TTI: 0-6639-13

MASH EVALUATION OF ALTERNATIVE SUPPORT MATERIALS FOR PORTABLE ROLL-UP SIGNS

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

Crash testing performed at:
TTI Proving Ground
3100 SH 47, Building 7091
Bryan, TX 77807

Test Report 0-6639-13-1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
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16. Abstract

Fiberglass members are commonly used as the frame for portable roll-up fabric signs. These signs can flex in windy conditions to a point that causes them to become illegible. Under high winds, the fiberglass stays can break and render the useless. The Amarillo District has experimented with aluminum frames of the same cross-sectional dimensions as the fiberglass frame members with little success due to the aluminum frames bending in high winds. Therefore, research was undertaken by Texas Tech University to determine which materials can provide improved wind resistance and more durable and reliable service in this application than either fiberglass or aluminum.

This report documents full-scale crash testing of a modified portable roll-up sign system designed to provide improved in-field service for wind loads. The modifications included use of carbon fiber wraps to increase stiffness in preferred directions, and a bolt through the vertical stay that delays separation of the stay from the base. The modified portable sign stand met *MASH* impact performance criteria.

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). 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 view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation, and its contents are not intended for construction, bidding, or permit purposes. In addition, the above listed agencies assume no liability for its contents or use thereof. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report. The engineer in charge of the project was Roger P. Bligh, P.E. (Texas, #78550).

TTI PROVING GROUND DISCLAIMER

The results of the crash testing reported herein apply only to the article being tested.

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ISO 17025 Laboratory
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CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Portable roll-up signs are currently used by the Texas Department of Transportation (TxDOT) for short-term, daytime maintenance/construction activities and emergency operations. These flexible fabric signs are supported by fiberglass frames attached to a multi-leg base. In windy conditions typical of the Texas coast and panhandle, the rollup sign panels lay back to a point that they become illegible. In more extreme conditions, the support can blow over or the fiberglass stays can break.

The cost of resetting signs and replacing those that fail involves not only direct materials and labor, but also the safety of maintenance personnel due to increased exposure and the motoring public due to lost information in the work zone. Research project 0-6399 was undertaken to understand the nature of wind loading on portable roll-up signs, and identify alternative materials to support the flexible sign substrates that will improve the performance of the sign support in windy conditions and reduce wind-induced failures without compromising crashworthiness.

1.2 OBJECTIVES/SCOPE OF RESEARCH

Alternate materials were identified by researchers at Texas Tech University that offer promise for improving field performance providing more durable and reliable service in windy conditions. The alternate materials were incorporated into a modified short term sign stand that is readily available in the marketplace. The crashworthiness of modified system was evaluated through a series of crash tests conducted in accordance with the American Association of State Highway Transportation Officials (AASHTO's) *Manual for Assessing Safety Hardware (MASH) (1)*. These tests were performed at the Texas A&M Transportation Institute (TTI) Proving Ground, and the results are reported herein.

CHAPTER 2. SYSTEM DETAILS

2.1 TEST ARTICLE DESIGN AND CONSTRUCTION

Two prototype portable roll-up sign assemblies were provided by researchers at Texas Tech University. The roll-up fabric sign substrates were 3M™ Diamond Grade™ RS24 roll-up sign sheeting that were obtained through TrafFix Devices, Inc. The sign sheeting is listed on the TxDOT 801-60-66 Prequalified Products List (QPL) "Sign Face, Roll-Up, Reflective, Construction and Work Zone." The sign panels incorporated plastic corner pockets into which the ends of the horizontal and vertical fiberglass stays were inserted.

The fiberglass stays were obtained from TrafFix Devices, Inc. The vertical stays were 66 inches long, 1.25 inches wide, and 5/16 inches thick. The horizontal stays were 66 inches long, 1.25 inches wide, and 3/16 inches thick.

Mbrace® CF 130 carbon fiber sheets were used to strengthen and reinforce portions of the fiberglass stays. Mbrace® CF 130 is a dry fabric constructed of very high strength aerospace grade carbon fibers that is manufactured by BASF Construction Chemicals, LLC. The carbon fiber sheets were applied using epoxy based resin, namely, Mbrace® Primer and Saturant.

The carbon fiber sheets were applied to the lower 40 inches of the vertical stays and the middle 24-inch region of the horizontal stays. One layer of carbon fiber sheet was wrapped around the stays, with an overlap on one of the long side of the stays to cover the starting edge of the sheet.

The bottom corner of the roll-up fabric signs were inserted into 22000 Series TrafFix Sign Stands that were obtained through TrafFix Devices, Inc. The four telescoping, tubular steel legs of the sign stand were extended to their fully open position. The legs were positioned in the lowest height adjustment, such that the mounting height from the pavement surface to the bottom corner of the roll-up fabric sign was 12 inches. The weight of the sign stand was 20 lb.

The assembled portable sign system was placed on a concrete apron for the crash testing. The first test was performed with a 40-lb sand bag placed at the end of each of the four legs of the sign stand. This is how they are typically deployed in the coastal and western regions of Texas that frequently experience high winds. A subsequent test was conducted without sand bags to determine their effect on the impact performance of the portable sign system.

General details of the roll-up sign support system are shown in Figure 2.1 and 2.2. Additional details of the system are provided in Appendix A. Photographs of the assembled test prototypes are shown in Figure 2.3.

2.2 MATERIAL SPECIFICATIONS

The roll-up fabric sign substrates were manufactured from 3M™ Diamond Grade™ RS24 roll-up sign sheeting. The material specifications for the sign sheeting are provided in Appendix B. Researchers at Texas Tech University conducted laboratory tests to characterize the material properties of the fiberglass stays. The tensile strength of the fiberglass stays varied from 67 ksi to 87 ksi, and Young's Modulus ranged from 5500 ksi to 5800 ksi. Mbrace® CF 130 carbon fiber sheets were used to strengthen and reinforce portions of the fiberglass stays as described above. The engineering properties of the carbon fibers are provided in Appendix C.

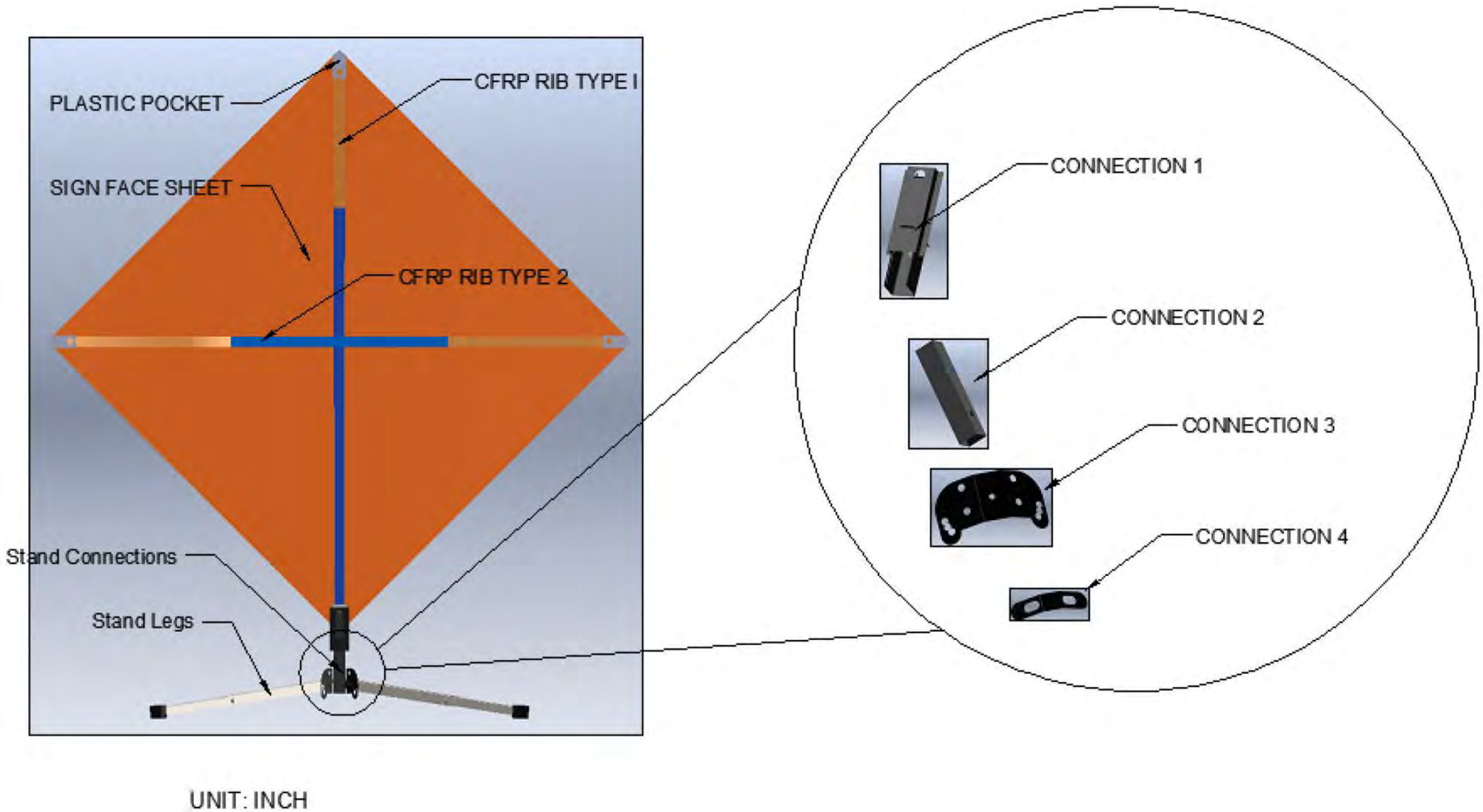


Figure 2.1. Components of the Portable Roll-Up Sign.

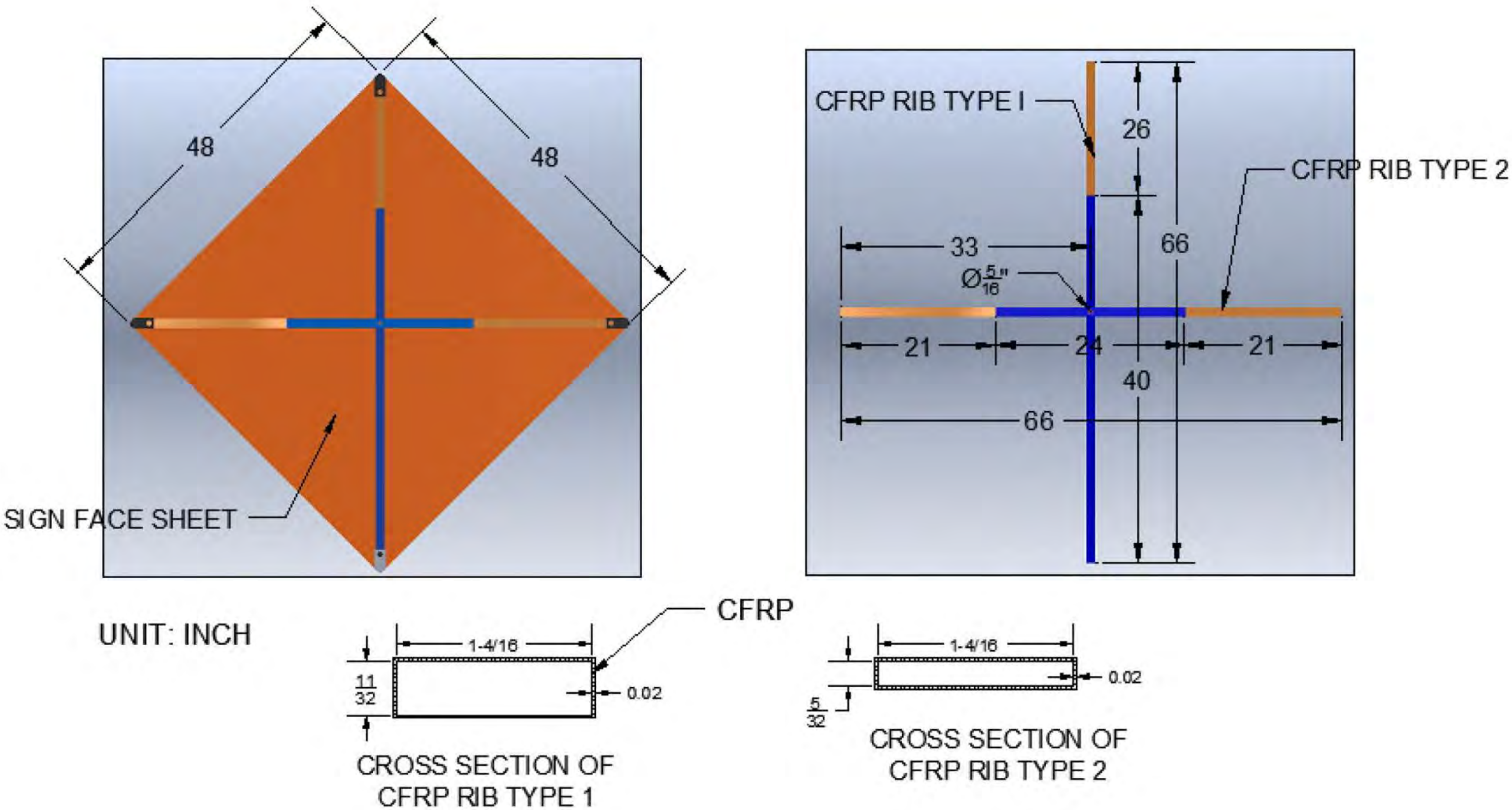
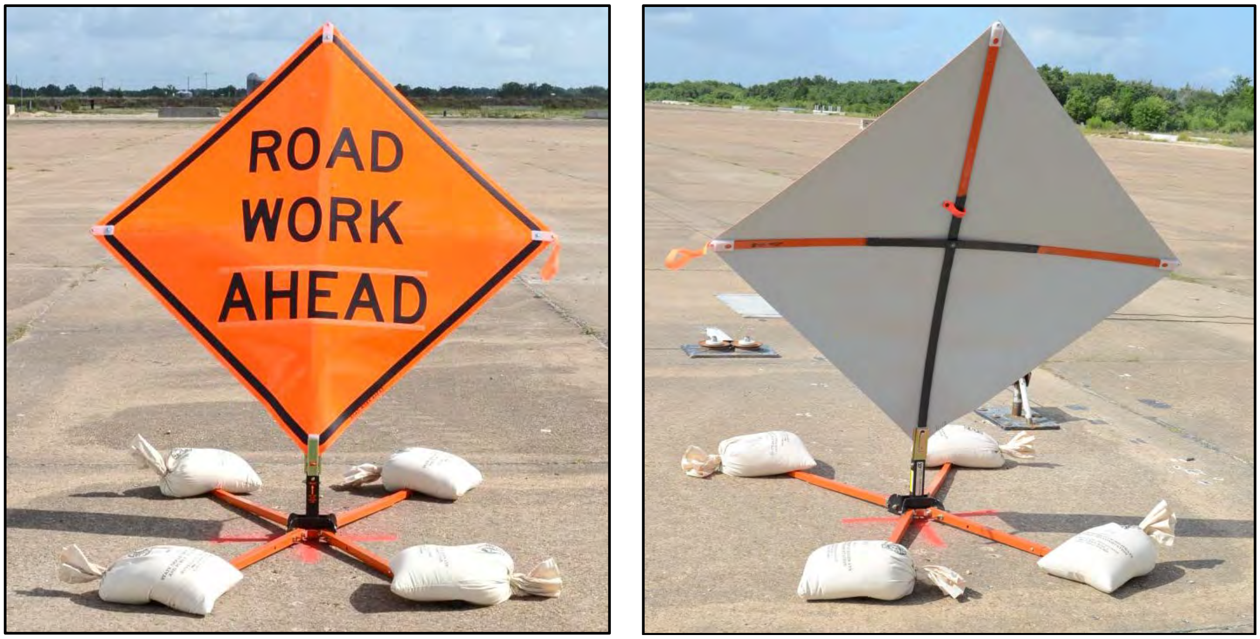


Figure 2.2. Dimensional Details of the Portable Roll-Up Sign Panel and Supports.



Portable Roll-Up Sign with Sandbags

Portable Roll-Up Sign without Sandbags

Figure 2.3. Portable Roll-Up Sign before Test No. 4663963-1 and 2.

CHAPTER 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 CRASH TEST MATRIX

According to *MASH*, up to three tests are recommended to evaluate work zone traffic control devices to Test Level 3 (TL-3):

- ***MASH* Test 3-70**: An 1100C (2420 lb/1100 kg) vehicle impacting the device at a nominal impact speed of 19 mi/h and critical impact angle (CIA) judged to have the greatest potential for test failure. This test evaluates a device's ability to successfully activate by breakaway, fracture, or yielding mechanism during low-speed impacts with a small vehicle.
- ***MASH* Test 3-71**: An 1100C (2420 lb/1100 kg) vehicle impacting the device at a nominal impact speed of 62 mi/h and CIA judged to have the greatest potential for test failure. This evaluates the behavior of the device during high-speed impacts with a small vehicle and the potential for intrusion of structural components into the vehicle.
- ***MASH* Test 3-72**: A 2270P (5000 lb/2270 kg) vehicle impacting the device at a nominal impact speed of 62 mi/h and CIA judged to have the greatest potential for test failure. This evaluates the behavior of the device during high-speed impacts with a pickup truck.

MASH test 3-71 was performed on the portable roll-up sign stands evaluated under this project. This test is considered to be the critical test for temporary work zone traffic control devices with a 1-ft mounting height due to the increased propensity for occupant compartment intrusion through the windshield of the small car at higher speeds. MASH states that Test 3-70 is considered optional for work-zone traffic control devices weighing less than 220 lb, because velocity changes during low-speed impacts with free-standing, lightweight features will be within acceptable limits. The higher hood height and longer wrap around distance from the ground to the base of the windshield makes test 3-72 with the pickup truck less critical for low-mounted signs. The 4 ft × 4ft fabric sign in a diamond configuration at a 1 ft mounting height stands approximately 6 ft-8 inches tall. The wrap around distance on a Dodge Ram 1500 pickup truck is approximately 7 ft-10 inches. Therefore, the sign would contact the hood rather than the windshield. Further, because the hood height of the pickup truck, which is approximately 3 ft-10 inches, matches the height of the center of the sign panel and exceeds the center of mass of the sign support system, it is likely that the sign panel will be carried forward by the truck even if it releases from its base.

FHWA requires the impact performance of temporary work zone sign supports to be evaluated for two different orientations. In addition to the common scenario involving the car impacting the device head-on (i.e., 0 deg.), an impact with the device turned either turned 90 degrees or laid on the ground, whichever is judged the more critical case, is also required. This test condition accounts for the common field practice of rotating or lying a device down out of view of traffic until it is needed again and/or picked up and moved to the next job site. In order to reduce testing cost, FHWA permits the evaluation of both the zero and ninety degree orientations using two separate devices impacted in sequence in a single crash test. When conducting such tests, consideration must be given to the fact that the first device impacted can potentially affect or interfere with the subsequent device. If the impact evaluation of the second device is hindered by interaction with the first device, a separate test is conducted to evaluate the second device.

In the initial testing of the portable roll-up sign system, single devices were tested headon at zero degrees. In subsequent testing of a modified sign stand, two separate devices oriented at zero and ninety degrees were impacted in a single crash test. The devices were separated by a distance of 30 ft.

The crash test and data analysis procedures followed under the project were in accordance with guidelines presented in *MASH*. Chapter 4 presents brief descriptions of these procedures.

3.2 EVALUATION CRITERIA

The performance of each portable roll-up sign was evaluated using all relevant *MASH* criteria for evaluation of work zone traffic control devices. Of primary concern regarding the impact behavior of a work zone traffic control device is penetration of the device or parts of the device into the occupant compartment. In order to minimize the potential for injury during impact, penetration or intrusion into the occupant compartment is not permitted. Any hole through the protective layer in the windshield constitutes a failure. In addition, the windshield cannot be shattered or damaged to the extent that it obstructs the vision of the driver or is deformed inward more than 3 inches. The appropriate safety evaluation criteria from Table 5-1 of *MASH* were used to evaluate the crash tests reported herein, and are listed in further detail under the assessment of each crash test.

CHAPTER 4. CRASH TEST PROCEDURES

4.1 TEST FACILITY

The full-scale crash tests reported herein was performed at Texas A&M Transportation Institute (TTI) Proving Ground, an International Standards Organization (ISO) 17025 accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing certificate 2821.01. The full-scale crash tests were performed according to TTI Proving Ground quality procedures and according to *MASH* guidelines and standards.

The TTI Proving Ground is a 2000-acre complex of research and training facilities located 10 miles northwest of the main campus of Texas A&M University. The site, formerly an Air Force base, has large expanses of concrete runways and parking aprons well-suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for placement and testing of the portable roll-up signs evaluated under this project was an out-of-service concrete apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15--ft blocks nominally 6 inches deep. The apron is over 60 years old, and the joints have some displacement, but are otherwise flat and level.

4.2 VEHICLE TOW AND GUIDANCE PROCEDURES

The test vehicles were towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A two-to-one speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site, after which the brakes were activated to bring it to a safe and controlled stop.

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation

MASH states "that lightweight free-standing features cannot cause sufficient velocity change to result in failure of the test under occupant risk criteria. Therefore, Tests 71 and 72 can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb (100 kg) or less." Consequently, the vehicles used in the testing program were uninstrumented except for a remote controlled braking package installed for safety purposes.

4.3.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of each 1100C vehicle. The dummy was uninstrumented.

4.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of each test included two high-speed cameras: one placed with a field of view perpendicular to the vehicle path, and one placed behind the installation at an oblique angle. A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The video from these high-speed cameras was analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-DV camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

CHAPTER 5. CRASH TEST RESULTS

5.1 CRASH TEST NO. 466393-1 (*MASH* TEST 3-71) -- WITH SANDBAGS

5.1.1 Test Designation and Actual Impact Conditions

MASH Test 3-71 involves an 1100C vehicle weighing 2420 lb ±55 lb and impacting the portable roll-up sign support at an impact speed of 62.2 mi/h ±2.5 mi/h. The centerline of the vehicle was aligned with the centerline of the roll-up sign. The 2009 Kia Rio used in the test weighed 2443 lb and the actual impact speed and angle were 63.4 mi/h and 0 degrees, respectively. The portable roll-up sign was impacted with the centerline of the vehicle aligned with the centerline of the device, with the device oriented 90 degrees to traffic flow.

5.1.2 Test Vehicle

The 2009 Kia Rio, shown in Figures 5.1 and 5.2, was used for the crash test. Test inertia weight of the vehicle was 2443 lb, and its gross static weight was 2622 lb. The height to the lower edge of the vehicle bumper was 6.75 inches, and the height to the upper edge of the bumper was 22.00 inches. Table D1 in Appendix D gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

5.1.3 Weather Conditions

The test was performed on the morning of July 22, 2013. Weather conditions at the time of testing were as follows: (a) wind speed: 11mi/h; (b) wind direction: 205 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); (c) temperature: 86°F; (d) relative humidity: 73 percent.

5.1.4 Test Description

The 2009 Kia Rio, traveling at an impact speed of 63.4 mi/h, contacted the portable roll-up sign with the centerline of the vehicle aligned with the centerline of the device, with the device oriented 90 degrees to traffic flow. At approximately 0.037 s after impact, the fabric sign panel and support stays began to ride up on the hood of the vehicle, and at 0.057 s, the top of the fabric sign panel and upper supports had contacted the windshield. The plastic sleeve at the top of the fabric sign panel and the top of the vertical stay punctured the windshield at 0.063 s. The fabric sign panel and attached stays reached maximum penetration at 0.148 s and subsequently began to rotate out of the windshield. At 0.208 s, the fabric sign panel and attached stays rode up the windshield and lost contact with the vehicle. The speed of the vehicle at loss of contact was 62.6 mi/h. The lower support base came to rest 1.4 ft downstream of impact. The fabric sign panel and stays came to rest 75 ft downstream of impact, and the vehicle came to a stop 262 ft downstream of impact and 8 ft to the right (toward traffic lanes) after application of brakes. Figure E1 in Appendix E shows sequential photographs of the test period.

Figure 5.1. Vehicle/Installation Geometrics for Test No. 466393-1.

Figure 5.2. Vehicle before Test No. 466393-1.

5.1.5 Damage to Test Installation

Figures 5.3 and 5.4 show damage to the work zone traffic control device. The fabric sign panel and stays separated from the lower base, contacted and penetrated the windshield, rode up and over the vehicle, and came to rest 75 ft downstream of impact. The base of the temporary sign support came to rest 1.4 ft downstream of impact. Two of the sandbags remained intact, one was torn open and emptied of sand, and the fourth was torn and partially emptied.

5.1.6 Vehicle Damage

Figure 5.5 shows damage to the 1100C vehicle. The bottom of the front bumper cover was fractured, and the hood sustained scuff marks. No measureable deformation was noted to the exterior hood or bumper. The windshield was punctured/cut by the top corner of the sign panel, leaving a 2-inch × 1.5-inch hole. The area around the puncture was depressed into the occupant compartment 1.5 inches, and the total area shattered measured 20 inches × 17.25 inches. Figure 5.6 shows the windshield damage from inside the occupant compartment. Table D2 and D3 in Appendix D provides exterior crush and occupant compartment measurements.

5.1.7 Occupant Risk Factors

Previous full-scale crash tests have shown that the acceleration levels experienced by the vehicle during impact with lightweight, free-standing work zone traffic control devices weighing less than 220 lb were not significant. Consequently, MASH does not require instrumentation of the vehicle, and the occupant risk factors were not calculated for this test. Figure 5.7 summarizes pertinent information from the test.

5.1.8 Assessment of Test Results

An assessment of the test based on the applicable *MASH* safety evaluation criteria is provided below.

5.1.8.1 Structural Adequacy

B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.

Results: The portable roll-up sign yielded to the vehicle by breaking away from its base. (PASS)

Figure 5.3. After Impact Locations for Test No. 466393-1.

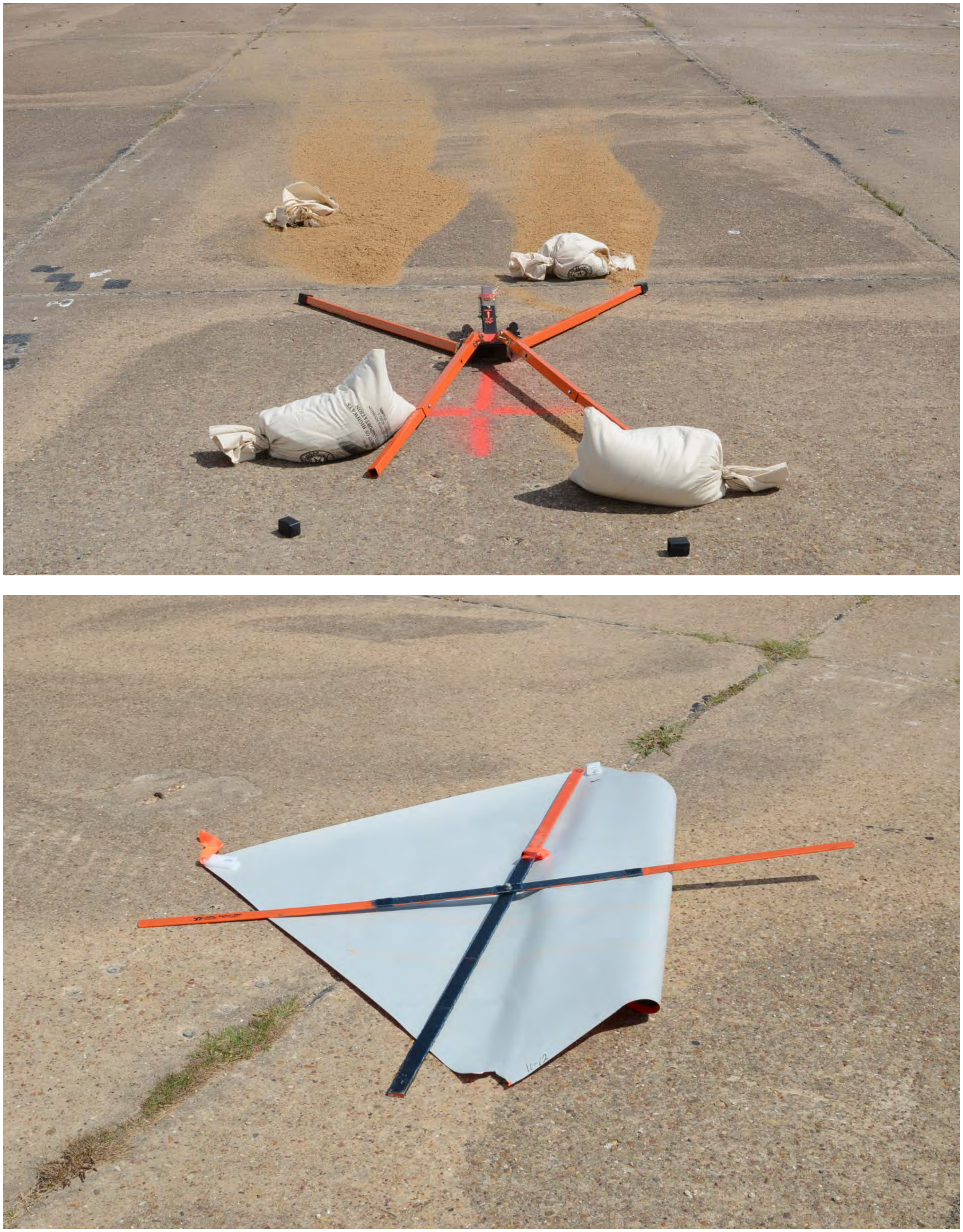
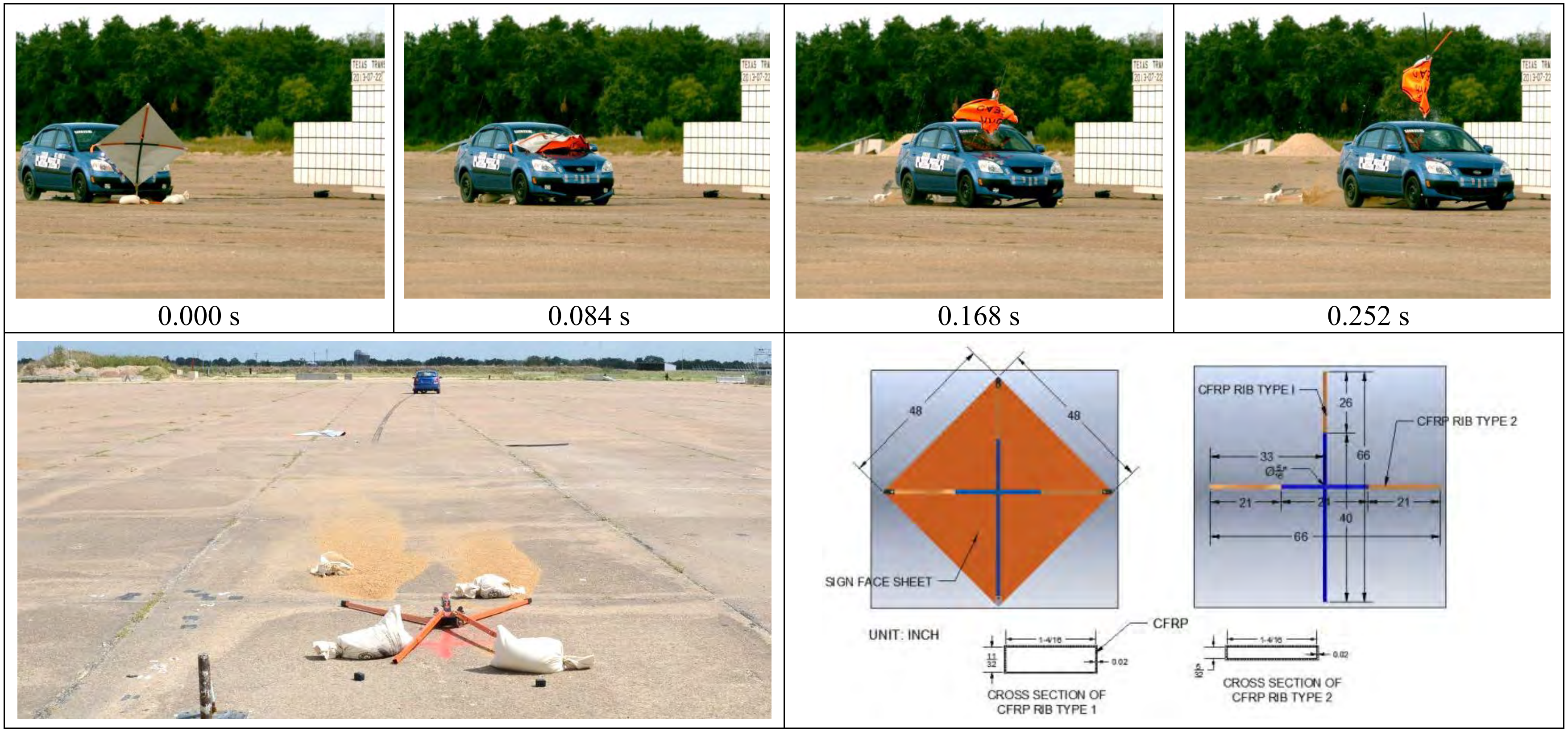


Figure 5.4. Installation after Test No. 466393-1.

Figure 5.5. Vehicle after Test No. 466393-1.

Figure 5.6. Interior of Vehicle for Test No. 466393-1.



General Information

Test Agency	Texas Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-71
TTI Test No.	466393-1
Test Date	2013-07-22

Test Article

Type	Work Zone Traffic Control Device
Name	Portable Roll-Up Sign with sandbags
Installation Height	1-ft mounting height
Material or Key Elements	Fabric sign substrate with carbon wrapped fiberglass stays and metal base ballasted with four 40-lb sandbags
Soil Type and Condition	Placed on concrete surface, dry

Test Vehicle

Type/Designation	1100C
Make and Model	2009 Kia Rio
Curb	2459 lb
Test Inertial	2443 lb
Dummy	179 lb
Gross Static	2622 lb

Impact Conditions

Speed	63.4 mi/h
Angle	0 degrees
Location/Orientation	90 degrees to traffic

Exit Conditions

Speed	62.6 mi/h
Angle	0 degrees

Post-Impact Trajectory

Stopping Distance	262 ft downstream 8 ft toward traffic

Test Article Deflections

Fabric Sign & Upper Supports	75 ft downstream
Lower Support/Base	1.4 ft downstream

Vehicle Damage

VDS	12FC1
CDC	12FCGN6
Max. Exterior Deformation	1.5 inches (windshield)
OCDI	FS0000000
Max. Occupant Compartment Deformation	1.5 inches (windshield)
Windshield Damage	Punctured

Figure 5.7. Summary of Results for *MASH* Test 3-71 on the Portable Roll-Up Sign with Sandbags.

5.1.8.2 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. Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

Results: The detached fabric sign panel and attached stays rotated into and penetrated the windshield into the occupant compartment. (FAIL)

E. Detached element, 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.

Results: The detached fabric sign panel momentarily blocked the driver's vision, but for less than 0.1 seconds. This short time frame would not affect the driver's ability to control the vehicle. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Results: The 1100C vehicle remained upright during and after the collision event. (PASS)

H. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
10 ft/s	*16.4 ft/s*

Results: The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb. (N/A)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb. (N/A)

5.1.8.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Result: The 1100C vehicle came to rest 262 ft downstream of the impact position of the portable roll-up sign. (PASS)

5.2 CRASH TEST NO. 466393-2 (*MASH* TEST 3-71) -- WITHOUT SANDBAGS

After failure of the initial design with sand bags, the same system was retested without sand bags. The objective was to determine if the sand bags affect the interaction of the portable roll-up sign system with the vehicle. It was hypothesized that the lighter weight sign stand (i.e., without the sand bags) could be accelerated more quickly and might delay release of the sign panel from the sign stand.

5.2.1 Test Designation and Actual Impact Conditions

MASH Test 3-71 involves an 1100C vehicle weighing 2420 lb ±55 lb and impacting the portable roll-up sign stand at an impact speed of 62.2 mi/h ±2.5 mi/h. The centerline of the vehicle was aligned with the centerline of the roll-up sign. The 2008 Kia Rio used in the test weighed 2437 lb and the actual impact speed and angle were 59.7 mi/h and 0 degrees, respectively. The portable roll-up sign was impacted with the centerline of the vehicle aligned with the centerline of the device, with the device oriented 90 degrees to traffic flow.

5.2.2 Test Vehicle

The 2008 Kia Rio, shown in Figures 5.8 and 5.9, was used for the crash test. Test inertia weight of the vehicle was 2437 lb, and its gross static weight was 2617 lb. The height to the lower edge of the vehicle bumper was 6.75 inches, and the height to the upper edge of the bumper was 22.00 inches. Table D4 in Appendix D gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

5.2.3 Weather Conditions

The test was performed on the afternoon of July 22, 2013. Weather conditions at the time of testing were as follows: (a) wind speed: 11mi/h; (b) wind direction: 179 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); (c) temperature: 94°F; (d) relative humidity: 55 percent.

Figure 5.8. Vehicle/Installation Geometrics for Test No. 466393-2.

Figure 5.9. Vehicle before Test No. 466393-2.

5.2.4 Test Description

The 2008 Kia Rio, traveling at an impact speed of 59.7 mi/h, contacted the portable roll-up sign with the centerline of the vehicle aligned with the centerline of the device, and with the device oriented 90 degrees to traffic flow. At approximately 0.051 s after impact, the fabric sign panel and stays began to ride up on the hood of the vehicle, and at 0.059 s, the top of the fabric sign panel and upper supports had contacted the windshield. The top corner of the fabric sign, along with the plastic pockets and stays punctured the windshield at 0.068 s. The fabric sign panel and attached stays reached maximum penetration at 0.146 s, and subsequently began to rotate out of the windshield. At 0.250 s, the fabric sign panel and stays rode up the windshield and lost contact with the vehicle. The lower support base rode under the vehicle for a time and came to rest 158 ft downstream of impact and 6 ft to the left. The fabric sign panel and attached stays came to rest 65 ft downstream of impact and 18 ft to the right. After application of the brakes, the vehicle came to a stop 210 ft downstream of impact and 3 ft to the right. Figure E2 in Appendix E shows sequential photographs of the test period.

5.2.5 Damage to Test Installation

Figures 5.10 and 5.11 show damage to the roll-up sign stand. The fabric sign panel and stays separated from the lower base, contacted and penetrated the windshield, rode up and over the vehicle and came to rest 65 ft downstream of impact. The base of the sign came to rest 158 ft downstream of impact.

5.2.6 Vehicle Damage

Figure 5.12 shows damage to the 1100C vehicle. The hood sustained scuff marks. No measureable deformation was noted to the exterior hood or bumper. The windshield had a 4-inch × 1.5-inch hole. The area around the hole was depressed into the occupant compartment 1.5 inches, and the total shattered area on the windshield measured 15 inches × 13 inches. Figure 5.13 shows the windshield damage from inside the occupant compartment. Table D5 and D6 in Appendix D provides exterior crush and occupant compartment measurements.

5.2.7 Occupant Risk Factors

Previous full-scale crash tests have shown that the acceleration levels experienced by the vehicle during impact with lightweight, free-standing work zone traffic control devices weighing less than 220 lb were not significant. Consequently, *MASH* does not require instrumentation of the vehicle, and the occupant risk factors were not calculated for this test. Figure 5.14 summarizes pertinent information from the test.

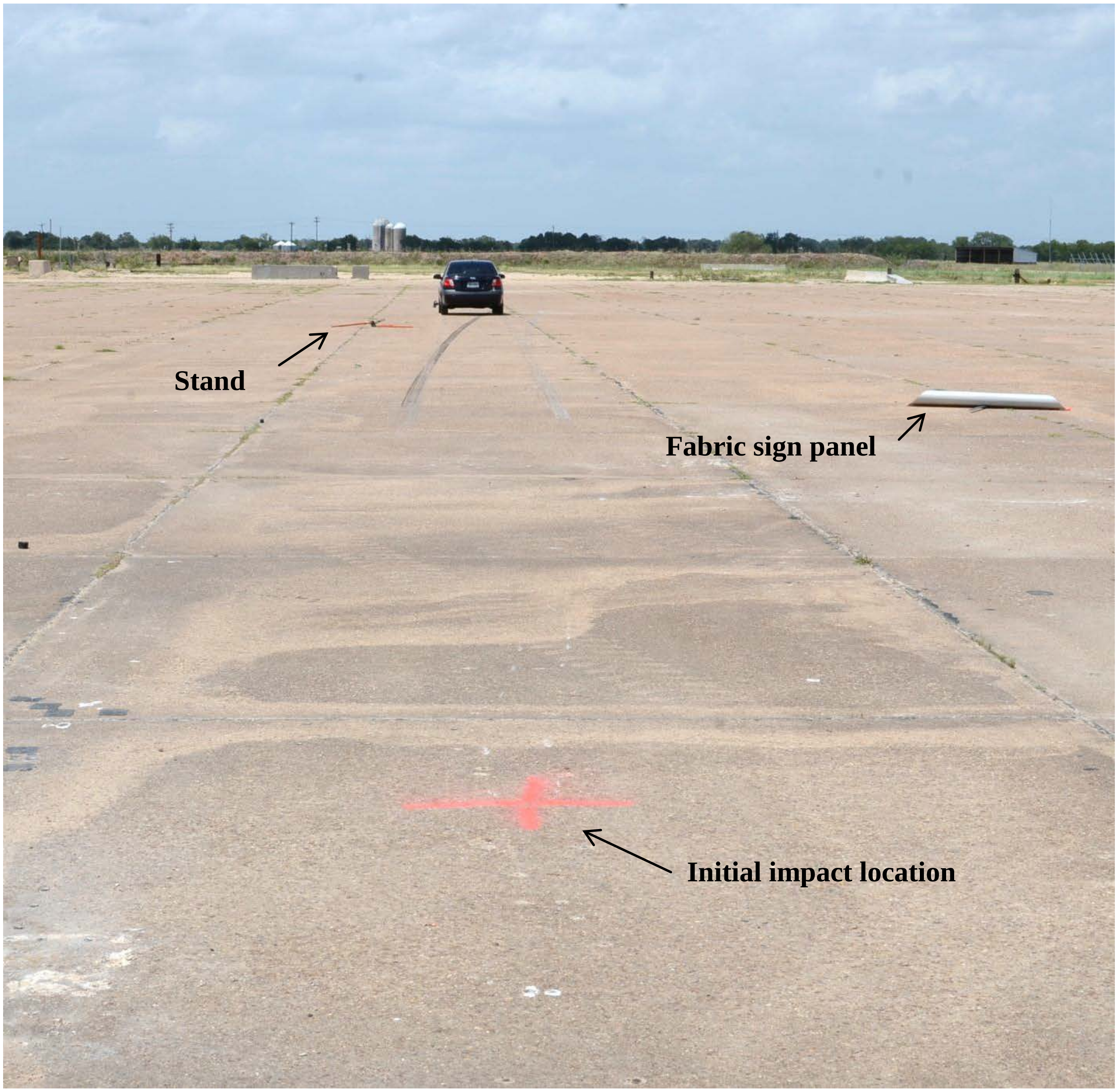


Figure 5.10. After Impact Locations for Test No. 466393-2.

Figure 5.11. Installation after Test No. 466393-2.

Figure 5.12. Vehicle after Test No. 466393-2.

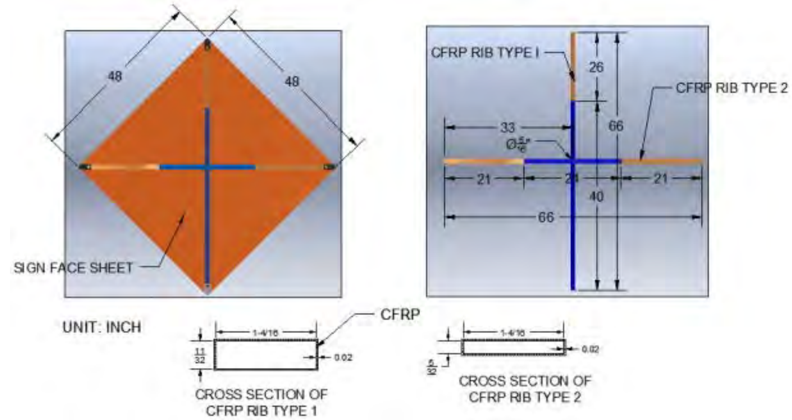
Figure 5.13. Interior of Vehicle for Test No. 466393-2.

0.000 s

0.100 s

0.200 s

0.300 s



General Information

Test Agency	Texas Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-71
TTI Test No.	466393-2
Test Date	2013-07-22

Test Article

Type	Work Zone Traffic Control Device
Name	Portable Roll-Up Sign without sandbags
Installation Height	1-ft mounting height
Material or Key Elements	Fabric sign substrate with carbon wrapped fiberglass stays and metal base ballasted with four 40-lb sandbags

Soil Type and Condition .... Placed on concrete surface, dry

Test Vehicle

Type/Designation	1100C
Make and Model	2008 Kia Rio
Curb	2301 lb
Test Inertial	2437 lb
Dummy	180 lb
Gross Static	2617 lb

Impact Conditions

Speed	59.7 mi/h
Angle	0 degrees
Location/Orientation	90 degrees to traffic

Exit Conditions

Speed	58.9 mi/h
Angle	0 degrees

Post-Impact Trajectory

Stopping Distance	210 ft downstream 3 ft toward traffic

Test Article Deflections

Fabric Sign & Upper Supports	65 ft downstream
Lower Support/Base	158 ft downstream

Vehicle Damage

VDS	12FC1
CDC	12FCGN6
Max. Exterior Deformation	1.5 inches (windshield)
OCDI	FS0000000
Max. Occupant Compartment Deformation	1.5 inches (windshield)
Windshield Damage	Punctured

Figure 5.14. Summary of Results for *MASH* Test 3-71 on the Portable Roll-Up Sign without Sandbags.

5.2.8 Assessment of Test Results

An assessment of the test based on the applicable *MASH* safety evaluation criteria is provided below.

5.2.8.1 Structural Adequacy

B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.

Results: The portable roll-up sign yielded to the vehicle by breaking away from the base. (PASS)

5.2.8.2 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. Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

Results: The detached fabric sign panel and attached stays rotated into and penetrated the windshield into the occupant compartment. (FAIL)

E. Detached element, 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.

Results: The detached fabric sign panel momentarily blocked the driver's vision, but for less than 0.1 seconds. This short time frame would not affect the driver's ability to control the vehicle. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Results: The 1100C vehicle remained upright during and after the collision event. (PASS)

I. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
10 ft/s	*16.4 ft/s*

Results: The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb. (N/A)

I. Occupant ridedown accelerations should satisfy the following:
Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb. (N/A)

5.2.8.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Result: The 1100C vehicle came to rest 210 ft downstream of the impact position of the portable roll-up sign.

5.3 CRASH TEST NO. 466393-3 (*MASH* TEST 3-71) – MODIFIED WITH SANDBAGS

After failure of the initial design, the portable roll-up sign system was modified. A ⅜-inch diameter bolt passed through the sign stand bracket and vertical fiberglass stay as shown in Figure 5.15. The objective of the modification was to delay or prevent release of the sign and, thereby, reduce or eliminate its interaction with the windshield.

5.3.1 Test Designation and Actual Impact Conditions

MASH Test 3-71 involves an 1100C vehicle weighing 2420 lb ±55 lb and impacting the portable roll-up sign support at an impact speed of 62.2 mi/h ±2.5 mi/h. In this test, two separate devices were impacted. The first sign was oriented perpendicular to the path of the vehicle and the second was placed 30 ft downstream and oriented parallel to the path of the vehicle. The centerline of the vehicle was aligned with the centerline of each roll-up sign. The 2008 Kia Rio used in the test weighed 2442 lb. The actual impact speed and angle were 62.6 mi/h and 0 degrees for the first sign, 61.1 mi/h and 0 degrees for the second sign, respectively. The portable roll-up signs were sequentially impacted with the centerline of the vehicle aligned with the centerline of the signs.

Figure 5.15. Bolt Added Through Stand Bracket and Vertical Stay.

5.3.2 Test Vehicle

The 2008 Kia Rio, shown in Figures 5.16 and 5.17, was used for the crash test. Test inertia weight of the vehicle was 2442 lb, and its gross static weight was 2617 lb. The height to the lower edge of the vehicle bumper was 6.75 inches, and the height to the upper edge of the bumper was 21.25 inches. Table D7 in Appendix D gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

5.3.3 Weather Conditions

The test was performed on the morning of August 23, 2013. Weather conditions at the time of testing were as follows: (a) wind speed: 5 mi/h; (b) wind direction: 168 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); (c) temperature: 96°F; (d) relative humidity: 52 percent.

5.3.4 Test Description

The 2008 Kia Rio, traveling at an impact speed of 62.6 mi/h, contacted the first portable roll-up sign with the centerline of the vehicle aligned with the centerline of the device, with the device oriented perpendicular to the path of the vehicle. Shortly after impact, the fabric sign panel and fiberglass stays wrapped around the hood of the vehicle. As the vehicle proceeded to ride over the sign stand, the connection bolt through the sign bracket and vertical fiberglass stay kept the fiberglass stays from releasing. The stays pulled out of the fabric roll-up sign substrate, and the plastic pocket at the top corner of the roll-up sign struck the bottom of the windshield. The prolonged contact with the stays caused the stand to rotate as the vehicle was passing over it. As the sign stand rotated, one of the legs of the stand punctured the gas tank of the vehicle. The sign stand rode under the vehicle for a time and came to rest 35 ft downstream of impact. The fabric sign panel remained draped across the hood of the vehicle as the vehicle approached and impacted the second portable roll-up sign support system.

The 2008 Kia Rio, traveling at an impact speed of 61.1 mi/h, contacted the second portable roll-up sign with the centerline of the vehicle aligned with the centerline of the device, with the device oriented parallel to the path of the vehicle. The fabric roll-up sign from the first sign system contacted the bottom edge of the fabric roll-up sign of the second sign support system just before impact. Immediately thereafter, the second fabric sign wrapped around the bumper and hood of the vehicle. Upon review of high-speed film, researchers concluded that the first fabric roll-up sign did not interfere with or influence the behavior or trajectory of the send sign system. As the vehicle progressed over the sign stand, the stays remained attached to the stand and were pulled out of the fabric roll-up sign. The plastic corner pocket at the top corner of the sign panel released from the fabric sign and struck the middle of the windshield. There was not direct contact between the fabric sign panel and the windshield of the vehicle.

Brakes were applied, and the vehicle came to a stop at 238 ft downstream of impact of the initial impact point with the first portable sign support system.

Figure 5.16. Vehicle/Installation Geometrics for Test No. 466393-3.

Figure 5.17. Vehicle before Test No. 466393-3.

5.3.5 Damage to Test Installation

Figures 5.18 and 5.19 show damage to the work zone traffic control device. The fabric sign panels separated from each of the lower bases. The plastic corner pocket at the top corner of the sign panel released from the fabric sign and struck the middle of the windshield. The fabric sign panels then rode up and over the vehicle. The base of the first work zone traffic control device came to rest 35 ft downstream of impact, and the second base came to rest 75 ft downstream of impact.

5.3.6 Vehicle Damage

Figure 5.20 shows damage to the 1100C vehicle. The hood sustained scuff marks. No measureable deformation was noted to the exterior hood or bumper. Contact with the top corner of the first fabric roll-up sign panel caused the windshield to shatter over an area measuring 3 inches × 3.5 inches. This area was deformed toward the occupant compartment 0.75 inches, but there was no penetration or tear of the plastic liner. Contact of the plastic corner pocket from the second roll-up sign caused cracking of the windshield in two other small areas measuring 2.5-inch × 2-inch and 1.5-inch × 1-inch. There was no deformation of these areas into the occupant compartment. The gas tank had a puncture measuring 1.85 inches × 0.26 inch. Figure 5.21 shows the damage to the gas tank. Table D8 and D9 in Appendix D provides exterior crush and occupant compartment measurements.

5.3.7 Occupant Risk Factors

Previous full-scale crash tests have shown that the acceleration levels experienced by the vehicle during impact with lightweight, free-standing work zone traffic control devices weighing less than 220 lb were not significant. Consequently, MASH does not require instrumentation of the vehicle, and the occupant risk factors were not calculated for this test. Figure 5.22 summarizes pertinent information from the test.

5.3.8 Assessment of Test Results – Sign Perpendicular to Path of Vehicle (First Impact)

An assessment of the test based on the applicable *MASH* safety evaluation criteria is provided below.

5.3.8.1 Structural Adequacy

B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.

<u>Results</u>: The portable roll-up sign yielded to the vehicle. (PASS)

Figure 5.18. After Impact Locations for Test No. 466393-3.

Figure 5.19. Installation after Test No. 466393-3.

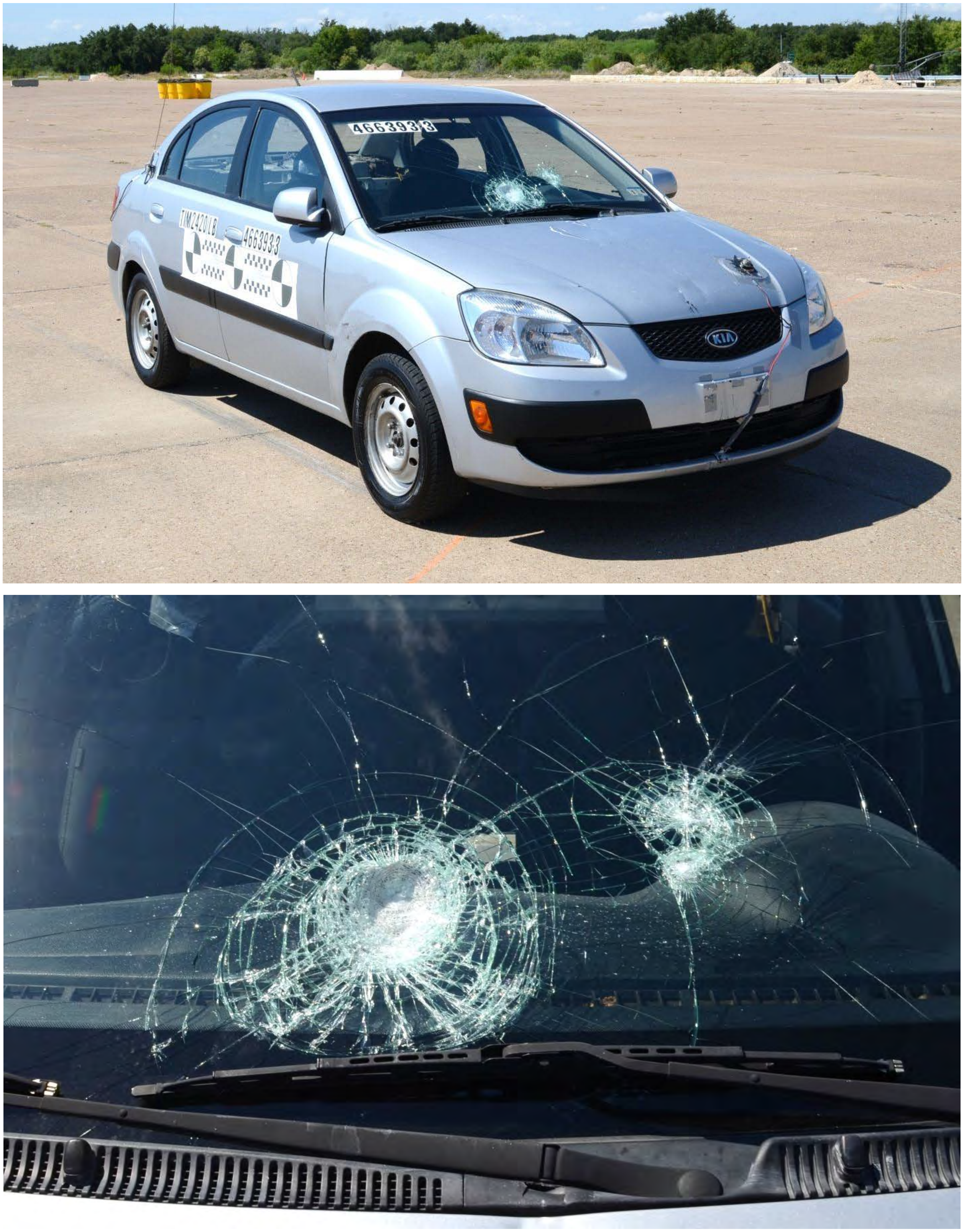


Figure 5.20. Vehicle after Test No. 466393-3.

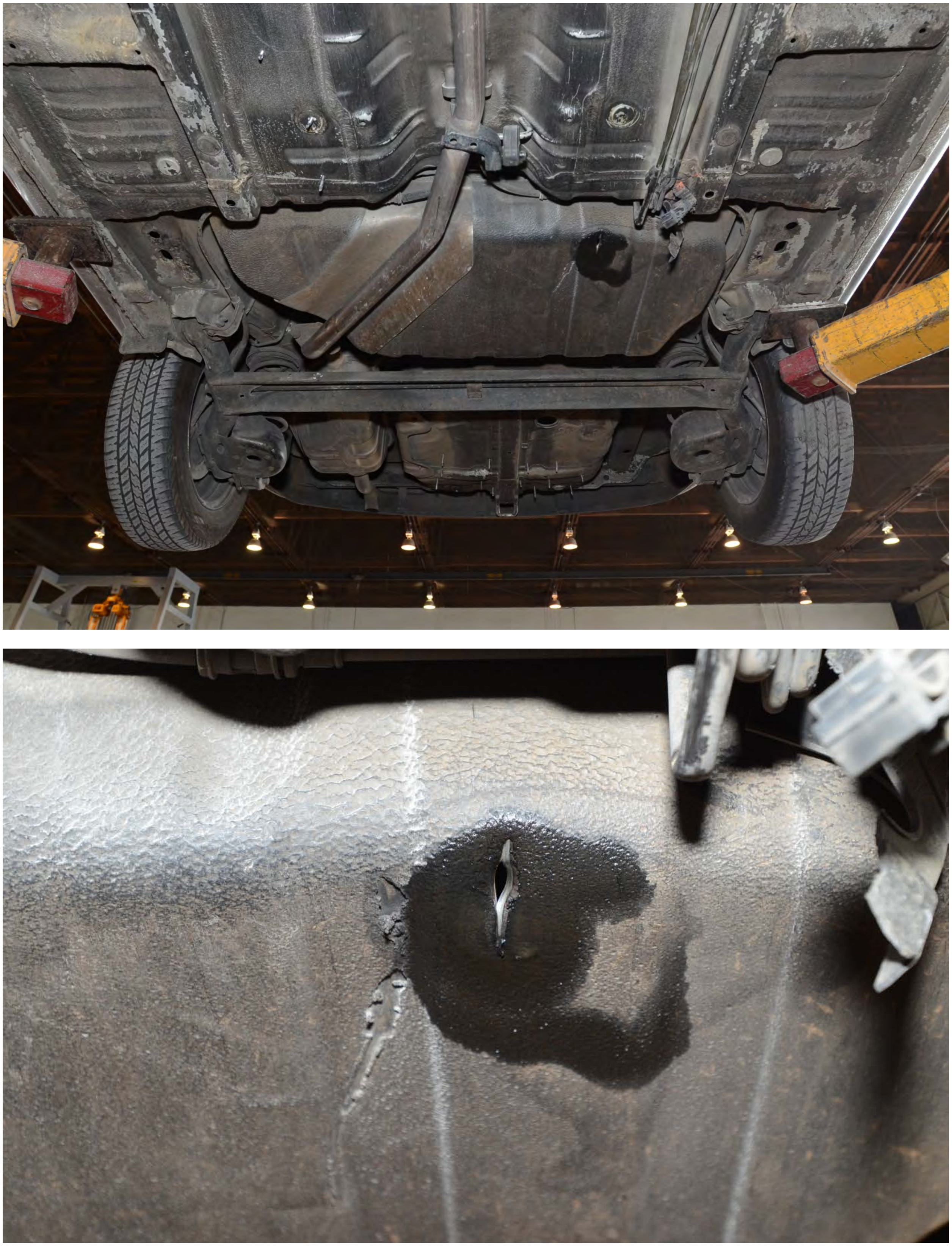
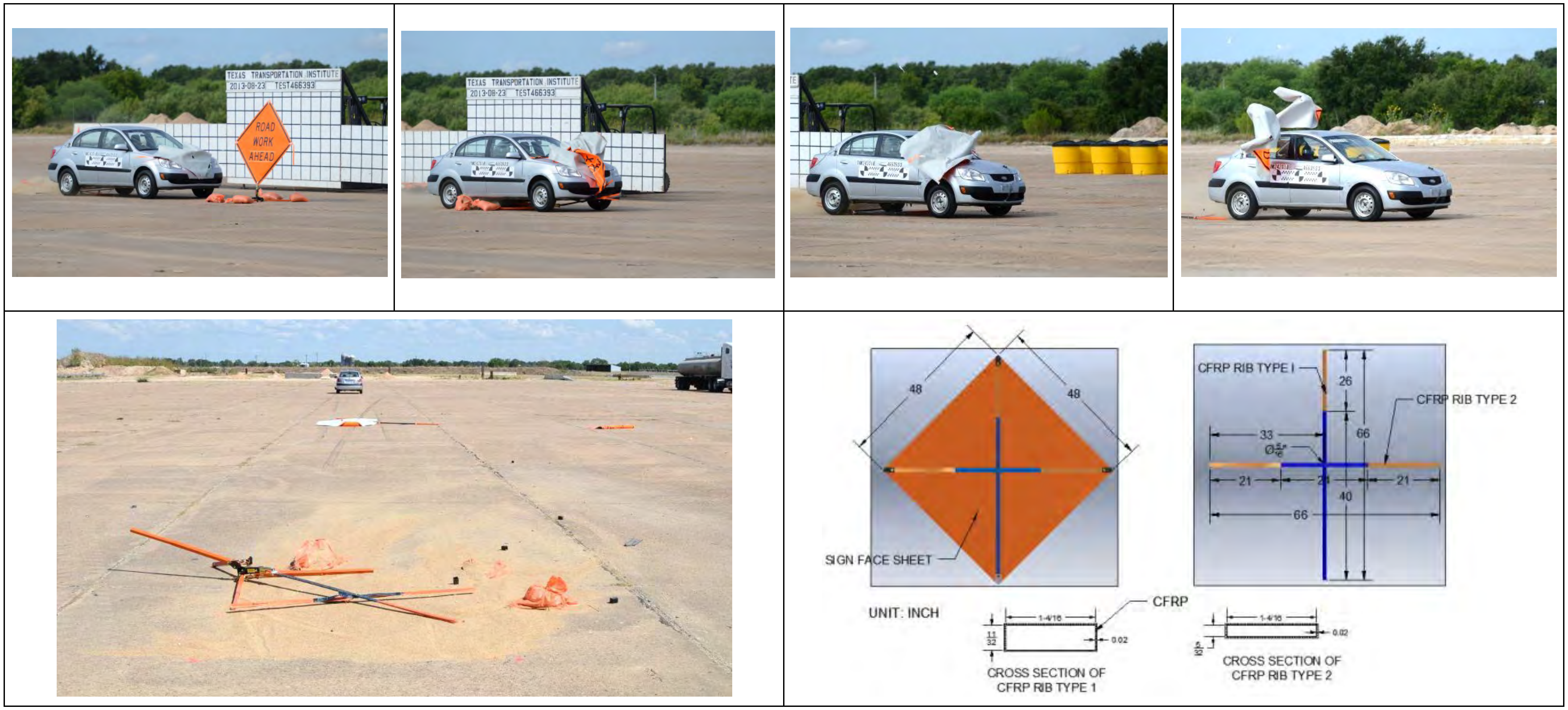


Figure 5.21. Vehicle Gas Tank after Test No. 466393-3.



General Information
- Test Agency .... Texas Transportation Institute (TTI)
- Test Standard Test No. .... MASH Test 3-71
- TTI Test No. 466393-3
- Test Date 2013-08-23

Test Article
- Type..................................... Work Zone Traffic Control Device
- Name .... Modified Portable Roll-Up Sign with sandbags
- Installation Height.................. 1-ft mounting height
- Material or Key Elements ...... Fabric sign substrate with carbon wrapped fiberglass stays bolted to metal base ballasted with four 40-lb sandbags

Soil Type and Condition......... Placed on concrete surface, dry

Test Vehicle
- Type/Designation 1100C
- Make and Model.........2008 Kia Rio
- Curb ....2427 lb
- Test Inertial ....2442 lb
- Dummy........................ 175 lb
- Gross Static................2617 lb

Impact Conditions
- Speed (first sign) ....62.6 mi/h
- Speed (second sign)....61.6 mi/h
- Angle..........................0 degrees
- Location/Orientation ....90 degrees to traffic

Exit Conditions
- Speed..........................
- Angle..........................2 degrees

Post-Impact Trajectory
- Stopping Distance .... 238 ft downstream

Test Article Deflections
- Fabric Sign & Upper Supports .. 75 ft downstream
- Lower Support/Base .... 35 ft downstream

Vehicle Damage
- VDS... 12FC1
- CDC 12FCGN6
- Max. Exterior Deformation .... 0.75 inches (windshield)
- OCDI FS0000000
- Max. Occupant Compartment Deformation........................ 0.75 inches (windshield)
- Windshield Damage .... Shattered 0.75 inch inward
- Damage to Gas Tank .... Punctured 1.8x0.26 inches

Figure 5.22. Summary of Results for *MASH* Test 3-71 on the Modified Portable Roll-Up Sign with Sandbags.

5.3.8.2 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. Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

Results: The fiberglass stays pulled out of the fabric roll-up sign panel and the top corner of the fabric sign and its plastic pocket contacted the windshield. The windshield was depressed toward the occupant compartment 0.75 inches and there was no penetration of the plastic liner. (PASS)

E. Detached element, 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.

Results: The detached fabric sign panel did not block the driver's vision nor affect the driver's ability to control the vehicle. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Results: The 1100C vehicle remained upright during and after the collision event. (PASS)

J. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
10 ft/s	*16.4 ft/s*

Results: The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb. (N/A)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb. (N/A)

5.3.8.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Result: The 1100C vehicle came to rest 238 ft downstream of the impact point with the first portable roll-up sign.

5.3.9 Assessment of Test Results – Sign Parallel to Path of Vehicle (Second Impact)

An assessment of the test based on the applicable *MASH* safety evaluation criteria is provided below.

5.3.9.1 Structural Adequacy

B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.

Results: The portable roll-up sign yielded to the vehicle. (PASS)

5.3.9.2 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. Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

Results: The sign panel never contacted the windshield. The plastic pocket at the top corner of the sign panel released and contacted the windshield causing some cracking over a small area. There was no deformation of the windshield toward the occupant compartment and no penetration of the plastic liner. (PASS)

E. Detached element, 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.

Results: The detached fabric sign panel did not block the driver's vision nor affect the driver's ability to control the vehicle. (PASS)

F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.

Results: The 1100C vehicle remained upright during and after the collision event. (PASS)

K. Occupant impact velocities should satisfy the following:
Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
10 ft/s	*16.4 ft/s*

Results: The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb. (N/A)

I. Occupant ridedown accelerations should satisfy the following:
Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb. (N/A)

5.3.9.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Result: The 1100C vehicle came to rest 238 ft downstream of the impact point with the first portable roll-up sign.

CHAPTER 6. SUMMARY AND CONCLUSIONS

Current portable roll-up signs have experienced field problems when subjected to high winds. In windy conditions typical of the Texas coast and panhandle, the rollup sign panels lay back to a point that they become illegible. In more extreme conditions, the support can blow over or the fiberglass stays can break. Under project 0-6399, research was performed by Texas Tech University to identify alternative materials to support flexible, roll-up sign substrates that will improve their performance in windy conditions.

The new design incorporates carbon fiber wraps around selected portions of the fiberglass support stays to increase their torsional stiffness without appreciably changing their bending stiffness. A prototype portable sign support system was submitted to TTI for full-scale crash testing and evaluation in accordance with *MASH* guidelines.

6.1 INITIAL PORTABLE ROLL-UP SIGN STAND SYSTEM

The portable roll-up sign yielded was initially tested with sand bags placed on each of the four legs of the sign stand as ballast. This is how these devices are typically deployed in areas such as the Texas panhandle that are subject to high winds. The test involved a small passenger car impacting the portable sign support head-on with the sign oriented perpendicular to the path of the impacting vehicle. The roll-up sign pulled out of the sign stand and contacted the windshield of the vehicle. The top corner of the sign panel penetrated the windshield, causing the system to fail Evaluation Criterion D of *MASH*. A summary of the test results in presented in Table 6.1.

After failure of the initial crash test, the same system was retested without sand bags to determine if the presence of sand bags affects the interaction of the portable roll-up sign system with the vehicle. Many portable sign systems have been tested without additional ballast. Testing without ballast might permit the sign stand to be accelerated more quickly and, thereby, delay release of the sign panel from the sign stand. The test involved a small passenger car impacting the portable sign support head-on with the sign oriented perpendicular to the path of the impacting vehicle. The behavior of the sign support system was very similar to that observed in the test with sand bags. The roll-up sign pulled out of the sign stand and contacted the windshield of the vehicle. The top corner of the sign panel penetrated the windshield, causing the system to fail Evaluation Criterion D of *MASH*. A summary of the test results in presented in Table 6.2.

6.2 MODIFIED PORTABLE ROLL-UP SIGN STAND SYSTEM

After failure of the initial design, the portable roll-up sign system was modified. A 3/8-inch diameter bolt was inserted through the sign stand bracket and vertical fiberglass stay. The purpose of the modification was to delay or prevent release of the sign panel from the sign stand and, thereby, reduce or eliminate interaction of the sign panel with the windshield.

In this test, two separate modified portable roll-up sign systems were impacted. The first sign was oriented perpendicular to the path of the vehicle and the second was placed 30 ft downstream and oriented parallel to the path of the vehicle. The test involved a small passenger car impacting the signs sequentially. As the vehicle proceeded to ride over the sign stand, the connection bolt through the sign bracket and vertical fiberglass stay kept the fiberglass stays from releasing. The stays pulled out of the fabric roll-up sign substrate, and the plastic pocket at the top corner of the roll-up sign struck the bottom of the windshield. The windshield was shattered and deformed inward toward the occupant compartment 0.75 inches. However, there was no penetration of the plastic liner, and the modified portable roll-up sign support orientated perpendicular to the path of the vehicle satisfied *MASH* evaluation criteria as summarized in Table 6.3.

It should be noted that the added connection bolt resulted in prolonged contact of the vehicle with the vertical fiberglass stay. As the sign stand rotated as a result of this interaction, one of the legs of the stand punctured a hole in the gas tank of the vehicle. MASH states:

> "Although not a specific factor in assessing test results, integrity of the test vehicle's fuel tank is a potential concern. It is preferable that the fuel tank remains intact and not be punctured. Damage to, or rupture of, the fuel tank, oil pan, or other features that might serve as a surrogate of a fuel tank should be reported."

The fabric roll-up sign from the first sign system was carried along on the hood of the vehicle and it contacted the bottom edge of the fabric roll-up sign of the second sign support system just before impact. However, upon review of high-speed film, researchers concluded that the first fabric roll-up sign did not interfere with or influence the behavior or trajectory of the second sign system. As the vehicle progressed over the sign stand, the stays remained attached to the stand and were pulled out of the fabric roll-up sign. The plastic corner pocket at the top corner of the sign panel released from the fabric sign and struck the middle of the windshield. Although there was some cracking, there was no deformation of the windshield toward the occupant compartment and no penetration of the plastic liner. As summarized in Table 6.4, the modified portable roll-up sign support orientated parallel to the path of the vehicle satisfied *MASH* evaluation criteria.

Table 6.1. Performance Evaluation Summary for *MASH* Test 3-71 on the Portable Roll-Up Sign with Sandbags.

Test Agency: Texas Transportation Institute   Test No.: 466393-1   Test Date: 2013-07-22

***MASH* Test 3-71 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> *B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.*	The portable roll-up sign yielded to the vehicle by breaking away from the base.	Pass
<u>Occupant Risk</u> *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 should not exceed limits set forth in Section 5.3 and Appendix E of MASH.*	The detached fabric sign panel and attached stays rotated into and penetrated the windshield into the occupant compartment.	Fail
E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	The detached fabric sign panel momentarily blocked the driver's vision, but for less than 0.1 seconds. This short time frame would not affect the driver's ability to control the vehicle.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 1100C vehicle remained upright during and after the collision event.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 10 ft/s, or at least below the maximum allowable value of 16.4 ft/s.	The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb.	N/A
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.		N/A
<u>Vehicle Trajectory</u> *N. Vehicle trajectory behind the test article is acceptable.*	The 1100C vehicle came to rest 262 ft downstream of the impact position of the portable roll-up sign.	Pass

Table 6.2. Performance Evaluation Summary for *MASH* Test 3-71 on the Portable Roll-Up Sign without Sandbags.

Test Agency: Texas Transportation Institute | Test No.: 466393-2 | Test Date: 2013-07-22

***MASH* Test 3-71 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> *B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.*	The portable roll-up sign yielded to the vehicle by breaking away from the base.	Pass
<u>Occupant Risk</u> *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 should not exceed limits set forth in Section 5.3 and Appendix E of MASH.*	The detached fabric sign panel and attached stays rotated into and penetrated the windshield into the occupant compartment.	Fail
E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	The detached fabric sign panel momentarily blocked the driver's vision, but for less than 0.1 seconds. This short time frame would not affect the driver's ability to control the vehicle.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 1100C vehicle remained upright during and after the collision event.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 10 ft/s, or at least below the maximum allowable value of 16.4 ft/s.	The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb.	N/A
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.		N/A
<u>Vehicle Trajectory</u> *N. Vehicle trajectory behind the test article is acceptable.*	The 1100C vehicle came to rest 210 ft downstream of the impact position of the portable roll-up sign.	Pass

Table 6.3. Performance Evaluation Summary for *MASH* Test 3-71 on Modified Portable Roll-Up Sign with Sandbags – Sign Perpendicular to Path of Vehicle (First Impact).

Test Agency: Texas Transportation Institute | Test No.: 466393-3 | Test Date: 2013-08-23

***MASH* Test 3-71 Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> B. *The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.*	The portable roll-up sign yielded to the vehicle.	Pass
<u>Occupant Risk</u> 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.*	The fiberglass stays pulled out of the fabric roll-up sign panel and the top corner of the fabric sign and its plastic pocket contacted the windshield.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	The windshield was depressed toward the occupant compartment 0.75 inches and there was no penetration of the plastic liner.	Pass
E. *Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.*	The detached fabric sign panel did not block the driver's vision nor affect the driver's ability to control the vehicle.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 1100C vehicle remained upright during and after the collision event.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 10 ft/s, or at least below the maximum allowable value of 16.4 ft/s.*	The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*		Pass
<u>Vehicle Trajectory</u> N. *Vehicle trajectory behind the test article is acceptable.*	The 1100C vehicle came to rest 238 ft downstream of the impact position of the portable roll-up sign.	Pass

Table 6.4. Performance Evaluation Summary for *MASH* Test 3-71 on Modified Portable Roll-Up Sign with Sandbags – Sign Parallel to Path of Vehicle (Second Impact).

Test Agency: Texas Transportation Institute | Test No.: 466393-3 | Test Date: 2013-08-23

***MASH* Test 3-71 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy *B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.*	The portable roll-up sign yielded to the vehicle.	Pass
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.*	The plastic pocket at the top corner of the sign panel released and contacted the windshield causing some cracking over a small area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	There was no deformation of the windshield toward the occupant compartment and no penetration of the plastic liner.	Pass
E. Detached elements, fragments, or other debris from the test article, of vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	The detached fabric sign panel did not block the driver's vision nor affect the driver's ability to control the vehicle.	Pass
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 1100C vehicle remained upright during and after the collision event.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 10 ft/s, or at least below the maximum allowable value of 16.4 ft/s.	The test vehicle was not instrumented based on the total weight of the test article being less than 220 lb.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.		Pass
Vehicle Trajectory *N. Vehicle trajectory behind the test article is acceptable.*	The 1100C vehicle came to rest 238 ft downstream of the impact position of the portable roll-up sign.	Pass

CHAPTER 7. IMPLEMENTATION STATEMENT

Portable roll-up signs are routinely used by TxDOT for short-term, daytime maintenance/construction activities and emergency operations. These flexible fabric signs are supported by fiberglass frames attached to a multi-leg base. In windy conditions typical of the Texas coast and panhandle, the rollup sign panels can lay back to a point that they become illegible. In more extreme conditions, the support can blow over or the fiberglass stays can break.

There is a direct cost associated with having to reset signs that blow down and replace those that fail. Additionally, these activities increase exposure for the maintenance personnel performing the work, and temporary loss of a sign and the information it is intended to convey could potentially pose a safety concern for both work zone personnel and the motoring public.

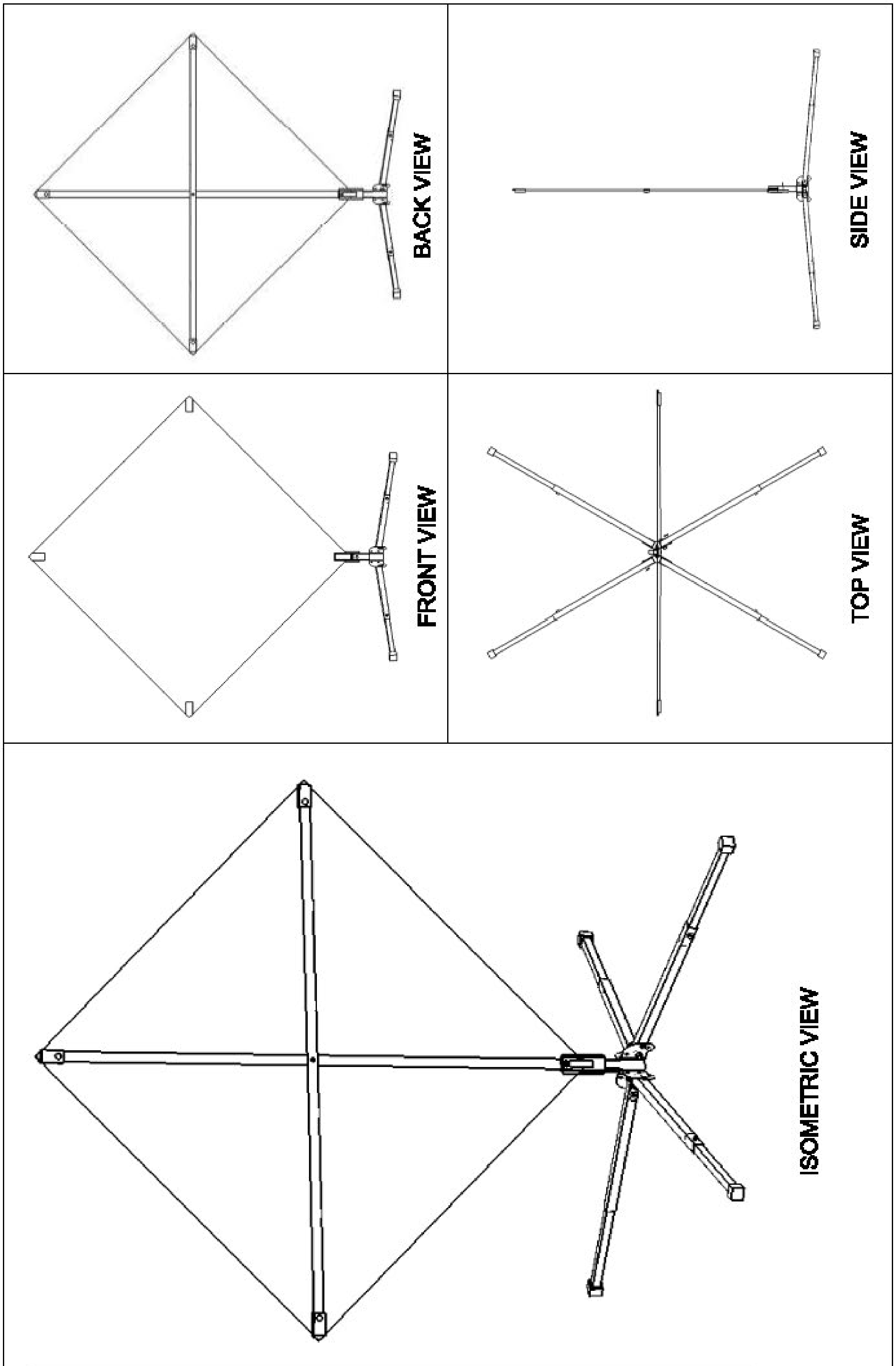
Under research project 0-6399, design modifications were developed to improve the performance of the sign support in windy conditions and reduce wind-induced failures. The crashworthiness of the modified portable roll-up sign support system was evaluated through a series of full-scale crash tests.

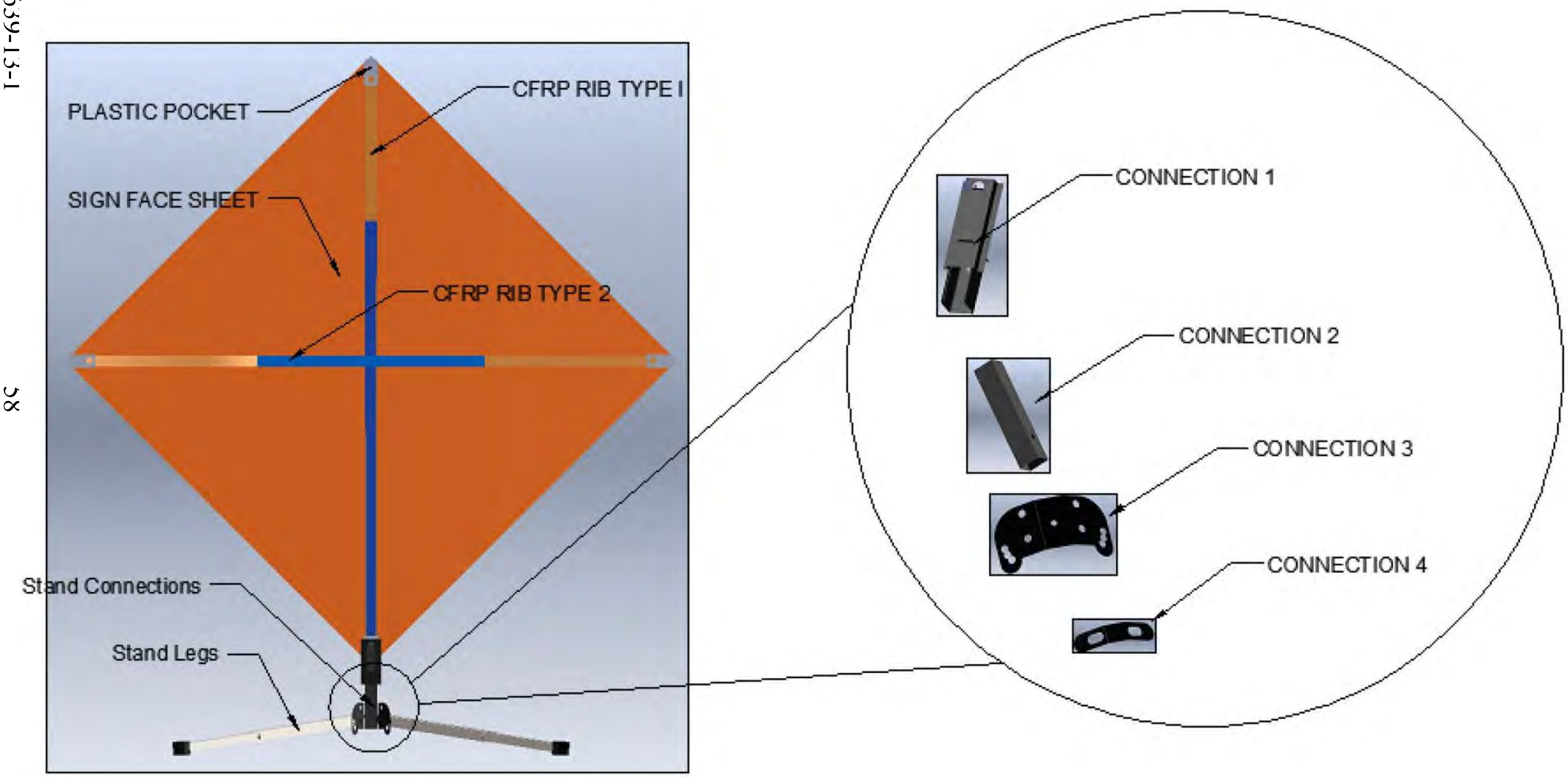
When a 3/8-inch diameter bolt was used to retain the vertical fiberglass stay and prevent it from separating from the sign stand, the modified design satisfied *MASH* evaluation criteria. Therefore, the portable sign support system with carbon wrapped fiberglass stays and a retaining bolt as tested and described herein, is considered suitable for implementation and further field evaluation. It should be noted that the use of the retaining bolt caused rotation of the sign stand during impact and resulted in one of the legs of the sign stand puncturing a hole in the gas tank of the impacting vehicle. Although this is not a specific factor in assessing test results, *MASH* states that it is preferable that the fuel tank remains intact and not be punctured. Any field implementation of this design should be done with knowledge and consideration of this behavior.

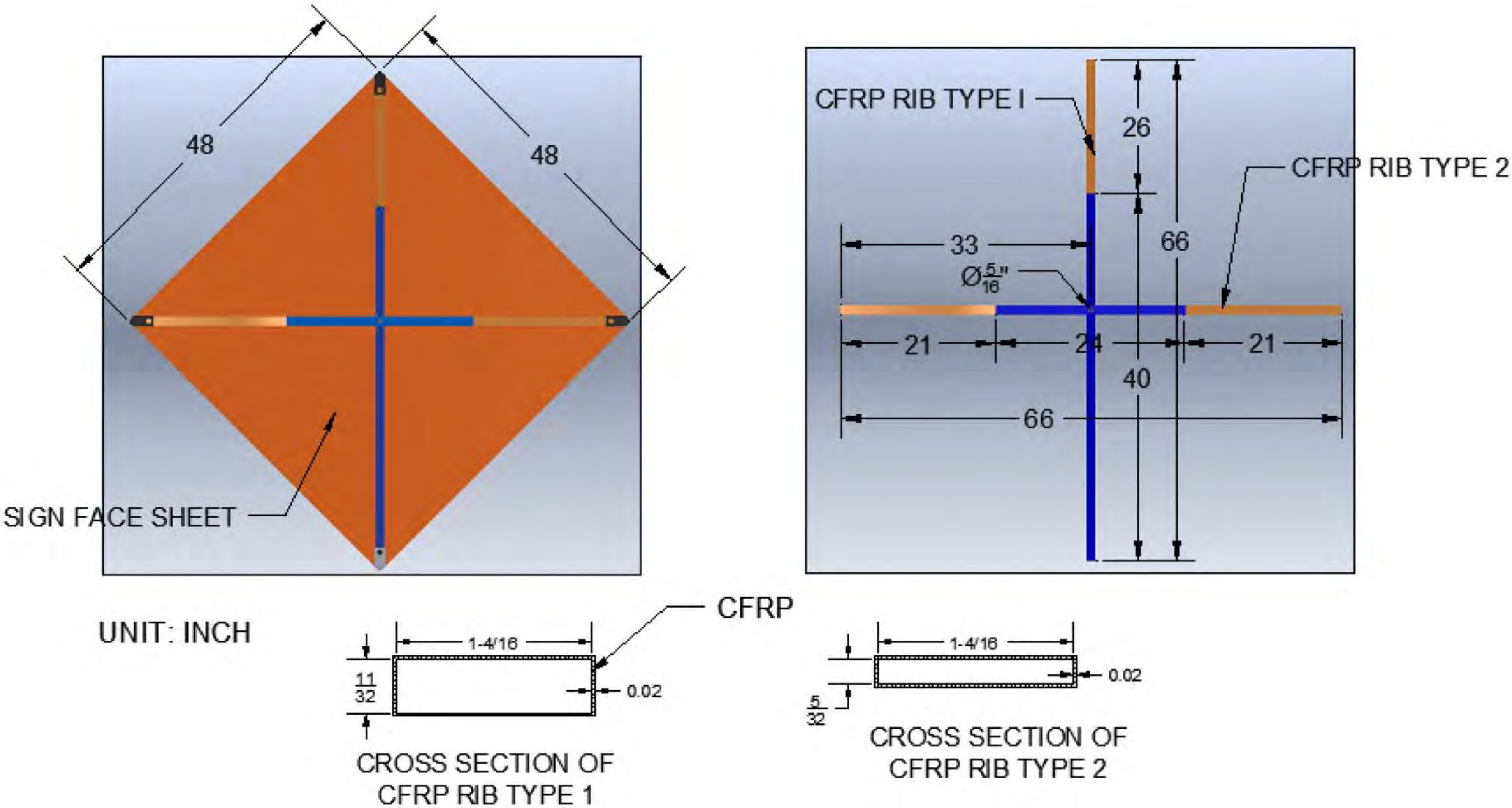
REFERENCES

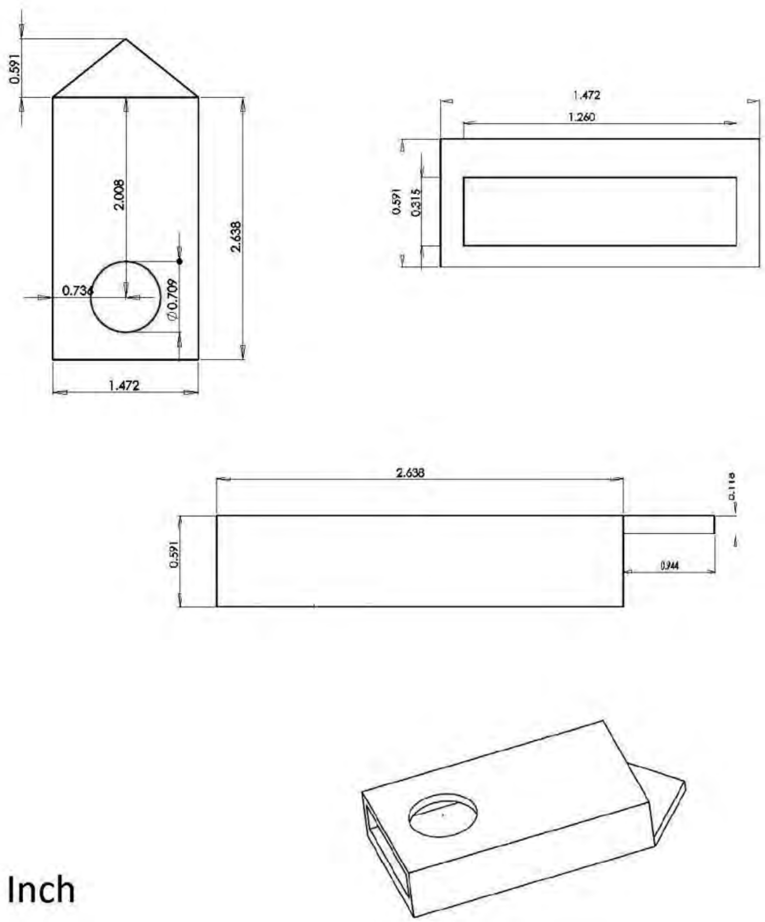
1. AASHTO, *Manual for Assessing Safety Hardware*, American Association of State Highway and Transportation Officials, Washington, D.C., 2009.

APPENDIX A. DETAILS OF THE PORTABLE ROLL-UP SIGN



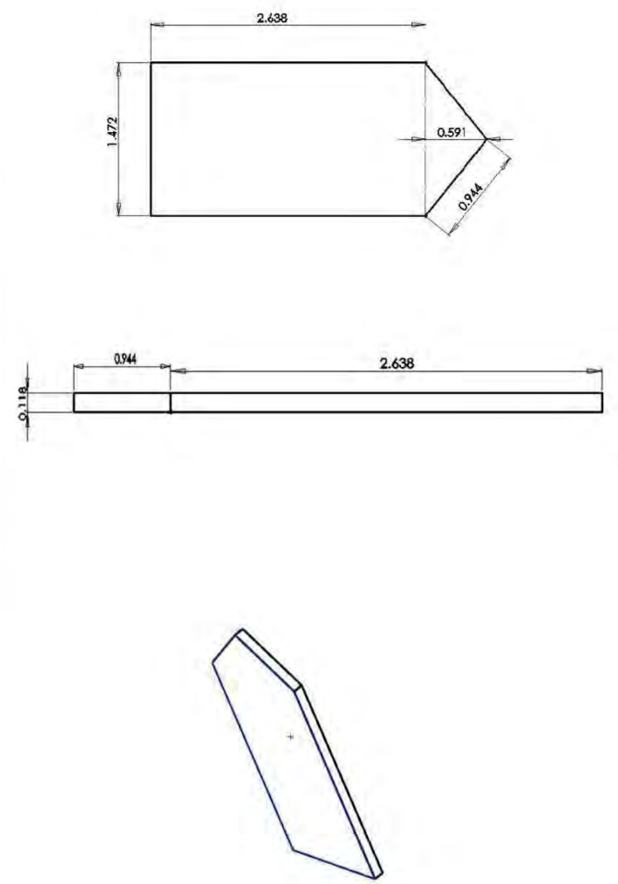

PLASTIC POCKET
CFRP RIB TYPE I
SIGN FACE SHEET
CFRP RIB TYPE 2
Stand Connections
Stand Legs
CONNECTION 1
CONNECTION 2
CONNECTION 3
CONNECTION 4


48
48
SIGN FACE SHEET
CFRP RIB TYPE I
CFRP RIB TYPE 2
26
66
33
Ø5/16"
21
24
21
40
66
UNIT: INCH
CFRP
1-4/16
11/32
0.02
CROSS SECTION OF
CFRP RIB TYPE 1
1-4/16
0.02
5/32
CROSS SECTION OF
CFRP RIB TYPE 2



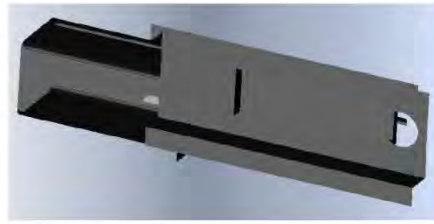
Unit: Inch

Plastic Pocket-Part 1

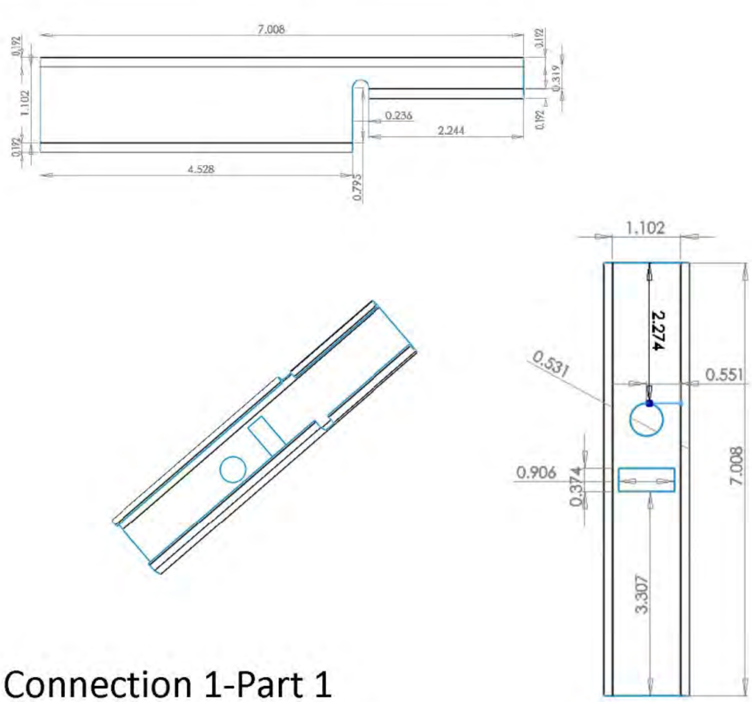


Plastic Pocket-Part 2

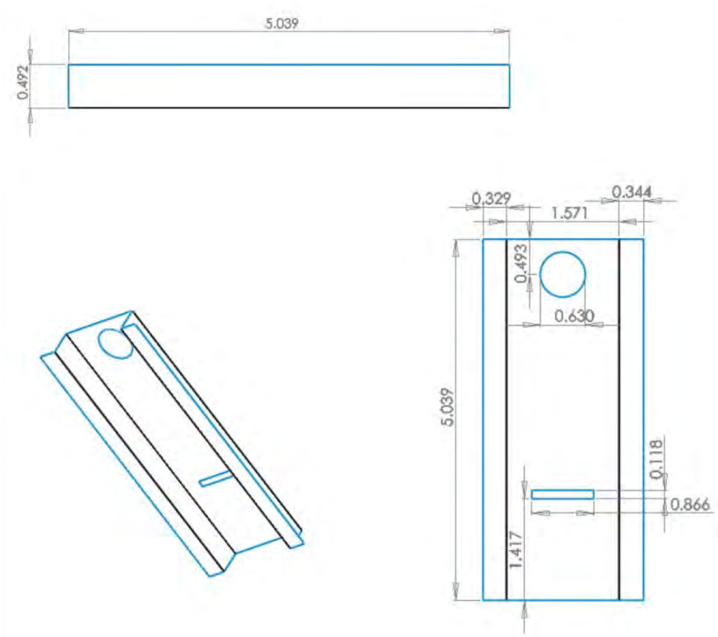
Connection 1



Unit: Inch

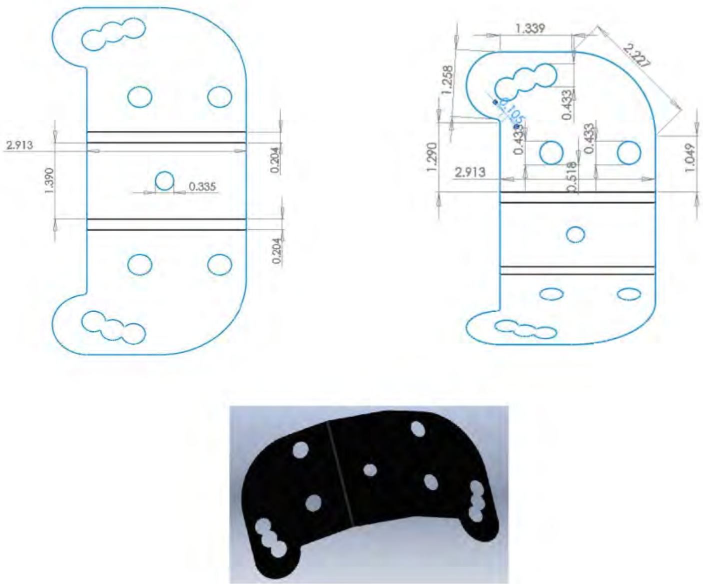


Connection 1-Part 1

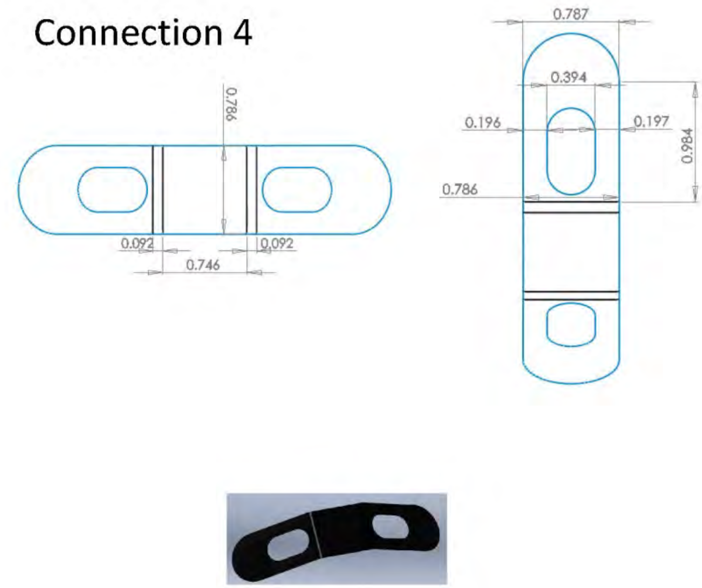


Connection 1-Part 2

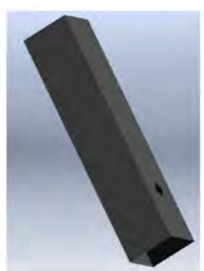
Connection 3

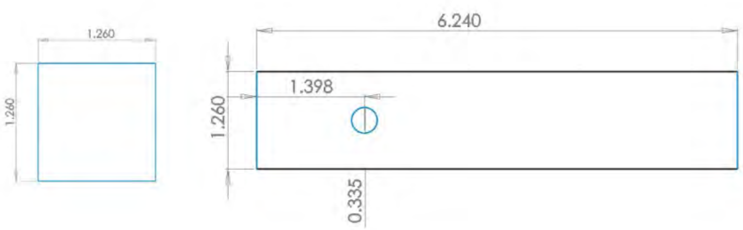


Connection 4

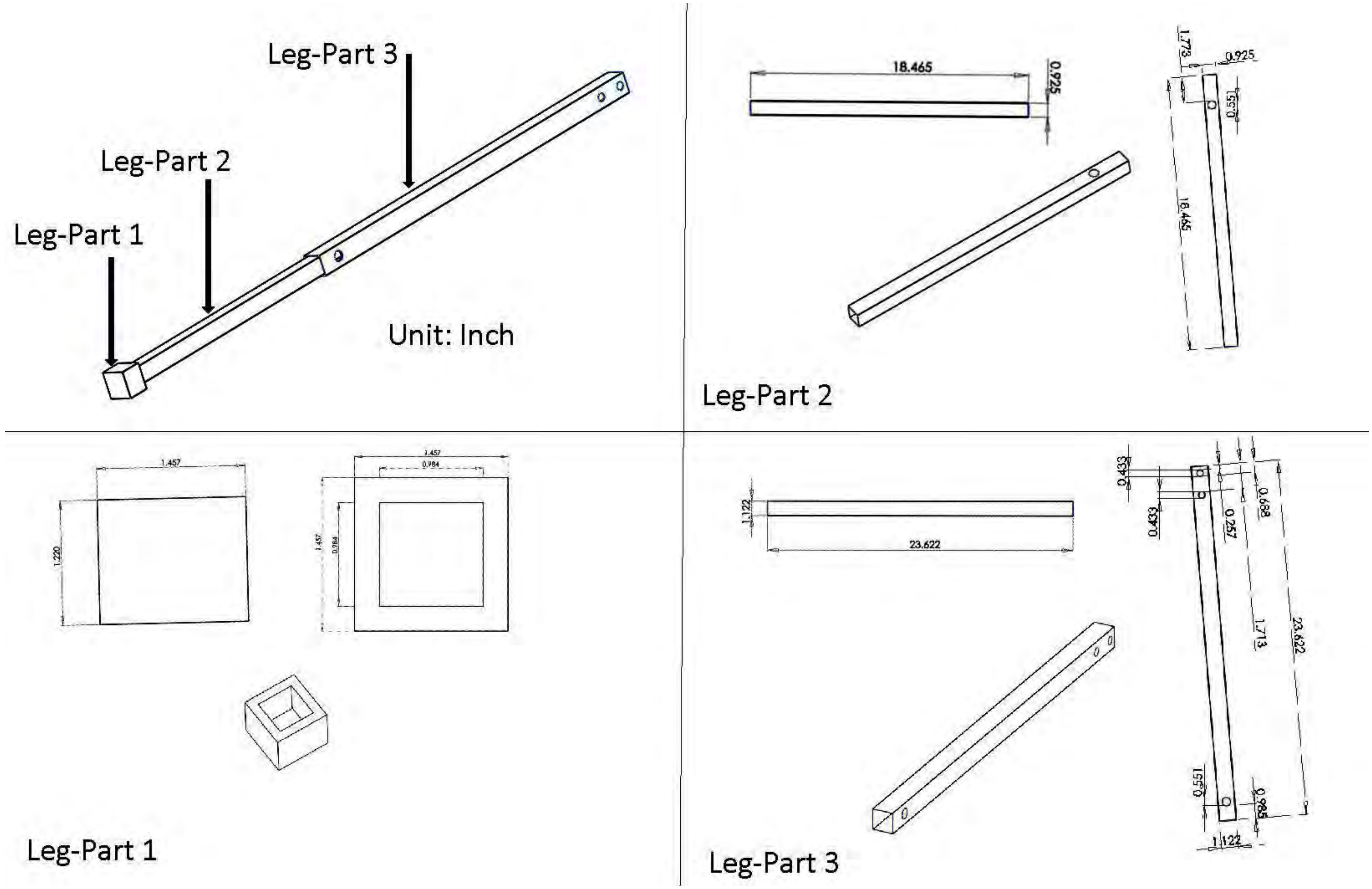


Connection 2





Unit: Inch


Leg-Part 3
Leg-Part 2
Leg-Part 1
Unit: Inch
18.465
0.925
1.778
0.925
0.551
18.465
Leg-Part 2
1.457
1.220
1.457
0.984
1.457
0.984
Leg-Part 1
1.122
23.622
0.433
0.433
0.688
0.257
1.713
23.622
0.551
0.985
1.122
Leg-Part 3

APPENDIX B. MATERIAL SPECIFICATIONS FOR SIGN SHEETING

3M

Diamond Grade™ Roll Up Sign Sheeting

Series RS20/RS24

Product Bulletin RS20/RS24 **December 2007**

Replaces PB RS24 dated July 1998

Description

3M™ Diamond Grade™ Roll Up Sign Sheeting Series RS20/RS24 is a visible light-activated fluorescent wide angle prismatic lens reflective sheeting designed for the production of roll up traffic control signs used in construction work zones. This sign sheeting is designed to provide higher nighttime sign brightness than sheetings that use glass bead lenses. RS24 sheeting has higher daytime brightness than ordinary (non-fluorescent) colored sheeting.

Series RS20/RS24 sheeting is backed with a strong, flexible, gray-coated fabric.

Color	Product Code
White	RS20
Fluorescent Orange	RS24

Photometrics

Daytime Color (x,y,Y)

The chromaticity coordinates and total luminance factor of the retroreflective sheeting conform to Table A.

Color Test – Fluorescent Sheetings

Conformance to standard chromaticity (x, y) and luminance factor (Y %) requirements shall be determined by instrumental method in accordance with ASTM E 991 on sheeting applied to smooth aluminum test panels cut from Alloy 6061-T6 or 5052-H38. The values shall be determined on a HunterLab ColorFlex 45/0 spectrophotometer. Computations shall be done for CIE Illuminant D65 and the 2° standard observer.[2]

Color Test – Ordinary Colored Sheeting

Conformance to standard chromaticity (x,y) and luminance factor (Y %) requirements shall be determined by instrumental method in accordance with ASTM E 1164 on sheeting applied to smooth aluminum test panels cut from Alloy 6061-T6 or 5052-H38. The values shall be determined on a HunterLab ColorFlex 45/0 spectrophotometer. Computations shall be done for CIE Illuminant D65 and the 2° standard observer.[2]

Table A - CIE Daytime Chromaticity Coordinate Limits[1] and Luminance Factor Minimum

Color	1		2		3		4		Luminance Factor Y (%)
	x	y	x	y	x	y	x	y	Min.
White	.303	.300	.368	.366	.340	.393	.274	.329	40
Fluorescent Orange	.583	.416	.535	.400	.595	.351	.645	.355	30

[1]The four pairs of chromaticity coordinates define the acceptable color limits for CIE D65 illumination in terms of the CIE 1931 Standard Colorimetric System.

[2]The instrumentally determined color values of retroreflective sheeting can vary significantly depending on the make and model of colorimetric spectrophotometer as well as the color and retroreflective optics of the sheeting (David M. Burns and Timothy J. Donahue, Measurement Issues in the Color Specification of Fluorescent Retroreflective Materials for High Visibility Traffic Signing and Personal Safety Applications, Proceedings of SPIE: Fourth Oxford Conference on Spectroscopy, 4826, pp. 39-49, 2003). For the purposes of this document, the HunterLab ColorFlex 45/0 spectrophotometer shall be the referee instrument.

Coefficients of Retroreflection (R_A)
The values in Table C are minimum coefficients of retroreflection expressed in candelas per lux per square meter (cd/lux/m²).

Test for Coefficients of Retroreflection
Conformance to coefficient of retroreflection requirements shall be determined by instrumental method in accordance with ASTM E-810 "Test Method for Coefficient of Retroreflection of Retroreflective Sheeting," and per E-810 the values of 0° and 90° rotation are averaged to determine the R_A in Table C.

Table C
Minimum Coefficient of Retroreflection
R_A for New Sheeting
(cd/lux/m²)

White

Observation[1] Angle	Entrance Angle[2]		
	-4°	30°	45°
0.2°	300	180	100
0.5°	200	75	60
1.0°	15	15	15

Fluorescent Orange

Observation[1] Angle	Entrance Angle[2]		
	-4°	30°	45°
0.2°	200	120	60
0.5°	120	50	30
1.0°	10	10	10

[1] Observation (Divergence) Angle - The angle between the illumination axis and the observation axis.

[2] Entrance (Incidence) Angle - The angle from the illumination axis to the retroreflector axis. The retroreflector axis is an axis perpendicular to the retroreflective surface.

Orientation

3M™ Diamond Grade™ Roll Up Sign Sheeting Series RS20/RS24 is designed to be an effective wide angle reflective sheeting regardless of its orientation on the substrate or ultimate orientation after installation. However, because the efficiency of light return from cube corner reflectors is not equal at all rotation angles, it is possible to get the widest entrance angle light return when the sheeting is oriented in a particular way.

For purposes of test measurement of RS24 sheeting, it is important for the material to have a datum mark (the orientation arrow) so that the sample can be properly oriented in the test machinery. In those situations where extra wide entrance angle performance is required, this arrow can be used to assure the preferred orientation.

Resistance to Accelerated Weathering

The retroreflective surface of the sheeting is weather resistant and shows no appreciable cracking, blistering, crazing, edge lifting or curling, or dimensional change of more than 1/32m (0.08cm) after one year's unprotected outdoor exposure in Florida, south facing and inclined 45° from the vertical, or after 1500 hours' exposure in xenon arc weatherometer in accordance with ASTM G26, Type B, Method A. Wash panels following exposure in a 5% HCL solution for 45 seconds, rinsed thoroughly with clean water, blotted with a soft clean cloth and brought to equilibrium at standard conditions. After cleaning, the coefficient of retroreflection is expected to be not less than 50% of Table C values when measured according to ASTM E-810. The color is expected to conform to the requirements of Table B. Where more than one panel is measured, the coefficient of retroreflection will be the average of all determinations.

Interlocking Diamond Seal Pattern

Diamond Grade sheeting is differentiated from other prismatic or encapsulated lens sheeting by the distinctive seal pattern in the sheeting. Under normal light, this seal pattern will appear lighter in color than the reflective portion (see Figure 1).

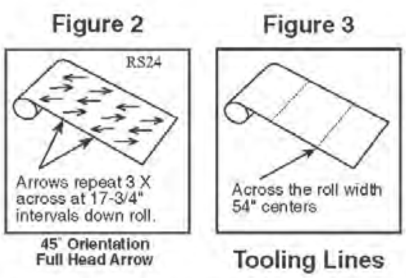
Orientation Marks (Arrows)

RS24 sheeting is made with small orientation (↖) arrows in the surface. These arrows point at a 45° angle. See Figure 2. The arrows assist in proper orientation of the sheeting for maximum angularity of signs (arrows point up and down). The arrows are the same color as the seal pattern and are repeated three times across a 48 inch roll and downweb at 17-3/4 inch intervals (see Figure 2). RS20 does not have orientation arrows.

Tooling Lines

The manufacturing of a prismatic sheeting results in tooling lines being present in the product. In Diamond Grade RS20/RS24 sheeting these lines (slightly thicker than the seal pattern legs) occur across the web every 54 inches. Tooling lines are noticeable in shop light but are not observable on the road either in daylight or at night under typical use conditions (Figure 3).

Figure 1 - Sheeting is positioned at 90° rotation angle.



Note: RS20 does not have orientation arrows.

Test Methods of Film Properties

A. Conditioning

1. Shrinkage, flexibility and gloss measurements are performed on new test specimens which have been conditioned for 24 hours at 73°F ± 3°F (23°C ± 1°C) and 50% ± 5% relative humidity before testing. This condition is maintained during the test.

B. Standard Test Panel and Application

Unless otherwise specified, apply the reflective sheeting according to the manufacturer's recommendations to smooth 0.040 inch (0.10 cm) minimum thickness 6061-T6 or equivalent aluminum panels that have been degreased and lightly etched. Lack of contamination of test panels must be confirmed by passing water break test and tape snap test as described in Information Folder 3.4.

Properties

1. Impact Resistance

Test Method
Apply Scotch™ Double Coated Tape 665 to an etched aluminum panel of Alloy 6061-T6 0.04 inch x 3 inch x 5 inch. Apply RS20/RS24 to the taped surface grey side down and condition as in A1 above. Subject sheeting to 50 inch-pounds (5.7 Nm) impact in accordance with ASTM D-2794.

Requirement
No separation from panel or cracking outside the immediate impact area.

2. Shrinkage

Test Method
Following conditioning of 9 inch x 9 inch samples, place specimen on flat surface with gray side up.

Requirement
Shrinkage not greater than 1/32 inch (0.8 mm) in 10 minutes, or more than 1/8 inch (3.2 mm) in 24 hours in any dimension.

3. Flexibility

Test Method
Condition a 1 inch x 6 inch sample. At standard conditions, bend in one second around 1/8 inch (3.2 mm) mandrel with gray side facing mandrel.

Requirement
No cracking.

4. Gloss

Test Method
Test in accordance with ASTM D523 using an 85° glossmeter.

Requirement
Rating not less than 50

5. Tensile Strength

Test Method
Test in accordance with Federal Standard 191 Method 5100 except using a 2 inch jaw gap and a cross head speed of 6 inches/minute.

Requirement
Typical force values of:
- Warp Direction – 130 pounds force
- Fill Direction – 150 pounds force

6. Tear Resistance

Test Method

Test in accordance with ASTM D1044 except use a cross head of 12 inches/minute.

Requirement

Typical tear values of:

- Warp Direction – 50 pounds force
- Fill Direction – 60 pounds force

Use

A. RS20/RS24 sheeting is designed for sewing or riveting corner pockets or snaps. Cross brace supports can then be used in conjunction with portable sign stands. Cross braces should not bow more than 1/2 inch when inserted. All corner pockets should be fabric, plastic or rubber. Plastic or rubber molded pockets should have rounded edges. Washers should be rubber or plastic. Metal washers should be backed with rubber or plastic washers.

B. Process Colors

Screening Method/Thinning/Conditioning for Processing

An off contact screen process method is the preferred screening method for 3M™ Diamond Grade™ Roll Up Sign Sheeting Series RS20/RS24. The screening table must be perfectly flat. When screening Diamond Grade roll up sheets, hold the sheets in place using a vacuum table or if a vacuum table is not available, sheets can be held in place on a non-porous table surface using a thin, uniform layer of low tack pressure sensitive adhesive. The screen mesh size should be in the (PE157 -PE 230) range of monofilament fabric. Stenciling the process colors or use of other screen fabric mesh sizes may not produce satisfactory color or durability and are not recommended.

3M™ Process Color Series 1805 (black) is the only recommended ink color for Diamond Grade roll up sheeting Series RS24. For thinning Series 1805, use only CGS 50 or CGS 80 thinner. Series 1805 colors must dry for 24 hours (on drying rack) before rolling up. See Product Bulletin 1800 or call 3M Technical Services at 1-800-553-1380 extension 4-1.

3M™ Process Color Series 990 is the only recommended ink for Diamond Grade Series RS20. Series 990 ink must be used with 4430R clear ink that protects the colors from rewetting. Series 990 colors must dry a minimum of three hours before the 4430R clear coat is applied.

D. Storage

Diamond Grade roll up sheeting should be stored in a cool, dry area, preferably at 65° to 75°F (18° to 24°C) and 30 to 50% relative humidity, and should be used within one year after purchase.

Unprocessed sheets should be stored flat.

See Information folder 1.11 for details of storage and packaging. Finished roll up signs should be stored dry and rolled up properly per OEM specifications.

Health and Safety Information

Read all health hazard, precautionary and first aid statements found in the Material Safety Data Sheet (MSDS), and/or product label of chemicals prior to handling or use.

General Performance Considerations

The durability of Series RS20/RS24 roll up sign sheeting will depend upon preparation, compliance with recommended application procedures, geographic area, exposure conditions, and maintenance.

Warranty

3M warrants that 3M™ Diamond Grade™ Roll Up Sign Sheeting Series RS20/RS24 sold by 3M to be used as components for roll up traffic control signs used in work zones in the United States and Canada will remain effective for its intended use and meet the stated minimum values for coefficient of retroreflection for three years, subject to the following provisions:

Minimum Coefficient of Retroreflection

Candelas per Footcandle per Square Foot or Candelas per Lux per Square Meter

Sheeting Color	Minimum Coefficient of Retroreflection (Three Years)
White	50% of stated values of Table C
Fluorescent Orange	50% of stated values of Table C

*All measurements shall be made after sign cleaning according to 3M recommendations and in accordance with ASTM E810 "Standard Test Method for Coefficient of Retroreflection of Retroreflective Sheeting."

If Series RS20/RS24 roll up sign surface is processed in accordance with all 3M application and fabrication procedures provided in 3M's product bulletins, information folders and technical memos (which will be furnished to the agency upon request), including the exclusive use of 3M matched component systems, process colors, and recommended application equipment; and

If the sign deteriorates due to natural causes to the extent that: 1) the sign is ineffective for its intended purpose when viewed from a moving vehicle under normal day and night driving conditions by drivers with normal vision, or 2) the coefficient of retroreflection is less than the minimum herein specified 3) RS24 fluorescent sheeting color retention does not meet requirement (weathered) in Table C, 3M's sole responsibility and purchaser's and user's exclusive remedy shall be that 3M will provide pro-rata replacement of the 3M materials.

Conditions

Such failure must be solely the result of design or manufacturing defects in the Series RS20/RS24 roll up sign sheeting and not of outside causes such as: improper fabrication, handling, maintenance or installation; process colors, thinner, coatings, or overlay films and sheetings not made by 3M; use of equipment not recommended by 3M; failure of sign hardware; exposure to chemicals, abrasion and other mechanical damage from fasteners used to mount the sign; collisions, vandalism or malicious mischief.

3M reserves the right to determine the method of replacement.

Replacement sheeting will carry the unexpired warranty of the sheeting it replaces.

Claims made under this warranty will be honored only if the signs have been dated at the time of sheeting application, which constitutes the start of the warranty period.

Claims made under this warranty will be honored only if 3M is notified of a failure within a reasonable time, reasonable information requested by 3M is provided, and 3M is permitted to verify the cause of the failure.

Limitation of Liability

3M's liability under this warranty is limited to replacement as stated herein, and 3M assumes no liability for any incidental or consequential damages, such as lost profits, business or revenues in any way related to the product regardless of the legal theory on which the claim is based. THIS WARRANTY IS MADE IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES OF MERCHANTABILITY, OF FITNESS FOR A PARTICULAR PURPOSE, AND ANY IMPLIED WARRANTY ARISING OUT OF A COURSE OF DEALING OR OF PERFORMANCE, CUSTOM OR USAGE OF TRADE.

Literature Reference (Available from 3M)

Screen Processing

PB1805	3M™ Process Colors

Application

IF 1.10	Cutting, Matching, Premasking & Prespacing Instructions
IF 1.11	Storage Maintenance and Removal Instructions

FOR INFORMATION OR ASSISTANCE
CALL:
1-800-553-1380

IN CANADA CALL:
1-800-265-1840

Fax-on-Demand in the U.S. and Canada:
1-800-887-3238

Internet:
www.3M.com/tss

3M assumes no responsibility for any injury, loss or damage arising out of the use of a product that is not of our manufacture. Where reference is made in literature to a commercially available product, made by another manufacturer, it shall be the user's responsibility to ascertain the precautionary measures for its use outlined by the manufacturer.

Important Notice

All statements, technical information and recommendations contained herein are based on tests we believe to be reliable, but the accuracy or completeness thereof is not guaranteed, and the following is made in lieu of all warranties, or conditions express or implied. Seller's and manufacturer's only obligation shall be to replace such quantity of the product proved to be defective. Neither seller nor manufacturer shall be liable for any injury, loss or damage, direct, special or consequential, arising out of the use of or the inability to use the product. Before using, user shall determine the suitability of the product for his/her intended use, and user assumes all risk and liability whatsoever in connection therewith. Statements or recommendations not contained herein shall have no force or effect unless in an agreement signed by officers of seller and manufacturer.

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Av. Santa Fe No. 55
Col. Santa Fe, Del. Alvaro Obregón
México, D.F. 01210

APPENDIX C. ENGINEERING PROPERTIES OF THE CARBON FIBER STAYS

BASF
The Chemical Company

PRODUCT DATA

3 03 01 00 **Maintenance of Concrete**

MBRACE® CF 130

Unidirectional high strength carbon fiber fabric for the MBrace® Composite Strengthening System

Description

MBrace® CF 130 is a dry fabric constructed of very high strength, aerospace grade carbon fibers. These fabrics are applied onto the surface of existing structural members in buildings, bridges, and other structures using the MBrace® family of performance polymers. The result is an externally bonded FRP (fiber reinforced polymer) reinforcement system that is engineered to increase the strength and structural performance of these members. Once installed, the MBrace® System delivers externally bonded reinforcement with outstanding long-term physical and mechanical properties.

Yield

269 ft² (25 m²) per roll

Packaging

Available in rolls 20 in (500 mm) wide, 162 ft (50 m) long

ROLL	WIDTH	LENGTH
269 ft² (25 m²)	20 in (508 mm)	162 ft (50 m)

Color

Black

Features	Benefits
• High strength to weight ratio	Can add significant strength to a structure without adding significant dead load
• Excellent resistance to creep and fatigue	Withstands sustained and cyclic load conditions
• Extremely durable	Extremely resistant to a wide range of environmental conditions
• Easy installation	Can be installed quickly, even in areas of limited access
• Low aesthetic impact	Easy to conceal, will not significantly change existing member dimensions, will form around complex surfaces

Shelf Life

3 years in unopened containers

Storage

Store in a cool, dry place (50 to 90 °F [10 to 32 °C]) away from direct sunlight, flame, or other hazards.

Where to Use

APPLICATION

- Increase load bearing capacity of concrete beams, slabs, walls and columns
- Improve the seismic ductility of concrete columns
- Improve the seismic response of concrete beam column connections, shear walls and collector elements
- Improve the seismic performance of masonry shear walls and in-fill walls
- Restore structural capacity to damaged or deteriorated concrete structures
- Increase the strength of concrete pipes, silos, tanks, chimneys and tunnels
- Substitute reinforcing steel mistakenly omitted in the construction of concrete and masonry structures
- Improve the blast resistance of concrete and masonry structures
- Strengthening of some steel and timber structures

LOCATION

- Vertical
- Horizontal
- Exterior
- Interior

SUBSTRATE

- Concrete
- Masonry
- Timber
- Steel

Technical Data

Composition

MBrace® CF 130 is composed of a dense network of high strength carbon fibers held in a unidirectional alignment with a light thermoplastic glass fiber cross weave yarn

Physical Properties

PROPERTY	REQUIREMENT
Fiber Material	High Strength Carbon
Fiber Tensile Strength	720 ksi (4950 MPa)
Areal Weight	0.062 lb/ft² [300 g/m²]
Fabric Width	20 inch [500 mm]
Nominal Thickness, t_f (1)	0.0065 in/ply [0.165 mm/ply]

Functional Properties

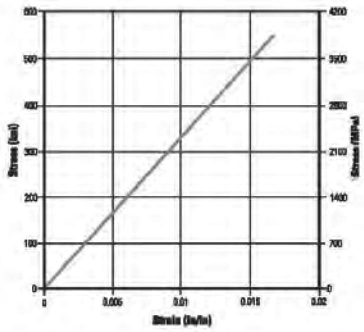
PROPERTY	REQUIREMENT
CTE	$-0.21 \cdot 10^{-6}$/F ($-0.38 \cdot 10^{-6}$/C
Thermal Conductivity	65.1 Btu·in/hr·ft²·F (9.38 W/m·K)
Electrical Resistivity	$1.6 \cdot 10^{-3}$ Ω·cm

0° Tensile Properties (2,3)

PROPERTY	REQUIREMENT
Ultimate Tensile Strength, f^*_{fu}	550 ksi [3800 MPa]
Tensile Modulus, E_f	33000 ksi [227 GPa]
Ultimate Tensile Strength per Unit Width, $f^*_{fu}\,t_f$	3.57 kips/in/ply [0.625 kN/mm/ply]
Tensile Modulus per Unit Width, $E_f\,t_f$	215 kips/in/ply [38 kN/mm/ply]
Ultimate Rupture Strain, ε^*_{fu}	1.67%

90° Tensile Properties (2,4)

PROPERTY	REQUIREMENT
Ultimate Tensile Strength	0
Tensile Modulus	0
Ultimate Rupture Strain	n/a



NOTES:

(1) The nominal fabric thickness is based on the total area of fibers (only) in a unit width. From experience, the actual cured thickness of a single ply laminate (fibers plus saturating resins) is 0.020 to 0.040 in (0.6 to 1.0 mm).

(2) The tensile properties given are those to be used for design. These values are derived by testing cured laminates (per ASTM D3039) and dividing the resulting strength and modulus per unit width by the nominal fabric thickness.

(3) The 0° direction denotes the direction along the length of the fabric.

(4) The 90° direction denotes the direction along the width of the fabric.

How to Apply

Surface Preparation

1. MBrace® CF 130 is applied to surfaces treated with MBrace® Primer, MBrace® Putty and MBrace® Saturant. Consult the data sheets for these materials for additional details.

Application

MBrace® CF 130 is only applied as a component of the MBrace® System.

1. The MBrace® CF 130 material should be cut to the proper dimensions (dimensions will vary based on project requirements) using heavy duty shears or a utility knife.

2. Cut sections of MBrace® CF 130 can be temporarily stored by carefully rolling fabric into a 12 inch (600 mm) (approximate) roll. Do not fold or crease the fabric. Fabric shoul dbe kept free of dust, oils, moisture and other contaminants at all times.

3. Apply the MBrace® CF 130 fabric directly into uncured MBrace® Saturant applied on the substrate. There is no need to "pre-wet" the MBrace® CF 130 fabric with MBrace® Saturant prior to applying the fabric against the substrate.

4. Using a rib roller or squeegee, press the fabric against the substrate until visual signs of MBrace® Saturant are observed bleeding through the fabric. The rib roller or squeegee should only be run along the direction of the primary fibers in the fabric.

5. Apply a layer of MBrace® Saturant over the top of the MBrace® CF 130 fabric to completely encapsulate the fabric. Consult with the MBrace® Saturant data sheet on details for applying MBrace® Saturant.

Maintenance

Periodically inspect the applied material and repair localized areas as needed. Consult an BASF representative for additional information. Visit us on the web for the most current product information and news: www.BuildingSystems.BASF.com

For Best Performance

- Use caution when applying MBrace® CF 130 around sensitize electrical equipment. Carbon fiber filaments can become airborne, infiltrate electrical equipment and cause electrical shorts.
- Make certain the most current versions of product data sheet and MSDS are being used; call Customer Service (1-800-433-9517) to verify the most current version.
- Proper application is the responsibility of the user. Field visits by BASF personnel are for the purpose of making technical recommendations only and are not for supervising or providing quality control on the jobsite.

Health and Safety

MBRACE® CF 130

Warning

MBrace® Fiber Reinforcements contain carbon, glass, and/or aramid fibers, MBrace® CF 130 contains carbon and glass fibers. While handling MBrace® Fiber Reinforcements CF 130, wear appropriate work clothing to minimize contact. Product Material Safety Data Sheets (MSDS) are available and should be consulted and on hand whenever handling these products. These products are for professional and industrial use only and are only installed by trained and qualified applicators. Trained applicators must follow installation instructions.

BASF Construction Chemicals, LLC – Building Systems

889 Valley Park Drive
Shakopee, MN, 55379

www.BuildingSystems.BASF.com

Customer Service 800-433-9517
Technical Service 800-243-6739

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APPENDIX D. TEST VEHICLE PROPERTIES AND INFORMATION

Table D1. Vehicle Properties for Test No. 466393-1.

Date: 2013-07-22 Test No.: 466393-1 VIN No.: KNADE223996535907

Year: 2009 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 96956 Tire Size: 165/65R14

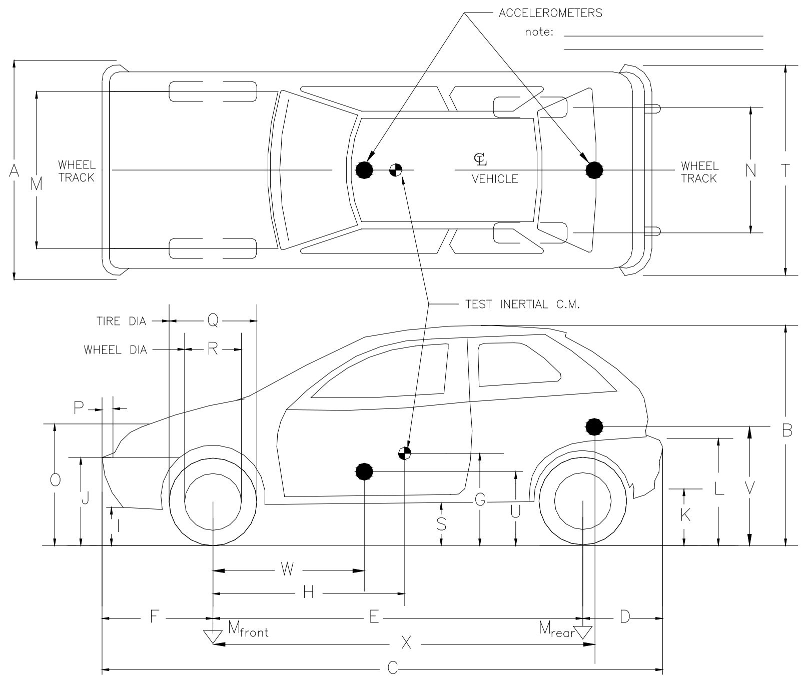
Describe any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

NOTES: ______

Engine Type: 4 cylinder
Engine CID: 4.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:

Dummy Data:
Type: 50th percentile male
Mass: 179 lb
Seat Position: Driver



Geometry: inches

A	66.38	F	33.00	K	11.75	P	4.12	U	----
B	57.75	G	----	L	25.25	Q	22.18	V	----
C	165.75	H	34.44	M	57.75	R	15.38	W	----
D	34.00	I	6.75	N	57.12	S	8.00	X	----
E	98.75	J	22.00	O	31.25	T	66.12		

Wheel Center Ht Front 11.00 Wheel Center Ht Rear 11.00

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1918	M_{front}	1603	1591	1675
Back	1874	M_{rear}	856	852	947
Total	3638	M_{Total}	2459	2443	2622

Mass Distribution:
lb LF: 798 RF: 793 LR: 421 RR: 431

Table D2. Exterior Crush Measurements for Test No. 466393-1.

Date: 2013-07-22 Test No.: 466393-1 VIN No.: KNADE223996535907

Year: 2009 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = _______
< 4 inches ________	
≥ 4 inches ________	

Note: Measure C_1 to C_6 from Driver to Passenger Side in Front or Rear impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	Slight scuff marks up the hood									
	Measurements recorded										
	in inches										

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

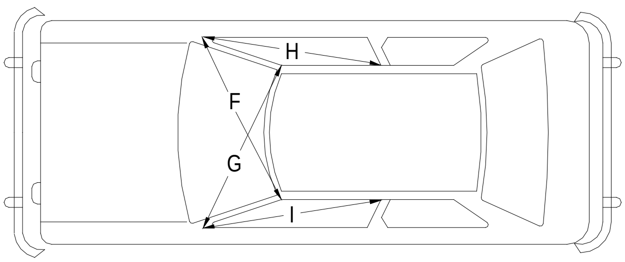
***Measure and document on the vehicle diagram the location of the maximum crush.

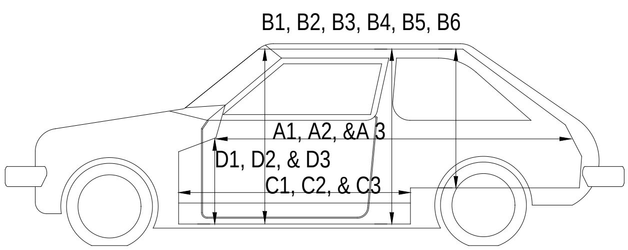
Note: Use as many lines/columns as necessary to describe each damage profile.

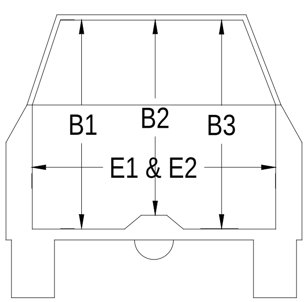
Table D3. Occupant Compartment Measurements for Test No. 466393-1.

Date: 2013-07-22 Test No.: 466393-1 VIN No.: KNADE223996535907

Year: 2009 Make: Kia Model: Rio







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	**After** (inches)
A1	67.75	67.75
A2	67.25	67.25
A3	67.50	67.50
B1	40.50	40.50
B2	36.50	36.50
B3	40.50	40.50
B4	36.25	36.25
B5	37.25	37.25
B6	36.25	36.25
C1	27.00	27.00
C2	----	----
C3	27.50	27.50
D1	9.75	9.75
D2	----	----
D3	9.75	9.75
E1	48.25	48.25
E2	51.00	51.00
F	50.00	50.00
G	50.00	50.00
H	36.50	36.50
I	36.50	36.50
J*	51.00	51.00

*Lateral area across the cab from driver's side kick panel to passenger's side kick panel.

Table D4. Vehicle Properties for Test No. 466393-2.

Date:	2013-07-22	Test No.:	466393-2	VIN No.:	KNADE123786431909
Year:	2008	Make:	Kia	Model:	Rio
Tire Inflation Pressure:	32 psi	Odometer:	64862	Tire Size:	165/65R14

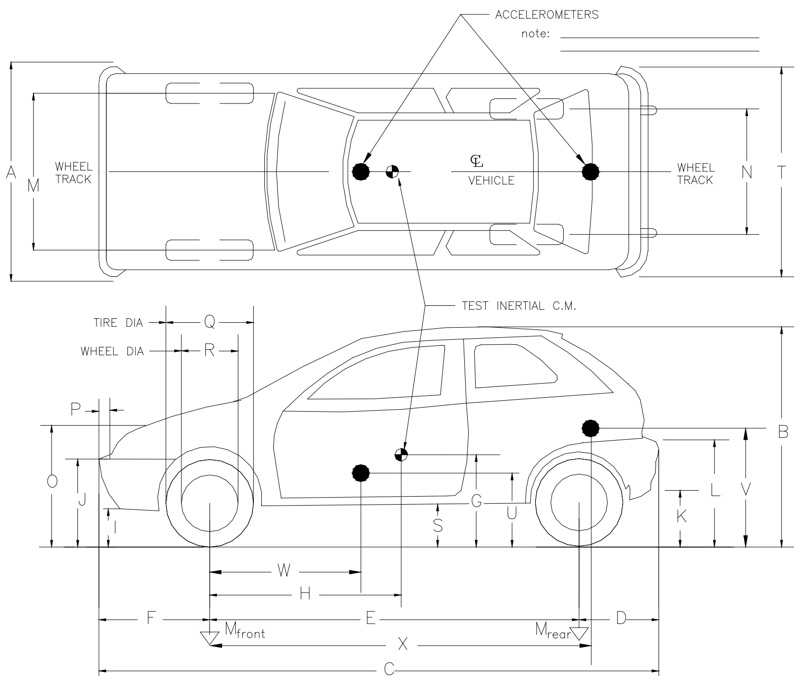
Describe any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

NOTES: ______

Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:

Dummy Data:
Type: 50th percentile male
Mass: 180 lb
Seat Position: Driver



Geometry: inches

A	66.38	F	33.00	K	11.75	P	4.12	U	----
B	57.75	G	----	L	25.25	Q	22.18	V	----
C	165.75	H	40.16	M	57.75	R	15.38	W	----
D	34.00	I	6.75	N	52.12	S	8.00	X	----
E	98.75	J	22.00	O	31.35	T	66.12		----

Wheel Center Ht Front ______ Wheel Center Ht Rear ______

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1918	M_{front}	1440	1446	1541
Back	1874	M_{rear}	861	991	1076
Total	3638	M_{Total}	2301	2437	2617

Mass Distribution:
lb LF: 732 RF: 714 LR: 493 RR: 498

Table D5. Exterior Crush Measurements for Test No. 466393-2.

Date: 2013-07-22 Test No.: 466393-2 VIN No.: KNADE123786431909

Year: 2008 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	**Side Damage**
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant $\frac{X1+X2}{2}$ = ______

Note: Measure C_1 to C_6 from Driver to Passenger Side in Front or Rear impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	Slight scuff marks up the hood									
	Measurements recorded										
	in inches										

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

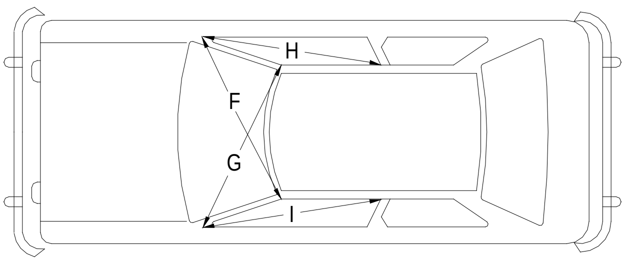
***Measure and document on the vehicle diagram the location of the maximum crush.

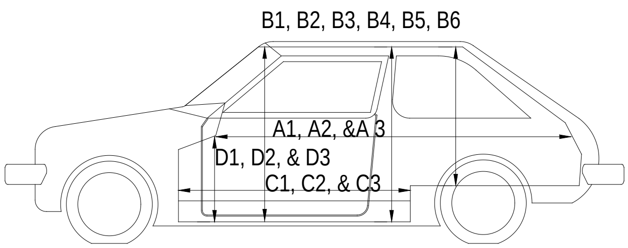
Note: Use as many lines/columns as necessary to describe each damage profile.

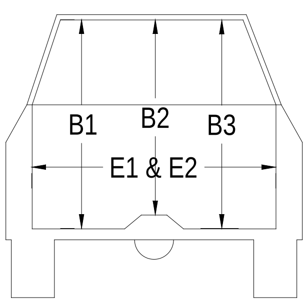
Table D6. Occupant Compartment Measurements for Test No. 466393-2.

Date: 2013-07-22 Test No.: 466393-2 VIN No.: KNADE123786431909

Year: 2008 Make: Kia Model: Rio







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	**After** (inches)
A1	67.75	67.75
A2	67.25	67.25
A3	67.50	67.50
B1	40.50	40.50
B2	36.50	36.50
B3	40.50	40.50
B4	36.25	36.25
B5	37.25	37.25
B6	36.25	36.25
C1	27.00	27.00
C2	----	----
C3	27.50	27.50
D1	9.75	9.75
D2	----	----
D3	9.75	9.75
E1	48.25	48.25
E2	51.00	51.00
F	50.00	50.00
G	50.00	50.00
H	36.50	36.50
I	36.50	36.50
J*	51.00	51.00

*Lateral area across the cab from driver's side kick panel to passenger's side kick panel.

Table D7. Vehicle Properties for Test No. 466393-3.

Date: 2013-08-23 Test No.: 466393-2 VIN No.: KNADE123286429839

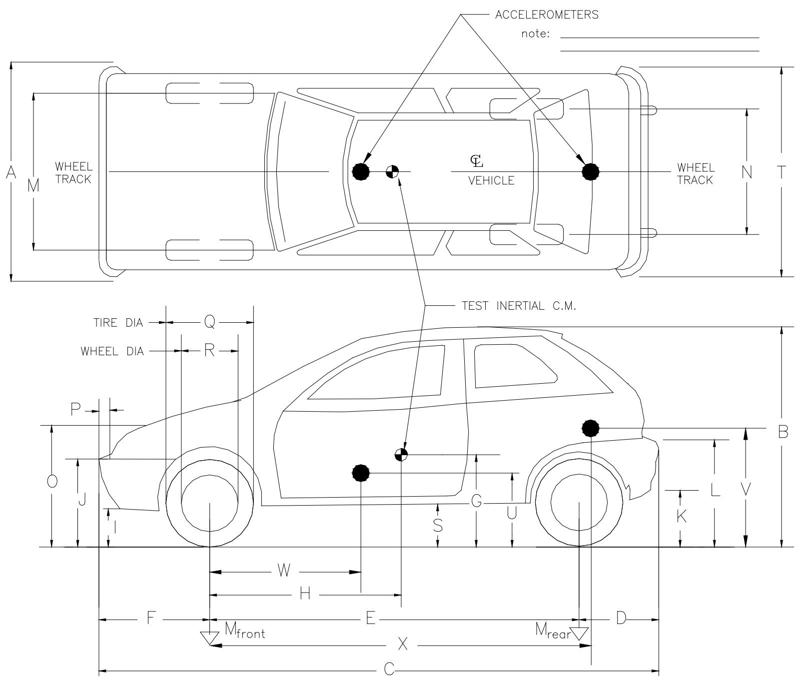
Year: 2008 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 257961 Tire Size: 165/65R14

Describe any damage to the vehicle prior to test:

● Denotes accelerometer location.

NOTES:



Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:

Dummy Data:
Type: 50th percentile male
Mass: 175 lb
Seat Position: Driver

Geometry: inches

A	66.38	F	33.00	K	11.00	P	4.12	U	----
B	58.00	G	----	L	24.00	Q	22.18	V	----
C	165.75	H	39.54	M	57.75	R	15.38	W	----
D	34.00	I	6.75	N	52.12	S	8.00	X	----
E	98.75	J	21.25	O	28.25	T	66.12		----

Wheel Center Ht Front 11.00 Wheel Center Ht Rear 11.00

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1918	M_{front}	1468	1464	1553
Back	1874	M_{rear}	859	978	1064
Total	3638	M_{Total}	2327	2442	2617

Mass Distribution:
lb LF: 744 RF: 724 LR: 417 RR: 442

Table D8. Exterior Crush Measurements for Test No. 466393-3.

Date: 2013-08-23 Test No.: 466393-2 VIN No.: KNADE123286429839

Year: 2008 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant $\frac{X1 + X2}{2} = $ _______

Note: Measure C_1 to C_6 from Driver to Passenger Side in Front or Rear impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	Slight scuff marks up the hood									
	Measurements recorded										
	in inches										

[1]Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc. Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

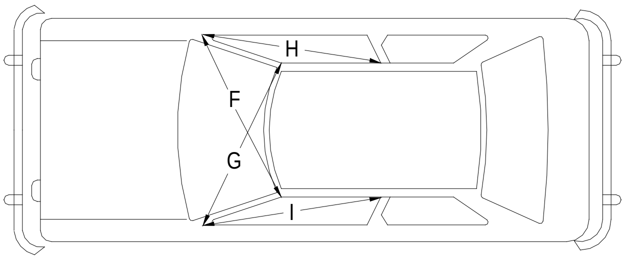
***Measure and document on the vehicle diagram the location of the maximum crush.

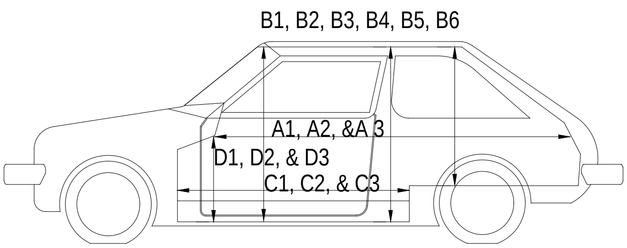
Note: Use as many lines/columns as necessary to describe each damage profile.

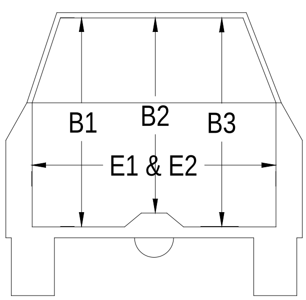
Table D9. Occupant Compartment Measurements for Test No. 466393-3.

Date: 2013-08-23 Test No.: 466393-2 VIN No.: KNADE123286429839

Year: 2008 Make: Kia Model: Rio







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	69.50	69.50
A2	69.00	69.00
A3	69.50	69.50
B1	40.50	40.50
B2	36.50	36.50
B3	41.00	41.00
B4	37.25	37.25
B5	37.00	37.00
B6	37.00	37.00
C1	21.75	21.75
C2	25.50	25.50
C3	21.50	21.50
D1	9.50	9.50
D2	10.00	10.00
D3	10.00	10.00
E1	48.25	48.25
E2	51.50	51.50
F	50.00	50.00
G	50.00	50.00
H	36.50	36.50
I	36.50	36.50
J*	51.00	51.00

*Lateral area across the cab from driver's side kick panel to passenger's side kick panel.

APPENDIX E. SEQUENTIAL PHOTOGRAPHS

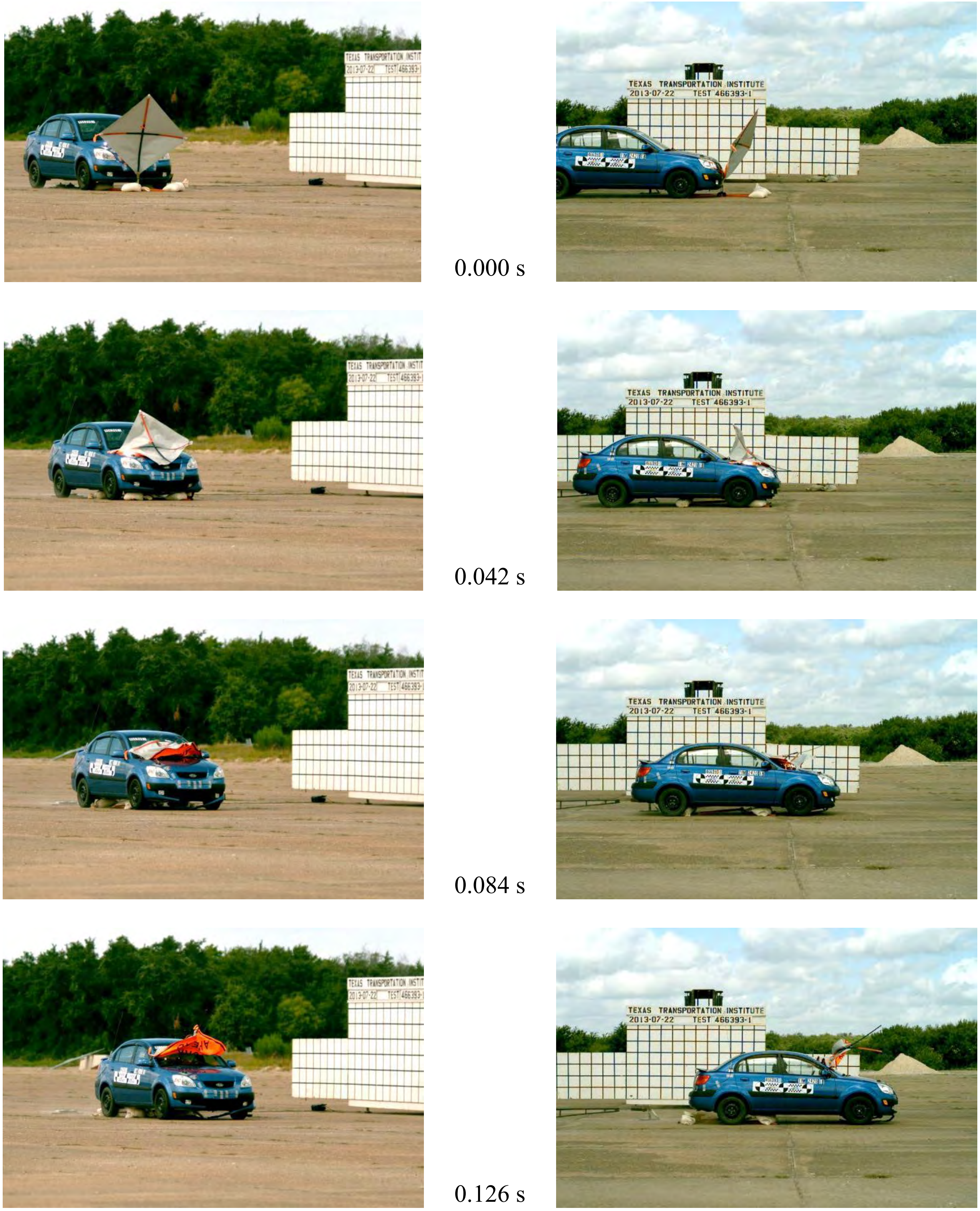


Figure E1. Sequential Photographs for Test No. 466393-1 (Oblique and Perpendicular Views).

0.168 s

0.210 s

0.252 s

0.294 s

Figure E1. Sequential Photographs for Test No. 466393-1 (Oblique and Perpendicular Views) (continued).

0.000 s

0.050 s

0.100 s

0.150 s

Figure E2. Sequential Photographs for Test No. 466393-2 (Oblique and Perpendicular Views).

0.200 s

0.250 s

0.300 s

0.350 s

Figure E1. Sequential Photographs for Test No. 466393-1 (Oblique and Perpendicular Views) (continued).