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SAFETY PERFORMANCE EVALUATION OF MINNESOTA'S ALUMINUM WORK ZONE SIGNS

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16. Abstract (Limit: 200 words)

A wide variety of traffic controlling devices are used in work zones, some of which are not normally found on the roadside or in the traveled way outside of the work zones. These devices are used to enhance the safety of the work zones by controlling the traffic through these areas. Due to the placement of the traffic control devices, the devices themselves may be potentially hazardous to both workers and errant vehicles. The impact performance of many work zone traffic control devices is mainly unknown and to date limited crash testing has been conducted, under the criteria of National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*.

The objective of the study was to evaluate the safety performance of existing aluminum sign support systems through full-scale crash testing. A total of six full-scale crash tests were conducted on sign supports to determine their safety performance according to the Test Level 3 (TL-3) criteria set forth in the NCHRP Report No. 350. Two of the six impacts on the sign support systems resulted in acceptable safety performances. Following the analysis of these crash tests as well as the test results from other testing programs, it has been found that slight variations in design features of the work zone traffic control devices can lead to very different performance results. Therefore, extreme care should be taken in applying crash test results from one work zone traffic control device to similar work zone traffic control devices with slight variations. The results of the crash tests were documented, and conclusions and recommendations pertaining to the safety performance of the existing work zone traffic control devices were made.

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State Highway Departments participating in the Midwest State's Regional Pooled Fund Research Program nor the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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1 INTRODUCTION

1.1 Problem Statement

A wide variety of traffic controlling devices are used in work zones, some of which are not normally found on the roadside or in the traveled way outside of the work zones. These devices are used to enhance the safety of the work zones by controlling the traffic through these areas. Due to the placement of the traffic control devices, the devices themselves may be potentially hazardous to both workers (or bystanders) and occupants of errant vehicles. Thus, the Federal Highway Administration (FHWA) and the *Manual on Uniform Traffic Control Devices (MUTCD)* (1) require that work zone traffic control devices must demonstrate acceptable crashworthy performance in order to be used within the roadway on the National Highway System (NHS).

The impact performance of many work zone traffic control devices is mainly unknown and limited crash testing has been conducted in accordance with the guidelines set forth in National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (2). The Texas Department of Transportation (TxDOT) has sponsored a number of studies at the Texas Transportation Institute (TTI) to assess the impact performance of various work zone traffic control devices, including plastic drums, sign substrates, barricades, and temporary sign supports (3-7). Full-scale crash testing on plastic drums, barricades, portable sign supports, and tall-mounted, rigid panel sign supports has also been previously conducted at the University of Nebraska-Lincoln (8-20). The previous studies have provided some useful information, but there remains unanswered questions regarding the performances of many work zone traffic control devices, which are slightly different from those crash tested.

1.2 Objective

The objective of the research project was to evaluate the safety performance of existing aluminum work zone sign supports through full-scale crash testing. The safety performance evaluations were conducted according to the Test Level 3 (TL-3) criteria set forth in the NCHRP Report No. 350 (2).

1.3 Scope

The research objective was achieved by performing several tasks. First, six full-scale vehicle crash tests were performed on several aluminum work zone traffic control devices. The six crash tests were completed in three runs with a centerline and a left-side quarter-point impact in each run, resulting in a total of six crashes. The full-scale crash tests were performed using a small car, weighing approximately 820 kg, with target impact speeds of 105.0 km/hr and 100.0 km/hr for the first and second impacts, respectively, and angles of 0 degrees and 90 degrees for the first and second impacts, respectively. Finally, the test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made that pertain to the safety performance of the existing aluminum work zone sign supports.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Work zone traffic control devices, such as aluminum work zone sign supports, must satisfy the requirements provided in NCHRP Report No. 350 to be accepted by FHWA for use on NHS construction projects or as a replacement for existing designs not meeting current safety standards. According to FHWA's Submission Guidelines attached to the July 1997 memorandum, *Action: Identifying Acceptable Highway Safety Features* (21), work zone traffic control devices are Category 2 devices, which are not expected to produce significant change in vehicular velocity, but may otherwise be hazardous since they have the potential to penetrate a windshield, injure a worker, or cause vehicle instability when driven over or lodged under a vehicle.

According to Test Level 3 (TL-3) of NCHRP Report No. 350 and FHWA's Submission Guidelines for acceptable Category 2 devices, work zone traffic control devices must be subjected to two full-scale vehicle crash tests: (1) an 820-kg small car impacting at a speed of 35.0 km/hr and at an angle of 0 degrees; and (2) an 820-kg small car impacting at a speed of 100.0 km/hr and at an angle of 0 degrees. The low-speed test is intended to evaluate the breakaway, fracture, or yielding mechanism of the device and occupant risk factors whereas the high-speed test is intended to evaluate vehicular stability, test article trajectory, and occupant risk factors. Since most work zone traffic control devices have a relatively small mass (less than 45 kg), the high-speed crash test is more critical due to the propensity of the test article to penetrate into the occupant compartment. Therefore, the 820-kg small car crash test, impacting at a speed of 35.0 km/hr and at an angle of 0 degrees, was deemed unnecessary for this project. However, these devices are often situated on the roadway where an impact could occur at other angle orientations, such as at 90 degrees at an intersecting roadway. Thus, it has become generally recognized that an additional test should be performed on such devices at the target speed of 100 km/hr and at a target impact angle of 90 degrees.

2.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the work zone traffic control device to break away, fracture, or yield in a predictable manner. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle, including windshield damage. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to cause subsequent multi-vehicle accidents, thereby subjecting occupants of other vehicles to undue hazards or to subject the occupants of the impacting vehicle to secondary collisions with other fixed objects. These three evaluation criteria are defined in Table 1. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in NCHRP Report No. 350 and for Category 2 devices.

Windshield damage is a major area of concern when evaluating the safety performance of a work zone traffic control device. The windshield should not be shattered nor damaged in a way that visibility is significantly obstructed. Minor chipping and cracking of the windshield is acceptable. Significant loss of visibility due to extensive "spider web" cracking at key regions of the windshield would deem the performance of the device unsatisfactory. Both layers of glass should not be fractured nor indented with the potential for the test article to penetrate the windshield. The five main failure criteria are defined in Table 2.

Table 1. NCHRP Report No. 350 Evaluation Criteria for 820C Small Car Crash Test (2)

Structural Adequacy	B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.
Occupant Risk	D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.
	E. Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.
	F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.
	H. Longitudinal occupant impact velocities should fall below the preferred value of 3 m/s, or at least below the maximum allowable value of 5 m/s.
	I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15 G's, or at least below the maximum allowable value of 20 G's.
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
	N. Vehicle trajectory behind the test article is acceptable.

Table 2. Failure Criteria

METHOD OF FAILURE	
1	Severe windshield cracking and fracture
2	Windshield indentation
3	Obstruction of driver visibility
4	Windshield penetration
5	Occupant compartment penetration other than windshield penetration

3 WORK ZONE SIGN SUPPORTS

3.1 General Descriptions

A total of six existing work zone traffic control devices were crash tested under this study and are described below. All six of the crash tests were conducted on aluminum work zone sign supports. All materials for the traffic control devices were supplied by the sponsor.

The four different aluminum work zone sign supports tested were:

1. (System Nos. 1 and 2) a 1,725-mm wide x 1,520-mm deep x 2,005-mm tall aluminum sign support with a 1,220-mm x 1,220-mm aluminum diamond-shaped aluminum sign panel with reflective material mounted at a height of 344 mm from the ground to the bottom of the sign panel;

2. (System No. 3) a 915-mm wide x 1,520-mm deep x 2,173-mm tall aluminum sign support with a 915-mm x 1,218-mm aluminum rectangular-shaped sign panel with reflective material mounted at a height of 344 mm from the ground to the bottom of the sign panel and a 915-mm x 610-mm aluminum rectangular-shaped sign panel with reflective material mounted at a height of 1,562 mm from the ground to the bottom of the sign panel;

3. (System No. 4) a 915-mm wide x 1,520-mm deep x 2,160-mm tall aluminum sign support with a 915-mm x 915-mm aluminum octagon-shaped sign panel with reflective material mounted at a height of 1,245 mm from the ground to the bottom of the sign panel; and

4. (System Nos. 5 and 6) a 1,724-mm wide x 1,230-mm deep x 2,137-mm tall aluminum sign support with a 1,219-mm x 1,219-mm aluminum diamond-shaped aluminum sign panel with reflective material mounted at a height of 473 mm from the ground to the bottom of the sign panel.

A list of the six crash tests are summarized in Table 3.

Table 3. List of Crash Tests Conducted

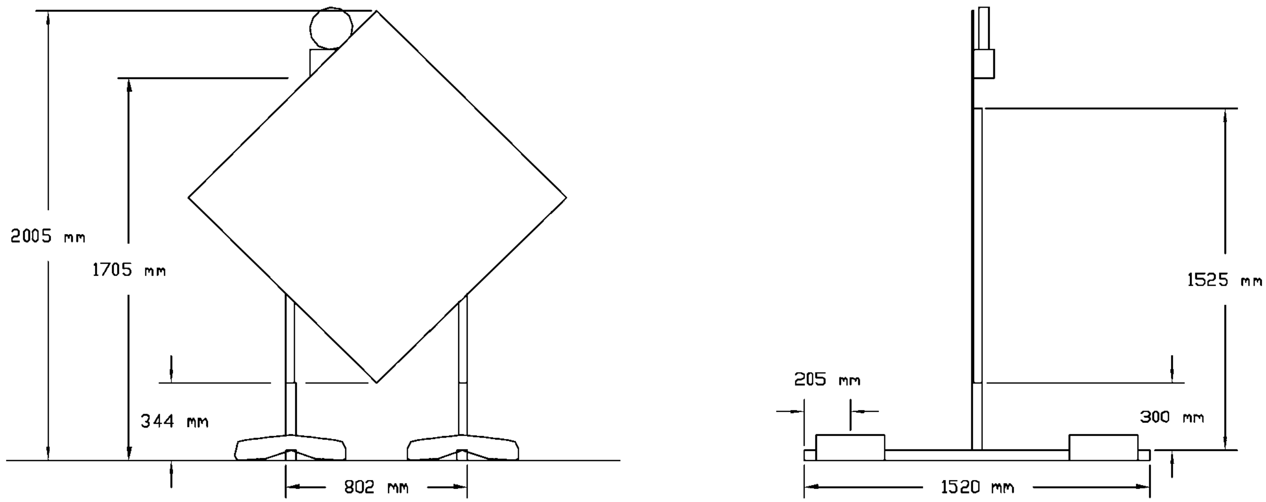
Work zone TRAFFIC CONTROL DEVICES

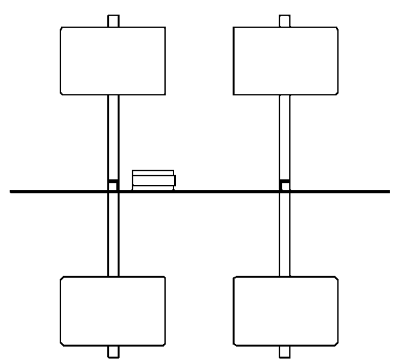
ALUMINUM WORK ZONE SIGN SUPPORTS

Test MNS-1	System No. 1	Aluminum Sign Support with a Diamond-Shaped Aluminum Panel, “Empco-Lite” Warning Light, Sandbag on Each Leg, Head-on Impact (0 degrees)
Test MNS-1	System No. 2	Aluminum Sign Support with a Diamond-Shaped Aluminum Panel, “Empco-Lite” Warning Light, Sandbag on Each Leg, End-on Impact (90 degrees)
Test MNS-2	System No. 3	Large Combination Sign System – Aluminum Sign Support with Two Aluminum Sign Panels (one mounted above the other), Sandbag on Each Leg, Head-on Impact (0 degrees)
Test MNS-2	System No. 4	Stop Sign System – Aluminum Sign Support with Aluminum Stop Sign Panel, Sandbag on Each Leg, End-on Impact (90 degrees)
Test MNS-3	System No. 5	Aluminum Sign Support with a Diamond-Shaped Aluminum Panel, “ToughLite 2000" Warning Light, Sandbag on Each Leg, Head-on Impact (0 degrees)
Test MNS-3	System No. 6	Aluminum Sign Support with a Diamond-Shaped Aluminum Panel, “ToughLite 2000" Warning Light, Sandbag on Each Leg, End-on Impact (90 degrees)

3.2 Aluminum Work Zone Sign Supports

The details of the aluminum work zone sign supports are shown in Figures 1 through 10. The dimensional measurements of the aluminum work zone sign supports are found in Appendix A.





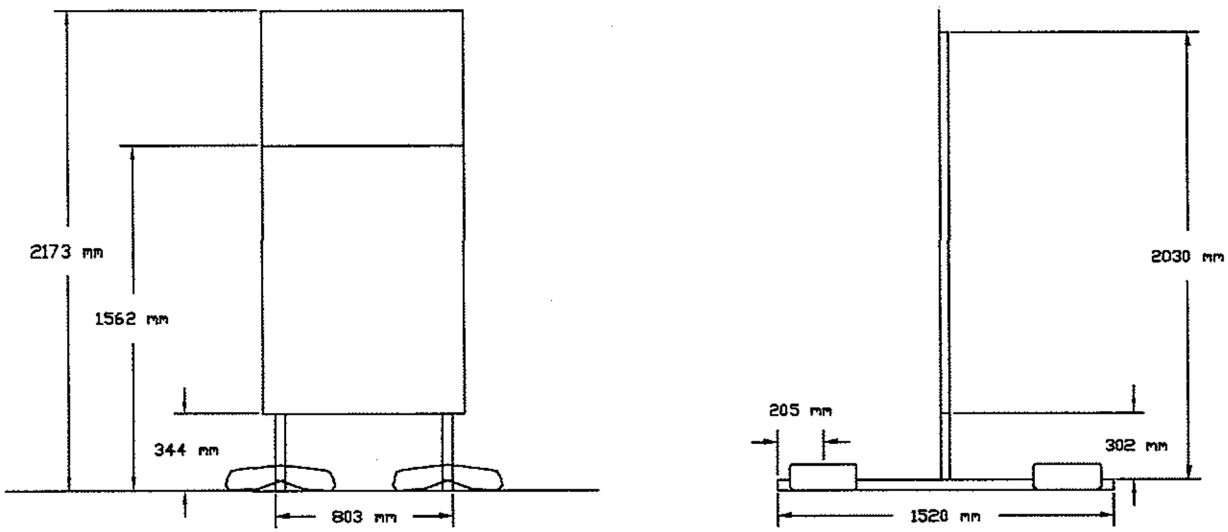
ALUMINUM TEMPORARY SIGN SUPPORT SYSTEM

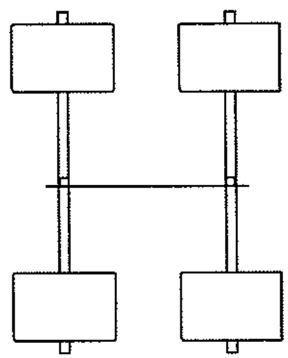
* Vertical Upright Masts – 38 mm x 38 mm x 2.7 mm wall x 1525 mm long telespar galvanized steel
* Legs, Horizontal Portion – 45 mm x 45 mm x 2.75 mm wall x 1520 mm long telespar galvanized steel
* Legs, Vertical Portion – 45 mm x 45 mm x 2.75 mm wall x 300 mm long telespar galvanized steel
* All telespar steel tubing contain 11.00 mm diameter punched holes, spaced 25.00 mm on center, along the total length
* Vertical portion of leg is welded to horizontal portion on all four sides
* Masts slide inside vertical portion of legs -- No bolt or fastening device used
* Panel – Reflective aluminum, 1220 mm wide x 1220 mm long with a 2.75 mm thickness
* Panel fastened to vertical mast supports with 7.9 mm x 57.2 mm pan head bolts
* Light – Empco Flashing Warning Light attached to the sign panel
* Ballast – 20.4-kg sandbag at end of each leg

Figure 1. System Nos. 1 and 2 Sign Details, Test MNS-1

Figure 2. System No. 1 Sign, Test MNS-1

Figure 3. System No. 2 Sign, Test MNS-1





LARGE COMBINATION TEMPORARY SUPPORT SYSTEM

* Vertical Upright Masts – 38 mm x 38 mm x 2.75 mm wall x 2030 mm long telespar galvanized steel
* Legs, Horizontal Portion – 45 mm x 45 mm x 2.75 mm wall x 1520 mm long telespar galvanized steel
* Legs, Vertical Portion – 45 mm x 45 mm x 2.75 mm wall x 302 mm long telespar galvanized steel
* All telespar steel tubing contain 11.50 mm diameter punched holes, spaced 25.50 mm on center, along the total length
* Vertical portion of leg is welded to horizontal portion on all four sides
* Masts slide inside vertical portion of legs –– No bolt or fastening device used
* Top Panel – Reflective aluminum, 915 mm wide x 610 mm long with a 2.80 mm thickness
* Bottom Panel – Reflective aluminum, 914 mm wide x 1218 mm long with a 2.70 mm thickness
* Panel fastened to vertical mast supports with 7.9 mm x 57.2 mm pan head bolts
* Ballast – 20.4–kg sandbag at end of each leg

Figure 4. System No. 3 Sign Details, Test MNS-2

Figure 5. System No. 3 Sign, Test MNS-2

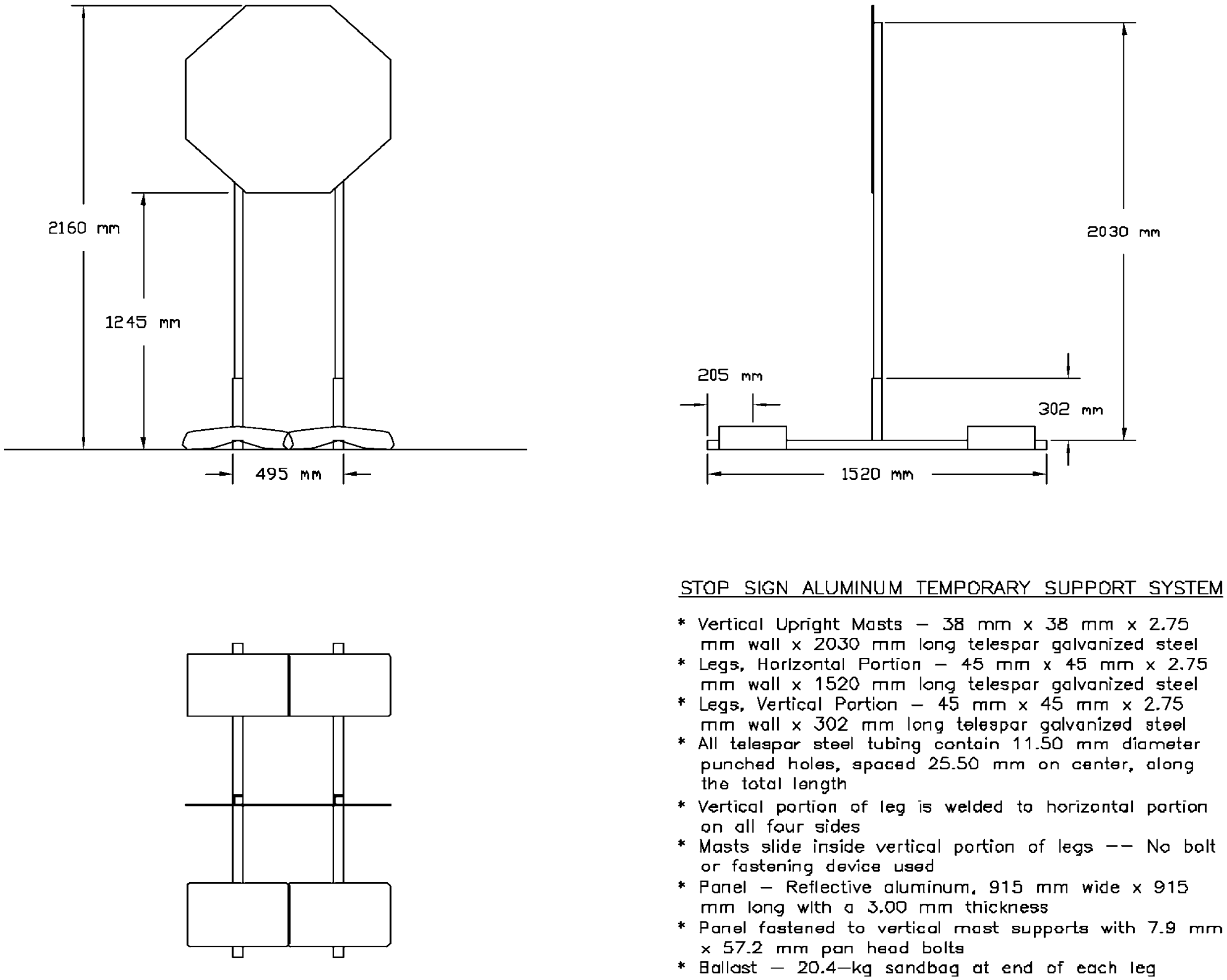


Figure 6. System No. 4 Sign Details, Test MNS-2

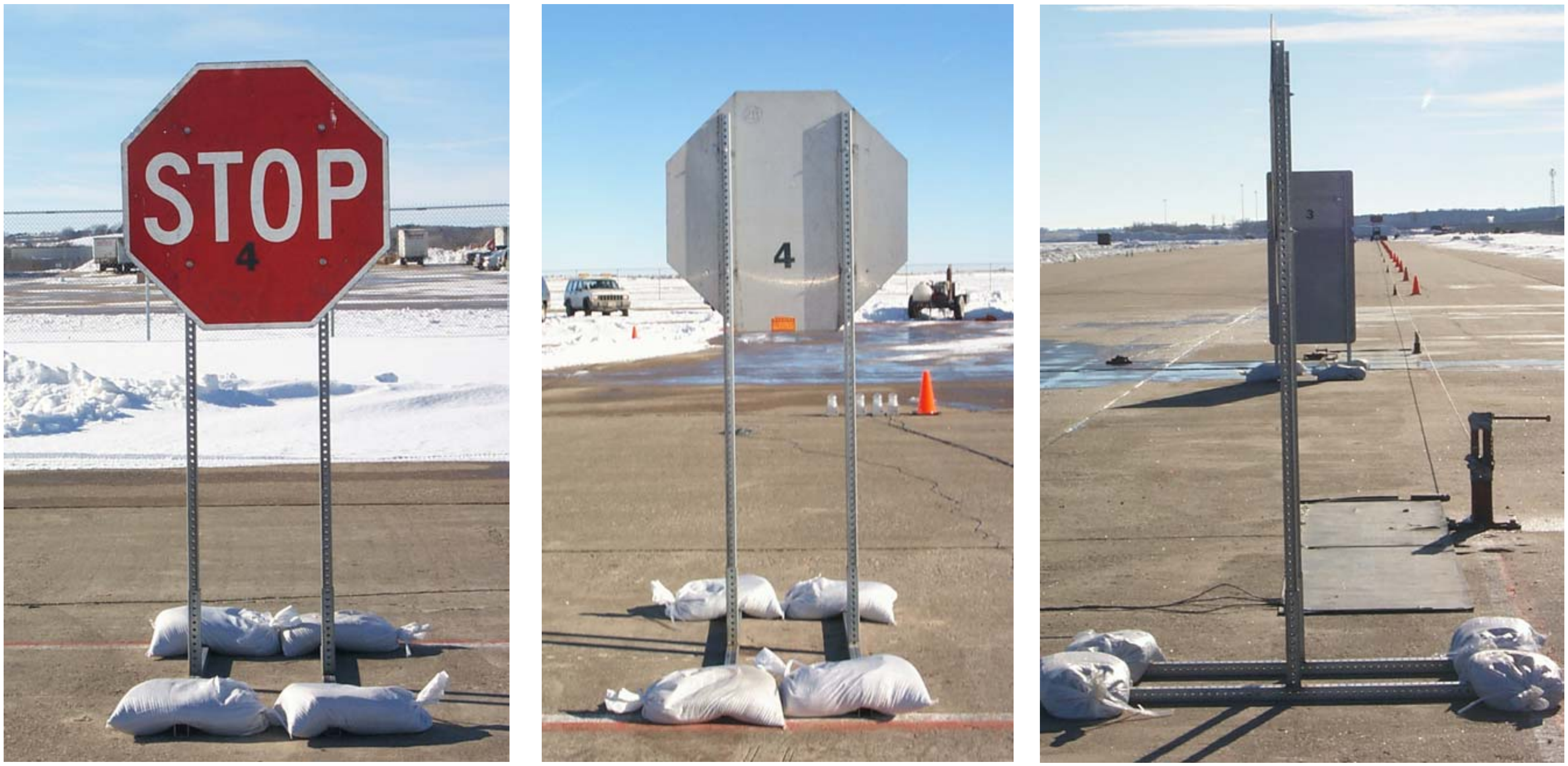
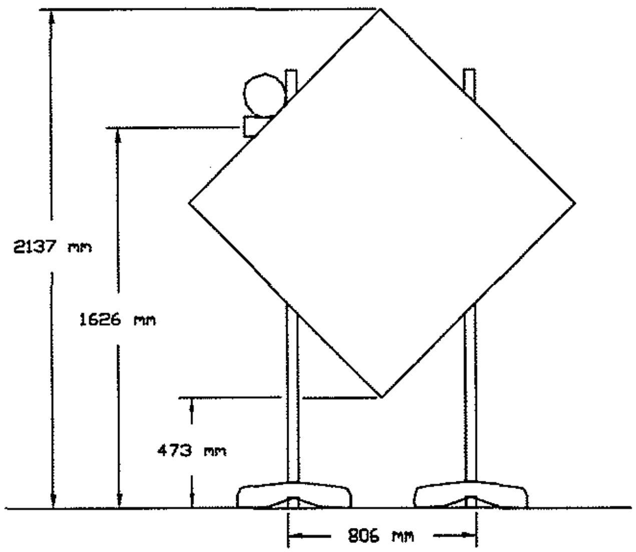
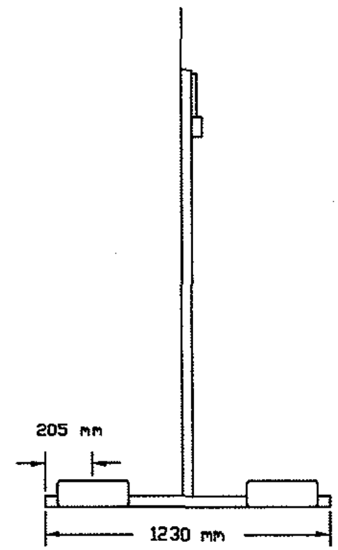
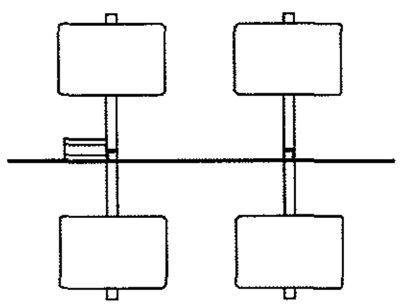


Figure 7. System No. 4 Sign, Test MNS-2







ALUMINUM TEMPORARY SIGN SUPPORT SYSTEM

* Vertical Upright Masts – 44.51 mm x 44.50 mm x 2.05 mm wall x 1829 mm long telespar galvanized steel
* Legs, Horizontal Portion – 44.42 mm x 44.42 mm x 2.72 mm wall x 1230 mm long telespar galvanized steel
* Legs, Vertical Portion – 38.11 mm x 38.06 mm x 2.75 mm wall x 302 mm long telespar galvanized steel
* All telespar steel tubing contain 10.72 mm diameter punched holes, spaced 25.13 mm on center, along the total length
* Vertical portion of leg is welded to horizontal portion on all four sides
* Masts slide outside vertical portion of legs –– No bolt or fastening device used
* Panel – Reflective aluminum, 1219 mm wide x 1219 mm long with a 2.95 mm thickness
* Panel fastened to vertical mast supports with 7.9 mm x 57.2 mm pan head bolts
* Light – Will Industries, Inc Flashing Warning Light attached to the sign panel
* Ballast – 20.4–kg sandbag at end of each leg

Figure 8. System Nos. 5 and 6 Sign Details, Test MNS-3

Figure 9. System No. 5 Sign, Test MNS-3

Figure 10. System No. 6 Sign, Test MNS-3

4 TEST CONDITIONS

4.1 Test Facility

The testing facility is located at the Lincoln Air-Park on the northwest (NW) side of the Lincoln Municipal Airport and is approximately 8.0 km NW of the University of Nebraska-Lincoln.

4.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicles. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the first work zone traffic control device. A digital speedometer was located on the tow vehicle to increase the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (22) was used to steer the test vehicle. A guide-flag, attached to the front-left wheel and the guide cable, was sheared off before impact with the second work zone traffic control device. The 9.5-mm diameter guide cable was tensioned to approximately 13.3 kN, and supported laterally and vertically every 30.48 m by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. The vehicle guidance system was approximately 304.8-m long.

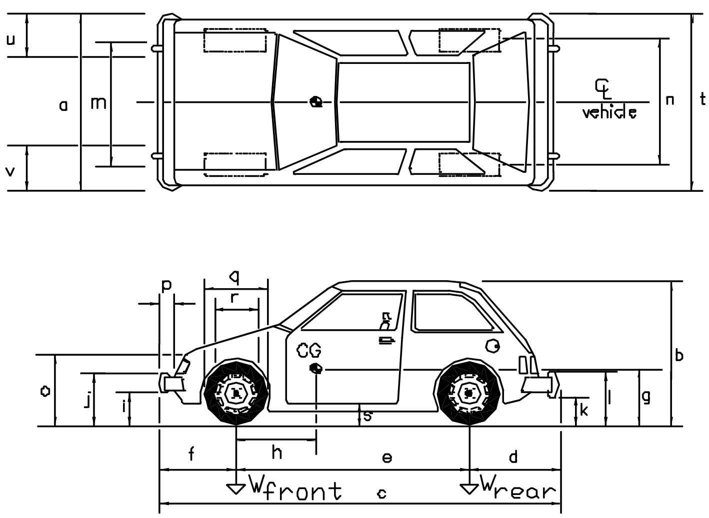
4.3 Test Vehicles

For test MNS-1, a 1994 Geo Metro was used as the test vehicle. The test inertial and gross static weights were 816 kg and 891 kg, respectively. The test vehicle is shown in Figure 11, and vehicle dimensions are shown in Figure 12.

For test MNS-2, a 1994 Geo Metro was used as the test vehicle. The test inertial and gross

Figure 11. Test Vehicle, Test MNS-1

Dates: 1/3/01 | Test Numbers: MNS-1 | Model: Metro
Make: GEO | Vehicle I.D.#: 2C1MR646XR6730749
Tire Size: 145/80 R12 | Year: 1994 | Odometer: 131,227



Vehicle Geometry - mm

a	1562	b	1353
c	3778	d	648
e	2375	f	756
g	546	h	944
i	356	j	476
k	235	l	559
m	1356	n	1340
o	521	p	76
q	527	r	330
s	286	t	1524
u	400	v	400

height of wheel center: 248

Engine Type: 3 cyl. gas

Engine size: 1.0 L

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Weight - kg	Curb	Test Inertial	Gross Static
W_{front}	489	492	528
W_{rear}	299	324	363
W_{total}	788	816	891

Damage prior to test: minor cracked windshield

Figure 12. Vehicle Dimensions, Test MNS-1

static weights were 819 kg and 894 kg, respectively. The test vehicle is shown in Figure 13, and vehicle dimensions are shown in Figure 14.

For test MNS-3, a 1995 Geo Metro was used as the test vehicle. The test inertial and gross static weights were 822 kg and 898 kg, respectively. The test vehicle is shown in Figure 15, and vehicle dimensions are shown in Figure 16.

The longitudinal component of the center of gravity was determined using the measured axle weights. The location of the final centers of gravity are shown in Figures 11 through 16.

Square, black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed E/cam video, as shown in Figures 17 through 19. One target was placed directly above each of the wheels on the driver and passenger sides of the test vehicle. A target was placed at each quarter point on the front of the vehicle's hood.

The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. Two 5B flash bulbs were mounted on both the left and right quarter points of the vehicle's roof to pinpoint the time of impact with each of the work zone traffic control devices on the high-speed E/cam video. The flash bulbs were fired by a pressure tape switch mounted at each of the quarter points on the front face of the bumper. A remote controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

4.4 Data Acquisition Systems

4.4.1 High-Speed Photography

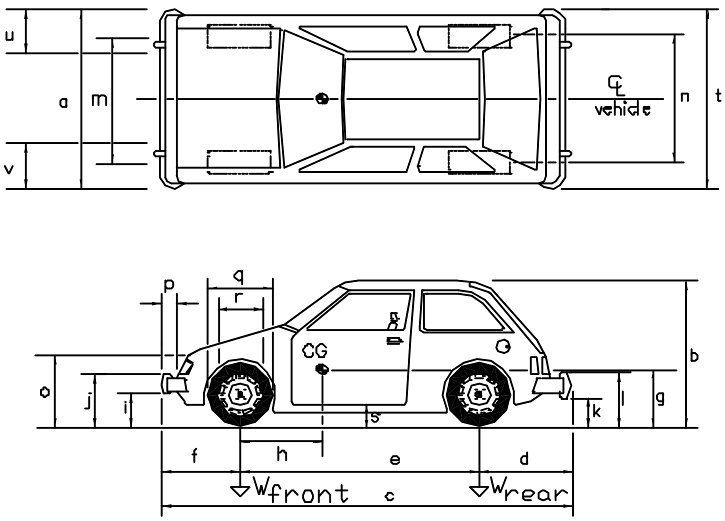
For tests MNS-1and MNS-2, two high-speed 16-mm Red Lake E/cam video cameras, with operating speeds of 500 frames/sec, were used to film the crash test. Three Canon digital video

Figure 13. Test Vehicle, Test MNS-2

Dates: 1/3/01 Test Numbers: MNS-2 Model: Metro

Make: GEO Vehicle I.D.#: 2C1MR6468R6777035

Tire Size: 145/80 R12 Year: 1994 Odometer: 45,338



Vehicle Geometry - mm

a	1549	b	1359
c	3785	d	686
e	2375	f	724
g	546	h	947
i	387	j	470
k	292	l	527
m	1353	n	1340
o	533	p	89
q	533	r	330
s	279	t	1524
u	394	v	394

height of wheel center 251

Engine Type 3 cyl. gas

Engine size 1.0 L

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

Weight - kg	Curb	Test Inertial	Gross Static
W_{front}	472	492	529
W_{rear}	283	327	365
W_{total}	755	819	894

Damage prior to test: __________

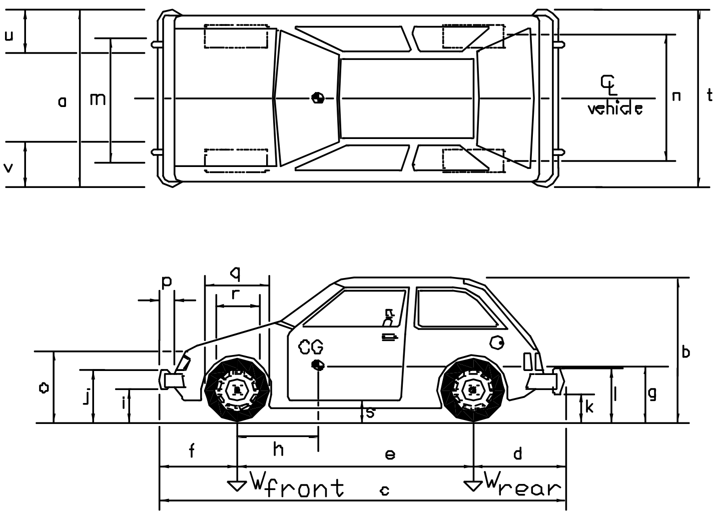
Figure 14. Vehicle Dimensions, Test MNS-2

Figure 15. Test Vehicle, Test MNS-3

Dates: 4/17/01 Test Numbers: MNS-3 Model: Metro

Make: GEO Vehicle I.D.#: 2C1MR2297S6743339

Tire Size: P155/80 R13 Year: 1995 Odometer: 100,523



Vehicle Geometry - mm

a	1549	b	1406
c	3785	d	597
e	2375	f	813
g	546	h	835
i	413	j	508
k	343	l	641
m	1384	n	1353
o	559	p	108
q	578	r	368
s	324	t	1549
u	387	v	387

height of wheel center 270

Engine Type 4 cyl. gas

Engine size 1.3 L

Transmission Type:

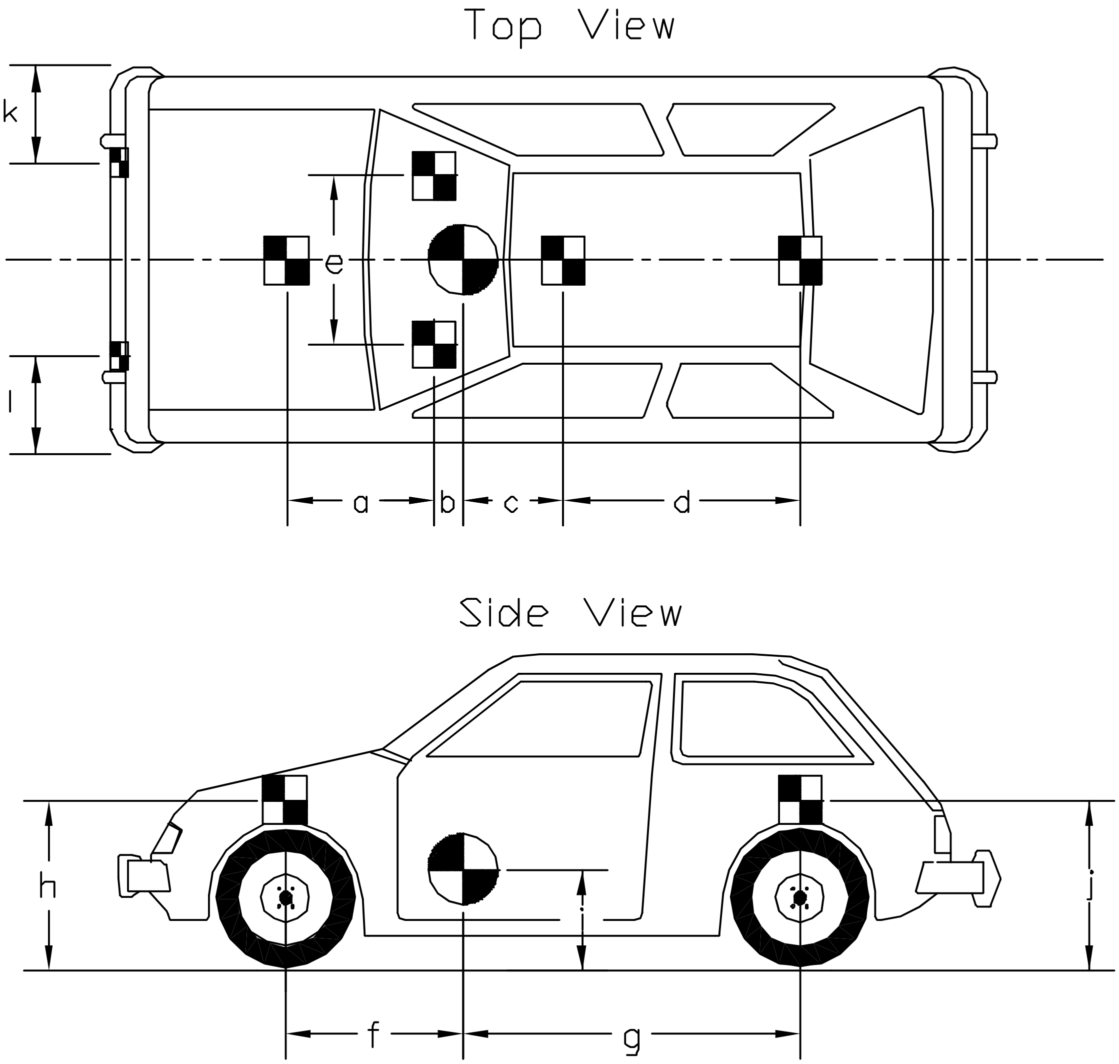
Automatic or Manual

FWD or RWD or 4WD

Weight - kg	Curb	Test Inertial	Gross Static
W_{front}	506	533	570
W_{rear}	252	289	328
W_{total}	758	822	898

Damage prior to test: ______________________

Figure 16. Vehicle Dimensions, Test MNS-3

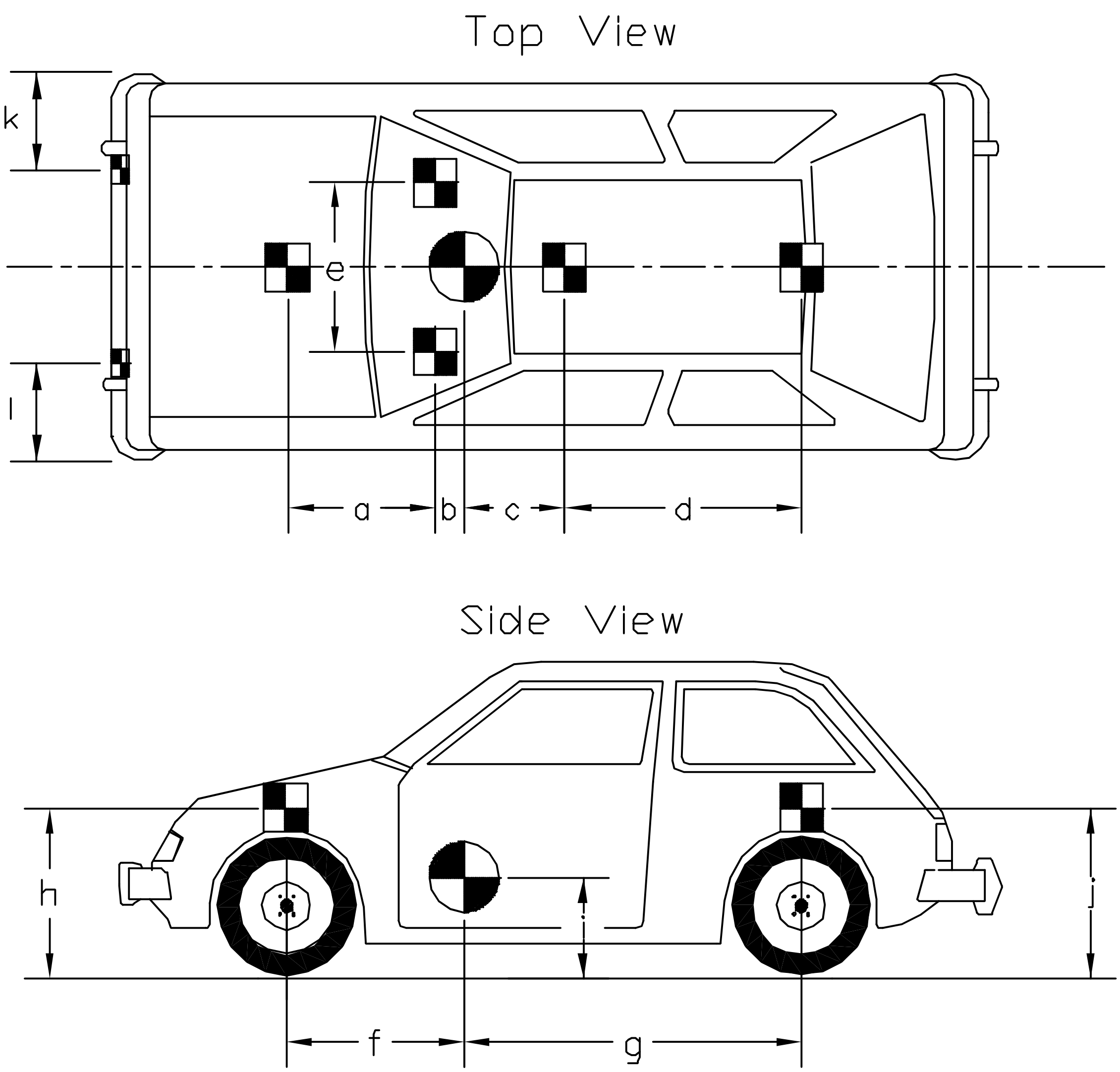


TEST #: MNS-1

TARGET GEOMETRY (mm)

a	---	b	---	c	---	d	---
e	---	f	944	g	1432	h	667
i	546	j	686	k	400	l	400

Figure 17. Vehicle Target Locations, Test MNS-1

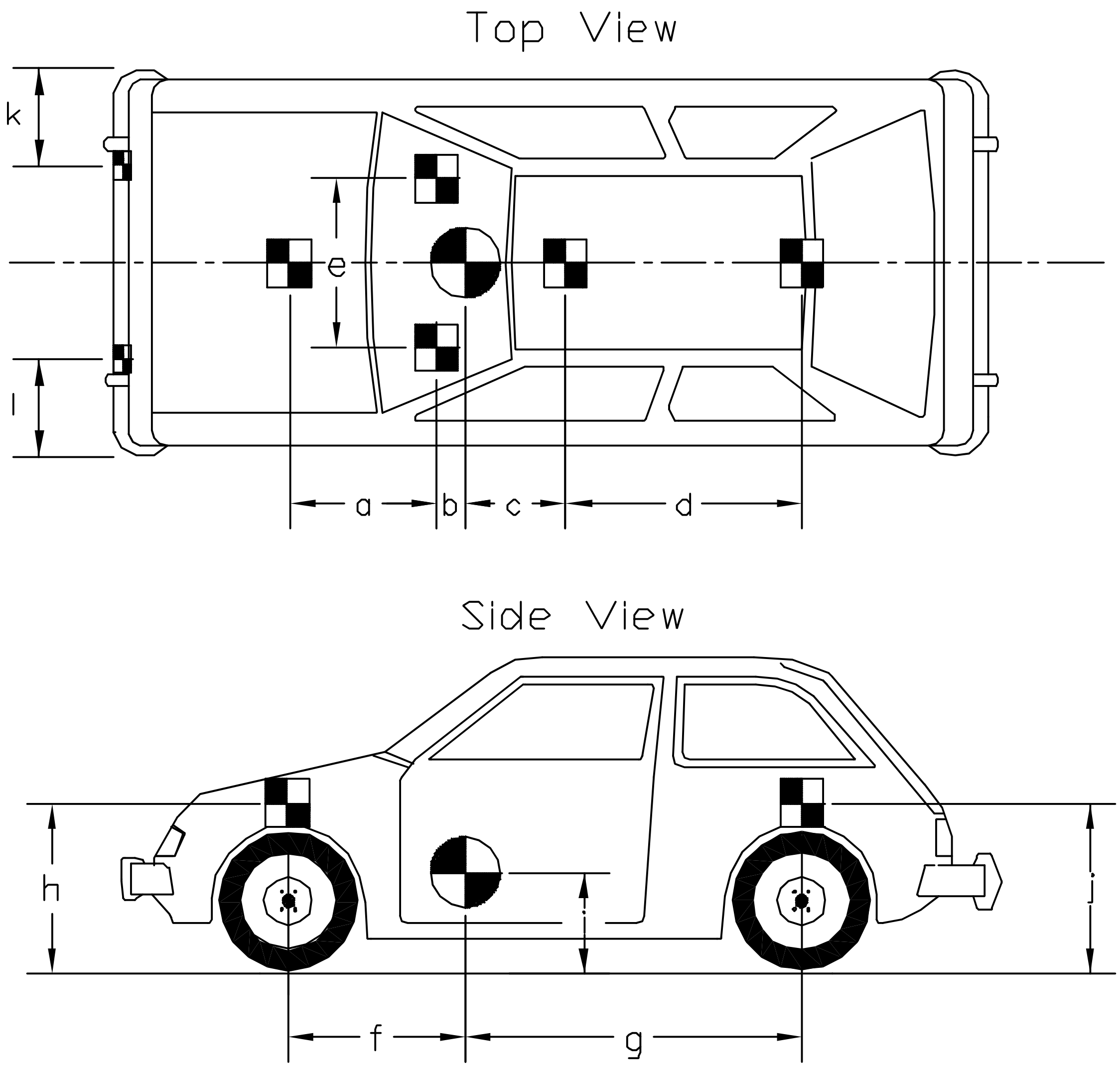


TEST #: MNS-2

TARGET GEOMETRY (mm)

a	---	b	---	c	---	d	---
e	---	f	947	g	1428	h	686
i	546	j	711	k	394	l	394

Figure 18. Vehicle Target Locations, Test MNS-2



TEST #: MNS-3

TARGET GEOMETRY (mm)

a	---	b	---	c	---	d	---
e	---	f	835	g	1540	h	730
i	546	j	778	k	387	l	387

Figure 19. Vehicle Target Locations, Test MNS-3

cameras, with a standard operating speed of 28.97 frames/sec, were also used to film the crash test. An E/cam high-speed video camera and a Canon digital video camera were placed on the right side of the impact orientation and had a field of view perpendicular to the impact of the second device. Another E/cam high-speed video camera and a Canon digital video camera were placed on the right side of the impact orientation and had a field of view perpendicular to the impact of the first device. Another Canon digital video camera was placed upstream and offset to the right from the first impact point and had an angled view of both impacts. A schematic of all five camera locations for tests MNS-1 and MNS-2 is shown in Figure 20.

For test MNS-3, two high-speed 16-mm Red Lake E/cam video cameras, with operating speeds of 500 frames/sec, were used to film the crash test. Three Canon digital video cameras, with a standard operating speed of 28.97 frames/sec, were also used to film the crash test. An E/cam high-speed video camera and a Canon digital video camera were placed on the right side of the impact orientation and had a field of view perpendicular to the impact of the second device. Another E/cam high-speed video camera and a Canon digital video camera were placed on the right side of the impact orientation and had a field of view perpendicular to the impact of the first device. Another Canon digital video camera was placed downstream and offset to the right from the second impact point and had an angled view of both impacts. A schematic of all five camera locations for test MNS-3 is shown in Figure 21.

4.4.2 Pressure Tape Switches

For tests MNS-1 through MNS-3, two sets of three pressure-activated tape switches, spaced at 2-m intervals, were used to determine the speed of the vehicle before impact with each device. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition

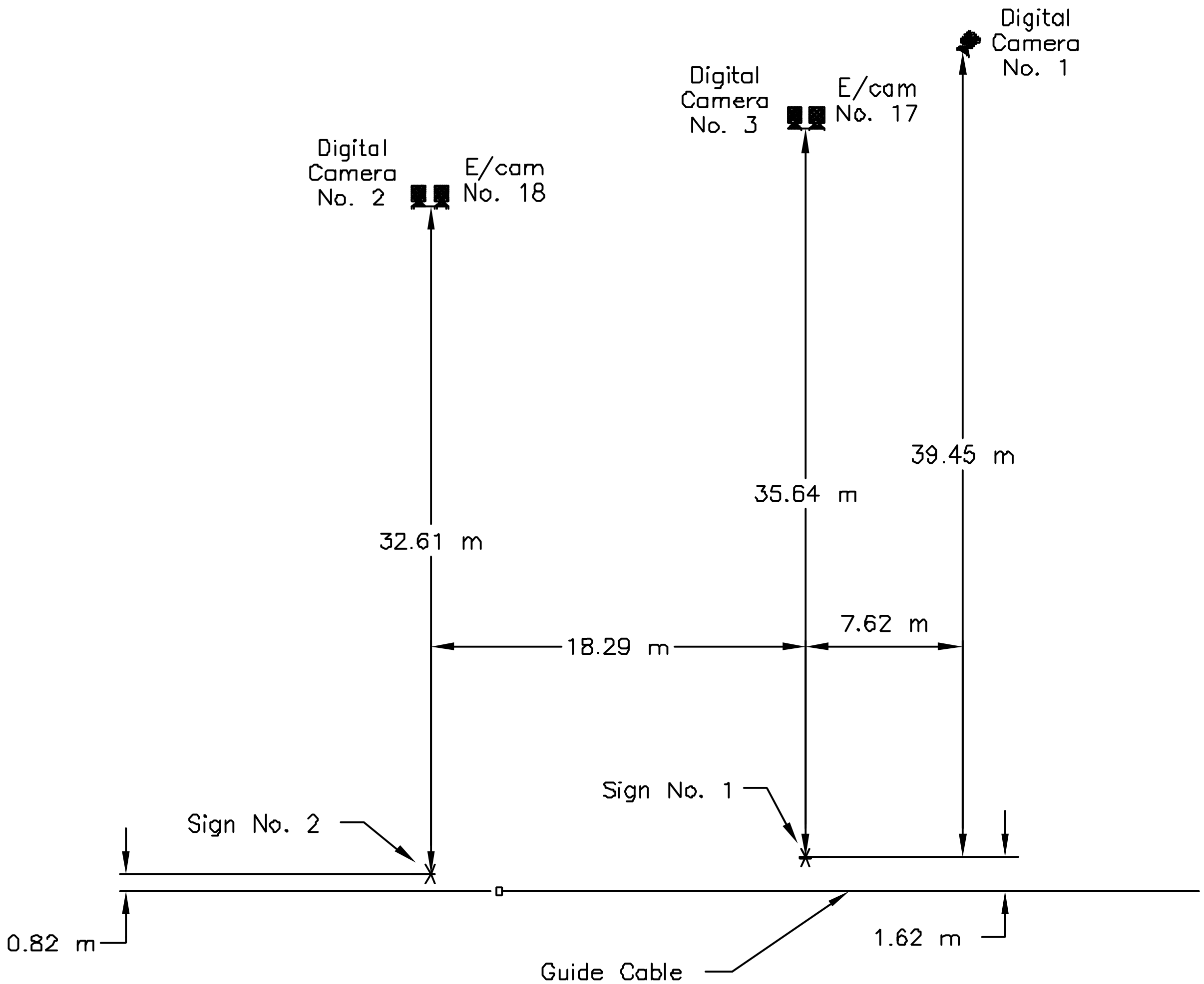


Figure 20. Location of High-Speed Cameras, Tests MNS-1 and MNS-2

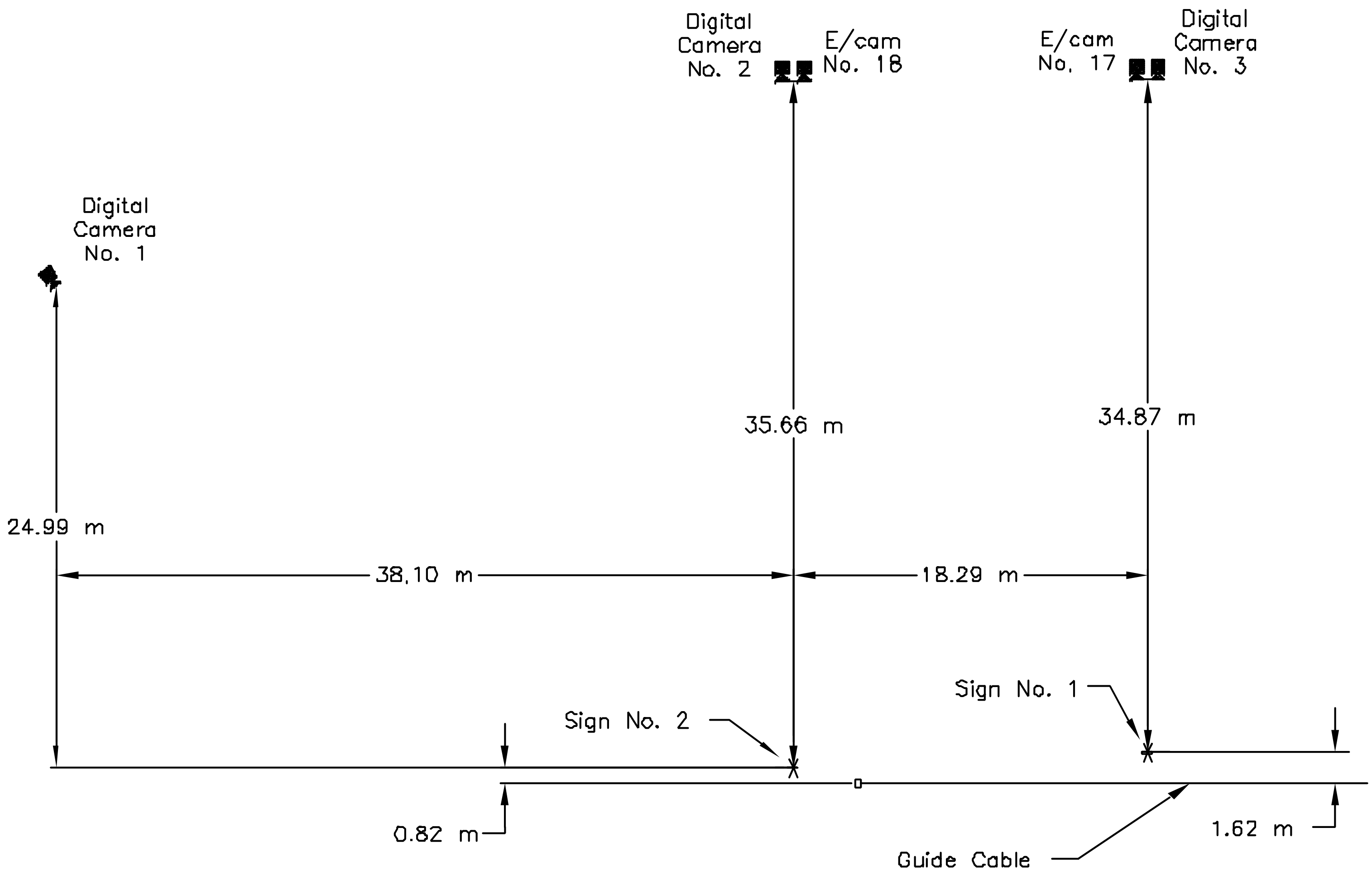


Figure 21. Location of High-Speed Cameras, Test MNS-3

system as the vehicle's front tire passed over it. For tests MNS-1 and MNS-2, the right-front tire of the test vehicle passed over both sets of tape switches. For test MNS-3, the right-front tire and the left-front tire passed over the first and second sets of tape switches, respectively. Test vehicle speed was determined from electronic timing mark data recorded using the "Test Point" software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speed cannot be determined from the electronic data.

5 CRASH TEST NO. 1 (SYSTEM NOS. 1 AND 2)

5.1 Test MNS-1

The 891-kg small car impacted System No. 1, an aluminum sign support with a diamond-shaped aluminum panel oriented head-on to the vehicle (perpendicular to the vehicle's path), at a speed of 107.5 km/hr and at an angle of 0 degrees. The small car then impacted System No. 2, an aluminum sign support with a diamond-shaped aluminum panel oriented end-on to the vehicle (parallel to the vehicle's path), at a speed of 99.2 km/hr and at an angle of 90 degrees. A summary of the test results and the sequential photographs are shown in Figures 22 and 23. Additional sequential photographs are shown in Figure 24. Documentary photographs of the crash tests are shown in Figures 25 through 27.

5.2 Test Description

The test vehicle impacted System No. 1 with the centerline of the vehicle's bumper aligned with the centerline of the sign support, as shown in Figure 28. At 0.012 sec after impact, both masts deformed around the front of the vehicle as the sign panel rotated toward the vehicle and windshield. At this same time, the legs still attached to the masts moved along with the vehicle. At 0.022 sec, the vertical portion of the legs bent away from the vehicle. At 0.032 sec, the left mast fractured where it had been deformed by the front bumper, and the right mast disengaged from the vertical upright of the right leg. At this same time, the sign panel continued to rotate toward the vehicle. At 0.038 sec, the left mast disengaged from the vertical upright of the left leg. At 0.044 sec, the warning light impacted the windshield as the panel deformed. At this same time, part of the front bumper was ripped off by the deformed masts. At 0.056 sec, the sign panel impacted the windshield as the masts and sign panel continued to rotate toward the vehicle. At this same time, the legs were positioned under the vehicle. At 0.086 sec, the warning light and the top of the sign panel remained in contact with the vehicle's windshield. At 0.112 sec, pieces of the bumper detached and became airborne. At this same time, the sign panel, with the deformed masts attached, remained in contact with the windshield. One leg from the sign support was located 20.12-m downstream and 0.18-m left from the original position. The other leg from the sign support was located 48.77-m downstream and 1.96-m right from the original position. The sign panel with the masts and warning light box still attached came to rest 25.60-m downstream and 2.01-m left of the initial position. Loose sand from the sandbags was scattered in a pattern bound by 0.0-m upstream, 9.14-m downstream, 1.52-m left, and 1.52-m right from the original position of the aluminum sign support.

Approximately 0.67 sec after impact with System No. 1, the vehicle impacted System No. 2 with the left-front quarter point of the vehicle aligned with the centerline of the sign support, as shown in Figure 28. At 0.035 sec after initial impact, the outside edge of the sign panel rotated into the vehicle as the left corner of the sign panel impacted the hood of the vehicle. At this same time, the non-impacted mast disengaged from the leg's vertical upright. At 0.104 sec, the sign panel rotated about its contact point with the hood of the vehicle. At 0.173 sec, the sign panel rotated above the vehicle to approximately 180 degrees counter-clockwise (CCW) from its initial position. At 0.449 sec, the sign panel continued to rotate CCW above the vehicle. One leg from the sign support was located 0.30-m downstream from the original position. The other leg from the sign support was located 0.46-m downstream from the original position. The sign panel with the masts and warning light still attached came to rest 55.78-m downstream and 13.41-m right of the initial position. Loose sand from the sandbags was scattered in a pattern bound by 0.0-m upstream, 1.52-m downstream, 0.76-m left, and 0.76-m right from the original position of the aluminum sign support.

The vehicle subsequently came to rest 97.84-m downstream from the longitudinal midpoint of the two impact points and 1.61-m left from the centerline of the vehicle's original path. The final positions of the vehicle and the sign supports are shown in Figures 22, 23, and 29.

5.3 System and Component Damage

Damage to System Nos. 1 and 2 is shown in Figures 29 through 32. System No. 1 encountered moderate damage. The vertical upright tube on both legs was bent, and the weld fractured on three sides. Both legs were also disengaged from the masts. Both masts were deformed at bumper height. The mast on the left side was cracked. The light portion of the warning light broke off while the bottom box portion was still attached to the sign panel. The sign panel encountered slight deformations as well as scuff and scrape marks. The sandbags were torn open with the sand scattered along the path of the vehicle, starting at the initial position of the first sign support.

System No. 2 encountered moderate damage. Both legs disengaged from the masts but remained undamaged. Three out of the four sides of both masts were fractured at the bottom sign panel bolts. The impacted mast was also deformed at bumper height. The non-impacted mast also released from the bottom sign panel bolt. The sign panel encountered a 76-mm long tear due to the impacted-side bottom sign panel bolt slicing through the sign panel. The sign panel also encountered scuff and scrape marks as well as deformation to the top corner. The warning light remained intact and attached to the sign panel. Three of the sandbags were torn open with the sand scattered along the path of the vehicle, starting at the initial position of the second sign support. The other sandbag remained undamaged.

5.4 Vehicle Damage

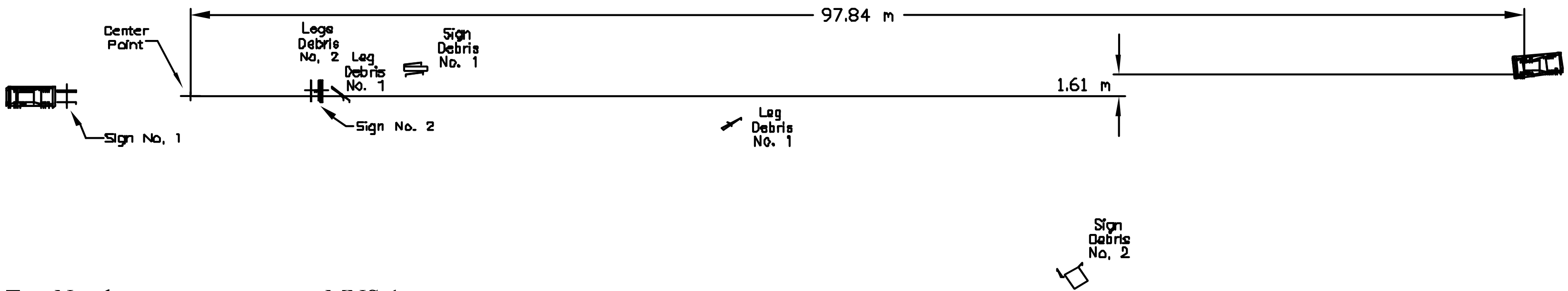
Exterior vehicle damage is shown in Figures 33 and 34. The front bumper and lower plastic shield encountered dents, tears, and contact marks. The right side of the bumper disengaged from the bumper clips. A small dent was located along the right-side quarter point of the hood. The hood encountered a major indentation along the left-side quarter point. The roof also encountered a dent starting at the front-center and extending 305 mm toward the rear. A 152-mm long scrape was located along the left-side door near the left-front fender. Both headlights were pushed inward toward the engine compartment but remained undamaged. The windshield sustained major "spider web" cracking throughout, with both layers of the windshield being cracked. Most of the structural integrity of the windshield was lost and the windshield indented inward toward the occupant compartment. A 305-mm long hole through the windshield was located near the center region of the left side. No damage was found to have occurred to the rear-end, fog lights, nor parking lights.

5.5 Discussion

Following test MNS-1, a safety performance evaluation was conducted, and the work zone traffic control device, System No. 1 was determined to be unacceptable according to the NCHRP Report No. 350 criteria. It was deemed unacceptable due to the "spider web" cracking, indentation, and hole in the windshield, resulting in obstructed driver visibility and loss of structure of both glass layers. Deformations of, or intrusion into, the occupant compartment did occur as detached elements and debris from System No. 1 penetrated the left-central region of the windshield.

System No. 2 was determined to be acceptable according to the NCHRP Report No. 350 criteria. Detached elements and debris from System No. 2 did not penetrate nor show potential for penetrating the occupant compartment. Deformations of, or intrusion into, the occupant compartment did not occur. The vehicle's trajectory did not intrude into adjacent traffic lanes.

0.000 sec | 0.022 sec | 0.038 sec | 0.056 sec | 0.086 sec



- Test Number MNS-1
- System Number 1
- Date 1/3/01
- Test Article
  - Type . . . . Traffic Control Device – Aluminum Sign Support with Diamond-Shaped Sign Panel
  - Stand Name . . . . Aluminum Sign Support
  - Sign Panel Name . . . . Rigid Aluminum, 1220 mm x 1220 mm
  - Key Elements
    - Size and/or dimension . 2.0 m high
    - Material . . . . Telespar ASTM A-653 Grade 50 Steel Tubing
  - Orientation . . . . Head-on with centerline
- Soil Type . . . . On dry pavement
- Vehicle Model . . . . 1994 Geo Metro
  - Curb . . . . 788 kg
  - Test Inertial . . . . 816 kg
  - Gross Static . . . . 891 kg
- Vehicle Speed
  - Impact . . . . 107.5 km/hr
  - Exit . . . . NA
- Vehicle Angle
  - Impact . . . . 0 deg
  - Exit . . . . 0 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . NA
  - Lateral (not required) . . . . NA
- Occupant Impact Velocity (Normalized)
  - Longitudinal . . . . NA
  - Lateral (not required) . . . . NA
- Vehicle Damage . . . . Windshield penetration
  - TAD[23] 12-FC-1
  - SAE[24] 12-FDAW6
- Vehicle Stopping Distance . . . . 97.84 m downstream 1.61 m left
- Test Article Damage . . . . Moderate – Broke apart

Figure 22. Summary of Test Results and Sequential Photographs, Test MNS-1, Impact No. 1

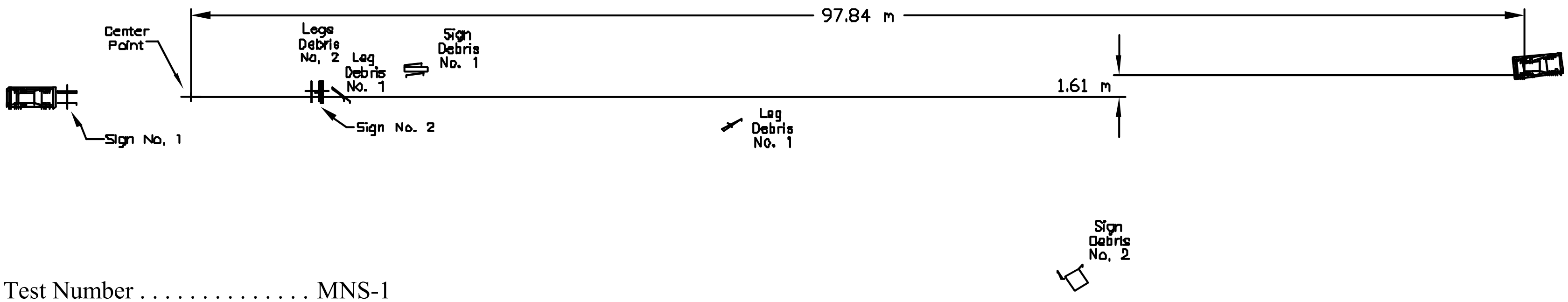
0.000 sec

0.035 sec

0.104 sec

0.173 sec

0.449 sec



- Test Number MNS-1
- System Number 2
- Date 1/3/01
- Test Article
  - Type . . . . Traffic Control Device – Aluminum Sign Support with Diamnond-Shaped Sign Panel
  - Stand Name . . . . Aluminum Sign Support
  - Sign Panel Name . . . . Rigid Aluminum, 1220 mm x 1220 mm
  - Key Elements
    - Size and/or dimension . 2.0 m high
    - Material . . . . Telespar ASTM A-653 Grade 50 Steel Tubing
  - Orientation . . . . End-on with left quarter point
- Soil Type . . . . On dry pavement
- Vehicle Model . . . . 1994 Geo Metro
  - Curb . . . . 755 kg
  - Test Inertial . . . . 819 kg
  - Gross Static . . . . 894 kg
- Vehicle Speed
  - Impact . . . . 99.2 km/hr
  - Exit . . . . NA
- Vehicle Angle
  - Impact . . . . 90 deg
  - Exit . . . . 90 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . NA
  - Lateral (not required) . . . . NA
- Occupant Impact Velocity (Normalized)
  - Longitudinal . . . . NA
  - Lateral (not required) . . . . NA
- Vehicle Damage . . . . Minimal
  - TAD[23] 12-FL-1
  - SAE[24] 12-FLEN5
- Vehicle Stopping Distance . . . . 97.84 m downstream 1.61 m left
- Test Article Damage . . . . Moderate – Broke apart

Figure 23. Summary of Test Results and Sequential Photographs, Test MNS-1, Impact No. 2

-0.017 sec

0.017 sec

0.052 sec

0.086 sec

0.190 sec

Figure 24. Additional Sequential Photographs, Test MNS-1

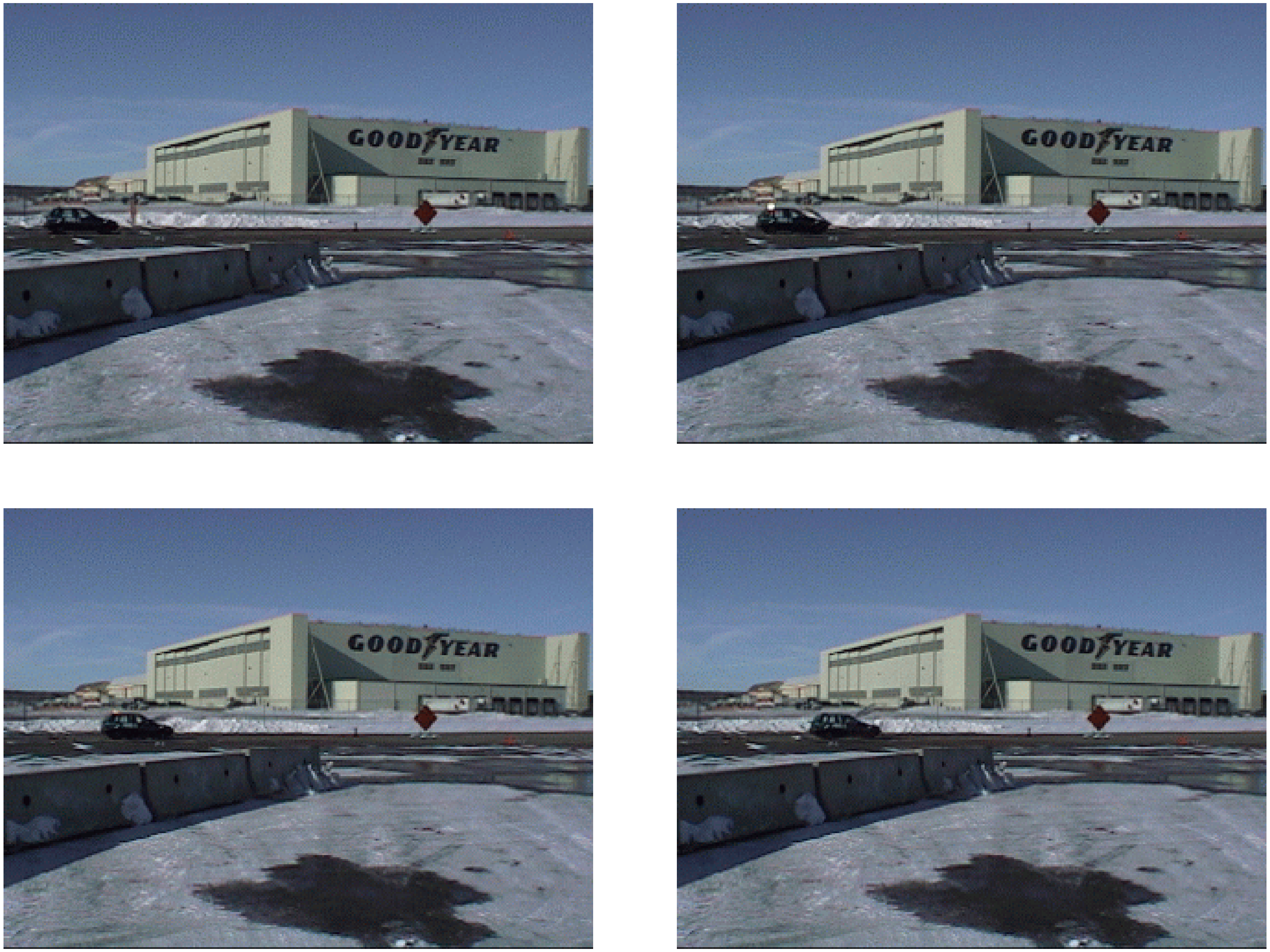


Figure 25. Documentary Photographs, Test MNS-1

Figure 26. Documentary Photographs, Test MNS-1

Figure 27. Documentary Photographs, Test MNS-1

Figure 28. Impact Location, Test MNS-1

Figure 29. Overall Damage and Final Positions, Test MNS-1

Figure 30. System No. 1 Damage, Test MNS-1

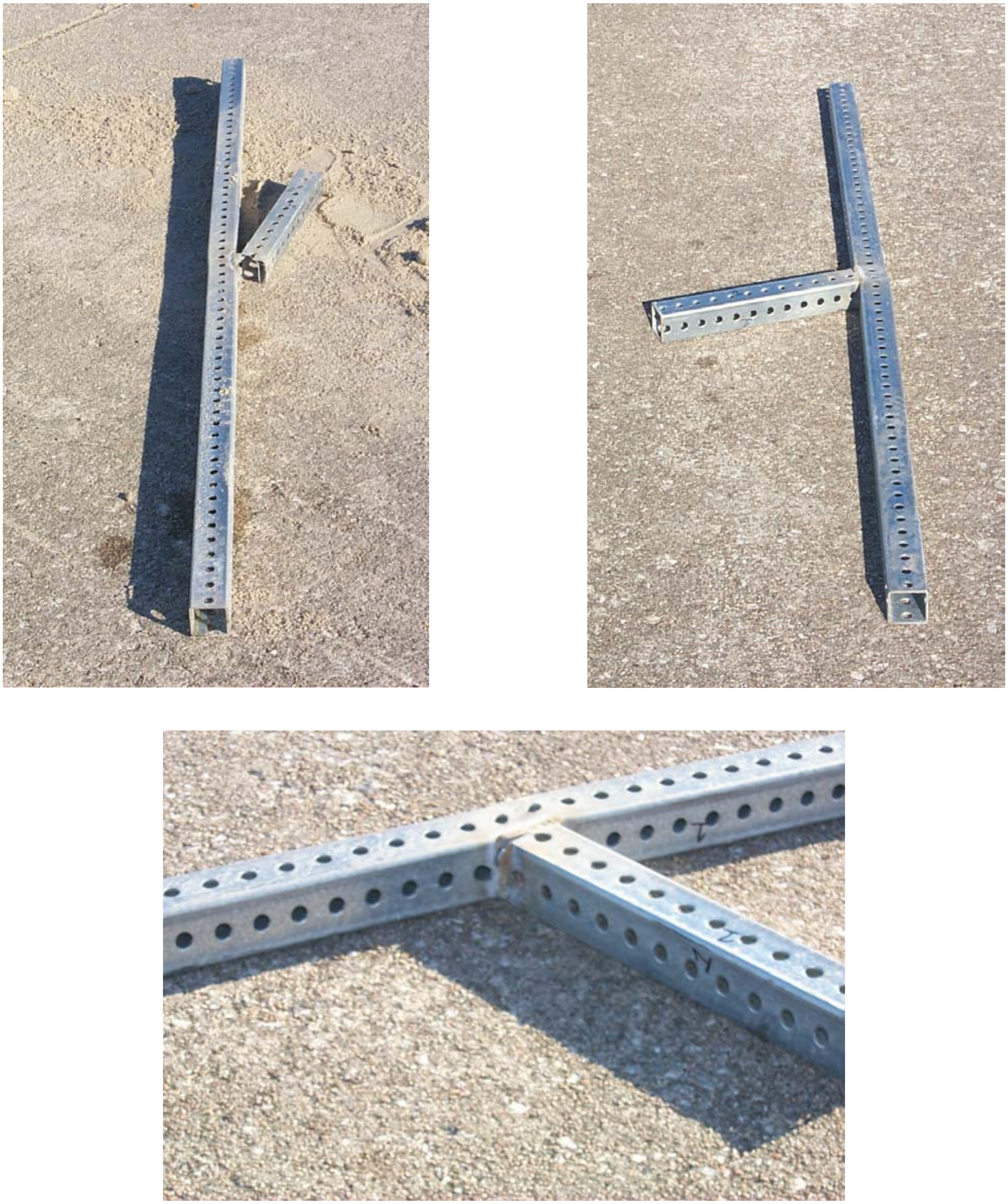


Figure 31. System No. 1 Damage, Test MNS-1

Figure 32. System No. 2 Damage, Test MNS-1

Figure 33. Vehicle Damage, Test MNS-1

Figure 34. Windshield Damage, Test MNS-1

6 CRASH TEST NO. 2 (SYSTEM NOS. 3 AND 4)

6.1 Test MNS-2

The 894-kg small car impacted System No. 3, an aluminum sign support with two aluminum sign panels oriented head-on to the vehicle, at a speed of 102.4 km/hr and at an angle of 0 degrees. The small car then impacted System No. 4, an aluminum sign support with an octagon-shaped sign panel oriented end-on to the vehicle, at a speed of 92.0 km/hr and an angle of 90 degrees. A summary of the test results and the sequential photographs are shown in Figures 35 and 36. Additional sequential photographs are shown in Figure 37. Documentary photographs of the crash tests are shown in Figures 38 through 40.

6.2 Test Description

The test vehicle impacted System No. 3 with the right-front quarter point of the vehicle's bumper aligned with the centerline of the sign support, as shown in Figure 41. At 0.010 sec after initial impact, both masts deformed around the front of the vehicle. At this same time, the bottom half of the sign panel bowed out away from the vehicle. At 0.016 sec, the legs slid along with the vehicle as the masts continued to deform around the front of the vehicle. At 0.026 sec, the hood deformed upward as the masts continued to deform. At this same time, the bottom half of the sign panel bowed and deformed away from the masts. At 0.030 sec, the legs raised up off the ground due to the deformation of the masts about the front of the vehicle. At this same time, the hood and masts continued to deform toward the vehicle. At 0.052 sec, the non-impacted ends of the legs rose into the air and to the height of the bumper. At 0.074 sec, the system rotated into the vehicle as it moved along with the vehicle. At this same time, the masts and panel were near the same angle as the windshield and the hood remained slightly deformed. At 0.110 sec, the system continued to rotate into the vehicle with the non-impacted ends of the legs still attached and positioned up above the vehicle's hood. At 0.172 sec, the top of the system rotated down and came close to impacting the roof/windshield interface. The intact system came to rest 102.41-m downstream and 2.57-m right from the original position. Loose sand from the sandbags was scattered in a pattern bounded by 0.0-m upstream, 12.19-m downstream, 12.19-m left, and 12.19-m right from the original postion of the aluminum sign support.

Approximately 0.73 sec after impact with System No. 3, the vehicle impacted System No. 4 with the left-front quarter point of the vehicle aligned with the centerline of the sign support, as shown in Figure 41. At 0.012 sec after initial impact, the impacted mast deformed and moved toward the other mast. At this same time, the sign panel began to rotate slightly CCW toward the vehicle. At 0.022 sec, the impacted mast contacted the other mast as the sign panel rotated CCW and downward into the vehicle. At 0.028 sec, both masts were in contact with and deformed about the front of the vehicle. At this same time, the impacted mast disengaged from the impacted leg. At 0.042 sec, the non-impacted mast disengaged from the corresponding leg as the sign panel and masts continued to rotate CCW toward the vehicle. At 0.066 sec, the sign panel impacted the windshield. At this same time, the deformed masts rotated away from the vehicle. At 0.094 sec, the sign panel and masts rotated CCW about the windshield contact point. At this same time, the masts lost contact with the front of the vehicle. At 0.146 sec, the sign panel and masts lost contact with the windshield, rotated CCW, and ascended into the air. One leg from the sign support was located 0.30-m downstream and 0.30-m right from the original position. The other leg from the sign support was located 0.46-m downstream and 0.30-m right from the original position. The sign panel with the masts still attached came to rest 41.76-m downstream and 6.71-m right of the initial position.

Loose sand from the sandbags was scattered in a pattern bound by 0.0-m upstream, 1.83-m downstream, 0.91-m left, and 0.91-m right from the original position of the aluminum sign support. The vehicle subsequently came to rest 89.61-m downstream from the longitudinal midpoint of the two impact points and 2.04-m right from the centerline of the vehicle's original path. The final positions of the vehicle and the sign supports are shown in Figures 35, 36, and 42.

6.3 System and Component Damage

Damage to System Nos. 3 and 4 is shown in Figures 42 through 44. System No. 3 remained intact with damage consisting of deformations to the masts and sign panels. Both masts were deformed at the bumper height. The bottom sign panel deformed outward toward the vehicle. The sandbags were torn open with the sand scattered along the path of the vehicle, starting at the initial position of the first sign support.

System No. 4 encountered moderate damage. Both legs disengaged from the masts but remained undamaged. Both masts were deformed and fractured approximately 457 mm from the bottom ends of the masts on three out of the four sides. The sign panel encountered scuff and scrape marks as well as deformation to the bottom corner of the impact side. Two of the sandbags were torn open with the sand scattered along the path of the vehicle, starting at the initial position of the second sign support. The other two sandbags remained undamaged.

6.4 Vehicle Damage

Exterior vehicle damage is shown in Figures 45 and 46. The bumper disengaged from the right-side, left-side, and top-front bumper clips. The hood was buckled upward toward the windshield. A small dent was located on the front-left quarter point of the roof. Both headlights were pushed inward toward the engine compartment but remained undamaged. The windshield sustained major “spider web” cracking on the left-side, with both layers of the left-side windshield being cracked. A large hole (slice) through the windshield was located near the outer region of the left side. No damage was found to have occurred to the right-side, rear-end, headlights, fog lights, nor parking lights.

6.5 Discussion

Following test MNS-2, a safety performance evaluation was conducted, and the work zone traffic control device, System No. 3, was determined to be acceptable according to the NCHRP Report No. 350 criteria. Detached elements and debris from System No. 3 did not penetrate nor show potential for penetrating the occupant compartment. Deformations of, or intrusion into, the occupant compartment did not occur.

System No. 4 was determined to be unacceptable according to the NCHRP Report No. 350 criteria. It was deemed unacceptable due to the “spider web” cracking, indentation, and hole in the windshield, resulting in obstructed drive visibility and loss of structure of both glass layers. Deformation of, or intrusion into, the occupant compartment did occur as detached elements and debris from System No. 4 penetrated the left region of the windshield. The vehicle’s trajectory did not intrude into adjacent traffic lanes.

It should be noted that the impact speed for System No. 4 was measured to be approximately 92.0 km/hr or 8.0 km/hr less than the 100 km/hr target speed. However, it is believed that the performance of the system was not significantly effected and a higher impact speed would not have resulted in any less severe vehicle damage.

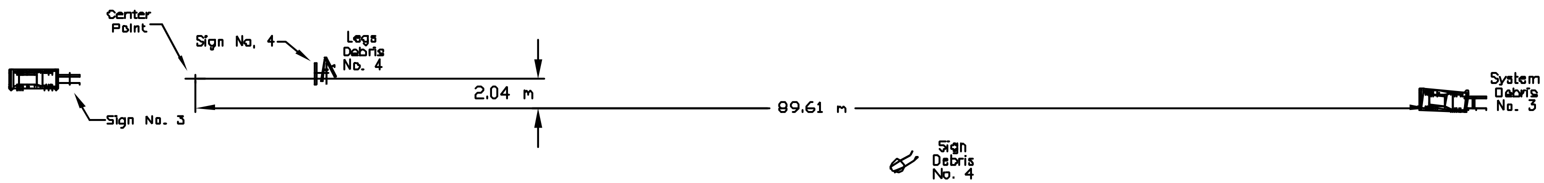
0.000 sec

0.016 sec

0.030 sec

0.052 sec

0.074 sec



- Test Number MNS-2
- System Number 3
- Date 1/3/01
- Test Article
  - Type . . . . Traffic Control Device – Aluminum Sign Support with Two Sign Panels
  - Stand Name . . . . Aluminum Sign Support
  - Sign Panel Name . . . . Rigid Aluminum, 915 mm x 1218 mm and 915 mm x 610 mm
  - Key Elements
    - Size and/or dimension . 2.2 m high
    - Material . . . . Telespar ASTM A-653 Grade 50 Steel Tubing
  - Orientation . . . . Head-on with centerline
- Soil Type . . . . On dry pavement
- Vehicle Model . . . . 1994 Geo Metro
  - Curb . . . . 755 kg
  - Test Inertial . . . . 819 kg
  - Gross Static . . . . 894 kg
- Vehicle Speed
  - Impact . . . . 102.4 km/hr
  - Exit . . . . NA
- Vehicle Angle
  - Impact . . . . 0 deg
  - Exit . . . . 0 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . NA
  - Lateral (not required) . . . . NA
- Occupant Impact Velocity (Normalized)
  - Longitudinal . . . . NA
  - Lateral (not required) . . . . NA
- Vehicle Damage . . . . Minimal
  - TAD[23] 12-FC-1
  - SAE[24] 12-FDEW5
- Vehicle Stopping Distance . . . . 89.61 m downstream 2.04 m left
- Test Article Damage . . . . Moderate – Remained intact

Figure 35. Summary of Test Results and Sequential Photographs, Test MNS-2, Impact No. 1

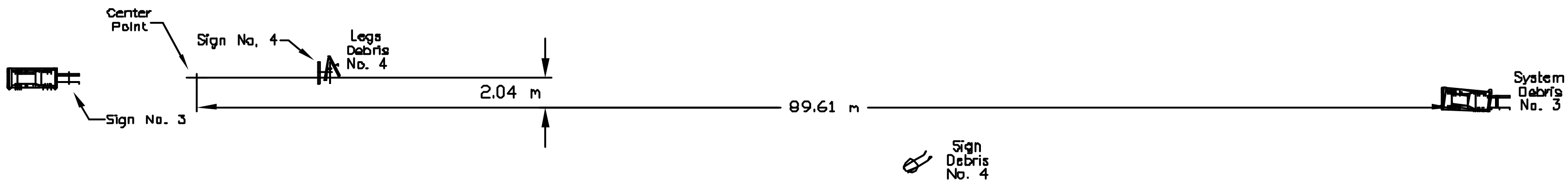
0.000 sec

0.022 sec

0.042 sec

0.066 sec

0.094 sec



- Test Number MNS-2
- System Number 4
- Date 1/3/01
- Test Article
  - Type .... Traffic Control Device – Aluminum Sign Support with Octagon-Shaped Sign Panel
  - Stand Name .... Aluminum Sign Support
  - Sign Panel Name .... Rigid Aluminum, 915 mm x 915 mm
  - Key Elements
    - Size and/or dimension . 2.2 m high
    - Material .... Telespar ASTM A-653 Grade 50 Steel Tubing
  - Orientation .... End-on with left quarter point
- Soil Type .... On dry pavement
- Vehicle Model .... 1994 Geo Metro
  - Curb .... 755 kg
  - Test Inertial .... 819 kg
  - Gross Static .... 894 kg
- Vehicle Speed
  - Impact .... 92.0 km/hr
  - Exit .... NA
- Vehicle Angle
  - Impact .... 90 deg
  - Exit .... 90 deg
- Vehicle Stability .... Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal .... NA
  - Lateral (not required) .... NA
- Occupant Impact Velocity (Normalized)
  - Longitudinal .... NA
  - Lateral (not required) .... NA
- Vehicle Damage .... Windshield penetration
  - TAD[23] 12-FL-1
  - SAE[24] 12-FLAN6
- Vehicle Stopping Distance .... 89.61 m downstream 2.04 m left
- Test Article Damage .... Moderate – Broke apart

Figure 36. Summary of Test Results and Sequential Photographs, Test MNS-2, Impact No. 2

-0017 sec

-0.017 sec

0.017 sec

0.017 sec

0.052 sec

0.052 sec

0.086 sec

0.086 sec

0.155 sec

0.155 sec

Figure 37. Additional Sequential Photographs, Test MNS-2

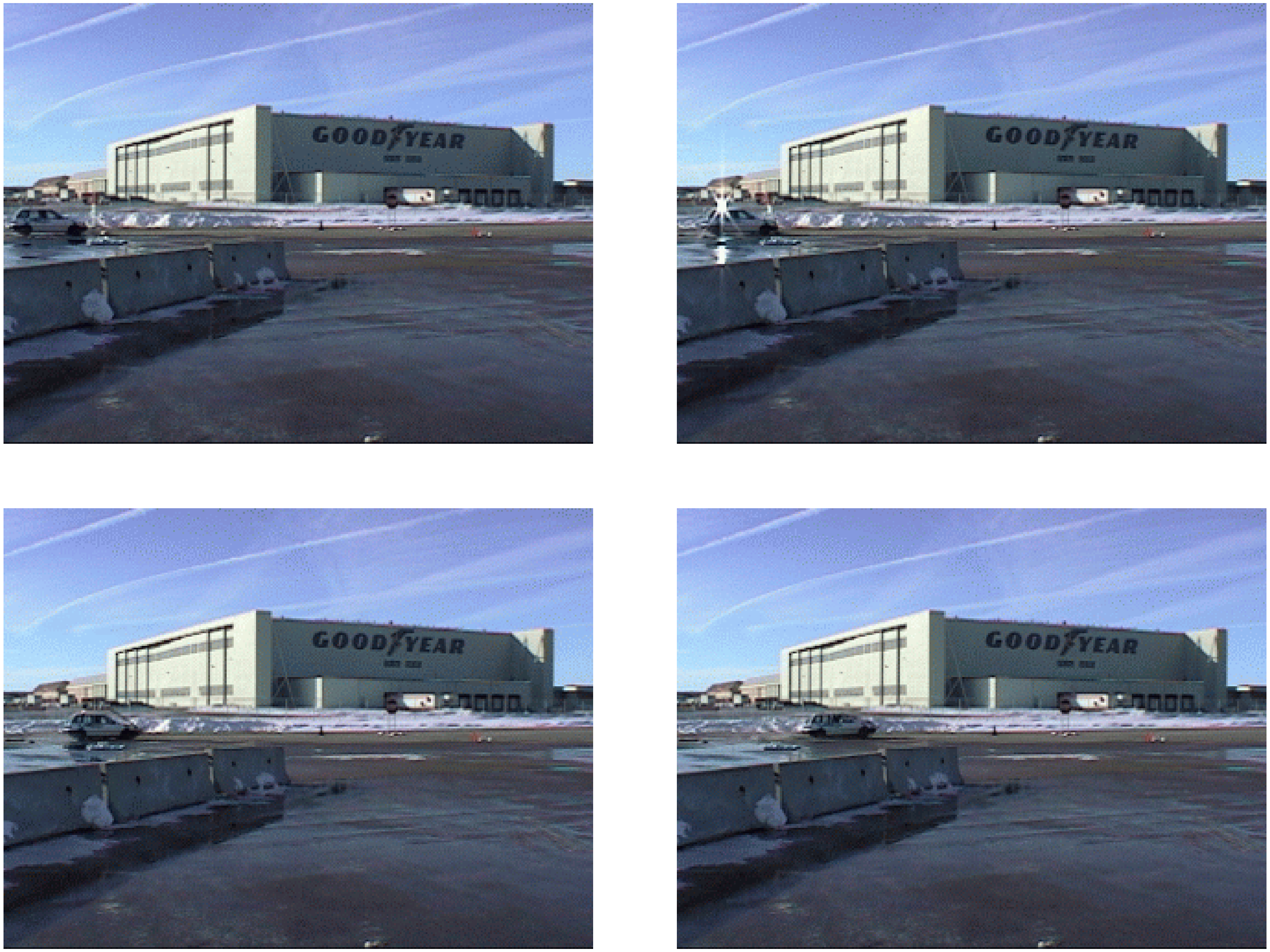


Figure 38. Documentary Photographs, Test MNS-2

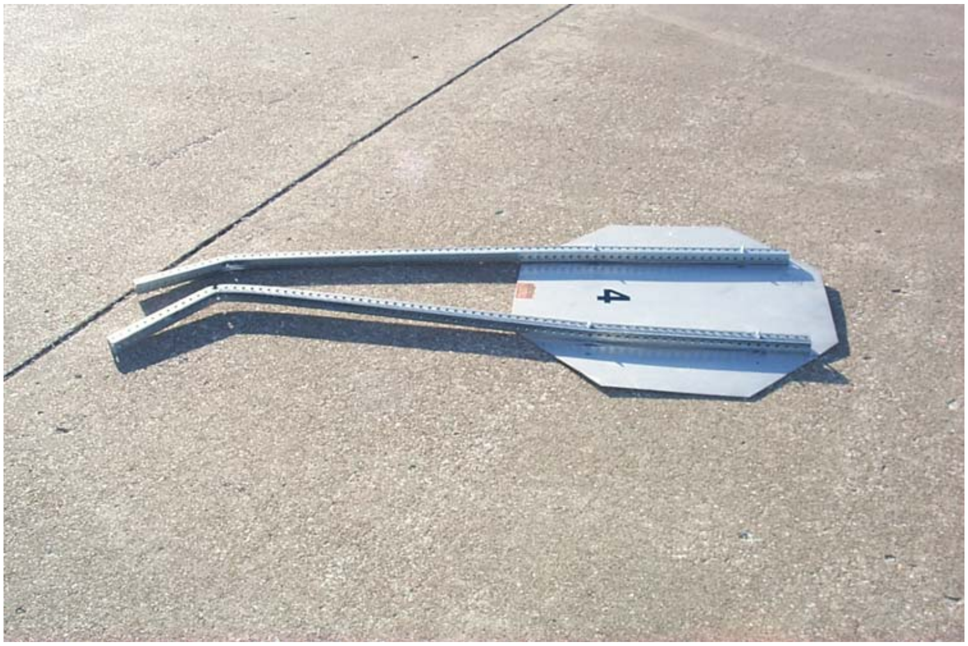
Figure 39. Documentary Photographs, Test MNS-2

Figure 40. Documentary Photographs, Test MNS-2

Figure 41. Impact Locations, Test MNS-2

Figure 42. Overall Damage and Final Positions, Test MNS-2

Figure 43. System No. 3 Damage, Test MNS-2



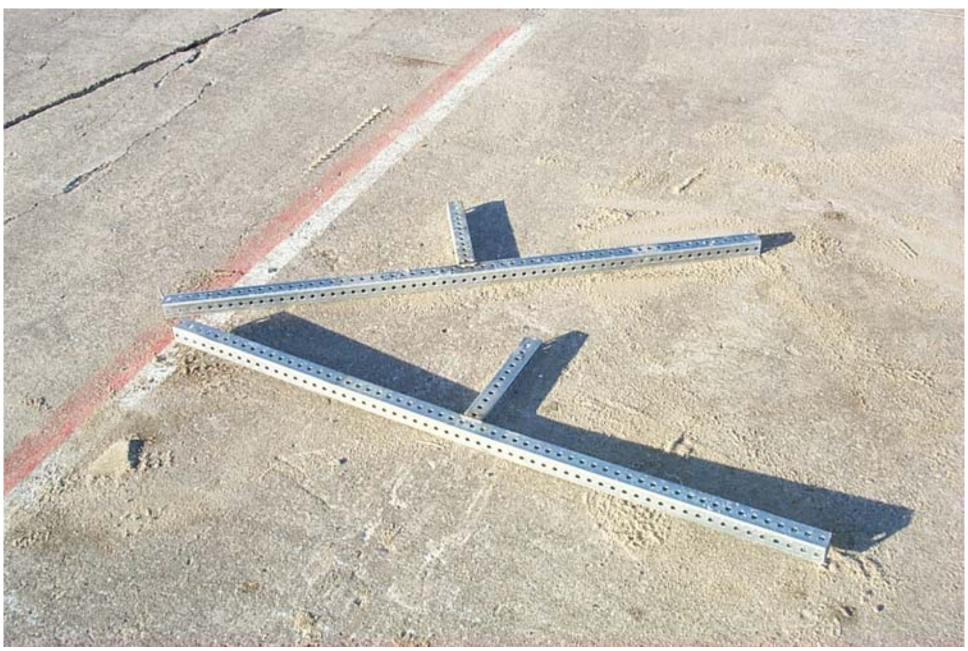


Figure 44. System No. 4 Damage, Test MNS-2

Figure 45. Vehicle Damage, Test MNS-2

Figure 46. Windshield Damage, Test MNS-2

7 CRASH TEST NO. 3 (SYSTEM NOS. 5 AND 6)

7.1 Test MNS-3

The 898-kg small car impacted System No. 5, an aluminum sign support with a diamond-shaped aluminum panel oriented head-on to the vehicle, at a speed of 105.9 km/hr and at an angle of 0 degrees. The small car then impacted System No. 6, an aluminum sign support with a diamond-shaped aluminum panel oriented end-on to the vehicle, at a speed of 100.1 km/hr and at an angle of 90 degrees. A summary of the test results and the sequential photographs are shown in Figures 47 and 48. Additional sequential photographs are shown in Figure 49. Documentary photographs of the crash tests are shown in Figures 50 through 52.

7.2 Test Description

The test vehicle impacted System No. 5 with the centerline of the vehicle's bumper aligned with the centerline of the sign support, as shown in Figure 53. At 0.004 sec after initial impact, both masts deformed around the front of the vehicle. At this same time, the legs' vertical uprights bent away from the vehicle. At 0.010 sec, the masts deformed significantly with the top of the masts and the sign panel rotating toward the vehicle. At this same time, the sign panel deformed slightly outward toward the vehicle. At 0.016 sec, both masts were bent to approximately 90 degree angles at the bumper height. At this same time, the system slid along with the vehicle as the masts began to disengage from the legs' vertical uprights. At 0.024 sec, the masts disengaged from the legs' vertical uprights as the legs continue to travel forward in front of the vehicle. At this same time, the top of the sign panel and masts continued to rotate into the vehicle. At 0.034 sec, the sign panel and masts rotated to approximately the same angle as the windshield. At this same time, the lower portion of the masts which had been deformed by the bumper were positioned perpendicular to the ground. At 0.046 sec, the sign panel and masts impacted the windshield and the legs were positioned between the front tires under the vehicle. At 0.058 sec, the sign panel and masts rotated about the windshield contact point. At 0.082 sec, the sign panel and masts continued to rotate CCW while the legs were positioned underneath the vehicle with the vertical uprights deformed downstream. At 0.146 sec, glass fragments broke away from the windshield. At 0.168 sec, the sign panel and masts were airborne and positioned perpendicular to the windshield. At this same time, the legs had cleared the rear of the vehicle. At 0.194 sec, the sign panel and masts continued to rise into the air. The sign support's right leg was located 2.57-m downstream and 0.03-m left from the original position. The sign support's left leg was located 3.00-m downstream and 0.64-m left from the original position. The sign panel, right mast, and light box were located 24.94-m downstream and 4.75-m left of the initial position. Half of the warning light top was located 25.22-m downstream and 3.84-m left from the original position. The other half of the warning light top was located 26.49-m downstream and 3.99-m left of the initial position. The left mast came to rest 27.66-m downstream and 1.09-m left from the original position. Loose sand from the sandbags was scattered in a pattern bound by 0.0-m upstream, 4.88-m downstream, 0.61-m left, and 0.61-m right from the original position of the aluminum sign support.

Approximately 0.69 sec after impact with System No. 5, the vehicle impacted System No. 6 with the left-front quarter point of the vehicle aligned with the centerline of the sign support, as shown in Figure 53. At 0.008 sec after initial impact, the impacted mast deformed around the front of the vehicle. At 0.016 sec, the impacted mast continued to deform around the front of the vehicle as the sign panel rotated CCW toward the vehicle. At 0.022 sec, the impacted mast disengaged from the leg's vertical upright tube. At this same time the bottom of the sign panel was in contact with the vehicle. At 0.028 sec the non-impacted leg rotated away from the vehicle as the sign panel rotated into the hood. At 0.038 sec, the right and left edges of the hood deformed upward as the sign panel indented the contact area on the hood. At this same time, the non-impacted mast disengaged from the vertical upright on the leg. At 0.056 sec, the sign panel and masts rotated about the windshield contact point. By this same time, the impacted leg had contacted the non-impacted leg and the windshield wipers were deformed. At 0.080 sec, the sign panel lost contact with the vehicle and rotated CCW above the windshield. At 0.118 sec, the sign panel continued to rotate CCW above the vehicle. At 0.144 sec, the impacted leg cleared the rear of the vehicle while located approximately at its original position. At 0.184 sec, the non-impacted leg cleared the rear of the vehicle and was located at approximately its original position. At this same time, the sign panel remained airborne and continued to rotate CCW in the air. The sign support's impacted leg was located 0.20-m upstream from the original position. The sign support's other leg was located 0.74-m downstream from the original position. The sign panel with the masts and warning light still attached came to rest 23.67-m downstream and 3.35-m right of the initial position. The vehicle subsequently came to rest 93.57-m downstream from the longitudinal midpoint of the two impact points and 4.56-m left from the centerline of the vehicle's original path. The final positions of the vehicle and the sign supports are shown in Figures 47, 48, and 54.

7.3 System and Component Damage

Damage to System Nos. 5 and 6 is shown in Figures 54 through 56. System No. 5 encountered moderate damage. The vertical upright tube on both legs was bent and the weld fractured on three sides. Both legs were also disengaged from the masts. Both masts deformed at the bumper location. The mast on the left side disengaged from both sign panel bolts. The sign panel encountered scuff and scrape marks as well as deformation to the top corner. The light portion of the warning light broke off while the bottom box portion was still attached to the sign panel. The right-side mast disengaged from the sign panel. Three of the sandbags were torn open with the sand scattered along the path of the vehicle, starting at the initial position of the second sign support. The other sandbag remained undamaged.

System No. 6 encountered moderate damage. Both legs disengaged from the masts but remained undamaged. The impacted mast fractured at the lower sign panel bolt but remained attached to the panel. The impacted mast also was deformed at the bumper location. The non-impacted mast fractured at and disengaged from the lower sign panel bolt. The sign panel encountered scuff and scrape marks. The warning light remained intact and attached to the sign panel. Two of the sandbags were torn open, but the sand remained in the opened bags. The other two sandbags remained undamaged.

7.4 Vehicle Damage

Exterior vehicle damage is shown in Figures 57 and 58. The front bumper and lower plastic shield encountered contact marks. Scuff and scrape marks were also located on the front of the hood. The hood encountered a slight indentation and scrape marks along the left-side quarter point. The front of the roof was indented near the roof/windshield interface. The windshield sustained major “spider web” cracking throughout, with both layers of the windshield being cracked. Most of the structural integrity of the windshield was lost, and the windshield indented inward toward the occupant compartment. A hole through the windshield was located near the lower-left region of the windshield. Two holes through the windshield were also located at center of the windshield quarter points. No damage was found to have occurred to the right-side, left-side, rear-end, headlights, fog lights, nor parking lights.

7.5 Discussion

Following test MNS-3, a safety performance evaluation was conducted, and the work zone traffic control device, System No. 5, was determined to be unacceptable according to the NCHRP Report No. 350 criteria. It was deemed unacceptable due to the "spider web" cracking, indentation, and holes in the windshield, resulting in obstructed driver visibility and loss of structure of both glass layers. Deformations of, or intrusion into, the occupant compartment did occur as detached elements and debris from System No. 5 penetrated the left- and right-quarter point regions of the windshield.

System No. 6 was determined to be unacceptable according to the NCHRP Report No. 350 criteria. It was deemed unacceptable due to the "spider web" cracking, indentation, and hole in the windshield, resulting in obstructed driver visibility and loss of structure of both glass layers. Deformations of, or intrusion into, the occupant compartment did occur as detached elements and debris from System No. 6 penetrated the left-side windshield. The vehicle's trajectory did not intrude into adjacent traffic lanes.

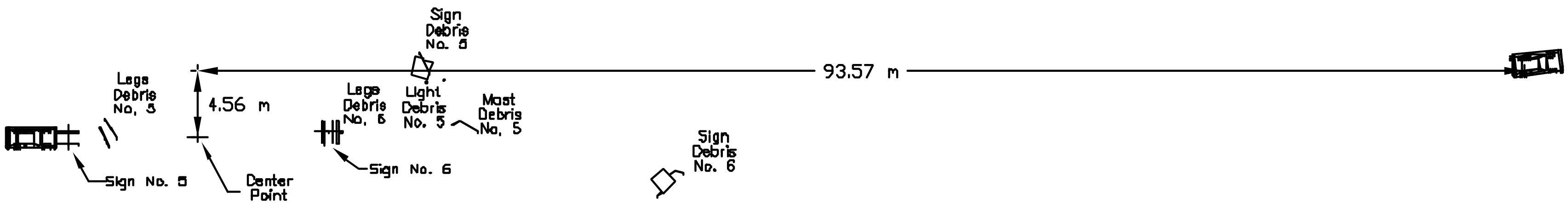
0.000 sec

0.016 sec

0.034 sec

0.046 sec

0.082 sec



- Test Number MNS-3
- System Number 5
- Date 4/17/01
- Test Article
  - Type . . . . Traffic Control Device – Aluminum Sign Support with Diamond-Shaped Sign Panel
  - Stand Name . . . . Aluminum Sign Support
  - Sign Panel Name . . . . Rigid Aluminum, 1219 mm x 1219 mm
  - Key Elements
    - Size and/or dimension . 2.1 m high
    - Material . . . . Telespar ASTM A-653 Grade 50 Steel Tubing
  - Orientation . . . . Head-on with centerline
- Soil Type . . . . On dry pavement
- Vehicle Model . . . . 1995 Geo Metro
  - Curb . . . . 757 kg
  - Test Inertial . . . . 822 kg
  - Gross Static . . . . 898 kg
- Vehicle Speed
  - Impact . . . . 105.9 km/hr
  - Exit . . . . NA
- Vehicle Angle
  - Impact . . . . 0 deg
  - Exit . . . . 0 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . NA
  - Lateral (not required) . . . . NA
- Occupant Impact Velocity (Normalized)
  - Longitudinal . . . . NA
  - Lateral (not required) . . . . NA
- Vehicle Damage . . . . Major windshield cracking and penetration
  - TAD[23] 12-FC-1
  - SAE[24] 12-FDAW7
- Vehicle Stopping Distance . . . . 93.57 m downstream 4.65 m left
- Test Article Damage . . . . Moderate – Broke apart

Figure 47. Summary of Test Results and Sequential Photographs, Test MNS-3, Impact No. 1

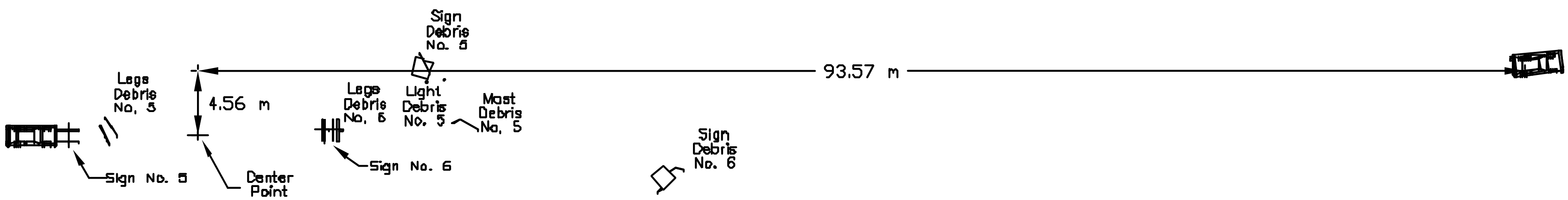
0.000 sec

0.008 sec

0.022 sec

0.038 sec

0.080 sec



- Test Number MNS-3
- System Number 6
- Date 4/17/01
- Test Article
  - Type . . . . Traffic Control Device – Aluminum Sign Support with Diamnond-Shaped Sign Panel
  - Stand Name . . . . Aluminum Sign Support
  - Sign Panel Name . . . . Rigid Aluminum, 1219 mm x 1219 mm
  - Key Elements
    - Size and/or dimension . 2.1 m high
    - Material . . . . Telespar ASTM A-653 Grade 50 Steel Tubing
  - Orientation . . . . End-on with left quarter point
- Soil Type . . . . On dry pavement
- Vehicle Model . . . . 1995 Geo Metro
  - Curb . . . . 757 kg
  - Test Inertial . . . . 822 kg
  - Gross Static . . . . 898 kg
- Vehicle Speed
  - Impact . . . . 100.1 km/hr
  - Exit . . . . NA
- Vehicle Angle
  - Impact . . . . 90 deg
  - Exit . . . . 90 deg
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration (10 msec avg.)
  - Longitudinal . . . . NA
  - Lateral (not required) . . . . NA
- Occupant Impact Velocity (Normalized)
  - Longitudinal . . . . NA
  - Lateral (not required) . . . . NA
- Vehicle Damage . . . . Windshield penetration
  - TAD[23] 12-FL-1
  - SAE[24] 12-FLAN6
- Vehicle Stopping Distance . . . . 93.573 m downstream
  4.56 m left
- Test Article Damage . . . . Moderate – Broke apart

Figure 48. Summary of Test Results and Sequential Photographs, Test MNS-3, Impact No. 2

0.000 sec

-0.017 sec

0.035 sec

0.017 sec

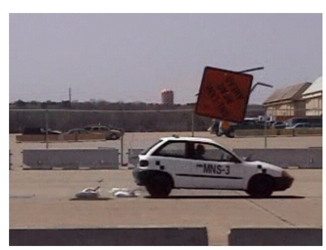
0.069 sec

0.052 sec

0.138 sec

0.086 sec

0.207 sec



0.190 sec

Figure 49. Additional Sequential Photographs, Test MNS-3

Figure 50. Documentary Photographs, Test MNS-3

Figure 51. Documentary Photographs, Test MNS-3

Figure 52. Documentary Photographs, Test MNS-3

Figure 53. Impact Location, Test MNS-3

Figure 54. Overall Damage and Final Positions, Test MNS-3

Figure 55. System No. 5 Damage, Test MNS-3

Figure 56. System No. 6 Damage, Test MNS-3

Figure 57. Vehicle Damage, Test MNS-3

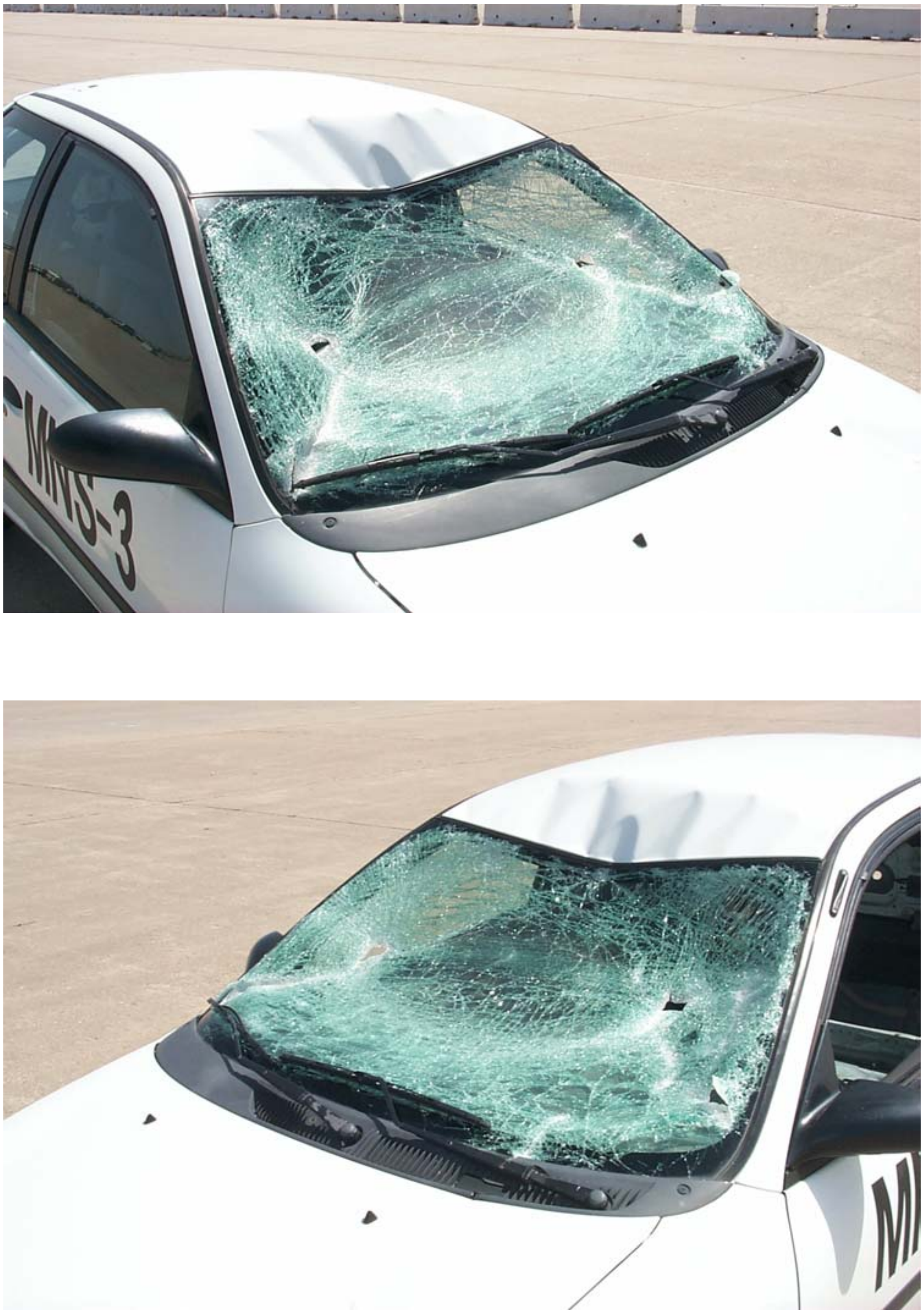


Figure 58. Windshield Damage, Test MNS-3

8 DISCUSSION

Following the analysis of the crash test results of tests MNS-1 through MNS-3, some general observations were made with respect to the following: (1) the vertical position, failure type, and release time of a sign support's fracture point, breakaway mechanism, or yielding hinge; (2) the stiffness and material of the vertical masts and leg's vertical uprights; (3) the vertical mounting height of the sign panel; and (4) the material of the sign panels. The extent of the damage encountered by the vehicle as well as the possible hazards to the adjacent traffic and work zone crews are also considered.

Masts that fracture instead of bend (or yield) reduce the amount of flex developed in the sign panels and masts. The relatively quick release of the masts from the feet of the sign support allows the sign panels and masts to fall upon the vehicle with little additional force than what was developed through the impact. Rigid aluminum sign panels and masts that released quickly from the sign supports' legs were found to rotate onto the hood and then rebound into the air with little or no contact with the windshield, especially in the end-on orientation (e.g., Test MNS-1, System No. 2). Sign panels and masts that did not release from the sign supports' legs were found to cause little or no damage to the vehicle (e.g., Test MNS-2, System No. 3).

On the other hand, when the mast bends, the sign panels and masts develop an additional load due to the lower part of the masts flexing away from the vehicle. When the mast is unloaded, the sign panels and masts have the tendency to "whip" downward onto the vehicle. In addition, masts that bend rather than fracture typically have a very slow release time (if one at all) from the legs, which adds to the amount of flex in the barricade panels and masts. It is more likely that the sign panels will impact the windshield when the masts bend or have a delayed release from the sign support's legs (e.g., Test MNS-1, System No. 1, Test MNS-2, System No. 4, and Test MNS-3, System Nos. 5 and 6).

The mounting height of the sign panel is a significant factor in determining the location and extent of damage to the vehicle. However, it is noted that this phenomenon is partially dependent on the sign panel's release time (if at all) from the sign support system. A lower mounting height can potentially cause significant interaction with the vehicle (e.g., Test MNS-1, System No. 1, Test MNS-3, System No. 5). Even in an end-on orientation, a low mounting height has the potential to accentuate this phenomenon. This is especially true if the masts slide over the vertical uprights on the legs (e.g., Test MNS-2, System No. 6). If the masts fit inside of the vertical uprights on the legs, the interaction with the vehicle was found to be limited to the hood area (e.g., Test MNS-1, System No. 2). A higher mounting height can also cause significant interaction with the vehicle's windshield (e.g., Test MNS-2, System No. 4). A mounting height of below the bumper height reduces the amount of flex that the sign panel and masts encounter, thereby decreasing the magnitude of interaction (if at all) with the vehicle (e.g., Test MNS-2, System No. 3).

Sign panels can potentially strike the vehicle with a concentrated impact force. However, as stated previously, it is noted that this phenomenon is partially dependent on the mast's release time from the legs of the sign support. Aluminum rigid sign panels were found to cause significant windshield damage (e.g., Test MNS-1, System No. 1, Test MNS-2, System No. 4, and Test MNS-3, System Nos. 5 and 6). These panels are not flexible nor capable of absorbing any of the energy when they strike the windshield. For the end-on orientation, the aluminum panels have been seen to act like a knife and slice through the windshield (e.g., Test MNS-2, System No. 4 and Test MNS-3, System No. 6).

Finally, following an analysis of the test results, it was evident that the debris from the sign supports tended to be thrown along the path of the impacting vehicle. The relative hazard posed to the traffic and work zone crews located adjacent to the sign supports is somewhat subjective in nature. Depending on the specific site conditions at which these devices are being used, the sign support debris was determined to be less of a hazard to adjacent traffic and work zone crews than the moving vehicle itself.

9 SUMMARY AND CONCLUSIONS

A total of six crash tests were conducted on the aluminum work zone sign supports. Two out of the six crash tests on these work zone traffic control devices satisfactorily met the TL-3 evaluation criteria set forth in NCHRP Report No. 350. A summary of the safety performance evaluation of each system is provided in Table 4.

From this testing and previous testing, slight differences in system design details can potentially lead to very different results. Therefore, extreme care should be taken when applying one crash test to variations in any design features without clearly understanding the complete work zone traffic control device performance. Also, extreme care should be taken when attempting to catagorize various products for one or more manufacturers.

Table 4. Summary of Safety Performance Evaluation Results

Evaluation Factors	Evaluation Criteria	Test MNS-1		Test MNS-2		Test MNS-3	
		#1	#2	#3	#4	#5	#6
		ASPL [1]	ASPL [1]	ASP [1]	ASP [1]	ASPL [1]	ASPL [1]
Structural Adequacy	B	S	S	S	S	S	S
Occupant Risk	D	U	S	S	U	U	U
	E	U	S	S	U	U	U
	F	S	S	S	S	S	S
	H	NA	NA	NA	NA	NA	NA
	I	NA	NA	NA	NA	NA	NA
Vehicle Trajectory	K	S	S	S	S	S	S
	N	S	S	S	S	S	S
NCHRP Report No. 350 Test Level		TL-3	TL-3	TL-3	TL-3	TL-3	TL-3
Method of Failure[2]		1,2,3,4	NA	NA	1,2,3,4	1,2,3,4	1,2,3,4
Pass/Fail		Fail	Pass	Pass	Fail	Fail	Fail

[1] Hardware Type:
AS – Aluminum Sign Support
ASP – Aluminum Sign Support with Sign Panel(s)
ASPL – Aluminum Sign Support with Sign Panel(s) and Warning Light

[2] Method of Failure:
1 - Severe windshield cracking and fracture
2 - Windshield indentation
3 - Obstruction of driver visibility
4 - Windshield penetration
5 - Occupant compartment penetration other than windshield penetration
6 - Test invalid due to flying debris from the first device contacting the second device before vehicle impact

S - Satisfactory
M - Marginal
U - Unsatisfactory
NA - Not Available

10 RECOMMENDATIONS

One work zone traffic control device satisfactorily met the evaluation criteria set forth in NCHRP Report No. 350 in the direction the system was oriented. The test for the other direction of impact has not been performed. This work zone traffic control device includes:

- Test No. MNS-2, System No. 3 – Minnesota's Large Combination Sign System – An aluminum sign support, with 20.4 kg of sand on each leg, and with a 915-mm wide x 610-mm tall, rectangular-shaped aluminum sign panel mounted above a 914-mm wide x 1218-mm tall, rectangular-shaped aluminum sign panel oriented head-on.

Three work zone traffic control devices performed unsatisfactorily according to the test evaluation criteria set forth in NCHRP Report No. 350 and are not recommended for field applications. These work zone traffic control devices include:

- Test No. MNS-1, System No. 1 – Minnesota's aluminum sign support, with 20.4 kg of sand on each leg, and with a 1220-mm wide x 1220-mm tall, diamond-shaped aluminum sign panel and an attached warning light model no. 400 ("Empco-Lite") oriented head-on. The same system performed satisfactorily when oriented end-on (Test No. MNS-1, System No. 2).

- Test No. MNB-2, System No. 4 – Minnesota's Stop Sign System – An aluminum sign support, with 20.4 kg of sand on each leg, and with a 915-mm wide x 915-mm tall, octagon-shaped aluminum sign panel oriented end-on.

- Test No. MNB-3, System Nos. 5 and 6 – Minnesota's aluminum sign support, with 20.4 kg of sand on each leg, and with a 1219-mm wide x 1219-mm tall, diamond-shaped aluminum sign panel and an attached warning light model "ToughLite 2000" oriented head-on and end-on, respectively.

For work zone traffic control devices, such as those presented herein, similar devices may be capable of meeting the performance requirements from NCHRP Report No. 350; however, it is noted that slight differences in design details can potentially lead to very different results. Therefore, it is suggested that the impact performance of work zone traffic control devices can only be verified through the use of full-scale vehicle crash testing. Thus, it is recommended that the research described herein be extended to determine the performance behavior of other similar work zone traffic control devices.

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12 APPENDICES

APPENDIX A

Dimensional Measurements of Portable Sign Support Systems

Table A-1. Portable Sign Support System Dimensional Measurements

System Number	Test Number	STAND		SIGN		
		Type [1]	Weight (kg)	Type [2]	Material [3]	Weight (kg)
1, 2	MNS-1	Aluminum Sign Stand (Legs & Two Masts)	20.865	Diamond-Shaped Rigid	6	6.350
3	MNS-2	Aluminum Sign Stand (Legs & Two Masts)	20.865	Two Panels Rigid	6	12.247
4	MNS-2	Aluminum Sign Stand (Legs & Two Masts)	20.865	Octagon-Shaped Rigid	6	5.443
5, 6	MNS-3	Aluminum Sign Stand (Legs & Two Masts)	19.051	Diamond-Shaped Rigid	6	6.350

[1] When more than one stand type is listed, they are different reference names for the same stand.
[2] When more than one sign type is listed, they are different reference names for the same sign.
[3] Description of material types: 1 - (Reflexite Superbright)
2 - (3M RS34)
3 - (3M Diamond Grade RS24)
4 - (Non-reflective Mesh)
5 - (Reflexite Non-reflective)
6 - (Aluminum)

Table A-2. Portable Sign Support System Dimensional Measurements

System Number	HEIGHTS TO			
	Bottom of Bottom (or Only) Sign Panel (mm)	Top of Bottom (or Only) Sign Panel (mm)	Top of Top Sign Panel (mm)	Top of Light (mm)
1, 2	344	2005	----	1705
3	344	1562	2173	----
4	1245	2160	----	----
5, 6	473	2137	----	1626

Table A-3. Portable Sign Support System Dimensional Measurements

Stand Type	LEGS				
	Horizontal Portion				
	Material	Dimension #1 (mm)	Dimension #2 (mm)	Thickness (mm)	Length (mm)
Aluminum Sign Stand	Telespar ASTM A-653 Grade 50 Steel	45	45	2.75	1520
Aluminum Sign Stand	Telespar ASTM A-653 Grade 50 Steel	45	45	2.75	1520
Aluminum Sign Stand	Telespar ASTM A-653 Grade 50 Steel	45	45	2.75	1520
Aluminum Sign Stand	Telespar ASTM A-653 Grade 50 Steel	44.42	44.42	2.72	1230

Table A-4. Portable Sign Support System Dimensional Measurements

Stand Type	LEGS				
	Vertical Portion				
	Material	Dimension #1 (mm)	Dimension #2 (mm)	Thickness (mm)	Length (mm)
Aluminum Sign Stand	Telespar ASTM A-653 Grade 50 Steel	45	45	2.75	300
Aluminum Sign Stand	Telespar ASTM A-653 Grade 50 Steel	45	45	2.75	302
Aluminum Sign Stand	Telespar ASTM A-653 Grade 50 Steel	45	45	2.75	302
Aluminum Sign Stand	Telespar ASTM A-653 Grade 50 Steel	38.11	38.06	2.75	302

Table A-5. Portable Sign Support System Dimensional Measurements

Stand Type	MASTS (VERTICAL UPRIGHTS)						
	Number of Masts	Material	Dimension #1 (mm)	Dimension #2 (mm)	Thickness (mm)	Length (mm)	Space between masts (out to out) (mm)
Aluminum Sign Stand	2	Telespar ASTM A-653 Grade 50 Steel	38	38	2.70	1525	802
Aluminum Sign Stand	2	Telespar ASTM A-653 Grade 50 Steel	38	38	2.75	2030	803
Aluminum Sign Stand	2	Telespar ASTM A-653 Grade 50 Steel	38	38	2.75	2030	495
Aluminum Sign Stand	2	Telespar ASTM A-653 Grade 50 Steel	44.51	44.50	2.05	1829	806

Table A-6. Portable Sign Support System Dimensional Measurements

Stand Type	HOLES		SMALL PANELS					
				BOTTOM PANEL				
							Thickness	
	Diameter of holes (mm)	Hole Spacings (center to center) (mm)	Number of Small Panels	Material	Length (mm)	Width (mm)	Thickest (mm)	Thinnest (mm)
Aluminum Sign Stand	11.00	25.00	----	----	----	----	----	----
Aluminum Sign Stand	11.50	25.50	----	----	----	----	----	----
Aluminum Sign Stand	11.50	25.50	----	----	----	----	----	----
Aluminum Sign Stand	10.72	25.13	----	----	----	----	----	----

Table A-7. Portable Sign Support System Dimensional Measurements

Stand Type	SMALL PANELS									
	MIDDLE PANEL					TOP PANEL				
	Material	Length (mm)	Width (mm)	Thickness		Material	Length (mm)	Width (mm)	Thickness	
				Thickest (mm)	Thinnest (mm)				Thickest (mm)	Thinnest (mm)
Aluminum Sign Stand	----	----	----	----	----	----	----	----	----	----
Aluminum Sign Stand	----	----	----	----	----	----	----	----	----	----
Aluminum Sign Stand	----	----	----	----	----	----	----	----	----	----
Aluminum Sign Stand	----	----	----	----	----	----	----	----	----	----

Table A-8. Portable Sign Support System Dimensional Measurements

Sign Type	SIGN PANELS						
	Material	Bottom (or Only) Panel			Top Panel		
		Thickness (mm)	Length (mm)	Width (mm)	Thickness (mm)	Length (mm)	Width (mm)
Diamond-Shaped Rigid	Aluminum	2.75	1220	1220	----	----	----
Two Panels Rigid	Aluminum	2.70	1218	915	2.80	610	915
Octagon-Shaped Rigid	Aluminum	3.00	915	915	----	----	----
Diamond-Shaped Rigid	Aluminum	2.95	1219	1219	----	----	----

Table A-9. Warning Light Dimensional Measurements

System No.	Manufacturer	Model No.	Model Name	Dimensional Measurements						
				Box (mm)			Light Diameter (mm)	Overall Height (mm)	Weight (kg)	
				Length	Width	Depth			w/o batteries	w/ batteries
1, 2	Empco-Lite	400	Empco-Lite	130	180	93	187	314	0.45	1.81
3	----	----	----	----	----	----	----	----	----	----
4	----	----	----	----	----	----	----	----	----	----
5, 6	Wil Industries, Inc.	----	ToughLite 2000	86	184	86	187	273	----	1.36