TESTING AND EVALUATION OF LARGE SIGNS SLIPBASE SUPPORT ON SLOPE AT MASH TEST LEVEL 3 IMPACT CONDITIONS

A Thesis

by

SARVESH GOEL

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Chair of Committee,	Stefan Hurlebaus
Committee Members,	Arash Noshadravan
	Jeffrey Falzarano
	Chiara Silvestri Dobrovolny
Head of Department,	Robin Autenrieth

August 2020

Major Subject: Civil Engineering

ABSTRACT

Breakaway support in large signs slipbase system is designed to lessen the impact on a vehicle if struck and thereby minimize injury to occupants and damage to vehicles. Several research studies are conducted related to breakaway devices but most of them are tested on flat level ground. In most of the states in the United States, it is common practice to install large signs in ditches along the highway. It is not known how the breakaway system will perform under the impact on sloped terrain. For this type of system, the mounting height of the post is greater than the system mounted on flat level ground. Certain other factors such as the geometry of the slope and encroachment speed and angle also influence the trajectory of the vehicle on traversing the slope.

In this research, a poll was conducted for the Department of Transportation agencies to identify the most common design details of the sign support breakaway devices to be considered for further investigation. Engineering and finite element analysis were performed to investigate the crashworthiness performance of the considered system. The research also investigated the practical and utilized installation conditions for large breakaway sign support on sloped terrain and will determine the most critical characteristics within the envelope of conditions. A full-scale crash test was conducted on the flat-level ground according to Manual for Assessing Safety Hardware Test Level 3 guidelines. As an extension of the research project, multiple other full-scale crash tests will be conducted, and the sign support system will be modified and validated based on the computer impact simulation and full-scale crash test results.

ACKNOWLEDGMENTS

I would like to thank my committee chair Dr. Stefan Hurlebaus, and my committee members, Dr. Arash Noshadravan from Zachry Department of Civil and Environmental Engineering and Dr. Jeffrey Falzarano from Department of Ocean Engineering, for their support and guidance throughout my work. Additionally, I would also like to thank my supervisor and special committee member, Dr. Chiara Silvestri Dobrovolny, for her continuous support since the beginning of this project. I also would like to thank Mr. Nauman Sheikh from Texas A&M Transportation Institute and Mr. Derwood Sheppard from the Florida Department of Transportation, for their valuable assistance and input on this project. Finally, I also want to thank my colleagues at Texas A&M Transportation Institute at RELLIS Campus and my family members for their constant support and help.

Finite element portions of this research were conducted with high-performance research computing resources provided by Texas A&M University (https://hprc.tamu.edu).

CONTRIBUTORS AND FUNDING SOURCES

This work was supervised by my committee chair Dr. Stefan Hurlebaus from the Zachry Department of Civil and Environmental Engineering and my committee members Dr. Arash Noshadravan of the Zachry Department of Civil and Environmental Engineering and Professor Dr. Jeffrey Falzarano of the Department of Ocean Engineering. On a daily basis, my work was supervised by Dr. Chiara Silvestri Dobrovolny from Texas A&M Transportation Institute.

The full-scale crash test was conducted and implemented by Texas A&M Transportation Institute Proving Ground, and the detailed design of the test in the same section was supported by Engineers and drafters at Texas A&M Transportation Institute-Roadside Safety Division.

All other work conducted for the thesis was completed by the student independently.

This work was made possible in part by the Roadside Safety Pooled Fund program organized by the Washington State Department of Transportation and especially due to the constant support from the Florida Department of Transportation.

Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Roadside Safety Pooled Fund Committee.

NOMENCLATURE

AALA	American Association for Laboratory Accreditation
AASHTO	American Association of State Highway & Transportation Official
BI	Bumper Impact
CG	Center of Gravity
CIP	Critical Impact Point
COE	Center of Excellence
DBC	Discrete Based Clamping
DOT	Department of Transportation
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
FHWA	Federal Highway Administration
ft	Feet
H	Horizontal
Hz	Hertz
in.	Inch
ISI	Institute for Scientific Information
ISO	International Standards Organization
lb	Pound
MASH	Manual for Assessing Safety Hardware
MDOT	Michigan Department of Transportation

MHTD	Missouri Highway and Transportation Department
mph	Miles per Hour
ms	Millisecond
NCHRP	National Cooperative Highway Research Program
NHS	National Highway System
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
OIV	Occupant Impact Velocity
ORA	Occupant Ridedown Acceleration
s	Seconds
SAE	Society of Automotive Engineers
SBC	Stress Based Clamping
TDAS	Tiny Data Acquisition System
TL	Test Level
TRAP	Test Risk Assessment Program
TRB	Transportation Research Board
TRID	Transportation Research Information Service Database
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
V	Vertical

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1. INTRODUCTION

1.1. Problem Statement

The underlying philosophy of the Manual for Assessing Safety Hardware (MASH) by the American Association of State Highway and Transportation Officials (AASHTO) in the development of the testing guidelines is that of "worst practical conditions." Crash testing is conducted under idealized conditions so that impact performance can be evaluated and compared under controlled situations. While MASH requires testing roadside safety hardware on flat level ground conditions, variations in field installation characteristics can materially affect the performance of some roadside safety features. This can be of particular relevance for breakaway structures (i.e., large and small signs) installed on slopes.

Breakaway support is designed to lessen the impact on a vehicle if struck and thereby minimize injury to occupants and damage to vehicles. It is unknown how a breakaway mechanism might perform under impacts that happen on sloped terrain rather than on the flat level ground. Some of the questions that are left unknown are whether the release mechanism of the breakaway structure might be affected by the different installation geometry and by the resulting impact vehicle dynamics. Also, it is unknown whether the post-impact behavior and trajectory of the test article due to the installation on a sloped terrain might result in a potential increase for occupant risk and unacceptable vehicle damage. This research project includes: (a) assess crashworthiness of a large breakaway sign support per MASH Test Level 3 (TL-3) conditions on flat level ground, (b) investigate the most practical and utilized installation conditions for large breakaway sign support on sloped terrain, (c) determine the most critical characteristics within this envelope of conditions, and (d) assess crashworthiness of the large breakaway sign support in combination with sloped installation conditions.

It is anticipated that a negative slope should be considered within this study. The information compiled from this research will provide the Federal Highway Administration (FHWA) and state Department of Transportation (DOT) Agencies with a first understanding of how a large sign slipbase breakaway support structure reacts to impact events when installing on a given slope under MASH TL-3 impact conditions. Outcomes from this research and testing study will support implementation guidelines review for large slipbase breakaway support structures on roadside slopes.

1.2. Background and Motivation

The 2016 MASH edition is the latest in a series of documents that guided testing and evaluation of roadside safety features (AASHTO, 2016). The original MASH document was published in 2009 and represents a comprehensive update to crash test and evaluation procedures to reflect changes in the vehicle fleet, operating conditions, and roadside safety knowledge and technology (AASHTO, 2009). The MASH documents supersede the National Cooperative Highway Research Program (NCHRP) Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features" standards (Ross et al., 1993).

The FHWA issued a memo on January 7th, 2016, mandating the AASHTO/FHWA Joint Implementation Agreement for MASH with compliance dates for installing MASH hardware that differs by hardware category. After December 31st, 2019, all roadside safety devices must have been successfully tested and evaluated according to the 2016 MASH standard edition. The FHWA will no longer issue eligibility letters for highway safety hardware that has not been successfully crash tested according to the 2016 MASH edition evaluation criteria. At a minimum, all barriers on high-speed roadways on the National Highway System (NHS) are required to meet TL-3 requirements.

The structural adequacy for sign support systems consists of three tests for MASH TL-3 conditions. It consists of a 2420-lb passenger car (denoted 1100C) impacting the barrier at 62 and 19 mph and 0 degrees with respect to the roadway and 5000-lb pickup truck (denoted 2270P) impacting a system at 62 mph and 0 degrees with respect to the roadway.

MASH was developed to incorporate significant changes and additions to procedures for safety-performance evaluation, and updates reflecting the changing character of the highway network and the vehicles using it. For example, MASH increased the weight of the pickup truck design test vehicle from 4409 lb to 5000 lb, changed the body style from a 0.75-ton, standard cab to a 0.5 ton, 4 doors, and imposed a minimum height for the vertical center of gravity of 28 in. The increase in vehicle mass represents an increase in impact severity of approximately 13 percent for TL-3 with the pickup truck design test vehicle with respect to the impact conditions of NCHRP Report 350. The increased impact severity may, therefore, result in increased impact forces and larger lateral barrier deflections compared to NCHRP Report 350.

MASH also adopted more quantitative and stringent evaluation criteria for occupant compartment deformation than NCHRP Report 350. An increase in impact severity might result in increased vehicle deformation and could fail in meeting the latest MASH evaluation criteria. For example, NCHRP Report 350 established a 6 in. threshold for occupant compartment deformation or intrusion. MASH, by comparison, limited the extent of roof crush to no more than 4 in. Also, MASH requires that the vehicle windshield would not sustain a deformation greater than 3 in. and would not have holes or tears in the safety lining as a result of the test impact. Although these evaluation criteria apply to all roadside safety devices testing, they are most relevant for sign supports design and testing. In addition, little evaluation of sign supports has been performed with larger vehicles such as the pickup. Systems that have been demonstrated to be crashworthy for passenger cars may not be geometrically compatible with pickup trucks.

Once a sign support system is installed on a slope, the local mounting height of the sign (calculated from ground level at the location of installation) will be greater than that for the same system installed on flat level ground. For a general installation of a sign support system on a slope at an offset distance “x” from the slope breakpoint, the depth “y” of the slope at the particular installation location contributes to an increase in the length of the support post and local mounting height of the sign (Figure 1).

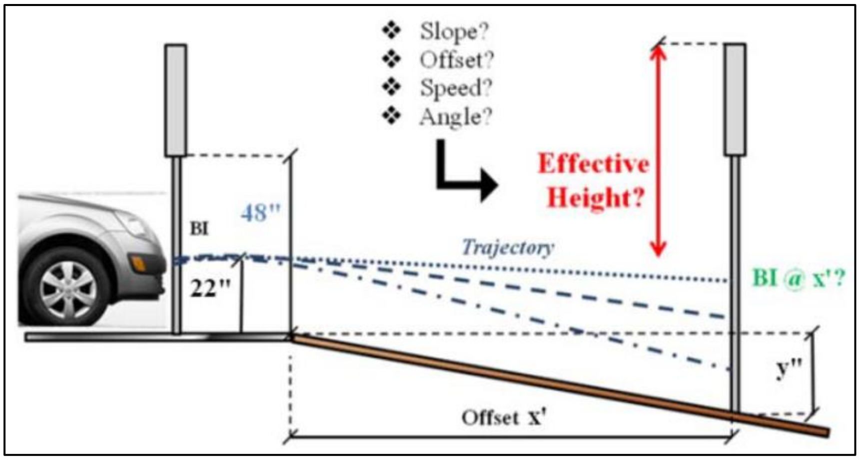


Figure 1. Effective Pole Height Variation for Sign Support Installation on Slope (Reprinted from Silvestri et al., 2013)

An additional consideration related to sign installations on slopes is related to the actual vehicle bumper impact location on the sign support. When an errant vehicle enters a roadside slope, certain factors influence its trajectory. These factors include the geometry of the slope, the encroachment speed, and the encroachment angle at which the vehicle enters the slope.

The bumper trajectory and offset distance of the support installation from the slope breakpoint determine the height of bumper contact above the local ground elevation. Consequently, the effective height of the post above the bumper can vary.

1.3. Benefits of Research

The information compiled from this research will provide the FHWA and State DOTs with a first understanding of how a large sign slipbase breakaway support structure reacts to impact events when installing on a given slope under existing MASH TL-3 impact conditions for flat-level ground. Outcomes from this research can be used to develop testing guidelines for breakaway devices installed on a slope. A better understanding of how they will behave will also help with any potential device or design modifications in large sign slipbase breakaway support structures reducing the risk of injury and injury severity.

2. PREVIOUS WORK AND LITERATURE REVIEW

2.1. Introduction

This section presents the overall review of what has been accomplished in the field of breakaway devices and especially in the slipbase support systems. The literature review is distributed into four different parts. The first part presents the development of crash testing criteria used for testing different test articles. The second part consists of a review of present MASH guidelines. The third part includes a review of breakaway devices and slipbase supports and the fourth part includes a review of the finite element method (FEM) used for evaluating roadside hardware.

The researcher developed a synthesis of relevant information by reviewing the research literature and state DOTs and local agency documents regarding large signs slipbase support systems. The synthesis consists of a literature review to obtain the best available knowledge on different topics. Bearing in mind the objective of the research, only articles related to breakaway devices and slipbase support systems were considered.

2.2. Crash Testing Criteria

NCHRP Report 153 "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances" (Bronstad & Michie, 1974) was published in 1974. This document recommends details of the testing criteria required for evaluating roadside appurtenances (yielding or breakaway supports for luminaires and signs) guardrails, terminals and transitions, median barriers, longitudinal barriers. Evaluation methods, data collection methods, and data reporting formats were also included in this report. The appraisal factors considered for the testing are: (a) impact severity (b) structural adequacy, and (c) vehicle trajectory hazard. The data procurement systems and performance evaluation were also detailed. These evaluation criteria gained wide acceptance throughout the United States following the publication, but it was predictable at the same time that regular updating of the report would be needed.

Published in 1978, Transportation Research Circular 191 “Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances” (Transportation Research Circular 191, 1978) provided changes to NCHRP 153 report. It includes minor changes requiring improved treatment of specific problem areas. These procedures are representations of technical input from more than 70 research individuals and agencies. It was expected that the "Procedures" will be revised again, expanded and republished by 1980 by a follow-up NCHRP project. This time, it was expected that the scope will be broadened to include testing with buses and trucks also. In 1981 another extensive revision and the update was carried out with the publication of the NCHRP Report 230 “Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances” (Michie, 1981). In 1993, TTI researchers published an NCHRP report 350 “Recommended Procedures for the Safety Performance Evaluation of Highway Features” (Ross et al., 1993) under the NCHRP project 22-7. This report included a detailed update to evaluation procedures and crash tests. It incorporated important changes and add-ons to the procedure for safety-performance assessment, and other updates reflecting the shifting character of the highway system and the different types of vehicles using it.

Another NCHRP project 22-14 “Improvement of Procedures for the Safety-Performance Evaluation of Roadside Features” (AASHTO, 2009) was carried out to update NCHRP Report 350. This research was conducted to incorporate important changes and add-ons to procedures for safety performance assessment, including principles for various performance levels, procedures, strategies for testing features not addressed earlier and translating the earlier documents to the metric system. In 2016, AASHTO again published an updated edition of the MASH (AASHTO, 2016). Figure 2 shows the development of crash testing criteria.

Figure 2. Development of Crash Testing Criteria

The FHWA again issued a memo in 2016 mandating the FHWA/AASHTO Joint Implementation Agreement for MASH compliance dates for installing MASH hardware that differs by hardware category. The FHWA will stop issuing eligibility letters for highway safety hardware that has not been successfully crash tested according to the 2016 MASH edition evaluation criteria.

2.3. Manual for Assessing Safety Hardware

The purpose of MASH is to provide guidelines for the actual crash test of both temporary and permanent highway structures such as barriers, support structures, crash cushions, terminals, etc. It also provides evaluation criteria to evaluate the test results. These guidelines and criteria incorporate the latest technology used in the field of roadside safety and also includes the expertise and judgment of professionals in this field. The main objective of any highway safety feature is to minimize the risk of an accident when a vehicle exits the roadway accidentally. The main goal is to redirect the vehicle, readily breaking of breakaway devices, allowing controlled penetration in a vehicle without causing any injury to vehicle occupants, work zone personnel, and other motorists.

Ideally, the roadside should be clear of any obstruction so that the driver can control the vehicle and return to the travel way. Though, many roadside features can't be removed. For these sites, appropriate safety treatment or feature is needed to minimize the risk of a departure from travel way.

According to MASH any new safety feature or revision to any existing design should be evaluated first through full-scale crash testing. Once it meets the required impact guidelines then the feature evaluations can be switched to in-service evaluation.

The test parameters such as impact speed, impact angle, and test vehicle should be for most critical or worst conditions. For example, the matrix of impact speed and angle represent almost ninety-two percentile of crashes worldwide. It is assumed that if any roadside feature is tested for any two extreme situations, then the feature will automatically work for all conditions in between. Another fundamental philosophy used for special features such as breakaway sign and luminaire support is the “state-of-the-possible”. This is done to make the evaluation criteria more stringent than other safety features.

The impact performance of any safety features cannot be measured only by crash testing. The safety feature should perform satisfactorily under real-world conditions as crash testing is necessary but not sufficient for all scenarios. Firstly, crash testing is conducted under ideal conditions. Secondly, there are performance limits in any device dictated by vehicle stability, physical laws, and vehicle crashworthiness.

The impact conditions (angle and speed of the vehicle) and the type of vehicle (from small passenger to large tractor tank trailer) define the test level for any safety feature. The longitudinal barrier can be tested up to six test levels while the other devices can be tested up to three test levels. The levels 1-3 are limited to passenger car and pickup truck whereas levels 4-6 consists of some forms of heavy vehicles also. The features on urban streets or local roads consist of tests with low speed and low volume whereas the features on freeway consist of tests with high speed and high volume.

All support structures such as luminaire, signs, breakaway utility poles, mailbox supports, etc. include vertical support which can be an obstacle for vehicles. The breakaway mechanism usually used with luminaire and signs includes mechanical fuse plates which require a minimum amount of kinetic energy for activation. The MASH guidelines include low-speed tests to evaluate these types of systems. To access the occupant impact factors such as compartment intrusions, vehicle instability, and excessive deceleration, high-speed tests are conducted. Table 1 illustrates the recommended tests as per MASH guidelines for support structures.

As per MASH guidelines, a critical impact angle should be determined for all tests performed. It should denote the worst-case scenario which is consistent with the manner in which the test article is positioned on the roadway. Testing can be conducted between 0 to 25 degrees, depending on the worst-case scenario. In the case of multiple CIA's, it can be judged based on the highest potential of test failure.

For single leg supports the center of the test article should be aligned with the quarter-point of the impacting vehicle. In multiple support systems such as dual or triple leg sign support systems, the impacting vehicle should engage a maximum number of leg supports.

As shown in Table 1 three full-scale crash tests are recommended for support structures. Two of these tests include high-speed tests with car and pickup truck to identify the prospective of support structure intrusion into vehicle. The slow speed test is conducted to evaluate the support structure's activation energy. The impact conditions for support structures are shown in Figure 3. The different evaluation guidelines are shown in Table 2.

Table 1. MASH Recommended Test Levels for Support Structures

Test Level	Test No.	Vehicle	Impact Speed (mph)	Impact Angle (Degree)	Acceptable KE Range kip-ft	Impact Point	Evaluation Criteria
1	1-60	1100C	19	CIA	≤34	(c)	B, D, F, H, I, N
	1-61	1100C	31	CIA	≥72	(c)	B, D, F, H, I, N
	1-62	2270P	31	CIA	≥148	(c)	B, D, F, H, I, N
2	2-60	1100C	19	CIA	≤34	(c)	B, D, F, H, I, N
	2-61	1100C	44	CIA	≥141	(c)	B, D, F, H, I, N
	2-62	2270P	44	CIA	≥291	(c)	B, D, F, H, I, N
3	3-60	1100C	19	CIA	≤34	(c)	B, D, F, H, I, N
	3-61	1100C	62	CIA	≥288	(c)	B, D, F, H, I, N
	3-62	2270P	62	CIA	≥594	(c)	B, D, F, H, I, N

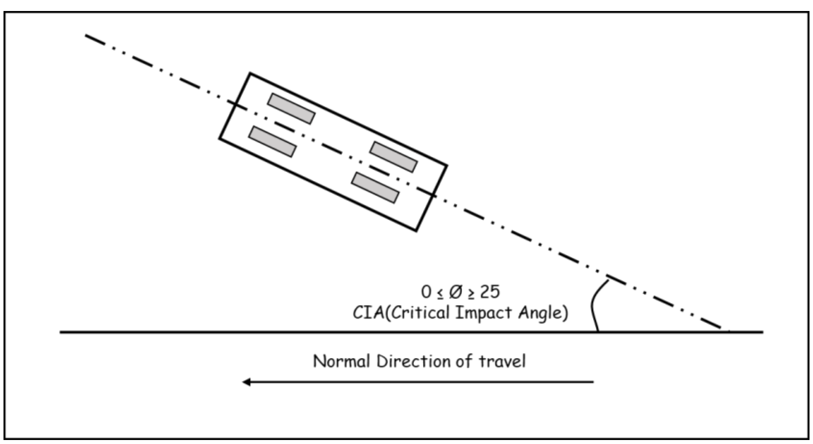


Figure 3. Impact Angle for Support Structures

Table 2. Safety Evaluation Guidelines (MASH, 2016)

<table>
<tr><th>Evaluation Criteria Code</th><th>Evaluation Factors</th><th>Evaluation Criteria</th></tr>
<tr><td>B</td><td>Structural Adequacy</td><td>The test article should readily activate predictably by breaking away, fracturing, or yielding.</td></tr>
<tr><td>D</td><td rowspan="2">Occupant Risk</td><td>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, pedestrian, or personnel in the work zone.
Deformation of, or intrusion into, the occupant compartment should not exceed the maximum limits.</td></tr>
<tr><td>F</td><td>The vehicle should remain upright during and after the collision. The maximum roll and pitch are not to exceed 75 degrees.</td></tr>
<tr><td>H</td><td rowspan="2">Occupant Risk</td><td>Occupant Impact Velocities (OIV) should satisfy the following limits:
<table><tr><th colspan="3">Occupant Impact Velocity Limits</th></tr><tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr><tr><td>Longitudinal</td><td>10 ft/s</td><td>16 ft/s</td></tr></table></td></tr>
<tr><td>I</td><td>The occupant ride down acceleration should satisfy the following limits:
<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr><tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr><tr><td>Longitudinal and Lateral</td><td>15 G</td><td>20.49 G</td></tr></table></td></tr>
<tr><td>N</td><td>Vehicle Trajectory</td><td>The vehicle trajectory behind the test article is acceptable.</td></tr>
</table>

2.4. Breakaway Devices and Slipbase Supports

The slipbase mechanism is used to support the small and large signs as well as luminaries and other roadside devices. These devices are designed to break away from the base on impact. It reduces the severity of occupant injury and impact resistance. The design of any roadside device should meet the requirements of the MASH report for crash safety criteria. Roadside devices can pose a serious safety threat to vehicles. Devices located on the roadside possess as a potential impact point for motorists. Effective and efficient breakaway systems are necessary for roadside signs and other devices to aim for the highest level of highway safety.

According to a report on “Break-away Components Produce Safer Roadside Signs” by Olson et al. (1967), in any highway design, roadside devices are employed in heavy numbers due to increased length of the state and interstate highways. According to the researchers, in 1962 there were 15 fatalities in Texas due to roadside sign accidents and this number increased to 39 by 1965. To study the impact behavior and reduce the number of accidents due to roadside devices, the Texas Department of Transportation (TxDOT) and TTI, in cooperation with the U.S. Bureau of Public Roads became actively involved. A large length of roads was under construction in Texas, there was an urgent requirement of the better design of roadside devices. Many designs were proposed by engineers of the TxDOT which were incorporated in experiments conducted. New procedures were developed to conduct control of vehicles with roadside devices. Mathematical simulations were also developed to correlate the dynamic behavior with the actual crash test results.

The research primarily involved the development of sign systems for large roadside signs. The spacing between posts in large signs was such that it involves any one of the supports during the collision of the test article with a vehicle. The three major characteristics of the sign support contributing to the severity of the collision are a.) Type of base connection, b.) Structural stiffness or rigidity and c.) The severity of a collision. Initially, special attention was given to brace leg structure as shown in Figure 4. A total of three tests were conducted, two of them included a fractured joint also known as a safety feature. The unbraced support system which will flip and break off under the impact was selected for the study. Breakaway base connection gave satisfactory results but further modifications were provided in the fractured joint to allow the colliding vehicle to pass under the post. After many modifications, the "hinge joint" (Figure 5) worked. In "hinge joint", the front flange and the web of the post were cut leaving the back flange intact. In the tests conducted it was seen that the minor damage was incurred by the vehicle during the impact. The selection of the angle for this research was based on the previous study by Stonex (1960) which indicated that more than 95 percent of vehicles exit the roadway at a 15-degree angle. "Reverse tow" procedure was selected to accelerate the vehicle into the test article for this experiment. In this procedure, the impact vehicle and the tow vehicle move in the opposite direction. A vehicle release mechanism was used to separate the cable between the impact vehicle and the tow vehicle before the impact.

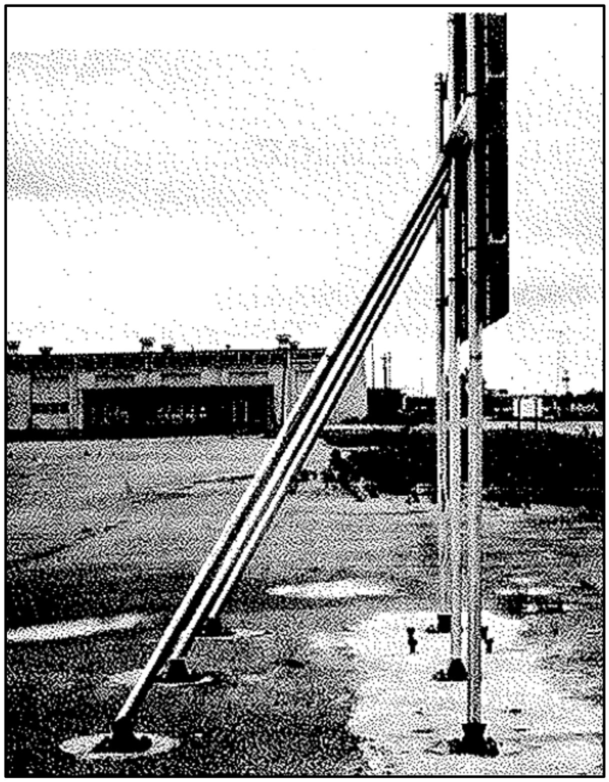


Figure 4. Braced-leg Sign Support Structure (Reprinted from Olson et al., 1967)

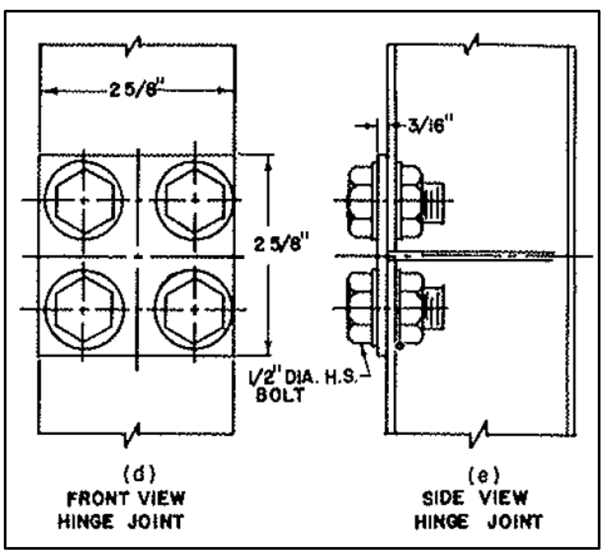


Figure 5. Hinge Joint of the Sign Support System (Reprinted from Olson et al., 1967)

Sometimes small signs are used with small post spacing. In small signs, the vehicle can collide with multiple legs of the sign. These signs are employed where the possibility of collision is very high like in the gore of exit ramp. In the first test conducted, mechanical failure occurred due to which the vehicle struck the left leg of the sign near the center of the hood. In the second test conducted, the sign supports failed at the base plate. Figure 6 shows the base plate failure. Later, same safety features such as slip base system were employed in small sign systems which were already used in large sign systems. According to the tests conducted, at 50 mph the horizontal base plates hit the trunk of the vehicle, and at 20 mph, sign hit the top of the vehicle. Figure 7 shows the impact behavior of sign at 50 mph and 20 mph. changing the angle of impact also did not make much difference.

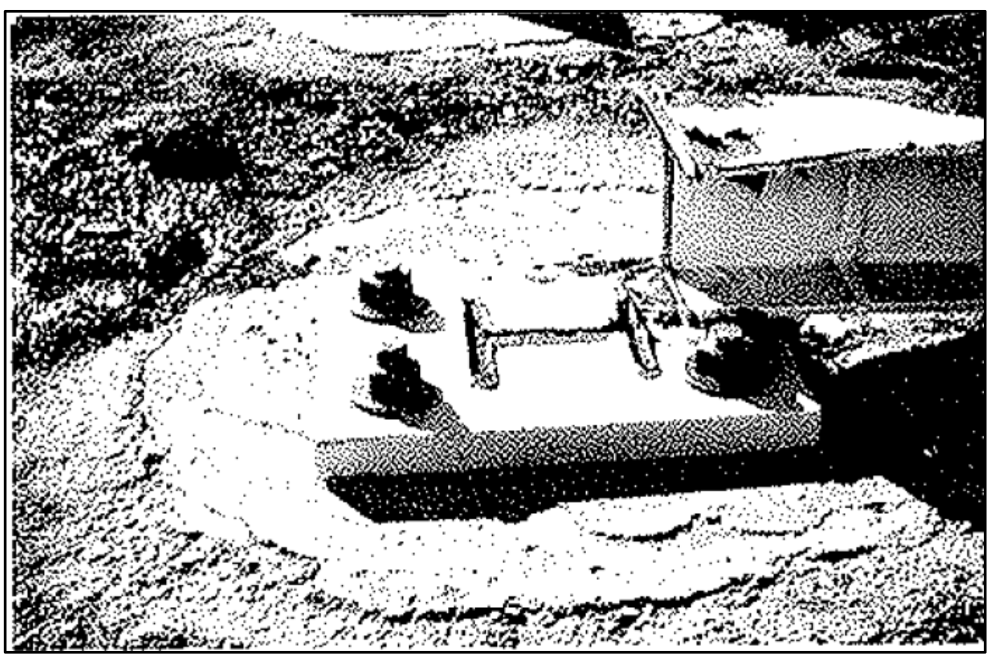


Figure 6. Base Plate Failure Due to Welding (Reprinted from Olson et al., 1967)

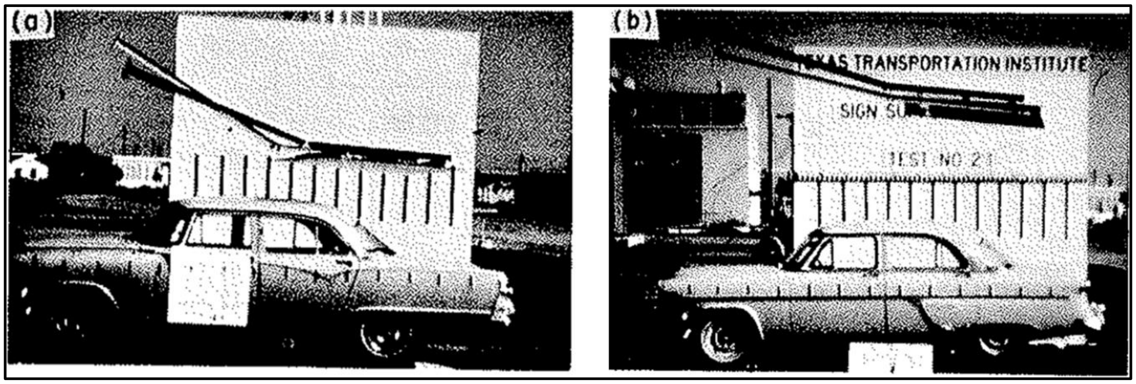


Figure 7. Impact Behavior of the Sign Support System (Reprinted from Olson et al., 1967)

Similar tests were also conducted with pipe supports for regulatory, warning, and small guide signs. A breakaway system was used for the pipe supports which was used in two-leg supports. At 45 mph the pipe support system worked properly, and only minor damage was occurred in the vehicle due to impact. However, the fractured joint did not work properly due to which secondary damage occurred. To avoid the secondary damage the system was rotated by 20 degrees. After modification, there were only minor damages that occurred to the front of the vehicle. It was seen that in large signs, that dual-pipe supports performed satisfactorily wherever needed.

Pennsylvania State used wood posts with notches as signposts to reduce the potential hazard (Wood Break-Away Posts Provide Additional Safety for Motorists, 1965). The accidents report shown satisfactory impact behavior. But the report did not say anything about phenomenological behavior. TTI conducted a controlled experiment on the Pennsylvania design and the design created by TTI. In design modified by TTI, a 2 in. oblong hole was created below the bumper level to reduce the shear capacity at the base.

During the impact test of Pennsylvania design, the top of the vehicle was struck by the slipped post deforming the top approximately. 2 to 5 in. However, in TTI design both the posts were thrown clear of the vehicle, rotating over its top. Figure 8 shows the Pennsylvania design and the design modified by TTI and Figure 9 shows the behavior of both the designs after impact.

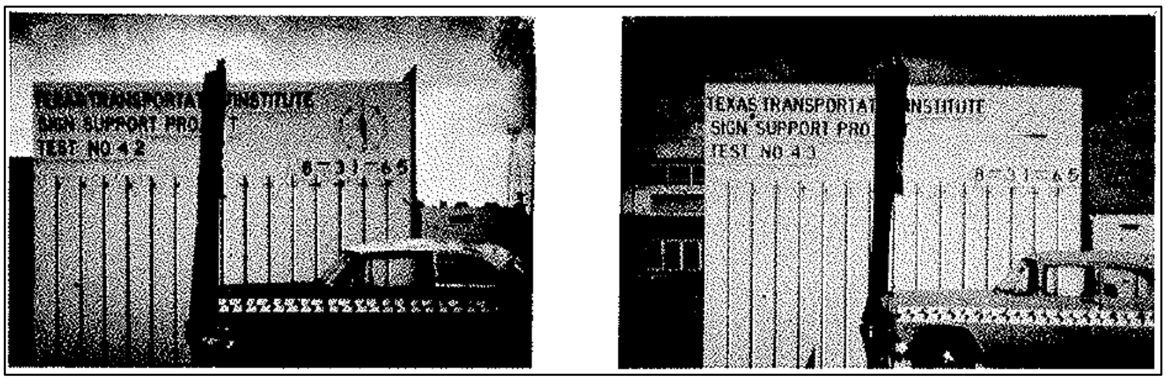


Figure 8. Impact Behavior of Pennsylvania and TTI Design (Reprinted from Olson et al., 1967)

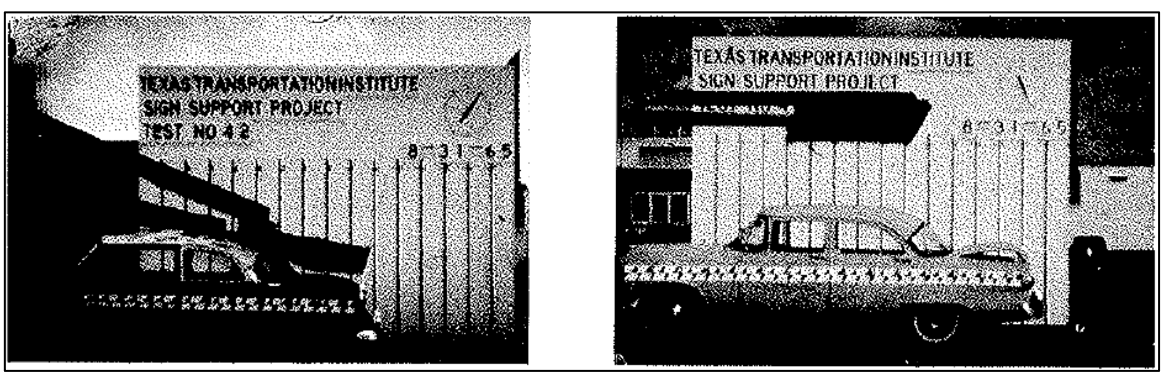


Figure 9. After the Impact Behavior of Pennsylvania and TTI design (Reprinted from Olson et al., 1967)

According to a report by the Michigan Department of Transportation (MDOT) (Steve & Till, 2006), during a storm on November 14, 2004, a breakaway light falls onto the highway striking a vehicle. The state police observed the incident and reported that light post failed due to high wind conditions. In a meeting held at MDOT, it was decided that all statewide breakaway lights will be inspected immediately. From the reports, it was confirmed that approximately 61 percent of breakaway light standards were in good condition. 36 percent of the light standard requires corrective action and the remaining 3 percent require removal action. It was observed that the possible cause of the failure can be a.) Movement in anchor bolts due to flexible bolt sizes on the steel screw-in foundation, b.) Not using the anchor clips in the breakaway transformer base c.) Improper installation of a non-improved breakaway transformer base. After a proper inspection, it was assured by MDOT that in future a proper margin of safety will be taken for calculating wind loads and proper measures will be taken for installation.

In 2011, researchers at TTI conducted a study on “Development Guidance for Sign Design Standards” (Silvestri et al., 2011). According to researchers the design practice used by TxDOT for small and large mounting details was established decades back. Due to changes in materials, production methods, and installation methods these details may not be appropriate. Through several research studies earlier, TxDOT brought all sign mounting detail standards into compliance with NCHRP-350. Under NCHRP project 22-14, a new document entitled “MASH” was published by AASHTO. This document superseded NCHRP report-350 with new guidelines such as updated test matrices, updated impact conditions, and updated design of test vehicles. For breakaway systems, MASH recommended three tests, one at low speed with 2420-lb passenger car and two tests at high speed with a 2420-lb passenger car and 5000-lb pickup truck. A detailed description of the tests is shown in Table 3. The evaluation criteria in MASH were more stringent than NCHRP-350. Some of the relevant evaluation criteria related to breakaway sign supports are 1.) Roof deformation should be less than 3.9 in. 2.) Windshield deformation should be less than 3 in. 3.) There should be no tears or holes in the windshield. Assessment of existing breakaway sign systems was performed and based on the comprehensive review it was determined whether there is a need to update or set new policies and standards related to existing breakaway sign systems. This research included multiple tasks such as comparison of wind loads, review of current standards for large guide signs, optimization of fuse plate, analysis of u-brackets, etc.

Table 3. MASH Test Description for Sign Support System (Reprinted from Silvestri et al., 2011)

Test	Vehicle	Speed	Angle
MASH Test 3-60	1100C (2425 lb/1100 Kg)	19 mph	Judged according to the conditions.
MASH Test 3-61	1100C (2425 lb/1100 Kg)	62 mph	
MASH Test 3-62	2270P (5000 lb/2270 Kg)	62 mph	

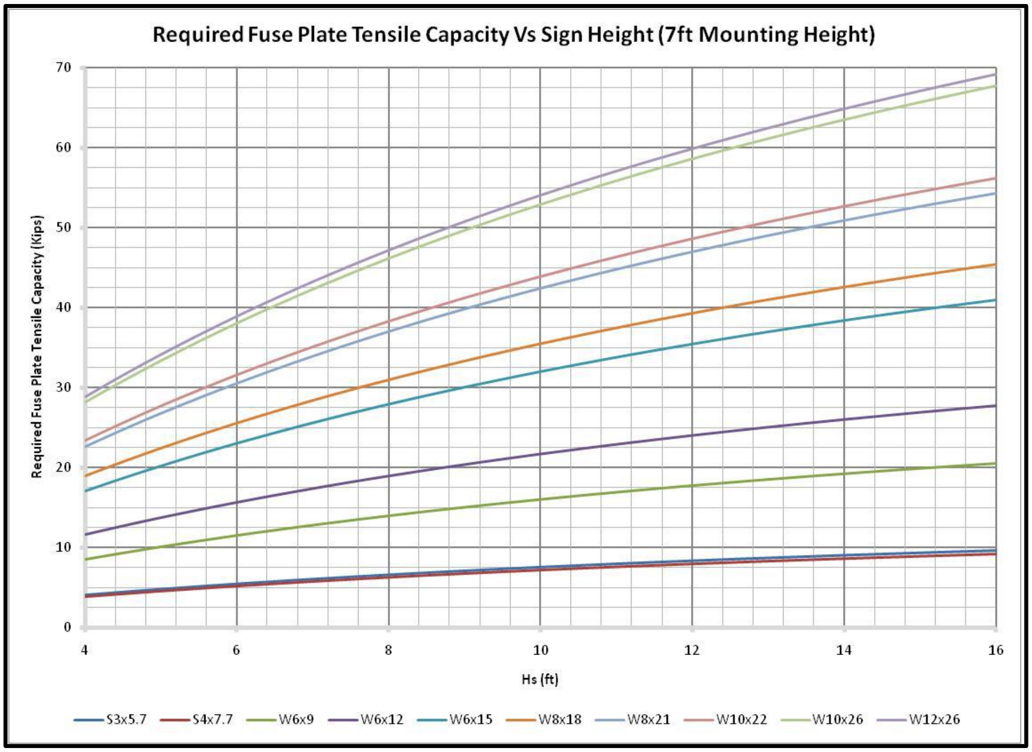


Figure 10. Minimum Fuse Plate Capacity (Reprinted from Silvestri et al., 2011)

Researchers performed an in-depth study to optimize the fuse plate capacities for large guide signs. The team recommended that the design of fuse may be optimized further to allow more effective use of standard support sections. To facilitate the recommendation, the fuse plate capacity for wind loading was plotted (Figure 10) for the mounting height of 7 ft. for different post sections. The system will be designated as inefficient if the fuse plate will control the maximum sign area instead of the post section. To overcome this issue, maximum fuse plate capacity was calculated based on the graph and according to that, the most optimum fuse plate was selected. The testing procedure performed was confirmed with the testing procedure according to MASH. A different test installation was selected for fabrication and testing. The small cars were more critical than pickup if the fuse plates fail as it was designed. Two impact conditions were selected for crash testing. The first system (Figure 11) provided high stiffness to a 10-ft wide panel and the second system (Figure 12) was selected to provide the weak system so that the fuse plate can fail before the post starts to yield or buckle.

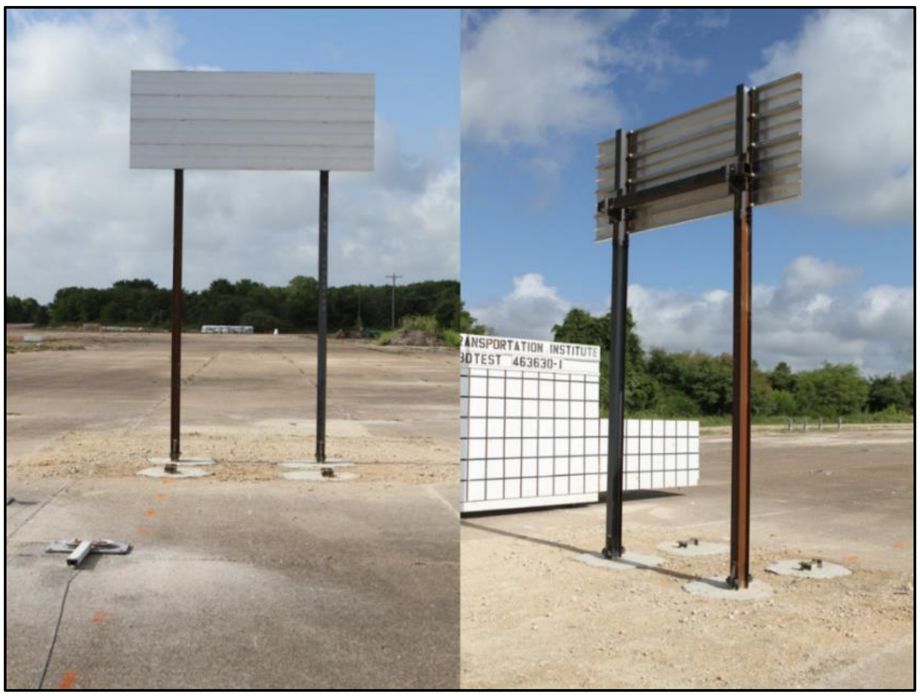


Figure 11. TxDOT W6x9 – 4-ft x 10ft Large Sign Support System (Reprinted from Silvestri et al., 2011)

Figure 12. TxDOT W8x18 – 16-ft x 10-ft Large Sign Support System (Reprinted from Silvestri et al., 2011)

The crash test performed was evaluated based on three major factors: occupant risk, structural adequacy, and post-impact vehicle trajectory. The slipbase and the upper hinge of both the test articles were readily activated when impacted by the small car at high speed. Occupant risk factors and other conditions were within limits specified by MASH. The detailed matrix of the test results is shown in Table 4 and

Table 5. It was seen that in both the test articles meet all assessment criteria defined in MASH and therefore considered crashworthy. TxDOT determined that there will be problems associated with transiting to new optimized fuse plates from the existing hinge plates used. Therefore, TxDOT updated the wind load charts with the setup already in use rather than using the optimized fused plate configuration.

Table 4. Detailed Test Assessment of TxDOT W6x9 – 4-ft x 10ft Large Sign Support System. (Reprinted from Silvestri et al., 2011)

MASH Test 3-61 Evaluation Criteria	*Test Results*	*Assessment*
Structural Adequacy B. *The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.*	When impacted by the 1100C vehicle, the W6×9 4 ft × 10-ft large sign support activated by breaking away at the slipbase and at the upper hinge connections.	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	The left support leg and sign panel separated from the installation. However, the 1100C vehicle traveled beneath these elements, which came to rest near impact. The elements did not penetrate or show potential for penetrating the occupant compartment, nor present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation occurred during the test with the 1100C vehicle.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were −1 degree for both.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 10 ft/s, or at least below the maximum allowable value of 16.4 ft/s.*	Longitudinal occupant impact velocity was 2.3 ft/s, and lateral occupant compartment impact velocity was 1.0 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Longitudinal ridedown acceleration was −0.3 G, and lateral ridedown acceleration was −0.3 G.	Pass
Vehicle Trajectory N. *Vehicle trajectory behind the test article is acceptable.*	The 1100C vehicle came to rest 525 ft toward the field side of the sign support	Pass

Table 5. Detailed Test Assessment of TxDOT W8x18 16-ft x 10ft Large Sign Support System (Reprinted from Silvestri et al., 2011)

MASH Test 3-61 Evaluation Criteria	*Test Results*	*Assessment*
Structural Adequacy B. *The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.*	When impacted by the 1100C vehicle, the W8×18 – 16-ft × 10-ft large sign support activated by breaking away at the slipbase and at the upper hinge connections.	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	The left support leg separated from the installation. However, the 1100C vehicle traveled beneath these elements, which came to rest near impact. The elements did not penetrate or show potential for penetrating the occupant compartment, nor present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	No occupant compartment deformation occurred during the test with the 1100C vehicle.	Pass
F. *The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.*	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were −5 degrees and −2 degrees.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 10 ft/s, or at least below the maximum allowable value of 16.4 ft/s.*	Longitudinal impact velocity was 4.6 ft/s, and lateral occupant impact velocity was 1.3 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Longitudinal ridedown acceleration was −1.0 G, and lateral ridedown acceleration was 0.5 G.	Pass
Vehicle Trajectory N. *Vehicle trajectory behind the test article is acceptable.*	The 1100C vehicle came to rest 212 ft behind the sign support installation.	Pass

Temporary large sign systems with embedded steel and wood post configuration were designed by researchers at TTI in the study "Temporary Large Guide Signs" (Bligh et al., 2013) for TxDOT. The designed systems were crash-tested per MASH guidelines. The impact performance, foundation requirement, and wind loads were considered in the design process. It was seen that conventional concrete foundations are time-consuming and costly to install. Different types of large signs were used along highway roadside in Texas including logo sign, destination signs, advance exit signs, etc. The standard work zone sign “Give us a break” has an area of 128 square feet. According to TxDOT personnel, work zone signs are the best sign configuration for the study because they are relocated most during the construction.

Based on the review of earlier research, researchers found that two 6 in. x 8 in. posts with 4 in. weakening holes and three 4 in. x 6 in. posts with 2 in. weakening holes have more potential for meeting MASH requirements. Detailed analysis as shown in Table 6 was performed to find the reasonable support configuration for specific wind speed.

Table 6. Sign Support Requirement Analysis (Reprinted from Bligh et al., 2013)

Wind Velocity	Sign Mounting Height	Post Size	Max Hole Size	Number of Posts	Minimum Post Spacing	Number of Posts Impacted
(mph)	(feet)	(in)	(in)		(feet)	
90	10	4x6	2.39	5	3.2	2,3
		6x8	5.26	3	5.33	2
	7	4x6	2.58	4	4	2
		6x8	4.31	2	8	1
100	10	4x6	1.98	6	2.67	3
		6x8	3.91	3	5.33	2
	7	4x6	2.7	5	3.2	2,3
		6x8	5.39	3	5.33	2

According to researchers, it was necessary to weaken the signposts just below the sign panel to allow the release of a single post in multiple support systems during impact. To weaken the post, researchers selected the option to provide holes of 3.625 in. along the weak axis approximately 4 in. below the sign panel. The test was performed with an 8 ft. tall and 16 ft. wide sign panel supported by 6 in. x 8 in. yellow pine wood supports. The detailed description of the setup is shown in Figure 13. MASH test 3-60 was performed with an impact speed of 19 mph and an impact angle of 0 degrees. It was seen that after the impact, the left support was fractured at the hole near the ground level, the middle leg was fractured at the hole near the ground level and near the hole just below sign panel. The right leg was intact, and the sign panel was detached from the right leg and before coming to the rest it contacted the roof of the vehicle.

Figure 14 shows the damage to the signpost system. The maximum passenger compartment deformation was 3.5 in., which was less than maximum allowable deformation according to MASH. The associated occupant risk factors observed from the accelerometer were also below the limits.

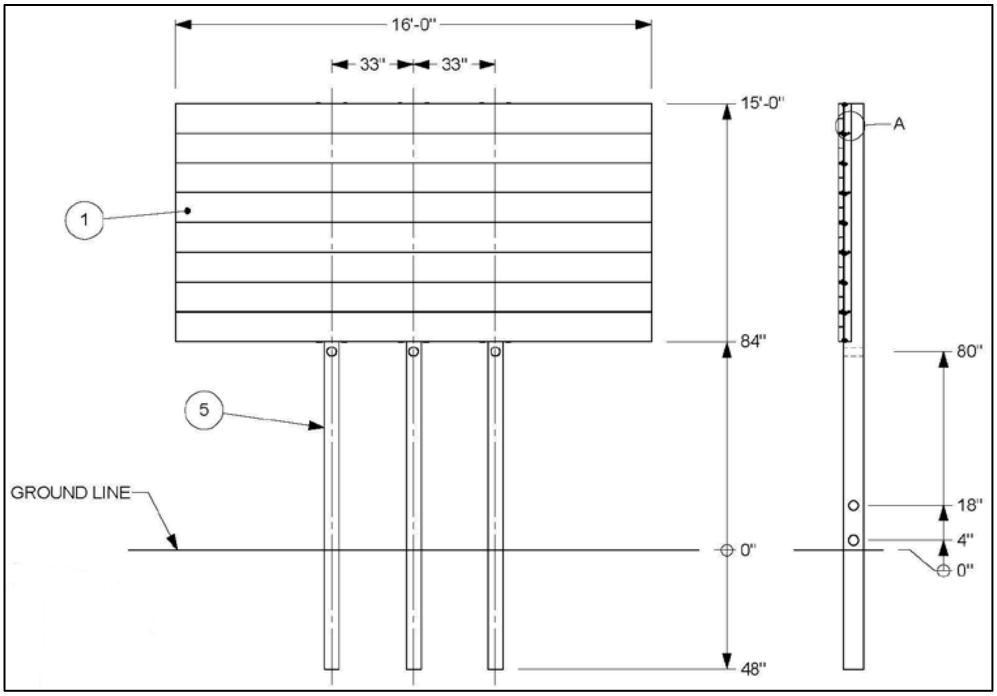


Figure 13. Direct Embedded Wood Support Temporary Guide Sign System (Reprinted from Bligh et al., 2013)


Figure 14. Wood Post Sign Support System After the Test (Reprinted from Bligh et al., 2013)

The same test article was also impacted by a passenger car at 62 mph and a 0-degree impact angle. It was seen that the windshield of the vehicle was penetrated with the fractured section of the post. Figure 15 illustrates the damage sustained by the impact vehicle. The test article fails the evaluation according to MASH criteria. Modified versions were developed by TTI researchers to overcome this problem. The modified test article consisted of two tests: a high-speed small car test and a high-speed pickup test. Both the tests passed the MASH evaluation criteria.

Figure 15. Vehicle After the Test at High Speed (Reprinted from Bligh et al., 2013)

For steel embedded design, 8 ft. x 16 ft. aluminum sign panel supported by two W6X9 posts at a 7 ft. mounting height was tested. The foundation of the system was like the size of support and was embedded at 3.5 ft. below ground. The detailed test article is shown in Figure 16. The car was traveling at the speed of 19 mph and the right support was impacted at 0 degrees. It was seen that the lower connection in the right support was slipped away and the upper connection was still hinged. In the left support, the lower connection was intact, but the support twisted by 80 degrees. As the vehicle traveled, the slip base of the system caught on the hood and the support galloped the front of the vehicle. However, there were no tears or holes in the windshield and the deformation was less than the maximum limits defined by MASH. As summarized in Table 7, direct embedded modified wood supports, and the direct embedded steel supports met all applicable MASH criteria.

Figure 16. Direct Embedded Steel Support System (Reprinted from Bligh et al., 2013)

Table 7. Summary of Modified Wood and Steel Support System (Reprinted from Bligh et al., 2013)

System	Test Type	Evaluation Criteria	Assessment
Direct Embedded Wood Support	MASH Test 3-60	Structural Adequacy	Pass
		Occupant Risk	Pass
		Vehicle Trajectory	Pass
	MASH Test 3-61	Structural Adequacy	Pass
		Occupant Risk	Fail
		Vehicle Trajectory	Pass
	MASH Test 3-61	Structural Adequacy	Pass

Modified Direct Embedded Wood Support		Occupant Risk	Pass
		Vehicle Trajectory	Pass
	MASH Test 3-62	Structural Adequacy	Pass
		Occupant Risk	Pass
		Vehicle Trajectory	Pass
Direct Embedded Steel Support	MASH Test 3-60	Structural Adequacy	Pass
		Occupant Risk	Pass
		Vehicle Trajectory	Pass

In 2013, researchers at TTI performed a study “MASH Full-Scale Crash Testing of 4-ft Mounting Height, 24"×30" Chevron Sign Installed on 5.5 H: 1 V Slope Ditch” (Silvestri et al., 2013) on the installation of Chevron signs in roadside ditches. Commonly in the state of Texas, chevron signs are installed in roadside ditches. For this type of installation, the required height of the signs is measured from the pavement surface. The mounting height of the sign installed in ditches is greater than the sign installed on the flat level ground. As shown in Figure 17, the depth “y” of the ditch leads to an increase in the mounting height of the sign panel and the height of the support post. The vehicle trajectory is also influenced by certain factors like encroachment speed and the angle at which the vehicle arrives the ditch and the geometry of the ditch. The Bumper Impact (BI) location on the sign pole depends on the above factors and the offset distance “x”.

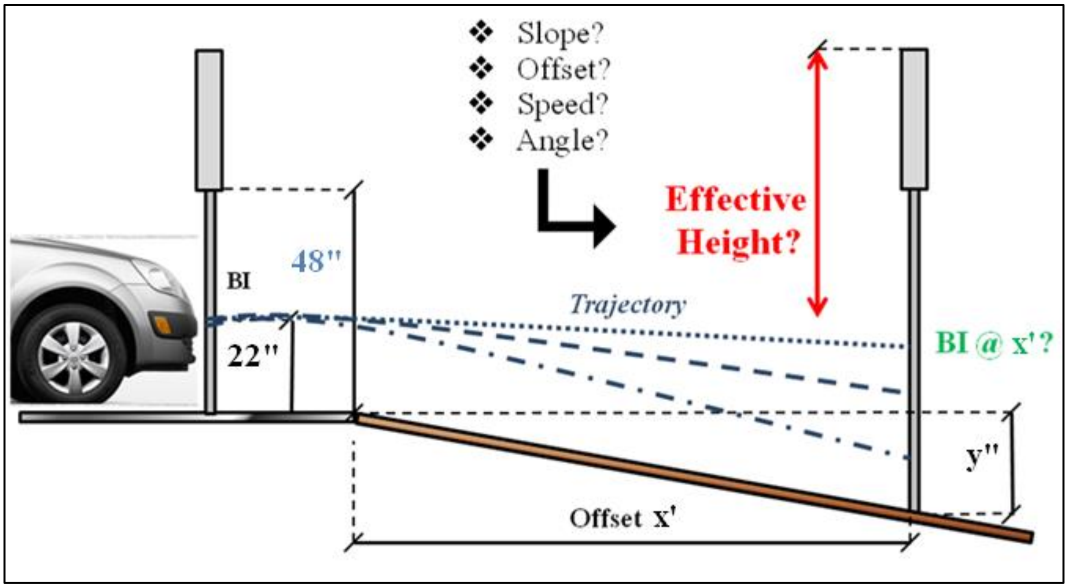


Figure 17. Effective Height Variation in Ditches (Reprinted from Silvestri et al., 2013)

For determining bumper trajectories, researchers performed trajectory analysis using CarSim by Mechanical Simulation (Mechanical Simulation Corporation, 1996) for 6H: 1V slope at different speeds (40 mph and 60 mph) and angles (5-degrees, 10-degrees, 25-degrees). Lateral offsets of signpost were between 2 ft. and 8 ft. based on the Texas standards. The vehicle entering the trajectory at 62 mph with an angle of 10 degrees was selected as a worst-case scenario based on the performed analysis in CarSim. For the full-scale crash test, the 5.5H: 1V slope ditch was used as it was more conservative and there are more chances that Chevron may impact the windshield of the vehicle. The research team concluded that high-speed small car is more critical than low speed for further evaluation. According to the researcher, high speed will result in more deformation of the support compared to the low-speed test. The need for the MASH Test 3-62 with a pickup truck was based on the results of MASH Test 3-61. It was seen that the sign support was not pulled out from the socket and the sign support deformed at ground level and bumper impact location and subsequently fractured near to bumper height.

Figure 18. Vehicle and Test Article for Slope Test (Reprinted from Silvestri et al., 2013)

Figure 18 shows the test article and Figure 19 shows the damage sustained by the vehicle during the impact test. There was no deformation in the windshield and the occupant compartment. Only hood, front bumper, and headlight got damaged. The chevron sign performed according to MASH criteria (Table 8).

Figure 19. Vehicle After the MASH 3-61 Test (Reprinted from Silvestri et al., 2013)

Table 8. Evaluation Summary of the MASH 3-61 Test (Reprinted from Silvestri et al., 2003)

MASH Test 3-61 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 sign support fractured approximately 21 inches above wedge and socket system.	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	The released sign support did not penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	There was no deformation of or intrusion into the occupant compartment.	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. Maximum roll and pitch angles were 13.4 and 3.9 degrees, respectively.	Pass
H. *Longitudinal and lateral occupant impact velocities should fall below the preferred value of 10 ft/s, or at least below the maximum allowable value of 16.4 ft/s.*	Longitudinal occupant impact velocity was 5.9 ft/s, and lateral occupant impact velocity was 0.328 ft/s.	Pass
I. *Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.*	Longitudinal occupant ridedown acceleration was 2.1 G, and lateral occupant ridedown acceleration was 1.1 G.	Pass
Vehicle Trajectory N. *Vehicle trajectory behind the test article is acceptable.*	The 1100C vehicle exited behind the test article.	Pass

2.5. Finite Element Modelling

According to the Transport Research Board (TRB), more than 1 million roadside crashes occur every year in the United States. This problem can be addressed through the development of better roadside safety features. The design of roadside safety devices includes many challenges and requires a detailed investigation of the interaction that occurs in roadside crashes. Crash testing of all roadside systems using vehicles is a very expensive undertaking. The matrix of tests to be conducted sums up to a large number due to the different versions of the vehicles for which safety compliance needs to be checked, the varied variety of devices to be tested, and the different impact conditions that need to be evaluated. Therefore, according to Escandarian et al. (1997) developments in the design of the roadside device's features are only incremental due to the lack of performance measures and comprehensive test data.

According to Ray, 1997 it is not feasible to conduct a full-scale crash test for each impact scenario. Any researcher tests roadside safety devices until the successful design is produced or funding for the research runs out. Analysis before the crash test can help to identify and rectify the major problems before the actual test. Several problems increase the use of analytical methods in roadside safety research. It is not possible to test the article with a full range of vehicle segments. Also, it is impractical to examine the effects due to different test conditions such as driver braking, side impacts, pre-impact trajectories, etc.

The author suggests that the Finite Element Analysis (FEA) can be integrated into a roadside safety assessment in three stages. The first step is to simulate a crash event that has been already tested. This will help to calibrate the FEA model with the system/testing conditions. The second step is to replicate an FE model of the proposed test article to predict the outcome before the actual crash test is conducted. This can be used to identify the most critical scenario. The ultimate and last stage is to use FEA to understand the performance of the new devices. The complete development of roadside safety hardware is shown in Figure 20. It will help researchers to examine crashes that are difficult or expensive to test in real-world conditions. As stated by the author, FEM is being used to solve non-linear dynamics problems since the 1990s. Since the 2000s it has been evolved rapidly as an influential method for executing realistic analysis of dynamically loaded structures.

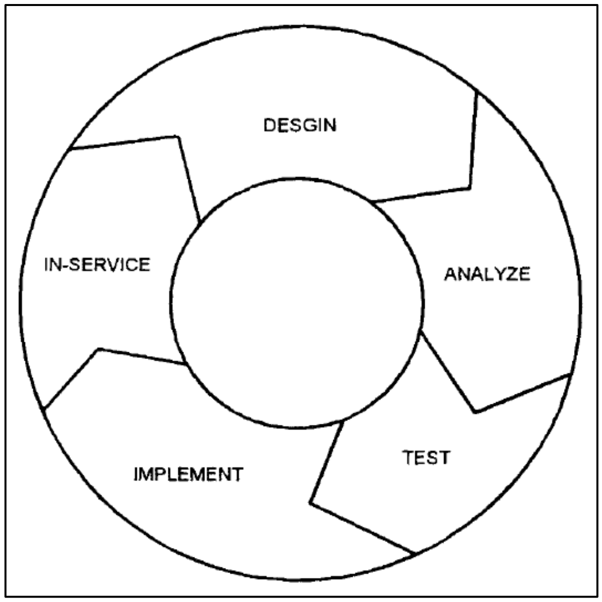


Figure 20. Roadside Safety Hardware Development Cycle (Reprinted from Ray, 1997).

The development of powerful software DYNA3D was started at Lawrence Livemore National Laboratory in the 1970s (Halquist J. O., 1976). The two important agencies National Highway Traffic Safety Administration (NHTSA) and FHWA actively promoted the use of the finite element method for the evaluation and design process of roadside devices (Halquist J., 1995). Generally, any crashworthiness model is created using different connection types, contact algorithms, FE meshes, and various material models. There is a wide range of material models in these programs, it is necessary to develop the exact parameters needed for specific materials used in different roadside devices. Different material properties were recommended by Wright & Ray, (1996) for steel and Plaxico et al., (1998) for soil and wood. In most of the researches, FE models are constructed by designing a roadside safety device and using the vehicle's model from the public domain which is developed elsewhere. It helps the researchers in focusing on designing roadside devices rather than difficult geometry vehicles.

FHWA started a series of research projects in 1994 to promote the development of the FEM for the modeling and analysis of various roadside safety devices (Reid, 2004). LS-Dyna was the first choice for most of the Center of Excellence's (COEs). FHWA funded various projects for this research. Dual-leg breakaway sign system was the first system funded by FHWA in which the leg of sign releases from its slip base and pivot on impact. The most difficult part of this system was to make the base connection "weak" for impact conditions and to make it "strong" for external weather conditions. Various studies conducted in this field depict how the FEM can be used to solve major design problems.

Paulsen & Reid (1996) used the FEM to design dual support breakaway sign systems. According to them, mathematical modeling can be used to develop roadside devices in a timely and cost-effective manner. For their research, the finite element model of the breakaway, sign systems were modeled in LS-DYNA3D, a non-linear finite element program. Different small components were modeled first and were compared with actual physical tests conducted in the past. The complete system model was validated with two actual crash tests. Finally, the finite element model was used to study various modifications and configurations of dual support breakaway sign system.

In another study "Design and Simulation of Large Breakaway Signs" by Reid and Paulsen (1996) breakaway supports are the most common devices used for supporting signs along the roadway. The safety performance of these devices was evaluated using non-linear FEM software. To develop confidence in the FEM, it was critical to develop a good baseline model and to validate the same with different physical tests. For multi-support systems, this test was done with dimensions 96 in. x 120 in. panel fixed to the supports 92 in. above the ground. Results from the actual crash test and finite element analysis are shown in Table 9. The impact sequence of low-speed simulation is shown in Figure 21. Prior research (Reid, 1996) has shown that the fuse plates on large sign systems cannot sustain service wind loads. To overcome the same, multiple designs with varied thicknesses of fuse and hinge plates were evaluated. Sign systems were evaluated using the FEM for safety performance. For the research, Multi-Hazard Threat Database (MHTD) plans were used as close as possible. In the designed finite element models, the bolts were modeled using springs (Paulsen and Reid, 1996). Both the design alternatives were meeting the NCHRP 350 criteria. The researchers recommended that models can be re-evaluated with an improved version of the slip base model for larger wind load capacities.

Table 9. Comparison of Actual Crash Test and Simulation Results (Reprinted from Reid and Paulsen, 1996)

Criteria	Low-Speed Tests		High-Speed Tests	
	Test	Simulation	Test	Simulation
Impact Speed	36 km/h	36 km/h	92 km/h	92 km/h
Impact Angle	25 degree	25 degree	27 degree	27 degree
Vehicle Static Crush	30 mm	50 mm	76 mm	80 mm
Slip base activation time	14 ms	14 ms	6 ms	6.5 ms
Gap develops in web of post	20 ms	19 ms	4 ms	4.5 ms
Fuse Plate Failure	240 ms	250 ms	10 ms	11 ms
Ridedown Acceleration	N/A	N/A	N/A	N/A
Occupant Impact Velocity	1.1 m/s	1.2 m/s	0.9 m/s	1.0 m/s

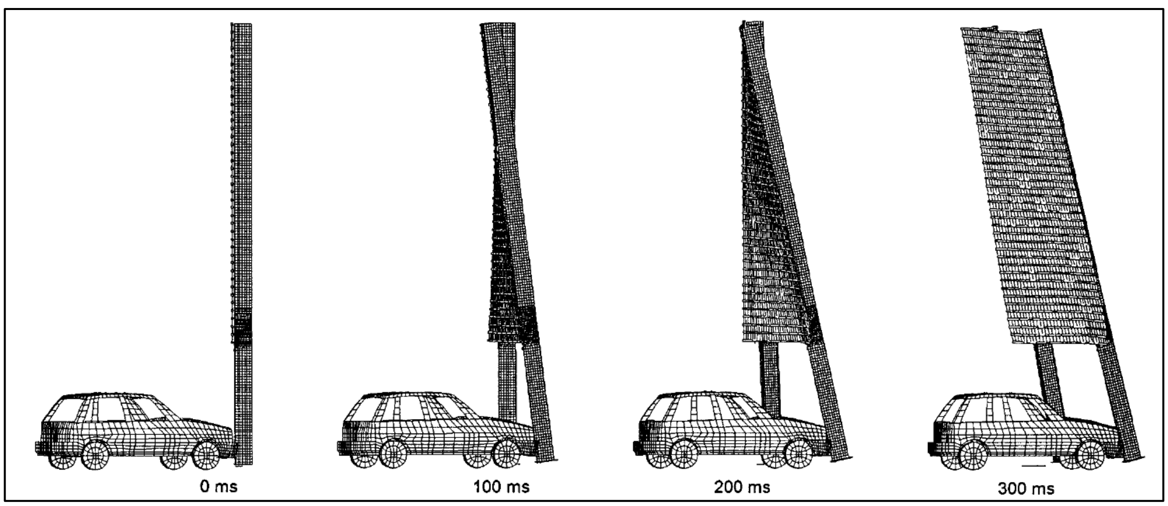


Figure 21. Impact Sequence of Slow Speed Simulation (Reprinted from Reid and Paulsen, 1996).

In the United States, safety along the highways has been improved greatly in the last few decades (Sicking & Mak, 2001). The continued drop in the fatality rate clearly shows the improvement in roadside safety. Improved vehicle designs, better occupant restraints, and improved roadside safety design were the major reasons for the drop in the fatality rate. There are multiple problems such as installation details, non-tracking impacts, roadside geometry, future vehicle trends, etc. which need be tackled for improving roadside safety to the maximum extent. The different matrix of roadside geometry which can be evaluated through an actual full-scale crash test is very difficult by construction at existing testing facilities. The full-scale crash tests associate high cost which is the biggest barrier in solving these problems. The use of nonlinear FE programs such as LS-DYNA is the only useful alternative to full-scale crash testing for the safety performance assessment of roadside safety devices. Any element modeled in any of the FE programs should be carefully calibrated with any past detailed component test to ensure that overall modeling is rationally correct. To achieve better results, significant efforts should be devoted for developing better links between occupant risks and vehicle kinematics. The comprehensive effort focused to achieve these goals will further reduce the fatality rate associated with roadside safety.

The Breakaway system commonly uses a slip base mechanism for roadside safety. The breakaway system of the base reduces the crash resistance, and the passenger injury when vehicles accidentally leave the roadway and hit roadside safety devices. Hiser and Reid in 2005 explained improved methods of modeling slip base systems using FE programs. Two different methods for designing bolts in slip base system were discussed.

One of the methods used bolt shaft elements and the other method used discrete spring element. Both methods produce similar results when impacted in simple shear conditions. Figure 22 shows the results of the weak axis impact. In the impact for stronger axis, bolt overloading and failure were observed in the model designed with shaft element and flange and post deformation was observed in the model designed with spring elements. Figure 23 shows the incapability of the rigid bolts to fail or deform. Thus, the Stress Based Clamping (SBC) technique modeled with shaft elements shown distinct advantages over the Discrete Based Clamping (DBC) technique modeled with spring elements. In conclusion, it was observed that the SBC technique has better abilities to capture slip base behavior in severe loading conditions.

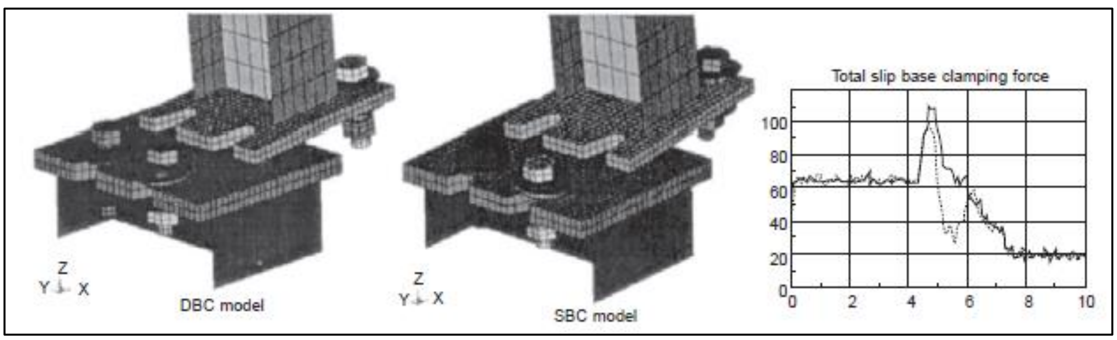


Figure 22. Weak Axis Impact Results (Reprinted from Hiser & Reid, 2005).

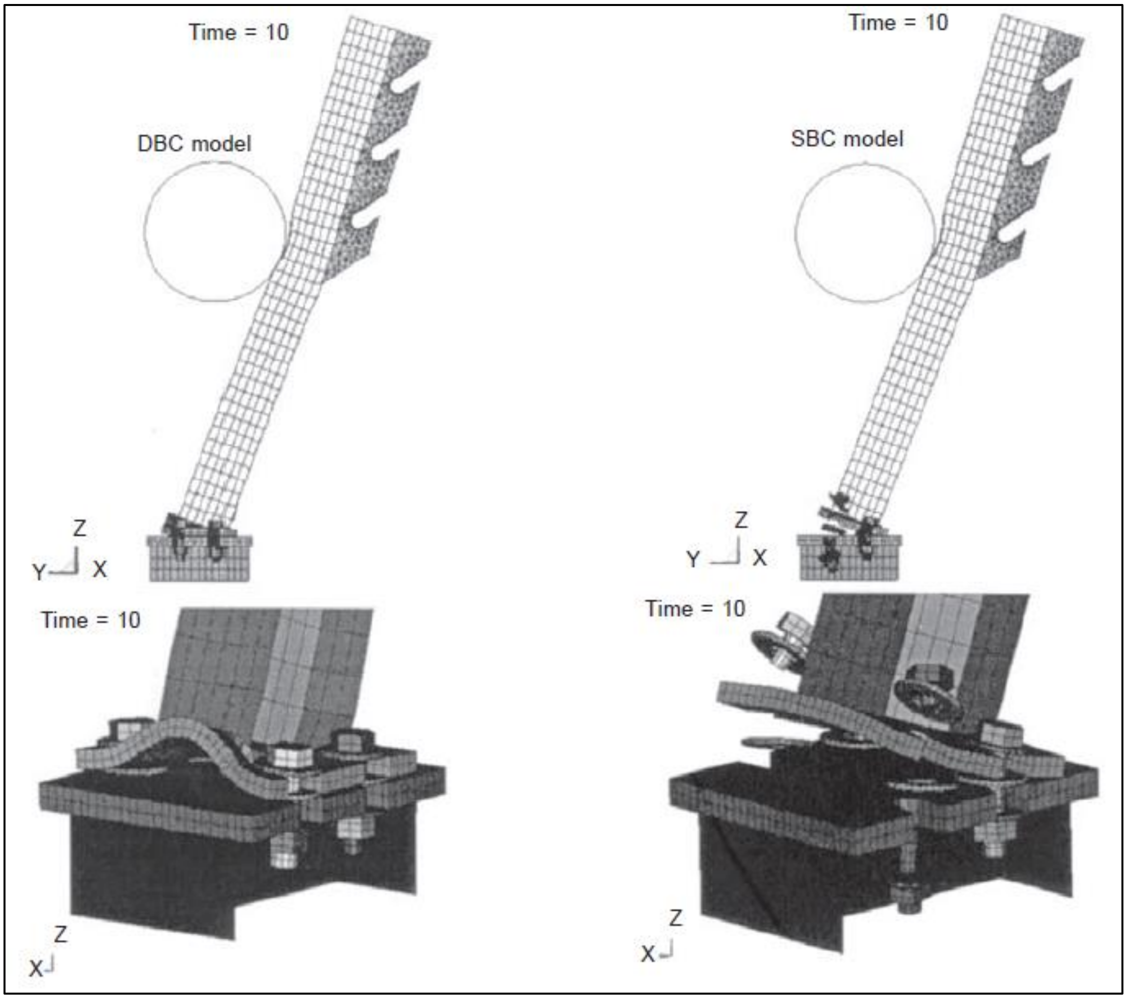


Figure 23. Stronger Axis Bumper Impact (Reprinted from Hiser & Reid, 2005).

TTI conducted a study for developing guidance for minimum sign area for slip base supports for the TxDOT project "Development Guidance for Sign Design Standard" (Silvestri et al., 2011). It was seen that the triangular slip base was the most commonly used sign breakaway system in Texas. It is a moment carrying splice connection connecting opposing fixtures with bolts. In normal conditions, this breakaway system should rotate over the vehicle. It was earlier seen that in some tests that this system rotates too quickly, impacting the roof of the impacted vehicle. To further predict the contact between impact vehicle and the support vehicle predictions, computer simulations were performed in LS-DYNA. Previously conducted studies at TTI was used to calibrate the behavior of the developed finite element model.

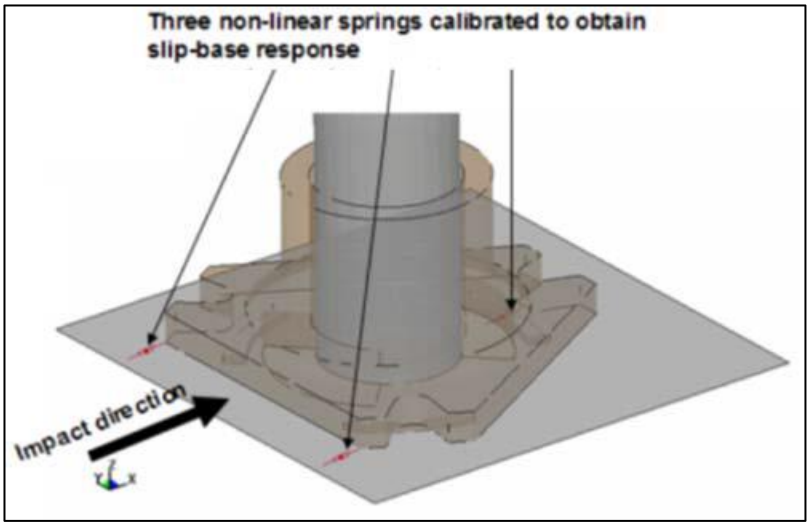


Figure 24. Finite Element Model of the Slipbase System (Reprinted from Silvestri et al., 2011).

In the second phase of the study, different FE simulation was performed to replicate the impact of the vehicle on sign support connected to the slip base system. As shown in Figure 24 the top casting of the system was modeled using solid elements with rigid material properties. The bolts used in the slip base system was also modeled explicitly using spring elements. The report shows the correlation achieved between the actual crash test and the validation model. The FE simulation predicted roof deformation of 8 in. whereas the actual deformation was 5.1 in. A similar simulation was conducted to validate the results of a pickup with existing full-scale crash tests performed under TxDOT projects (No. 455266 and 405872). In this simulation, FE predicted deformation in the roof of 6.3 in. whereas the actual deformation was 6.5 in. A detailed comparison between finite element and actual crash tests is shown in Figure 25. It was seen that the FEM was able to predict the location of the sign after the release of the slipbase up to a good extent. The main reasons for over or underprediction of the roof deformation can be due to the vehicles. Because the vehicles used in the FE was not exactly similar to the actual crash test ones. There can be also some minor differences in the measurements of the test articles used in the finite element and the actual crash test. After all these considerations, researchers decided to use the FEM for further simulations, keeping in mind that the model over predicts certain values.

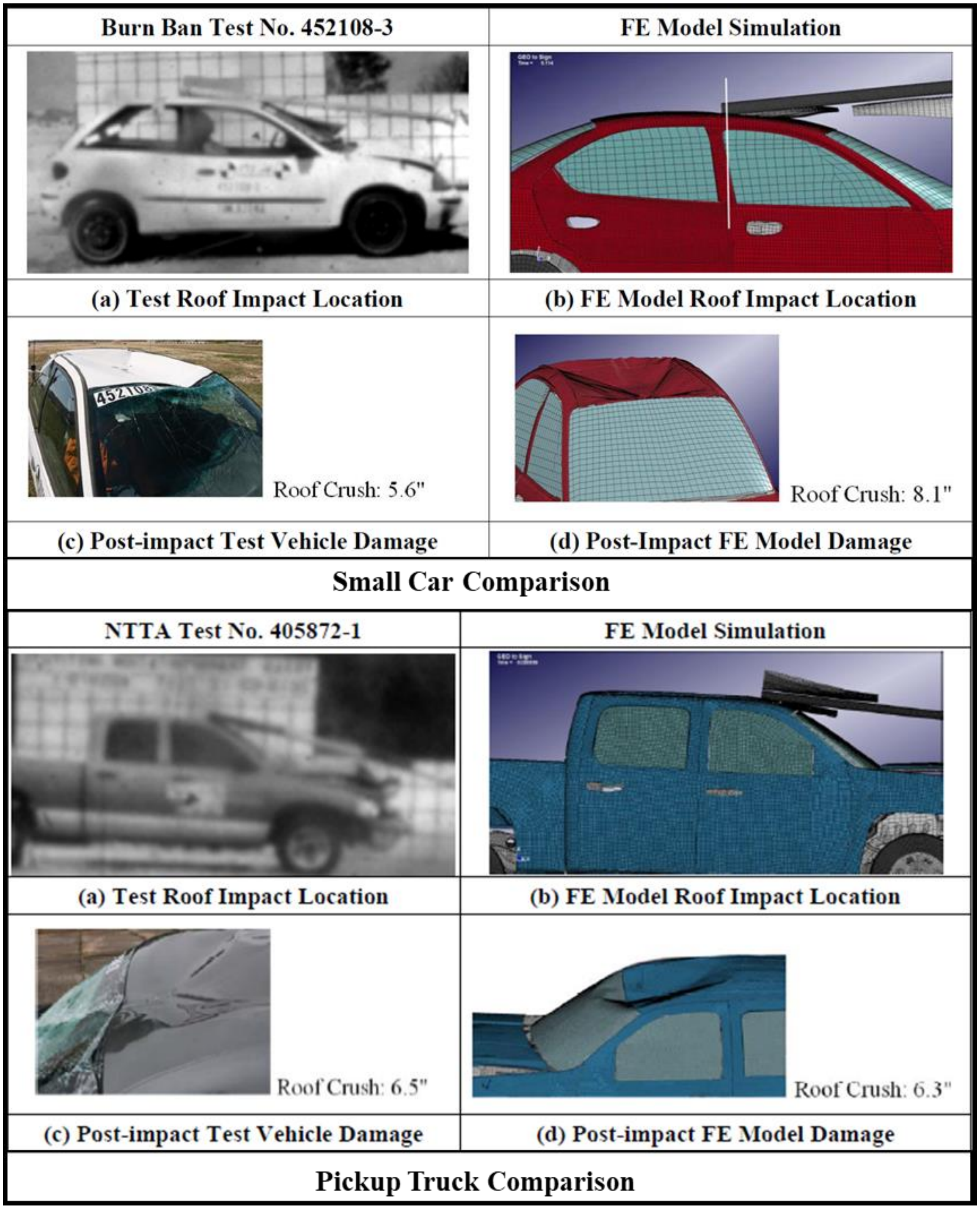


Figure 25. Comparison Between Actual and Finite Element Models (Reprinted from Silvestri et al., 2011).

3. SELECTION OF SIGNPOST SYSTEM

3.1. Introduction

This study developed a survey that was completed by TTI Pooledfund agency offices with knowledge of current large sign breakaway systems inventory and the agency's management approach and practices. From a large pool of Roadside Safety Pooled Fund agencies office personnel, 18 participants completed the survey. The key findings of the survey are highlighted in this section. Based on the survey, the most used and critical large sign support system was selected for further research.

3.2. Survey

The survey contained multiple questions related to large sign breakaway systems, such as whether the agency office wants to maintain the submitted standards as MASH compliant system or earlier under which criteria the developed system was evaluated. Table 10 lists the questions developed for this survey. Some of the questions have relevant questions tagged with the original questions. For example, questions 3, 4, 5, and 6 have relevant questions that are tagged with the original questions. Most of the questions, as listed in the table, required multiple or single choice inputs. Other questions require written inputs from the survey participants.

Table 10. List of Survey Questions

Survey Questions
Question 1: Please provide contact information. 1. Name 2. Professional Title 3. DOT Office 4. Email Address 5. Phone Number

Table 10. Continued

<u>Question 2:</u> Please provide standard plans/documents used by your DOT for the design of large sign support.

1. Links
2. Attachments

<u>Question 3:</u> Are you planning to maintain the submitted standards as MASH compliant system(s)?

1. Yes
2. No
3. Other (Please Explain)

<u>Question 4:</u> Please indicate under which criteria were the large sign support evaluated.

1. MASH
2. NCHRP Report 350
3. Other (Please Specify)

<u>Question 5:</u> Please indicate how the large sign support was evaluated.

1. Full-Scale Crash Tests
2. Component Testing (Pendulum, Surrogate Vehicles, etc.)
3. Engineering Analysis
4. Numerical Computer Simulations
5. Other (Please Specify)
6. None

<u>Question 6:</u> Please indicate at what test level is the submitted standard implemented.

1. Box for response

<u>Question 7:</u> Please indicate the anticipated usual offset of supports from the edge of the travel way.

1. Box for response

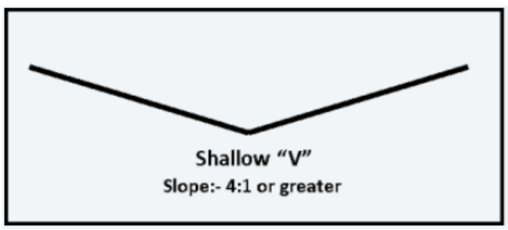
Table 10. Continued

<u>Question 8:</u> Within the clear zone, what approximate percentage of signs are installed on negative and positive slopes.

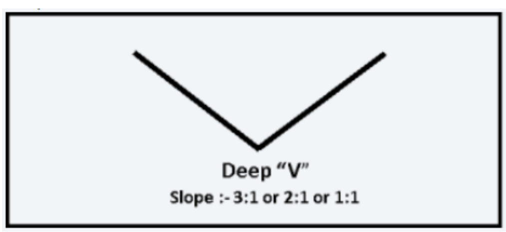
1. Negative
2. Positive
3. None

<u>Question 9:</u> If sign support is mounted in a ditch, please indicate the type of ditch.

1. Shallow "V"



2. Deep "V"



3. Trapezoidal

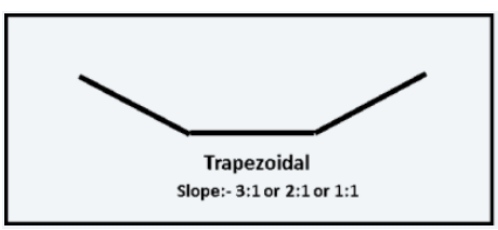


Table 10. Continued

<u>Question 10:</u> Please indicate whether sign supports are also installed in medians. If so, please indicate the common median slope and offset of installation from the travel way. 1. Box for Response **<u>Question 11:</u>** Please share any other relevant information, including studies, test reports, drawings, articles, standards, protocols, etc. 1. Box for Response

Question 2 was asked to provide standard plans/documents used by the agency for the design of large sign support. Respondents with a response to this question either uploaded a document or shared the link of the standard plans/documents. Table 42 in Appendix A lists the individual responses from different agencies for question 2. To keep the document concise the standard plans provided by the participating states are not included.

Question 3 was whether the agencies want to maintain the submitted standard as MASH compliant system(s) or not. Most of the respondents for this question said "yes", that they want to maintain the existing standard as MASH compliant. Some of the respondents selected "no" and "others". Figure 26 illustrates the percentage distribution of the response selected.

Table 43 in Appendix A lists individual responses from agency offices for question 3.

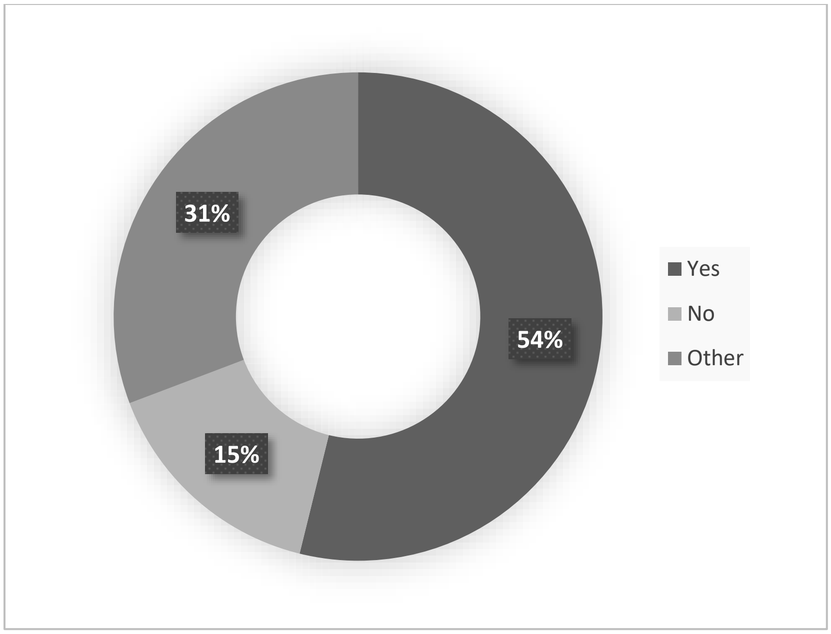


Figure 26. Response for Question 3

Question 4 was asked to know under which criteria the large sign support was evaluated. Most of the respondents selected NCHRP Report 350. Some of the respondents also selected MASH and “other”. Respondents who selected “other” criteria also provided comments. Figure 27 illustrates the percentage distribution of each response selected.

Table 44 in Appendix A lists individual responses from agency offices for question 4.

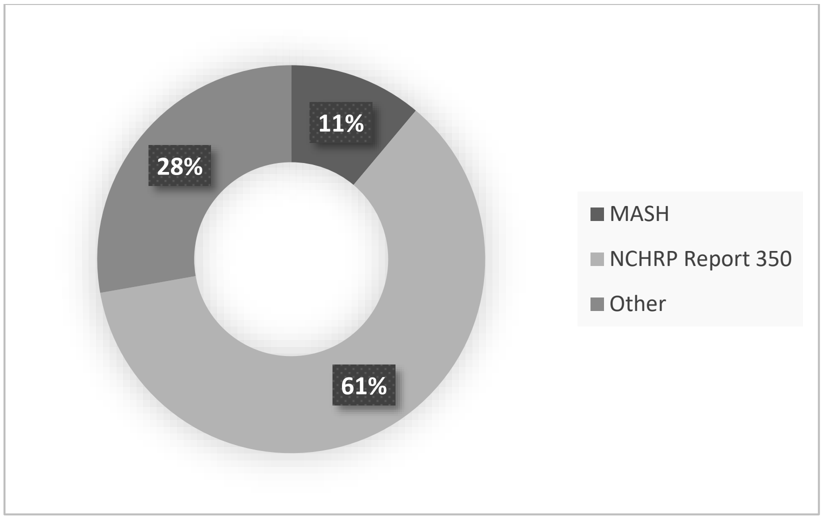


Figure 27. Response for Question 4

1. Regarding the testing criteria for evaluating large sign supports, the respondents were diversified in terms of the criteria. Most of the respondents selected “full-scale crash test” and “pendulum testing” as testing criteria. Some of the respondents also selected “others” and provided comments. Figure 28 illustrates the number of responses for each testing criteria.

Table 45 in Appendix A lists individual responses from agency offices for question 5.

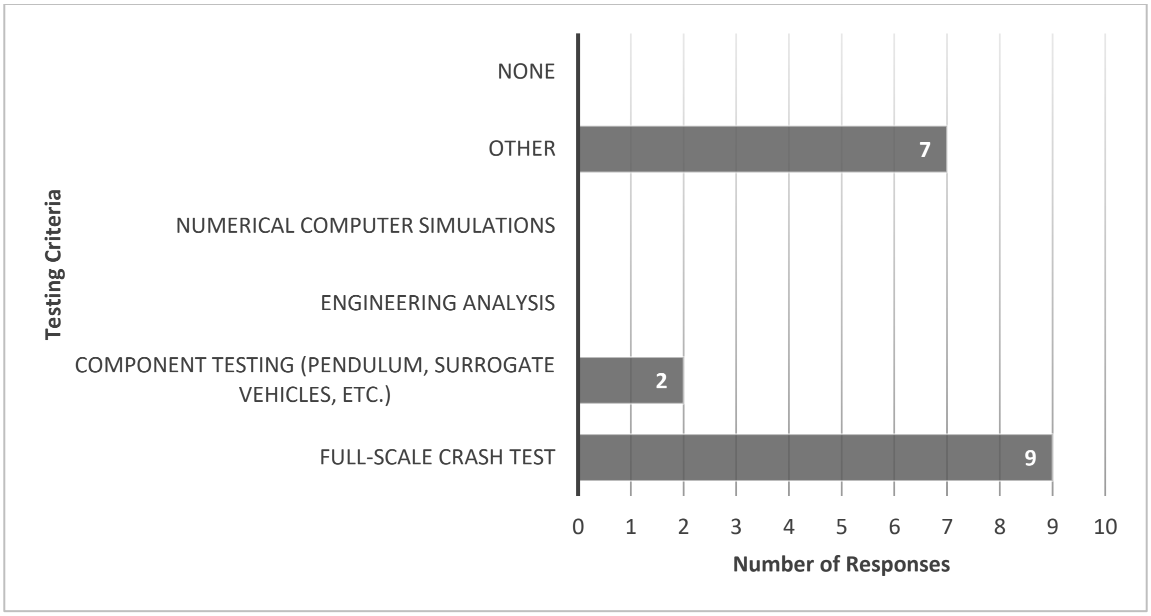


Figure 28. Response for Question 5

2. Question 6 was asked to know under what test level the submitted standard was evaluated. The respondents were diversified in terms of testing criteria. Figure 29 shows the different test levels used by agencies to evaluate the test article. It was found that around 75 percent of agencies use Test Level 3 and the other 25 percent use NCHRP 350 and AASHTO pendulum testing criteria.

Table 45 in Appendix A lists individual responses received from different agencies.

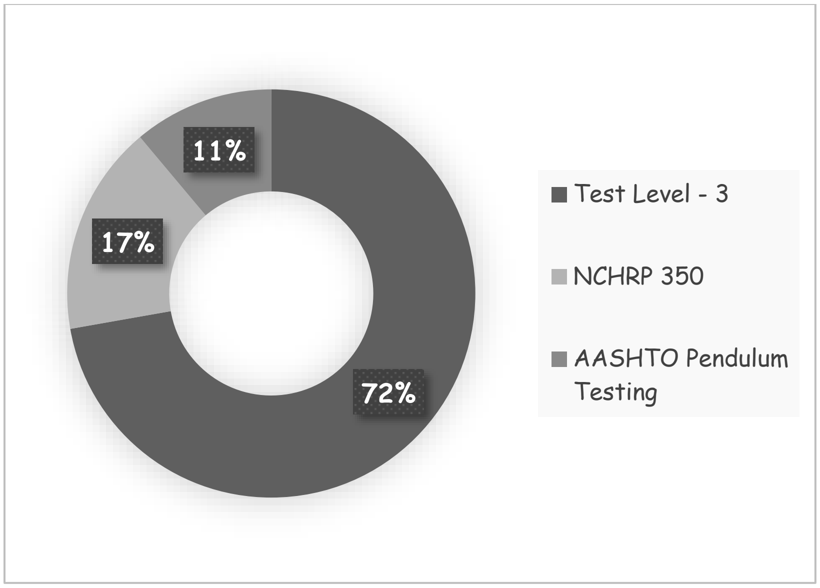


Figure 29. Response for Question 6

3. Question 7 asks for the usual offset distance of sign supports from the edge of the travel way. It was found that most of the agencies use 12 ft. offset distance from the edge of travel way. Figure 30 and Figure 31 illustrates the number of responses for minimum and maximum offset distance used by different agencies.

Table 47 in Appendix A lists individual responses received from different agencies.

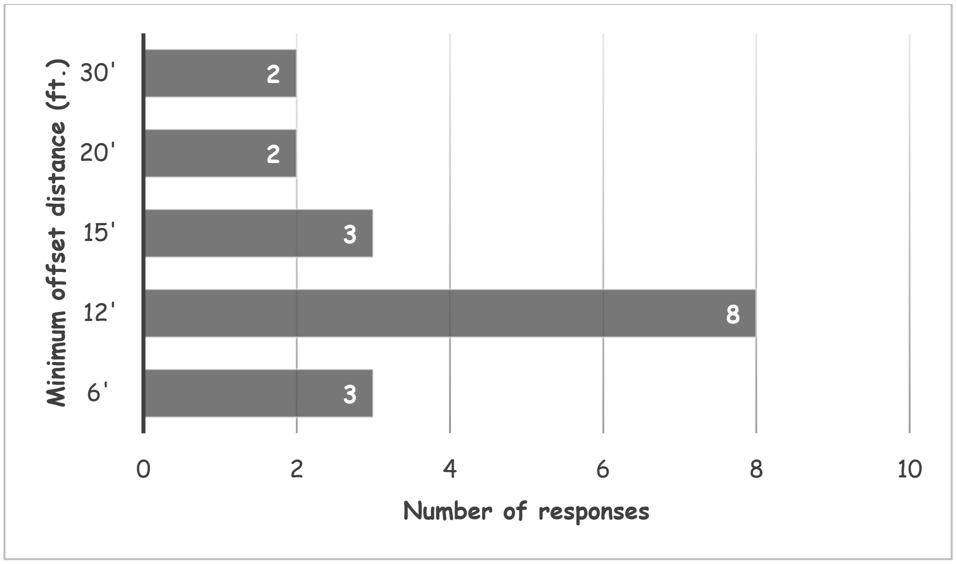


Figure 30. Response for Question 7 (Minimum Offset Distance)

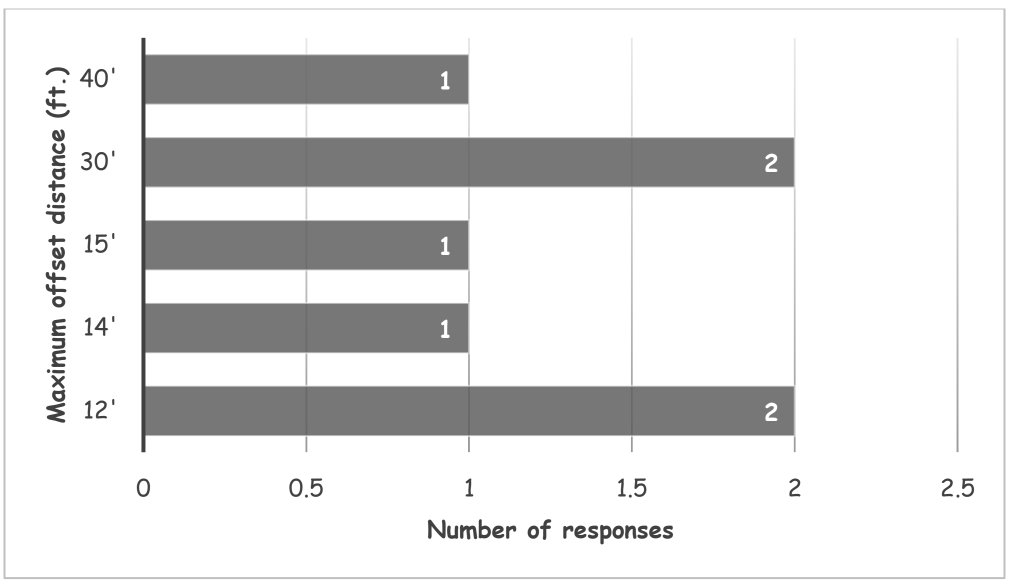


Figure 31. Response for Question 7 (Maximum Offset Distance)

Question 8 asks for the approximate percentage of sign supports installed on a negative or positive slope. 82 percent of respondents said that they install sign supports on the negative slope and 12 percent said that they install on the positive slope. Figure 32 illustrates the percentage distribution of each response selected by the agency. Table 48 in Appendix A lists individual responses for question 8 received from different agencies.

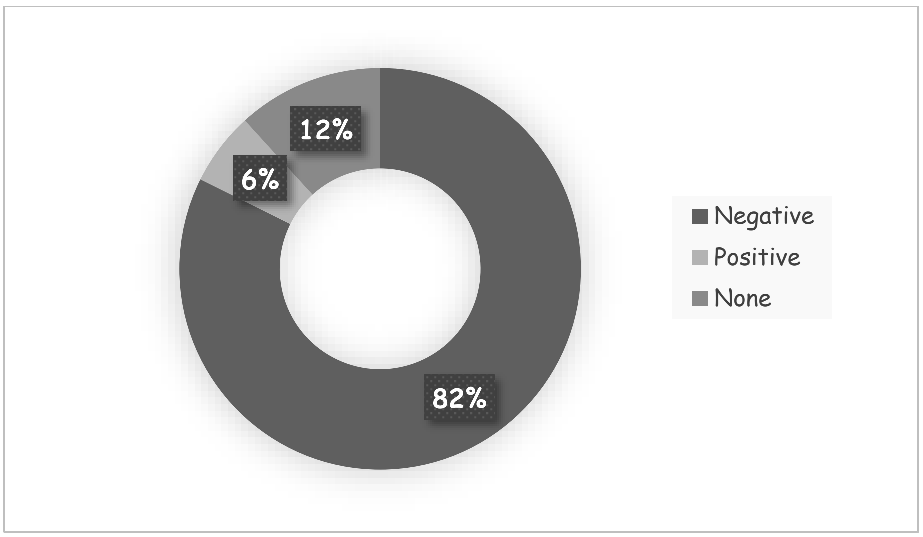


Figure 32. Response for Question 8

4. Question 9 asks about the type of ditch in which sign supports are mounted. Most of the respondents selected the "Shallow V" ditch. 21 percent of respondents selected the "trapezoidal" ditch and the remaining 11 percent of respondents selected the "Deep V" ditch. Figure 33 illustrates the percentage distribution of each response selected by the agency.

Table 49 in Appendix A lists individual responses for question 9 received from different agencies.

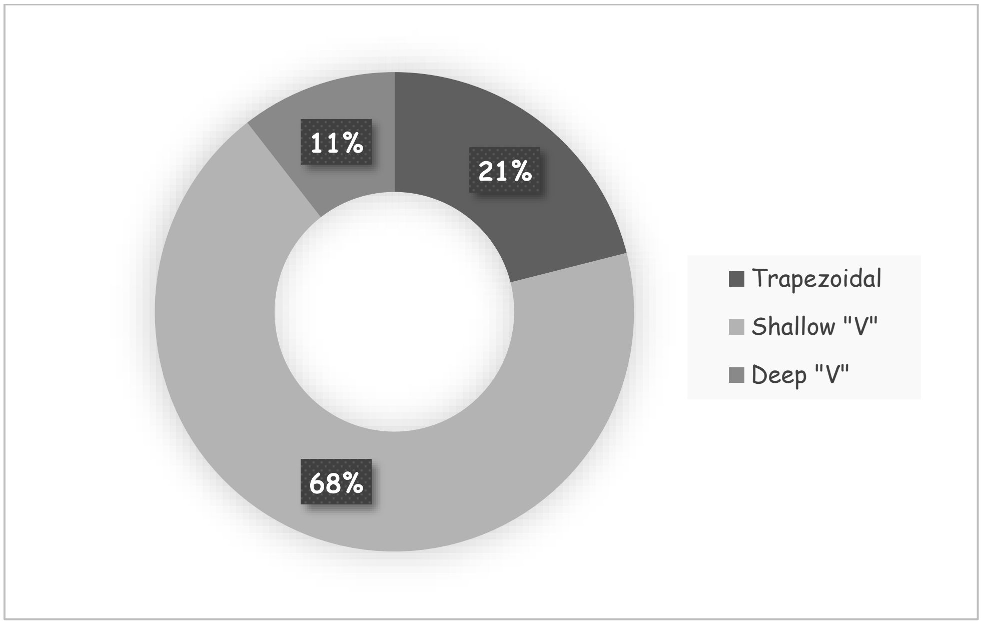


Figure 33. Response for Question 9

Question 10 confirms whether agencies also install sign supports in medians. They were also asked about the common median slope and offset of installation from the edge of the travel way. Figure 34 illustrates the number of responses for different offset distances used by agencies and Figure 35 illustrates the number of responses for different slopes. Table 50 in Appendix A lists individual responses received from different agencies.

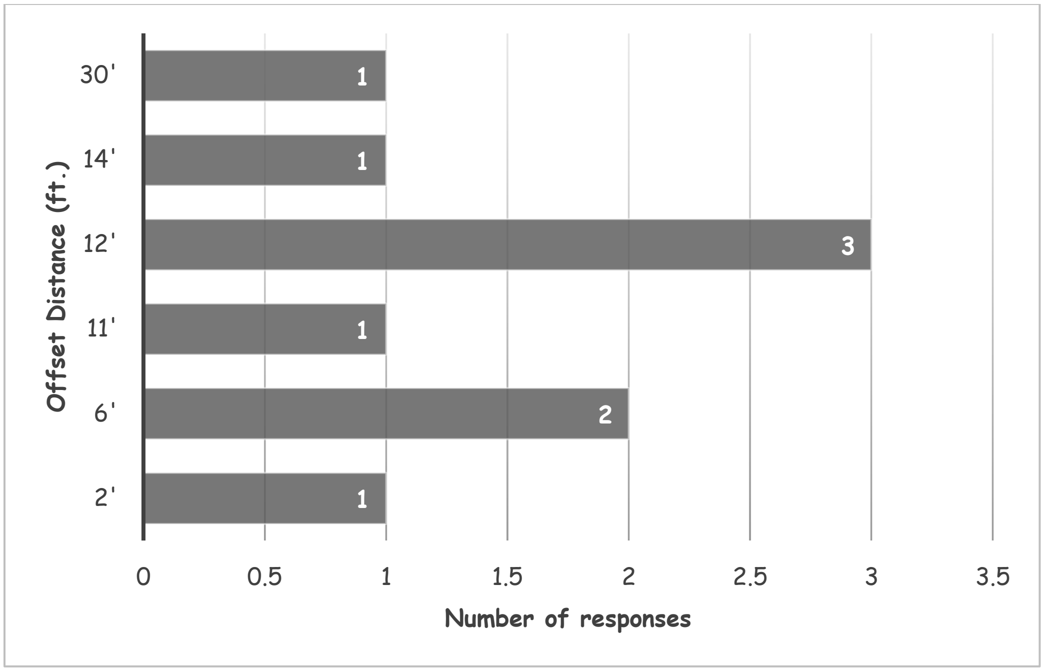


Figure 34. Response for Question 10 (Offset Distance)

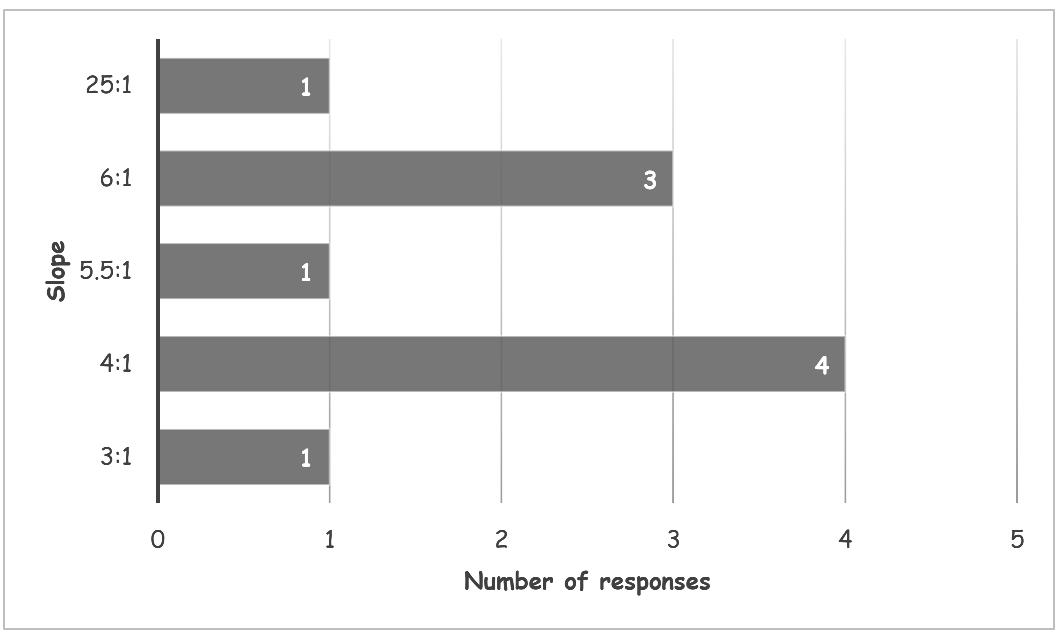


Figure 35. Response for Question 10 (Slope)

Question 11 was asked to provide additional information such as past studies, test reports, drawings, articles, standards, etc. relevant to sign support system. Respondents either uploaded a document or shared the link of the additional information. Table 51 in Appendix Alists the individual responses from different agencies for question 11.

5. In the follow-up email to state agencies, a question was asked to provide the most used W-section post size used by the state. It was found that W6X12 is the most used W-section size used by various agencies. The next most used W shape sections were W8X18 and W6X15. Figure 36 illustrates the number of responses for each testing criteria.

Table 52 in Appendix A lists individual responses from agency offices for follow-up question 1.

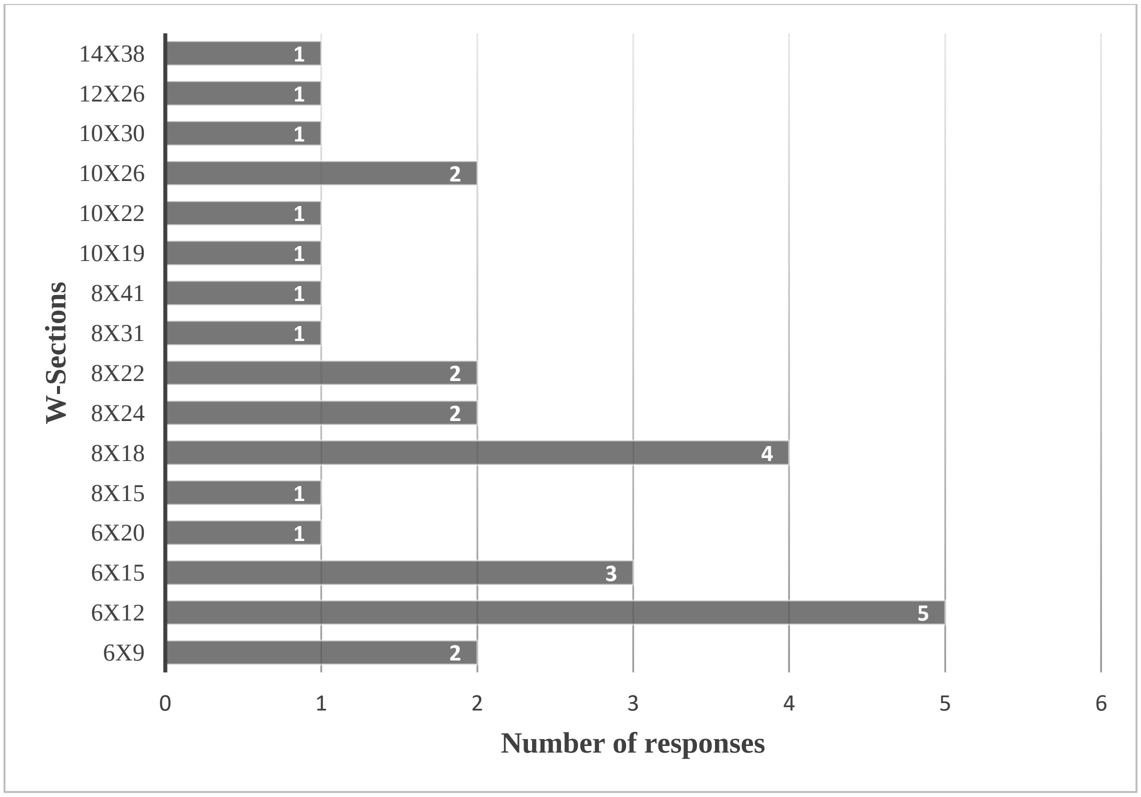


Figure 36. Responses for Follow-up Question 1

To know the maximum size of the sign used by the state for the 2-legged and 3-legged system, another follow-up question was asked. The respondents were diversified in terms of the maximum size of the sign used. It was found that most of the agencies use the rule of thumb or wind loads plots for that area to find the maximum size of the sign. Table 53 in Appendix A lists individual responses for follow-up question 2.

6. Follow-up question 3 was asked to know the width of the ditch in which sign supports are installed. There was a wide variety of responses to this question and it was found that most of the agencies use ditch as per site requirements.

Table 54 in Appendix A lists individual responses for follow-up question 2.

3.3. Conclusion

This section presents the response of the survey performed to find the most used large sign support system by different agencies. The survey results show a comprehensive picture of current large sign breakaway systems inventory and the agency's management approach and practices. A very wide variety of responses from agencies was received. For the research, the design used by Florida DOT was used. The other site conditions such as edge distance, type of ditch, the slope were used based on survey responses. The deep “V” ditch was used for the analysis as more than 80 percent of agencies who responded install the sign support systems in this type of ditch. The sign support system was installed 12 ft. away from the shoulder breakpoint. For the analysis, 6H: 1V slope was used as it was the most frequently used slope by agencies. Figure 37 below illustrates the details of the design used for analysis.

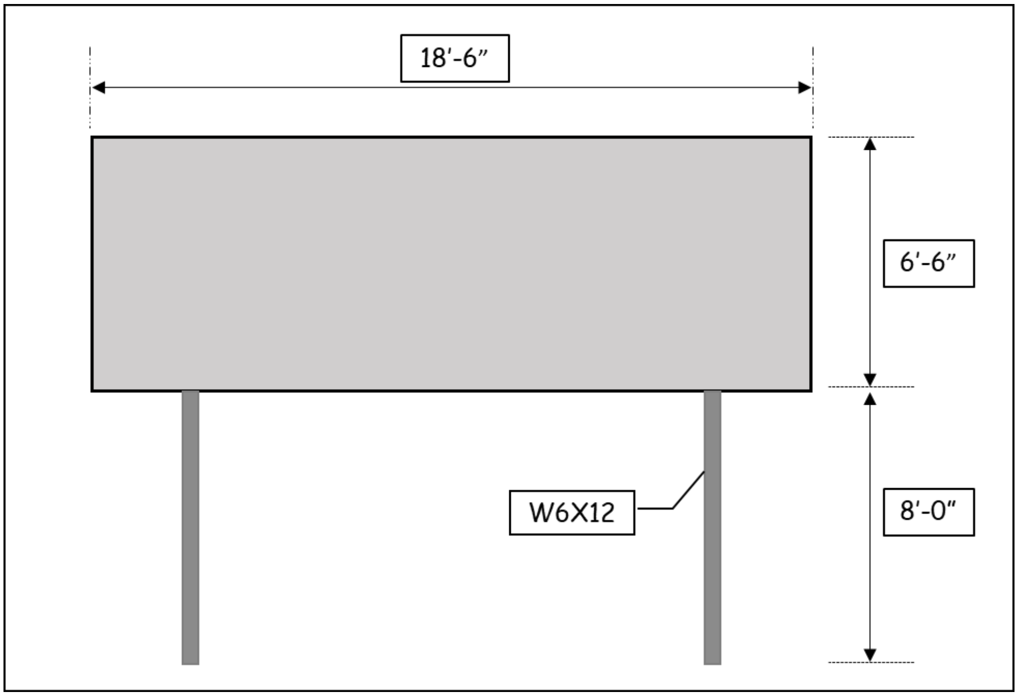


Figure 37. Signboard Design Details.

4. FINITE ELEMENT PRELIMINARY ANALYSIS

4.1. Introduction

Executing several different actual full-scale crash tests to judge the performance of the test article based on the survey results from section 3 would be an expensive affair and not practical for the research. In its place, FE computer simulations were performed to estimate and compare the crashworthiness of the proposed test article concept using the existing FE model of a car and a pickup truck, under MASH TL-3 conditions.

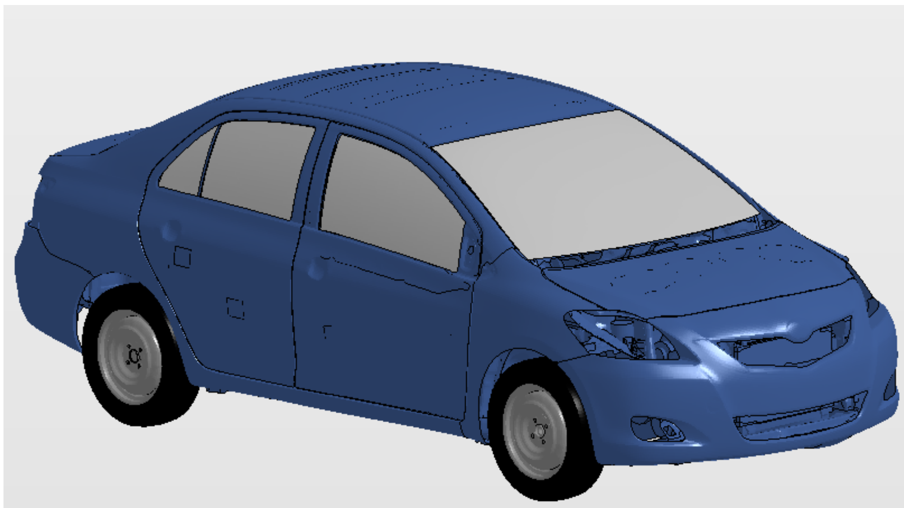
LS-DYNA an FE software package was used to simulate the behavior of vehicular impacts with a sign support system. LS-DYNA is an all-purpose, explicit FE analysis code. It is extensively used to simulate the nonlinear, dynamic response of three-dimensional problems and for capturing intricate interactions of the vehicle with a sign support system. LS-DYNA is also very capable of producing dynamic load-time history responses for any impact. Before modeling the actual system, the researcher used the earlier study by TTI for calibrating the LS-Dyna FE analysis model. The explicit FE code LS-DYNA was used to perform critical impact simulations using the developed sign support system and available vehicles model.

4.2. Available Finite Element Computer Models

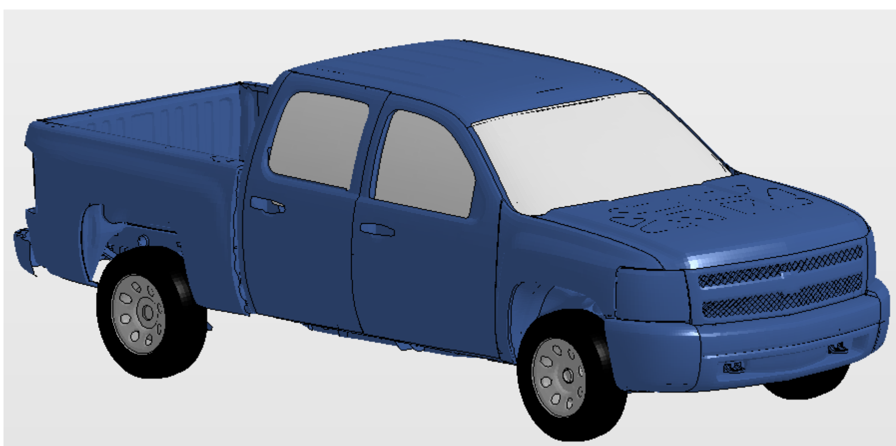
4.2.1. Finite Element Models of Vehicles

Figure 38 illustrates the available FE models of the vehicles. These models include: (a) Toyota Yaris model representing a 2,420-lb (1100C) MASH small car test vehicle, and (b) Chevrolet Silverado model representing a 5,000-lb (2270P) MASH pickup truck test vehicle.

These FE models are compared with the actual vehicle models employed during the tests (Kia Rio, and Dodge RAM 1500 pickup, respectively) in Figure 39.



Toyota Yaris FE Model



Chevrolet Silverado FE Model

Figure 38. Available Finite Element Models of Vehicles.

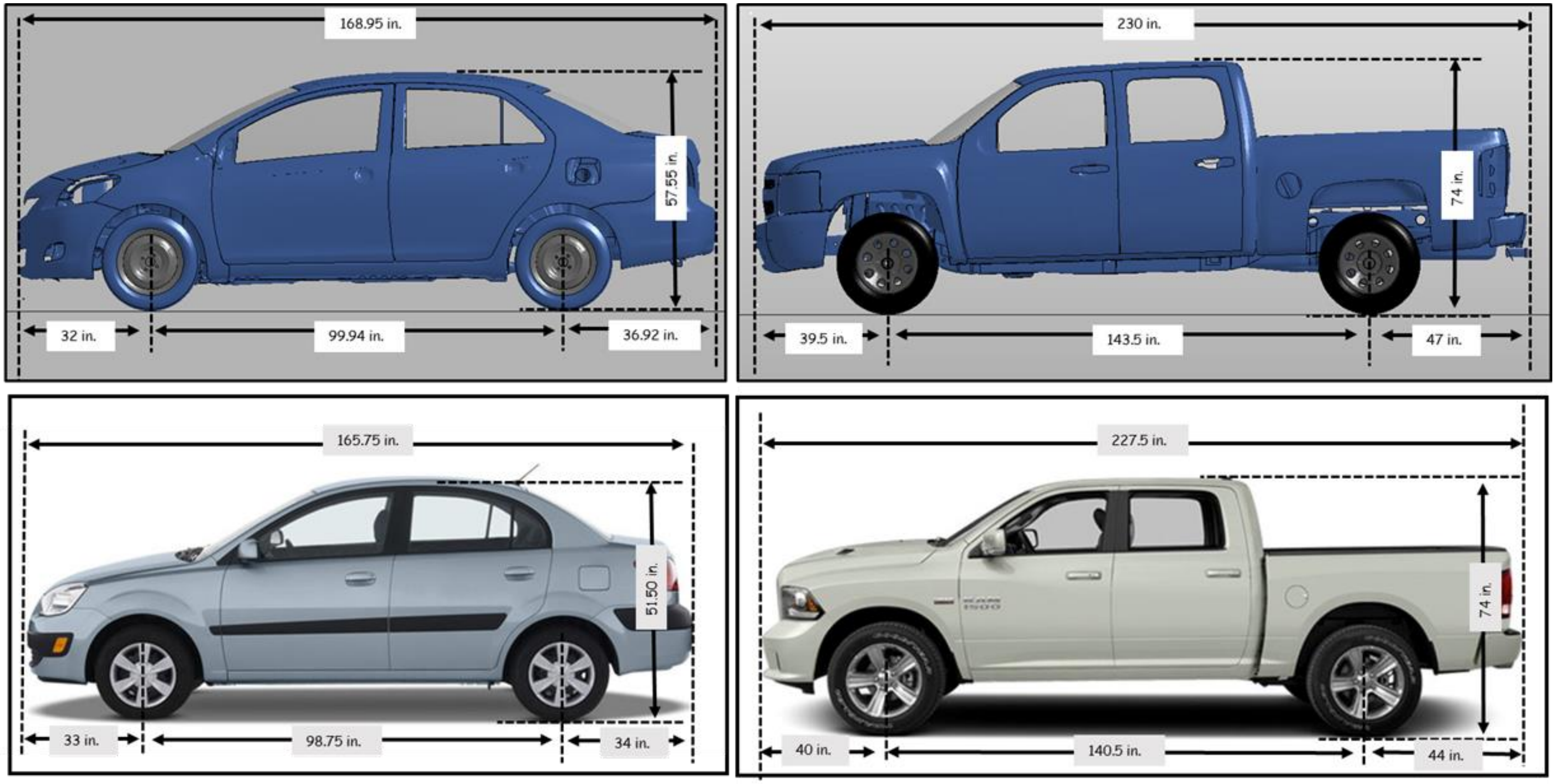


Figure 39. Comparison of Finite Element Models Used for Simulations and Actual Vehicles.

4.2.2. Finite Element Model of the Slipbase

For calibrating the LS-DYNA model, the researcher modeled the slipbase system of the system to be tested. Figure 40 shows the slipbase system attached to the W section. The top slipbase steel plate feet welded to W section was explicitly modeled to properly account for the inertial properties of the sign support system. The slipbase feet were modeled using solid elements and a rigid material representation and the slip plate was modeled using shell element and rigid material representation. Since the bottom rectangular slip-plate remains fixed to the foundation without any significant movement, it was not explicitly modeled.

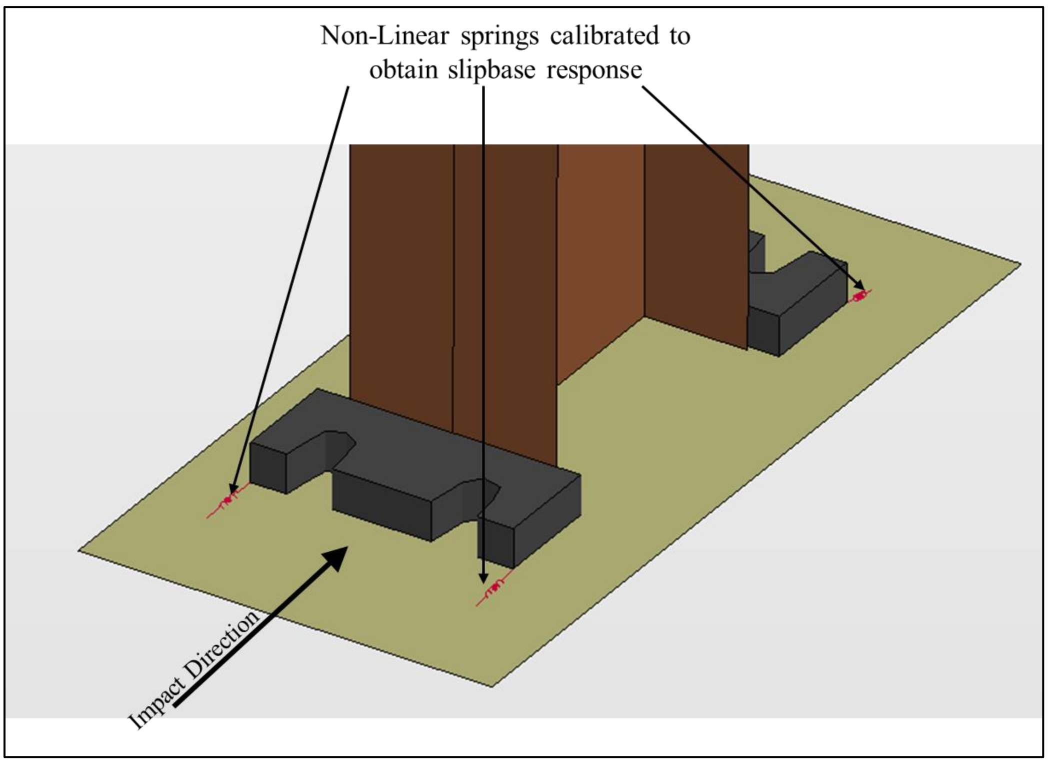


Figure 40. Finite Element Model of Slipbase Sign Support.

The bolts of the triangular slipbase were also not modeled explicitly. Instead, four nonlinear springs were modeled (see Figure 40). One end of each spring was attached to the top slipbase feet, and the other end was attached to the rigid bottom plate. The force-deflection properties of the springs were calibrated using an earlier FE model and from the actual crash test results. The complexity of the slipbase model was greatly reduced using the above-mentioned modeling techniques without significant loss of accuracy of results. This technique enabled multiple impact simulations to be conducted within the resources of the project. Available crash test data was used for FE computer validation of the slipbase system.

4.3. Model Calibration

4.3.1. Full-Scale Crash Test

The researcher used a 4 ft. × 10 ft. large sign support system with W6×9 leg supports tested for TxDOT under the TTI project (Development Guidance for Sign Design Standards) for calibrating the LS-Dyna finite element analysis model. The researchers at TTI conducted MASH Test 3-61 on this large sign support system which was used to calibrate the results of the developed system in LS-DYNA by comparing vehicle impact behavior and stability, as well as occupant risks and sign support performance upon vehicle impact.

Vehicle stability, occupant risk, and structural adequacy were evaluated using the Test Risk Assessment Program (TRAP) (TRAP, 2011). Vehicle angular velocities, also known as roll, pitch, and yaw angles, were used to evaluate vehicle stability. Figure 41 shows, roll, pitch, and yaw angles describing the vehicle rotation about the x-axis, y-axis, and z-axis, respectively. MASH specifies that the maximum roll and pitch angles should not exceed 75 degrees. Occupant risk describes the risk of hazard to occupants. It was evaluated from the data collected by the accelerometer located at the center of gravity in the vehicle. Two factors were mainly analyzed in preliminary simulations through the acceleration data: Occupant Impact Velocity (OIV), Occupant Ridedown Acceleration (ORA). OIV and ORA are the change in velocity which the hypothetical occupant feels at impact and the acceleration from the collision just after impact. MASH requires the OIV to be lower than 40 ft/s and ORA to be smaller than 20.49 G in longitudinal and lateral directions. The structural adequacy of the system is determined by the activation of the breakaway device predictably by breaking away, fracturing, or yielding.

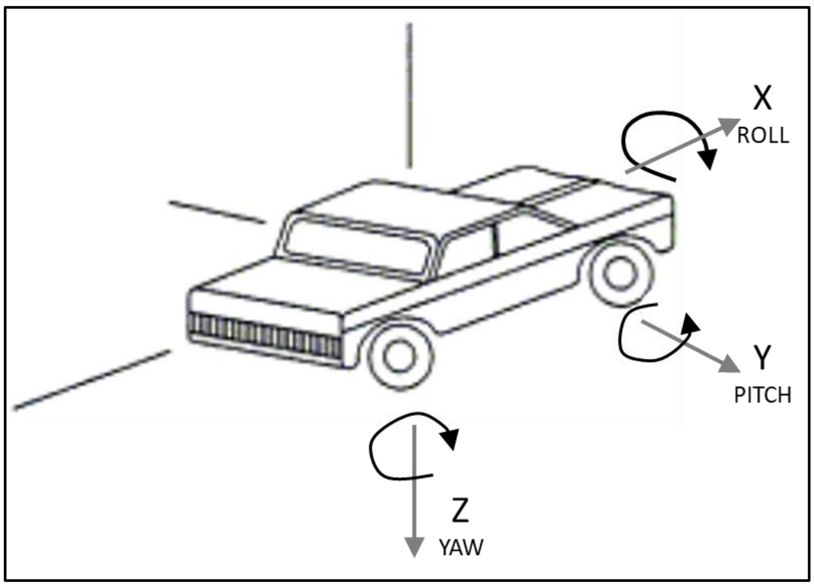


Figure 41. Row, Pitch, and Yaw Illustration.

The 2004 Kia Rio passenger car was used in the test. The actual impact speed and angle were 62 mph and 0 degrees, respectively. Figure 42 illustrates the actual constructed large sign system from different views.

	
Front View	Perspective Side View

Bottom View

Figure 42. LS-DYNA Sign Post System Model without Vehicle (Silvestri et al., 2011)

The test installation was constructed to support a 10-ft × 4-ft tall sign at a mounting height of 12 ft. The sign assembly was constructed using four 1-ft × 10-ft long extruded aluminum panels. Panels were fastened together using 3/8-in. × 3/4-in. bolts and washers spaced every 24 in. along the length of the panels. Each panel was fastened to the support post using a cast sign clip and aluminum bolt that locked into slots incorporated into the design of the extruded panels.

The support post was constructed using a W6×9 hot rolled section. The support post was constructed in three sections: top, middle, and ground stub. The top section was a 52-in. long W6×9 beam section and had four 11/16-in. holes drilled through the flanges at one end to allow splicing of the support section using milled fuse plates. The holes were drilled 1 inch from the end and at a center-to-center spacing of 2.25 in., centered about the central axis of the beam.

The middle section was fabricated from an 11-ft. 5 in. long piece of the W6×9 section. This section again had the same hole pattern that was found in the top section at one end. The hole pattern allowed for the splicing of the top and middle sections using a milled fuse plate. The other end of the middle section had two slipbase feet, meeting TxDOT's W6×9 specifications, welded to each flange. These plates were made from 2×5×¾-in. plates. The two slots were cut into each plate at a spacing of 2 ¾-in. Each slot was fabricated to receive a ⅝-in. slipbase connecting bolt. Then, a 2×5×½-in. gusset plate supported the slipbase feet. The slipbase foot assembly was centered on each of the external flanges of the W6×9 beam support section.

The ground stub was fabricated from a 24-in. long W6×9 beam section. Again, the slipbase foot assemblies, described above, were attached to one end of the ground stub. Four 2 ¾-in. long and ⅝-in. diameter A325 bolts were used in the slipbase connection to splice the ground stub to the middle support section. A 30-gauge slipbase bolt keeper plate was placed between the ground stub and the middle support section to hold the bolts in the slots until an errant vehicle impacted the support. A single ⅝-in. washer was placed between the keeper plate and the middle support section to reduce friction in the slipbase connection. Each slipbase connecting bolt was tightened to torque between 36 and 38 ft-lb.

The ground stub was installed in a 48-in. deep 24-in. diameter concrete foundation. The foundation was reinforced with eight 42-in. #5 vertical rebars. The foundations were shear reinforced using a single #2 spiral rebars with a 6-in. pitch with three flat turns at the top and one flat turn at the bottom. The foundations were spaced 72 in. on center. Each ground stub protruded 3 in. out of the foundation.

An HSS 4.5×4.5×¼-in. stiffener was attached to the back of the W6×9 support post using a specialty torsional bracket sleeve, which is designed so that it could be used with any of the approved torsional stiffeners. The bracket sleeve was also designed to fill all standard support sections (W6×9 through W12×26) without modification. The bracket was designed to clamp to the W6×9 post section, removing the need to drill holes in the top post section.

The sleeve bracket was made of four main components.

a.) First is the HSS 5×5×3/16-in. sleeve, which allows for a telescoping fit to all 4 ½ in. stiffener sections. Each sleeve had two set-screws to hold the torsional stiffener in place.

b.) Second is the 9×15×½-in. bracket base plate. This plate has a total of eight 11/16 in. bolt holes allowing the bracket to attach to any of the standard size support posts.

c.) The third is the ¼-in. bracket gusset plate. This plate prevents the bracket sleeve from rotating when resisting torsional stresses.

d.) Finally, two 2×9×½-in. clamp plates. Each of these fabricated plates has a total of four 11/16-in. holes allowing the bracket to attach to all of the standard post section sizes. In this case, four ⅝×8-in. A325 bolts were used to clamp the W6×9 post section between the sleeve base plate and the clamp plate, creating a torsion-resisting connection. The stiffener was centered 12 in. above the bottom of the sign panel.

Two milled fuse plates were used to splice each top and middle support post sections. Each fuse plate was milled from a 4 × 3 ⅞ × ¼ - in. A36 plate. The plate was attached to the support post sections at two locations, each using ⅝ × 1½-in. A325 bolts and nuts. Four drilled holes at the splice location weakened the plate. These holes were spaced at 15/16 in. center-to-center spacing and the pattern was centered on the face of the plate. Figure 43 is a diagram of the test installation as tested.

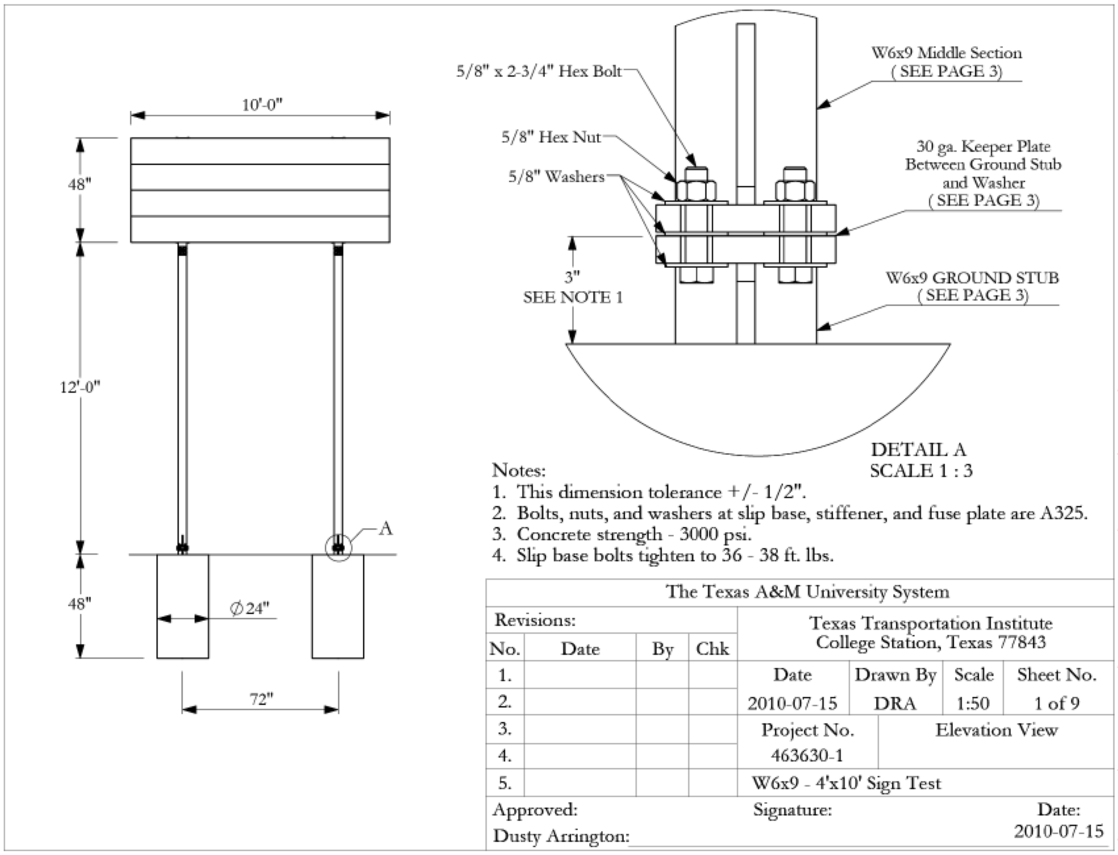


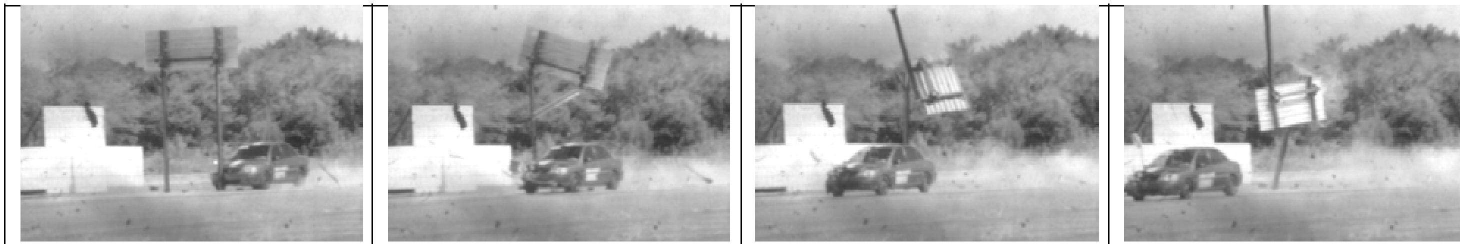
Figure 43. Details of the Large Sign Support Test Installation for Crash test

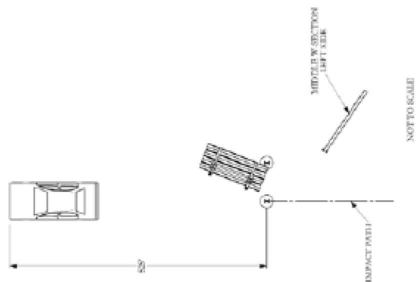
All hot rolled W-sections conform to A992 material specifications. Every tube section conforms to A500 grade B specification. All bolts and nuts meet A325 material specifications. The State of Texas Prison System supplied all extruded sign panels and post clamps, which meet AASHTO and TxDOT material specifications. All other steel sections and plates meet A36 specifications. The concrete used in the foundation has a compression strength of over 3000 psi. Figure 44 illustrates the test article and the impacting vehicle before and after the test. Figure 45 shows the summary of the test results for the TxDOT large sign support system.

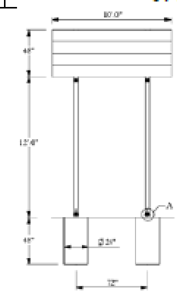
Test Article and Vehicle Before the Test.

Test Article and Vehicle After the Test.

Figure 44. TxDOT Large Sign Support System Before and After Crash Test (Silvestri et al., 2011)







General Information
- Test Agency .... Texas Transportation Institute (TTI)
- Test Standard Test No. .... *MASH* Test 3-61
- TTI Test No. 463630-1
- Date 2010-07-30

Test Article
- Type .... Sign Support
- Name .... TxDOT W6x9 – 4-ft x 10-ft Large Sign Support
- Installation Height .... 12 ft mounting height
- Material or Key Elements ....

Soil Type and Condition .... Concrete footing in crush limestone, dry

Test Vehicle
- Type/Designation 1100C
- Make and Model .... 2004 Kia Rio
- Curb .... 2423 lb
- Test Inertial .... 2414 lb
- Dummy .... 161 lb
- Gross Static .... 2575 lb

Impact Conditions
- Speed .... 62.0 mi/h
- Angle .... 0 degrees
- Location/Orientation .... Right qtr point

Exit Conditions
- Speed .... 58.0 mi/h
- Angle .... 0 degrees

Occupant Risk Values
- Impact Velocity
  - Longitudinal .... 2.3 ft/s
  - Lateral .... 1.0 ft/s
- Ridedown Accelerations
  - Longitudinal .... −0.3 G
  - Lateral .... −0.3 G
- THIV .... 2.6 km/h
- PHD .... 0.4 G
- ASI 0.11
- Max. 0.050-s Average
  - Longitudinal .... −1.3 G
  - Lateral .... 0.4 G
  - Vertical .... 0.5 G

Post-Impact Trajectory
- Stopping Distance .... 525 ft dwnstrm

Vehicle Stability
- Maximum Yaw Angle .... 1 degree
- Maximum Pitch Angle .... −1 degree
- Maximum Roll Angle .... −1 degree
- Vehicle Snagging .... No
- Vehicle Pocketing .... No

Test Article Deflections
- Dynamic ....
- Permanent ....
- Working Width ....

Vehicle Damage
- VDS 12RF2
- CDC 12FREW2
- Max. Exterior Deformation .... 3.5 inches
- OCDI RF0000000
- Max. Occupant Compartment Deformation 0

Figure 45. Summary of Test Results for TxDOT Large Sign Support System (Silvestri et al., 2011)

4.3.2. Computer Model Simulations

LS Pre-Post was used to develop a large sign support system. A sign support system was developed with multiple different material and section properties. Sign supports were modeled with MAT001-Elastic to define steel posts material properties. MAT001 was also used to define material properties of sign panels, fuse plates, and heavy steel base to which springs are attached. MAT020-Rigid was used to define top slotted solid plate material properties which is welded to post. The torsional resistance elements (see Figure 46) such as stiffener bracket, socket and clamp plates were also modeled using MAT001.

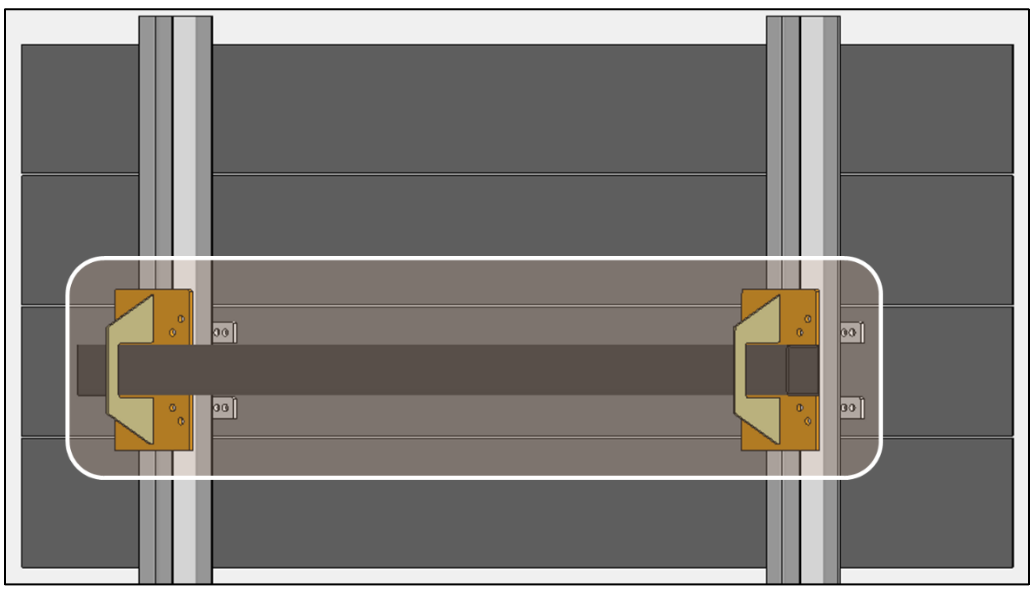


Figure 46. Finite Element Model of Torsional Resistance Elements

MAT024 - Piecewise linear plasticity was used to define the material properties of the fuse plates. The fuse plates (Figure 47) connects the top and the middle signpost section. MAT 000-ADD EROSION was used to provide erosion to the fuse plate to incorporate the failure of the plate due to vehicle impact. The maximum principal stress at failure for the erosion of 498 MPa (N/mm^2) was determined by iteration through model simulation testing and comparing the results with actual crash test values. The bolts for connecting base plate and bolt keeper plate was modeled using spring elements. MATS06-Spring general nonlinear was used to define spring element material properties. Figure 48 shows the LS DYNA finite element model of the signpost system used for calibration/validation.

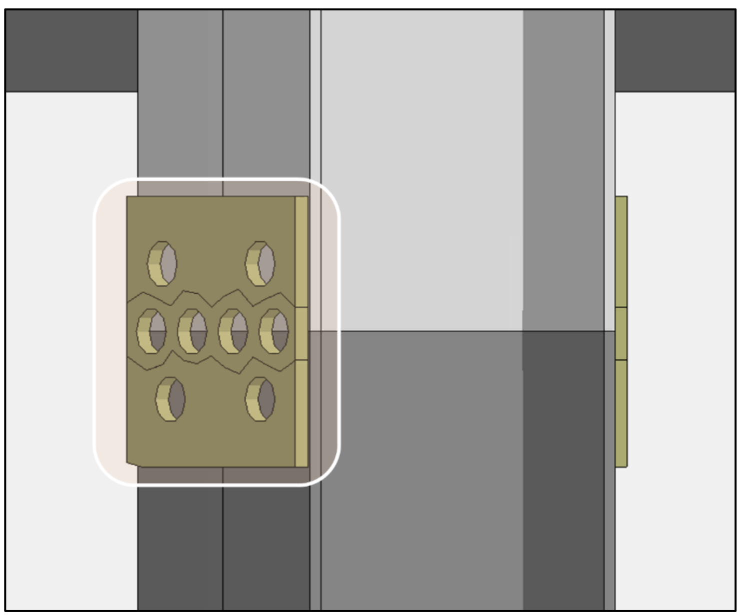


Figure 47. Finite Element Model of Fuse Plate

Available validated Toyota Yaris passenger car model was used as the test vehicle Kia Rio with a similar weight used for the actual crash test. The test vehicle actual impact speed and angle orientation were implemented in the computer simulation. Figure 49 shows the finite element model of the test article and vehicle. Figure 50 illustrates the displacements (roll, pitch, and yaw angular) of the calibrated computer model.

Table 11 shows the sequential of the simulated computer model impact event. TRAP program was used to evaluate occupant risk factors based on the applicable MASH safety evaluation criteria. Table 12 compares frames from the actual full-scale crash test and the calibrated computer model impact simulation. Table 13 summarizes occupant risk, vehicle stability information, and system deflection values from the comparison between the actual crash test values and the simulated impact event.

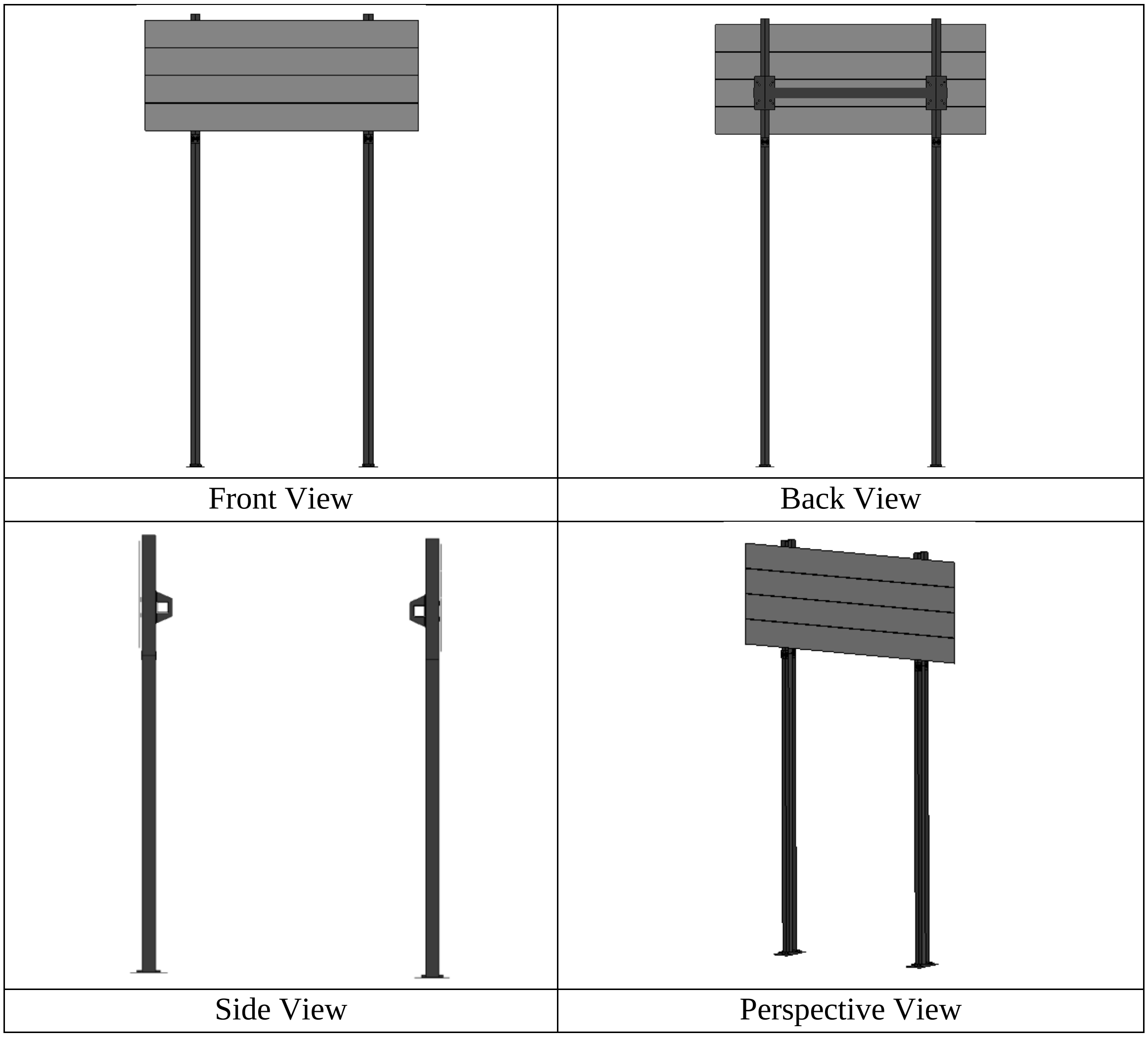
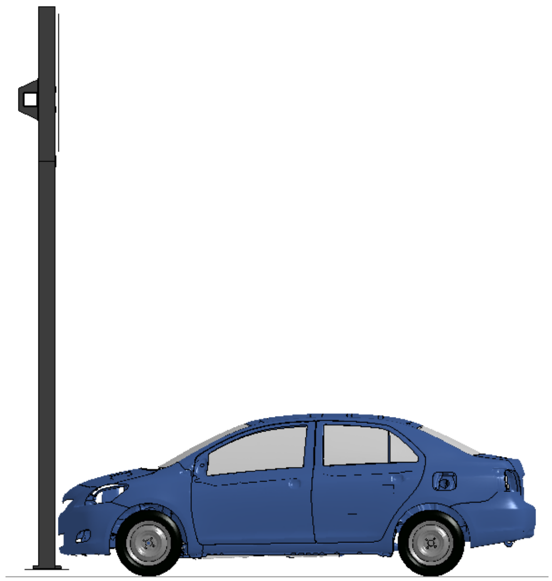
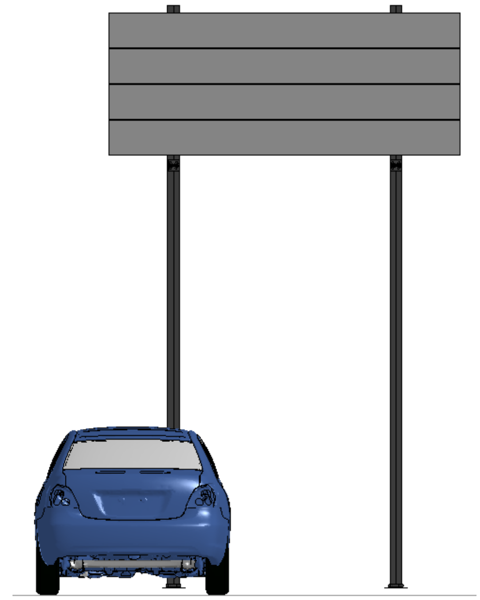


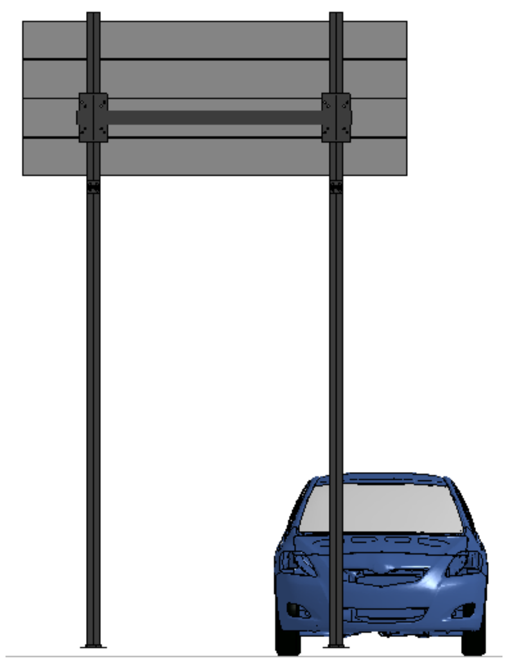
Figure 48. Different Views of the Finite Element Model for Validation



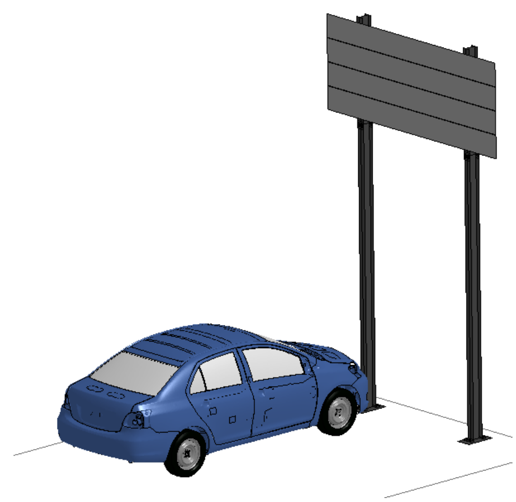
Side View



Front View



Back view



Perspective Front View

Figure 49. Different Views of the Finite Element Model of Test Article and Vehicle

Table 11. Sequential Images of the Finite Element Simulations

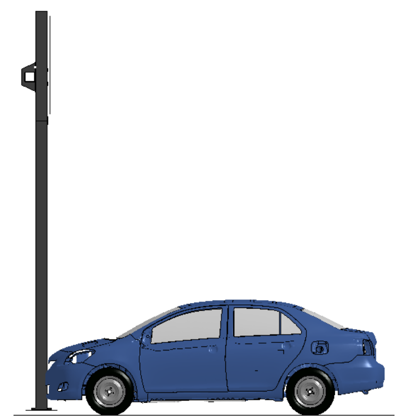
	
0.0 s	**0.04 s**
	
0.01 s	**0.05 s**
	
0.02 s	**0.06 s**

Table 11. Continued

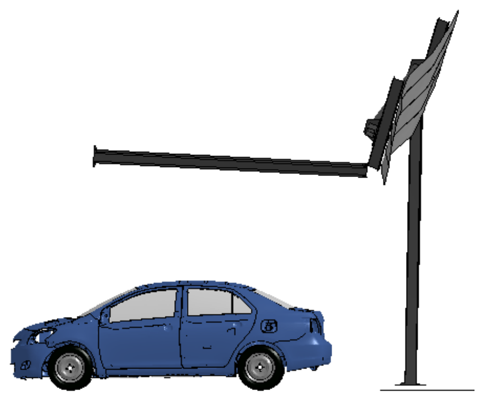
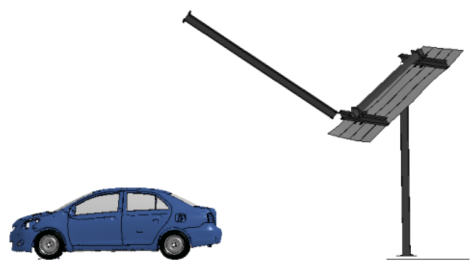
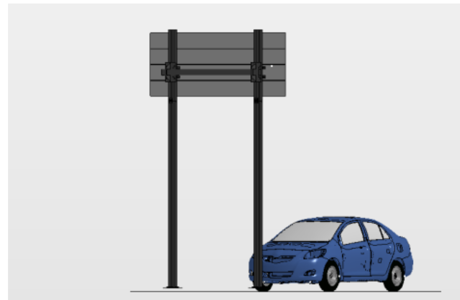
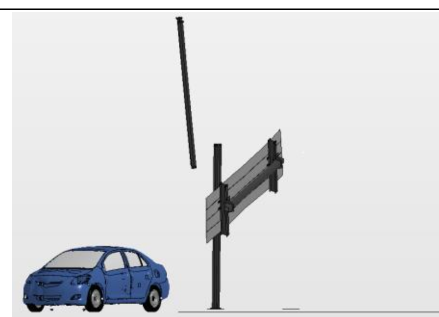
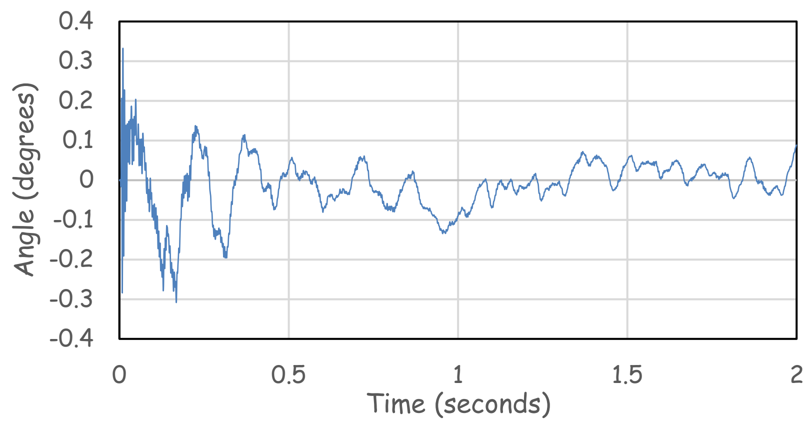
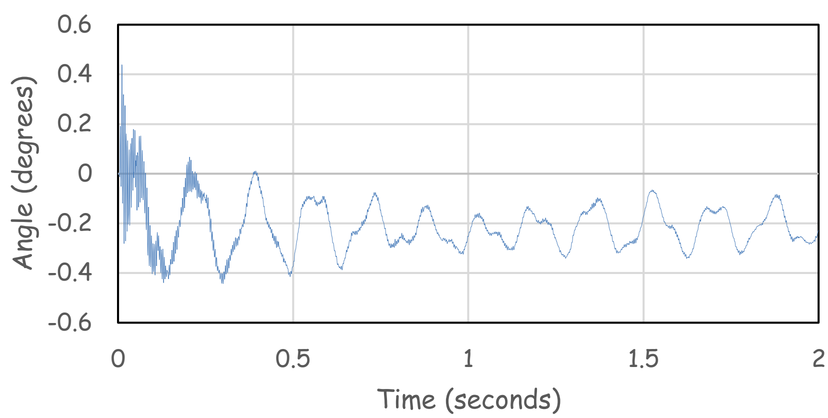
	
0.07 s	**0.14 s**
	
0.08 s	**0.2 s**
	
0.1 s	**0.3 s**

Table 12. Comparison of Sequential Frames for Actual Crash Test and Finite Element Simulations

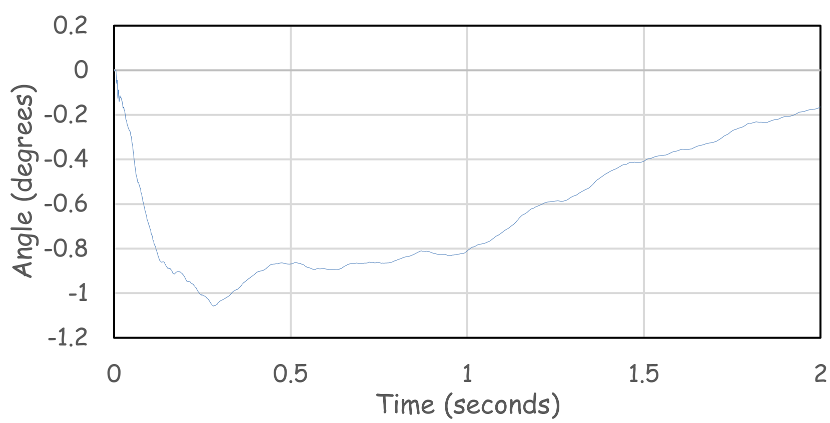
	
0.0 s	
	
0.139 s	
	
0.282 s	
	
0.421sec	



Roll



Pitch



Yaw

Figure 50. Roll, Pitch, and Yaw Values from Finite Element Model

Table 13. Comparison of Occupant Risk Assessment Values of Actual Crash Test and FEA Simulation

	Actual Crash Test	FEA Simulation
Longitudinal OIV Lateral OIV	2.3 ft/s 1.0ft	2.62 ft/s 0.65 ft/s
Longitudinal Ridedown Lateral Ridedown	-0.3 g -0.3 g	2.5 g -0.8 g
Max 0.050-s Average		
Longitudinal Lateral Vertical	-1.3 g 0.4 g 0.5g	-1.7 g -1.0 g 2.0 g
Maximum Roll Maximum Pitch Maximum Yaw	-1 deg -1 deg 1 deg	0.3 deg -0.4 deg -1.1 deg

4.4. Conclusion

A comparison of LS DYNA simulation results and actual crash test values reveals that the computer models (system and vehicle) can be considered calibrated to the actual crash test. The simulated impact event closely matches the actual crash test events. The longitudinal ridedown acceleration value is over predicted in the computer model to the actual result obtained through the full-scale crash test because the values are very low in general. The general behavior of the test article in the simulations was exactly similar to the actual crash test. Also, the FEA model closely replicates the testing outcomes, in terms of vehicle stability and general behavior during an impact event.

4.5. Full-Scale Impact Simulations

Multiple FE simulations were conducted for the most used large signpost system. The developed option of the signpost system was designed considering the results obtained from the survey. The developed computer impact simulations were performed with both car and pickup truck. The researcher investigated impact details, such as impact angles and critical impact locations based on additional vehicle dynamic analysis. Such analysis characterized the behavior of the vehicle once entering and traversing the slope. The following full-scale crash simulations were conducted for further consideration:

1. Impact Simulations on Flat-Level Ground (As per MASH TL-3 conditions).
2. Parametric Impact Simulations on Sloped Terrain.

For option 2, a parametric study was conducted to investigate potential critical angle and edge distance for vehicular impacts.

4.6. Limitations of LS-DYNA

The calculation time in LS-DYNA is huge, as it involves the inversion of the stiffness matrix at each degree of freedom of numerous nodes. The LS-DYNA is better in explicit time integration but lags for not counting the effects of inertia. LS-DYNA includes multiple properties which is a huge advantage but at the same time complexity of using these material properties is very high.

In LS-DYNA, when there is very high pressure between the interfaces, such as in the process with ironing. There is a plane stress assumption for the shell element, if the normal stress is too high, this assumption will be broken. In this case, maybe a solid element should be used if the CPU costs are affordable. When the dynamic effect is big, such as in crash forming simulation. In this case, less mass scaling and low punch velocity should be used.

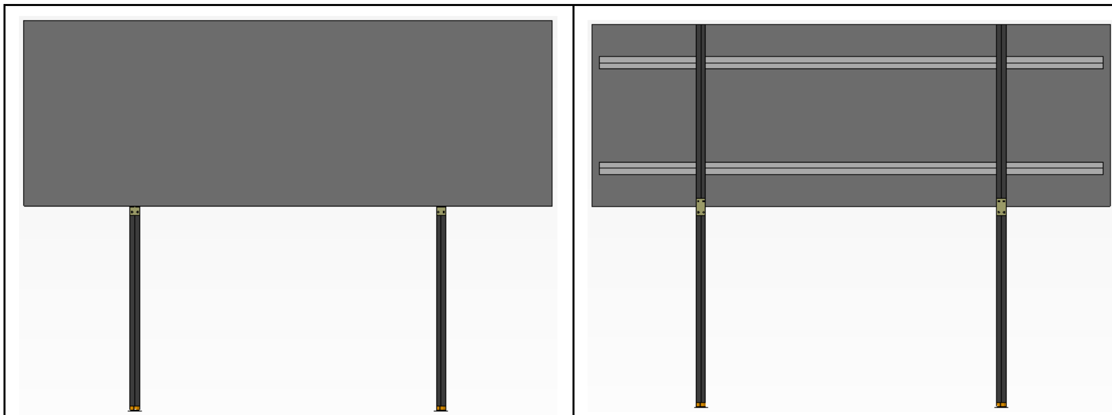
As element size decreased, the element-maintained capacity for large strains that exceed what is expected. While the formulation does have an option to manually adjust post-peak scaling based on element size and the use of this feature does improve consistency of the behavior predicted by the element, the accuracy, is not improved. Additionally, users should be cautious of using element sizes, as this was shown to cause erroneous results.

5. FINITE ELEMENT SIMULATIONS ON FLAT-LEVEL GROUND ACCORDING TO MASH

5.1. Introduction

The section herein presents a detailed design of a large signpost system. Comprehensive finite element computer modeling of the systems was performed. The detailed FE model of the large signpost system included a realistic replica of the large signposts, sign panels, slip base system, and connection details, such as fuse plates, zee channels, etc. Simulations based on MASH TL-3 test conditions were conducted with a 1100C car and 2270P pickup truck impacting the large sign support system. Two simulation cases were considered for each vehicle: 1) vehicle impacting test article at low speed; 2) vehicle impacting test article at high speed.

Figure 51 illustrates the FE model developed in LS-DYNA for simulations on the flat-level ground.



Front View	Back View

Figure 51. Developed Finite Element Model

For modeling, different sectional and material properties were defined in LS-Pre post. Shell elements were used to model all the elements except the top base plate and springs. The sign panel and sign supports were modeled using elastic material (MAT001). The top slipbase plate was modeled using a solid section and rigid material (MAT020). The bolts of the triangular slipbase were also not modeled explicitly. Instead, four nonlinear springs were modeled. One end of each spring was attached to the top slipbase plate, and the other end was attached to the rigid bottom plate. The force-deflection properties of the springs were calibrated from the FE model used for preliminary validation. The complexity of the slipbase model was greatly reduced using the above-mentioned modeling techniques without significant loss of accuracy of results. This technique enabled multiple impact simulations to be conducted within the resources of the project. The springs were modeled using the discrete element and were given spring general non-linear (MATS06) element properties. Figure 52 illustrates the slipbase system with springs. MAT024 - Piecewise linear plasticity was used to define the material properties of the fuse plate. To incorporate the failure of the hinge plate due to vehicle impact, MAT 000-ADD EROSION was used. The ADD EROSION option provides a way of including failure in the model although the option can also be applied to constitutive models with other failure/erosion criteria. The maximum principal stress of 498 MPa at failure for the erosion was used. It was determined from the validation model which was used for fuse plate erosion keyword values. Figure 53 shows the local finite model of the fuse and hinge plate.

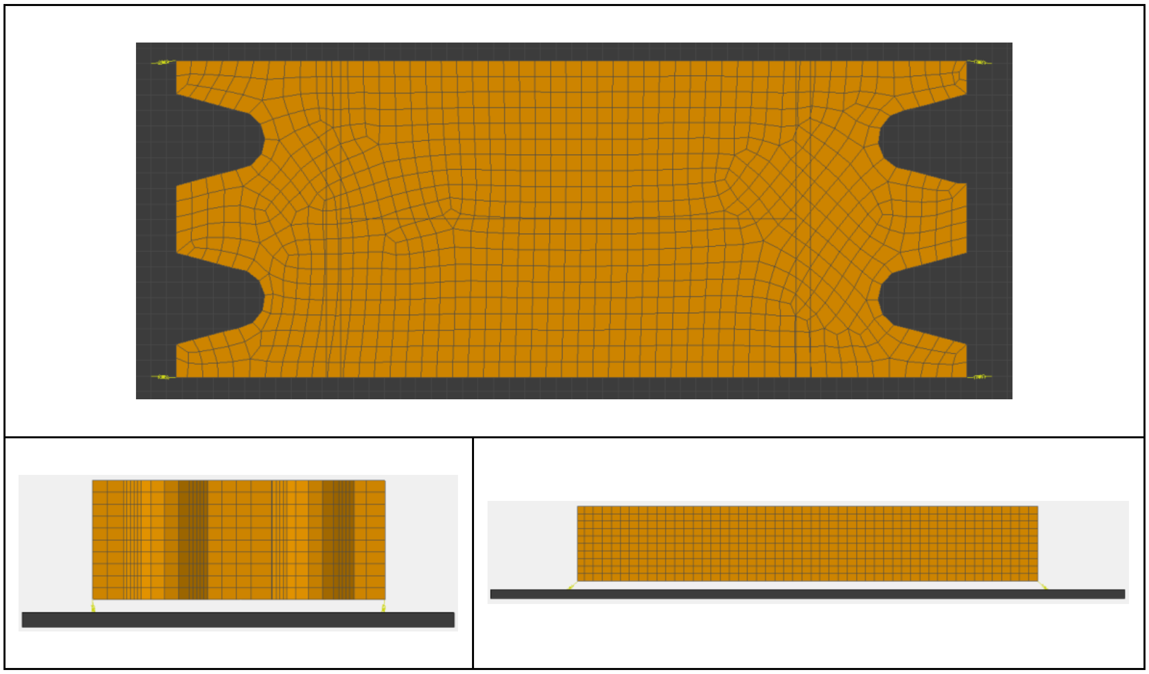
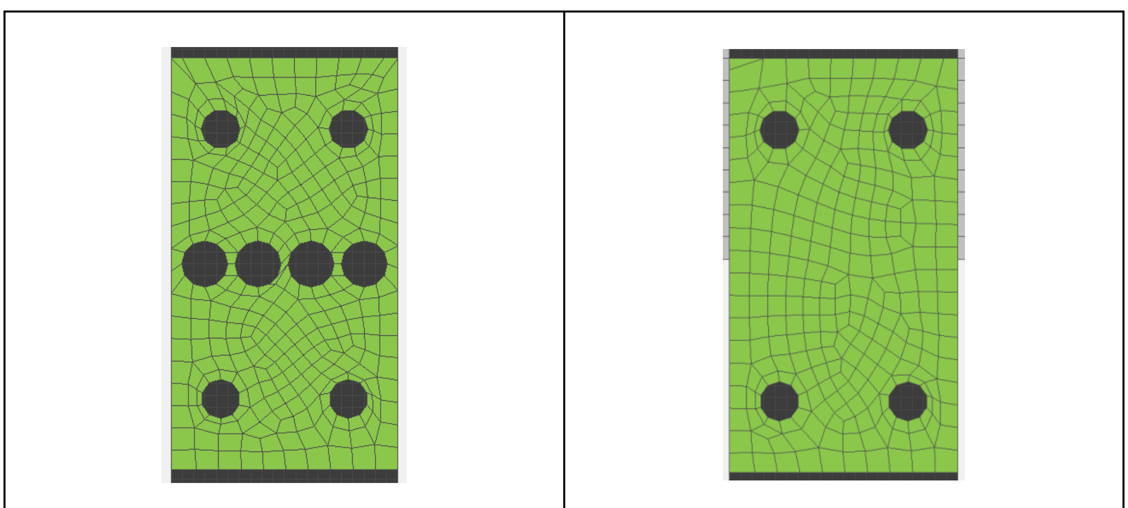


Figure 52. Finite Element Model of Slipbase Plate



Fuse Plate	Hinge Plate

Figure 53. Finite Element Model of Fuse Plate and Hinge Plate

The W6×12 section was used for sign supports. The thickness of the slipbase plate was 1 5/8 in. and the thickness of the fuse plate was 3/8 in. The thickness of the hinge plate was exactly like the thickness of the sign support flange. The keeper plate between the top and bottom slipbase plates is 0.0149 in. (28 gauge) thick.

Single Point Constraint Boundary connection was used to fix the steel plate to top slipbase plates. Constrained Nodal Rigid Body connection was provided to connect the fuse plate with sign supports. Constrained Extra Nodes Set was used to attach slipbase plates to sign supports. Rigid Wall was used to provide contact between vehicle tires and travel way.

After running various simulations of the sign support system acting under gravity with stability, the model was used for the actual impact simulations with car and pickup truck models.

5.2. Detailed Finite Element Analysis of Sign Post System with Car (1100C)

The sign support system was impacted with small vehicle (1100C) at low speed (19 mph) and high speed (62 mph). The vehicle impacted the sign support system at an angle of 0 degrees to the roadway. Based on MASH requirements, the simulation event involves a 1100C vehicle weighing around 2420 lb. For simulations, the already calibrated finite element model of Toyota Yaris was used.

5.2.1. Low-Speed MASH Test Level 3 (Test No. 3-60)

5.2.1.1. Vehicle Stability and Sign Support System Performance

The finite element model of the small vehicle (1100C), traveling at a speed of 19 mph and 0 degrees angle, impacted the large sign support system. The centerline of the left leg support was impacted by the quarter point of the vehicle. Immediately after the impact, the left leg started moving and slipped away at the base.

At 0.08 s, the fuse plate attached to the impact side got activated. The vehicle lost the contact with the support leg at 0.09 s and was traveling at 18 mph. The hinge on the left support got activated at 0.3 s.

By 0.36 s, the upper fuse and hinge plate connection on the left support leg was completely ruptured. After the complete rupture of connection plates of the left leg, the support began to move in the direction of the vehicle. At the same time sign panel started rotating in the direction of the vehicle with the right leg still intact. Support and sign panel did not come in contact with the vehicle. At 0.7 s the vehicle safely crossed the signpost assembly. Table 14 shows the complete sequential photographs of the simulations.

Table 14. Sequential Images of the FE Simulations for Car at Low Speed

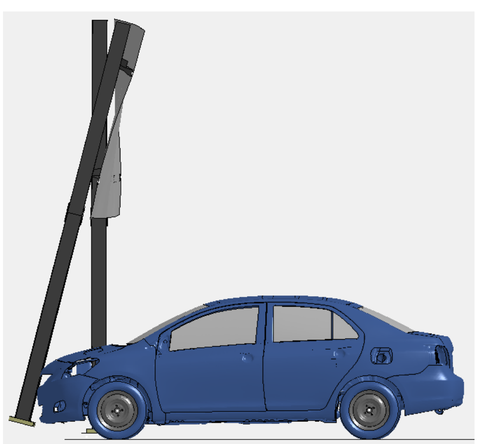
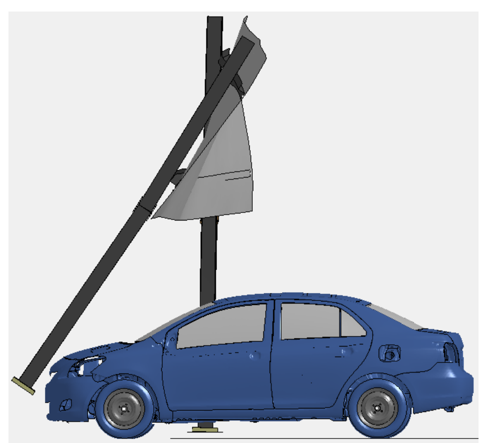
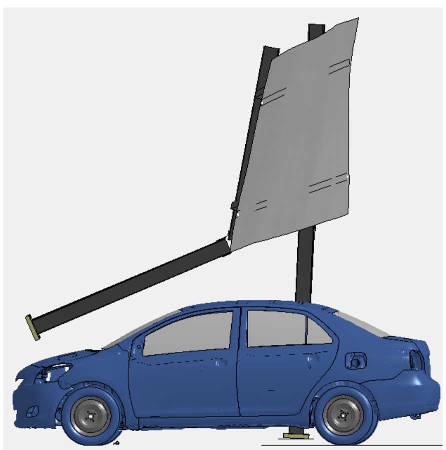
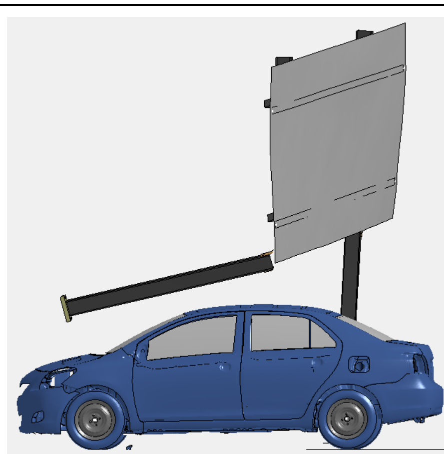
	
0 s	0.12 s
	
0.04 s	0.16 s
	
0.08 s	0.2 s

Table 14. Continued

	
0.3 s	0.5 s
	
0.35 s	0.7 s
	
0.4 s	0.9 s

5.2.1.2. Occupant Risk Assessment

Data from the accelerometer, located in the vehicle at the center of gravity was used to compute occupant risk factors based on MASH safety criteria. The TRAP program was used to digitize the values obtained from the finite element model. In the longitudinal direction, the occupant impact velocity and the occupant ridedown acceleration was very low as there was no impact in the vehicle interior. The maximum 0.050-s average acceleration in the longitudinal direction was −1.3 Gs between 0.0055 and 0.0555 s. In the lateral direction, the average acceleration was −0.7 Gs between 0.7875 and 0.8375 s. The maximum roll, pitch, and yaw angles were -0.3, -0.6, and -2.1 degrees respectively (See Figure 54). Figure 55 summarizes the above data and other important information from the test.

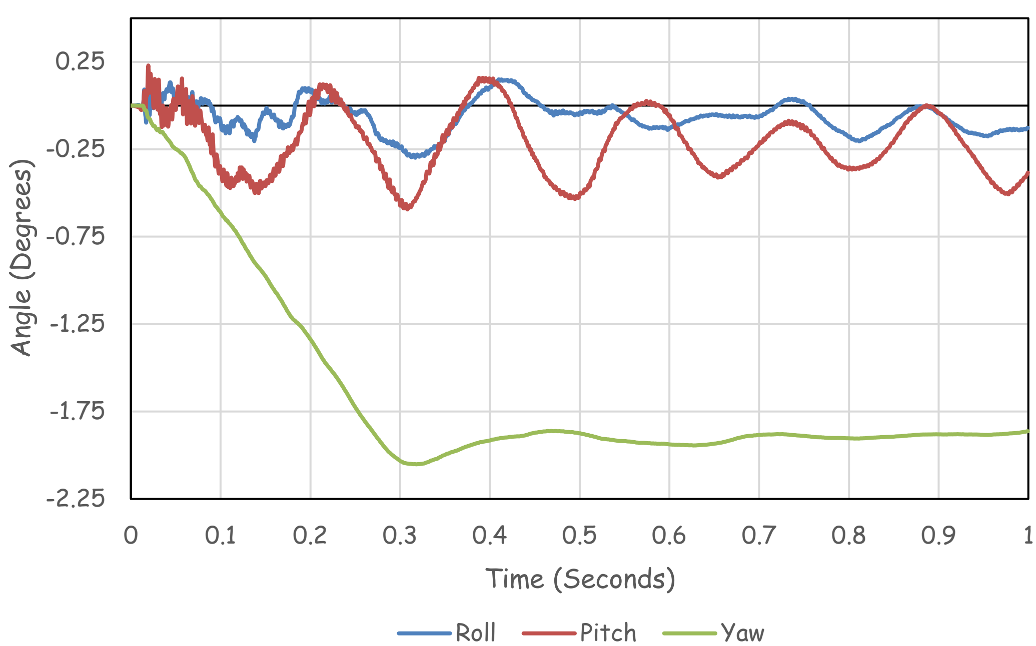


Figure 54. Angular Displacements for 1100C Vehicle at Low Speed

5.2.1.3. Summary

An assessment of the impact simulation based on the applicable MASH safety evaluation criteria is provided below.

1. The test article should readily activate predictably by breaking away, fracturing, or yielding.

   Results: When impacted by the 1100C vehicle, the left leg of the large sign support activated by breaking away at the slipbase and the upper hinge connections. (PASS)

2. 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 outlined in Section 5.3 and Appendix E of MASH: deformation in the roof should be less than equal to 4.0 inches; deformation in windshield should be less than equal to 3.0 inches; there should be no shattering by test article structural member inside windows; deformation in wheel/ footwell/ toe pan should be less than 9.0 inches; deformation in forward A-pillar should be less than 12.0 inches; deformation in front side door area above seats should be less than 9.0 inches and in front side door below seat should be less than 12.0 inches; deformation in floor pan/transmission tunnel area should be less than 12.0 inches.

   Results: The left support leg separated from the installation. However, the 1100C vehicle traveled beneath these elements. The elements did not penetrate or show potential for penetrating the occupant compartment, nor to present a hazard to others in the area. No occupant compartment deformation occurred during the test with the 1100C vehicle. (PASS)

3. The vehicle should remain upright during and after the collision. The maximum roll and pitch angles should not exceed 75 degrees.

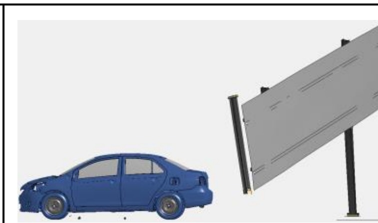
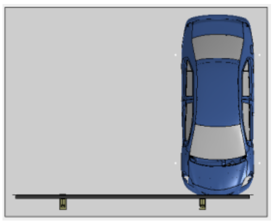
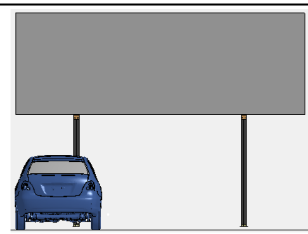
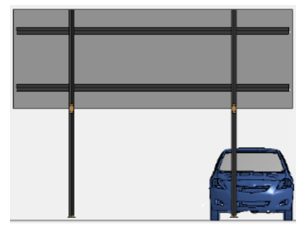
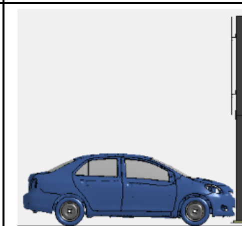
   Results: The 1100C vehicle remained upright during and after the collision event. The maximum roll and pitch angles were −1 degree for roll and pitch angles. (PASS)

4. Longitudinal and Lateral impact velocity should be less than 16.4 ft/s

   Result: Longitudinal and lateral occupant impact velocity were less than the maximum limits. (PASS)

5. Occupant ridedown acceleration should be less than 20.49 G.

   Result: Longitudinal and lateral ridedown acceleration were very low. (PASS)

			
0.00 s	0.2 s	0.4 s	0.9 s
			
Top View	Front View	Back View	Side View

General Information
Test Agency: Texas A&M Transportation Institute
Test Standard Test No. MASH TL-3 (3-60)

Test Article
Type: Sign Support System
Name: MASH TL-3 Sign Support System
Material or Key Elements: Steel
Soil Type: Concrete Pavement

Test Vehicle
Type/Designation: 1100C
Make and Model: Finite Element Yaris
Curb: 2420 lb
Dummy: No Dummy

Impact Conditions
Speed: 19 mph
Angle: 0 degrees
Location/Orientation: Left Leg

Occupant Risk Values
Longitudinal OIV: Nil
Lateral OIV: Nil
Longitudinal Ridedown: Nil
Lateral Ridedown: Nil

Max. 0.050-s Average
Longitudinal: -1.8 G
Lateral: 0.7 G
Vertical: 1.1 G

Post-Impact Trajectory
Stopping Distance: N/A

Vehicle Stability
Maximum Roll Angle: -0.3 degrees
Maximum Pitch Angle: -0.6 degrees
Maximum Yaw Angle: -2.1 degrees

Vehicle Roof Deformation: 0 in.

Figure 55. Summary of Finite Element Simulation for 1100C Vehicle at Low Speed.

5.2.2. High-Speed MASH Test Level 3 (Test No. 3-61)

5.2.2.1. Vehicle Stability and Sign Support System Performance

The FE model of the small vehicle (1100C), traveling at a speed of 62 mph and 0 degrees angle, impacted the large sign support system. The centerline of the left leg support was impacted by the quarter point of the vehicle. Immediately after the impact, the left leg started moving and slipped away at the base.

At 0.016 s, the fuse plate attached to the impact side got activated. The vehicle lost the contact with the support leg at 0.066 s and was traveling at 58.93 mph. The hinge on the left support hot activated at 0.074 s. The fuse plate on right was activated at 0.12 s.

By 0.134 s, the upper fuse and hinge plate connection on the left support leg was completely ruptured. After the complete rupture of left leg connection plates, the support began to move in the direction of the vehicle. At the same time, the sign panel started tilting towards the vehicle with the right leg still in position. The hinge plate on the right leg was activated at 0.158 s. Support and sign panel did not come in contact with the vehicle. At 0.25 s the vehicle safely crossed the signpost assembly. Table 28 shows the complete sequential photographs of the simulations.

Table 15. Sequential Images of the FE Simulations for Car at High Speed

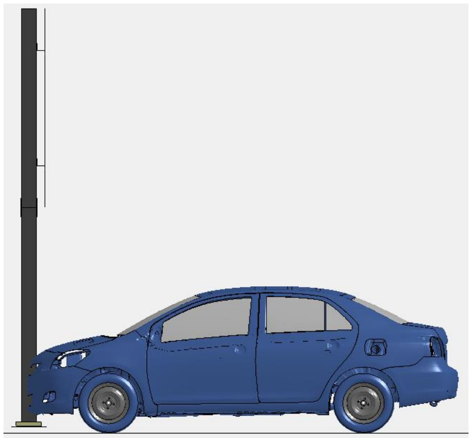
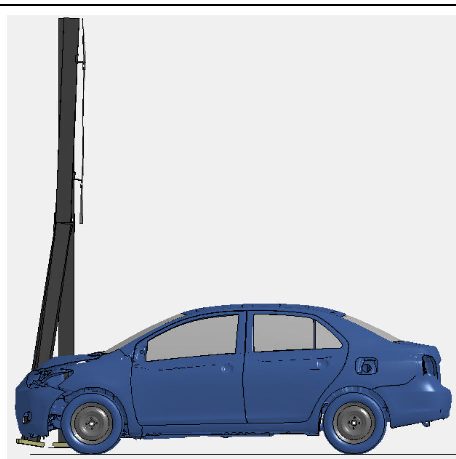
	
0 s	0.03 s
	
0.01 s	0.04 s
	
0.02 s	0.05 s

Table 15. Continued

	
0.07 s	0.13 s
	
0.09 s	0.15 s
	
0.11 s	0.2 s

5.2.2.2. Occupant Risk Assessment

Data from the accelerometer, located in the vehicle at the center of gravity was used to compute occupant risk factors based on MASH safety criteria. The TRAP program was used to digitize the values obtained from the FE model. In the longitudinal direction, the occupant impact velocity and the occupant ridedown acceleration was very low as there was no impact in the vehicle interior. The maximum 0.50-s average acceleration in the longitudinal direction was −3.2 Gs between 0.0020 and 0.0520 s. In the lateral direction, the average acceleration was −1.9 Gs between 0.0110 and 0.0610 s. The maximum roll, pitch, and yaw angles were 0.5, -0.5, and -6.5 degrees respectively (See Figure 56). Figure 57 summarizes the above data and other important information from the test.

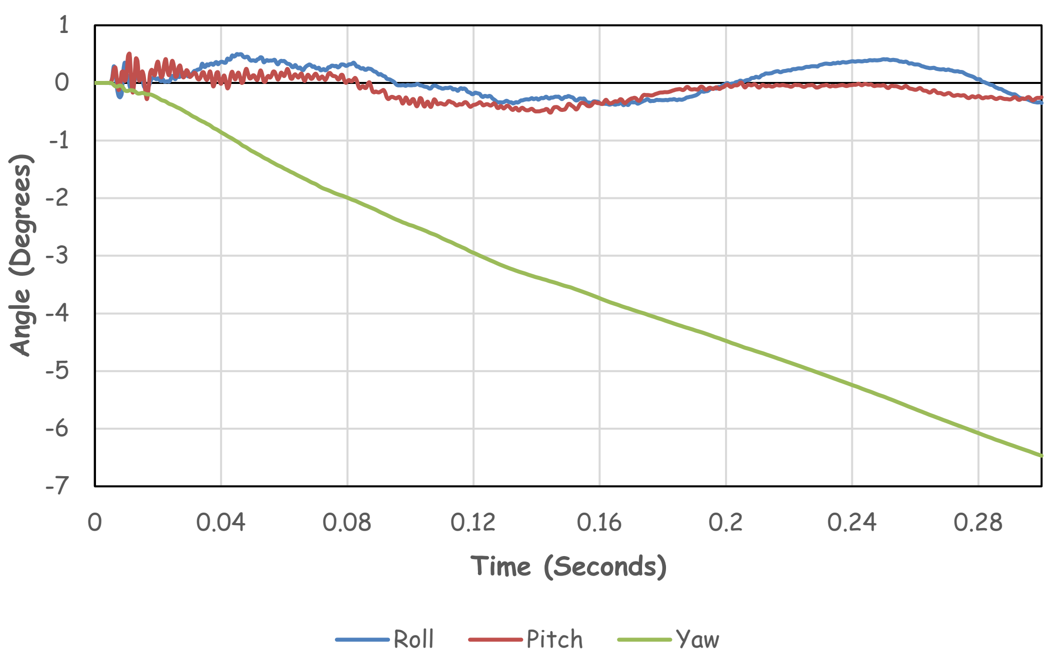


Figure 56. Angular Displacements for 1100C Vehicle at High Speed

5.2.2.3. Summary

An assessment of the impact simulation on the applicable MASH safety evaluation criteria is provided below.

1. The test article should readily activate predictably by breaking away, fracturing, or yielding.

   Results: When impacted by the 1100C vehicle, the left leg of the large sign support activated by breaking away at the slipbase and at the upper hinge connections. (PASS)

2. 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 outlined in Section 5.3 and Appendix E of MASH: *deformation in the roof should be less than equal to 4.0 inches; deformation in windshield should be less than equal to 3.0 inches; there should be no shattering by test article structural member inside windows; deformation in wheel/ footwell/ toe pan should be less than 9.0 inches; deformation in forward A-pillar should be less than 12.0 inches; deformation in front side door area above seats should be less than 9.0 inches and in front side door below seat should be less than 12.0 inches; deformation in floor pan/transmission tunnel area should be less than 12.0 inches.*

Results: The left support leg separated from the installation. However, the 1100C vehicle traveled beneath these elements. The elements did not penetrate or show potential for penetrating the occupant compartment, nor to present a hazard to others in the area. No occupant compartment deformation occurred during the test with the 1100C vehicle. (PASS)

3. The vehicle should remain upright during and after the collision. The maximum roll and pitch angles should not exceed 75 degrees.

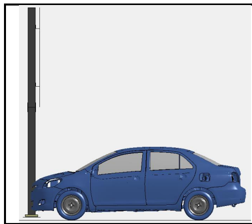
   Results: The 1100C vehicle remained upright during and after the collision event. The maximum roll and pitch angles were less than 1 degree for roll and pitch. (PASS)

4. Longitudinal and Lateral impact velocity should be less than 16.4 ft/s

   Result: Longitudinal and lateral occupant impact velocities were less than the maximum limits. (PASS)

5. Occupant ridedown acceleration should be less than 20.49 G.

   Result: Longitudinal and lateral ridedown acceleration were very low. (PASS)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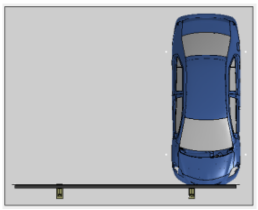
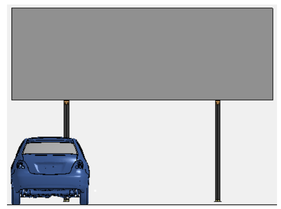
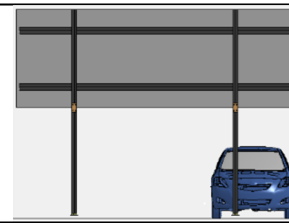
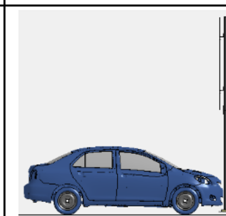
			
Top View	Front View	Back View	Side View

General Information
Test Agency: Texas A&M Transportation Institute
Test Standard Test No. MASH TL-3 (3-61)

Test Article
Type: Sign Support System
Name: MASH TL-3 Sign Support System
Material or Key Elements: Steel
Soil Type: Concrete Pavement

Test Vehicle
Type/Designation: 1100C
Make and Model: Finite Element Yaris
Curb: 2420 lb
Dummy: No Dummy

Impact Conditions
Speed: 62 mph
Angle: 0 degrees
Location/Orientation: Left Leg

Occupant Risk Values
Longitudinal OIV: Nil
Lateral OIV: Nil
Longitudinal Ridedown: Nil
Lateral Ridedown: Nil

Max. 0.050-s Average
Longitudinal: -3.2 G
Lateral: -1.9 G
Vertical: 2.0 G

Post-Impact Trajectory
Stopping Distance: N/A

Vehicle Stability
Maximum Roll Angle: 0.5 degrees
Maximum Pitch Angle: -0.5 degrees
Maximum Yaw Angle: -6.5 degrees

Vehicle Roof Deformation: 0 in.

Figure 57. Summary of Finite Element Simulation for 1100C Vehicle at High Speed

5.3. Detailed Finite Element Analysis of Sign Post System with Pickup Truck (2270P)

The sign support system was impacted with a pickup truck (2270P) at high speed (62 mph) and low speed (19 mph). The vehicle impacted the sign support system at an angle of 0 degrees with respect to the roadway. Based on MASH requirements, the simulation event involves a 2270C vehicle weighing around 5000 lb. For simulations, an already calibrated finite element model of Silverado RAM was used.

5.3.1. High-Speed MASH Test Level 3 (Test No. 3-62)

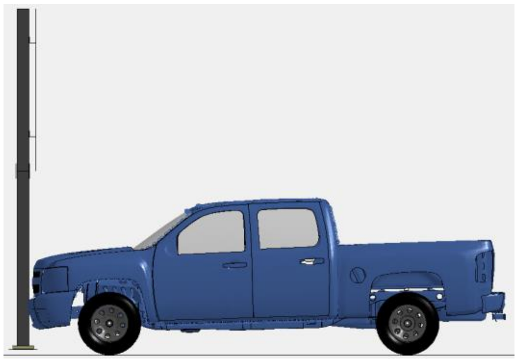
5.3.1.1. Vehicle Stability and Sign Support System Performance

The finite element model of the small vehicle (2270P), traveling at a speed of 62 mph and 0 degrees angle, impacted the large sign support system. The centerline of the left leg support was impacted by the quarter point of the vehicle. Immediately after the impact, the left leg started moving and slipped away at the base.

At 0.13 s, the fuse plate attached to the impact side got activated. The hinge on the left support got activated at 0.53 s. The vehicle lost the contact with the support leg at 0.59 s and was traveling at 60.59 mph. At 0.089 s, the fuse plate attached to right got activated.

The hinge on the right leg got activated at 0.118 s. By 0.13 s, the upper fuse and hinge plate connection on the left support leg was completely ruptured. After the complete rupture of left leg connection plates, the support began to move in the direction of the vehicle. The right leg also started rotating about its axis. Support and sign panel both came in contact with the roof of the vehicle. The maximum deformation of 2.708 in. was seen in the roof. At 0.224 s the vehicle safely crossed the signpost assembly. Table 16 shows the complete sequential photographs of the simulations.

Table 16. Sequential Images of the FE Simulations for Pickup Truck at High Speed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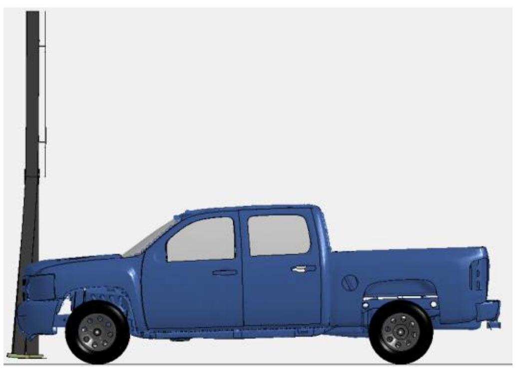	
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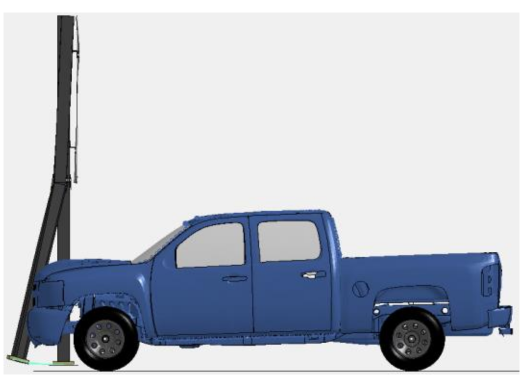	
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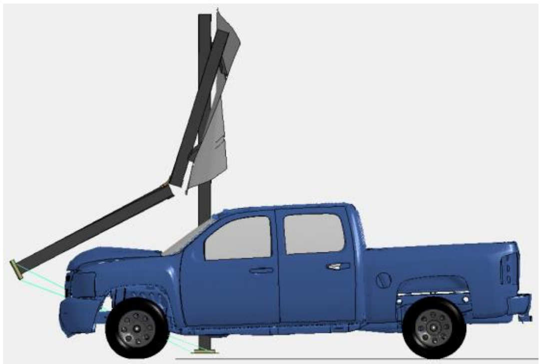
Table 16. Continued

	
0.07 s	0.13 s
	
0.09 s	0.15 s
	
0.11 s	0.2 s

5.3.1.2. Occupant Risk Assessment

Data from the accelerometer, located in the vehicle at the center of gravity was used to compute occupant risk factors based on MASH safety criteria. The TRAP program was used to digitize the values obtained from the FE model. In the longitudinal direction, the occupant impact velocity and the occupant ridedown acceleration was very low as there was no impact in the vehicle interior. The maximum 0.050-s average acceleration in the longitudinal direction was -2.6 Gs between 0.0035 and 0.0535 s. In the lateral direction, the average acceleration was -1.7 Gs between 0.0750 and 0.1250 s. The maximum roll, pitch, and yaw angles were -0.5, -0.6, and -0.9 degrees respectively (See Figure 58). Figure 59 summarizes the above data and other important information from the test.

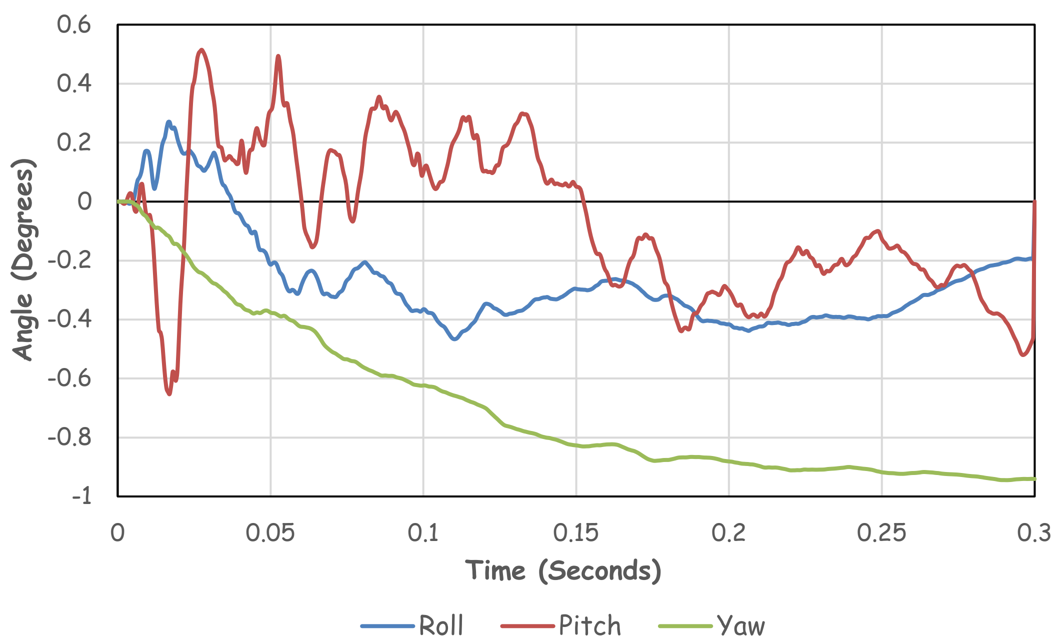


Figure 58. Angular Displacements for 2270P Vehicle at Low Speed.

5.3.1.3. Summary

An assessment of the impact simulation based on the applicable MASH safety evaluation criteria is provided below.

1. The test article should readily activate predictably by breaking away, fracturing, or yielding.

   Results: When impacted by the 2270P vehicle, the left leg of the large sign support activated by breaking away at the slipbase and the upper hinge connections. (PASS)

2. 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 outlined in Section 5.3 and Appendix E of MASH: deformation in the roof should be less than equal to 4.0 inches; deformation in windshield should be less than equal to 3.0 inches; there should be no shattering by test article structural member inside windows; deformation in wheel/ footwell/ toe pan should be less than 9.0 inches; deformation in forward A-pillar should be less than 12.0 inches; deformation in front side door area above seats should be less than 9.0 inches and in front side door below seat should be less than 12.0 inches; deformation in floor pan/transmission tunnel area should be less than 12.0 inches.

   Results: The left support leg separated from the installation. However, the 2270P vehicle traveled beneath these elements. The elements did not penetrate or show

potential for penetrating the occupant compartment, nor to present a hazard to others in the area. (PASS)

The deformation of 2.708 in. was occurred in the roof during the test with the 2270P vehicle. The maximum allowed deformation in the roof is 4 in. (PASS)

3. The vehicle should remain upright during and after the collision. The maximum roll and pitch angles should not exceed 75 degrees.

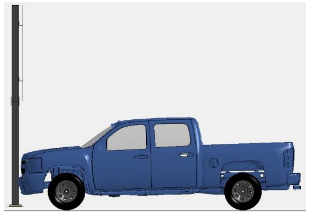
   Results: The 2270C vehicle remained upright during and after the collision event. The maximum roll and pitch angles were less than 1 degree. (PASS)

4. Longitudinal and Lateral impact velocity should be less than 16.4 ft/s

   Result: Longitudinal and lateral occupant impact velocities were less than the maximum limits. (PASS)

5. Occupant ridedown acceleration should be less than 20.49 G.

   Result: Longitudinal and lateral ridedown acceleration were very low. (PASS)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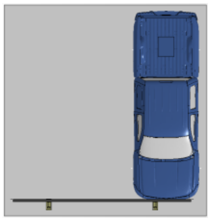
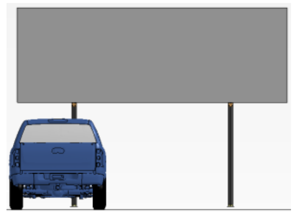
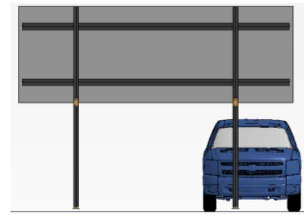
			
Top View	Front View	Back View	Side View

General Information Test Agency: Texas A&M Transportation Institute Test Standard Test No. MASH TL-3 (3-62) **Test Article** Type: Sign Support System Name: MASH TL-3 Sign Support System Material or Key Elements: Steel **Soil Type**: Concrete Pavement **Test Vehicle** Type/Designation: 2270P Make and Model: Finite Element Silverado Curb: 5000 lb. Dummy: No Dummy	**Impact Conditions** Speed: 62 mph Angle: 0 degrees Location/Orientation: Left Leg **Occupant Risk Values** Longitudinal OIV: Nil Lateral OIV: Nil Longitudinal Ridedown: Nil Lateral Ridedown: Nil **Max. 0.050-s Average** Longitudinal: -2.6 G Lateral: -1.7 G Vertical: 1.4 G	**Post-Impact Trajectory** Stopping Distance: N/A **Vehicle Stability** Maximum Roll Angle: -0.5 degrees Maximum Pitch Angle: -0.6 degrees Maximum Yaw Angle: -0.9 degrees **Vehicle Roof Deformation: Yes** Max Deformation: 2.708 in. (68.8 mm)

Figure 59. Summary of Finite Element Simulation for 2270P Vehicle at High Speed

5.3.2. Low Speed (*Non-Standard*)

The MASH does not require investigation of a pickup truck (2270P) impacting the test article at low speed. But to investigate the activation of the breakaway system and to find the interaction between the roof of the vehicle and the sign, the test was also conducted at 19 mph.

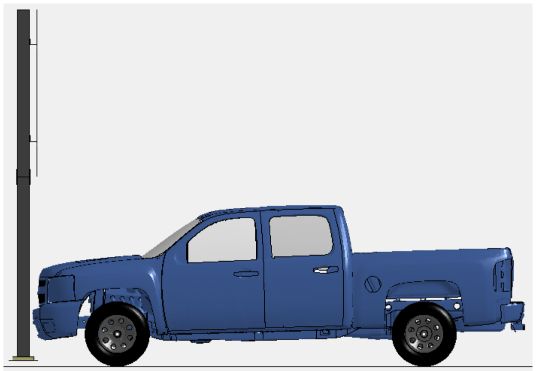
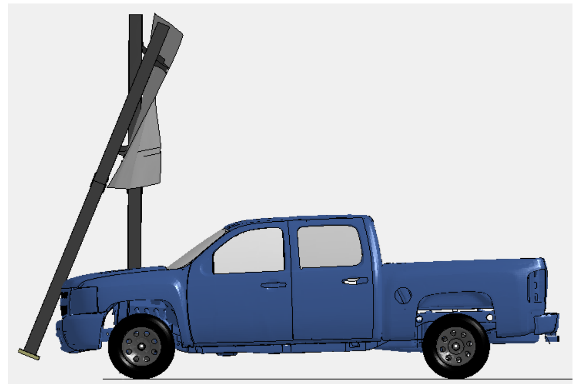
5.3.2.1. Vehicle Stability and Sign Support System Performance

The FE model of the small vehicle (2270P), traveling at a speed of 19 mph and 0 degrees angle, impacted the large sign support system. The centerline of the left leg support was impacted by the quarter point of the vehicle. Immediately after the impact, the left leg started moving and slipped away at the base.

At 0.13 s, the fuse plate attached to the impact side got activated. The vehicle lost the contact with the support leg at 0.21 s and was traveling at 19.19 mph. The hinge on the left support got activated at 0.33 s.

By 0.37 s, the upper fuse and hinge plate connection on the left support leg was completely ruptured. After the complete rupture of left leg connection plates, the support began to move in the direction of the vehicle. At the same time sign panel started rotating in the longitudinal direction and the right leg was still in position. The hinge plate on the right leg was activated at 0.53 s and was completely ruptured by 0.64 s. The right leg also started rotating about its axis. Support and sign panel both came in contact with the roof of the vehicle. The maximum deformation of 3.574 in. was seen in the roof. At 0.83 s the vehicle safely crossed the signpost assembly. Table 17 shows the complete sequential photographs of the simulations.

Table 17. Sequential Images of the FE Simulations for Pickup Truck at Low Speed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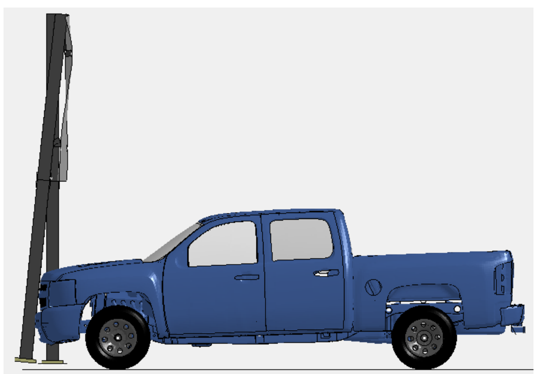	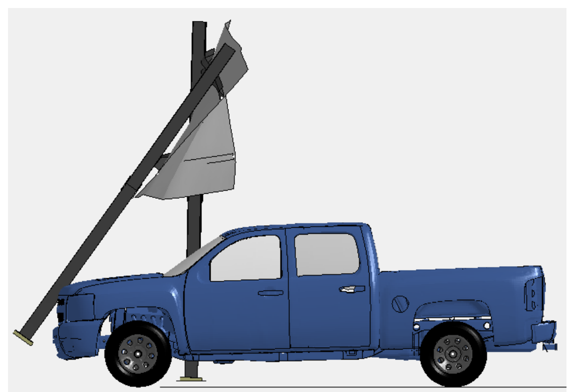
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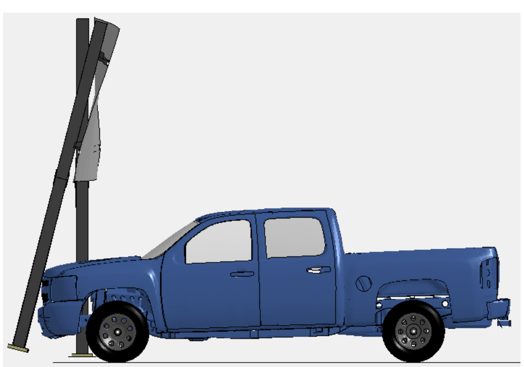
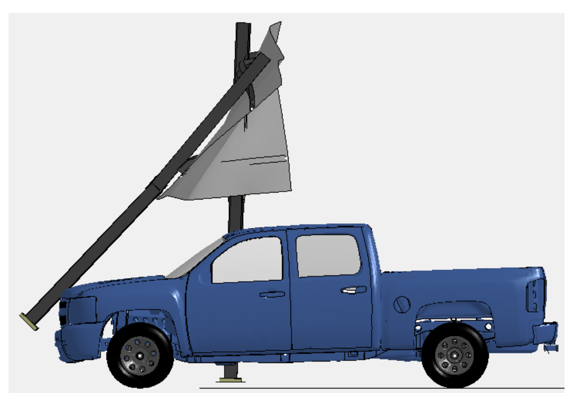
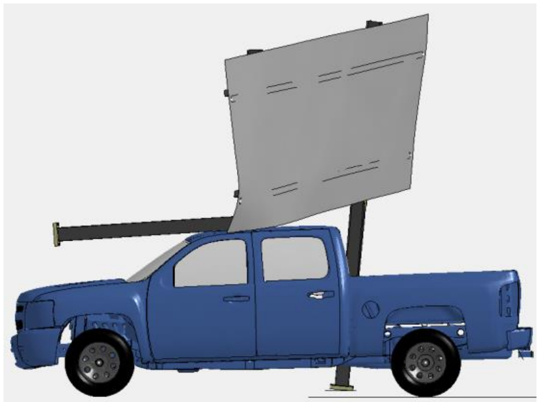
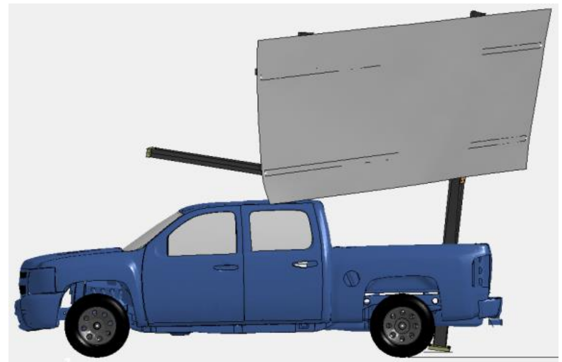
	
0.08 s	0.25 s

Table 17. Continued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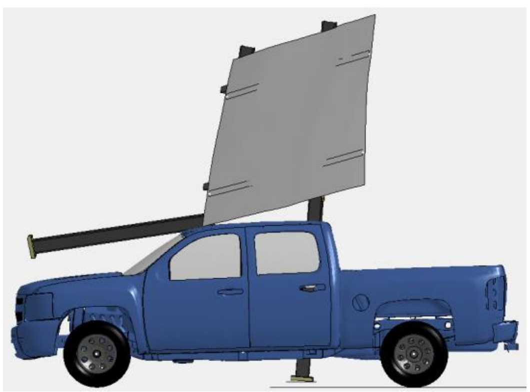	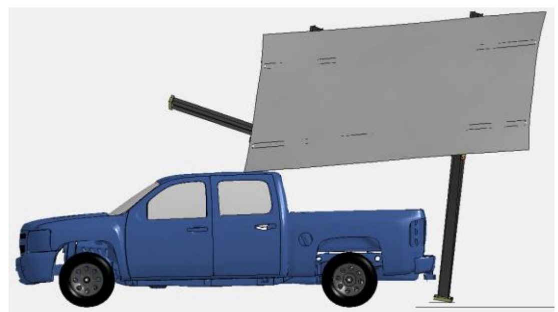
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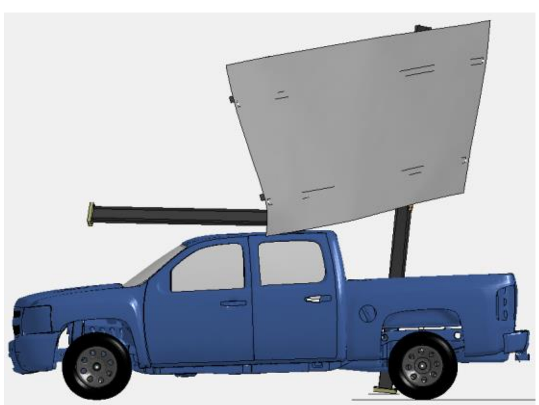
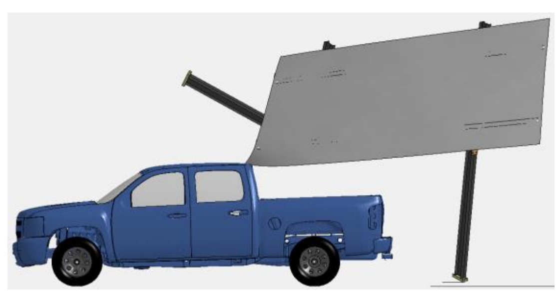
	
0.5 s	0.8 s

5.3.2.2. Occupant Risk Assessment

Data from the accelerometer, located in the vehicle at the center of gravity was used to compute occupant risk factors based on MASH safety criteria. The TRAP program was used to digitize the values obtained from the finite element model. In the longitudinal direction, the occupant impact velocity and the occupant ridedown acceleration was very low as there was no impact in the vehicle interior. The maximum 0.050-s average acceleration in the longitudinal direction was 1.6 Gs between 0.4480 and 0.4980 s. In the lateral direction, the average acceleration was 1.4 Gs between 0.6425 and 0.6925 s. The maximum roll, pitch, and yaw angles were 0.5, -0.9, and -0.2 degrees respectively (See Figure 60). Figure 61 summarizes the above data and other important information from the test.

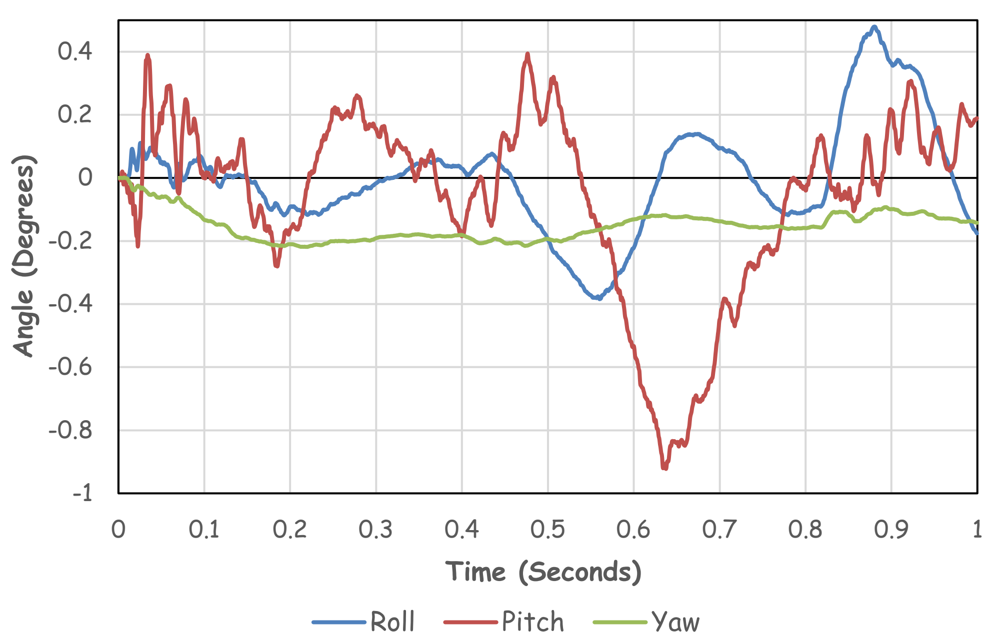


Figure 60. Angular Displacements for 2270P Vehicle at Low Speed.

5.3.2.3. Summary

An assessment of the impact simulation based on the applicable MASH safety evaluation criteria is provided below.

1. The test article should readily activate predictably by breaking away, fracturing, or yielding.

   Results: When impacted by the 2270P vehicle, the left leg of the large sign support activated by breaking away at the slipbase and the upper hinge connections. (PASS)

2. 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 outlined in Section 5.3 and Appendix E of MASH: deformation in the roof should be less than equal to 4.0 inches; deformation in windshield should be less than equal to 3.0 inches; there should be no shattering by test article structural member inside windows; deformation in wheel/ footwell/ toe pan should be less than 9.0 inches; deformation in forward A-pillar should be less than 12.0 inches; deformation in front side door area above seats should be less than 9.0 inches and in front side door below seat should be less than 12.0 inches; deformation in floor pan/transmission tunnel area should be less than 12.0 inches.

   Results: The left support leg separated from the installation. However, the 2270P vehicle traveled beneath these elements. The elements did not penetrate or show

potential for penetrating the occupant compartment, nor to present a hazard to others in the area. 3.574 in. compartment deformation occurred during the test with the 2270P vehicle. The maximum allowed deformation in the roof is 4 in. (PASS)

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

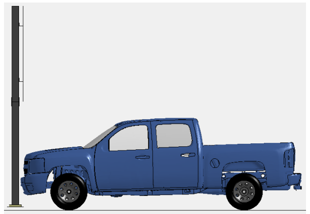
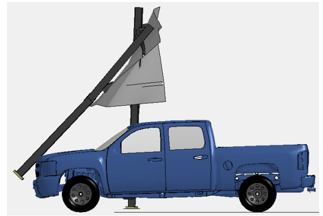
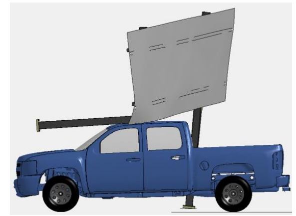
   Results: The 2270C vehicle remained upright during and after the collision event. The maximum roll and pitch angles were less than 1 degree. (PASS)

4. Longitudinal and Lateral impact velocity should be less than 16.4 ft/s

   Result: Longitudinal and lateral occupant impact velocities were less than the maximum limits. (PASS)

5. Occupant ridedown acceleration should be less than 20.49 G.

   Result: Longitudinal and lateral ridedown acceleration were very low. (PASS)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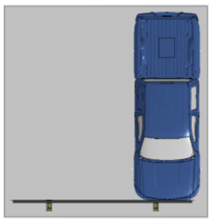
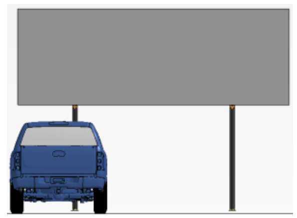
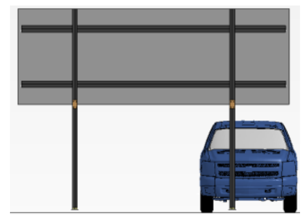
			
Top View	Front View	Back view	Side View

General Information
Test Agency: Texas A&M Transportation Institute
Test Standard Test No. Non-Standard

Test Article
Type: Sign Support System
Name: MASH TL-3 Sign Support System
Material or Key Elements: Steel
Soil Type: Concrete Pavement

Test Vehicle
Type/Designation: 2270P
Make and Model: Finite Element Silverado
Curb: 5000 lb.
Dummy: No Dummy

Impact Conditions
Speed: 19 mph
Angle: 0 degrees
Location/Orientation: Left Leg

Occupant Risk Values
Longitudinal OIV: N/A
Lateral OIV: N/A
Longitudinal Ridedown: N/A
Lateral Ridedown: N/A

Max. 0.050-s Average
Longitudinal: 1.6 G
Lateral: 1.4 G
Vertical: -1.3 G

Post-Impact Trajectory
Stopping Distance: N/A

Vehicle Stability
Maximum Roll Angle: 0.5 degrees
Maximum Pitch Angle: -0.9 degrees
Maximum Yaw Angle: -0.2 degrees

Vehicle Roof Deformation: Yes
Max Deformation: 3.574 in. (90.78 mm)

Figure 61. Summary of Finite Element Simulation for 2270P Vehicle at Low Speed.

5.4. Conclusion

Detailed finite element analysis was conducted to forecast the performance of the large signpost system on the flat-level ground. A detailed finite element model was developed based on the actual MASH compliant design. MASH test level 3 situations were replicated in the detailed impact simulations.

For the different impact simulations of test articles at low and high speed with passenger car (1100C) and a pickup truck (2270P), the slipbase of the test article was readily activated predictably. Also, there was no detachment of elements or fragments from the test article. However, there was a deformation in the roof of the pickup truck at low (19 mph) and high (62 mph) speed, but it was less than the maximum permissible limits of MASH. There was no deformation in the windshield, side windows, forward of A-pillar, front side door area above the seat, front side door area below the seat and floor plan/transmission tunnel. In conducted impact simulations on the flat-level ground, the recorded maximum angular displacements were way below the required MASH limits, passing the MASH requirements for vehicle stability.

Table 18 summarizes the different assessments performed, occupant risk factors, and angular displacements recorded in the preliminary simulations. Recorded occupant risks for each of the performed simulations were all well within MASH limits.

The FE impact simulations conducted on the flat-level ground indicated that it passed the MASH criteria. It was concluded that the test article passed all the MASH requirements on the flat-level ground. To verify the FE results, full-scale crash testing was proposed for the most critical case. The first full-scale crash test proposed is the pickup truck at high speed

(62mph) for the already installed article by Florida DOT which is MASH compliant. Based on the results of the full-scale crash test, the FE model will be calibrated. If needed, another full-scale crash test will be performed with the car at low or high speed.

It was also decided to investigate the behavior of test articles on sloped terrain. The standard MASH does not indicate any criteria for testing and evaluation of roadside support on sloped terrain. However, MASH indicates that "underlying philosophy in the development of the guidelines is that of worst practical conditions". It also indicates that "when selecting test parameters, such as the test vehicle, impact speed, angle combination, point of impact, test matrix, etc., every effort is made to specify the worst or most critical conditions". Therefore, a series of impact simulations were conducted on sloped terrain using different parameters. The impact simulations were conducted on 6H: 1V slope with parametric variables such as offset, impact angles, nominal speed, and orientation of impact. Detailed computer modeling and simulations for test article on sloped terrain is shown in chapter 8.

Table 18. Summary of Finite Element Simulations Performed on Flat Level Ground.

Test	Speed	Slipbase Activation	Occupant Compartment Penetration	Compartment Deformation (in.)	OIV (ft/s)		ORA (G)		Max 0.050s Avg. Acceleration (G)		Roll	Pitch	Yaw	Result
					Longitudinal	Lateral	Longitudinal	Lateral	Longitudinal	Lateral				
Car (1100C)	19 mph	Yes	No	Nil	Nil	Nil	Nil	Nil	-1.8	0.7	-0.3	-0.6	-2.1	PASS
	62 mph	Yes	No	Nil	Nil	Nil	Nil	Nil	-3.2	-1.9	0.5	-0.5	-6.5	PASS
Pickup (2270P)	62 mph	Yes	No	2.708	Nil	Nil	Nil	Nil	-2.6	-1.7	-0.5	-0.6	-0.9	PASS
	19 mph	Yes	No	3.574	Nil	Nil	Nil	Nil	1.6	1.4	0.5	-0.9	-0.2	PASS

6. FLAT-LEVEL GROUND FULL-SCALE CRASH TEST PLAN ACCORDING TO MASH

6.1. Test Plan

Based on engineering evaluation and FE impact simulations results, the researcher determined the design details and installation characteristics for the large sign support systems on the flat level ground to be advanced for construction and testing.

For this task, the researcher worked closely with the technical representative of the project and the other Roadside Pooled Fund DOTs members to determine details of the installation characteristics of the sign support system to be constructed.

Appropriate drawings (see Figure 62 - Figure 71) was developed to aid the construction of the approved systems and to guide installation procedures for the full-scale crash testing plan. The approved system will be constructed according to MASH 2016 requirements.

The first objective of the proposed testing program is to evaluate the crashworthiness of a large breakaway sign support per MASH TL-3 conditions, on flat level ground. The second objective was to investigate the most practical and utilized installation conditions for large breakaway sign support on sloped terrain. The third objective was to determine the most critical characteristics within this envelope of conditions. The last objective was to access the crashworthiness of the large breakaway sign support in combination with the sloped installation condition.

To accomplish these objectives, the proposed testing program involves a full-scale vehicular (passenger car and pickup truck) crash tests. The proposed testing plan is based on the present opinion of the research team based on the AASHTO MASH requirements, FE analysis and results of a literature review performed in conjunction with the proposed testing plan.

6.2. MASH Test Requirements

The tests will be performed at TL-3 conditions. According to MASH, three tests are recommended for evaluating support structures at TL-3

6.2.1. *MASH* Test Designation 3-60:

A 2420-lb vehicle (1100C) impacting the critical impact point (CIP) of the support structure at a nominal impact speed of 19 mph and an impact angle of 0 degrees, respectively. This test investigates support structures ability to successfully activate the breakaway devices

6.2.2. *MASH* Test Designation 3-61:

A 2420-lb vehicle (1100C) impacting the CIP of the support structure at a nominal impact speed of 62 mph and an impact angle of 0 degrees, respectively. This test identifies the prospective of support structure intrusion into a vehicle with an emphasis on structural adequacy, vehicle stability, and occupant risk.

6.2.3. *MASH* Test Designation 3-62:

A 5000-lb pickup truck (2270P) impacting the CIP of the support structure at a nominal impact speed of 62 mph and an impact angle of 0 degrees, respectively. This test identifies the prospective of support structure intrusion into a vehicle with an emphasis on structural adequacy, vehicle stability, and occupant risk.

6.3. Test Conditions

6.3.1. Testing Site

A flat paved surface should be used to accelerate the vehicle at the desired speed and to provide for the unobstructed trajectory of the vehicle the following impact. The surface should be free of ditches, curbs, swales, and any other irregularities which could influence impact behavior. It may not be possible to provide a smooth and flat surface for the test vehicle to accelerate at the required speed, and this may result in bouncing off the vehicle. At impact, it is important that the test vehicle is not bouncing excessively and the bumper impact should be within 2 in. of the nominal bumper height.

The full-scale crash tests proposed in this memo will be performed at any agency registered with the International Standards Organization (ISO) 17025-accredited laboratory with the American Association for Laboratory Accreditation (AALA) Mechanical Testing certificate 2821.01. The full-scale crash tests should be performed according to the MASH guidelines and standards.

6.3.2. Propulsion, Guidance, and Braking

The test vehicle can be towed into the test installation using any reliable techniques such as pushing, towing, or self-propelled. Before the impact, the vehicle should be detached from the pushing and towing mechanism and should be wheeling freely just before and after the impact. The engine of the vehicle system should be switched off just before the impact. Live drivers should be avoided for accelerating vehicles. If needed, precautions should be taken for driver protection from vehicle rollover and high vehicle acceleration.

Any method which is consistent for controlling test vehicles into the test articles is satisfactory, provided the controlling system can be detached from the test vehicle just before the impact and should be assured that any components remaining attached to the vehicle do not influence the outcome/results of the test.

The braking should be delayed as long as possible to establish the vehicle's post-impact trajectory and attitude. The brakes should not be applied for a minimum of 2 seconds after the vehicle lost contact with the test article. The brake should be delayed until the vehicle stability is established.

6.4. Data Acquisition Systems

6.4.1. Vehicle Instrumentation and Data Processing

Each test vehicle should be 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, which 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, solid-state units designed 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. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data should be downloaded from the TDAS Pro unit into a laptop computer at the test site. The raw data can be decoupled using one of the commonly available procedures, such as the Test Risk Assessment Program (TRAP) program that processes the raw data to produce detailed reports of the test results.

Each of the TDAS Pro units should be returned to the factory annually for complete recalibration. Accelerometers and rate transducers should also be calibrated annually with traceability to the National Institute for Standards and Technology (NIST). All accelerometers should be calibrated annually according to SAE J211 4.6.1 using an ENDEVCO 2901, precision primary vibration standard. The device and its support instruments should be returned to the factory annually for the NIST traceable calibration. The subsystems of each data channel should also be evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Acceleration data should be measured with an expanded uncertainty of ±1.7 percent at a confidence factor of 95 percent (k=2).

The conversion programs such as 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 the change in vehicle velocity at the end of a given impulse period. Also, the 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 should be filtered with a 60-Hz low-pass 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, then plots yaw, pitch, and roll versus time. These displacements should be about the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact. The rate of rotation data should be measured with an expanded uncertainty of ±0.7 percent at a confidence factor of 95 percent (k=2).

6.4.2. Photographic Instrumentation Data Processing

Photographic coverage of each test should include two high-speed cameras:

1. One placed behind the installation at an angle.
2. The third camera will be placed to have a field of view parallel to and aligned with the installation at the downstream end.

A flashbulb on each of the impacting vehicles should be activated by a pressure-sensitive tape switch to indicate the instant of contact with the concrete median barrier. The flashbulb should be visible from each camera to synchronize timing from the impact event. The videos from these high-speed cameras should be analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A mini-digital video camera and still cameras should record and document the conditions of each test vehicle and the installation before and after each test.

6.5. Evaluation Criteria for *MASH* Testing

The vehicle crash impact tests will be evaluated by the relevant criteria presented in *MASH*. The impact performance of the sign support will be judged based on four factors: structural adequacy, occupant risk, and post-impact vehicle trajectory. Structural adequacy is based upon the sign support's ability to break away by fracturing or yielding. Occupant risk criteria evaluate 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. The MASH occupant risk criteria include occupant impact velocity and ridedown acceleration, which are computed using the acceleration-time histories measured at the vehicle's center of gravity. These criteria are based on a "flail space" model that assumes an unrestrained occupant.

Post impact vehicle trajectory will also be assessed as part of the MASH evaluation criteria to determine the potential for secondary impact of the impacting vehicle with other vehicles or fixed objects that can create a further risk of injury to occupants of the impacting vehicle and/or risk of injury to occupants in other vehicles.

The specific safety evaluation criteria (from table 5-1 of MASH) that will be used to evaluate the passenger vehicle crash tests are summarized below.

1. The test article should readily activate predictably by breaking away, fracturing, or yielding.
2. 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 outlined in Section 5.3 and Appendix E of MASH: deformation in the roof should be less than equal to 4.0 inches; deformation in windshield should be less than equal to 3.0 inches; there should be no shattering by test article structural member inside windows; deformation in wheel/ footwell/ toe pan should be less than 9.0 inches; deformation in forward A-pillar should be less than 12.0 inches; deformation in front side door area above seats should be less than 9.0 inches and in front side door below seat should be less than 12.0 inches; deformation in floor pan/transmission tunnel area should be less than 12.0 inches.

3. The vehicle should remain upright during and after the collision. The maximum roll and pitch angles are not to exceed 75 degrees.
4. Occupant impact velocities should be less than 40ft/s
5. Occupant ridedown acceleration should be less than 20.49 G.

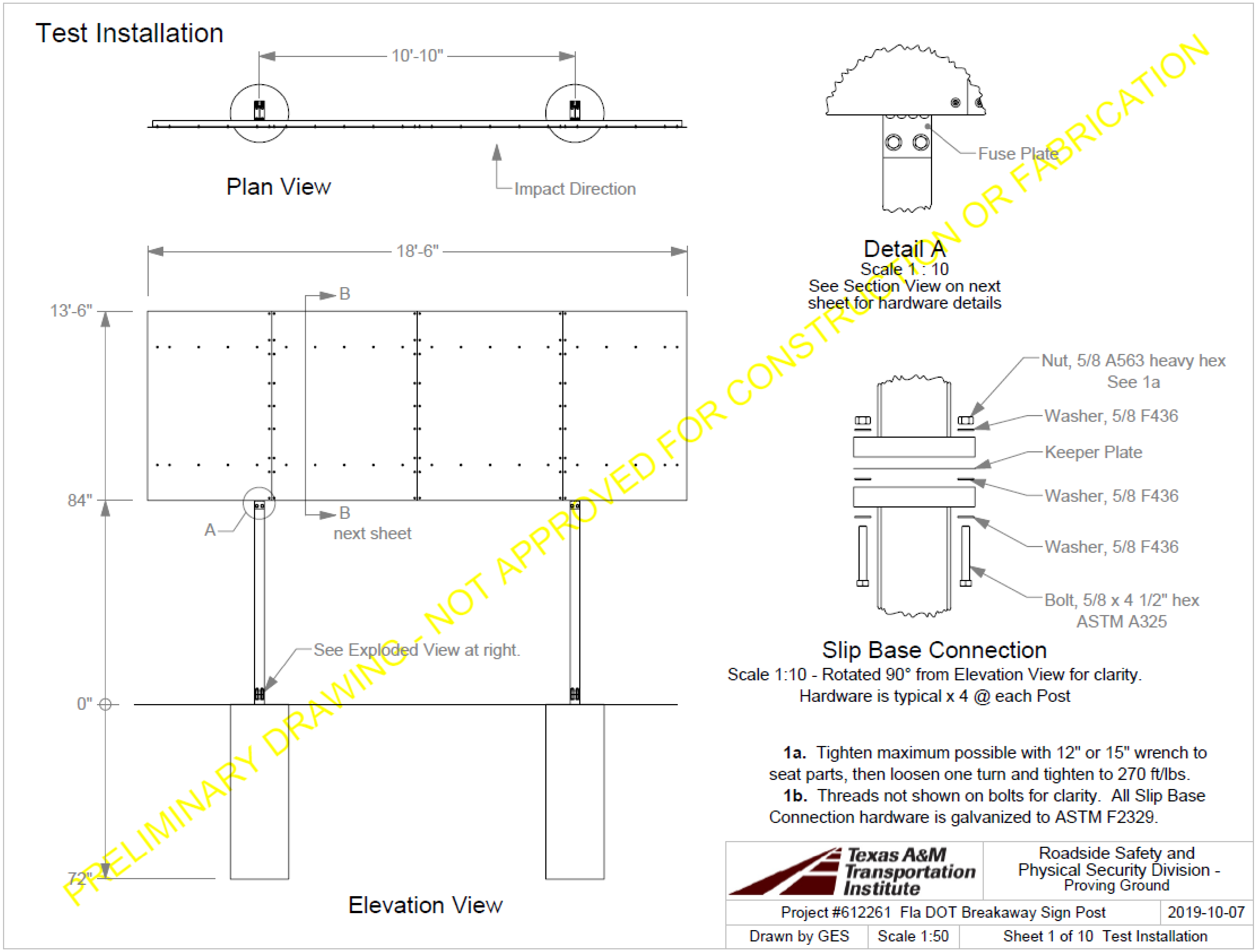


Figure 62. Preliminary Drawing (Sheet 1 of 10).

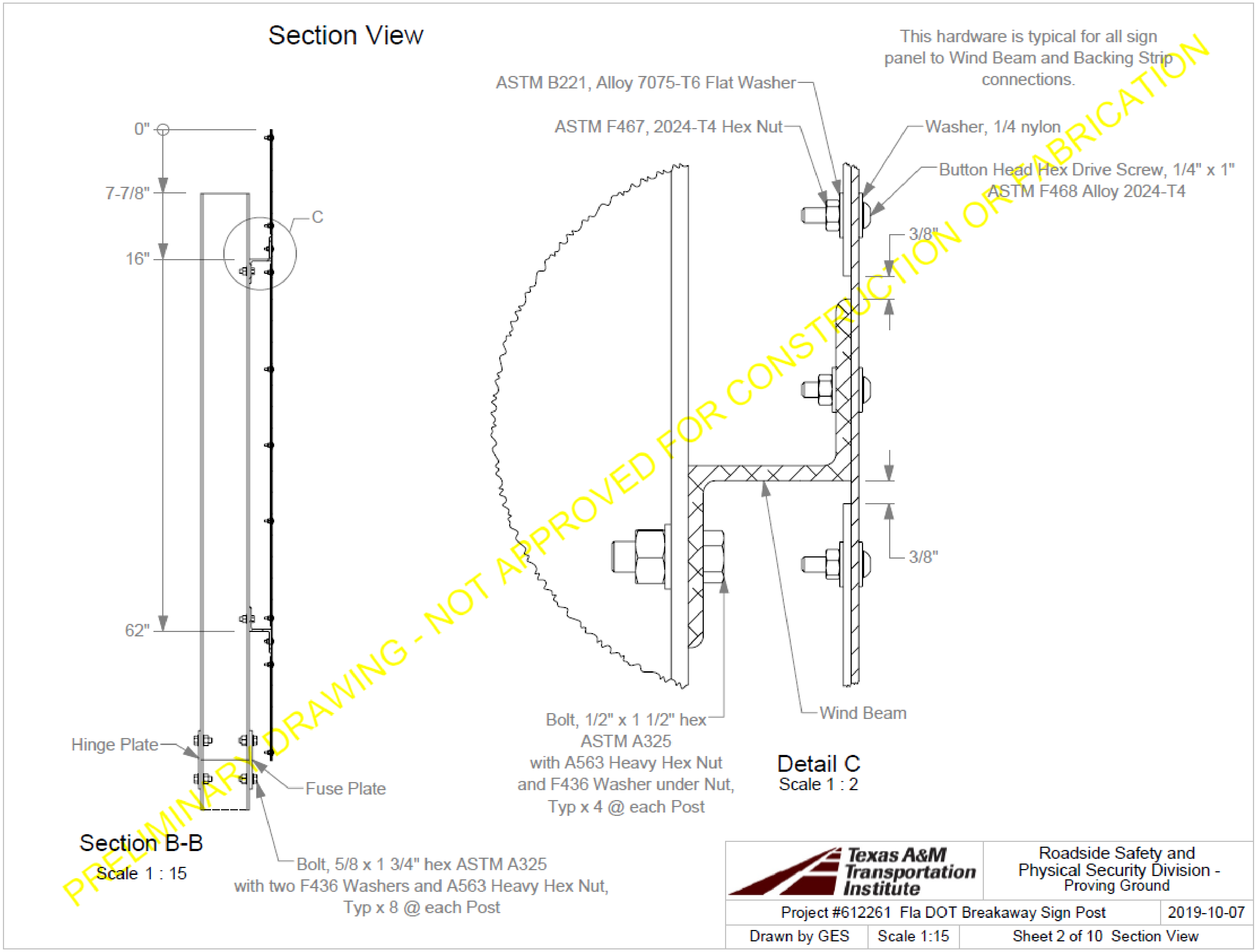


Figure 63. Preliminary Drawing (Sheet 2 of 10).

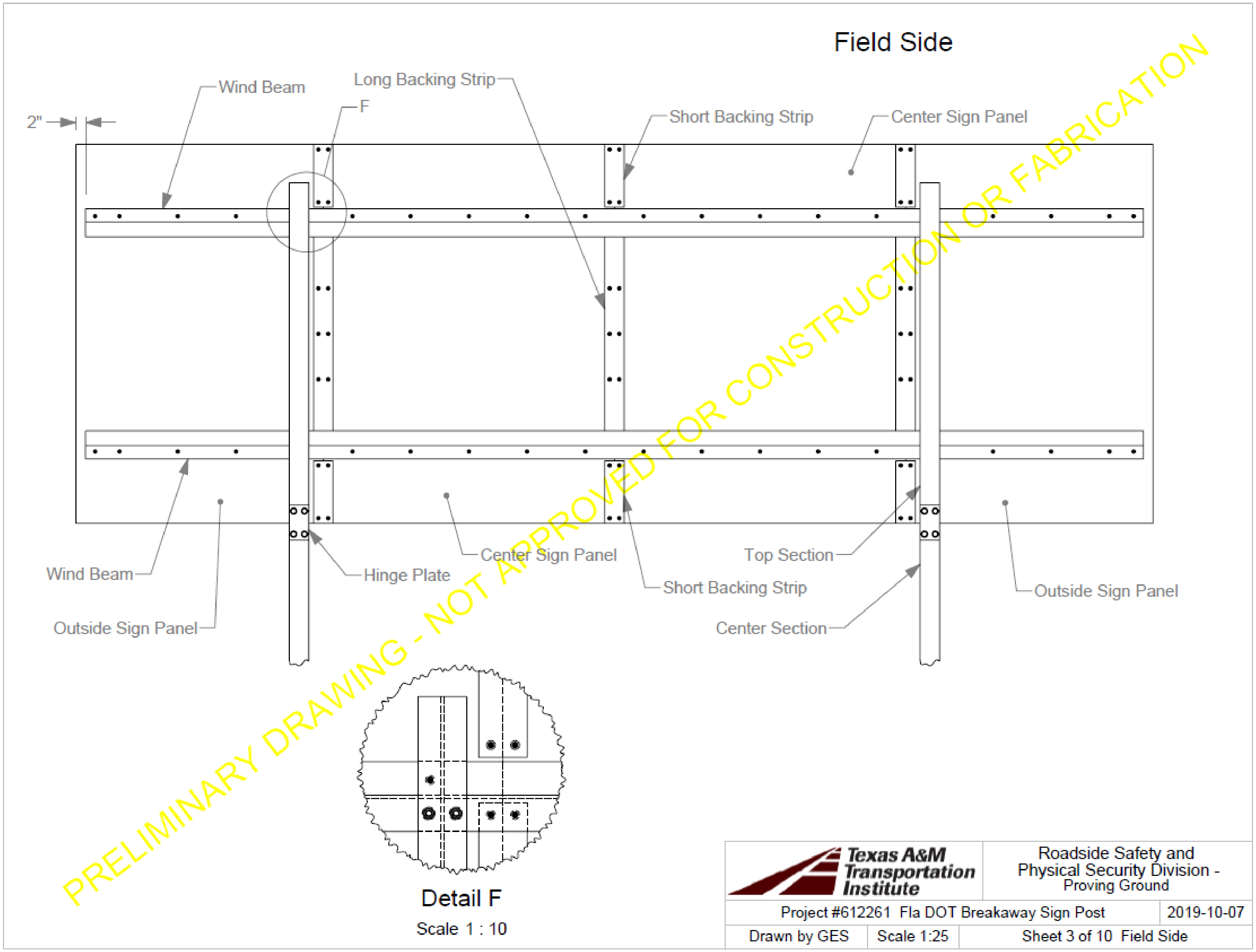


Figure 64. Preliminary Drawing (Sheet 2 of 10).

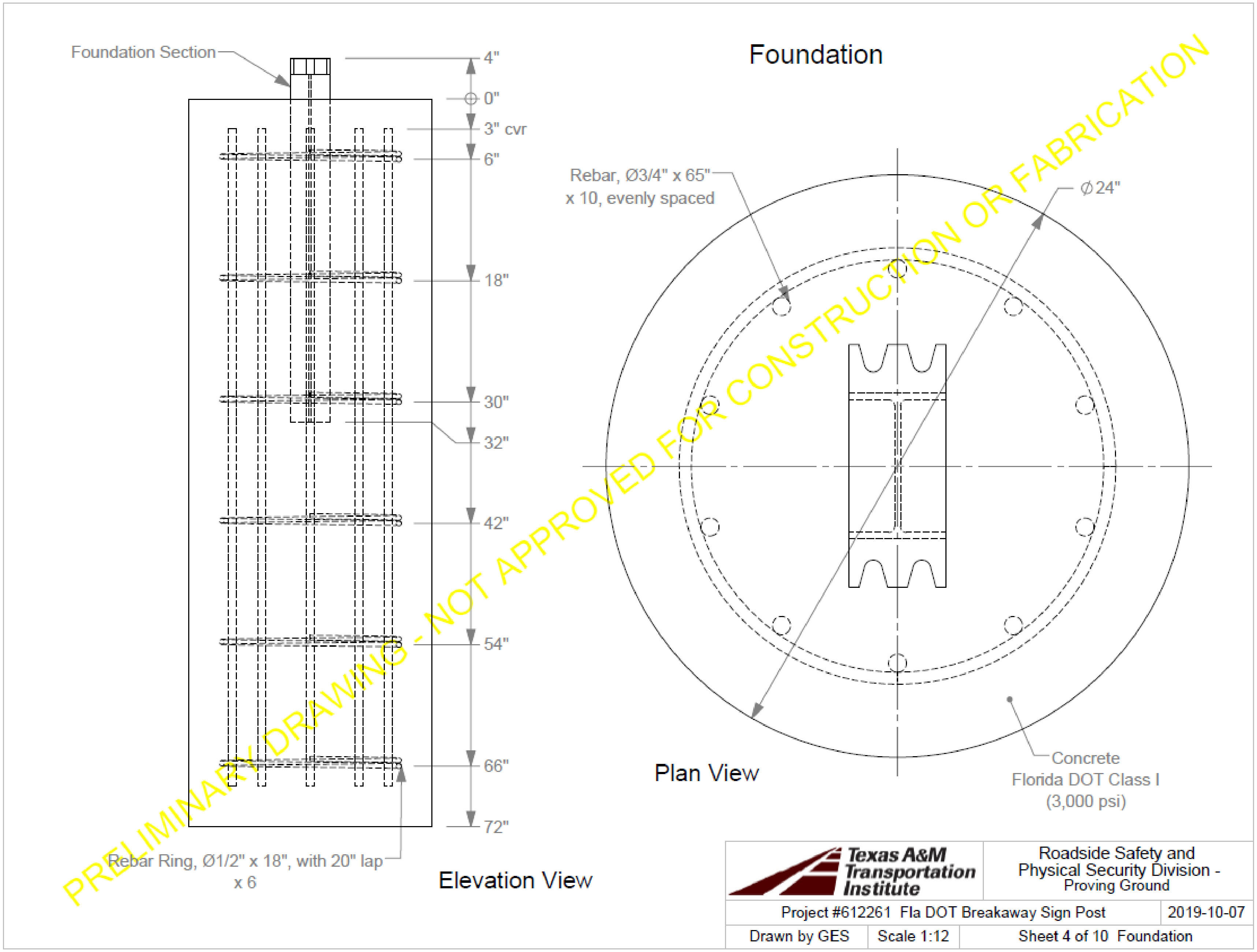


Figure 65. Preliminary Drawing (Sheet 4 of 10).

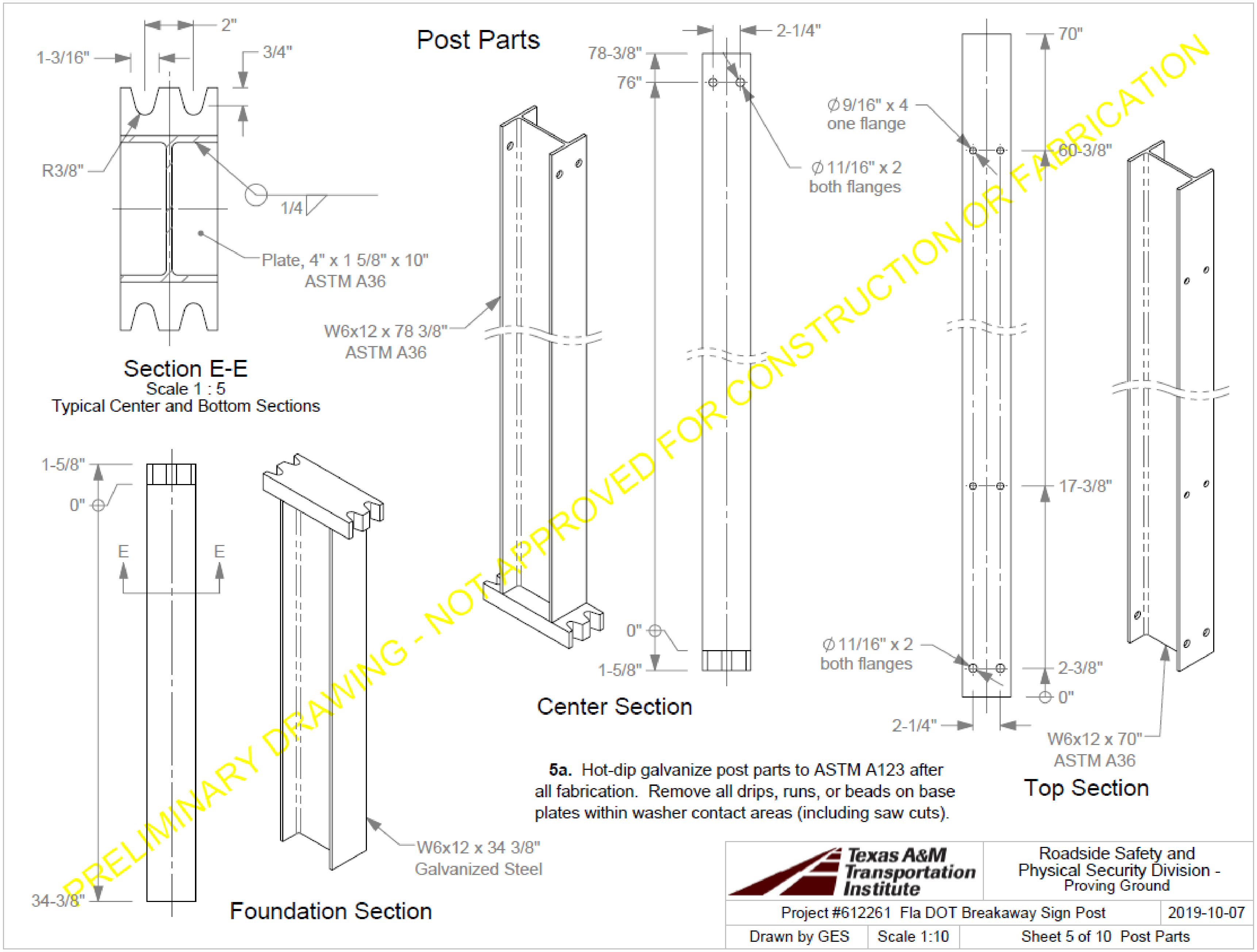


Figure 66. Preliminary Drawing (Sheet 5 of 10).

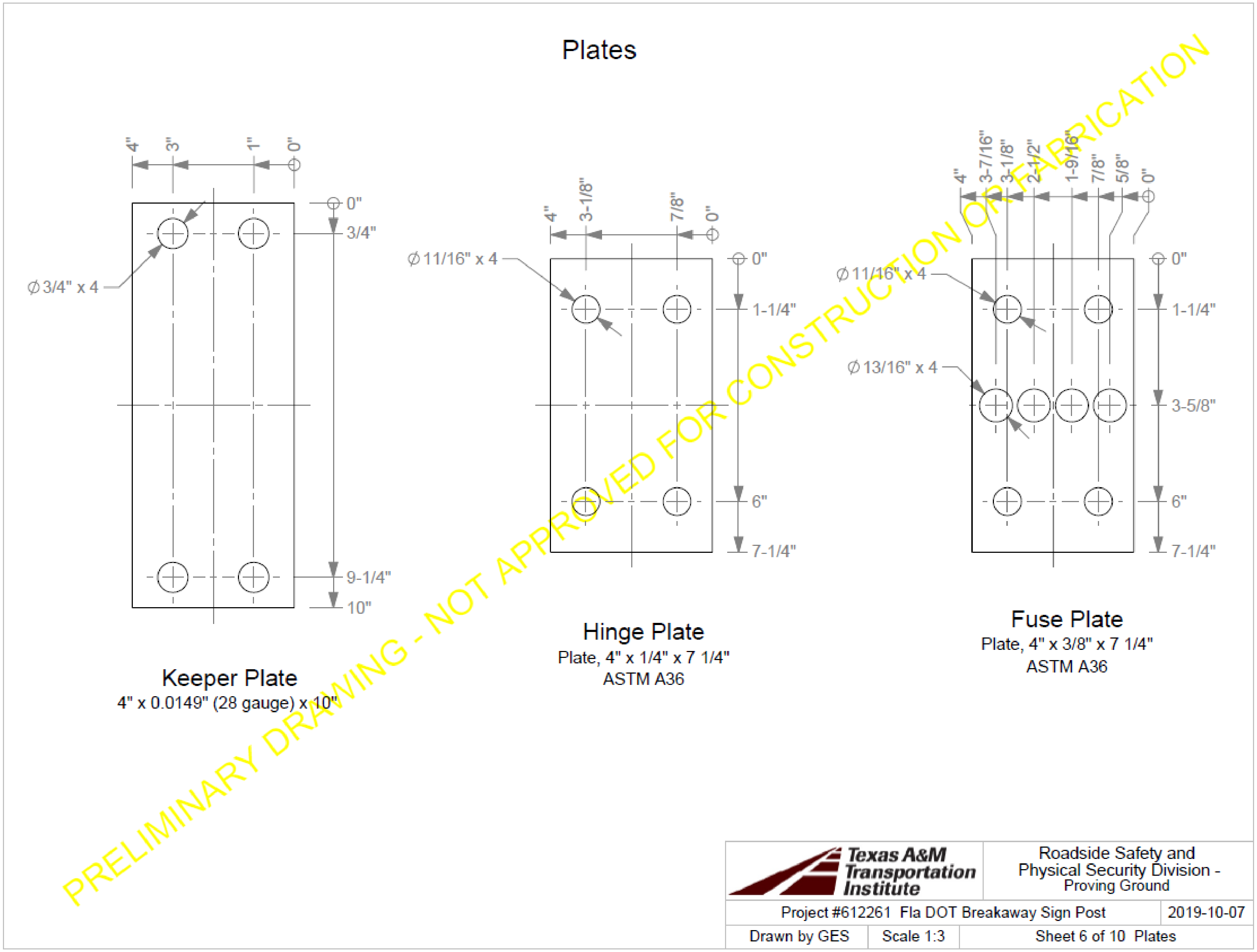


Figure 67. Preliminary Drawing (Sheet 6 of 10).

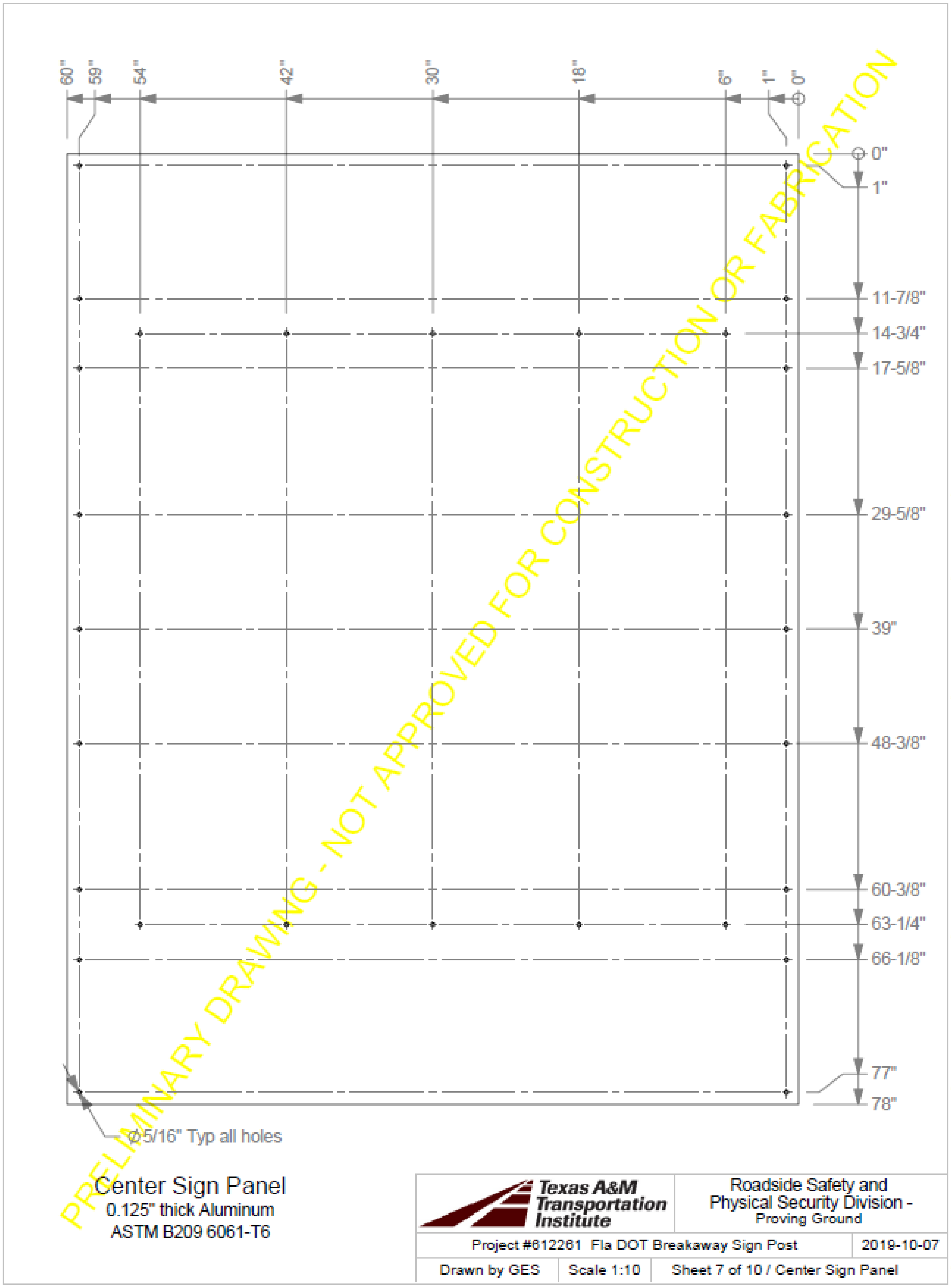


Figure 68. Preliminary Drawing (Sheet 7 of 10).

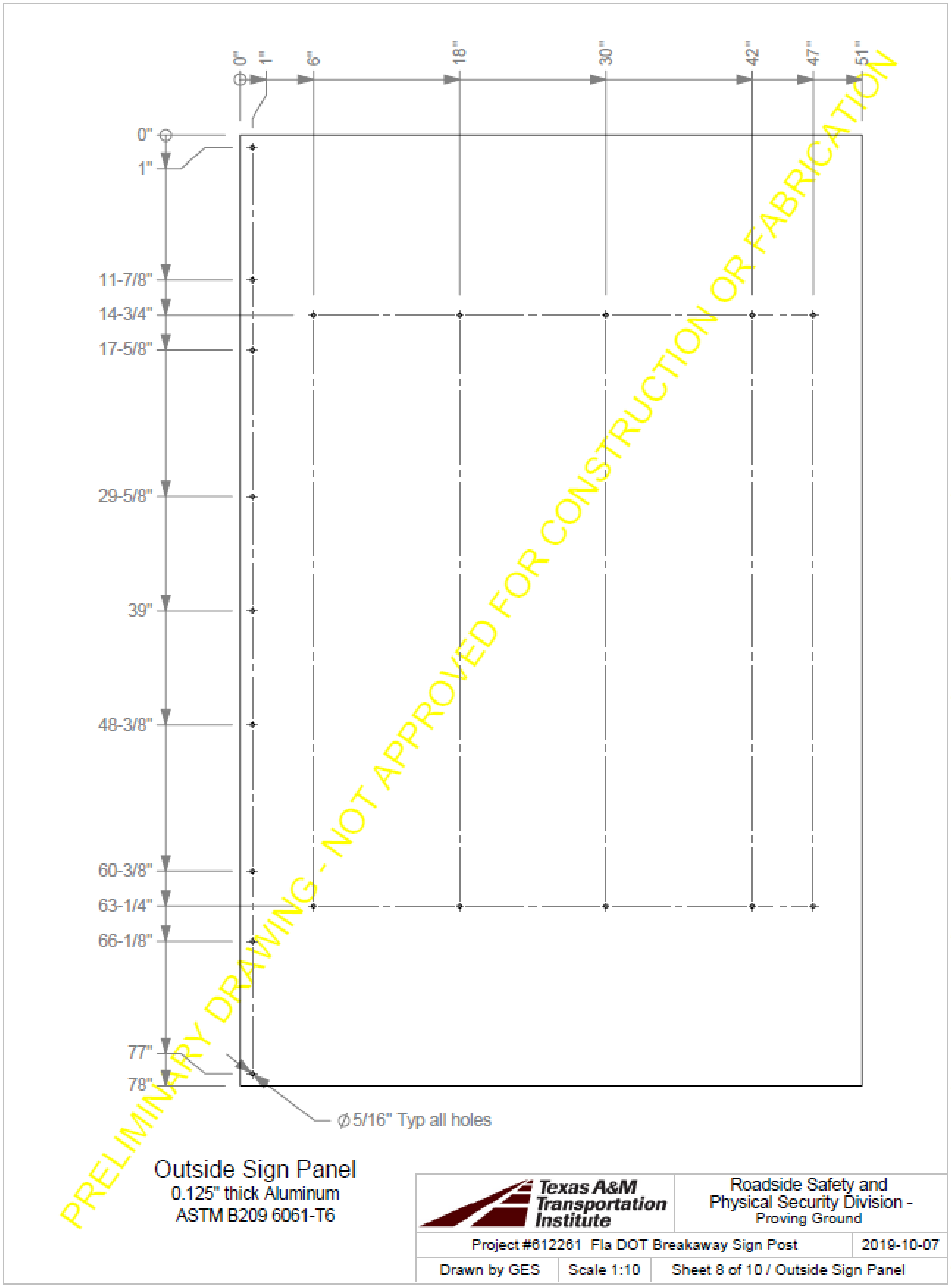


Figure 69. Preliminary Drawing (Sheet 8 of 10).

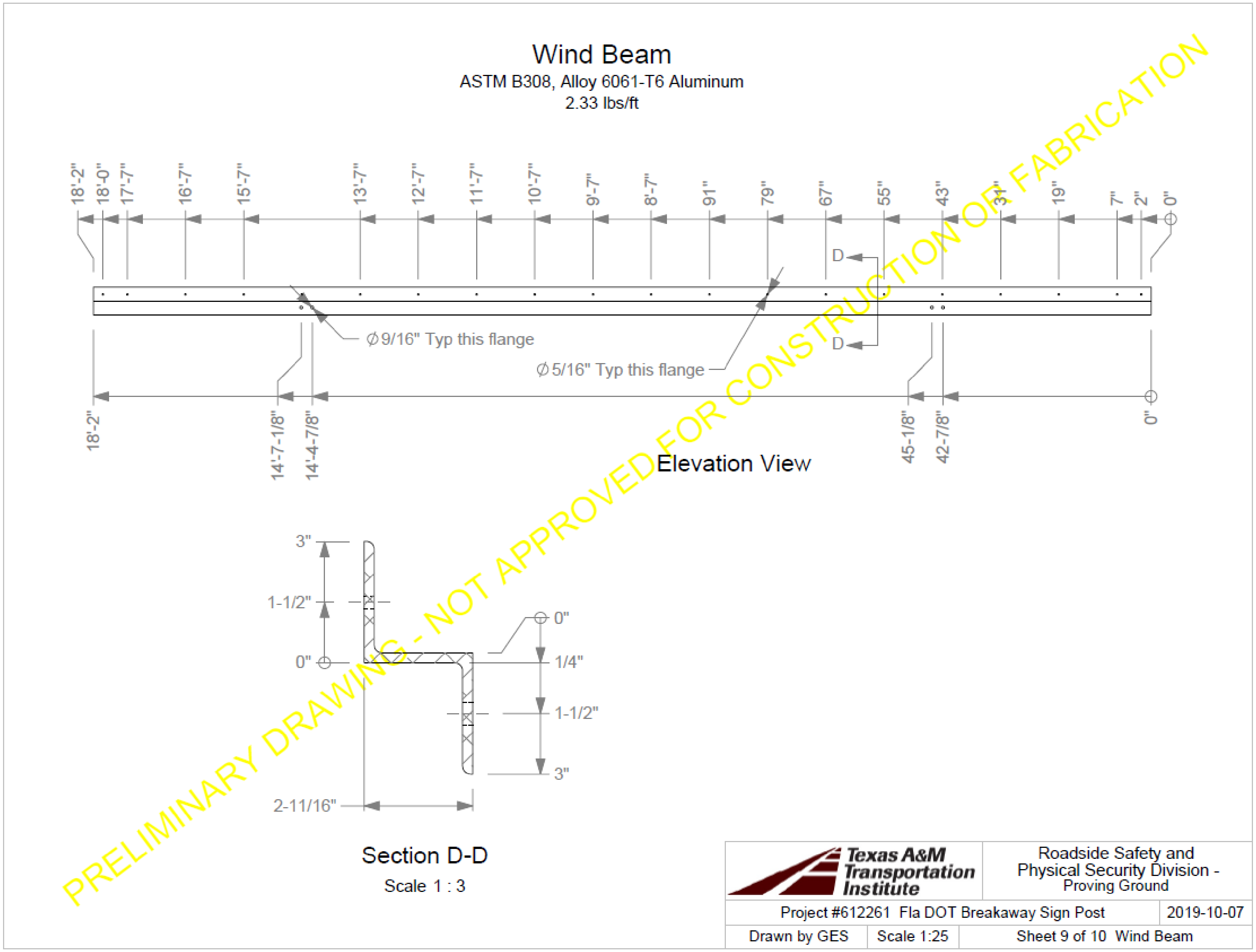


Figure 70. Preliminary Drawing (Sheet 9 of 10).

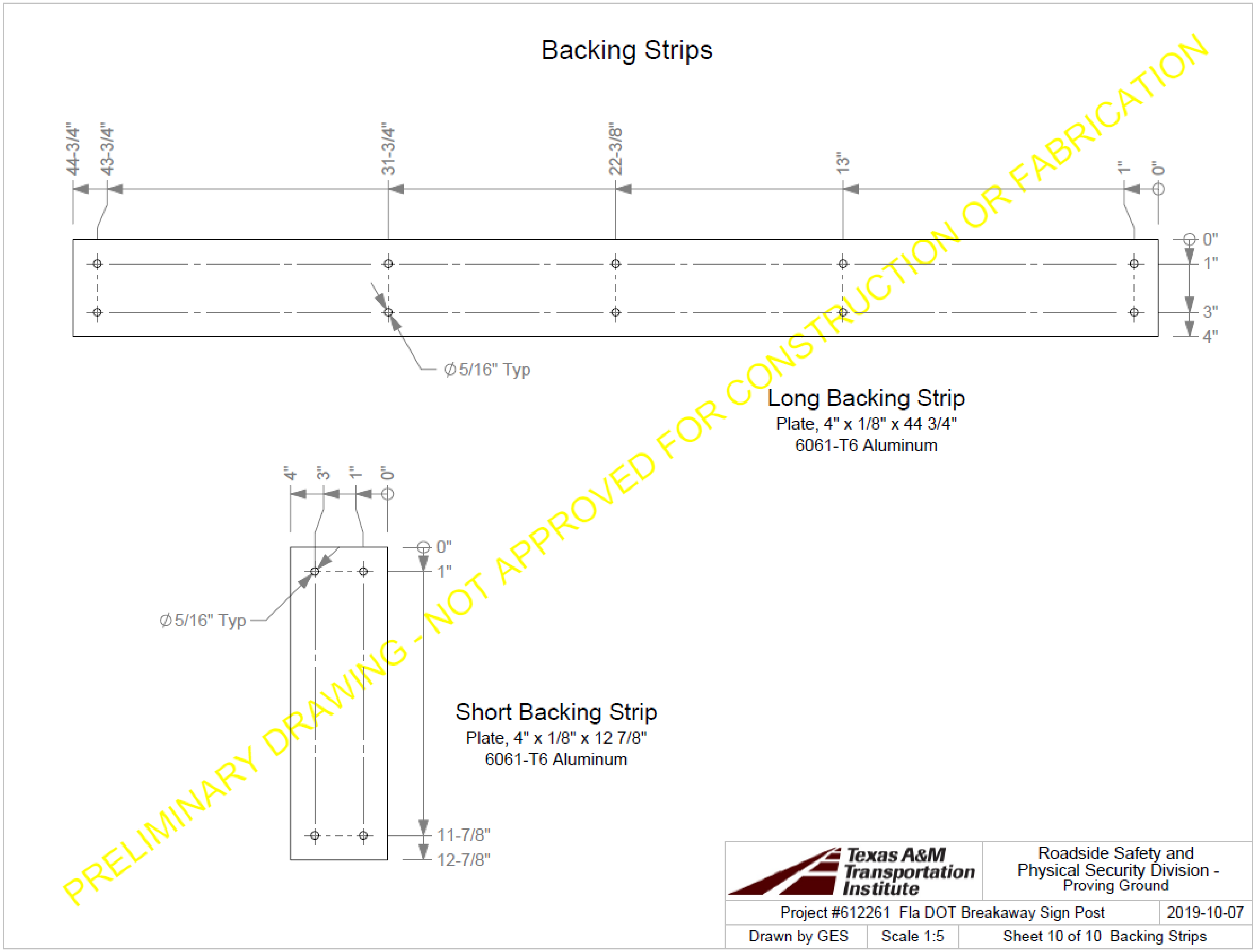


Figure 71. Preliminary Drawing (Sheet 10 of 10).

7. FULL-SCALE CRASH TEST

7.1. Introduction

The large signpost was constructed in the field as designed. A full-scale crash test was conducted to evaluate the crashworthiness of the large signpost and to compare the finite element analysis results. MASH Test Designation 3-62, a 5000-lb pickup truck (2270P) impacting the CIP of the support structure at a nominal impact speed of 62 mph and an impact angle of 0 degrees, respectively was conducted. This test identifies the prospective of support structure intrusion into a vehicle with an emphasis on structural adequacy, vehicle stability, and occupant risk.

7.2. Test Article and Installation Details

The test installation was a breakaway sign with four panels, consisting of two center sign panels each at 60 in. long and 78 in. tall, and two outside sign panels each at 51 in. long and 78 in. tall for a total dimension of 18 ft-6 in. long and 78 in. tall. All panels were comprised of 0.125-in. thick Aluminum ASTM B209 6061-T6. The sign panel was held at 84 in. above grade by two W-beam posts spaced at 10 ft-10 in. and held off the posts by two wind beams. These posts both consist of three sections with a hinge plate just below the sign, and a slip base 2⅜ in. above grade joining the sections together. The installation was secured by being set 32 in. deep into a concrete foundation 72 in. deep with a 24 in. diameter.

Figure 72 presents overall information on the test article and Figure 73 provides photographs of the installation. Drawings were provided by the Florida Department of Transportation, and construction was performed by Tucker Construction.

7.3. Material Specifications

Appendix B provides material certification documents for the materials used to install/construct the test article.

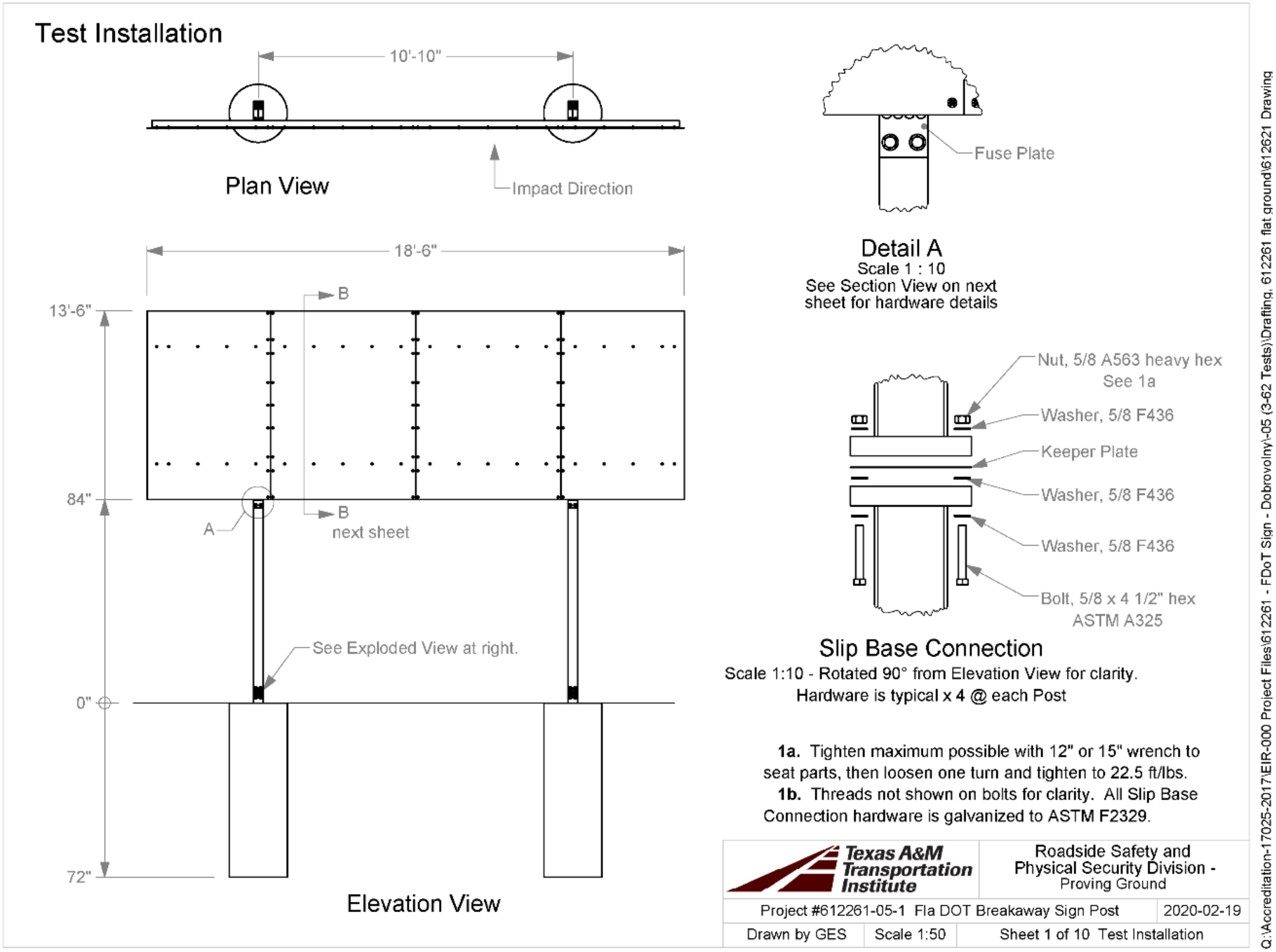


Figure 72. Test Article Details

Figure 73. Test Article before Testing

7.4. Test Designation and Actual Impact Conditions

MASH Test 3-62 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIA of the support structure at an impact speed of 62 mi/h ±2.5 mi/h and CIA of 0° ±1.5°. The target impact point on the test article was 12 inches ±1 ft from the centerline to the driver's side aligned with the centerline of the left post. Figure 74 depicts the target impact setup.

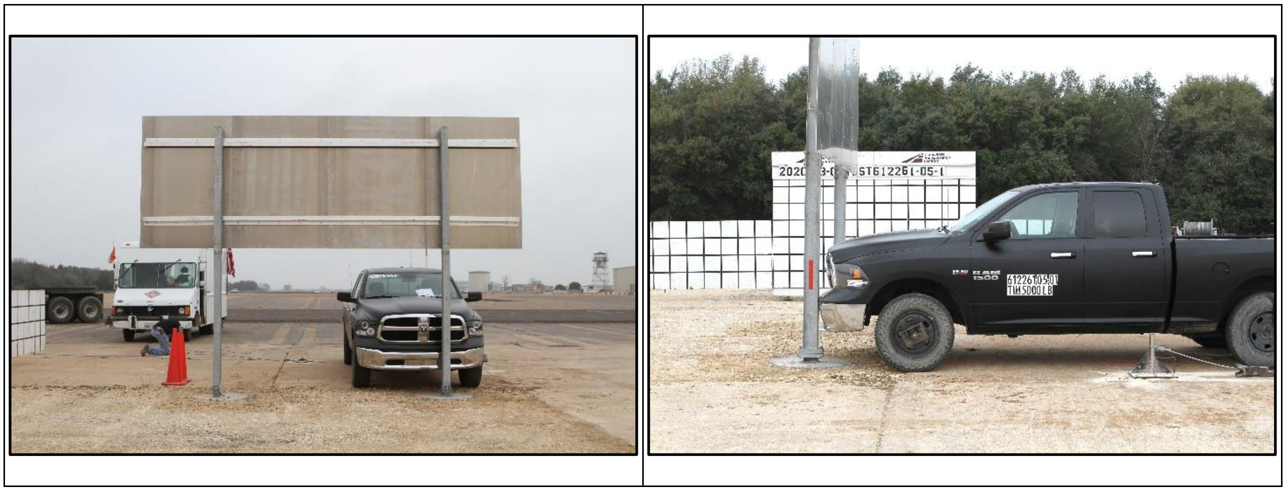


Figure 74 Test Article and Vehicle before Testing

The 2270P vehicle used in the test weighed 5040 lb, and the actual impact speed and angle were 62.4 mi/h and 0°. The actual impact point was 12 inches from the centerline to the driver's side aligned with the centerline of the left post. The minimum target kinetic energy (KE) was 594 kip-ft, and the actual KE was 656 kip-ft.

7.5. Weather Conditions

The test was performed on the morning of March 3, 2020. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 360° (vehicle was traveling at the magnetic heading of 180°); temperature: 72°F; relative humidity: 92%.

7.6. Test Vehicle

Figure 5.2 shows the 2014 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5040 lb, and its gross static weight was 5040 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height of the vehicle's center of gravity was 29.25 inches. Appendix B gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system and was released to be freewheeling and unrestrained just before impact.

Figure 75. Test Vehicle before Testing

7.7. Test Description

Table 19 lists events that occurred during Test No. 612261-05-1. Figures in Appendix B present sequential photographs during the test.

Table 19. Events during Test

TIME (s)	EVENTS
0.0000	Vehicle impacts the left leg of a sign support
0.0020	The base of left sign support begins to slip
0.0060	The base of left sign support free from the base at grade
0.0820	Vehicle loses contact with sign support while traveling at 60.0 mi/h
0.3290	Vehicle completely clear of sign

Brakes on the vehicle were applied at 1.6 s after impact, and the vehicle subsequently came to rest 309 ft downstream of the impact location.

7.8. Damage to Test Installation

Figure 76 shows the damage to the test article. The left slip base activated upon impact. The hinge plates did not activate for either post. The panel connected to the right-side post was removed and landed 6 feet to the right of impact. The left support post and a partial sign panel landed 22 ft to the right and 11 ft downstream. The right support base did not activate and leaned to the left at 10 degrees to the left from vertical with a slight clockwise twist.

Figure 76. Test Article after Test

7.9. Damage to Test Vehicle

Figure 77 shows the damage sustained by the vehicle. The front bumper, hood, grill, radiator and support, and left front fender were damaged. No fuel tank damage was observed. The maximum exterior crush to the vehicle was 8.0 inches in the front plane at the left of the centerline at bumper height. No occupant compartment deformation or intrusion was observed. Figure 78 shows the interior of the vehicle. Appendix B provides exterior crush and occupant compartment measurements.

Figure 77. Test Vehicle after Test.

Figure 78. Interiors of Test Vehicle after Test.

7.10. Occupant Risk Factors

Data from the accelerometers were digitized for the evaluation of occupant risk, and the results are shown in Table 20. Figures in Appendix B show the vehicle angular displacements and acceleration versus time traces. Figure 79 summarizes pertinent information from the test.

Table 20. Occupant Risk Factors for Test

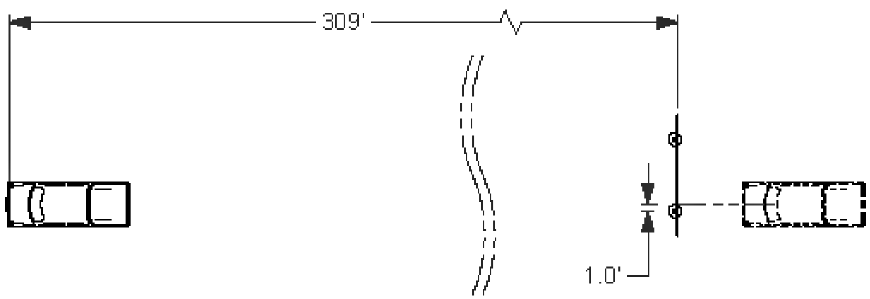
Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	3.3 ft/s	at 0.7128 s on the front of the interior.
Lateral	2.0 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	0.3 g	0.8482 – 0.8582 s
Lateral	1.0 g	0.7512 – 0.7612 s
Theoretical Head Impact Velocity (THIV)	1.2 m/s	at 0.7095 s on front of interior
Acceleration Severity Index (ASI)	0.2	0.0164 – 0.0664 s
Maximum 50-ms Moving Average		
Longitudinal	-1.8 g	0.0007 – 0.0507 s
Lateral	0.6 g	0.7353 – 0.7853 s
Vertical	-0.8 g	0.1490 – 0.1990 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	2°	1.4227 s
Pitch	3°	1.4632 s
Yaw	2°	1.5000 s

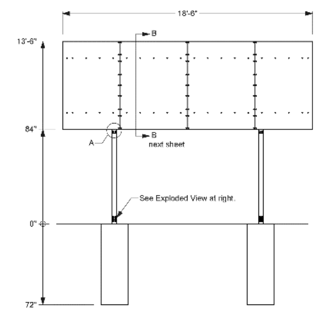
0.000 s

0.100 s

0.200 s

0.300 s





General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-62
TTI Test No.	612261-05-1
Test Date	2020-03-03

Test Article

Type	Support Structure – Sign Support
Name	
Installation Height	84 inches
Material or Key Elements	
Soil Type and Condition	M147-65(2004) “Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses.”

Test Vehicle

Type/Designation	2270P
Make and Model	2014 RAM 1500 Pickup Truck
Curb	4920 lb
Test Inertial	5040 lb
Dummy	No dummy
Gross Static	5040 lb

Impact Conditions

Speed	62.4 mi/h
Angle	0°
Location/Orientation	Left of centerline with left support
Kinetic Energy	656 kip-ft

Exit Conditions

Speed	60.0 mi/h
Trajectory/Heading Angle	0°

Occupant Risk Values

Longitudinal OIV	3.3 ft/s
Lateral OIV	2.0 ft/s
Longitudinal Ridedown	0.3 g
Lateral Ridedown	1.0 g
THIV	1.2 m/s
ASI	0.2
Max. 0.050-s Average	
Longitudinal	-1,8 g
Lateral	0.6 g
Vertical	-0.8 g

Post-Impact Trajectory

Stopping Distance	309 ft behind

Vehicle Stability

Maximum Yaw Angle	2°
Maximum Pitch Angle	3°
Maximum Roll Angle	2°

Test Article Debris Scatter

Longitudinal	11 ft
Lateral	22 ft

Vehicle Damage

VDS	12FL2
CDC	12FLEN2
Max. Exterior Deformation	8.0 inches
OCDI	FS0000000
Max. Occupant Compartment Deformation	None

Figure 79. Summary of Results for MASH Test 3-62

Table 21. Performance Evaluation Summary for MASH Test 3-62.

MASH **Test 3-62 Evaluation Criteria**		**Test Results**
Structural Adequacy		
B.	The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	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.	PASS
	Deformations of, or intrusions into, the occupant compartment should not exceed limits outlined in Section 5.2.2 and Appendix E of MASH.	PASS
F.	The vehicle should remain upright during and after the collision. The maximum roll and pitch angles are not to exceed 75 degrees.	PASS
H.	Occupant impact velocities (OIV) should satisfy the following limits: The preferred value of 10 ft/s, or maximum allowable value 16 ft/s.	PASS
I.	The occupant ridedown accelerations should satisfy the following limits: The preferred value of 15.0 g, or maximum allowable value of 20.49 g.	PASS
Vehicle Trajectory		
N.	The vehicle trajectory behind the test article is acceptable.	PASS

7.11. Assessment of Test Results

The crash test reported herein was performed following *MASH* Test 3-62, which involves a 2270P vehicle impacting the test article at a target impact speed and impact angle of 62 mi/h and 0°, respectively. An assessment of the test based on the applicable safety evaluation criteria for MASH Test 3-62 for a large signboard is provided in Table 21.

7.12. Comparison between original FEA and Full-Scale Crash Test

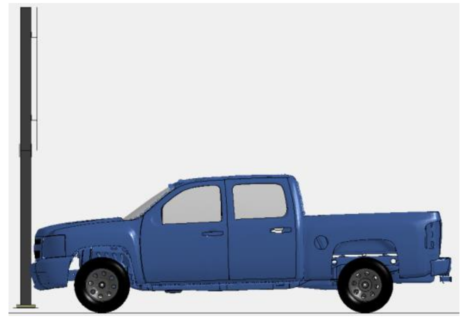
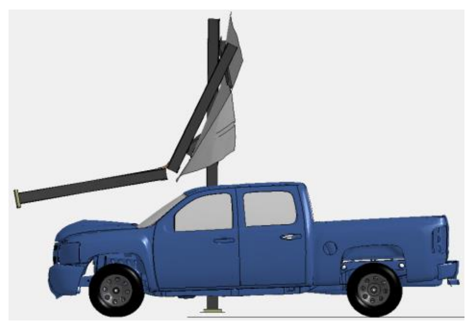
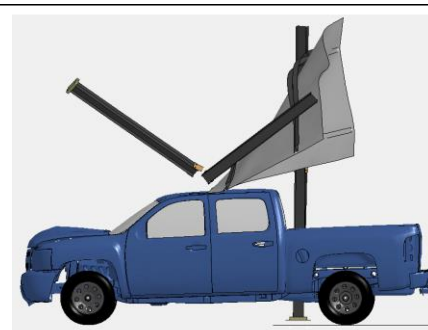
In this section, the original finite element simulation results of the detailed large signboard were compared with the full-scale crash test results of MASH test 3-62. Minor differences were found in vehicle roll, pitch, and yaw angles and impact velocity, and ridedown acceleration. Significant differences were found in the fracture of hinge and fuse plates. Further analysis was conducted. After reviewing the crash test film and original FEA results, modifications were made to the large signboard FE models for more accurate simulation results.

The simulated impact event closely matches the actual crash test events. As shown in Table 22, the ridedown accelerations and impact velocities values are very low in general. Table 23 compares the frame by frame of FEA simulation and actual crash test. The general behavior of the test article in the simulations was exactly like the actual crash test except the fracturing of hinge and fuse plates. Also, the FEA model closely replicates the testing outcomes, in terms of vehicle stability and general behavior during an impact event.

Table 22. TRAP Values Comparison between Original FEA and Full-Scale Crash Test

	Actual Crash Test	FEA Simulation
Longitudinal OIV	3.3 ft/s	Nil
Lateral OIV	2.0ft	Nil
Longitudinal Ridedown	0.3 g	Nil
Lateral Ridedown	1.0 g	Nil
Max 0.050-s Average		
Longitudinal	-1.8 g	-2.6 g
Lateral	0.6 g	-1.7 g
Vertical	-0.8 g	1.4 g
Maximum Roll	2 deg	-0.5 deg
Maximum Pitch	3 deg	-0.6 deg
Maximum Yaw	2 deg	-0.9 deg

Table 23. Sequential Frame Comparison between Original FEA and Full-Scale Test

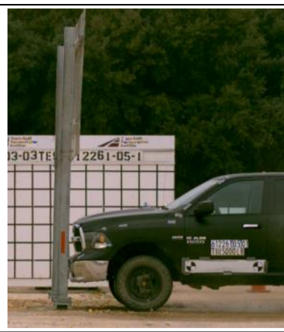
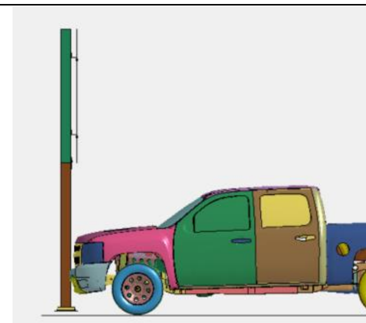
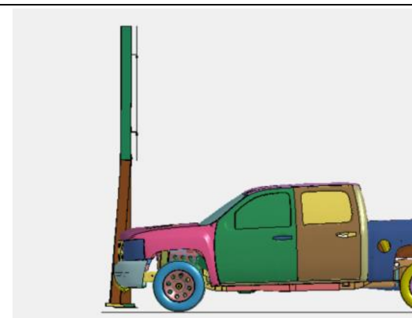
	
0.0 s	
	
0.1 s	
	
0.2 s	
	
0.3 s	

In FEA simulation, both hinge and fuse plates got activated after 0.1 s and got completely fractured by 0.3 s. Whereas, in the full-scale crash test the hinge and fuse plates did not activate. Further modifications were performed in the FEA simulation for achieving the results similar to the full-scale crash test.

7.13. FEA Modification and Validation

To achieve the results like the performed full-scale crash test, the FEM model was re-validated. Multiple trial and error methods were performed. By increasing the erosion values (MAT_ADD_EROSION) of fuse and hinge plate to very high values (1.0 e+04 MPa), similar results were obtained. Different frames observed during the analysis and actual crash test are shown in Table 24. All other properties of the large sign system and the vehicle were kept the same as earlier.

Table 24. Sequential Frame Comparison between Original FEA and Full-Scale Test after Modification

	
0.0 s	
	
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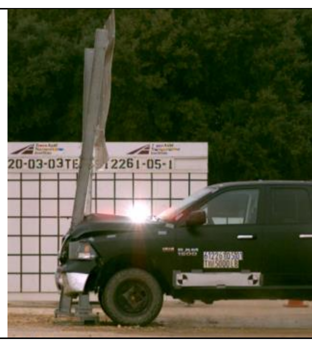
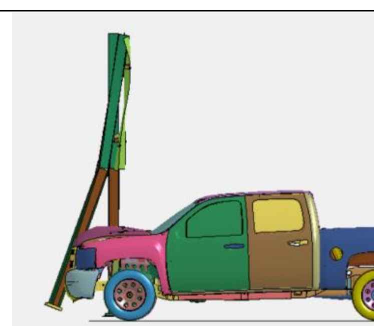
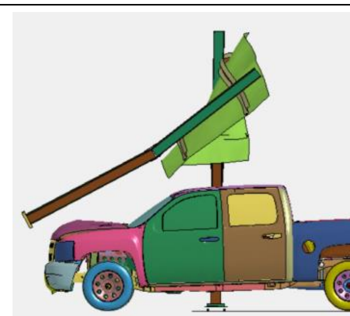
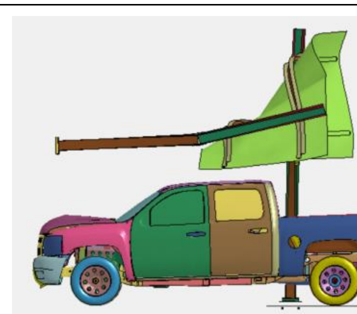
	
0.02 s	
	
0.03 s	

Table 24. Continued

	
0.04 s	
	
0.05 s	
	
0.1 s	
	
0.15 s	

7.14. Conclusion

The test article passed the performance criteria for *MASH* Test 3-62 for large signboards. Modifications were made to the FE models since discrepancy was found between the original detailed simulation and full-scale crash test. The frame by frame comparison suggested that modified FEA realistically replicated the results observed from the full-scale crash test.

8. FINITE ELEMENT SIMULATIONS ON SLOPED TERRAIN

8.1. Introduction

The section herein presents a detailed design of a large signpost system on sloped terrain. A set of vehicle impact simulations were performed to investigate the system behavior when impacted by errant passenger vehicles while installed on sloped terrain. Slope characteristics, however, as well as other installation characteristics were determined based on the results obtained from the survey. For the developed option, an FE parametric study was conducted to investigate the most critical situation for the impact. Different parameters such as impact angle, impact location, edge distance, vehicle speed, and vehicle type were considered for parametric study. As anticipated earlier, the negative slope was considered for the impact simulations. Set of computer simulations were performed for both passenger car and pickup truck vehicles impacting the test article. CARSIM was used to compare and verify the worst-case impact scenarios, such as impact angles and critical impact locations. This analysis was performed to characterize the behavior of the vehicle once entering and traversing the slope. The full-scale crash tests will be proposed based on the computer simulations results for most critical systems. The detailed FE model of the large signpost system included a realistic replica of the large signposts, sign panels, slip base system, and connection details, such as fuse plates, zee channels, etc. Figure 80 illustrates the FE model developed in LS-DYNA for simulations on the flat-level ground.

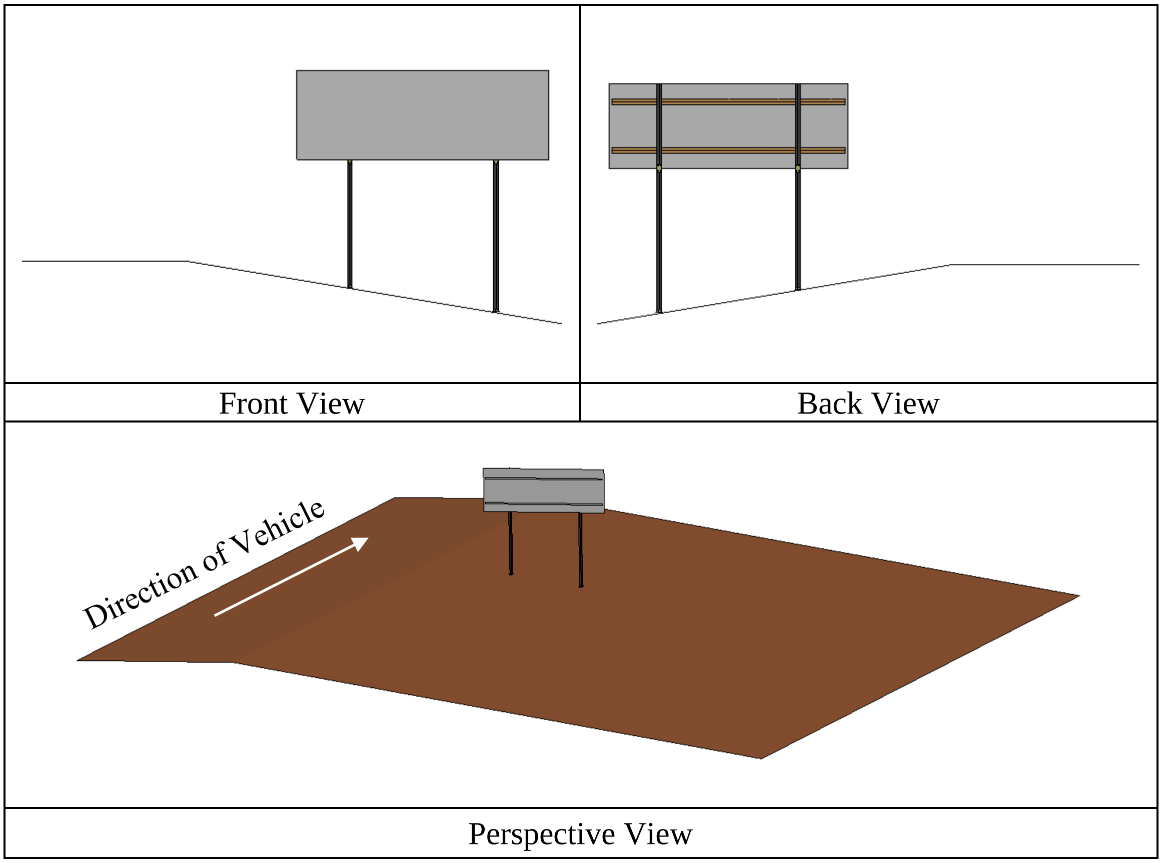


Figure 80. Developed Finite Element Model.

The testing and evaluation criteria for the sloped terrain were decided based on the engineering experience and judgment. The present MASH criteria for support structures on the flat-level ground was adapted for evaluating impact simulation of the test article on sloped-terrain.

The current MASH testing and evaluation criteria suggest selecting test parameters, such as impact angle and speed, point of impact, test matrix, etc. based on the worst practical condition. Multiple FE impact simulations were performed based on different parameters to find the most critical case. Details of different parameters are shown in. Figure 81 illustrates the different impact angles and impact locations used in the simulations. To find the most critical impact angle, angular displacements were compared for different preliminary impact simulations results. Based on engineering judgment and preliminary results of simulation from LS-DYNA and CARSIM it was observed that vehicle impacting the first leg of the test article at 25 degrees will be most critical. For the preliminary analysis, an offset of 12 ft. from the shoulder breakpoint to the edge of the sign panel was chosen.

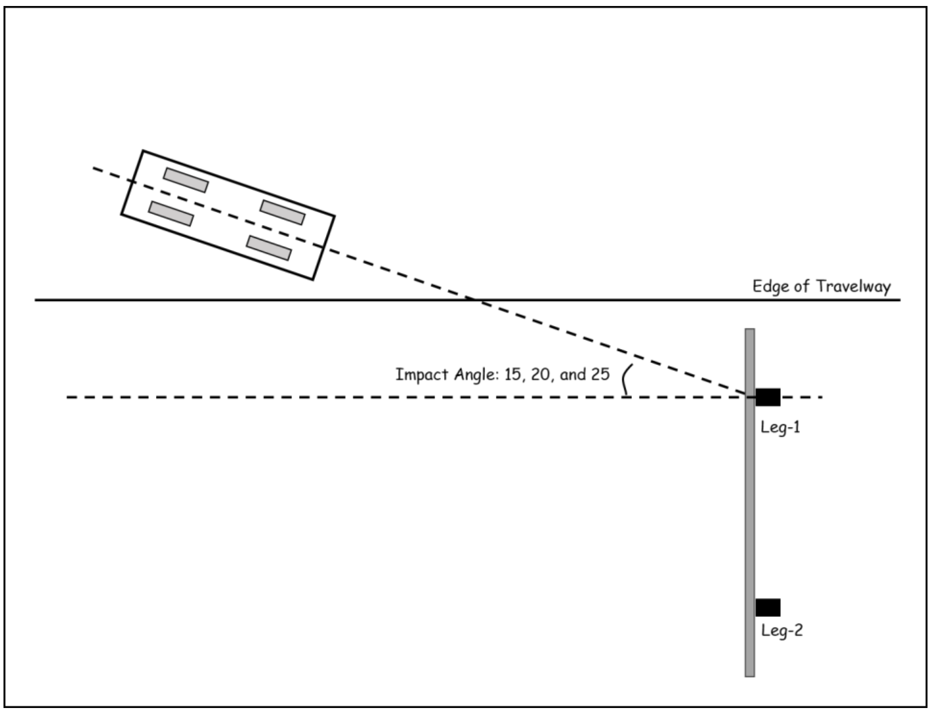


Figure 81. Different Impact Angles and impact Locations used in the Simulations.

Table 25 and Table 26 shows the different FE simulations performed on sloped terrain with car and pickup truck. Table 27, Table 28, Table 29, and Table 30 illustrates the roll, pitch and yaw angles at 15, 20, and 25 degrees angles for pickup truck and passenger car impacting the first and second leg at high speed.

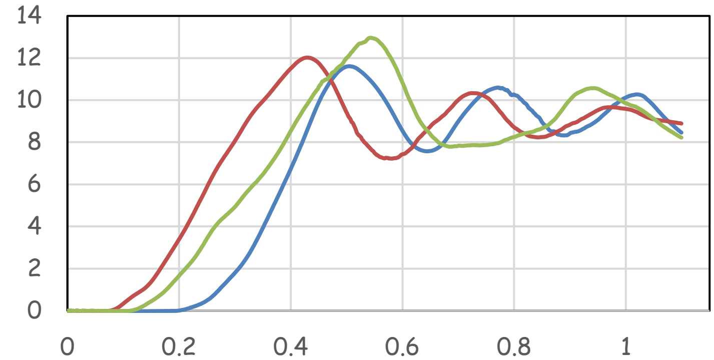
Table 25. Different Finite Element Simulations Performed on Sloped Terrain with Car (1100C)

Simulation no.	Vehicle	Speed	Leg	Edge Distance (ft.)	Angle (degrees)
1	Car (1100C)	19 mph	1st	12	15
2					20
3					25
4				24	15
5					20
6					25
7			2nd	12	15
8					20
9					25
10				24	15
11					20
12					25
13	Car (1100C)	62 mph	1st	12	15
14					20
15					25
16				24	15
17					20
18					25
19			2nd	12	15
20					20
21					25
22				24	15
23					20
24					25

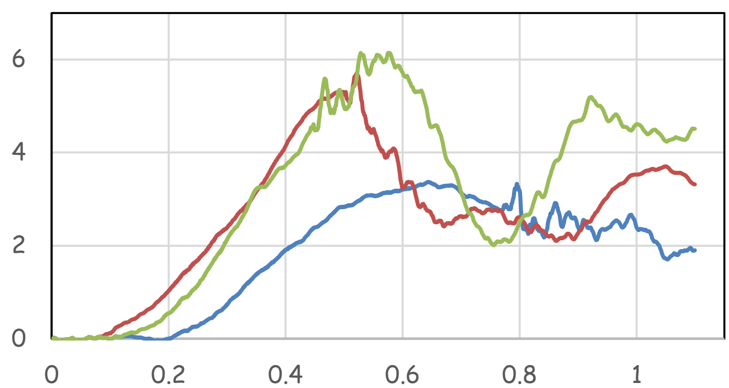
Table 26. Different Finite Element Simulations Performed on Sloped Terrain with Pickup Truck (2270P)

Simulation no.	Vehicle	Speed	Leg	Edge Distance (ft.)	Angle (degrees)
25	Pickup Truck (2270P)	19 mph	1st	12	15
26					20
27					25
28				24	15
29					20
30					25
31			2nd	12	15
32					20
33					25
34				24	15
35					20
36					25
37	Pickup Truck (2270P)	62 mph	1st	12	15
38					20
39					25
40				24	15
41					20
42					25
43			2nd	12	15
44					20
45					25
46				24	15
47					20
47					25

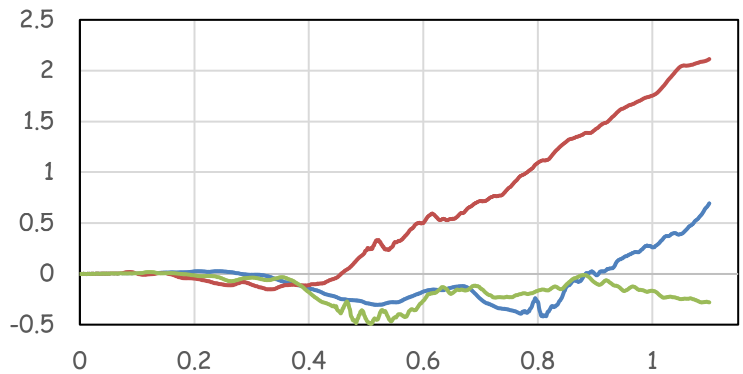
Table 27. Roll, Pitch, and Yaw Angles for Pickup Truck Impacting Leg-1.



Roll



Pitch



Yaw

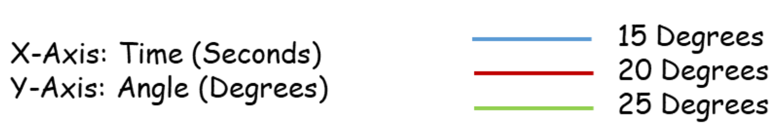


Table 28. Roll, Pitch, and Yaw Angles for Pickup Truck Impacting Leg-2.

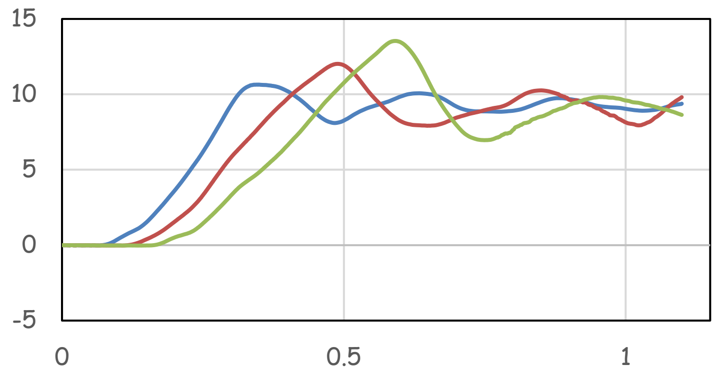
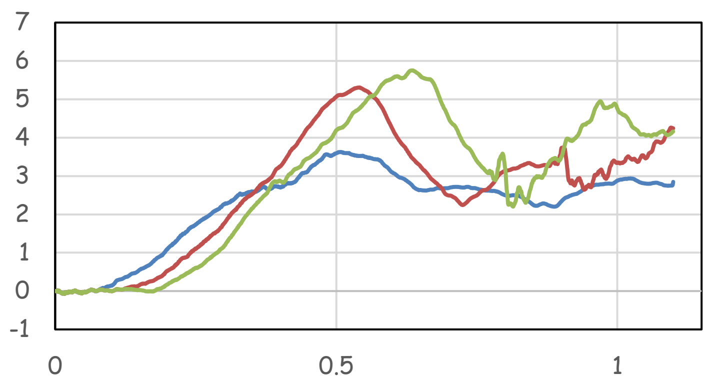
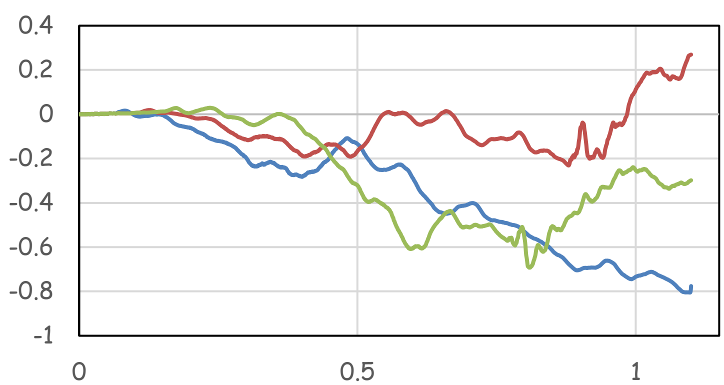
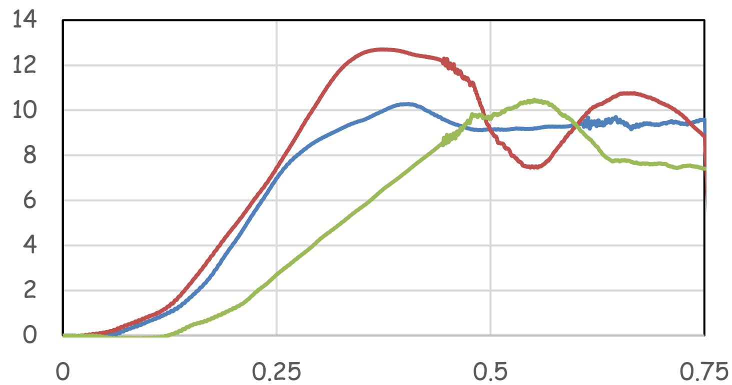
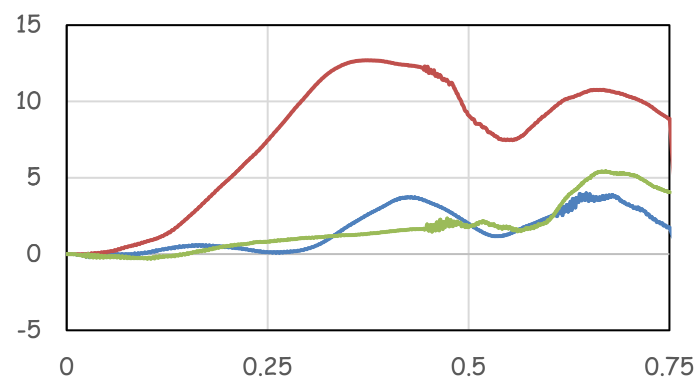

Roll

Pitch

Yaw
X-Axis: Time (Seconds) Y-Axis: Angle (Degrees) 15 Degrees 20 Degrees 25 Degrees

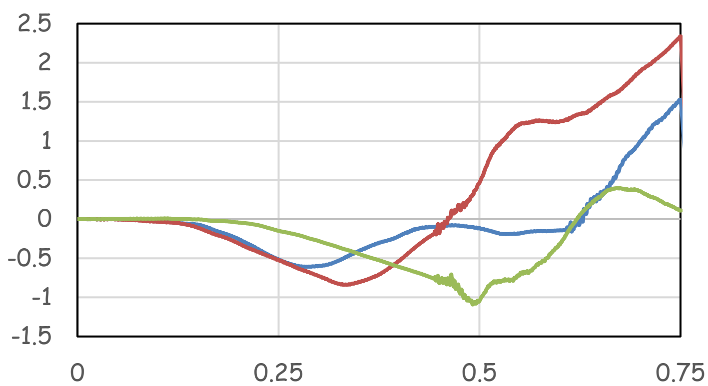
Table 29. Roll, Pitch, and Yaw Angles for Car Impacting Leg-1.



Roll



Pitch

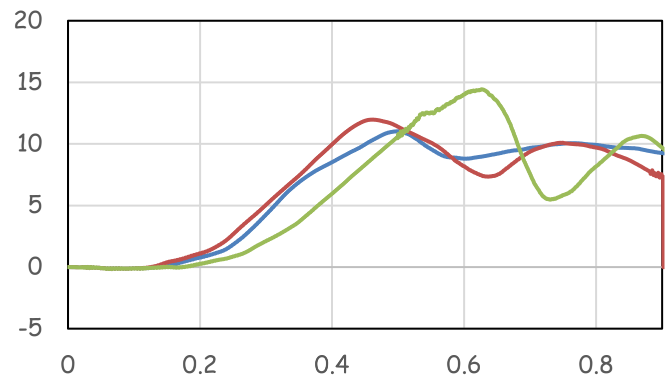


Yaw

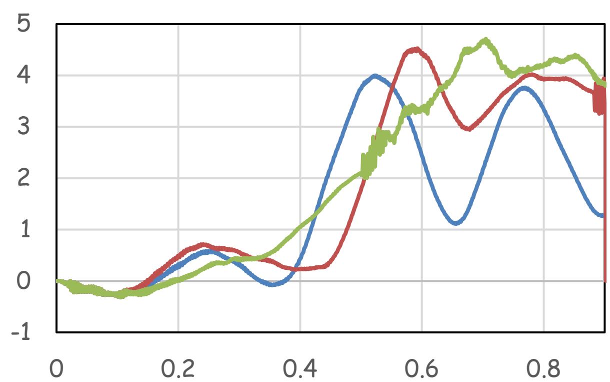
X-Axis: Time (Seconds)
Y-Axis: Angle (Degrees)

15 Degrees
20 Degrees
25 Degrees

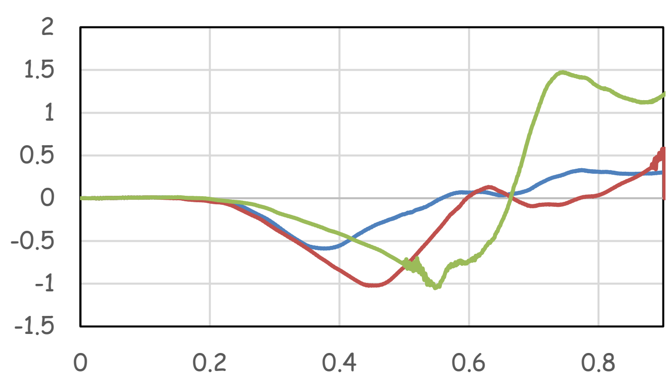
Table 30. Roll, Pitch, and Yaw Angles for Car Impacting Leg-2.



Roll



Pitch



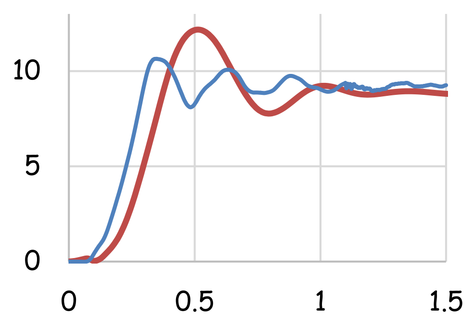
Yaw

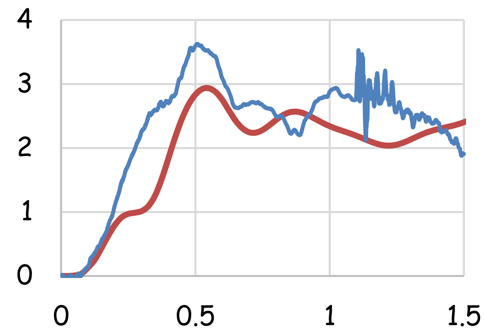
X-Axis: Time (Seconds)
Y-Axis: Angle (Degrees)

15 Degrees
20 Degrees
25 Degrees

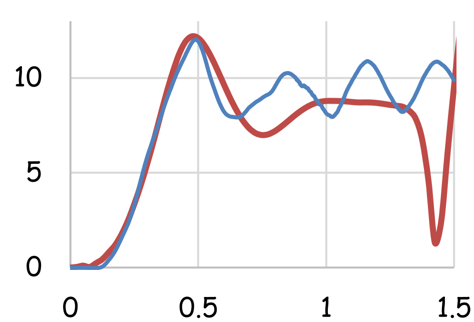
The angular displacements of passenger car and a pickup truck for high speed with different parameters were compared and verified with trajectory simulations performed in CARSIM software. Table 31 and Table 32 illustrates the comparison of CARSIM and LS-DYNA angular displacement values for the pickup truck and a small car. The results obtained from CARSIM closely matches with LS-Dyna results. As anticipated earlier, it was observed from the angular displacements (roll, pitch, and yaw) values, that vehicle impacting the signpost assembly at 25 degrees is most critical. A complete comparison of occupant risk values and angular displacements is shown in the tables below. Table 33 and Table 34 illustrates the occupant risk and angular displacement for car impacting the first and second leg. Table 35 and Table 36 illustrates the occupant risk and angular displacement for pickup truck impacting the first and second leg. Detailed analysis of the impact simulations of car and pickup truck impacting the test article at 25 degrees with respect to the roadway at low and high speeds are also shown in this section.

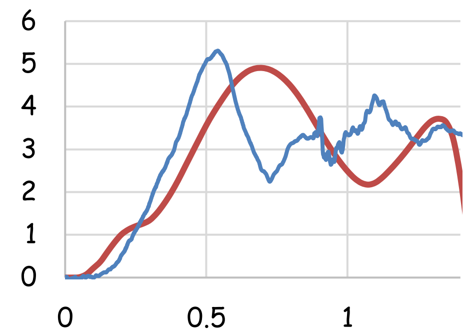
Table 31. Comparison of CARSIM and LS-DYNA Angular Displacement Values for Pickup Truck.



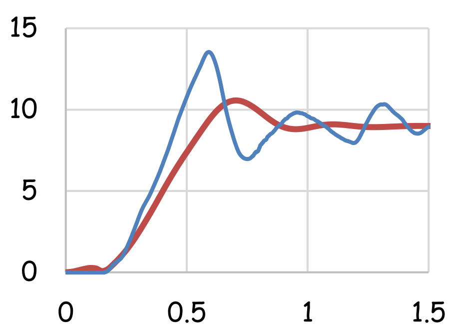


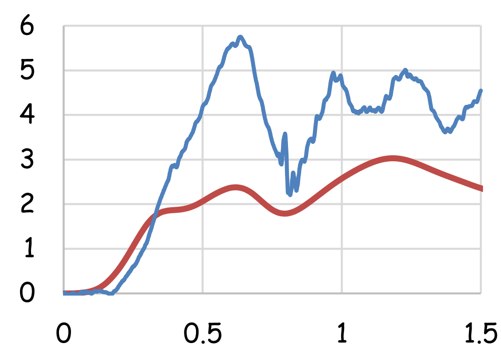
15 Degrees





20 Degrees

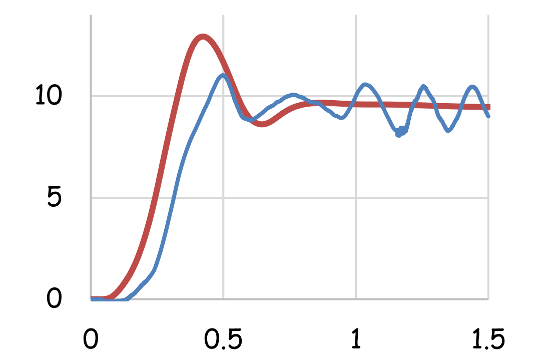


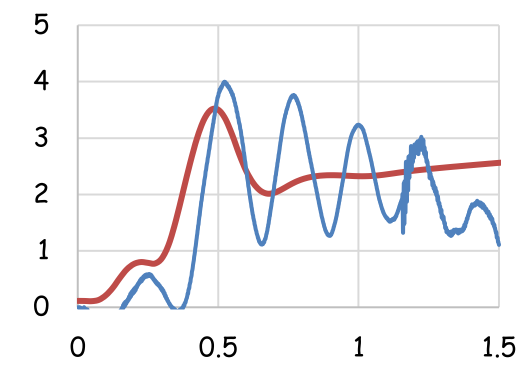


25 Degrees

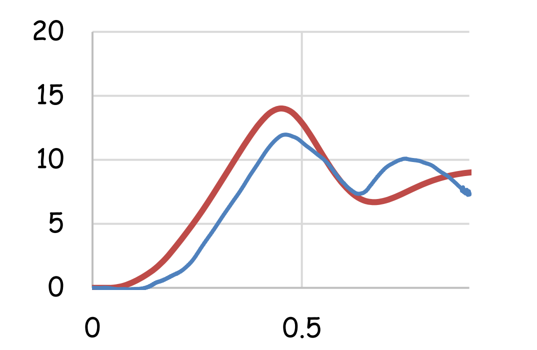
X-Axis: Time (Seconds)	LS-DYNA
Y-Axis: Angle (Degrees)	CARSIM

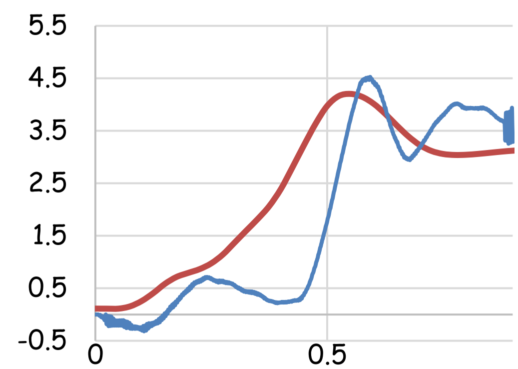
Table 32. Comparison of CARSIM and LS-DYNA Angular Displacement Values for Small Car.



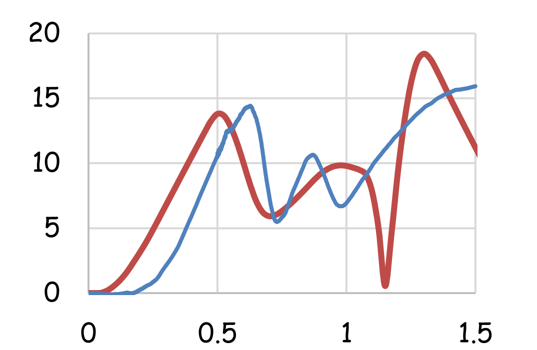


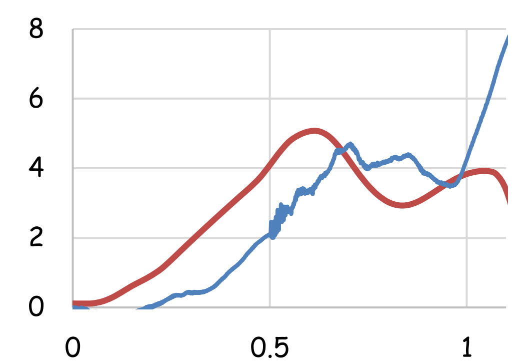
15 Degrees





20 Degrees





25 Degrees

X-Axis: Time (Seconds) — LS-DYNA

Y-Axis: Angle (Degrees) — CARSIM

Table 33. Occupant Risk and Maximum Angular Displacements of Car Impacting First Leg at High Speed.

Angle	OIV (ft./s)		ORA (G)		Roll	Pitch	Yaw
	Longitudinal	Lateral	Longitudinal	Lateral	Deg	Deg	Deg
15	N/A	N/A	N/A	N/A	10.3	3.9	1.5
20	9.84	6.23	2.99	1.89	12	5.0	1.9
25	9.18	1.96	1.6	1.4	10.4	5.4	-0.9

Table 34. Occupant Risk and Maximum Angular Displacements of Car Impacting Second Leg at High Speed.

Angle	OIV (ft./s)		ORA (G)		Roll	Pitch	Yaw
	Longitudinal	Lateral	Longitudinal	Lateral	Deg	Deg	Deg
15	5.57	1.31	1.0	-1.5	11.0	4.0	7.1
20	-0.98	3.60	-11.0	2.8	12	4.5	-0.9
25	11.48	0.98	7.6	-3.1	16.9	19.6	1.7

Table 35. Occupant Risk and Maximum Angular Displacements of Pickup truck Impacting the First Leg at High Speed.

Angle	OIV (ft/s)		ORA (G)		Roll	Pitch	Yaw
	Longitudinal	Lateral	Longitudinal	Lateral	Deg	Deg	Deg
15	1.31	3.28	-6.9	-4.6	11.6	3.4	0.9
20	3.28	2.62	-2.0	-4.5	12	5.6	2.1
25	2.62	4.92	3.9	-5.7	13	6.1	0.3

Table 36. Occupant Risk and Maximum Angular Displacements of Pickup Truck Impacting Second Leg at High Speed.

Angle	OIV (ft/s)		ORA (G)		Roll	Pitch	Yaw
	Longitudinal	Lateral	Longitudinal	Lateral	Deg	Deg	Deg
15	-2.95	5.57	12.5	5.3	10.6	3.6	1.8
20	2.29	3.28	-6.5	-3.7	12	5.3	0.7
25	1.96	1.64	-3.3	7.2	13.6	5.7	-1.2

8.2. Detailed Finite Element Analysis of Sign Post System with Car (1100C)

The sign support system on sloped terrain was impacted with small vehicle (1100C) at low speed (19 mph) and high speed (62 mph). The vehicle impacted the sign support system at an angle of 25 degrees with respect to the roadway. For the impact simulations, the already calibrated finite element model of Toyota Yaris was used.

8.2.1. Low Speed

8.2.1.1. Vehicle Stability and Sign Support System Performance

The FE model of the small vehicle (1100C), traveling at a speed of 19 mph and 25 degrees angle, impacted the large sign support system. The centerline of the left leg support was impacted by the center point of the vehicle. Immediately after the impact, the left leg started moving and slipped away at the base.

At 1.35 s, the fuse plate attached to the impact side got activated. The vehicle lost the contact with the support leg at 1.45 s and was traveling at 18.611 mph. The hinge on the left support and fuse plate on the right support got activated at 1.6 s.

By 1.7 s, the upper fuse and hinge plate connection on the left support leg was completely ruptured. After the complete rupture of connection plates of the left leg, the support began to move in the direction of the vehicle. At the same time, the sign panel started tilting towards the vehicle with the right leg still intact. Support and sign panel didn’t come in contact with the vehicle. At 2.0 s the vehicle safely crossed the signpost assembly. Table 37 shows the complete sequential photographs of the simulations.

Table 37. Sequential Images of FE Simulations for Car at Low Speed.

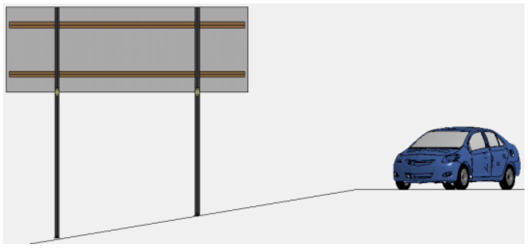
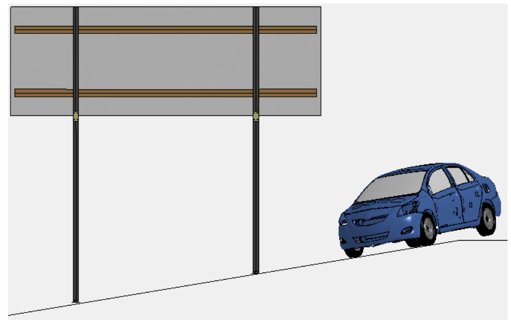
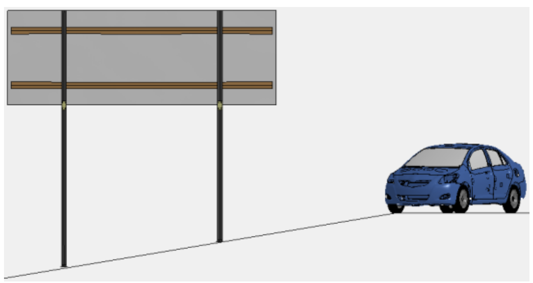
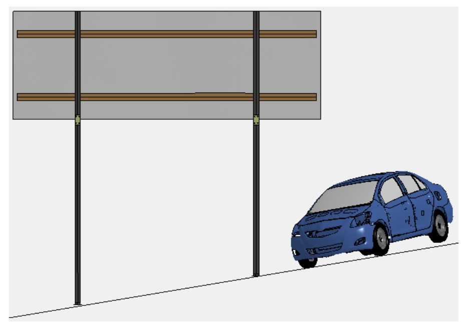
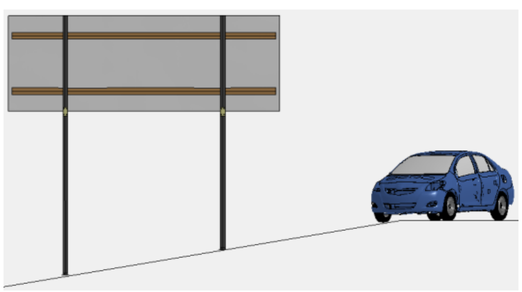
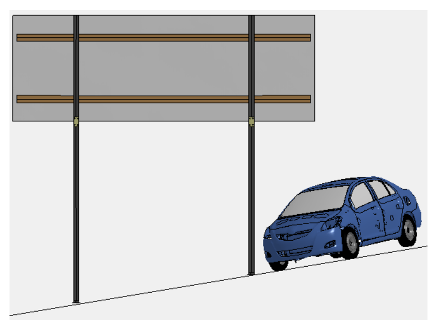
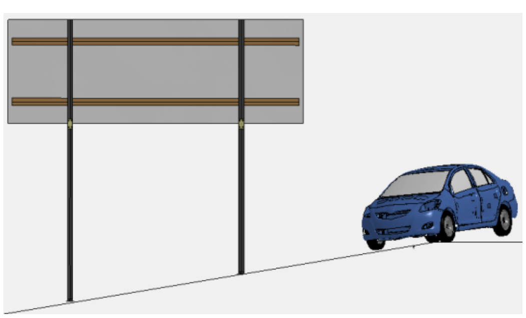
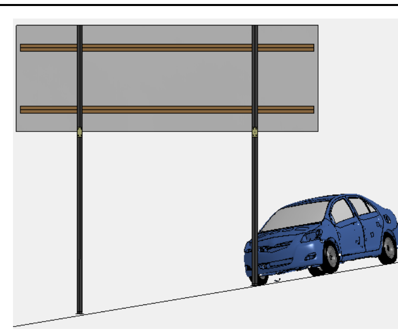
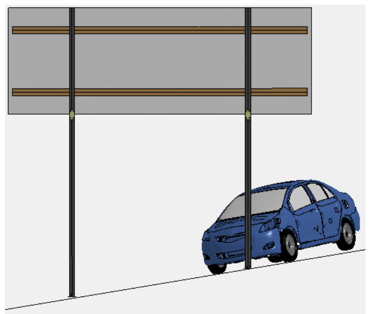
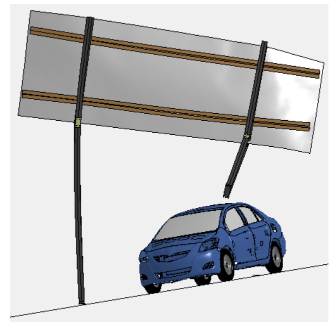
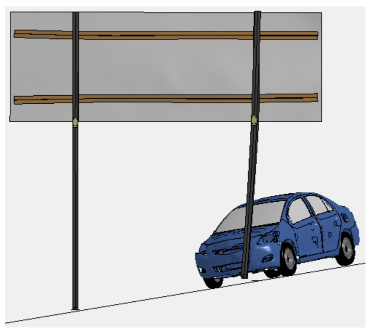
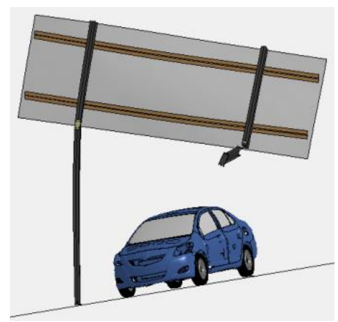
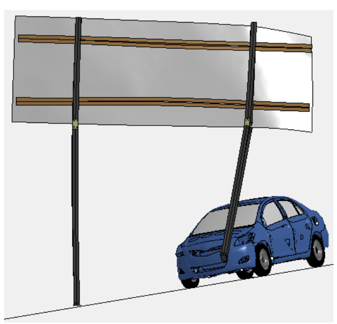
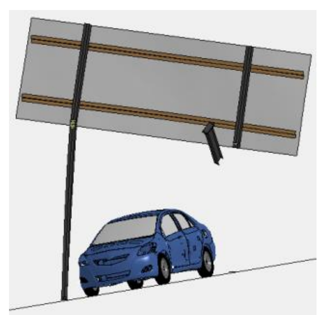
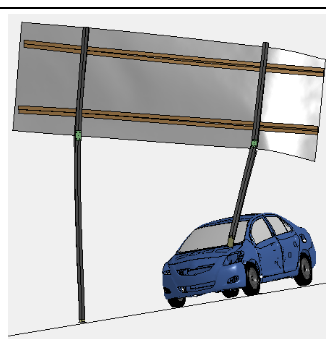
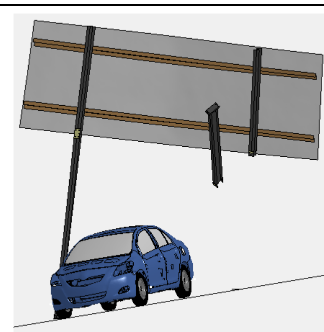
	
0 s	0.8 s
	
0.3 s	1 s
	
0.4 s	1.1 s
	
0.6 s	0.42 s

Table 37. Continued

	
1.35 s	1.7 s
	
1.4 s	1.8 s
	
1.5 s	1.9 s
	
1.6 s	2 s

8.2.1.2. Occupant Risk Assessment

Data from the accelerometer, located in the vehicle at the center of gravity was used to compute occupant risk factors based on MASH safety criteria for flat-level ground. The TRAP program was used to digitize the values obtained from the finite element model. In the longitudinal direction, the occupant impact velocity was 7.21 ft/s at 1.24 seconds, the highest 10-ms occupant ridedown acceleration was -9.3 G from 1.353 to 1.363 seconds, and the maximum 50-ms average acceleration was -2.6 G between 1.346 and 1.396 seconds. In the lateral direction, the occupant impact velocity was 3.28 ft/s at 1.24 seconds, the highest 10-ms occupant ridedown acceleration was 3.4 G from 1.357 to 1.367 seconds, and the maximum 50-ms average was -1.7 G between 1.198 and 1.248 seconds. The maximum roll, pitch, and yaw angles were 9.8, 5.4, and -6.4 degrees respectively (See Figure 82). Figure 83 summarizes the above data and other important information from the test.

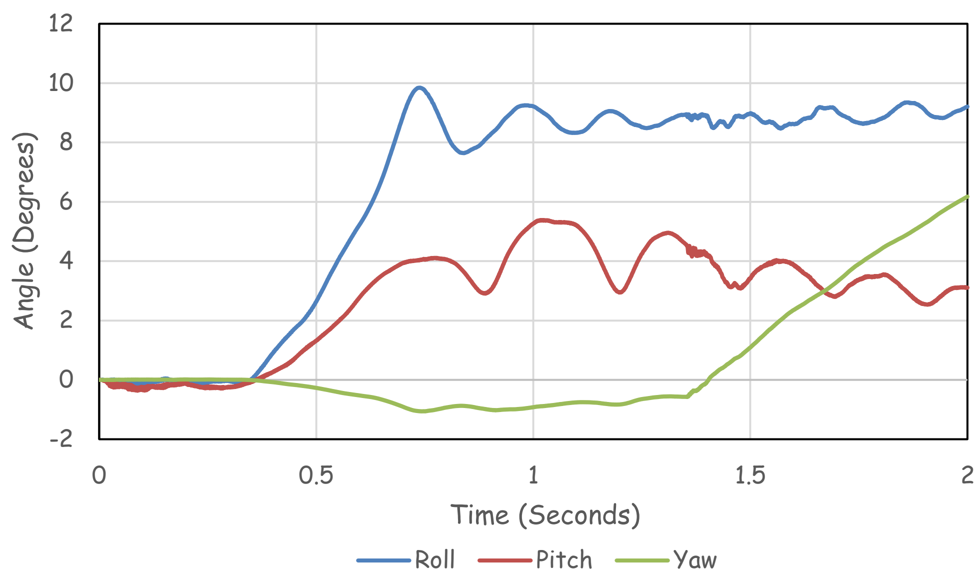


Figure 82. Angular Displacement for 1100C Vehicle at Low Speed.

8.2.1.3. Summary

An assessment of the test based on the applicable MASH safety evaluation criteria for flat level terrain is provided below.

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

   Results: When impacted by the 1100C vehicle, the left leg of the large sign support activated by breaking away at the slipbase and the upper hinge connections.

2. 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 outlined in Section 5.3 and Appendix E of MASH for support systems on the flat-level ground: deformation in the roof should be less than equal to 4.0 inches; deformation in windshield should be less than equal to 3.0 inches; there should be no shattering by test article structural member inside windows; deformation in wheel/ footwell/ toe pan should be less than 9.0 inches; deformation in forward A-pillar should be less than 12.0 inches; deformation in front side door area above seats should be less than 9.0 inches and in front side door below seat should be less than 12.0 inches; deformation in floor pan/transmission tunnel area should be less than 12.0 inches.

   Results: The left support leg separated from the installation. However, the 1100C vehicle traveled beneath these elements. The elements did not penetrate or show potential for penetrating the occupant compartment, nor to present a hazard to others in the area. No occupant compartment deformation occurred during the test with the 1100C vehicle.

3. The vehicle should remain upright during and after the collision. The maximum roll and pitch angles should not exceed 75 degrees.

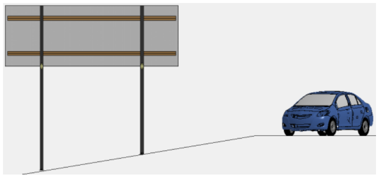
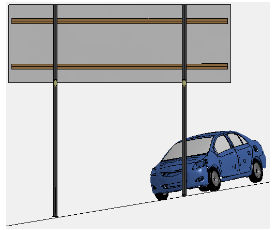
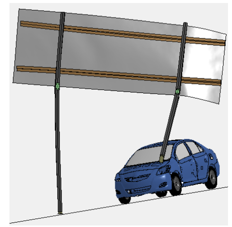
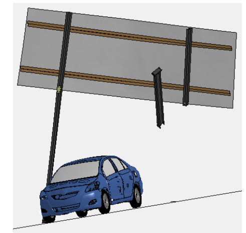
   Results: The 1100C vehicle remained upright during and after the collision event. The maximum roll and pitch angles were less than 10 degrees.

4. Longitudinal and Lateral impact velocity should be less than 16.4 ft/s

   Result: Longitudinal and lateral occupant impact velocities less than the maximum limits.

5. Occupant ridedown acceleration should be less than 20.49 G.

   Result: Longitudinal and lateral ridedown acceleration were also less than the required limits.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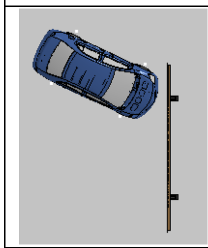
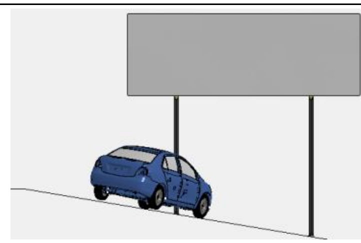
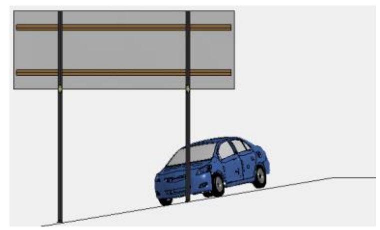
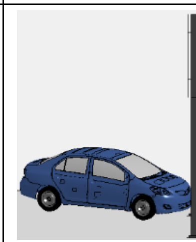
			
Top View	Front View	Back View	Side View

General Information
Test Agency: Texas A&M Transportation Institute
Test Standard: Sloped Terrain; Car (1100C); Low Speed

Test Article
Type: Sign Support System
Name: MASH TL-3 Sign Support System
Material or Key Elements: Steel
Soil Type: Concrete Pavement

Test Vehicle
Type/Designation: 1100C
Make and Model: Finite Element Yaris
Curb: 2420 lb.
Dummy: No Dummy

Impact Conditions
Speed: 19 mph
Angle: 25 degrees
Location/Orientation: Left Leg

Occupant Risk Values
Longitudinal OIV: -7.21 ft./s
Lateral OIV: 3.28 ft./s
Longitudinal Ridedown: -9.3 G
Lateral Ridedown: 3.4 G

Max. 0.050-s Average
Longitudinal: -2.6 G
Lateral: -1.7 G
Vertical: -1.9 G

Post-Impact Trajectory
Stopping Distance: N/A

Vehicle Stability
Maximum Roll Angle: 9.8 degrees
Maximum Pitch Angle: 5.4 degrees
Maximum Yaw Angle: -6.4 degrees

Vehicle Roof Deformation: Yes
Max Deformation: Nil

Figure 83. Summary of Finite Element Simulation for 1100C Vehicle at Low Speed.

8.2.2. High Speed

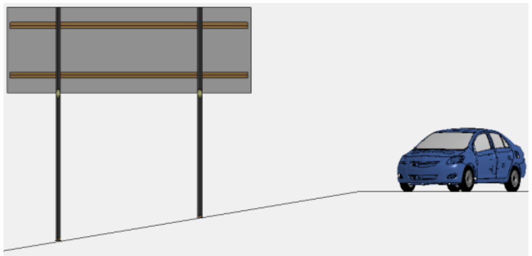
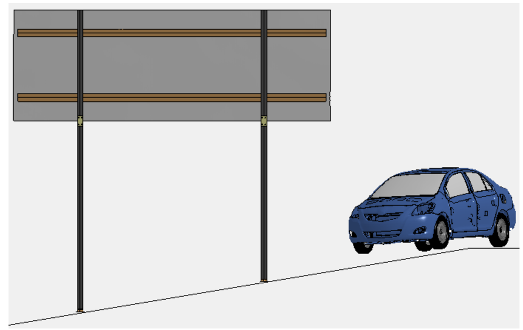
8.2.2.1. Vehicle Stability and Sign Support System Performance

The finite element model of the small vehicle (1100C), traveling at a speed of 62 mph and 25 degrees angle, impacted the large sign support system. The centerline of the left leg support was impacted by the center point of the vehicle. Immediately after the impact, the left leg started moving and slipped away at the base.

At 0.48 s, the fuse plate attached to the impact side got activated. The vehicle lost the contact with the support leg at 0.52 s and was traveling at 55.39 mph. The fuse plate on the right leg got activated at 0.54 s and the hinge on the left support got activated at 0.56 s.

The hinge on the right support was activated at 0.62 s. By 0.66 s, the upper fuse and hinge plate connection on the left support leg was completely ruptured. After the complete rupture of connection plates of the left leg, the support began to move in the direction of the vehicle. At the same time, the sign panel started tilting towards the vehicle with the right leg still intact. Support and sign panel didn't come in contact with the vehicle. At 0.7 s the vehicle safely crossed the signpost assembly. By 0.7 s, the connection on the right support was completely ruptured. Table 38 shows the complete sequential photographs of the simulations.

Table 38. Sequential Images of FE Simulations for Car at High Speed.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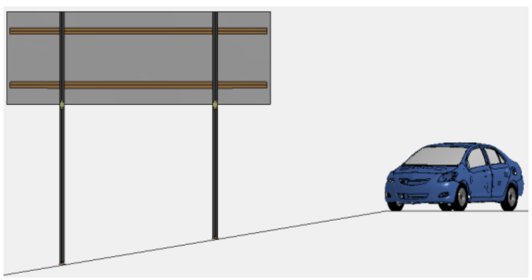	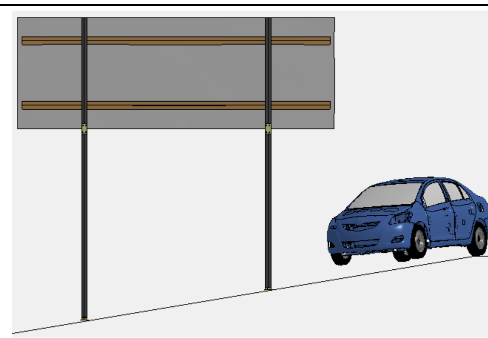
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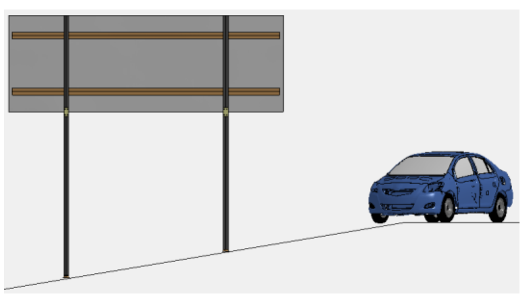	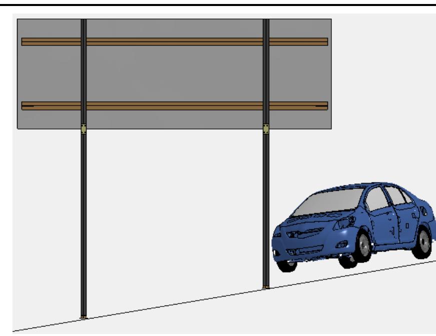
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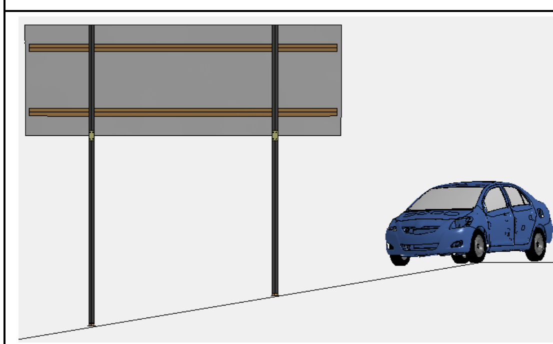
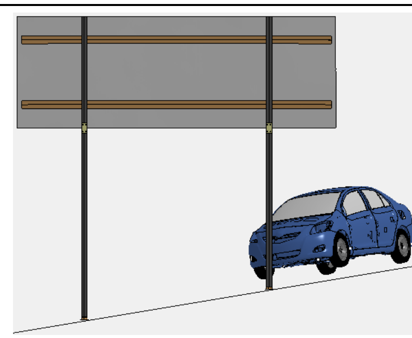
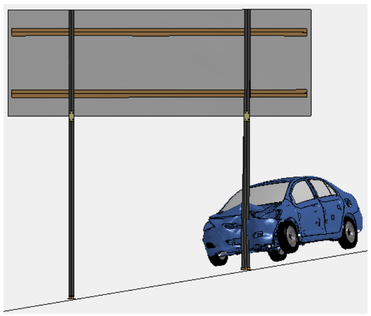
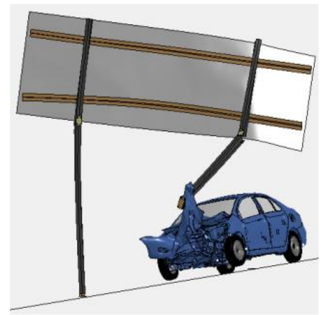
	
0.22 s	0.42 s

Table 38. Continued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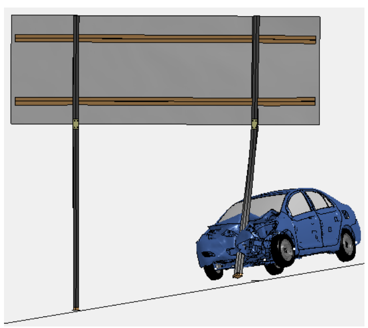	
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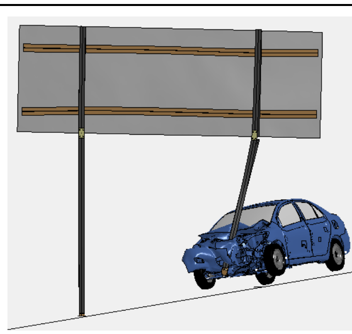
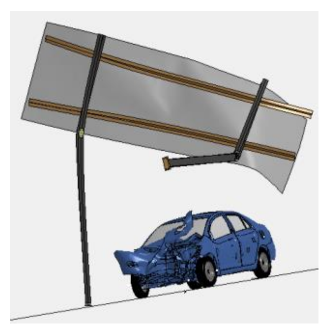
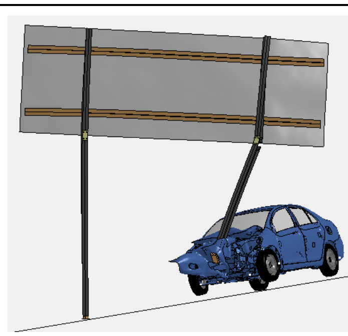
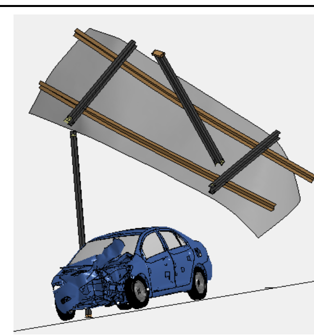
	
0.5 s	0.62 s
	
0.52 s	0.75 s

8.2.2.2. Occupant Risk Assessment

Data from the accelerometer, located in the vehicle at the center of gravity was used to compute occupant risk factors based on MASH safety criteria. The TRAP program was used to digitize the values obtained from the finite element model. In the longitudinal direction, the occupant impact velocity was 9.18 ft/s at 0.65 seconds, the highest 10-ms occupant ridedown acceleration was 1.6 G from 0.6715 to 0.6815 seconds, and the maximum 50-ms average acceleration was -6.7 G between 0.4285 and 0.4796 seconds. In the lateral direction, the occupant impact velocity was 1.97 ft/s at 0.658 seconds, the highest 10-ms occupant ridedown acceleration was 1.4 G from 0.695 to 0.705 seconds, and the maximum 50-ms average was -1.4 G between 0.4185 and 0.4685 seconds. The maximum roll, pitch, and yaw angles were 10.4, 5.4, and -0.9 degrees respectively (See Figure 84). Figure 85 summarizes the above data and other important information from the test.

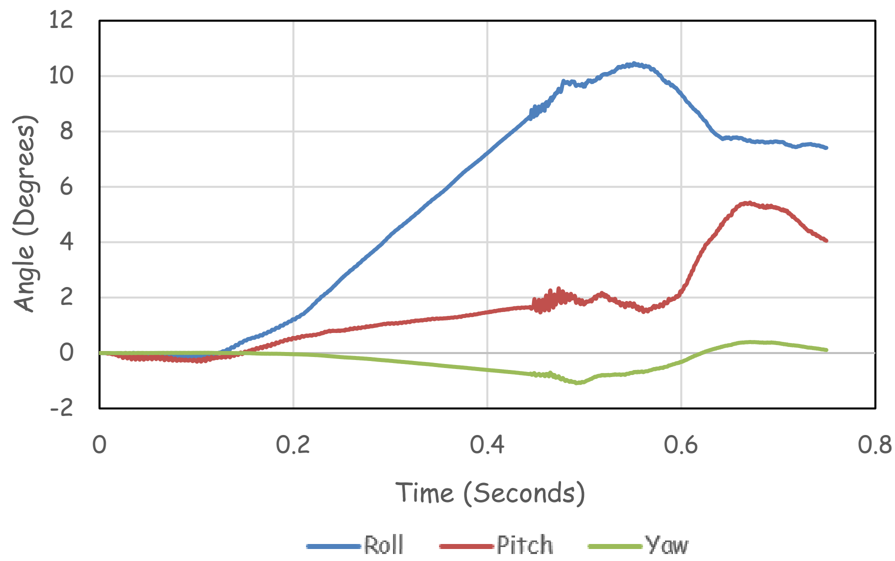


Figure 84. Angular Displacement for 1100C Vehicle at High Speed.

8.2.2.3. Summary

An assessment of the test based on the applicable MASH safety evaluation criteria for flat-level terrain is provided below.

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

   Results: When impacted by the 1100C vehicle, the left leg of the large sign support activated by breaking away at the slipbase and the upper hinge connections.

2. 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 outlined in Section 5.3 and Appendix E of MASH for support systems on the flat-level ground: deformation in the roof should be less than equal to 4.0 inches; deformation in windshield should be less than equal to 3.0 inches; there should be no shattering by test article structural member inside windows; deformation in wheel/ footwell/ toe pan should be less than 9.0 inches; deformation in forward A-pillar should be less than 12.0 inches; deformation in front side door area above seats should be less than 9.0 inches and in front side door below seat should be less than 12.0 inches; deformation in floor pan/transmission tunnel area should be less than 12.0 inches.

Results: The left support leg separated from the installation. However, the 1100C vehicle traveled beneath these elements. The elements did not penetrate or show potential for penetrating the occupant compartment, nor to present a hazard to others in the area. No occupant compartment deformation occurred during the test with the 1100C vehicle.

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

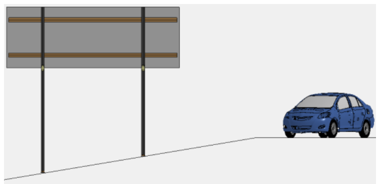
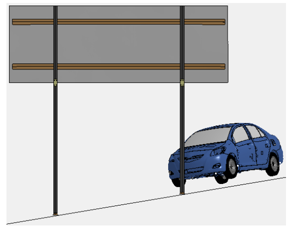
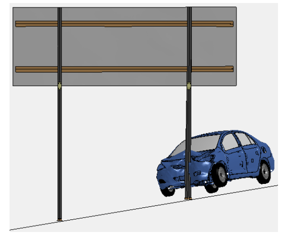
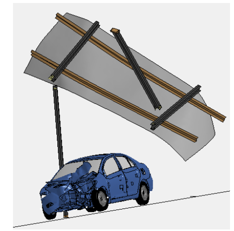
   Results: The 1100C vehicle remained upright during and after the collision event. The maximum roll and pitch angles were 10.4 degrees and 5.4 degrees.

4. Longitudinal and Lateral impact velocity should be less than 16.4 ft/s

   Result: Longitudinal and lateral occupant impact velocities less than the maximum limits.

5. Occupant ridedown acceleration should be less than 20.49 G.

   Result: Longitudinal and lateral ridedown acceleration were very low.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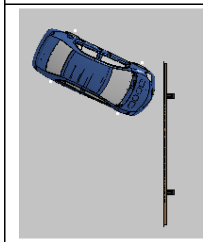
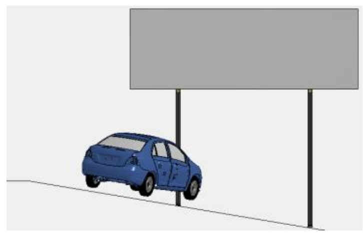
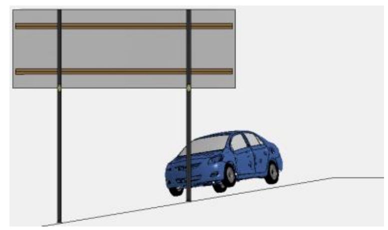
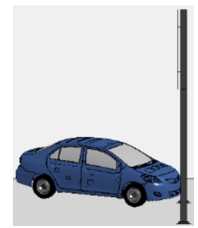
			
Top View	Front View	Back View	Side View

General Information
Test Agency: Texas A&M Transportation Institute
Test Standard: Sloped Terrain; Car (1100C); High Speed

Test Article
Type: Sign Support System
Name: MASH TL-3 Sign Support System
Material or Key Elements: Steel
Soil Type: Concrete Pavement

Test Vehicle
Type/Designation: 1100C
Make and Model: Finite Element Yaris
Curb: 2420 lb.
Dummy: No Dummy

Impact Conditions
Speed: 62 mph
Angle: 25 degrees
Location/Orientation: Left Leg

Occupant Risk Values
Longitudinal OIV: 9.18 ft./s
Lateral OIV: 1.96 ft/s
Longitudinal Ridedown: 1.6 G
Lateral Ridedown: 1.4 G

Max. 0.050-s Average
Longitudinal: -6.7 G
Lateral: -1.4 G
Vertical: -3.1 G

Post-Impact Trajectory
Stopping Distance: N/A

Vehicle Stability
Maximum Roll Angle: 10.4 degrees
Maximum Pitch Angle: 5.4 degrees
Maximum Yaw Angle: -0.9 degrees

Vehicle Roof Deformation: Yes
Max Deformation: Nil

Figure 85. Summary of Finite Element Simulation for 1100C Vehicle at High Speed.

8.3. Detailed Finite Element Analysis of Sign Post System with Pickup Truck (2270P)

The sign support system on sloped terrain was impacted with a pickup truck (2270P) at low speed (19 mph) and high speed (62 mph). The vehicle impacted the sign support system at an angle of 25 degrees with respect to the roadway. For simulations, an already calibrated finite element model of Silverado RAM was used.

8.3.1. Low Speed

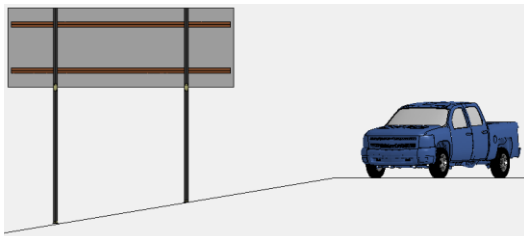
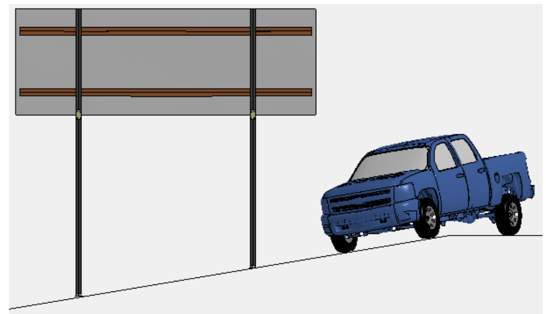
8.3.1.1. Vehicle Stability and Sign Support System Performance

The finite element model of the pickup truck (2270P), traveling at a speed of 19 mph and 25 degrees angle, impacted the large sign support system. The centerline of the left leg support was impacted by the center point of the vehicle. Immediately after the impact, the left leg started moving and slipped away at the base.

The vehicle lost contact with the support leg at 1.35 s and the fuse plate attached to the impact side got activated at 1.4 s. The vehicle was traveling at 19.98 mph at 1.41 s. The hinge on the left support hot activated at 1.55 s.

By 1.7 s, the upper fuse and hinge plate connection on the left support leg was completely ruptured. After the complete rupture of connection plates of the left leg, the support began to move in the direction of the vehicle. At the same time, the sign panel started tilting toward the vehicle with the right leg still intact. Support and sign panel didn’t come in contact with the vehicle. At 2.15 s the vehicle safely crossed the signpost assembly. Table 39 shows the complete sequential photographs of the simulations.

Table 39. Sequential Images of FE Simulations for Pickup Truck at Low Speed.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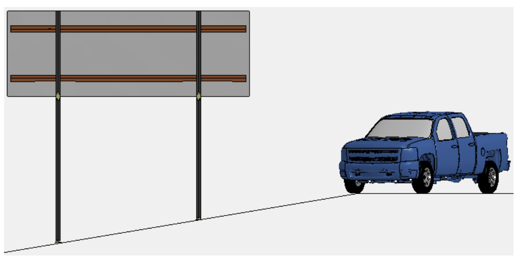	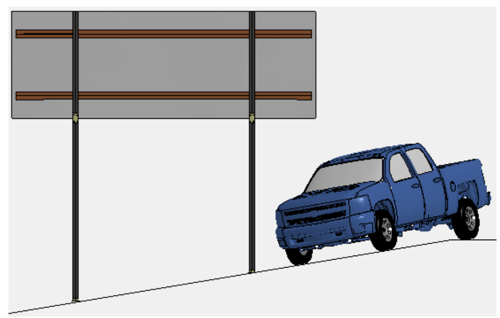
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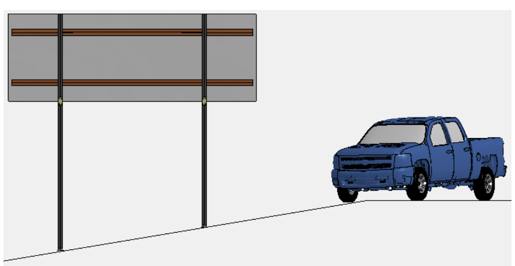	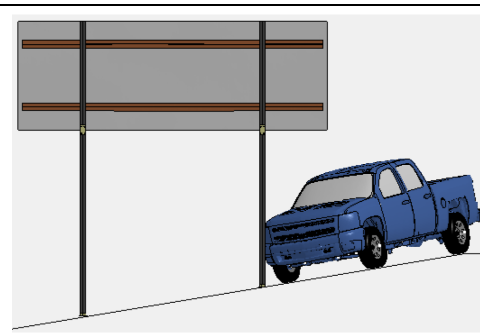
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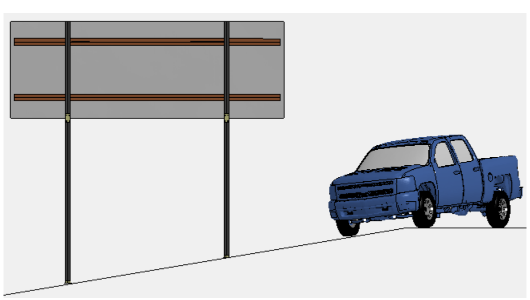	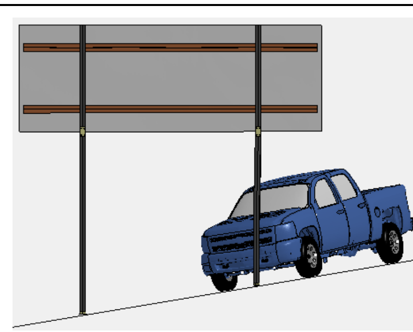
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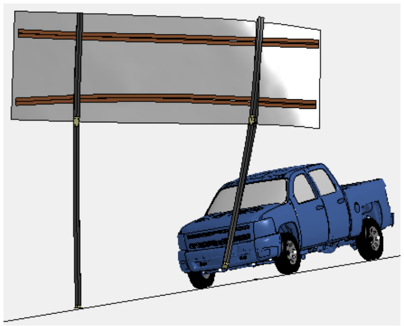	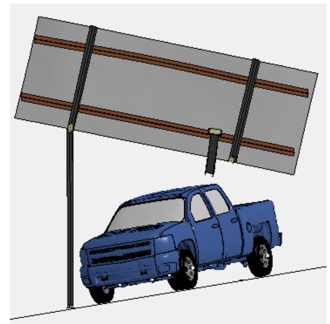
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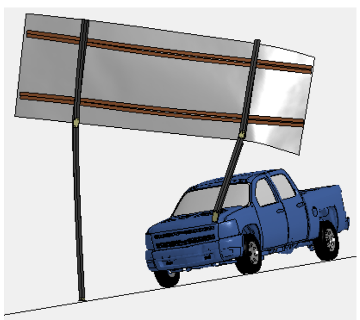	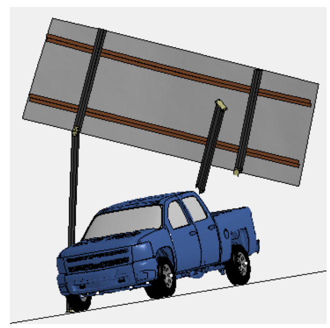
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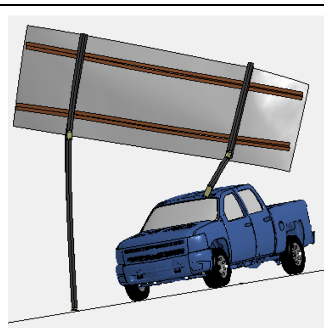	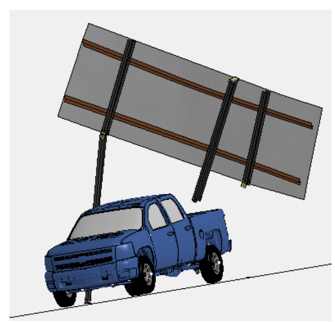
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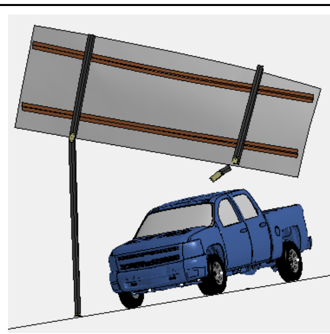
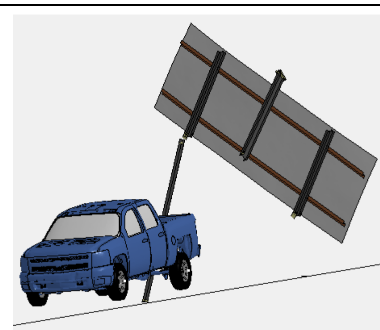
	
1.75 s	2.5 s

8.3.1.2. Occupant Risk Assessment

Data from the accelerometer, located in the vehicle at the center of gravity was used to compute occupant risk factors based on MASH safety criteria. The TRAP program was used to digitize the values obtained from the finite element model. In the longitudinal direction, the occupant impact velocity was -1.31 ft/s at 1.2080 seconds, the highest 10-ms occupant ridedown acceleration was -6 G from 1.338 to 1.348 seconds, and the maximum 50-ms average acceleration was -1.7 G between 1.322 and 1.3720 seconds. In the lateral direction, the occupant impact velocity was 0.98 ft/s at 1.208 seconds, the highest 10-ms occupant ridedown acceleration was 6.8 G from 1.737 to 1.747 seconds, and the maximum 50-ms average was 1.9 G between 1.711 and 1.761 seconds. The maximum roll, pitch, and yaw angles were 9.3, 5.3, and 5.1 degrees respectively (See Figure 86). Figure 87 summarizes the above data and other important information from the test.

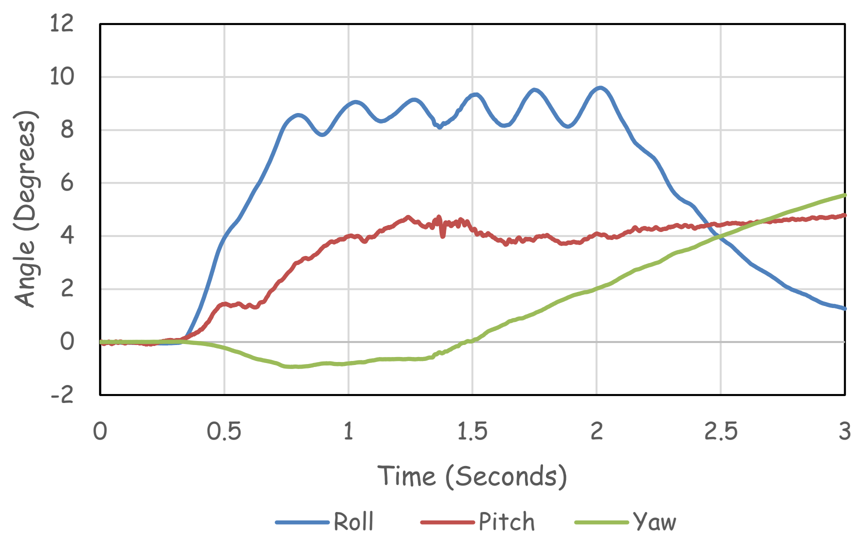


Figure 86. Angular Displacement for 2270P Vehicle at Low Speed.

8.3.1.3. Summary

An assessment of the test based on the applicable MASH safety evaluation criteria for flat-level terrain is provided below.

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

   Results: When impacted by the 2270P vehicle, the left leg of the large sign support activated by breaking away at the slipbase and the upper hinge connections.

2. 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 outlined in Section 5.3 and Appendix E of MASH for support systems on the flat-level ground: deformation in the roof should be less than equal to 4.0 inches; deformation in windshield should be less than equal to 3.0 inches; there should be no shattering by test article structural member inside windows; deformation in wheel/ footwell/ toe pan should be less than 9.0 inches; deformation in forward A-pillar should be less than 12.0 inches; deformation in front side door area above seats should be less than 9.0 inches and in front side door below seat should be less than 12.0 inches; deformation in floor pan/transmission tunnel area should be less than 12.0 inches.

   Results: The left support leg separated from the installation. However, the 2270P vehicle traveled beneath these elements. The elements did not penetrate or show

potential for penetrating the occupant compartment, nor to present a hazard to others in the area. No occupant compartment deformation occurred during the test with the 2270P vehicle.

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

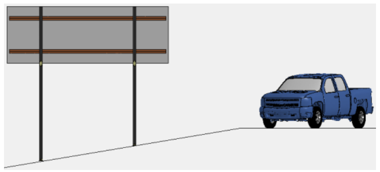
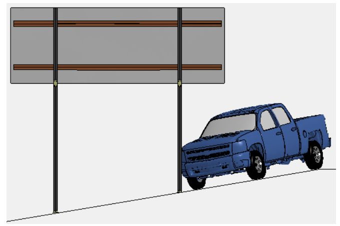
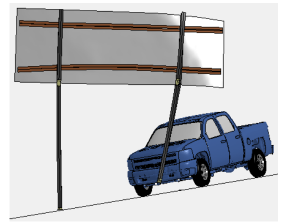
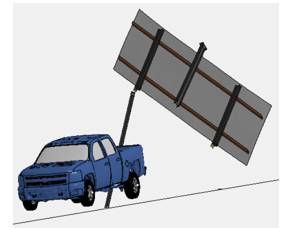
   Results: The 2270P vehicle remained upright during and after the collision event. The maximum roll and pitch angles were less than 10 degrees for both.

4. Longitudinal and Lateral impact velocity should be less than 16.4 ft/s

   Result: Longitudinal and lateral occupant impact velocities less than the maximum limits.

5. Occupant ridedown acceleration should be less than 20.49 G.

   Result: Longitudinal and lateral ridedown acceleration were very low.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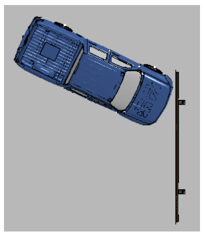
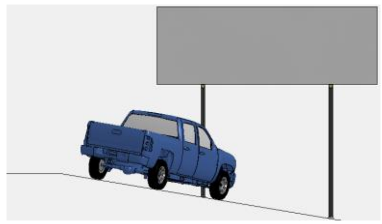
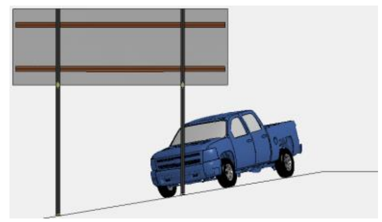
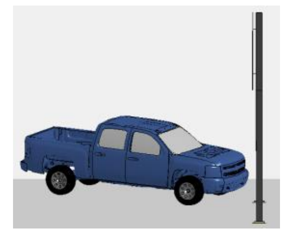
			
Top View	Front View	Back View	Side View

General Information
Test Agency: Texas A&M Transportation Institute
Test Standard: Sloped Terrain; Pickup Truck (2270P); High Speed

Test Article
Type: Sign Support System
Name: MASH TL-3 Sign Support System
Material or Key Elements: Steel
Soil Type: Concrete Pavement

Test Vehicle
Type/Designation: 2270P
Make and Model: Finite Element Silverado
Curb: 5000 lb
Dummy: No Dummy

Impact Conditions
Speed: 19 mph
Angle: 25 degrees
Location/Orientation: Left Leg

Occupant Risk Values
Longitudinal OIV: -1.31 ft/s
Lateral OIV: 0..98 ft/s
Longitudinal Ridedown: -6.0 G
Lateral Ridedown: 6.8 G

Max. 0.050-s Average
Longitudinal: -1.7 G
Lateral: -1.9 G
Vertical: -1.3 G

Post-Impact Trajectory
Stopping Distance: N/A

Vehicle Stability
Maximum Roll Angle: 9.6 degrees
Maximum Pitch Angle: 5.3 degrees
Maximum Yaw Angle: 5.1 degrees

Vehicle Roof Deformation: Yes
Max Deformation: Nil

Figure 87. Summary of Finite Element Simulation for 2270P Vehicle at Low Speed.

8.3.2. High Speed

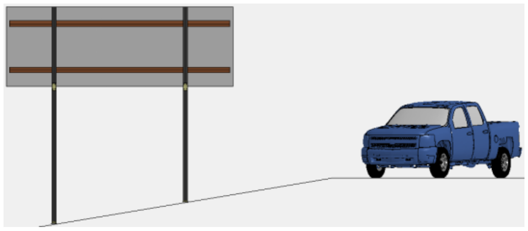
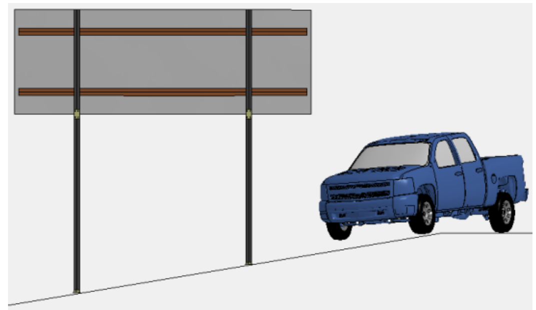
8.3.2.1. Vehicle Stability and Sign Support System Performance

The finite element model of the pickup truck (2270P), traveling at a speed of 62 mph and 25 degrees angle, impacted the large sign support system. The centerline of the left leg support was impacted by the quarter point of the vehicle. Immediately after the impact, the left leg started moving and slipped away at the base.

At 0.46 s, the fuse plate attached to the impact side got activated. The vehicle lost the contact with the support leg at 0.52 s and was traveling at 59.24 mph. The hinge on the left support hot activated at 0.54 s.

By 0.64 s, the upper fuse and hinge plate connection on the left support leg was completely ruptured. After the complete rupture of connection plates of the left leg, the support began to move in the direction of the vehicle. At the same time, the sign panel started tilting toward the vehicle with the right leg still intact. Support and sign panel didn't come in contact with the vehicle. At 0.72 s the vehicle safely crossed the signpost assembly. Table 40 shows the complete sequential photographs of the simulations.

Table 40. Sequential Images of FE Simulation for Pickup Truck at High Speed.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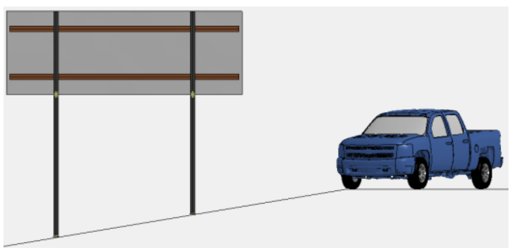	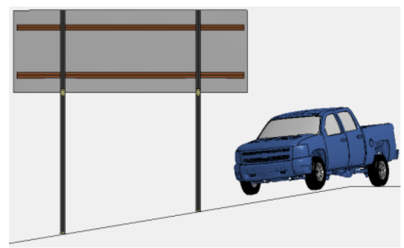
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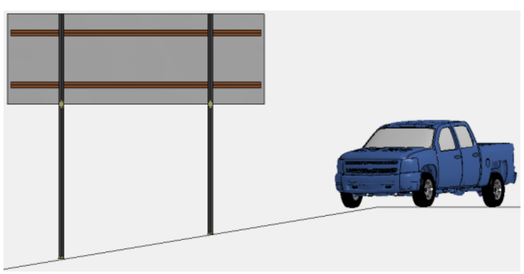	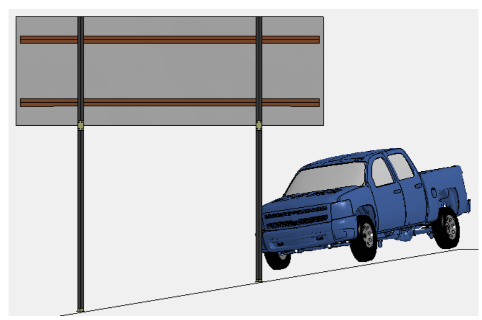
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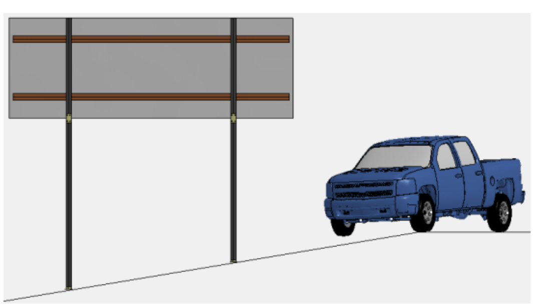	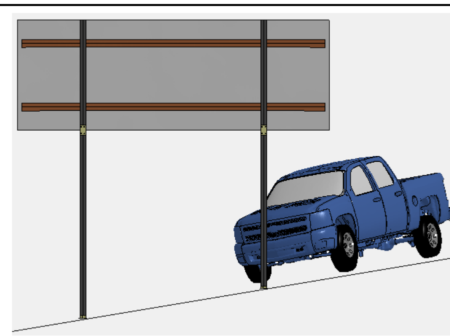
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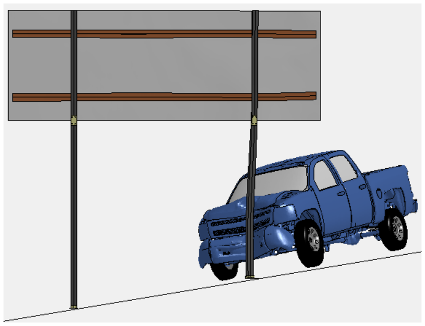
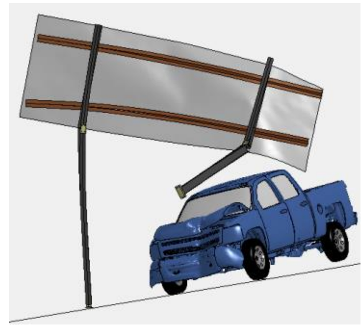
Table 41. Continued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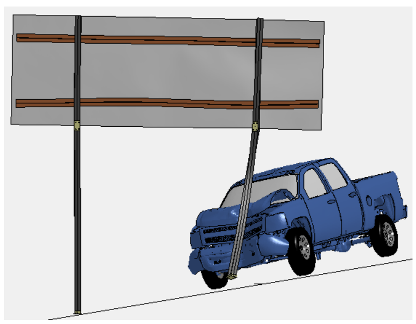	
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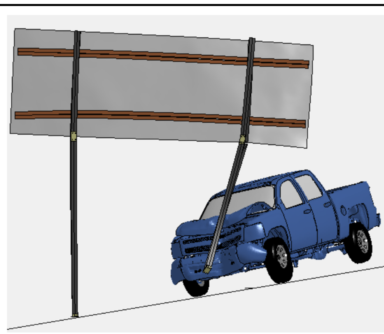	
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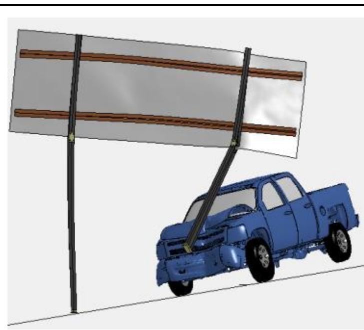	
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8.3.2.2. Occupant Risk Assessment

Data from the accelerometer, located in the vehicle at the center of gravity was used to compute occupant risk factors based on MASH safety criteria. The TRAP program was used to digitized the values obtained from the finite element model. In the longitudinal direction, the occupant impact velocity was 2.621 ft/s at 0.752 seconds, the highest 10-ms occupant ridedown acceleration was 3.9 G from 0.9515 to 0.9615 seconds, and the maximum 50-ms average acceleration was -3.7 G between 0.425 and 0.475 seconds. In the lateral direction, the occupant impact velocity was 4.92 ft/s at 0.752 seconds, the highest 10-ms occupant ridedown acceleration was -5.7 G from 0.9535 to 0.9635 seconds, and the maximum 50-ms average was -1.9 G between 0.63 and 0.68 seconds. The maximum roll, pitch, and yaw angles were 10.4, 5.4, and -0.9 degrees respectively (See Figure 88). Figure 89 summarizes the above data and other important information from the test.

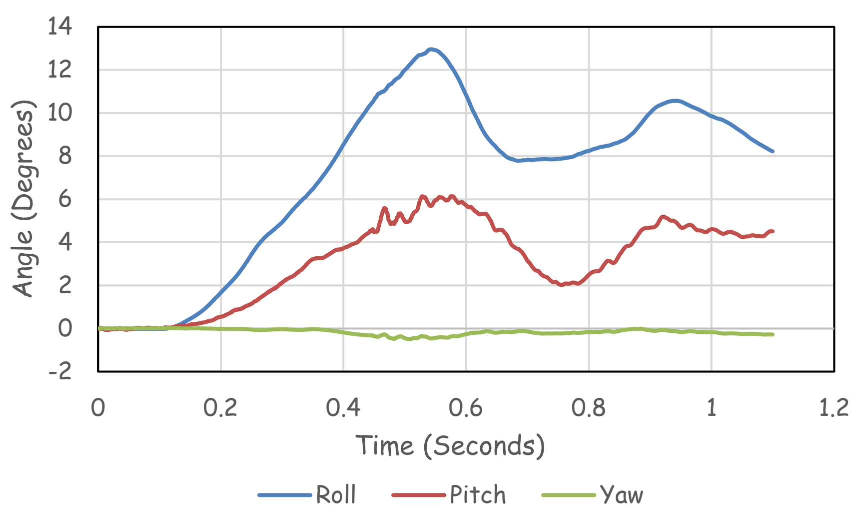


Figure 88. Angular Displacement for 2270P Vehicle at High Speed.

8.3.2.3. Summary

An assessment of the test based on the applicable MASH safety evaluation criteria for flat-level terrain is provided below.

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

   Results: When impacted by the 2270P vehicle, the left leg of the large sign support activated by breaking away at the slipbase and at the upper hinge connections.

2. 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 for support systems on flat-level ground: deformation in roof should be less than equal to 4.0 inches; deformation in windshield should be less than equal to 3.0 inches; there should be no shattering by test article structural member inside windows; deformation in wheel/ footwell/ toe pan should be less than 9.0 inches; deformation in forward A-pillar should be less than 12.0 inches; deformation in front side door area above seats should be less than 9.0 inches and in front side door below seat should be less than 12.0 inches; deformation in floor pan/transmission tunnel area should be less than 12.0 inches.

   Results: The left support leg separated from the installation. However, the 2270P vehicle traveled beneath these elements. The elements did not penetrate or show

potential for penetrating the occupant compartment, nor to present a hazard to others in the area. No occupant compartment deformation occurred during the test with the 2270P vehicle.

3. The vehicle should remain upright during and after the collision. The maximum roll and pitch angles should not exceed 75 degrees.

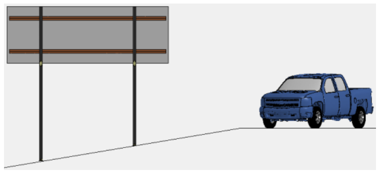
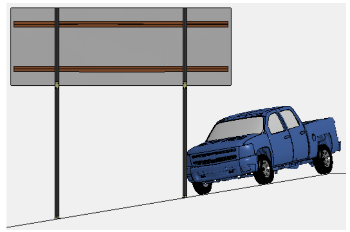
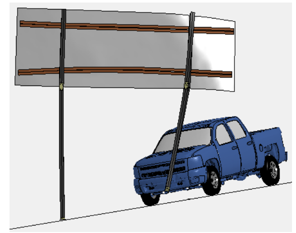
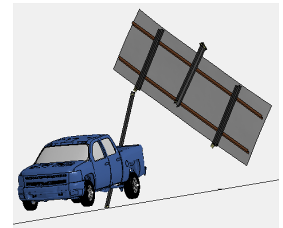
   Results: The 2270P vehicle remained upright during and after the collision event. The maximum roll and pitch angles were 13 degrees and 6.1 degrees.

4. Longitudinal and Lateral impact velocity should be less than 16.4 ft/s

   Result: Longitudinal and lateral occupant impact velocities less than the maximum limits.

5. Occupant ridedown acceleration should be less than 20.49 G.

   Result: Longitudinal and lateral ridedown acceleration were very low.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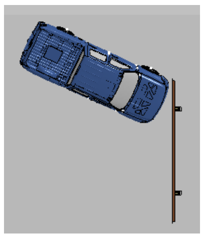	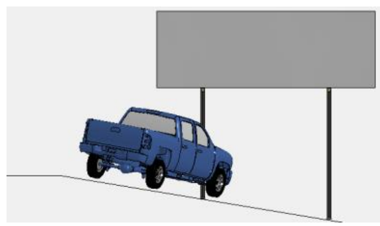	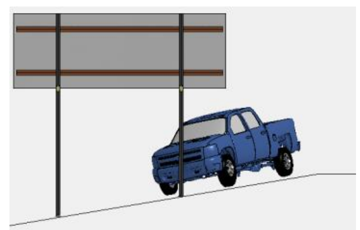	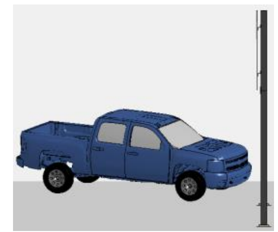
Top View	Front View	Back View	Side View

General Information
Test Agency: Texas A&M Transportation Institute
Test Standard: Sloped Terrain; Pickup Truck (2270P); High Speed
Test Article
Type: Sign Support System
Name: MASH TL-3 Sign Support System
Material or Key Elements: Steel
Soil Type: Concrete Pavement

Test Vehicle
Type/Designation: 2270P
Make and Model: Finite Element Silverado
Curb: 5000 lb.
Dummy: No Dummy

Impact Conditions
Speed: 62 mph
Angle: 25 degrees
Location/Orientation: Left Leg

Occupant Risk Values
Longitudinal OIV: 2.62 ft/s
Lateral OIV: 4.92 ft/s
Longitudinal Ridedown: 3.9 G
Lateral Ridedown: -5.7 G

Max. 0.050-s Average
Longitudinal: 3.7 G
Lateral: -1.9 G
Vertical: 2.8 G

Post-Impact Trajectory
Stopping Distance: N/A

Vehicle Stability
Maximum Roll Angle: 13 degrees
Maximum Pitch Angle: 6.1 degrees
Maximum Yaw Angle: 0.3 degrees

Vehicle Roof Deformation: Yes
Max Deformation: Nil

Figure 89. Summary of Finite Element Simulation for 2270P Vehicle at High Speed.

8.4. Conclusion

Detailed finite element analysis was conducted to forecast the performance of the large signpost system on the sloped terrain. A complete FE model was developed based on the actual design used for installation on the flat-level ground. MASH test level 3 situations for flat-level ground were replicated in detailed computer simulations.

For the different impact simulations performed with different parameters such as impact angle, impact speed, edge distance, impact point, etc. for passenger car and a pickup truck, the slipbase of the test article on sloped terrain was readily activated in a predictable manner. Also, there was no detachment of elements or fragments from the test article in any test. There was no deformation in the windshield, roof, side windows, forward of A-pillar, front side door area above the seat, front side door area below the seat, and floor plan/transmission tunnel. In all simulations, the recorded maximum angular displacements were below the required MASH limits for flat-level ground.

Table 41 summarizes the result of different simulations performed with different parameters. Based on these simulations performed on sloped-terrain, it was concluded that the test article passed all the MASH evaluation criteria for flat-level ground. To verify the results obtained through predicted impact simulations, it was suggested to conduct full-scale crash tests on sloped terrain. It was proposed to test the article with a passenger car and pickup truck at high speed impacting the first leg at 25 degrees.

Table 41. Summary of Finite Element Simulations Performed on Sloped Terrain.

Test	Speed	Slipbase Activation	Occupant Compartment Penetration	Compartment Deformation (in.)	OIV (ft/s)		ORA (G)		Max 0.050s Avg. Acceleration (G)		Roll	Pitch	Yaw	Result
					Longitudinal	Lateral	Longitudinal	Lateral	Longitudinal	Lateral				
Car (1100C)	19 mph	Yes	No	Nil	7.21	3.28	30.51	11.15	-2.6	-1.7	9.8	5.4	-6.4	PASS
	62 mph	Yes	No	Nil	9.18	1.96	5.25	4.6	-6.7	-1.4	10.4	5.4	-0.9	PASS
Pickup (2270P)	19 mph	Yes	No	Nil	-1.31	0.98	-19.68	22.30	-1.7	-1.9	9.6	5.3	5.1	PASS
	62 mph	Yes	No	Nil	2.62	4.92	12.8	-18.7	3.7	-1.9	13	6.1	0.3	PASS

9. CONCLUSION

A large sign slip base support on flat level ground and sloped terrain were developed. It was unknown how a breakaway mechanism might perform under impacts that happen on sloped terrain rather than on the flat level ground. The large sign support system was connected to the ground with a breakaway system. Breakaway support is designed to lessen the impact on a vehicle if struck and thereby minimize injury to occupants and damage to vehicles. Multiple finite element simulations were conducted to assess the crashworthiness of the test article. A full-scale crash test with a pickup truck (2270) on the flat-level ground was conducted. Based on the results, a set of full-scale crash tests will be performed on sloped terrain to evaluate the crashworthiness of this large sign support system.

The research provides the FHWA and State DOTs with a first understanding of how a large sign slipbase breakaway support structure will react to impact events when installed on a given slope under MASH 2016 test level 3 impact conditions. Outcomes from this research and testing study also support implementation guidelines review for large slipbase breakaway support structures on roadside slopes to help with a better roadside device design and implementation to reduce the risk of injury and injury severity of related crashes.

A finite element simulation analysis was conducted to determine the most critical scenario. Initially, the finite element model was calibrated with an existing full-scale crash test of the signpost system. Two different cases were considered for the simulations – on the flat-level ground and on sloped terrain. Simulations were performed with the car

(1100C) and a pickup truck (2270P) at low speed (19 mph) and high speed (62 mph) as per MASH test level 3 requirements. Slope characteristics, however, as well as other installation characteristics such as impact angle and impact location were determined from the finite element parametric study performed. This analysis characterized the behavior of the vehicle once entering and traversing the slope.

Results showed that the test article on flat level ground when impacted with the car (1100C) had acceptable and consistent results. The same article when impacted with a pickup truck (2270P) at low and high speed showed some deformations in the roof of the vehicle. The deformations were below the maximum permissible limits of MASH. There was no deformation in the windshield and other critical areas. The recorded maximum angular displacements for all simulations performed on the flat level ground were way below the required MASH limits, passing the MASH requirements for vehicle stability.

The test article passed the performance criteria for MASH Test 3-62 for large signboards in full-scale crash test. Modifications were made to the FE models since discrepancy was found between the original detailed simulation and full-scale crash test.

The detailed finite element simulations of the test article on sloped terrain when impacted with a car (1100C) and a pickup truck (2270) on low and high speed for different parameters such as impact angle, slope, etc. demonstrated acceptable results. There was no contact between the signboard and vehicle because of more clear distance and also there was no deformation or damage in the windshield and any other critical area. Additional vehicle dynamic analysis was performed in CARSIM to evaluate and compare the most critical impact scenarios. The maximum roll and pitch values were around 15 degrees which are below the required MASH limits for flat-level ground. To verify the results obtained through predicted impact simulations, it was suggested to conduct full-scale crash tests on sloped terrain.

10. FUTURE SCOPE OF WORK

This study was conducted as a portion of the pilot project in an attempt to evaluate the crashworthiness of support structures such as large sign supports systems on sloped terrain. Following are some suggestions for future research developments:

1. Further efforts are suggested to validate the full-scale crash test on the flat-level ground with the complete FE model of the test article and vehicle.
2. It is also suggested to validate the developed complete FE model of the test article on sloped terrain with the full-scale crash test
3. The researcher suggests investigating the large sign support system when installed in the median between travel ways or on the backslope.
4. It is also suggested to deploy airbags in future studies to investigate occupant risk on frontal impact with the support structure.
5. Future studies can be conducted to investigate the crashworthiness of support structures when installing on a positive slope.
6. The researcher suggests conducting a similar study to determine the correlation for occupant injury risk in frontal impacts with the employment of a dummy to verify if similar correlation results are obtained.
7. Real-world crash data study can be performed to obtain a worst-case scenario for vehicular impact on support structures.
8. A new study can be conducted to develop a testing and evaluation standard section in MASH for vehicular impact into support structures on sloped terrain.

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APPENDIX A

Table 42. Individual Responses for Question 2

State	Response
Alabma	We only provide standards for ground-mounted signs. ALL overhead sign structures (butterflies, cantilevers, and bridges) require contractor designed structures with the sizes, placements, and soil information provided in the contract plans. ALDOT requires approved shop drawings, etc. prior to fabrication and installation. On the rare occasion, our Bridge Bureau lets us hang signs on roadway bridges, those details are usually provided in the contract bridge plans.
Alaska	Highway Preconstruction Manual subsection 1170.7 Standard Plans: S-00, S-05, S-30, S-31, S-32 See attachment: AK sign support documents.pdf
Colorado	Okay
Delaware	https://www.transpo.com/roads-highways-rh/safety-products/breakaway-supports/break-safe-sign-post
Florida	https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/design/standardplans/2020/idx/700-020.pdf?sfvrsn=52ca080a_2 https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/design/standardplans/2020/spi/spi-700-020.pdf?sfvrsn=472213e0_2
Illinois	IDOT base sheets BAW-A-1 and BAQ-A-2. On our website under structures base sheets.
Iowa	Iowa DOT Standard Road Plans can be found at this link - https://iowadot.gov/design/stdplne_si Standards that apply to the large signs are SI-102, SI-111, SI-112, SI-113, SI-114, SI-132.
Louisiana	We have another standard for truss mounted overhead signs but those are not breakaway and are not crash tested. If you would like those standards as well, please let me know.
Maryland	See Attached
Michigan	https://mdotjboss.state.mi.us/TSSD/getSubCategoryDocuments.htm?prjNumber=1403888&category=Traffic%20Signing&subCategory=Signing%20Standards&subCategoryIndex=subcat2Traffic%20Signing&categoryPrjNumbers=1403886,1403887,1403888,1403889,1403890

State	Response
Michigan	https://mdotjboss.state.mi.us/TSSD/getCategoryDocuments.htm?categoryPrjNumbers=1403886,1403887,1403888,1403889,1403890&category=Traffic%20Signing
Minnesota	I-Beam Signs
Missouri	see attached
Ontario	See attached 2 standard drawings
Pennsylvania	Standards are found in our Publication 111. Attached is a specific section for Type A signs.
Tennessee	https://www.tn.gov/content/tn/tdot/roadway-design/traffic-operations-division-resources/standard-traffic-operations-drawings.html T-S-Series
Utah	Attached all signing standards. SN15A - SN17D applies to large sign supports.
Washington	See attached WSDOT Standard Plans for Large Sign Support systems.
West Virginia	Document attached.

Table 43. Individual Responses for Question 3.

State	Response	Comments
Alabama	Other	Our current systems as provided are NOT MASH compliant. We're in the process of evaluating and updating.
Alaska	Yes	
Colorado	Yes	
Delaware	Yes	
Florida	Yes	
Illinois	Other	(Yes, if allowed under MASH)
Iowa	Other	(If they meet MASH crash testing, yes.)
Louisiana	Other	(We intend to compare our standards to MASH compliant systems and change them as necessary.)
Maryland	Other	Currently, we are not aware of breakaway base systems that have been tested for MASH 2016. Standards would need to be updated to meet the standards for successfully tested systems.
Michigan	No	
Michigan	No	
Minnesota	Yes	

State	Response	Comments
Missouri	Other	I would have to consult with our Safety and Traffic Division as to whether or not we currently meet MASH with our standards.
Ontario	No	
Pennsylvania	Other	The Transpo system that we use in MASH compliant, but we may need to make some changes to our
Tennessee	Yes	
Utah	Other	We are planning on continuing the use of our standard based upon the findings of TTI reports 6782-1 and 6363-1. Based on future testing on slopes, changes may be required. TTI report 6782-1 Pg 58 states The slip base used in TxDOT large guide sign.
Washington	Other	Yes, but we are waiting for the industry to step up and become MASH compliant.
West Virginia	Yes	

Table 44. Individual Responses for Question 4.

State	Response	Comments
Alabama	Other	Our overhead structures are typically protected by a barrier, guardrail, etc.
Alaska	Other	Specifications for Structural Support of Highway Signs, Luminaires, and Traffic Signals (1994 edition)
Colorado	NCHRP Report 350	
Delaware	MASH	
Florida	NCHRP Report 350	
Illinois	NCHRP Report 350	
Iowa	NCHRP Report 350	
Louisiana	NCHRP Report 350	

State	Response	Comments
Maryland	Other	Maryland has not performed any crash testing for MASH 2016. Our existing standards are based on AASHTO Criteria.
Michigan	NCHRP Report 350	
Michigan	NCHRP Report 350	
Minnesota	MASH	
Missouri	NCHRP Report 350	
Ontario	NCHRP Report 350	
Pennsylvania	NCHRP Report 350	
Tennessee	NCHRP Report 350	
Utah	Other	NCHRP 350. All the original standards are based on the NCHRP 350 test. If TTI reports 6782 and 6363 can be used as documentation, then we can state MASH evaluation.
Washington	Other	(Transpo BreakSafe was approved under NCHRP 230.)
West Virginia	NCHRP Report 350	

Table 45. Individual Responses for Question 5.

State	Response	Comments
Alabama	Other	
Alaska	Other	Adapted from Nat'l research via the Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals
Colorado	Full-Scale Crash Test	
Delaware	Other	Sign Support Program based off of AASHTO Specifications
Florida	Full-Scale Crash Test	

State	Response	Comments
Illinois	Full-Scale Crash Test	
Iowa	Other	Not sure, but they are listed on the FHWA web site.
Louisiana	Full-Scale Crash Test	
Maryland	Other	Maryland has not performed any own testing. Existing standards based on successfully tested systems.
Michigan	Component Testing (Pendulum, Surrogate Vehicles, etc.)	
Michigan	Component Testing (Pendulum, Surrogate Vehicles, etc.)	
Minnesota	Full-Scale Crash Test	
Missouri	Other	I do not know this answer; our Safety and Traffic Division would know this.
Ontario	Full-Scale Crash Test	
Pennsylvania	Component Testing (Pendulum, Surrogate Vehicles, etc.)	
Tennessee	Full-Scale Crash Test	
Utah	Full-Scale Crash Test	
Washington	Other	Dependent upon post size and post shape was either by full-scale test or component testing.
West Virginia	Full-Scale Crash Test	

Table 46. Individual Responses for Question 6.

State	Response
Alabama	I believe ALDOT required TL-3 on all our hardware, but most of our sign drawings have not been updated in several years.
Alaska	TL-3
Colorado	TL3
Delaware	Mostly TL-3, Some TL-4
Florida	TL-3
Illinois	TL 3
Iowa	Don't know.
Louisiana	We assume our details are NCHRP 350 Test Level 3 compliant
Maryland	AASHTO Pendulum Testing
Michigan	NCHRP 350
Michigan	NCHRP 350
Minnesota	TL-3
Missouri	TL-3 at a minimum
Ontario	TL-3
Pennsylvania	NCHRP 350 and 2001 AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals
Tennessee	TL-3
Utah	NCHRP TL-3
Washington	Other than Transpo BreakSafe, the test level was NCHRP 350 TL 3.
West Virginia	NCHRP-350 Test Level 1, 2, and 3

Table 47. Individual Responses for Question 7.

State	Response
Alabama	Sign placement is design specific in every case. There are too many factors involved to have standard placements.
Alaska	Rural cross-section (no gutter/curb): 12' minimum to the near edge of the sign Urban cross-section (with gutter/curb): 2' minimum to the near edge of the sign Because offset is to the edge of the sign, and placement of the sign support is dependent on the width of the sign, I cannot provide a "usual offset: to the sign support.
Colorado	Curb - 30 feet No Curb - 12-15 feet
Delaware	6 to 12 feet.

State	Response
Florida	From a Minimum of 12-ft to 40-ft (if possible). However, once you go beyond the clear zone the slope rate is highly variable. Our slope requirement is 1:6 from the shoulder slope break to the clear zone.
Illinois	30 feet
Iowa	See standard road plan SI-102
Louisiana	It depends on the sign. Small signs on single posts are typically 2'-0" from the edge of the travel way. Large signs requiring 2 or more supports are 15'-0" from the edge of the travel way. (30'-0" if installed on interstates or multi-lane highways)
Maryland	Edge of Sign is typically 6 ft from the edge of the roadway. The edge of the sign is a minimum of 6 ft from the edge of the curb in rural areas and a minimum of 2 ft from the edge of the curb in urban areas.
Michigan	20 feet
Michigan	20 feet
Minnesota	30 feet
Missouri	the edge of the sign is 6' min. from EOS or face of the curb
Ontario	Minimum 6.5m from edge of the traveled lane to the edge of the signboard
Pennsylvania	30' typical from the edge of pavement (shoulder), 15' minimum.
Tennessee	Refer to T-S-9
Utah	UDOT sign standards are 15' from the edge of traveled way to the edge of the sign. Distance to support will vary. Using our MANDLI data, our average offset for large signs supports is 14.29'. Distance from the edge of the sign to support varies from 1' to 4'. Usual offset from the edge of traveled way to sign support is approximated to be 15.29' to 18.29' for existing signs.
Washington	A minimum of 12 feet from the edge of travel way.
West Virginia	The attached detail sheet TP3-1B contains this information. Note, the table with the suggested offsets based on the slope for 60 mph and greater roadways is based on bumper trajectory information that was contained in the RDG.

Table 48. Individual Responses for Question 8.

State	Response	Comments
Alabama	Negative	
Alaska	Negative	70%-80%
Colorado	None	

Delaware	Negative	
Florida	Negative	80%
Illinois	Negative	75%
Iowa	Positive	85%
Louisiana	Negative	95%
Maryland	Negative	
Michigan	Negative	85%
Michigan	Negative	85%
Minnesota	Negative	80%
Missouri	Negative	80%
Ontario	Negative	50%
Pennsylvania	Negative	
Tennessee	Negative	80%
Utah	Negative	75%
Washington	None	
West Virginia	Negative	85%

Table 49. Individual Responses for Question 9.

State	Response
Alabama	Trapezoidal
Alaska	Shallow "V"
Colorado	Shallow "V"
Delaware	Shallow "V"
Florida	Trapezoidal
Illinois	Shallow "V"
Iowa	Trapezoidal
Louisiana	Deep "V"
Maryland	Shallow "V"
Michigan	Shallow "V"
Michigan	Shallow "V"
Minnesota	Shallow "V"
Missouri	Trapezoidal
Ontario	Deep "V"
Pennsylvania	Shallow "V"
Tennessee	Shallow "V"
Utah	Shallow "V"
Washington	Shallow "V"
West Virginia	Shallow "V"

Table 50. Individual Responses for Question 10.

State	Response
Alabama	This is too site-specific to answer generally.
Alaska	Not typically placing larger signs (like interchange sequence signs) in medians except as required by MUTCD, such as one-way, wrong-way, at-grade intersection signs (stop or yield), or object markers on the nose of raised medians.
Colorado	These types of signs are not typically located in medians. Exceptions apply, slopes greater than 3:1 require the use of guardrail. The offset distance is completely dependent on the median width but could be as small as 4-5 feet.
Delaware	2 feet, 4%
Florida	Yes, Slope 1:8 with a typical offset of 12-ft to 14-ft
Illinois	occasional 4:1 at 30 feet offset
Iowa	A most common type of median is in the exit gore area. Offset is a minimum of 6'
Louisiana	We do not typically install signs in the median.
Maryland	Yes, varies
Michigan	Yes, usually 1 on 4.
Michigan	Supports are used in medians. 1:4
Minnesota	no
Missouri	We try to limit sign installations in the median. Our typical median slope is 5.5:1 and offsets are typically 6' min. from EOS.
Ontario	Large signs are not constructed in depressed medians in Ontario
Pennsylvania	Type A signs are not installed in medians.
Tennessee	Divided freeway depressed median slopes are typically 6:1 offset is the same.
Utah	Signs are allowed in medians. 4:1 to 6:1 is the range for the average median slope. We do have some signs on 3:1 back slopes. The average offset for median mounted signs is 11.08'. Distance from the edge of the sign to support is 1' to 4'. Offset from the edge of traveled way to sign support is approximated to be 12.08' to 15.08'.
Washington	The perforated square steel tube posts are installed in the median. Typically on 6H:1V or flatter slope and a minimum of 12 feet from travel way.
West Virginia	Typically only signs that are required to be dual installed. Signs of that type are typically smaller size signs and are installed typically on S4x7.7 supports. The slope is typically 4:1 or flatter. offset information contained on attached detail TP3-1B

Table 51. Individual Responses for Question 11.

State	Response
Alabama	NA
Alaska	NA
Colorado	Attached
Delaware	DE MUTCD
Florida	NA
Illinois	NA
Iowa	NA
Louisiana	NA
Maryland	NA
Michigan	NA
Michigan	https://mdotjboss.state.mi.us/TSSD/getCategoryDocuments.htm?categoryPrjNumbers=1403886,1403887,1403888,1403889,1403890&category=Traffic%20Signing
Minnesota	Attached
Missouri	NA
Ontario	Attached
Pennsylvania	NA
Tennessee	NA
Utah	https://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:4715,
Washington	Attached
West Virginia	NA

Table 52. Individual Responses for Follow-up Question 1.

State	Response
Alabama	W6X12; W8X18
Alaska	Largest signs are used using w-sections
Colorado	W6X15
Delaware	-
Florida	W6X12
Illinois	W14X38
Iowa	W6X12; W8X21; W12X26
Louisiana	W6X12; W8X18
Maryland	W8X21; W10X26; W14X30
Michigan	3# Steel
Michigan	3# Steel
Minnesota	W6X20; W8X24; W8X28
Missouri	W6X9; W6X15; W8X15

State	Response
Ontario	W8X28; W8X31; W8X40
Pennsylvania	-
Tennessee	W6X15; W6X20
Utah	W10X19; W10X26
Washington	Square 2.5" tube
West Virginia	S4X7.7 - 40%; W6X12 - 30%; W8X18 - 25%; W10X22 - 5%

Table 53. Individual Responses for Follow-up Question 2.

State	Response
Alabama	It depends on wind loading and moment arm.
Alaska	For 100 mph: W6X20: Area: 46-60 sqft per post; Height: 11 ft- 15 ft
Colorado	It depends on wind loading and moment arm. (Attached Excel)
Delaware	-
Florida	-
Illinois	7 Posts: 40ft x 10ft; 3 Posts: 20ft x 14ft
Iowa	Depends on Moment Arm; Rule of Thumb: W6X21: 80sqft; W8X21: 130sqft; W12X26 (2-post): 200sqft; W12X26 (3-post): 300sqft
Louisiana	For Wind Pressure 42 lb/sqft: W6X12: 11ftx3ft; W8x18: 19ftx3ft
Maryland	For the non-breakaway system 2 Post: W8X21: 30ft x 18ft x 4ft; W10X26: 30ft x 20ft x 5ft; W14X30: 30ft x 20ft x 6ft 3 Post: W8X21: 30ft x 20ft x 5ft; W10X26: 30ft x 20ft x 7ft; W14X30: 30ft x 20ft x 8ft
Michigan	3# Steel: 7.5 sqft W8X13: 45-150 sqft W8X18: 150-230 sqft

State	Response
Michigan	3# Steel: 7.5 sqft W8X13: 45-150 sqft W8X18: 150-230 sqft
Minnesota	W6X20: 50-155 sqft; W8X24: 80-240 sqft; W8X28: 90-280 sqft
Missouri	W6X9: 8' x 13' to 30' x 5'; W6X15: 8' x 19' to 30' x 8'; W8X15: 25' x 12' to 30' x 11'
Ontario	W8X40: 142" x 236"
Pennsylvania	-
Tennessee	Details not available for W sections.
Utah	-
Washington	1 Post: 16 sqft; 2 Post: 32 sqft 3 Post: 48 sqft
West Virginia	Sign Area per pole for maximum dimension between the bottom of sign plate and center of sign: S4X7.7 - 0-15 sqft; W8X18 - 20-55 sqft; W6X12 - 0-20 sqft; W10X22 - 55-90 sqft

Table 54. Individual Responses for Follow-up Question 3.

State	Response
Alabama	The current standard is 4 ft wide (at the bottom) trapezoidal ditch for traversability reasons, but signposts are not allowed in them.
Alaska	Sign slopes are installed on the slopes, not in the ditch bottom.
Colorado	It can be installed anywhere based on engineering judgment. 2' on both sides of sign + sigh width
Delaware	-
Florida	-
Illinois	Entire sign on a negative slope. The width of the ditch is intensely variable.
Iowa	Usually installing a sign in the ditch is avoided. 10 ft wide ditch is common in regard to the standard design.
Louisiana	Most interstates and major highways don't have ditch. Ditches vary all over the state.
Maryland	Varies from site to site
Michigan	Several different cross-sections are used.

State	Response
Michigan	Several different cross-sections are used.
Minnesota	The ditch is usually wider that sign
Missouri	Do not have any specs with regard to ditches. Typically footing is kept out of the flow line of the ditches to avoid erosion. Most of the ditches are not the wide flat bottom like the image.
Ontario	Width of ditches varies depending on the terrain, height of embankment and right of way width. The typical ditches slope is 3:1.
Pennsylvania	Width of the ditch should be less than 22' in order for a 2 post sign to completely span it.
Tennessee	Attached
Utah	Information not available and it varies greatly
Washington	Standard is to place sign 4 ft from the centerline of the ditch on the back slope.
West Virginia	Placements of supports within ditches are discouraged.

APPENDIX B

Eastern Metal Supply, Inc.
9400 Telge Rd; Houston, TX 77095
1-800-996-6061 (281) 656-2297-fax

Certification of Compliance

To:		DATE	
Customer PO# CF19-25210	**Customer Name** CUSTOM FABRICATORS & REPAIR	EMS	

Product Identification

Product Code	Description of Material Furnished	Quantity	
	6061T6 MF STRUCTURAL ZEE BAR		
12-61-201	3X2.688X1/4X25'	3 PCS	

Mechanical Properties (representation)

Specification	Ultimate Strength KSI	Yield Strength KSI	Elongation Percent

Chemical Composition Limits of Wrought Aluminum Alloys

Alloy	Silicon	Iron	Copper	Manganese	Magnesium	Chromium	Zin/	TI
1100	.95 SI + FE		0.50+0.20	0.05			0.10	
3003	0.60	0.70	0.50+0.20	1.0-1.5			0.10	
5052	0.25	0.40	0.10	0.10	2.2-2.8	0.15-0.35	0.10	
6005	0.6-0.9	0.35	0.10	0.10	0.4-0.6	0.10	0.10	0.10
6061	0.4-0.8	0.70	0.15-0.4	0.15	0.8-1.2	0.04-0.35	0.25	0.15
6063	0.20-0.60	0.35 max.	0.10	0.10 max.	0.45-0.90	0.10 max.	0.10 max.	0.10 max.
6105	0.75-0.85	0-0.25	0-.05	0-0.50	.55-.70	0-0.05	0-0.05	0.01-0.05

Composition in percent maximum, unless shown in range – Mechanical properties are LBs/SQ IN

This form indicates that the above material was processed in accordance with the specifications listed, as reported by the manufacturer.

Signature: Sally Gentry **Date:** 02/04/20

Figure 90. Supporting Certification Document

Eastern Metal Supply, Inc.

9400 Telge Rd; Houston, TX 77095

1-800-996-6061 (281) 656-2297-fax

Certification of Compliance

To:		DATE	02/04/20
Customer PO# CF19-25210	Customer Name CUSTOM FABRICATORS & REPAIR	EMS	

Product Identification

Product Code	Description of Material Furnished	Quantity	
	6061T6 MF STRUCTURAL ZEE BAR		
12-61-201	3X2.688X1/4X25'	1 PCS	

Mechanical Properties (representation)

Specification	Ultimate Strength KSI	Yield Strength KSI	Elongation Percent

Chemical Composition Limits of Wrought Aluminum Alloys

Alloy	Silicon	Iron	Copper	Manganese	Magnesium	Chromium	Zin/	TI
1100	.95 SI + FE		0.50+0.20	0.05			0.10	
3003	0.60	0.70	0.50+0.20	1.0-1.5			0.10	
5052	0.25	0.40	0.10	0.10	2.2-2.8	0.15-0.35	0.10	
6005	0.6-0.9	0.35	0.10	0.10	0.4-0.6	0.10	0.10	0.10
6061	0.4-0.8	0.70	0.15-0.4	0.15	0.8-1.2	0.04-0.35	0.25	0.15
6063	0.20-0.60	0.35 max.	0.10	0.10 max.	0.45-0.90	0.10 max.	0.10 max.	0.10 max.
6105	0.75-0.85	0-0.25	0-.05	0-0.50	.55-.70	0-0.05	0-0.05	0.01-0.05

Composition in percent maximum, unless shown in range – Mechanical properties are LBs/SQ IN

This form indicates that the above material was processed in accordance with the specifications listed, as reported by the manufacturer.

Signature: Sally Gentry **Date:** 02/19/20

Figure 91. Supporting Certification Document

JSW Steel (USA) INC.
5200,East McKinney Road,
BAYTOWN, TX 77523

METALLURGICAL TEST REPORT

MET - 04 Rev. No.: 3 Rev. Date:02/27/2018

6/27/2019

Bulletin	Order Item	Heat	PO No.	Shipping Mode		Order Dimensions	Slab Origin	TC No.
T057248	JSW12607-01	S27592		TRUCK		1.625x120x420	MEXICO	T057248-7592-1

Plates Certified for the Following grades
ASTM-A516-70, ASME-SA516-70 2017 EDITION PN LCVN

Hot Rolled Carbon Steel Plates
Plates Manufactured In the USA

Specifications
PLATE NORMALIZED AT 1650 °F FOR 50 MINS

Marking Instructions
Stencil in 2 location(s); X Loc. 18 Y Loc. 30; CUST; MADEINUSA PN PO; DIM GRADE; FREIGHT ORDERITEM PLATEID SHIPWEEK SLABID TRANSMODE Stamp in 2 location(s); X Loc. 18 Y Loc. 12; Slab ID; Slab ID; Slab ID

Sold To:

Ship To:

Test	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	N	V	B	Ti	Nb	Ca	CE
LADLE	0.20	1.11	0.011	0.001	0.19	0.006	0.017	0.013	0.000	0.002	0.034	0.0028	0.004	0.0002	0.002	0.002	0.0021	0.39

Carbon Equivalent CE = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15
PCM = C + Si/30 + Mn/20 + Cu/20 + Ni/60+ Cr/20 + Mo/15 + V/10 + 5B

Plate	Slab Identity	Gauge Tested	Test Cond	Test Dir.	Yield Point	Tensile Stgth.	Elong in 2"	YS/UTS Ratio	Yield Strenght Determind At
1135470A	02A	1.6250	PN	T	51	74	29.0%	0.69	0.2%

Impact Test (LCVN) Full Energy in Ft/Lb °F								
Temp	Test1	Test2	Test3	Avg	Test1	Test2	Test3	Avg
-50	49	40	42	44				

Plates Certified For The Above Tests

Material	Thick(IN)	Width (IN)	Len(IN)	Wgt(LB)
1135470A	1.6250	120.000	420.00	23226.840

Material	Thick(IN)	Width(IN)	Len (IN)	Wgt(LB)

Material	Thick(IN)	Width(IN)	Len(IN)	Wgt(LB)

9 / 20 / 2019

SFI-GRAY STEEL

Customer Name:
Customer PO #:
Thickness: 1 5/8" SFI PO #: 702844
Heat & Slab: S27592-02A
Plate #: 58561

DIN: EN 10204 2004 3.1 This is to certify that the product decribed herein was manufactured, sampled, and tested in accordance with the specifications and requirements in such specifications. Fine Grain, Si-Al Fully Killed Steel. We certify that delivery of this product with the requirement of the specification and purchase order received from customer. DRC Conflict Free. Does not contain Hg . No intentional addition of Pb, Se or S

Cheyenne Lee

cheyenne lee 22813837845 cheyenne.lee@jswsteel.us

Page 1 of 1

Figure 92. Supporting Certification Document

GERDAU

CERTIFIED MATERIAL TEST REPORT

Page 1/1

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
KLOECKNER METALS US 4606 SINGLETON BLVD DALLAS,TX 75212-3502 USA	KLOECKNER METALS CORPORATION 500 COLONIAL CENTER PKWY ROSWELL,GA 30076-8853 USA	A992/A572-50	Wide Flange Beam / 6 X 12# / 150 X 18.0	0000395918

LENGTH	PCS	WEIGHT	HEAT / BATCH
40'00"	89	42,720 LB	59089275/02

SALES ORDER	CUSTOMER MATERIAL Nº
8365961/000010	B612W401400

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
7452718	1327-0000351754	12/23/2019

SPECIFICATION / DATE or REVISION
ASTM A6-17
ASTM A709-17
ASTM A992-11 (2015), A572-15
CSA G40.21-13 345WM

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.12	1.06	0.016	0.010	0.24	0.44	0.10	0.20	0.024	0.009	0.007	0.018	0.004

CHEMICAL COMPOSITION

CEqvA6 %
0.38

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	Y/T rati %	G/L Inch
59660	73972	411	510	0.810	8.000
60741	76489	419	527	0.790	8.000

MECHANICAL PROPERTIES

G/L mm	Elong. %
200.0	23.30
200.0	22.70

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. Weld repair has not been performed on this material. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR
Phone: (409) 267-1071 Email: Bhaskar.Yalamanchili@gerdau.com

WADE LUMPKINS
QUALITY ASSURANCE MGR.
Phone: 972-779-3118 Email: Wade.Lumpkins@gerdau.com

01-09-2020 23:55 Load - 3492395 BL - 3876821 blr466
Custom Fabricators Heat - 59089275
Cust. PO - CF19-25210 Order - 18147108

Figure 93. Supporting Certification Document

004882

CERTIFIED INSPECTION REPORT **Arconic** DAVENPORT WORKS 4879 State Street Bettendorf, IA 52722

We hereby certify that the material covered by this certificate has been inspected with, and has been found to meet the applicable requirements described therein, including any specifications forming a part of the description and that samples representative of the material met the composition limits and had the mechanical properties shown on the face of this sheet.

This test report shall not be reproduced except in full, without the written approval of the Quality Department. No alteration, addition or other change is authorized to be made to this certificate. The recording of false, fictitious, or otherwise fraudulent statements or entries on this certificate by any recipient may be punished as a felony under applicable law.
Per:

Nandu Srinivasan
Manufacturing Director - Davenport & Satellites

Terrence Thom
Quality Assurance Manager

Ship From: RIVERDALE, IA.

3897372 Ship Date	0 B.L. No.	Invoice No.	Arconic No.	Item
2019-10-25	12230801	00000	1001138561-1	DP-38561-02-1

P.O. No./Govt Contract No.	Customer	Arconic Item	
M2099341	RYERSON - NORCROSS	G041099726R12	GB8

Page 1 of 2

Ship To: RYERSON PROCUREMENT CORP
4405 SOUTH OLD PEACHTREE ROAD
GOLD BUILDING
NORCROSS 30071 GA

Item Description
0.125 IN TK (+0.0000 -.0070) X 60.0 IN W (+.0625 -.0625) CAT X 44274 (N) A/T 6061-T6 COIL SHEET
FOR DISTRIBUTORS TOLERANCE GUARANTEED 160002225. AMS4027 REV N ASME-SB-209 REV 15 ASTMB209 REV 14 ((NOT MARKED))
LIGHTLY OILED COIL SIZES: ID 20 IN COIL WGTS:
MIN 5000 LB MAX 7500 LB MAX GROSS
SKID WGT: 8000 LB QUAN TOL +/-25 %
CQR 0214659 REV 12 CUST REQ 19-09-15 *** W/E 19-09-21 ***

Num	Package Ticket	Lot	Weight	Quantity	UOM	Inspector Clock Numbers
1	634228	726311	4647	1	PC	47441 27586

Notes for CQR: 0214659.12
PRODUCT PRODUCED TO THE REQUIREMENTS OF AMS4027 REV N ALSO MEET THE REQUIREMENTS OF AMS-QQ-A-250_11 ORIGINAL REVISIO N DATED 1997-08-01.

CQR: 0214659.12 - -Specification Limits

Tmpr	Dir		UTS KSI	TYS KSI	EL4D PCT
T6	Long Transv.	Max			
		Min	42.0	35.0	10

Chemical Composition		SI	FE	CU	MN	MG	CR	ZN	TI	Other Each	Other Total	Aluminum
	Max	0.8	0.7	0.40	0.15	1.2	0.35	0.25	0.15	0.05	0.15	
Alloy 6061	Min	0.40		0.15		0.8	0.04					REMAIN

Lot: 726311 - Mechanical, Physical, Metallography, Quantometer Results

Tmpr	Dir	No-> Test	UTS KSI	TYS KSI	EL4D PCT
T6	Long Transv.	2	47.4	41.1	14

Figure 94. Supporting Certification Document

GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
KLOECKNER METALS US 4606 SINGLETON BLVD DALLAS,TX 75212-3502 USA	KLOECKNER METALS CORPORATION 500 COLONIAL CENTER PKWY ROSWELL,GA 30076-8853 USA	A992/A572-50	Wide Flange Beam / 6 X 12# / 150 X 18.0	0000395918

LENGTH	PCS	WEIGHT	HEAT / BATCH
40'00"	89	42,720 LB	59089275/02

SALES ORDER	CUSTOMER MATERIAL Nº
8365961/000010	B612W401400

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
7452718	1327-0000351754	12/23/2019

SPECIFICATION / DATE or REVISION
ASTM A6-17
ASTM A709-17
ASTM A992-11 (2015), A572-15
CSA G40.21-13 345WM

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
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200.0	22.70

COMMENTS / NOTES

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01-09-2020 23:55 Load - 3492395 BL - 3876821 blr466
Custom Fabricators Heat - 59089275
Cust. PO - CF19-25210 Order - 18147108

Figure 95. Supporting Certification Document

Griffin Trade Group, LLC

Phone: 281-970-6030
Fax: 281-970-6024

12777 Jones Rd. Suite 315
Houston, TX 77375

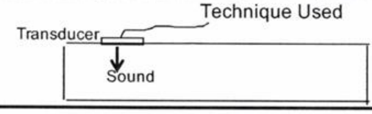
UT CERTIFIED TEST REPORT

Date Received: 9/13/19	Specification: SA578 LVL C 100% Scan	Report #: GTG-UT-751	Rev.
Date Complete: 9/13/19		Release# GTC144342	
	Procedure: Griffin Trade Group UT-01		
	Deviations: N/A	Page 1 of 1	
	UT Instrument: RFD 30	Serial# :12110701	
	Couplant: Water	Calibration Due: 5/22/20	
	Batch #: N/A		

Material	Dimensions	Slab #/ID#	Heat #		Surface	Reject (RESULTS)	Acceptable (RESULTS)
⇨ SA/A51670 N	1-5/8 120 420	02A	S27592		ROUGH	0	1
SA/A51670 N	1-1/2 120 240	03A	S25206		ROUGH	0	1

CALIBRATION BLOCKS				TRANSDUCERS				
DBS	Calibration	Serial #	Reflector size	Serial #	Brand	Size	Degree	Frequency
Longitudinal								
77	80% FSH	N/A	1/8" FBH	B14808	Britek	1"	0	2.25 Mhz

Technique Used



Comments:

All tests are performed using calibrated equipment on samples provided by Griffin Trade Group, unless noted in the data section. This data applies only to samples tested by Griffin Trade Group, LLC. This test report may be reproduced in its entirety without permission from Grffin Trade Group, LLC. All requirements of Grffin Trade Group, LLC Quality Operating Procedures, Dated 1/16/2014 have been fulfilled.

Tested By: Jarrod Harris ASNT Level II Date: 9/13/19

Signature: [signature]

Figure 96. Supporting Certification Document

Date: 2020-3-3 Test No.: 612261-05-01 VIN No.: 1C6RR6GT2ES293323

Year: 2014 Make: RAM Model: 1500

Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 152503

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None

Engine Type: V-8

Engine CID:

Transmission Type:

☑ Auto or ☐ Manual

☐ FWD ☑ RWD ☐ 4WD

Optional Equipment:

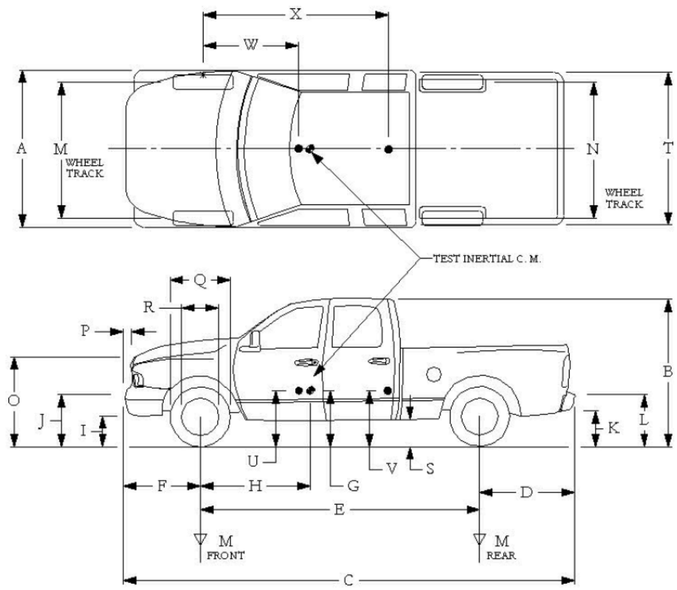
None

Dummy Data:

Type: No dummy

Mass: 0 lb

Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	29.25	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.27	M	68.50	R	18.00	W	61.25
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		

Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.50
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	22.50

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

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	3700	M_{front}	2900	2842	2842
Back	3900	M_{rear}	2020	2198	2198
Total	6700	M_{Total}	4920	5040	5040

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

Mass Distribution:

lb LF: 1442 RF: 1400 LR: 1133 RR: 1065

Figure 97. Vehicle Properties and Information.

Date: 2020-3-3 Test No.: 612261-05-01 VIN: 1C6RR6GT2ES293323

Year: 2014 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 152503

Engine: V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 130 (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70 R 17

Measured Vehicle Weights: (lb)						
LF:	1442	RF:	1400	Front Axle:	2842	
LR:	1133	RR:	1065	Rear Axle:	2198	
Left:	2575	Right:	2465	Total:	5040	
					5000 ±110 lb allowed	
Wheel Base:	140.50 inches	Track: F:	68.50 inches	R:	68.00	inches
	148 ±12 inches allowed		Track = (F+R)/2 = 67 ±1.5 inches allowed			
Center of Gravity, SAE J874 Suspension Method						
X:	61.27 inches	Rear of Front Axle	(63 ±4 inches allowed)			
Y:	-0.74 inches	Left - Right +	of Vehicle Centerline			
Z:	29.25 inches	Above Ground	(minumum 28.0 inches allowed)			

Hood Height: 46.00 inches Front Bumper Height: 27.00 inches

43 ±4 inches allowed

Front Overhang: 40.00 inches Rear Bumper Height: 30.00 inches

39 ±3 inches allowed

Overall Length: 227.50 inches

237 ±13 inches allowed

Figure 98. Measurments of Vehicle Vertical CG

Date:	2020-3-3	Test No.:	612261-05-01	VIN No.:	1C6RR6GT2ES293323
Year:	2014	Make:	RAM	Model:	

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bmp ht	4	8	32	2	8	3	-	-	-	-12
	Measurements recorded										
	☑ **inches** or ☐ **mm**										

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

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

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

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

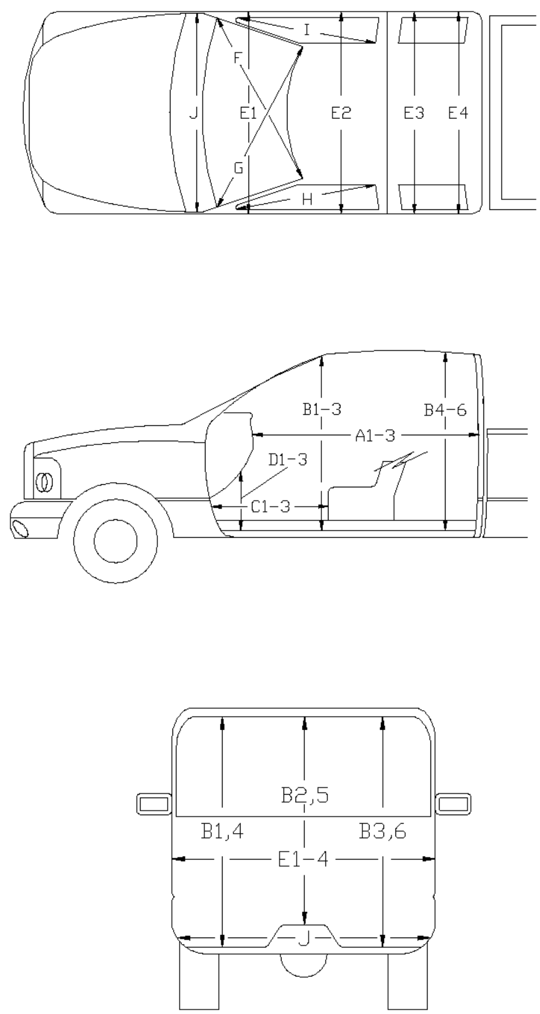
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Figure 99. Exterior Crush Measurement

Date: 2020-3-3 Test No.: 612261-05-01 VIN No.: 1C6RR6GT2ES293323

Year: 2014 Make: RAM Model: 1500



OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	58.50	0.00
E2	63.50	63.50	0.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	25.00	0.00

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

Figure 100. Occupant Compartment Measurement

Table 55. Crash Test Sequential Photographs

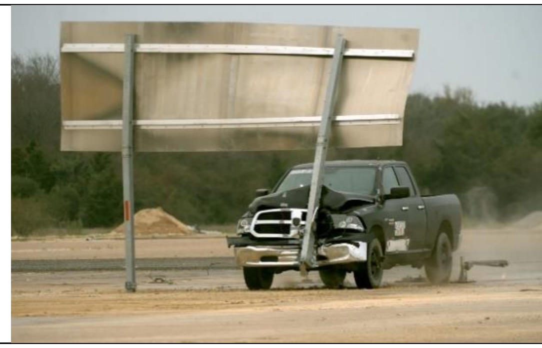
	
0.0 s	
	
0.1 s	
	
0.2 s	
	
0.3 s	

Table 55. Crash Test Sequential Photographs (Cont.)

	
0.4 s	
	
0.5 s	
	
0.6 s	
	
0.7 s	

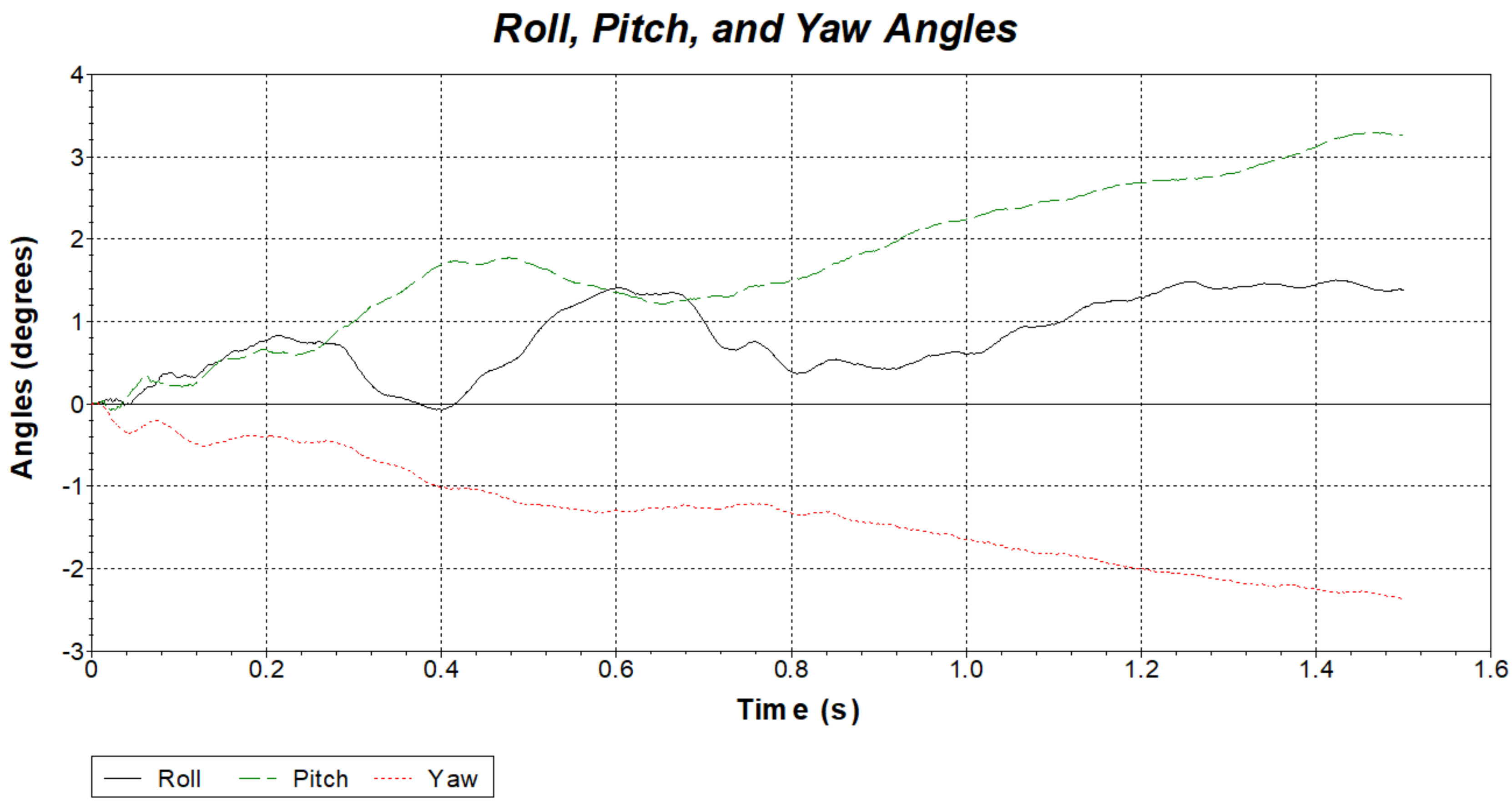


Figure 101. Vehicle Angular Displacements

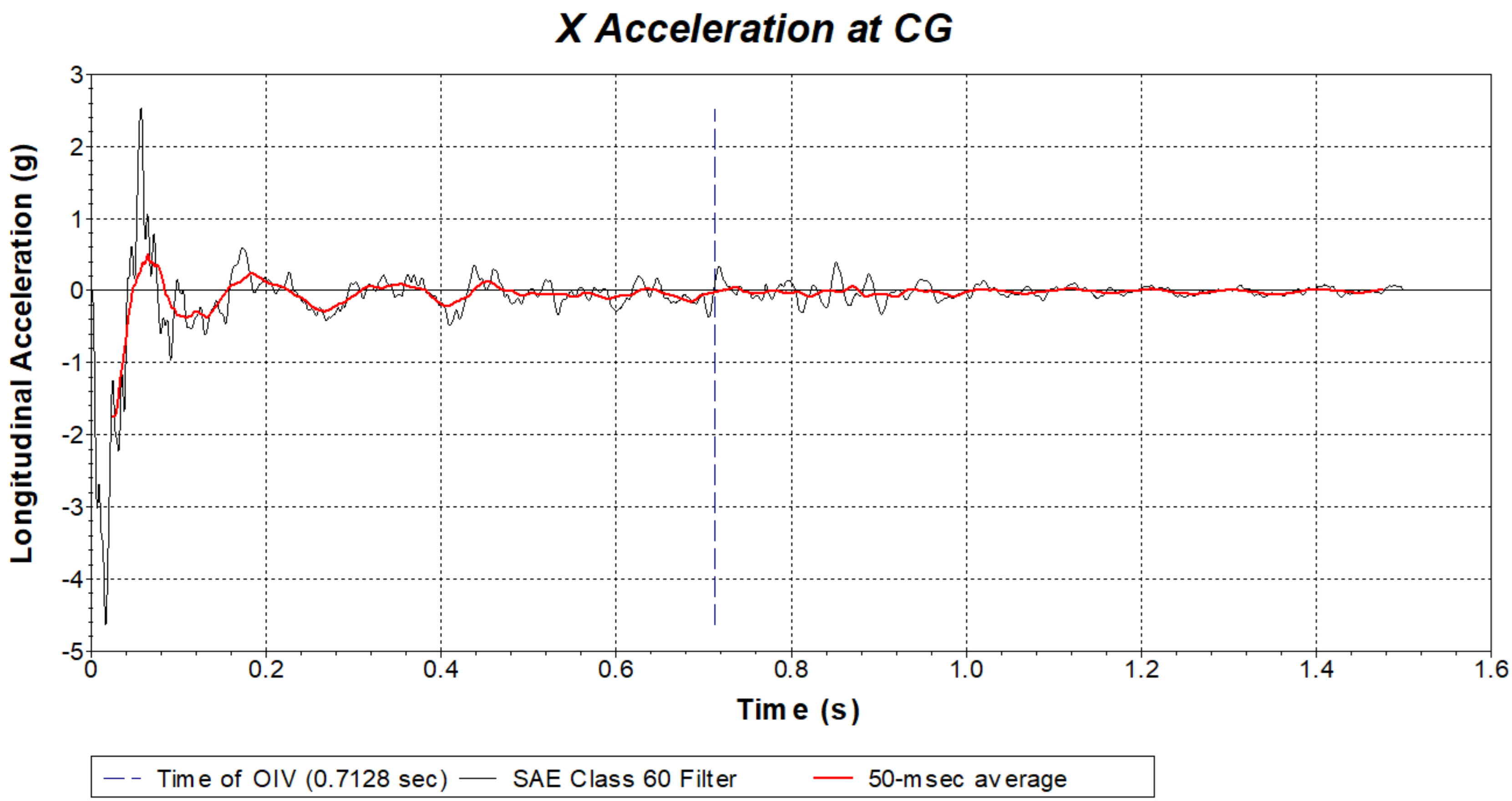


Figure 102. Vehicle Longitudinal Accelerometer Trace

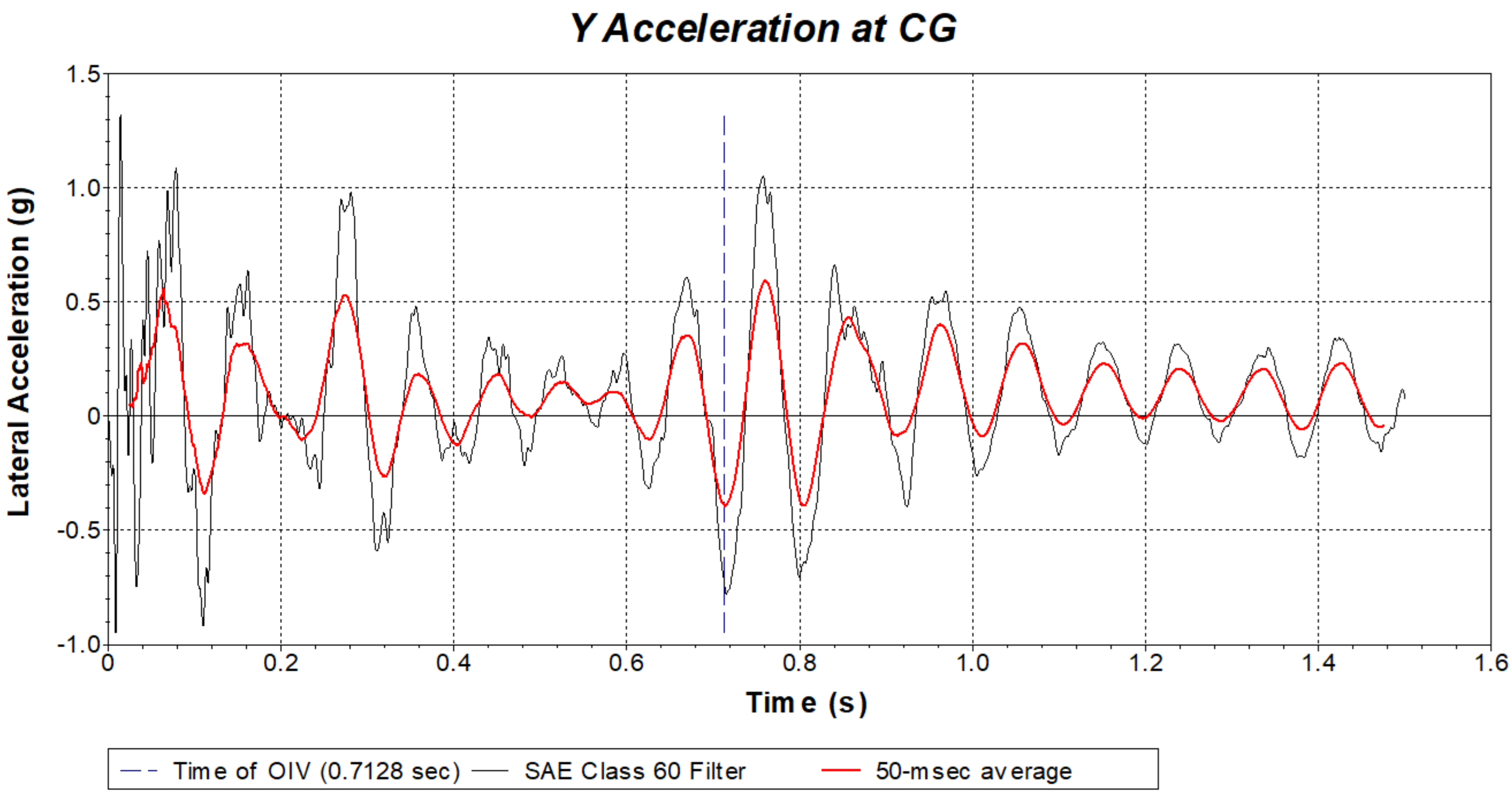


Figure 103. Vehicle Lateral Accelerometer Trace

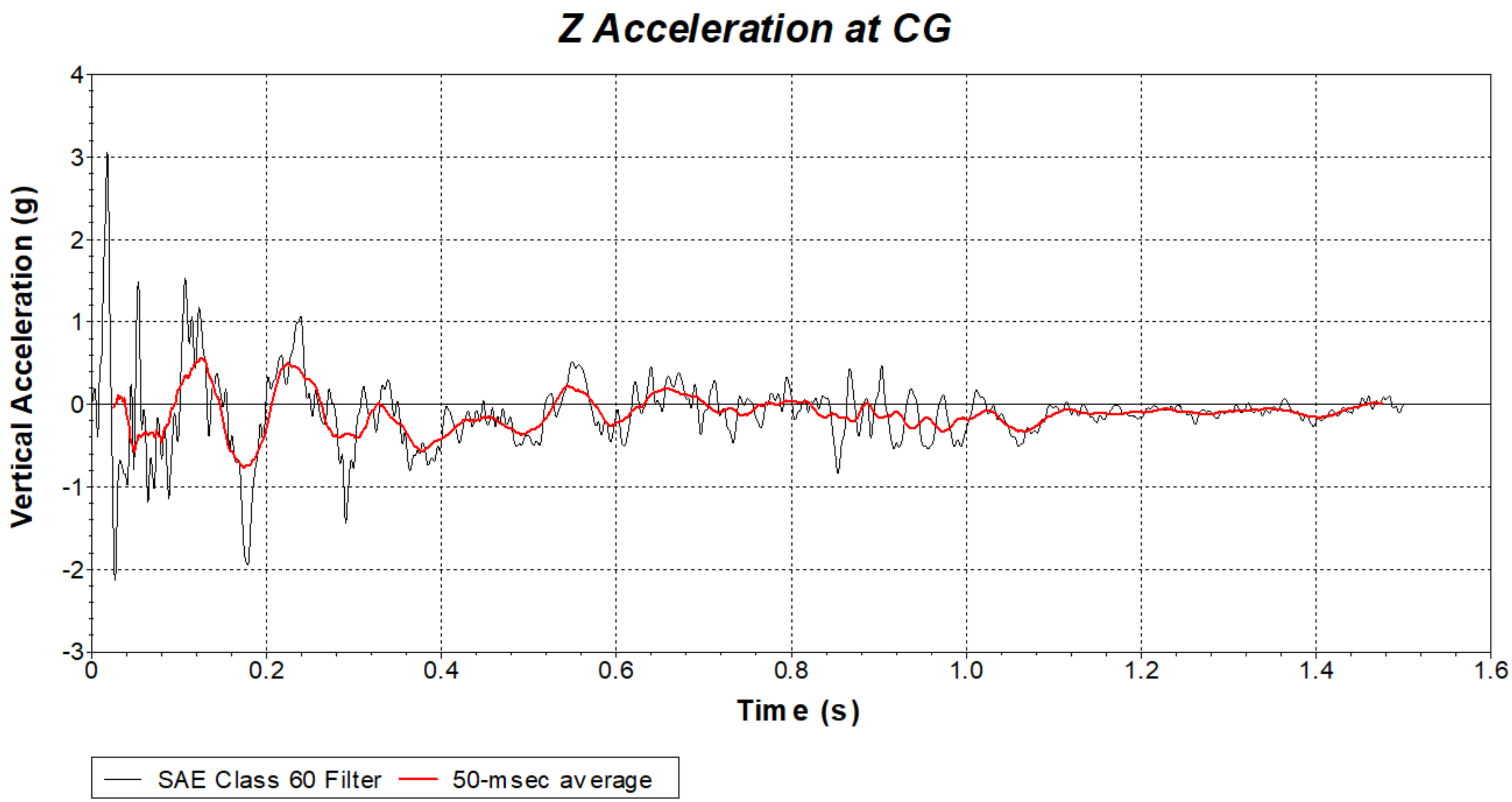


Figure 104. Vehicle Vertical Accelerometer Trace