FULL-SCALE CRASH TESTS
on
PLASTIC DRUMS
with
TYPE III OBJECT MARKERS

by

John A. Magdaleno
Research Graduate Assistant
University of Nebraska

Ronald K. Faller
Research Graduate Assistant
University of Nebraska

Kyle R. Kittrell
Highway Design Engineer
Missouri Highway and Transportation Commission

Edward R. Post
Professor of Civil Engineering
University of Nebraska

Sponsored by

Missouri Highway and Transportation Commission
Report No. 87-2

April 1988

DISCLAIMER

ABSTRACT

The Missouri Highway and Transportation Department is proposing the use of a two-piece breakaway channelizer for delineating traffic. This configuration consists of a Plastic Drum with a Type III Object Marker mounted on top of it using two polycarbonate plastic connectors between the drum and the object marker. The reason for using this type of channelizer stemmed from many anticipated benefits such as: First, plastic connectors pose a lesser threat to traffic than metal connectors if detachment should occur. Second, since the object markers are above the splash zone, they stay cleaner during extreme weather conditions. Third, the object markers are less expensive than warning lights and, with the exception of cleaning, no maintenance is required after installation. To determine whether or not the configuration was satisfactory for implementation, two full-scale crash tests were conducted in accordance with the "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," from the National Cooperative Highway Research Program Report 230, Transportation Research Board; March, 1981.

Results of both tests showed that all of the required performance criteria had been met; therefore, the Plastic Drum with a Type III Object Marker was considered satisfactory.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

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

<u>Federal Highway Administration</u>

Donald F. James

Safety Programs Engineer

Missouri Division

<u>Estrada Incorporated</u>

Designer of polycarbonate connectors

<u>University of Nebraska</u>

Michael Cacak (Manager - Automobile Support Services)

Patrick Barrett (Assistant Manager - Automobile Support Services)

James Dunlap (Manager - Photographic Productions)

Vince Ullman (Photographic Technician)

Gerald Fritz (E.E. Technician)

Tom Grady (E.E. Technician)

William Kelly (Professor and C.E. Chairman)

Eugene Matson (C.E. Research Technician)

Brian Pfeifer (M.E. Student)

Terry Brown (C.E. Student)

Mary Lou Tomka (C.E. Administrative Assistant)

Mary Lou Wegener (C.E. Secretary - Typist)

Marilyn Mues (C.E. Secretary - Typist)

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

For safety purposes, federal requirements have made it mandatory that all roadside signs and luminaires located within a designated clear zone be designed to breakaway under impact. Therefore, the Missouri Highway and Transportation Department is proposing the use of Plastic Drums with Type III Object Markers. This system is considered a two-piece breakaway channelizer and uses two polycarbonate plastic connectors to attach the object marker to the drum. Since this system has never been tested to determine what happens to the device after impact, the following objectives were established. First is the effect that impact has on the operation of the vehicle. Second is the effect that impact has on the safety of the vehicle occupants. Third is the amount of damage done to the channelizer and vehicle.

The major concern of this project was to see if the object marker would remain attached to the drum. If it detached, the next concern was whether or not it would penetrate, or show potential to penetrate, the passenger compartment of the vehicle or present undue hazard to other traffic. In order to certify the effectiveness of the polycarbonate connectors in keeping the object marker attached to the drum, testing procedures were conducted in accordance with the criteria given by the National Cooperative Highway Research Program Report 230 (NCHRP 230) (1), and the American Association of State Highway and Transportation Officials (AASHTO) (2), specifications.

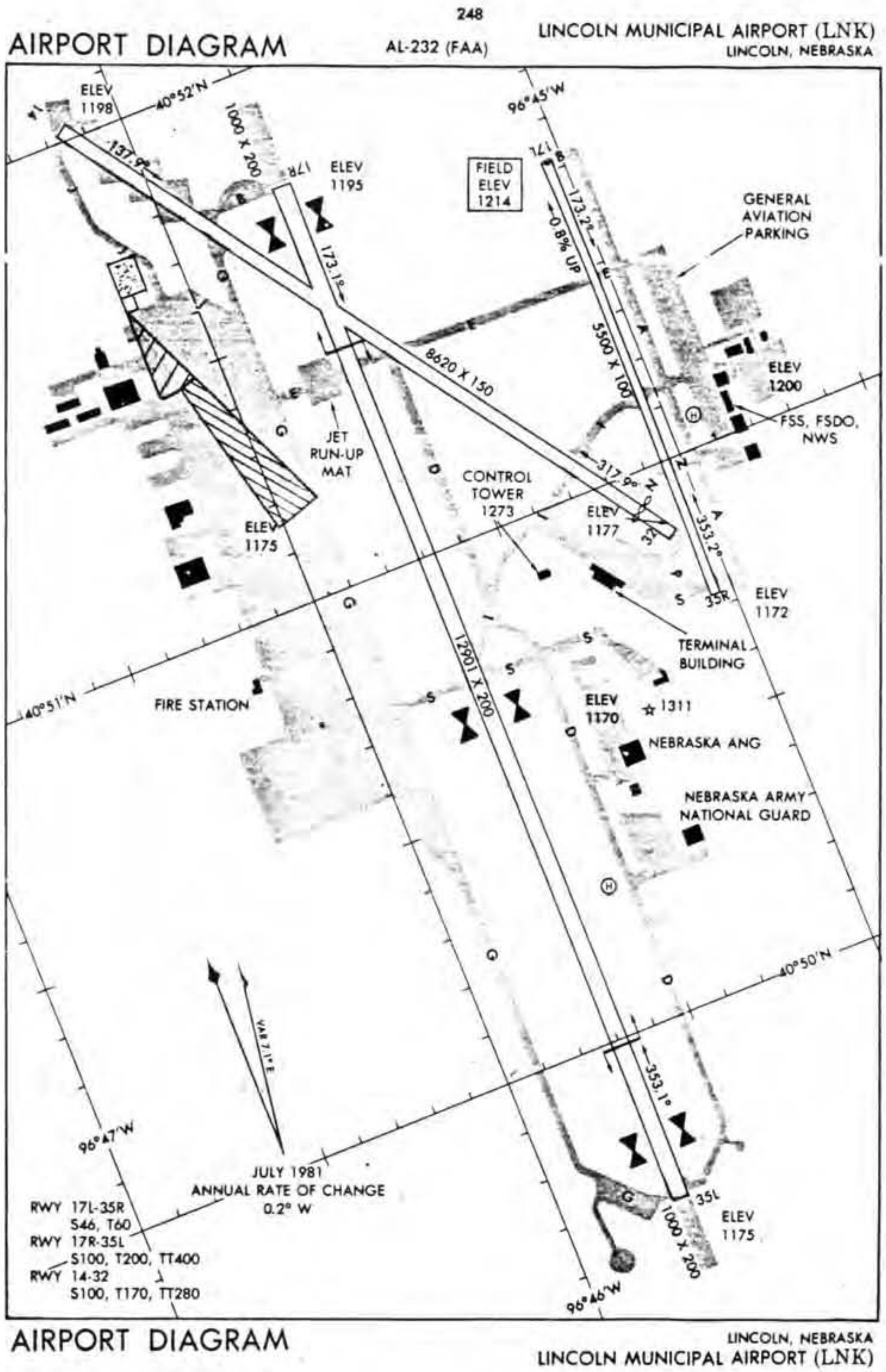
FULL-SCALE CRASH TEST DETAILS

TEST FACILITY

The test site facility was located at Lincoln Air-Park on the northwest corner of the west apron of the Lincoln Municipal Airport. The test facility, shown in Figure 1, is approximately 7 miles northwest of the University of Nebraska-Lincoln.

A reverse cable tow system, with a 1:2 mechanical advantage, was used to propel the test vehicle. Thus, the distance traveled and the speed of the test vehicle were twice that of the tow vehicle. The test vehicle was released from the tow cable approximately 6 feet before impact with the plastic drum. A sketch of the tow system is shown in Figure 2 and a photograph of the tow vehicle is shown in Figure 3.

The cable guidance system, developed by Hinch (3), was used to guide the test vehicle as shown in Figure 3. A guide-flag, which attached the front-left wheel of the test vehicle to the guide cable, was sheared off approximately 6 feet before impact with the plastic drum. The 3/8 in. diameter guide cable was tensioned to 3,000 lbs. and was supported laterally and vertically every 50 feet by hinged stanchions. The stanchions were knocked down by the guide-flag as the vehicle passed. The cable guidance system was approximately 1,000 feet for the first test when the 1,800 lb. test vehicle was used, and approximately 1,500 feet for the second test when the 4,500 lb. test vehicle was used.



ZONE	ZONE USAGE	LENGTH (ft)
	Automobiles, Pickups, etc.	1,300
	Buses, Lg. Trucks, etc.	3,000
	Hardware to be Tested	200
	Vehicle Runout Area	500

Figure 1. Test Site Facility

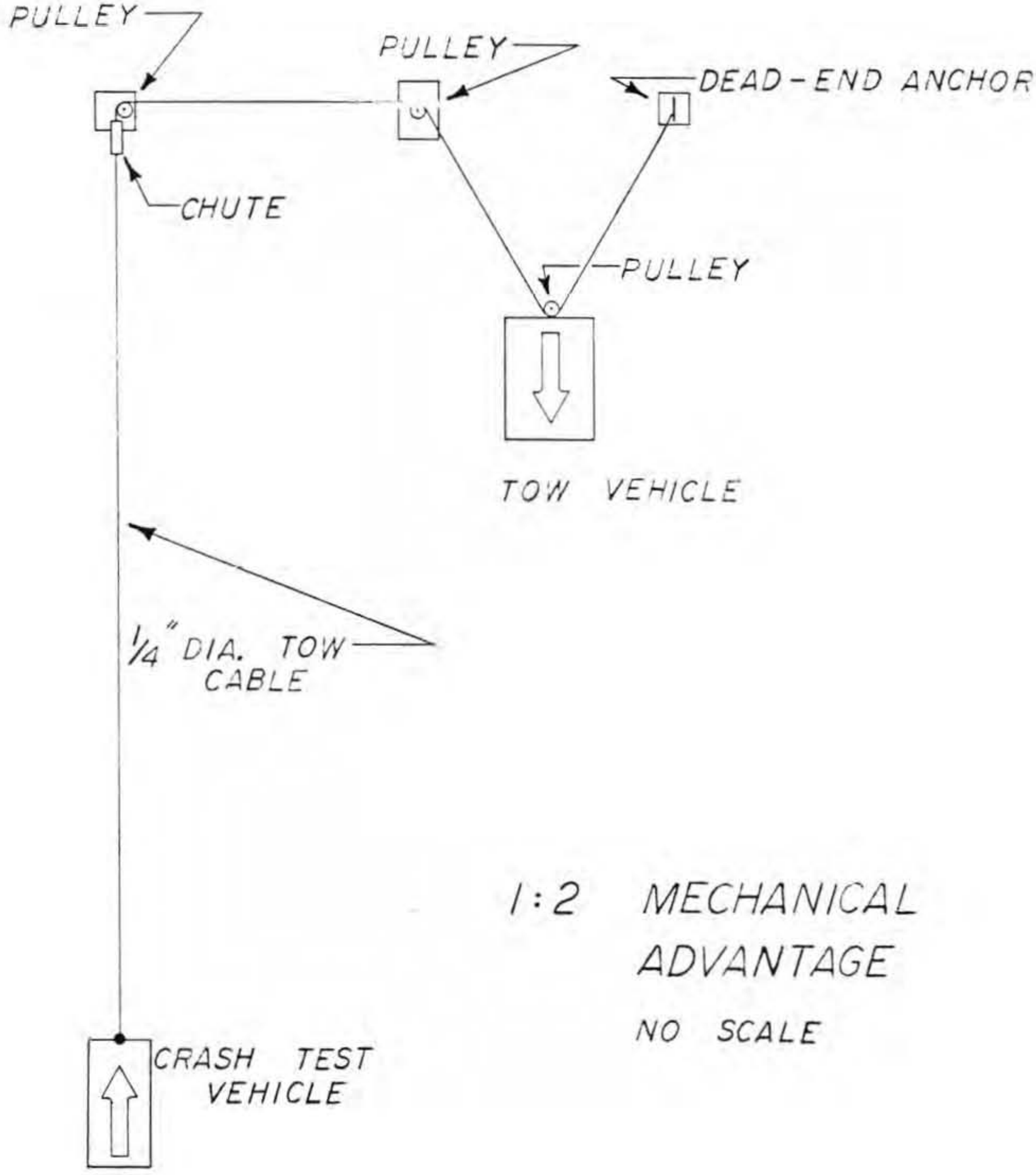


FIGURE 2. SKETCH OF CABLE TOW SYSTEM

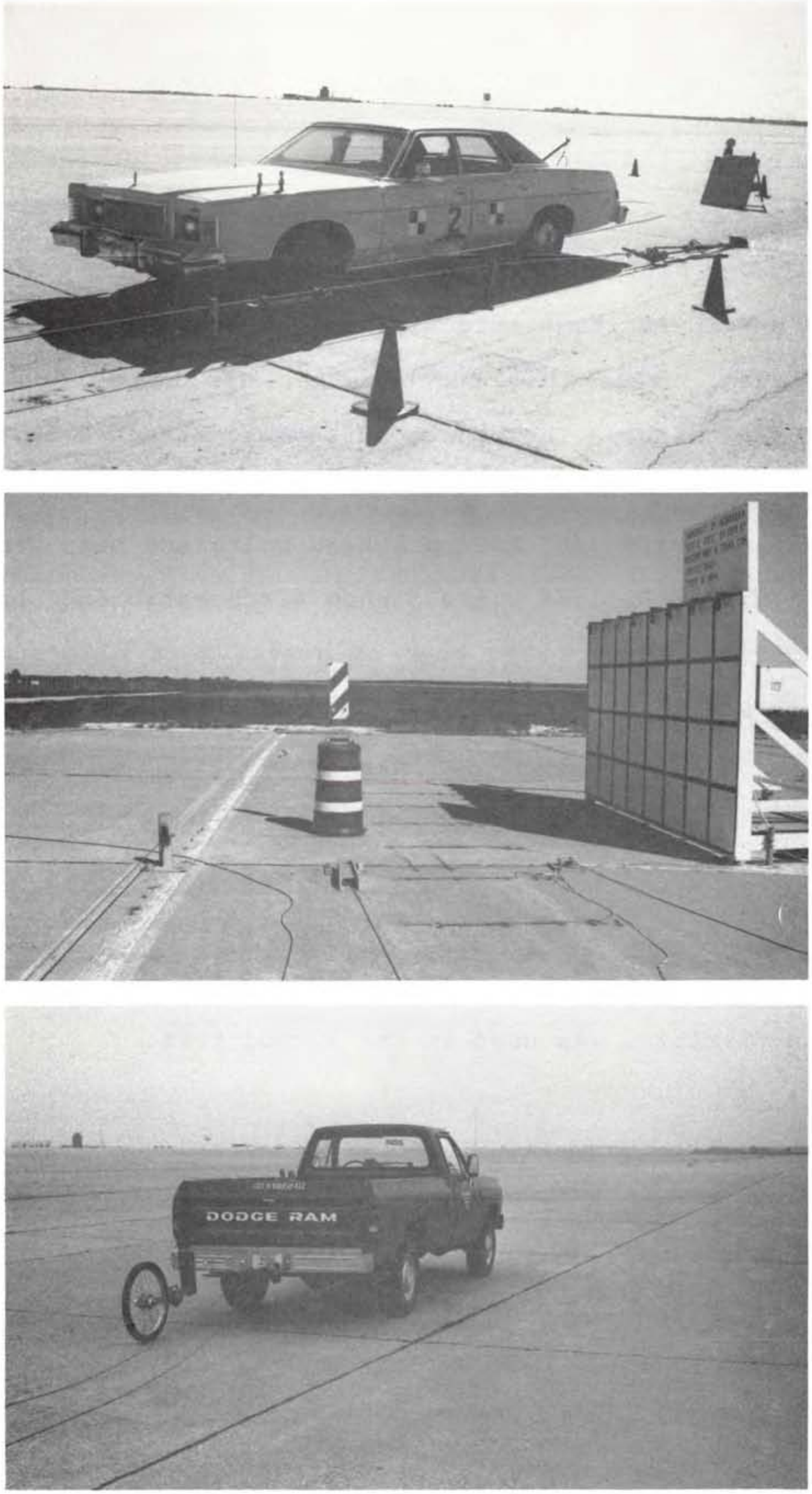


Figure 3. Cable Guidance System and Tow Vehicle

TEST ARTICLE

The test article was a flexible non-metallic drum-like channelizer with a Type III Object Marker. The drum was an 18,000 HMW-LD-PE (high molecular weight-low density-polyethylene) channelizer, while the object marker was an 8" x 24" x 1/16" panel of aluminum. The object marker was attached to the drum by two 1 1/2" x 17" x 3/8" clear polycarbonate plastic connectors, and fastened with 3/8" A307 hex-head bolts and nuts with a washer on each side. Figures 4 and 5 show a schematic and photos of the test article. Two 30 lb. bags of gravel were placed inside each drum for stabilizing purposes.

Two different kinds of high-intensity reflective sheeting were used to cover the drum and object marker. In the first test, a flexible reflective sheeting was used. This sheeting was developed by '3M' and can be recognized by its honeycomb grid pattern. An engineering grade type II reflective sheeting, which was non-flexible, was used in the second test.

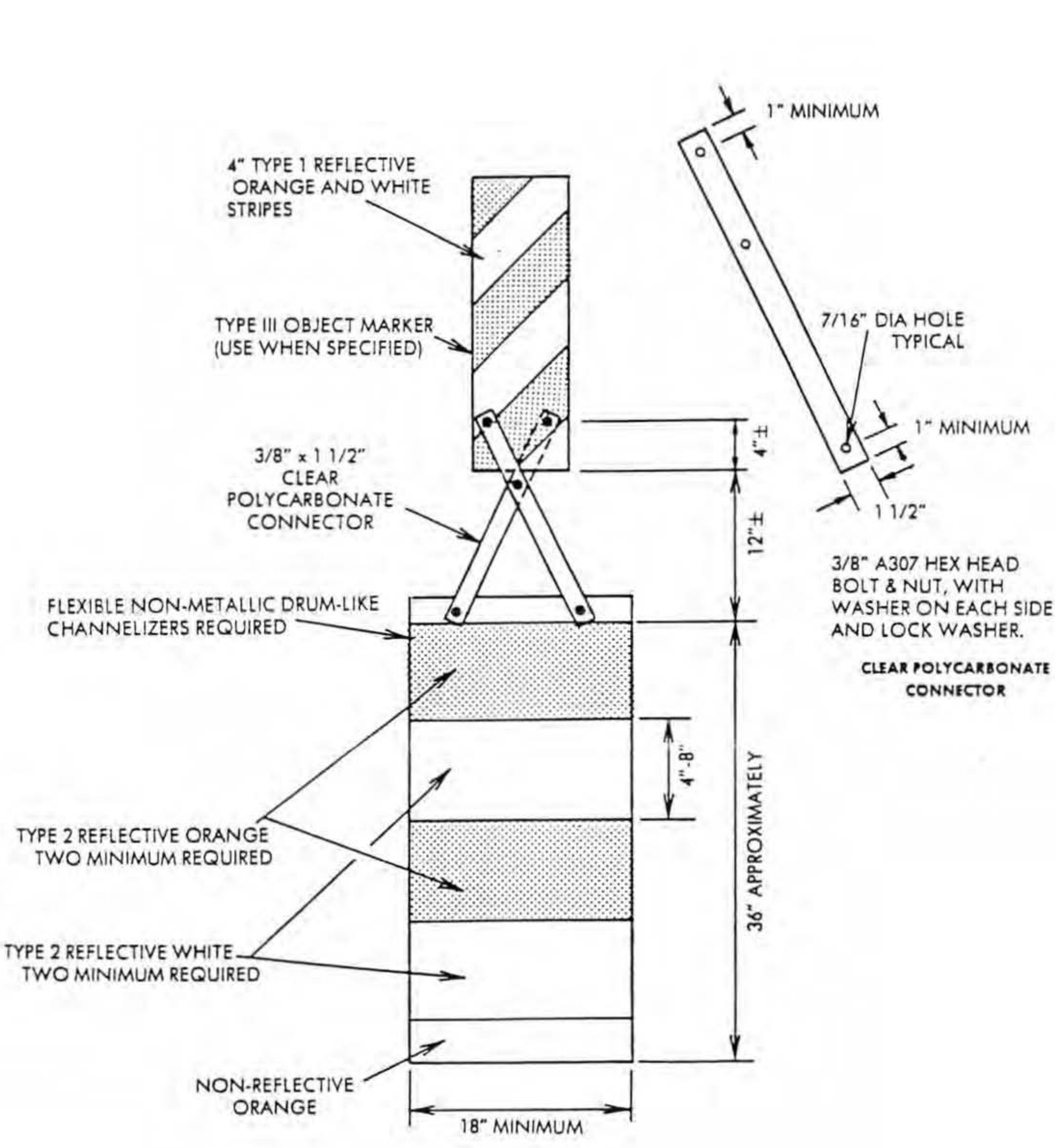


Figure 4. Schematic of Plastic Drum with Type III Object Marker

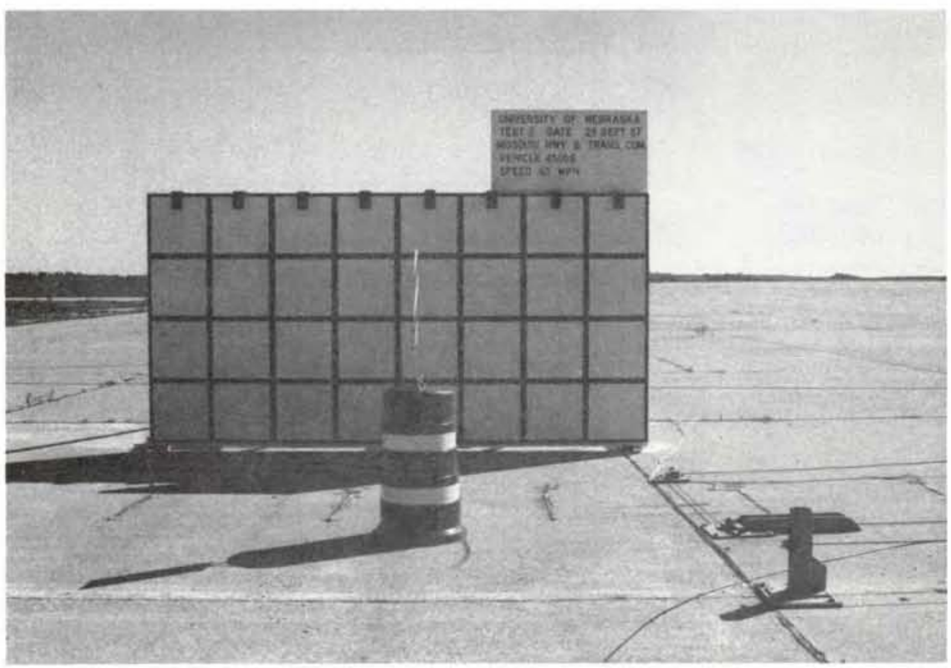


Figure 5. Photos of Plastic Drum with Type III Object Marker

TEST VEHICLES

Two different test vehicles were used in the testing. A 1979 Volkswagon Rabbit, weighing approximately 1,840 lbs., was used in the first test and a 1978 Mercury Grand Marquis, weighing approximately 4,590 lbs., was used in the second test. Pictures of the test vehicles are shown in Figures 6 and 8, with vehicle dimensions shown in Figures 7 and 9.

The front wheels of both vehicles were aligned to a toe-in value of zero-zero so that the vehicle would track properly along the guide-cable.

Two 8 in. square, black and white targets were placed 42 inches apart (on center) on the test vehicles to aid with the analysis of the high-speed film. In addition to the targets, two 5B flash-bulbs were mounted on the hood of both vehicles to record the time of impact with the drum on the high-speed film. The flash-bulbs were fired by a pressure switch which was taped to the front of the bumper.

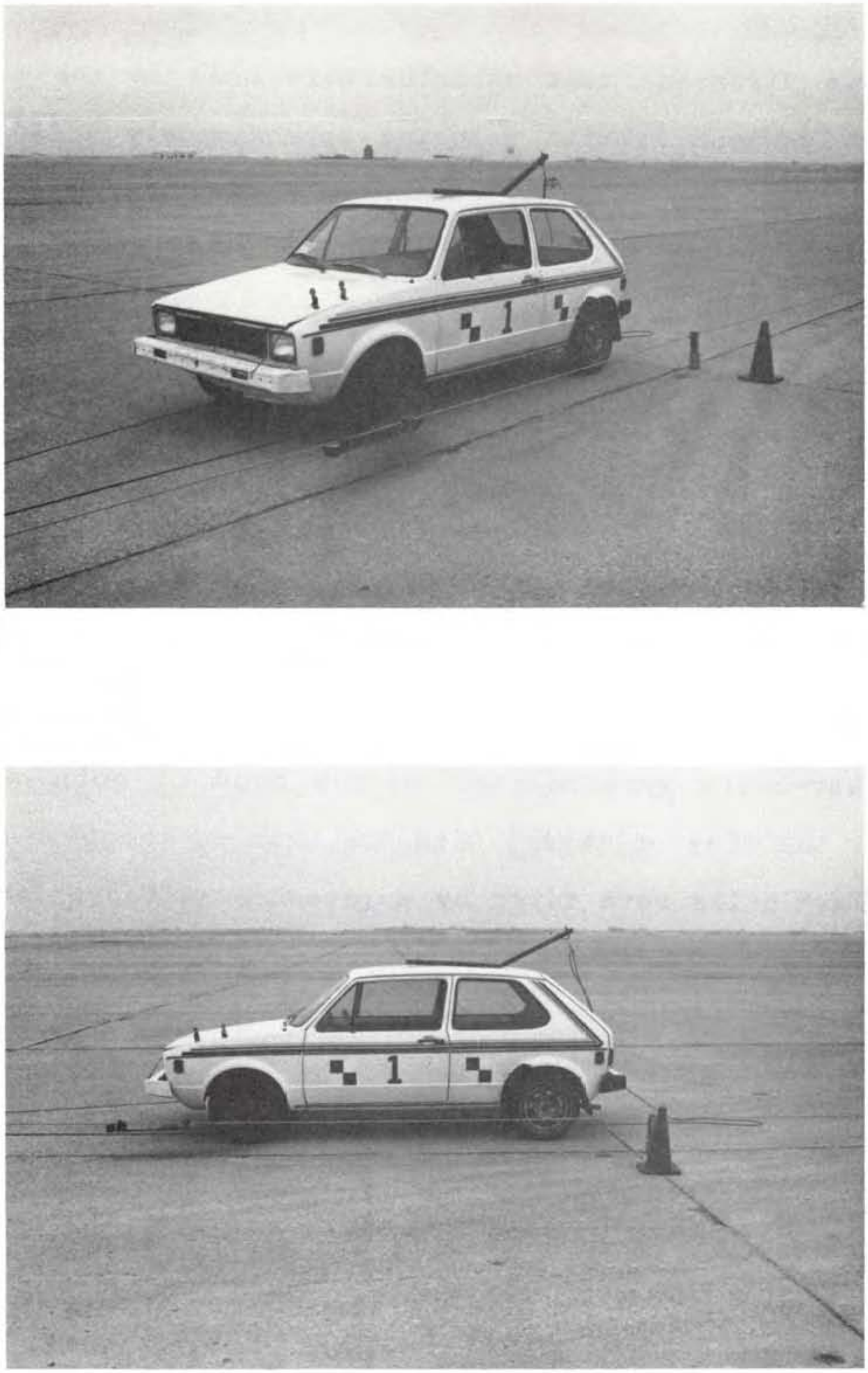
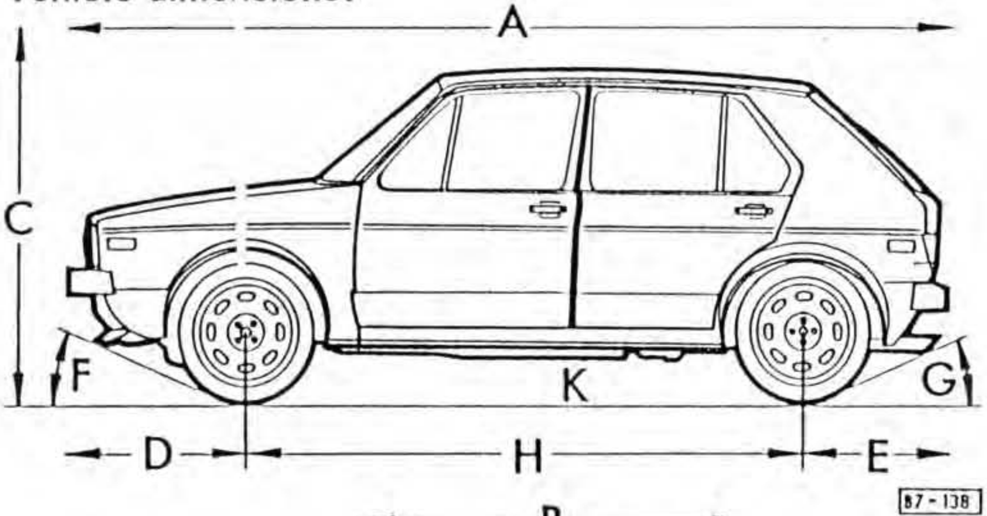
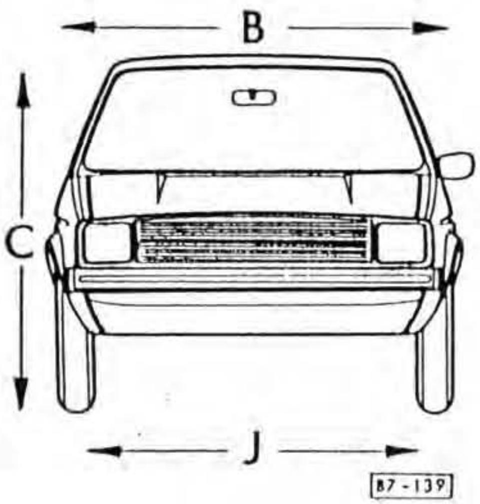


Figure 6. Test Vehicle No. 1

Vehicle dimensions:





A	– Length	155.3 in/3945 mm
B	– Width	63.4 in/1610 mm
C	– Height (unladen)	55.5 in/1410 mm
D	– Overhang, front	32.7 in/ 830 mm
E	– Overhang, rear	27.2 in/ 693 mm
F	– Ramp angle, front	24°
G	– Ramp angle, rear	22.5°
H	– Wheelbase	94.5 in/2400 mm
J	– Front track	54.7 in/1390 mm
	Rear track	53.1 in/1350 mm
K	– Ground clearance	4.8 in/ 122 mm

Measured at gross vehicle weight, except item C, which is measured at unladen weight.

Turning circle diameter – approximately 31.5 ft/9.6 m curb to curb.

Gross Vehicle Weight:	2822 lbs.	
Gross Axle Weight:	1609 lbs.	(front)
Gross Axle Weight:	1278 lbs.	(rear)

Figure 7. Test Vehicle No. 1 Dimensions

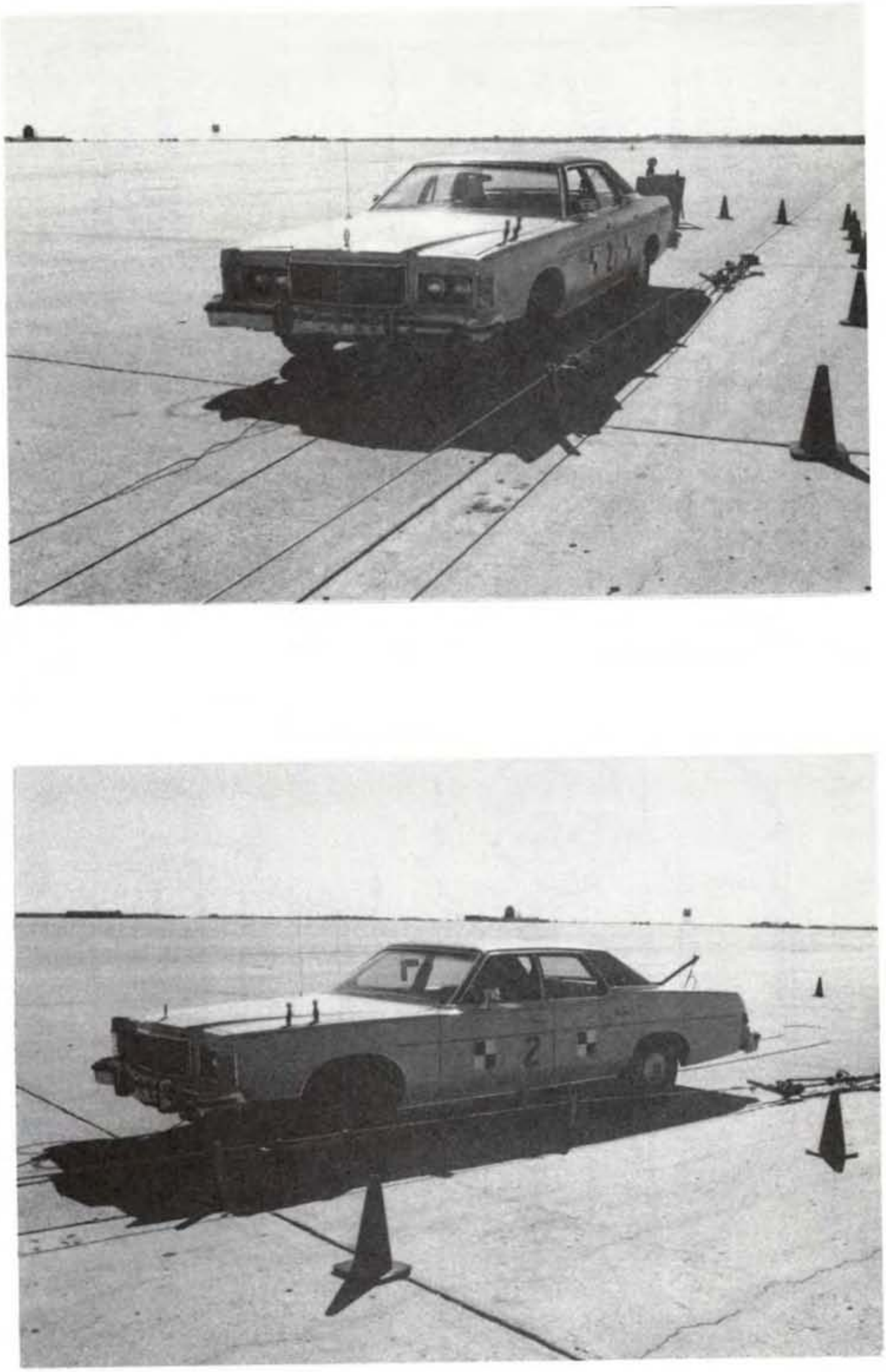
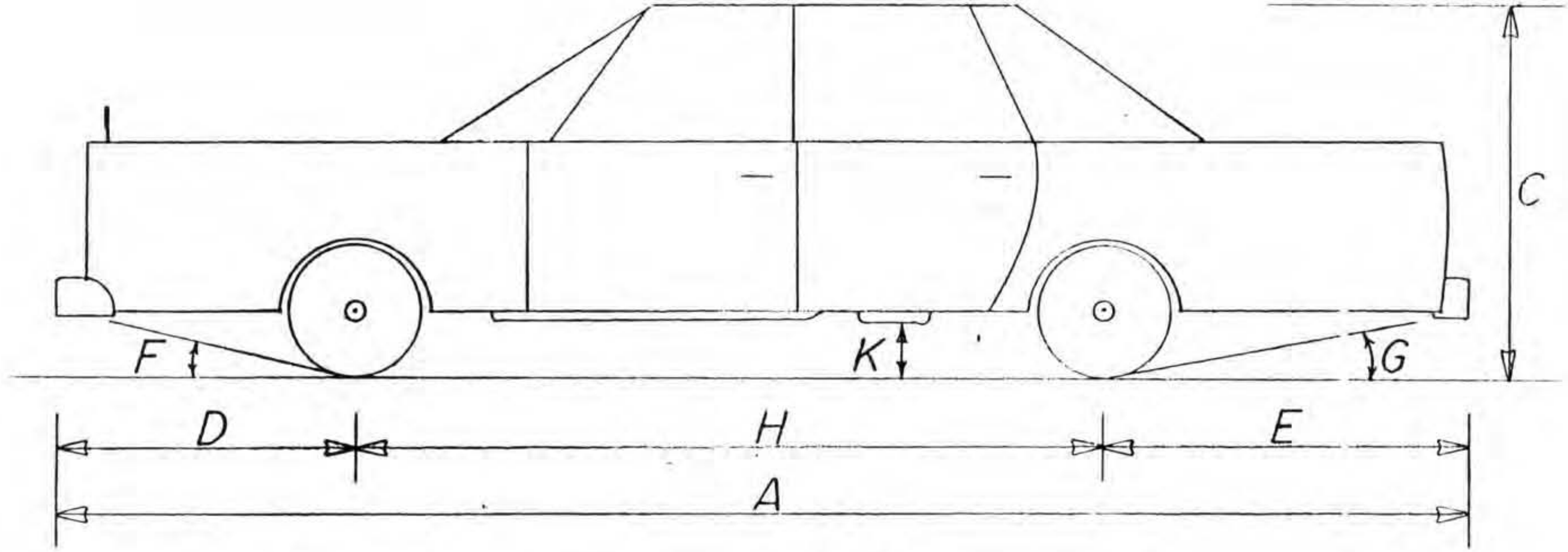
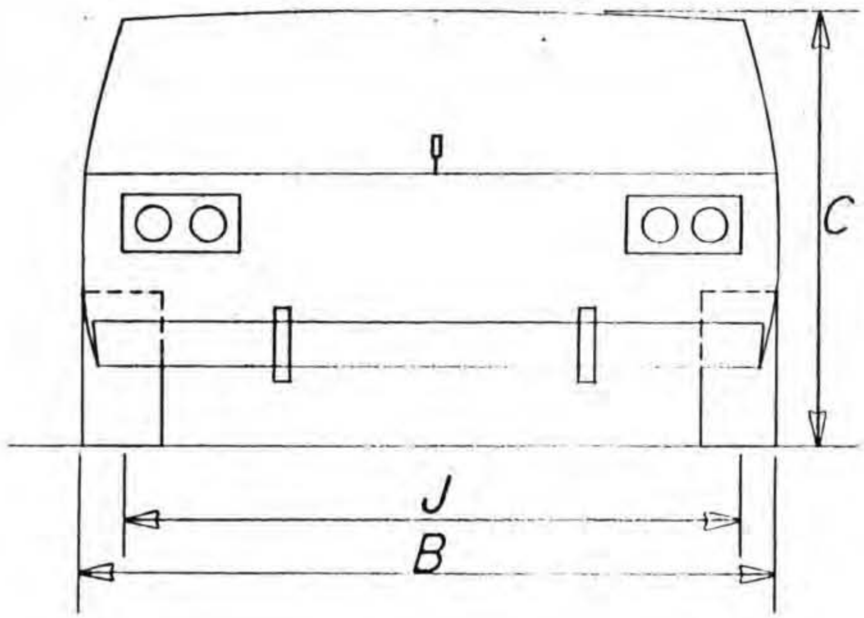


Figure 8. Test Vehicle No. 2





A	- Length	230"
B	- Width	79"
C	- Height (unladen)	59"
D	- Overhang, front	45"
E	- Overhang, rear	63"
F	- Ramp angle, front	18°
G	- Ramp angle, rear	14.5°
H	- Wheelbase	123.5"
J	- Front track	64"
	Rear track	63.5"
K	- Ground clearance	10"

Figure 9. Test Vehicle No. 2 Dimensions

DATA ACQUISITION SYSTEMS

Two piezoresistive accelerometers, with a sensitivity range of 2 g's to 200 g's, were used to measure the accelerations in the longitudinal direction of the test vehicle. Each accelerometer was attached to an aluminum block which was fixed to the vehicle's floorboard. In the first test the accelerometers were mounted in the front of the vehicle, one on the passenger's side and one on the driver's side. In the second test, the accelerometers were mounted on the hump of the floorboard; however, one was in the front of the vehicle and one was in the back. Photos of the accelerometers mounted in the test vehicles are shown in Figure 10. The signals from the accelerometers were sent to the Metraplex FM multiplexed data acquisition system which received and conditioned the signals so that they could be transmitted over a common FM frequency. Then, the frequency was sent to a Honeywell 101 Analog Tape Recorder where it was recorded for permanent storage. A flow chart and photos of the data acquisition system are shown in Figures 11 and 12.

Two cameras were used to film both tests. The cameras used 16 mm high-speed film and ran at approximately 500 frames/second. The first camera was a Red Lake Locam that had a wide angle lens. It was placed approximately 85 feet perpendicular to the centerline of the vehicle's path of travel. The second camera was a Photec IV and was placed approximately 135 feet perpendicular to the centerline of the test vehicle's path of travel. Figure 13 shows photos of both cameras and Figure 14 shows a schematic of the camera layout.

An 8 ft. high by 16 ft. long backboard, with a 2 ft. line grid layout, was used as a reference for the analysis of the high-speed film. The backboard was placed facing the cameras 12 feet from the centerline of the vehicle's path of travel. The camera divergence correction factors were also taken into consideration in the analysis of the high-speed film.

Eight pressure switches, spaced at 5 ft. intervals, were used to determine the speed of the vehicle before and after impact. Four switches were placed in front of the channelizer and four switches were placed in back of the channelizer along the vehicle's path. Each switch would fire a 5B flash-bulb, which was mounted on the backboard, as the right front tire of the vehicle rode over it. Then, since the distance between pressure switches was known, by counting the number of frames from the high-speed film between flashes and calibrating the camera speed in frames per second, one could determine the speed of the test vehicle as it passed over a particular pressure switch.

A VanGuard Motion Analyzer was used to analyze the high-speed film frame by frame.

Figure 10. Photos of Mounted Accelerometers

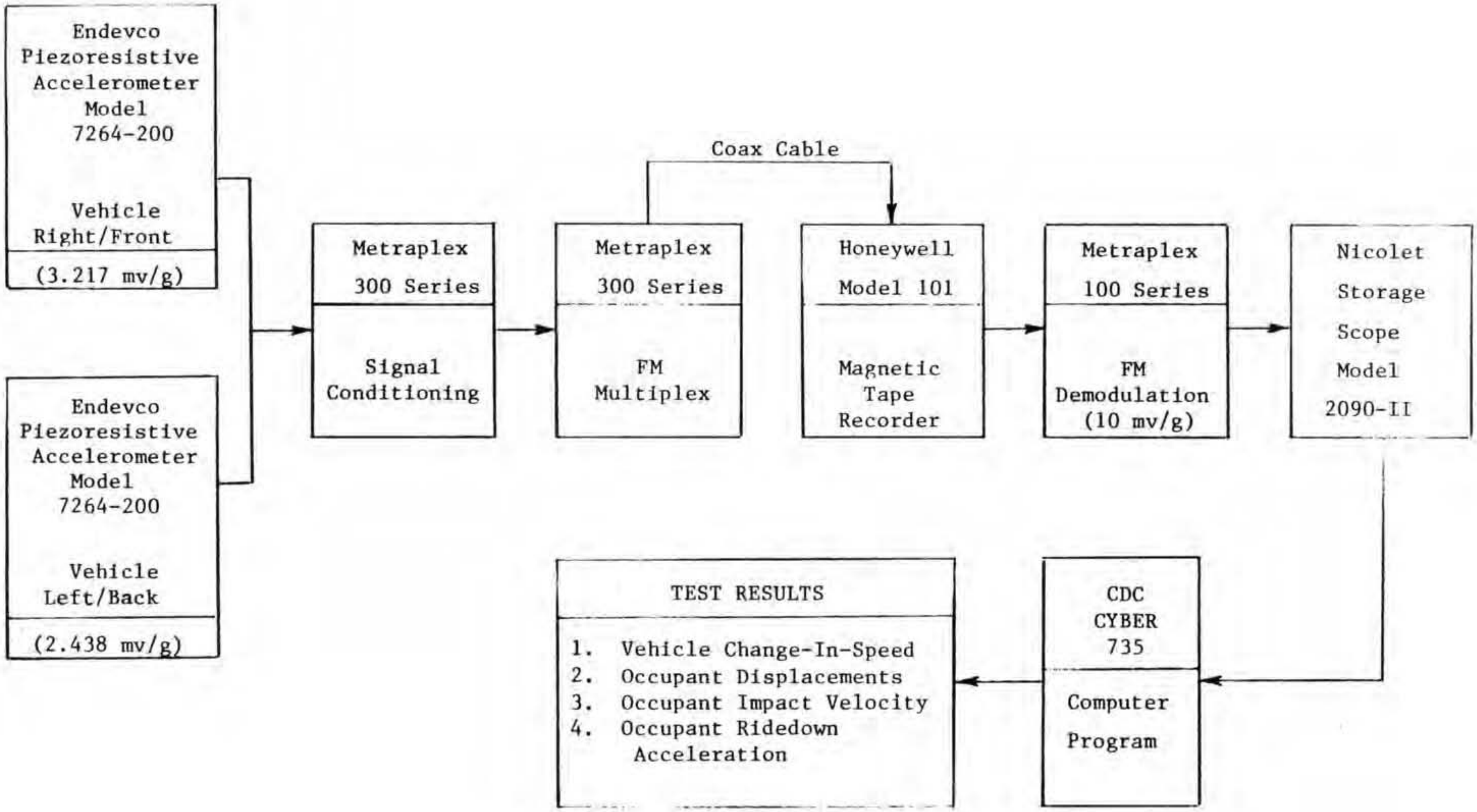
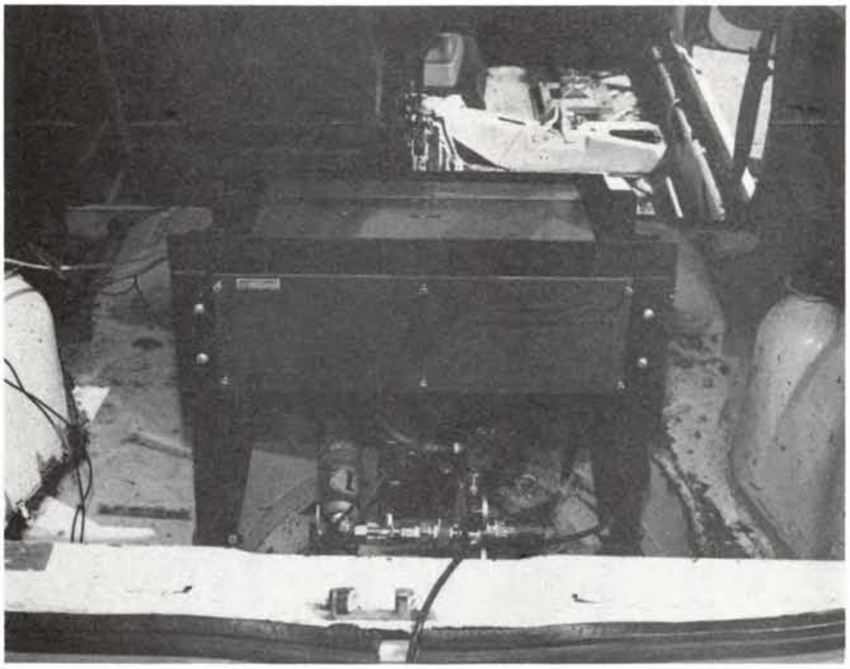


Figure 11. Flowchart of Metraplex Data Acquisition System



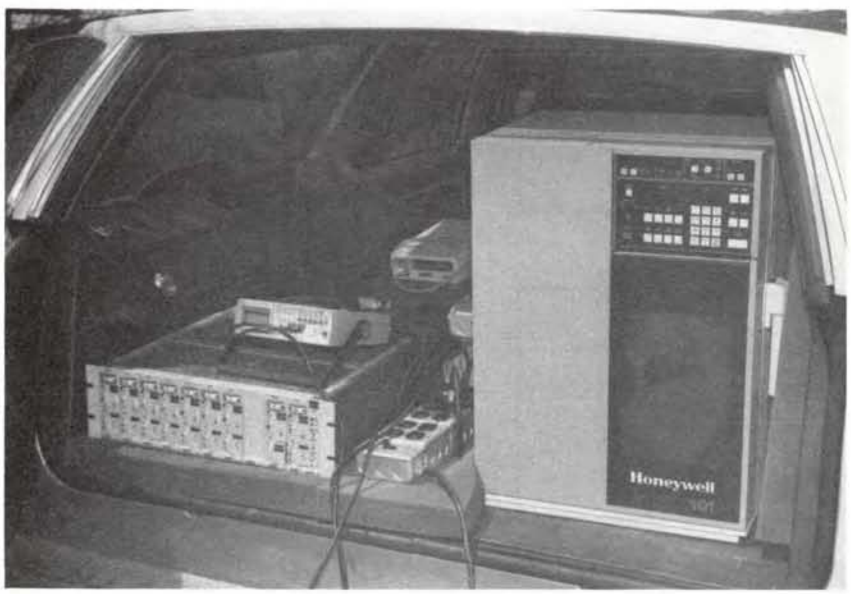


Figure 12. Photos of Data Acquisition System

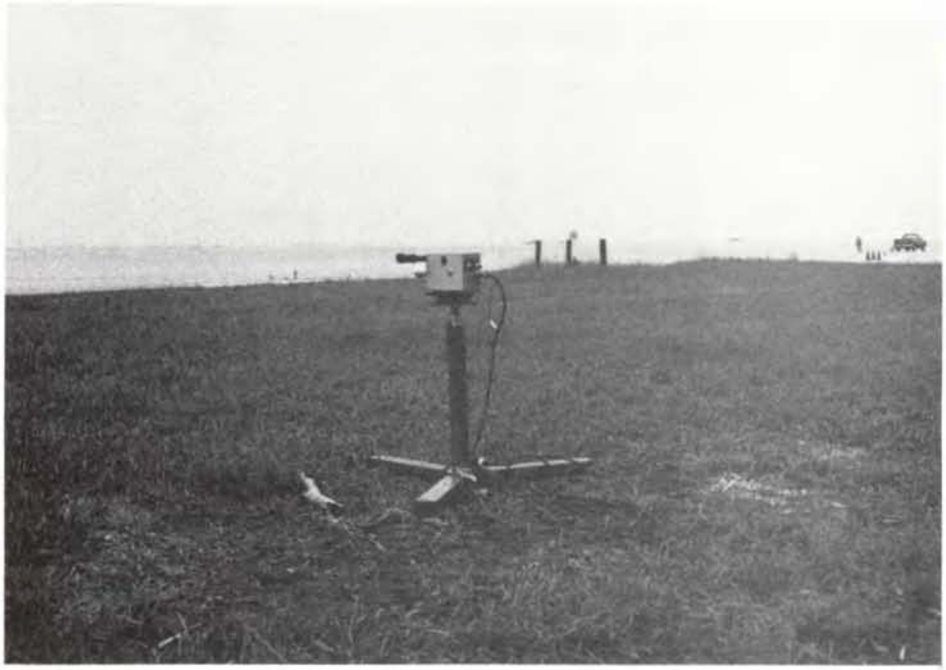


Figure 13. High-Speed Cameras

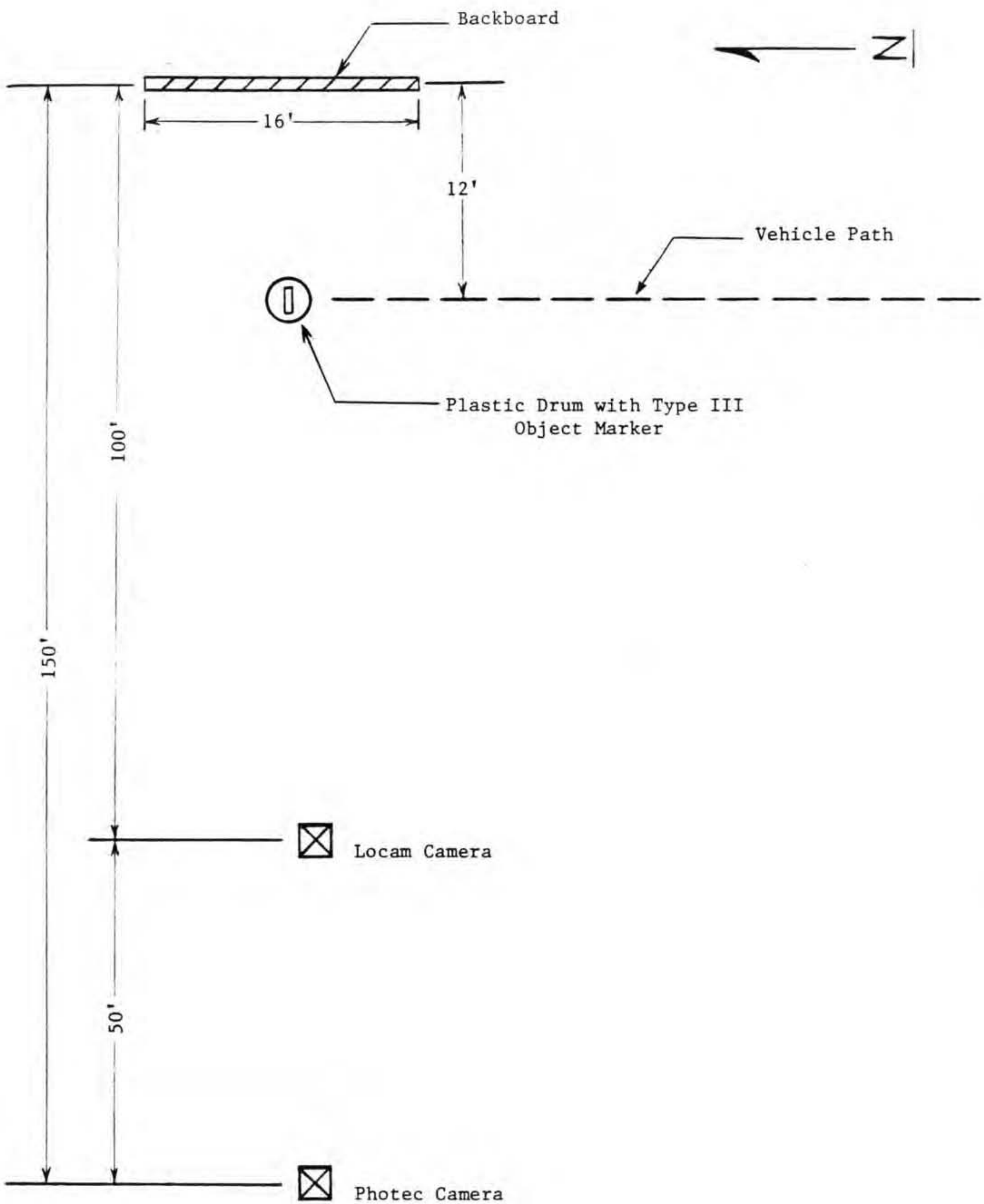


Figure 14. Schematic of Camera Layout

PERFORMANCE STANDARDS

Currently there are no established guidelines or performance criteria that directly deal with the full scale crash testing of channelizers. However, AASHTO defines breakaway supports as all types of sign, luminaire, and traffic signal supports which are safely displaced under vehicle impact, whether the release mechanism is a slip plane, plastic hinges, fracture elements, or a combination of these. Therefore, it was assumed that these drum-like channelizers should comply with the safety standards required for a breakaway or yielding device.

According to AASHTO, "satisfactory dynamic performance is indicated when the maximum change in velocity for a standard 1,800 lb. (816.5 kg.) vehicle, or its equivalent, striking a breakaway support at speeds from 20 mph to 60 mph (29.33 fps to 88 fps) (32 kmph to 97 kmph) does not exceed 15 fps (4.57 mps), but preferably does not exceed 10 fps (3.05 mps) or less." (2)

Other specifications require that detached elements, fragments, or other debris from the test article (two-piece breakaway channelizer) shall not penetrate, or show potential for penetrating, the occupant compartment or provide undue hazard to other traffic. Also, the vehicle shall remain upright during and after impact (1).

Because test conditions are sometimes difficult to control, a tolerance limit is presented. It is called the Impact Severity (IS). For structural adequacy, it is preferable for the actual impact severity to be greater than the target value rather than below it. The IS target value for the 60 mph test when using an 1,800 lb. vehicle is $216^{-21,+37}$ ft-kips respectively (1).

It should be noted here, that according to the recommended test procedures from NCHRP 230, a 4,500 lb. vehicle is not required in testing a breakaway or yielding device. However, the Missouri Highway and Transportation Commission requested the use of a 4,500 lb. vehicle to assure the adequacy of the designed object marker connectors. Also, for testing breakaway or yielding devices at 60 mph, NCHRP 230 recommends that the point of impact be at the quarter point of the bumper on the test vehicle (1). However, according to AASHTO, the 60 mph off-center impact recommended by NCHRP 230 may be more stringent than can be easily met under current testing procedures. AASHTO suggests that the off-center impact be considered a goal and the acceptance of high-speed testing be based on a centerline impact (2). Therefore, both tests were conducted with impact at the centerline of the bumper.

TEST RESULTS

The individual results of both full-scale crash tests are included in the following section; a summary of the results is given in Table 1.

Though accelerometers were used in the testing, they were not applicable in the tests analysis. The reason for this was because the 'g' force produced by the impact was not large enough to be recorded by the lower sensitivity range of the accelerometers (2 g's). Therefore, the impact speed and the change in velocity were obtained by analyzing the high-speed film.

Because the 'g' force was less than 2 g's in both tests, the occupant displacement was negligible. Hence, the results of the tests were compared to vehicle braking. This was done to compare the change in velocity experienced by an occupant in the test vehicle, to the change in velocity experienced by an occupant in a vehicle if the brakes were applied and skidding occurred. In figuring the change in velocity due to braking, the coefficient of friction between the tires and the concrete pavement was taken as 0.63 as recommended by the National Research Council, Highway Research Board (4).

Table 1. Summary of Test Results

Test Number	Actual Vehicle Weight (lbs)	Target Impact Speed (mph)	Actual Impact Speed (mph)	Change in Velocity (mph/fps)	Occupant Displacement (in)	Actual Impact Severity (ft/kips)	Detached Elements
1	1840	60	59.7	1.7/2.5	Negligible	219.0	None
2	4590	60	58.6	2.0/2.9	Negligible	N.A.*	None

* Not Applicable

Test No. 1

The first full-scale crash test was conducted with the 1,800 lb. vehicle at a target impact speed of 60 mph. The point of impact was at the center of the bumper. The results of the first test are given in Table 2 and sequential photos taken from the high speed film are shown in Figure 15 with the corresponding time-event summary given in Table 3.

The actual impact speed of the vehicle was 59.7, while the corresponding change in velocity after impact was 1.7 mph (2.5 fps) from the point of impact to a point 20 feet behind the channelizer. This is shown in Figure 16. After impact, the vehicle lost contact with the channelizer at approximately 84 milliseconds but regained contact at approximately 247 milliseconds. The vehicle then continued to push the channelizer approximately 500 feet until the vehicle stopped.

Upon impact, the channelizer buckled but remained upright and in front of the vehicle. When the channelizer buckled, the object marker deflected down touching the hood momentarily and then rebounded back to a position very close to its original position. After close examination, there was no visible evidence of fracture in the polycarbonate connectors. There was no damage done to the test vehicle and the only damage done to the flexible reflective sheeting was some tearing due to impact. The sheeting conformed with the deformation of the channelizer without any evidence of cracking or peeling. Figures 17-19 show photos of the channelizer, object marker, and test vehicle after the test.

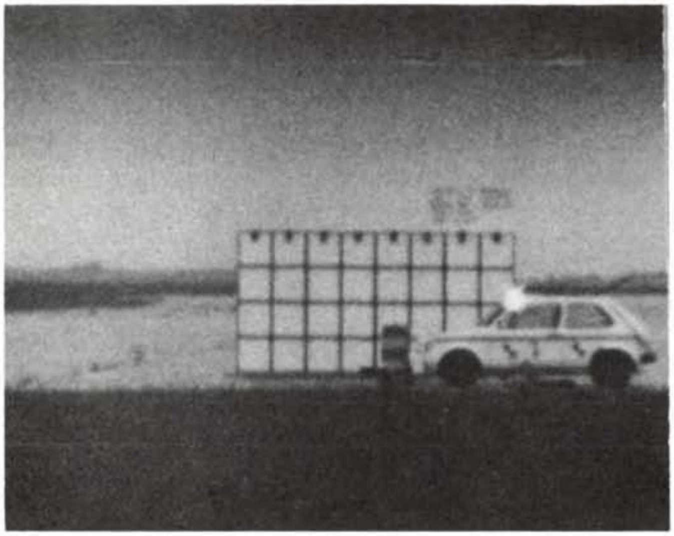
During the test, at approximately 50 feet before impact, the hood of the test vehicle unlatched and flew up. After talking to the Missouri Highway and Transportation Commission about this incident, it was decided that the test was still good since this did not affect the results of the test in any way.

TABLE 2

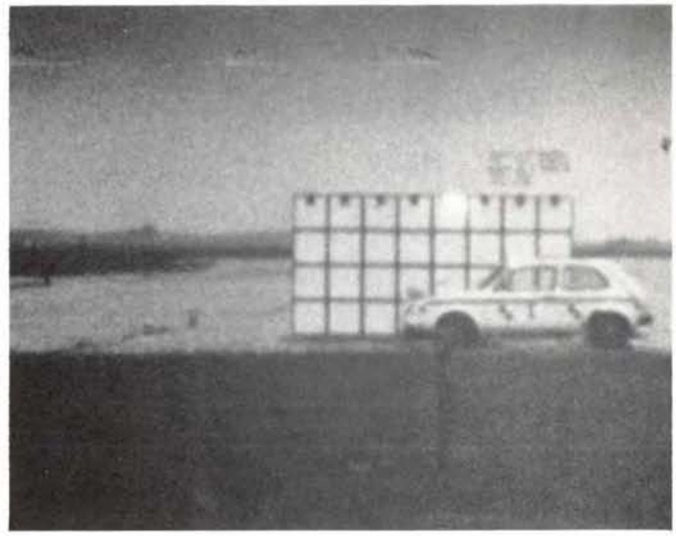
SUMMARY OF RESULTS, TEST NO. 1

<u>VEHICLE DATA</u>	
Make	Volkswagon
Model	Rabbit
Year	1979
Weight	1,840 lbs.
Impact Point	Center
<u>CHANNELIZER DATA</u>	
Channelizer	Plastic Drum #18,000 HMW LD PE
Object Marker	8" x 24" x 1/16" Aluminum Panel
Object Marker Supports	2 - 1 1/2" x 17" x 3/8" Clear Polycarbonate Connectors
Reflective Sheeting	Flexible (Type III)
Ballast	2 - 30 lb. bags of gravel
<u>VEHICLE AND OCCUPANT KINEMATICS</u>	
Impact Velocity	59.7 mph
Change-In-Velocity	1.7 mph (2.5 fps)
Occupant Displacement	Negligible
Impact Severity	219.0 ft-kips
<u>VEHICLE DAMAGE CLASSIFICATION</u>	
TAD*	None
VDI**	None
Did test article detach and penetrate passenger compartment?	No
Was windshield broken?	No

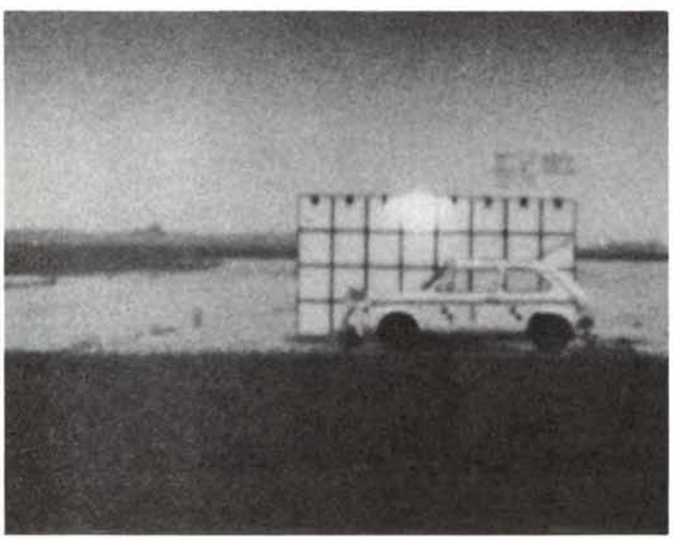
* Traffic accident data scale (5)
** Vehicle damage index (6)



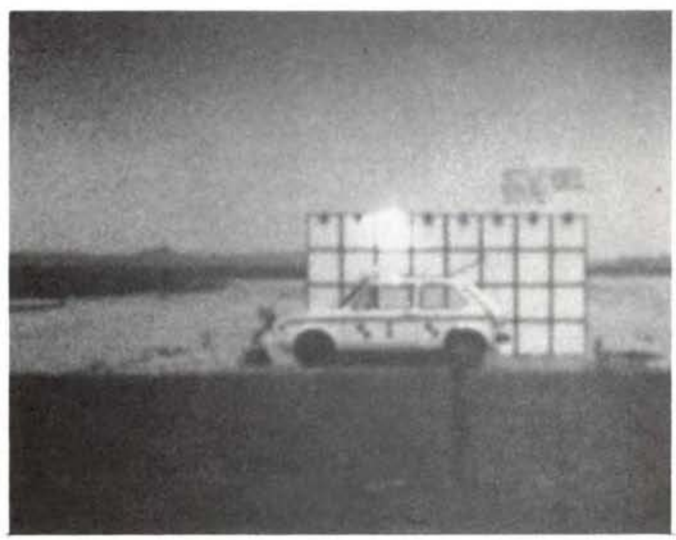
Impact



0.036 sec



0.070 sec



0.127 sec

Figure 15. Sequential Photos, Test No. 1

TABLE 3

TIME-EVENT SUMMARY FOR TEST NO. 1

TIME (SEC.)	EVENT
0.000	Impact
0.036	Object marker bending over hood
0.070	Object marker touching hood
0.127	Plastic Drum being pushed by vehicle. Object marker off hood

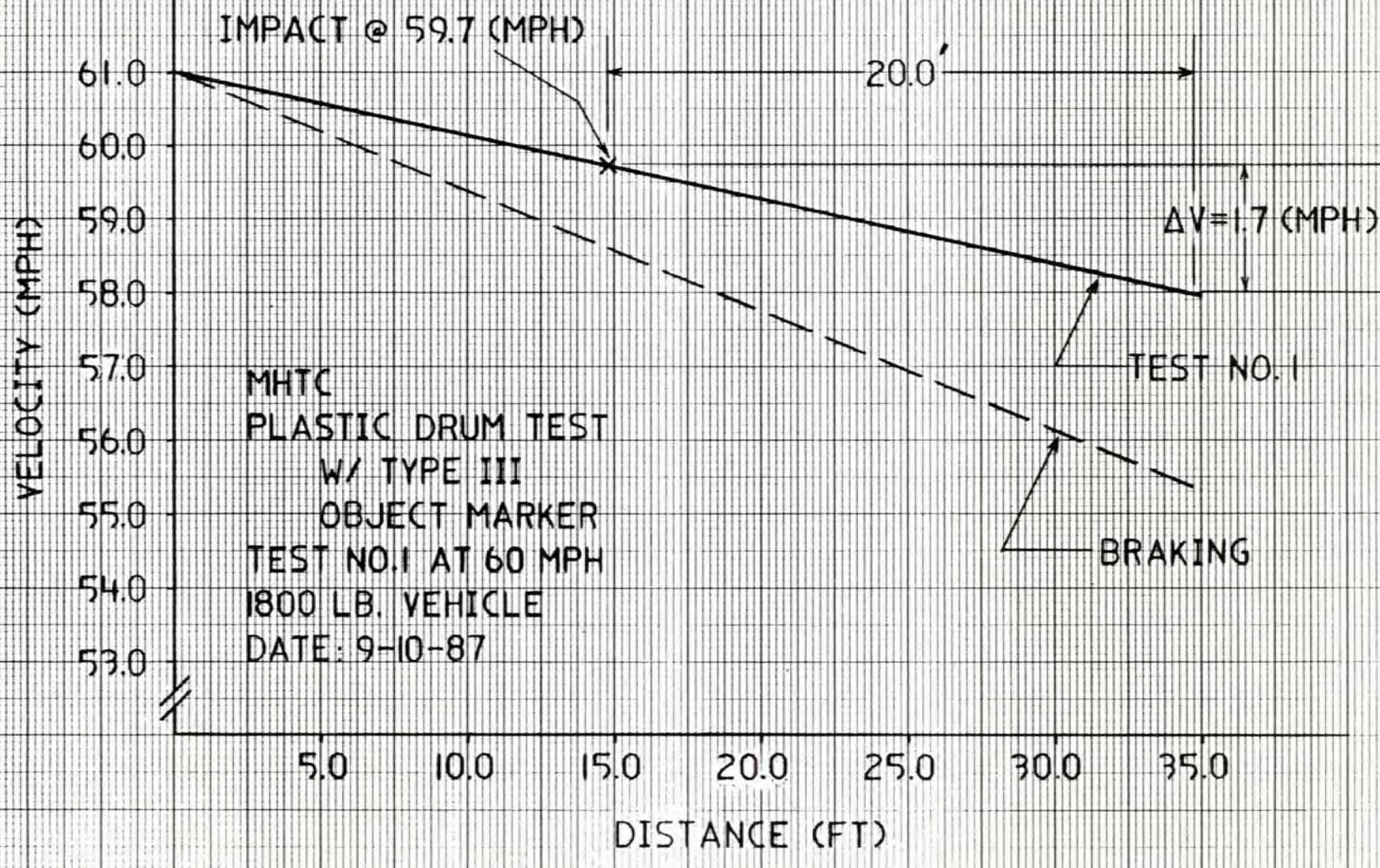
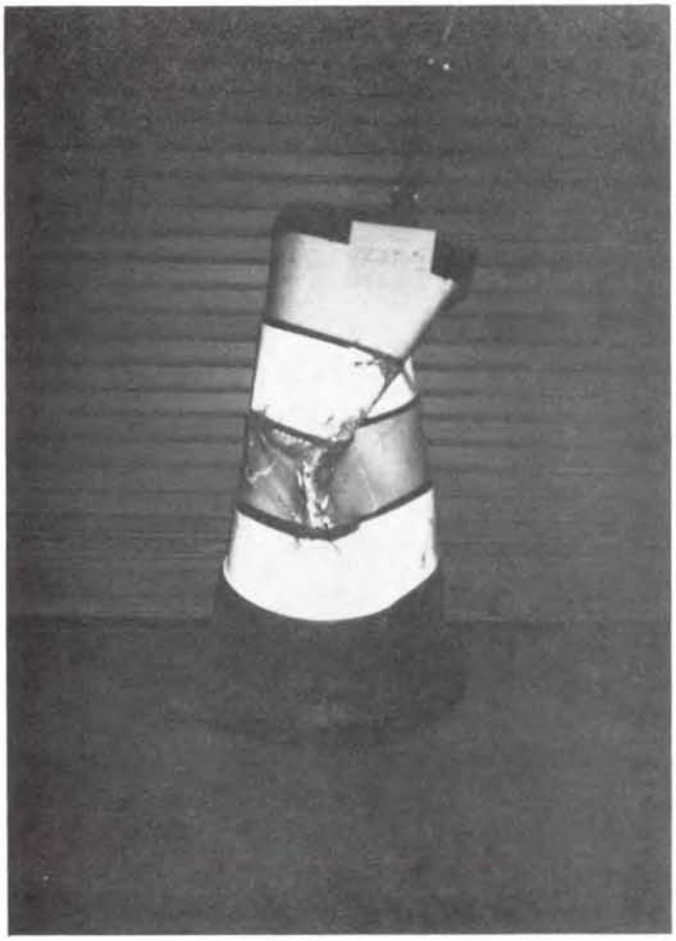


FIGURE 16. CHANGE IN VELOCITY, TEST NO.1



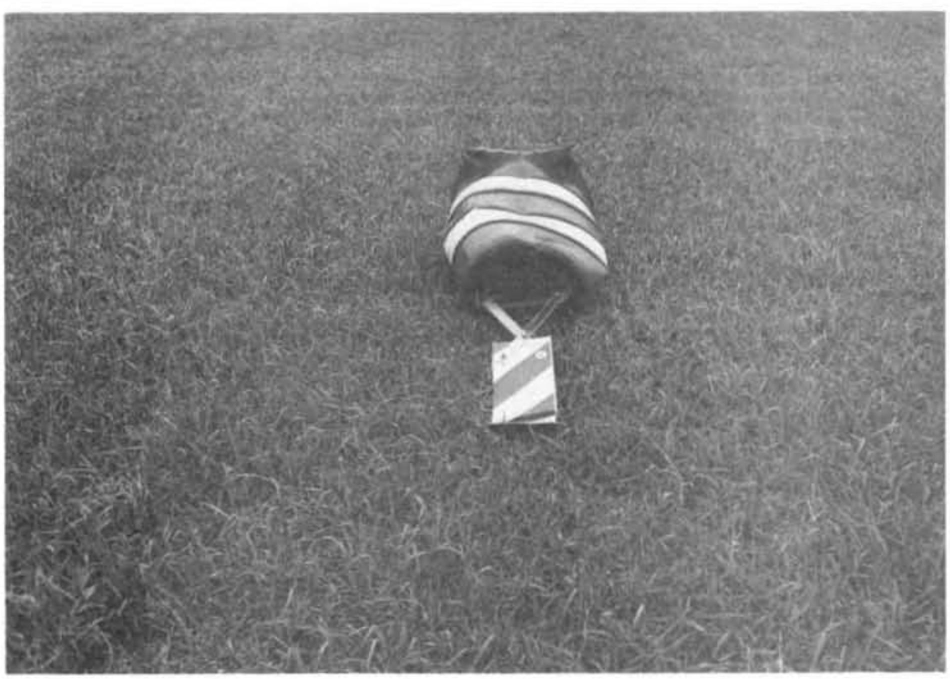
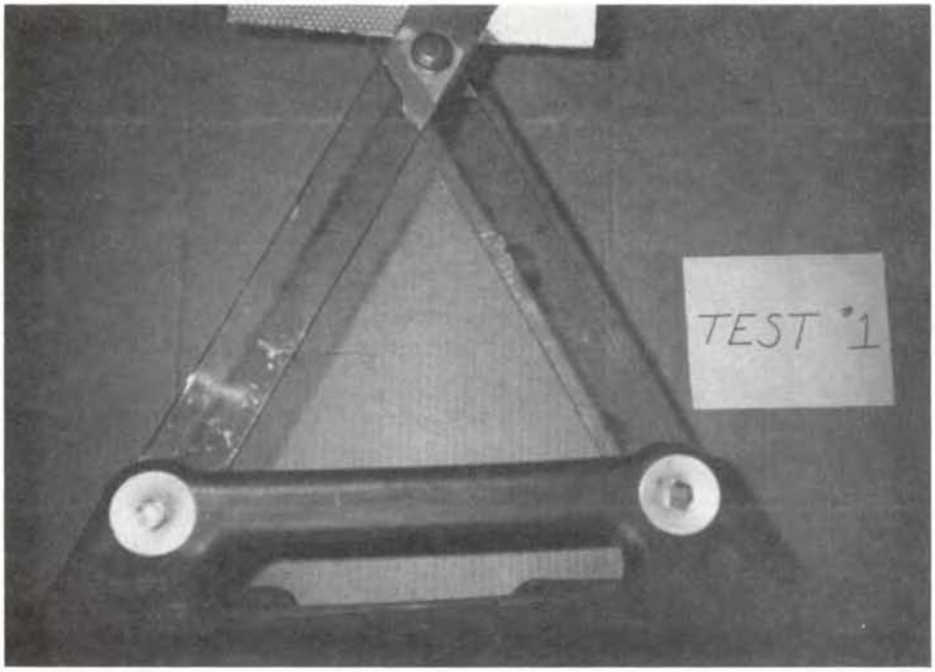


Figure 17. Damages to Plastic Drum Channelizer, Test No. 1



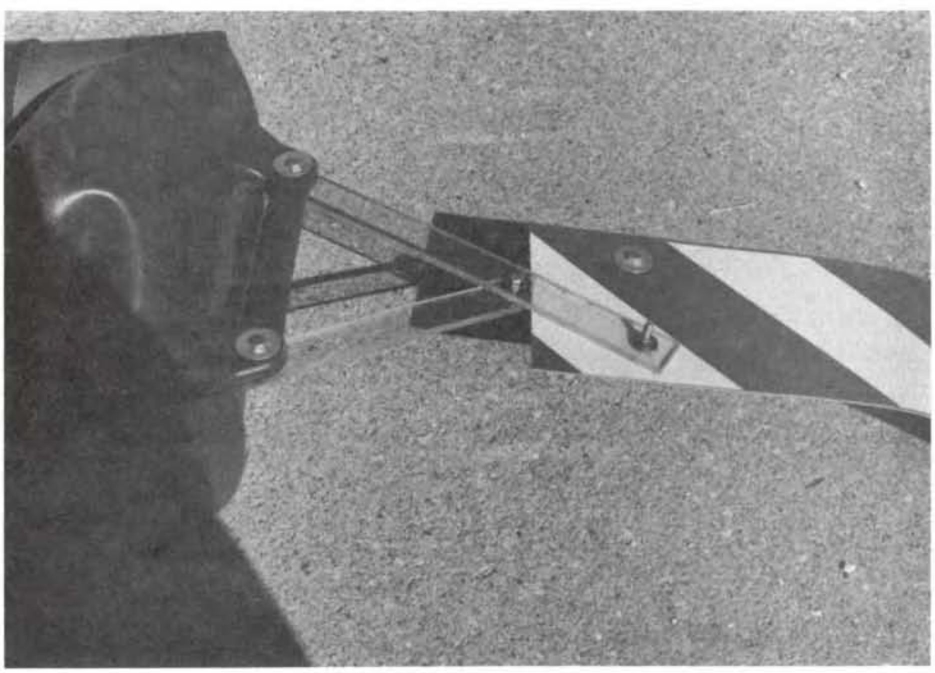


Figure 18. Polycarbonate Connectors After Test No. 1

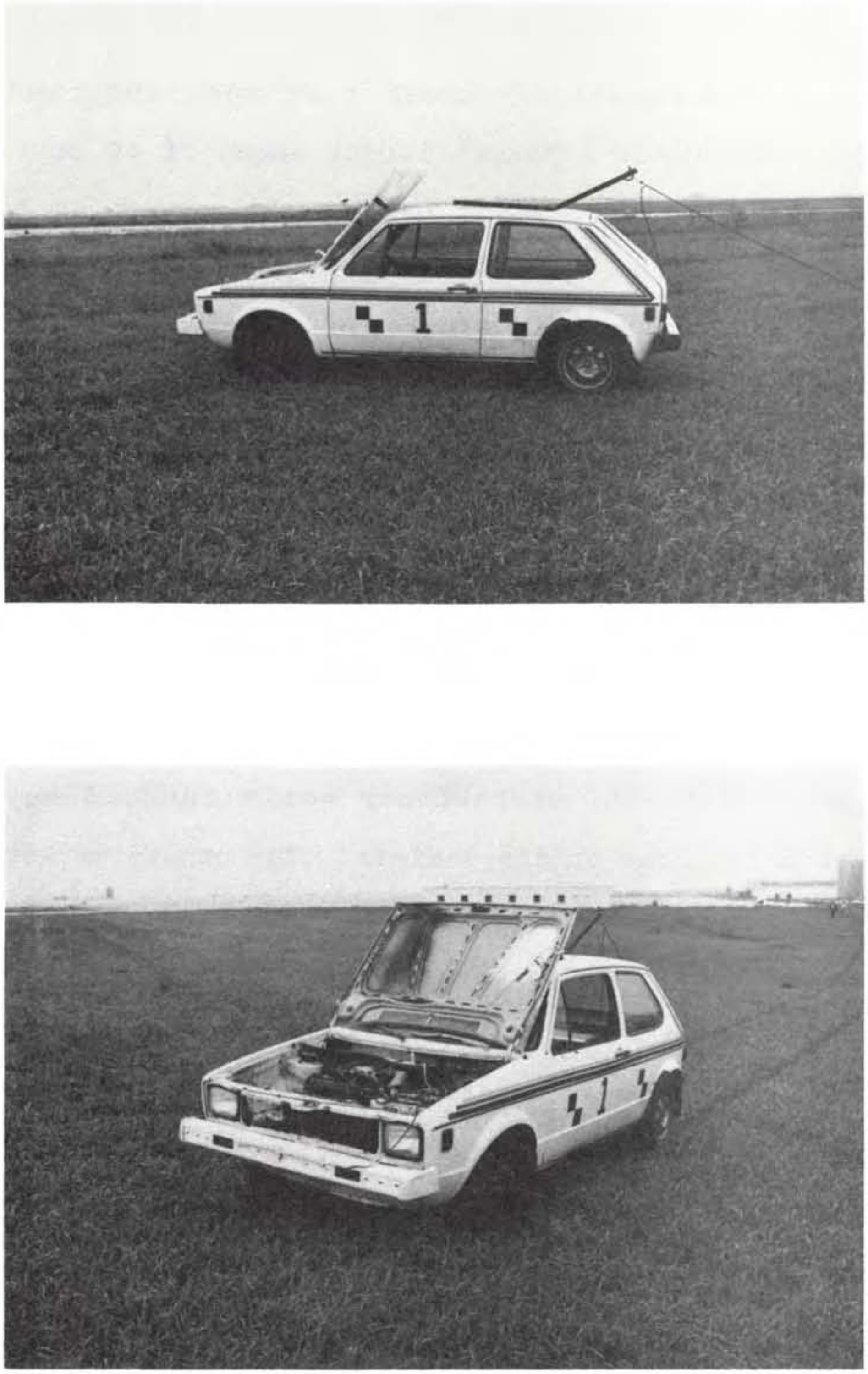


Figure 19. Damage to Test Vehicle, Test No. 1

TEST NO. 2

The second full-scale crash test was conducted with the 4,500 lb. vehicle at a target impact speed of 60 mph. Like the first test, the impact point was at the center of the bumper. Test results for the second test are given in Table 4, with the sequential photos shown in Figure 20 and the corresponding time-event summary given in Table 5.

The results of the second test were quite similar to those of the first test. The actual impact speed was 58.6 mph, and the change in velocity after impact was 2.0 mph (2.9 fps) over a distance of 20 feet as shown in Figure 21. After impact, the test vehicle never lost contact with the channelizer until the vehicle came to a stop.

Upon impact, the channelizer again buckled but remained upright and in front of the vehicle. The object marker deflected but rebounded back to its original position and after examination, showed no evidence of fracture in the polycarbonate connectors. Unlike the first test, the reflective sheeting in the second test was a non-flexible engineering-grade reflective sheeting. Examination of the channelizer after the test showed that there was considerably more cracking and peeling of the reflective sheeting than in the first test. However, the sheeting in the second test was definitely reusable on the same channelizer. Figures 22-24 show photos of the channelizer, object marker and test vehicle after the test.

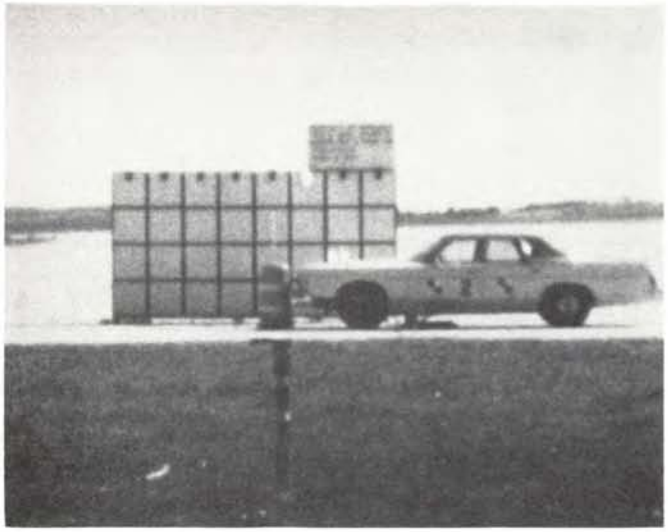
TABLE 4

SUMMARY OF RESULTS, TEST NO. 2

VEHICLE DATA	
Make	Mercury
Model	Marquis
Year	1978
Weight	4,590 lbs.
Impact Point	Center
CHANNELIZER DATA	
Channelizer	Plastic Drum #18,000 HMW LD PE
Object Marker	8" x 24" x 1/16" Aluminum Panel
Object Marker Supports	2 - 1 1/2" x 17" x 3/8" Clear Polycarbonate Connectors
Reflective Sheeting	Non-flexible Engineering Grade Type II
Ballast	2 - 30 lb. bags of gravel
VEHICLE AND OCCUPANT KINEMATICS	
Impact Velocity	58.6 mph
Change-In-Velocity	2.0 mph (2.9 fps)
Occupant Displacement	Negligible
Impact Severity	N.A. ***
VEHICLE DAMAGE CLASSIFICATION	
TAD*	None
VDI**	None
Did test article detach and penetrate passenger compartment?	No
Was windshield broken?	No

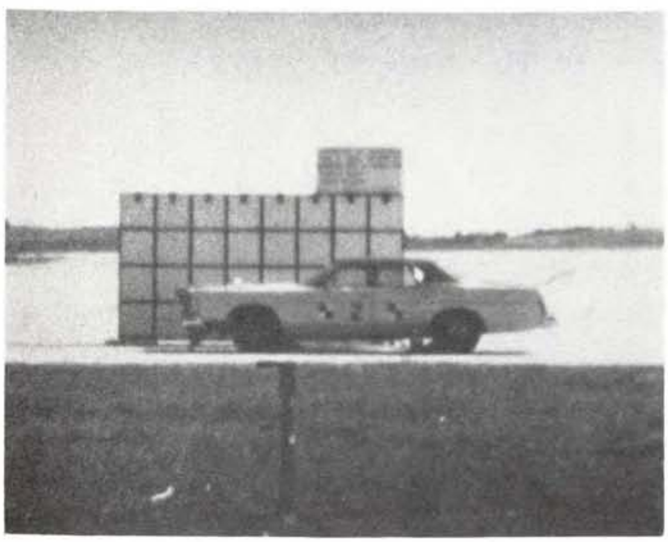
* Traffic accident data scale (5) *** Not applicable

** Vehicle damage index (6)



Impact

0.036 sec



0.068 sec

0.093 sec

Figure 20. Sequential Photos, Test No. 2

TABLE 5

TIME-EVENT SUMMARY FOR TEST NO. 2

TIME (sec.)	EVENT
0.000	Impact
0.036	Object marker bending over hood
0.068	Object marker flat on hood
0.093	Plastic drum in full compression with object marker coming off hood

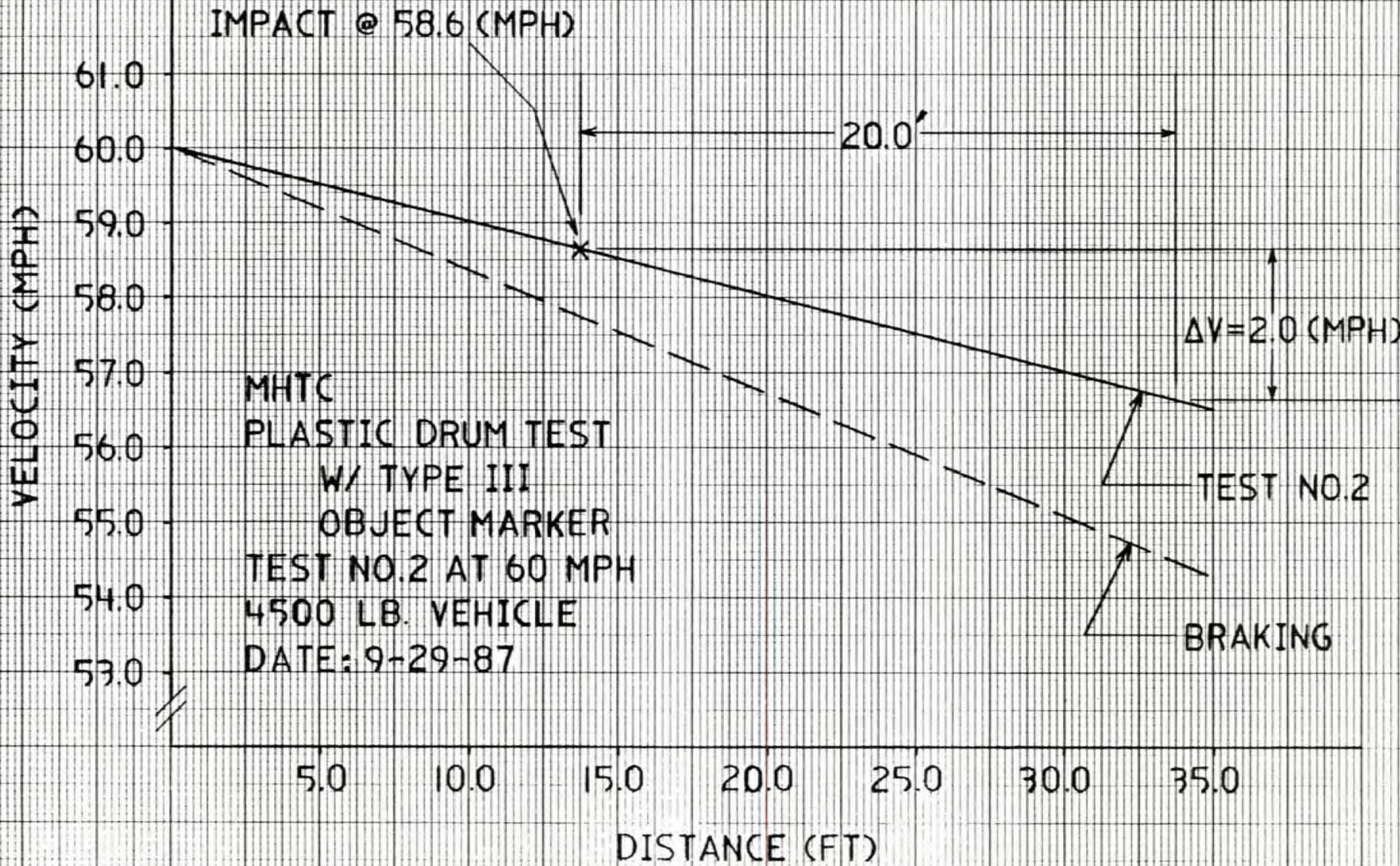


FIGURE 21. CHANGE IN VELOCITY, TEST NO. 2

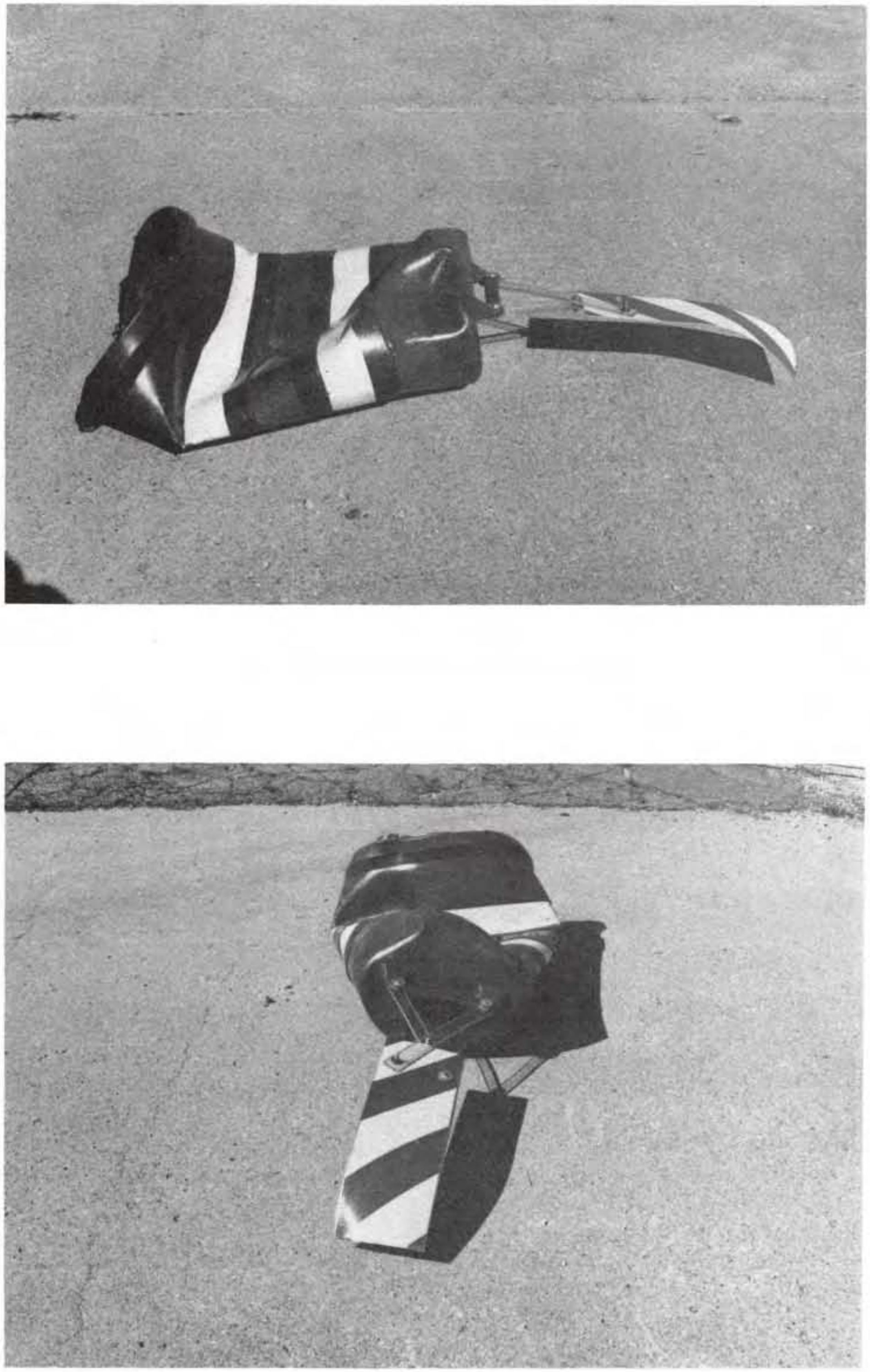


Figure 22. Damages to Plastic Drum Channelizer, Test No. 2

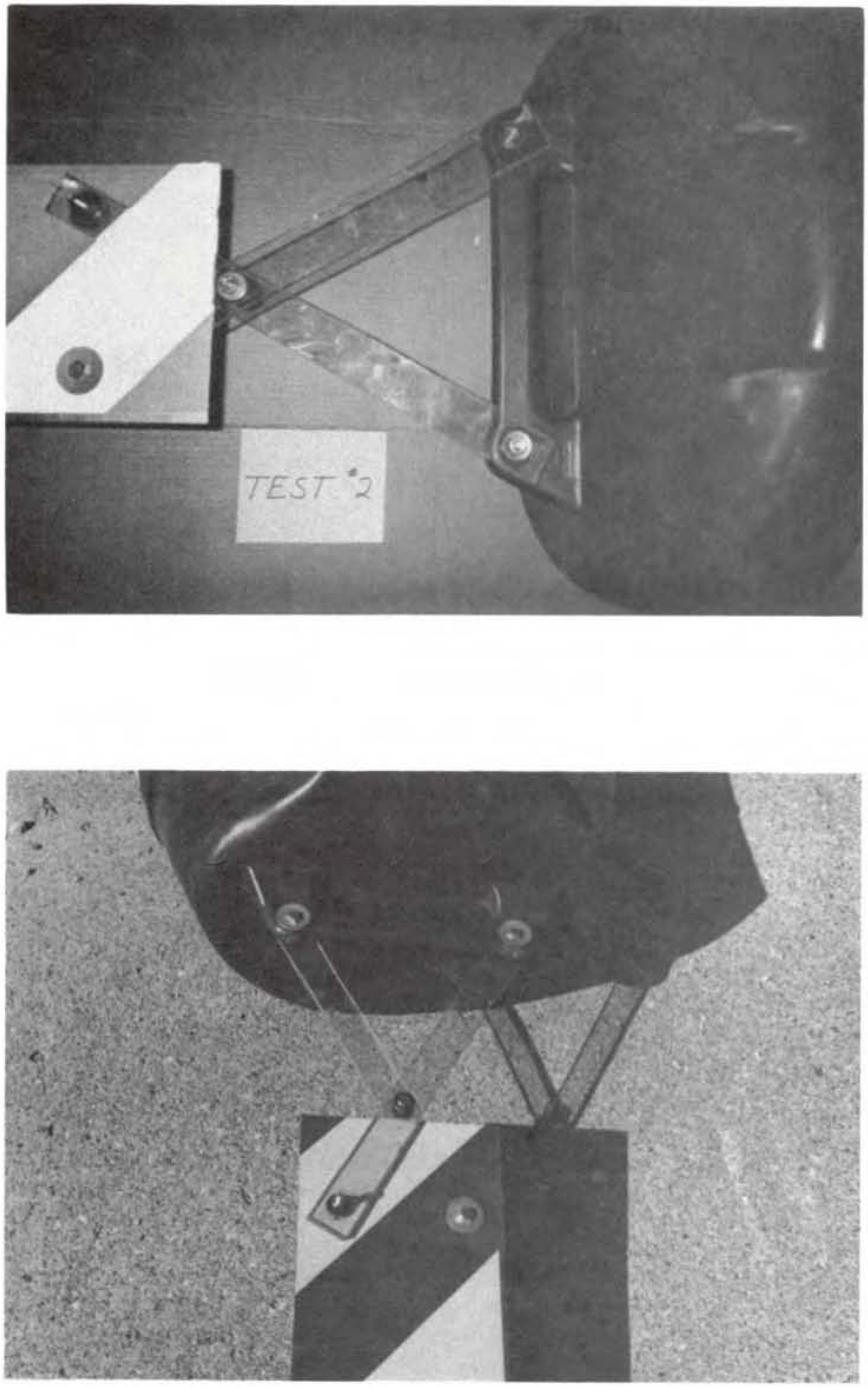


Figure 23. Polycarbonate Connectors After Test No. 2

Figure 24. Damage to Test Vehicle, Test No. 2

CONCLUSIONS

Two full-scale crash tests were conducted on Plastic Drums with Type III Object Markers using 1,800 lb. and 4,500 lb. vehicles. Analysis of these tests showed that the overall general performance of this type of configuration was satisfactory in accordance with the criteria specified in both NCHRP 230 (1), and AASHTO (2). The following results were obtained from the tests:

A. Structural Adequacy

1. The configuration displaced at impact in a manner that was predicted for both tests.
2. In both tests the object marker remained attached to the plastic drum. Therefore, no detached elements or fragments penetrated, or showed potential to penetrate, the passenger compartment of the vehicle and no undue hazard to other traffic was possible.

B. Occupant Risk

1. In both tests the vehicle remained upright and stable during and after impact and showed no sign of hazardous redirection. Also, there were no damages assessed to the vehicle after either test.
2. In Test No. 1, the actual impact severity was within recommended limits. For Test No. 2, the impact severity is not applicable since a 4,500 lb. vehicle is not required in testing a breakaway or yielding device.

C. Vehicle Trajectory

1. For both tests, the change in velocity of the vehicle was well below the recommended limit of 10.2 mph (15.0 fps) and the preferable limit of 6.8 mph (10.0 fps).

From the above results, it is the recommendation of the University of Nebraska that the Missouri Highway and Transportation Department regard Type III Object Markers on Plastic Drums as being satisfactory for implementation in delineating traffic.

TEST ARTICLE RECOMMENDATIONS

Though the tests were successful, these suggestions might be considered for a more effective configuration if cost-efficiency permits:

1. A plastic object marker instead of aluminum could decrease the chance of passenger compartment penetration if the object marker would happen to detach.
2. Use of 1 bag of sand (40-60 lbs.), instead of 2 bags, for better chassis clearance.
3. Recommend use of flexible reflective sheeting especially in cold weather environments instead of non-flexible reflective sheeting.
4. Do not drill holes in polycarbonate connectors too big. This tends to weaken connectors and chance of failure increases.

REFERENCES

1. National Cooperative Highway Research Program Report 230 (NCHRP 230), "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," Transportation Research Board, Washington D.C., March, 1981.
2. American Association of State Highway and Transportation Officials (AASHTO), "Standard Spcifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals," Section 7, 1985.
3. J. Hinch, T-L Yang, and R. Owings, "Guidance Systems for Vehicle Testing," ENSCO, Inc., Springfield, VA, 1986.
4. National Research Council, "Roughness and Skid Resistance," Highway Research Board, Bulletin No. 37, 1951.
5. "Vehicle Damage Scale for Traffic Accident Investigators," Traffic Accident Data Project Technical Bulletin No. 1, National Safety Council, Chicago, Ill., 1971.
6. "Collision Deformation Classification - SAE J224 Mar 80," SAE Handbook Vol. 4, Society of Automotive Engineers, Warrendale, Penn., 1985.