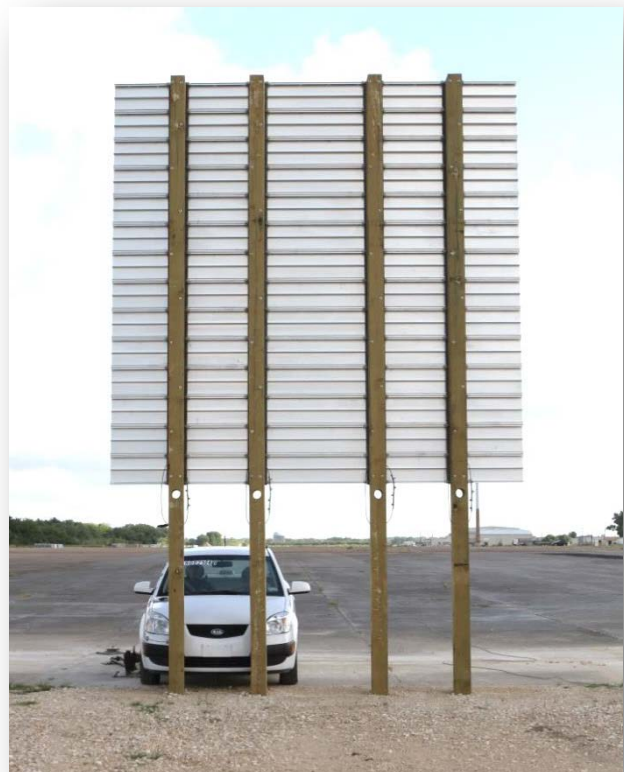




CRASH TEST AND EVALUATION OF TEMPORARY WOOD SIGN SUPPORT SYSTEM FOR LARGE GUIDE SIGNS



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

Test Report 9-1002-15-4

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

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

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16. Abstract <p>The objective of this research task was to evaluate the impact performance of a temporary wood sign support system for large guide signs. It was desired to use existing TxDOT sign hardware in the design to the extent possible. The full-scale crash testing followed the procedures recommended in the American Association of State Highway and Transportation Officials' (AASHTO) <i>Manual for Assessing Safety Hardware (MASH)</i>.</p> <p>In <i>MASH</i> Test 3-60, the Temporary Wood Sign Support System for Large Guide Signs readily activated by fracturing in various designed locations. The fractured posts did not penetrate or show potential for penetrating the occupant compartment, and did not present hazard to others in the area. The sign panel came to rest on the roof of the vehicle with resulting occupant compartment deformation of 2.5 inches. Occupant risk factors were within the limits specified in <i>MASH</i>.</p> <p>In <i>MASH</i> Test 3-61, the TxDOT Large Temporary Wood Sign Support readily activated by fracturing in various designed locations. The fractured posts did not penetrate or show potential for penetrating the occupant compartment, and did not present hazard to others in the area. No occupant deformation or intrusion occurred. Occupant risk factors were within the preferred limits specified in <i>MASH</i>.</p> <p>The Temporary Wood Sign Support System for Large Guide Signs performed acceptably for <i>MASH</i> Tests 3-60 and 3-61. Accompanying wind load charts and foundation embedment depths were developed and presented for all acceptable temporary wood support sizes deemed crashworthy based on the tests performed under this project and previous research efforts. These design charts and tables can be used to develop standard detail sheets to aid designers in the selection of appropriate support details for a given sign.</p>					
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DISCLAIMER


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

TTI PROVING GROUND DISCLAIMER

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




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CHAPTER 1. INTRODUCTION

1.1 INTRODUCTION

This project was set up to provide the Texas Department of Transportation (TxDOT) with a mechanism to quickly and effectively evaluate high priority issues related to roadside safety devices. Roadside safety devices shield motorists from roadside hazards such as non-traversable terrain and fixed objects. Some obstacles that cannot be moved out of the clear zone (e.g., mailboxes, sign supports) are designed to breakaway. To maintain the desired level of safety for the motoring public, these safety devices must be designed to accommodate a variety of site conditions, placement locations, and a changing vehicle fleet. Periodically, there is a need to assess the compliance of existing safety devices with current vehicle testing criteria.

Under this project, roadside safety issues are identified and prioritized for investigation. Each roadside safety issue is addressed with a separate work plan, and the results are summarized in an individual test report. The particular issue addressed in this report deals with the temporary mounting of large guide signs on wood supports.

1.2 BACKGROUND

A common issue during phased highway construction projects is the need to temporarily relocate large guide signs on the roadside or install new guide signs for temporary use. Many of these signs are significantly larger than 100 ft² and cannot be accommodated on small sign supports. The conventional concrete foundations used for large guide signs are costly and time-consuming to install. They are equally costly to remove after construction is completed and, consequently, they are often left in place. This creates problems for mowing and other maintenance operations.

There is a need for something more temporary than steel reinforced drilled concrete shafts for the temporary placement or relocation of large guide signs, and more cost-effective to install and remove. Any such system must be crashworthy and capable of accommodating wind load requirements.

A direct embedded wood support temporary guide sign system was developed and successfully crash tested in accordance with *MASH* guidelines under TxDOT Research Project 0-6782. The direct embedded wood supports incorporate weakening holes at the ground line and below the sign panel to facilitate breakaway performance during an impact. Direct embedment of the supports eliminates the need for reinforced concrete foundations and provides a cost-effective option for supporting guide signs during highway construction projects.

The full-scale crash testing performed under Project 0-6782 establishes an upper limit on post strength. Various post combinations are considered acceptable provided their combined strength is less than or equal to the strength of two 6-inch × 8-inch posts with 4-inch weakening holes, which is the post configuration that was successfully crash tested.

While this research exceeded the original design objective and can accommodate a broad range of temporary guide sign sizes, TxDOT engineers determined based on real-world

applications that there were still some unmet needs in this area. It was therefore desired to expand upon the previous research to include temporary support options that can be used for even larger guide signs.

1.3 OBJECTIVES/SCOPE OF RESEARCH

The objective of this research task was to design and evaluate the impact performance of a direct embedded wood sign support for large temporary guide signs that can accommodate larger signs than the system that was successfully crash tested under TxDOT Project 0-6782. It was desired to use existing TxDOT sign mounting hardware and design details previously developed under Project 0-6782 to the extent possible. The full-scale crash testing followed the procedures recommended in the American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware (MASH) (1)*.

Reported herein are details of the Temporary Wood Sign Support System for Large Guide Signs, descriptions of the tests performed, assessment of the test results, and implementation recommendations including design charts.

CHAPTER 2. SYSTEM DETAILS

2.1 TEST ARTICLE DESIGN AND CONSTRUCTION

The test installation involved a 14-ft tall \times 14-ft wide (196 ft²) extruded aluminum sign panel supported by four 6-inch \times 10-inch, Grade 1, treated Southern Yellow Pine (SYP) wood support posts at a mounting height of 7 ft from the ground to the bottom of the sign panel.

The posts were each 26 ft in length and were embedded 5 ft deep into drilled holes and backfilled with compacted standard soil per *MASH*. The spacing of the four wood support posts was 33 inches/48 inches/33 inches center to center. The spacing was adjusted slightly to ensure the test vehicle would simultaneously impact two of the four supports without impacting a third. Standard uniform spacing would have been sufficient to provide this impact condition, but the spacing was modified to provide a reasonable degree of impact tolerance for the test vehicle.

The extruded aluminum sign panel was comprised of fourteen 12-inch wide \times 14-ft long \times 0.081-inch thick extruded aluminum sections. Each section had a 2-inch tall continuous bolting flange channel running along the top and bottom edges, and a 2-inch tall \times 0.125-inch thick stiffener web running along the center. Each segment was attached to adjacent segments using $\frac{3}{8}$ -inch diameter UNC-16 \times $\frac{3}{4}$ -inch long Grade 2 hex bolts, hex nuts, and two flat washers beginning 6 inches from each end and equally spaced at approximately 24 inches along the length of each panel section.

An 8-inch wide \times 14-ft long \times $\frac{1}{4}$ -inch thick ASTM A36 steel mounting plate was attached to the front face of the support posts to facilitate mounting of the extruded aluminum sign panel to the supports. Twelve $\frac{1}{2}$ -inch diameter holes were drilled $1\frac{3}{4}$ -inch off of the centerline of each plate. Two holes (one on each side of the plate centerline) were located 3 inches from the top and bottom of the plate. The eight interior holes were staggered on either side of the plate centerline at a spacing of 18 inches. Matching holes were drilled through the support posts. The mounting plates were attached to the front face of each support post using twelve $\frac{3}{8}$ -inch diameter \times 12-inch long UNC 16, ASTM A193 Grade 2 all-thread rods with a hex nut, flat washer, and lock washer on each side (front and back) of the support post.

The sign panels were attached to the edges of the mounting plates with sign clips fitted with $\frac{3}{8}$ -inch diameter UNC-16 \times $2\frac{1}{4}$ -inch long square head bolts and flange nuts (ANSI B 18.2.1) (see TxDOT Dwg SMD (2-1)-08). The clips were installed on both sides of each plate on approximately 12-inch vertical spacing with the square heads of the bolts sliding into the $\frac{11}{16}$ -inch wide \times $\frac{1}{4}$ -inch deep channels on the top and bottom edges of the extruded aluminum sign panel segments.

Two 4-inch diameter holes were drilled along the strong axis of each of the support posts (i.e., parallel to the orientation of the sign panel) at heights of 4 inches and 18 inches above grade to facilitate fracture of the support just above grade.

A $3\frac{5}{8}$ -inch diameter hole was drilled along the weak axis of each support post (i.e., perpendicular to the orientation of the sign panel) 4 inches below the bottom of the sign panel to facilitate fracture of the support just below the sign panel. A $\frac{1}{2}$ -inch diameter hole was

drilled along the strong axis of the post (i.e., parallel to the orientation of the sign panel) 12 inches above and below the top weakening hole. A ¼-inch diameter cable was looped through the holes and clamped. The cable is designed to tether the middle section of the support to the sign panel after it fractures through both sets of weakening holes. This causes the post to swing up and out of the way of a impacting vehicle.

Figure 2.1 shows overall details of the direct embedded wood support system for temporary guide signs used for Test Nos. 490025-1 and 490025-2. Figure 2.2 shows photographs of the test installation prior to testing. Appendix A provides detailed construction drawings for the system, and Appendix B provides certification documents for the materials used in the construction of the system.

2.2 MATERIAL SPECIFICATIONS

The posts for this sign support system were Grade 1, SYP produced to Sustainable Forestry Initiative (SFI) standards, and were pressure treated against rot and insects (chromated copper arsenate [CCA-C], “Wolmanized,” or equivalent). The mounting plates attached to the support posts to facilitate mounting of the extruded aluminum sign panels were fabricated from ASTM A36 steel plate. The bolts used to connect the extruded aluminum sign panel sections to one another were SAE Grade 2. The all-thread rod used to attach the mounting plates to the support posts was ASTM A193 Grade 2.

2.2 SOIL PROPERTIES

The test installation was installed in standard soil meeting AASHTO standard specifications for “Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses,” designated M147-65(2004), grading B.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During construction of the Temporary Wood Sign Support for Large Guide Signs for full-scale crash testing, two W6×16 posts were embedded in the ground in the immediate vicinity of the test installation, utilizing the same fill materials and installation procedures used in the standard dynamic testing previously performed to establish soil strength requirements.

As determined using the procedures established in Appendix B of *MASH*, the minimum post load required at deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, is 3940 lb, 5500 lb, and 6540 lb, respectively (90 percent of static load for the initial standard installation). On the day of the first test, June 26, 2015, load on the soil test post at deflections of 5 inches, 10 inches, and 15 inches was 10,404 lbf, 8888 lbf, and 7,575 lbf, respectively. The strength of the backfill material in which the Temporary Wood Sign Support for Large Guide Signs was installed met minimum requirements.

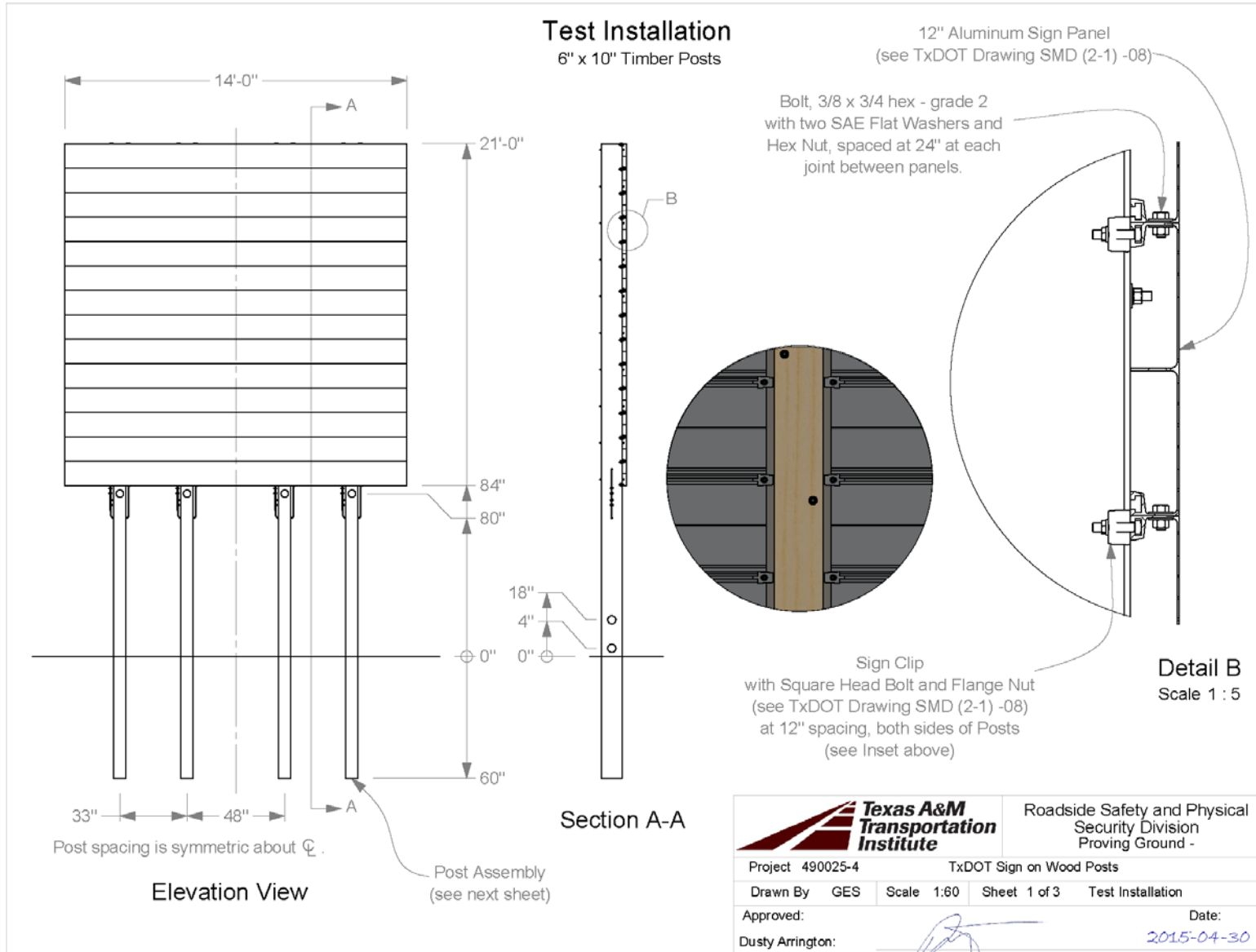


Figure 2.1. Overall Details of the Temporary Wood Sign Support for Large Guide Signs.

T:\2014-2015\490025 - TxDOT\4-4 Temp Wood Sign Supports\Drafting\490025-4 Drawing

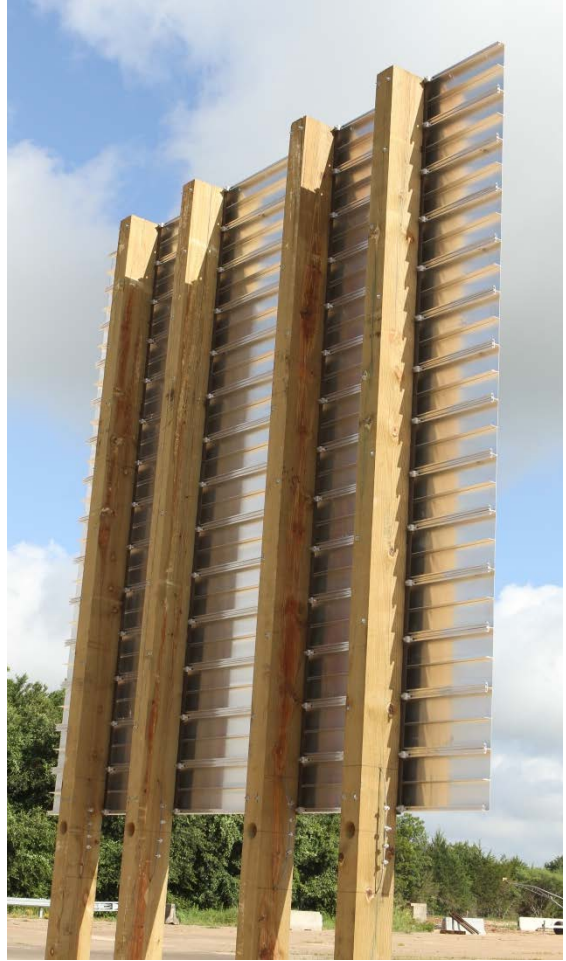
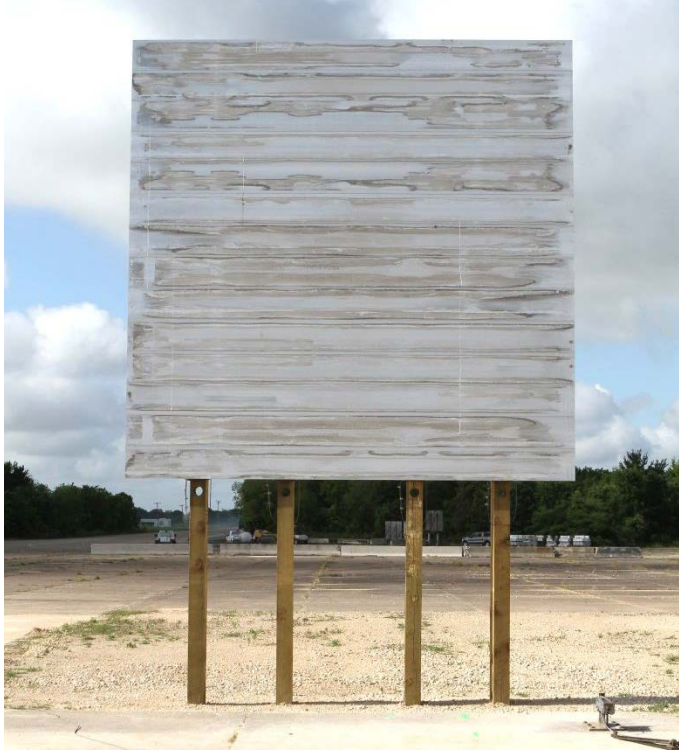


Figure 2.2. Temporary Wood Sign Support for Large Guide Signs before Testing.

CHAPTER 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 CRASH TEST MATRIX

The full-scale crash testing performed under this project was in accordance with the guidelines and procedures set forth in *MASH*. The recommended matrix for evaluating breakaway support structures to test level 3 (TL-3) consists of three tests:

- ***MASH Test 3-60*** is a low-speed impact with an 1100C test vehicle striking the test article at the critical impact angle (CIA) at an impact speed of 19 mi/h. This test is designed to evaluate the kinetic energy required to activate the breakaway, fracture, or yielding mechanism in the support. The primary concern for this test is the potential for excessive velocity change, intrusion of structural components into the floor pan, and occupant compartment deformation caused by damage to roof or windshield of the impacting vehicle. Occupant risk is also a concern for this test.
- ***MASH Test 3-61*** is a high-speed impact with an 1100C test vehicle striking the test article at the CIA at a speed of 62 mi/h.
- ***MASH Test 3-62*** is a high-speed impact with a 2270P test vehicle striking the test article at the CIA at a speed of 62 mi/h.

The high-speed (62 mi/h) tests are intended to evaluate the behavior of the feature during high-speed impacts. The most common risks of failure for the high-speed tests include intrusion of a structural component of the test installation into the occupant compartment, excessive deformation of the vehicle windshield or roof, and the potential for vehicle instability. Occupant risk is also a concern for these two tests.

The CIA represents the worst case impact condition consistent with the manner in which the sign support will be installed on the roadway and judged to have the greatest potential for test failure. The crash tests on the direct embedded wood support system were performed using an impact angle of zero degrees. This permitted both support posts to be simultaneously impacted, thus providing the most critical case for evaluating occupant risk and secondary contact of the fractured supports with the vehicle.

MASH Tests 3-60 and 3-61 were performed on the Temporary Wood Sign Support for Large Guide Signs. *MASH* Test 3-62 with the 2270P pickup truck was not performed. The higher mass of the 2270P vehicle makes Test 3-62 less critical than the small passenger car tests in regard to occupant risk evaluation. Further, previous testing performed under TxDOT Research Project 0-6782 demonstrated that the wood support posts will readily fracture and rotate up and away from the vehicle without any secondary contact with the roof or windshield. Based on these factors, the researchers concluded that *MASH* Test 3-62 did not need to be performed to evaluate the impact performance of the sign support system under *MASH* criteria.

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

3.2 EVALUATION CRITERIA

The researchers evaluated the crash tests in accordance with the criteria presented in *MASH*. The performance of the Temporary Wood Sign Support for Large Guide Signs was evaluated based on three factors:

- Structural adequacy criteria considers the ability of the Temporary Wood Sign Support for Large Guide Signs to breakaway and permit controlled penetration of the vehicle through the system.
- 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.
- Post-impact vehicle trajectory is assessed to determine potential for secondary impact with other vehicles or fixed objects, creating further risk of injury to occupants of the impacting vehicle and/or risk of injury to occupants in other vehicles.

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

CHAPTER 4. CRASH TEST PROCEDURES

4.1 TEST FACILITY

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

The test facilities at the TTI Proving Ground consist of a 2000-acre complex of research and training facilities situated 10 miles northwest of the main campus of Texas A&M University. The site, formerly a United States Army Corps Base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and evaluation of roadside safety hardware. The site selected for the installation of the Temporary Wood Sign Support for Large Guide Signs was in the middle of a wide out-of-service apron. Sections of the apron were removed to permit direct embedment of the support posts into the ground. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches thick. The apron was built in 1942, and the joints have some displacement but are otherwise flat and level.

4.2 VEHICLE TOW AND GUIDANCE PROCEDURES

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

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

The test vehicles were 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 that Diversified Technical Systems, Inc. produced. 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. Once data are recorded, internal batteries back these up inside the unit should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark as well as initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

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

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

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals, then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact. Rate of rotation data is measured with an expanded uncertainty of ± 0.7 percent at a confidence factor of 95 percent ($k=2$).

4.3.2 Anthropomorphic Dummy Instrumentation

In each test, a dummy was positioned in the 1100C vehicle per *MASH* requirements. The Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy used for the tests was restrained with lap and shoulder belts. The dummy was uninstrumented.

4.3.3 Photographic Instrumentation and Data Processing

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

CHAPTER 5. MASH TEST 3-60

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-60 involves an 1100C vehicle weighing 2420 lb \pm 55 lb impacting the sign support at an impact speed of 19 mi/h \pm 2.5 mi/h and 0 degrees \pm 1.5 degrees. The target impact point was centerline of the vehicle aligned with the centerline between two supports. The 2009 Kia Rio used in the test weighed 2434 lb, and the actual impact speed and angle were 18.5 mi/h and 0 degrees, respectively. The actual impact point was centerline of the vehicle aligned with the centerline between the two supports on the right side of the sign support system. Target kinetic energy (KE) was \leq 34 kip-ft, and actual KE was 28 kip-ft.

5.2 WEATHER CONDITIONS

The test was performed on the morning of June 26, 2015. Weather conditions at the time of testing were as follows: wind speed: 7 mi/h; wind direction: 203 degrees with respect to the vehicle (vehicle was traveling in a southerly direction); temperature: 84°F; relative humidity: 79 percent.

5.3 TEST VEHICLE

The 2009 Kia Rio, shown in Figures 5.1 and 5.2, was used for the crash test. Test inertia weight of the vehicle was 2434 lb, and its gross static weight was 2599 lb. The height to the lower edge of the vehicle bumper was 9.5 inches, and the height to the upper edge of the bumper was 21.5 inches. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact.



Figure 5.1. Vehicle/Installation Geometrics for Test No. 490025-4-1.



Figure 5.2. Vehicle before Test No. 490025-4-1.

5.4 TEST DESCRIPTION

The 2009 Kia Rio, traveling at a speed of 18.5 mi/h, impacted the two supports on the right side of the sign support installation (posts 3 and 4) at 0 degrees with the centerline of the vehicle aligned with the midpoint between the two supports. At 0.012 s after impact, the hood of the vehicle began to deform, and at 0.021 s, post 3 and post 4 began to deflect toward the field side. Posts 3 and 4 began to fracture at bumper height of the vehicle at 0.028 s, and then fractured completely at the holes near ground level at 0.039 s. At 0.039 s, post 3 fractured at the hole at bumper height,. Post 1 began to deflect towards the field side at 0.100 s. At 0.174 s, post 2 fractured at the top hole just beneath the sign panel, and at 0.368 s, post 1 splintered and fractured at the top hole just beneath the sign panel. Posts 2 and 1 fractured at the hole at ground level at 0.485 s and 0.490 s, respectively. Brakes on the vehicle were not applied, and at 0.1458 s, the vehicle subsequently came to rest under the fractured sign supports and sign panel 65 inches downstream of the point of impact. Figure C.1 in Appendix C.2 shows sequential photographs of the test period.

5.5 DAMAGE TO TEST INSTALLATION

Figures 5.3 and 5.4 show damage to the sign support system after the test. Post 1 fractured at the hole just beneath the sign panel in a torsional manner. Post 2 fractured at all three weakening hole locations. Posts 3 and 4 both fractured at the holes near and above ground level. The sign panel remained intact and came to rest partially on top of the vehicle.

5.6 VEHICLE DAMAGE

Damage to the vehicle is shown in Figure 5.5. The front bumper, hood, roof, and right C-post were deformed. The windshield sustained stress cracks radiating from the right corner of the roof, and the rear glass was shattered. Maximum external crush to the vehicle was 2.5 inches in the roof and 2.0 inches in the front plane at the right front corner of the bumper at bumper height. Figure 5.6 shows the interior of the vehicle before and after the test. Maximum occupant compartment deformation was 2.5 inches in the roof. Exterior vehicle crush and occupant compartment measurements are shown in Appendix C2, Tables C.2 and C.3.



Figure 5.3. Vehicle/Installation Positions after Test No. 490025-4-1.



Figure 5.4. Installation after Test No. 490025-4-1.



Figure 5.5. Vehicle after Test No. 490025-4-1.



Figure 5.6. Interior of Vehicle for Test No. 490025-4-1.

5.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity (OIV) was 16.1 ft/s at 0.170 s, the highest 0.010-s occupant ridedown acceleration (RDA) was 2.1 Gs from 0.228 to 0.238 s, and the maximum 0.050-s average acceleration was -7.4 Gs between 0.003 and 0.053 s. In the lateral direction, the OIV was 1.0 ft/s at 0.170 s, the highest 0.010-s occupant RDA was 1.6 Gs from 1.977 to 1.987 s, and the maximum 0.050-s average was -1.0 Gs between 1.951 and 2.001 s. Theoretical Head Impact Velocity (THIV) was 17.7 km/h or 4.9 m/s at 0.170 s; Post-Impact Head Decelerations (PHD) was 2.1 Gs between 0.228 and 0.238 s; and Acceleration Severity Index (ASI) was 0.67 between 0.022 and 0.072 s. Figure 5.7 summarizes these data and other pertinent information from the test. Appendix C.3, Figure C.2, shows vehicle angular displacements, and Appendix C.4, Figures C.3 through C.8 show the accelerations versus time traces.

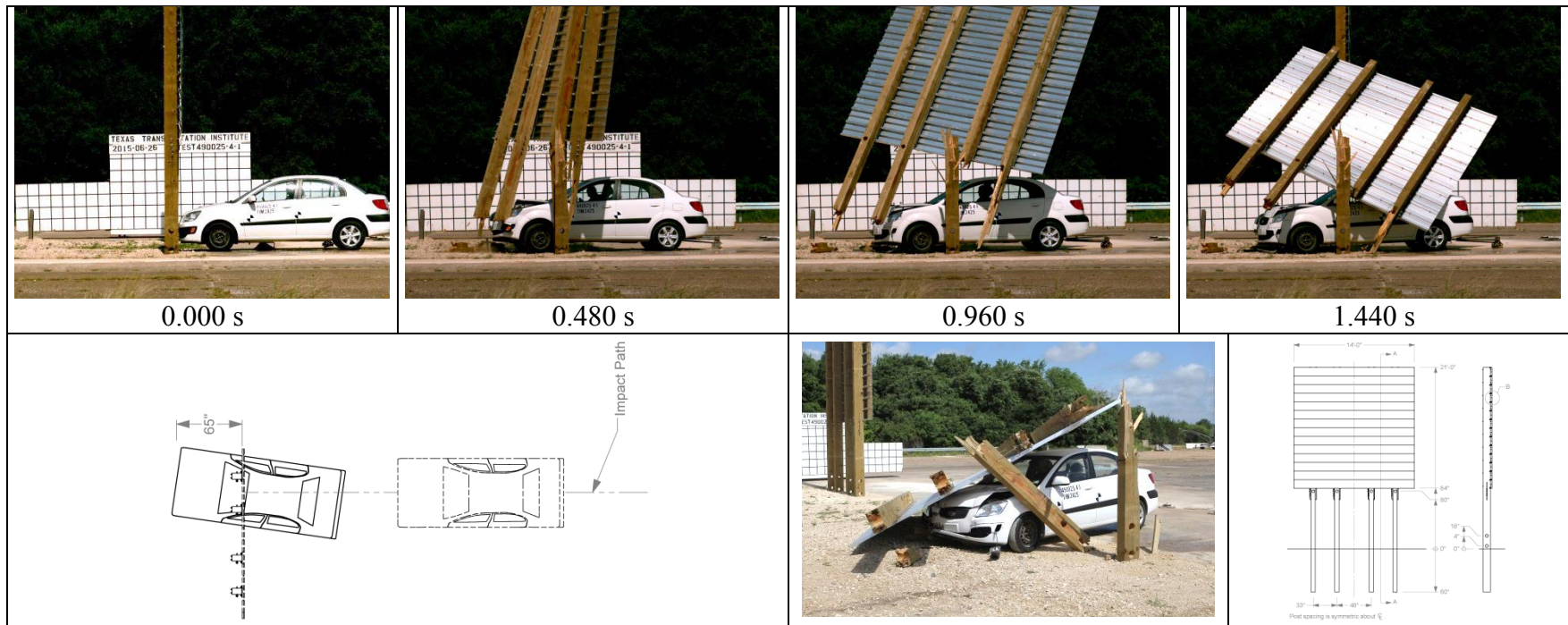
5.8 ASSESSMENT OF RESULTS

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

5.8.1 Structural Adequacy

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

Results: The Temporary Wood Sign Support for Large Guide Signs readily activated by fracturing in various design locations. (PASS)



General Information

Test Agency Texas A&M Transportation Institute (TTI)
 Test Standard Test No. MASH Test 3-60
 TTI Test No. 490025-4-1
 Test Date 2015-06-26

Test Article

Type Sign Support
 Name Temporary Wood Sign Support for Large Guide Signs
 Installation Mounting Height .. 84 inches
 Material or Key Elements 14-ft tall x 14-ft wide extruded aluminum sign panel supported by four 6-inch x 10-inch, Grade 1, treated SYP wood support posts

Soil Type and Condition Standard Soil, Dry

Test Vehicle

Type/Designation 1100C
 Make and Model 2009 Kia Rio
 Curb 2454 lb
 Test Inertial 2434 lb
 Dummy 165 lb
 Gross Static 2599 lb

Impact Conditions

Speed 18.5 mi/h
 Angle
 Location/Orientation Centerline btw support posts

Kinetic Energy 28 kip-ft

Exit Speed Stopped

Occupant Risk Values

Longitudinal OIV 16.1 ft/s
 Lateral OIV 1.0 ft/s
 Longitudinal RDA 2.1 G
 Lateral RDA 1.6 G
 THIV 17.7 km/h
 PHD 2.1 G
 ASI 0.67
 Longitudinal 0.050-s Avg -7.4 G
 Lateral 0.050-s Avg -1.0 G
 Vertical 0.050-s Avg -1.7 G

Post-Impact Trajectory

Stopping Distance 65 inches downstrm

Vehicle Stability

Maximum Yaw Angle 15 degrees
 Maximum Pitch Angle 2 degrees
 Maximum Roll Angle 5 degrees
 Vehicle Snagging No
 Vehicle Pocketing No

Vehicle Damage

VDS 12RF2
 CDC 12FREW2
 Max. Exterior Deformation 2.5 inches
 OCDI RR0100000
 Max. Occupant Compartment Deformation 2.5 inches

Test Article Debris Scatter

Longitudinal 65 inches
 Lateral 118 inches

Figure 5.7. Summary of Results for MASH Test 3-60 on the Temporary Wood Sign Support for Large Guide Signs.

5.8.2 Occupant Risk

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

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

Results: The fractured posts did not penetrate or show potential for penetrating the occupant compartment, and did not present hazard to others in the area. (PASS)

The sign panel came to rest on the roof of the vehicle causing an occupant compartment deformation of 2.5 inches. (PASS)

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

Results: The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 5 degrees and 2 degrees, respectively. (PASS)

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

Longitudinal and Lateral Occupant Impact Velocity

Preferred

10 ft/s

Maximum

16.4 ft/s)

Results: Longitudinal OIV was 16.1 ft/s, and lateral OIV was 1.0 ft/s. (PASS)

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

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred

15.0 Gs

Maximum

20.49 Gs

Results: Maximum longitudinal RDA was 2.1 Gs, and maximum lateral RDA was 1.6 Gs. (PASS)

5.8.3 Vehicle Trajectory

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

Result: The 1100C vehicle came to rest 65 inches behind the sign support. (PASS)

CHAPTER 6. MASH TEST 3-61 RESULTS

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-61 involves an 1100C vehicle weighing 2420 lb \pm 55 lb impacting the sign support at an impact speed of 62 mi/h \pm 2.5 mi/h and 0 degrees \pm 1.5 degrees. The target impact point was centerline of the vehicle aligned with the centerline between two supports. The 2009 Kia Rio used in the test weighed 2433 lb, and the actual impact speed and angle were 61.6 mi/h and 0 degrees, respectively. The actual impact point was centerline of the vehicle aligned with the centerline between two supports. Acceptable KE is \geq 288 kip-ft, and actual KE was 309 kip-ft.

6.2 WEATHER CONDITIONS

The test was performed on the morning of June 26, 2015. Weather conditions at the time of testing were as follows: wind speed: 7 mi/h; wind direction: 184 degrees with respect to the vehicle (vehicle was traveling in a southerly direction); temperature: 92°F; relative humidity: 55 percent.

6.3 TEST VEHICLE

The 2009 Kia Rio, shown in Figures 6.1 and 6.2, was used for the crash test. Test inertia weight of the vehicle was 2433 lb, and its gross static weight was 2598 lb. The height to the lower edge of the vehicle bumper was 9.5 inches, and the height to the upper edge of the bumper was 21.5 inches. Table D.1 in Appendix D.1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using the cable reverse tow and guidance system and was released to be free-wheeling and unrestrained just prior to impact.



Figure 6.1. Vehicle/Installation Geometrics for Test No. 490025-4-2.

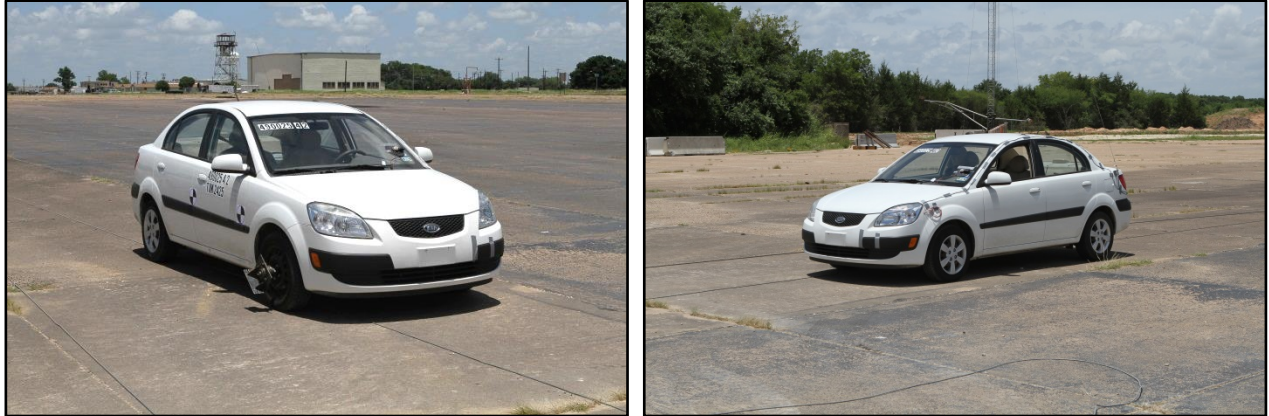


Figure 6.2. Vehicle before Test No. 490025-4-2.

6.4 TEST DESCRIPTION

The 2009 Kia Rio, traveling at a speed of 61.6 mi/h, impacted the two supports on the right side of the sign support installation (posts 3 and 4) at 0 degrees with the centerline of the vehicle aligned with the midpoint between the two supports. At 0.003 s after impact, the hood of the vehicle began to deform and posts 3 and 4 began to deflect toward the field side. Post 4 began to fracture along the longitudinal axis of the post at 0.006 s, and then fractured at the hole near ground level at 0.007 s. At 0.012 s, post 4 fractured at the hole below the sign panel, and at 0.013 s, post 3 fractured at the hole near ground level. The sign panel began to rotate counterclockwise at 0.023 s, and the fractured end of post 3 contacted the ground surface at 0.028 s. Post 4 and 3 fractured at bumper height at 0.030 s and 0.048 s, respectively. At 0.097 s, post 2 fractured at the hole below the sign panel, and at 0.117 s, posts 3 and 4 were oriented horizontal to the ground as they rotated up and away from the vehicle. At 0.145 s, the vehicle lost contact with the sign supports traveling at an exit speed of 55.8 mi/h. Brakes on the vehicle were not applied, and the vehicle came to rest 235 ft behind the installation. Figure D.1 in Appendix D.2 shows sequential photographs of the test period.

6.5 DAMAGE TO TEST INSTALLATION

Figures 6.3 and 6.4 show damage to the sign support system after the test. Post 2 partially fractured at the hole just below sign panel. Posts 3 and 4 fractured at all three weakening holes as designed, and remained attached to the sign panel by the restraining cables.

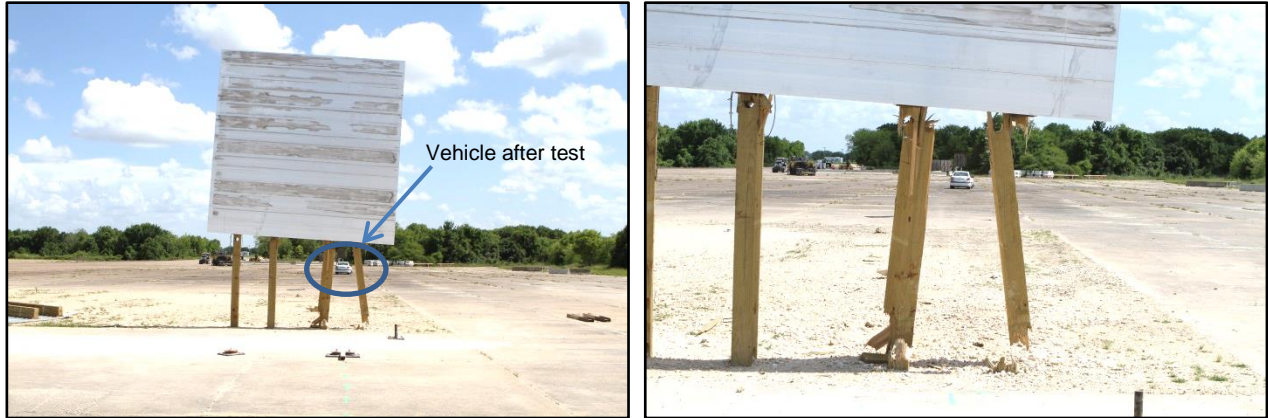


Figure 6.3. Vehicle/Installation Positions after Test No. 490025-4-2.



Figure 6.4. Installation after Test No. 490025-4-2.

6.6 VEHICLE DAMAGE

Damage to the vehicle is shown in Figure 6.5. The front bumper, hood, and roof were deformed. The windshield sustained a crack radiating from the left front corner of the roof. Maximum external deformation of the vehicle was 3.26 inches in the front plane at the left quarter point of the bumper at bumper height. No occupant compartment deformation was noted. Figure 6.6 shows the interior of the vehicle. Exterior vehicle crush and occupant compartment measurements are shown in Appendix D2, Tables D.2 and D.3.

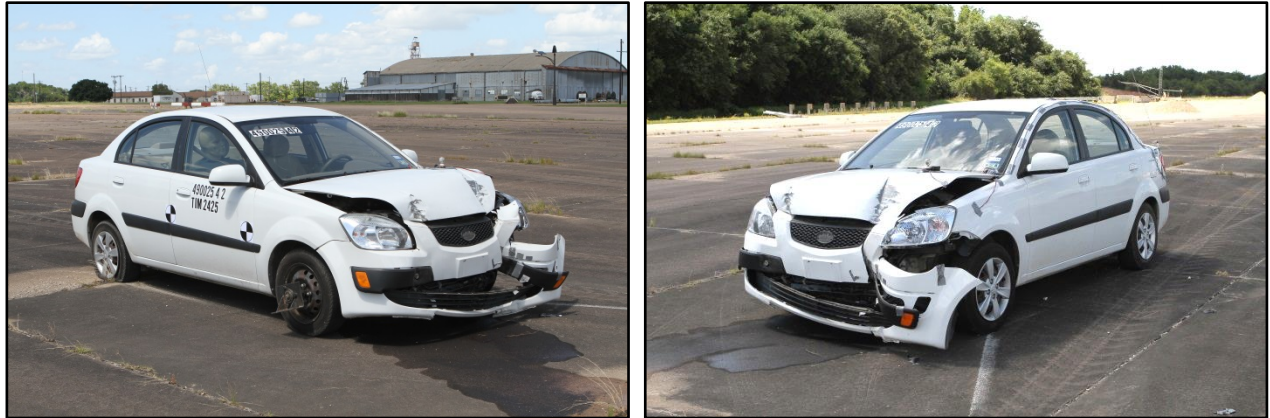
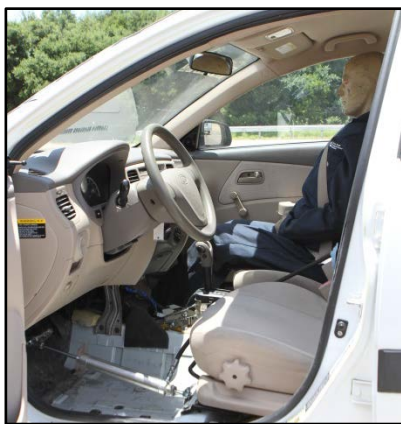


Figure 6.5. Vehicle after Test No. 490025-4-2.



Before Test No. 490025-4-2

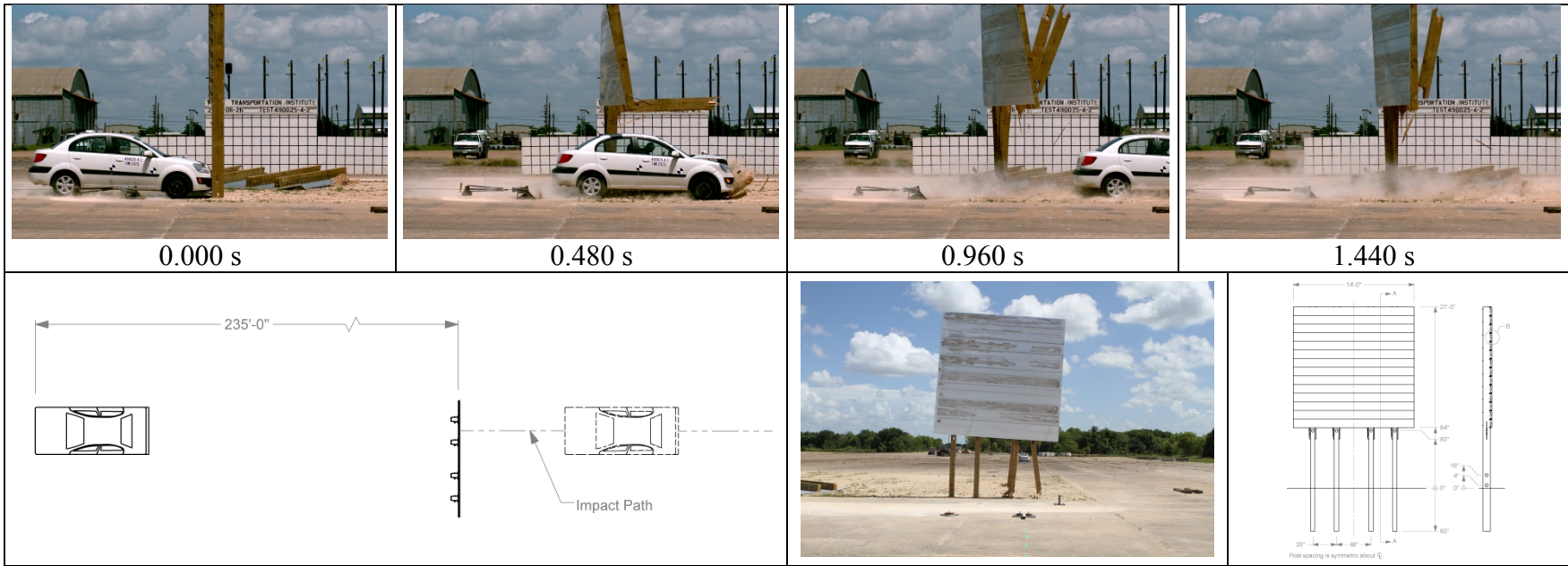


After Test No. 490025-4-2

Figure 6.6. Interior of Vehicle for Test No. 490025-4-2.

6.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the OIV was 9.8 ft/s at 0.213 s, the highest 0.010-s occupant RDA was 2.1 Gs from 0.261 to 0.271 s, and the maximum 0.050-s average acceleration was -6.0 Gs between 0.000 and 0.050 s. In the lateral direction, the OIV was less than 0.1 ft/s at 0.213 s, the highest 0.010-s occupant RDA was 1.8 Gs from 0.269 to 0.279 s, and the maximum 0.050-s average was 0.8 Gs between 0.230 and 0.280 s. THIV was 10.8 km/h or 3.0 m/s at 0.213 s; PHD was 2.3 Gs between 0.261 and 0.271 s; and ASI was 0.63 between 0.008 and 0.058 s. Figure 6.7 summarizes these data and other pertinent information from the test. Figure D.2 in Appendix D.3 shows vehicle angular displacements, and Figures D.3 through D.8 in Appendix D.4 show accelerations versus time traces.



General Information

Test Agency Texas A&M Transportation Institute (TTI)
 Test Standard Test No. MASH Test 3-61
 TTI Test No. 490025.4-2
 Test Date 2015-06-26

Test Article

Type Sign Support
 Name Temporary Wood Sign Support for Large Guide Signs
 Installation Mounting Height 84 inches
 Material or Key Elements 14-ft tall x 14-ft wide (196 ft²) extruded aluminum sign panel supported by four 6-inch x 10-inch, Grade 1, treated SYP wood support posts

Soil Type and Condition

..... Standard Soil, Dry

Test Vehicle

Type/Designation 1100C
 Make and Model 2009 Kia Rio
 Curb 2461 lb
 Test Inertial 2433 lb
 Dummy 165 lb
 Gross Static 2598 lb

Impact Conditions

Speed 61.6 mi/h
 Angle
 Location/Orientation Centerline btw support posts

Kinetic Energy

..... 309 kip-ft

Exit Speed

..... 55.8 mi/h

Occupant Risk Values

Longitudinal OIV 9.8 ft/s
 Lateral OIV <0.1 ft/s
 Longitudinal RDA 2.1 G
 Lateral RDA 1.8 G
 THIV 10.8 km/h
 PHD 2.3 G
 ASI 0.63
 Longitudinal 0.050-s Avg ... -6.0 G
 Lateral 0.050-s Avg 0.8 G
 Vertical 0.050-s Avg -3.0 G

Post-Impact Trajectory

Stopping Distance 235 ft dwnstrm

Vehicle Stability

Maximum Yaw Angle 2 degrees
 Maximum Pitch Angle 2 degrees
 Maximum Roll Angle 2 degrees
 Vehicle Snagging No
 Vehicle Pocketing No

Vehicle Damage

VDS 12FR2
 CDC 12FREW2
 Max. Exterior Deformation 3.25 inches
 OCDI FS0000000
 Max. Occupant Compartment Deformation None

Test Article Debris Scatter

Longitudinal All debris
 Lateral remained at impact

Figure 6.7. Summary of Results for MASH Test 3-61 on the Temporary Wood Sign Support for Large Guide Signs.

6.8 ASSESSMENT OF RESULTS

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

6.8.1 Structural Adequacy

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

Results: The Temporary Wood Sign Support for Large Guide Signs readily activated by fracturing in various designed locations. (PASS)

6.8.2 Occupant Risk

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

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

Results: The fractured posts did not penetrate or show potential for penetrating the occupant compartment, and did not present hazard to others in the area. (PASS)

No occupant deformation or intrusion occurred. (PASS)

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

Results: The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 5 degrees and 2 degrees, respectively. (PASS)

- I. *Occupant impact velocities should satisfy the following:*

<u>Preferred</u>	<u>Maximum</u>
10 ft/s	16.4 ft/s

Results: Longitudinal OIV was 9.8 ft/s, and lateral OIV was less than 0.1 ft/s. (PASS)

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

<u>Preferred</u>	<u>Maximum</u>
15.0 Gs	20.49 Gs

Results: Maximum longitudinal RDA was 2.1 Gs, and maximum lateral RDA was 1.8 Gs. (PASS)

6.8.3 Vehicle Trajectory

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

Result: The vehicle came to rest 235 ft behind the sign support installation. (PASS)

CHAPTER 7. WINDLOAD AND FOUNDATION DESIGN CHARTS

7.1 POST WEAKENING HOLES

Weakening holes must be drilled in the support posts to meet occupant risk requirements within *MASH*, and to allow the sign supports to readily fracture in a controlled manner when impacted by an errant vehicle. There are different locations where the support is weakened. First, the support is weakened near ground level and near bumper height. This allows the support to fracture and cleanly breakaway when struck by the vehicle's bumper. Second, the support is weakened just below the sign support. This allows the support to fracture just below the sign so that it can swing up and out of the way of the impacting vehicle. Each support post size requires a specific size weakening hole at each weakening location. The bottom holes are drilled along the strong axis of the support (parallel to the sign panel) while the holes below the sign are drilled along the weak axis of the support (perpendicular to the sign panel). Table 7.1 lists the hole sizes for each support size that is used in the design charts presented in Section 7.2.

Table 7.1. Weakening Hole Sizes.

WEAKENING HOLE SIZES		
Support Size	Near Ground level (inches)	Near Bottom of Sign (inches)
6-inches × 10-inches	3 ⁵ / ₈	4
6-inches × 8-inches	3 ⁵ / ₈	4
4-inches × 6-inches	1 ¹ / ₂	2
4-inches × 4-inches	1	0

7.2 DESIGN CHARTS

The design wind pressure for a sign support system is based on the basic wind speed and the anticipated design life of the structure. As shown on TxDOT Standard Sheet WV&IZ-96 "Wind Velocity and Ice Zone Worksheet," design wind speeds of 70 mi/h and 80 mi/h cover almost the entire state of Texas with the exception of some higher wind zones on the extreme coast and the extreme tip of the panhandle. These design wind speeds are based on a 25-year mean recurrence interval. The AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals* recommends a 10-year mean recurrence interval for permanent roadside sign structures (2). For a 10-year mean recurrence interval, the design wind speeds that cover the state of Texas drop to 60 mi/h and 70 mi/h, respectively.

Given that the direct embedded wood post system is intended for temporary applications, the researchers concluded that a 10-year mean recurrence interval would be more than satisfactory for this design application. Design charts for the direct embedded wood post system were developed using the legacy method described in the AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals* to be consistent with TxDOT's other wind load charts and design standards. Two charts were developed for the Direct Embedded Temporary Wood Sign Support System for Large Guide Signs to address both 60 mi/h and 70 mi/h wind speeds.

The support sizes incorporated into the design charts include 4-inch×4-inch, 4-inch×6-inch, 6-inch×8-inch, and 6-inch×10-inch. Note that any of these posts can be purchased rough sawn or surfaced on four sides (S4S). A rough sawn post will have actual cross sectional dimensions corresponding to the nominal dimensions of the post. For example, a rough sawn 6-inch×8-inch post will be 6 inches wide and 8 inches deep. The actual dimensions of an S4S post will be slightly less than the nominal dimensions of the post due to the planing operation that makes the post's surfaces more smooth and uniform. For example, an S4S 4-inch×4-inch post will have actual dimensions of 3½-inches×3½-inches.

The 4-inch×4-inch and 4-inch×6-inch posts available at many local lumber yards and home improvement stores are commonly S4S. However, they can be ordered as rough sawn posts. The larger 6-inch×8-inch and 6-inch×10-inch post sized are not commonly available at local home improvement stores, but can be readily ordered. When ordering wood supports for use in the direct embedded sign support system, it is logical to order rough sawn posts. The rough sawn posts will likely be less expensive due to elimination of the planing process, and the larger cross section has more capacity than a similarly sized S4S post. To simplify the complexity of the wind load charts, only rough-sawn dimensions and Grade 1 materials are considered.

However, some contractors may find it convenient to purchase immediately available material from their local home improvement store or lumber yard. Since wind loads are based on probability of occurrence over a 10-year interval, and many of the temporary applications have durations much less than this, the design charts can be considered conservative. For this reason it is considered acceptable to utilize these design charts for surfaced post sizes even though they have a slightly reduced flexural and shear capacity.

Figures 7.1 and 7.2 present the post selection charts for 60-mi/h and 70-mi/h design wind speeds, respectively, for rough sawn lumber. The x-axis of the charts is the sign panel width and the y-axis of the charts is sign panel height. Note that different height axes are available for use depending on the mounting height of the sign with respect to the local terrain. Different axes are available for sign mounting heights of 7, 10, 13, and 16 ft. The nominal mounting height of a large guide sign is 7 ft with respect to the roadway surface. Because roadside terrain typically includes slopes and ditches to provide required hydraulic capacity, the actual mounting height from the local ground to the bottom of the sign panel is often greater than the nominal mounting height. This actual mounting height dictates the required moment capacity of the support post.

The sign dimensions used to develop the charts correspond to those used on TxDOT Standard Sheet SMD(8W1)-08, "Large Roadside Sign Supports Post Selection Worksheet." The grey area at the top of each chart represents sign panel sizes that the direct embedded wood post system cannot currently accommodate. The full-scale crash testing that was successfully performed on the system establishes the permissible size and spacing of the support posts. Note that no such areas exist on the design chart for a 60 mi/h design wind speed.

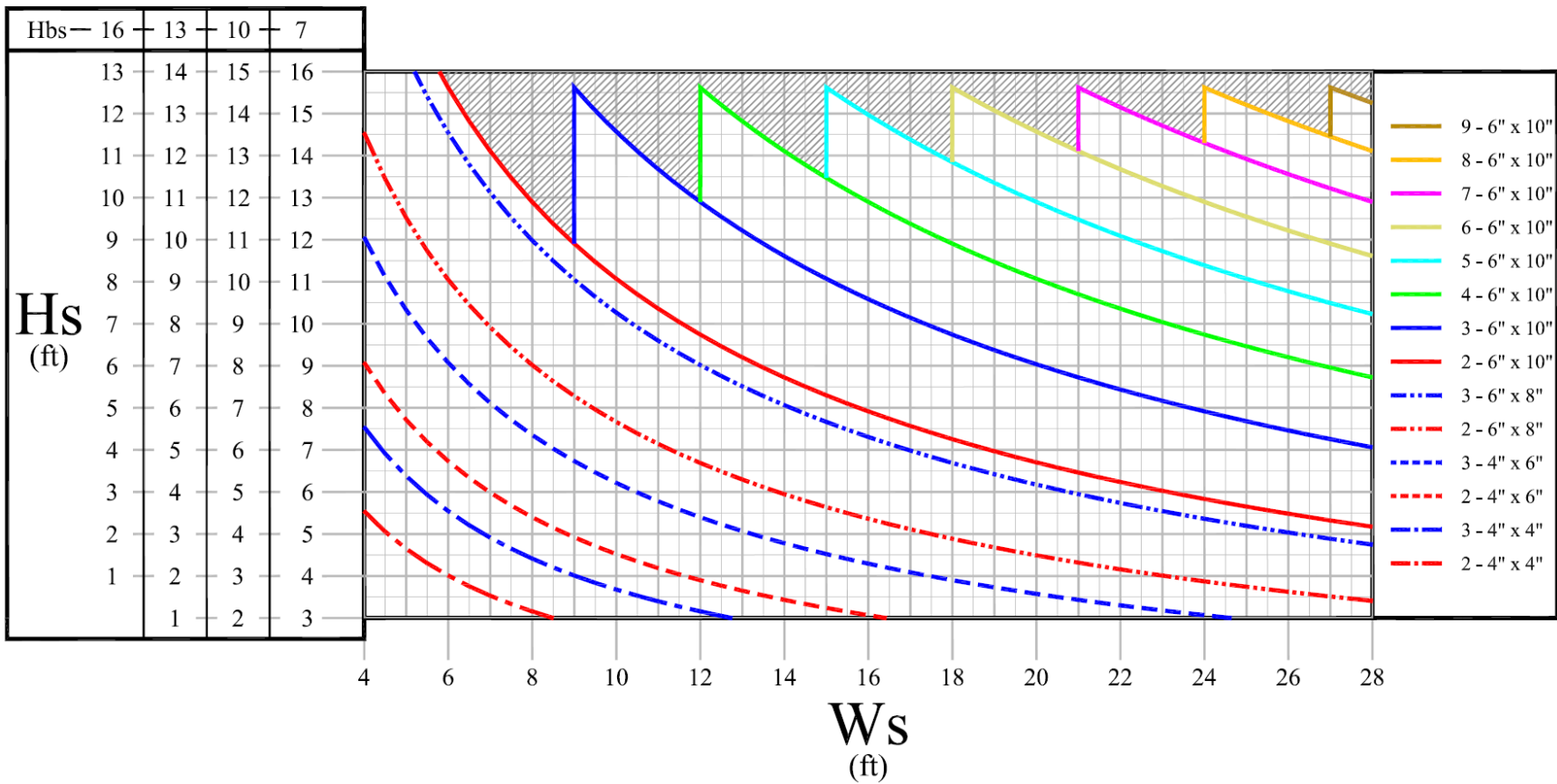


Figure 7.1. Design Chart for Temporary Wood Sign Support System for Large Guide Signs for 70-mi/h Design Wind Speed.

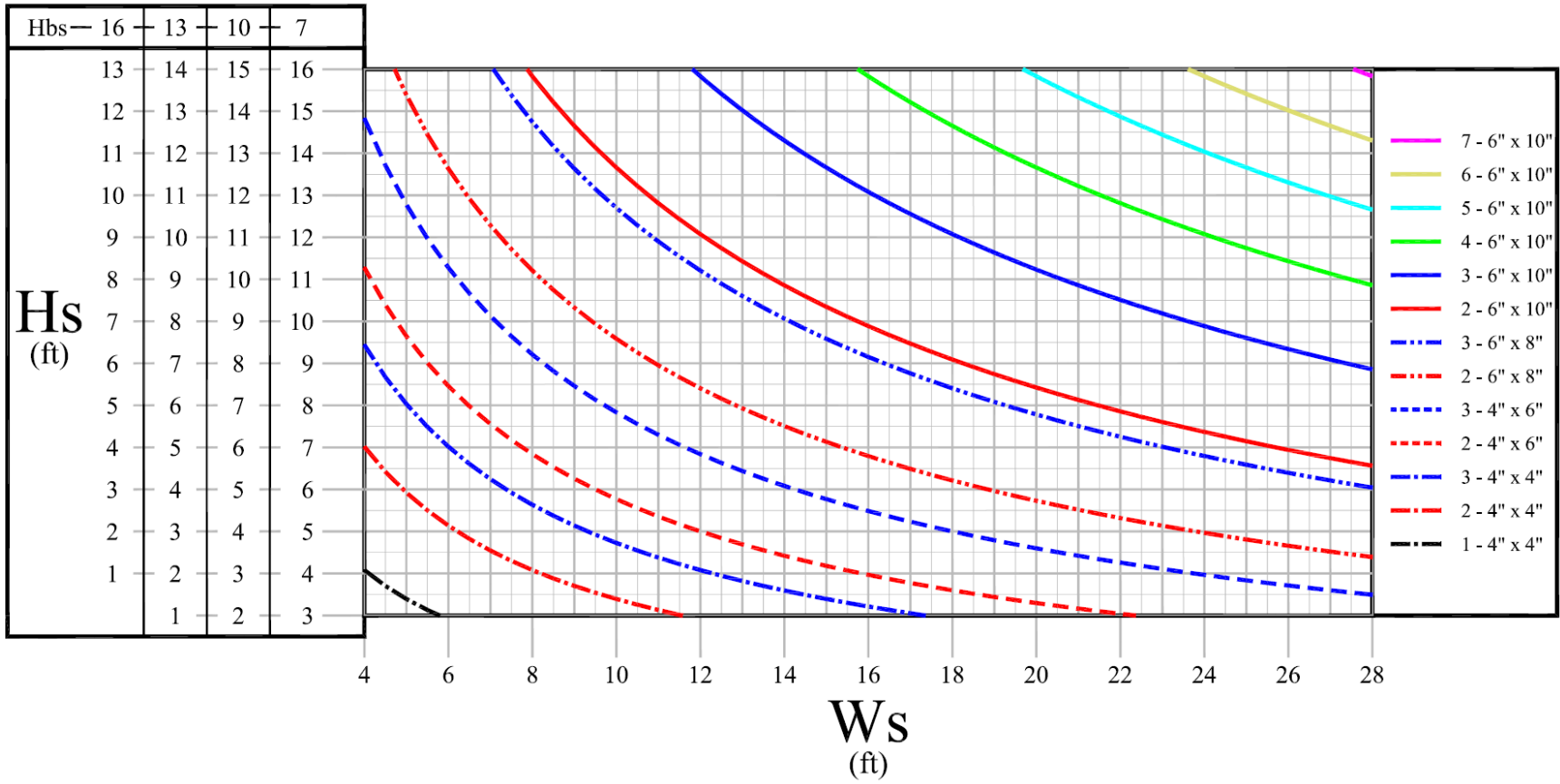


Figure 7.2. Design Chart for Temporary Wood Sign Support System for Large Guide Signs for 60-mi/h Design Wind Speed.

The following example illustrates the use of the design charts.

Example: Select the appropriate number and size of supports for a direct-embedded wood support system for a 12-ft tall × 16-ft wide sign panel. The mounting height is 7 ft (i.e., flat roadside), and the sign will be installed in a 60-mi/h design wind speed zone.

Solution: With reference to Figure 7.2, find the intersection point for a sign that is 12-ft tall (using 7-ft mounting height axis) and 16-ft wide. Determine the curve that is above the projected point. With reference to the legend, it can be seen that three 6-inch×10-inch posts are required to support the sign.

7.3 DIRECT EMBEDMENT DEPTH

The support posts for the Direct Embedded Temporary Wood Sign Support System for Large Guide Signs are directly embedded into soils on the roadside. Contractors and designers need to know how deep these supports need to be embedded to resist wind loads and achieve desired impact performance. The AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* suggests using Brom’s method for designing foundations for sign support structures. This method has two complimentary models for analyzing foundation requirements. One model is for the design of foundations in cohesionless soils, such as sand, and the other is intended to be used for cohesive soils, such as clay.

Table 7.2 presents the results of an analysis of the required embedment depth for the direct embedded wood support posts of interest. A cohesive soil with a cohesion, *c*, of 3100 psf was assumed in the analysis. It can be seen that the required embedment depth for a 4-inch×8-inch post is 4.0 ft. The embedment depth for a 4-inch×4-inch post is only 2.5 ft. If the supports are to be placed in non-cohesive soils, it is recommended that the foundation embedment depth be reanalyzed using Brom’s method for cohesionless soils. If soils are known to be stronger than the values assumed herein, the analysis can be repeated using actual soil values to take advantage of the stronger soil conditions to reduce the required embedment depth.

Table 7.2. Embedment Depths for Direct Embedded Wood Sign Supports – Cohesive Soil.

Timber Grade	Embedment Length (ft)
4×4 Grade 1	2.5
6×4 Grade 1	3.0
6×8 Grade 1	4.0
6×10 Grade 1	5.0

CHAPTER 8. SUMMARY AND CONCLUSIONS

8.1 SUMMARY OF TEST RESULTS

8.1.1 *MASH* Test 3-60 (Crash Test No. 490025-4-1)

The Temporary Wood Sign Support System for Large Guide Signs readily activated by fracturing in various designed locations. The fractured posts did not penetrate or show potential for penetrating the occupant compartment, and did not present hazard to others in the area. The sign panel came to rest on the roof of the vehicle and deformed the roof 2.5 inches, and occupant compartment deformation was also 2.5 inches. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 5 degrees and 2 degrees, respectively. Occupant risk factors were within the limits specified in *MASH*. The 1100C vehicle came to rest 60 inches behind the sign support.

8.1.2 *MASH* Test 3-61 (Crash Test No. 490025-4-2)

The Temporary Wood Sign Support System for Large Guide Signs readily activated by fracturing in various designed locations. The fractured posts did not penetrate or show potential for penetrating the occupant compartment, and did not present hazard to others in the area. No occupant deformation or intrusion occurred. The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 5 degrees and 2 degrees, respectively. Occupant risk factors were within the preferred limits specified in *MASH*. The vehicle came to rest 235 ft behind the sign support.

8.2 CONCLUSIONS

Table 8.1 and 8.2 show the Temporary Wood Sign Support System for Large Guide Signs performed acceptably for *MASH* Tests 3-60 and 3-61. Based on previous testing results with the pickup truck under TxDOT Project 0-6782 (ref. TxDOT Report 0-6782-1), TTI researchers concluded that *MASH* Test 3-62 is not required to assess the impact performance of the larger wood supports evaluated herein.

Table 8.1. Performance Evaluation Summary for MASH Test 3-60 on the TxDOT Large Temporary Wood Sign Support.

Test Agency: Texas A&M Transportation Institute

Test No.: 490025-4-1

Test Date: 2015-06-26

MASH Test 3-60 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. <i>The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The Direct Embedded Temporary Wood Sign Support System for Large Guide Signs readily activated by fracturing in various designed locations.	Pass
Occupant Risk		
D. <i>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.</i>	The fractured posts did not penetrate or show potential for penetrating the occupant compartment, and did not present hazard to others in the area.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>	The sign panel came to rest on the roof of the vehicle and deformed the roof 2.5 inches.	Pass
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 5 degrees and 2 degrees, respectively.	Pass
H. <i>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.</i>	Longitudinal OIV was 16.1 ft/s, and lateral OIV was 1.0 ft/s.	Pass
I. <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.</i>	Maximum longitudinal RDA was 2.1 Gs, and maximum lateral RDA was 1.6 Gs.	Pass
Vehicle Trajectory		
N. <i>Vehicle trajectory behind the test article is acceptable.</i>	The 1100C vehicle came to rest 60 inches behind the sign support.	Pass

Table 8.2. Performance Evaluation Summary for MASH Test 3-61 on the TxDOT Large Temporary Wood Sign Support.

Test Agency: Texas A&M Transportation Institute

Test No.: 490025-4-2

Test Date: 2015-06-26

MASH Test 3-61 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
B. <i>The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</i>	The Direct Embedded Temporary Wood Sign Support System for Large Guide Signs readily activated by fracturing in various designed locations.	Pass
Occupant Risk		
D. <i>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.</i>	The fractured posts did not penetrate or show potential for penetrating the occupant compartment, and did not present hazard to others in the area.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.</i>	No occupant deformation or intrusion occurred.	Pass
F. <i>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>	The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 5 degrees and 2 degrees, respectively.	Pass
H. <i>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.</i>	Longitudinal OIV was 9.8 ft/s, and lateral OIV was less than 0.1 ft/s.	Pass
I. <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.</i>	Maximum longitudinal RDA was 2.1 Gs, and maximum lateral RDA was 1.8 Gs.	Pass
Vehicle Trajectory		
N. <i>Vehicle trajectory behind the test article is acceptable.</i>	The vehicle came to rest 235 ft behind the sign support.	Pass

CHAPTER 9. IMPLEMENTATION STATEMENT

A temporary support system for large guide signs was developed and successfully crash tested in accordance with *MASH* guidelines. This system provides a cost-effective option for highway construction projects in which there exists a need to temporarily relocate large guide signs on the roadside or install new guide signs for temporary use. The wooden support posts are directly embedded in the ground, thus eliminating the need for reinforced concrete foundations that are costly and time consuming to both install and remove at the completion of the construction project.

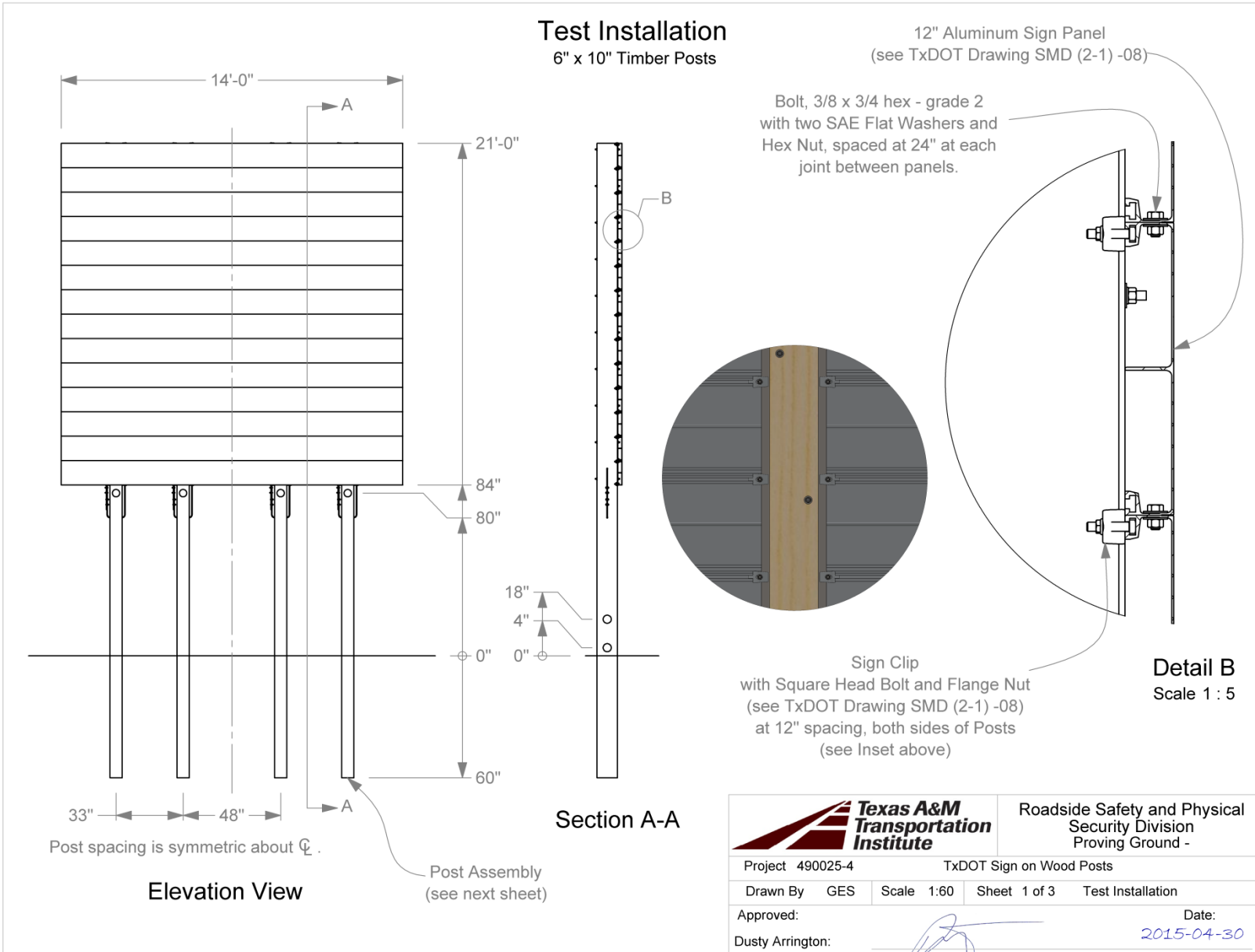
The direct embedded wood support temporary guide sign system met all *MASH* evaluation criteria and is considered suitable for implementation. Recommended design details, which can be applied to a variety of different support sizes, are presented in Appendix A.

Engineering analyses were performed to develop design charts for the proper selection of the size and number of wood support posts for the direct embedded wood sign support system. The charts include various post sizes that permit an economical support selection for a given size sign panel. Guidance has also been developed regarding recommended embedment depth for the direct embedded wood support post sizes incorporated in the design charts.

Implementation of the direct embedded wood support temporary guide sign system for the temporary support of large guide signs can be achieved through development of standard detail sheets that provide the design details in a general context along with the design selection charts and embedment table.

REFERENCES

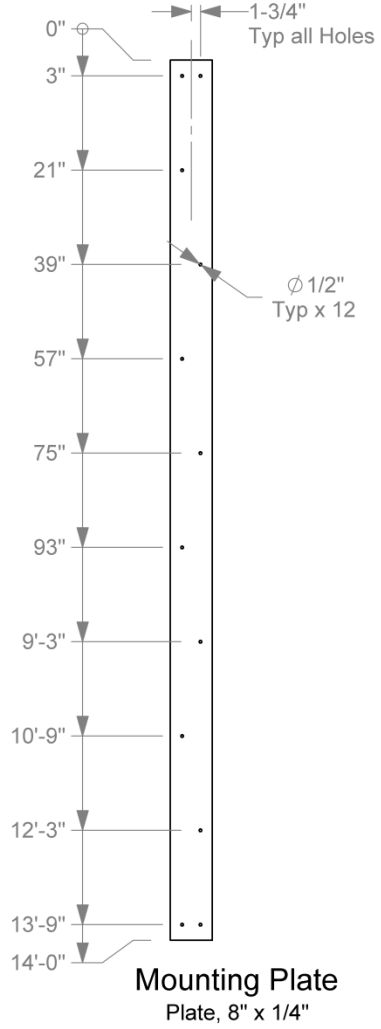
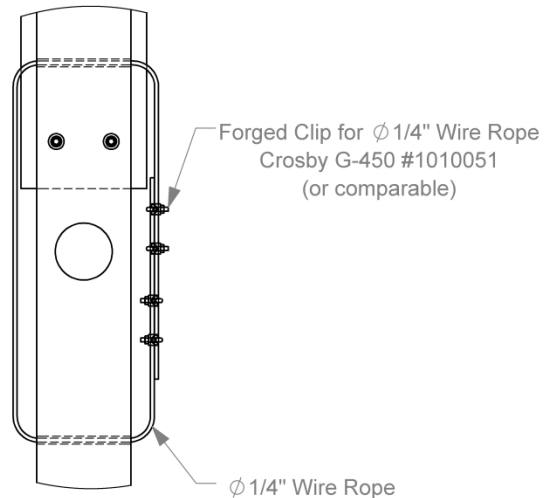
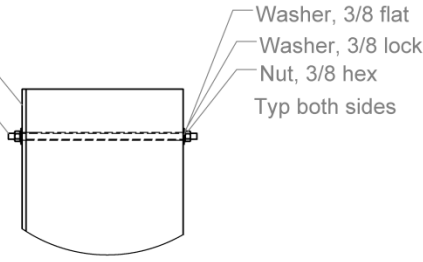
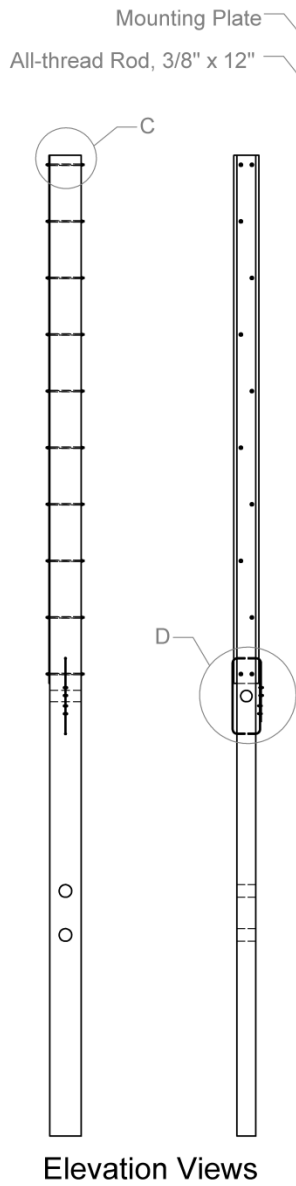
1. AASHTO, *Manual for Assessing Safety Hardware*, American Association of State Highway and Transportation Officials, Washington, D.C., 2009.
2. AASHTO, *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*, American Association of State Highway and Transportation Officials, Washington, D.C., 2013.
3. R. P. Bligh, D. R. Arrington, and W. L. Menges. *Temporary Large Guide Signs*. Test Report No. 0-6782-1, Texas A&M Transportation Institute, College Station, TX, May 2014.



T:\2014-2015\490025 - TxDOT\4 Temp Wood Sign Supports\Drafting\490025-4 Drawing

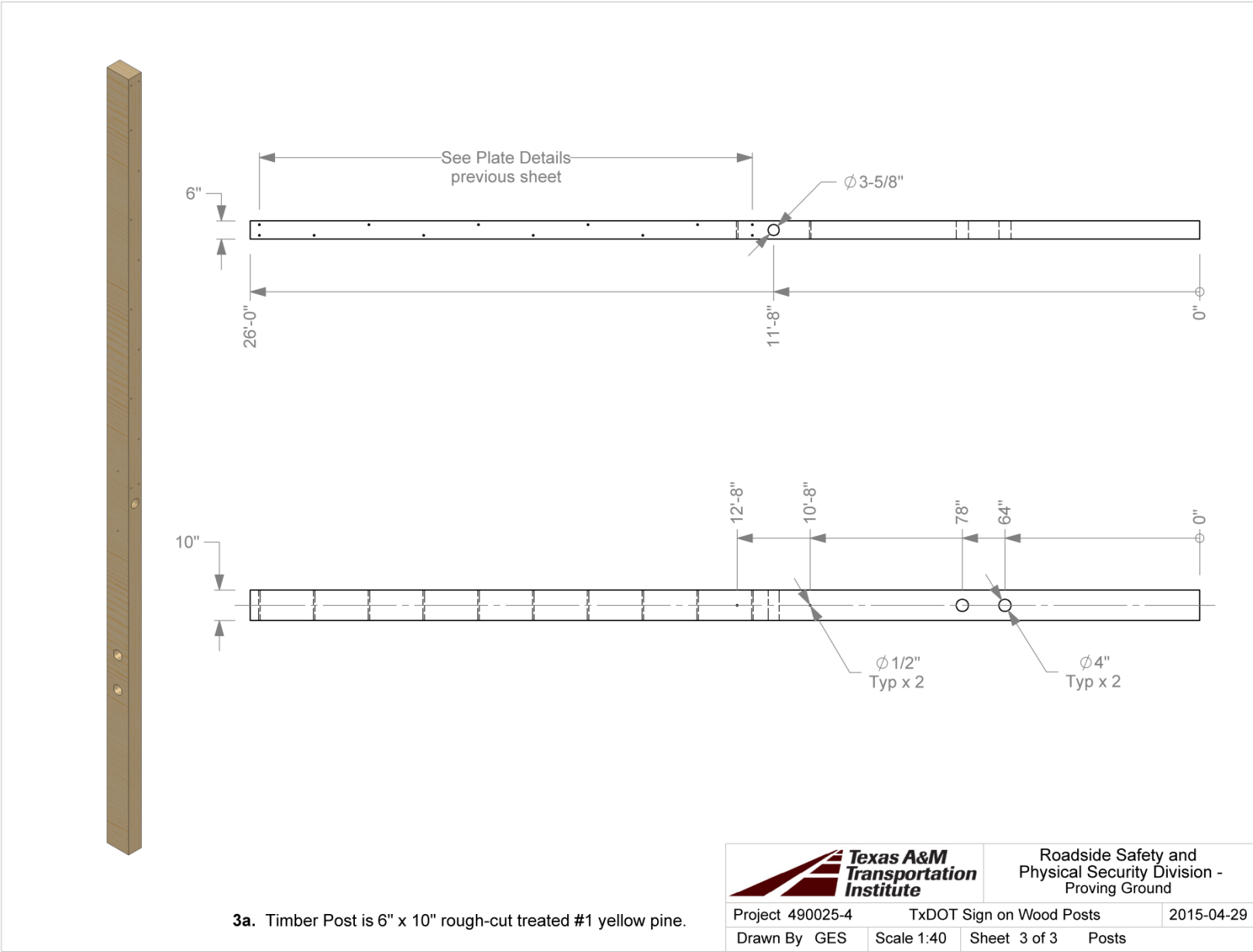
APPENDIX A. DETAILS OF THE TEST ARTICLE

Post Assembly



		Roadside Safety and Physical Security Division - Proving Ground	
Project 490025-4	TxDOT Sign on Wood Posts	2015-04-29	
Drawn By GES	Scale 1:50	Sheet 2 of 3	Post Assembly

T:\2014-2015\490025 - TxDOT\4 Temp Wood Sign Supports\Drafting\490025-4 Drawing



APPENDIX B. CERTIFICATION DOCUMENTATION

MATERIAL USED

TEST NUMBER 490025-4
TEST NAME Temporary Wood Sign Supports
DATE 2015-06-26

#	DATE RECEIVED	DESCRIPTION	GRADE	YIELD	TENSILE	SUPPLIER
14-059	2015-05-04	Plate, 1/4 x 8 x 20'	A529 grade 55	69,400 / 68,600	84,000 / 83,700	Mack Bolt & Steel
14-060	2015-05-04	all-thread, 3/8 x 12		no paperwork		Mack Bolt & Steel
14-061	2015-05-04	3/8 washers and nuts		no paperwork		Mack Bolt & Steel

05-01-2015 03:00
Mack Bolt & Steel
Cust. PO - 29060

Load - 2254541

BL - 3770134

Heat - JW15100421

14-059

BLR466

Order-Line - 12355408 / 1

Nucor Steel 4/7/2015 9:48:34 AM PAGE 2/008 Fax Server

NUCOR
NUCOR CORPORATION
NUCOR STEEL TEXAS

Mill Certification
4/7/2015

MTR #: 0000092343
8812 Hwy 79 W
Jewett, TX 75846
(903) 626-4481
Fax: (903) 626-6290

Sold To: KLOECKNER METALS CORP
500 COLONIAL CENTER PARKWAY
SUITE 500
ROSWELL, GA 30076-0000
(678) 259-8917
Fax: (678) 259-8894

Ship To: KLOECKNER METALS
2560 SOUTH LOOP 4
BUDA, TX 78810
(512) 472-5533

Customer P.O.	6914092	Sales Order	217107.31
Product Group	Merchant Bar Quality	Part Number	532508002405300
Grade	ASTM A529/A529M-05 GR 55	Lot #	JW1510042151
Size	1/4x8" Flat	Heat #	JW15100421
Product	1/4x8" Flat 20' A529 Gr55	B.L. Number	J1-701760
Description	A529 Gr55	Load Number	J1-305306
Customer Spec		Customer Part #	MB148WFLTM5290240

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.

Roll Date: 1/23/2015 Melt Date: 1/16/2015 Qty Shipped LBS: 9,800 Qty Shipped Pcs: 72

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	CEA529
0.14%	1.03%	0.011%	0.030%	0.20%	0.31%	0.15%	0.14%	0.055%	0.0042%	0.033%	0.42%
CBV	MN/C										
0.040%	07.36%										

CEA529: A529 CARBON EQUIVALENT
CBV: CB+V
MNC: MN/C

Yield 1: 69,400psi Tensile 1: 84,000psi Elongation: 20% in 8"(% in 203.3mm)
Yield 2: 68,600psi Tensile 2: 83,700psi Elongation 24% in 8"(% in 203.3mm)

Specification Comments: COMPLIES WITH DIN 50049 PARA 3.1B & EN 10204-3.1

Comments: E-mail: websales@nstexas.com

- All manufacturing processes of the steel, including melting, have been performed in the U.S.A.
- Mercury in any form has not been used in the production or testing of this product.
- Welding or weld repair was not performed on this material.
- This material conforms to the specifications described on this document and may not be reproduced, except in full, without written approval of Nucor Corporation.
- Results reported for ASTM E45 (inclusion content) and ASTM E381 (Macro-etch) are provided as interpretation of ASTM procedures.

Bhargava R Vantari

Bhargava R Vantari
Division Metallurgist

APPENDIX C. MASH TEST 3-60 (CRASH TEST 490025-4-1)

C.1 TEST VEHICLE INFORMATION

Table C.1. Vehicle Properties for Test No. 490025-4-1.

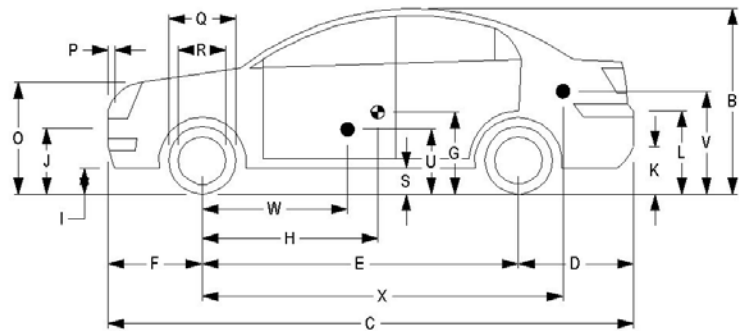
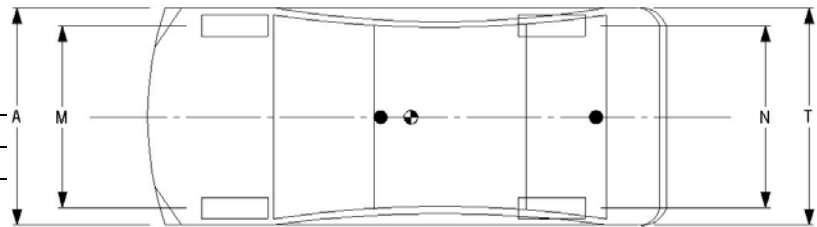
Date: 2015-06-19 Test No.: 490025-4-1 VIN No.: KNADE223X96553428
 Year: 2009 Make: Kia Model: Rio
 Tire Inflation Pressure: 32 psi Odometer: 103094 Tire Size: 185/65R14
 Describe any damage to the vehicle prior to test: NA

• Denotes accelerometer location.

NOTES: NA

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

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



Geometry: inches

A	<u>66.38</u>	F	<u>33.00</u>	K	<u>12.75</u>	P	<u>4.12</u>	U	<u>14.50</u>
B	<u>58.25</u>	G	<u>-----</u>	L	<u>25.00</u>	Q	<u>22.19</u>	V	<u>21.50</u>
C	<u>165.75</u>	H	<u>35.92</u>	M	<u>57.75</u>	R	<u>15.38</u>	W	<u>44.00</u>
D	<u>34.00</u>	I	<u>9.50</u>	N	<u>57.12</u>	S	<u>9.00</u>	X	<u>109.00</u>
E	<u>98.75</u>	J	<u>21.50</u>	O	<u>31.50</u>	T	<u>66.12</u>		
Wheel Center Ht Front		<u>11.00</u>		Wheel Center Ht Rear		<u>11.00</u>			

RANGE LIMIT: A = 65 ±3 inches; C = 168 ±8 inches; E = 98 ±5 inches; F = 35 ±4 inches; G = 39 ±4 inches;
 O = 24 ±4 inches; M+N/2 = 56 ±2 inches

GVWR Ratings:

	Mass: lb	Curb	Test Inertial	Gross Static
Front	<u>1918</u>	<u>1576</u>	<u>1548</u>	<u>1635</u>
Back	<u>1874</u>	<u>878</u>	<u>886</u>	<u>964</u>
Total	<u>3638</u>	<u>2454</u>	<u>2434</u>	<u>2599</u>

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

Mass Distribution:

lb LF: 773 RF: 775 LR: 427 RR: 459

Table C.2. Exterior Crush Measurements for Test No. 490025-4-1.

Date: 2015-06-19 Test No.: 490025-4-1 VIN No.: KNADE223X96553428
 Year: 2009 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET¹

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 C₁ to C₆ from Driver to Passenger Side in Front or Rear impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	----	2.0	----	----	----	----	----	----	----	----
	Measurements recorded										
	in inches										

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

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

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

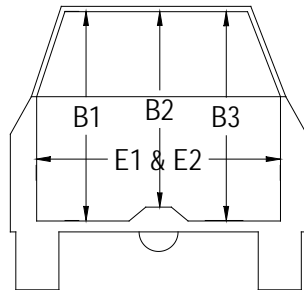
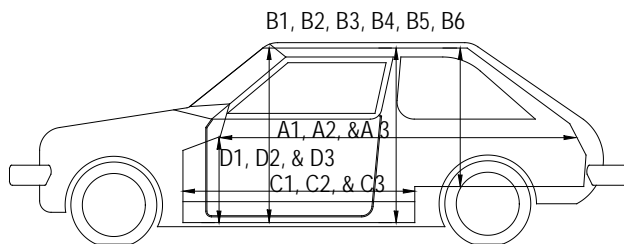
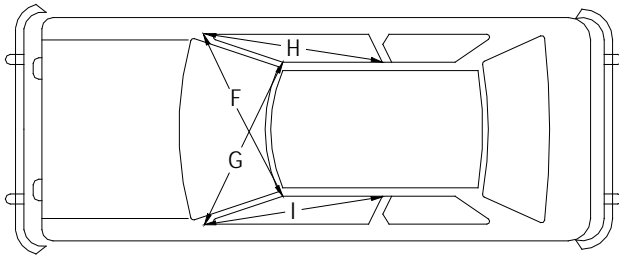
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Table C.3. Occupant Compartment Measurements for Test No. 490025-4-1.

Date: 2015-06-19 Test No.: 490025-4-1 VIN No.: KNADE223X96553428
 Year: 2009 Make: Kia Model: Rio



OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	69.25	69.25
A2	68.25	68.25
A3	69.25	69.25
B1	40.50	40.50
B2	36.00	36.00
B3	40.50	40.50
B4	36.25	36.25
B5	36.00	34.00
B6	36.25	33.75
C1	27.50	27.50
C2	-----	-----
C3	26.50	26.50
D1	9.50	9.50
D2	-----	-----
D3	9.50	9.50
E1	51.50	51.50
E2	51.00	51.00
F	51.00	51.00
G	51.00	51.00
H	37.00	37.00
I	37.00	37.00
J*	51.00	51.00

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

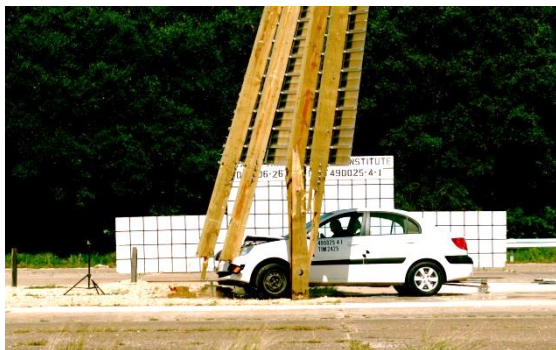
C.2 SEQUENTIAL PHOTOGRAPHS



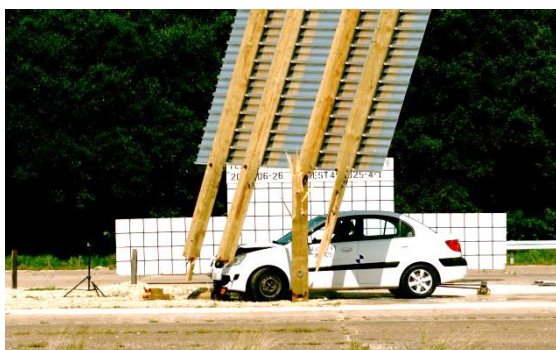
0.000 s



0.240 s



0.480 s



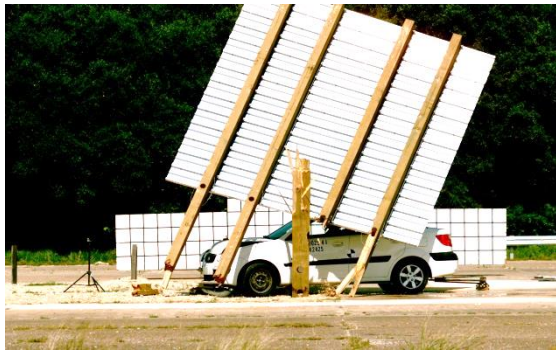
0.720 s



Figure C.1. Sequential Photographs for Test No. 490025-4-1 (Perpendicular and Frontal Views).



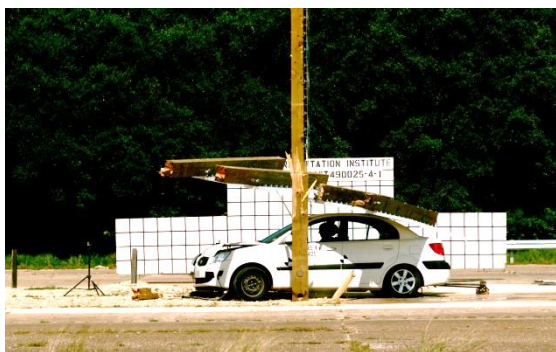
0.960s



1.200 s



1.440 s

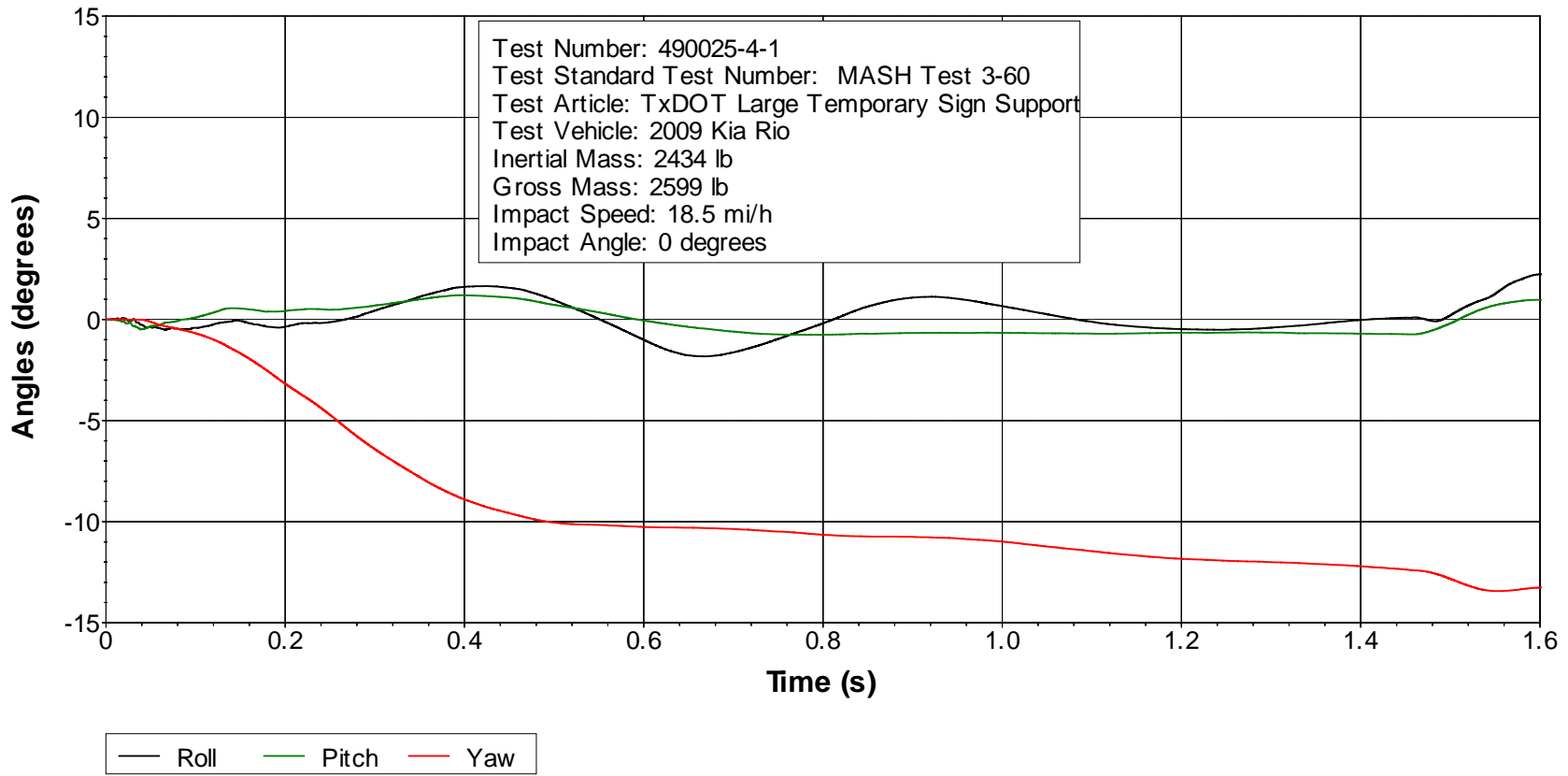


1.680 s



Figure C.1. Sequential Photographs for Test No. 490025-4-1 (Perpendicular and Frontal Views) (continued).

Roll, Pitch, and Yaw Angles



Axes are vehicle-fixed.
 Sequence for determining orientation:

1. Yaw.
2. Pitch.
3. Roll.

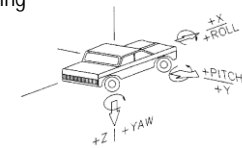


Figure C.2. Vehicle Angular Displacements for Test No. 490025-4-1.

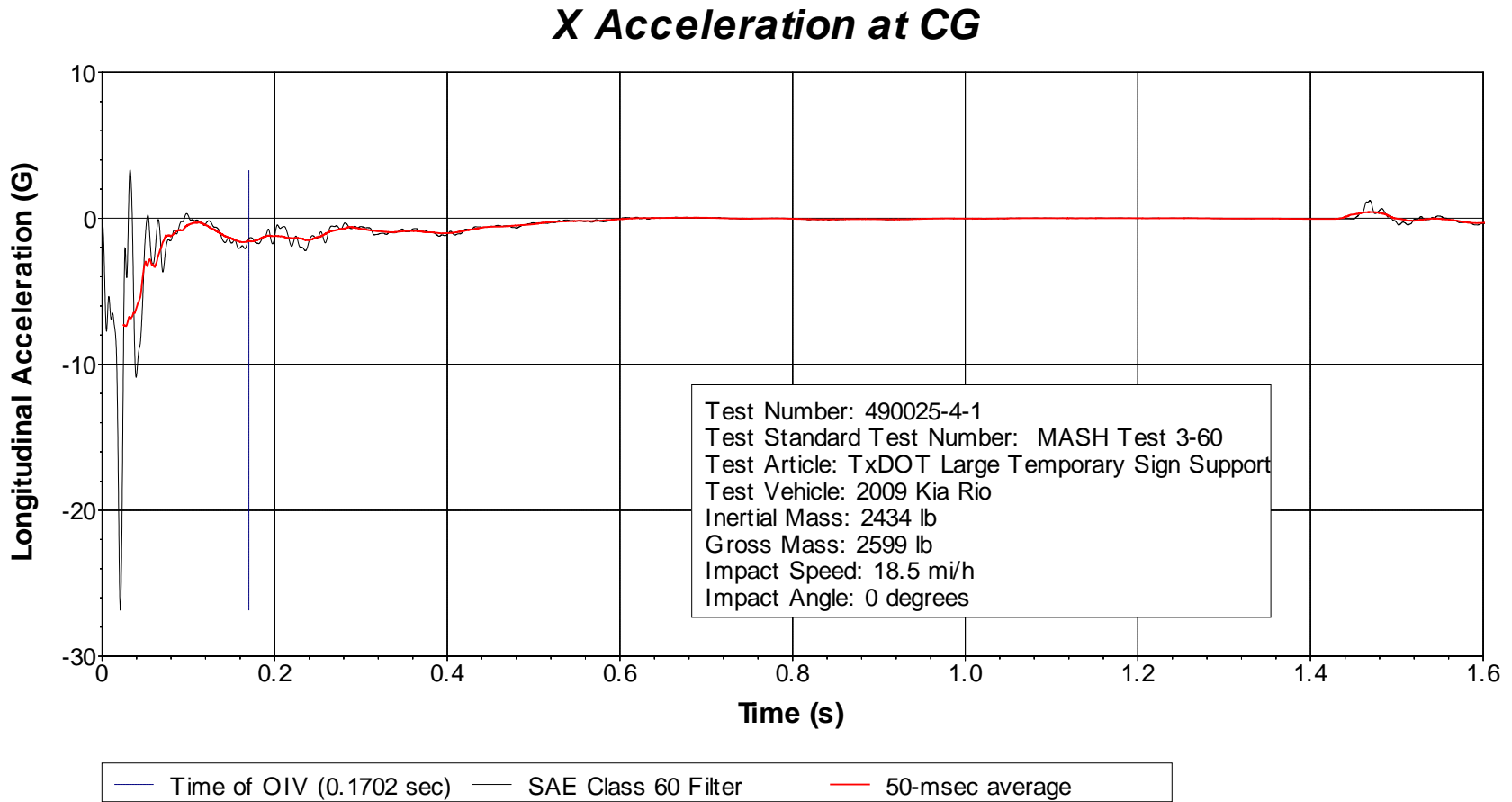


Figure C.3. Vehicle Longitudinal Accelerometer Trace for Test No. 490025-4-1 (Accelerometer Located at Center of Gravity).

Y Acceleration at CG

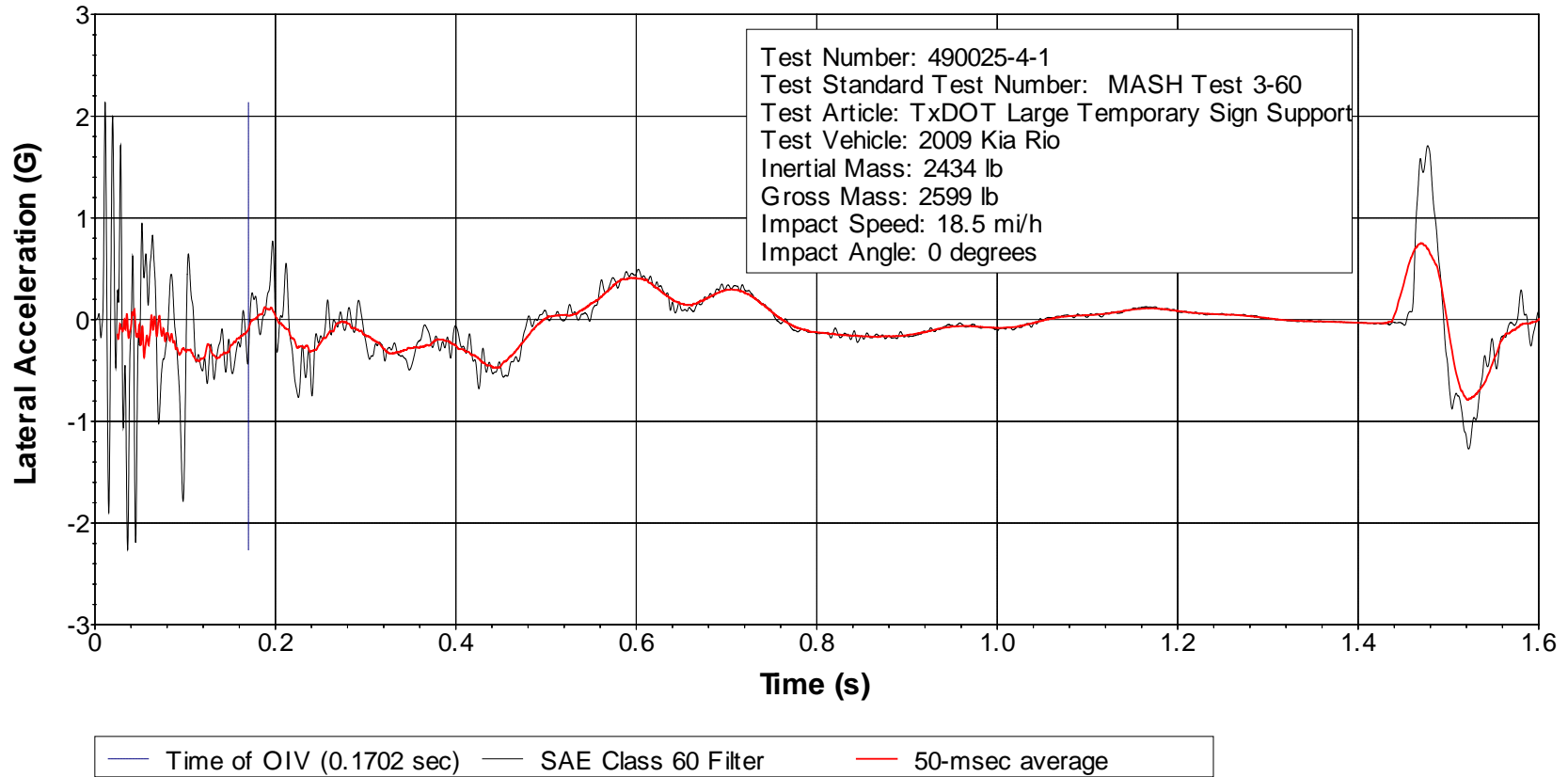


Figure C.4. Vehicle Lateral Accelerometer Trace for Test No. 490025-4-1 (Accelerometer Located at Center of Gravity).

Z Acceleration at CG

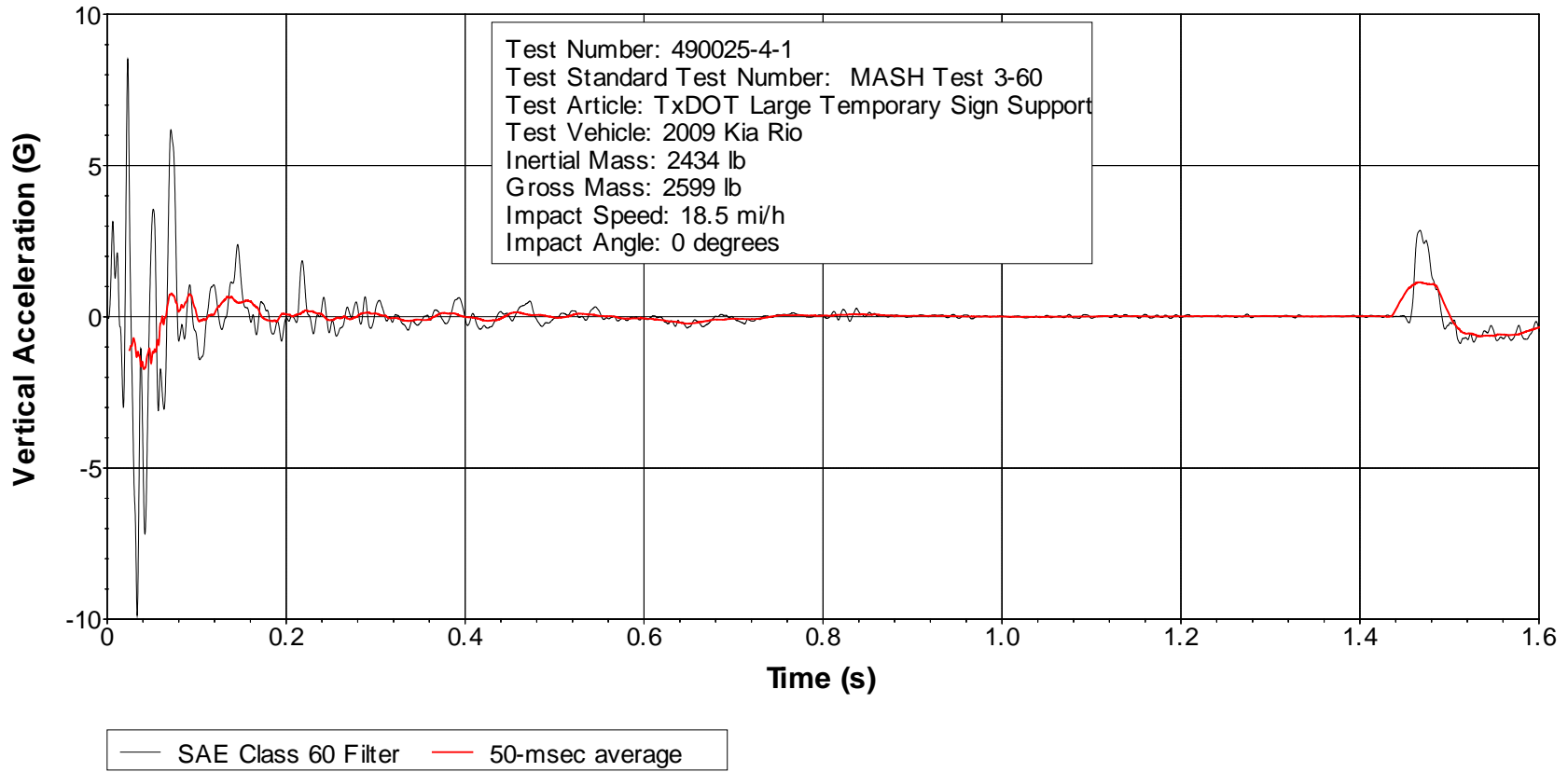
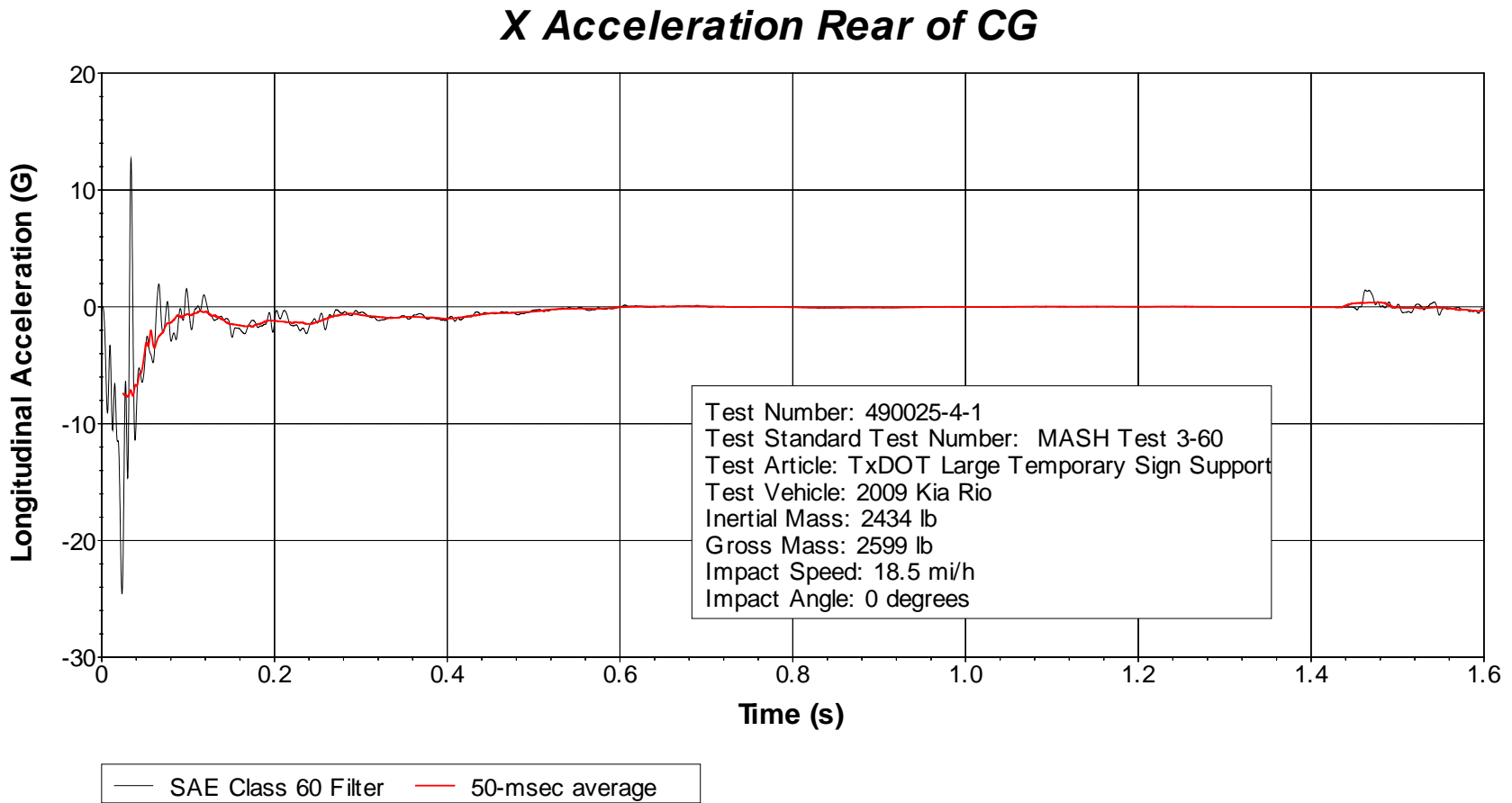


Figure C.5. Vehicle Vertical Accelerometer Trace for Test No. 490025-4-1 (Accelerometer Located at Center of Gravity).



**Figure C.6. Vehicle Longitudinal Accelerometer Trace for Test No. 490025-4-1
(Accelerometer Located Rear of Center of Gravity).**

Y Acceleration Rear of CG

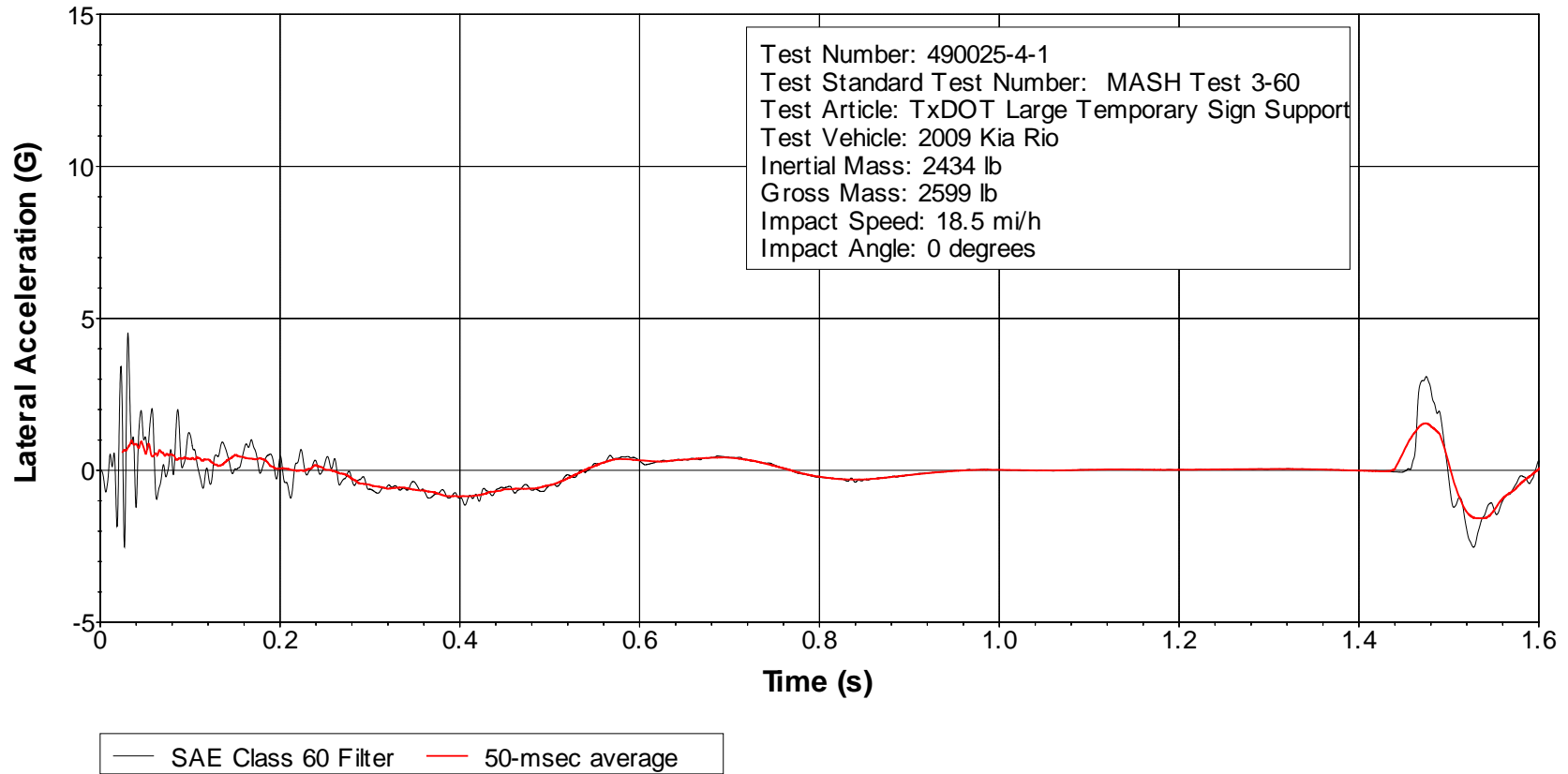
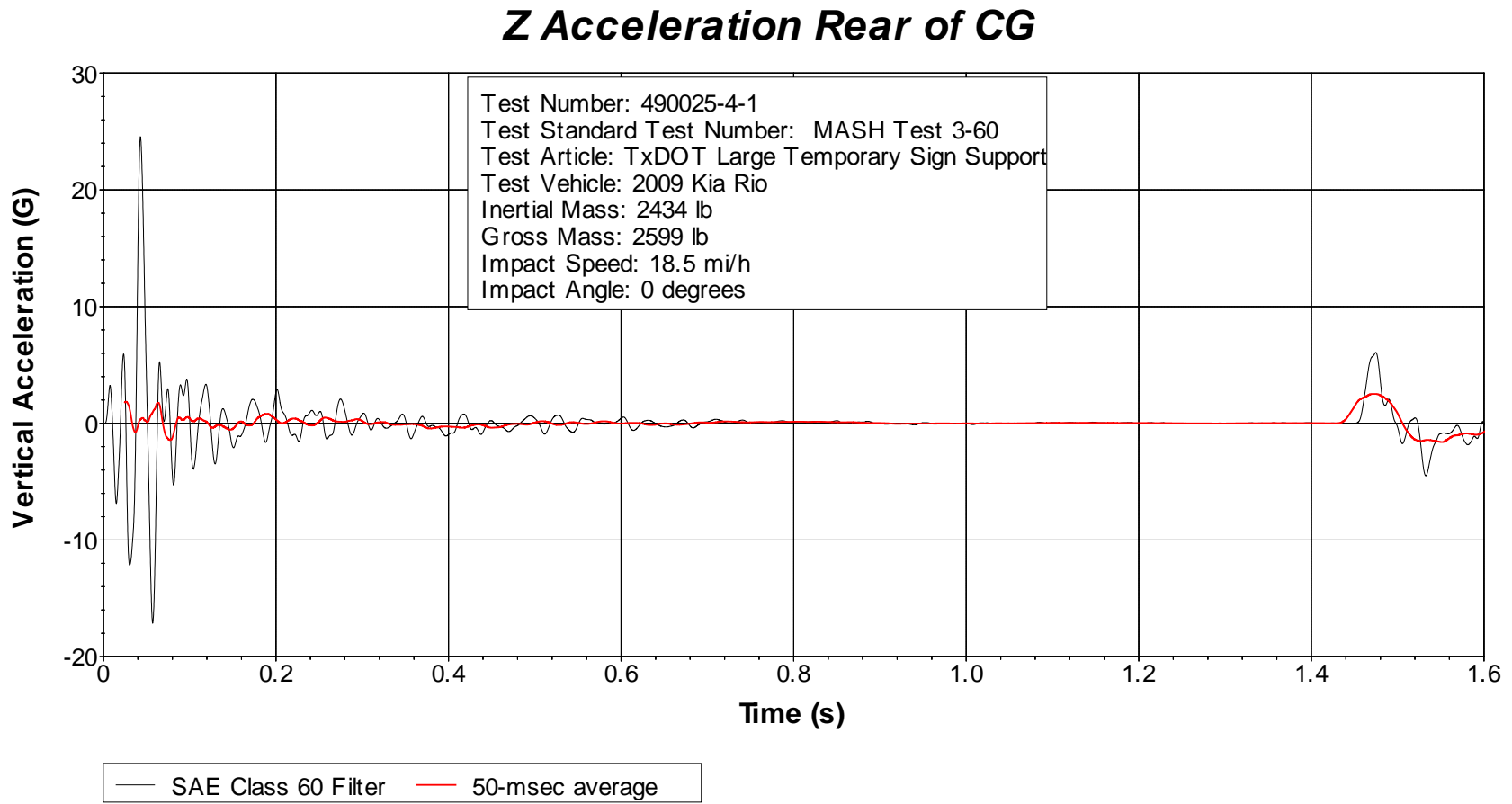


Figure C.7. Vehicle Lateral Accelerometer Trace for Test No. 490025-4-1 (Accelerometer Located Rear of Center of Gravity).



**Figure C.8. Vehicle Vertical Accelerometer Trace for Test No. 490025-4-1
 (Accelerometer Located Rear of Center of Gravity).**

APPENDIX D. MASH TEST 3-61 (CRASH TEST 490025-4-2)

D.1 TEST VEHICLE INFORMATION

Table D.1. Vehicle Properties for Test No. 490025-4-2.

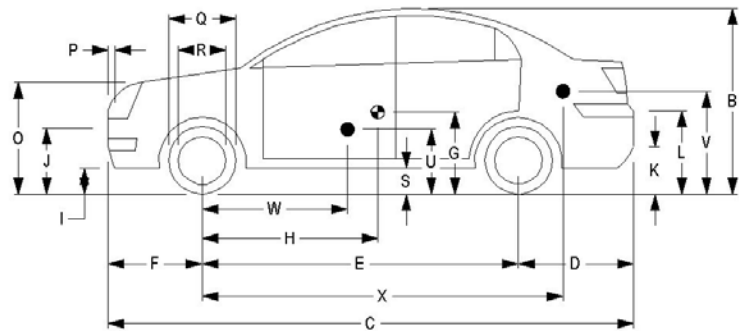
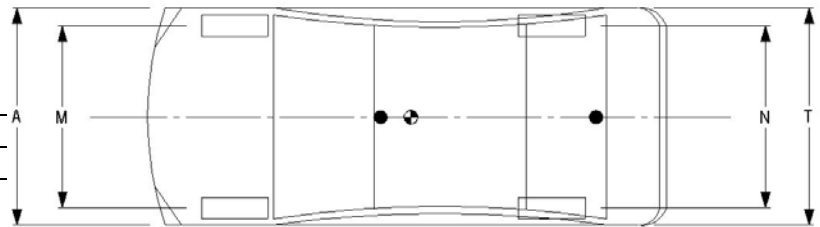
Date: 2015-06-19 Test No.: 490025-4-2 VIN No.: KNADE223196476999
 Year: 2009 Make: Kia Model: Rio
 Tire Inflation Pressure: 32 psi Odometer: 114116 Tire Size: 185/65R14
 Describe any damage to the vehicle prior to test: NA

• Denotes accelerometer location.

NOTES: NA

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

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



Geometry: inches

A	<u>66.38</u>	F	<u>33.00</u>	K	<u>12.75</u>	P	<u>4.12</u>	U	<u>14.50</u>
B	<u>58.25</u>	G	<u>-----</u>	L	<u>25.00</u>	Q	<u>22.19</u>	V	<u>21.50</u>
C	<u>165.75</u>	H	<u>35.96</u>	M	<u>57.75</u>	R	<u>15.38</u>	W	<u>44.00</u>
D	<u>34.00</u>	I	<u>9.50</u>	N	<u>57.12</u>	S	<u>9.00</u>	X	<u>109.00</u>
E	<u>98.75</u>	J	<u>21.50</u>	O	<u>31.50</u>	T	<u>66.12</u>		
Wheel Center Ht Front		<u>11.00</u>	Wheel Center Ht Rear		<u>11.00</u>				

RANGE LIMIT: A = 65 ±3 inches; C = 168 ±8 inches; E = 98 ±5 inches; F = 35 ±4 inches; G = 39 ±4 inches;
 O = 24 ±4 inches; M+N/2 = 56 ±2 inches

GVWR Ratings:	Mass: lb	Curb	Test Inertial	Gross Static
Front	<u>1918</u>	<u>M_{front}</u>	<u>1567</u>	<u>1634</u>
Back	<u>1874</u>	<u>M_{rear}</u>	<u>886</u>	<u>964</u>
Total	<u>3638</u>	<u>M_{Total}</u>	<u>2433</u>	<u>2598</u>

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

Mass Distribution:

lb LF: 773 RF: 774 LR: 433 RR: 453

Table D.2. Exterior Crush Measurements for Test No. 490025-4-2.

Date: 2015-06-19 Test No.: 490025-4-2 VIN No.: KNADE223196476999
 Year: 2009 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET¹

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)	$\frac{X1 + X2}{2} = \underline{\hspace{2cm}}$
< 4 inches _____	
≥ 4 inches _____	

Note: Measure C₁ to C₆ from Driver to Passenger Side in Front or Rear impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	±D
		Width** (CDC)	Max*** Crush								
1	Front plane at bumper ht	----	3.25	----	----	----	----	----	----	----	----
	Measurements recorded										
	in inches										

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

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

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

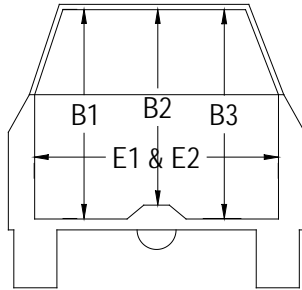
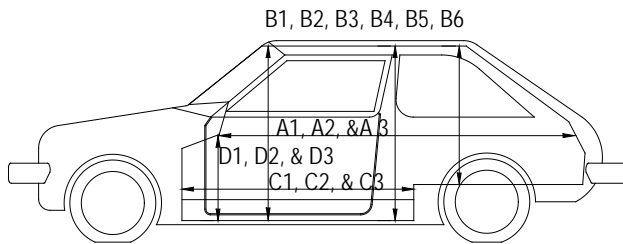
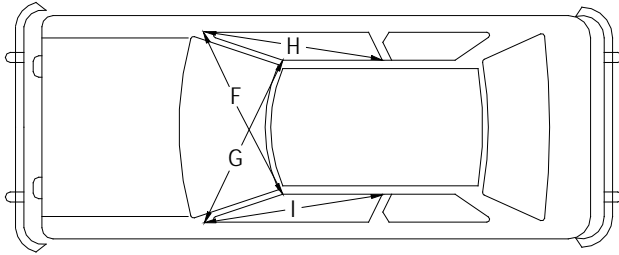
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

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

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

Table D.3. Occupant Compartment Measurements for Test No. 490025-4-2.

Date: 2015-06-19 Test No.: 490025-4-2 VIN No.: KNADE223196476999
 Year: 2009 Make: Kia Model: Rio



OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	After (inches)
A1	69.25	69.25
A2	68.25	68.25
A3	69.25	69.25
B1	40.50	40.50
B2	36.00	36.00
B3	40.50	40.50
B4	36.25	36.25
B5	36.00	36.00
B6	36.25	36.25
C1	27.50	27.50
C2	-----	-----
C3	26.50	26.50
D1	9.50	9.50
D2	-----	-----
D3	9.50	9.50
E1	51.50	51.50
E2	51.00	51.00
F	51.00	51.00
G	51.00	51.00
H	37.00	37.00
I	37.00	37.00
J*	51.00	51.00

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

D.2 SEQUENTIAL PHOTOGRAPHS



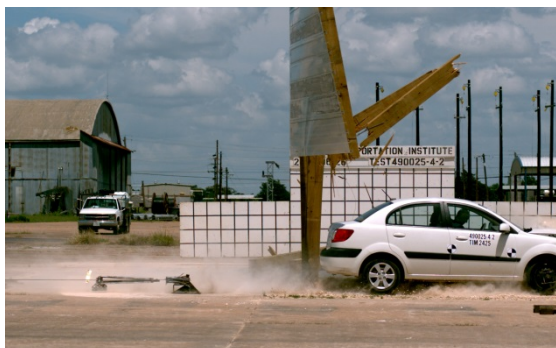
0.000 s



0.060 s



0.120 s



0.180 s



Figure D.1. Sequential Photographs for Test No. 490025-4-2 (Perpendicular and Frontal Views).



0.240s



0.300 s



0.360 s

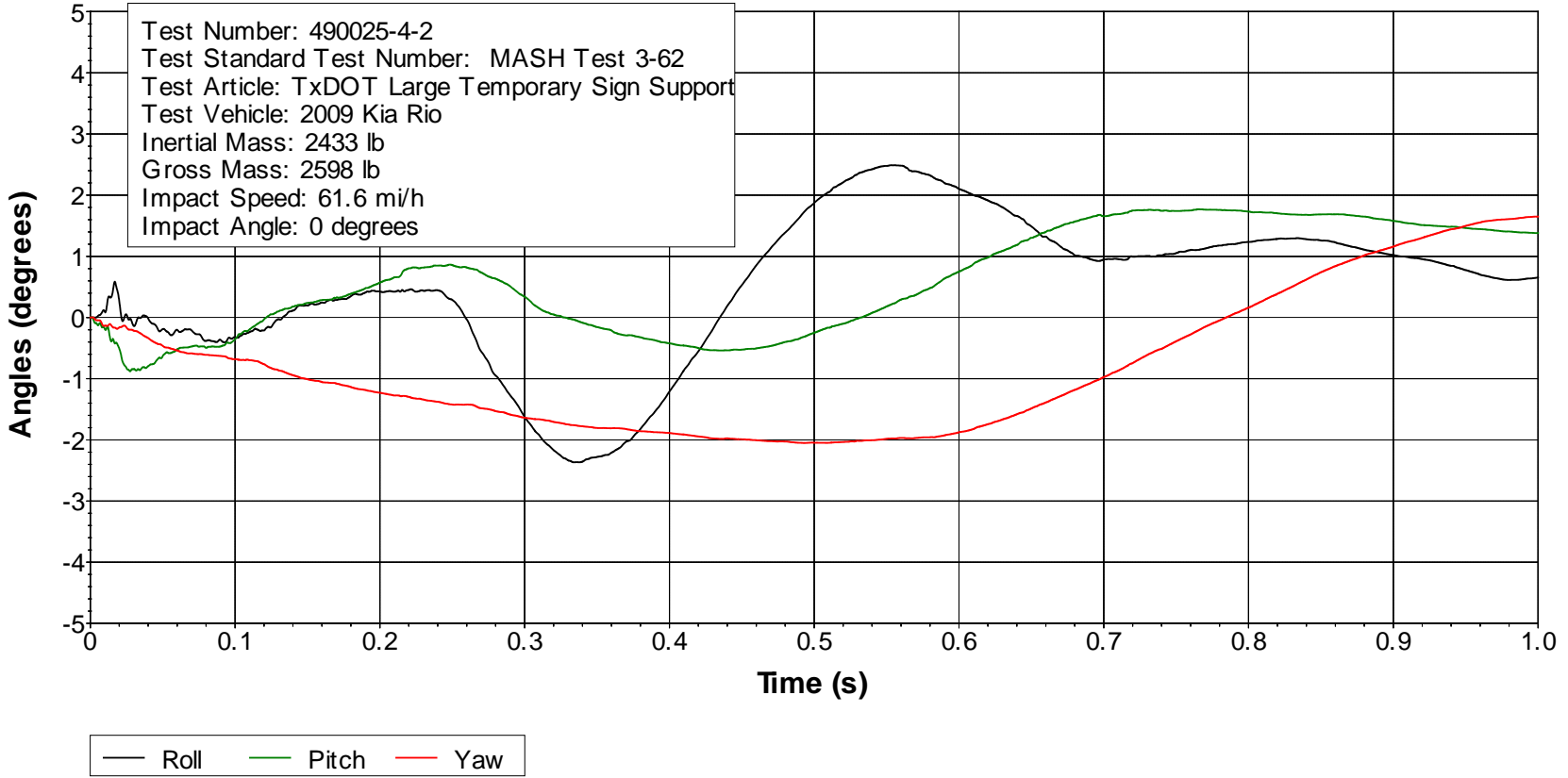


0.420 s



Figure D.1. Sequential Photographs for Test No. 490025-4-2 (Perpendicular and Frontal Views) (continued).

Roll, Pitch, and Yaw Angles



Axes are vehicle-fixed.
 Sequence for determining orientation:

1. Yaw.
2. Pitch.
3. Roll.

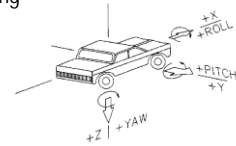
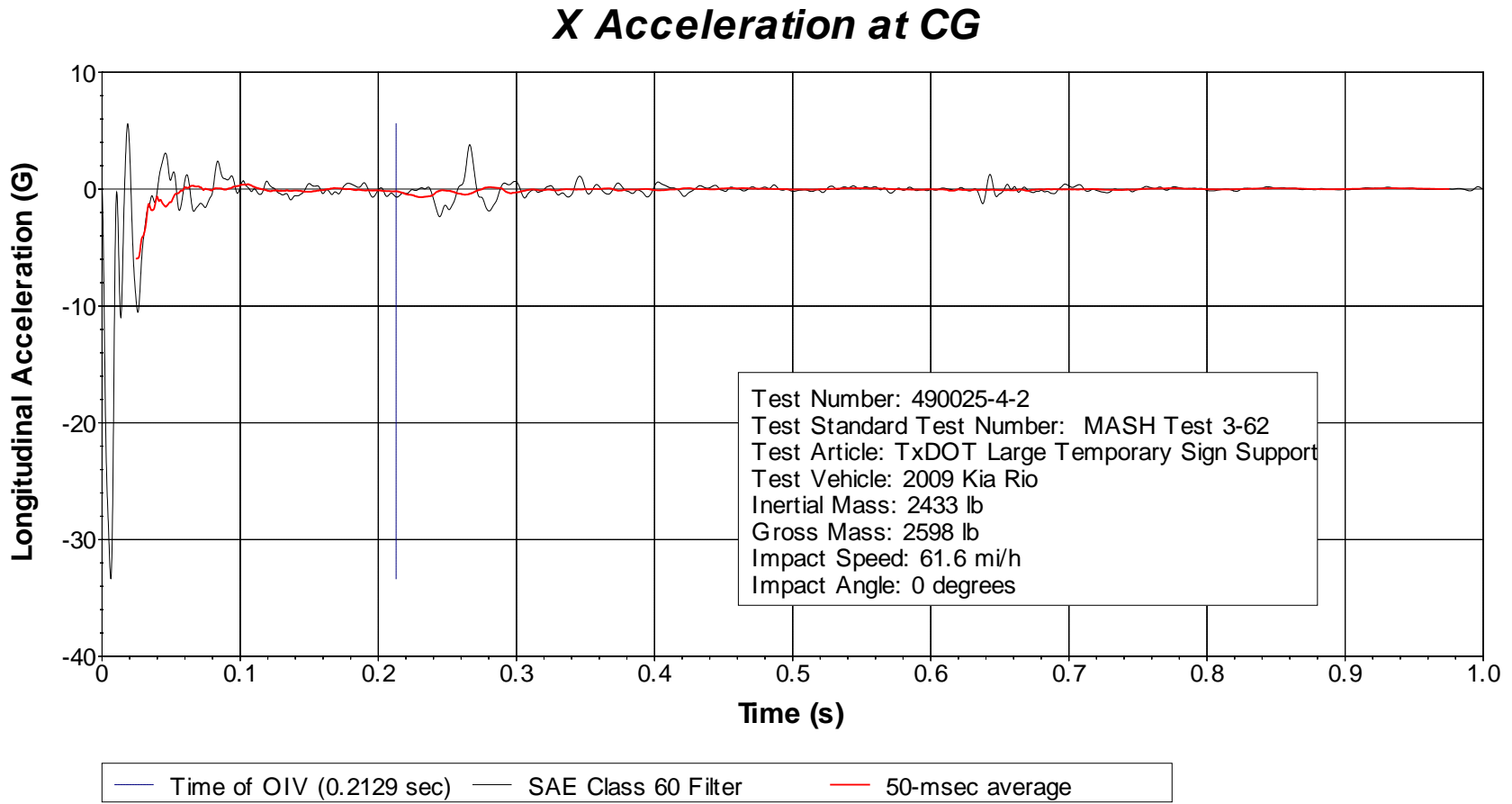


Figure D.2. Vehicle Angular Displacements for Test No. 490025-4-2.



**Figure D.3. Vehicle Longitudinal Accelerometer Trace for Test No. 490025-4-2
 (Accelerometer Located at Center of Gravity).**

Y Acceleration at CG

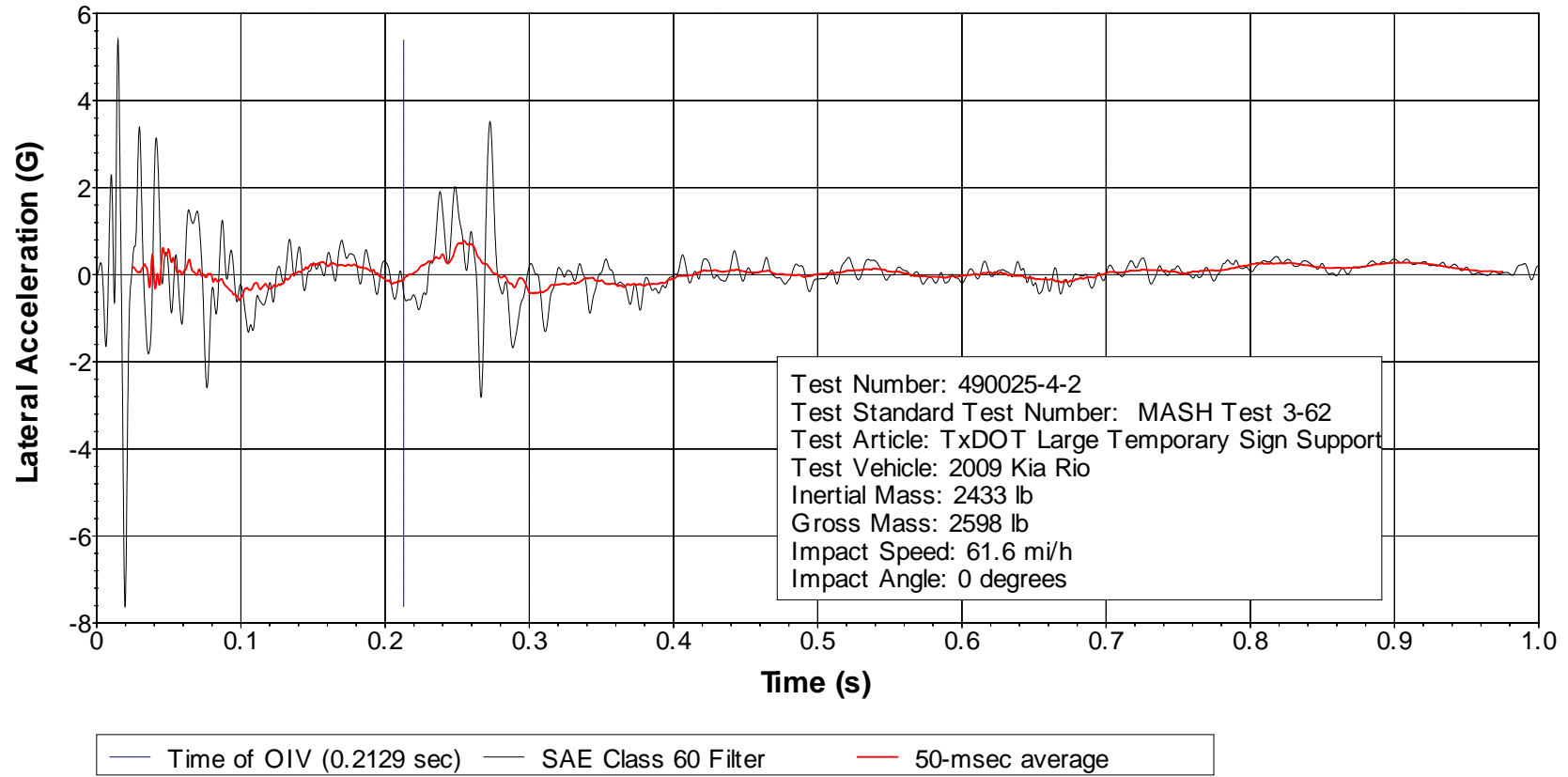
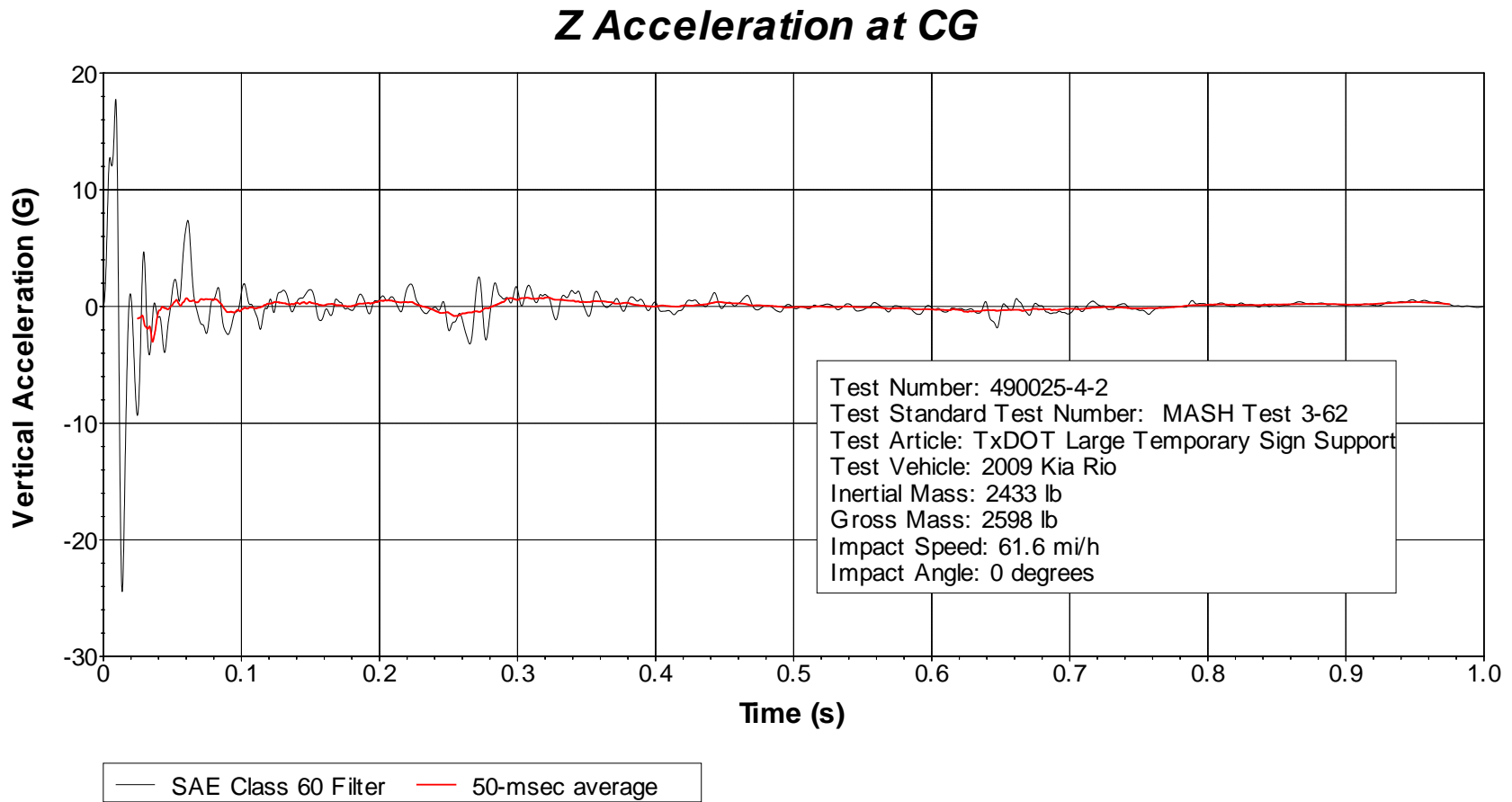
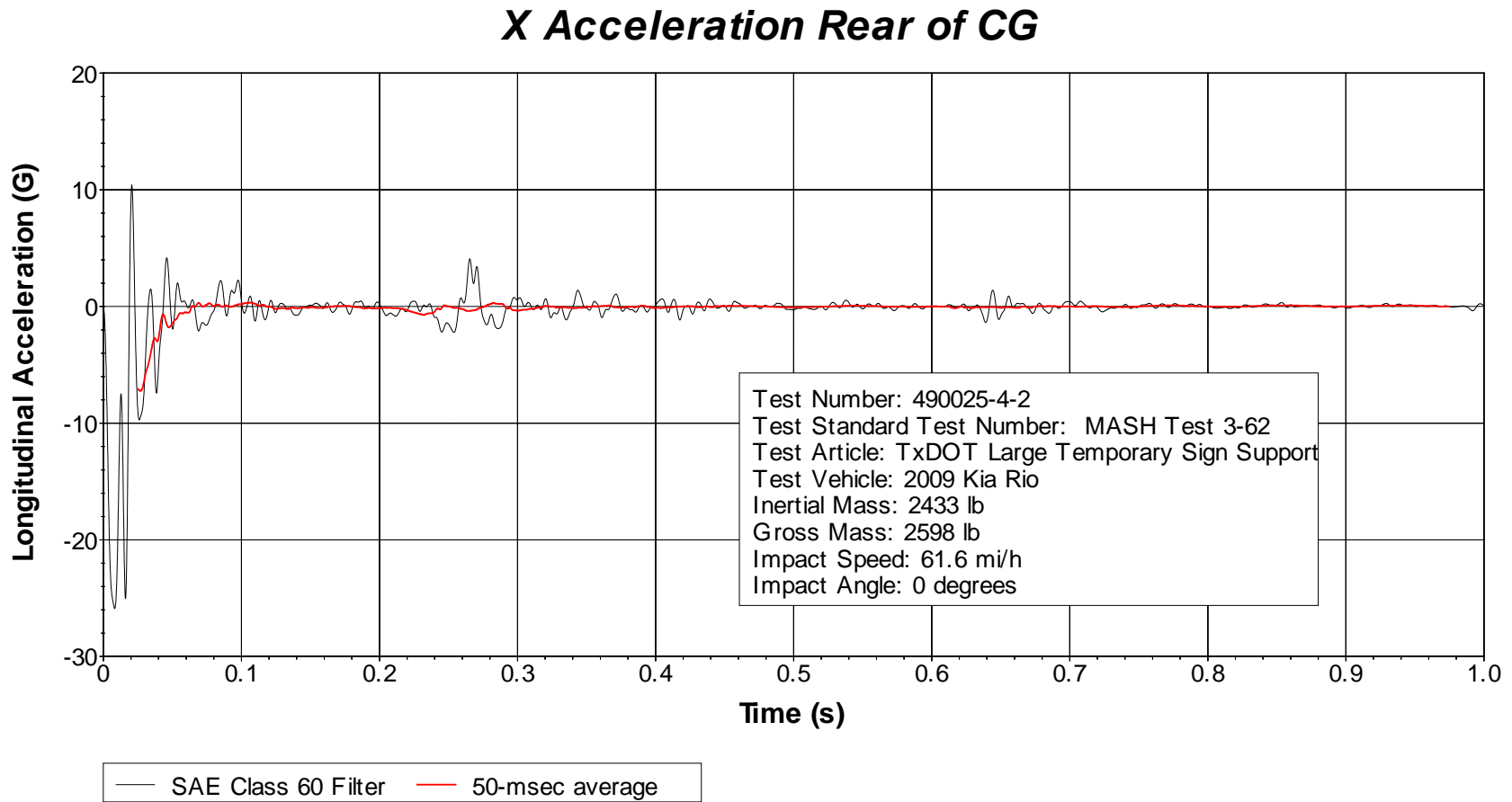


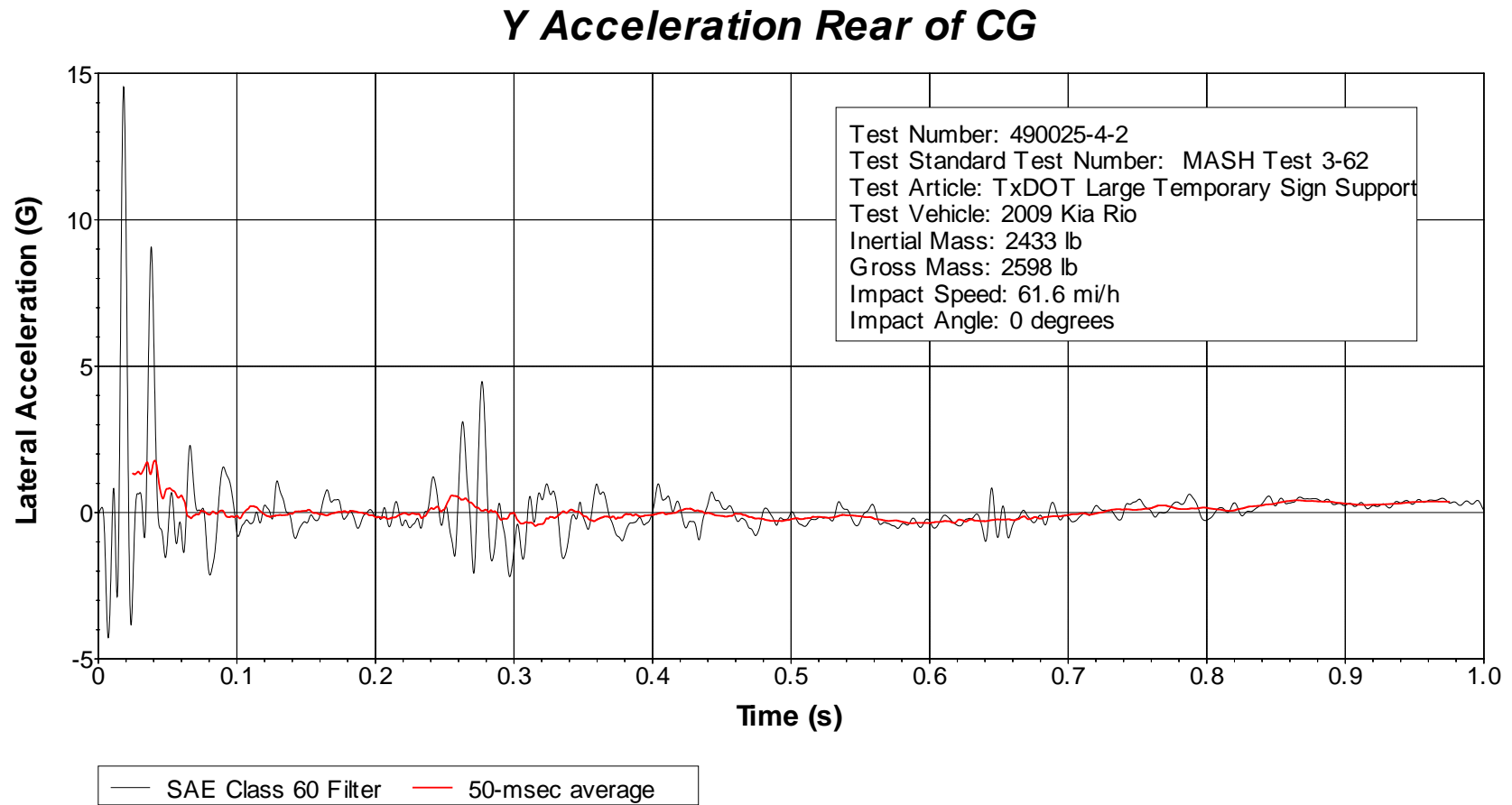
Figure D.4. Vehicle Lateral Accelerometer Trace for Test No. 490025-4-2 (Accelerometer Located at Center of Gravity).



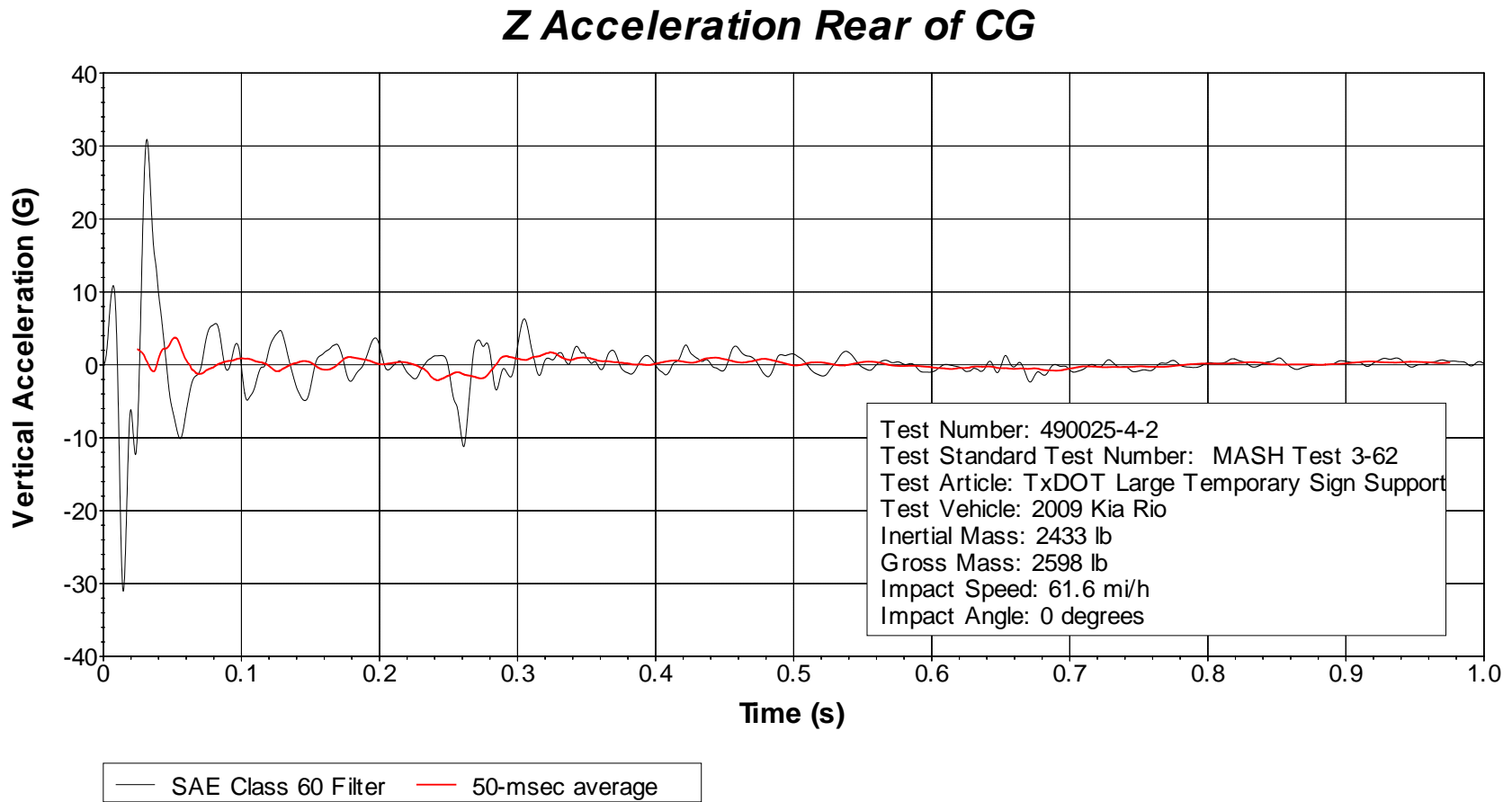
**Figure D.5. Vehicle Vertical Accelerometer Trace for Test No. 490025-4-2
(Accelerometer Located at Center of Gravity).**



**Figure D.6. Vehicle Longitudinal Accelerometer Trace for Test No. 490025-4-2
(Accelerometer Located Rear of Center of Gravity).**



**Figure D.7. Vehicle Lateral Accelerometer Trace for Test No. 490025-4-2
(Accelerometer Located Rear of Center of Gravity).**



**Figure D.8. Vehicle Vertical Accelerometer Trace for Test No. 490025-4-2
(Accelerometer Located Rear of Center of Gravity).**