SAFETY PERFORMANCE EVALUATION OF MICHIGAN'S 4X5 PORTABLE SIGN SUPPORT

Submitted by

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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 Michigan's existing work-zone traffic control device through full-scale crash testing. A total of two full-scale crash tests were conducted on one 4-ft by 5-ft portable tall-mounted, rigid rectangular-shaped plywood panel sign support to determine its safety performance according to the Test Level 3 (TL-3) criteria set forth in the NCHRP Report No. 350. Neither of impacts on the tall-mounted, rigid panel sign supports 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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DISCLAIMER STATEMENT

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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 (8-25). 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 Michigan's existing 1.2-m by 1.5-m portable sign support through full-scale crash testing. The safety performance evaluation was 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, two full-scale vehicle crash tests were performed on one work-zone traffic control device. The two crash tests were completed in one run with a right-side quarter-point and a centerline impact, resulting in a total of two 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 90 and 0 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 work-zone traffic control device.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Work-zone traffic control devices, such as portable mounted traffic control signs, 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* (26), 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 and endorsed by the FHWA as described in "Questions and Answers about Crash Testing of Work-Zone Safety Appurtenances" 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 (27).

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
6	Roof deformations greater than 127 mm

3 WORK-ZONE TRAFFIC CONTROL DEVICES

3.1 General Descriptions

One work-zone traffic control device was crash tested in two orientations under this study, as described below. The traffic control devices were supplied by the sponsor.

The tall-mounted, rigid panel sign support system tested was a 1,219-mm wide x 1,829-mm deep x 3,048-mm tall steel sign support with a 1,219-mm wide x 1,524-mm long x 17.3-mm thick plywood rectangular-shaped sign panel with reflective material mounted at a height of 1,524 mm from the ground to the bottom of the sign panel and with 31.75 kg of sandbags at the end of each leg. The two crash tests are summarized in Table 3.

3.2 Tall-Mounted, Rigid Panel Sign Supports

The details of the tall-mounted, rigid panel sign support systems are shown in Figures 1 through 3. The dimensional measurements of the tall-mounted, rigid panel sign support systems are found in Appendix A. Additional system details are found in Appendix B.

Table 3. List of Crash Tests Conducted

WORK-ZONE TRAFFIC CONTROL DEVICES

TALL-MOUNTED, RIGID PANEL SIGN SUPPORT

Test MI-4	System No. 7	Steel Sign Support with a Rectangular-Shaped Wood Panel, Sandbags on Each Leg, End-on Impact (90 degrees)
Test MI-4	System No. 8	Steel Sign Support with a Rectangular-Shaped Wood Panel, Sandbags on Each Leg, Head-on Impact (0 degrees)

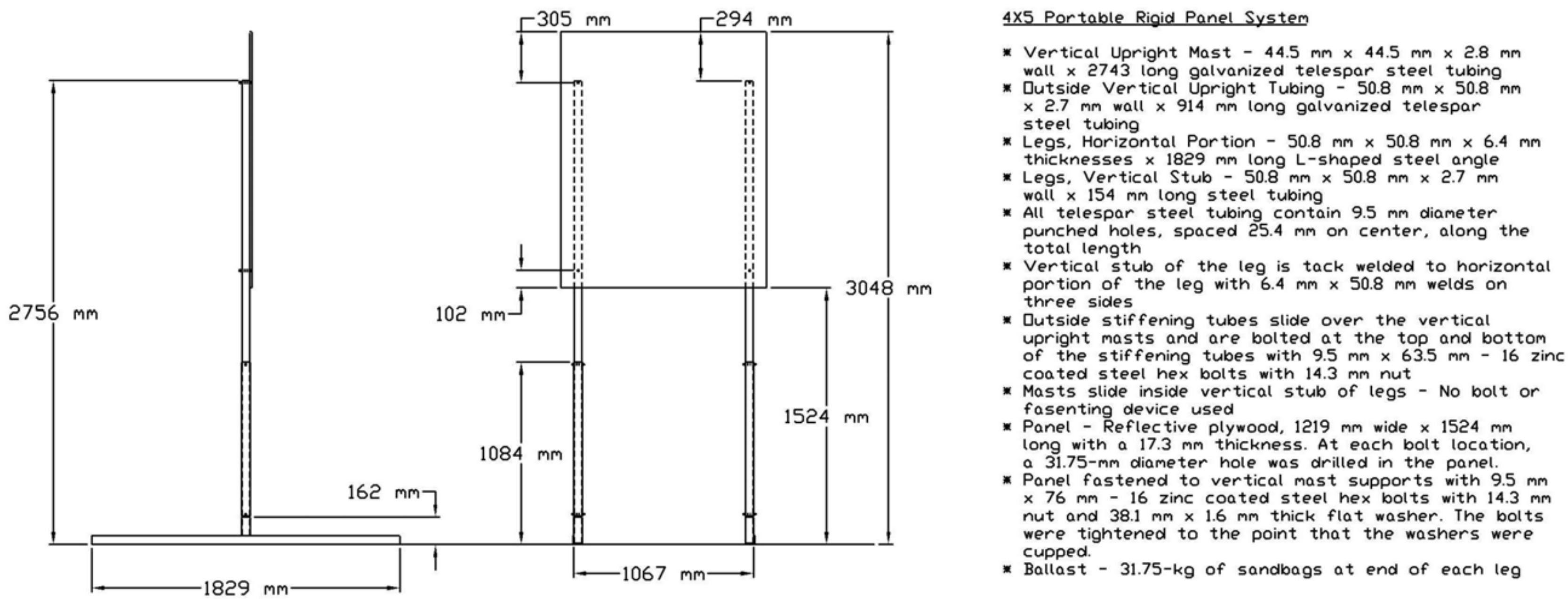


Figure 1. System Nos. 7 and 8 Sign Support Details, Test MI-4

Figure 2. System Nos. 7 and 8 Signs, Test MI-4

Figure 3. System Nos. 7 and 8 Signs, Test MI-4

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 (28) 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 15.6 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 305-m long.

4.3 Test Vehicles

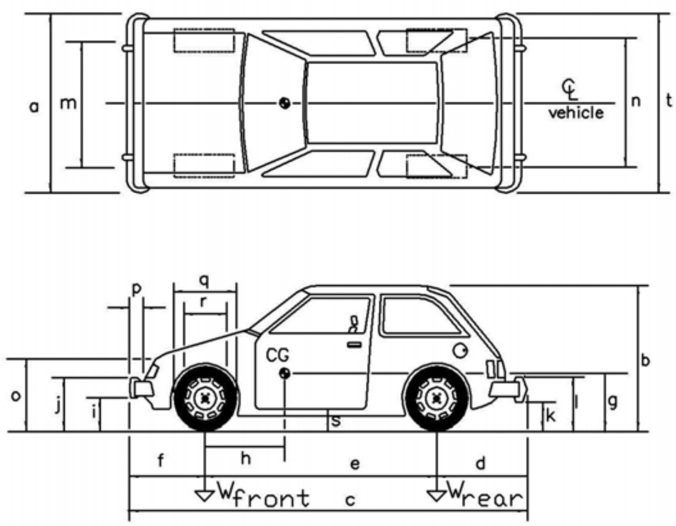
For test MI-4, a 1996 Geo Metro was used as the test vehicle. The test inertial and gross static weights were 818 kg and 893 kg, respectively. The test vehicle is shown in Figure 4, and vehicle dimensions are shown in Figure 5.

Figure 4. Test Vehicle, Test MI-4

Dates: 4/9/03 Test Numbers: MI-4 Model: Metro 2-dr.

Make: GEO Vehicle I.D.#: 2C1MR2299T6722090

Tire Size: P155/80R13 Year: 1996 Odometer: 94,617



Vehicle Geometry - mm

a	1556	b	1422
c	3785	d	686
e	2350	f	749
g	546	h	867
i	292	j	546
k	292	l	660
m	1387	n	1349
o	597	p	102
q	565	r	362
s	330	t	1549

height of wheel center 267

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}	503	509	545
W_{rear}	308	308	348
W_{total}	811	817	893

Damage prior to test: None

Figure 5. Vehicle Dimensions, Test MI-4

The longitudinal component of the center of gravity was determined using the measured axle weights. The location of the final center of gravity are shown in Figure 5.

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 Figure 6. One target was placed directly above each of the wheels on the passenger side 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 test MI-4, three high-speed 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 29.97 frames/sec, were also used to film the crash test. A high-speed E/cam 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 high-speed E/cam 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 high-speed E/cam

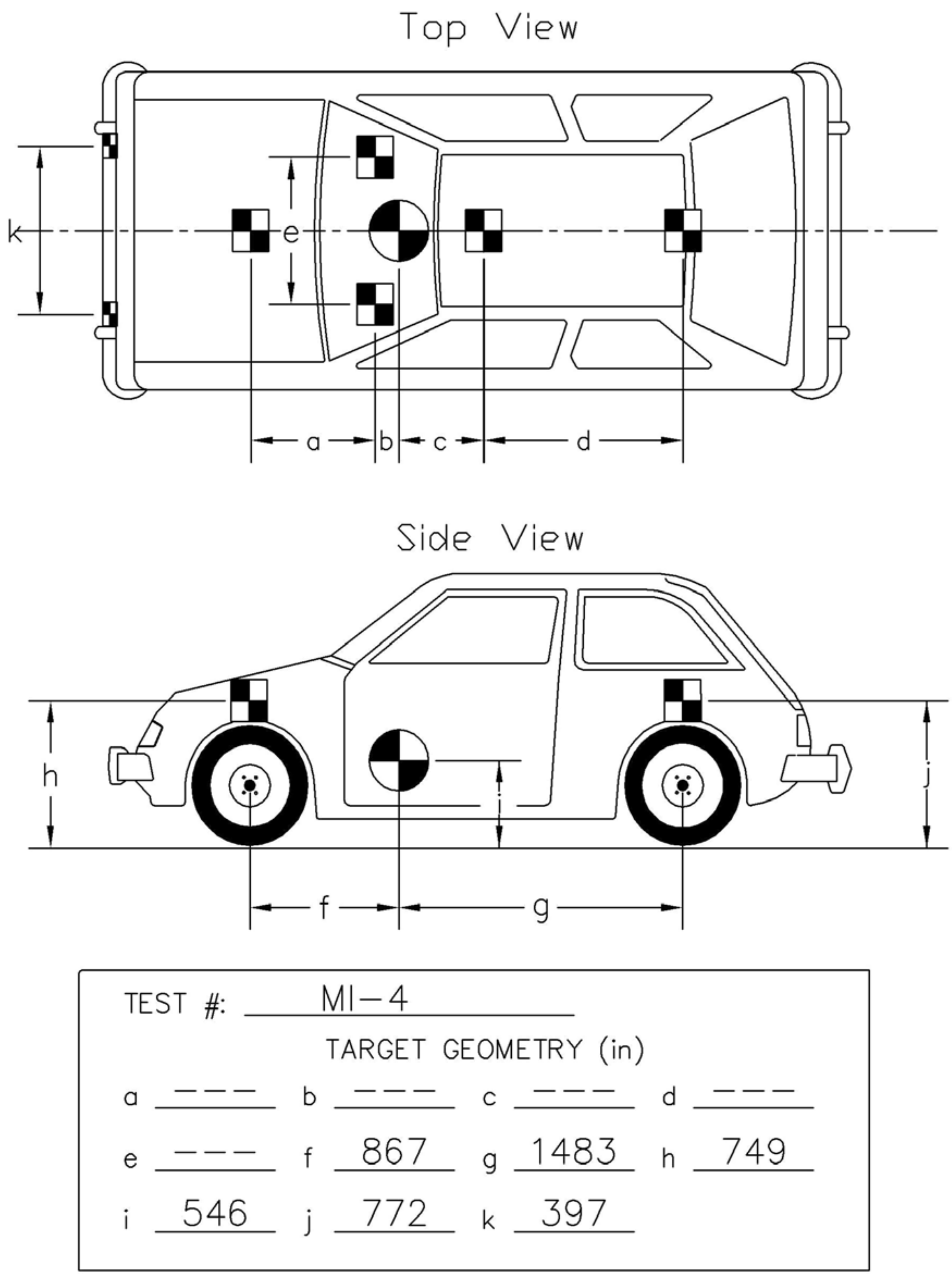


Figure 6. Vehicle Target Locations, Test MI-4

video camera and a Canon digital video camera were placed downstream and offset to the right from the second impact point and had an angled view of both impacts. A schematic of all six camera locations for test MI-4 is shown in Figure 7. The film was analyzed using the Redlake Motion Scope software. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed and digital video.

4.4.2 Pressure Tape Switches

For test MI-4, 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 vehicle’s front tire passed over it. For test MI-4, 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.

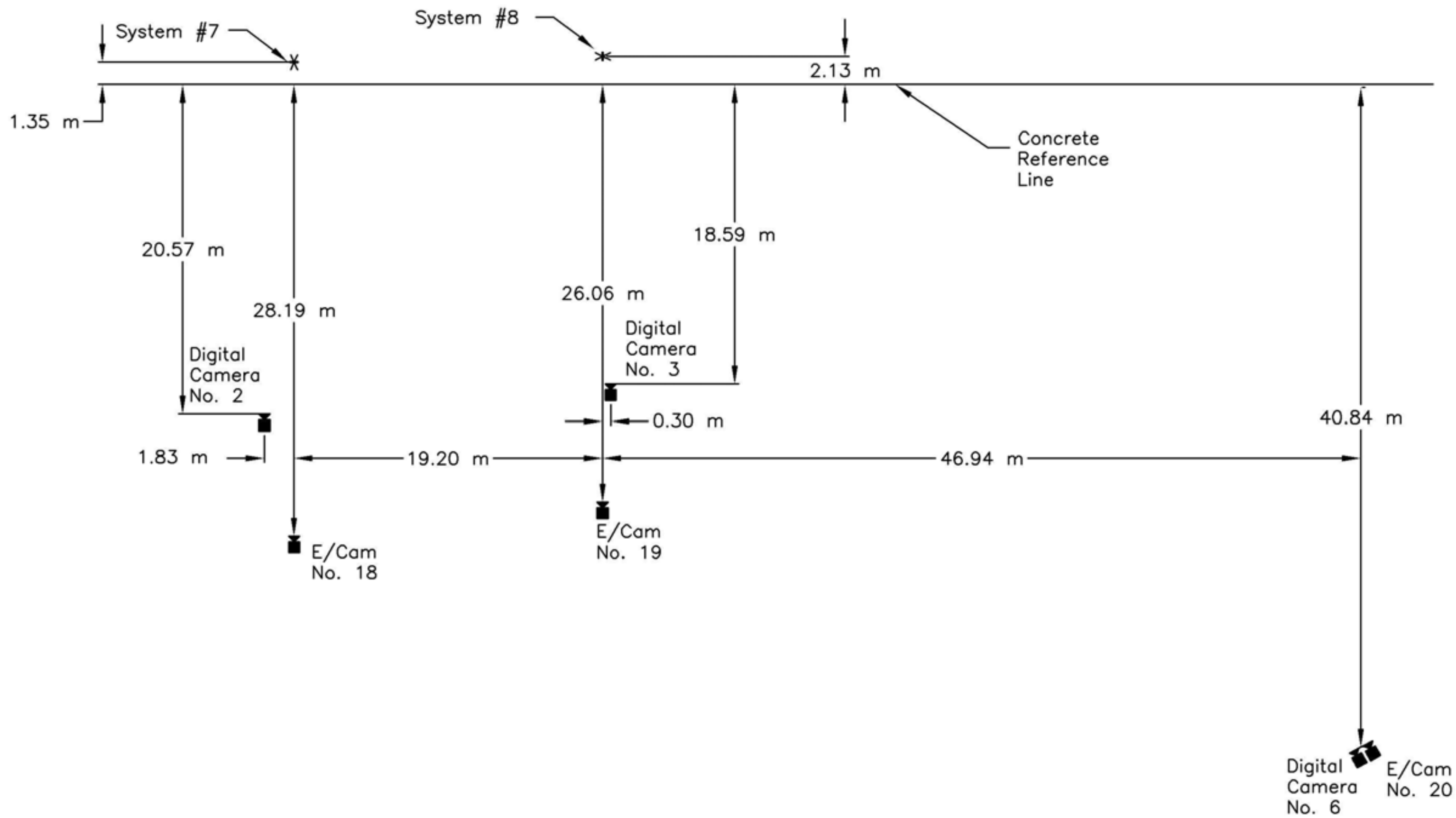


Figure 7. Location of High-Speed Cameras, Test MI-4

5 CRASH TEST NO. 4 (SYSTEM NOS. 7 AND 8)

5.1 Test MI-4

The 893-kg small car impacted System No. 7, Michigan's 1.2-m by 1.5-m portable sign with a rectangular-shaped plywood panel oriented end-on to the vehicle (parallel to the vehicle's path), at a speed of 103.6 km/hr and at an angle of 90 degrees. The small car then impacted System No. 8, Michigan's 1.2-m by 1.5-m portable sign with a rectangular-shaped plywood panel oriented head-on to the vehicle (perpendicular to the vehicle's path), at a speed of 91.7 km/hr and at an angle of 0 degrees. A summary of the test results and the sequential photographs are shown in Figures 8 and 9. Additional sequential photographs are shown in Figures 10 and 11. Documentary photographs of the crash tests are shown in Figures 12 through 15.

5.2 Test Description

The test vehicle impacted System No. 7 with the right-front quarter point of the vehicle aligned with the centerline of the sign support, as shown in Figure 16. At 0.014 sec after initial contact, the impacted mast deformed around the front of the vehicle and translated toward the non-impacted mast. At 0.042 sec, the sign panel rotated counter-clockwise (CCW) down toward the vehicle as the non-impacted mast rotated away from the vehicle. At this same time, the impacted mast deformed around the front of the vehicle and contacted the non-impacted mast. Shortly thereafter, the non-impacted leg disengaged from the mast. At 0.062 sec, the impacted mast disengaged from the leg and was deformed to approximately a 90 degree angle around the front of the vehicle. At this same time, the sign panel continued to rotate CCW toward the vehicle. At 0.098 sec, the sign panel contacted the roof and windshield. At 0.118 sec, the sign panel crushed the roof inward toward the occupant compartment. At 0.144 sec, the sign panel, which was positioned parallel to the ground, remained in contact with the roof and windshield. At this same time, the right-rear window shattered. At 0.174 sec, the sign panel and mast rebounded off the vehicle as the vehicle's roof remained permanently deformed. At this same time, the non-impacted mast released from the sign panel. At 0.208 sec, the sign panel and impacted mast were airborne above the vehicle and continued to rotate CCW. The deformed L-shaped portion of the impacted leg was located 1.83-m downstream and 0.43-m right from the original position. The non-impacted leg was located 3.96-m downstream and 0.03-m left from the original position. The vertical upright tube of the impacted leg was location 5.18-m downstream and 3.68-m left from the original position. The sign panel was located 27.43-m downstream and 11.81-m right from the original position. The non-impacted mast and outer tube were located 59.74-m downstream and 1.78-m left from the original position. The impacted mast and outer tube were located 105.77-m downstream and 5.77-m right from the original position.

Approximately 0.73 sec after impact with System No. 7, the vehicle impacted System No. 8 with the centerline of the vehicle aligned with the centerline of the sign support, as shown in Figure 16. At 0.020 sec, both masts deformed around the front of the vehicle as the top of the sign panel rotated down toward the vehicle. At 0.038 sec, the sign panel, both masts, and both legs all still intact traveled along with the vehicle. Shortly after this time, the sign panel released from the top-left, bottom-left, and the bottom-right panel bolts. At 0.064 sec, the masts were still in contact with the front of the vehicle as they rotated about the front of the vehicle. At this same time, the sign panel descended toward the vehicle. At 0.106 sec, the bottom of the sign panel contacted the roof and upper region of the windshield. At this same time, the top of the left mast remained attached to the sign panel. At 0.140 sec, the entire sign panel was in contact with the roof as the right-side door's window shattered. At this same time, the right mast and leg, still attached, were airborne in front of the vehicle. At 0.170 sec, the sign panel remained in contact with the roof. At this same time, the left mast disengaged from the leg and rotated into the air. At 0.200 sec, the sign panel was positioned behind the vehicle with the left mast still attached to it. At 0.234 sec, the sign panel and left mast remained airborne and continued to rotate CCW behind the vehicle. At 0.268 sec, the sign panel and left mast descended toward the ground. At 0.334 sec, the left mast disengaged from the sign panel. The sign panel was located 31.09-m downstream and 0.05-m right from the original position. The right-side mast, outer tube, and leg were located 51.05-m downstream and 1.96-m right from the original position and still connected together. The left mast and outer tube still intact were located 53.80-m downstream and 4.72-m left from the original position. The left leg was located 92.20-m downstream and 0.20-m left from the original position. The vehicle subsequently came to rest 87.63-m downstream from the longitudinal midpoint of the two impact points and 2.76-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 8, 9, and 17.

5.3 System and Component Damage

Damage to System Nos. 7 and 8 is shown in Figures 17 through 22. System No. 7 encountered moderate damage. Both legs disengaged from the masts. The impacted leg's vertical upright tube disengaged from the angle portion due to fracture of the welds. The disengaged vertical upright tube was deformed on the non-impacted side. Both legs' angles were deformed near their center points. The impacted outer tube and mast were deformed at bumper height and near the lower panel bolts and also fractured near bumper height. The non-impacted outer tube and mast were deformed near the lower panel bolts. The sign panel disengaged from both masts and the panel bolts remained attached to the masts. The sign panel encountered moderate deformations on the impact side. The sign panel also was torn at each of the four panel bolt holes with more significant tears occurring at the bolt holes on the non-impact side. Five of 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. The other three sandbags remained undamaged.

System No. 8 encountered moderate damage. The right mast, outer tube, and leg remained attached, and the mast and outer tube encountered minor deformations. The left leg disengaged from the mast and was undamaged. The left mast and outer tube were deformed near the center of the outer tube. The sign panel disengaged from both masts and the panel bolts remained attached to the masts. The sign panel encountered moderate deformations on all edges. The sign panel also deformed at each of the four panel bolt holes and was slightly torn at the bottom right hole. All eight 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.

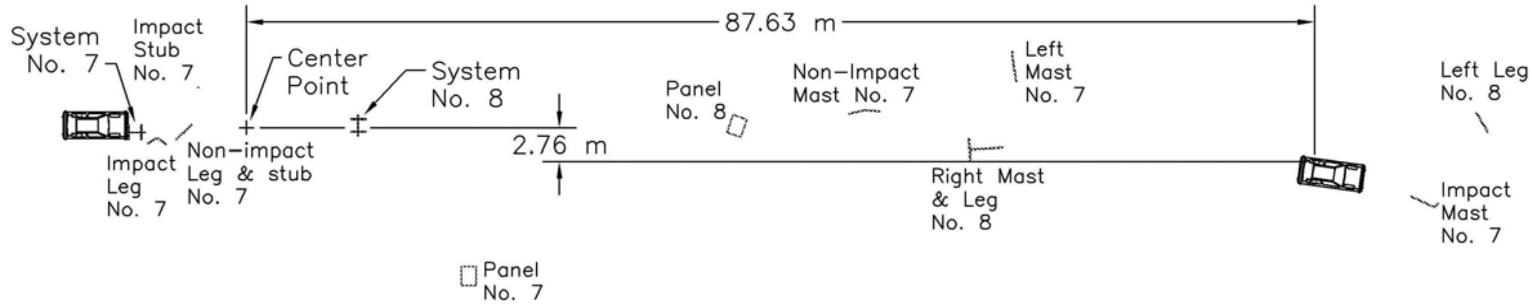
5.4 Vehicle Damage

Exterior vehicle damage is shown in Figures 23 through 25. The front bumper and lower plastic shield encountered minor dents and contact marks. The hood encountered minor scuff and scrape marks. The right side of the roof encountered major indentation (maximum of 133 mm) and subsequent penetration. The right-side A-pillar was crushed extensively in toward the occupant compartment. The roof also sustained scuff and scrape marks. The right-side headlight and park light broke, while the left-side park light was cracked. The right-side door and right-rear windows were shattered. The windshield sustained major "spider web" cracking throughout, with both layers of the right-side and upper-middle regions of the windshield being cracked. Most of the structural integrity of the windshield on the right side and upper middle was lost and the windshield indented inward toward the occupant compartment. A large hole (slice) through the windshield was located near the center region of the right side. No damage was found to have occurred to the left side, rear end, left-side headlight, nor parking lights.

5.5 Discussion

Following test MI-4, a safety performance evaluation was conducted, and the work-zone traffic control devices, System Nos. 7 and 8 were 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. In addition, deformations of, or intrusion into, the occupant compartment did occur. Detached elements and debris from System No. 7 penetrated the right region of the windshield and the right side of the roof. Detached elements and debris from System No. 8 deformed the upper middle region of the windshield. In addition, the severity of the impact with System Nos. 7 and 8 caused the right-side rear and right-side door windows to shatter, respectively. The vehicle’s trajectory did not intrude into adjacent traffic lanes.

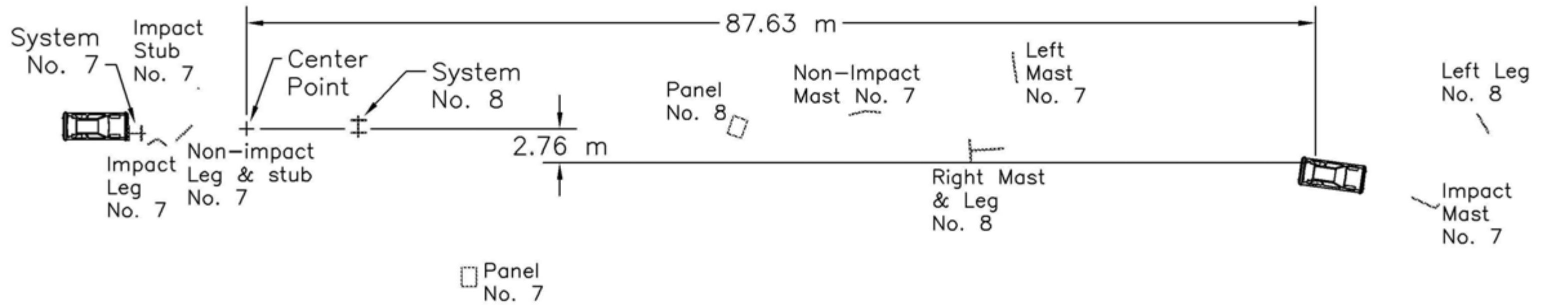
0.000 sec | 0.042 sec | 0.098 sec | 0.144 sec | 0.174 sec



- Test Number MI-4
- System Number 7
- Date 4/9/03
- Test Article
  - Type . . . . Traffic Control Device – Steel Sign Support With Wood Sign Panel
  - Stand . . . . Michigan's 4x5 Portable Sign Support
  - Sign Panel . . . . Rigid Plywood, 1219 x 1524 x 17.3-mm thick
    - Height above ground . . . . 1,524 mm to panel bottom
  - Warning Light . . . . none
  - Key Elements
    - Size and/or dimension . . . 3.0 m high
    - Material . . . . Telespar Steel Tubing
  - Orientation . . . . End-on with right quarter point
- Soil Type . . . . On dry pavement
- Vehicle Model . . . . 1996 Geo Metro
  - Curb . . . . 811 kg
  - Test Inertial . . . . 818 kg
  - Gross Static . . . . 893 kg
- Vehicle Speed
  - Impact . . . . 103.6 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 . . . . Roof and windshield penetration
  - TAD[29] 12-FR-1
  - SAE[30] 12-FRAN9
- Vehicle Stopping Distance . . . . 87.63 m downstream
  2.76 m right
- Test Article Damage . . . . Moderate – Broke apart

Figure 8. Summary of Test Results and Sequential Photographs, Test MI-4, Impact No. 1

0.000 sec | 0.038 sec | 0.106 sec | 0.140 sec | 0.200 sec



- Test Number MI-4
- System Number 8
- Date 4/9/03
- Test Article
  - Type . . . . Traffic Control Device – Steel Sign Support With Wood Sign Panel
  - Stand . . . . Michigan’s 4x5 Portable Sign Support
  - Sign Panel . . . . Rigid Plywood, 1219 x 1524 x 17.3-mm thick
    - Height above ground . . . . 1,524 mm to panel bottom
  - Warning Light . . . . none
  - Key Elements
    - Size and/or dimension . . . 3.0 m high
    - Material . . . . Telespar Steel Tubing
  - Orientation . . . . Head-on with centerline
- Soil Type . . . . On dry pavement
- Vehicle Model . . . . 1996 Geo Metro
  - Curb . . . . 811 kg
  - Test Inertial . . . . 818 kg
  - Gross Static . . . . 893 kg
- Vehicle Speed
  - Impact . . . . 91.7 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 cracking and indentation
  - TAD[29] 12-FC-1
  - SAE[30] 12-FCAW9
- Vehicle Stopping Distance . . . . 87.63 m downstream 2.76 m right
- Test Article Damage . . . . Moderate – Broke apart

Figure 9. Summary of Test Results and Sequential Photographs, Test MI-4, Impact No. 2

0.000 sec

0.030 sec

0.108 sec

0.210 sec

0.374 sec

0.732 sec

0.780 sec

0.852 sec

0.978 sec

1.048 sec

Figure 10. Additional Sequential Photographs, Test MI-4

0.017 sec

0.000 sec

0.083 sec

0.067 sec

0.150 sec

0.133 sec

0.217 sec

0.200 sec

0.284 sec

0.267 sec

Figure 11. Additional Sequential Photographs, Test MI-4

Figure 12. Documentary Photographs, Test MI-4

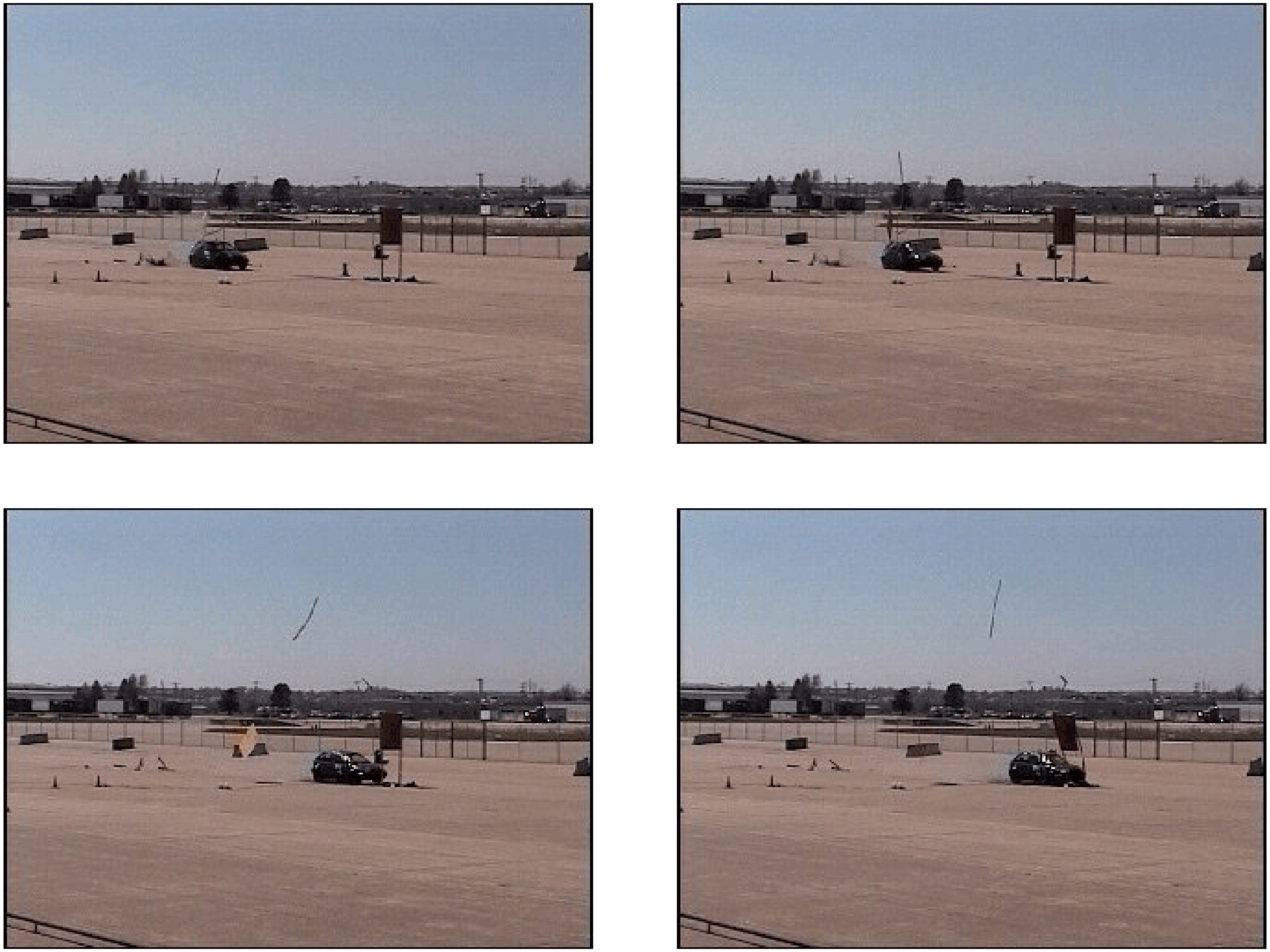


Figure 13. Documentary Photographs, Test MI-4

Figure 14. Documentary Photographs, Test MI-4

Figure 15. Documentary Photographs, Test MI-4

Figure 16. Impact Location, Test MI-4

Figure 17. Overall Damage and Final Positions, Test MI-4

Figure 18. System No. 7 Impact Mast and Leg Damage, Test MI-4

Figure 19. System No. 7 Non-impact Mast and Leg Damage, Test MI-4

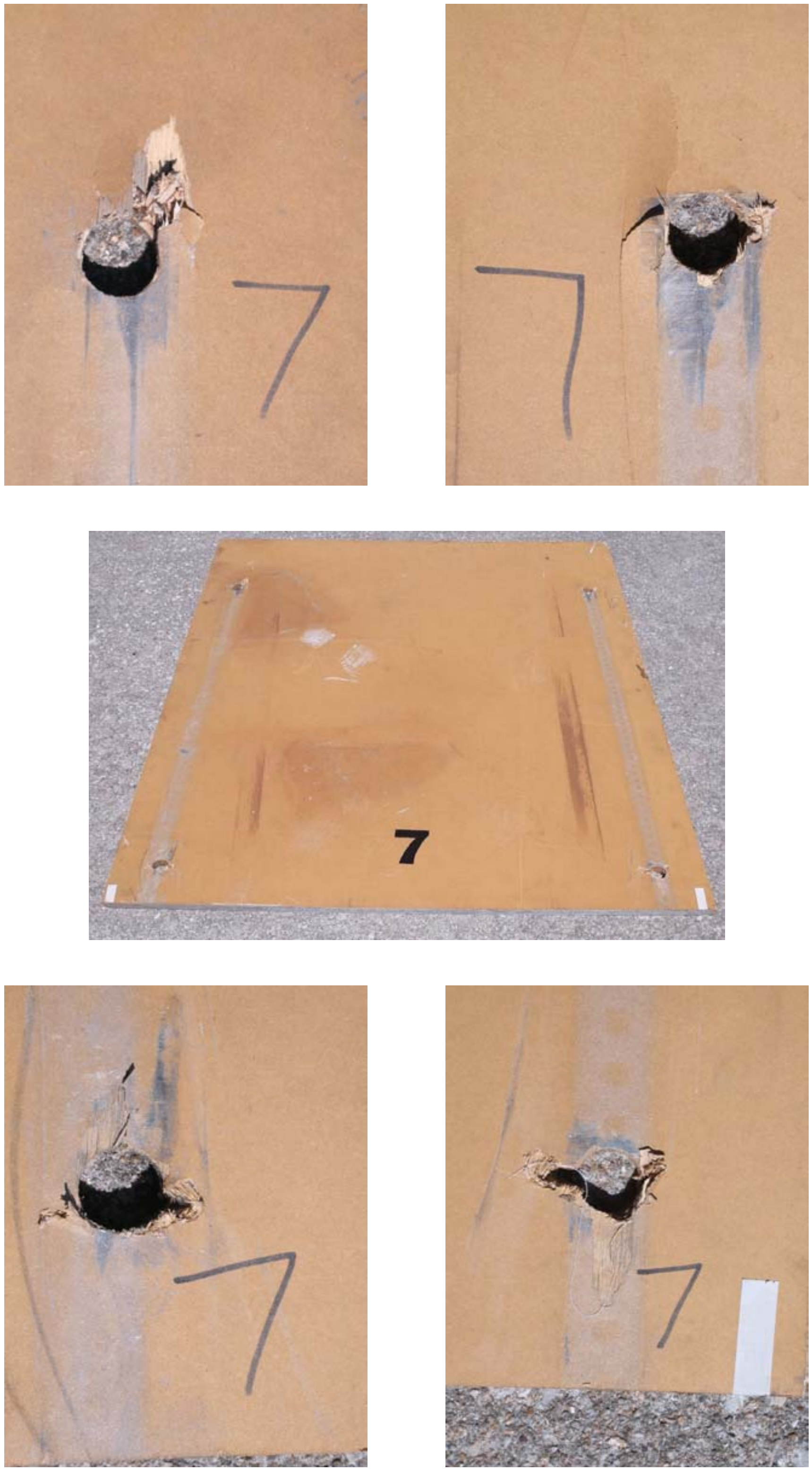


Figure 20. System No. 7 Panel Damage, Test MI-4

Figure 21. System No. 8 Damage, Test MI-4

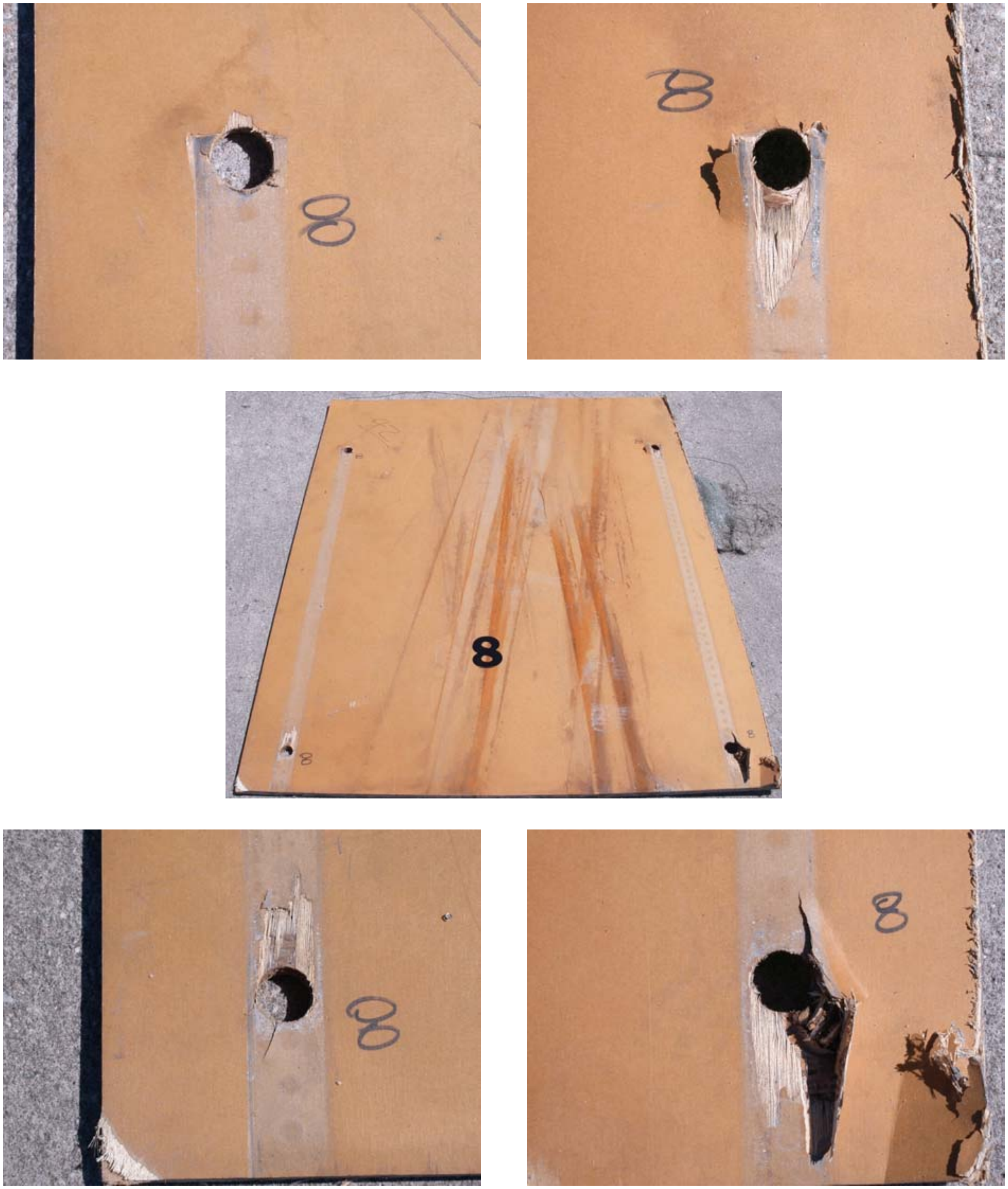


Figure 22. System No. 8 Panel Damage, Test MI-4

Figure 23. Vehicle Damage, Test MI-4

Figure 24. Vehicle Front-End and Right-Side Windows Damage, Test MI-4

Figure 25. Windshield and Roof Damage, Test MI-4

6 DISCUSSION

A full-scale crash test was conducted on Michigan's 1.2-m by 1.5-m tall-mounted, portable rigid panel sign support system which utilized a rectangular-shaped plywood panel according to the NCHRP Report No. 350 safety standards. This system's safety performance was unacceptable at both the 0-degree and 90-degree orientations.

During the 90-degree impact event, the vehicle struck the left mast, causing it to deform around the vehicle's front-end before it released from the support leg. Deformation occurred to the impact-side leg angle as the lower part of the mast was pushed in front of the vehicle. Furthermore, the sign panel did not release from the masts. As a result, the impact side of the panel rotated and was pulled down toward the vehicle. Following this, the impact side of the panel contacted and penetrated the vehicle's roof and windshield. In addition, the right-side rear window was shattered from the severity of the panel impact.

During the 0-degree impact event, the vehicle struck the masts, causing the right mast to separate from the sign panel. Furthermore, the panel was supported in the air by the top of the left mast. Subsequently, the mast rotated about the front of the vehicle causing the panel to contact the roof and windshield. As a result of the panel contact, the vehicle's right-side door window was shattered and the windshield encountered major "spider web" cracking with a concentrated impact area.

Finally, following an analysis of the test results, it was evident that the debris from these work-zone traffic control devices 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 system debris was determined to be less of a hazard to adjacent traffic and work-zone crews than the moving vehicle itself.

7 SUMMARY AND CONCLUSIONS

A total of two crash tests were conducted on a tall-mounted, rigid panel sign supports with sandbags. Both of the crash tests on these work-zone traffic control devices did not meet 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 MI-4	
		#7	#8
		LSP [1]	LSP [1]
Structural Adequacy	B	U	U
Occupant Risk	D	U	U
	E	U	U
	F	S	S
	H	NA	NA
	I	NA	NA
Vehicle Trajectory	K	S	S
	N	S	S
NCHRP Report No. 350 Test Level		TL-3	TL-3
Method of Failure[2]		1,2,3,4,5,6	1,2,3
Pass/Fail		Fail	Fail

[1] Hardware Type: LSP – Large Sign Support 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 - Roof deformations greater than 127 mm
7 - 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

8 RECOMMENDATIONS

The work-zone traffic control device performed unsatisfactorily according to the test evaluation criteria set forth in NCHRP Report No. 350 and is not recommended for field applications. This work-zone traffic control device includes:

- Test No. MI-4, System Nos. 7 and 8 – Michigan's 1.2-m by 1.5-m Portable Sign Support – A steel sign support, with 31.8 kg of sand on each leg, and with a 1,219-mm wide x 1,524-mm tall x 17.3-mm thick, rectangular-shaped plywood sign panel, oriented end-on and head-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 tall-mounted, rigid panel sign supports 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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10 APPENDICES

APPENDIX A

Dimensional Measurements of Tall-Mounted, Rigid Panel Sign Support Systems

Table A-1. Tall-Mounted, Rigid Panel Sign Support System Dimensional Measurements

System Number	Test Number	STAND		SIGN		
		Type [1]	Weight (kg)	Type [2]	Material [3]	Weight (kg)
7, 8	MI-4	Steel Sign Stand (Legs, Two Masts, & Two Outer Tubes)	41.730	Rigid Panel	7	19.051

[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)
7 - (Plywood)

Table A-2. Tall-Mounted, Rigid Panel Sign Support System Dimensional Measurements

System Number	HEIGHTS TO		
	Bottom of Sign Panel (mm)	Top of Sign Panel (mm)	Top of Light (mm)
7, 8	1524	3048	----

Table A-3. Tall-Mounted, Rigid Panel Sign Support System Dimensional Measurements

Stand Type	System Number	LEGS				
		Horizontal Portion				
		Material	Dimension #1 (mm)	Dimension #2 (mm)	Thickness (mm)	Length (mm)
Steel Sign Stand	7, 8	ASTM A-36 Steel Angle Iron	50.80	50.80	6.35	1829

Table A-4. Tall-Mounted, Rigid Panel Sign Support System Dimensional Measurements

Stand Type	System Number	LEGS				
		Vertical Portion				
		Material	Dimension #1 (mm)	Dimension #2 (mm)	Thickness (mm)	Length (mm)
Steel Sign Stand	7, 8	ASTM A-36 Steel Tubing	50.80	50.80	2.69	154

Table A-5. Tall-Mounted, Rigid Panel Sign Support System Dimensional Measurements

Stand Type	System Number	MASTS (VERTICAL UPRIGHTS)					
		Number of Masts	Material	Dimension #1 (mm)	Dimension #2 (mm)	Thickness (mm)	Length (mm)
Steel Sign Stand	7, 8	2	Telespar Steel Tubing	44.45	44.45	2.79	2743

Table A-6. Tall-Mounted, Rigid Panel Sign Support System Dimensional Measurements

Stand Type	System Number	MASTS (OUTER VERTICAL TUBES)							HOLES	
		Number of Outer Masts	Material	Dimension #1 (mm)	Dimension #2 (mm)	Thickness (mm)	Length (mm)	Space between masts (out to out) (mm)	Diameter of holes (mm)	Hole Spacings (center to center) (mm)
Steel Sign Stand	7, 8	2	Telespar ASTM A-653 Grade 50 Steel Tubing	50.80	50.80	2.74	914	1067	9.53	25.40

Table A-7. Tall-Mounted, Rigid Panel Sign Support System Dimensional Measurements

Sign Type	System Number	SIGN PANEL			
		Material	Thickness (mm)	Length (mm)	Width (mm)
Rigid Panel	7, 8	Plywood	17.27	1524	1219

54

APPENDIX B

Tall-Mounted, Rigid Panel Sign Support System Details

Figure B-1. Portable Rigid Sign Panel System (Test MI-4)

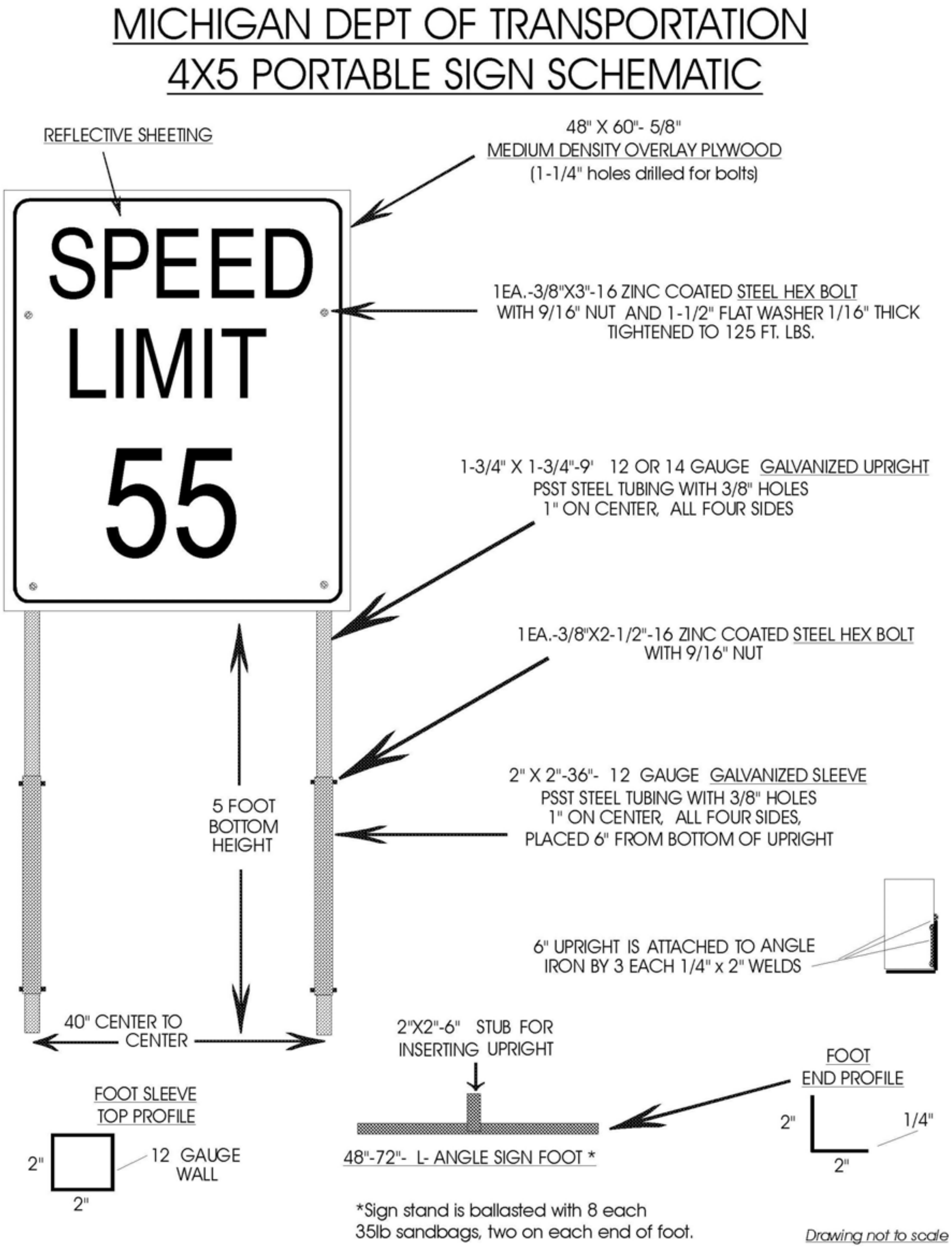

Figure B-1. Portable Mounted Rigid Panel System (Test MI-4)