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SAFETY PERFORMANCE EVALUATION OF MINNESOTA'S ALUMINUM TYPE III BARRICADES

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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 type III barricade systems through full-scale crash testing. A total of four full-scale crash tests were conducted on type III barricades to determine their safety performance according to the Test Level 3 (TL-3) criteria set forth in the NCHRP Report No. 350. All of the impacts on the barricade systems resulted in acceptable safety performances. Following the analysis of the crash tests and test results from other testing programs, it was 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 results of one work-zone traffic control device crash test to another 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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DISCLAIMER STATEMENT

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TABLE OF CONTENTS

Page

List of Figures

Page

List of Tables

Page

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 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 (8-18). 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 type III barricades 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, four full-scale vehicle crash tests were performed on the aluminum type III barricades. The four crash tests were completed in two runs with a right-side quarter-point and a left-side quarter-point impact in each run, resulting in a total of four 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 portable sign supports.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Work-zone traffic control devices, such as type III barricades, 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* (19), work-zone traffic control devices are Category 2 devices, which are not expected to produce significant change in vehicular velocity, but may 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 TYPE III BARRICADES

3.1 General Descriptions

A total of four existing work-zone traffic control devices were crash tested under this study and are described below. All four of the crash tests were conducted on aluminum type III barricades. All materials for the traffic control devices were supplied by the sponsor.

The four different aluminum type III barricades tested were:

1. (System No. 1) a 1,829-mm wide x 1,528-mm deep x 1,594-mm tall aluminum type III barricade;

2. (System No. 2) a 1,829-mm wide x 1,524-mm deep x 1,591-mm tall aluminum type III barricade,

3. (System No. 3) a 1,829-mm wide x 1,528-mm deep x 1,595-mm tall aluminum type III barricade with a 1,219-mm x 765-mm aluminum sign panel with reflective material mounted at a height of 1,449-mm from the ground to the bottom of the sign panel; and

4. (System No. 4) a 1,829-mm wide x 1,528-mm deep x 1,592-mm tall aluminum type III barricade with a 1,226-mm x 762-mm aluminum sign panel with reflective material mounted at a height of 1,410-mm from the ground to the bottom of the sign panel.

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

Table 3. List of Crash Tests Conducted

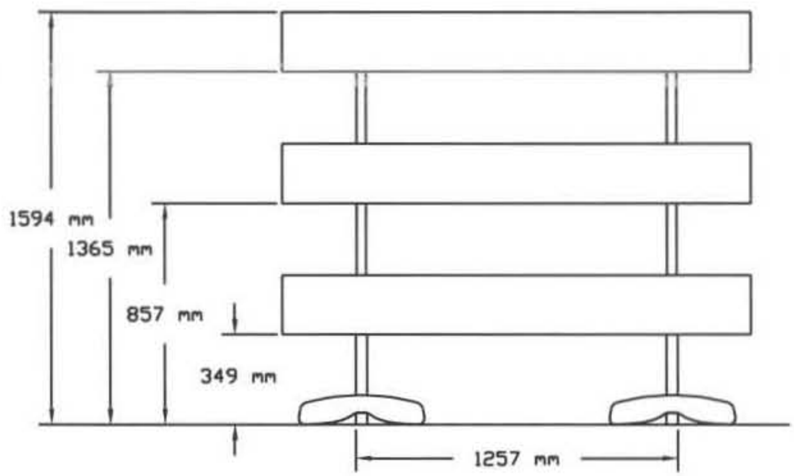
WORK-ZONE TRAFFIC CONTROL DEVICES

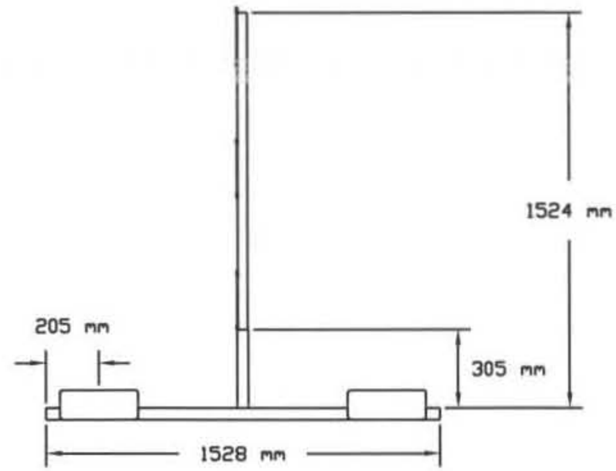
ALUMINUM BARRICADES

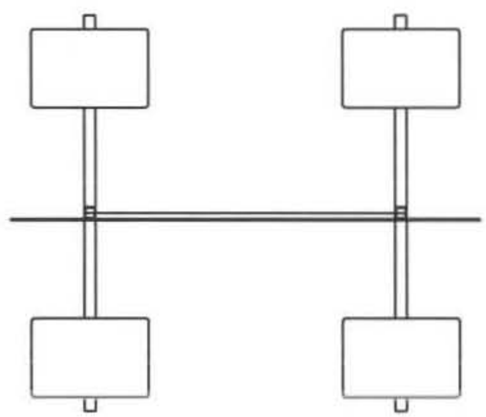
Test MNB-1	System No. 1	Aluminum Type III Barricade, Head-on Impact (0 degrees)
Test MNB-1	System No. 2	Aluminum Type III Barricade, End-on Impact (90 degrees)
Test MNB-2	System No. 3	Aluminum Type III Barricade, Aluminum Sign Panel with Reflective Material, Head-on Impact (0 degrees)
Test MNB-2	System No. 4	Aluminum Type III Barricade, Aluminum Sign Panel with Reflective Material, End-on Impact (90 degrees)

3.2 Aluminum Type III Barricades

The details of the aluminum type III barricades are shown in Figures 1 through 8. The dimensional measurements of the aluminum type III barricades are found in Appendix A. A detailed drawing of the small panels on each barricade is found in Appendix B.





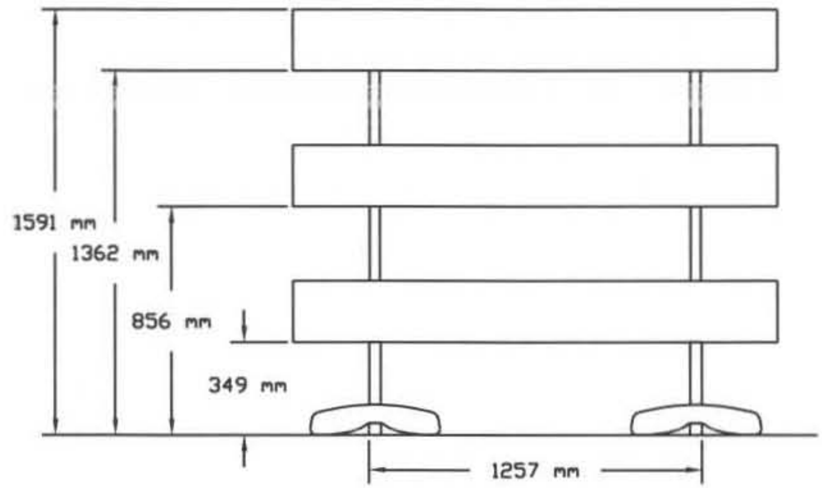


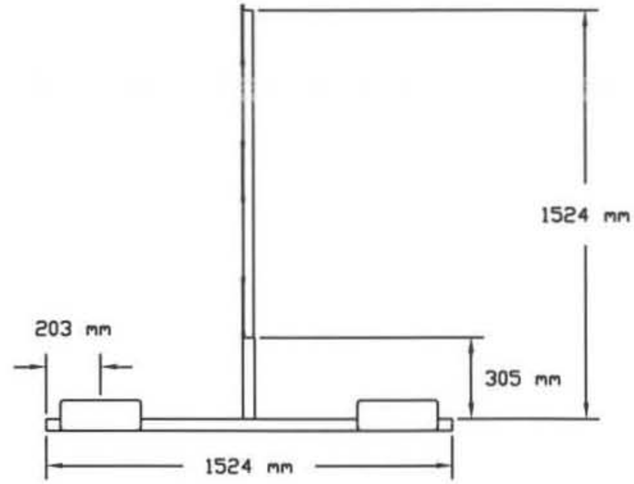
ALUMINUM TYPE III BARRICADE

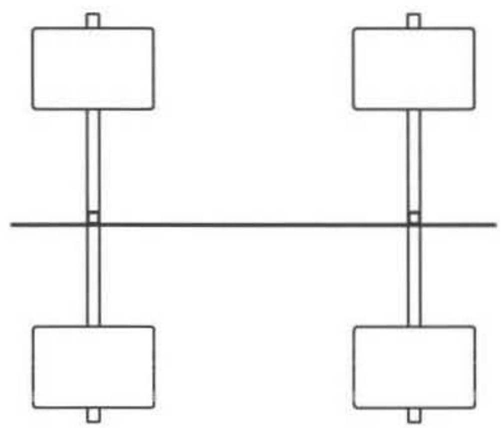
- Vertical Upright Masts – 38.13 mm x 38.05 mm x 3.07 mm wall x 1524 mm long telespar galvanized steel
- Legs, Horizontal Portion – 44.67 mm x 44.45 mm x 1.93 mm wall x 1528 mm long telespar galvanized steel
- Legs, Vertical Portion – 44.36 mm x 44.28 mm x 1.94 mm wall x 305 mm long telespar galvanized steel
- All telespar steel tubing contain 11.35 mm diameter punched holes, spaced 25.31 mm on center, along the total length
- Small Panels – aluminum "dog-bone" extrusions
  - Top Panel – 229 mm wide x 1829 mm long
  - Middle Panel – 229 mm wide x 1829 mm long
  - Bottom Panel – 230 mm wide x 1829 mm long
- Ballast – 20.4-kg sandbag at end of each leg
- Panels fastened to vertical supports with 50.8 mm corner bolts
- 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

Figure 1. System No. 1 Barricade Details, Test MNB-1

Figure 2. System No. 1 Barricade, Test MNB-1







ALUMINUM TYPE III BARRICADE

- Vertical Upright Masts – 38.21 mm x 38.05 mm x 3.02 mm wall x 1524 mm long telespar galvanized steel
- Legs, Horizontal Portion – 44.56 mm x 44.47 mm x 1.92 mm wall x 1524 mm long telespar galvanized steel
- Legs, Vertical Portion – 44.48 mm x 44.33 mm x 1.94 mm wall x 305 mm long telespar galvanized steel
- All telespar steel tubing contain 11.25 mm diameter punched holes, spaced 25.20 mm on center, along the total length
- Small Panels – aluminum "dog-bone" extrusions
  - Top Panel – 229 mm wide x 1829 mm long
  - Middle Panel – 227 mm wide x 1829 mm long
  - Bottom Panel – 229 mm wide x 1829 mm long
- Ballast – 20.4-kg sandbag at end of each leg
- Panels fastened to vertical supports with 50.8 mm corner bolts
- 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

Figure 3. System No. 2 Barricade Details, Test MNB-1

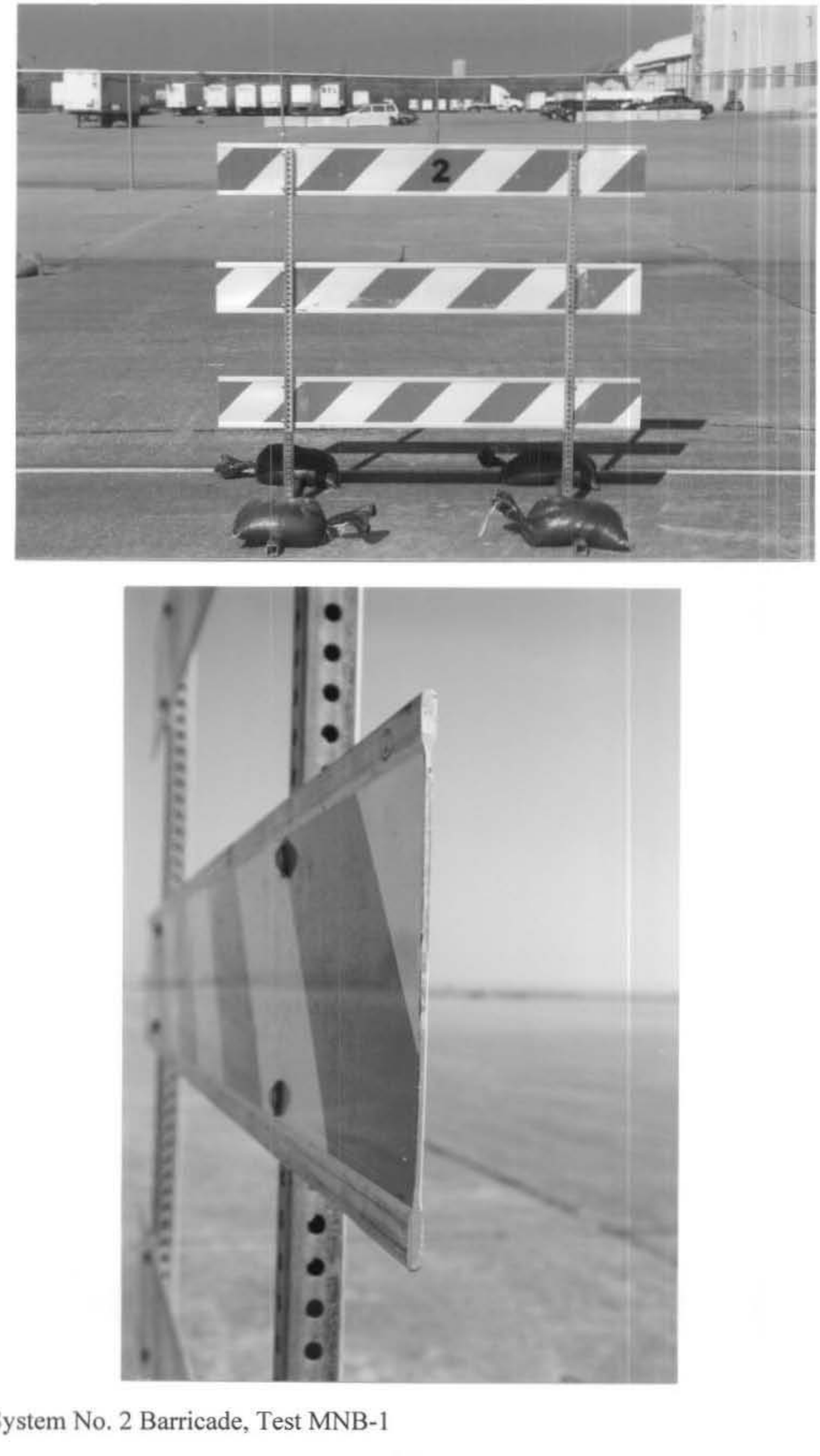
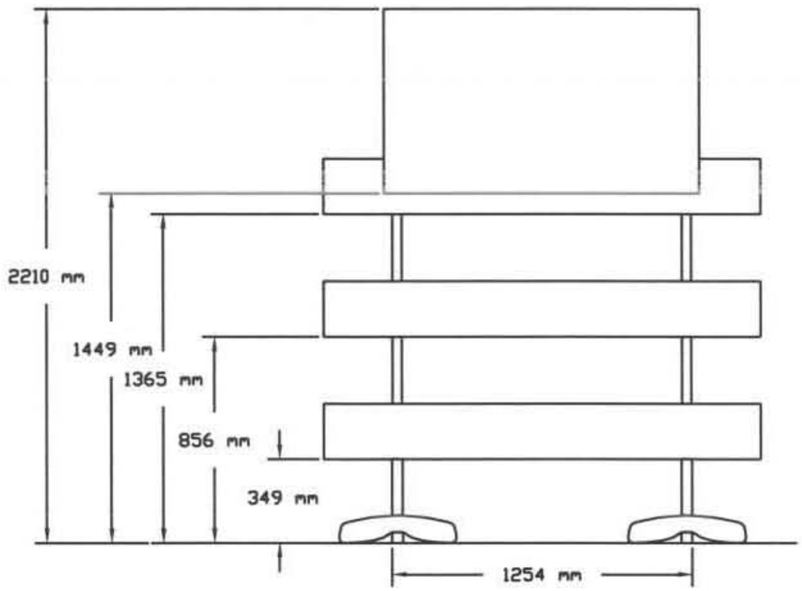
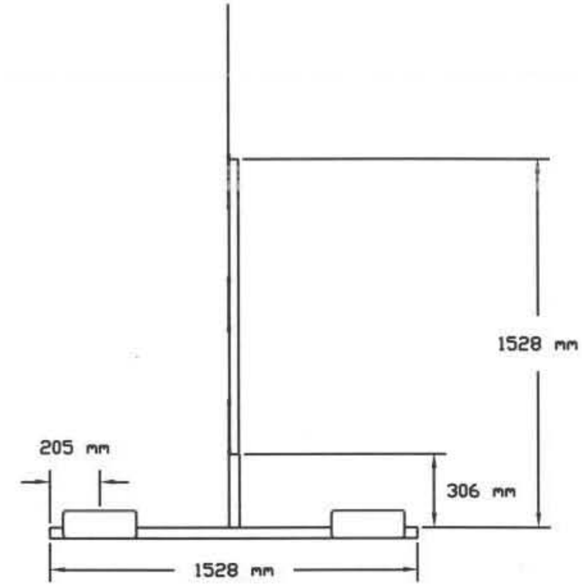
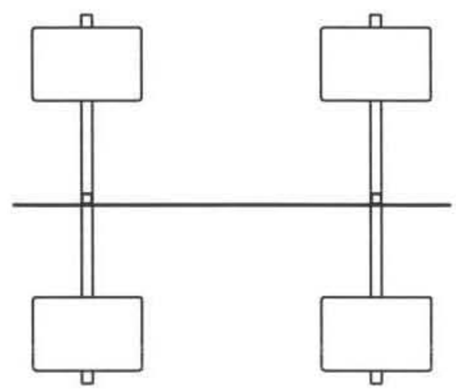


Figure 4. System No. 2 Barricade, Test MNB-1







ALUMINUM TYPE III BARRICADE

* Vertical Upright Masts – 38.17 mm x 38.07 mm x 3.05 mm wall x 1528 mm long telespar galvanized steel
* Legs, Horizontal Portion – 44.60 mm x 44.50 mm x 1.93 mm wall x 1528 mm long telespar galvanized steel
* Legs, Vertical Portion – 44.30 mm x 44.27 mm x 1.92 mm wall x 306 mm long telespar galvanized steel
* All telespar steel tubing contain 11.34 mm diameter punched holes, spaced 25.24 mm on center, along the total length
* Small Panels – aluminum "dog-bone" extrusions
  - Top Panel – 230 mm wide x 1829 mm long
  - Middle Panel – 230 mm wide x 1829 mm long
  - Bottom Panel – 229 mm wide x 1829 mm long
* Ballast – 20.4-kg sandbag at end of each leg
* Panels fastened to vertical supports with 50.8 mm corner bolts
* 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

RIGID SIGN

* Panel – Reflective aluminum, 765 mm x 1219 mm with 2.70 mm thickness
* Attached to top barricade panel with 7.9 mm x 57.2 mm pan head bolts with a 76.2-mm square washer on back side of barricade panel

Figure 5. System No. 3 Barricade Details, Test MNB-2

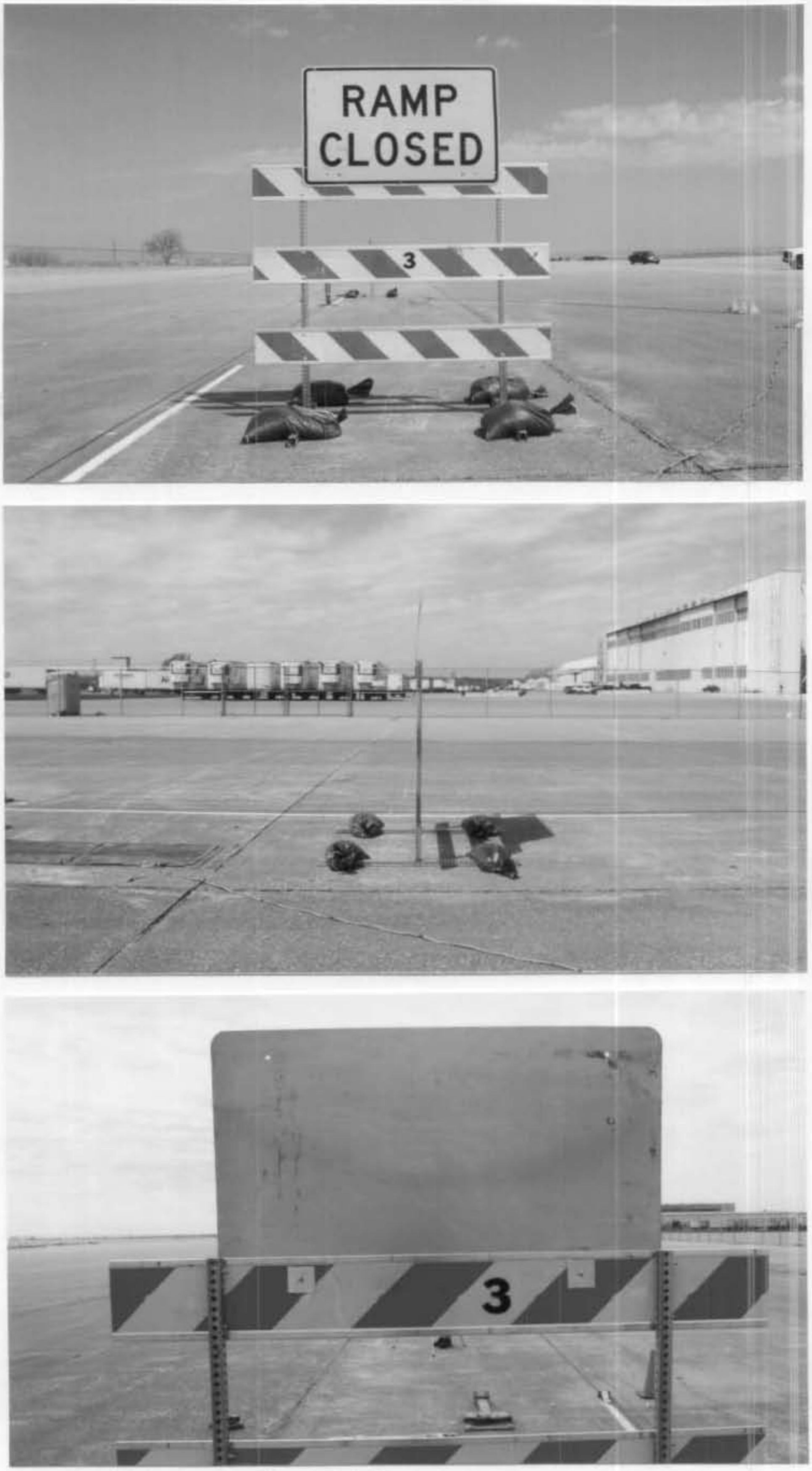
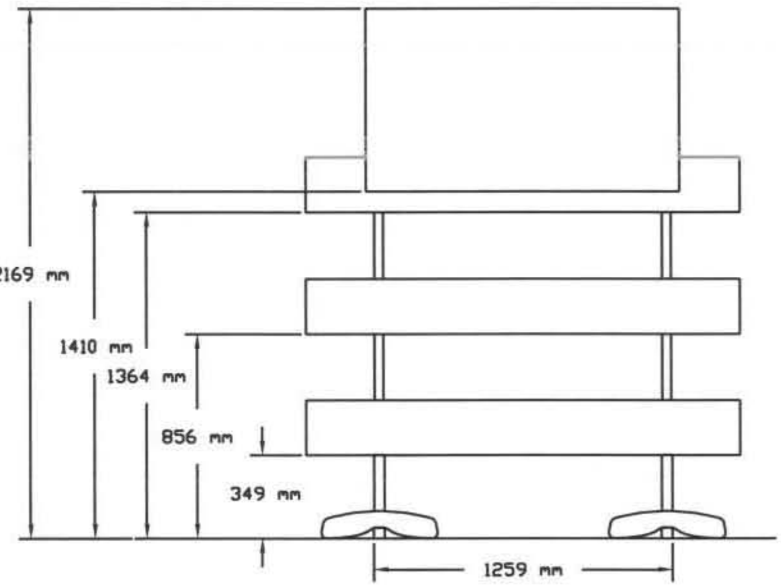
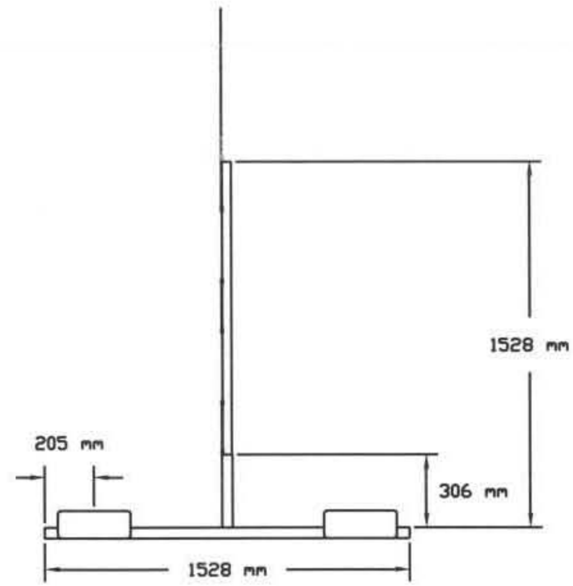
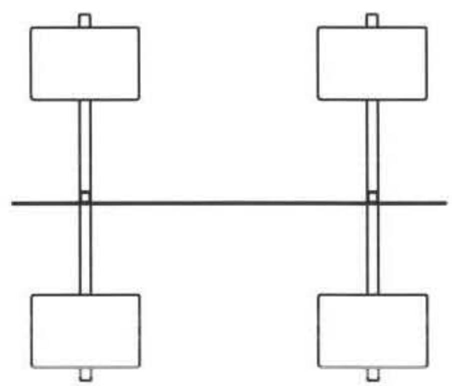


Figure 6. System No. 3 Barricade, Test MNB-2







ALUMINUM TYPE III BARRICADE

- Vertical Upright Masts – 38.11 mm x 38.10 mm x 3.01 mm wall x 1528 mm long telespar galvanized steel
- Legs, Horizontal Portion – 44.64 mm x 44.43 mm x 1.92 mm wall x 1528 mm long telespar galvanized steel
- Legs, Vertical Portion – 44.41 mm x 44.30 mm x 1.93 mm wall x 306 mm long telespar galvanized steel
- All telespar steel tubing contain 11.30 mm diameter punched holes, spaced 25.24 mm on center, along the total length
- Small Panels – aluminum "dog-bone" extrusions
  - Top Panel – 229 mm wide x 1829 mm long
  - Middle Panel – 229 mm wide x 1829 mm long
  - Bottom Panel – 229 mm wide x 1829 mm long
- Ballast – 20.4-kg sandbag at end of each leg
- Panels fastened to vertical supports with 50.8 mm corner bolts
- 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

RIGID SIGN

- Panel – Reflective aluminum, 762 mm x 1226 mm with 2.68 mm thickness
- Attached to top barricade panel with 7.9 mm x 57.2 mm pan head bolts with a 76.2-mm square washer on back side of barricade panel

Figure 7. System No. 4 Barricade Details, Test MNB-2

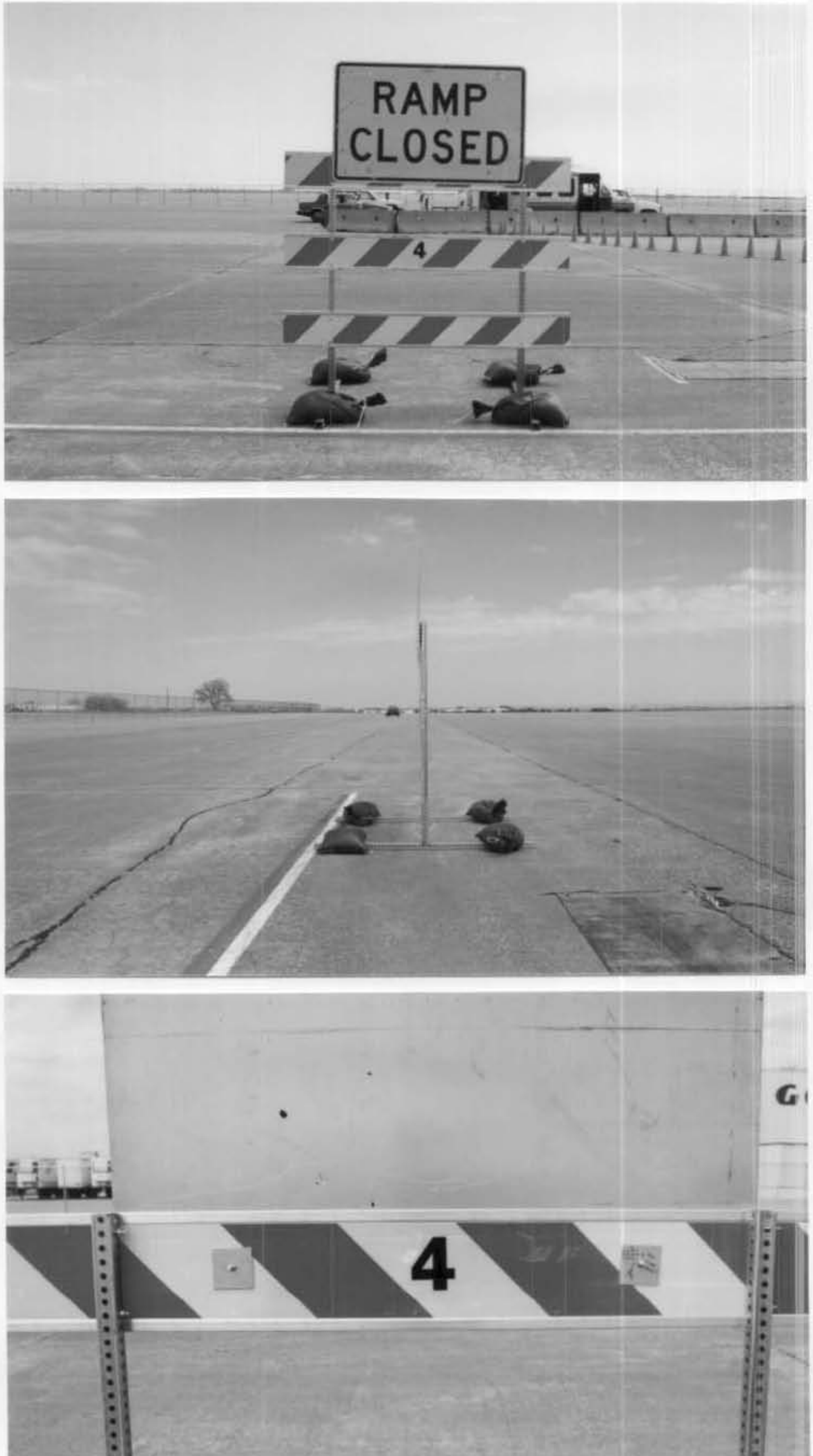


Figure 8. System No. 4 Barricade, Test MNB-2

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 (20) 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 MNB-1, a 1994 Geo Metro was used as the test vehicle. The test inertial and gross static weights were 817 kg and 893 kg, respectively. The test vehicle is shown in Figure 9, and vehicle dimensions are shown in Figure 10.

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

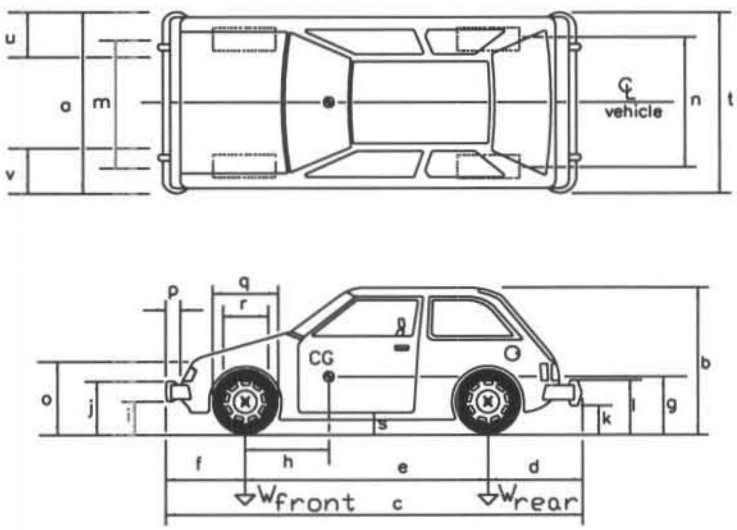
Figure 9. Test Vehicle, Test MNB-1

Dates: 4/18/00 Test Numbers: MNB-1 Model: Metro

Make: GEO Vehicle I.D.#: 2C1MR2466R6799639

Tire Size: 155R12 Year: 1994 Odometer: 94,048

Vehicle Geometry - mm



a	1530	b	1321
c	3747	d	707
e	2267	f	775
g	546	h	842
i	387	j	470
k	279	l	533
m	1365	n	1343
o	546	p	102
q	540	r	330
s	273	t	1524
u	378	v	378

height of wheel center 254

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}	514	514	549
W_{rear}	289	304	344
W_{total}	803	818	893

Damage prior to test: __________

Figure 10. Vehicle Dimensions, Test MNB-1

static weights were 808 kg and 883 kg, respectively. The test vehicle is shown in Figure 11, and vehicle dimensions are shown in Figure 12.

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 9 through 12.

Square, black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film, as shown in Figures 13 through 14. 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 device on the high-speed film. 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

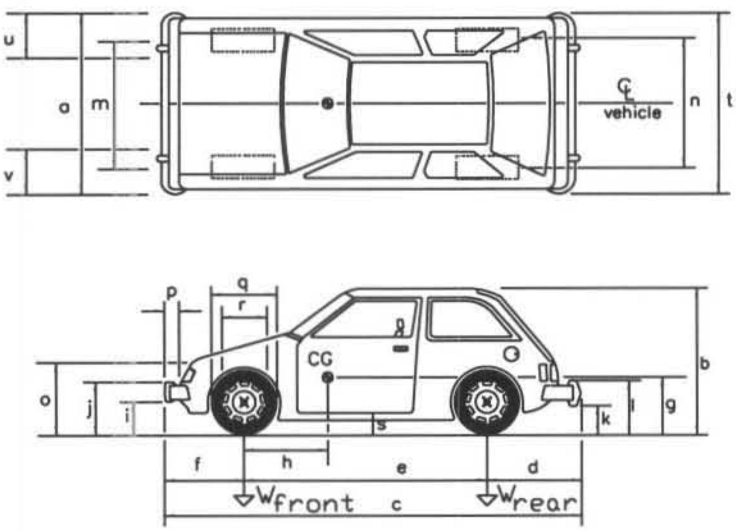
For tests MNB-1and MNB-2, three high-speed 16-mm Red Lake Locam cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. One high-speed Red Lake E/cam video camera, with an operating speed of 500 frames/sec, and one Canon digital video camera, with an operating speed of 1000 frames/sec, were also used to film the crash test. A SVHS video camera and a 35-mm still camera were placed downstream and offset to the right from

Figure 11. Test Vehicle, Test MNB-2

Dates: 4/18/00 Test Numbers: MNB-2 Model: Metro

Make: GEO Vehicle I.D.#: 2C1MR2460R6708073

Tire Size: 155R12 Year: 1994 Odometer: 110,887



Vehicle Geometry - mm

a	1556	b	1346
c	3823	d	705
e	2267	f	851
g	546	h	953
i	381	j	464
k	279	l	533
m	1365	n	1340
o	533	p	95
q	540	r	330
s	273	t	1524
u	381	v	381

height of wheel center 254

Engine Type 3 cyl. gas

Engine size 1.0 L

Transmission Type:

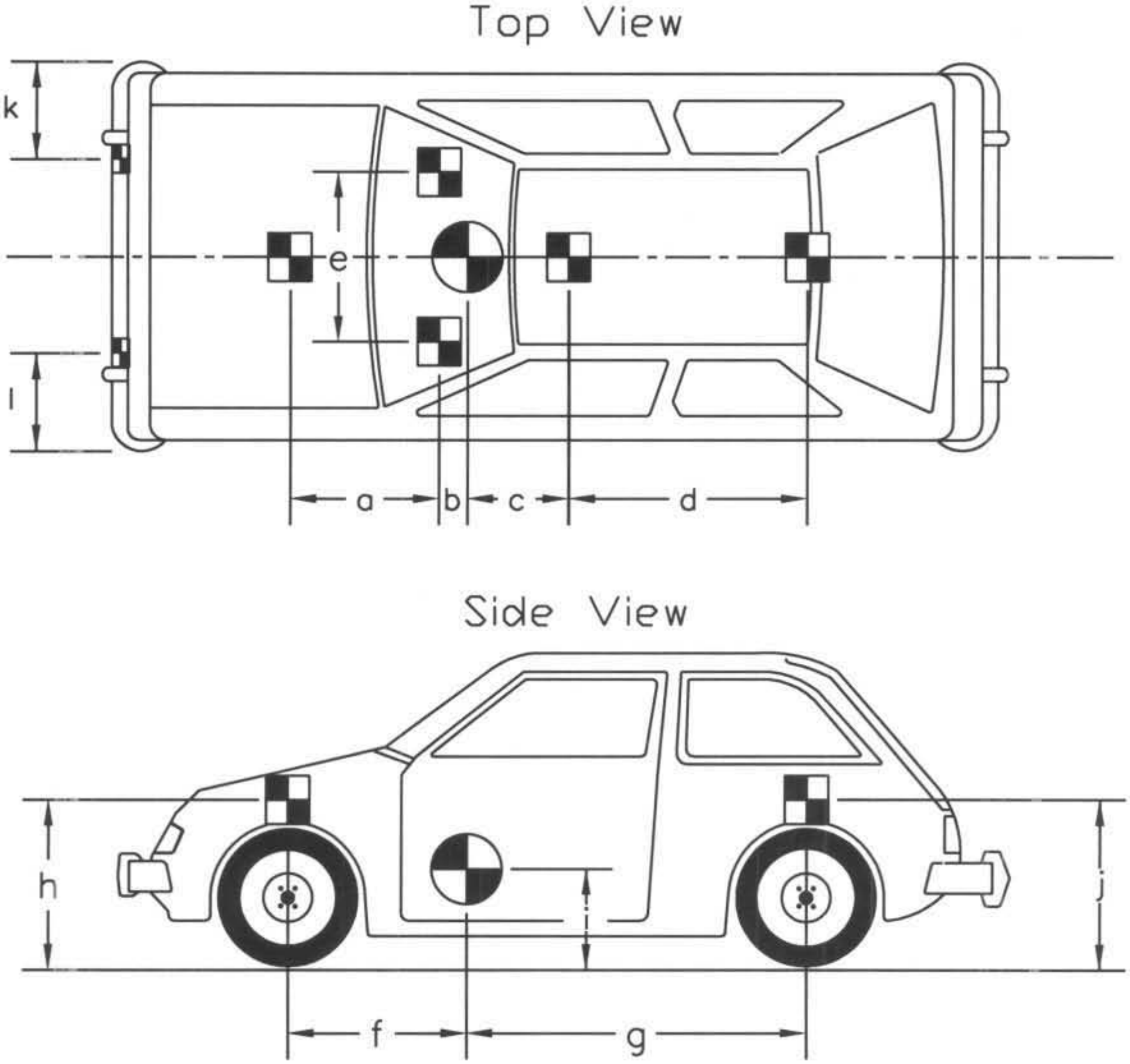
Automatic or Manual

FWD or RWD or 4WD

Weight - kg	Curb	Test Inertial	Gross Static
W_{front}	435	468	503
W_{rear}	304	340	380
W_{total}	739	808	883

Damage prior to test: ______

Figure 12. Vehicle Dimensions, Test MNB-2

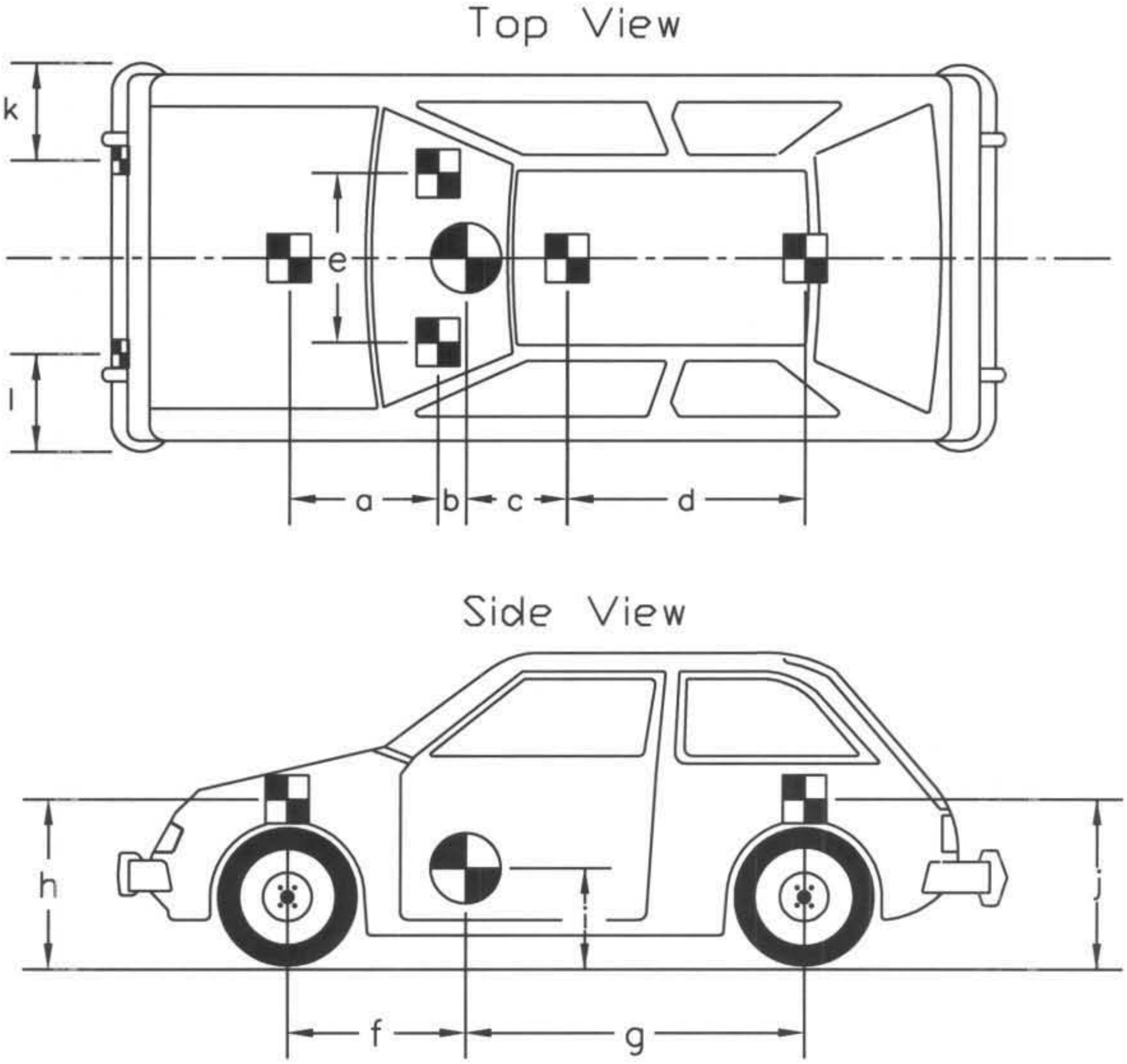


TEST #: MNB-1

TARGET GEOMETRY (mm)

a	---	b	---	c	---	d	---
e	---	f	842	g	1425	h	679
i	546	j	699	k	378	l	378

Figure 13. Vehicle Target Locations, Test MNB-1



TEST #: MNB-2

TARGET GEOMETRY (mm)

a	---	b	---	c	---	d	---
e	---	f	953	g	1314	h	705
i	546	j	718	k	391	l	391

Figure 14. Vehicle Target Locations, Test MNB-2

the impact points and had an angled view of the impacts. A Locam, with a 16 to 64-mm zoom lens, and a SVHS 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 Locam was placed on the right side of the impact orientation and had a closer perpendicular view of the impact of the second device. An E/cam high-speed video camera was placed downstream and offset to the right from the first impact point and had an angled view of the impact of the first device. A Canon digital video camera was placed on the right side of the impact orientation and had a field of view perpendicular to the impact of the first device. A SVHS video camera was placed downstream and offset to the right from the first impact point and had a panning view of both impacts. A schematic of all nine camera locations for tests MNB-1 and MNB-2 is shown in Figure 15. The film was analyzed using the Vanguard Motion Analyzer. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

4.4.2 Pressure Tape Switches

For tests MNB-1 and MNB-2, 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 system as the right-front tire of the test vehicle passed over both sets of tape switches. 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.

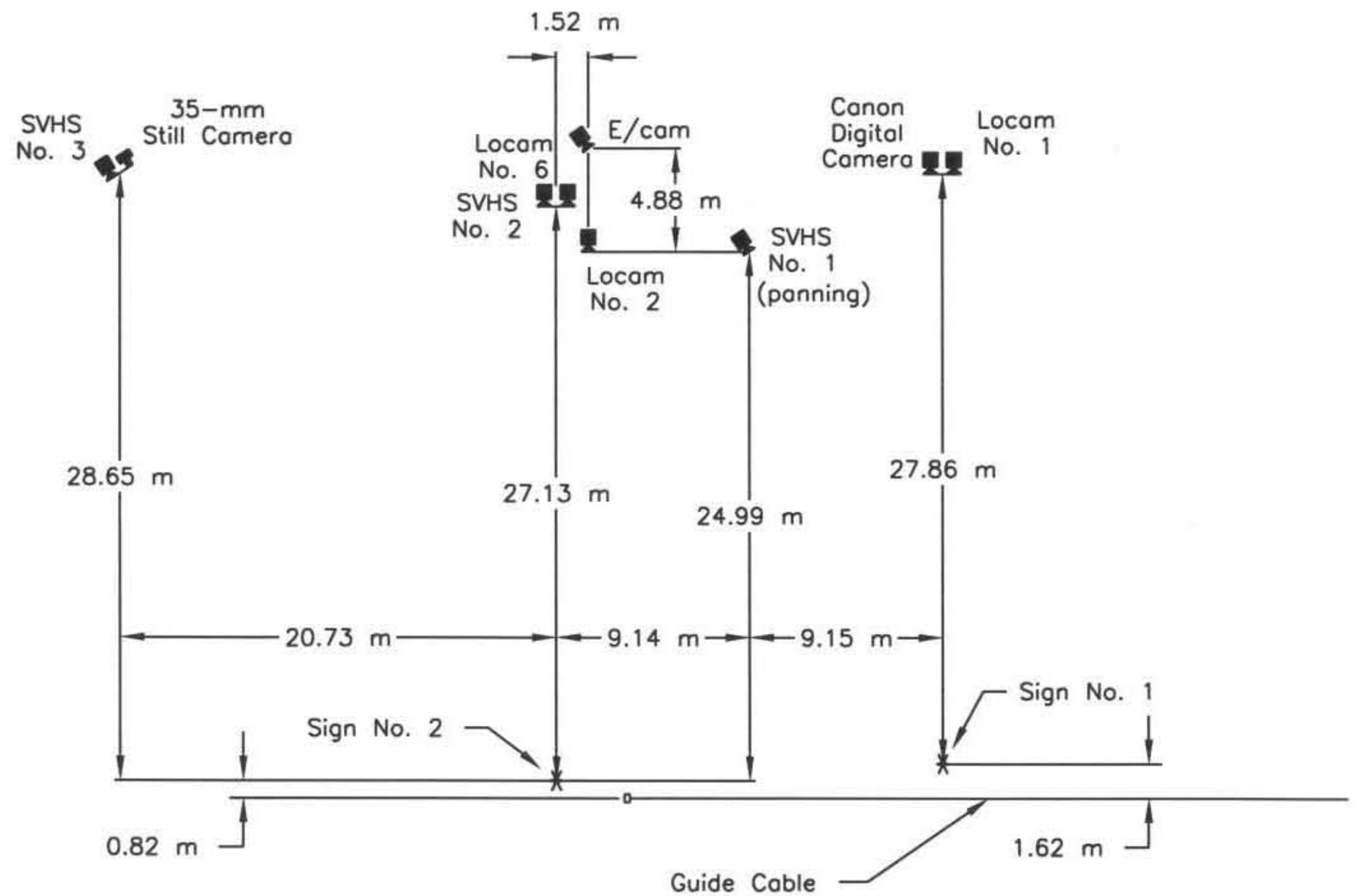


Figure 15. Location of High-Speed Cameras, Tests MNB-1 and MNB-2

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

5.1 Test MNB-1

The 893-kg small car impacted System No. 1, an aluminum type III barricade oriented head-on to the vehicle (perpendicular to the vehicle's path), at a speed of 105.1 km/hr and an angle of 0 degrees. The small car then impacted System No. 2, an aluminum type III barricade oriented end-on to the vehicle (parallel to the vehicle's path), at a speed of 99.3 km/hr and an angle of 90 degrees. A summary of the test results and the sequential photographs are shown in Figures 16 and 17. Documentary photographs of the crash tests are shown in Figures 18 through 19.

5.2 Test Description

The test vehicle impacted System No. 1 with the right-front quarter point of the vehicle's bumper aligned with the centerline of the barricade, as shown in Figure 20. At 0.008 sec after initial impact, the contact point on the left mast deformed around the front of the vehicle. At this same time, the system wrapped around the right side of the vehicle. At 0.030 sec, the mast continued to deform around the top of the lower panel. At 0.040 sec, the leg of the left mast disengaged from the rest of the barricade as the top of the barricade rotated counter-clockwise (CCW) toward the vehicle. At 0.059 sec, the barricade system slid along the hood as the barricade panels deformed. At 0.083 sec, the barricade system was still in contact with the vehicle as it traveled downstream. At 0.148 sec, the barricade system slid along the vehicle's windshield. At this same time, the disengaged left leg was airborne in front of the vehicle. At 0.234 sec, the barricade system rested across the vehicle's windshield and roof as it traveled with the vehicle. At 0.344 sec, the barricade system moved toward the rear of the vehicle along the vehicle's roof. The leg that disengaged from the barricade was located 13.72-m downstream and 4.09-m right from the original position. The remainder of the barricade system came to rest 31.39-m downstream and 3.78-m right of the initial position. Loose sand from the sandbags was scattered in a pattern bound by 0.0-m upstream, 12.19-m downstream, 0.18-m left, and 4.09-m right from the original position of the barricade.

Approximately 0.64 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 barricade, as shown in Figure 20. At 0.010 sec after initial impact, the outside edge of the barricade's bottom panel crushed toward the mast closest to the vehicle. At 0.014 sec, the impacted mast deformed about the front of the vehicle. At 0.024 sec, the panels deformed toward the non-impacted mast. At this same time, the mast closest to the vehicle disengaged from the leg's vertical upright. At 0.030 sec, the barricade system traveled with the vehicle as the panels continued to deform. At 0.038 sec, the bottom of the detached mast was pulled along the ground. At 0.042 sec, the hood became slightly ajar. At 0.049 sec, the impacted mast and the panels continued to deform as the hood opened further. The piece of the detached leg without the vertical upright was located 1.83-m downstream and 1.22-m left from the original position. The other piece of the detached leg with the vertical upright was located 3.05-m downstream and 1.52-m left from the original position. The remainder of the barricade system came to rest 51.21-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, 7.62-m downstream, 0.61-m left, and 1.52-m right from the original position of the barricade. The vehicle subsequently came to rest 96.93-m downstream from the longitudinal midpoint of the two impact points and 3.75-m left from the centerline of the vehicle's original path. The final positions of the vehicle and the sign support are shown in Figures 16, 17, and 21.

5.3 System and Component Damage

Damage to System Nos. 1 and 2 is shown in Figures 21 through 25. System No. 1 encountered moderate damage. The leg on the left side was bent and disengaged from the mast. The left mast fractured above the lower panel. The vertical mast on the right side was deformed. All three of the barricade panels encountered 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 barricade.

System No. 2 encountered moderate damage. The leg closest to the vehicle disengaged and fractured at the vertical upright portion of the leg. The mast closest to the vehicle was bent to an approximate angle of 60 degrees and at a location below the bottom panel. All three of the barricade panels buckled from the side closest to the vehicle to the side furthest from the vehicle. All components of the barricade encountered scuff and scrape marks. Two of the sandbags were torn open with the sand scattered along the path of the vehicle to approximately 7.62-m downstream from the initial position of the second barricade. The other two sandbags remained undamaged.

5.4 Vehicle Damage

Exterior vehicle damage is shown in Figures 26 and 27. The front bumper and lower plastic shield encountered dents, contact and scuff marks, and tears at each of the quarter points. Both sides of the bumper disengaged from the bumper clips. Contact marks and scrape marks were also found on the hood and both front fenders. A 51-mm long hole was found on the hood near the center of the left-quarter point. The right-front fender was dented near the door area. The plastic shield around left-front headlight was deformed and disengaged from the front of the vehicle. The left-front fog light was broken. A 102-mm long scrape was located along the right-side door frame. The right-side door encountered a major scrape near the front-right fender. The right windshield wiper blade was partially ripped off of the wiper arm. The right-side windshield sustained minor cracking near the right-outside edge. However, the degree of cracking was judged insufficient to hinder visibility nor cause weak spots in both layers of glass. No damage was found to have occurred to the parking lights, headlights, nor right-side fog light. There were no interior occupant compartment deformations to the vehicle.

5.5 Discussion

Following test MNB-1, a safety performance evaluation was conducted, and the work-zone traffic control devices, System Nos. 1 and 2, were determined to be acceptable according to the NCHRP Report No. 350 criteria. Detached elements and debris from the traffic control systems did not penetrate or show potential for penetrating the occupant compartment. Deformations of, or intrusion into, the occupant compartment did not occur. The minor cracking occurring at the center-right side of the windshield was judged to not obstruct the driver's visibility. The vehicle's trajectory did not intrude into adjacent traffic lanes.

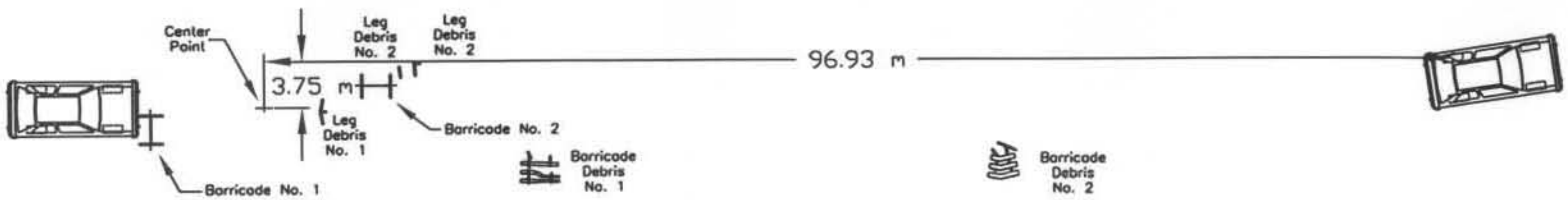
0.000 sec

0.030 sec

0.059 sec

0.083 sec

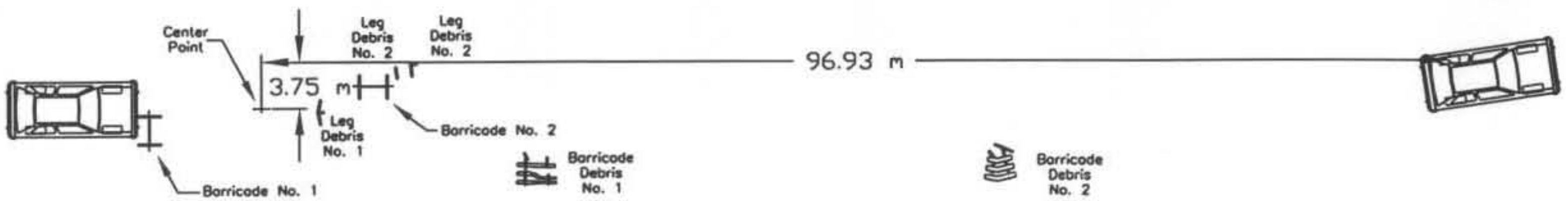
0.148 sec



- Test Number MNB-1
- System Number 1
- Date 4/18/00
- Test Article
  - Type . . . . Traffic Control Device – Type III Barricade
  - Stand Name . . . . Aluminum Type III Barricade
  - Sign Panel Name . . . . None
  - Key Elements
    - Size and/or dimension . 1.6 m high
    - Material . . . . Telespar ASTM A-653 C
  - Orientation . . . . Head-on with right quarter point
- Soil Type . . . . On dry pavement
- Vehicle Model . . . . 1994 Geo Metro
  - Curb . . . . 803 kg
  - Test Inertial . . . . 818 kg
  - Gross Static . . . . 893 kg
- Vehicle Speed
  - Impact . . . . 105.1 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 windshield cracking
  - TAD[21] 12-FR-1
  - SAE[22] 12-FRAN1
- Vehicle Stopping Distance . . . . 96.93 m downstream 3.75 m left
- Test Article Damage . . . . Moderate – Broke apart

Figure 16. Summary of Test Results and Sequential Photographs, Test MNB-1, Impact No. 1

0.000 sec | 0.014 sec | 0.024 sec | 0.028 sec | 0.042 sec



- Test Number MNB-1
- System Number 2
- Date 4/18/00
- Test Article
  - Type .... Traffic Control Device – Type III Barricade
  - Stand Name .... Aluminum Type III Barricade
  - Sign Panel Name .... None
  - Key Elements
    - Size and/or dimension . 1.6 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 .... 803 kg
  - Test Inertial .... 818 kg
  - Gross Static .... 893 kg
- Vehicle Speed
  - Impact .... 99.3 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[21] 12-FL-1
  - SAE[22] 12-FLAN1
- Vehicle Stopping Distance .... 96.93 m downstream 3.75 m left
- Test Article Damage .... Moderate – Broke apart

Figure 17. Summary of Test Results and Sequential Photographs, Test MNB-1, Impact No. 2

Figure 18. Documentary Photographs, Test MNB-1

Figure 19. Documentary Photographs, Test MNB-1

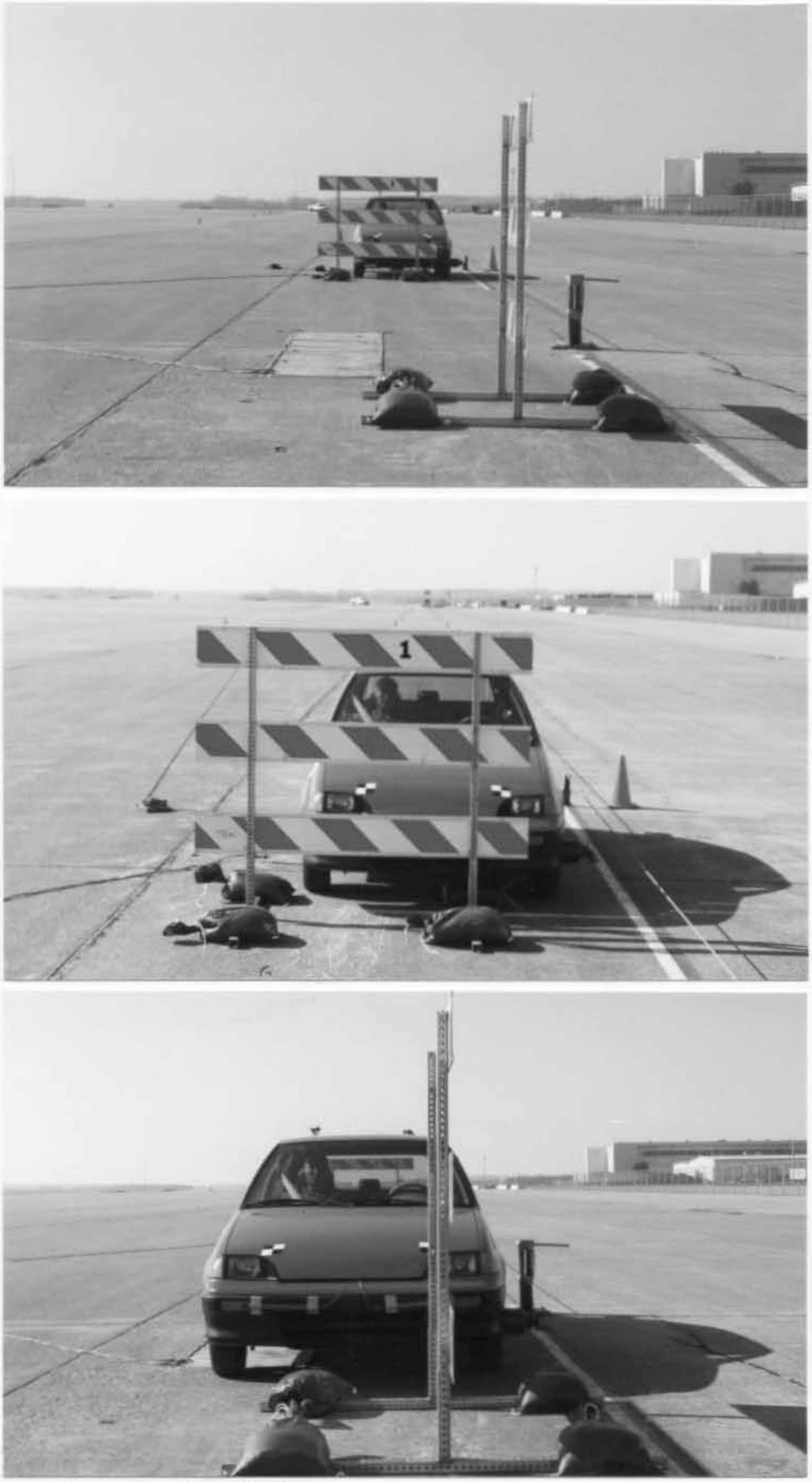


Figure 20. Impact Location, Test MNB-1

Figure 21. Overall Damage and Final Positions, Test MNB-1

Figure 22. System No. 1 Damage, Test MNB-1

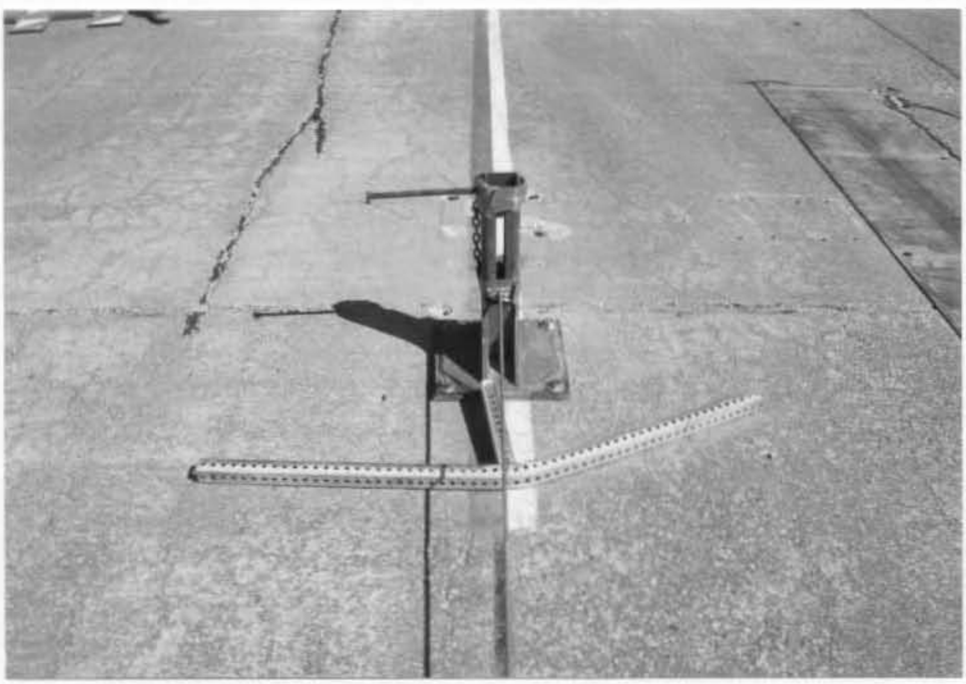


Figure 23. System No. 1 Damage, Test MNB-1

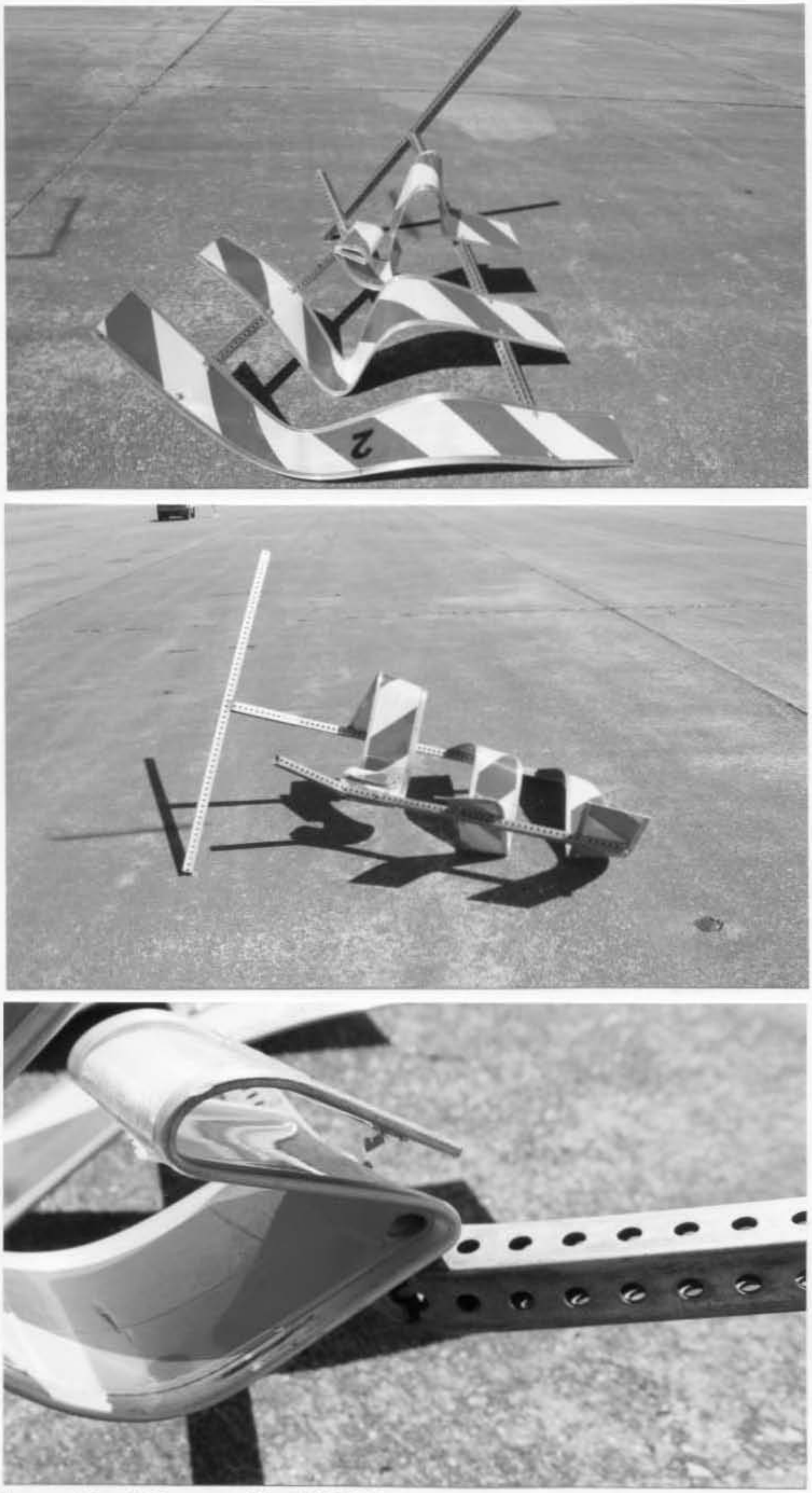


Figure 24. System No. 2 Damage, Test MNB-1

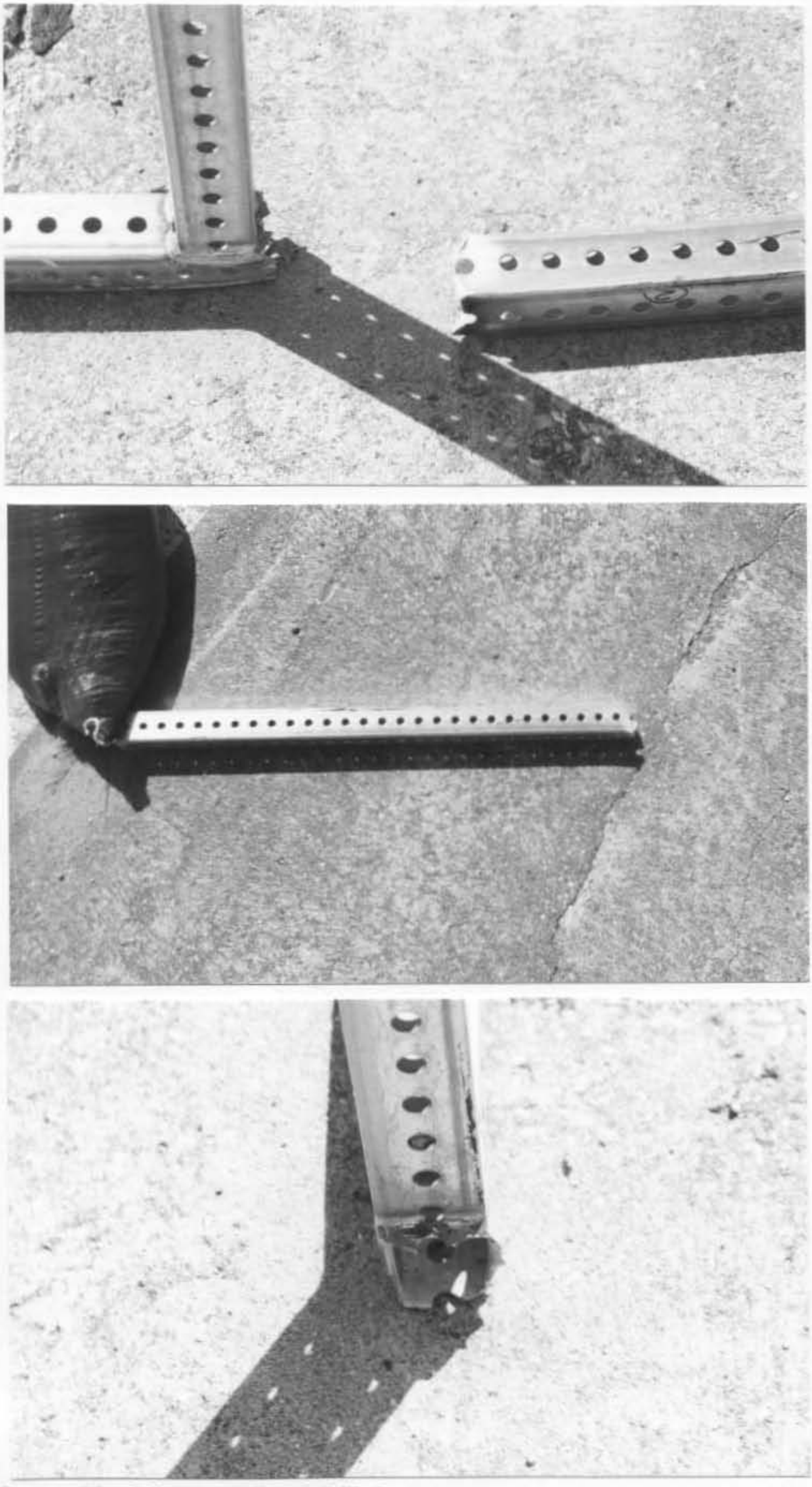


Figure 25. System No. 2 Damage, Test MNB-1

Figure 26. Vehicle Damage, Test MNB-1

Figure 27. Windshield Damage, Test MNB-1

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

6.1 Test MNB-2

The 883-kg small car impacted System No. 3, an aluminum type III barricade oriented head-on to the vehicle, at a speed of 105.9 km/hr and an angle of 0 degrees. The small car then impacted System No. 4, an aluminum type III barricade oriented end-on to the vehicle, at a speed of 97.4 km/hr and an angle of 90 degrees. A summary of the test results and the sequential photographs are shown in Figures 28 and 29. Documentary photographs of the crash tests are shown in Figures 30 through 31.

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 barricade, as shown in Figure 32. At 0.012 sec after initial impact, the contact point on the left mast deformed around the front of the vehicle. At 0.022 sec, the system wrapped around the right side of the vehicle as the top of the system rotated CCW toward the vehicle. At 0.048 sec, the left leg was airborne as the top of the system and sign panel continued to rotate CCW toward the vehicle. At 0.077 sec, the sign panel contacted the right windshield frame of the vehicle. At 0.097 sec, the barricade system continued to rotate CCW toward the vehicle. At 0.123 sec, the leg of the left mast disengaged from the rest of the barricade system. At this same time, the system continued to wrap around the right-front corner of the vehicle. At 0.160 sec, the barricade system slid along the windshield and roof. At this same time, the disengaged left leg was airborne in front of the vehicle. At 0.253 sec, the barricade system was airborne above the center of the vehicle with only the sign panel still in contact with the vehicle. At 0.412 sec, the barricade system was approximately perpendicular to the vehicle's roof. The disengaged leg was located

78.33-m downstream and 15.42-m right from the original position. The remainder of the barricade system came to rest 42.37-m downstream and 1.35-m right of the initial position. Loose sand from the sandbags was scattered in a pattern bounded by 0.0-m upstream, 18.29-m downstream, 1.70-m left, and 4.39-m right from the original position of the barricade.

Approximately 0.65 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 barricade, as shown in Figure 32. At 0.012 sec after initial impact, the outside edge of the barricade's bottom panel crushed toward the mast closest to the vehicle. At 0.018 sec, the front of the vehicle impacted the mast closest to the vehicle. At 0.022 sec, the impacted mast deformed about the front of the vehicle and the hood became slightly ajar. At 0.032 sec, the barricade system rotated CCW toward the vehicle as the impacted mast slid toward the non-impacted mast, thus deforming the barricade panels. At 0.048 sec, the mast deformed to approximately a 90 degree angle and at a location below the bottom panel. At this same time, the barricade panels continued to deform. At 0.075 sec, the impacted mast contacted the other mast. At this same time, the sign panel deformed, and the top of the barricade system continued to rotate CCW toward the vehicle. At 0.085 sec, the end of the top panel impacted the windshield as the mast laid across the hood. At 0.214 sec, the sign panel impacted the seam between the windshield and roof as the rest of the system rotated into the air. At 0.293 sec, the barricade system rebounded off of the vehicle and was airborne above the vehicle. The disengaged leg was located 1.83-m downstream and 0.30-m right from the original position. The remainder of the barricade system came to rest 71.63-m downstream and 3.35-m left of the initial position. Loose sand from the sandbags was scattered in a pattern bounded by 0.0-m upstream, 15.24-m downstream, 1.68-m left, and 2.13-m right from the original position of the barricade. The vehicle subsequently came to rest 92.05-m downstream from the longitudinal midpoint of the two impact points and 10.76-m left from the centerline of the vehicle's original path. The final positions of the vehicle and the sign support are shown in Figures 28, 29, and 33.

6.3 System and Component Damage

Damage to System Nos. 3 and 4 is shown in Figures 33 through 36. System No. 3 encountered moderate damage. The left-side leg was slightly deformed and disengaged from the mast. The left-side mast fractured above the bottom panel. The vertical mast on both sides deformed with the one on the left encountering more severe deformations. All three of the barricade panels as well as the sign panel encountered deformations and scuff and scrape marks. The sandbags were torn open with the sand scattered along the path of the vehicle.

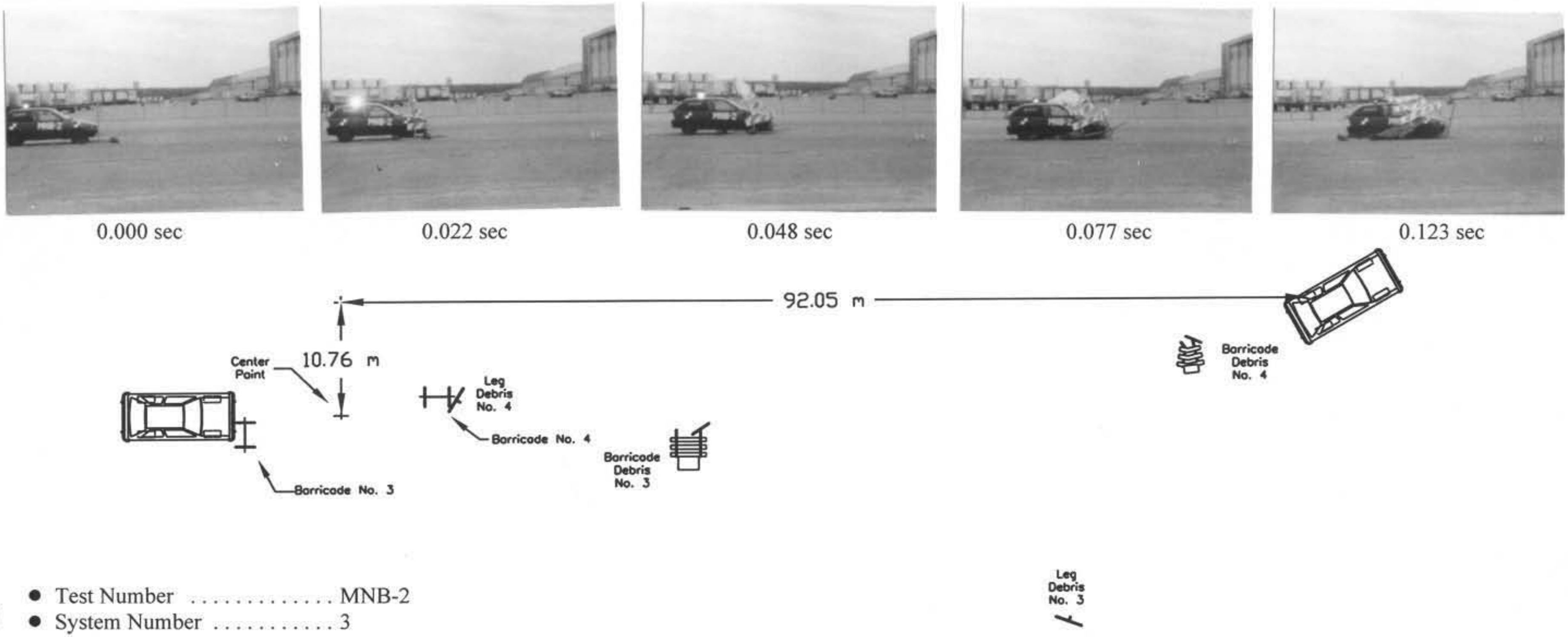
System No. 4 encountered moderate damage. The leg closest to the vehicle disengaged and was slightly deformed. The mast closest to the vehicle was bent to an approximate angle of 45 degrees and at a location below the bottom panel. The mast on the non-impact side was also deformed. All three of the barricade panels buckled from the side closest to the vehicle to the side furthest from the vehicle. The sign panel was also deformed. Three of the sandbags were torn open with the sand scattered along the path of the vehicle. The other sandbag remained undamaged.

6.4 Vehicle Damage

Exterior vehicle damage is shown in Figures 37 and 38. The left side of the front bumper and lower plastic shield disengaged from the bumper clips. The center of the hood encountered a major dent. A 279-mm long cut was located along the left-side quarter-point of the hood. Scuff and scape marks were found on the hood, the bumper, the top of both front fenders, the right side of the roof, and the lower-center region of the right-side door. A tear was found in the right-front fender near the parking light. The right-side parking light and the left-side fog light were broken. The windshield on the right side sustained minor starring and cracking near the top-left, top-right, and lower-center regions of the windshield. The windshield on the left side sustained "spider web" cracking and slight cracking of both layers of glass. However, the degree of cracking was judged insufficient to hinder visibility nor cause weak spots in both layers of glass. The headlights, right fog light, and left parking light were undamaged. There were no interior occupant compartment deformations to the vehicle.

6.5 Discussion

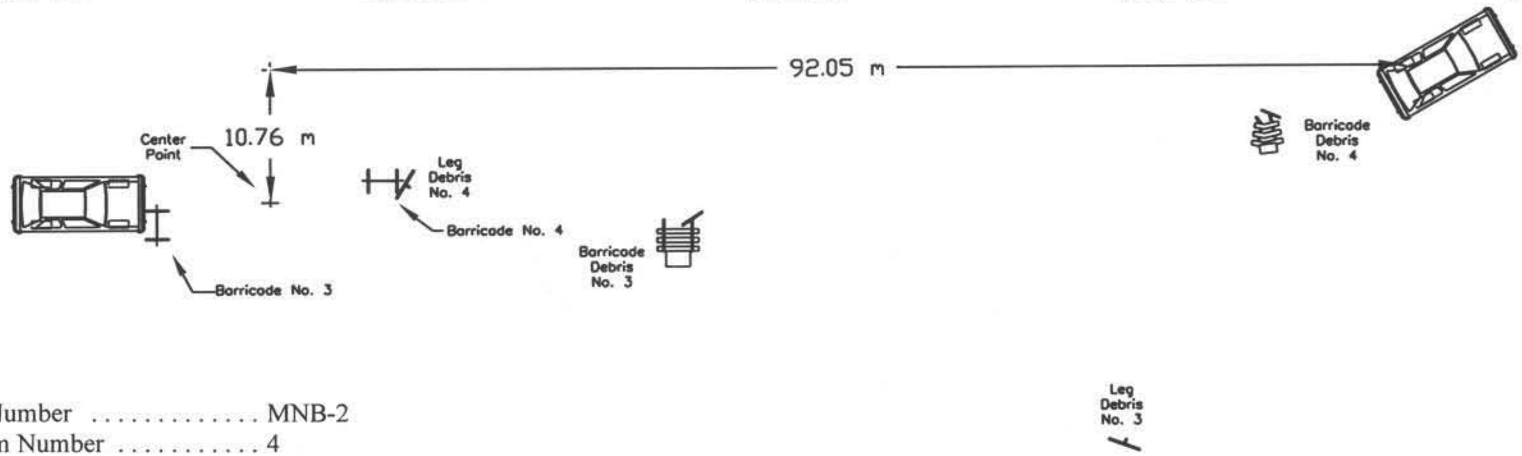
Following test MNB-2, a safety performance evaluation was conducted, and the work-zone traffic control devices, System Nos. 3 and 4, were determined to be acceptable according to the NCHRP Report No. 350 criteria. Detached elements and debris from the traffic control systems did not penetrate or show potential for penetrating the occupant compartment. Deformations of the occupant compartment did occur as the center-right region of the windshield was indented slightly into the occupant compartment, but was determined to be acceptable. Intrusions into the occupant compartment did not occur. The cracking occurring at the center-left and upper-right side of the windshield was judged to not obstruct the driver's visibility, and the structure of both glass layers was not lost. The vehicle's trajectory did not intrude into adjacent traffic lanes.



- Test Number MNB-2
- System Number 3
- Date 4/18/00
- Test Article
  - Type .... Traffic Control Device – Type III Barricade with Sign Panel
  - Stand Name .... Aluminum Type III Barricade
  - Sign Panel Name .... Rigid Aluminum, 765 mm x 1219 mm
  - Key Elements
    - Size and/or dimension . 2.2 m high
    - Material .... Telespar ASTM A-653 Grade 50 Steel Tubing
  - Orientation .... Head-on with right quarter point
- Soil Type .... On dry pavement
- Vehicle Model .... 1994 Geo Metro
  - Curb .... 739 kg
  - Test Inertial .... 808 kg
  - Gross Static .... 883 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 .... Minimal windshield cracking
  - TAD[21] 12-FR-1
  - SAE[22] 12-FRAN1
- Vehicle Stopping Distance .... 92.05 m downstream
  10.76 m left
- Test Article Damage .... Moderate – Broke apart

Figure 28. Summary of Test Results and Sequential Photographs, Test MNB-2, Impact No. 1

0.000 sec 0.020 sec 0.046 sec 0.067 sec 0.119 sec



- Test Number MNB-2
- System Number 4
- Date 4/18/00
- Test Article
  - Type .... Traffic Control Device – Type III Barricade with Sign Panel
  - Stand Name .... Aluminum Type III Barricade
  - Sign Panel Name .... Rigid Aluminum, 762 mm x 1226 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 .... 739 kg
  - Test Inertial .... 808 kg
  - Gross Static .... 883 kg
- Vehicle Speed
  - Impact .... 97.4 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 .... Moderate windshield cracking and slight indentation
  - TAD[21] 12-FL-1
  - SAE[22] 12-FLAN1
- Vehicle Stopping Distance .... 92.05 m downstream 10.76 m left
- Test Article Damage .... Moderate – Broke apart

Figure 29. Summary of Test Results and Sequential Photographs, Test MNB-2, Impact No. 2

Figure 30. Documentary Photographs, Test MNB-2

Figure 31. Documentary Photographs, Test MNB-2

Figure 32. Impact Locations, Test MNB-2

Figure 33. Overall Damage and Final Positions, Test MNB-2

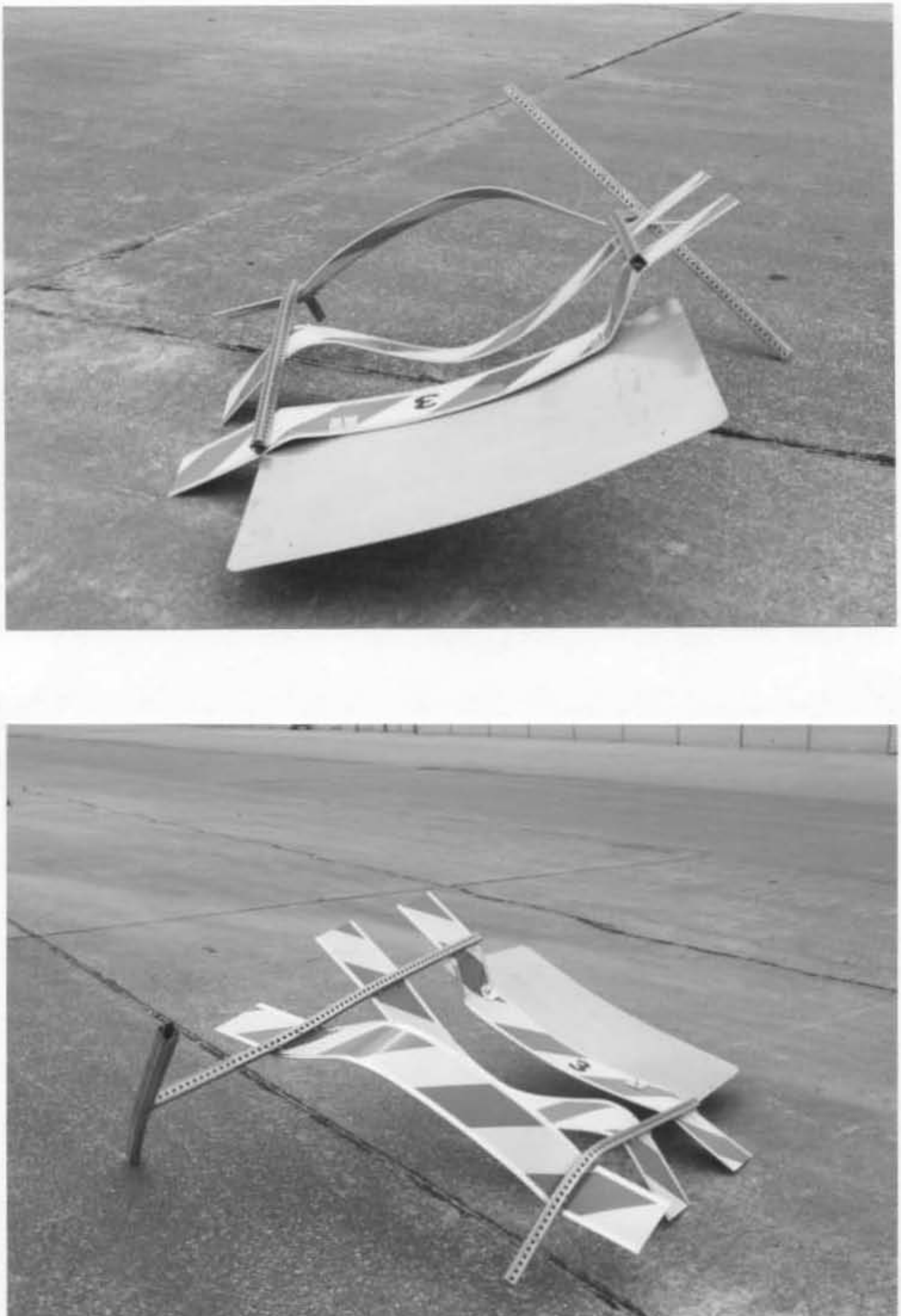


Figure 34. System No. 3 Damage, Test MNB-2

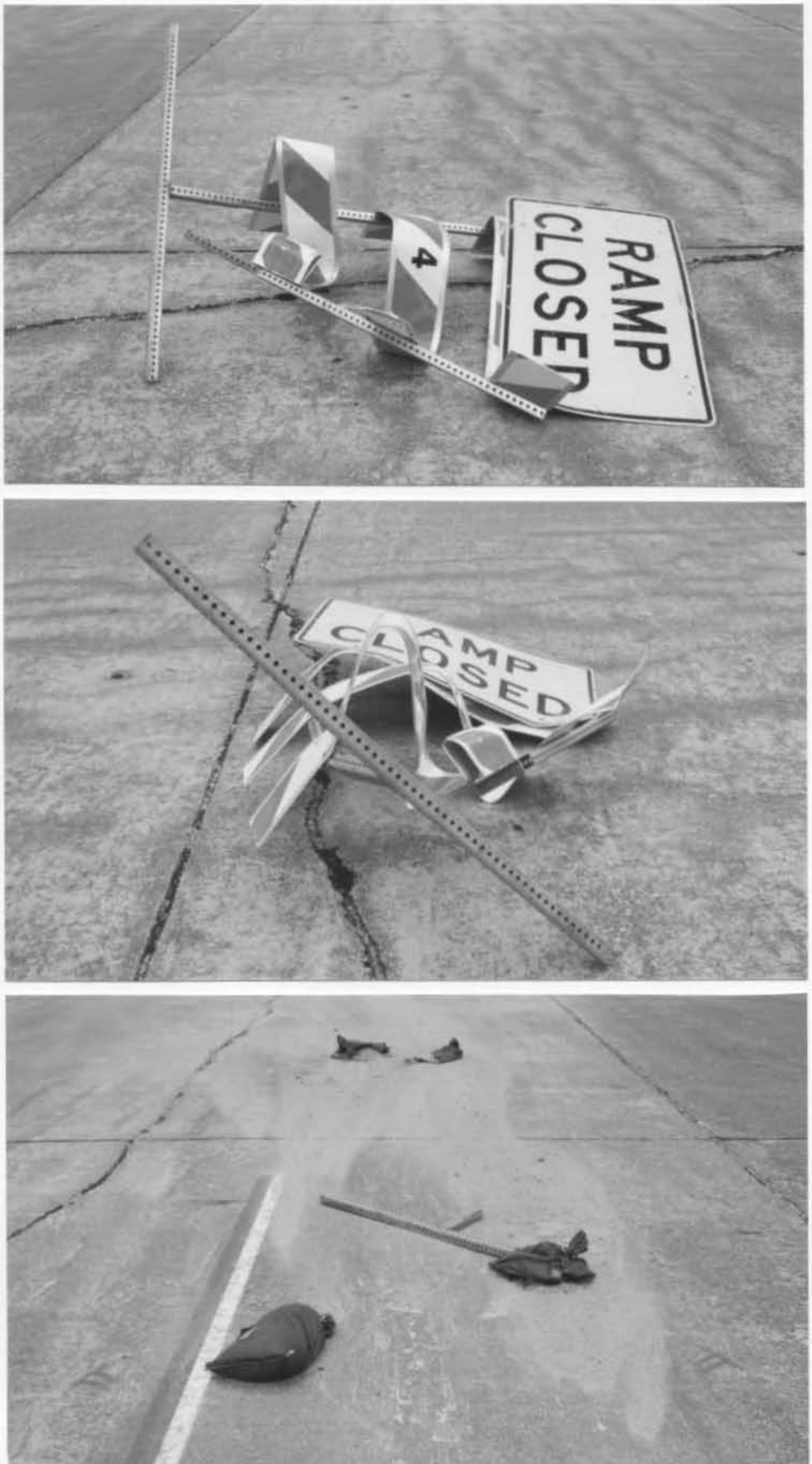


Figure 35. System No. 4 Damage, Test MNB-2

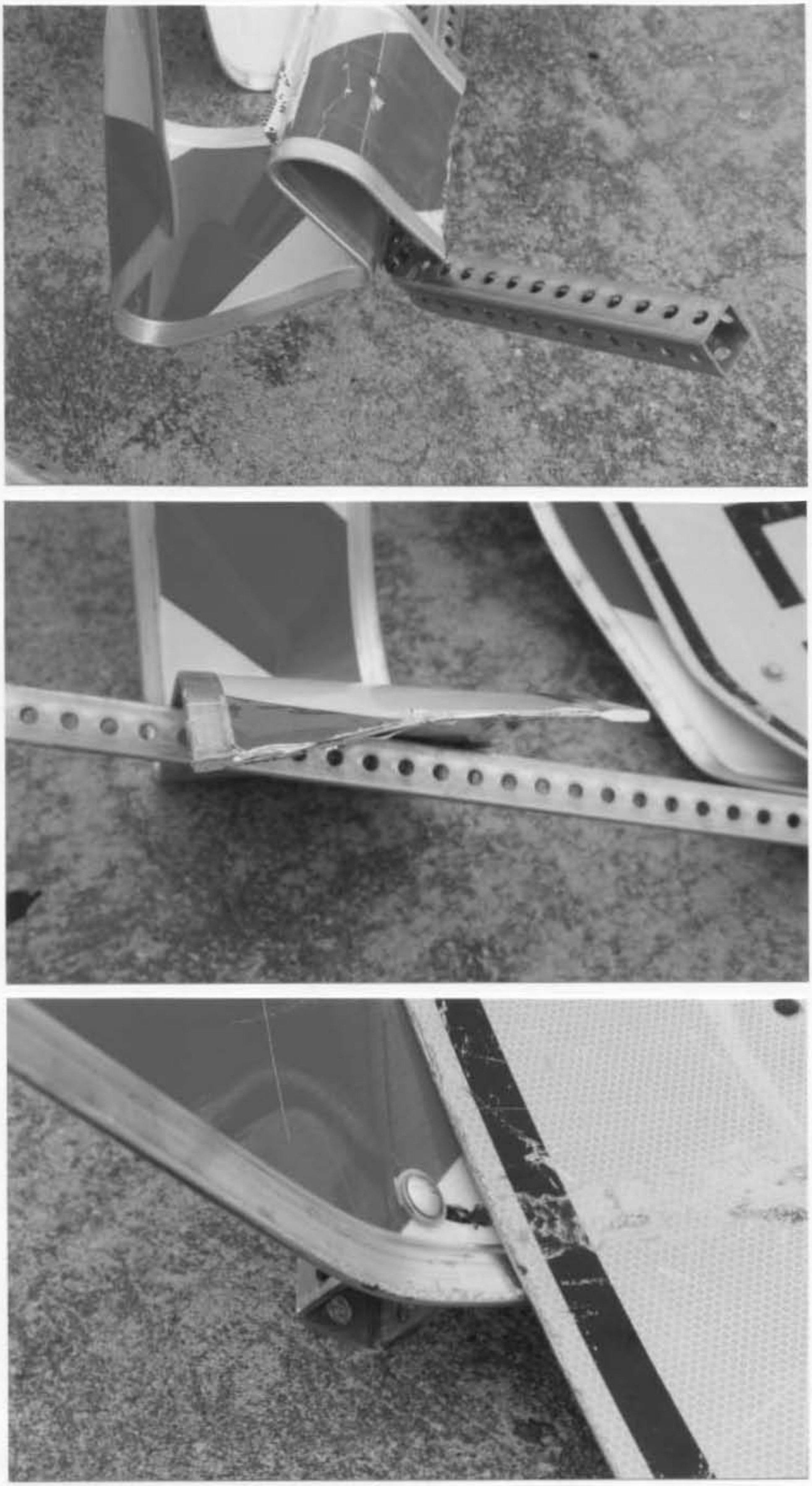


Figure 36. System No. 4 Damage, Test MNB-2

Figure 37. Vehicle Damage, Test MNB-2

Figure 38. Windshield Damage, Test MNB-2

7 DISCUSSION

Following the analysis of the crash test results of tests MNB-1 and MNB-2, some general observations were made with respect to the following: (1) the vertical position, failure type, and release time of a barricade's fracture point, breakaway mechanism, or yielding hinge; (2) the stiffness and material of the vertical masts; (3) the vertical mounting height of the sign panel; and (4) the material of the barricade 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 barricade panels and masts. This relatively quick release of the masts from the feet of the barricade allows the barricade panels and masts to fall upon the vehicle with little additional force than what was developed through the impact (i.e., Test MNB-1, System Nos. 1 and 2 and Test MNB-2, System Nos. 3 and 4). On the other hand, when the mast bends, the barricade 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 barricade 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 barricade panels will impact the windshield when the masts bend or have a delayed fracture, resulting in a slow release time. The hood and/or windshield are likely to be impacted by the sign panel when the masts bend and do not release from the barricade legs until much later (i.e., Test MNB-1, System Nos. 1 and 2 and Test MNB-2, System Nos. 3 and 4).

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 barricade system. A lower mounting height can potentially cause significant interaction with the vehicle (e.g., Test MNB-2, System No. 3). Even in an end-on orientation, a low mounting height has the potential to accentuate this phenomenon (e.g., Test MNB-2, System No. 4).

The barricade panels were fabricated from aluminum material with a "dog-bone" end shape. The aluminum material with the "dog-bone" shape produced semi-rigid panels that allowed for energy absorption when impacted (i.e., Test MNB-1, System Nos. 1 and 2 and Test MNB-2, System Nos. 3 and 4). For the end-on orientation, the aluminum "dog-bone" panels buckled and absorbed some of the impact energy, thereby reducing the amount of impact force encountered by the vehicle (i.e., Test MNB-1, System No. 2 and Test MNB-2, System No. 4).

Finally, following an analysis of the test results, it was evident that the debris from the type III barricades 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 barricades is somewhat subjective in nature. Depending on the specific site conditions at which these devices are being used, the barricade debris was determined to be less of a hazard to adjacent traffic and work-zone crews than the moving vehicle itself.

8 SUMMARY AND CONCLUSIONS

A total of four crash tests were conducted on the aluminum type III barricade devices. All four of the 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 MNB-1		Test MNB-2	
		#1	#2	#3	#4
		AB[1]	AB[1]	ABS[1]	ABS[1]
Structural Adequacy	B	S	S	S	S
Occupant Risk	D	S	S	S	S
	E	S	S	S	S
	F	S	S	S	S
	H	NA	NA	NA	NA
	I	NA	NA	NA	NA
Vehicle Trajectory	K	S	S	S	S
	N	S	S	S	S
NCHRP Report No. 350 Test Level		TL-3	TL-3	TL-3	TL-3
Method of Failure[2]		NA	NA	NA	NA
Pass/Fail		Pass	Pass	Pass	Pass

[1] Hardware Type: AB – Aluminum Barricade
ABS – Aluminum Barricade with Sign Panel

[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

9 RECOMMENDATIONS

Both work-zone traffic control devices satisfactorily met the evaluation criteria set forth in NCHRP Report No. 350 and are recommended for field implementation. These work-zone traffic control device include:

- Test No. MNB-1, System Nos. 1 and 2 – Minnesota's aluminum type III barricade oriented head-on and end-on, respectively.
- Test No. MNB-2, System Nos. 3 and 4 – Minnesota's aluminum type III barricade with an aluminum, 1219-mm wide x 762-mm tall, sign panel 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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11 APPENDICES

APPENDIX A

Dimensional Measurements of Barricade Systems

Table A-1. Barricade System Dimensional Measurements

System Number	Test Number	STAND		SIGN		
		Type [1]	Weight (kg)	Type [2]	Material [3]	Weight (kg)
1	MNB-1	Aluminum Type III Barricade	28.123	----	----	----
2	MNB-1	Aluminum Type III Barricade	28.123	----	----	----
3	MNB-2	Aluminum Type III Barricade	28.123	Rigid	6	6.350
4	MNB-2	Aluminum Type III Barricade	28.123	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. Barricade System Dimensional Measurements

System Number	HEIGHTS TO					
	Bottom of Bottom Small Panel (mm)	Bottom of Middle Small Panel (mm)	Bottom of Top Small Panel (mm)	Top of Top Small Panel (mm)	Bottom of Sign Panel (mm)	Top of Sign Panel (mm)
1	349	857	1365	1594	----	----
2	349	856	1362	1591	----	----
3	349	856	1365	1595	1449	2210
4	349	856	1364	1592	1410	2169

Table A-3. Barricade System Dimensional Measurements

Stand Type	LEGS				
	Horizontal Portion				
	Material	Dimension #1 (mm)	Dimension #2 (mm)	Thickness (mm)	Length (mm)
Aluminum Type III Barricade	Telespar ASTM A-653 Grade 50 Steel	44.67	44.45	1.93	1528
Aluminum Type III Barricade	Telespar ASTM A-653 Grade 50 Steel	44.56	44.47	1.92	1524
Aluminum Type III Barricade	Telespar ASTM A-653 Grade 50 Steel	44.60	44.50	1.93	1528
Aluminum Type III Barricade	Telespar ASTM A-653 Grade 50 Steel	44.64	44.43	1.92	1528

Table A-4. Barricade System Dimensional Measurements

Stand Type	LEGS				
	Vertical Portion				
	Material	Dimension #1 (mm)	Dimension #2 (mm)	Thickness (mm)	Length (mm)
Aluminum Type III Barricade	Telespar ASTM A-653 Grade 50 Steel	44.36	44.28	1.94	305
Aluminum Type III Barricade	Telespar ASTM A-653 Grade 50 Steel	44.48	44.33	1.94	305
Aluminum Type III Barricade	Telespar ASTM A-653 Grade 50 Steel	44.30	44.27	1.92	306
Aluminum Type III Barricade	Telespar ASTM A-653 Grade 50 Steel	44.41	44.30	1.93	306

Table A-5. Barricade 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 Type III Barricade	2	Telespar ASTM A-653 Grade 50 Steel	38.13	38.05	3.07	1524	1257
Aluminum Type III Barricade	2	Telespar ASTM A-653 Grade 50 Steel	38.21	38.05	3.02	1524	1257
Aluminum Type III Barricade	2	Telespar ASTM A-653 Grade 50 Steel	38.17	38.07	3.05	1528	1254
Aluminum Type III Barricade	2	Telespar ASTM A-653 Grade 50 Steel	38.11	38.1	3.01	1528	1259

Table A-6. Barricade 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 Type III Barricade	11.35	25.31	3	Aluminum	1829	230	6.02	3.27
Aluminum Type III Barricade	11.25	25.20	3	Aluminum	1829	229	6.10	3.32
Aluminum Type III Barricade	11.34	25.24	3	Aluminum	1829	229	6.03	3.20
Aluminum Type III Barricade	11.30	25.24	3	Aluminum	1829	229	6.12	3.25

Table A-7. Barricade 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 Type III Barricade	Aluminum	1829	229	6.00	3.33	Aluminum	1829	229	6.14	3.20
Aluminum Type III Barricade	Aluminum	1829	227	6.10	3.24	Aluminum	1829	229	6.10	3.23
Aluminum Type III Barricade	Aluminum	1829	230	6.09	3.27	Aluminum	1829	230	6.03	3.31
Aluminum Type III Barricade	Aluminum	1829	229	6.12	3.20	Aluminum	1829	229	6.11	3.28

Table A-8. Barricade System Dimensional Measurements

Sign Type	SIGN PANEL			
	Material	Thickness (mm)	Length (mm)	Width (mm)
----	----	----	----	----
----	----	----	----	----
Rigid	Aluminum	2.70	765	1219
Rigid	Aluminum	2.68	762	1226

APPENDIX B

Barricade's Small Panel Blade Details

Figure B-1. Barricade's Small Panel Blade Details

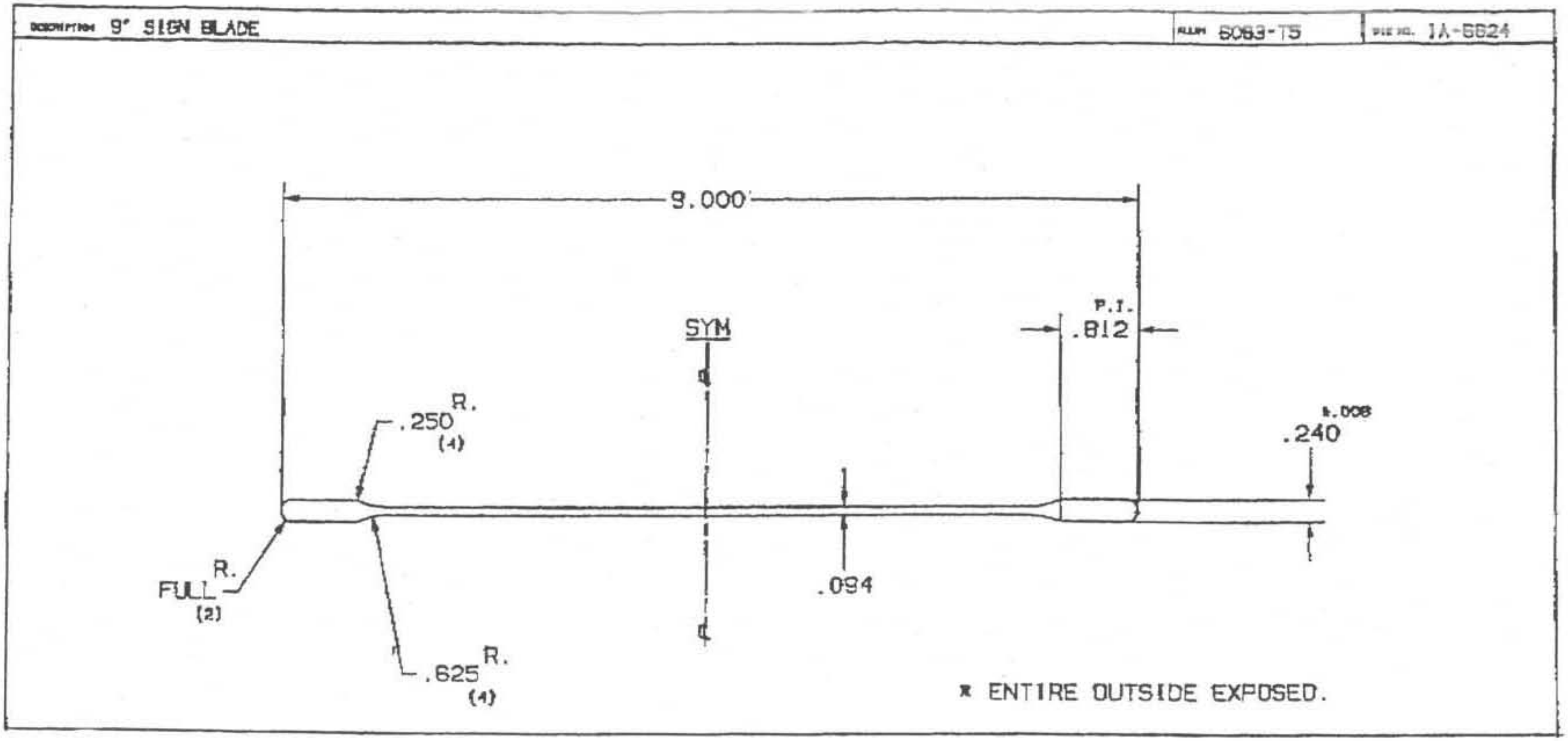

Figure B-1. Barricade's Small Panel Blade Details