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Safety Performance Evaluation of Minnesota's Temporary Rigid Panel Sign Stand Systems

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SAFETY PERFORMANCE EVALUATION OF MINNESOTA'S TEMPORARY RIGID PANEL SIGN STAND SYSTEMS

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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 remains unknown, even though previous crash testing on work-zone traffic control devices 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 various work-zone traffic control devices through dynamic bogie testing according to the Test Level 3 (TL-3) criteria set forth in the NCHRP Report No. 350. The impacts on the temporary rigid panel sign supports presented within 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 work-zone traffic control devices were made.

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DISCLAIMER STATEMENT

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

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1 INTRODUCTION

1.1 Problem Statement

A wide variety of traffic controlling devices are used in work zones, some of which are not normally found on the roadside nor 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 remains unknown, even though previous 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). Full-scale crash testing on plastic drums, barricades, portable sign supports, and rigid panel sign supports has been previously conducted at the University of Nebraska-Lincoln (3-22). The previous studies have provided some useful information, but there remain unanswered questions regarding the performances of many work-zone traffic control devices, which are slightly different from those crash tested. Furthermore, a list of previous crash test and approved work-zone systems can be found in the list of FHWA acceptance letters for category 2 work zone devices (23).

1.2 Objective

The objective of the research project was to evaluate the safety performance of existing rigid

panel portable sign supports through compliant bogie 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, fourteen compliant bogie tests were performed on several work-zone traffic control devices. The fourteen crash tests were completed on seven different systems. These crash tests were performed using a bogie vehicle, weighing approximately 1,119 kg (2,467 lbs), with target impact speeds of 100.0 km/h (62.1 mph) and angles of 0 or 90 degrees for the impacts. Finally, the test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made that pertain to the safety performance of the work-zone traffic control devices.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Work-zone traffic control devices, such as portable sign supports, must satisfy the requirements provided in NCHRP Report No. 350 to be accepted by FHWA for use on NHS construction projects or as a replacement for existing designs not meeting current safety standards. According to FHWA's Submission Guidelines attached to the July 1997 memorandum, *Action: Identifying Acceptable Highway Safety Features* (24), 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 (1,808-lb) small car impacting at a speed of 35.0 km/h (21.7 mph) and at an angle of 0 degrees; and (2) an 820-kg (1,808-lb) small car impacting at a speed of 100.0 km/h (62.1 mph) 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 or 99 lbs), 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 (1,808-lb) small car crash test, impacting at a speed of 35.0 km/h (21.7 mph) 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/h (62.1 mph) and at a target impact angle of 90 degrees (25).

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 (26). 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 (9.8 ft/s), or at least below the maximum allowable value of 5 m/s (16.4 ft/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 TEST CONDITIONS

3.1 Bogie Vehicle

A rigid frame bogie, constructed from FHWA specifications (27), was used to impact the retrofitted design. The bogie was modified by adding a combination HDPE and steel tube frame which simulated the bumper, front clip, hood, windshield, A-pillars, and roof of a 1994 Geo Metro, as shown in Figures 1 and 2.

3.2 Bogie Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the bogie vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the bogie vehicle. For the bogie test, the bogie guide track length was 182.9 m (600 ft). The guide track was constructed with 57-mm (2 ¼-in.) diameter steel pipes, with wall thicknesses and lengths of 4.76 mm (3/16 in.) and 2,965 mm (116 ft - 9 in.), respectively. The pipes were supported every 3,048 mm (10 ft) by steel stanchions. The bogie vehicle was released from the tow cable and the bogie guide track before impact with the work-zone traffic control device, allowing the bogie to become a free projectile as it came off the bogie guide track.

3.3 Data Acquisition Systems

3.3.1 High-Speed Photography

For bogie tests MN1C0, MN1C90, MN2C0, MN2C90, MN5A0, MN6A0, MN6A90, MN8A0, and MN8A90, two high-speed Red Lake E/cam video cameras, with operating speeds of 500 frames/sec, and a Canon digital video camera were placed on the left side of the impact orientation and had a field of view perpendicular to the impact. A Canon digital video camera was also placed on the left side of the system and upstream of impact and had a behind the bogie view

Figure 1. Modified Bogie Vehicle

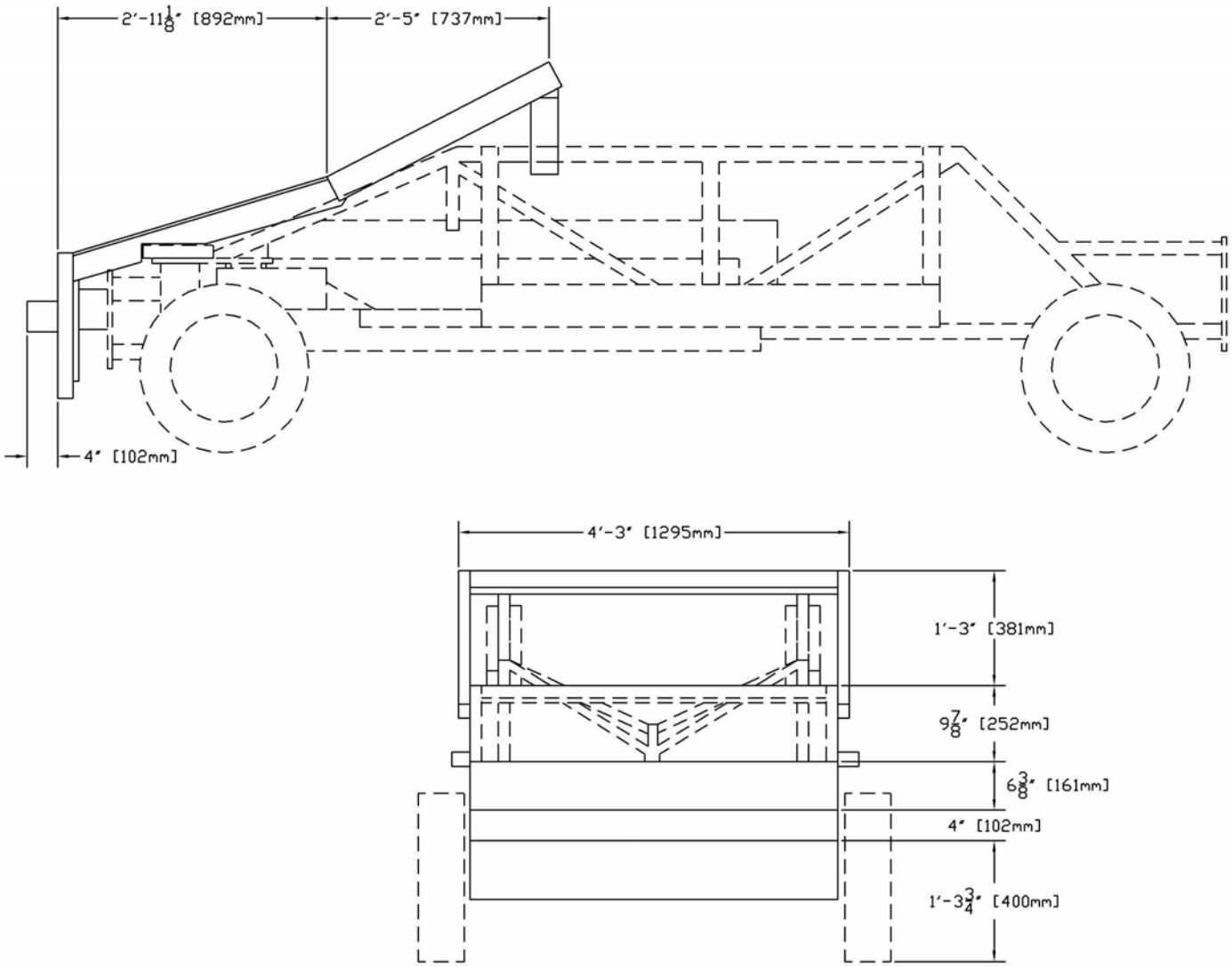

Figure 2. Modified Bogie Vehicle Dimensions

of the system and impact.

For bogie tests MN3B0-2, MN3B90, MN7A0, and MN7A90, two high-speed Photron video cameras, with operating speeds of 500 frames/sec, and a Canon digital video camera were placed on the left side of the impact orientation and had a field of view perpendicular to the impact.

For bogie test MN5C90-2, two high-speed AOS VITcam video cameras, with operating speeds of 500 frames/sec, and a Canon digital video camera were placed on the left side of the impact orientation and had a field of view perpendicular to the impact.

3.3.2 Pressure Tape Switches

One set of three pressure-activated tape switches, spaced at 2-m (6.56-ft) intervals, were used to determine the speed of the bogie vehicle before impact with the device. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the left-front tire of the bogie vehicle passed over the set of tape switches. Test bogie vehicle speed was determined from electronic timing mark data recorded using the “Test Point” software.

4 WORK ZONE PORTABLE SIGN SUPPORTS

A total of twenty-six work-zone traffic control devices were crash tested under this study, as described below. The crash tests were all conducted on portable rigid panel sign supports. All materials for the traffic control devices were supplied by the sponsor. A list of the twenty-six crash tests are summarized in Table 3. It should be noted that this report only contains details of the tests on the systems which were acceptable in the 0 and 90 degree orientations.

Table 3. List of Crash Tests Conducted

WORK ZONE TRAFFIC CONTROL DEVICES	
MINNESOTA DEPARTMENT OF TRANSPORTATION'S RIGID PANEL SIGN SUPPORTS	
Test No. MN1A0	Minnesota Department of Transportation's Stop Sign System (0 degrees)
Test No. MN1B0	Minnesota Department of Transportation's Stop Sign System (0 degrees)
Test No. MN1B02	Minnesota Department of Transportation's Stop Sign System (0 degrees)
Test No. MN1C0	Minnesota Department of Transportation's Stop Sign System (0 degrees)
Test No. MN1C90	Minnesota Department of Transportation's Stop Sign System (90 degrees)
Test No. MN2C0	Minnesota Department of Transportation's Route Marker Assembly System (0 degrees)
Test No. MN2C90	Minnesota Department of Transportation's Route Marker Assembly System (90 degrees)
Test No. MN3A0	Minnesota Department of Transportation's 24" x 36" and 48" x 36" Work Zone Speed Limit System (0 degrees)
Test No. MN3A0	Minnesota Department of Transportation's 24" x 36" and 48" x 36" Work Zone Speed Limit System (0 degrees)
Test No. MN3A90	Minnesota Department of Transportation's 24" x 36" and 48" x 36" Work Zone Speed Limit System (90 degrees)
Test No. MN3B0	Minnesota Department of Transportation's 24" x 36" and 48" x 36" Work Zone Speed Limit System (0 degrees)
Test No. MN3B02	Minnesota Department of Transportation's 24" x 36" and 48" x 36" Work Zone Speed Limit System (0 degrees)
Test No. MN3B90	Minnesota Department of Transportation's 24" x 36" and 48" x 36" Work Zone Speed Limit System (0 degrees)
Test No. MN3C0	Minnesota Department of Transportation's 24" x 36" and 48" x 36" Work Zone Speed Limit System (0 degrees)
Test No. MN4A0	Minnesota Department of Transportation's 48" x 60" Rectangle Panel Work Zone System (0 degrees)
Test No. MN4B0	Minnesota Department of Transportation's 48" x 60" Rectangle Panel Work Zone System (0 degrees)
Test No. MN5A0	Minnesota Department of Transportation's 36" x 36" Diamond Panel Work Zone System, Warning Light (0 degrees)
Test No. MN5A90	Minnesota Department of Transportation's 36" x 36" Diamond Panel Work Zone System, Warning Light (90 degrees)
Test No. MN5B90	Minnesota Department of Transportation's 36" x 36" Diamond Panel Work Zone System, Warning Light (90 degrees)
Test No. MN5C90	Minnesota Department of Transportation's 36" x 36" Diamond Panel Work Zone System, Warning Light (90 degrees)
Test No. MN5C902	Minnesota Department of Transportation's 36" x 36" Diamond Panel Work Zone System, Warning Light (90 degrees)
Test No. MN6A0	Minnesota Department of Transportation's 48" x 48" Diamond Panel Work Zone System with 5' Mounting Height, Warning Light (0 degrees)
Test No. MN6A90	Minnesota Department of Transportation's 48" x 48" Diamond Panel Work Zone System with 5' Mounting Height, Warning Light (90 degrees)
Test No. MN7A0	Minnesota Department of Transportation's 48" x 48" Diamond Panel Work Zone System with 7' Mounting Height, Warning Light (0 degrees)
Test No. MN7A90	Minnesota Department of Transportation's 48" x 48" Diamond Panel Work Zone System with 7' Mounting Height, Warning Light (90 degrees)
Test No. MN8A0	Minnesota Department of Transportation's Stop Sign System with 7' Mounting Height (0 degrees)
Test No. MN8A90	Minnesota Department of Transportation's Stop Sign System with 7' Mounting Height (90 degrees)

5 PERFORMANCE ANALYSIS OF THE MINNESOTA DEPARTMENT OF TRANSPORTATION'S STOP SIGN SYSTEM

Bogie Test MN1C-0 (Head-on device)

1. System: Stop Sign System
   - Vertical Upright Masts – 57.2 mm (2.25 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.90 mm (0.114 in.) wall thickness and a length of 1,524 mm (60 in.).
   - Outside Vertical Upright Tubing – 63.5 mm (2.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.30 mm (0.130 in.) wall thickness and a length of 911 mm (35.875 in.).
   - Legs, Outer Horizontal Portion – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.79 mm (0.110 in.) thickness and a length of 1,521 mm (59.875 in.).
   - Legs, Middle Horizontal Portion - 50.8 mm (2.0 in) sq. x 762 mm (30 in) long galvanized telespar ASTM A-653 Grade 50 steel tubing.
   - Legs, Vertical Stub – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.77 mm (0.109 in.) thickness and a length of 305 mm (12 in.).
   - Vertical stub of the leg is welded to the middle horizontal portion of the leg on all four sides, and the horizontal middle portion of the leg is welded to the outer horizontal portion of the legs on all four sides.
   - Outside vertical upright tubing slide over the vertical upright mast - 9.5 mm (0.375 in.) diameter x 76.2 mm (3 in.) long hex head Grade 5 bolt were used to fasten the outer vertical upright tube to the mast.
   - Vertical portion of legs slide into vertical upright masts.

   Sign: Rigid
   - Panel - Rigid aluminum, 762 mm (30 in.) wide x 762 mm (30 in.) long with a 2.31 mm (0.091 in.) thickness.
   - Panels fastened to vertical mast support with two 7.9 mm (0.3125 in) diameter x 76.2 mm (3 in.) long Grade 5 bolts. A front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.

   Height to Bottom of Bottom Sign: 876 mm (34.5 in.)
   Height to Top of Outer Tube: 962 mm (37.875 in.)
   Height to Top of Top Sign: 1,638 mm (64.5 in.)

2. Weights of Sign System

Legs:	14.969 kg (33 lbs)
Panel, Mast, and Outside Tube:	13.154 kg (29 lbs)
Total System Weight:	28.123 kg (62 lbs)

Ballast (sandbags): 20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 3/17/04

5. Impact Speed: 98.7 km/h (61.3 mph)
   Impact Orientation: 0 degrees

6. Velocity Change: 9.5 km/h (5.9 mph)

7. System Performance – Minor mast deformation was observed. The sign panel, mast, and legs remained intact. The top of the sign panel and mast rotated toward the vehicle, but no contact nor damage to the simulated windshield was observed. Throughout the entire test, the system remained in front of the vehicle and never became a potential hazard to the bogie nor the occupant compartment.

Bogie Test MN1C-90 (End-on device)

1. System: Stop Sign System
   - Vertical Upright Masts – 57.2 mm (2.25 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.82 mm (0.111 in.) wall thickness and a length of 1,524 mm (60 in.).
   - Outside Vertical Upright Tubing – 63.5 mm (2.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.30 mm (0.130 in.) wall thickness and a length of 911 mm (35.875 in.).
   - Legs, Outer Horizontal Portion – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.74 mm (0.108 in.) thickness and a length of 1,521 mm (59.875 in.).
   - Legs, Middle Horizontal Portion - 50.8 mm (2.0 in) sq. x 762 mm (30 in) long galvanized telespar ASTM A-653 Grade 50 steel tubing.
   - Legs, Vertical Stub – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.74 mm (0.108 in.) thickness and a length of 305 mm (12 in.).
   - Vertical stub of the leg is welded to the middle horizontal portion of the leg on all four sides, and the horizontal middle portion of the leg is welded to the outer horizontal portion of the legs on all four sides.
   - Outside vertical upright tubing slide over the vertical upright mast - 9.5 mm (0.375 in.) diameter x 76.2 mm (3 in.) long hex head Grade 5 bolt were used to fasten the outer vertical upright tube to the mast.
   - Vertical portion of legs slide into vertical upright masts.

   Sign: Rigid
   - Panel - Rigid aluminum, 762 mm (30 in.) wide x 762 mm (30 in.) long with a 2.29 mm (0.090 in.) thickness.

- Panels fastened to vertical mast support with two 7.9 mm (0.3125 in) diameter x 76.2 mm (3 in.) long Grade 5 bolts. A front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.

Height to Bottom of Bottom Sign: 879 mm (34.625 in.)
Height to Top of Outer Tube: 962 mm (37.875 in.)
Height to Top of Top Sign: 1,641 mm (64.625 in.)

2. Weights of Sign Systems

Legs:	14.969 kg (33 lbs)
Panel, Mast, and Outside Tube:	13.154 kg (29 lbs)
Total System Weight:	28.123 kg (62 lbs)
Ballast (sandbags):	20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 3/17/04

5. Impact Speed: 100.0 km/h (62.2 mph)
   Impact Orientation: 90 degrees

6. Velocity Change: 9.7 km/h (6.0 mph)

7. System Performance – Minor mast and panel deformations were observed. The mast disengaged completely from the base. The top of the sign panel and mast rotated toward the vehicle and contacted the hood, but no contact nor damage to the simulated windshield was observed. After contact with the hood, the system rebounded off the bogie and traveled up and away from the bogie and was never considered to be a potential hazard to the bogie nor the occupant compartment.

Figure 3. Stop Sign System, Bogie Tests MN1C-0 and MN1C-90

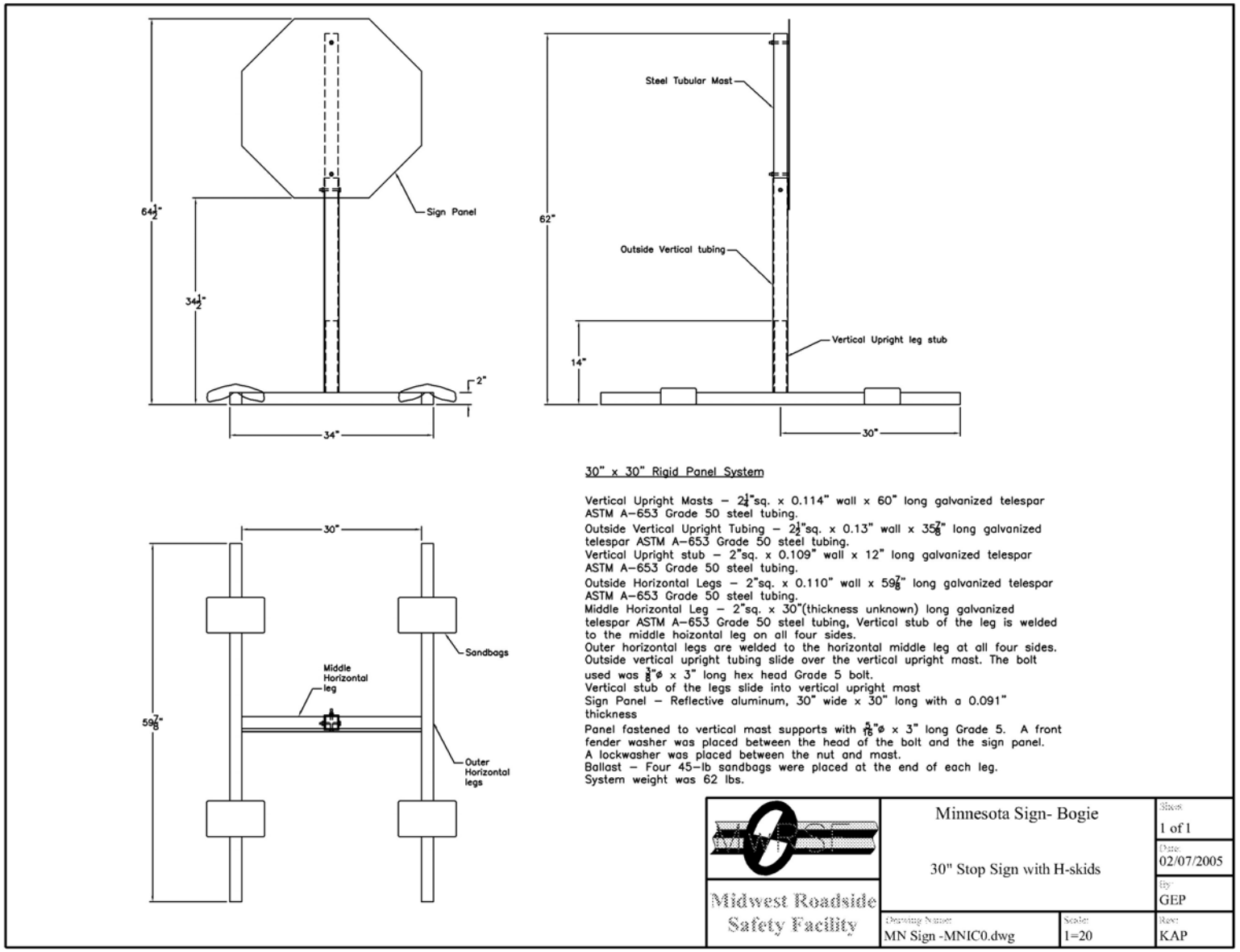

Figure 4. Stop Sign System Design Details, Bogie Test MN1C-0

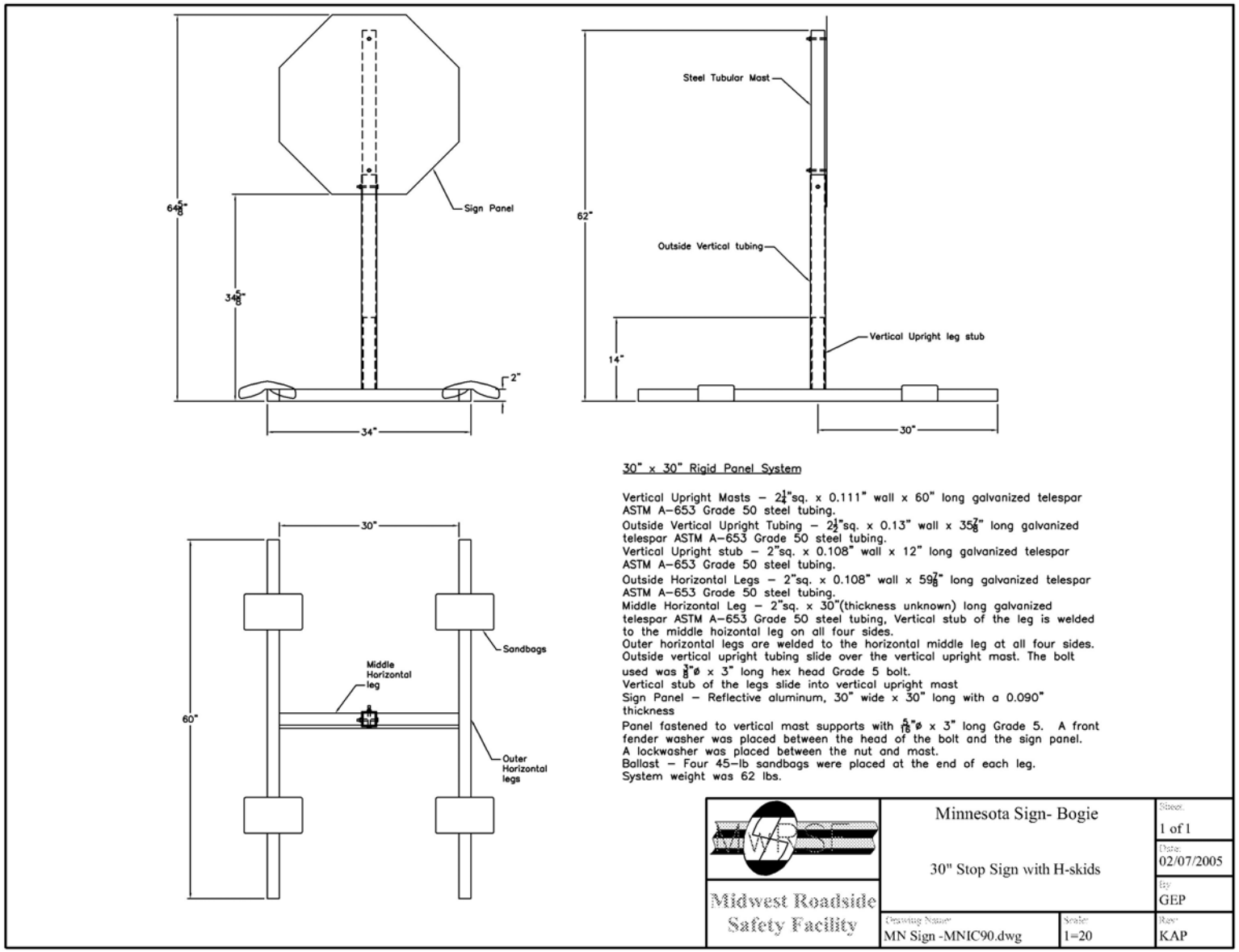

Figure 5. Stop Sign System Design Details, Bogie Test MN1C-90

Figure 6. Stop Sign System Damage, Bogie Test MN1C-0 (0 degrees)

Figure 7. Stop Sign System Damage, Bogie Test MN1C-90 (90 degrees)

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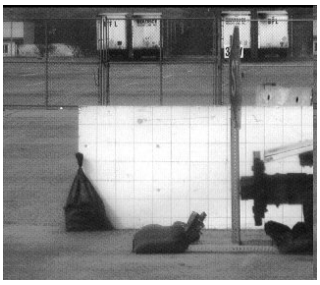

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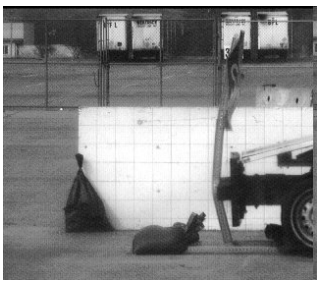
0.020 sec



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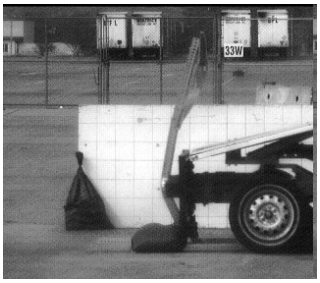
0.042 sec



0.020 sec

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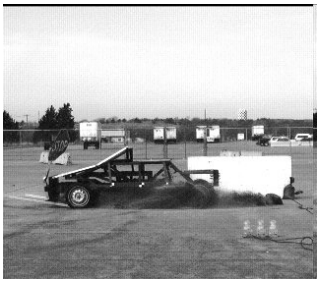
0.036 sec



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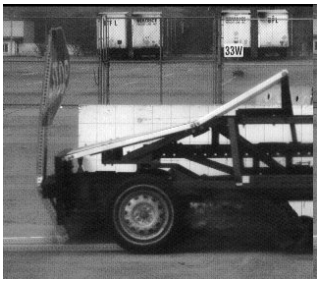


0.054 sec

Figure 8. Sequential Photographs – 0 degree orientation, Bogie Test MN1C-0

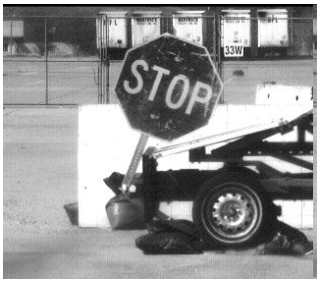
0.000 sec

0.000 sec

0.010 sec

0.012 sec

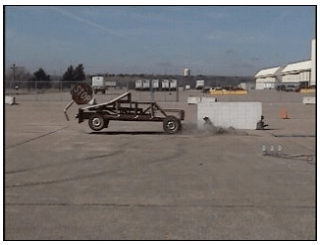
0.028 sec



0.028 sec

0.060 sec

0.040 sec



0.122 sec

0.054 sec

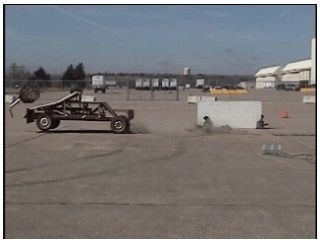


Figure 9. Sequential Photographs – 90 degree orientation, Bogie Test MN1C-90

6 PERFORMANCE ANALYSIS OF THE MINNESOTA DEPARTMENT OF TRANSPORTATION'S ROUTE MARKER ASSEMBLY SYSTEM

Bogie Test MN2C-0 (Head-on device)

1. System: Route Marker Assembly System
   - Vertical Upright Masts – 57.2 mm (2.25 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.54 mm (0.10 in.) wall thickness and a length of 1,826 mm (71.875 in.).
   - Outside Vertical Upright Tubing – 63.5 mm (2.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.56 mm (0.140 in.) wall thickness and a length of 921 mm (36.25 in.).
   - Legs, Outer Horizontal Portion – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.72 mm (0.107 in.) thickness and a length of 1,524 mm (60 in.).
   - Legs, Middle Horizontal Portion - 50.8 mm (2.0 in) sq. x 762 mm (30 in) long galvanized telespar ASTM A-653 Grade 50 steel tubing.
   - Legs, Vertical Stub – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.79 mm (0.110 in.) thickness and a length of 305 mm (12 in.).
   - Vertical stub of the leg is welded to the middle horizontal portion of the leg on all four sides, and the horizontal middle portion of the leg is welded to the outer horizontal portion of the legs on all four sides.
   - Outside vertical upright tubing slide over the vertical upright mast - 9.5 mm (0.375 in.) diameter x 76.2 mm (3 in.) long hex head Grade 5 bolt were used to fasten the outer vertical upright tube to the mast.
   - Vertical portion of legs slide into vertical upright masts.

   Sign: Rigid
   - Panel No. 1 - Rigid aluminum, 610 mm (24 in.) wide x 305 mm (12 in.) tall with a 2.44 mm (0.096 in.) thickness.
   - Panel No. 2 - Rigid aluminum, 610 mm (24 in.) wide x 606 mm (23.875 in.) tall with a 2.59 mm (0.102 in.) thickness.
   - Panel No. 3 - Rigid aluminum, 533 mm (21 in.) wide x 368 mm (15 in.) tall with a 3.53 mm (0.139 in) thickness.
   - Panels fastened to vertical mast support with two 7.9 mm (0.3125 in) diameter x 76.2 mm (3 in.) long Grade 5 bolts. A front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.

   Height to Bottom of Bottom Sign: 562 mm (22.125 in.)
   Height to Top of Outer Tube: 972 mm (38.25 in.)
   Height to Top of Top Sign: 1,883 mm (74.125 in.)

2. Weights of Sign System

Legs:	13.154 kg (29 lbs)
Panel, Mast, and Outside Tubes:	15.876 kg (35 lbs)
Total System Weight:	29.030 kg (64 lbs)
Ballast (sandbags):	20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 3/17/04

5. Impact Speed: 101.5 km/h (63.0 mph)
   Impact Orientation: 0 degrees

6. Velocity Change: 7.0 km/h (4.4 mph)

7. System Performance – Minor mast deformation was observed. The sign panels, mast, and legs remained intact. The top of the sign panels and mast rotated toward the vehicle, but no contact nor damage to the windshield was observed. Throughout the entire test, the system remained in front of the vehicle and never became a potential hazard to the bogie nor the occupant compartment.

Bogie Test MN2C-90 (End-on device)

1. System: Route Marker Assembly System
   - Vertical Upright Masts – 57.2 mm (2.25 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.82 mm (0.111 in.) wall thickness and a length of 1,826 mm (71.875 in.).
   - Outside Vertical Upright Tubing – 63.5 mm (2.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.56 mm (0.140 in.) wall thickness and a length of 924 mm (36.375 in.).
   - Legs, Outer Horizontal Portion – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.72 mm (0.110 in.) thickness and a length of 1,524 mm (60 in.).
   - Legs, Middle Horizontal Portion - 50.8 mm (2.0 in) sq. x 762 mm (30 in) long galvanized telespar ASTM A-653 Grade 50 steel tubing.
   - Legs, Vertical Stub – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.77 mm (0.109 in.) thickness and a length of 305 mm (12 in.).
   - Vertical stub of the leg is welded to the middle horizontal portion of the leg on all four sides, and the horizontal middle portion of the leg is welded to the outer horizontal portion of the legs on all four sides.

- Outside vertical upright tubing slide over the vertical upright mast - 9.5 mm (0.375 in.) diameter x 76.2 mm (3 in.) long hex head Grade 5 bolt were used to fasten the outer vertical upright tube to the mast.
- Vertical portion of legs slide into vertical upright masts.

Sign: Rigid

- Panel No. 1 - Rigid aluminum, 610 mm (24 in.) wide x 305 mm (12 in.) tall with a 2.46 mm (0.097 in.) thickness.
- Panel No. 2 - Rigid aluminum, 610 mm (24 in.) wide x 606 mm (23.875 in.) tall with a 2.44 mm (0.096 in.) thickness.
- Panel No. 3 - Rigid aluminum, 533 mm (21 in.) wide x 368 mm (15 in.) tall with a 2.31 mm (0.091 in) thickness.
- Panels fastened to vertical mast support with two 7.9 mm (0.3125 in) diameter x 76.2 mm (3 in.) long Grade 5 bolts. A front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.

Height to Bottom of Bottom Sign: 568 mm (22.375 in.)
Height to Top of Outer Tube: 975 mm (38.375 in.)
Height to Top of Top Sign: 1,876 mm (73.875 in.)

2. Weights of Sign Systems

Legs:	14.515 kg (32 lbs)
Panel, Mast, and Outside Tubes:	16.329 kg (36 lbs)
Total System Weight:	30.844 kg (68 lbs)
Ballast (sandbags):	20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 3/17/04

5. Impact Speed: 100.4 km/h (62.4 mph)
   Impact Orientation: 90 degrees

6. Velocity Change: 8.0 km/h (5.0 mph)

7. System Performance – Minor mast and panel deformations were observed. The mast disengaged completely from the base. The top of the sign panels and mast rotated toward the vehicle and contacted the hood, but no contact nor damage to the simulated windshield was observed. After contact with the hood, the system rebounded off the bogie and traveled up and away from the bogie and was never considered to be a potential hazard to the bogie nor the occupant compartment.

Figure 10. Route Marker Assembly System, Bogie Tests MN2C-0 and MN2C-90

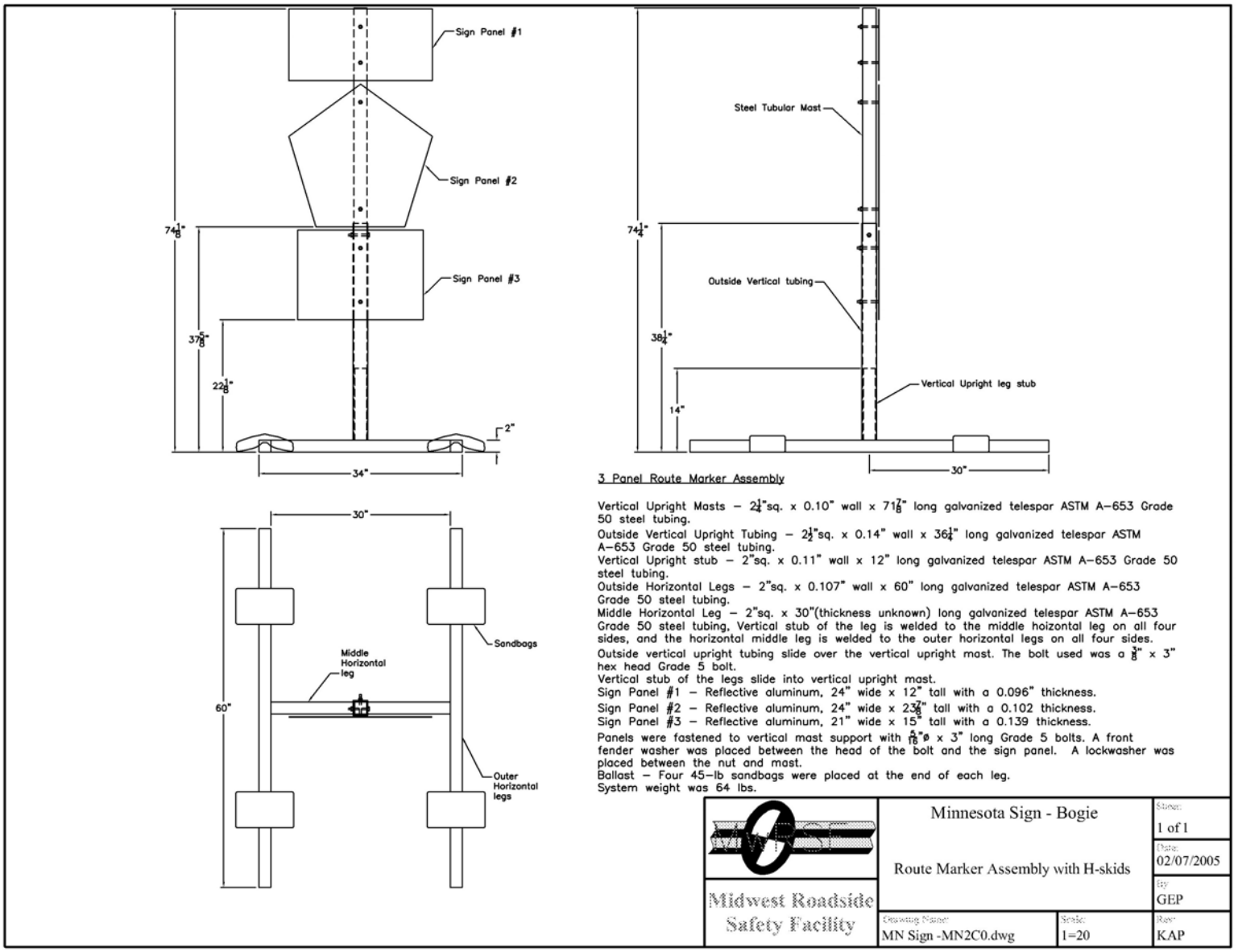


Figure 11. Route Marker Assembly System Design Details, Bogie Test MN2C-0

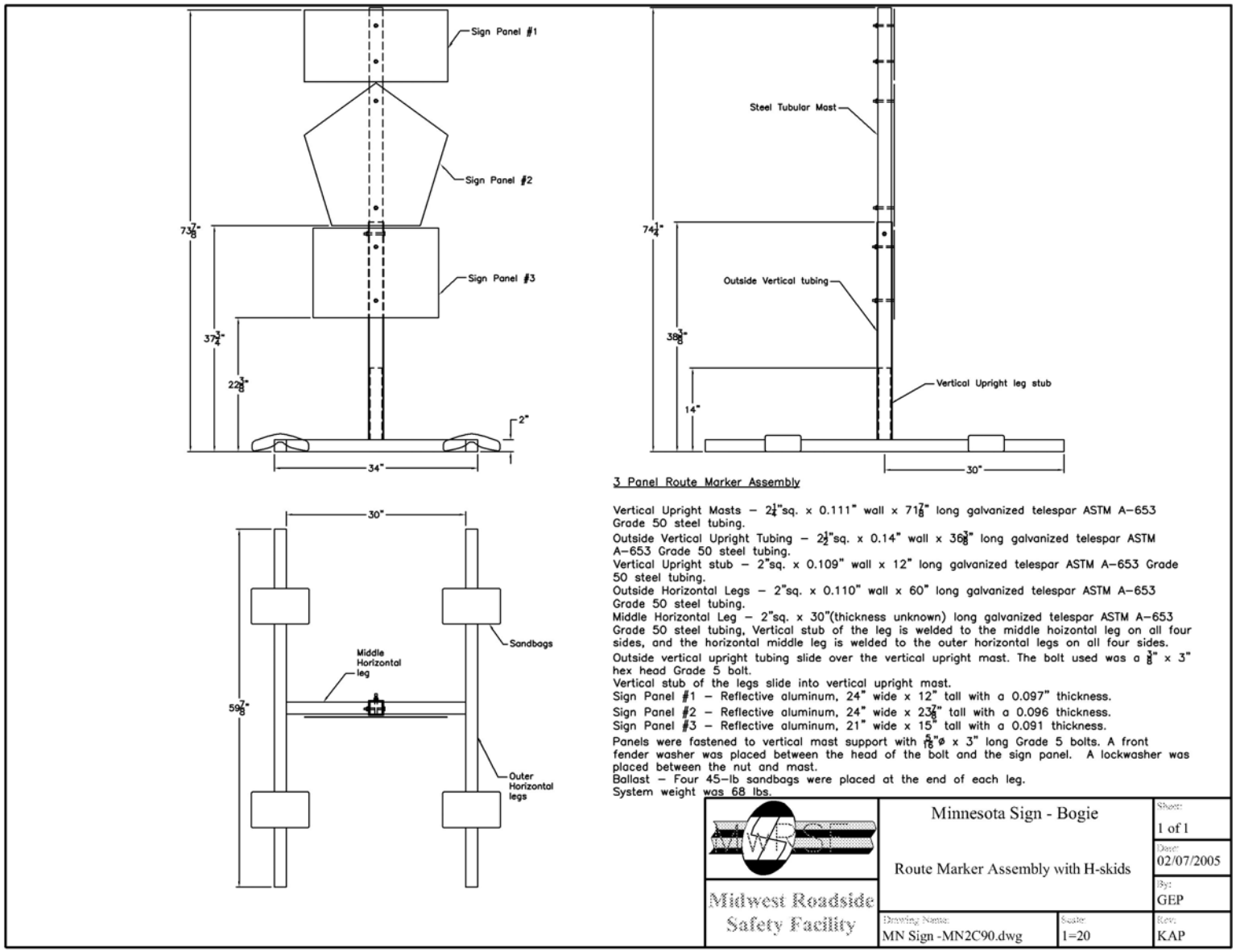


Figure 12. Route Marker Assembly System Design Details, Bogie Test MN2C-90

Figure 13. Route Marker Assembly System Damage, Bogie Test MN2C-0 (0 degrees)

Figure 14. Route Marker Assembly System Damage, Bogie Test MN2C-90 (90 degrees)

0.000 sec

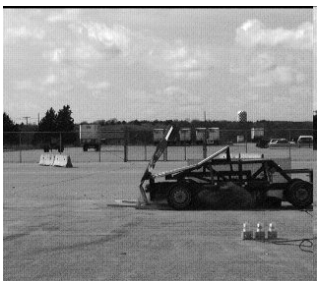
0.000 sec

0.020 sec

0.004 sec

0.038 sec

0.022 sec



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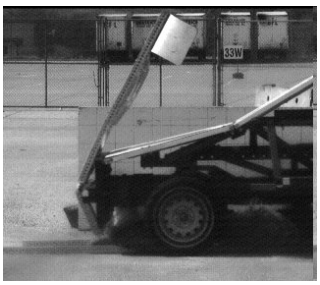

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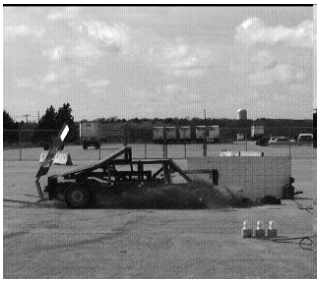


0.158 sec

0.060 sec

Figure 15. Sequential Photographs – 0 degree orientation, Bogie Test MN2C-0

0.000 sec

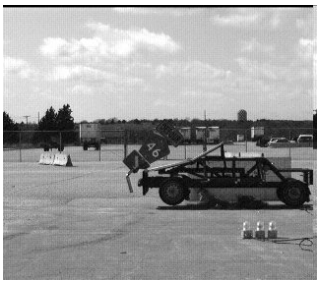
0.000 sec

0.020 sec

0.014 sec

0.042 sec

0.028 sec



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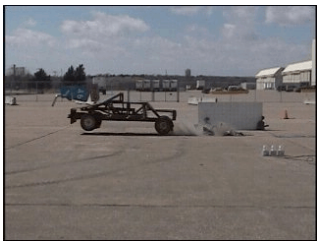

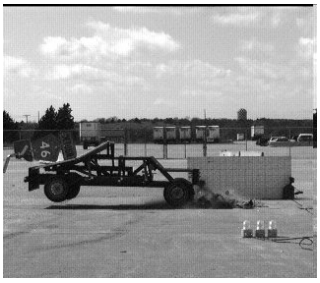

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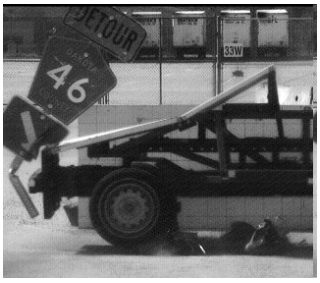


0.060 sec

Figure 16. Sequential Photographs – 90 degree orientation, Bogie Test MN2C-90

7 PERFORMANCE ANALYSIS OF THE MINNESOTA DEPARTMENT OF TRANSPORTATION'S 24" x 36" AND 48" x 36" WORK ZONE SPEED LIMIT SYSTEM

Bogie Test MN3B-0-2 (Head-on device)

1. System: 24" x 36" and 48" x 36" Work Zone Speed Limit System
   - Vertical Upright Masts – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.38 mm (0.133 in.) wall thickness and a length of 2,337 mm (92 in.).
   - Outside Vertical Upright Tubing – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 4.01 mm (0.158 in.) wall thickness and a length of 914 mm (36 in.).
   - Legs, Horizontal Portion – 38.1 mm (1.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.10 mm (0.122 in.) thickness and a length of 1,524 mm (60 in.).
   - Legs, Vertical Stub – 38.1 mm (1.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.88 mm (0.113 in.) thickness and a length of 302 mm (11.875 in.).
   - Vertical stub of the leg is welded to the horizontal portion of the leg on all four sides
   - Outside vertical upright tubing slide over the vertical upright mast - 9.5 mm (0.375 in.) diameter x 63.5 mm (2.5 in.) long hex head Grade 5 bolt were used to fasten the outer vertical upright tube to the mast.
   - Vertical portion of legs slide into vertical upright masts.

   Sign: Rigid
   - Panel No. 1 - Rigid aluminum, 914 mm (36 in.) wide x 610 mm (24 in.) tall with a 3.10 mm (0.122 in.) thickness.
   - Panel No. 2 - Rigid aluminum, 914 mm (36 in.) wide x 1,219 mm (48 in.) tall with a 2.59 mm (0.102 in.) thickness.
   - Panels fastened to vertical mast support with four 7.9 mm (0.3125 in) diameter x 63.5 mm (2.5 in.) long Grade 5 plug bolts. A 31.75 mm (1.25 in.) O.D. x 3.2 mm (0.125 in.) thick washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.

   Height to Bottom of Bottom Sign: 619 mm (24.375 in.)
   Height to Top of Outer Tube: 949 mm (37.375 in.)
   Height to Top of Top Sign: 2,451 mm (96.5 in.)

2. Weights of Sign System

Legs:	9.072 kg (20 lbs)
Panels, Masts, and Outside Tubes:	30.391 kg (67 lbs)
Total System Weight:	39.463 kg (87 lbs)

Ballast (sandbags): 20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 9/24/04

5. Impact Speed: 98.6 km/h (61.3 mph)
   Impact Orientation: 0 degrees

6. Velocity Change: 5.2 km/h (3.2 mph)

7. System Performance – Minor mast deformation was observed. The sign panels, masts, and legs remained intact. The top of the sign panels and masts rotated toward the vehicle and contacted the roof, but no contact nor damage to the simulated windshield was observed. After contact with the roof, the system rebounded off the bogie and traveled up and away from the bogie and was never considered to be a potential hazard to the bogie nor the occupant compartment.

Bogie Test MN3B-90 (End-on device)

1. System: 24" x 36" and 48" x 36" Work Zone Speed Limit System
   - Vertical Upright Masts – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.38 mm (0.133 in.) wall thickness and a length of 2,337 mm (92 in.).
   - Outside Vertical Upright Tubing – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.92 mm (0.115 in.) wall thickness and a length of 914 mm (36 in.).
   - Legs, Horizontal Portion – 38.1 mm (1.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.72 mm (0.107 in.) thickness and a length of 1,524 mm (60 in.).
   - Legs, Vertical Stub – 38.1 mm (1.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.84 mm (0.112 in.) thickness and a length of 302 mm (11.875 in.).
   - Vertical stub of the leg is welded to the horizontal portion of the leg on all four sides
   - Outside vertical upright tubing slide over the vertical upright mast - 9.5 mm (0.375 in.) diameter x 63.5 mm (2.5 in.) long hex head Grade 5 bolt were used to fasten the outer vertical upright tube to the mast.
   - Vertical portion of legs slide into vertical upright masts.

   Sign: Rigid
   - Panel No. 1 - Rigid aluminum, 914 mm (36 in.) wide x 610 mm (24 in.) tall with a 3.05 mm (0.120 in.) thickness.

- Panel No. 2 - Rigid aluminum, 914 mm (36 in.) wide x 1,219 mm (48 in.) tall with a 2.74 mm (0.108 in.) thickness.
- Panels fastened to vertical mast support with four 7.9 mm (0.3125 in) diameter x 63.5 mm (2.5 in.) long Grade 5 plug bolts. A 31.75 mm (1.25 in.) O.D. x 3.2 mm (0.125 in.) thick washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.

Height to Bottom of Bottom Sign: 616 mm (24.25 in.)
Height to Top of Outer Tube: 949 mm (37.375 in.)
Height to Top of Top Sign: 2,445 mm (96.25 in.)

2. Weights of Sign Systems

Legs:	9.072 kg (20 lbs)
Panels, Masts, and Outside Tubes:	31.298 kg (69 lbs)
Total System Weight:	40.370 kg (89 lbs)
Ballast (sandbags):	20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 9/22/04

5. Impact Speed: 99.8 km/h (62.0 mph)
   Impact Orientation: 90 degrees

6. Velocity Change: 3.3 km/h (2.0 mph)

7. System Performance – Mast and panel deformations were observed. One side of the legs fractured. The impacted side of the sign panels and masts rotated toward the vehicle and contacted the roof, but no contact nor damage to the simulated windshield was observed. After contact with the roof, the system rebounded off the bogie and traveled up and away from the bogie and was never considered to be a potential hazard to the bogie nor the occupant compartment.

Figure 17. Work Zone Speed Limit Sign System, Bogie Tests MN3B-0-2 and MN3B-90

Figure 18. Work Zone Speed Limit Sign System, Bogie Tests MN3B-0-2 and MN3B-90

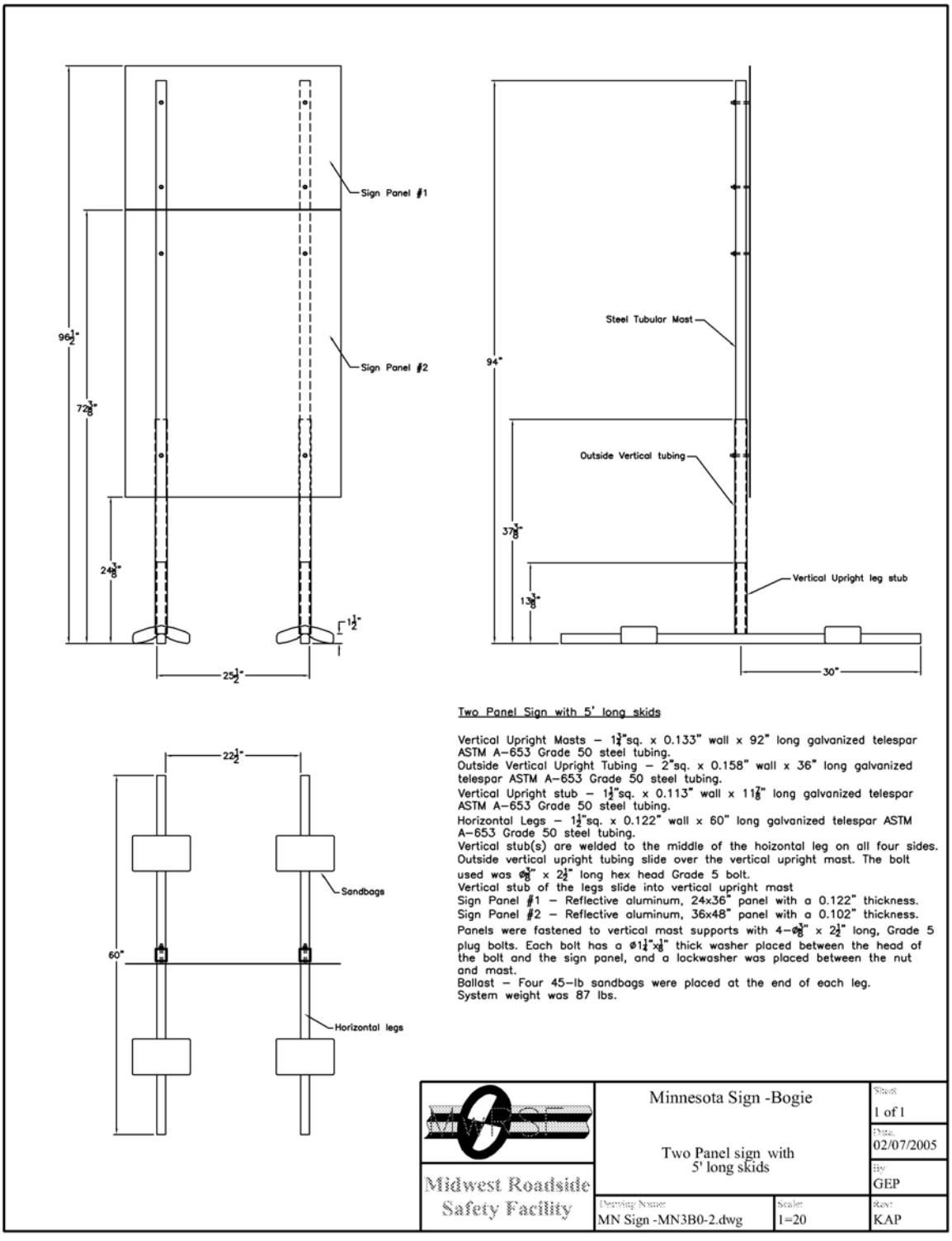


Figure 19. Work Zone Speed Limit Sign System, Bogie Test MN3B-0-2

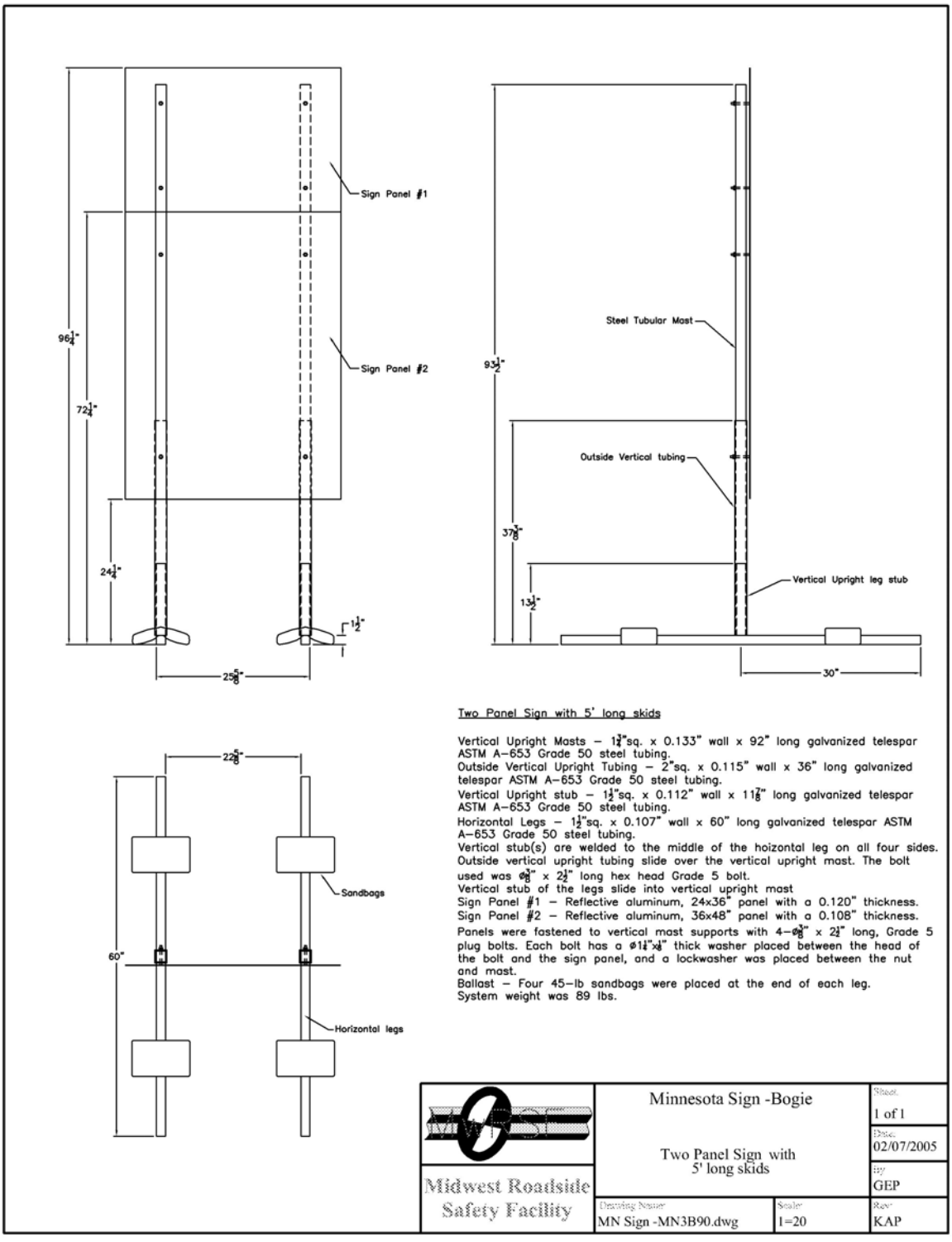


Figure 20. Work Zone Speed Limit Sign System, Bogie Test MN3B-90

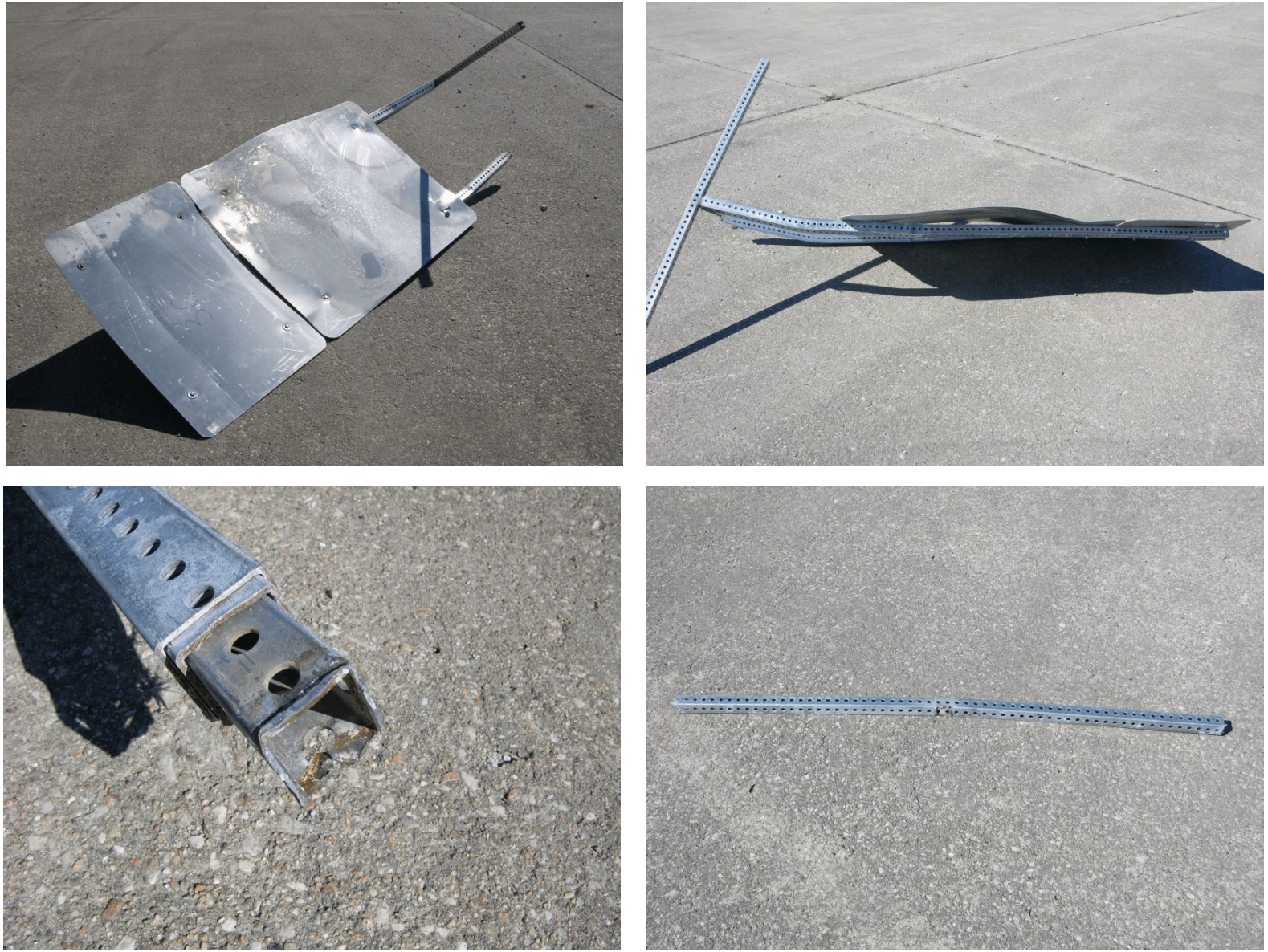


Figure 21. Work Zone Speed Limit Sign System Damage, Bogie Test MN3B-0-2 (0 degrees)

Figure 22. Work Zone Speed Limit Sign System Damage, Bogie Test MN3B-90 (90 degrees)

0.000 sec

0.000 sec

0.028 sec

0.008 sec

0.054 sec

0.044 sec

0.138 sec

0.072 sec

0.258 sec

0.100 sec

Figure 23. Sequential Photographs – 0 degree orientation, Bogie Test MN3B-0-2

0.000 sec

0.000 sec

0.020 sec

0.010 sec

0.078 sec

0.026 sec

0.186 sec

0.072 sec

0.260 sec

0.152 sec

Figure 24. Sequential Photographs – 90 degree orientation, Bogie Test MN3B-90

8 PERFORMANCE ANALYSIS OF THE MINNESOTA DEPARTMENT OF TRANSPORTATION'S 36" x 36" DIAMOND PANEL WORK ZONE SYSTEM

Bogie Test MN5A-0 (Head-on device)

1. System: 36" x 36" Diamond Panel Work Zone System
   - Vertical Upright Masts – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.79 mm (0.110 in.) wall thickness and a length of 1,524 mm (60 in.).
   - Outside Vertical Upright Tubing – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.30 mm (0.130 in.) wall thickness and a length of 914 mm (36 in.).
   - Legs, Horizontal Portion – 38.1 mm (1.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.79 mm (0.110 in.) thickness and a length of 1,524 mm (60 in.).
   - Legs, Vertical Stub – 38.1 mm (1.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.79 mm (0.110 in.) thickness and a length of 302 mm (11.875 in.).
   - Vertical stub of the leg is welded to the horizontal portion of the leg on all four sides
   - Outside vertical upright tubing slide over the vertical upright mast - 9.5 mm (0.375 in.) diameter x 63.5 mm (2.5 in.) long hex head Grade 5 bolt was used to fasten the outer vertical upright tube to the mast.
   - Vertical portion of legs slide into vertical upright masts.

   Sign: Rigid
   - Panel - Rigid aluminum, 914 mm (36 in.) wide x 914 mm (36 in.) wide with a 2.79 mm (0.110 in.) thickness.
   - Panel fastened to vertical mast support with four 7.9 mm (0.3125 in) diameter x 63.5 mm (2.5 in.) long Grade 5 plug bolt. A front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.
   - Warning Light – "Toughlite 2000" attached to the sign panel.

   Height to Bottom of Sign: 740 mm (29.125 in.)
   Height to Top of Outer Tube: 953 mm (37.5 in.)
   Height to Top of Sign: 1,988 mm (78.25 in.)

2. Weights of Sign System

Legs:	9.072 kg (20 lbs)
Panel, Masts, and Outside Tubes:	21.772 kg (48 lbs)
Warning Light:	1.814 kg (4 lbs)
Total System Weight:	32.658 kg (72 lbs)

Ballast (sandbags): 20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 3/17/04

5. Impact Speed: ~ 100 km/h (61.3 mph)
   Impact Orientation: 0 degrees

6. Velocity Change: ~5 km/h (3 mph)

7. System Performance – Minor mast deformation was observed. The sign panel, masts, and legs remained intact. The top of the sign panel and masts rotated toward the vehicle, but no contact nor damage to the simulated windshield was observed. Throughout the entire test, the system remained in front of the vehicle and never became a potential hazard to the bogie nor the occupant compartment.

Bogie Test MN5C-90-2 (End-on device)

1. System: 36" x 36" Diamond Panel Work Zone System
   - Vertical Upright Masts – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.79 mm (0.110 in.) wall thickness and a length of 1,524 mm (60 in.).
   - Outside Vertical Upright Tubing – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.30 mm (0.130 in.) wall thickness and a length of 914 mm (36 in.).
   - Legs, Horizontal Portion – 38.1 mm (1.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.79 mm (0.110 in.) thickness and a length of 1,524 mm (60 in.).
   - Legs, Vertical Stub – 38.1 mm (1.5 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.79 mm (0.110 in.) thickness and a length of 302 mm (11.875 in.).
   - Horizontal Bumper Strut – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.79 mm (0.110 in.) wall thickness and a length of 632 mm (24.875 in.).
   - Vertical stub of the leg is welded to middle of the horizontal portion of the leg on all four sides.
   - Outside vertical upright tubing slide over the vertical upright mast
   - Horizontal bumper strut is bolted to the vertical masts and outer tubing with two 9.5 mm (0.375 in.) diameter x 114 mm (4.5 in.) long hex head Grade 5 bolts with a washer between both the bolt head and mast and the nut and mast.
   - Vertical portion of legs slide into vertical upright masts.

Sign: Rigid

- Panel - Rigid aluminum, 914 mm (36 in.) wide x 914 mm (36 in.) wide with a 2.54 mm (0.100 in.) thickness.
- Panel fastened to vertical mast support with four 7.9 mm (0.3125 in) diameter x 63.5 mm (2.5 in.) long Grade 5 plug bolt. A front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.
- Warning Light – "Toughlite 2000" attached to the sign panel.

Height to Bottom of Sign:	740 mm (29.125 in.)
Height to Top of Outer Tube:	953 mm (37.5 in.)
Height to Top of Sign:	1,988 mm (78.25 in.)

2. Weights of Sign Systems

Legs:	9.072 kg (20 lbs)
Panel, Masts, Outside Tubes, and Struts:	23.586 kg (52 lbs)
Warning Light:	1.814 kg (4 lbs)
Total System Weight:	34.473 kg (76 lbs)
Ballast (sandbags):	20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 3/23/05

5. Impact Speed: 100.7 km/h (62.6 mph)
   Impact Orientation: 90 degrees

6. Velocity Change: 4.3 km/h (2.7 mph)

7. System Performance – Minor mast and panel deformations were observed. The leg on the impact side fractured. The bumper strut disengaged from the rest of the system and remained embedded in the bumper of the bogie. The impacted side of the sign panel and masts rotated toward the vehicle, but no contact nor damage to the simulated windshield was observed. Throughout the entire test, the system remained in front of the vehicle and never became a potential hazard to the bogie nor the occupant compartment.

Acceptable System Modifications for Bogie Tests MN5A-0 and MN5C-90-2

It should be noted that the 90-degree orientation of the original system did not perform satisfactorily. Thus, the system design was modified and performed satisfactorily as shown in bogie

test MN5C-90-2. However, the 0-degree orientation of the modified system tested in bogie test MN5C-90-2 was not tested. It was believed that adding the bumper strut to the system would not affect the performance of the 0-degree orientation test of this system. Therefore, it is believed that the system would perform similarly to that behavior observed in the bogie test results of the original system, bogie test MN5A-0. The final design is shown in Figures 27 and 29.

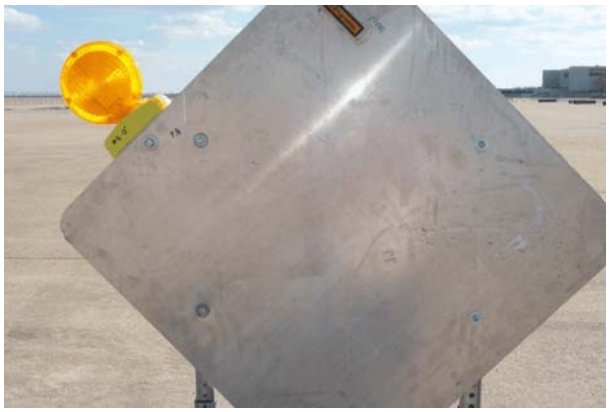


Figure 26. 36" x 36" Diamond Work Zone Sign System, Bogie Tests MN5A-0

Figure 27. 36" x 36" Diamond Work Zone Sign System, Bogie Tests MN5C-90-2

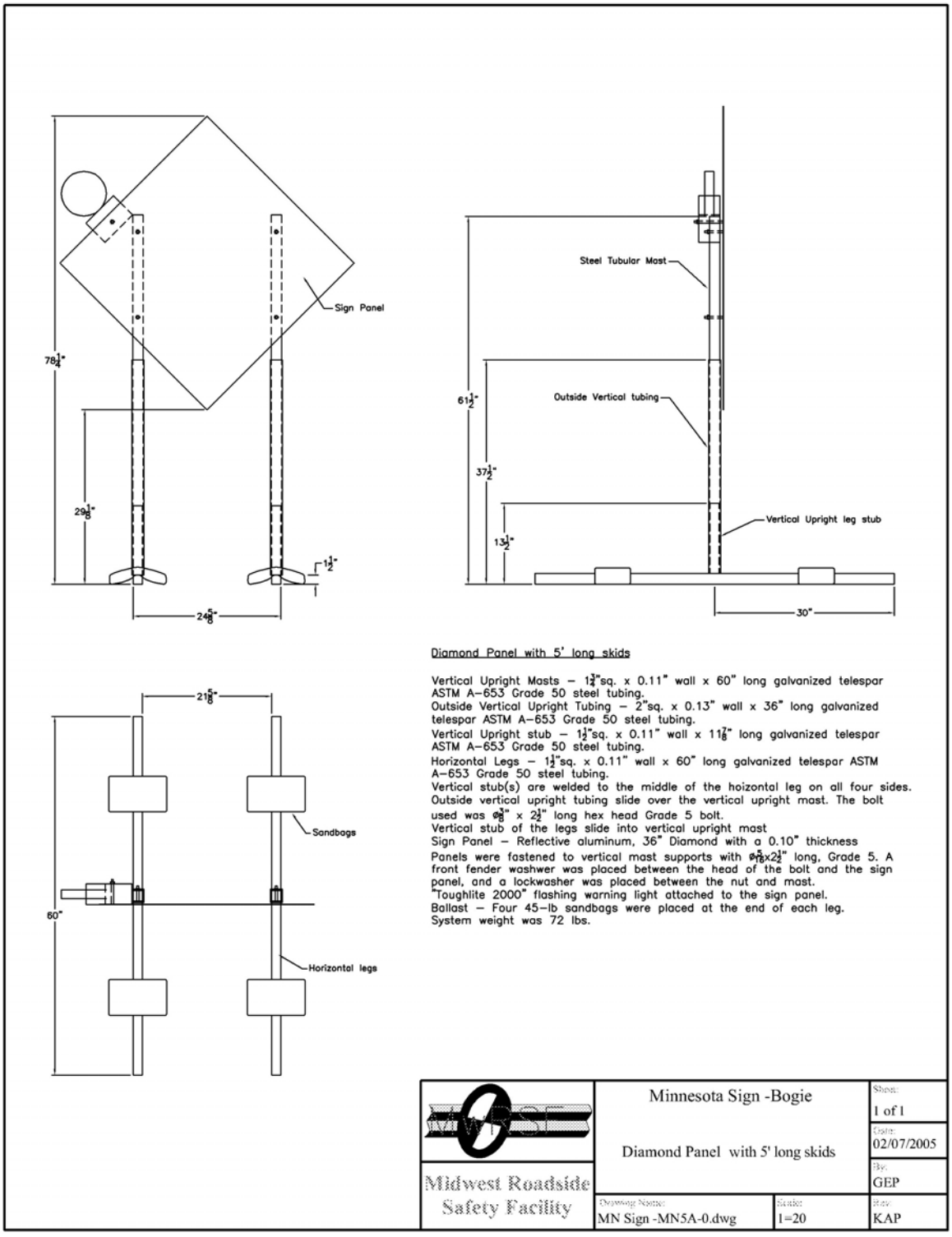


Figure 28. 36" x 36" Diamond Work Zone Sign System, Bogie Test MN5A-0

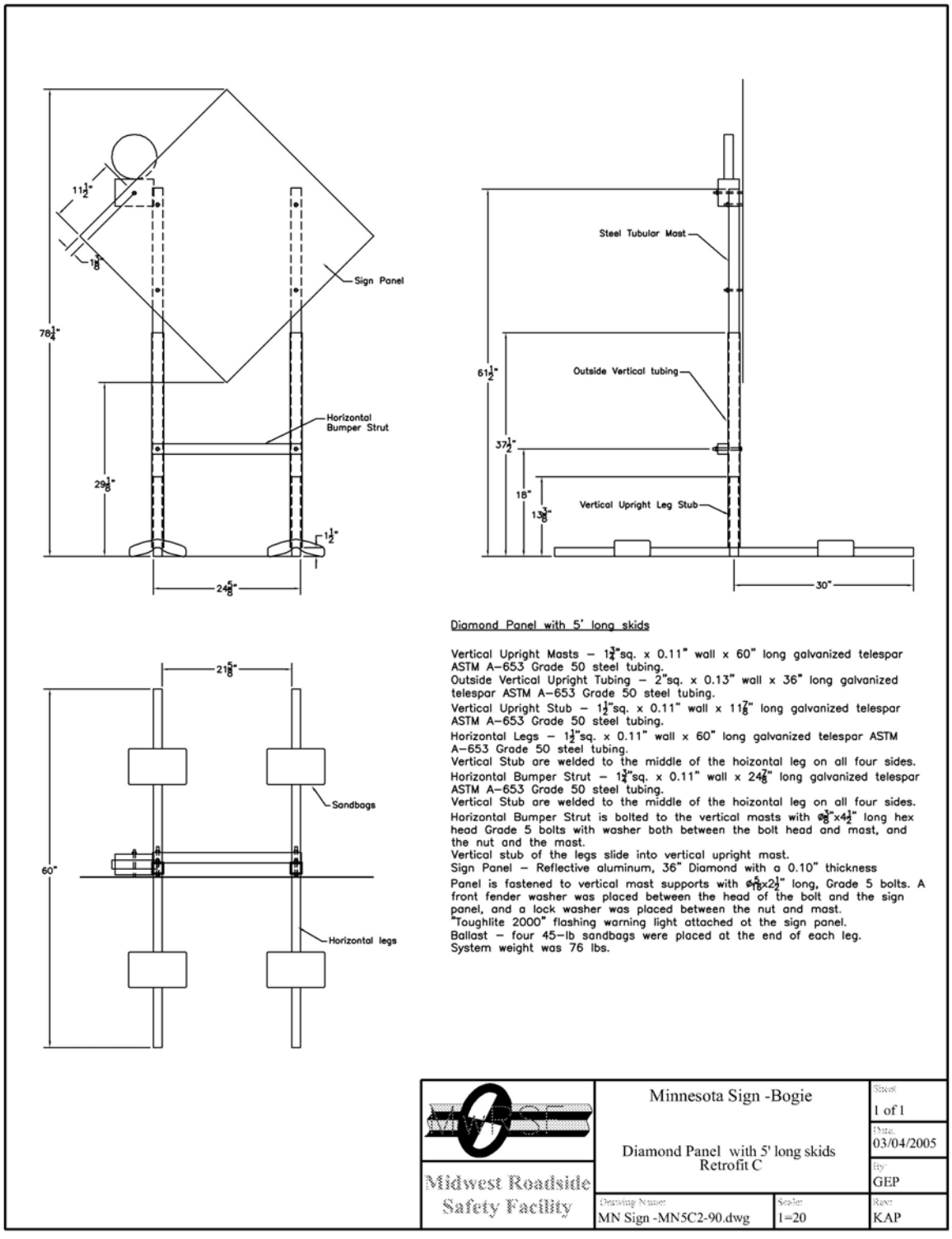


Figure 29. 36" x 36" Diamond Work Zone Sign System, Bogie Test MN5C-90-2

Figure 30. 36" x 36" Diamond Work Zone Sign System Damage, Bogie Tests MN5A-0

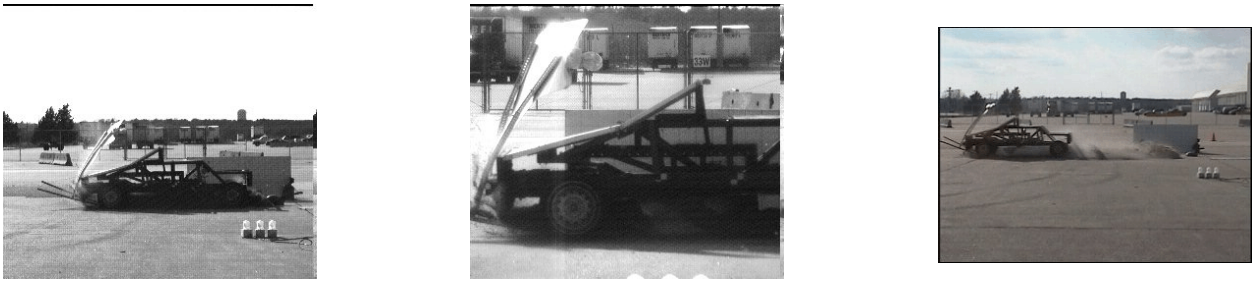
Figure 31. 36" x 36" Diamond Work Zone Sign System Damage, Bogie Tests MN5C-90-2

0.000 sec 0.000 sec

0.022 sec 0.010 sec

0.050 sec 0.018 sec

0.088 sec 0.038 sec



0.136 sec 0.068 sec

Figure 32. Sequential Photographs – 0 degree orientation, Bogie Test MN5A-0

0.000 sec

0.000 sec

0.018 sec

0.012 sec

0.042 sec

0.024 sec

0.096 sec

0.048 sec

0.136 sec

0.062 sec

Figure 33. Sequential Photographs – 90 degree orientation, Bogie Test MN5C-90-2

9 PERFORMANCE ANALYSIS OF THE MINNESOTA DEPARTMENT OF TRANSPORTATION'S 48" x 48" DIAMOND PANEL WORK ZONE SYSTEM WITH 5' MOUNTING HEIGHT

Bogie Test MN6A-0 (Head-on device)

1. System: 48" x 48" Diamond Panel Work Zone System with 5' Mounting Height
   - Vertical Upright Masts – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.73 mm (0.147 in.) wall thickness and a length of 2,740 mm (107.875 in.).
   - Outside Vertical Upright Tubing – 57.2 mm (2.25 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.30 mm (0.130 in.) wall thickness and a length of 914 mm (36 in.).
   - Legs, Horizontal Portion – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.84 mm (0.112 in.) thickness and a length of 1,829 mm (72 in.).
   - Legs, Vertical Stub – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.84 mm (0.112 in.) thickness and a length of 305 mm (12 in.).
   - Vertical stub of the leg is welded to the middle horizontal portion of the leg on all four sides.
   - Outside vertical upright tubing slide over the vertical upright mast - 9.5 mm (0.375 in.) diameter x 76.2 mm (3 in.) long hex head Grade 5 bolt were used to fasten the outer vertical upright tube to the mast.
   - Vertical portion of legs slide into vertical upright masts.

   Sign: Rigid
   - Panel - Rigid aluminum, 1,219 mm (48 in.) wide x 1,219 mm (48 in.) tall with a 2.57 mm (0.101 in.) thickness.
   - Panel fastened to vertical mast support with four 7.9 mm (0.3125 in) diameter x 76.2 mm (3 in.) long Grade 5 bolts. A front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.
   - Warning Light – "Toughlite 2000" attached to the sign panel.

   Height to Bottom of Sign: 1,565 mm (61.625 in.)
   Height to Top of Outer Tube: 965 mm (38 in.)
   Height to Top of Sign: 3,229 mm (127.125 in.)

2. Weights of Sign System

Legs:	12.701 kg (28 lbs)
Panel, Masts, Outside Tubes, and Light:	39.009 kg (86 lbs)
Total System Weight:	51.710 kg (114 lbs)

Ballast (sandbags): 20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 3/18/04

5. Impact Speed: 107.5 km/h (66.8 mph)
   Impact Orientation: 0 degrees

6. Velocity Change: 18.4 km/h (7.9 mph)

7. System Performance – Minor mast and panel deformations were observed. The sign panel, masts, and one leg remained intact. One leg disengaged from the rest of the system. The top of the sign panel and mast rotated toward the vehicle and lightly contacted the front of the roof, but no contact nor damage to the simulated windshield was observed. Throughout the entire test, the system remained in front of the vehicle and never became a potential hazard to the bogie nor the occupant compartment.

Bogie Test MN6A-90 (End-on device)

1. System: 48" x 48" Diamond Panel Work Zone System with 5' Mounting Height
   - Vertical Upright Masts – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.95 mm (0.116 in.) wall thickness and a length of 2,740 mm (107.875 in.).
   - Outside Vertical Upright Tubing – 57.2 mm (2.25 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.05 mm (0.120 in.) wall thickness and a length of 911 mm (35.875 in.).
   - Legs, Horizontal Portion – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.87 mm (0.113 in.) thickness and a length of 1,826 mm (71.875 in.).
   - Legs, Vertical Stub – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.87 mm (0.113 in.) thickness and a length of 305 mm (12 in.).
   - Vertical stub of the leg is welded to the middle horizontal portion of the leg on all four sides.
   - Outside vertical upright tubing slide over the vertical upright mast - 9.5 mm (0.375 in.) diameter x 76.2 mm (3 in.) long hex head Grade 5 bolt were used to fasten the outer vertical upright tube to the mast.
   - Vertical portion of legs slide into vertical upright masts.

   Sign: Rigid
   - Panel - Rigid aluminum, 1,219 mm (48 in.) wide x 1,219 mm (48 in.) tall with a 2.64 mm (0.104 in.) thickness.

- Panel fastened to vertical mast support with four 7.9 mm (0.3125 in) diameter x 76.2 mm (3 in.) long Grade 5 bolts. A front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.
- Warning Light – "Toughlite 2000" attached to the sign panel.

Height to Bottom of Sign: 1,568 mm (61.75 in.)
Height to Top of Outer Tube: 959 mm (37.75 in.)
Height to Top of Sign: 3,232 mm (127.25 in.)

2. Weights of Sign Systems

Legs:	13.154 kg (29 lbs)
Panel, Masts, Outside Tubes, and Light:	39.463 kg (87 lbs)
Total System Weight:	52.617 kg (116 lbs)
Ballast (sandbags):	20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 3/18/04

5. Impact Speed: 102.5 km/h (63.7 mph)
   Impact Orientation: 90 degrees

6. Velocity Change: 11.6 km/h (8.0 mph)

7. System Performance – Minor mast and panel deformations were observed. The impacted mast and leg disengaged completely from the system The non-impacted leg fractured. The top of the sign panel and mast rotated toward the vehicle and contacted the roof, but no contact nor damage to the simulated windshield was observed. After contact with the roof, the system rebounded off the bogie and traveled up and away from the bogie and was never considered to be a potential hazard to the bogie nor the occupant compartment.

Figure 34. 48" x 48" Diamond Panel Work Zone Sign System with 5' Mounting Height, Bogie Tests MN6A-0 and MN6A-90

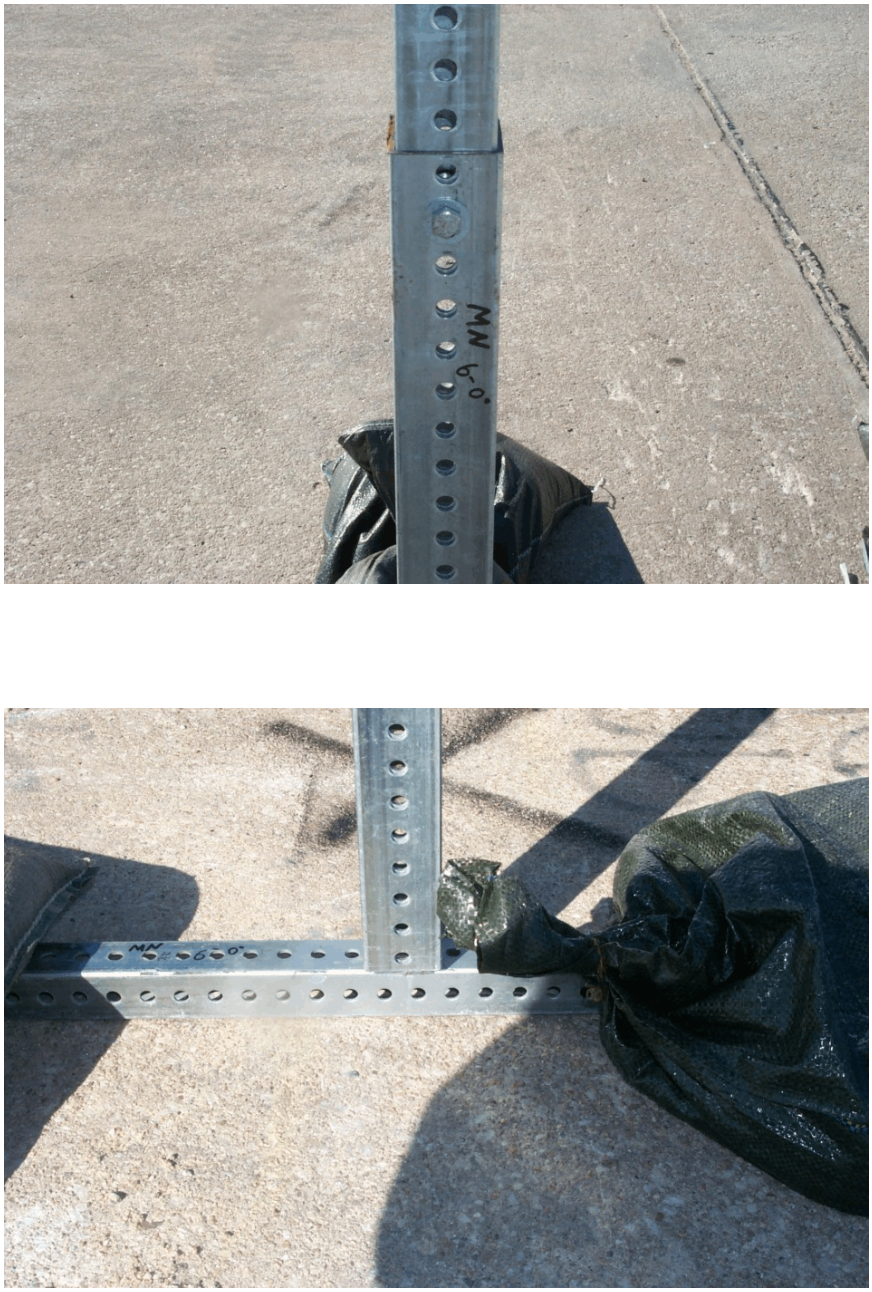


Figure 35. 48" x 48" Diamond Panel Work Zone Sign System with 5' Mounting Height, Bogie Tests MN6A-0 and MN6A-90

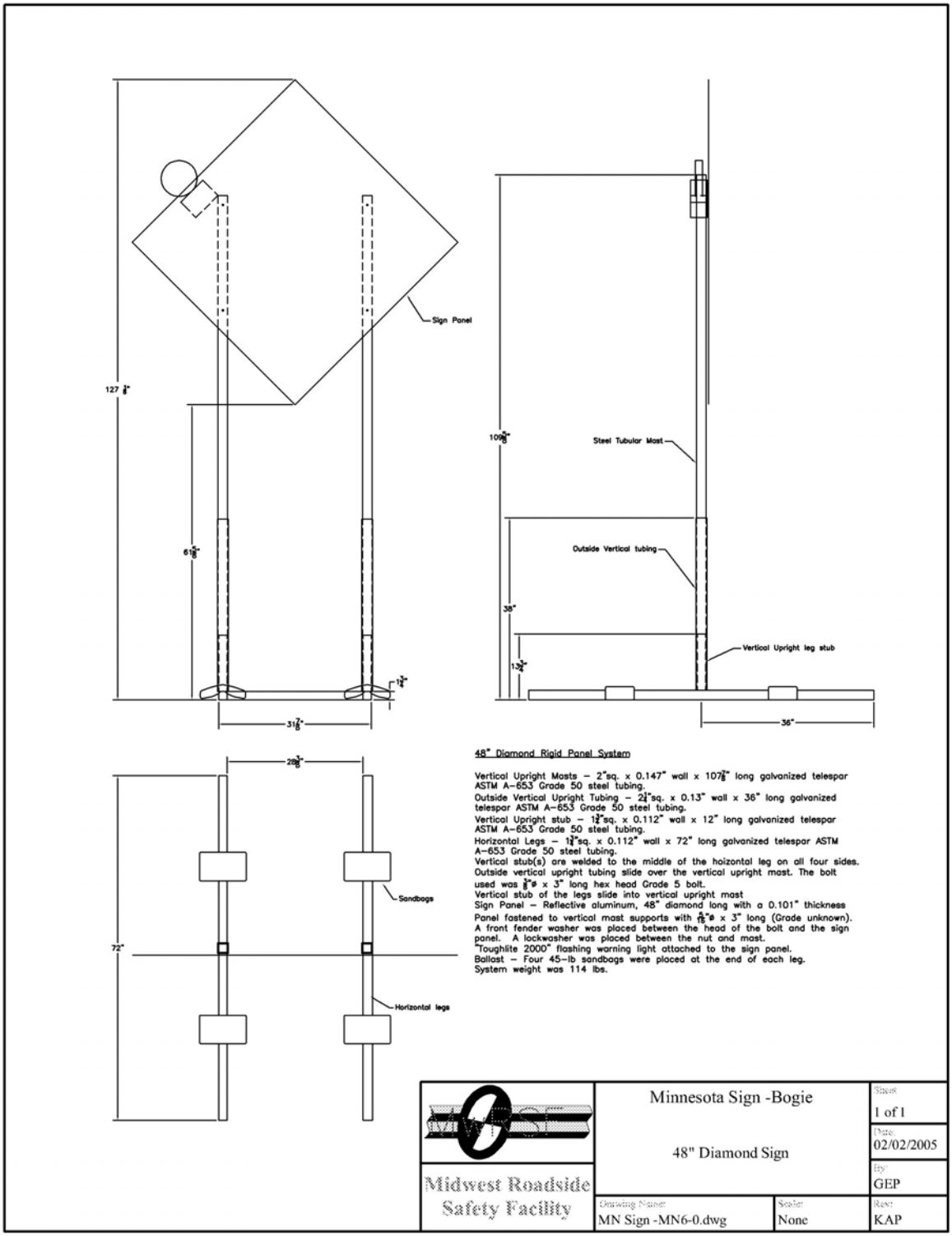


Figure 36. 48" x 48" Diamond Panel Work Zone Sign System with 5' Mounting Height Design Details, Bogie Test MN6A-0

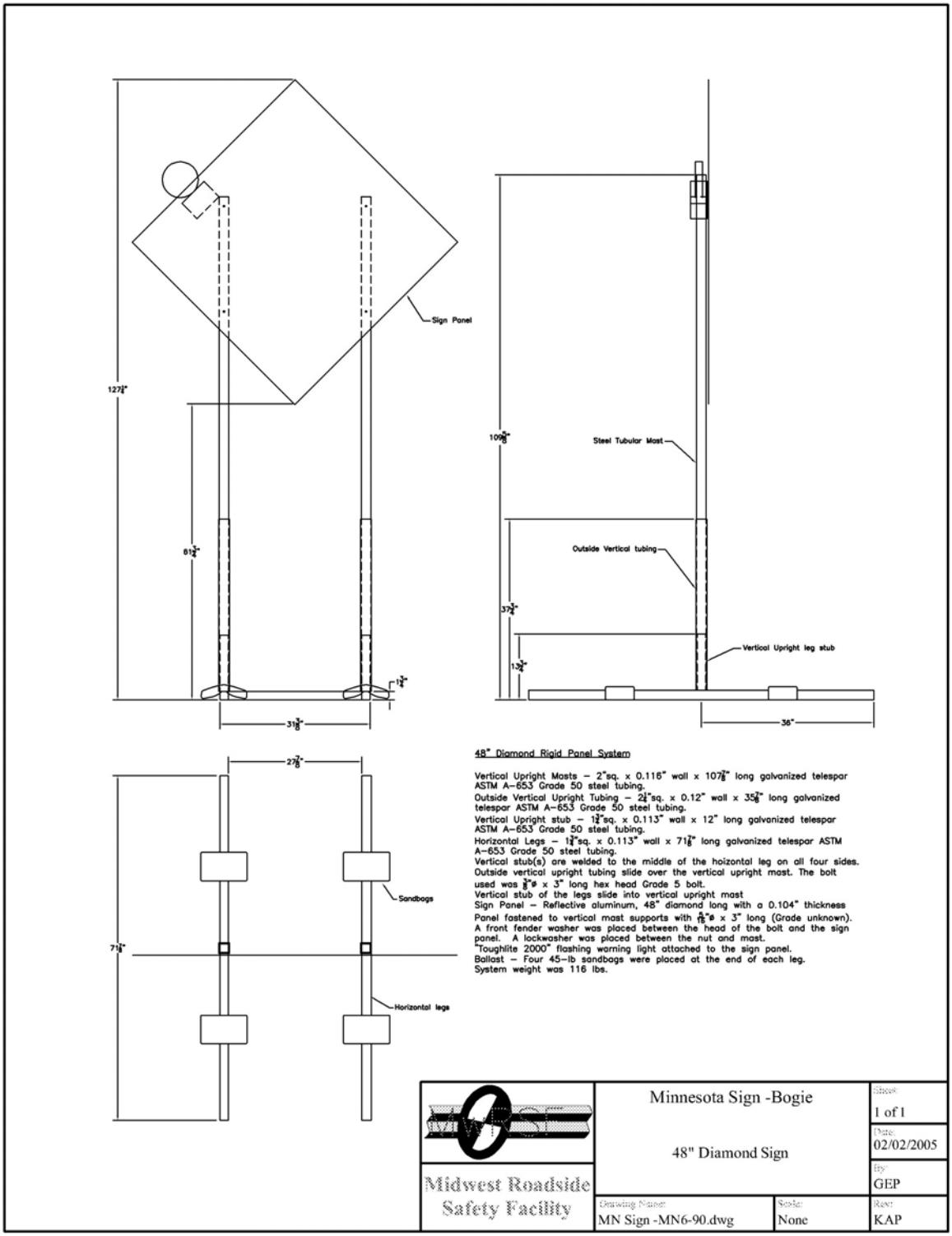


Figure 37. 48" x 48" Diamond Panel Work Zone Sign System with 5' Mounting Height Design Details, Bogie Test MN6A-90

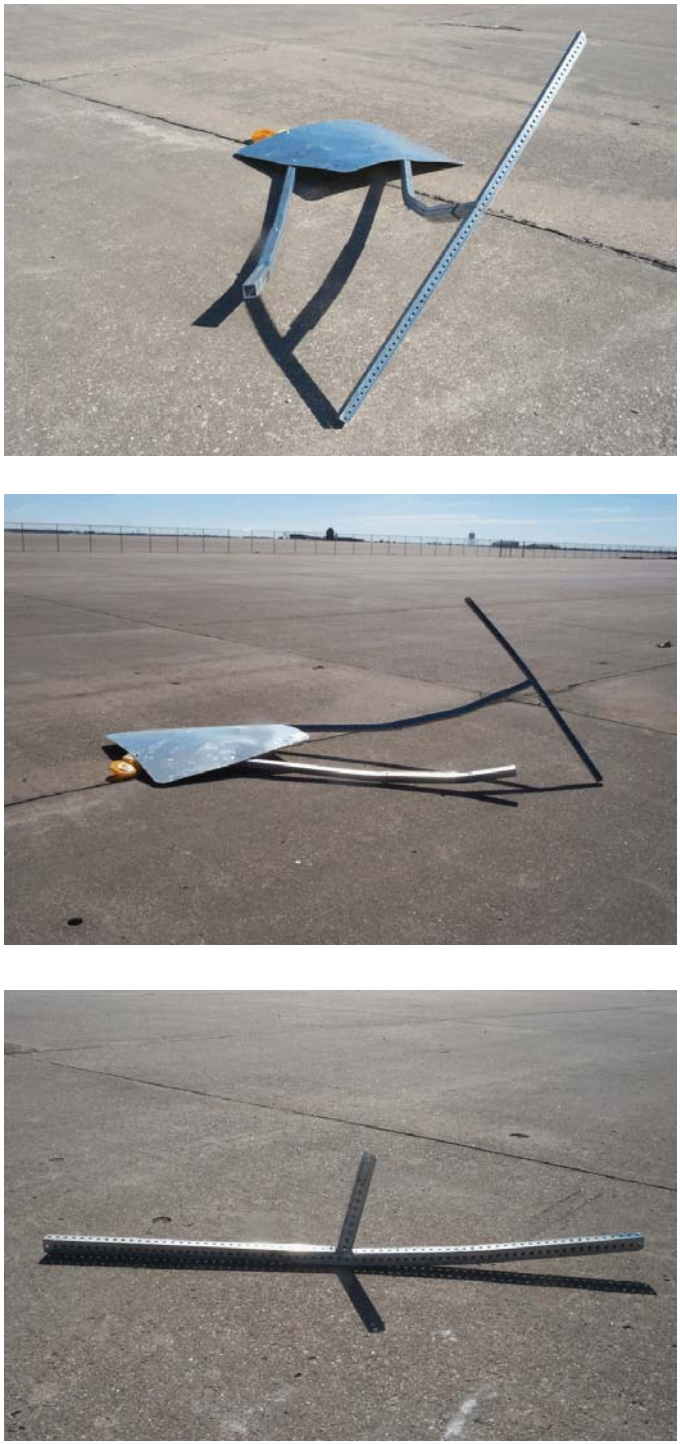


Figure 38. 48" x 48" Diamond Panel Work Zone Sign System with 5' Mounting Height Damage, Bogie Test MN6A-0 (0 degrees)

Figure 39. 48" x 48" Diamond Panel Work Zone Sign System with 5' Mounting Height Damage, Bogie Test MN6A-90 (90 degrees)

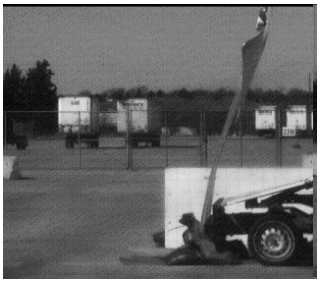
0.000 sec

0.000 sec

0.022 sec

0.008 sec

0.072 sec



0.022 sec

0.178 sec

0.040 sec

0.224 sec

0.072 sec

Figure 40. Sequential Photographs – 0 degree orientation, Bogie Test MN6A-0

0.000 sec

0.000 sec

0.026 sec

0.026 sec

0.066 sec

0.040 sec

0.128 sec

0.066 sec

0.220 sec

0.128 sec

Figure 41. Sequential Photographs – 90 degree orientation, Bogie Test MN6A-90

10 PERFORMANCE ANALYSIS OF THE MINNESOTA DEPARTMENT OF TRANSPORTATION'S 48"x 48" DIAMOND PANEL WORK ZONE SYSTEM WITH 7' MOUNTING HEIGHT

Bogie Test MN7A-0 (Head-on device)

1. System: 48" x 48" Diamond Panel Work Zone System with 7' Mounting Height
   - Vertical Upright Masts – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.30 mm (0.130 in.) wall thickness and a length of 3,327 mm (131 in.).
   - Outside Vertical Upright Tubing – 57.2 mm (2.25 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.05 mm (0.120 in.) wall thickness and a length of 911 mm (35.875 in.).
   - Legs, Horizontal Portion – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.90 mm (0.114 in.) thickness and a length of 1,829 mm (72 in.).
   - Legs, Vertical Stub – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.84 mm (0.112 in.) thickness and a length of 305 mm (12 in.).
   - Vertical stub of the leg is welded to the middle horizontal portion of the leg on all four sides.
   - Outside vertical upright tubing slide over the vertical upright mast - 9.5 mm (0.375 in.) diameter x 69.9 mm (2.75 in.) long hex head Grade 5 bolt were used to fasten the outer vertical upright tube to the mast.
   - Vertical portion of legs slide into vertical upright masts.

   Sign: Rigid
   - Panel - Rigid aluminum, 1,219 mm (48 in.) wide x 1,219 mm (48 in.) tall with a 2.54 mm (0.100 in.) thickness.
   - Panel fastened to vertical mast support with four 9.5 mm (0.375 in) diameter x 69.9 mm (2.75 in.) long Grade 5 bolts. A 31.8 mm (1.25 in.) O.D. x 1.9 mm (0.074 in.) thick front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.
   - Warning Light – "Toughlite 2000" attached to the sign panel.

Height to Bottom of Sign:	2,134 mm (84 in.)
Height to Top of Outer Tube:	965 mm (38 in.)
Height to Top of Sign:	3,787 mm (149 in.)

2. Weights of Sign System

Legs:	13.154 kg (29 lbs)
Panel, Masts, Outside Tubes, and Light:	40.370 kg (89 lbs)
Total System Weight:	53.524 kg (118 lbs)

Ballast (sandbags): 20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 9/22/04

5. Impact Speed: 102.2 km/h (63.5 mph)
   Impact Orientation: 0 degrees

6. Velocity Change: 5.7 km/h (3.5 mph)

7. System Performance – Minor mast deformations were observed. The sign panel and masts remained intact, while the legs disengaged from the rest of the system. Both legs encountered weld failure at the vertical upright stub. The top of the sign panel and masts rotated toward the vehicle, but no contact nor damage to the simulated windshield was observed. As the system rotated over the top of the bogie, no contact with the bogie was observed, and the system was never considered to be a potential hazard to the bogie nor the occupant compartment.

Bogie Test MN7A-90 (End-on device)

1. System: 48" x 48" Diamond Panel Work Zone System with 7' Mounting Height
   - Vertical Upright Masts – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.82 mm (0.111 in.) wall thickness and a length of 3,327 mm (131 in.).
   - Outside Vertical Upright Tubing – 57.2 mm (2.25 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.00 mm (0.118 in.) wall thickness and a length of 911 mm (35.875 in.).
   - Legs, Horizontal Portion – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 3.02 mm (0.119 in.) thickness and a length of 1,829 mm (72 in.).
   - Legs, Vertical Stub – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.87 mm (0.113 in.) thickness and a length of 305 mm (12 in.).
   - Vertical stub of the leg is welded to the middle horizontal portion of the leg on all four sides.
   - Outside vertical upright tubing slide over the vertical upright mast - 9.5 mm (0.375 in.) diameter x 69.9 mm (2.75 in.) long hex head Grade 5 bolt were used to fasten the outer vertical upright tube to the mast.
   - Vertical portion of legs slide into vertical upright masts.

   Sign: Rigid
   - Panel - Rigid aluminum, 1,219 mm (48 in.) wide x 1,219 mm (48 in.) tall with a 2.54

mm (0.100 in.) thickness.

- Panel fastened to vertical mast support with four 9.5 mm (0.375 in) diameter x 69.9 mm (2.75 in.) long Grade 5 bolts. A 31.8 mm (1.25 in.) O.D. x 1.9 mm (0.074 in.) thick front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.
- Warning Light – "Toughlite 2000" attached to the sign panel.

Height to Bottom of Sign:	2,134 mm (84 in.)
Height to Top of Outer Tube:	965 mm (38 in.)
Height to Top of Sign:	3,787 mm (149 in.)

2. Weights of Sign Systems

Legs:	13.154 kg (29 lbs)
Panel, Masts, Outside Tubes, and Light:	41.731 kg (92 lbs)
Total System Weight:	54.885 kg (121 lbs)
Ballast (sandbags):	20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 7/24/04

5. Impact Speed: 101.5 km/h (63.1 mph)
   Impact Orientation: 90 degrees

6. Velocity Change: 5.9 km/h (3.7 mph)

7. System Performance – Minor mast and panel deformations were observed. The welds on the legs for the vertical upright stubs fractured. The impacted side of the sign panel and masts rotated toward the vehicle and contacted the front of the roof, but no contact nor damage to the simulated windshield was observed. After contact with the front of the roof, the system continued to rotate over the top of the bogie, the system was never considered to be a potential hazard to the bogie nor the occupant compartment.

Figure 42. 48" x 48" Diamond Panel Work Zone Sign System with 7' Mounting Height, Bogie Tests MN7A-0 and MN7A-90

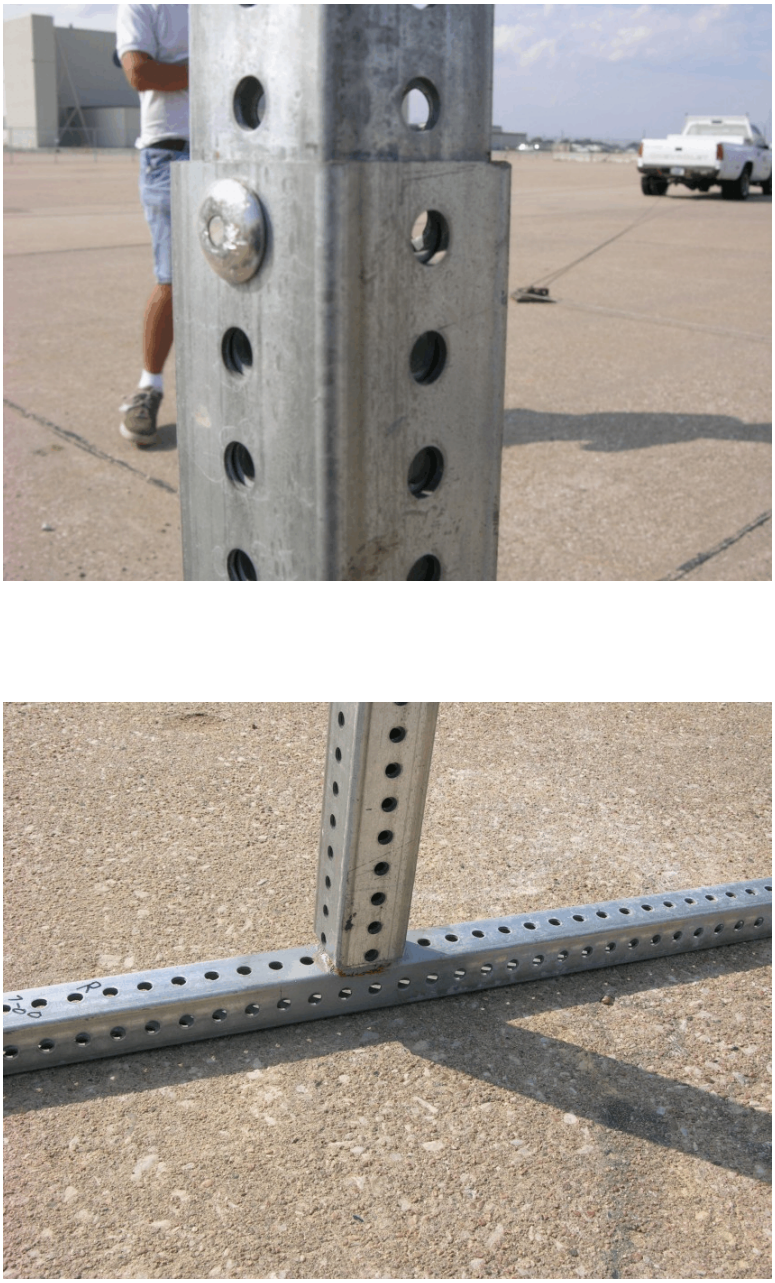


Figure 43. 48" x 48" Diamond Panel Work Zone Sign System with 7' Mounting Height, Bogie Tests MN7A-0 and MN7A-90

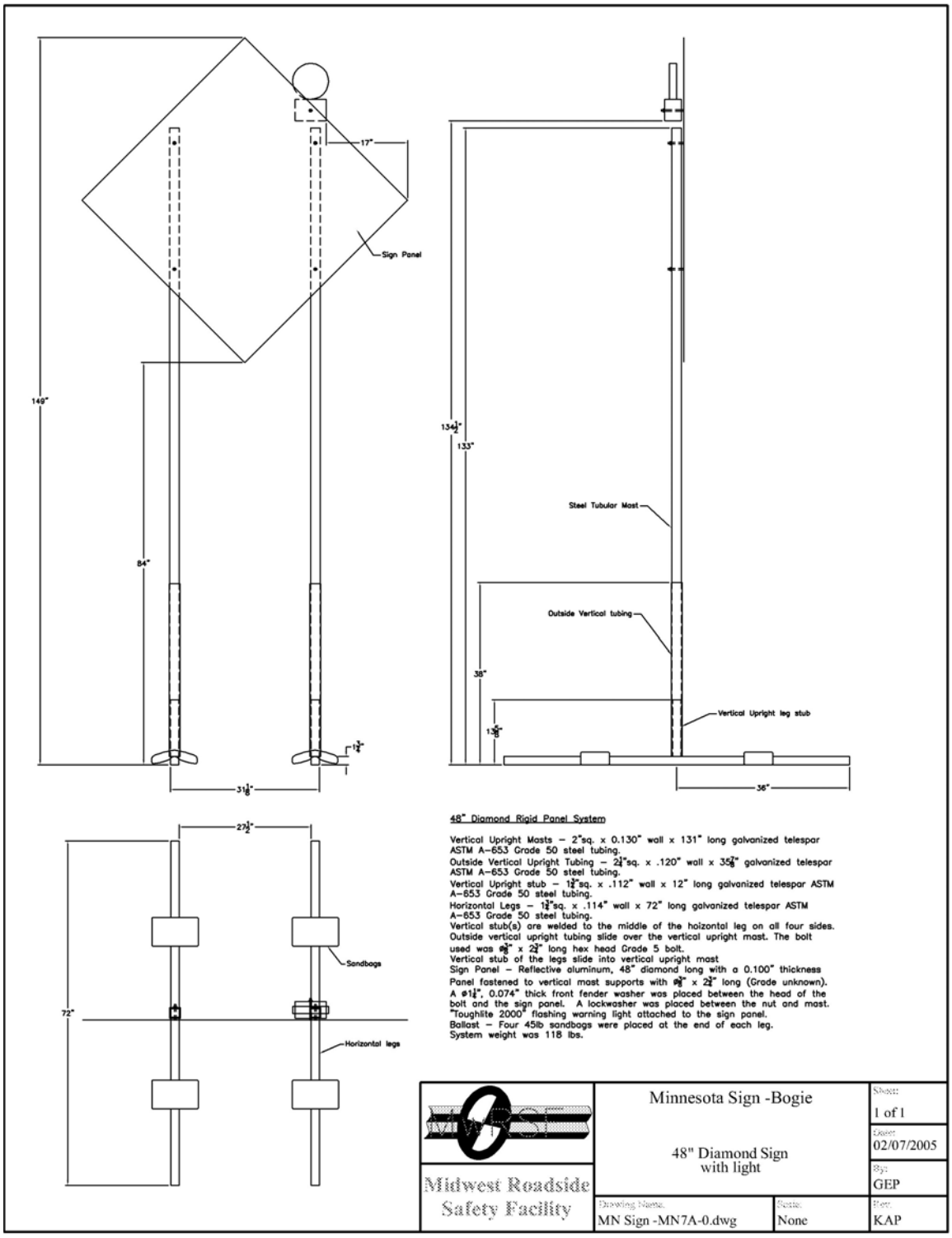


Figure 44. 48" x 48" Diamond Panel Work Zone Sign System with 7' Mounting Height, Bogie Test MN7A-0

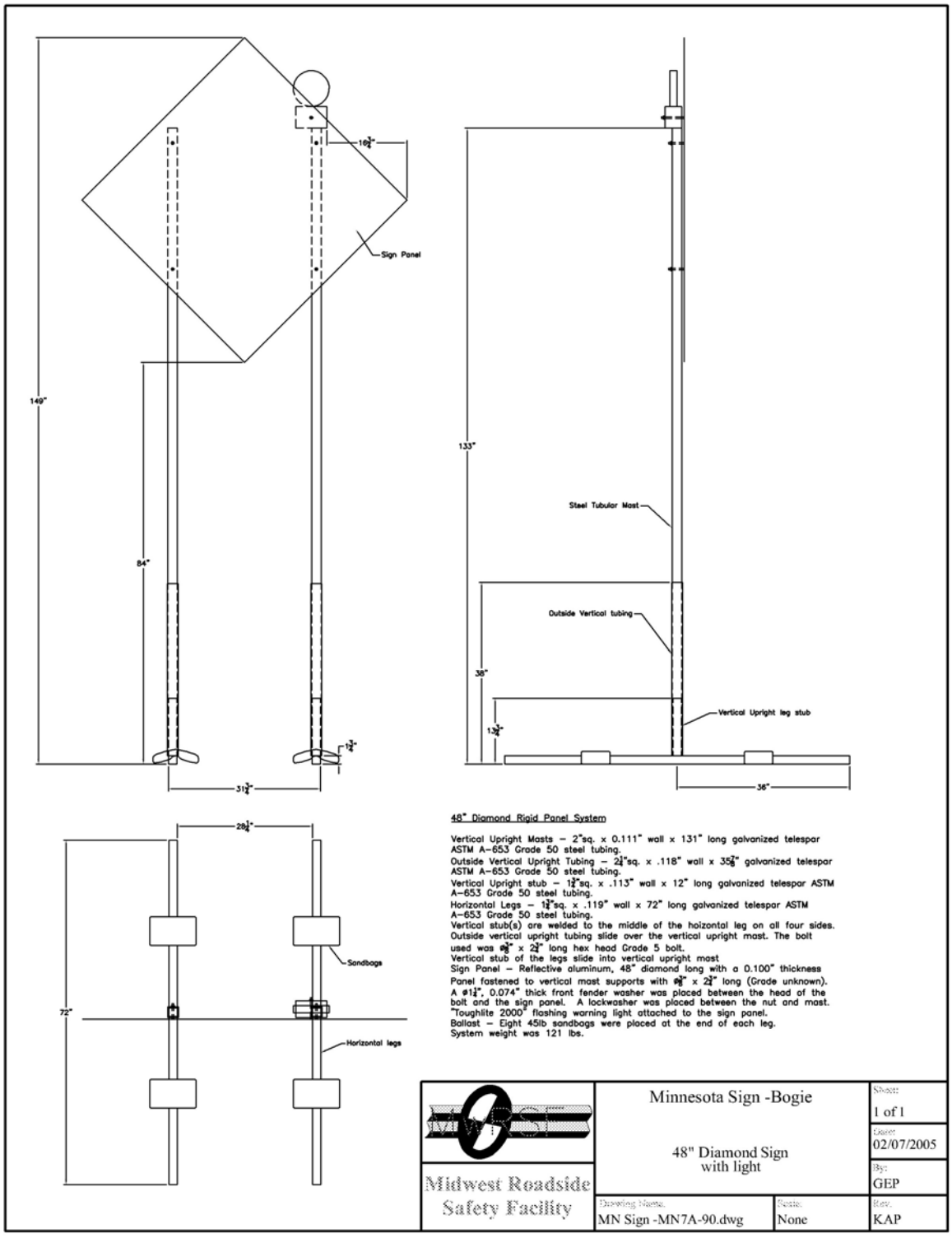


Figure 45. 48" x 48" Diamond Panel Work Zone Sign System with 7' Mounting Height, Bogie Test MN7A-90

Figure 47. 48" x 48" Diamond Panel Work Zone Sign System with 7' Mounting Height Damage, Bogie Test MN7A-0 (0 degrees)

Figure 48. 48" x 48" Diamond Panel Work Zone Sign System with 7' Mounting Height Damage, Bogie Test MN7A-90 (90 degrees)

0.000 sec

0.000 sec

0.018 sec

0.014 sec

0.068 sec

0.030 sec

0.168 sec

0.060 sec

0.234 sec

0.102 sec

Figure 49. Sequential Photographs – 0 degree orientation, Bogie Test MN7A-0

0.000 sec

0.000 sec

0.072 sec

0.016 sec

0.150 sec

0.030 sec

0.206 sec

0.076 sec

0.300 sec

0.150 sec

Figure 50. Sequential Photographs – 90 degree orientation, Bogie Test MN7A-90

11 PERFORMANCE ANALYSIS OF THE MINNESOTA DEPARTMENT OF TRANSPORTATION'S STOP SIGN SYSTEM WITH 7' MOUNTING HEIGHT

Bogie Test MN8A-0 (Head-on device)

1. System: Stop Sign System with 7' Mounting Height
   - Vertical Upright Masts – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.79 mm (0.110 in.) wall thickness and a length of 2,794 mm (110 in.).
   - Legs, Outer Horizontal Portion – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.92 mm (0.115 in.) thickness and a length of 1,518 mm (59.75 in.).
   - Legs, Middle Horizontal Portion – 50.8 mm (2.0 in) sq. x 762 mm (30 in) long galvanized telespar ASTM A-653 Grade 50 steel tubing.
   - Legs, Vertical Stub – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.84 mm (0.112 in.) thickness and a length of 305 mm (12 in.).
   - Vertical stub of the leg is welded to the middle horizontal portion of the leg on all four sides, and the horizontal middle portion of the leg is welded to the outer horizontal portion of the legs on all four sides.
   - Vertical upright mast slides into vertical portion of legs.

   Sign: Rigid
   - Panel - Rigid aluminum, 762 mm (30 in.) wide x 762 mm (30 in.) long with a 2.69 mm (0.106 in.) thickness.
   - Panel fastened to vertical mast support with two 7.9 mm (0.3125 in) diameter x 63.5 mm (2.5 in.) long Grade 5 bolts. A front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.

   Height to Bottom of Sign: 2,143 mm (84.375 in.)
   Height to Top of Sign: 2,905 mm (114.375 in.)

2. Weights of Sign System

Legs:	14.515 kg (32 lbs)
Panel and Mast:	10.886 kg (24 lbs)
Total System Weight:	25.401 kg (56 lbs)
Ballast (sandbags):	20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 3/18/04

5. Impact Speed: 101.4 km/h (63.0 mph)
   Impact Orientation: 0 degrees

6. Velocity Change: 6.5 km/h (4.0 mph)

7. System Performance – Mast deformation was observed. The sign panel and mast remained intact. The welds around the vertical upright stub failed. The top of the sign panel and mast rotated toward the vehicle, but no contact nor damage to the simulated windshield was observed. Throughout the entire test, the system never became a potential hazard to the bogie nor the occupant compartment.

Bogie Test MN8A-90 (End-on device)

1. System: Stop Sign System with 7' Mounting Height
   - Vertical Upright Masts – 44.5 mm (1.75 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.74 mm (0.108 in.) wall thickness and a length of 2,791 mm (109.875 in.).
   - Legs, Outer Horizontal Portion – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.77 mm (0.109 in.) thickness and a length of 1,521 mm (59.875 in.).
   - Legs, Middle Horizontal Portion – 50.8 mm (2.0 in) sq. x 762 mm (30 in) long galvanized telespar ASTM A-653 Grade 50 steel tubing.
   - Legs, Vertical Stub – 50.8 mm (2.0 in.) sq. galvanized telespar ASTM A-653 Grade 50 steel tubing with 2.79 mm (0.110 in.) thickness and a length of 305 mm (12 in.).
   - Vertical stub of the leg is welded to the middle horizontal portion of the leg on all four sides, and the horizontal middle portion of the leg is welded to the outer horizontal portion of the legs on all four sides.
   - Vertical upright mast slides into vertical portion of legs.

   Sign: Rigid
   - Panel - Rigid aluminum, 762 mm (30 in.) wide x 762 mm (30 in.) long with a 2.68 mm (0.105 in.) thickness.
   - Panel fastened to vertical mast support with two 7.9 mm (0.3125 in) diameter x 63.5 mm (2.5 in.) long Grade 5 bolts. A front fender washer was placed between the head of the bolt and the sign panel. A lockwasher was placed between the nut and mast.

   Height to Bottom of Sign: 2,143 mm (84.375 in.)
   Height to Top of Sign: 2,905 mm (114.375 in.)

2. Weights of Sign Systems
   Legs: 12.701 kg (28 lbs)
   Panel and Mast: 10.886 kg (24 lbs)

Total System Weight:	23.587 kg (52 lbs)
Ballast (sandbags):	20.4 kg (45 lbs) – 1 sandbag at end of each leg

3. Bogie Vehicle Weight: 1,119 kg (2,467 lbs)

4. Test Date: 3/18/04

5. Impact speed: 101.4 km/h (63.0 mph)
   Impact orientation: 90 degrees

6. Velocity Change: 7.8 km/h (4.9 mph)

7. System performance – Mast and panel deformations were observed. The sign panel and mast remained intact. The welds around the vertical upright stub failed. The top of the sign panel and mast rotated toward the vehicle and contacted the front of the roof, but no contact nor damage to the simulated windshield was observed. After contact with the roof, the system rebounded off the bogie and traveled up and away from the bogie and was never considered to be a potential hazard to the bogie nor the occupant compartment.

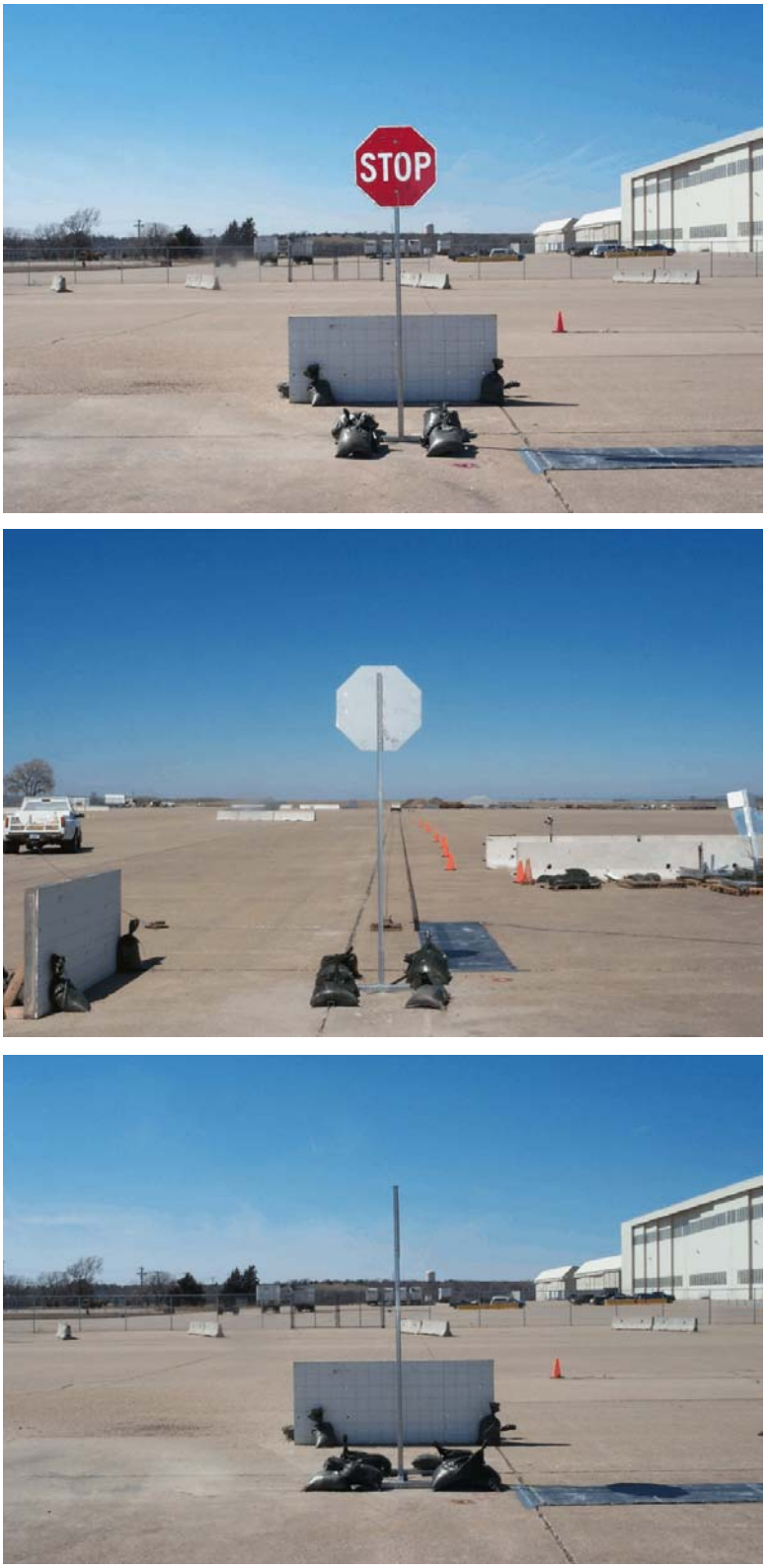


Figure 51. Stop Sign System with 7' Mounting Height, Bogie Tests MN8A-0 and MN8A-90

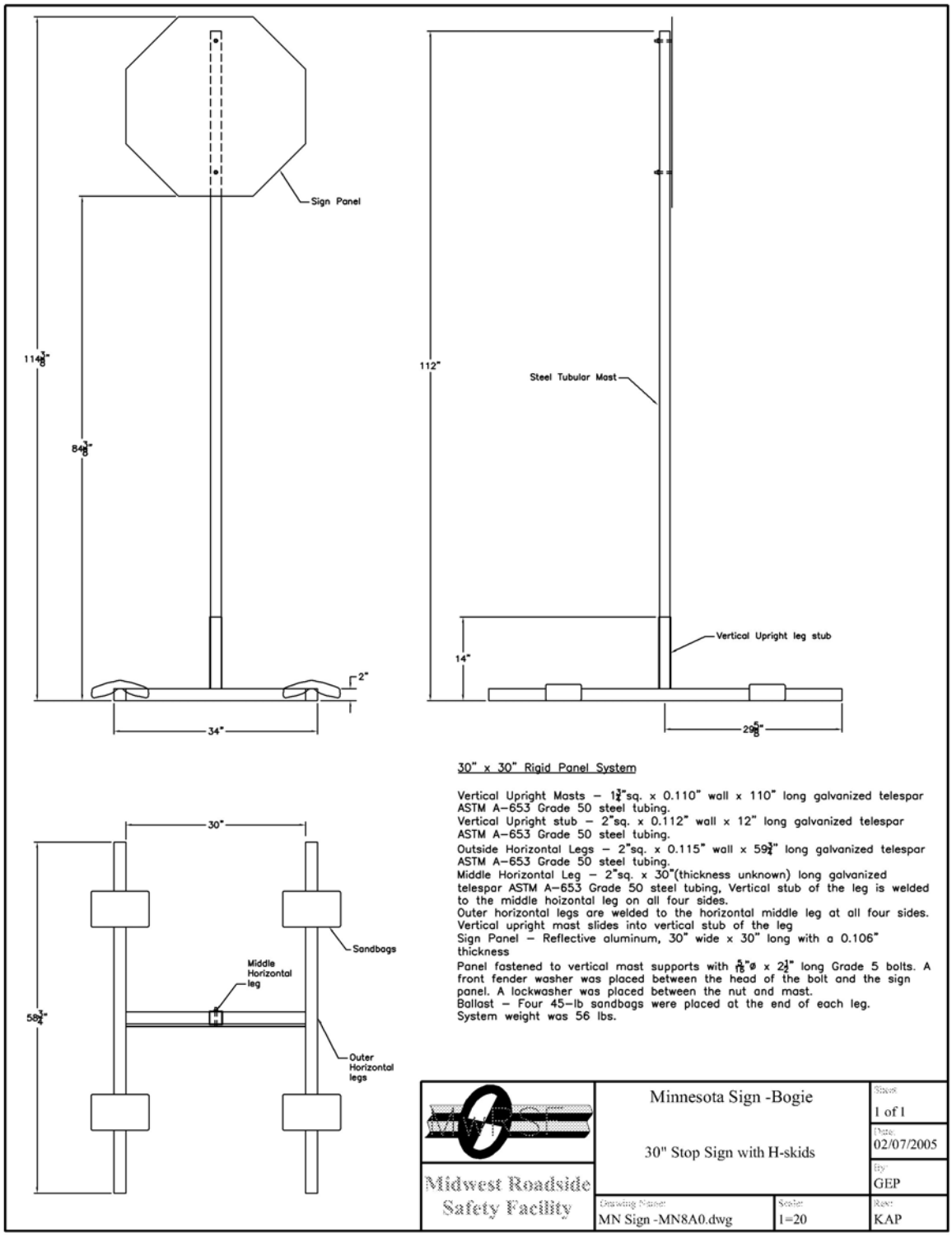


Figure 52. Stop Sign System with 7' Mounting Height Design Details, Bogie Test MN8A-0

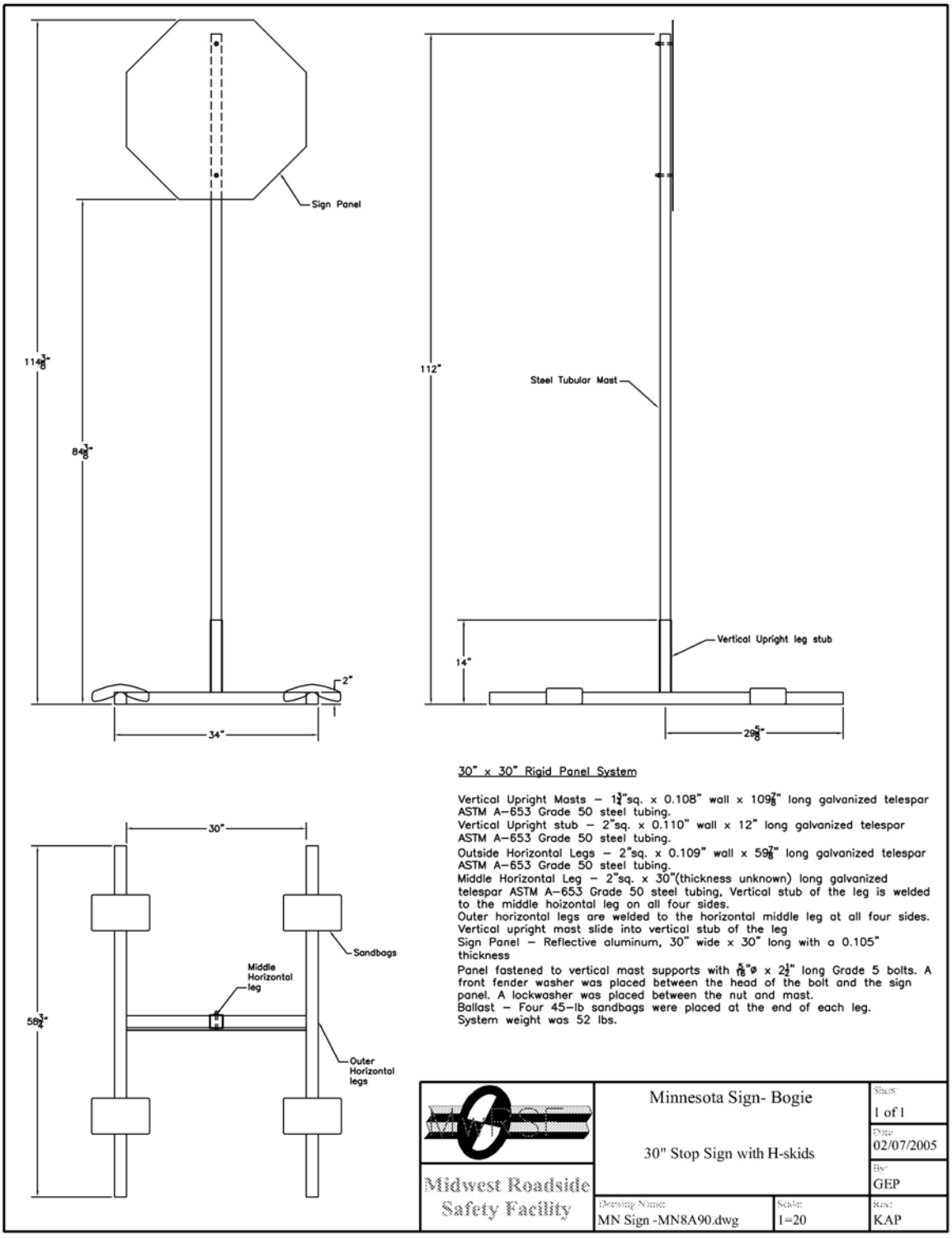


Figure 53. Stop Sign System with 7' Mounting Height Design Details, Bogie Test MN8A-90

Figure 54. Stop Sign System with 7' Mounting Height Damage, Bogie Test MN8A-0 (0 degrees)

Figure 55. Stop Sign System with 7' Mounting Height Damage, Bogie Test MN8A-90 (90 degrees)

0.000 sec

0.000 sec

0.028 sec

0.012 sec

0.102 sec

0.050 sec

0.188 sec

0.086 sec

0.232 sec

0.146 sec

Figure 56. Sequential Photographs – 0 degree orientation, Bogie Test MN8A-0

0.000 sec

0.000 sec

0.026 sec

0.014 sec

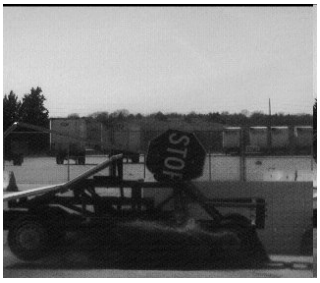
0.044 sec

0.040 sec

0.080 sec

0.080 sec

0.160 sec



0.120 sec

Figure 57. Sequential Photographs – 90 degree orientation, Bogie Test MN8A-90

12 SUMMARY AND CONCLUSIONS

A total of twenty-six crash tests were conducted on various rigid panel work-zone traffic control devices with sandbags. Fourteen 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 and were reported herein. A summary of the safety performance evaluation of each reported system is provided in Table 4.

For portable sign supports from this testing and previous testing, the performance of these sign supports is based on the behavior of many sign features, such as the stiffness and strength of the mast and stand, the sign panel stiffness and strength, and the panel attachment mechanism. Consequently, 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	System 1		System 2		System 3		System 4		System 5		System 6		System 7	
		Test MN1C0	Test MN1C90	Test MN2C0	Test MN2C90	Test MN3B02	Test MN3B90	Test MN5A0	Test MN5C902	Test MN6A0	Test MN6A90	Test MN7A0	Test MN7A90	Test MN8A0	Test MN8A90
		LS [1]	LS [1]	LS [1]	LS [1]	LS [1]	LS [1]	LSL [1]	LSL [1]	LS[L] [1]	LSL [1]	LSL [1]	LSL [1]	LS [1]	LS [1]
Structural Adequacy	B	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Occupant Risk	D	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	E	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	F	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	H	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vehicle Trajectory	K	S	S	S	S	S	S	S	S	S	S	S	S	S	S
	N	S	S	S	S	S	S	S	S	S	S	S	S	S	S
NCHRP Report No. 350 Test Level		TL-3	TL-3	TL-3	TL-3	TL-3	TL-3	TL-3	TL-3	TL-3	TL-3	TL-3	TL-3	TL-3	TL-3
Method of Failure[2]		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pass/Fail		Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

[1] Hardware Type: LS – Large Sign
LSL – Large Sign with Warning Light

[2] Method of Failure:
1 - Severe windshield cracking and fracture
2 - Windshield indentation
3 - Obstruction of driver visibility
4 - Windshield penetration
5 - Occupant compartment penetration other than windshield penetration

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

13 RECOMMENDATIONS

Seven work-zone traffic control devices satisfactorily met the TL-3evaluation criteria set forth in NCHRP Report No. 350 and are recommended for field implementation. These work-zone traffic control devices include:

- Bogie Tests MN1C0 and MN1C90 – Minnesota's Department of Transportation Stop Sign System oriented head-on and end-on, respectively.
- Bogie Tests MN2C0 and MN2C90 – Minnesota's Department of Transportation Route Marker Assembly System oriented head-on and end-on, respectively.
- Bogie Tests MN3B0-2 and MN3B90 – Minnesota's Department of Transportation 24" x 36" and 48" x 36" Work Zone Speed Limit System oriented head-on and end-on, respectively.
- Bogie Tests MN5A0 and MN5C90-2 – Minnesota's Department of Transportation 36" x 36" Diamond Panel Work Zone System with warning light oriented head-on and end-on, respectively.
- Bogie Tests MN6A0 and MN6A90 – Minnesota's Department of Transportation 48" x 48" Diamond Panel Work Zone System with 5-foot mounting height and warning light oriented head-on and end-on, respectively.
- Bogie Tests MN7A0 and MN7A90 – Minnesota's Department of Transportation 48" x 48" Diamond Panel Work Zone System with 7-foot mounting height and warning light oriented head-on and end-on, respectively.
- Bogie Tests MN8A0 and MN8A90 – Minnesota's Department of Transportation Stop Sign System with 7-foot mounting height oriented head-on and end-on, respectively.

For portable sign supports and rigid panel sign supports, such as those presented herein, similar devices may be capable of meeting the performance requirements of TL-3 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 portable 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.

14 REFERENCES

1. Part VI of the Manual on Uniform Traffic Control Devices (MUTCD), entitled, *Standards and Guides for Traffic Controls for Street and Highway Construction, Maintenance, Utility and Incident Management Operations*, 1988 Edition, Revision 3, September 1993.

2. Ross, H.E., D.L. Sicking, R.A. Zimmer, R.A., and Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Research Program (NCHRP) Report No. 350, Transportation Research Board, Washington, D.C., 1993.

3. Magdaleno, J.A., Faller, R.K., Kittrell, K.R., and Post, E.R., *Full-Scale Crash Tests on Plastic Drums with Type III Object Markers*, Final Report to the Missouri Highway and Transportation Department, Transportation Research Report No. 87-2, University of Nebraska-Lincoln, April 1988.

4. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Crash Tests of Work Zone Traffic Control Devices*, Final Report to Dicke Tool Company, Transportation Research Report No. TRP-03-79-98, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, December 7, 1998.

5. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Crash Tests of Work Zone Traffic Control Devices – Phase II*, Final Report to Dicke Tool Company, Transportation Research Report No. TRP-03-81-99, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, April 6, 1999.

6. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Compliance Testing of Iowa's Skid-Mounted Sign Device*, Final Report to Iowa Department of Transportation, Transportation Research Report No. TRP-03-86-99, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, July 23, 1999.

7. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Crash Tests of Work Zone Traffic Control Devices – Phase III*, Final Report to Dicke Tool Company, Transportation Research Report No. TRP-03-87-99, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, July 27, 1999.

8. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Evaluation of Temporary Sign Stands and Flag Systems – Phase I*, Final Report to Lang Products International, Inc., Transportation Research Report No. TRP-03-82-99, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, September 1, 1999.

9. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Crash Testing of MDI's Portable Work Zone Signs – 1999 – Phase I*, Final Report to Marketing Displays International, Transportation Research Report No. TRP-03-89-99, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, September 16, 1999.

10. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Crash Tests of Work Zone Traffic Control Devices – Phase IV*, Final Report to Dicke Tool Company, Transportation Research Report No. TRP-03-92-99, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, March 21, 2000.

11. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Crash Tests of Endurance™ Work Zone Signs*, Final Report to Reflexite North America and General Electric Company, Transportation Research Report No. TRP-03-93-00, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, May 19, 2000.

12. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Crash Tests of Work Zone Traffic Control Devices – Phase V*, Final Report to Dicke Tool Company, Transportation Research Report No. TRP-03-96-00, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, July 18, 2000.

13. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Safety Performance Evaluation of Minnesota's Aluminum Type III Barricades*, Final Report to the Midwest State's Regional Pooled Fund Program, Transportation Research Report No. TRP-03-101-00, Project No. SPR-3(017)-Year 10, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, October 19, 2000.

14. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Safety Performance Evaluation of Missouri's Temporary Sign Stands*, Final Report to Missouri Department of Transportation, Transportation Research Report No. TRP-03-97-00, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, December 13, 2000.

15. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Safety Performance Evaluation of the PST-III Portable Type III Barricade*, Final Report to Plastic Safety Systems, Inc., Transportation Research Report No. TRP-03-103-00, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, December 15, 2000.

16. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Safety Performance Evaluation of Minnesota's Aluminum Work Zone Signs*, Final Report to the Midwest State's Regional Pooled Fund Research Program, Transportation Research Report No. TRP-03-107-01, Project No. SPR-3(017)-Year 11, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, January 29, 2002.

17. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Crash Tests of Work Zone Traffic Control Devices - Phase VI*, Final Report to Dicke Tool Company, Transportation Research Report No. TRP-03-112-01, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, March 20, 2002.

18. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Safety Performance Evaluation of Plastic Safety System's Work Zone Devices*, Final Report to Plastic Safety Systems, Inc., Transportation Research Report No. TRP-03-108-01, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, August 7, 2002.

19. Polivka, K.A., Faller, R.K., Holloway, J.C.,and Rohde, J.R., *Safety Performance Evaluation of Minnesota's Low-Height, Temporary Rigid Panel Sign Stand*, Final Report to the Midwest State's Regional Pooled Fund Program, Transportation Research Report No. TRP-03-129-03, Project No. SPR-3(017)-Year 12, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, January 23, 2003.

20. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Safety Performance Evaluation of Michigan's Temporary Traffic Control Devices*, Final Report to the Michigan Department of Transportation, Transportation Research Report No. TRP-03-128-02, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, January 27, 2003.

21. Polivka, K.A., Faller, R.K., Holloway, J.C., Rohde, J.R., and Sicking, D.L., *Safety Performance Evaluation of Michigan's 4x5 Portable Sign Support*, Final Report to the Michigan Department of Transportation, Transportation Research Report No. TRP-03-135-03, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, June 20, 2003.

22. Polivka, K.A., Faller, R.K., Rohde, J.R., Holloway, J.C., and Sicking, D.L., *Safety Performance Evaluation of Missouri's Ground-Mounted Temporary Sign Stands - Phase II*, Final Report to the Missouri Department of Transportation, Transportation Research Report No. TRP-03-158-05, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, March 8, 2005.

23. Federal Highway Administration (FHWA) Safety, Acceptable Crashworthy Category 2 Hardware for Work Zone, Revised: January 20, 2006, Available: <http://safety.fhwa.dot.gov/roadway_dept/road_hardware/listing.cfm?code=workzone> [2006, September 21].

24. *Memorandum on Action: Identifying Acceptable Highway Safety Features*, July 25, 1997, File Designation HNG-14, Federal Highway Administration (FHWA), Washington, D.C., 1997.

25. Federal Highway Administration (FHWA), *Questions and Answers About Crash Testing of Work Zone Safety Appurtenances*, Revised May 22, 2002, Available: <http://safety.fhwa.dot.gov/fourthlevel/qanda.htm>.

26. Artimovich, N., *Windshield Damage for Category II Work Zone Traffic Control Devices - DRAFT GUIDANCE FOR PASS/FAIL*, Federal Highway Administration (FHWA), Washington, D.C., 2000.

27. Hargrave, M.W., and Hansen, A.G., *Federal Outdoor Impact Laboratory - A New Facility for Evaluating Roadside Safety Hardware*, Transportation Research Record 1198, Transportation Research Board, National Research Council, Washington, D.C., 1988, pp. 90-96.