GEORGIA DOT RESEARCH PROJECT 16-26

FINAL REPORT

CRASH TESTS ON GUARDRAIL SYSTEMS EMBEDDED IN ASPHALT VEGETATION BARRIERS IN ACCORDANCE WITH GDOT DESIGN SPECIFICATIONS

Georgia Department of Transportation

OFFICE OF PERFORMANCE-BASED MANAGEMENT AND RESEARCH
15 KENNEDY DRIVE
FOREST PARK, GA 30297-2534

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16. Abstract:
The Georgia Department of Transportation authorized a series of tests to be performed on guardrails installed in accordance with GDOT Standard Detail S-4-2002, which was used in Georgia prior to 2017 and includes an asphalt mow strip with nearby curb. The University of Nebraska's Midwest Roadside Safety Facility (MwRSF) was selected to perform the tests in accordance with AASHTO's *Manual for Assessing Safety Hardware* (MASH 2016). A single crash test was performed using Test Vehicle 1100C, a small passenger car. The crash test results exceeded multiple MASH safety evaluation criteria, including occupant compartment deformation, windshield crushing, and maximum allowable Occupant Ridedown Acceleration (ORA). Thus, the Midwest Guardrail System (MGS) installed in an asphalt mow strip with a curb placed behind the barrier was deemed to be unacceptable according to the TL-3 safety performance criteria for test designation no. 3-10 provided in MASH 2016.

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Final Report

CRASH TESTS ON GUARDRAIL SYSTEMS EMBEDDED IN ASPHALT VEGETATION BARRIERS IN ACCORDANCE WITH GDOT DESIGN SPECIFICATIONS

By

David Scott, Associate Professor

Lauren Stewart, Assistant Professor

Donald White, Professor

Georgia Tech Research Corporation
Atlanta, Georgia

Contract with

Georgia Department of Transportation

In cooperation with

U.S. Department of Transportation
Federal Highway Administration

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EXECUTIVE SUMMARY

Steel guardrail is the most common roadside barrier installed along Georgia's 20,000 miles of interstates and state routes. The objective of this multiphase research program is to evaluate the structural behavior of guardrail posts embedded through asphalt layers. Phase I of this research focused on static evaluation and numerical simulation of the structural performance of guardrail posts installed in accordance with current Georgia Department of Transportation (GDOT) procedures to include a mow strip as well as alternative installation options developed in consultation with GDOT. A subset of the most promising alternative installation methods was selected for further evaluation under subcomponent dynamic loading in the Phase II effort. The results from the dynamic tests were used to refine and expand the results of finite element analysis (FEA) of both the subcomponent tests as well as full-scale crash test simulations. Phase III of the research program presents the results of a *Manual for Assessing Safety Hardware* (MASH 2016) full-scale crash test performed on a standard guardrail system installed with an asphalt mow strip; the results of this test are the subject of the present report.

The Georgia Department of Transportation authorized a series of tests to be performed on guardrails installed in accordance with GDOT Standard Detail S-4-2002. The University of Nebraska's Midwest Roadside Safety Facility (MwRSF), located in Lincoln, Nebraska, was selected to perform the tests in accordance with AASHTO's MASH 2016. A single crash test was performed using Test Vehicle 1100C, a small passenger car, on February 14, 2017.

The crash test results exceeded multiple MASH safety evaluation criteria, including occupant compartment deformation, windshield crushing, and maximum allowable

Occupant Ridedown Acceleration (ORA). Thus, the barrier installation in test GAA-1 exhibited unacceptable safety performance. There were some minor discrepancies between the test site and the GDOT S-4-2002 drawing detail. However, the failure of test GAA-1 to satisfy MASH criteria cannot be attributed to those discrepancies.

The GDOT S-4-2002 mow strip configuration is no longer in use by GDOT. Beginning March 15, 2017, GDOT directed that all new guardrail construction projects on Georgia roadways use asphalt layers that are paved up to the face of the post, leaving the post itself and the area behind unrestrained.

ACKNOWLEDGEMENTS

The following individuals at GDOT provided many valuable suggestions throughout this study: Mr. Brent Story, State Design Policy Engineer; Mr. Daniel Pass, Assistant State Design Policy Engineer; Mr. Beau Quarles, Assistant Construction Engineer; and Mr. David Jared, Assistant Office Head (Research), Office of Performance-based Management and Research.

The opinions and conclusions expressed herein are those of the authors and do not represent the opinions, conclusions, policies, standards, or specifications of GDOT or of other cooperating organizations.

The MASH testing described herein was performed at the University of Nebraska's Midwest Roadside Safety Facility in Lincoln, Nebraska. Ron Faller, John Reid, Karla Lechtenberg, Michael Sweigard, and Erin Urbank facilitated the setup and completion of the testing, and submitted the final report detailing the crash test results.

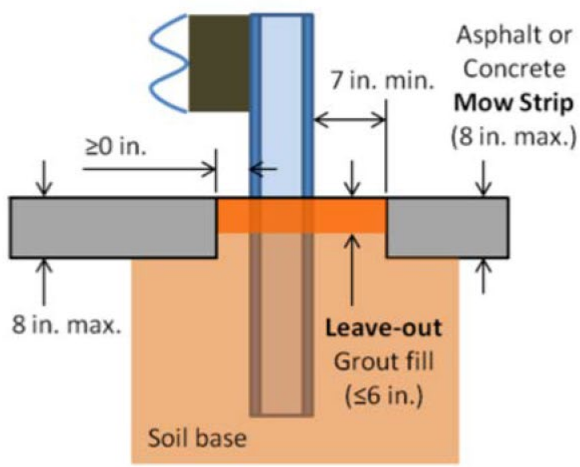
The authors express their profound gratitude to all of these individuals for their assistance and support during the completion of this research project.

CHAPTER 1. INTRODUCTION AND BACKGROUND

1.1 Problem Statement

Prior to March 2017, the preferred procedure for steel guardrail installation in the state of Georgia [1,2] employed a post-installation machine, which is typically hydraulic, to drive the posts through a layer of asphalt (i.e., a "mow strip") placed to retard vegetation growth around the system (Figure 1a). This procedure was outlined in Georgia Department of Transportation (GDOT) Standard Detail S-4-2002 (referred to hereafter as GDOT S-4-2002). However, to avoid undesirable restraint at the ground line, the Fourth Edition of the AASHTO *Roadside Design Guide* [3] recommends a post installed incorporating grout leave-outs (LOs) (Figure 1b). This recommendation is based on research performed by the Texas Transportation Institute (TTI) [4,5].

(a)



(b)

FIGURE 1 Guardrail Installations: (a) Typical Installation in Georgia; (b) Installation Incorporating Grout Leave-outs as Recommended in the *Roadside Design Guide* [3]

1.2 Project Objectives

The objective of this research program was to evaluate the structural behavior of guardrail posts embedded through asphalt layers. Phase I of this research focused on static evaluation and numerical simulation of the structural performance of guardrail posts installed in accordance with current GDOT procedures that include a mow strip [6], as well as alternative installation options developed in consultation with GDOT. A subset of the most promising alternative installation methods was selected for further evaluation under subcomponent dynamic loading in the Phase II effort [7]. The dynamic tests' results were used to refine and expand the results of finite element analyses (FEAs) of both the subcomponent tests as well as full-scale crash test simulations. Phase III of the research program entailed a *Manual for Assessing Safety Hardware* (MASH) [8] full-scale crash test performed on a standard guardrail system installed in accordance with GDOT S-4-2002; the results of this test are the subject of the present report.

Steel guardrail is the most common roadside barrier installed along Georgia's 20,000 miles of interstates and state routes [9]. This multiphase research program addresses a specific concern raised by GDOT personnel relating to the safety and efficacy of current state guardrail installation procedures in comparison to guidelines found in the *Roadside Design Guide*. The safety and effectiveness of the guardrail systems installed using these procedures must be rigorously evaluated to ensure compliance with Federal Highway Administration (FHWA) guidelines.

1.3 Background

A large volume of work exists in the literature regarding the testing and evaluation of guardrail posts and systems. Summaries of representative work specifically related to crash testing on longitudinal barriers are presented below.

1.3.1 Full-scale Crash Testing Using NCHRP 350 Guidelines

Mak et al. [10] classified the most frequently used guardrail systems into six categories (i.e., Cable, W-beam weak post, W-beam strong post, Box-beam, Thrie-beam, and Modified Thrie-beam) and performed eight full-scale crash tests in accordance with National Cooperative Highway Research Program (NCHRP) Report 350 [11] guidelines. The purpose of their experimental study was to evaluate the crash performance of all existing guardrail systems and to inform if the devices in the systems need to be redesigned to improve their crash performance. Bullard et al. [12] tested a modified W-beam guardrail system replacing W6×9 (W150×13.5) steel flange blockouts (also known as “rail spacer” or “offset block”) with nominal 6-in.×8-in. (152 mm × 203 mm) timber blockouts. The guardrail system showed a satisfactory crash performance under the same test conditions as the previous study. Bligh et al. [13] tested a combination of shorter (5 ft 6 in.) steel posts with less embedment depth (38 in. [965 mm]) and reduced-size (6-in.×6-in.) timber blockouts compared to those same parameters (6 ft 0 in., 44 in. [1118 mm], and 6-in.×8-in., respectively) of the previous study by Bullard et al. [12].

Researchers have performed multiple experimental studies evaluating specific design modifications that incorporate alternative components of the guardrail system. Bligh and Menges [14] tested guardrail systems with standard steel posts and recycled polyethylene blockouts. Buth et al. [15] tested a modified guide rail in conjunction with the current W-beam guardrail system.

W-beam guardrail systems under specific roadside conditions were also investigated. Bullard and Menges [16] tested a guardrail system consisting of wood posts installed with 4-inch-high asphaltic curb under the rail. Rohde and Herr [17] investigated the performance of guardrail systems when steel posts were installed in rock foundation.

The Midwest Guardrail System (MGS) [18], tested and evaluated under NCHRP 350, is a non-proprietary guardrail system developed by the Midwest Roadside Safety Facility (MwRSF). Several full-scale crash tests [19–21] demonstrated that design modifications improved the crash performance of the system, compared to the performance and failure modes observed in previous crash test results performed by TTI [10,15]. Polivka et al. [22] performed a total of six full-scale crash tests to investigate the alternative design of the guardrail system with reduced post spacing (half and quarter) and a design configured with 6-inch-tall concrete curbs under the rail. Bielenberg et al. [23] performed two full-scale crash tests to investigate the application of the MGS with long-span culverts.

1.3.2 Full-scale Crash Testing Using MASH Guidelines

Wiebelhaus et al. [24] tested the performance of the MGS (Midwest Guardrail System) placed adjacent to steep roadside slopes in accordance with the MASH guidelines. The system, incorporating 9-ft-long steel posts with a standard post spacing of 75 in., showed satisfactory performance under the MASH full-scale crash test criteria as well as under NCHRP 350 criteria.

Bligh et al. [25] reviewed the W-beam guardrail standards and installation methods of the Texas Department of Transportation (TxDOT) using MASH. This research group evaluated a 31-in.-tall W-beam guardrail system incorporating conventional 8-in.-deep offset blocks, and the system met all required MASH performance criteria.

Williams and Menges [26] performed a research study testing the W-beam guardrail on a low-fill box culvert in accordance with MASH. This study incorporated the use of standard W6×9 steel posts with welded base plate details and an epoxy anchoring system for a simplified installation. The guardrail system was tested under the MASH Test 3-11 conditions and performed acceptably.

Stolle et al. [27] evaluated the MGS with two different mounting-height and embedment-depth combinations and then established the maximum mounting height of the system under MASH. While there had been a recommended minimum top rail mounting height of 27¾ in. according to the full-scale tests in compliance with NCHRP 350, no maximum height recommendation existed. This research group performed two full-scale crash tests on the different MGS setups: (1) 34-in. height and 37-in. depth and (2) 36-in. height and 35-in. depth. Both system heights/depths were found to meet the MASH evaluation criteria.

Schrum et al. [28] evaluated the MGS without offset blocks. Since a narrow roadside condition hinders the use of standard 12-in. offset blocks in the W-beam guardrail system, several state departments of transportation requested the development of a non-proprietary, non-blocked MGS, which can be a comparable option to the proprietary guardrail systems with higher costs. Accordingly, the non-blocked MGS was modified to have additional rail components, and the modified MGS was successfully tested using a small passenger car (MASH Test 3-10) and a pickup truck (MASH Test 3-11). The research showed an alternative for W-beam guardrail installation when the roadside width is restricted.

Weiland et al. [29] investigated the minimum effective guardrail length for the MGS. Compared to the recommended standard minimum length of 175 ft based on crash testing in accordance with NCHRP 350 and MASH, the research group showed a reduced 75-ft-long MGS performing satisfactorily under the MASH 3-11 full-scale test condition. The researchers also suggested by computer simulation results the possible use of the shorter length of 50-ft and 62-ft 6-in. MGS configurations, but no crash tests were performed on those configurations.

Rosenbaugh et al. [30] performed a series of dynamic impact tests on weak steel posts (S3×5.7) embedded in different ground restraint conditions including concrete mow strips, asphalt mow strips, and steel sockets with shear plates. A total of 11 bogie vehicle tests were run and one test configuration with 6-in.-thick asphalt mow strip and 30-in. embedment depth of the socket was successfully tested under MASH Test 3-11. The research team showed a weak-post, W-beam guardrail system with mow strip is crashworthy when properly designed and installed.

Jowza et al. [31] investigated the performance of wood guardrail posts encased in asphalt mow strips and placed on slopes. Dynamic bogie vehicle tests were performed on wood posts encased in 2-in. asphalt mow strip. In the majority of the tests, wood posts could rotate backward and break the asphalt layer but with an increase in post-soil resistance as compared to tests conducted without the asphalt mow strip.

1.4 Report Organization

Chapter 2 of this report summarizes the planning and setup of the MASH test program used to evaluate the performance of a standard guardrail system installed in accordance with GDOT S-4-2002.

Chapter 3 summarizes the results from this test program carried out in February 2017. Key findings from the tests are presented.

Chapter 4 contains the conclusions for Phase III of this research program.

Chapter 5 contains the references cited in this report.

The Appendix contains the full report submitted by the University of Nebraska Midwest Roadside Safety Facility (MwRSF) for the MASH crash test performed at their facility.

CHAPTER 2. MASH TEST SCOPE AND TEST SETUP

2.1 Selection of MASH Test Location and Scope of Testing

To provide a more definitive assessment of the dynamic performance of steel guardrails installed in asphalt layers without leaveouts, the Georgia Department of Transportation authorized a series of tests to be performed on guardrails installed in accordance with GDOT S-4-2002. After a thorough background investigation by the research team, the University of Nebraska's Midwest Roadside Safety Facility, located in Lincoln, Nebraska, was selected to perform the tests. This organization was selected based on its extensive experience with both NCHRP 350 and MASH testing on a broad range of roadside safety hardware.

In consultation with GDOT personnel in the Office of Design Policy and Support along with MwRSF technical experts, the following intial scope of work was agreed upon:

1. Development of 3-D CAD details and 2-D plans for the 175-ft-long MGS barrier installation with asphalt mow strip and curb
2. Acquisition of construction materials, mill certifications, material specifications, and Certificates of Conformity
3. Construction of test article at MwRSF's outdoor proving grounds
4. Execution of one test level 3 (TL-3) full-scale vehicle crash test with an 1100C small passenger car at 62 mph and 25 degrees into the barrier system according to MASH Test 3-10
5. Execution of one TL-3 full-scale vehicle crash test with a 2270P pickup truck at 62 mph and 25 degrees into the barrier system according to MASH Test 3-11
6. Analysis and evaluation of crash test results

7. Removal of damaged hardware from barrier and asphalt systems, as well as disposal of debris and site restoration
8. Documentation and preparation of summary research report

2.2 Test Site Design and Construction

A test installation site approximately 182 ft in length was constructed at the MwRSF proving grounds beginning in December 2016, with completion in February 2017. The general layout for the test installation is shown in Figure 2.

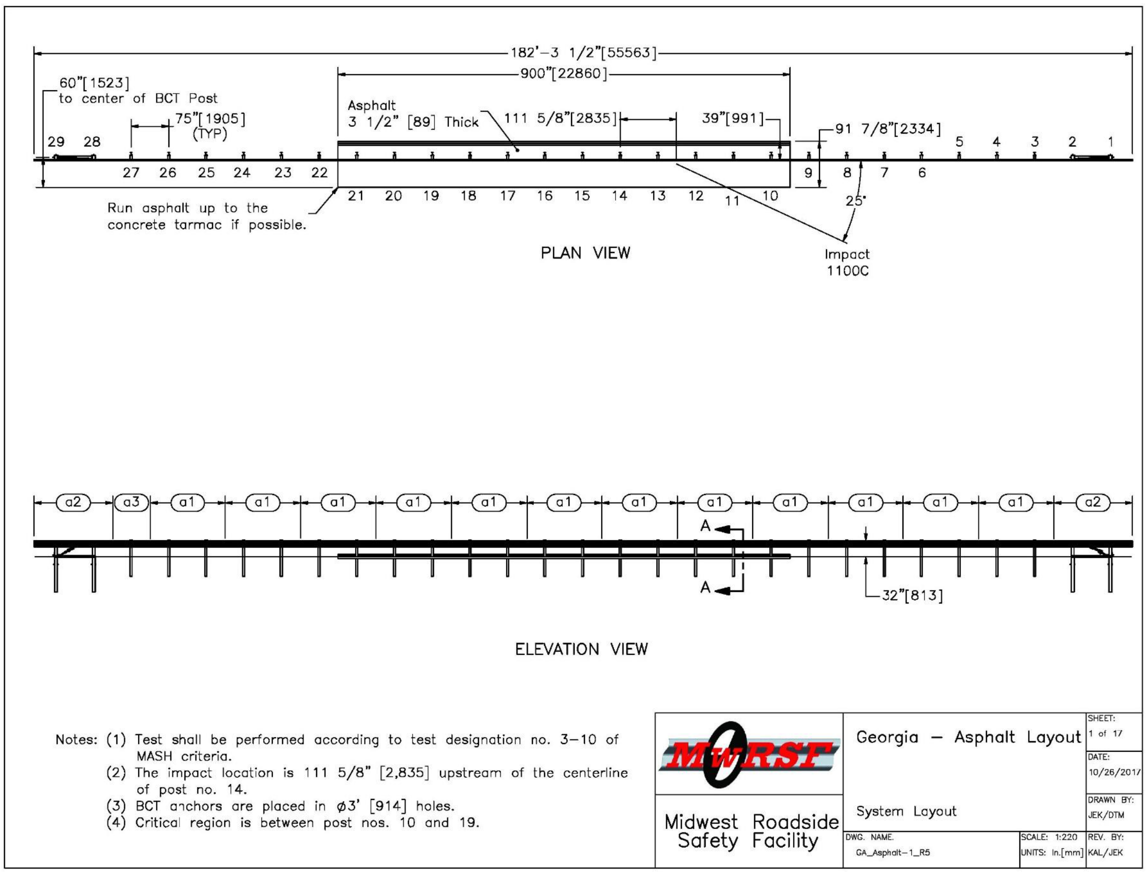


FIGURE 2 Test Installation Layout for MASH Test 3-10

A detailed description of the test bed construction is given in Chapter 3 of the MwRSF report found in the Appendix. In general, the installation of the test site appeared to adhere to the material specifications and dimensions found in GDOT S-4-2002. One variation was noted in that the GDOT detail indicates a graded slope located approximately 42 in. behind the face of the guardrail, as shown in Figure 3. As can be seen in Figure 4, the area behind the post in the test installation was graded horizontal, with an additional pad/test bed located behind the test bed.

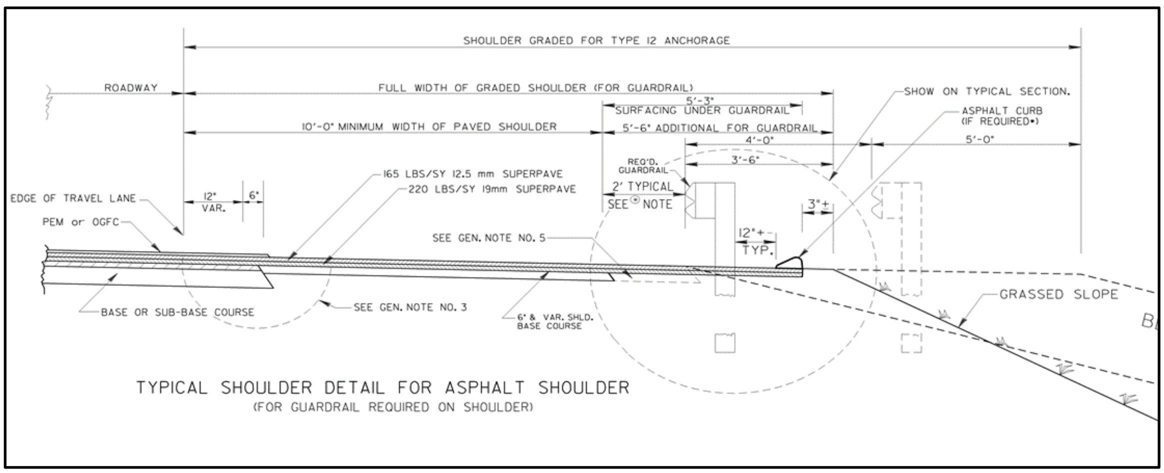


FIGURE 3 GDOT Drawing Detail S-4-2002 [2]

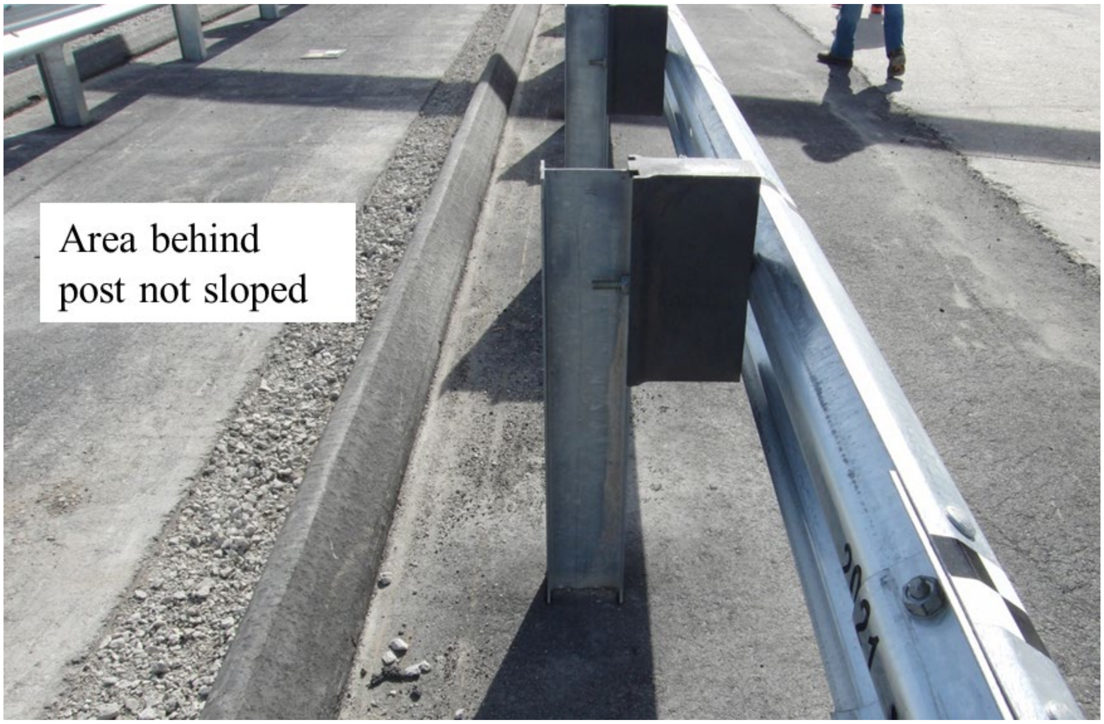


FIGURE 4 Test Bed Site – View Showing Area Directly Behind the Post

One other variation was noted in the test bed compared to a standard installation on Georgia roadways. As shown in Figure 5, in Georgia, posts are installed by driving them through the asphalt using a hydraulic post driver. However, for the test bed installation at the MwRSF proving grounds, the ends of each post were first heated using a torch to a high temperature. The heated posts were then driven through the asphalt layer, effectively melting the asphalt around the installation location. As such, there was no fracturing in the asphalt layer around the post, as is commonly seen in installations in Georgia. A typical installed post on the test bed site is shown in Figure 6.

FIGURE 5 Typical Post Installation Procedure in Georgia

FIGURE 6 Typical Post Installation at MwRSF Test Site

2.3 Test Conditions and Evaluation Criteria

Detailed information on the test conditions and evaluation criteria can be found in Chapter 2 of the MwRSF report located in the Appendix. A summary of pertinent details is presented in this section. Longitudinal barriers such as W-beam guardrails must satisfy impact safety standards set forth in the guidelines and procedures found in the MASH criteria. To satisfy test level 3 of MASH, the barriers must be subjected to two full-scale vehicle crash tests, as summarized in Table 1.

TABLE 1 MASH Test Level 3 Crash Test Conditions

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight (lb)	Impact Conditions		Evaluation Criteria[1]
				Speed (mph)	Angle (deg)	
Longitudinal Barrier	3-10	1100C	2425	62.0	25	A,D,F,H,I
	3-11	2270P	5000	62.0	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the barrier (i.e., W-beam guardrail system installed in an asphalt mow strip with a curb placed behind the barrier) to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria used for the test at MwRSF are summarized in Table 2.

TABLE 2 MASH Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g's</td><td>20.49 g's</td></tr>
</table>

2.4 Test Vehicle / Simulated Occupant / Instrumentation

Detailed information on the test vehicle setup and instrumentation can be found in Chapter 4 of the MwRSF report located in the Appendix. A summary of pertinent details is presented in this section. The first test to be performed was labeled by MwRSF as GAA-1. The vehicle used in this test was a 2011 Kia Rio as shown in Figure 7. A Hybrid II

50th-Percentile Adult Male Dummy, equipped with clothing and footware, was placed in the right-front of the test vehicle as shown in Figure 8.

FIGURE 7 2011 Kia Rio Used as Test Vehicle for GAA-1, TL 3-10

FIGURE 8 Simulated Occupant in Test Vehicle for GAA-1, TL 3-10

A wide range of sensors and instrumentation was used in the test, including accelerometers, rate transducers, retroflective optics, load cells, and high-speed digital photography and video. Detailed descriptions of sensor types, locations, and data acquisition procedures may be found in Section 4.5 of the MwRSF report located in the Appendix.

A reverse-cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed. A vehicle guidance system was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system.

CHAPTER 3. FULL-SCALE CRASH TEST GAA-1 UNDER TEST CONDITION TL 3-10

Detailed information on the crash test and the resulting evaluation of results may be found in Chapter 5 of the MwRSF report located in the Appendix. Pertinent results from this test are presented in this chapter. Test GAA-1 was conducted on February 14, 2017, at approximately 2:15 p.m. The weather conditions at the time of the test are shown in Table 3.

TABLE 3 Weather Conditions for Test GAA-1 on 02/14/2017

Temperature	53°F
Humidity	32%
Wind Speed	17 mph
Wind Direction	320° from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in.
Previous 7-Day Precipitation	0.01 in.

3.1 Test Description and Results

The small car, with a test inertial weight of 2,392 lb, impacted the strong-post, W-beam guardrail system installed with posts driven into an asphalt mow strip with a curb placed behind the barrier at a speed of 62.8 mph and at an angle of 25.1 degrees. Damage to the barrier was extensive, and consisted of rail deformation, contact marks on the front face of the guardrail, guardrail disengagement from posts, deformed steel posts, buckling of numerous posts at the groundline, and asphalt gouging. Damage to the vehicle was also extensive, with the majority concentrated on the right-front corner and the front side of the vehicle. A series of sequential photographs is shown in Figure 9. A sequential description of impact events is given in Table 4. A summary of the safety performance evaluation for the test is given in Table 5. The occupant compartment deformation for the roof was 5.125 in., which exceeded the MASH limit of 4 in. The windshield was crushed inward 7.125 in., which exceeded the MASH limit of 3 in. The maximum longitudinal ORA value of −21.80 g's exceeded the MASH limit of 20.49 g's. Thus, the barrier installation in test GAA-1 exhibited unacceptable safety performance. Based on this test result, the second planned test using test vehicle 2270P (pickup truck) was cancelled.

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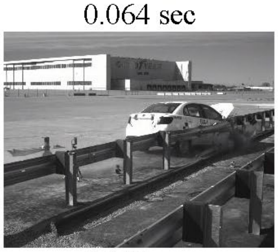

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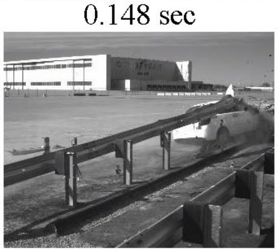

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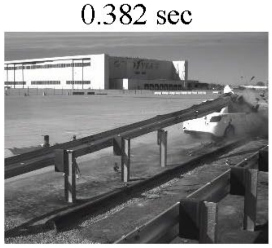

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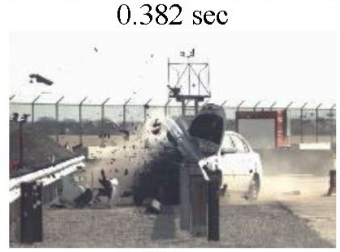

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FIGURE 9 Sequential Photographs for Test GAA-1, TL 3-10 on 2/14/17

TABLE 4 Sequential Description of Impact Events for Test GAA-1

Time (s)	Event
0.000	Vehicle's right front bumper contacted rail between posts 12 and 13.
0.005	Post no. 13 deflected backward.
0.010	Post no. 11 twisted clockwise. Vehicle's right headlight shattered.
0.024	Vehicle's right front door contacted rail and deformed.
0.028	Vehicle's right A-pillar deformed.
0.038	Vehicle's right front tire contacted post no. 13.
0.041	Vehicle underrode rail.
0.052	Rail disengaged from bolt at post no. 13.
0.062	Vehicle's right-side airbag deployed.
0.064	Vehicle pitched downward and left-side airbag deployed.
0.068	Vehicle's windshield shattered from right-side airbag deployment.
0.074	Post no. 14 deflected downstream.
0.082	Vehicle's front bumper contacted post no. 14.
0.092	Rail disengaged from bolt at post no. 10.
0.098	Vehicle's right mirror contacted rail and deformed.
0.104	Rail disengaged from bolt at post no. 14, along with vehicle's bumper.
0.120	Rail disengaged from bolt at post no. 6.
0.136	Rail disengaged from bolt at post no. 8.
0.138	Rail disengaged from bolt at post nos. 4 and 7.
0.182	Vehicle's left front tire became airborne.
0.186	Rail disengaged from bolt at post no. 12. Vehicle's left-front bumper disengaged. Vehicle's front bumper contacted post no. 15.
0.202	Blockout no. 15 disengaged from rail at post no. 15.
0.207	Vehicle's left-front headlight disengaged and blockout no. 15 disengaged from post no. 15.
0.220	Vehicle's right A-pillar contacted rail.
0.285	Vehicle underrode rail and rail disengaged from bolt at post no. 16.
0.348	Vehicle contacted post no. 16.
0.360	Vehicle's roof underrode rail.
0.526	Vehicle contacted post no. 17.
0.648	Rail disengaged from bolt at post no. 17.
1.217	Vehicle came to rest.

TABLE 5 Summary of Safety Performance Evaluation Results for Test GAA-1

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. GAA-1[1]</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>U</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td rowspan="4">U</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
<tr><td colspan="5">MASH 2016 Test Designation No.</td><td>3-10</td></tr>
<tr><td colspan="5">Final Evaluation (Pass or Fail)</td><td>Fail</td></tr>
</table>

[1] S – Satisfactory U – Unsatisfactory NA – Not Applicable

3.2 Posttest Analysis of Asphalt Layer Characteristics

It was noted that many of the posts impacted during test GAA-1 did not translate at all in the asphalt layer, with a hinge forming right at the groundline and the post buckling as shown in Figure 10. This behavior differed significantly compared to static and dynamic subcomponent testing done at Georgia Tech during Phases 1 and 2 of this research program, where significant post translation at the groundline was typically observed.

FIGURE 10 Buckled Post from Test GAA-1

At the request of the Georgia Tech research team, a number of these posts were excavated and the resulting holes examined. Rough estimates using hand rulers indicated that the asphalt layer may have been slightly thicker than the 3.5 inches specified in GDOT S-4-2002. As such, three cores were recovered from the test site asphalt layer for analysis and testing. To determine a representative strength, each specimen was taken from a different location: (1) near the impact point of the crash vehicle, (2) the upstream section, and (3) the downstream section. Based on the heights of the cores taken from the test site, the asphalt strip at the site ranged from 3.75 to at least 4.25 inches in thickness. Though this was higher than the value specified in the GDOT detail, asphalt mow strips of this thickness and more are routinely encountered in Georgia. Compression tests on the cores were performed at the Structural Engineering Mechanics and Materials (SEMM) Laboratory on the Georgia Tech campus. All test protocols were based on ASTM D1074-09: "Standard Test Method for Compressive Strength of Bituminous Mixtures" [32]. Figure 11 includes compression test results and other test information including specimen dimension, test condition, and photographs taken during the test. All specimens showed a similar failure mode represented by lateral expansion and vertical cracks. The average compressive strength from the 3 cores was approximately 400 psi. This value was higher than the average value of approximately 250 psi found for the asphalt used in the laboratory testing, but asphalt strengths in Georgia could reasonably be expected to approach this value in cold weather months. In addition, the cylinders from the MwRSF test site did fail in a manner similar to that seen in cores from asphalt used in Phases 1 and 2 of the research program. As such, the asphalt layer was not considered to be significantly unrepresentative of mow strips found on Georgia roadways.

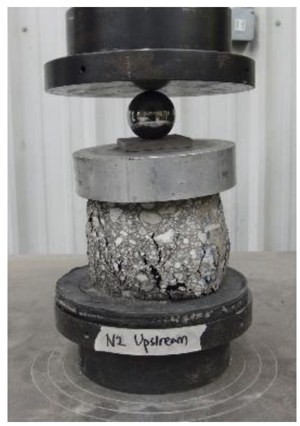
Specimen	N-01	N-02	N-03
Core location	Near the impact point	Upstream section	Downstream section
Test picture (setup)			
Test picture (failure)			
Actual diameter	3.70 in.	3.70 in.	3.70 in.
Thickness (height)	4.25 in.	3.75 in.	3.80 in.
Test temperature	70°F	71°F	67°F
Age of specimen	76 days (curing time from asphalt placement)		
Compressive strength	371.0 psi	396.5 psi	430.6 psi
	Average compressive strength = 399.4 psi		

FIGURE 11 Test Results from Asphalt Cores Taken from MwRSF Site After Test GAA-1

CHAPTER 4. CONCLUSIONS

The following conclusions can be drawn from the Phase 3 research project:

1. The guardrail installation including an asphalt layer used in Test GAA-1 at the Midwest Roadside Safety Facility in Lincoln, Nebraska, on 02/14/17 failed to satisfy safety performance criteria as designated in the AASHTO *Manual for Assessing Safety Hardware* 2016 edition.
2. There were some discrepancies between the test site and the GDOT S-4-2002 drawing detail. These discrepancies included a lack of a sloped region behind the layer installation, and a slightly thicker asphalt layer than that specified. In addition, the posts were installed by melting through the asphalt layer instead of being driven through as they are in Georgia. The asphalt used on the test site also had a higher compressive strength than that used in laboratory testing during this research program, but the average compressive strength determined from test site cores would not be considered unusual compared to asphalt used on Georgia roadways. As such, the failure of test GAA-1 to satisfy MASH criteria cannot be attributed to these discrepancies.
3. The GDOT S-4-2002 mow strip configuration is no longer in use by GDOT. Beginning March 15, 2017, all new GDOT guardrail construction projects on Georgia roadways were directed to use asphalt layers that were paved up to the face of the post, leaving the post itself and the area behind unrestrained. As such, new guardrail post installations will not be subject to additional restraint by asphalt layers.

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APPENDIX RESEARCH REPORT TRP-03-377-17 FROM THE MIDWEST ROADSIDE SAFETY FACILITY

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Research Project Number RH099-S1

MASH 2016 TEST NO. 3-10 OF MGS INSTALLED IN AN ASPHALT MOW STRIP WITH NEARBY CURB (TEST NO. GAA-1)

Submitted by

Michael E. Sweigard
Undergraduate Research Assistant

Karla A. Lechtenberg, M.S.M.E., E.I.T.
Research Engineer

Ronald K. Faller, Ph.D., P.E.
Research Associate Professor
Director, MWRSF

John D. Reid, Ph.D.
Professor

Erin L. Urbank, B.A.
Research Communication Specialist

MIDWEST ROADSIDE SAFETY FACILITY
Nebraska Transportation Center
University of Nebraska-Lincoln

Main Office
Prem S. Paul Research Center at Whittier School
Room 130, 2200 Vine Street
Lincoln, Nebraska 68583-0853
(402) 472-0965

Outdoor Test Site
4630 NW 36th Street
Lincoln, Nebraska 68524

Submitted to

GEORGIA INSTITUTE OF TECHNOLOGY
790 Atlantic Drive
Atlanta, Georgia 30332

MwRSF Research Report No. TRP-03-377-17

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Nebraska Transportation Center
University of Nebraska-Lincoln
Main Office:
Prem S. Paul Research Center at Whittier School
Room 130, 2200 Vine Street
Lincoln, Nebraska 68583-0853
Outdoor Test Site:
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16. Abstract

The objective of this research study was to evaluate the performance of a Georgia Department of Transportation's (GDOT) strong-beam, W-beam guardrail system with posts driven through an asphalt mow strip with the inclusion of a nearby curb. The Midwest Roadside Safety Facility (MwRSF) conducted one full-scale crash test on the standard Midwest Guardrail System (MGS) installed in an asphalt shoulder with a nearby asphalt curb in accordance with GDOT Standard Detail S-4-2002. The test was conducted and evaluated according to test designation no. 3-10 using the Test Level 3 (TL-3) criteria found in the *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016).

Test no. GAA-1 consisted of a 2,392-lb (1,085-kg) small car impacting the MGS at a speed of 62.8 mph (101.1 km/h) and at an angle of 25.1 degrees for an impact severity of 56.8 kip-ft (77 kJ). The vehicle was contained, but it did not redirect the vehicle as it came to rest within the system. A 1-in. (25-mm) long tear was found in the vehicle's left-rear floor pan, the occupant compartment deformation limit for the roof exceeded the MASH 2016 limit, and a maximum longitudinal ORA value of -21.80 g's exceeded the MASH 2016 limit of 20.49 g's. Thus, the MGS installed in an asphalt mow strip with a curb placed behind the barrier was deemed to be unacceptable according to the TL-3 safety performance criteria for test designation no. 3-10 provided in MASH 2016.

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Highway Safety, Crash Test, Roadside Appurtenances, Compliance Test, MASH 2016, Asphalt, Mow Strip, Paved Shoulder, Curb, MGS, Midwest Guardrail System, Guardrail</td><td colspan="2">18. Availability Statement
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DISCLAIMER STATEMENT

This report was completed with funding from the Georgia Institute of Technology (GT). The contents of this report reflect the views and opinions 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 views or policies of the Georgia Institute of Technology. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Scott K. Rosenbaugh, Research Engineer.

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Midwest Roadside Safety Facility

J.C. Holloway, M.S.C.E., E.I.T., Assistant Director – Physical Testing Division
R.W. Bielenberg, M.S.M.E., E.I.T., Research Engineer
J.D. Schmidt, Ph.D., P.E., Research Assistant Professor
C.S. Stolle, Ph.D., Research Assistant Professor
M. Asadollahi Pajouh, Ph.D., Post-Doctoral Research Associate
S.A. Ranjha, Ph.D., Post-Doctoral Research Associate
A.T. Russell, B.S.B.A., Testing and Maintenance Technician II
S.M. Tighe, Construction and Testing Technician I
D.S. Charroin, Construction and Testing Technician I
M.A. Rasmussen, Construction and Testing Technician I
E.W. Krier, B.S., Construction and Testing Technician II
M.T. Ramel, B.S.C.M., Construction and Testing Technician I
R.M. Novak, Construction and Testing Technician I
J.E. Kohtz, B.S.M.E., CAD Technician
Undergraduate and Graduate Research Assistants

Georgia Department of Transportation

Beau Quarles, P.E., Assistant State Construction Engineer
Brent Story, P.E., State Design Policy Engineer
David M. Jared, P.E., Assistant Office Head / Research Section Head, Office of Performance-based Management and Research

Georgia Institute of Technology

David Scott, Ph.D., Associate Professor, Civil and Environmental Engineering
Don White, Ph.D., Professor, Civil and Environmental Engineering
Jeremy Mitchell, Facility Manager, Civil and Environmental Engineering

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1 INTRODUCTION

1.1 Background

The Georgia Department of Transportation (GDOT) is currently investigating the performance of a strong-beam, W-beam guardrail system with posts driven through an asphalt mow strip, which may also be referred to as a paved shoulder, with the inclusion of a nearby curb. Midwest Roadside Safety Facility (MwRSF) of the University of Nebraska-Lincoln (UNL) was contracted to conduct a full-scale crash test on the standard Midwest Guardrail System (MGS) installed in an asphalt mow strip with a nearby curb in accordance with GDOT Standard Detail S-4-2002 and typical curb detail, shown in Appendix A.

1.2 Objective/Scope

The objective of this research study was to evaluate the safety performance of the MGS with shoulder paving and surfacing under the barrier as well as a curb placed behind the barrier. The system was to be evaluated according to the Test Level 3 (TL-3) criteria found in the *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) [1]. One full-scale crash test was conducted according to MASH 2016 test designation no. 3-10. Data obtained from this crash test was analyzed, and the results were utilized to make conclusions and recommendations.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as W-beam guardrails, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [1]. Note that there is no difference between MASH 2009 and MASH 2016 for most longitudinal barriers, such as the guardrail system tested and evaluated in this project. According to TL-3 of MASH 2016, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 1.

Table 1. MASH 2016 TL-3 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed, mph (km/h)	Angle, deg.	
Longitudinal Barrier	3-10	1100C	2,425 (1,100)	62.0 (100.0)	25	A,D,F,H,I
	3-11	2270P	5,000 (2,268)	62.0 (100.0)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

2.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the barrier (i.e., W-beam guardrail system installed in an asphalt mow strip with a curb placed behind the barrier) to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH 2016. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in MASH 2016.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported. Additional discussion on PHD, THIV and ASI is provided in MASH 2016.

2.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH 2016, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, additional W6x16 (W152x23.8) posts are installed along the barrier system in critical regions, such as near the impact point and the end anchorages, utilizing the same installation procedures as the system itself. Prior to full-scale crash testing, a dynamic impact (i.e., bogie) test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips (33.4 kN) at post deflections between 5 and 20 in. (127 and 508 mm) measured at a height of 25 in. (635 mm). If dynamic testing near the system is not desired, MASH 2016 permits a static test to be conducted in lieu of the bogie test, where the new results are compared to the results from a previously-established baseline test. In this situation, the soil must provide a resistance of at least 90% of the static baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Further details can be found in Appendix B of MASH 2016.

Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
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<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

3 DESIGN DETAILS

The test installation measured 182 ft – 3½ in. (55.6 m) long and consisted of standard MGS installed in an asphalt mow strip and with a curb placed behind the barrier, as shown in Figures 1 through 17. A second guardrail system was installed behind the primary system (test no. GAA-1) for the subsequent test in this series that was not conducted. Photographs of test construction and installation are shown in Figures 18 through 22. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix C.

Standard 12-gauge (2.7-mm) thick W-beam rail segments were supported by 72-in. (1,829-mm) long, W6x8.5 (W152x12.6) steel posts. The W-beam rail was mounted with a top-rail height of 32 in. (813 mm). Rail splices were located at midspans between posts, as shown in Figure 3. The lap splice connections between the rail sections were configured to reduce the potential for vehicle snag at the splice during impact. The posts were spaced at 75 in. (1,905 mm) on center. Holes 36 in. (914 mm) wide were cored and filled with densely-compacted, coarse crush limestone strong soil at post locations before asphalt was laid, as recommended by MASH 2016 [1]. Post nos. 10 through 21 were driven through the approximately 3½-in. (89-mm) thick asphalt mow strip to an embedment depth of 39 in. (991 mm). A Mondo Polymer MGS14SH [2] blockout was used to offset the rail away from the front face of each steel post.

The upstream and downstream ends of the guardrail installation were configured with a trailing-end anchorage system. The guardrail anchorage system was utilized to simulate the tensile strength of other crashworthy end terminals. Each anchorage system consisted of timber posts, foundation tubes, anchor cables, bearing plates, rail brackets, and channel struts, which closely resembled the hardware used in the Modified BCT system and was consistent with hardware used in a crashworthy, downstream trailing end terminal [3-6]. Load cell assemblies were spliced into the upstream and downstream anchorage anchor cables to measure the loads experienced during full-scale crash testing.

A one-layer 75-ft (22.9-m) long by 3½-in. (89-mm) thick asphalt mow strip was located below the guardrail system. A 5-in. (127-mm) tall by 8-in. (203-mm) wide asphalt curb was placed 39 in. (991 mm) behind the front face of the guardrail or 14⅛ in. (359 mm) behind the back face of the posts. The total width of the asphalt mow strip behind the back face of the post was approximately 23 in. (584 mm). According to GDOT specifications, 12.5 mm Superpave asphalt should be used. This was substituted with NE SPR Binder PG 64-22 asphalt. Asphalt cores were taken from the downstream end, upstream end, and impact region of the system to evaluate asphalt thickness. Testing at the Structural Engineering Mechanics and Materials Laboratory at Georgia Institute of Technology found that core thickness ranged from 3¾ in. (95 mm) to 4¼ in. (108 mm) and the asphalt demonstrated an average compressive strength of approximately 400 psi. Further details are provided in Appendix B.

A heating system was used to ensure that the soil was not frozen during construction and before the full-scale crash test was conducted, as seen in Figure 19. The heating system is capable of thawing 18 in. (457 mm) of soil over a 12-hour period. Holes were drilled through the asphalt and into the frozen soil. Soil temperature was taken at a depth of 3 ft (914 mm) using an infrared thermometer probe. Prior to conducting the crash test, the soil temperature at bottom of the holes was approximately 60 degrees.

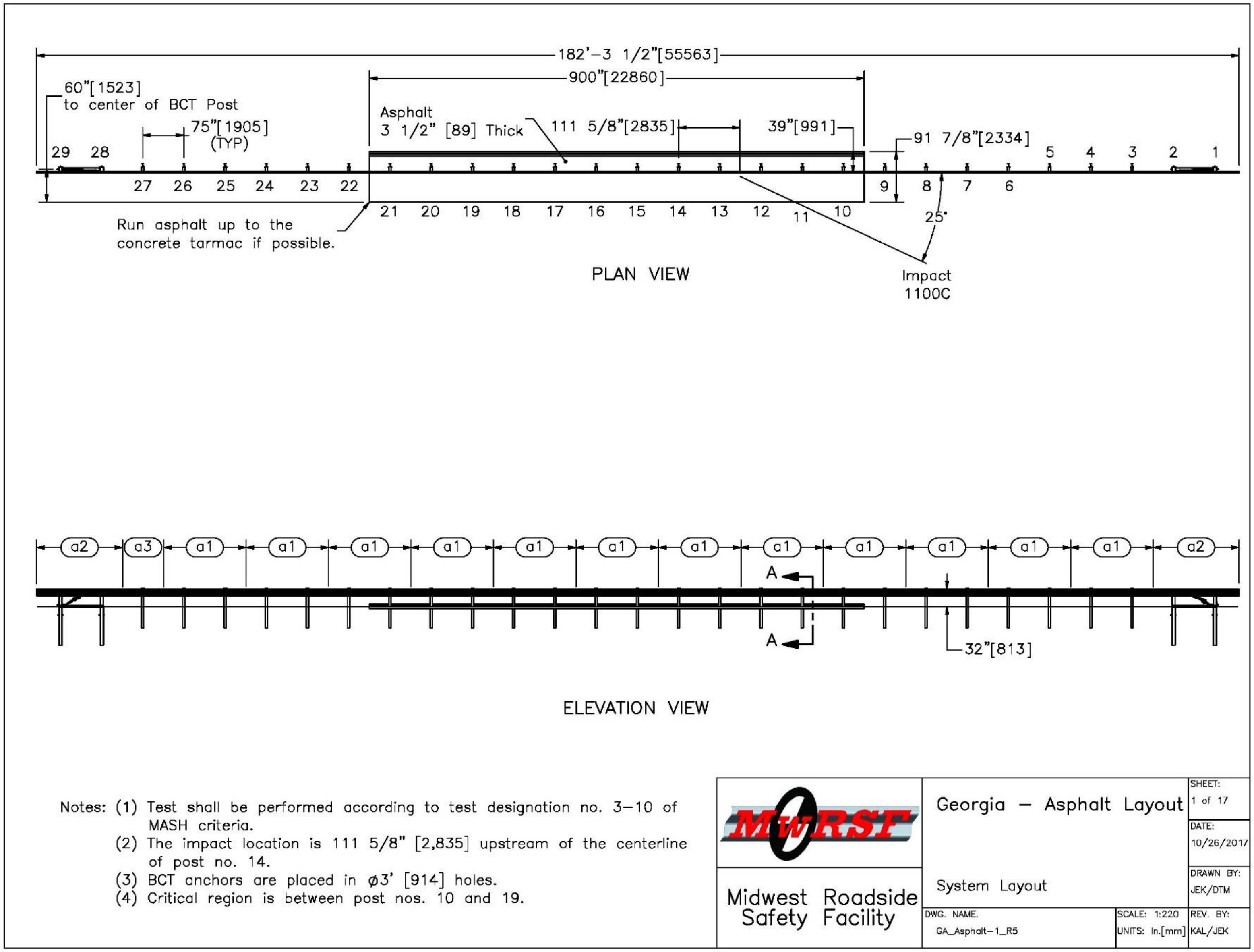


Figure 1. Test Installation Layout, Test No. GAA-1

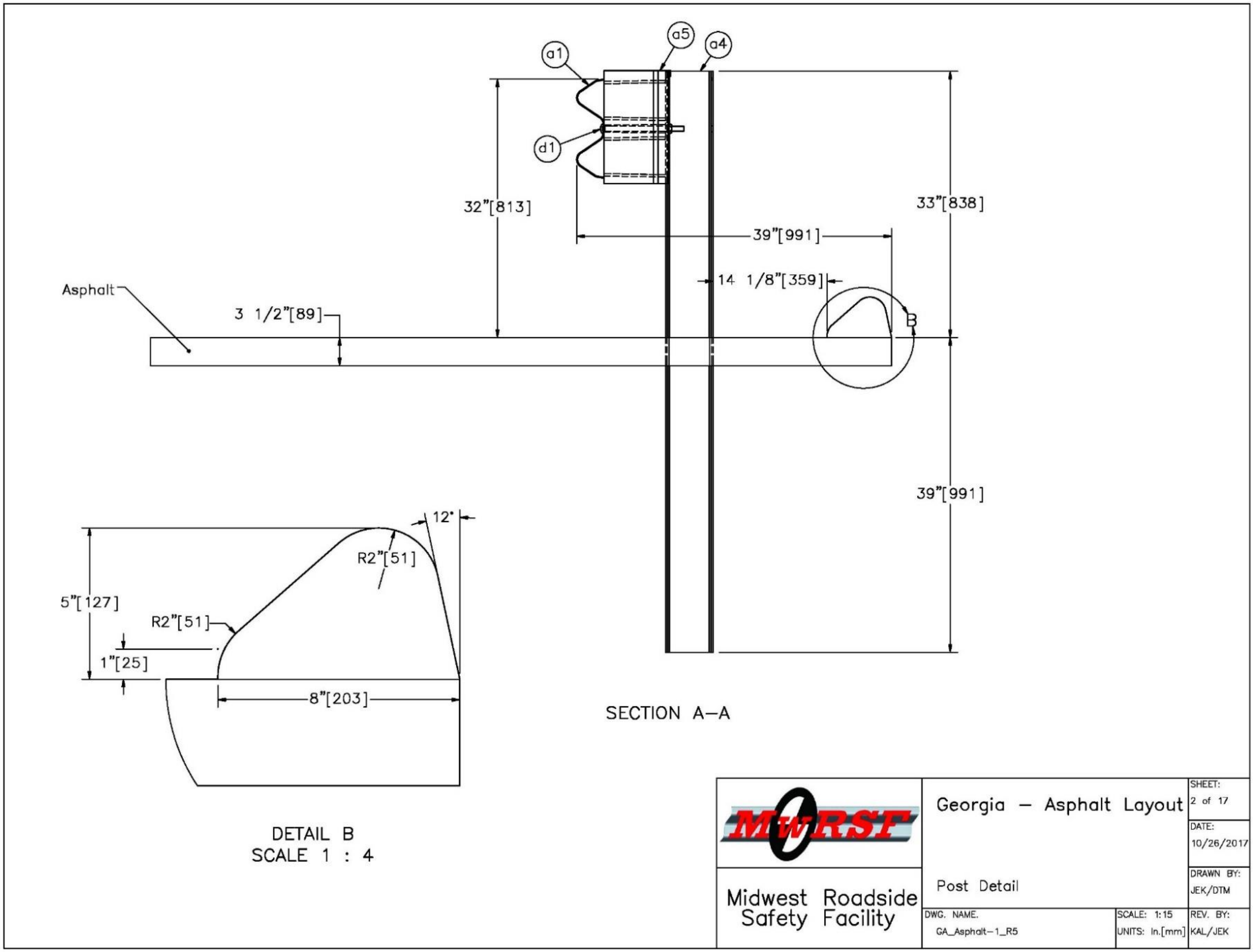


Figure 2. Post and Curb Detail, Test No. GAA-1

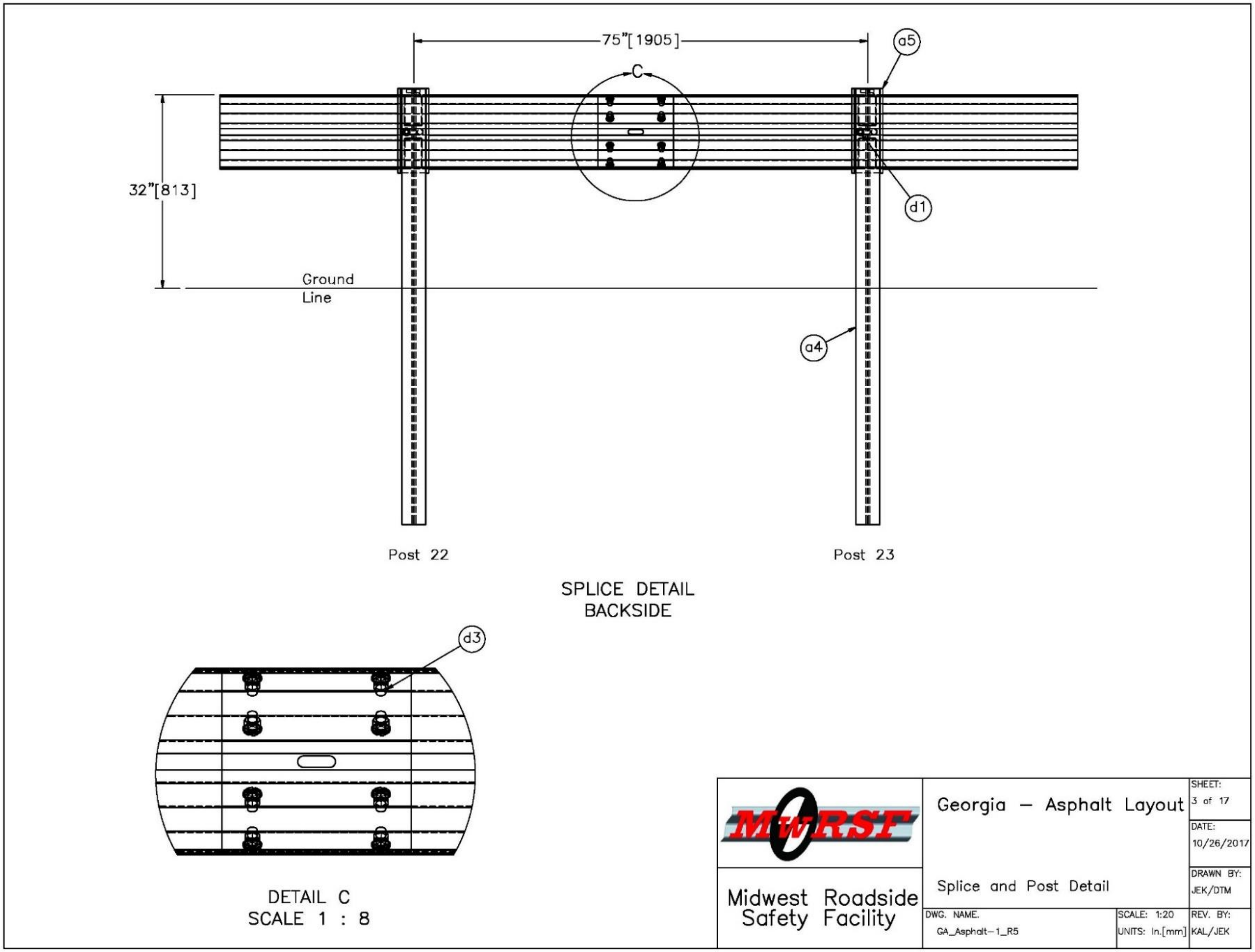


Figure 3. Splice Detail, Test No. GAA-1

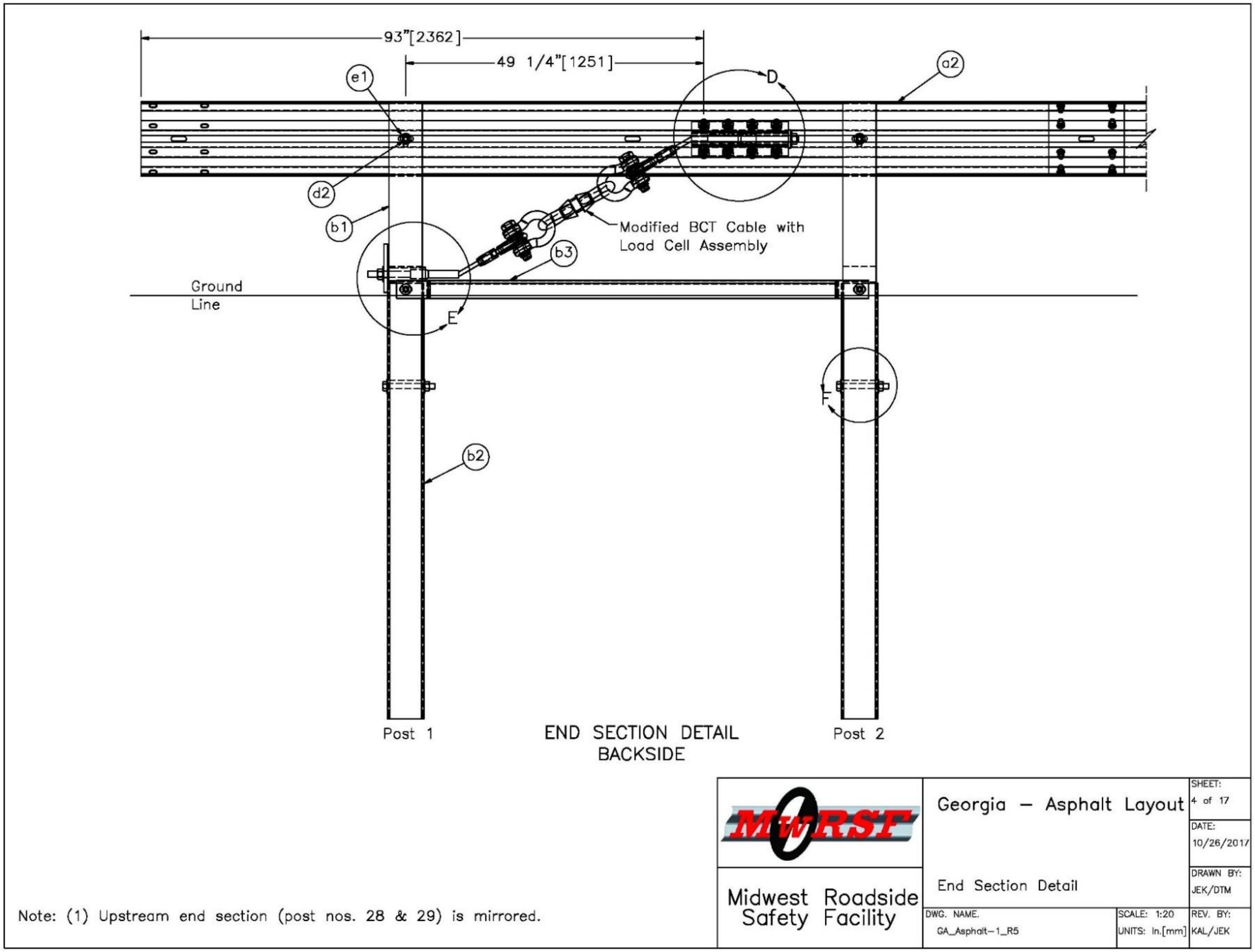


Figure 4. End Anchorage Detail, Test No. GAA-1

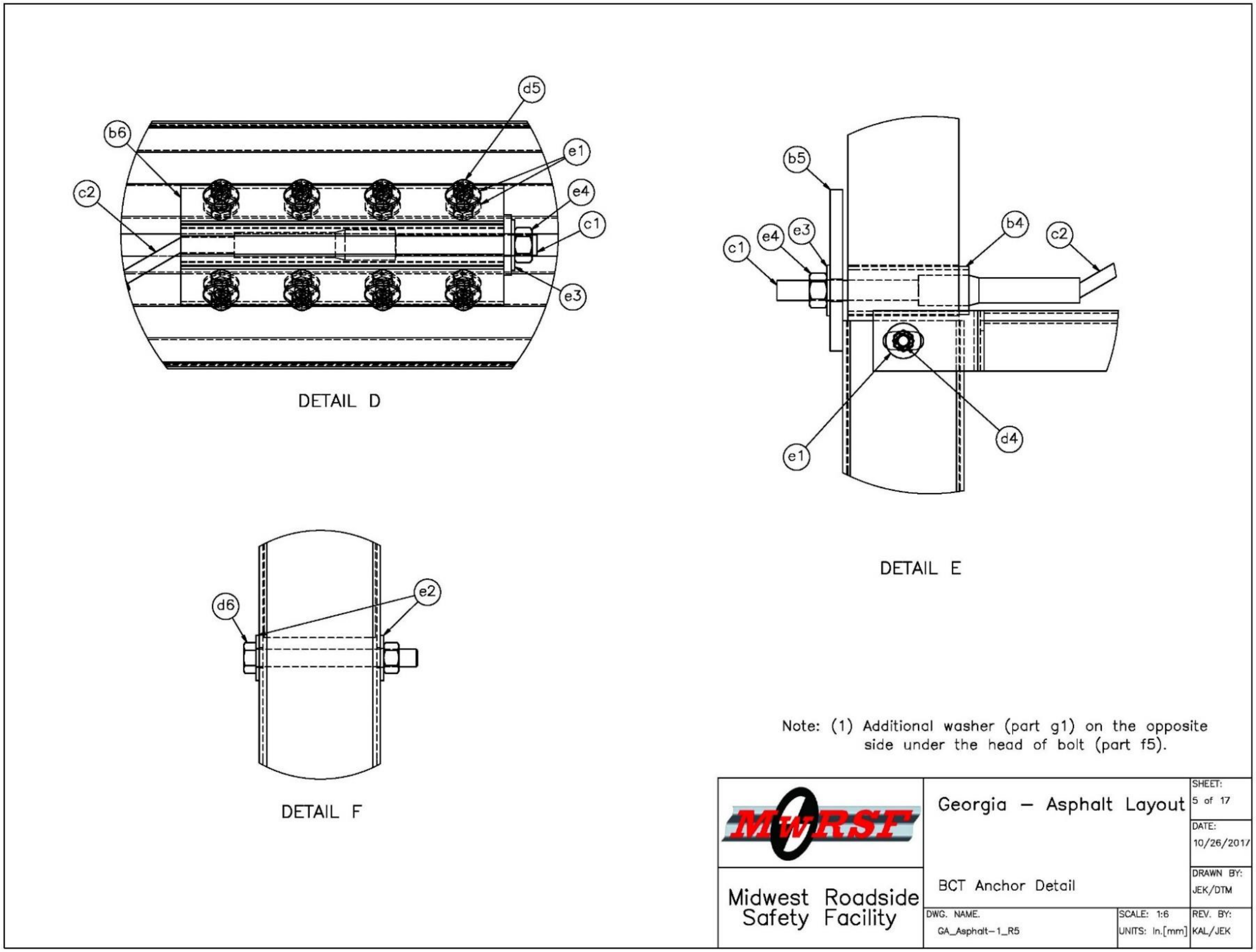


Figure 5. Anchorage Component Details, Test No. GAA-1

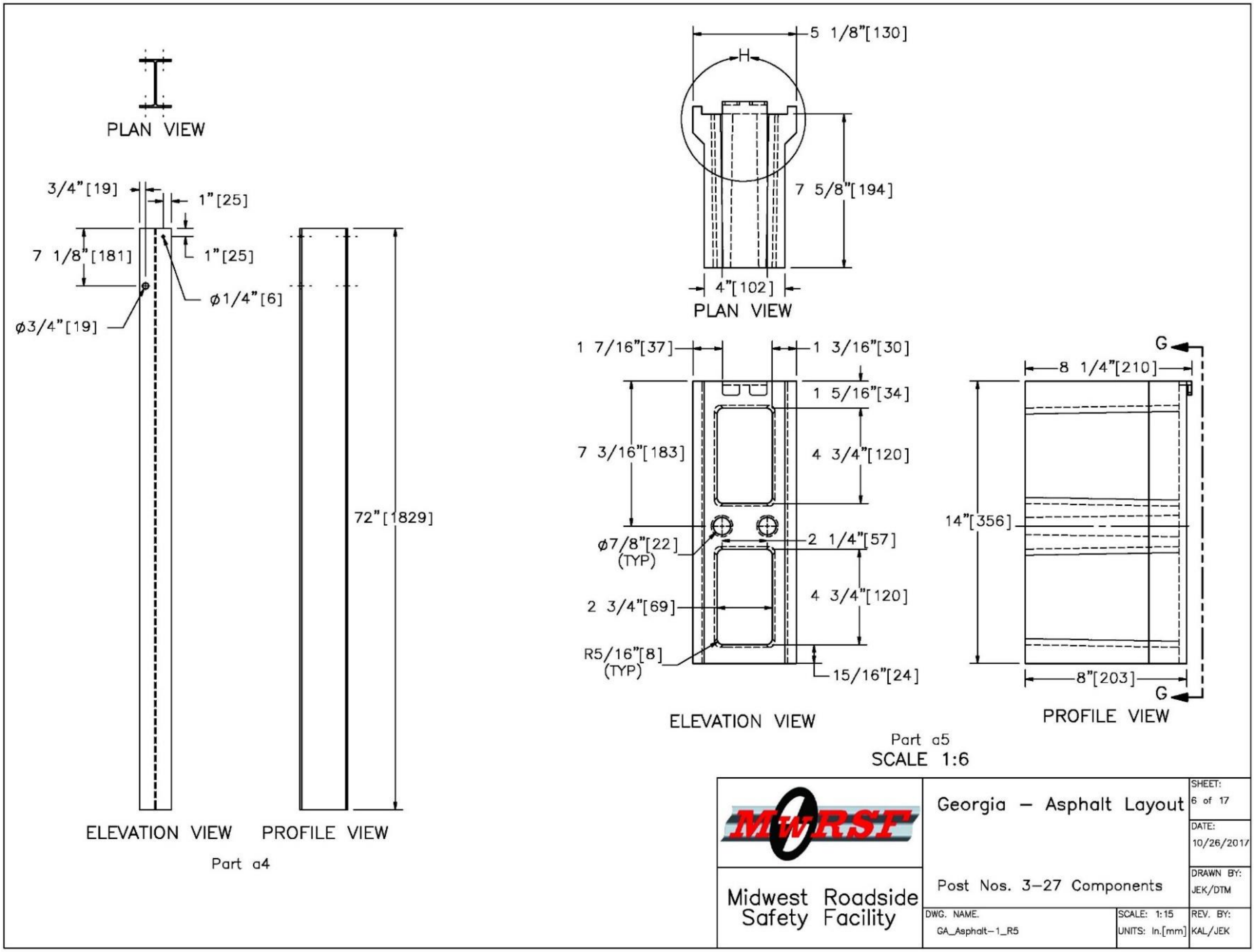


Figure 6. Post Nos. 3 through 29 and Plastic Blockout Details, Test No. GAA-1

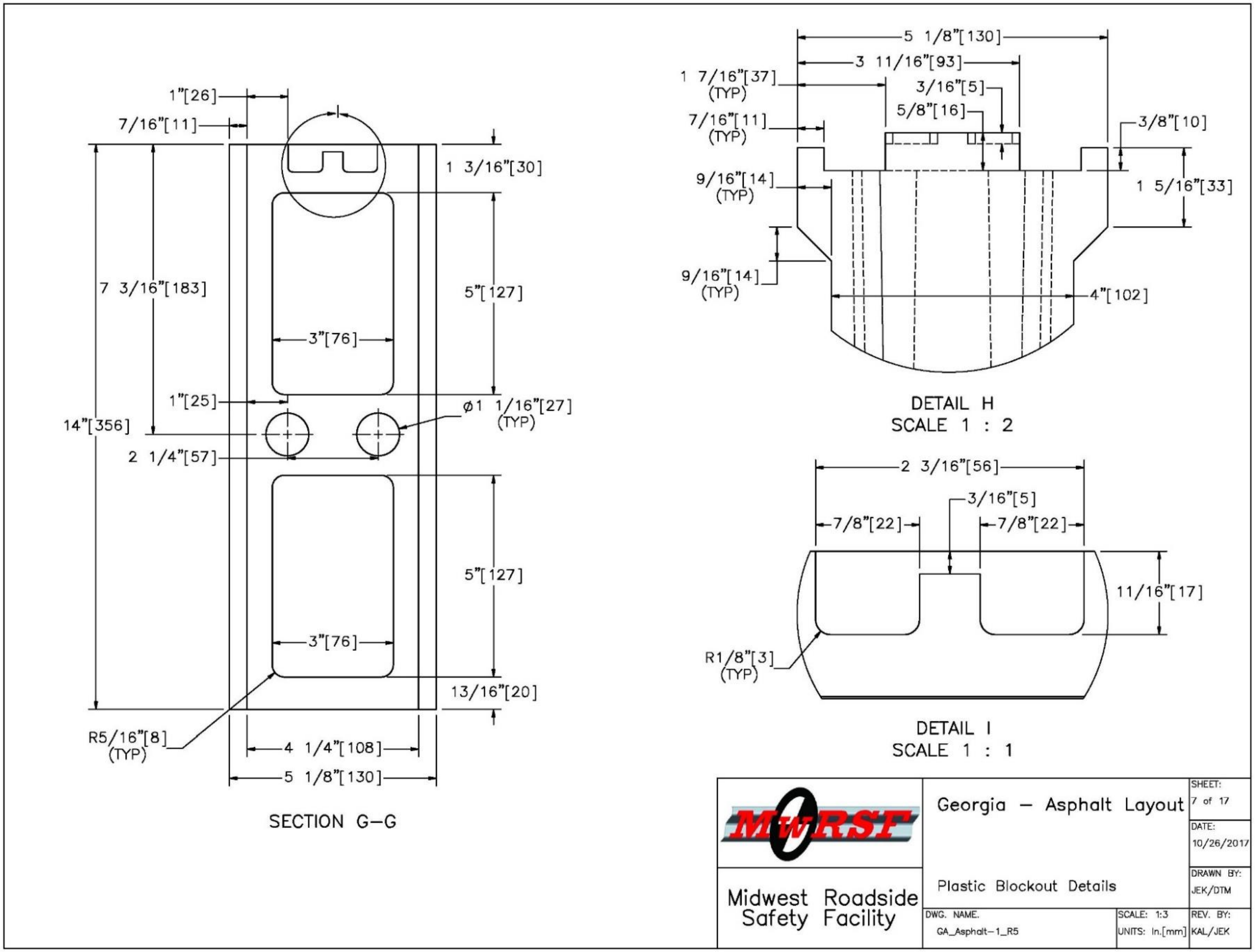


Figure 7. Additional Plastic Blockout Details, Test No. GAA-1

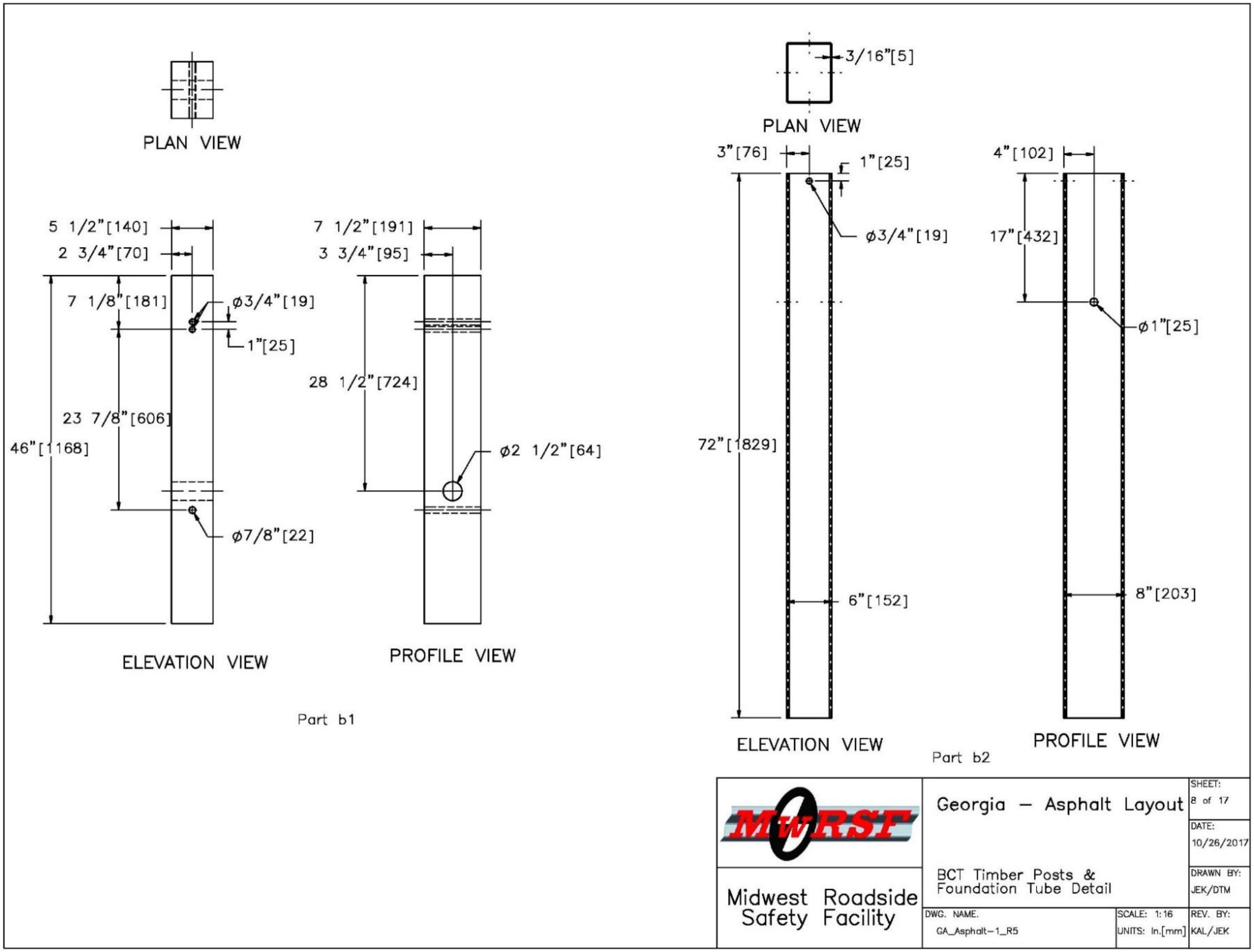
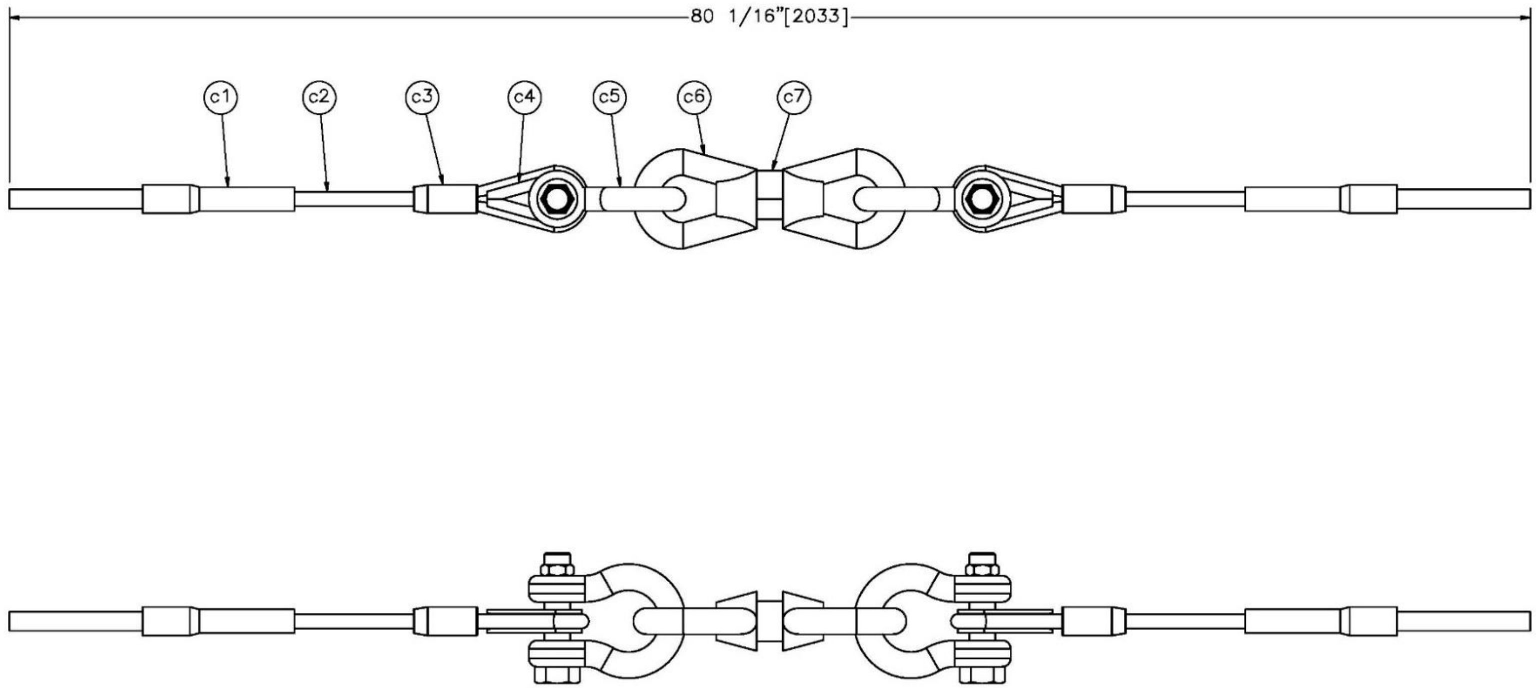


Figure 8. BCT Timber Posts and Foundation Tube Details, Test No. GAA-1



Note: (1) 6x25 IWRC IPS cables meet the minimum breaking strength of 42.7 kips [190 kN] and may be substituted for the 6x19 IWRC IPS cables.

MwRSF Midwest Roadside Safety Facility	Georgia – Asphalt Layout		SHEET: 9 of 17 DATE: 10/26/2017
	BCT Anchor Cable & Load Cell Detail		DRAWN BY: JEK/DTM
	DWG. NAME. GA_Asphalt-1_R5	SCALE: 1:8 UNITS: in.[mm]	REV. BY: KAL/JEK

Figure 9. BCT Anchor Cable and Load Cell Detail, Test No. GAA-1

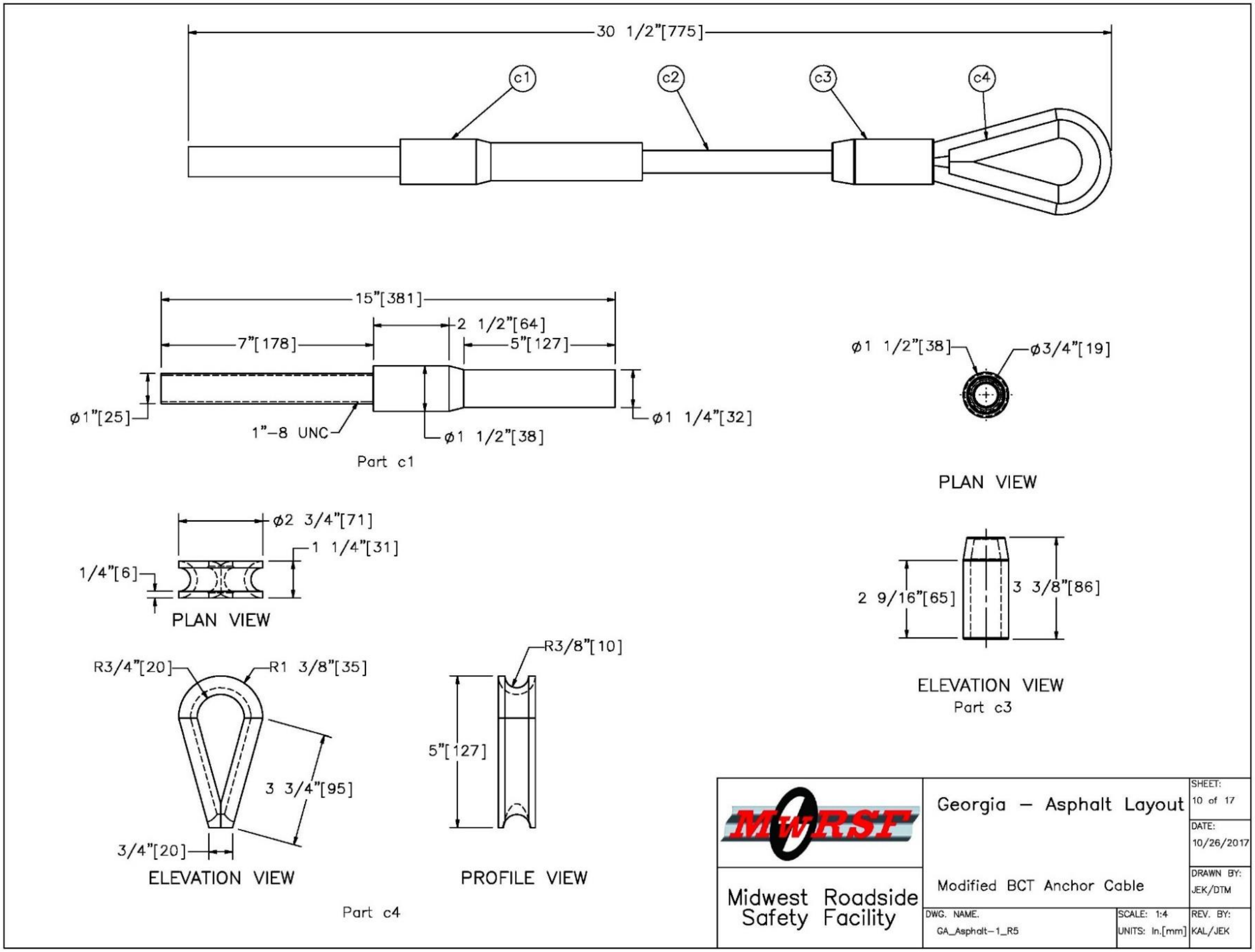


Figure 10. Modified BCT Anchor Cable Detail, Test No. GAA-1

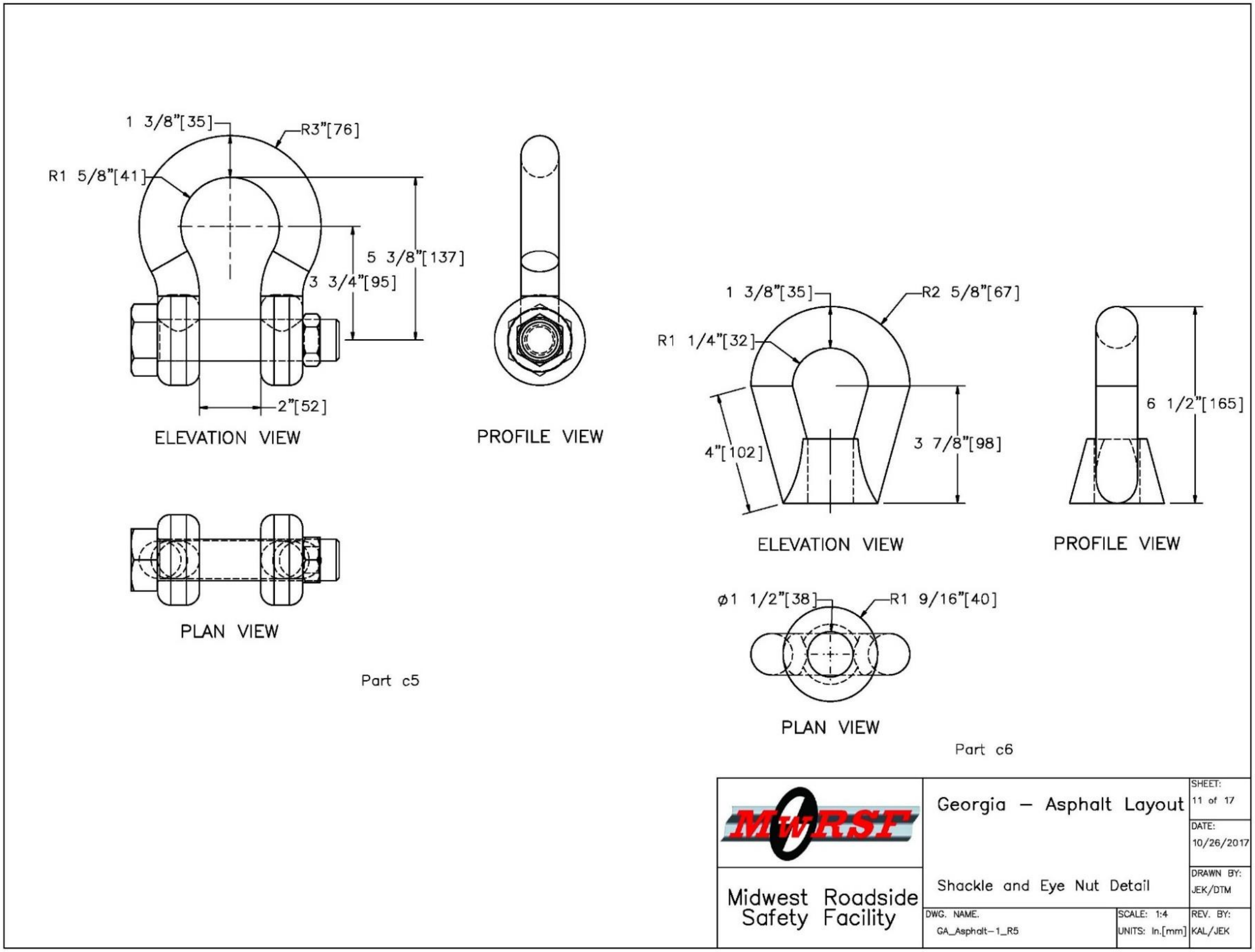


Figure 11. Shackle and Eye Nut Detail, Test No. GAA-1

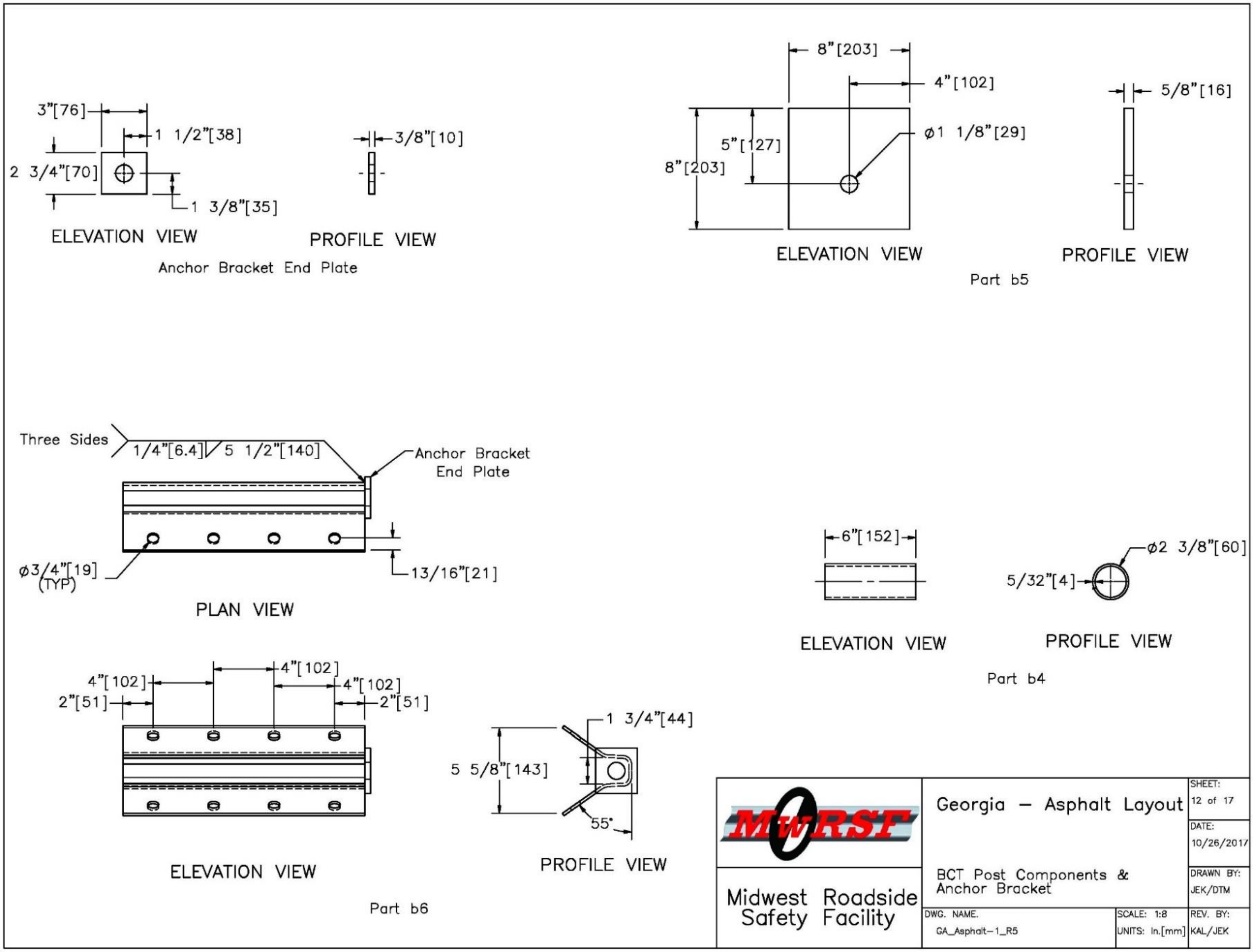


Figure 12. BCT Post Components and Anchor Bracket Details, Test No. GAA-1

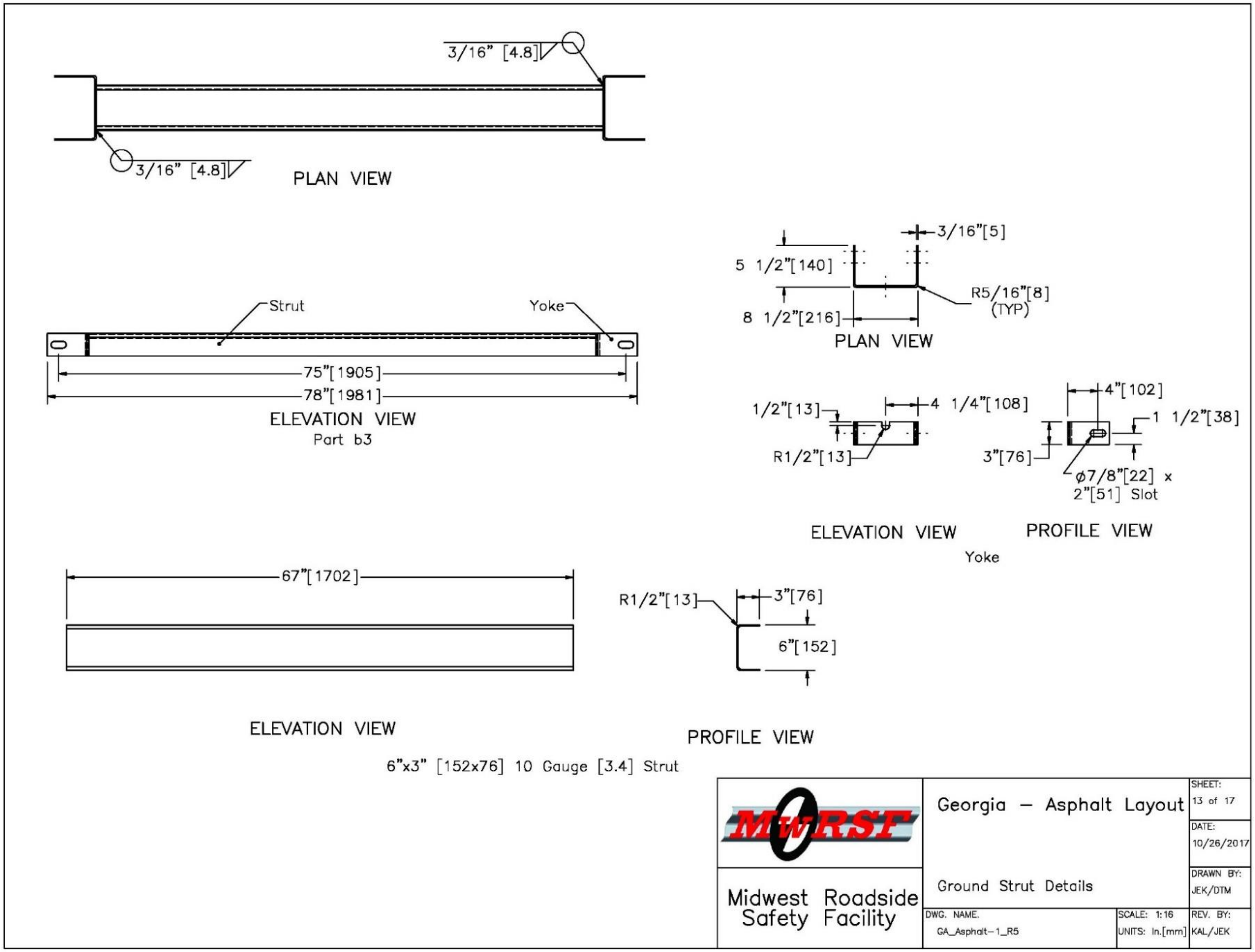


Figure 13. Ground Strut Details, Test No. GAA-1

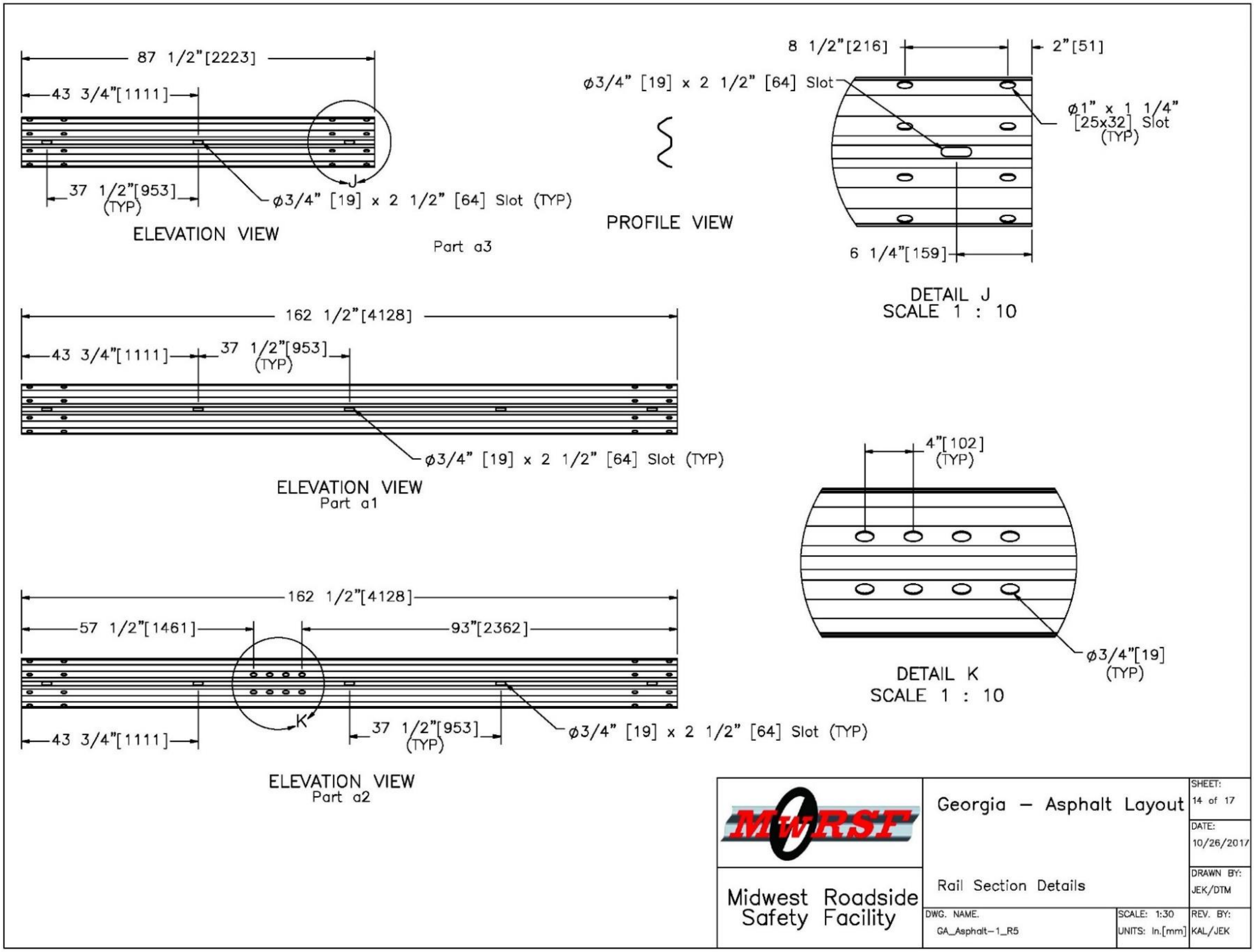


Figure 14. Rail Section Details, Test No. GAA-1

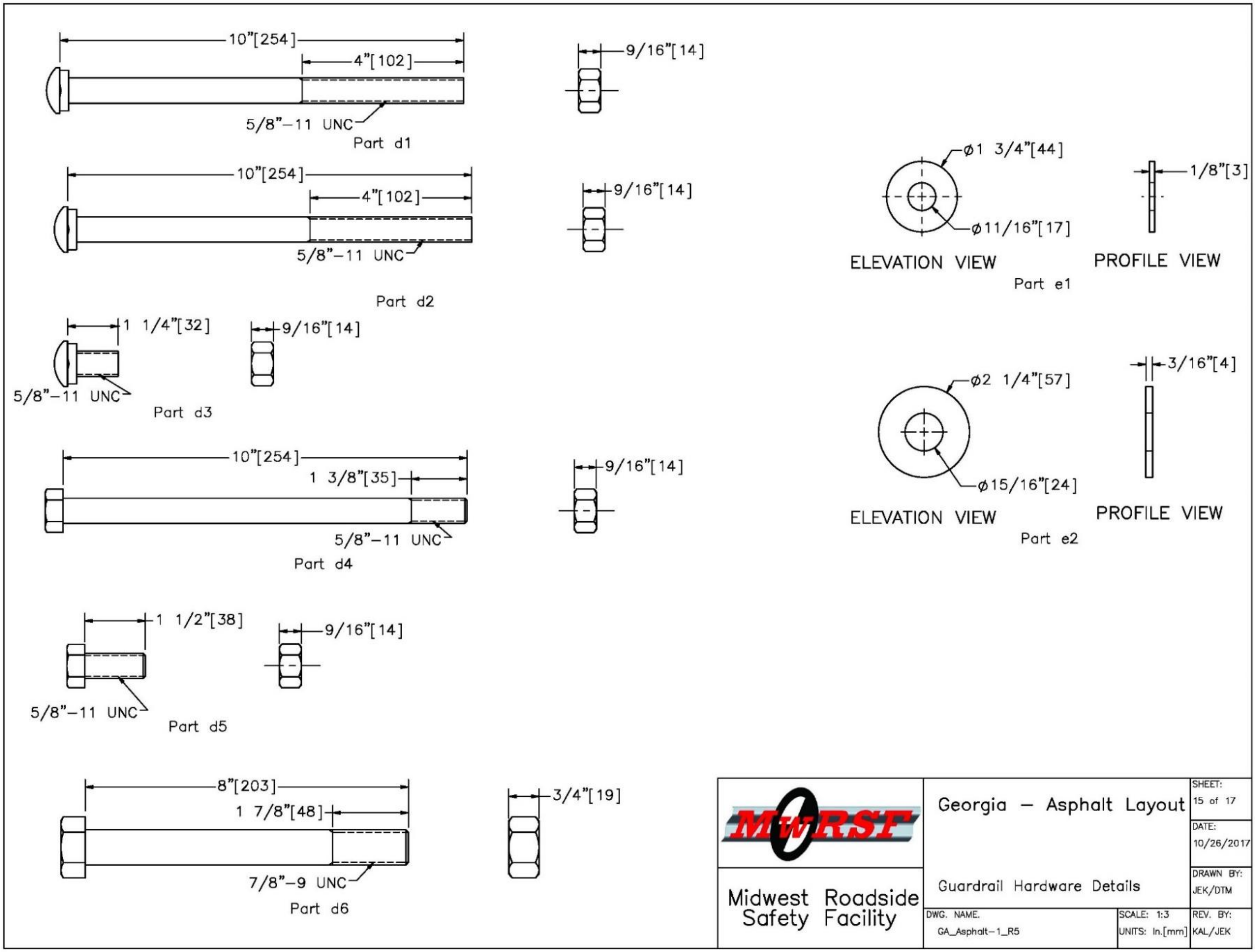


Figure 15. Guardrail Hardware Details, Test No. GAA-1

Item No.	QTY.	Description	Material Specification	Galvanization Specification	Hardware Guide
–	1	Asphalt	GA 12.5 mm Superpave (NE SPR Binder PG 64–22)	–	–
–	1	Curb	GA 4.75 mm or 9.5 mm Superpave Level A Mixture (NE SPR Binder PG 64–22)	–	–
a1	12	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
a2	2	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS End Section	AASHTO M180	ASTM A123 or A653	RWM14a
a3	1	6'–3" [1,905] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
a4	25	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post	ASTM A992	ASTM A123	PWE06
a5	25	5 1/8"x8"x14" [130x203x356] Composite Recycled Blockout	Mondo Polymer MGS14SH or Equivalent	–	–
b1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots +/– 18" [457] from ground on tension face)	–	–
b2	4	72" [1829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123	PTE06
b3	2	Ground Strut Assembly	ASTM A36	ASTM A123	PFP02
b4	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	FMM02
b5	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
b6	2	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
c1	4	BCT Anchor Cable End Swaged Fitting	Fitting – ASTM A576 Gr. 1035 Stud – ASTM F568 Class C	Fitting – ASTM A153 Stud – ASTM A153 or B695	–
c2	4	3/4" [190] Dia. 6x19, 24 1/2" [622] Long IWRC IPS Wire Rope	IPS	ASTM A741 Type II Class A	–
c3	4	115–HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–	–
c4	4	Crosby Heavy Duty HT – 3/4" [19] Dia. Cable Thimble	Stock No. 1037773	As Supplied	–
c5	4	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 – As Supplied	–	–
c6	4	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNC 6 [M36x4]	Stock No. 107 – As Supplied	–	–
c7	2	TLL–50K–PTB Load Cell	–	–	–

Midwest Roadside Safety Facility	Georgia – Asphalt Layout	SHEET: 16 of 17
		DATE: 10/26/2017
	Bill of Materials	DRAWN BY: JEK/DTM
	DWG. NAME. GA_Asphalt–1_R5 / SCALE: None UNITS: in.[mm]	REV. BY: KAL/JEK

Figure 16. Bill of Materials, Test No. GAA-1

Item No.	QTY.	Description	Material Specification	Galvanization Specification	Hardware Guide
d1	25	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB03
d2	4	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB03
d3	114	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB01
d4	4	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
d5	16	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
d6	4	7/8" [22] Dia. UNC, 8" [203] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	–
e1	44	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
e2	8	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
e3	4	1" [25] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC24a
e4	4	1" [25] Dia. Hex Nut	ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX24a

MwRSF Midwest Roadside Safety Facility	Georgia – Asphalt Layout		SHEET: 17 of 17 DATE: 10/26/2017
	Bill of Materials		DRAWN BY: JEK/DTM
	DWG. NAME. GA_Asphalt-1_R5	SCALE: None UNITS: In.[mm]	REV. BY: KAL/JEK

Figure 17. Bill of Materials, Test No. GAA-1

Figure 18. Test Construction, Test No. GAA-1

Figure 19. Test Construction – Soil and Asphalt Heating, Test No. GAA-1

Figure 20. Test Installation, Test No. GAA-1

Figure 21. Test Installation, Test No. GAA-1

Upstream Anchorage

Downstream Anchorage

Figure 22. End Anchorages, Test No. GAA-1

4 TEST CONDITIONS

4.1 Test Facility

The Outdoor Test Site is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles (8.0 km) northwest of the University of Nebraska-Lincoln.

4.2 Vehicle Tow and Guidance System

A reverse-cable, tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch [7] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable. As the vehicle was towed down the cable line, the guide flag struck and knocked each stanchion to the ground.

4.3 Test Vehicles

For test no. GAA-1, a 2011 Kia Rio was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,326 lb (1,055 kg), 2,392 lb (1,085 kg), and 2,552 lb (1,158 kg), respectively. The test vehicle is shown in Figures 23 and 24, and vehicle dimensions are shown in Figure 25.

The longitudinal component of the center of gravity (c.g.) was estimated using the measured axle weights. The vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [8]. The location of the final c.g. is shown in Figures 25 and 26. Data used to calculate the location of the c.g. and ballast information are shown in Appendix D.

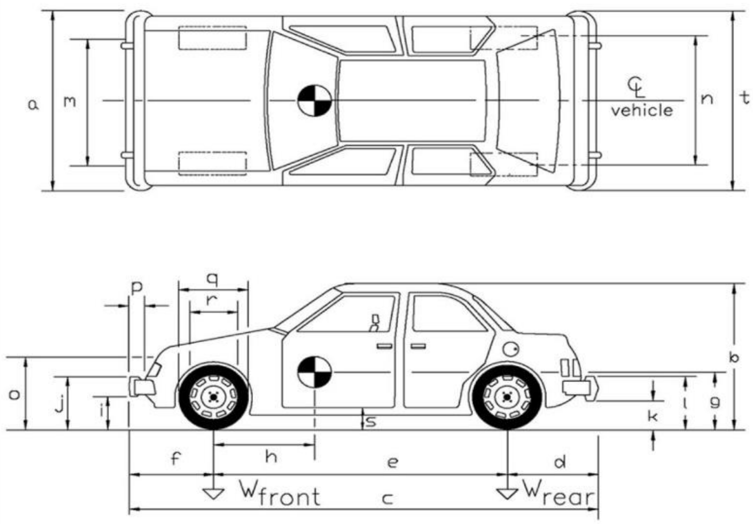
Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure 26. Round, checkered targets were placed on the c.g. on the left-side door, the right-side door, and the roof of the vehicle.

The front wheels of the test vehicle were aligned to vehicle standards except the toe-in value was adjusted to zero so that the vehicle would track properly along the guide cable. A 5B flash bulb was mounted under the vehicle's left-side windshield wiper and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed digital videos. A remote-controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

Figure 23. Test Vehicle, Test No. GAA-1

Figure 24. Test Vehicle’s Interior Floorboards, Test No. GAA-1

Date:	2/14/2017	Test Number:	GAA-1	VIN:	KNADH4A36B6915197
Year:	2011	Make:	Kia	Model:	Rio
Tire Size:	175/R14	Tire Inflation Pressure:	32 Psi	Odometer:	107384



Vehicle Geometry - in. (mm)
Target Ranges listed below

a:	65 3/8	(1661)	b:	57 3/4	(1467)
	65±3 (1650±75)				
c:	167 1/4	(4248)	d:	34 3/4	(883)
	169±8 (4300±200)				
e:	98 3/8	(2499)	f:	33	(838)
	98±5 (2500±125)			35±4 (900±100)	
g:	22 3/8	(568)	h:	39 1/2	(1003)
				39±4 (990±100)	
i:	8 7/8	(225)	j:	19	(483)
k:	11 1/2	(292)	l:	23 3/4	(603)
m:	57 3/4	(1467)	n:	58	(1473)
	56±2 (1425±50)			56±2 (1425±50)	
o:	30 3/8	(772)	p:	2 1/4	(57)
	24±4 (600±100)				
q:	23 5/8	(600)	r:	15 1/4	(387)
s:	7 5/8	(194)	t:	65 1/2	(1664)

Mass Distribution lb (kg)

Gross Static	LF	746	(338)	RF	769	(349)
	LR	509	(231)	RR	528	(239)

Weights lb (kg)	Curb		Test Inertial		Gross Static	
W-front	1450	(658)	1432	(650)	1515	(687)
W-rear	876	(397)	960	(435)	1037	(470)
W-total	2326	(1055)	2392	(1085)	2552	(1158)
			2420±55 (1100±25)		2585±55 (1175±50)	

Top of radiator core support:	29 1/2	(749)
Wheel Center Height (Front):	11	(279)
Wheel Center Height (Rear):	11	(279)
Wheel Well Clearance (Front):	25 3/4	(654)
Wheel Well Clearance (Rear):	24 3/4	(629)
Bottom Frame Height (Front):	6 7/8	(175)
Bottom Frame Height (Rear):	15 5/8	(397)
Engine Type:	Gasoline	
Engine Size:	1.6L	
Transmission Type:	Manual	
Drive Type:	FWD	

GVWR Ratings lb

Front:	1918
Rear:	1874
Total:	3638

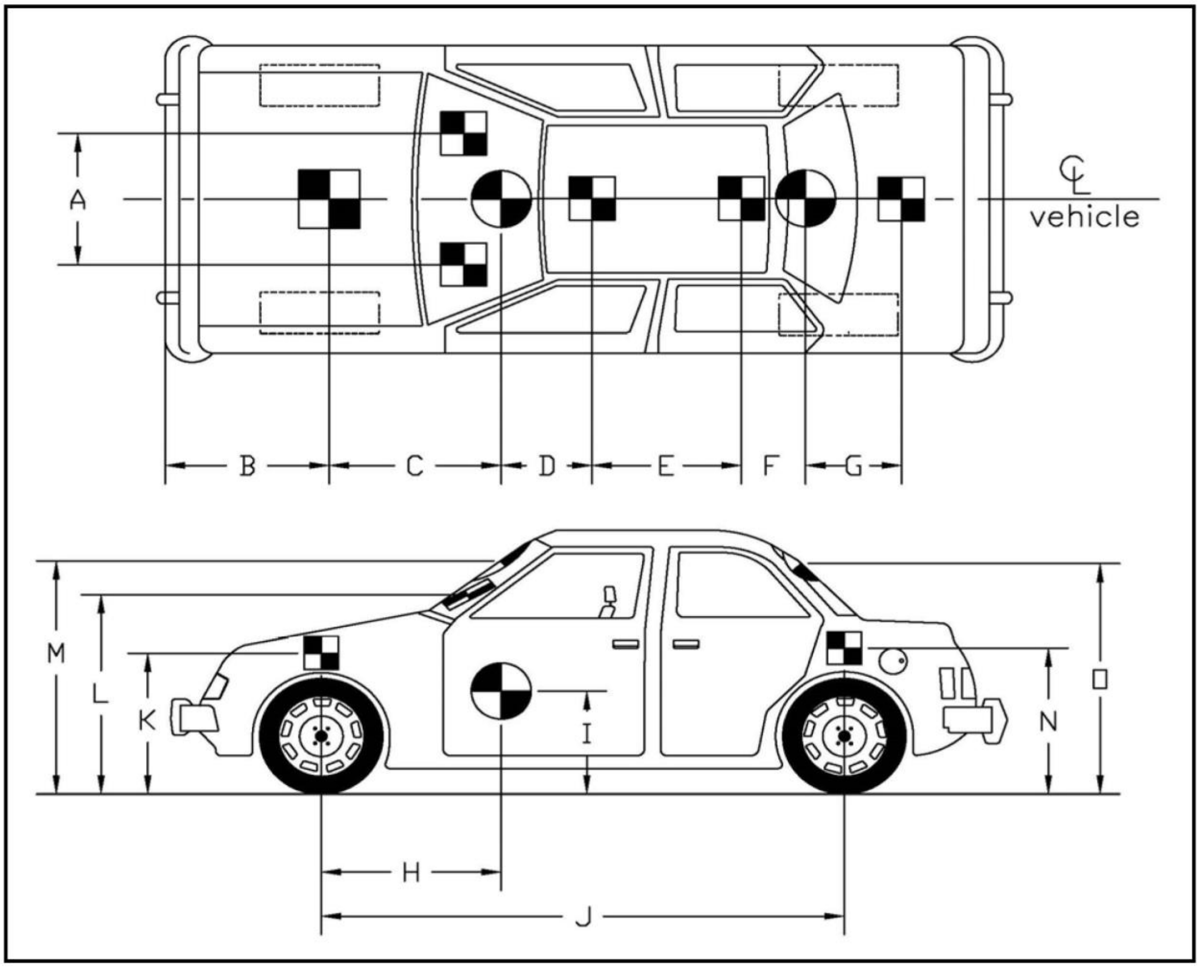
Dummy Data

Type:	Hybrid II
Mass:	160 lb
Seat Position:	Driver

Note any damage prior to test: none

Figure 25. Vehicle Dimensions, Test No. GAA-1

Date:	2/14/2017	Test Name:	GAA-1	VIN:	KNADH4A36B6915197
Year:	2011	Make:	Kia	Model:	Rio



TARGET GEOMETRY - in. (mm)

A	24 3/8	(619)	F	9	(229)	K	28 3/8	(721)
B	25 7/8	(657)	G	26 3/4	(679)	L	49	(1245)
C	46 1/4	(1175)	H	39 5/8	(1006)	M	54 1/4	(1378)
D	9 1/4	(235)	I	22 1/8	(562)	N	29 1/2	(749)
E	35 3/4	(908)	J	98 1/2	(2502)	O	54 5/8	(1387)

Figure 26. Target Geometry, Test No. GAA-1

4.4 Simulated Occupant

For test no. GAA-1, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the right-front seat of the test vehicle with the seat belt fastened. The dummy, which had a final weight of 160 lb (73 kg), was represented by model no. 572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH 2016, the dummy was not included in calculating the c.g. location.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both of the accelerometers were mounted near the c.g. of the test vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [9].

The two systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SLICE-2 unit was designated as the primary system. The acceleration sensors were mounted inside the bodies of custom-built SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

Two identical angle rate sensor systems were mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders and were used to measure the rates of rotation of the test vehicle. Each SLICE MICRO Triax ARS had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessors. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

4.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the test vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the vehicle. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

4.5.4 Load Cells

Load cells were installed on the upstream and downstream anchor cables for test no. GAA-1. The load cells were Transducer Techniques model no. TLL-50K with a load range up to 50 kips (222 kN). During testing, output voltage signals were sent from the transducers to a National Instruments PCI-6071E data acquisition board, acquired with LabView software, and stored on a personal computer at a sample rate of 10,000 Hz. The positioning and set up of the transducers are shown in Figures 27 and 28. Note that the load cell data was deemed to be erroneous and was not used, as detailed in Section 5.7.

4.5.5 Digital Photography

Five AOS high-speed digital video cameras, eight GoPro digital video cameras, and four JVC digital video cameras were utilized to film test no. GAA-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 29.

The high-speed videos were analyzed using ImageExpress MotionPlus and RedLake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A digital still camera was also used to document pre- and post-test conditions for the test.

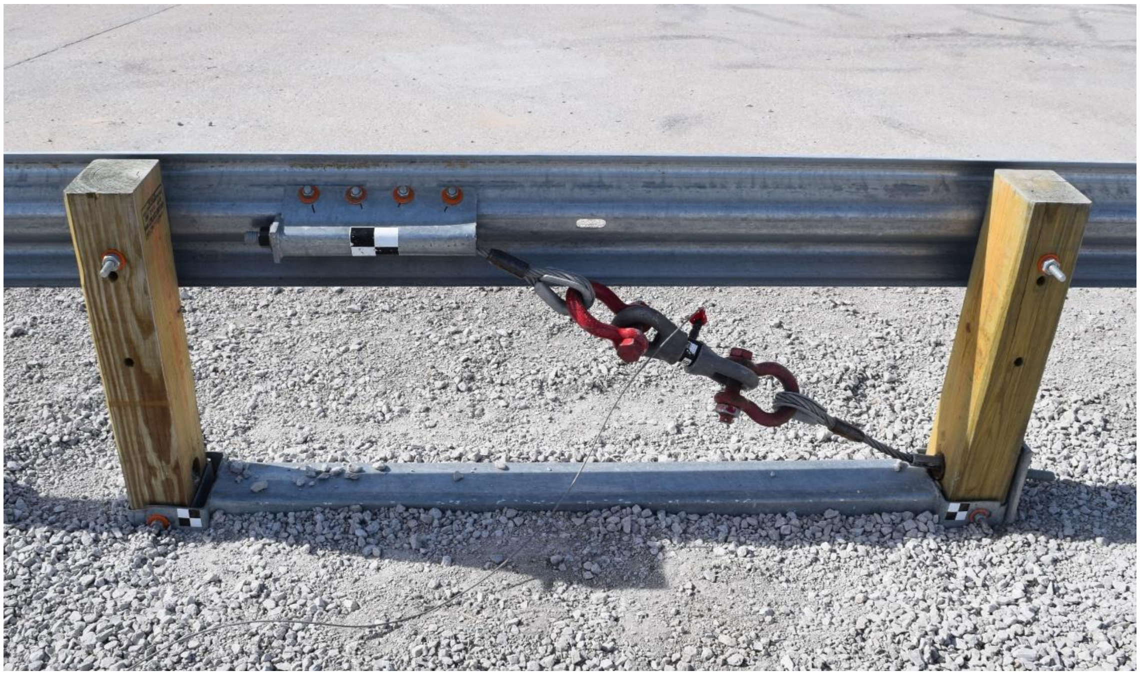
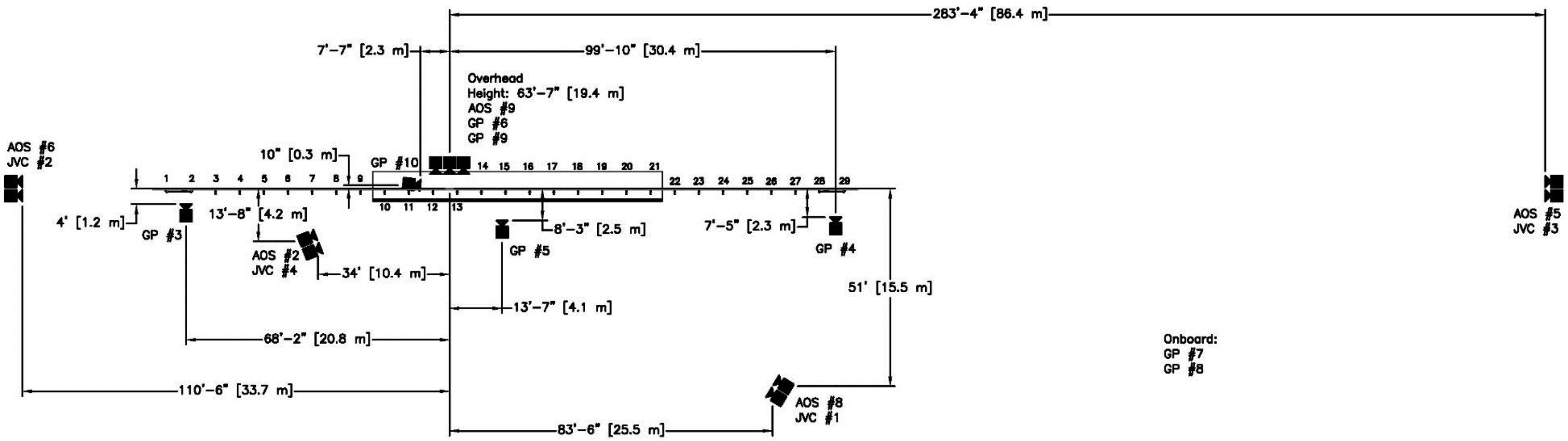


Figure 27. Location of Load Cell (Downstream Anchorage)

Figure 28. Location of Load Cell (Upstream Anchorage)



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam CTM	500	KOWA 25 mm Fixed	-
AOS-5	AOS X-PRI Gigabit	500	VIVITAR 135 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	SIGMA 28-70	70
AOS-8	AOS S-VIT 1531	500	SIGMA 28-70 DG	70
AOS-9	AOS TRI-VIT	500	KOWA 12 mm Fixed	-
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	240		
GP-10	GoPro Hero 4	240		
JVC-1	JVC – GZ-MC500 (Everio)	29.97		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 29. Camera Locations, Speeds, and Lens Settings, Test No. GAA-1

5 FULL-SCALE CRASH TEST NO. GAA-1

5.1 Static Soil Test

Before full-scale crash test no. GAA-1 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The static test results, as shown in Appendix E, demonstrated that the post-soil resistance was above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

5.2 Weather Conditions

Test no. GAA-1 was conducted on February 14, 2017 at approximately 2:15 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

Table 3. Weather Conditions, Test No. GAA-1

Temperature	53° F
Humidity	32 %
Wind Speed	17 mph
Wind Direction	320° from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in.
Previous 7-Day Precipitation	0.01 in.

5.3 Test Description

The small car, with a test inertial weight of 2,392 lb (1,085 kg), impacted the strong-post, W-beam guardrail system installed with posts driven into an asphalt mow strip with a curb placed behind the barrier at a speed of 62.8 mph (101.1 km/h) and at an angle of 25.1 degrees. A summary of the test results and sequential photographs are shown in Figure 30. Additional sequential photographs are shown in Figures 31 through 32. Documentary photographs of the crash test are shown in Figure 33. Note that a second guardrail system was installed behind the primary barrier system (test no. GAA-1) for the subsequent test in this series that was not conducted. The second system is visible in the sequential, documentary, and damage photographs.

Initial vehicle impact was to occur 111⅝ in. (2,835 mm) upstream from the centerline of post no. 14., as shown in Figure 34, which was selected using the CIP plots found in Section 2.3 of MASH 2016 to maximize vehicle pocketing, wheel snag, and the propensity for rail rupture. The actual point of impact was 104.3 in. (2,649 mm) upstream from the centerline of post no. 14. A sequential description of the impact events is contained in Table 4. The vehicle came to rest underneath the guardrail approximately 296 in. (7,518 mm) downstream from the impact point. The vehicle’s trajectory and final position are shown in Figures 30, 35, and 36.

Table 4. Sequential Description of Impact Events, Test No. GAA-1

TIME (sec)	EVENT
0.000	Vehicle's right-front bumper contacted rail between post nos. 12 and 13 and deformed.
0.005	Post no. 13 deflected backward.
0.010	Post no. 11 twisted clockwise. Vehicle right headlight shattered.
0.024	Vehicle's right-front door contacted rail and deformed.
0.028	Vehicle's right A-pillar deformed.
0.038	Vehicle's right-front tire contacted post no. 13.
0.041	Vehicle underrode rail.
0.052	Rail disengaged from bolt at post no. 13.
0.062	Vehicle's right-side airbag deployed.
0.064	Vehicle pitched downward and left-side airbag deployed.
0.068	Vehicle's windshield shattered from right-side airbag deployment.
0.074	Post no. 14 deflected downstream.
0.082	Vehicle front bumper contacted post no. 14.
0.092	Rail disengaged from bolt at post no. 10.
0.098	Vehicle's right mirror contacted rail and deformed.
0.104	Rail disengaged from bolt at post no. 14. Vehicle's right-front bumper disengaged.
0.120	Rail disengaged from bolt at post no. 6.
0.136	Rail disengaged from bolt at post no. 8.
0.138	Rail disengaged from bolts at post nos. 4 and 7.
0.182	Vehicle's left-front tire became airborne.
0.186	Rail disengaged from bolt at post no. 12. Vehicle's left-front bumper disengaged. Vehicle's front bumper contacted post no. 15.
0.202	Blockout no. 15 disengaged from rail at post no. 15.
0.207	Vehicle's left-front headlight disengaged and blockout no. 15 disengaged from post no. 15.
0.220	Vehicle's right A-pillar contacted rail.
0.285	Vehicle underrode rail and rail disengaged from bolt at post no. 16.
0.348	Vehicle contacted post no. 16.
0.360	Vehicle's roof underrode rail.
0.526	Vehicle contacted post no. 17.
0.648	Rail disengaged from bolt at post no. 17.
1.217	Vehicle came to rest.

5.4 Barrier Damage

Damage to the barrier was extensive, as shown in Figures 37 through 44. Barrier damage consisted of rail deformation, contact marks on the front face of the guardrail, guardrail disengagement from posts, deformed steel posts, and asphalt gouging. The length of vehicle contact along the barrier was approximately 27 ft – 7⅝ in. (8.4 m), which spanned from 38⅜ in. (975 mm) downstream from the centerline of post no. 12 through 5 in. (127 mm) upstream from the centerline of post no. 17. The maximum vehicle pocketing angle was 20 degrees.

The bottom corrugation of the rail was flattened, starting 25 in. (635 mm) upstream from the centerline of post no. 14 and extending downstream 54 in. (1,372 mm). The post bolt holes in the rail tore at post nos. 12 through 16. A 2-in. (51-mm) long kink was found on the top edge of the rail at the centerline of post no. 12. Vertical kinks, 3 in. (76 mm) and 1 in. (25 mm) long, were located 1 in. (25 mm) downstream from the centerline of post no. 12 on the middle corrugation and at the bottom edge of the rail, respectively. Contact marks on the guardrail began at the centerline of the impact target and extended continuously downstream to 5 in. (127 mm) upstream from the centerline of post no. 17. A 3-in. (76-mm) long kink was found 8 in. (203 mm) upstream from the centerline of post no. 13. Additional kinking with lengths of 2 in. (51 mm), 3 in. (76 mm), and 6 in. (152 mm) was located at 5 in. (127 mm), 26 in. (660 mm), and 34 in. (864 mm) downstream from the centerline of post no. 13, respectively. A 14-in. (356-mm) long kink was located 7 in. (178 mm) downstream from the centerline of post no. 14 on the top edge of the rail. An 8-in. (203-mm) long kink was found on the bottom edge of the rail at the centerline of post no. 15. A 5-in. (127-mm) long kink was located 3 in. (76 mm) downstream of post no. 16. A 10-in. (254-mm) long bend occurred on the top corrugation at the centerline of post no. 17. A 2-in. (51-mm) long kink was found on the bottom edge of the rail 10 in. (254 mm) downstream from the centerline of post no. 17. The rail at the centerline of post no. 18 had a ½-in. (13-mm) long kink on the top edge.

Post nos. 13 through 17 buckled at the groundline. Post nos. 9 and 17 through 27 twisted counterclockwise. Post nos. 14 and 15 had full blockout disengagement, and post no. 13 had the bottom half of the blockout disengaged. At the groundline, post no. 13 had a 1½-in. (38-mm) horizontal tear on its front upstream flange and a ½-in. (13-mm) horizontal tear on the downstream edge of the front flange. Contact marks were found on post no. 13 starting 3 in. (76 mm) above the groundline on the front flange and extended vertically 18 in. (457 mm). The post bolt for post no. 13 was bent. Contact marks were found on post no. 14 on the edge of the upstream flanges extending vertically the height of the post and on the front face of the upstream flange starting 3 in. (76 mm) above the groundline and extending 16 in. (406 mm) upward. The front upstream flange of post no. 14 was bent backward 3 in. (76 mm) starting at the groundline and extending vertically 8 in. (203 mm). A 2-in (51-mm) long horizontal tear was found on the upstream flanges of post no. 15 just above the groundline. Two 1½-in. (38-mm) tears were located 1 in. (25 mm) above the groundline on the upstream flanges of post no. 16. Contact marks were found on post no. 17 beginning 9 in. (229 mm) above the groundline and extending 7 in. (178 mm) upward. Gouging was found on the front upstream and downstream edges of the blockout at post no. 17.

Post no. 1 had a 5½-in. (140-mm) soil gap on the upstream side and a 37-in. (940-mm) diameter by 4½-in. (114-mm) tall soil heave on the downstream side. Post no. 2 had a soil gap of 4½ in. (114 mm) on the upstream side and a 29-in. (737-mm) diameter by 5-in. (127-mm) tall soil heave on the downstream side. Post nos. 13, 14, 15, and 17 also had minor gaps in the asphalt. For the downstream BCT wood posts and foundation tubes, no longitudinal movement or damage was observed, as documented in Figure 45. More specifically, the wood posts were not cracked or split at the post bolt locations, as depicted in Figure 46.

The maximum lateral permanent set of the rail and post deflection were 17⅝ in. (448 mm) at the rail at post no. 14 and 12¼ in. (311 mm) at post no. 13, respectively, as measured in the field. The maximum lateral dynamic rail and post deflection were 28 in. (712 mm) at post no. 14 and 22.3 in. (566 mm) at post no. 13, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 59.3 in. (1,507 mm), also determined from high-speed digital video analysis.

5.5 Vehicle Damage

The damage to the vehicle was extensive, as shown in Figures 47 through 50. The maximum occupant compartment deformations are listed in Table 5 along with the deformation limits established in MASH 2016 for various areas of the occupant compartment. The MASH 2016-established deformation limit for the roof was violated with a maximum deformation of 5⅛ in. (130 mm). Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix F.

Table 5. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH 2016 ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	1⅝ (41)	≤ 9 (229)
Floor Pan & Transmission Tunnel	⅜ (10)	≤ 12 (305)
A-Pillar	⅞ (22)	≤ 5 (127)
A-Pillar (Lateral)	¾ (19)	≤ 3 (76)
B-Pillar	¼ (6)	≤ 5 (127)
B-Pillar (Lateral)	¼ (6)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	⅞ (22)	≤ 12 (305)
Side Door (Above Seat)	¼ (6)	≤ 9 (229)
Side Door (Below Seat)	¼ (6)	≤ 12 (305)
Roof	**5⅛ (130)**	≤ 4 (102)
Windshield	**7⅛ (181)**	≤ 3 (76)

The majority of the damage was concentrated on the right-front corner and the front side of the vehicle. The radiator was crushed and bent inward approximately 6 in. (152 mm). The front bumper, right and left headlights, and right hood attachment disengaged from the vehicle. The roof was crushed, while the windshield was deformed and shattered, as shown in Figures 48 and 49.

Further windshield crush details are provided in Appendix F. The hood was dented and buckled in numerous locations, as shown in Figure 48. The entire right side had contact and scrape marks and dents. The right-side mirror had contact marks and broke, but remained attached. Contact and scrape marks, denting, and buckling were found along the right-side fender. A ¼-in. (6-mm) gap was found at the bottom between the right fender and right-front door. A ¼-in. (6-mm) overlap occurred near the center between the right-front door and the right fender. A ½-in. (13-mm) long gap was found between the right-front door and the roof and a ⅝-in. (16-mm) gap was found at the top of the right-front and right-rear doors. The right-side A-pillar was crushed at the front. The right-front tire rim was bent inward approximately 3 in. (76 mm). A ¼-in. (6-mm) gap was found between the left fender and the A-pillar of the vehicle. The left forward frame element of the vehicle was bent inward 6 in. (152 mm). A 1-in. (25-mm) long tear was found in the right-rear floor pan, and a tear was found in the oil pan, as depicted in Figures 49 and 50. The peak SAE CFC60 longitudinal acceleration was found to be approximately -35.87 g's and -21.09 g's for SLICE-1 and SLICE-2, respectively, as shown in Figure 51.

5.6 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 6. The longitudinal ORA exceeded the suggested limits provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 6. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 30. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix G.

Table 6. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. GAA-1

Evaluation Criteria		**Transducer**		**MASH 2016 Limits**
		SLICE-1	**SLICE-2 (primary)**	
OIV ft/s (m/s)	Longitudinal	-27.02 (-8.23)	-26.19 (-7.98)	±40 (12.2)
	Lateral	-12.70 (-3.87)	-13.28 (-4.05)	±40 (12.2)
ORA g's	Longitudinal	**-22.60**	**-21.80**	±20.49
	Lateral	8.89	-7.88	±20.49
MAX. ANGULAR DISPL. deg.	Roll	-8.46°	-9.66°	±75
	Pitch	-5.90°	-6.15°	±75
	Yaw	-11.31°	-12.59°	not required
THIV ft/s (m/s)		27.79 (8.47)	27.53 (8.39)	not required
PHD g's		23.27	22.52	not required
ASI		1.04	0.98	not required

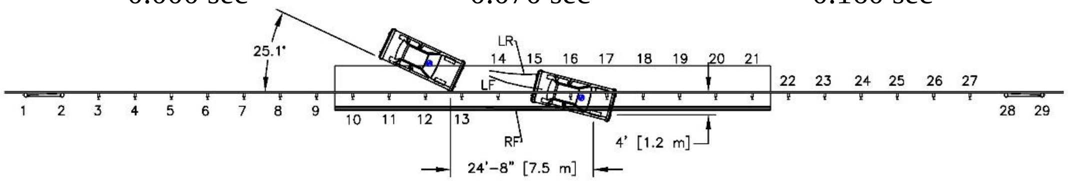
5.7 Load Cells

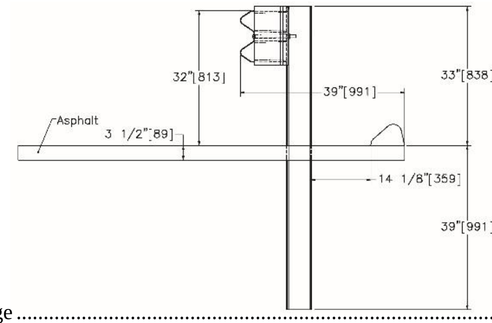
The pertinent data from the load cells was extracted from the bulk signal and analyzed using the transducer's calibration factor. After analysis, it was observed that the upstream and downstream loads were inconsistent and could not be correlated with the observed end anchor deflections. Therefore, the load cell data was deemed to be erroneous and was not used.

5.8 Discussion

The analysis of the test results for test no. GAA-1 showed that the barrier system adequately contained the 1100C vehicle with controlled lateral displacements of the barrier. There were no detached elements or fragments that presented undue hazard to other traffic, however, deformations of, or intrusions into, the occupant compartment that could have caused serious injury did occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix G, were deemed acceptable, because they did not adversely influence occupant risk safety criteria nor cause rollover. The maximum longitudinal ORA value of -21.80 g's recorded by SLICE-2 (the primary data recorder) exceeded the MASH 2016 limit of 20.49 g's. Therefore, test no. GAA-1 was determined to be unacceptable according to the TL-3 MASH 2016 safety performance criteria provided for test designation no. 3-10.

0.000 sec | 0.070 sec | 0.160 sec | 0.270 sec | 0.648 sec





- Test Agency .... MwRSF
- Test Number GAA-1
- Date 2/14/17
- MASH Test Designation 3-10
- Test Article .... MGS with Asphalt Mow Strip and Curb
- Total Length .... 182 ft – 3½ in. (55.6 m)
- Key Component – W-Beam Guardrail
  - Thickness .... 12 gauge (2.66 mm)
  - Top Mounting Height .... 32 in. (813 mm)
- Key Component – Steel Post (Driven)
  - Shape W6x8.5 (W152x12.6)
  - Length .... 72 in. (1,829 mm)
  - Embedment Depth .... 39 in. (991 mm)
  - Spacing .... 75 in. (1,905 mm)
- Soil Type .... 3½-in. (89-mm) thick Asphalt Mow Strip on coarse, crushed limestone
- Vehicle Make /Model .... 2011 Kia Rio 1100
  - Curb .... 2,326 lb (1,055 kg)
  - Test Inertial .... 2,392 lb (1,085 kg)
  - Gross Static .... 2,552 lb (1,158 kg)
- Impact Conditions
  - Speed .... 62.8 mph (101.1 km/h)
  - Angle .... 25.1 deg
  - Impact Location .... 104.3 in. (2,649 mm) upstream from centerline of post no. 14
- Impact Severity (IS) ...... 56.8 kip-ft (77 kJ) > 51 kip-ft (69.1 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... N/A
  - Angle .... N/A
- Exit Box Criterion .... N/A (Did not exit system)
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 24 ft – 8 in. (7.3 m) Downstream within system
- Vehicle Damage .... Extensive
  - VDS [10] 1-FR-7
  - CDC [11] 01-FDAW-9
  - Maximum Interior Deformation .... 5⅛ in. (130 mm)
- Test Article Damage .... Extensive
- Maximum Test Article Deflections
  - Permanent Set .... 17⅝ in. (448 mm)
  - Dynamic .... 28 in. (712 mm)
  - Working Width .... 59.3 in. (1,507 mm)
- Transducer Data

Evaluation Criteria		Transducer SLICE-1	Transducer SLICE-2 (Primary)	MASH Limit
OIV ft/s (m/s)	Longitudinal	-27.02 (-8.23)	-26.19 (-7.98)	±40 (12.2)
	Lateral	-12.70 (-3.87)	-13.28 (-4.05)	±40 (12.2)
ORA g's	Longitudinal	**-22.60**	**-21.80**	±20.49
	Lateral	8.89	-7.88	±20.49
MAX ANGULAR DISP. deg.	Roll	-8.46°	-9.66°	±75
	Pitch	-5.90°	-6.15°	±75
	Yaw	-11.31°	-12.59°	not required
THIV – ft/s (m/s)		27.79 (8.47)	27.53 (8.39)	not required
PHD – g's		23.27	22.52	not required
ASI		1.04	0.98	not required

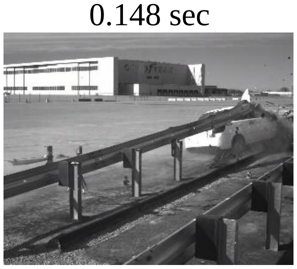
Figure 30. Summary of Test Results and Sequential Photographs, Test No. GAA-1

0.000 sec

0.038 sec

0.064 sec

0.148 sec



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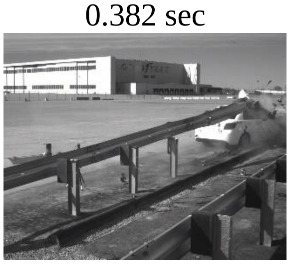

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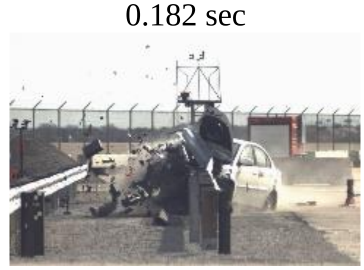

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Figure 31. Additional Sequential Photographs, Test No. GAA-1

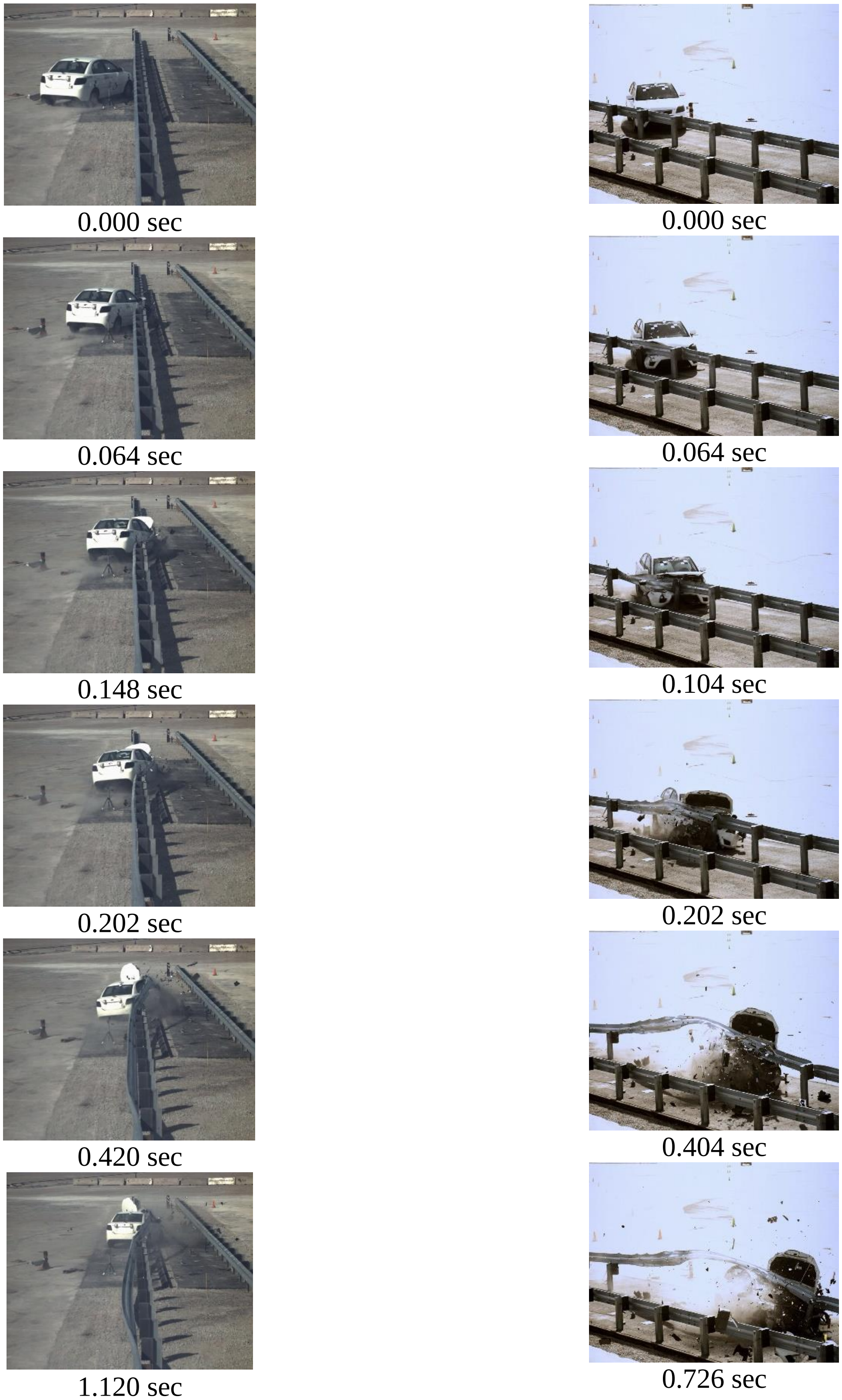

Figure 32. Additional Sequential Photographs, Test No. GAA-1

Figure 33. Documentary Photographs, Test No. GAA-1

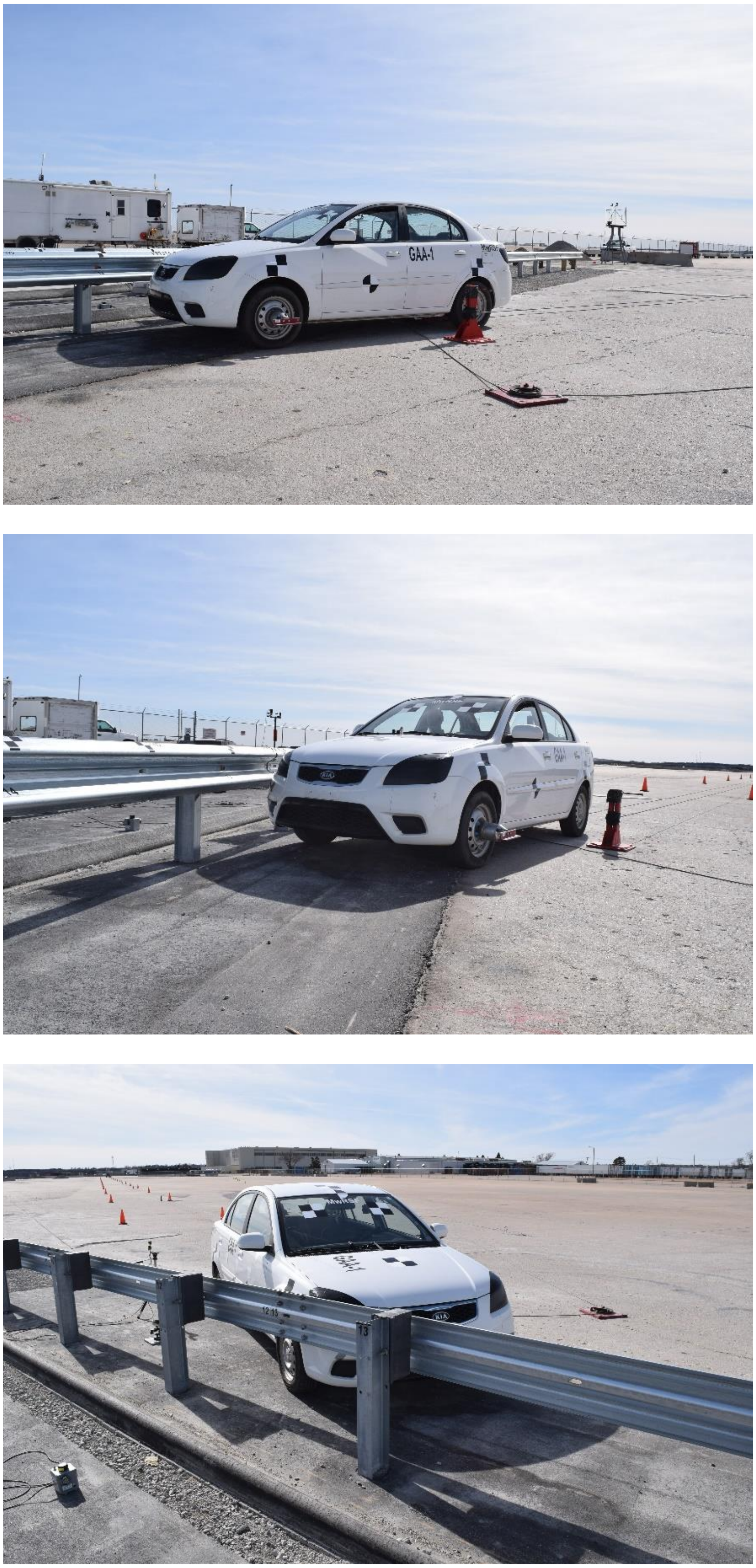

Figure 34. Impact Location, Test No. GAA-1

Figure 35. Vehicle Final Position and Trajectory Marks, Test No. GAA-1

Figure 36. Vehicle Final Position, Test No. GAA-1

Figure 37. System Damage, Test No. GAA-1

Figure 38. System Damage – Post Nos. 4 through 15, Test No. GAA-1

Figure 39. System Damage – Post Nos. 16 through 27, Test No. GAA-1

Figure 40. Post No. 12 Damage, Test No. GAA-1

Figure 41. Post No. 13 Damage, Test No. GAA-1

Figure 42. Post No. 14 Damage, Test No. GAA-1

(a) (b)

Figure 43. Damage to Post Nos. (a) 15 and (b) 16, Test No. GAA-1

Figure 44. Upstream End Anchor Movement, Test No. GAA-1

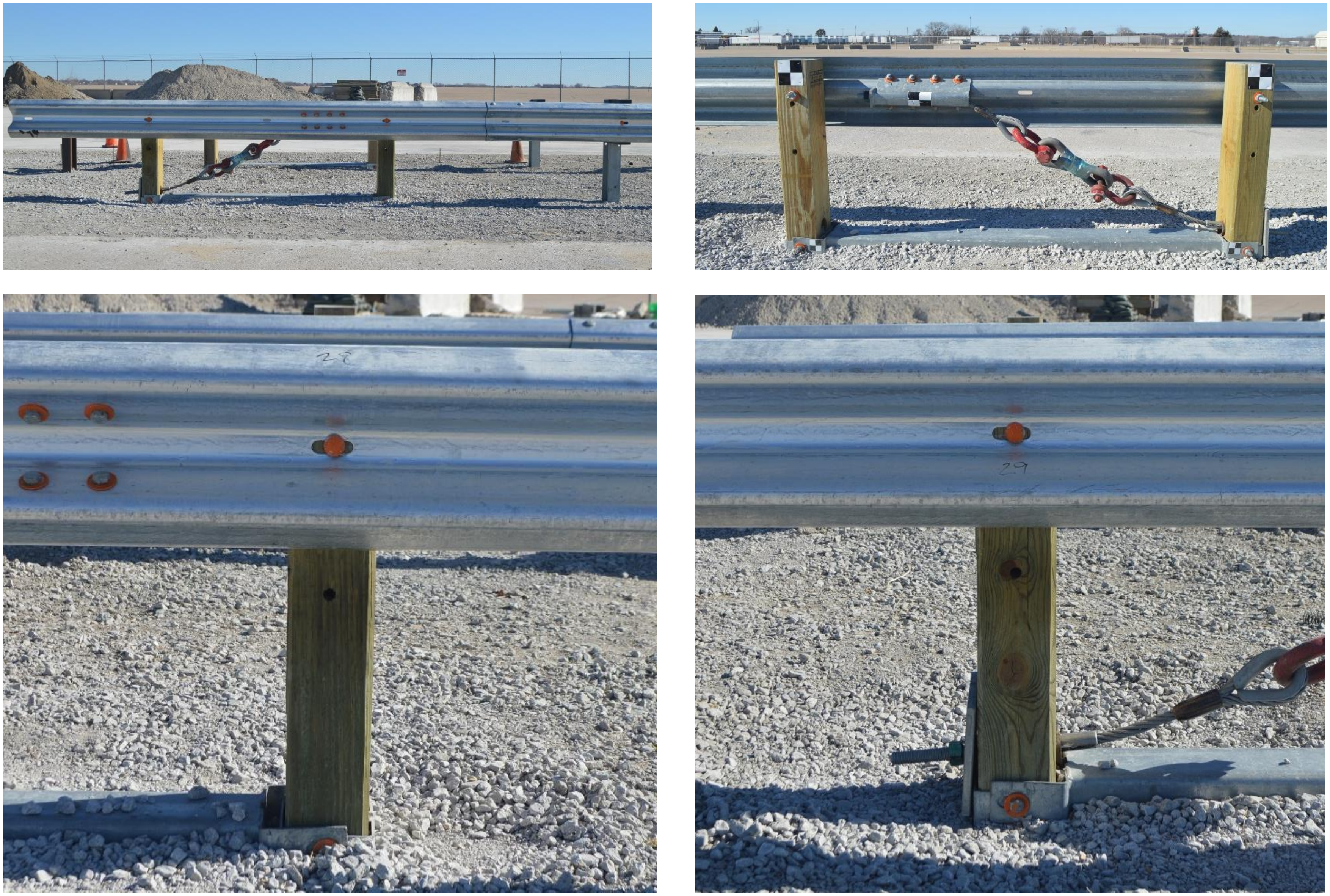

Figure 45. Downstream End Anchorage Movement, Test No. GAA-1

Figure 46. Post Nos. 28 and 29, Downstream End Anchorage, Test No. GAA-1

Figure 47. Vehicle Damage, Test No. GAA-1

Figure 48. Vehicle Damage, Test No. GAA-1

Figure 49. Occupant Compartment Deformation, Test No. GAA-1

Figure 50. Vehicle Undercarriage Damage, Test No. GAA-1

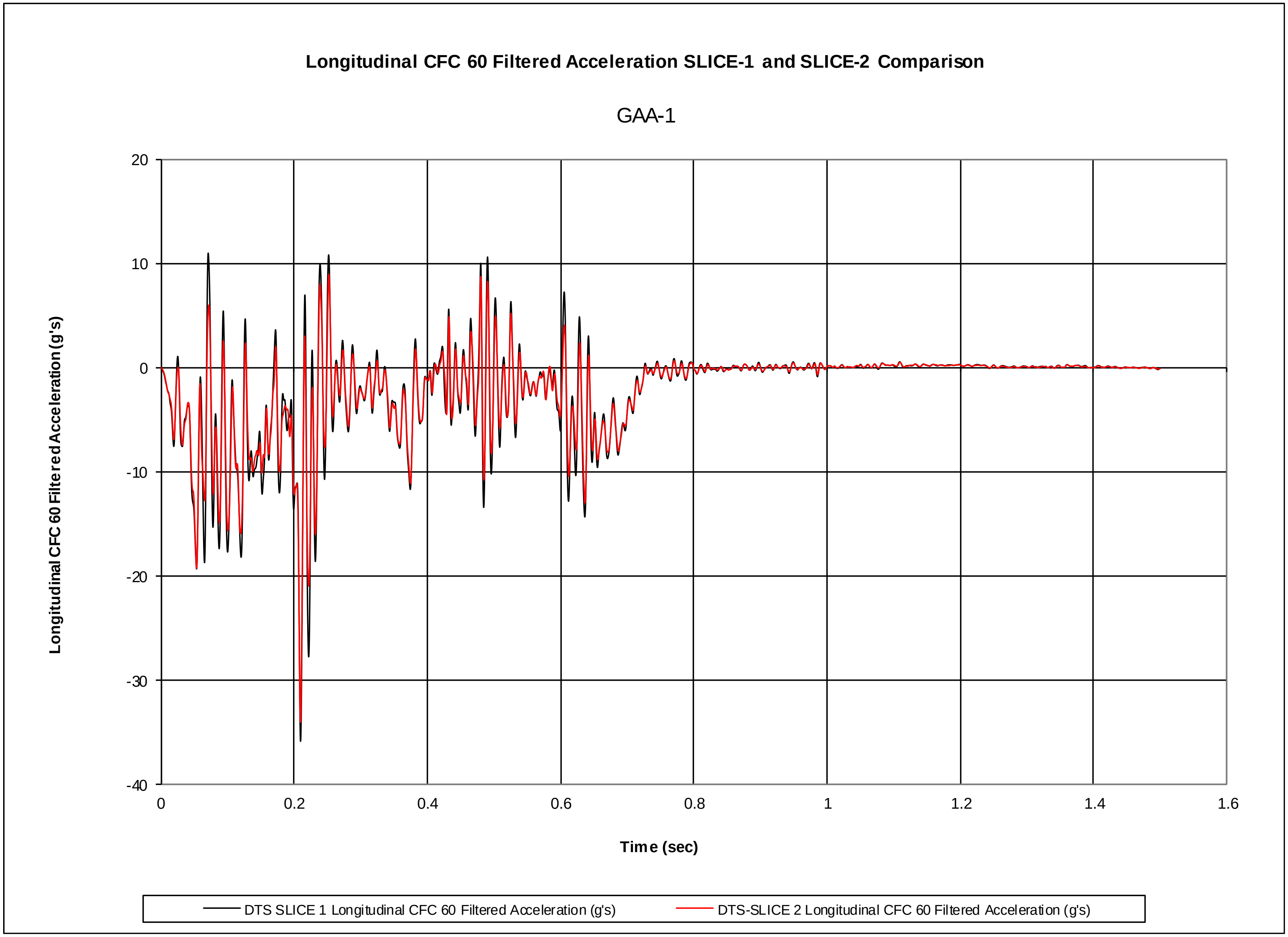

Figure 51. SAE CFC60 Longitudinal Acceleration (SLICE-1 and SLICE-2), Test No. GAA-1

6 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

An MGS was installed in an asphalt mow strip with an asphalt curb placed behind it, as shown in Figures 2 and 20. The barrier system was crash tested and evaluated according to MASH 2016. One full-scale crash test was performed according to the TL-3 safety performance criteria, specifically test designation no. 3-10. Test no. GAA-1 consisted of a 2,392-lb (1,085-kg) small car impacting the MGS at a speed of 62.8 mph (101.1 km/h) and at an angle of 25.1 degrees for an impact severity of 56.8 kip-ft (77 kJ). The vehicle was brought to a stop while in contact with the system. A 1-in. (25-mm) tear was found in the left-rear floor pan. The occupant compartment deformation for the roof was 5⅛ in. (130 mm), which exceeded the MASH 2016 limit of 4 in. (102 mm), and the windshield was crushed in 7⅛ in. (181 mm), which exceeded the MASH 2016 limit of 3 in. (76 mm). The maximum longitudinal ORA value of -21.80 g's recorded by SLICE-2 (the primary data recorder) exceeded the MASH 2016 limit of 20.49 g's. Note, the secondary data recorder value also exceeded the maximum longitudinal ORA value. Thus, the MGS that was installed in an asphalt mow strip with a curb placed behind it was unacceptable according to the safety performance criteria presented in MASH 2016. A summary of the safety performance evaluation is provided in Table 7.

Table 7. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. GAA-1</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td></tr>
<tr><td rowspan="11">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>U</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td rowspan="4">U</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
<tr><td colspan="5">MASH 2016 Test Designation No.</td><td>3-10</td></tr>
<tr><td colspan="5">Final Evaluation (Pass or Fail)</td><td>Fail</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

7 REFERENCES

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8. MacInnis, D., Cliff, W., and Ising, K., *A Comparison of the Moment of Inerita Estimation Techniques for Vehicle Dynamics Simulation*, SAE Technical Paper Series – 970951, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1997.

9. Society of Automotive Engineers (SAE), *Instrumentation for Impact Test – Part 1 – Electronic Instrumentation*, SAE J211/1 MAR95, New York City, NY, July, 2007.

10. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

11. *Collision Deformation Classification – Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

8 APPENDICES

Appendix A. Georgia DOT Standard Details - 2002 Revision

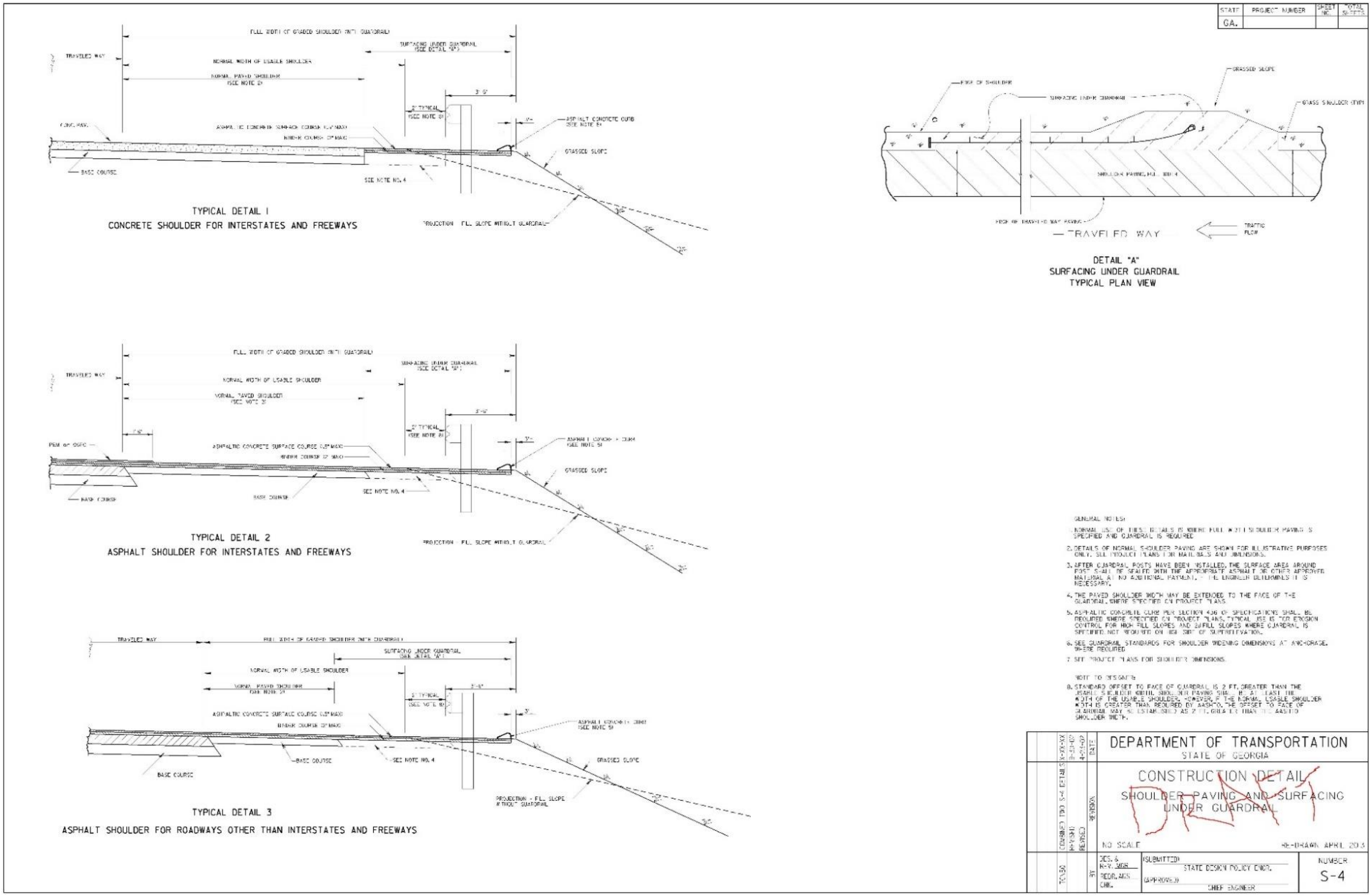

Figure A-1. Georgia DOT Construction Detail S-4

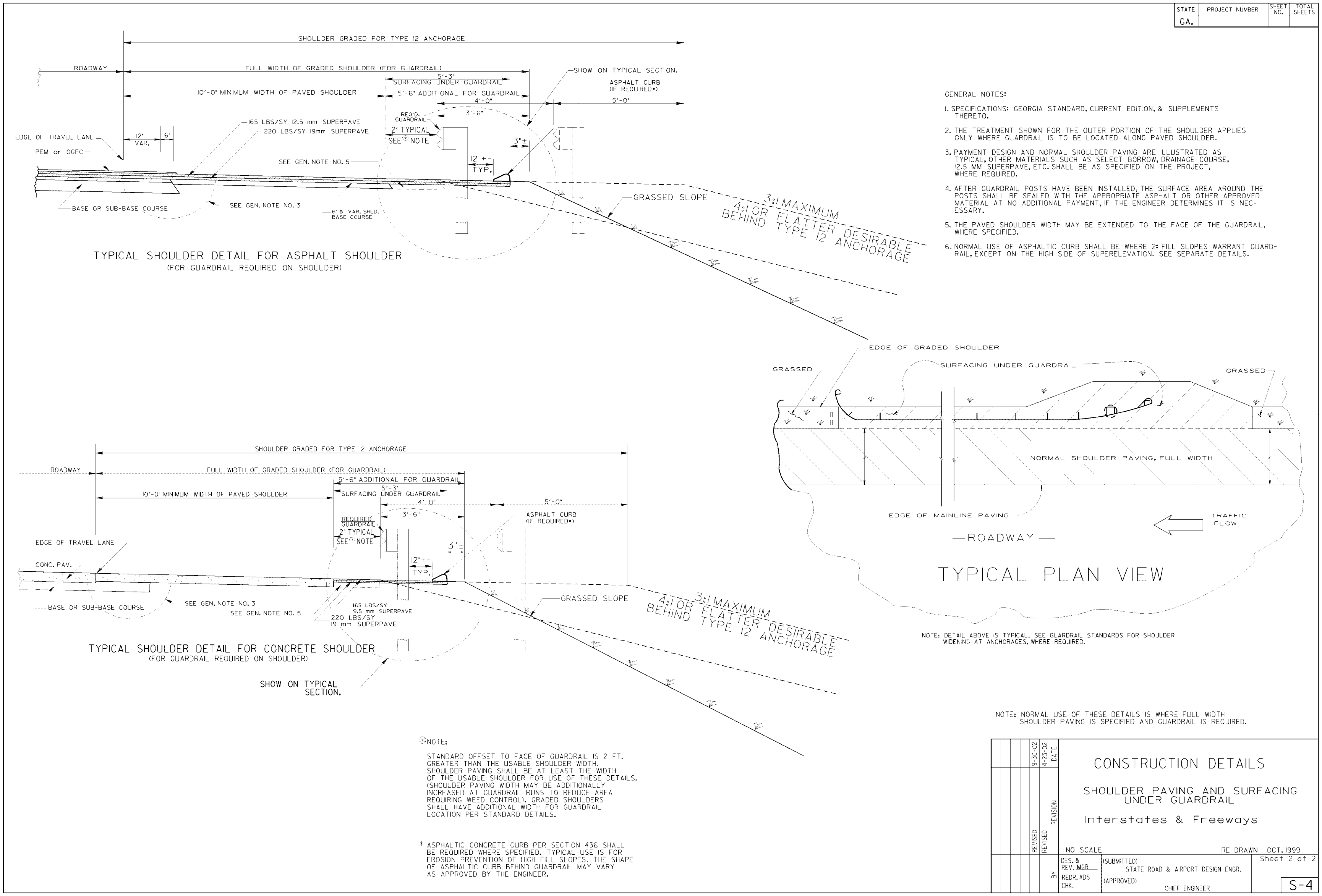

Figure A-2. Georgia DOT Construction Detail S-4

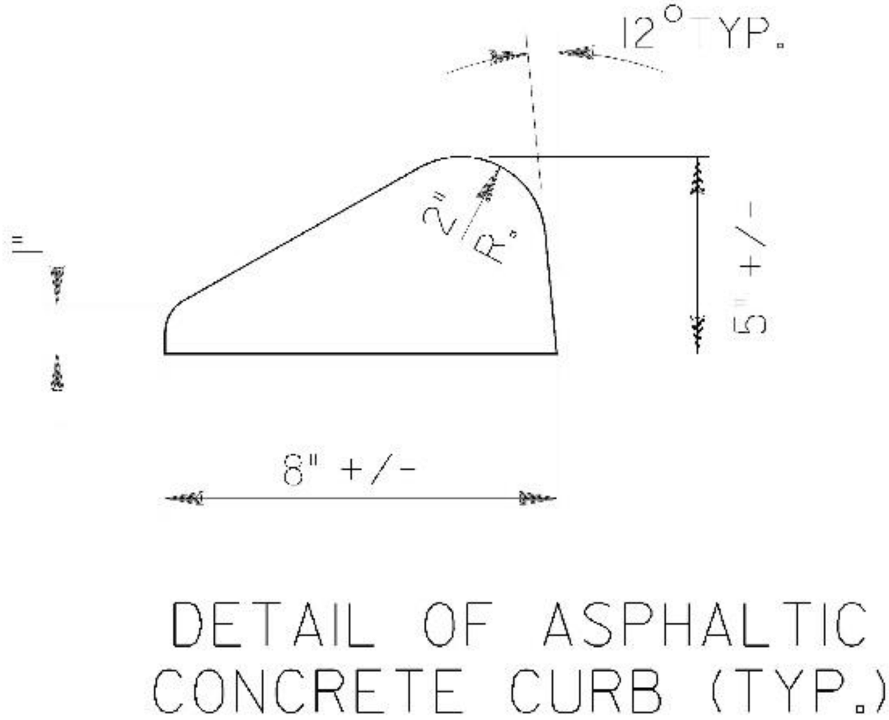

Figure A-3. Georgia DOT Asphalt Curb Detail

Appendix B. Asphalt Core Test Results

February 22, 2017

Compressive Strength of Asphalt Cores Taken from MASH Test Site

Overview:

A series of compression tests were performed on cylindrical asphalt specimens cored from the site prepared for full-scale Manual of Assessing Safety Hardware (MASH) crash tests. The crash test site is located at the Midwest Roadside Safety Facility (MwRSF) in Lincoln, NE. Based on the heights of the cores taken from the test site, the asphalt strip at the site ranges from 3.75 to at least 4.25 inches in thickness.

The compression tests on the cores were performed at the Structural Engineering Mechanics and Materials (SEMM) Laboratory on the Georgia Tech campus. All test protocols are based on ASTM D1074 – 09: "Standard Test Method for Compressive Strength of Bituminous Mixtures." The recommended specimen size is 4 by 4 in. (nominal height and diameter) and loading rate is 0.2 in./min. This loading rate is slow enough to observe the failure shape and the propagation of cracks in specimens.

For reference, also presented are representative test results from cores taken at Georgia Tech during the Phase 1 (static) and Phase 2 (dynamic) subcomponent experimental investigations.

MwRSF specimen test:

Three specimens cored from asphalt mow strip at MwRSF test site were tested on 2/21/2017. To determine a representative strength, each specimen was taken from different location: (1) near the impact point of crash vehicle, (2) upstream section, and (3) downstream section. Table 1 includes compression test results and other test information including specimen dimension, test condition, and photographs taken during the test. All specimens showed a similar failure mode represented by lateral expansion and vertical cracks. The average compressive strength from the 3 cores was approximately 400 psi.

Table 1. MwRSF Specimen Test Sheet

Specimen	N-01	N-02	N-03
Core location	Near the impact point	Upstream section	Downstream section
Test picture (setup)			
Test picture (failure)			
Actual diameter	3.70 in.	3.70 in.	3.70 in.
Thickness (Height)	4.25 in.	3.75 in.	3.80 in.
Test temperature	70 °F	71 °F	67 °F
Age of specimen	76 days (curing time from asphalt placement)		
Compressive strength	371.0 psi	396.5 psi	430.6 psi
	Average compressive strength = 399.4 psi		

<u>Georgia Tech core tests (reference):</u>

In the Phase 1 GDOT research project involving static tests of guardrail posts driven through an asphalt layer, a total of 35 compression tests were performed to investigate the effect of aging/curing on asphalt strength (from 11/12/2014 to 4/17/2015). Figure 1 shows the trend of asphalt strength gain over time.

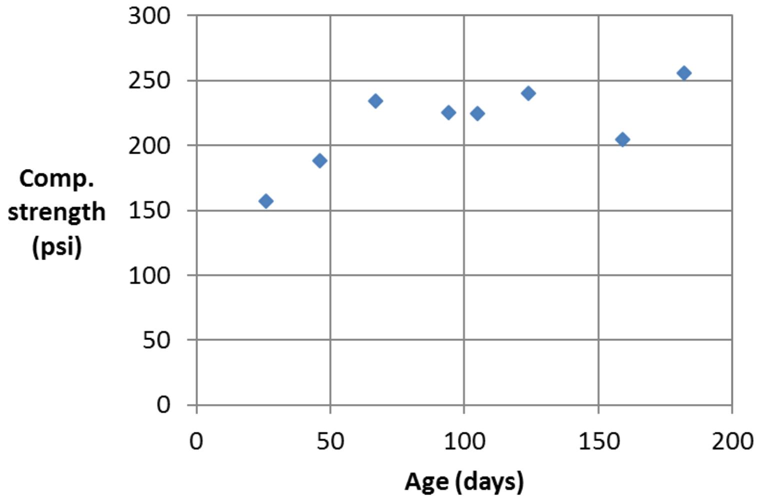

Figure 1. Average Compressive Strength Versus Age (specimens from Georgia Tech static test site)

In the Phase 2 GDOT research project focusing on dynamic testing of guardrail posts driven through an asphalt layer, a modified asphalt mix design was used for a fast-track repetition of dynamic test and asphalt mow strip placement in given project duration. By using a specific type of mix, the reference compressive strength was achieved in approximately 2 weeks from the asphalt placement.

Table 2 shows a summary of all specimen test information performed at Georgia Tech. Vertical cracks and horizontal expansion was similarly observed in most of the tested specimens. The average compressive strength values were approximately 240 psi.

Table 2. Georgia Tech Specimen Test Summary Sheet

Type	Reference asphalt mix in Georgia	Modified asphalt mix
Description of mix	Hot mix asphalt, PG 76-22 binder, 19 mm max. aggregate	Portland cement added (10% by weight) Cold mix asphalt, 9 mm max. aggregate
Test picture (failure)		
No. of tested specimen	9	10
Test temperature	68 °F	66 ~ 71 °F (average: 68.2)
Age of specimen	124 days	11 ~ 14 days (average: 12.9)
Average compressive strength	240.5 psi (60.2% of MwRSF)	239.3 psi (59.9% of MwRSF)

Prepared by:
David W. Scott Principal Investigator
Seo-Hun Lee Graduate Research Assistant
School of Civil and Environmental Engineering
Georgia Institute of Technology

Appendix C. Material Specifications

Table C-1. Bill of Materials, Test No. GAA-1

Item No.	Description	Material Specification	References
-	Asphalt	GA 12.5 mm Superpave	Project No. NH-STP-92-6(121), Design No. 2016-2
-	Curb	GA 4.75 mm or 9.5 mm Superpave Level A Mixture	Project No. NH-STP-92-6(121), Design No. 2016-2
a1	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS Section	AASHTO M180	H#9411949
a2	12'-6" [3,810] 12 gauge [2.7] W-Beam MGS End Section	AASHTO M180	H#9411949
a3	6'-3" [1,905] 12 gauge [2.7] W-Beam MGS Section	AASHTO M180	R#12-0368 RedPaint WB2
a4	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post	ASTM A992	Post#3-9,13,14,16-27 H#55044258; Post#10-12 H#2413988; Post#15 H#55028671
a5	5 1/8"x8"x14" [130x203x356] Composite Recycled Blockout	Mondo Polymer MGS14SH or Equivalent	L#160428/1000
b1	BCT Timber Post - MGS Height	SYP Grade No. 1 or better (No knots +/- 18" [457] from ground on tension face)	Post#1-2 Ch#22215, Post#28-29 Ch#22927
b2	72" [1829] Long Foundation Tube	ASTM A500 Gr. B	H#0173175
b3	Ground Strut Assembly	ASTM A36	R#090453-8, BOL#43073
b4	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	H#E86298
b5	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	H#6106195
b6	Anchor Bracket Assembly	ASTM A36	H#4153095
b7	BCT Cable Anchor Assembly	-	North: H#DL15103032, South: SO#1210536, BOL#79448
d1	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#150424L Nuts: H#10446960
d2	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#150424L Nuts: H#10446960
d3	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#20337380 Nuts: H#10446960
d4	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#DL15107048 Nuts: R#16-0217 P#36713 C#210101526
d5	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#7366484, 7367052, 7368369 Nuts: R#16-0217 P#36713 C#210101526
d6	7/8" [22] Dia. UNC, 8" [203] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#2038622 Nuts: H#NF12101054
e1	5/8" [16] Dia. Plain Round Washer	ASTM F844	n/a
e2	7/8" [22] Dia. Plain Round Washer	ASTM F844	n/a

Georgia Asphalt Mix
SMT

State of Nebraska

#2-12982-SPR-16-MD

Department of Roads
Asphalt Concrete Design

Project Manager: JESSE DE LOS SANTOS
Project No: NH-STP-92-6(121)
Name of Road: N-92, MEAD - YUTAN
Type of Asphalt Concrete: SPR
Design No: 2016-2

Date: 06-17-16 Approved

ASPHALT BINDER
Source: FLINT HILLS
Grade: PG ~~64-34~~ 64-22 was used as per specification

GRADATION OF MATERIALS PROPOSED						SIEVE ANALYSIS (WASH)								
MATERIAL	PIT LOCATION					19.0	12.5	9.50	4.75	2.36	1.18	600	300	75
	%	1/4	SEC	T	R	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#200
RC-1 LIMESTONE	10	KERFORD				100.0	53.6	22.1	5.5	3.5	3.0	2.7	2.5	1.5
MAN SAND	27	MARTIN MARIETTA				100.0	100.0	100.0	92.6	49.8	26.0	12.0	6.6	4.6
47B GRAVEL	10	NE	23	16N	1E	100.0	99.6	98.2	91.6	72.3	50.9	30.0	10.6	0.6
SCREENINGS	8	KERFORD				100.0	100.0	100.0	94.4	62.0	51.6	40.7	30.5	16.0
RAP	45	ON PROJECT				97.6	94.2	91.3	77.5	58.6	37.5	23.6	16.9	8.0
		COMBINED GRADATION				98.9	92.7	88.1	77.1	52.4	33.4	20.4	13.1	6.3
		SPECIFICATION RANGE				98		81		46			12	4
						100		89		56			21	9

JOB MIX IDENTIFICATION			
JMF #	110		
TOTAL BINDER	5.10%		

CONSENSUS PROPERTIES		FAA SP.GR.
FAA Results	44.3	2.585
CAA Results	97	
Sand Equivalent	78	
F & E Particles	2	
Dust to Asph. Ratio	1.12	
Design Gsb	2.585	

Addition of 2.31% of type PG 64-34 asphalt binder for a total of 5.10% (by wt.of mix) has been selected by the contractor to be the target asphalt binder content.

*Note: 1.25% Hydrated Lime, by weight of virgin aggregate, will added during construction of this design.

This constitutes verification of the job-mix gradation and superpave criteria values proposed by the contractor. If it is necessary to change the job mix either before or after the job starts, including the asphalt binder %, the contractor shall notify the P.E. / P.M.

cc: Constructor's Inc.
Ron Vajgrt
Andy Dearmont
Robert Rea
Matt Beran
File

REMARKS: **This new mix design is due to gradation changes in the RAP material and will start with Lot 1-3. Please use a +0.3% correction for the asphalt binder content during construction. RR/jp**

Validated by Robert C. Rea & Materials and Research Division
Fax (402) 479-3882

Figure C-1. Asphalt Mix, Test No. GAA-1

Gregory Industries 13:54:11 Jun 24 2015 Page 1

HEAT MASTER LISTING

Heat No.	Mill#	Name	YR	Primary Grade	Secondary Grade	CODE	Original Heat Number
9411949	ARC03	ARCELOR MITTAL USA, LLC	15	1021		8534	

******* Chemistry *******

Cr	Si	P	C	Mn	S	Cu	Ni	Mo	Sn	Al	V	Cb	N	Ti
0.0400	0.0100	0.0100	0.2100	0.7500	0.0060	0.0200	0.0100	0.0100	0.0020	0.0580	0.0020	0.0020	0.0042	0.0020

Ca
0.0003

******* Mechanical Test *******

YIELD	TENSILE	ELONGATION	ROCKWELL
56527	75774	27.15	78

Guardrail W-Beam
20ct/25'
100ct/12'
10ct/25ft w/MGS Anchor Panel
July 2015 SMT

Figure C-2. W-beam Guardrail at Post Nos. 1 through 26, 28, and 29, Test No. GAA-1

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1164746
Customer PO: 2563
BOL Number: 69500
Document #: 1
Shipped To: NE
Use State: KS

As of: 5/16/12

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
50	6G	12/6'3/S	M-180	A	2	515691	64,000	72,300	27.0	0.060	0.740	0.009	0.008	0.010	0.021	0.04	0.032	0.000	4
			M-180	A	2	4111321	63,100	80,200	29.0	0.210	0.710	0.009	0.007	0.010	0.030	0.000	0.030	0.000	4
			M-180	A	2	515659	67,000	75,200	26.0	0.064	0.790	0.012	0.008	0.008	0.022	0.000	0.025	0.000	4
			M-180	A	2	515660	66,800	74,300	27.0	0.064	0.740	0.012	0.006	0.009	0.017	0.000	0.025	0.000	4
			M-180	A	2	515662	63,900	72,900	28.0	0.064	0.770	0.010	0.006	0.009	0.016	0.000	0.025	0.000	4
			M-180	A	2	515663	64,900	76,500	21.0	0.064	0.740	0.009	0.007	0.007	0.023	0.000	0.026	0.000	4
			M-180	A	2	515668	66,700	75,500	27.0	0.063	0.770	0.014	0.007	0.010	0.024	0.000	0.030	0.000	4
			M-180	A	2	515668	70,200	80,800	21.0	0.063	0.770	0.014	0.007	0.010	0.024	0.000	0.030	0.000	4
			M-180	A	2	515669	64,500	74,100	26.0	0.063	0.790	0.014	0.007	0.009	0.017	0.000	0.028	0.000	4
			M-180	A	2	515687	63,400	74,100	30.0	0.068	0.750	0.012	0.010	0.008	0.025	0.000	0.060	0.000	4
			M-180	A	2	515687	65,100	74,400	28.0	0.068	0.750	0.012	0.010	0.008	0.025	0.000	0.060	0.000	4
			M-180	A	2	515690	63,000	71,800	27.0	0.059	0.720	0.010	0.008	0.013	0.024	0.000	0.042	0.000	4
			M-180	A	2	515696	62,900	72,500	28.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515696	63,900	73,400	29.0	0.058	0.740	0.013	0.008	0.011	0.029	0.000	0.046	0.000	4
			M-180	A	2	515700	67,800	77,700	28.0	0.065	0.800	0.013	0.009	0.012	0.036	0.000	0.035	0.000	4
			M-180	A	2	616068	62,900	71,600	27.0	0.061	0.740	0.013	0.010	0.012	0.027	0.000	0.064	0.000	4
			M-180	A	2	616068	66,700	74,200	30.0	0.061	0.740	0.013	0.010	0.012	0.027	0.000	0.064	0.000	4
			M-180	A	2	616071	64,000	74,000	28.0	0.061	0.760	0.016	0.007	0.011	0.021	0.000	0.028	0.000	4
			M-180	A	2	616072	63,800	74,200	29.0	0.066	0.750	0.014	0.009	0.010	0.026	0.000	0.039	0.000	4
			M-180	A	2	616073	63,900	73,300	27.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
			M-180	A	2	616073	65,000	74,500	28.0	0.064	0.760	0.016	0.009	0.012	0.024	0.000	0.041	0.000	4
30	60G	12/25/6'3/S	M-180	A	2	4111321	63,100	80,200	29.0	0.210	0.710	0.009	0.007	0.010	0.030	0.00	0.030	0.000	4
			M-180	A	2	515656	63,600	73,600	27.0	0.066	0.720	0.012	0.006	0.011	0.021	0.000	0.026	0.000	4
			M-180	A	2	515658	64,800	74,300	26.0	0.069	0.740	0.010	0.006	0.011	0.022	0.000	0.021	0.000	4
			M-180	A	2	515659	67,000	75,200	26.0	0.064	0.790	0.012	0.008	0.008	0.022	0.000	0.025	0.000	4
			M-180	A	2	515663	64,900	76,500	21.0	0.064	0.740	0.009	0.007	0.007	0.023	0.000	0.026	0.000	4

1 of 4

Figure C-3. W-Beam Guardrail at Post No. 27, Test No. GAA-1

GERDAU

CERTIFIED MATERIAL TEST REPORT

Page 1/1

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
HIGHWAY SAFETY CORP 473 W FAIRGROUND ST MARION,OH 43302-1701 USA	HIGHWAY SAFETY CORP GLASTONBURY,CT 06033-0358 USA	A992/A709-36	Wide Flange Beam / 6 X 8.5# / 150 X 13.0	0000000000

LENGTH	WEIGHT	HEAT / BATCH
42'00"	44,982 LB	55044258/02

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
3399484/000010		ASTM A6-14 ASTM A709-13A ASTM A992-11 CSA G40.21-13 345WM

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
0001677045 IB-B0600800	1323-0000067091	03/30/2016

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %
0.13	0.90	0.010	0.028	0.18	0.29	0.10	0.06	0.031	0.016	0.016	0.000

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	G/L Inch	Elong. %
52000	71200	359	491	8.000	20.50
51600	69800	356	481	8.000	23.40

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

Figure C-4. W6x8.5 Posts, Post Nos. 3 through 9, 13 through 14, and 16 through 27, Test No. GAA-1

NUCOR STEEL BERKELEY
P.O. Box 2259
Mt. Pleasant, S.C. 29464
Phone: (843) 336-6000

CERTIFIED MILL TEST REPORT

12/22/14 18:46:36
100% MELTED AND MANUFACTURED IN THE USA
All beams produced by Nucor-Berkeley are cast and rolled to a fully killed and fine grain practice.
Mercury has not been used in the direct manufacturing of this material.

Sold To: HIGHWAY SAFETY CORP
PO BOX 358
GLASTONBURY, CT 06033

Ship To: HIGHWAY SAFETY CORP
473 WEST FAIRGROUND STREET
MARION, OH 43301

Customer #.: 352 - 3
Customer PO: 1627044
B.O.L. #...: 1110076
MOS: I

SPECIFICATIONS: Tested in accordance with ASTM specification A6/A6M-14 and A370. Quality Manual Rev #27.
ASTM : A572 5013a:A529-14-50 IB-B0600800

Description	Heat# / Grade(s) / Test/Heat JW	Yield/ Tensile Ratio	Yield (PSI) (MPa)	Tensile (PSI) (MPa)	Elong %	C / Cr / ******	Mn / Mo / Ti	P / Sn / ******	S / B / ******	Si / V / N	Cu / Nb / ******	Ni / ****** / CI	CE1 / CE2 / Pcm
W6X8.5	2413985	.83	57200	69300	25.54	.07	.84	.013	.039	.21	.20	.05	.25
042' 00.00"	A572 5013a		394	478		.06	.01	.0091	.0005	.005	.015		.2835
W150X12.6	A992-11	.82	56400	69100	26.69		.001			.0051		4.59	.1404
012.8016m	ANS		389	476	90 Pc(s) 32,130 lbs							Inv#:	0
W6X8.5	2413988	.83	58300	70600	26.70	.07	.86	.014	.034	.17	.23	.06	.25
042' 00.00"	A572 5013a		402	487		.06	.01	.0091	.0005	.004	.015		.2773
W150X12.6	A992-11	.82	57200	69800	28.55		.001			.0051		4.87	.1356
012.8016m	ANS		394	481	36 Pc(s) 12,852 lbs							Inv#:	0

2 Heat(s) for this MTR.

R#15-0515 H#2413988

W6x8.5x6'

April 2015 SMT

Elongation based on 8" (20.32cm) gauge length. 'No Weld Repair' was peformed.
CI = 26.01Cu+3.88Ni+1.20Cr+1.49Si+17.28P (7.29Cu*Ni) (9.10Ni*P) 33.39(Cu*Cu)
Pcm = C+(Si/30)+(Mn/20)+(Cu/20)+(Ni/60)+(Cr/20)+(Mo/15)+(V/10)+5B
CE1 = C+(Mn/6)+((Cr+Mo+V)/5)+((Ni+Cu)/15)
CE2 = C+((Mn+Si)/6)+((Cr+Mo+V+Cb)/5)+((Ni+Cu)/15)

I hereby certify that the contents of this report are accurate and correct. All test results and operations performed by the material manufacturer are in compliance with material specifications, and when designated by the Purchaser, meet applicable specifications.

Bruce A. Work
Metallurgist

Figure C-5. W6x8.5 Posts, Post Nos. 10 through 12, Test No. GAA-1

CERTIFIED MATERIAL TEST REPORT Page 1/1

GERDAU

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
HIGHWAY SAFETY CORP 473 W FAIRGROUND ST MARION,OH 43302-1701 USA	HIGHWAY SAFETY CORP GLASTONBURY,CT 06033-0358 USA	A992/A709-36	Wide Flange Beam / 6 X 8.5#

LENGTH	WEIGHT	HEAT / BATCH
42'00"	37,485 LB	55028671/02

SALES ORDER	CUSTOMER MATERIAL N°
448220/000020	

SPECIFICATION / DATE or REVISION
1-ASTM A6/A6M-11
2-A992/A992M-11
3-A709/A709M-11
4-A36/A36M-08

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
001562143 IB-B0600800	1323-0000008317	07/17/2013

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	N %	Pb %
0.14	0.90	0.015	0.020	0.19	0.29	0.10	0.07	0.034	0.016	0.002	0.0090	0.0080

CHEMICAL COMPOSITION

Sn %
0.012

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS 0.2% PSI	YS MPa
20.20	8.000	74300	512	50900	351
22.10	8.000	74000	510	54800	378

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

Figure C-6. W6x8.5 Posts, Post No. 15, Test No. GAA-1

MONDO POLYMER TECHNOLOGIES INC.
Plastics From Today for Tomorrow...

P.O. BOX 250
27620 ST. RT. 7 NORTH
RENO, OH 45773

Phone: 740-376-9396
Fax: 740-376-9960
(888) 607-4790

MATERIAL CERTIFICATE

SHIPMENT NUMBER: 28384
PURCHASE ORDER Verbal Karla
SHIPMENT DATE: 12/8/2016

PAGE: 1

CONSIGNED TO

Midwest Roadside Safety
4800 N.W. 35th Street
Lincoln, NE 68524

SHIP TO

4800 N.W. 35th Street
Lincoln, NE 68524

CONSIGNED	ITEM NUMBER	DESCRIPTION	LOT#	SHIP VIA
40	GB14SH1	Composite Guardrail Block 14" for Steel Post w/hanger	160428/1000	UPS Freight

MADE IN USA

Mondo Polymer Technologies, Inc.'s product, the Polymer Offset Block named MondoBlock, is of the same formulation, composition and test properties which were qualified and NCHRP 350 crash tested and approved by the Federal Highway Administration Approval No. #HSA-10/B-39A

All materials meet specifications required

NOTARIAL SEAL STATE OF OHIO
Cindy L. Fogle
CINDY L FOGLE
Notary Public - State of Ohio
My Commission Expires
10/27/2021
12-8-16

Approved by: Maggie Ellis   Date: 12/8/16

Print Name: MAGGIE ELLIS   Position: GENERAL MANAGER

Figure C-7. Composite Blockout, Test No. GAA-1

CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

R#16-692 5.5x7.5x46" Timber Post
Black Paint tags COC
June2016 SMT

Date: 5/24/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10054053

Customer PO# 3260 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GS6846PST	5.5-7.5-46" BCT	42	22215	.634
GS6806.5PST	5.5x7.5-6.5' Rub Post	42	22225	.633
GS68065PST	5.5x7.5-6.5' Rub Post	42	22226	.660
GS68065PST	5.5x7.5-6.5' Rub Post	168	22185	.650
GS6823BLK	6x8-23" Rub Block	168	22240	.730

I certify the above referenced material has been produced, treated and tested in accordance with AWPA standards and conforms to AASHTO M133 & M168.

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

Nick Sowl, General Counsel

5/24/16
Date

Figure C-8. BCT Timber Post, Post Nos. 1 and 2, Test No. GAA-1

CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

R#17-282 BCT Posts 70 Acct AND Wood Blocks for Bullnose
Nov2016 SMT Wood Blockouts are painted Light Blue

Date: 11/11/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10055387

Customer PO# 3339 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GR6806.5PST	6x8-6.5" PST	35	22973	.679
GR6806.5CRT	6x8-6.5" CRT	35	22973	.679
GS6846PST	5.5-7.5-46" BCT	42	22927	.638
GR61214BLK	6x12-14" OCD	168	22927	.638

I certify the above referenced material has been produced, treated and tested in accordance with AWPA standards and conforms to AASHTO M133 & M168.

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

Nick Sowl, General Counsel

11/11/16
Date

Figure C-9. BCT Timber Post, Post Nos. 28 and 29, Test No. GAA-1

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: STOCK

Order Number: 1215324 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2884
BOL Number: 80821 Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/14/14

Foundation Tubes Green Paint
R#15-0157 September 2014 SMT

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	701A	.25X11.75X16 CAB ANC	A-36			A3V3361	48,600	69,000	29.1	0.180	0.410	0.010	0.005	0.040	0.270	0.000	0.070	0.001	4
	701A		A-36			JJ4744	50,500	71,900	30.0	0.150	1.060	0.010	0.035	0.240	0.270	0.002	0.090	0.021	4
12	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
15	736G	5'/TUBE SL/.188"X6"X8"FLA	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
12	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
5	783A	5/8X8X8 BEAR PL 3/16 STP	A-36			10903960	56,000	79,500	28.0	0.180	0.810	0.009	0.005	0.020	0.100	0.012	0.030	0.000	4
	783A		A-36			DL13106973	57,000	72,000	22.0	0.160	0.720	0.012	0.022	0.190	0.360	0.002	0.120	0.050	4
20	3000G	CBL 3/4X6'6/DBL	HW			99692													
25	4063B	WD 6'0 POST 6X8 CRT	HW			43360													
15	4147B	WD 3'9 POST 5.5"X7.5"	HW			2401													
20	15000G	6'0 SYT PST/8.5/31" GR HT	A-36			34940	46,000	66,000	25.3	0.130	0.640	0.012	0.043	0.220	0.310	0.001	0.100	0.002	4
10	19948G	.135(10Ga)X1.75X1.75	HW			P34744													
2	33795G	SYT-3"AN STRT 3-HL 6'6	A-36			JJ6421	53,600	73,400	31.3	0.140	1.050	0.009	0.028	0.210	0.280	0.000	0.100	0.022	4
4	34053A	SRT-31 TRM UP PST 2'6.625	A-36			JJ5463	56,300	77,700	31.3	0.170	1.070	0.009	0.016	0.240	0.220	0.002	0.080	0.020	4

1 of 3

Figure C-10. Foundation Tubes, Test No. GAA-1

425 E. O'Connor
Lima, OH

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

Pieces	Description
64	5/8"X10" GR BOLT A307
192	5/8"X18" GR BOLT A307
32	1" ROUND WASHER F844
64	1" HEX NUT A563
192	WD 6'0 POST 6X8 CRT
192	WD BLK 6X8X14 DR
64	NAIL 16d SRT
64	WD 3'9 POST 5.5X7.5 BAND
32	STRUT & YOKE ASSY
128	SLOT GUARD '98
32	3/8 X 3 X 4 PL WASHER

MGSBR

Ground Strut
090453-8

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB
State of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public:
Commission Expires

Trinity Highway Products, LLC
Certified By:

2 of 4

05/04/2009 16:36 402-761-3288

Figure C-11. Ground Strut Assembly, Test No. GAA-1

09Mar'15 13:22 TEST CERTIFICATE No: MAR 268339

INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 4500240795
Rel
S/O No MAR 280576-001
B/L No MAR 163860-003 Shp 09Mar'15
Inv No Inv

Sold To: (5016)
STEEL & PIPE SUPPLY
1003 FORT GIBSON ROAD
CATOOSA, OK 74015

Ship To: (1)
STEEL & PIPE SUPPLY
1003 FORT GIBSON ROAD
CATOOSA, OK 74015

Tel: 918-266-6325 Fax: 918 266-4652

CERTIFICATE of ANALYSIS and TESTS Cert. No: MAR 268339
05Mar'15

Part No 0010
ROUND A500 GRADE B(C)
2.375"OD (2"NPS) X SCH40 X 21' Pcs 111 Wgt 8,508

Heat Number	Tag No	Pcs	Wgt
E86298	927111	37	2,836
	YLD=69600/TEN=79070/ELG=24.2		
E86298	927113	37	2,836
E86298	927114	37	2,836

Heat Number *** Chemical Analysis ***
E86298 C=0.1700 Mn=0.5100 P=0.0100 S=0.0110 Si=0.0190 Al=0.0450
Cu=0.0300 Cr=0.0300 Mo=0.0030 V=0.0010 Ni=0.0100 Cb=0.0010
MELTED AND MANUFACTURED IN THE USA

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.

R#15-0626 H#E86298
BCT Pipe Sleeves
June 2015 SMT

CURRENT STANDARDS:
.................................A500/A500M-13
.................................A513-12
.................................A252-10
.................................A847/A847M-12

MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

Page: 1 .... Last

Figure C-12. BCT Post Sleeve, Test No. GAA-1

Certified Analysis

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

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Project: RESALE

Order Number: 1095199
Customer PO: 2841
BOL Number: 24481
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/20/08

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/6'3/8	M-180	A		24964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.040	0.080	0.000	0.060	0.000	4
20	701A	.25X11.75X16 CAB ANC	A-36			4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	6'0 TUBE SL/.188X8X6	A-500			A8P1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
20	782G	5/8"X8"X8" BEAR PL/OF	A-36			6106195	46,700	69,900	23.5	0.180	0.330	0.010	0.005	0.020	0.230	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180	A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	4

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

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 20th day of June, 2008

Notary Public:
Commission Expires

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires

Trinity Highway Products, LLC
Certified By:

Stefanie Onal.a

Figure C-13. Anchor Bearing Plate and Bracket Assembly, Test No. GAA-1

NUCOR
FASTENER DIVISION

LOT NO.
366055B

Post Office Box 6100
Saint Joe. Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
8061 STRUCTURAL BOLT CO LLC
TEST REPORT SERIAL# FB482520
TEST REPORT ISSUE DATE 1/08/16
DATE SHIPPED 1/21/16
NAME OF LAB SAMPLER: JOSEPH BYERLY, LAB TECHNICIAN

NUCOR ORDER # 957233
CUST PART #
CUSTOMER P.O. # 18131

****************CERTIFIED MATERIAL TEST REPORT****************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175647	3600	366055B	1-8 GR DH HV H.D.G. HEX NUT H.D.G./GREEN LUBE

MANUFACTURE DATE 10/01/15

--CHEMISTRY MATERIAL GRADE -1045L

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI	
RM030068	DL15103032	.45	.67	.003	.019	.20	NUCOR STEEL - SOUTH CAROL

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-07a

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH (LBS)	DEG-WEDGE STRESS (PSI)
N/A	30.8	PASS	N/A	N/A
N/A	28.6	PASS	N/A	N/A
N/A	26.6	PASS	N/A	N/A
N/A	26.2	PASS	N/A	N/A
N/A	24.5	PASS	N/A	N/A
AVERAGE VALUES FROM TESTS	27.3			

PRODUCTION LOT SIZE 42800 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-07a 80 PCS. SAMPLED LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-13 - GALVANIZING PERFORMED IN THE U.S.A.

1. 0.00278 2. 0.00892 3. 0.00428 4. 0.00237 5. 0.00321 6. 0.00228 7. 0.00603
8. 0.00676 9. 0.00315 10. 0.00321 11. 0.00371 12. 0.00264 13. 0.00252 14. 0.00348
15. 0.00287

AVERAGE THICKNESS FROM 15 TESTS .00388
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2012

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.823	1.833
Thickness	32	0.978	0.996

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO INTENTIONAL ADDITIONS OF BISMUTH, SELENIUM, TELLURIUM, OR LEAD WERE USED IN THE STEEL USED TO PRODUCE THIS PRODUCT.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

A2LA ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 01/31/16

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

Figure C-14. BCT Cable Anchor Assembly, Test No. GAA-1

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801

Customer: GUARDRAIL SYSTEMS, INC
8000 SERUM AVE.

RALSTON, NE 68127

Sales Order: 1210536
Customer PO: VERBAL TRENT
BOL # 79448
Document # 1

Print Date: 12/6/13
Project: RESALE
Shipped To: NE
Use State: NE

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Ohio, County of Allen. Sworn and Subscribed before me this 6th day of December, 2013

Notary Public:
Commission Expires: 9/23/2016

STATE OF OHIO
ANGELA COUNTS
NOTARY PUBLIC
ID# 2011NT8014
Commission Expires
January 22, 2016
AUGLAIZE COUNTY

Trinity Highway Products, LLC
Certified By:
Quality Assurance

2 of 2

Figure C-15. BCT Cable Anchor Assembly, Test No. GAA-1

35006

Trinity Metals Laboratory
A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD. 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214.589.7591 FAX: 214.589.7594

Trinity MSB Metals Lab

NVLAP
NVLAP LAB CODE 200654-0

TEST REPORT

Lab No: 15040472F

KEITH HAMBURG
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM
LIMA, OH 45801

Received Date: 04/22/2015
Heat Code: 150424L
Heat Number:
PO or Work Order: 55-87382
Test Spec: F606 ASTM METHODS
Other Information:

Completion Date: 04/23/2015
Weld Spec:
Material Type: A 307 A
Material Size: 5/8" x 10" GR BOLT

OTHER TEST:

Type: HARDNESS ROCKWELL BW — Quantity amount: 12
Test Spec: E-18

Bolt "A": 86.0 - 85.5 - 87.3 - 85.5

Bolt "B": 88.4 - 85.2 - 86.7 - 85.0

Bolt "C": 85.5 - 82.3 - 85.2 - 84.2

Type: BOLT TENSILE STRENGTH — Quantity amount: 3
Test Spec: F606

Bolt tensile "A" fractured @ 16,383 lbs. in the threads (min. 13,550 lbs.).

Bolt tensile "B" fractured @ 16,522 lbs. in the threads (min. 13,550 lbs.).

Bolt tensile "C" fractured @ 16,349 lbs. in the threads (min. 13,550 lbs.).

Type: HEAD MARKINGS — Quantity amount: 1
TRN 307A USA S

We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification. NVLAP Certificate of Accreditation effective through 12-31-15.This report may not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

Lab Director, Michael S. Beaton, PE

Page 1 of 1

Figure C-16. 10-in. (254-mm) Post Bolts, Test No. GAA-1

33406

CHARTER STEEL
A Division of Charter Manufacturing Company, Inc

LOAD

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
Fax (262) 268-2570

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Cust P.O.	109642
Customer Part #	T10005
Charter Sales Order	50039700
Heat #	10446960
Ship Lot #	4416398
Grade	1018 R AK FG RHQ 1-5/32
Process	HRCC
Finish Size	1-5/32
Ship date	29-JUL-16

Elgin Fastener Group LLC - Berea Plant
777 West Bagley Road
Berea,OH-44017
Kind Attn :Jeff Leisinger

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and that it satisfies these requirements. The recording of false, fictitious and fraudulent statements or entries on this document may be punishable as a felony under federal statute.

Test results of Heat Lot # 10446960

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.18	.65	.008	.014	.080	.05	.08	.02	.10	.009	.003
	AL	N	B	TI	NB						
	.024	.0090	.0001	.001	.001						

MACTYP=R
MACRO ETCH SURFACE=1 MACRO ETCH RANDOM=1 MACRO ETCH CENTER=1

Test results of Rolling Lot # 1189121

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE (KSI)	2	65.5	65.6	65.6	TENSILE LAB = 0358-02
REDUCTION OF AREA (%)	2	55	55	55	RA LAB = 0358-02
ROCKWELL B (HRBW)	2	71	71	71	RB LAB = 0358-02

NUM DECARB=1
REDUCTION RATIO=29:1

AVE DECARB (Inch)=.004

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 12/12/13
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M Revision = 15 Dated = 01-NOV-15

Additional Comments:

Melt Source:
Charter Steel
Saukville, WI, USA

Rem: Load1,Fax0,Mail0

ACCREDITED Testing Laboratory

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
Printed Date : 07/29/2016

Figure C-17. ⅝-in. (16-mm) Dia. Nut, Test No. GAA-1

CHARTER STEEL
A Division of Charter Manufacturing Company, Inc.

EMAIL

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
Fax (262) 268-2570

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Johnstown Wire Technologies
124 Laurel Ave.
Johnstown,PA-15906

Cust P.O.	87110
Customer Part #	AXA15CA-5/8
Charter Sales Order	30084035
Heat #	20337380
Ship Lot #	2072992
Grade	1015 X AKFG RHQ 5/8
Process	HR
Finish Size	5/8
Ship date	07-OCT-14

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and that it satisfies these requirements. The recording of false, fictitious and fraudulent statements or entries on this document may be punishable as a felony under federal statute.

Test results of Heat Lot # 20337380

Lab Code: 125544

CHEM %Wt	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
	.13	.35	.008	.002	.070	.03	.08	.01	.05	.003	.001
	AL	N	B	TI	NB						
	.050	.0050	.0001	.001	.002						

JOMINY(HRC)
J1
40

JOMINY SAMPLE TYPE ENGLISH=C DI=.19

Test results of Rolling Lot # 2072992

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE (KSI)	2	57.8	58.4	58.1	TENSILE LAB = 0358-04
REDUCTION OF AREA (%)	2	67	67	67	RA LAB = 0358-04

NUM DECARB=2
REDUCTION RATIO=160:1

AVE DECARB (inch)=.002

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 9/12/12
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = RW007-RW100 Revision = Dated = 31-DEC-00

Additional Comments:

Charter Steel
Cuyahoga Heights, OH, USA

ACCREDITED Testing Laboratory

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
Printed Date : 10/07/2014

Rem: Load1,Fax0,Mail0

Page 1 of 2

Figure C-18. 1¼-in. (32-mm) Splice Bolts, Test No. GAA-1

NUCOR

NUCOR CORPORATION
NUCOR STEEL SOUTH CAROLINA

Mill Certification
3/11/2016

MTR #: C1-366222
300 Steel Mill Road
DARLINGTON, SC 29540
(843) 393-5841
Fax: (843) 395-8701

Sold To: BIRMINGHAM FASTENER & SUPPLY
PO BOX 10323
BIRMINGHAM, AL 35202-0323
(205) 595-3511
Fax: (205) 591-0244

Ship To: BIRMINGHAM FASTENER & SUPPLY
931 AVE W
PO BOX 10323
BIRMINGHAM, AL 35202-0000
(205) 595-3511
Fax: (205) 591-0244

Customer P.O.	M7812	Sales Order	238747.1
Product Group	Merchant Bar Quality	Part Number	30000562480DES0
Grade	ASTM A307-55, F1554-07a gr 55, S1. AASHTO M314 GR 55, S1	Lot #	DL1510704804
Size	9/16" (.5625) Round	Heat #	DL15107048
Product	9/16" (.5625) Round 40' A307-55	B.L. Number	C1-686468
Description	A307-55	Load Number	C1-366222
Customer Spec		Customer Part #	

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: 1/28/2016 Melt Date: 12/5/2015 Qty Shipped LBS: 17,494 Qty Shipped Pcs: 517

Melt Date: 12/5/2015

C	Mn	V	Si	S	P	Cu	Cr	Ni	Mo	Cb	CE1554
0.22%	0.82%	0.0410%	0.27%	0.010%	0.007%	0.20%	0.10%	0.06%	0.015%	0.001%	0.37%

CE1554: CE per F1554 GR55, S1

Roll Date: 1/28/2016

Yield 1: 67,000psi	Tensile 1: 87,000psi	Elongation: 21% in 8"(% in 203.3mm)
Yield 2: 66,000psi	Tensile 2: 88,000psi	Elongation 21% in 8"(% in 203.3mm)
Reduction of Area: 50.43%	Reduction of Area #2: 53.52%	

Specification Comments:

1. WELDING OR WELD REPAIR WAS NOT PERFORMED ON THIS MATERIAL
2. MELTED AND MANUFACTURED IN THE USA
3. MERCURY, RADIUM, OR ALPHA SOURCE MATERIALS IN ANY FORM HAVE NOT BEEN USED IN THE PRODUCTION OF THIS MATERIAL

James H. Blew
Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 2

Figure C-19. 10-in. (254-mm) Hex Bolts, Test No. GAA-1

07/18/2008 11:19 330-670-3198 REPUBLIC ENGINEER PAGE 03/04

ATTN CARINA SMITH

Republic ENGINEERED PRODUCTS 1807 EAST 28TH ST. PHONE: 330-438-5694 LORAIN, OH 4405 FAX: 330-438-569

CERTIFICATE OF TESTS REPUBLIC ENGINEERED PRODUCTS July 9, 2008 PAGE 1 OF 2

PURCHASE ORD:	127595M	PURCHASE ORDER DATE:	4/14/2008
PART NUMBER:	100941B	ACCOUNT NUMBER:	5550-3007-01
ORDER NUMBER:	1379747 - 01	SCHEDULE:	4116-85
HEAT:	7366484	REVISION:	1

CHARGE ADDRESS

TRINITY INDUSTRIES INC
HIGHWAY SAGETY PRODUCTS INC
P O BOX 568887 4TH FLOOR
DALLAS, TX 75356-8887

SHIP TO

TRINITY INDUSTRIES INC
C/O BCS METALS PREP
5800 STERLING AVE
MAPLE HTS, OH 44137

MATERIAL DESCRIPTION

HOT ROLLED STEEL COILS CARBON AISI-1015 AK AL KILLED FINE GRAIN COLD WORKING QUALITY TEST REPORTS OF MECHANICAL PROPERTIES FOR INFO ONLY EXTRA TESTING
SIZE: RDS .6390 DIAM X COIL
RDS 16.2306MM DIAM X COIL

LADLE CHEMISTRY %

C	MN	P	S	SI	CU	NI	CR
0.13	0.38	0.007	0.002	0.10	0.03	0.04	0.06
V	MO	SN	AL	CB	N		
0.002	0.02	0.001	0.037	0.001	0.0040		

CALCULATED TESTS

REDUCTION RATIO 112.3 TO 1

AUSTENITIC GRAIN SIZE 5 OR FINER BASED ON A TOTAL ALUMINUM CONTENT EQUAL TO OR GREATER THAN .020% PER ASTM A29.

SEMI - FINISHED RESULTS

FINISHED SIZE RESULTS

TENSILE TEST STANDARD FORMAT

	TENSILE PSI	YIELD(0.2%) PSI	RA %	E %
PCE 10427	59700	422000	72.4	49.0

HARDNESS TEST ASTM E10/ASTM A370 HBW AS-RLD/CD HBW

	MID-RADIUS
PCE 10428	107

NOTES

CHEMICAL ANALYSIS CONFORMS TO APPLICABLE SPECS: ASTM E415, LBL10129, LBL10130, ASTM E1019, LBL10158, LBL10114, AND ASTM E1085, LBL10184, LBL10188.

REPUBLIC ENGINEERED PRODUCTS HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

CERTIFICATE OF TESTS SHALL NOT BE REPRODUCED EXCEPT IN FULL.

ALL TESTING HAS BEEN PERFORMED USING THE CURRENT REVISION OF THE TESTING SPECIFICATIONS.

RECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELONY UNDER FED STATUES TITLE 18 CHAPTER 47.

THE MATERIAL WAS NOT EXPOSED TO MERCURY OR ANY METAL ALLOY THAT IS LIQUID AT AMBIENT TEMPERATURE DURING PROCESSING OR WHILE IN OUR POSSESSION.

NO WELD OR WELD REPAIR WAS PERFORMED ON THIS MATERIAL.

R. A. SZELIGA
MANAGER TECH. SERVICES
R. A. Szeliga

BY JANET K. HARTLINE

Figure C-20. 1½-in. (38-mm) Splice Bolts, Test No. GAA-1

Republic 1807 EAST 28TH ST. PHONE: 330-438-5694 LORAIN, OH 44055 FAX: 330-438-5695

CERTIFICATE OF TESTS REPUBLIC ENGINEERED PRODUCTS September 12, 2008 PAGE 1 OF 2

PURCHASE ORD:	127595M	PURCHASE ORDER DATE:	4/14/2008
PART NUMBER:	100941B	ACCOUNT NUMBER:	5550-3007-01
ORDER NUMBER:	1379747 - 01	SCHEDULE:	7327-85
HEAT:	7367052	REVISION:	1

CHARGE ADDRESS

TRINITY INDUSTRIES INC
HIGHWAY SAGETY PRODUCTS INC
P O BOX 568887 4TH FLOOR
DALLAS, TX 75356-8887

SHIP TO

TRINITY INDUSTRIES INC
C/O BCS METALS PREP
5800 STERLING AVE
MAPLE HEIGHTS, OH 44137

MATERIAL DESCRIPTION

HOT ROLLED STEEL COILS CARBON AISI-1015 AK AL KILLED FINE GRAIN COLD WORKING QUALITY TEST REPORTS OF MECHANICAL PROPERTIES FOR INFO ONLY EXTRA TESTING
SIZE: RDS .6390 DIAM X COIL
RDS 16.2306MM DIAM X COIL

LADLE CHEMISTRY %

C	MN	P	S	SI	CU	NI	CR
0.15	0.49	0.008	0.002	0.06	0.03	0.02	0.05
V	MO	SN	AL	CB	N		
0.002	0.01	0.001	0.029	0.001	0.0050		

CALCULATED TESTS

REDUCTION RATIO 112.3 TO 1

AUSTENITIC GRAIN SIZE 5 OR FINER BASED ON A TOTAL ALUMINUM CONTENT EQUAL TO OR GREATER THAN .020% PER ASTM A29.

SEMI - FINISHED RESULTS

FINISHED SIZE RESULTS

TENSILE TEST STANDARD FORMAT

	TENSILE PSI	YIELD(0.2%) PSI	RA %	E %
PCE 14133	60850	45000	64.4	44.0

HARDNESS TEST ASTM E10/ASTM A370 HBW AS-RLD/CD HBW

	MID-RADIUS
PCE 14134	116

NOTES

CHEMICAL ANALYSIS CONFORMS TO APPLICABLE SPECS: ASTM E415, LBL10129, LBL10130, ASTM E1019, LBL10158, LBL10114, AND ASTM E1085, LBL10184, LBL10188.

REPUBLIC ENGINEERED PRODUCTS HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

CERTIFICATE OF TESTS SHALL NOT BE REPRODUCED EXCEPT IN FULL.

ALL TESTING HAS BEEN PERFORMED USING THE CURRENT REVISION OF THE TESTING SPECIFICATIONS.

RECORDING OF FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHED AS A FELONY UNDER FED STATUES TITLE 18 CHAPTER 47.

THE MATERIAL WAS NOT EXPOSED TO MERCURY OR ANY METAL ALLOY THAT IS LIQUID AT AMBIENT TEMPERATURE DURING PROCESSING OR WHILE IN OUR POSSESSION.

NO WELD OR WELD REPAIR WAS PERFORMED ON THIS MATERIAL.

R. A. SZELIGA
MANAGER TECH. SERVICES
R. A. Szeliga

BY JANET K. HARTLINE

Figure C-21. 1½-in. (38-mm) Splice Bolts, Test No. GAA-1

Republic
1807 EAST 28TH ST.
PHONE: 330-438-5694
LORAIN, OH 44055
FAX: 330-438-5695

CERTIFICATE OF TESTS

REPUBLIC ENGINEERED PRODUCTS

October 31, 2008
PAGE 1
OF 2

PURCHASE ORD:	129120M	PURCHASE ORDER DATE:	8/27/2008
PART NUMBER:	100941B	ACCOUNT NUMBER:	5550-3007-01
ORDER NUMBER:	1396203 - 01	SCHEDULE:	9510-85
HEAT:	7368369	REVISION:	1

CHARGE ADDRESS

TRINITY INDUSTRIES INC
HIGHWAY SAGETY PRODUCTS INC
P O BOX 568887 4TH FLOOR
DALLAS, TX 75356-8887

SHIP TO

TRINITY INDUSTRIES INC
C/O BCS METALS PREP
5800 STERLING AVE
MAPLE HEIGHTS, OH 44137

MATERIAL DESCRIPTION

HOT ROLLED STEEL COILS CARBON AISI-1015 AK AL KILLED FINE GRAIN COLD WORKING QUALITY TEST REPORTS OF MECHANICAL PROPERTIES FOR INFO ONLY EXTRA TESTING

SIZE: RDS .6390 DIAM X COIL
RDS 16.2306MM DIAM X COIL

LADLE CHEMISTRY %

C	MN	P	S	SI	CU	NI	CR
0.14	0.43	0.006	0.008	0.06	0.04	0.02	0.06
V	MO	SN	AL	CB	N		
0.002	0.02	0.001	0.034	0.001	0.0050		

CALCULATED TESTS

REDUCTION RATIO 112.3 TO 1

AUSTENITIC GRAIN SIZE 5 OR FINER BASED ON A TOTAL ALUMINUM CONTENT EQUAL TO OR GREATER THAN .020% PER ASTM A29.

SEMI - FINISHED RESULTS

FINISHED SIZE RESULTS

TENSILE TEST STANDARD FORMAT

	TENSILE PSI	YIELD(0.2%) PSI	RA %	E %
PCE 15910	58600	43200	63.9	47.0

HARDNESS TEST ASTM E10/ASTM A370 HBW AS-RLD/CD HBW

	MID-RADIUS
PCE 15911	111

NOTES

CHEMICAL ANALYSIS CONFORMS TO APPLICABLE SPECS: ASTM E415, LBL10129, LBL10130, ASTM E1019, LBL10158, LBL10114, AND ASTM E1085, LBL10184, LBL10188.

REPUBLIC ENGINEERED PRODUCTS HEREBY CERTIFY THAT THE MATERIAL LISTED HEREIN HAS BEEN INSPECTED AND TESTED IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE GOVERNING SPECIFICATIONS AND BASED UPON THE RESULTS OF SUCH INSPECTION AND TESTING HAS BEEN APPROVED FOR CONFORMANCE TO THE SPECIFICATIONS.

CERTIFICATE OF TESTS SHALL NOT BE REPRODUCED EXCEPT IN FULL.

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NO WELD OR WELD REPAIR WAS PERFORMED ON THIS MATERIAL.

R. A. SZELIGA
MANAGER TECH. SERVICES
R. A. Szeliga

BY JANET K. HARTLINE

Figure C-22. 1½-in. (38-mm) Splice Bolts, Test No. GAA-1

R#16-0217
BCT Hex Nuts
December 2015 SMT
Fastenal part#36713
Control# 210101523

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

- Sales Order #: 129980
- Part No: AFH2G0625C
- Cust Part No: 36713
- Quantity (PCS): 1200
- Description: 5/8-11 Fin Hx Nut Gr2 HDG/TOS 0.020
- Specification: SAE J995(99) - GRADE 2 / ANSI B18.2.2
- Stelfast I.D. NO: 595689-O201087
- Customer PO: 210101523
- Warehouse: DAL

The data in this report is a true representation of the information provided by the material supplier certifying that the product meets the mechanical and material requirements of the listed specification. This certificate applies to the product shown on this document, as supplied by STELFAST INC. Alterations to the product by our customer or a third party shall render this certificate void.

This document may only be reproduced unaltered and only for certifying the same or lesser quantity of the product specified herein. Reproduction or alteration of this document for any other purpose is prohibited.

Stelfast certifies parts to the above description. The customer part number is only for reference purposes.

David Biss
Quality Manager

December 07, 2015

Page 1 of 1

Figure C-23. ⅝-in. (16-mm) Dia. Hex Nut, Test No. GAA-1

Customer Name	Customer PO#	Invoice No	Shipper No	Heat Number
GAFFNEY BOLT CO.	5-7-2015 MIKE	701917	680907	2038622

CMC STEEL SOUTH CAROLINA
310 New State Road
Cayce SC 29033-3704

CERTIFIED MILL TEST REPORT
For additional copies call
800-637-3227

We hereby certify that the test results presented here are accurate and conform to the reported grade specification

Richard S. Ray
Richard S. Ray - CMC Steel SC
Quality Assurance Manager

1SERIES-BPS ®

	SOLD TO	SHIP TO	
HEAT NO.:2038622 SECTION: ROUND 7/8 x 40'0" A36/52950 GRADE: ASTM A36-12/A529-05 Gr 50 ROLL DATE: 09/09/2014 MELT DATE: 09/08/2014	Infra-Metals - Mars 1601 Broadway St Marseilles IL US 61341-9326 8009875283	Infra-Metals - Mars 1601 Broadway St Marseilles IL US 61341-9326 8009875283	Delivery#: 81471569 BOL#: 70533247 CUST PO#: CE-485729 CUST P/N: DLVRY LBS / HEAT: 9075.000 LB DLVRY PCS / HEAT: 111 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.16%	Elongation Gage Lgth test 1	8IN		
Mn	0.73%	Reduction of Area test 1	58%		
P	0.013%	Yield to tensile ratio test1	0.75		
S	0.021%	Yield Strength test 2	56.9ksi		
Si	0.22%	Tensile Strength test 2	76.5ksi		
Cu	0.32%	Elongation test 2	25%		
Cr	0.13%	Elongation Gage Lgth test 2	8IN		
Ni	0.10%	Reduction of Area test 2	57%		
Mo	0.027%	Yield to tensile ratio test2	0.74		
V	0.000%	C+(Mn/6)	0.28%		
Cb	0.026%				
Sn	0.010%				
Al	0.000%				
Ti	0.001%				
N	0.0084%				
Carbon Eq A529	0.38%				
Yield Strength test 1	57.1ksi				
Tensile Strength test 1	76.3ksi				
Elongation test 1	23%				

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

ALSO MEETS ASTM GRADE A36 REV-03A, A529 GR.50, A572-2013A GR.50, A709 GR.36, A709 GR.50, A992, AASHTO GRADE M270 GR.36, M270 GR.50, CSA G40.21-04 GRADE 44W, 50WASME SA-36 2008A ADDEND A.

03/18/2015 14:05:35
Page 1 OF 1

Figure C-24. ⅞-in. (22-mm) Dia., 8-in. (203-mm) Long Hex Bolt, Test No. GAA-1

INSPECTION CERTIFICATE

Customer	Specification	Size	Lot No.	Date
	ASTM A-563 GRADE DH HEAVY HEX NUT	7/8- 9 UNC	WA651	Jun. 29,'12

UNYTITE, INC.
One Unytite Drive
Peru, Illinois 61354
815-224-2221 — FAX# 815-224-3434

Mechanical properties tested in accordance to ASTM F606/F606M, ASTM A370, ASTM E18

Chemical Composition (%)

Mill Maker	Material Size	Heat No.	Spec.	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	
NUCOR	CARBON			0.20 0.55	-	MIN. 0.60	MAX. 0.040	MAX. 0.050	-	-	-	-	-
STEEL	STEEL	12101054		0.43	0.24	0.87	0.015	0.020	0.09	0.04	0.08	-	-

Mechanical Property Inspection

Item	Proof Load	Cone stripping	Hardness	After Heat Treatment Hardness	Absorbed Energy	Heat Treatment
Spec.	80,850 lbf	- kN·kgf·lbf	24-38 HrC	HrB·HB	J·kgfm·ftlbf	T:MIN.800 F
Results	n 5 Results GOOD	n - Results -	29.4 28.9 29.7 29.7 29.5 29.4	5 Piece Average After Heat Treament Hardness Treatment After 24 Hr.X °F(°C)	at °F(°C)	Q:FORGING Q (W.Q.) T:1058 F/45M. (W.C.) Q: Quenching T: Tempering ST: Solution Treatment

Shape & Dimension	
Inspection	ANSI B18.2.2 GOOD
Thread Precision Inspection	ANSI B1.1 CLASS 2B GOOD
Appearance Inspection	GOOD

Remarks:

"DH U"

Production Quantity
22,391 pcs.

BCT Foundation Tube
Keeper Bolt Nuts
R#15-0600 June 2015 SMT

OFFICIAL SEAL
JEAN MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES 10/18/13

07-10-12

Material used for the nut was melted and manufactured in the USA. The nut was manufactured in the USA to the above specification.

We hereby certify that the material described has been manufactured and inspected satisfactorily with the requirement of the above specification.

Chief of Quality Assurance Section

Figure C-25. ⅞-in. (22-mm) Dia. Hex Nut, Test No. GAA-1

Appendix D. Vehicle Center of Gravity Determination

Date:	2/14/2017	Test Name:	GAA-1	VIN:	KNADH4A36B6915197
Year:	2011	Make:	Kia	Model:	Rio

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)
+	Unbalasted Car (Curb)	2326
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	22
+	Strobe/Brake Battery	5
+	Brake Reciever/Wires	5
+	CG Plate including DAS	13
-	Battery	-31
-	Oil	-5
-	Interior	-65
-	Fuel	-13
-	Coolant	-8
-	Washer fluid	-8
+	Water Ballast (In Fuel Tank)	112
+	Onboard Battery	14
	DTS Rack	17

Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle

Estimated Total Weight (lb.) 2410

Vehicle Dimensions for C.G. Calculations

Roof Height:	57 3/4	in.	Front Track Width:	57 3/4	in.
Wheel Base:	98 3/8	in.	Rear Track Width:	58	in.

Center of Gravity	1100C MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb.)	2420 ± 55	2392	-28
Longitudinal CG (in.)	39 ± 4	39.48161	0.4816054
Lateral CG (in.)	NA	-0.33873	NA
Vertical CG (in.)	NA	22.40248	NA

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb.)

	Left	Right
Front	745	705
Rear	432	444

FRONT	1450	lb.
REAR	876	lb.
TOTAL	2326	lb.

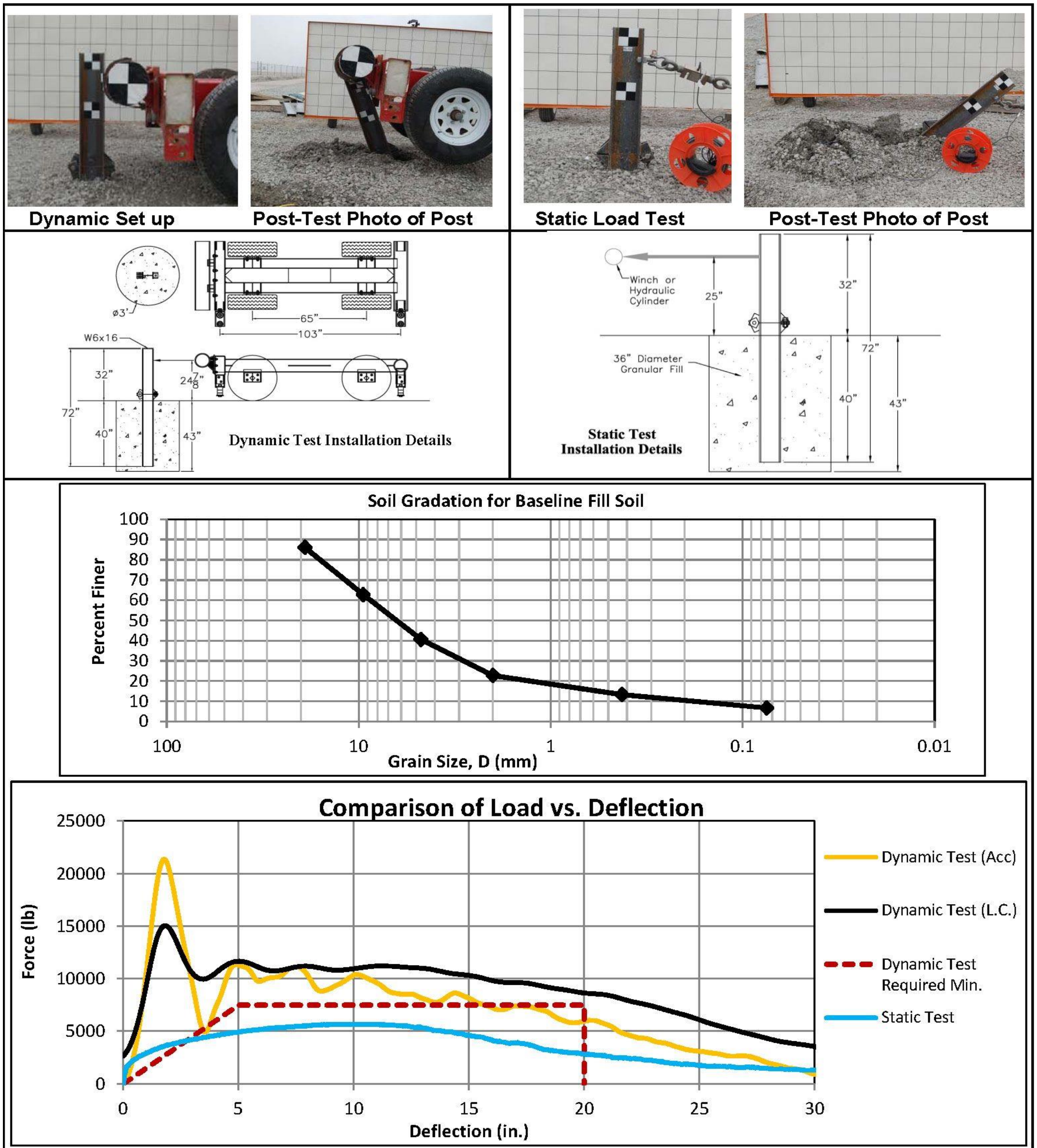
TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	729	703
Rear	481	479

FRONT	1432	lb.
REAR	960	lb.
TOTAL	2392	lb.

Figure D-1. Vehicle Mass Distribution, Test No. GAA-1

Appendix E. Static Soil Tests

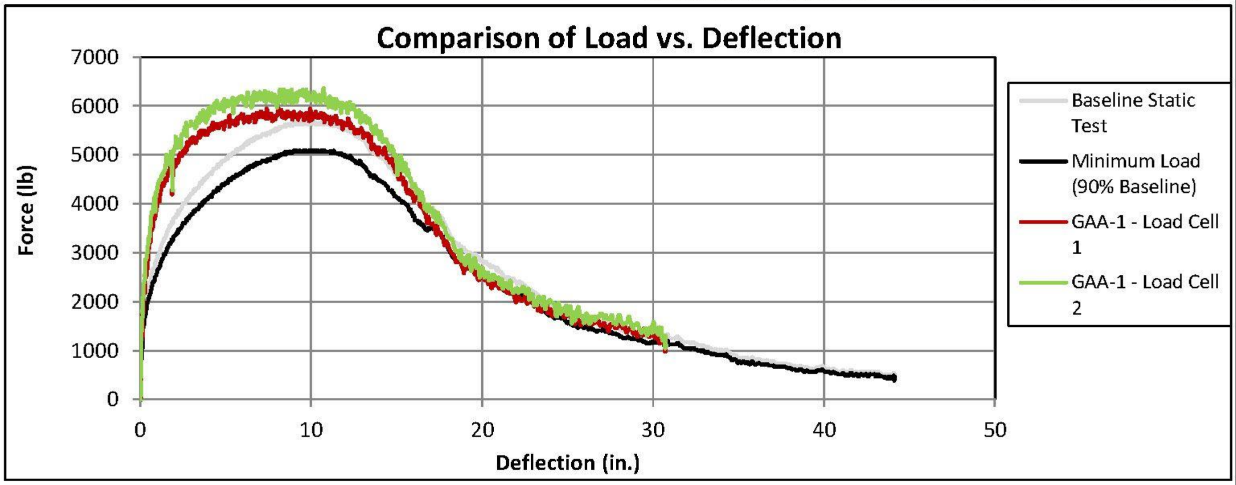


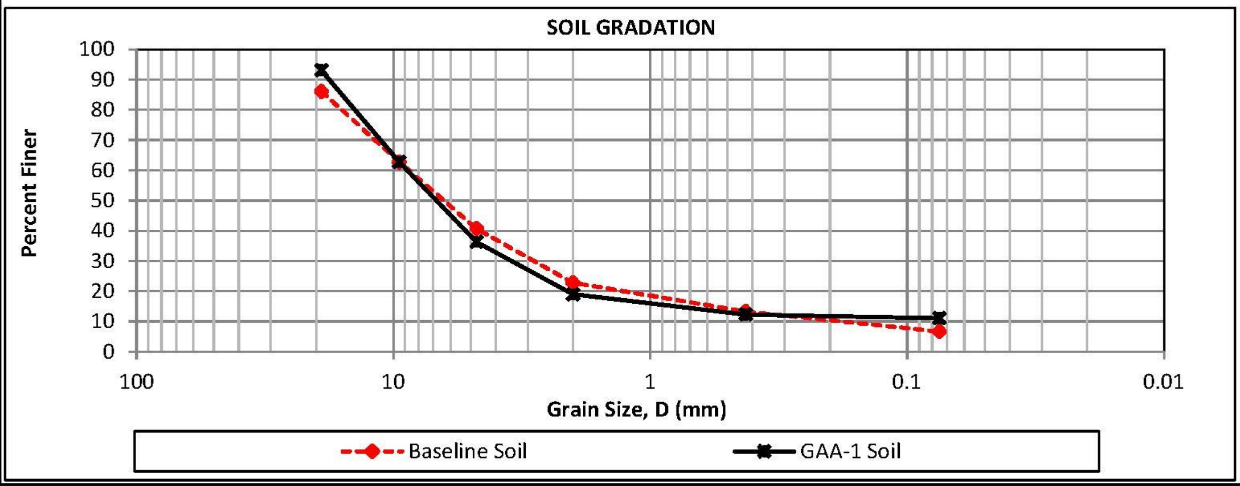
Date	5/17/2013	
Test Facility & Site Location	Midwest Roadside Safety Facility	
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)	
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)	
Description of fill placement procedure	H.E.-8	
Bogie Weight	1857 lb	842 kg
Impact Velocity	20.6 mph	33.2 km/h

Figure E-1. Soil Strength, Initial Calibration Tests, Test No. GAA-1

Static Load Test Setup

Post-Test Photo of Post





Date..	2/14/2017
Test Facility & Site Location.....................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)...........	Well-Graded Gravel (GW)
Fill material description (ASTM D2487).........	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure........	8-inch lifts tamped with a pneumatic compactor

Figure E-2. Static Soil Test, Test No. GAA-1

Appendix F. Vehicle Deformation Records

Date: 2/14/2017 Test Name: GAA-1 VIN: KNADH4A36B6915197
Year: 2011 Make: Kia Model: Rio

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	44.164	8.911	0.768	44.215	8.839	0.956	0.051	-0.072	0.188	0.208
2	44.434	14.272	1.094	44.441	14.220	1.299	0.007	-0.052	0.205	0.212
3	44.638	20.068	1.228	44.506	19.852	1.448	-0.132	-0.217	0.220	0.336
4	42.307	24.739	4.216	41.174	23.689	4.600	-1.132	-1.050	0.384	1.591
5	41.138	8.995	-1.085	41.174	8.943	-0.944	0.036	-0.051	0.140	0.153
6	41.683	14.422	-0.562	41.691	14.377	-0.342	0.007	-0.045	0.220	0.224
7	42.008	20.122	-0.320	41.984	20.019	-0.092	-0.024	-0.104	0.229	0.252
8	41.057	25.443	1.126	39.938	24.497	1.494	-1.118	-0.946	0.368	1.511
9	37.658	9.274	-2.817	37.605	9.198	-2.732	-0.053	-0.076	0.085	0.126
10	37.769	14.297	-2.595	37.717	14.322	-2.486	-0.052	0.025	0.109	0.123
11	37.366	20.455	-2.536	37.339	20.374	-2.311	-0.028	-0.081	0.225	0.240
12	37.683	26.095	-2.524	37.667	25.810	-2.281	-0.016	-0.285	0.243	0.375
13	34.234	9.243	-2.626	34.265	9.198	-2.566	0.031	-0.045	0.061	0.082
14	34.486	14.486	-2.763	34.503	14.453	-2.713	0.018	-0.033	0.050	0.062
15	34.391	20.691	-2.695	34.442	20.671	-2.623	0.051	-0.020	0.072	0.091
16	34.292	25.914	-2.647	34.343	25.728	-2.660	0.051	-0.185	-0.013	0.193
17	28.247	9.338	-3.450	28.340	9.287	-3.422	0.092	-0.051	0.028	0.109
18	28.712	14.664	-2.820	28.792	14.617	-2.688	0.079	-0.047	0.131	0.160
19	29.822	21.186	-2.699	29.906	21.176	-2.693	0.084	-0.010	0.006	0.085
20	30.209	26.239	-2.972	30.272	26.020	-3.093	0.063	-0.219	-0.122	0.259
21	23.054	9.386	-3.352	23.140	9.317	-3.355	0.086	-0.069	-0.004	0.110
22	23.220	13.964	-3.073	23.279	13.878	-3.021	0.058	-0.086	0.053	0.117
23	23.797	21.007	-2.699	23.837	20.917	-2.695	0.039	-0.090	0.004	0.098
24	24.115	26.757	-2.900	24.185	26.538	-2.889	0.069	-0.218	0.011	0.229
25	15.056	8.523	0.675	15.039	8.502	0.582	-0.017	-0.021	-0.092	0.096
26	15.066	12.482	0.634	15.074	12.482	0.582	0.008	0.000	-0.052	0.053
27	15.096	19.543	0.768	15.162	19.441	0.770	0.066	-0.102	0.001	0.121
28	15.227	25.934	0.958	15.315	25.828	1.022	0.088	-0.106	0.064	0.152

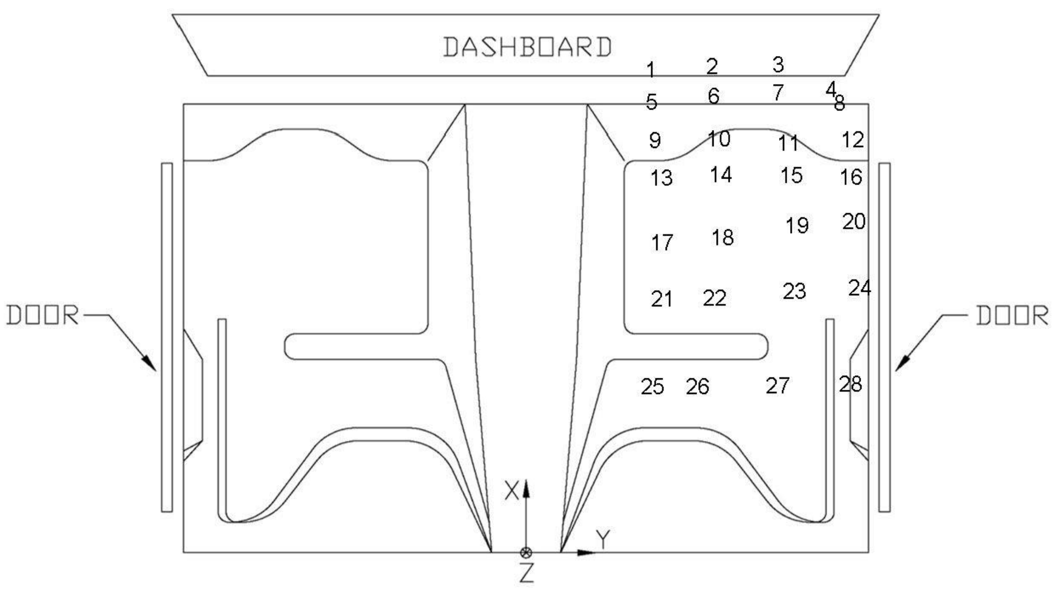


Figure F-1. Floor Pan Deformation Data – Set 2, Test No. GAA-1

Date: 2/14/2017 Test Name: GAA-1 VIN: KNADH4A36B6915197
Year: 2011 Make: Kia Model: Rio

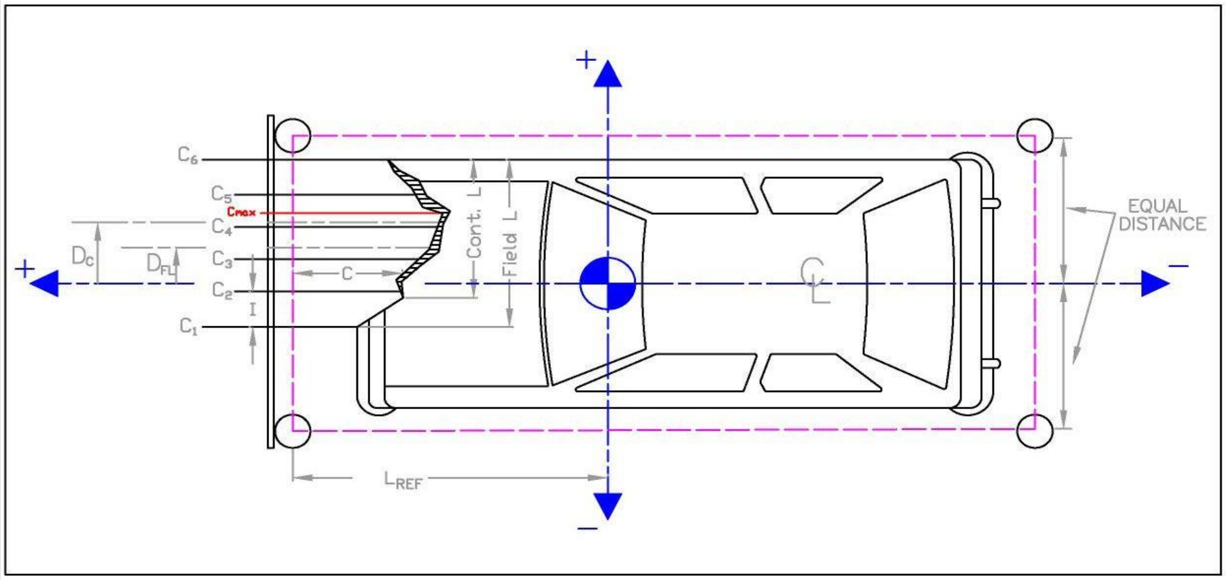
VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	28.401	3.445	25.359	28.320	3.350	25.394	-0.081	-0.094	0.035	0.129
	2	30.058	16.464	25.147	29.984	16.235	25.263	-0.074	-0.229	0.116	0.267
	3	29.636	25.895	24.810	29.579	25.893	24.989	-0.057	-0.002	0.179	0.188
	4	24.144	2.402	16.249	24.071	2.315	16.307	-0.073	-0.087	0.058	0.128
	5	27.751	17.271	18.932	27.720	17.092	19.024	-0.031	-0.179	0.091	0.203
	6	27.221	26.670	17.885	27.194	26.528	18.113	-0.027	-0.142	0.228	0.270
SIDE PANEL	7	39.121	29.131	3.386	39.111	28.357	3.783	-0.011	-0.774	0.397	0.870
	8	38.085	28.955	8.553	37.978	28.200	8.809	-0.108	-0.755	0.256	0.804
	9	33.769	29.184	4.342	34.131	28.670	4.926	0.362	-0.514	0.584	0.858
IMPACT SIDE DOOR	10	28.872	29.857	23.544	28.836	29.743	23.622	-0.036	-0.115	0.078	0.143
	11	15.833	29.944	24.380	15.770	29.989	24.504	-0.063	0.044	0.124	0.146
	12	2.584	30.084	25.262	2.533	30.253	25.156	-0.051	0.169	-0.105	0.206
	13	28.118	30.677	10.817	28.094	30.528	10.987	-0.024	-0.149	0.171	0.228
	14	15.835	30.698	13.746	15.754	30.829	13.879	-0.081	0.131	0.133	0.204
	15	5.118	30.707	13.142	5.052	30.796	13.141	-0.066	0.089	-0.001	0.111
ROOF	16	16.788	2.020	40.717	15.290	2.215	37.236	-1.498	0.194	-3.480	3.794
	17	16.566	7.129	40.854	14.959	7.235	36.540	-1.607	0.106	-4.314	4.605
	18	16.461	11.908	40.791	14.888	11.864	35.958	-1.573	-0.044	-4.833	5.083
	19	16.047	16.617	40.665	14.730	16.388	36.822	-1.317	-0.229	-3.843	4.069
	20	15.422	21.376	40.450	14.915	20.844	38.694	-0.506	-0.532	-1.756	1.904
	21	10.021	1.766	43.399	8.659	1.918	40.155	-1.361	0.152	-3.244	3.522
	22	9.266	7.205	43.578	7.702	7.104	39.709	-1.564	-0.101	-3.870	4.175
	23	8.862	11.193	43.567	7.357	10.989	39.313	-1.505	-0.204	-4.254	4.517
	24	8.246	15.789	43.455	7.317	15.356	40.426	-0.928	-0.434	-3.029	3.198
	25	8.239	19.965	43.135	7.554	19.281	41.314	-0.685	-0.684	-1.821	2.063
	26	4.597	1.401	44.268	3.960	1.592	42.712	-0.638	0.191	-1.555	1.692
	27	4.354	6.615	44.331	3.173	6.565	41.422	-1.181	-0.050	-2.909	3.140
	28	4.158	10.751	44.276	2.954	10.585	40.745	-1.204	-0.165	-3.532	3.735
	29	3.971	15.299	44.091	2.976	15.131	41.093	-0.996	-0.168	-2.998	3.163
	30	3.735	18.755	43.886	3.171	18.228	42.349	-0.564	-0.526	-1.537	1.719
A PILLAR	31	16.390	23.742	38.588	16.256	23.051	38.254	-0.134	-0.691	-0.334	0.779
	32	21.814	24.929	35.762	21.826	24.196	35.355	0.012	-0.733	-0.407	0.839
	33	27.130	26.098	32.739	27.200	25.606	32.405	0.070	-0.492	-0.334	0.599
	34	34.208	27.609	27.906	34.263	27.235	27.964	0.054	-0.374	0.057	0.382
B PILLAR	35	0.443	29.372	13.602	0.504	29.263	13.582	0.061	-0.109	-0.020	0.126
	36	-4.298	29.329	12.791	-4.228	29.250	12.821	0.069	-0.080	0.030	0.110
	37	-1.108	29.271	20.365	-1.118	29.113	20.430	-0.010	-0.158	0.065	0.171
	38	-5.036	29.317	20.171	-5.037	29.187	20.105	0.000	-0.130	-0.066	0.145
	39	-2.474	27.891	30.624	-2.552	27.606	30.551	-0.078	-0.286	-0.073	0.305
	40	-6.392	27.893	30.355	-6.432	27.645	30.390	-0.040	-0.248	0.035	0.254

Figure F-2. Occupant Compartment Deformation Data – Set 2, Test No. GAA-1

Date: 2/15/2017 Test Number: GAA-1

Year: 2011 Make: Kia Model: Rio



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	74	(1880)
Total Width of Vehicle:	65 3/8	(1661)
Width of contact and induced crush - Field L:	65 3/8	(1661)
Crush measurement spacing interval (L/5) - I:	13 1/8	(333)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	65 3/8	(1661)
Distance from center of vehicle to center of contact damage - D_C:	0	()

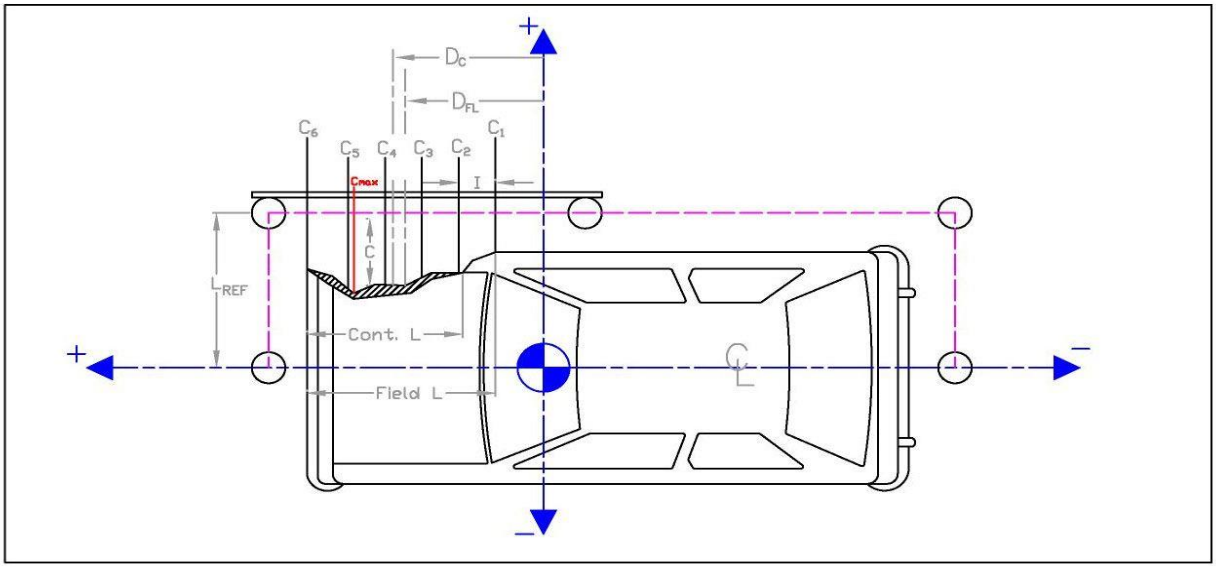
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	NA	NA	-32 3/4	-(832)	24	(610)	-4 5/8	-(117)	NA	NA
C_2	29	(737)	-19 5/8	-(498)	8 1/2	(216)			25 1/8	(638)
C_3	11	(279)	-6 1/2	-(165)	6 1/8	(156)			9 1/2	(241)
C_4	16	(406)	6 5/8	(168)	6 1/8	(156)			14 1/2	(368)
C_5	3	(76)	19 3/4	(502)	8 1/2	(216)			- 7/8	-(22)
C_6	na	NA	32 7/8	(835)	24	(610)			NA	NA
C_{MAX}	18	(457)	12	(305)	6 3/4	(171)			15 7/8	(403)

Figure F-3. Exterior Vehicle Crush (NASS) - Front, Test No. GAA-1

Date: 42781 Test Number: GAA-1

Year: 2011 Make: Kia Model: Rio



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	38	(965)
Total Vehicle Length:	167 1/4	(4248)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-11 1/8	-(283)
Width of contact and induced crush - Field L:	56	(1422)
Crush measurement spacing interval (L/5) - I:	11 1/4	(286)
Distance from vehicle c.g. to center of Field L - D_{FL}:	41	(1041)
Width of Contact Damage:	52	(1321)
Distance from vehicle c.g. to center of contact damage - D_C:	41	(1041)

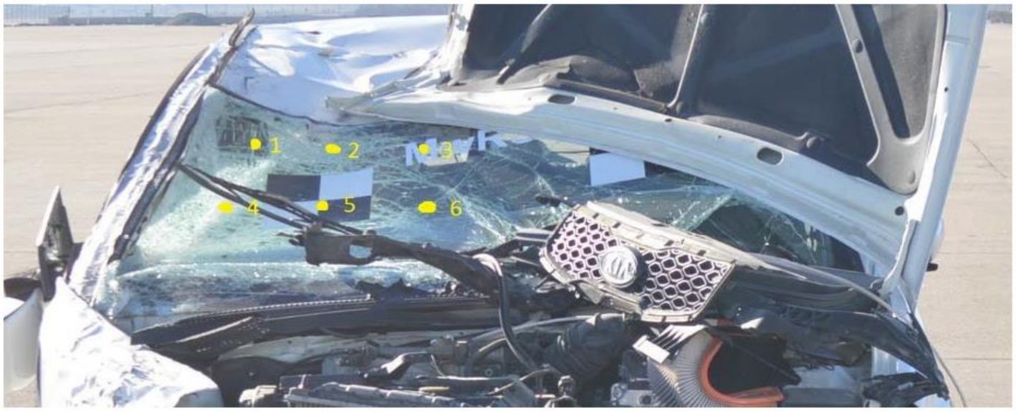
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	5 3/4	(146)	13	(330)	3 3/4	(95)	2	(51)	0	()
C_2	6 3/4	(171)	24 1/4	(616)	3 5/8	(92)			1 1/8	(29)
C_3	na	NA	35 1/2	(902)	3 1/4	(83)			NA	NA
C_4	12	(305)	46 3/4	(1187)	3 1/4	(83)			6 3/4	(171)
C_5	10	(254)	58	(1473)	5	(127)			3	(76)
C_6	16 1/2	(419)	69 1/4	(1759)	12 1/2	(318)			2	(51)
C_{MAX}	17	(432)	17	(432)	3 3/4	(95)			11 1/4	(286)

Figure F-4. Exterior Vehicle Crush (NASS) - Side, Test No. GAA-1

Point	Vertical on Left Side A-pillar (from top corner) (in.)	Lateral from Left Side A-pillar (from top corner) (in.)	Reference Vehicle (in)	Test No. GAA-1 (in.)	Crush (in.)
1	6	8	5.375	10	4 5/8
2	6	12.5	5	12	7
3	6	19	4.875	12	7 1/8
4	15	7	5 1/4	8.25	3
5	15	12	5	8 1/2	3 1/2
6	15	18.5	4 3/4	10 3/4	6

GAA-1 test vehicle



Undamaged Reference Vehicle

Figure F-5. Windshield Crush, Test No. GAA-1

Appendix G. Accelerometer and Rate Transducer Data Plots, Test No. GAA-1

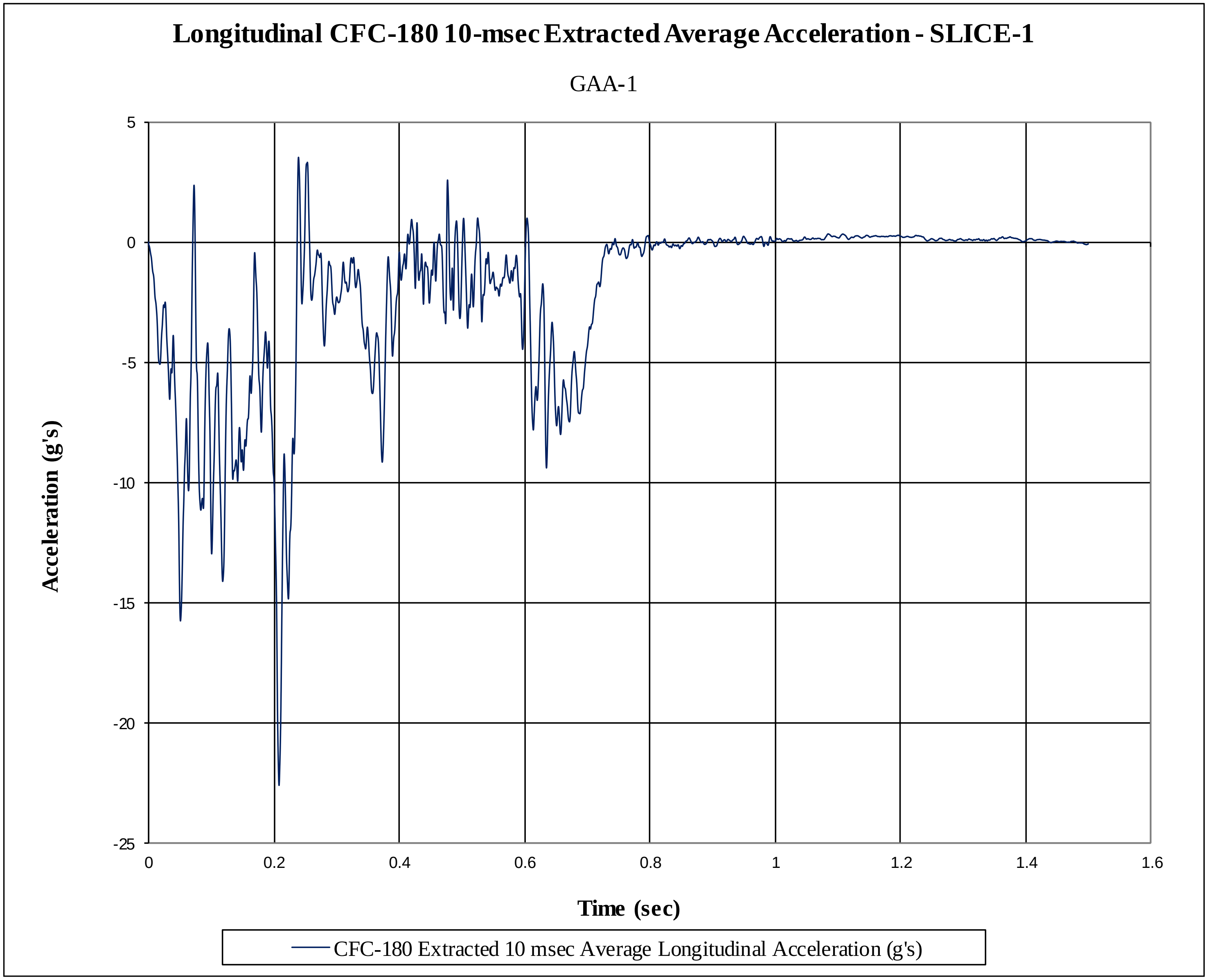


Figure G-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. GAA-1

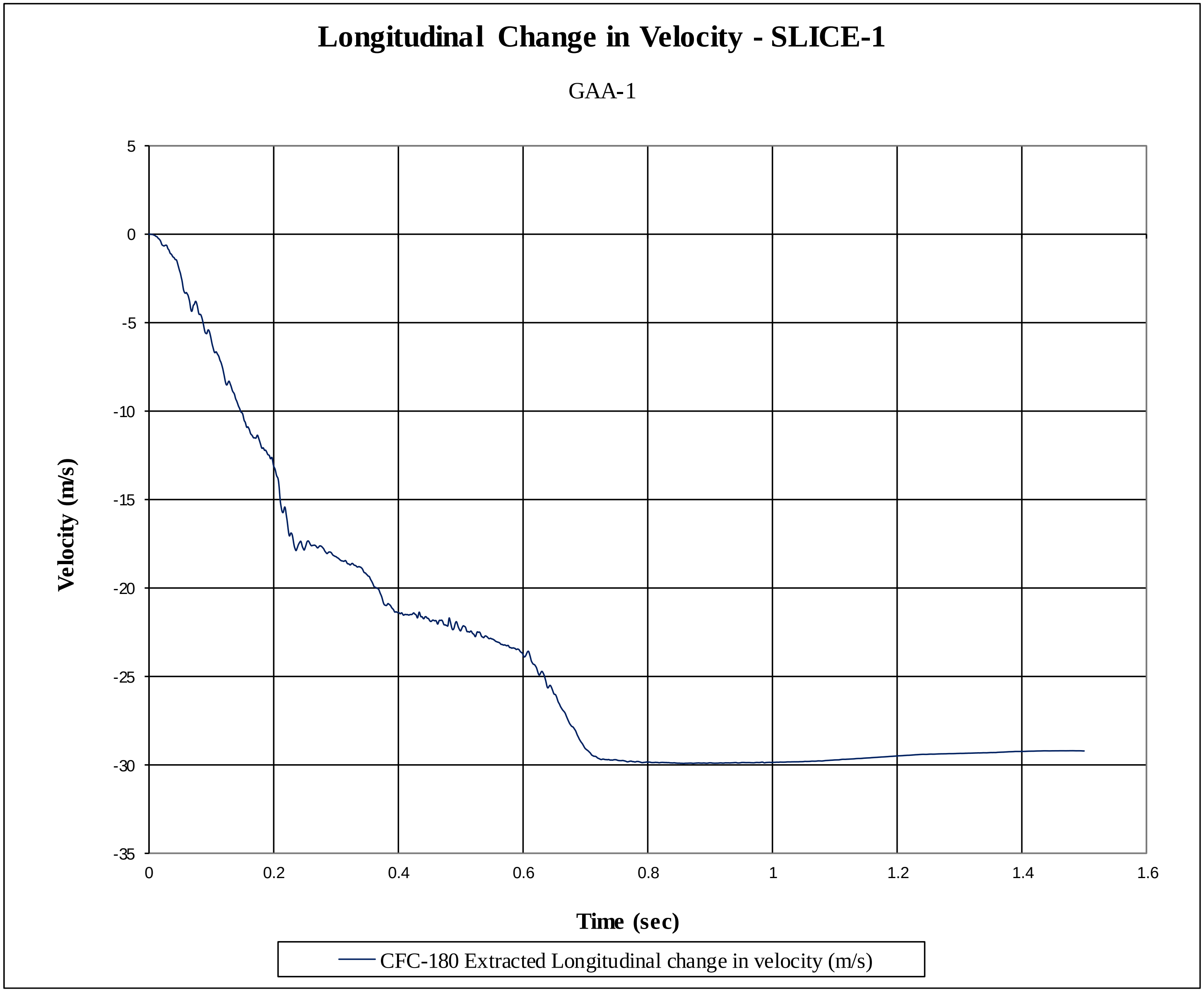


Figure G-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. GAA-1

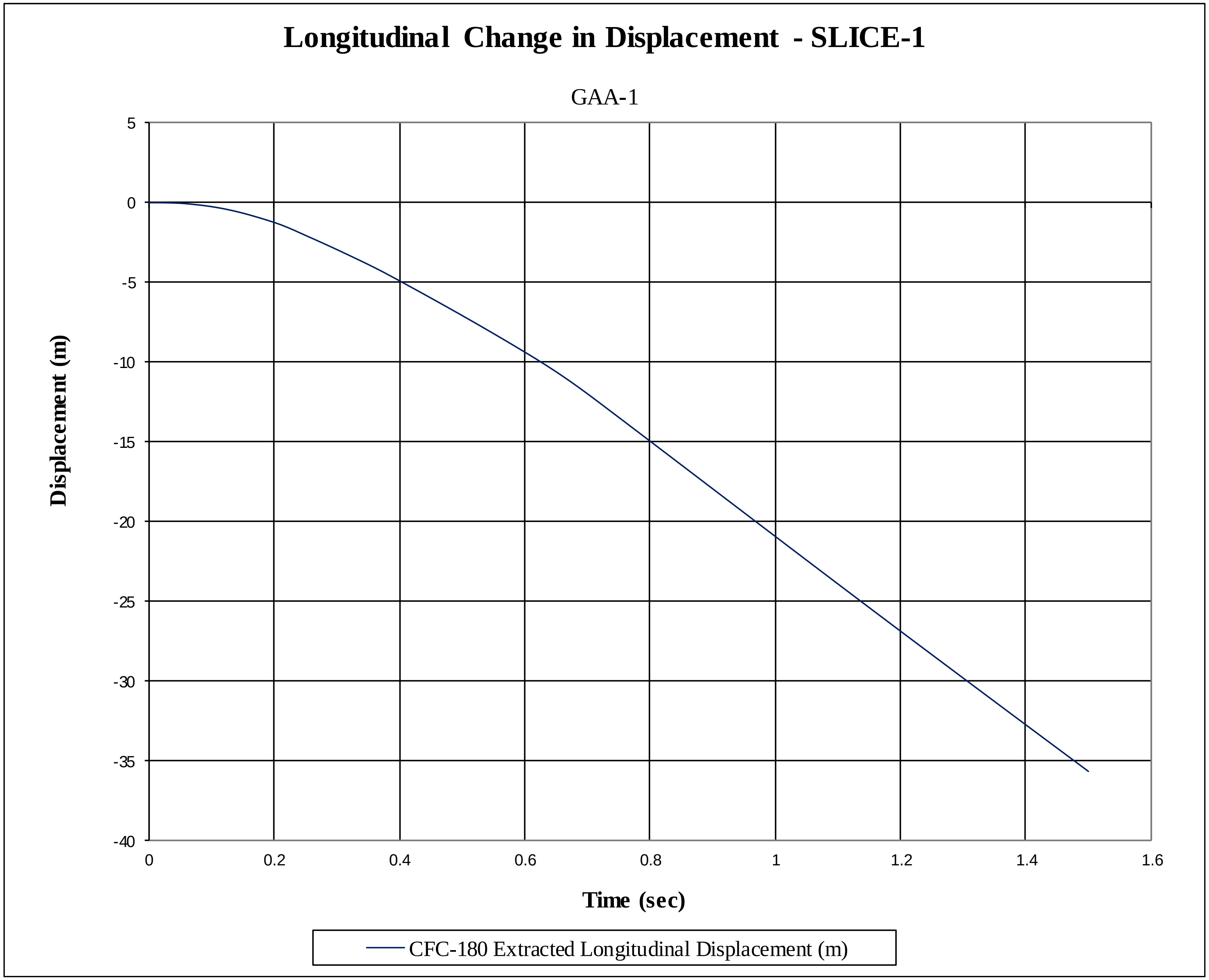


Figure G-3. Longitudinal Occupant Displacement (SLICE-1), Test No. GAA-1

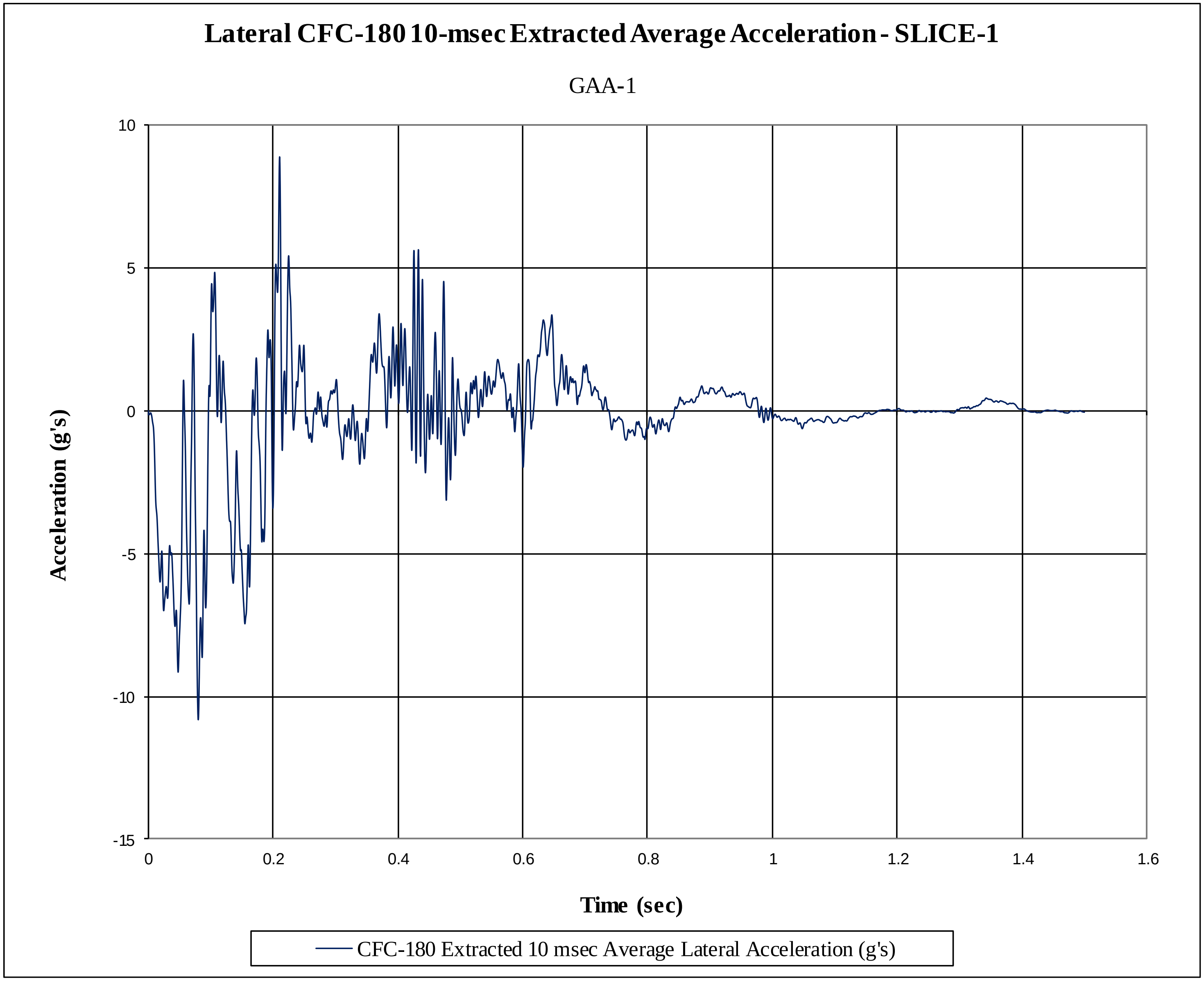


Figure G-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. GAA-1

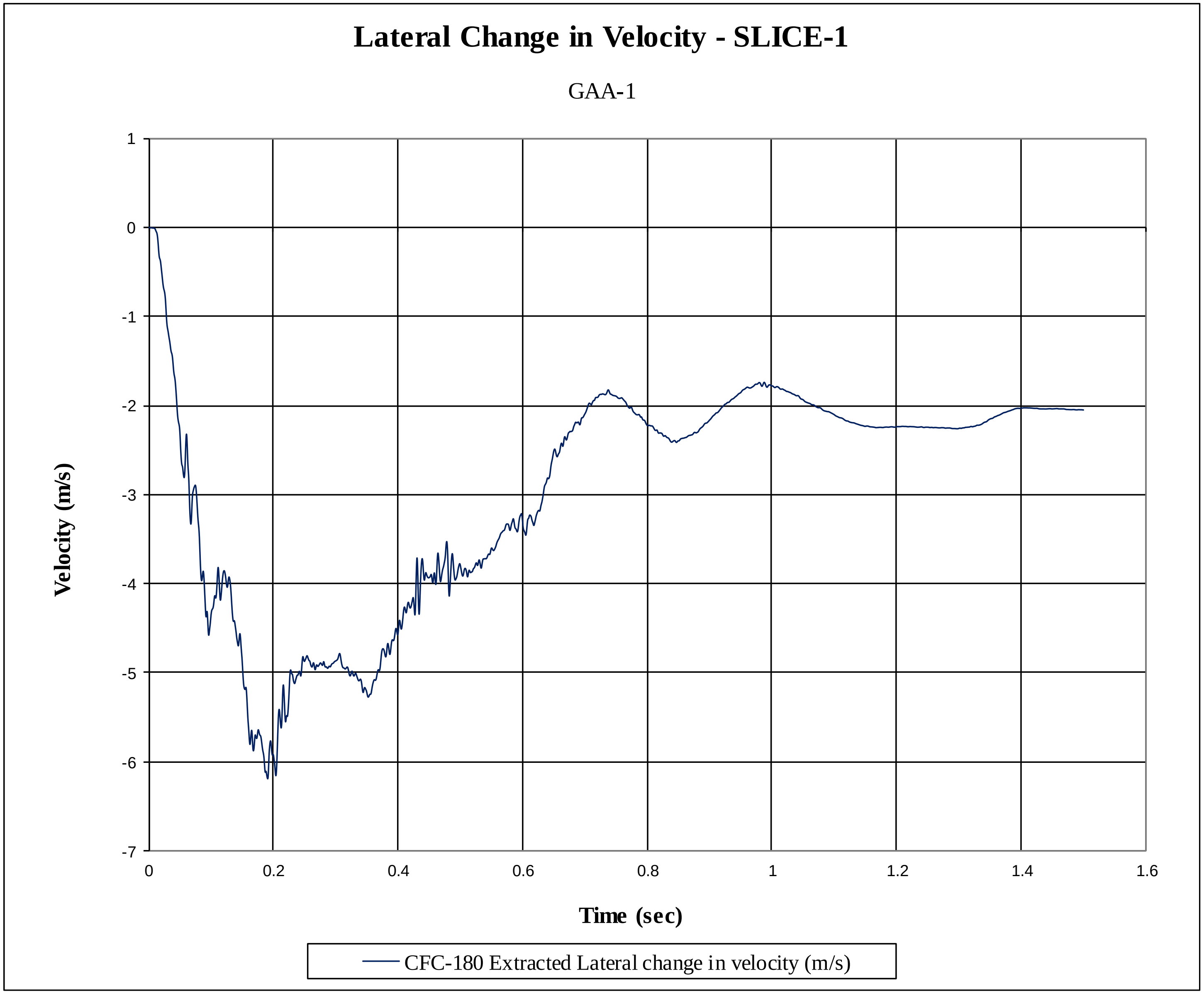


Figure G-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. GAA-1

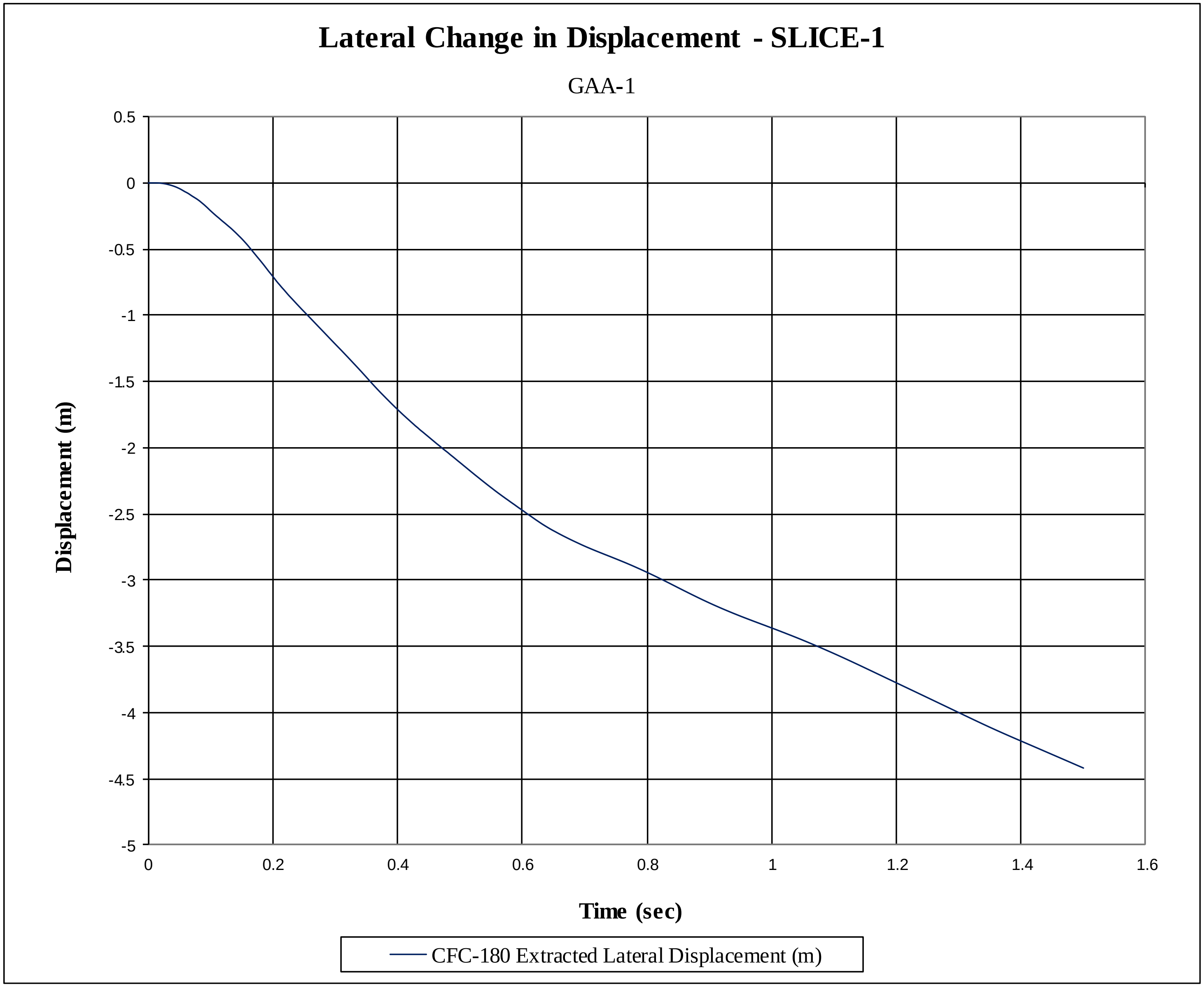


Figure G-6. Lateral Occupant Displacement (SLICE-1), Test No. GAA-1

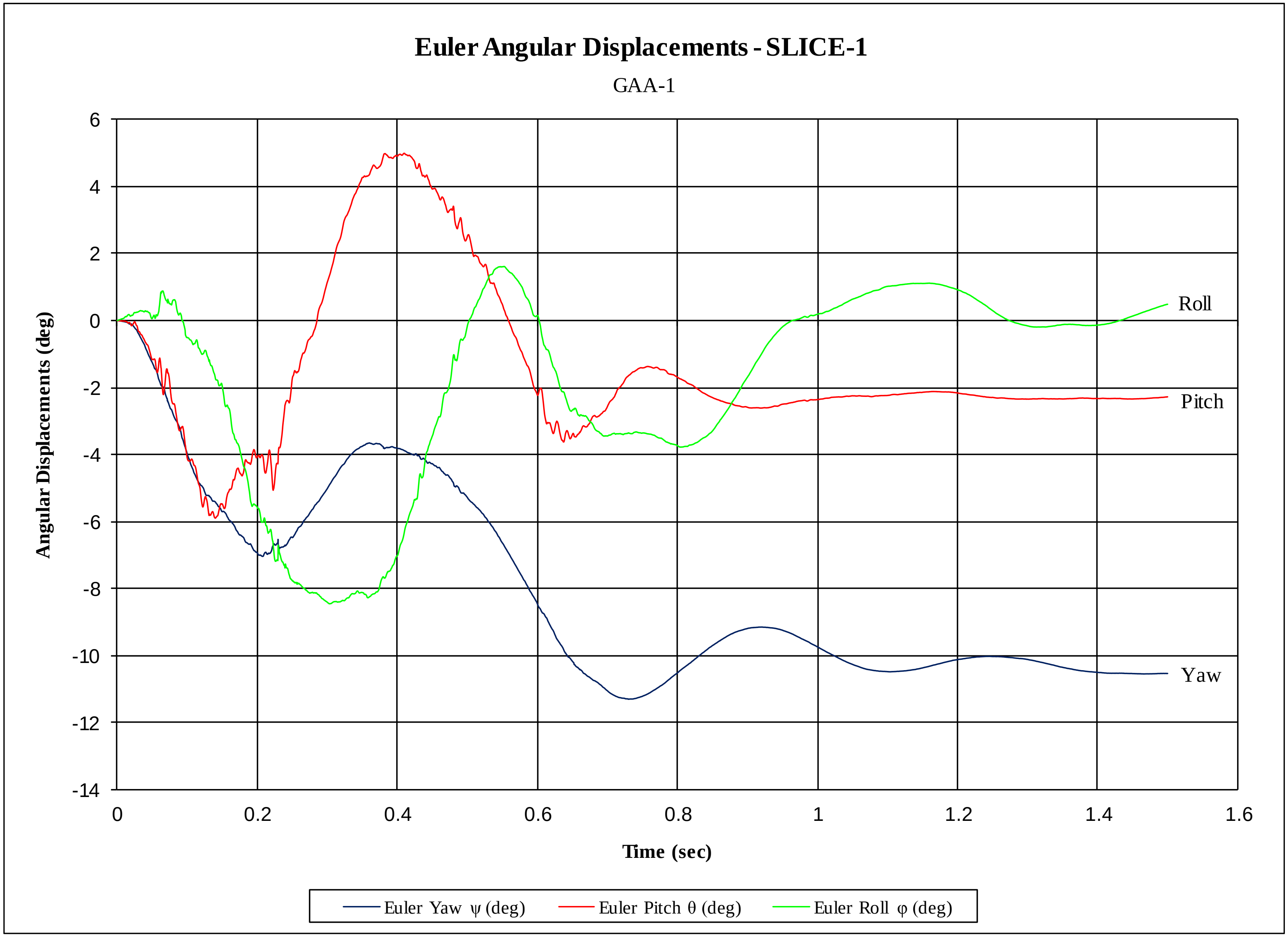


Figure G-7. Vehicle Angular Displacements (SLICE-1), Test No. GAA-1

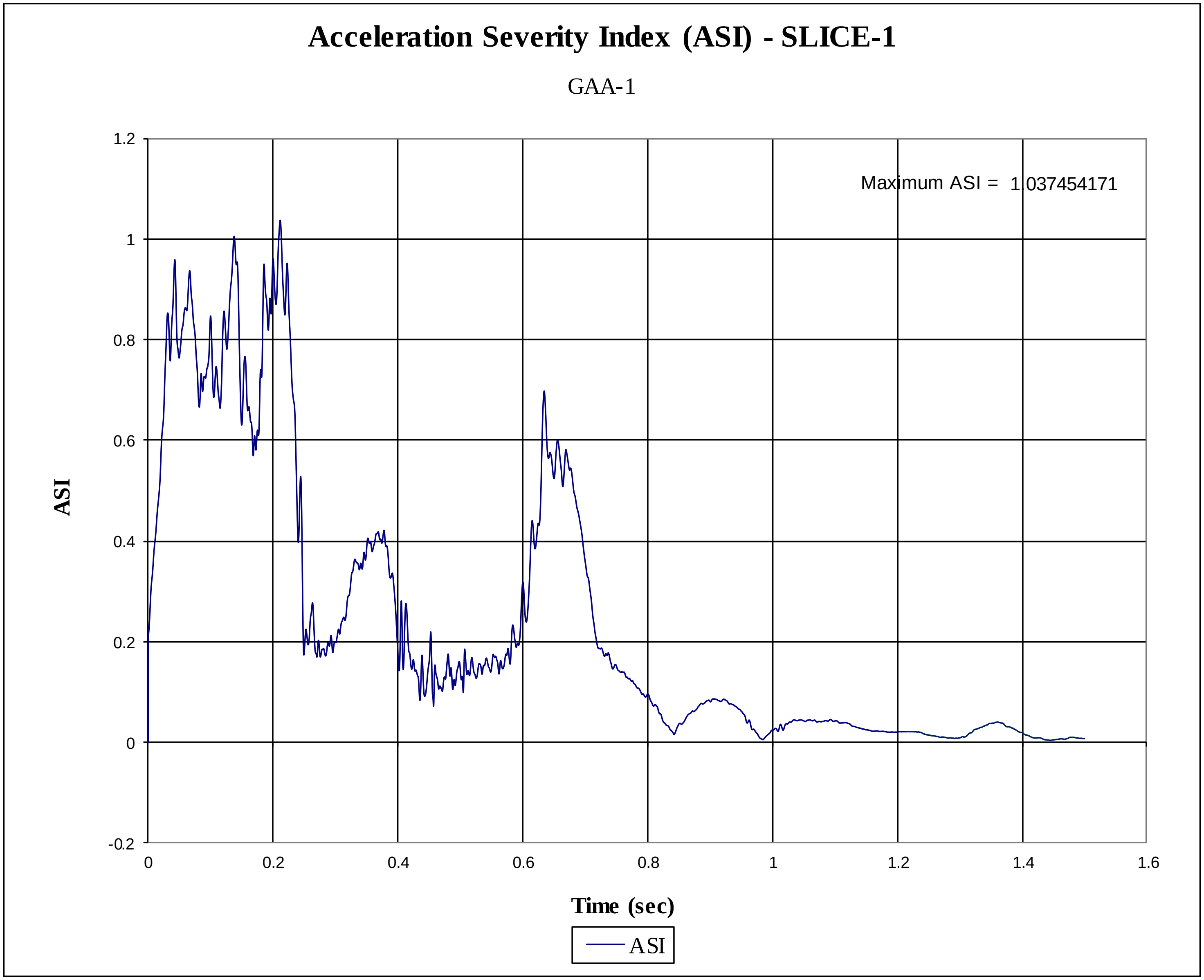


Figure G-8. Acceleration Severity Index (SLICE-1), Test No. GAA-1

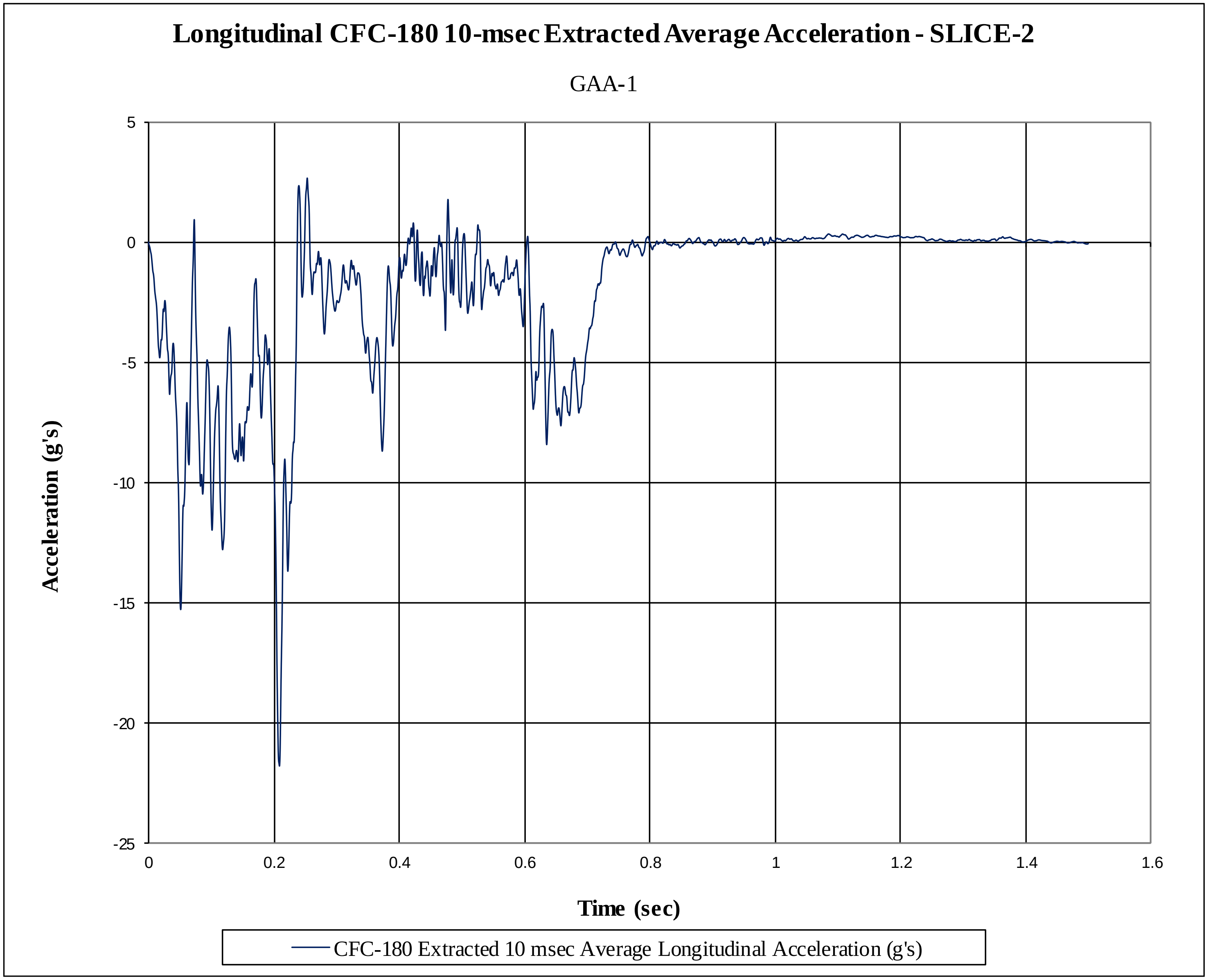


Figure G-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. GAA-1

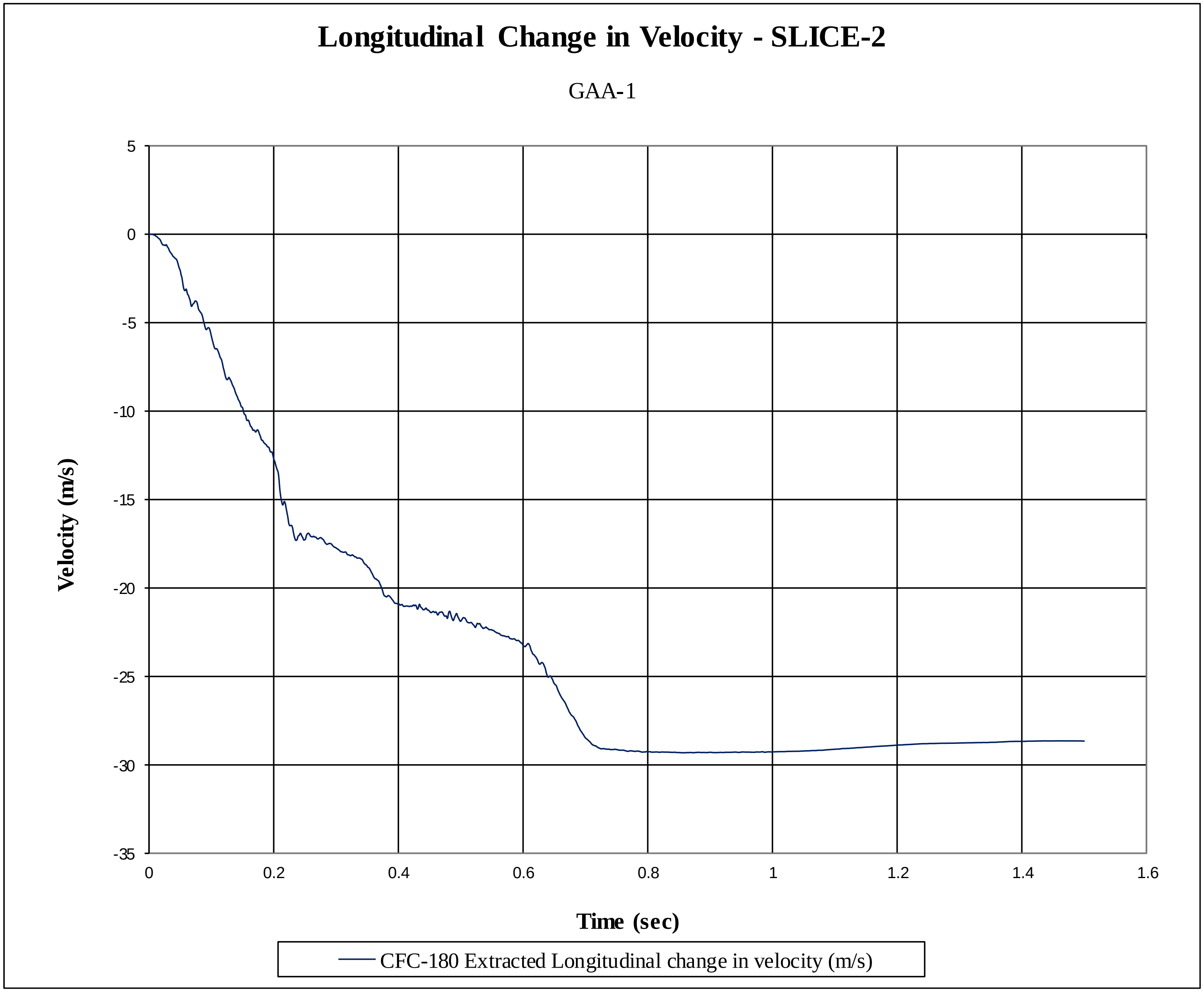


Figure G-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. GAA-1

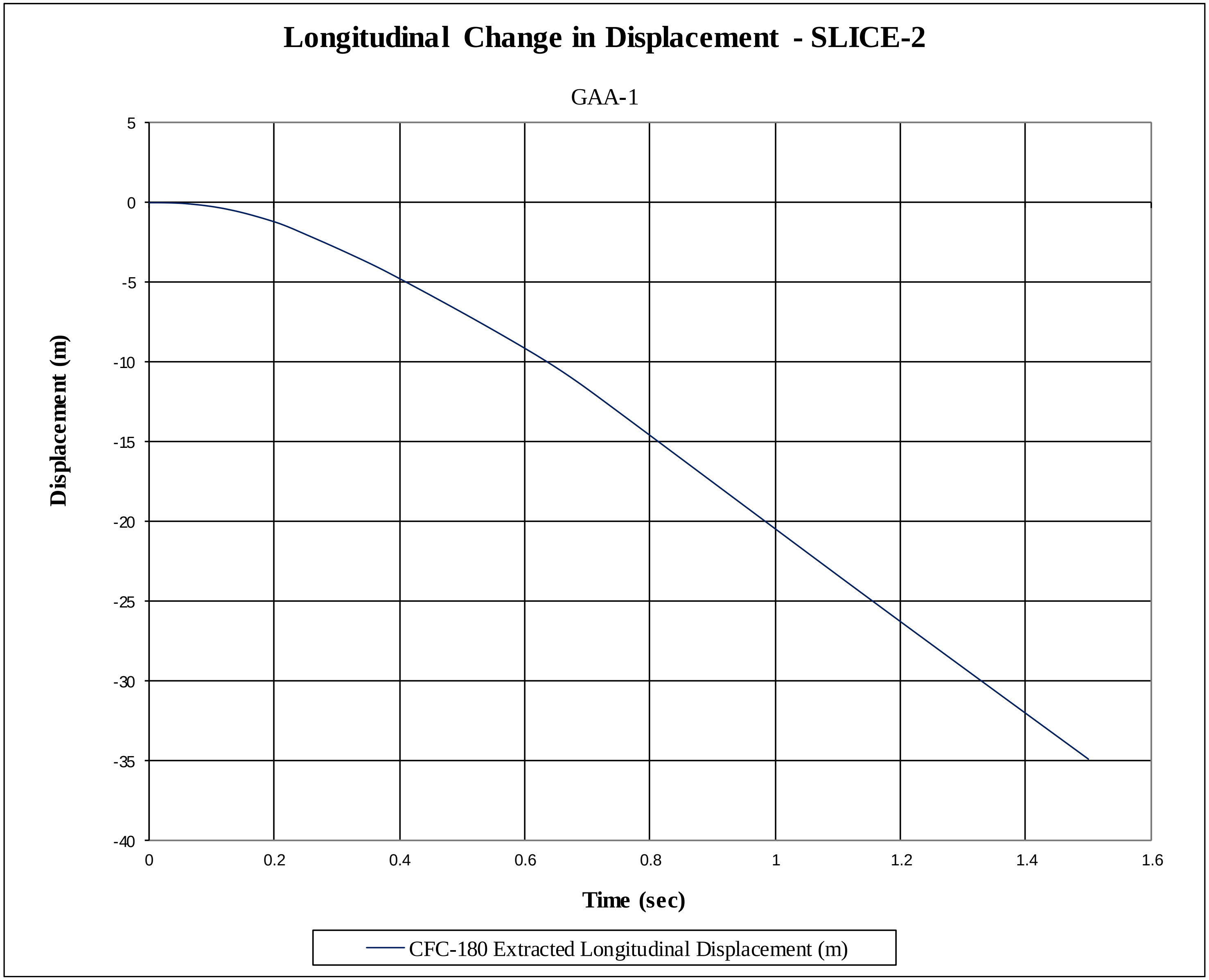


Figure G-11. Longitudinal Occupant Displacement (SLICE-2), Test No. GAA-1

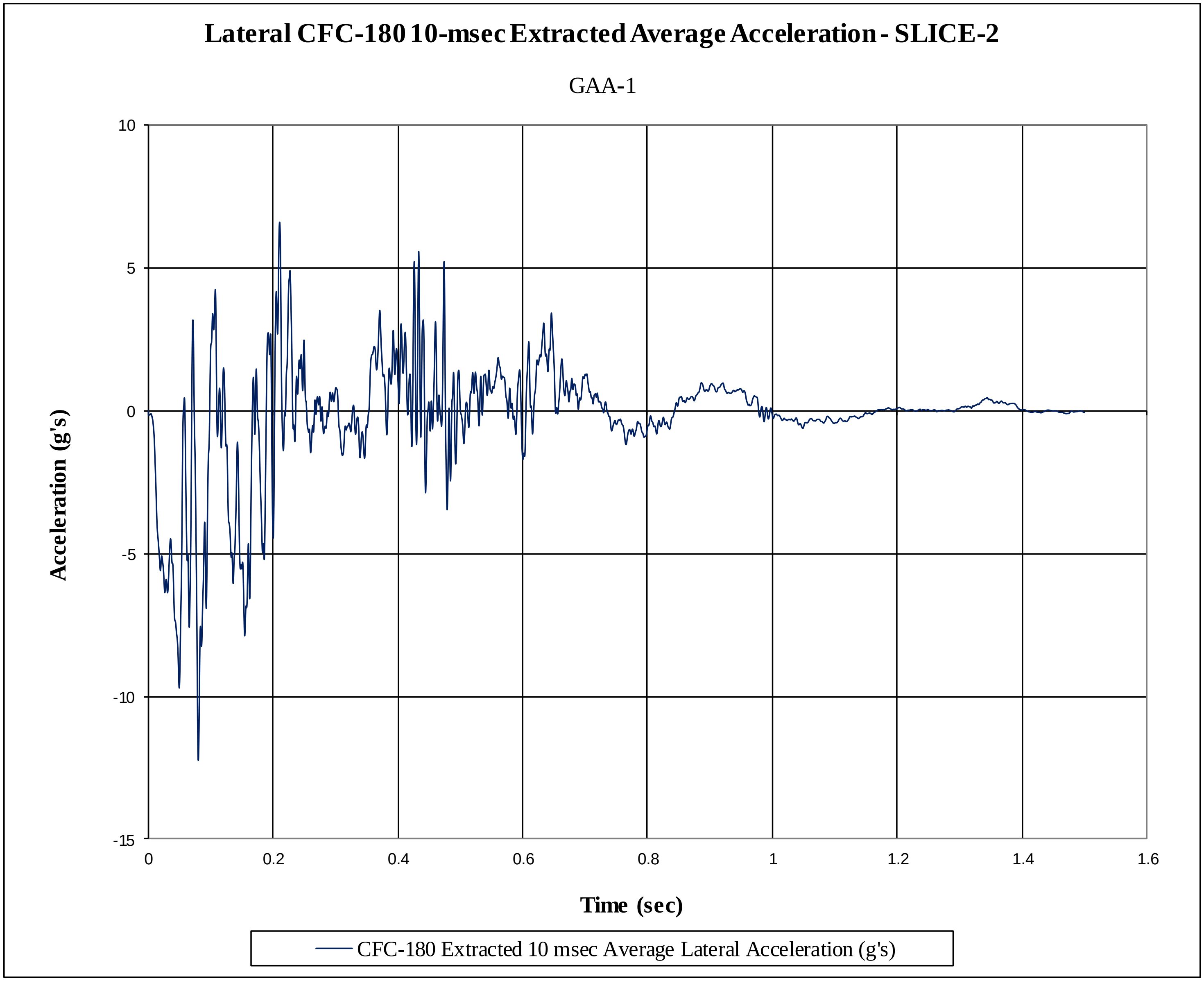


Figure G-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. GAA-1

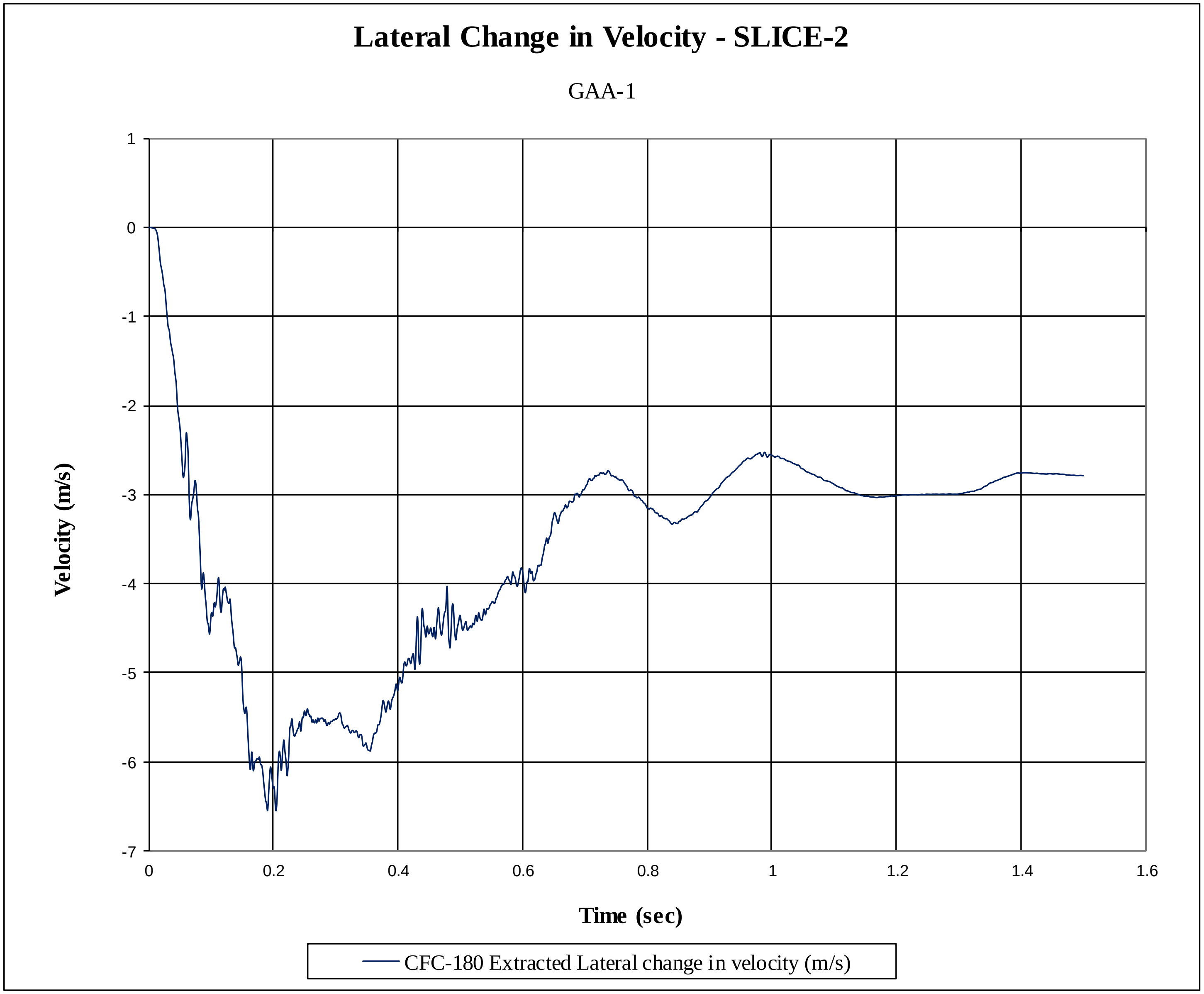


Figure G-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. GAA-1

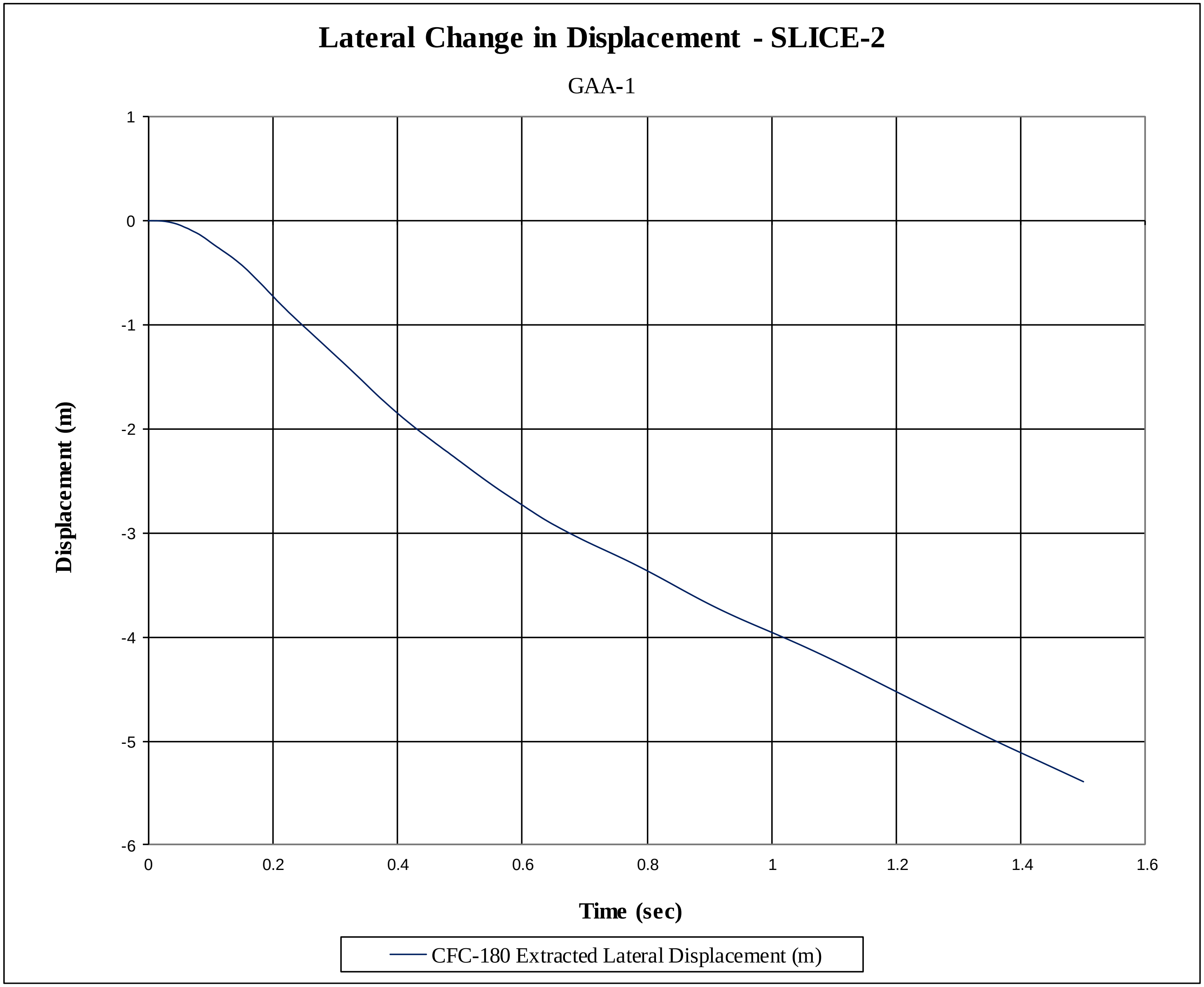


Figure G-14. Lateral Occupant Displacement (SLICE-2), Test No. GAA-1

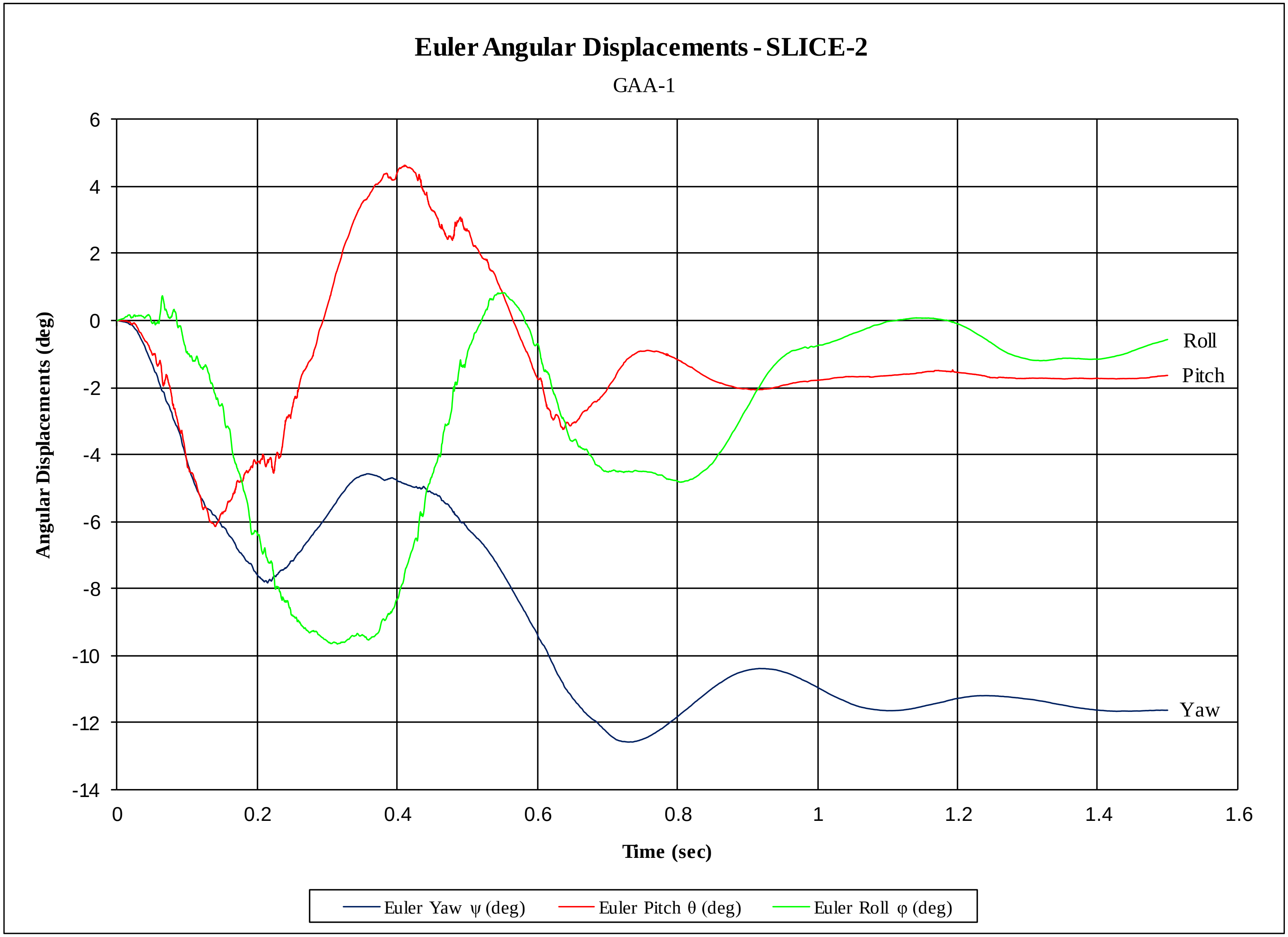


Figure G-15. Vehicle Angular Displacements (SLICE-2), Test No. GAA-1

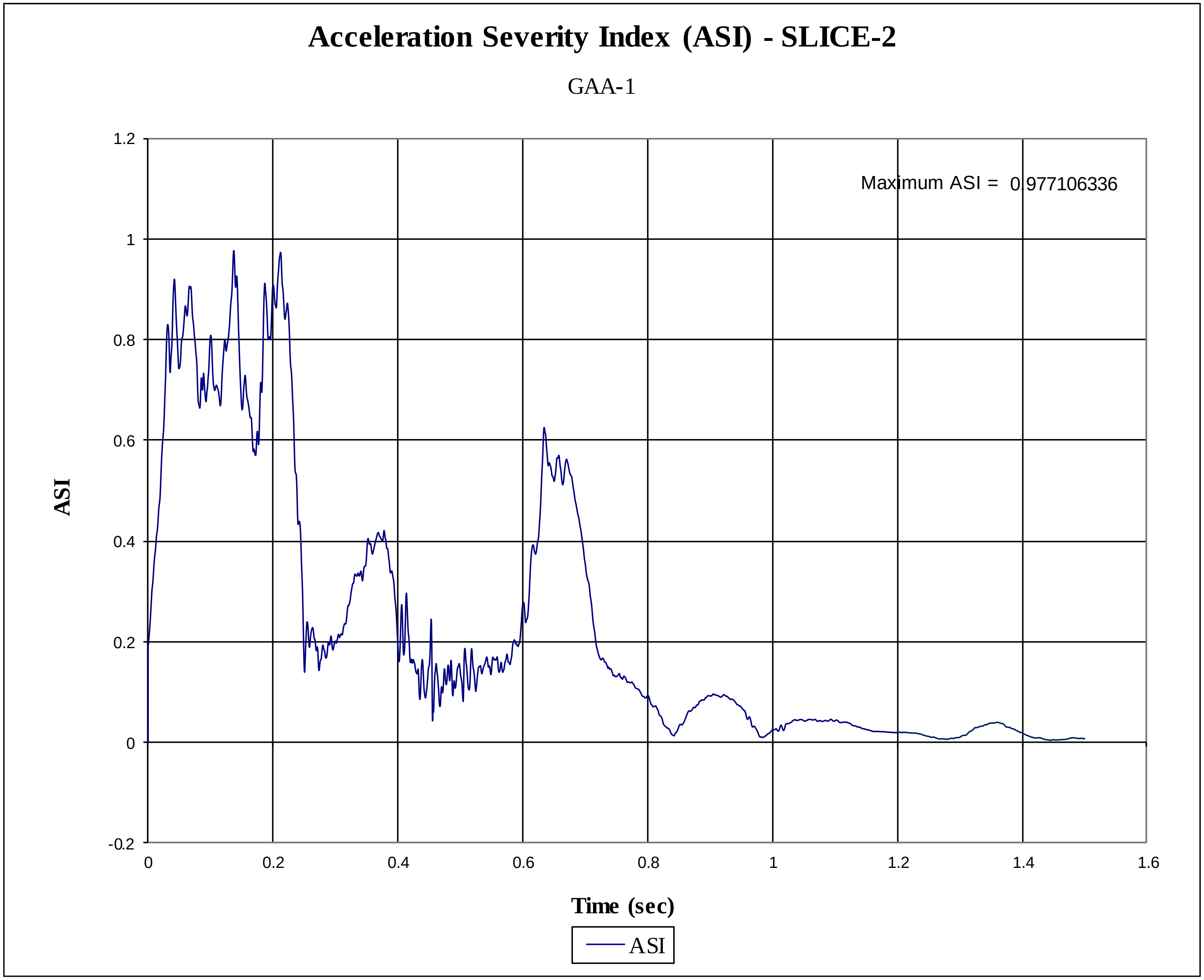


Figure G-16. Acceleration Severity Index (SLICE-2), Test No. GAA-1

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