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Development and *MASH* Full-Scale Crash Testing of a High-Mounting-Height Temporary Single Sign Support with Aluminum Sign

Test Report No. 9-1002-12-5

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
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16. Abstract

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 and the Manual on Uniform Traffic Control Devices require work zone traffic control devices to be crashworthy. That is, they should not pose a safety hazard to motorists and/or work zone personnel if impacted by errant vehicles. The objective of this research was to develop a nonproprietary, lightweight, crashworthy, work-zone single sign support for use with an aluminum sign substrate mounted at a height of 7 ft. The device is intended to meet the evaluation criteria in *MASH*.

Texas A&M Transportation Institute (TTI) researchers decided to utilize perforated steel tubing for the frame of the new temporary single sign support system to accommodate requests to help make the system lightweight, durable, easy to assemble, and adjustable. Design concepts were developed and evaluated through engineering analysis, developmental full-scale crash tests, and finite element computer simulations. Results were reviewed with the project monitoring committee and a system was selected by TxDOT for evaluation through full-scale crash testing.

MASH Test 3-72 with the 2270P pickup truck was performed to evaluate the behavior of the sign support oriented at both 90 degrees and 0 degrees. The sign support system oriented at 0 degrees passed all the *MASH* evaluation criteria. Secondary contact between the pickup truck and the aluminum sign panel of the sign support system oriented at 90 degrees caused a cut in the roof that constituted occupant compartment intrusion. Consequently, the sign support system did not pass MASH occupant risk criteria. The report recommendations possible design modifications to mitigate this behavior and improve impact performance for the pickup truck.

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DEVELOPMENT AND *MASH* FULL-SCALE CRASH TESTING OF A HIGH-MOUNTING-HEIGHT TEMPORARY SINGLE SIGN SUPPORT WITH ALUMINUM SIGN

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DISCLAIMER

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

TTI PROVING GROUND DISCLAIMER

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

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CHAPTER 1. INTRODUCTION

1.1 RESEARCH PROBLEM STATEMENT

Traffic control devices such as temporary sign supports are a primary means of communicating information to motorists in work zones. The Federal Highway Administration (FHWA) and the Manual on Uniform Traffic Control Devices (MUTCD) require work zone traffic control devices to be crashworthy (*1*). That is, they should not pose a safety hazard to motorists and/or work zone personnel if impacted by errant vehicles. The American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) contains recommended procedures for testing and evaluation of work zone traffic control devices such as temporary sign supports (*2*).

Maintenance personnel and contractors have expressed interest in lightweight sign support systems that are easy to handle and transport. For these reasons, perforated steel tubing has become a popular choice for the fabrication of frames for temporary sign support systems. Perforated steel tubing is relatively lightweight compared to other materials such as wood, thus making it easier to handle and transport. The galvanized steel also provides good durability and low maintenance (e.g., it does not require painting). However, the single, temporary sign support system fabricated from perforated steel tubing requires the use of a corrugated plastic sign panel. The Texas Department of Transportation (TxDOT) expressed desire to develop a nonproprietary, lightweight, crashworthy, temporary single sign support system that can be used with an aluminum sign substrate, which is stiffer and more durable than corrugated plastic.

1.2 RESEARCH OBJECTIVES

The objective of this research was to develop a nonproprietary, lightweight, crashworthy, temporary single sign support system that can be used with an aluminum sign substrate. The device is intended to meet the evaluation criteria in *MASH*. In addition to crashworthiness, due consideration is given to cost and functionality. It was further desired that the sign support frame possess a reasonable degree of adjustability to achieve the 7-ft mounting height and accommodate placement under varying site conditions. Texas A&M Transportation Institute (TTI) researchers decided to utilize perforated steel tubing for the frame of the new temporary single sign support system to help accommodate the requests that the system be lightweight, durable, easy to assemble, and adjustable.

In order to understand the impact behavior and failure modes of perforated steel tubing, previous crash tests were critically analyzed. Three different design concepts were developed through engineering analysis and developmental full-scale crash tests with a *MASH* 1100C vehicle. Impact behavior was analyzed and finite element computer simulations were performed to help predict whether or not secondary contact between the support system and a *MASH* 2270P vehicle would occur, and the probable location of the contact. Additional engineering analysis and computer simulation were conducted to modify the designs to include height adjustability for placement in ditches. Results were reviewed with the project monitoring committee and a system was selected by TxDOT for evaluation with full-scale crash tests.

This report summarizes the findings of the project. Chapter 2 describes testing requirements for work-zone devices. The state of the practice pertaining to work-zone traffic control devices as determined from a review of the literature and ongoing research is summarized in Chapter 3. Chapter 4 describes the developmental full-scale crash tests conducted with a *MASH* 1100C vehicle to evaluate the proposed single support design alternatives. Chapter 5 contains computer simulation analyses performed in support to the design evaluation. A *MASH* full-scale crash test of the selected temporary single sign support system with a 2270P pickup truck is reported in Chapter 6. Chapter 7 contains a summary and recommendations for future work regarding the temporary single sign support.

1.3 TESTING REQUIREMENTS FOR WORK ZONE DEVICES

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 mph. This test is recommended to accurately identify the potential for test article intrusion into 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 mph. This test is recommended to accurately identify the potential for test article intrusion into 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 CIP of the LON of the barrier at a nominal impact speed and angle of 62 mph. This test is recommended to accurately identify the potential for test article intrusion into the windshield or roof of a light truck and sport utility vehicle when impacting the test article at a high speed.

FHWA 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. In order to reduce testing cost, FHWA permits the evaluation of both the 0 and 90 degree orientations using two separate devices impacted in sequence in a single crash test.

The crash tests and data analysis procedures performed for this research were in accordance with guidelines presented in *MASH*. The tests reported herein correspond to *MASH*

Test 3-71 (2425-lb passenger car, 62 mph, 90- and 0-degree sign orientation) and *MASH* Test 3-72 (5000-lb pickup, 62 mph, 90 and 0-degree sign orientation).

1.4 EVALUATION CRITERIA FOR WORK ZONE DEVICES

The crash tests were evaluated in accordance with the criteria presented in *MASH*. The performance of the work-zone support structures is judged on the basis of three factors: structural adequacy, occupant risk, and post impact vehicle trajectory. Structural adequacy is judged upon the ability of the support structure to readily activate in a predictable manner by breaking away, fracturing, or yielding. Occupant risk criteria evaluates the potential risk of hazard to occupants in the impacting vehicle, and to some extent other traffic, pedestrians, or workers in construction zones, if applicable. Post impact vehicle trajectory is assessed to determine 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 described in further detail under the assessment of each crash test.

CHAPTER 2. CRASH TEST PROCEDURES

2.1 TEST FACILITY

The full-scale crash test reported herein was performed at Texas A&M Transportation Institute (TTI) Proving Ground. TTI Proving Ground is an International Standards Organization (ISO) 17025 accredited laboratory with American Association for Laboratory Accreditation (A2LA) 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 an Air Force base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for testing of the temporary sign support evaluated under this project was on the surface of an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5 ft by 15 ft blocks nominally 6 inches deep. The apron is over 60 years old, and the joints have some displacement, but are otherwise flat and level.

2.2 VEHICLE TOW AND GUIDANCE PROCEDURES

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

2.3 DATA ACQUISITION SYSTEMS

2.3.1 Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems, Inc. The accelerometers, that measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra small size, solid state units designs for crash test service. The TDAS Pro hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 values per second with a resolution of one part in 65,536. Once recorded, the data are backed up inside the unit by internal batteries should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark as well as initiating the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The raw data are then processed by the Test Risk Assessment Program (TRAP) software to produce detailed reports of the test results. Each of the TDAS Pro units are returned to the factory annually for complete recalibration. Accelerometers and rate transducers are also calibrated annually with traceability to the National Institute for Standards and Technology.

TRAP uses the data from the TDAS Pro to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact.

2.3.2 Anthropomorphic Dummy Instrumentation

Use of a dummy in the 2270P vehicle is optional according to *MASH*, and there was no dummy used in the test with the 2270P vehicle. The tests run with the 1100C vehicle were developmental in nature, and no dummy was used in the tests.

2.3.3 Photographic Instrumentation and Data Processing

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked motion analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-DV camera and still cameras recorded and documented conditions of the test vehicle and installation before and after the test.

CHAPTER 3. LITERATURE REVIEW AND ENGINEERING ANALYSIS*

3.1 CATEGORIES OF WORK ZONE DEVICES

Along with FHWA's formal adoption of *NCHRP Report 350* came many questions from the manufacturers, suppliers, and user agencies regarding the requirements for testing various work-zone devices ranging from traffic cones, delineators, and drums to barricades, temporary sign supports, work-zone barriers, and truck-mounted attenuators. Although some of these devices are obviously benign in nature, others can represent significant hazards to occupants of the impacting vehicle, surrounding traffic, and nearby workers. *NCHRP Report 350* recognizes that, depending on the nature of the device, less rigorous test procedures may be appropriate (refer to Section 3.2.3.2 of *NCHRP Report 350*). For example, for tests of free-standing objects with masses less than 99 lb, instrumentation can be reduced. However, to remove some of the subjectivity and provide further clarification of this issue, FHWA defined four categories of work-zone devices in the July 25, 1997, memorandum, "Identifying Acceptable Highway Safety Features." These categories are used to determine an appropriate level of effort needed to demonstrate crashworthiness. These categories are defined as follows:

- Category 1 includes small and lightweight channelizing and delineating devices that have been in common use for many years and are known to be crashworthy by crash testing of similar devices or years of demonstrable safe performance. These devices include cones, tubularmarkers, flexible delineator posts, and plastic drums with and without warning lights securely attached. These devices may be allowed for use on the NHS based on the developer's self-certification subject to approval by the individual highway agencies.

- Category 2 includes devices that are not expected to produce significant vehicular velocity change but may otherwise be hazardous. Examples of this class are barricades, portable sign supports, intrusion alarms, and drums with sign panels attached. Testing of devices in this category is required. However, they may qualify for the reduced testing requirements, and less instrumentation than required in *NCHRP Report 350* may be acceptable.

- Category 3 is for hardware that is expected to cause significant velocity change or other potentially harmful reactions to impacting vehicles. Hardware in this category must be tested to the full requirement of *NCHRP Report 350.* Barriers, fixed sign supports, crash cushions, and other work-zone devices not meeting the definitions of Category 1 or 2 are examples from this category.

- Category 4 includes portable or trailer-mounted devices such as flashing arrow panels, temporary traffic signals, area lighting supports, and portable changeable message signs. Per FHWA Acceptance Letter WZ-161, dated

* TTI Proving Ground is an ISO 17025 accredited laboratory with A2LA Mechanical Testing certificate 2821.01. The scope of this certificate does not include simulation/engineering analysis.

> December 24, 2004, FHWA will look at the state of the art of the portable sign industry and the number and severity of real-world crashes with these devices in order to establish policy on their use. The current deadline for this policy review is October 1, 2006.

3.2 STATE OF THE PRACTICE

3.2.1 Recent Research and Testing

Research and testing programs have emphasized the need to evaluate the impact performance of portable sign supports. Over the years, TxDOT has been very active in assessing the impact performance of various work-zone traffic control devices, and seeking input from manufacturers, contractors, and state maintenance personnel in the process. The objective of the TxDOT research has been to provide generic, cost-effective work-zone traffic control devices meeting the national safety performance guidelines contained in *NCHRP Report 350* and, more recently, *MASH*.

3.2.1.1 High-Mounting-Height Dual Sign Support

The researchers reviewed past tests performed with high-mounting-height dual sign supports to understand and evaluate the behavior of these systems. Particular attention was given to the material used for the sign support system and the criteria used for testing and evaluation (*NCHRP Report 350* or *MASH*). A brief design description and summary of test results for each test investigated is presented in Appendix A.

3.2.1.2 High-Mounting-Height Single Sign Support

The researchers reviewed past tests performed with high-mounting-height single sign supports to understand and evaluate the behavior of these systems. Particular attention was given to the material used for the sign support system and the criteria used for testing and evaluation (*NCHRP Report 350* or *MASH*). A brief design description and summary of test results for each test investigated is presented in Appendix B.

3.2.2 Design Considerations

During the design of the work-zone temporary single sign support, the researchers considered various factors that can influence the impact performance, function, and utility of the device to help ensure that it would be effectively and efficiently meet its intended purpose.

3.2.2.1 Factors Influencing Crashworthiness

The work-zone temporary single sign support device must be compliant with *MASH* guidelines before it can be implemented on the National Highway System (NHS). There are different factors that can affect the impact performance of the device. These include, but are not necessarily limited to, mass of the primary components, connection details between the structural components, failure mode of said connections, sign substrate material, sign panel size, and mounting height.

The mass of the system components is known to influence the tendency for and severity of occupant compartment deformation or intrusion (*3, 4, 5*). A small change in size or dimension of the system components can considerably improve impact performance (*5*). The impact performance of the device can also depend on the failure mode of its supports and/or connections. Some devices incorporate components that breakaway or fracture at impact (*3, 6*), while other devices are designed to yield and bend at their base (*3, 7*). A breakaway system may rotate over the impacting vehicle without any secondary contact. A yielding system may remain intact after the collision and, thereby, reduce the tendency for released components to penetrate the occupant compartment.

3.2.2.2 Functional Design Considerations

In addition to being crashworthy, a work-zone single sign support should also satisfy certain functional design requirements. For example, it should have sufficient structural capacity to withstand anticipated service loads and be durable enough to accommodate frequent handling and transportation. The uprights of temporary work-zone sign supports should be designed to accommodate the flexural stresses induced by wind loading, and sufficient ballast should be provided to prevent overturn of skid-mounted designs. The wind loads on a structure are determined by applying the appropriate wind pressure to the exposed areas of any vertical supports, braces, and the sign panel. Once the loads have been determined, the stresses in the support members can be computed and compared to the allowable stresses. Due to the probabilistic nature and uncertainty of wind load events, the specifications permit a 33 percent increase in allowable stresses when making these computations. Calculations of wind pressure follow the procedures prescribed in the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals* 5th ed. (*8*).

Given a design wind speed, the associated wind pressure is computed by the following formulas:

$$P = 0.00256 KzGV^2 C_d I_r \quad (1)$$
$$V = C_v V_w \quad (2)$$

where

P = wind pressure (psf).
V = adjusted wind speed (mph).
V_w = wind speed (mph).
C_d = drag coefficient.
C_v = velocity conversion factor.
K_z = height exposure factor.
G = gust effect factor.
I_r = wind importance factor.

The design wind speed varies with geographic location and the life expectancy of the structure. Since permanent roadside sign structures are considered to have a relatively short life expectancy, they are typically designed for wind speeds based on a 10-year mean recurrence interval per AASHTO Specifications (*8*). The duration of work zone activities is typically much less than 10 years. However, no guidance is given regarding an appropriate design wind speed or mean recurrence interval for use in the design of work zone traffic control devices. Therefore, it was necessary to derive or estimate wind loads for use in the design of temporary sign supports.

3.3 HIGH-MOUNTING HEIGHT SIGN SUPPORTS WITH ALUMINUM SIGNS

While some of the characteristics of a rigid substrate may be desirable from a cost or functional standpoint, their rigidity and mass make them more critical than other substrate materials from a crashworthiness standpoint. High-mounting-height temporary sign supports with rigid aluminum or plywood substrates can be critical in terms of impact performance. When impacted, the support need to readily release or fracture, otherwise it may deform around the front of the impacting vehicle and cause the sign panel and top of the support to contact the windshield and/or roof of the vehicle. 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 roof sheet metal. Some successful crash tests have involved the early release of the rigid substrate or fracture of the support mast at or near bumper height. Combinations of design modifications can be incorporated to allow the sign panel and fractured supports to rotate higher above the vehicle. Secondary contact between the sign components and vehicle may still occur, but the degree of damage can be reduced.

3.3.1 Design Considerations

3.3.1.1 Sign Substrate and Mounting Height

For purposes of this project, TxDOT specified a desire for using an aluminum diamond-shaped sign substrate at a mounting height of 7 ft. Use of rigid sign substrate has been shown to be acceptable for high-mounting-heights, primarily because direct windshield contact can be avoided. The size of the sign panel was selected to be 36 inches × 36 inches.

3.3.1.2 Wind Load Analysis

The uprights of temporary work-zone sign supports were sized to accommodate the flexural stresses induced by wind loading for the selected mounting height and sign panel size. Calculations of wind pressure followed the procedures prescribed in the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals* (*8*).

3.3.2 Overturn

Sufficient ballast is required to prevent overturn of skid-mounted designs. The maximum overturning moment that needs to be resisted by the sign support was determined for a 7 ft mounting height by applying the design wind pressure on the exposed area of the sign panel based on a design wind speed of 45 mph. This moment was then used to determine the amount of ballast (sandbags) required to prevent overturn of the sign support.

3.3.3 Structural Adequacy

Additional analysis was conducted to determine the support member sizes required to accommodate the selected design wind speed. The moment generated at the base of the support by the wind load on a 36 inches × 36 inches sign panel at a 7-ft mounting height was compared to the allowable moment capacity of different sizes of perforated square steel tubing. Perforated square steel tubing used in steel-framed sign support systems is commonly manufactured from ASTM A-446 steel, which has a yield stress of 33,000 psi. The section modulus varies with the size and thickness of the tubing. The section modulus for a 1-3⁄4-inch square, 12-gauge steel tube is 0.265 inch^3. The allowable moment capacity based on yield strength is 729 ft-lb. Calculations show that a single 1-3⁄4-inches square, 12-gauge steel tube has sufficient flexural capacity to accommodate a 36-inch × 36-inch sign panel at a mounting height of 7 ft when the proper amount of ballast (2 × 40-lb sandbags) is provided at the base of the structure.

3.3.4 Design Alternatives

Having defined the basic requirements for the system (e.g., mounting height, sign substrate, support material type and size) to accommodate service loads, the researchers developed design alternatives with the potential to meet impact performance requirements and provide some desirable functional characteristics. Factors that were considered include durability, handling, and fabrication/repair. A total of eight high-mounting-height, temporary single sign support concepts were developed for review and prioritization. A brief summary of each of these systems is presented in the following sections.

3.3.4.1 Design 1: Telescopic Connection at Top and Bottom (4-inch)

Figure 3.1 shows that the sign support uses 12-gauge perforated steel tubing to support a 36-inch × 36-inch aluminum, diamond-shaped sign panel mounted 7 ft above ground. The bottom of the vertical support is inserted into a long sleeve attached to the H-base and the top of the support is inserted into the bottom of the sign assembly without bolted connections. The bottom of the vertical support rests on top of the H-base and the insertion depth of the upper end of the vertical support is controlled by a through bolt in the vertical sign support brace. The short sleeve and unbolted connections are incorporated to provide slip connections that will facilitate the release of the uprights from the base after impact. The top slip connection was included with the expectation that the sign assembly would be ejected from the sign support after impact and land behind the vehicle without contacting the occupant compartment. The 4-inch sleeve is considered sufficient for developing the moment capacity of the upright to accommodate service loads.

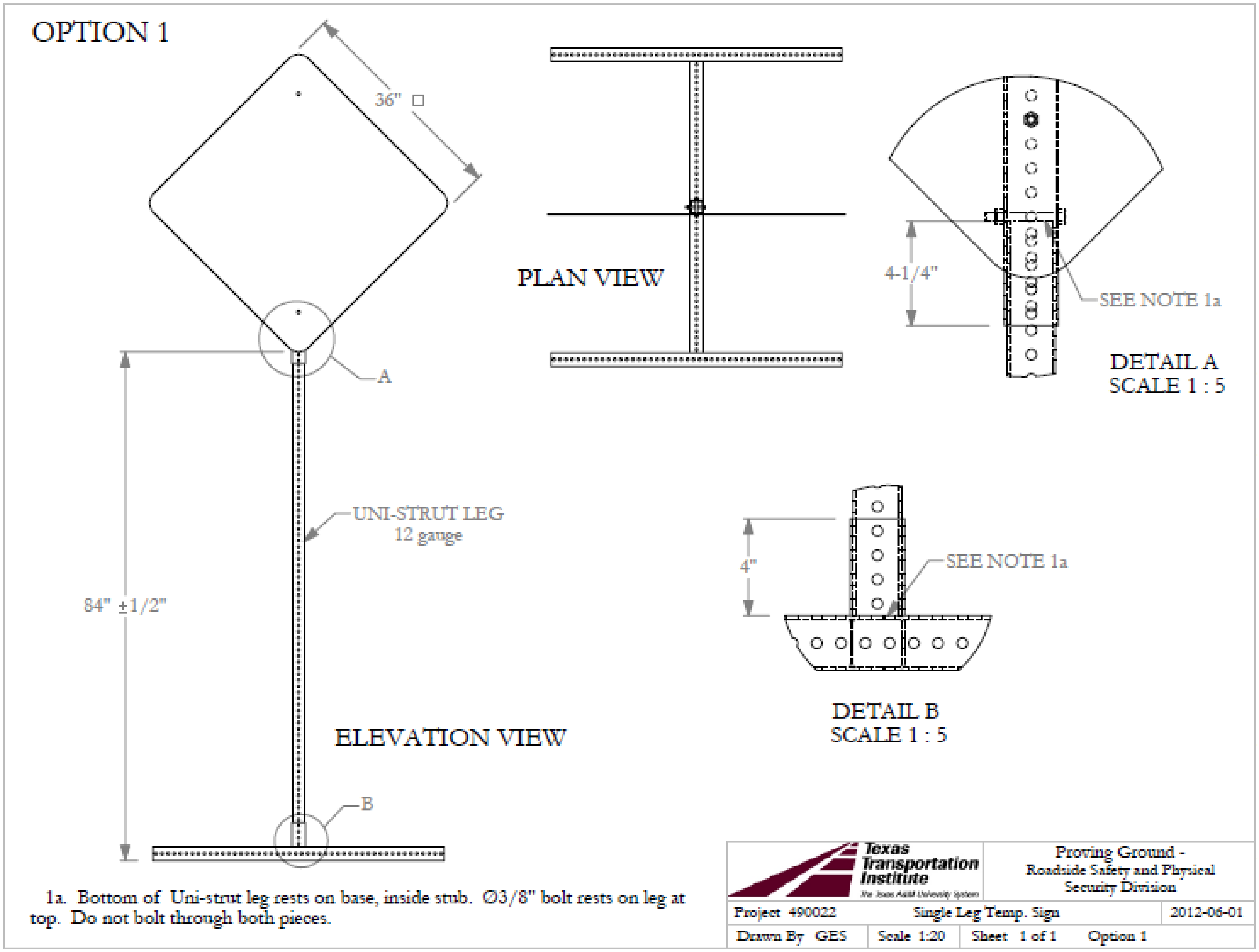


Figure 3.1. Design 1: Telescopic Connection at Top and Bottom (4-inch).

3.3.4.2 Design 2: Telescopic Connection at Top and Bottom (34-inch)

The sign support shown in Figure 3.2 is similar to Design 1 except that the bottom of the vertical support is inserted into a longer, 34-inch sleeve compared to a short, 4-inch sleeve. The unbolted connections are incorporated to provide slip connections to facilitate the release of the upright and sign after impact. The insertion depth of the vertical support is controlled by through bolts in the sleeve and vertical sign support brace. The bottom sleeve is 34-inches tall to position the lower slip joint above bumper height of the vehicle.

3.3.4.3 Design 3: Telescopic Connection Only at Bottom (4-inch)

The sign support shown in Figure 3.3 is similar to Design 1 except that it only incorporates the lower slip joint with the 12-gauge perforated steel tube support inserted into a 4-inch sleeve. The support post extends up to brace the sign panel in one piece. This is a simpler design that might have promise if the release of the sign panel from the support is found to be unnecessary.

3.3.4.4 Design 4: Telescopic Connection Only at Bottom (34-inch)

The sign support shown in Figure 3.4 is similar to Design 3 except that the lower slip joint is raised to 34-inches through the use of a longer sleeve. This places the slip joint above the vehicle bumper, which might provide a more efficient release mechanism during impact as the support member begins to deform.

3.3.4.5 Design 5: Rigidized Sign

The sign support shown in Figure 3.5 incorporates a lower slip connection similar to Design 1 in combination with a rigidized sign panel. The aluminum sign substrate is rigidized by adding perforated steel tubing along the sides and across the back of the sign panel. The concept is to raise the center of mass by increasing the mass of the sign assembly. This, in turn, increases the point of rotation of the released sign support system and may reduce the potential for secondary impact with the roof or windshield. The addition of the perforated steel tubing along the sides of the sign panel also increases the contact surface area of the sign edge in the event that secondary contact does occur in a 90-degree impact. This can help distribute the impact load to the roof and prevent cutting of the sign substrate into the roof. However, the increased mass can also increase the amount of roof deformation.

3.3.4.6 Design 6: Perforated Sign Panel

The sign support shown in Figure 3.6 incorporates a lower slip connection similar to Design 1 in combination with a perforated aluminum sign panel. The aluminum sign has two rows of vertical perforations. The perforations may help the corner of the sign bend when contacting the roof of the vehicle in a 90-degree impact. The intent is to mitigate the potential for the edge of the aluminum panel cutting into the roof.

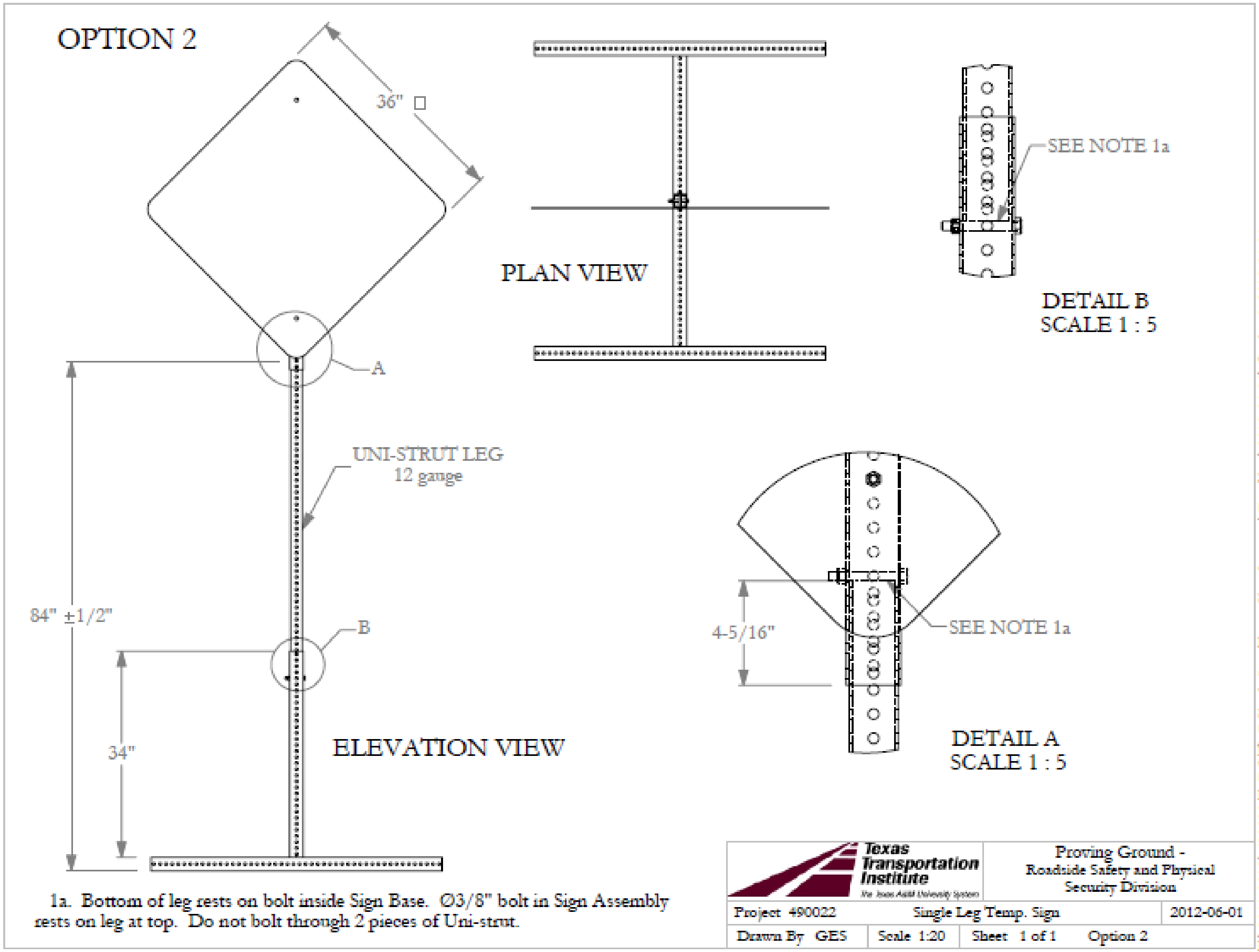


Figure 3.2. Design 2: Telescopic Connection at Top and Bottom (34-inch).

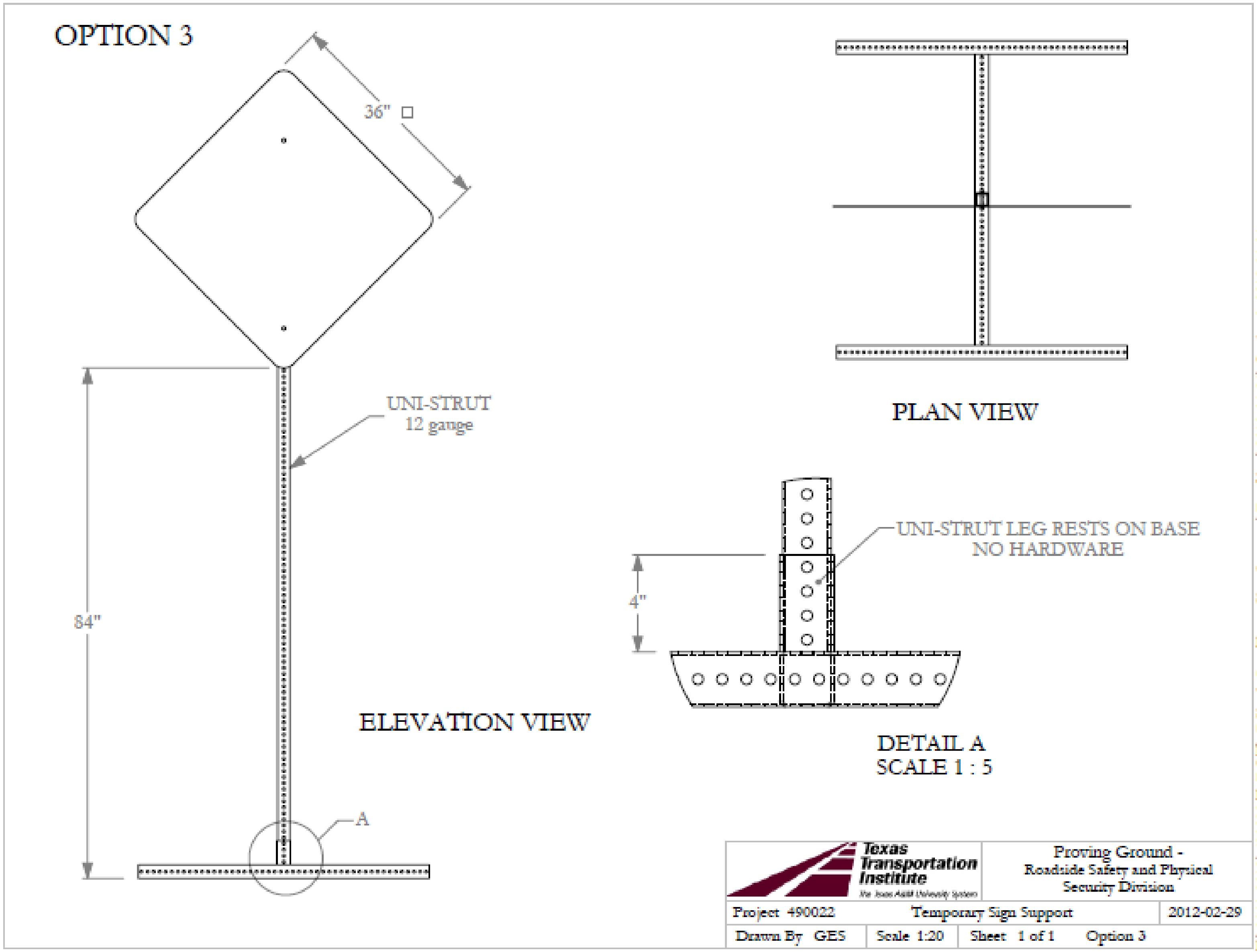


Figure 3.3. Design 3: Telescopic Connection only at Bottom (4-inch).

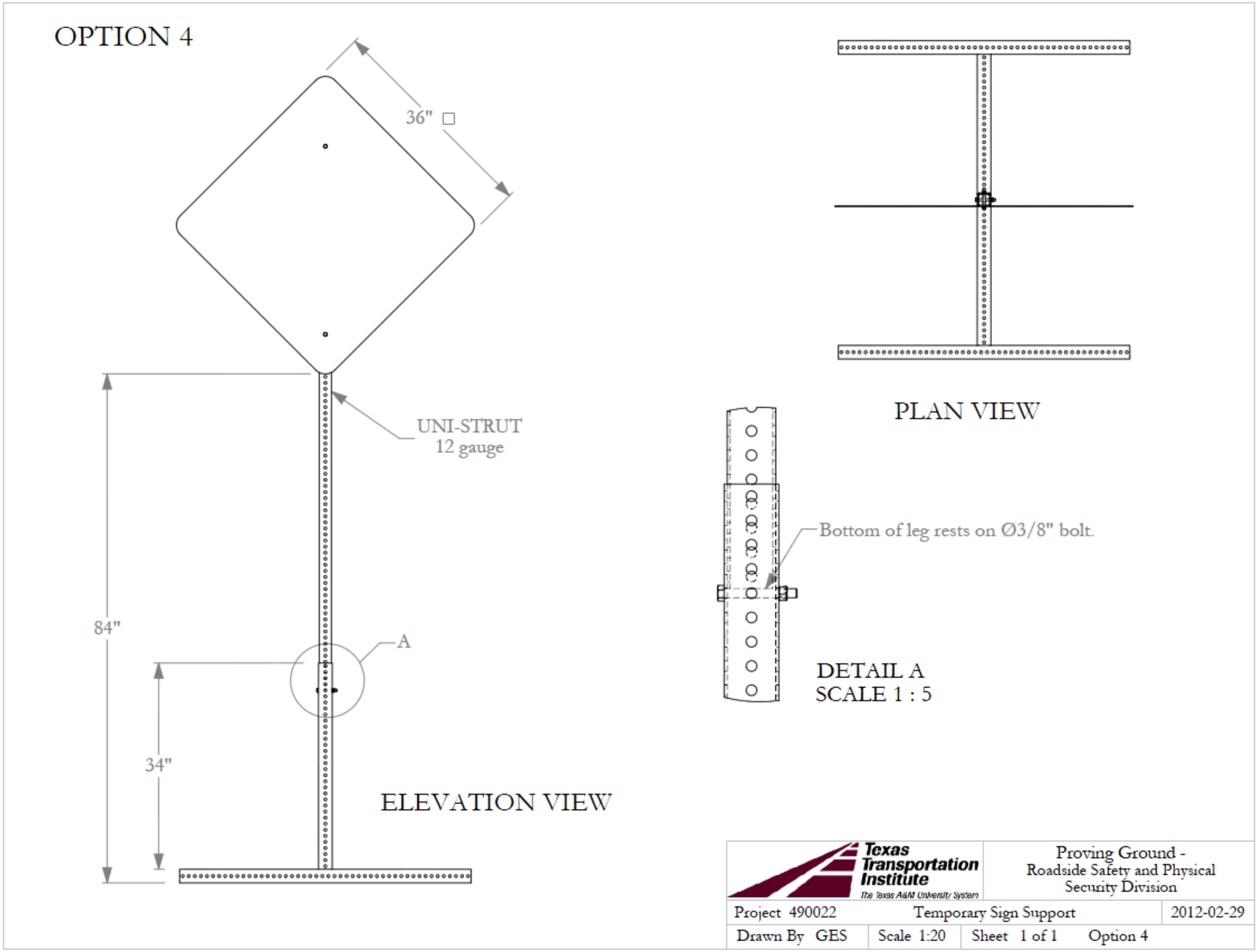


Figure 3.4. Design 4: Telescopic Connection only at Bottom (34-inch).

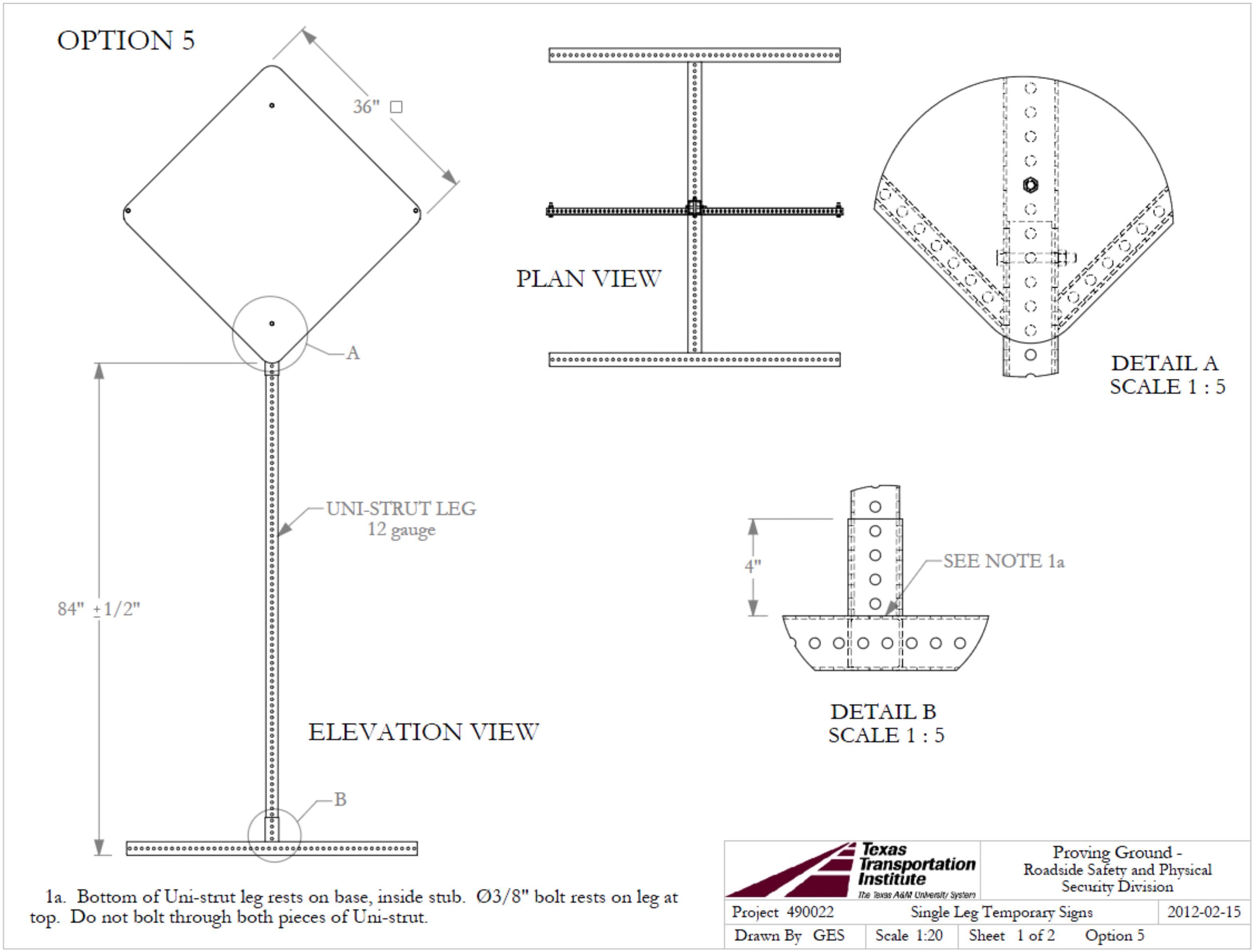


Figure 3.5. Design 5: Rigidized Sign.

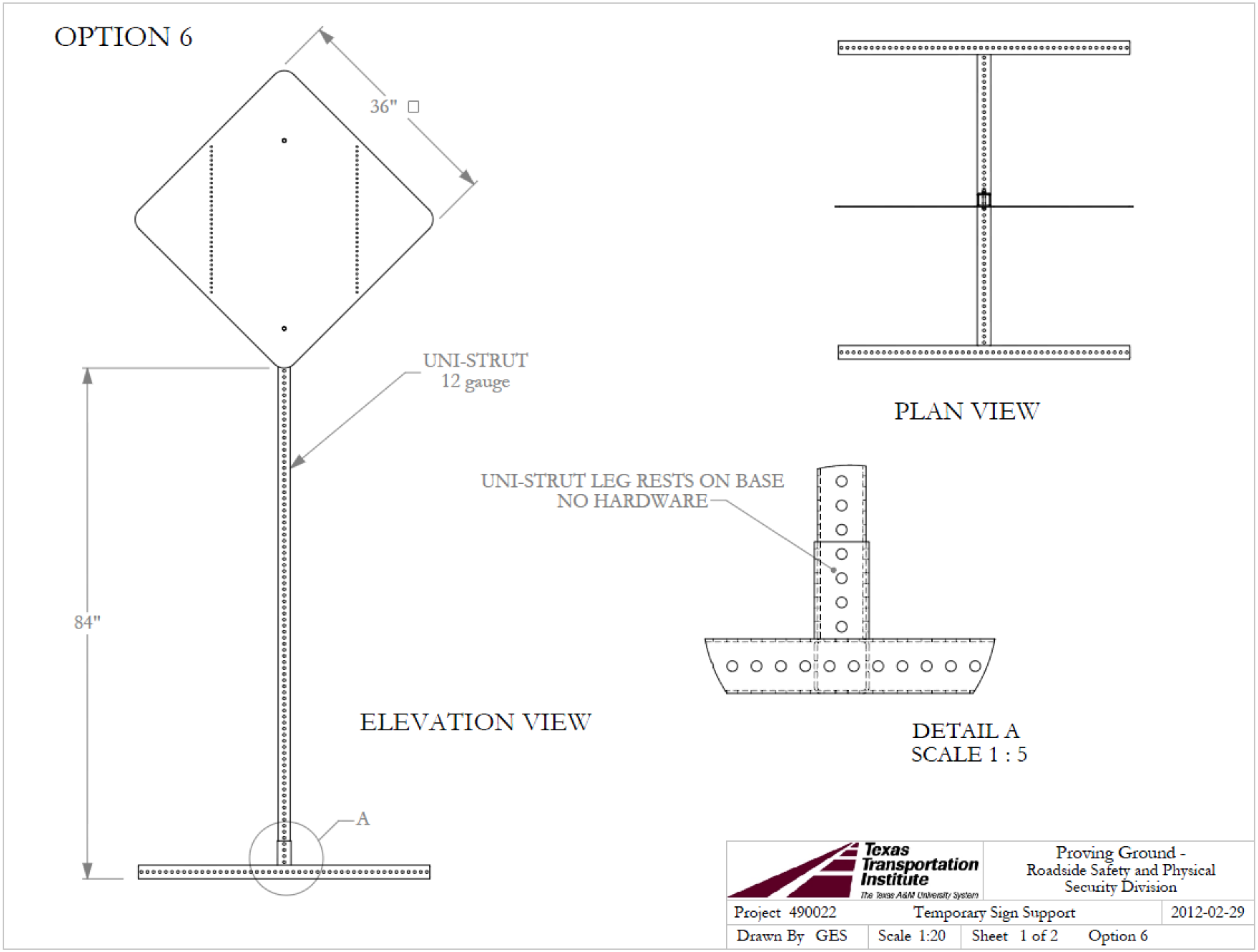


Figure 3.6. Design 6: Perforated Sign Panel.

3.3.4.7 Design 7: Pivot at Sign Support Connection (4-inch)

The sign support shown in Figure 3.7 is similar to Design 1 except that it incorporates a pivoting or hinged connection between the vertical support and sign assembly rather than a slip connection. The top of the vertical support is connected to the bottom of the sign assembly by steel plates similar to the fuse plate concept used on large guide signs. During impact, the plates on the tension side are designed to fracture, and the sign assembly hinges about the plates on the compression side. This behavior is intended to reduce the rotational inertia of the sign assembly, thus reducing the severity of any secondary contact between the sign assembly and vehicle.

3.3.4.8 Design 8: Pivot at Sign Support Connection (34-inch)

The sign support shown in Figure 3.8 is similar to Design 7 except that the lower slip joint is raised to 34 inches. This places the slip joint above the vehicle bumper, which might provide a more efficient release mechanism during impact as the support member begins to deform.

3.4.5 Prioritization

The design alternatives developed for high-mounting height temporary single sign supports with rigid sign substrates were critically reviewed by the research team. The researchers ranked the systems with consideration given to expected impact performance. External input regarding constructability, handling, set up, and maintenance was also obtained from representatives of a work zone contractor. The ranking analysis resulted in the following prioritization of the design concepts:

1. Design 2: Slip Connection at Top and Bottom (34-inch).
2. Design 4: Slip Connection Only at Bottom (34-inch).
3. Design 8: Pivot at Sign Support Connection (34-inch).
4. Design 1: Slip Connection at Top and Bottom (4-inch).
5. Design 3: Slip Connection Only at Bottom (4-inch).
6. Design 7: Pivot at Sign Support Connection (4-inch).
7. Design 5: Rigidized Sign.
8. Design 6: Perforated Sign Panel.

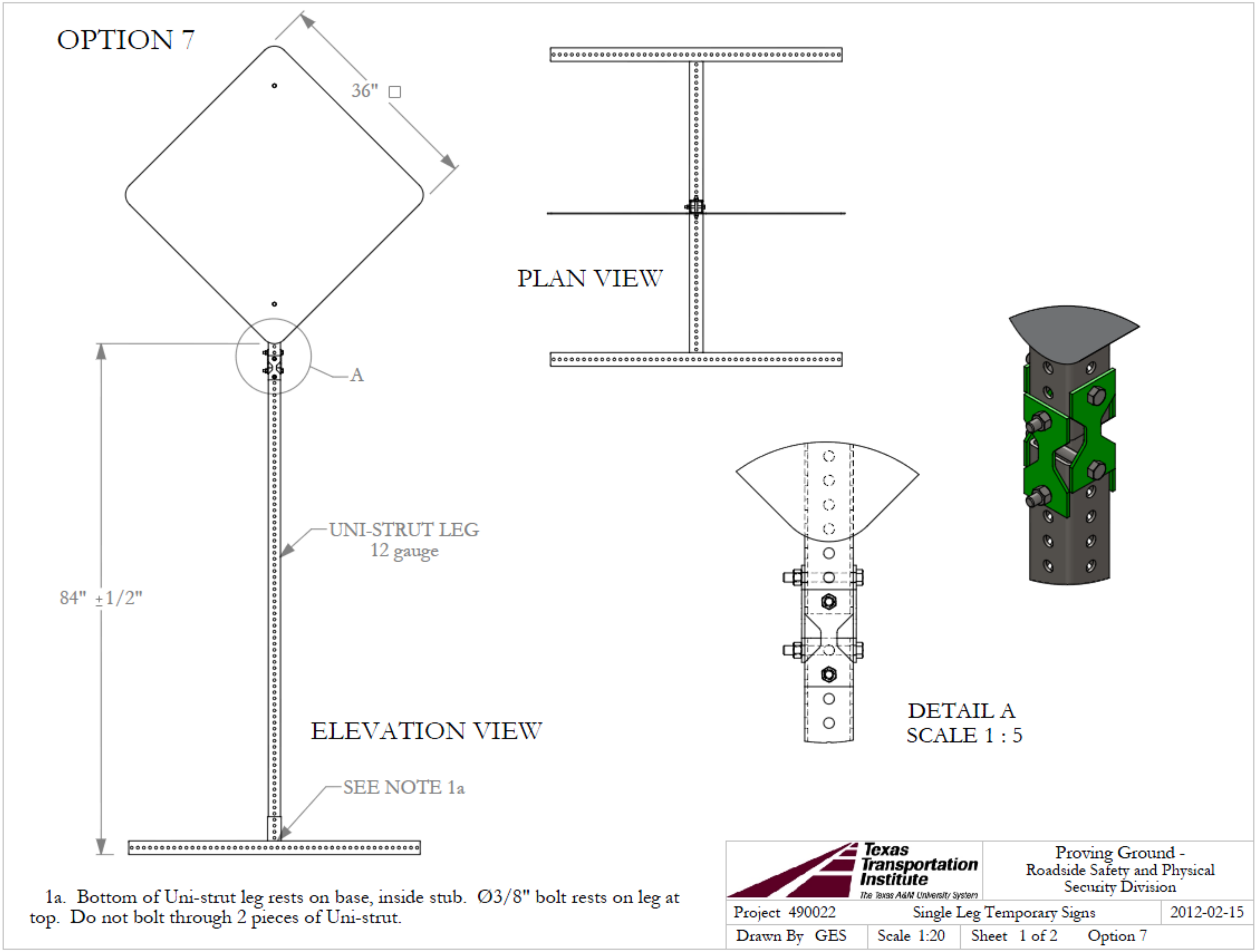


Figure 3.7. Design 7: Pivot at Sign to Support Connection. Telescopic Connection at 4 inches from the Bottom.

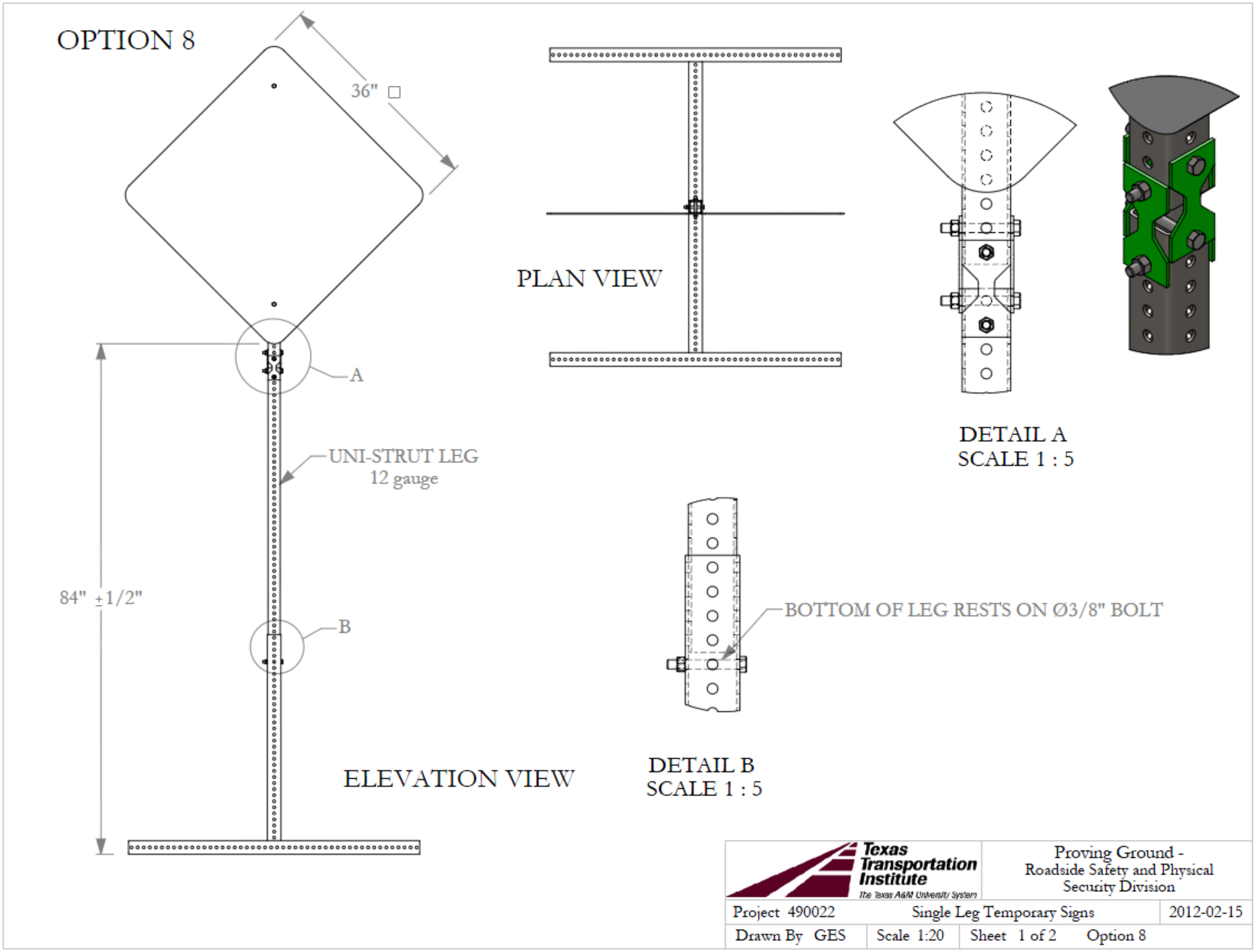


Figure 3.8. Design 8: Pivot at Sign to Support Connection. Telescopic Connection at 34 inches from the Bottom.

The top three devices were evaluated with developmental full-scale, high-speed crash tests. The purpose of these crash tests was primarily to assess the capability of these devices to readily activate after impact with the vehicle. Consideration was given to the use of a reusable bogie impact vehicle. However, the researchers wanted to analyze the trajectory of the test article during and after impact, and determine if there was any secondary contact between the test article and the vehicle. For this reason, the developmental tests were run with a *MASH* 1100C vehicle (passenger car). The tests were performed with the temporary single sign supports oriented 90 degrees (i.e., parallel to the path of the vehicle), because this was considered to be the worst case orientation. Details of the developmental full-scale crash tests conducted on these designs are described in the following chapter.

CHAPTER 4. DEVELOPMENTAL FULL-SCALE CRASH TESTS

4.1 FULL-SCALE CRASH TESTING WITH 90° SIGN ORIENTATION AND 1100C VEHICLE – MODIFIED DESIGN 2 (TEST 490022-7-1)

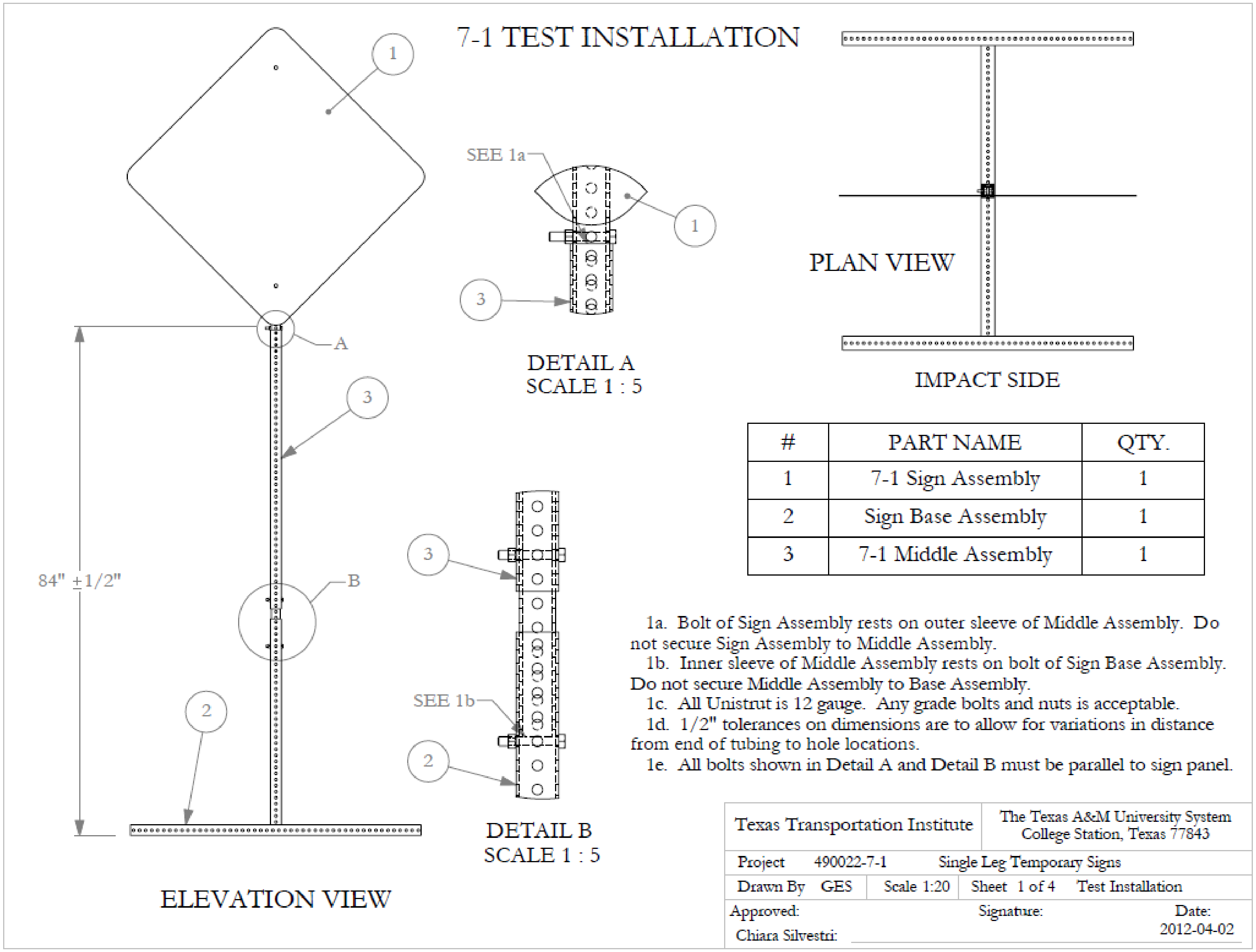
MASH test 3-71 was performed on a temporary single sign support with telescopic top and bottom slip connections and a 36-inch × 36-inch aluminum sign panel. This was a variation of Design 2, with a nested vertical support (rather than single vertical support) incorporated to provide height adjustability in the field.

4.1.1 Test Installation Description

Three 1-3/4 inch perforated square steel tubes with a nominal wall thickness of 0.108 inch were welded together to form an H-base assembly system. Each tube forming the H-base was 48 inches long. A 1-3/4 inch square steel tube with a nominal wall thickness of 0.108 inch and a total length of 34 inches was welded to the center of the H-base assembly. The vertical support of the temporary single sign support was comprised of two parts: a 1-1/2 inch square tube, with a thickness of 0.108 inch and a length of 46 inches, and a 1-3/4 inch square tube, with a thickness of 0.108 inch and a length of 46 inches. The tubes were nested inside each other to provide height adjustment to the sign assembly. They were bolted together using an ASTM A307 3/8-inch diameter × 2-1/2 inch long bolt. This inner 1-1/2 inch tube of the telescopic connection was extended 4-1/2 inches beyond the edge of the 1-3/4 inch square outer tube. This extension was inserted into the top of the sleeve and rested on a bolt to provide a slip connection.

A 48 inch length of 1-1/2 inch square steel tube was used to provide bracing for the sign panel. A 36-inch × 36-inch × 0.1-inch thick aluminum diamond-shaped sign was attached to the 1-1/2 inch tube in two locations: 18 inches top and bottom of the horizontal centerline of the sign. The sign was attached to the tube using 3/8-inch diameter bolts. The 1-1/2 inch tube extended beyond the bottom of the sign panel and was inserted into the top of the 1-3/4 inch vertical support tube to form an upper slip connection. The insertion depth of 4 ½ inches was controlled by a bolt inserted through the 1-1/2 inch sign brace tube that rested on the top edge of the vertical support. The mounting height to the bottom of the sign blank was 7 ft. Figures 4.1 through 4.4 give details of the sign support system.

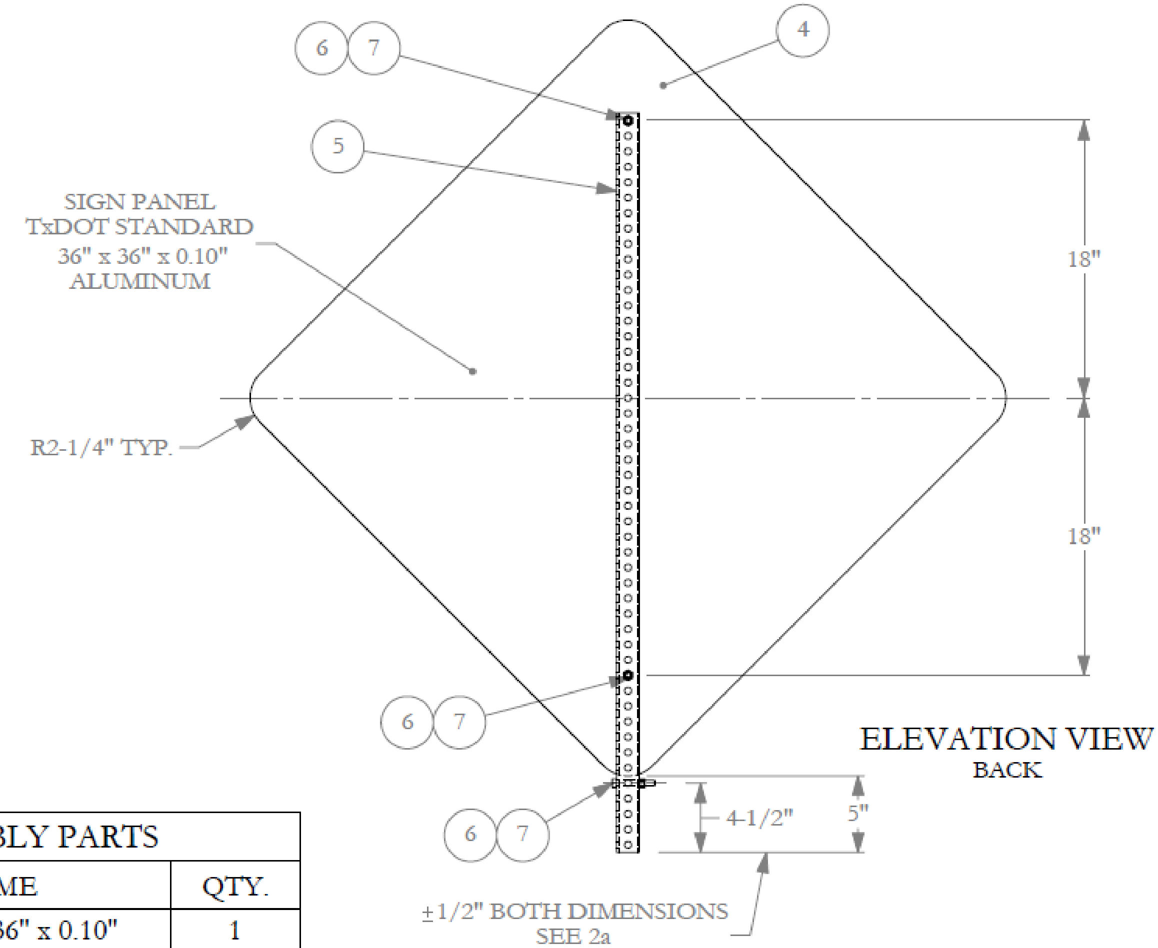
A 40-lb sand bag was laid on each side of the base assembly. All perforated square steel tubing was 12 gauge. All bolts were ASTM A307, but any grade bolt was considered acceptable. Figure 4.5 presents photographs of the completed test installation.



#	PART NAME	QTY.
1	7-1 Sign Assembly	1
2	Sign Base Assembly	1
3	7-1 Middle Assembly	1

Figure 4.1. Details of the Temporary Single Sign Support System Used for Test No. 490022-7-1.

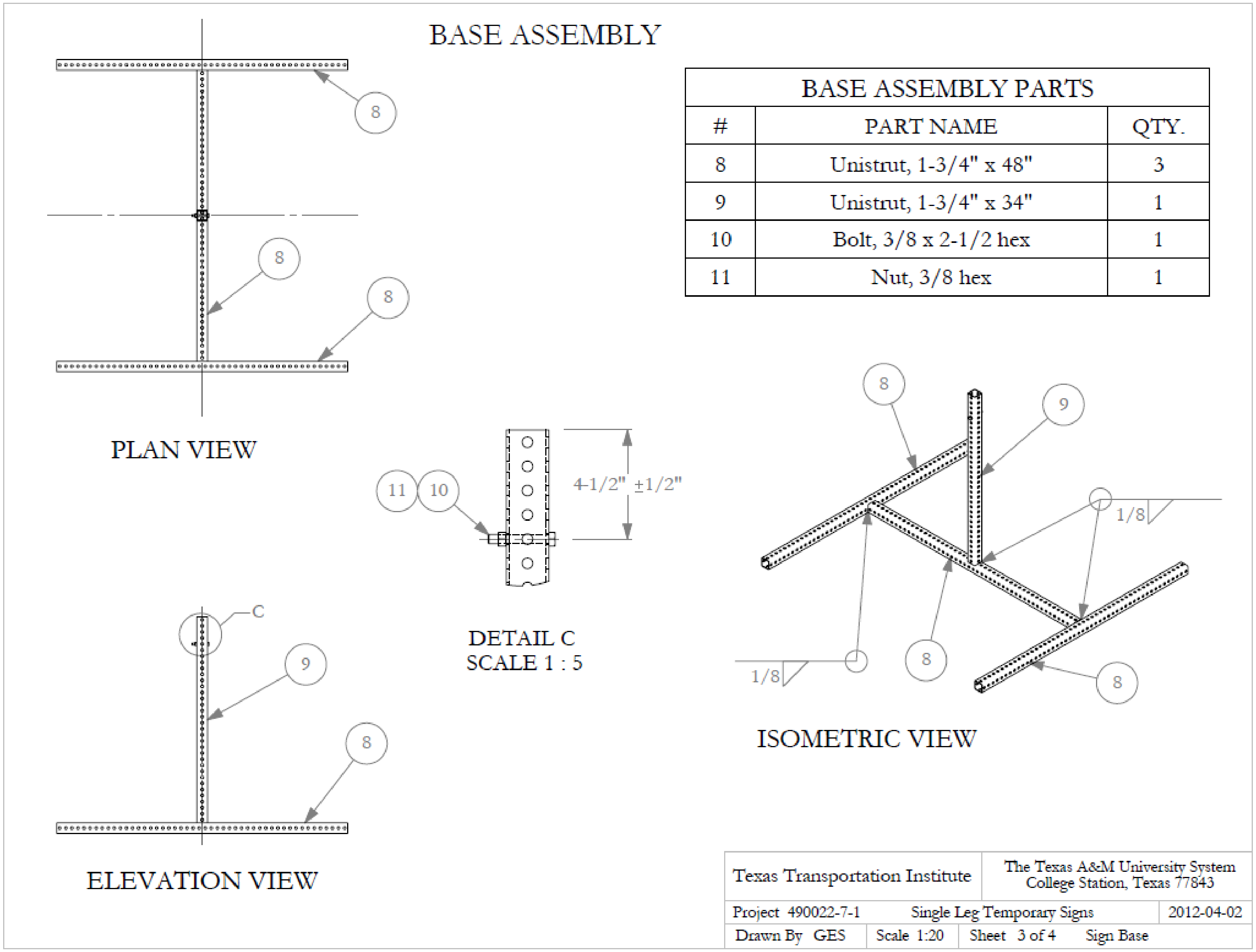
SIGN ASSEMBLY



SIGN ASSEMBLY PARTS		
#	PART NAME	QTY.
4	Sign Panel, 36" x 36" x 0.10"	1
5	Unistrut, 1-1/2" x 48"	1
6	Nut, 3/8 hex	3
7	Bolt, 3/8 x 2-1/2 hex	3

Texas Transportation Institute	The Texas A&M University System College Station, Texas 77843		
Project 490022-7-1	Single Leg Temporary Signs		2012-04-02
Drawn By GES	Scale 1:10	Sheet 2 of 4	Sign Assembly

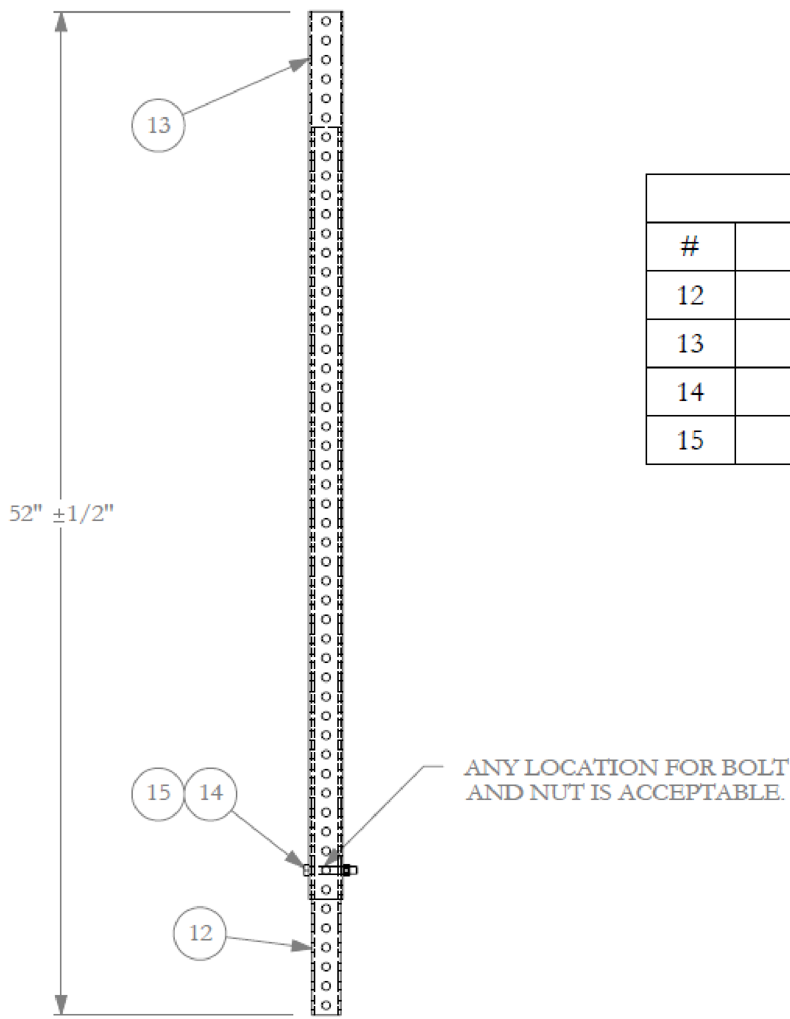
Figure 4.2. Details of the Sign Assembly Used in Test No. 490022-7-1.



BASE ASSEMBLY PARTS		
#	PART NAME	QTY.
8	Unistrut, 1-3/4" x 48"	3
9	Unistrut, 1-3/4" x 34"	1
10	Bolt, 3/8 x 2-1/2 hex	1
11	Nut, 3/8 hex	1

Figure 4.3. Details of the Base Assembly Used in Test No. 490022-7-1.

MIDDLE ASSEMBLY



MIDDLE ASSEMBLY PARTS		
#	PART NAME	QTY.
12	Unistrut, 1-1/2" x 46"	1
13	Unistrut, 1-3/4" x 46"	1
14	Bolt, 3/8 x 2-1/2 hex	1
15	Nut, 3/8 hex	1

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Project 490022-7-1 Single Leg Temporary Signs 2012-04-02
Drawn By GES Scale 1:8 Sheet 4 of 4 Middle Assembly

Figure 4.4. Details of the Middle Assembly Used in Test No. 490022-7-1.

Figure 4.5. Temporary Sign Support System prior to Test No. 490022-7-1.

4.1.2 Test Designation and Actual Impact Conditions

MASH test 3-71 involves an 1100C vehicle weighing 2420 lb ±55 lb and impacting the sign support at an impact speed of 62 mph ±2.5 mph. Researchers identified the 90 degrees sign orientation case (i.e., sign parallel to the path of the vehicle) as the most critical for this type of test article. Consequently, the researchers decided to evaluate the impact performance of the temporary single sign support at 90 degrees in the developmental test. It was understood that another *MASH* 3-71 test would need to be performed with the test article oriented at 0 degrees (i.e., perpendicular to the path of the vehicle) to complete the compliance testing.

The target impact point was the left quarter point of the vehicle aligned with the centerline of the support. The 2003 Kia Rio passenger car used in the test weighed 2425 lb, and the actual impact speed and angle were 62.9 mph and 90 degrees, respectively. The actual impact point was the left front quarter point of the vehicle with the centerline of the sign support.

4.1.3 Test Vehicle

A 2003 Kia Rio passenger car (shown in Figures 4.6 and 4.7) was used for the crash test. This test vehicle was previously used in testing of flexible delineators and had some minor damage (e.g., broken head light, dented hood). However, it was concluded that this minor damage would not influence the impact performance or trajectory of the light weight, skid-mounted temporary sign support. Test inertia weight of the vehicle was 2425 lb, and gross static weight was 2425 lb. The height to the lower edge of the vehicle front bumper was 8.5 inches, and the height to the upper edge of the front bumper was 22.75 inches. Table C1 of Appendix C gives additional dimensions and information on the vehicle. The passenger car was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling prior to impact.

4.1.4 Weather Conditions

The crash test was performed on the morning of April 12, 2012. Weather conditions at the time of testing were: wind speed: 8 mph; temperature: 68.5°F; relative humidity: 86 percent.

4.1.5 Test Description

The 1100C vehicle, traveling at an impact speed of 62.9 mph, contacted the sign support at an impact angle of 90 degrees, with the left front quarter point aligned with the centerline of the support. At approximately 0.015 s after impact, the vertical tube sleeve attached to the H-base assembly started to fracture, but never separated. At approximately 0.017 s, the lower slip joint activated and released the nested vertical support and sign assembly from the base. At 0.125 s, the released support and sign assembly were parallel to the ground. The top released as the sign assembly was rotating toward the ground and had reached a rotation angle of almost 180 degrees from the initial configuration. The released vertical support and sign assembly never contacted the vehicle. The vehicle subsequently came to rest 242 ft-6 inches downstream of impact. Figure C1 in Appendix C presents sequential photographs of the test period.

Figure 4.6. Vehicle/Installation Geometrics for Test No. 490022-7-1.

Figure 4.7. Vehicle before Test No. 490022-7-1.

4.1.6 Test Article and Component Damage

Figure 4.8 shows damage to the sign support system. Both slip joints activated, but the upper slip joint only activated after significant rotation (almost 180 degrees) of the released vertical support. The vertical sign brace was deformed, and the sign assembly came to rest 20 ft downstream of the impact point. The base assembly was resting 77.5 ft downstream of the impact point.

4.1.7 Test Vehicle Damage

The 1100C vehicle did not sustain any damage during the impact with the temporary single sign support. Figure 4.9 shows photographs of the exterior of the vehicle.

4.1.8 Occupant Risk Values

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 71 "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. In this case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors." The weight of the temporary sign support system was 75 lb.

4.1.9 Assessment of Test Results

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

<u>4.1.9.1 Structural Adequacy</u>

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

<u>Results</u>: The temporary sign support activated readily by yielding to the vehicle and through activation of the slip connections. (PASS)

<u>4.2.9.2 Occupant Risk</u>

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.

Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.

<u>Results</u>: The detached elements did not penetrate or show potential to penetrate the occupant compartment, or to present hazard to others in the area. (PASS) No deformation or intrusion into the occupant compartment occurred. (PASS)

Figure 4.8. Installation after Test No. 490022-7-1.

Figure 4.9. Vehicle after Test No. 490022-7-1.

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. Although roll and pitch angles were not recorded, it is clear from film analysis that they did not exceed 75 degrees during the impact event. (PASS)

H. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity	
Preferred	*Maximum*
10 ft/s	*16 ft/s*

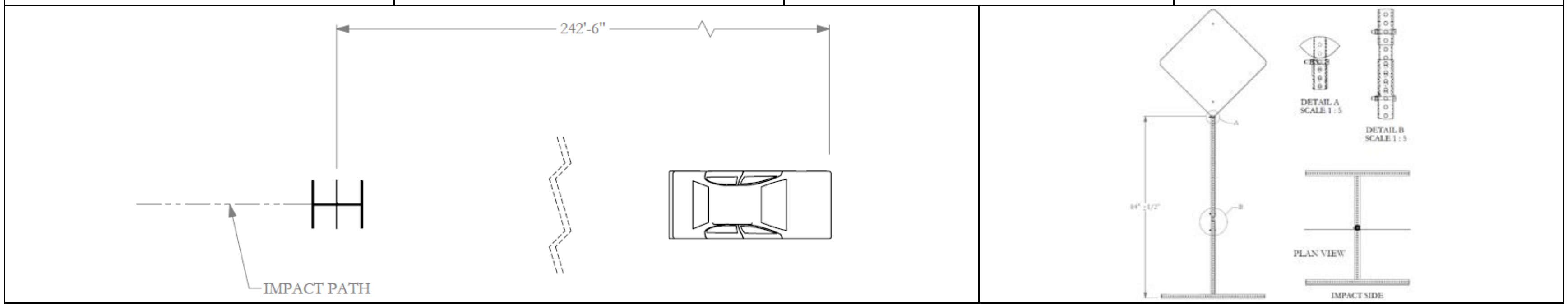
Results: Not required for test articles having a total weight of 220 lb or less. The weight of the temporary sign support system was 75 lb. (N/A)

4.2.9.3 Vehicle Trajectory

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

Result: The 1100C vehicle exited behind the test article. (PASS)

A summary of the results from Test No. 490022-7-1 is presented in Figure 4.10.



General Information
Test Agency........................ Texas A&M Transportation Institute
MASH Test No. .... *MASH* Test 3-71
TTI-PG Test No. 490022-7-1
Date 2012-04-12

Test Article
Type.................................... Temporary Single Sign Support
Name .... Top and bottom slip connections/9 ft^2 aluminum sign panel
Installation Height .... 7 ft to bottom of sign panel
Material or Key Elements .... Aluminum sign panel mounted on 1-3/4 inch perforated steel tubing with H-base

Soil Type and Condition....... Concrete Pavement, Dry

Test Vehicle
Type/Designation................ 1100C
Make and Model .... 2003 Kia Rio
Curb.................................... 2411 lb
Test Inertial......................... 2425 lb
Dummy .... No dummy
Gross Static .... 2425 lb

Impact Conditions
Speed ....62.9 mph
Angle ....90 degrees
Location/Orientation ....Left quarter point of vehicle with centerline of sign support

Exit Conditions
Speed ....61.67 mph
Angle ....0 degrees

Occupant Risk Values
Impact Velocity
Longitudinal ....N/A
Lateral ....N/A
Ridedown Accelerations
Longitudinal ....N/A
Lateral ....N/A
THIV ....N/A
ASI.......................................N/A
Max. 0.050-s Average
Longitudinal ....N/A
Lateral ....N/A
Vertical ....N/A

Post-Impact Trajectory
Stopping Distance 242-ft 6-inches

Vehicle Stability
Maximum Yaw Angle...................... N/A
Maximum Pitch Angle..................... N/A
Maximum Roll Angle .... N/A
Vehicle Snagging .... No
Vehicle Pocketing........................... No

Test Article Deflections
Dynamic 242-ft 6-inches
Permanent...................................... 242-ft 6-inches
Working Width .... N/A

Vehicle Damage
VDS 12FD1
CDC... 12FDEN1
Max. Exterior Deformation.............. None
OCDI.. FS0000000
Max. Occupant Compartment Deformation.............................. None

Figure 4.10. Summary of Results for *MASH* Test 3-71 (Test No. 490022-7-1) on Temporary Single Sign Support with Top and Bottom Telescopic Slip Connections (Modified Design #2).

4.2 FULL-SCALE CRASH TESTING WITH 90° SIGN ORIENTATION AND 1100C VEHICLE – DESIGN 4 (TEST 490022-7-2)

MASH Test 3-71 was performed on a temporary single sign support with a 34-inch sleeve and bottom slip connection. This system corresponded to Design 4 described in the previous chapter.

4.2.1 Test Installation Description

Three 1-3/4 inch perforated square steel tubes with a nominal wall thickness of 0.108 inch were welded together to form an H-base assembly system. Each tube forming the H-base was 48 inches long. A 1-3/4 inch square steel tube sleeve with a nominal wall thickness of 0.108 inch and a total length of 34 inches was welded to the center of the H-base assembly. A 98-inch long piece of 1-1/2 inch square steel tubing was used as the vertical support and bracing for the sign panel. The vertical support inserted 4-1/2 inches into the top of the sleeve and rested on a bolt inserted through the sleeve.

A 36-inch × 36-inch × 0.1-inch thick aluminum diamond-shaped sign was attached to the 1-1/2 inch vertical support tube in two locations: 18 inches top and bottom of the horizontal centerline of the sign. The sign was attached to the tube using 3/8-inch diameter bolts. The mounting height to the bottom of the sign blank was 7 ft. Figures 4.11 through 4.13 give details of the sign support system.

A 40-lb sand bag was laid on each side of the base assembly. All perforated square steel tubing was 12 gauge. All bolts were ASTM A307, but any grade bolt was considered acceptable. The test installation was placed on a concrete surface. Figure 4.14 presents photographs of the completed test installation.

4.2.2 Test Designation and Actual Impact Conditions

MASH Test 3-71 involves an 1100C vehicle weighing 2420 lb ±55 lb and impacting the sign support at an impact speed of 62 mph ±2.5 mph. Researchers identified the 90 degrees sign orientation case (i.e., sign parallel to the path of the vehicle) as the most critical for this type of test article. Consequently, the researchers decided to evaluate the impact performance of the temporary single sign support at 90 degrees in the developmental test. It was understood that another *MASH* 3-71 test would need to be performed with the test article oriented at 0 degrees (i.e., perpendicular to the path of the vehicle) to complete the compliance testing.

The target impact point was the right quarter point of the vehicle aligned with the centerline of the support. The same 2003 Kia Rio passenger car used in the previous test (test 490022-7-1) was used in this test. The vehicle weighed 2425 lb and the actual impact speed and angle were 62.4 mph and 90 degrees, respectively. The actual impact point was the right front quarter point of the vehicle with the centerline of the sign support.

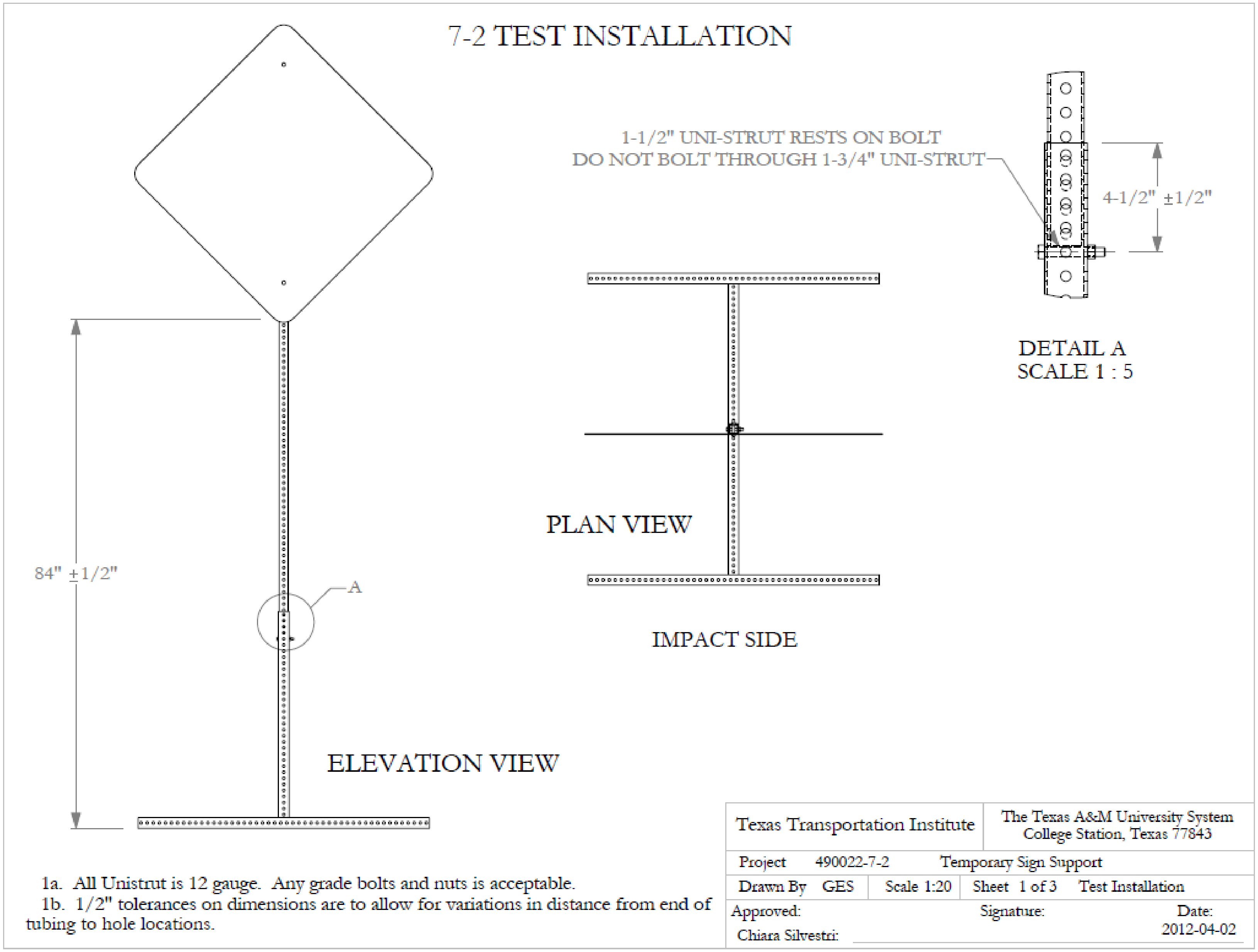
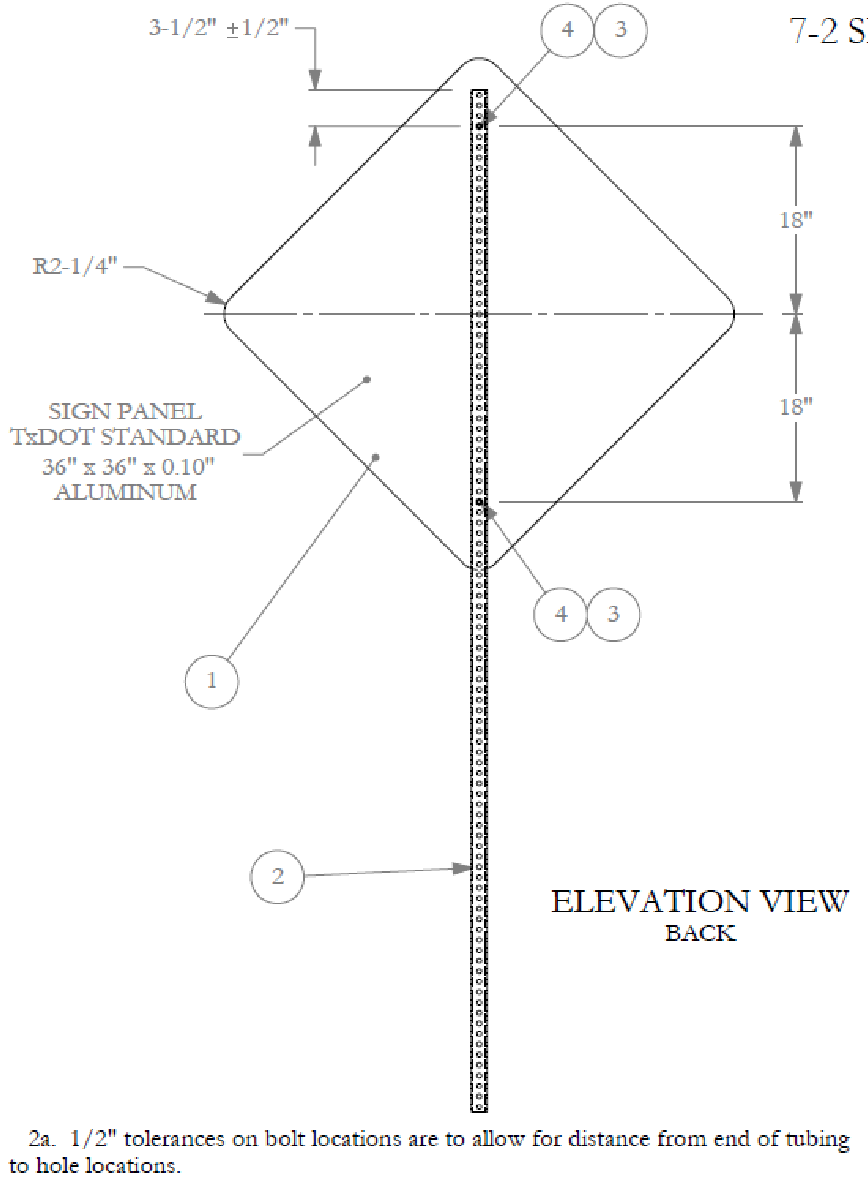


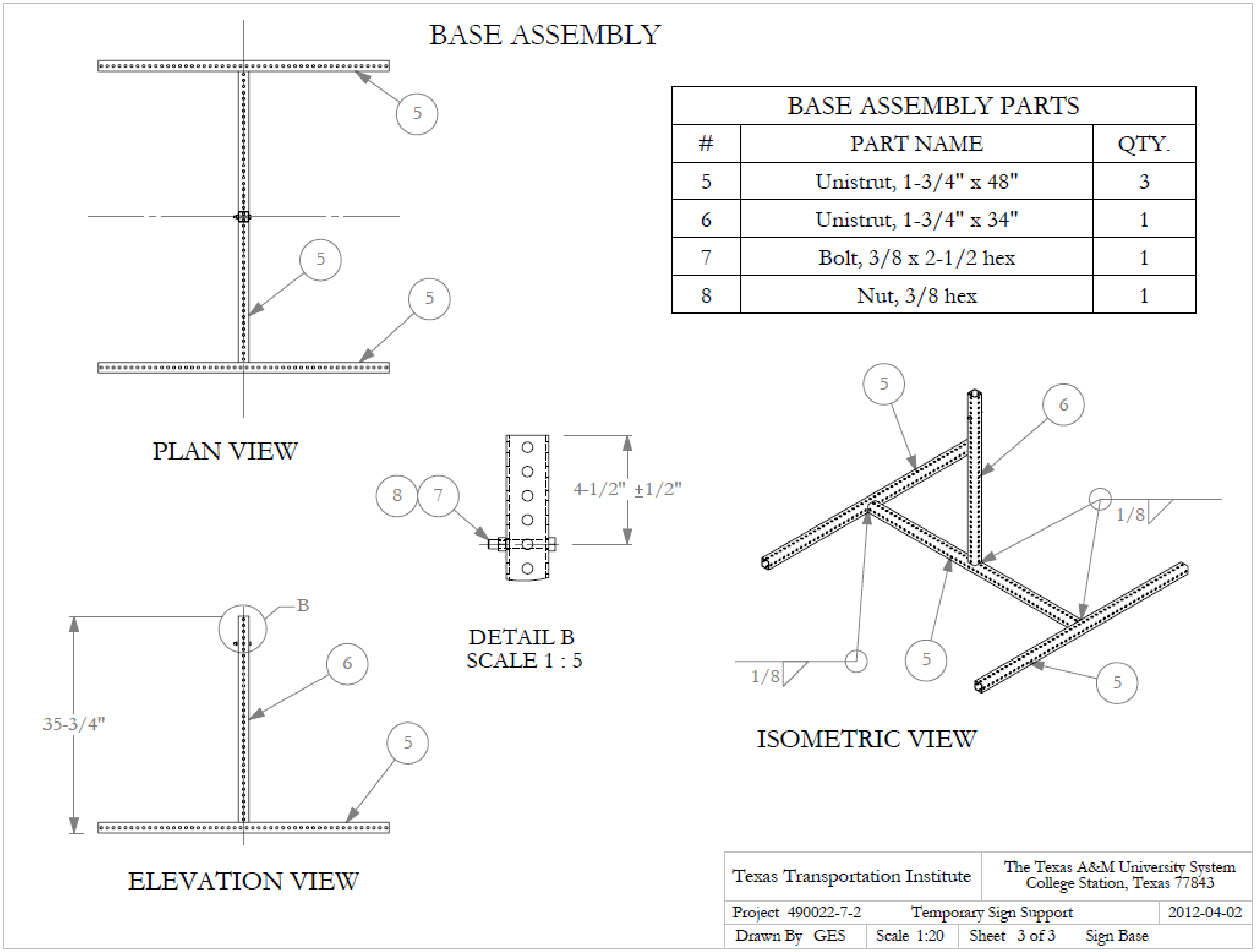
Figure 4.11. Details of the Temporary Single Sign Support System Used for Test No. 490022-7-2.



SIGN ASSEMBLY PARTS

#	PART NAME	QTY.
1	Sign Panel, 36" x 36" x 0.10"	1
2	Unistrut, 1-1/2" x 98"	1
3	Nut, 3/8 hex	2
4	Bolt, 3/8 x 2-1/2 hex	2

Figure 4.12. Details of the Sign Assembly Used in Test No. 490022-7-2.



BASE ASSEMBLY PARTS		
#	PART NAME	QTY.
5	Unistrut, 1-3/4" x 48"	3
6	Unistrut, 1-3/4" x 34"	1
7	Bolt, 3/8 x 2-1/2 hex	1
8	Nut, 3/8 hex	1

Figure 4.13. Details of the Base Assembly Used in Test No. 490022-7-2.

Figure 4.14. Temporary Sign Support System prior to Test No. 490022-7-2.

4.2.3 Test Vehicle

A 2003 Kia Rio passenger car (shown in Figures 4.15 and 4.16) was used for the crash test. Test inertia weight of the vehicle was 2425 lb, and gross static weight was 2425 lb. The height to the lower edge of the vehicle front bumper was 8.5 inches, and the height to the upper edge of the front bumper was 22.75 inches. Table D1 of Appendix D gives additional dimensions and information on the vehicle. The passenger car was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

4.2.4 Weather Conditions

The crash test was performed on the morning of April 12, 2012. Weather conditions at the time of testing were: wind speed: 12 mph; temperature: 74°F; relative humidity: 73 percent.

4.2.5 Test Description

The 1100C vehicle, traveling at an impact speed of 62.4 mph, contacted the sign support at an impact angle of 90 degrees, with the right front quarter point aligned with the centerline of the support. At approximately 0.019 s, the lower telescopic slip connection activated, releasing the vertical support and sign panel from the base assembly. At 0.119 s, the released post and sign assembly was parallel to the ground level. The released support and sign panel did not impact the vehicle. The vehicle subsequently came to rest 232 ft-6 inches downstream of impact. Figure D1 in Appendix D presents sequential photographs of the test period.

4.2.6 Test Article and Component Damage

Figure 4.17 shows damage to the sign support system. The telescopic slip connection activated as designed and released the vertical support and sign panel from the base. The vertical sleeve and middle brace in the H-base to which it was attached were both deformed. The support post and sign panel came to rest 17.5 ft downstream of the impact point. The base assembly came to rest 82.5 ft downstream of the impact point.

4.2.7 Test Vehicle Damage

The 1100C vehicle did not sustain any additional damage during the impact with the temporary single sign support. Figure 4.18 shows photographs of the exterior of the vehicle.

4.2.8 Occupant Risk Values

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 71 “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. In this case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors.” The weight of the temporary sign support system was 67 lb.

Figure 4.15. Vehicle/Installation Geometrics for Test No. 490022-7-2.

Figure 4.16. Vehicle before Test No. 490022-7-2.

Figure 4.17. Installation after Test No. 490022-7-2.

Figure 4.18. Vehicle after Test No. 490022-7-2.

4.2.9 Assessment of Test Results

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

4.2.9.1 Structural Adequacy

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

Results: The temporary sign support activated readily by yielding to the vehicle and through activation of the slip connection. (PASS)

4.2.9.2 Occupant Risk

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.
Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.

Results: No deformation or intrusion into the occupant compartment was recorded. (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. Although roll and pitch angles were not recorded, it is clear that they did not exceed 75 degrees during the impact event. (PASS)

I. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
10 ft/s	*16 ft/s*

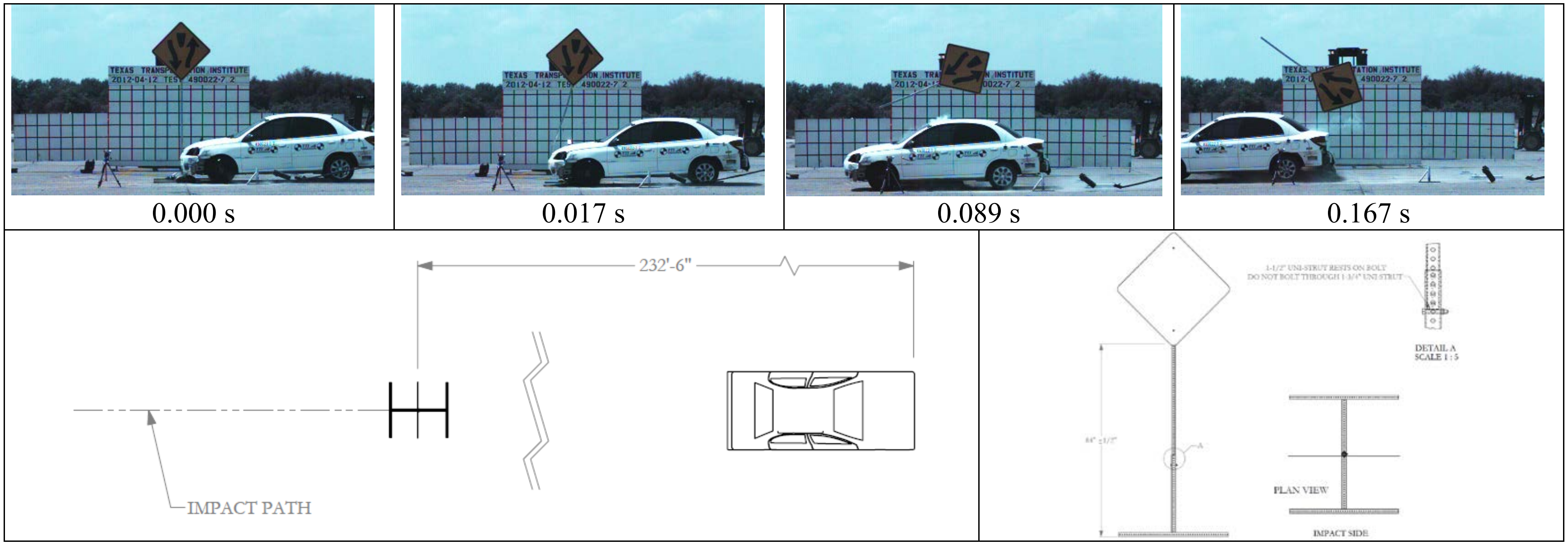
Results: Not required for test articles having a total weight of 220 lb or less. The weight of the temporary sign support system was 67 lb. (N/A)

4.2.9.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Result: The 1100C vehicle exited behind the test article. (PASS)

A summary of the results from Test No. 490022-7-2 is presented in Figure 4.19.



General Information
Test Agency........................ Texas A&M Transportation Institute
MASH Test No. .... *MASH* Test 3-71
TTI-PG Test No. 490022-7-2
Date 2012-04-12

Test Article
Type.................................... Temporary Single Sign Support
Name .... Bottom telescopic slip joint/9 ft^2 aluminum sign panel
Installation Height .... 7 ft to bottom of sign panel
Material or Key Elements .... Aluminum sign panel mounted on 1-1/2-inch perforated steel tubing; H-base fabricated from 1-3/4 inch steel tubing

Soil Type and Condition....... Concrete Pavement, Dry

Test Vehicle
Type/Designation................ 1100C
Make and Model .... 2003 Kia Rio
Curb.................................... 2411 lb
Test Inertial .... 2425 lb
Dummy .... No dummy
Gross Static .... 2425 lb

Impact Conditions
Speed ....62.4 mph
Angle ....90 degrees
Location/Orientation ....Right quarter point of vehicle with centerline of sign support

Exit Conditions
Speed ....62.4 mph
Angle ....0 degrees

Occupant Risk Values
Impact Velocity
Longitudinal ....N/A
Lateral ....N/A
Ridedown Accelerations
Longitudinal ....N/A
Lateral ....N/A
THIV ....N/A
ASI.......................................N/A
Max. 0.050-s Average
Longitudinal ....N/A
Lateral ....N/A
Vertical ....N/A

Post-Impact Trajectory
Stopping Distance 232-ft 6-in

Vehicle Stability
Maximum Yaw Angle...................... N/A
Maximum Pitch Angle...................... N/A
Maximum Roll Angle .... N/A
Vehicle Snagging .... No
Vehicle Pocketing........................... No

Test Article Deflections
Dynamic 232-ft 6-in
Permanent...................................... 232-ft 6-in
Working Width .... N/A

Vehicle Damage
VDS 12FD1
CDC.. 12FDEN1
Max. Exterior Deformation.............. None
OCDI... FS0000000
Max. Occupant Compartment Deformation.............................. None

Figure 4.19. Summary of Results for *MASH* Test 3-71 (Test No. 490022-7-2) on Temporary Single Sign Support with Bottom Telescopic Slip Connection (Design #4).

4.3 FULL-SCALE CRASH TESTING WITH 90° SIGN ORIENTATION AND 1100C VEHICLE – MODIFIED DESIGN 8 (TEST 490022-7-3)

MASH Test 3-71 was performed on a temporary single sign support with a telescopic bottom slip connections and a pivot connection below the sign panel. This was a variation of Design 8, with a different variation of the fuse plate than shown in Chapter 3.

4.3.1 Test Installation Description

Three 1-3/4 inch perforated square steel tubes with a nominal wall thickness of 0.108 inch were welded together to form an H-base assembly system. Each tube forming the H-base was 48 inches long. A 1-3/4 inch square steel tube with a nominal wall thickness of 0.108 inch and a total length of 34 inches was welded to the center of the H-base assembly. A 48-inch long piece of 1-1/2 inch square steel tubing served as the vertical support. The vertical support inserted 4-1/2 inches into the top of the sleeve and rested on a bolt inserted through the sleeve. A 48-inch long section of 1-1/2-inch perforated square steel tube was used to provide bracing for the sign panel. Two 1-1/2 inch wide × 8-1/2-inch long × 1/8-inch thick ASTM A36 steel fuse plates were used to connect the vertical support and sign panel brace. The fuse plates incorporated a 1-inch diameter weakening hole and were attached to the perforated steel tubing using four 3/8-inch diameter ASTM A307 bolts.

A 36-inch × 36-inch × 0.1-inch thick aluminum diamond-shaped sign was attached to the 1-1/2 inch brace in two locations: 18 inches top and bottom of the horizontal centerline of the sign. The sign was attached to the tube using 3/8-inch diameter bolts. The mounting height to the bottom of the sign blank was 7 ft. Figures 4.20 through 4.22 give details of the sign support system.

A 40-lb sand bag was laid on each side of the base assembly. All perforated square steel tubing was 12 gauge. All bolts were ASTM A307, but any grade bolt was considered acceptable. The test installation was placed on a concrete surface. Figure 4.23 presents photographs of the completed test installation.

4.3.2 Test Designation and Actual Impact Conditions

MASH Test 3-71 involves an 1100C vehicle weighing 2420 lb ±55 lb and impacting the sign support at an impact speed of 62 mph ±2.5 mph. Researchers identified the 90 degrees sign orientation case (i.e., sign parallel to the path of the vehicle) as the most critical for this type of test article. Consequently, the researchers decided to evaluate the impact performance of the temporary single sign support at 90 degrees in the developmental test. It was understood that another *MASH* 3-71 test would need to be performed with the test article oriented at 0 degrees (i.e., perpendicular to the path of the vehicle) to complete the compliance testing.

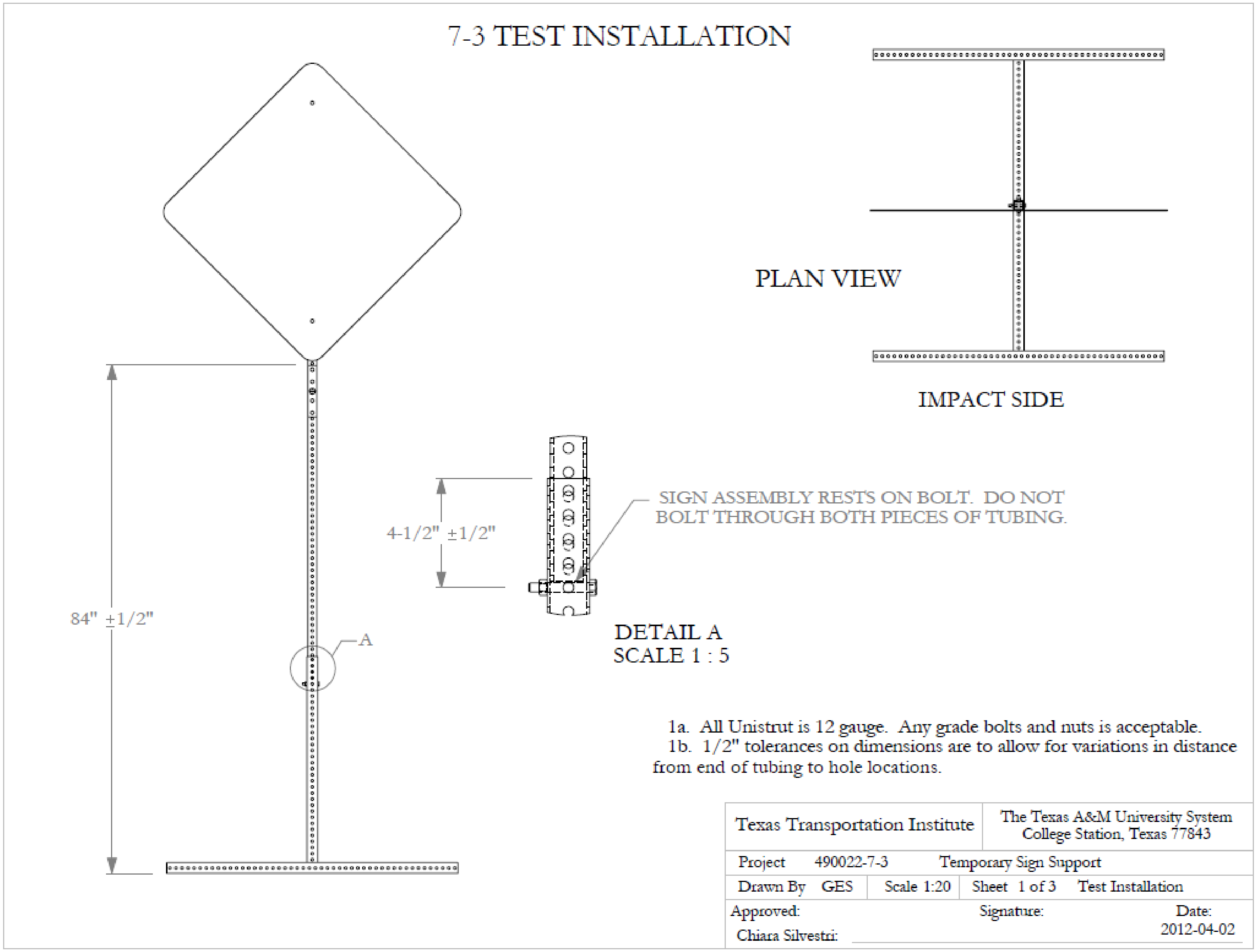
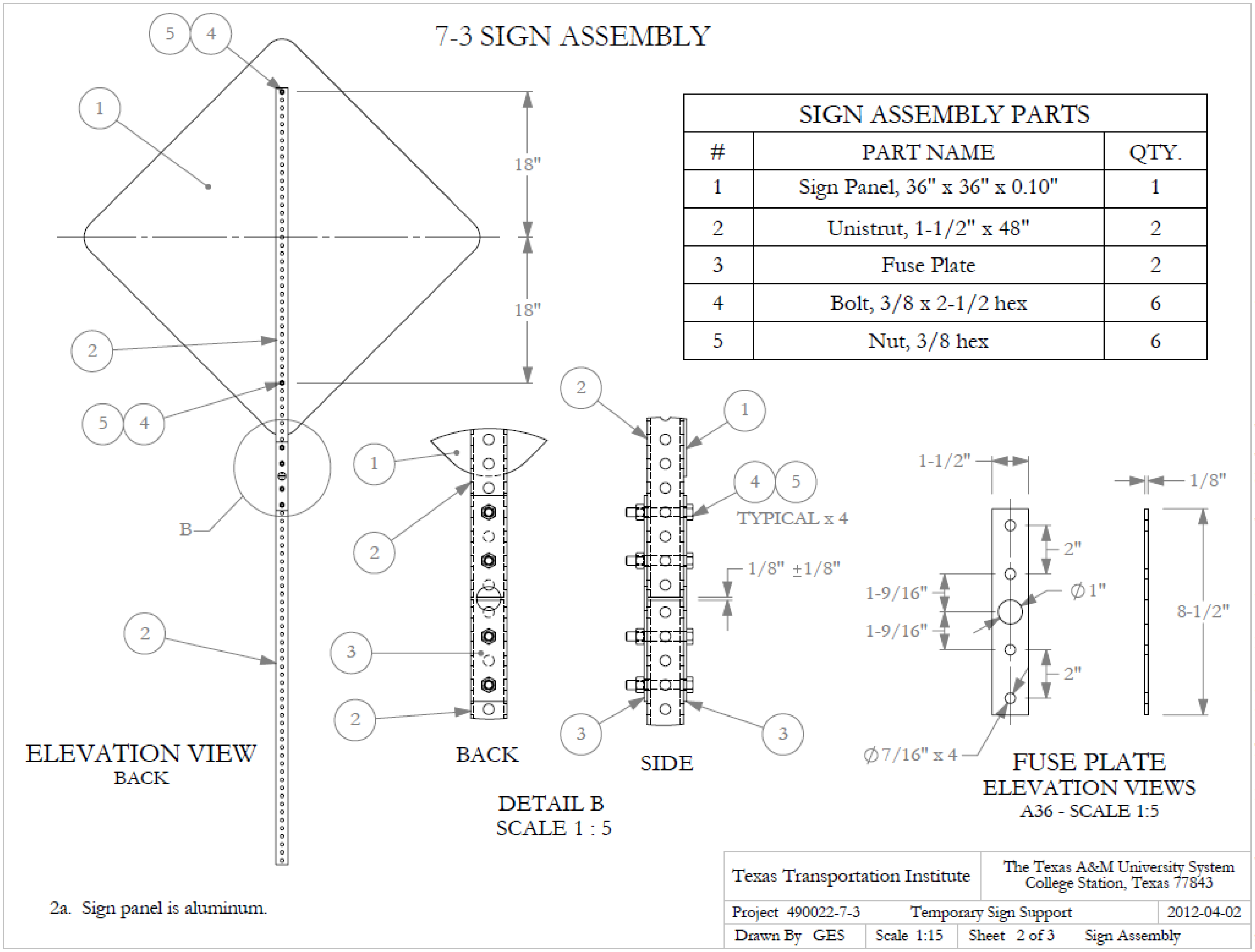


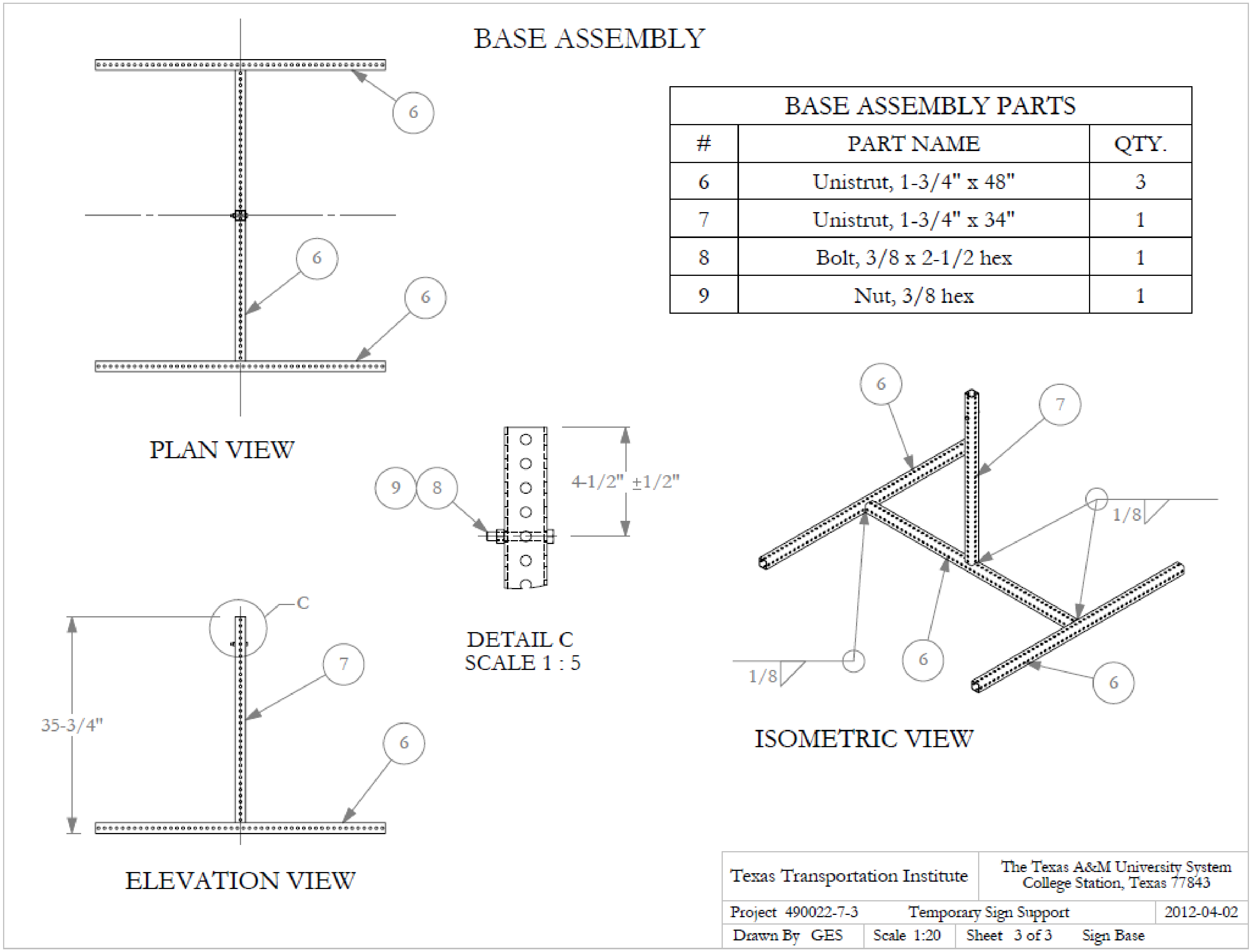
Figure 4.20. Details of the Temporary Single Sign Support System Used for Test No. 490022-7-3.



SIGN ASSEMBLY PARTS

#	PART NAME	QTY.
1	Sign Panel, 36" x 36" x 0.10"	1
2	Unistrut, 1-1/2" x 48"	2
3	Fuse Plate	2
4	Bolt, 3/8 x 2-1/2 hex	6
5	Nut, 3/8 hex	6

Figure 4.21. Details of the Sign Assembly Used in Test No. 490022-7-3.



BASE ASSEMBLY PARTS		
#	PART NAME	QTY.
6	Unistrut, 1-3/4" x 48"	3
7	Unistrut, 1-3/4" x 34"	1
8	Bolt, 3/8 x 2-1/2 hex	1
9	Nut, 3/8 hex	1

Figure 4.22. Details of the Base Assembly Used in Test No. 490022-7-3.

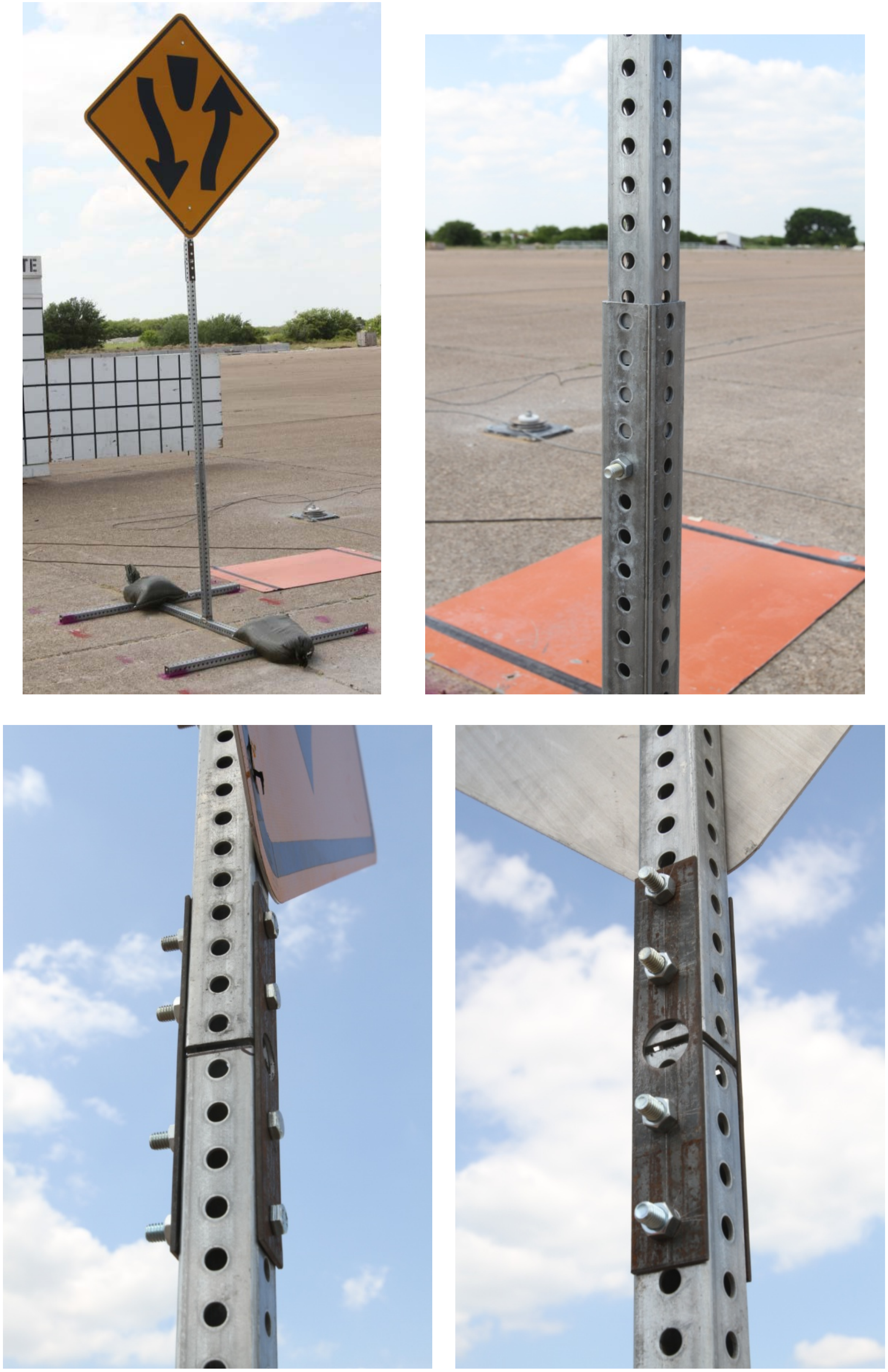


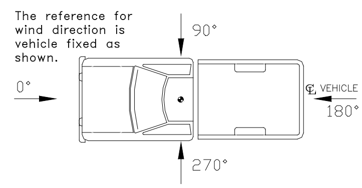
Figure 4.23. Temporary Sign Support System prior to Test No. 490022-7-3.

The target impact point was the right quarter point of the vehicle aligned with the centerline of the support. The same 2003 Kia Rio passenger car used in the previous tests (tests 490022-7-1 and 490022-7-2) was used in this test. The vehicle weighed 2425 lb and the actual impact speed and angle were 63.6 mph and 90 degrees, respectively. The actual impact point was the right front quarter point of the vehicle with the centerline of the sign support.

4.3.3 Test Vehicle

A 2003 Kia Rio passenger car (shown in Figures 4.24 and 4.25) was used for the crash test. Test inertia weight of the vehicle was 2425 lb, and gross static weight was 2425 lb. The height to the lower edge of the vehicle front bumper was 8.5 inches, and the height to the upper edge of the front bumper was 22.75 inches. Table E1 of Appendix E give additional dimensions and information on the vehicle. The passenger car was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

4.3.4 Weather Conditions



The crash test was performed on the morning of April 12, 2012. Weather conditions at the time of testing were: wind speed: 12 mph; temperature: 81°F; relative humidity: 55 percent.

4.3.5 Test Description

The 1100C vehicle, traveling at an impact speed of 63.6 mph, contacted the sign support at an impact angle of 90 degrees, with the centerline point aligned with the centerline of the support. At approximately 0.016 s, the lower telescopic slip connection activated, releasing the vertical support and sign assembly from the base. At the same time, the tension side of the fuse plates began to fracture. At 0.076 s, the vertical support was parallel to the ground level and at 0.110 s the edge of the sign was parallel to the ground. The vertical support and sign assembly cleared the vehicle and impacted the ground at 0.508 s. The vehicle subsequently came to rest 225 ft downstream of impact. Figure E1 in Appendix E presents sequential photographs of the test period.

4.3.6 Test Article and Component Damage

Figure 4.26 shows damage to the sign support system. The lower telescopic slip connection and fuse plates activated as designed. The support post and sign assembly came to rest only a few inches downstream of the impact point. The base assembly was resting 225 ft downstream of the impact point, underneath the vehicle body.

4.3.7 Test Vehicle Damage

The 1100C vehicle did not sustain any additional damage during the impact with the temporary single sign support. Figure 4.27 shows photographs of the exterior of the vehicle.

Figure 4.24. Vehicle/Installation Geometrics for Test No. 490022-7-3.

Figure 4.25. Vehicle before Test No. 490022-7-3.

Figure 4.26. Installation after Test No. 490022-7-3.

Figure 4.27. Vehicle after Test No. 490022-7-3.

4.3.8 Occupant Risk Values

No accelerometer or other types of instrumentation were installed in the vehicle. *MASH* states that Test 71 “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. In this case, vehicle intrusion, windshield damage, and vehicle stability are the primary performance evaluation factors.” The weight of the temporary sign support system was 67 lb.

4.3.9 Assessment of Test Results

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

4.3.9.1 Structural Adequacy

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

Results: The temporary sign support activated readily by yielding to the vehicle and through activation of the slip connection. The fuse plates fractured on their tensile sides as designed. (PASS)

4.3.9.2 Occupant Risk

D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*
Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.

Results: No deformation or intrusion into the occupant compartment was recorded. (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. Although roll and pitch angles were not recorded, it is clear from film analysis that they did not exceed 75 degrees throughout the impact event. (PASS)

J. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
10 ft/s	*16 ft/s*

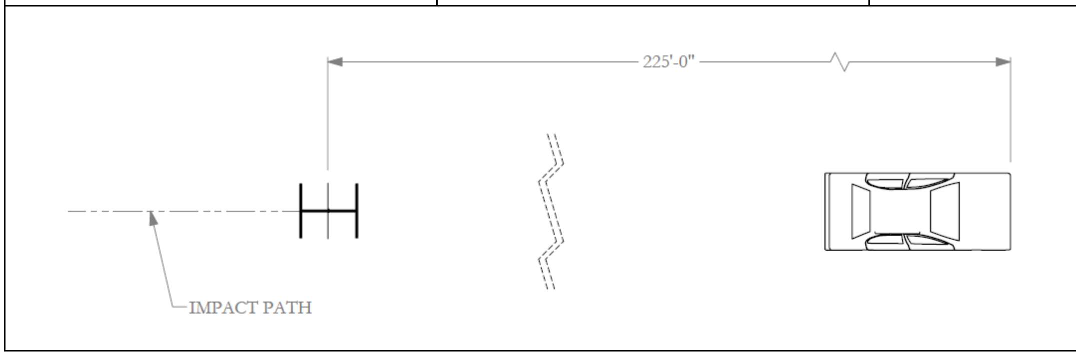
Results: Not required for test articles having a total weight of 220 lb or less. The weight of the temporary sign support system was 67 lb. (N/A)

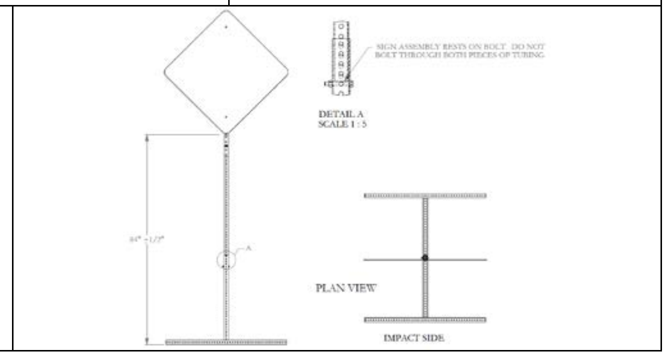
4.3.9.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Result: The 1100C vehicle exited behind the test article. (PASS)

A summary of the results from Test No. 490022-7-3 is presented in Figure 4.28.





General Information
- Test Agency........................ Texas A&M Transportation Institute
- MASH Test No. .... *MASH* Test 3-71
- TTI-PG Test No. 490022-7-3
- Date 2012-04-12

Test Article
- Type.................................... Temporary Single Sign Support
- Name .... Bottom telescopic slip connection and upper fuse plates/9 ft^2 sign panel
- Installation Height .... 7 ft to bottom of sign panel
- Material or Key Elements .... Aluminum sign panel mounted on a 1-1/2-inch perforated steel tube support; 1-3/4 perforated steel tube H-base

Soil Type and Condition....... Concrete Pavement, Dry

Test Vehicle
- Type/Designation................. 1100C
- Make and Model .... 2003 Kia Rio
- Curb.................................... 2411 lb
- Test Inertial.......................... 2425 lb
- Dummy .... No dummy
- Gross Static .... 2425 lb

Impact Conditions
- Speed ....63.6 mph
- Angle ....90 degrees
- Location/Orientation ....Centerline of vehicle with centerline of sign support

Exit Conditions
- Speed ....62.93 mph
- Angle ....0 degrees

Occupant Risk Values
- Impact Velocity
  - Longitudinal ....N/A
  - Lateral ....N/A
- Ridedown Accelerations
  - Longitudinal ....N/A
  - Lateral ....N/A
- THIV ....N/A
- ASI ....N/A
- Max. 0.050-s Average
  - Longitudinal ....N/A
  - Lateral ....N/A
  - Vertical ....N/A

Post-Impact Trajectory
- Stopping Distance 225-ft

Vehicle Stability
- Maximum Yaw Angle....................... N/A
- Maximum Pitch Angle...................... N/A
- Maximum Roll Angle .... N/A
- Vehicle Snagging .... No
- Vehicle Pocketing .... No

Test Article Deflections
- Dynamic 225-ft
- Permanent 225-ft
- Working Width .... N/A

Vehicle Damage
- VDS 12FD1
- CDC.. 12FDEN1
- Max. Exterior Deformation............... None
- OCDI... FS0000000
- Max. Occupant Compartment Deformation.............................. None

Figure 4.28. Summary of Results for *MASH* Test 3-71 (Test No. 490022-7-3) of Temporary Single Sign Support with Bottom Telescopic Slip Connection and Upper Fuse Plates (Modified Design #8).

4.4 SUMMARY OF TEST RESULTS

4.4.1 Test 490022-7-1 (*MASH* Test No. 3-71) of Temporary Single Sign Support with Top and Bottom Telescopic Slip Connections (Modified Design #2)

The temporary sign support yielded to the vehicle and the bottom slip connection activated as designed. The upper slip connection activated only after the released support rotated almost 180 degrees. There was no secondary contact between the test article and the vehicle. The 1100C vehicle remained upright and stable during and after the collision event.

4.4.2 Test 490022-7-2 (*MASH* Test No. 3-71) of Temporary Single Sign Support with Bottom Telescopic Slip Connection (Design #4)

The temporary sign support yielded to the vehicle and the bottom slip connection activated as designed. There was no secondary contact between the test article and the vehicle. The 1100C vehicle remained upright and stable during and after the collision event.

4.4.3 Test 490022-7-3 (*MASH* Test No. 3-71) of Temporary Single Sign Support with Bottom Telescopic Slip Connection and Upper Fuse Plate Connection (Modified Design #8)

The temporary sign support yielded to the vehicle and the bottom slip connection activated as designed. The fuse plates fractured on their tension sides as design. There was no secondary contact between the test article and the vehicle. The 1100C vehicle remained upright and stable during and after the collision event.

4.4.4 Test Outcome Comparison

All three temporary single sign support designs behaved acceptably without any secondary contact with the vehicle windshield or roof. In all three cases, the lower telescopic connection activated as designed, releasing the inner support post and sign assembly from the base and permitting it to rotate up and over the vehicle. In the first design, the upper telescopic slip connection released the sign panel from the support post, but only after the support post had rotated almost 180 degrees after impact. Thus, no substantial difference was noted in the performance or trajectory of the sign supports evaluated in test 1 (modified Design #2) and test 2 (Design #4).

In test 3 (Design #8), the fuse plates fractured on their tensile sides as designed. The permitted the sign assembly to hinge or rotate with respect to the vertical support. This reduced the rotational inertia of the sign assembly compared to the other designs.

Table 4.1 presents side-by-side sequential images of the tests performed on the three designs. This permits visual comparison of the three temporary single sign support systems.

Table 4.1. Frame Comparison of Crash Tests on Possible Designs.

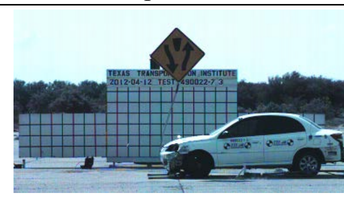
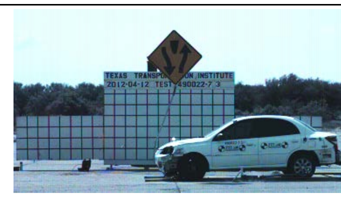
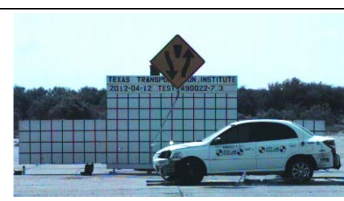
Time (sec)	**Design #1** (Telescopic Bottom & Top Connections)	**Design #2** (Telescopic Bottom Connection)	**Design #3** (Telescopic Bottom Connection & Top Frangible Plate)
0.000			
	Impact Time	Impact Time	Impact Time
0.013			
0.015			
	Lower Post Fractures		
0.016			
			Middle Post Leaves Lower Telescopic Connection & Plate Starts Fracuring
0.017			
	Middle Post Leaves Lower Telescopic Connection		
0.019			
		Middle Post Leaves Lower Telescopic Connection	

Table 4.1. Frame Comparison of Crash Tests on Possible Designs (Continued).

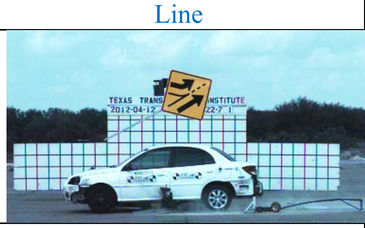
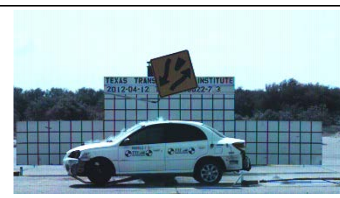
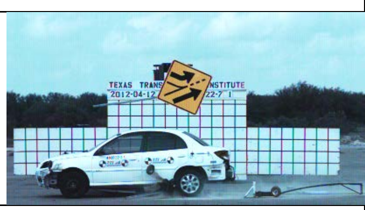
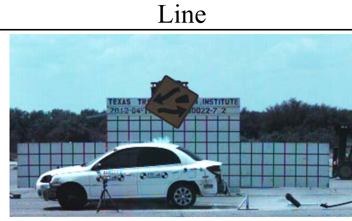
Time (sec)	**Design #1** (Telescopic Bottom & Top Connections)	**Design #2** (Telescopic Bottom Connection)	**Design #3** (Telescopic Bottom Connection & Top Frangible Plate)
0.027			
			Plate is Completely Broken at Tension Side
0.060			
0.075			
0.086			
	Sign Reaches 1st Horizontal Line		
0.089			
		Sign Reaches 1st Horizontal Line	
0.110			
			Sign Reaches 1st Horizontal Line

Table 4.1. Frame Comparison of Crash Tests on Possible Designs (Continued).

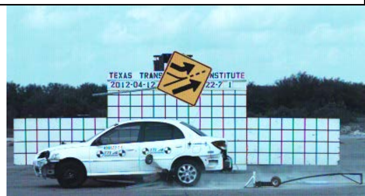
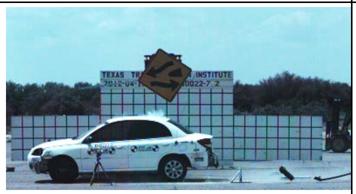
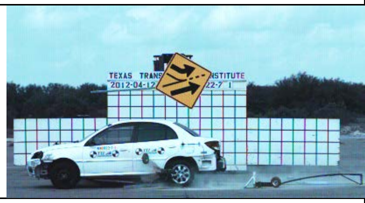
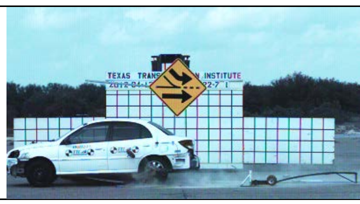
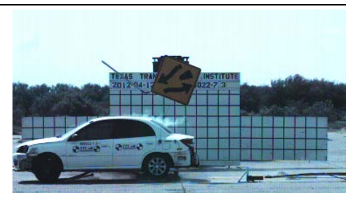
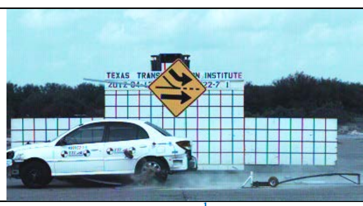
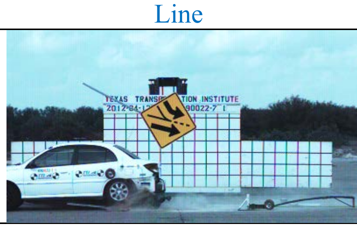
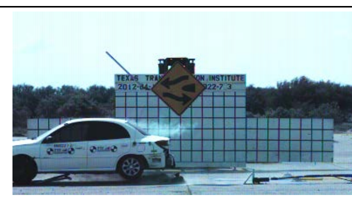
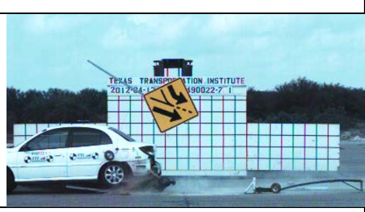
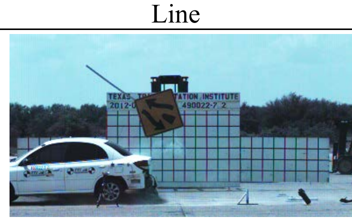
Time (sec)	**Design #1** (Telescopic Bottom & Top Connections)	**Design #2** (Telescopic Bottom Connection)	**Design #3** (Telescopic Bottom Connection & Top Frangible Plate)
0.112			
	Sign Reaches 2nd Horizontal Line		
0.117			
		Sign Reaches 2nd Horizontal Line	
0.135			
			Sign Reaches 2nd Horizontal Line
0.137			
	Sign Reaches 3rd Horizontal Line		
0.160			
		Sign Reaches 3rd Horizontal Line	
0.167			
			Sign Reaches 3rd Horizontal Line

Table 4.1. Frame Comparison of Crash Tests on Possible Designs (Continued).

Time (sec)	**Design #1** (Telescopic Bottom & Top Connections)	**Design #2** (Telescopic Bottom Connection)	**Design #3** (Telescopic Bottom Connection & Top Frangible Plate)
0.213			
			Plate Completely Re-closes in "Straight" Position

4.4.5 Conclusions

The objective of this task was to evaluate the performance of three temporary single sign support designs when impacted by an 1100C vehicle. Full-scale, high-speed crash tests conforming to *MASH* Test 3-71 were performed to evaluate impact performance and trajectory of the released sign support system. The tests were performed with the test article oriented at 90 degrees (i.e., with the sign panel oriented parallel to the path of the vehicle). Tables 4.2 through 4.4 summarize the evaluation of each system according to the relevant *MASH* criteria.

All three designs exhibited acceptable impact performance with vehicle 1100C with no secondary contact between the support system and the vehicle windshield or roof. The researchers chose Design #4 for further evaluation using finite element simulation because it was the simplest and least expensive design to construct. The purpose of the simulation effort was to assess performance of the selected design with the 2270P vehicle.

Table 4.2. Performance Evaluation Summary for *MASH* Test 3-71 of Temporary Single Sign Support with Top and Bottom Telescopic Slip Connections (Modified Design #2).

Test Agency: Texas A&M Transportation Institute — Test No.: 490022-7-1 — Test Date: 2012-04-12

***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 temporary sign support yielded to the vehicle and the slip connections activated as designed.	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. *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.*	No deformation or intrusion into the occupant compartment was recorded.	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. Roll and pitch angles were not recorded, but it is clearly evident from film analysis that they did not exceed 75 degrees.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 3.0 m/s (10 ft/s), or at least below the maximum allowable value of 5.0 m/s (16.4 ft/s).	Assessment of occupant impact velocity is not required for test articles having a total weight of 220 lb or less. The weight of the temporary sign support system was 75 lb.	N/A
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 1100C vehicle exited behind the test article.	Pass

Table 4.3. Performance Evaluation Summary for *MASH* Test 3-71 of Temporary Single Sign Support with Bottom Telescopic Slip Connection (Design #4).

Test Agency: Texas A&M Transportation Institute — Test No.: 490022-7-2 — Test Date: 2012-04-12

***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 temporary sign support yielded to the vehicle and the slip connection activated as designed.	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.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.*	No deformation or intrusion into the occupant compartment was recorded.	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. Roll and pitch angles were not recorded, but it is clearly evident from film analysis that they did not exceed 75 degrees.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 3.0 m/s (10 ft/s), or at least below the maximum allowable value of 5.0 m/s (16.4 ft/s).*	Assessment of occupant impact velocity is not required for test articles having a total weight of 220 lb or less. The weight of the temporary sign support system was 67 lb.	N/A
Vehicle Trajectory		
N. *Vehicle trajectory behind the test article is acceptable.*	The 1100C vehicle exited behind the test article.	Pass

Table 4.4. Performance Evaluation Summary for *MASH* Test 3-71 of Temporary Single Sign Support with Bottom Telescopic Slip Connection and Upper Fuse Plates (Modified Design #8).

Test Agency: Texas A&M Transportation Institute | Test No.: 490022-7-3 | Test Date: 2012-04-12

***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 temporary sign support yielded to the vehicle and the slip connection and fuse plates activated as designed.	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.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.*	No deformation or intrusion into the occupant compartment was recorded.	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. Roll and pitch angles were not recorded, but it is clearly evident from film analysis that they did not exceed 75 degrees.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 3.0 m/s (10 ft/s), or at least below the maximum allowable value of 5.0 m/s (16.4 ft/s).*	Assessment of occupant impact velocity is not required for test articles having a total weight of 220 lb or less. The weight of the temporary sign support system was 67 lb.	Pass
Vehicle Trajectory N. *Vehicle trajectory behind the test article is acceptable.*	The 1100C vehicle exited behind the test article.	Pass

CHAPTER 5. FINITE ELEMENT ANALYSIS*

5.1 FINITE ELEMENT MODELS OF THE VEHICLES USED FOR FE SIMULATIONS

Figures 5.1 and 5.2 illustrate the finite element models of the small passenger car (Toyota Yaris) and the pickup truck (Chevrolet Silverado) used in the computer simulations performed during this project, and compares them to the actual vehicles used in the full-scale crash tests (i.e., Kia Rio and Dodge Ram 1500 pickup, respectively). The analyses were performed using the nonlinear finite element software LS-DYNA (*9*).

5.2 FINITE ELEMENT SIMULATIONS ANALYSIS

5.2.1 Simulation of Test No. 490022-7-2 (*MASH* Test 3-71)

A finite element model of temporary sign support system Design #4 was developed and validated using data from the small car development test (Test No. 490022-7-2).

Figure 5.3 shows the finite element model of the temporary single sign support. The 1-3/4 inch square steel tubing used in the H-base assembly was 0.108 inch thick and was modeled using piecewise linear plasticity material properties. A 36-inch × 36-inch × 0.10-inch thick aluminum diamond-shaped sign panel was modeled with elastic material properties and constrained to the 1-1/2 inch steel vertical support using nodal rigid body constraints at the locations of connecting bolts. The 1-1/2 inch vertical support was inserted 4½ inches into the 1-3/4 inch sleeve tube. The vertical support rested on null shells that were modeled to represent the bolt. The mounting height to the bottom of the sign panel was 7 ft.

Figure 5.4 shows the passenger car vehicle model impacting the temporary single sign support model (Design #4) at a speed of 62.4 mph and a 90 degree angle. These impact conditions matched the actual crash test conditions. The impact location was the right quarter point of the vehicle aligned with the center of the sign support.

Table 5.1 compares the results of the simulated impact to those of the crash test. Very good correlation was achieved between simulation and test results. The FE simulation correctly replicated the trajectory of the temporary single sign support during and after the impact event. Figure 5.5 shows the energy balance for the FE simulation. Both hourglass and sliding interface energy values remain under 5 percent as preferred during FE computer simulations.

* TTI Proving Ground is an ISO 17025 accredited laboratory with A2LA Mechanical Testing certificate 2821.01. This certificate does not include simulation/engineering analysis.

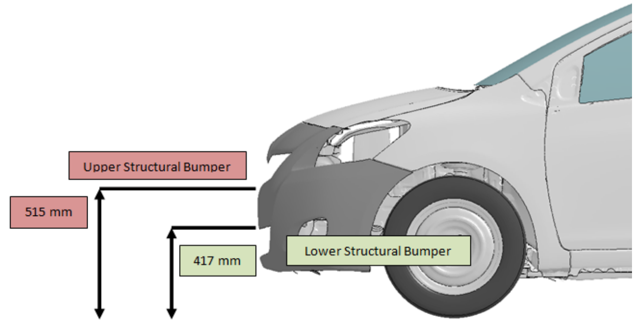
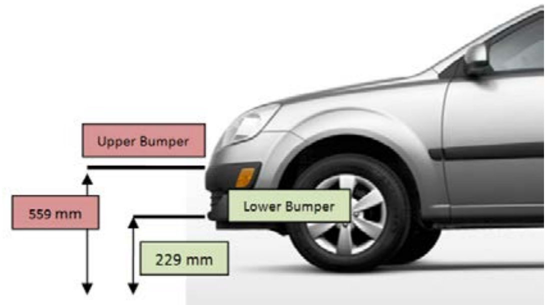
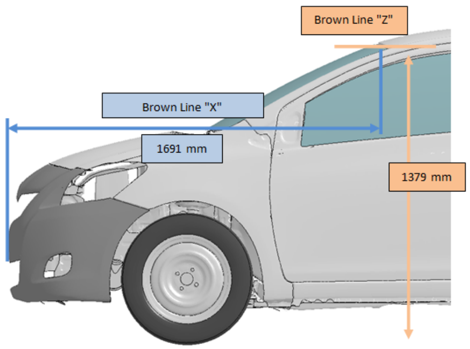
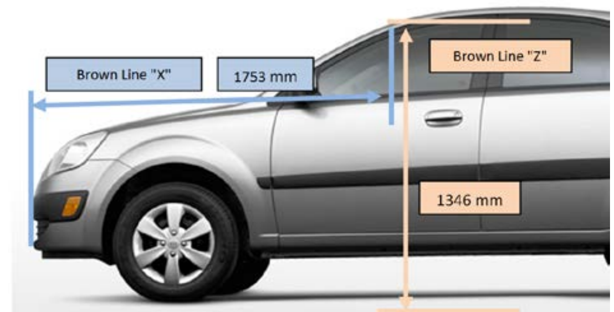
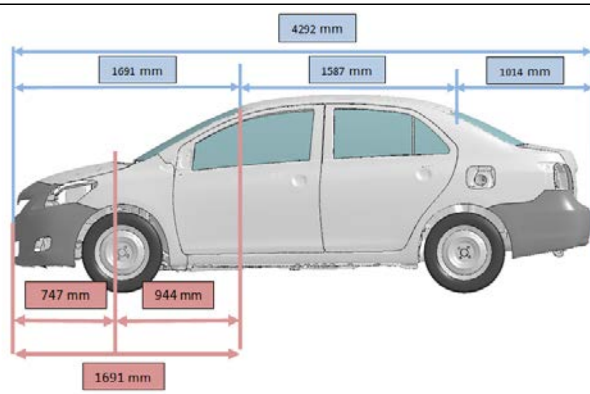
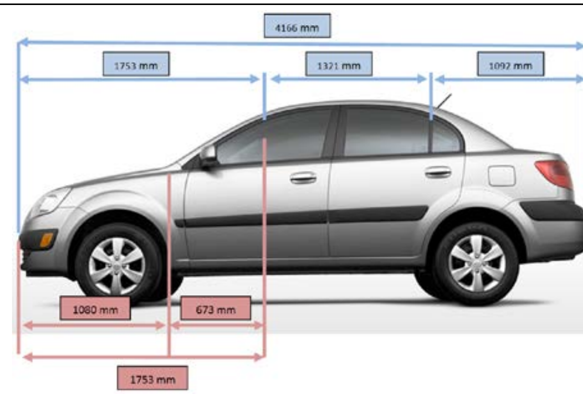
<table>
<tr><th>Vehicle</th><th>Toyota Yaris</th><th>Kia Rio</th></tr>
<tr><td>Bumper Dimensions</td><td>
</td><td>
</td></tr>
<tr><td>Brow Line Dimensions</td><td>
</td><td>
</td></tr>
<tr><td>General Dimensions</td><td>
</td><td>
</td></tr>
</table>

Figure 5.1. Dimensions Comparison between Toyota Yaris FE Model and Kia Rio Test Vehicle.

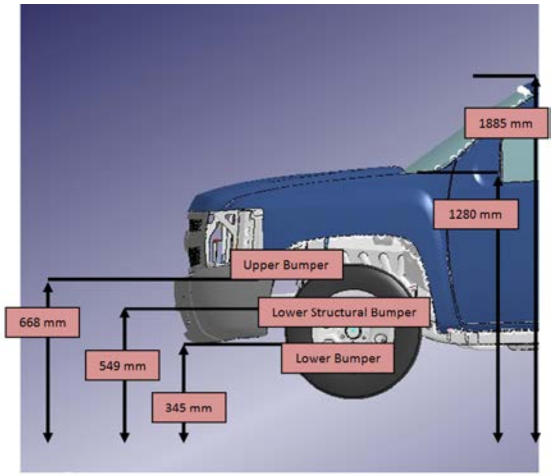
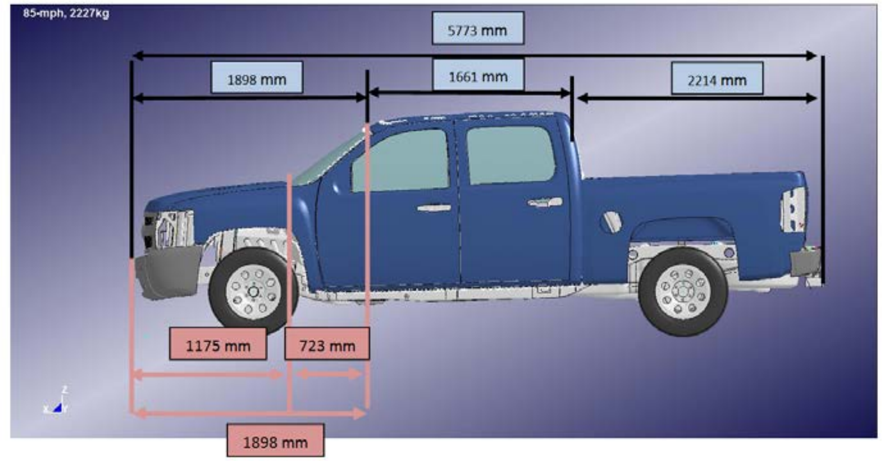
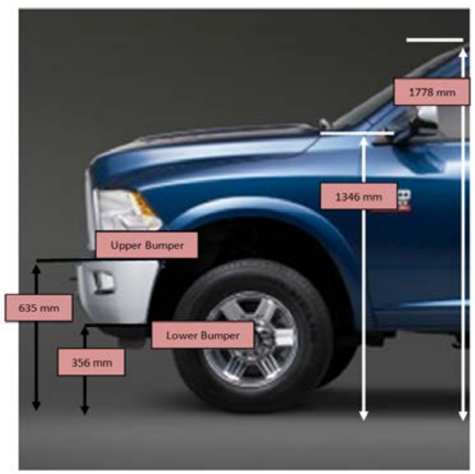
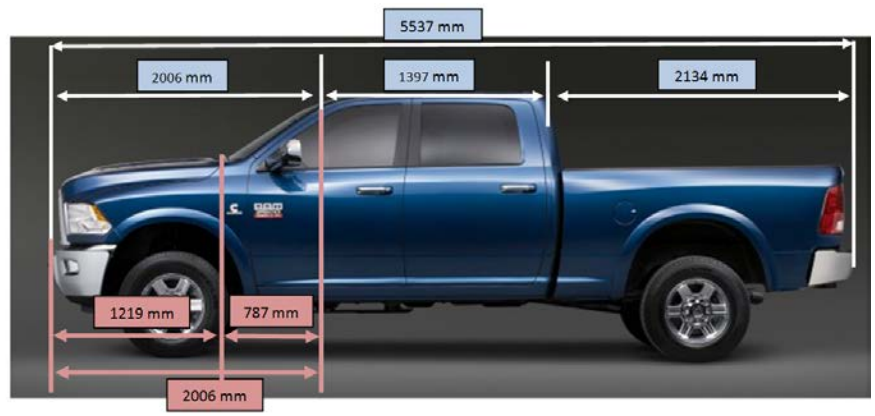
<table>
<tr><th>Vehicle</th><th>Bumper Dimensions</th><th>General Dimensions</th></tr>
<tr><td>Chevrolet Silverado</td><td>
</td><td>
</td></tr>
<tr><td>Dodge Ram</td><td>
</td><td>
</td></tr>
</table>

Figure 5.2. Dimensional Comparison between the Chevrolet Silverado FE Model and the Dodge Ram Test Vehicle.

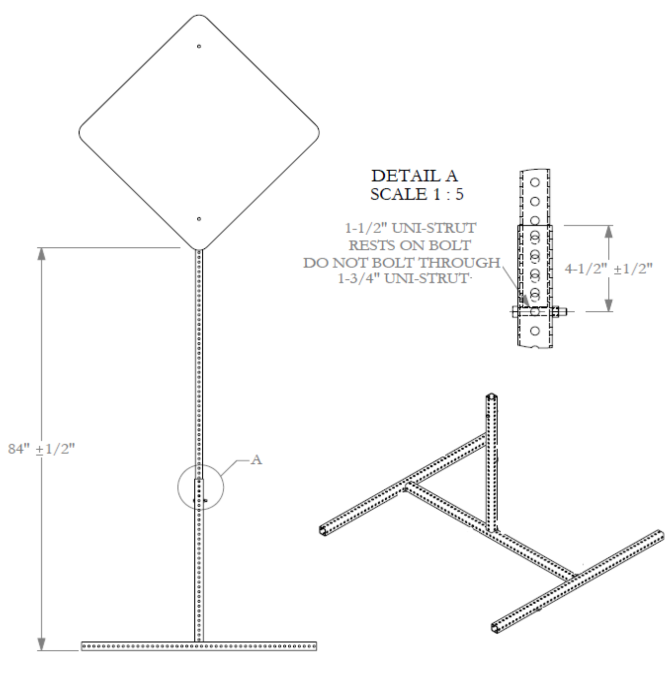
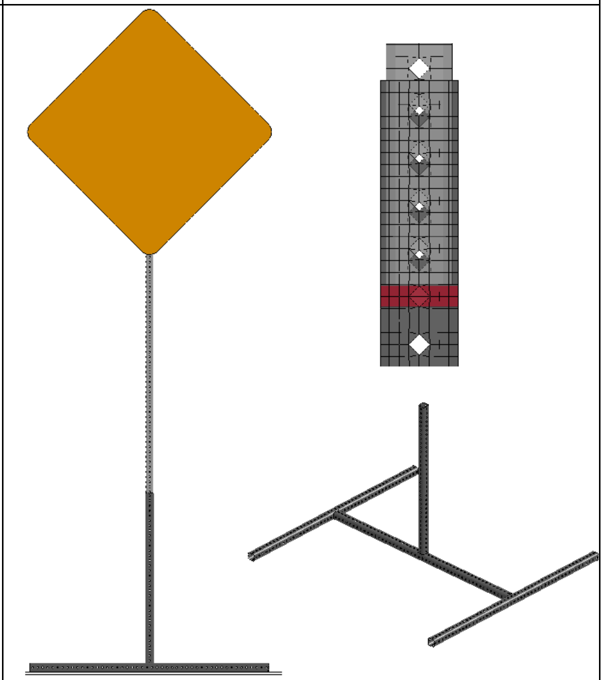
Test No. 490022-7-2	FE Model
	
(a) Details of Temporary Sign Support System Used in Test No. 490022-7-2	**(b) Details of FE Temporary Sign Support System**

Figure 5.3. Comparison between Test No. 490022-7-2 and FE Model Temporary Single Sign Support System Configurations.

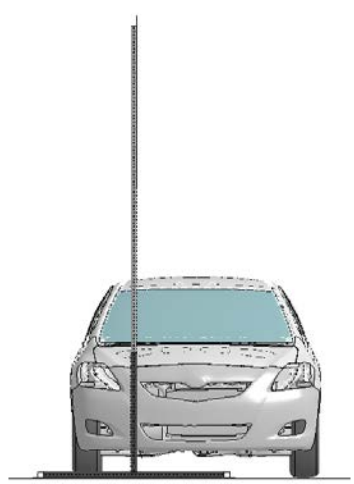
Pre-Impact Frontal Configuration		Impact Conditions
Kia Rio Test Vehicle	**Toyota Yaris FE Model**	➢ Impact Speed: 62.4 mph ➢ Impact Angle: 90 degrees ➢ Impact Location: right quarter point aligned with centerline of sign support
		
(a) Test No. 490022-7-2	**(b) FE Simulation**	

Figure 5.4. Comparison between TxDOT Test No. 490022-7-2 and FE Model Impact Conditions.

Table 5.1. Comparison of 490022-7-2 Crash Test and FE Impact Simulation with Passenger Car (Yaris).

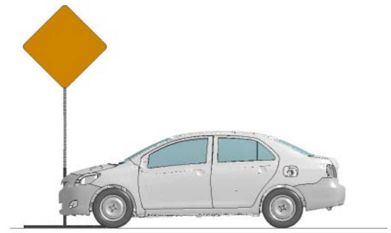
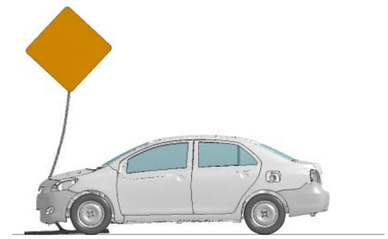
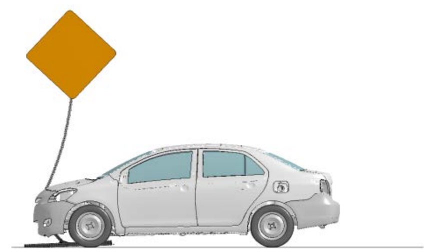
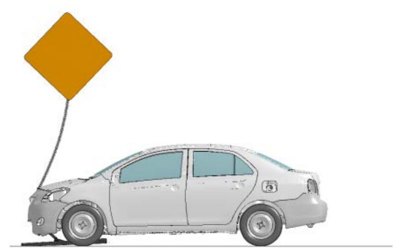
Time (sec)	490022-7-2 Crash Test	FE Simulation
0.000		
	Impact Time	
0.014		
0.016		
0.018 – 0.019		
	Middle Post Leaves Lower Telescopic Connection (0.019 sec)	(0.018 sec)

Table 5.1. Comparison of 490022-7-2 Crash Test and FE Impact Simulation with Passenger Car (Yaris). (Continued)

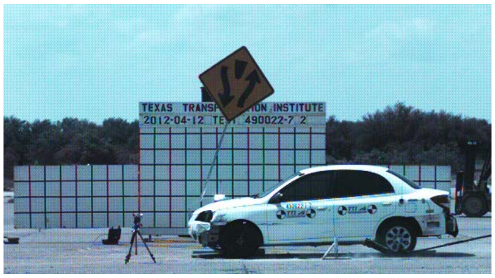
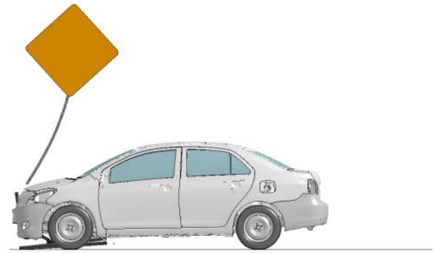
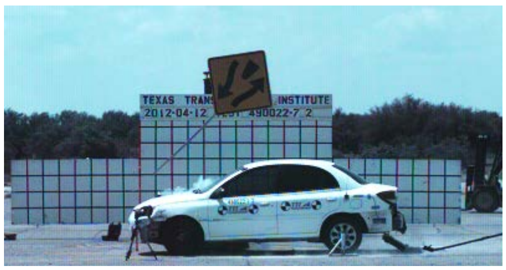
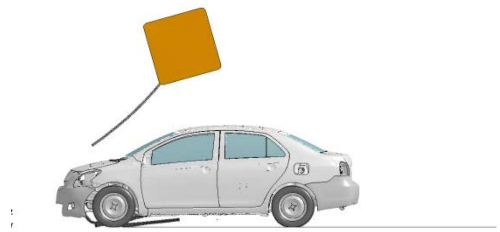
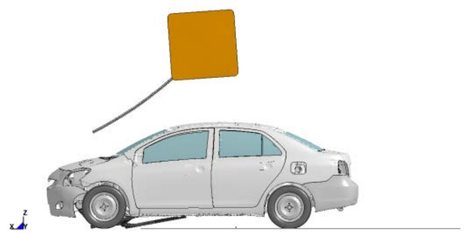
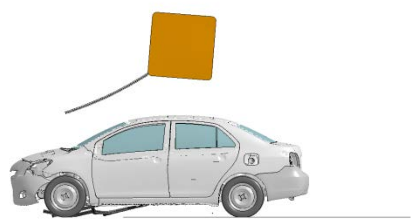
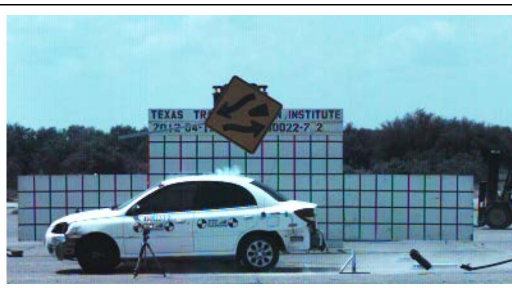
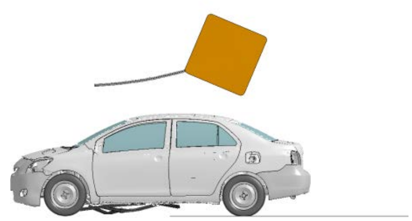
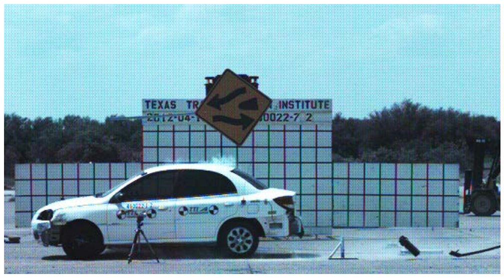
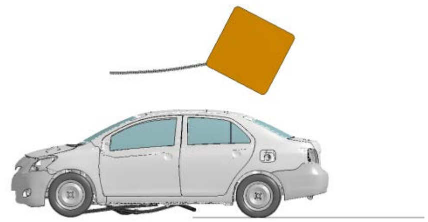
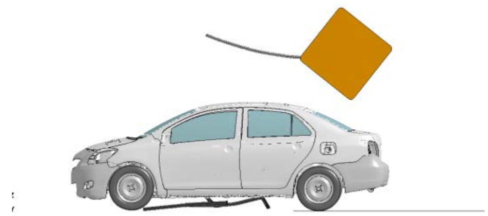
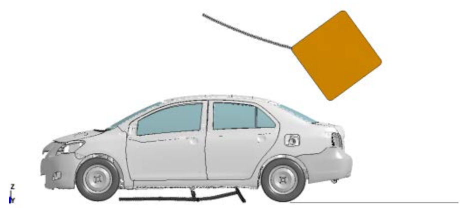
Time (sec)	490022-7-2 Crash Test	FE Simulation
0.026		
0.060		
0.074		
0.086		
0.110		

Table 5.1. Comparison of 490022-7-2 Crash Test and FE Impact Simulation with Passenger Car (Yaris). (Continued)

Time (sec)	490022-7-2 Crash Test	FE Simulation
0.116		
0.136		
0.152		

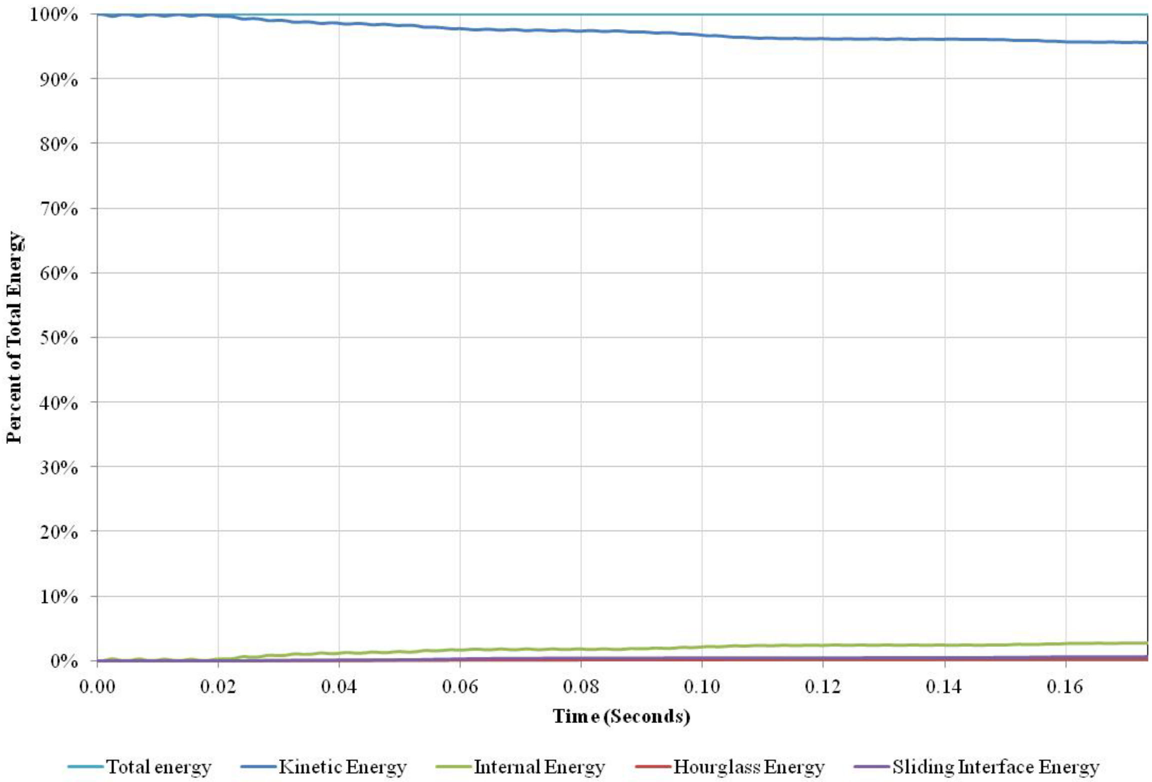


Figure 5.5. Energy Distribution from Finite Element Simulation of 490022-7-2.

5.2.2 Predictive Simulation with 2270P Vehicle

The impact performance of the selected temporary single sign support system (Design #4) with the 2270P pickup truck was evaluated using FE simulation. Figure 5.6 shows the initial simulation setup of the finite element model of the temporary single sign support and pickup truck. The impact speed was 62.4 mph, and the sign panel was oriented at 90 degrees. The initial impact location the right quarter point of the vehicle aligned with the centerline of the sign support. Figure 5.7 shows the interaction between the sign support system and the pickup truck vehicle model during the simulation. The simulation predicts contact of the corner of the sign panel with the windshield of the pickup truck. This interaction is likely to result in unacceptable occupant compartment deformation.

Figure 5.8 presents the energy balance from the FE impact simulation. Both hourglass and sliding interface energy values remain under 5 percent as preferred during FE computer simulations. Table 5.2 compares the results of the simulated impact with the 2270P vehicle to those of the FE simulation with the 1100C vehicle.

Impact Configurations		**Initial Impact Conditions**
		➢ Impact Speed: 62.4 mph ➢ Impact Angle: 90 degrees ➢ Impact Location: right quarter point from vehicle's centerline (passenger's side)
(a) Frontal View	**(b) Lateral View**	

Figure 5.6. Initial Configuration for Finite Element Impact Simulation with *MASH* 2270P Vehicle (Design #4).

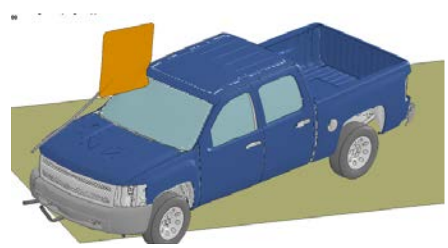
Windshield Impact Configurations	
	
(a) Frontal View	**(b) Perspective View**

Figure 5.7. Predicted Windshield Impact in Finite Element Simulation with *MASH* 2270P Vehicle (Design #4).

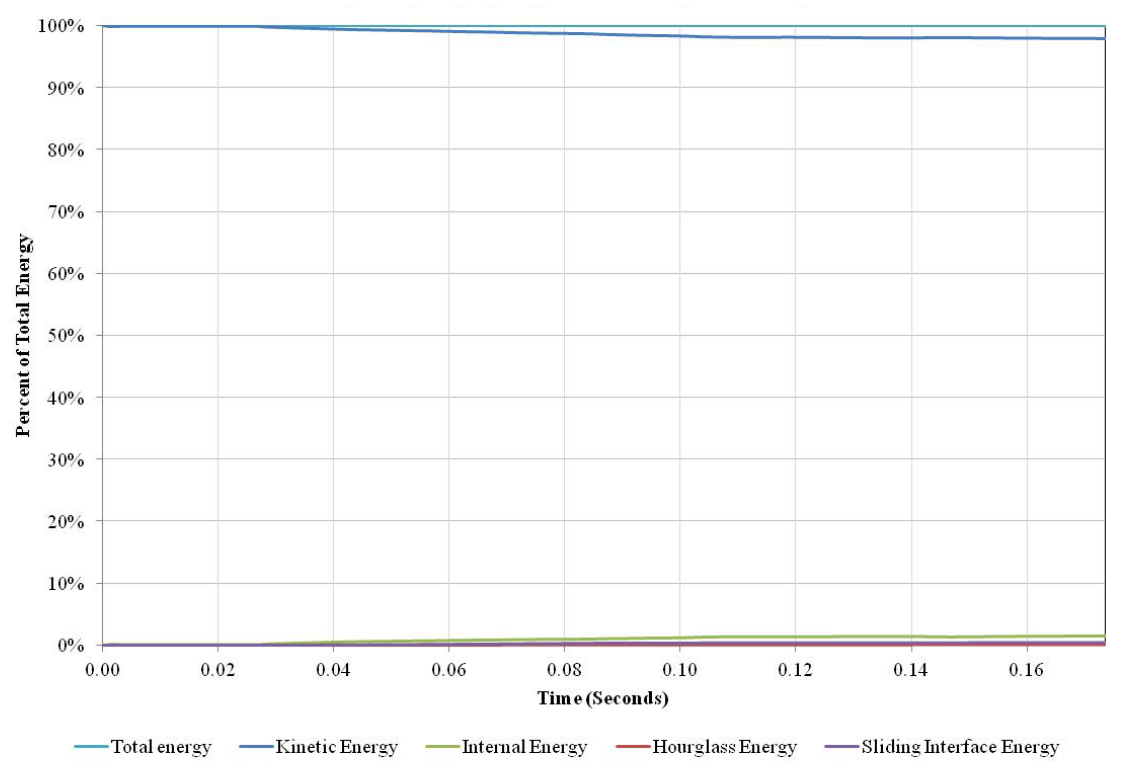


Figure 5.8. Energy Balance from Finite Element Simulation of Impact of Design #4 with *MASH* 2270P Vehicle.

Table 5.2. Comparison of FE Simulation of Design #4
with 1100C Vehicle and 2270P Vehicle.

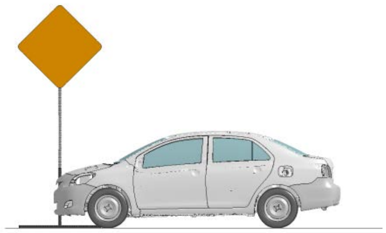
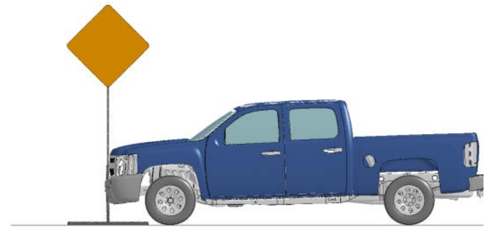
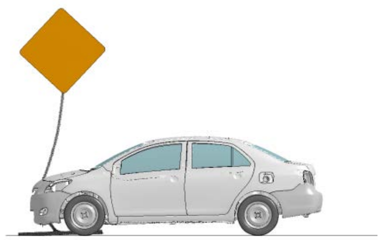
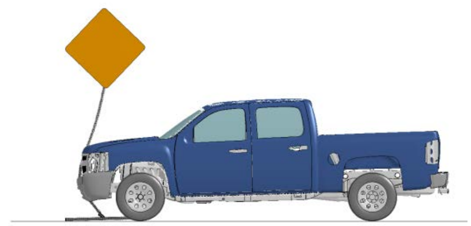
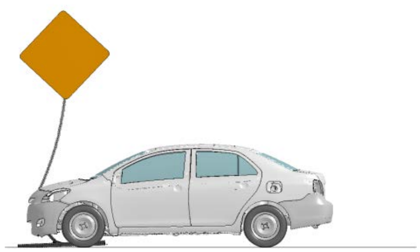
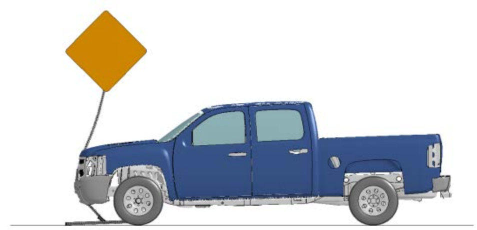
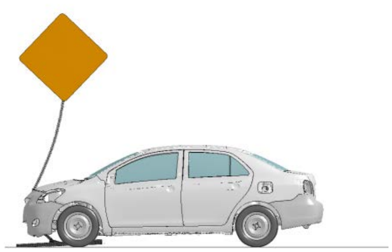
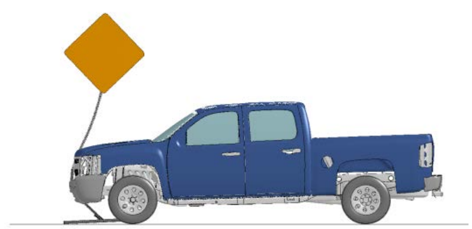
Time (sec)	1100C FE Simulation (Design #2)	2270P FE Simulation (Design #2)
0.000		
	Impact	
0.014		
0.016		
0.018		
	Telescopic Connection Releases	

Table 5.2. Comparison of FE Simulation of Design #4 with 1100C Vehicle and 2270P Vehicle. (Continued)

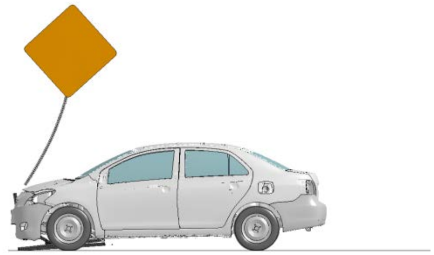
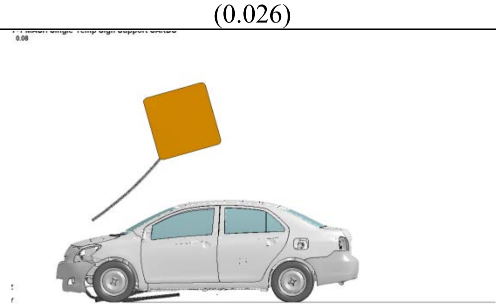
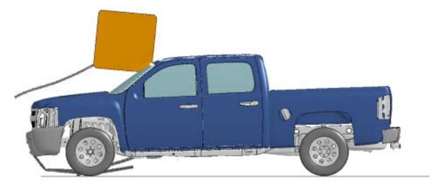
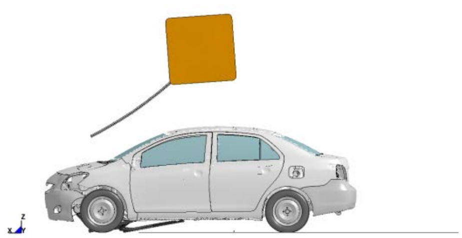
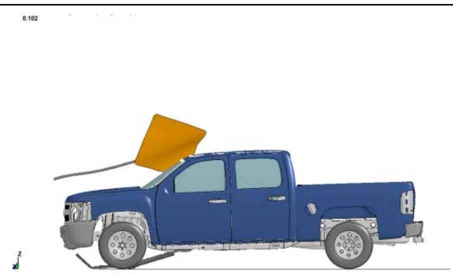
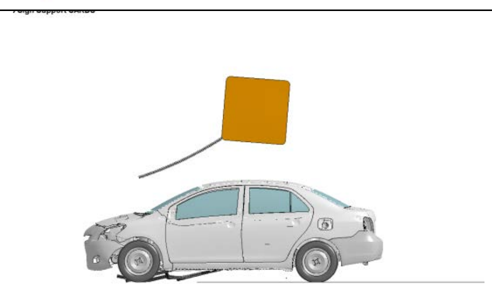
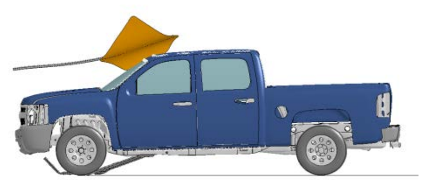
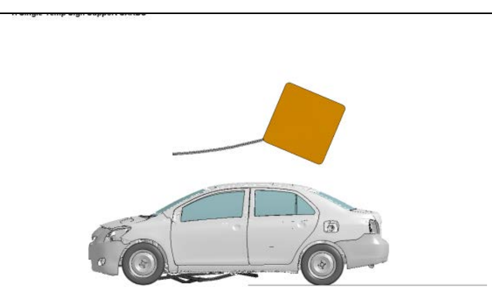
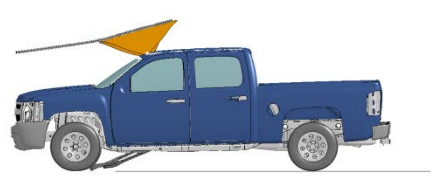
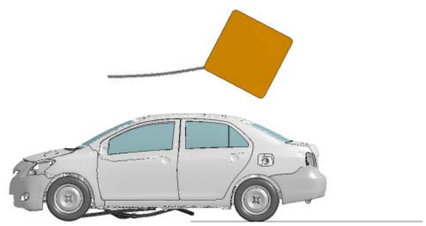
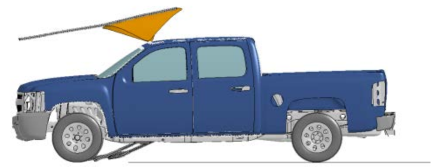
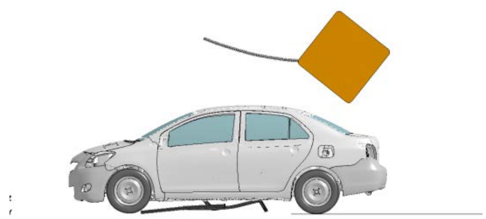
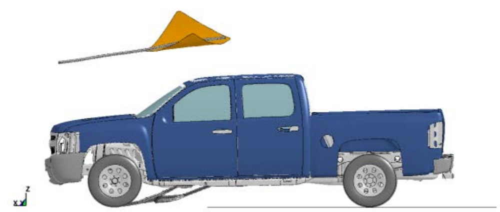
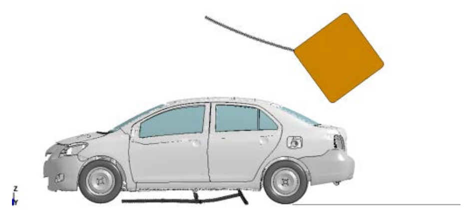
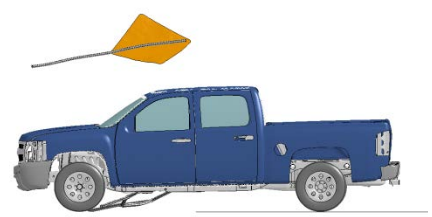
Time (sec)	1100C FE Simulation (Design #2)	2270P FE Simulation (Design #2)
0.026 – 0.028		
	(0.026)	Telescopic Connection Releases (0.028)
0.060		
0.074		
0.086		
0.110		

Table 5.2. Comparison of FE Simulation of Design #4 with 1100C Vehicle and 2270P Vehicle. (Continued)

Time (sec)	1100C FE Simulation (Design #2)	2270P FE Simulation (Design #2)
0.116		
0.136		
0.152		

Various design modifications were considered to mitigate the windshield contact associated with Design #4. Two modified designs were modeled:

- Raise Telescopic Slip Connection from 34 inches to 5 ft height above ground.
- Raise Telescopic Slip Connection from 34 inches to 5 ft height above ground and nest tube inside vertical support post to provide height adjustability in the field.

The modified designs were modeled and used in predictive FE vehicle impact simulations with both 1100C and 2270P vehicles. Of particular interest was the assessment of any secondary contact between the sign support system and 2270P vehicle. Results obtained from the computer simulations were used to select a temporary single sign support system for full-scale crash testing.

5.2.3 Design Modification #1: Telescopic Slip Connection 5-ft from Ground

The purpose of raising the height of the slip connection was to release the sign panel at a greater height and, thereby, avoid impacting the windshield. Figures 5.9 to 5.11 show details of the modified design.

Figure 5.12 shows the finite element model of the modified design. The base assembly was similar to the previous design except the length of the 1-3/4-inch perforated square steel vertical sleeve was increased from 34 inches to 60 inches. The length of the 1-1/2-perforated square steel vertical support was correspondingly decreased to 72 inches. The vertical support was inserted 4 ½ inches into the sleeve and rested on null shells that were modeled to represent the bolt. The mounting height to the bottom of the sign panel was 7 ft.

Figure 5.13 shows the initial simulation setup for both the 1100C and 2270P vehicles impacting the modified temporary single sign support at 62.2 mph and 90 degrees. These impact conditions correspond to MASH tests 3-71 and 3-72, respectively. The initial impact location for each simulation was the right quarter point of the vehicle aligned with the centerline of the sign support system.

The FE simulation did not predict any second impact between the released sign support assembly and the 1100C vehicle (see Figure 5.14 (a and b)). However, although contact with the windshield was avoided, secondary contact between the sign support assembly and the roof was predicted in the simulation with the 2270P vehicle (see Figure 5.14 (c and d)). Figures 5.15 and 5.16 show the energy balance for the 1100C and 2270P simulations, respectively. Hourglass and sliding interface energy values remained under 5 percent for both simulations. Table 5.3 compares the sign support trajectory for the 1100C and 2270P vehicle simulations.

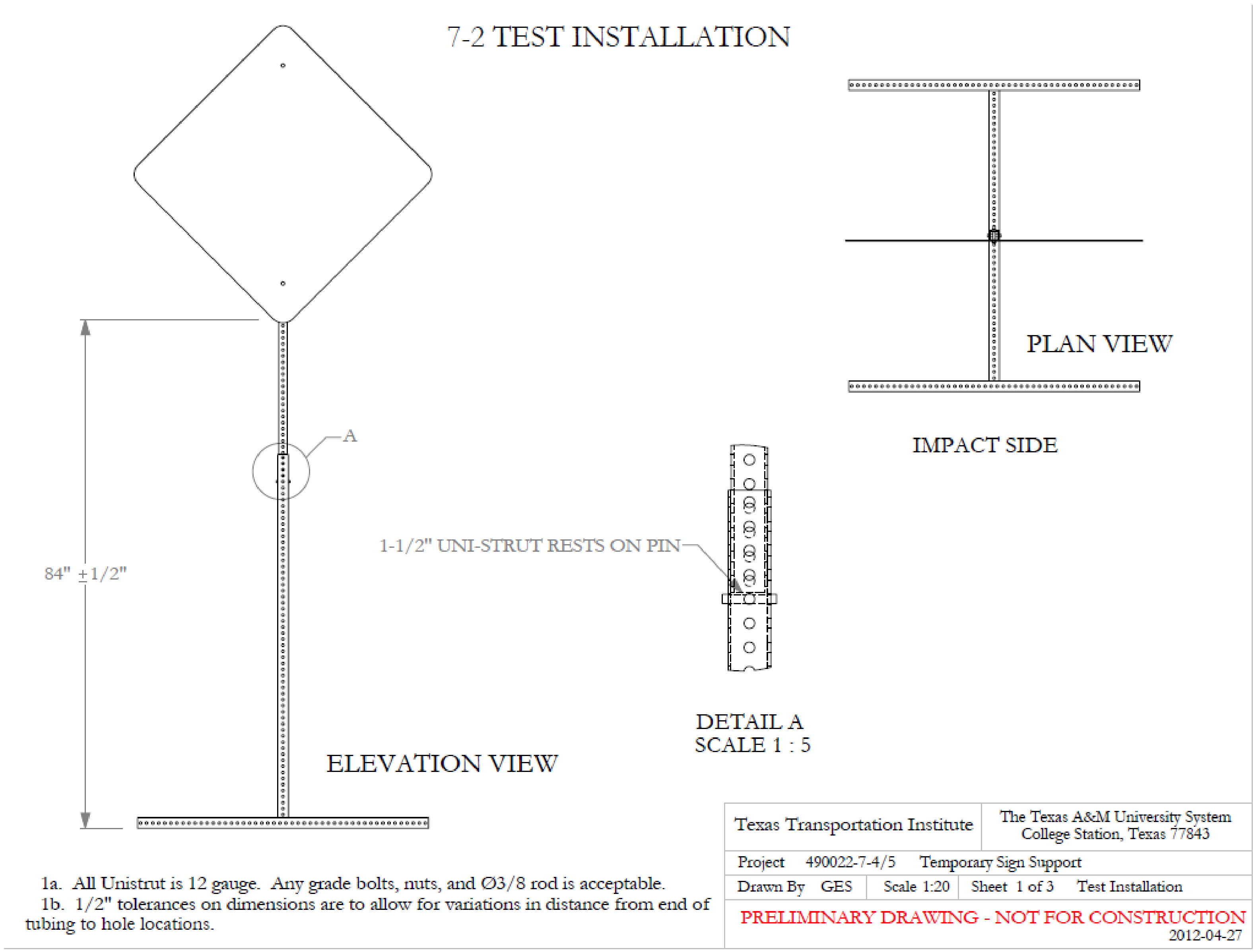
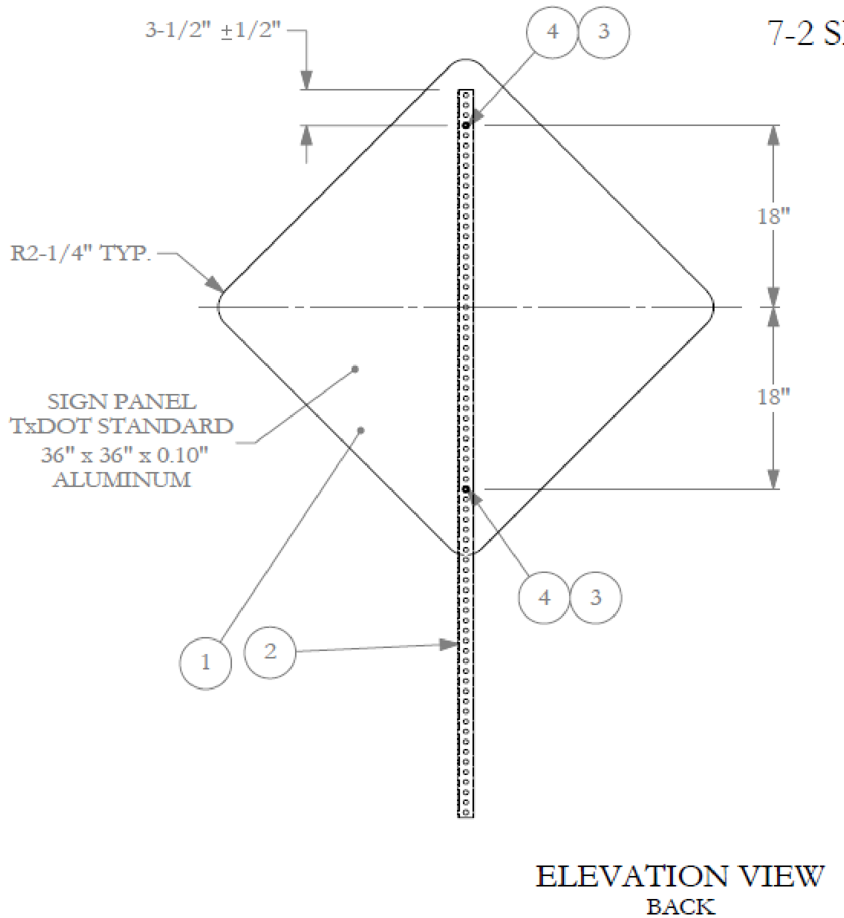


Figure 5.9. Details of Design Modification #1 to Temporary Single Sign Support System.

7-2 SIGN ASSEMBLY



SIGN ASSEMBLY PARTS		
#	PART NAME	QTY.
1	Sign Panel	1
2	Unistrut, 1-1/2 x 72"	1
3	Nut, 3/8 hex	2
4	Bolt, 3/8 x 2-1/2 hex	2

2a. 1/2" tolerances on bolt locations are to allow for distance from end of tubing to hole locations.

Texas Transportation Institute	The Texas A&M University System College Station, Texas 77843
Project 490022-7-4/5 Temporary Sign Support	2012-04-27
Drawn By GES Scale 1:15 Sheet 2 of 3	Sign Assembly

Figure 5.10. Details of Design Modification #1 to Temporary Single Sign Support System – Sign Assembly.

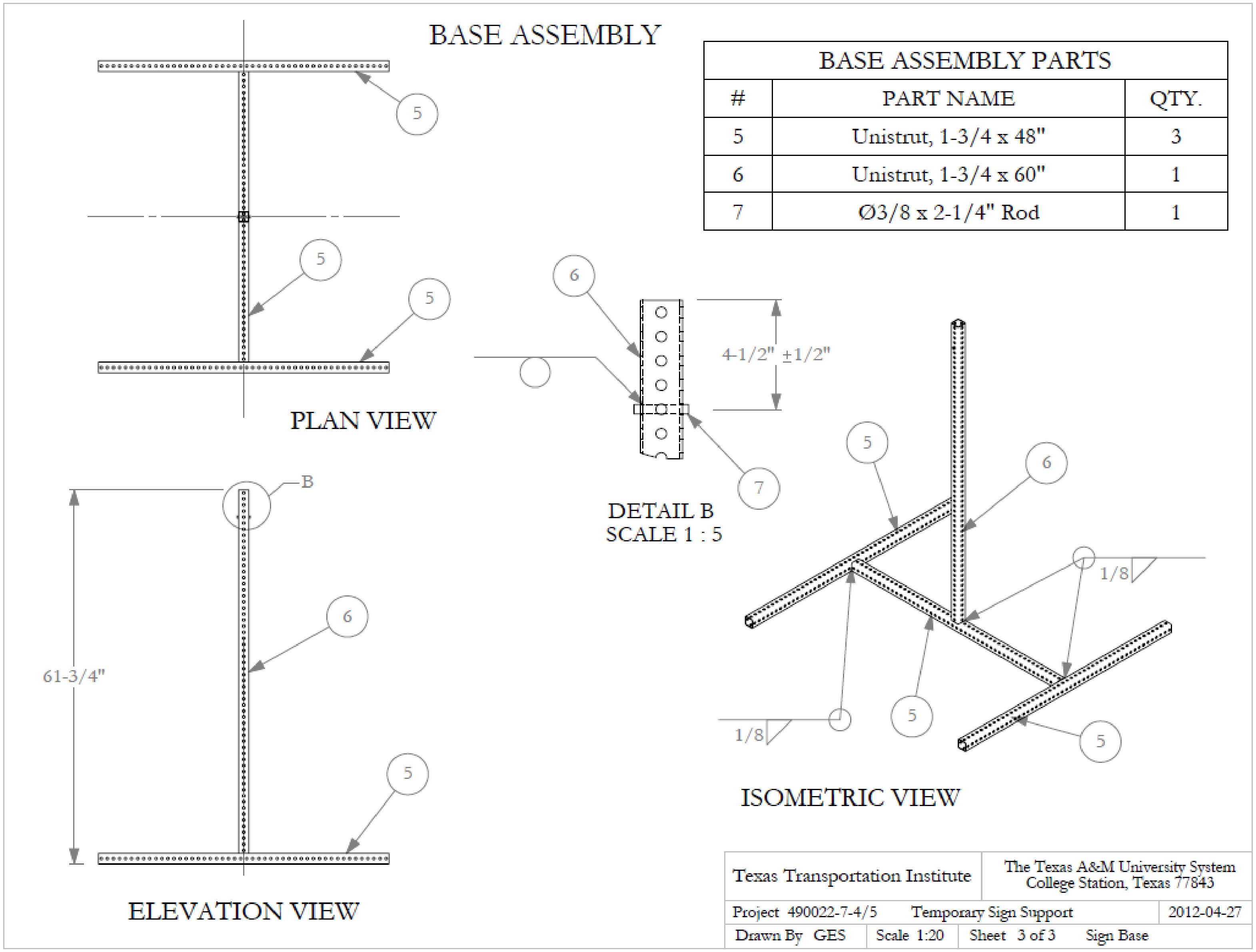


Figure 5.11. Details of Design Modification #1 to Temporary Single Sign Support System – Base Assembly.

FE Model

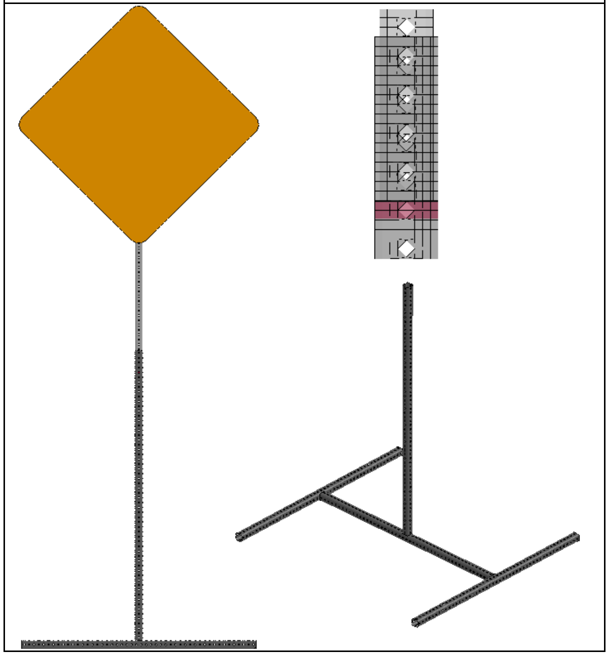


Figure 5.12. FE Model of Temporary Single Sign Support System – Design Modification #1.

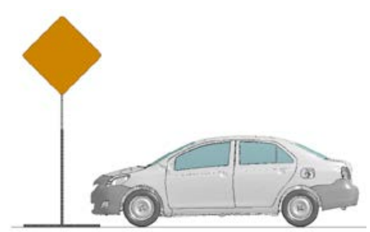
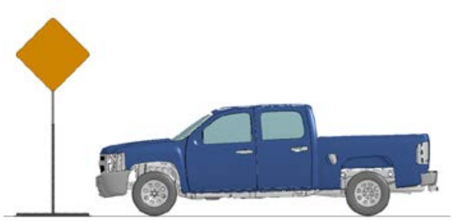
<table>
<tr><th colspan="2">Initial Configurations</th><th>Initial Impact Conditions</th></tr>
<tr><td></td><td></td><td rowspan="4">Impact Speed: 62.2 mph
Impact Angle: 90 degrees
Impact Location: right quarter point aligned with centerline of sign support</td></tr>
<tr><td>(a) Frontal View – 1100C Vehicle</td><td>(b) Lateral View – 1100C Vehicle</td></tr>
<tr><td></td><td></td></tr>
<tr><td>the Frontal View – 2270P Vehicle</td><td>(d) Lateral View – 2270P Vehicle</td></tr>
</table>

Figure 5.13. Initial Configuration for the Finite Element Simulation with (a and b) *MASH* 1100C and (c and d) *MASH* 2270P Vehicles (Design Modification #1).

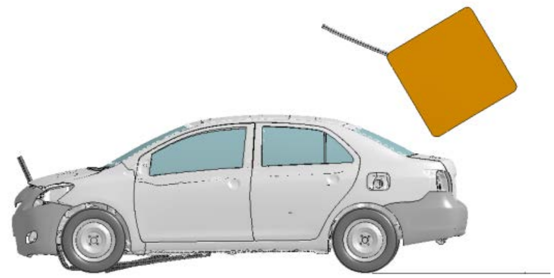
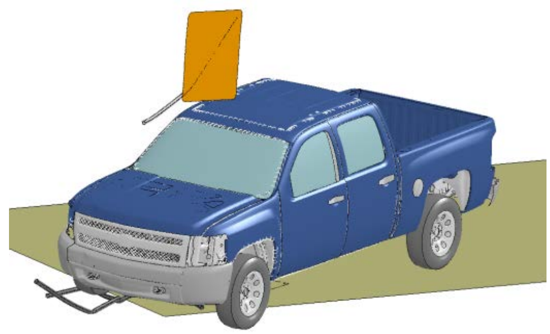
Final Configurations	
	
(a) Frontal View – 1100C Vehicle	**(b) Lateral View – 1100C Vehicle**
	
the Frontal View – 2270P Vehicle	**(d) Perspective View – 2270P Vehicle**

Figure 5.14. Predicted Outcomes of Finite Element Simulations with (a and b) *MASH* 1100C and (c and d) *MASH* 2270P Vehicles (Design Modification #1).

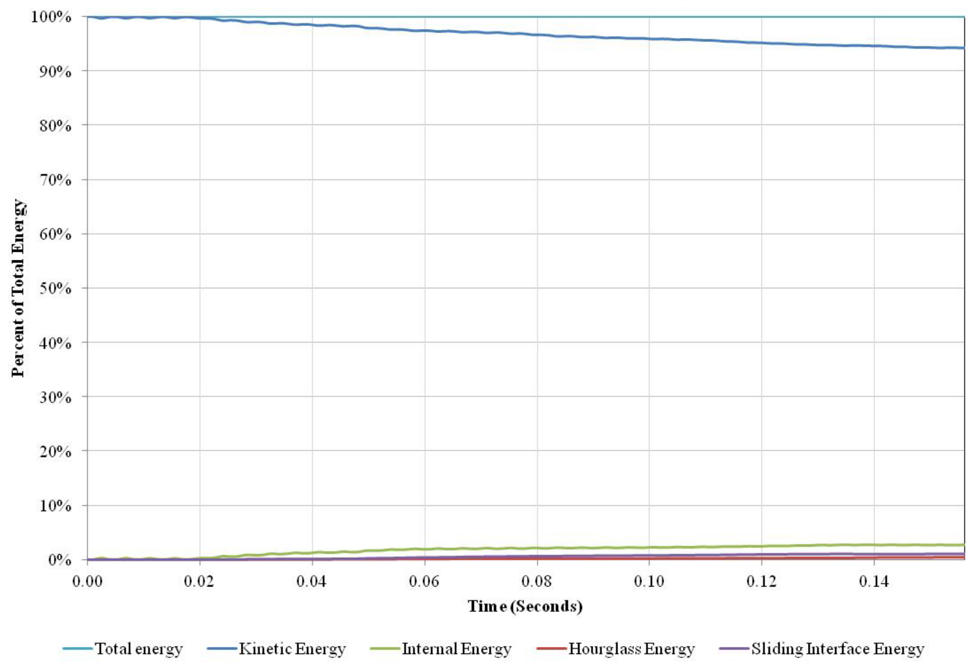


Figure 5.15. Energy Balance from Finite Element Simulation with 1100C Vehicle (Design Modification #1).

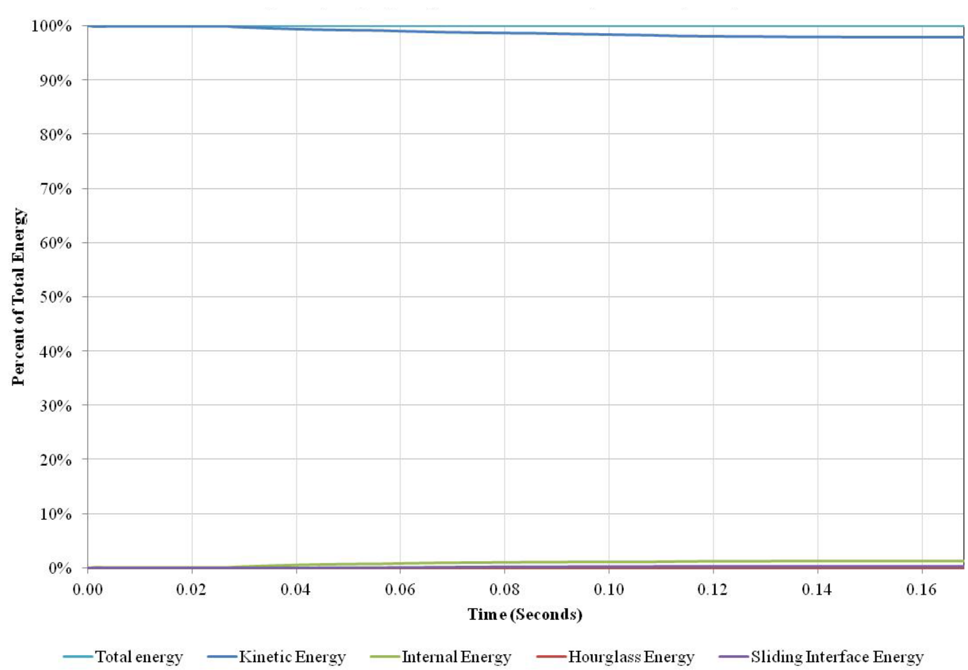


Figure 5.16. Energy Balance from Finite Element Simulation with 2270P Vehicle (Design Modification #1).

Table 5.3. Comparison of FE Simulations with 1100C and 2270P Vehicles (Design Modification #1).

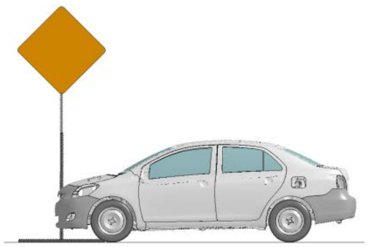
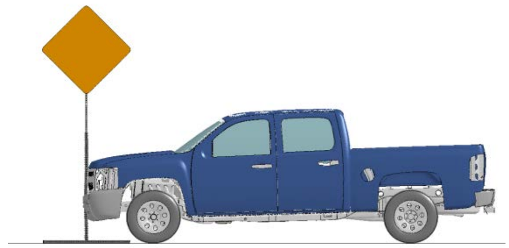
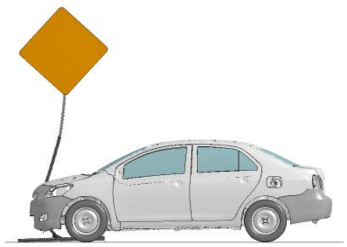
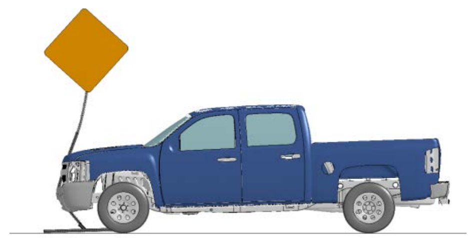
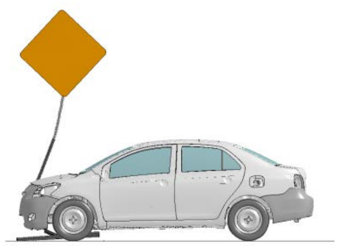
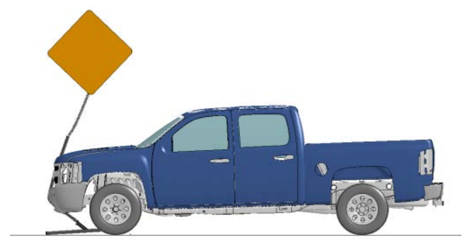
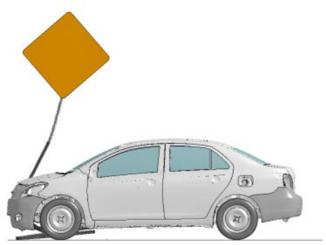
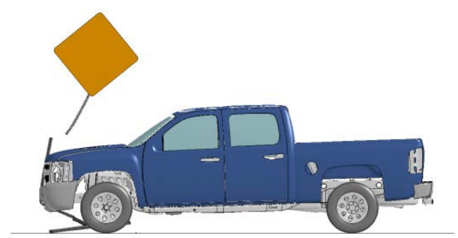
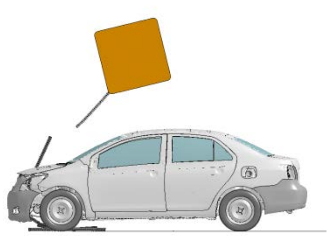
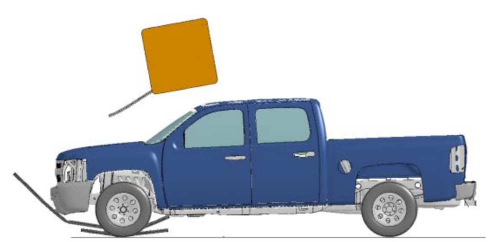
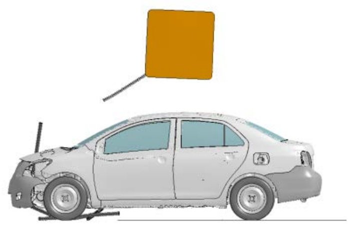
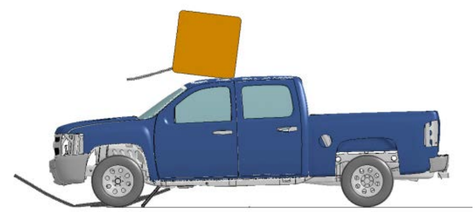
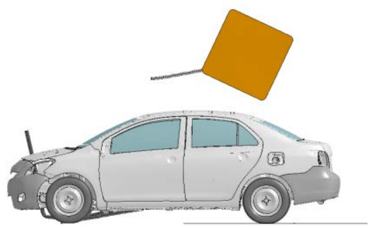
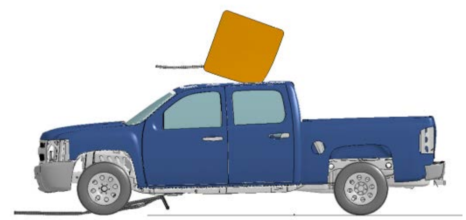
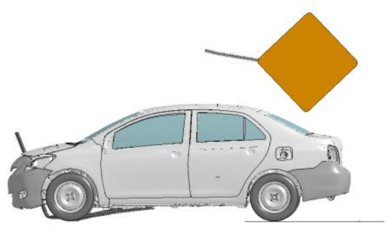
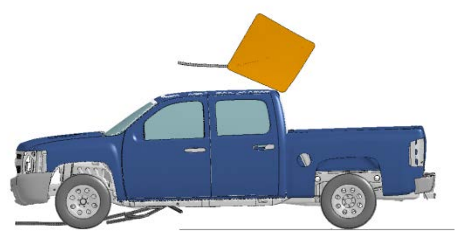
Time (sec)	1100C Simulation (Design #2 Mod1)	2270P Simulation (Design #2 Mod1)
0.000		
	Impact	
0.014		
0.020		
		Telescopic Connection Releases
0.028		
	Telescopic Connection Releases	
0.062		

Table 5.3. Comparison of FE Simulations with 1100C and 2270P Vehicles (Design Modification #1) (Continued).

Time (sec)	1100C Simulation (Design #2 Mod1)	2270P Simulation (Design #2 Mod1)
0.082		
		Roof Impact
0.110		
0.136		

5.2.4 Design Modification #2: Telescopic Slip Connection 5-ft from Ground and Nested Post for Height Adjustability

The second design modification evaluated was similar to the first, but included a feature that permitted height adjustment in the field to account for placement on sloped terrain. In this design, the vertical support post was increased in size to match the size of the vertical sleeve. A 1-1/2-inch piece of perforated square steel tubing was nested inside the 1-3/4-inch vertical support. The nested tube extended from the bottom of the vertical support and inserted into the top of vertical sleeve to form a slip connection. Further extension of the nested tube increases the height of the sign panel as needed to accommodate field conditions. Figures 5.17 to 5.19 show details of Design Modification #2.

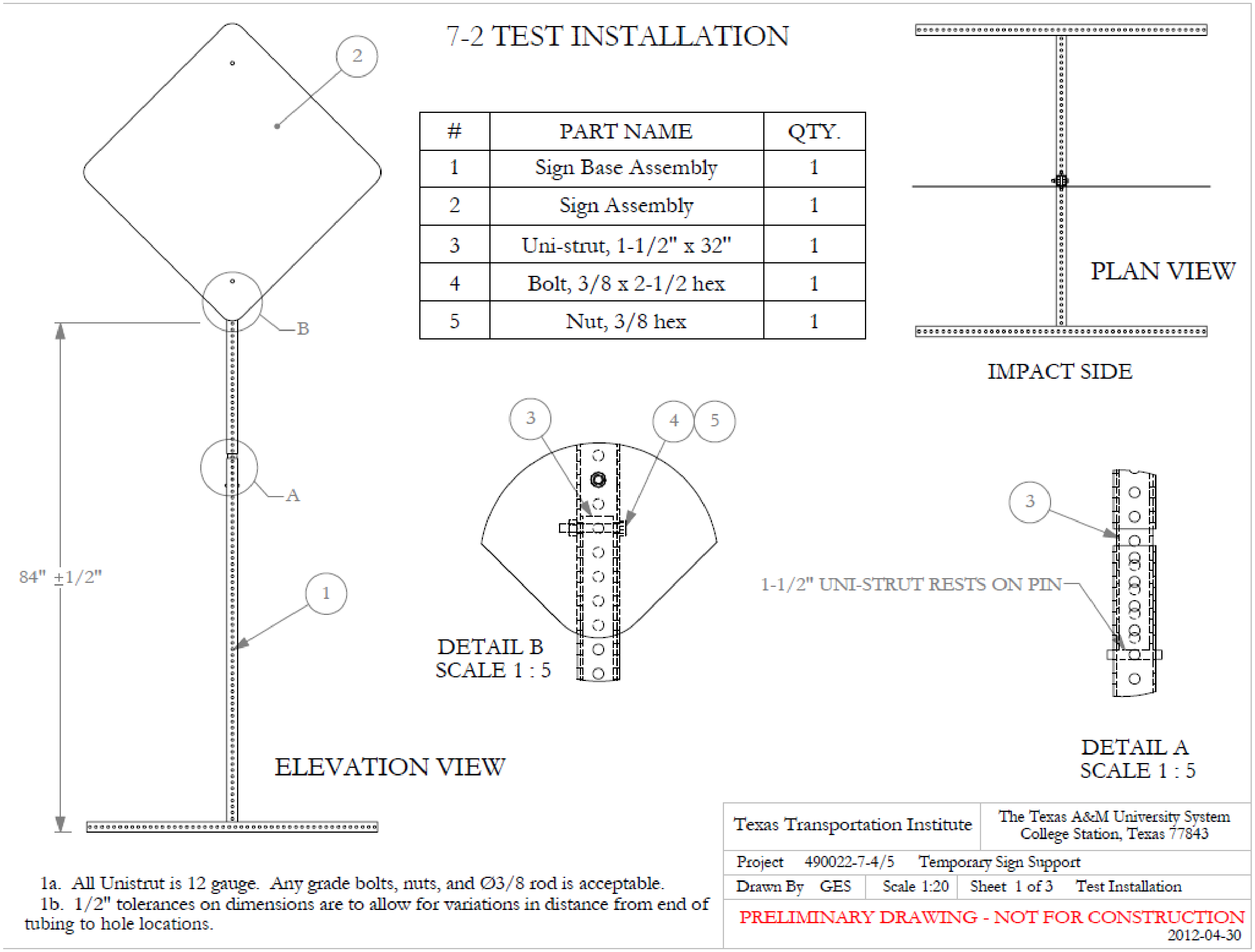
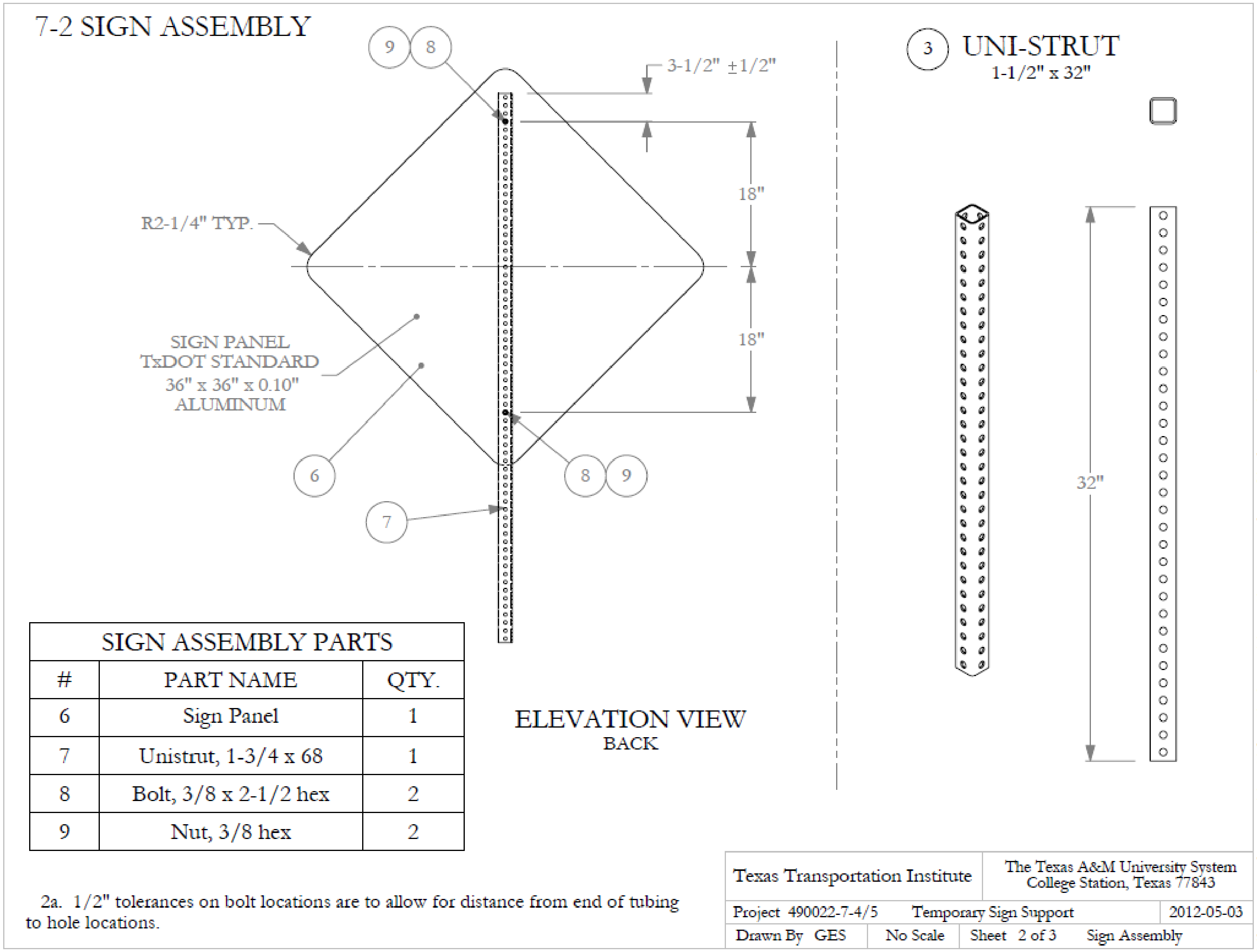


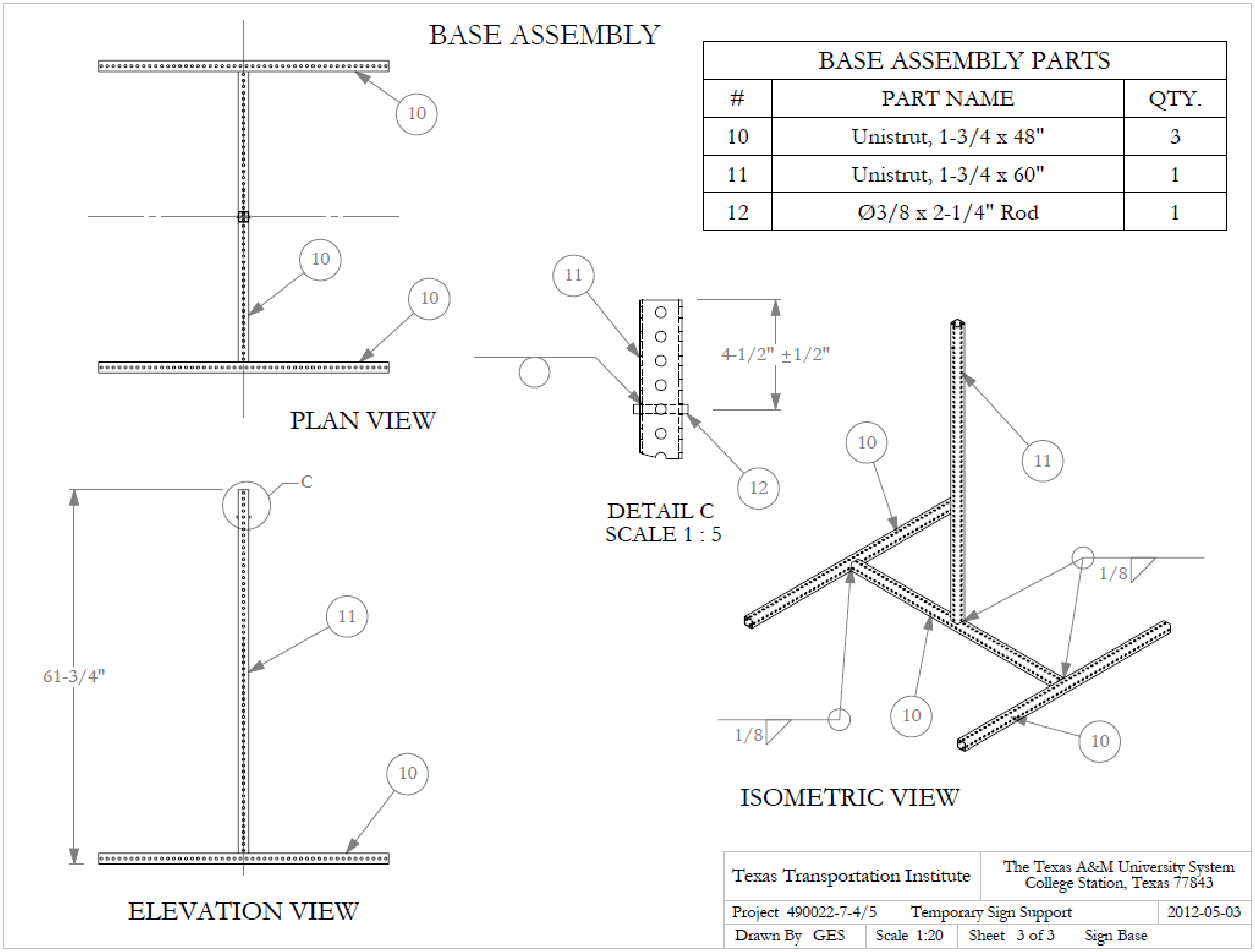
Figure 5.17. Details of Design Modification #2 Temporary Single Sign Support System.



SIGN ASSEMBLY PARTS		
#	PART NAME	QTY.
6	Sign Panel	1
7	Unistrut, 1-3/4 x 68	1
8	Bolt, 3/8 x 2-1/2 hex	2
9	Nut, 3/8 hex	2

2a. 1/2" tolerances on bolt locations are to allow for distance from end of tubing to hole locations.

Figure 5.18. Details of Design Modification #2 Temporary Single Sign Support System – Sign Assembly.



BASE ASSEMBLY PARTS		
#	PART NAME	QTY.
10	Unistrut, 1-3/4 x 48"	3
11	Unistrut, 1-3/4 x 60"	1
12	Ø3/8 x 2-1/4" Rod	1

Figure 5.19. Details of Design Modification #2 Temporary Single Sign Support System – Base Assembly.

Figure 5.20 shows the finite element model of Design Modification #2. Figure 5.21 shows the initial simulation setup for both the 1100C and 2270P vehicles impacting Design Modification #2 at 62.2 mph and 90 degrees. These impact conditions correspond to MASH tests 3-71 and 3-72, respectively. The initial impact location for each simulation was the right quarter point of the vehicle aligned with the centerline of the sign support system.

The FE simulation did not predict any second impact between the released sign support assembly and the 1100C vehicle (see Figure 5.22 (a and b)). However, although contact with the windshield was avoided, secondary contact between the sign support assembly and the roof was predicted in the simulation with the 2270P vehicle (see Figure 5.22 (c and d)). Figures 5.23 and 5.24 show the energy balance for the 1100C and 2270P simulations, respectively. Hourglass and sliding interface energy values remained under 5 percent for both simulations. Table 5.4 compares the sign support trajectory for the 1100C and 2270P vehicle simulations.

5.2.5 Conclusions

The researchers presented both the tested and the modified design options for the temporary single sign support to TxDOT representatives. TxDOT decided to proceed with full-scale crash testing of the Design Modification #2. This system allows for height adjustability when required. In agreement with TxDOT, the researchers decided to perform the 2270P vehicle (pickup truck) test first, because it was identified as the most critical in the computer simulations. The simulations predicted contact between the sign support and roof of the pickup. A test needed to be run to evaluate the occupant compartment deformation resulting from this contact. *MASH* permits up to 4 inches of roof deformation.

FE Model

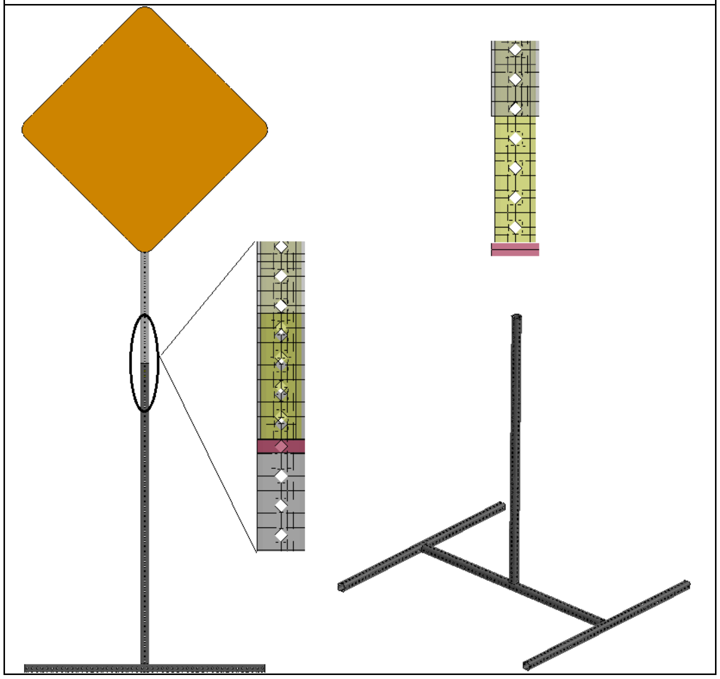


Figure 5.20. FE Model of Temporary Single Sign Support System Design Modification #2.

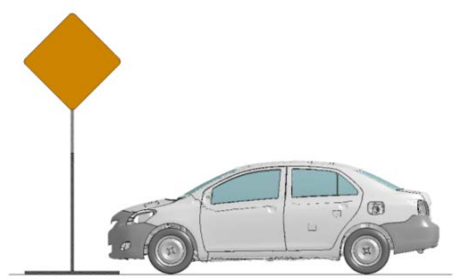
Initial Configurations		Initial Impact Conditions
		➢ Impact Speed: 62.0 mph ➢ Impact Angle: 90 degrees ➢ Impact Location: right quarter point from vehicle's centerline (passenger's side)
(a) Frontal View – 1100C Vehicle	**(b) Lateral View – 1100C Vehicle**	
		
the Frontal View – 2270P Vehicle	**(d) Lateral View – 2270P Vehicle**	

Figure 5.21. Initial Configuration for the Finite Element Simulation with (a and b) *MASH* 1100C and (c and d) *MASH* 2270P Vehicles (Design Modification #2).

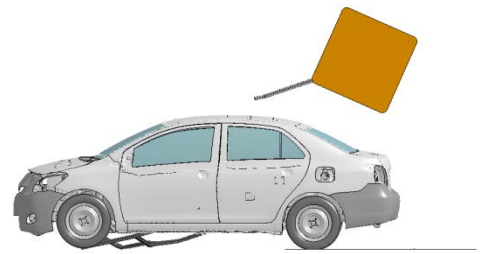
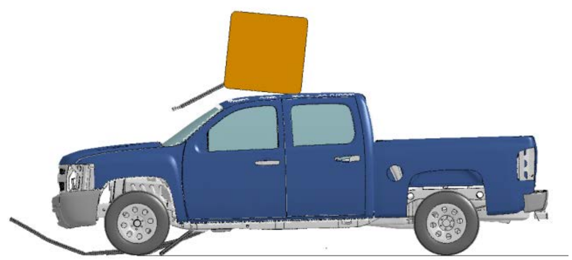
Final Configurations	
	
(a) Frontal View – 1100C Vehicle	**(b) Lateral View – 1100C Vehicle**
	
the Frontal View – 2270P Vehicle	**(d) Perspective View – 2270P Vehicle**

Figure 5.22. Predicted Outcomes of Finite Element Simulations with (a and b) *MASH* 1100C and (c and d) *MASH* 2270P Vehicles (Design Modification #2).

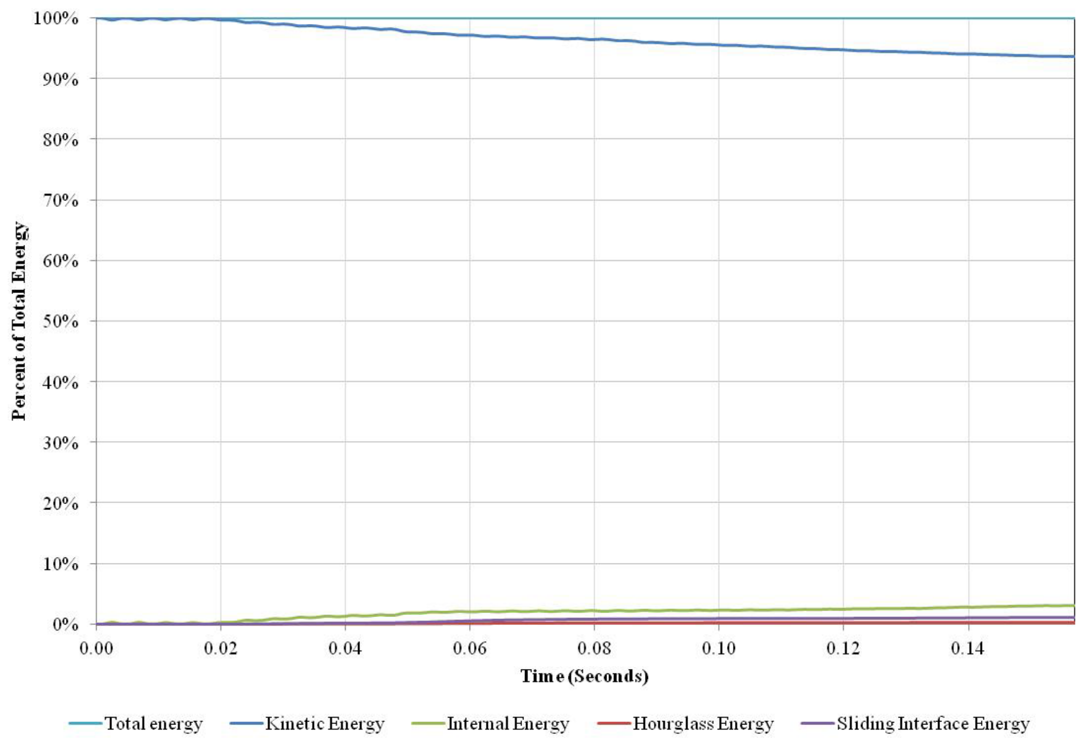


Figure 5.23. Energy Balance for Finite Element Simulation of Design Modification #2 with *MASH* 1100C Vehicle.

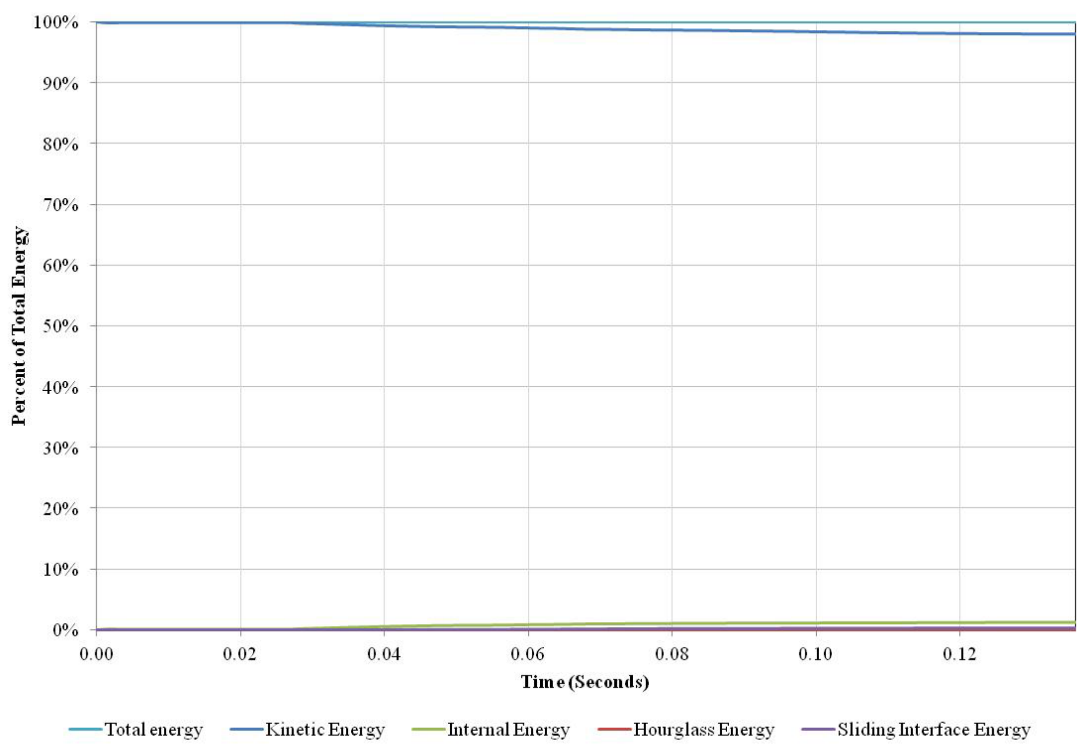


Figure 5.24. Energy Balance for Finite Element Simulation of Design Modification #2 with MASH 2270P Vehicle.

Table 5.4. Comparison of FE Simulations with 1100C and 2270P Vehicles (Design Modification #2).

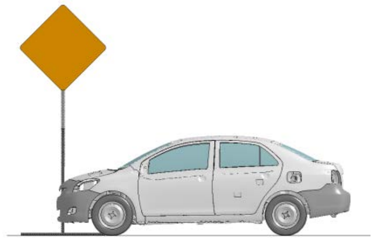
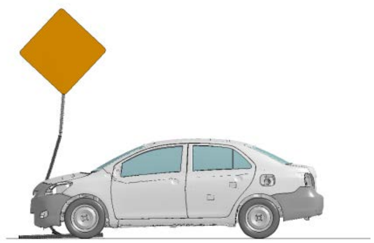
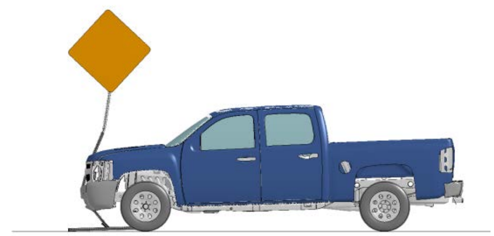
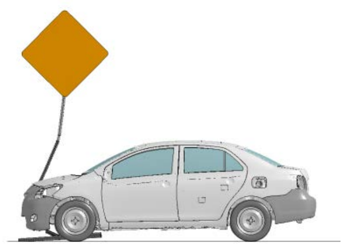
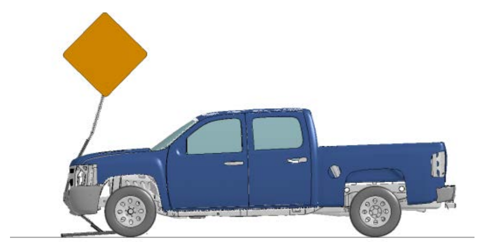
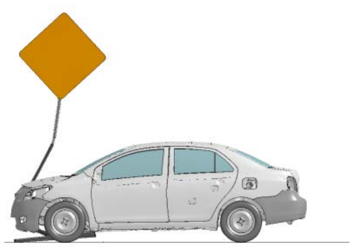
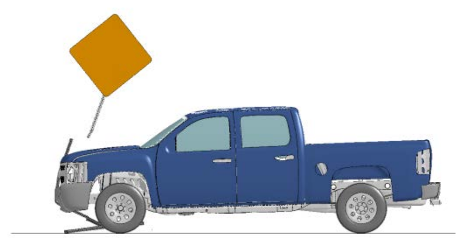
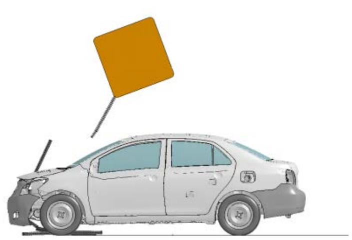
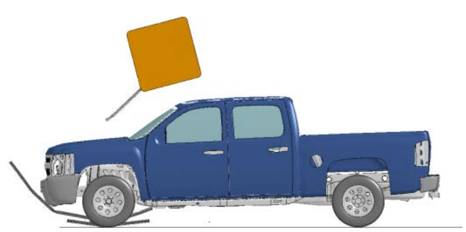
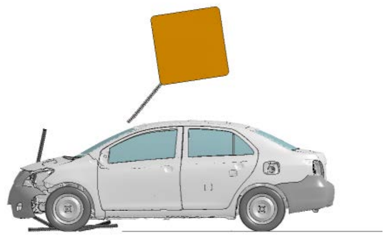
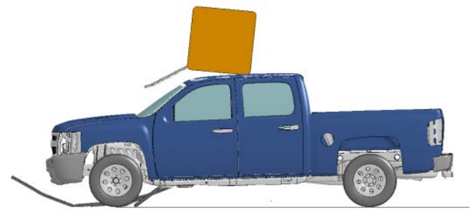
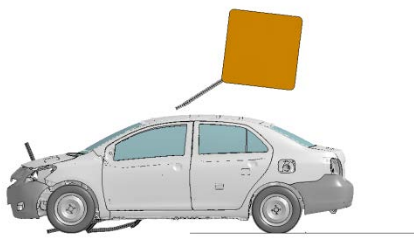
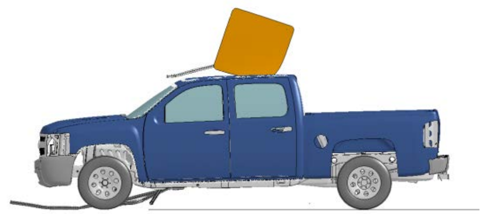
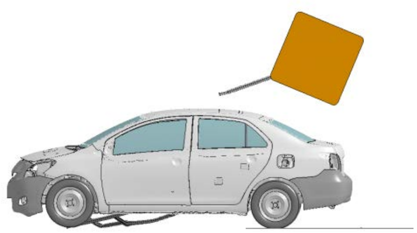
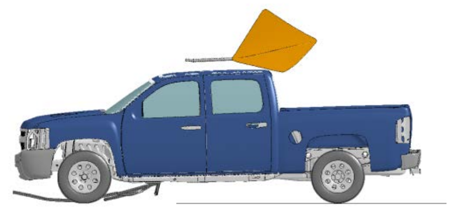
Time (sec)	1100C Simulation (Design #2 Mod2)	2270P Simulation (Design #2 Mod2)
0.000		
	Impact	
0.014		
0.020		
		Telescopic Connection Releases
0.024		
	Telescopic Connection Releases	
0.062		

Table 5.4. Comparison of FE Simulations with 1100C and 2270P Vehicles (Design Modification #2) (Continued).

Time (sec)	1100C Simulation (Design #2 Mod2)	2270P Simulation (Design #2 Mod2)
0.082-0.088		
	(0.082)	Roof Impact (0.088)
0.110		
0.136		

CHAPTER 6. FULL-SCALE CRASH TEST

6.1 FULL-SCALE CRASH TESTING WITH 2270P VEHICLE (TEST 490022-7-4)

MASH Test 3-72 was performed on a temporary single sign support system with telescopic slip connection at a height of 60 inches and a tube nested inside the vertical support post to permit height adjustability of the sign to accommodate conditions in the field. The details correspond to Design Modification #2 as described in Chapter 5. Details of the test are presented below.

6.1.1 Test Installation Description

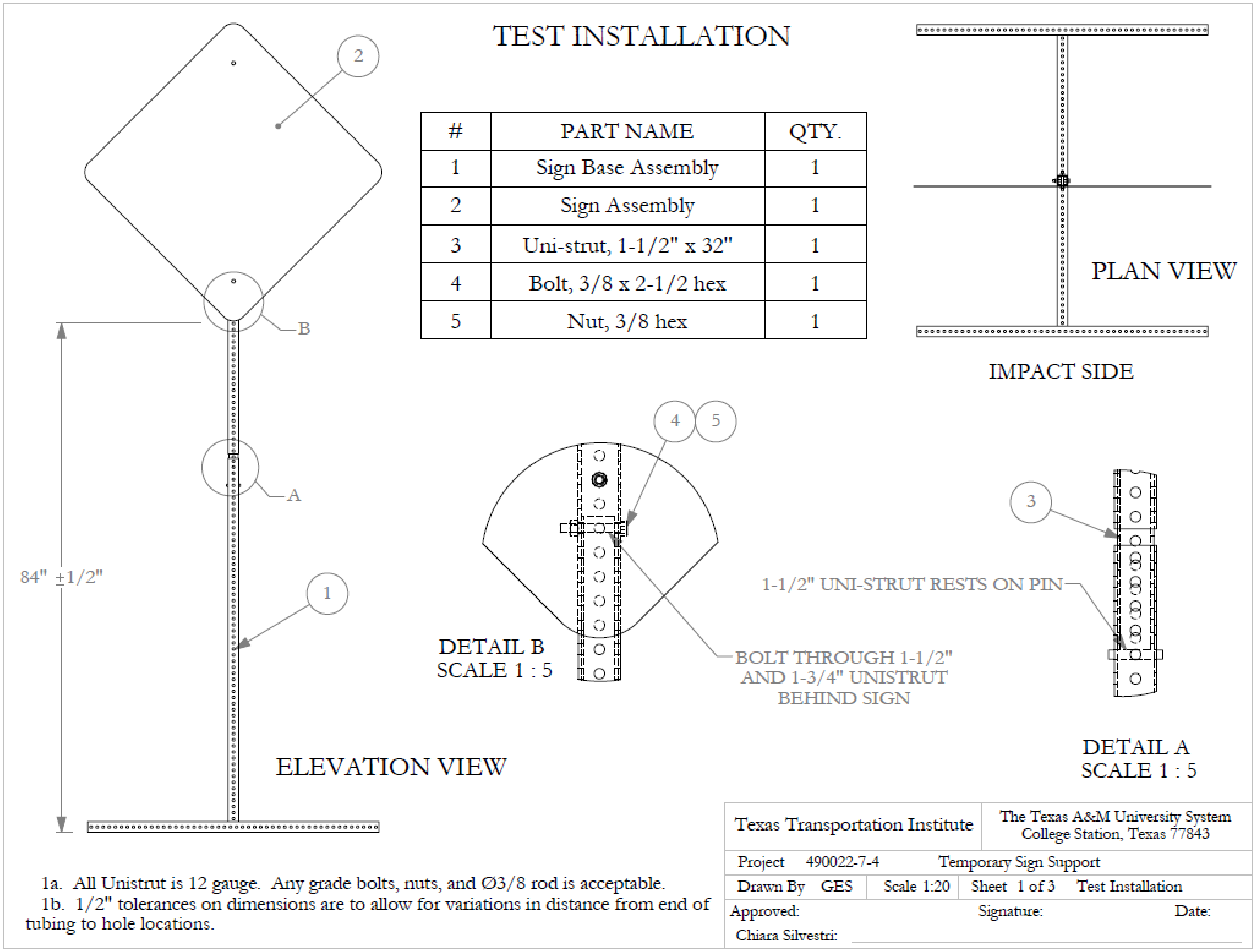
Three 1-3/4 inch perforated square steel tubes with a nominal wall thickness of 0.108 inch were welded together to form an H-base assembly system. Each tube forming the H-base was 48 inches long. A 1-3/4 inch square steel tube with a nominal wall thickness of 0.108 inch and a total length of 60 inches was welded to the center of the H-base assembly. A 68-inch piece of 1-3/4-inch perforated square steel tubing served as the vertical support and bracing for the sign panel. A 32 inch long section of 1-1/2-inch steel tubing was nested inside the vertical support to provide height adjustability of the sign panel. The nested tube extended from the bottom of the vertical support, inserted 4 ½ inches into the top of vertical sleeve, and rested on a bolt to form a slip connection. A 3/8-inch diameter bolt passed through the nested tubes to provide the desired mounting height of 7 ft from the ground to the bottom of the sign panel.

A 36-inch × 36-inch × 0.1-inch thick aluminum diamond-shaped sign was attached to the 1-1/2 inch tube in two locations: 18 inches top and bottom of the horizontal centerline of the sign. The sign was attached to the tube using 3/8-inch diameter bolts. Figures 6.1 through 6.3 give details of the sign support system.

A 40-lb sand bag was laid on each side of the base assembly. All perforated square steel tubing was 12 gauge. All bolts were ASTM A307, but any grade bolt was considered acceptable. The test installation was placed on a concrete surface. Figure 6.4 presents photographs of the completed test installation.

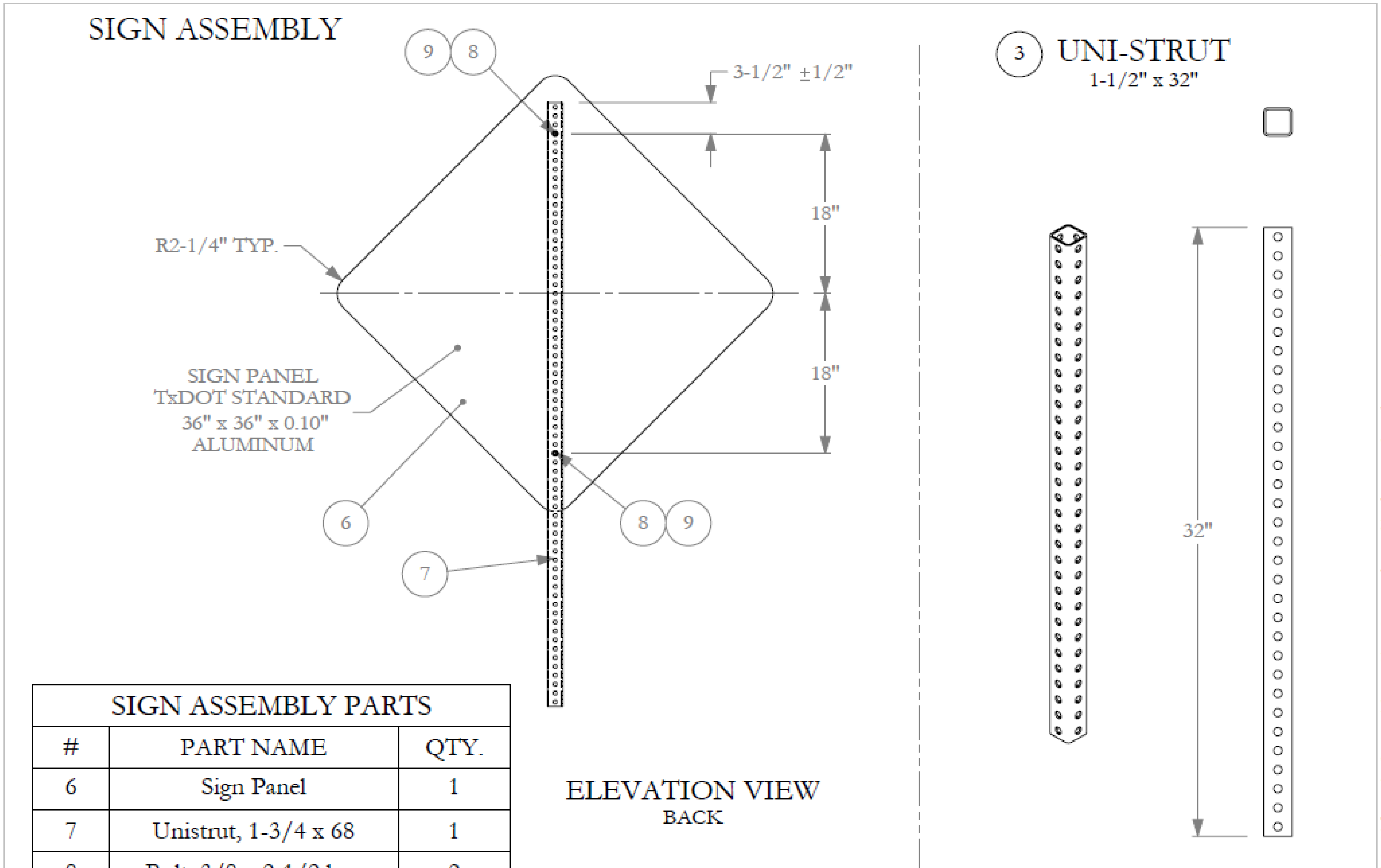
6.1.2 Test Designation and Actual Impact Conditions

MASH test 3-72 involves a 2270P vehicle weighing 5000 lb ± 110 lb and impacting the sign support at an impact speed of 62 mph ± 2.5 mph. FHWA 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.



#	PART NAME	QTY.
1	Sign Base Assembly	1
2	Sign Assembly	1
3	Uni-strut, 1-1/2" x 32"	1
4	Bolt, 3/8 x 2-1/2 hex	1
5	Nut, 3/8 hex	1

Figure 6.1. Details of the Temporary Single Sign Support System Used for Test No. 490022-7-4.



SIGN ASSEMBLY PARTS		
#	PART NAME	QTY.
6	Sign Panel	1
7	Unistrut, 1-3/4 x 68	1
8	Bolt, 3/8 x 2-1/2 hex	2
9	Nut, 3/8 hex	2

2a. 1/2" tolerances on bolt locations are to allow for distance from end of tubing to hole locations.

Texas Transportation Institute		The Texas A&M University System College Station, Texas 77843	
Project 490022-7-4	Temporary Sign Support		2012-05-03
Drawn By GES	No Scale	Sheet 2 of 3	Sign Assembly

Figure 6.2. Details of the Sign Assembly Used in Test No. 490022-7-4.

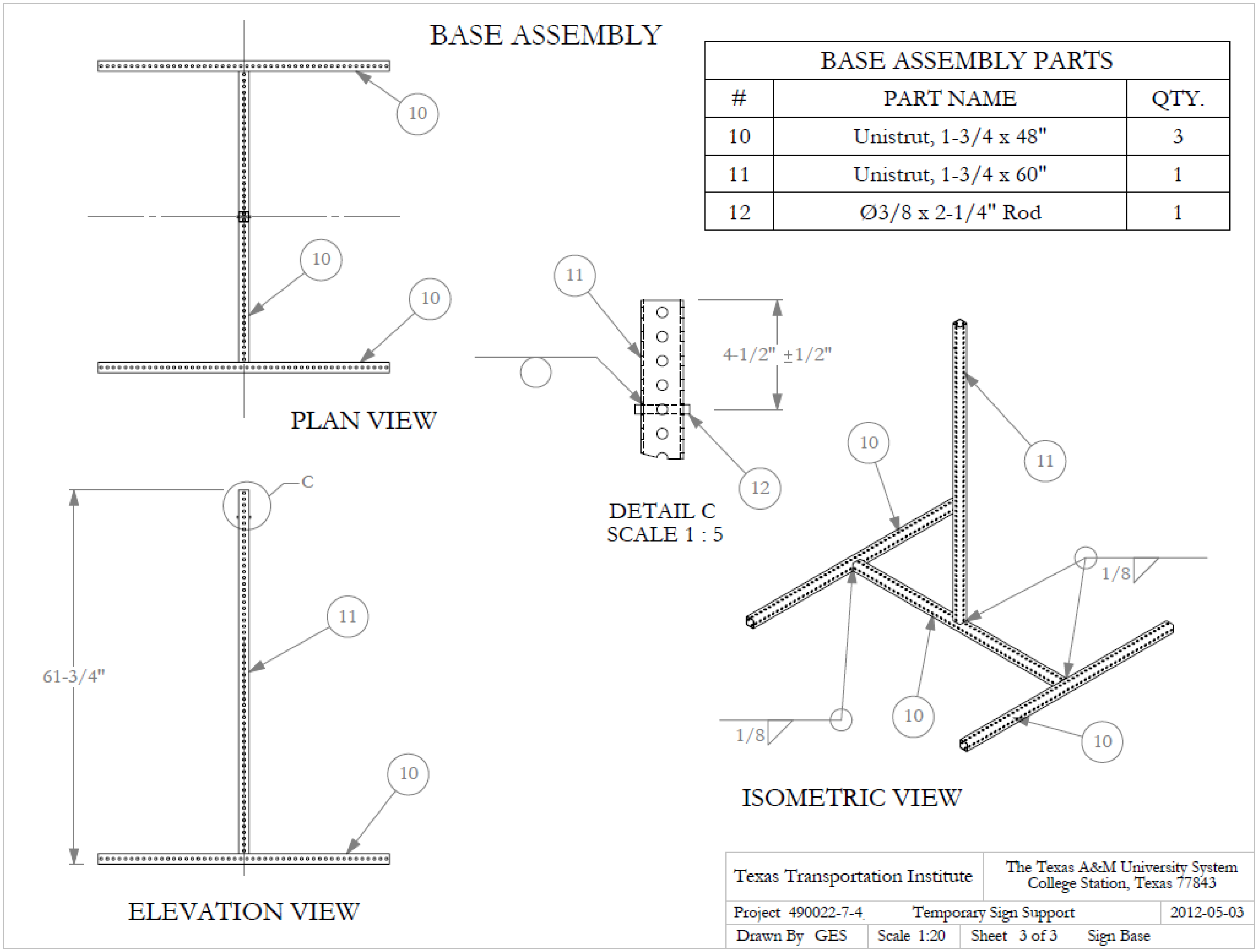


Figure 6.3. Details of the Base Assembly Used in Test No. 490022-7-4.

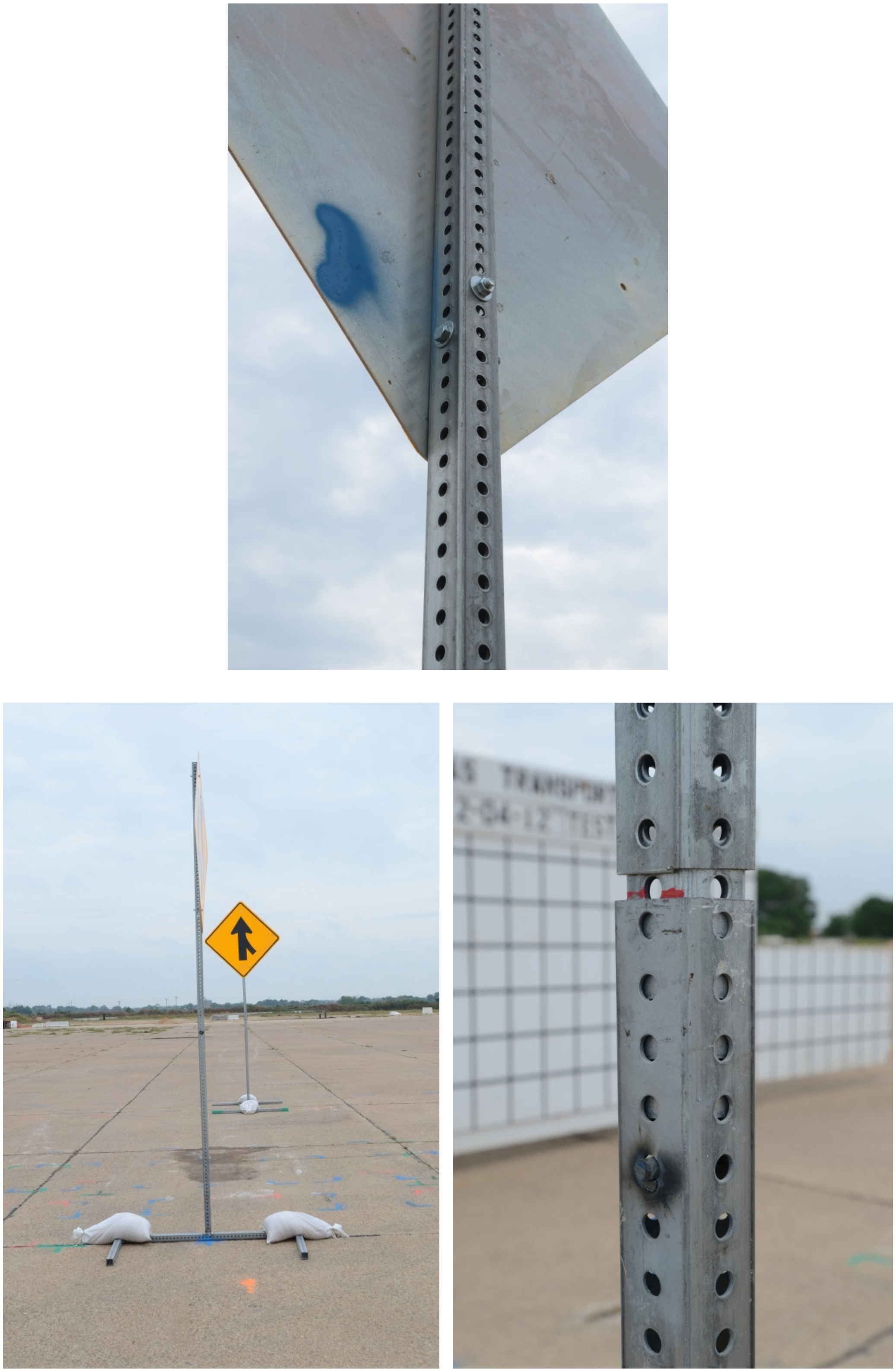


Figure 6.4. Temporary Sign Support System prior to Test No. 490022-7-4.

In order to reduce testing cost, FHWA permits the evaluation of both the 0 and 90 degree orientations using two separate devices impacted in sequence in a single crash test. This approach was used to evaluate the temporary single sign support system tested under this project. Two separate sign support systems were placed on a concrete apron in the path of the vehicle approximately 30 ft apart from one another. The first system was oriented at 90 degrees (i.e., parallel to the path of the vehicle) and the second at 0 degrees (i.e., perpendicular to the path of the vehicle). In the event that the first system interferes with the evaluation of the second system, another crash test needs to be performed in order to complete the impact performance evaluation.

The target impact points were 10 inches from the centerline of the vehicle on the driver's side for the 90 degrees impact and 10 inches from the centerline of the vehicle on the passenger's side for the 0 degree impact. These impact points were aligned with the centerline of the supports (90-degree and 0-degree support, respectively). The actual speed and angle for impact with the support system oriented at 90 degrees were 60.9 mph and 90 degrees, respectively. The actual speed and angle for impact with the support system oriented at 0 degrees were 60.9 mph and 0 degrees, respectively. The actual impact points were 10 inches from the centerline of the vehicle on the driver's side for the 90 degrees impact and 10 inches from the centerline of the vehicle on the passenger's side for the 0 degree impact.

6.1.3 Test Vehicle

A 2006 Dodge Ram 1500 pickup truck (shown in Figures 6.5 and 6.6) was used for the crash test. Test inertia weight of the vehicle was 5050 lb, and gross static weight was 5050 lb. The height to the lower edge of the vehicle front bumper was 13.75 inches, and the height to the upper edge of the front bumper was 25.375 inches. Tables F1 and F2 of Appendix F give additional dimensions and information on the vehicle. The passenger car was directed into the installation using the cable reverse tow and guidance system, and was released to be unrestrained just prior to impact.

6.1.4 Weather Conditions

The crash test was performed on the morning of May 9, 2012. Weather conditions at the time of testing were: wind speed: 4 mph; wind direction: 40° (vehicle was traveling in a northerly direction); temperature: 71°F; relative humidity: 88 percent.

Figure 6.5. Vehicle/Installation Geometrics for Test No. 490022-7-4.

Figure 6.6. Vehicle before Test No. 490022-7-4.

6.1.5 Test Description

The 2270P vehicle, traveling at an impact speed of 60.9 mph, contacted the 90-degree oriented temporary single sign support at an impact angle of 90 degrees, with the centerline of the support aligned at 10 inches from the centerline of the vehicle, on the driver's side. At approximately 0.018 s after impact, the telescopic slip connection activated, releasing the support post and sign assembly from the base. At 0.069 s, the sign impacted the roof of the vehicle. The sign lost contact with roof at approximately 0.139 s. The vehicle subsequently impacted the second test article, positioned approximately 30 ft downstream from the first and oriented at 0 degrees with respect to the direction of vehicle travel. At approximately 0.014 s after impact with the second test article, the lower telescopic slip connection activated, releasing the vertical support post and sign assembly from the base. The sign assembly did not have any secondary contact with the vehicle, and landed on the ground behind the vehicle at approximately 0.691 s. Brakes on the vehicle were applied 1.19 s after impact. The vehicle subsequently came to rest 270 ft downstream of impact. Figures F1 and F2 in Appendix F presents sequential photographs of the test period.

6.1.6 Test Article and Component Damage

Figure 6.7 shows damage to the sign support systems. The lower telescopic slip connection activated on both test articles as designed. The sign post assembly of the 90-degree oriented test article came to rest 137 ft downstream of the impact point. The vertical sleeve of the 90-degree oriented sign support system broke off the H-base assembly. The H-base assembly and the vertical sleeve came to rest 46 ft and 74 ft downstream of the impact point, respectively. The sign post assembly of the 0-degree oriented test article was slightly deformed and came to rest 10 ft downstream of the impact point. The vertical sleeve of the 0-degree oriented sign support system broke off the H-base assembly. The H-base assembly and the vertical sleeve came to rest 25 ft and 335 ft downstream of the impact point, respectively.

6.1.7 Test Vehicle Damage

The 2270P vehicle sustained a small dent in the bumper, hood, and grill, due to the initial impact with the 90-degree oriented sign support. A secondary impact of the edge of the aluminum sign panel caused a 29-inch long cut in the roof of the pickup truck. Additionally, the roof was deformed over an area measuring 51 inches in length and 40 inches in width.

The 2270P vehicle sustained a small dent in the bumper, hood, and grill, due to the initial impact with the 0-degree oriented sign support. There was no secondary impact between the 0-degree oriented sign assembly and the vehicle after release of the sign support assembly at the telescopic slip connection. Figures 6.8 and 6.9 show photographs of the exterior and interior of the vehicle after the test.

Figure 6.7. Installation after Test No. 490022-7-4.

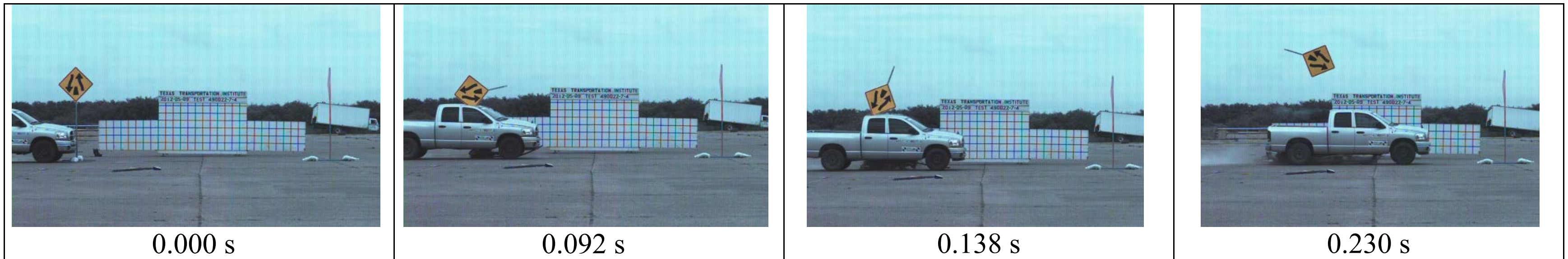
Figure 6.8. Vehicle after Test No. 490022-7-4.

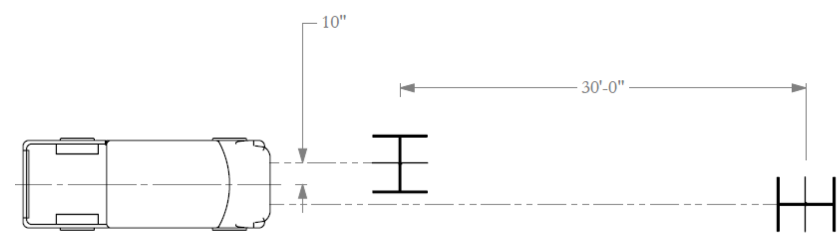
Figure 6.9. Occupant Compartment Interior of Vehicle after Test No. 490022-7-4.

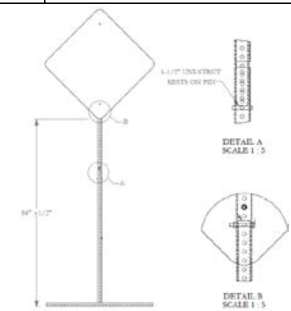
6.1.8 Occupant Risk Values

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. During impact of the vehicle with the 90-degree oriented temporary single sign support, no occupant contact occurred in the longitudinal or lateral directions. The maximum longitudinal 0.050-s average acceleration was −0.6 Gs between 0.0979 and 0.1479 s, and the maximum lateral 0.050-s average was −1.2 Gs between 0.2106 and 0.2606 s. Theoretical Head Impact Velocity (THIV) and Post-Impact Head Decelerations (PHD) were not calculated due to no occupant impact. Acceleration Severity Index (ASI) was 0.15 between 0.1132 and 0.1632 s. Figure 6.10 summarizes these data and other pertinent information from the impact with the 90-degree oriented test article.

During impact of the vehicle with the 0-degree oriented temporary single sign support, no occupant contact occurred in the longitudinal or lateral directions. The maximum longitudinal 0.050-s average acceleration was −0.9 Gs between 0.0308 and 0.0808 s, and the maximum lateral 0.050-s average was −1.2 Gs between 0.0099 and 0.0599 s. Theoretical Head Impact Velocity (THIV) and Post-Impact Head Decelerations (PHD) were not calculated due to no occupant impact. Acceleration Severity Index (ASI) was 0.14 between 0.0081 and 0.0581 s. Figure 6.11 summarizes these data and other pertinent information from the impact with the 0-degree oriented test article. Figures F2 through F8 in Appendix F present the vehicle angular displacements and accelerations versus time traces.







General Information
- Test Agency .... Texas A&M Transportation Institute
- MASH Test No. .... *MASH* Test 3-72
- TTI-PG Test No. .... 490022-7-4 90-degree Impact
- Date 2012-05-09

Test Article
- Type .... Temporary Single Sign Support
- Name .... Telescopic slip connection at 5-ft; internal post for height adjustability; 9 ft^2 sign panel
- Installation Height .... 7 ft to bottom of sign panel
- Material or Key Elements .. Aluminum sign panel mounted on a 1-3/4-inch steel tube support; 1-3/4 steel tube base assembly; internal 1-1/2-inch steel tube

Soil Type and Condition ..... Dry concrete surface

Test Vehicle
- Type/Designation 2270P
- Make and Model .... 2006 Dodge Ram 1500
- Curb .... 4792 lb
- Test Inertial .... 5050 lb
- Dummy .... No dummy
- Gross Static .... 5050 lb

Impact Conditions
- Speed .... 60.9 mph
- Angle .... 90 degrees
- Location/Orientation .... 10 inches from centerline of vehicle (driver's side)

Exit Conditions
- Speed .... 59.0 mph
- Angle .... 90 degrees

Occupant Risk Values
- Impact Velocity
  - Longitudinal .... No Contact
  - Lateral .... No Contact
- Ridedown Accelerations
  - Longitudinal .... No Contact
  - Lateral .... No Contact
- THIV .... No Contact
- PHD .... No Contact
- ASI 0.15
- Max. 0.050-s Average
  - Longitudinal .... -0.6 G
  - Lateral .... -1.2 G
  - Vertical .... 1.0 G

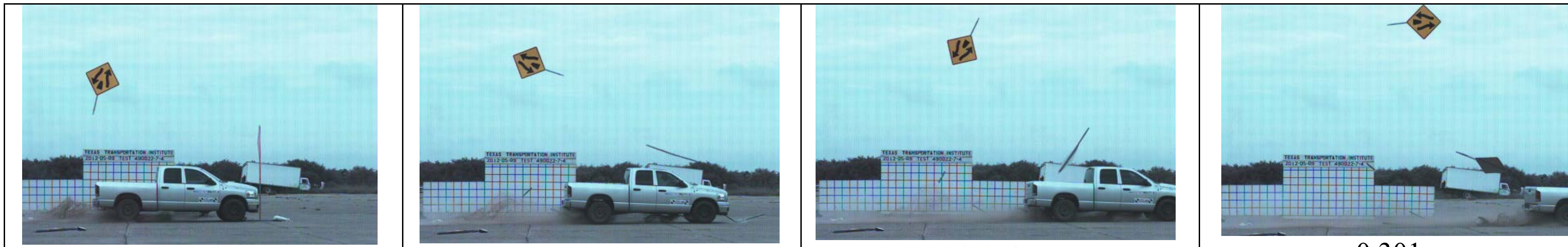
Post-Impact Trajectory
- Stopping Distance .... 270 ft

Vehicle Stability
- Maximum Yaw Angle .... -0.5
- Maximum Pitch Angle 0.6
- Maximum Roll Angle 1.5
- Vehicle Snagging .... No
- Vehicle Pocketing .... No

Test Article Deflections
- Dynamic .... 270 ft
- Permanent .... 270 ft
- Working Width .... N/A

Vehicle Damage
- VDS 12FL1
- CDC 12FLEN1
- Max. Exterior Deformation .... None
- OCDI FS0100000
- Max. Occupant Compartment Deformation .... 1.5 inches

Figure 6.10. Summary of Results for *MASH* Test 3-72 (Test No. 490022-7-4/90-Degree Impact).



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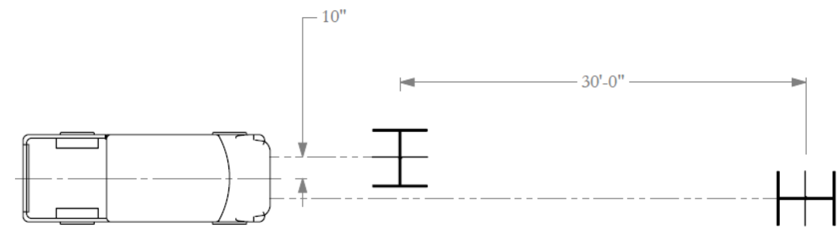

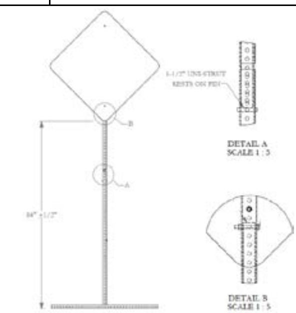

General Information
- Test Agency....................... Texas A&M Transportation Institute
- MASH Test No. .... *MASH* Test 3-72
- TTI-PG Test No. .... 490022-7-4 0-degree Impact
- Date 2012-05-09

Test Article
- Type.................................. Temporary Single Sign Support
- Name .... Telescopic slip connection at 5-ft; internal post for height adjustability; 9 ft^2 sign panel
- Installation Height .... 7 ft to bottom of sign panel
- Material or Key Elements .. Aluminum sign panel mounted on a 1-3/4-inch steel tube support; 1-3/4 steel tube base assembly; internal 1-1/2-inch steel tube

Soil Type and Condition..... Dry concrete surface

Test Vehicle
- Type/Designation..............
- Make and Model 2270P
- Curb.................................. 2006 Dodge Ram 1500
- Test Inertial........................ 4792 lb
- Dummy .... 5050 lb
- Gross Static .... No dummy 5050 lb

Impact Conditions
- Speed 59.0mph
- Angle ....0 degrees
- Location/Orientation ....10 inches from centerline of vehicle (passenger's side)

Exit Conditions
- Speed 58.9
- Angle ....0 degrees

Occupant Risk Values
- Impact Velocity
  - Longitudinal ....No Contact
  - Lateral ....No Contact
- Ridedown Accelerations
  - Longitudinal ....No Contact
  - Lateral ....No Contact
- THIV ....No Contact
- PHD ....No Contact
- ASI 0.14
- Max. 0.050-s Average
  - Longitudinal ....-0.9 G
  - Lateral ....-1.2 G
  - Vertical .... 0.8 G

Post-Impact Trajectory
- Stopping Distance .... 270 ft

Vehicle Stability
- Maximum Yaw Angle............... -0.7
- Maximum Pitch Angle.............. -1.1
- Maximum Roll Angle .... -1.9
- Vehicle Snagging .... No
- Vehicle Pocketing.................... No

Test Article Deflections
- Dynamic .... 270 ft
- Permanent............................... 270 ft
- Working Width .... N/A

Vehicle Damage
- VDS 12FR1
- CDC.. 12FREN1
- Max. Exterior Deformation....... None
- OCDI FS0000000
- Max. Occupant Compartment Deformation....................... None

Figure 6.11. Summary of Results for *MASH* Test 3-72 (Test No. 490022-7-4/0-Degree Impact).

6.1.9 Assessment of Test Results for Impact with the 90-Degree Oriented Test Article

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

6.1.9.1 Structural Adequacy

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

Results: The temporary sign support yielding to the vehicle and activation of the slip connection released the sign support assembly from its base. (PASS)

6.1.9.2 Occupant Risk

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH. (roof ≤4.0 inches; windshield = ≤3.0 inches; side windows = no shattering by test article structural member; wheel/foot well/toe pan ≤9.0 inches; forward of A-pillar ≤12.0 inches; front side door area above seat ≤9.0 inches; front side door below seat ≤12.0 inches; floor pan/transmission tunnel area ≤12.0 inches).

Results: The secondary impact of the edge of the sign with the roof of the vehicle in the 90-degree orientation caused a 29-inch long cut in the roof and the sign panel penetrated into the occupant compartment before subsequently exiting from the vehicle. (FAIL)

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. Maximum roll and pitch angles were 1.5 and 0.6 degrees, respectively. (PASS)

K. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
10 ft/s	*16 ft/s*

Results: No occupant contact occurred in the longitudinal or lateral directions. (PASS)

6.1.9.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Result: The 2270P vehicle exited behind the test article. (PASS)

6.1.10 Assessment of Test Results for Impact with the 0-Degree Oriented Test Article

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

6.1.10.1 Structural Adequacy

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

Results: The temporary sign support yielding to the vehicle and activation of the slip connection released the sign support assembly from its base. (PASS)

6.1.10.2 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: There was no secondary impact between the 0-degree oriented sign assembly and the vehicle after its release from the base. The sign panel assembly rotated over the vehicle, and the base components were carried along by the vehicle. (PASS)

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

Results: The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were −1.9 and −1.1 degrees, respectively. (PASS)

L. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
10 ft/s	*16 ft/s*

Results: No occupant contact occurred in the longitudinal or lateral directions. (PASS)

6.1.10.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

Result: The 2270P vehicle exited behind the test article. (PASS)

6.2 SUMMARY OF TEST RESULTS

The objective of this test was to evaluate the impact performance of a temporary single sign support design with telescopic slip connection at 5 ft from the ground and inner nested tube for height adjustment of the sign panel. *MASH* Test 3-72 was performed with the 2270P vehicle to evaluate the behavior of the test article oriented at both 90 degrees and 0 degrees. Tables 6.1 and 6.2 provide a summary of the evaluation of both impacts in accordance with relevant *MASH* criteria.

In both tests, the telescopic slip connection activated as designed and released the sign support assembly from its base. In the impact with the sign system oriented at 0 degrees, the released sign panel assembly did not come in contact with the vehicle, and all *MASH* criteria were satisfied. However, during the impact with the sign system oriented at 90 degrees, the edge of the sign panel contacted, deformed, and cut the roof of the vehicle. It was evident from review of the high-speed video and inspection of the vehicle and sign panel that the corner of the sign panel penetrated into the occupant compartment. *MASH* states that "detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment..." Therefore, the impact with the sign system oriented at 90-degrees did not satisfy Occupant Risk Criterion "D" of *MASH*.

Table 6.1. Performance Evaluation Summary for *MASH* Test 3-72 with 90-Degree Oriented Temporary Single Sign Support.

Test Agency: Texas A&M Transportation Institute | Test No.: 490022-7-4 | Test Date: 2012-05-09

***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 temporary sign support yielding to the vehicle and activation of the slip connection released the sign support assembly from its base.	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. *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.*	The secondary impact of the edge of the sign with the roof of the vehicle caused a 29-inch long cut in the roof and the sign panel penetrated into the occupant compartment before subsequently exiting from the vehicle.	Fail
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. Maximum roll and pitch angles were 1.5 and 0.6 degrees, respectively.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 3.0 m/s (10 ft/s), or at least below the maximum allowable value of 5.0 m/s (16.4 ft/s).	No occupant contact occurred in the longitudinal or lateral directions.	Pass
Vehicle Trajectory		
N. Vehicle trajectory behind the test article is acceptable.	The 2270P vehicle exited behind the test article.	Pass

Table 6.2. Performance Evaluation Summary for *MASH* Test 3-72 with 0-Degree Oriented Temporary Single Sign Support.

Test Agency: Texas A&M Transportation Institute | Test No.: 490022-7-4 | Test Date: 2012-05-09

***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 temporary sign support yielding to the vehicle and activation of the slip connection released the sign support assembly from its base.	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.* *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.*	There was no secondary impact between the 0-degree oriented sign assembly and the vehicle after its release from the base. The sign panel assembly rotated over the vehicle and the base components were carried along by the vehicle.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were −1.9 and −1.1 degrees, respectively.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 3.0 m/s (10 ft/s), or at least below the maximum allowable value of 5.0 m/s (16.4 ft/s).*	No occupant contact occurred in the longitudinal or lateral directions.	Pass
Vehicle Trajectory *N.* *Vehicle trajectory behind the test article is acceptable.*	The 2270P vehicle exited behind the test article.	Pass

CHAPTER 7. FINDINGS AND RECOMMENDATIONS

7.1 SUMMARY

The objective of this research was to develop a nonproprietary, lightweight, MASH compliant, temporary single sign support acceptable for use with an aluminum sign substrate. The researchers utilized perforated steel tubing for the frame of the temporary single sign support system to help make it lightweight, durable, easy to assemble, and adjustable.

Three different design concepts were developed through engineering analysis and evaluated using developmental full-scale crash tests with a *MASH* 1100C vehicle. Finite element simulations were used to help evaluate modified designs that avoid windshield contact during impacts with pickup trucks and provide height adjustability of the sign panel to accommodate placement in ditches. The project monitoring committee selected a design that incorporates a telescopic slip connection 5 ft above ground level and a nested support post for adjustable height. *MASH* Test 3-72 was performed to evaluate the behavior of the sign support system when impacted by pickup truck at sign orientations of 90 degrees and 0 degrees.

In both tests, the telescopic slip connection activated as designed and released the sign support assembly from its base. In the impact with the sign system oriented at 0 degrees, the released sign panel assembly did not come in contact with the vehicle, and all *MASH* criteria were satisfied. However, during the impact with the sign system oriented at 90 degrees, the edge of the sign panel cut into the roof of the vehicle. The associated occupant compartment penetration caused the system to fail to meet the MASH occupant risk criteria.

7.2 ADDITIONAL FINITE ELEMENT ANALYSIS*

TTI researchers investigated the effect of the height of the telescopic slip connection on the trajectory of the sign support and probability of secondary contact during impacts with a pickup truck. Several design variations were evaluated with finite element simulations. The simulated impact conditions involved a 2270P vehicle impacting the sign support in a 90 degree orientation at a speed of 62 mph. The different test article configurations evaluated included:

- Telescopic slip connection at both top (below sign) and at bottom (4 inches from base assembly).
- Telescopic slip connection only at bottom (4 inches from base assembly).
- Telescopic slip connection only at top (7-ft).
- Telescopic slip connection only at top (6-ft).

In all cases, the computer simulation predicted secondary impact between the sign support system and either the windshield or roof of the pickup. For this reason, none of these designs was recommended for further evaluation through full-scale crash testing.

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* TTI Proving Ground is an ISO 17025 accredited laboratory with A2LA Mechanical Testing certificate 2821.01. This certificate does not include simulation/engineering analysis.

7.3 PROPOSED DESIGN OPTIONS

Although project resources did not permit design and evaluation of other alternatives, the researchers proposed three different options that can be further considered under future research efforts. These options include:

- Use of a modified fuse plate design between support post and sign panel assembly.
- Reducing the friction at the slip connection.
- Shielding the corners (or all edges) of the sign panel.

7.3.1 Option #1: Fuse Plate Design (Modified)

The researchers suggest further investigation of the fuse plate concept evaluated in the small car developmental full-scale crash test (test 490022-7-3). However, it is recommended that the fuse plates be located directly behind the sign panel to eliminate the presence of a stub protruding below the sign that could interact with the roof of the pickup truck. This would require that the fuse plates by oriented perpendicularly to the sign panel face in order to avoid interference with the sign panel that could hinder attachment or activation. It is recommended that the slip connection be retained in the design and located 5 ft above ground level.

7.3.2 Option #2: Friction Reduction at Support Slip Connection

The idea behind this concept is that reduced friction in the slip connection will permit more rapid activation of the slip connection at a reduced rotation angle. This could reduce the rotation velocity of the released support and help mitigate the occurrence and/or severity of any secondary contact of the sign panel assembly with the roof of the pickup truck. Friction reduction can possibly be achieved through two means:

- a) use of a low friction coating on the components in the slip connection (e.g., interior of sleeve and exterior of vertical support; or
- b) increase the size of the sleeve and add a collapsible or crushable bushing material between internal surface of the sleeve and external surface of the vertical support post.
-

The bushing concept is based on failure or collapse of the bushing material during an impact. The additional tolerance created around the exterior of the support post would permit it to slip out of the sleeve at a smaller slip or rotation angle. The bushing material would need to be strong enough to resist service loads, but crush or collapse during the dynamic impact event.

The above options will require appropriate material selection and evaluation and extensive engineering analysis. The researchers also recommend small scale component testing in conjunction with the development effort.

7.3.3 Option #3: Sign Corner/Edge Shielding

This concept involves shielding the edges of the sign panel with a material that will increase the effective surface area of the panel edge and, thereby, help distribute the impact forces between the sign panel and roof over a wider area. This would mitigate the cutting effect observed in the full-scale crash test. The sign edges could be shielded with a rubber, plastic, or even steel material to provide a wider edge to contact the roof during a secondary impact. Engineering analysis and testing would be required to evaluate the required width and stiffness of the shielding material to effectively distribute the impact forces over a wide enough area to avoid both cutting and excessive deformation of the roof structure.

REFERENCES

1. Manual on Uniform Traffic Control Devices (MUTCD): http://mutcd.fhwa.dot.gov Last accessed August 9, 2012.

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

3. K. K. Mak, R. P. Bligh, and W. L. Menges. "Evaluation of Work Zone Barricades and Temporary Sign Supports," Research Report 5388-1F, Texas Transportation Institute, College Station, TX, February 1996.

4. K. K. Mak, R. P. Bligh, and L. R. Rhodes, Jr. "Crash Testing and Evaluation of Work Zone Traffic Control Devices," Transportation Research Record 1650, TRB, National Research Council, Washington, D.C., 1998, pp. 45–54.

5. R. P. Bligh, D. L. Bullard, W. L. Menges, and S. K. Schoeneman. "Impact Performance Evaluation of Work Zone Traffic Control Devices," Research Report 1792-2, Texas Transportation Institute, College Station, TX, 2000.

6. K. K. Mak, R. P. Bligh, and W. L. Menges. "Evaluation of Work Zone Barricades," Research Report 3910-S, Texas Transportation Institute, College Station, TX, October 1997.

7. K. K. Mak, W. L. Menges, and S. K. Schoeneman. Project RF 473220-13: NCHRP Report 350 Test 3-71 of Lang Products Crosswind™ Portable Sign Support, Texas Transportation Institute, College Station, TX, November 1999.

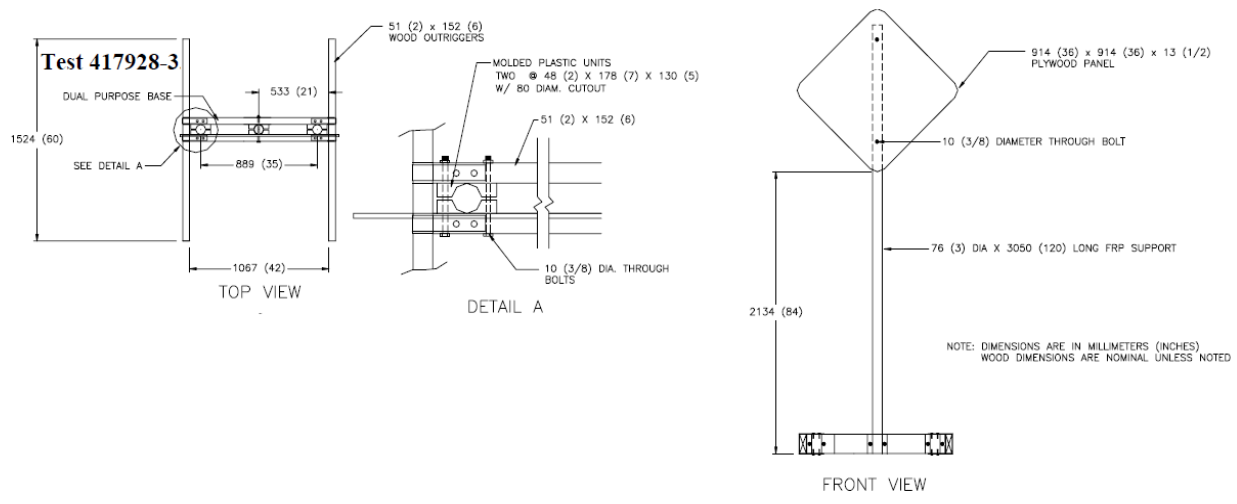
8. AASHTO, "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals," American Association of State Highway and Transportation Officials, Washington, D.C., 2009.

9. Hallquist, J.O., "LS-DYNA: Keyword User's Manual, Version 971" Livermore Software Technology Corporation (LSTC), Livermore, California, 2007.

APPENDIX A: SINGLE SUPPORT TESTED OR PROPOSED

Single FRP Support in Dual-Purpose Base, 7 ft MH TESTED
Crash Test #: 417928-3
Reference: R.P. Bligh, D.L. Bullard, W.L. Menges, and S.K. Schoeneman. "Impact Performance Evaluation of Work Zone Traffic Control Devices," Research Report FHWA/TX-01/1792-2, Texas Transportation Institute, College Station, TX, December 2000. [Test No. 417928-3].
Single fiberglass reinforced plastic support in a dual-purpose base. The single vertical support was a 76 mm (3 inch) diameter fiberglass reinforced plastic pipe 3050 mm (120 inch) long. A 914 mm × 914 mm × 13 mm (36 inch × 36 inch × ½ inch) plywood sign panel was attached to the support with two 10 mm (3/8 inch) diameter through bolts. The support was inserted into a wood dual-purpose base. The base consisted of two 51 mm × 152 mm (2 inch × 6 inch) boards with 51 mm × 152 mm (2 inch × 6 inch) outriggers 1524 mm (60 inch) long. Height to the bottom of the sign panel was 2134 mm (84 inch), and to the top of the panel it was 3355 mm (132 inch).
Speed: 100.1 km/hr
Angle: 0 deg
NCHRP Report 350: **Passed**
Upon impact, the sign post moved and the post pulled out of the dual-purpose base. The post was completely separated from the base and the sign post bounced off the bumper and lost contact with the vehicle. The vehicle received minor scrapes on front bumper and hood.

Single FRP Support in Dual-Purpose Base, 7 ft MH

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0.049 s

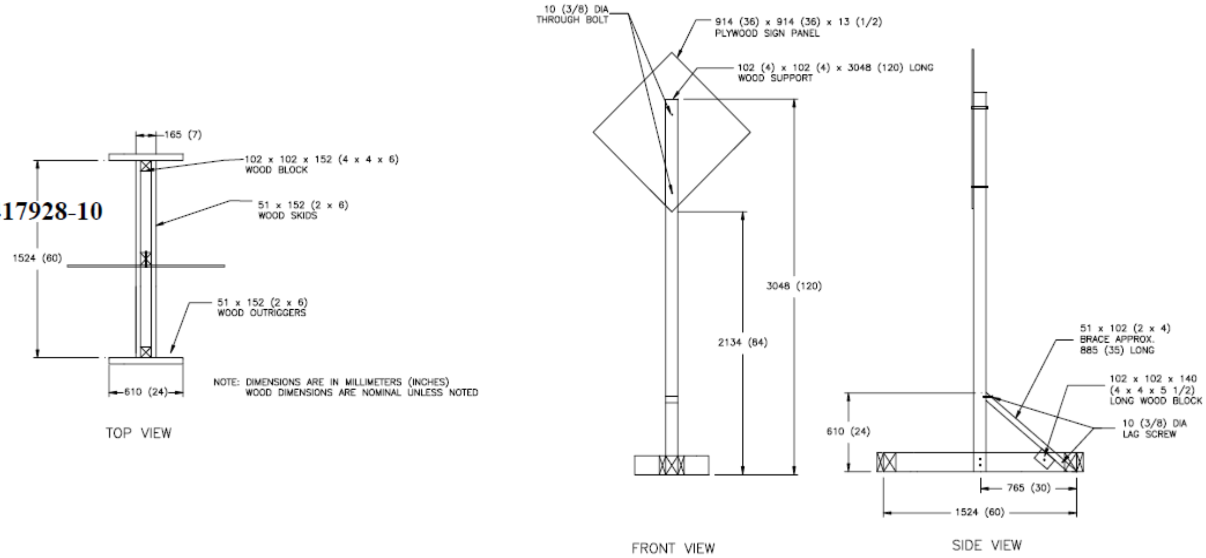

0.122 s

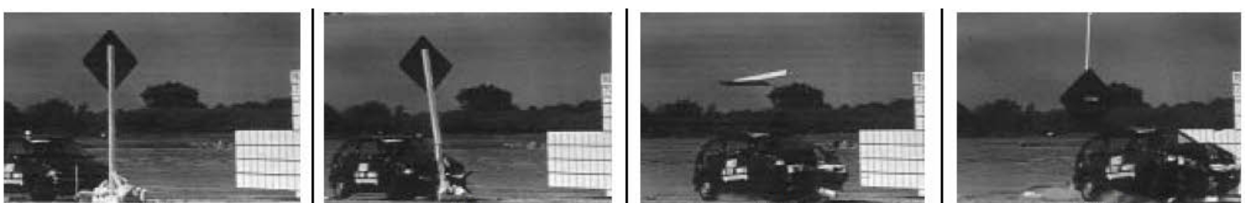

0.268 s

Wood Sign Support in H-leg Base, 7 ft MH TESTED
Crash Test #: 417928-10
Reference: R.P. Bligh, D.L. Bullard, W.L. Menges, and S.K. Schoeneman. "Impact Performance Evaluation of Work Zone Traffic Control Devices," Research Report FHWA/TX-01/1792-2, Texas Transportation Institute, College Station, TX, December 2000. [Test No. 417928-10].
A single 102 mm × 102 mm (4 inch × 4 inch) wood vertical support 3048 mm (120 inch) long was used in the barricade. A 76 mm × 76 mm × 13 mm (3 inch × 3 inch × ½ inch) plywood sign panel was attached to the support using two 10 mm (3/8 inch) diameter through bolts. The vertical support was inserted into the H-leg base, which consisted of a pair of 51 mm × 152 mm × 1605 mm (2 inch × 6 inch × 63 inch) long skids. A 51 mm × 152 mm × 610 mm (2 inch × 6 inch × 24 inch) long outrigger was attached at each end of the skid forming the "H." Height to the bottom of the sign panel was 2134 mm (84 inch).
Speed: 100.2 km/hr
Angle: 0 deg
NCHRP Report 350: **Passed**
The bumper contacted the wooden post, the hood of the vehicle deformed as it contacted the post. The post fractured and the entire sign rotated up and over the vehicle. Only bumper, hood, and grill received damage. No deformation or intrusion of the occupant compartment occurred.

Wood Sign Support in H-leg Base, 7 ft MH

417928-10





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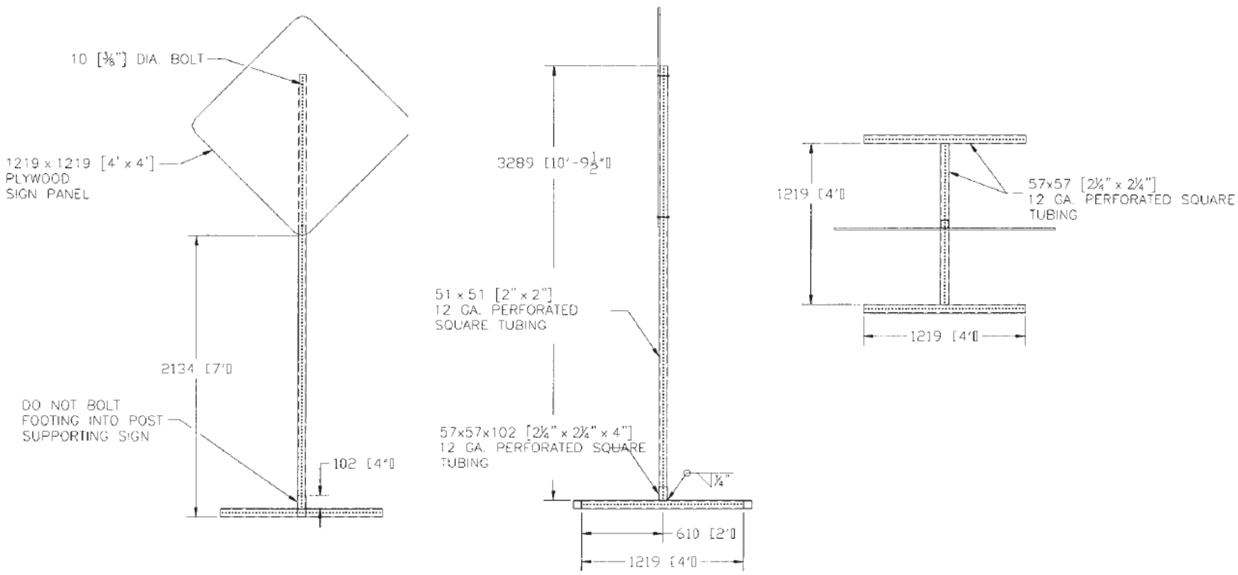
Single Steel-Upright Sign Support with Slip Connection, 7 ft MH PROPOSED

Reference: R.P. Bligh, W.L. Menges, and R.R. Haug. “Crashworthy Work-Zone Traffic Control Devices,” National Cooperative Highway Research Program Report 553, Transportation Research Board, Washington, D.C., 2006. [Proposed Test].

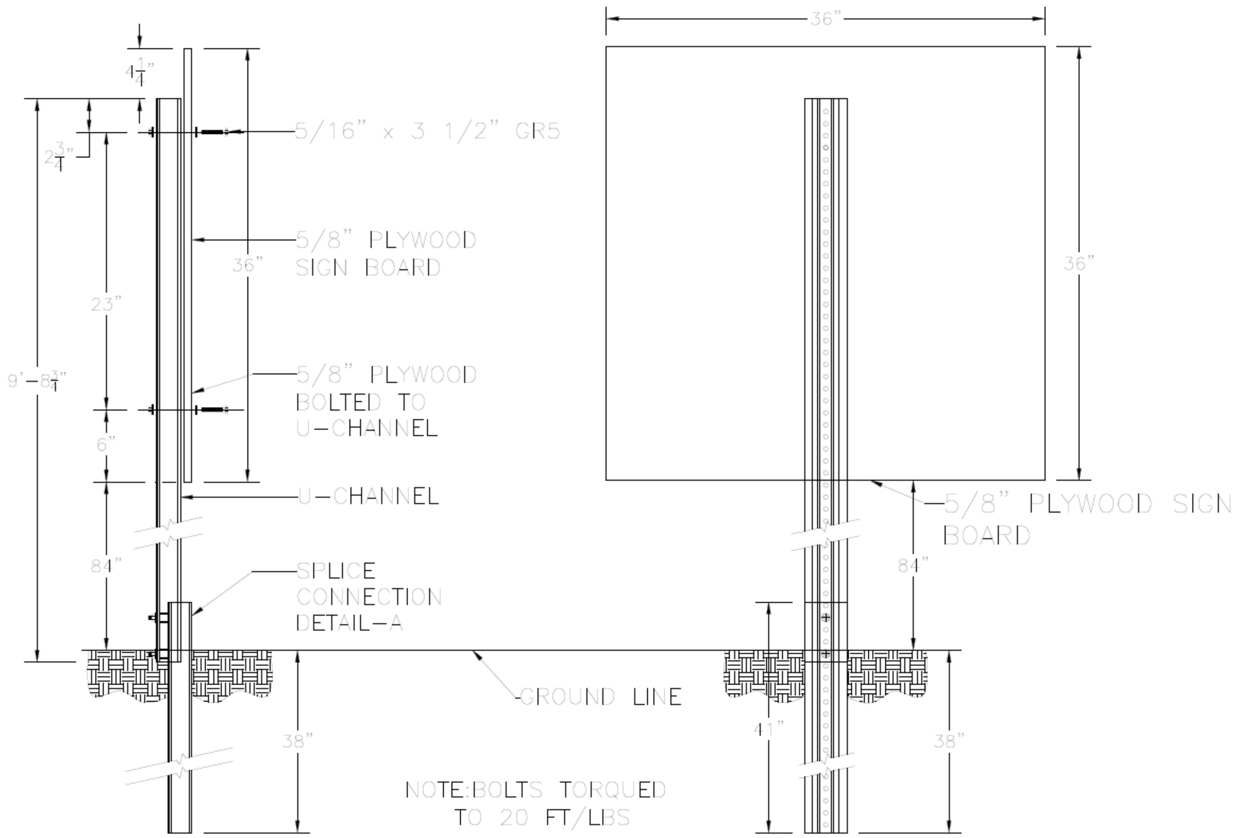
Increasing the size of the dual perforated steel-tube uprights above the minimum sizes required to handle wind loads may be desirable in order to incrementally increase the probability of successful impact performance. If the size of the upright is 51 mm (2-inch) square, 12 gauge or larger, Table 8.5 indicates that a single support can accommodate service loads associated with a 1.2 m × 1.2 m (4-ft × 4-ft) sign panel mounted at a height of 2.1 m (7 ft). The sign support system shown in Figure 8.8 has an I-shaped base with one central upright fabricated from 51 mm (2-inch) square, perforated steel tubing. The central member of the I-shaped base is welded to the center of each skid and a short sleeve is welded to the center of this central member. The upright is inserted into the sleeve but is not bolted to it. This slip mechanism is similar to that incorporated into Design H1. The rigid sign panel is mounted to the single upright using a minimum of two bolts. This system is a relatively simple design and requires less material than a dual-upright system. However, the savings in material cost are likely offset by a small increase in the required amount of welding. Handling may be facilitated by the lighter weight of the single upright. Assembly and disassembly also may be nominally faster because there is only one upright to insert or remove from a sleeve. However, signs mounted on single vertical supports will be more susceptible to flutter in windy conditions. Further, this design does not possess any side to side adjustability for placement on slopes.

Single Steel-Upright Sign Support with Slip Connection, 7 ft MH PROPOSED



4 lb/ft U-Channel Sign Support, 7 ft MH TESTED
Crash Test #: 476460-1
Reference: D.L. Bullard, R.P. Bligh, W.L. Menges, and R.R. Haug. "Volume I: Evaluation of Existing Roadside Safety Hardware Using Updated Criteria – Technical Report," National Cooperative Highway Research Program Web-Only Document 157, NCHRP Project 22-14(03), Transportation Research Board, Washington, D.C., 2010. [Test No. 476460-1]
A 4 lb/ft steel U-channel support manufactured by NuCor Steel Marion was erected in standard soil. The overall length of the sign support was 9 ft-8¾ inches. The sign support was attached to a 41 inches long 4 lb/ft steel U-channel ground stub. The sign support and ground stub were joined together using a 5 inch lap splice. Two 5/16 inch × 1½ inch grade 9 bolts were used in the lap splice and spaced 4 inch on-center. To prevent the U-channel sign support and ground stub from being over-nested or too firmly clamped together, two ½ inch long, ¾ inch diameter schedule 40 pipe spacers were placed between the ground stub and sign support at each of the two lap splice bolt locations. The overall lap splice length was 5 inches. A 36 inch × 36 inch × 5/8 inch plywood sign was attached to the support using two 5/16 inch diameter × 3½ inch long grade 5 bolts with flat washers and nuts. The sign mounting bolts were spaced 6 inches from the edge of the sign blank. The bottom of sign mounting height was 84 inches.
Speed: 63.3 mph
Angle: 0 deg
MASH: **Passed**
The 4 lb/ft U-channel sign support readily activated upon impact by the 2270P vehicle by fracturing at the ground stub and bumper height. The upper portion of the fractured sign support traveled with the vehicle. Contact of the U-channel support with the windshield and roof was minimal and the support did not penetrate or show potential for penetrating the occupant compartment. The largest piece of this support weighed 33.6 lb, but the trajectory was relatively low and should not cause undue hazard to others in the area.

4 lb/ft U-channel Sign Support, 7 ft MH



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Perforated Square Steel Tube Support, 7 ft MH TESTED

Crash Test #: 476460-2

Reference: D.L. Bullard, R.P. Bligh, W.L. Menges, and R.R. Haug. “Volume I: Evaluation of Existing Roadside Safety Hardware Using Updated Criteria – Technical Report,” National Cooperative Highway Research Program Web-Only Document 157, NCHRP Project 22-14(03), Transportation Research Board, Washington, D.C., 2010. [Test No. 476460-2]

A 12 gauge perforated, 2 inch square steel tube (PSST) support manufactured by Northwest Pipe was erected in standard soil. The overall length of the sign support was 10 ft-4¾ inches. The sign support was anchored into a 36 inches long, 12 gauge perforated, 2¼ inch square steel tube ground stub. The sign support was inserted into the ground stub 10 inches. A 5/16 inch diameter corner bolt, nut, and washer were used to anchor the support to the ground stub. A 36 inch × 36 inch × 5/8 inch plywood sign was attached to the support using two 5/16 inch diameter × 3½ inch long grade 5 bolts with flat washers and nuts. The sign mounting bolts were spaced 6 inches from the edge of the sign blank. The bottom of sign mounting height was 84 inches.

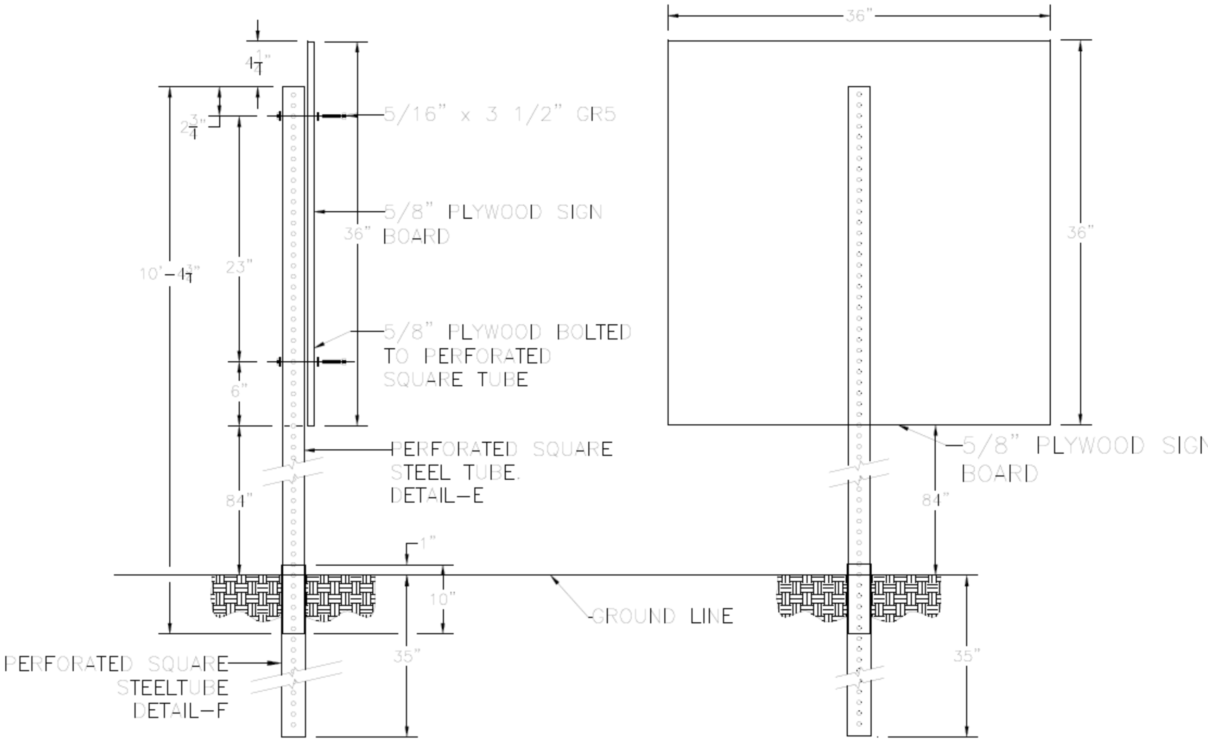
Speed: 61.7 mph

Angle: 0 deg

MASH: Failed

The Perforated Square Steel Tubing sign support readily activated upon impact by the 2270P vehicle by fracturing at the ground stub and at bumper height. The upper portion of the sign support traveled with the vehicle. The upper section of the support and sign panel contacted the windshield near the roof line. No tear of the plastic lining of the windshield occurred, however, the windshield was deformed inward 3.5 inches. MASH Section 5.3 and Appendix E limits deformation of the windshield to 3 inches.

Perforated Square Steel Tube Support, 7 ft MH




0.187 s


0.254 s

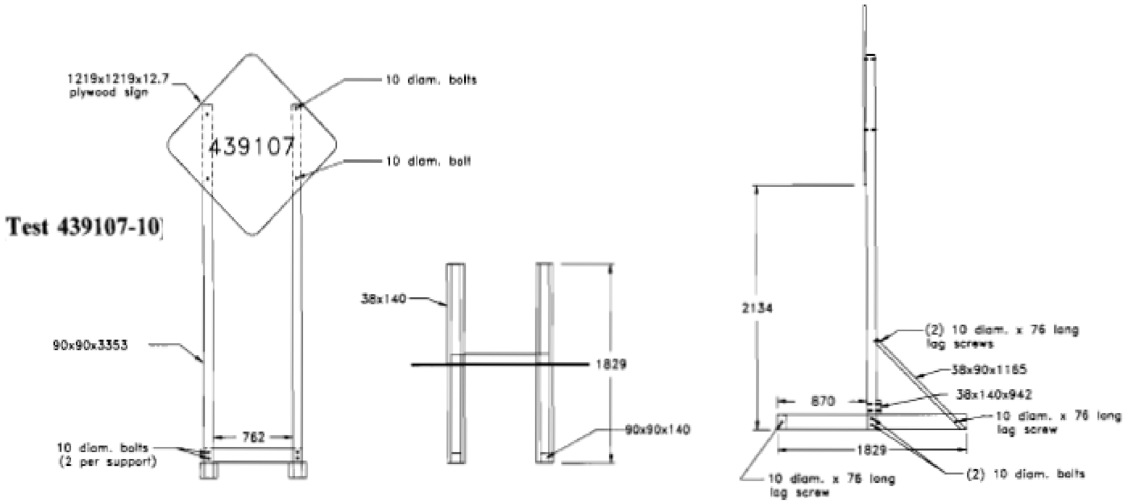

0.313 s

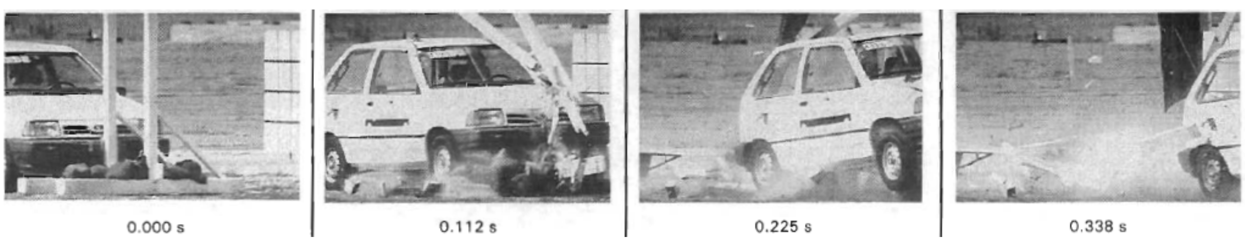

0.376 s

APPENDIX B: DOUBLE SUPPORT TESTED OR PROPOSED

Skid-Mounted Sign Support, 7 ft MH TESTED
Crash Test #: 439107-10
Reference: K.K. Mak, R.P. Bligh, and W.L. Menges. "Evaluation of Work Zone Barricades," Research Report TX-97/3910-S, Texas Transportation Institute, College Station, TX, November 1997. [Test No. 439107-10].
Skid-mounted sign support with 1219 mm × 1219 mm plywood sign panel mounted at a height of 2134 mm from bottom of sign panel to ground. Placed on dry soil.
Speed: 99.23 km/hr
Angle: 90 deg
NCHRP Report 350: **Passed**
The base for vertical support on impact side started to move and at the same time the support brace on the non-impacts ide broke away, causing pieces of wood from the vertical support to break away. The impact-side vertical support contacted the non-impact side. The base of the vertical support on the non-impact side then rolled over and separated into pieces. Both supports contacted vehicle with the support on the impact side, contacting the vehicle's roof just above the windshield.

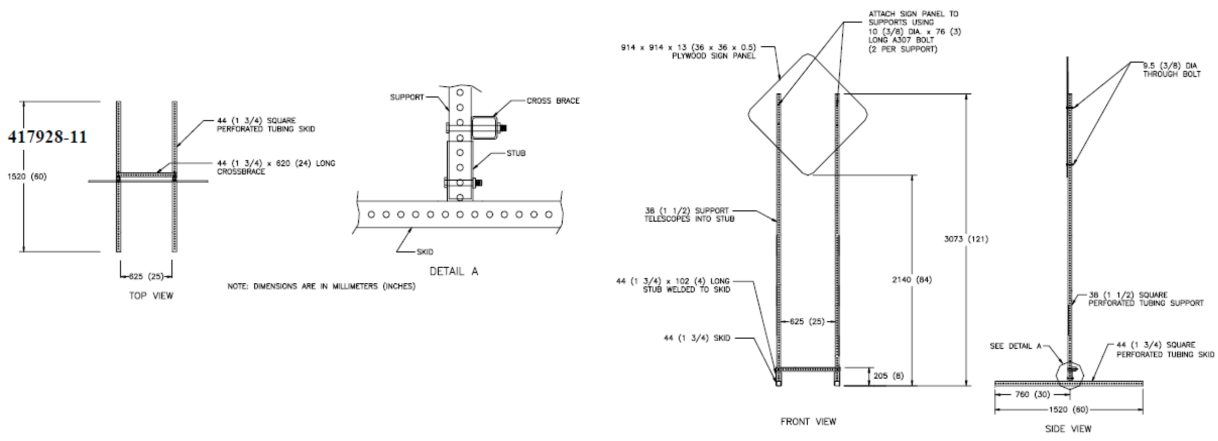
Skid-Mounted Sign Support, 7 ft MH





Dual Perforated Steel Tube Skid Mounted Sign Support, 7 ft MH TESTED
Crash Test #: 417928-11
Reference: R.P. Bligh, D.L. Bullard, W.L. Menges, and S.K. Schoeneman. "Impact Performance Evaluation of Work Zone Traffic Control Devices," Research Report FHWA/TX-01/1792-2, Texas Transportation Institute, College Station, TX, December 2000. [Test No. 417928-11].
A dual perforated steel tube skid mounted sign support was tested. Two 38 mm (1.5 inch) square perforated tubes 3073 mm (121 inch) long telescoped into and bolted to a 44 mm (1.75 inch) square perforated tube stub. The stub was welded to 44 mm (1.75 inch) square perforated tubes 1520 mm (60 inch) long. A cross brace of 44 mm (1.75 inch) square perforated tubing 625 mm (24.5 inch) long was attached to the vertical supports at a height of 205 mm (8 inch). Height to the bottom of the sign panel was 2140 mm (84 inch).
Speed: 93.8 km/hr
Angle: 0 deg
NCHRP Report 350: Failed
Upon impact, the left steel post fractured at the steel base, and the sign panel contacted the roof of the vehicle. The windshield shattered. The steel sign support penetrated the occupant compartment in the windshield area and deformed the roof. Maximum deformation into the occupant compartment was 99 mm (3.9 inch) (11 percent reduction of space) in the floor pan near the transmission tunnel.

Dual Perforated Steel Tube Skid Mounted Sign Support, 7 ft MH




0.000 s

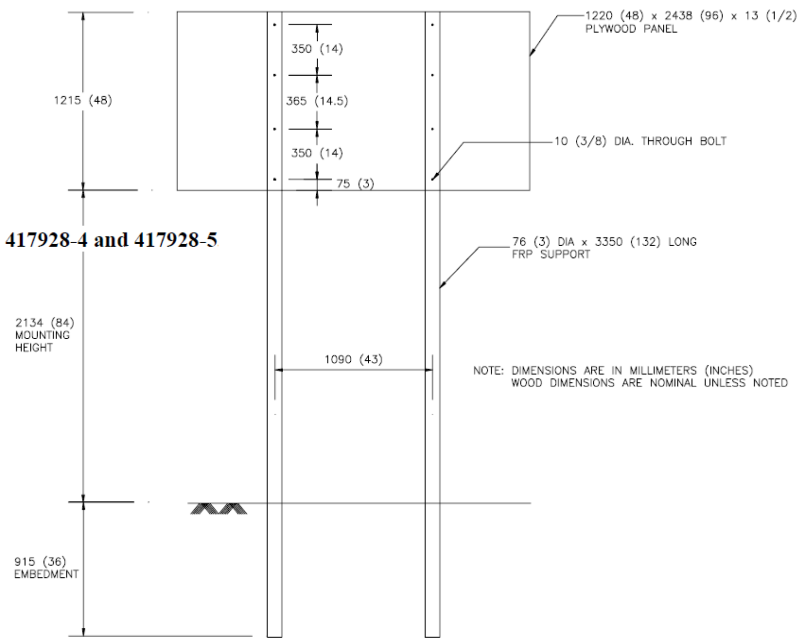

0.048 s

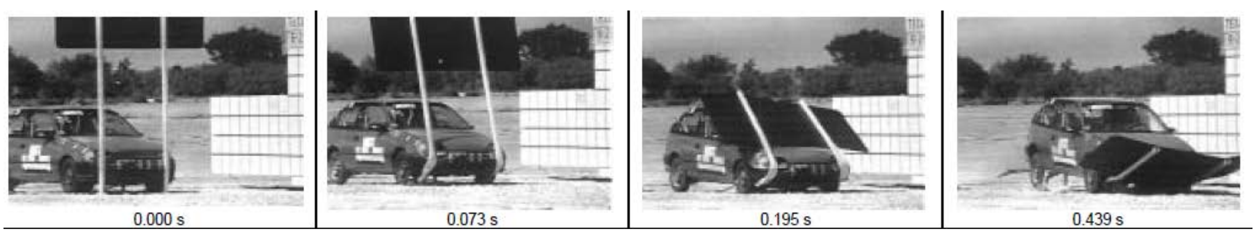

0.134 s


0.207 s

Dual FRP Sign Support, 7 ft MH TESTED
Crash Test #: 417928-4
Reference: R.P. Bligh, D.L. Bullard, W.L. Menges, and S.K. Schoeneman. "Impact Performance Evaluation of Work Zone Traffic Control Devices," Research Report FHWA/TX-01/1792-2, Texas Transportation Institute, College Station, TX, December 2000. [Test No. 417928-4].
A dual ground mounted FRP sign support was used in these two tests. Two 76 mm (3 inch) Outside Diameter (OD) × 4270 mm (168 inch) long fiberglass reinforced plastic pipes spaced 1065 mm (42 inch) apart were embedded in NCHRP Report 350 standard soil at a depth of 914 mm (36 inch). A 1220 mm × 2438 mm × 13 mm (48 inch × 96 inch × ½ inch) plywood sign panel was attached to the supports with four each support 10 mm (3/8 inch) diameter through bolts. Height to the bottom of the sign panel was 2135 mm (84 inch) and to the top of the sign panel it was 3350 mm (132 inch).
Speed: 21.2 km/hr
Angle: 0 deg
NCHRP Report 350: **Passed**
The sign posts deformed around the front bumper. The plywood sign panel contacted the hood of the vehicle. The cover of the front right of the bumper of the vehicle separated from the vehicle. The hood received two scrapes, and there was minor damage to the bumper cover. The sign panel shattered the windshield, but it did not penetrate or show potential to penetrate the occupant compartment, or present undue hazard to others in the area. No deformation or intrusion of the occupant compartment occurred.

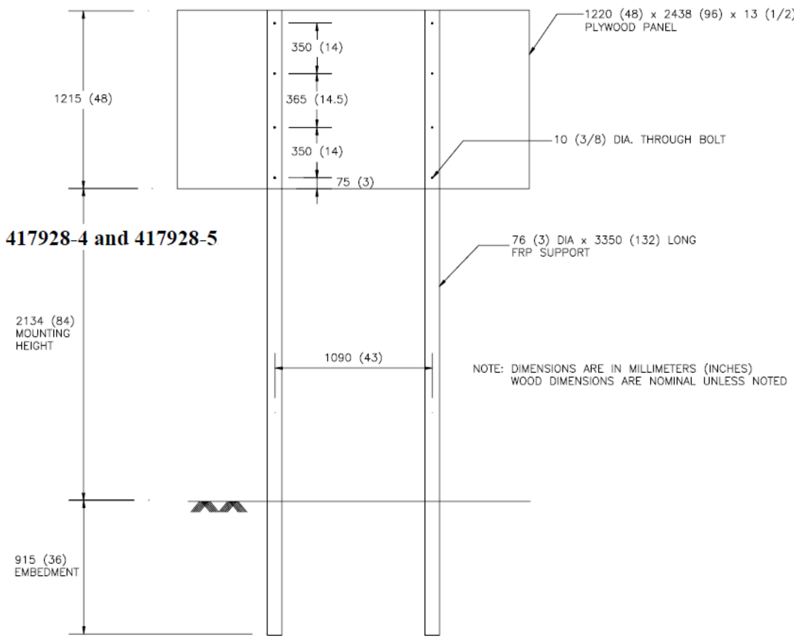
Dual FRP Sign Support, 7 ft MH





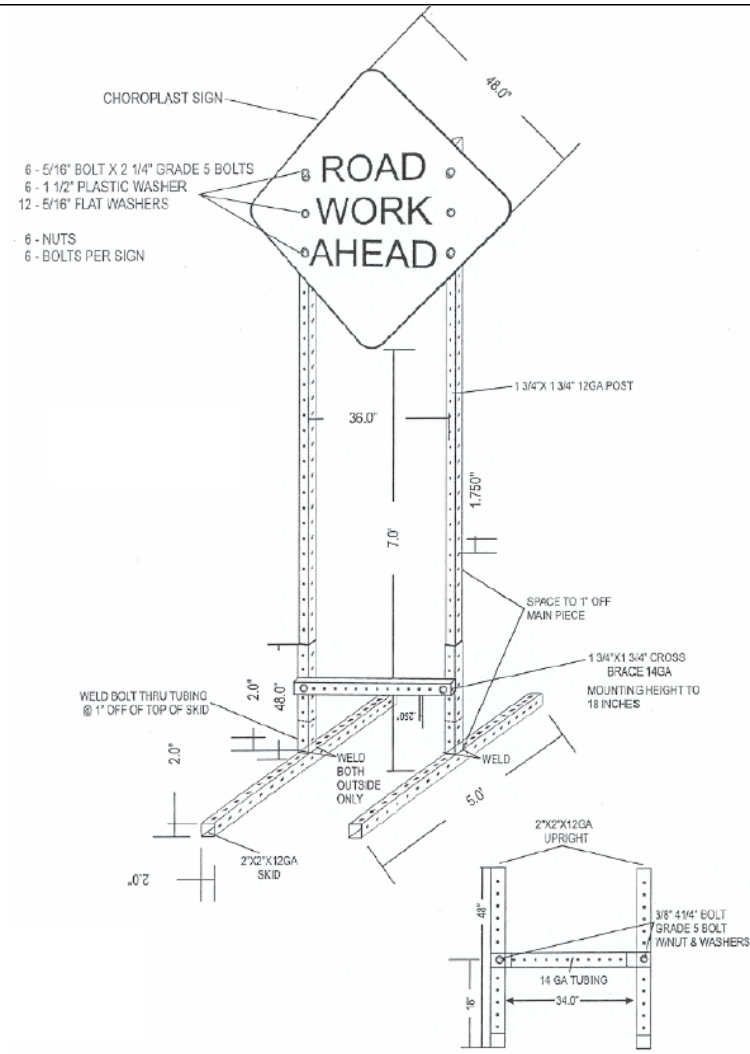
Dual FRP Sign Support, 7 ft MH TESTED
Crash Test #: 417928-5
Reference: R.P. Bligh, D.L. Bullard, W.L. Menges, and S.K. Schoeneman. “Impact Performance Evaluation of Work Zone Traffic Control Devices,” Research Report FHWA/TX-01/1792-2, Texas Transportation Institute, College Station, TX, December 2000. [Test No. 417928-5].
A dual ground mounted FRP sign support was used in these two tests. Two 76 mm (3 inch) Outside Diameter (OD) × 4270 mm (168 inch) long fiberglass reinforced plastic pipes spaced 1065 mm (42 inch) apart were embedded in NCHRP Report 350 standard soil at a depth of 914 mm (36 inch). A 1220 mm × 2438 mm × 13 mm (48 inch × 96 inch × ½ inch) plywood sign panel was attached to the supports with four each support 10 mm (3/8 inch) diameter through bolts. Height to the bottom of the sign panel was 2135 mm (84 inch) and to the top of the sign panel it was 3350 mm (132 inch).
Speed: 98.6 km/hr
Angle: 0 deg
NCHRP Report 350: **Passed**
The sign posts deformed around the front of the bumper and were pulled out of the ground. The plywood sign panel contacted the roof of the vehicle. The sign panel contacted the roof and cracked the windshield, but it did not penetrate or show potential to penetrate the occupant compartment, or present undue hazard to others in the area. No deformation or intrusion of the occupant compartment occurred.

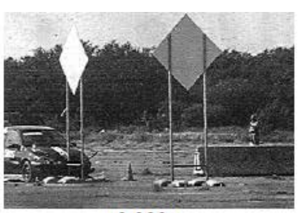
Dual FRP Sign Support, 7 ft MH

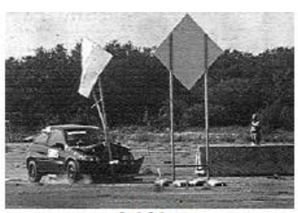


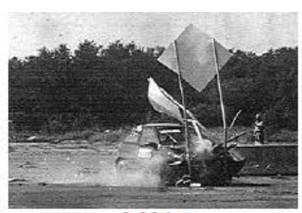
Dual-Leg Perforated Square Steel Tube, 7 ft MH TESTED
Crash Test #: 400001-ATC1
Reference: R.P. Bligh, W.L. Menges, and R.R. Haug. "NCHRP Report 350 Test 3-71 on the Allied Tube & Conduit Dual Leg Perforated Square Steel Tube Temporary Sign Support," Report No. 400001-ATC1, Texas Transportation Institute, College Station, TX, December 2004. [Test No. 400001-ATC1].
A 48-inch (1219 mm) long vertical sleeve fabricated from 2-inch (51 mm) square, 12-gauge perforated steel tubing was welded to the center of a 5-ft (1.5 m) long skid fabricated from the same material. A 3/8-inch (10 mm) diameter bolt was inserted through prefabricated holes in the sleeve approximately 1 inch (25 mm) off the top surface of the skid and welded in place. A 1 ¾-inch (44 mm) square × 11 ft (3.4 m) long, 12-gauge perforated steel upright was inserted into the sleeve until it rested on the 3/8-inch (10 mm) diameter offset bolt. A 1 ¾-inch (44 mm) square × 38-inch long, 14-gauge cross brace was bolted to the sleeves and uprights at a height of 18 inches (457 mm) above ground using two 3/8-inch (10 mm) diameter × 4-1/4 inch (108 mm) long through bolts. The two vertical supports were spaced 36 inches (914 mm) apart center to center. A 4 ft × 4 ft × 3/8 inch (1.2 m × 1.2 m × 10 mm) Choroplast corrugated plastic sign panel was attached to the vertical supports in a diamond configuration using six 5/16-inch (8 mm) diameter hex-head bolts—three through each support. A 1-1/2-inch (38 mm) diameter plastic washer was used between the head of the bolts and sign substrate. A 40-lb (18.2 kg) sandbag was placed on front and back of each skid for a total of four sand bags. The unballasted weight of the sign support system was 88.5 lb (40.2 kg). The Choroplast sign panel weighed 8 lb (3.6 kg).
Speed: 88.3 km/hr
Angle: 90-0 deg
NCHRP Report 350: **Passed**
The Allied Tube & Conduit dual-leg perforated square steel tube temporary sign support system activated as designed by yielding to the small car and fracturing. There were detached elements, fragments, and debris resulting from the test. However, the debris was primarily strewn along the path of the vehicle and was not considered to present undue hazard to others in the area. Further, none of the detached elements, fragments, and debris penetrated or showed potential for penetrating the occupant compartment. There was no deformation of or intrusion into the occupant compartment.

Dual-Leg Perforated Square Steel Tube, 7 ft MH




0.000 s

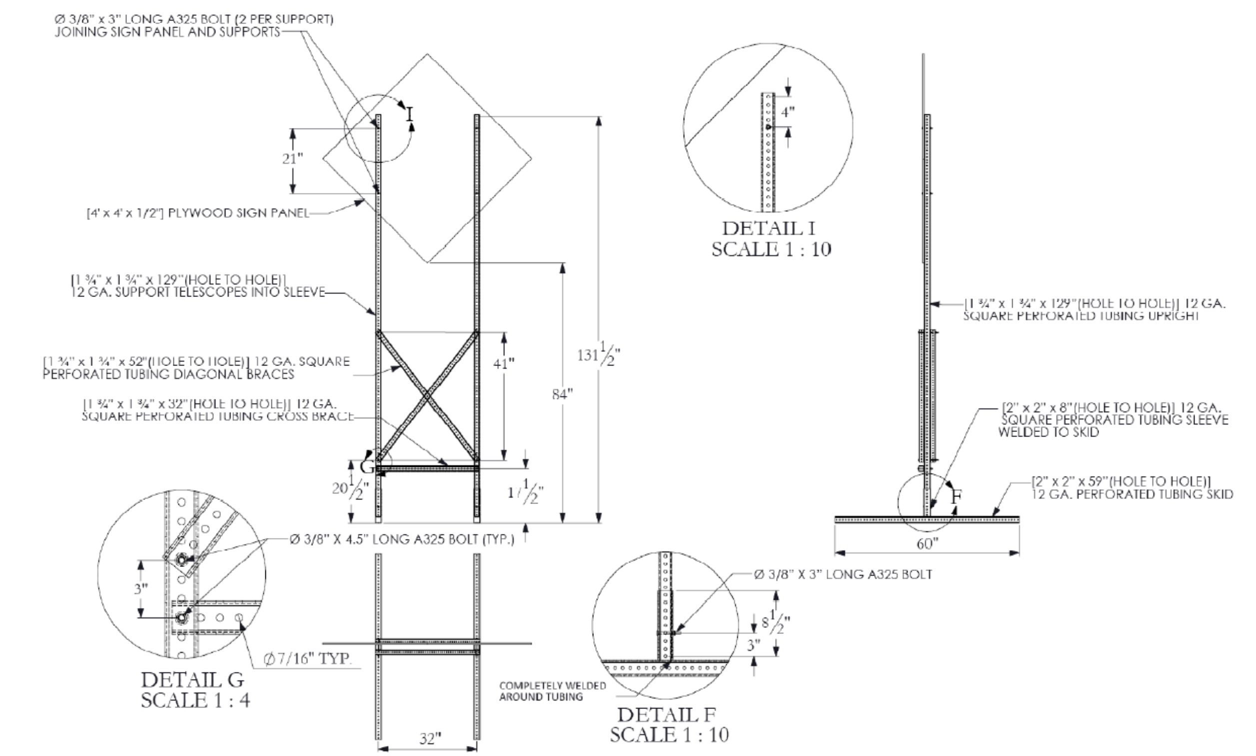

0.101 s


0.304 s


0.507 s

Dual-Support Temporary Sign Support, 7 ft MH TESTED
Crash Test #: 463849-1
Reference: P. Carlson, R.P. Bligh, A. Pike, J. Miles, W.L. Menges, and S. Paulus. "On-Going Evaluation of Traffic Control Devices," Research Report FHWA/TX-10/0-6384-1, Texas Transportation Institute, College Station, TX, November 2009. [Test No. 463849-1].
A 9-inch long vertical sleeve fabricated from 2-inch square, 12-gauge perforated steel tubing was welded to the center of each of two 5-ft long skids fabricated from the same material. A 1¾-inch square × 10.75 ft long, 12-gauge perforated steel upright was inserted into the vertical sleeve and secured using a ⅜-inch diameter × 3-inch long A325 bolt. A 1¾-inch square × 32-inch long, 12-gauge horizontal cross brace was bolted to the uprights at a height of 17½ inches above ground using two ⅜-inch diameter × 4½-inch long A325 through bolts. The two vertical supports were spaced 32 inches apart center to center. Two 1¾-inch square × 52-inch long, 12-gauge braces are bolted diagonally across the vertical uprights just above the horizontal cross brace using a ⅜-inch diameter × 4½-inch long A325 through bolt at each end. A 4 ft × 4 ft × ½ inch thick plywood sign panel was attached to the vertical supports in a diamond configuration using four ⅜-inch diameter × 3 inch long A325 bolts—two through each support. A 40-lb sandbag was placed on the front and back of each skid for a total of four sand bags. The unballasted weight of the sign support system was 130 lb.
Speed: 60.6 mph
Angle: 0-90 deg Evaluated only 0 deg
NCHRP Report 350: **Passed**
The first temporary sign support readily activated as designed by yielding to the vehicle. The first temporary sign support yielded to the vehicle. The detached elements did not penetrate or show potential to penetrate the occupant compartment. The support rode along with the vehicle and did not present undue hazard to others in the area. The windshield damage was not associated with the initial impact with the first support, but occurred after the second sign support accelerated the first sign support system into the windshield.

Dual-Support Temporary Sign Support, 7 ft MH




0.000 s

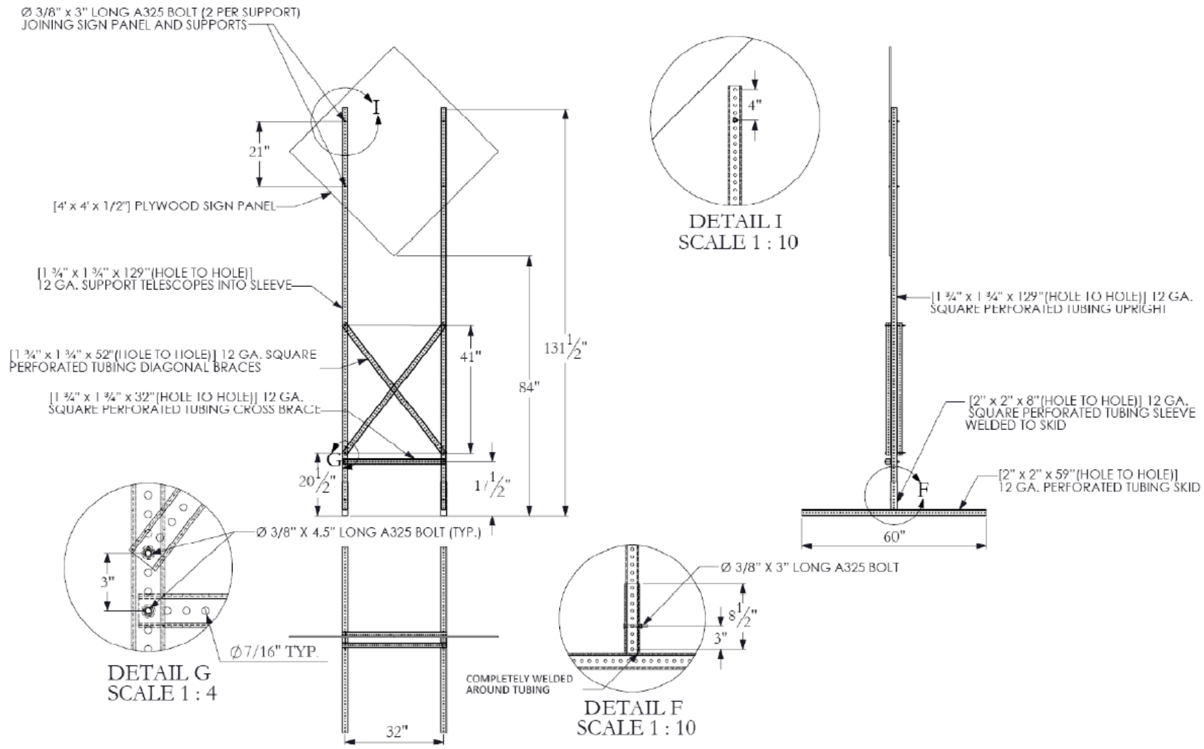

0.100 s


0.200 s


0.300 s

Dual-Support Temporary Sign Support, 7 ft MH TESTED
Crash Test #: 463849-2
Reference: P. Carlson, R.P. Bligh, A. Pike, J. Miles, W.L. Menges, and S. Paulus. "On-Going Evaluation of Traffic Control Devices," Research Report FHWA/TX-10/0-6384-1, Texas Transportation Institute, College Station, TX, November 2009. [Test No. 463849-2].
A 9-inch long vertical sleeve fabricated from 2-inch square, 12-gauge perforated steel tubing was welded to the center of each of two 5-ft long skids fabricated from the same material. A 1¾-inch square × 10.75 ft long, 12-gauge perforated steel upright was inserted into the vertical sleeve and secured using a ⅜-inch diameter × 3-inch long A325 bolt. A 1¾-inch square × 32-inch long, 12-gauge horizontal cross brace was bolted to the uprights at a height of 17½ inches above ground using two ⅜-inch diameter x 4½-inch long A325 through bolts. The two vertical supports were spaced 32 inches apart center to center. Two 1¾-inch square × 52-inch long, 12-gauge braces are bolted diagonally across the vertical uprights just above the horizontal cross brace using a ⅜-inch diameter × 4½-inch long A325 through bolt at each end. A 4 ft × 4 ft × ½ inch thick plywood sign panel was attached to the vertical supports in a diamond configuration using four ⅜-inch diameter × 3 inch long A325 bolts—two through each support. A 40-lb sandbag was placed on the front and back of each skid for a total of four sand bags. The unballasted weight of the sign support system was 130 lb.
Speed: 62 mph
Angle: 90 deg
NCHRP Report 350: **Passed**
The temporary sign support readily activated as designed by yielding to the vehicle. The temporary sign support yielded to the vehicle. The detached elements did not penetrate or show potential to penetrate the occupant compartment. The support rode along with the vehicle and did not present undue hazard to others in the area. No deformation of the occupant compartment occurred.

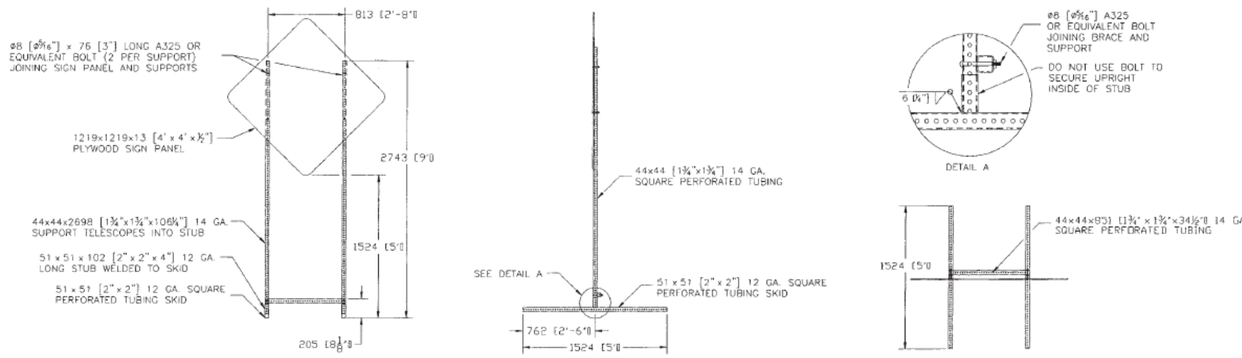
Dual-Support Temporary Sign Support, 7 ft MH



0.000 s | 0.072 s | 0.144 s | 0.216 s

Dual Uprights with Slip Connection, 7 ft MH TESTED
Crash Test #: 474010-8
Reference: R.P. Bligh, W.L. Menges, and R.R. Haug. "Crashworthy Work-Zone Traffic Control Devices," National Cooperative Highway Research Program Report 553, Transportation Research Board, Washington, D.C., 2006. [Tests No. 474010-8].
The sign support uses two uprights fabricated from 44 mm (13⁄4-inch) square, 14-gauge perforated steel tubing. A 1.2 m × 1.2 m × 13 mm (4-ft × 4-ft × 1⁄2-in) plywood sign panel is attached to each upright using two 8 mm (5⁄16-inch) diameter, 76 mm (3-inch) long, A325 or equivalent grade bolts. The mounting height from the ground to the bottom edge of the sign panel was 1.5 m (5 ft). A 102 mm (4-inch) long sleeve fabricated from 51 mm (2-inch) square, 12-gauge perforated steel tubing is vertically welded to the center of a 1.5 m (5-ft) long skid fabricated from the same material. The uprights are inserted into the sleeves but are not bolted to them. A horizontal cross brace fabricated from 44 mm (13⁄4-inch) square, 14-gauge perforated steel tubing is bolted to each upright just above the height of the sleeve using 8 mm (5⁄16-inch) diameter, A325 or equivalent bolts. Two identical sign support systems were placed on a paved concrete surface in the path of the vehicle approximately 9 m (30 ft) apart from one another—one perpendicular to the path of the vehicle and one parallel to the path of the vehicle. Each system was ballasted with four 18 kg (40-lb) sandbags.
Speed: 60.2 mph
Angle: 0-90 deg
NCHRP Report 350: **Failed**
Debris remained scattered along the vehicle path. The roof of the vehicle was deformed inward 200 mm (7.9 inch). The windshield was torn and separated from its frame (FHWA Case 1 and 2). During the test, the sign panel reached a maximum penetration of 302 mm (11.9 inch). There was no other measurable occupant compartment deformation.

Dual Uprights with Slip Connection, 7 ft MH



0.000 s	0.146 s	0.342 s	0.466 s

Strong Dual Uprights with Slip Connection, 7 ft MH TESTED

Crash Test #: 474010-9

Reference: R.P. Bligh, W.L. Menges, and R.R. Haug. "Crashworthy Work-Zone Traffic Control Devices," National Cooperative Highway Research Program Report 553, Transportation Research Board, Washington, D.C., 2006. [Tests No. 474010-9].

The two uprights are fabricated from 57 mm (2¼-inch) square, 12-gauge perforated steel tubing. A 1.2 m × 1.2 m × 13 mm (4-ft × 4-ft × ½-inch) plywood sign panel is attached to each upright using two 8 mm (5⁄16-inch) diameter, A325 or equivalent grade bolts. The mounting height from the ground to the bottom edge of the sign panel was 1.5 m (5 ft). A 102 mm (4-inch) long sleeve fabricated from 64 mm (2½-inch) square, 12-gauge perforated steel tubing is vertically welded to the center of a 1.5 m (5-ft) long skid fabricated from the same material. The uprights are inserted into the sleeves but are not bolted to them. A horizontal cross brace fabricated from 57 mm (2¼-inch) square, 12-gauge perforated steel tubing is bolted to each upright 0.5 m (1 ft-6½ inches) above ground using 8 mm (5⁄16-inch) diameter, A325 or equivalent bolts. The height of the cross brace corresponds to the centerline of the bumper of a small passenger car. In the 90-degree impact, the theory was that the cross brace would help transfer momentum to both uprights simultaneously and reduce the degree of deformation that might otherwise be experienced by the first upright that is contacted. Two identical sign support systems were placed on a paved concrete surface in the path of the vehicle approximately 9 m (30 ft) apart from one another—one perpendicular to the path of the vehicle and one parallel to the path of the vehicle. Each system was ballasted with four 18 kg (40-lb) sandbags.

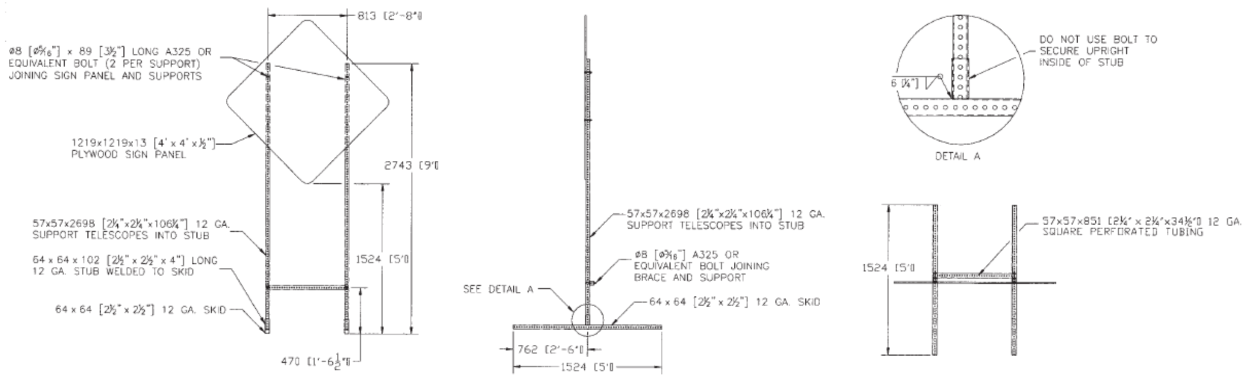
Speed: 62.1 mph

Angle: 0-90 deg

NCHRP Report 350: **Passed**

Both tall, dual-leg sign supports readily activated as designed by yielding and fracturing. Debris remained scattered along the vehicle path. The roof was deformed inward 25 mm (1.0 inch). The windshield was not damaged (no holes or tears), nor was the windshield separated from its frame. There was no other measurable occupant compartment deformation.

Strong Dual Uprights with Slip Connection, 7 ft MH




0.000 s

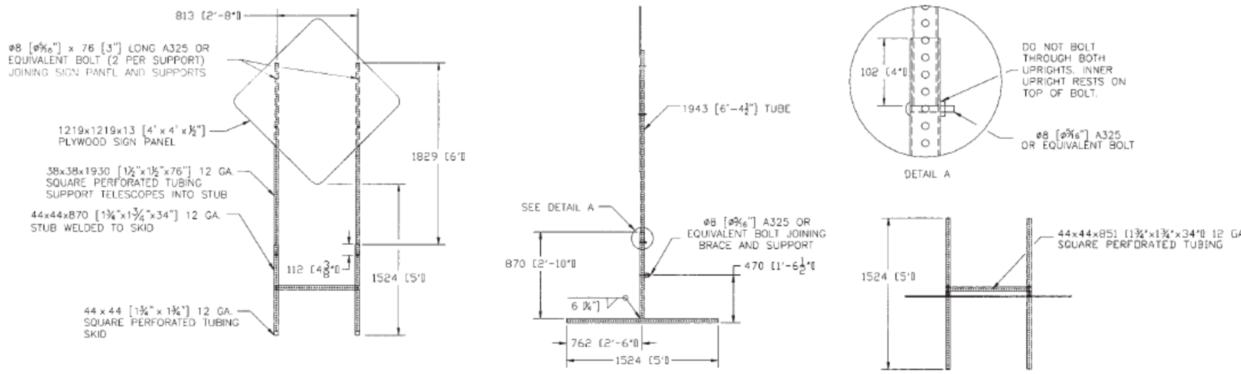

0.175 s


0.356 s


0.604 s

Dual Uprights with Raised Slip Joint, 7 ft MH TESTED
Crash Test #: 474010-10
Reference: R.P. Bligh, W.L. Menges, and R.R. Haug. "Crashworthy Work-Zone Traffic Control Devices," National Cooperative Highway Research Program Report 553, Transportation Research Board, Washington, D.C., 2006. [Tests No. 474010-10].
The objective of this test was to determine if raising the slip joint from a height of 152 mm to 870 mm (6 in to 34¼ inches) can improve impact performance and permit smaller, lighter weight tubular sections to be used in lieu of the larger, heavier sections evaluated in Test 9.
Speed: 61.9 mph
Angle: 0-90 deg
NCHRP Report 350: **Failed**
Debris remained scattered along the vehicle path. The roof of the vehicle was deformed inward 62 mm (2.4 inch) near the windshield, and 40 mm (1.6 inch) near the center. The windshield was shattered and deformed inward 92 mm (3.6 inch) with a small hole (FHWA Case 1). The windshield was not separated from its frame. There was no other measurable occupant compartment deformation.

Dual Uprights with Raised Slip Joint, 7 ft MH



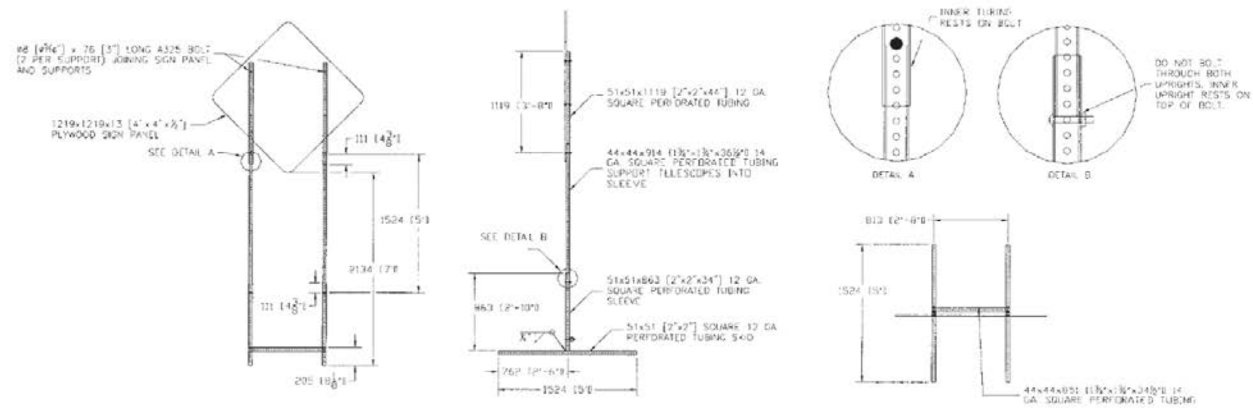
0.000 s | 0.112 s | 0.345 s | 0.454 s

Steel-Frame Sign Support with Three-Piece Uprights, 7 ft MH PROPOSED

Reference: R.P. Bligh, W.L. Menges, and R.R. Haug. "Crashworthy Work-Zone Traffic Control Devices," National Cooperative Highway Research Program Report 553, Transportation Research Board, Washington, D.C., 2006. [Test Proposed].

It is differentiated from Design H6 through the addition of an upper slip joint below the sign panel. Thus, the upright is effectively composed of three pieces of tubing. The middle section of the three-piece upright slides into the sleeve to form a slip connection similar to the one used in Design H6. The insertion depth into the sleeve is limited to 102 mm (4 inch) by a stop bolt on which the lower end of the middle section rests. The upper section of the three-piece upright is the same size as the sleeve and slides over the top end of the middle section. The insertion depth of the middle section into the upper section is limited to 102 mm (4 inch) by a stop bolt on which the lower end of the upper section rests. Thus, there are two slip connections in this system. In theory, this design should permit the upright to separate into two pieces during impact. Each component will thus have a mass that is less than the combined mass of the system, which should help reduce the severity of contact with the vehicle should a secondary impact occur. Release of the sign panel at an increased height above ground will also potentially increase the height of its point of rotation, thereby reducing the likelihood of secondary contact with the impacting vehicle. The slip connections should result in quick assembly. However, fabrication and handling may be complicated by the multiple components that compose the system.

Steel-Frame Sign Support with Three-Piece Uprights, 7 ft MH PROPOSED

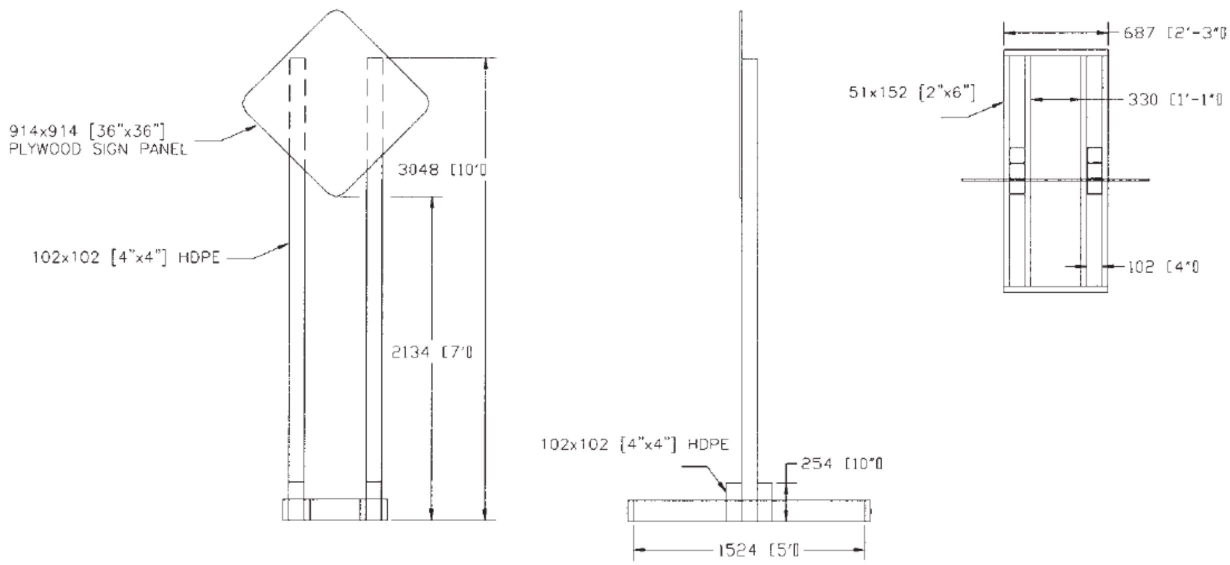


Dual HDPE-Upright Sign Support with Slip Connection, 7 ft MH PROPOSED

Reference: R.P. Bligh, W.L. Menges, and R.R. Haug. "Crashworthy Work-Zone Traffic Control Devices," National Cooperative Highway Research Program Report 553, Transportation Research Board, Washington, D.C., 2006. [Test Proposed].

It is a combination wood and plastic support system. The skids are fabricated from wooden 51 mm × 152 mm (2-inch × 6-inch) dimensional lumber. The uprights are lightweight, hollow-profile, 102 mm × 102 mm (4-inch × 4-inch) tubes fabricated from HDPE similar to those used in some barricade designs. The HDPE uprights are inserted between the legs of each skid. Rotation of the uprights is resisted by two short, hollow-profile plastic blocks bolted inside the skids on either side of the uprights. This slip connection will permit the uprights to release from the skids upon impact. This design is relatively inexpensive and easily constructed from readily available materials. However, the hollow-profile plastic and dimensional lumber may be less durable than the steel-frame designs, and handling will be more difficult because the wooden skids increase the weight. If desired, the weight of the system can be reduced to improve handling characteristics by using 51 mm × 152 mm (2-inch × 6-inch) HPPL in lieu of the dimensional lumber. As with the other designs, placement of the sign support on roadside slopes can be accommodated in the HDPE/wooden sign support system by adjusting the attachment of one of the uprights to the sign panel. This adjustment will require drilling additional holes in the upright or sign panel.

Dual HDPE-Upright Sign Support with Slip Connection, 7 ft MH
PROPOSED

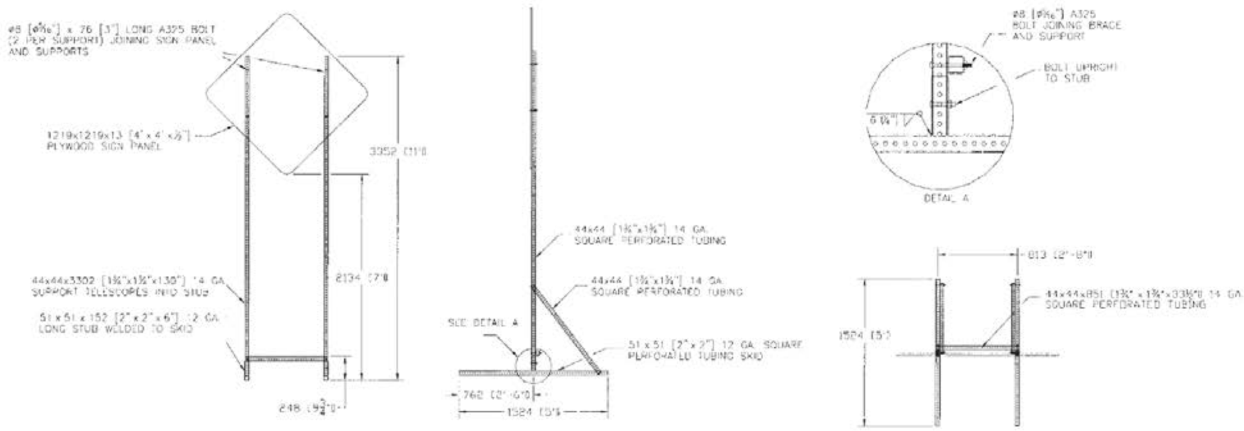


Dual Steel-Upright Sign Support with Knee Braces, 7 ft MH PROPOSED

Reference: R.P. Bligh, W.L. Menges, and R.R. Haug. "Crashworthy Work-Zone Traffic Control Devices," National Cooperative Highway Research Program Report 553, Transportation Research Board, Washington, D.C., 2006. [Test Proposed].

The knee brace is attached to the uprights above the bumper height of the impacting vehicle. In theory, upon impact, the deformation and rotation of the uprights toward the car will be initially resisted by the knee brace. Typically, the uprights will hinge and rotate about a point near the vehicle bumper, which is the first point of contact between the uprights and vehicle. The presence of the knee braces above bumper height will constrain the movement of the uprights toward the vehicle until a hinge forms in the uprights above the height of the knee braces or the uprights fracture near the points of attachment to the knee braces. The concept is that the sign support system will have been accelerated by the impacting vehicle before fracture or hinging of the uprights, thus reducing the rotational velocity of the uprights toward the vehicle. Because release of the uprights out of the sleeves will be restricted by the knee braces, a slip mechanism is not required in this design. Thus, the sleeve height can be increased (e.g., 152 mm to 229 mm [6 inch to 9 inch]) and the uprights can be bolted inside the sleeve. Bolting the uprights into the sleeves can facilitate the telescopic adjustment of the uprights to accommodate placement of the sign support system on roadside slopes. The upright on the downhill side of the slope can be raised within the sleeve and bolted to it to maintain the desired elevation. This ability eliminates the need for adjusting the connection points of the downhill upright on the sign panel. Transportation and on-site erection of this system will be more difficult than those designs incorporating a slip connection. The bolts connecting the knee braces to the uprights and the bolts connecting the uprights to the sleeves will need to be removed to disassemble the system for transportation. These same bolts will need to be installed to erect the system. Although Figure 8.7 illustrates this design concept using 14-gauge, 44 mm (13⁄4-inch) uprights (the lightest considered acceptable for the selected design wind load), the knee braces can be used in combination with larger upright sizes to further delay the hinging or fracture of the uprights. The same considerations discussed for Design H2 would be relevant to such a change. The discussion of this system has thus far focused on a frontal, 0-degree impact. The researchers have concerns regarding the impact performance of this system in a 90-degree impact, because the ability of the knee braces to control the deformation of the uprights will be reduced. Because the uprights would not be permitted to release from the sleeves, the uprights may deform around the front end of the impacting vehicle and permit undesirable damage to the windshield and roof. Such behavior may be overcome through the use of a larger, stronger perforated tube for the uprights.

Dual Steel-Upright Sign Support with Knee Braces, 7 ft MH PROPOSED

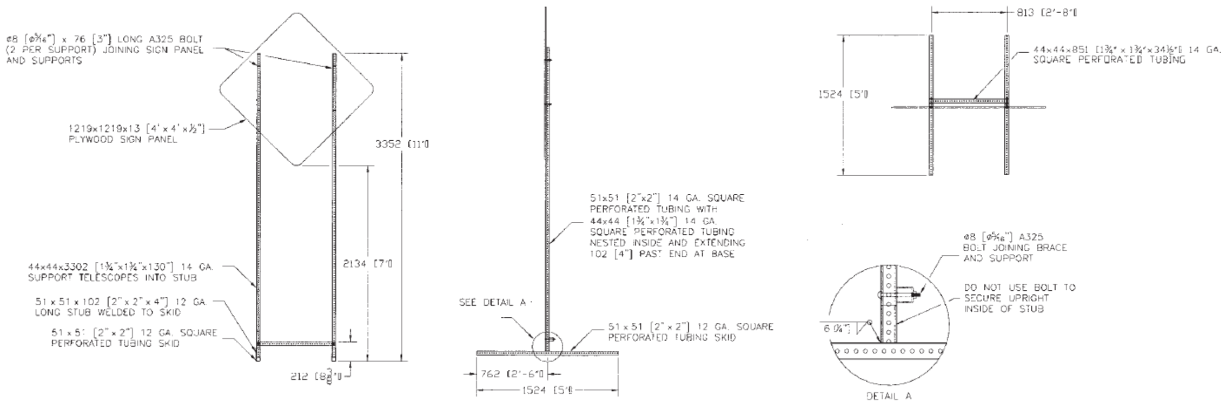


Dual Nested Uprights, 7 ft MH PROPOSED

Reference: R.P. Bligh, W.L. Menges, and R.R. Haug. "Crashworthy Work-Zone Traffic Control Devices," National Cooperative Highway Research Program Report 553, Transportation Research Board, Washington, D.C., 2006. [Test Proposed].

Another means of increasing the flexural strength of the uprights to reduce deformation during impact is to nest smaller sections of perforated steel tubing inside slightly larger tubing to form a composite section. In the design shown in Figure 8.6, a 44 mm (13⁄4-inch) square, perforated steel tube is nested inside a 51 mm (2-inch) square tube. To maintain the slip connection without using a third size of tubing for the sleeves and skids, the nested uprights are bolted together in a manner that leaves a 102 mm (4-inch) portion of the 44 mm (13⁄4-inch) square inner tube extended past the end of the outer tube. This extended portion is inserted into a 51 mm (2-inch) square, 102 mm (4-inch) long sleeve that is welded to a 51 mm (2-inch) square, perforated steel-tube skid. When finalizing the designs of high-mounting-height systems for consideration by the panel, the researchers learned that a system similar to Design H3 was successfully crash tested for the Michigan DOT (*16*). The successful crash test of the similar system led the panel to not prioritize Design H3 under this study. However, this design is discussed in the report for informational purposes and to make readers aware of the successfully crash-tested sign support system.

Dual Nested Uprights, 7 ft MH PROPOSED



APPENDIX C: CRASH TEST 490022-7-1

C1. VEHICLE INFORMATION

Table C1. Vehicle Properties for Vehicle Used in Test No. 490022-7-1.

Date: 2012-03-12 Test No.: 490022-1 VIN No.: KNADC125736239356

Year: 2003 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 151350 Tire Size: 185/65R14

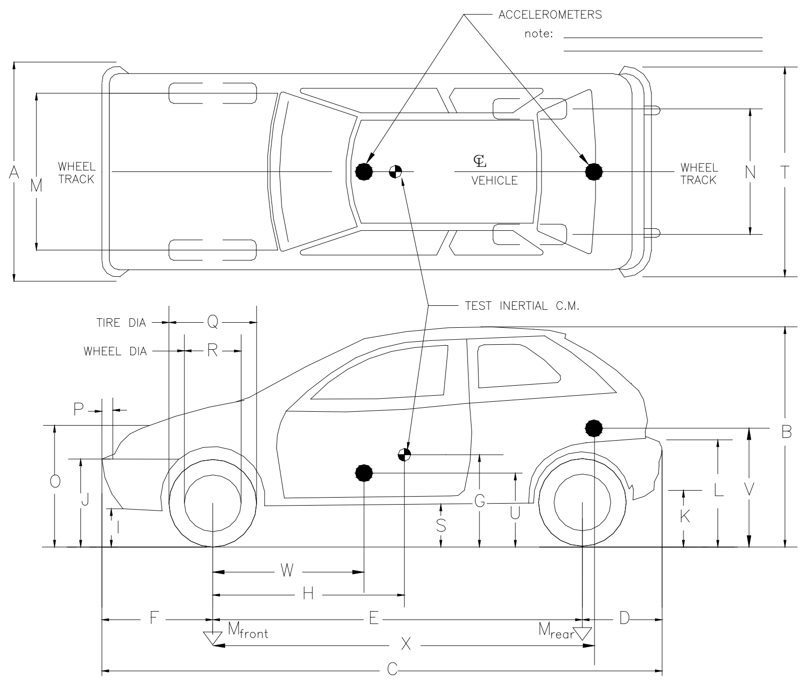
Describe any damage to the vehicle prior to test:

● Denotes accelerometer location.

NOTES:

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

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



Geometry: inches

A	62.50	F	32.00	K	12.00	P	3.25	U	----
B	56.12	G		L	24.25	Q	22.50	V	----
C	164.25	H		M	56.50	R	15.50	W	----
D	32.00	I	8.50	N	57.00	S	8.62	X	----
E	95.25	J	22.75	O	28.00	T	63.00		----

Wheel Center Ht Front 10.75 Wheel Center Ht Rear 11.125

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1691	M_{front}	1540	1490	
Back	1557	M_{rear}	871	935	
Total	3750	M_{Total}	2411	2425	

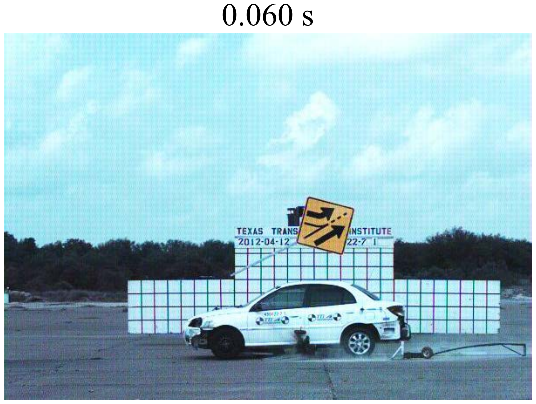
Mass Distribution:
lb LF: 757 RF: 733 LR: 472 RR: 463

C2. SEQUENTIAL PHOTOGRAPHS

0.000 s

0.030 s

0.060 s



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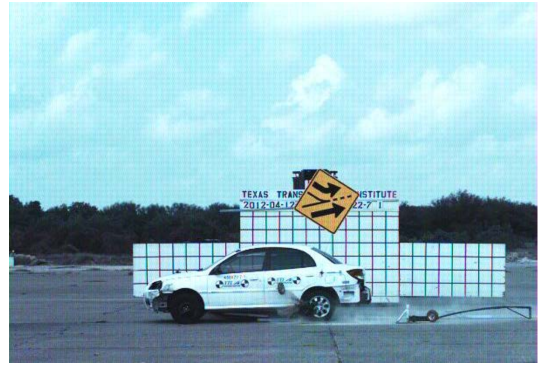

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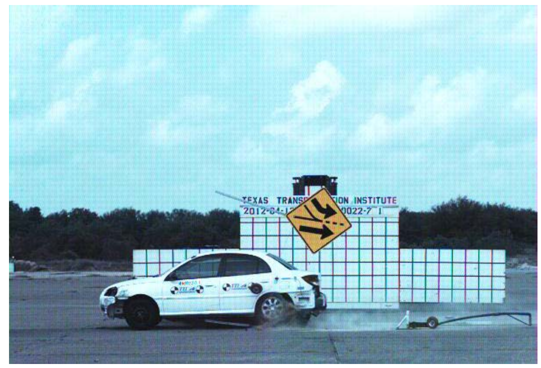

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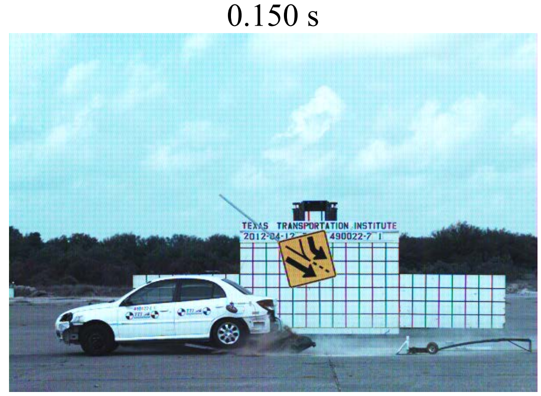

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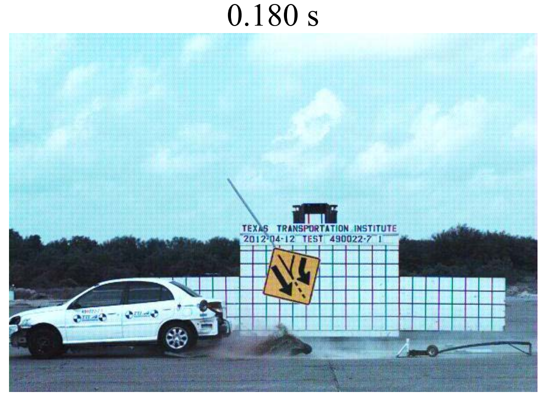


0.210 s

Figure C1. Sequential Photographs for Test No. 490022-7-1 (Perpendicular View).

APPENDIX D: CRASH TEST 490022-7-2

D1. VEHICLE INFORMATION

Table D1. Vehicle Properties for Vehicle Used in Test No. 490022-7-2.

Date: 2012-03-12 Test No.: 490022-2 VIN No.: KNADC125736239356

Year: 2003 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 151350 Tire Size: 185/65R14

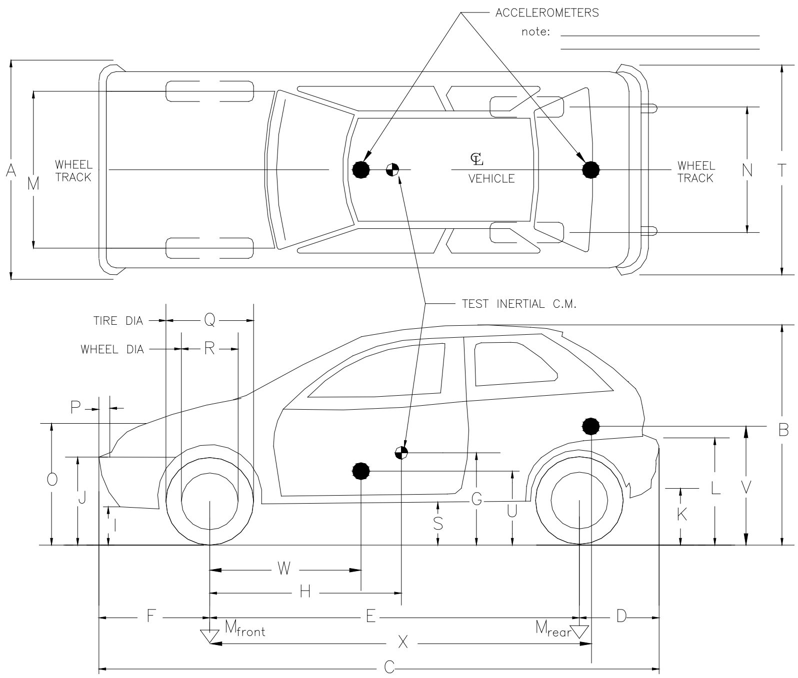
Describe any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

NOTES: ______

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

Dummy Data:
Type: No dummy used
Mass: ______
Seat Position: ______



Geometry: inches

A	62.50	F	32.00	K	12.00	P	3.25	U	----
B	56.12	G		L	24.25	Q	22.50	V	----
C	164.25	H		M	56.50	R	15.50	W	----
D	32.00	I	8.50	N	57.00	S	8.62	X	----
E	95.25	J	22.75	O	28.00	T	63.00		----

Wheel Center Ht Front 10.75 Wheel Center Ht Rear 11.125

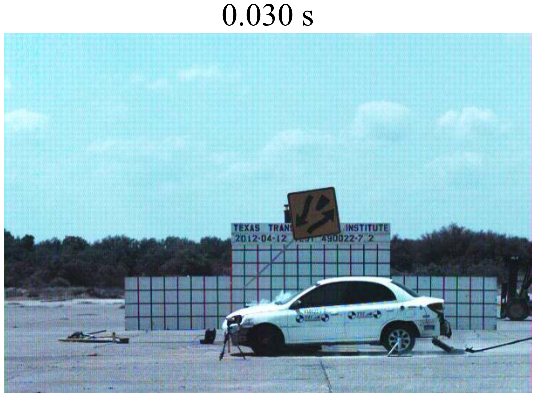
GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1691	M_{front}	1540	1490	
Back	1557	M_{rear}	871	935	
Total	3750	M_{Total}	2411	2425	

Mass Distribution:
lb LF: 757 RF: 733 LR: 472 RR: 463

D2. SEQUENTIAL PHOTOGRAPHS

0.000 s

0.030 s



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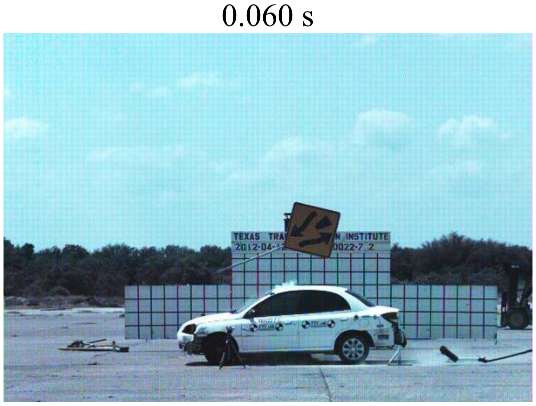

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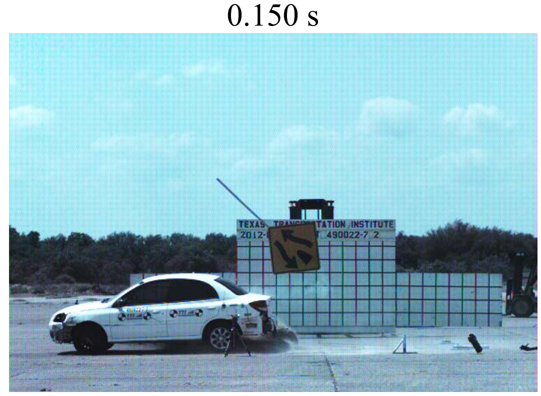

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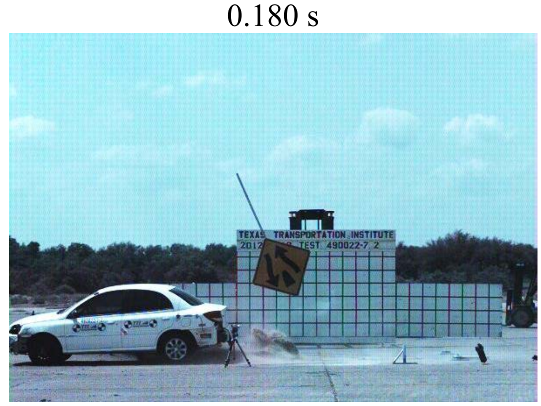


0.210 s

Figure D1. Sequential Photographs for Test No. 490022-7-2 (Perpendicular View).

APPENDIX E: CRASH TEST 490022-7-3

E1. VEHICLE INFORMATION

Table E1. Vehicle Properties for Vehicle Used in Test No. 490022-7-3.

Date: 2012-03-12 Test No.: 490022-3 VIN No.: KNADC125736239356

Year: 2003 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 151350 Tire Size: 185/65R14

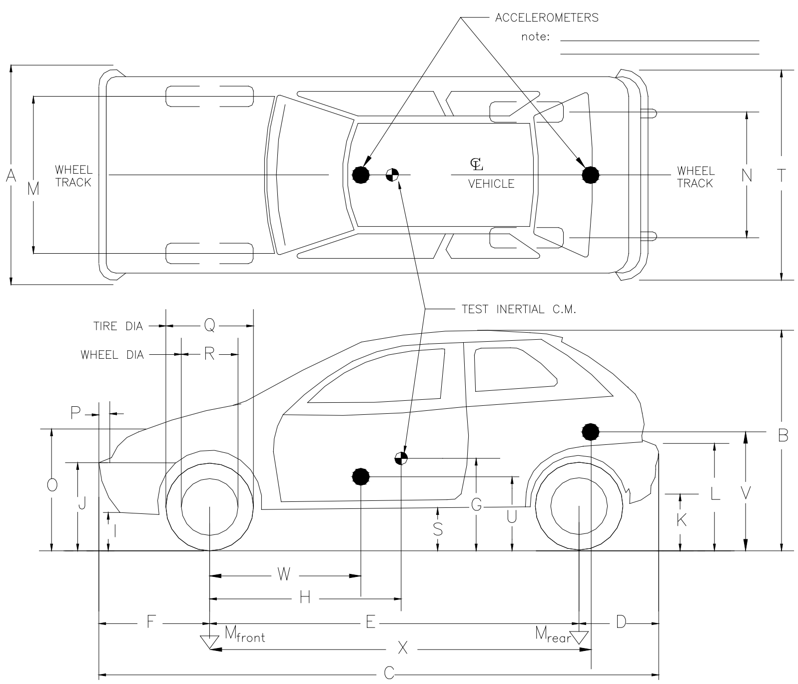
Describe any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

NOTES: ______

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

Dummy Data:
Type: No dummy used
Mass: ______
Seat Position: ______



Geometry: inches

A	62.50	F	32.00	K	12.00	P	3.25	U	----
B	56.12	G		L	24.25	Q	22.50	V	----
C	164.25	H		M	56.50	R	15.50	W	----
D	32.00	I	8.50	N	57.00	S	8.62	X	----
E	95.25	J	22.75	O	28.00	T	63.00		----

Wheel Center Ht Front 10.75 Wheel Center Ht Rear 11.125

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1691	M_{front}	1540	1490	
Back	1557	M_{rear}	871	935	
Total	3750	M_{Total}	2411	2425	

Mass Distribution:
lb LF: 757 RF: 733 LR: 472 RR: 463

E2. SEQUENTIAL PHOTOGRAPHS

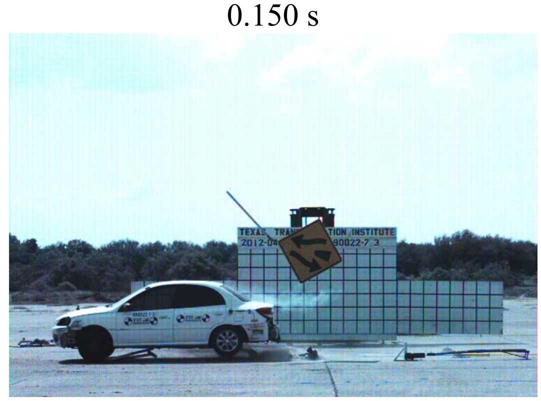
0.000 s

0.120 s

0.030 s

0.150 s

0.060 s



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0.090 s

0.210 s

Figure E1. Sequential Photographs for Test No. 490022-7-3 (Perpendicular View).

APPENDIX F: CRASH TEST 490022-7-4

F1. VEHICLE INFORMATION

Table F1. Vehicle Properties for Vehicle Used in Test No. 490022-7-4.

Date: 2012-05-09 Test No.: 490022-7-4 VIN No.: 1D7HA18N265568145

Year: 2006 Make: Kia Model: Rio

Tire Size: P265/70R17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 164337

Note any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

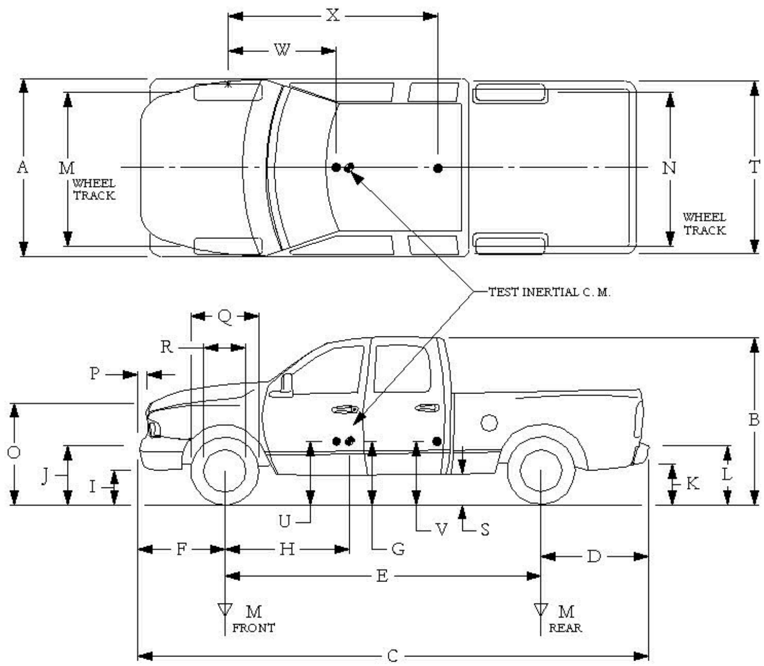
NOTES: ______

Engine Type: V-8
Engine CID: 4.7 liter

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

Optional Equipment: ______

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



Geometry: inches

A	78.25	F	36.00	K	20.50	P	2.88	U	28.50
B	75.00	G	28.06	L	29.12	Q	31.25	V	29.50
C	223.75	H	60.65	M	68.50	R	18.38	W	60.50
D	47.25	I	13.75	N	68.00	S	12.00	X	101.00
E	140.50	J	25.38	O	44.50	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	5.00	Bottom Frame Height - Front	17.125
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	10.25	Bottom Frame Height - Rear	24.75

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2797	2870	
Back	3900	M_{rear}	1995	2180	
Total	6700	M_{Total}	4792	5050	

Mass Distribution:
lb LF: 1440 RF: 1430 LR: 1090 RR: 1090

Table F2. Measurements of Vehicle Vertical CG for Test No. 490022-7-4.

Date: 2012-05-09 Test No.: 490022-7-4 VIN: 1D7HA18N265568145

Year: 2006 Make: Dodge Model: Ram 1500

Body Style: Quad Cab Mileage: 164337

Engine: 4.7 liter Transmission: Automatic

Fuel Level: Empty Ballast: 180 lbs at front of bed (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: P265/70R17

Measured Vehicle Weights: (lb)

LF:	1440	RF:	1430	Front Axle:	2870
LR:	1090	RR:	1090	Rear Axle:	2180
Left:	2530	Right:	2520	Total:	5050
					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

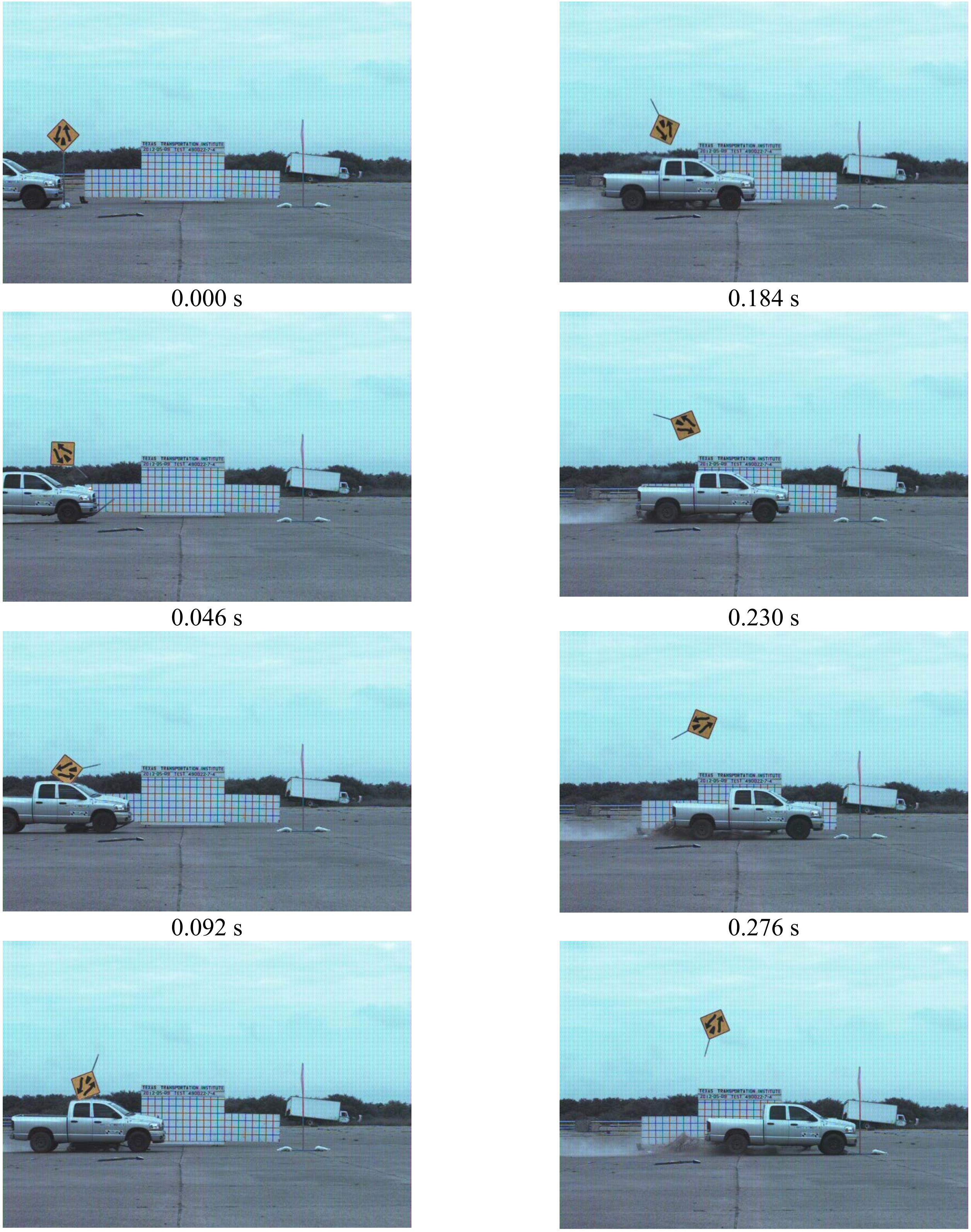
X:	60.65	in	Rear of Front Axle	(63 ±4 inches allowed)
Y:	-0.07	in	Left - Right +	of Vehicle Centerline
Z:	28.0625	in	Above Ground	(minumum 28.0 inches allowed)

Hood Height: 44.50 inches (43 ±4 inches allowed) Front Bumper Height: 25.375 inches

Front Overhang: 36.00 inches (39 ±3 inches allowed) Rear Bumper Height: 29.125 inches

Overall Length: 23.75 inches (237 ±13 inches allowed)

F2. SEQUENTIAL PHOTOGRAPHS



0.000 s

0.184 s

0.046 s

0.230 s

0.092 s

0.276 s

0.138 s

0.322 s

Figure F1. Sequential Photographs for Test No. 490022-7-4/90-Degree Impact (Perpendicular View).

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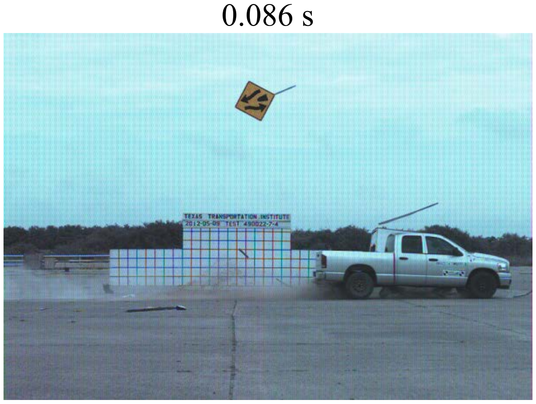
0.043 s

0.086 s



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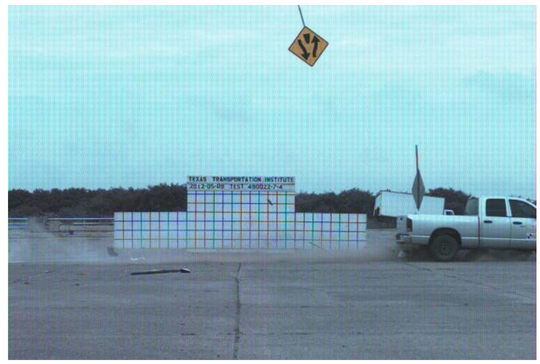
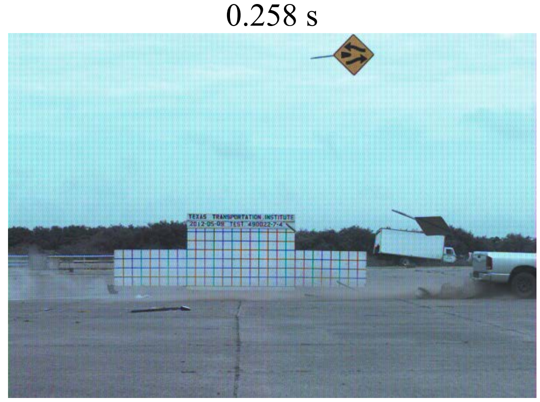
0.172 s



0.215 s

0.258 s



0.301 s

Figure F2. Sequential Photographs for Test No. 490022-7-4/0-Degree Impact (Perpendicular View).