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TEXAS TRANSPORTATION INSTITUTE

TESTING AND EVALUATION OF WORK ZONE TRAFFIC CONTROL DEVICES PROVIDED BY FLASHER EQUIPMENT COMPANY

Prepared by

King K. Mak, P. E.
Research Engineer

and

W. L. Campise
Research Associate

Project No. 71770

Sponsored by

Flasher Equipment Company
246 West Josephine Street
San Antonio, Texas 78212

January 1991

Texas Transportation Institute
Texas A&M University System
College Station, Texas 77843

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February 7, 1991

Mr. Herb Gruen
Flasher Equipment Company
246 West Josephine St.
San Antonio, Texas 78212

RE: TTI Project No. RF 7177, "Crash Testing and Evaluation of Work Zone Traffic Control Devices Provided by Flasher Equipment Company"

Dear Mr. Gruen,

Enclosed is one (1) original and three (3) copies of the final report for the referenced project. This completes all requirements for the contract. If you have any questions or comments regarding the final report or the project, please do not hesitate to call me.

It has been a pleasure working with you and Mr. Rick Milton. Looking forward to working with you again in the future.

Best regards.

Sincerely,

King K. Mak
Research Engineer

cc: Dr. C. V. Wootan
Mr. Bruce Cunningham, TAMRF

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TRAFFIC CONTROL DEVICES

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DISCLAIMER

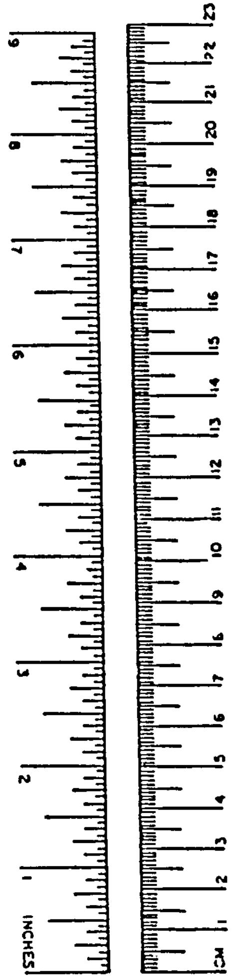
The contents of this report reflect the views of the authors who are solely responsible for the opinions, findings, and conclusions presented herein. The report does not necessarily reflect the official views or policies of the Flasher Equipment Company. This report does not constitute a standard, specification, or regulation.

It is the policy of Texas Transportation Institute (TTI) and the Texas A&M University System not to endorse any specific manufacturers, trademarks, or products. Therefore, this report does not constitute endorsement by TTI or the Texas A&M University System of the work zone traffic control devices designed and manufactured by Flasher Equipment Company that were crash tested and evaluated in this study.

METRIC CONVERSION FACTORS

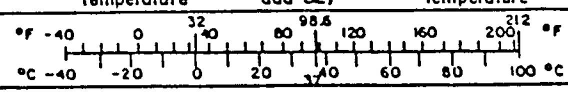
APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I. INTRODUCTION

Flasher Equipment Company of San Antonio, Texas contracted with the Texas Transportation Institute (TTI) to conduct full-scale crash tests on various work zone traffic control devices designed and manufactured by Flasher Equipment Company. The key feature of these proprietary work zone traffic control devices is a spring-loaded mechanism that allows the traffic control device, upon impact by an errant vehicle, to return to its pre-impact position. This would provide continuity in the service of the traffic control devices and greatly reduce the need for maintenance of these traffic control devices due to vehicular impacts. The objective of this study was to assess the impact performance of these proprietary work zone traffic control devices.

It should be noted that Flasher Equipment Company provided all the materials and the personnel and equipment to install the test installations, which were then crash tested without any adjustment or modification by the project staff. Also, most of the tested devices were prototype units. Depending on changes, if any, made to the designs in the manufacturing process, the performance of the prototype units may or may not be indicative of that of actual production units. Readers are referred to Flasher Equipment Company for details on their proprietary work zone traffic control devices. For identification purposes, the model numbers for the various traffic control devices tested in this study, as provided by Flasher Equipment Company, are shown in Table 1.

As can be seen from the table, there were five major types of work zone traffic control devices included in the testing:

1. Single vertical panels
2. Double vertical panels
3. Delineators
4. Chevron signs, and
5. Simulated barrel signs.

Depending on the application, these work zone traffic control devices might be mounted on one of the following four types of bases:

1. Driveable base
2. Portable base
3. Fixed base attached to the pavement with epoxy or bituminous material, and
4. Special mounting for use on top of concrete safety shaped barrier.

Table 1. Model Numbers of Traffic Control Devices Tested

Traffic Control Device	Base Type	Light	Model No.
Single Vertical Panel	Fixed	No	300-WHRRN-101R0
	Barrier Mounted	No	300-WHRRN-104R0
	Portable	No	300-WHRRN-105R0
	Driveable	No	300-WHRRN-106R0
	Driveable	Yes	300-WHRRN-106R1
Double Vertical Panel	Fixed	No	300-WHRRL-101R0
	Fixed	Yes	300-WHRRL-101R1
	Portable	No	300-WHRRL-105R0
Delineator	Fixed	No	200-WEFA-101R0
	Driveable	No	200-WEFA-106R
Chevron Sign	Fixed	No	405-WHL-101B0
Simulated Barrel Sign	Fixed	No	409-WEFN-101R0
	Fixed	Yes	409-WEFN-101R1
	Portable	No	409-WEFN-105R0

Also, flashing or steady-burn lights may be used with some of these traffic control devices.

A total of 17 crash tests were conducted in this study, covering various combinations of traffic control device, base type, and presence or absence of lighting fixture as well as two different nominal impact speeds of 45 or 60 miles per hour (mi/h). Section II describes the study approach, including the test installations, test procedures and evaluation criteria. The test results are summarized in Section III and a summary of findings and conclusions are presented in Section IV of this report.

II. STUDY APPROACH

Currently there are no established standards or guidelines governing the conduct or evaluation of full-scale crash tests of work zone traffic control devices. Under previous work at Texas Transportation Institute,[1,2] a study approach was developed for full-scale crash testing of work zone traffic control devices based on information from available literature and experience gained from other crash testing programs. The study approach covered such items as test installations, test procedures, and evaluation criteria. This study approach was adopted for the conduct and evaluation of the crash tests performed under this study. Brief discussions on each item of the study approach are presented in this section.

TEST INSTALLATIONS

Table 2 summarizes the 17 crash tests conducted in this study. As mentioned previously, these tests covered various combinations of traffic control devices, base types, presence/absence of lights, and nominal impact speeds. It should be noted that the single vertical panel mounted on a wood box weighted with sand bags tested in test 15 is the current field practice of mounting single vertical panels for use in work zones in San Antonio, Texas and the test was intended for comparison purposes. Also, tests 16 and 17 involving single vertical panels mounted on top of concrete safety shaped barriers were intended for demonstration purposes.

A typical test installation would consist of two to four assemblies of the work zone traffic control device being tested arranged in a straight line. The assemblies would be spaced 45 feet apart for a 45 mi/h nominal impact speed test and 60 feet apart for a 60 mi/h nominal impact speed test. Flashing light units might also be attached to selected assemblies, as determined by Flasher Equipment Company personnel who installed the test installation. Description of the individual test installations are provided for each test under the section on "Study Results".

For the fixed bases, two different types of materials were used to attach the bases to the pavement: epoxy and bituminous material. These bases were installed by Flasher Equipment Company personnel approximately 36 hours prior to crash testing to ensure sufficient bonding strength. The actual traffic control device assemblies were attached to the bases shortly prior to the crash tests.

Table 2. Crash Test Matrix

Test No.	Traffic Control Device	Base Type	Presence/Absence of Light	Nominal Impact Speed
1	Single Vertical Panel	Driveable	None	45 mi/h
2	Single Vertical Panel	Driveable	Light on First Panel	60 mi/h
3	Delineator	Driveable	None	60 mi/h
4	Single Vertical Panel	Portable	None	60 mi/h
5	Double Vertical Panel	Portable	None	45 mi/h
6	Simulated Barrel Sign	Portable	None	45 mi/h
7	Simulated Barrel Sign	Portable	None	60 mi/h
8	Repeat of Test No. 2 Single Vertical Panel	Driveable	Light on First Panel	60 mi/h
9	Double Vertical Panel	Fixed	Light on Fourth Panel	45 mi/h
10	Chevron Sign	Fixed	None	45 mi/h
11	Simulated Barrel Sign	Fixed	Light on Fourth Panel	45 mi/h
12	Delineator Post	Fixed	None	60 mi/h
13	Single Vertical Panel	Fixed	None	60 mi/h
14	Chevron Sign	Fixed	None	60 mi/h
15	Single Vertical Panel	Mounted on Wood Box	None	60 mi/h
16	Single Vertical Panel	Barrier Mounted	None	45 mi/h
17	Single Vertical Panel	Barrier Mounted	None	60 mi/h

TEST PROCEDURES

A 1982 Honda Civic (shown in Figure 1) was used for the first fifteen tests (i.e., tests 1 through 15). The test inertia weight of the vehicle was 1,800 lb and gross static weight was 1,967 lb. The damages sustained by the vehicle during the tests were mostly minor and cosmetic in nature, thus allowing the same vehicle to be used for all 15 tests. After each test, the vehicle was repaired to the extent possible. A utility truck (provided by Flasher Equipment Company) with a 2-inch diameter pipe extended from the side was used for tests 16 and 17.

The vehicles were driven into the work zone traffic control devices for all tests except test 15 in which the vehicle was directed into the device using a cable-reverse tow and guidance system. In all cases, the vehicle was released to be free-wheeling and unrestrained just prior to impact with the devices. Pressure sensitive contact switches on the bumper of the Honda were 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 produced an "event" mark on the data record to establish the exact instant of impact as well as actuate a flash unit placed in view of the videotape and high-speed cameras. The vehicle remained virtually free-wheeling, i.e., with minimal or no steering and no braking inputs, until the vehicle cleared the traffic control devices, at which time brakes on the vehicle were actuated to bring the vehicle to a safe, controlled stop.

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates, and a triaxial accelerometer near the center-of-gravity to measure longitudinal, lateral, and vertical acceleration levels. The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant band width FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Provision was made for the transmission of calibration signals before and after the tests, and an accurate time reference signal was simultaneously recorded with the data.

The multiplex of data channels, transmitted on one radio frequency, was received at the data acquisition station, and demultiplexed into separate tracks of Intermediate Range Instrumentation Group (IRIG) tape recorders. After each test, the data were played back from the tape machines, filtered with a Class 180 filter, and digitized using a microcomputer, for analysis and evaluation of performance. The digitized data were then processed using two computer programs:

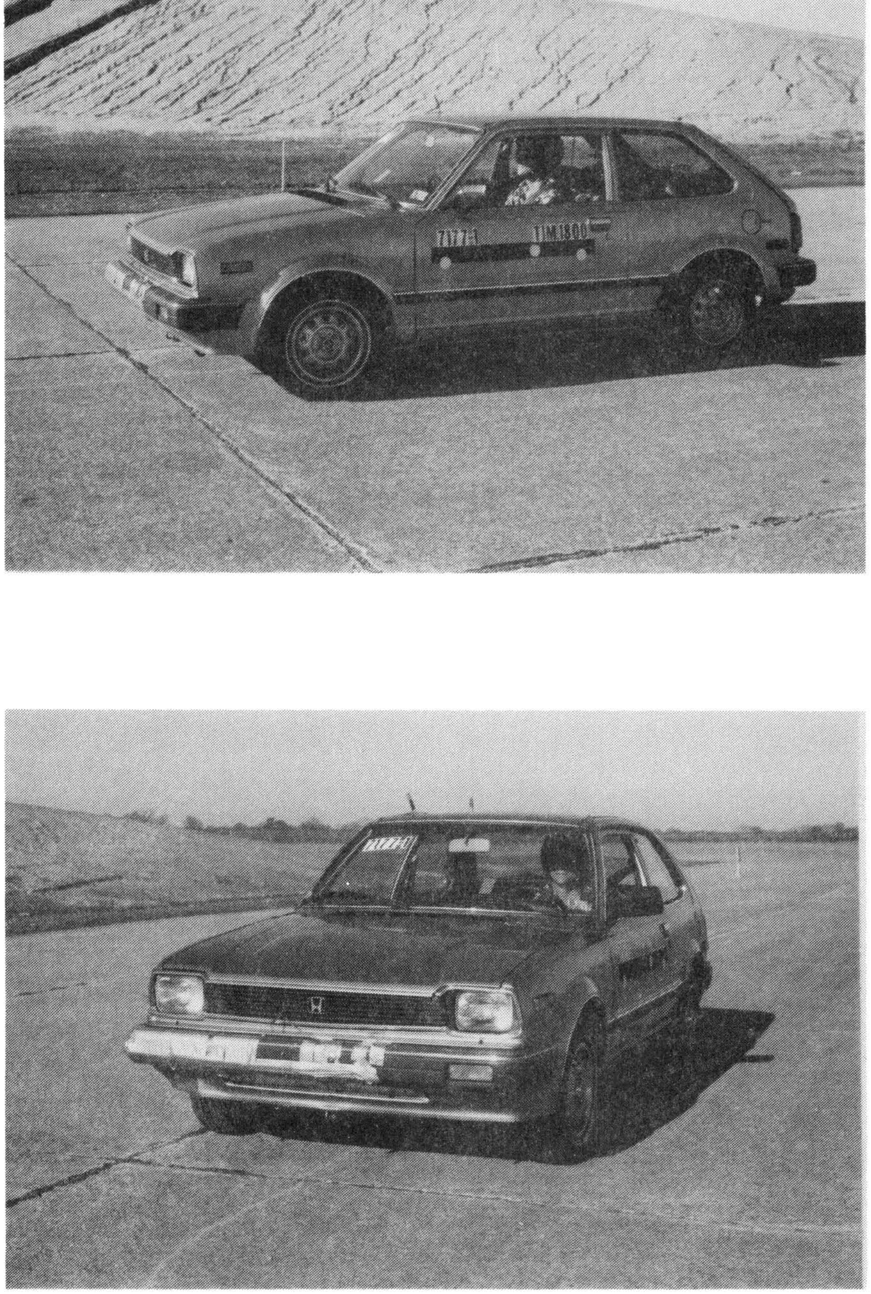

Figure 1. 1982 Honda Civic used in tests 1-15.

DIGITIZE and PLOTANGLE. Brief descriptions of the functions of these two computer programs are provided as follows.

The DIGITIZE program uses digitized data from the vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-msec 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-msec intervals in each of the three directions are computed. Acceleration versus time curves for the longitudinal, lateral, and vertical directions are then plotted from the digitized data of the vehicle-mounted linear accelerometers using a commercially available software package (QUATTRO PRO).

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 1-msec 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 coverage of the tests included one 3/4-inch videotape camera placed downstream from the point of impact, and one 16-mm high-speed camera placed perpendicular to the vehicle path at the first traffic control device. The videotape and film from these cameras were used for analysis and documentation of the crash tests. In addition, still cameras were used for documentary purposes.

EVALUATION CRITERIA

Since there are no established criteria or guidelines for evaluating the impact performance of work zone traffic control devices, the evaluation criteria developed under previous work [1,2] were adopted for use in this study. These evaluation criteria were based on information from such sources as National Cooperative Highway Research Program (NCHRP) Report 230 [3] and Transportation Research Circular (TRC) 191 [4], keeping in mind the uniqueness of the work zone environment. The following is a brief description of the evaluation criteria developed under the previous studies and used in this project.

1. Occupant risk. Occupant risk is a measure of the probability for serious injury to occupant(s) of the impacting vehicle, measured in terms of the

occupant impact speed and highest 10-msec average ridedown acceleration as outlined in NCHRP Report 230. This provides an indication of the severity of impact with the traffic control device itself.

2. Damages to vehicle and traffic control devices. Damages to the vehicle and the traffic control devices provide an indication of the impact severity and the associated property damages.

3. Vehicle trajectory. Vehicle trajectory is a subjective assessment of the potential hazard associated with the trajectory of the vehicle after impact. Items of consideration include such factors as the roll, pitch, and yaw of the vehicle induced by impact with the traffic control devices, the stability of the vehicle (e.g., instability caused by the traffic control device wedged beneath a tire, excessive yaw or pitch, etc.), and the path of the vehicle after impact and the potential for intrusion into adjacent traffic lanes.

4. Debris from traffic control devices. This evaluation criterion provides a subjective assessment of the potential hazard caused by debris formed by the impact. This potential hazard can be viewed from three different perspectives:

   a. Potential intrusion into the passenger compartment. This is considered unacceptable because of the significant increase in the risk of injury to its occupants. This may include intrusion through the windshield, firewall, floor, or body panels by parts of the test device, or intrusion into the windshield by the vehicle hood. Of particular concern is debris impacting the windshield which may break the windshield resulting in broken glass entering the passenger compartment or adversely affecting the ability of the driver to see out of the windshield, which may in turn lead to secondary collisions. Finally, puncture of the fuel tank resulting in fuel leakage was considered unacceptable because of fire risk.

   b. Debris thrown into adjacent traffic lanes could pose a potential hazard by causing oncoming drivers to make emergency evasive action leading to loss of control and a secondary collision. Sand or other debris scattered on the pavement may also lead to loss of control of other vehicles, especially motorcycles.

   c. Debris thrown into the work zone could present a hazard to the workers because of the close proximity of construction workers to the traffic control devices. This involves a subjective assessment of whether the debris would constitute a hazard, based on such factors as size, rigidity, and trajectory of the debris.

Another consideration not included in the evaluation criteria of the previous studies, but added to this study, is the functionality and condition of the traffic control device after impact by the vehicle. This consideration is specific to this project since the key feature of these proprietary work zone traffic control devices is a spring-loaded mechanism that allows the traffic control device to return to its pre-impact position, thus providing continuity in the service of the traffic control devices and reducing the need for maintenance of these traffic control devices due to vehicular impacts.

III. STUDY RESULTS

A summary of the results for each of the 17 crash tests are presented in this section. Note that the various work zone traffic control devices were supplied and installed by Flasher Equipment Company and descriptions of the test installations are limited to the general setup of the traffic control device assemblies. The readers will have to contact Flasher Equipment Company for more detailed information on the traffic control devices themselves.

Test 7177-1

The test installation (shown in Figures 2 and 3) consisted of four (4) single vertical panel assemblies with driveable bases (Model No. 300-WHRRN-106RO) arranged in a straight line. The assemblies were located one foot off the pavement and spaced 45 feet apart for a nominal impact speed of 45 mi/h. The driveable bases were driven into the soil with a sledge hammer. It should be noted that the soil where the driveable bases were installed was uncompacted and untreated, thus not necessarily representative of typical soil conditions found on the shoulder or roadside areas next to highways.

The test vehicle was travelling at a speed of 43.9 mi/h as it contacted the first device. The impact point was the right quarter point of the vehicle bumper. The driver had to make a slight steering correction after the vehicle impacted the second device. This was probably the result of the cross slope on the soil surface and not caused by the impact with the single vertical panel assemblies. The vehicle traversed over all four single vertical panel assemblies smoothly and in a stable manner. All four vertical panels sprang up to their pre-impact positions after the vehicle went over them. The panels were scraped and slightly bent and the bolt on the top connection of the fourth panel broke off. The vehicle sustained minor scrapes to the hood which were polished out before the next test. Damage to the traffic control devices and the vehicle are shown in Figures 4 through 8.

There was no occupant impact during the test period. The maximum 50-msec average accelerations were -0.3 g between 44 and 94 msec in the longitudinal direction and -0.2 g between 19 and 69 msec in the lateral direction.

The vehicle received cosmetic damages only and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a relatively straight, smooth path through the test site with no intrusion into

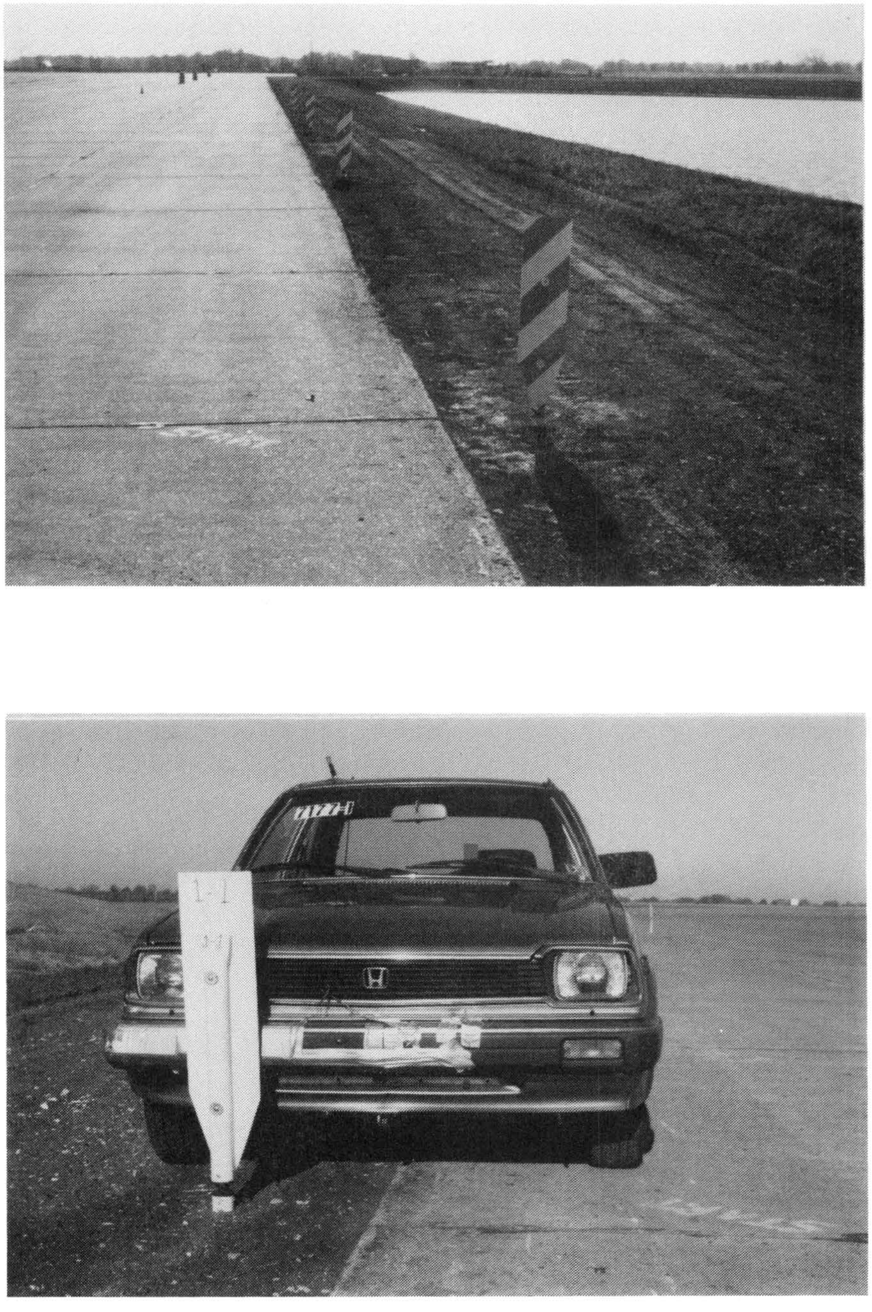

Figure 2. Installation and vehicle before test 7177-1.

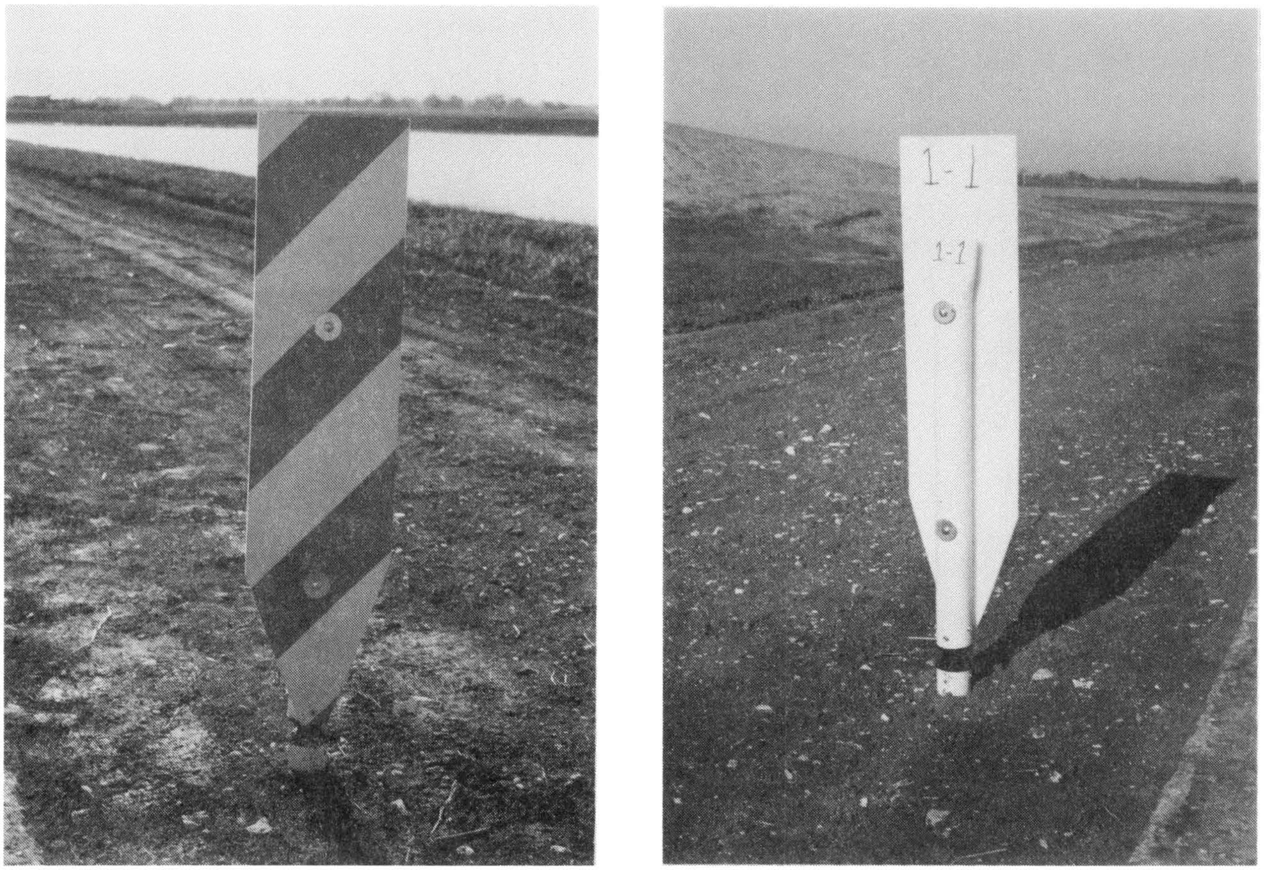

Figure 3. Typical device used in test 7177-1.

Figure 4. Vehicle and test site after test 7177-1.

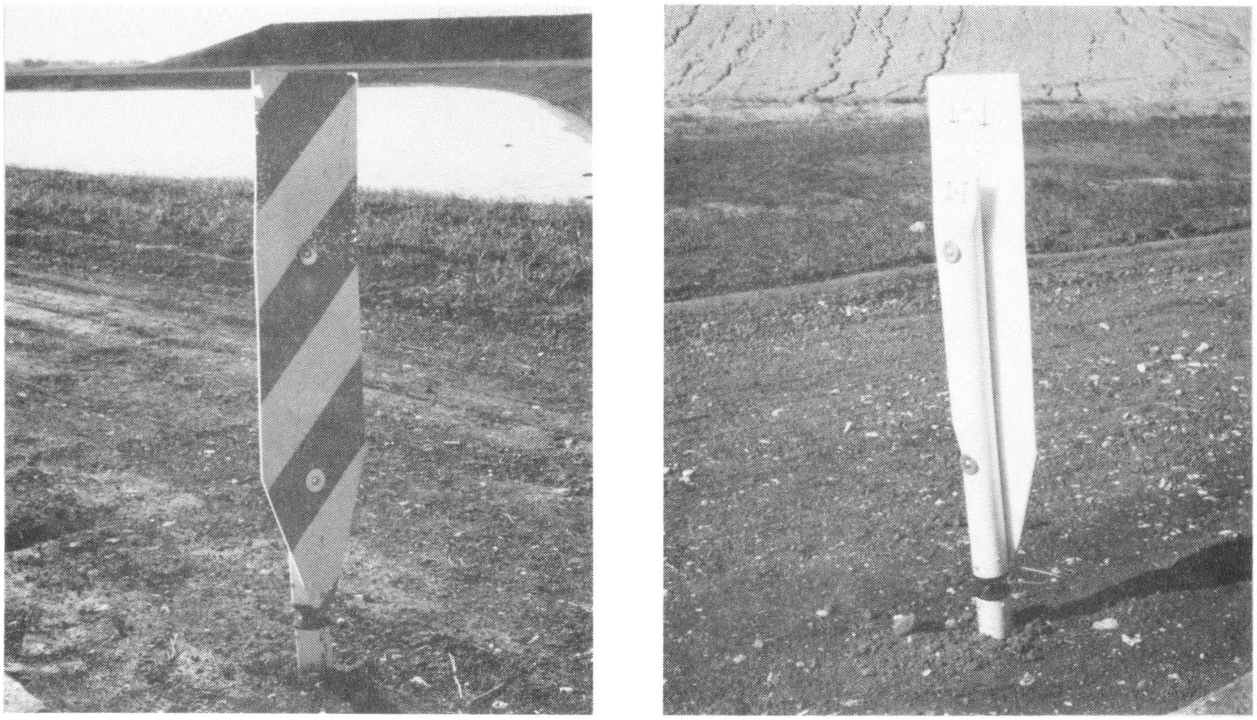

Figure 5. Damage to first device, test 7177-1.

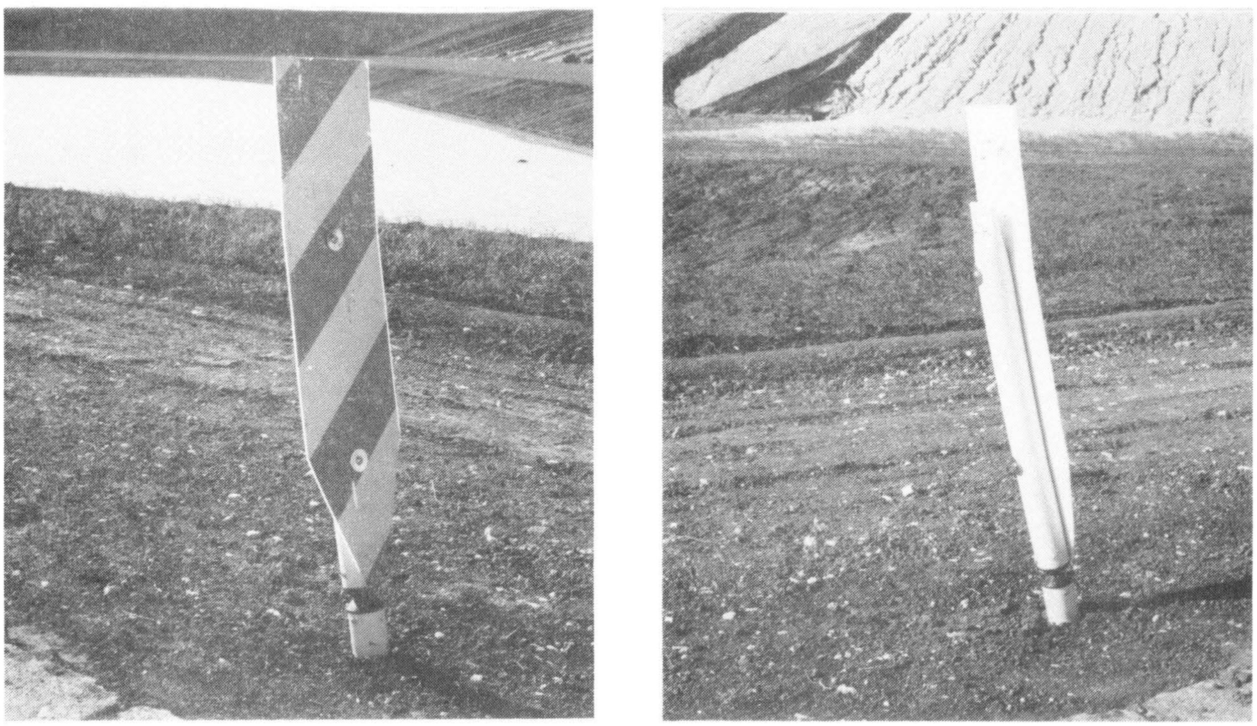

Figure 6. Damage to second device, test 7177-1.

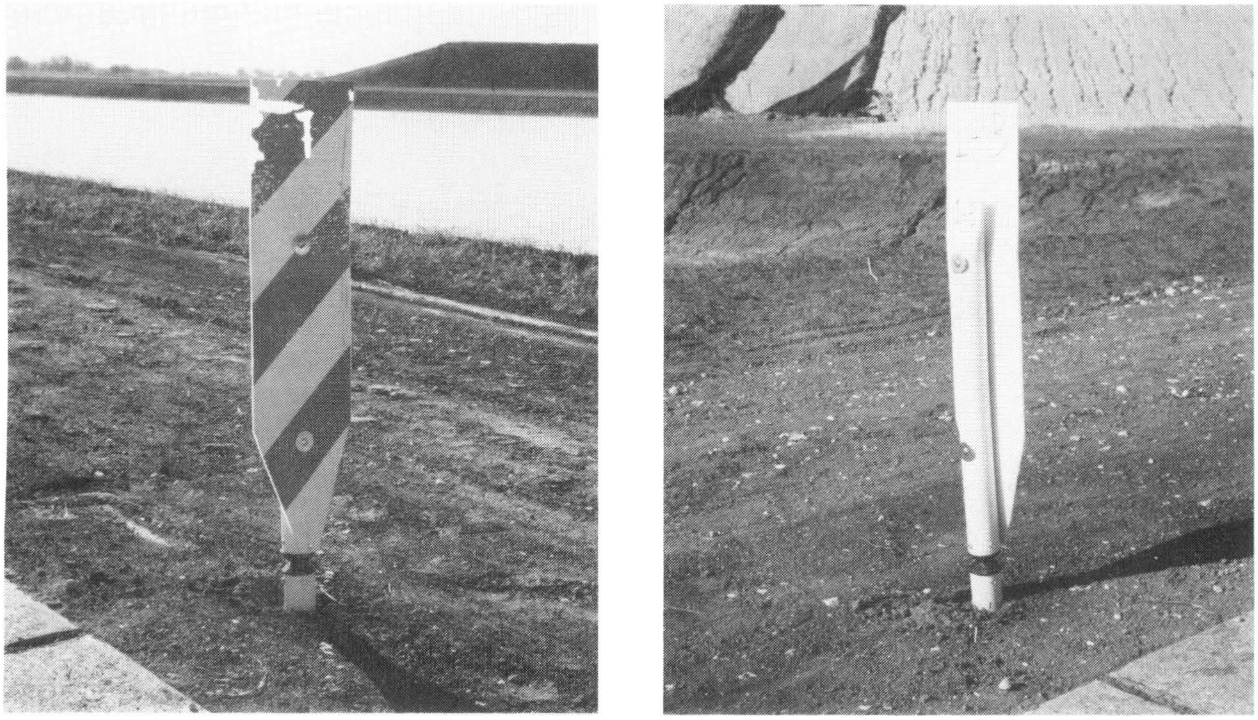

Figure 7. Damage to third device, test 7177-1.

Figure 8. Damage to fourth device, test 7177-1.

adjacent traffic lanes. The vehicle remained stable throughout the test sequence. The vertical panels remained intact and sustained only minor damages.

Test 7177-2

This test installation consisted of one (1) driveable single vertical panel assembly with flashing light unit and battery packs attached (Model No. 300-WHRRN-106R1) in the first position, followed by three (3) driveable single vertical panel assemblies (Model No. 300-WHRRN-106R0). The assemblies were arranged in a straight line located one foot off the pavement and spaced 60 feet apart for a nominal impact speed of 60 mi/h. The driveable bases were driven into the soil with a sledge hammer. As mentioned previously, the soil where the driveable bases were installed was uncompacted and untreated, thus not necessarily representative of typical soil conditions found on the shoulder or roadside areas next to highways. The flashing light unit was attached to the top of the post while the two battery packs were attached separately to the post near the base. Photographs of the test installation are shown in Figures 9 through 11.

The test vehicle impacted the first device with the right quarter point of the vehicle bumper, travelling at a speed of 60.0 mi/h. As the vehicle traversed over the first device, the whole assembly was pulled out of the ground and came to rest 105 feet down and 6 feet to the left of the impact point. One of the two battery packs separated from the post and came to rest 22 feet down from the impact point. There was no driver input as the vehicle rode smoothly over the following three devices which sprang up after the vehicle cleared them. All three panels were scraped and bent and the fastening bolts broke in the top connection of the third and fourth devices. The vehicle again received only minor scrapes to the hood which were quickly repaired before the next test. Damage to the traffic control devices and the vehicle are shown in Figures 12 through 16.

In the longitudinal direction, the occupant impact velocity was 6.2 ft/s at 427 msec, the highest 10-msec average ridedown acceleration was -0.4 g from 498 to 508 msec, and the maximum 50-msec average acceleration was -2.1 g between 31 and 81 msec. In the lateral direction, the occupant impact velocity was 5.5 ft/s at 463 msec, the highest 10-msec average ridedown acceleration was -1.3 g from 498 to 508 msec, and the maximum 50-msec average acceleration was -1.5 g between 95 and 145 msec.

Figure 9. Installation and vehicle prior to test 7177-2.

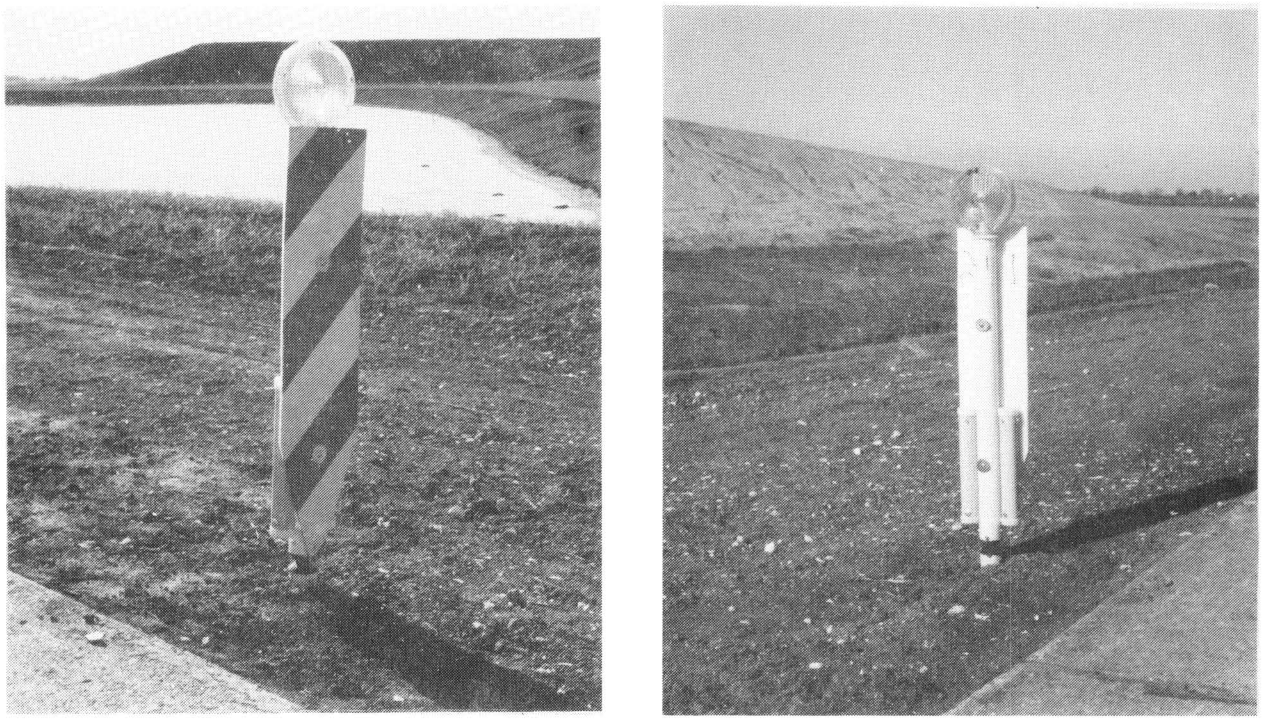

Figure 10 . First device of installation before test 7177-2.

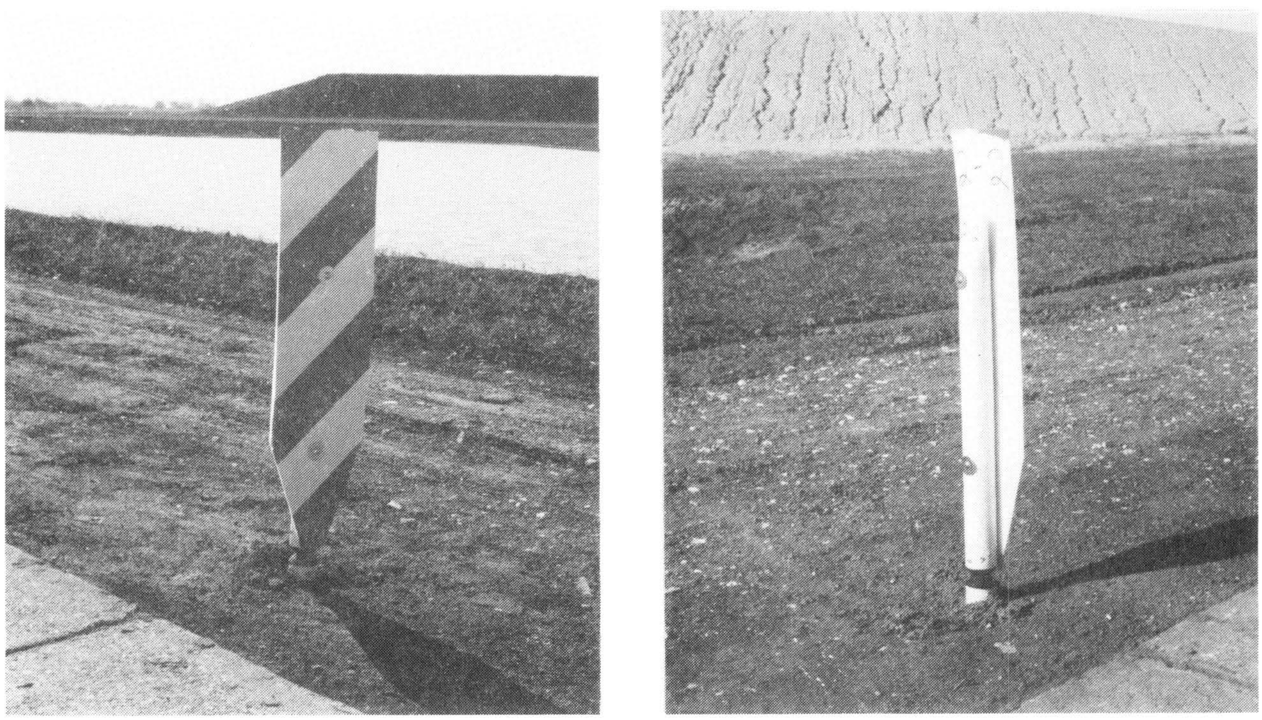

Figure 11 . Typical device used in position 2, 3, and 4 (before test 7177-2).

Figure 12. Vehicle and test site after test 7177-2.

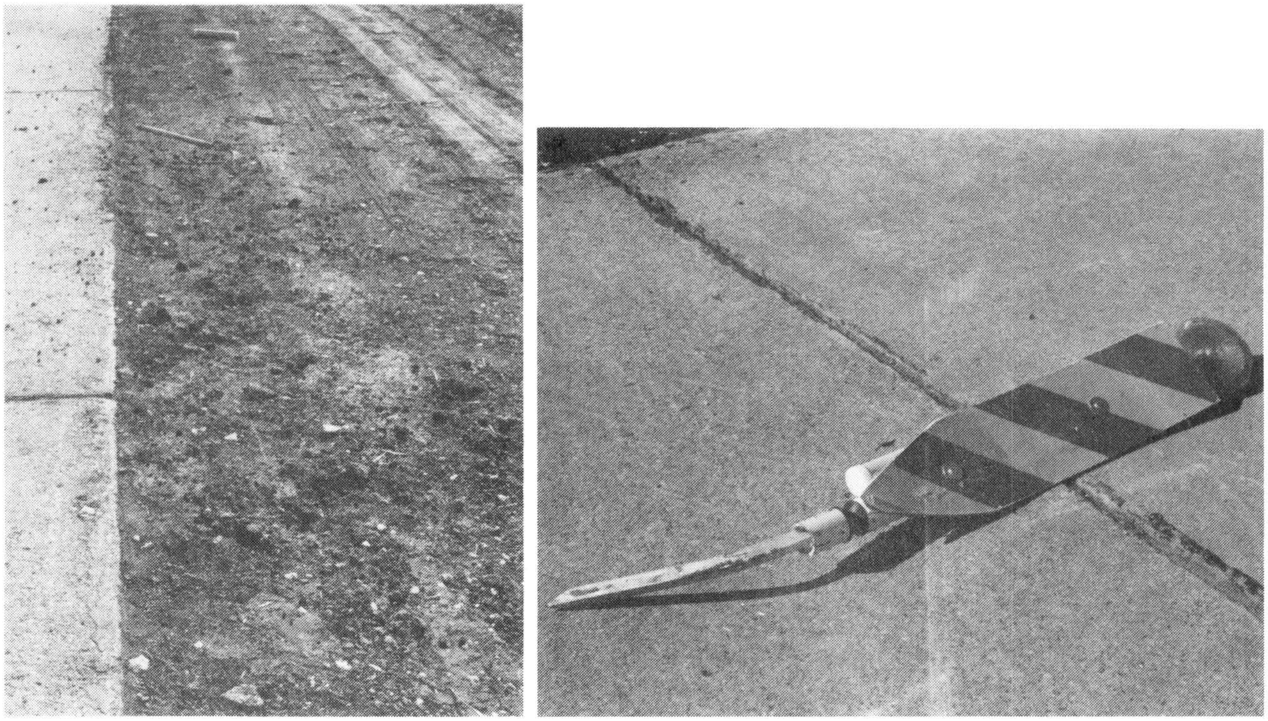

Figure 13. Damage to first device, test 7177-2.

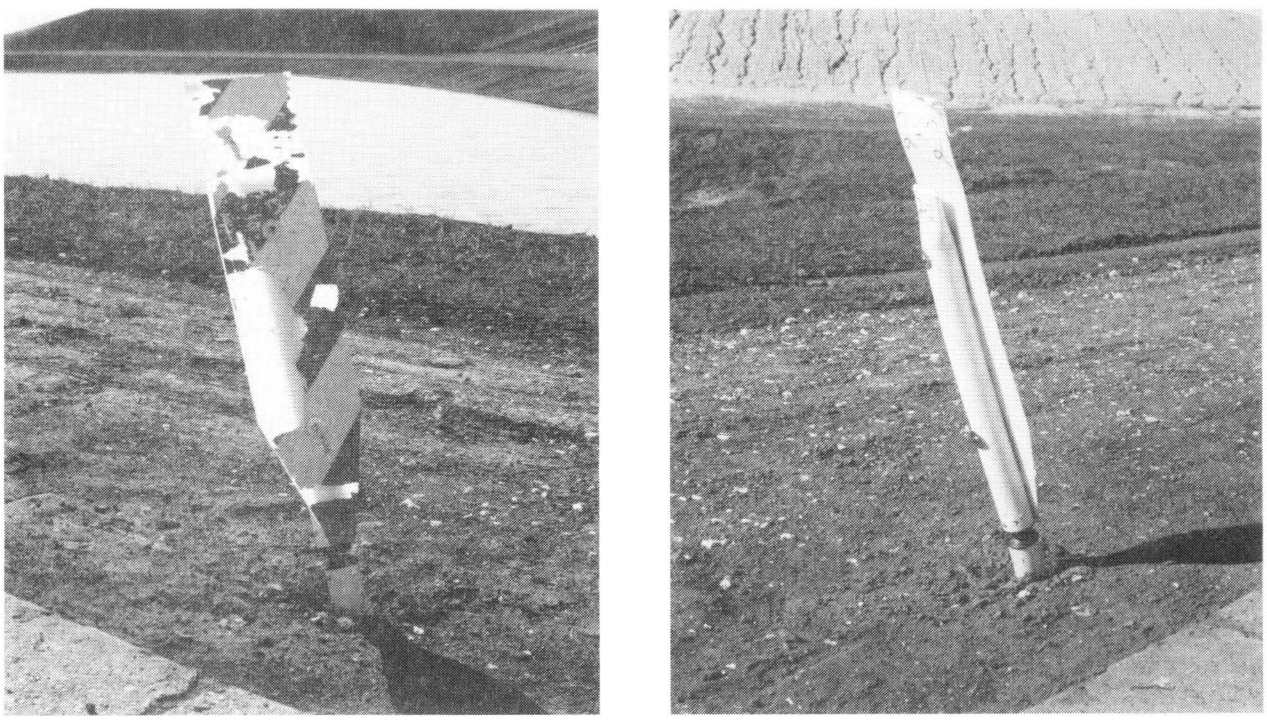

Figure 14. Damage to second device, test 7177-2.

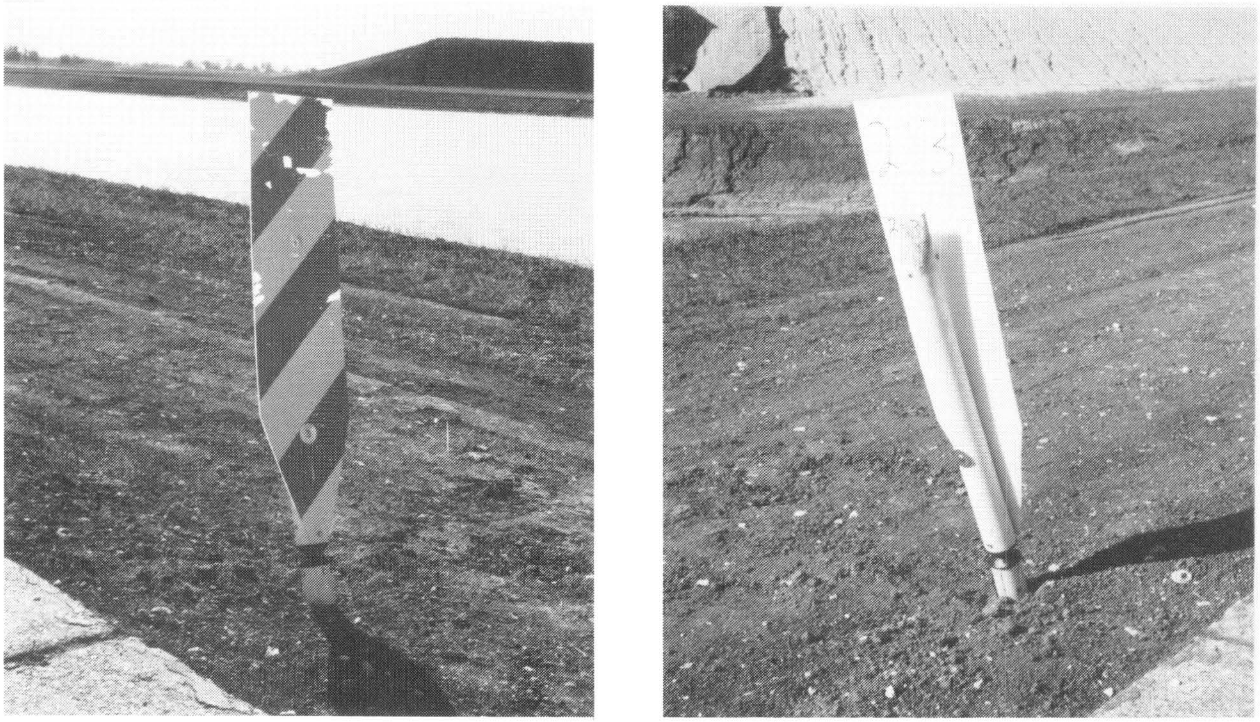

Figure 15. Damage to third device, test 7177-2.

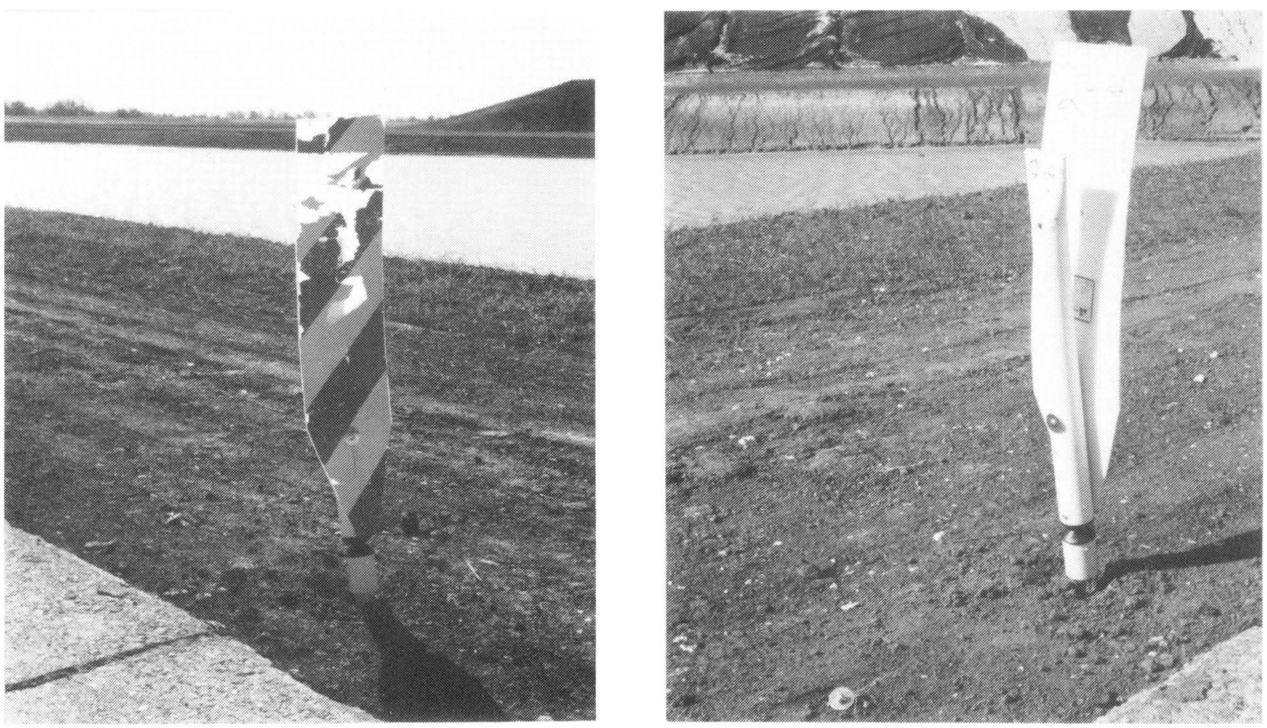

Figure 16. Damage to fourth device, test 7177-2.

The vehicle received cosmetic damages only and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a straight, smooth path through the test site with no intrusion into adjacent traffic lanes. The vehicle remained stable throughout the test sequence. The first vertical panel assembly was pulled out of the ground completely and thrown for some distance. The battery pack also separated from the assembly, but remained relatively close to the point of impact. It appeared that the low frictional properties of the uncompacted and untreated soil might have contributed to the assembly being pulled out of the ground as well as the added weight from the flashing light unit and the accompanying battery packs.

Test 7177-3

The installation used for test 3 (shown in Figures 17 and 18) consisted of four (4) driveable delineator posts (Model No. 200-WEFA-106R) arranged in a straight line one foot off the pavement and spaced 60 feet apart for a nominal impact speed of 60 mi/h. The driveable bases were driven into the soil with a sledge hammer. Again, the soil where the driveable bases were installed was uncompacted and untreated, thus not necessarily representative of typical soil conditions found on the shoulder or roadside areas next to highways.

The test vehicle was travelling at a speed of 58.2 mi/h as it contacted the first device with the right quarter point of the vehicle bumper. The driver again had to make a slight steering correction after the vehicle impacted with the third device due to the cross slope on the soil surface. Nevertheless, the vehicle traversed over all four devices smoothly and in a stable manner. All four delineator posts were bent and the reflective surface scraped, but the vehicle did not sustain any damage at all. Photographs of the delineators and the vehicle after the test are shown in Figures 19 through 23.

There was no occupant impact in the longitudinal direction and the maximum 50-msec average acceleration was -1.2 g between 25 and 75 msec. In the lateral direction, the occupant impact velocity was 4.5 ft/s at 526 msec, the highest 10-msec average ridedown acceleration was -0.5 g from 526 to 536 msec, and the maximum 50-msec average acceleration was -0.6 g between 12 and 62 msec.

The vehicle received no damage during the test and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a relatively straight, smooth path through the test site with no intrusion

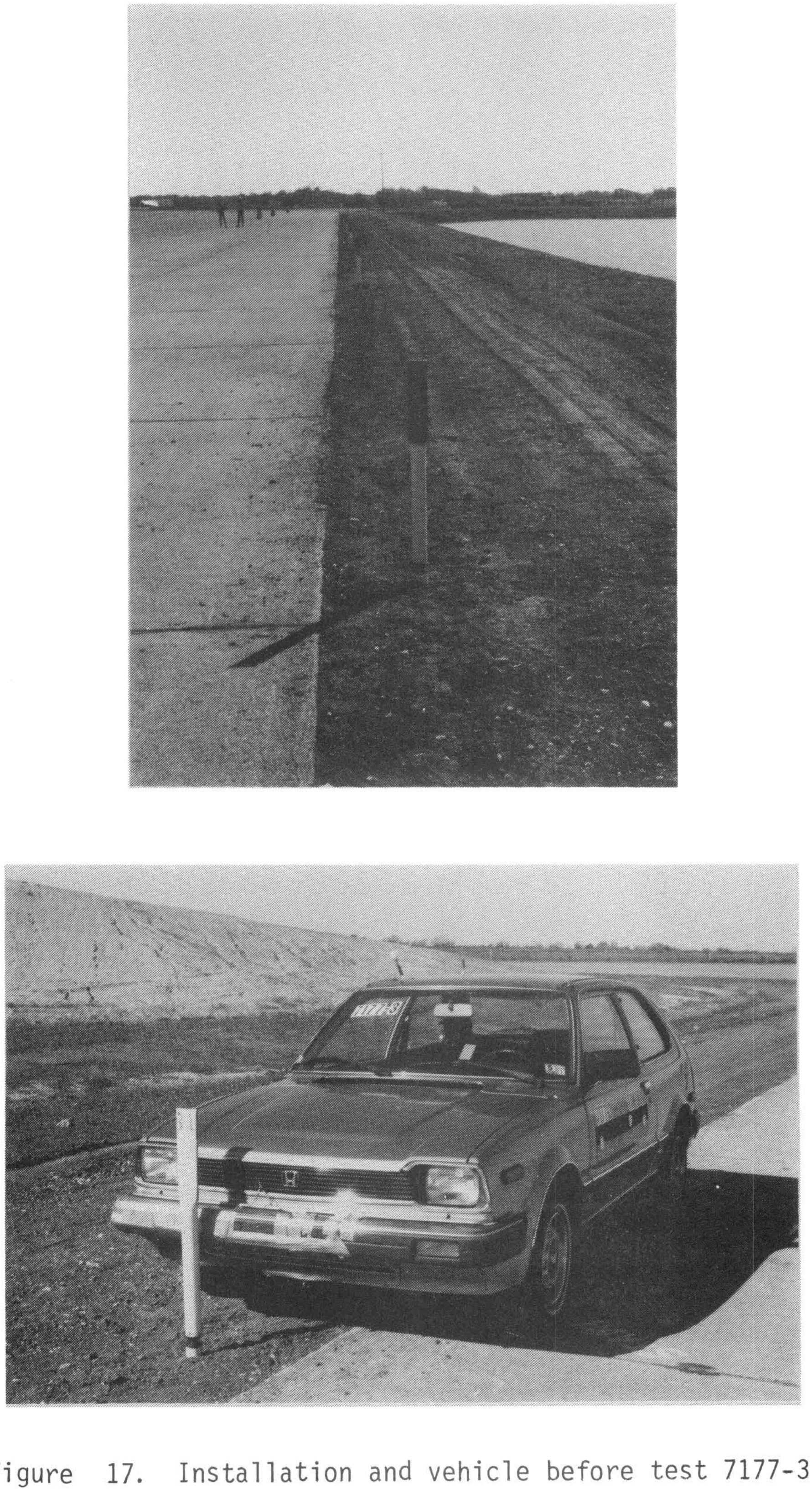

Figure 17. Installation and vehicle before test 7177-3.

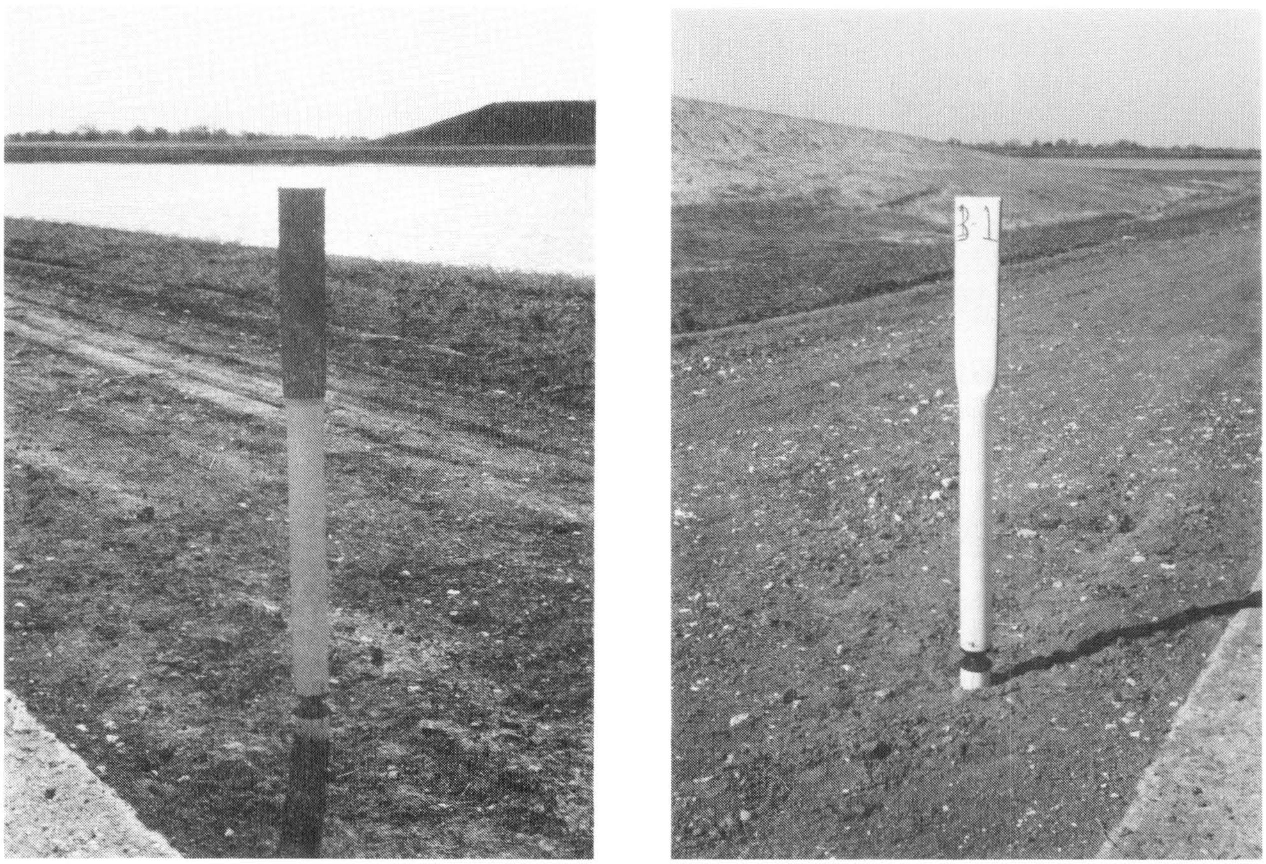

Figure 18. Typical device used in test 7177-3.

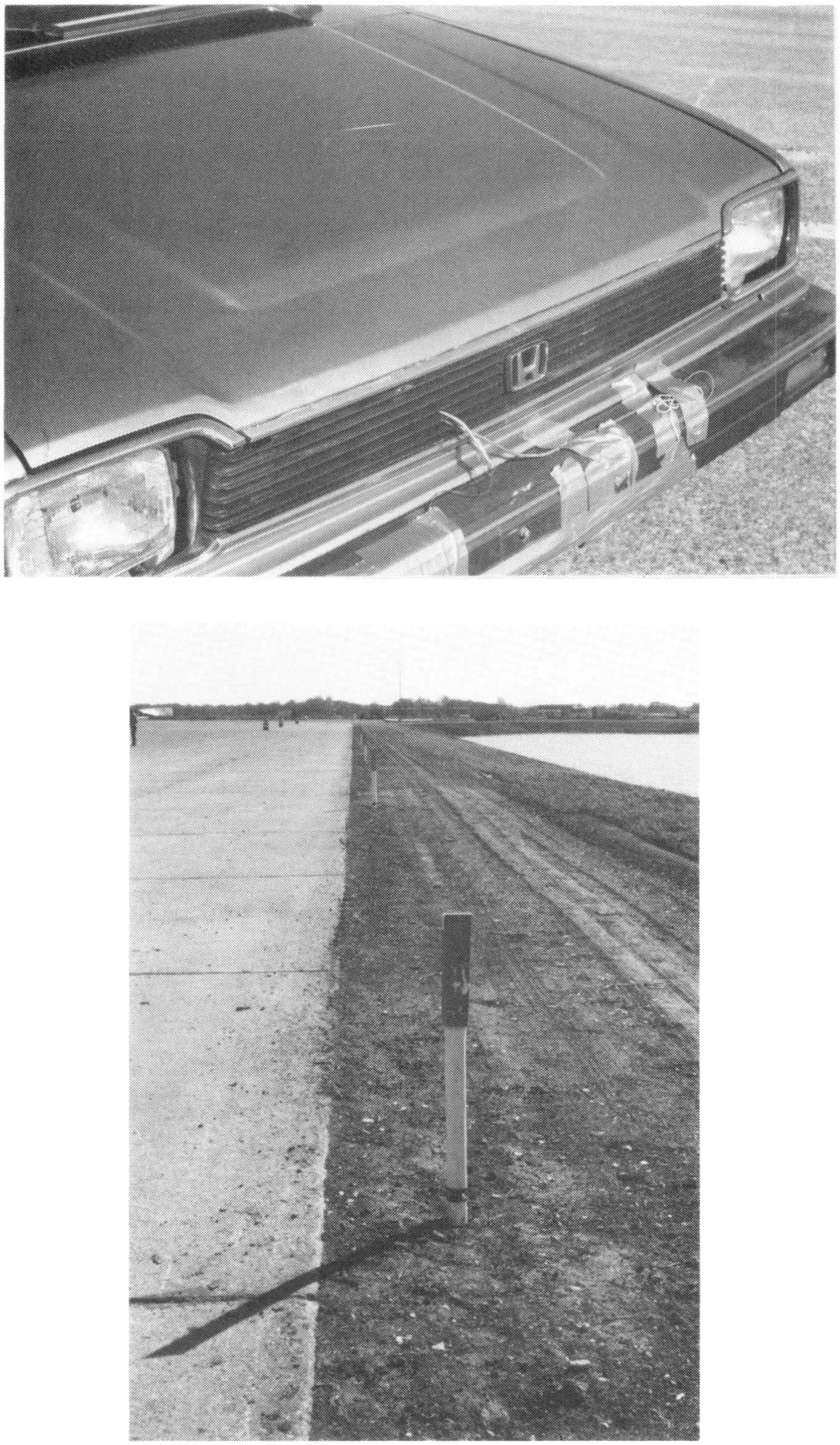

Figure 19. Vehicle and test site after test 7177-3.

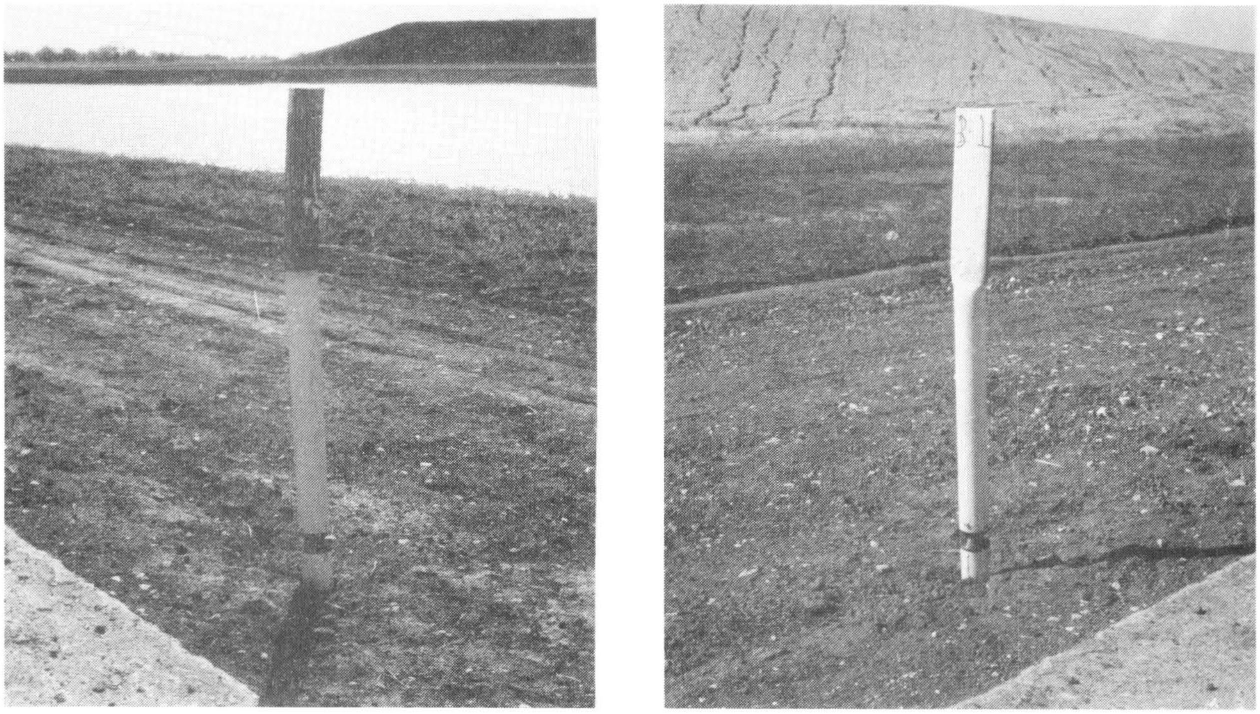

Figure 20. Damage to first device, test 7177-3.

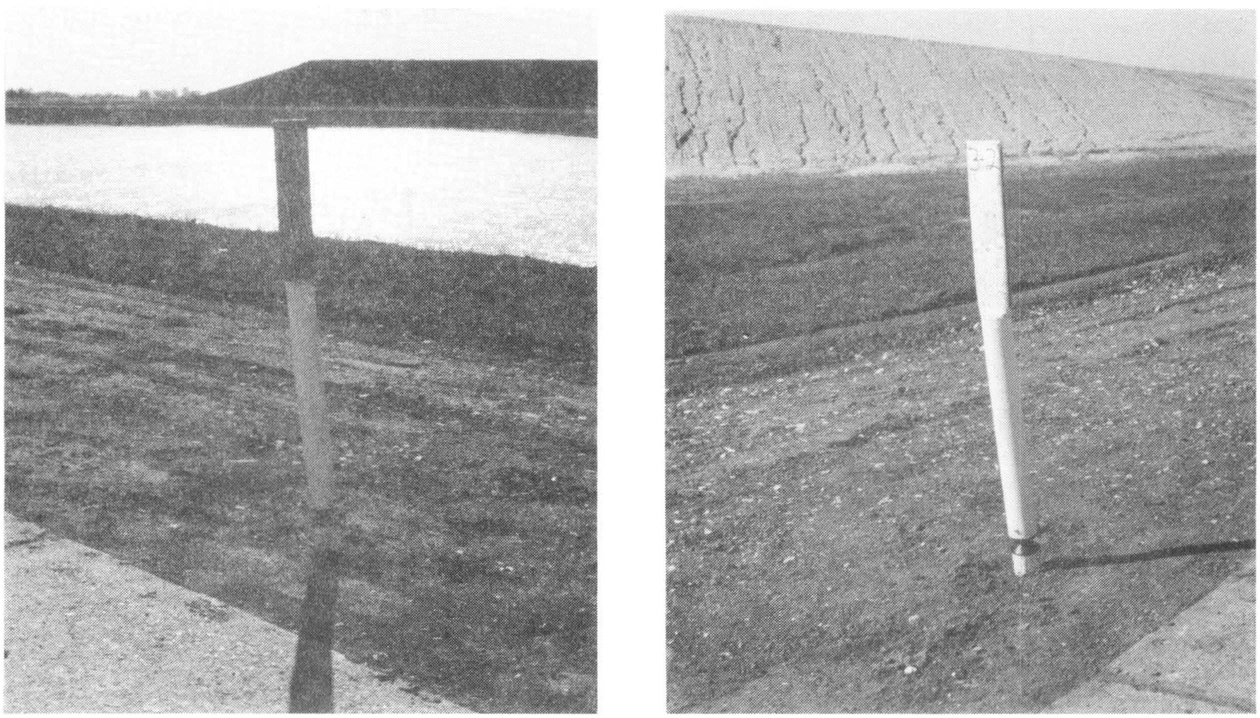

Figure 21. Damage to second device, test 7177-3.

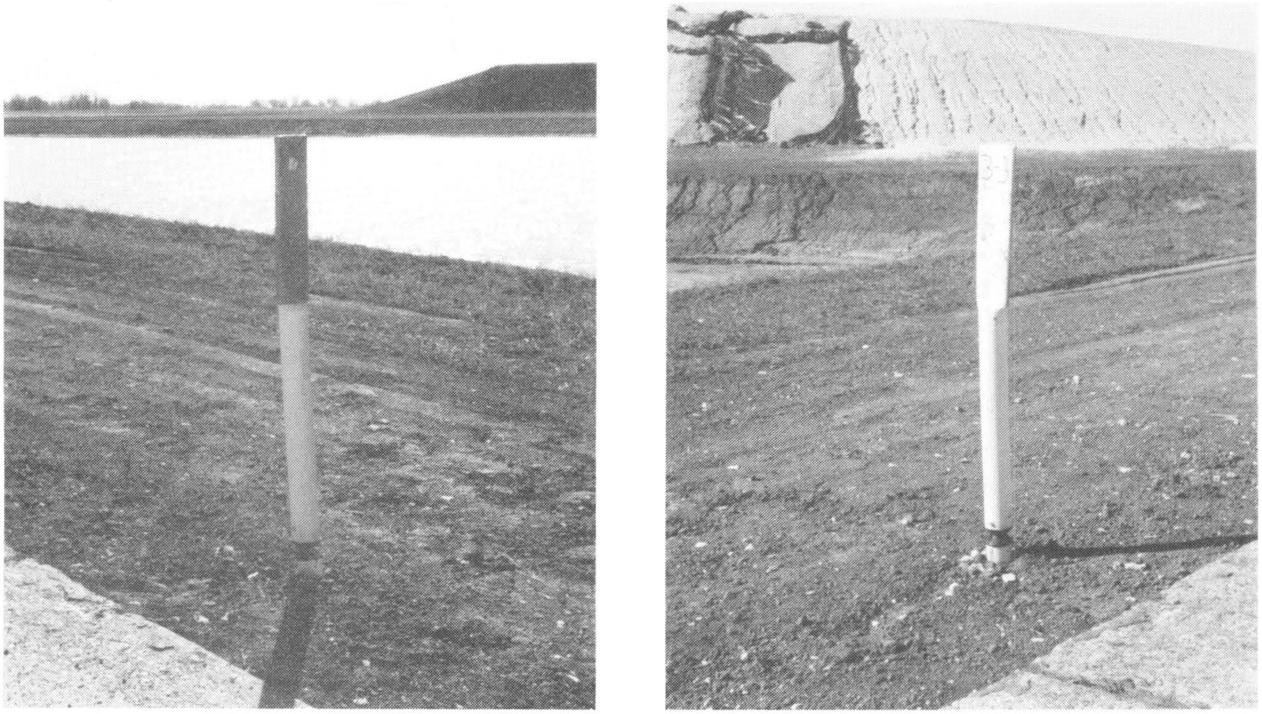

Figure 22. Damage to third device, test 7177-3.

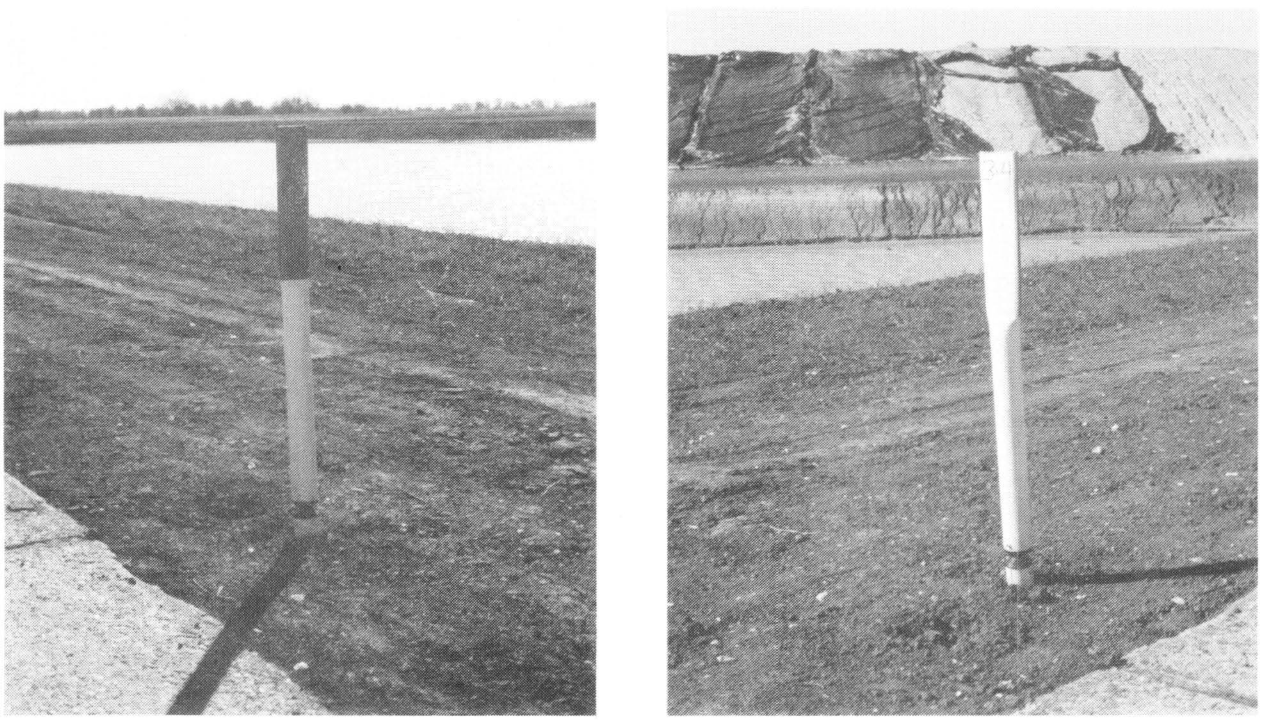

Figure 23. Damage to fourth device, test 7177-3.

into adjacent traffic lanes. The vehicle remained stable throughout the test sequence. The delineators remained intact and sustained only minor damages.

Test 7177-4

Two (2) portable single vertical panel assemblies (Model No. 300-WHRRN-105R0) spaced 60 feet apart were used in this test at a nominal impact speed of 60 mi/h. The installation is pictured in Figures 24 and 25.

The vehicle impacted the first device at 59.7 mi/h with the right quarter point of the vehicle bumper. There was no driver input as the vehicle traversed over the devices. Both devices were moved slightly from the impacts by the vehicle. The first device moved 5.2 feet down and 0.25 feet to the left, and the lower fastener was pulled from the panel. The second device moved 8.2 feet down and 0.5 feet to the left, and the lower fastener was also pulled from the panel. The knuckle on the second device was cracked, but remained functional. Damage to the devices is shown in Figures 26 and 27. There was no damage to the vehicle.

There was no occupant impact during the test period. The maximum 50-msec average accelerations were -0.7 g between 31 and 81 msec in the longitudinal direction and -0.4 g between 28 and 78 msec in the lateral direction.

There was no damage to the vehicle and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a straight, smooth path through the test site with no intrusion into adjacent traffic lanes. The vehicle remained stable throughout the test sequence. The panels were bent and scraped and the lower fasteners were torn off the panels. Also, the devices were moved slightly from impacts by the vehicle, but remained relatively close to their pre-impact positions.

Test 7177-5

Two (2) portable double vertical panel assemblies (Model No. 300-WHRRL-105R0) spaced 45 feet apart were set up for testing at a nominal impact speed of 45 mi/h. The installation is shown in Figures 28 and 29.

The vehicle was travelling at a speed of 43.3 mi/h as it impacted the first device with the right quarter point of the vehicle bumper. There was no driver input during the test period. The vehicle rode over the first device which bounced about 12 inches off the ground as the vehicle cleared the device. The device came to rest 12.2 feet down and 3.0 feet to the left. The top fasteners

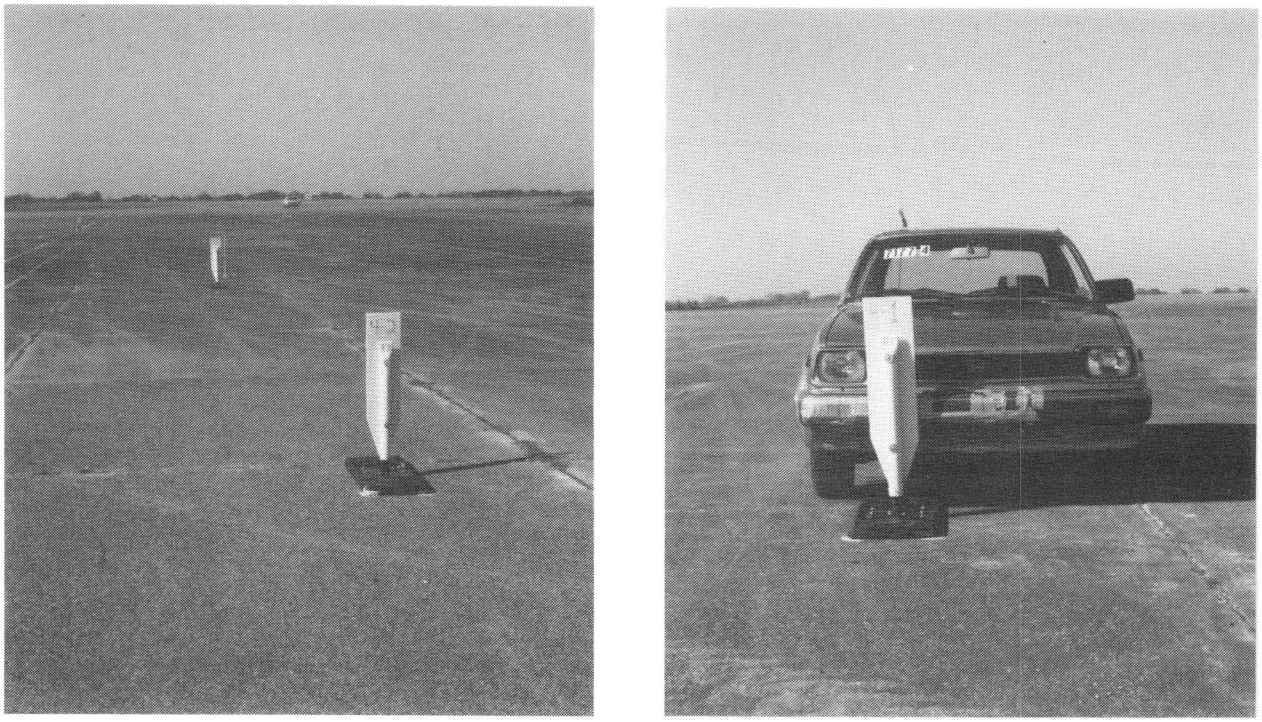

Figure 24. Installation and vehicle prior to test 7177-4.

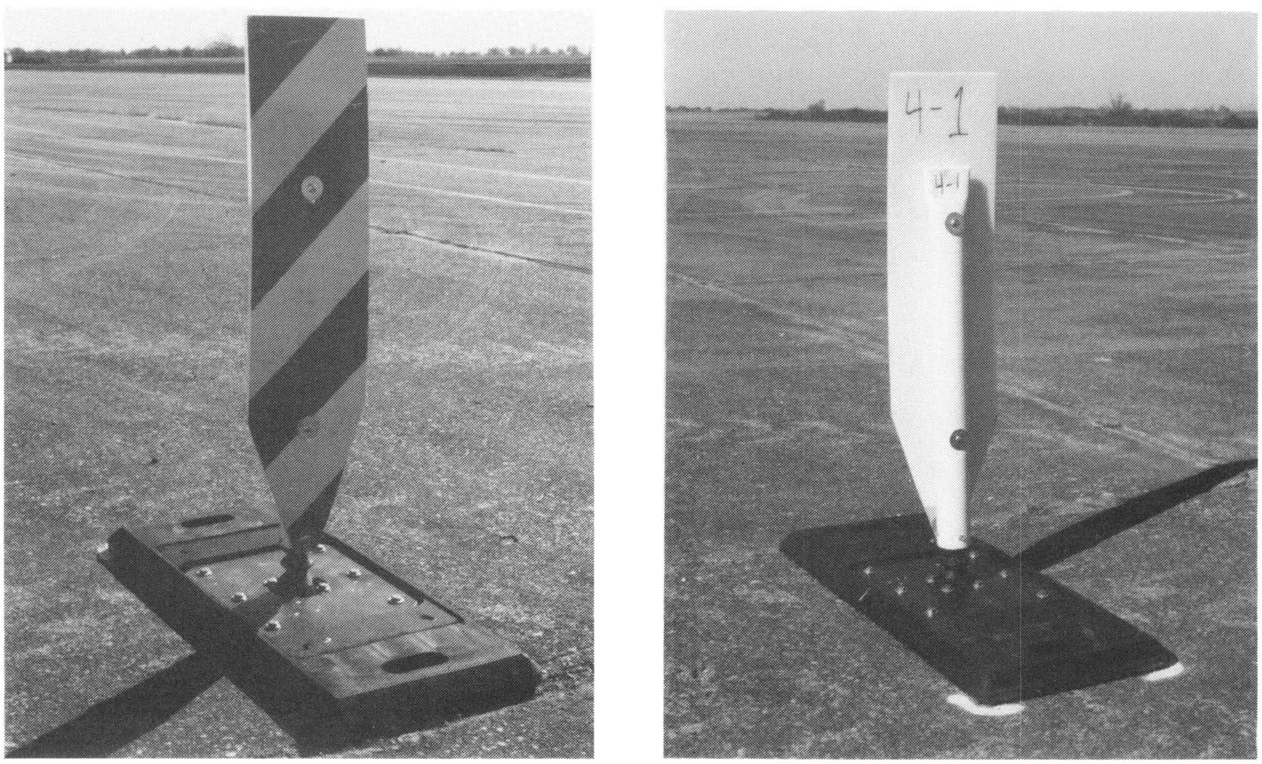

Figure 25 . Typical device used in test 7177-4.

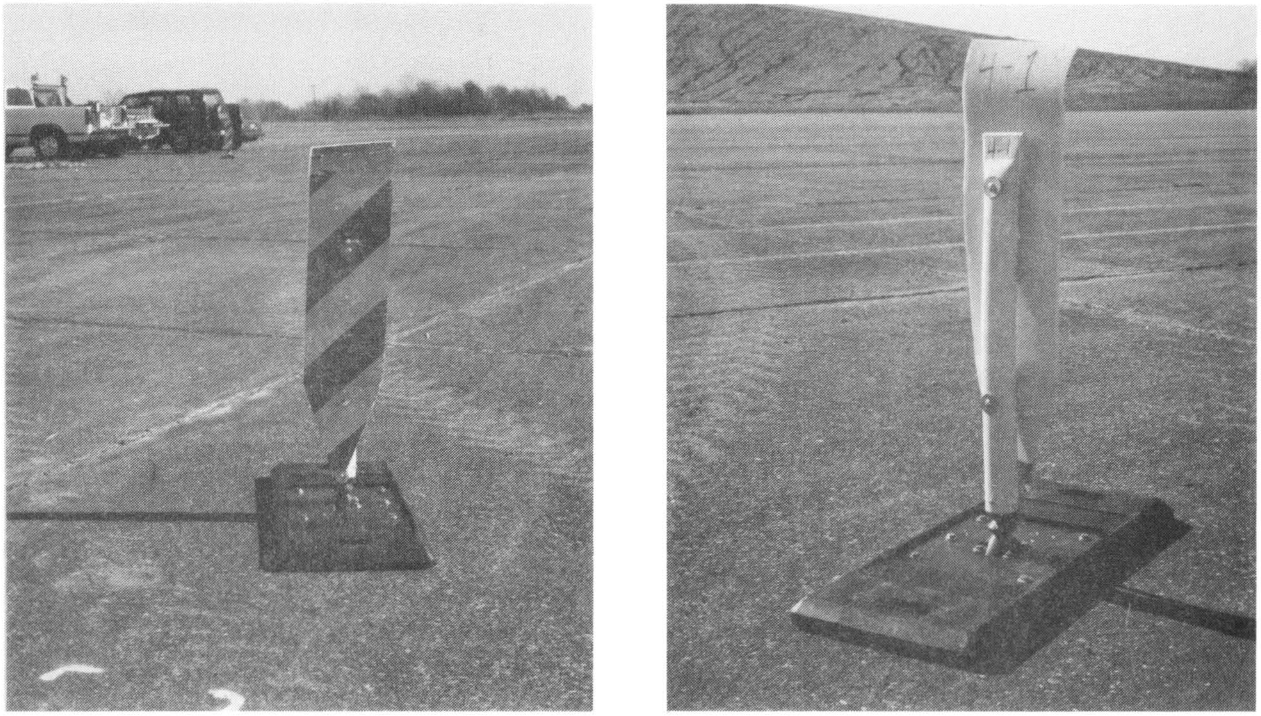

Figure 26. Damage to first device, test 7177-4.

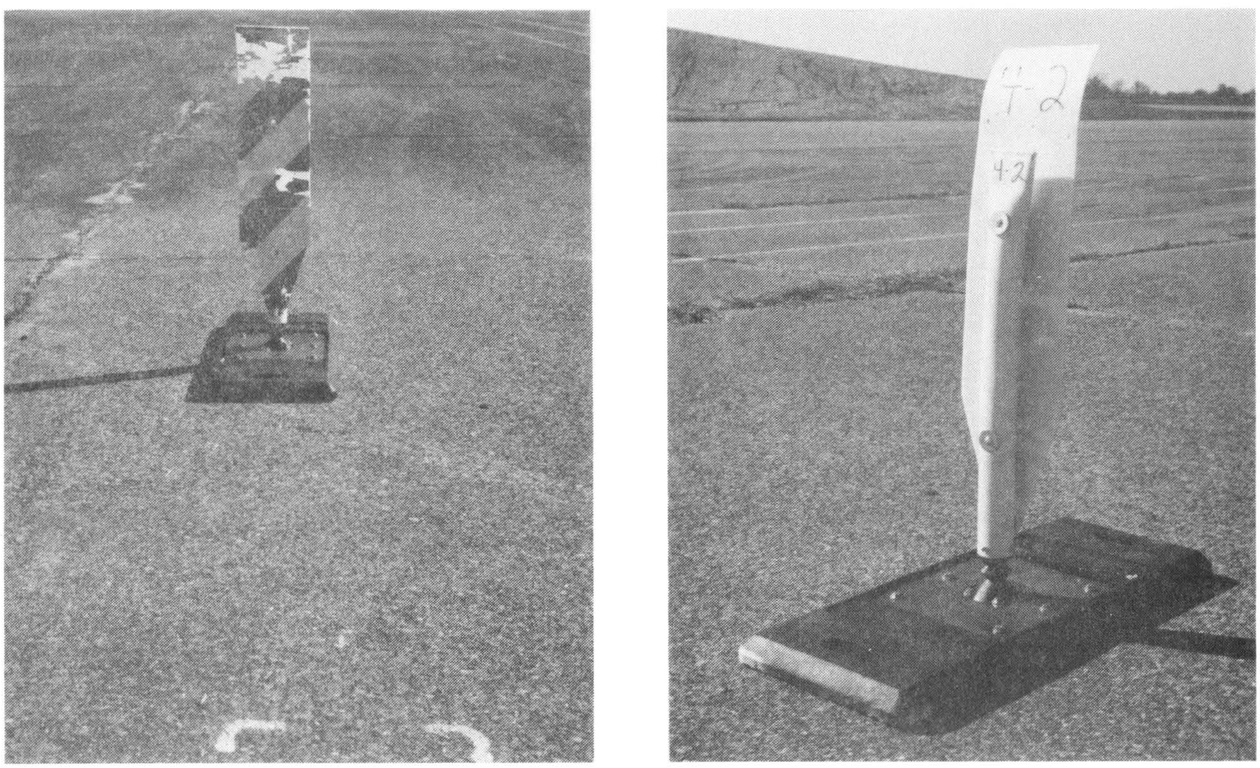

Figure 27. Damage to second device, test 7177-4.

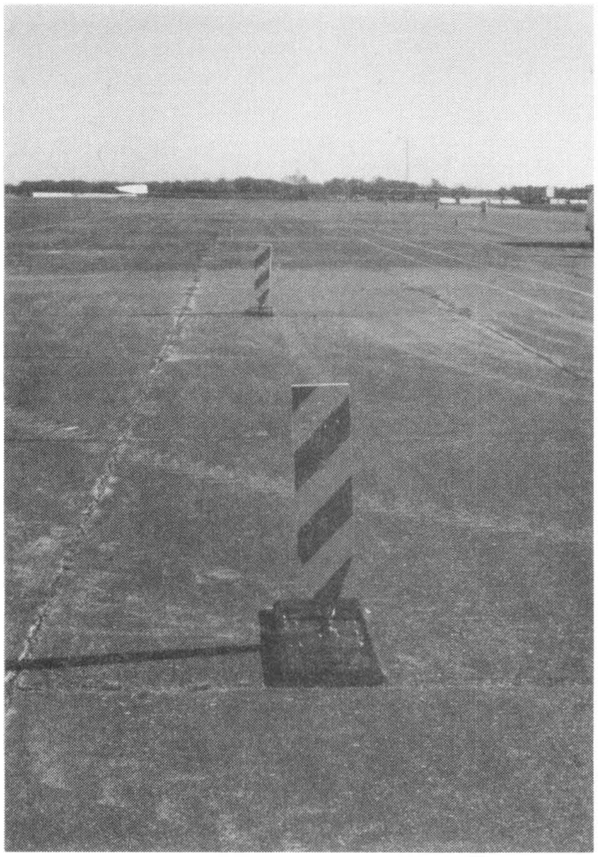

Figure 28. Installation and vehicle before test 7177-5.

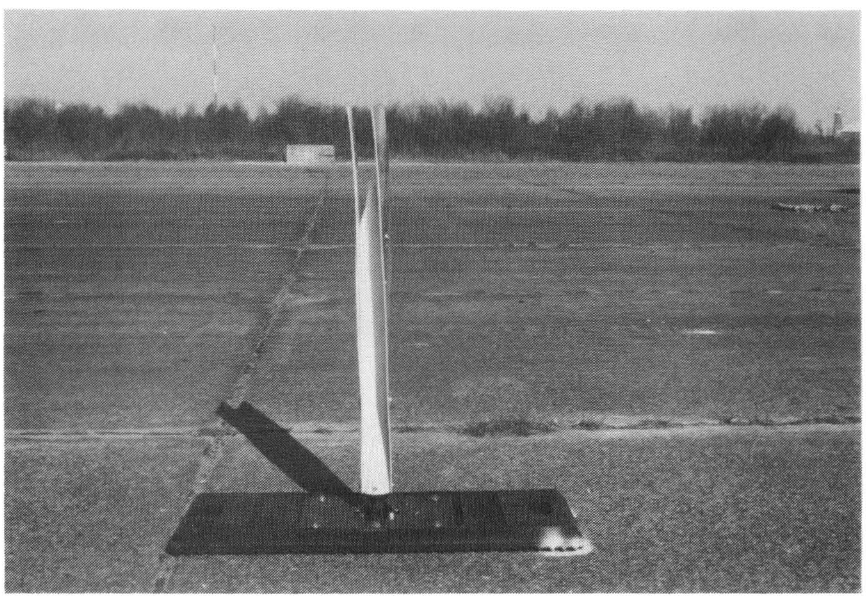

Figure 29. Typical device used in test 7177-5.

came loose and the vertical panels were partially detached from the posts. Also, a 1-in x 1-in x 6-in lead insert broke loose from the portable base. As the vehicle traversed the second device, the rear wheel rode over the device, moving it 5.1 feet down and 2.0 feet to the left. The vehicle sustained no damage as shown in Figure 30. After-test photographs of the devices are shown in Figures 30 and 31.

In the longitudinal direction, the occupant impact velocity was 5.5 ft/s at 474 msec, the highest 10-msec average ridedown acceleration was 0.3 g from 494 to 504 msec, and the maximum 50-msec average acceleration was -2.2 g between 55 and 105 msec. There was no occupant impact in the lateral direction and the maximum 50-msec average acceleration was -1.5 g between 53 and 103 msec.

There was no damage to the vehicle and no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a straight, smooth path through the test site with no intrusion into adjacent traffic lanes. The vehicle remained stable throughout the test sequence. The devices were moved slightly due to impacts by the vehicle, but remained relatively close to the vehicle path. The base of the first assembly bounced off the ground as the vehicle cleared the device. A piece of lead insert was found separated from the base. It was explained by Flasher Equipment Company personnel that the lead insert was a temporary setup for the prototype base and will be eliminated from the production unit. The vertical panels on the first assembly were badly scraped and partially detached from the post as a result of the top fasteners pulled out from the panels. The vertical panels on the second assembly were also scraped and slightly bent.

<u>Test 7177-6</u>

This test installation consisted of two (2) portable simulated barrel signs assemblies (Model No. 409-WEFN-105RO) spaced 45 feet apart for a nominal impact speed of 45 mi/h. Photographs of the site before the test are shown in Figures 32 and 33.

The speed of the vehicle as it impacted the first device was 43.9 mi/h. The impact point was the right quarter point of the vehicle bumper. There was no driver input as the vehicle went smoothly through the test site. Both devices were moved by the impacts with the vehicle; the first 6.75 feet down and 4.3 feet to the left, and the second 10.1 feet down and 5.1 feet to the left. Other than scrapes to the simulated barrel sign panels, there was no other damage to the

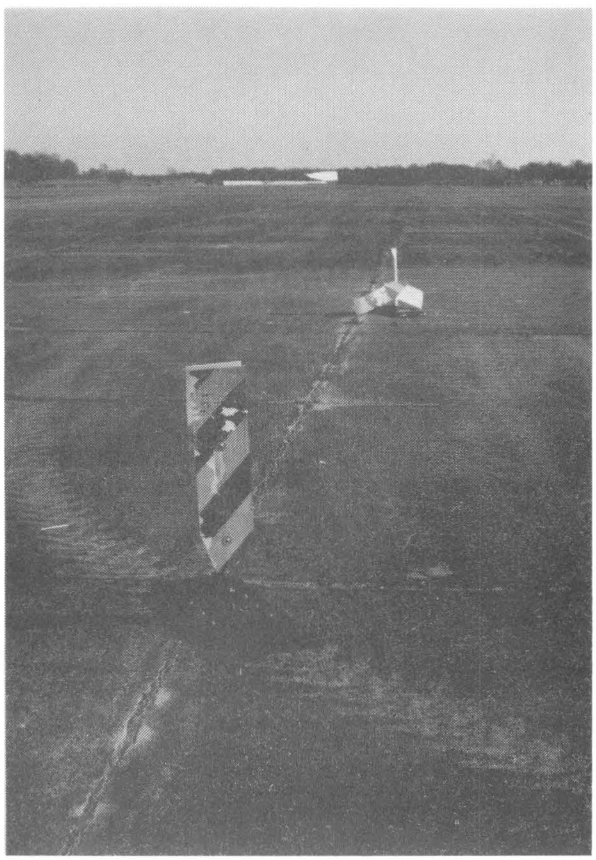

Figure 30. Vehicle and test site after test 7177-5.

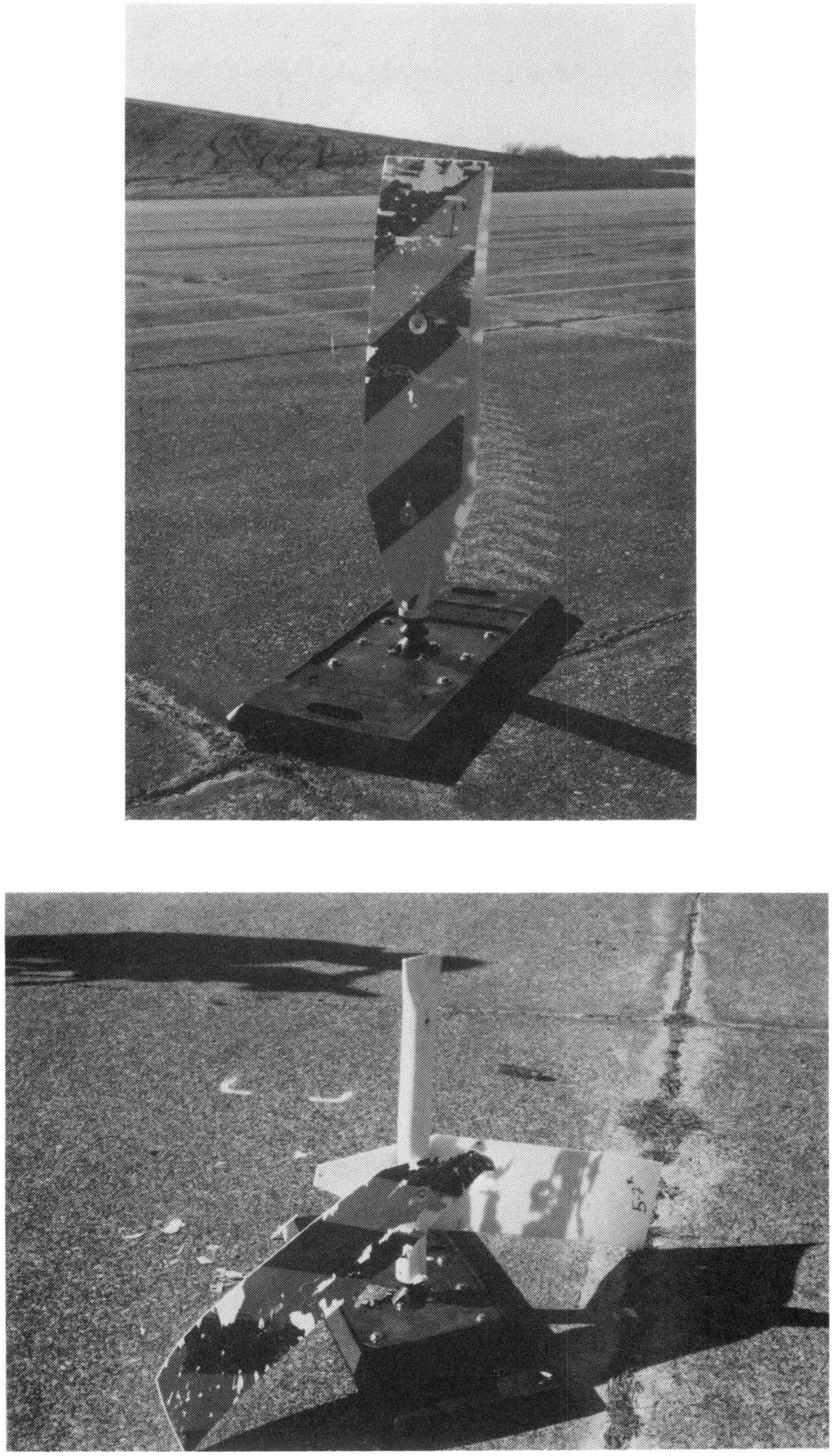

Figure 31 . Damage to devices, test 7177-5.

Figure 32. Installation and vehicle before test 7177-6.

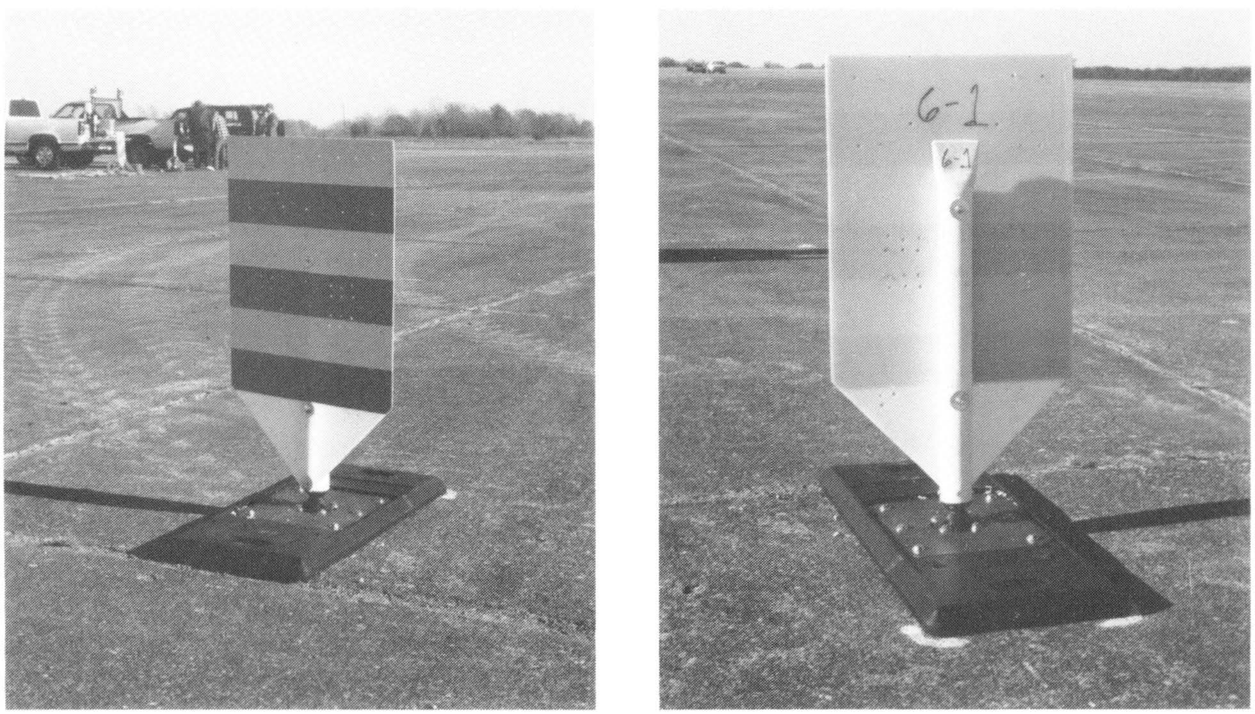

Figure 33. Typical device used in test 7177-6.

devices as shown in Figures 34 and 35. The vehicle received a scraped grill and is shown in Figure 36.

There was no longitudinal occupant impact and the maximum 50-msec average acceleration was -1.5 g between 55 and 105 msec. In the lateral direction, the occupant impact velocity was 4.5 ft/s at 564 msec, the highest 10-msec average ridedown acceleration was 0.5 g from 571 to 581 msec, and the maximum 50-msec average acceleration was 1.2 g between 102 and 152 msec.

The vehicle sustained cosmetic damage only and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a straight, smooth path through the test site with no intrusion into adjacent traffic lanes. The vehicle remained stable throughout the test sequence. The devices moved but remained relatively close to the vehicle path. The sign panels were slightly bent with minor scrapes to the reflective surfaces.

Test 7177-7

The purpose of this test was to examine the stability of the vehicle when a tire rode directly over the portable base. One (1) of the portable simulated barrel sign assembly (Model No. 409-WEFN-105RO) previously used in test 6 was set up for this test. The impact point was the right corner of the vehicle bumper, i.e., the right corner of the vehicle bumper was lined up with the center of the sign assembly, such that the tires on the right side of the vehicle would ride over the device. The nominal impact speed was 60 mi/h. The impact configuration is shown in Figure 37.

The test vehicle was travelling at a speed of 57.4 mi/h as it impacted the device. As the right front tire of the vehicle rode over the device, the device contacted the front spoiler under the bumper. The device was moved slightly by the impact, 2.0 feet down and 0.5 ft to the left, as shown in Figure 38. The vehicle received a dent in the spoiler as shown in Figure 39.

There was no occupant impact in the longitudinal direction and the maximum 50-msec average acceleration was -0.8 g between 1 and 51 msec. In the lateral direction, the occupant impact velocity was 4.5 ft/s, the highest 10-msec average ridedown acceleration was 0.2 g from 531 to 541 msec, and the maximum 50-msec average acceleration was -0.6 g between 6 and 56 msec.

The vehicle sustained minor damage and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a straight, smooth path through the test site with no intrusion into adjacent

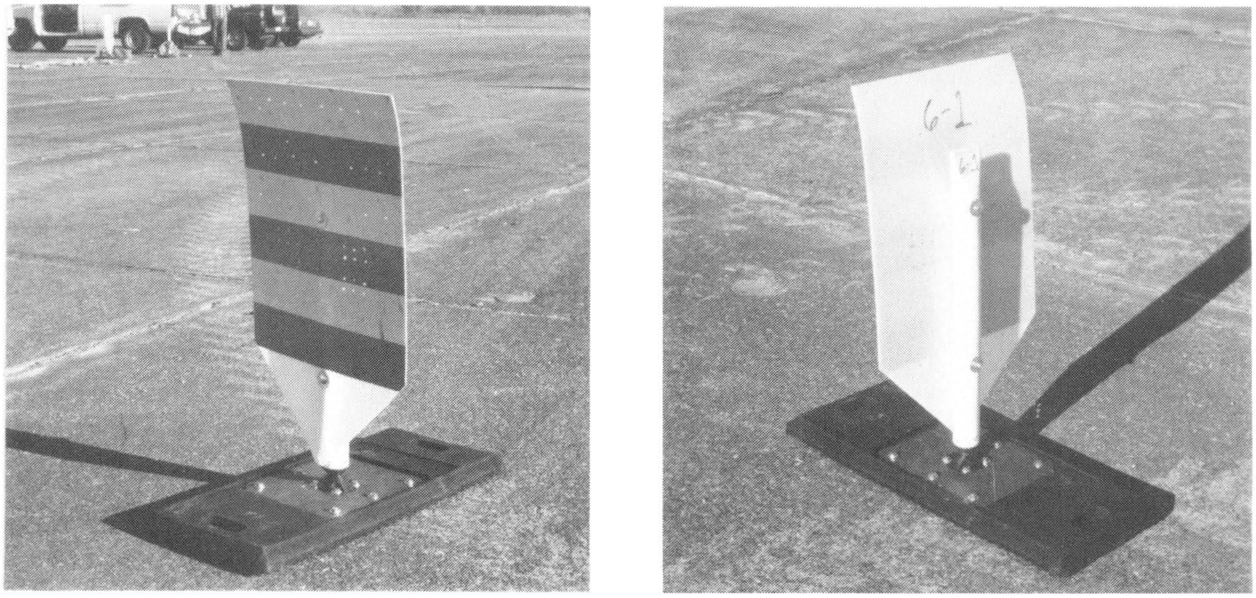

Figure 34. Damage to first device, test 7177-6.

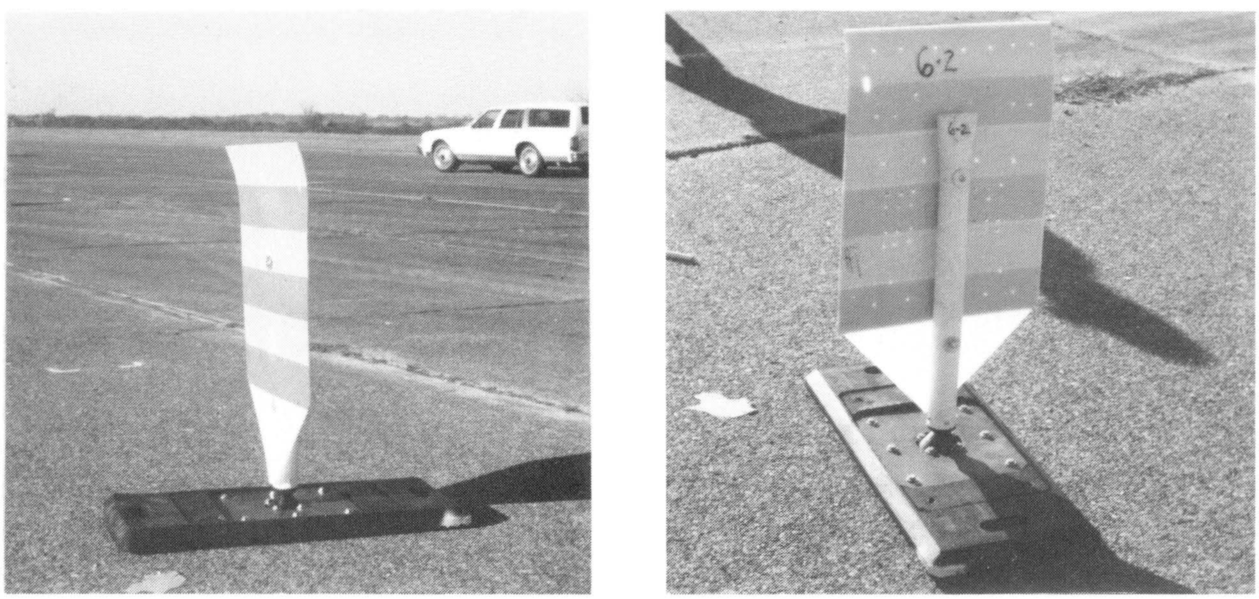

Figure 35. Damage to second device, test 7177-6.

Figure 36. Vehicle after test 7177-6.

Figure 37. Vehicle and device used in test 7177-7.

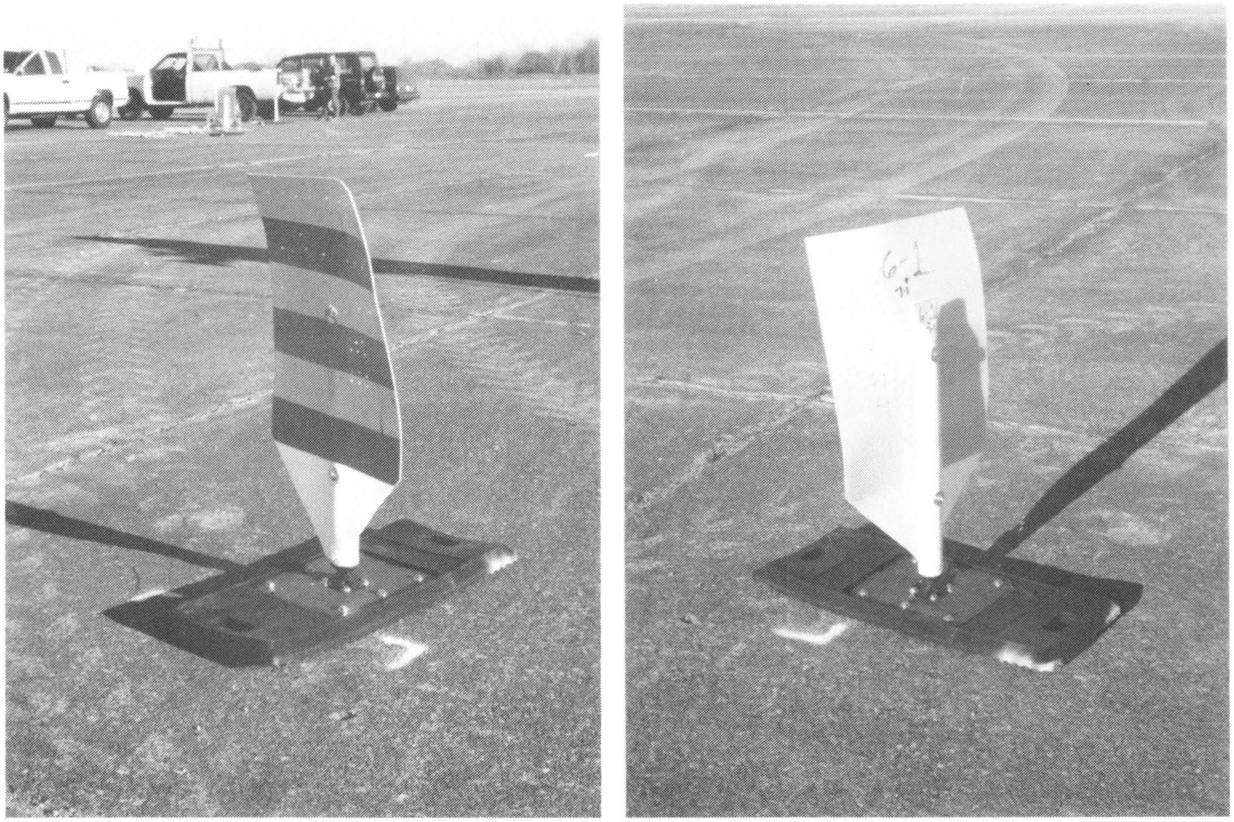

Figure 38. Damage to device, test 7177-7.

Figure 39. Damage to vehicle, test 7177-7.

traffic lanes. The vehicle remained stable throughout the test sequence. The device was moved slightly by the impact, but remained near the point of impact.

Test 7177-8

This test was a repeat of test 2, except for the use of a stronger and longer driveable base. In test 2, the first single vertical panel assembly was pulled out completely from the ground. The failure was attributed to the low frictional properties of the uncompacted and untreated soil and the added weight from the flashing light unit and the accompanying battery packs. It was believed that a stronger and longer driveable base might eliminate that problem, thus resulting in this test.

Except for the driveable bases, the test installation was identical to that in test 2, consisting of one (1) single vertical panel assembly with flashing light unit and battery packs attached (Model No. 300-WHRRN-106R1) in the first position, followed by three (3) single vertical panel assemblies (Model No. 300-WHRRN-106R0). The assemblies were arranged in a straight line located one foot off the pavement and spaced 60 feet apart for a nominal impact speed of 60 mi/h. The driveable bases were driven into the soil with a sledge hammer. Again, the soil where the driveable bases were installed was uncompacted and untreated, and not necessarily representative of typical soil conditions found on the shoulder or roadside areas next to highways. The flashing light unit was attached to the top of the post while the two battery packs were attached separately to the post near the base. Photographs of the test installation are shown in Figures 40 through 42.

The vehicle was travelling at a speed of 57.9 mi/h as it impacted the first device with the right quarter point of the vehicle bumper. As the vehicle travelled over the first device, a weld connecting the post and panel unit to the base broke, allowing the post and panel unit to become detached from the base and came to rest 96.0 ft down and 8.0 ft to the left from the point of impact. The lens of the flashing light unit attached to the top of the post was also broken. The vehicle rode smoothly over the three remaining devices, resulting in only slight bending and scraping to the vertical panels. Damages to the devices and the vehicle (cosmetic in nature) are shown in Figures 43 through 47.

No occupant impact occurred during this test. The longitudinal maximum 50-msec average acceleration was -0.7 g between 4 and 54 msec and the lateral maximum 50-msec average acceleration was -0.5 g between 450 and 500 msec.

Figure 40. Installation and vehicle before test 7177-8.

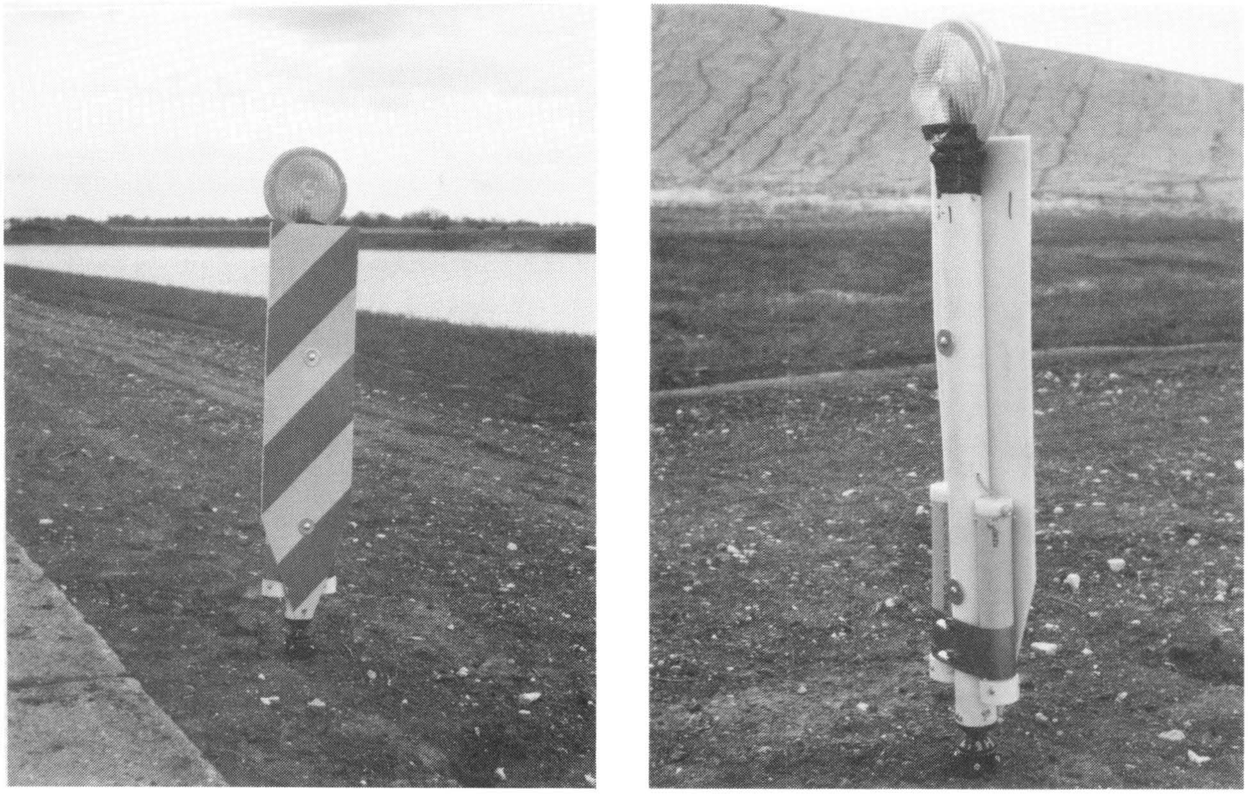

Figure 41. First device before test 7177-8.

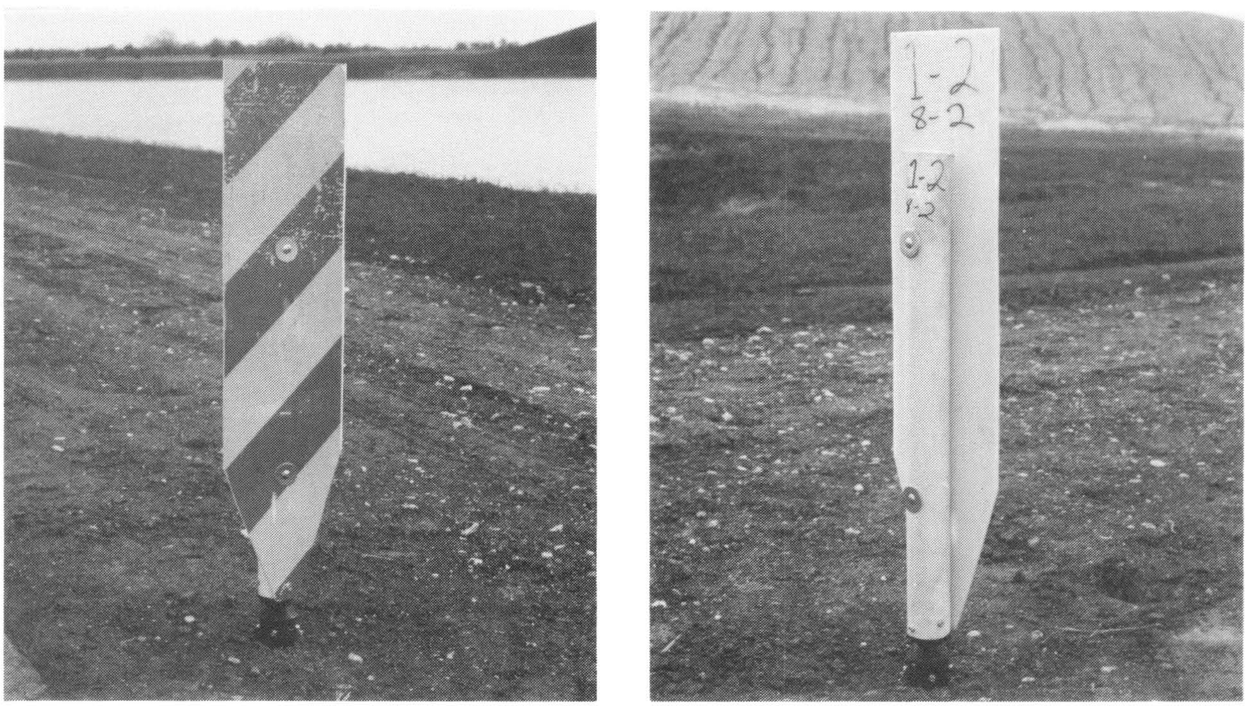

Figure 42. Typical device used in position 2, 3, and 4.

Figure 43. Vehicle and test site after test 7177-8.

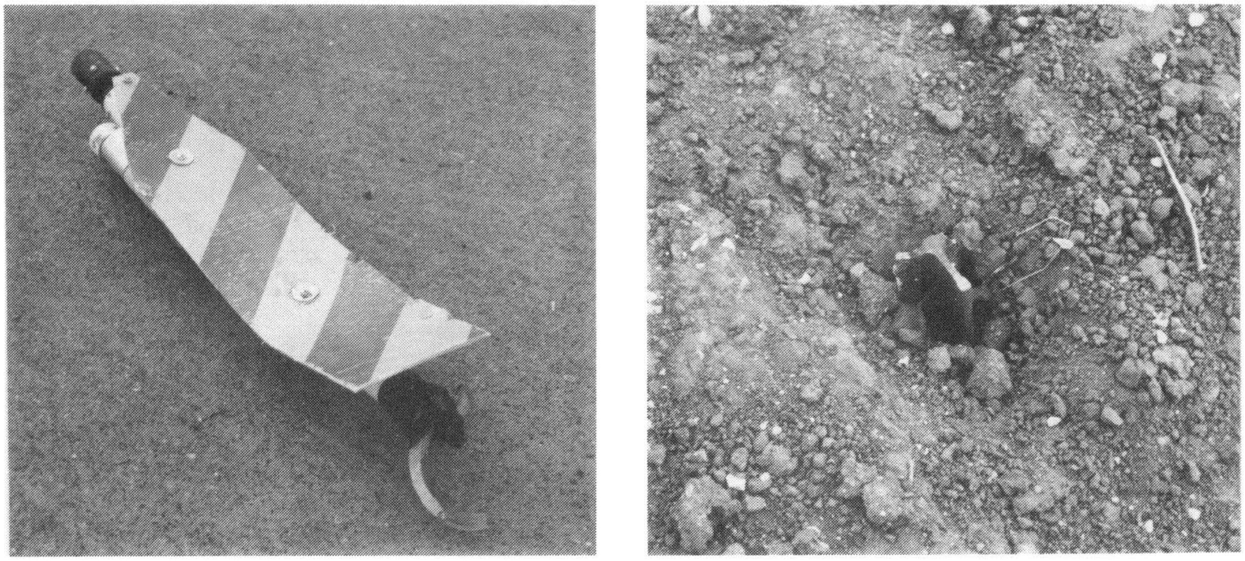

Figure 44. Damage to first device, test 7177-8.

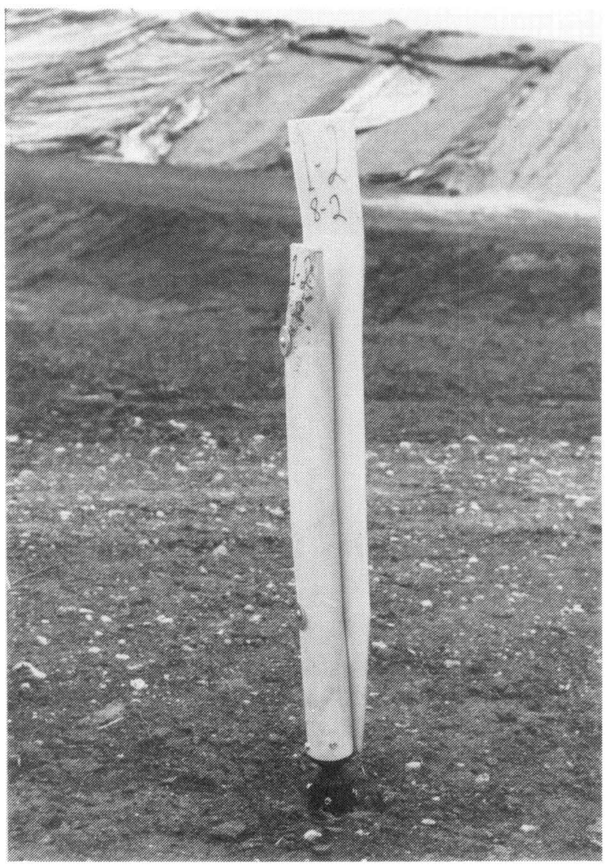

Figure 45. Damage to second device, test 7177-8.

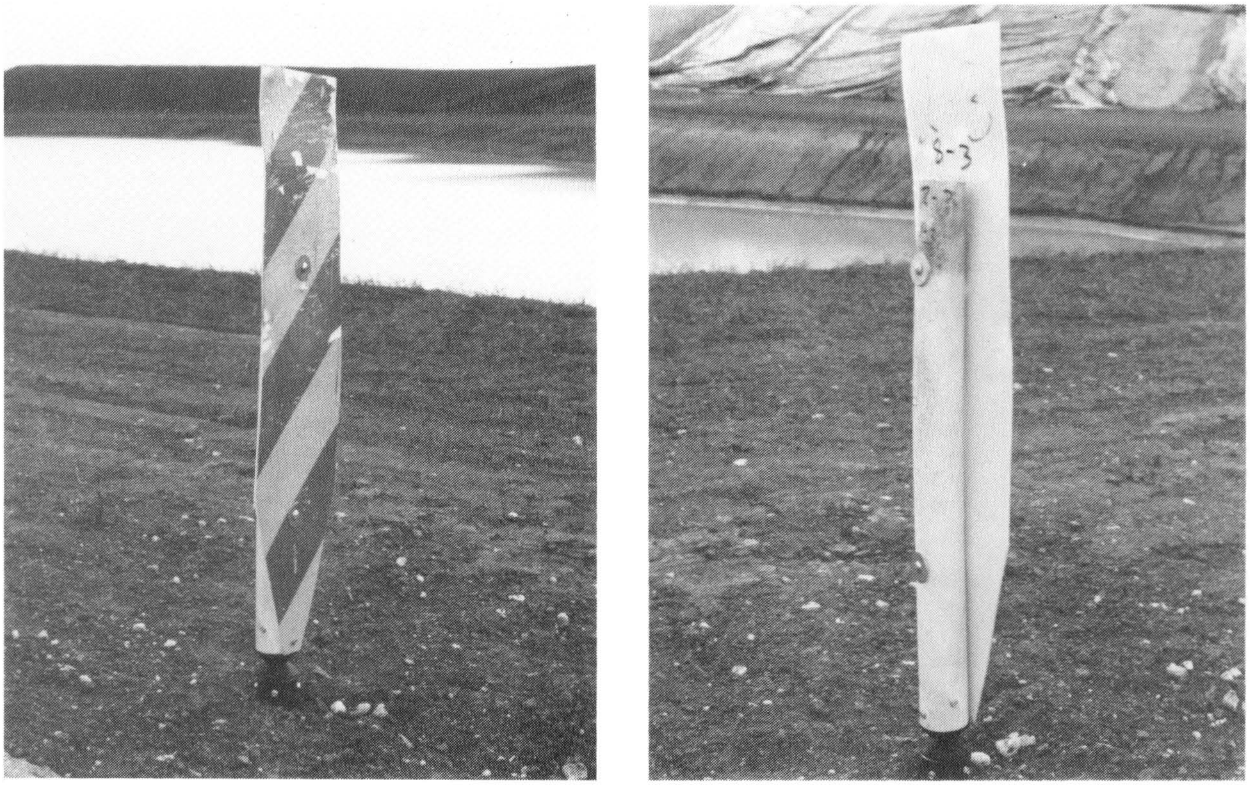

Figure 46. Damage to third device, test 7177-8.

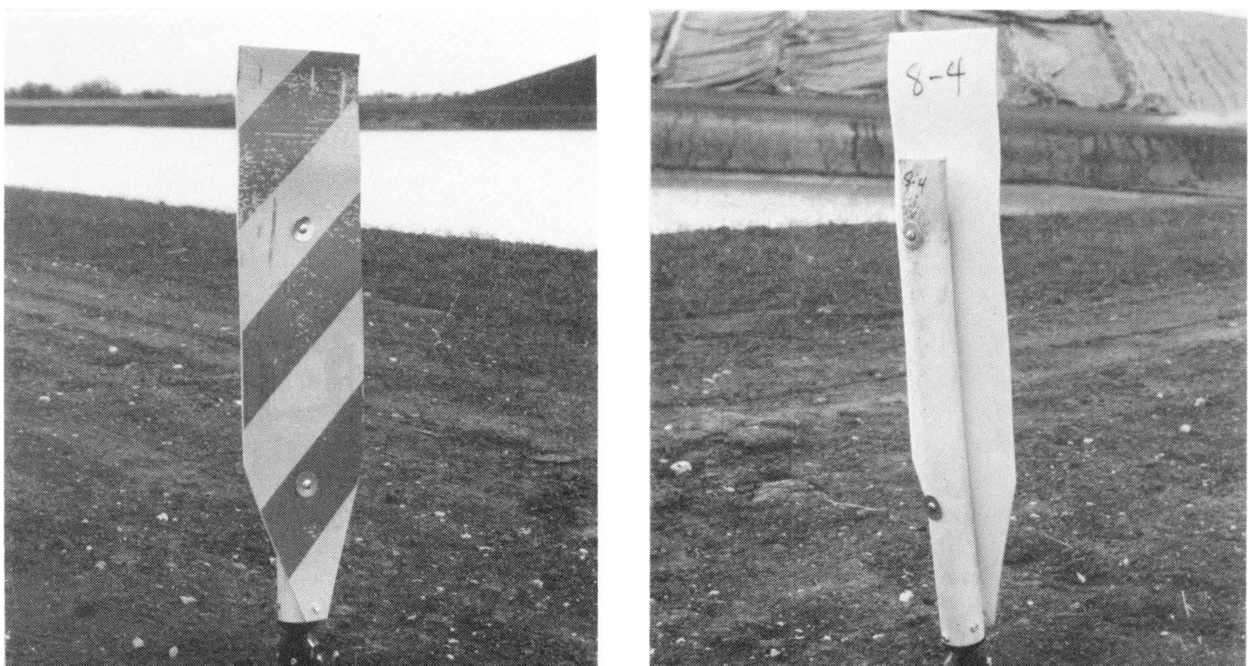

Figure 47. Damage to fourth device, test 7177-8.

The vehicle received cosmetic damage only and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a straight, smooth path through the test site with no intrusion into adjacent traffic lanes. The vehicle remained stable throughout the test period. The post and panel unit of the first assembly broke off from the driveable base and was thrown for some distance.

Test 7177-9

This test installation consisted of a total of four (4) double vertical panel assemblies mounted on fixed bases. A flashing light unit with separate battery packs were attached to the fourth fixed double vertical panel assembly (Model No. 300-WHRRL-101R1) while the first three (3) fixed double vertical panel assemblies (Model No. 300-WHRRL-101R0) were without the light attachments. The devices were arranged in a straight line and spaced 45 feet apart for a nominal impact speed of 45 mi/h as shown in Figure 48. The first two bases were attached to the pavement with an epoxy material while the last two bases were secured with a bituminous material.

The test vehicle was travelling at a speed of 44.9 mi/h as it contacted the first device with the right quarter point of the vehicle bumper. There was no driver input during the test sequence. The vehicle smoothly traversed the first three assemblies. However, as the vehicle impacted the fourth assembly, the base was torn loose from the pavement as the vehicle wheel rode over the device and the assembly came to rest 66 feet down and 18 feet to the right of point of impact. The lens of the flashing light unit was broken and separated from the attachment and came to rest 88 feet from the point of impact. The vehicle received no damage other than minor scrapes. Post-test photographs of the vehicle and devices are shown in Figures 50 through 54.

There was no occupant impact during this test. The maximum 50-msec average accelerations were -0.4 g between 105 and 155 msec in the longitudinal direction and 0.2 g between 300 and 350 msec in the lateral direction.

The vehicle received cosmetic damage only and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a straight, smooth path through the test site with no intrusion into adjacent traffic lanes. The base of the fourth assembly with the flashing light unit and accompanying battery packs were pulled loose from the pavement and the assembly was thrown some distance from the impact point.

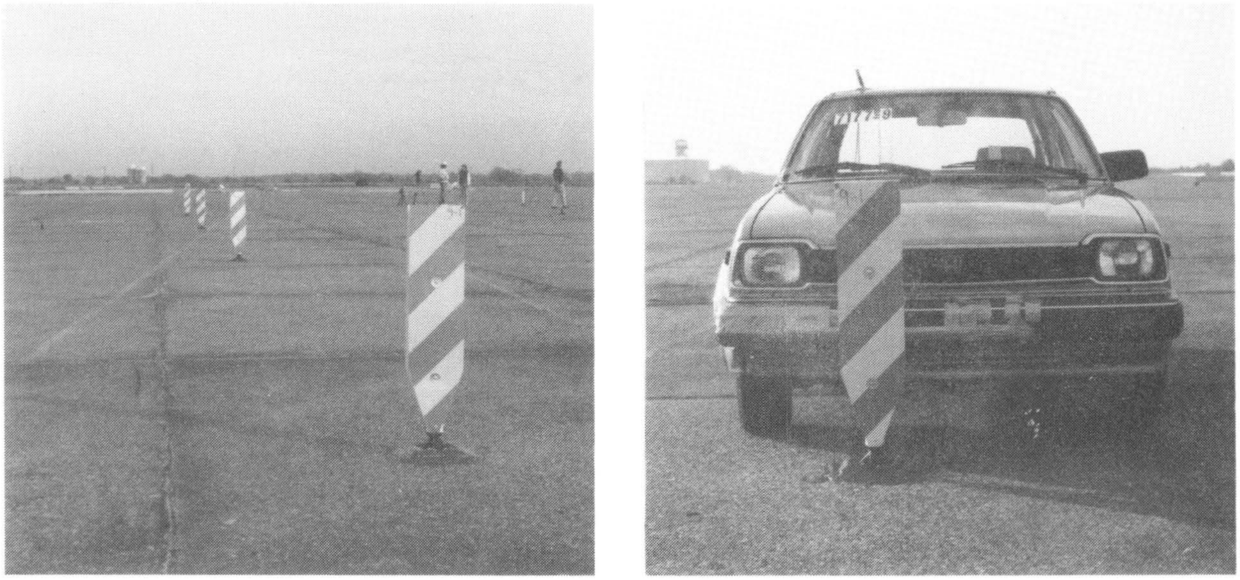

Figure 48. Installation and vehicle prior to test 7177-9.

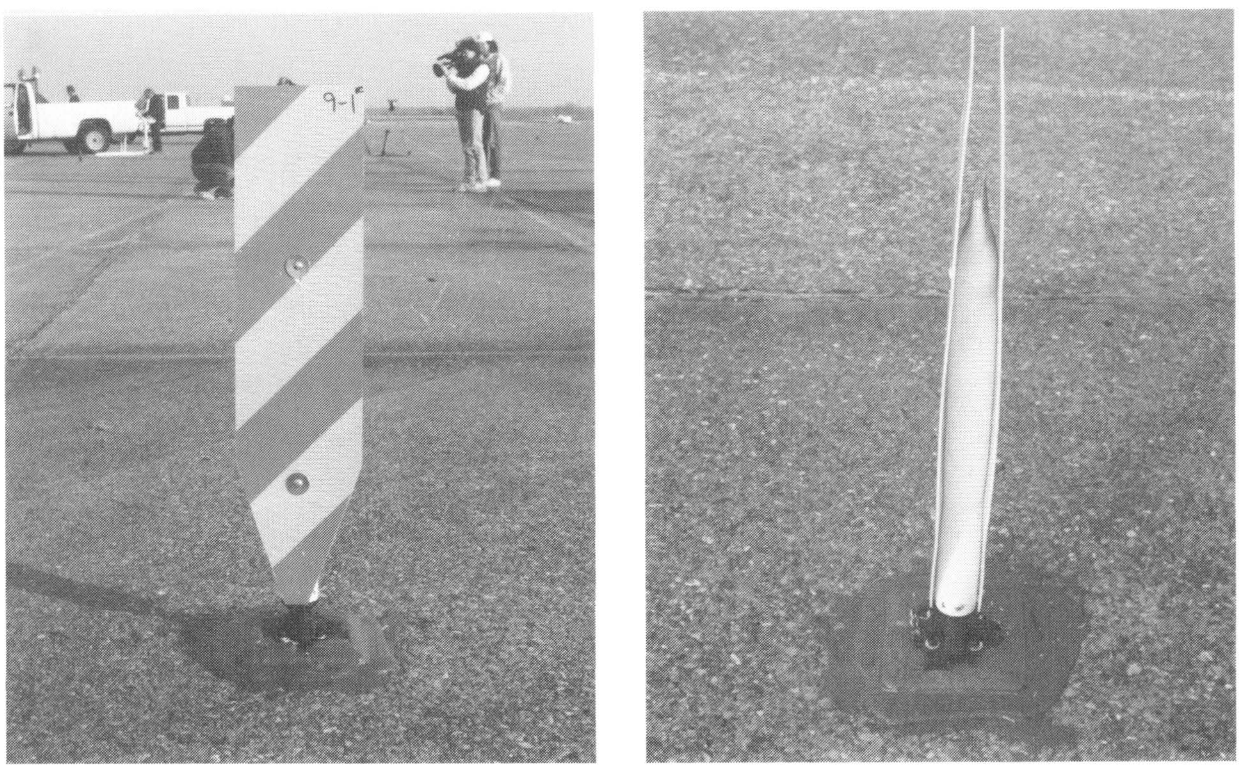

Figure 49. Typical device used in test 7177-9.

Figure 50. Vehicle and test site after test 7177-9.

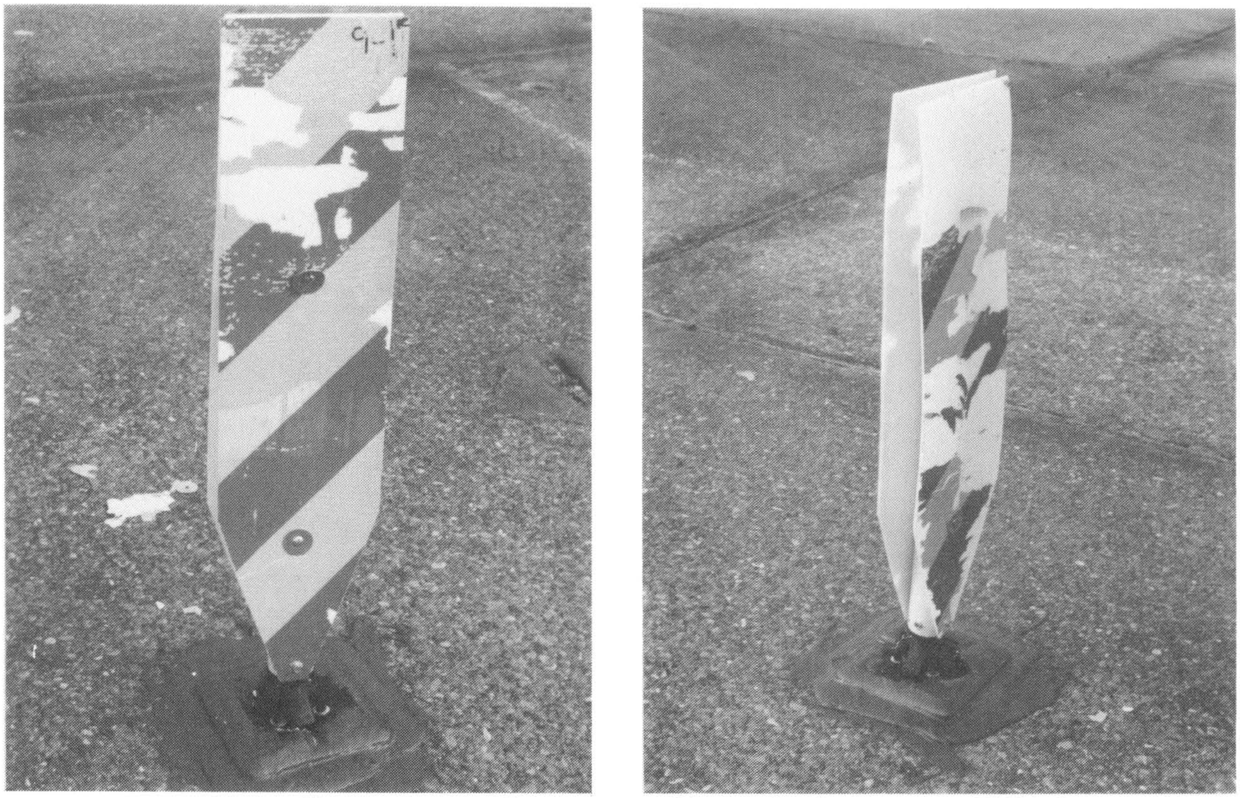

Figure 51. Damage to first device, test 7177-9.

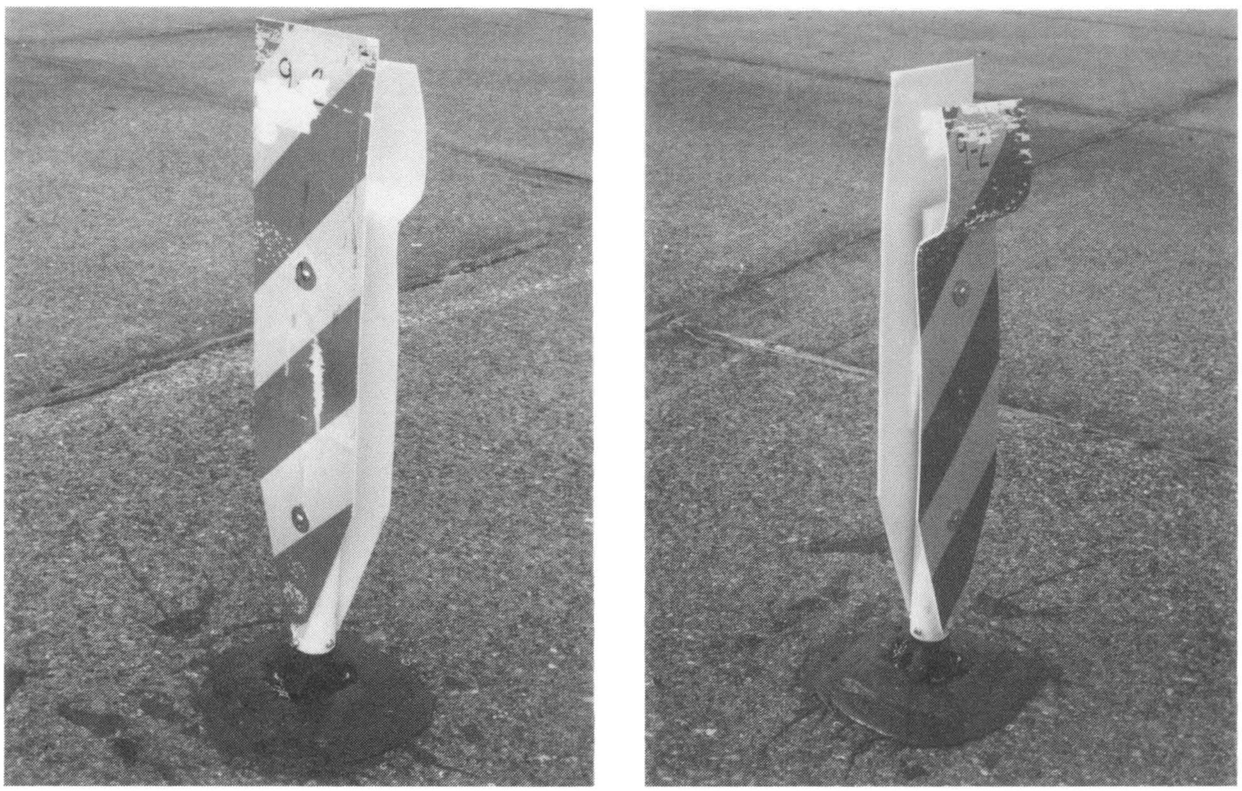

Figure 52. Damage to second device, test 7177-9.

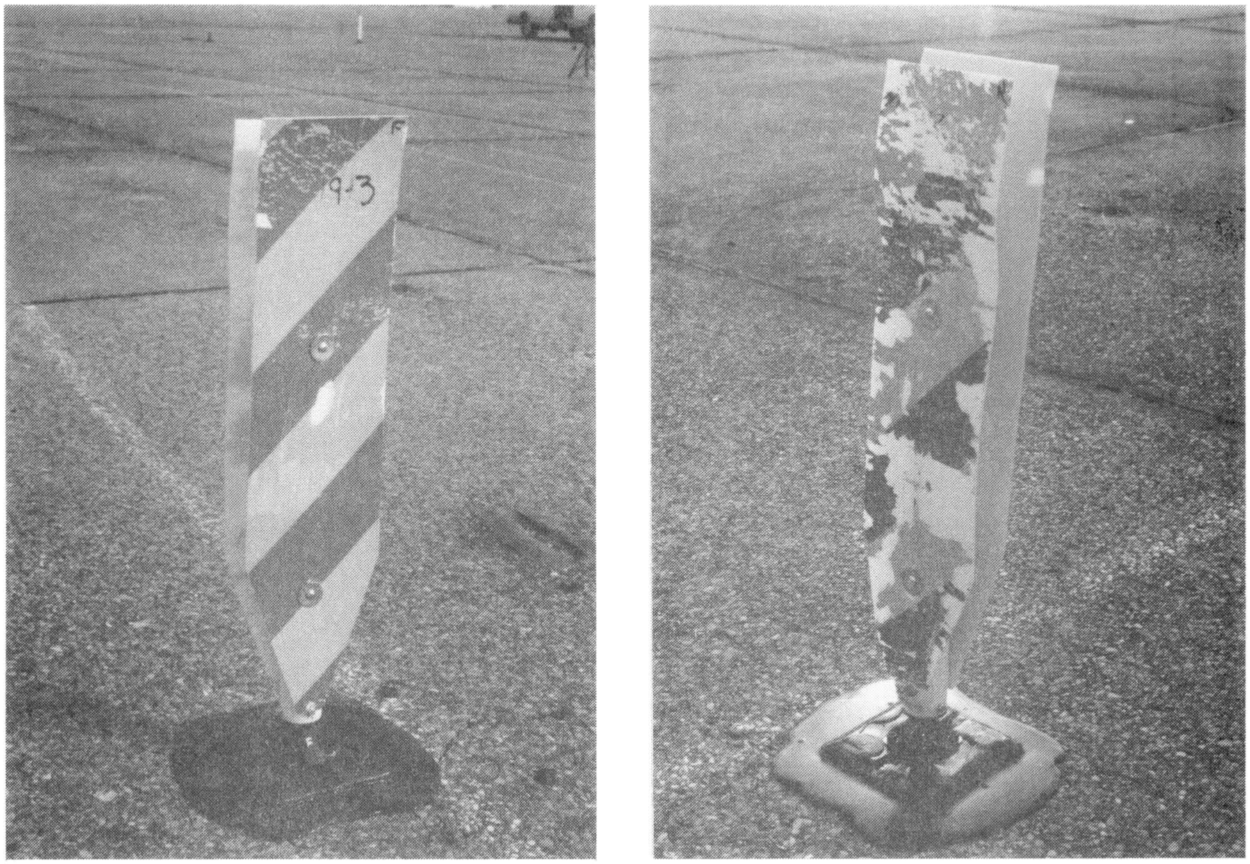

Figure 53 . Damage to third device, test 7177-9.

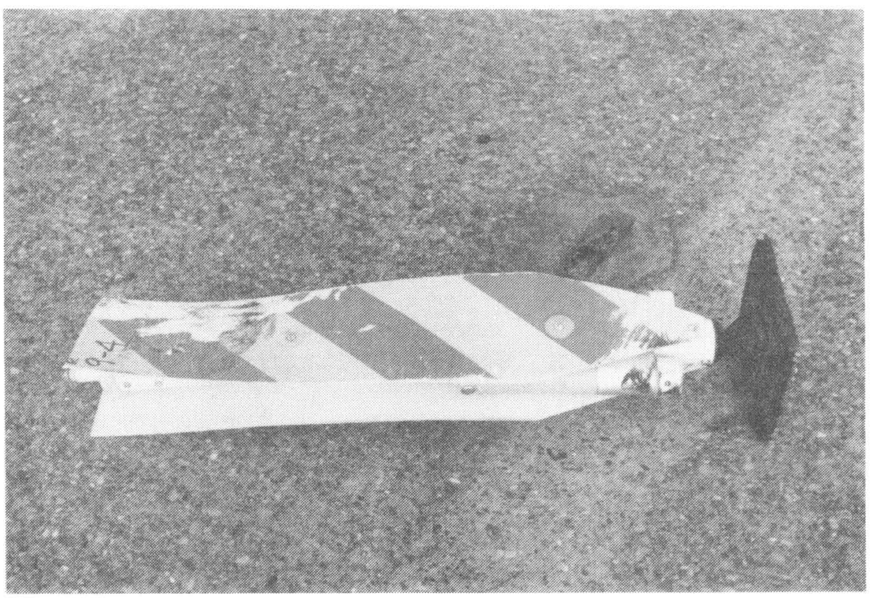

Figure 54 . Damage to fourth device, test 7177-9.

Test 7177-10

The test installation (shown in Figures 55 and 56) consisted of three (3) fixed chevron sign assemblies (Model No. 405-WHL-101B0) arranged in a straight line and spaced 45 feet apart for testing at a nominal impact speed of 45 mi/h. All three bases were attached to the pavement using an epoxy material.

The vehicle was travelling at a speed of 43.5 mi/h as it contacted the first device with the right quarter point of the vehicle bumper. There was no driver input to the vehicle during the test sequence. As the vehicle impacted each assembly, the chevron sign panel slapped the front of the vehicle causing damage to the hood, bumper and headlight rings. The sign panels were scraped and warped from the impact. Figures 57 through 60 depict damage to the devices and the vehicle.

No occupant impact occurred during this test. The maximum 50-msec average acceleration in the longitudinal direction was -0.6 g between 0 and 50 msec and -0.3 g between 27 and 77 msec in the lateral direction.

The vehicle sustained minor damage to the hood, bumper and headlight rings and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained in a stable manner and maintained a straight, smooth path through the test site with no intrusion into adjacent traffic lanes. The chevron sign assemblies remained intact with slight bending to the posts and panels and minor scrapes to the reflective surfaces of the panels.

Test 7177-11

This test installation consisted of a total of four (4) simulated barrel sign assemblies mounted on fixed bases. A flashing light unit with separate battery packs were attached to the fourth assembly (Model No. 409-WEFN-101R1) while the first three (3) assemblies (Model No. 409-WEFN-101R0) were without the light attachments. The devices were arranged in a straight line and spaced 45 feet apart for a nominal impact speed of 45 mi/h. All four bases were attached to the pavement with an epoxy material. Photographs of the vehicle and devices used in this test are shown in Figure 61.

The vehicle, travelling at 44.8 mi/h, impacted the first device with the right front quarter point of the vehicle bumper and continued through the test site with no driver input. The vehicle smoothly traversed the first three devices. As the vehicle impacted the fourth device, the lens of the flashing light unit hit the ground and shattered and then the tire ran over the device.

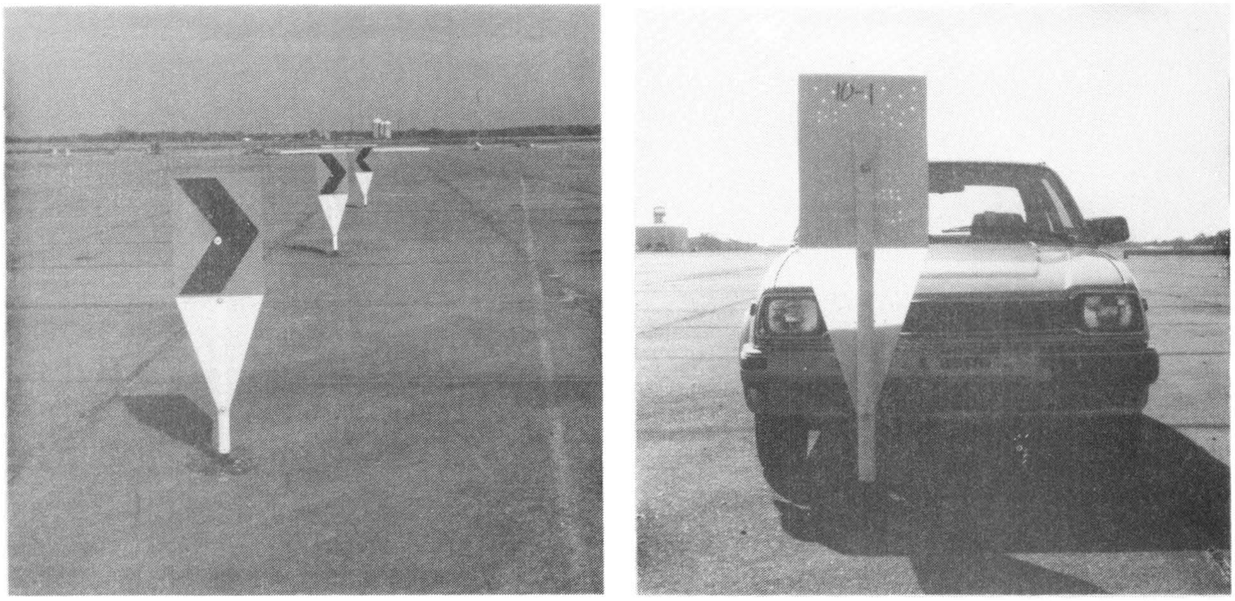

Figure 55. Installation and vehicle before test 7177-10.

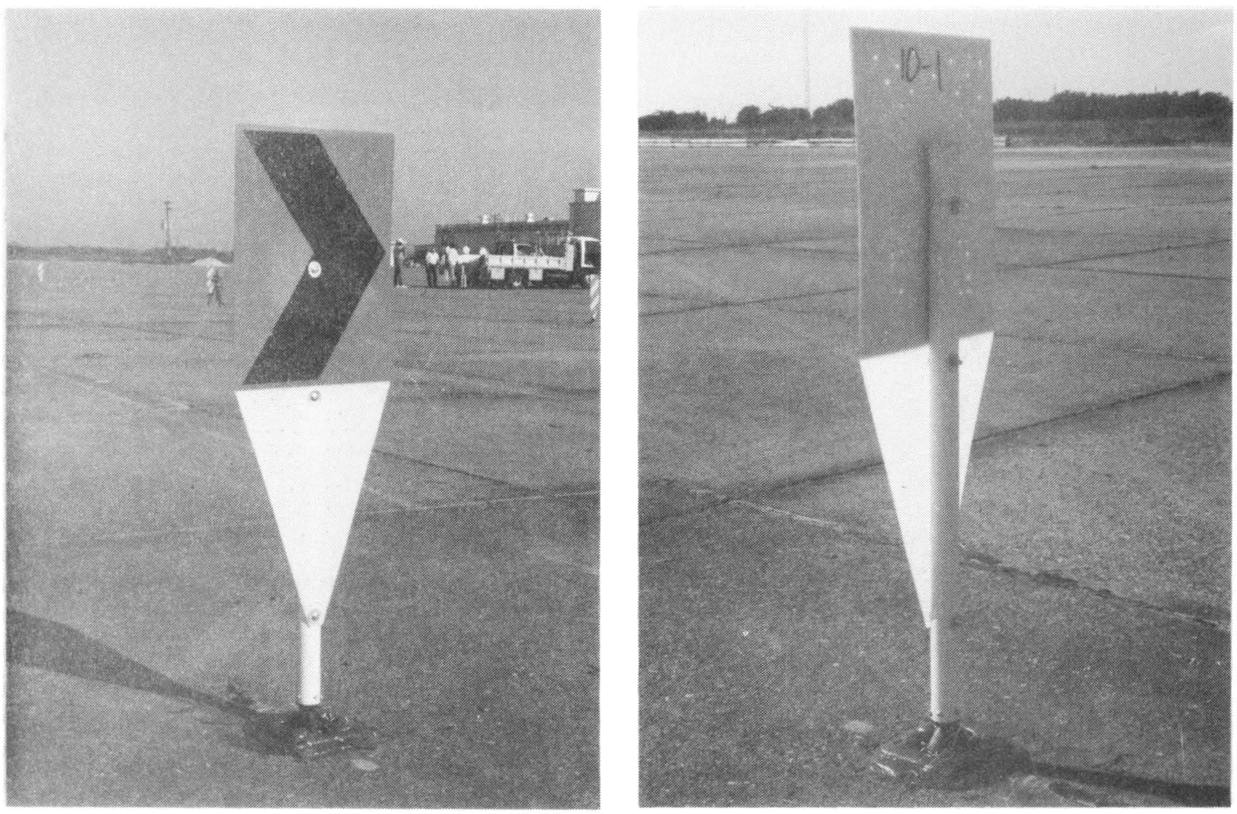

Figure 56. Typical device used in test 7177-10.

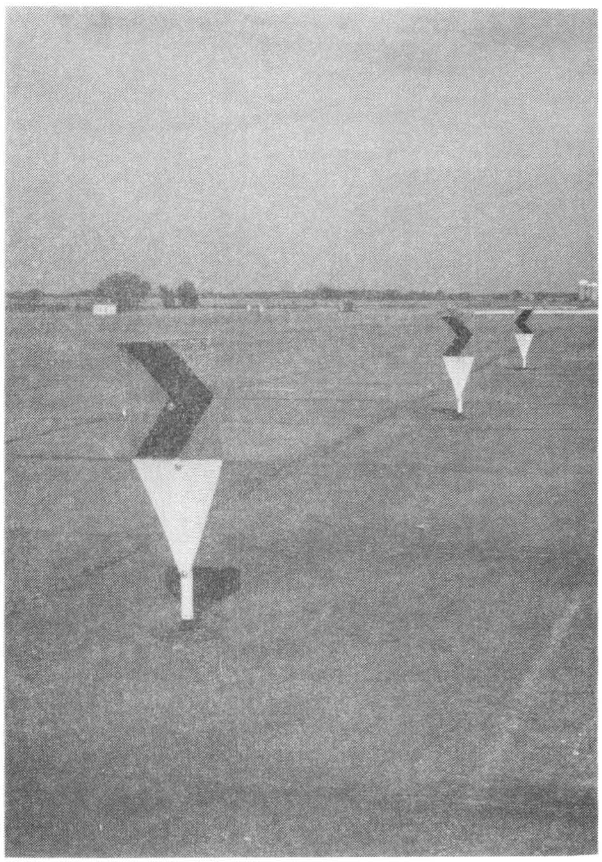

Figure 57. Vehicle and test site after test 7177-10.

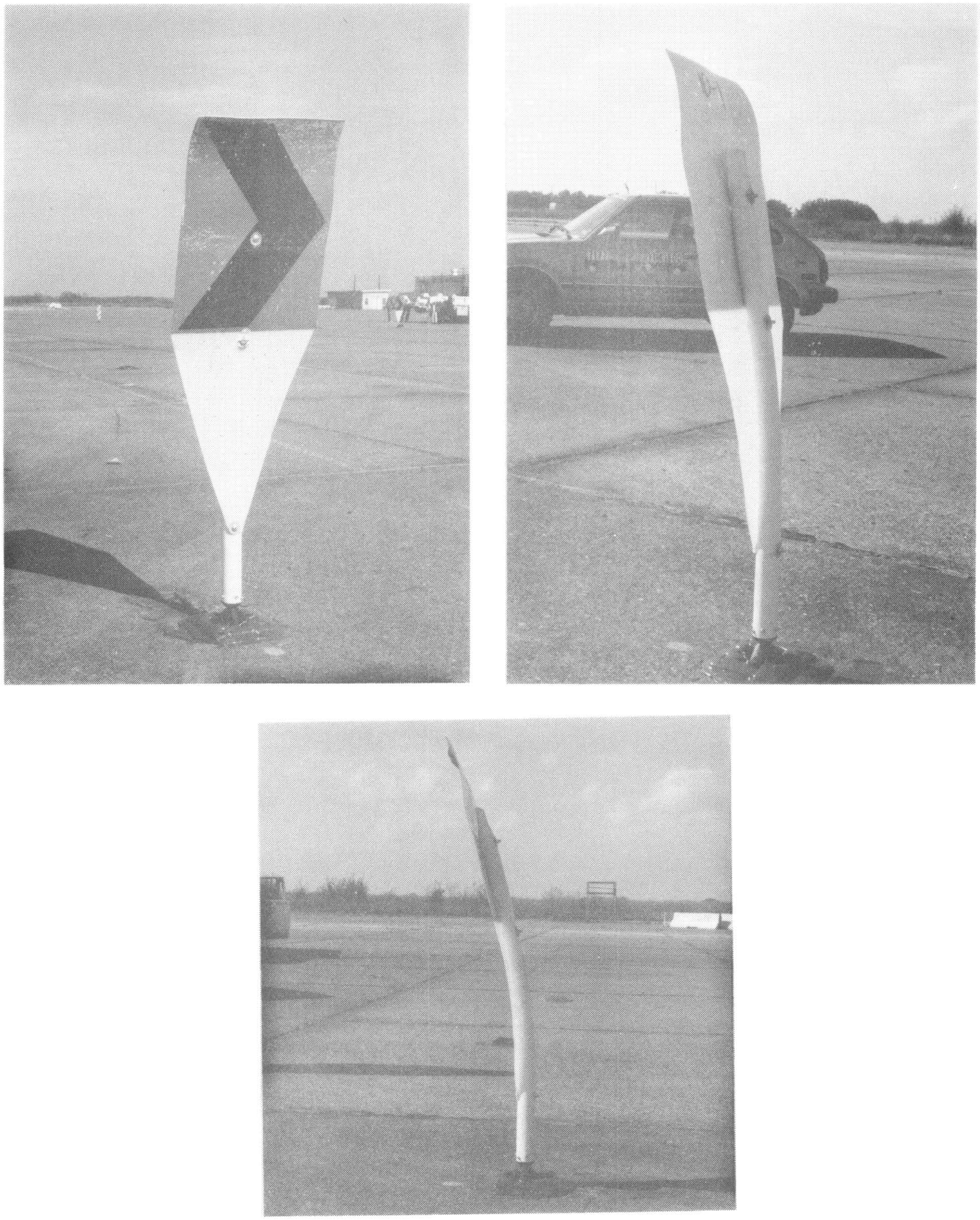

Figure 58. Damage to first device, test 7177-10.

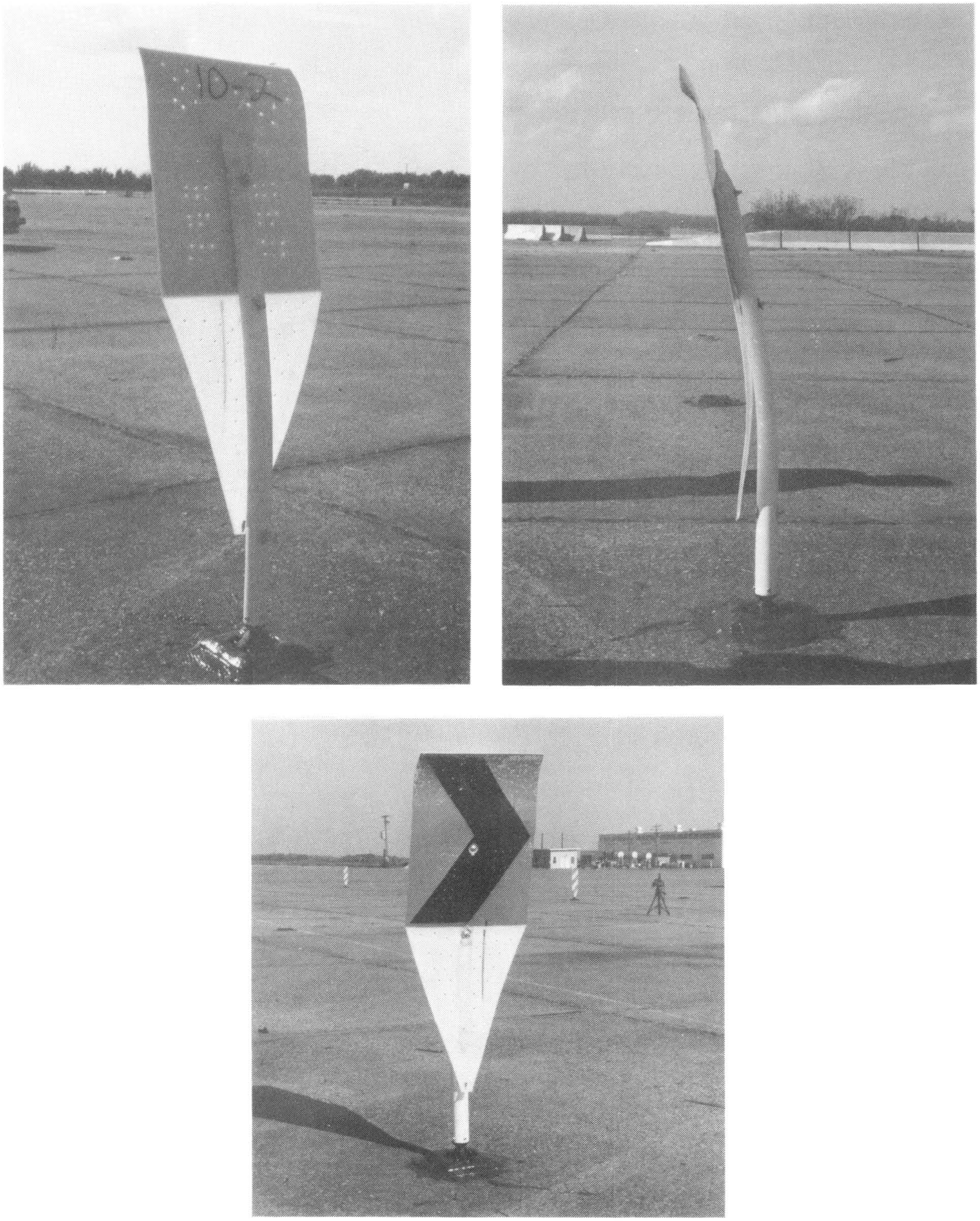

Figure 59. Damage to second device, test 7177-10.

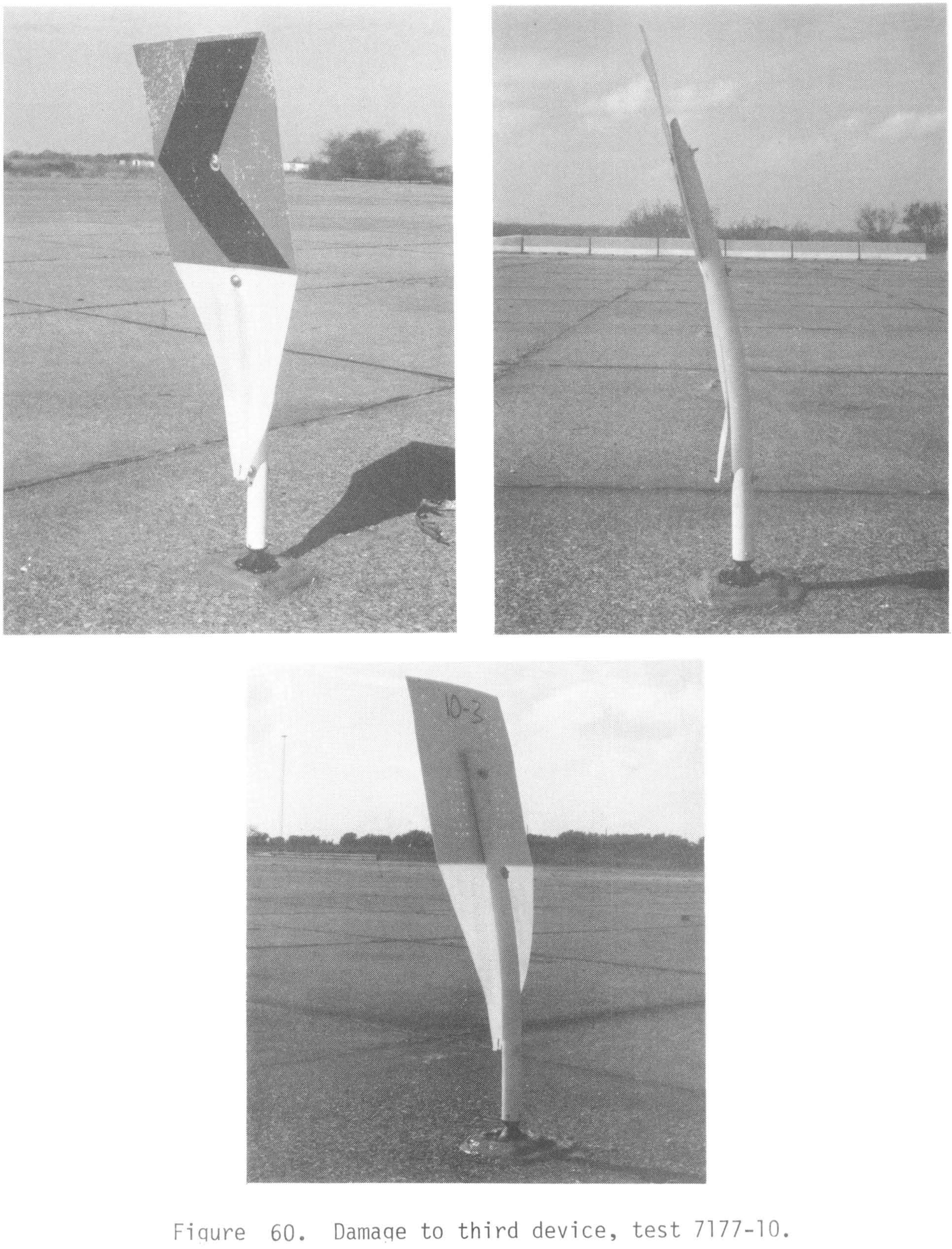

Figure 60. Damage to third device, test 7177-10.

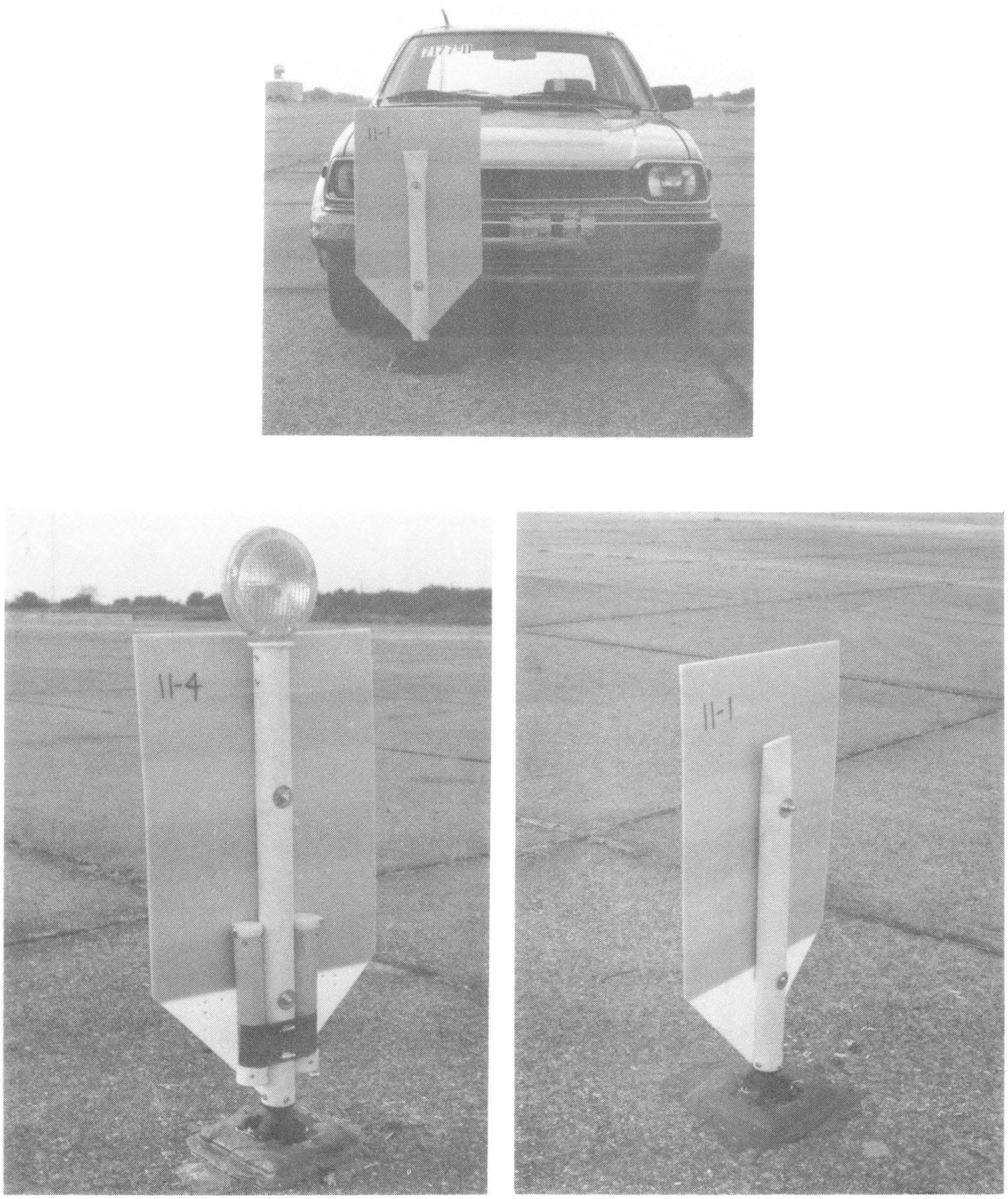

Figure 61. Vehicle and typical devices for test 7177-11.

There was no damage to the vehicle and little damage to the devices as shown in Figures 62 through 65.

There was no occupant impact during the test. The maximum 50-msec averages acceleration were -0.2 g between 0 and 50 msec in the longitudinal direction and -0.1 g between 26 and 76 msec in the lateral direction.

No damage was sustained by the vehicle and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a relatively straight, smooth path through the test site with no intrusion into adjacent traffic lanes. The vehicle remained stable throughout the test period. The devices remained in place and sustained little damage except for the broken lens of the flashing light unit attached to the fourth assembly.

Test 7177-12

This test installation (shown in Figures 66 and 67) consisted of four (4) fixed delineator posts (Model No. 200-WEFA-101RO) spaced 60 feet apart for a nominal impact speed of 60 mi/h. The first two bases were attached to the pavement with an epoxy material while the last two bases were secured with a bituminous material.

The vehicle impacted the first delineator post at 61.1 mi/h with the right quarter point of the vehicle bumper. The vehicle travelled smoothly through the test site with no driver input. There was little damage to the delineator posts as shown in Figures 68 through 71, and no damage to the vehicle.

No occupant impact occurred during the test. The maximum longitudinal and lateral 50-msec average accelerations were -0.3 g between 7 and 57 msec and -0.2 g between 15 and 65 msec, respectively.

No damage was sustained by the vehicle and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a straight, smooth path through the test site with no intrusion into adjacent traffic lanes. The vehicle remained stable throughout the test period. The devices remained intact with little damage.

Test 7177-13

The installation set for this test consisted of four (4) fixed single vertical panel assemblies (Model No. 300-WHRRN-101RO) spaced 60 feet apart for a nominal impact speed of 60 mi/h. Again, the first two bases were attached to

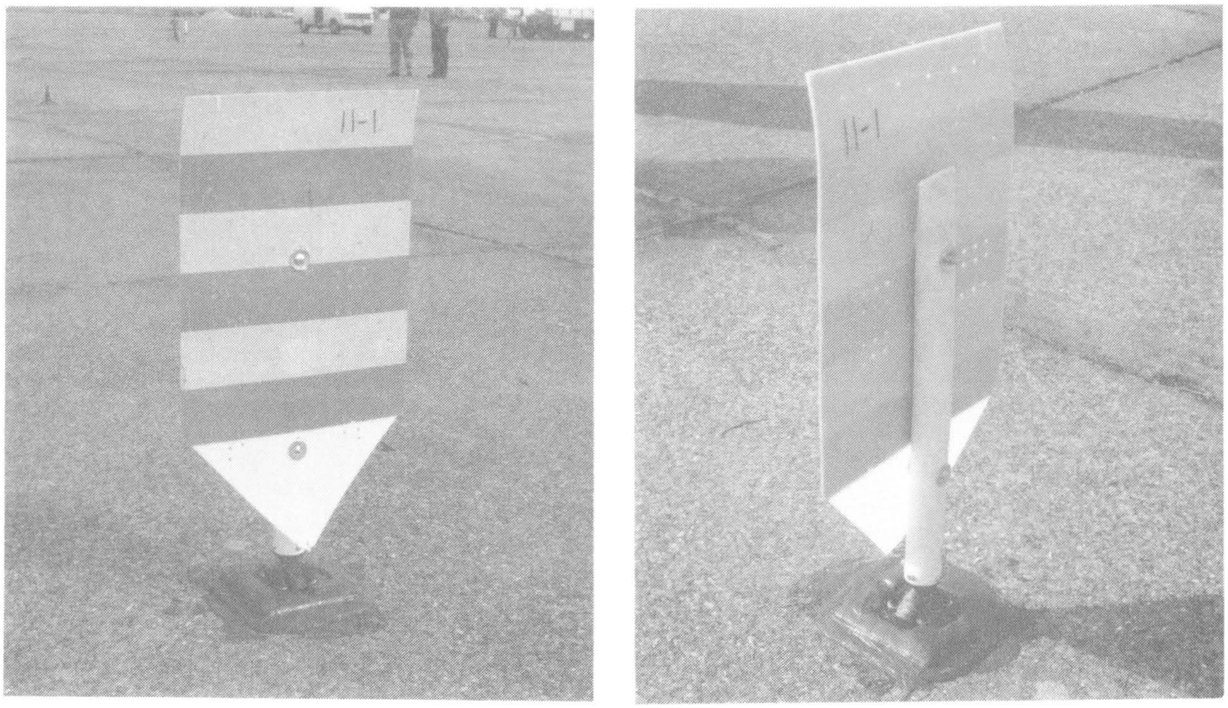

Figure 62 . Damage to first device, test 7177-11.

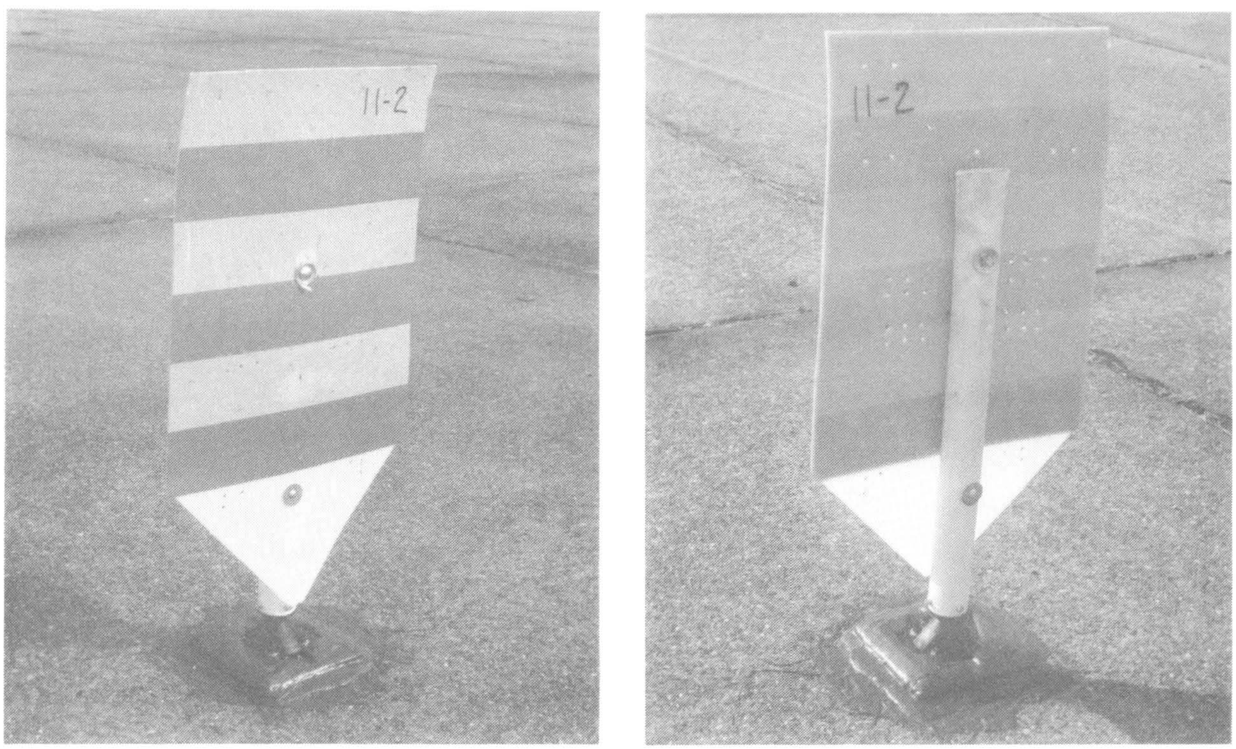

Figure 63 . Damage to second device, test 7177-11.

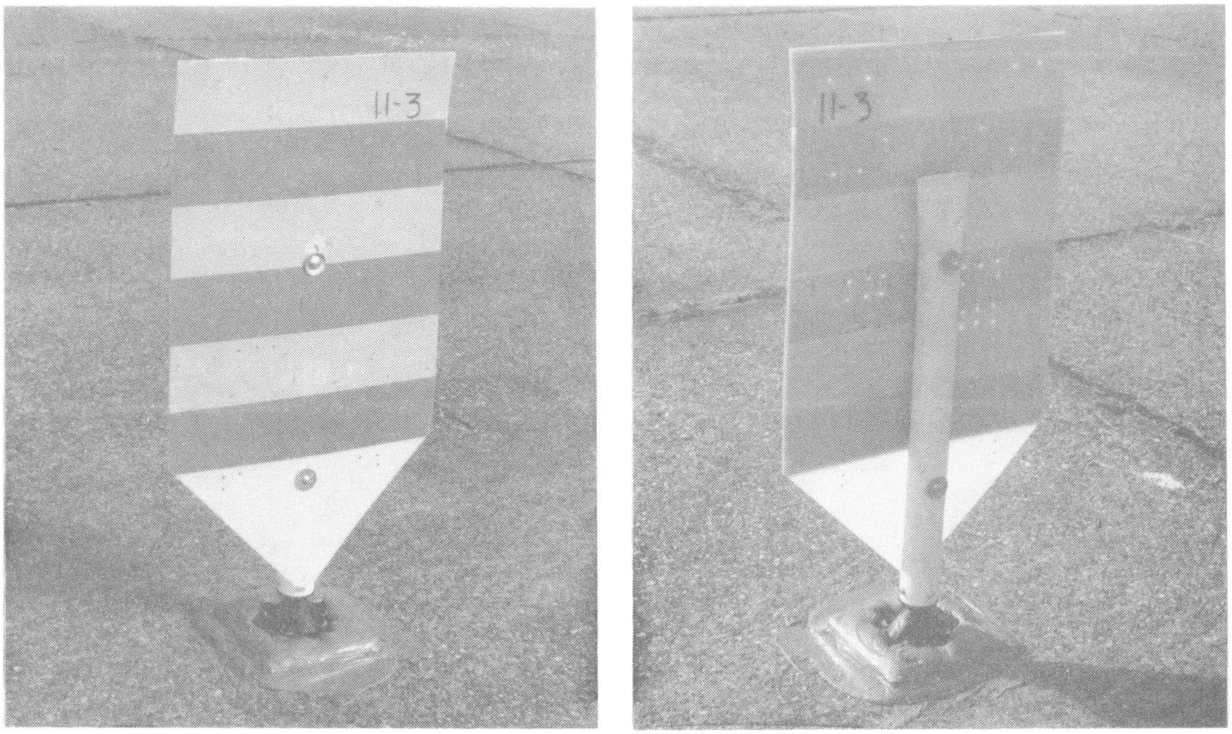

Figure 64 . Damage to third device, test 7177-11.

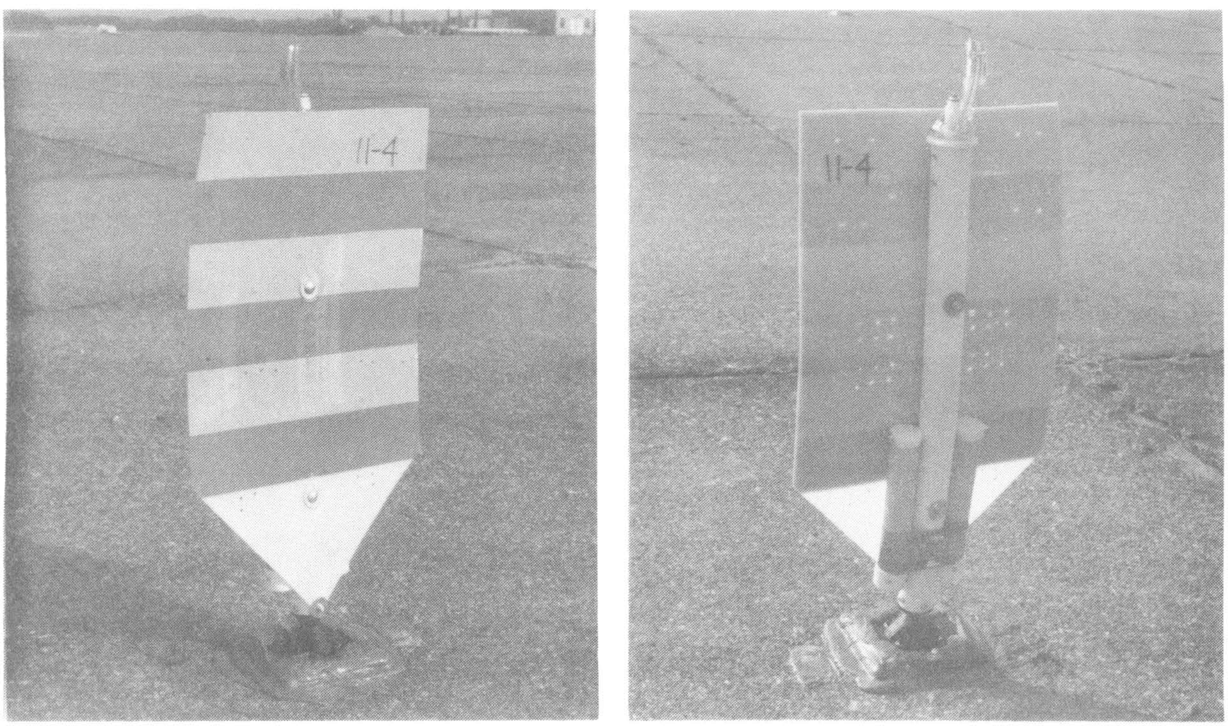

Figure 65 . Damage to fourth device, test 7177-11.

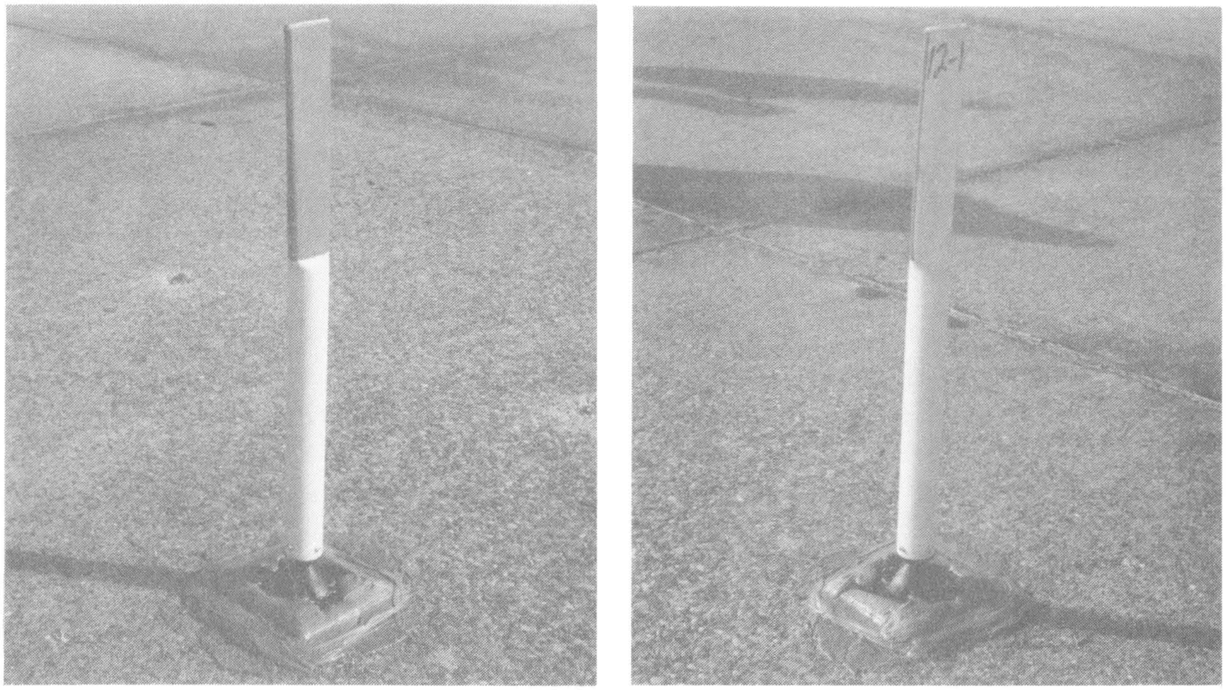

Figure 66 . Typical device for test 7177-12.

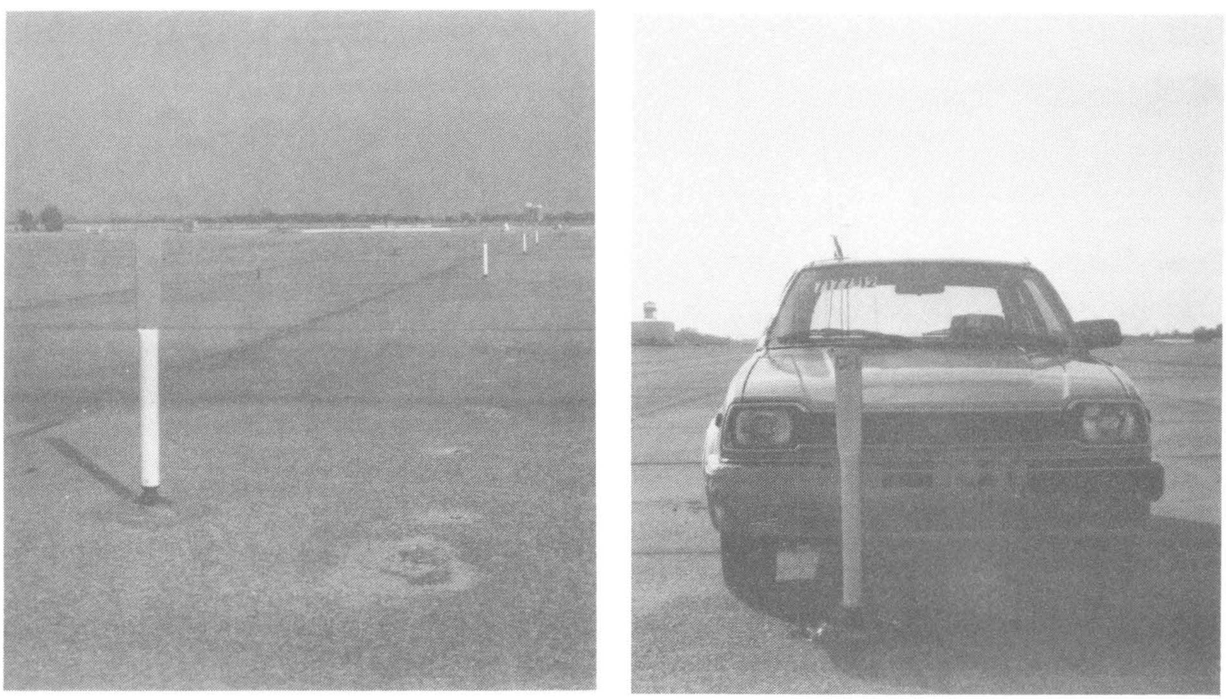

Figure 67 . Installation and vehicle before test 7177-12.

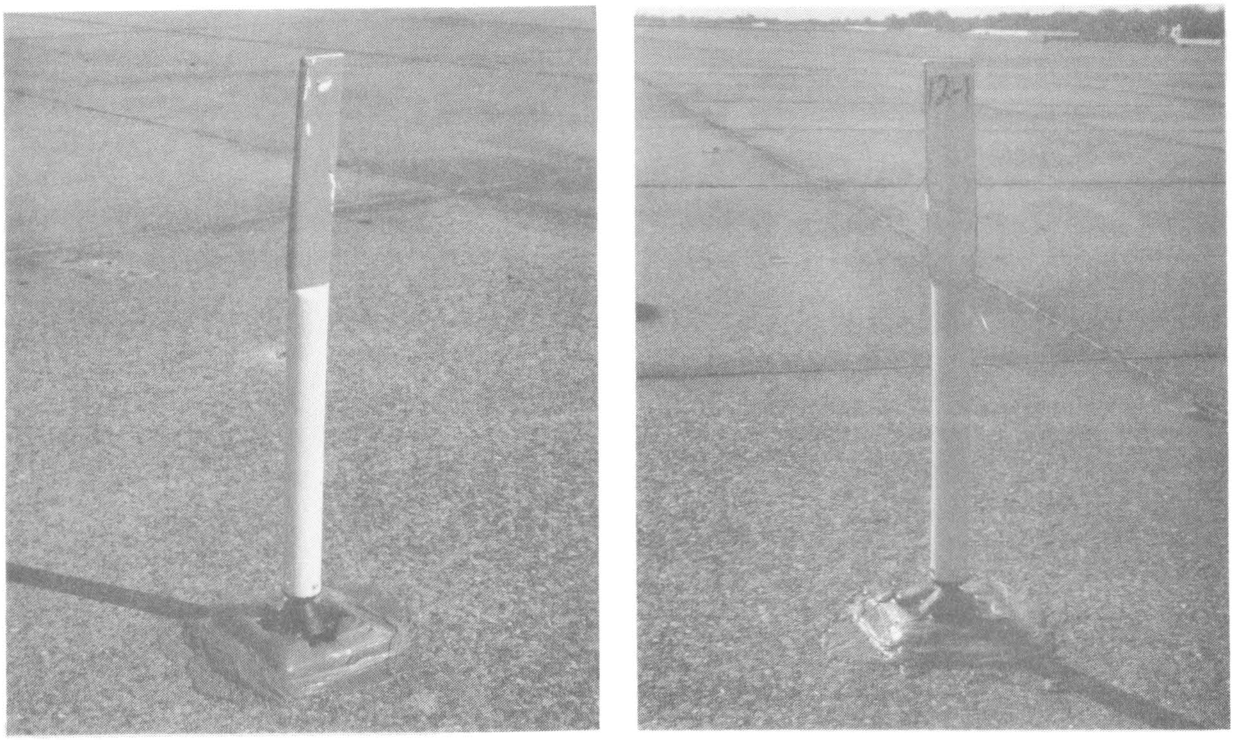

Figure 68 . Damage to first device, test 7177-12.

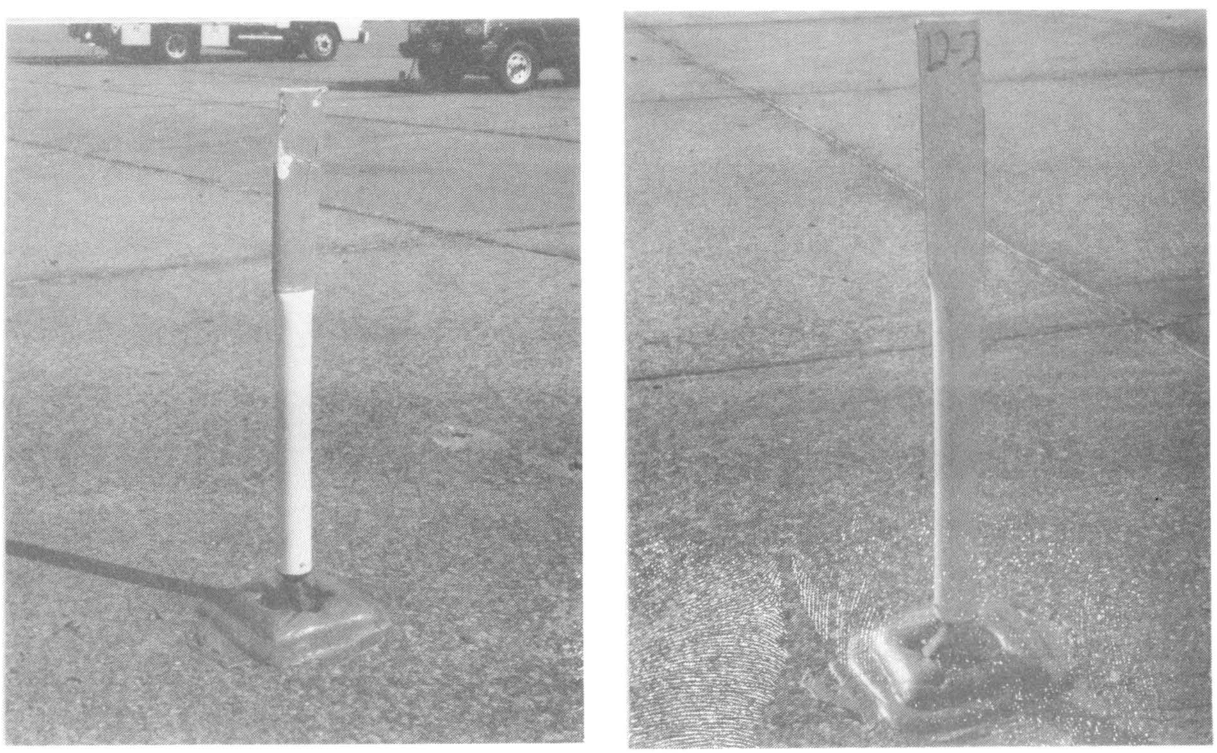

Figure 69 . Damage to second device, test 7177-12.

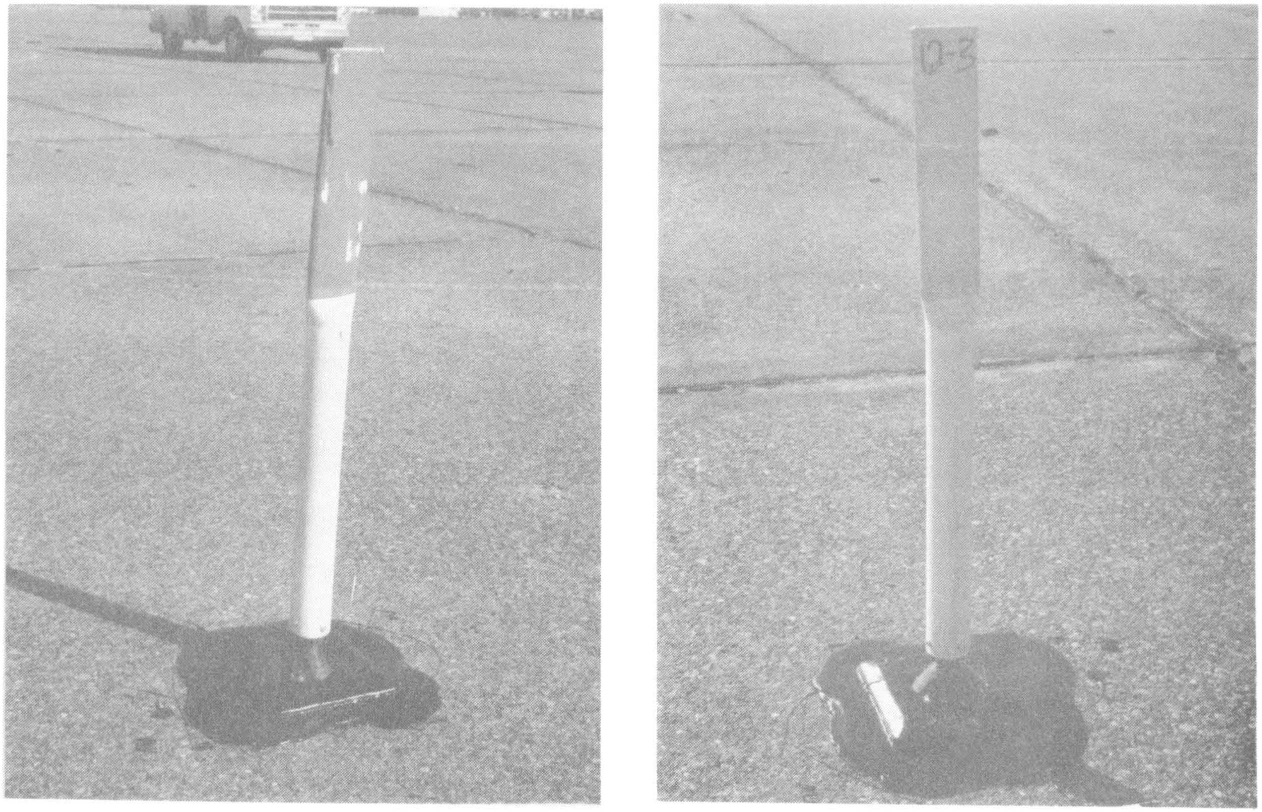

Figure 70 . Damage to third device, test 7177-12.

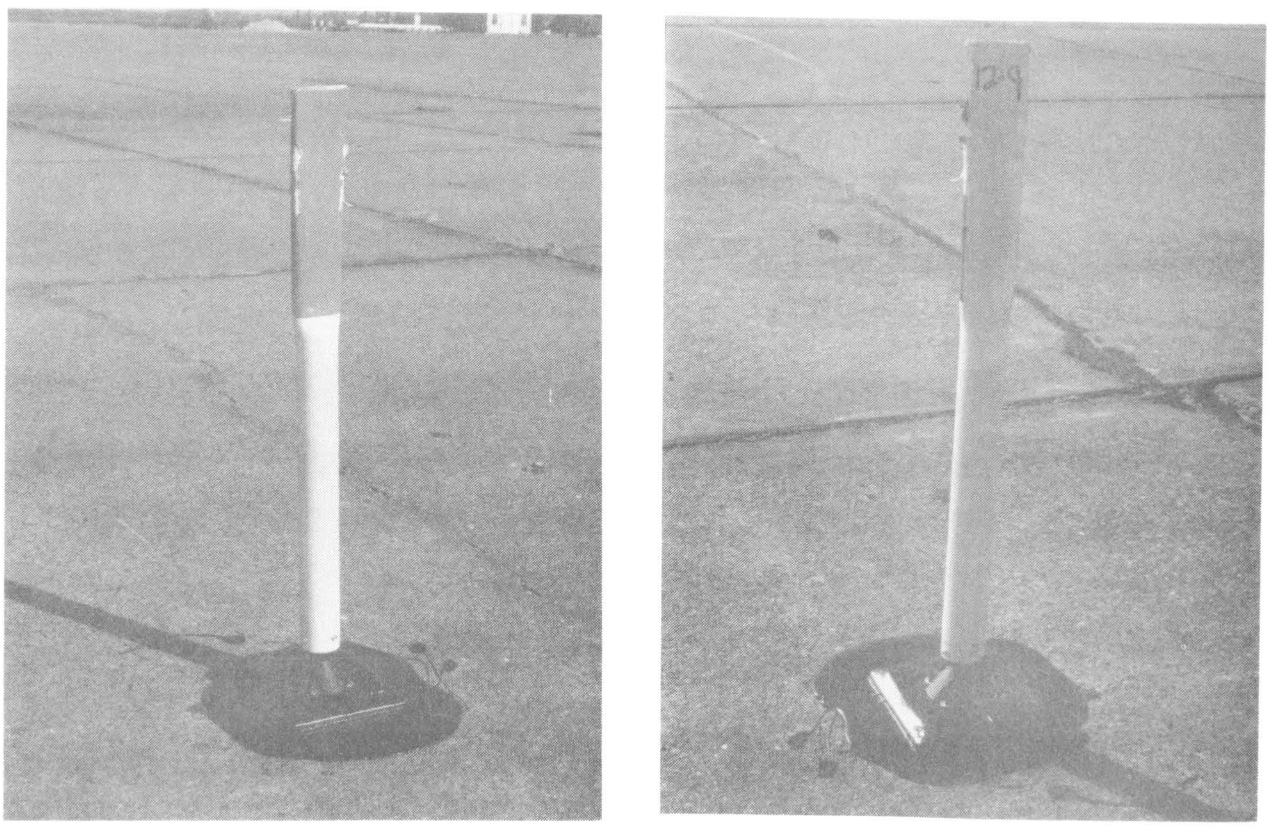

Figure 71 . Damage to fourth device, test 7177-12.

the pavement with an epoxy material while the last two bases were secured with a bituminous material. Photographs of the device are shown in Figure 72.

Speed of the vehicle as it contacted the first device was 57.9 mi/h. The impact point was the right quarter point of the vehicle bumper. The vehicle travelled smoothly through the test site with no driver input. The base of the third assembly was torn loose from the pavement and the assembly came to rest approximately 35 feet down and 1 foot to the left of the point of the impact. The remaining three assemblies stayed in place. The vehicle sustained only minor scrapes. Post-test photographs of the test installation and the vehicle are shown in Figures 73 through 76.

There was no occupant impact velocity during the test period. The maximum 50-msec average acceleration in the longitudinal direction was -0.3 g between 22 and 72 msec and -0.1 g between 20 and 70 msec in the lateral direction.

The vehicle received cosmetic damage only and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a straight, smooth path through the test site with no intrusion into adjacent traffic lanes. The vehicle remained stable throughout the test period. The base of the third assembly was torn loose from the pavement, but the assembly was thrown only a short distance from the point of impact.

<u>Test 7177-14</u>

This test installation was identical to that of Test 10, i.e., three (3) fixed chevron sign assemblies (Model No. 405-WHL-101BO) arranged in a straight line, except for the spacing between the devices which was increased to 60 feet to account for the higher nominal impact speed of 60 mi/h. The bases were all secured to the pavement with an epoxy material. Photographs of the installation are shown in Figure 77.

The vehicle was travelling at a speed of 61.5 mi/h as it impacted the first device with the right quarter point of the vehicle bumper. As the vehicle struck each chevron sign assembly, the sign panel wrapped around the grill of the vehicle. All three sign assemblies were damaged substantially. The post and panel units remained bent and did not fully return to their pre-impact positions. The epoxy compound around the base of the first sign assembly was cracked. The vehicle sustained minor dents to the hood and scrapes to the grill. Damage to the vehicle and devices is shown in Figures 78 through 81.

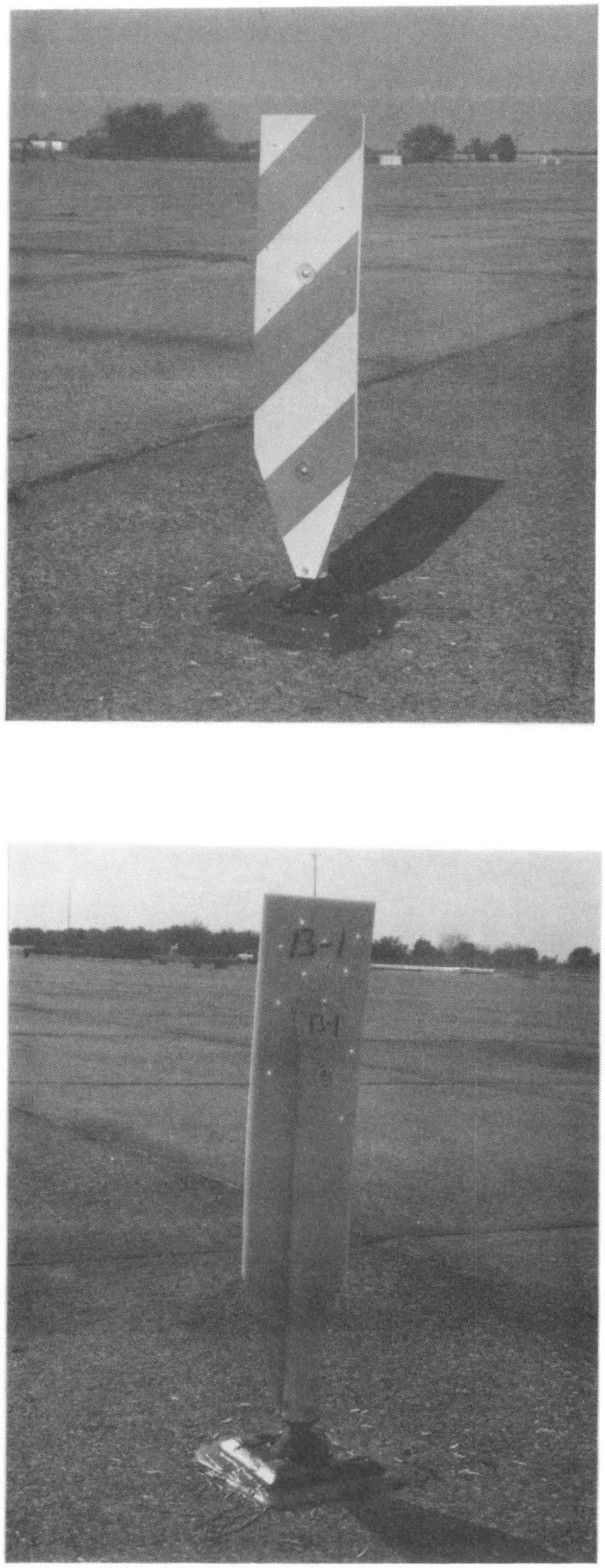

Figure 72 . Typical device used for test 7177-13.

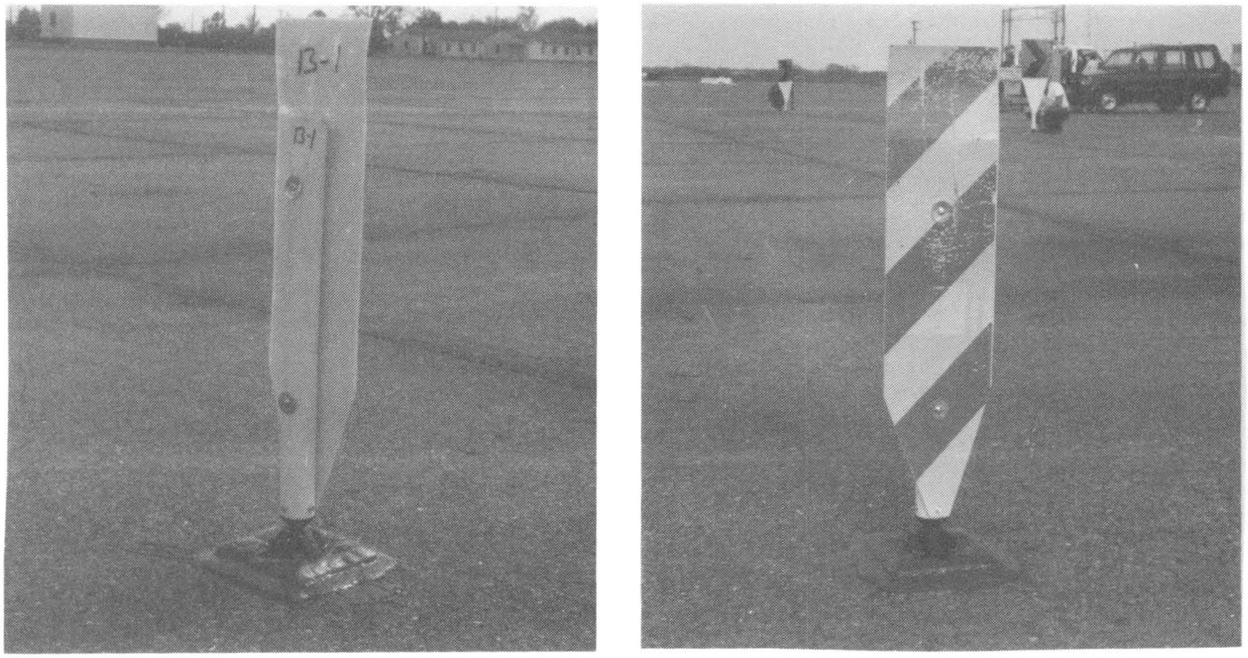

Figure 73 . Damage to first device, test 7177-13.

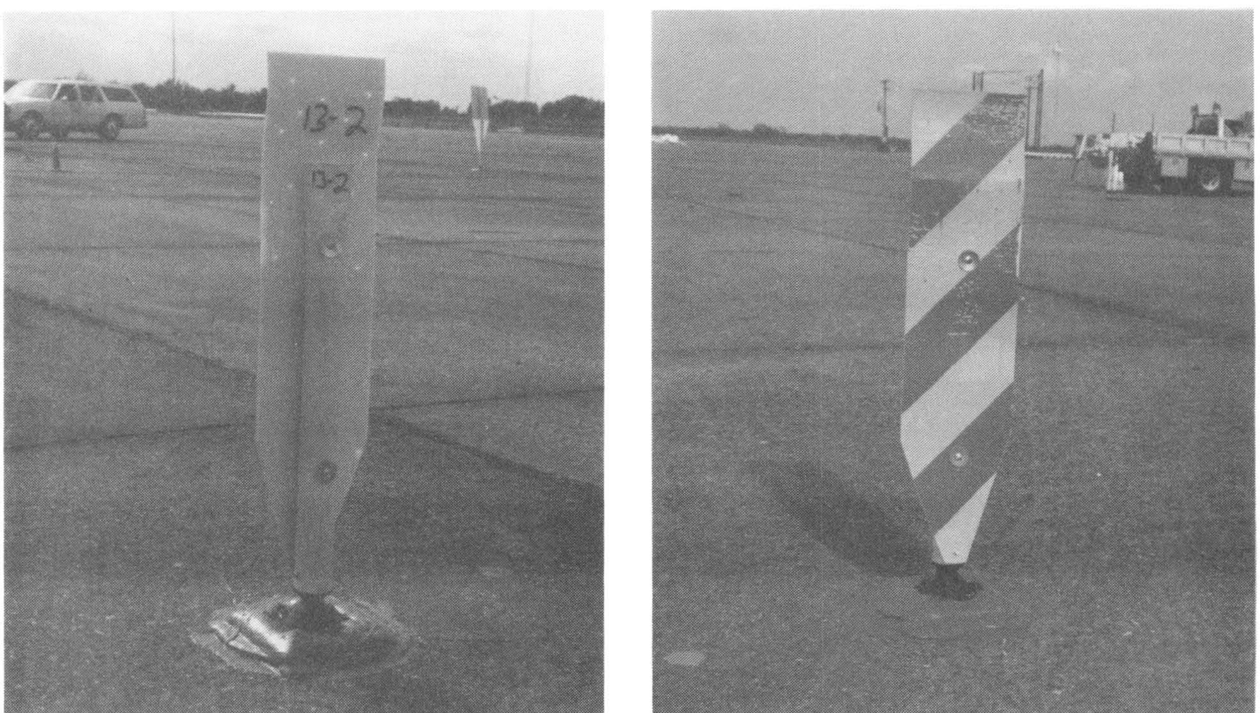

Figure 74 . Damage to second device, test 7177-13.

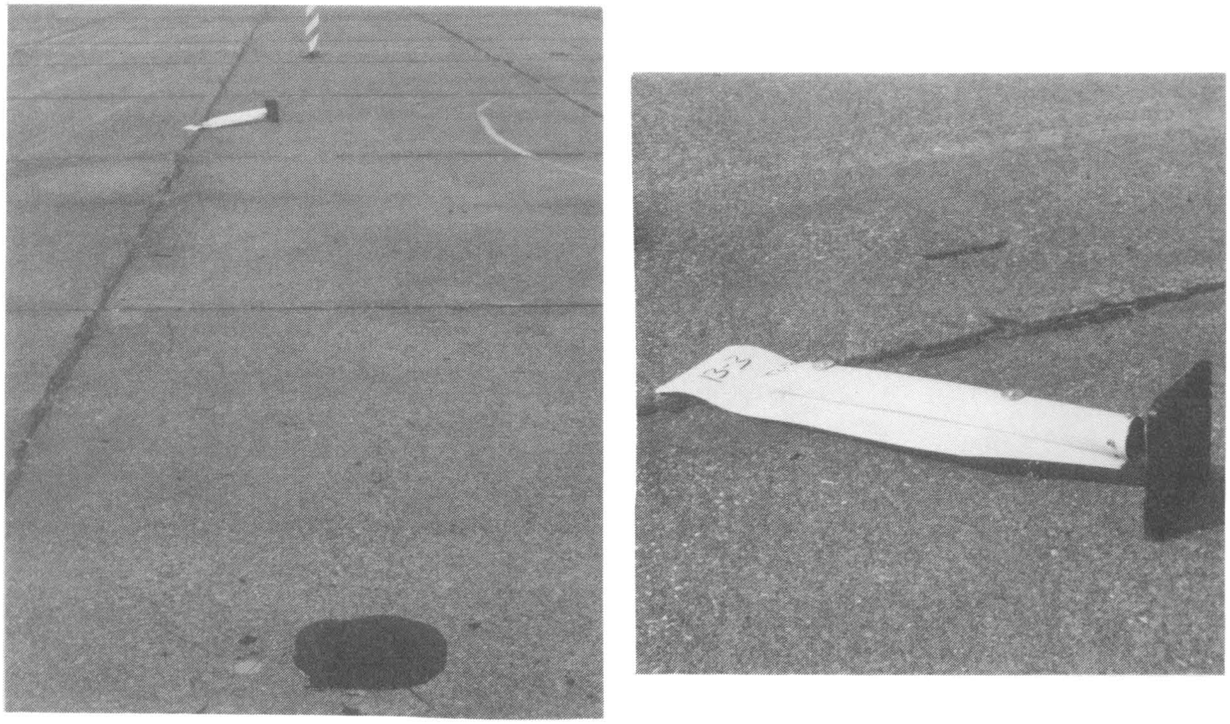

Figure 75 . Damage to third device, test 7177-13.

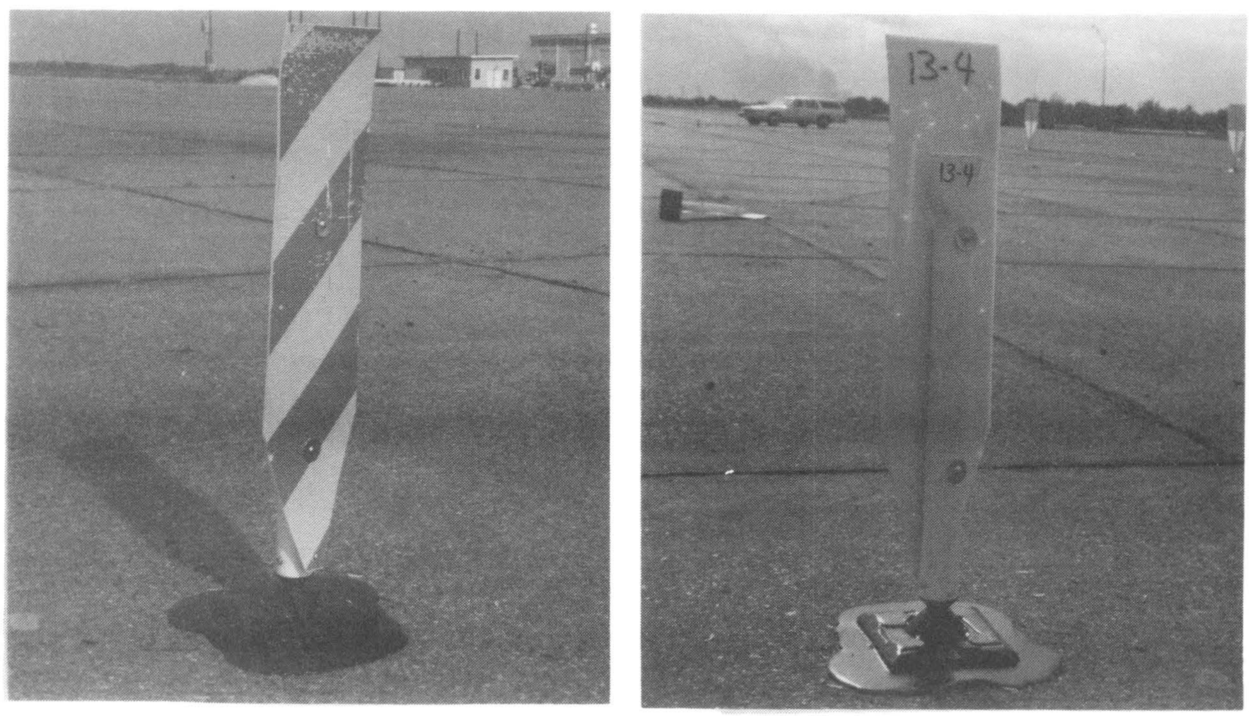

Figure 76 . Damage to fourth device, test 7177-13.

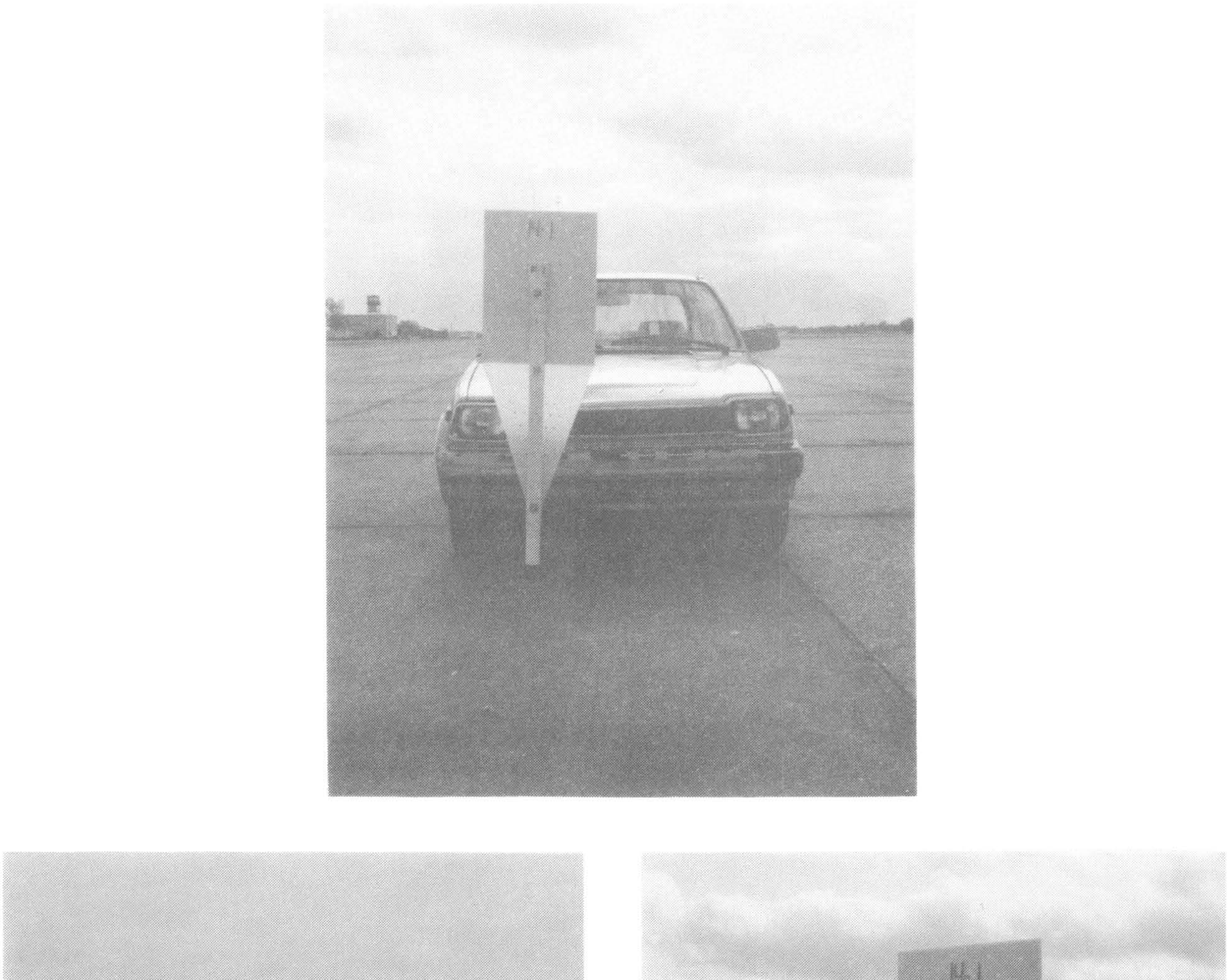

Figure 77. Installation and vehicle used for test 7177-14.

Fiqure 78. Vehicle and test site after test 7177-14.

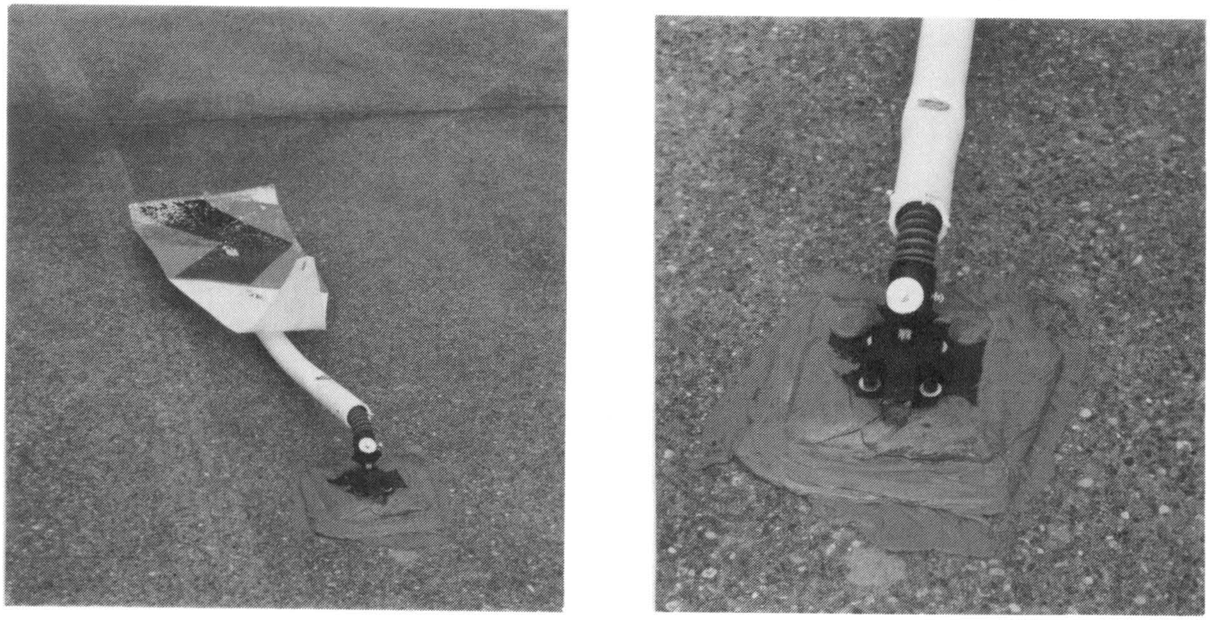

Figure 79. Damage to first device, test 7177-14.

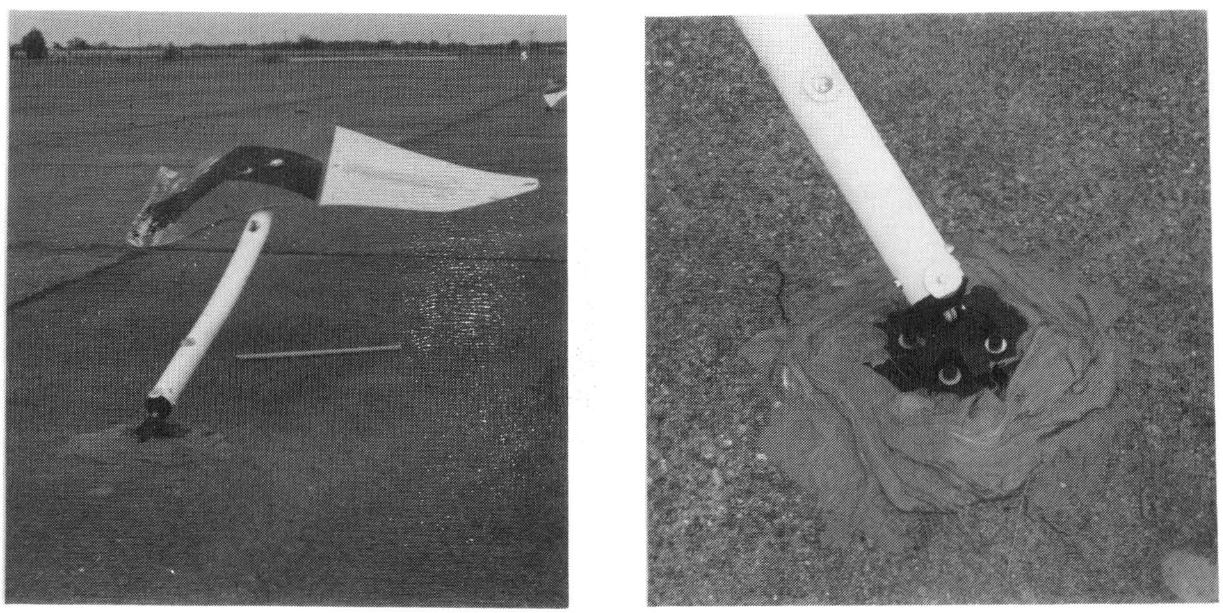

Figure 80. Damage to second device, test 7177-14.

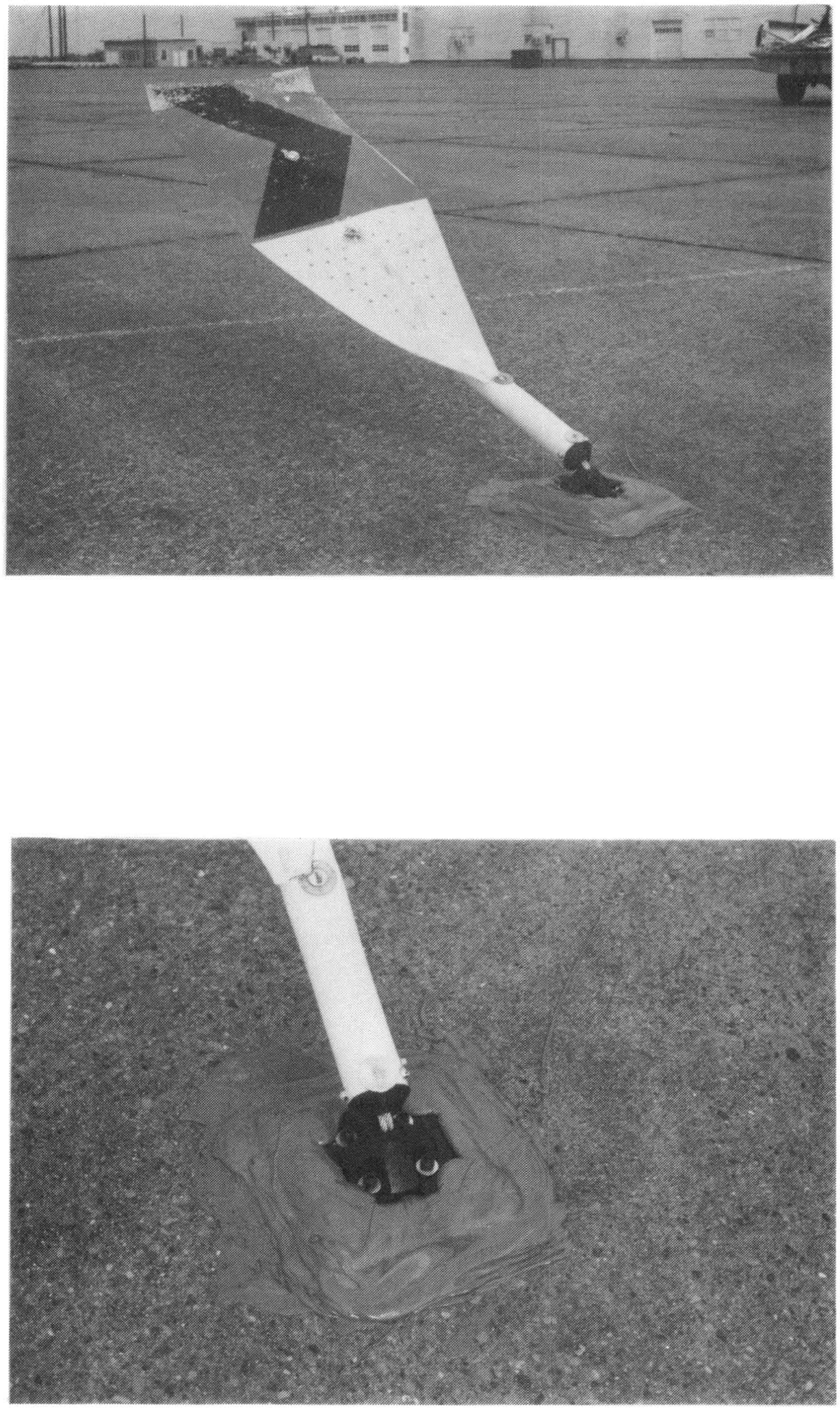

Figure 81. Damage to third device, test 7177-14.

No occupant impact occurred during the test. The maximum 50-msec average accelerations were -1.2 g between 3 and 53 msec in the longitudinal direction and -0.3 g between 28 and 78 msec in the lateral direction.

The vehicle received minor, repairable damage to the hood and grill and there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a straight, smooth path through the test site with no intrusion into adjacent traffic lanes. The sign assemblies received substantial damage but remained in place.

Test 7177-15

A vertical panel mounted on a wooden box weighted with sandbags, as shown in Figure 82, was used in this test. This vertical panel assembly is typical of those currently used in work zones in San Antonio, Texas. The purpose of this test was to provide some baseline of comparison for assessment of the impact performance of the various work zone traffic control devices crash tested in this study.

The vehicle was directed into the device using a cable-reverse tow and guidance system and was released to be unrestrained just prior to impact with the device. The impact point was the right corner of the bumper such that the right front tire rode over the device.

The vehicle was travelling at a speed of 62.6 mi/h as it contacted the device. As the vehicle rode over the device, the wooden box came apart from the impact force. Sand and debris, some of which were of considerable size, were strewn along the vehicle path over a relatively wide area. The device was totally destroyed and the vehicle received damage to the lower front spoiler and the right front quarter panel. Damage to the device and the vehicle are shown in Figures 83 and 84.

The longitudinal occupant impact velocity was 5.8 ft/s at 540 msec, the highest 10-msec ridedown acceleration was 0.6 g from 588 to 598 msec, and the maximum 50-msec average acceleration was -1.3 g between 245 and 295 msec. There was no occupant impact in the lateral direction and the maximum 50-msec average acceleration was 1.1 g between 9 and 59 msec.

The vehicle sustained minor damage to the right side but there was no penetration or intrusion of the occupant compartment of the vehicle. The vehicle remained on a relatively straight, smooth path through the test site with minimal intrusion into adjacent traffic lanes. The vehicle remained relatively stable

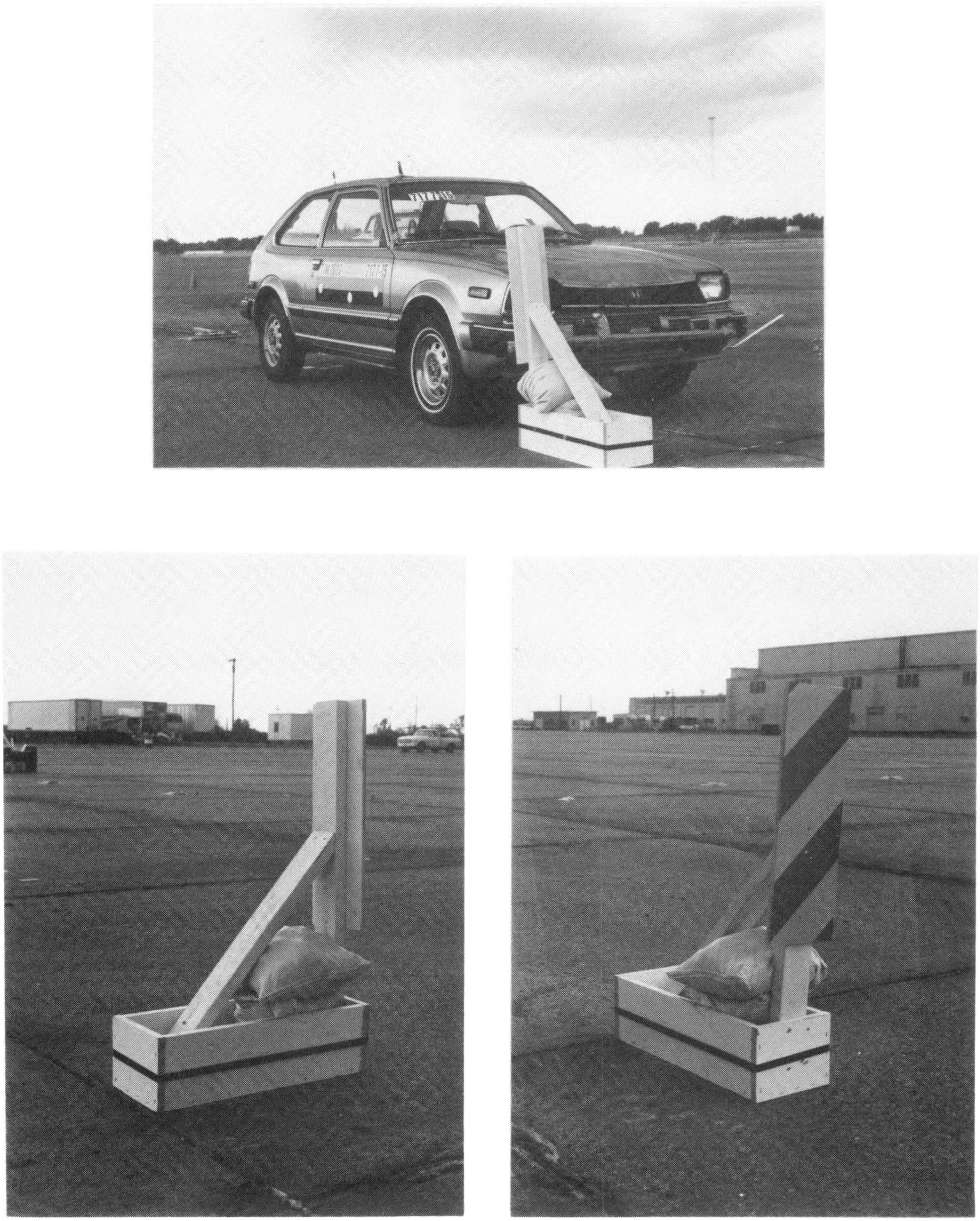

Figure 82. Device and vehicle prior to test 7177-15.

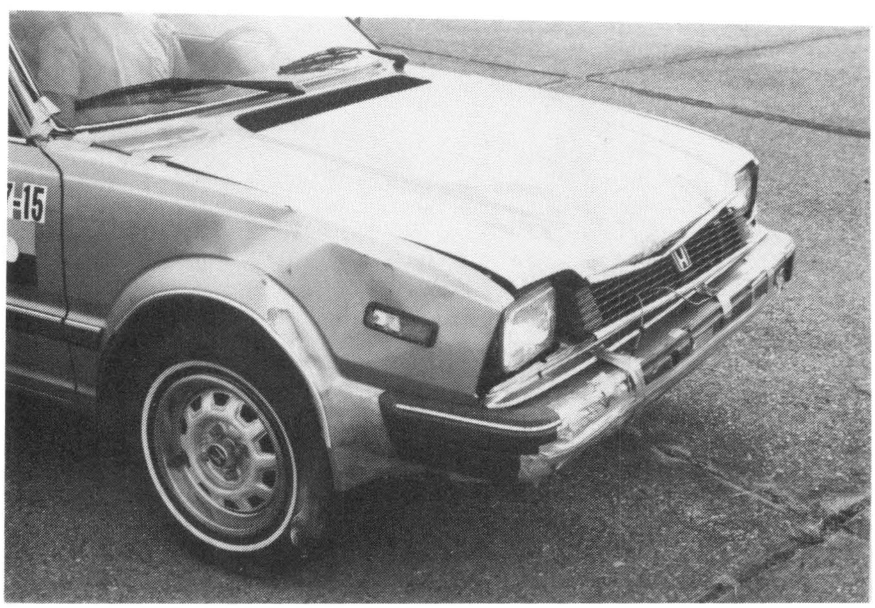

Figure 83. Vehicle after test 7177-15.

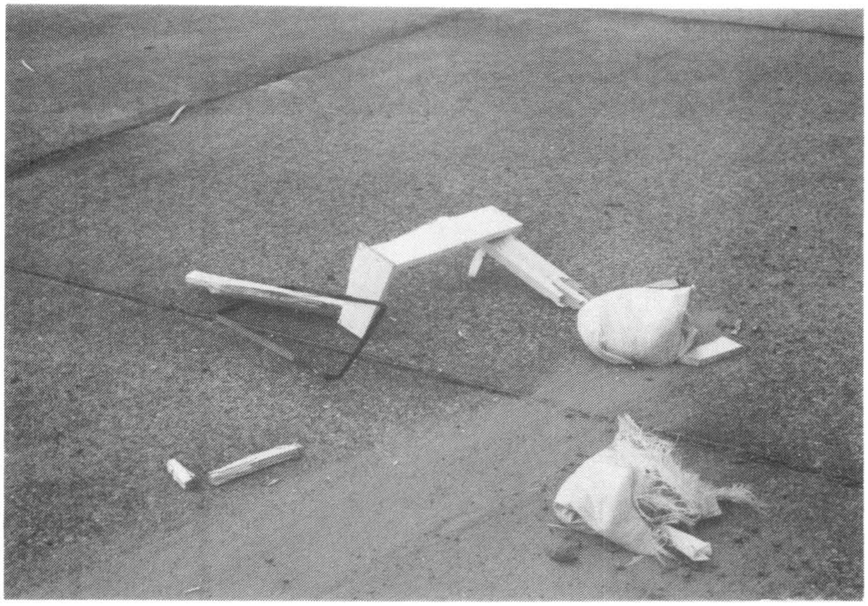

Figure 84. Damage to device, test 7177-15.

throughout the test sequence. The device came completely apart upon impact and debris was strewn along the vehicle path over a wide area.

Tests 7177-16 and 7177-17

Tests 16 and 17 involved testing of vertical panel assemblies designed for mounting on top of concrete safety shaped barriers. Three (3) vertical panel assemblies (Model No. 300-WHRRN-104R0) were mounted on top of a segment of safety shaped concrete median barrier as shown in Figure 85. The first assembly used a conventional saddle mount while the second and third assemblies used a plate base mount designed by Flasher Equipment Company.

A 2-inch pipe was welded to a back-up structure on the bed of a utility truck (provided by Flasher Equipment Company) in such a manner that the pipe extended approximately four feet beyond the side of the truck. The height of the pipe was five feet above ground so that the pipe would hit the center of the vertical panels as the truck travelled beside the barrier.

The truck was travelling at an approximate speed of 45 mi/h as it impacted the three vertical panel assemblies in test 16. No damage was sustained by the vertical panel assemblies except for minor scrapes on the panels, as shown in Figure 86.

In test 17, the speed of the truck as it impacted the vertical panel assemblies was increased to approximately 60 mi/h. The saddle mount on the first vertical panel assembly became detached from the barrier as the pipe struck the vertical panel and the vertical panel assembly was thrown a short distance from the barrier. The remaining two vertical panel assemblies sustained minor damage, including bending of the posts and panels and scrapes to the reflective sheeting as shown in Figure 87. It should be noted that the saddle mount used to attach the first vertical panel assembly to the top of the concrete barrier was designed for barriers constructed to Texas specifications. The concrete barrier segment used in the test was constructed to Oklahoma specifications and the saddle mount was a little too narrow for a proper fit. This probably accounted for the failure of the saddle mount and the detachment of the first vertical panel assembly.

No electronic data was recorded for these tests since they were intended for demonstration purposes only.

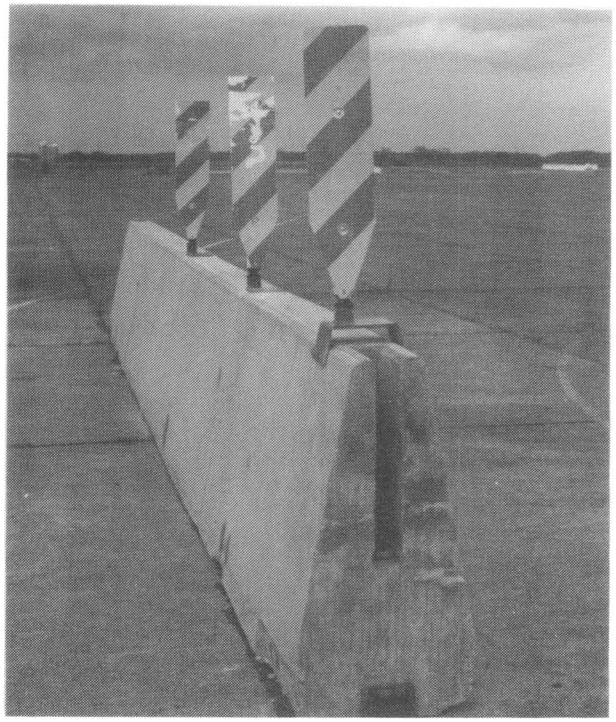

Figure 85. Installation used in tests 7177-16 and 17.

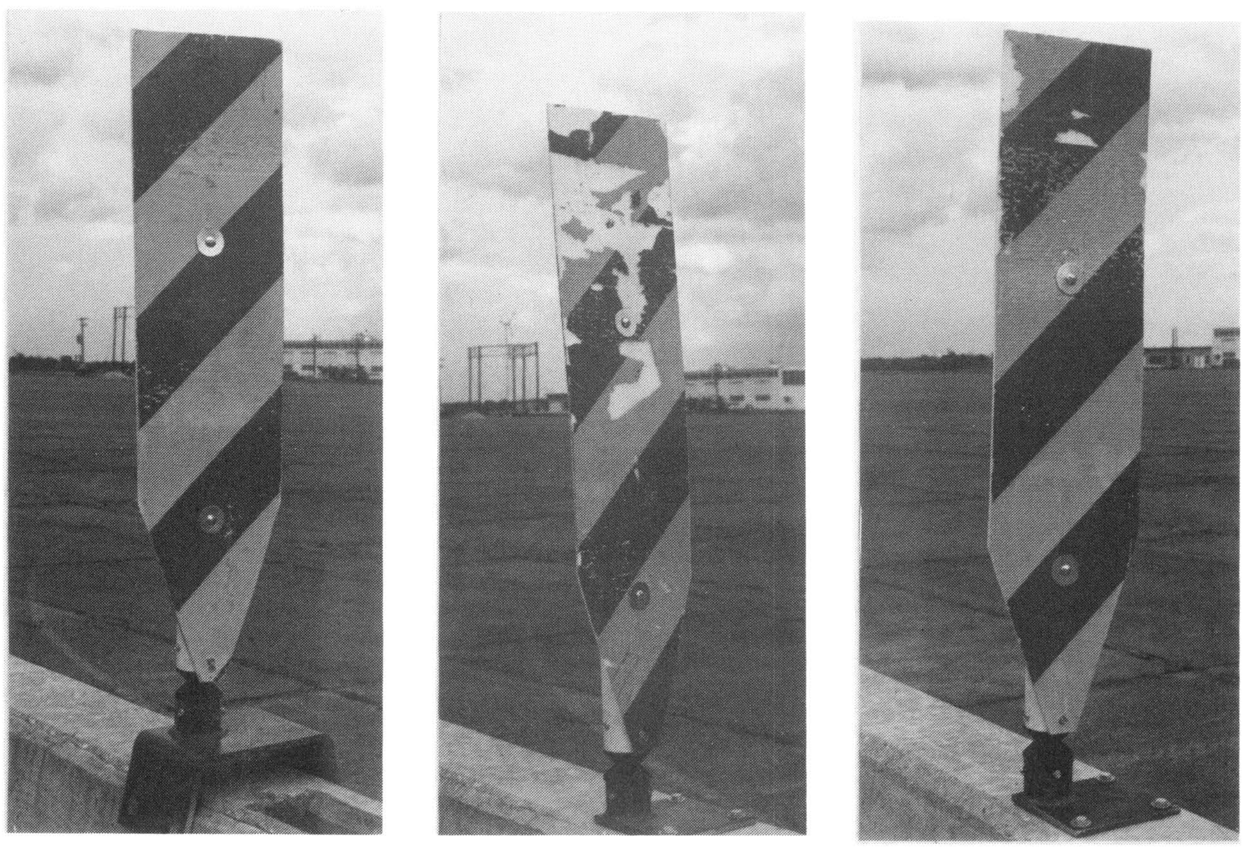

Figure 86. Devices after test 7177-16.

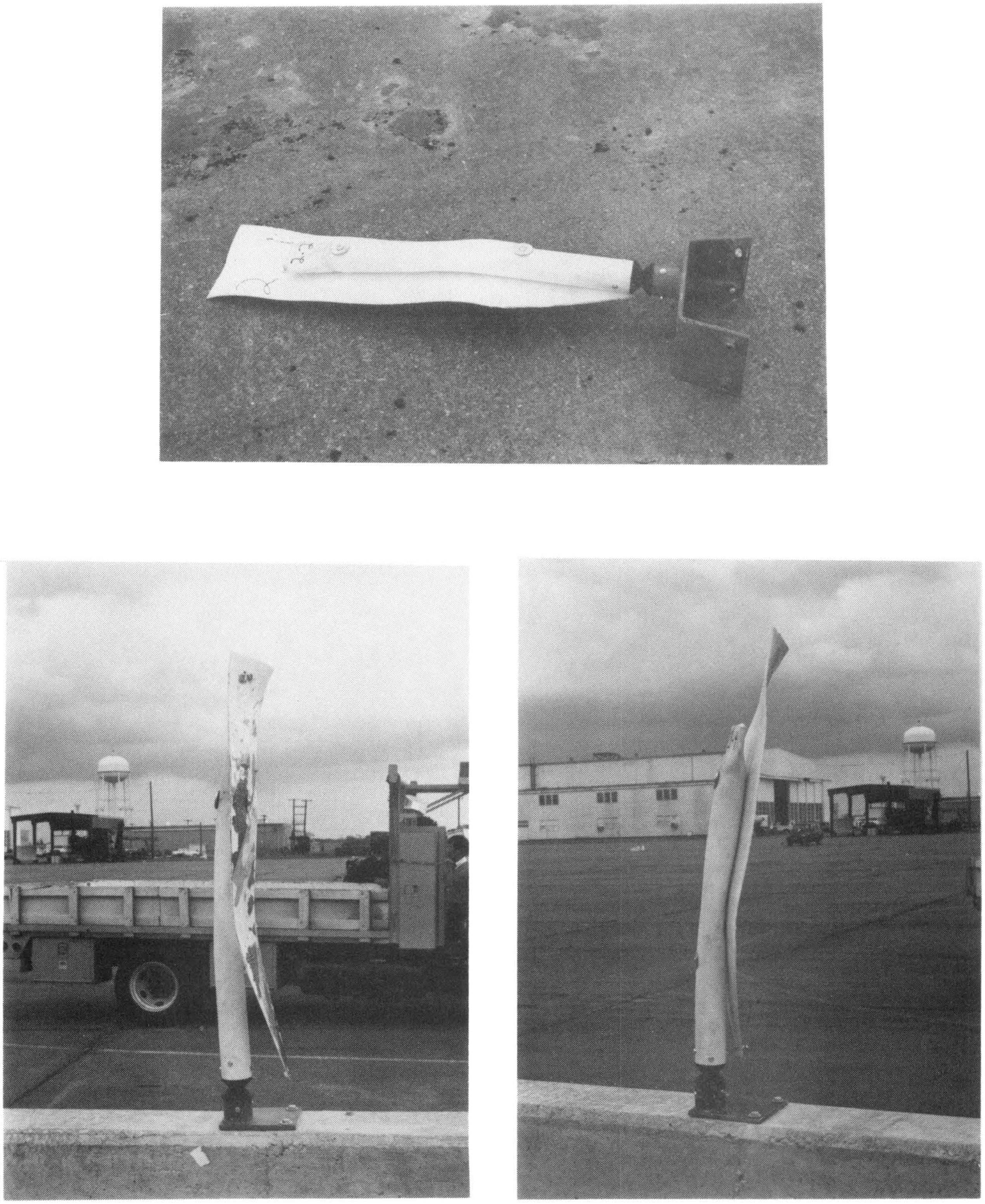

Figure 87. Devices after test 7177-17.

IV. SUMMARY

Various selected installations of work zone traffic control devices provided by Flasher Equipment Company were crash tested at nominal impact speeds of 45 and 60 miles per hour in this study. Description of the test installations and results of the crash tests are presented in previous sections. A number of conclusions and observations can be made based on the crash test results and are presented as follows:

- All the work zone traffic control devices tested in this study pose little hazard to the impacting vehicle from the occupant risk standpoint. Table 3 summarizes the occupant impact velocity, the highest 10-msec average ridedown acceleration, and the maximum 50-msec average acceleration for tests 1 through 15. It is evident from Table 3 that these values are well below the recommended limits set forth in NCHRP Report 230, indicating low potential for serious occupant injuries.
- The vehicle exhibited very stable behavior during impact with these work zone traffic control devices, even in tests where the tires of the vehicle were purposely lined up to ride directly over the devices. The vehicle did not appear to pose any potential threat to traffic in adjacent lanes.
- Damage to the vehicle from impacts with these work zone traffic control devices ranged from none to very minor cosmetic damage.
- Except for one 60 mi/h test involving chevron signs mounted on fixed bases (test 14), the spring-loaded mechanism successfully returned the traffic control devices to their pre-impact positions with mostly minor damage to the panel and the reflective sheeting. This indicates that these traffic control devices will likely remain functional after vehicular impacts, even without any maintenance. In comparison, the vertical panel mounted on a wooden box and weighted with sandbags came completely apart upon impact by the vehicle.

  While the spring-loaded mechanism worked well for traffic control devices mounted on portable bases, the assemblies were typically moved around by the impacting vehicle. This could render the traffic control devices out of position for their intended applications and might require some maintenance to return them to their proper positions.
- Except in situations where a driveable base was pulled out from the ground or a fixed base torn loose from the pavement, there were no debris from

Table 3. Summary of Crash Test Results

			Longitudinal Direction			Lateral Direction		
Test No.	Installation Type	Impact Speed	Occupant Impact Velocity	10-ms Ridedown	50-ms Average	Occupant Impact Velocity	10-ms Ridedown	50-ms Average
7177-1	Driveable Single VP	43.9 mi/h	None	N/A	-0.3 g 044-094 ms	None	N/A	-0.2 g 019-069 ms
7177-2	Driveable Single VP	60.0 mi/h	6.2 ft/s at 427 ms	-0.4 g 498-508 ms	-2.1 g 031-081 ms	5.5 ft/s at 463 ms	-1.3 g 498-508 ms	-1.5 g 095-145 ms
7177-3	Driveable Delineator	58.2 mi/h	None	N/A	-1.2 g 025-075 ms	4.5 ft/s at 526 ms	-0.5 g 526-536 ms	-0.6 g 012-062 ms
7177-4	Portable Single VP	59.7 mi/h	None	N/A	-0.7 g 031-081 ms	None	N/A	-0.4 g 028-078 ms
7177-5	Portable Double VP	43.3 mi/h	5.5 ft/s at 474 ms	0.3 g 494-504 ms	-2.2 g 055-105 ms	None	N/A	-1.5 g 053-103 ms
7177-6	Portable Simulated Barrel Sign	43.9 mi/h	None	N/A	-1.5 g 055-105 ms	4.5 ft/s at 564 ms	0.5 g 571-581 ms	1.2 g 102-152 ms
7177-7	Portable Simulated Barrel Sign	57.4 mi/h	None	N/A	-0.8 g 001-051 ms	4.5 ft/s at 478 ms	0.2 g 531-541 ms	-0.6 g 006-056 ms
7177-8	Driveable Single VP (Repeat of Test 2)	57.9 mi/h	None	N/A	-0.7 g 004-054 ms	None	N/A	-0.5 g 450-500 ms
7177-9	Fixed Double VP	44.9 mi/h	None	N/A	-0.4 g 105-155 ms	None	N/A	0.2 g 300-350 ms
7177-10	Fixed Chevron Sign	43.5 mi/h	None	N/A	-0.6 g 000-050 ms	None	N/A	-0.3 g 027-077 ms

Table 3. Summary of Crash Test Results (continued)

			Longitudinal Direction			Lateral Direction		
Test No.	Installation Type	Impact Speed	Occupant Impact Velocity	10-ms Ridedown	50-ms Average	Occupant Impact Velocity	10-ms Ridedown	50-ms Average
7177-11	Fixed Simulated Barrel Sign	44.8 mi/h	None	N/A	-0.2 g 000-050 ms	None	N/A	-0.1 g 026-076 ms
7177-12	Fixed Delineator	61.1 mi/h	None	N/A	-0.3 g 007-057 ms	None	N/A	-0.2 g 015-065 ms
7177-13	Fixed Single VP	57.9 mi/h	None	N/A	-0.3 g 022-072 ms	None	N/A	-0.1 g 020-070 ms
7177-14	Fixed Chevron Sign	61.5 mi/h	None	N/A	-1.2 g 003-053 ms	None	N/A	-0.3 g 028-078 ms
7177-15	Wood Box Mounted Single VP	62.6 mi/h	5.8 ft/s at 540 ms	0.6 g 588-598 ms	-1.3 g 245-295 ms	None	N/A	1.1 g 009-059 ms

the traffic control devices to pose any potential hazard to the impacting vehicle, adjacent traffic, or the workers. In comparison, the impact with the vertical panel mounted on a wooden box weighted with sandbags results in the scatter of debris and sand over a wide area.

- Of the four base failures, three were associated with assemblies with flashing light unit and accompanying battery packs attached. Further investigation in the effect of attaching the flashing light unit and the accompanying battery packs on the impact performance of the traffic control devices is recommended.

  Also, both of the fixed base failures had bituminous material as the bonding agent. Additional study into the bonding strength of the bituminous material is recommended to determine if the bituminous material has the required bonding strength to keep the fixed bases from being pulled loose from the pavement.

In summary, most of the work zone traffic control devices provided by Flasher Equipment Company for testing in this study performed very well in the crash tests. The impacting vehicle exhibited very stable behavior during impact with these traffic control devices and did not appear to pose any potential threat to traffic in adjacent lanes. The vehicle sustained very minor damage with low potential for serious occupant injury. There were generally no debris or detachments from the traffic control devices to pose any potential hazard to the impacting vehicle, adjacent traffic, or the workers. The spring-loaded mechanism successfully returned the traffic control devices to their pre-impact positions in all but one test. The damage sustained by the traffic control devices was limited to mostly bent panels and scrapes in the reflective sheeting, which should not significantly affect the functionality of the traffic control devices.

V. REFERENCES

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2. Mak, K. K., and Campise, W. L., "Testing and Evaluation of Traffic Control Devices for Use in Work Zones," Final Report, TTI Project No. 19170, Texas Transportation Institute, Texas A&M University System, College Station, Texas, August 1990.
3. Michie, J. D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report No. 230, National Cooperative Highway Research Program, Transportation Research Board, Washington, D. C., March 1981.
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