TTI: 9-1002-12

MASH Full-Scale Crash Testing of 4-ft Mounting Height, 24"×30" Chevron Sign Installed on 5.5H:1V Slope Ditch

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

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

Test Report No. 9-1002-12-6

Cooperative Research Program

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

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
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16. Abstract

Current TxDOT practice allows installation of all existing chevron sizes on 7-ft mounting height, but restricts the use of 4-ft mounting height for the three smallest existing chevron signs—that is, 12 inches × 18 inches, 18 inches × 24 inches, and 24 inches × 30 inches. A common TxDOT practice is to install chevron sign systems in roadside ditches. For this type of installation, the specified sign mounting height is measured from the pavement surface. When 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 the same mounting height evaluated for the same sign installed on flat level ground. Previous crash testing was performed with the chevron installed on flat, level ground. Since it is common practice for TxDOT to install chevron signs in ditches at a 4-ft mounting height and a lateral offset between 2 and 8 ft from the pavement surface, the actual ground mounting height varies. TxDOT research project 0-6363 suggested the crashworthiness of this configuration be evaluated.

The scope of this study was to evaluate the impact performance of a 24-inch × 30-inch chevron sign at a 4-ft mounting height from the pavement surface, installed at an 8-ft lateral offset in a 5.5H:1V sloped ditch. The chevron sign support performed acceptably for *MASH* Test 3-61 (1100C vehicle impacting at 62 mi/h and 10 degree nominal conditions). Thus, the current TxDOT practice of installing the three smallest chevron signs (12 inches × 18 inches, 18 inches × 24 inches, and 24 inches × 30 inches) at 4-ft mounting height in roadside ditches is acceptable.

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MASH Full-Scale Crash Testing of 4-ft Mounting Height 24"×30" Chevron Sign Installed on 5.5H:1V Slope Ditch

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Performed in cooperation with the
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and the
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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.

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

Crash testing performed at:
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3100 SH 47, Building 7091
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

The Chevron Alignment (W1-8) sign is used to "provide additional emphasis and guidance for a change in horizontal alignment. This sign may also be used as an alternate or supplement to standard delineators on curves or to the One-Direction Large Arrow (W1-6) sign" (*1*). According to the Texas Department of Transportation (TxDOT) standards reported in the "Barricade and Construction Channelizing Devices Standard" BC(9)-07 sheet, the chevron shall be a vertical rectangle with a minimum size of 12 inches × 18 inches (*2*). Five chevron sizes are acceptable for use in Texas (see Table 1.1) and their use is related to the type of road and the road speed (*3*).

Table 1.1. Chevron Alignment Sign Sizes.

Sign Description	Sign Number or Series	Minimum	Low Speed Conventional Road (<55 mph)	High Speed Conventional Road (≥55 mph)	Expressway	Freeway	Oversized
Rectangular	W1 – Arrows	36 x 18	48 x 24	48 x 24	---	---	60 x 30
	W1 – Chevron	12 x 18	18 x 24	24 x 30	30 x 36	36 x 48	---
	W12-3T	66 x 12	84 x 24	84 x 24	84 x 24	84 x 24	96 x 18
	W13-2, 3, 5	24 x 30	24 x 30	36 x 48	36 x 48	48 x 60	---

The current TxDOT "Typical Delineator and Object Marker Placement Details" (D&OM(2)-04) standards require a minimum 4 ft mounting height, evaluated from the pavement surface, for chevron signs installed on a wedge and anchor system (*4*).

Current TxDOT practice allows installation of all existing chevron sizes at a 7-ft mounting height, but restricts the use of 4-ft mounting height to the three smallest chevron signs—that is, 12 inches × 18 inches, 18 inches × 24 inches, and 24 inches × 30 inches.

1.2 OBJECTIVE/SCOPE OF RESEARCH

This study seeks to investigate the crashworthiness of a 24-inch × 30-inch chevron sign mounted at a 4-ft mounting height when installed at an 8 ft offset in a 5.5H:1V slope ditch. The recommendation to perform this type of full-scale crash test emanated from TxDOT research project 0-6363, which reviewed current installation practices associated with chevron signs (*5*). The impact performance of the chevron sign installation was evaluated through a full-scale crash test. The test was performed and evaluated in accordance with the *Manual for Assessing Safety Hardware (MASH)* (*6*). The chevron installation was impacted by a 2420-lb passenger car traveling at a nominal speed of 62 mi/h and entering the ditch at a nominal 10-degree angle. This was representative of *MASH* Test 3-61.

1.3 LITERATURE REVIEW

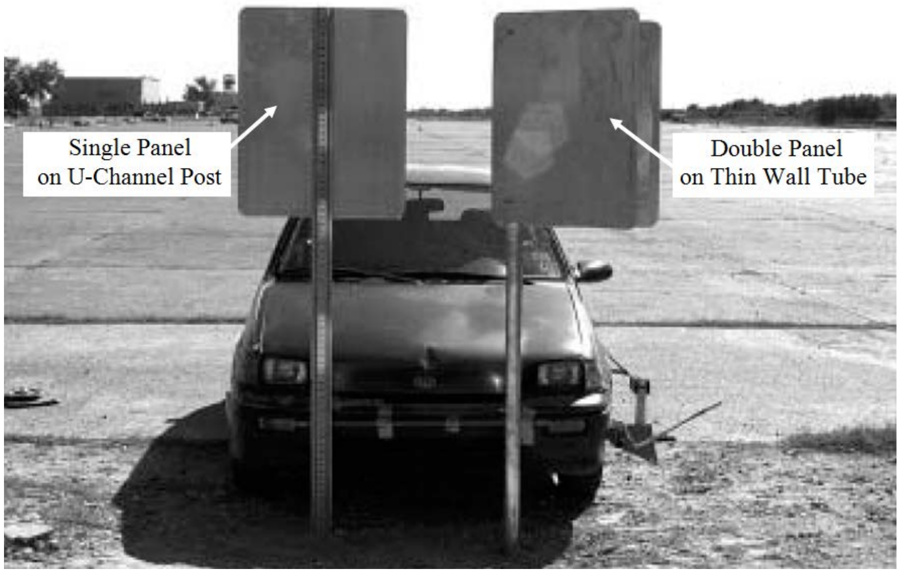
Under TxDOT research project 0-6363, a literature review and engineering analysis was performed to evaluate the crashworthiness of chevron signs in relation to different mounting heights. Researchers used the results of previous crash tests performed at Texas A&M Transportation Institute (TTI) to better understand post-impact behavior of a chevron sign when impacted by a vehicle at high speed.

TxDOT project "Impact Performance Evaluation of Work Zone Traffic Control Devices" included the testing and evaluation of various traffic control devices for use in work zones (*7*). The testing was performed in accordance with National Cooperative Highway Research Program (NCHRP) *Report 350* guidelines (*8*). Under this research project, one test performed was a high-speed passenger car impact two chevron installations with the panels at a 4-ft mounting height on flat, level ground. Figure 1.1[a] shows that the installation had one system that consisted of a single chevron panel through-bolted to a U channel post, and another system with two panels attached to a 13 BWG post using standard sign panel mounting brackets. The U-channel chevron support failed to meet the requirements of *NCHRP Report 350*. The system contacted the windshield and cut the roof just behind the windshield frame, thereby showing potential for penetrating the occupant compartment. The thin wall chevron support performed acceptably according to the guidelines of *NCHRP Report 350*. The post yielded at the bumper impact location and pulled out the socket as designed. There was not secondary impact of the released support with the impacting vehicle (see Figure 1.1[c]). The sign panels slid off the support post and impacted the windshield, but this contact did not result in any deformation or intrusion in the occupant compartment. Because of the successful result from Test no. 417929-3, all chevron sizes up to 24 inches × 30 inches were considered acceptable when mounted at a 4-ft mounting height using a wedge-and-socket system.

In 1995, the New Hampshire Department of Transportation initiated a crash-test program in cooperation with the Vermont Agency of Transportation with the scope of evaluating the safety performance of small sign supports used in their states (*9*). The performance of a 12 ft^2 aluminum sign panel (36-inch × 48-inch), mounted on a 4-inch diameter Schedule 10 support at a 7-ft mounting height on flat, level ground, was evaluated (see Figure 1.2[a]). Test results were evaluated according to *NCHRP Report 350* criteria. Based on the successful results from Test nos. 405231-7 and 405231-9, all chevron sizes up to 36 inches × 48 inches were considered acceptable when mounted at a height of 7 ft.

Table 1.2 summarizes the TxDOT standards for chevron installation based on mounting height and sign size. These research projects highlighted two very distinct support post behaviors during a vehicle impact. In Test No. 417929-3, the post yielded at bumper level, pulled out of the socket, and was carried away by the vehicle. No contact occurred between the post and the vehicle's occupant compartment. However, in both Test nos. 405231-7 and 405231-9, the post had secondary contact with the roof of the passenger car after yielding at bumper level and being pulled out the foundation socket. These two different post-impact behaviors are related to the different mass of the systems and, more importantly, the height or length of the post.

In Test no. 417929-3, which had a mounting height of 4 ft and a sign height of 30 inches, the total height of the support post was 78 inches. Considering a bumper impact location at approximately 22 inches from ground level, the effective post height above the bumper was approximately 56 inches (see Figure 1.3[a]). In Test nos. 405231-7 and 405231-9, the mounting height was 7 ft and the sign height was 48 inches. Figure 1.3(b) shows that the effective post height above the vehicle bumper was approximately 110 inches.



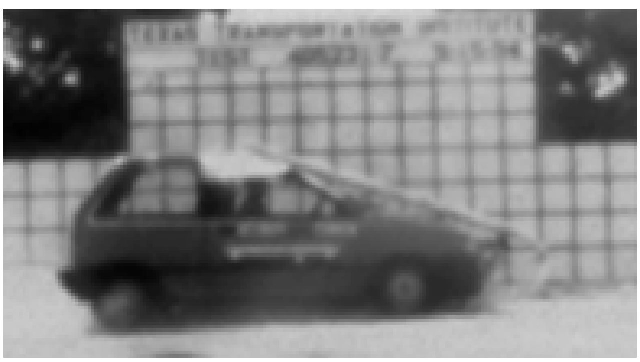
(a) Dual chevron installation

(b) Initial Configuration

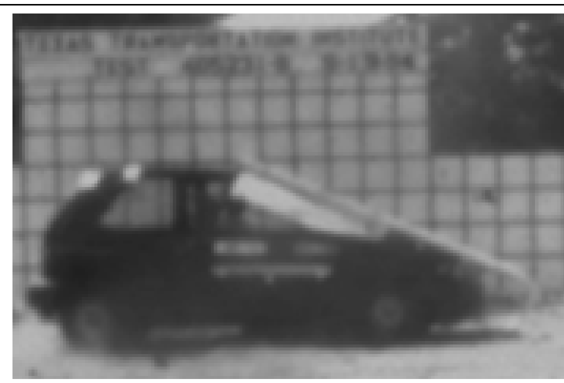
(c) Post-Impact Configuration

Figure 1.1. Dual Chevron Support Test No. 417929-3.

(a) Initial Configuration for Test Nos. 405231-7 and 405231-9



(b) Roof Impact Location Test No. 405231-7

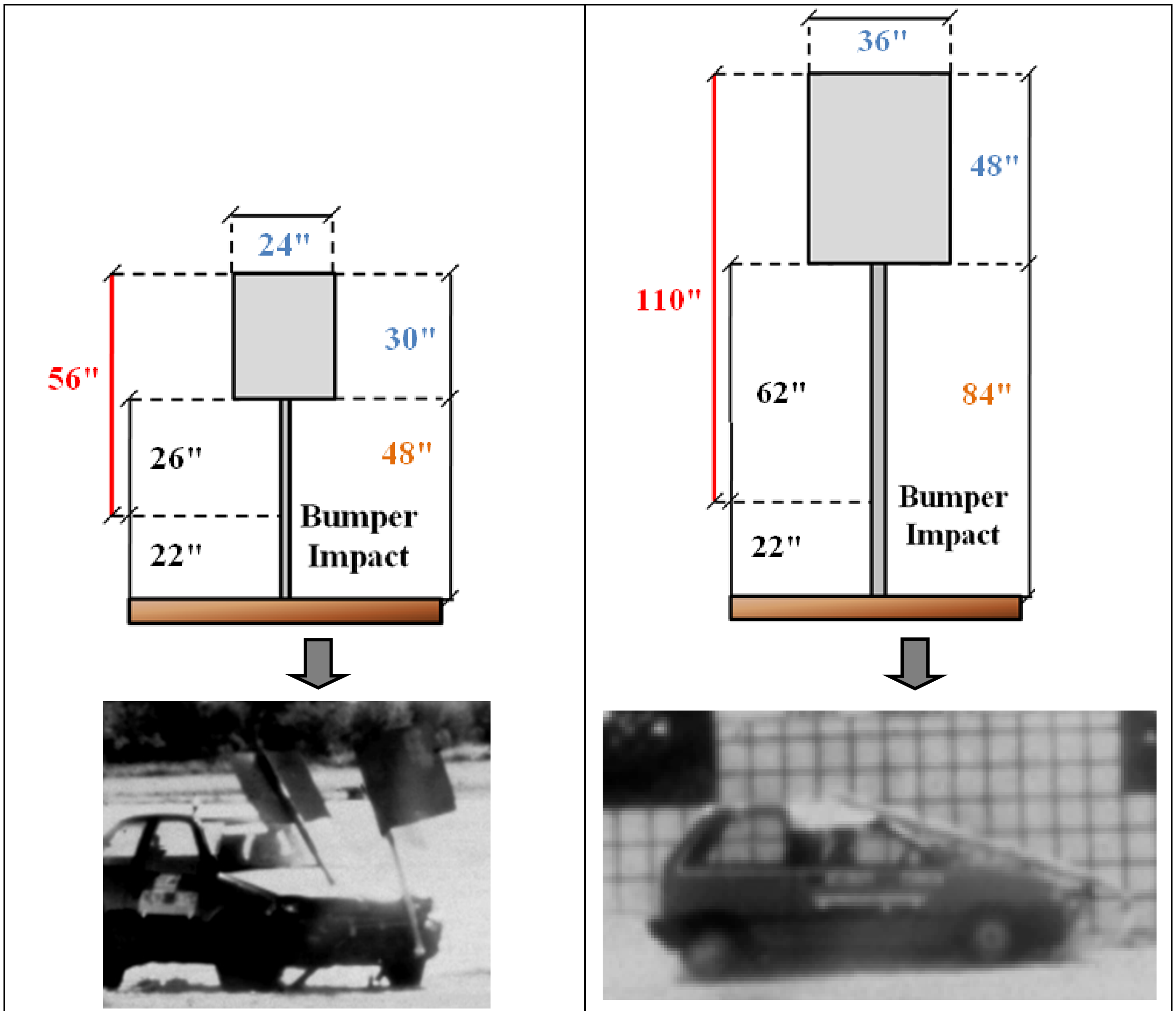


(c) Roof Impact Location Test No. 405231-9

Figure 1.2. Thin-Walled Aluminum Sign Support Tests Nos. 405231-7 and 405231-9.

Table 1.2. Thin-Walled Aluminum Sign Support Tests Nos. 405231-7 and 405231-9.

Chevron Sign Sizes	4 ft Mounting Height	7 ft Mounting Height
12-inch × 18-inch	✓	✓
18-inch × 24-inch	✓	✓
24-inch × 30-inch	✓	✓
30-inch × 36-inch	✗	✓
36-inch × 48-inch	✗	✓



(Pole pushed away from vehicle)	(Pole impacts occupant compartment)
(a) Test No. 417929-3	**(b) Test Nos. 405231-7 and 405231-9**

Figure 1.3. Support System's Effective Height and Post-Impact Pole System Behavior.

A common TxDOT practice is to install chevron sign systems in roadside ditches. For this type of installation, TxDOT standards specify that the sign mounting height be established from the pavement surface. 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 break point, the depth "y" of the ditch at the particular installation location contributes to an increase in the length of the support post and local mounting height of the sign (see Figure 1.4).

An additional consideration related to chevron sign installations in ditches is related to the actual vehicle bumper impact (BI) location on the sign pole. When an errant vehicle enters a roadside ditch, certain factors influence its trajectory. These factors include the geometry of the ditch, the encroachment speed, and encroachment angle at which the vehicle enters the ditch.

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

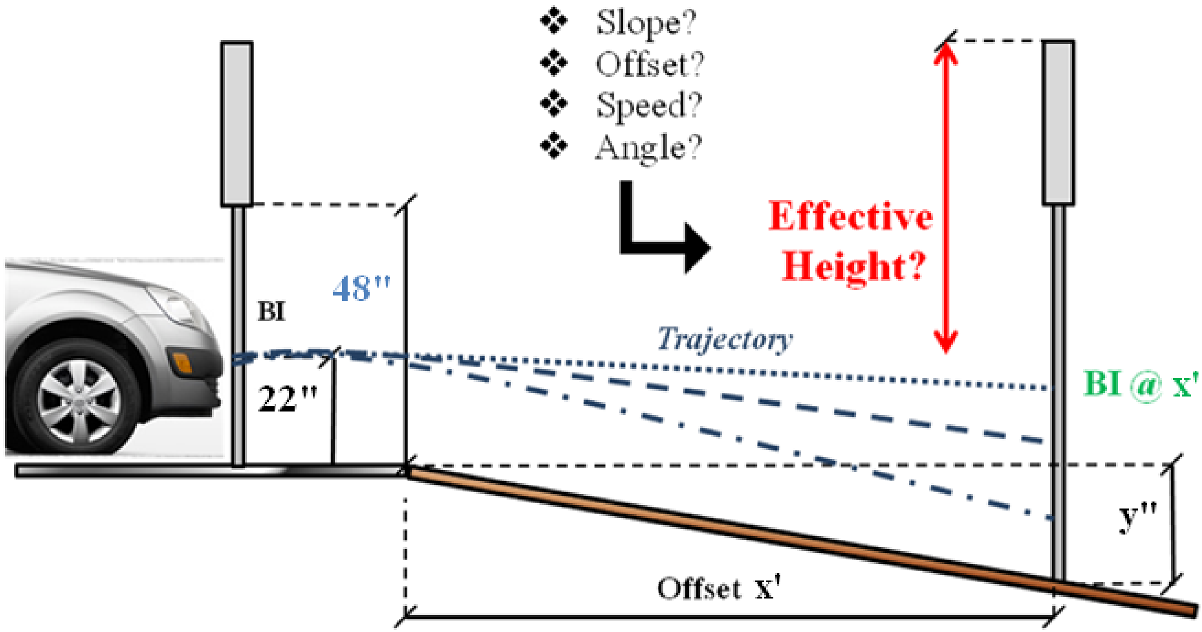


Figure 1.4. Effective Pole Height Variation for Chevron Installation in Ditch.

The post-impact behavior of the sign support system has been evaluated for effective post heights of 56 inches and 110 inches above the bumper in projects FHWA/TX-01/1792-2 and 405231-1F, respectively (*8, 9*). The lower effective height resulted in no secondary post contact and the higher effective height resulted in contact with the vehicle roof. Effective post heights between these two values have not been investigated, and there exists a possibility that an intermediate effective post height could result in the sign support contacting the windshield of the vehicle. Since it is common practice for TxDOT to install chevron signs in ditches at a 4-ft mounting height and a lateral offset between 2 and 8 ft from the pavement edge, and this practice results in effective post heights between those tested, TxDOT research project 0-6363 recommended that this installation practice be evaluated. Under TxDOT project 0-6363, TTI researchers performed vehicle dynamics simulations to determine bumper trajectories for passenger cars entering a ditch with 6H:1V slopes at different speeds (40 and 60 mi/h) and angles (5, 10, and 25 degrees). A 6H:1V slope ditch was chosen in conjunction with TxDOT personnel because it was considered to represent a reasonable and typical design condition in Texas. Lateral offsets between 2 ft and 8 ft from the slope break point were considered based on TxDOT standard practice. The trajectory analyses were performed using a computer program called CarSim® (*10*).

As a result of this study, the worst case design scenario was determined to be a vehicle encroachment into the ditch at high speed (62 mi/h) and an angle of 10 degrees. In this case, the effective post length above the bumper is maximized for a given lateral offset of system.

Further, the maximum post length above the bumper was reached when the chevron sign system was installed at an 8-ft lateral offset from the slope break point.

A full-scale crash test was recommended to evaluate the impact performance of the chevron sign installation in a roadside ditch. Researchers recommended use of a 24-inch × 30-inch sign size at a 4-ft mounting height from the pavement surface, installed at a lateral offset of 8-ft from the break point of a 6H:1V slope ditch. The chevron installation should be impacted by a passenger car traveling at 62 mi/h and entering the ditch at a 10-degree angle. Test results would be evaluated in accordance with *MASH* guidelines.

The TTI Proving Ground Facility had an existing V-ditch section with 5.5H:1V slopes. Use of a 5.5H:1V slope ditch is more conservative (i.e., further increases the effective post height above the bumper and the chance of the chevron support system impacting the windshield of a small passenger car) and accounts for field construction variations, erosion, etc. Thus, the 5.5H:1V slope ditch configuration was used for the full-scale crash test.

CHAPTER 2. SYSTEM DETAILS

2.1 TEST ARTICLE DESIGN AND CONSTRUCTION

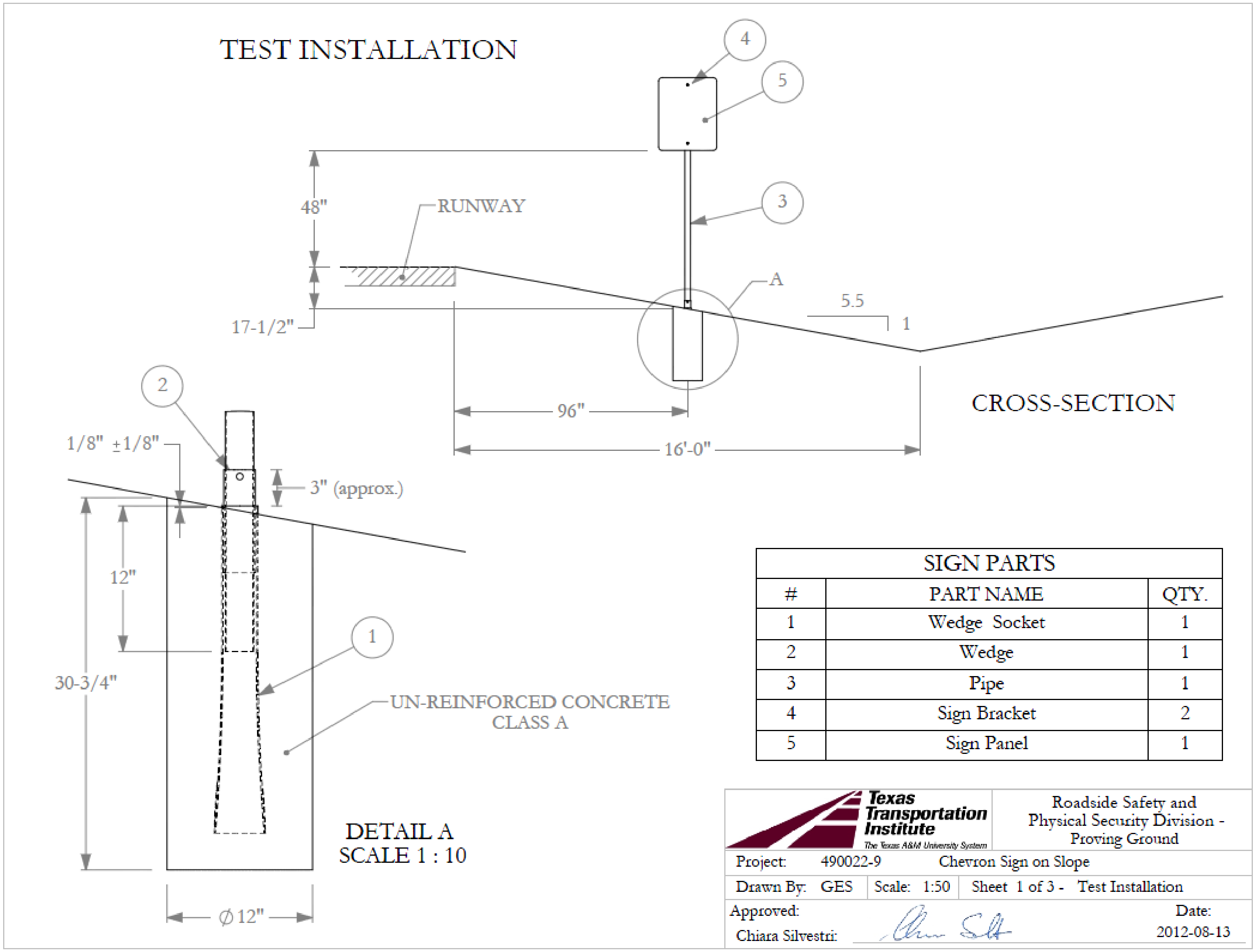
A 13 BWG galvanized steel tube with an outside diameter of 2.375 inches and a nominal wall thickness of 0.095 inches was used as the vertical support for the chevron sign system. A 24-inch × 30-inch × 0.08-inch thick aluminum sign blank was attached to the 2.375-inch O.D. vertical support using two sign brackets. The sign brackets used to attach the sign panel to the vertical support were located 3 inches from the upper and lower edges of the sign panel.

The test article was installed on a 5.5H:1V slope ditch at a lateral offset of 96-inch (8 ft) from the break point of the ditch (which corresponded to the edge of the concrete runway). The mounting height measured from the pavement level to the bottom of the sign blank was 48 inches (4 ft). The total mounting height of the support system measured from the local terrain to the bottom of the sign blank was 65.5 inches (5 ft-5.5 inches). Figures 2.1 through 2.4 give details of the test installation and the sign support system.

A wedge anchor and steel socket foundation system was installed in *MASH* standard soil following details of TxDOT standard drawing SMD (TWT)-08 (*11*). The wedge and socket system consisted of a 2.375-inch O.D. wedge and a 2.375-inch O.D., 27 inch long socket. The socket was embedded in a 12-inch diameter un-reinforced concrete footing. The 13BWG support tube was inserted 12 inches into the socket. The wedge was driven between the outer wall of the 13BWG support and the inner wall of the socket. The wedge was installed such that the top of the wedge was approximately 3 inches above the top edge of the socket.

2.2 MATERIAL SPECIFICATIONS

The steel material for the 13BWG tube, wedge, and socket met the ASTM A 1011, Grade 50 standard specification for hot rolled carbon sheet steel. The specified minimum yield strength after cold-forming is 50 ksi, and the minimum tensile strength is 65 ksi. The concrete used for the footer complied with TxDOT Class A. The footer was installed in soil meeting AASHTO standard specifications for "Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses," designated M147-65(2004), grading B. Appendix A contains information regarding material specifications and certifications.



SIGN PARTS		
#	PART NAME	QTY.
1	Wedge Socket	1
2	Wedge	1
3	Pipe	1
4	Sign Bracket	2
5	Sign Panel	1

Figure 2.1. Details of the Chevron Sign on Slope Ditch Installation Used for Test No. 490022-9.

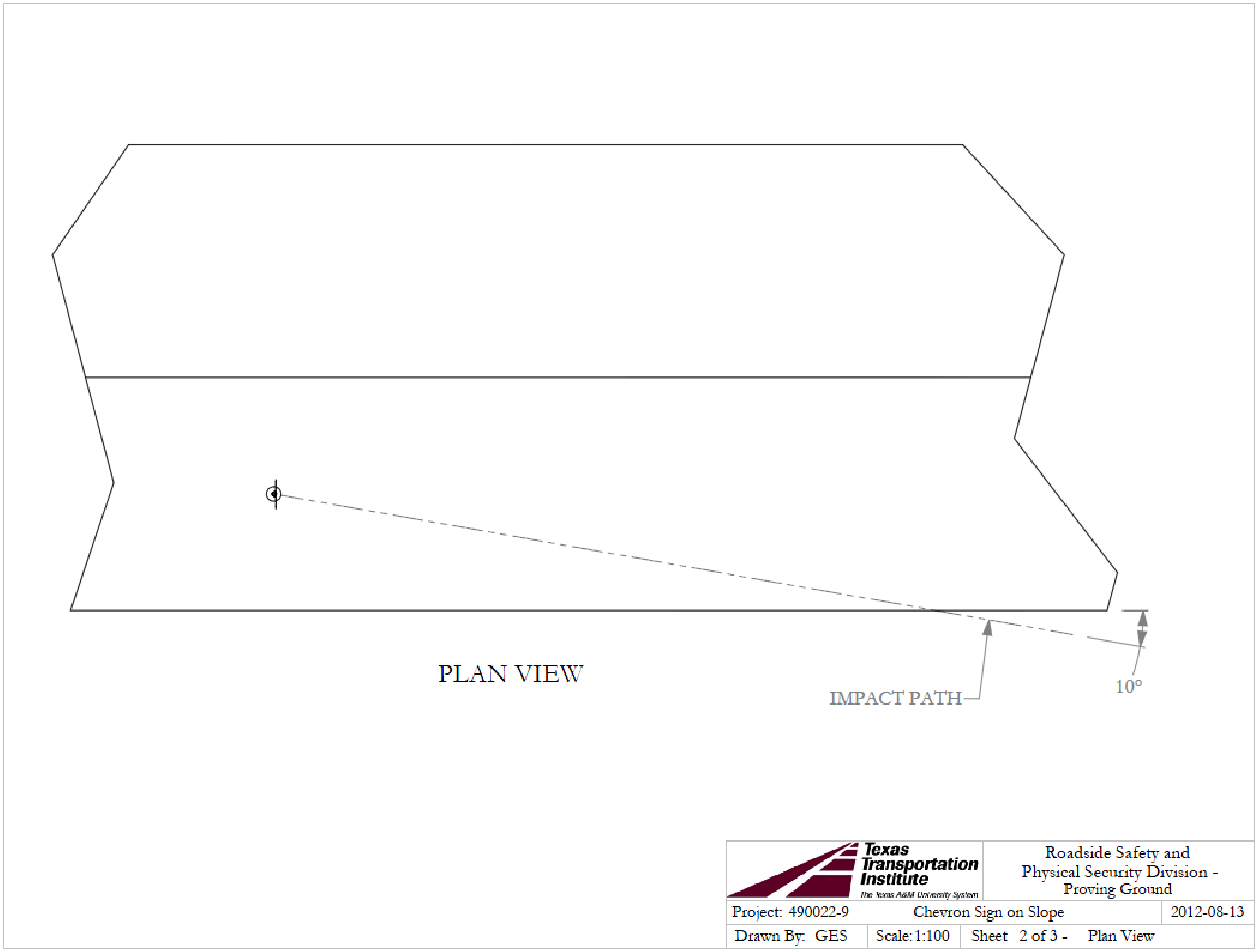


Figure 2.2. Details of the Impact Path for Test No. 490022-9.

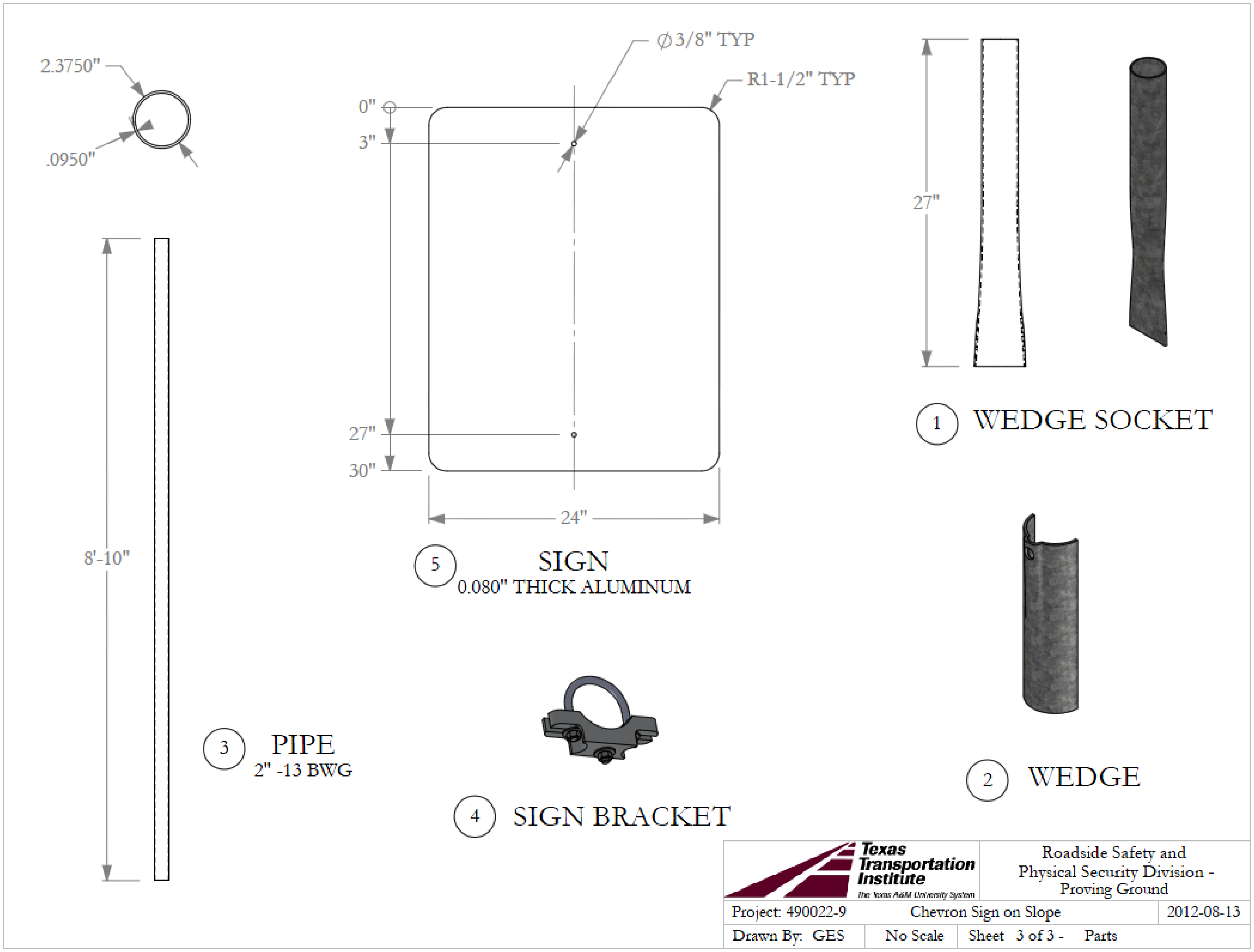


Figure 2.3. Details of the Chevron Sign on Slope Ditch Components Used for Test No. 490022-9.

Figure 2.4. Sign Support Geometrics for Test No. 490022-9.

CHAPTER 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 CRASH TEST MATRIX

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

> ***MASH* Test Designation 3-60:** A 2425-lb vehicle impacting the support structure at a nominal impact speed of 19 mi/h and the critical impact angle between 0 and 25 degrees. This test investigates the activation of the breakaway mechanism of the support structure when impacted at low speed by a small passenger vehicle.
>
> ***MASH* Test Designation 3-61:** A 2425-lb vehicle impacting the support structure at a nominal impact speed of 62 mi/h and the critical impact angle between 0 and 25 degrees. This test investigates vehicle stability and the potential for test article intrusion into the windshield or roof of a small passenger vehicle.
>
> ***MASH* Test Designation 3-62:** A 5000-lb pickup truck impacting the support structure at a nominal impact speed of 62 mi/h and the critical impact angle between 0 and 25 degrees. This test investigates the potential for test article intrusion into the windshield or roof of a pickup truck vehicle.

The test reported here corresponds to Test 3-61 of *MASH* (2425-lb small passenger car, 62 mi/h), with a nominal impact angle of 10 degrees. Based on previous test experience with similar test articles, the project team concluded that the high-speed test (Test 3-61) is more critical than the low-speed test for evaluation of occupant compartment deformation and intrusion. The higher impact speed will result in more deformation of the support structure and increased secondary impact forces compared to the low speed test. For these reasons, Test 3-60 was not considered warranted.

The need for a test with a pickup truck (Test 3-62) is to be judged based on the results of Test 3-61. If the test with the small car does not result in any secondary contact with the vehicle windshield, then the test with the pickup truck is not necessary. The geometry of the pickup provides a greater "wrap-around distance" compared to the small passenger car. The "wrap-around distance" is defined as the distance from the terrain around the front of the vehicle and across the hood to the base of the windshield. For yielding support systems, such as the wedge and socket system, the thin wall support post will yield around the front of the vehicle. The wrap-around distance is an indicator of the potential for secondary contact of the yielded support with the windshield. The greater wrap around distance of the pickup assures that if the chevron support does not contact the windshield of the small car, it will not impact the windshield of the pickup truck. If some contact with the windshield of the small car occurs, the behavior of the sign support will be evaluated to determine if its trajectory poses a concern for the pickup truck design vehicle.

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 crash test was evaluated in accordance with the criteria presented in *MASH*. The performance of the chevron sign support is judged on the basis of three factors: structural adequacy, occupant risk, and post impact vehicle trajectory. Structural adequacy is judged upon the ability of the sign support to readily activate in a predictable manner by breaking away, fracturing, or yielding. Occupant risk criteria evaluate the potential risk or 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 test reported herein. These criteria are listed in detail under the assessment of the crash test.

CHAPTER 4. CRASH TEST PROCEDURES

4.1 TEST FACILITY

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

The Texas A&M Transportation Institute Proving Ground is a 2000-acre complex of research and training facilities located 10 miles northwest of the main campus of Texas A&M University. The site, formerly an Air Force base, has large expanses of concrete runways and parking aprons well-suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for installation and testing of the chevron sign support evaluated under this project was in a ditch constructed along the edge of an out-of-service runway. The symmetric "V-shaped" ditch was 32-ft wide and had 5.5H:1V slopes. The slope break or hinge point of the ditch was directly adjacent to the concrete runway. The approach runway consists of an unreinforced jointed-concrete pavement in 12.5 ft × 15 ft blocks nominally 6 inches deep. The runway is over 60 years old, and the joints have some displacement, but are otherwise flat and level.

4.2 VEHICLE TOW AND GUIDANCE PROCEDURES

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A two-to-one speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be unrestrained. The vehicle remained free-wheeling (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 vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems, Inc. The accelerometers that measure the x, y, and z axis of vehicle acceleration are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors measuring vehicle roll, pitch, and yaw rates are ultra-small size, solid state units 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 the 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 and 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 are returned to the factory annually for complete recalibration. Accelerometers and rate transducers are also calibrated annually with traceability to the National Institute for Standards and Technology.

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

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

4.3.2 Anthropomorphic Dummy Instrumentation

According to *MASH*, use of a dummy in the 1100C vehicle is required. Researchers used an Alderson Research Laboratories Hybrid II, 50^{th} percentile male anthropomorphic dummy, restrained with lap and shoulder belts, in the driver's position. The dummy was uninstrumented.

4.3.3 Photographic Instrumentation and Data Processing

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

CHAPTER 5. CRASH TEST RESULTS

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

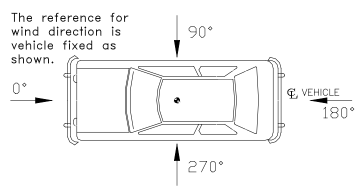
MASH Test 3-61 involves a 1100C vehicle weighing 2425 lb ±55 lb impacting the chevron sign support at an impact speed of 62 mi/h ±2.5 mi/h and the critical impact angle between 0 and 25 degrees. For this test, an angle of 10 degrees ±1.5 degrees was selected as the critical impact angle based on vehicle dynamics simulations. The target impact point was the centerline of the vehicle aligned with the centerline of the sign support to help account for variations in vehicle trajectory arising during the ditch traversal. The 2007 Kia Rio small passenger car used in the test weighed 2406 lb and the actual impact speed and angle were 61.4 mi/h and 10.0 degrees, respectively. The actual impact point was at 18 inches from the vehicle's centerline, on the driver's side. Impact severity (IS) was 9.8 kip-ft.

5.2 TEST VEHICLE

A 2007 Kia Rio small passenger car, shown in Figures 5.1 and 5.2, was used for the crash test. The test inertia and the gross static weights were 2406 and 2573 lb, respectively. The height to the lower edge of the vehicle bumper was 7.125 inches, and it was 21 inches to the upper edge of the bumper. Table B1 in Appendix B 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 unrestrained just prior to impact.

5.3 WEATHER CONDITIONS

The test was performed on the morning of August 13, 2012. Weather conditions at the time of testing were: wind speed: 11 mi/h; wind direction: 234 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 90.1°F; relative humidity: 56 percent.



5.4 TEST DESCRIPTION

The 2007 Kia Rio small passenger car, traveling at an impact speed of 61.4 mi/h, impacted the chevron sign support 18 inches from the vehicle's centerline, on the driver's side. The encroachment angle at time of the release of the guide cable as the vehicle entered the ditch was 10.0 degrees. At 0.0035 s after impact, the sign support began to deflect. At 0.042 s, the sign impacted the hood of the vehicle and began to fold. The sign post ruptured at 0.065 s. At 0.070 s, the sign post lost contact with the front of the vehicle, and at 0.077 s, the top sign bracket slid off the sign post. Brakes on the vehicle were applied 0.54 s after impact, and the vehicle subsequently came to rest 187 ft downstream of impact. Figure C1 in Appendix C shows sequential photographs of the test period.

Figure 5.1. Vehicle/Installation Geometrics for Test No. 490022-9.

Figure 5.2. Vehicle before Test No. 490022-9.

5.5 DAMAGE TO TEST INSTALLATION

As shown in Figures 5.3 and 5.4, the sign support did not completely pull out of the socket. The support deformed at bumper height and ground level, and subsequently fractured near bumper height approximately 21 inches above ground. During impact, the support post wrapped around the front end of the vehicle and the sign impacted the hood. The sign panel slid up the support post, causing the upper sign bracket to slide of the top of the post while remaining connected to the sign. The support and the sign panel came to rest 126 ft downstream of the impact point.

5.6 VEHICLE DAMAGE

Figure 5.5 shows damage sustained by the 1100C vehicle. The front bumper, hood, and left head light were damaged. The impact of the chevron sign support system with the vehicle caused a 31-inch × 21-inch dent in the left-central portion of the hood. Maximum exterior crush to the vehicle was 1.75 inches on the hood. Figure 5.5 shows deformation and striations left by the sign during impact with the vehicle's hood. The upper edge of the striations caused by contact with the sign panel was approximately 8.5 inches from the base of the windshield. There was no deformation to the occupant compartment. Tables B2 and B3 in Appendix B provide exterior crush and occupant compartment measurements, respectively.

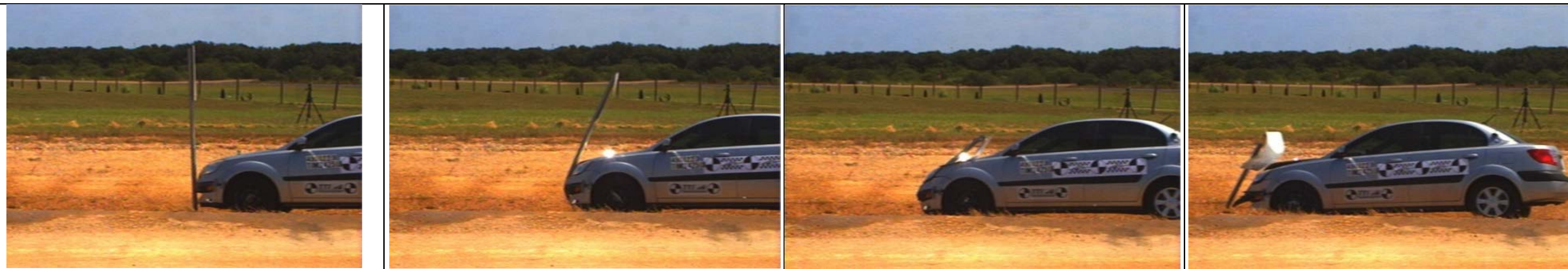
5.7 OCCUPANT RISK FACTORS

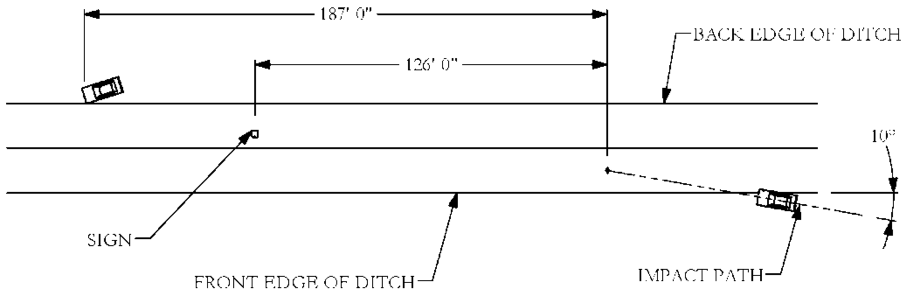
Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. In the longitudinal direction, the occupant impact velocity was 5.9 ft/s at 0.3699 s, the highest 0.010-s occupant ridedown acceleration was −2.1 Gs from 1.9645 to 1.9745 s, and the maximum 0.050-s average acceleration was −3.4 Gs between 0.0076 and 0.0576 s. In the lateral direction, the occupant impact velocity was 0.328 ft/s at 0.3699 s, the highest 0.010-s occupant ridedown acceleration was −1.1 Gs from 0.4376 to 0.4476 s, and the maximum 0.050-s average was 0.9 Gs between 0.0074 and 0.0574 s. Theoretical Head Impact Velocity (THIV) was 6.7 km/h or 1.9 m/s at 0.3690 s; Post-Impact Head Deceleration (PHD) was 2.1 Gs between 1.9645 and 1.9745 s; and Acceleration Severity Index (ASI) was 0.31 between 0.0075 and 0.0575 s. Figure 5.6 summarizes these data and other pertinent information from the test. Figures D1 through D7 in Appendix D present the vehicle angular displacements and accelerations versus time traces.

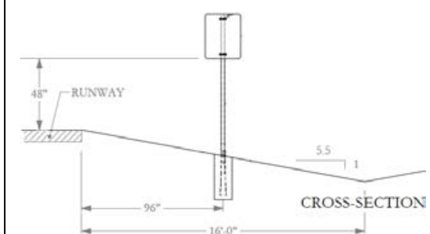
Figure 5.3. Vehicle/Installation after Test No. 490022-9.

Figure 5.4. Installation after Test No. 490022-9.

Figure 5.5. Vehicle after Test No. 490022-9.







General Information

Test Agency	Texas A&M Transportation Institute
Test Standard Test No.	MASH Test 3-61
TTI Test No.	490022-9
Test Date	2012-08-13

Test Article

Type	Chevron Sign Support
Name	TxDOT T131RC Bridge Rail
Installation Type	On 5.5:1 ditch slope, 8 ft from hinge point
Material or Key Elements	24-inch × 30-inch aluminum sign at 4-ft mounting height; 13 BWG support with wedge and socket
Soil Type and Condition	Wedge and Socket in Concrete Foundation

Test Vehicle

Type/Designation	1100C
Make and Model	2007 Kia Rio
Curb	2461 lb
Test Inertial	2406 lb
Dummy	167 lb
Gross Static	2573 lb

Impact Conditions

Speed	61.4 mi/h
Angle	10.0 degrees
Location/Orientation	

Impact Severity	9.8 kip-ft

Exit Conditions

Speed	53.6 mi/h
Angle	N/A

Occupant Risk Values

Impact Velocity	
Longitudinal	5.9 ft/s
Lateral	0.328 ft/s
Ridedown Accelerations	
Longitudinal	2.1 G
Lateral	1.1 G
THIV	6.7 km/h
PHD	2.1 G
ASI	0.31
Max. 0.050-s Average	
Longitudinal	-3.4 G
Lateral	0.9 G
Vertical	-1.2 G

Post-Impact Trajectory

Stopping Distance	187 ft dwnstrm

Vehicle Stability

Maximum Yaw Angle	21 degrees
Maximum Pitch Angle	4 degrees
Maximum Roll Angle	13 degrees
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	126 ft
Permanent	126 ft
Working Width	N/A

Vehicle Damage

VDS	01LF2
CDC	01FLEW2
Max. Exterior Deformation	1.75 inches
OCDI	LF0000000
Max. Occupant Compartment Deformation	None

Figure 5.6. Summary of Results for *MASH* Test 3-61 on the Chevron Sign Support.

CHAPTER 6. SUMMARY AND CONCLUSIONS

6.1 ASSESSMENT OF TEST RESULTS

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

6.1.1 Structural Adequacy

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

Results: The sign support fractured at approximately 21 inches above wedge and socket system. (PASS)

6.1.2 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 released sign support did not penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area. (PASS)
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.

Results: 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. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity

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

Results: Longitudinal occupant impact velocity was 5.9 ft/s, and lateral occupant impact velocity was 0.328 ft/s. (PASS)

I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20.49 Gs*

Results: Longitudinal occupant ridedown acceleration was 2.1 G, and lateral occupant ridedown acceleration was 1.1 G. (PASS).

6.1.3 Vehicle Trajectory

N. Vehicle trajectory behind the test article is acceptable.

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

6.2 CONCLUSIONS

The chevron sign support performed acceptably for *MASH* Test 3-61 (see Table 6.1).

Table 6.1. Performance Evaluation Summary for *MASH* Test 3-61 on the Chevron Sign on Slope Ditch.

Test Agency: Texas A&M Transportation Institute | Test No.: 490022-9 | Test Date: 2012-08-13

***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

CHAPTER 7. IMPLEMENTATION STATEMENT

Current TxDOT practice allows installation of all existing chevron panel sizes at a 7-ft mounting height, but restricts the use of 4-ft mounting height to the three smallest chevron signs—namely, 12 inches × 18 inches, 18 inches × 24 inches, and 24 inches × 30 inches.

A common TxDOT practice is to install chevron sign systems in roadside ditches. For this type of installation, TxDOT standards specify that the sign mounting height be measured from the pavement surface. When a sign support system is installed on a slope, the mounting height of the sign (calculated from ground level at the location of installation) will be greater than the same mounting height for a sign installed on flat level ground. This creates an interaction height with the vehicle different from those previously tested.

This study evaluated the crashworthiness of a 24-inch × 30-inch chevron sign mounted at a 4-ft mounting height installed at an 8 ft offset in a 5.5H:1V slope ditch. This represents worst case design practice in terms of sign size and lateral offset. The test was performed and evaluated in accordance with the *Manual for Assessing Safety Hardware (MASH)*. The chevron installation was impacted by a 2420-lb passenger car traveling at 62 mi/h and entering the ditch at a 10-degree angle. Vehicle dynamics simulation determined that the 10-degree encroachment angle was the critical angle for evaluating the impact performance of the chevron in the selected ditch configuration.

The 24 inch × 30 inch chevron sign panel at 4-ft mounting height installed at an 8-ft offset from the break point on a 5.5H:1V slope performed acceptably for *MASH* Test 3-61. The research team concluded that this high-speed test was more critical than the low-speed test for evaluation of occupant compartment deformation and intrusion, and that Test 3-60 was not warranted. Furthermore, since the chevron support did not contact the windshield of the small car, and the geometry of the pickup provides a greater "wrap-around distance" compared to the small car, Test 3-62 is not necessary.

Thus, the current TxDOT practice of installing 4-ft mounting height chevron signs in roadside ditches is acceptable. This applies to chevron signs smaller than or equal to 24 inches × 30 inches in size. Larger chevron panels should be installed at a 7-ft mounting height. The results of this research should be implemented through continued use of the Delineator & Object Marker (D&OM) standard sheets.

REFERENCES

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2. TxDOT Standard: Barricade and Construction Channelizing Devices Standard - BC(9)-07, ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/traffic/bc07.pdf, retrieved on June 2011.

3. *Texas Manual on Uniform Traffic Control Devices (MUTCD),* Sign Appendix, Ed. 2006, http://www.txdot.gov/txdot_library/publications/tmutcd.htm, retrieved on July 2011.

4. TxDOT Standard: Typical Delineator and Object Marker Placement Details - D&OM(2) 04, ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/traffic/dom1-10.pdf, retrieved on June 2011.

5. C. Silvestri, D. Arrington, R.P. Bligh, and W.L. Menges. Development Guidance for Sign Design Standards, Test Report No. 463631, Texas Transportation Institute, Texas A&M University, College Station, TX, March 2012.

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

7. R.P. Bligh, L.D. Bullard, W.L. Menges and S.K. Schoeneman. Impact Performance Evaluation of Work Zone Traffic Control Devices, Test Report No. FHWA/TX-01/1792-2, Texas Transportation Institute, Texas A&M University, College Station, TX, 2000.

8. H. E. Ross, D. L. Sicking, R. A. Zimmer, and J. D. Michie, "Recommended Procedures for the Safety Performance Evaluation," *NCHRP Report 350*, National Academy Press, National Cooperative Highway Research Program, Washington, D.C. 1993.

9. D. L. Bullard, Jr., and W.L. Menges. Evaluation of the Crashworthiness of Thin-Walled Aluminum and Steel U-Channel Sign Supports, Test Report No. 405231-1F, Texas Transportation Institute, Texas A&M University, College Station, TX, June 1995.

10. Mechanical Simulation Corporation, *CARSIM. Version: 8.0.* Ann Arbor, MI, 1996.

11. TxDOT standard (SMD (TWT)-08): ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/traffic/smdgen.pdf.

APPENDIX A. CERTIFICATION DOCUMENTATION

MATERIAL USED

TEST NUMBER	490022-9
TEST NAME	Chevron on Slope
DATE	2012-08-13

DATE RECEIVED	ITEM NUMBER	DESCRIPTION	SUPPLIER	HEAT #
2012-08-09	Pipe-08	2'' 13 BWG x 10'	Trinity	generic Trinity
2012-08-09	Socket-01	for 2-3/8'' OD Pipe	Trinity	generic Trinity
2012-08-09	Wedge-01	for Socket	Trinity	generic Trinity
2012-08-09	Sign-01	24 x 30 x 0.080 alum.	N-Line	*

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth, TX 76111

A

Customer: SAMPLES,TESTING,TRAINING MTRLS
2525 STEMMONS FRWY

DALLAS, TX 75207

Sales Order: 1151007
Customer PO: Samples
BOL # 43569
Document # 1

Print Date: 8/8/12
Project: SAMPLES
Shipped To:
Use State: TX

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SMALL SIGNS SUPPORT **

NCHRP Report 350 Compliant

Pieces	Description	Part No
1	2.375RD13@120 G210	720477G
1	2.375RD 27 SOCKET G210	720745G
1	2.375RD WEDGE	720750G

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

TL -3 or TL-4 COMPLIANT when installed according to manufactures specifications

The Steel supplied meets the standard specification for hot rolled carbon sheet steel, ASTM A 1011, Grade 50. The average minimum yield strength after cold-forming is a minimum of 50ksi
ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
Post supplied have been hot-dipped galvanized interior and exterior in accordance with ASTM A653, G90 structural quality grade 50 Class1. All corner welds have been zinc coated after scarfing. The steel has been coated with a chromate conversion coating and a clear organic polymer topcoat.

Chemistry Requirements "Max values"

C	Mn	P	S	Cu	Ni	Cr	Mo	V	Cb	Ti
0.25	1.35	0.035	0.04	0.20	0.20	0.15	0.06	0.008	0.008	0.025

Mechanical Requirements

Yield Strength	Tensile Strength	Elongation
50,000 "Min"	65,000 "Min"	17%

State of Texas, County of Tarrant. Sworn and Subscribed before me this 8th day of August, 2012

Notary Public:
Commission Expires: JOMARY LUGINSLAND MY COMMISSION EXPIRES May 24, 2015

Trinity Highway Products, LLC
Certified By:
Quality Assurance

N-LINE
TRAFFIC MAINTENANCE®

Sales Order

ORDER DATE	S.O. #
8/8/2012	5462B

SHIPPING DATE
08/08/2012

BILL TO	SHIP TO
Texas Transportation Institute Texas A&M University System Attn: Business Office MS 3135 College Station, TX 77843-3135	CUSTOMER PICK UP GARY GERKE 936-825-4661

P.O. NO.	TERMS	REP	SHIPPING METHOD	PROJECT
490022	Net 30	KDK	CPU	

ITEM	DESCRIPTION	UNIT	QTY	RATE	AMOUNT
ALUMRec24x...	24" x 30" Rectangle .080 Aluminum Sign Blank.		1	15.75	15.75
6-54238SET	2 3/8" U-bolt assembly. Includes (2) 2-3/8" U-Bolts, (2) Sign Casting Brackets, (2) 5/16" x 1" Sign Bolts, (6) Lock Washers, (2) Nylon Washers, (2) Flat Washers, (6) Nuts.	EA	1	5.75	5.75

RECEIVED
AUG 0 8 2012
TTI-ROADSIDE SAFETY & PHYSICAL SECURITY DIVISION

NOT AN INVOICE

SIGNATURE ____________________

Total $21.50

AUSTIN BRYAN WACO

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

Table B1. Vehicle Properties for Test No. 490022-9.

Date: 2012-08-13 Test No.: 490022-9 VIN No.: KNADE123476256257

Year: 2007 Make: Kia Model: Rio

Tire Inflation Pressure: 32 psi Odometer: 90094 Tire Size: 185/65R14

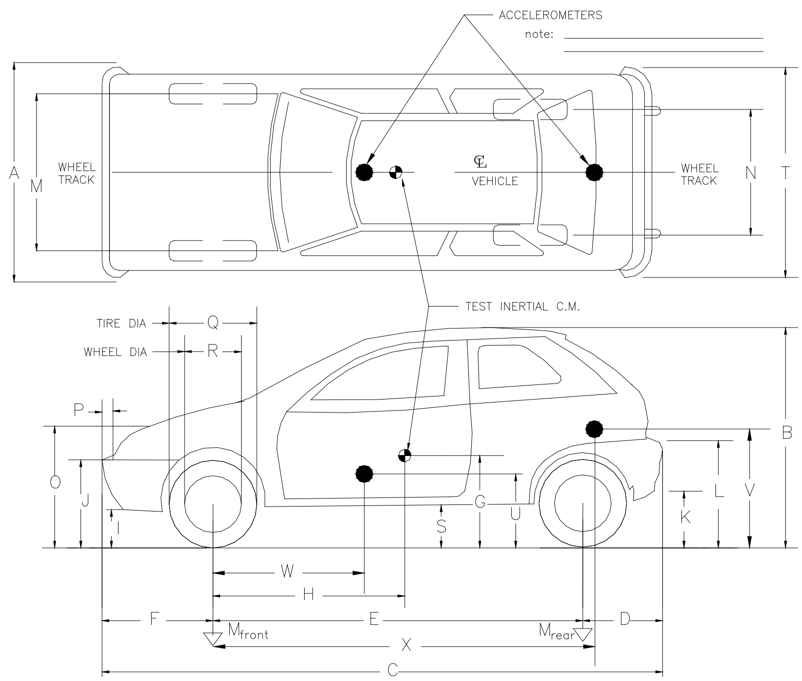
Describe any damage to the vehicle prior to test: ______

● Denotes accelerometer location.

NOTES: ______

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

Dummy Data:
Type: 50th percentile male
Mass: 167 lb
Seat Position: Driver



Geometry: inches

A	66.38	F	33.00	K	11.00	P	4.12	U	15.75
B	57.75	G		L	24.12	Q	22.19	V	21.50
C	165.75	H	36.08	M	57.75	R	15.38	W	43.50
D	34.00	I	7.12	N	57.12	S	7.62	X	108.50
E	98.75	J	21.00	O	30.68	T	66.12		

Wheel Center Ht Front ______ Wheel Center Ht Rear ______

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	918	M_{front}	1547	1527	1616
Back	1874	M_{rear}	914	879	957
Total	3638	M_{Total}	2461	2406	2573

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

Mass Distribution:
lb LF: 785 RF: 742 LR: 735 RR: 444

Table B2. Exterior Crush Measurements for Test No. 490022-9.

Date: 2012-08-13 Test No.: 490022-9 VIN No.: KNADE123476256257

Year: 2007 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

Note: Measure C_1 to C_6 from Driver to Passenger <u>S</u>~~s~~ide in Front or Rear <u>I</u>~~i~~mpacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Measurements recorded										
	in inches										

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

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

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

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

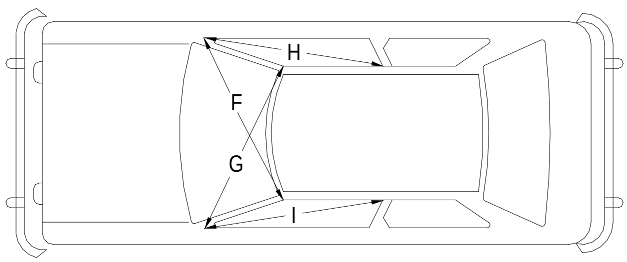
***Measure and document on the vehicle diagram the location of the maximum crush.

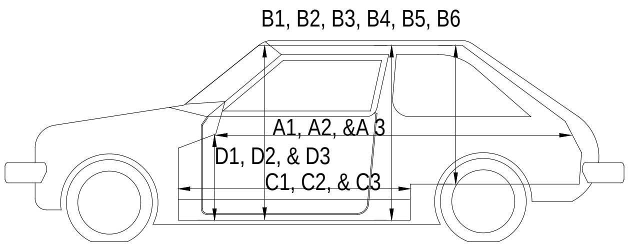
Note: Use as many lines/columns as necessary to describe each damage profile.

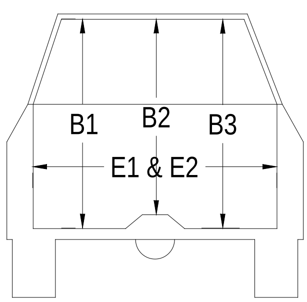
Table B3. Occupant Compartment Measurements for Test No. 490022-9.

Date: 2012-08-13 Test No.: 490022-9 VIN No.: KNADE123476256257

Year: 2007 Make: Kia Model: Rio







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before (inches)	**After** (inches)
A1	67.75	67.75
A2	66.50	66.50
A3	67.50	67.50
B1	40.50	40.50
B2	39.00	39.00
B3	40.50	40.50
B4	36.25	36.25
B5	35.75	35.75
B6	36.25	36.25
C1	27.00	27.00
C2	----	----
C3	27.00	27.00
D1	9.75	9.75
D2	----	----
D3	9.75	9.75
E1	48.25	48.25
E2	51.00	51.00
F	50.75	50.75
G	50.75	50.75
H	36.50	36.50
I	36.50	36.50
J*	51.00	51.00

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

APPENDIX C. SEQUENTIAL PHOTOGRAPHS

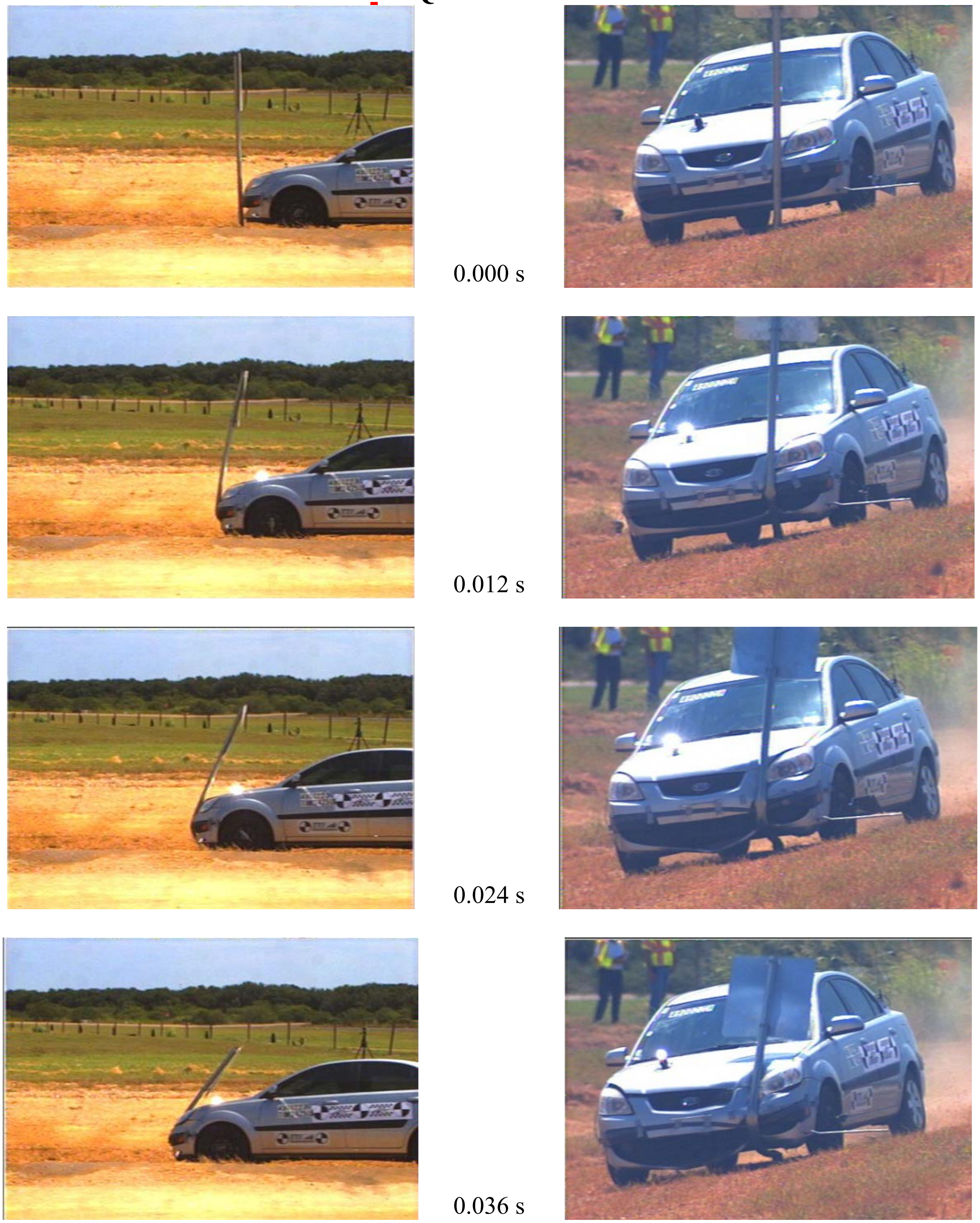


Figure C1. Sequential Photographs for Test No. 490022-9.

0.048s

0.060 s

0.072 s

0.084 s

Figure C1. Sequential Photographs for Test No. 490022-9 (continued).

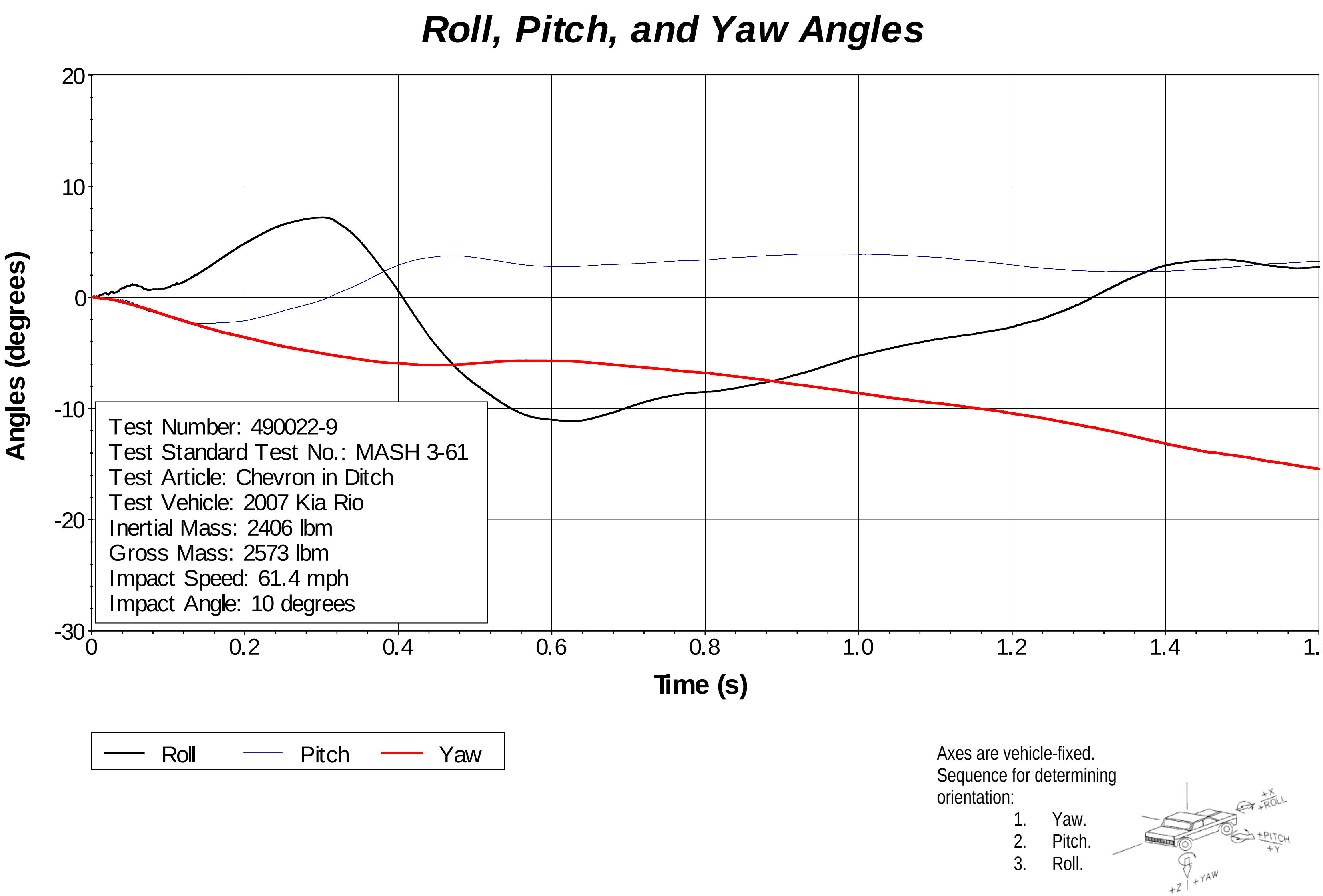


Figure D1. Vehicle Angular Displacements for Test No. 490022-9.

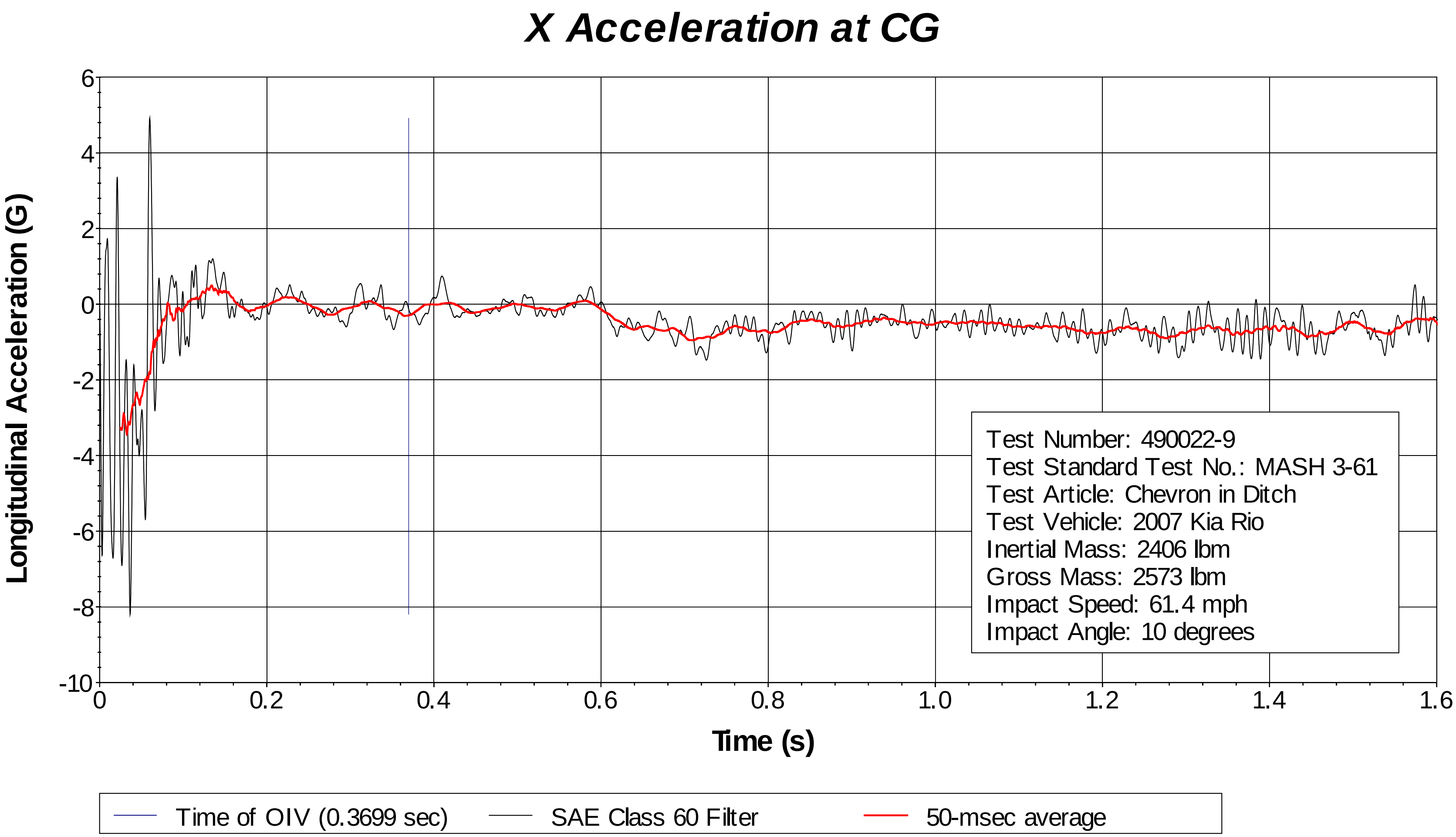


Figure D2. Vehicle Longitudinal Accelerometer Trace for Test No. 490022-9 (Accelerometer Located at Center of Gravity).

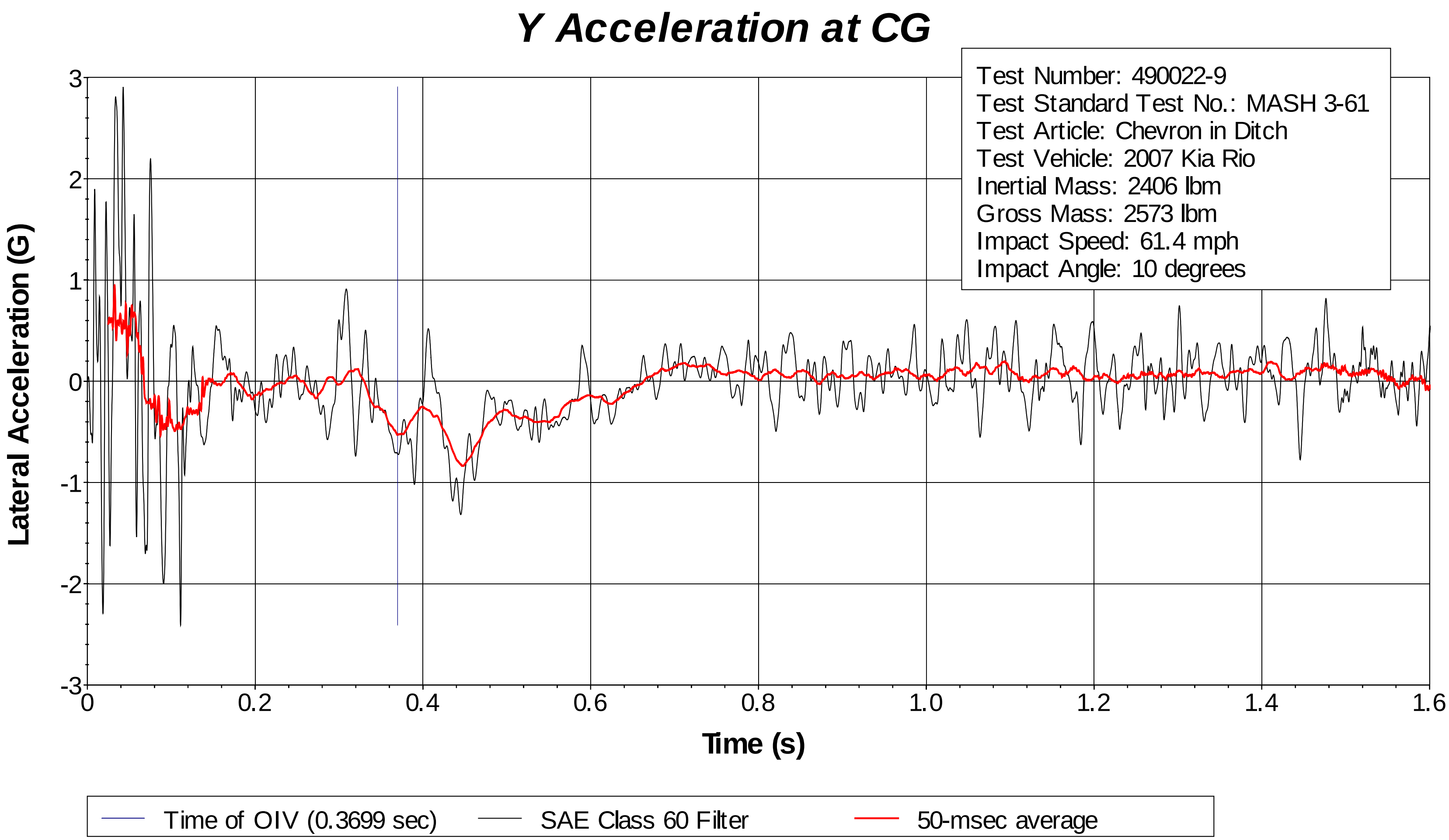


Figure D3. Vehicle Lateral Accelerometer Trace for Test No. 490022-9 (Accelerometer Located at Center of Gravity).

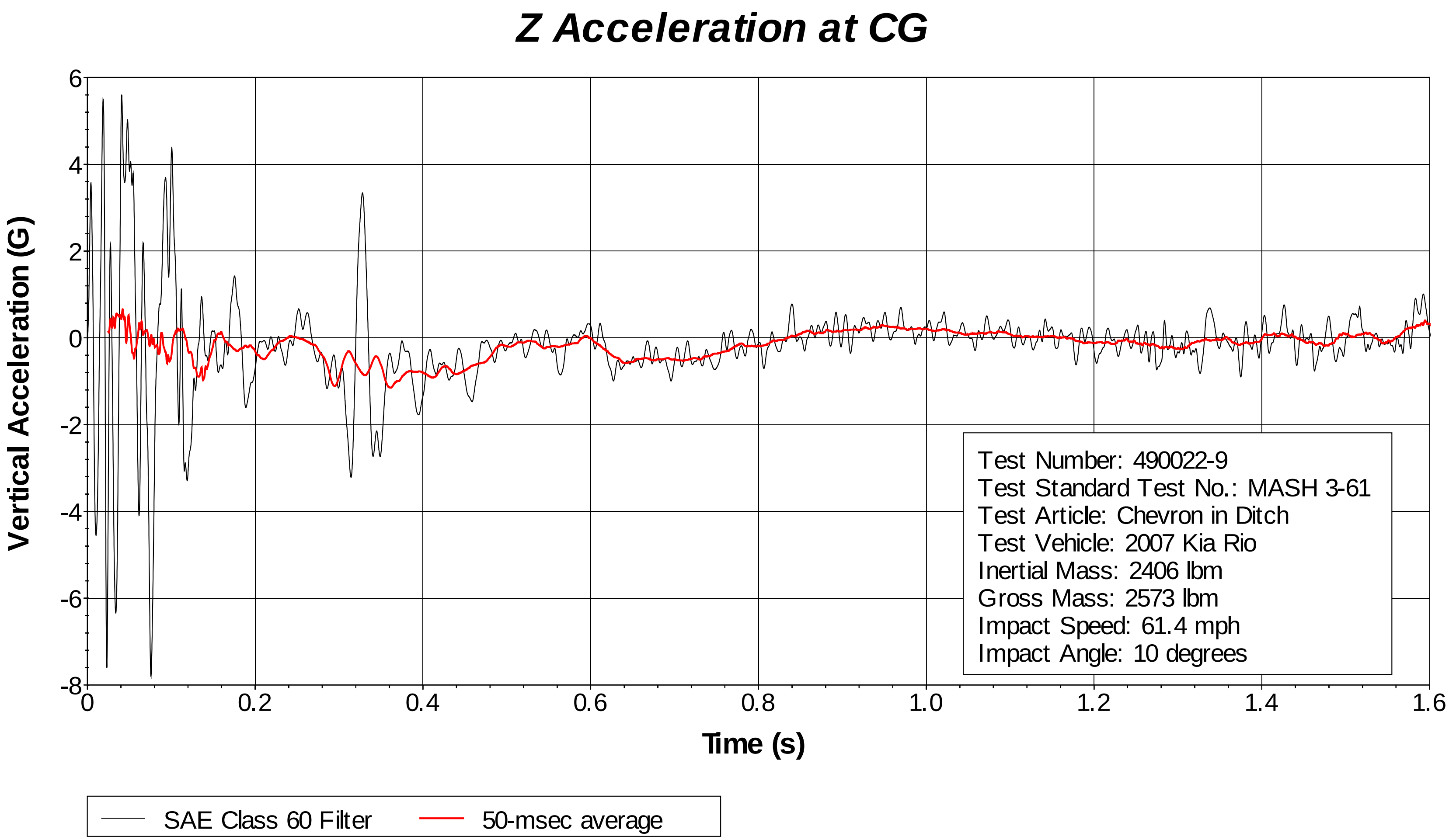


Figure D4. Vehicle Vertical Accelerometer Trace for Test No. 490022-9 (Accelerometer Located at Center of Gravity).

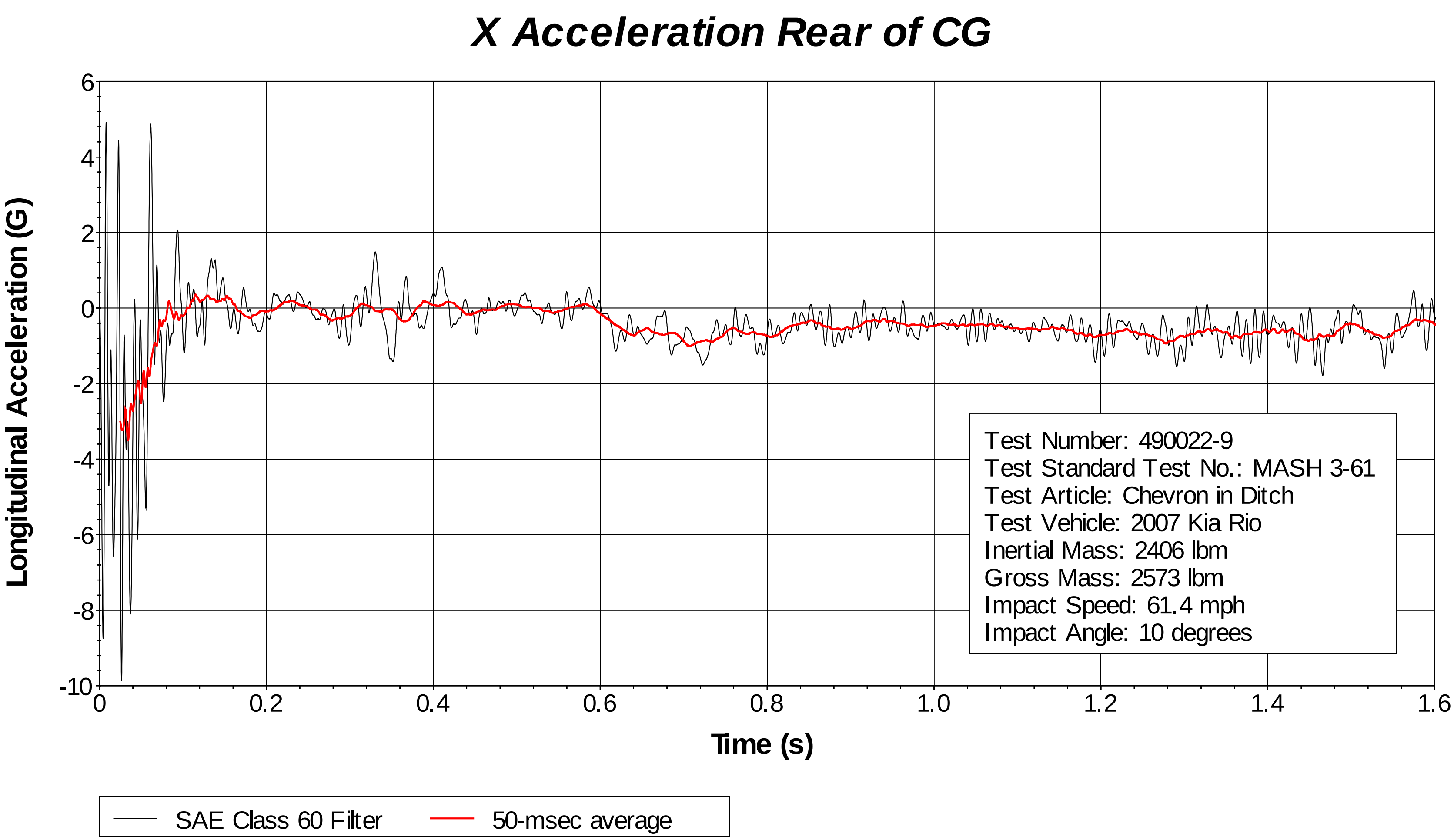


Figure D5. Vehicle Longitudinal Accelerometer Trace for Test No. 490022-9 (Accelerometer Located Rear of Center of Gravity).

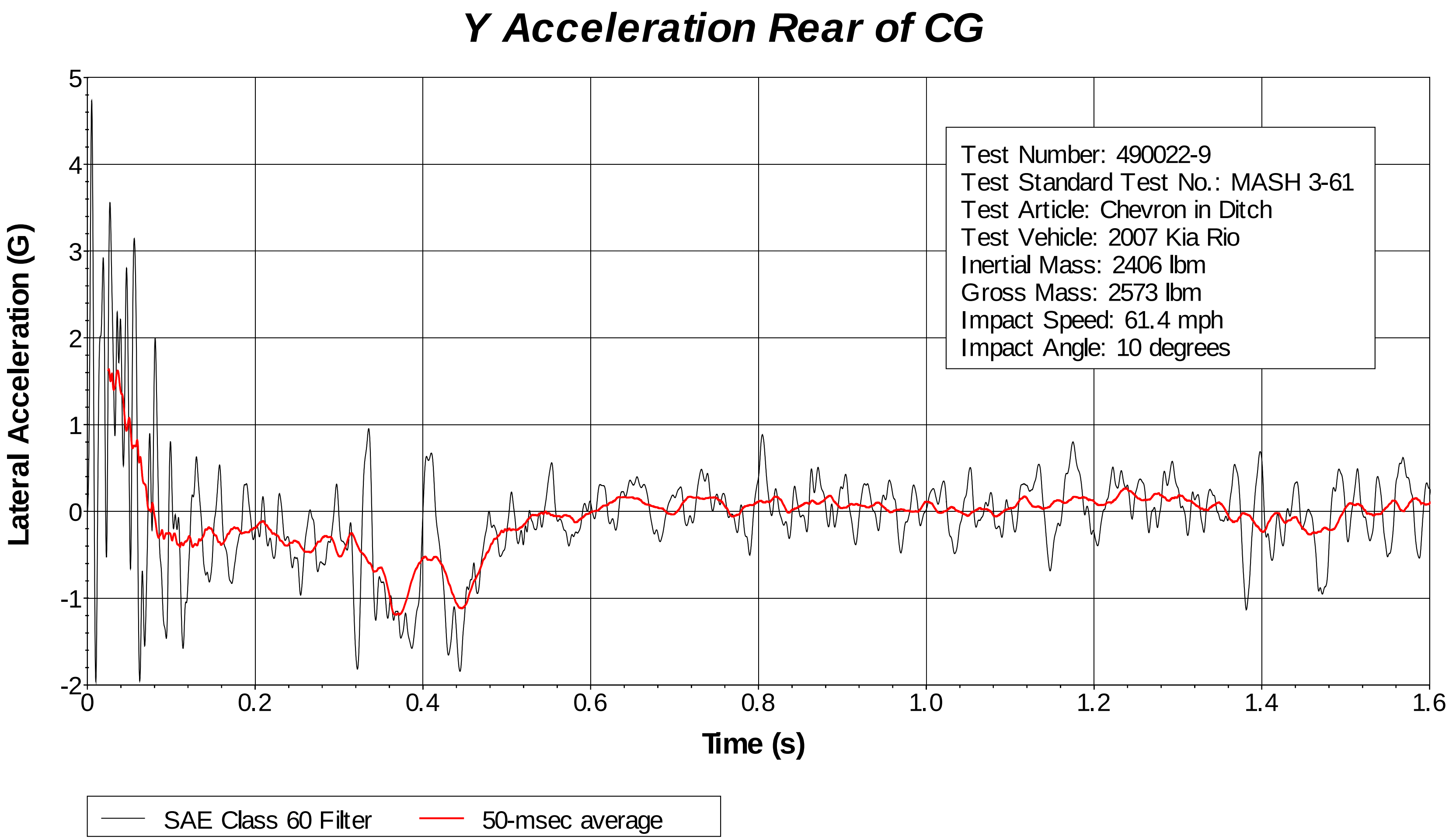


Figure D6. Vehicle Lateral Accelerometer Trace for Test No. 490022-9 (Accelerometer Located Rear of Center of Gravity).

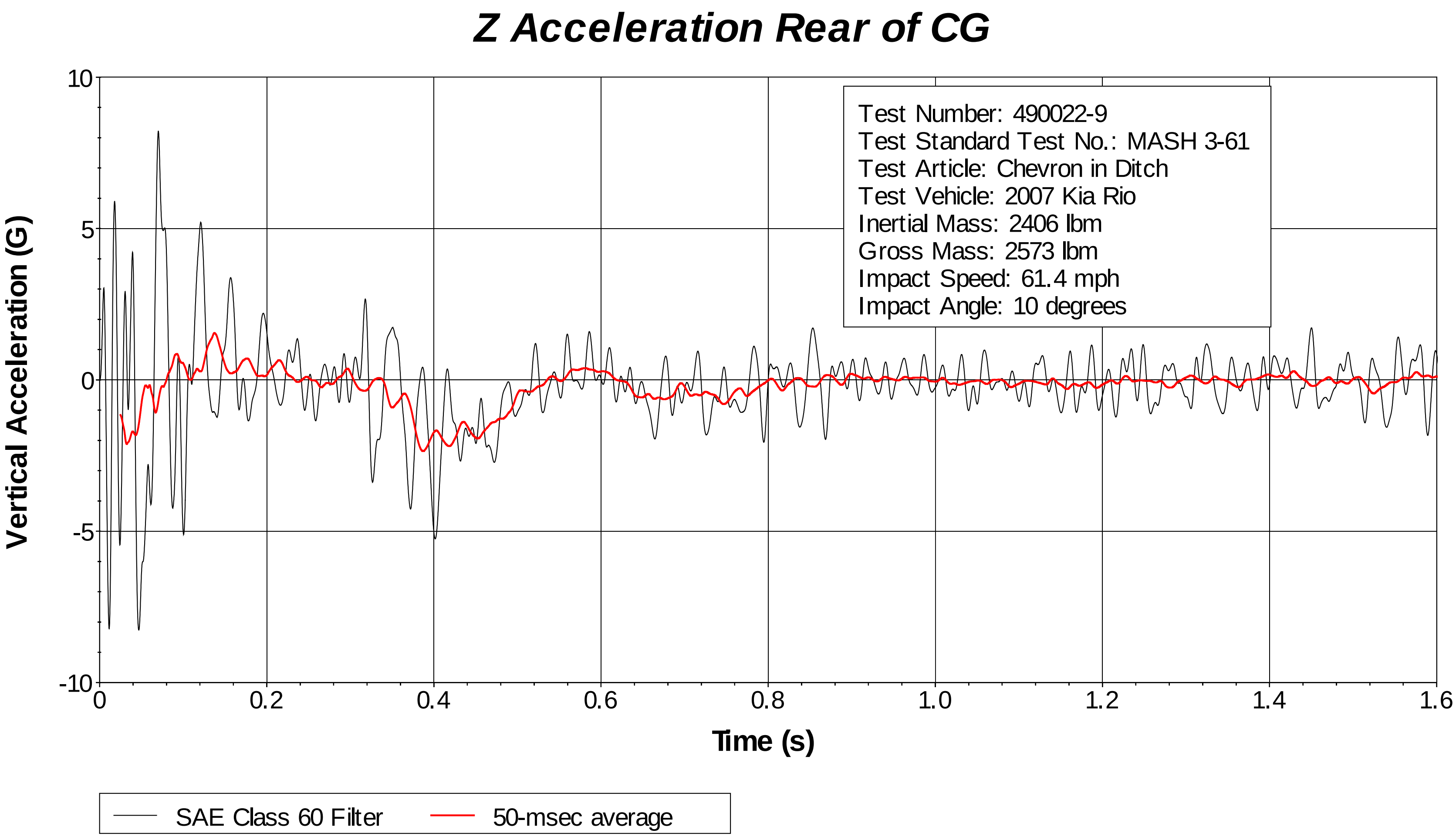


Figure D7. Vehicle Vertical Accelerometer Trace for Test No. 490022-9 (Accelerometer Located Rear of Center of Gravity).