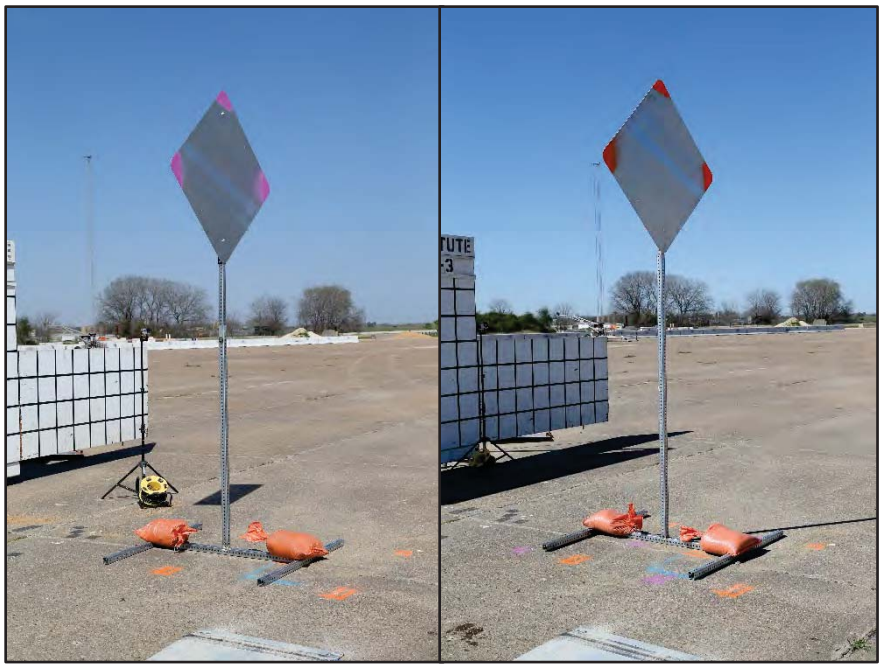
TTI: 9-1002-15

Texas A&M Transportation Institute

MASH EVALUATION OF TxDOT HIGH-MOUNTING-HEIGHT TEMPORARY WORK ZONE SIGN SUPPORT SYSTEM



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 9-1002-15-8

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

The objective of this research was to develop a nonproprietary, lightweight, crashworthy, temporary work-zone single sign support for use with an aluminum sign substrate. The device is intended to meet the evaluation criteria in American Association of State Highway and Transportation Officials *Manual for Assessing Safety Hardware* (*MASH*). In addition to crashworthiness, consideration was given to cost, functionality, and accommodating a high-mounting-height (7 ft). An aluminum sign substrate was also a design requirement stipulated by the Texas Department of Transportation. Texas A&M Transportation Institute researchers used perforated steel tubing for the frame of the new temporary single sign support system to accommodate the requests for a lightweight, durable, and easy to assemble structure. Slip joints were incorporated into the vertical support to help mitigate the severity of secondary contact between the sign substrate and roof of the impacting vehicle.

The proposed design options were full-scale crash tested with an 1100C and 2270P vehicles under required *MASH* TL-3 conditions. Two out of the three proposed new designs for temporary work zone sign supports functioned acceptably under the impacted *MASH* TL-3 conditions. A third design was judged to have potential for intrusion into the occupant compartment due to a tear in the roof of the 2270P vehicle during *MASH* Test 3-72 at 90 degrees.

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Project Title: Roadside Safety Device Crash Testing

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

February 2017

TEXAS A&M TRANSPORTATION INSTITUTE
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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. This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Roger P. Bligh, Texas Professional Engineer #78550. 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.

TTI PROVING GROUND DISCLAIMER

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

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01
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ACKNOWLEDGMENTS

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Chapter 1. INTRODUCTION

1.1. RESEARCH PROBLEM STATEMENT

Work zone traffic control devices, such as temporary single sign supports, are a primary means to communicate information to motorists in work zone areas. The Federal Highway Administration (FHWA) and the *Manual on Uniform Traffic Control Devices* require work zone traffic control devices to be crashworthy (*1*). The American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) contains procedures recommended for testing and evaluation of work zone traffic control devices (*2*).

State maintenance personnel and contractors prefer lightweight sign support systems that are easy to handle and transport. Temporary work zone sign support systems fabricated from perforated steel tubing are relatively lightweight compared to other materials such as timber. When galvanized, perforated steel tubing also provides good durability and resistance to environmental attack and does not need painting, which is a maintenance requirement for timber systems.

An existing temporary single sign support system fabricated from perforated steel tubing requires the use of a corrugated plastic sign panel. The Texas Department of Transportation (TxDOT) expressed a desire to develop a nonproprietary, lightweight, and crashworthy temporary single sign support system that uses an aluminum sign substrate, which is stiffer and more durable than the corrugated plastic signs.

1.2. RESEARCH OBJECTIVES

The objective of this research was to develop a nonproprietary, lightweight, and crashworthy temporary work-zone single sign support system with an aluminum sign substrate. The device is intended to meet the evaluation criteria in *MASH*. In addition to crashworthiness, consideration was given to cost, functionality, and accommodation of a high-mounting-height (7 ft). The use of an aluminum sign substrate was also a stipulated requirement.

Test results and recommendations from a previous research study were reviewed (*3*). Three different design concepts were developed for evaluation. Texas A&M Transportation Institute (TTI) researchers used perforated steel tubing for the frame of the new temporary single sign support system to accommodate the requests for a lightweight, durable, and easy to assemble system. Slip joints were incorporated into the vertical support to help mitigate the severity of secondary contact between the sign substrate and roof of the impacting vehicle.

This report summarizes the findings of the project. Chapter 2 presents the design criteria for the work zone devices to be tested. Chapter 3 describes testing requirements for work-zone devices. Chapter 4 describes the test facility, test vehicle guidance, and instrumentation. Chapters 5 through 7 contain details of the crash tests performed on the three design options evaluated. Chapter 8 contains a summary and conclusions of the testing performed. Chapter 9 provides implementation recommendations for the temporary single sign support designs.

Chapter 2. DESIGN ALTERNATIVES

2.1. HIGH-MOUNTING SIGN SUPPORTS WITH ALUMINUM SIGNS

While rigid sign substrate materials may be desirable for improved durability, their rigidity and mass can make them more critical than other substrate materials, from a crashworthiness standpoint, in certain orientations. In particular, impacts with high-mounting-height sign supports oriented 90 degrees to the travel path of the vehicle have caused the rigid substrate to penetrate the windshield and/or the roof sheet metal. Therefore, high-mounting-height temporary work zone sign supports with aluminum or plywood substrates must be properly designed to achieve acceptable impact performance. Some successful crash tests have involved the early release of the rigid substrate or fracture of the vertical support at or near bumper height. Combinations of design modifications can be incorporated to allow the sign panel and supports to rotate above and over the vehicle. Secondary contact may still occur between the sign components and vehicle, but the degree of damage can be mitigated to acceptable levels.

2.2. DESIGN ALTERNATIVES

The TxDOT project panel specified the use of a 36 inch × 36 inch aluminum sign at a mounting height of 7 ft. Perforated steel tubing was preferred for its light weight, durability, and ease of fabrication. Having defined the basic requirements for the system (e.g., mounting height, sign substrate, support material type and size), the researchers developed design alternatives with potential to meet impact performance requirements.

Three high-mounting-height, temporary single sign support designs were developed and evaluated through full-scale crash testing. Design details and test results for each of the three options are presented in Chapters 5 through 7.

Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST MATRIX

According to *MASH*, three tests are recommended to evaluate work-zone support structures to test level three (TL-3):

> ***MASH* Test Designation 3-70:** A 2425 lb vehicle impacting the support structure at a nominal impact speed of 19 mi/h. This test is recommended to evaluate the potential for test article intrusion through the windshield or roof of a small passenger car when impacting the test article at a low speed.
>
> ***MASH* Test Designation 3-71:** A 2425 lb vehicle impacting the support structure at a nominal impact speed of 62 mi/h. This test is recommended to evaluate the potential for test article intrusion through the windshield or roof of a small passenger car when impacting the test article at a high speed.
>
> ***MASH* Test Designation 3-72:** A 5000 lb pickup truck impacting the support structure at a nominal impact speed and angle of 62 mi/h. This test is recommended to evaluate the potential for test article intrusion through the windshield or roof of a light truck vehicle when impacting the test article at a high speed.

FHWA/AASHTO requires the impact performance of temporary work zone sign supports be evaluated for two different orientations. In addition to the common scenario involving the vehicle impacting the device head-on (i.e., 0 deg.), an impact with the device turned 90 degrees is also required. This test condition accounts for the common field practice of rotating a device out of view of traffic until it is needed again and/or picked up and moved by work zone personnel.

The tests reported herein correspond to *MASH* Test 3-71 (2425-lb passenger car, 62 mi/h, 90- and 0-degree sign orientation) and *MASH* Test 3-72 (5000-lb pickup, 62 mi/h, 90- and 0-degree sign orientation). *MASH* Test 3-70 was deemed to be unnecessary for the successful performance of the considered devices.

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*.

3.2. EVALUATION CRITERIA

The crash test results for each test were evaluated in accordance with the criteria presented in *MASH*. The impact performance of the temporary work zone sign supports was judged based on the following factors:

- The temporary work zone sign supports should readily activate in a predictable manner by breaking away, fracturing, or yielding.

- Risk of occupant compartment deformation or intrusion by detached elements, fragments, or other debris from the temporary work zone sign supports, which evaluates the potential risk of hazard to occupants, and, to some extent, other traffic, pedestrians, or workers in construction zones, if applicable.
- Occupant risk values, for which longitudinal and lateral occupant impact velocity and ridedown accelerations for the 1100C and 2270P vehicles must be within the limits specified in *MASH*, and determines the risk of injury to the occupants.
- Detached elements, fragments, or other debris from the temporary work zone sign supports, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.
- Post-impact vehicle trajectory, which considers potential for secondary impact with other vehicles or fixed objects, creating further risk of injury to occupants of the impacting vehicle and/or risk of injury to occupants in other vehicles.

The appropriate safety evaluation criteria from Table 5-1 of *MASH* were used to evaluate the crash tests reported herein. These criteria are listed in further detail under the assessment of each crash test.

Chapter 4. TEST CONDITIONS

4.1. TEST FACILITY

The full-scale crash test reported here was performed at the TTI Proving Ground, an International Standards Organization 17025-accredited laboratory with American Association for Laboratory Accreditation Mechanical Testing certificate 2821.01. The full-scale crash test was performed according to TTI Proving Ground quality procedures, and according to the *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 a United States Army Air Corps base, has large expanses of concrete runways and parking aprons that are 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 construction and testing of the temporary work zone sign supports was on the surface of an existing out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were built in 1942, and the joints have some displacement, but are otherwise flat and level.

4.2 VEHICLE TOW AND GUIDANCE SYSTEM

The test vehicles were towed into the temporary work zone sign supports using a steel cable guidance and reverse tow system. A steel cable for guiding each 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 each 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 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the temporary work zone sign supports, the test vehicle was released and ran 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, if needed, to bring each test vehicle to a safe and controlled stop.

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

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 3-71 and 3-72 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 un-instrumented 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 front seat on the opposite side of impact in the 1100C vehicle. The dummy was not instrumented.

According to *MASH*, use of a dummy in the 2270P vehicle is optional. No dummy was used in the tests with the 2270P vehicle reported herein.

4.3.3 Photographic Instrumentation Data Processing

Photographic coverage of each test included two high-speed cameras:

- One placed behind the installation at an angle.
- Another placed to have a field of perpendicular to the vehicle path and aligned with the sign installation.

A flashbulb on each impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with each temporary work zone sign support. The flashbulb was visible from each camera. The videos from these high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-digital video camera and still cameras recorded and documented conditions of each test vehicle and each temporary work zone sign support before and after the test.

Chapter 5. OPTION A TEMPORARY WORK ZONE SIGN SUPPORT

5.1 OPTION A DESIGN AND CONSTRUCTION

The test installation for Design Option A was fabricated using a single aluminum sign mounted on 1¾-inch, 12-gauge (0.105 inch) nominal thickness perforated steel tubing containing $^{7}/_{16}$-inch diameter holes on 1-inch spacing on all four sides. The test sign panel measured 36 inches square and was fabricated from 0.100-inch thick aluminum. The sign was mounted in a diamond configuration with a tip-to-tip distance of 49⅛ inches as a result of each corner having a 2-inch radius. The vertical support post and sign were mounted to an H-shaped base measuring 48 inches × 51½ inches comprised of three 48-inch long sections of 1¾-inch perforated steel tubing. Junctions of the 3-piece base and lower section of the segmented vertical support post were joined with fillet welds. The sign was attached to the upper section of the segmented vertical support post with two ⅜-inch diameter × 2½-inch long SAE grade 5 hex bolts, nuts, and flat and lock washers. Two 40-lb sandbags were placed on top of the H-shaped base; one at the midpoint of each outrigger. The outriggers and sign panel were oriented parallel to the direction of impact. The approximate total weight of the test assembly was 60 lb (16-lb sign panel, 20-lb sectional vertical support post, and 24-lb 3-piece base) exclusive of the two 40-lb sandbags.

The upper and lower sections of the vertical support post were connected with an 8-inch long sleeve fabricated from 1½-inch, 12-gauge perforated steel tubing. This insert was secured in the lower section with a ⅜-inch diameter × 2½-inch long smooth pin located in the holes 2½ inches below the joint. The pin was welded to one side of the lower post once the insert was installed. The joint between the upper and lower sections of the vertical support post was located 67¾ inches above grade. The bottom of the aluminum sign was 83½ inches above grade.

Figure 5.1 shows details of the Option A temporary work zone sign support installation. Figure 5.2 provides photographs of the completed installation.

5.2 *MASH* TEST 3-72 AT 90 DEGREES (CRASH TEST NO. 490026-2-1)

5.2.1 Test Designation and Actual Impact Conditions

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the Option A temporary work zone sign support with the quarter point of the front of the vehicle at an impact speed of 62.2 mi/h ±2.5 mi/h at the critical impact angle (CIA) ±1.5 degrees. The CIA for *MASH* Test 3-72 on the temporary work zone sign support was 90 degrees. The 2010 Dodge Ram 1500 pickup truck used in the test weighed 5014 lb, and the actual impact speed and angle were 62.9 mi/h and 90 degrees, respectively. The impact point was 10 inches to the right of centerline of the vehicle. The target kinetic energy (KE) was ≥594 kip-ft, and the actual KE at impact was 663 kip-ft.

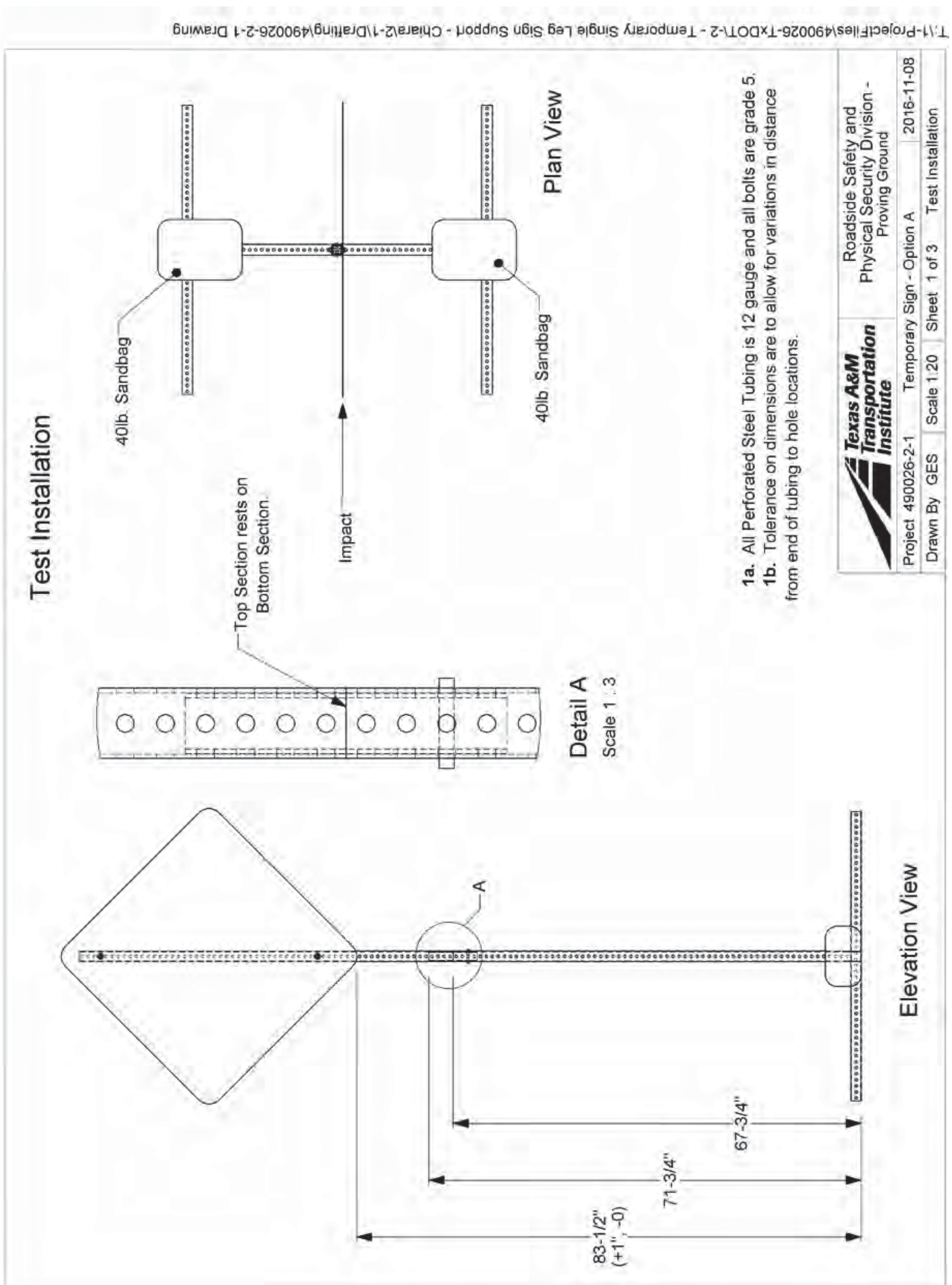


Figure 5.1. Details of the Option A Temporary Work Zone Sign Support.

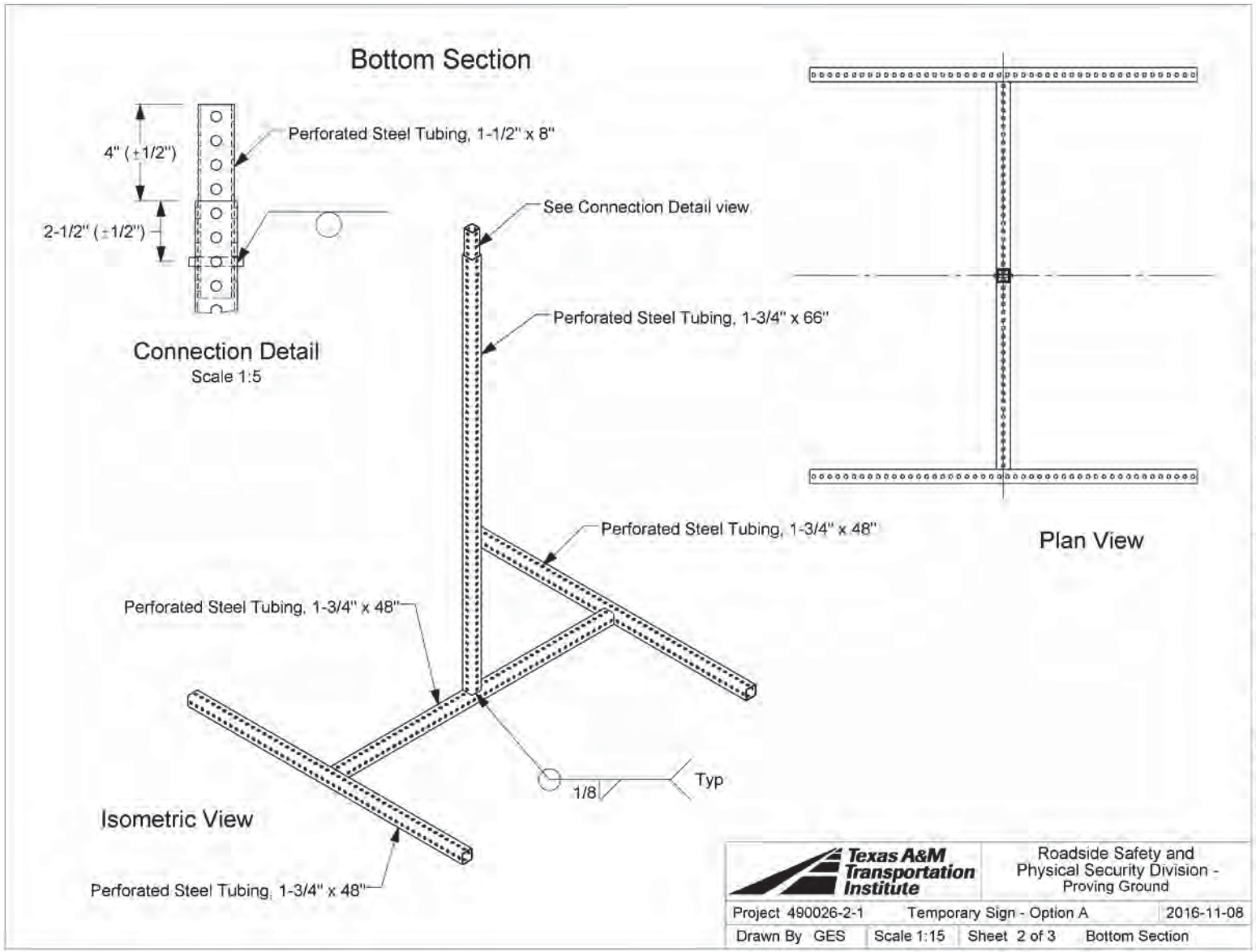


Figure 5.1. Details of the Option A Temporary Work Zone Sign Support (Continued).

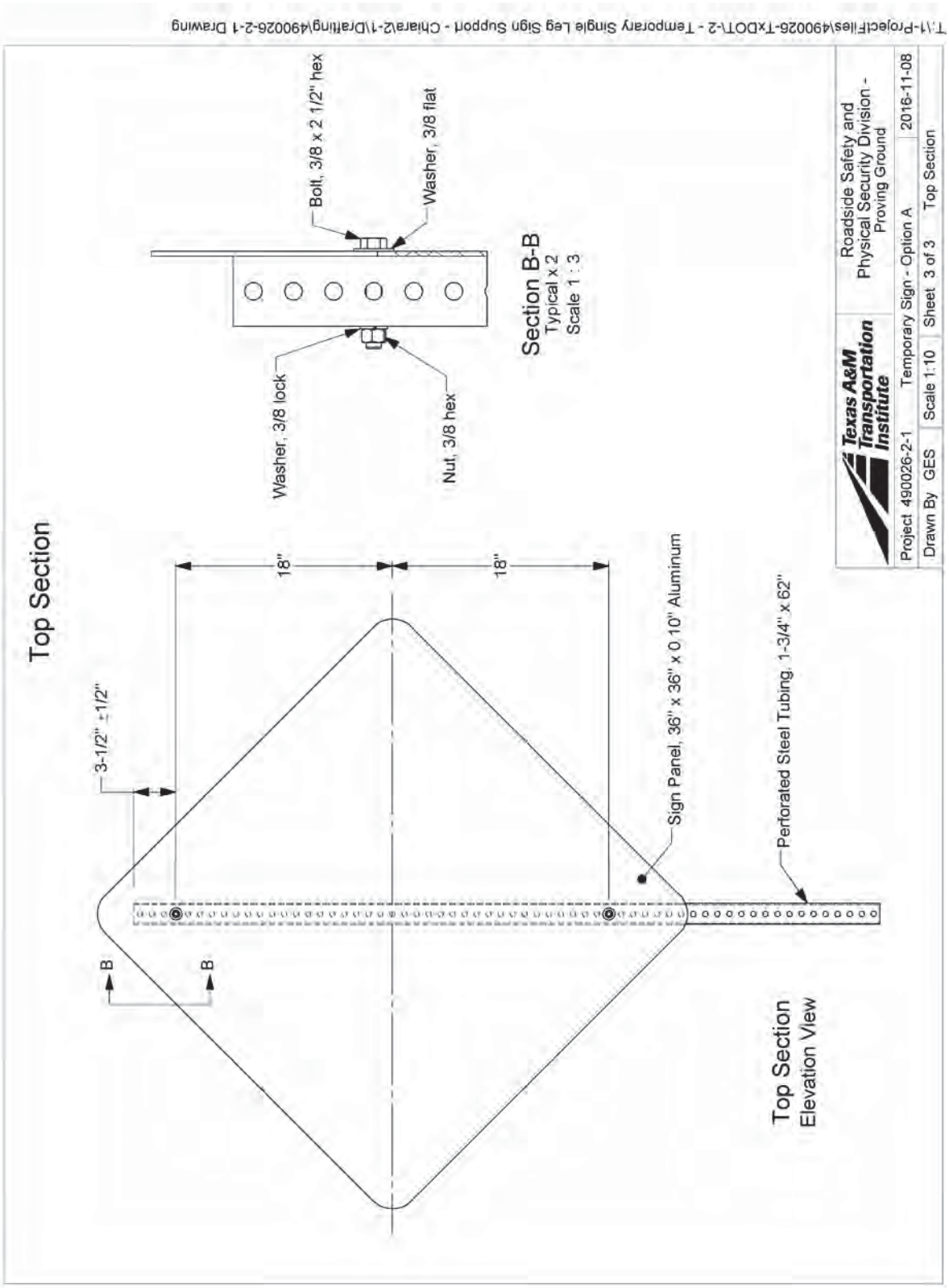


Figure 5.1. Details of the Option A Temporary Work Zone Sign Support (Continued).

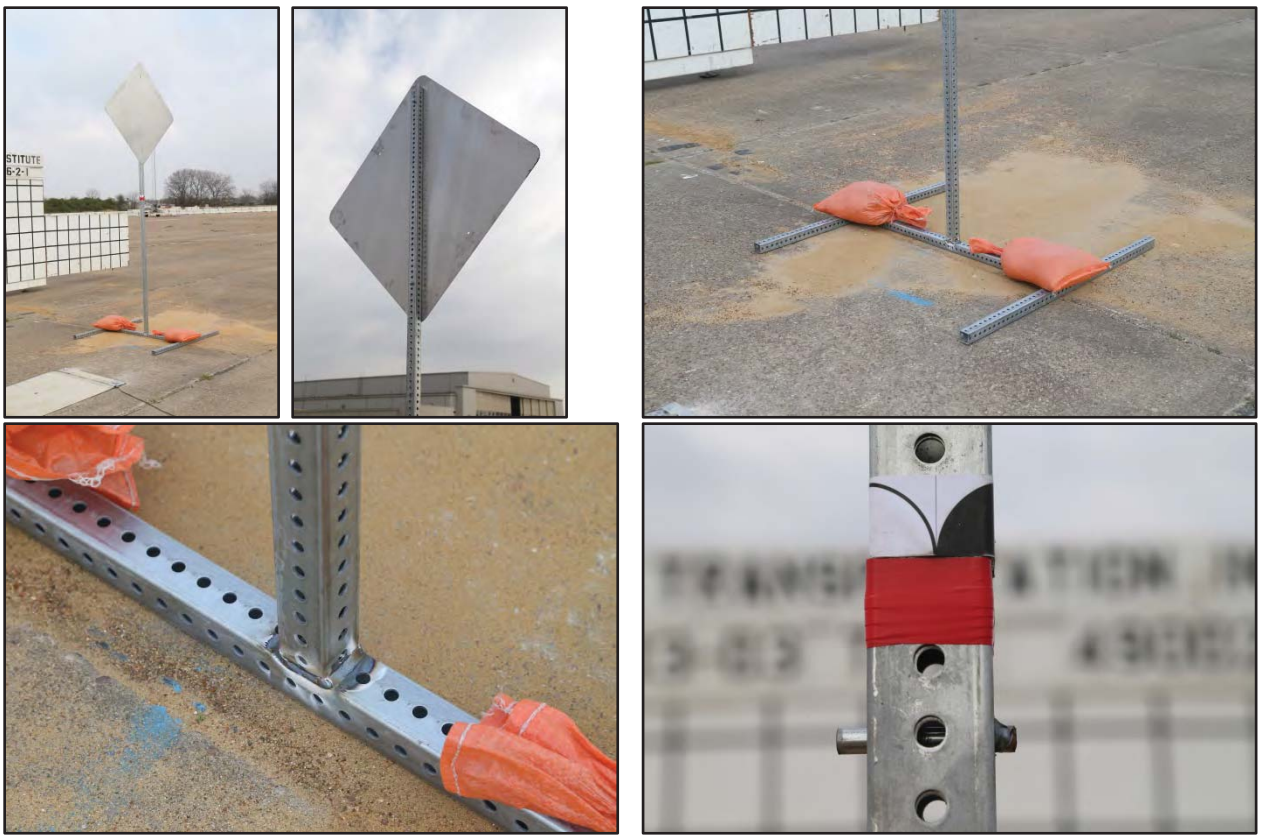


Figure 5.2. Option A Temporary Work Zone Sign Support Used for Test No. 490026-2-1.

5.2.2 Weather Conditions

The test was performed on the morning of March 3, 2016. Weather conditions at the time of testing were as follows: wind speed: 9 mi/h; wind direction: 248 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 74°F; relative humidity: 81 percent.

5.2.3 Test Vehicle

The 2010 Dodge Ram 1500 pickup, shown in Figure 5.3, was used for the crash test. The vehicle's test inertia weight was 5014 lb, and its gross static weight was 5014 lb. The height to the lower edge of the vehicle bumper was 12.5 inches, and the height to the upper edge of the vehicle bumper was 27.5 inches. The height to the vehicle's center of gravity was 28.4 inches. Tables A.1 and A.2 in Appendix A1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 5.3. Test Vehicle before Test No. 490026-2-1.

5.2.4 Test Description

The 2010 Dodge Ram 1500 pickup, traveling at an impact speed of 62.9 mi/h, contacted the Option A temporary work zone sign support 10 inches to the right of centerline of the vehicle at an impact angle of 90 degrees. At 0.003 s after impact, the support contacted the upper grill, and at 0.004 s, the base of the support began to lift off the concrete pavement. The right front tire contacted the base at 0.008 s, and the upper section of the vertical support began to release from the lower section of the vertical support at 0.009 s. At 0.012 s, the lower section of the vertical support began to rupture at bumper height, and at 0.020 s, the upper section of the vertical support lost contact with the lower section of the vertical support. The lower section of the support contacted the concrete pavement at 0.071 s, and the sign panel contacted the right side of the roof 8.5 inches behind the top of the windshield at 0.079 s. A corner of the sign panel contacted the right rear of the roof at 0.117 s and lost contact with the roof at 0.140 s. At loss of contact with the sign panel, the vehicle was traveling at a speed of 61.8 mi/h. Brakes on the vehicle were applied after loss of contact with the sign panel, and the vehicle came to rest 280 ft downstream from the point of impact and 38 ft to the right of centerline of the impact path. Figure A.1 in Appendix A2 presents sequential photographs during the test.

5.2.5 Damage to Test Installation

Figure 5.4 shows the damage to the Option A temporary work zone sign support. The sign panel and a portion of the upright came to rest 20 ft downstream of impact and 6 ft to the right of centerline of the impact path. The lower section of the vertical support post fractured 24 inches above grade and the fractured section came to rest 29 ft downstream and 5 ft to the right of centerline. The H-shaped base with the remaining piece of the lower section of the vertical support post came to rest 98 ft downstream of impact and 12 ft left of centerline of the impact path.

Figure 5.4. Option A Temporary Work Zone Sign Support after Test No. 490026-2-1.

5.2.6 Vehicle Damage

Figure 5.5 shows the damage sustained by the vehicle. The bumper, hood, grill, and roof were damaged. Maximum exterior crush to the vehicle was 2.5 inches in the front plane at the right quarter point at bumper height. On the rear of the roof, there was a 16-inch long scratch that ended in a 5-inch long tear on the outer surface. The cut did not extend into the passenger compartment. The interior roof in the area of the cut was only dented approximately 1 inch, as shown in Figure 5.6. No other occupant compartment deformation or intrusion was noted. Tables A.3 and A.4 in Appendix A1 provide exterior crush and occupant compartment measurements.

Figure 5.5. Test Vehicle after Test No. 490026-2-1.

Figure 5.6. Interior of Test Vehicle after Test No. 490026-2-1.

5.2.7 Occupant Risk Factors

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 3-72 "can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb or less. In this

case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors." The weight of the temporary work zone sign support system was 60 lb.

5.2.8 Assessment of Test Results

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 3-72 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 Option A temporary work zone sign support readily activated by yielding to the 2270P vehicle and fracturing. (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 Option A temporary work zone sign support released and fractured into three pieces. The sign panel and the attached upper section of the vertical support post contacted the roof of the 2270P vehicle causing a 16-inch long scratch that ended in a 5-inch long tear on the outer surface of the roof at the rear of the cab. This was determined to be of concern for potential intrusion into the vehicle. (FAIL)

The 5-inch cut did not penetrate the occupant compartment, but the interior section of the roof was dented inward approximately 1 inch at this location. No other occupant compartment deformation or intrusion was noted. (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 released and fractured pieces of the Option A temporary work zone sign support did not block the driver's view and would not cause the driver to lose control of the 2270P 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 2270P 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: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 G	*20.49 G*

Results: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

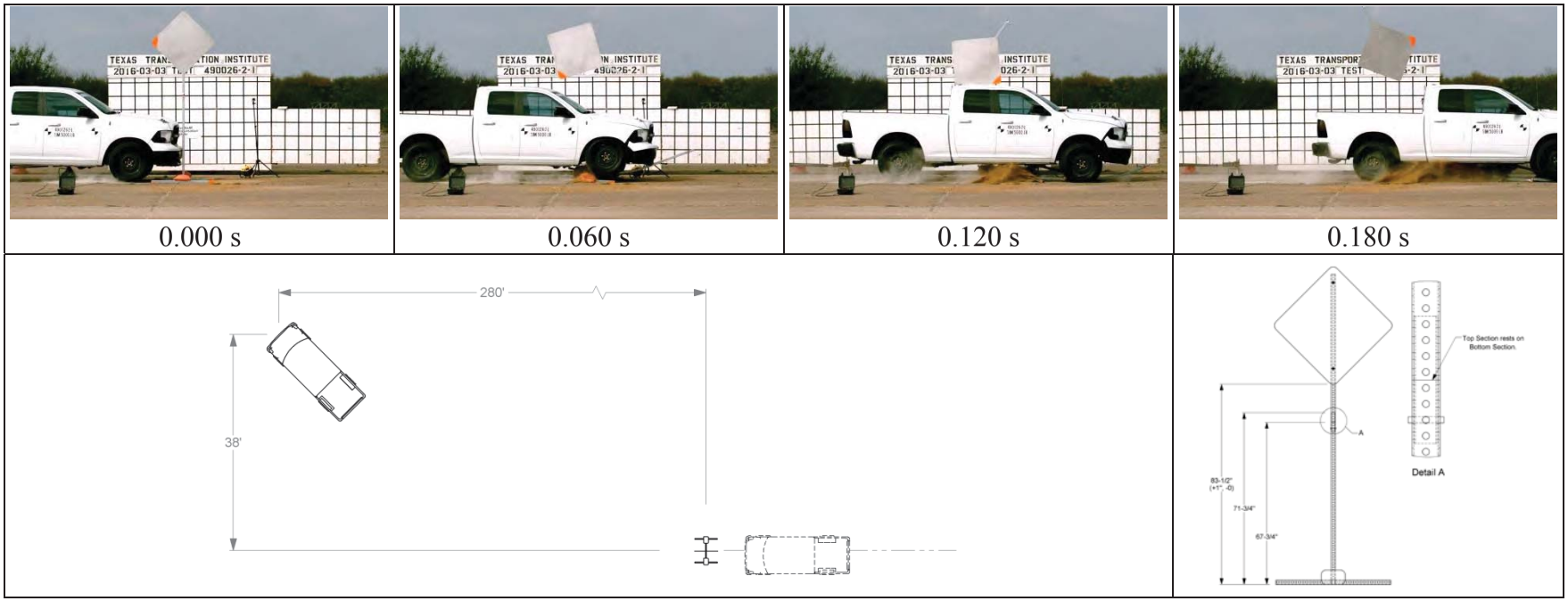
5.2.8.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Results: The 2270P vehicle came to rest 280 ft behind the point of impact with the Option A temporary work zone sign support. (PASS)

5.2.9 Conclusions

Figure 5.7 provides a summary of the results of the test. The slip connection incorporated into the vertical support post of the Option A temporary work zone sign support allowed the top of the system to release from the lower section of the vertical support post and base as intended. The corner of the sign panel impacted the vehicle roof, and no tear occurred with this first impact. However, as the vehicle continued forward, the sign panel continued to rotate and impacted the rear of the roof causing a 5-inch long tear in the exterior of the roof. The tear did not extend into the occupant compartment, but did cause a 1-inch dent in the interior roof panel at this location of the right rear passenger compartment. Due to the extent of the external roof tear, the Option A temporary work zone sign support was judged to have potential for intrusion into the occupant compartment.



General Information
- Test Agency: Texas A&M Transportation Institute (TTI)
- Test Standard Test No.: MASH Test 3-72
- TTI Test No.: 490026-2-1
- Test Date: 2016-03-03

Test Article
- Type: Temporary Work Zone Sign Support
- Name: Option A Temporary Work Zone Sign Support
- Installation Height: 83½ inches to bottom of sign; 132 ⅝ to top
- Material or Key Elements: Upper & lower sections connected with 8-inch long insert sleeve of 1½-inch, 12-gauge perforated square steel tubing secured with ⅜-inch diameter × 2½-inch long smooth pin located in holes 2½ inches below joint
- **Soil Type and Condition**: Placed on dry concrete surface

Test Vehicle
- Type/Designation: 2270P
- Make and Model: 2010 Dodge Ram 1500
- Curb: 4898 lb
- Test Inertial: 5014 lb
- Dummy: No dummy
- Gross Static: 5014 lb

Impact Conditions
- Speed: 62.9 mi/h
- Angle: 90 degrees
- Location/Orientation: 10 inches right of centerline

Kinetic Energy: 663 kip-ft

Exit Conditions
- Speed: 61.8 mi/h
- Angle: NA

Occupant Risk Values: Assessment of occupant risk factors not required for test articles of 60 lb

Test Article Debris Scatter
- Longitudinal: 98 ft downstream
- Lateral: 12 ft left of center

Post-Impact Trajectory
- Stopping Distance: 280 ft downstream 38 ft right of center

Vehicle Stability
- Maximum Yaw Angle: Vehicle
- Maximum Pitch Angle: remained
- Maximum Roll Angle: upright
- Vehicle Snagging: No
- Vehicle Pocketing: No

Vehicle Damage
- VDS: 12FR1
- CDC: 12FREN1
- Max. Exterior Deformation: 2.5 inches
- OCDI: RR0000000
- Max. Occupant Compartment Deformation: 1 inch

Figure 5.7. Summary of Results for *MASH* Test 3-72 at 90 Degrees on the Option A Temporary Work Zone Sign Support.

Chapter 6. OPTION B TEMPORARY WORK ZONE SIGN SUPPORT

6.1 OPTION B DESIGN AND CONSTRUCTION

The Option B test installations were each fabricated with a single aluminum sign mounted on a 3-piece vertical support post fabricated from 1¾-inch and 1½-inch, 12-gauge (0.105 inch) nominal thickness perforated square steel tubing containing $^{7}/_{16}$-inch diameter holes on 1-inch spacing on all four sides. The sign panel measured 36 inches square and was fabricated from 0.100-inch thick aluminum. The sign was mounted in a diamond configuration with a tip-to-tip distance of 49⅛ inches as a result of each corner having a 2-inch radius. The vertical support post and sign were mounted to an H-shaped base measuring 48 inches × 51½ inches comprised of three 48-inch long sections of 1¾-inch perforated square steel tubing. Junctions of the 3-piece base and the lower section of the vertical support post were joined with fillet welds. The sign was attached to the uppermost section of the vertical support post with two ⅜-inch diameter × 2½-inch long SAE grade 5 hex bolts, nuts, and flat and lock washers. Two 40- lb sandbags were placed on top of the H-shaped base; one at the midpoint of each outrigger. The approximate total weight of each test assembly was 58 lb (16-lb sign panel, 18-lb sectional vertical support post, and 24-lb 3-piece base) exclusive of two 40 lb sandbags).

For Option B, the vertical support post was comprised of three sections. The middle and upper sections of the vertical support post were fabricated from 1½-inch, 12-gauge (0.105 inch) nominal thickness perforated square steel tubing. The 39-inch long top section and 26-inch long middle section were joined with two opposing fuse plates, each 1½ inch wide × 8½ inches long × ⅛ inch thick. The fuse plates had four $^{7}/_{16}$-inch diameter holes located to match hole locations in the perforated square steel tubing, and one centrally located 1-inch diameter weakening hole. These fuse plates joined the upper and middle vertical support post sections using four ⅜-inch diameter × 2½-inch long hex bolts, lock washers, and nuts. The lower end of the assembled middle section of the vertical support post was inserted approximately $4^{9}/_{32}$ inches into the 64-inch long, 1¾-inch square bottom section of the vertical support post and rested on a ⅜-inch diameter × 2½-inch long hex bolt (with nut) located in the holes 4½ inches below the upper edge of the bottom section. The head of the bolt was welded in place and the nut was snugly tightened. The top of the lower joint in the vertical support post was 65¾ inches above grade. The bottom and top corners of the sign panel were 83½ inches and 132⅝ inches above grade, respectively. The installation was oriented to impact the sign from the reverse direction during the zero degree impacts.

Figure 6.1 shows details of the Option B sign support installation. Figure 6.2 provides photographs of the completed installation.

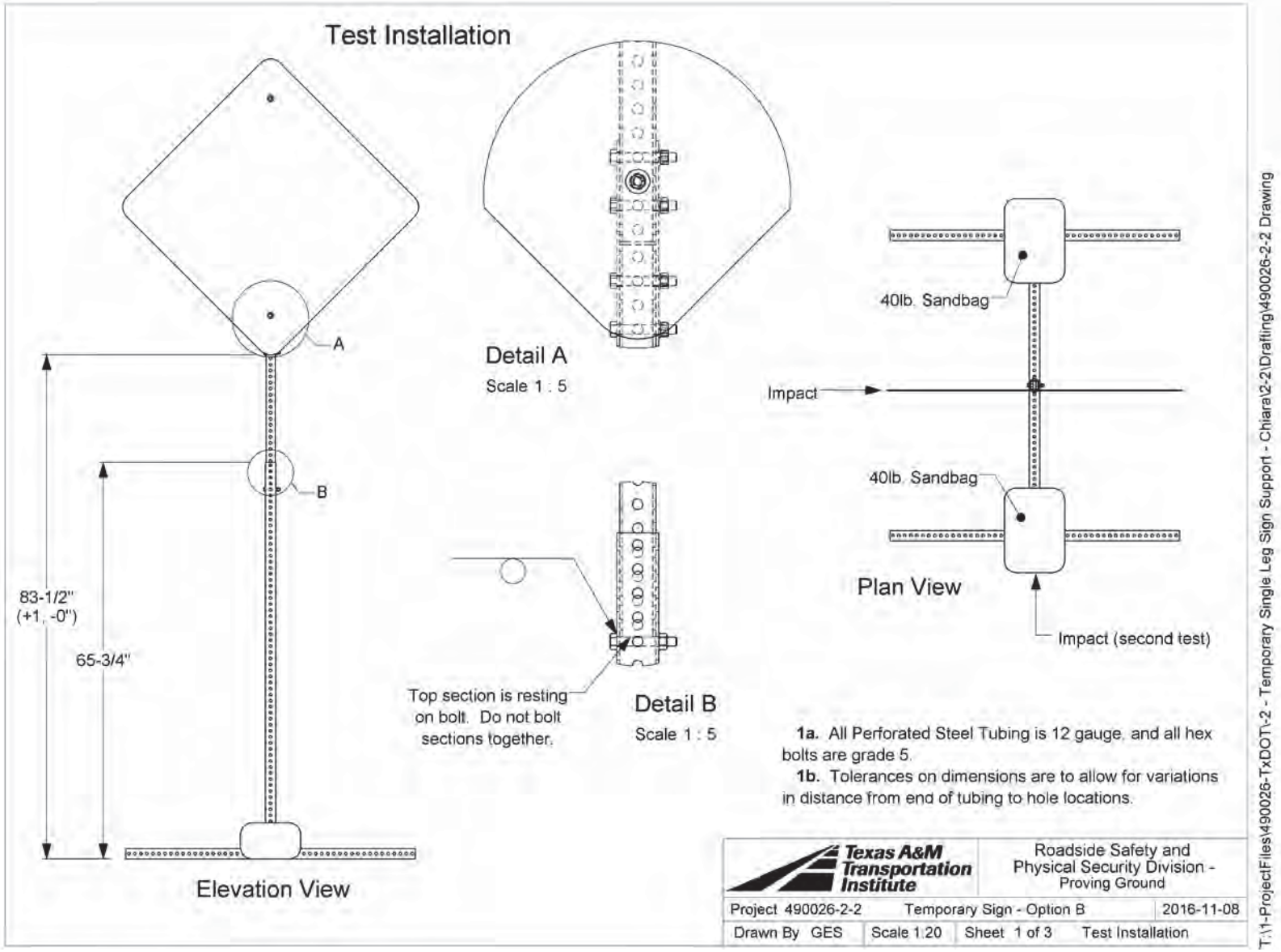


Figure 6.1. Details of the Option B Temporary Work Zone Sign Support.

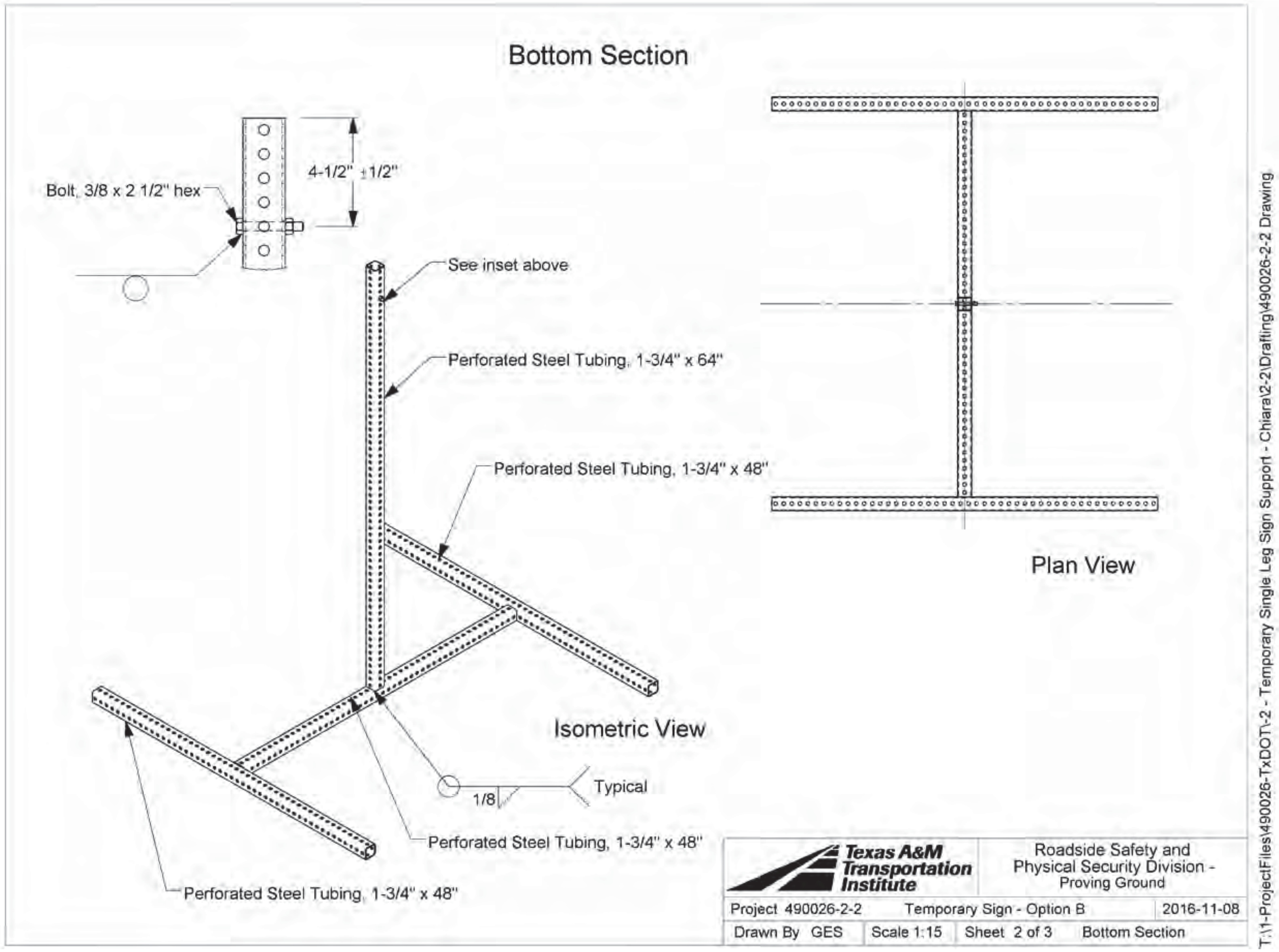


Figure 6.1. Details of the Option B Temporary Work Zone Sign Support (Continued).

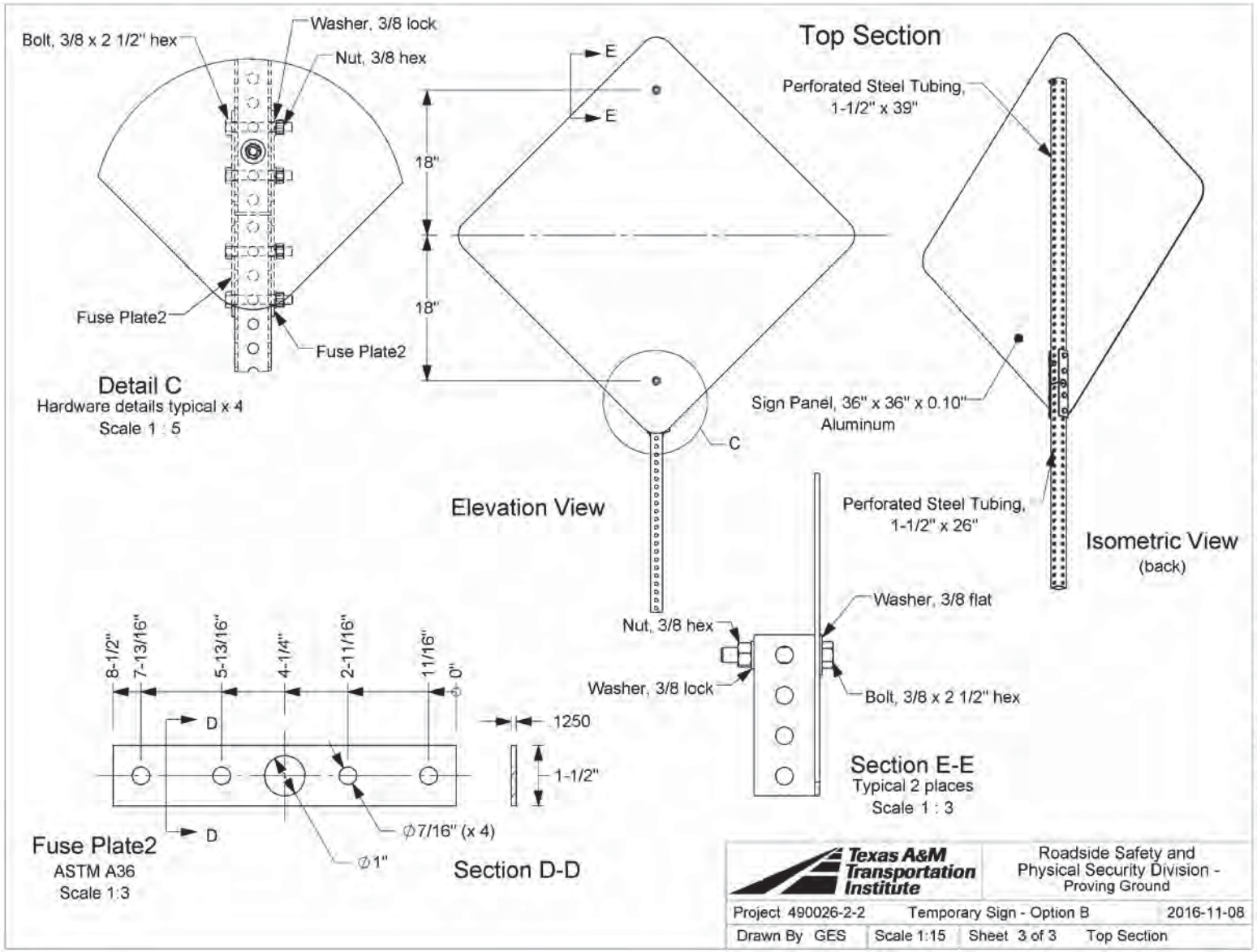


Figure 6.1. Details of the Option B Temporary Work Zone Sign Support (Continued).

6.2 *MASH* TEST 3-72 AT 90 DEGREES (CRASH TEST NO. 490026-2-2)

6.2.1 Test Designation and Actual Impact Conditions

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the Option B temporary work zone sign support at an impact speed of 62.2 mi/h ±2.5 mi/h and CIA ±1.5 degrees. The CIA for *MASH* Test 3-72 on the temporary work zone sign support was 90 degrees. The 2010 Dodge Ram 1500 pickup truck used in the test weighed 5014 lb, and the actual impact speed and angle were 62.6 mi/h and 90 degrees, respectively. The actual impact point was 10 inches to the left of centerline of the vehicle. Target KE was ≥594 kip-ft, and actual KE was 655 kip-ft.

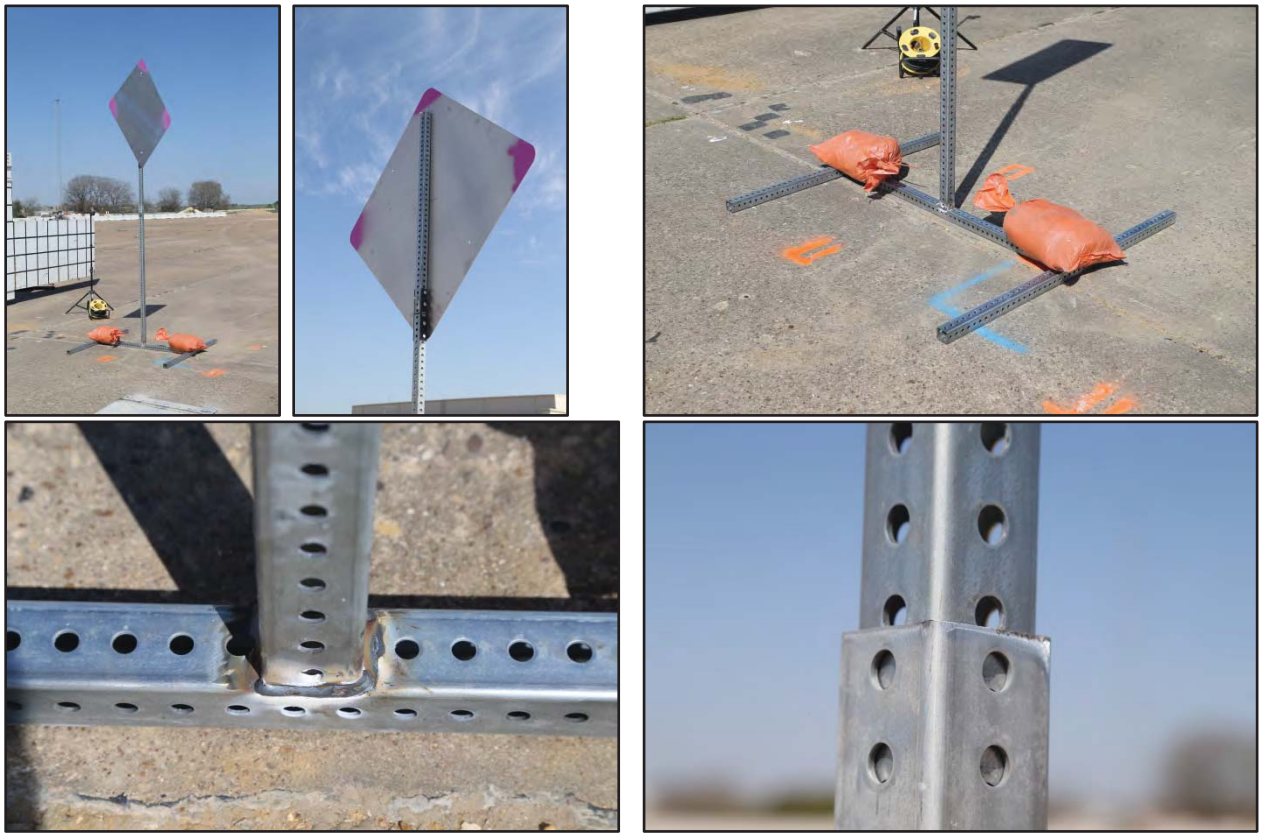


Figure 6.2. Option B Temporary Work Zone Sign Support Used for Test No. 490026-2-2.

6.2.2 Weather Conditions

The test was performed in the late morning of March 3, 2016. Weather conditions at the time of testing were as follows: wind speed: 12 mi/h; wind direction: 360 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 79°F; relative humidity: 53 percent.

6.2.3 Test Vehicle

The 2010 Dodge Ram 1500 pickup, shown in Figure 6.3, was used for the crash test. The vehicle's test inertia weight was 5014 lb, and its gross static weight was 5014 lb. The height to the lower edge of the vehicle bumper was 12.5 inches, and the height to the upper edge of the bumper was 27.5 inches. The height to the vehicle's center of gravity was 28.4 inches. Tables B.1 and B.2 in Appendix B1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.3. Test Vehicle before Test No. 490026-2-2.

6.2.4 Test Description

The 2010 Dodge Ram 1500 pickup, traveling at an impact speed of 62.6 mi/h, contacted the Option B temporary work zone sign support 10 inches to the left of centerline of the vehicle at an impact angle of 90 degrees. At 0.004 s after impact, the support contacted the upper grill, and at 0.005 s, the upstream end of the base began to lift off the concrete pavement. The middle section of the vertical support began to pull out of the lower section of the support at 0.007 s, and the lower section of the support began to deform at bumper height at 0.009 s. At 0.018 s, the middle and upper section of the support lost contact with the lower section, and at 0.085 s, the lower section of the support contacted the pavement. The sign panel and upper section of the support was parallel with and above the roof of the vehicle at 0.094 s, and the sign panel contacted the roof 50 inches behind the windshield at 0.114 s. At 0.133 s, the sign panel lost contact with the roof and the vehicle was traveling at a speed of 61.6 mi/h. Brakes on the vehicle were applied after loss of contact with the sign panel, and the vehicle came to rest 305 ft downstream of the impact point and 13 ft to the left of the vehicle impact path. Figure B.1 in Appendix B2 presents sequential photographs during the test.

6.2.5 Damage to Test Installation

Figure 6.4 shows the damage to the Option B temporary work zone sign support. The sign panel and middle and upper sections of the vertical support came to rest 10 ft downstream of impact and 2 ft to the left of centerline of the impact path. The fuse plates connecting the middle and upper sections of the vertical support were activated. The bottom section of the vertical

support fractured 24 inches above grade and the piece came to rest 77 ft downstream of impact and 3 ft to the right of centerline of the impact path. The H-shaped base and lower portion of the bottom section of the vertical support came to rest 108 ft downstream of impact and 6 ft right of centerline of the impact path.

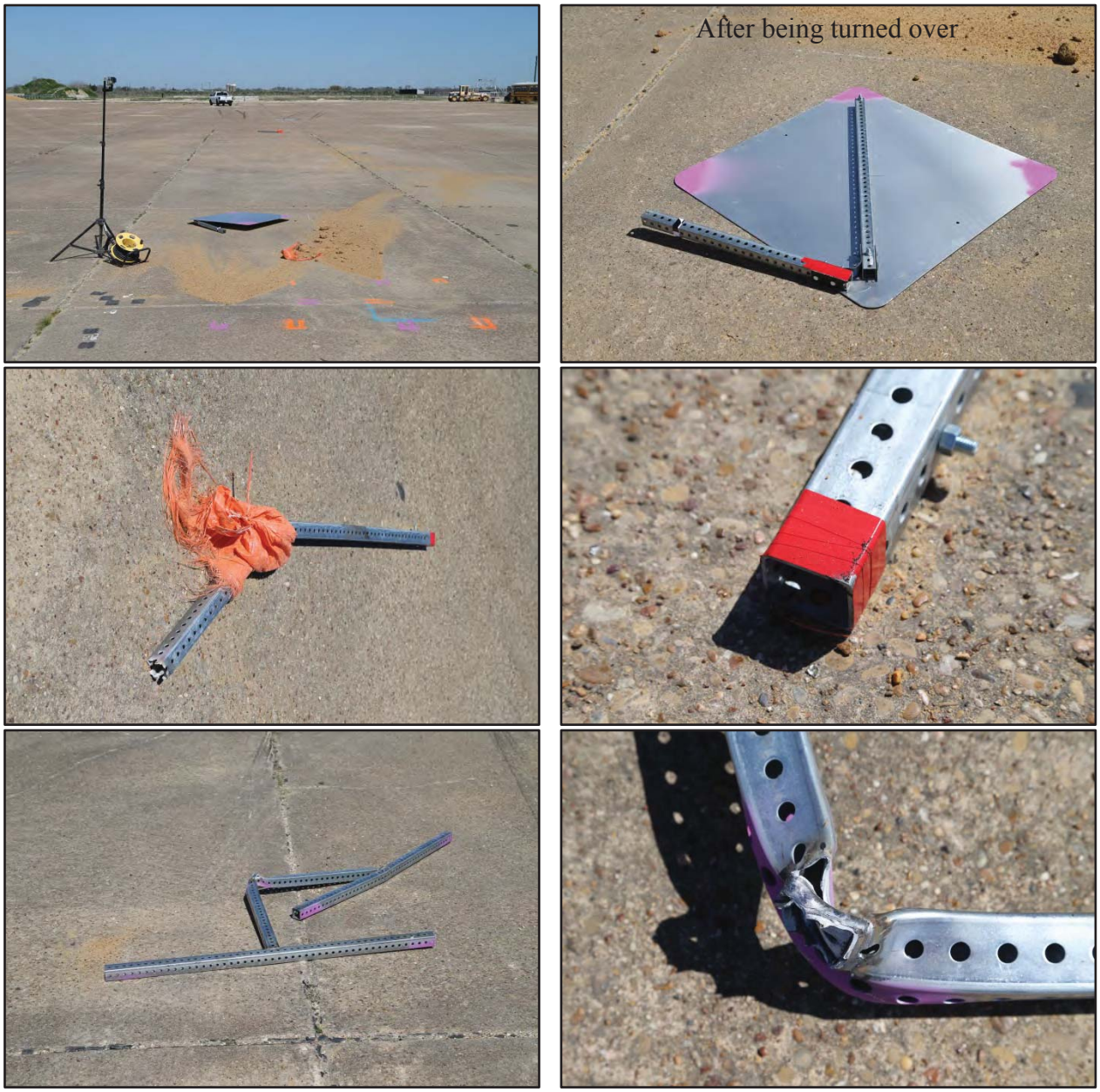


Figure 6.4. Option B Temporary Work Zone Sign Support after Test No. 490026-2-2.

6.2.6 Vehicle Damage

Figure 6.5 shows the damage sustained by the vehicle. The bumper and roof were scraped. A small tear in the transmission pan was noted, but did not show evidence of penetration or intrusion. Maximum exterior crush to the vehicle was 2.5 inches in the front plane

at the left quarter point at bumper height. On the left side of the roof of the cab, there was a 10-inch long dent on the outer surface, but no penetration into the passenger compartment. Figure 6.6 shows the interior of the vehicle. No occupant compartment deformation or intrusion was noted. Tables B.3 and B.4 in Appendix B1 provide exterior crush and occupant compartment measurements.

Figure 6.5. Test Vehicle after Test No. 490026-2-2.

Before Test After Test

Figure 6.6. Interior of Test Vehicle for Test No. 490026-2-2.

6.2.7 Occupant Risk Factors

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 3-72 "can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb or less. In this case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors." The weight of the temporary work zone sign support system was 58 lb.

6.2.8 Assessment of Test Results

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 3-72 is provided below.

6.2.8.1 Structural Adequacy

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

Results: The Option B temporary work zone sign support readily activated by yielding to the 2270P vehicle and fracturing. (PASS)

6.2.8.2 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 Option B temporary work zone sign support released and fractured into three pieces; however, there was no concern for potential deformation or intrusion into the vehicle. (PASS)

No occupant compartment penetration, deformation, or intrusion was noted. (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 released and fractured pieces of the Option B temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 2270P 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 2270P 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: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 G	*20.49 G*

Results: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

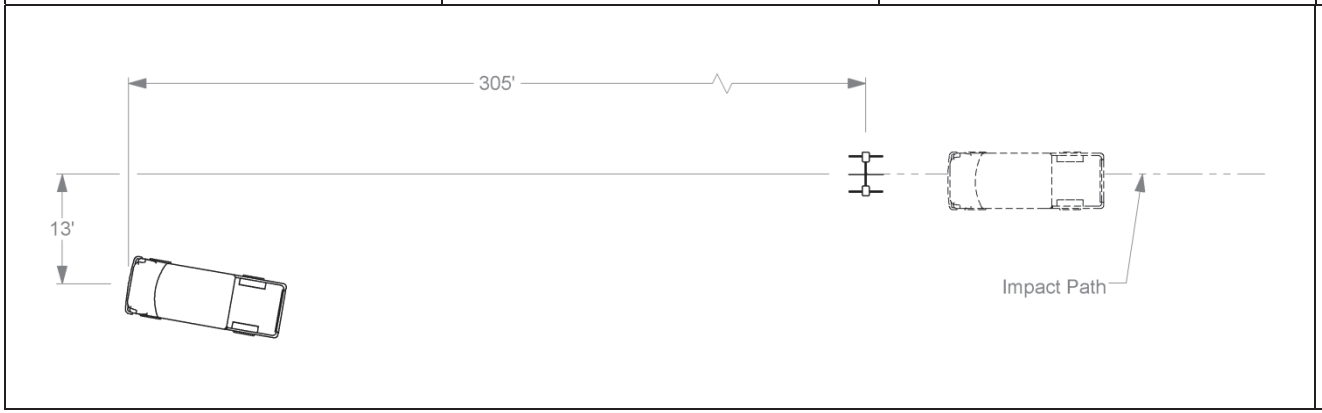
6.2.8.3 Vehicle Trajectory

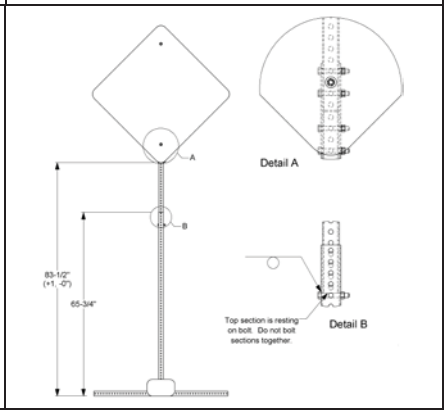
N. *Vehicle trajectory behind the test article is acceptable.*

Results: The 2270P vehicle came to rest 305 ft behind the Option B temporary work zone sign support. (PASS)

6.2.9 Conclusions

Figure 6.7 provides a summary of the results of the test. The slip connection between the bottom and middle sections of the vertical support performed as designed and released the middle and upper sections and sign panel from the lower section and base. The fuse plate between the upper and middle sections of the vertical support activated as designed. Although the sign panel impacted the roof, this contact did not result in any tear or penetration of the roof. The slight roof deformation that occurred was within *MASH* criteria.





General Information
- Test Agency: Texas A&M Transportation Institute (TTI)
- Test Standard Test No.: MASH Test 3-72
- TTI Test No.: 490026-2-2
- Test Date: 2016-03-03

Test Article
- Type: Temporary Work Zone Sign Support
- Name: Option B Temporary Work Zone Sign Support
- Installation Height: 83½ inches to bottom of sign; 132⅝ to top
- Material or Key Elements: Upper & middle sections joined with two opposing fuse plates; smaller 1½ inch middle section had telescopic slip joint inside 1 ¾ inch lower section of vertical support
- **Soil Type and Condition**: Placed on dry concrete surface

Test Vehicle
- Type/Designation: 2270P
- Make and Model: 2010 Dodge Ram 1500
- Curb: 4898 lb
- Test Inertial: 5014 lb
- Dummy: No dummy
- Gross Static: 5014 lb

Impact Conditions
- Speed: 62.6 mi/h
- Angle: 90 degrees
- Location/Orientation: 10 inches left of centerline 655 kip-ft
- **Kinetic Energy**: 61.6 mi/h
- **Exit Conditions**: NA
- Speed: Assessment of
- Angle: occupant risk factors not
- **Occupant Risk Values**: required for test articles of 58 lb

Test Article Debris Scatter
- Longitudinal: 108 downstream
- Lateral: 2 ft left – 6 ft right

Post-Impact Trajectory
- Stopping Distance: 305 ft downstream 13 ft left of center

Vehicle Stability
- Maximum Yaw Angle: Vehicle
- Maximum Pitch Angle: remained
- Maximum Roll Angle: upright
- Vehicle Snagging: No
- Vehicle Pocketing: No

Vehicle Damage
- VDS: 12FL1
- CDC: 12FLEN1
- Max. Exterior Deformation: 2.5 inches
- OCDI: RR0000000
- Max. Occupant Compartment Deformation: None

Figure 6.7. Summary of Results for *MASH* Test 3-72 at 90 Degrees on the Option B Temporary Work Zone Sign Support.

6.3 *MASH* TEST 3-71 AT 90 DEGREES (CRASH TEST NO. 490026-2-4)

6.3.1 Test Designation and Actual Impact Conditions

MASH Test 3-71 involves an 1100C vehicle weighing 2425 lb ±55 lb and impacting the Option B temporary work zone sign support at an impact speed of 62.2 mi/h ±2.5 mi/h and CIA ±1.5 degrees. The CIA for *MASH* Test 3-71 on the temporary work zone sign support was 90 degrees. The 2011 Kia Rio used in the test weighed 2443 lb, and the actual impact speed and angle were 60.9 mi/h and 90 degrees, respectively. The actual impact point was 10 inches right of the vehicle centerline. The target KE was ≥288 kip-ft, and the actual KE at impact was 303 kip-ft. Figure 6.8 shows the installation before the test.

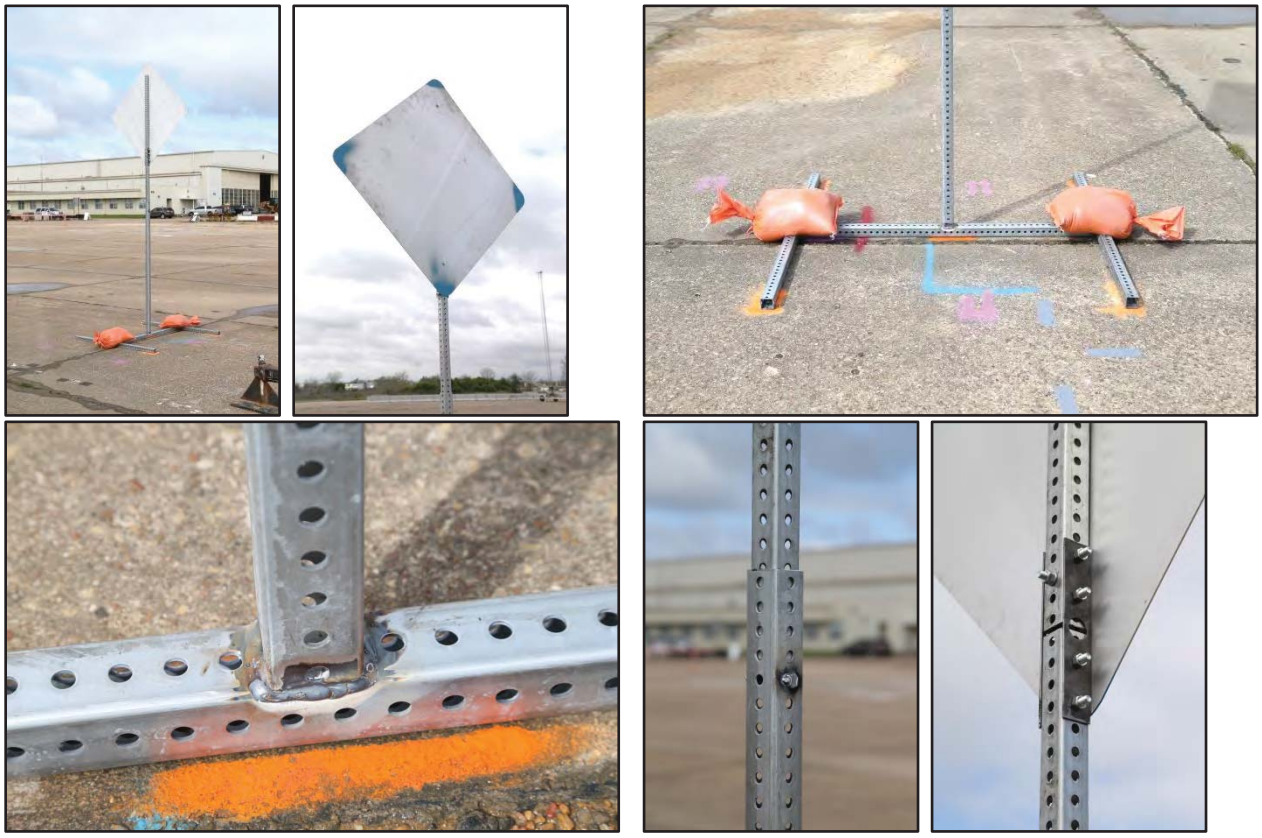


Figure 6.8. Option B Temporary Work Zone Sign Support Used for Test No. 490026-2-4.

6.3.2 Weather Conditions

The test was performed on the morning of March 11, 2016. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 205 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 66°F; relative humidity: 89 percent.

6.3.3 Test Vehicle

The 2011 Kia Rio, shown in Figure 6.9, was used for the crash test. The vehicle's test inertia weight was 2443 lb, and its gross static weight was 2608 lb. The height to the lower edge of the vehicle bumper was 8.0 inches, and the height to the upper edge of the vehicle bumper was 21.5 inches. Table C.1 in Appendix C1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.9. Test Vehicle before Test No. 490026-2-4.

6.3.4 Test Description

The 2011 Kia Rio, traveling at an impact speed of 60.9 mi/h, contacted the Option B temporary work zone sign support 10 inches to the right of centerline of the vehicle at an impact angle of 90 degrees. At 0.003 s after impact, the base of the support began to lift off the concrete pavement, and at 0.007 s, the middle section of the support began to release from the lower section at the slip joint. The middle and upper sections of the support lost contact with the lower section at 0.024 s, and the vehicle lost contact with the support at 0.140 s traveling at a speed of 58.8 mi/h. Brakes on the vehicle were applied after loss of contact with the support, and the vehicle came to rest 468 ft downstream of impact. Figure C.1 in Appendix C2 presents sequential photographs during the test.

6.3.5 Damage to Test Installation

Figure 6.10 shows the damage to the Option B temporary work zone sign support. The sign panel and middle and upper sections of the vertical support came to rest 3 ft downstream of impact and on the centerline of the impact path. The fuse plates connecting the middle and upper section of the support were activated. The remainder of the temporary work zone sign support rode along with the 1100C vehicle. As the vehicle came to a stop, the support slid ahead of the vehicle and came to rest 483 ft downstream of impact and on the centerline of the impact path. The lower section of the vertical support was bent at bumper height.

Figure 6.10. Option B Temporary Work Zone Sign Support after Test No. 490026-2-4.

6.3.6 Vehicle Damage

Figure 6.11 shows the damage sustained by the vehicle. The 1100C vehicle sustained only scrapes to the bumper and hood with no measureable exterior vehicle deformation. Figure 6.12 shows the interior of the vehicle. No occupant compartment deformation or intrusion was noted. Tables C.2 and C.3 in Appendix C1 provide exterior crush and occupant compartment measurements.

Figure 6.11. Test Vehicle after Test No. 490026-2-4.

Before Test After Test

Figure 6.12. Interior of Test Vehicle for Test No. 490026-2-4.

6.3.7 Occupant Risk Factors

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 3-72 "can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb or less. In this

case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors." The weight of the temporary work zone sign support system was 58 lb.

6.3.8 Assessment of Test Results

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 3-71 is provided below.

6.3.8.1 Structural Adequacy

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

Results: The Option B temporary work zone sign support readily activated by yielding to the 1100C vehicle and releasing at a slip joint as designed. (PASS)

6.3.8.2 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 Option B temporary work zone sign support released into two pieces; however, there was no potential for penetration into the vehicle. The lower portion of the sign support rode along with the 1100C vehicle and came to rest 15 ft ahead of the vehicle. (PASS)

No occupant compartment deformation or intrusion was noted. (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 released pieces of the Option B temporary work zone sign support did not block the driver's view and would not cause the driver to lose control of the 1100C 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: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 G	*20.49 G*

Results: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

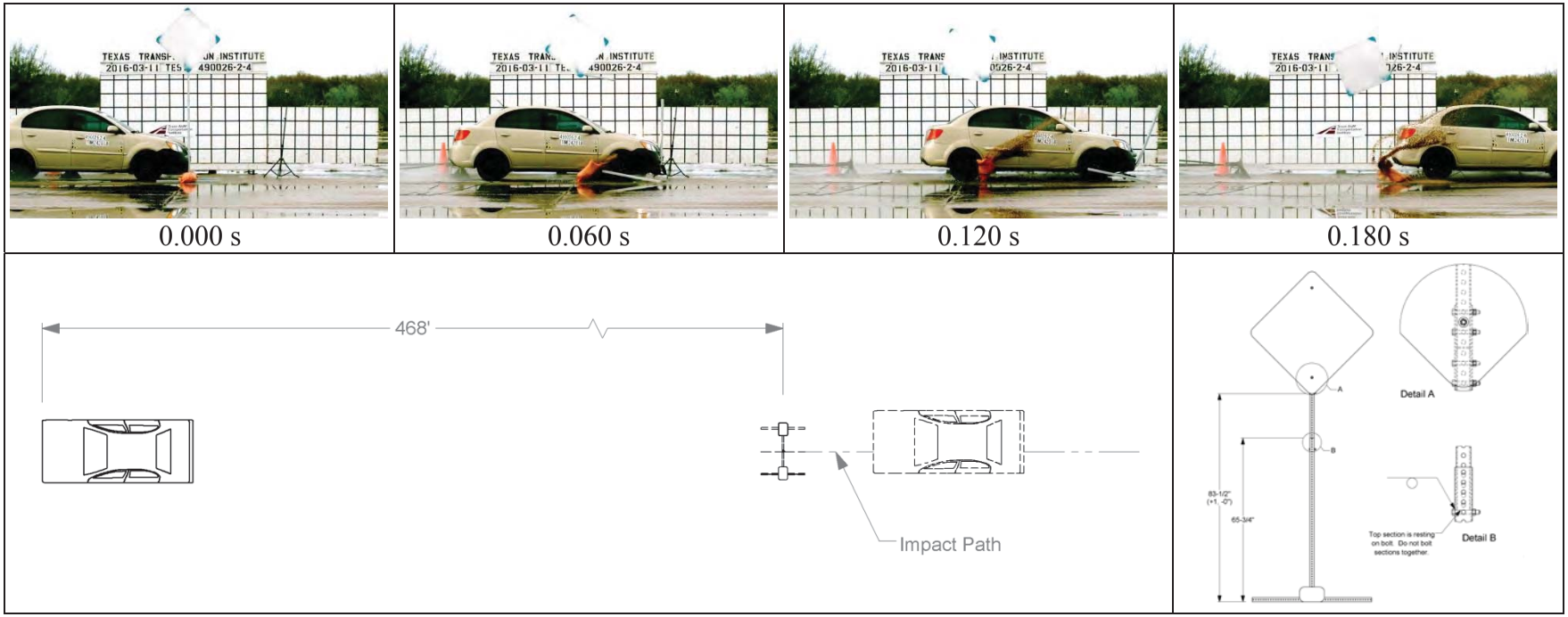
6.3.8.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Results: The 1100C vehicle came to rest 468 ft behind the Option B temporary work zone sign support. (PASS)

6.3.9 Conclusions

Figure 6.13 provides a summary of the results of the test. The slip connection between the bottom and middle sections of the vertical support performed as designed and released the middle and upper sections and sign panel from the lower section and base. The fuse plate between the upper and middle sections of the vertical support activated as designed. There was no secondary contact between the sign panel and the roof of the vehicle.



General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 3-71
- TTI Test No. 490026-2-4
- Test Date 2016-03-11

Test Article
- Type ..... Temporary Work Zone Sign Support
- Name ..... Option B Temporary Work Zone Sign Support
- Installation Height ..... 83½ inches to bottom; 132⅝ to top
- Material or Key Elements .... Upper & lower sections joined with two opposing fuse plates, Upper & middle sections joined with two opposing fuse plates; smaller 1½ inch middle section had telescopic slip joint inside 1 ¾ inch lower section of vertical support
- **Soil Type and Condition** ..... Placed on dry concrete surface

Test Vehicle
- Type/Designation 1100C
- Make and Model ..... 2011 Kia Rio
- Curb ..... 2479 lb
- Test Inertial ..... 2443 lb
- Dummy ..... 165 lb
- Gross Static ..... 2608 lb

Impact Conditions
- Speed ..... 60.9 mi/h
- Angle ..... 90 degrees
- Location/Orientation ..... 10 inches right of centerline 303 kip-ft

Kinetic Energy ..... 58.8 mi/h

Exit Conditions NA
- Speed ..... Assessment of occupant
- Angle ..... risk factors not required

Occupant Risk Values .... for test articles of 58 lb

Test Article Debris Scatter
- Longitudinal ..... 483 downstream
- Lateral ..... Centerline

Post-Impact Trajectory
- Stopping Distance ..... 468 ft downstream Centerline

Vehicle Stability
- Maximum Yaw Angle ..... Vehicle
- Maximum Pitch Angle ..... remained
- Maximum Roll Angle ..... upright
- Vehicle Snagging ..... No
- Vehicle Pocketing ..... No

Vehicle Damage
- VDS 12FR1
- CDC 12FREN1
- Max. Exterior Deformation ..... None
- OCDI RF0000000
- Max. Occupant Compartment Deformation ..... None

Figure 6.13. Summary of Results for *MASH* Test 3-71 at 90 Degrees on the Option B Temporary Work Zone Sign Support.

6.4 *MASH* TEST 3-71 AT 0 DEGREES (CRASH TEST NO. 490026-2-6)

6.4.1 Test Designation and Actual Impact Conditions

MASH Test 3-71 involves a 1100C vehicle weighing 2425 lb ±55 lb and impacting the Option B temporary work zone sign support 10 inches to the right of centerline of the vehicle at an impact speed of 62.2 mi/h ±2.5 mi/h and CIA ±1.5 degrees. The CIA for *MASH* Test 3-71 on the temporary work zone sign support was 0 degrees. The 2011 Kia Rio used in the test weighed 2443 lb, and the actual impact speed and angle were 61.7 mi/h and 0 degrees, respectively. The actual impact point was the right quarter point of the front of the vehicle. The target KE was ≥288 kip-ft, and the actual KE at impact was 311 kip-ft. Figure 6.14 shows the installation before the test.

Figure 6.14. Option B Temporary Work Zone Sign Support Used for Test No. 490026-2-6.

6.4.2 Weather Conditions

The test was performed on the afternoon of March 11, 2016. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 146 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 72°F; relative humidity: 73 percent.

6.4.3 Test Vehicle

The 2011 Kia Rio used in the previous test 490026-2-4, shown in Figure 6.15, was used for the crash test. The vehicle's test inertia weight was 2443 lb, and its gross static weight was 2608 lb. The height to the lower edge of the vehicle bumper was 8.0 inches, and the height to the upper edge of the vehicle bumper was 21.5 inches. Table D.1 in Appendix D1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.15. Test Vehicle before Test No. 490026-2-6.

6.4.4 Test Description

The 2011 Kia Rio, traveling at an impact speed of 61.7 mi/h, contacted the Option B temporary work zone sign support 10 inches to the right of centerline of the vehicle at an impact angle of 0 degrees. At 0.001 s after impact, the right front tire contacted the base of the support, and at 0.003 s, the base began to lift off the concrete pavement. The upper section of the support began to release from the lower section at 0.006 s, and the lower section of the support fractured at bumper height at 0.010 s. At 0.017 s, the upper section of the support lost contact with the lower section, and the lower section lost contact with the bumper at 0.055 s. The top of the lower section of the support contacted the concrete pavement at 0.086 s, and the vehicle contacted the lower section of the support again at 0.172 s. The vehicle was traveling at a speed of 59.7 mi/h. Brakes on the vehicle were applied after loss of contact with the support, and the vehicle came to rest 438 ft downstream of impact. Figure D.1 in Appendix D2 presents sequential photographs during the test.

6.4.5 Damage to Test Installation

Figure 6.16 shows the damage to the Option B temporary work zone sign support. The sign panel and the attached upper and middle sections of the vertical support came to rest 3 ft downstream of impact. The lower section of the vertical support fractured into two pieces16 inches above ground level. The upper fractured piece came to rest 185 ft downstream of impact and 12 ft to the right of centerline of the vehicle path. The remaining lower portion and H-base of the temporary work zone sign support came to rest 83 ft downstream of impact.

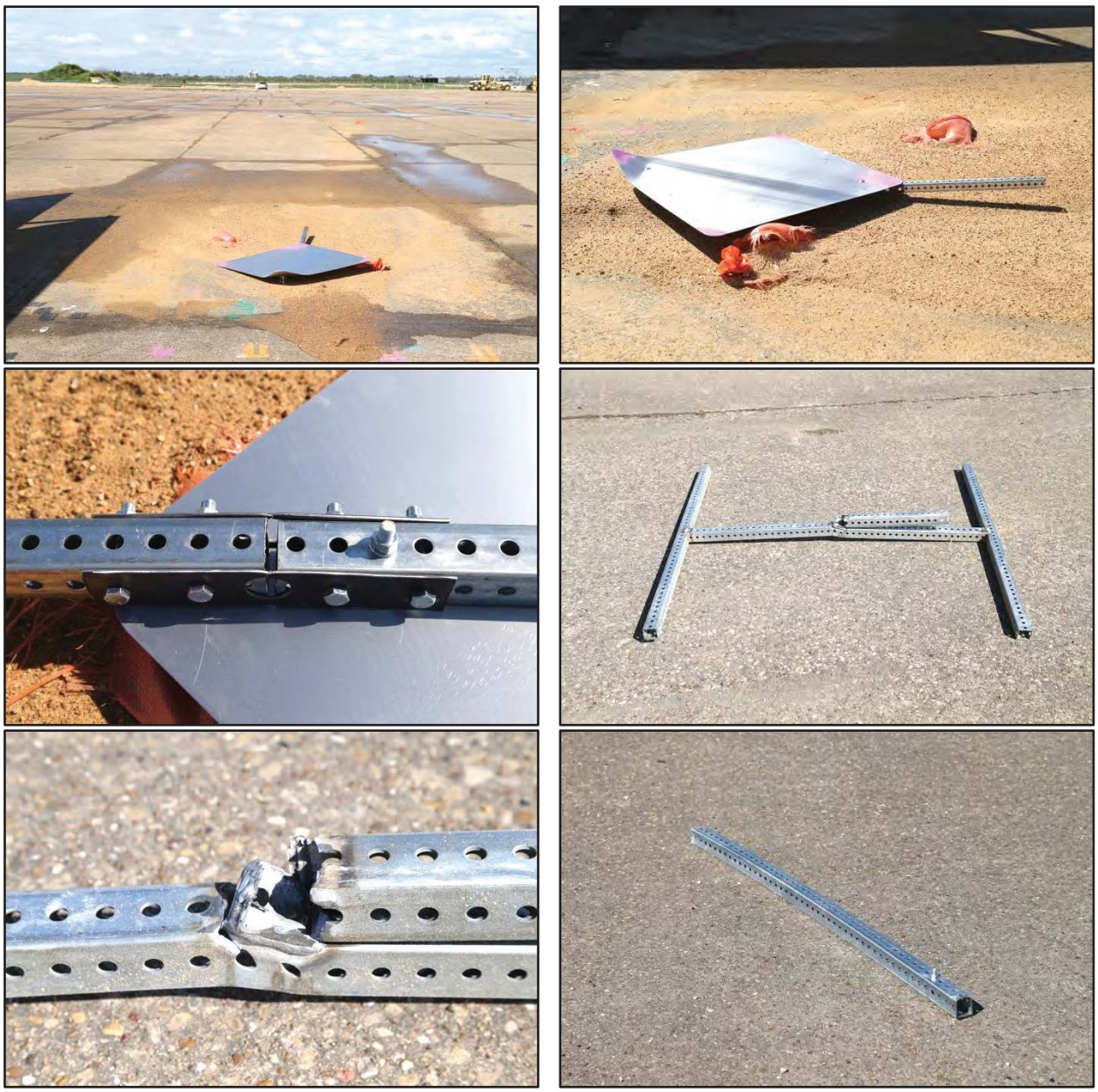
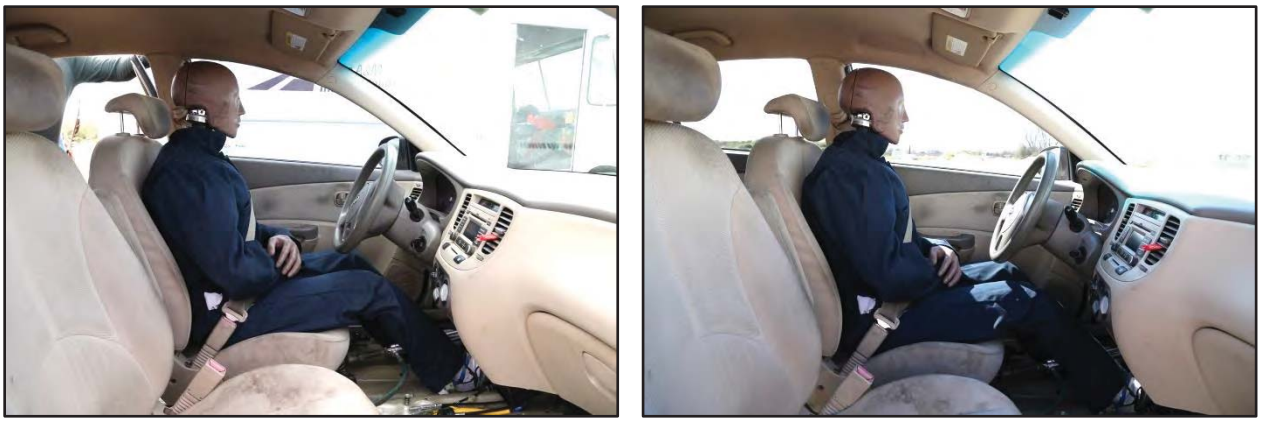


Figure 6.16. Option B Temporary Work Zone Sign Support after Test No. 490026-2-6.

6.4.6 Vehicle Damage

Figure 6.17 shows the damage sustained by the vehicle. The 1100C vehicle sustained only scrapes to the bumper and hood with no measureable exterior vehicle deformation. Figure 6.18 shows the interior of the vehicle. No occupant compartment penetration, deformation, or intrusion was noted. Tables D.2 and D.3 in Appendix D1 provide exterior crush and occupant compartment measurements.

Figure 6.17. Test Vehicle after Test No. 490026-2-6.



Before Test After Test

Figure 6.18. Interior of Test Vehicle for Test No. 490026-2-6.

6.4.7 Occupant Risk Factors

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 3-71 "can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb or less. In this

case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors." The weight of the temporary work zone sign support system was 58 lb.

6.4.8 Assessment of Test Results

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 3-71 is provided below.

6.4.8.1 Structural Adequacy

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

Results: The Option B temporary work zone sign support readily activated by yielding to the 1100C vehicle, releasing at the slip joint, and fracturing. (PASS)

6.4.8.2 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 Option B temporary work zone sign support released and fractured into three pieces; however, there was no concern for penetration or intrusion into the vehicle. The lower portion of the sign support rode along with the 1100C vehicle for a distance and came to rest 83 ft downstream of impact and along the centerline of the vehicle path. (PASS)

No occupant compartment deformation or intrusion was noted. (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 fractured pieces of the Option B temporary work zone sign support did not block the driver's view and would not cause the driver to lose control of the 1100C 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: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 G	*20.49 G*

Results: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

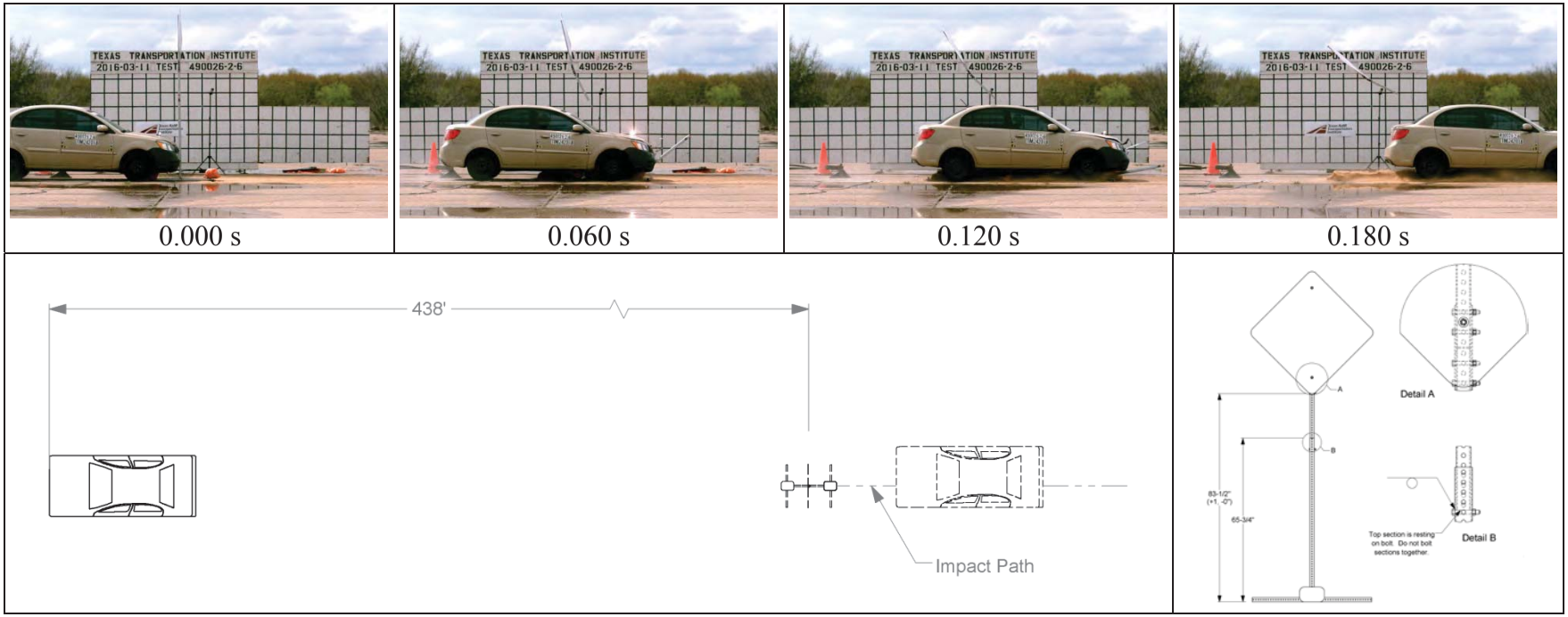
6.4.8.3 Vehicle Trajectory

N. *Vehicle trajectory behind the test article is acceptable.*

Results: The 1100C vehicle came to rest 438 ft behind the Option B temporary work zone sign support. (PASS)

6.4.9 Conclusions

Figure 6.19 provides a summary of the results of the test. The slip connection of Option B temporary work zone sign support performed as designed and permitted the top of the system to release from the lower section. There was no secondary contact between the sign panel and the roof of the vehicle.



General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 3-71
- TTI Test No. 490026-2-6
- Test Date 2016-03-11

Test Article
- Type ..... Temporary Work Zone Sign Support
- Name ..... Option B Temporary Work Zone Sign Support
- Installation Height ..... 83½ inches to bottom; 132⅝ to top
- Material or Key Elements .... Upper & middle sections joined with two opposing fuse plates; smaller 1½ inch middle section had telescopic slip joint inside 1 ¾ inch lower section of vertical support

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

Test Vehicle
- Type/Designation 1100C
- Make and Model ..... 2011 Kia Rio
- Curb ..... 2479 lb
- Test Inertial ..... 2443 lb
- Dummy ..... 165 lb
- Gross Static ..... 2608 lb

Impact Conditions
- Speed ..... 61.7 mi/h
- Angle ..... 0 degrees
- Location/Orientation ..... 10 inches right of centerline 311 kip-ft

Kinetic Energy ..... 59.7 mi/h

Exit Conditions NA
- Speed ..... Assessment of occupant
- Angle ..... risk factors not required

Occupant Risk Values ..... for test articles of 58 lb

Test Article Debris Scatter
- Longitudinal ..... 185 ft downstream
- Lateral ..... 12 ft right of center

Post-Impact Trajectory
- Stopping Distance ..... 438 ft downstream Centerline

Vehicle Stability
- Maximum Yaw Angle ..... Vehicle
- Maximum Pitch Angle ..... remained
- Maximum Roll Angle ..... upright
- Vehicle Snagging ..... No
- Vehicle Pocketing ..... No

Vehicle Damage
- VDS 12FR1
- CDC 12FREN1
- Max. Exterior Deformation ..... None
- OCDI RF0000000
- Max. Occupant Compartment Deformation ..... None

Figure 6.19. Summary of Results for *MASH* Test 3-71 at 0 Degrees on the Option B Temporary Work Zone Sign Support.

6.5 *MASH* TEST 3-72 AT 0 DEGREES (CRASH TEST NO. 490026-2-8)

6.5.1 Test Designation and Actual Impact Conditions

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the Option B temporary work zone sign support at an impact speed of 62.2 mi/h ±2.5 mi/h and CIA ±1.5 degrees. The CIA for *MASH* Test 3-72 on the temporary work zone sign support was 0 degrees. The 2010 Dodge Ram 1500 pickup truck used in the test weighed 5014 lb, and the actual impact speed and angle were 62.1 mi/h and 0 degrees, respectively. The actual impact point was 10 inches left of vehicle's centerline. The target KE was ≥594 kip-ft, and the actual KE at impact was 646 kip-ft. Figure 6.20 shows the installation before the test.

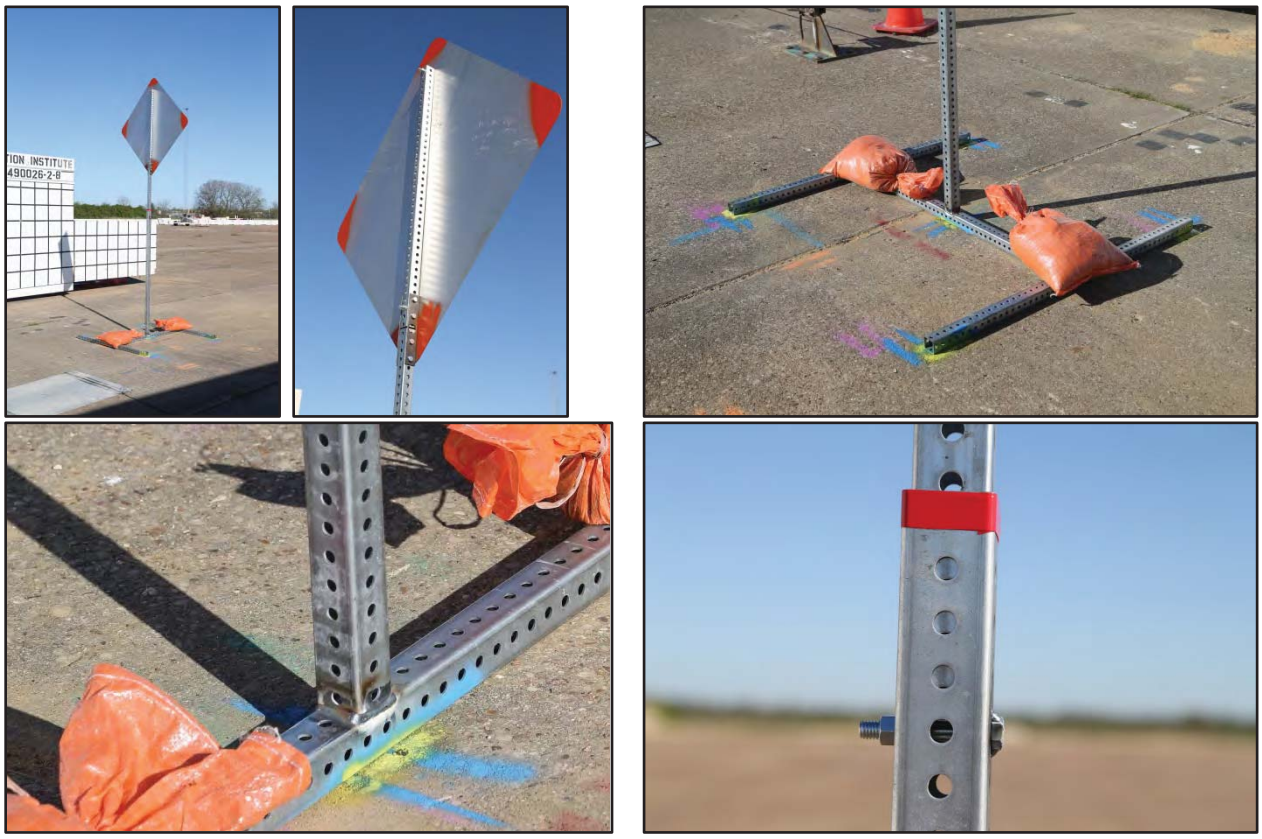


Figure 6.20. Option A Temporary Work Zone Sign Support Used for Test No. 490026-2-8.

6.5.2 Weather Conditions

The test was performed on the morning of March 14, 2016. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 192 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 70°F; relative humidity: 63 percent.

6.5.3 Test Vehicle

The 2010 Dodge Ram 1500 pickup, shown in Figure 6.21, was used for the crash test. The vehicle's test inertia weight was 5014 lb, and its gross static weight was 5014 lb. The height to the lower edge of the vehicle bumper was 12.5 inches, and the height to the upper edge of the vehicle bumper was 27.5 inches. The height to the vehicle's center of gravity was 28.4 inches. Tables E.1 and E.2 in Appendix E1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 6.21. Test Vehicle before Test No. 490026-2-8.

6.5.4 Test Description

The 2010 Dodge Ram 1500 pickup, traveling at an impact speed of 62.1 mi/h, contacted the Option B temporary work zone sign support 10 inches to the left of centerline of the vehicle at an impact angle of 0 degrees. At 0.004 s after impact, the support contacted the upper grill, and at 0.005 s, the base of the support began to lift off and slide along the surface of the concrete pavement. The upper section of the support began to slide out of the lower section at 0.007 s, and the upper section lost contact with the lower section of the support at 0.018 s. At 0.020 s, the lower section of the vertical support began to rupture at bumper height, and at 0.058 s, the vehicle lost contact with the lower section of the support. The lower section of the support contacted the concrete pavement at 0.075 s. At loss of contact with the support, the vehicle was traveling at a speed of 61.1 mi/h. Brakes on the vehicle were applied after loss of contact with the sign panel, and the vehicle came to rest 409 ft downstream of impact and 21 ft to the left of centerline of the impact path. Figure E.1 in Appendix E2 presents sequential photographs during the test.

6.5.5 Damage to Test Installation

Figure 6.22 shows the damage to the Option B temporary work zone sign support. The sign panel and the attached middle and upper sections of the vertical support came to rest 10 ft downstream of impact and 3 ft to the right of centerline of the impact path. The lower section of the vertical support fractured into two pieces 24 inches above ground level. The upper fractured piece came to rest 125 ft downstream and 15 ft to the left of centerline of the vehicle path. The

remaining lower portion and H-base of the temporary work zone sign support came to rest 83 ft downstream of impact. The H-shaped base came to rest 8 ft downstream of impact.

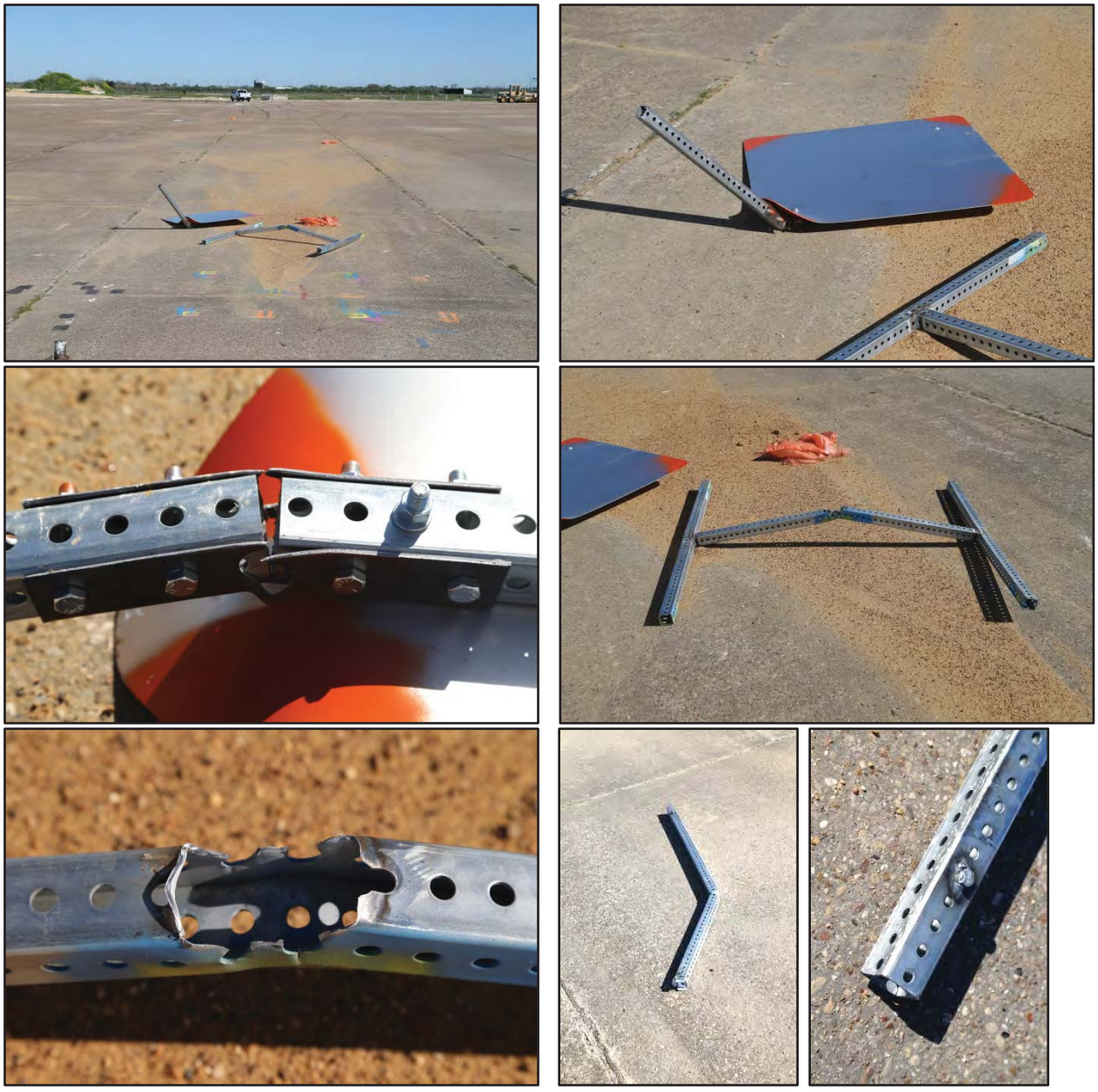


Figure 6.22. Option A Temporary Work Zone Sign Support after Test No. 490026-2-8.

6.5.6 Vehicle Damage

Figure 6.23 shows the damage sustained by the vehicle. The bumper and hood were damaged. Maximum exterior crush to the vehicle was 4.0 inches in the front plane at the left quarter point at bumper height. Figure 6.24 shows the interior of the vehicle. No occupant compartment deformation or intrusion was noted. Tables E.3 and E.4 in Appendix E1 provide exterior crush and occupant compartment measurements.

Figure 6.23. Test Vehicle after Test No. 490026-2-8.

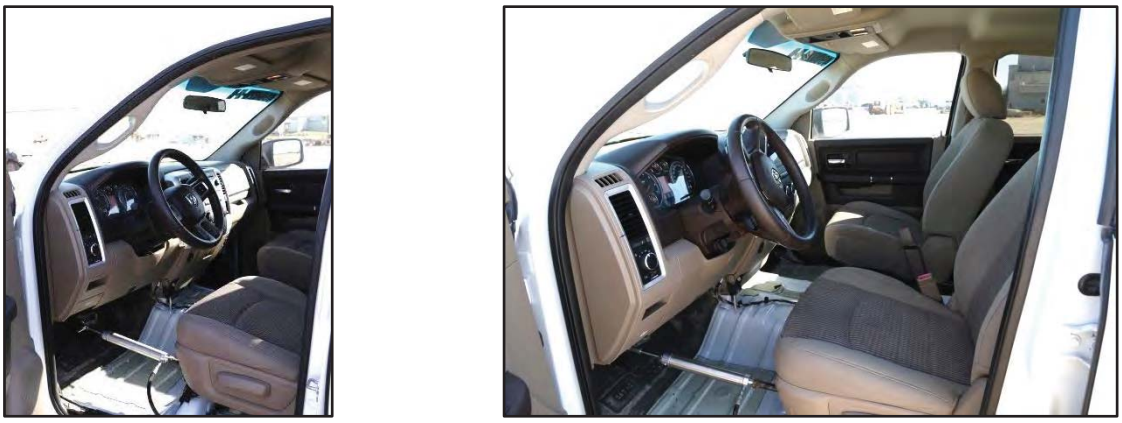


Figure 6.24. Interior of Test Vehicle after Test No. 490026-2-8.

6.5.7 Occupant Risk Factors

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 3-72 "can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb or less. In this case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors." The weight of the temporary work zone sign support system was 62 lb.

6.5.8 Assessment of Test Results

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 3-72 is provided below.

6.5.8.1 Structural Adequacy

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

Results: The Option B temporary work zone sign support readily activated by yielding to the 2270P vehicle, releasing at the slip joint, and fracturing. (PASS)

6.5.8.2 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 Option B temporary work zone sign support released and fractured but did not penetrate or show signs for potential penetration of the vehicle. (PASS)

No occupant compartment penetration, deformation, or intrusion was noted. (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 released and fractured pieces of the Option B temporary work zone sign support did not block the driver's view and would not cause the driver to lose control of the 2270P 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 2270P 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: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 G	*20.49 G*

Results: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

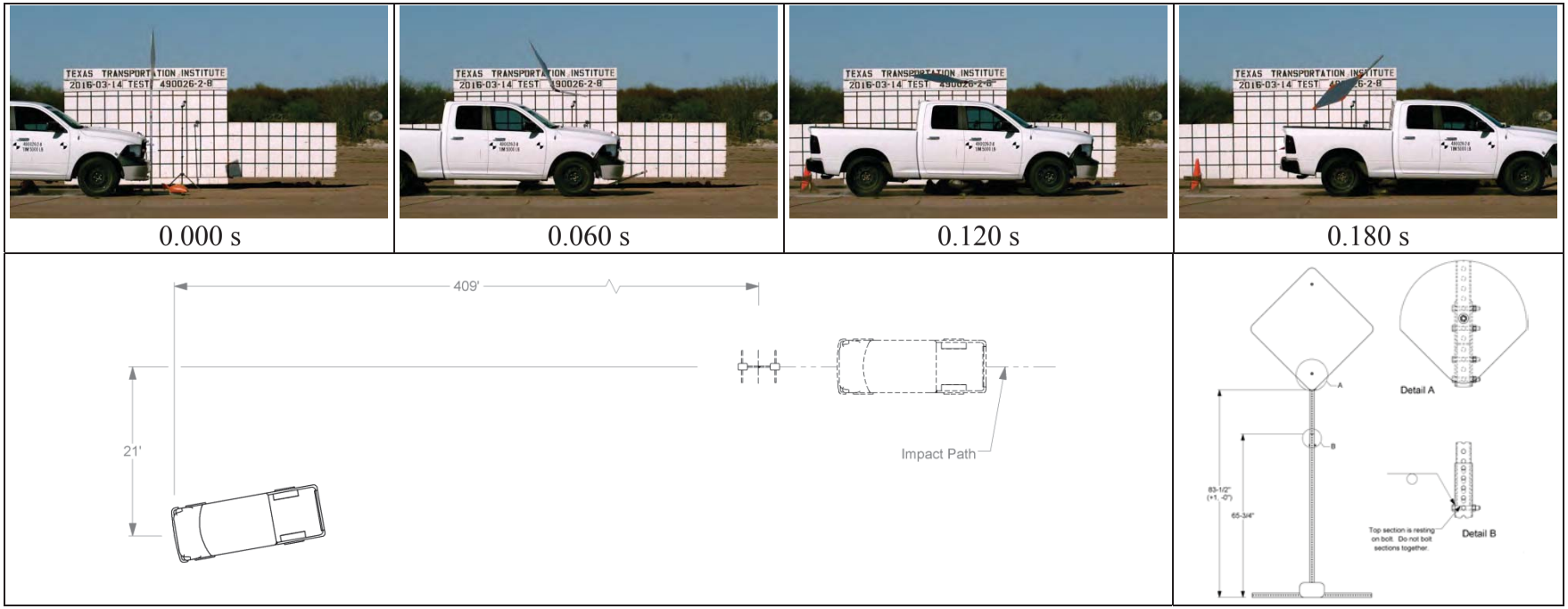
6.5.8.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Results: The 2270P vehicle came to rest 409 ft behind the installation. (PASS)

6.5.9 Conclusions

Figure 6.25 provides a summary of the results of the test. The slip connection of Option B temporary work zone sign supports performed as designed and the top of the system released from the lower section. The lower section of the vertical support fractured but did not penetrate or show potential for penetrating the vehicle. No occupant compartment deformation or intrusion was noted. The fractured pieces of the Option B temporary work zone sign support did not block the driver's view and would not cause the driver to lose control of the 2270P vehicle. The 2270P vehicle remained upright during and after the collision event. The 2270P vehicle came to rest 409 ft behind the installation.



General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 3-72
- TTI Test No. 490026-2-8
- Test Date 2016-03-14

Test Article
- Type ..... Temporary Work Zone Sign Support
- Name ..... Option B Temporary Work Zone Sign Support
- Installation Height ..... 83½ inches to bottom; 132⅝ to top
- Material or Key Elements .... Upper & middle sections joined with two opposing fuse plates; smaller 1½ inch middle section had telescopic slip joint inside 1 ¾ inch lower section of vertical support ,
- **Soil Type and Condition** ..... Placed on dry concrete surface

Test Vehicle
- Type/Designation 2270P
- Make and Model ..... 2010 Dodge Ram 1500
- Curb ..... 4898 lb
- Test Inertial ..... 5014 lb
- Dummy ..... No dummy
- Gross Static ..... 5014 lb

Impact Conditions
- Speed ..... 62.1 mi/h
- Angle ..... 0 degrees
- Location/Orientation ..... 10 inches left of centerline
- **Kinetic Energy** ..... 646 kip-ft

Exit Conditions
- Speed ..... 61.1 mi/h
- Angle ..... NA
- **Occupant Risk Values** ..... Assessment of occupant risk factors not required for test articles of 58 lb

Test Article Debris Scatter
- Longitudinal ..... 125 downstream
- Lateral ..... 15 ft left of center 3 ft right of center

Post-Impact Trajectory
- Stopping Distance ..... 409 ft downstream 21 ft left of center

Vehicle Stability
- Maximum Yaw Angle ..... Vehicle
- Maximum Pitch Angle ..... remained
- Maximum Roll Angle ..... upright
- Vehicle Snagging ..... No
- Vehicle Pocketing ..... No

Vehicle Damage
- VDS 01FL1
- CDC 01FLEN1
- Max. Exterior Deformation ..... 4.0 inches
- OCDI FR0000000
- Max. Occupant Compartment Deformation ..... None

Figure 6.25. Summary of Results for *MASH* Test 3-72 at 0 Degrees on the Option B Temporary Work Zone Sign Support.

Chapter 7. OPTION C TEMPORARY WORK ZONE SIGN SUPPORT

7.1 OPTION C DESIGN AND CONSTRUCTION

The Option C test installation consisted of a single aluminum sign mounted on a two-piece vertical supported fabricated from 1¾-inch and 1½-inch, 12-gauge (0.105 inch) nominal thickness perforated square steel tubing containing $^{7}/_{16}$-inch diameter holes on 1-inch spacing on all four sides. The sign panel measured 36 inches square and was fabricated from 0.100-inch thick aluminum. The sign was mounted in a diamond configuration with a tip-to-tip distance of 49⅛ inches as a result of each corner having a 2-inch radius. The vertical support and sign were mounted to an H-shaped base measuring 48 inches × 51½ inches comprised of three 48-inch long sections of 1¾-inch perforated square steel tubing. Junctions of the 3-piece base and lower section of the vertical support post were joined with fillet welds. The sign was attached to the upper section of the vertical support with two ⅜-inch diameter × 2½-inch long SAE grade 5 hex bolts, nuts, and flat and lock washers. Two 40-lb sandbags were placed on top of the H-shaped base, one at the midpoint of each outrigger. The approximate total weight of each test assembly was 57 lb (16-lb sign panel, 17-lb sectional post, and 24-lb 3-piece base) exclusive of two 40-lb sandbags.

For Option C, the upper section of the vertical support was comprised of a 48-inch length of 1½-inch, 12-gauge (0.105-inch) nominal thickness perforated square steel tubing. This upper section was inserted approximately $4^{9}/_{32}$ inches into the lower section of 1¾-inch perforated square steel tubing to form a slip joint. The upper section rested on a ⅜-inch diameter × 2¼-inch long smooth pin located in the holes 4½ inches below the top end of the lower section. The pin was welded to one side of the lower section. The top of the lower section was 83¾ inches above grade. The bottom and top of the sign panel were 84½ inches and 133⅝ inches above grade, respectively.

Figure 7.1 shows details of the Option C temporary work zone sign and post installation. Figure 7.2 provides photographs of the completed installation.

7.2 *MASH* TEST 3-72 AT 90 DEGREES (CRASH TEST NO. 490026-2-3)

7.2.1 Test Designation and Actual Impact Conditions

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the Option C temporary work zone sign support at an impact speed of 62.2 mi/h ±2.5 mi/h and CIA ±1.5 degrees. The CIA for *MASH* Test 3-72 on the temporary work zone sign support was 90 degrees. The 2010 Dodge Ram 1500 pickup truck used in the test weighed 5014 lb, and the actual impact speed and angle were 62.5 mi/h and 90 degrees, respectively. The actual impact point was the centerline of the front of the vehicle. The target KE was ≥594 kip-ft, and the actual KE at impact was 653 kip-ft. Figure 7.2 shows the installation before the test.

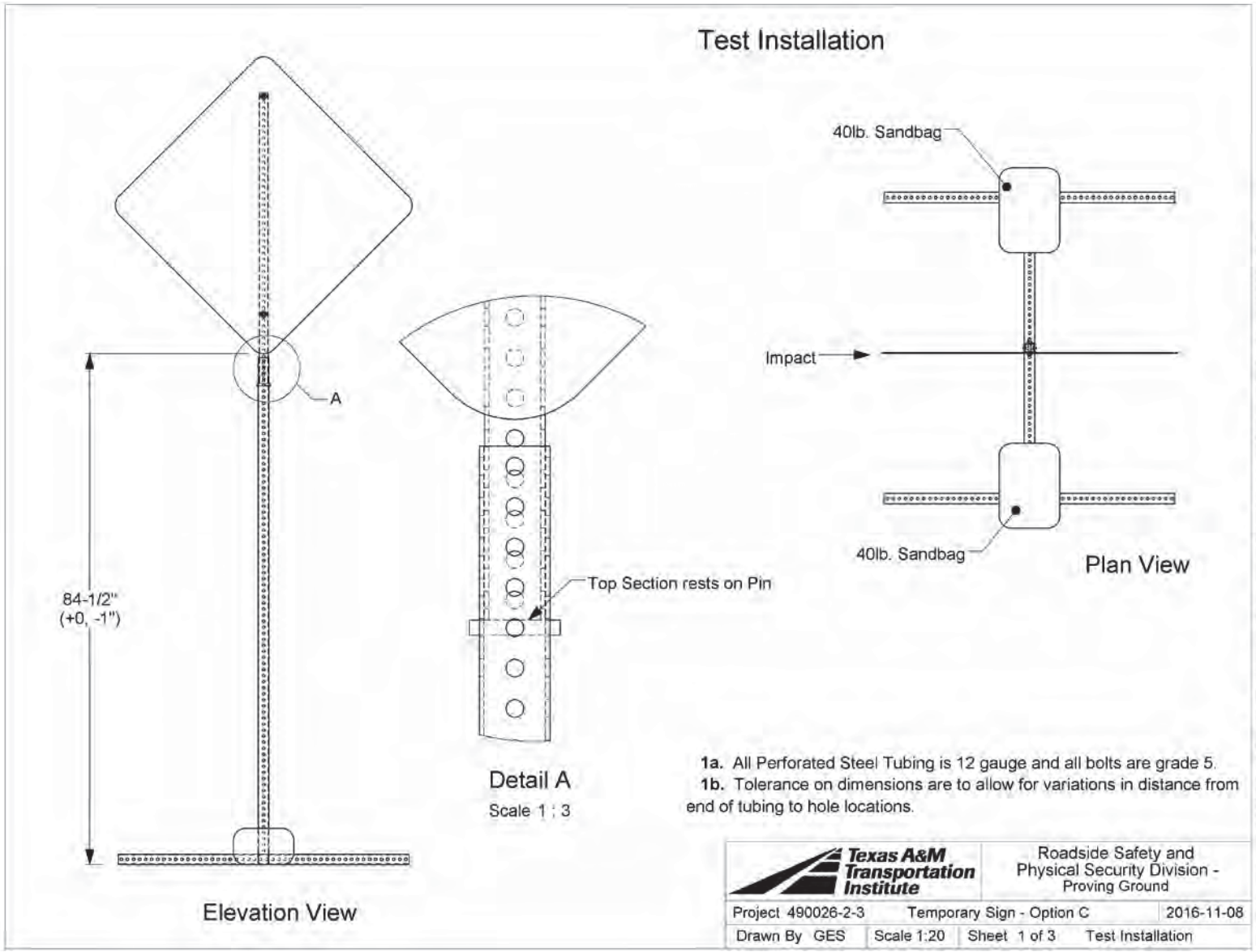


Figure 7.1. Details of the Option C Temporary Work Zone Sign Support.

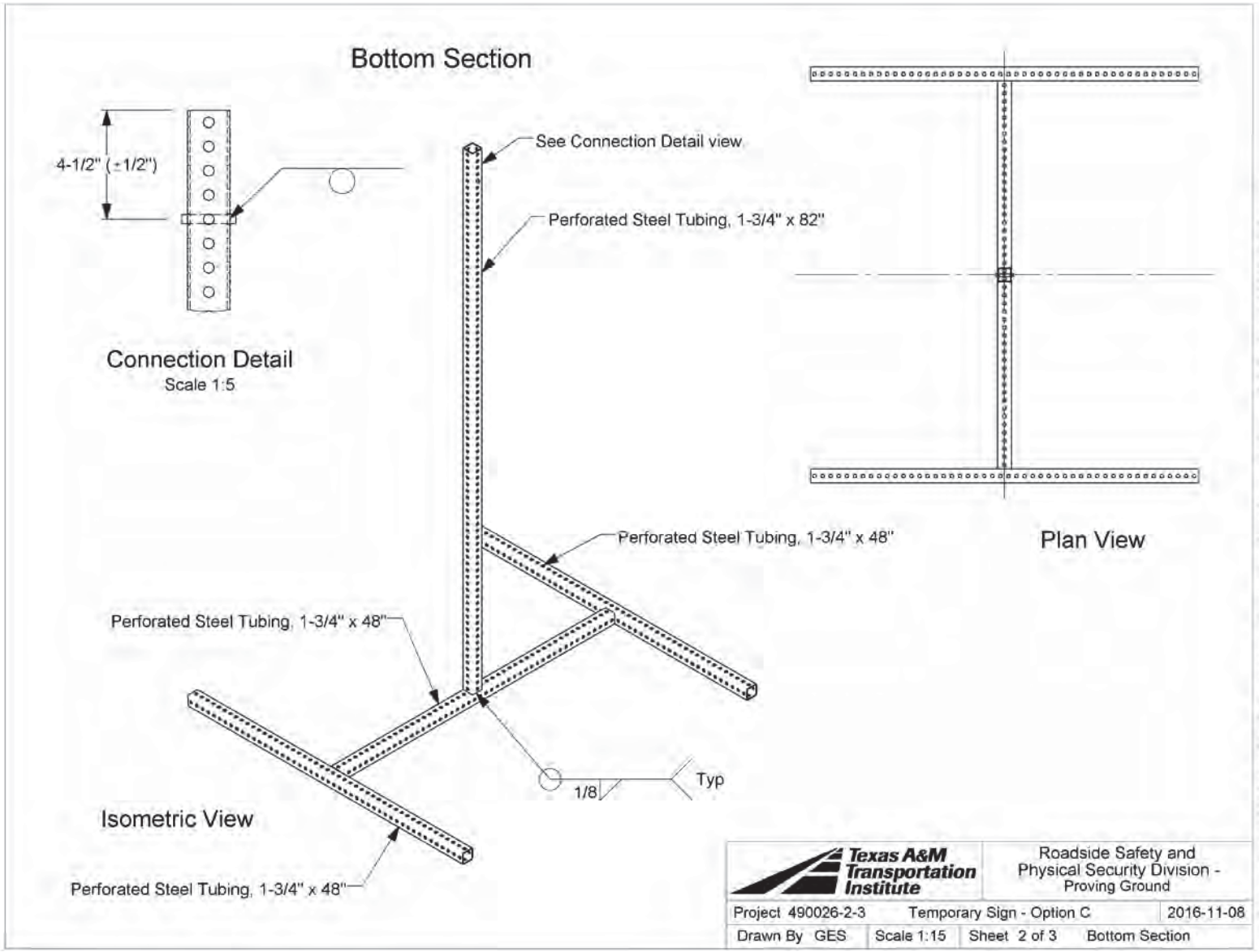


Figure 7.1. Details of the Option C Temporary Work Zone Sign Support (Continued).

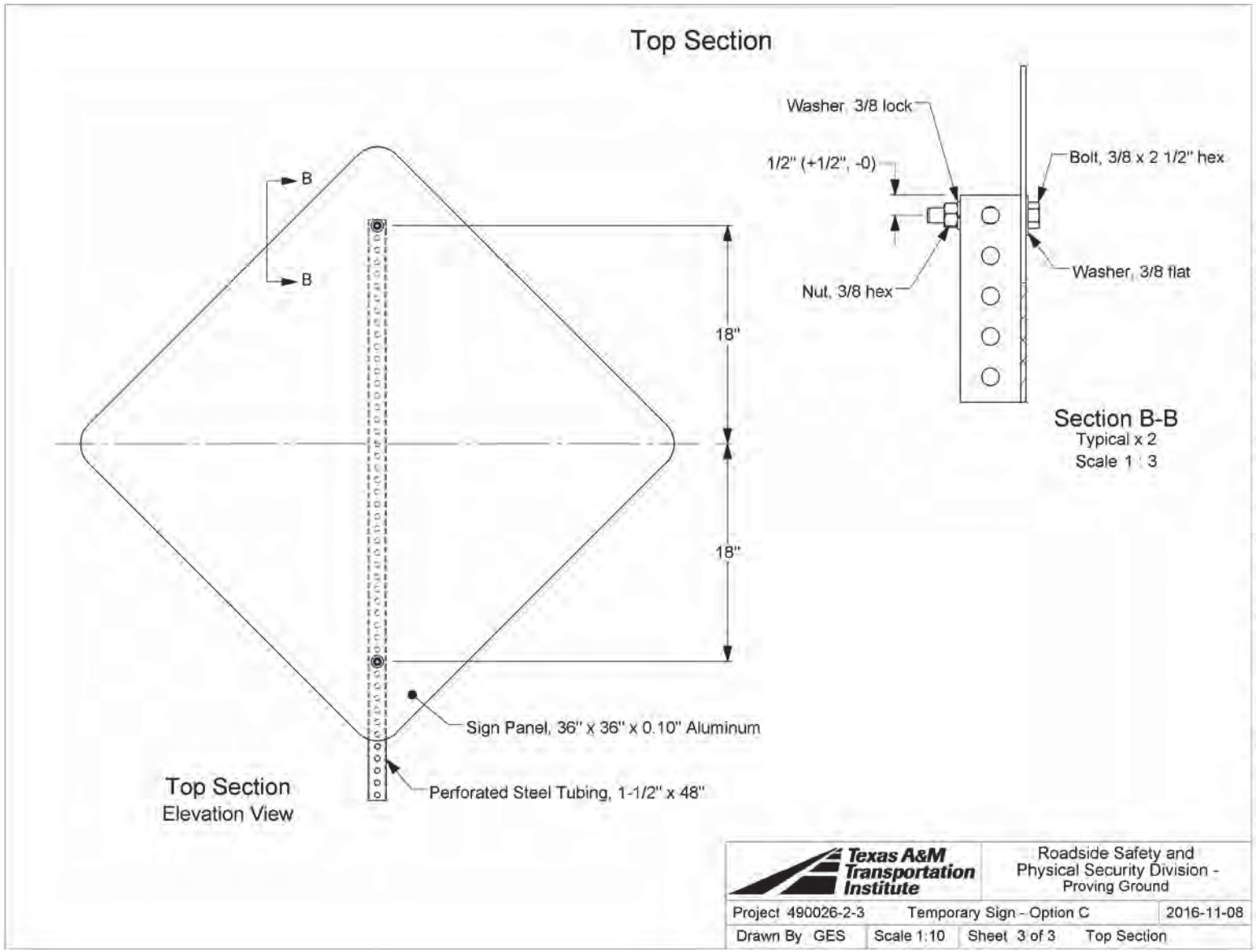


Figure 7.1. Details of the Option C Temporary Work Zone Sign Support (Continued).

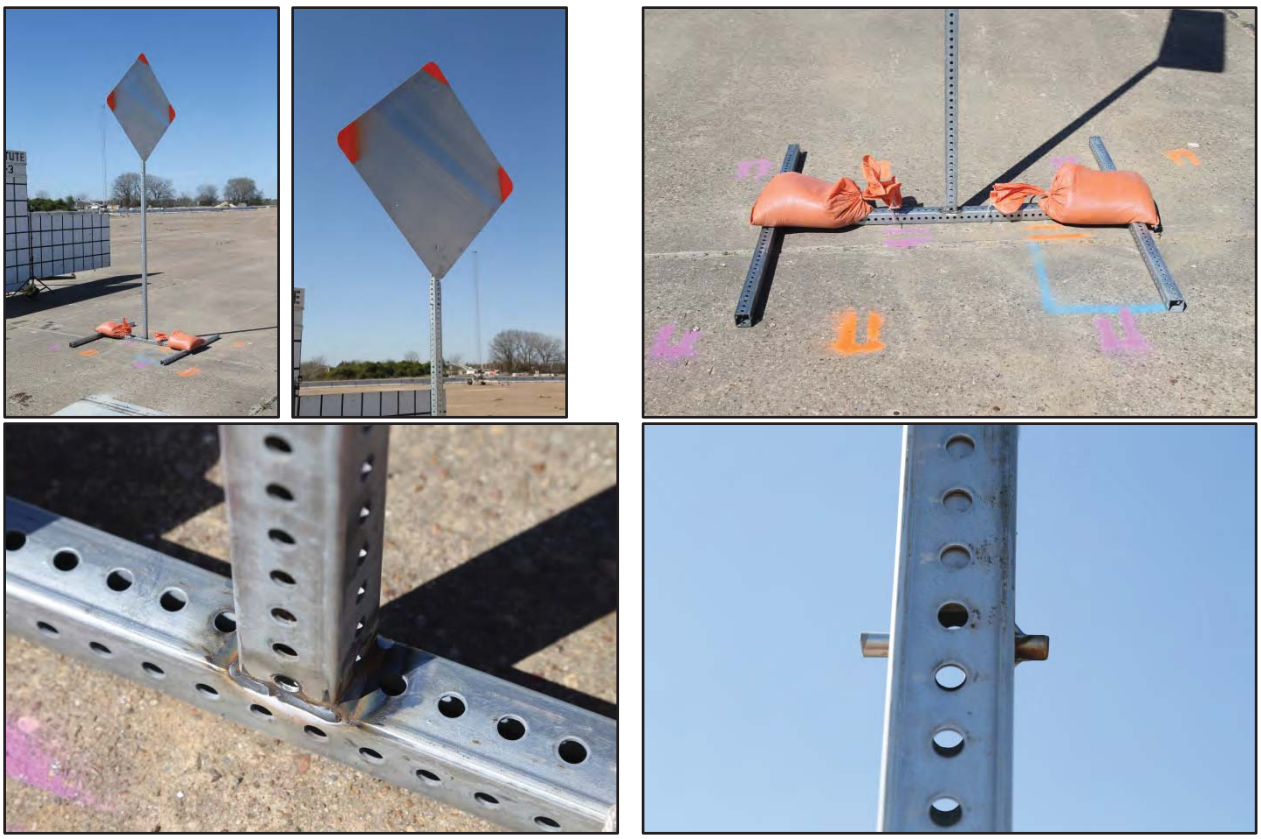


Figure 7.2. Option C Temporary Work Zone Sign Support Used for Test No. 490026-2-3.

7.2.2 Weather Conditions

The test was performed on the afternoon of March 3, 2016. Weather conditions at the time of testing were as follows: wind speed: 14 mi/h; wind direction: 350 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 81°F; relative humidity: 29 percent.

7.2.3 Test Vehicle

The 2010 Dodge Ram 1500 pickup, shown in Figure 7.3, was used for the crash test. The vehicle's test inertia weight was 5014 lb, and its gross static weight was 5014 lb. The height to the lower edge of the vehicle bumper was 12.5 inches, and the height to the upper edge of the vehicle bumper was 27.5 inches. The height to the vehicle's center of gravity was 28.4 inches. Tables F.1 and F.2 in Appendix F1 give 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.

Figure 7.3. Test Vehicle before Test No. 490026-2-3.

7.2.4 Test Description

The 2010 Dodge Ram 1500 pickup, traveling at an impact speed of 62.5 mi/h, contacted the Option C temporary work zone sign support with the centerline of the front bumper at an impact angle of 90 degrees. At 0.003 s, the support contacted the upper grill of the vehicle, and at 0.004 s, the base of the support began to lift off the concrete pavement. The upper section of the support began to pull out of the lower section at 0.008 s, the upper section of the support lost contact with the lower section at 0.032 s, and the sign panel was traveling above and parallel with the roof of the vehicle at 0.078 s. At 0.086 s, the sign panel contacted the roof 16.5 inches behind the windshield, and at 0.111 s, the sign panel lost contact with the roof. The vehicle was traveling at a speed of 60.8 mi/h at loss of contact. Brakes on the vehicle were applied after loss of contact with the sign panel, and the vehicle came to rest 347 ft downstream of impact. Figure F.1 in Appendix F2 presents sequential photographs during the test.

7.2.5 Damage to Test Installation

Figure 7.4 shows the damage to the Option C temporary work zone sign support. The sign panel and the attached upper section of the vertical support came to rest 35 ft downstream of impact and 3 ft to the right of centerline of the impact path. The remainder of the temporary work zone sign support became lodged under the 2270P vehicle and traveled along with the vehicle, which came to rest 347 ft downstream of impact and on the centerline of the impact path.

Figure 7.4. Option C Temporary Work Zone Sign Support after Test No. 490026-2-3.

7.2.6 Vehicle Damage

Figure 7.5 shows the damage sustained by the vehicle. The bumper, hood, and roof were scraped. Maximum exterior crush to the vehicle was 6 inches in the front plane at the centerline at bumper height. There was a 3-inch long dent on the outer surface of the front of the roof of the cab, but it did not extend into the passenger compartment. Figure 7.6 shows the interior of the vehicle. No occupant compartment deformation or intrusion was noted. Tables F.3 and F.4 in Appendix F1 provide exterior crush and occupant compartment measurements.

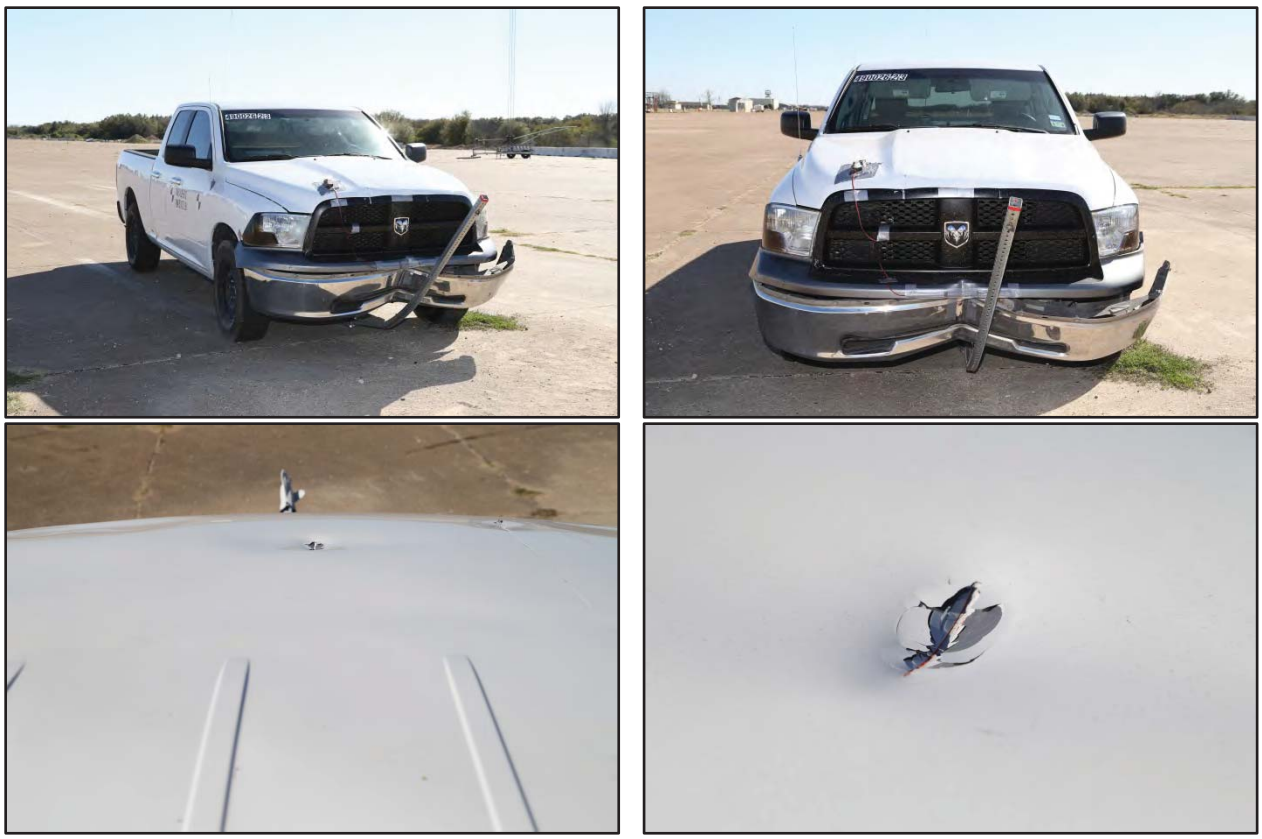


Figure 7.5. Test Vehicle after Test No. 490026-2-3.

Before Test After Test

Figure 7.6. Interior of Test Vehicle for Test No. 490026-2-3.

7.2.7 Occupant Risk Factors

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 3-71 "can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb or less. In this

case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors." The weight of the temporary work zone sign support system was 57 lb.

7.2.8 Assessment of Test Results

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 3-72 is provided below.

7.2.8.1 Structural Adequacy

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

Results: The Option C temporary work zone sign support readily activated by yielding to the 2270P vehicle and releasing at the slip joint. (PASS)

7.2.8.2 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 Option C temporary work zone sign support released at the slip joint into two pieces; however, there was no concern for penetration or intrusion into the vehicle. The lower portion of the sign support lodged under the truck and traveled with the vehicle. (PASS)

No occupant compartment deformation or intrusion was noted. (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 fractured pieces of the Option C temporary work zone sign support did not block the driver's view and would not cause the driver to lose control of the 2270P 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 2270P 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: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 G	*20.49 G*

Results: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

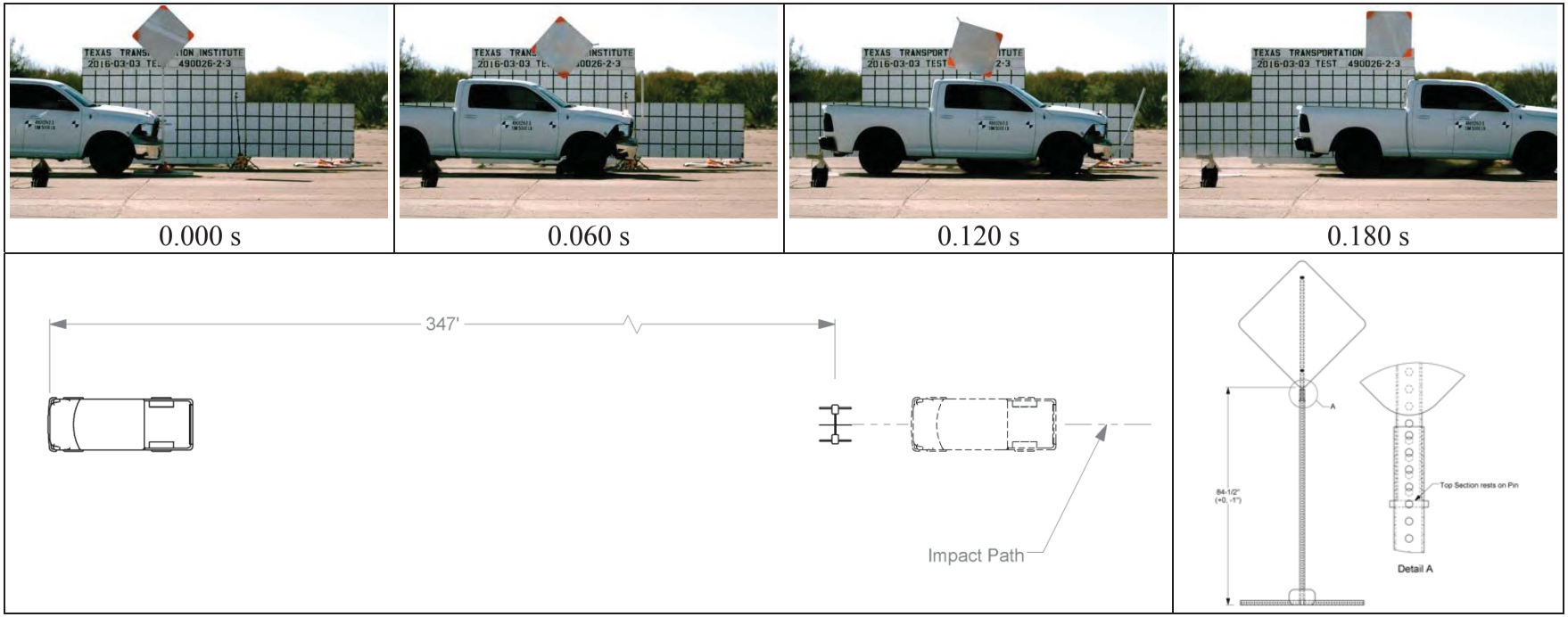
7.2.8.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Results: The 2270P vehicle came to rest 347 ft behind the original position of the Option C temporary work zone sign support. (PASS)

7.2.9 Conclusions

Figure 7.7 provides a summary of the results of the test. The slip connection for Option C temporary work zone sign support performed as designed and the top of the system released from the lower section. The sign panel contacted the roof; however, it did not cause any tears or penetration. The resulting roof deformation was within *MASH* criteria.



General Information
- Test Agency ..... Texas A&M Transportation Institute (TTI)
- Test Standard Test No. ..... MASH Test 3-72
- TTI Test No. 490026-2-3
- Test Date 2016-03-03

Test Article
- Type ..... Temporary Work Zone Sign Support
- Name ..... Option C Temporary Work Zone Sign Support
- Installation Height ..... 84½ inches to bottom; 133⅝ to top
- Material or Key Elements .... Upper section inserted $4^{9}/_{32}$ inches into the lower 1¾-inch square tubing post and rested on a ⅜-inch diameter × 2¼-inch long smooth pin located in holes 4½ inches below the top of post
- **Soil Type and Condition** ..... Placed on dry concrete surface

Test Vehicle
- Type/Designation 2270P
- Make and Model ..... 2010 Dodge Ram 1500
- Curb ..... 4898 lb
- Test Inertial ..... 5014 lb
- Dummy ..... No dummy
- Gross Static ..... 5014 lb

Impact Conditions
- Speed ..... 62.5 mi/h
- Angle ..... 90 degrees
- Location/Orientation ..... Centerline

Kinetic Energy ..... 653 kip-ft

Exit Conditions
- Speed ..... 60.8 mi/h
- Angle ..... NA

Occupant Risk Values .... Assessment of occupant risk factors not required for test articles of 57 lb

Test Article Debris Scatter
- Longitudinal ..... 347 downstream
- Lateral ..... Centerline

Post-Impact Trajectory
- Stopping Distance ..... 347 ft downstream on center

Vehicle Stability
- Maximum Yaw Angle ..... Vehicle
- Maximum Pitch Angle ..... remained
- Maximum Roll Angle ..... upright
- Vehicle Snagging ..... No
- Vehicle Pocketing ..... No

Vehicle Damage
- VDS 12FC1
- CDC 12FCEN1
- Max. Exterior Deformation ..... 6.0 inches
- OCDI RR0000000
- Max. Occupant Compartment Deformation ..... None

Figure 7.7. Summary of Results for *MASH* Test 3-72 at 90 Degrees on the Option C Temporary Work Zone Sign Support.

7.3 *MASH* TEST 3-71 AT 90 DEGREES (CRASH TEST NO. 490026-2-5)

7.3.1 Test Designation and Actual Impact Conditions

MASH Test 3-71 involves an 1100C vehicle weighing 2425 lb ±55 lb impacting the Option C temporary work zone sign support at an impact speed of 62.2 mi/h ±2.5 mi/h and CIA ±1.5 degrees. The CIA for *MASH* Test 3-71 on the temporary work zone sign support was 90 degrees. The 2011 Kia Rio used in the test weighed 2443 lb, and the actual impact speed and angle were 61.5 mi/h and 90 degrees, respectively. The actual impact point was 10 inches to the left of centerline of the vehicle. The target KE was ≥288 kip-ft, and the actual KE at impact was 309 kip-ft. Figure 7.8 shows the installation before the test.

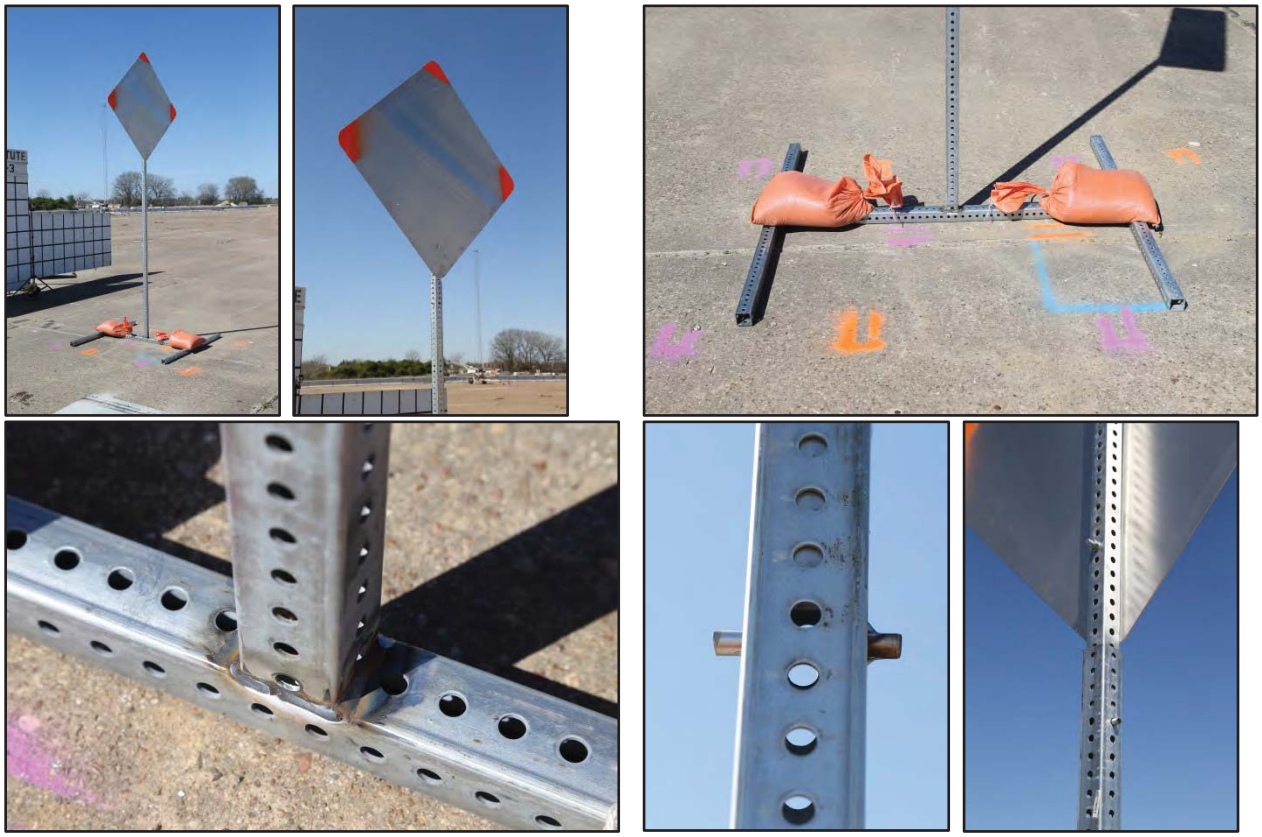


Figure 7.8. Option C Temporary Work Zone Sign Support Used for Test No. 490026-2-5.

7.3.2 Weather Conditions

The test was performed afternoon on March 11, 2016. Weather conditions at the time of testing were as follows: wind speed: 2 mi/h; wind direction: 205 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 67°F; relative humidity: 86 percent.

7.3.3 Test Vehicle

The 2011 Kia Rio for the previous test (test 490026-2-4), shown in Figure 7.9, was used for the crash test. The vehicle's test inertia weight was 2443 lb, and its gross static weight was 2608 lb. The height to the lower edge of the vehicle bumper was 8.0 inches, and the height to the upper edge of the vehicle bumper was 21.5 inches. Table G.1 in Appendix G1 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.

Figure 7.9. Test Vehicle before Test No. 490026-2-5.

7.3.4 Test Description

The 2011 Kia Rio, traveling at an impact speed of 61.5 mi/h, contacted the Option C temporary work zone sign support 10 inches to the left of centerline of the vehicle at an impact angle of 90 degrees. At 0.004 s after impact, the upstream end of the base of the support began to lift off the concrete pavement, and at 0.007 s, the upper section of the support began to release from the lower section. The upper section of the support separated from the lower section at 0.024 s. At 0.140 s, the vehicle was traveling at a speed of 59.5 mi/h. Brakes on the vehicle were applied after loss of contact with the support, and the vehicle came to rest 500 ft downstream of impact. Figure G.1 in Appendix G2 presents sequential photographs during the test.

7.3.5 Damage to Test Installation

Figure 7.10 shows the damage to the Option C temporary work zone sign support. The sign panel and attached upper section of the vertical support came to rest at the point of impact. The remainder of the temporary work zone sign support rode along with the 1100C vehicle for a distance and then came to rest 230 ft downstream of impact and 25 ft to the left of centerline of the impact path.

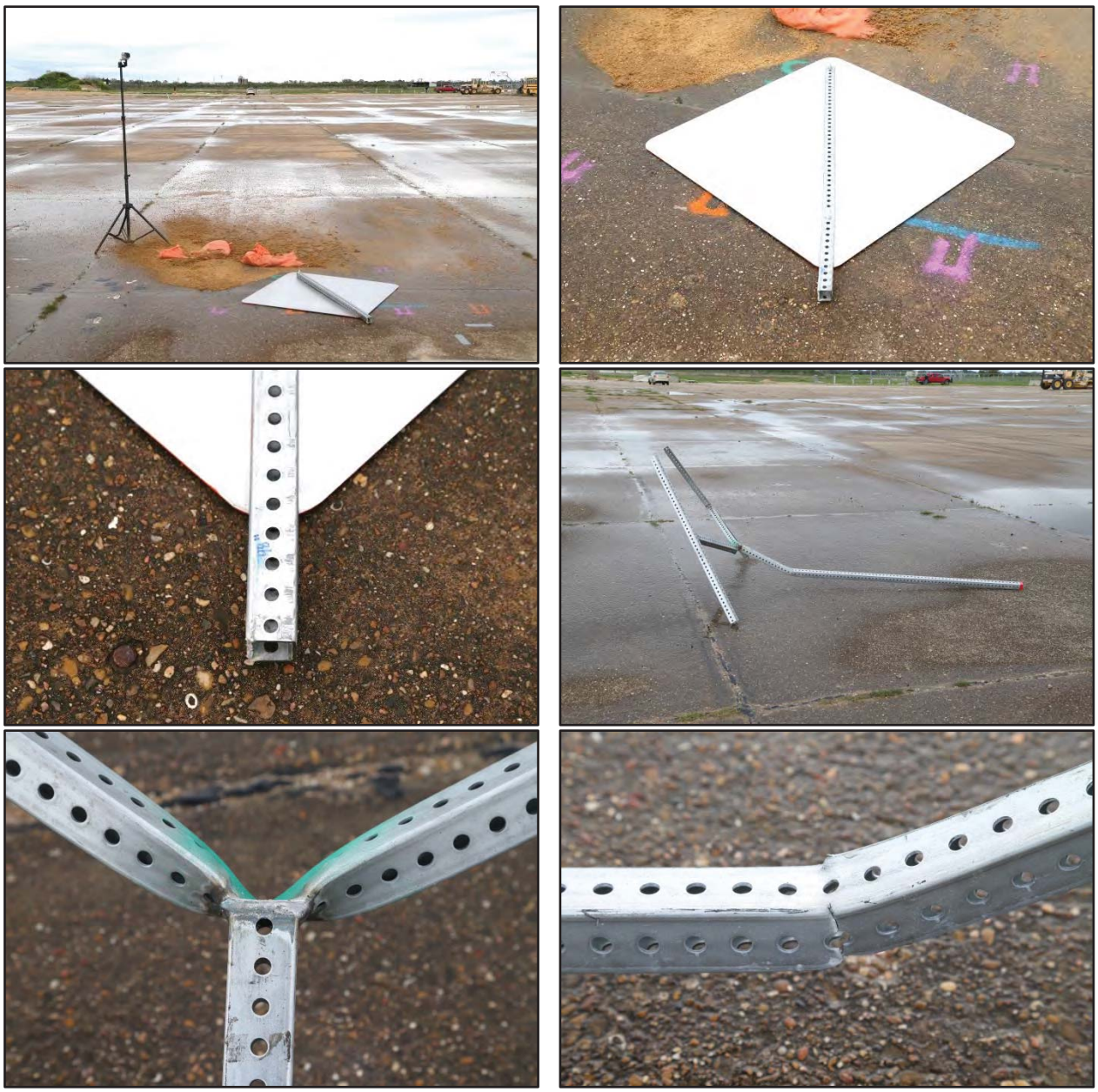
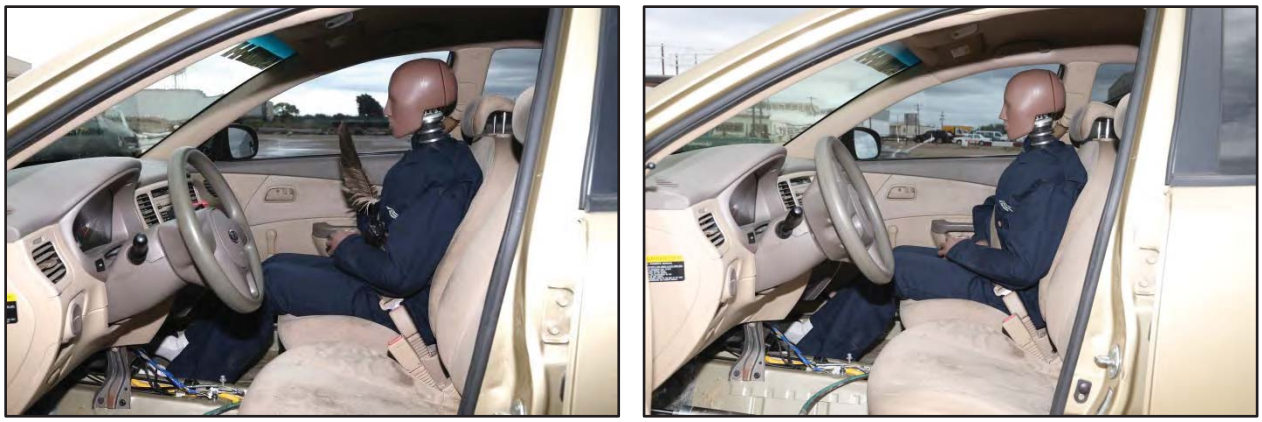


Figure 7.10. Option C Temporary Work Zone Sign Support after Test No. 490026-2-5.

7.3.6 Vehicle Damage

Figure 7.11 shows the damage sustained by the vehicle. The 1100C vehicle sustained only scrapes to the bumper and hood with no measureable exterior vehicle deformation. Figure 7.12 shows the interior of the vehicle. No occupant compartment deformation or intrusion was noted. Tables G.2 and G.3 in Appendix G1 provides exterior crush and occupant compartment measurements.

Figure 7.11. Test Vehicle after Test No. 490026-2-5.



Before Test After Test

Figure 7.12. Interior of Test Vehicle for Test No. 490026-2-5.

7.3.7 Occupant Risk Factors

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 3-71 "can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb or less. In this

case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors." The weight of the temporary work zone sign support system was 57 lb.

7.3.8 Assessment of Test Results

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 3-71 is provided below.

7.3.8.1 Structural Adequacy

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

Results: The Option C temporary work zone sign support readily activated by yielding to the 1100C vehicle and releasing at the slip joint. (PASS)

7.3.8.2 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 Option C temporary work zone sign support released into two pieces; however, there was no concern for penetration or intrusion into the vehicle. The sign panel and upper portion of the support remained at the impact site. The lower portion of the sign support rode along with the 1100C vehicle for a distance and came to rest 230 ft downstream of impact and 25 ft left of the centerline of the vehicle path. (PASS)

No occupant compartment deformation or intrusion was noted. (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 released upper section of the Option C temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 1100C 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: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 G	*20.49 G*

Results: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

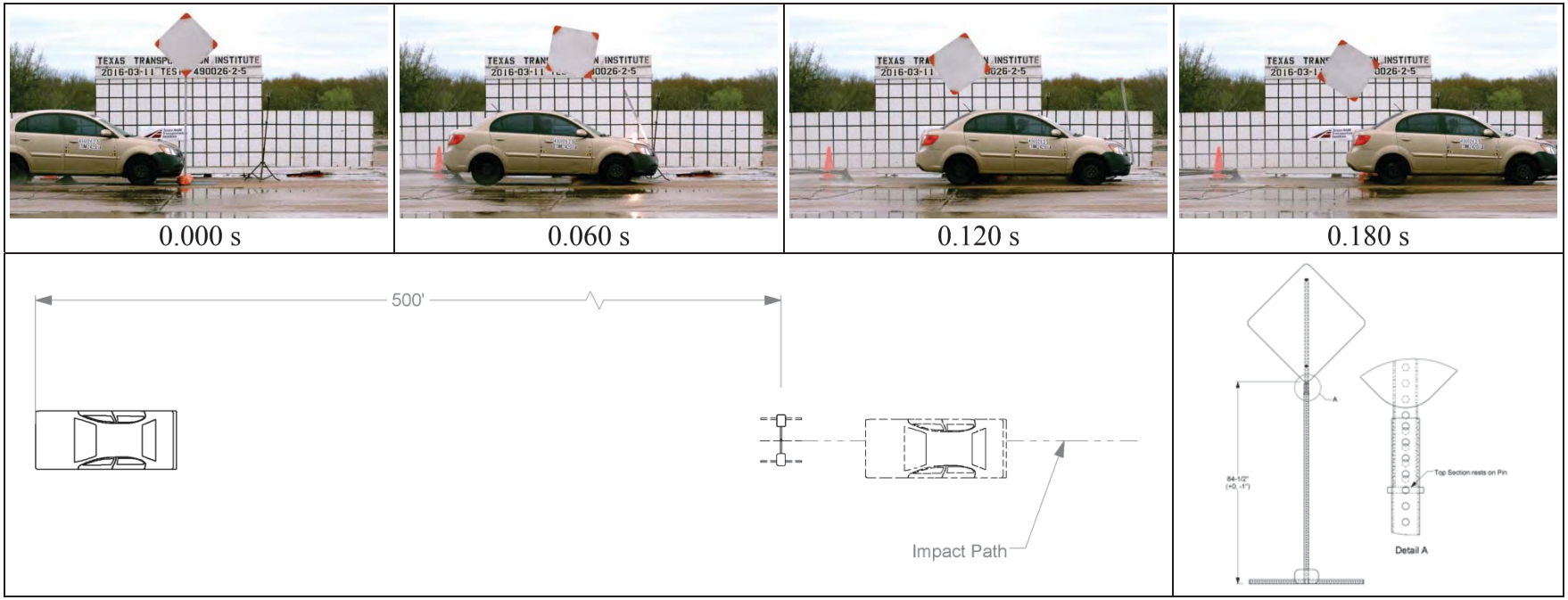
7.3.8.3 Vehicle Trajectory

N. *Vehicle trajectory behind the test article is acceptable.*

Results: The 1100C vehicle came to rest 500 ft behind the Option C temporary work zone sign support. (PASS)

7.3.9 Conclusions

Figure 7.13 provides a summary of the results of the test. The slip connection of Option C temporary work zone sign support performed as designed and the top of the system released from the lower section at vehicle impact. The support structure contacted the bumper and hood, but the sign panel did not contact the roof of the vehicle.



General Information
- Test Agency: Texas A&M Transportation Institute (TTI)
- Test Standard Test No.: MASH Test 3-71
- TTI Test No.: 490026-2-5
- Test Date: 2016-03-11

Test Article
- Type: Temporary Work Zone Sign Support
- Name: Option C Temporary Work Zone Sign Support
- Installation Height: 84½ inches to bottom; 133⅝ to top
- Material or Key Elements: Upper section inserted $4^{9}/_{32}$ inches into the lower 1¾-inch square tubing post and rested on a ⅜-inch diameter × 2¼-inch long smooth pin located in holes 4½ inches below the top of post
- **Soil Type and Condition**: Placed on dry concrete surface

Test Vehicle
- Type/Designation: 1100C
- Make and Model: 2011 Kia Rio
- Curb: 2479 lb
- Test Inertial: 2443 lb
- Dummy: 165 lb
- Gross Static: 2608 lb

Impact Conditions
- Speed: 61.5 mi/h
- Angle: 90 degrees
- Location/Orientation: 10 inches left of centerline

Kinetic Energy: 309 kip-ft

Exit Conditions
- Speed: 59.5 mi/h
- Angle: NA

Occupant Risk Values: Assessment of occupant risk factors not required for test articles of 57 lb

Test Article Debris Scatter
- Longitudinal: 230 downstream
- Lateral: 25 ft left of center

Post-Impact Trajectory
- Stopping Distance: 500 ft downstream Centerline

Vehicle Stability
- Maximum Yaw Angle: Vehicle
- Maximum Pitch Angle: remained
- Maximum Roll Angle: upright
- Vehicle Snagging: No
- Vehicle Pocketing: No

Vehicle Damage
- VDS: 12FL1
- CDC: 12FLEN1
- Max. Exterior Deformation: None
- OCDI: LF0000000
- Max. Occupant Compartment Deformation: None

Figure 7.13. Summary of Results for *MASH* Test 3-71 at 90 Degrees on the Option C Temporary Work Zone Sign Support.

7.4 *MASH* TEST 3-71 AT 0 DEGREES (CRASH TEST NO. 490026-2-7)

7.4.1 Test Designation and Actual Impact Conditions

MASH Test 3-71 involves an 1100C vehicle weighing 2425 lb ±55 lb and impacting the Option C temporary work zone sign support at an impact speed of 62.2 mi/h ±2.5 mi/h and CIA ±1.5 degrees. The CIA for *MASH* Test 3-71 on the temporary work zone sign support was 0 degrees. The 2011 Kia Rio used in the test weighed 2443 lb, and the actual impact speed and angle were 61.9 mi/h and 90 degrees, respectively. The actual impact point was 10 inches to the left of centerline of the vehicle. Target KE was ≥288 kip-ft, and actual KE was 313 kip-ft. Figure 7.14 shows the installation before the test.

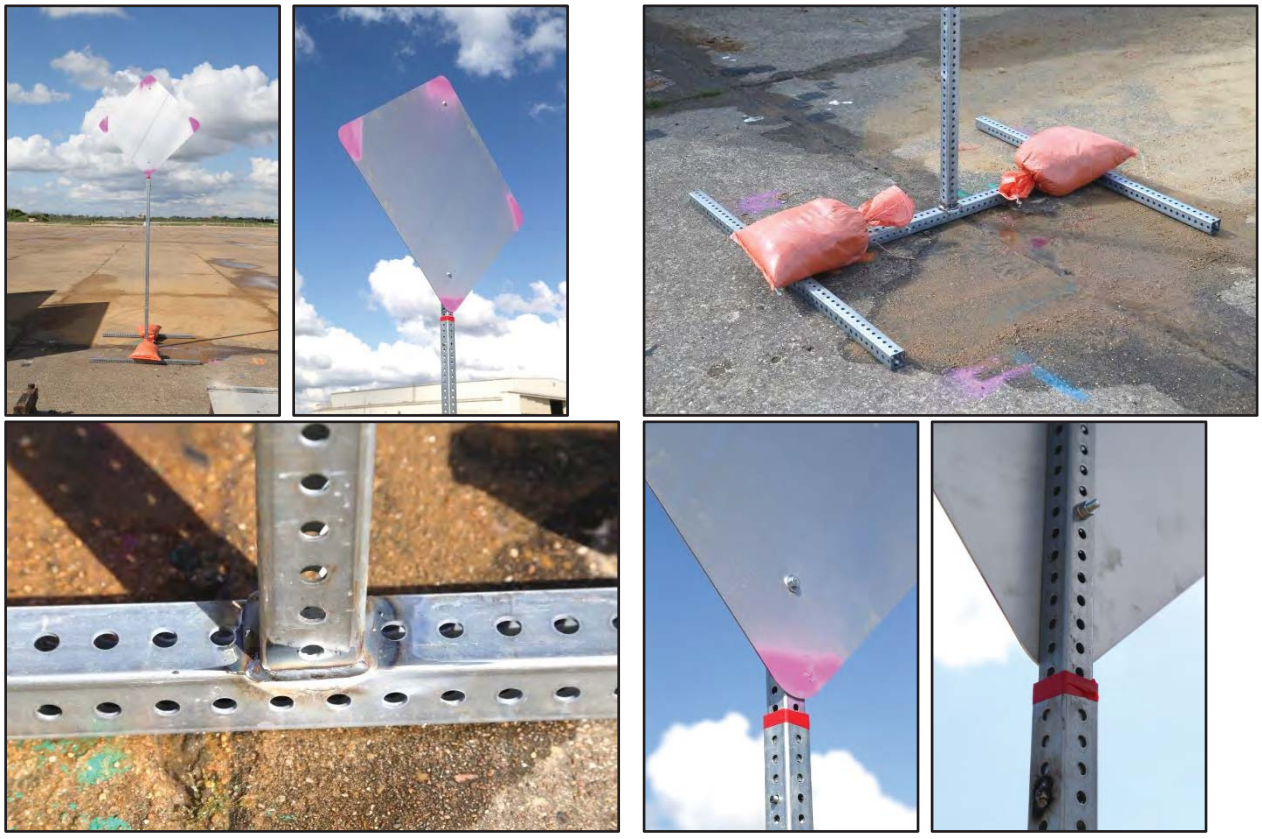


Figure 7.14. Option C Temporary Work Zone Sign Support Used for Test No. 490026-2-7.

7.4.2 Weather Conditions

The test was performed on the afternoon of March 11, 2016. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 163 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 76°F; relative humidity: 63 percent.

7.4.3 Test Vehicle

The 2011 Kia Rio used in the tests 490026-2-4 and 2-5, shown in Figure 7.15, was used for the crash test. The vehicle's test inertia weight was 2443 lb, and its gross static weight was 2608 lb. The height to the lower edge of the vehicle bumper was 8.0 inches, and the height to the upper edge of the vehicle bumper was 21.5 inches. Table H.1 in Appendix H1 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.

Figure 7.15. Test Vehicle before Test No. 490026-2-7.

7.4.4 Test Description

The 2011 Kia Rio, traveling at an impact speed of 61.9 mi/h, contacted the Option C temporary work zone sign support 10 inches to the left of centerline of the vehicle at an impact angle of 0 degrees. At 0.003 s after impact, the base of the support began to lift off the concrete pavement and slide in front of the vehicle. The upper section of the support began to separate from the lower section at 0.008 s, and the lower section fractured at bumper height at 0.012 s. At 0.021 s, the upper section of the support lost contact with the lower section, and the lower section lost contact with the vehicle at 0.099 s. The vehicle was traveling at a speed of 59.8 mi/h. Brakes on the vehicle were applied after loss of contact with the support and came to rest 480 ft downstream and 19 ft to the left of centerline of the impact path. Figure H.1 in Appendix H2 presents sequential photographs during the test.

7.4.5 Damage to Test Installation

Figure 7.16 shows the damage to the Option C temporary work zone sign support. The sign panel and attached upper section of the vertical support came to rest 2 ft downstream of impact and 2 ft to the left of centerline of the vehicle path. The lower portion of the temporary work zone sign support came to rest 143 ft downstream of impact and 9 ft to the right of centerline of the impact path, and was deformed 85 degrees. A piece of the vertical section fractured away from the lower support 18 inches above ground level, and came to rest 275 ft downstream of impact and 18 ft to the right of centerline of the vehicle path.

Figure 7.16. Option C Temporary Work Zone Sign Support after Test No. 490026-2-7.

7.4.6 Vehicle Damage

Figure 7.17 shows the damage sustained by the vehicle. The 1100C vehicle sustained only scrapes to the bumper and hood with no measureable exterior vehicle deformation. Figure 7.18 shows the interior of the vehicle. No occupant compartment deformation or intrusion was noted. Tables H.2 and H.3 in Appendix H1 provides exterior crush and occupant compartment measurements.

Figure 7.17. Test Vehicle after Test No. 490026-2-7.

Before Test After Test

Figure 7.18. Interior of Test Vehicle for Test No. 490026-2-7.

7.4.7 Occupant Risk Factors

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 3-71 "can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb or less. In this

case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors." The weight of the temporary work zone sign support system was 57 lb.

7.4.8 Assessment of Test Results

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 3-71 is provided below.

7.4.8.1 Structural Adequacy

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

Results: The Option C temporary work zone sign support readily activated by yielding to the 1100C vehicle and releasing and fracturing. (PASS)

7.4.8.2 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 Option C temporary work zone sign support released and fractured into three pieces; however, there was no concern for penetration or intrusion into the vehicle. The lower portion of the sign support rode along with the 1100C vehicle for a distance and came to rest 275 ft downstream of impact and 18 ft to the right of centerline of the vehicle path. (PASS)

No occupant compartment deformation or intrusion was noted. (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 fractured pieces of the Option C temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 1100C 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: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 G	*20.49 G*

Results: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

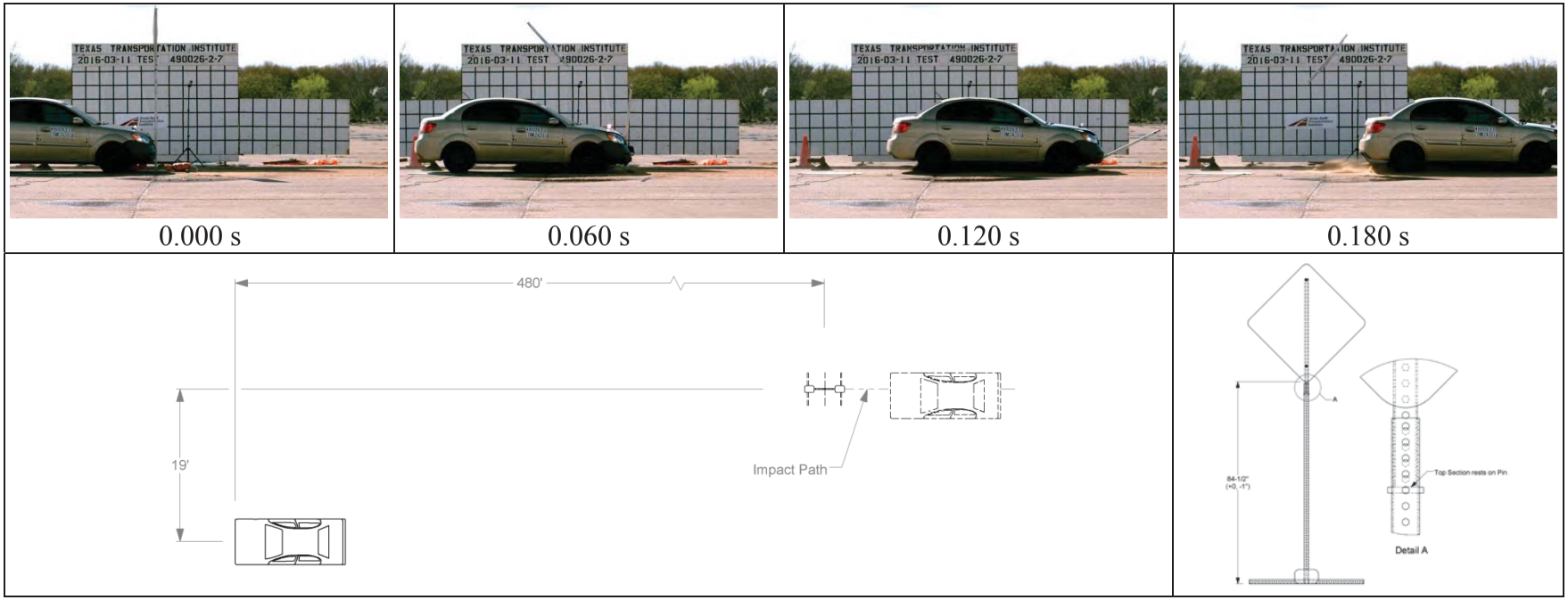
7.4.8.3 Vehicle Trajectory

N. *Vehicle trajectory behind the test article is acceptable.*

Results: The 1100C vehicle came to rest 480 ft behind the original position of the Option C temporary work zone sign support. (PASS)

7.4.9 Conclusions

Figure 7.19 provides a summary of the results of the test. The slip connection of Option C temporary work zone sign support performed as designed and the top of the system released from the lower section. The support structure contacted the bumper and hood, but the sign panel did not contact the roof of the vehicle.



General Information
- Test Agency: Texas A&M Transportation Institute (TTI)
- Test Standard Test No.: MASH Test 3-71
- TTI Test No.: 490026-2-7
- Test Date: 2016-03-11

Test Article
- Type: Temporary Work Zone Sign Support
- Name: Option C Temporary Work Zone Sign Support
- Installation Height: 84½ inches to bottom; 133⅝ to top
- Material or Key Elements: Upper section inserted $4^{9}/_{32}$ inches into the lower 1¾-inch square tubing post and rested on a ⅜-inch diameter × 2¼-inch long smooth pin located in holes 4½ inches below the top of post
- **Soil Type and Condition**: Placed on dry concrete surface

Test Vehicle
- Type/Designation: 1100C
- Make and Model: 2011 Kia Rio
- Curb: 2479 lb
- Test Inertial: 2443 lb
- Dummy: 165 lb
- Gross Static: 2608 lb

Impact Conditions
- Speed: 61.9 mi/h
- Angle: 0 degrees
- Location/Orientation: 10 inches left of centerline

Kinetic Energy: 311 kip-ft

Exit Conditions
- Speed: 59.8 mi/h
- Angle: NA

Occupant Risk Values: Assessment of occupant risk factors not required for test articles of 57 lb

Test Article Debris Scatter
- Longitudinal: 275 downstream
- Lateral: 18 ft right – 2 ft left

Post-Impact Trajectory
- Stopping Distance: 480 ft downstream 19 ft left of center

Vehicle Stability
- Maximum Yaw Angle: Vehicle
- Maximum Pitch Angle: remained
- Maximum Roll Angle: upright
- Vehicle Snagging: No
- Vehicle Pocketing: No

Vehicle Damage
- VDS: 12FL1
- CDC: 12FLEN1
- Max. Exterior Deformation: None
- OCDI: LF0000000
- Max. Occupant Compartment Deformation: None

Figure 7.19. Summary of Results for *MASH* Test 3-71 at 0 Degrees on the Option C Temporary Work Zone Sign Support.

7.5 *MASH* TEST 3-72 AT 0 DEGREES (CRASH TEST NO. 490026-2-9)

7.5.1 Test Designation and Actual Impact Conditions

MASH Test 3-72 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the Option C temporary work zone sign support at an impact speed of 62.2 mi/h ±2.5 mi/h and CIA ±1.5 degrees. The CIA for *MASH* Test 3-72 on the temporary work zone sign support was 0 degrees. The 2010 Dodge Ram 1500 pickup truck used in the test weighed 5014 lb, and the actual impact speed and angle were 62.9 mi/h and 0 degrees, respectively. The actual impact point was 10 inches to the left of centerline of the vehicle. The target KE was ≥594 kip-ft, and the actual KE at impact was 663 kip-ft. Figure 7.20 shows the installation before the test.

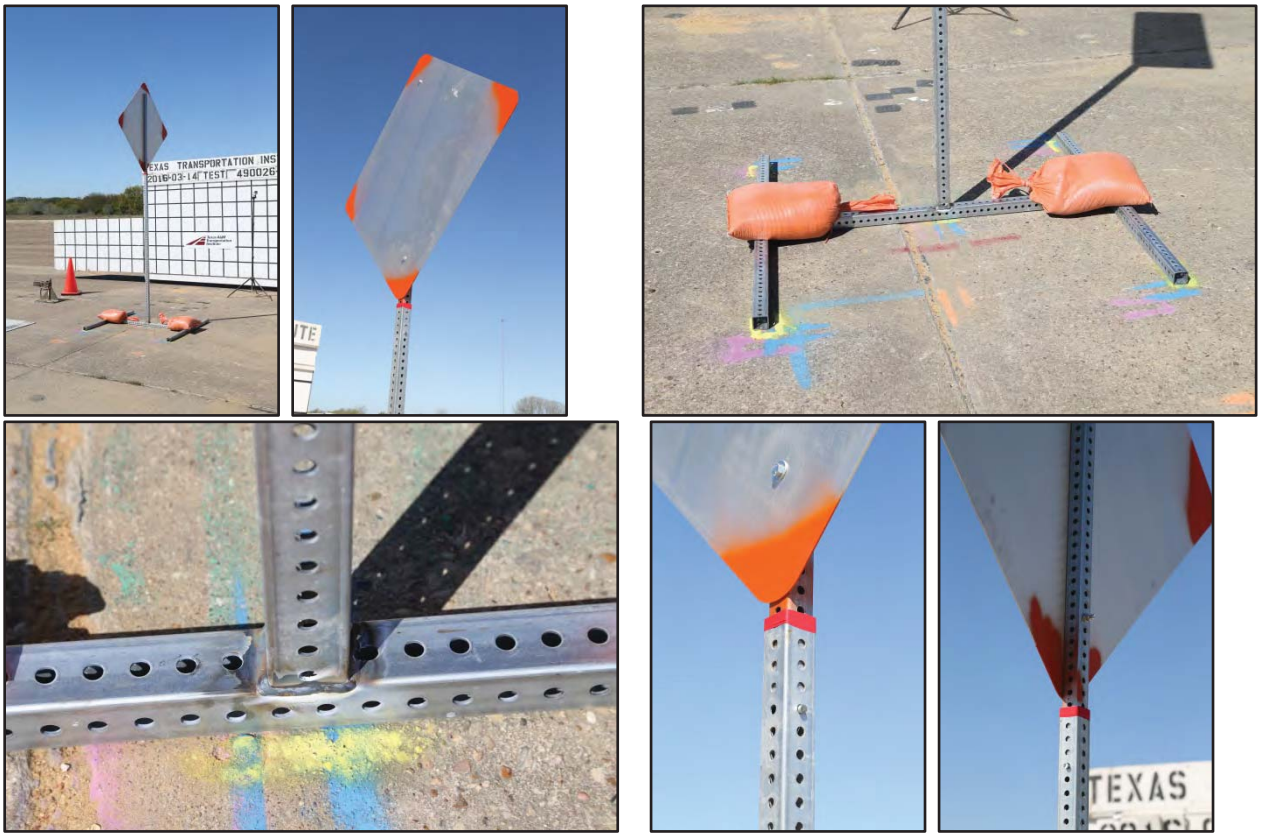


Figure 7.20. Option C Temporary Work Zone Sign Support Used for Test No. 490026-2-9.

7.5.2 Weather Conditions

The test was performed at noon on March 14, 2016. Weather conditions at the time of testing were as follows: wind speed: 9 mi/h; wind direction: 209 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 80°F; relative humidity: 43 percent.

7.5.3 Test Vehicle

The 2010 Dodge Ram 1500 pickup, shown in Figure 7.21, was used for the crash test. The vehicle's test inertia weight was 5014 lb, and its gross static weight was 5014 lb. The height to the lower edge of the vehicle bumper was 12.5 inches, and the height to the upper edge of the vehicle bumper was 27.5 inches. The height to the vehicle's center of gravity was 28.4 inches. Tables I.1 and I.2 in Appendix I1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 7.21. Test Vehicle before Test No. 490026-2-9.

7.5.4 Test Description

The 2010 Dodge Ram 1500 pickup, traveling at an impact speed of 62.9 mi/h, contacted the Option C temporary work zone sign support 10 inches to the left of centerline of the vehicle at an impact angle of 0 degrees. At 0.003 s, the support contacted the upper grill of the vehicle, and at 0.006 s, the base of the support began to lift off the concrete pavement and slide along the surface. The upper section of the support began to pull out of the lower section at 0.007 s, and the lower section of the support fractured at bumper height at 0.009 s. At 0.020 s, the upper section of the support lost contact with the lower section, and at 0.078 s, the vehicle lost contact with the support. The vehicle was traveling at a speed of 61.9 mi/h at loss of contact. Brakes on the vehicle were applied after loss of contact with the sign panel, and the vehicle came to rest 405 ft downstream of impact and 6 ft to the left of centerline of the impact path. Figure I.1 in Appendix I2 presents sequential photographs during the test.

7.5.5 Damage to Test Installation

Figure 7.22 shows the damage to the Option C temporary work zone sign support. The sign panel and the attached upper section of the vertical support came to rest 7 ft downstream of impact. A vertical piece fractured from the lower section of the support at 24 inches above ground and came to rest 125 ft downstream of impact. The remainder of the temporary work zone sign support came to rest 120 ft downstream of impact and 10 ft to the right of centerline of the impact path.

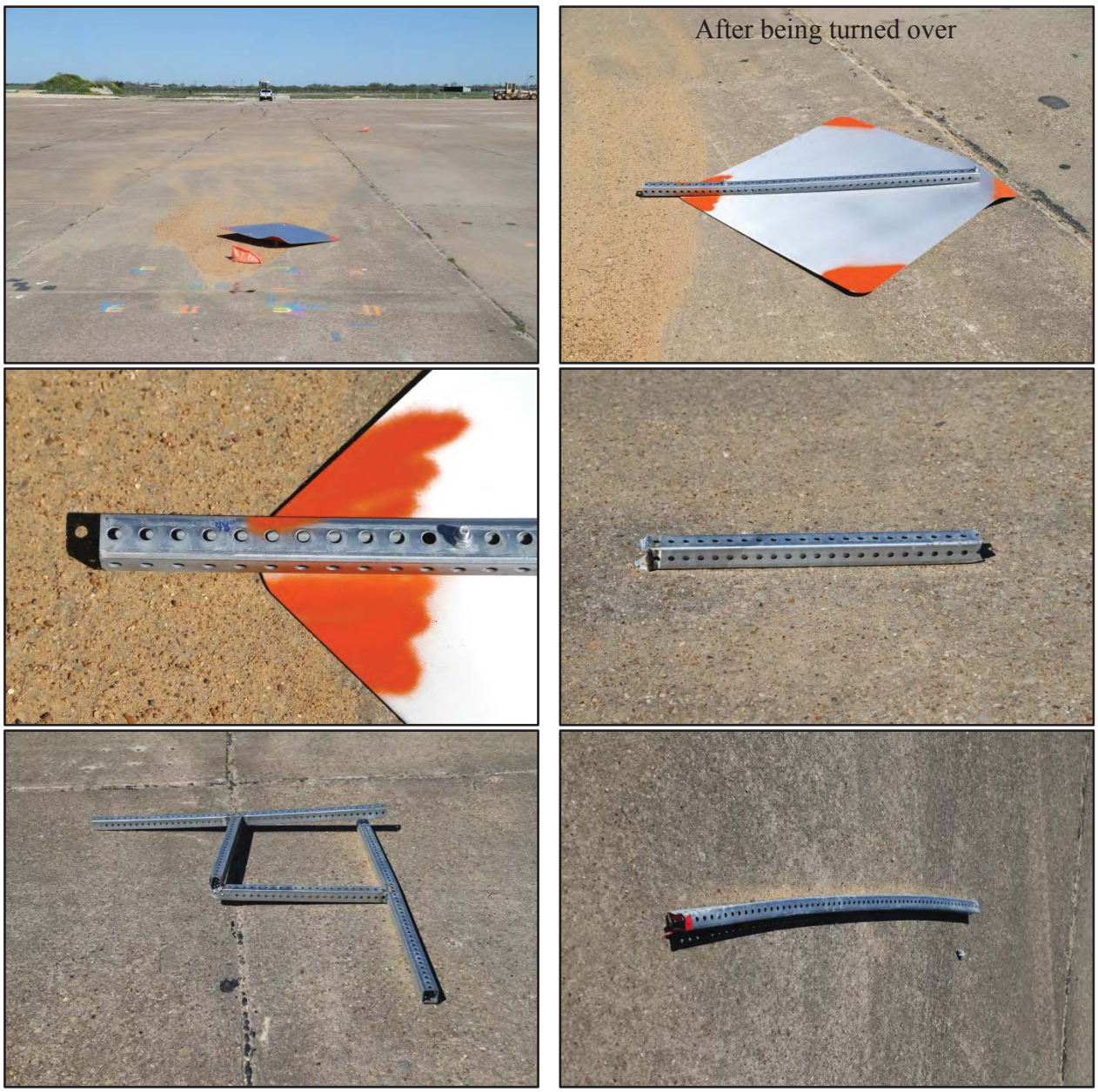


Figure 7.22. Option C Temporary Work Zone Sign Support after Test No. 490026-2-9.

7.5.6 Vehicle Damage

Figure 7.23 shows the damage sustained by the vehicle. The bumper and hood were scraped. Maximum exterior crush to the vehicle was 3.5 inches in the front plane at the left quarter point at bumper height. Figure 7.24 shows the interior of the vehicle. No occupant compartment deformation or intrusion was noted. Tables I.3 and I.4 in Appendix I1 provides exterior crush and occupant compartment measurements.

Figure 7.23. Test Vehicle after Test No. 490026-2-9.

Before Test After Test

Figure 7.24. Interior of Test Vehicle for Test No. 490026-2-9.

7.5.7 Occupant Risk Factors

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 3-71 "can be conducted without the instrumentation necessary for determining occupant risk whenever the test article has a total weight of 220 lb or less. In this case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors." The weight of the temporary work zone sign support system was 57 lb.

7.5.8 Assessment of Test Results

An assessment of the test based on the applicable *MASH* safety evaluation criteria for *MASH* test 3-72 is provided below.

7.5.8.1 Structural Adequacy

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

Results: The Option C temporary work zone sign support readily activated by yielding to the 2270P vehicle and releasing and fracturing. (PASS)

7.5.8.2 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 Option C temporary work zone sign support released and fractured into three pieces; however, there was no concern for penetration or intrusion into the vehicle. The lower portion of the sign support lodged under the truck and traveled with the vehicle. (PASS)

No occupant compartment deformation or intrusion was noted. (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 released and fractured pieces of the Option C temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 2270P 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 2270P 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: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15 G	*20.49 G*

Results: Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. (NA)

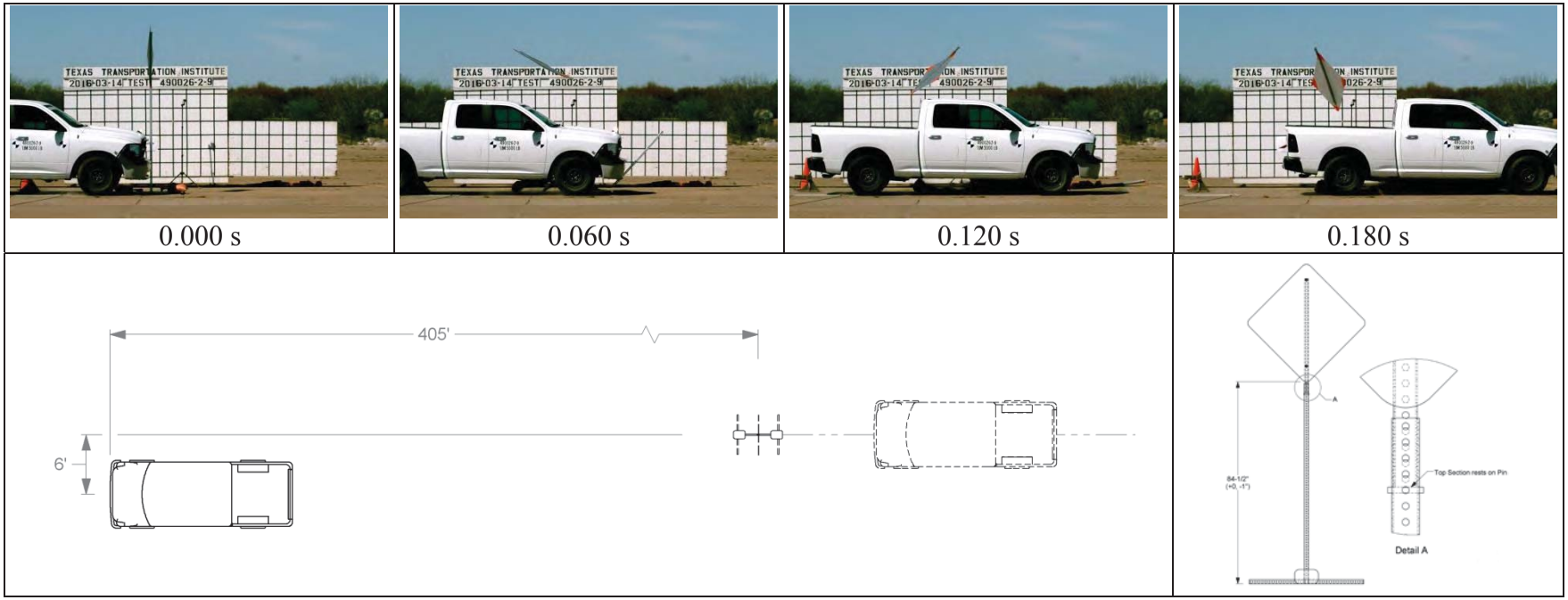
7.5.8.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Results: The 2270P vehicle came to rest 405 ft behind the Option C temporary work zone sign support. (PASS)

7.5.9 Conclusions

Figure 7.25 provides a summary of the results of the test. The slip connection for Option C temporary work zone sign support performed as designed, and the top of the system released from the lower section at vehicle impact. The released and fractured pieces gave no concern for penetration or intrusion into the vehicle. The sign panel did not contact the roof. The 2270P vehicle remained upright during and after the collision event. The 2270P vehicle came to rest 405 ft behind the Option C temporary work zone sign support.



General Information
- Test Agency: Texas A&M Transportation Institute (TTI)
- Test Standard Test No.: MASH Test 3-72
- TTI Test No.: 490026-2-9
- Test Date: 2016-03-14

Test Article
- Type: Temporary Work Zone Sign Support
- Name: Option C Temporary Work Zone Sign Support
- Installation Height: 84½ inches to bottom; 133⅝ to top
- Material or Key Elements: Upper section inserted $4^{9}/_{32}$ inches into the lower 1¾-inch square tubing post and rested on a ⅜-inch diameter × 2¼-inch long smooth pin located in holes 4½ inches below the top of post
- **Soil Type and Condition**: Placed on dry concrete surface

Test Vehicle
- Type/Designation: 2270P
- Make and Model: 2010 Dodge Ram 1500
- Curb: 4898 lb
- Test Inertial: 5014 lb
- Dummy: No dummy
- Gross Static: 5014 lb

Impact Conditions
- Speed: 62.9 mi/h
- Angle: 0 degrees
- Location/Orientation: 10 inches left of centerline
- **Kinetic Energy**: 663 kip-ft

Exit Conditions
- Speed: 61.9 mi/h
- Angle: NA
- **Occupant Risk Values**: Assessment of occupant risk factors not required for test articles of 57 lb

Test Article Debris Scatter
- Longitudinal: 120 downstream
- Lateral: 10 ft right of center

Post-Impact Trajectory
- Stopping Distance: 405 ft downstream 6 ft left of center

Vehicle Stability
- Maximum Yaw Angle: Vehicle
- Maximum Pitch Angle: remained
- Maximum Roll Angle: upright
- Vehicle Snagging: No
- Vehicle Pocketing: No

Vehicle Damage
- VDS: 12FL1
- CDC: 12FLEN1
- Max. Exterior Deformation: 3.5 inches
- OCDI: FR0000000
- Max. Occupant Compartment Deformation: None

Figure 7.25. Summary of Results for *MASH* Test 3-72 at 0 Degrees on the Option C Temporary Work Zone Sign Support.

Chapter 8. SUMMARY AND CONCLUSIONS

8.1 ASSESSMENT OF TEST RESULTS

8.1.1 Option A Temporary Work Zone Sign Support

During *MASH* Test 3-72 at 90 degrees, the slip connection of the Option A temporary work zone sign support performed as designed and the top of the system released from the lower section at vehicle impact. The corner of the sign panel impacted the vehicle roof, and no tear occurred during this first impact. However, as the vehicle continued forward, the sign panel continued to rotate and impacted the rear of the roof causing a 5-inch long tear in the exterior of the roof. The tear did not extend into the occupant compartment, but did cause a 1-inch dent in the interior roof of the right rear passenger compartment. Due to this tear, the Option A temporary work zone sign support was judged to have potential for intrusion into the occupant compartment. Therefore, the Option A temporary work zone sign support was deemed not to meet the criteria for *MASH* Test 3-72, and additional testing was not performed.

8.1.2 Option B Temporary Work Zone Sign Support

During *MASH* Test 3-72 at 90 degrees, the slip connection of Option B temporary work zone sign support performed as designed and the top of the system released from the lower section at vehicle impact. The fuse plate activated as designed. The sign panel impacted the roof; however, it did not cause any tears. The slight roof deformation was within *MASH* criteria.

The slip connection of Option B temporary work zone sign supports performed as designed and the top of the system released from the lower section at vehicle impact during *MASH* Test 3-72 at 0 degrees. The Option B temporary work zone sign support did not penetrate or show signs for potential penetration of the vehicle. No occupant compartment deformation or intrusion was noted. The released and fractured pieces of the Option B temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 2270P vehicle. The 2270P vehicle remained upright during and after the collision event. The 2270P vehicle came to rest 409 ft behind the installation.

The slip connection of Option B temporary work zone sign support performed as designed and the top of the system released from the lower section at vehicle impact during *MASH* Test 3-71 at 90 degrees. The fuse plate activated as designed. The support structure contacted the bumper and hood, but the sign panel did not contact the roof of the vehicle.

During *MASH* Test 3-71 at 0 degrees, the slip connection of Option B temporary work zone sign support performed as designed and the top of the system released from the lower section at vehicle impact. The support structure contacted the bumper and hood, but the sign panel did not contact the roof of the vehicle.

8.1.3 Option C Temporary Work Zone Sign Support

During *MASH* Test 3-72, the slip connection for Option C temporary work zone sign support performed as designed and the top of the system released from the lower section at

vehicle impact. The sign panel contacted the roof; however, it did not cause any tears. The resulting roof deformation was minor and within *MASH* criteria.

The slip connection for Option C temporary work zone sign support performed as designed and the top of the system released from the lower section at vehicle impact during *MASH* Test 3-72. The released and fractured pieces gave no concern for penetration or intrusion into the vehicle. The sign panel did not contact the roof. The 2270P vehicle remained upright during and after the collision event. The 2270P vehicle came to rest 405 ft behind the Option C temporary work zone sign support.

The slip connection of Option C temporary work zone sign support performed as designed and the top of the system released from the lower section at vehicle impact during MASH Test 3-71 at 90 degrees. The support structure contacted the bumper and hood, but the sign panel did not contact the roof of the vehicle.

During *MASH* Test 3-71 at 0 degrees, the slip connection of Option C temporary work zone sign support performed as designed and the top of the system released from the lower section at vehicle impact. The support structure contacted the bumper and hood, but the sign panel did not contact the roof of the vehicle.

8.2 CONCLUSIONS

Table 8.1 shows that the Option A temporary work zone sign support did not perform acceptably for *MASH* Test 3-72 at 90 degrees. Due to a tear in the roof of the 2270P vehicle, the Option A temporary work zone sign support was judged to have potential for intrusion into the occupant compartment.

Tables 8.2 through 8.5 show that the Option B temporary work zone sign support functioned acceptably in all four *MASH* tests performed.

Tables 8.6 through 8.9 show that the Option C temporary work zone sign support performed acceptably in all four *MASH* tests performed.

Table 8.1. Performance Evaluation Summary for *MASH* Test 3-72 at 90 Degrees on the Option A Temporary Work Zone Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 490026-2-1 Test Date: 2016-03-03

***MASH* Test 3-72 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 Option A temporary work zone sign support readily activated by yielding to the 2270P 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 sign panel and a portion of the upright contacted the roof of the 2270P vehicle causing a 16-inch long scratch that ended in a 5-inch long cut on the outer surface of the rear cab. This was determined to be of concern for potential intrusion into the vehicle.	Fail
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	The interior roof in the area of the 5-inch cut did not penetrate the occupant compartment, but the interior was dented inward approximately 1 inch. No other occupant compartment deformation or intrusion was noted.	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 fractured pieces of the Option A temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 2270P 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 2270P 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.	Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. The weight of the Option A temporary work zone sign support system was 60 lb.	NA
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.		NA
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 2270P vehicle came to rest 280 ft behind the Option A temporary work zone sign support.	Pass

Table 8.2. Performance Evaluation Summary for *MASH* Test 3-72 at 90 Degrees on the Option B Temporary Work Zone Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 490026-2-2 Test Date: 2016-03-03

***MASH* Test 3-72 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 Option B temporary work zone sign support readily activated by yielding to the 2270P 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 Option B temporary work zone sign support fractured into several pieces; however, there was no concern for potential deformation or intrusion into the vehicle.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion was noted.	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 fractured pieces of the Option B temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 2270P 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 2270P 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.	Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. The weight of the Option B temporary work zone sign support system was 58 lb.	NA
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.		NA
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 2270P vehicle came to rest 305 ft behind the Option B temporary work zone sign support.	Pass

Table 8.3. Performance Evaluation Summary for *MASH* Test 3-71 at 90 Degrees on the Option B Temporary Work Zone Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 490026-2-4 Test Date: 2016-03-11

***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 Option B temporary work zone sign support readily activated by yielding to the 1100C 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 Option B temporary work zone sign support fractured into several pieces; however, there was no concern for potential deformation or intrusion into the vehicle.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion was noted.	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 fractured pieces of the Option B temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 1100C 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.	Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less.	NA
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.	The weight of the Option B temporary work zone sign support system was 58 lb.	NA
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 1100C vehicle came to rest 468 ft behind the Option B temporary work zone sign support.	Pass

Table 8.4. Performance Evaluation Summary for *MASH* Test 3-71 at 0 Degrees on the Option B Temporary Work Zone Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 490026-2-6 Test Date: 2016-03-11

***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 Option B temporary work zone sign support readily activated by yielding to the 1100C 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 Option B temporary work zone sign support fractured into several pieces; however, there was no concern for potential deformation or intrusion into the vehicle.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion was noted.	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 fractured pieces of the Option B temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 1100C 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.	Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less.	NA
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.	The weight of the Option B temporary work zone sign support system was 58 lb.	NA
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 1100C vehicle came to rest 500 ft behind the Option B temporary work zone sign support.	Pass

Table 8.5. Performance Evaluation Summary for *MASH* Test 3-72 at 0 Degrees on the Option B Temporary Work Zone Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 490026-2-8 Test Date: 2016-03-14

***MASH* Test 3-72 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 Option B temporary work zone sign support readily activated by yielding to the 2270P 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 Option B temporary work zone sign support fractured but did not penetrate or show signs for potential penetration of the vehicle.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion was noted.	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 fractured pieces of the Option B temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 2270P 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 2270P 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.	Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. The weight of the Option A temporary work zone sign support system was 58 lb.	NA
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.		NA
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 2270P vehicle came to rest 409 ft behind the installation.	Pass

Table 8.6. Performance Evaluation Summary for *MASH* Test 3-72 at 90 Degrees on the Option C Temporary Work Zone Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 490026-2-3 Test Date: 2016-03-03

***MASH* Test 3-72 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 Option C temporary work zone sign support readily activated by yielding to the 2270P 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 Option C temporary work zone sign support fractured into several pieces; however, there was no concern for potential deformation or intrusion into the vehicle.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion was noted.	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 fractured pieces of the Option C temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 2270P 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 2270P 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.	Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. The weight of the Option C temporary work zone sign support system was 57 lb.	NA
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.		NA
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 2270P vehicle came to rest 347 ft behind the Option C temporary work zone sign support.	Pass

Table 8.7. Performance Evaluation Summary for *MASH* Test 3-71 at 90 Degrees on the Option C Temporary Work Zone Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 490026-2-5 Test Date: 2016-03-11

***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 Option C temporary work zone sign support readily activated by yielding to the 1100C 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 Option C temporary work zone sign support fractured into several pieces; however, there was no concern for potential deformation or intrusion into the vehicle.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion was noted.	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 fractured pieces of the Option C temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 1100C 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.	Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. The weight of the Option C temporary work zone sign support system was 57 lb.	NA
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.		NA
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 1100C vehicle came to rest 500 ft behind the Option C temporary work zone sign support.	Pass

Table 8.8. Performance Evaluation Summary for *MASH* Test 3-71 at 0 Degrees on the Option C Temporary Work Zone Sign Support.

Test Agency: Texas A&M Transportation Institute Test No.: 490026-2-7 Test Date: 2016-03-11

***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 Option C temporary work zone sign support readily activated by yielding to the 1100C 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 Option C temporary work zone sign support fractured into several pieces; however, there was no concern for potential deformation or intrusion into the vehicle.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion was noted.	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 fractured pieces of the Option C temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 1100C 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.	Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less. The weight of the Option C temporary work zone sign support system was 57 lb.	NA
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.		NA
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 1100C vehicle came to rest 480 ft behind the Option C temporary work zone sign support.	Pass

Table 8.9. Performance Evaluation Summary for *MASH* Test 3-72 at 0 Degrees on the Option C Temporary Work Zone Sign Support.

Test Agency: Texas A&M Transportation Institute | Test No.: 490026-2-9 | Test Date: 2016-03-14

***MASH* Test 3-72 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 Option C temporary work zone sign support readily activated by yielding to the 2270P 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 Option C temporary work zone sign support fractured into several pieces; however, there was no concern for potential deformation or intrusion into the vehicle.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation or intrusion was noted.	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 fractured pieces of the Option C temporary work zone sign support did not block the driver's view or otherwise cause the driver to lose control of the 1100C 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 2270P 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.	Assessment of occupant risk factors is not required for test articles having a total weight of 220 lb or less.	NA
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.	The weight of the Option C temporary work zone sign support system was 57 lb.	NA
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 2270P vehicle came to rest 480 ft behind the Option C temporary work zone sign support.	Pass

Chapter 9. IMPLEMENTATION STATEMENT

The objective of this research was to develop a nonproprietary, lightweight, crashworthy temporary work-zone single sign support with an aluminum sign substrate. The device was intended to meet the evaluation criteria in *MASH*. In addition to crashworthiness, due consideration was given to cost and functionality. The system was designed for a mounting-height of 7 ft. The researchers used perforated steel tubing for the frame of the new temporary single sign support system. Use of perforated steel tubing makes the system relatively lightweight, durable, easy to assemble, and adjustable.

The Option B and Option C temporary work zone sign supports functioned acceptably in all four *MASH* tests performed. Therefore, these options are considered suitable for implementation on Texas roads.

REFERENCES

1. Manual on Uniform Traffic Control Devices (MUTCD): http://mutcd.fhwa.dot.gov Last accessed August 01, 2016.

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

3. Silvestri C., D. R. Arrington, R. P. Bligh, and W. L. Menges. "Development and *MASH* Full-Scale Crash Testing of a High-Mounting-Height Temporary Single Sign Support with Aluminum Sign," Research Report 9-1002-12-7, Texas A&M Transportation Institute, College Station, TX, August 2012.

APPENDIX A. CRASH TEST NO. 490026-2-1 (*MASH* TEST 3-72)

A1 VEHICLE PROPERTIES AND INFORMATION

Table A.1. Vehicle Properties for Test No. 490026-2-1 through 490026-2-3.

Date: 2016-03-03 Test No.: 490026-2-1/2/3 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 173708

Note any damage to the vehicle prior to test: None noted

● Denotes accelerometer location.

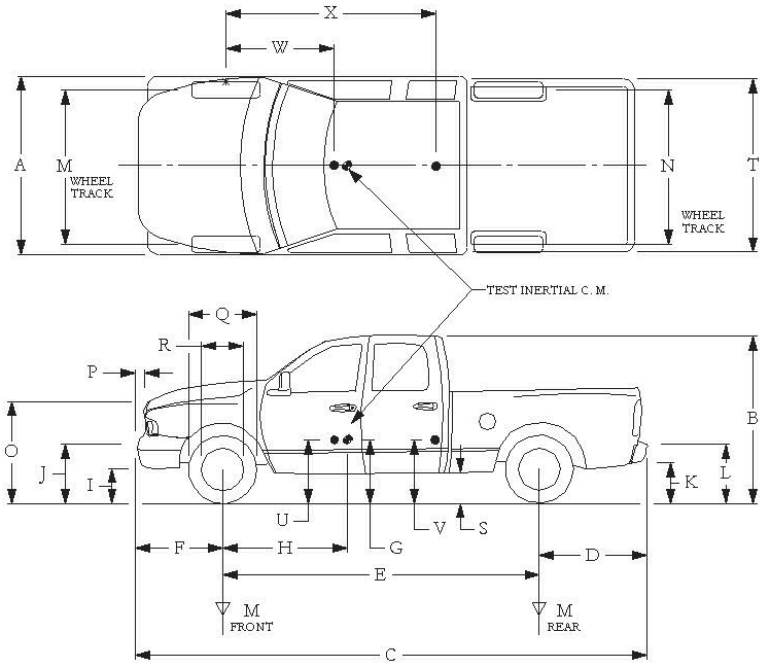
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

Transmission Type:
x Auto or ___ Manual
___ FWD x RWD ___ 4WD

Optional Equipment:
None

Dummy Data:
Type: No dummy
Mass: NA
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	19.50	P	3.00	U	-----
B	74.00	G	28.38	L	29.00	Q	30.50	V	-----
C	227.50	H	62.43	M	68.50	R	18.00	W	-----
D	47.00	I	12.50	N	68.00	S	13.00	X	-----
E	140.50	J	27.50	O	46.50	T	77.00		-----

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	17.00
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	25.50

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; M+N/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2850	2786	----
Back	3900	M_{rear}	2048	2228	----
Total	6700	M_{Total}	4898	5014	----

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1388 RF: 1398 LR: 1084 RR: 1144

Table A.2. Measurements of Vehicle Vertical CG for Test No. 490026-2-1 through 490026-2-3.

Date: 2016-03-03 Test No.: 490026-2-1/2/3 VIN: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 173708

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 228 lb (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70R17

Measured Vehicle Weights: (lb)					
LF:	1388	RF:	1398	Front Axle:	2786
LR:	1084	RR:	1144	Rear Axle:	2228
Left:	2472	Right:	2542	Total:	5014
					5000 ±110 lb allowed
Wheel Base:	140.5 inches	Track: F:	68.5 inches	R:	68 inches
	148 ±12 inches allowed		Track = (F+R)/2 = 67 ±1.5 inches allowed		

Center of Gravity, SAE J874 Suspension Method			
X:	62.43 in	Rear of Front Axle	(63 ±4 inches allowed)
Y:	0.48 in	Left - Right +	of Vehicle Centerline
Z:	28.375 in	Above Ground	(minumum 28.0 inches allowed)

Hood Height: 46.5 inches
43 ±4 inches allowed

Front Bumper Height: 27.5 inches

Front Overhang: 40.0 inches
39 ±3 inches allowed

Rear Bumper Height: 29.0 inches

Overall Length: 227.5 inches
237 ±13 inches allowed

Table A.3. Exterior Crush Measurements for Test No. 490026-2-1.

Date: 2016-03-03 Test No.: 490026-2-1 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

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		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	---	2.5	---	---	---	---	---	---	---	---
	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).

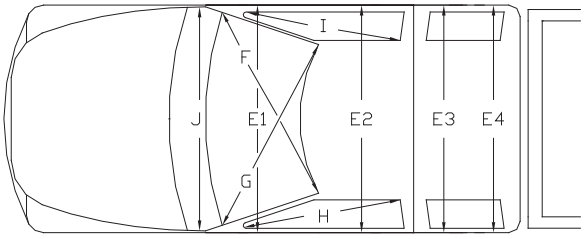
***Measure and document on the vehicle diagram the location of the maximum crush.

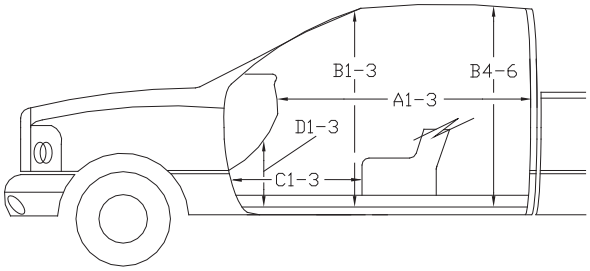
Note: Use as many lines/columns as necessary to describe each damage profile.

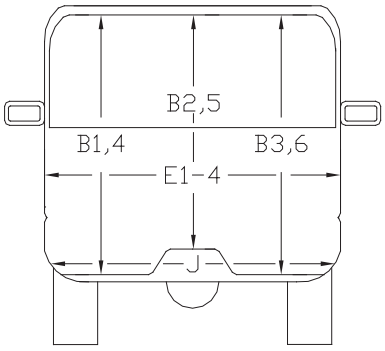
Table A.4. Occupant Compartment Measurements for Test No. 490026-2-1.

Date: 2016-03-03 Test No.: 490026-2-1 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	65.50	65.50
A2	63.50	63.50
A3	65.50	65.50
B1	45.00	45.00
B2	37.75	37.75
B3	45.00	45.00
B4	39.50	39.50
B5	41.00	41.00
B6	39.50	39.50
C1	26.50	26.50
C2	-----	-----
C3	26.00	26.00
D1	11.25	11.25
D2	-----	-----
D3	11.25	11.25
E1	58.50	58.50
E2	63.50	63.50
E3	63.50	63.50
E4	63.25	63.25
F	59.00	59.00
G	59.00	59.00
H	37.50	37.50
I	37.50	37.50
J*	23.00	23.00

A2 SEQUENTIAL PHOTOGRAPHS

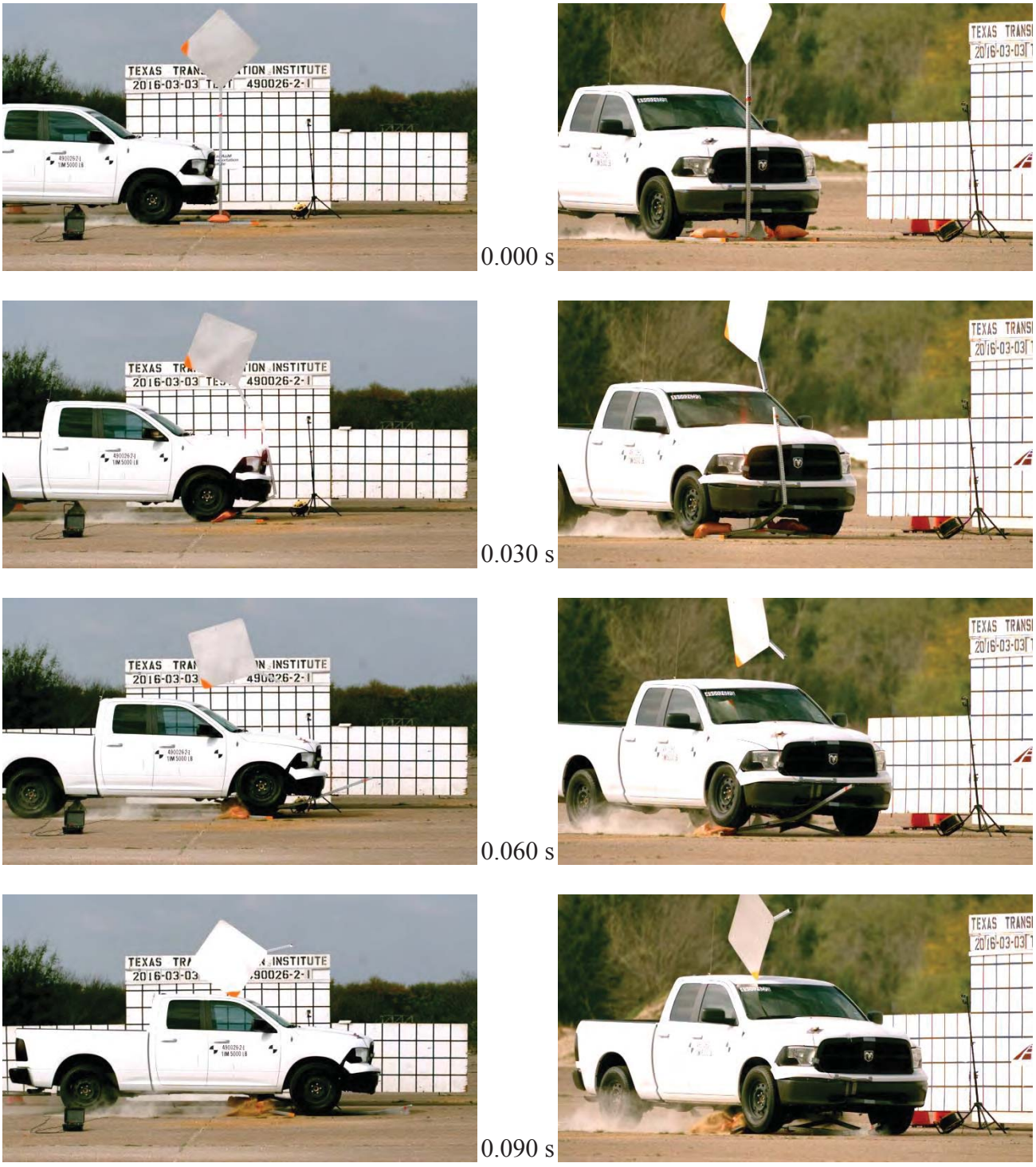


Figure A.1. Sequential Photographs for Test No. 490026-2-1 (Perpendicular and Oblique Views).

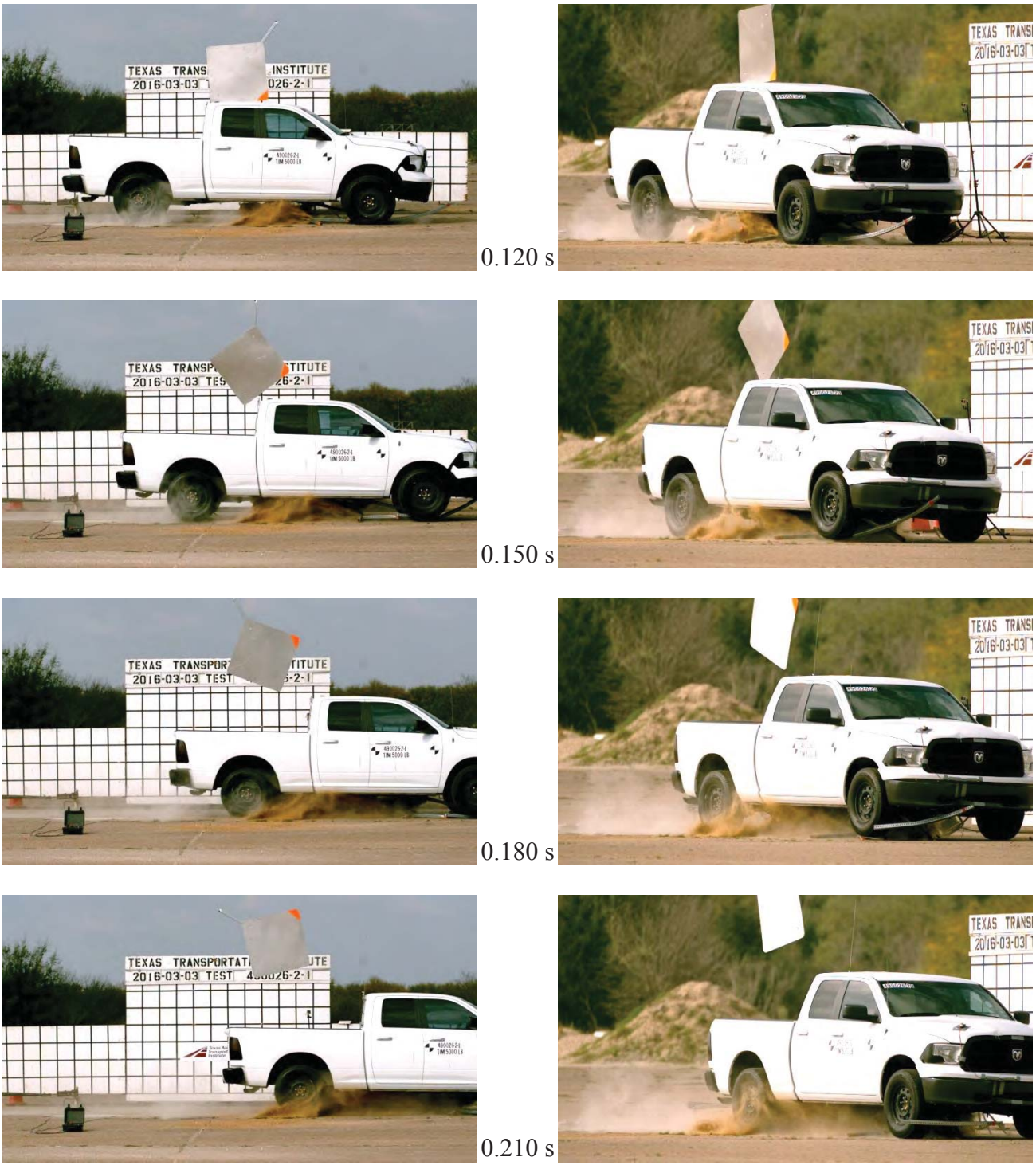


Figure A.1. Sequential Photographs for Test No. 490026-2-1 (Perpendicular and Oblique Views) (Continued).

APPENDIX B. CRASH TEST NO. 490026-2-2 (*MASH* TEST 3-72)

B1 VEHICLE PROPERTIES AND INFORMATION

Table B.1. Vehicle Properties for Test No. 490026-2-2.

Date: 2016-03-03 Test No.: 490026-2-1/2/3 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 173708

Note any damage to the vehicle prior to test: None noted

● Denotes accelerometer location.

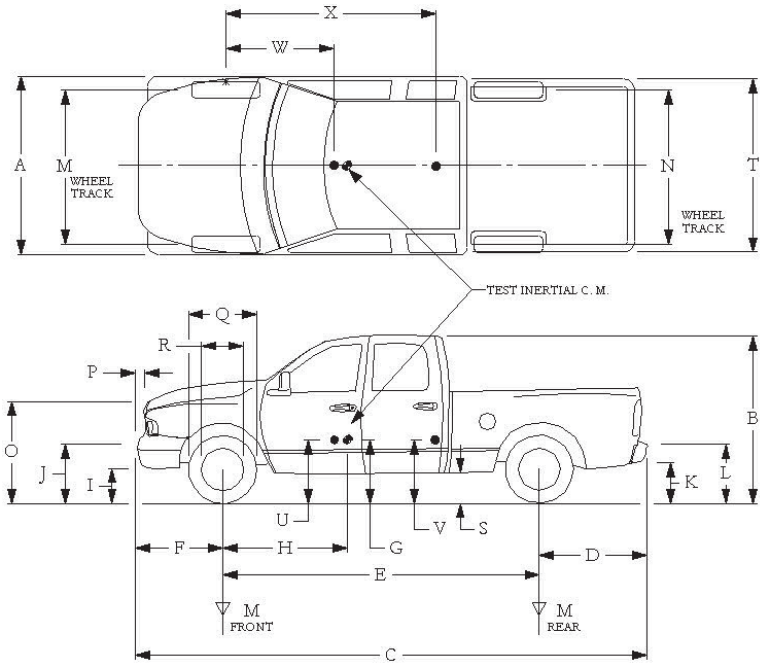
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

Transmission Type:
x Auto or ___ Manual
___ FWD x RWD ___ 4WD

Optional Equipment:
None

Dummy Data:
Type: No dummy
Mass: NA
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	19.50	P	3.00	U	-----
B	74.00	G	28.38	L	29.00	Q	30.50	V	-----
C	227.50	H	62.43	M	68.50	R	18.00	W	-----
D	47.00	I	12.50	N	68.00	S	13.00	X	-----
E	140.50	J	27.50	O	46.50	T	77.00		-----

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	17.00
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	25.50

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; M+N/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2850	2786	----
Back	3900	M_{rear}	2048	2228	----
Total	6700	M_{Total}	4898	5014	----

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1388 RF: 1398 LR: 1084 RR: 1144

Table B.2. Measurements of Vehicle Vertical CG for Test No. 490026-2-2.

Date: 2016-03-03 Test No.: 490026-2-1/2/3 VIN: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 173708

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 228 lb (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70R17

Measured Vehicle Weights: (lb)								
LF:	1388		RF:	1398		Front Axle:	2786	
LR:	1084		RR:	1144		Rear Axle:	2228	
Left:	2472		Right:	2542		Total:	5014	
							5000 ±110 lb allowed	
Wheel Base:	140.5	inches	Track: F:	68.5	inches	R:	68	inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed				
Center of Gravity, SAE J874 Suspension Method								
X:	62.43	in	Rear of Front Axle	(63 ±4 inches allowed)				
Y:	0.48	in	Left -	Right +	of Vehicle Centerline			
Z:	28.375	in	Above Ground	(minumum 28.0 inches allowed)				

Hood Height: 46.5 inches (43 ±4 inches allowed)

Front Bumper Height: 27.5 inches

Front Overhang: 40.0 inches (39 ±3 inches allowed)

Rear Bumper Height: 29.0 inches

Overall Length: 227.5 inches (237 ±13 inches allowed)

Table B.3. Exterior Crush Measurements for Test No. 490026-2-2.

Date: 2016-03-03 Test No.: 490026-2-2 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

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		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	---	2.5	---	---	---	---	---	---	---	---
	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).

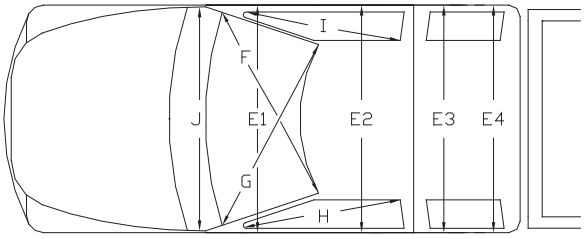
***Measure and document on the vehicle diagram the location of the maximum crush.

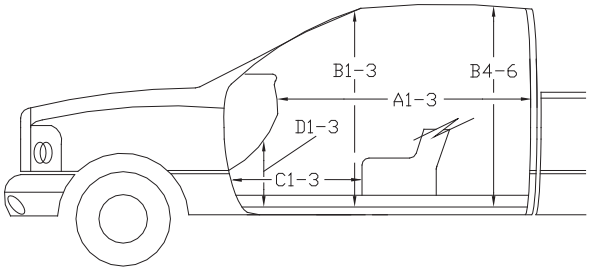
Note: Use as many lines/columns as necessary to describe each damage profile.

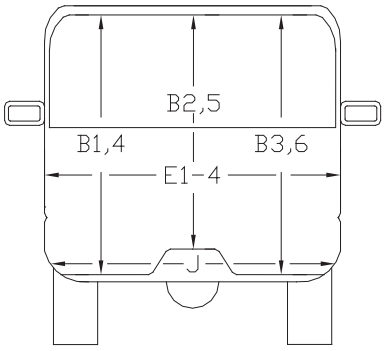
Table B.4. Occupant Compartment Measurements for Test No. 490026-2-2.

Date: 2016-03-03 Test No.: 490026-2-2 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	65.50	65.50
A2	63.50	63.50
A3	65.50	65.50
B1	45.00	45.00
B2	37.75	37.75
B3	45.00	45.00
B4	39.50	39.50
B5	41.00	41.00
B6	39.50	39.50
C1	26.50	26.50
C2	-----	-----
C3	26.00	26.00
D1	11.25	11.25
D2	-----	-----
D3	11.25	11.25
E1	58.50	58.50
E2	63.50	63.50
E3	63.50	63.50
E4	63.25	63.25
F	59.00	59.00
G	59.00	59.00
H	37.50	37.50
I	37.50	37.50
J*	23.00	23.00

B2 SEQUENTIAL PHOTOGRAPHS

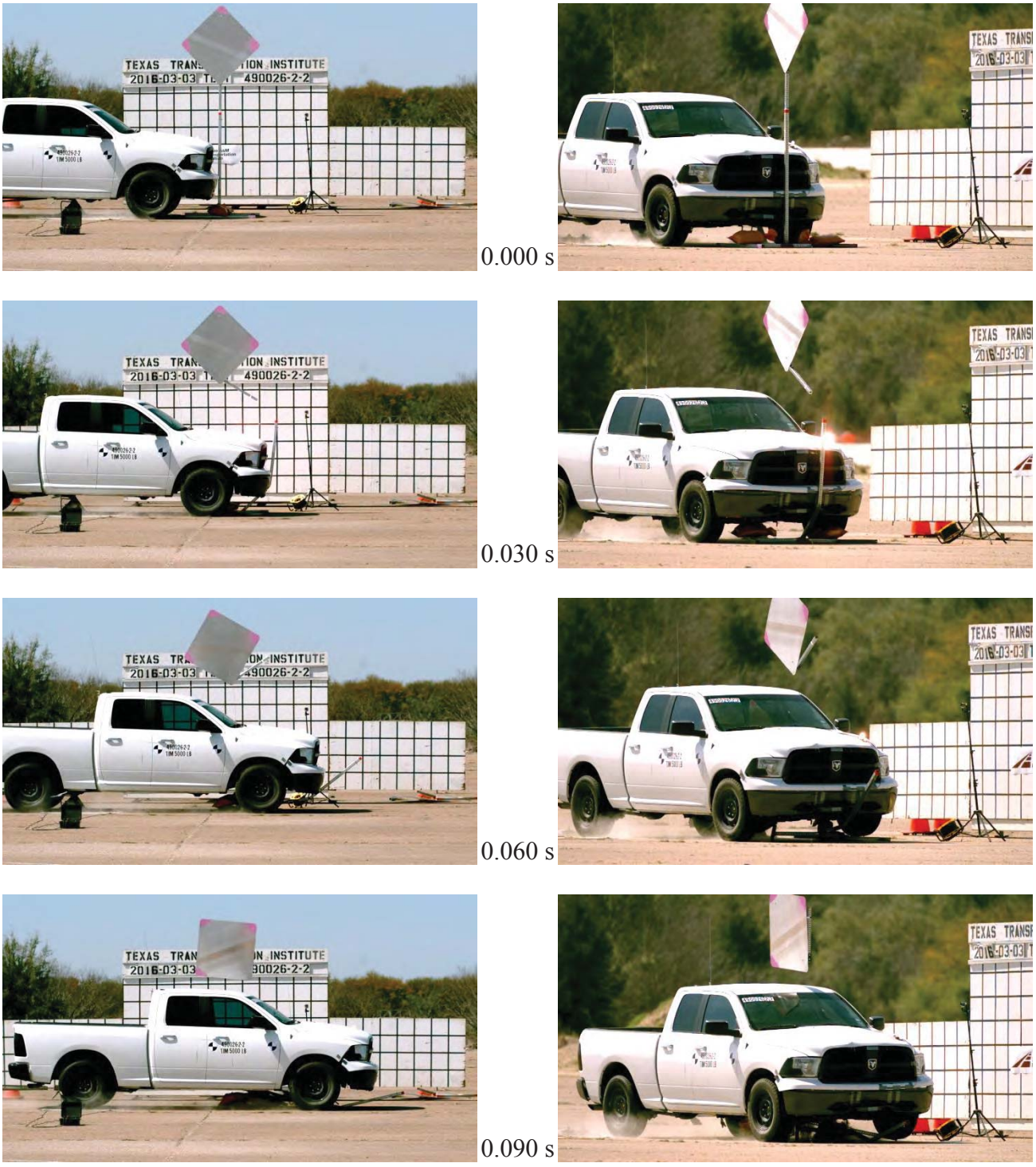


Figure B.1. Sequential Photographs for Test No. 490026-2-2 (Perpendicular and Oblique Views).

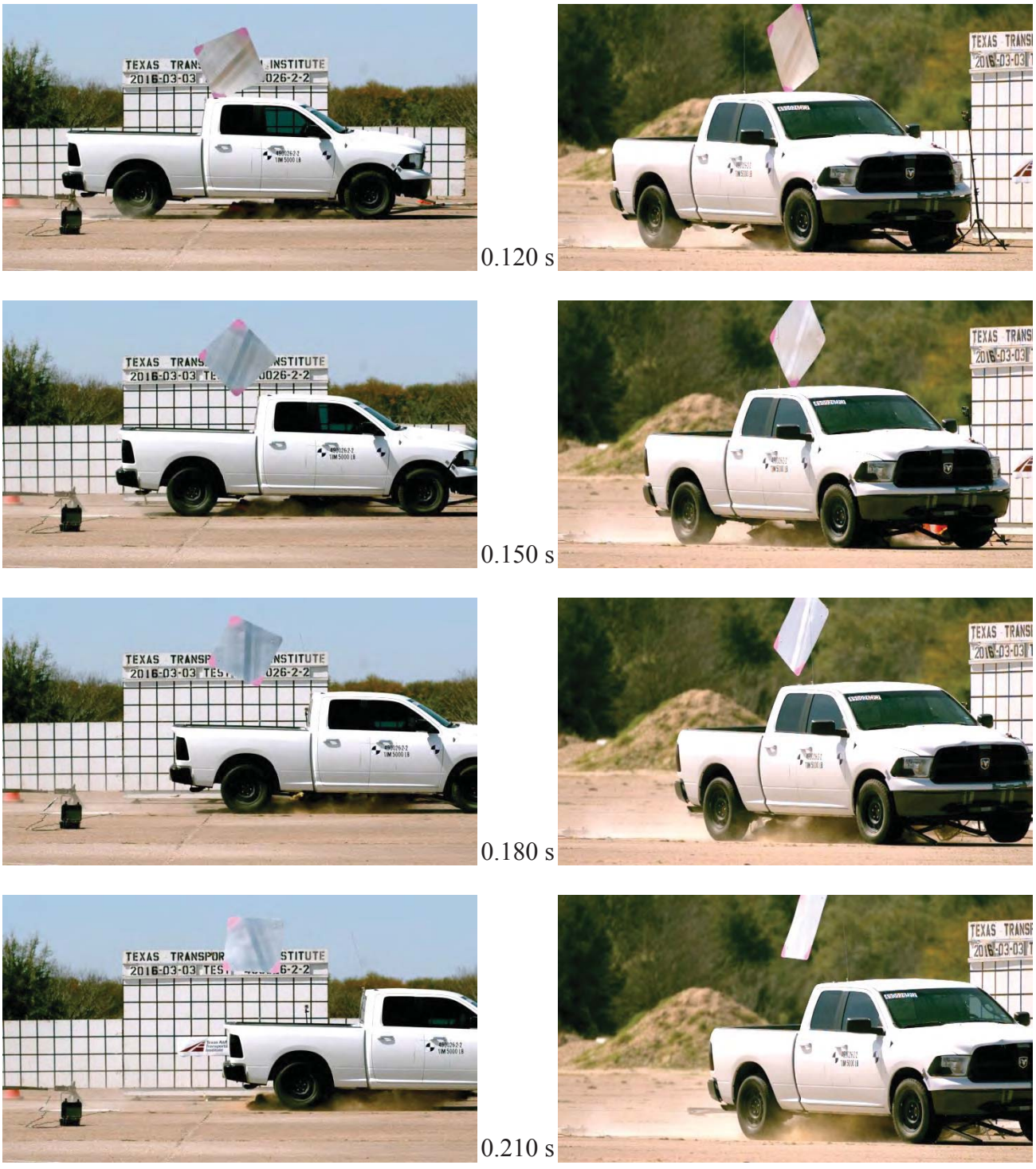


Figure B.1. Sequential Photographs for Test No. 490026-2-2 (Perpendicular and Oblique Views) (Continued).

APPENDIX C. CRASH TEST NO. 490026-2-4 (*MASH* TEST 3-71)

C1 VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test Nos. 490026-2-4.

Date: 2016-03-11 Test No.: 490026-2-4/5/6/7 VIN No.: KNAD14A35B6916812

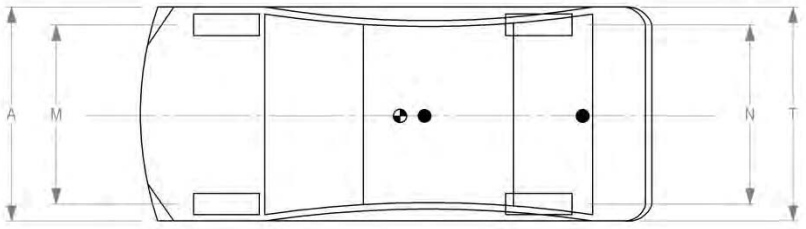
Year: 2011 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 95120 Tire Size: P185/65R14

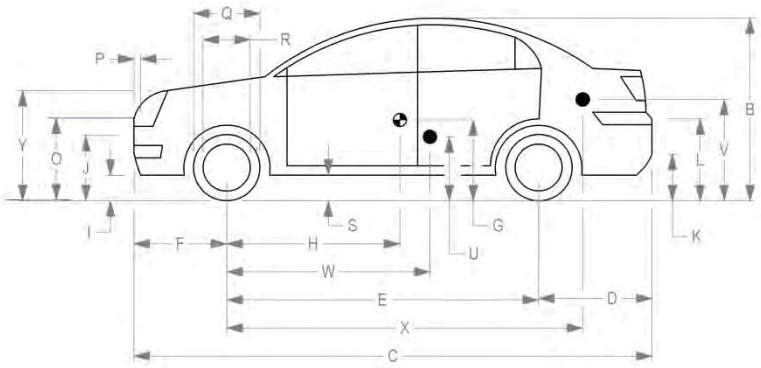
Describe any damage to the vehicle prior to test: None

• Denotes accelerometer location.

NOTES: None



Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:
None



Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Driver

Geometry: inches

A	66.38	F	33.00	K	12.20	P	4.12	U	NA
B	58.00	G	-----	L	25.00	Q	22.50	V	NA
C	165.75	H	35.93	M	57.75	R	15.50	W	NA
D	34.00	I	8.00	N	57.10	S	7.25	X	NA
E	98.75	J	21.50	O	28.25	T	66.20	Y	27.00
Wheel Center Ht Front		11.00		Wheel Center Ht Rear		11.00		W-H	NA

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1918	M_{front}	1579	1554	1640
Back	1874	M_{rear}	900	889	968
Total	3638	M_{Total}	2479	2443	2608

Allowable TIM = 2420 lb ±55 lb | Allowable GSM = 2585 lb ± 55 lb

Mass Distribution:
lb LF: 800 RF: 754 LR: 440 RR: 449

Table C.2. Exterior Crush Measurements for Test No. 490026-2-4.

Date: 2016-03-11 Test No.: 490026-2-4 VIN No.: KNAD14A35B6916812

Year: 2011 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		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	0	0	---	---	---	---	---	---	---	---
	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).

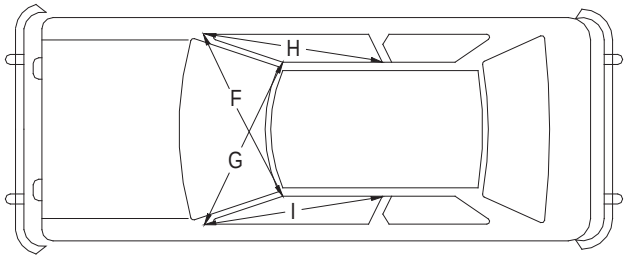
***Measure and document on the vehicle diagram the location of the maximum crush.

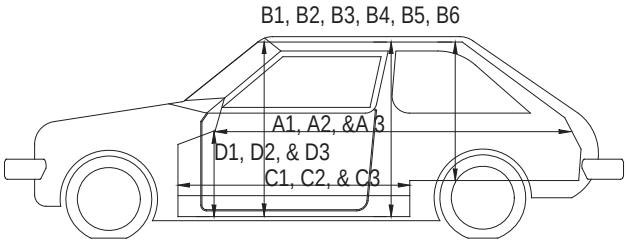
Note: Use as many lines/columns as necessary to describe each damage profile.

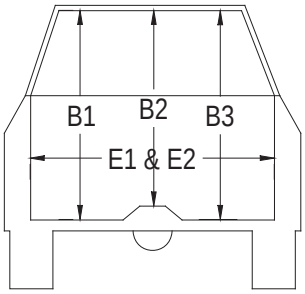
Table C.3. Occupant Compartment Measurements for Test No. 490026-2-4.

Date: 2016-03-11 Test No.: 490026-2-4 VIN No.: KNAD14A35B6916812

Year: 2011 Make: Kia Model: Rio







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	67.50	67.50
A2	67.25	67.25
A3	67.75	67.75
B1	40.50	40.50
B2	35.75	35.75
B3	40.50	40.50
B4	36.00	36.00
B5	32.50	32.50
B6	36.00	36.00
C1	27.25	27.25
C2	-----	-----
C3	27.00	27.00
D1	9.50	9.50
D2	-----	-----
D3	9.25	9.25
E1	51.50	51.50
E2	51.00	51.00
F	51.00	51.00
G	51.00	51.00
H	37.50	37.50
I	37.50	37.50
J*	51.00	51.00

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

C2 SEQUENTIAL PHOTOGRAPHS

Figure C.1. Sequential Photographs for Test No. 490026-2-4 (Perpendicular and Oblique Views).

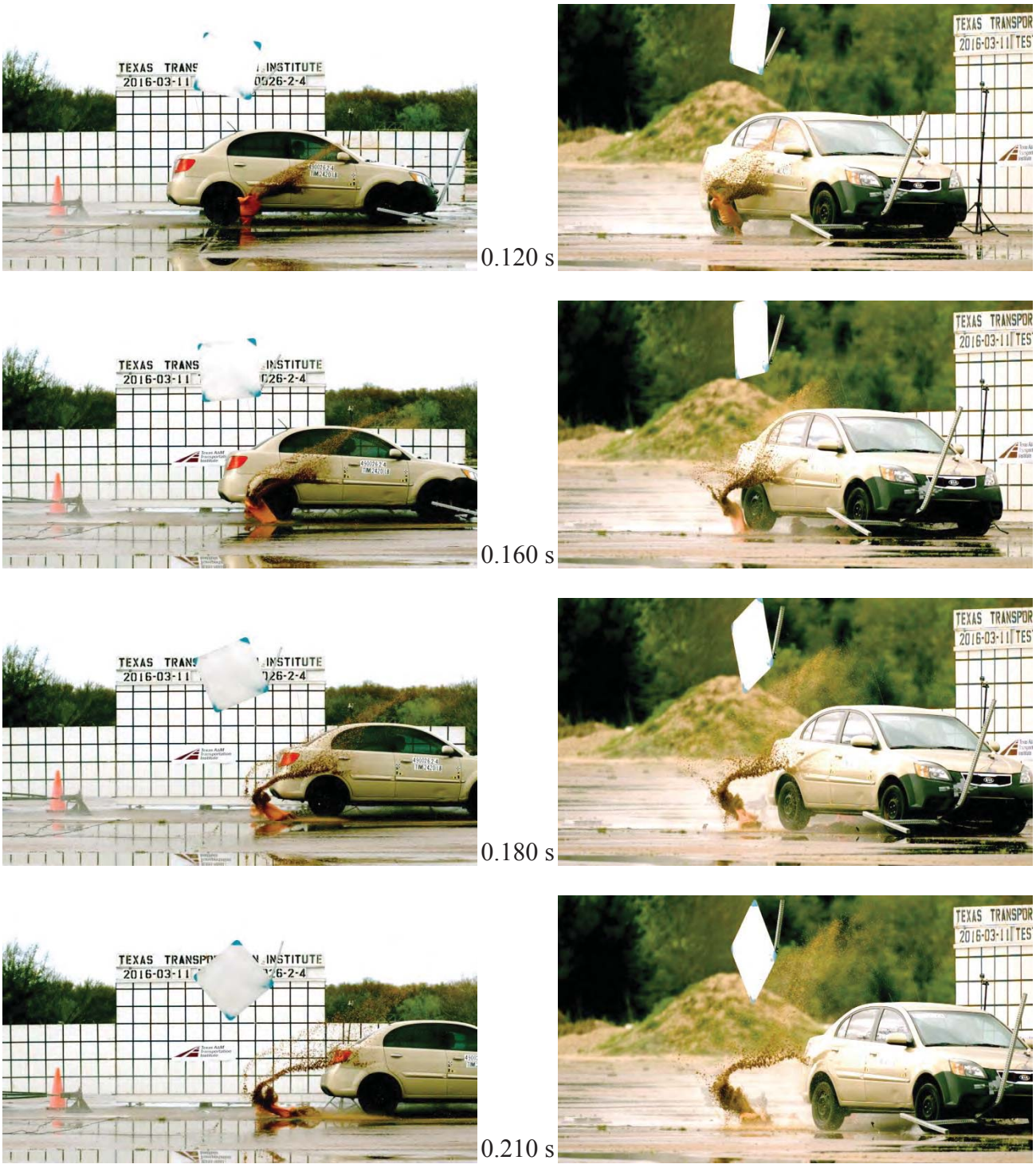


Figure C.1. Sequential Photographs for Test No. 490026-2-4 (Perpendicular and Oblique Views) (Continued).

APPENDIX D. CRASH TEST NO. 490026-2-6 (*MASH* TEST 3-71)

D1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 490026-2-6.

Date: 2016-03-11 Test No.: 490026-2-6 VIN No.: KNAD14A35B6916812

Year: 2011 Make: Kia Model: Rio

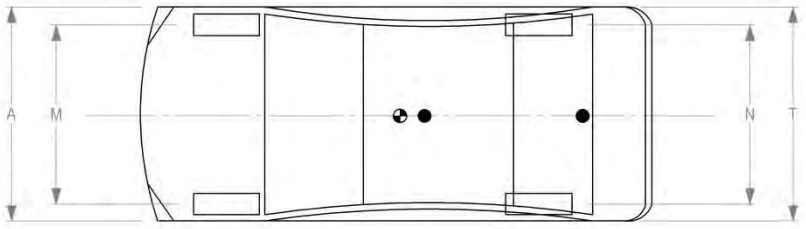
Tire Inflation Pressure: 32 psi Odometer: 95120 Tire Size: P185/65R14

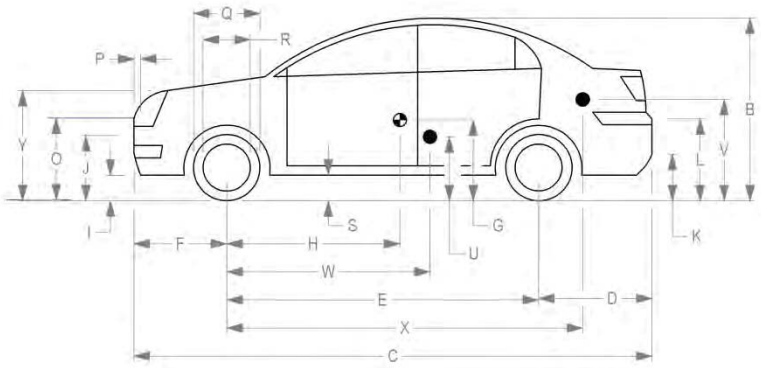
Describe any damage to the vehicle prior to test: None

• Denotes accelerometer location.

NOTES: None

Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:
None





Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Driver

Geometry: inches

A	66.38	F	33.00	K	12.20	P	4.12	U	NA
B	58.00	G	-----	L	25.00	Q	22.50	V	NA
C	165.75	H	35.93	M	57.75	R	15.50	W	NA
D	34.00	I	8.00	N	57.10	S	7.25	X	NA
E	98.75	J	21.50	O	28.25	T	66.20	Y	27.00
	Wheel Center Ht Front		11.00		Wheel Center Ht Rear		11.00	W-H	NA

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1918	M_{front}	1579	1554	1640
Back	1874	M_{rear}	900	889	968
Total	3638	M_{Total}	2479	2443	2608

Allowable TIM = 2420 lb ±55 lb | Allowable GSM = 2585 lb ± 55 lb

Mass Distribution:
lb LF: 800 RF: 754 LR: 440 RR: 449

Table D.2. Exterior Crush Measurements for Test No. 490026-2-6.

Date: 2016-03-11 Test No.: 490026-2-6 VIN No.: KNAD14A35B6916812

Year: 2011 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		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	0	0	---	---	---	---	---	---	---	---
	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).

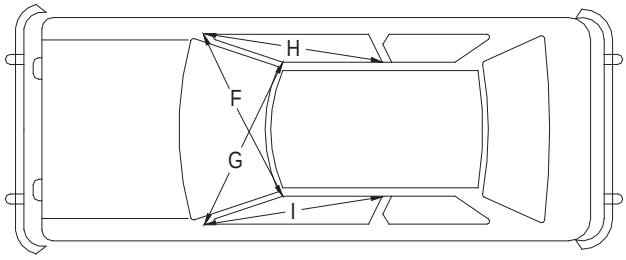
***Measure and document on the vehicle diagram the location of the maximum crush.

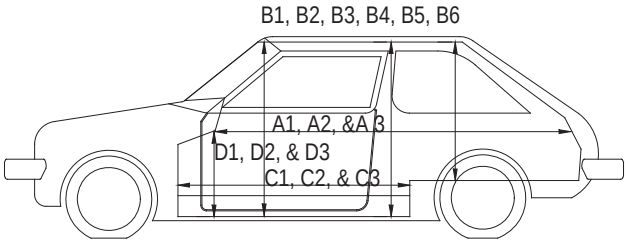
Note: Use as many lines/columns as necessary to describe each damage profile.

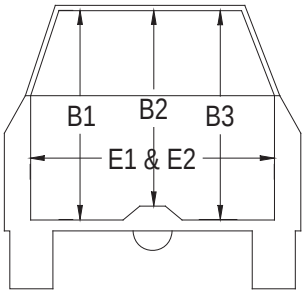
Table D.3. Occupant Compartment Measurements for Test No. 490026-2-6.

Date: 2016-03-11 Test No.: 490026-2-6 VIN No.: KNAD14A35B6916812

Year: 2011 Make: Kia Model: Rio







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	67.50	67.50
A2	67.25	67.25
A3	67.75	67.75
B1	40.50	40.50
B2	35.75	35.75
B3	40.50	40.50
B4	36.00	36.00
B5	32.50	32.50
B6	36.00	36.00
C1	27.25	27.25
C2	-----	-----
C3	27.00	27.00
D1	9.50	9.50
D2	-----	-----
D3	9.25	9.25
E1	51.50	51.50
E2	51.00	51.00
F	51.00	51.00
G	51.00	51.00
H	37.50	37.50
I	37.50	37.50
J*	51.00	51.00

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

D2 SEQUENTIAL PHOTOGRAPHS

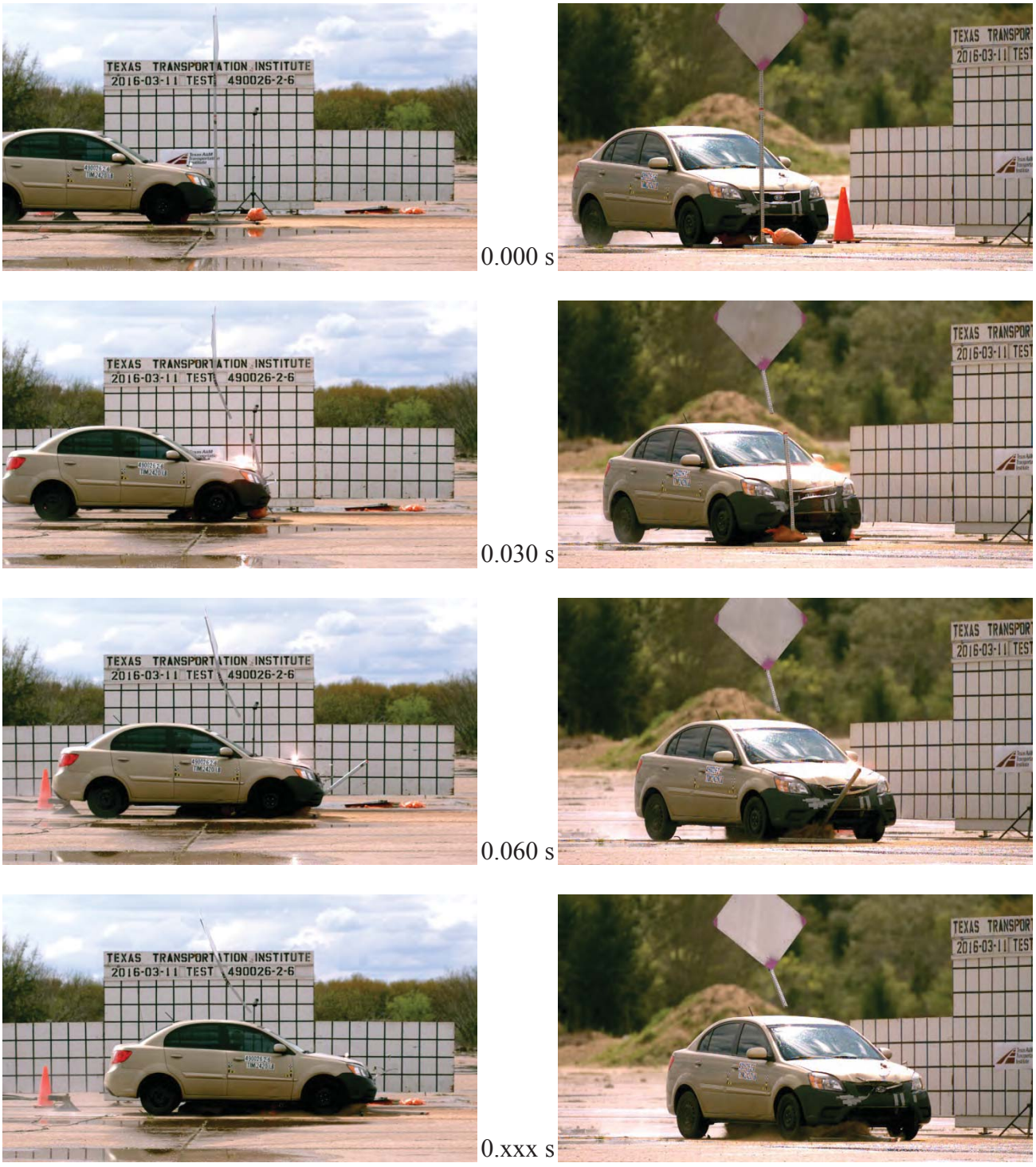


Figure D.1. Sequential Photographs for Test No. 490026-2-6 (Perpendicular and Oblique Views).

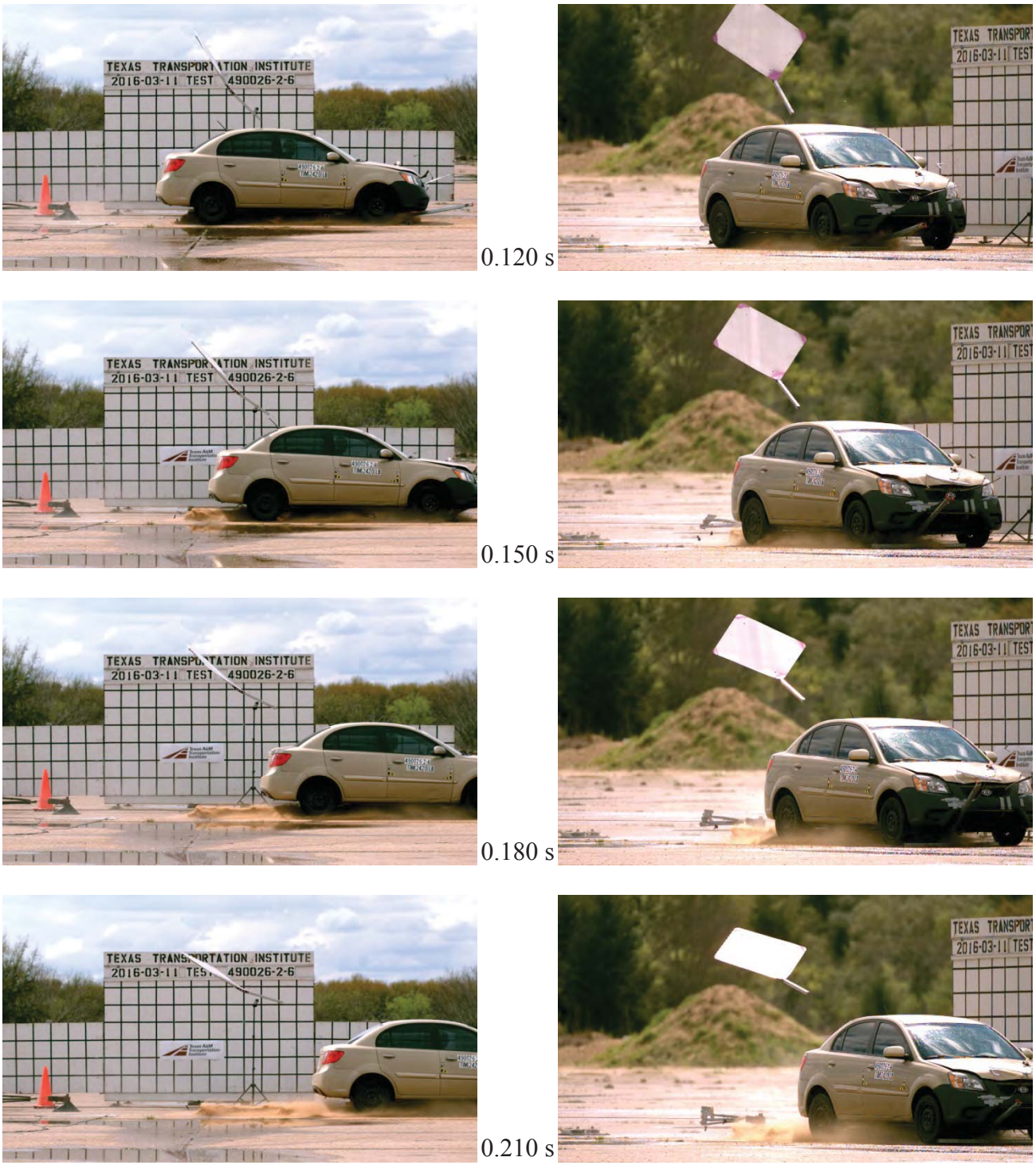


Figure D.1. Sequential Photographs for Test No. 490026-2-6 (Perpendicular and Oblique Views) (Continued).

APPENDIX E. CRASH TEST NO. 490026-2-8 (*MASH* TEST 3-72)

E1 VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 490026-2-8.

Date: 2016-03-03 Test No.: 490026-2-8 and 9 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 173708

Note any damage to the vehicle prior to test: None noted

● Denotes accelerometer location.

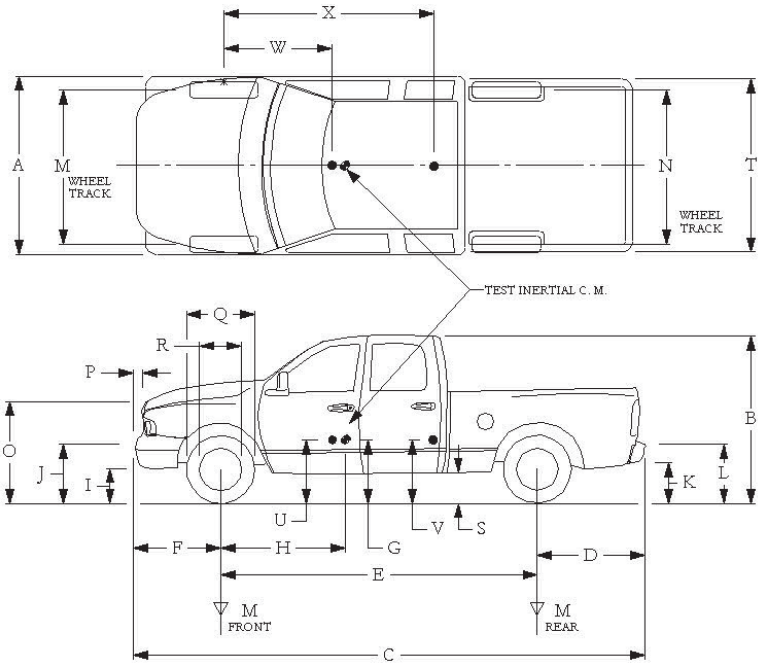
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

Transmission Type:
x Auto or ___ Manual
___ FWD x RWD ___ 4WD

Optional Equipment:
None

Dummy Data:
Type: No dummy
Mass: NA
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	19.50	P	3.00	U	-----
B	74.00	G	28.38	L	29.00	Q	30.50	V	-----
C	227.50	H	62.43	M	68.50	R	18.00	W	-----
D	47.00	I	12.50	N	68.00	S	13.00	X	-----
E	140.50	J	27.50	O	46.50	T	77.00		-----

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	17.00
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	25.50

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; M+N/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2850	2786	----
Back	3900	M_{rear}	2048	2228	----
Total	6700	M_{Total}	4898	5014	----

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1388 RF: 1398 LR: 1084 RR: 1144

Table E.2. Measurements of Vehicle Vertical CG for Test No. 490026-2-8.

Date: 2016-03-03 Test No.: 490026-2-8 & 9 VIN: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 173708

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 228 lb (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70R17

Measured Vehicle Weights: (lb)								
LF:	1388	RF:	1398	Front Axle:	2786			
LR:	1084	RR:	1144	Rear Axle:	2228			
Left:	2472	Right:	2542	Total:	5014			
				5000 ±110 lb allowed				
Wheel Base:	140.5 inches	Track: F:	68.5 inches	R:	68 inches			
148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed					
Center of Gravity, SAE J874 Suspension Method								
X:	62.43 in	Rear of Front Axle	(63 ±4 inches allowed)					
Y:	0.48 in	Left -	Right +	of Vehicle Centerline				
Z:	28.375 in	Above Ground	(minumum 28.0 inches allowed)					

Hood Height: 46.5 inches
43 ±4 inches allowed

Front Bumper Height: 27.5 inches

Front Overhang: 40.0 inches
39 ±3 inches allowed

Rear Bumper Height: 29.0 inches

Overall Length: 227.5 inches
237 ±13 inches allowed

Table E.3. Exterior Crush Measurements for Test No. 490026-2-8.

Date: 2016-03-03 Test No.: 490026-2-8 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

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		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	---	4.0	---	---	---	---	---	---	---	---
	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).

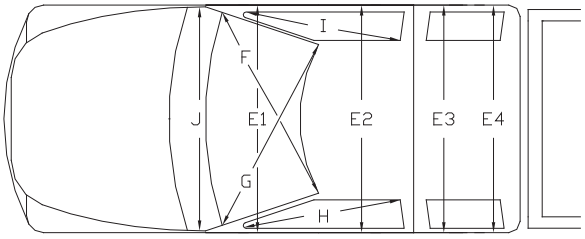
***Measure and document on the vehicle diagram the location of the maximum crush.

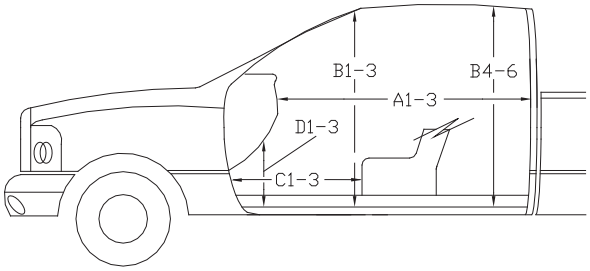
Note: Use as many lines/columns as necessary to describe each damage profile.

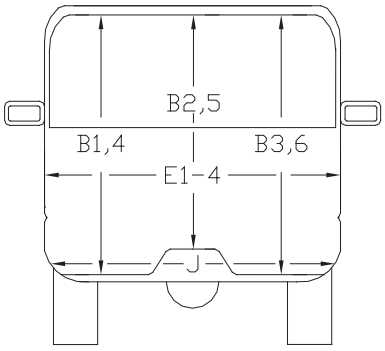
Table E.4. Occupant Compartment Measurements for Test No. 490026-2-8.

Date: 2016-03-03 Test No.: 490026-2-8 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	65.50	65.50
A2	63.50	63.50
A3	65.50	65.50
B1	45.00	45.00
B2	37.75	37.75
B3	45.00	45.00
B4	39.50	39.50
B5	41.00	41.00
B6	39.50	39.50
C1	26.50	26.50
C2	-----	-----
C3	26.00	26.00
D1	11.25	11.25
D2	-----	-----
D3	11.25	11.25
E1	58.50	58.50
E2	63.50	63.50
E3	63.50	63.50
E4	63.25	63.25
F	59.00	59.00
G	59.00	59.00
H	37.50	37.50
I	37.50	37.50
J*	23.00	23.00

E2 SEQUENTIAL PHOTOGRAPHS

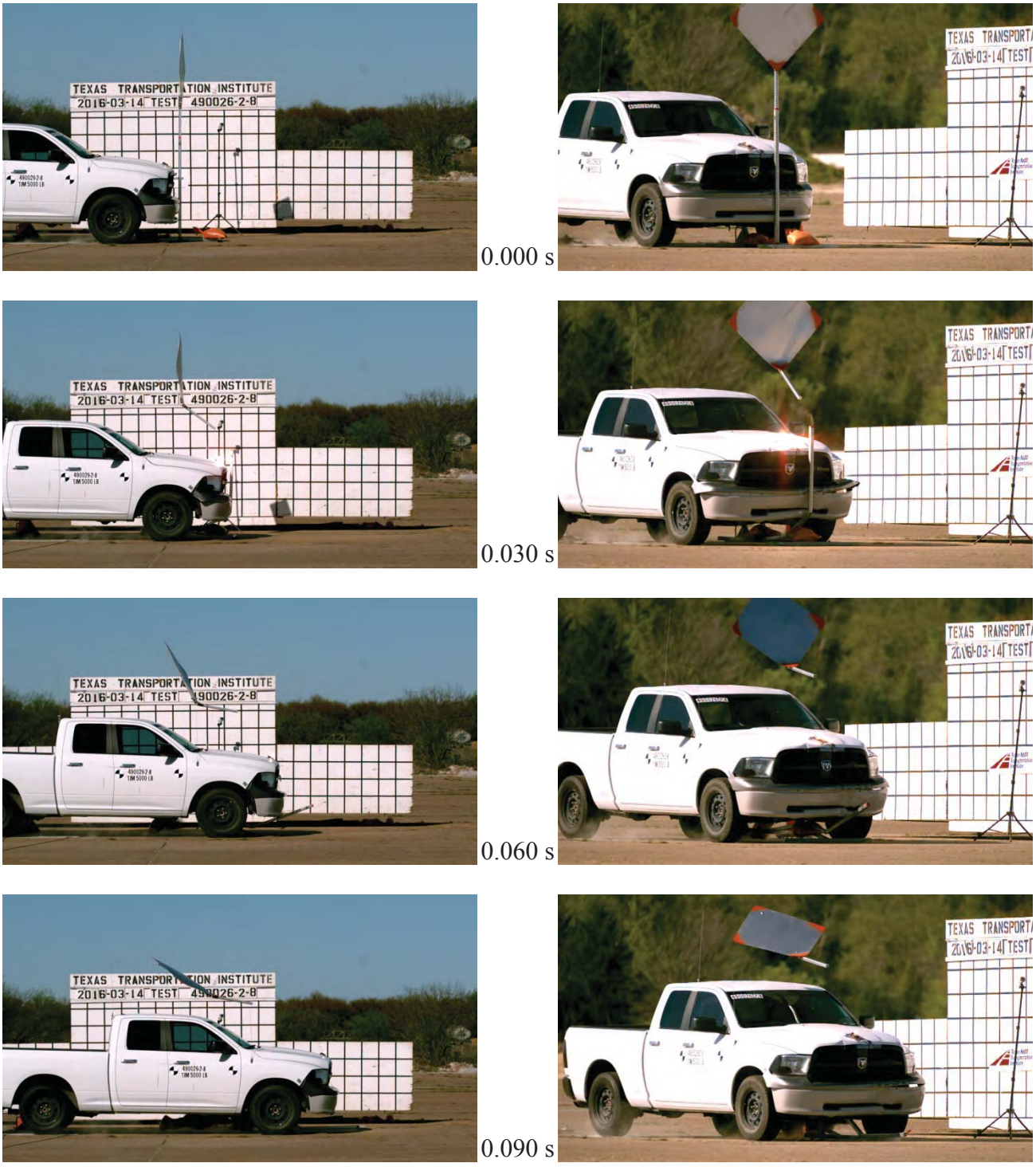


Figure E.1. Sequential Photographs for Test No. 490026-2-8 (Perpendicular and Oblique Views).

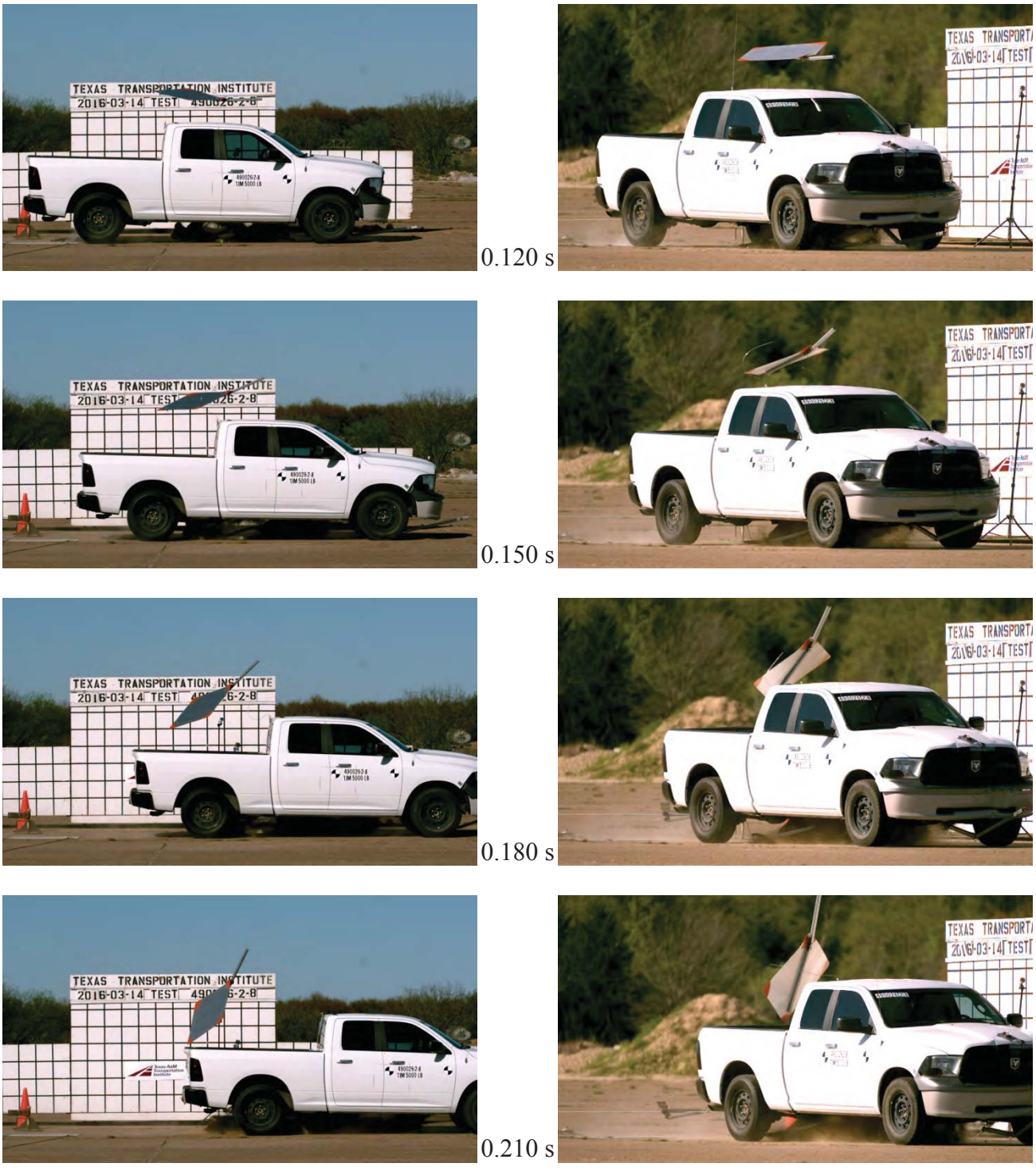


Figure E.1. Sequential Photographs for Test No. 490026-2-8 (Perpendicular and Oblique Views) (Continued).

APPENDIX F. CRASH TEST NO. 490026-2-3 (*MASH* TEST 3-72)

F1 VEHICLE PROPERTIES AND INFORMATION

Table F.1. Vehicle Properties for Test No. 490026-2-3.

Date: 2016-03-03 Test No.: 490026-2-1/2/3 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 173708

Note any damage to the vehicle prior to test: None noted

● Denotes accelerometer location.

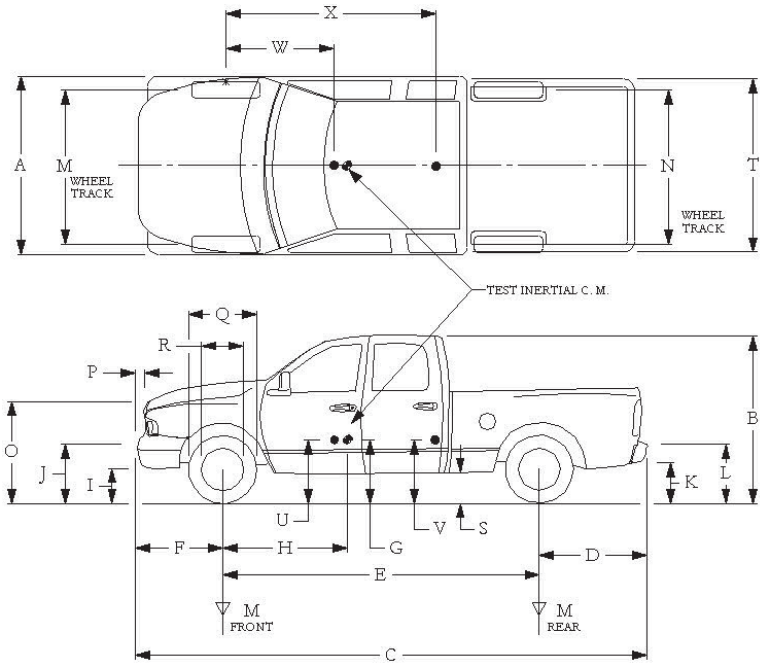
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

Transmission Type:
x Auto or ___ Manual
___ FWD x RWD ___ 4WD

Optional Equipment:
None

Dummy Data:
Type: No dummy
Mass: NA
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	19.50	P	3.00	U	-----
B	74.00	G	28.38	L	29.00	Q	30.50	V	-----
C	227.50	H	62.43	M	68.50	R	18.00	W	-----
D	47.00	I	12.50	N	68.00	S	13.00	X	-----
E	140.50	J	27.50	O	46.50	T	77.00		-----

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	17.00
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	25.50

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; M+N/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2850	2786	----
Back	3900	M_{rear}	2048	2228	----
Total	6700	M_{Total}	4898	5014	----

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1388 RF: 1398 LR: 1084 RR: 1144

Table F.2. Measurements of Vehicle Vertical CG for Test No. 490026-2-3.

Date: 2016-03-03 Test No.: 490026-2-1/2/3 VIN: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 173708

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 228 lb (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70R17

Measured Vehicle Weights: (lb)								
LF:	1388	RF:	1398	Front Axle:	2786			
LR:	1084	RR:	1144	Rear Axle:	2228			
Left:	2472	Right:	2542	Total:	5014			
				5000 ±110 lb allowed				
Wheel Base:	140.5 inches	Track: F:	68.5 inches	R:	68 inches			
148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed					
Center of Gravity, SAE J874 Suspension Method								
X:	62.43 in	Rear of Front Axle	(63 ±4 inches allowed)					
Y:	0.48 in	Left -	Right +	of Vehicle Centerline				
Z:	28.375 in	Above Ground	(minumum 28.0 inches allowed)					

Hood Height: 46.5 inches (43 ±4 inches allowed)

Front Bumper Height: 27.5 inches

Front Overhang: 40.0 inches (39 ±3 inches allowed)

Rear Bumper Height: 29.0 inches

Overall Length: 227.5 inches (237 ±13 inches allowed)

Table F.3. Exterior Crush Measurements for Test No. 490026-2-3.

Date: 2016-03-03 Test No.: 490026-2-3 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

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		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	---	2.5	---	---	---	---	---	---	---	---
	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).

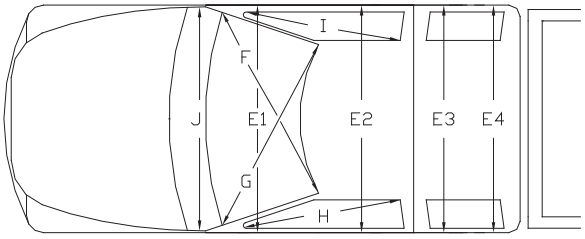
***Measure and document on the vehicle diagram the location of the maximum crush.

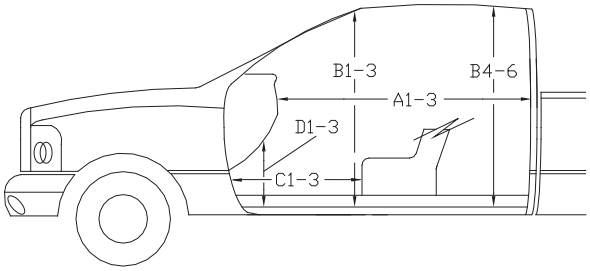
Note: Use as many lines/columns as necessary to describe each damage profile.

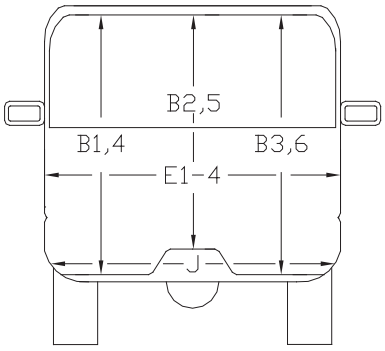
Table F.4. Occupant Compartment Measurements for Test No. 490026-2-3.

Date: 2016-03-03 Test No.: 490026-2-3 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	65.50	65.50
A2	63.50	63.50
A3	65.50	65.50
B1	45.00	45.00
B2	37.75	37.75
B3	45.00	45.00
B4	39.50	39.50
B5	41.00	41.00
B6	39.50	39.50
C1	26.50	26.50
C2	-----	-----
C3	26.00	26.00
D1	11.25	11.25
D2	-----	-----
D3	11.25	11.25
E1	58.50	58.50
E2	63.50	63.50
E3	63.50	63.50
E4	63.25	63.25
F	59.00	59.00
G	59.00	59.00
H	37.50	37.50
I	37.50	37.50
J*	23.00	23.00

F2 SEQUENTIAL PHOTOGRAPHS

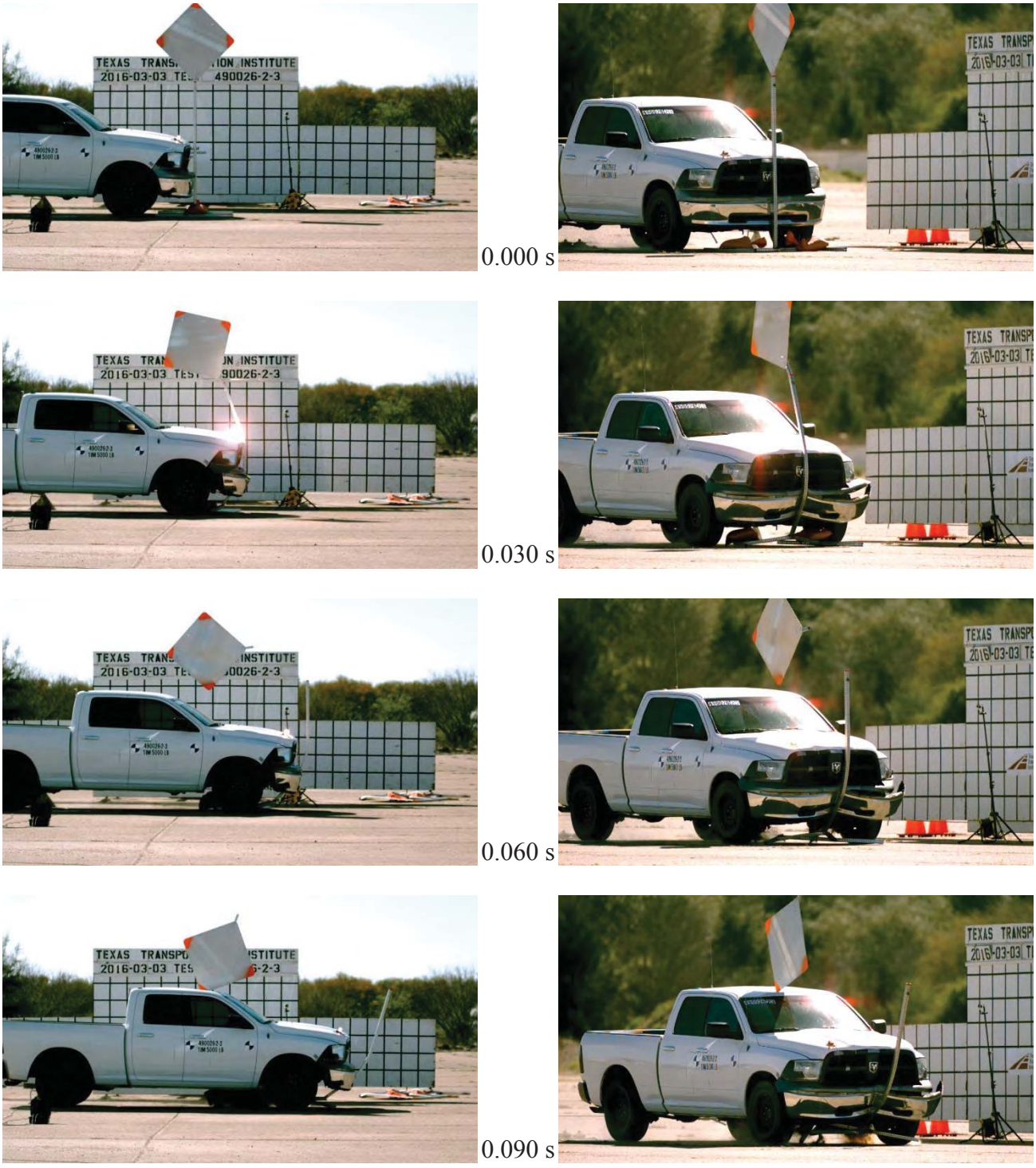


Figure F.1. Sequential Photographs for Test No. 490026-2-3 (Perpendicular and Oblique Views).

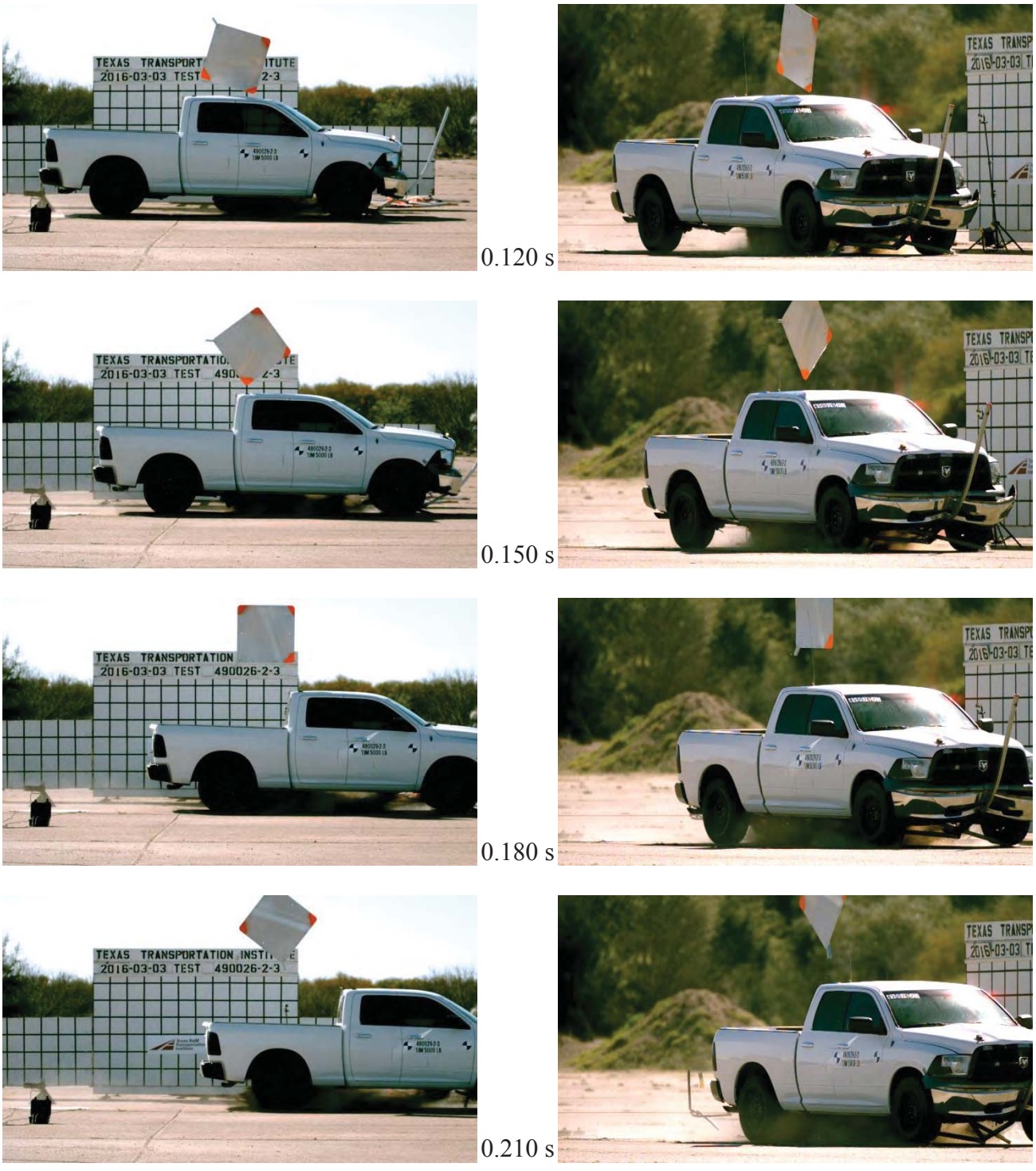


Figure F.1. Sequential Photographs for Test No. 490026-2-3 (Perpendicular and Oblique Views) (Continued).

APPENDIX G. CRASH TEST NO. 490026-2-5 (*MASH* TEST 3-71)

G1 VEHICLE PROPERTIES AND INFORMATION

Table G.1. Vehicle Properties for Test No. 490026-2-5.

Date: 2016-03-11 Test No.: 490026-2-4/5/6/7 VIN No.: KNAD14A35B6916812

Year: 2011 Make: Kia Model: Rio

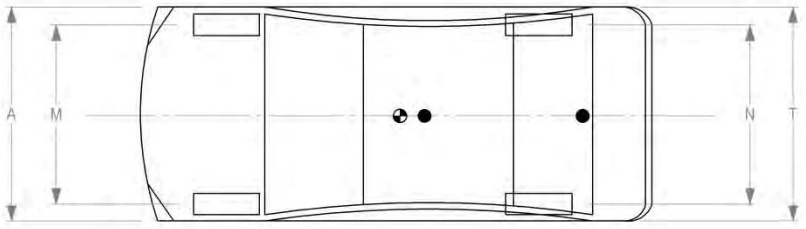
Tire Inflation Pressure: 32 psi Odometer: 95120 Tire Size: P185/65R14

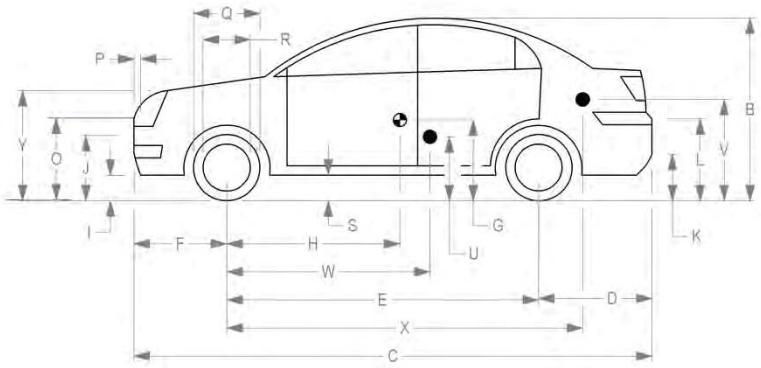
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None

Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:
None





Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Driver

Geometry: inches

A	66.38	F	33.00	K	12.20	P	4.12	U	NA
B	58.00	G	-----	L	25.00	Q	22.50	V	NA
C	165.75	H	35.93	M	57.75	R	15.50	W	NA
D	34.00	I	8.00	N	57.10	S	7.25	X	NA
E	98.75	J	21.50	O	28.25	T	66.20	Y	27.00
Wheel Center Ht Front		11.00		Wheel Center Ht Rear		11.00		W-H	NA

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1918	M_{front}	1579	1554	1640
Back	1874	M_{rear}	900	889	968
Total	3638	M_{Total}	2479	2443	2608

Allowable TIM = 2420 lb ±55 lb | Allowable GSM = 2585 lb ± 55 lb

Mass Distribution:
lb LF: 800 RF: 754 LR: 440 RR: 449

Table G.2. Exterior Crush Measurements for Test No. 490026-2-5.

Date: 2016-03-11 Test No.: 490026-2-5 VIN No.: KNAD14A35B6916812

Year: 2011 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		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	0	0	---	---	---	---	---	---	---	---
	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).

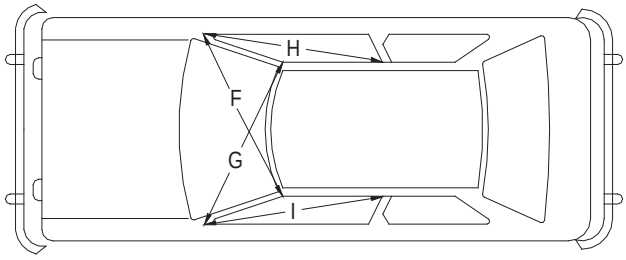
***Measure and document on the vehicle diagram the location of the maximum crush.

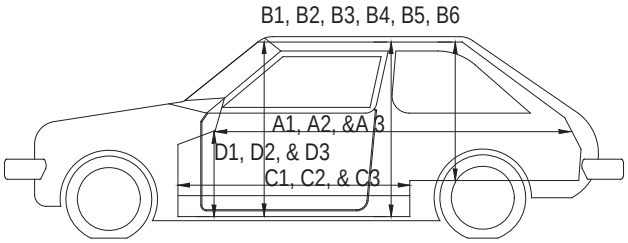
Note: Use as many lines/columns as necessary to describe each damage profile.

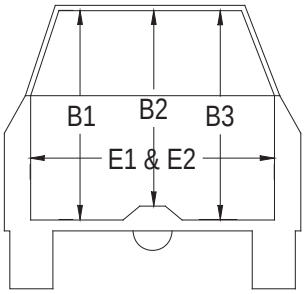
Table G.3. Occupant Compartment Measurements for Test No. 490026-2-5.

Date: 2016-03-11 Test No.: 490026-2-5 VIN No.: KNAD14A35B6916812

Year: 2011 Make: Kia Model: Rio







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	67.50	67.50
A2	67.25	67.25
A3	67.75	67.75
B1	40.50	40.50
B2	35.75	35.75
B3	40.50	40.50
B4	36.00	36.00
B5	32.50	32.50
B6	36.00	36.00
C1	27.25	27.25
C2	-----	-----
C3	27.00	27.00
D1	9.50	9.50
D2	-----	-----
D3	9.25	9.25
E1	51.50	51.50
E2	51.00	51.00
F	51.00	51.00
G	51.00	51.00
H	37.50	37.50
I	37.50	37.50
J*	51.00	51.00

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

G2 SEQUENTIAL PHOTOGRAPHS

Figure G.1. Sequential Photographs for Test No. 490026-2-5 (Perpendicular and Oblique Views).

0.120 s

0.150 s

0.180 s

0.210 s

Figure G.1. Sequential Photographs for Test No. 490026-2-5 (Perpendicular and Oblique Views) (Continued).

APPENDIX H. CRASH TEST NO. 490026-2-7 (*MASH* TEST 3-71)

H1 VEHICLE PROPERTIES AND INFORMATION

Table H.1. Vehicle Properties for Test No. 490026-2-7.

Date: 2016-03-11 Test No.: 490026-2-7 VIN No.: KNAD14A35B6916812

Year: 2011 Make: Kia Model: Rio

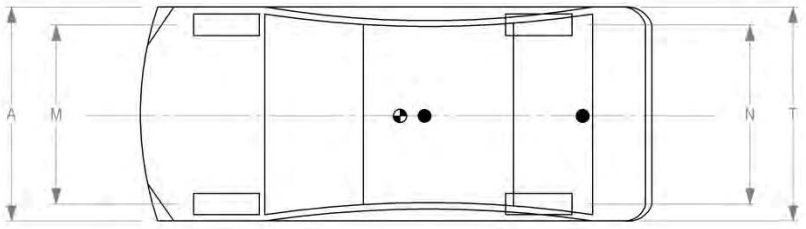
Tire Inflation Pressure: 32 psi Odometer: 95120 Tire Size: P185/65R14

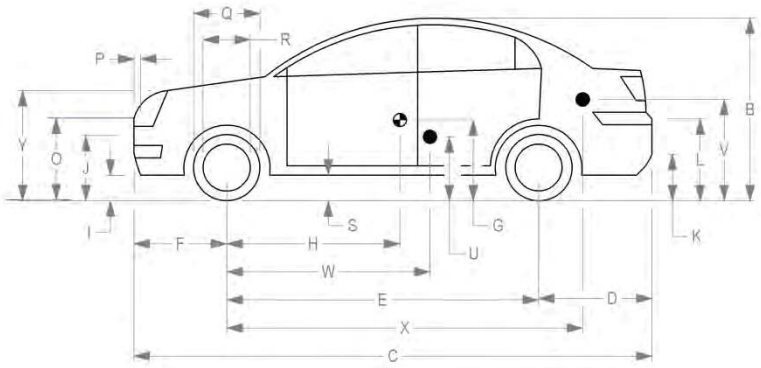
Describe any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None

Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:
None





Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Driver

Geometry: inches

A	66.38	F	33.00	K	12.20	P	4.12	U	NA
B	58.00	G	-----	L	25.00	Q	22.50	V	NA
C	165.75	H	35.93	M	57.75	R	15.50	W	NA
D	34.00	I	8.00	N	57.10	S	7.25	X	NA
E	98.75	J	21.50	O	28.25	T	66.20	Y	27.00
	Wheel Center Ht Front		11.00		Wheel Center Ht Rear		11.00	W-H	NA

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1918	M_{front}	1579	1554	1640
Back	1874	M_{rear}	900	889	968
Total	3638	M_{Total}	2479	2443	2608

Allowable TIM = 2420 lb ±55 lb | Allowable GSM = 2585 lb ± 55 lb

Mass Distribution:
lb LF: 800 RF: 754 LR: 440 RR: 449

Table H.2. Exterior Crush Measurements for Test No. 490026-2-7.

Date: 2016-03-11 Test No.: 490026-2-7 VIN No.: KNAD14A35B6916812

Year: 2011 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		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	0	0	---	---	---	---	---	---	---	---
	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).

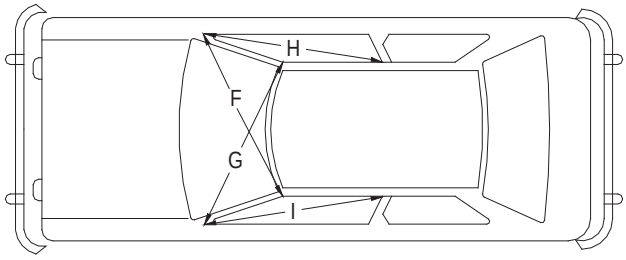
***Measure and document on the vehicle diagram the location of the maximum crush.

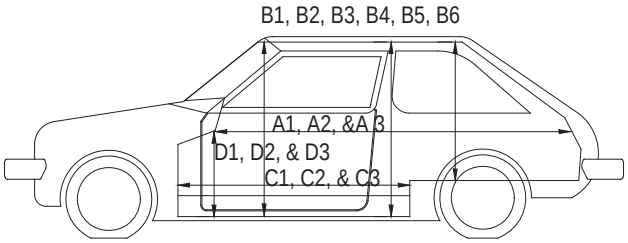
Note: Use as many lines/columns as necessary to describe each damage profile.

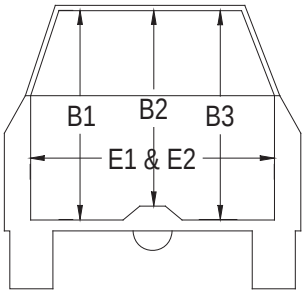
Table H.3. Occupant Compartment Measurements for Test No. 490026-2-7.

Date: 2016-03-11 Test No.: 490026-2-7 VIN No.: KNAD14A35B6916812

Year: 2011 Make: Kia Model: Rio







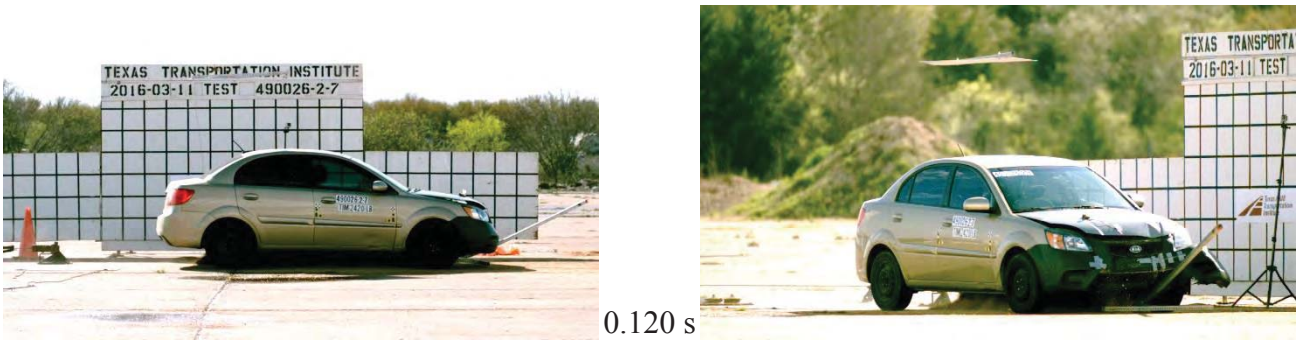
OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

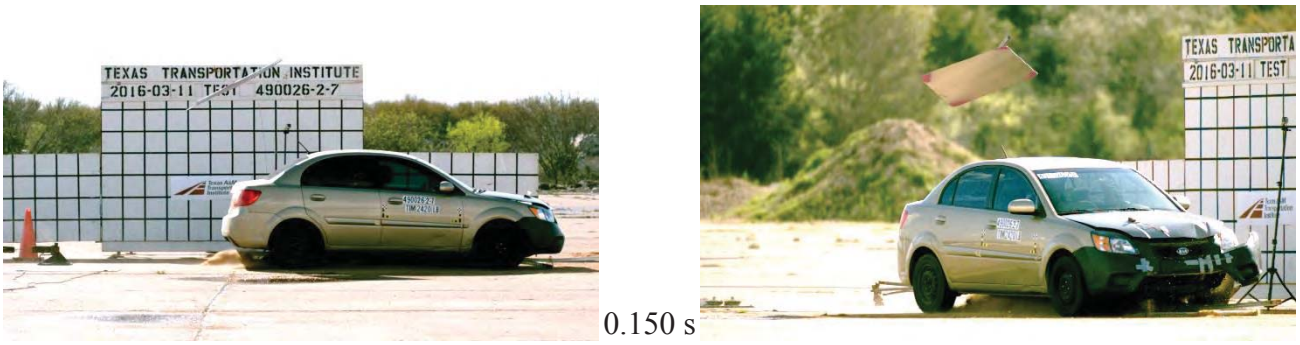
	Before (inches)	After (inches)
A1	67.50	67.50
A2	67.25	67.25
A3	67.75	67.75
B1	40.50	40.50
B2	35.75	35.75
B3	40.50	40.50
B4	36.00	36.00
B5	32.50	32.50
B6	36.00	36.00
C1	27.25	27.25
C2	-----	-----
C3	27.00	27.00
D1	9.50	9.50
D2	-----	-----
D3	9.25	9.25
E1	51.50	51.50
E2	51.00	51.00
F	51.00	51.00
G	51.00	51.00
H	37.50	37.50
I	37.50	37.50
J*	51.00	51.00

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

H2 SEQUENTIAL PHOTOGRAPHS

Figure H.1. Sequential Photographs for Test No. 490026-2-7 (Perpendicular and Oblique Views).





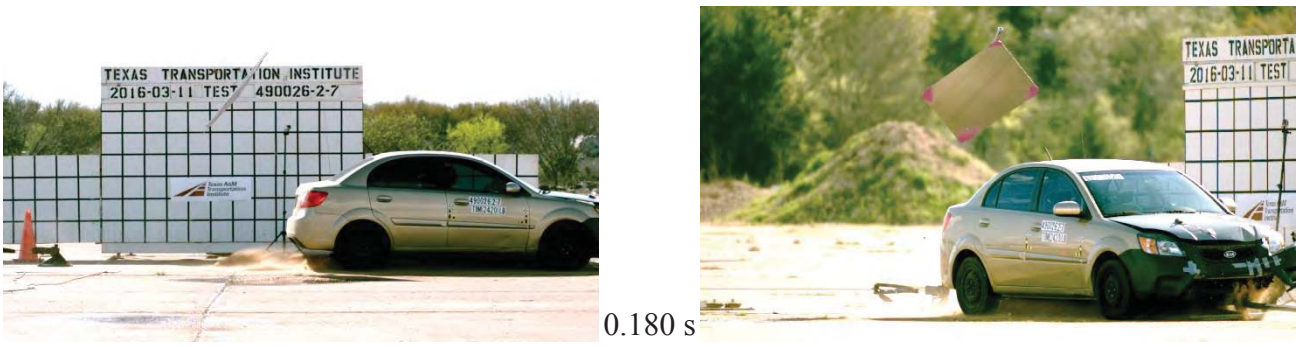


Figure H.1. Sequential Photographs for Test No. 490026-2-7 (Perpendicular and Oblique Views) (Continued).

APPENDIX I. CRASH TEST NO. 490026-2-9 (*MASH* TEST 3-72)

I1 VEHICLE PROPERTIES AND INFORMATION

Table I.1. Vehicle Properties for Test No. 490026-2-9.

Date: 2016-03-03 Test No.: 490026-2-9 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

Tire Size: 265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 173708

Note any damage to the vehicle prior to test: None noted

● Denotes accelerometer location.

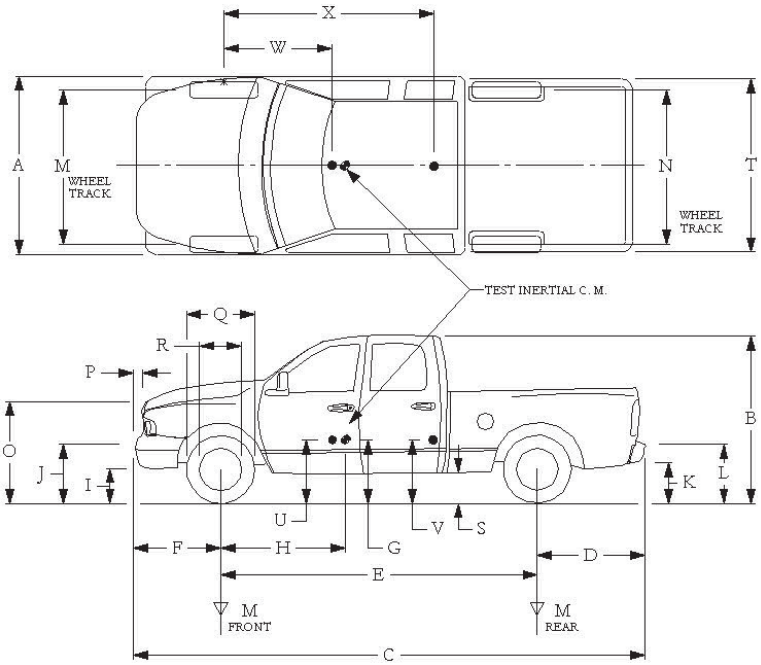
NOTES: None

Engine Type: V-8
Engine CID: 4.7 liter

Transmission Type:
x Auto or ___ Manual
___ FWD x RWD ___ 4WD

Optional Equipment:
None

Dummy Data:
Type: No dummy
Mass: NA
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	19.50	P	3.00	U	-----
B	74.00	G	28.38	L	29.00	Q	30.50	V	-----
C	227.50	H	62.43	M	68.50	R	18.00	W	-----
D	47.00	I	12.50	N	68.00	S	13.00	X	-----
E	140.50	J	27.50	O	46.50	T	77.00		-----

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	17.00
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	25.50

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; M+N/2=67 ±1.5 inches

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2850	2786	----
Back	3900	M_{rear}	2048	2228	----
Total	6700	M_{Total}	4898	5014	----

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:
lb LF: 1388 RF: 1398 LR: 1084 RR: 1144

Table I.2. Measurements of Vehicle Vertical CG for Test No. 490026-2-9.

Date: 2016-03-03 Test No.: 490026-2-8 & 9 VIN: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 173708

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 228 lb (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70R17

Measured Vehicle Weights: (lb)								
LF:	1388	RF:	1398	Front Axle:	2786			
LR:	1084	RR:	1144	Rear Axle:	2228			
Left:	2472	Right:	2542	Total:	5014			
				5000 ±110 lb allowed				
Wheel Base:	140.5 inches	Track: F:	68.5 inches	R:	68 inches			
148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed					
Center of Gravity, SAE J874 Suspension Method								
X:	62.43 in	Rear of Front Axle	(63 ±4 inches allowed)					
Y:	0.48 in	Left -	Right +	of Vehicle Centerline				
Z:	28.375 in	Above Ground	(minumum 28.0 inches allowed)					

Hood Height: 46.5 inches
43 ±4 inches allowed

Front Bumper Height: 27.5 inches

Front Overhang: 40.0 inches
39 ±3 inches allowed

Rear Bumper Height: 29.0 inches

Overall Length: 227.5 inches
237 ±13 inches allowed

Table I.3. Exterior Crush Measurements for Test No. 490026-2-9.

Date: 2016-03-03 Test No.: 490026-2-9 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500

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		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	---	3.5	---	---	---	---	---	---	---	---
	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).

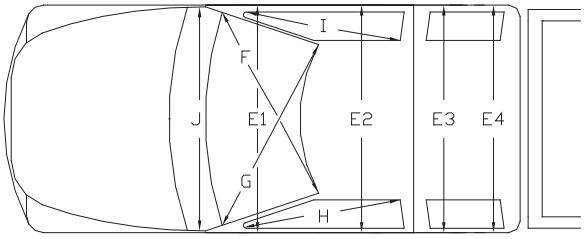
***Measure and document on the vehicle diagram the location of the maximum crush.

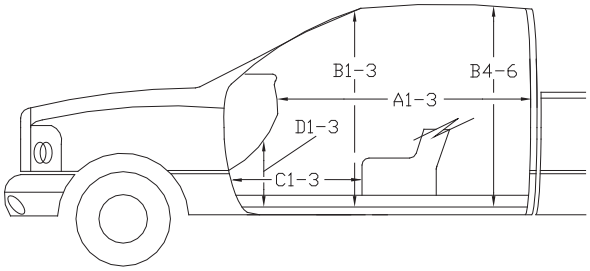
Note: Use as many lines/columns as necessary to describe each damage profile.

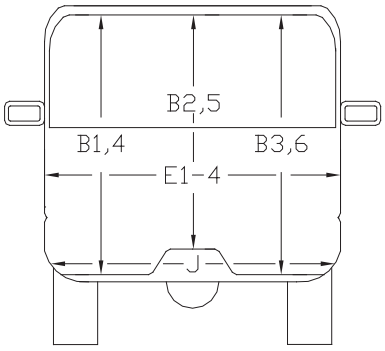
Table I.4. Occupant Compartment Measurements for Test No. 490026-2-9.

Date: 2016-03-03 Test No.: 490026-2-9 VIN No.: 1D7RB1GP5AS126554

Year: 2010 Make: Dodge Model: Ram 1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	65.50	65.50
A2	63.50	63.50
A3	65.50	65.50
B1	45.00	45.00
B2	37.75	37.75
B3	45.00	45.00
B4	39.50	39.50
B5	41.00	41.00
B6	39.50	39.50
C1	26.50	26.50
C2	-----	-----
C3	26.00	26.00
D1	11.25	11.25
D2	-----	-----
D3	11.25	11.25
E1	58.50	58.50
E2	63.50	63.50
E3	63.50	63.50
E4	63.25	63.25
F	59.00	59.00
G	59.00	59.00
H	37.50	37.50
I	37.50	37.50
J*	23.00	23.00

I2 SEQUENTIAL PHOTOGRAPHS

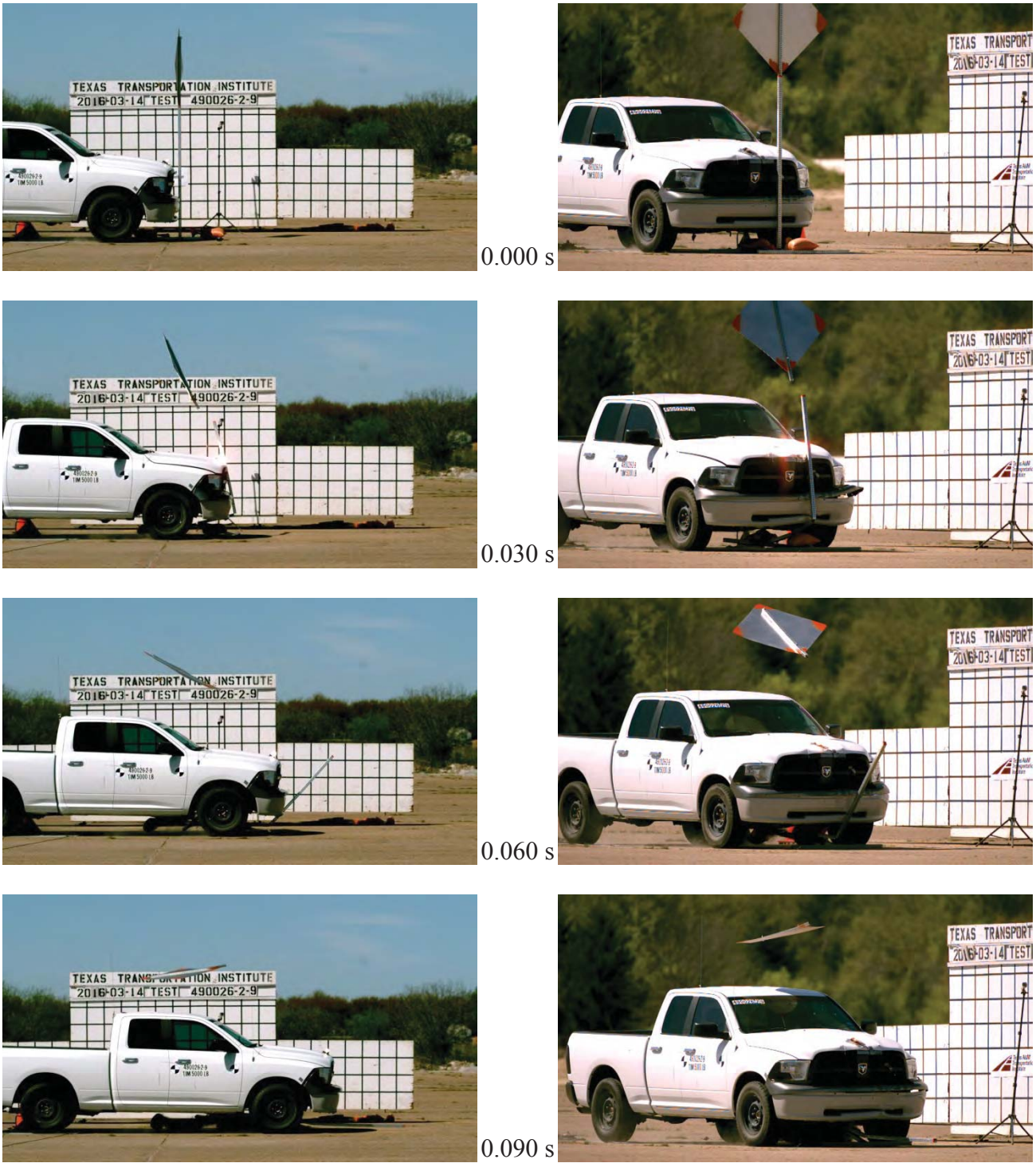


Figure I.1. Sequential Photographs for Test No. 490026-2-9 (Perpendicular and Oblique Views).

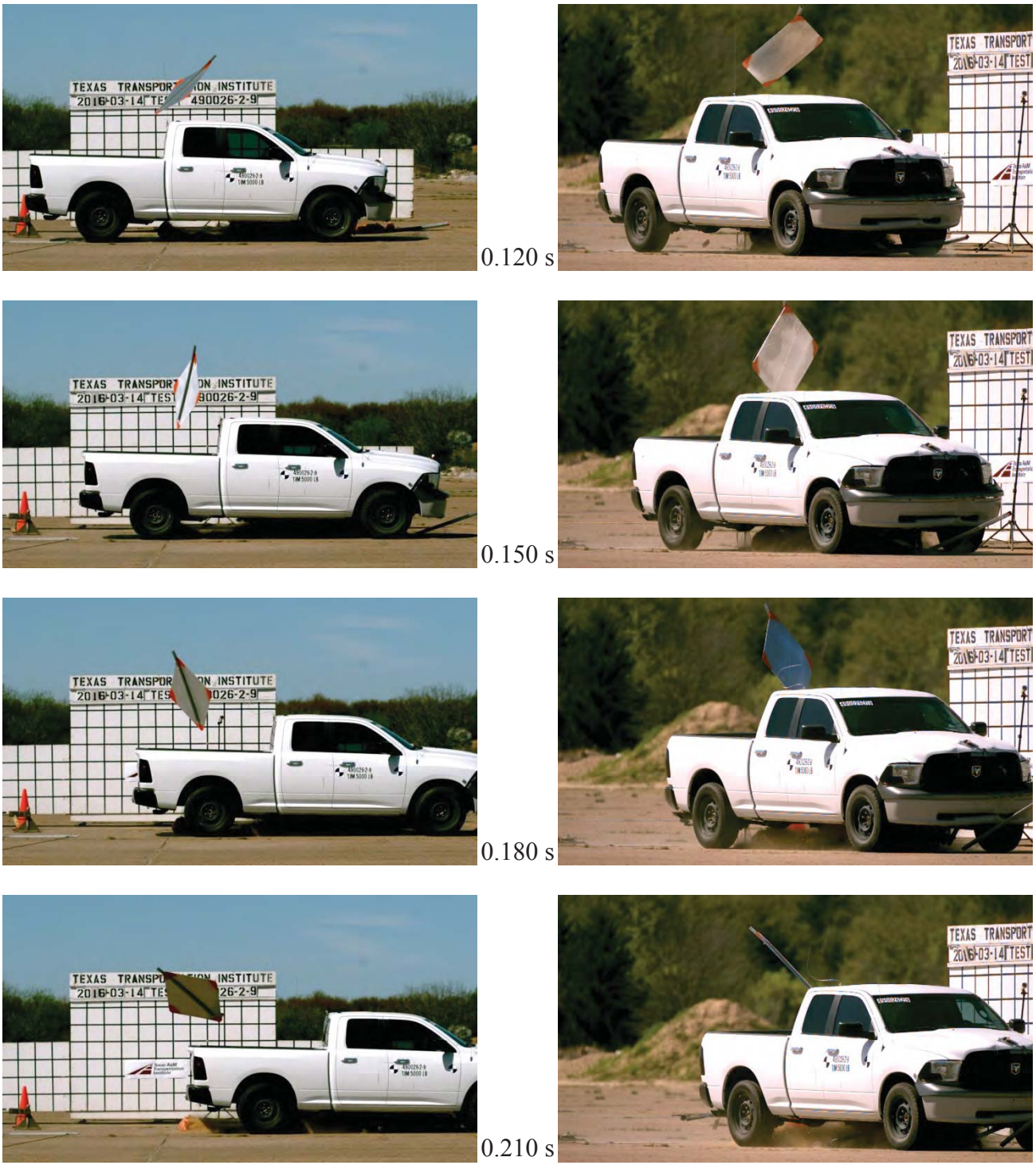


Figure I.1. Sequential Photographs for Test No. 490026-2-9 (Perpendicular and Oblique Views) (Continued).