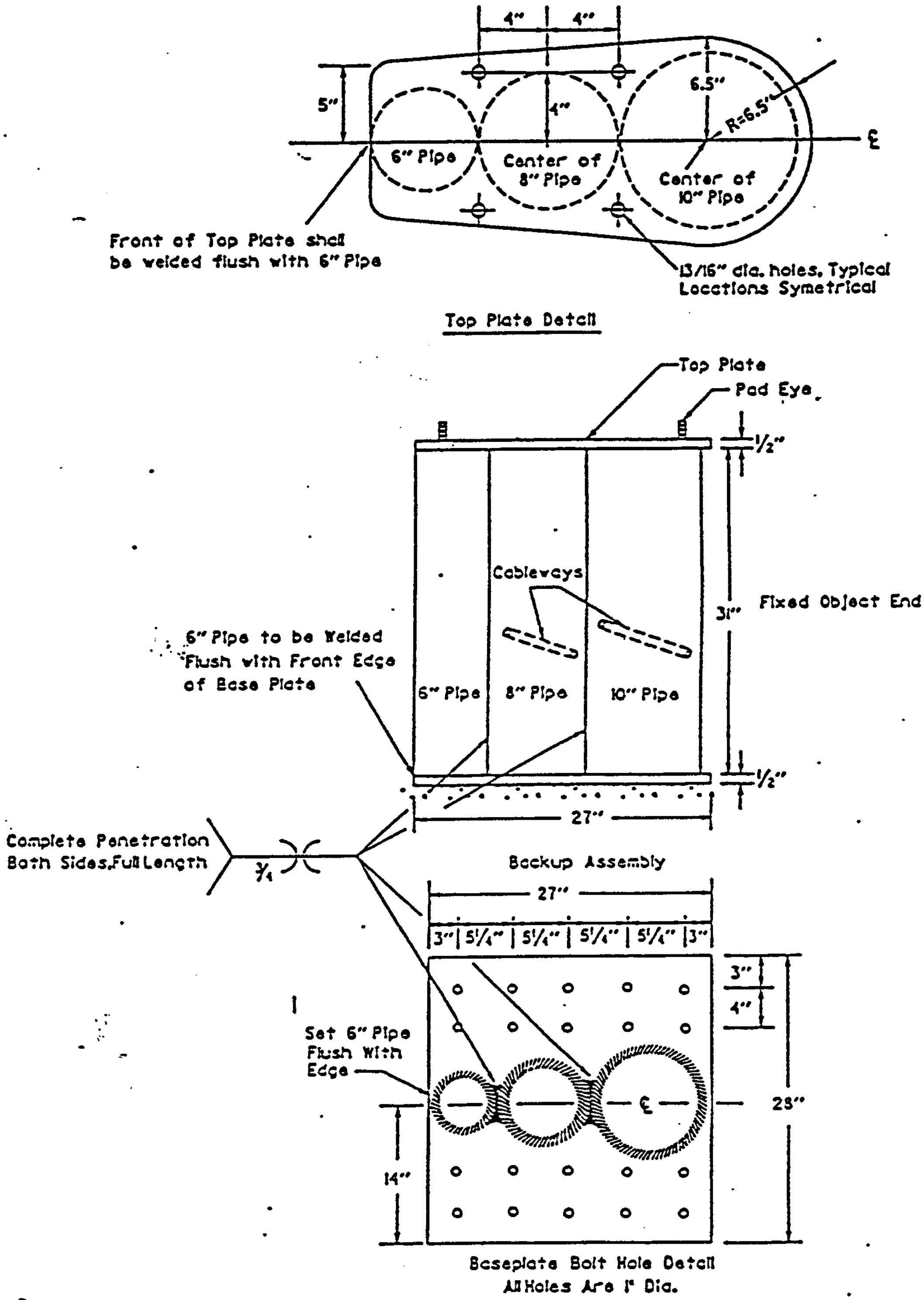



Figure 2. Drawings for backup assembly.

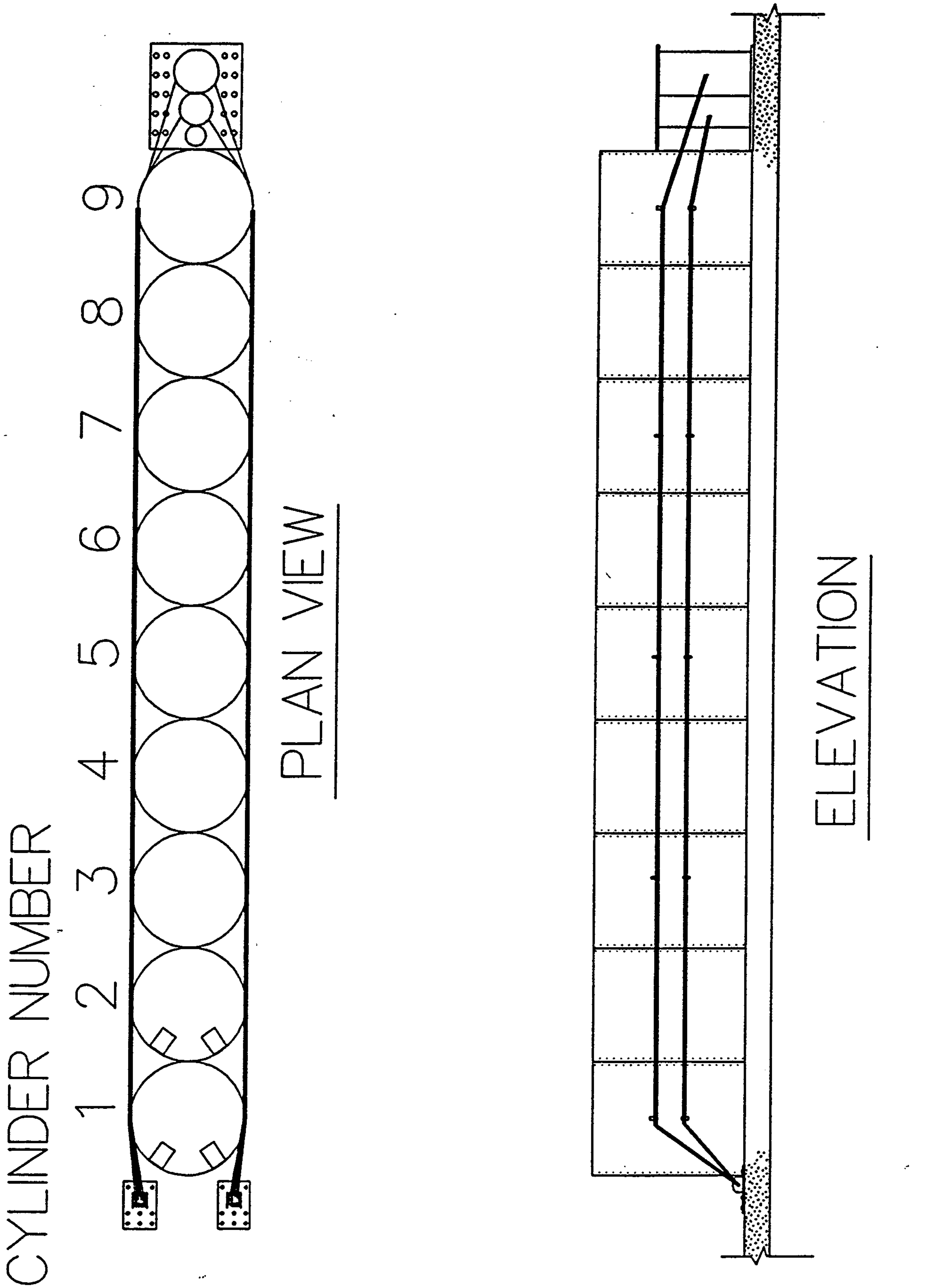



Figure 3. Drawings for cylinder system.

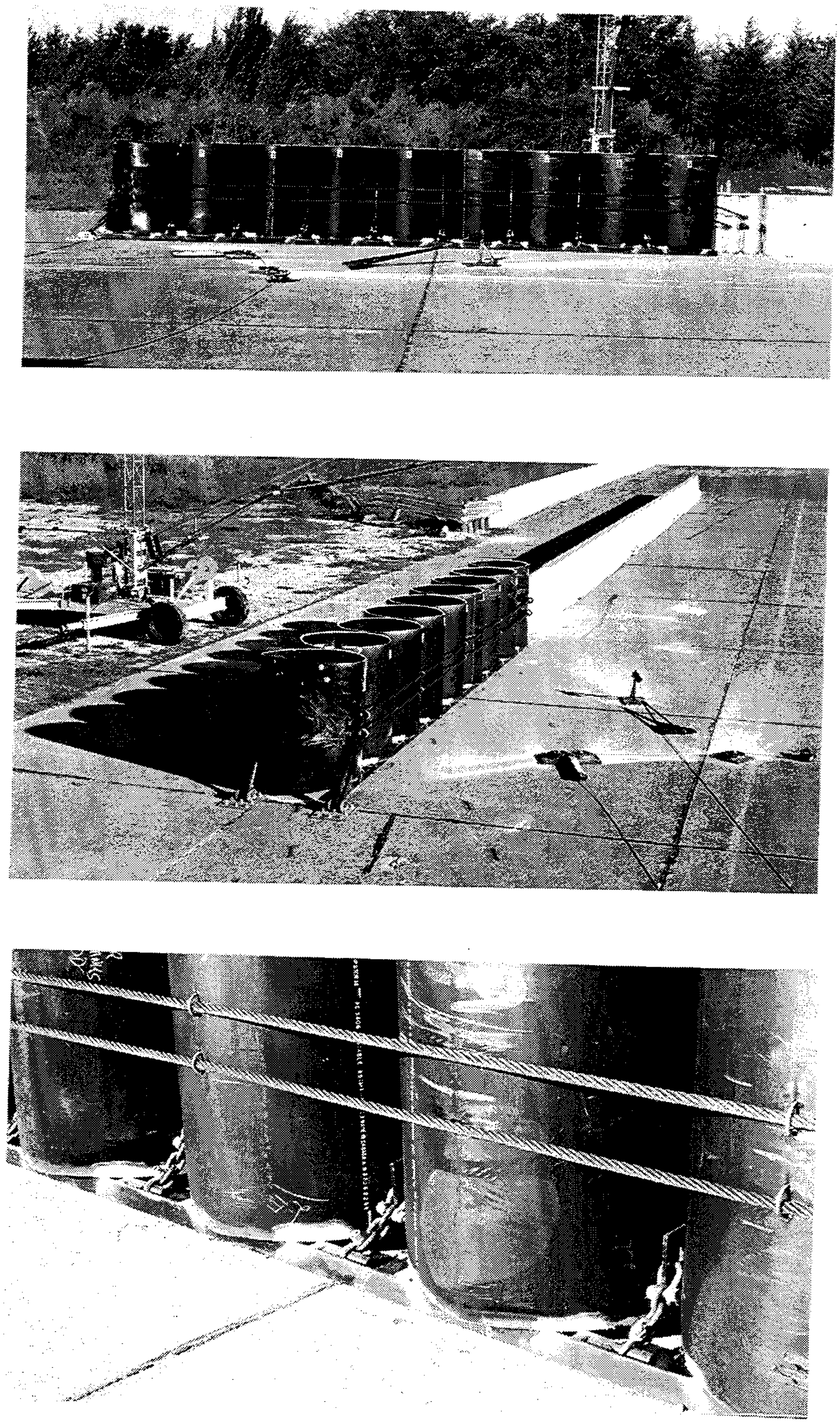


Figure 4 . Installation before test 472380-6.

# CRASH TEST AND DATA ANALYSIS PROCEDURES

The crash test and data analysis procedures were in accordance with guidelines presented in NCHRP Report 350.[1] Brief descriptions of these procedures are presented as follows.

## ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

Each test vehicle is instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer near the vehicle center-of-gravity to measure longitudinal, lateral, and vertical acceleration levels, and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. The accelerometers are strain gauge type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers and transducers are transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals are recorded before and after the test, and an accurate time reference signal is simultaneously recorded with the data. Pressure sensitive switches on the bumper of the impacting vehicle are actuated just prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an "event" mark on the data record to establish the exact instant of contact with the crash cushion.

The multiplex of data channels, transmitted on one radio frequency, is received at the data acquisition station, and demultiplexed into separate tracks of Inter-Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data is played back from the tape machines, filtered with an SAE J211 filter, and digitized using a microcomputer, for analysis and evaluation of impact performance. The digitized data are then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these two computer programs are provided as follows.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are then filtered with a 60 Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using a commercially available software package (QUATTRO PRO).

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.001-second intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

## PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included four high-speed cameras; one placed behind and downstream of the crash cushion; one overhead with a field of view perpendicular to the ground and directly over the impact point; a third placed downstream and aligned with the installation, and a forth placed upstream and aligned with the installation. A flash bulb activated by pressure sensitive tapeswitches was positioned on the impacting vehicle to indicate the instant of contact with the crash cushion and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement and angular data. A professional video camera and a Betacam videotape recorder along with still cameras were used for documentary purposes and to record conditions of the test vehicle and Reusable Polyethylene Narrow Impact Attenuation System before and after the test.

## TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was stretched along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. Another steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2 to 1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the terminal system, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling with no steering or braking inputs throughout the crash sequence.

## CRASH TEST RESULTS

TEST 472380-6

A 1988 Chevrolet 3/4 ton pickup, shown in Figures 5 and 6, was used for the crash test. Test inertia weight of the vehicle was 2000 kg (4409 lb) and its gross static weight was the same as there was no dummy in the vehicle. The height to the lower edge of the vehicle bumper was 410 mm (16.1 in) and it was 630 mm (24.8 in) to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in Figure 7. The vehicle was directed into the crash cushion using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The left front corner of the bumper lightly contacted cylinder 5 at a speed of 98.17 km/h (61.00 mi/h) and 21.43 degrees.

As the vehicle impacted the fifth cylinder, the system began to deflect. Cylinder 6 began to deform at 0.023 second. Deformation of cylinder 6 caused deformation of cylinder 7 at 0.030 second. Cylinder 7 was then contacted at 0.045 second. Cylinder 8 began deforming at 0.055 and the vehicle contacted cylinder 8 at 0.086 second. Cylinder 9 began deforming at 0.089 second andwas contacted at 0.115 second. The front and rear anchors began to pull out at 0.135 second simultaneously. By 0.165 second the vehicle contacted the backup structure and subsquently contacted the concrete barrier at 0.180 second. Cylinder 8 displaced laterally 0.77 m (2.52 ft)at 0.188 second which was the maximum dynamic deflection of the system. At 0.350 second the vehicle was parallel to the system and traveling 41.61 km/h (25.86 mi/h). The vehicle separated from the concrete barriers at 0.662 second traveling 33.31 km/h (20.70 mi/h) and 1.0 degrees. Subsequently, the vehicle came to rest on the passenger side with the center of mass located 20.73 m (68.0 ft) downstream and 3.05 m (10.0 ft) in front of the point of impact. Sequential photographs are shown in Figures 8 and 9.

As can be seen in Figures 10, 11,and 12, the backup assembly received considerable damage. Concrete around the anchor bolts at both the front and rear anchors failed allowing the assembly to rotate away from the impact. The base plate for the assembly was bent during rotation. The maximum post test residual deformation was 0.74 m (2.43 ft) at cylinder 6 in the lateral direction. Immediately after the test, the installation length was 7.98 m (26.17 ft).

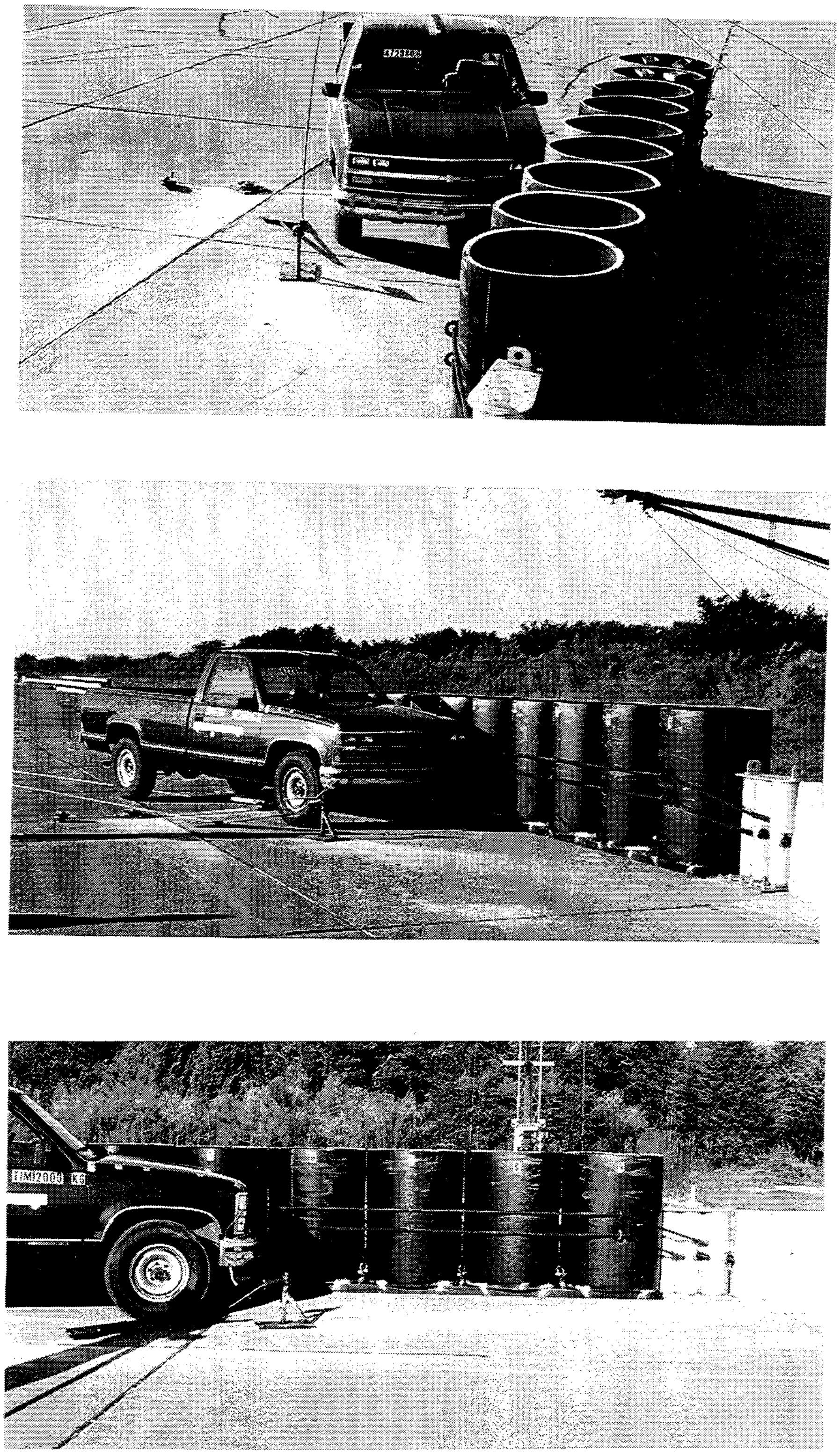


Figure 5 . Vehicle/installation geometrics before test 472380-6.

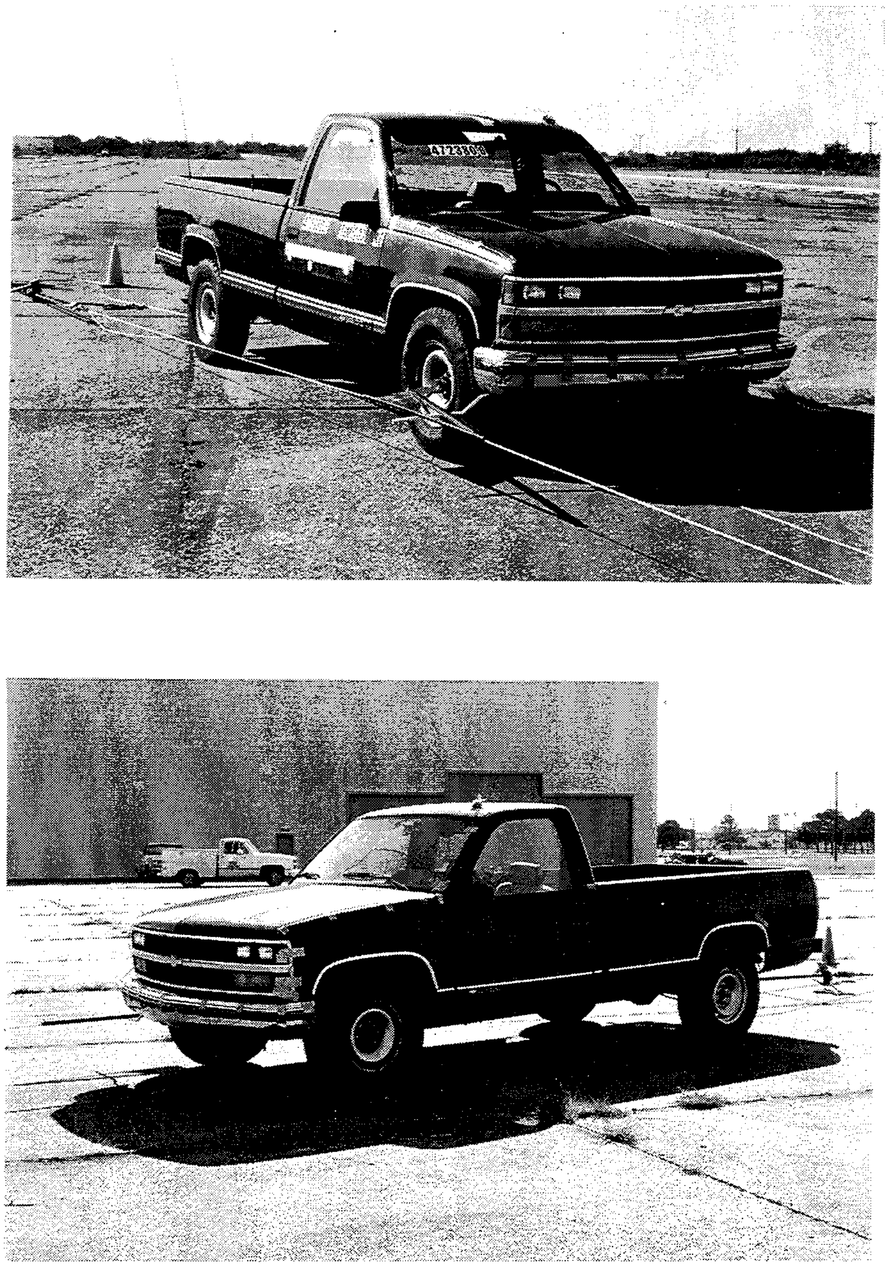


Figure 6 . Vehicle before test 472380-6.

DATE: 9-27-94 TEST NO.: 472380-6 VIN NO.: 2GCFC24ZJ1143182 MAKE: Chevy

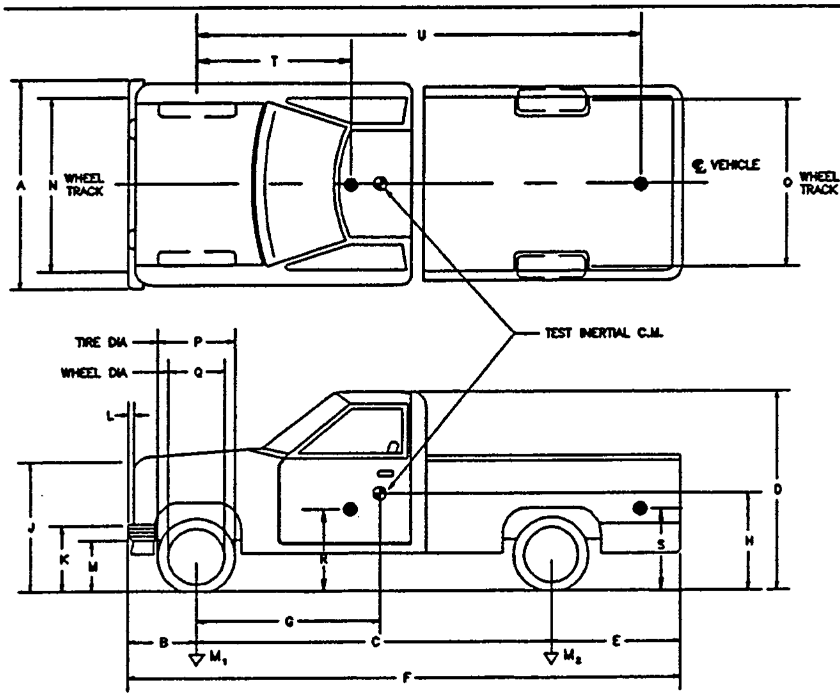
MODEL: 2500 Silverado YEAR: 1988 ODOMETER: 175194 GVW:

TIRE SIZE: LT 235 85R16 TIRE INFLATION PRESSURE: TREAD TYPE: Hwy

MASS DISTRIBUTION (kg) LF 535 RF 523 LR 488 RR 454

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Windshield cracked (marked)




● Denotes accelerometer location.

NOTES: R 70mm to lt

ENGINE TYPE: 6 cyl

ENGINE CID: 4.3 L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

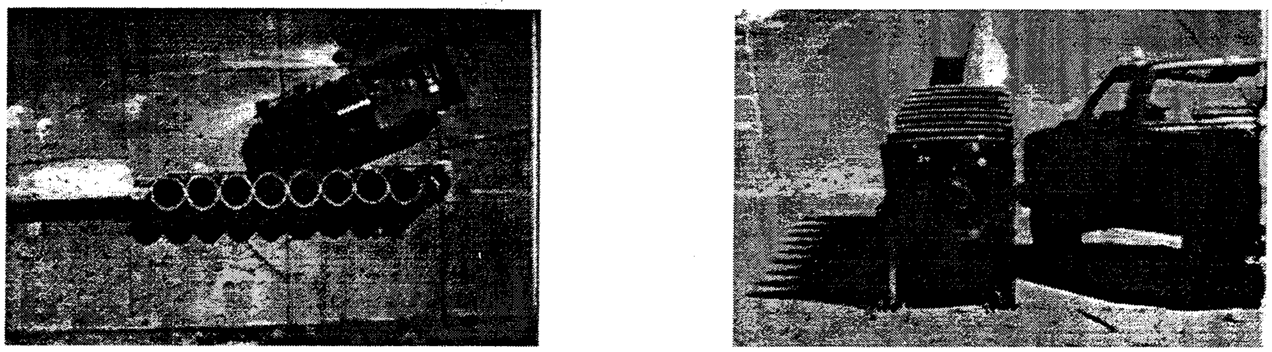
SEAT POSITION:

GEOMETRY – (mm)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| A | 1910 | E | 1200 | J | 1035 | N | 1585 | R | 700 |
| B | 780 | F | 5330 | K | 630 | O | 1630 | S | 1040 |
| C | 3350 | G | | L | 90 | P | 790 | T | 1390 |
| D | 1800 | H | | M | 410 | Q | 445 | U | 4230 |

| MASS – (kg) | CURB | TEST INERTIAL | GROSS STATIC |
|---|---|---|---|
| $M_1$ | 1043 | 1058 | |
| $M_2$ | 798 | 942 | |
| $M_T$ | 1841 | 2000 | |

Figure 7. Vehicle properties for test 472380-6.



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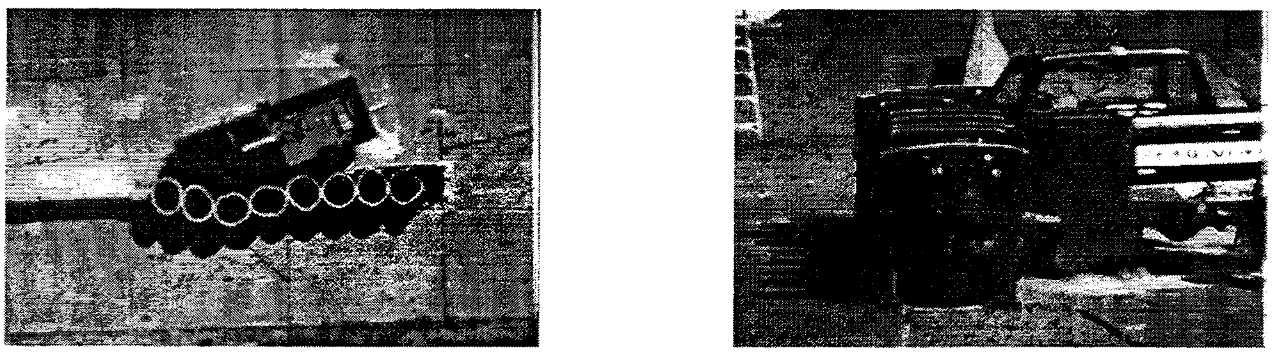
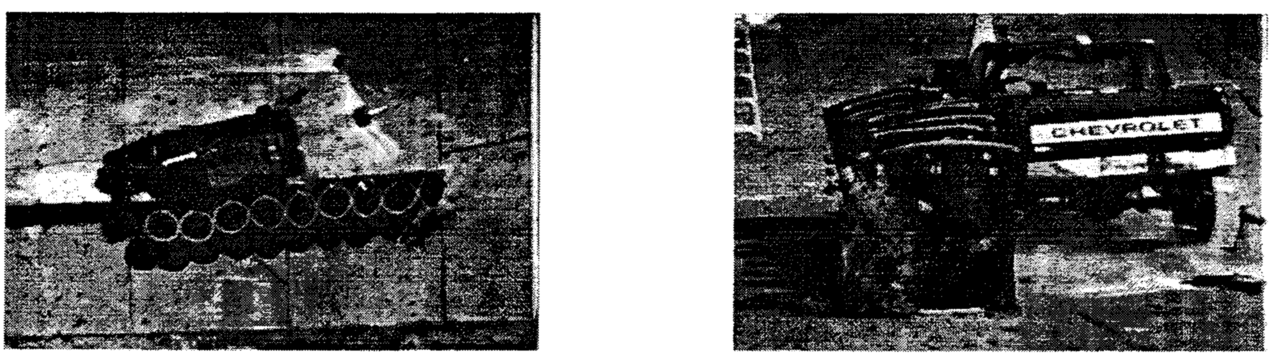
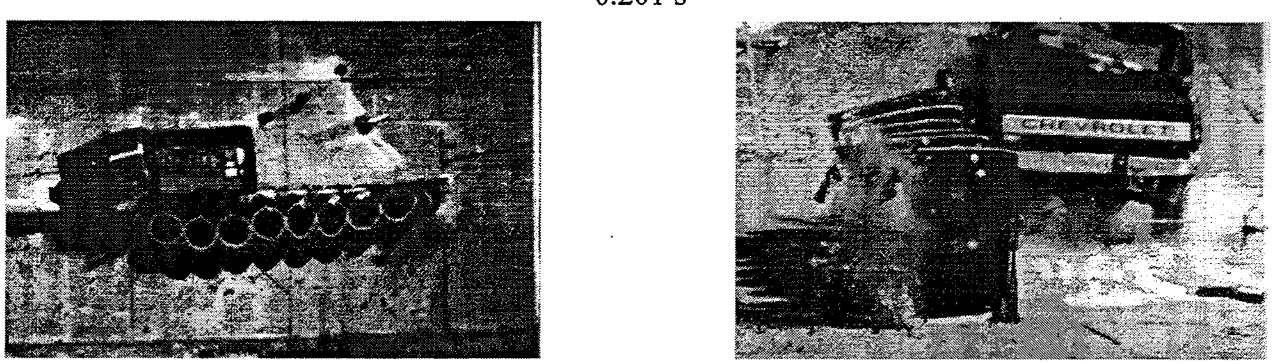


0.100 s

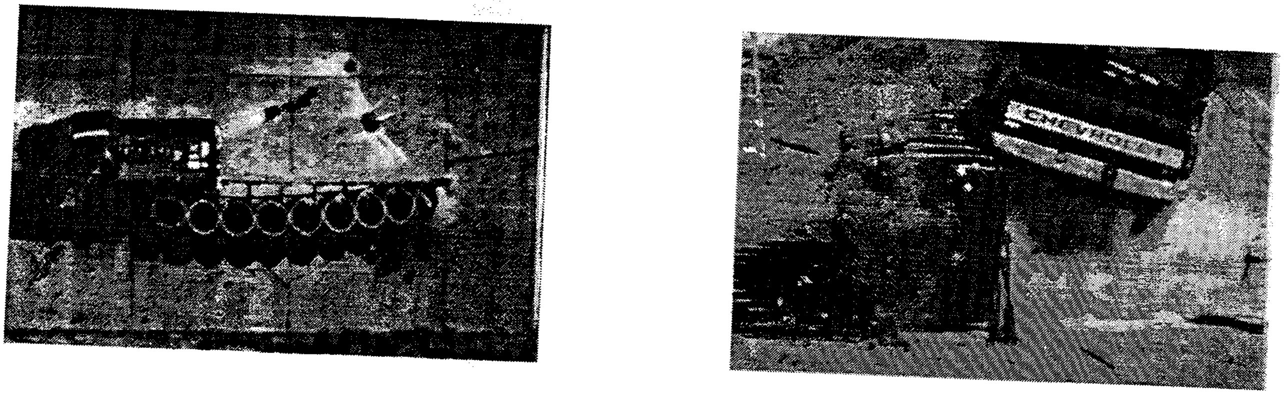



0.201 s

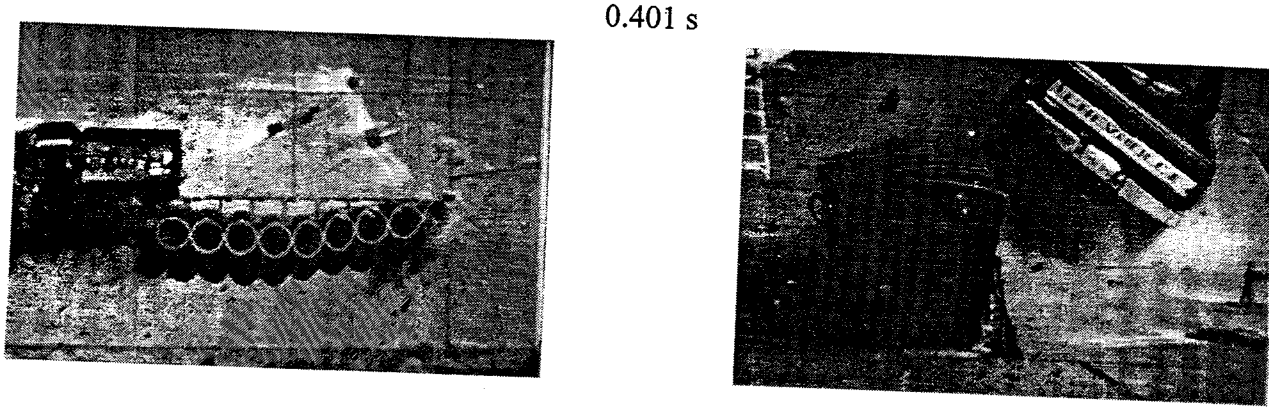


0.301 s

Figure 8 . Sequential photographs for test 472380-6.
(overhead and frontal views)



0.401 s



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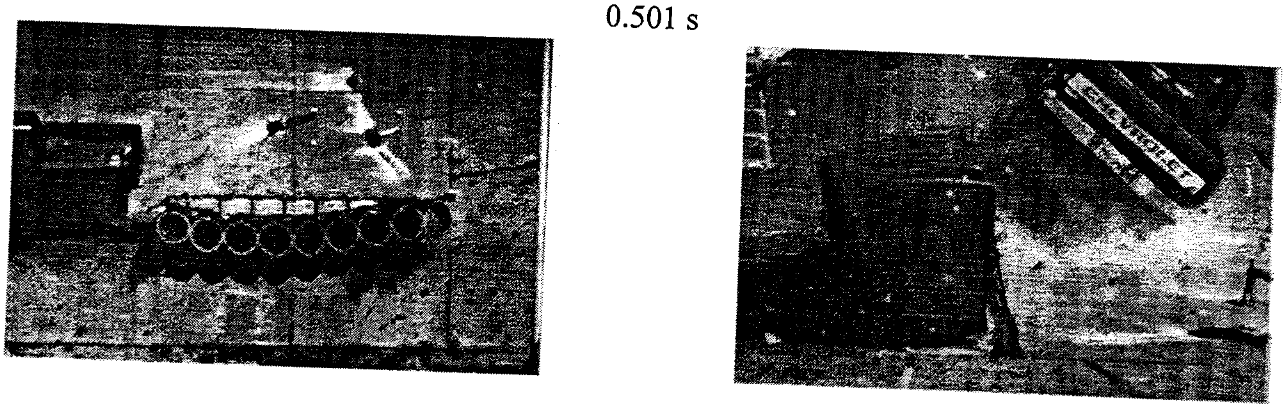
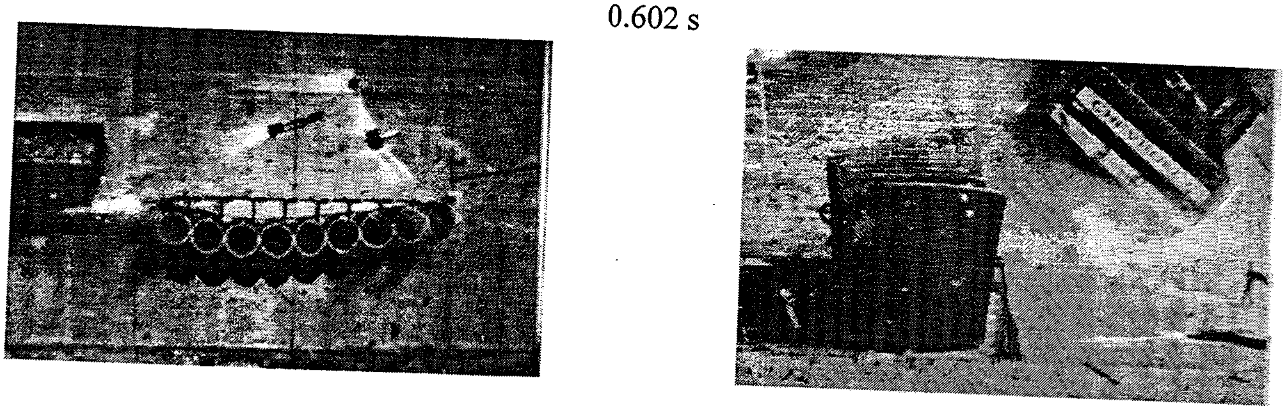
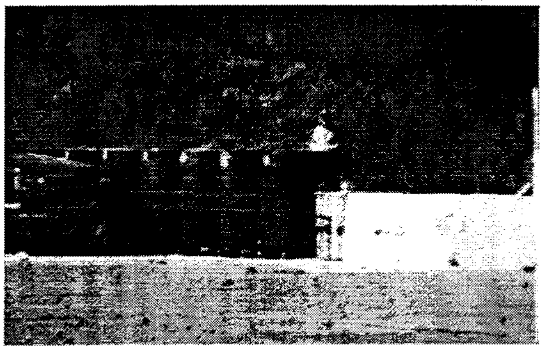


0.602 s



0.702 s

Figure 8 . Sequential photographs for test 472380-6 (continued).
(overhead and frontal views)



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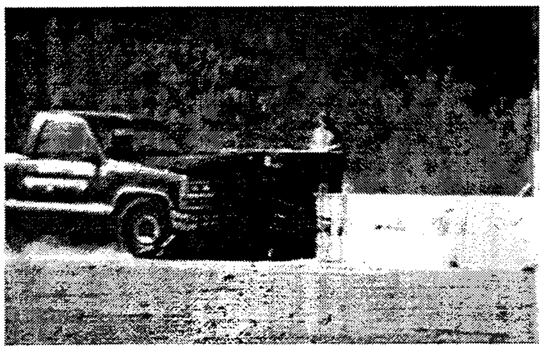
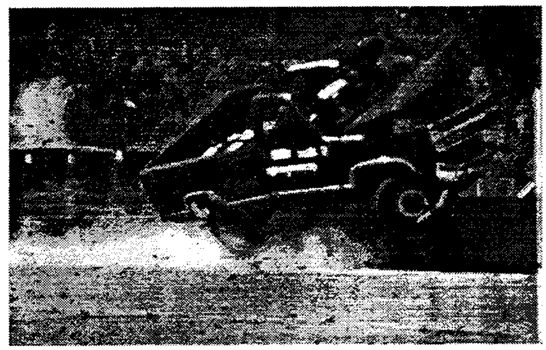


0.100 s

0.201 s

0.401 s

0.401 s



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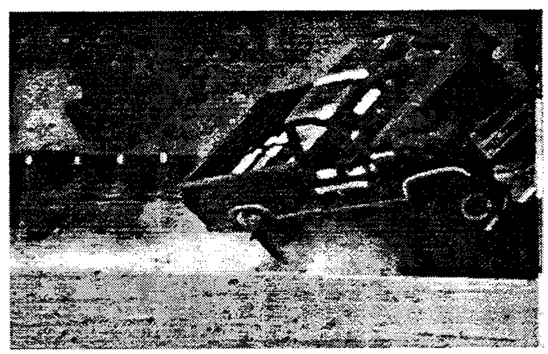

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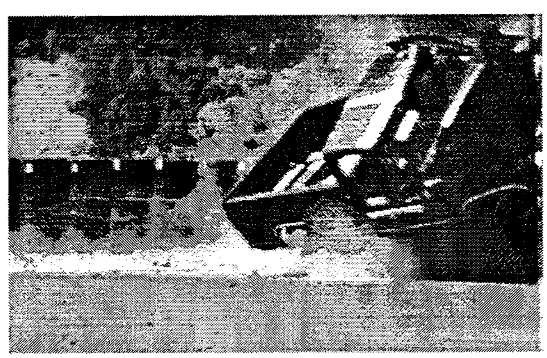


0.702 s

Figure 9 . Sequential photographs for test 472380-6.
(oblique view)

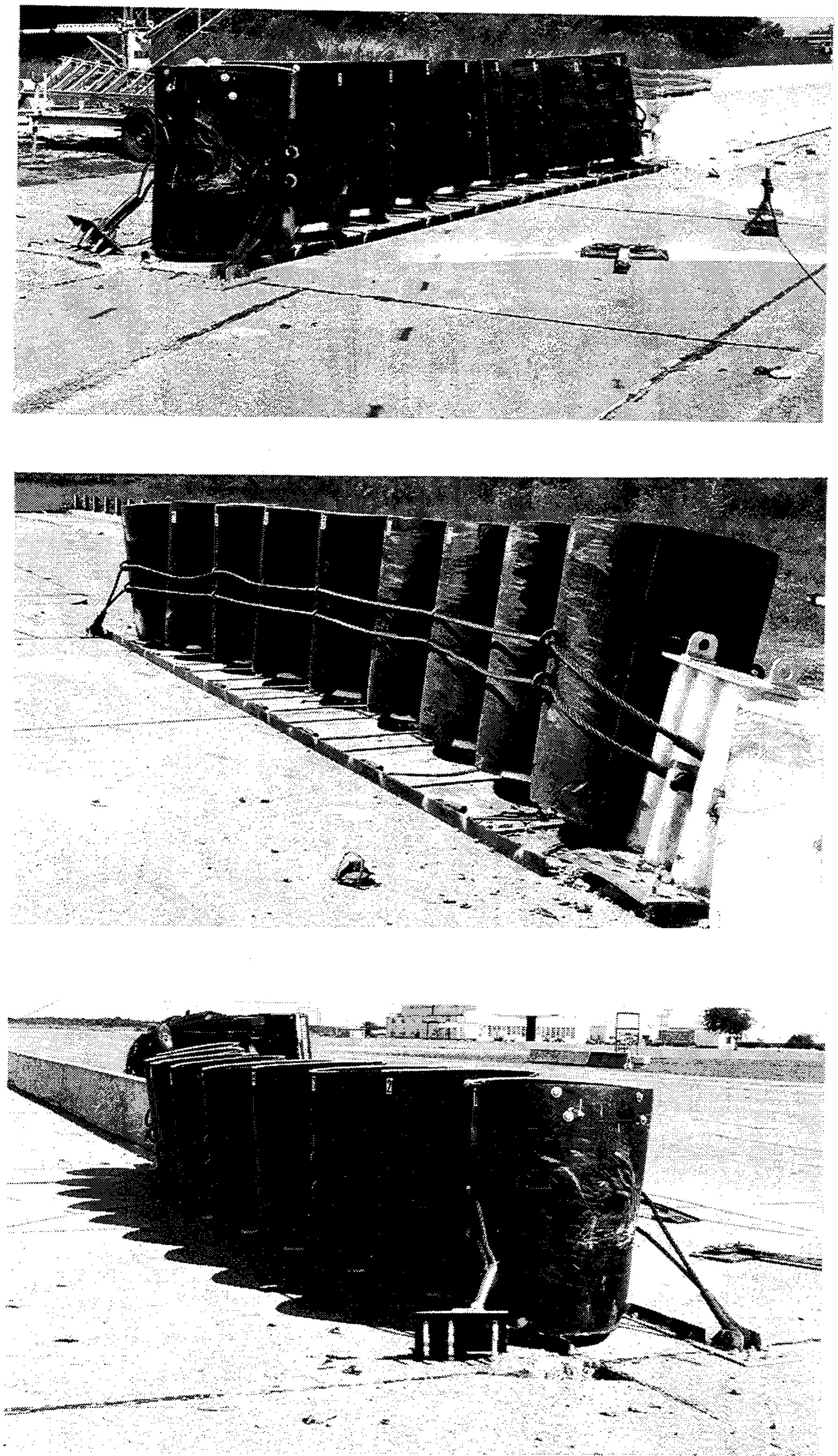
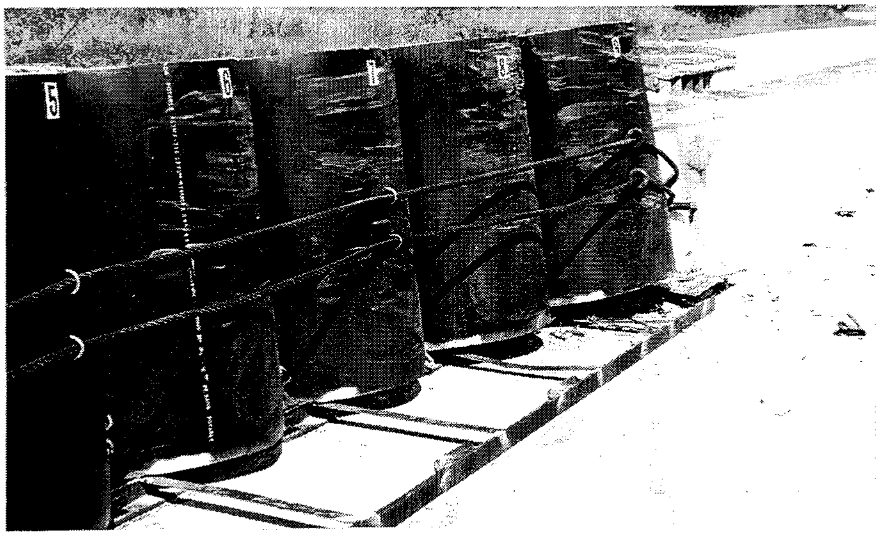
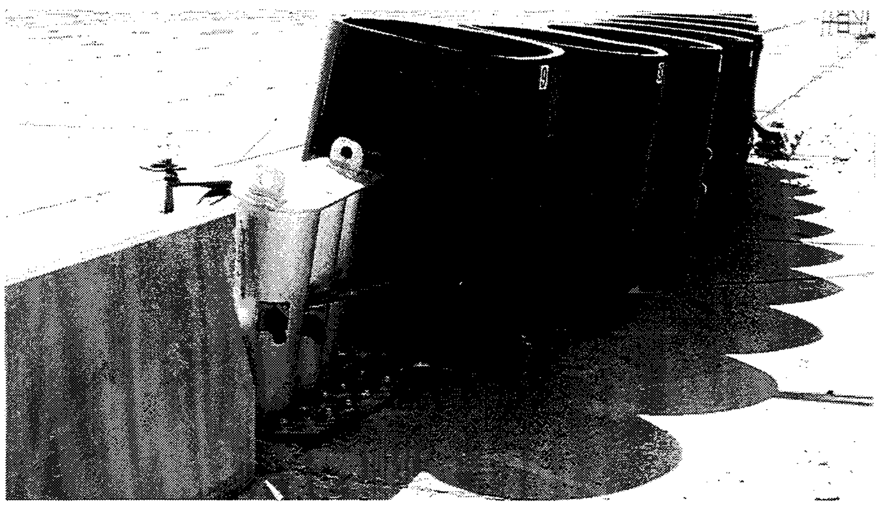


Figure 11 . Installation after test 472380-6.





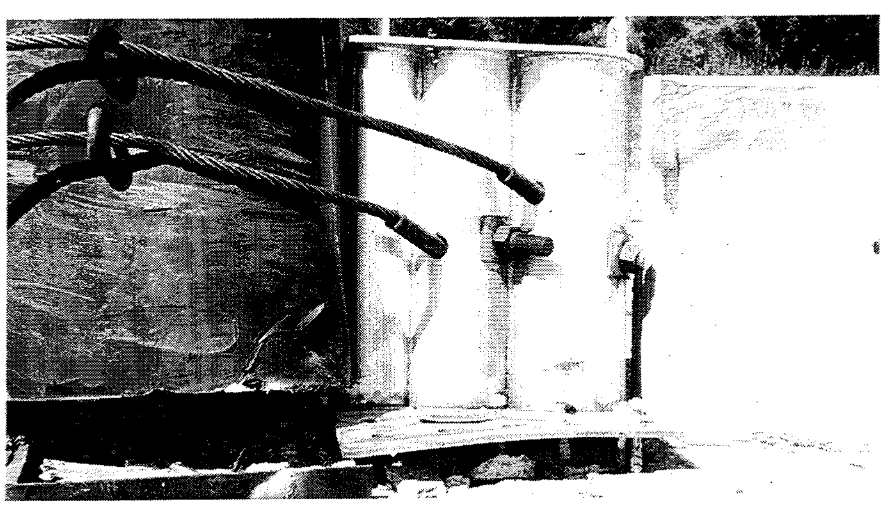


Figure 11 . Installation after test 472380-6 (continued).

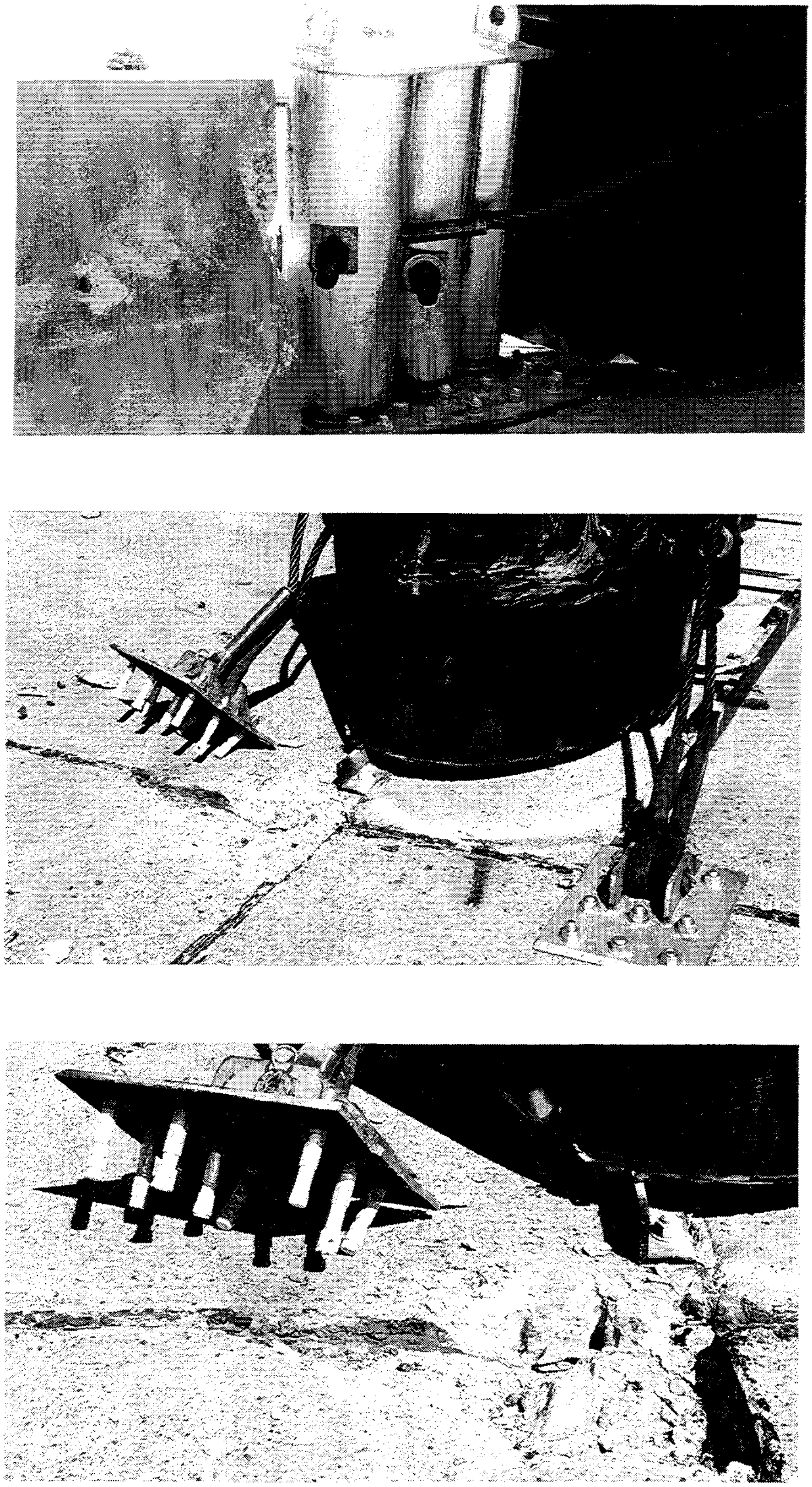
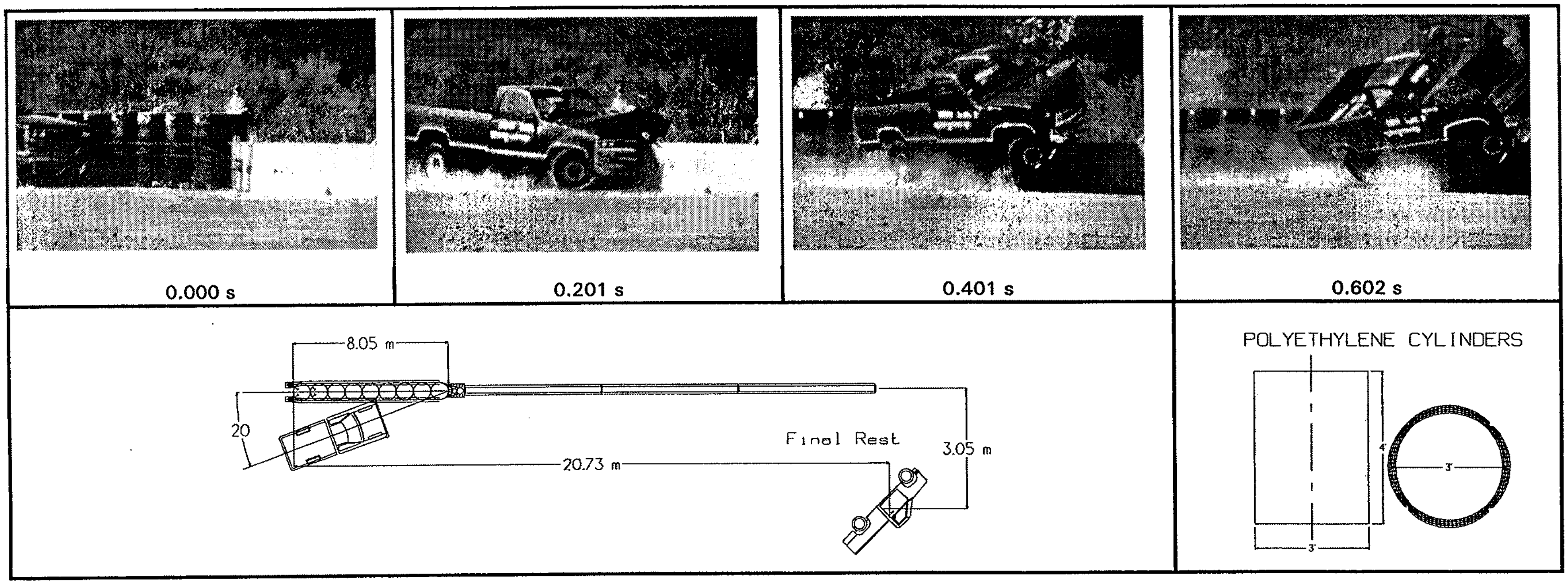


Figure 12 . Damaged front and rear anchors after test 472380-6.

The vehicle sustained significant damage to the left front corner as shown in Figure 13. Maximum deformation at the left front corner of the vehicle was 690 mm (27.2 in). As a result of this large deformation the occupant compartment was shortened by 192 mm (7.6 in). Additional damage was sustained by the front bumper, hood, grill, radiator and fan, both front fenders, roof, windshield, entire left and righ side sheet metal, left front tire and rim, left rear tire and rim, drive shaft, rear transmission mount and roof.

Data from the accelerometers, located at the center-of-gravity, were digitized for evaluation and the occupant risk values were computed as follows. In the longitudinal direction, occupant impact velocity was 10.56 m/s (34.6 ft/s) at 0.173 s, the highest 0.010-s average ridedown acceleration was -16.60 g between 0.200 and 0.210 s, and the maximum 0.050-s average acceleration was -13.31 g between 0.152 and 0.202 s. Lateral occupant impact velocity was -5.23 m/s (-17.1 ft/s) at 0.160 s, the highest 0.010-s occupant ridedown acceleration was 15.75 g between 0.204 and 0.214 s and the maximum 0.050-s average acceleration was 6.69 g between 0.163 and 0.213 s. These data and other pertinent information from the test are summarized in Figure 14. Vehicular angular displacements are displayed in Figure 15. All vehicular accelerations versus time traces filtered digitally at 60 Hz are presented in Figures 16 through 18.


Figure 13 . Vehicle after test 472380-6.




| | |
|---|---|
| **General Information** | |
| Test Agency | Texas Transportation Institute |
| Test No. | 472380-6 |
| Date | 09/29/94 |
| **Test Article** | |
| Type | Vanderbilt Crash Cushion |
| Name or Manufacturer | |
| Installation Length (m) | 8.08 (26.52 ft) |
| Size and/or dimension and material of key elements | Polyethylene Cylinder 1.22 m tall 0.91 m dia. |
| Soil Type and Condition | N/A |
| **Test Vehicle** | |
| Type | 1988 Chevrolet Pickup |
| Designation | 2000P |
| Model | 2500 Series |
| Mass (kg) Curb | 1881 (4147 lb) |
| Test Inertial | 2000 (4409 lb) |
| Dummy | 0 |
| Gross Static | 2000 (4409 lb) |

| | |
|---|---|
| **Impact Conditions** | |
| Speed (km/h) | 98.17(61.0 mi/h) |
| Angle (deg) | 21.43 |
| **Exit Conditions** | |
| Speed (km/h) | 33.31 (20.7 mi/h) |
| Angle (deg) | 1.00 |
| **Occupant Risk Values** | |
| Impact Velocity (m/s) | |
| x-direction | 10.56 (34.6 ft/s) |
| y-direction | -5.23 (-17.1 ft/s) |
| THIV (optional) | |
| Ridedown Accelerations (g's) | |
| x-direction | -16.60 |
| y-direction | 15.75 |
| PHD (optional) | |
| ASI (optional) | |
| Max. 0.050-sec Average (g's) | |
| x-direction | -13.31 |
| y-direction | 6.69 |
| z-direction | -8.69 |

| | |
|---|---|
| **Test Article Deflections (m)** | |
| Dynamic | 0.77 (2.52 ft) |
| Permanent | 0.74 (2.43 ft) |
| **Vehicle Damage** | |
| Exterior | |
| VDS | 12FL-6 |
| CDC | 12FLEW5 |
| Interior | |
| OCDI | LF1124111 |
| Maximum Exterior Vehicle Crush (mm) | 690 (27.2 in) |
| Max. Occ. Compart. Deformation (mm) | 192 (7.6 in) |
| **Post-Impact Behavior** | |
| Max. Roll Angle (deg) | 90 |
| Max. Pitch Angle (deg) | 12.52 |
| Max. Yaw Angle (deg) | 24.21 |

Figure 14. Summary of results for test 472380-6.

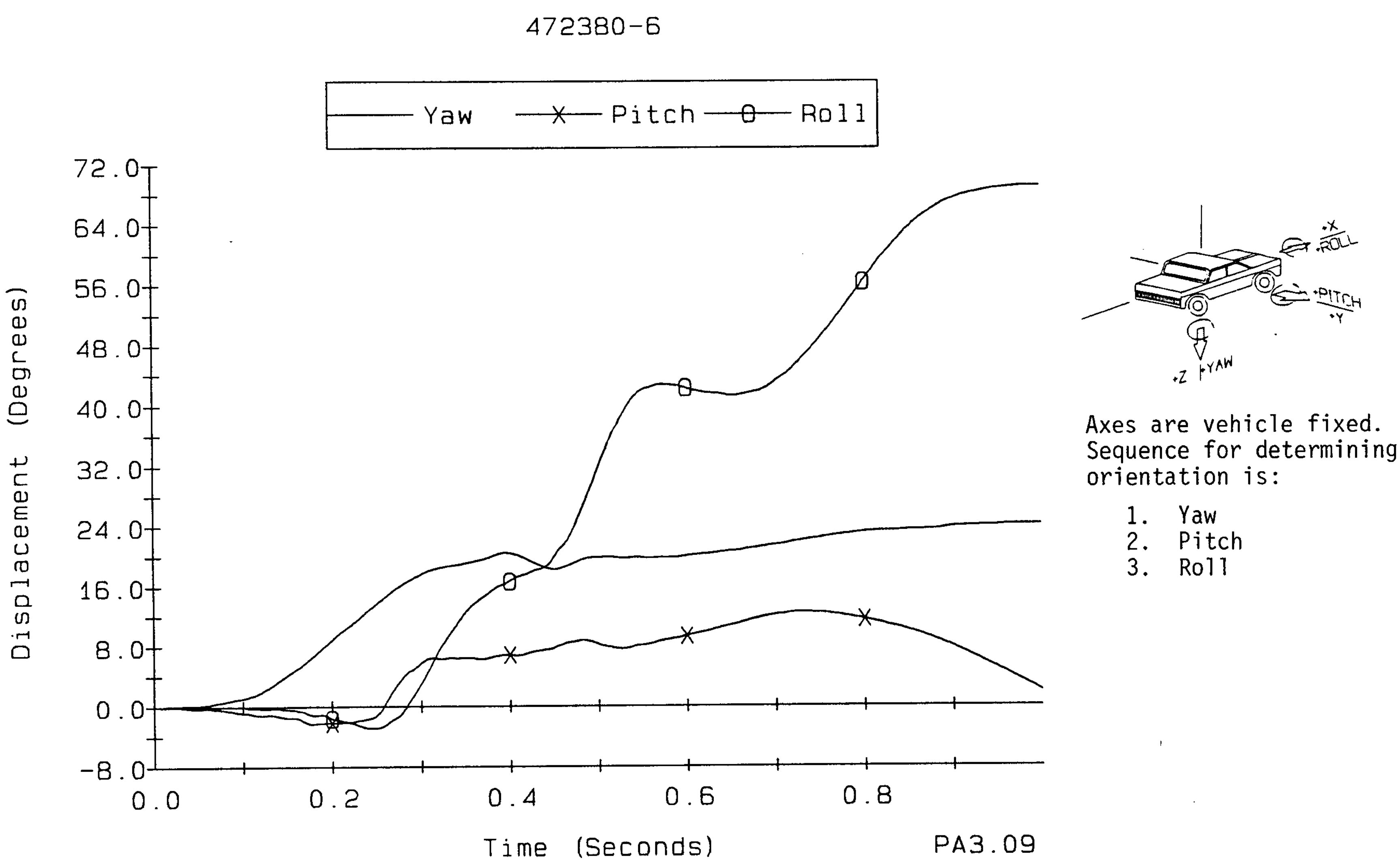



Figure 15. Vehicle angular displacements during test 472380-6.

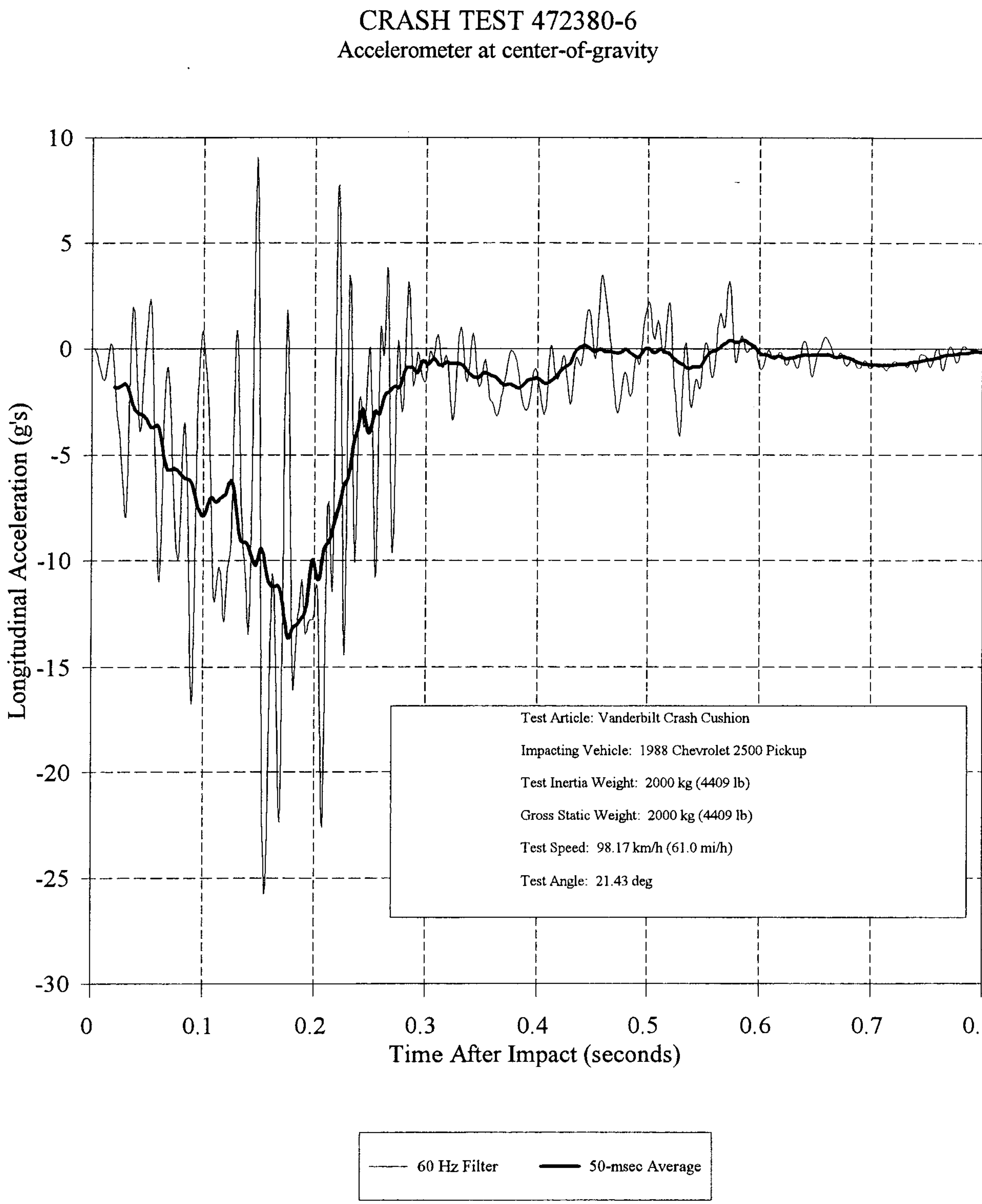



Figure 16 . Longitudinal accelerometer trace for impacting vehicle during test 472380-6.

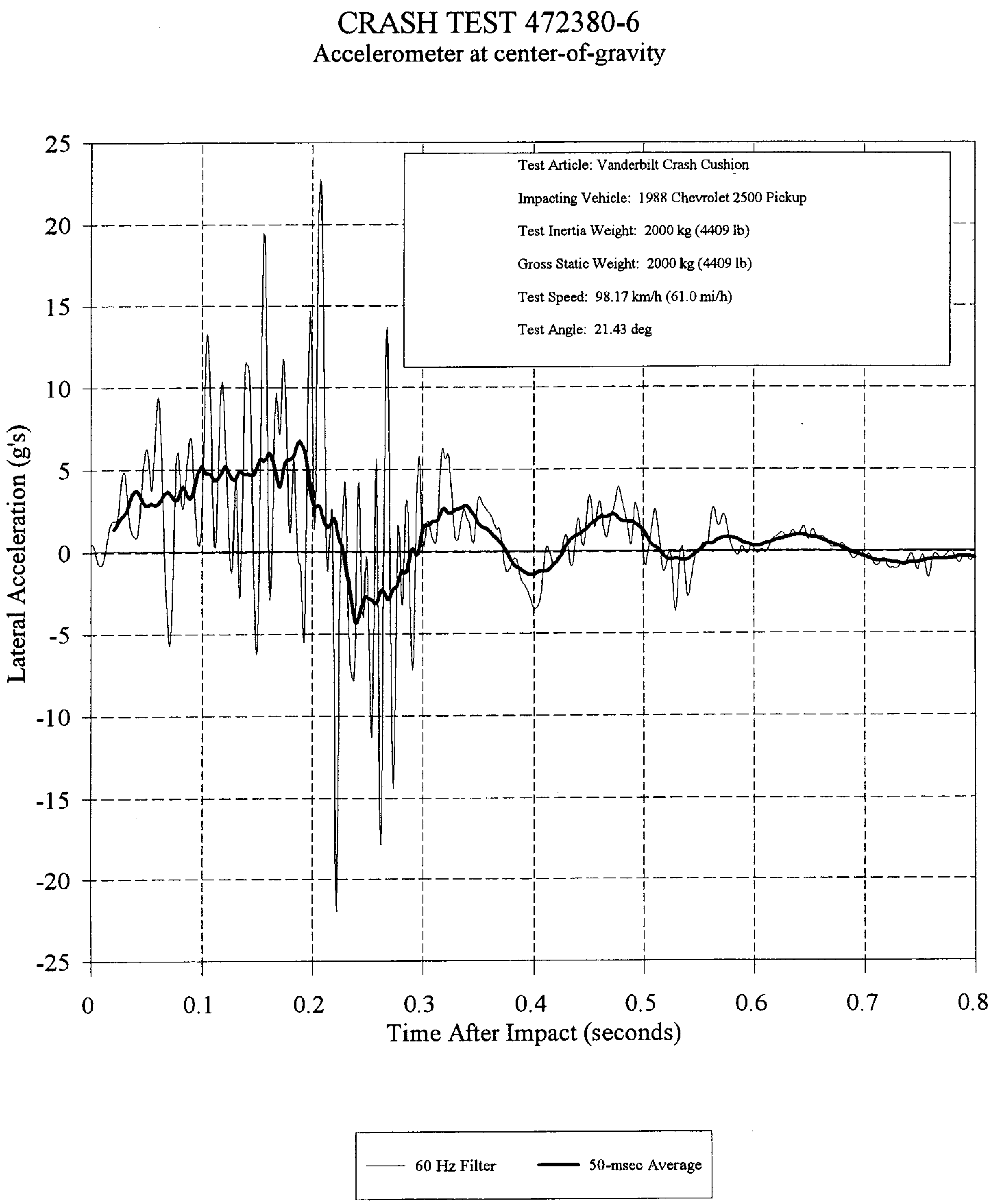



Figure 17 . Lateral accelerometer trace for impacting vehicle during test 472380-6.

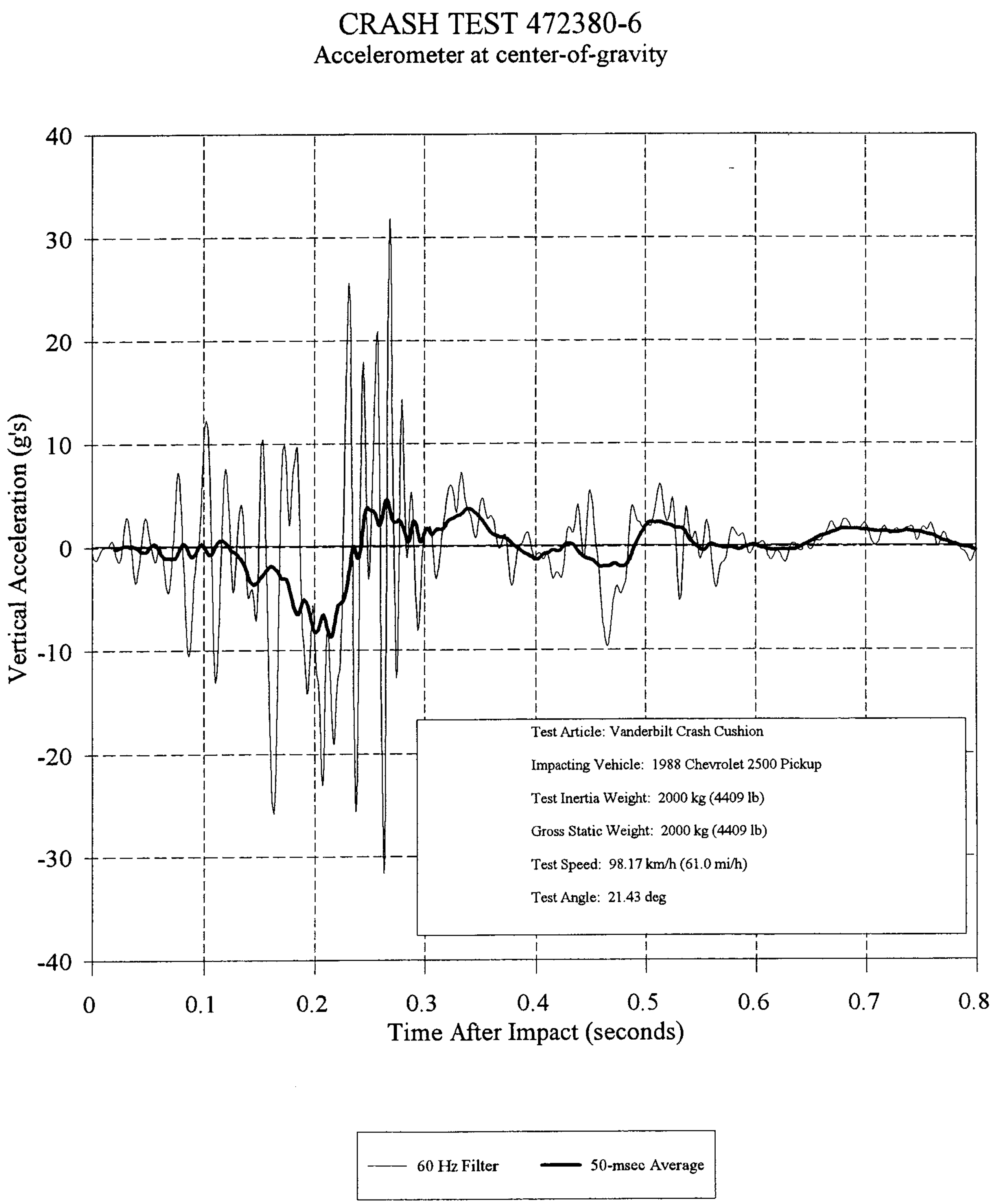



Figure 18 . Vertical accelerometer trace for impacting vehicle during test 472380-6.

# FINDINGS AND CONCLUSIONS

## SUMMARY OF FINDINGS

In the test, the Reusable Polyethylene Narrow Impact Attenuation System failed to function as intended. The vehicle was redirected, however, there was excessive deformation into the occupant compartment and the permanent backup assembly as well as one of the front anchors was damaged. After redirecting, the vehicle overturned onto the passenger side.

## CONCLUSIONS

The Reusable Polyethylene Narrow Impact Attenuation System did not meet the NCHRP Report 350 criteria (D) for Test 3-38 as seen in Table 1. Therefore, the impact performance of the system was judged as unsatisfactory for this test configuration.

Table 1. Assessment of results of test with small vehicle on RPNIAS.

Test No.: 472380-6 | Test Date: 09/29/94 | Test Agency: Texas Transportation Institute

| Evaluation Criteria | Test Results | Assessment |
|---|---|---|
| Structural Adequacy | | |
| A. Test Article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable. | The vehicle was redirected by the system. | Pass |
| Occupant Risk | | |
| D. Detached elements should not penetrate the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of the occupant compartment that could cause serious injuries should not be permitted. | There were **no** detached elements from the CRNIAS. There was deformation into the occupant compartment. | Fail |
| F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable. | The vehicle overturned after impact. | Fail |
| Vehicle Trajectory | | |
| K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes. | Slight intrusion into adjacent lanes. | Pass |
| L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's. | Contact Velocity = 10.568 m/s<br>Ridedown Acceleration = -16.60 G's | Pass |
| M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device. | The vehicle exit angle was 1.0 degrees | Pass |

## REFERENCES

1. Ross, Jr., H. E., Sicking, D. L., Zimmer, R. A., and Michie, J. D., "Recommended Procedures for the Safety Performance Evaluation of Highway Features," *NCHRP Report 350*, Transportation Research Board, National Research Council, Washington, D. C., 1993.