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DYNAMIC TESTING AND EVALUATION OF CULVERT-MOUNTED, STRONG-POST MGS TO TL-3 GUIDELINES OF MASH 2016



Submitted by

Mojdeh Asadollahi Pajouh, Ph.D., P.E.
Research Assistant Professor

Jennifer D. Rasmussen, Ph.D., P.E.
Research Associate Professor

Ronald K. Faller, Ph.D., P.E.
Research Professor and MwRSF Director

Robert W. Bielenberg, M.S.M.E., E.I.T.
Research Engineer

Fengtao Bai, Ph.D.
Former Post-Doctoral Research Associate

James C. Holloway, M.S.M.E., E.I.T.
Research Engineer & Assistant Director –
Physical Testing Division

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 N.W. 36th Street
Lincoln, Nebraska 68524

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| 16. Abstract <p>A modified design of the MGS was evaluated for installation on a low-fill culvert with a strong-post attachment using to the culvert, half-post spacing, and a 12-in. (305-mm) offset from the back of the post to the culvert headwall through full-scale crash testing. A four-cell, concrete culvert with 8-in. (203-mm) thick slab and 9-in. (229-mm) deep soil fill was utilized. The test installation consisted of 182.3-ft (55.6-m) long MGS with a 31-in. (787-mm) top rail height, supported by twenty-three W6x8.5 by 72-in. (1,829-mm) long posts upstream and downstream of the culvert and fourteen W6x9 by 41-in. (1,041-mm) long posts attached to the culvert's top slab using a deformable baseplate and through-bolts.</p> <p>Two crash tests were conducted according to the American Association of State Highway Transportation Officials (AASHTO) <i>Manual for Assessing Safety Hardware</i> 2016 (MASH) Test Level 3 (TL-3) impact safety criteria. In test no. CMGS-1, a 2,428-lb (1,101-kg) car impacted the culvert-mounted MGS at a speed of 61.3 mph (98.7 km/h) and at an angle of 25.1 degrees. In test no. CMGS-2, a 5,013-lb (2,274-kg) pickup truck impacted the MGS attached to the culvert at a speed of 62.8 mph (101.1 km/h) and an angle of 25.7 degrees. In both tests, the vehicle was safely redirected and captured. Both tests were deemed acceptable according to TL-3 safety criteria in MASH. Recommendations were made for the implementation of MGS on low-fill culverts as well as transitioning from the standard MGS to the culvert-mounted MGS.</p> | | | |
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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 Dr. Cody Stolle, E.I.T., Research Assistant Professor.

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K.A. Lechtenberg, M.S.M.E., E.I.T., Research Engineer
S.K. Rosenbaugh, M.S.C.E., E.I.T., Research Engineer
C.S. Stolle, Ph.D., E.I.T., Research Assistant Professor
J.S. Steelman, Ph.D., P.E., Associate Professor
A.T. Russell, B.S.B.A., Testing and Maintenance Technician II
E.W. Krier, B.S., Construction and Testing Technician II
S.M. Tighe, Construction and Testing Technician I
D.S. Charroin, Construction and Testing Technician I
R.M. Novak, Construction and Testing Technician I
T.C. Donahoo, Construction and Testing Technician I
J.T. Jones, Construction and Testing Technician I
C.I. Sims, Former Construction and Testing Technician I
J.E. Kohtz, B.S.M.E., CAD Technician
E.L. Urbank, B.A., Research Communication Specialist
Z.Z. Jabr, Engineering Technician
Undergraduate and Graduate Research Assistants

Wisconsin Department of Transportation

Jerry Zogg, P.E., Former Chief Roadway Standards Engineer
Erik Emerson, P.E., Standards Development Engineer
Rodney Taylor, P.E., Roadway Design Standards Unit Supervisor

Nebraska Department of Transportation

Jodi Gibson, Former Research Coordinator
Mark Fischer, P.E., Research Program Manager

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1 INTRODUCTION

1.1 Background

Concrete box culverts are routinely installed under roadways to allow water drainage without affecting the motoring public. The ends of these culverts and their associated drop-offs can also represent a hazard on the roadside when they do not extend outside of the clear zone and often require shielding in the form of roadside barriers. The most common safety barriers utilized to shield these areas are W-beam guardrail systems. However, low-fill culverts with less than 40 in. (1,016 mm) of soil fill prevent the proper installation of standard guardrail posts due to a lack of available embedment depth. Previous crash testing has shown that in some cases W-beam installations with shallow post embedment do not perform adequately and are prone to vehicle override [1]. Therefore, low-fill culverts require specialized guardrail systems to safely treat the hazard. Currently, three types of guardrail systems are being used to treat cross-drainage box culverts: (1) long-span guardrail systems; (2) guardrail systems anchored to the culvert headwall; and (3) guardrail systems anchored to the top slab of the culvert.

Long-span guardrail systems contain unsupported lengths of W-beam rail that span over the top of culverts. These barrier systems do not require attachment to the culvert, thus allowing the culvert and the barrier system to operate independently. One *Manual for Assessing Safety Hardware* (MASH) compliant long-span system, developed at the Midwest Roadside Safety Facility (MwRSF), consists of a single layer of 12-gauge (2.67-mm thick), 31-in. (787-mm) tall W-beam guardrail centered over a 25-ft (7.6-m) unsupported span length [2-3]. The long-span systems do not require additional components for attachment to the culvert and provide a cost-effective method for shielding culverts. However, these long-span systems are limited to a maximum unsupported span length of 25 ft (7.6 m).

For low-fill culverts of widths exceeding the maximum unsupported length of long-span systems, few W-beam guardrail designs are available for direct attachment to the culvert's headwalls. One such guardrail system was a side-mounted socket system for weak-post Midwest Guardrail System (MGS) attached to the outside face of culvert headwalls developed by MwRSF in 2014, as shown in Figure 1 [4]. The posts were inserted into side-mounted, steel sockets that would remain undamaged during impacts. The system utilized a top rail height of 31 in. (787 mm) supported by S3x5.7 (S76x8.5) posts, spaced 37½ in. (953 mm) on center and positioned within HSS4x4x¾ steel socket tubes attached to the outside face of the culvert headwall.



Figure 1. Side-Mounted Configuration for Guardrail on Culvert Headwalls [4]

There are many installations where the culvert or roadway geometry is not compatible with the side-mounted system. Additionally, there may be a fill slope between the edge of the roadway and the culvert headwall, and the side-mounted guardrail system was only designed for level terrain applications. Therefore, there was a need for guardrail systems attached to the top slab of the low-fill culverts. One such guardrail system was developed by MwRSF in 2002, as shown in Figure 2 [5]. This system utilized a 27³/₄-in. (705-mm) top rail height, a 37¹/₂-in. (953-mm) post spacing, a deformable 1/2-in. (13-mm) thick steel plate welded to the bottom of each guardrail post with a 5/16-in. (8-mm) three-pass fillet weld on the front (tension) flange and a 1/4-in. (6-mm) fillet weld on the web and back (compression) flange. The post assembly was anchored to the culvert slab using four 1-in. (25-mm) diameter through bolts. Finally, the system posts were spaced 3 ft – 1¹/₂ in. (953-mm) on centers, and the back side of the posts were offset 18 in. (457 mm) from the inside of the culvert headwall to prevent interaction between the posts and the rigid headwall as the system deflects during an impact event. This system was successfully developed and full-scale crash tested according to the Test Level 3 (TL-3) safety performance guidelines found in National Cooperative Highway Research Program (NCHRP) Report No. 350 [6].

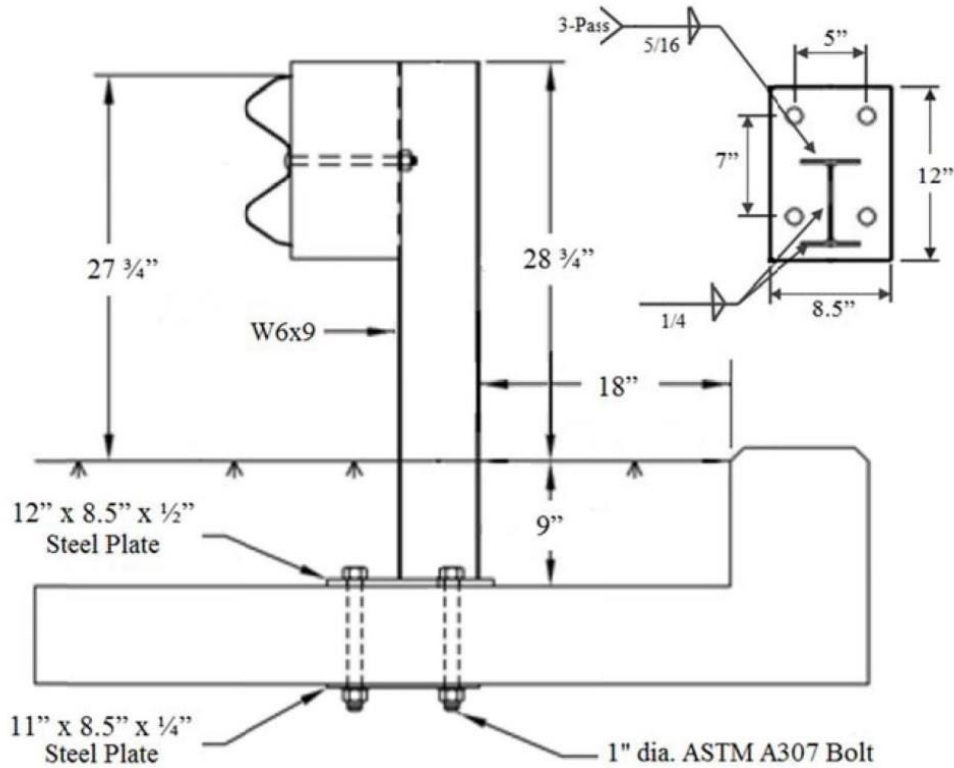


Figure 2. NCHRP Report No. 350-Compliant, Modified G4(1S) Guardrail Attachment to Low-Fill Culvert [5]

During evaluation of the barrier system it was shown that a potential exists for vehicular instabilities or rollover to occur if the guardrail is placed too close to the culvert headwall. This phenomenon was the result of the system’s posts being unable to rotate near the base due to contact with the top of the headwall, thus resulting in wheel snag on the posts. From analysis of the crash test results, it was recommended that the back-side face of the steel posts be positioned a minimum of 10 in. (254 mm) away from the front face of the culvert’s headwall with a minimum soil fill depth of 9 in. (229 mm) to maintain acceptable barrier performance [5].

For further investigation, an identical culvert-mounted MGS was crash tested with a ¾-ton pickup truck according to TL-3 safety performance criteria presented in NCHRP Report No. 350 [5]. For this design, the steel posts were spaced 1 in. (25 mm) away from the front of the culvert’s headwall. During vehicle redirection, the pickup truck rolled over and the test was determined to be unacceptable. The vehicle’s instability was attributed to the interaction of the vehicle’s front tire and suspension with the steel post immediately downstream from impact. The headwall of the culvert prevented the post from continuing to rotate backward, and subsequently caused a snag point for the vehicle’s tire.

Following the NCHRP Report No. 350 evaluation of the culvert-mounted guardrail system, a subsequent research effort was undertaken to determine alternatives to the original attachment design [7]. The first objective was to determine if an alternative weld detail could be utilized to simplify the three-pass fillet weld on the front flange of the post. The second objective was to develop an epoxy anchor alternative to bolting through the top slab of the culvert. These system

modifications were evaluated through a series of four dynamic bogie tests conducted under the same impact conditions utilized in the original development study. The study found that proposed changes to the weld details were not feasible, but that epoxy anchorages could be used successfully. This research led to the development of an epoxy anchoring option for the post anchor utilizing 1-in. (25-mm) diameter, ASTM A307 threaded rods and an 8-in. (203-mm) embedment depth. Anchor pullout was encountered for an embedment depth of 6 in. (152 mm), while an 8-in. (203-mm) embedment showed no signs of anchor failure. Thus, an 8-in. (203-mm) minimum embedment depth was recommended for the epoxied anchorage design.

In 2011, the Texas A&M Transportation Institute (TTI) developed and tested a slightly different version of the strong-post culvert attachment for use with a 31-in. (787-mm) tall W-beam guardrail with midspan splices at standard post spacing, as shown in Figure 3 [8]. For this design, W6x9 steel posts were welded to $\frac{7}{8}$ -in. (22-mm) thick steel base plates and spaced 6 ft – 3 in. (1,905 mm) on centers with midspan rail splices. The posts were attached to the culvert using four $\frac{7}{8}$ -in. (22-mm) diameter rods that were epoxied into the concrete with a 6-in. (152-mm) minimum embedment depth and a Hilti chemical adhesive anchoring system. The posts were also located 18 in. (457 mm) from the culvert headwall. The guardrail system was designed for use with a minimum soil fill depth of 9 in. (229 mm). Testing of this design under the MASH 2009 TL-3 criteria [9] with the 2770P vehicle was successful. However, it should be noted that partial tearing of the rail was observed in the impact region, which indicated that the rail tensile forces were high, and the potential exists for rail rupture. The thicker base plate used in this system may have increased the stiffness of the barrier and led to the increased rail loads.

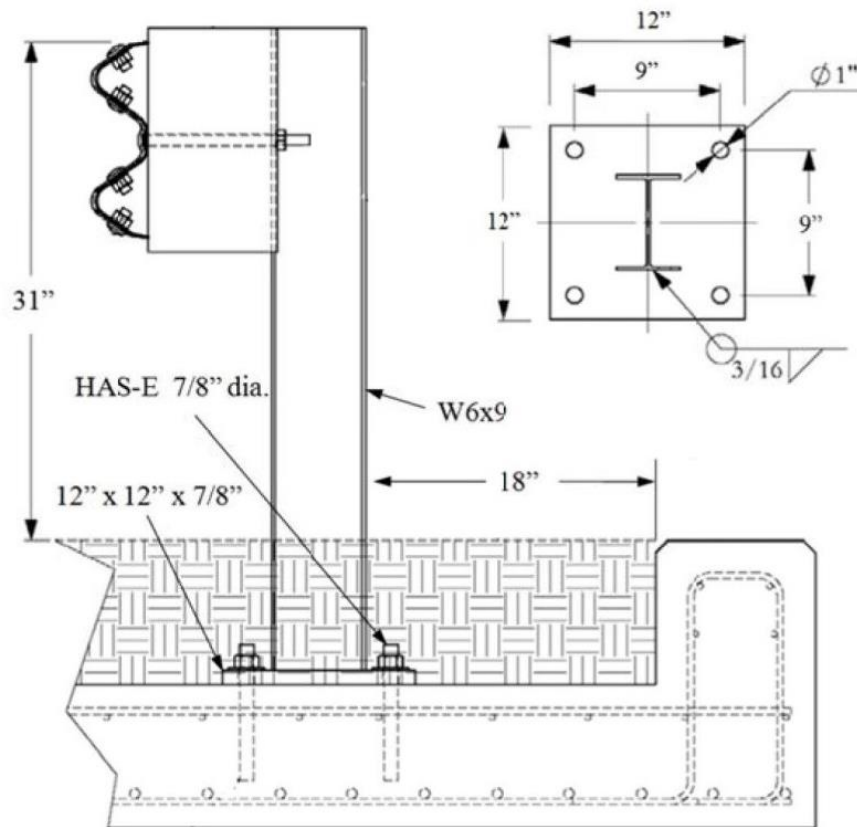


Figure 3. MASH-Compliant, MGS Guardrail Attachment to Low-Fill Culvert [8]

MwRSF provided previous, un-tested guidance on using the MwRSF version of the strong-post attachment to meet MASH 2016 criteria [10] when used with the MGS. Based on the successful testing of the TTI mounting system, it was believed that there would be a good potential for the system to perform safely under the MASH 2016 criteria. However, MwRSF recommended the following if the states wish to use the design: (1) the half-post spacing of the NCHRP Report No. 350 tested system be retained and (2) the minimum offset from the back of the post to the headwall be increased to 18 in. (457 mm).

These recommendations were made to provide a conservative approach to using the MwRSF version of the strong-post attachment based on the original testing of that system and the subsequent testing the TTI design. However, the performance of the MwRSF version of the strong-post attachment under MASH 2016 TL-3 criteria could not be fully determined without full-scale crash testing.

Based on the previous NCHRP Report No. 350 and MASH 2009 testing of similar culvert-mounted guardrail systems, Wisconsin Department of Transportation desired to evaluate the MGS installed on a culvert with the MwRSF version of the strong-post attachment, half-post spacing, and a 12-in. (305-mm) offset from the back of the post to the culvert headwall.

1.2 Research Objective

The objective of this research effort was to conduct full-scale crash testing on the MGS installed on a culvert with the MwRSF version of the strong-post attachment using through-bolts and epoxy anchorage, half-post spacing, and a 12-in. (305-mm) offset from the back of the post to the culvert headwall. All tests were performed according to the TL-3 impact safety standards found in MASH 2016 [10]. Additionally, the transition from standard MGS to the culvert-mounted MGS was to be analyzed and recommendations were made regarding the potential performance of the transition.

1.3 Scope

The research began with development of the design details for the modified MGS installed on a low-fill culvert with the MwRSF version of the strong-post attachment with through-bolts and epoxy anchorage, half-post spacing, and a 12-in. (305-mm) offset from the back of the post to the culvert headwall was recommended for full-scale crash testing. MASH 2016 guidance was utilized to determine the critical impact points for full-scale crash testing. Two full-scale crash tests were conducted according to the MASH 2016 test designation nos. 3-10 and 3-11 to evaluate the length-of-need of the designed culvert-mounted, MGS attachment. Finally, the test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made pertaining to the safety performance of the tested version of culvert-mounted, strong-post MGS. Additionally, the transition from the standard MGS to the culvert-mounted MGS was analyzed and recommendations relative to that transition performance were given.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as W-beam guardrail systems attached to concrete box culverts, 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 [10]. Note that there is no difference between MASH 2009 and MASH 2016 for longitudinal barriers such as the system tested in this project, except that additional occupant compartment deformation measurements, photographs, and documentation are required by MASH 2016. 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.

Critical impact points (CIPs) for both impacts were determined based on calculated post and guardrail beam strengths and the use of MASH 2016 Figures 2-8 and 2-11 for the 1100C and 2270P vehicle impacts, respectively.

Table 1. MASH 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 (100) | 25 | A,D,F,H,I |
| | 3-11 | 2270P | 5,000 (2,268) | 62 (100) | 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 culvert-mounted MGS 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 documented herein 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.

Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barrier

| | | | |
|---------------------|--|-----------|-----------|
| Structural Adequacy | A. 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. | | |
| Occupant Risk | D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016. | | |
| | F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees. | | |
| | H. Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits: | | |
| | Occupant Impact Velocity Limits | | |
| | Component | Preferred | Maximum |
| | Longitudinal and Lateral | 30 ft/s | 40 ft/s |
| Occupant Risk | I. The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits: | | |
| | Occupant Ridedown Acceleration Limits | | |
| | Component | Preferred | Maximum |
| | Longitudinal and Lateral | 15.0 g's | 20.49 g's |

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, W6x16 (W150x24) posts were installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale testing, dynamic impact testing was 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) above the ground line. If dynamic testing near the system is not desired, MASH 2016 permits a static test to be conducted instead and compared against the results of 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.

3 DESIGN DETAILS

For test nos. CMGS-1 and CMGS-2, a simulated four-cell concrete box culvert system was constructed at MwRSF's Outdoor Test Site. The four-cell system was selected to ensure that the research results were representative of actual box culvert site conditions. The strong post MGS was then mounted on the culvert. In the following sections, design details for the test installation are provided.

3.1 Culvert Design and Construction

The basic design of the box culvert was based on the design used in the original NCHRP Report No. 350 full-scale testing and evaluation of the strong post culvert attachment for W-beam guardrail [5]. In this study, the researchers reviewed a variety of culvert design used by state DOTs and selected a culvert configuration with a 7-in. (178-mm) thick concrete top slab. Additionally, the simulated test culvert utilized no. 4 steel reinforcement bars spaced on 12-in. (305-mm) centers and placed in two rows throughout the 7-in. (178-mm) thick slab. This combination of slab thickness and steel reinforcement were believed to provide a non-conservative slab design for resisting dead and live loads but still provide sufficient capacity to minimize concrete damage. Therefore, if satisfactory barrier performance were observed in the crash testing program, then comparable barrier performance would be expected for top slab designs with capacities equal to or greater than that used in the crash tests. Review of Wisconsin standard culvert details found that their culvert designs utilized a minimum thickness of 8 in. (203 mm). In order to be consistent with the Wisconsin details while still providing a relatively non-conservative design, the simulated culvert design for the barrier systems evaluated herein was constructed with the same basic layout and reinforcement as the original NCHRP Report No. 350 tested system, but an 8-in. (203-mm) thick slab was utilized to match the Wisconsin standards. Additionally, the vertical support width was increased to 12 in. (305 mm) to provide increased soil bearing beneath the supports.

A soil test pit was excavated to a depth of approximately 66 in. (1,674 mm) to provide enough clearance for constructing the concrete box culvert. After the soil was excavated from the test pit, five reinforced concrete vertical support walls and a soil retaining wall were constructed on the bottom of the test pit, as shown in Figure 4. Design details of the culvert and bill of materials are shown in Figures 4 through 17. Construction photographs of the culvert are shown in Figures 18 through 21.

The three inner concrete vertical supports had a center-to-center spacing of 127 in. (3,226 mm). The vertical supports were constructed perpendicular to the roadway. As shown in Figure 8, the inner vertical supports measured 12 in. (305 mm) wide, 60 in. (1,524 mm) long, and 48 in. (1,219 mm) high. The two exterior concrete vertical supports measured 12 in. (305 mm) wide, 128 in. (3,251 mm) long, and 48 in. (1,219 mm) high, as shown in Figure 9. The soil retaining wall measured 8 in. (203 mm) wide, 43 ft – 4 in. (13.2 m) long, and 48 in. (1,219 mm) high and was constructed on the front of the culvert to prevent the soil from filling in beneath the simulated culvert, as shown in Figure 14.

The top slab measured 68 in. (1,727 mm) wide, 8 in. (203 mm) thick, and 43 ft – 4 in. (13.2 m) long, as shown in Figure 11. The headwall, constructed above the top slab, measured 10 in. (254 mm) wide, 10 in. (254 mm) high, and 43 ft – 4 in. (13.2 m) long and was located at the back

side of the deck. A 9-in. (229-mm) deep soil fill was used to create a level ground surface for testing.

The concrete used for the concrete vertical supports, the soil retaining wall, top slab, and headwall consisted of a Nebraska 47-BD Mix with a minimum compressive strength of 4,000 psi (27.6 MPa). The actual concrete compressive strength of the vertical supports on test day, as determined from concrete cylinder testing, was found to be approximately 4,665 psi (32.1 MPa). A minimum concrete cover of 1½ in. (38 mm) was used for all rebar placed within the concrete vertical supports, soil retaining wall, top slab and headwall. All steel reinforcement was ASTM A615 Grade 60 epoxy-coated rebar.

The steel reinforcement for the vertical supports utilized No. 4 bars for the transverse, vertical, and bent vertical bars, as shown in Figures 5 through 9 and 12 through 16. The transverse bars of the inner vertical wall supports were 76 in. (1,930 mm) long and spaced 15½ in. (394 mm) apart, as shown in Figure 8. The bent vertical bars of the inner vertical supports were 64 in. (1,626 mm) long and spaced 12 in. (305 mm) apart on center, as shown in Figures 9, 11, and 17. The transverse bars of the exterior vertical walls were 130¾ in. (3,321 mm) long and spaced 16¾ in. (425 mm) apart on center, as shown in Figure 9. The vertical dowel bars in the exterior vertical supports were 45 in. (1,143 mm) long and spaced 20 in. (508 mm) apart on center. The long and short bent vertical bars of the two exterior vertical supports were 64 in. (1,626 mm) and 60½ in. (1,537 mm) long, respectively, and they were spaced 18 in. (457 mm) apart on center, as shown in Figure 9.

The steel reinforcement for the soil retaining wall also utilized No. 4 bars for the longitudinal and vertical bars, as shown in Figures 14 through 16. Each of the six longitudinal rebar in the soil retaining wall was 43 ft (13.1 m) long. The length of the longitudinal bar can be varied as long as the minimum lap length of 18 in. (457 mm) is maintained. The vertical dowel bars were 64 in. (1,626 mm) long and spaced 32 in. (813 mm) apart on center, as shown in Figure 14.

The steel reinforcement for the top slab utilized No. 4 bars for the longitudinal and transverse bars, as shown in Figures 5, 11, 15, and 16. Each of the fourteen longitudinal rebar in the top slab was 43 ft (13.1 m) long. The transverse bars in the top slab were 57 in. (1,448 mm) long, and their spacing varied longitudinally. At the outside vertical supports, the loop bars were spaced 11¾ in. (298 mm) apart on center, as shown in Figure 5. The loop bar spacing on either side of the inside vertical supports was 10 in. (254 mm) on center. Between the supports, the spacing of the loop bars was 12 in. (305 mm) apart on center. The vertical spacing between the transverse bars was 4½ in. (114 mm) apart on center.

The steel reinforcement for the headwall utilized No. 4 bars for the longitudinal and loop bars. Each of the four longitudinal rebar in the headwall were 43 ft (13.1 m) long. The headwall loop bars were 53⅜ in. (1,356 mm) long, and their spacing varied longitudinally, as shown in Figures 5, 11, 15, and 16.

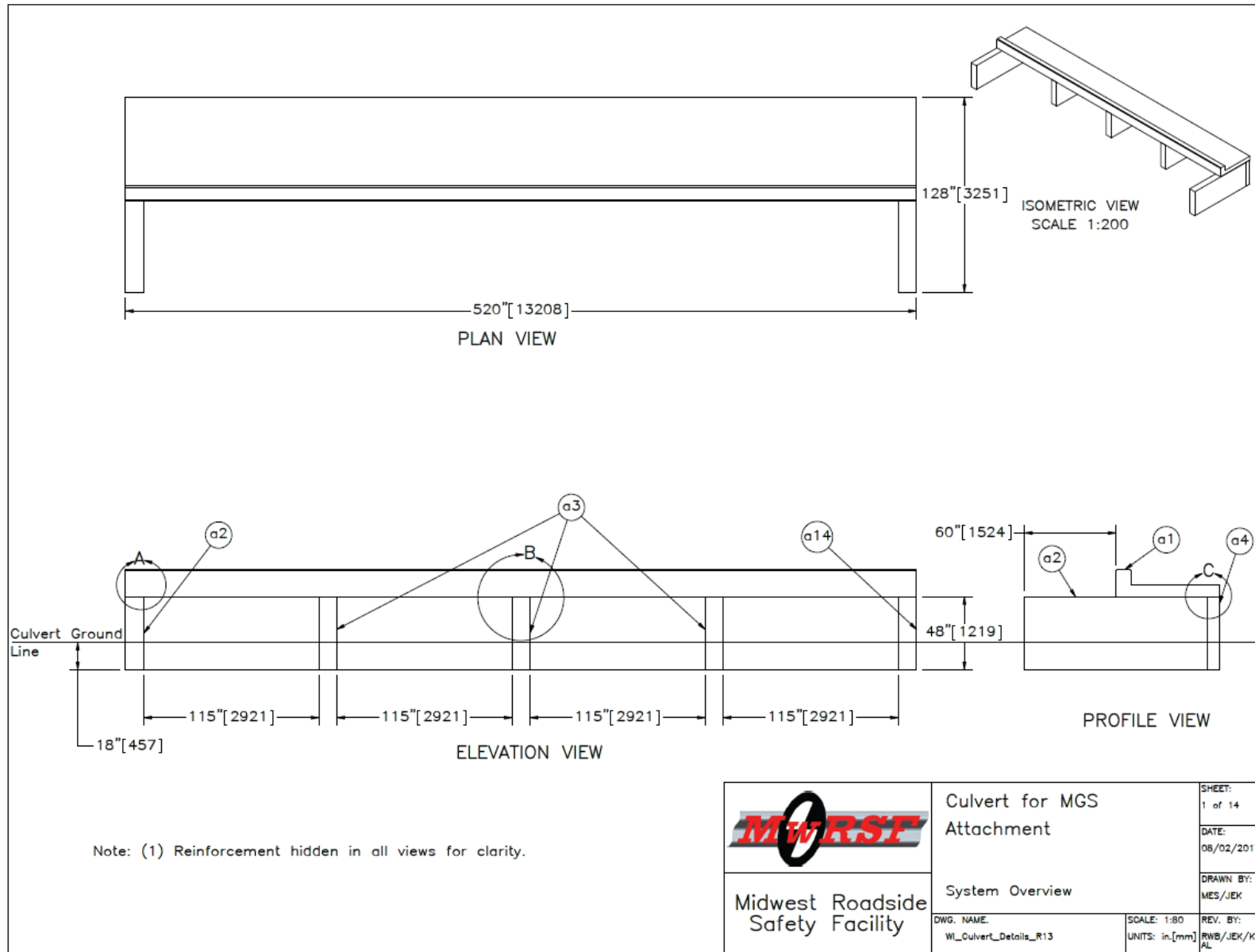


Figure 4. Culvert System Overview, Test Nos. CMGS-1 and CMGS-2

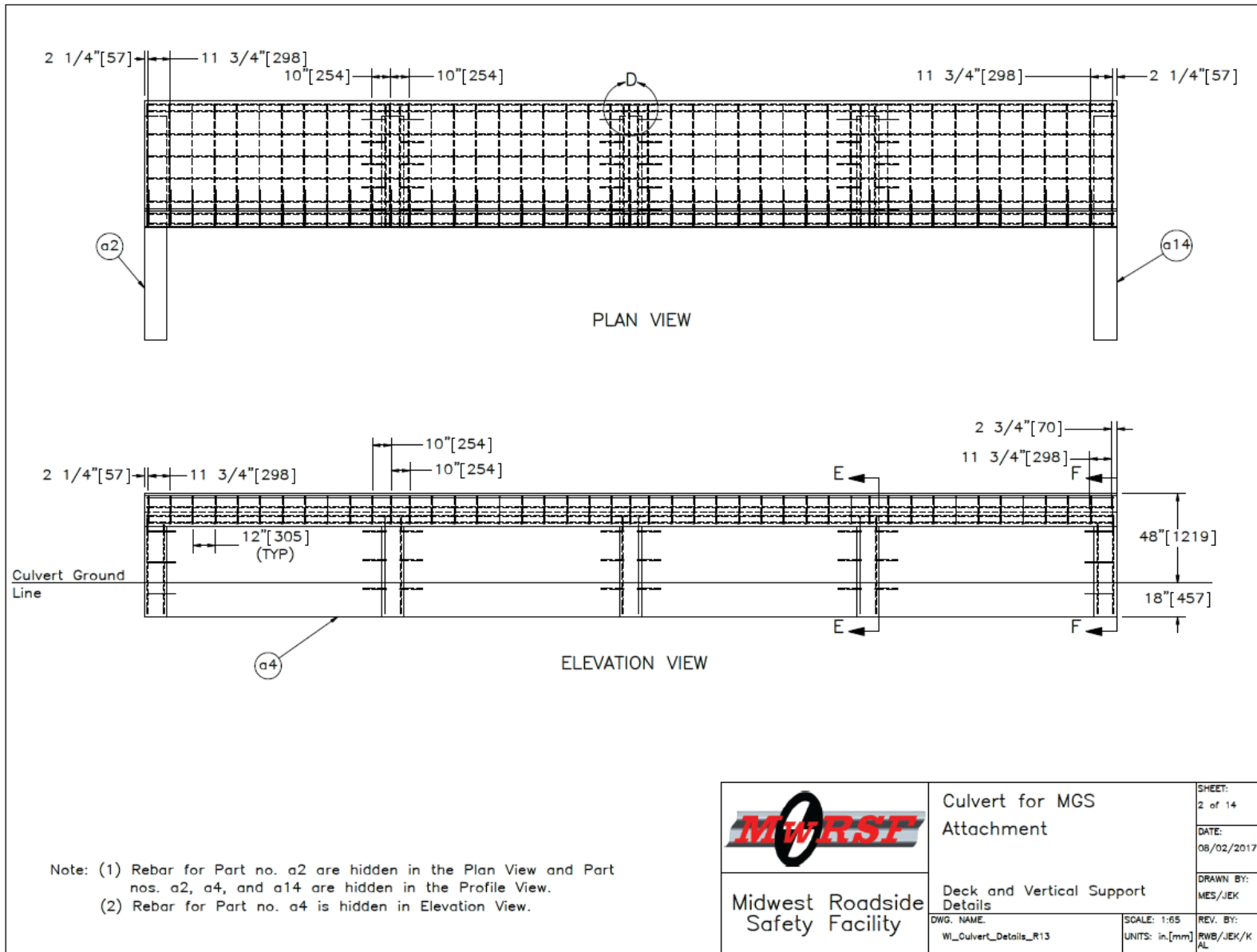


Figure 5. Top Slab and Vertical Support Wall Details, Test Nos. CMGS-1 and CMGS-2

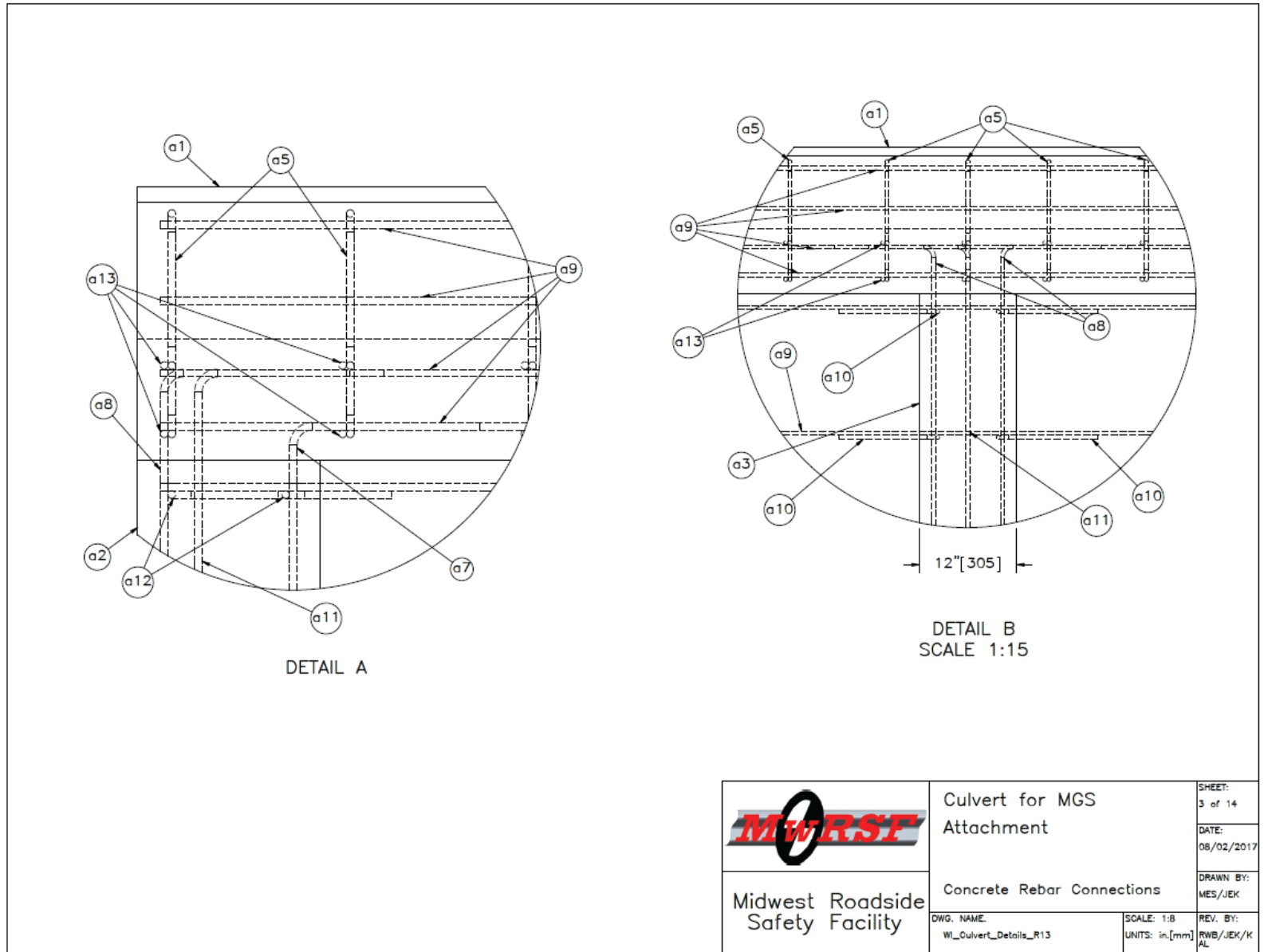


Figure 6. Concrete Rebar Connections, Test Nos. CMGS-1 and CMGS-2

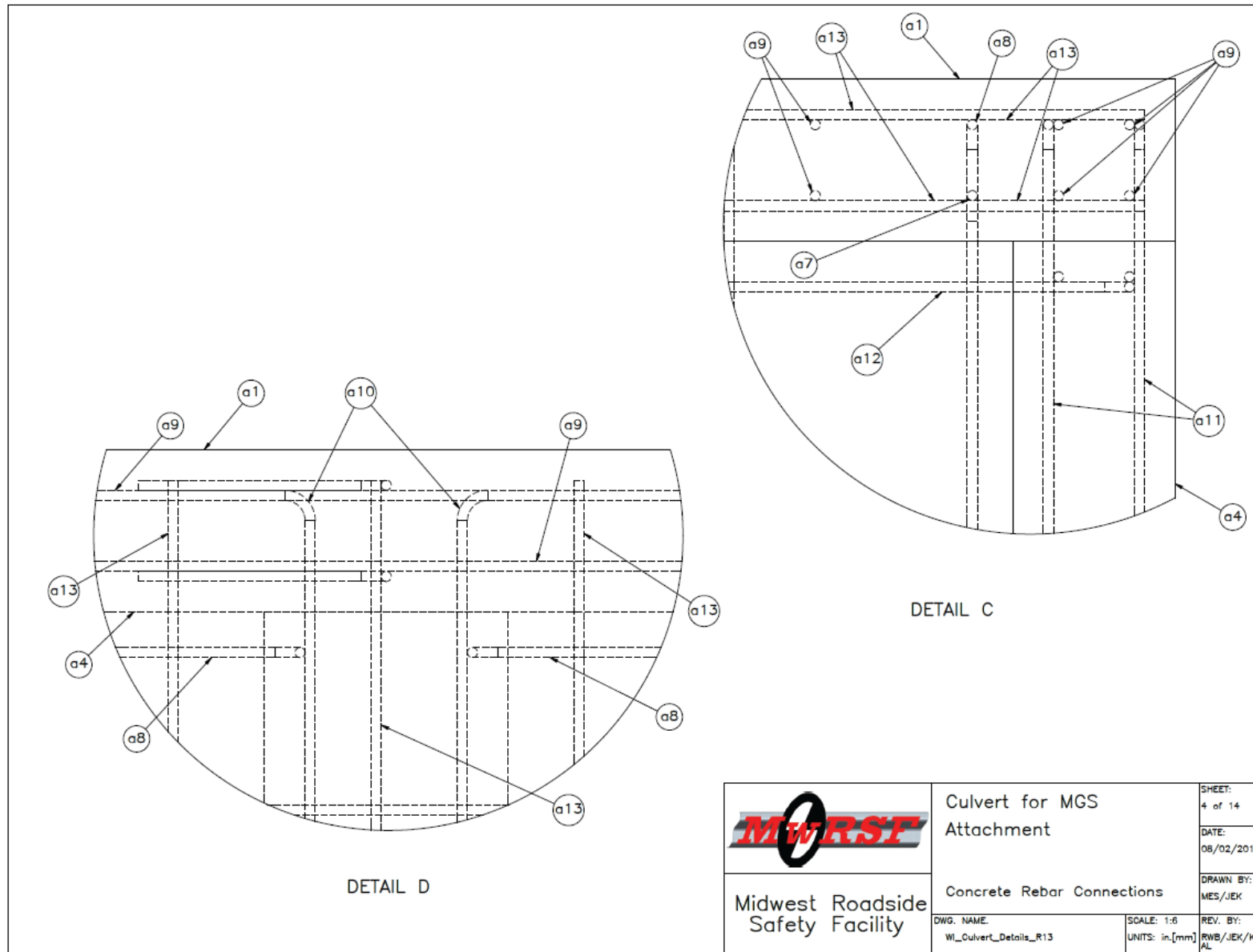


Figure 7. Concrete Rebar Connections (Cont.), Test Nos. CMGS-1 and CMGS-2

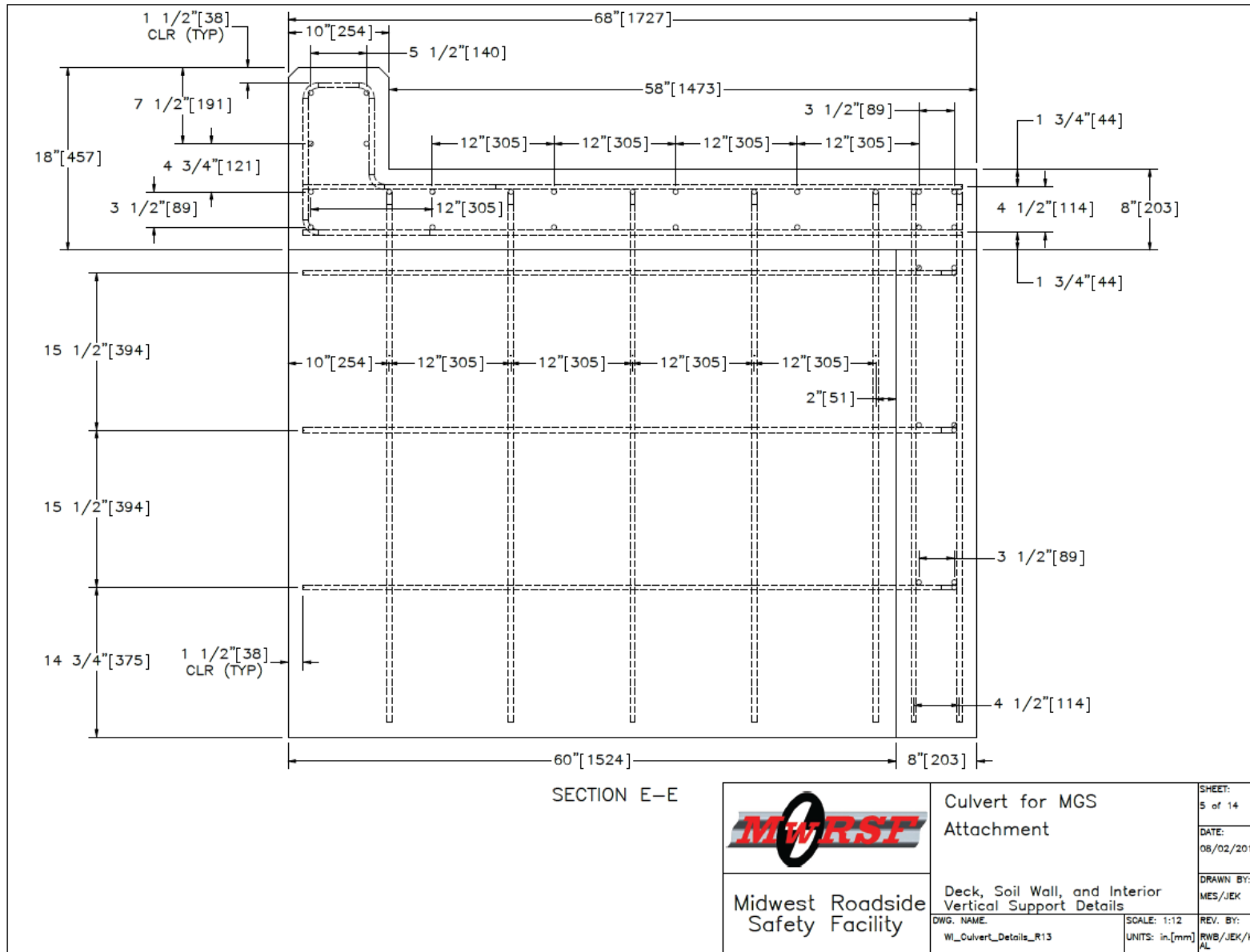


Figure 8. Top Slab, Soil Retaining Wall, Interior Vertical Support Wall Details, Test Nos. CMGS-1 and CMGS-2

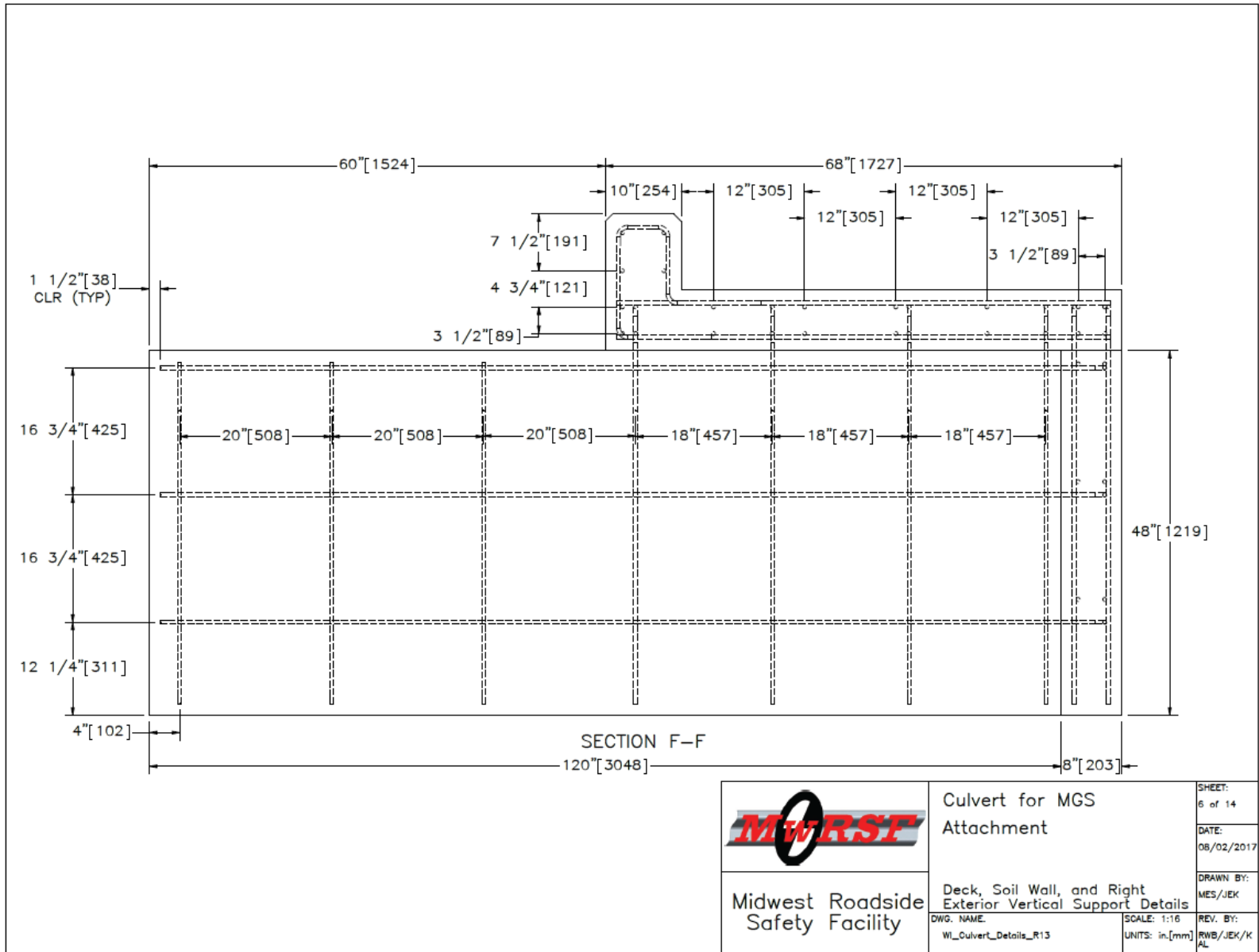


Figure 9. Top Slab, Soil Retaining Wall, Right Exterior Vertical Support Wall Details, Test Nos. CMGS-1 and CMGS-2

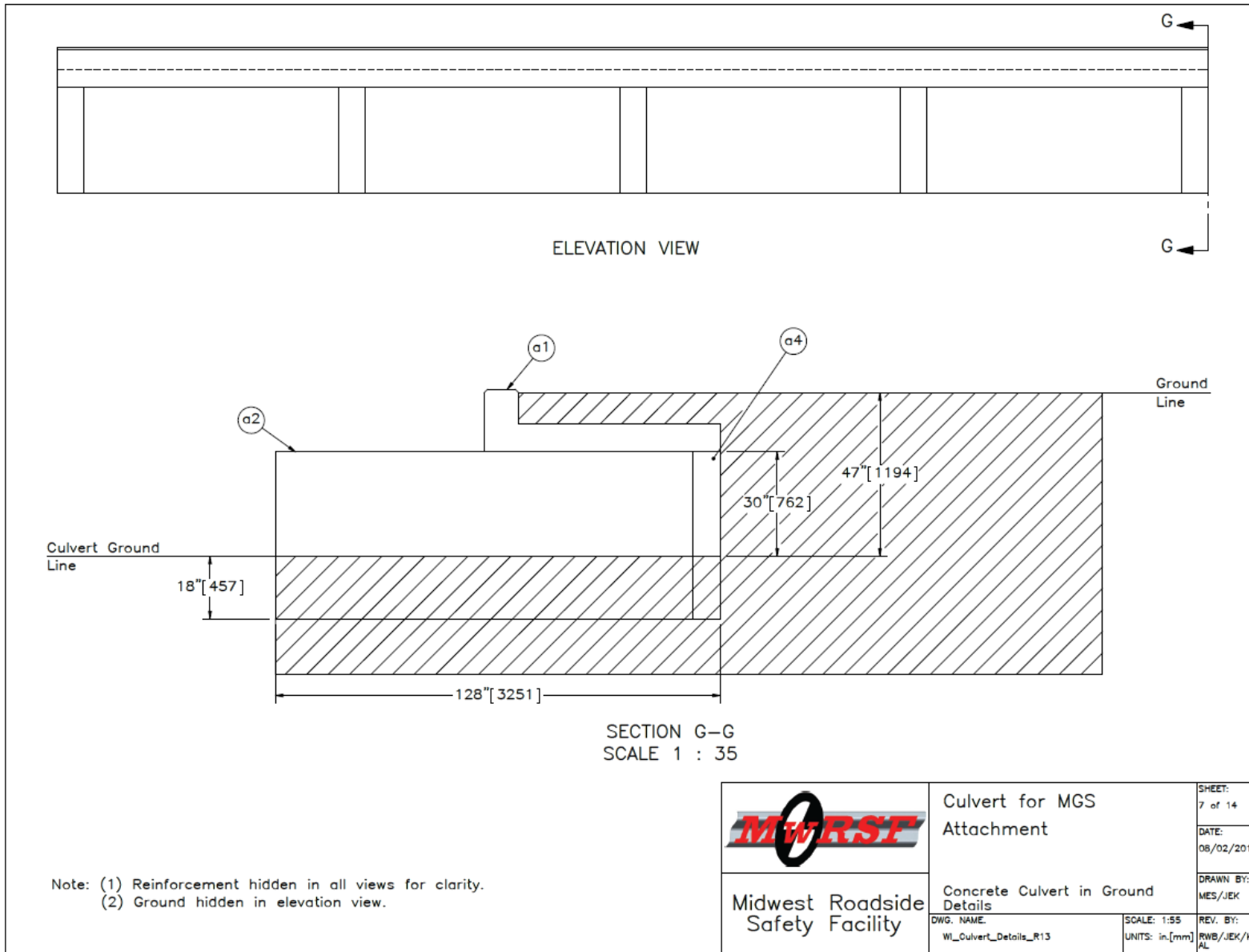


Figure 10. Concrete Culvert in Ground Details, Test Nos. CMGS-1 and CMGS-2

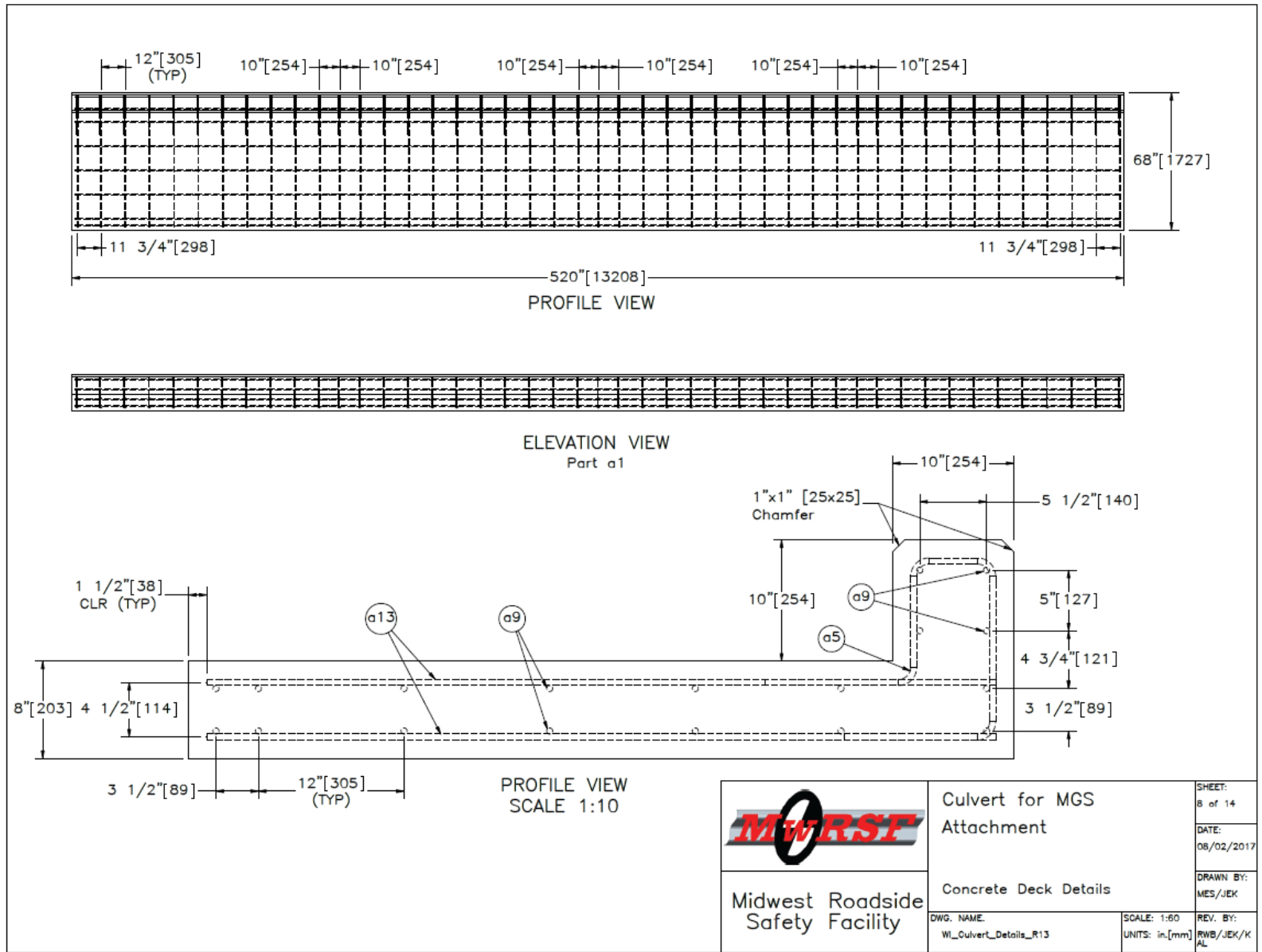


Figure 11. Concrete Top Slab Details, Test Nos. CMGS-1 and CMGS-2

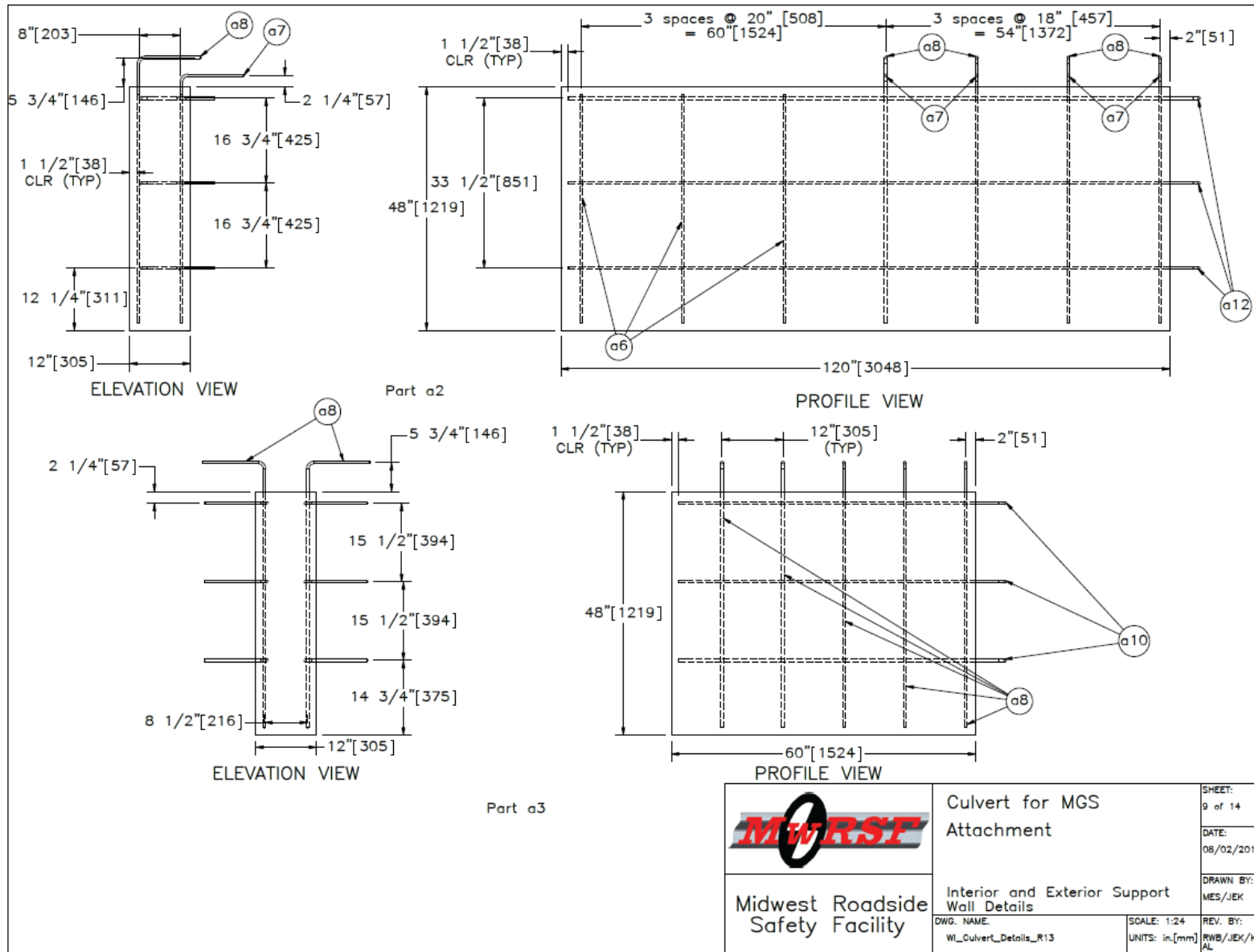


Figure 12. Interior and Exterior Support Wall Details, Test Nos. CMGS-1 and CMGS-2

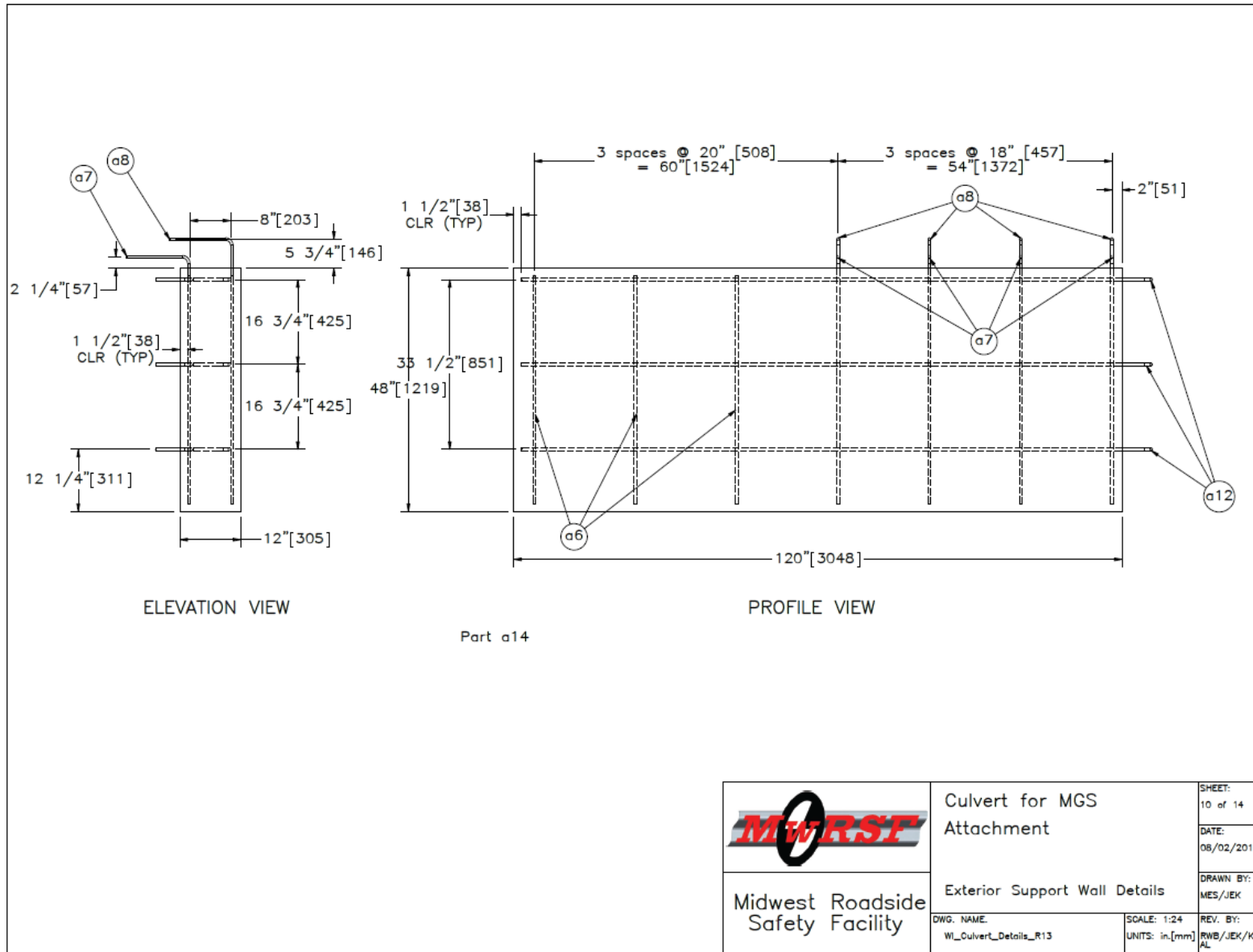


Figure 13. Exterior Support Wall Details, Test Nos. CMGS-1 and CMGS-2

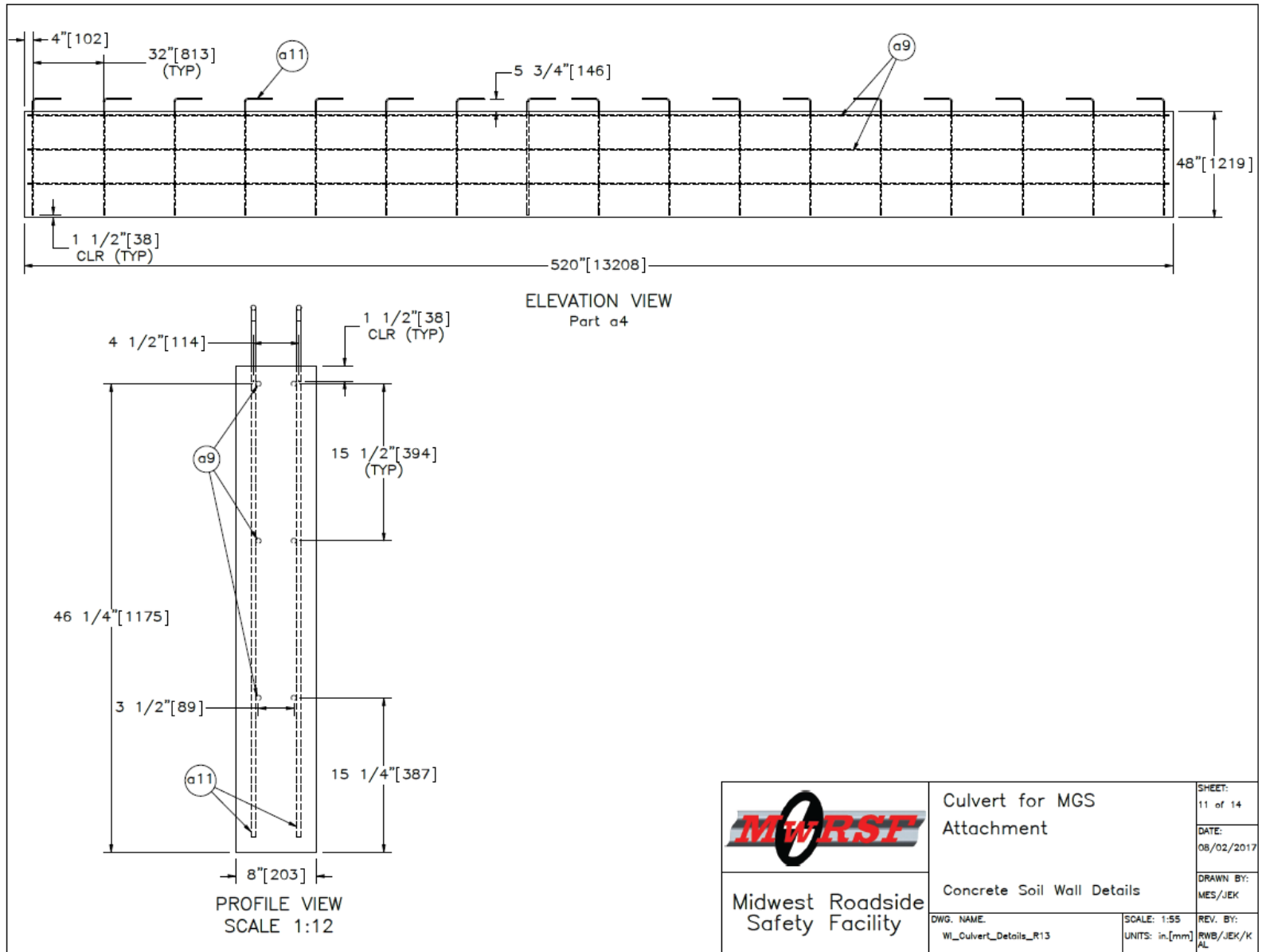


Figure 14. Concrete Soil Retaining Wall Details, Test Nos. CMGS-1 and CMGS-2

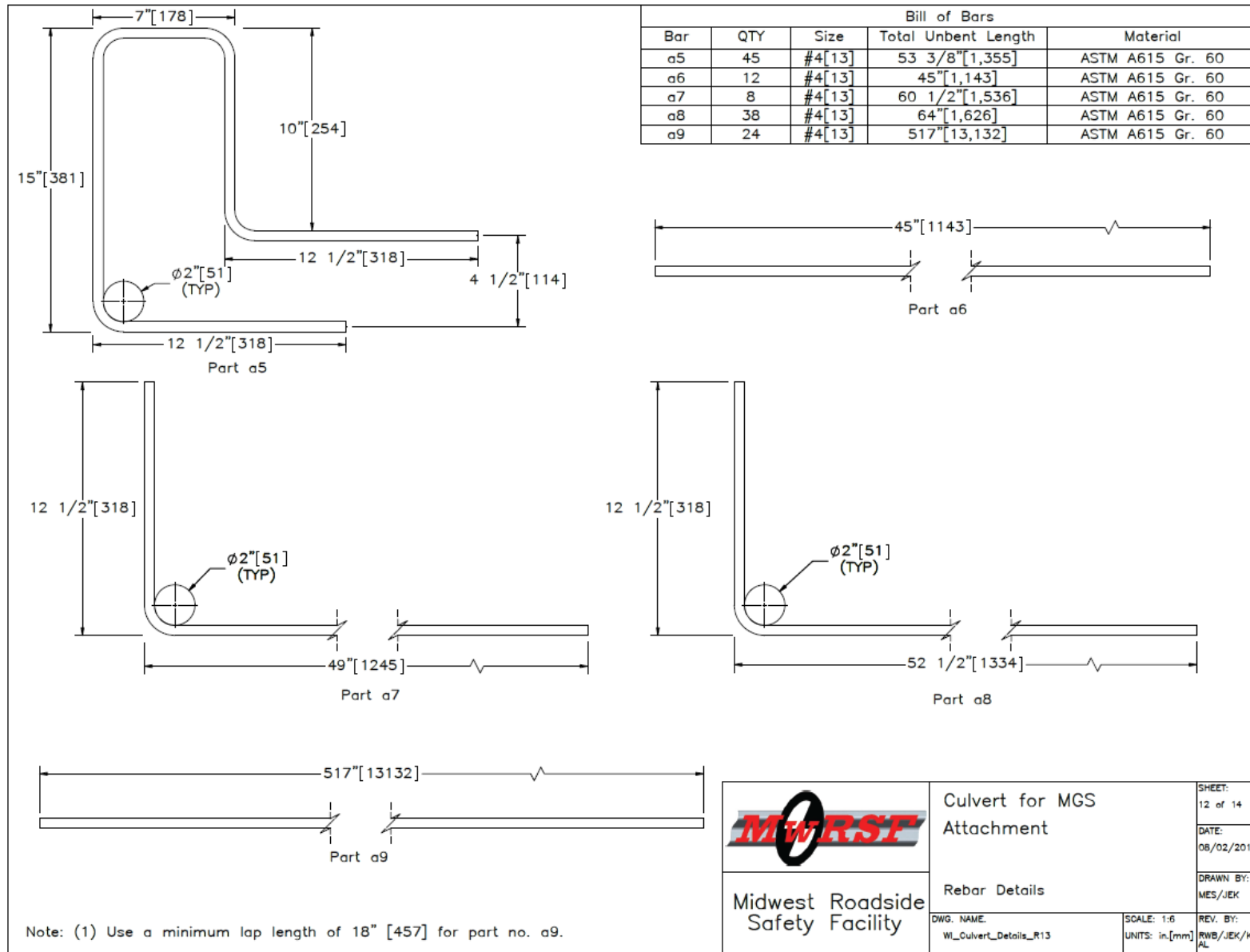


Figure 15. Rebar Details, Test Nos. CMGS-1 and CMGS-2

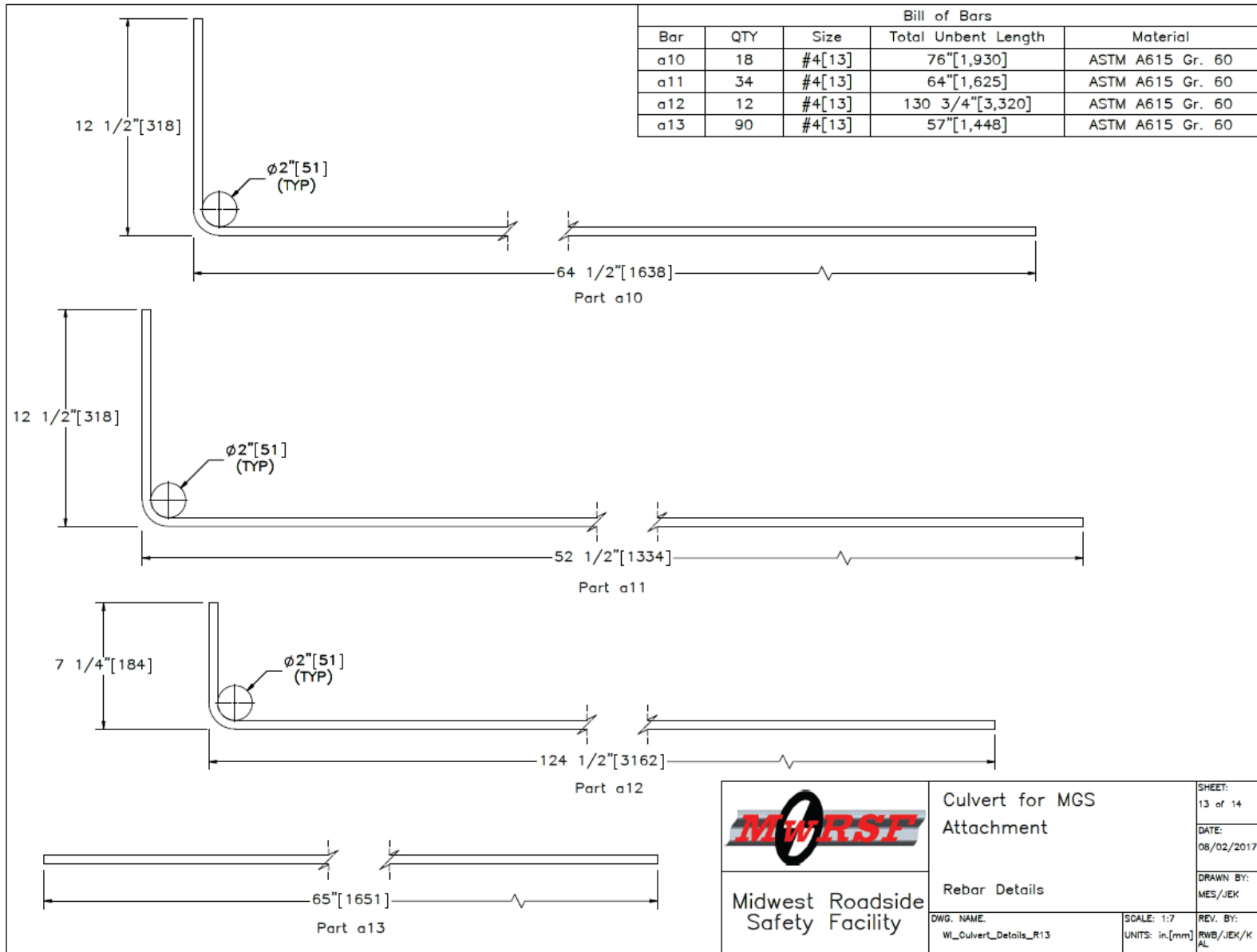



Figure 16. Rebar Details (Cont.), Test Nos. CMGS-1 and CMGS-2

| | | |
|--|-------------------------------|-----------------------------|
|  Midwest Roadside Safety Facility | Culvert for MGS Attachment | SHEET: 13 of 14 |
| | Rebar Details | DATE: 08/02/2017 |
| DWG. NAME: WL_Culvert_Details_R13 | SCALE: 1:7 UNITS: in./mm | DRAWN BY: MES/JEK |
| | | REV. BY: RWB/JEK/K AL |

| Item No. | QTY. | Description | Material Spec | Galvanization Spec |
|----------|------|---|--|----------------------------------|
| a1 | 1 | 520"x17"x60" [13,208x432x1,524] Reinforce Concrete Culvert Deck/Headwall | Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD | - |
| a2 | 1 | 12"x48"x120" [305x1,219x3,048] Reinforced Concrete Exterior Support Wall | Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD | - |
| a3 | 3 | 12"x48"x60" [305x1,219x1,524] Reinforce Concrete Interior Support Wall | Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD | - |
| a4 | 1 | 8"x48"x520" [203x1,219x13,208] Reinforced Concrete Soil Wall | Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD | - |
| a5 | 45 | #4 [#13] Unbent Bent Rebar, Vertical Loop, 53 3/8" [1,355] Total Length | ASTM A615 Gr. 60 | Epoxy Coated (ASTM A775 or A934) |
| a6 | 12 | #4 [#13] Straight Rebar, 45" [1,143] Long | ASTM A615 Gr. 60 | Epoxy Coated (ASTM A775 or A934) |
| a7 | 8 | #4 [#13] Unbent Bent Rebar, Support Wall Hook, 60 1/2" [1,536] Total Length | ASTM A615 Gr. 60 | Epoxy Coated (ASTM A775 or A934) |
| a8 | 38 | #4 [#13] Unbent Bent Rebar, Support Wall Hook, 64" [1,626] Total Length | ASTM A615 Gr. 60 | Epoxy Coated (ASTM A775 or A934) |
| a9 | 24 | #4 [#13] Straight Rebar, 517" [13,132] Long | ASTM A615 Gr. 60 | Epoxy Coated (ASTM A775 or A934) |
| a10 | 18 | #4 [#13] Bent Rebar, Support Wall Hook, 76" [1,930] Total Length | ASTM A615 Gr. 60 | Epoxy Coated (ASTM A775 or A934) |
| a11 | 34 | #4 [#13] Bent Rebar, Soil Wall Hook, 64" [1,625] Total Length | ASTM A615 Gr. 60 | Epoxy Coated (ASTM A775 or A934) |
| a12 | 12 | #4 [#13] Bent Rebar, Support Wall Hook, 130 3/4" [3,320] Total Length | ASTM A615 Gr. 60 | Epoxy Coated (ASTM A775 or A934) |
| a13 | 90 | #4 [#13] Straight Rebar, 65" [1,651] Long | ASTM A615 Gr. 60 | Epoxy Coated (ASTM A775 or A934) |
| a14 | 1 | 12"x48"x120" [305x1,219x3,048] Reinforced Concrete Exterior Support Wall | Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD | - |


| | | |
|---|--------------------------------|-------------------------|
|  Midwest Roadside Safety Facility | Culvert for MGS Attachment | SHEET: 14 of 14 |
| | Bill of Materials | DATE: 08/02/2017 |
| DWG. NAME: WI_Culvert_Details_R13 | SCALE: None UNITS: in, [mm] | DRAWN BY: MES/JEK |
| | | REV. BY: RWB/JEK/KAL |

Figure 17. Bill of Materials, Test Nos. CMGS-1 and CMGS-2



Figure 18. Concrete Culvert Support Walls Framework, Test Nos. CMGS-1 and CMGS-2

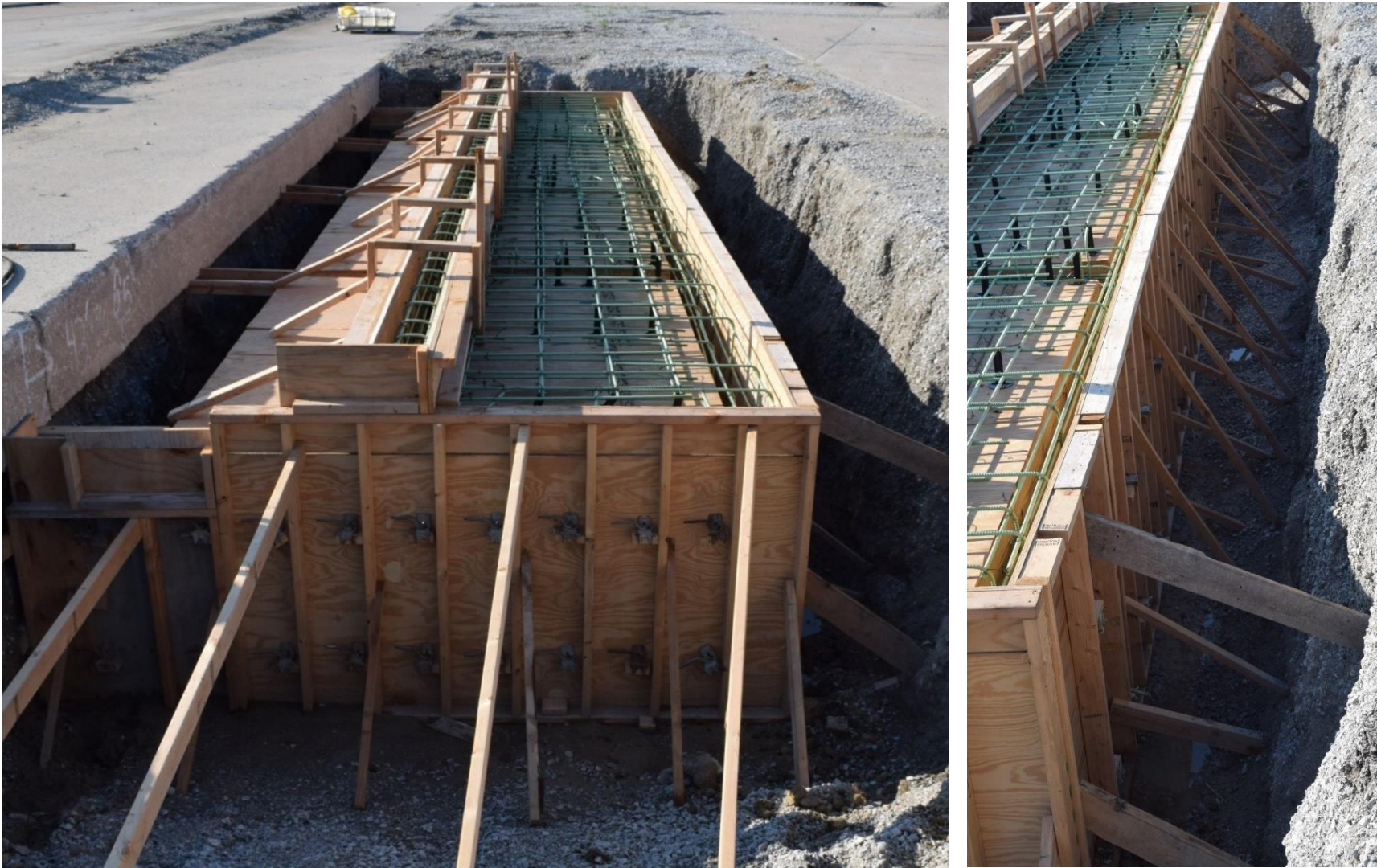


Figure 19. Concrete Top Slab, Headwall, and Soil Retaining Wall Framework, Test Nos. CMGS-1 and CMGS-2



Figure 20. Concrete Top Slab and Headwall Construction, Test Nos. CMGS-1 and CMGS-2



Figure 21. Concrete Culvert Superstructure, Top Slab, Headwall, and Vertical Supports, Test Nos. CMGS-1 and CMGS-2

3.2 Culvert-Mounted, Strong Post MGS

The test installation consisted of 182.3 ft (55.6 m) of MGS supported by steel posts with a top mounting rail height of 31 in. (787 mm), as shown in Figures 22 through 40. The test installation is shown in Figures 41 through 43. Test nos. CMGS-1 and CMGS-2 were conducted on the same installation; however, post nos. 14 through 21 were replaced before conducting test no. CMGS-2.

Anchorage systems similar to those used on tangent guardrail terminals were utilized on both the upstream and downstream ends of the guardrail system. The system was constructed using 41 posts. Post nos. 3 through 12 and 27 through 39 were galvanized ASTM A992 steel W6x8.5 sections measuring 72 in. (1,829 mm) long. Post nos. 13 through 26 were ASTM A992 steel W6x9 sections measuring 40½ in. (1,029 mm) long. Post nos. 1, 2, 40, and 41 were BCT posts measuring 5½ in. x 7½ in. x 46 in. (140 mm x 191 mm x 1,168 mm) and were placed in a steel foundation tube. Post nos. 1 through 8 and 32 through 41 were spaced 75 in. (1,905 mm) apart on center. Post nos. 8 through 32 were spaced 37½ in. (952 mm) apart on center, as shown in Figure 22. For post nos. 3 through 12 and 27 through 39, the soil embedment depth was 40 in. (1,016 mm). For post nos. 13 through 26, the soil embedment depth was 9 in. (229 mm). The posts were placed in a compacted, coarse, crushed limestone material with a strength that satisfied MASH 2016 criteria. For all posts, 6-in. x 12-in. x 14¼-in. (152-mm x 305-mm x 362-mm) wood blockouts were used to offset the rail away from the front face of the steel posts.

Post nos. 13 through 26 were anchored to the top of the concrete culvert using welded steel plates. A ½-in. thick x 8½-in. wide x 12-in. long (13-mm thick x 216-mm wide x 305-mm long) ASTM A572 steel plate was welded to the bottom of each post. The thickness of the baseplate was selected to allow some deformation of the base plate and corresponding energy absorption. In order to fully develop the connection between the baseplate and the W6x9 post sections, a special weld detail was utilized that incorporated a 3-pass, 5/16-in. (8-mm) fillet weld on the front flange of the post and a ¼-in. (6-mm) fillet weld on the web and back flange of the post. The backside of these posts was positioned 12 in. (305 mm) from the culvert's headwall.

Post nos. 13 through 15, 17 through 22, and 24 through 26 were anchored to the top concrete slab using four through-bolts, as shown in Figure 24. Four 1-in. (25-mm) diameter by 10½-in. (267-mm) long ASTM A307 hex head bolts were placed through each top base plate and the concrete deck and were held in place with 8½-in. wide x 12-in. long x ¼-in. (216-mm wide x 305-mm long x 6-mm) thick steel washer plates below the top slab. Note that the one-piece washer plate below the top slab used for testing could be replaced by individual 3½-in. wide x 3½-in. long x ¼-in. (89-mm wide x 89-mm long x 6-mm) square washer plates if desired. Post nos. 16 and 23 were anchored using 10-in. (254-mm) long epoxied threaded rods with an 8-in. (203 mm) embedded length due to the presence of the culvert's interior wall support, as shown in Figure 25. This alternative anchorage detail was developed in previous research effort [7].

A concrete culvert, as previously described in Section 3.1, was constructed at the center of the system. The maximum dimensions of the culvert's top slab were 60 in. (1,524 mm) wide and 8 in. (203 mm) thick with a 10-in. (254-mm) wide x 9-in. (229-mm) high headwall positioned flush with the backside of the top slab, as previously described. The length of the culvert was 43 ft – 4 in. (13.2 m) long, and the culvert spanned from 16¼ in. (413 mm) upstream from the center of post no. 13 to 16¼ in. (413 mm) downstream from the center of post no. 26.

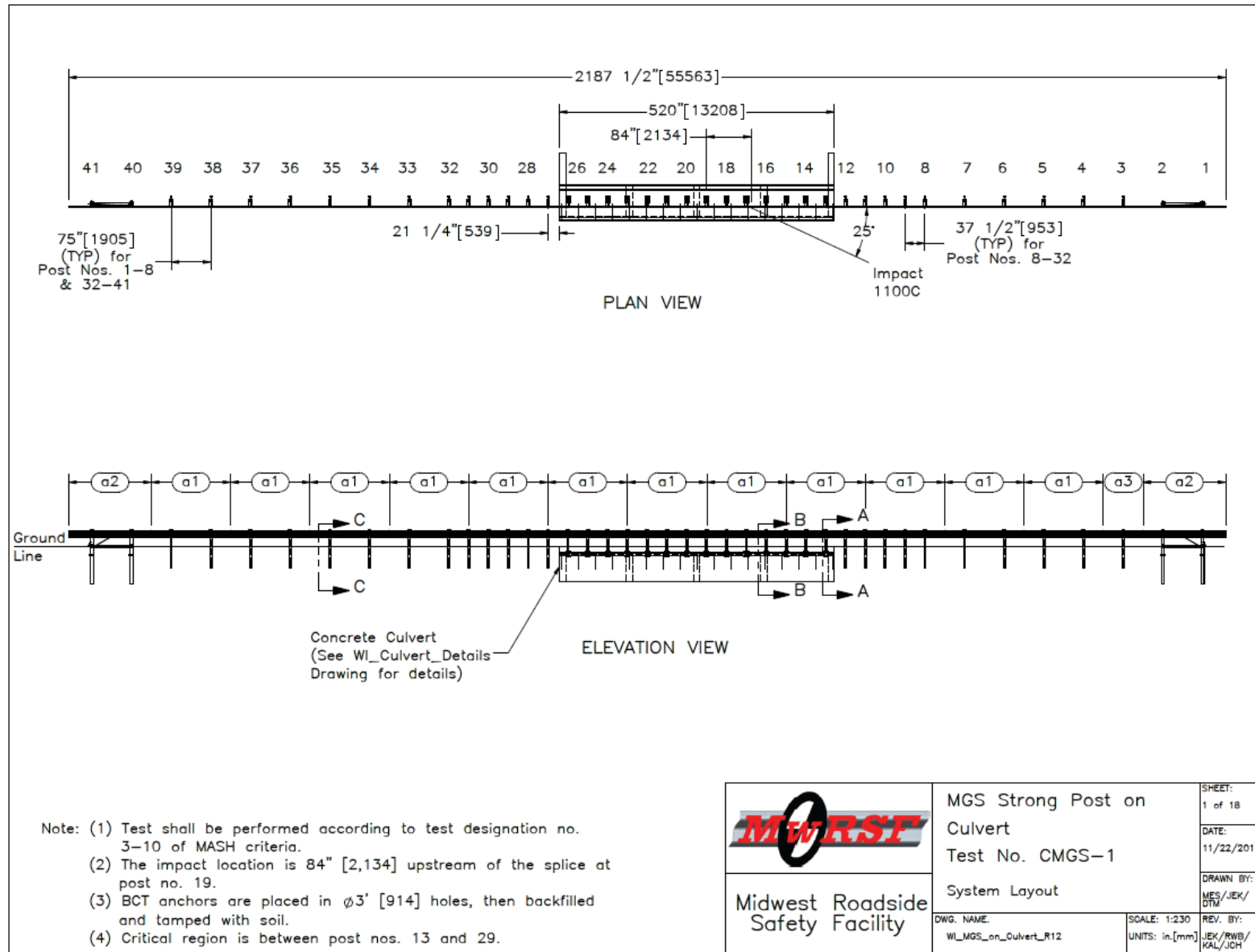


Figure 22. System Layout, Test No. CMGS-1

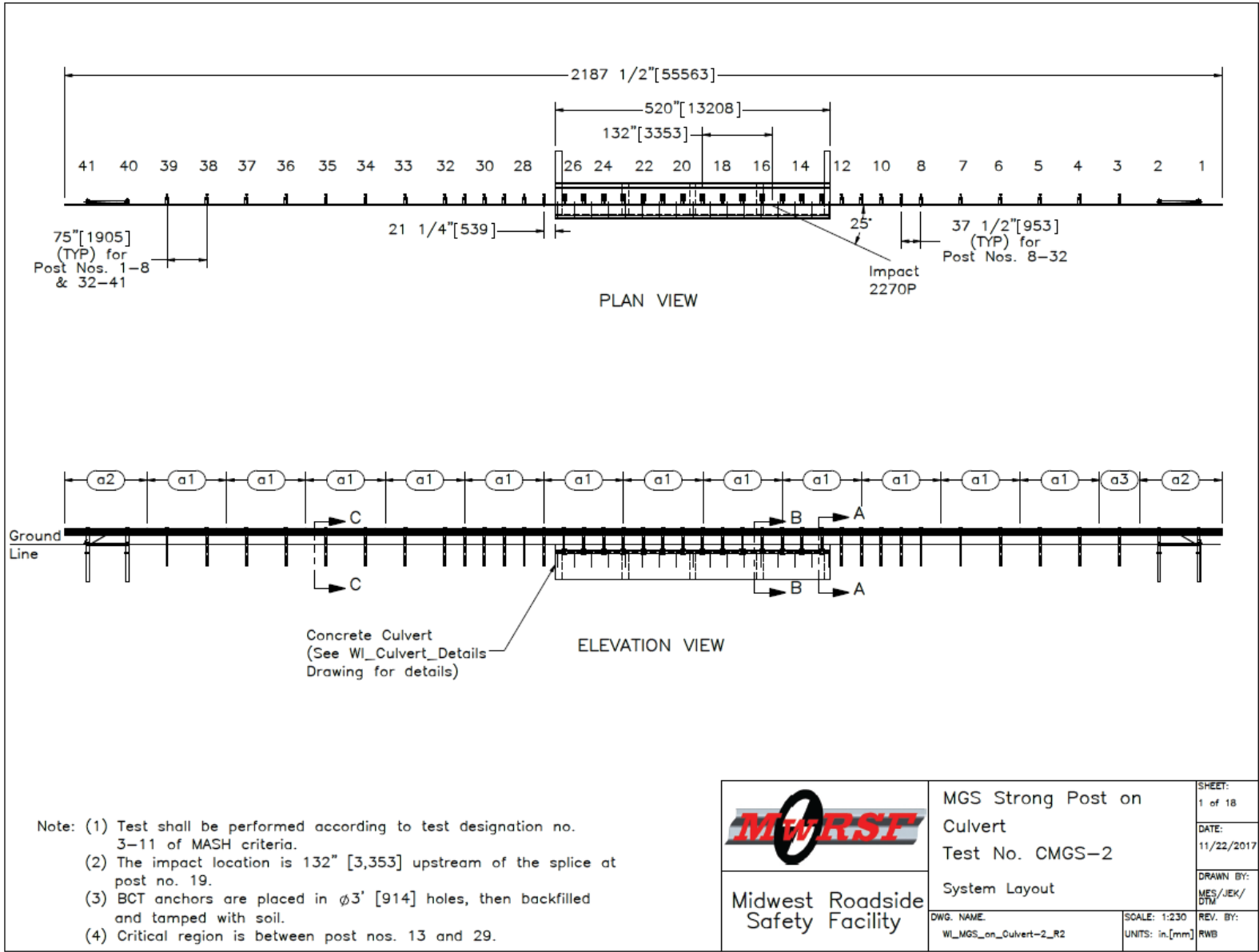


Figure 23. System Layout, Test No. CMGS-2

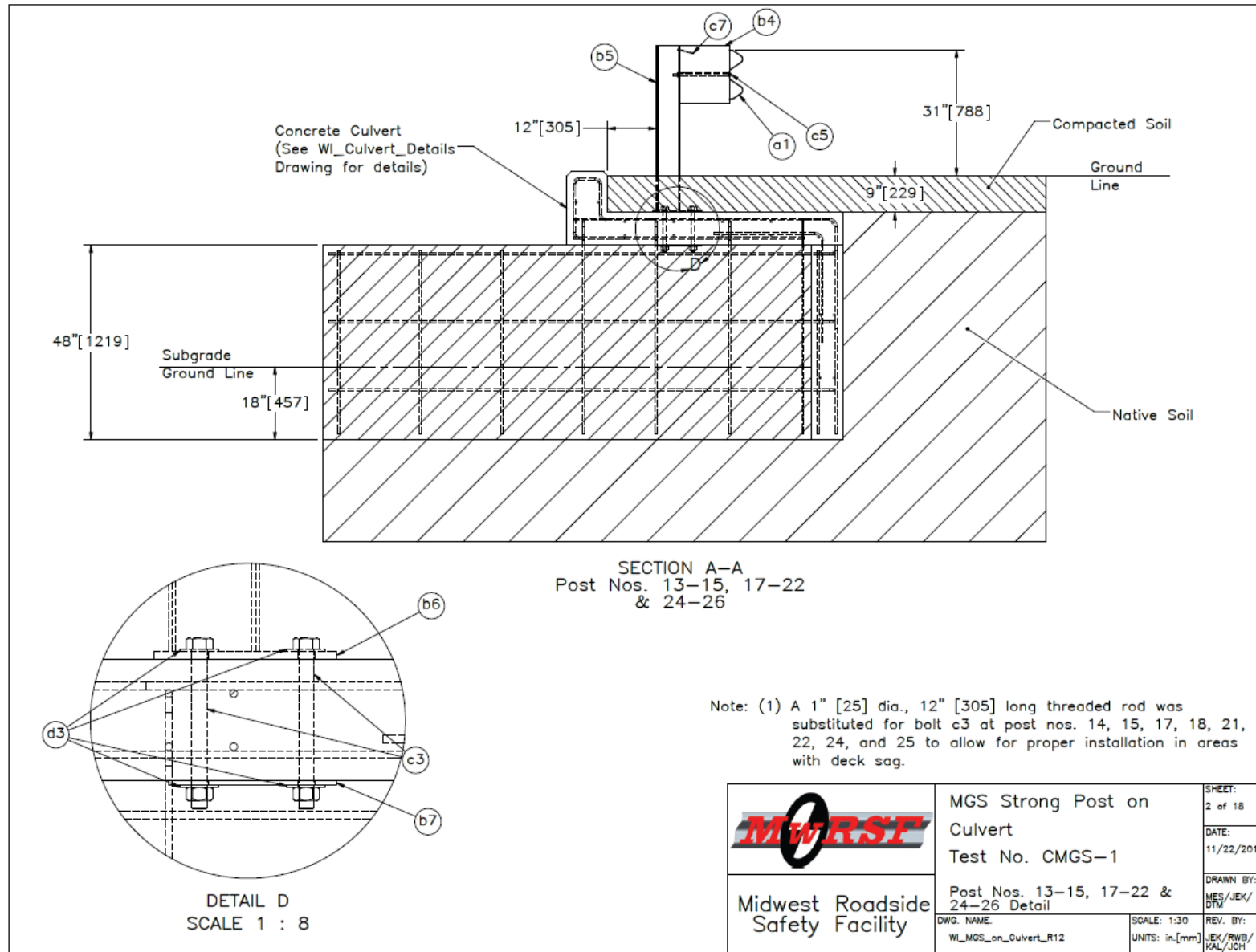


Figure 24. Post Nos. 13 through 15, 17 through 22, and 24 through 26 Details, Test Nos. CMGS-1 and CMGS-2

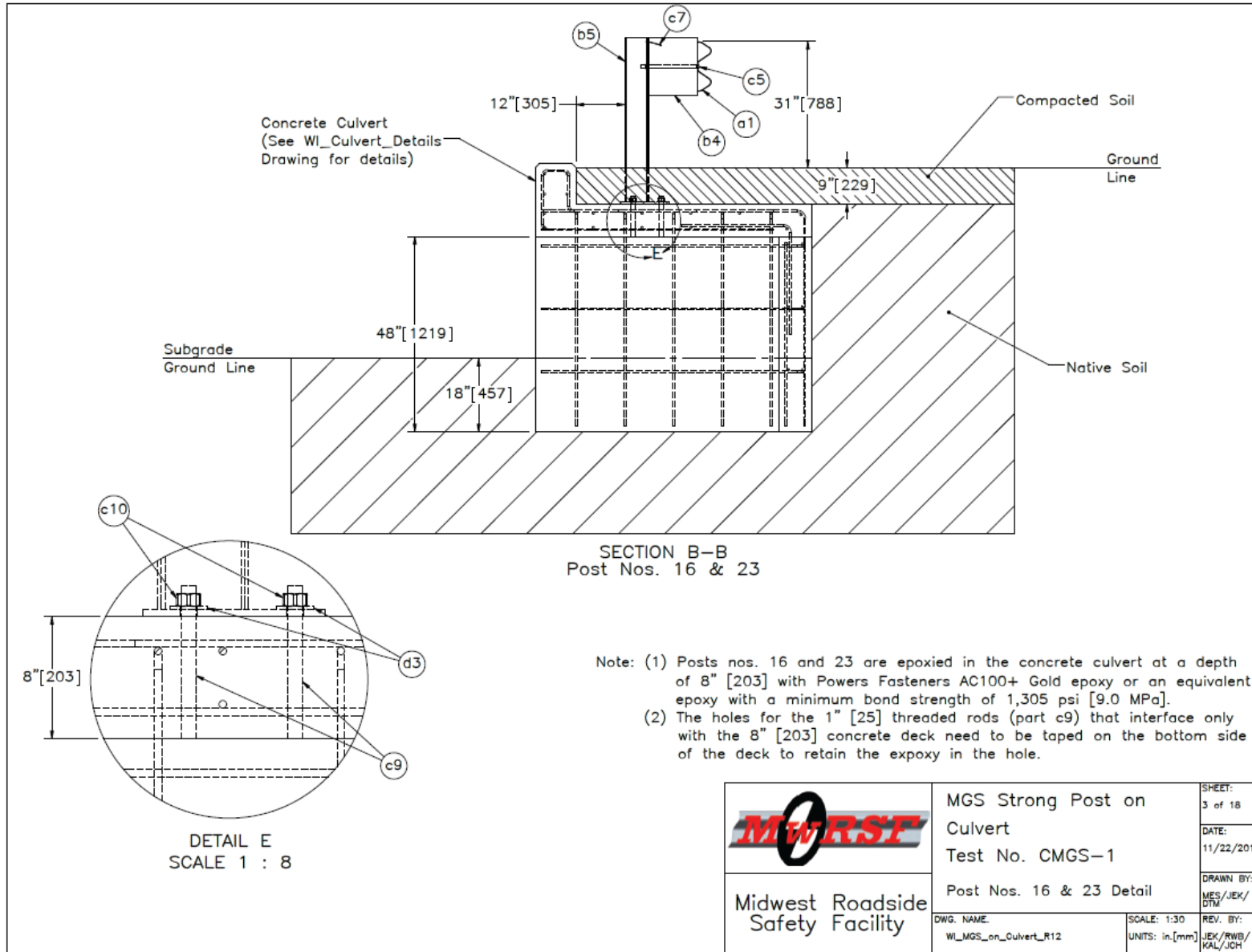


Figure 25. Post Nos. 16 and 23 Details, Test Nos. CMGS-1 and CMGS-2

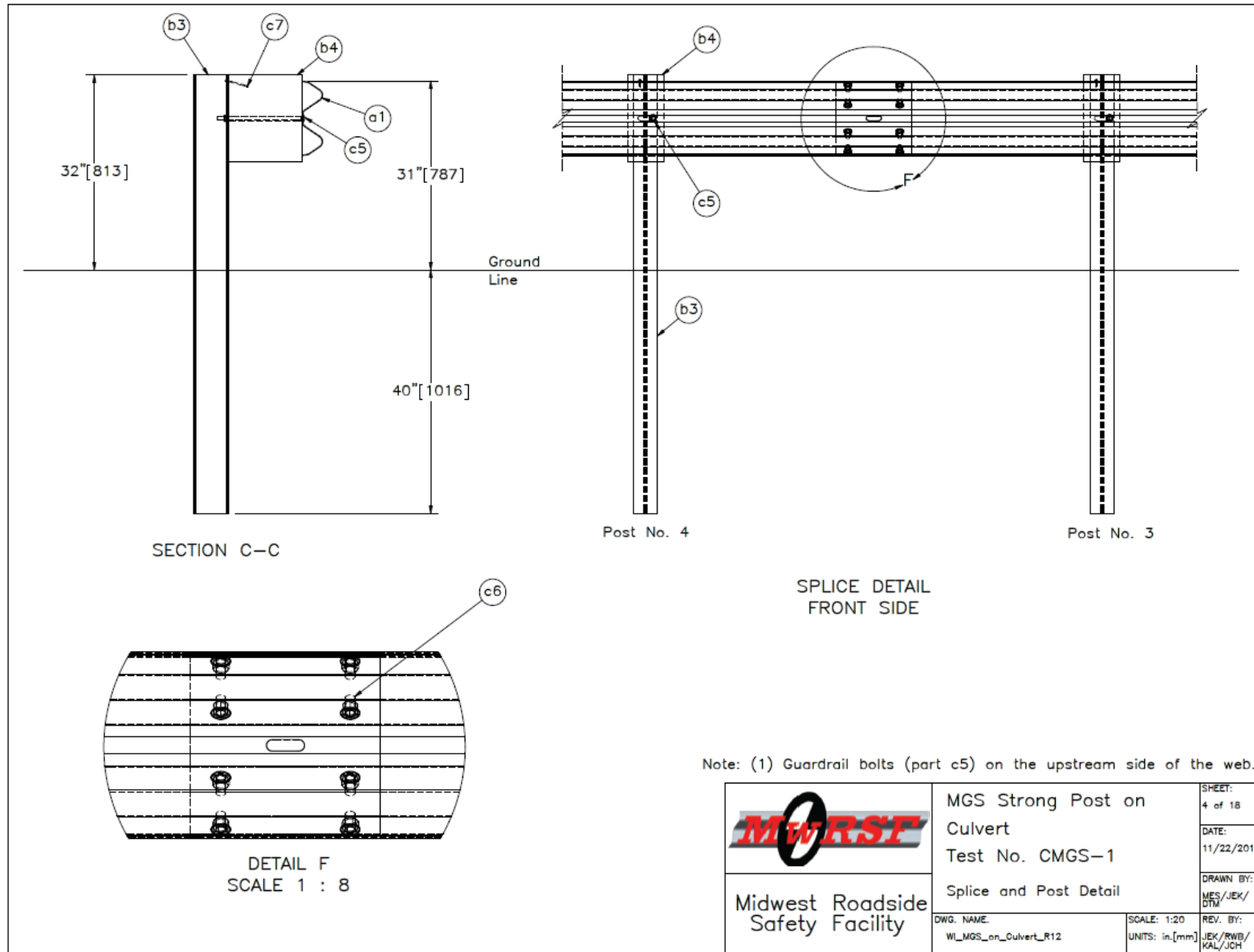


Figure 26. Splice and Post Details, Test Nos. CMGS-1 and CMGS-2

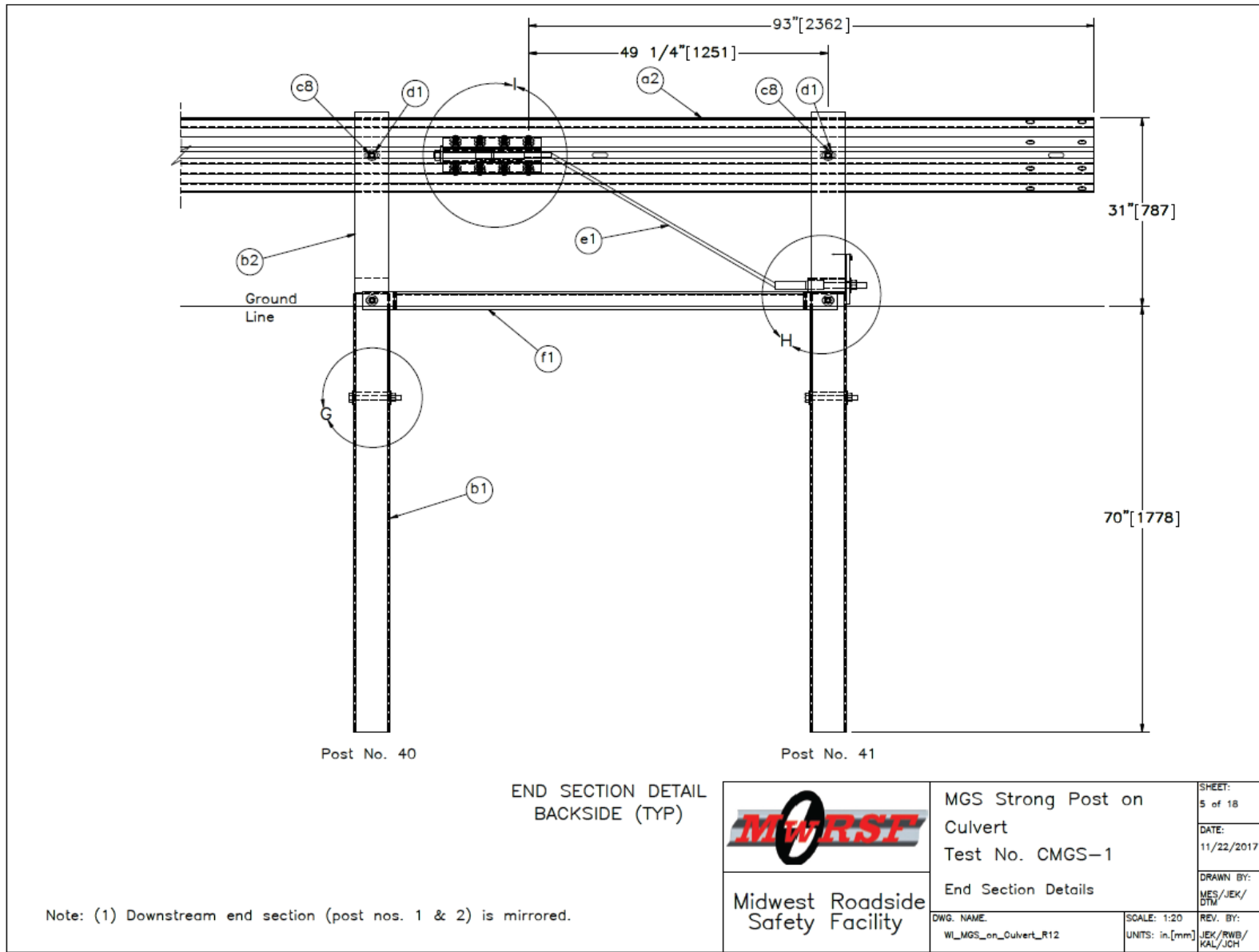


Figure 27. End Section Details, Test Nos. CMGS-1 and CMGS-2

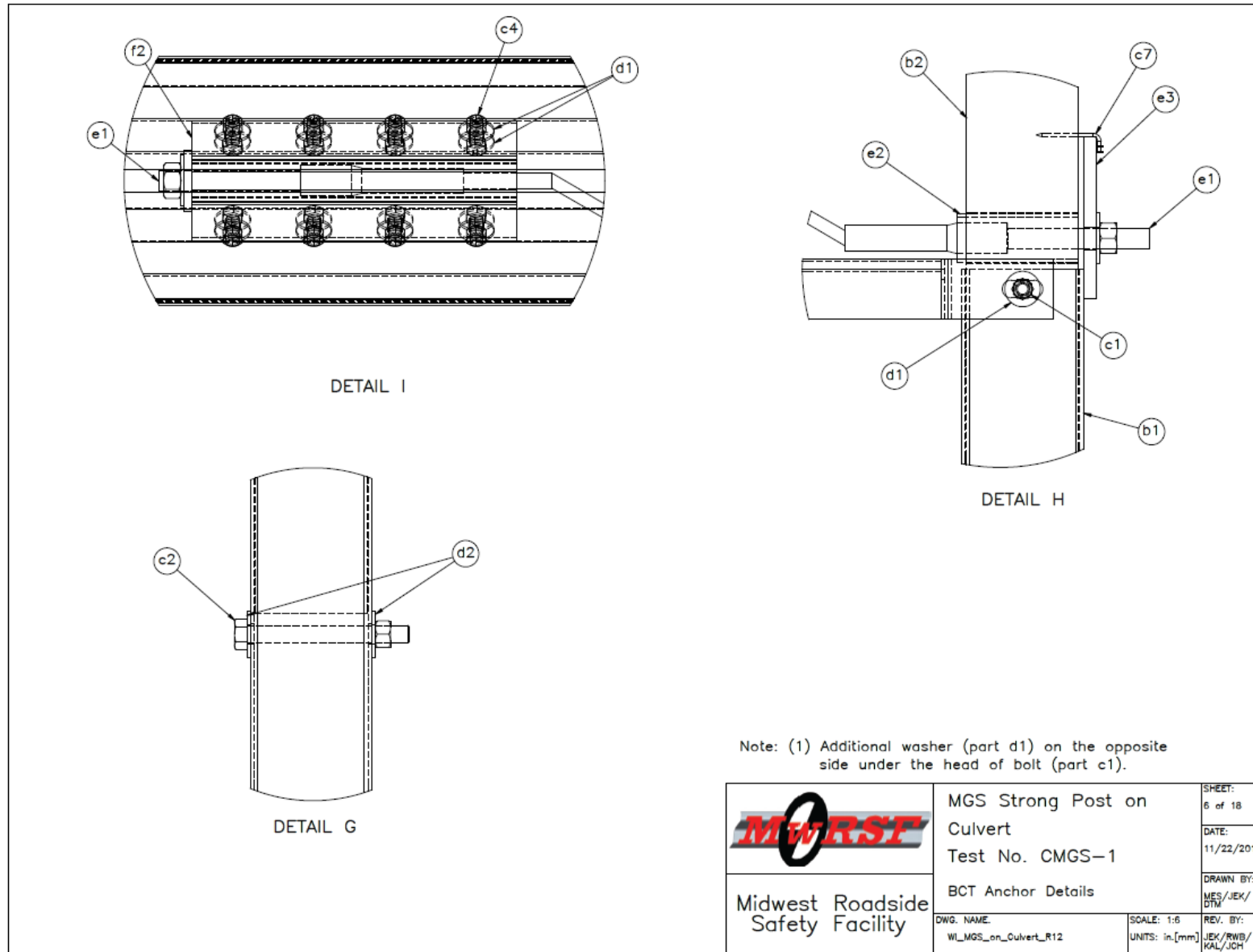


Figure 28. BCT Anchor Details, Test Nos. CMGS-1 and CMGS-2

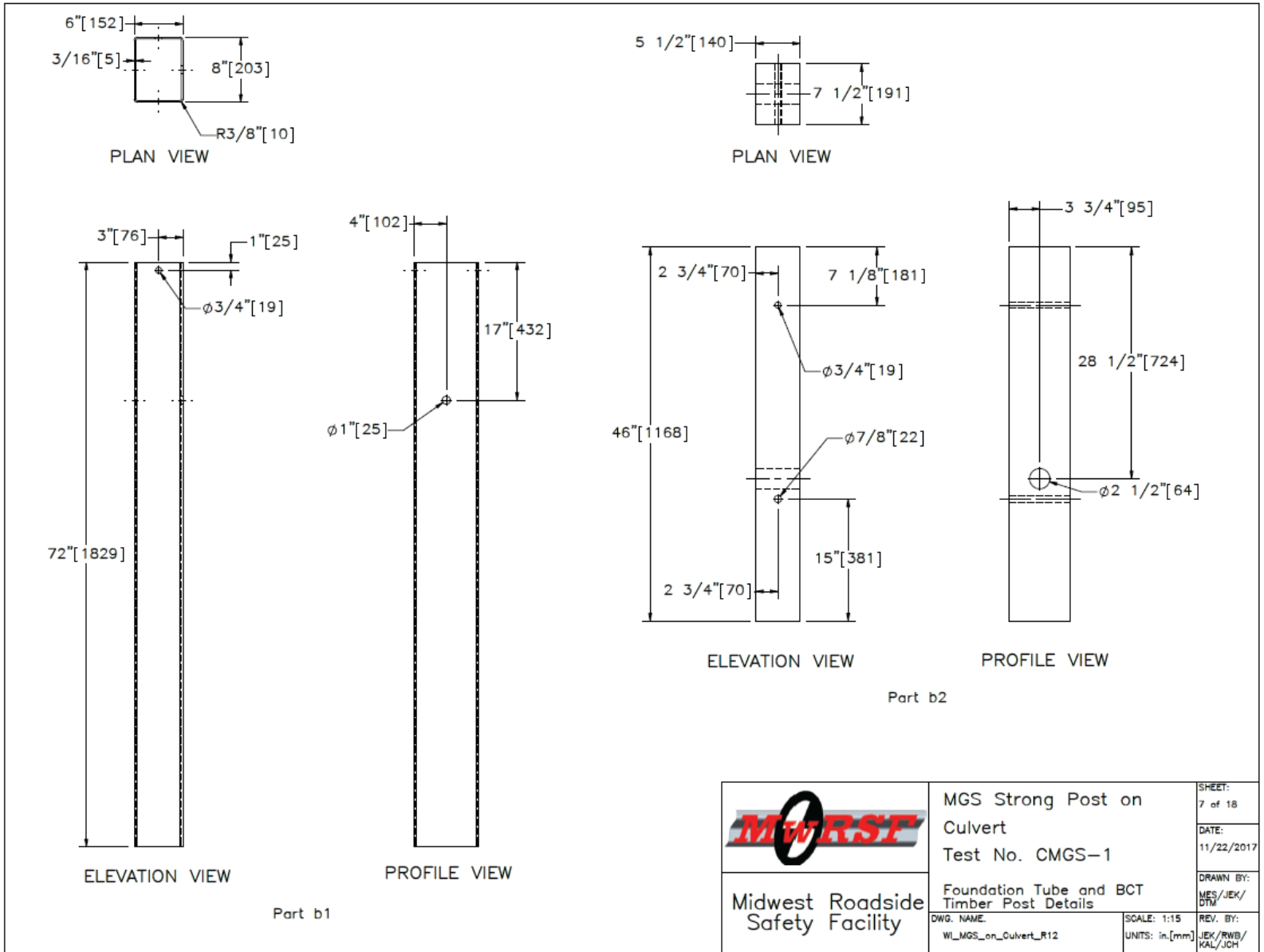


Figure 29. Foundation Tube and BCT Timber Post Details, Test Nos. CMGS-1 and CMGS-2

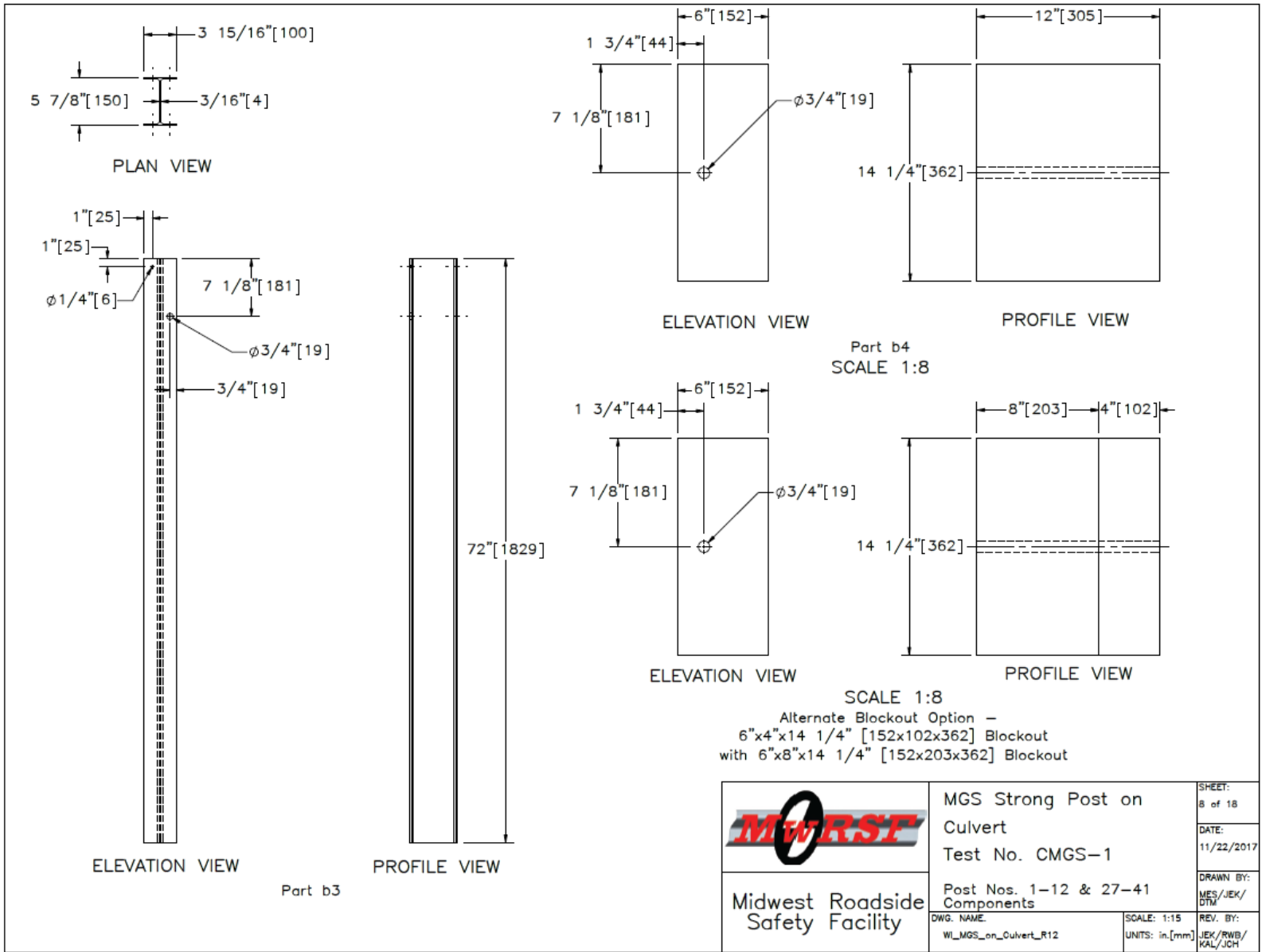


Figure 30. Post Nos. 1 through 12 and 27 through 41 Component Details, Test Nos. CMGS-1 and CMGS-2

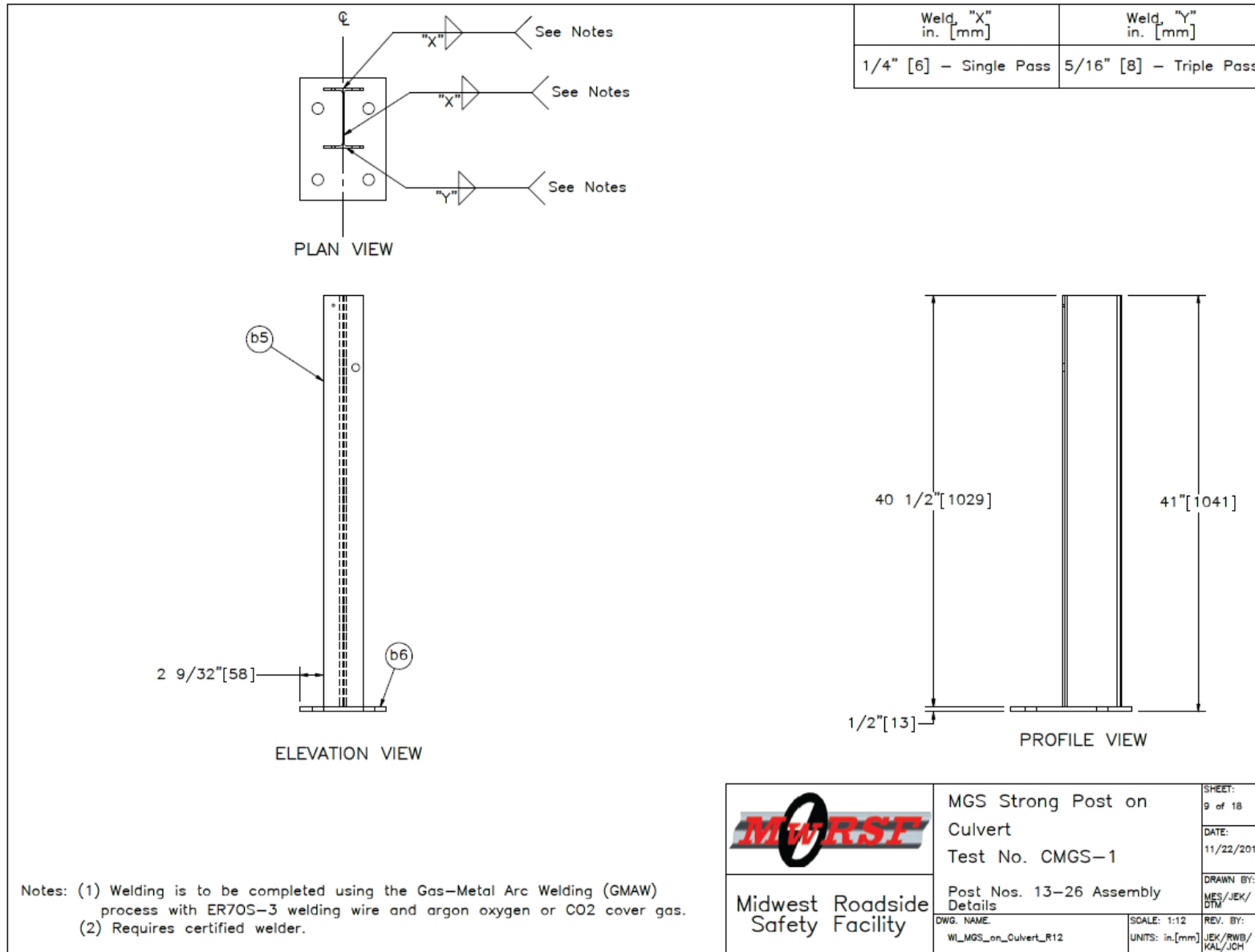


Figure 31. Post Nos. 13 through 26 Assembly Details, Test Nos. CMGS-1 and CMGS-2

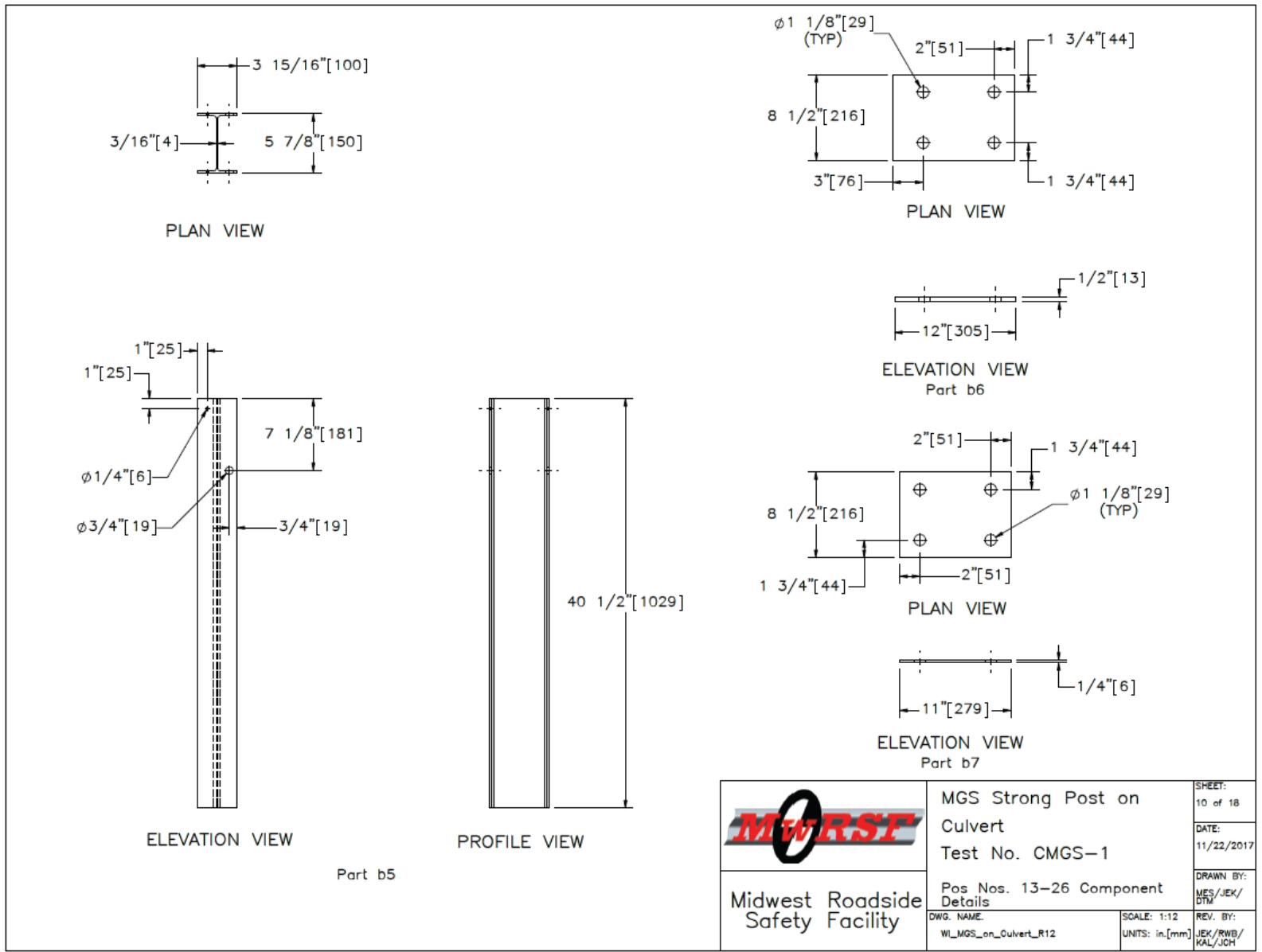


Figure 32. Post Nos. 13 through 26 Component Details, Test Nos. CMGS-1 and CMGS-2

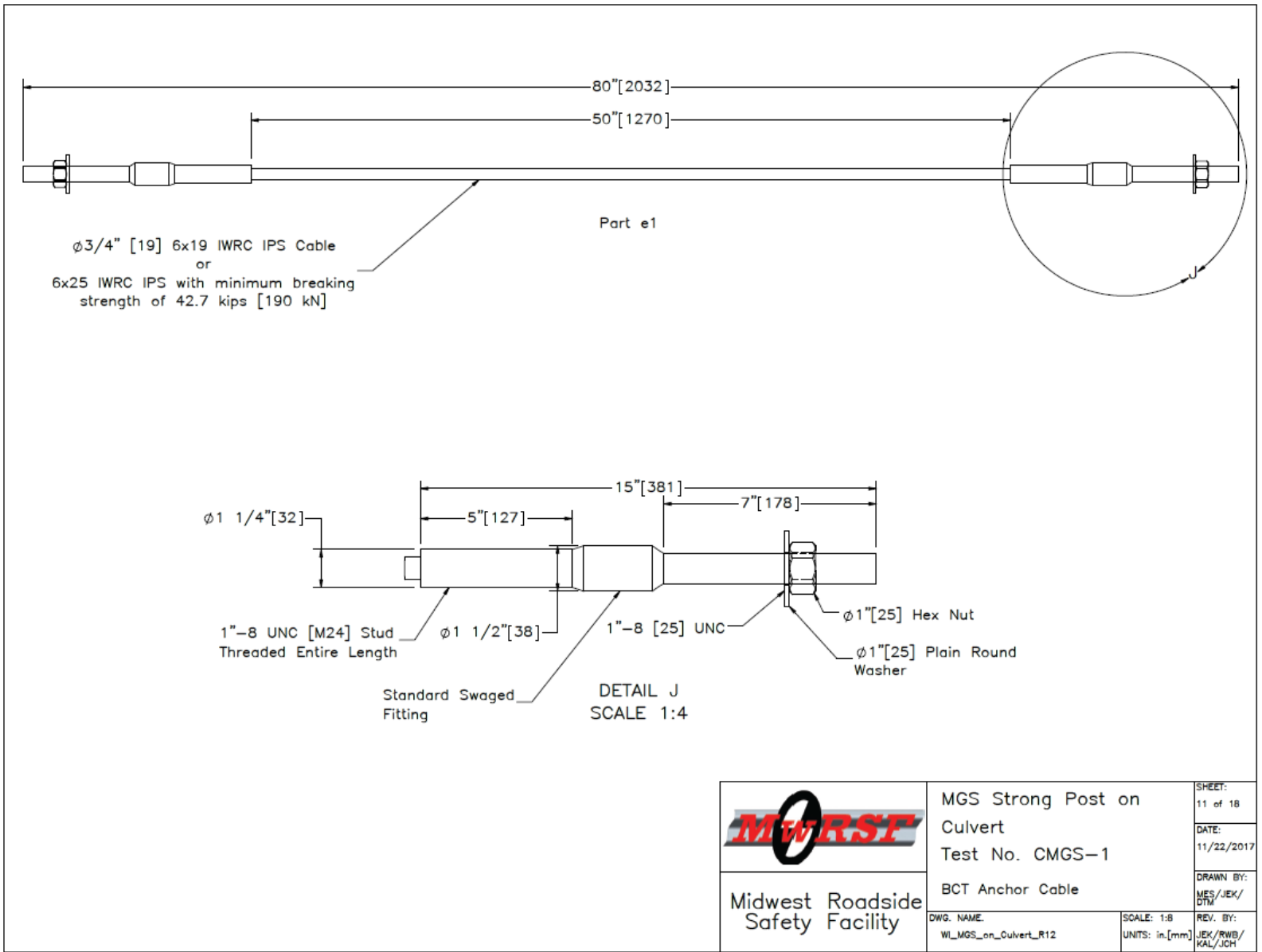


Figure 33. BCT Anchor Cable, Test Nos. CMGS-1 and CMGS-2

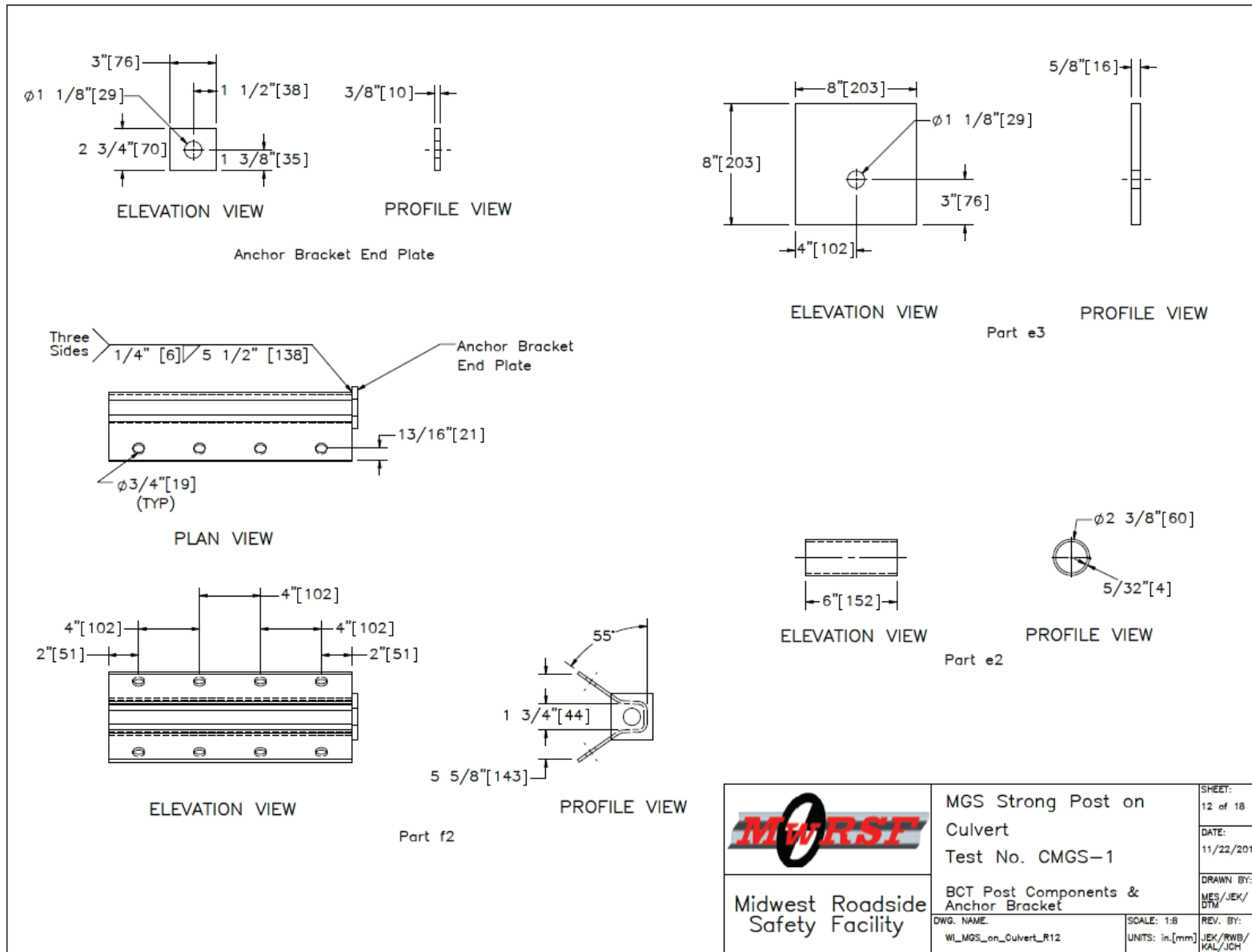



Figure 34. BCT Post Components and Anchor Bracket, Test Nos. CMGS-1 and CMGS-2

| | | |
|---|--|---------------------------------|
|  | MGS Strong Post on Culvert Test No. CMGS-1 | SHEET: 12 of 18 |
| | BCT Post Components & Anchor Bracket | DATE: 11/22/2017 |
| Midwest Roadside Safety Facility | DWG. NAME: WL_MGS_on_Oulvert_R12 | DRAWN BY: MES/JEK/ DTM |
| | SCALE: 1:8 UNITS: in./mm | REV. BY: JEK/RWB/ KAL/JCH |

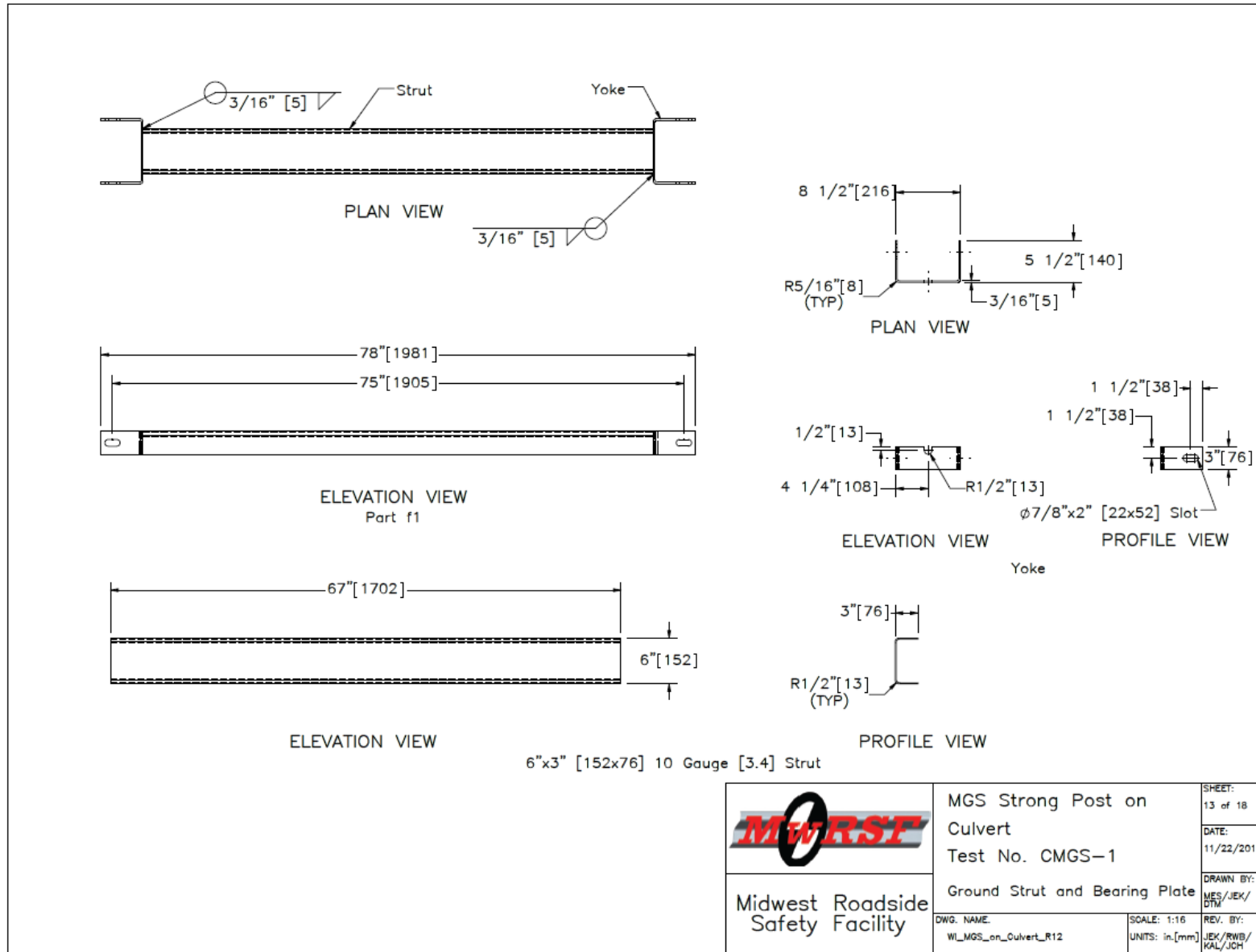


Figure 35. Ground Strut and Bearing Plate, Test Nos. CMGS-1 and CMGS-2

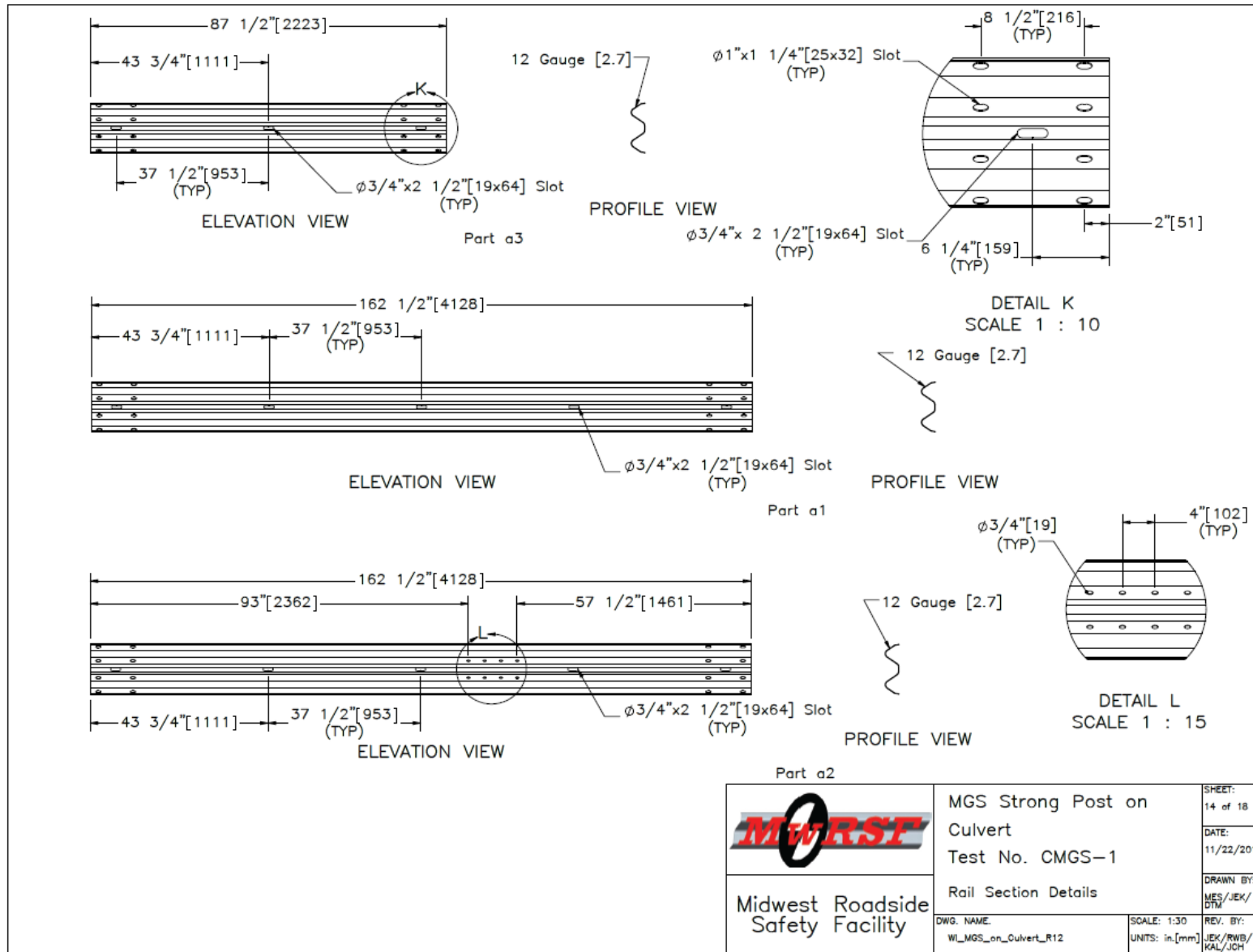


Figure 36. Rail Section Details, Test Nos. CMGS-1 and CMGS-2

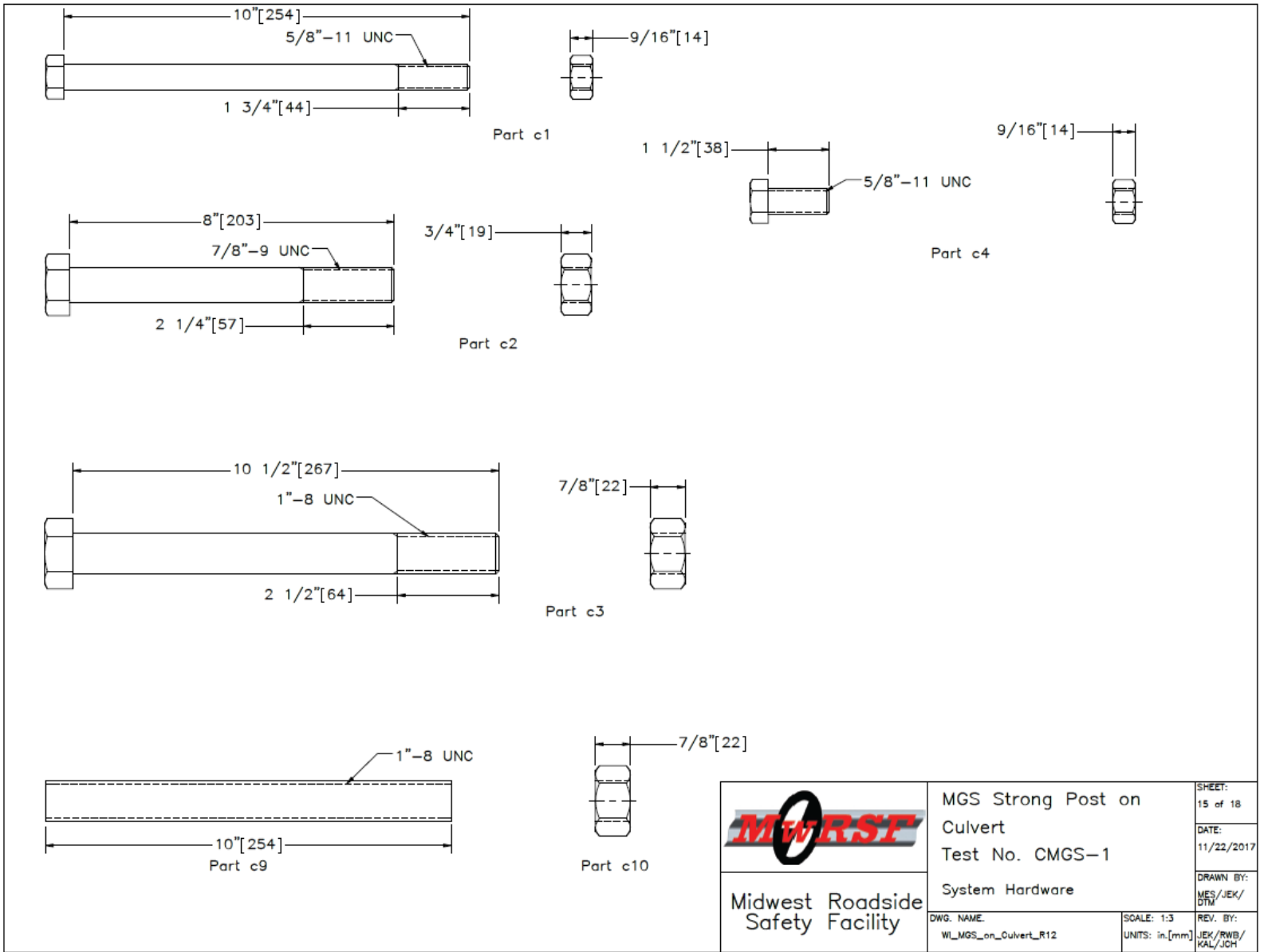


Figure 37. System Hardware Details, Test Nos. CMGS-1 and CMGS-2

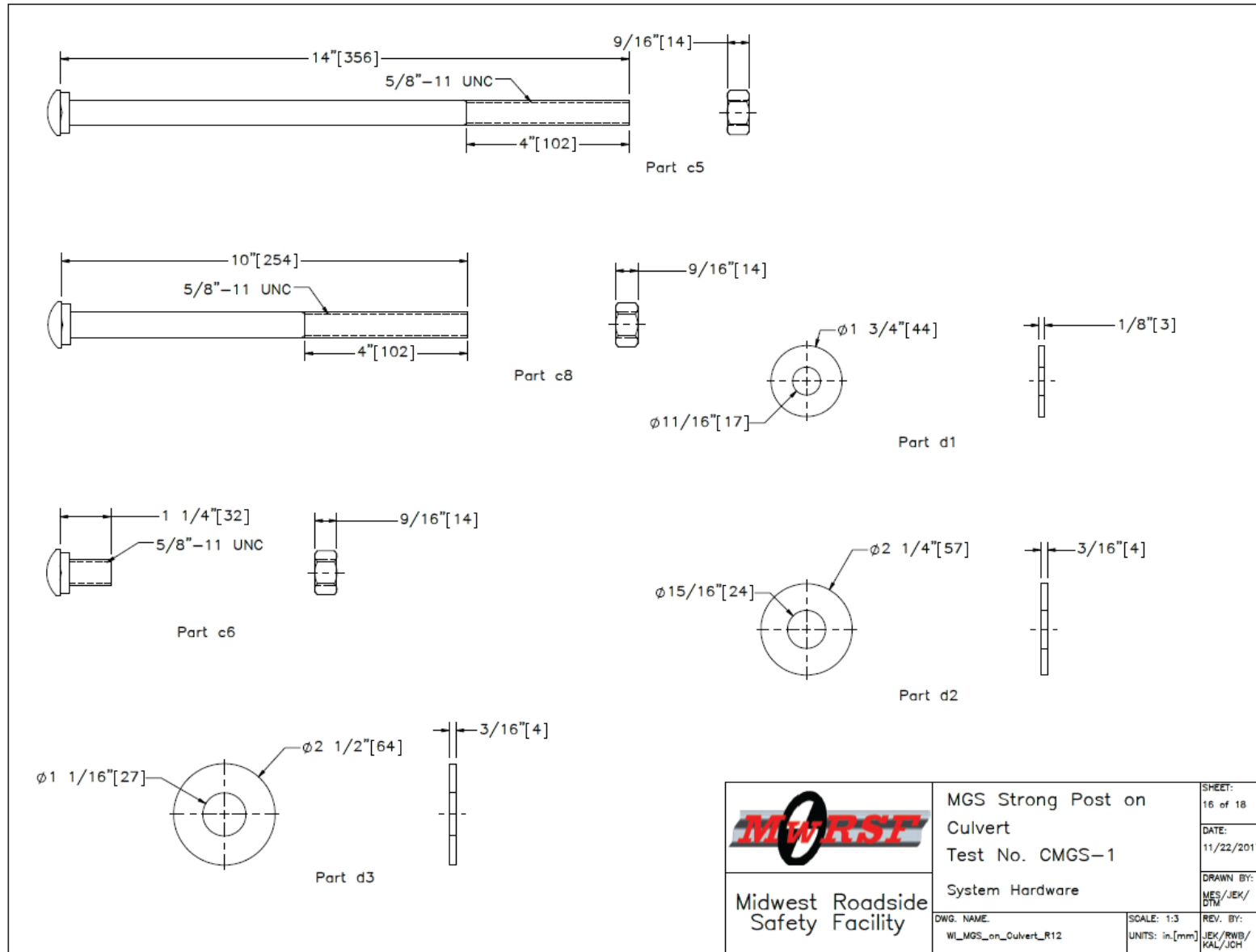


Figure 38. System Hardware Details, Test Nos. CMGS-1 and CMGS-2

| Item No. | QTY. | Description | Material Specification | Galvanization Specification | Hardware Guide |
|----------|------|--|---|-------------------------------------|----------------|
| 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 |
| b1 | 4 | 72" [1829] Long Foundation Tube | ASTM A500 Gr. B | ASTM A123 | PTE06 |
| b2 | 4 | BCT Timber Post – MGS Height | SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face) | – | PDF01 |
| b3 | 23 | W6x8.5 [152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post | ASTM A992 | ASTM A123 | PWE06 |
| b4 | 37 | 6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts | SYP Grade No. 1 or better | – | PDB10a |
| b5 | 14 | W6x8.5 [W152x12.6] or W6x9 [W152x13.4] Post, 40 1/2" [1029] Long | ASTM A992 | ASTM A123 | SGR25 |
| b6 | 14 | 8 1/2"x12"x1/2" [216x305x13] Top Base Plate | ASTM A572 Gr. 50 | ASTM A123 | SGR25 |
| b7 | 13 | 8 1/2"x11"x1/4" [216x280x6] Bottom Post Plate | ASTM A572 Gr. 50 | ASTM A123 | SGR25 |
| c1 | 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 |
| c2 | 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 | – |
| c3 | 52 | 1" [25] Dia. UNC, 10 1/2" [267] Long Hex Head Bolt and Nut | Bolt – ASTM A307 Gr. A Nut – ASTM A563A | ASTM A153 or B695 Class 55 or F2329 | FBX24a |
| c4 | 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 |
| c5 | 37 | 5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut | Bolt – ASTM A307 Gr. A Nut – ASTM A563A | ASTM A153 or B695 Class 55 or F2329 | FBB06 |
| c6 | 112 | 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 |
| c7 | 39 | 16D Double Head Nail | – | – | – |
| c8 | 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 |
| c9 | 4 | 1" [25] Dia. UNC, 10" [254] Long Threaded Rod | ASTM A307 Gr. A | ASTM A153 or B695 Class 55 or F2329 | FRR24a |
| c10 | 8 | 1" [25] Dia. Hex Nut | ASTM A563A | ASTM A153 or B695 Class 55 or F2329 | FNX24a |

Note: (1) A 25' [7.6 m] guardrail segment may be used in place of two 12.5' [3.8 m] segments outside of the critical region.



| | | |
|---|---|---|
|  Midwest Roadside Safety Facility | MGS Strong Post on Culvert Test No. CMGS-1 | SHEET: 17 of 18 DATE: 11/22/2017 DRAWN BY: MES/JEK/ DTM |
| | Bill of Materials | REV. BY: JEK/RWB/ KAL/JCH |
| DWG. NAME: WL_MGS_on_Culvert_R12 | SCALE: None UNITS: in./mm | |

Figure 39. Bill of Materials, Test Nos. CMGS-1 and CMGS-2

| Item No. | QTY. | Description | Material Specification | Galvanization Specification | Hardware Guide |
|----------|------|--|--|-----------------------------|----------------|
| d1 | 44 | 5/8" [16] Dia. Plain Round Washer | ASTM F844 | ASTM A123 or A153 or F2329 | FWC16a |
| d2 | 8 | 7/8" [22] Dia. Plain Round Washer | ASTM F844 | ASTM A123 or A153 or F2329 | - |
| d3 | 104 | 1" [25] Dia. Plain Round Washer | ASTM F844 | ASTM A123 or A153 or F2329 | FWC24a |
| e1 | 2 | BCT Anchor Cable | - | - | FCA01 |
| e2 | 2 | 2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve | ASTM A53 Gr. B Schedule 40 | ASTM A123 | FMM02 |
| e3 | 2 | 8"x8"x5/8" [203x203x16] Anchor Bearing Plate | ASTM A36 | ASTM A123 | FPB01 |
| f1 | 2 | Ground Strut Assembly | ASTM A36 | ASTM A123 | PFP01 |
| f2 | 2 | Anchor Bracket Assembly | ASTM A36 | ASTM A123 | FPA01 |
| - | 1 | Concrete Culvert* | Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD | - | - |

* See WI_Culvert_Details_as_built drawing for details on concrete culvert.



Midwest Roadside Safety Facility

| | | |
|-------------------------------------|-------------------------------|---------------------------------|
| MGS Strong Post on Culvert | | SHEET: 18 of 18 |
| Test No. CMGS-1 | | DATE: 11/22/2017 |
| Bill of Materials | | DRAWN BY: MES/JEK/ DTM |
| DWG. NAME: WI_MGS_on_Culvert_R12 | SCALE: None UNITS: in.[mm] | REV. BY: JEK/RWB/ KAL/JCH |

Figure 40. Bill of Materials (Cont.), Test Nos. CMGS-1 and CMGS-2



Figure 41. System Installation, Test Nos. CMGS-1 and CMGS-2



Figure 42. Posts Attached to Culvert, Test Nos. CMGS-1 and CMGS-2



Figure 43. Bottom-Side Steel Post Connection Details and End Anchorage Systems, Test Nos. CMGS-1 and CMGS-2

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 [11] was used to steer the test vehicle. A guide flag, attached to the right-front wheel and the guide cable, was sheared off before impact with the barrier system. The $\frac{3}{8}$ -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, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

4.3 Test Vehicles

For test no. CMGS-1, a 2010 Hyundai Accent was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,471 lb (1,121 kg), 2,428 lb (1,101 kg), and 2,588 lb (1,174 kg), respectively. The test vehicle is shown in Figures 44 and 45, and vehicle dimensions are shown in Figure 46.

For test no. CMGS-2, a 2010 Dodge Ram 1500 Crew Cab was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,292 lb (2,400 kg), 5,013 lb (2,274 kg), and 5,175 lb (2,347 kg), respectively. The test vehicle is shown in Figures 47 and 48, and vehicle dimensions are shown in Figure 49. It should be noted that the test vehicles used were within six years of the research project contract date.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [12]. The location of the final c.g. is shown in Figures 46 and 50. Data used to calculate the location of the c.g. and ballast information is shown in Appendix B.

Square, black- and white-checked targets were placed on the test vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 50 and 51. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

The front wheels of the test vehicles 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 vehicles' right-side and left-side windshield wipers for test nos. CMGS-1 and CMGS-2, respectively, 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 vehicles could be brought safely to a stop after the test.



Figure 44. Test Vehicle, Test No. CMGS-1

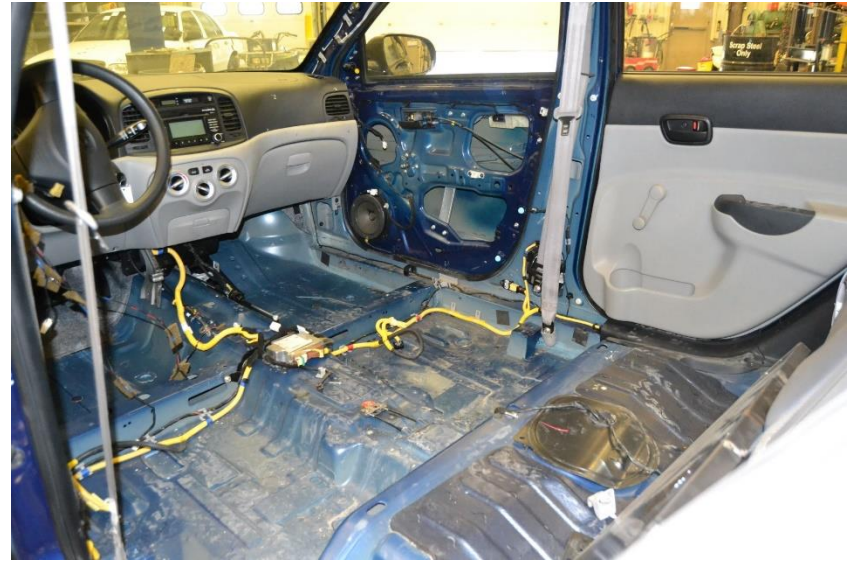


Figure 45. Test Vehicle's Undercarriage and Interior Floorboards, Test No. CMGS-1

| | | | | | |
|------------------------------|--|--|--|--------------------------------|--|
| Date: <u>10/26/2017</u> | | Test Number: <u>CMGS-1</u> | | VIN: <u>KMHCHN4AC0AU423259</u> | |
| Year: <u>2010</u> | | Make: <u>Hyundai</u> | | Model: <u>Accent</u> | |
| Tire Size: <u>185/65 R14</u> | | Tire Inflation Pressure: <u>32 Psi</u> | | Odometer: <u>140104</u> | |

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

| | |
|---------------------------------|-------------------------------|
| a: <u>63 1/8 (1603)</u> | b: <u>57 3/4 (1467)</u> |
| <small>65±3 (1650±75)</small> | |
| c: <u>168 3/4 (4286)</u> | d: <u>36 3/4 (933)</u> |
| <small>169±8 (4300±200)</small> | |
| e: <u>98 3/4 (2508)</u> | f: <u>33 1/4 (845)</u> |
| <small>98±5 (2500±125)</small> | <small>35±4 (900±100)</small> |
| g: <u>23 (584)</u> | h: <u>36 3/8 (924)</u> |
| | <small>39±4 (990±100)</small> |
| i: <u>14 (356)</u> | j: <u>20 3/4 (527)</u> |
| k: <u>16 1/4 (413)</u> | l: <u>23 1/4 (591)</u> |
| m: <u>57 3/8 (1457)</u> | n: <u>57 1/4 (1454)</u> |
| <small>56±2 (1425±50)</small> | <small>56±2 (1425±50)</small> |
| o: <u>26 (660)</u> | p: <u>3 3/4 (95)</u> |
| <small>24±4 (600±100)</small> | |
| q: <u>23 (584)</u> | r: <u>15 1/2 (394)</u> |
| s: <u>12 (305)</u> | t: <u>65 (1651)</u> |

Mass Distribution lb. (kg)

| | | | | |
|--------------|----|------------------|----|------------------|
| Gross Static | LF | <u>795 (361)</u> | RF | <u>819 (371)</u> |
| | LR | <u>483 (219)</u> | RR | <u>491 (223)</u> |

| Weights lb. (kg) | Curb | Test Inertial | Gross Static |
|------------------|--------------------|----------------------------------|----------------------------------|
| W-front | <u>1582 (718)</u> | <u>1534 (696)</u> | <u>1614 (732)</u> |
| W-rear | <u>889 (403)</u> | <u>894 (406)</u> | <u>974 (442)</u> |
| W-total | <u>2471 (1121)</u> | <u>2428 (1101)</u> | <u>2588 (1174)</u> |
| | | <small>2420±55 (1100±25)</small> | <small>2585±55 (1175±50)</small> |

| | |
|-------------------------------|---------------------|
| Top of radiator core support: | <u>28 7/8 (733)</u> |
| Wheel Center Height (Front): | <u>10 1/2 (267)</u> |
| Wheel Center Height (Rear): | <u>11 1/8 (283)</u> |
| Wheel Well Clearance (Front): | <u>25 3/8 (645)</u> |
| Wheel Well Clearance (Rear): | <u>25 (635)</u> |
| Bottom Frame Height (Front): | <u>7 1/2 (191)</u> |
| Bottom Frame Height (Rear): | <u>15 5/8 (397)</u> |

| | |
|--------------------|--------------------|
| Engine Type: | <u>Gasoline</u> |
| Engine Size: | <u>1.4L 4 cyl.</u> |
| Transmission Type: | <u>Automatic</u> |
| Drive Type: | <u>FWD</u> |

| | | | |
|-------------------------|-------------|-------------------|------------------------|
| GVWR Ratings lb. | | Dummy Data | |
| Front: | <u>1918</u> | Type: | <u>Hybrid II</u> |
| Rear: | <u>1874</u> | Mass: | <u>160</u> |
| Total: | <u>3638</u> | Seat Position: | <u>Passenger/Right</u> |

Note any damage prior to test: _____ none

Figure 46. Vehicle Dimensions, Test No. CMGS-1



Figure 47. Test Vehicle, Test No. CMGS-2



57

Figure 48. Test Vehicle's Undercarriage and Interior Floorboards, Test No. CMGS-2

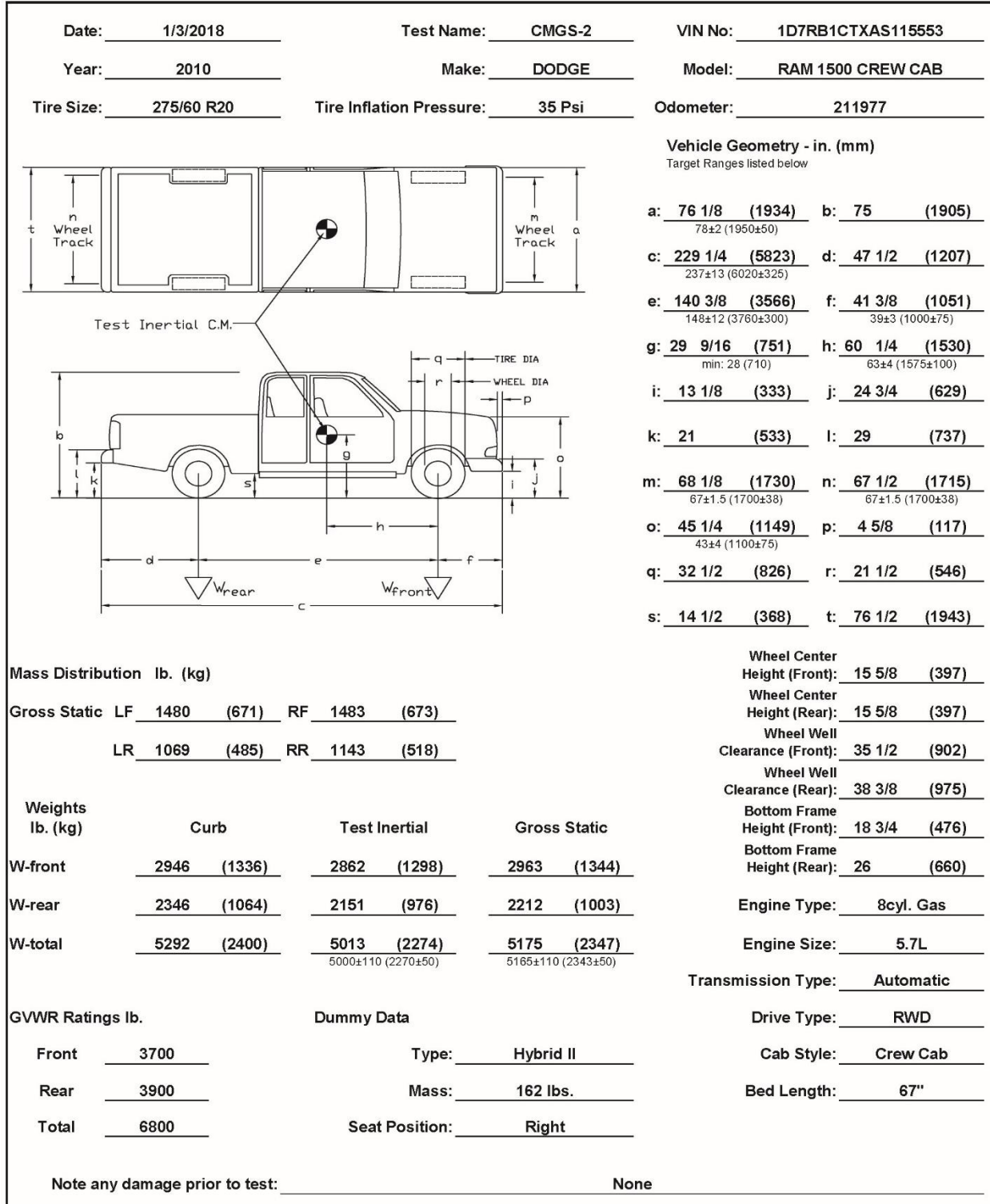


Figure 49. Vehicle Dimensions, Test No. CMGS-2

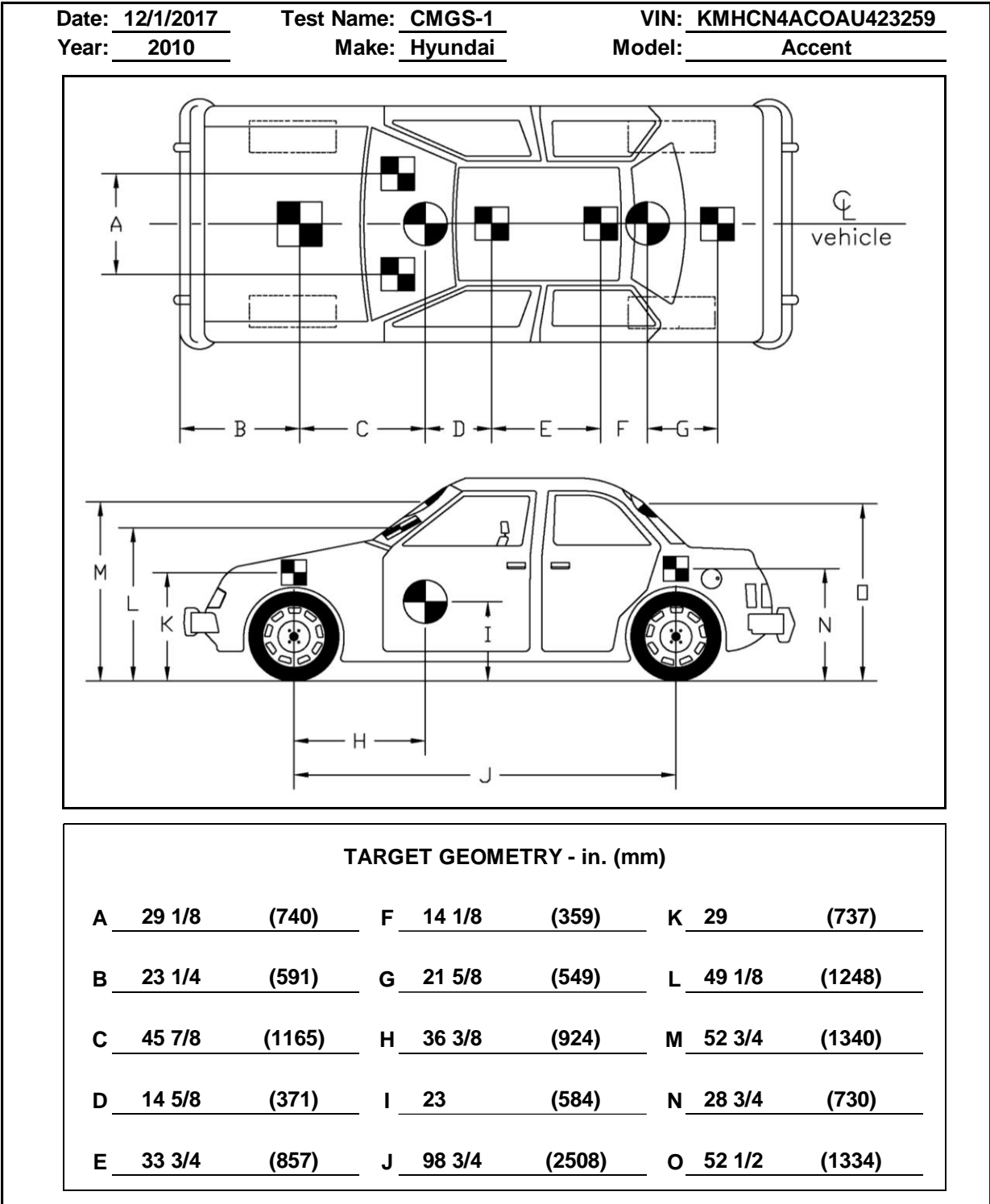


Figure 50. Target Geometry, Test No. CMGS-1

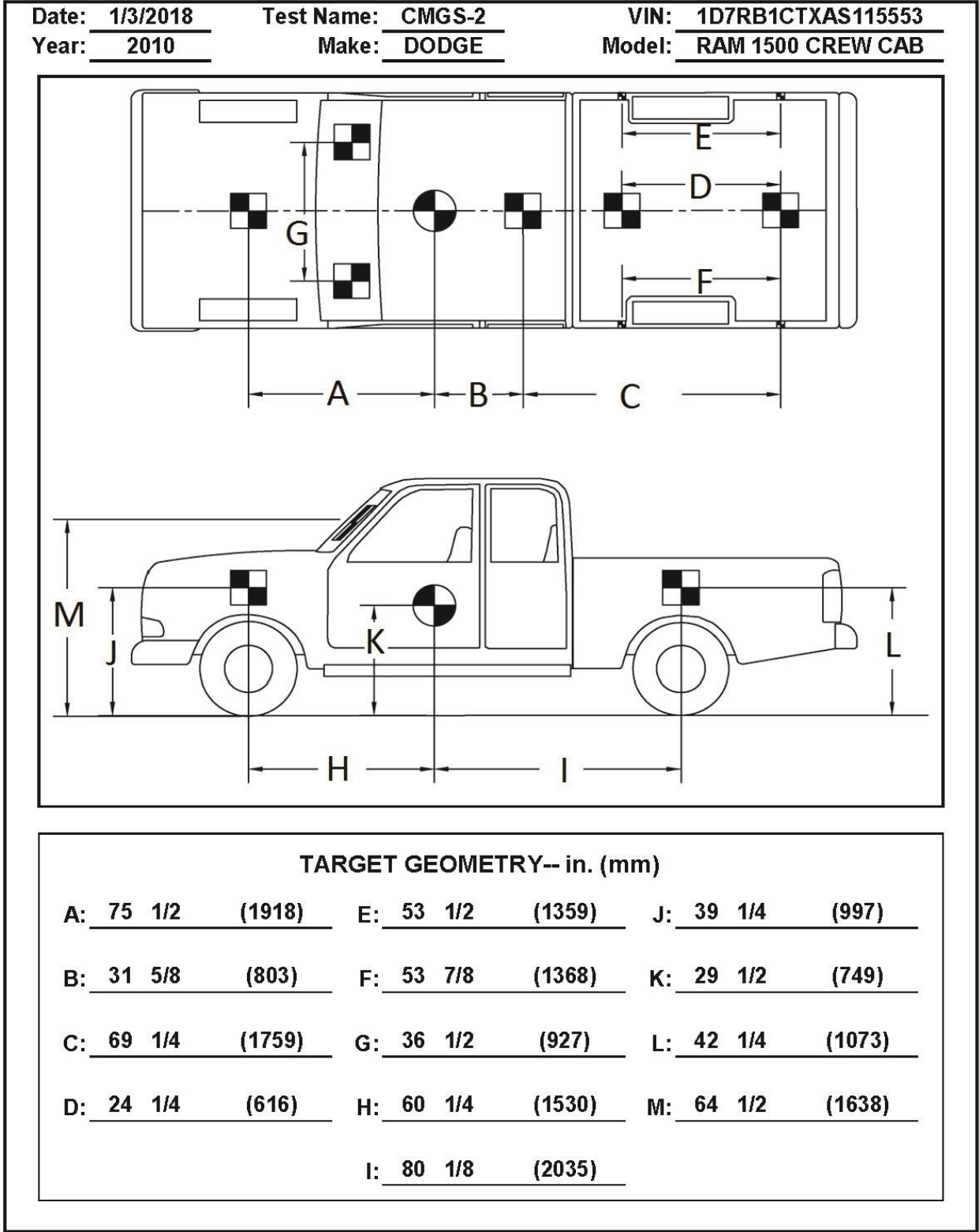


Figure 51. Target Geometry, Test No. CMGS-2

4.4 Simulated Occupant

For test nos. CMGS-1 and CMGS-2, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the right-front seat of the test vehicles with the seat belt fastened. The simulated occupant had a final weight of 160 lb (72.6 kg) and 162 (73.5 kg) in test nos. CMGS-1 and CMGS-2, respectively. As recommended by MASH 2016, the simulated occupant 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 accelerometer systems 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 [13].

The two accelerometer systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. In test nos. CMGS-1 and CMGS-2, the SLICE-1 and the SLICE-2 unit was designated as the primary system, respectively. 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 angular rate sensor systems mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders 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.

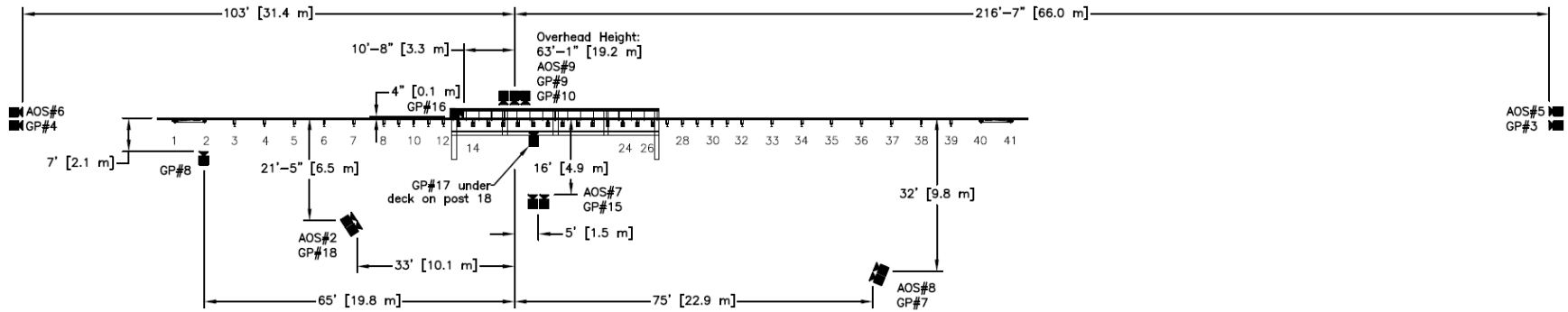
4.5.3 Retroreflective Optic Speed Trap

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 Digital Photography

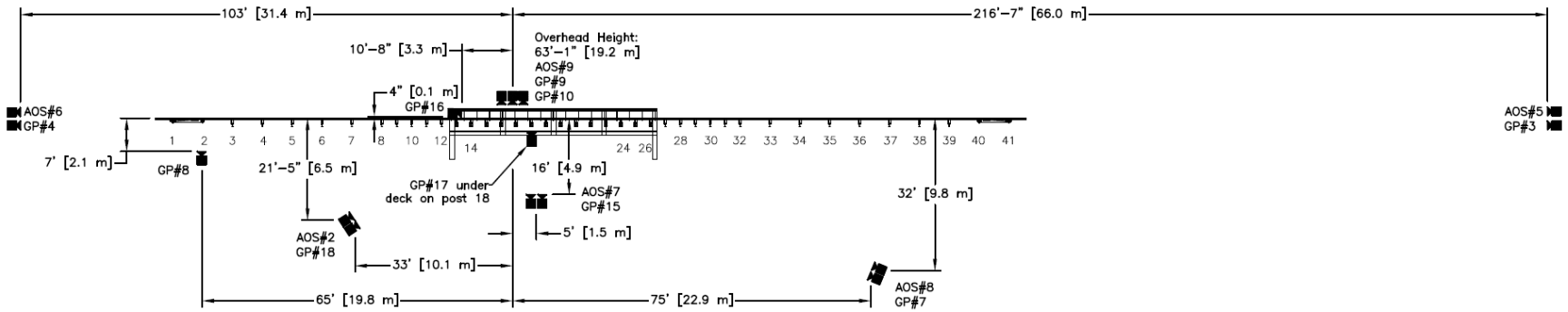
Six AOS high-speed digital video cameras and twelve GoPro digital video cameras were utilized to film test nos. CMGS-1 and CMGS-2. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figures 52 and 53.

The high-speed digital videos were analyzed using TEMA Motion 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 all tests.



| No. | Type | Operating Speed (frames/sec) | Lens | Lens Setting |
|-------|-------------------|------------------------------|---------------------|--------------|
| AOS-2 | AOS Vitcam CTM | 500 | Fujinon 35mm Fixed | - |
| AOS-5 | AOS X-PRI Gigabit | 500 | Fujinon 135mm Fixed | - |
| AOS-6 | AOS X-PRI Gigabit | 500 | Fujinon 50mm Fixed | - |
| AOS-7 | AOS X-PRI Gigabit | 500 | Kowa 16mm Fixed | - |
| AOS-8 | AOS S-VIT 1531 | 500 | Sigma 28-70 | 50 |
| AOS-9 | AOS TRI-VIT 2236 | 1000 | Kowa 12mm 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 | 240 | | |
| GP-8 | GoPro Hero 4 | 120 | | |
| GP-9 | GoPro Hero 4 | 120 | | |
| GP-10 | GoPro Hero 4 | 240 | | |
| GP-15 | GoPro Hero 4 | 240 | | |
| GP-16 | GoPro Hero 4 | 120 | | |
| GP-17 | GoPro Hero 4 | 120 | | |
| GP-18 | GoPro Hero 4 | 240 | | |

Figure 52. Camera Locations, Speeds, and Lens Settings, Test No. CMGS-1



| No. | Type | Operating Speed (frames/sec) | Lens | Lens Setting |
|-------|-------------------|------------------------------|---------------------|--------------|
| AOS-2 | AOS Vitcam CTM | 500 | Fujinon 35mm Fixed | — |
| AOS-5 | AOS X-PRI Gigabit | 500 | Fujinon 135mm Fixed | — |
| AOS-6 | AOS X-PRI Gigabit | 500 | Fujinon 50mm Fixed | — |
| AOS-7 | AOS X-PRI Gigabit | 500 | Kowa 16mm Fixed | — |
| AOS-8 | AOS S-VIT 1531 | 500 | Sigma 28-70 | 50 |
| AOS-9 | AOS TRI-VIT 2236 | 1000 | Kowa 12mm 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 | 240 | | |
| GP-8 | GoPro Hero 4 | 120 | | |
| GP-9 | GoPro Hero 4 | 120 | | |
| GP-10 | GoPro Hero 4 | 240 | | |
| GP-15 | GoPro Hero 4 | 240 | | |
| GP-16 | GoPro Hero 4 | 120 | | |
| GP-17 | GoPro Hero 4 | 120 | | |
| GP-18 | GoPro Hero 4 | 240 | | |

Figure 53. Camera Locations, Speeds, and Lens Settings, Test No. CMGS-2

5 FULL-SCALE CRASH TEST NO. CMGS-1

5.1 Static Soil Test

Before full-scale crash test no. CMGS-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 C, demonstrated a soil resistance 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. CMGS-1 was conducted on December 1, 2017 at approximately 2:30 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. CMGS-1

| | |
|------------------------------|----------------------|
| Temperature | 59° F |
| Humidity | 29% |
| Wind Speed | 13 mph |
| Wind Direction | 210° from True North |
| Sky Conditions | Sunny |
| Visibility | 10 Statute Miles |
| Pavement Surface | Dry |
| Previous 3-Day Precipitation | 0.00 in. |
| Previous 7-Day Precipitation | 0.00 in. |

5.3 Test Description

Initial vehicle impact was to occur at 84 in. (2,134 mm) upstream from post no. 19, as shown in Figure 54, which was selected using Table 2-8 of MASH 2016. The 2,428-lb (1,101-kg) Hyundai Accent impacted the test installation at a speed of 61.3 mph (98.7 km/h) and at an angle of 25.1 degrees, resulting in an impact severity of 54.8 kip-ft (74.3 kJ). The actual point of impact was 8 in. (203 mm) upstream from the target impact. As the vehicle was redirected, a partial rail tear occurred through the lower hump of the W-beam rail at the downstream end of the rail splice at post no. 19. This tear did not rupture the rail nor compromise the integrity of the W-beam rail element. At 0.259 sec after impact, the vehicle became parallel to the system with a speed of 26.5 mph (42.6 km/h). At 0.464 sec, the vehicle exited the system at a speed of 24.7 mph (39.8 km/h) and at angle of 17.0 degrees. The vehicle came to rest approximately 173 ft – 6 in. (52.9 m) downstream and 43 ft – 11 in. laterally in front of the system from the point of impact. The vehicle was successfully contained and redirected.

A detailed sequential description of the impact events is contained in Table 4. Sequential photographs are shown in Figures 55 through 57. Documentary photographs of the crash test are shown in Figure 58. The vehicle trajectory and final position are shown in Figure 59.



Figure 54. Impact Location, Test No. CMGS-1

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

| TIME (sec) | EVENT |
|------------|--|
| 0.000 | Vehicle's right-front bumper contacted rail between post nos. 16 and 17. |
| 0.008 | Vehicle's right fender contacted rail and right headlight deformed. |
| 0.012 | Vehicle's hood deformed. |
| 0.016 | Post nos. 16 and 17 deflected backward. |
| 0.018 | Post no. 18 deflected backward. |
| 0.022 | Vehicle's right headlight shattered and vehicle's right fender and grille deformed. |
| 0.024 | Post no. 18 deflected downstream. |
| 0.026 | Vehicle's right fender shattered. |
| 0.028 | Vehicle's front bumper deformed. |
| 0.034 | Vehicle's right-front door deformed. |
| 0.041 | Vehicle yawed away from barrier. |
| 0.042 | Post no. 18 rotated counterclockwise. |
| 0.044 | Post no. 19 deflected downstream. |
| 0.050 | Post no. 17 rotated backward. Vehicle rolled away from barrier. Right-side airbags deployed. |
| 0.054 | Vehicle pitched downward. Blockout no. 18 fractured. |
| 0.056 | Vehicle right-front wheel snagged on post no. 18. |
| 0.058 | Rail disengaged from bolt at post no. 18. |
| 0.060 | Blockout disengaged from post no. 18. |
| 0.062 | Post no. 19 deflected backward. Right-front airbag deployed. |
| 0.064 | Vehicle's right-rear tire became airborne. |
| 0.070 | Vehicle's right-front tire contacted post no. 18. |
| 0.072 | Post no. 18 bent downstream. |
| 0.076 | Post no. 19 rotated downstream. Post no. 20 deflected backward. |
| 0.080 | Post no. 19 twisted counterclockwise. |
| 0.098 | Rail disengaged from bolt at post no. 19. |
| 0.104 | Post no. 21 deflected backward. |
| 0.112 | Post no. 20 deflected downstream. |
| 0.116 | Vehicle's right-front wheel snagged on post no. 18. |
| 0.120 | Vehicle's front bumper contacted ground. |
| 0.144 | Rail disengaged from bolt at post no. 20. |
| 0.196 | Blockout no. 21 fractured. |
| 0.259 | Vehicle was parallel to system at a speed of 26.5 mph (42.6 km/h). |

Table 5. Sequential Description of Impact Events, Test No. CMGS-1

| TIME (sec) | EVENT |
|---------------|--|
| 0.262 | Vehicle's left-rear tire became airborne. |
| 0.280 | Vehicle pitched upward. |
| 0.316 | Vehicle's right-rear tire regained contact with ground. |
| 0.333 | Vehicle's right quarter panel contacted rail. |
| 0.338 | Vehicle's right-rear door deformed. |
| 0.370 | Vehicle's rear bumper contacted rail. |
| 0.382 | Vehicle's left-front tire became airborne. |
| 0.428 | Vehicle rolled away from barrier. |
| 0.464 | Vehicle exited system at a speed of 24.7 mph (39.8 km/h) and an angle of 17.0 degrees. |
| 0.502 | Vehicle's left-front tire regained contact with ground. |
| 0.686 | Vehicle's left-rear tire regained contact with ground. |
| 0.794 | Disengaged right-front tire contacted culvert headwall. |
| 0.915 | Vehicle yawed toward barrier. |



0.000 sec



0.100 sec



0.200 sec



0.300 sec



0.400 sec



0.500 sec



0.000 sec



0.100 sec



0.200 sec



0.300 sec



0.400 sec



0.500 sec

Figure 55. Sequential Photographs, Test No. CMGS-1



0.000 sec



0.100 sec



0.200 sec



0.300 sec



0.400 sec



0.500 sec



0.000 sec



0.100 sec



0.200 sec



0.300 sec



0.400 sec



0.500 sec

Figure 56. Sequential Photographs, Test No. CMGS-1

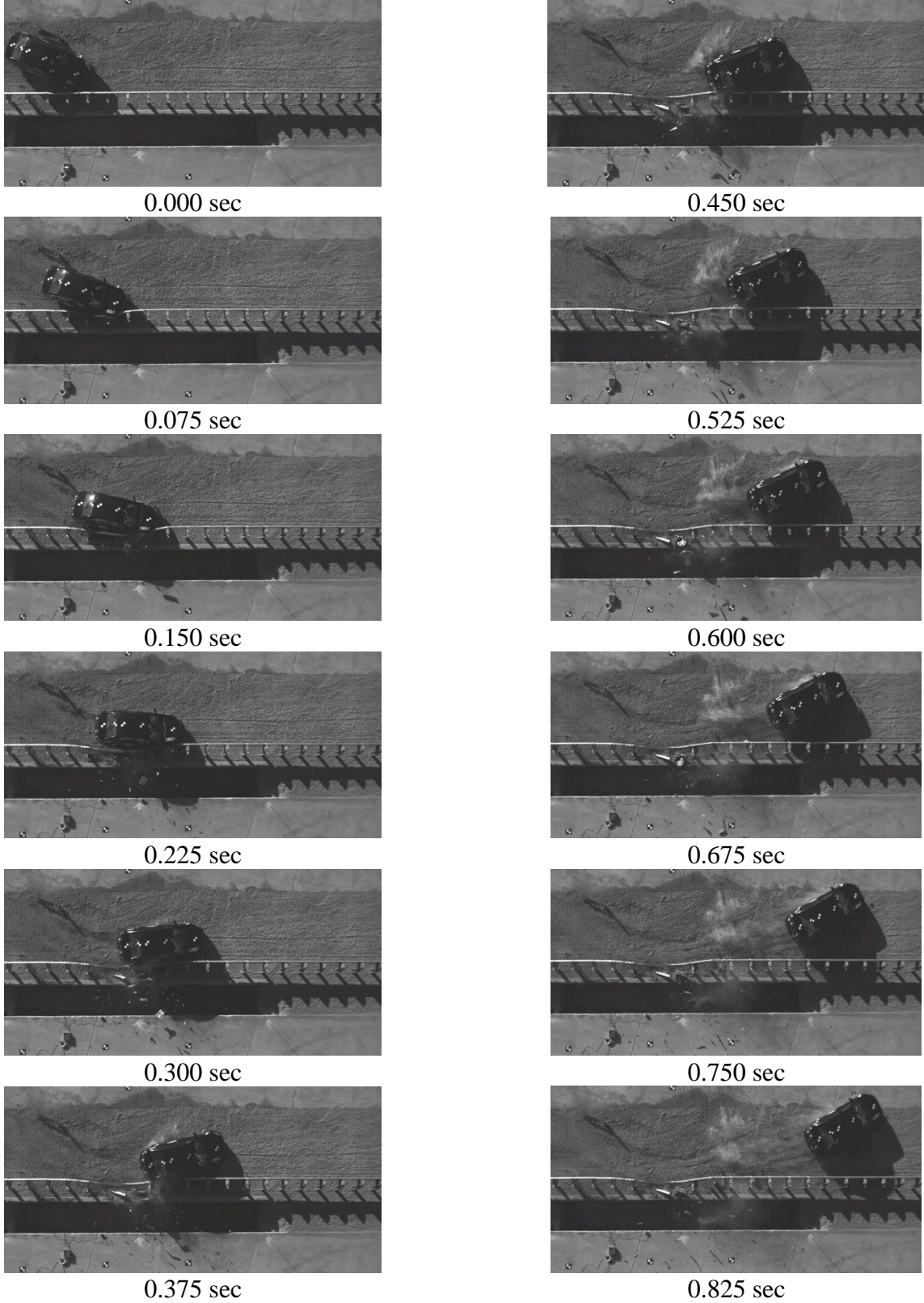


Figure 57. Additional Sequential Photographs, Test No. CMGS-1

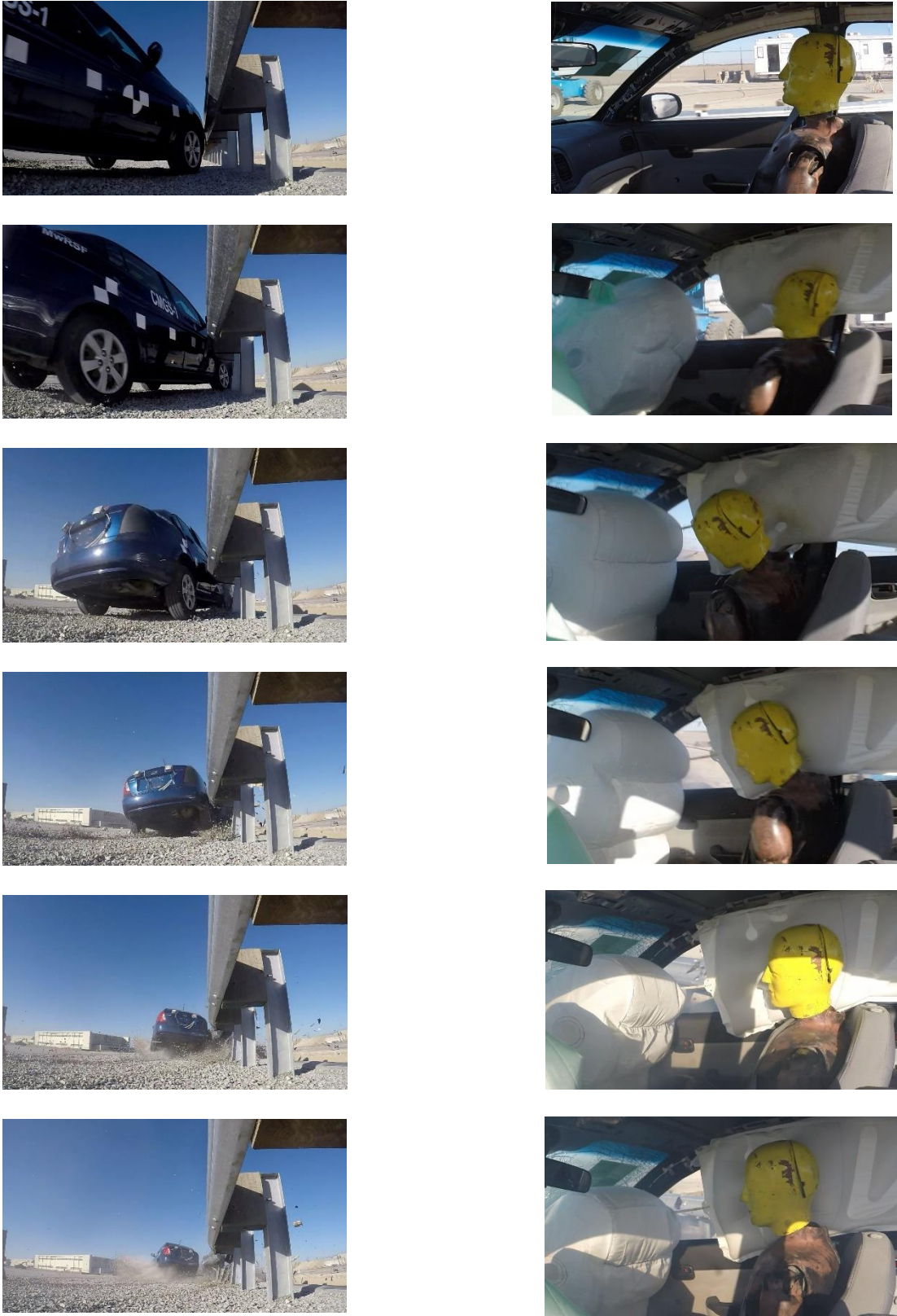


Figure 58. Documentary Photographs, Test No. CMGS-1



Figure 59. Vehicle Trajectory and Final Position, Test No. CMGS-1

5.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 60 through 66. Barrier damage consisted mostly of deformed W-beam, contact marks on the guardrail sections, and deformed posts. The length of vehicle contact along the barrier was approximately 16 ft which spanned from 12 $\frac{5}{8}$ in. (321 mm) downstream from post no. 16 to 15 $\frac{1}{2}$ in. (394 mm) downstream from post no. 21.

The guardrail damage consisted moderate deformation and flattening of the impacted section of the W-beam between post nos. 16 and 22. The W-beam was pulled out from the bolts at post nos. 18 through 21. Contact marks were found on the guardrail between post nos. 16 through 21. A partial rail tear was observed through the lower hump of the W-beam rail at the downstream end of the rail splice at post no. 19, as shown in Figures 60 and 61. No significant guardrail damage occurred upstream from post no. 16 nor downstream from post no. 22.

Post no. 17 slightly deflected backward. Post nos. 18 and 19 were bent longitudinally toward the ground in the downstream direction. Post no. 20 was bent slightly longitudinally downstream. Contact marks were found on the front face of post nos. 18 and 19. No significant post damage occurred to post nos. 1 through 16 nor 21 through 41. The upstream and downstream anchorage systems remained unmoved and the posts in both anchorage systems were not damaged. The wooden blockout at post nos. 18, 19, and 21 disengaged from the system. The blockout at post no. 20 rotated but did not disengage. The blockouts at post nos. 3 through 17 and 22 through 39 were undamaged.

Following the test, the soil on top of the culvert headwall was removed for inspection of the damage to the posts and base plates as well as to review any potential damage to the culvert. Deformation of the post base plates was observed on post nos. 17 through 21. Minor cracking was observed on the weld at the front flange of the base plate of post no. 17. The upstream side of the front flange of post no. 18 was torn up to the web near the base plate weld. All anchorage bolts and epoxied threaded rods were intact and remained secure, although some minor deformation of the bolts and rods was observed. No damage was observed to the concrete culvert slab or the headwall.

The maximum lateral permanent set of the barrier system was 11 $\frac{7}{8}$ in. (302 mm), which occurred at the back of post no. 18, as measured in the field. The maximum lateral dynamic deflection was 12 in. (305 mm) at post no. 18, as determined from high-speed digital video analysis. The working width of the system was 33.1 in. (842 mm) at post no. 18, also determined from high-speed digital video analysis. A schematic of the permanent set, dynamic deflection, and working width is shown in Figure 67.



Figure 60. System Damage, Test No. CMGS-1



Figure 61. Damage to Post Nos. 15 through 22, Test No. CMGS-1



Figure 62. Damage to Post and Base Plate Nos. 17 through 21 (After Removal of Soil Fill Post and Base), Test No. CMGS-1

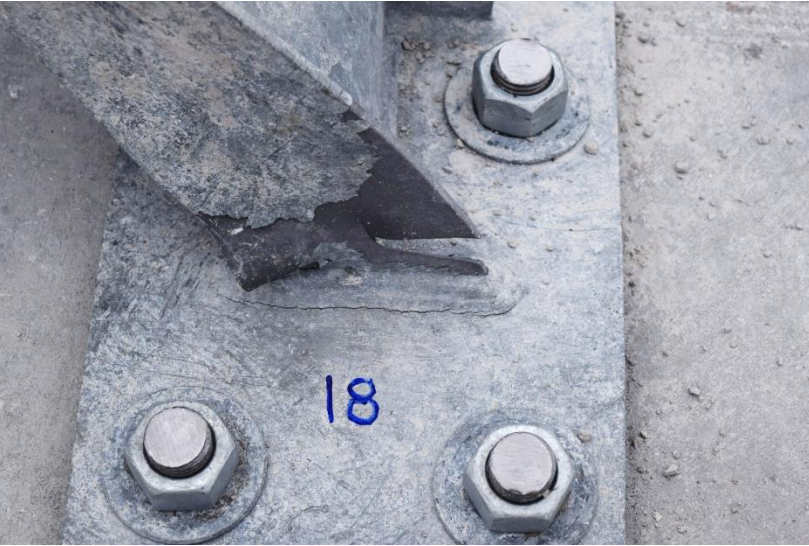
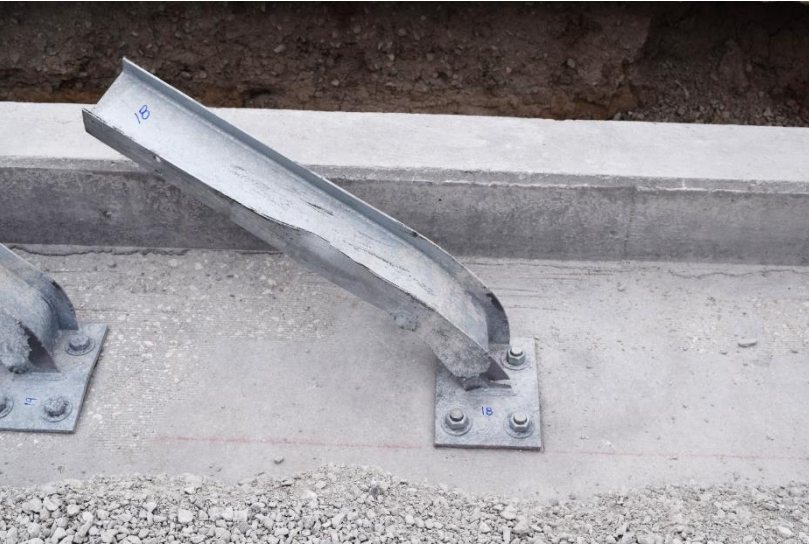


Figure 63. Damage to Post and Base Plate Nos. 18 and 19, Test No. CMGS-1



Figure 64. Damage to Post and Base Plate No. 21, Test No. CMGS-1



Figure 65. Washer Plate Nos. 18 through 22 After Test, Test No. CMGS-1



(a)



(b)

Figure 66. (a) Upstream Anchorage System After Test, and (b) Downstream Anchorage System After Test, Test No. CMGS-1

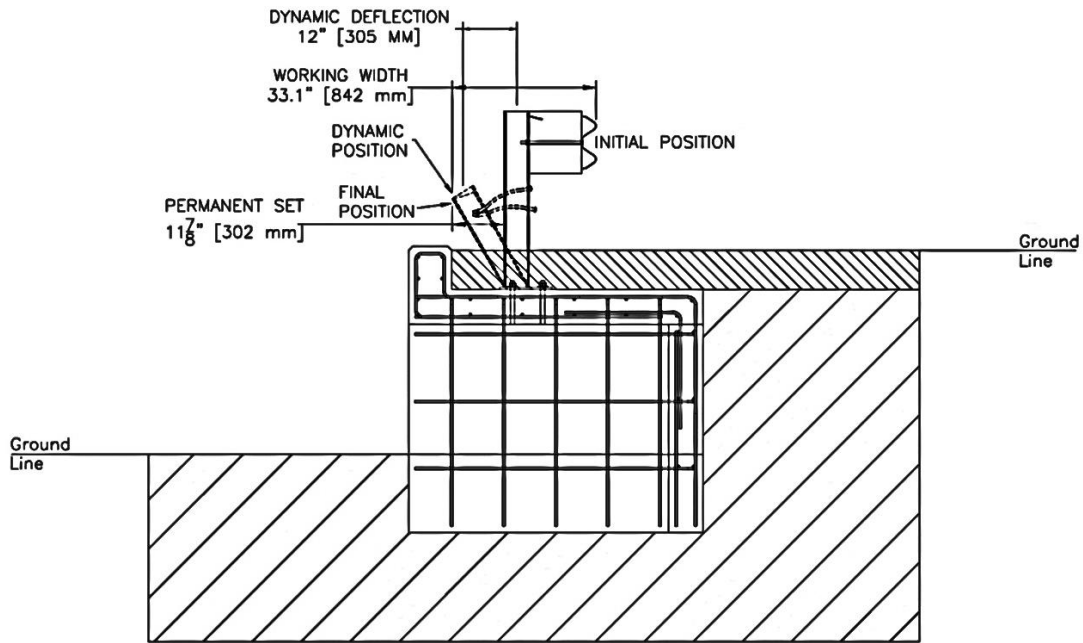


Figure 67. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. CMGS-1

5.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 68 through 72. The maximum occupant compartment deformations are listed in Table 6 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. The maximum deformation of the windshield was measured to be $3\frac{3}{8}$ in. (86 mm) which was not observed on the test day, as shown in Figure 70. Prior to the vehicle deformation measurements, the snow and ice on the windshield caused an additional caving in deformation. Therefore, this deformation exceeding the MASH deformation criteria was not due to the impact event and is not critical to the test evaluation. All other occupant compartment deformations were within MASH limits. Complete occupant compartment and vehicle deformations as well as the corresponding locations are provided in Appendix D.

Majority of the vehicle damage was concentrated on the right-front corner, where primary impact occurred. The right-front wheel contacted post nos. 18 and 19 and was disengaged, and the left-front tire was deflated. The right corner of the hood buckled. The side and front airbags on both the passenger and driver side deployed, which caused the windshield on the passenger side to shatter but remain intact. The right-rear quarter panel was crushed inward.

The roof, the left side, and the rear of the vehicle remained undamaged. The left-side and rear window glass also remained undamaged. The front right strut broke at the weld point on the top of the gas cylinder, and only the top portion of the shock absorber was still intact. The right-side wheel hub attachment point detached from the steering rack, and the tie rod was bent. The right-front brake assembly disengaged from the car. There was no damage to the vehicle's frame, rear suspension, or rear shocks and springs.



Figure 68. Vehicle Damage, Test No. CMGS-1



Figure 69. Additional Vehicle Damage, Test No. CMGS-1



(a)

(b)

Figure 70. Vehicle Windshield Damage, (a) on Test Site on Test Day, (b) in Vehicle Shop Prior to Measurement, Test No. CMGS-1



Figure 71. Occupant Compartment Damage, Test No. CMGS-1



Figure 72. Vehicle Undercarriage Damage, Test No. CMGS-1

Table 6. Maximum Occupant Compartment Deformations by Location, Test No. CMGS-1

| LOCATION | MAXIMUM INTRUSION in. (mm) | MASH 2016 ALLOWABLE INTRUSION in. (mm) |
|---|--|---|
| Wheel Well & Toe Pan | 1 $\frac{7}{8}$ (48) | ≤ 9 (229) |
| Floor Pan & Transmission Tunnel | $\frac{3}{4}$ (19) | ≤ 12 (305) |
| A-Pillar | 1 $\frac{1}{8}$ (29) | ≤ 5 (127) |
| A-Pillar (Lateral) | $\frac{7}{8}$ (22) | ≤ 3 (76) |
| B-Pillar | 1 $\frac{3}{8}$ (35) | ≤ 5 (127) |
| B-Pillar (Lateral) | $\frac{3}{4}$ (19) | ≤ 3 (76) |
| Side Front Panel (in Front of A-Pillar) | $\frac{1}{4}$ (6) | ≤ 12 (305) |
| Side Door (Above Seat) | $\frac{3}{4}$ (19) | ≤ 9 (229) |
| Side Door (Below Seat) | 1 (25) | ≤ 12 (305) |
| Roof | $\frac{1}{4}$ (6) | ≤ 4 (102) |
| Windshield | 3 $\frac{3}{8}$ (86) ² | ≤ 3 (76) |
| Side Window | No shattering of side windows occurred | No shattering resulting from contact with structural member of test article |
| Dash | $\frac{7}{8}$ (22) | N/A ¹ |

¹ – N/A - No MASH 2016 criteria exist for this location

² – Deformation was not present on test day but occurred after snow and ice on windshield caused deformation prior to measurement

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 7. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 7. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Table 7. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

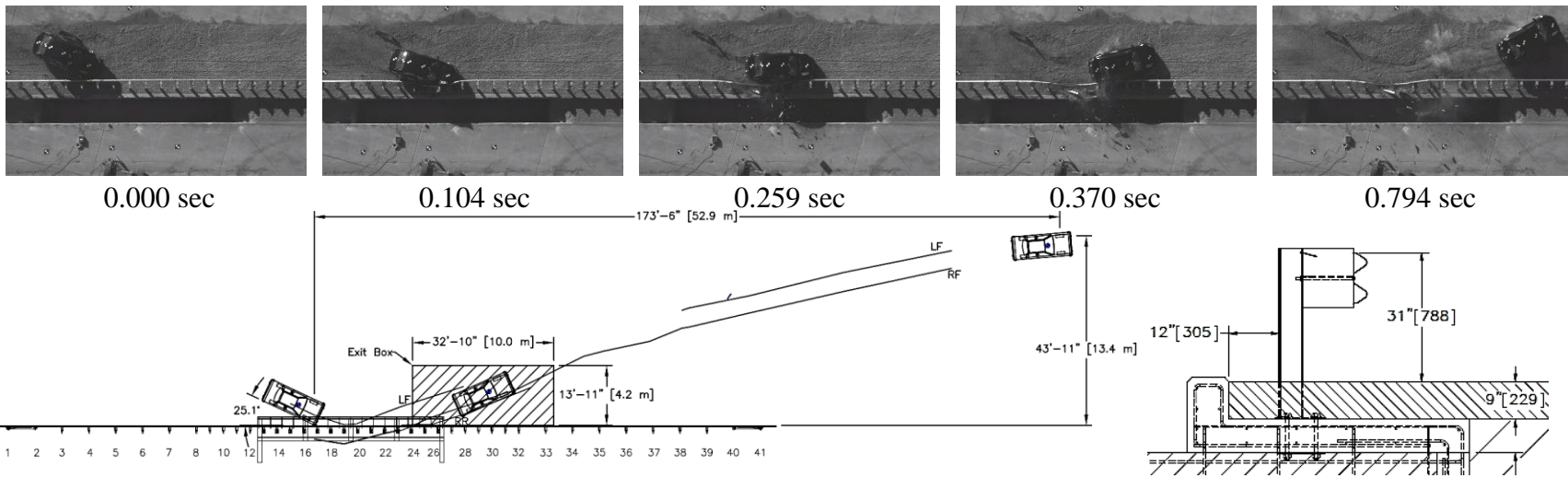
Table 7. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. CMGS-1

| Evaluation Criteria | | Transducer | | MASH 2016 Limits |
|--|--------------|----------------------|----------------|------------------------|
| | | SLICE-1 (Primary) | SLICE-2 | |
| OIV ft/s (m/s) | Longitudinal | -27.34 (-8.33) | -27.57 (-8.40) | ± 40 (12.2) |
| | Lateral | -20.01 (-6.10) | -19.49 (-5.94) | ± 40 (12.2) |
| ORA g's | Longitudinal | -16.96 | -15.45 | ± 20.49 |
| | Lateral | -11.51 | -11.18 | ± 20.49 |
| MAX ANGULAR DISPLACEMENT deg. | Roll | 15.2 | -11.3 | ± 75 |
| | Pitch | -6.9 | -4.7 | ± 75 |
| | Yaw | -53.4 | -53.7 | not required |
| THIV ft/s (m/s) | | 33.47 (10.20) | 31.49 (9.60) | not required |
| PHD g's | | 18.32 | 17.61 | not required |
| ASI | | 1.37 | 1.34 | not required |

5.7 Discussion

The analysis of the test results for test no. CMGS-1 showed that the strong post MGS attached to the culvert's top slab adequately contained and redirected the 1100C vehicle with controlled displacement of the barrier. A summary of the test results and sequential photographs are shown in Figure 73. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. Note, the maximum windshield deformation of 3³/₈ in. (86 mm) was not from the impact event, and therefore, it was not critical to the test evaluation.

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 E, were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 17 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. CMGS-1 conducted on the culvert mounted, strong post MGS was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-10.



- Test AgencyMwRSF
- Test Number..... CMGS-1
- Date..... 12/01/2017
- MASH Test Designation No.3-10
- Test Article..... Culvert-Mounted, Strong Post MGS
- Total Length 182.3 ft (55.6 m)
- Distance between Posts and Headwall 12 in. (305 mm)
- Key Component – MGS Rail
 - Thickness 12 gauge (2.7 mm)
 - Top Mounting Height..... 31 in. (787 mm)
- Key Component – Steel Posts
 - Post Type W6x9 by 40½ in. (1,029 mm)
 - Post Spacing 37½ in. (952 mm) on center
- Soil Type Compacted, coarse, crushed limestone
- Vehicle Make /Model..... 2010 Hyundai Accent
 - Curb..... 2,471 lb (1,121 kg)
 - Test Inertial..... 2,428 lb (1,101 kg)
 - Gross Static..... 2,588 lb (1,174 kg)
- Impact Conditions
 - Speed 61.3 mph (98.7 km/h)
 - Angle 25.1 deg
 - Impact Location..... 92 in. (2,337 mm) upstream from post no. 19
- Impact Severity 58.5 kip-ft (79.3 kJ) > 51 kip-ft (69.1 kJ) Limit from MASH
- Exit Conditions
 - Speed 24.7 mph (39.8 km/h)
 - Angle 17 deg
- Exit Box Criterion..... Pass
- Vehicle Stability..... Satisfactory
- Vehicle Stopping Distance 173 ft - 6 in. (52.9 m) Downstream within the system

- Vehicle Damage..... Moderate
 - VDS [14] 1-RFQ-6
 - CDC [15]..... 1-RZAK-5
 - Maximum Interior Deformation 3¾ in. (86 mm)
- Test Article Damage Moderate
- Maximum Test Article Deflections
 - Dynamic..... 12.0 in. (305 mm)
 - Working Width..... 33.1 in. (842 mm)
 - Permanent Set 117% in. (302 mm)
- Transducer Data

| Evaluation Criteria | | Transducer | | MASH 2016 Limit |
|-------------------------------------|--------------|-------------------|----------------|-----------------|
| | | SLICE-1 (primary) | SLICE-2 | |
| OIV ft/s (m/s) | Longitudinal | -27.34 (-8.33) | -27.57 (-8.40) | ± 40 (12.2) |
| | Lateral | -20.01 (-6.10) | -19.49 (-5.94) | ± 40 (12.2) |
| ORA g's | Longitudinal | -16.96 | -15.45 | ± 20.49 |
| | Lateral | -11.51 | -11.18 | ± 20.49 |
| MAX ANGULAR DISPLACEMENT deg. | Roll | 15.2 | -11.4 | ±75 |
| | Pitch | -6.9 | -4.7 | ±75 |
| | Yaw | -53.4 | -53.7 | not required |
| THIV – ft/s (m/s) | | 33.47 (10.20) | 31.49 (9.60) | not required |
| PHD – g's | | 18.32 | 17.60 | not required |
| ASI | | 1.37 | 1.34 | not required |

90

Figure 73. Summary of Test Results and Sequential Photographs, Test No. CMGS-1

6 FULL-SCALE CRASH TEST NO. CMGS-2

6.1 Static Soil Test

Before full-scale crash test no. CMGS-2 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 C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

6.2 Weather Conditions

Test no. CMGS-2 was conducted on February 14, 2018 at approximately 12:45 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 8.

Table 8. Weather Conditions, Test No. CMGS-2

| | |
|------------------------------|----------------------|
| Temperature | 42° F |
| Humidity | 79% |
| Wind Speed | 9 mph |
| Wind Direction | 210° from True North |
| Sky Conditions | Sunny |
| Visibility | 7 Statute Miles |
| Pavement Surface | Dry |
| Previous 3-Day Precipitation | 0.00 in. |
| Previous 7-Day Precipitation | 0.15 in. |

6.3 Test Description

Initial vehicle impact was to occur 132 in. (3,353 mm) upstream from post no. 19, as shown in Figure 74, which was selected using Table 2-8 of MASH 2016. The 5,013-lb (2,274-kg) crew cab pickup truck impacted the test installation at a speed of 62.8 mph (101.1 km/h) and at an angle of 25.7 degrees, resulting in an impact severity of 124.7 kip-ft (169.1 kJ). The actual point of impact was 129.1 in. (3,279 mm) upstream from post no. 19. During the impact event, the right-front wheel snagged on post nos. 17 through 19 and was disengaged, but the vehicle remained stable and was safely redirected. At 0.270 sec after impact, the vehicle became parallel to the system with a speed of 36.9 mph (59.5 km/h). At 0.520 sec, the vehicle exited the system at a speed of 33.1 mph (53.2 km/h) and at an angle of 17.4 degrees. The vehicle came to rest approximately 173 ft – 6 in. (52.9 m) downstream from the point of impact.

A detailed sequential description of the impact events is shown in Table 9. Sequential photographs are shown in Figures 75 and 76. Documentary photographs of the crash test are shown in Figure 78. The vehicle trajectory and final position are shown in Figure 79.



Figure 74. Impact Location, Test No. CMGS-2

Table 9. Sequential Description of Impact Events, Test No. CMGS-2

| TIME (sec) | EVENT |
|---------------|--|
| 0.000 | Vehicle's front bumper contacted rail between post nos. 15 and 16. |
| 0.002 | Vehicle's front bumper deformed. |
| 0.006 | Vehicle's right fender contacted rail and deformed. |
| 0.012 | Vehicle's right-front tire contacted rail. |
| 0.014 | Post no. 16 deflected backward. |
| 0.016 | Post no. 15 deflected backward. |
| 0.018 | Post no. 17 deflected backward. Soil heave formed on non-traffic flange of post no. 16. Vehicle's right headlight shattered. |
| 0.020 | Vehicle's grille deformed. |
| 0.022 | Vehicle's right-front wheel rim deformed. |
| 0.032 | Post no. 14 deflected backward. |
| 0.040 | Post no. 17 deflected downstream. |
| 0.046 | Post no. 18 deflected backward. |
| 0.048 | Post no. 17 rotated counterclockwise. |
| 0.060 | Vehicle yawed away from system. |
| 0.070 | Post no. 18 twisted counterclockwise. Vehicle's right-front tire contacted post no. 17. |
| 0.076 | Post no. 17 bent downstream. |
| 0.078 | Rail disengaged from bolt at post no. 17. |
| 0.086 | Post nos. 19 and 20 deflected backward. Rail disengaged from bolt at post no. 18. Blockout no. 17 fractured. |
| 0.090 | Blockout disengaged from post no. 17. |
| 0.094 | Post no. 19 rotated counterclockwise. |
| 0.104 | Post no. 17 contacted culvert headwall. |
| 0.108 | Post no. 19 deflected downstream. |
| 0.110 | Vehicle pitched downward. |
| 0.114 | Vehicle rolled toward system. |
| 0.120 | Post no. 17 pulled out of soil. |
| 0.124 | Rail disengaged from bolt at post no. 19. |
| 0.128 | Post no. 21 deflected backward. Post no. 20 twisted counterclockwise. |
| 0.133 | Vehicle's right-front tire contacted post no. 18. |
| 0.134 | Blockout disengaged from post no. 18. |
| 0.136 | Vehicle's right-front wheel became disengaged. |
| 0.140 | Post no. 20 deflected downstream. |
| 0.144 | Post no. 22 deflected backward. Soil heave formed on non-traffic flange of post no. 21. |

Table 10. Sequential Description of Impact Events, Test No. CMGS-2

| TIME (sec) | EVENT |
|---------------|--|
| 0.148 | Blockout disengaged from post no. 19. |
| 0.152 | Vehicle's right-front tire contacted blockout no. 19. |
| 0.158 | Post no. 20 rotated downstream. |
| 0.160 | Post no. 18 contacted culvert headwall. |
| 0.168 | Blockout no. 19 fractured. Rail disengaged from bolt at post no. 20. |
| 0.172 | Post no. 18 pulled out of soil. |
| 0.174 | Post no. 19 bent downstream. |
| 0.176 | Vehicle's right-rear tire contacted rail. |
| 0.184 | Post no. 21 deflected downstream. |
| 0.194 | Vehicle's rear bumper contacted rail and deformed. |
| 0.202 | Blockout disengaged from post no. 20. |
| 0.204 | Blockout no. 20 fractured. Post no. 21 rotated counterclockwise. |
| 0.210 | Vehicle's right-front tire contacted blockout no. 20. |
| 0.214 | Vehicle's right-front tire contacted post no. 20. Vehicle's left-rear tire became airborne. |
| 0.216 | Post no. 20 bent downstream. |
| 0.238 | Rail disengaged from bolt at post no. 21. |
| 0.244 | Vehicle rolled away from system. |
| 0.270 | Vehicle was parallel to system at a speed of 36.9 mph (59.5 km/h). |
| 0.384 | Vehicle's left-front tire became airborne. |
| 0.456 | Vehicle's left-front tire regained contact with ground. |
| 0.520 | Vehicle's right-rear tire became airborne. Vehicle exited system at a speed of 33.1 mph (53.2 km/h) and at an angle of 17.4 degrees. |



0.000 sec



0.150 sec



0.300 sec



0.450 sec



0.600 sec



0.750 sec



0.000 sec



0.150 sec



0.300 sec



0.450 sec



0.600 sec



0.750 sec

Figure 75. Sequential Photographs, Test No. CMGS-2



0.000 sec



0.150 sec



0.300 sec



0.450 sec



0.600 sec



0.750 sec



0.000 sec



0.040 sec



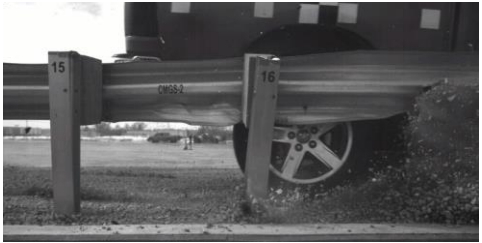
0.080 sec



0.120 sec



0.160 sec



0.200 sec

Figure 76. Additional Sequential Photographs, Test No. CMGS-2

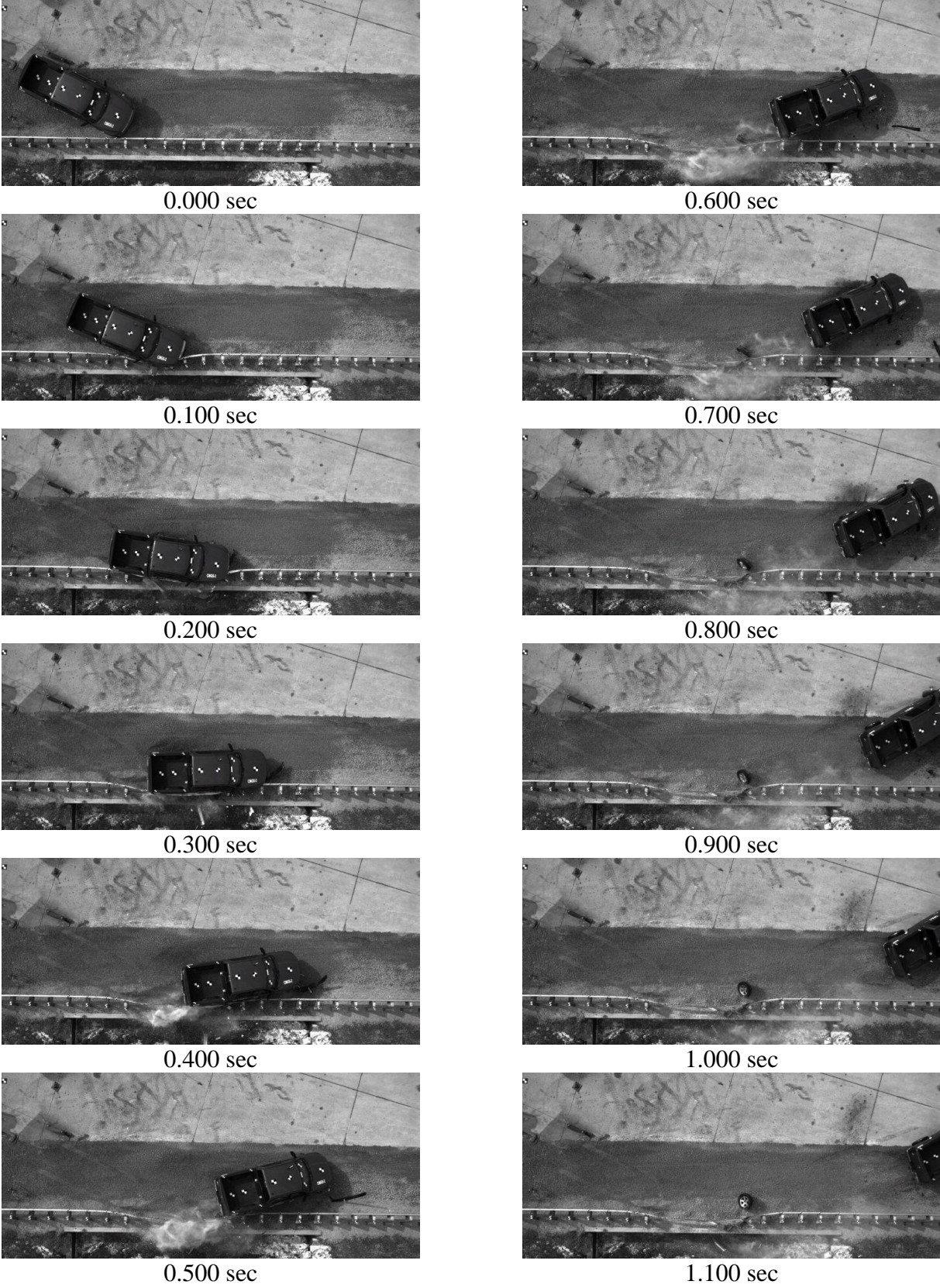


Figure 77. Additional Sequential Photographs, Test No. CMGS-2



Figure 78. Documentary Photographs, Test No. CMGS-2



Figure 79. Vehicle Trajectory and Final Position, Test No. CMGS-2

6.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 80 through 89. Barrier damage consisted mostly of deformed W-beam, contact marks on the guardrail sections, and deformed posts. The length of vehicle contact along the barrier was approximately 24 ft – 1 in. (7.3 m) which spanned from 7 in. (178 mm) downstream from post no. 15 to the downstream edge of the rail splice at post no. 23.

The guardrail damage consisted moderate deformation and flattening of the impacted section of the W-beam between post nos. 15 and 23. The W-beam disengaged from post nos. 17 through 21. Contact marks were found on the guardrail between post nos. 15 through 23. Small horizontal rail tearing was observed at and upstream from post no. 16, as shown in Figure 84. No significant guardrail damage occurred upstream from post no. 15 nor downstream from post no. 23.

Post nos. 15 and 16 slightly deflected backward. Post nos. 17 and 18 broke away from the base plate and were pulled out of the soil. However, this did not adversely affect the system's performance, and the disengaged posts did not pose secondary hazard to traffic. Post nos. 19 through 21 also deflected longitudinally toward the ground in the downstream direction but remained attached to the culvert. Contact marks were found on the front face of post nos. 18 and 19. No significant post damage occurred to post nos. 1 through 15 or 24 through 41. The upstream anchorage system was displaced nearly 1 in. (25 mm) and the downstream anchorage system remained unmoved. The posts in both the upstream and downstream anchorage systems were not damaged. The wooden blockouts at post nos. 17 through 20 disengaged from the system. The blockout at post no. 21 rotated but did not disengage from the rail. The blockouts at post nos. 3 through 16 and 22 through 39 remained undamaged.

Following the test, the soil on top of the culvert headwall was removed for inspection of the damage to the posts and base plates as well as to review any potential damage to the culvert. Deformation of the post base plates was observed on post nos. 16 through 22. Post nos. 17 and 18 fractured at the base of the post above the weld line at the front flange and web of the post and through the weld at the back flange of the post. The upstream side of the front flange of post nos. 20 and 21 was torn up to the web near the base plate weld. All anchorage bolts and epoxied threaded rods were intact and remained secure, although some minor deformation of the bolts and rods was observed. No damage was observed to the concrete culvert slab or the headwall.

The maximum lateral permanent set of the barrier system was 15¾ in. (400 mm) which occurred at the back of rail at post no. 19, as measured in the field. The maximum dynamic barrier deflection was 29.6 in. (752 mm) at post no. 17. The working width of the system was 50.8 in. (1,290 mm) at post no. 17, also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 90.



Figure 80. System Damage, Test No. CMGS-2



Figure 81. Damage to Post Nos. 15 through 21, Test No. CMGS-2

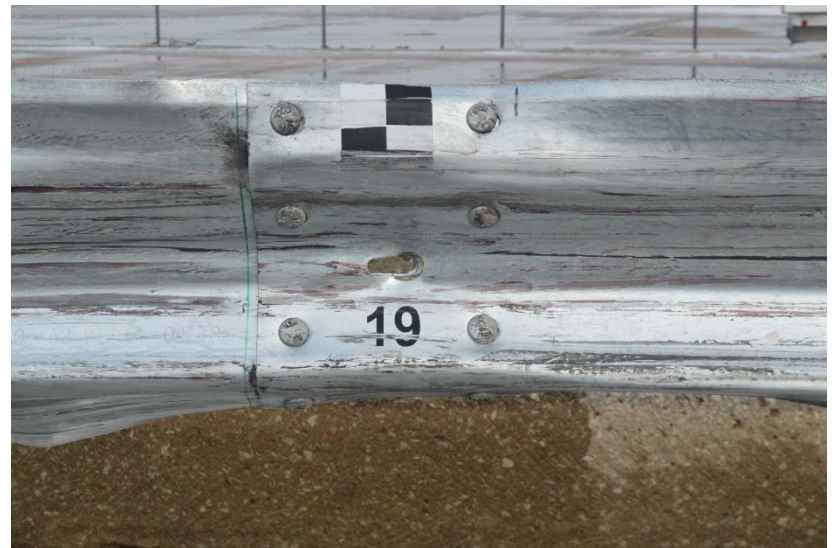


Figure 82. Guardrail Damage, Post Nos. 15 through 19, Test No. CMGS-2



Figure 83. Guardrail Damage, Post Nos. 15 through 22, Test No. CMGS-2



Figure 84. Rail Tears at Post No. 16, Test No. CMGS-2

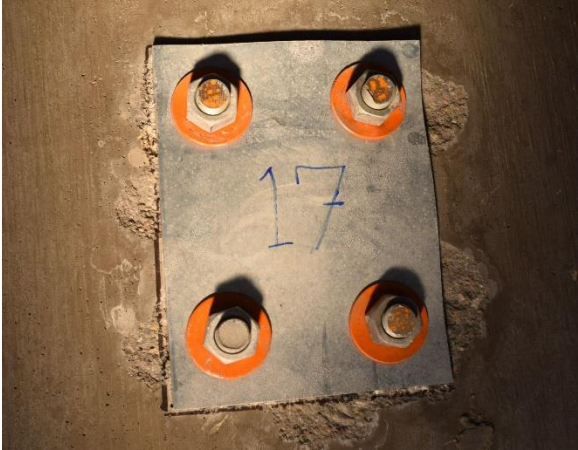


Figure 85. Damage to Base Plates of Post Nos. 17 through 22, Test No. CMGS-2



Figure 86. Damage to Base Plate Nos. 16 through 18 – After Soil Removal, Test No. CMGS-2



Figure 87. Damage to Post Nos. 17 through 22 Damage – After Soil Removal, Test No. CMGS-2



Figure 88. Culvert Deck after Removal of Soil Fill and Posts and Downstream Anchorage System Deformation, Test No. CMGS-2



Figure 89. Damage to Upstream Anchorage System, Test No. CMGS-2

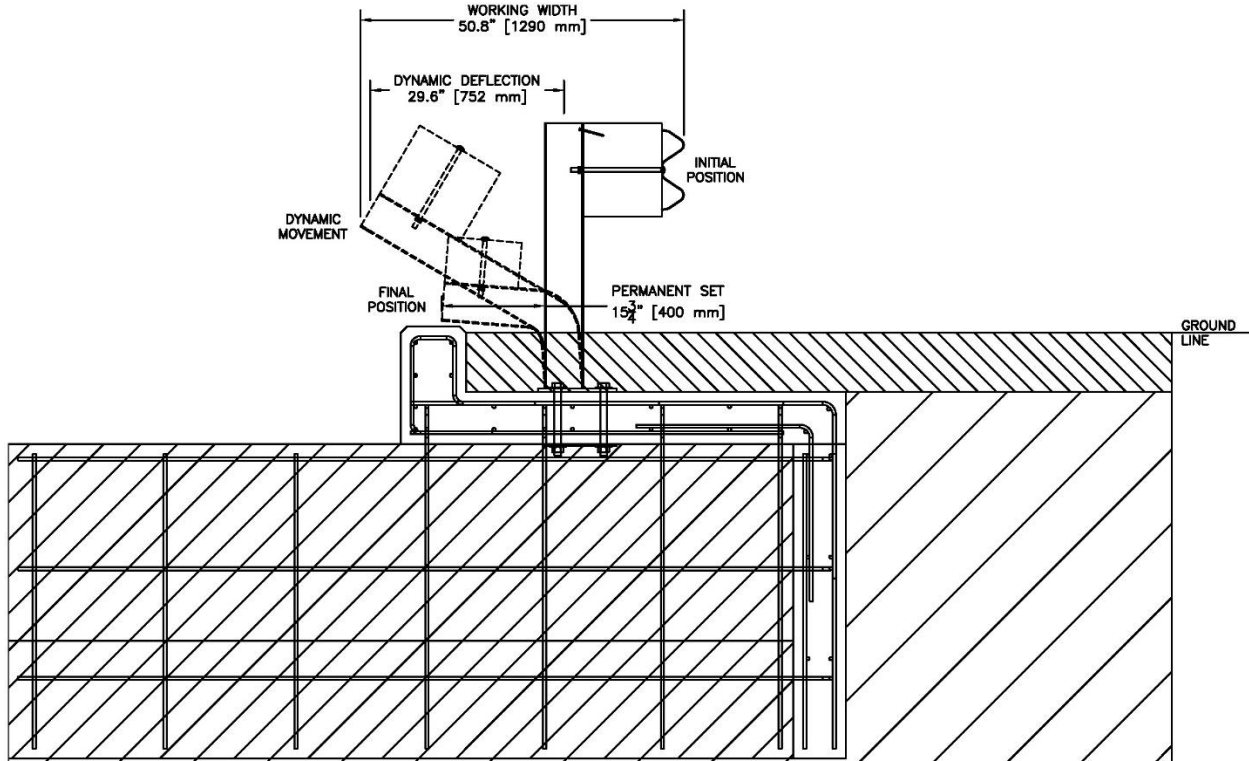


Figure 90. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. CMGS-2

6.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 91 through 95. The maximum occupant compartment deformations are listed in Table 11 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. Complete occupant compartment and vehicle deformations as well as the corresponding locations are provided in Appendix D.

The majority of the vehicle damage was concentrated on the right-front corner, where primary impact occurred. The vehicle's front bumper was crushed inward. The lower passenger side grille was broken. The front bumper cover was torn off except for the two bolts on the driver side. The vehicle right-front wheel was disengaged, and right-rear tire was deflated. The airbags did not deploy during the impact. The right corner of the rear bumper on the passenger side buckled inward and the rear corner of the right-rear fender was deformed from the impact with the barrier.

The roof, the hood, and the left side remained undamaged. The left-side and rear window glass also remained undamaged. The airbags did not deploy during the impact. The overall undercarriage damage included a 2-in. (51 mm) bend in the lower control arm, and the steering knuckle broke along with the steering arm on the passenger side. The front passenger-side brake line was disconnected. Interior occupant compartment deformations were moderate with a maximum of 1 1/8 in. (29 mm), which did not violate the limits established in MASH 2016.



Figure 91. Vehicle Damage, Test No. CMGS-2



Figure 92. Additional Vehicle Damage, Test No. CMGS-2



Figure 93. Vehicle Windshield Damage, Test No. CMGS-2



Figure 94. Vehicle Occupant Compartment Damage, Test No. CMGS-2

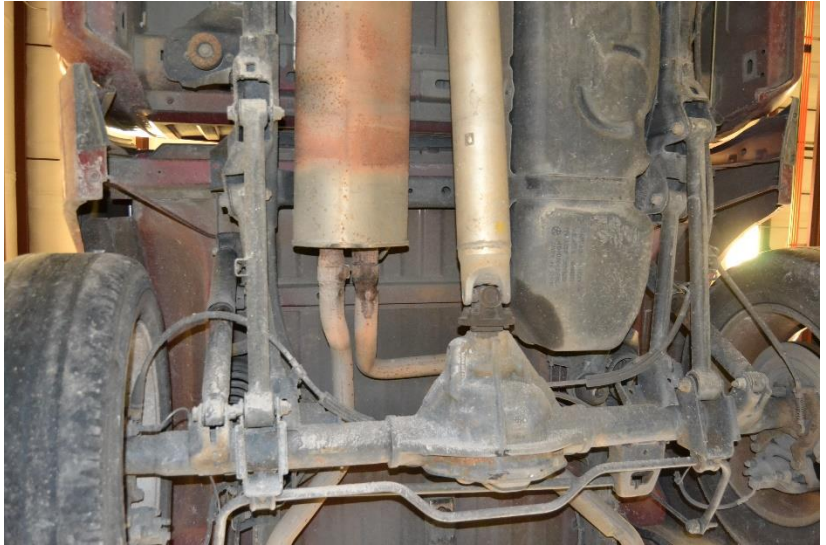


Figure 95. Vehicle Undercarriage Damage, Test No. CMGS-2

Table 11. Maximum Occupant Compartment Intrusions by Location, Test No. CMGS-2

| LOCATION | MAXIMUM INTRUSION in. (mm) | MASH ALLOWABLE INTRUSION in. (mm) |
|---|--|---|
| Wheel Well & Toe Pan | ½ (13) | ≤ 9 (229) |
| Floor Pan & Transmission Tunnel | ½ (13) | ≤ 12 (305) |
| A-Pillar | ¾ (10) | ≤ 5 (127) |
| A-Pillar (Lateral) | ¼ (6) | ≤ 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) | 1⅛ (29) | ≤ 9 (229) |
| Side Door (Below Seat) | ¾ (19) | ≤ 12 (305) |
| Roof | ½ (13) | ≤ 4 (102) |
| Windshield | 0 | ≤ 3 (76) |
| Side Window | No shattering of side windows occurred | No shattering resulting from contact with structural member of test article |
| Dash | ¼ (6) | N/A ¹ |

N/A¹ – No MASH 2016 criteria exist for this location

6.6 Occupant Risk

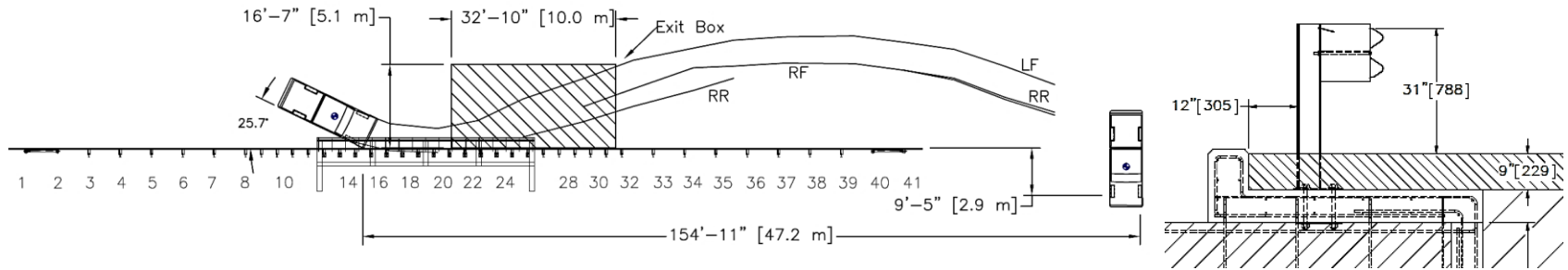
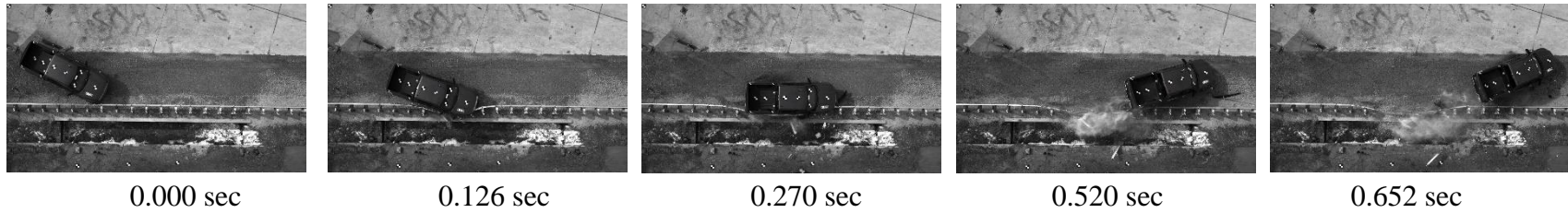
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 12. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 12. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 96. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix F.

Table 12. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. CMGS-2

| Evaluation Criteria | | Transducer | | MASH 2016 Limits |
|--|--------------|----------------|-------------------|------------------|
| | | SLICE-1 | SLICE-2 (Primary) | |
| OIV ft/s (m/s) | Longitudinal | -21.86 (-6.66) | -19.60 (-5.97) | ± 40 (12.2) |
| | Lateral | -15.36 (-4.68) | -16.58 (-5.05) | ± 40 (12.2) |
| ORA g's | Longitudinal | -12.88 | -13.78 | ± 20.49 |
| | Lateral | -11.05 | -10.24 | ± 20.49 |
| MAX ANGULAR DISPLACEMENT deg. | Roll | 22.6 | 15.4 | ± 75 |
| | Pitch | -7.9 | -9.5 | ± 75 |
| | Yaw | -57.0 | -57.4 | not required |
| THIV ft/s (m/s) | | 24.66 (7.52) | 23.68 (7.22) | not required |
| PHD g's | | 16.11 | 16.22 | not required |
| ASI | | 1.02 | 0.96 | not required |

6.7 Discussion

The analysis of the test results for test no. CMGS-2 showed that the strong post MGS attached to the culvert's top slab using through-bolts adequately contained and redirected the 2270P vehicle with controlled displacement of the barrier. A summary of the test results and sequential photographs are shown in Figure 96. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Two posts in the system were disengaged from their base plates and ejected laterally behind the barrier system. It is not anticipated that these disengaged posts would pose a hazard to other traffic, pedestrians, or work-zone personnel when ejected behind the system and into the flow channel of the culvert. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not 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 E, were deemed acceptable because they did not adversely influence occupant risk safety criteria nor cause rollover. After impact, the vehicle exited the barrier at an angle of 17.4 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. CMGS-2 conducted on the culvert mounted, strong post MGS was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.



- Test AgencyMwRSF
- Test Number..... CMGS-2
- Date.....2/14/2018
- MASH Test Designation No.3-11
- Test Article.....Culvert-Mounted, Strong Post MGS
- Total Length 182.3 ft (55.6 m)
- Distance between Posts and Headwall 12 in. (305 mm)
- Key Component – MGS Rail
 - Thickness 12 gauge (2.7 mm)
 - Top Mounting Height..... 31 in. (787 mm)
- Key Component – Steel Posts
 - Post Type W6x9 by 40½ in. (1,029 mm)
 - Post Spacing..... 37½ in. (952 mm) on center
- Soil TypeCompacted, coarse, crushed limestone
- Vehicle Make /Model..... 2010 Dodge Ram
 - Curb.....5,292 lb (2,400 kg)
 - Test Inertial.....5,013 lb (2,274 kg)
 - Gross Static.....5,175 lb (2,347 kg)
- Impact Conditions
 - Speed62.8 mph (101.1 km/h)
 - Angle 25.7 deg
 - Impact Location..... 129.1 in. (3,279 mm) upstream from post no. 19
- Impact Severity 124.7 kip-ft (169.1 kJ) > 106 kip-ft (144 kJ) Limit from MASH
- Exit Conditions
 - Speed33.1 mph (53.2 km/h)
 - Angle 17.4 deg
- Exit Box CriterionPass
- Vehicle Stability..... Satisfactory
- Vehicle Stopping Distance 173 ft - 6 in. (52.9 m) Downstream within the system
- Vehicle DamageModerate

- VDS [14] 1-RFQ-6
- CDC [15]..... 1-RZAK-5
- Maximum Interior Deformation 1⅝ in. (29 mm)
- Test Article Damage Moderate
- Maximum Test Article Deflections
 - Dynamic29.6 in. (752 mm)
 - Working Width..... 50.8 in. (1,290 mm)
 - Permanent Set 15¾ in. (400 mm)
- Transducer Data

| Evaluation Criteria | | Transducer | | MASH 2016 Limit |
|-------------------------------------|--------------|-------------------|----------------|-----------------|
| | | SLICE-1 (primary) | SLICE-2 | |
| OIV ft/s (m/s) | Longitudinal | -21.86 (-6.66) | -19.60 (-5.97) | ± 40 (12.2) |
| | Lateral | -15.36 (-4.68) | -16.58 (-5.05) | ± 40 (12.2) |
| ORA g's | Longitudinal | -12.88 | -13.78 | ± 20.49 |
| | Lateral | -11.05 | -10.24 | ± 20.49 |
| MAX ANGULAR DISPLACEMENT deg. | Roll | 22.6 | 15.4 | ±75 |
| | Pitch | -7.9 | -9.5 | ±75 |
| | Yaw | -57.0 | -57.4 | not required |
| THIV – ft/s (m/s) | | 24.66 (7.52) | 23.68 (7.22) | not required |
| PHD – g's | | 16.11 | 16.22 | not required |
| ASI | | 1.02 | 0.96 | not required |

Figure 96. Summary of Test Results and Sequential Photographs, Test No. CMGS-2

7 STIFFNESS TRANSITION FROM MGS TO CULVERT-MOUNTED MGS

Following two successful full-scale crash tests on culvert-mounted MGS, it was desired to evaluate the performance of the transition between the standard MGS and the culvert-mounted MGS. This system installation consists of four sections, including the anchorage system, standard MGS, half-post spacing MGS, and culvert-mounted MGS, as shown in Figure 97.

The anchorage systems consisted of timber posts (post nos. 1 and 2, 40 and 41) measuring 5½ in. wide x 7½ in. deep x 46 in. long (140 mm wide x 191 mm deep x 1,168 mm long) and were placed in 6-ft (1.8-m) long steel foundation tubes. The timber BCT posts and foundation tubes were part of the end anchor systems that are representative of a tangent guardrail terminal. The safety performance of these downstream anchorage systems also has been evaluated to MASH through full-scale crash testing [16]. Alternative crashworthy anchorage systems, including energy-absorbing end terminals are also acceptable.

The culvert-mounted MGS, as described in detail in Section 3.2, consisted of MGS with a 31-in. top rail height, supported by fourteen steel W6x9 posts (post nos. 13 through 26), measuring 40½ in. (1,029 mm) long, spaced at 37½ in. (953 mm) on center, attached to a low-fill culvert's top slab with a 12-in. (305-mm) offset from the back of the post to the culvert headwall. For culvert-mounted MGS posts, the soil embedment depth was 9 in. (229 mm). Two successful crash tests were conducted according to MASH 2016 Test Level 3 impact safety criteria.

The standard MGS consisted of steel W6x8.5 guardrail posts measuring 6 ft (1.8 m) long with a top mounting rail height of 31 in. (787 mm). The posts were spaced at 75 in. (1,905 mm) on center with a soil embedment depth of 40 in. (1,016 mm). For posts within the MGS, 6-in. wide x 12-in. deep x 14¼-in. long (152-mm wide x 305-mm deep x 362-mm long) wood spacer blockouts were used to offset the rail away from the front face of the steel posts. The standard MGS has been previously successfully crash tested to MASH TL-3 criteria [17-18].

The half-post spacing MGS was identical to the standard MGS except that the original guardrail system utilizes a post spacing of 37½ in. (953 mm) on center. This configuration was previously considered crashworthy under NCHRP Report No. 350 evaluation criteria and was carried over to the design evaluated herein to provide for a more conservative transition between standard MGS and the culvert-mounted system. However, half-post spacing MGS has not been successfully evaluated to MASH 2016. Thus, it desired to compare the behavior of standard 40-in. (1,016-mm) embedded posts to the culvert-mounted posts to verify that the behavior of half-post spacing MGS and the transition between half-post spacing MGS and culvert-mounted MGS would be similar.

When transitioning from the standard MGS to half-post spacing MGS, the reduced post spacing increases the system stiffness, and consequently, potential for vehicle snag. Therefore, further investigation was needed to confirm the safety performance of the transition in redirection of vehicles. Additionally, it was unknown if there was a change in system stiffness when transitioning from the half-post spacing MGS with 40-in (1,016-mm) soil embedded posts to culvert-mounted MGS with 9-in (229-mm) soil embedded post. Thus, further analysis was conducted to evaluate these two transitions: (1) transition from standard MGS to half-post spacing MGS; and (2) transition from half-post spacing MGS to culvert-mounted MGS.

It should be noted that, recent full-scale crash testing of stiffened or reduced deflection MGS systems have resulted in rail ruptures. Texas A&M Transportation Institute (TTI) has recently conducted testing on the MGS with reduced post spacing and transitions from standard post spacing to reduced post spacing. TTI researchers first evaluated a quarter-post spacing system (18¾ in.) with MASH test designation nos. 3-11 and 3-10. The quarter-post spacing system successfully passed both MASH tests. TTI researchers also tested a transition between quarter-(18¾ in.) and full-(75 in.) spacing according to MASH test designation no. 3-21 impact conditions. This transition used single, W-beam rail elements and did not incorporate any nested rail sections. In this test, the pickup truck ruptured the rail and penetrated beyond the barrier. TTI researchers attributed the failure to rail pocketing caused by the short transition in lateral barrier stiffness. Finally, TTI researchers also tested a half-post spacing (37½ in.) variation of the MGS under this project. In this test, the pickup truck ruptured the rail and penetrated beyond the barrier. Published reports for these research efforts are not yet available and are not referenced herein.

These recent test failures involving 2270P impacts into the MGS with reduced post spacing suggests that there is potential for rail failure during impacts into stiffened MGS applications and/or applications where increased localized rail deflection and pocketing may occur.

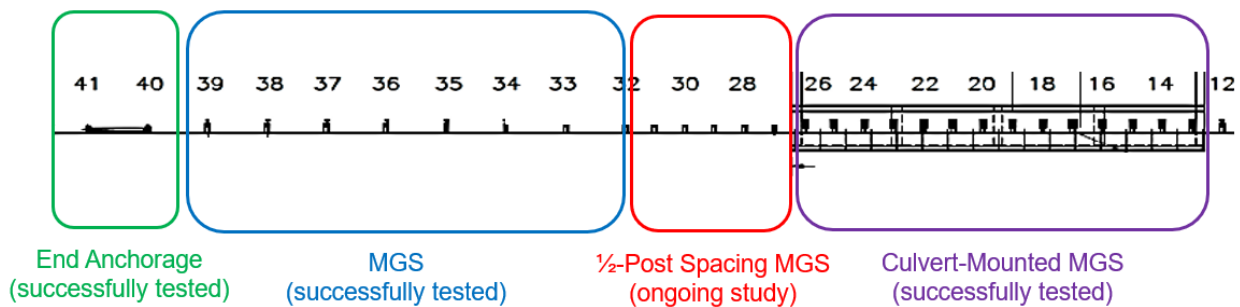


Figure 97. System Sections within Test Installation

7.1 Transition from Half-Post Spacing MGS to Culvert-Mounted MGS

For the stiffness transition from culvert-mounted posts to soil-embedded posts within the MGS, the load-deflection curve of each post is the key parameter to determine its resistance. The load-deflection curves from previous W6x8.5 posts embedded 40 in. (1,016 mm) in soil were compared to a W6x9 culvert-mounted post.

MwRSF researchers previously conducted a similar component test, namely, test no. CGSA-4, which was conducted on an ASTM A992 W6x9 (W152x13.4) steel post with the same geometry of the culvert-mounted posts in test no. CMGS-2, as shown in Figure 98a [7]. The post was bolted on the concrete grade. The impact height for the CGSA-4 post was 30⅝ in. (778 mm), which would correspond to an impact height of 21⅝ in. (549 mm) above grade for a 9-in (229 mm) embedment. Component level bogie tests, test nos. MH-1 and MH-4 had been previously conducted on a similar post embedded 40 in. (1,016 mm) in soil, as shown in Figure 98b. Details of these tests can be found in reports [19-20]. The bogie test key parameters are summarized in Table 13. The load- and energy-deflection results are plotted in Figures 99 and 100, respectively. Note that the force and deflection data from test no. CGSA-4 was adjusted to account for the

difference in impact height between the two tests. In test no. CGSA-4, the post was bolted to the concrete, and upon impact the bogie had large vibrations, as shown in Figure 99, whereas in test nos. MH-1 and MH-4, the soil damped out some of the bogie vibrations, so less force variation occurred.

The culvert-mounted post and standard 40-in. (1,016-mm) embedded posts had very similar average forces, as shown in Table 13 and Figure 99. Additionally, the culvert-mounted post had nearly identical energy dissipation to the standard posts. Based on the similar stiffness and energy dissipation between the culvert mounted post and standard guardrail posts, it was believed that no stiffness transition would be required between the standard 40-in. (1,016-mm) embedded posts at half-post spacing and the culvert-mounted posts as half-post spacing.



Figure 98. (a) Soil Embedment Post Test Nos. MH-1 and MH-4; (b) Concrete-Mounted Post Test No. CGSA-4

Table 13. Load-Deflection Comparison

| Test No. | Embedment Depth in. (mm) | Actual Impact Height in. (mm) | Steel Post Size | Post Grade | Impact speed mph (km/h) | Bogie Weight lb (kg) | Peak Force Kips (kN) | Average Force kips (kN) at displacement | | |
|----------|--------------------------|--------------------------------------|--------------------|------------|-------------------------|----------------------|----------------------|---|-------------|------------|
| | | | | | | | | 10 in. | 15 in. | 20 in. |
| MH-1 | 40.0 (1,016) | 24 ⁷ / ₈ (632) | W6x8.5 (W152x12.6) | A36 | 20.0 (32.2) | 1,745 (792) | 14.0 (62.3) | 9.8 (43.6) | 9.5 (42.3) | 8.8 (39.1) |
| MH-4 | 40.0 (1,016) | 24 ⁷ / ₈ (632) | W6x8.5 (W152x12.6) | A36 | 20.0 (32.2) | 1,745 (792) | 12.9 (57.4) | 9.6 (42.7) | 9.5 (42.3) | 8.9 (39.6) |
| CGSA-4 | N.A.* | 30 ³ / ₈ (778) | W6x9 (W152x13.4) | A992 | 10.0 (16) | 4,888 (2217) | 19.0 (85.3) | 10.7 (47.6) | 10.9 (48.4) | 9.8 (43.6) |

*N.A. = not available on bolted connection

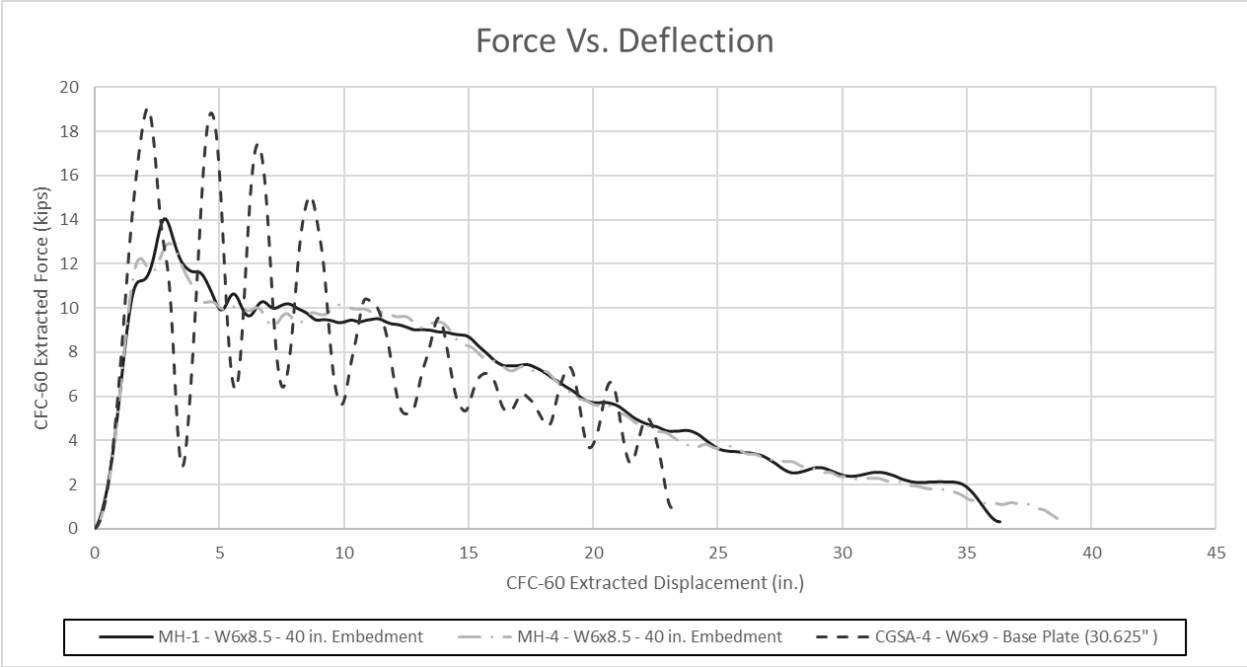


Figure 99. Load-Deflection Curves Comparison

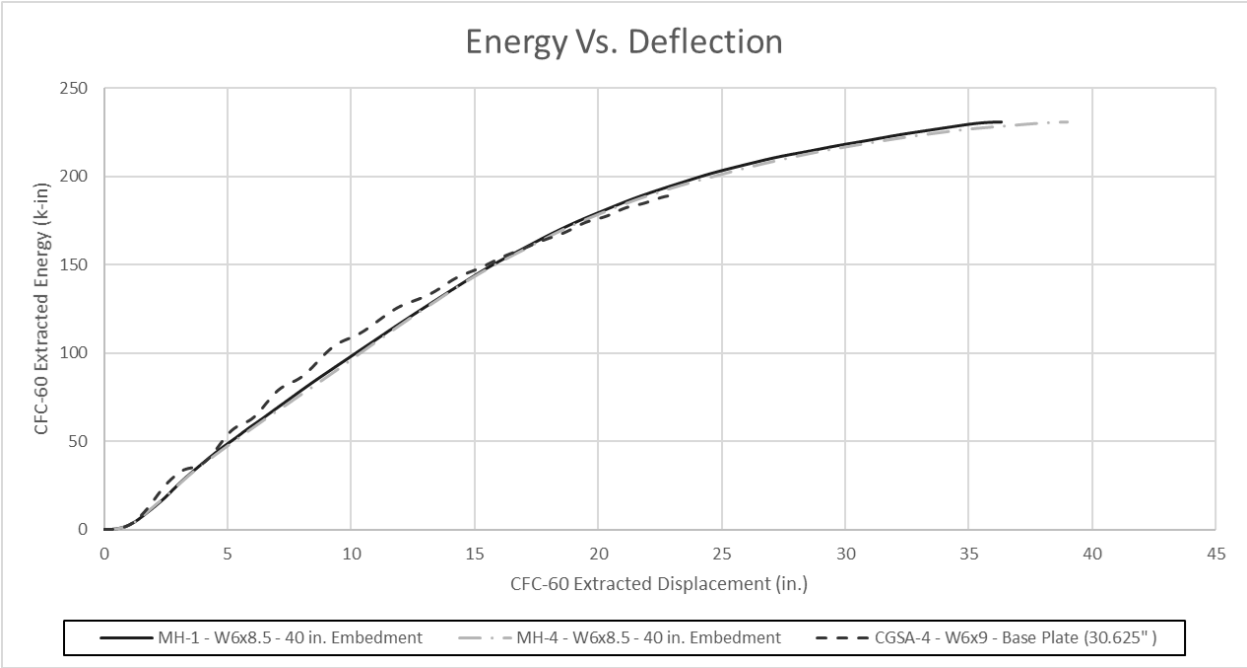


Figure 100. Energy-Deflection Curves Comparison

7.2 Transition from Standard MGS to Half-Post Spacing MGS

In transition from the standard MGS to half-post spacing MGS, the potential for rail pocketing, wheel snag, and higher accelerations exists due to the increased barrier stiffness of the half-post spacing region. MwRSF researchers previously conducted research and full-scale crash testing of a similar MGS transition, namely, test no. MWTSP-2 [21].

In test no. MWTSP-2, an upstream stiffness transition between the MGS and a thrie beam approach guardrail transition was crash tested according to TL-3 safety performance criteria set forth in MASH 2009, as shown in Figure 101. The barrier was constructed with several components, including (1) standard W-beam rail; (2) asymmetrical, W-beam to thrie-beam transition element; (3) standard thrie-beam guardrail; (4) nested thrie-beam guardrail; and (5) thrie-beam and channel bridge railing system, as shown in Figure 102a. All guardrails had a top rail height of 31 in. (787 mm). Post nos. 1 through 8 and 8 through 12 were ASTM A36 W6x9 posts embedded 40 in. (1,016 mm) and were spaced 75 in. (1,905 mm) and 37½ in. (953 mm), respectively. In test no. MWTSP-2, a 5,158-lb (2,340-kg) pickup truck impacted the upstream stiffness transition at a speed of 61.2 mph (98.5 km/h) and at an angle of 26.3 degrees. The barrier was impacted in the span where the full post spacing MGS approached the half-post spacing MGS 37.5 in. (953 mm) upstream from post no. 8), as shown in Figure 102b, which was determined to be the critical impact point for snag and rail pocketing based on a Barrier VII analysis. In test no. MWTSP-2, the pickup truck was safely contained, and test no. MWTSP-2 was determined to be acceptable according to test designation no. 3-21 of MASH.

The transition in test no. MWTSP-2 is similar to the transition between standard MGS and half-post spacing MGS in terms of the post configuration and rail section. Thus, test no. MWTSP-2 was considered as a reference to evaluate the transition from standard MGS to half-post spacing MGS within the test installation in test nos. CMGS-1 and CMGS-2. Since test no. MWTSP-2 was tested to be at a critical point for snag and rail pocketing relative to the transition from standard MGS and half-post spacing MGS and it was successful, it was also believed that the standard MGS to half-post spacing MGS utilized upstream of the culvert-mounted MGS would also be adequate. Therefore, the transition between standard MGS and half-post spacing MGS was believed to not expose errant vehicles to any additional hazards. Additionally, numerical simulations were carried out to confirm the critical impact point and evaluate the need for a separate transition from standard MGS to half-post spacing MGS.

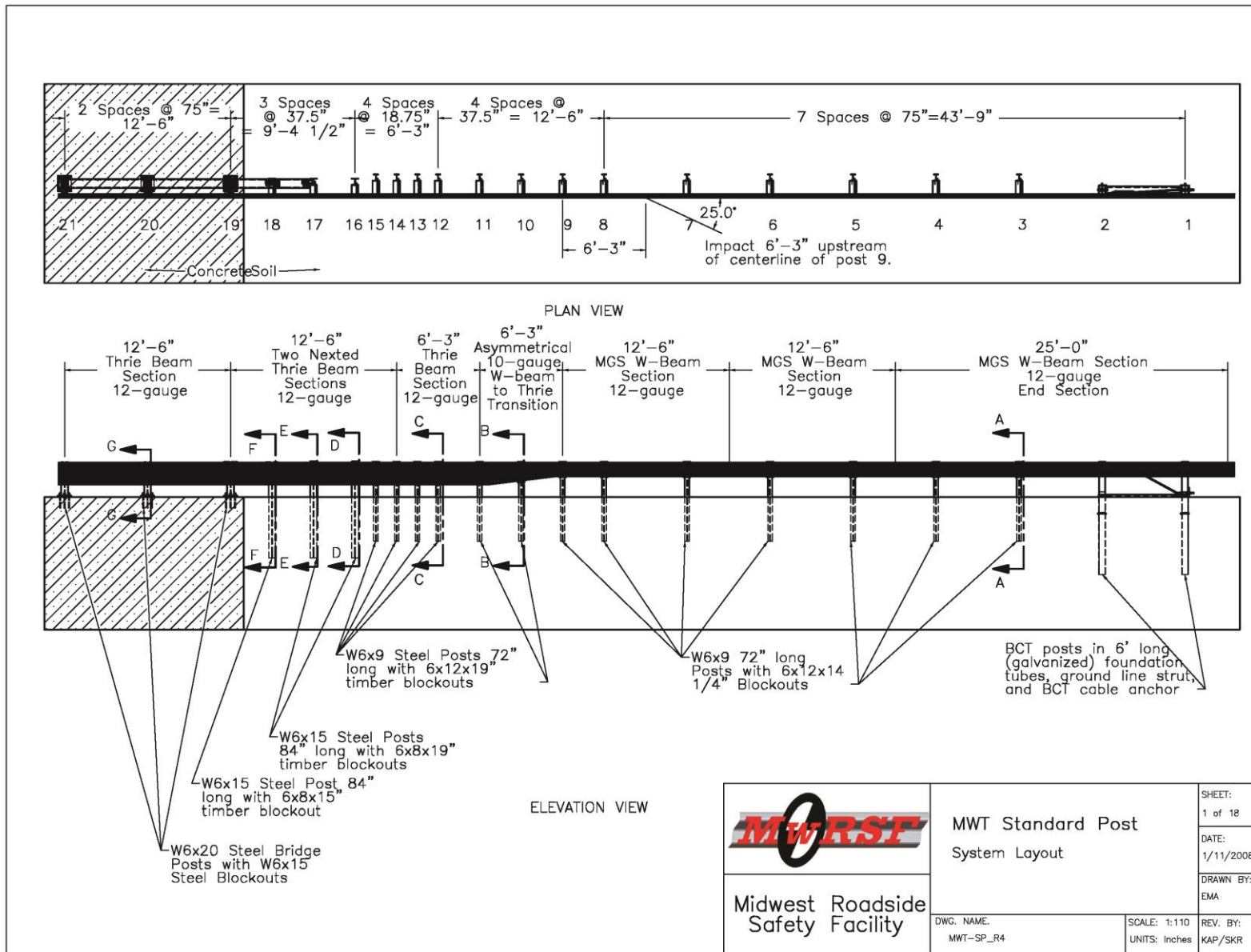
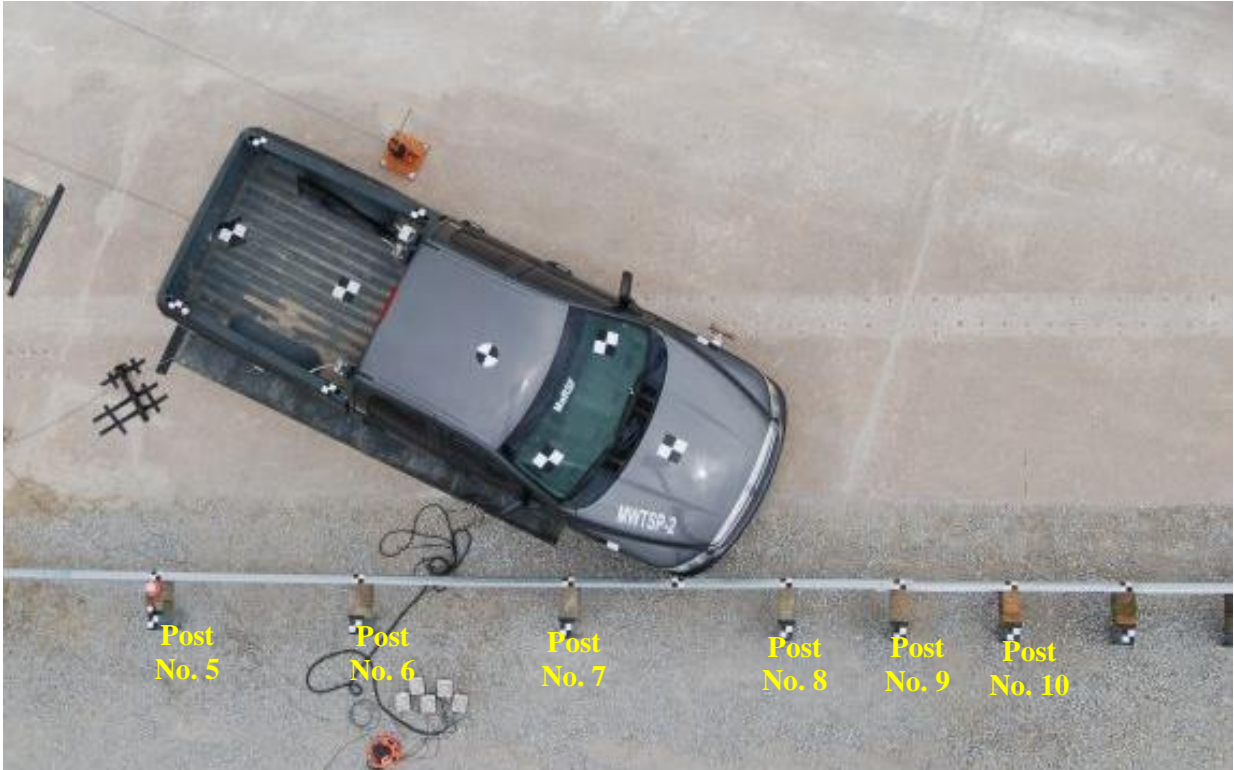


Figure 101. System Details and Layout, Test No. MWTSP-2



(a)



(b)

Figure 102. (a) System Installation; (b) Impact Location, Test No. MWTSP-2

7.2.1 Evaluation of MGS to Half-Post Spacing MGS

A baseline simulation of MGS was modified to simulate the culvert-mounted MGS impacted by a 2270P pickup truck and was compared to crash test no. CMGS-2 [22]. Then, several impact points in the transition area from full-post spacing MGS to half-post spacing MGS were evaluated. The analysis focused on impacts with the 2270P vehicle as the pickup truck was expected to deflect the barrier more as compared to the small car, leading to increased pocketing and vehicle snag in the transition region. Two cases with and without wheel and tire disengagement were considered in order to bracket the simulation analysis.

7.2.2 Simulation of Culvert-Mounted Midwest Guardrail System

The culvert-mounted MGS model was developed by modifying the standard MGS model. The standard MGS model consisted of twenty-nine steel posts with a 75 in. (1,905 mm) post spacing. The soil was modeled with soil springs in both guardrail longitudinal and lateral directions that provided equivalent resistance to soil. The standard MGS model was validated in a previous project using NCHRP Report No. W179 procedures for verification and validation of computer simulations used for roadside safety applications [22]. The standard MGS model was modified by reducing the post spacing at the culvert location and the transition areas, as shown in Figure 103, to represent test installation in test no. CMGS-2. The culvert-mounted MGS consisted of a total of forty-one steel posts. The standard post spacing of 75 in. (1,905 mm) occurred from post nos. 1 through 8 and 32 through 41. The reduced post span length of 37½ in. (952.5 mm) occurred from post nos. 8 through 32 at the culvert and the transition. The bolted connections between culvert-mounted post base plates and the culvert were explicitly modeled. The welds between the culvert-mounted posts and base plates were simplified by merging nodes between the two parts, as shown in Figure 104. Since no damage occurred to the culvert in test nos. CMGS-1 and CMGS-2, the culvert was modeled with rigid material. The parts, elements, and materials used in the culvert-mounted MGS model are shown in Table 14. Note that the components added to the existing standard MGS model are described in Table 14. Further details of the baseline MGS model can be found in NCHRP Report No. W179 [22].

The reduced-element, 2270P Chevrolet Silverado pickup truck model, originally developed by the National Crash Analysis Center (NCAC) and modified by MwRSF, was previously validated with an MGS test, test no. 2214MG-2 [17, 22]. The standard vehicle model does not incorporate failure in the suspension parts, nor tire deflation or wheel disengagement capacities. This vehicle model was used for the baseline culvert-mounted MGS model.

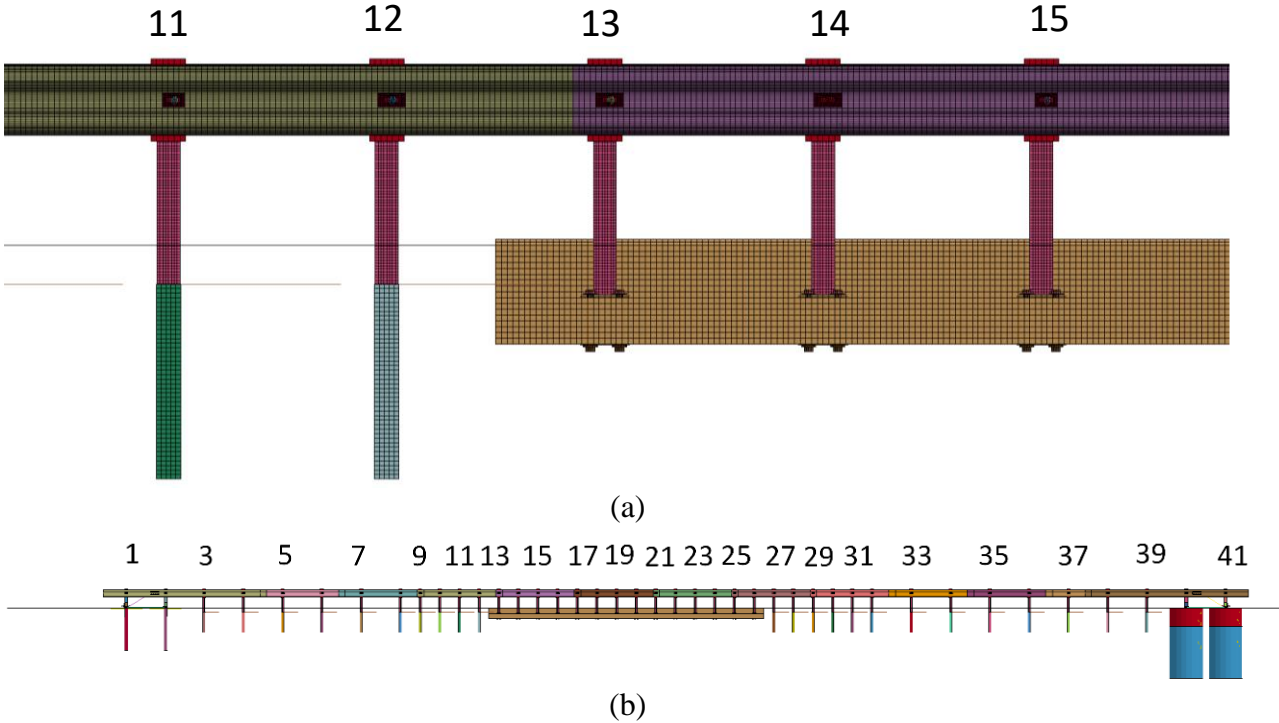


Figure 103. Culvert-Mounted MGS Model: (a) Transition from Half-Post Spacing MGS to Culvert-Mounted MGS; and (b) System Installation Model Overview

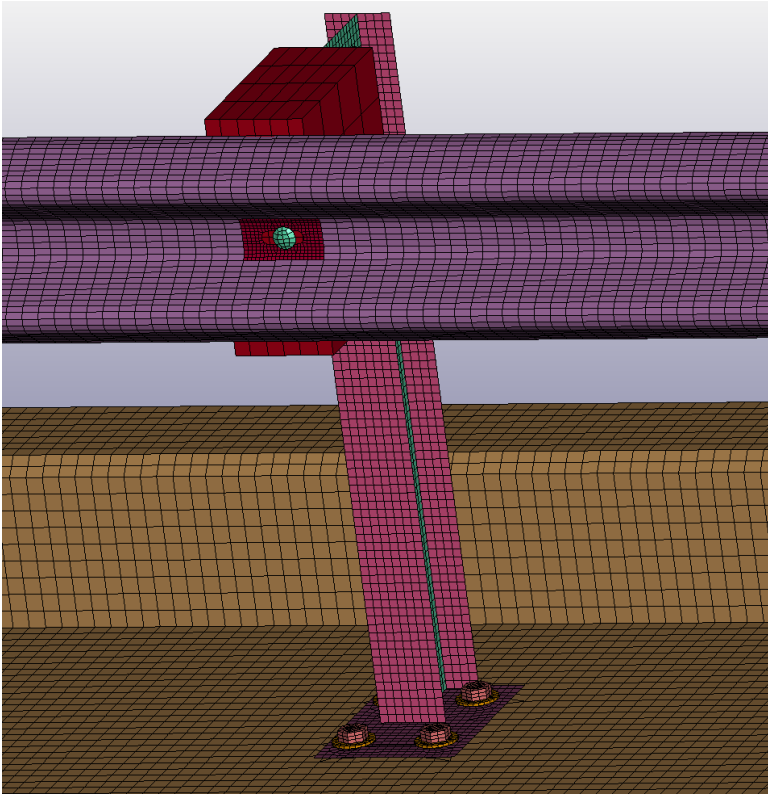


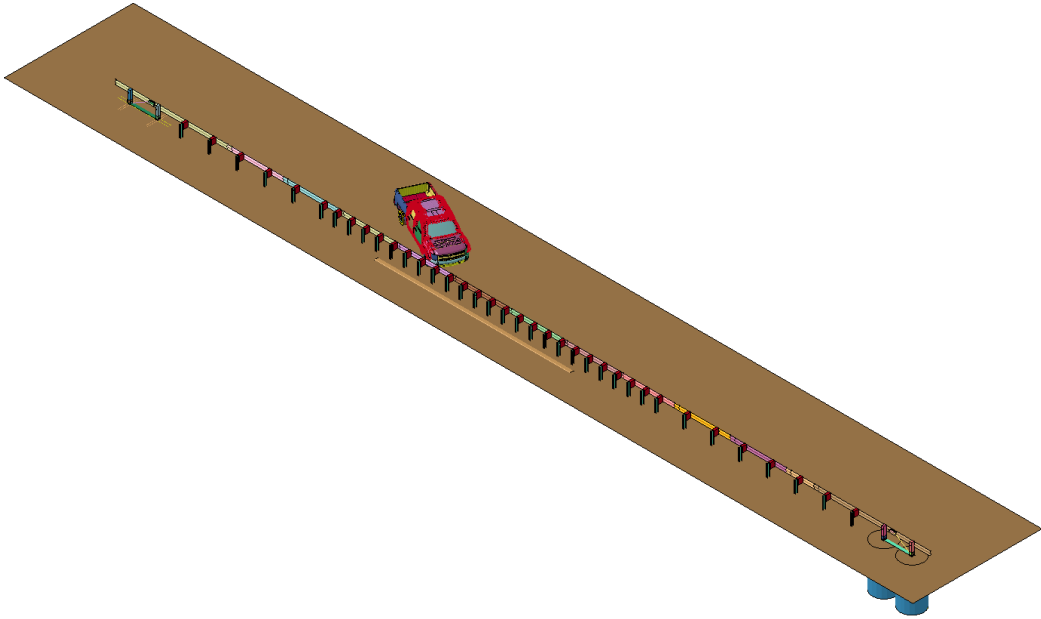
Figure 104. Culvert-Mounted Post Simulation Details

Table 14. List of Simulation Model Parts and LS-DYNA Parameters

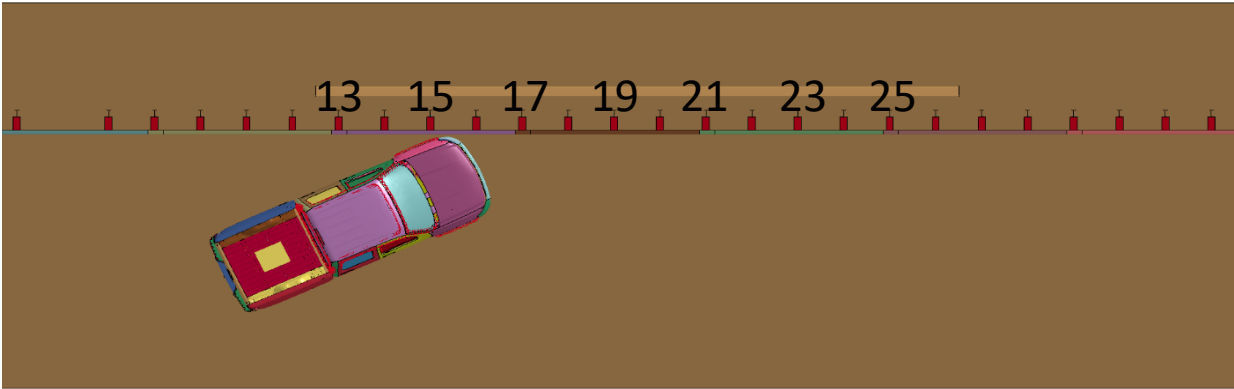
| Part Name | Element Type | Element Formulation | Material Type | Material Formulation |
|------------------|--------------|---------------------|------------------------|------------------------------|
| Concrete Culvert | Solid | Constant Stress | Normal Weight Concrete | Rigid Solid |
| Base plates | Shell | Hughes-Liu | ASTM A572 Steel | Piecewise, Linear Plasticity |
| Washers | Solid | Fully Integrated | ASTM F844 Steel | Piecewise, Linear Plasticity |
| Bolts | Solid | Fully Integrated | ASTM A307 Steel | Piecewise, Linear Plasticity |
| Nuts | Solid | Fully Integrated | A563 Steel | Piecewise, Linear Plasticity |

In test no. CMGS-2, the vehicle was a 5,013-lb (2,274-kg) Dodge Ram 1500, while the simulated vehicle was a 5,005-lb (2,270-kg) Chevrolet Silverado 1500. The impact angle and speed in the numerical model were 25 degrees and 62.8 mph (101.1 km/h), whereas the impact angle and speed in the test no. CMGS-2 were 25.7 degrees and 62.8 mph (101.1 km/h). The impact point in both test and numerical models was 129 in. (3,277 mm) upstream of post no. 19. The simulated system before the impact and the sequential comparison of test CMGS-2 and baseline CMGS simulation are shown in Figures 105 and 106, respectively.

The data obtained from test no. CMGS-2 was compared to the two baseline simulations' results: one with wheel disengagement and one without, as shown in Table 15. Specifically, change in velocities, deflections, and vehicle Euler angles were compared in detail.



(a)



(b)

Figure 105. LS-DYNA Model for Test No. CMGS-2: (a) Isometric View; and (b) Overhead View

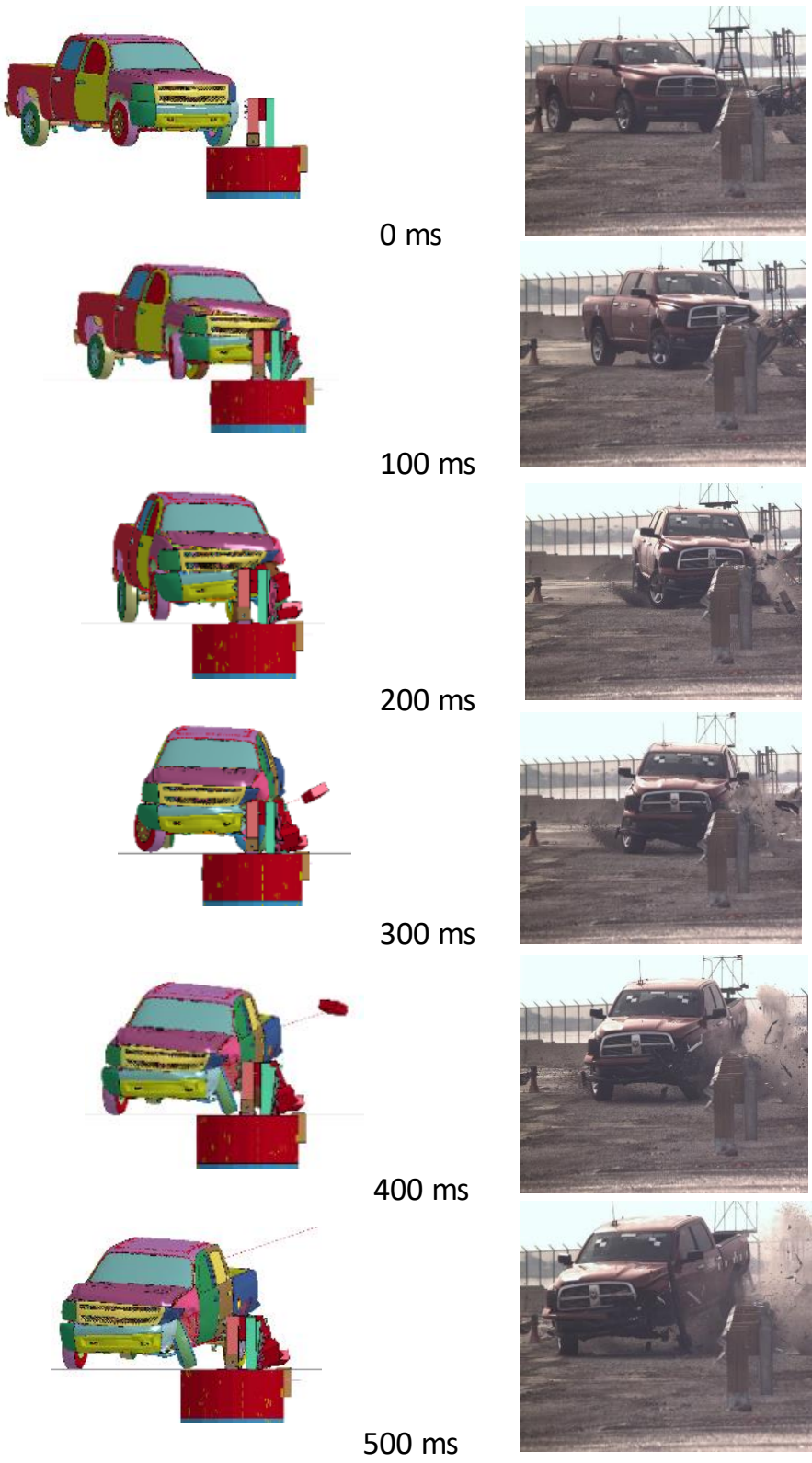


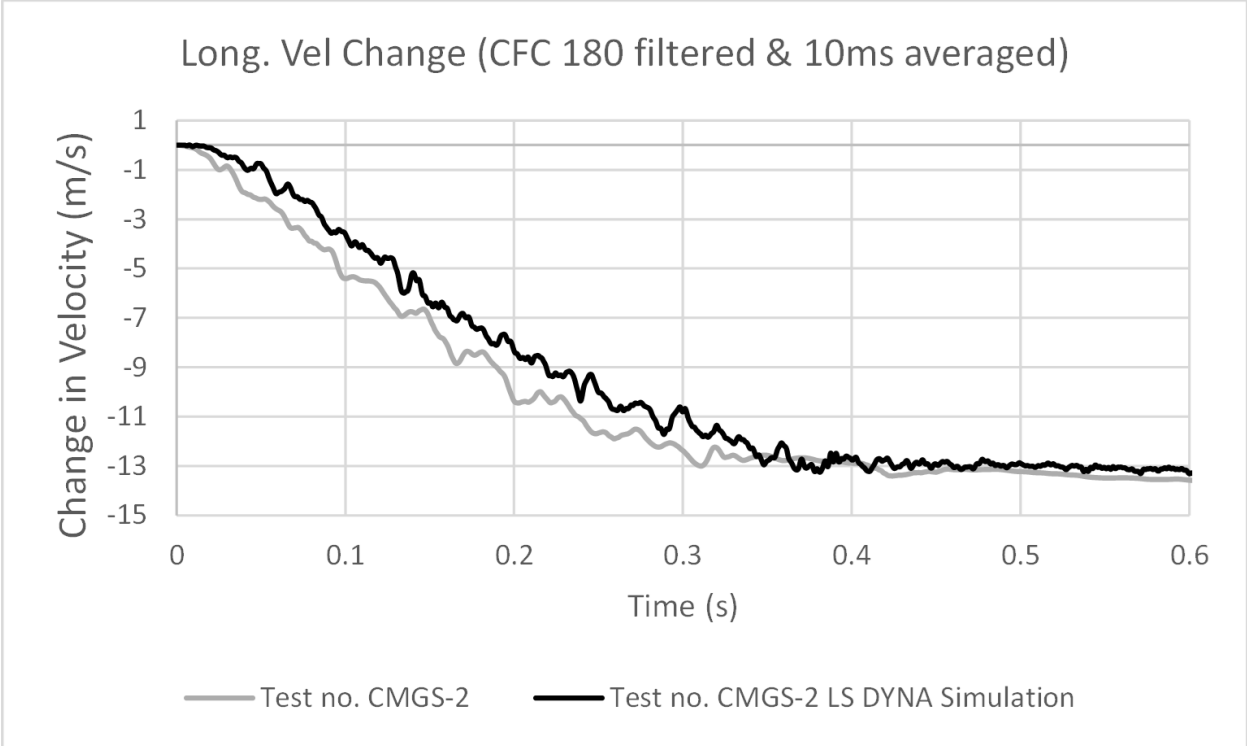
Figure 106. Downstream Vehicle Position Comparison, Baseline CMGS Simulation and Test No. CMGS-2

Table 15. Comparison of Test No. CMGS-2 and Simulation Results

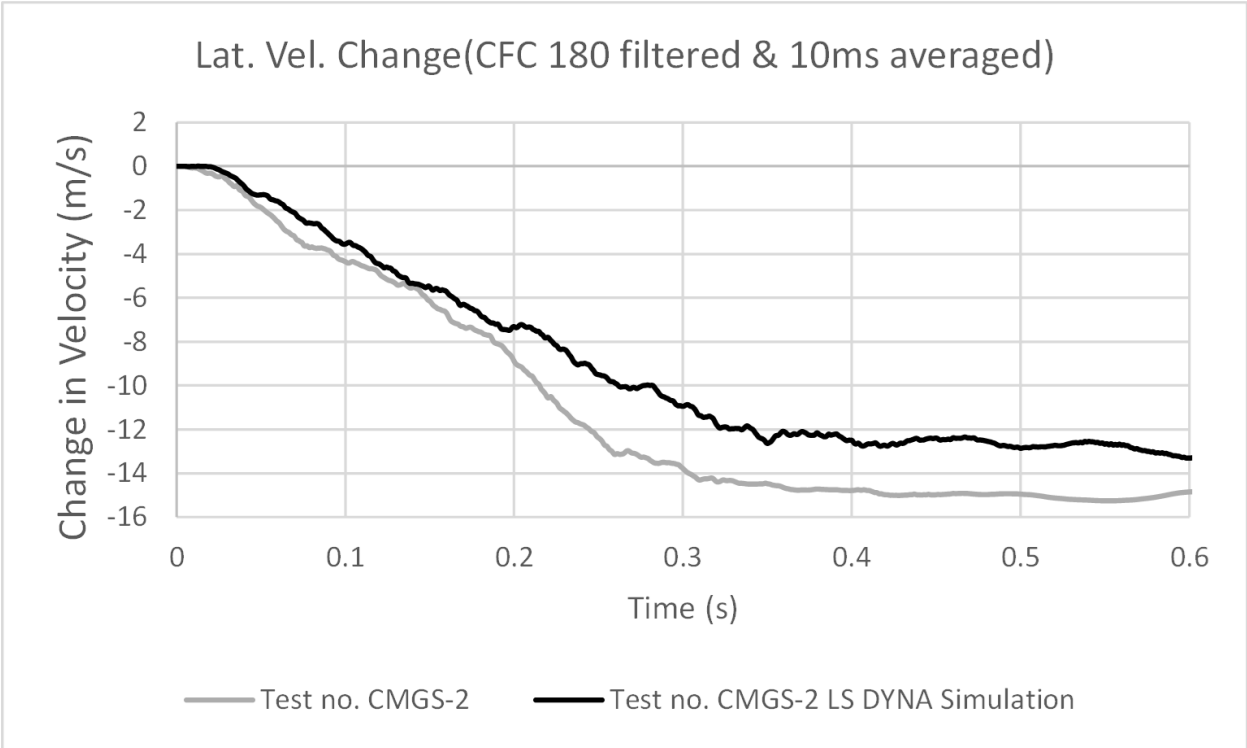
| | | Test | Simulation | Simulation |
|---|--|--------------------------|------------------------------|--------------------------------------|
| Parameters | | Test No. CMGS-2 | Baseline CMGS | Baseline CMGS Wheel Disengaged |
| Vehicle | Year, Make, and Model | 2010, Dodge, RAM 1500 | Chevrolet, Silverado 1500 | Chevrolet, Silverado 1500 |
| | Test Inertial Weight, lb (kg) | 5,013 (2,274) | 5,005 (2,270) | 5,005 (2,270) |
| Impact Conditions | Speed, mph (km/h) | 62.8 (101.1) | 62.8 (101.1) | 62.8 (101.1) |
| | Angle, deg | 25.7 | 25.0 | 25.0 |
| | Impact Point in. (mm), from upstream from Post 19 | 129.1 (3,279) | 129.0 (3,277) | 129.0 (3,277) |
| Impact Severity, kip-ft (kN-m) | | 124.7 (169.1) | 117.9 (159.9) | 117.9 (159.9) |
| Parallel Conditions | Speed, mph (km/h) | 36.9 (59.5) | 38.2 (61.5) | 39.6 (63.7) |
| | Time, ms | 270 | 253 | 250 |
| Exit Conditions | Speed, mph (km/h) | 33.1 (53.2) | 33.2 (53.4) | 33.2 (53.4) |
| | Angle, deg | 19.5 | 15.4 | 15.7 |
| | Time, (ms) | 520 | 660 | 620 |
| t*, seconds | | 0.1225 | 0.1324 | 0.1324 |
| ORA, g's | Longitudinal | -13.78 | -12.30 | -12.54 |
| | Lateral | -10.24 | -7.44 | -8.64 |
| OIV, ft/s (m/s) | Longitudinal | -19.60 (-6.0) | -19.03 (-5.8) | -19.03 (-5.8) |
| | Lateral | -16.58 (-5.1) | -17.39 (-5.3) | -17.4 (-5.3) |
| Test Article Deflection | Max Rail deflection, in. (mm) | 22.4 (569) | 25.3 (643) | 26.8 (681) |
| | Max Rail deflection Time, ms | 192 | 177 | 350 |
| | Max Post deflection, in. (mm) | 29.6 (752) | 15.3 (389) | 15.6 (396) |
| | Max Post deflection Time, ms | 137 | 110 | 110 |
| | Working Width, in. (mm) | 50.8 (1,290) | 42.5 (1,080) | 41.5 (1,054) |
| | Working Width Location (Post No.) | 17 | 18 | 18 |
| Euler Angles | Max Roll, Deg | 3.4 | 6.1 | 11.6 |
| | Max Roll Time, ms | 257 | 350 | 626 |
| | Max Pitch, Deg | -9.0 | -4.7 | -6.1 |
| | Max Pitch Time, ms | 600 | 360 | 473 |
| | Max Yaw, Deg | -40.7 | -40.7 | -42.2 |
| | Max Yaw Time, ms | 600 | 621 | 651 |
| Disengaged Post Nos. | | 18, 19 | N.A. | N.A. |
| Posts Impacted by Leading Tire | | 18, 19 | 17 through 21 | 17 through 21 |
| Deflected Posts | | 15 through 23 | 15 through 23 | 15 through 23 |
| Total Length of Vehicle Contact, in. (mm) | | 289 (7,341) | 300 (7,620) | 300 (7,620) |
| Time Leading Tire Disengaged, ms | | 155 | N.A. | 150-160 |

Initial comparisons were made between the full-scale crash test and the baseline simulation model without wheel disengagement. The maximum tested and simulated dynamic rail deflection was 22.4 in. (569 mm) and 25.3.8 in. (643 mm), respectively. The Euler angles for the test and the model also have similar results before the wheel completely disengaged during the test. As shown in Figure 107, the tested and simulated vehicle longitudinal velocity changes were similar. However, there was some discrepancy in the lateral velocity change after 200 ms. This discrepancy may have been caused by wheel disengagement during the test. Failure of control arms, wheels, and tires was not incorporated in the standard vehicle model, as it was computationally expensive and could not be reliably predicted.

The deflected rail shape for test no. CMGS-2 and the baseline simulation model without wheel disengagement were compared at 192 ms, when the maximum rail dynamic deflection occurred, as shown in Figure 108. The tested rail deflection was obtained using high-speed videos. The maximum tested and simulated rail deflections at 192 ms were generally in good agreement.



(a)



(b)

Figure 107. Velocity Comparison, Test and Baseline Simulation (No Wheel Disengagement): (a) Longitudinal Change in Velocity; (b) Lateral Change in Velocity

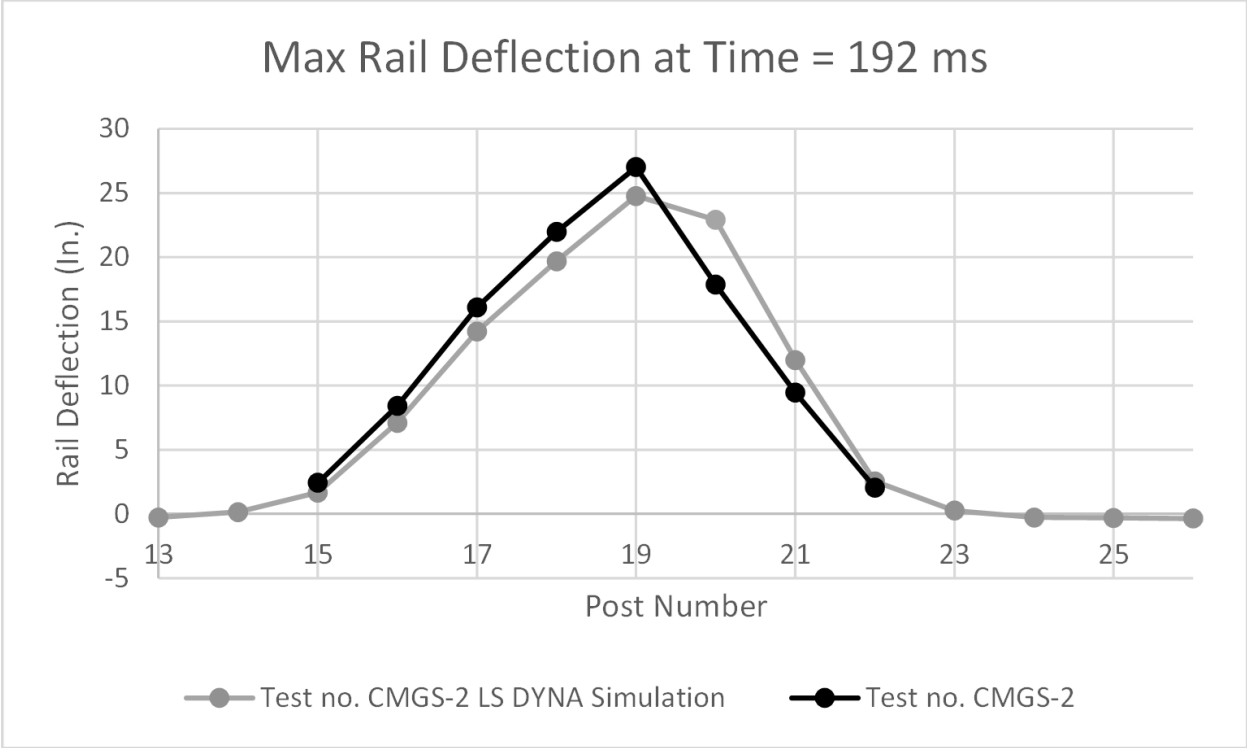


Figure 108. Deflection Comparison, Test and Baseline Simulation (No Wheel Disengagement)

The roll, pitch and yaw angles were compared between the test and baseline simulation model without wheel disengagement, as shown in Figure 109. The simulated vehicle had a maximum roll of 6.1 degrees, while the maximum vehicle roll during test no. CMGS-2 was 3.4 degrees while in contact with barrier, and 10.2 degrees after exiting the barrier. The simulated vehicle pitch was -4.6 degrees while it was still in contact with the barrier. Whereas the test vehicle pitch was -9.5 degrees after the vehicle exited the barrier. The simulated and test vehicle yaw angles agreed well until 300 ms but the difference remained within 20% until the simulated vehicle exited the barrier at 660 ms. Overall, the roll, pitch, and yaw in test no. CMGS-2 and simulation agreed well before 300 ms. However, after 300 ms, the trajectory of the vehicle in the test and simulation deviated.

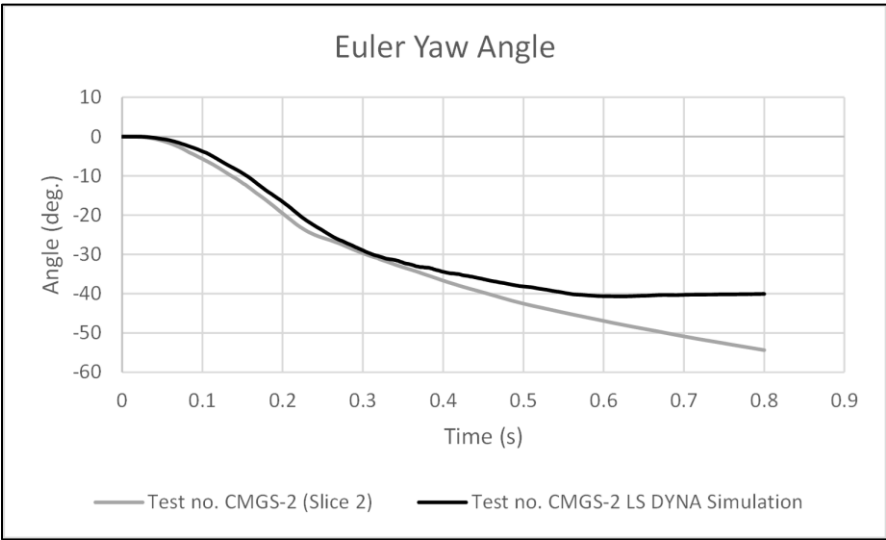
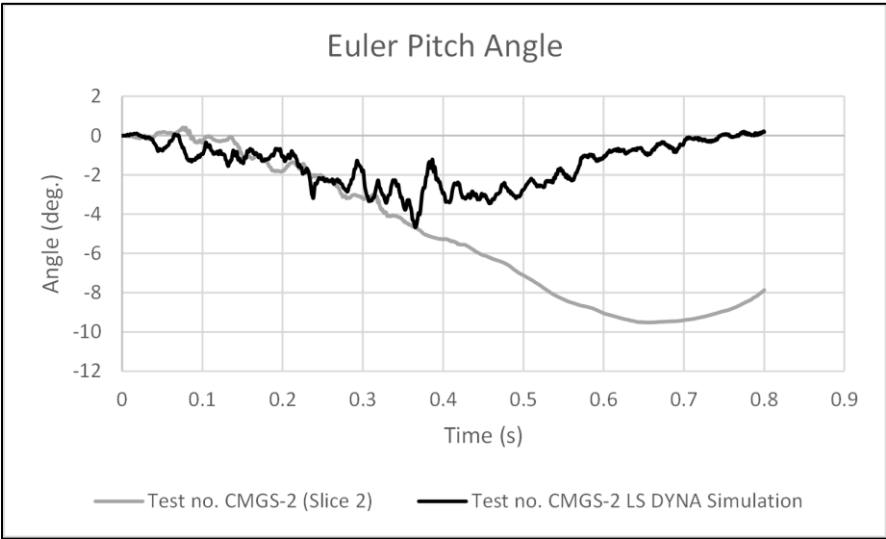
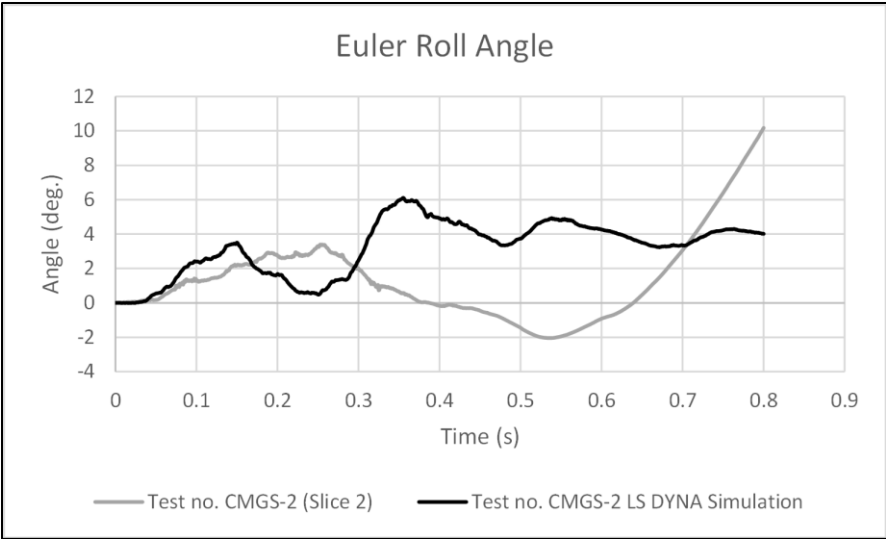


Figure 109. Roll, Pitch and Yaw Angles Comparison, Baseline Simulation

In test no. CMGS-2, the impact-side wheel of the test vehicle snagged on posts nos. 18 and 19 and was disengaged. However, the initial baseline model did not have wheel disengagement enabled. Thus, a modified model with wheel disengagement capabilities was configured. Note that failure of wheel and suspension parts cannot be reliably predicted. Thus, time-based failure was enabled in the vehicle model. This wheel disengagement model required a prescribed time to initialize the three-stage wheel disengagement process, which involves disengaging upper, lower, and steering control arms from the vehicle model. The disengagement time was estimated using test videos. Specifically, the front wheel at the guardrail side started disengaging at time 150 ms and the wheel was completely disengaged at time 160 ms. This wheel disengagement time corresponded to the approximate wheel disengagement time of 155 ms during the test. Other than the wheel disengagement, everything else in the barrier and vehicle models was kept the same with the initial baseline model. Sequential time comparisons of the baseline model without wheel disengagement, the modified model with wheel disengagement, and test no. CMGS-2 are shown in Figure 110.

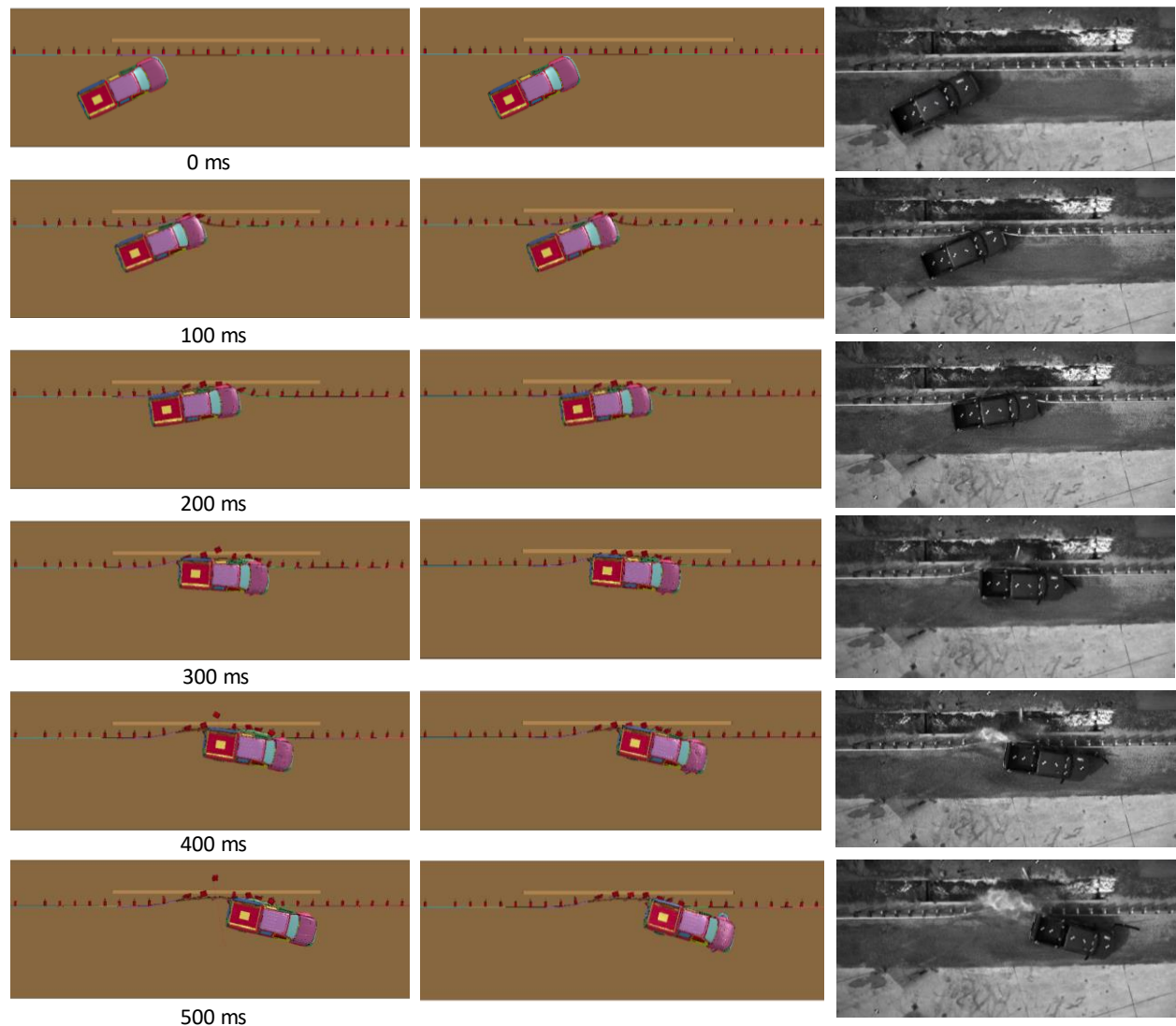


Figure 110. Simulation without Wheel Disengagement (Left), Simulation with Wheel Disengaged (Middle), and Test No. CMGS-2 (Right)

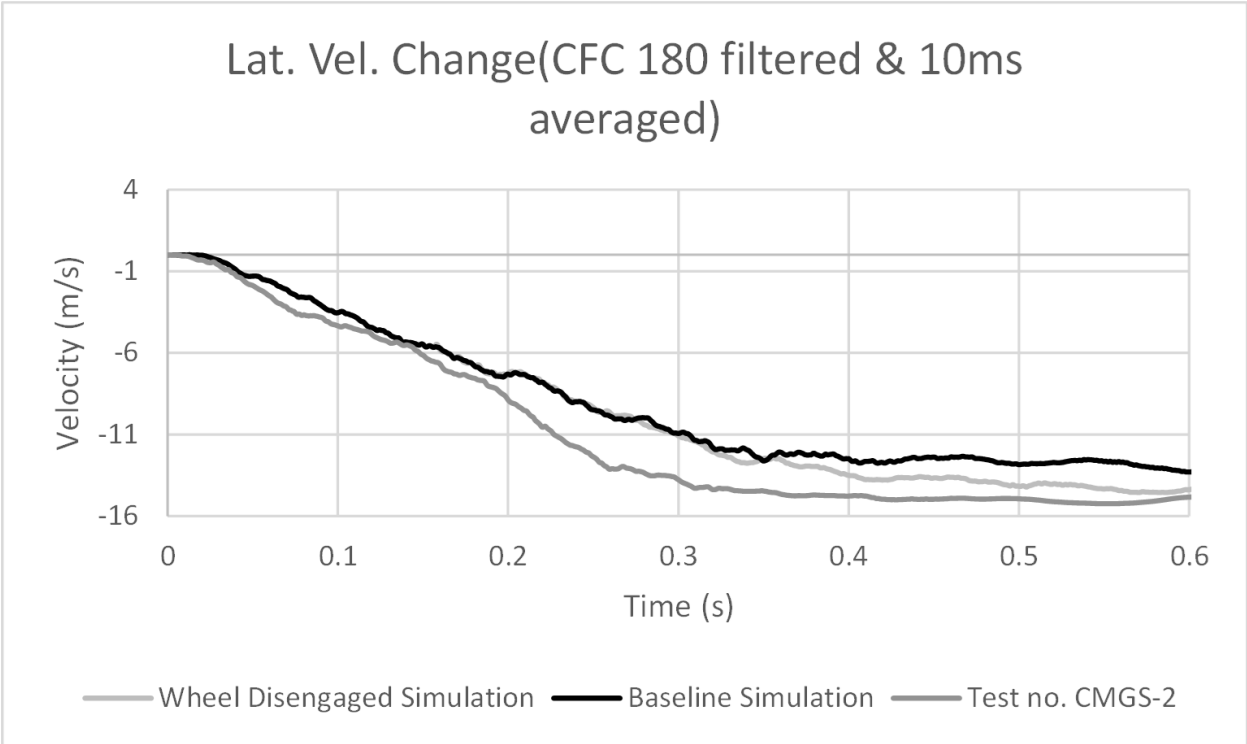
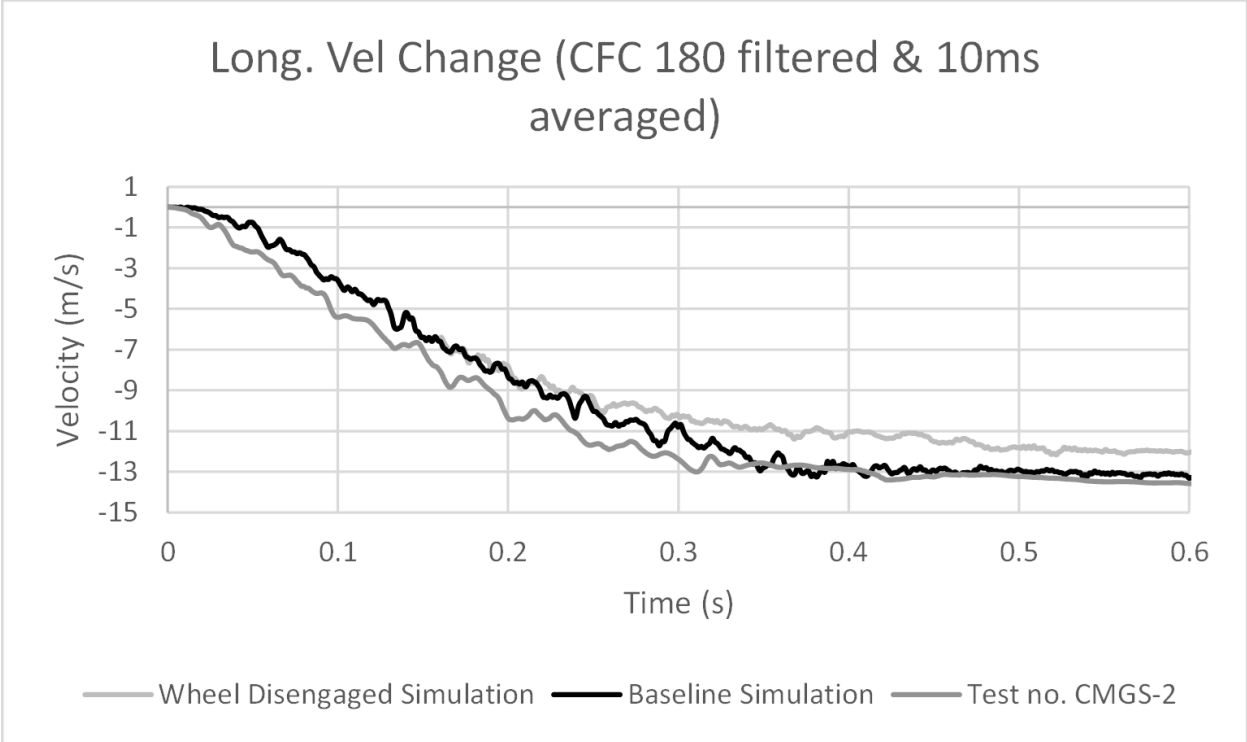


Figure 111. Change of Velocity Comparison, Baseline and Wheel Disengaged Models

The lateral change in velocity in the wheel disengaged model was closer to test no. CMGS-2 than the baseline model, as shown in Figure 111. However, the longitudinal change in velocity deviated more significantly. Additionally, several other wheel failure times were explored, but

none of them were able to replicate the wheel disengagement behavior that occurred in test no. CMGS-2.

Important metrics were similar in Table 15, and the tested and simulated velocity and Euler angle curves also agreed well. However, the wheel disengaged during test no. CMGS-2, and the current modeling techniques could not replicate the wheel disengagement. Note that the baseline model accurately represented rail deformation and deflection, which was believed to be the most important metric when evaluating the transition. Additionally, the standard MGS model had been previously validated, and the impact points for the transition areas were located near the standard MGS. Thus, the culvert MGS model was considered sufficient to evaluate the impact point in transition between the standard MGS to half-post spacing MGS.

7.2.3 Determination of Critical Impact Point

After development of the culvert-mounted MGS model, eight impact points at the transition area from standard MGS to half-post spacing MGS were simulated, as illustrated in Figure 112. The detailed results are summarized in Table 16.

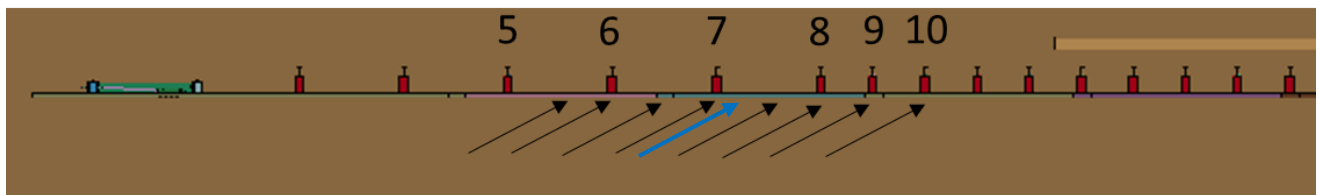


Figure 112. Illustration of Impact Points at Transition from Standard MGS to Half-Post Spacing MGS with Critical Impact Point Denoted in Blue

Starting from the midspan of post nos. 5 and 6, eight impact points were selected at an interval of $37\frac{1}{2}$ in. (953 mm) through post no. 10. The results of eight cases are summarized and compared to the baseline model in Table 16. As shown in Table 16, longitudinal ORA at the midspan of post nos. 7 and 8 had the largest value, which corresponded with significant wheel snag. At this impact point, other metrics including OIV (both lateral and longitudinal), anchor force, roll and pitch angles also had higher values. Thus, the critical impact point in this transition area was determined as the mid-span of post nos. 7 and 8 (i.e., $37\frac{1}{2}$ in. (953 mm) from the first reduced span post).

This critical impact point was the same as impact point in test no. MWTSP-2. Since test no. MWTSP-2 was successful and had similar post sections, posts spacing, and rail sections in the impact region, the standard MGS to half-post spacing MGS transition region was believed to not expose errant vehicles to any additional hazards. Thus, a separate transition was not believed to be necessary between standard MGS and half-post spacing MGS based on the simulation analysis and comparison with existing test no. MWTSP-2. However, as noted previously, recent research at TTI with reduced post spacings suggests that the potential for rail rupture exists in regions with reduced posts spacings or transitions in post spacing under MASH TL-3 impact conditions. Thus, the researchers finding that a separate transition region is not needed between the standard MGS and half-post spacing MGS may need revision based on new full-scale crash test results or further findings from the ongoing TTI studies.

Table 16. Transition Simulated Impacts Comparison

| Comparison of Results | | Stiffness Transition Simulations | | | | | | | | Baseline Simulation |
|--------------------------------|--|----------------------------------|---------------|---------------|---------------|---------------|---------------|----------------|----------------|---------------------|
| Vehicle | Year, Make, Model | Chevy, Silverado 1500 | | | | | | | | |
| | Test Inertial Weight, lb (kg) | 5005 (2270) | | | | | | | | |
| Impact Conditions | Speed, mph (km/h) | 62.1 (100.0) | | | | | | | | 62.8 (101.1) |
| | Angle, Deg | 25 | | | | | | | | |
| | Impact Post No. | 5.5* | 6 | 6.5 | 7 | 7.5 | 8 | 9 | 10 | 15.57 |
| Impact Severity, kip-ft (kN-m) | | 115.2 (156.3) | | | | | | | | 117.9 (159.8) |
| Parallel Conditions | Speed, mph (km/h) | 43.8 (70.5) | 37.0 (59.5) | 40.7 (65.5) | 40.7 (65.5) | 39.2 (63.1) | 39.2 (63.1) | 38.4 (61.8) | 40.0 (64.4) | 37.5 (60.3) |
| | Time, ms | 258 | 258 | 252 | 255 | 254 | 254 | 268 | 263 | 250 |
| t*, seconds | | 0.1551 | 0.1567 | 0.1525 | 0.1516 | 0.1474 | 0.1422 | 0.1402 | 0.1394 | 0.1324 |
| ORA, g's | Longitudinal | -8.5 | -10.9 | -11.9 | -14.8 | -16.1 | -10.2 | -14.3 | -15. | -12.3 |
| | Lateral | -10.1 | -7.8 | -9.7 | -8.4 | -9.5 | -8.5 | -9.4 | -7.9 | -7.4 |
| OIV, ft/s (m/s) | Longitudinal | -16.8 (-5.1) | -17.5 (-5.3) | -18.2 (-5.6) | -20.3 (-6.2) | -19.2 (-5.9) | -20.8 (-6.3) | -19.4 (-5.9) | -16.9 (-5.2) | -19.0 (-5.8) |
| | Lateral | -16.7 (-5.1) | -16.5 (-5.0) | -17.2 (-5.2) | -17.2 (-5.2) | -18.1 (-5.5) | -17.8 (-5.4) | -16.9 (-5.2) | -16.2 (-4.9) | -17.4 (-5.3) |
| Test Article Deflections | Max Rail Deflection, in (mm.) | 35.5 (902) | 36.3 (922) | 32.9 (836) | 32.3 (820) | 30.4 (772) | 28.1 (714) | 28.8 (732) | 28.4 (721) | 25.3 (643) |
| | Max Rail Location, from Post No. 5, in. (mm) | 182.4 (4,633) | 211.2 (5,364) | 259.2 (6,584) | 288.0 (7,315) | 326.4 (8,291) | 384.0 (9,754) | 403.2 (10,241) | 441.6 (11,217) | 637.5 (16,193) |
| | Max Rail Deflection Time, ms | 360 | 350 | 173 | 160 | 160.00 | 200 | 170 | 173 | 177 |

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Table 17. Transition Simulated Impacts Comparison, Cont.

| Comparison of Results | | Stiffness Transition Simulations | | | | | | | | Baseline Simulation |
|-----------------------|---|----------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|---------------------|
| Euler Angles | Max Roll, Deg | 5.5 | 4.1 | 5.5 | 4.2 | 6.5 | 4.1 | 5.7 | 5.0 | 6.1 |
| | Max Roll Time, ms | 363 | 414 | 372 | 194 | 420 | 186 | 377 | 389 | 350 |
| | Max Pitch, Deg | -3.9 | -4.3 | -3.7 | -4.4 | -5.2 | -4.2 | -4.7 | -5.1 | -4.7 |
| | Max Pitch Time, ms | 395 | 360 | 338 | 241 | 336 | 275 | 291 | 393 | 360 |
| | Max Yaw, Deg | -45.8 | -47.0 | -47.2 | -49.4 | -43.0 | -45.2 | -45.7 | -38.9 | -40.7 |
| | Max Yaw Time, ms | 524 | 529 | 795 | 795 | 568 | 526 | 753 | 792 | 621 |
| Pocketing Angle | Angle, Deg | -25.8 | -24.6 | -22.7 | -24.1 | -23.0 | -23.8 | -23.7 | -24.1 | -21.4 |
| | Time, ms | 500 | 500 | 340 | 430 | 190 | 150 | 530 | 470 | 150 |
| Section Forces | Max Upstream Anchor, kips (kN) | 40.1 (178.4) | 39.3 (174.8) | 38.6 (171.7) | 39.9 (177.5) | 35.2 (156.6) | 37.0 (164.6) | 36.9 (164.1) | 33.1 (174.2) | 26.1 (116.1) |
| | Time, ms | 131 | 143 | 164 | 147 | 155 | 118 | 158 | 119 | 116 |
| | Max Downstream Anchor, kips (kN) | 11.2 (49.8) | 11.3 (50.3) | 11.6 (51.6) | 10.9 (48.5) | 12.4 (55.2) | 10.3 (45.8) | 11.7 (52.0) | 12.5 (55.6) | 13.8 (61.4) |
| | Time, ms | 162 | 170 | 137 | 165 | 160 | 139 | 137 | 88 | 114 |
| | Max Neighboring Upstream Rail, kips (kN) | 57.3 (254.9) | 52.9 (235.3) | 50.0 (222.4) | 49.9 (222.0) | 51.7 (230.0) | 53.0 (235.8) | 48.9 (217.5) | 48.1 (214.0) | N.A.** |
| | Time, ms | 129 | 134 | 161 | 137 | 133 | 138 | 93 | 117 | N.A. |
| | Max section force right after post no. 2, kips (kN) | 52.5 (233.5) | 47.4 (210.8) | 44.1 (196.2) | 46.1 (205.1) | 43.6 (193.9) | 42.8 (190.4) | 39.0 (173.5) | 38.7 (172.1) | 28.1 |
| | Time, ms | 129 | 149 | 162 | 156 | 151 | 136 | 114 | 114 | 151 |

*5.5 represents the mid-span between post nos. 5 and 6

** N.A. = not available

7.3 Transition Recommendations for Culvert Mounted MGS System

The strong post, culvert mounted MGS system utilized a stiffened barrier configuration as compared to the standard MGS. This design uses W6x9 posts as half-post spacing bolted to the top of the culvert slab. Attachment of this system to the standard MGS on each end of the culvert utilized a minimum of five posts at half-post spacing in soil prior to the culvert mounted posts. This transition required analysis of two distinct transition regions on the approach to the culvert mounted guardrail: 1) the transition from half-post spaced posts in soil to half-post spaced culvert mounted posts; and 2) the transition from standard MGS to half-posts spacing MGS. The downstream transition was not considered in the analysis as transitioning from a stiffened to a less stiff region of the barrier system is not considered a hazard. The analysis of the two transition regions led to the following recommendations.

1. For the transition from half-post spaced posts in soil to half-post spaced culvert mounted posts, no additional transition was recommended as comparison of the stiffness and energy dissipation of the W6x8.5 posts embedded 40 in. (1,016 mm) in soil and the W6x9 culvert-mounted post were virtually identical. This would indicate that there would be little difference in barrier stiffness and performance in that region of the system.
2. For the transition from standard MGS to half-posts spacing MGS, LS-DYNA analysis was used to determine the critical impact point of the transition region. The simulation analysis indicated that the critical impact point for this transition region was the mid-span of post nos. 7 and 8 (i.e., 37½ in. (953 mm) from the first reduced span post). This point was the same impact point that was previously impacted in test no. MWTSP-2 on the MGS upstream stiffness transition for three beam approach guardrail transitions. The upstream stiffness transition in test no. MWTSP-2 similar post sections, posts spacing, and rail sections in the impact region as the proposed transition region in the culvert mounted MGS design. Based on comparison with this similar, successful full-scale crash test, it was recommended that no additional transition was needed between the standard MGS and the half-post spacing MGS system. However, it was noted that further research may be needed to alleviate concerns raised in parallel ongoing research conducted at TTI. The results of those research studies are ongoing and may affect future recommendations for the culvert-mounted guardrail transition.

8 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this research was to evaluate the safety performance of the MGS installed on a culvert with a strong-post attachment using W6x9 steel posts welded to anchored baseplates at half-post spacing and offset 12 in. (305 mm) from the back of the post to the culvert headwall. Test nos. CMGS-1 and CMGS-2 were conducted according to MASH 2016 test designation nos. 3-10 and 3-11, respectively. The installation in each test consisted of 182.3 ft (55.6 m) of guardrail constructed atop a 43.3-ft (13.2-m) long simulated four-cell concrete box culvert. The culvert-mounted MGS was supported by steel posts with a top mounting rail height of 31 in. (787 mm). A summary of the test evaluation is shown in Table 18.

In test no. CMGS-1, the 2,428-lb (1,101-kg) car impacted the culvert-mounted MGS system at a speed of 61.3 mph (98.7 km/h), an angle of 25.1 degrees, and at a location of 92 in. (2,337 mm) upstream from post no. 19, thus resulting in an impact severity of 54.8 kip-ft (74.3 kJ). The vehicle was successfully contained and smoothly redirected with moderate damage to both the barrier system and the vehicle. All occupant crush, ORAs, and OIVs fell within the recommended safety limits established in MASH 2016. The vehicle trajectory did not violate the bounds of the exit box. Therefore, test no. CMGS-1 was successful according to the safety criteria of MASH 2016 test designation no. 3-10.

In test no. CMGS-2, the 5,013-lb (2,274-kg) pickup truck impacted the culvert-mounted MGS system at a speed of 62.8 mph (101.1 km/h), an angle of 25.7 degrees, and at a location of 129.1 in. (3,279 mm) upstream from post no. 19, thus resulting in an impact severity of 124.7 kip-ft (169.1kJ) The vehicle was successfully contained and smoothly redirected with moderate damage to both the barrier system and the vehicle. All occupant crush, ORAs, and OIVs fell within the recommended safety limits established in MASH 2016. Therefore, test no. CMGS-2 was successful according to the safety criteria of MASH 2016 test designation no. 3-11. Therefore, the culvert-mounted MGS with a 12-in. (305-mm) offset from the back of the post to the culvert headwall met all the requirements of MASH 2016 test designation nos. 3-10 and 3-11.

Following two successful full-scale crash tests on culvert-mounted MGS, the performance of the transition between the MGS and the culvert-mounted MGS was evaluated. Two stiffness transitions in this system were further investigated: (1) transition from half-post spacing MGS to culvert-mounted MGS; and (2) transition from the standard MGS to half-post spacing MGS.

For transition from the half-post spacing MGS to culvert-mounted MGS, a separate transition system is not necessary, because the resistance of the culvert-mounted posts and the posts embedded 40 in. (1,016 mm) in soil were found very similar through component-level bogie tests.

For transitioning from the standard MGS to the culvert-mounted MGS, at least five posts embedded 40 in. (1,016 mm) in soil at half-post spacing are recommended to be installed both upstream and downstream from the culvert-mounted posts.

For transition from the standard MGS and half-post spacing MGS, no additional stiffness transition is required, as this transition has been successfully tested during a previous similar test, test no. MWTSP-2 [21]. In test no. MWTSP-2, a 5,158-lb (2,340-kg) pickup truck impacted the full-spacing MGS that was transitioned to half-post spacing MGS at a speed of 61.2 mph (98.5

km/h) and at an angle of 26.3 degrees. The pickup truck was safely contained, and test no. MWTSP-2 was determined to be acceptable according to test designation no. 3-21 of MASH. Additional LS-DYNA numerical simulations confirmed the critical impact point as similar to the impact point in test no. MWTSP-2. Since the transition from standard MGS to half-post spacing MGS with this critical impact point did not result in any out of limit metrics specified in MASH in test no. MWTSP-2, this transition was believed to not expose errant vehicles to any additional hazards. However, it was noted that further research may be needed to alleviate concerns raised in parallel ongoing research conducted at TTI. The results of those research studies are ongoing and may affect future recommendations for the culvert-mounted guardrail transition.

8.1 Recommendations

The culvert-mounted MGS is unrestricted in terms of increased system length and could be implemented on culverts with lengths longer than the as-tested culvert. In terms of shorter installation lengths, there would be no reason that system lengths could not theoretically be as short as a single post. However, other solutions such as the MGS long span guardrail system and the MGS with an omitted post would likely be more practical solutions for very short culvert type post obstructions. Additionally, it is recommended to retain the half-post spacing transition region adjacent to the culvert mounted MGS system regardless of the system length.

It is recommended that at least five posts embedded 40 in. (1,016 mm) in soil at half-post spacing are installed both upstream and downstream from the culvert-mounted posts. This half-post spacing region outside of the culvert mounted posts was utilized in the original NCHRP Report No. 350 tested system and was carried over to this design to provide a more conservative transition between standard MGS and the culvert-mounted system. There is potential that this transition region could be omitted, but further research into the would be recommended prior to implementing a less conservative transition region. In order to prevent interference with post rotation in soil, the first guardrail post within the half-post spacing MGS adjacent to the culvert should have a minimum 12-in. (305-mm) clear distance to any part of the culvert. This clearance should limit a rotated and displaced guardrail post from interacting with the culvert.

The culvert mounted MGS system evaluated herein was tested utilizing an 8-in. (203-mm) thick culvert slab with non-conservative reinforcement. No damage was noted to the culvert slab following the full-scale crash testing. Installation of the system on culvert slabs with equal or greater thickness and structural reinforcement are expected to provide similar performance. The original NCHRP Report No. 350 full-scale crash testing of this design utilized a 7-in. (178-mm) thick culvert slab with similar reinforcement and displayed little to no damage. Because this system the same post section, baseplate, and anchorage, it is believed that the previously tested 7-in. (178-mm) thick culvert slab would also perform acceptably. Installations on thinner culvert slabs with lesser reinforcement may result in increased culvert slab damage and potential changes in post behavior. Thus, it is recommended that the system be implemented on culvert designs with similar or greater structural capacity than the simulated culvert slabs previously full-scale crash tested.

The culvert mounted MGS system evaluated herein was tested utilizing an embedment depth of 9 in. (229 mm). This should be considered the minimum allowable embedment depth for the culvert mounted MGS system. Installing the posts at shallower embedments shortens the moment arm of the post and stiffens the response of each post. This, in turn, can lead to increased rail loads and pocketing which may degrade the performance of the system. Additionally,

installation of the posts at shorter embedment increases the propensity for wheel snag on the posts as the lower section of the post cannot rotate and displace as much. This also can degrade the system performance. Soil fill deeper than 9 in. (229 mm) over the deck offers more support to culvert-mounted posts, therefore it does not cause concern. Greater depth of soil material would result in a post more similar to an embedded steel post in soil within the standard MGS. As such, larger embedments less than 40 in. (1016 mm) would be allowable. The top mounting height of the guardrail should remain at 31 in. (787 mm) above the top of the soil fill.

Similarly, the culvert mounted MGS system evaluated herein was tested utilizing an offset from back of the post to the culvert headwall of 12 in. (305 mm). Shorter offsets are not recommended at this time as they would tend to limit post rotation and may result in increased rail pocketing and rail loading. Offsets larger than 12 in. (305 mm) would be considered acceptable.

The culvert mounted guardrail post should not be placed too close to the upstream or downstream ends of a culvert. If a post and anchorage is placed near the end of a headwall, the attachment anchors may not have enough concrete cover to develop the required shear and/or tension loads. Thus, a minimum of 4 in. (102 mm) should be used between a free end of a culvert headwall and the center of any attachment anchor.

Anchorage of the culvert mounted posts in the full-scale crash tested barrier system was primarily accomplished with through bolts. In areas of the installation where slab support walls interfered with through bolting, an alternative epoxy anchorage was utilized than had previously be developed for the culvert post attachment through a series of dynamic bogie tests. The dynamic bogie testing demonstrated that the alternative epoxy anchorage was capable of fully developing the capacity of the culvert-mounted W6X9 post would be considered acceptable for installation of the culvert-mounted MGS system. However, it should be noted that the epoxy anchorage requires 8 in. (203mm) of embedment. As such, installation of the epoxy anchorage should ensure that the culvert slab has sufficient thickness to adequately install the anchor. Full details and recommendations for the installation of the epoxy anchorage for the culvert mounted W6x9 posts can be found in the original research report [7].

Often, culvert headwalls may extend 6.0 in. (152 mm) or more above the groundline. Headwall extensions of this magnitude would represent a vertical curb adjacent to the barrier and could pose a stability hazard or adversely affect barrier performance. Thus, it is recommended that the culvert headwall extend no higher than 2.0 in. (51 mm) above the groundline and that any extensions greater than 2.0 in. (51 mm) be ground down to match the ground profile.

It may be desired to install the culvert-mounted MGS system adjacent to a fill-slope. Placement of the culvert mounted posts adjacent to or at the slope break point of a fill slope may change the lateral resistance of the post due to the reduction of soil fill behind the post and subsequently affect the barrier performance. Because the effect of placement of the culvert-mounted posts adjacent to a fill slope is not currently quantified, it is recommended to use a minimum of 2 ft (610 mm) of level terrain from the back of the post to the start of the fill slope in order to provide consistent post response. Additionally, the system was designed and evaluated for use on low-fill culverts with relatively flat grading. It is recommended that the system only be used with approach slopes of 10H:1V or flatter.

Finally, installations should be implemented with the guardrail terminals (or end anchorages) located a sufficient distance from the culvert to prevent the two systems from interfering with the proper performance of one another. As such, the following implementation guidelines should be considered in addition to guardrail length of need requirements:

1. A recommended minimum length of 12 ft – 6 in. (3.8 m) of standard MGS between the first post at half-post spacing and the interior end of an acceptable TL-3 guardrail end terminal.
2. A recommended minimum barrier length of 50 ft (15.2 m) before the first post at half-post spacing, which includes standard MGS and a crashworthy guardrail end terminal. This guidance applies to the downstream end as well.
3. For flared guardrail applications, a minimum length of 25 ft (7.6 m) is recommended between the first post at half-post spacing and the start of the flared section (i.e. bend between flared and tangent sections).

Table 18. Summary of Safety Performance Evaluation

| Evaluation Factors | Evaluation Criteria | Test No. CMGS-1 | Test No. CMGS-2 | |
|---------------------------------------|---|-------------------|--------------------|-----------|
| Structural Adequacy | A. 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. | S | S | |
| Occupant Risk | D. 1. 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. 2. 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. | S | S | |
| | F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees. | S | S | |
| | H. Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits: | S | S | |
| | Occupant Impact Velocity Limits | | | |
| | Component | | | Preferred |
| | Longitudinal and Lateral | 30 ft/s (9.1 m/s) | 40 ft/s (12.2 m/s) | |
| | I. The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits: | S | S | |
| Occupant Ridedown Acceleration Limits | | | | |
| Component | Preferred | | | Maximum |
| Longitudinal and Lateral | 15.0 g's | 20.49 g's | | |
| MASH Test Designation No. | | 3-10 | 3-11 | |
| Final Evaluation (Pass or Fail) | | Pass | Pass | |

S – Satisfactory U – Unsatisfactory NA - Not Applicable

9 MASH EVALUATION

In this study, the safety performance of the MGS installed on a culvert with a strong-post attachment using W6x9 steel posts welded to anchored baseplates at half-post spacing and offset 12 in. (305 mm) from the back of the post to the culvert headwall was evaluated through full-scale crash testing. The system consisted of strong post MGS mounted on a simulated four-cell concrete box culvert system. Anchorage systems were utilized at both the upstream and downstream ends of the guardrail system. Steel post nos. 3 through 12 and 27 through 39 were embedded in soil a depth of 40 in. (1,016 mm). Post nos. 13 through 26 were embedded a depth of 9 in. (229 mm) and anchored to the top of the concrete culvert using welded steel baseplates. Post nos. 13 through 15, 17 through 22, and 24 through 26 were anchored to the top concrete slab using four through-bolts, and post nos. 16 and 26 were anchored using 10-in. (254-mm) long epoxied threaded rods with an 8-in. (203 mm) embedded length due to the presence of the culvert's interior wall support.

9.1 MASH Crash Test Matrix

According to TL-3 evaluation criteria in MASH 2016, two tests are required for evaluation of longitudinal barrier systems: (1) test designation no. 3-10 – an 1100C small car and (2) test designation no. 3-11 – a 2270P pickup truck. Critical impact points (CIPs) for both impacts were determined based on calculated post and guardrail beam strengths and the use of MASH 2016 Figures 2-8 and 2-11 for the 1100C and 2270P vehicle impacts, respectively.

9.2 Full-Scale Crash Testing

In test no. CMGS-1, a 2,428-lb (1,101-kg) sedan with a simulated occupant seated in the right-front passenger seat, impacted the MGS atop culvert system at a speed of 61.3 mph (98.7 km/h) and at an angle of 25.1 degrees, resulting in an impact severity of 54.8 kip-ft (74.3 kJ). At 0.259 sec after impact, the vehicle became parallel to the system with a speed of 26.5 mph (42.6 km/h). At 0.464 sec, the vehicle exited the system at a speed of 24.7 mph (39.8 km/h) and at an angle of 17.0 degrees. The vehicle was successfully contained and smoothly redirected.

Exterior vehicle damage was moderate. Interior occupant compartment deformations were moderate with a maximum of 3 $\frac{3}{8}$ in. (86 mm), which was not observed on the test day. Prior to the vehicle deformations' measurements, the snow and ice on the windshield caused an additional caving in deformation. Therefore, this deformation exceeding the MASH deformation criteria was not from the impact event and was not critical to the test evaluation.

Damage to the system was also moderate, consisting mostly of deformed W-beam, contact marks on the guardrail sections, and deformed posts. The maximum lateral permanent set of the barrier system was 11 $\frac{7}{8}$ in. (302 mm). The maximum dynamic barrier deflection was 12.0 in. (305 mm), which included vehicle overhang along the MGS. The working width of the system was 33.1 in. (842 mm). All occupant risk measures were within the recommended limits, and the occupant compartment deformations were also deemed acceptable. Therefore, the MGS atop culvert system successfully met all the safety performance criteria of MASH 2016 test designation no. 3-10.

In test no. CMGS-2, a 5,013-lb (2,274-kg) pickup truck with a simulated occupant seated in the right-front passenger seat, impacted the MGS atop culvert system at a speed of 62.8 mph (101.1 km/h) and at an angle of 25.7 degrees, resulting in an impact severity of 124.7 kip-ft (169.1

kJ). At 0.270 sec after impact, the vehicle became parallel to the system with a speed of 36.9 mph (59.5 km/h). At 0.520 sec, the vehicle exited the system at a speed of 33.1 mph (53.2 km/h) and at an angle of 17.4 degrees. The vehicle was successfully contained and smoothly redirected.

Exterior vehicle damage was moderate. Interior occupant compartment deformations were moderate with a maximum of 1½ in. (29 mm), which did not violate the limits established in MASH 2016. Damage to the system was also moderate, consisting of contact marks on the front face of the guardrail sections and deformation of W-beam and posts. The maximum lateral permanent set of the barrier system was 15¾ in. (400 mm). The maximum dynamic barrier deflection was 29.6 in. (753 mm), which included vehicle overhang along the MGS. The working width of the system was 50.8 in. (1,290 mm). All occupant risk measures were within the recommended limits, and the occupant compartment deformations were also deemed acceptable. Therefore, the MGS atop culvert system successfully met all the safety performance criteria of MASH 2016 test designation no. 3-11.

9.3 MASH 2016 Evaluation

Based on the results of the two successful full-scale crash tests conducted herein, the culvert-mounted MGS system meets all of the safety requirements for MASH 2016 TL-3.

Additionally, an analysis of the transition between the MGS and the culvert-mounted MGS was completed. Two stiffness transitions in this system were investigated: (1) transition from half-post spacing MGS to culvert-mounted MGS; and (2) transition from the standard MGS to half-post spacing MGS. For transition from the half-post spacing MGS to culvert-mounted MGS, a separate transition system was not necessary, because the resistance of the culvert-mounted posts and the posts embedded 40 in. (1,016 mm) in soil were found very similar through component-level bogie tests [19-20].

For transitioning from the standard MGS to the culvert-mounted MGS, at least five posts embedded 40 in. (1,016 mm) in soil at half-post spacing were recommended to be installed both upstream and downstream from the culvert-mounted posts. No additional stiffness transition was believed to be required, as a similar transition region had been successfully tested during a full-scale crash testing of the MGS upstream stiffness transition to thrie beam approach guardrail transitions in test no. MWTSP-2 [21]. Additional LS-DYNA numerical simulations confirmed the critical impact point for the transition from standard to half-post spacing MGS as similar to the impact point in test no. MWTSP-2. Since the transition from standard MGS to half-post spacing MGS with this critical impact point did not result in any out of limit metrics specified in MASH in test no. MWTSP-2, this transition was believed to not expose errant vehicles to any additional hazards. However, it was noted that further research may be needed to alleviate concerns raised in parallel ongoing research conducted at TTI. The results of those research studies are ongoing and may affect future recommendations for the culvert-mounted guardrail transition.

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11 APPENDICES

Appendix A. Material Specifications

Table A-1. Bill of Materials, Test Nos. CMGS-1 and CMGS-2

| Item No. | Description | Material Specification | References |
|----------|---|---|--|
| 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 Red Paint |
| b1 | 72" [1829] Long Foundation Tube | ASTM A500 Gr. B | H#0173175 |
| b2 | BCT Timber Post - MGS Height | SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face) | R#17-505 Orange Paint |
| b3 | W6x8.5 [152x12.6] or W6x9 [W152x13.4], 72" [1,829] Long Steel Post | ASTM A992 | R#16-692 Black Paint H#55044251 |
| b4 | 6"x12"x14¼" [152x305x368] Timber Blockout for Steel Posts | SYP Grade No. 1 or better | R#16-692 Black, Charge#23422 R#18-288 White, R#17-282 Light Blue, R#14-0554 Green |
| b5 | W6x8.5 [W152x12.6] or W6x9 [W152x13.4 Post, 40½" [1029] Long | ASTM A992 | H#A134108 |
| b6 | 8½"x12"x½" [216x305x13] Top Base Plate | ASTM A572 Gr. 50 | H#A7D898 |
| b7 | 8½"x11"x¼" [216x280x6] Bottom Post Plate | ASTM A572 Gr. 50 | CMGS-1: H#A608874 CMGS-2: H#A7R1834-02 |
| c1 | ⅝" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut | Bolt - ASTM A307 Gr. A Nut - ASTM A563A | Bolts: R#16-692 H#DL15107048 L#208977 Orange Paint Nuts: R#16-0217 P#36713 C#210101526 |
| c2 | ⅞" [22] Dia. UNC, 8" [203] Long Hex Head Bolt and Nut | Bolt - ASTM A307 Gr. A Nut - ASTM A563A | Bolts: R#15-0600 H#2038622 L#39685 Nuts: R#15-0600 H#NF12101054 L#WA651 |
| c3 | 1" [25] Dia. UNC, 10½" [267] Long Hex Head Bolt and Nut REPLACED BY PART C9 | Bolt - ASTM A307 Gr. A Nut - ASTM A563A | CMGS-1: P#47657 Control#200125104 CMGS-2: Bolts: P#47641 Nuts: P#36719 |
| c4 | ⅝" [16] Dia. UNC, 1½" [38] Long Hex Head Bolt and Nut | Bolt - ASTM A307 Gr. A Nut - ASTM A563A | Bolts: R#17-507 H#816070039 Nuts: R#16-0217 P#36713 C#210101526 |

Table A-2. Bill of Materials, Test Nos. CMGS-1 and CMGS-2, Cont.

| Item No. | Description | Material Specification | References |
|----------|---|---|---|
| c5 | 5/8" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut | Bolt - ASTM A307 Gr. A Nut - ASTM A563A | H#NF16202178 Yellow Paint Nuts: H#20479830 |
| c6 | 5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut | Bolt - ASTM A307 Gr. A Nut - ASTM A563A | Bolts: H#20460760 Nuts: H#20479830 |
| c7 | 16D Double Head Nail | - | COC PO E000357170 |
| c8 | 5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut | Bolt - ASTM A307 Gr. A Nut - ASTM A563A | R#16-692 H#20351510 L#150424L Orange Paint |
| c9 | 1" [25] Dia. UNC, 10" [254] Long Threaded Rod | ASTM A307 Gr. A | Part#47641 H#604061 |
| c10 | 1" [25] Dia. Hex Nut | ASTM A563A | P#36719 H#1623764; NUTS: 36719 120282576 GL17036-5 R#17-732 |
| d1 | 5/8" [16] Dia. Plain Round Washer | ASTM F844 | n/a |
| d2 | 7/8" [22] Dia. Plain Round Washer | ASTM F844 | n/a |
| d3 | 1" [25] Dia. Plain Round Washer | ASTM F844 | n/a |
| e1 | BCT Anchor Cable | - | Yellow Paint R#17-700 Washers: R#17-715 L#16H-168236-30 Orange Paint Nuts: P#38210 H#DL15105591 |
| e2 | 2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve | ASTM A53 Gr. B Schedule 40 | H#A79999 |
| e3 | 8"x8"x5/8" [203x203x16] Anchor Bearing Plate | ASTM A36 | North: R#17-282 South: R#09-0453 |
| f1 | Ground Strut Assembly | ASTM A36 | North: R#09-0453 South: H#163375 |
| f2 | Anchor Bracket Assembly | ASTM A36 | R#17-282 |
| - | Concrete Culvert | Min. f _c = 4,000 psi [27.6 MPa] NE Mix 47BD | See Table A-3 |

Table A-3. Bill of Materials, Culvert, Test Nos. CMGS-1 and CMGS-2

| Item No. | Description | Material Specification | References |
|----------|---|--|--------------|
| a1 | 520"x17"x60" [13,208x432x1,524] Reinforce Concrete Culvert Deck/Headwall | Min. f _c = 4,000 psi [27.6 MPa] NE Mix 47BD | R#18-250 |
| a2 | 8"x48"x120" [203x1,219x3,048] Reinforced Concrete Exterior Support Wall | Min. f _c = 4,000 psi [27.6 MPa] NE Mix 47BD | R#18-250 |
| a3 | 12"x48"x60" [305x1,219x1,524] Reinforce Concrete Interior Support Wall | Min. f _c = 4,000 psi [27.6 MPa] NE Mix 47BD | R#18-250 |
| a4 | 8"x48"x520" [203x1,219x13,208] Reinforced Concrete Soil Wall | Min. f _c = 4,000 psi [27.6 MPa] NE Mix 47BD | R#18-250 |
| a5 | #4 [#13] Bent Rebar, Vertical Loop, 53 ³ / ₈ " [1,355] Total Length, Unbent | ASTM A615 Gr. 60 | H#KN15106961 |
| a6 | #4 [#13] Straight Rebar, 57" [1,448] Long | ASTM A615 Gr. 60 | H#KN15106961 |
| a7 | #4 [#13] Straight Rebar, 517" [13,132] Long | ASTM A615 Gr. 60 | H#KN15106961 |
| a8 | #4 [#13] Straight Rebar, 45" [1,143] Long | ASTM A615 Gr. 60 | H#KN15106961 |
| a9 | #4 [13] Straight Rebar, 117" [2,972] Long | ASTM A615 Gr. 60 | H#KN15106961 |
| a10 | #4 [#13] Bent Rebar, Support Wall Hook, 64" [1,626] Total Length, Unbent | ASTM A615 Gr. 60 | H#KN15106961 |
| a11 | #4 [#13] Bent Rebar, Support Wall Hook, 60 ¹ / ₂ " [1,536] Total Length, Unbent | ASTM A615 Gr. 60 | H#KN15106961 |
| a12 | 8"x48"x120" [203x1,219x3,048] Reinforced Concrete Exterior Support Wall | Min. f _c = 4,000 psi [27.6 MPa] NE Mix 47BD | R#18-250 |
| a13 | #4 [#13] Bent Rebar, L- Shaped, 4' 6" Total Length, Unbent | ASTM A615 Gr. 60 | H#62139047 |

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Customer: UNIVERSITY OF NEBRASKA-LINCOLN
 401 CANFIELD ADMIN BLDG
 P O BOX 880439
 LINCOLN, NE, 68588-0439

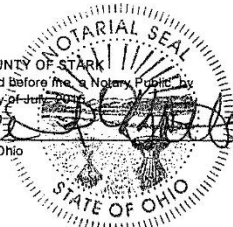
Test Report
 Ship Date: 7/9/2015
 Customer P. O.: 4500274709/ 07/07/2015
 Shipped to: UNIVERSITY OF NEBRASKA-LINCOLN
 Project: TESTING COIL
 GHP Order No.: 183306

| HT # code | Heat # | C. | Mn. | P. | S. | Si. | Tensile | Yield | Elong. | Quantity | Class | Type | Description |
|-----------|---------|------|------|------|-------|------|---------|-------|--------|----------|-------|------|----------------------------------|
| 8534 | 9411949 | 0.21 | 0.75 | 0.01 | 0.006 | 0.01 | 75774 | 56527 | 27.15 | 10 | A | 2 | 12GA 25FT WB T2 MGS ANCHOR PANEL |
| 8534 | 9411949 | 0.21 | 0.75 | 0.01 | 0.006 | 0.01 | 75774 | 56527 | 27.15 | 100 | A | 2 | 12GA 12FT6IN/3FT1 1/2IN WB T2 |
| 8534 | 9411949 | 0.21 | 0.75 | 0.01 | 0.006 | 0.01 | 75774 | 56527 | 27.15 | 20 | A | 2 | 12GA 25FT0IN 3FT1 1/2IN WB T2 |

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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.
 All other galvanized material conforms with ASTM-123 & ASTM-653
 All Galvanizing has occurred in the United States
 All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
 All Steel used meets Title 23CFR 635.410 - Buy America
 All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
 All Bolts and Nuts are of Domestic Origin
 All material fabricated in accordance with Nebraska Department of Transportation
 All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

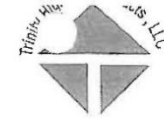
By: 
 Andrew Artar, VP of Sales & Marketing
 Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
 Sworn to and subscribed Before me a Notary Public by
 Andrew Artar this 17 day of June 2015

 Notary Public, State of Ohio

DAWN R. BATTON
 NOTARY PUBLIC
 STATE OF OHIO
 Comm. Expires
 March 03, 2018
 Recorded in
 Portage County

Figure A-1. 12-ft – 6-in. (3,810-mm) 12-gauge (2.7-mm) W-Beam MGS Section and End Section, Test Nos. CMGS-1 and CMGS-2

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

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| 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 | 0.000 | 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 |

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Figure A-2. 6-ft – 3-in. (1,905-mm) 12-gauge (2.7-mm) W-Beam MGS Section, Test Nos. CMGS-1 and CMGS-2

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"/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' | 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

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Figure A-3. 72-in. (1,829-mm) Long Foundation Tube, Test Nos. CMGS-1 and CMGS-2



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

R#17-505
 BCT Posts
 Orange Paint March 2017 SMT

Date: 3/2/17

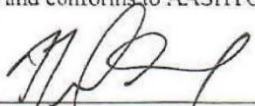
CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10056187
 Customer PO# 3396 Preservative: CCA - C 0.60 pcf AWP/UC4B

| Part # | Physical Description | # of Pieces | Charge # | Tested Retention |
|------------|----------------------|-------------|----------|------------------|
| 656806SPST | 6x8 - 6.5 Rub Post | 168 | 23489 | .649 |
| 656806SPST | 6x8 - 6.5' Rub Post | 42 | 23490 | .724 |
| 656806SPST | 6x8.5 - CRT PST | 42 | 23490 | .724 |
| 656846PST | 6x8 - 4.5" BCT | 42 | 23491 | .651 |
| | | | | |
| | | | | |
| | | | | |

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

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


 Nick Sowl, General Counsel

3/2/17
 Date

Figure A-4. BCT Timber Posts, Test Nos. CMGS-1 and CMGS-2



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

CERTIFIED MATERIAL TEST REPORT

Page 1/1

| | | | | | | |
|--|--|--|--------------------|--|---|-----------------------------|
| CUSTOMER SHIP TO HIGHWAY SAFETY CORP 473 W FAIRGROUND ST MARION, OH 43302-1701 USA | | CUSTOMER BILL TO HIGHWAY SAFETY CORP GLASTONBURY, CT 06033-0358 USA | | GRADE A992/A709-36 | SHAPE / SIZE Wide Flange Beam / 6 X 8.5# / 150 X 13.0 | DOCUMENT ID: 0000006197 |
| SALES ORDER 3399484/000010 | | CUSTOMER MATERIAL N° IB-80600800 | | LENGTH 42'00" | WEIGHT 44,982 LB | HEAT / BATCH 55044251/02 |
| CUSTOMER PURCHASE ORDER NUMBER 000167 PO# 1677003 | | BILL OF LADING 1323-0000066391 | DATE 03/16/2016 | SPECIFICATION / DATE OF REVISION ASTM A6-14 ASTM A709-13A ASTM A992-11 CSA G40.21-13 345WM | | |

| CHEMICAL COMPOSITION | | C | Mn | P | S | Si | Cr | Ni | Cu | Mo | Sn | V | Nb |
|----------------------|--|------|------|-------|-------|------|------|------|------|-------|-------|-------|-------|
| | | % | % | % | % | % | % | % | % | % | % | % | % |
| | | 0.14 | 0.90 | 0.014 | 0.019 | 0.19 | 0.28 | 0.08 | 0.09 | 0.023 | 0.012 | 0.017 | 0.000 |

| MECHANICAL PROPERTIES | | YS | UTS | YS | UTS | G/L | Elong. |
|-----------------------|--|-------|-------|-----|-----|-------|--------|
| | | 0.2% | PSI | MPa | MPa | Inch | % |
| | | 56700 | 77700 | 391 | 536 | 8.000 | 21.30 |
| | | 54800 | 75700 | 378 | 522 | 8.000 | 22.60 |

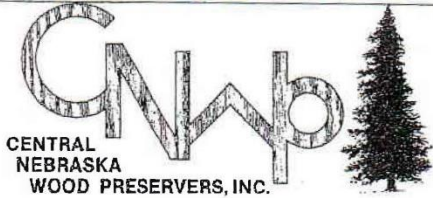
COMMENTS / NOTES

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. CMTIR complies with EN 10204 3.1.

Bhaskar
BHASKAR YALAMANCHILI
QUALITY DIRECTOR

Yan Wang
YAN WANG
QUALITY ASSURANCE MGR.

Figure A-5. W6x8.5 (152x12.6), 72-in. (1,829-mm) Long Steel Posts, Test Nos. CMGS-1 and CMGS-2



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

R#16-692 6x12x14 Timber Blockouts
COC June2016 SMT Black Paint Tags

Date: 10/29/15

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery BOL# 10052937
 Customer PO# 3161 Preservative: CCA - C 0.60 pcf AWPA UC4B

| Part # | Physical Description | # of Pieces | Charge # | Tested Retention |
|--------|----------------------|-------------|----------|------------------|
| | 6x12-14" ocd Block | 84 | 21327 | .658 pcf |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

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 G.M.
 Nick Sowl, General Counsel

10/29/15
 Date

Figure A-6. Timber Blockouts for Steel Posts, Test Nos. CMGS-1 and CMGS-2



1098 East Maple St
 Sutton, NE 68979
 Phone: 402.773.4319
 Email: nick@nebraskawood.com


CERTIFICATE OF COMPLIANCE

Shipped To: Midwest Machinery and Supply
 BOL# 10057873
 Customer PO# 3475
 Preservative: CCA - C 0.60D pcf AWPA UC4B

| Part # | Physical Description | # of Pieces | Charge # | Tested Retention |
|----------------|--------------------------------|-------------|----------|------------------|
| GR61219 BLK | 6x12-19" TRANS Hole BLK | 56 | 24245 | .616 |
| GR6819 BLK | 6x8-19" OCD BLOCK | 168 | 24253 | .611 |
| GR61214 BLK | 6x12-14" Thrie Hole BLK OCD | 84 | 23422 | .660 |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

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

VA: Iowa 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.



 Nicholas Sowl, General Counsel

9/1/2017
 Date

Figure A-7. Timber Blockouts for Steel Posts, Test Nos. CMGS-1 and CMGS-2



P. O. Box 630 • Sutton, NE 68979
Phone 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

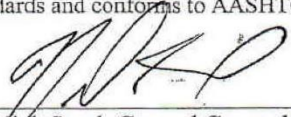
Shipped TO: Midwest Machinery & Supply BOL# 100 55387

Customer PO# 3339 Preservative: CCA - C 0.60 pcf AWWA UC4B

| Part # | Physical Description | # of Pieces | Charge # | Tested Retention |
|-------------|----------------------|-------------|----------|------------------|
| GR6806.SPT | 6x8-6.5" PST | 35 | 22973 | .679 |
| GR6806.SCRT | 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 AWWA 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 AWWA 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 A-8. Timber Blockouts for Steel Posts, Test Nos. CMGS-1 and CMGS-2



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

CWNP Invoice 10048570
 Shipped To MIDWEST-MIABO
 Customer PO 2892

Central Nebraska Wood Preservers, Inc.
Certification of Inspection

Date: 4/23/14

Specifications: Highway Construction Use

Preservative: CCA - C 0.60 pcf

| Charge # | Date Treated | Grade | Material Size, Length & Dressing | # Pieces | White Moisture Readings | Penetration # of Borings & % Conforming | Actual Retentions % Conforming |
|----------|--------------|-------|----------------------------------|----------|-------------------------|---|--------------------------------|
| 18379 | 4/16/14 | #1 | 6x12-14" Blocks | 756 | 19 | 1/20 95% | .651 pcf |
| 18379 | 4/16/14 | #1 | 6x8-22" Blocks | 84 | 19 | 1/20 95% | .651 pcf |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Number of pieces rejected and reason for rejection:
~~None~~

Statement: The above reference material was treated and inspected in accordance with the above referenced specifications.

Kurt Andres
 Kurt Andres, General Manager

4/23/14
 Date

MGS Wood Blockouts 6x12x14" R#14-0554
 GREEN TAGS don't mistaken these for the 2part blockouts
 because they are also GREEN. July 2014 SMT

Figure A-9. Timber Blockouts for Steel Posts, Test Nos. CMGS-1 and CMGS-2



CERTIFIED MILL TEST REPORT

Printed: 05 / 29 / 2017
Produced: 04 / 11 / 2017

(260) 625-8100 (260) 625-8950 FAX
Quality Steel 100% EAF Melted and Manufactured in the USA
Recycled content: PC = 79.6%, PI = 18.0%
ISO 9001:2008 and ABS Certified

Ship to:
Steel & Pipe Supply
401 New Century Parkway
New Century KS, 66031 US
Attn: Receiving

Customer # 000058

Bill to:
Steel & Pipe Supply - Kansas
555 Poyntz Avenue
PO Box 1688
Manhattan KS, 66505 US
Attn: David Chizek

| GENERAL INFORMATION | | SPECIFICATIONS | | SHIPMENT DETAILS | |
|---------------------|---|-----------------------|-----------------|--------------------------------|--------------------------------|
| Product | Wide Flange Beam | Standards | Grades | Bundle / ASN # | BOL # 0000455326 - 7200 00 lbs |
| Size | W6X9 W150X13.5 | ASTM A6/A6M - 16a | | Length | 50' 0" |
| Heat Number | A134108 | ASTM A992/A992M - 11 | A992 / A992M | pcs | 16 |
| Condition(s) | As-Rolled Fine Grained Fully Killed No Weld Repair | ASTM A709/A709M - 16a | A709 gr50/gr345 | Cust PO Recv PO Job | 4500287984 |
| | | ASTM A572/A572M - 15 | A572 gr50/gr345 | | |
| | | AASHTO M270/M270 - 12 | M270 gr345/gr50 | | |
| | | CSA G40.21-13 | 50WM/345WM | | |

CHEMICAL ANALYSIS (weight percent)

| C | Mn | P | S | Si | Cu | Ni | Cr | Mo | Sn | V | Nb/Cb | Al | N | B | *C1 | *C2 | *C3 | *PC | *I | Analysis Type |
|-----|-----|------|------|-----|-----|-----|-----|------|------|------|-------|------|-------|-------|-----|-----|-----|-----|------|---------------|
| .06 | .93 | .015 | .011 | .25 | .30 | .12 | .11 | .035 | .012 | .023 | <.001 | .002 | .0100 | .0003 | .28 | .32 | .26 | .15 | 5.75 | Heat |

MECHANICAL TESTING

| Test | Yield (fy) Strength ksi / MPa | Tensile (fu) Strength ksi / MPa | fy / fu ratio | % Elong. {8" gage} |
|------|-------------------------------------|---------------------------------------|------------------|-----------------------|
| 1 | 63 / 436 | 80 / 550 | .79 | 26 |
| 2 | 64 / 444 | 80 / 554 | .80 | 25 |
| 3 | | | | |
| 4 | | | | |

CHARPY IMPACT TESTS (available only when specified at time of order)

| Test | Temp | Absorbed Energy | | | Average | Minimum |
|------|-------|-----------------|------------|------------|---------|---------|
| | F / C | Specimen 1 | Specimen 2 | Specimen 3 | | |
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |

Notes: *Calculated Chemistry Values Carbon Equivalents (C1 C2 C3 PC) Corrosion Index (I) I (ASTM G101)= 26 01(Cu)+3 88(Ni)+1 20(Cr)+1 49(Si)+17 29(P)+7 29(Cu)(Ni)+9 10(Ni)(P)+33 39(Cu)
CE1 ((W)-C+Mn)/5+(Cr+Mo+V)/5+(Ni+Cu)/15 CE2 (AWS)-C+(Mn+Si)/5+(Cr+Mo+V)/5+(Ni+Cu)/15 CE3 (CET) = C + (Mn/5) + (Si/24) + (Cr/5) + (Ni/40) + (Mg/4) + (V/14) Pcm(AWS) = C+S/30+Mn/20+Cu/20+N/60+Cr/20+mo/15+V/10+5B

I hereby certify that the material described herein has been made to the applicable specification by the electric arc furnace/continuous cast process and tested in accordance with the requirements of American Bureau of Shipping Rules with satisfactory results.

Signed: _____

I hereby certify that the content of this report are accurate and correct All tests and operations performed by this material manufacturer are in compliance with the requirements of the material specifications and applicable purchaser designated requirements

Signed: **Todd Bashford** *Todd Bashford*
Quality Manager

ABS CERTIFICATION

State of Indiana. County of Whitley Sworn to and subscribed before me

this _____ day of _____

Signed: _____ My commission expires: _____
Notary Public

Form F-6103-002-054 rev B
ASTM A6 - 14 6 A signature is not required on the test report; however the document shall clearly identify the organization submitting the report
Notwithstanding the absence of a signature, the organization submitting the report is responsible for the content of the report
Page 3 of 7

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Figure A-10. W6x9 (W150x13.5) 40½-in. (1,029-mm) Long Post, Test No. CMGS-1 and CMGS-2

November 2, 2020
MWRSF Report No. TRP-03-383-20-R1

SSAB

Preliminary Test Certificate

Form TC1: Revision 2: Date 23 Apr 2014

1770 Bill Sharp Boulevard, Muscatine, IA 52761-9412, US **Official copy to follow**

| Customer: STEEL & PIPE SUPPLY P.O. BOX 1688 MANHATTAN KS 66502 | | Customer P.O. No.: 4500287649 | Mill Order No.: 41-504804-02 | Shipping Manifest : MT318692 | | | | | | | | | | | | | | | |
|---|-------------------|-------------------------------|------------------------------|-------------------------------------|-----------|--------|---------------------|---------|----------|---|------|------|---------|--|------|---------|---------|--------------|-------------------|
| Product Description: ASTM A572-50/M345(15)/A709-50/M345(16A) | | | Ship Date: 21 Jun 17 | Cert No: 061649975 (Page 1 of 1) | | | | | | | | | | | | | | | |
| Size: 0.500 X 96.00 X 240.0 (IN) | | | | | | | | | | | | | | | | | | | |
| Tested Pieces | | | Tensiles | | | | Charpy Impact Tests | | | | | | | | | | | | |
| Heat Id | Piece Id | Tested Thickness | Tst Loc | YS (KSI) | UTS (KSI) | %RA | Elong % 2in 8in | Tst Dir | Hardness | Abs. Energy(FTLB) | | | % Shear | | | Tst Tmp | Tst Dir | Tst Siz (mm) | BDWTT Tmp %Shr |
| A7D898 | D19 | 0.496 (DISCRT) | L | 61 | 73 | | 38 | T | | | | | | | | | | | |
| A7F058 | D31 | 0.497 (DISCRT) | L | 55 | 68 | | 37 | T | | | | | | | | | | | |
| B7D657 | D18 | 0.507 (DISCRT) | L | 57 | 77 | | 28 | T | | | | | | | | | | | |
| Heat Id | Chemical Analysis | | | | | | | | | | | | | | ORGN | | | | |
| | C | Mn | P | S | Si | Tot Al | Cu | Ni | Cr | Mo | Cb | V | Ti | | | | | | |
| A7D898 | .05 | 1.32 | .014 | .004 | .10 | .034 | .30 | .14 | .15 | .03 | .024 | .027 | .008 | | | | USA | | |
| A7F058 | .05 | 1.21 | .012 | .006 | .02 | .028 | .31 | .14 | .10 | .04 | .002 | .053 | .001 | | | | USA | | |
| B7D657 | .16 | 1.14 | .013 | .007 | .03 | .029 | .30 | .15 | .17 | .04 | .002 | .033 | .006 | | | | USA | | |
| <p>KILLED STEEL MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT. MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT 100% MELTED AND MANUFACTURED IN THE USA. PRODUCTS SHIPPED: B7D657 D18 PCES: 2, LBS: 6534 A7F058 D31 PCES: 1, LBS: 3267 A7D898 D19 PCES: 3, LBS: 9801</p> | | | | | | | | | | | | | | | | | | | |
| (iii) Cust Part # : 721696240A2 | | | | | | | | | | <p>WE HEREBY CERTIFY THAT THIS MATERIAL WAS TESTED IN ACCORDANCE WITH, AND MEETS THE REQUIREMENTS OF, THE APPROPRIATE SPECIFICATION</p> <p style="text-align: right;">SENIOR METALLURGIST - PRODUCT</p> | | | | | | | | | |

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Figure A-11. 8½-in. x 12-in. x ½-in. (216-mm x305-mm x 13-mm) Top Base Plate, Test No. CMGS-1 and CMGS-2



SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 10/07/2016
TIME 20:41:17
USER GIANGRER

S
O
L
D

T
O

66031-1127

S
H
I
P

T
O

13716
Kansas City Warehouse
401 New Century Parkway
NEW CENTURY KS

| Order | Material No. | Description | Quantity | Weight | Customer Part | Customer PO | Ship Date |
|---------------|--------------|-----------------------------------|----------|--------|---------------|-------------|------------|
| 40272379-0010 | 70860240A2 | 1/4 60 X 240 A572GR50 STP MIL PLT | 4 | 4,084 | | | 10/07/2016 |

Chemical Analysis

Heat No. A608874 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA

Produced from Coil

| Carbon | Manganese | Phosphorus | Sulphur | Silicon | Nickel | Chromium | Molybdenum | Boron | Copper | Aluminum | Titanium | Vanadium | Columbium | Nitrogen | Tin |
|--------|-----------|------------|---------|---------|--------|----------|------------|--------|--------|----------|----------|----------|-----------|----------|--------|
| 0.0600 | 0.8100 | 0.0160 | 0.0010 | 0.0400 | 0.0300 | 0.0600 | 0.0100 | 0.0001 | 0.1100 | 0.0220 | 0.0010 | 0.0030 | 0.0160 | 0.0068 | 0.0040 |

Mechanical / Physical Properties

Mill Coil No. 168640645

| Tensile | Yield | Elong | Rckwl | Grain | Charpy | Charpy Dr | Charpy Sz | Temperature | Olsen |
|-----------|-----------|-------|-------|-------|--------|-----------|-----------|-------------|-------|
| 73500.000 | 62300.000 | 30.00 | | | 0 | NA | | | |
| 72600.000 | 63500.000 | 26.30 | | | 0 | NA | | | |
| 71900.000 | 61500.000 | 33.20 | | | 0 | NA | | | |
| 71900.000 | 62200.000 | 29.80 | | | 0 | NA | | | |

Batch 0004493721 4 EA 4,084 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

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Figure A-12. 8½-in. x 11-in. x ¼-in. (216-mm x 280-mm x 6-mm) Bottom Post Plates, Test No. CMGS-1

November 2, 2020
MWRSF Report No. TRP-03-383-20-R1



MILL TEST CERTIFICATE

1700 HOLT RD N.E.
Tuscaloosa, AL 35404-1000
800 800-8204
customerservice@nucortusk.com

| Load Number | Tally | Mill Order Number | PO NO Line NO | Part Number | Certificate Number | Prepared |
|---|---------------|-------------------|-----------------|---|--------------------|------------------|
| B152559 | 0000000725694 | N-155738-023 | P0181329-09 23 | | S72569401-1 | 05/07/2017 13:20 |
| Grade | | | | Customer: | | |
| Order Description: Hot Roll Plate From Coil A572 50, 0.2500 IN x 96.000 IN x 240.000 IN Quality Plan Description: A57250 LO SI IMP: ASTM A572-50-15/A70950-15/M27050 H Freq impacts | | | | Sold TO: SUPERIOR SUPPLY AND STEEL CATOOSA OK Ship TO: SUPERIOR SUPPLY AND STEEL Catoosa OK Sent TO: | | |

| Shipped Item | Heat/Slab Number | Certified By | C | Mn | P | S | Si | Cu | Ni | Cr | Mo | Cb | V | Al | Ti | N2 | B | Ca | Sn | CEV | ACI |
|--------------|------------------|--------------|------|------|-------|-------|------|------|------|------|-------|-------|-------|-------|-------|-------|--------|--------|----|------|-----|
| 7E0085B | A7R1834-02 *** | A7R1834 | 0.07 | 1.14 | 0.011 | 0.005 | 0.03 | 0.17 | 0.06 | 0.23 | 0.023 | 0.038 | 0.005 | 0.026 | 0.011 | 0.009 | 0.0001 | 0.0015 | | 0.33 | |

| Shipped Item | Certified By | Heat Number | Yield ksi | Tensile ksi | Y/T % | ELONGATION % | | Bend OK? | Hard HB | Charpy Impacts (ft-lbs) | | | | Shear % | | | Test Temp | | | | | |
|--------------|--------------|-------------|-----------|-------------|-------|--------------|----|----------|---------|-------------------------|----|-----|----|---------|-----|---|-----------|---|---|-----|--|-------|
| | | | | | | 2" | 8" | | | Size | mm | 1 | 2 | 3 | Avg | 1 | | 2 | 3 | Avg | | |
| 7E0085B | S7E0085FTT | A7R1834 *** | 58.3 | 69.4 | 84.0 | 30.6 | | | | | | | | | | | | | | | | |
| 7E0085B | S7E0085BLI | A7R1834 *** | | | | | | | | 5.0 | 90 | 89 | 77 | 85.3 | | | | | | | | -22 F |
| 7E0085B | S7E0085FLI | A7R1834 *** | | | | | | | | 5.0 | 82 | 83 | 88 | 84.3 | | | | | | | | -22 F |
| 7E0085B | S7E0085MLI | A7R1834 *** | | | | | | | | 5.0 | 88 | 102 | 72 | 87.3 | | | | | | | | -22 F |
| 7E0085B | S7E0085MTT | A7R1834 *** | 63.1 | 72.1 | 87.5 | 25.4 | | | | | | | | | | | | | | | | |

Items: 1 PCS: 5 Weight: 8168 LBS

Mercury has not come in contact with this product during the manufacturing process nor has any mercury been used by the manufacturing process. Certified in accordance with EN 10204 3.1. No weld repair has been performed on this material. Manufactured to a fully killed fine grain practice. NUTEMPER TEMPER PASSED plate from coil ISO 9001:2015 Registered, PED Certified

We hereby certify that the product described above passed all of the tests required by the specifications.

Quilin Yu
Dr. Quilin Yu - Metallurgist

*** indicates Heats melted and Manufactured in the U.S.A.

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Figure A-13. 8½-in. x 11-in. x ¼-in. (216-mm x 280-mm x 6-mm) Bottom Post Plates, Test No. CMGS-2

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) 395-6701

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 | 30000562480DESO |
| 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% |

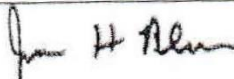
CE1554: CE per F1554 GR55, S1

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

Figure A-14. 5/8-in. (16-mm) Diameter, 10-in. Hex Head Bolts, Test Nos. CMGS-1 and CMGS-2

**Certified Material Test Report to BS EN 10204-2004 3.1
FOR ASTM A563, GRADE A HEX FIN NUTS**

| | |
|---|---------------------------|
| FACTORY: IFI & Morgan Ltd. Haiyan Office | REPORT DATE: 2017-7-20 |
| ADDRESS: No.583-28 · CHANG'AN NORTH ROAD WUYUAN TOWN, HAIYAN, ZHEJIANG CHINA | |
| Tel: (852) 2542 3366 | |
| CUSTOMER: | MFG LOT NUMBER: GL17089-2 |
| SAMPLE SIZE: ACC. TO ASME B18.18-11; ASTM F1470-12 | PO NUMBER: 210133243 |
| SIZE: 1-8 HDG QTY: 15150 PCS | PART NO: 36719 |

STEEL PROPERTIES
STEEL GRADE: ML08AL HEAT NUMBER: 1623764

| | | | | |
|---|--------------------|----------------|---------------------|---------------------|
| CHEMISTRY SPEC: ASTM A563 GRADE A TEST: | C %*100 0.55max | Mn%*100 min | P %*1000 0.12max | S %*1000 0.15max |
| | 0.06 | 0.4 | 0.01 | 0.006 |

| DIMENSIONAL INSPECTIONS | | SPECIFICATION: ASME-B18.2.2-2010 | | | |
|-------------------------|-------------------|----------------------------------|---------------|------|------|
| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
| APPEARANCE | ASTM F812-2013 | | PASSED | 29 | 0 |
| THREAD | ASME B1.3-2003 2B | | PASSED | 15 | 0 |
| WIDTH A/F | 1.500-1.450 | | 1.488-1.485 | 4 | 0 |
| WIDTH A/C | 1.732-1.653 | | 1.708-1.704 | 4 | 0 |
| HEIGHT | 0.887-0.831 | | 0.856-0.852 | 4 | 0 |

| MECHANICAL PROPERTIES: 1/4" to 1 1/2" | | SPECIFICATION: ASTM A563-07a GR-A | | | |
|---------------------------------------|----------------|-----------------------------------|---------------|------|------|
| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
| HARDNESS : | ASTM F606-2014 | B68-C32 Max(107HRB) | C25-27 | 15 | 0 |
| PROOF LOAD : | ASTM F606-2014 | Min 68 Ksi | 70-72 Ksi | 4 | 0 |

| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|--------------------|---------------|-------------|---------------|------|------|
| HOT DIP GALVANIZED | ASTM F2329-05 | MIN 2.10miu | 2.3-2.5miu | 4 | 0 |

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM OR SAE SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.


(SIGNATURE OF Q.A. CONTROL MGR.)
(NAME OF MANUFACTURER)

Figure A-15. 5/8-in. (16-mm) Diameter, Hex Head Nuts, Test Nos. CMGS-1 and CMGS-2

From: FAXmaker To: 1-815-877-0734 Page: 1/1 Date: 5/14/2015 4:00:16 PM

Heat Number
2038622

Shipper No
680907

Invoice No
701917

Customer PO#
5-7-2015 MIKE

Customer Name
GAFFNEY BOLT CO.



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®

| | | | | | |
|--|----------------------------|---|----------------------------|---|--|
| 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 | S O L D T O | Infra-Metals - Mars 1601 Broadway St Marseilles IL US 61341-9328 8009875283 | S H I P T O | Infra-Metals - Mars 1601 Broadway St Marseilles IL US 61341-9328 8009875283 | Delivery#: 81471669 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

This fax was sent with GFI FAXmaker fax server. For more information, visit: <http://www.gfi.com>

Figure A-16. 7/8-in. (22-mm) Diameter, 8-in. (203-mm) Long Hex Head Bolts, Test Nos. CMGS-1 and CMGS-2

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

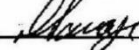
Mechanical properties tested in accordance to ASTM F606/F606M, ASTM A370, ASTM E18

| Chemical Composition (%) | | | | | | | | | | | | Shape & Dimension | | | |
|--------------------------------|---------------|----------------|--------------------------------------|--|-----------------|--|-------|-------|------|------|------|-------------------|---|--------------|--|
| Mill Maker | Material Size | Heat No. | Spec. | C | Si | Mn | P | S | Cu | Ni | Cr | Mo | Inspection | ANSI B18.2.2 | |
| NUCOR | CARBON | | | 0.20 | | MIN. | MAX. | MAX. | | | | | | GOOD | |
| STEEL | STEEL | 12101054 | | 0.43 | 0.24 | 0.87 | 0.015 | 0.020 | 0.09 | 0.04 | 0.08 | | | | |
| Mechanical Property Inspection | | | | | | | | | | | | Thread Precision | | | |
| Item | Proof Load | Cone stripping | Hardness | After Heat Treatment Hardness | Absorbed Energy | Heat Treatment | | | | | | Inspection | ANSI B1.1 CLASS 2B | | |
| Spec. | 80,850 lbf | - | 24-38 HRC | | | T: MIN. 800 F | | | | | | GOOD | | | |
| | n | n | | 5 Piece Average After Heat Treatment | | Q: FORGING Q (W.Q.) | | | | | | | Remarks: | | |
| | 5 | - | 29.4 28.9 29.7 29.7 29.5 | | | T: 1058 F/45M (W.C.) | | | | | | | "DH U" | | |
| Results | GOOD | - | 29.4 | Hardness Treatment After 24 Hr.X °F °C | at °F °C | Q: Quenching T: Tempering ST: Solution Treatment | | | | | | | Production Quantity 22,391 pcs. BCT Foundation Tube Keeper Bolt Nuts R#15-0600 June 2015 SMT | | |

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



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Figure A-17. 7/8-in. (22-mm) Diameter, Hex Head Nuts, Test Nos. CMGS-1 and CMGS-2

Feb. 14. 2018 11:23AM Fastenal-NELIN

No. 4249 P. 2



Certificate of Compliance

| | |
|---------------------------------------|--|
| Sold To: UNL TRANSPORTATION | Purchase Order: tighe picking up |
| | Job: |
| | Invoice Date: 10/23/2017 |

THIS IS TO CERTIFY THAT WE HAVE SUPPLIED YOU WITH THE FOLLOWING PARTS.
THESE PARTS WERE PURCHASED TO THE FOLLOWING SPECIFICATIONS.

50 PCS 1"-8 A-563 Grade DH Hot Dip Galvanized Heavy Hex Nut SUPPLIED UNDER OUR TRACE NUMBER 210119800 AND UNDER PART NUMBER 36761

4 PCS 1"-8 x 12 ft ASTM A307 Gr A Hot Dip Galvanized Low Carbon Steel Threaded Rod SUPPLIED UNDER OUR TRACE NUMBER 200125104 AND UNDER PART NUMBER 47657

This is to certify that the above document is true and accurate to the best of my knowledge.

Please check current revision to avoid using obsolete copies.

This document was printed on 02/14/2018 and was current at that time.

Fastenal Account Representative Signature

Fastenal Store Location/Address

3201 N. 23rd Street STE 1
LINCOLN, NE 68321
Phone #: (402)476-7900
Fax #: 402/476-7958

Printed Name

2/14/18

Date

Page 1 of 1

Figure A-18. 1-in. (25-mm) Diameter, 10½-in. (267-mm) Long Hex Head Bolts, Test Nos. CMGS-1 and CMGS-2

MANGAL STEEL ENTERPRISES LTD.
FINAL INSPECTION CERTIFICATE

DATE : 20.06.2017

CUSTOMER : FASTENAL COMPANY PURCHASING IMPORT TRAFFIC

PART NAME : CARBON STEEL ALL THREADED RODS

SIZE : 1" - 8 X 10 FT **DATE :** 09.03.2017

PART NO. (Customer) : 47641 **REPORT NO. :** M 18

MATERIAL/DIA : 25 MM **SHIPPING NO.** 120280178 (LOT#3)

HEAT NO. : 604061 **ORDER NO. :** 120280178

LOT QTY. : 30 PCS **LOT NO. :** 25 V - 5/16

SPECIFICATION : ASTM A 307 GRADE A; 1A THREAD FIT

QUANTITY TESTED : 2 PCS

| INSPECTION ITEM | SPECIFICATION | | INSPECTION RESULT | | REMARKS |
|------------------|---------------|-----|-------------------|------------|---------|
| | Min | Max | 1st Sample | 2nd Sample | |
| 1 TENSILE (ksi) | 60 | - | 74.6 | 74.7 | OK |
| 2 YIELD STRENGTH | | | | | |
| 3 ELONGATION | | | | | |
| 4 HARDNESS | 69 - 100 HRB | | 84 HRB | 84 HRB | OK |
| 5 COATING (HDG) | 45 μ | | 48 μ | 50 μ | OK |
| 6 APPEARANCE | VISUAL | | OK | OK | OK |

| PHYSICAL DIMENSIONS | SPECIFICATION | | INSPECTION RESULT | | REMARKS |
|----------------------|--------------------|--------|-------------------|---------------|---------|
| | Min | Max | 1st Sample | 2nd Sample | |
| 1 MAJOR DIA (inches) | 0.975" | 0.998" | 0.992" | 0.993" | OK |
| 2 PITCH DIA (inches) | 0.906" | 0.916" | 0.909" | 0.910" | OK |
| 3 LENGTH (ft) | 10' ($\pm 1/8"$) | | 10' | 10' | OK |
| 4 GO GAUGE | PASS | | PASS | PASS | OK |
| 5 NO-GO GAUGE | DOES NOT PASS | | DOES NOT PASS | DOES NOT PASS | OK |

INSPECTED BY : 


CERTIFIED BY : 

Figure A-19. 1-in. (25-mm) Diameter, 10-in. (254-mm) Long Threaded Rod, Test Nos. CMGS-1 and CMGS-2

**Certified Material Test Report to BS EN 10204-2004 3.1
FOR ASTM A563, GRADE A HEX FIN NUTS**

FACTORY: IFI & Morgan Ltd. Haiyan Office
ADDRESS: No.583-28 · CHANG'AN NORTH ROAD
WUYUAN TOWN,HAIYAN,ZHEJIANG CHINA
Tel: (852)2542 3366
CUSTOMER:

REPORT DATE: 2017-4-15

MFG LOT NUMBER: GL17036-5

SAMPLE SIZE: ACC. TO ASME B18.18-11; ASTM F1470-12
SIZE: 1"-8 HDG QTY: 10800 PCS

PO NUMBER: 120282576

PART NO: 36719

STEEL PROPERTIES
STEEL GRADE: ML08A1

HEAT NUMBER: 1623764

CHEMISTRY SPEC:
ASTM A563 GRADE A
TEST:

| C %*100 | Mn %*100 | P %*1000 | S %*1000 |
|---------|----------|----------|----------|
| 0.55max | min | 0.12max | 0.15max |
| 0.06 | 0.4 | 0.01 | 0.006 |

DIMENSIONAL INSPECTIONS

SPECIFICATION: ASME-B18.2.2-2010

| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|-----------------|-------------------|-----------|---------------|------|------|
| APPEARANCE | ASTM F812-2013 | | PASSED | 22 | 0 |
| THREAD | ASME B1.3-2003 2B | | PASSED | 15 | 0 |
| WIDTH A/F | 1.500-1.450 | | 1.478-1.475 | 4 | 0 |
| WIDTH A/C | 1.732-1.653 | | 1.722-1.720 | 4 | 0 |
| HEIGHT | 0.887-0.831 | | 0.853-0.851 | 4 | 0 |

MECHANICAL PROPERTIES: 1/4" to 1 1/2"

SPECIFICATION: ASTM A563-07a GR-A

| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|--------------------|----------------|---------------------|---------------|------|------|
| HARDNESS : | ASTM F606-2014 | B68-C32 Max(107HRB) | C20-23 | 15 | 0 |
| PROOF LOAD : | ASTM F606-2014 | Min68 Ksi | 70-72 Ksi | 4 | 0 |
| HOT DIP GALVANIZED | ASTM F2329-05 | MIN 0.0017" | 0.0020-0.0021 | 4 | 0 |

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM OR SAE SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.


 (SIGNATURE OF Q.A. LAB MGR.)
 (NAME OF MANUFACTURER)

Figure A-20. 1-in. (25-mm) Diameter Hex Nut, Test Nos. CMGS-1 and CMGS-2

**CERTIFIED MATERIAL TEST REPORT
FOR ASTM A307, GRADE A - MACHINE BOLTS**

FACTORY: NINGBO ECONOMIC & TECHNICAL DEVELOPMENT REPORT DATE:2016/12/29
ZONE YONGGANG FASTENERS CO., LTD. R#17-507 H#816070039
ADDRESS: FuShan South Road No.17,BeiLun NingBo China BCT Cable Bracket Bolts
MANUFACTURE DATE:2016/12/2

TEL#(852)25423366
CUSTOMER: FASTENAL MFG LOT NUMBER:M-2016HT927-9
SAMPE SIZE: ACC.TO Dimension:ASME B18.18-11;Mechanical Properties:ASTM F1470-12
MANU QTY: 4800PCS SHIPPED QTY: 4800PCS
SIZE: 5/8-11X1 1/2 HDG
HEADMARKS: 307A PLUS NY PO NUMBER: 220023115
PART NO: 1191919

STEEL PROPERTIES:
MATERIAL TYPE:Q195 HEAT NUMBER: 816070039

CHEMISTRY SPEC:
Grade A ASTM A307-12

| | | | |
|---------|----------|----------|----------|
| C %*100 | Mn%*100 | P %*1000 | S %*1000 |
| 0.29max | 1.20 max | 0.04max | 0.15max |
| 0.07 | 0.28 | 0.016 | 0.003 |

TEST:
DIMENSIONAL INSPECTIONS Unit:inch SPECIFICATION: ASME B18.2.1 - 2012
CHARACTERISTICS SPECIFIED ACTUAL RESULT ACC. REJ.

| | | | | |
|---------------|------------------------------|-------------|----|---|
| VISUAL | ASTM F788-2013 | PASSED | 22 | 0 |
| THREAD | ASME B1.1-2003,3A GO,2A NOGO | PASSED | 15 | 0 |
| WIDTH FLATS | 0.906-0.938 | 0.915-0.928 | 4 | 0 |
| WIDTH A/C | 1.033-1.083 | 1.048-1.057 | 4 | 0 |
| HEAD HEIGHT | 0.378-0.444 | 0.394-0.424 | 4 | 0 |
| THREAD LENGTH | 1.420-1.560 | 1.435-1.541 | 15 | 0 |
| LENGTH | 1.420-1.560 | 1.435-1.541 | 15 | 0 |

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A307-2012 GR-A

| | | | | | |
|-----------------|----------------|------------|---------------|-------|-------|
| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
| ***** | ***** | ***** | ***** | ***** | ***** |
| CORE HARDNESS : | ASTM F606-2014 | 69-100 HRB | 76-79 HRB | 4 | 0 |
| WEDGE TENSILE: | ASTM F606-2014 | Min 60 KSI | 65-69 KSI | 4 | 0 |
| CHARACTERISTICS | TEST METHOD | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |

COATINGS OF ZINC: SPECIFICATION:ASTM F2329-2013
HOT DIP GALVANIZED ASTM B568-98(2104) Min 0.0017" 0.0017" -0.0018" 4 0

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE
ASTM SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF
INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

Maker's ISO# 00109Q16722R3M/3302
NINGBO ECONOMIC & TECHNICAL DEVELOPMENT
ZONE YONGGANG FASTENERS CO., LTD
(SIGNATURE: ZHANG A. YEAB MGR.)
(NAME OF MANUFACTURER)

Figure A-21. 5/8-in. (16-mm) Diameter, 1 1/2-in. (38-mm) Long Hex Head Bolts, Test Nos. CMGS-1 and CMGS-2

3510

CERTIFICATE OF COMPLIANCE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 178379

SHIPPER #: 058326
DATE SHIPPED: 08/03/2016

LOT#: 28899-B

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE: SPEC: 60,000 psi*min RESULTS: 77,659
76,735
HARDNESS: 100 max 91.30
90.70

*Pounds Per Square Inch.

COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
ROGERS GALVANIZE: 28899-B

CHEMICAL COMPOSITION

| MILL | GRADE | HEAT# | C | Mn | P | S | Si |
|-------|-------|------------|-----|-----|------|------|-----|
| NUCOR | 1010 | NF16202178 | .12 | .54 | .007 | .035 | .17 |

QUANTITY AND DESCRIPTION:

3,325 PCS 5/8" X 14" GUARD RAIL BOLT
P/N .3540G

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL AT OUR FACILITY IN ROCKFORD, ILLINOIS, USA. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE USA. WE FURTHER CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENT PER ABOVE SPECIFICATION.

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS

4th DAY OF August 20 16
Merry F. Shane

Linda Melomas
APPROVED SIGNATORY

8/4/16
DATE



Figure A-22. 5/8-in. (16-mm) Diameter, 14-in. (356-mm) Long Guardrail Bolts, Test Nos. CMGS-1 and CMGS-2



**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

Melted in USA Manufactured in USA

CHARTER STEEL TEST REPORT

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

| | |
|---------------------|-----------------------|
| Cust P.O. | 91893 |
| Customer Part # | AXA18CB-5/16 |
| Charter Sales Order | 30124802 |
| Heat # | 20479830 |
| Ship Lot # | 2117839 |
| Grade | 1018 X AK FG RHQ 5/16 |
| Process | HR |
| Finish Size | 5/16 |
| Ship date | 13-JAN-17 |

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 # 20479830

Lab Code: 125544

| CHEM | C | MN | P | S | SI | NI | CR | MO | CU | SN | V |
|------|------|-------|-------|------|------|-----|-----|-----|-----|------|------|
| %Wt | .16 | .84 | .008 | .004 | .060 | .03 | .05 | .01 | .04 | .003 | .001 |
| | AL | N | B | TI | NB | | | | | | |
| | .051 | .0050 | .0001 | .001 | .001 | | | | | | |

CAT DI=.35

Test results of Rolling Lot # 2117839

| | # of Tests | Min Value | Max Value | Mean Value | |
|-----------------------|------------|-----------|-----------|------------|-----------------------|
| TENSILE (KSI) | 1 | 68.6 | 68.6 | 68.6 | TENSILE LAB = 0368-04 |
| REDUCTION OF AREA (%) | 1 | 72 | 72 | 72 | RA LAB = 0368-04 |

NUM DECARB=1
REDUCTION RATIO=837:1

AVE DECARB (Inch)=.000

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 = RW007-RW100 Revision = Dated = 08-NOV-13

Additional Comments:

Melt Source:
Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1, Fax0, Mail0



Page 1 of 2

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Janice Barnard Division Mgr. of Quality Assurance
bamard.j@chartersteel.com
Printed Date : 01/13/2017

Figure A-23. 5/8-in. (16-mm) Diameter Guardrail Nuts, Test Nos. CMGS-1 and CMGS-2



**CHARTER
STEEL**

A Division of
Charter Manufacturing Company, Inc.

Melted in USA Manufactured in USA

LOAD

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

CHARTER STEEL TEST REPORT

Rockford Bolt & Steel
126 Mill St.
Rockford, IL-61101
Kind Attn :Linda McComas

| | |
|---------------------|------------------------|
| Cust P.O. | P37098 |
| Customer Part # | 100905 |
| Charter Sales Order | 70075879 |
| Heat # | 20460760 |
| Ship Lot # | 3242161 |
| Grade | 1010 A AK FG RHQ 19/32 |
| Process | HPSA |
| Finish Size | 19/32 |
| Ship date | 01-NOV-16 |

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 # 20460760

| | | | | | | | | | | | | |
|------------------|------|-------|-------|------|------|-----|-----|-----|-----|------|------|--|
| Lab Code: 125544 | | | | | | | | | | | | |
| CHEM | C | MN | P | S | SI | NI | CR | MO | CU | SN | V | |
| %Wt | .09 | .33 | .006 | .003 | .060 | .03 | .06 | .01 | .08 | .006 | .001 | |
| | AL | N | B | TI | NB | | | | | | | |
| | .025 | .0070 | .0001 | .001 | .001 | | | | | | | |

Test results of Rolling Lot # 2110397

REDUCTION RATIO=177:1

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: MELTED AND ROLLED IN THE USA

Melt Source:
Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1, Fax0, Mail0.



This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Janice Barnard Division Mgr. of Quality Assurance
barnardj@chartersteel.com
Printed Date : 11/01/2016

Figure A-24. 5/8-in. (16-mm) Diameter, 1 1/4 in. (32-mm) Long Guardrail Bolt, Test Nos. CMGS-1 and CMGS-2



Certificate of Compliance

600 N County Line Rd
Elmhurst IL 60126-2081
630-600-3600
chi.sales@mcmaster.com

University of Nebraska
Midwest Roadside Safety Facility
M W R S F
4630 Nw 36TH St
Lincoln NE 68524-1802
Attention: Shaun M Tighe
Midwest Roadside Safety Facility

Purchase Order
E000357170
Order Placed By
Shaun M Tighe
McMaster-Carr Number
2098331-01

Page 1 of 1

| Line | Product | Ordered | Shipped |
|------|---|--------------------|----------|
| 1 | 97812A109 Steel Double-Headed Nail Size 16D, 3" Length, .16" Shank Diameter, 200 Pieces/Pack, Packs of 5 | 5 Packs | 5 |

Certificate of compliance

This is to certify that the above items were supplied in accordance with the description and as illustrated in the catalog. Your order is subject only to our terms and conditions, available at www.mcmaster.com or from our Sales Department.


Sarah Weinberg
Compliance Manager

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Figure A-25. 16D Double Head Nail, Test Nos. CMGS-1 and CMGS-2

R#16-692 5/8"x10" GR Bolt
Orange Paint H#20351510 L#150424L

3500G

TRINITY HIGHWAY PRODUCTS, LLC
 425 East O'Connor Ave.
 Lima, Ohio 45801
 419-227-1296



MATERIAL CERTIFICATION

Customer: Stock Date: December 16, 2015
 Invoice Number: _____
 Lot Number: 150424L
 Part Number: 3500G Quantity: 16,702 Pcs.
 Description: 5/8" x 10" G.R. Bolt Heat Numbers: 20351510 16,702

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

| Heat | C | MN | P | S | SI | NI | CR | MO | CU | SN | V | AL | N | B | TI | NB |
|----------|-----|-----|------|------|-----|-----|-----|-----|-----|------|------|------|------|-------|------|------|
| 20351510 | .09 | .33 | .007 | .002 | .06 | .04 | .05 | .01 | .06 | .004 | .001 | .028 | .007 | .0001 | .001 | .001 |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave. Thickness / Mills) 2.52 (2.0 Mills Minimum)

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A
 WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS
 CORRECT.

[Signature]
 TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
 SWORN AND SUBSCRIBED BEFORE ME THIS 12-17-15
[Signature] NOTARY PUBLIC
 425 E. O'CONNOR AVENUE LIMA, OHIO



Figure A-26. 5/8-in. (16-mm) Diameter, 10-in. (254-mm) Long Guardrail Bolt, Test Nos. CMGS-1 and CMGS-2



Feb 15th 2017

SOLD TO:
GREGORY INDUSTRIES, INC.
4100 13TH ST. SW
CANTON, OH. 44710

SHIP TO:
HIGHWAY – FINISHED GOODS
GREGORY INDUSTRIES, INC.
ATTN: STEVE PENNINGTON
CANTON, OH 44710

R#17-700

CERTIFICATON BCT Cables Yellow Paint

CGLP ORDER# 256284
GREGORY PO# 36454

THIS LETTER AND THE ENCLOSED ATTACHMENTS ARE TO CERTIFY THAT THE FOLLOWING ITEMS WERE 100% MANUFACTURED IN THE UNITED STATES OF AMERICA.

1,330 PCS, PART# 3012G, 3/4IN X 6FT 6IN DOUBLE SWAGE GUARD RAIL ASSEMBLYS.

THEY SHOW THE DOMESTICITY OF ALL MATERIAL USED, 100% MELTED & MANUFACTURED IN THE USA. THESE ITEMS ARE HOT DIPPED GALVANIZED TO ASTM-153 SPECIFICATIONS AND STANDARDS, GALV PROCESS ALSO TOOK PLACE IN THE U.S.A.

ATTACHMENTS:

(WIRE ROPE) WIRECO WORLD GROUP REEL# 428-671806-1; HEAT# .15R582807; 16R584001; 72987C; 16R586548; 73253F; 16R588160; 16R584967; 16R585464; 16R586547; 14R574048; 14R571682; 16R586549; 16R586401; (ROCKY MOUNTAIN STEEL / EVRAZ)

(END FITTINGS) REMLINGER MFG: HEAT#S 75063022; 75062074; 765063075 (GERDAU NORTH AMERICA)

VERY TRULY YOURS

BILL KOTARSKI
GEN MGR CLEV OFFICE

| HEADQUARTERS | FLINT BRANCH | CLEVELAND BRANCH |
|--|---|--|
| 12801 UNIVERSAL DRIVE TAYLOR, MI 48180 NEW PH# (734) 947-4000 NEW FAX# (734) 947-4004 | G2427 E. JUDD ROAD BURTON, MI 48529 PH# (810) 744-4540 FAX# (810) 744-1588 | 5213 GRANT AVE CLEVELAND, OH 44105 PH# (216) 641-4100 FAX# (216) 641-1814 |

Figure A-27. BCT Anchor Cable, Test Nos. CMGS-1 and CMGS-2

Certified Material Test Report to BS EN ISO 10204-2004 3.1 FOR USS FLAT WASHER HDG

COUNTRY OF ORIGIN: CHINA
 CUSTOMER: FASTENAL
 FACTORY NAME: IFI & MORGAN LTD.
 FACTORY ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China

DESCRIPTION: 1 DATE: 2016-10-08
 INVOICE NBR: TD16680155 ORDER NBR. 210114135
 PART NBR.: 33188 QUANTITY: 3240PCS
 LOT NO.: 16H-168236-30

DIMENSIONS (UNIT: INCH)

| | STANDARD | RESULT | | | | |
|-------------|-------------|--------|-------|-------|-------|-------|
| | | 1 | 2 | 3 | 4 | 5 |
| INSIDE DIA | 1.055-1.092 | 1.068 | 1.068 | 1.067 | 1.069 | 1.068 |
| OUTSIDE DIA | 2.493-2.530 | 2.514 | 2.513 | 2.514 | 2.514 | 2.511 |
| THICKNESS | 0.136-0.192 | 0.146 | 0.149 | 0.152 | 0.152 | 0.147 |

WE HEREBY CERTIFY THAT THIS WAS PRODUCED AS PER CUSTOMER'S REQUIREMENT.

| CHARACTERISTICS | SPECIFIED | ACTUAL RESULT | ACC. | REJ. |
|-------------------------------|-----------|---------------|------|------|
| HOT DIP GALVANIZED ASTM F2329 | Min 43 um | 48-64um | 8 | 0 |

NOTE

1. QUANTITY OF SAMPLES: 5 PCS

2. JUDGEMENT: GOOD

3. CHIEF INSPECTOR: _____



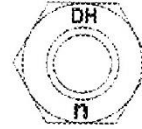
Figure A-28. BCT Cable Washers, Test Nos. CMGS-1 and CMGS-2

NUCOR
FASTENER DIVISION

LOT NO.
371123B

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

CUSTOMER NO/NAME
8001 FASTENAL COMPANY-KS
TEST REPORT SERIAL# FB488556
TEST REPORT ISSUE DATE 3/04/16
DATE SHIPPED 8/17/16
NAME OF LAB SAMPLER: SANDRA NEUMANN-PLUMMER, LAB TECHNICIAN
*****CERTIFIED MATERIAL TEST REPORT*****
NUCOR PART NO QUANTITY LOT NO. DESCRIPTION
175647 3600 371123B 1-8 GR DH HV H.D.G.
MANUFACTURE DATE 1/07/16 HEX NUT H.D.G./GREEN LUBE



--CHEMISTRY MATERIAL GRADE -1045L
MATERIAL HEAT **CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER
NUMBER NUMBER C MN P S SI NUCOR STEEL - SOUTH CAROL
RM030412 DL15105591 .44 .64 .005 .020 .20

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-07a
SURFACE CORE PROOF LOAD TENSILE STRENGTH
HARDNESS HARDNESS 90900 LBS DEG-WEDGE
(R30N) (RC) (LBS) STRESS (PSI)
N/A 26.6 PASS N/A N/A
N/A 27.0 PASS N/A N/A
N/A 27.6 PASS N/A N/A
N/A 28.9 PASS N/A N/A
N/A 26.7 PASS N/A N/A
AVERAGE VALUES FROM TESTS
27.4
PRODUCTION LOT SIZE 90800 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. 0.00294 2. 0.00311 3. 0.00346 4. 0.00235 5. 0.00218 6. 0.00270 7. 0.00353
8. 0.00322 9. 0.00406 10. 0.00269 11. 0.00275 12. 0.00315 13. 0.00487 14. 0.00253
15. 0.00416
AVERAGE THICKNESS FROM 15 TESTS .00318
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010
CHARACTERISTIC #SAMPLES TESTED MINIMUM MAXIMUM
Width Across Corners 8 1.824 1.844
Thickness 32 0.980 1.001

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.



MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/17

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Figure A-29. BCT Cable Nuts, Test Nos. CMGS-1 and CMGS-2



1000 BURLINGTON STREET, NORTH KANSAS CITY, MO 64116 1-816-474-8210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

Certified Test Report

| | | | |
|--|---|---|---------------------|
| Customer: SPS - New Century 401 New Century Parkway NEW CENTURY KS 66031-1127 | Size: 02.375 | Customer Order No: 4500269918 | Date: 07/26/2016 |
| | Gauge: .154 | Delivery No: 82799116 Load No: 3774661 | |
| | Specification: ASTM A500-13 Gr.B/C, ASTM A53-12 Gr.B BNT*, ASME SA53 Gr.B BNT* | | |

| | | | |
|---------|-------------|-------------|-------------------|
| Heat No | Yield | Tensile | Elongation |
| A79999 | KSI 63.2 | KSI 67.3 | % 2 inch 31.00 |

R#17-175 H#A79999
BCT Post Sleeves QTY 8
Oct 2016 SMT

| | | | | | | | | | | |
|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Heat No | C | MN | P | S | SI | CU | NI | CR | MO | V |
| A79999 | 0.0700 | 0.8400 | 0.0110 | 0.0040 | 0.0200 | 0.1500 | 0.0500 | 0.0600 | 0.0200 | 0.0010 |

This material was melted & manufactured in the U.S.A.
We hereby certify that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade titles above. This product was manufactured in accordance with your purchase order requirements.
BNT=Grade B not pressure tested - meets tensile & chemical properties ONLY.

This material has not come into direct contact with mercury, any of its compounds, or any mercury bearing devices during our manufacturing process, testing, or inspections.

This material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

This material has passed NDE (eddy current, A309) testing. This material has passed flattening tests.

Tensile test completed using test specimen with 3/4" reduced area.

STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe
Quality Assurance Manager

Figure A-30. BCT Post Sleeves, Test Nos. CMGS-1 and CMGS-2

Certified Analysis



Trinity Highway Products, LLC
 550 East Robb Ave.
 Lima, OH 45801 Phn:(419) 227-1296
 Customer: MIDWEST MACH.& SUPPLY CO.
 P. O. BOX 703

 MILFORD, NE 68405
 Project: RESALE

Order Number: 1269489 Prod Ln Grp: 3-Guardrail (Dom)
 Customer PO: 3346
 BOL Number: 97457 Ship Date:
 Document #: 1
 Shipped To: NE
 Use State: NE

Asof: 11/7/16

| Qty | Part # | Description | Spec | CL | TY | Heat Code/ Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Cb | Cr | Vn | ACW |
|-------|--------|----------------------------|-------|----|----|-----------------------|--------|--------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| | 701A | <i>Anchor Box</i> | A-36 | | | JK16101488 | 56,172 | 75,460 | 25.0 | 0.160 | 0.780 | 0.017 | 0.028 | 0.200 | 0.280 | 0.001 | 0.140 | 0.028 | 4 |
| | 701A | | A-36 | | | 535133 | 43,300 | 68,500 | 33.0 | 0.019 | 0.460 | 0.013 | 0.016 | 0.013 | 0.090 | 0.001 | 0.090 | 0.002 | 4 |
| 4 | 729G | TS 8X6X3/16X8'-0" SLEEVE | A-500 | | | A49248 | 64,818 | 78,412 | 32.0 | 0.200 | 0.810 | 0.014 | 0.002 | 0.040 | 0.020 | 0.000 | 0.040 | 0.001 | 4 |
| 20 | 738A | 5" TUBE SL.188X6X8 1/4" PL | A-36 | | 2 | 4182184 | 45,000 | 67,900 | 31.0 | 0.210 | 0.760 | 0.012 | 0.008 | 0.010 | 0.050 | 0.001 | 0.030 | 0.002 | 4 |
| | 738A | | A-500 | | | A49248 | 64,818 | 78,412 | 32.0 | 0.200 | 0.810 | 0.014 | 0.002 | 0.040 | 0.020 | 0.000 | 0.040 | 0.001 | 4 |
| 6 | 749G | TS 8X6X3/16X6'-0" SLEEVE | A-500 | | | A49248 | 64,818 | 78,412 | 32.0 | 0.200 | 0.810 | 0.014 | 0.002 | 0.040 | 0.020 | 0.000 | 0.040 | 0.001 | 4 |
| 6 | 782G | 5/8"X8"X8" BEAR PL/OF | A-36 | | | DL15103543 | 58,000 | 74,000 | 25.0 | 0.150 | 0.750 | 0.013 | 0.025 | 0.200 | 0.360 | 0.003 | 0.090 | 0.000 | 4 |
| 20 | 783A | 5/8X8X8 BEAR PL 3/16 STP | A-36 | | | PL14107973 | 48,167 | 69,811 | 25.0 | 0.160 | 0.740 | 0.012 | 0.041 | 0.190 | 0.370 | 0.000 | 0.220 | 0.002 | 4 |
| | 783A | | A-36 | | | DL15103543 | 58,000 | 74,000 | 25.0 | 0.150 | 0.750 | 0.013 | 0.025 | 0.200 | 0.360 | 0.003 | 0.090 | 0.000 | 4 |
| 45 | 3000G | CBL 3/4X6'/DBL | HW | | | I19048 | | | | | | | | | | | | | |
| 7,000 | 3340G | 5/8" GR HEX NUT | HW | | | 0055551-116146 | | | | | | | | | | | | | |
| 4,000 | 3360G | 5/8"X1.25" GR BOLT | HW | | | 0053777-115516 | | | | | | | | | | | | | |
| 450 | 3500G | 5/8"X10" GR BOLT A307 | HW | | | 28971-B | | | | | | | | | | | | | |
| 1,225 | 3540G | 5/8"X14" GR BOLT A307 | HW | | | 29053-B | | | | | | | | | | | | | |

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Figure A-31. North-Side Anchor Bearing Plate and Anchor Bracket Assembly, Test Nos. CMGS-1 and CMGS-2

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

Order Number: 1095199
 Customer PO: 2041
 BOL Number: 24481
 Document #: 1
 Shipped To: NE
 Use State: KS

As of 6/20/08

Project: RESSALE

| Qty | Part# | Description | Spec | CL | TY | Heat Code/ Heat# | Yield | TS | Elg | C | Mn | P | S | SI | Ca | Co | Cr | Va | ACW |
|-----|-------|-----------------------|--------|----|----|------------------|--------|--------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| 25 | 6G | 12/63/8 | 64-100 | A | | 84964 | 64,730 | 81,200 | 25.4 | 0.180 | 0.720 | 0.012 | 0.001 | 0.040 | 0.040 | 0.000 | 0.050 | 0.000 | 4 |
| 20 | 701A | .25X11.75X16 CAB ANC | A-36 | | | 4153095 | 44,900 | 60,800 | 34.0 | 0.240 | 0.759 | 0.012 | 0.003 | 0.020 | 0.020 | 0.000 | 0.040 | 0.002 | 4 |
| 10 | 742G | 60 TUBS 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"X3"X8" BEAR PL/OF | A-36 | | | 6105195 | 46,700 | 69,900 | 23.5 | 0.180 | 0.830 | 0.010 | 0.005 | 0.020 | 0.230 | 0.000 | 0.070 | 0.006 | 4 |
| 40 | 907G | 12/BUFFER/ROLLED | M-160 | 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:



Trinity Highway Products, LLC
Certified By:

Stelania Amal...

Figure A-32. South-Side Anchor Bearing Plate and North-Side Ground Strut Assembly, Test Nos. CMGS-1 and CMGS-2

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: 1214903 Prod Ln Grp: 9-End Terminals (Dom)

Customer PO: 2878

BOL Number: 80278

Document #: 1

Shipped To: NE

Use State: KS

Ship Date:

As of: 3/7/14

| Qty | Part # | Description | Spec | CL | TY | Heat Code/ Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Cb | Cr | Vn | ACW | |
|-----|--------|------------------------------|------------------|----|----|-----------------|--------|--------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|--|
| 36 | 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 | |
| 20 | 3000G | CBL 3/4X6'6/DBL | | HW | | 98790 | | | | | | | | | | | | | | |
| 22 | 9852A | STRUT & YOKE ASSY | A-1011-SS | | | 163375 | 48,380 | 64,020 | 32.9 | 0.190 | 0.520 | 0.011 | 0.003 | 0.030 | 0.110 | 0.000 | 0.050 | 0.000 | 4 | |
| | 9852A | | A-36 | | | 11237730 | 45,500 | 70,000 | 30.0 | 0.170 | 0.500 | 0.010 | 0.008 | 0.020 | 0.080 | 0.000 | 0.070 | 0.001 | 4 | |

Ground Strut Green Paint

R#15-0157 September 2014 SMT

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 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 ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH - 46000 LB

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Figure A-33. South-Side Ground Strut Assembly, Test Nos. CMGS-1 and CMGS-2

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: RESSALE

Order Number: 1095199

Customer PO: 2041

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 | Zlg | C | Mn | P | S | SI | Ca | Ch | Cr | Va | ACW |
|-----|-------|-------------------------|-------|----|----|-------------------|--------|--------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|
| 25 | 6G | 12G3/8 | M-180 | A | | 84964 | 64,230 | 81,360 | 25.4 | 0.180 | 0.720 | 0.012 | 0.001 | 0.040 | 0.080 | 0.060 | 0.060 | 0.000 | 4 |
| 20 | 701A | 25K11.25X16 CAB ANC | A-36 | | | 4153095 | 44,900 | 60,860 | 34.0 | 0.240 | 0.750 | 0.012 | 0.003 | 0.020 | 0.020 | 0.000 | 0.040 | 0.002 | 4 |
| 10 | 742G | 60 TUBB SL/188X9X6 | 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"X3/8" BEAR PL/OF | A-36 | | | 6105195 | 46,700 | 69,900 | 23.5 | 0.180 | 0.830 | 0.010 | 0.005 | 0.020 | 0.230 | 0.000 | 0.070 | 0.006 | 4 |
| 40 | 807G | 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.

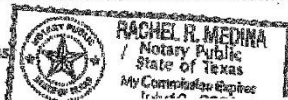
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

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-1085 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:



Trinity Highway Products, LLC
Certified By:

Stelanie Ansel...

Figure A-34. South-Side Anchor Bearing Plate, Test Nos. CMGS-1 and CMGS-2

Certified Analysis



Trinity Highway Products, LLC
550 East Robb Ave.

Lima, OH 45801 Phn:(419) 227-1296

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405

Project: RESALE

Order Number: 1269489 Prod Ln Grp: 3-Guardrail (Dom)

Customer PO: 3346

BOL Number: 97457

Document #: 1

Shipped To: NE

Use State: NE

Ship Date:

As of: 11/7/16

| Qty | Part # | Description | Spec | CL | TY | Heat Code/ Heat | Yield | TS | Elg | C | Mn | P | S | Si | Cu | Cb | Cr | Vn | ACW | |
|-----|--------|--------------------------|-------|----|----|-----------------|--------|--------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-----|---|
| 175 | 3580G | 5/8"X18" GR BOLT A307 | HW | | | 29145-B | | | | | | | | | | | | | | |
| 6 | 6696G | CBL 5/8"X14.75/DBL BTN | HW | | | 248853 | | | | | | | | | | | | | | |
| 400 | 6740B | PLYMR BLK 6X12X14 MT | HW | | | 27950 | | | | | | | | | | | | | | |
| 4 | 9852A | STRUT & YOKE ASSY | A-36 | | | 195070 | 52,940 | 69,970 | 31.1 | 0.190 | 0.520 | 0.014 | 0.004 | 0.020 | 0.110 | 0.000 | 0.050 | 0.000 | 4 | |
| 7 | 12379G | T12/12/6/SPEC/S 34"RCX | RHC | | 2 | L34713 | | | | | | | | | | | | | | 4 |
| | | | M-180 | A | 2 | 172876 | 55,930 | 72,020 | 31.4 | 0.190 | 0.720 | 0.014 | 0.002 | 0.020 | 0.130 | 0.000 | 0.080 | 0.000 | 4 | |
| | | | M-180 | A | 2 | 172876 | 55,930 | 72,020 | 31.4 | 0.190 | 0.720 | 0.014 | 0.002 | 0.020 | 0.130 | 0.000 | 0.080 | 0.000 | 4 | |
| 6 | 12383G | T12/12/6/63/SPEC SLOTS/S | RHC | | | L33814 | | | | | | | | | | | | | | 4 |
| | | | M-180 | A | | 182997 | 58,340 | 76,890 | 26.9 | 0.180 | 0.730 | 0.014 | 0.004 | 0.010 | 0.130 | 0.000 | 0.060 | 0.001 | 4 | |
| | | | M-180 | A | | 182998 | 60,310 | 78,910 | 25.4 | 0.200 | 0.730 | 0.012 | 0.006 | 0.010 | 0.140 | 0.000 | 0.050 | 0.001 | 4 | |
| | | | M-180 | A | | 182997 | 58,340 | 76,890 | 26.9 | 0.180 | 0.730 | 0.014 | 0.004 | 0.010 | 0.130 | 0.000 | 0.060 | 0.001 | 4 | |
| | | | M-180 | A | | 182998 | 60,310 | 78,910 | 25.4 | 0.200 | 0.730 | 0.012 | 0.006 | 0.010 | 0.140 | 0.000 | 0.050 | 0.001 | 4 | |
| 3 | 12385G | T12/12/6/SPEC/S 5"RCX | | | 2 | L34416 | | | | | | | | | | | | | | 4 |
| | | | M-180 | A | 2 | 208318 | 64,140 | 81,540 | 24.5 | 0.190 | 0.720 | 0.011 | 0.003 | 0.020 | 0.110 | 0.000 | 0.060 | 0.000 | 4 | |
| 24 | 19361G | BNT PL 3/16X12-5/8X5-1/2 | A-36 | | | B4M5475 | 46,800 | 70,400 | 29.1 | 0.180 | 0.840 | 0.007 | 0.008 | 0.060 | 0.170 | 0.000 | 0.070 | 0.001 | 4 | |

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT, 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

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Figure A-35. Anchor Bracket Assembly, Test Nos. CMGS-1 and CMGS-2



Ready Mixed Concrete Company
6200 Cornhusker Hwy, Lincoln, NE 68529
Phone: (402) 434-1844 Fax: (402) 434-1877

Customer's Signature: _____

| PLANT | TRUCK | DRIVER | CUSTOMER | PROJECT | TAX | PO NUMBER | DATE | TIME | TICKET |
|--|---------------------|------------------|-------------------------------------|---------------------|-----------------|---|-------------------|----------------|---------|
| 4 | 0212 | 9264 | 00003 | 3 | | HOLLOWAY 450 625 | 8/17/17 | 9:20 AM | 4197075 |
| Customer CIA---MIDWEST ROADSIDE SAFETY | | | Delivery Address 4630 NW 36TH ST | | | Special Instructions N/SIDE OF GOODYEAR HANGAR | | | |
| LOAD QUANTITY | CUMULATIVE QUANTITY | ORDERED QUANTITY | PRODUCT CODE | PRODUCT DESCRIPTION | | UOM | UNIT PRICE | EXTENDED PRICE | |
| 9.00 | 9.00 | 18.00 | 470031PF | 47BD (1PF) WO/R | | yd | \$118.91 | \$1,070.19 | |
| Water Added On Job At Customer's Request: | | SLUMP 4.00 in | Notes: | | TICKET SUBTOTAL | | \$1,070.19 | | |
| | | | | | SALES TAX | | \$0.00 | | |
| | | | | | TICKET TOTAL | | \$1,070.19 | | |
| | | | | | PREVIOUS TOTAL | | | | |
| | | | | | GRAND TOTAL | | \$1,070.19 | | |



CAUTION FRESH CONCRETE
KEEP CHILDREN AWAY

Contains Portland cement. Freshly mixed cement, mortar, concrete or grout may cause skin injury. Avoid prolonged contact with skin. Always wear appropriate Personal Protective Equipment (PPE). In case of contact with eyes or skin, flush thoroughly with water. If irritation persists, seek medical attention promptly.

Terms & Conditions

This concrete is produced with the ASTM standard specifications for ready mix concrete. Strengths are based on a 3" slump. Drivers are not permitted to add water to the mix to exceed this slump, except under the authorization of the customer and their acceptance of any decrease in compressive strength and any risk of loss as a result thereof. Cylinder tests must be handled according to ACI/ASTM specifications and drawn by a licensed testing lab and/or certified technician. Ready Mixed Concrete Company will not deliver any product beyond any curb lines unless expressly told to do so by customer and customer assumes all liability for any personal or property damage that may occur as a result of any such directive. The purchaser's exceptions and claims shall be deemed waived unless made in writing within 3 days from time of delivery. In such a case, seller shall be given full opportunity to investigate any such claim. Seller's liability shall in no event exceed the purchase price of the materials against which any claims are made.

| MATERIAL | DESCRIPTION | DESIGN QTY | REQUIRED | BATCHED | % VAR | % MOISTURE | ACTUAL WATER |
|----------|------------------|------------|------------|------------|--------|------------|--------------|
| G47B | 47B GRAVEL | 1975.0 lb | 17994.9 lb | 17960.0 lb | -0.19% | 1.24% A | 26.3 gl |
| L47B | 47B ROCK | 840.0 lb | 7635.6 lb | 7660.0 lb | 0.10% | 1.00% M | 9.1 gl |
| CEM1PF | 1PF CEMENT | 658.0 lb | 5922.0 lb | 5900.0 lb | -0.37% | | |
| WATER | WATER | 31.6 gl | 258.0 gl | 257.6 gl | -0.14% | | 257.6 gl |
| LRWR | POZZ 322N LOV | 34.0 oz | 306.0 oz | 306.0 oz | 0.00% | | |
| AIR | MB AE 200 air ei | 5.9 oz | 53.1 oz | 53.0 oz | -0.19% | | |

Actual Num Batches: 1 Manual Actual: 293.0 gl

Load: 33692 lb Design W/C: 0.40 Water/Cement: 0.41 A Design Water: 284.4 gl

Slump: 4.00 in # Water in Truck: 0.0 gl Adjust Water: 0.0 gl / Load Trim Water: 0.0 gl / CYDS

Actual W/C Ratio 0.41 Actual Water: 293 gl Batched Cement: 5900 lb Allowable Water: 0 lb To Add: 0.0 gl

Figure A-36. Concrete Culvert, Test Nos. CMGS-1 and CMGS-2



Customer's Signature: _____

| PLANT | TRUCK | DRIVER | CUSTOMER | PROJECT | TAX | PO NUMBER | DATE | TIME | TICKET | |
|--|---------------------|------------------|-------------------------------------|---------------------|-----|---|-----------------|----------------|------------|--|
| 4 | 0228 | 5806 | 00003 | 3 | | HOLLOWAY 450 625 | 8/17/17 | 9:39 AM | 4197078 | |
| Customer CIA---MIDWEST ROADSIDE SAFETY | | | Delivery Address 4630 NW 36TH ST | | | Special Instructions N/SIDE OF GOODYEAR HANGAR | | | | |
| LOAD QUANTITY | CUMULATIVE QUANTITY | ORDERED QUANTITY | PRODUCT CODE | PRODUCT DESCRIPTION | | UOM | UNIT PRICE | EXTENDED PRICE | | |
| 9.00 | 18.00 | 18.00 | 470031PF | 47BD (1PF) WO/R | | yd | \$118.91 | \$1,070.19 | | |
| Water Added On Job At Customer's Request: | | SLUMP 4.00 in | Notes: | | | | TICKET SUBTOTAL | | \$1,070.19 | |
| | | | | | | SALES TAX | | \$0.00 | | |
| | | | | | | TICKET TOTAL | | \$1,070.19 | | |
| | | | | | | PREVIOUS TOTAL | | \$1,070.19 | | |
| | | | | | | GRAND TOTAL | | \$2,140.38 | | |



CAUTION FRESH CONCRETE
KEEP CHILDREN AWAY

Contains Portland cement. Freshly mixed cement, mortar, concrete or grout may cause skin injury. Avoid prolonged contact with skin. Always wear appropriate Personal Protective Equipment (PPE). In case of contact with eyes or skin, flush thoroughly with water. If irritation persists, seek medical attention promptly.

Terms & Conditions

This concrete is produced with the ASTM standard specifications for ready mix concrete. Strengths are based on a 3" slump. Drivers are not permitted to add water to the mix to exceed this slump, except under the authorization of the customer and their acceptance of any decrease in compressive strength and any risk of loss as a result thereof. Cylinder tests must be handled according to ACI/ASTM specifications and drawn by a licensed testing lab and/or certified technician. Ready Mixed Concrete Company will not deliver any product beyond any curb lines unless expressly told to do so by customer and customer assumes all liability for any personal or property damage that may occur as a result of any such directive. The purchaser's exceptions and claims shall be deemed waived unless made in writing within 3 days from time of delivery. In such a case, seller shall be given full opportunity to investigate any such claim. Seller's liability shall in no event exceed the purchase price of the materials against which any claims are made.

| MATERIAL | DESCRIPTION | DESIGN QTY | REQUIRED | BATCHED | % VAR | % MOISTURE | ACTUAL WATER |
|----------|-----------------|------------|------------|------------|--------|------------|--------------|
| G47B | 47B GRAVEL | 1975.0 lb | 17996.9 lb | 17940.0 lb | -0.32% | 1.25% A | 26.5 gl |
| L47B | 47B ROCK | 840.0 lb | 7635.6 lb | 7600.0 lb | -0.14% | 1.00% M | 9.0 gl |
| CEM1PF | 1PF CEMENT | 658.0 lb | 5922.0 lb | 5900.0 lb | -0.37% | | |
| WATER | WATER | 31.6 gl | 257.8 gl | 258.6 gl | 0.33% | | 258.6 gl |
| LRWR | POZZ 322N LOV | 34.0 oz | 306.0 oz | 306.0 oz | 0.00% | | |
| AIR | MB AE 200 air e | 5.9 oz | 53.1 oz | 54.0 oz | 1.69% | | |

Actual Num Batches: 1 Manual

Load: 33621 lb Design W/C: 0.40 Water/Cement: 0.42 A Design Water: 284.4 gl Actual: 294.1 gl

Slump: 4.00 in # Water in Truck: 0.0 gl Adjust Water: 0.0 gl / Load Trim Water: 0.0 gl / CYDS

Actual W/C Ratio 0.42 Actual Water: 294 gl Batched Cement: 5900 lb Allowable Water: 0 lb To Add: 0.0 gl

Figure A-37. Concrete Culvert, Test Nos. CMGS-1 and CMGS-2



LINCOLN OFFICE
825 "M" Street Suite 100
Lincoln, NE 68508
Phone: (402) 479-2200
Fax: (402) 479-2276

COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 6x12

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility
Project Name: Miscellaneous Concrete Testing
Placement Location: WI MGS Culvert

Date: 13-Sep-17

Mix Designation:

Required Strength:

Laboratory Test Data

| Laboratory Identification | Field Identification | Date Cast | Date Received | Date Tested | Days Cured in Field | Days Cured in Laboratory | Age of Test, Days | Length of Specimen, in. | Diameter of Specimen, in. | Cross-Sectional Area, sq.in. | Maximum Load, lbf | Compressive Strength, psi. | Required Strength, psi. | Type of Fracture | ASTM Practice for Capping Specimen |
|---------------------------|----------------------|-----------|---------------|-------------|---------------------|--------------------------|-------------------|-------------------------|---------------------------|------------------------------|-------------------|----------------------------|-------------------------|------------------|------------------------------------|
| URR- 12 | A | 8/17/2017 | 9/13/2017 | 9/13/2017 | 27 | 0 | 27 | 12 | 6.02 | 28.46 | 132,704 | 4,660 | | 5 | C 1231 |
| URR- 13 | 1B | 8/17/2017 | 9/13/2017 | 9/13/2017 | 27 | 0 | 27 | 12 | 6.01 | 28.37 | 132,547 | 4,670 | | 5 | C 1231 |

1 cc: Ms. Karla Lechtenberg
Midwest Roadside Safety Facility

Remarks:

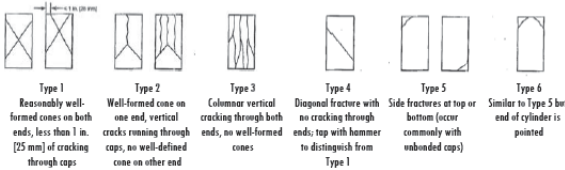
All concrete test data in this report was produced by Benesch personnel using ASTM Standard Methods and Practices unless otherwise noted.

Test results presented relate only to the concrete sampled by Benesch personnel as referenced above.

This report shall not be reproduced except in full, without the written approval of Alfred Benesch & Company.

Report Number 2147369527
Page 1

Sketches of Types of Fractures



**ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY**

By 
Brant Wells, Field/Lab Operations Manager

Figure A-38. Concrete Culvert, Test Nos. CMGS-1 and CMGS-2

| Concrete Industries 6300 Cornhusker Highway P.O. Box 29529 Lincoln, NE 68529 Phone: (402)434-1800 FAX: (402)434-1899 | | | | JOB NUMBER 8000MISC. | | RELEASE NUMBER WES-RSF | | REQ. DELIVERY DATE | | PAGE 1 of 1 | | | | | | | | | |
|--|----------------------------------|------|--------|-------------------------|-------|---------------------------|-------|---------------------------------|-------|----------------|---|-----|-------|---|---|---|---|----|-----|
| MATERIAL TYPE Rebar, Grade 60, Epoxy | | | | REFERENCE | | DRAWING ID | | DESCRIPTION CULVERTS FOR MGS | | | | | | | | | | | |
| Job Name | JOB COMPLETE | | | | | | | | | | | CC | RSFS | | | | | | |
| Customer | MIDWEST ROADSIDE SAFETY FACILITY | | | | | | | | | | | BY | wrb | | | | | | |
| Item | Qty | Size | Length | Mark | Shape | Lbs | A | B | C | D | E | F/R | G | H | J | K | O | BC | |
| 1 | 8 | 4 | 5-05 | A10 | S10 | 29 | | 1-002 | 4-042 | | | | | | | | | | 202 |
| 2 | 38 | 4 | 5-01 | A11 | S10 | 129 | | 1-002 | 4-01 | | | | | | | | | | 202 |
| 3 | 45 | 4 | 4-09 | A5 | S5 | 143 | 1-002 | 1-03 | 0-07 | 0-10 | | | 1-002 | | | | | | 110 |
| 4 | 44 | 4 | 20-00 | A7 | | 588 | | | | | | | | | | | | | 0 |
| 5 | 12 | 4 | 9-09 | A9 | | 78 | | | | | | | | | | | | | 0 |
| 6 | 22 | 4 | 6-01 | A7LAP | | 89 | | | | | | | | | | | | | 0 |
| 7 | 108 | 4 | 4-09 | A6 | | 343 | | | | | | | | | | | | | 0 |
| 8 | 46 | 4 | 3-09 | A8 | | 115 | | | | | | | | | | | | | 0 |
| 323 | | | | | | 1514 | | | | | | | | | | | | | |

Total Weight: 1,514 Lbs

Longest Length: 20-00

INSPECTOR

WEIGHT SUMMARY

| TOTAL | | | | STRAIGHT | | | LIGHT BENDING | | | HEAVY BENDING | | |
|-------------------------------|-------|--------|-------|----------|--------|-------|---------------|--------|-----|---------------|--------|-----|
| SIZE | ITEMS | PIECES | LBS | ITEMS | PIECES | LBS | ITEMS | PIECES | LBS | ITEMS | PIECES | LBS |
| Rebar, Grade 60, Epoxy | | | | | | | | | | | | |
| 4 | 8 | 323 | 1,514 | 5 | 232 | 1,213 | 3 | 91 | 301 | 0 | 0 | 0 |
| | 8 | 323 | 1,514 | 5 | 232 | 1,213 | 3 | 91 | 301 | 0 | 0 | 0 |

Total Weight: 1,514 Lbs

Longest Length: 20-00

GERDU 62140165

*ALL OTHER #4
IS: NUOR
KN15106961*

Reinforcing steel represented by the heat numbers shown have been tested and approved by Nebraska Department of Roads, Materials & Research Division.

This steel may be incorporated into the Project provided that no damage has occurred by Handling or shipping.

The complete shipping Report covering these materials will be issued by the Materials & Research Division.

Concrete Industries

Mary Barrett

JUN 07 2017
FOR CONSTRUCTION

Figure A-39. #4 (#13) Rebar, Test Nos. CMGS-1 and CMGS-2



GERDAU

US-ML-ST PAUL
1678 RED ROCK ROAD
SAINT PAUL, MN 55119
USA

CERTIFIED MATERIAL TEST REPORT

| | | | | | | |
|--|--|---|--------------------|-------------------|--|-----------------------------|
| CUSTOMER SHIP TO SIMCOTE INC 1645 RED ROCK RD SAINT PAUL, MN 55119 USA | | CUSTOMER BILL TO SIMCOTE INC 1645 RED ROCK ROAD SAINT PAUL, MN 55119-6014 USA | | GRADE 60 (420) | SHAPE / SIZE Rebar / #4 (13MM) | |
| SALES ORDER 2492020/000050 | | CUSTOMER MATERIAL N° | | LENGTH 60'00" | WEIGHT 17,435 LB | HEAT / BATCH 62139047/32 |
| CUSTOMER PURCHASE ORDER NUMBER 3621 | | BILL OF LADING 1332-0000032142 | DATE 08/26/2015 | | SPECIFICATION / DATE or REVISION ASTM A615/A615M-14 | |

| | | | | | | | | | | | | | | | | | | | | | |
|----------------------|--|--|--|--|--|--|--|------|------|-------|-------|------|------|------|------|-------|-------|-------|-------|---|--|
| CHEMICAL COMPOSITION | | | | | | | | C | Mn | P | S | Si | Cu | Ni | Cr | Mo | Sn | V | Nb | | |
| | | | | | | | | % | % | % | % | % | % | % | % | % | % | % | % | % | |
| | | | | | | | | 0.41 | 1.11 | 0.015 | 0.026 | 0.20 | 0.26 | 0.11 | 0.18 | 0.023 | 0.024 | 0.005 | 0.002 | | |

| | | | | | | |
|-----------------------|--|-------|--------|-----|-------|-------|
| MECHANICAL PROPERTIES | | YS | UTS | UTS | G/L | G/L |
| | | PSI | PSI | MPa | Inch | mm |
| | | 70000 | 110500 | 762 | 8.000 | 203.2 |
| | | 483 | | | | |

| | | |
|-----------------------|--------|----------|
| MECHANICAL PROPERTIES | Elong. | BendTest |
| | % | |
| | 15.00 | OK |

| | | | |
|---------------------------|---------|---------|-----------|
| GEOMETRIC CHARACTERISTICS | | | |
| % Hgt | Def Hgt | Def Gap | Def Spnce |
| in | Inch | Inch | Inch |
| 2.25 | 0.033 | 0.104 | 0.333 |

COMMENTS / NOTES

Material 100% melted and rolled in the USA. Manufacturing processes for this steel, which may include scrap melted in an electric arc furnace and hot rolling, has been performed at Gerdau St. Paul Mill, 1678 Red Rock Rd., St. Paul, Minnesota, USA. All products produced from strand cast billets. Silicon killed (deoxidized) steel. No weld repairment performed. Steel not exposed to mercury or any liquid alloy which is liquid at ambient temperatures during processing or while in Gerdau St. Paul Mill's possession. Any modification to this certification as provided by Gerdau St. Paul Mill without the expressed written consent of Gerdau St. Paul Mill negates the validity of this test report. This report shall not be reproduced except in full, without the expressed written consent of Gerdau St. Paul Mill. Gerdau St. Paul Mill is not responsible for the inability of this material to meet specific applications.

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.

Manoj

BIHASKAR YALAMANCHILI
QUALITY DIRECTOR

M R

ALEX BRANDENBURG
QUALITY ASSURANCE MGR.

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Figure A-40. #4 (#13) Bent Rebar, L-Shaped, 4 ft – 6 in. (1,372 mm) Total Length, Unbent, Test Nos. CMGS-1 and CMGS-2

Appendix B. Vehicle Center of Gravity Determination

Date: 12/1/2017 Test Name: CMGS-1 VIN: KMHCN4AC0AU423259
 Year: 2010 Make: Hyundai Model: Accent

Vehicle CG Determination

| VEHICLE | Equipment | Weight (lb.) |
|---------|-----------------------------------|--------------|
| + | Unbalasted Car (Curb) | 2471 |
| + | Hub | 19 |
| + | Brake activation cylinder & frame | 7 |
| + | Pneumatic tank (Nitrogen) | 22 |
| + | Strobe/Brake Battery | 5 |
| + | Brake Reciever/Wires | 6 |
| + | CG Plate including DAS | 13 |
| - | Battery | -31 |
| - | Oil | -12 |
| - | Interior | -57 |
| - | Fuel | -18 |
| - | Coolant | -7 |
| - | Washer fluid | -8 |
| + | Water Ballast (In Fuel Tank) | 0 |
| + | Onboard Battery | 14 |

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

Estimated Total Weight (lb.) 2424

Vehicle Dimensions for C.G. Calculations

Roof Height: 57 3/4 in. Front Track Width: 57 3/8 in.
 Wheel Base: 98 3/4 in. Rear Track Width: 57 1/4 in.

| Center of Gravity | 1100C MASH Targets | Test Inertial | Difference |
|----------------------------|--------------------|---------------|------------|
| Test Inertial Weight (lb.) | 2420 ± 55 | 2428 | 8 |
| Longitudinal CG (in.) | 39 ± 4 | 36.36017 | -2.639827 |
| Lateral CG (in.) | NA | -0.40128 | NA |
| Vertical CG (in.) | NA | 23.01861 | 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 | 804 | 778 |
| Rear | 447 | 442 |
| FRONT | 1582 | lb |
| REAR | 889 | lb |
| TOTAL | 2471 | lb |

| TEST INERTIAL WEIGHT (lb.) | | |
|----------------------------|------|-------|
| | Left | Right |
| Front | 775 | 759 |
| Rear | 456 | 438 |
| FRONT | 1534 | lb |
| REAR | 894 | lb |
| TOTAL | 2428 | lb |

Figure B-1. Vehicle Mass Distribution, Test No. CMGS-1

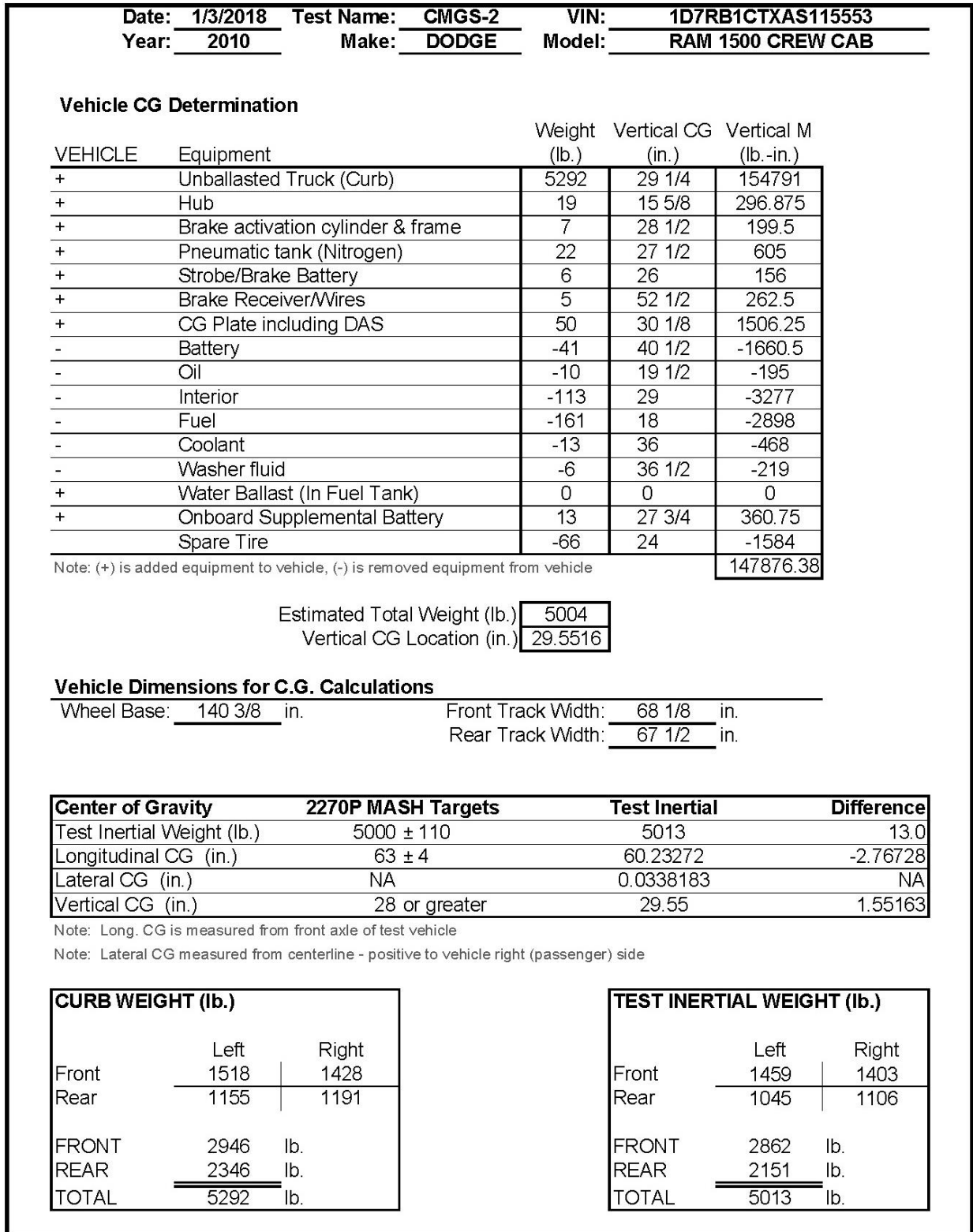


Figure B-2. Vehicle Mass Distribution, Test No. CMGS-2

Appendix C. Static Soil Tests

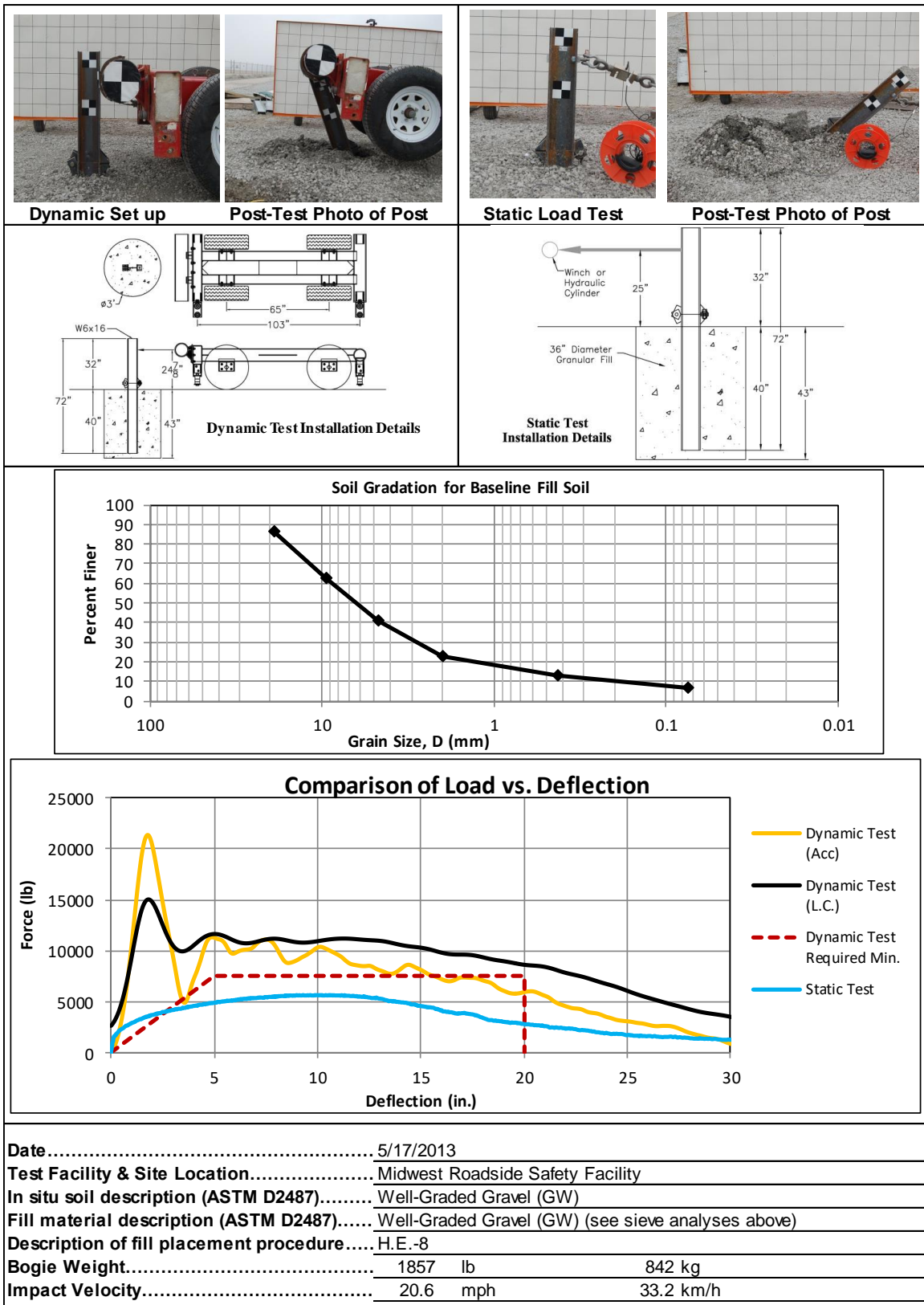
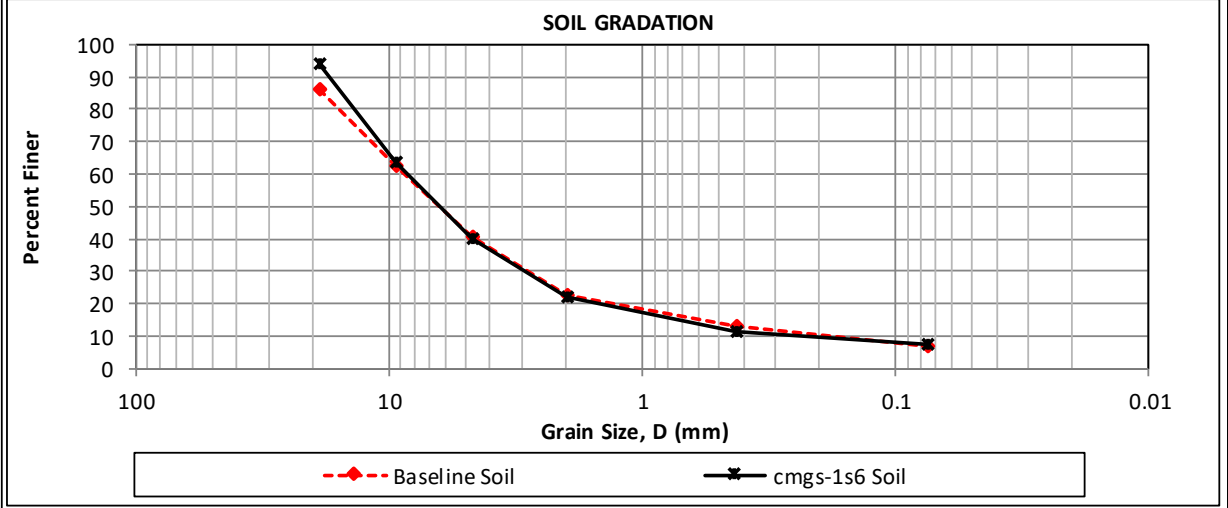
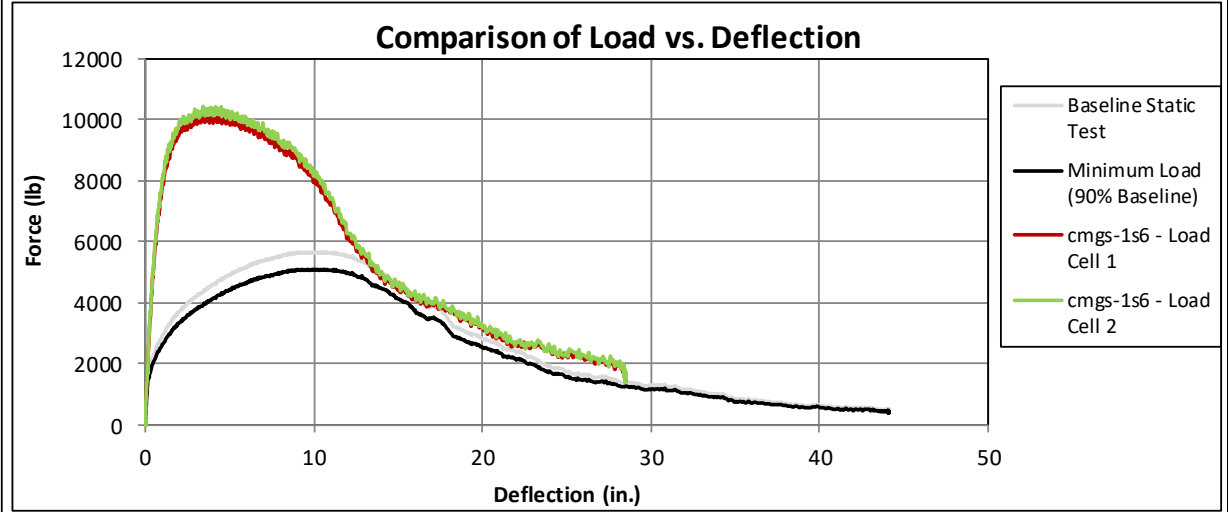
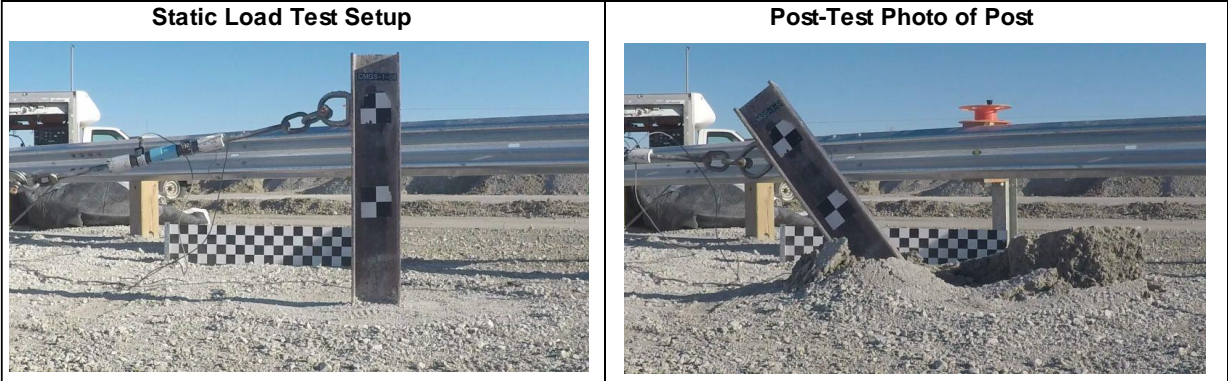


Figure C-1. Soil Strength, Initial Calibration Tests, Test No. CMGS-1



| | |
|--|--|
| Date..... | 12/1/2017 |
| 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 C-2. Static Soil Test, Test No. CMGS-1

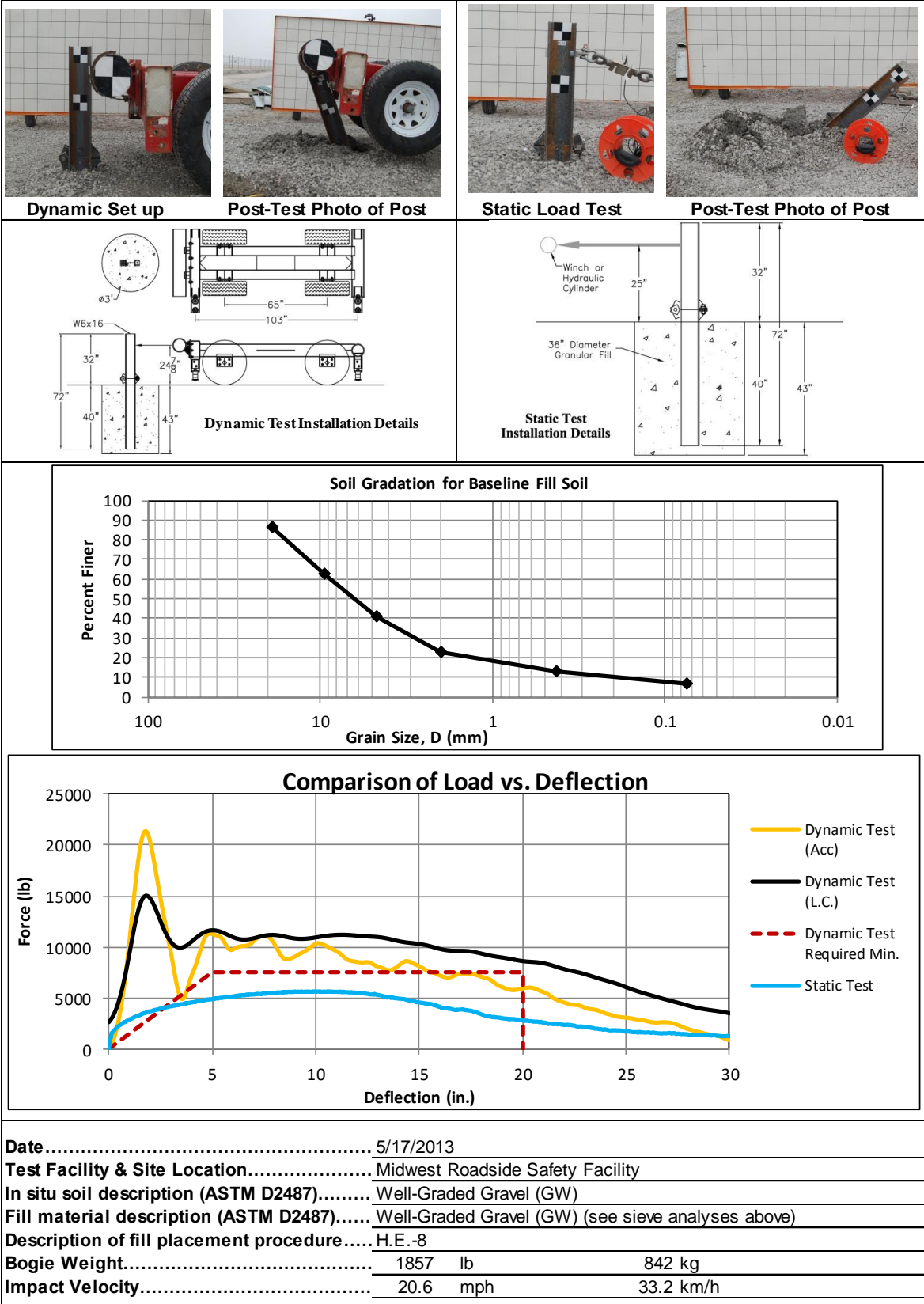


Figure C-3. Soil Strength, Initial Calibration Tests, Test No. CMGS-2

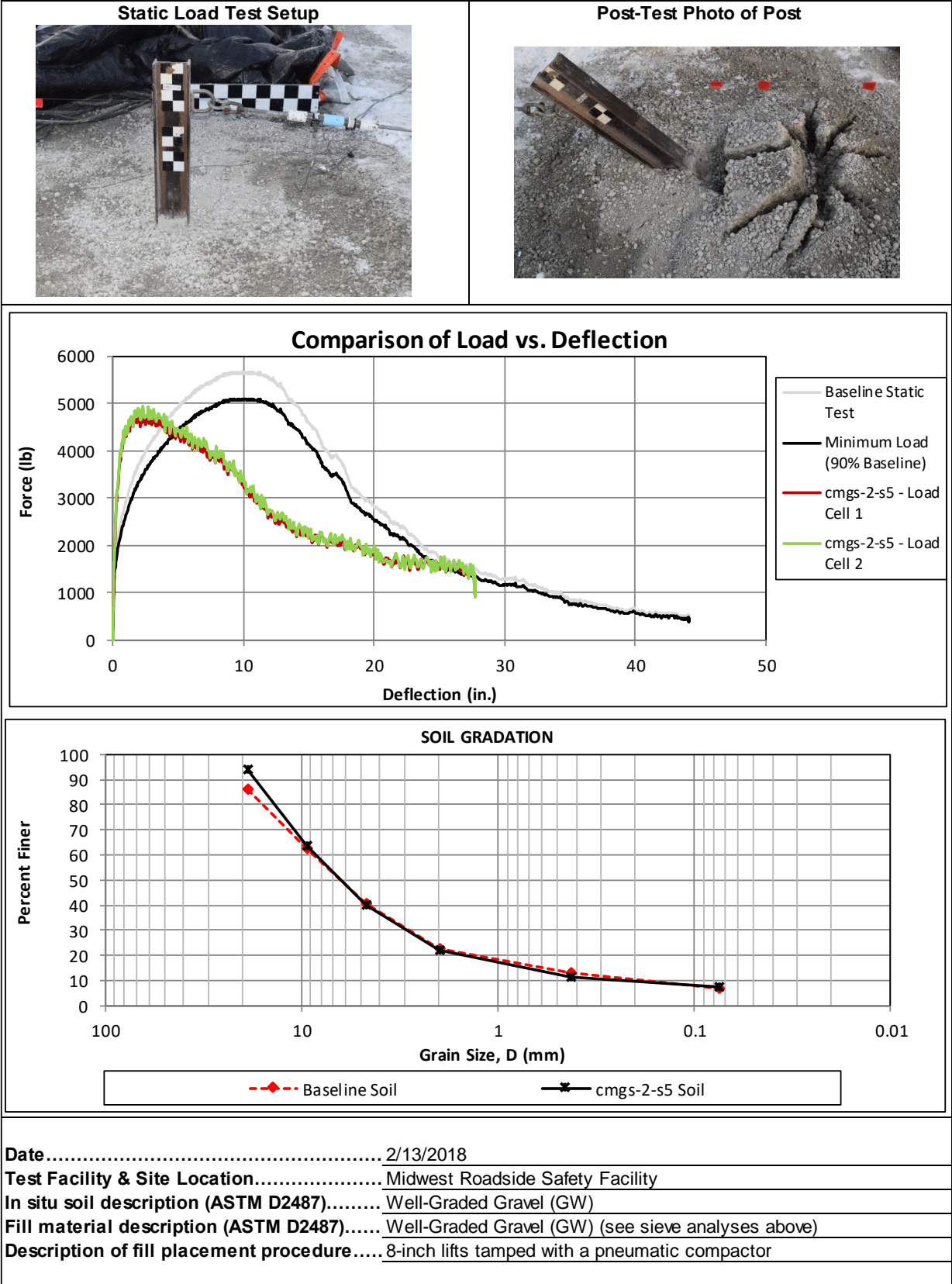


Figure C-4. Static Soil Test, Test No. CMGS-2

Appendix D. Vehicle Deformation Records

The following figures and tables describe all occupant compartment measurements taken on the test vehicles used in full-scale crash testing herein. MASH 2016 defines intrusion as the occupant compartment being deformed and reduced in size with no penetration. Outward deformations, which are denoted as negative numbers within this Appendix, are not considered as crush toward the occupant, and are not subject to evaluation by MASH 2016 criteria.

Date: 12/1/2017
Year: 2010

Test Name: CMGS-1
Make: Hyundai

VIN: KMHCN4AC0AU423259
Model: Accent

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

| POINT | X (in.) | Y (in.) | Z (in.) | X (in.) | Y (in.) | Z (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) | Total Δ (in.) |
|-------|---------|---------|---------|---------|---------|---------|----------|----------|----------|---------------|
| 1 | 26.022 | 10.369 | -2.981 | 24.767 | 12.320 | -2.774 | -1.256 | 1.951 | 0.208 | 2.329 |
| 2 | 25.897 | 15.105 | -2.961 | 24.458 | 17.093 | -2.833 | -1.439 | 1.988 | 0.128 | 2.458 |
| 3 | 25.683 | 19.029 | -2.692 | 24.009 | 20.935 | -2.555 | -1.674 | 1.906 | 0.137 | 2.541 |
| 4 | 25.168 | 23.426 | -1.838 | 23.286 | 25.291 | -1.769 | -1.883 | 1.864 | 0.070 | 2.651 |
| 5 | 22.247 | 10.452 | -4.969 | 21.101 | 12.316 | -4.824 | -1.146 | 1.863 | 0.145 | 2.192 |
| 6 | 22.432 | 14.973 | -4.830 | 21.069 | 16.817 | -4.844 | -1.363 | 1.844 | -0.014 | 2.293 |
| 7 | 22.452 | 18.834 | -4.394 | 20.823 | 20.675 | -4.285 | -1.629 | 1.841 | 0.109 | 2.461 |
| 8 | 22.587 | 24.128 | -4.495 | 20.735 | 25.919 | -4.400 | -1.852 | 1.791 | 0.095 | 2.578 |
| 9 | 19.146 | 10.691 | -5.466 | 18.689 | 11.093 | -5.300 | -0.457 | 0.402 | 0.166 | 0.631 |
| 10 | 18.872 | 15.054 | -5.432 | 18.387 | 15.509 | -5.285 | -0.485 | 0.455 | 0.147 | 0.680 |
| 11 | 18.983 | 18.555 | -5.294 | 18.393 | 18.974 | -5.144 | -0.591 | 0.418 | 0.150 | 0.739 |
| 12 | 18.823 | 23.251 | -5.503 | 18.321 | 23.690 | -5.328 | -0.502 | 0.439 | 0.176 | 0.689 |
| 13 | 16.652 | 10.752 | -5.587 | 16.304 | 11.126 | -4.873 | -0.348 | 0.374 | 0.714 | 0.878 |
| 14 | 16.562 | 15.192 | -5.448 | 16.034 | 15.576 | -5.326 | -0.529 | 0.384 | 0.122 | 0.665 |
| 15 | 16.310 | 18.887 | -5.421 | 15.716 | 19.285 | -5.295 | -0.594 | 0.398 | 0.126 | 0.726 |
| 16 | 16.352 | 23.481 | -5.601 | 15.798 | 23.933 | -5.445 | -0.554 | 0.452 | 0.156 | 0.732 |
| 17 | 14.150 | 10.659 | -5.871 | 13.807 | 11.089 | -5.320 | -0.343 | 0.430 | 0.552 | 0.779 |
| 18 | 13.873 | 15.404 | -5.360 | 13.308 | 15.761 | -5.259 | -0.566 | 0.357 | 0.101 | 0.677 |
| 19 | 13.492 | 19.773 | -5.322 | 12.906 | 20.128 | -5.191 | -0.586 | 0.355 | 0.131 | 0.697 |
| 20 | 13.292 | 24.331 | -5.876 | 12.663 | 24.740 | -5.725 | -0.629 | 0.409 | 0.150 | 0.765 |
| 21 | 8.439 | 10.574 | -5.853 | 8.067 | 10.949 | -5.616 | -0.372 | 0.375 | 0.238 | 0.579 |
| 22 | 8.239 | 15.454 | -5.161 | 7.765 | 15.742 | -5.064 | -0.474 | 0.288 | 0.097 | 0.563 |
| 23 | 7.925 | 20.084 | -5.106 | 7.401 | 20.367 | -4.986 | -0.524 | 0.283 | 0.121 | 0.607 |
| 24 | 7.481 | 24.511 | -5.764 | 6.968 | 24.818 | -5.588 | -0.513 | 0.306 | 0.177 | 0.623 |
| 25 | -1.031 | 8.841 | -1.228 | -1.301 | 8.980 | -1.210 | -0.270 | 0.139 | 0.018 | 0.304 |
| 26 | -1.393 | 13.778 | -1.204 | -1.725 | 14.010 | -1.123 | -0.332 | 0.232 | 0.082 | 0.413 |
| 27 | -1.454 | 18.832 | -1.172 | -1.882 | 19.055 | -1.026 | -0.427 | 0.223 | 0.146 | 0.503 |
| 28 | -1.913 | 24.861 | -1.104 | -2.285 | 24.889 | -0.871 | -0.372 | 0.028 | 0.233 | 0.440 |

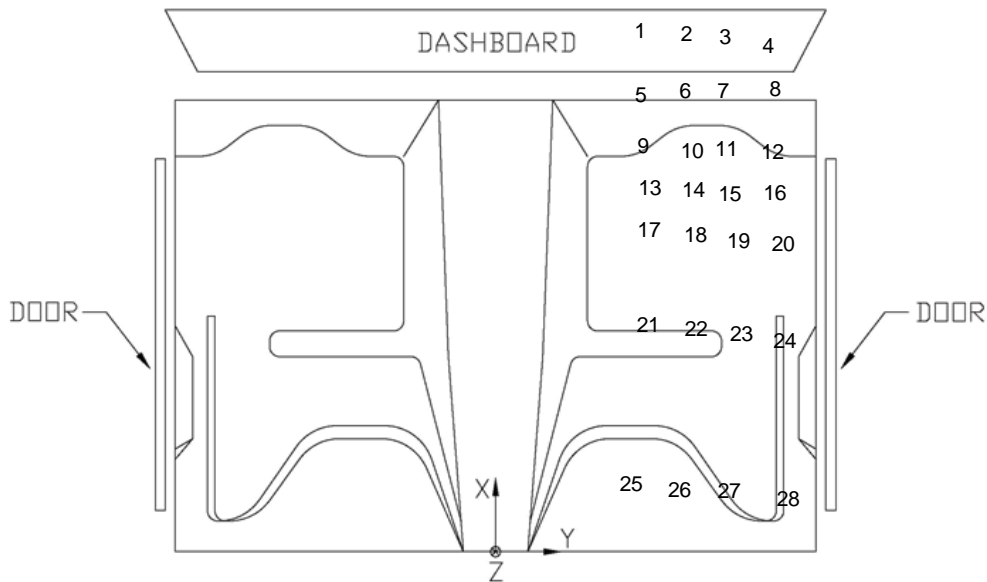


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. CMGS-1

Date: 12/1/2017
Year: 2010

Test Name: CMGS-1
Make: Hyundai

VIN: KMHCN4AC0AU423259
Model: Accent

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 | 52.751 | 11.566 | 0.776 | 52.703 | 11.530 | 0.842 | -0.048 | -0.036 | 0.067 | 0.090 |
| 2 | 52.683 | 16.317 | 0.848 | 52.647 | 16.311 | 0.679 | -0.036 | -0.006 | -0.169 | 0.173 |
| 3 | 52.457 | 20.206 | 1.129 | 52.384 | 20.175 | 0.862 | -0.072 | -0.031 | -0.267 | 0.278 |
| 4 | 51.891 | 24.644 | 1.972 | 51.847 | 24.578 | 1.528 | -0.044 | -0.066 | -0.444 | 0.451 |
| 5 | 49.086 | 11.672 | -1.386 | 49.159 | 11.670 | -1.407 | 0.072 | -0.002 | -0.020 | 0.075 |
| 6 | 49.301 | 16.228 | -1.194 | 49.362 | 16.166 | -1.511 | 0.061 | -0.062 | -0.317 | 0.329 |
| 7 | 49.317 | 20.106 | -0.726 | 49.287 | 20.041 | -1.036 | -0.030 | -0.065 | -0.311 | 0.319 |
| 8 | 49.507 | 25.366 | -0.760 | 49.479 | 25.280 | -1.251 | -0.029 | -0.085 | -0.491 | 0.499 |
| 9 | 46.019 | 11.909 | -2.018 | 46.716 | 10.562 | -1.993 | 0.696 | -1.348 | 0.025 | 1.517 |
| 10 | 45.797 | 16.362 | -1.962 | 46.644 | 14.987 | -2.075 | 0.846 | -1.375 | -0.112 | 1.619 |
| 11 | 45.905 | 19.794 | -1.796 | 46.822 | 18.449 | -1.996 | 0.917 | -1.345 | -0.200 | 1.640 |
| 12 | 45.759 | 24.484 | -1.983 | 47.006 | 23.158 | -2.270 | 1.247 | -1.327 | -0.288 | 1.843 |
| 13 | 43.584 | 12.008 | -2.248 | 44.316 | 10.725 | -1.699 | 0.732 | -1.283 | 0.549 | 1.576 |
| 14 | 43.469 | 16.415 | -2.090 | 44.302 | 15.173 | -2.247 | 0.833 | -1.243 | -0.157 | 1.504 |
| 15 | 43.269 | 20.175 | -2.049 | 44.177 | 18.893 | -2.301 | 0.907 | -1.282 | -0.252 | 1.591 |
| 16 | 43.303 | 24.755 | -2.199 | 44.508 | 23.526 | -2.531 | 1.205 | -1.228 | -0.332 | 1.752 |
| 17 | 41.064 | 11.918 | -2.665 | 41.849 | 10.806 | -2.282 | 0.784 | -1.112 | 0.383 | 1.413 |
| 18 | 40.748 | 16.639 | -2.136 | 41.590 | 15.498 | -2.333 | 0.842 | -1.142 | -0.197 | 1.432 |
| 19 | 40.434 | 21.034 | -2.085 | 41.414 | 19.880 | -2.367 | 0.980 | -1.154 | -0.282 | 1.540 |
| 20 | 40.248 | 25.588 | -2.619 | 41.439 | 24.486 | -2.998 | 1.192 | -1.102 | -0.379 | 1.667 |
| 21 | 35.371 | 11.833 | -2.924 | 36.134 | 10.952 | -2.891 | 0.762 | -0.880 | 0.033 | 1.165 |
| 22 | 35.163 | 16.696 | -2.208 | 36.052 | 15.766 | -2.444 | 0.889 | -0.931 | -0.236 | 1.309 |
| 23 | 34.856 | 21.309 | -2.139 | 35.925 | 20.403 | -2.470 | 1.069 | -0.906 | -0.331 | 1.440 |
| 24 | 34.444 | 25.806 | -2.787 | 35.757 | 24.857 | -3.176 | 1.313 | -0.950 | -0.389 | 1.667 |
| 25 | 25.705 | 10.088 | 1.222 | 26.451 | 9.557 | 1.027 | 0.746 | -0.531 | -0.196 | 0.937 |
| 26 | 25.327 | 15.109 | 1.262 | 26.285 | 14.602 | 0.999 | 0.958 | -0.507 | -0.264 | 1.115 |
| 27 | 25.249 | 20.106 | 1.326 | 26.386 | 19.649 | 0.995 | 1.138 | -0.456 | -0.331 | 1.270 |
| 28 | 24.878 | 26.075 | 1.424 | 26.279 | 25.499 | 1.022 | 1.401 | -0.576 | -0.402 | 1.567 |

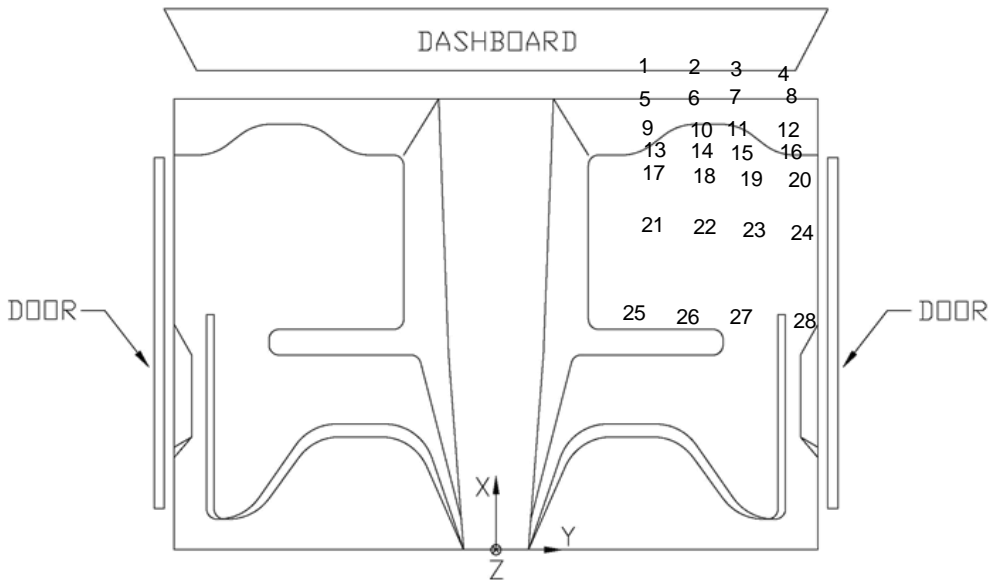


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. CMGS-1

Date: 12/1/2017 Test Name: CMGS-1 VIN: KMHCH4AC0AU423259
Year: 2010 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

| | POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) | Total Δ (in.) |
|------------------|-------|------------|------------|------------|-------------|-------------|-------------|---------------------|---------------------|---------------------|-------------------------|
| DASH | 1 | 12.945 | 3.187 | 23.438 | 13.329 | 3.090 | 23.536 | 0.384 | -0.097 | 0.099 | 0.408 |
| | 2 | 13.442 | 15.878 | 21.719 | 13.761 | 15.830 | 21.843 | 0.319 | -0.048 | 0.125 | 0.345 |
| | 3 | 12.971 | 25.434 | 21.705 | 13.286 | 25.306 | 21.879 | 0.315 | -0.129 | 0.174 | 0.382 |
| | 4 | 9.018 | 2.458 | 16.202 | 9.299 | 2.444 | 16.339 | 0.281 | -0.014 | 0.137 | 0.312 |
| | 5 | 11.505 | 17.525 | 16.970 | 11.770 | 17.437 | 17.170 | 0.265 | -0.088 | 0.201 | 0.344 |
| | 6 | 10.657 | 25.550 | 16.631 | 10.907 | 25.389 | 16.792 | 0.251 | -0.161 | 0.162 | 0.339 |
| SIDE PANEL | 7 | 16.772 | 29.237 | 0.861 | 16.874 | 29.101 | 1.140 | 0.103 | -0.136 | 0.279 | 0.327 |
| | 8 | 16.804 | 29.243 | 2.453 | 16.934 | 29.098 | 2.643 | 0.130 | -0.145 | 0.190 | 0.272 |
| | 9 | 19.491 | 29.419 | 0.009 | 19.626 | 29.142 | 0.392 | 0.135 | -0.277 | 0.383 | 0.491 |
| IMPACT SIDE DOOR | 10 | 9.266 | 29.799 | 21.090 | 9.309 | 29.683 | 21.303 | 0.044 | -0.116 | 0.214 | 0.247 |
| | 11 | -0.152 | 29.427 | 21.983 | -0.047 | 29.468 | 22.217 | 0.105 | 0.041 | 0.234 | 0.260 |
| | 12 | -9.959 | 28.958 | 23.071 | -9.929 | 29.111 | 23.437 | 0.030 | 0.153 | 0.366 | 0.398 |
| | 13 | 3.598 | 30.092 | 9.679 | 3.566 | 30.661 | 10.039 | -0.033 | 0.568 | 0.360 | 0.674 |
| | 14 | -2.810 | 29.832 | 11.850 | -2.782 | 30.313 | 12.171 | 0.028 | 0.482 | 0.322 | 0.580 |
| | 15 | -11.617 | 29.489 | 12.197 | -11.510 | 29.848 | 12.572 | 0.107 | 0.359 | 0.375 | 0.530 |
| ROOF | 16 | 0.412 | 19.897 | 38.649 | 0.480 | 19.873 | 38.879 | 0.068 | -0.025 | 0.230 | 0.241 |
| | 17 | 1.428 | 13.605 | 38.957 | 1.543 | 13.608 | 39.126 | 0.114 | 0.003 | 0.170 | 0.205 |
| | 18 | 1.993 | 9.098 | 39.071 | 2.074 | 9.050 | 39.248 | 0.081 | -0.048 | 0.177 | 0.200 |
| | 19 | 2.262 | 5.670 | 39.155 | 2.424 | 5.579 | 39.304 | 0.162 | -0.091 | 0.149 | 0.238 |
| | 20 | 2.493 | 1.703 | 39.171 | 2.554 | 1.699 | 39.349 | 0.061 | -0.004 | 0.178 | 0.188 |
| | 21 | -5.405 | 18.611 | 41.227 | -5.261 | 18.557 | 41.429 | 0.143 | -0.054 | 0.202 | 0.253 |
| | 22 | -4.560 | 14.266 | 41.467 | -4.511 | 14.159 | 41.685 | 0.049 | -0.107 | 0.218 | 0.247 |
| | 23 | -3.895 | 10.182 | 41.604 | -3.698 | 10.025 | 41.773 | 0.196 | -0.156 | 0.169 | 0.302 |
| | 24 | -3.591 | 6.923 | 41.691 | -3.448 | 6.774 | 41.864 | 0.144 | -0.148 | 0.173 | 0.269 |
| | 25 | -3.908 | 1.858 | 41.907 | -3.655 | 1.725 | 42.038 | 0.252 | -0.133 | 0.131 | 0.314 |
| | 26 | -9.902 | 17.578 | 42.261 | -9.766 | 17.428 | 42.456 | 0.136 | -0.151 | 0.196 | 0.282 |
| | 27 | -8.144 | 13.817 | 42.301 | -7.973 | 13.687 | 42.485 | 0.171 | -0.130 | 0.183 | 0.283 |
| | 28 | -7.418 | 10.099 | 42.419 | -7.267 | 9.956 | 42.601 | 0.151 | -0.143 | 0.182 | 0.276 |
| | 29 | -6.588 | 6.486 | 42.422 | -6.477 | 6.362 | 42.604 | 0.111 | -0.124 | 0.182 | 0.246 |
| | 30 | -6.089 | 2.002 | 42.422 | -5.771 | 1.788 | 42.547 | 0.318 | -0.214 | 0.125 | 0.403 |
| A PILLAR | 31 | 3.629 | 24.589 | 34.809 | 3.754 | 24.460 | 35.116 | 0.125 | -0.130 | 0.307 | 0.356 |
| | 32 | 7.160 | 25.535 | 32.688 | 7.287 | 25.401 | 33.005 | 0.126 | -0.134 | 0.317 | 0.367 |
| | 33 | 9.830 | 26.269 | 30.832 | 9.998 | 26.137 | 31.121 | 0.168 | -0.132 | 0.288 | 0.359 |
| | 34 | 13.443 | 27.226 | 28.258 | 13.649 | 27.081 | 28.596 | 0.205 | -0.145 | 0.338 | 0.421 |
| B PILLAR | 35 | -17.939 | 27.390 | 22.735 | -17.708 | 27.463 | 23.007 | 0.231 | 0.072 | 0.272 | 0.364 |
| | 36 | -21.723 | 27.294 | 22.333 | -21.485 | 27.242 | 22.547 | 0.238 | -0.052 | 0.214 | 0.325 |
| | 37 | -18.625 | 26.517 | 28.198 | -18.362 | 26.406 | 28.449 | 0.263 | -0.111 | 0.250 | 0.380 |
| | 38 | -22.485 | 26.511 | 27.849 | -22.235 | 26.415 | 28.127 | 0.250 | -0.096 | 0.279 | 0.387 |
| | 39 | -19.964 | 23.437 | 36.441 | -19.463 | 23.414 | 36.525 | 0.500 | -0.023 | 0.085 | 0.508 |
| | 40 | -22.990 | 23.524 | 36.231 | -22.621 | 23.386 | 36.452 | 0.369 | -0.139 | 0.221 | 0.452 |

Figure D-3. Occupant Compartment Deformation Data – Set 1, Test No. CMGS-1

Date: 12/1/2017
Year: 2010

Test Name: CMGS-1
Make: Hyundai

VIN: KMHCHN4AC0AU423259
Model: Accent

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 | 38.167 | 4.280 | 26.554 | 38.400 | 5.083 | 26.570 | 0.232 | 0.803 | 0.016 | 0.836 |
| | 2 | 38.715 | 17.003 | 24.884 | 38.951 | 17.789 | 24.664 | 0.235 | 0.785 | -0.221 | 0.849 |
| | 3 | 38.281 | 26.538 | 24.948 | 38.496 | 27.264 | 24.495 | 0.215 | 0.726 | -0.453 | 0.882 |
| | 4 | 34.575 | 3.730 | 19.165 | 34.764 | 4.306 | 19.178 | 0.189 | 0.576 | 0.013 | 0.606 |
| | 5 | 37.044 | 18.701 | 20.101 | 37.219 | 19.309 | 19.860 | 0.176 | 0.608 | -0.241 | 0.677 |
| | 6 | 36.229 | 26.686 | 19.734 | 36.396 | 27.254 | 19.287 | 0.167 | 0.568 | -0.447 | 0.742 |
| SIDE PANEL | 7 | 43.110 | 30.453 | 4.357 | 43.211 | 30.662 | 3.914 | 0.101 | 0.209 | -0.444 | 0.501 |
| | 8 | 43.086 | 30.450 | 5.981 | 43.189 | 30.687 | 5.418 | 0.103 | 0.237 | -0.564 | 0.620 |
| | 9 | 45.911 | 30.622 | 3.672 | 45.999 | 30.685 | 3.315 | 0.088 | 0.063 | -0.357 | 0.373 |
| IMPACT SIDE DOOR | 10 | 34.647 | 30.908 | 24.156 | 34.566 | 31.634 | 23.623 | -0.081 | 0.725 | -0.533 | 0.904 |
| | 11 | 25.217 | 30.555 | 24.569 | 25.173 | 31.447 | 24.032 | -0.044 | 0.892 | -0.537 | 1.043 |
| | 12 | 15.326 | 30.099 | 25.214 | 15.239 | 31.126 | 24.720 | -0.086 | 1.027 | -0.494 | 1.143 |
| | 13 | 29.583 | 31.290 | 12.495 | 29.443 | 32.405 | 12.047 | -0.139 | 1.116 | -0.448 | 1.210 |
| | 14 | 23.071 | 31.034 | 14.293 | 22.988 | 32.106 | 13.838 | -0.082 | 1.072 | -0.455 | 1.168 |
| | 15 | 14.261 | 30.703 | 14.236 | 14.251 | 31.659 | 13.774 | -0.010 | 0.956 | -0.462 | 1.061 |
| ROOF | 16 | 24.800 | 20.926 | 41.199 | 24.776 | 22.168 | 40.875 | -0.024 | 1.242 | -0.324 | 1.284 |
| | 17 | 25.783 | 14.644 | 41.518 | 25.810 | 15.908 | 41.298 | 0.027 | 1.264 | -0.220 | 1.284 |
| | 18 | 26.401 | 10.104 | 41.620 | 26.323 | 11.353 | 41.533 | -0.077 | 1.248 | -0.086 | 1.254 |
| | 19 | 26.644 | 6.712 | 41.699 | 26.662 | 7.883 | 41.674 | 0.018 | 1.171 | -0.025 | 1.172 |
| | 20 | 26.760 | 2.756 | 41.744 | 26.781 | 4.004 | 41.799 | 0.021 | 1.248 | 0.056 | 1.249 |
| | 21 | 18.883 | 19.681 | 43.456 | 18.902 | 20.908 | 43.134 | 0.019 | 1.227 | -0.321 | 1.269 |
| | 22 | 19.737 | 15.330 | 43.706 | 19.627 | 16.514 | 43.513 | -0.110 | 1.185 | -0.193 | 1.206 |
| | 23 | 20.389 | 11.212 | 43.851 | 20.425 | 12.383 | 43.723 | 0.036 | 1.171 | -0.128 | 1.178 |
| | 24 | 20.705 | 7.884 | 43.932 | 20.663 | 9.134 | 43.889 | -0.042 | 1.249 | -0.044 | 1.251 |
| | 25 | 20.358 | 2.914 | 44.102 | 20.435 | 4.089 | 44.147 | 0.077 | 1.176 | 0.045 | 1.179 |
| | 26 | 14.395 | 18.611 | 44.241 | 14.346 | 19.804 | 43.937 | -0.050 | 1.193 | -0.304 | 1.232 |
| | 27 | 16.127 | 14.808 | 44.348 | 16.126 | 16.062 | 44.133 | 0.000 | 1.254 | -0.215 | 1.272 |
| | 28 | 16.746 | 11.087 | 44.494 | 16.817 | 12.333 | 44.358 | 0.071 | 1.246 | -0.136 | 1.255 |
| | 29 | 17.673 | 7.485 | 44.501 | 17.597 | 8.739 | 44.471 | -0.076 | 1.254 | -0.030 | 1.257 |
| | 30 | 18.076 | 2.998 | 44.512 | 18.295 | 4.164 | 44.538 | 0.219 | 1.165 | 0.026 | 1.186 |
| A PILLAR | 31 | 28.196 | 25.646 | 37.560 | 28.259 | 26.679 | 37.210 | 0.063 | 1.033 | -0.351 | 1.093 |
| | 32 | 31.885 | 26.595 | 35.591 | 31.903 | 27.576 | 35.276 | 0.018 | 0.981 | -0.314 | 1.031 |
| | 33 | 34.663 | 27.332 | 33.892 | 34.714 | 28.274 | 33.528 | 0.050 | 0.942 | -0.364 | 1.011 |
| | 34 | 38.420 | 28.297 | 31.541 | 38.498 | 29.165 | 31.187 | 0.078 | 0.868 | -0.354 | 0.941 |
| B PILLAR | 35 | 7.299 | 28.541 | 24.409 | 7.491 | 29.478 | 23.900 | 0.192 | 0.938 | -0.509 | 1.084 |
| | 36 | 3.549 | 28.455 | 23.808 | 3.744 | 29.254 | 23.240 | 0.195 | 0.799 | -0.568 | 0.999 |
| | 37 | 6.293 | 27.626 | 29.853 | 6.541 | 28.525 | 29.318 | 0.249 | 0.900 | -0.535 | 1.076 |
| | 38 | 2.476 | 27.640 | 29.267 | 2.691 | 28.533 | 28.787 | 0.214 | 0.893 | -0.481 | 1.037 |
| | 39 | 4.575 | 24.546 | 37.883 | 4.997 | 25.688 | 37.378 | 0.422 | 1.142 | -0.506 | 1.319 |
| | 40 | 1.608 | 24.594 | 37.606 | 1.848 | 25.662 | 37.134 | 0.240 | 1.069 | -0.472 | 1.193 |

Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. CMGS-1

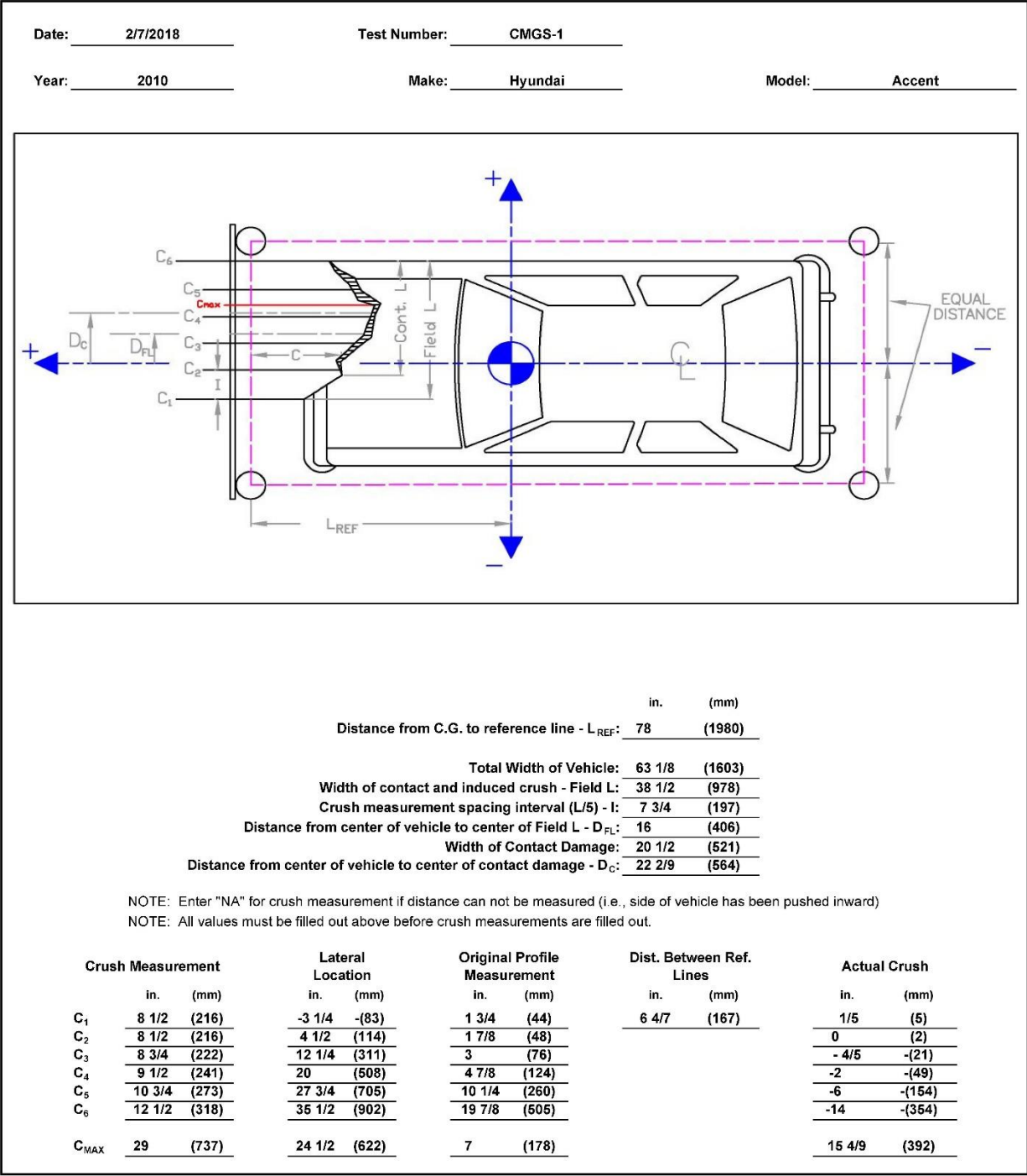


Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. CMGS-1

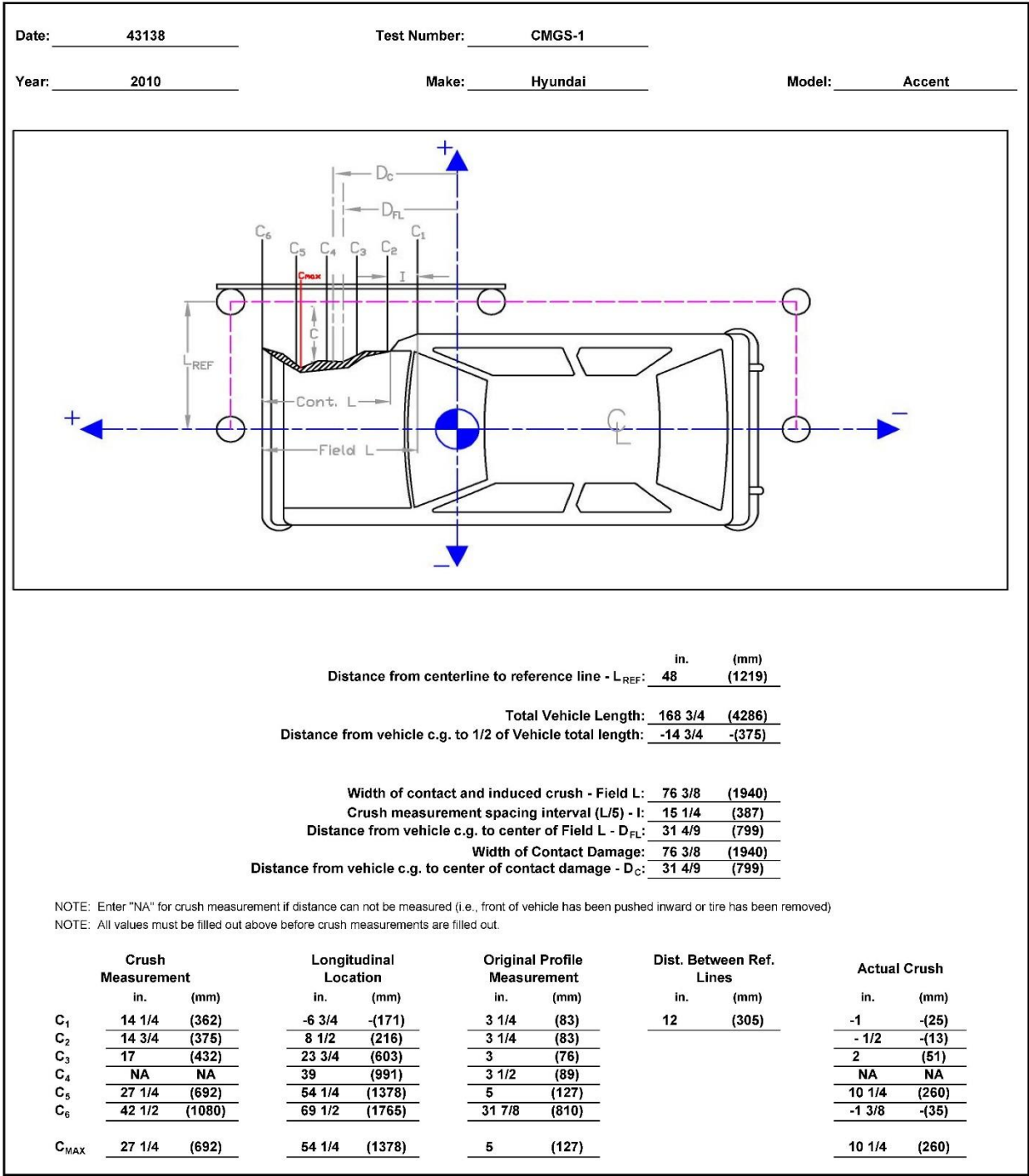


Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. CMGS-1

Date: 2/14/2018 Test Name: CMGS-2 VIN: 1D7RB1CTXAS115553
Year: 2010 Make: DODGE Model: RAM 1500 CREW CAB

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

| POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) | Total Δ (in.) |
|-------|---------|---------|---------|----------|----------|----------|----------|----------|----------|---------------|
| 1 | 65.518 | 46.148 | 6.804 | 65.168 | 45.889 | 6.878 | -0.350 | -0.259 | 0.074 | 0.442 |
| 2 | 66.258 | 44.195 | 5.965 | 66.100 | 44.039 | 6.021 | -0.158 | -0.156 | 0.056 | 0.229 |
| 3 | 66.636 | 42.319 | 5.191 | 66.616 | 42.228 | 5.335 | -0.020 | -0.090 | 0.144 | 0.171 |
| 4 | 66.385 | 39.467 | 5.298 | 66.274 | 39.434 | 5.284 | -0.111 | -0.033 | -0.014 | 0.117 |
| 5 | 64.722 | 36.877 | 6.431 | 64.579 | 36.896 | 6.468 | -0.143 | 0.019 | 0.038 | 0.149 |
| 6 | 63.161 | 34.712 | 7.485 | 63.063 | 34.788 | 7.573 | -0.098 | 0.076 | 0.088 | 0.153 |
| 7 | 62.548 | 47.661 | 3.262 | 62.350 | 47.428 | 3.244 | -0.198 | -0.233 | -0.019 | 0.306 |
| 8 | 62.705 | 44.748 | 2.632 | 62.698 | 44.641 | 2.530 | -0.007 | -0.107 | -0.103 | 0.148 |
| 9 | 62.546 | 40.947 | 2.660 | 62.460 | 40.793 | 2.584 | -0.086 | -0.154 | -0.077 | 0.192 |
| 10 | 62.453 | 37.434 | 3.493 | 62.384 | 37.386 | 3.443 | -0.068 | -0.048 | -0.050 | 0.097 |
| 11 | 61.468 | 35.368 | 6.191 | 61.289 | 35.393 | 6.172 | -0.179 | 0.026 | -0.018 | 0.182 |
| 12 | 60.886 | 33.653 | 7.206 | 60.693 | 33.688 | 7.203 | -0.193 | 0.035 | -0.003 | 0.196 |
| 13 | 58.414 | 47.168 | 0.565 | 58.359 | 47.085 | 0.535 | -0.055 | -0.083 | -0.030 | 0.104 |
| 14 | 58.533 | 44.575 | 0.675 | 58.498 | 44.521 | 0.632 | -0.034 | -0.054 | -0.043 | 0.077 |
| 15 | 58.501 | 42.142 | 0.676 | 58.545 | 42.065 | 0.650 | 0.044 | -0.078 | -0.026 | 0.093 |
| 16 | 58.623 | 38.645 | 0.708 | 58.618 | 38.573 | 0.642 | -0.005 | -0.072 | -0.066 | 0.097 |
| 17 | 57.787 | 36.394 | 2.868 | 57.716 | 36.339 | 2.774 | -0.071 | -0.056 | -0.095 | 0.131 |
| 18 | 56.916 | 33.060 | 5.272 | 56.844 | 33.005 | 5.280 | -0.072 | -0.056 | 0.008 | 0.092 |
| 19 | 51.751 | 48.299 | -1.175 | 51.696 | 48.235 | -1.263 | -0.055 | -0.064 | -0.088 | 0.122 |
| 20 | 51.643 | 45.766 | -1.035 | 51.666 | 45.652 | -1.132 | 0.023 | -0.113 | -0.098 | 0.151 |
| 21 | 51.699 | 42.321 | -1.021 | 51.664 | 42.200 | -1.122 | -0.035 | -0.121 | -0.102 | 0.162 |
| 22 | 51.727 | 39.208 | -1.018 | 51.724 | 39.095 | -1.113 | -0.003 | -0.113 | -0.096 | 0.148 |
| 23 | 51.708 | 36.446 | -0.988 | 51.629 | 36.372 | -1.083 | -0.079 | -0.075 | -0.095 | 0.145 |
| 24 | 50.533 | 30.501 | 2.091 | 50.471 | 30.320 | 2.016 | -0.062 | -0.181 | -0.075 | 0.206 |
| 25 | 42.983 | 46.101 | -1.396 | 42.889 | 45.952 | -1.449 | -0.094 | -0.149 | -0.052 | 0.184 |
| 26 | 42.879 | 41.991 | -1.329 | 42.858 | 41.959 | -1.400 | -0.021 | -0.032 | -0.072 | 0.081 |
| 27 | 42.736 | 38.281 | -1.300 | 42.716 | 38.202 | -1.374 | -0.020 | -0.079 | -0.075 | 0.111 |
| 28 | 42.582 | 34.062 | -1.277 | 42.564 | 33.946 | -1.341 | -0.018 | -0.117 | -0.065 | 0.134 |
| 29 | 36.114 | 43.585 | 2.687 | 36.159 | 43.478 | 2.736 | 0.046 | -0.106 | 0.049 | 0.126 |
| 30 | 35.944 | 34.487 | 2.765 | 35.986 | 34.423 | 2.726 | 0.042 | -0.065 | -0.040 | 0.087 |

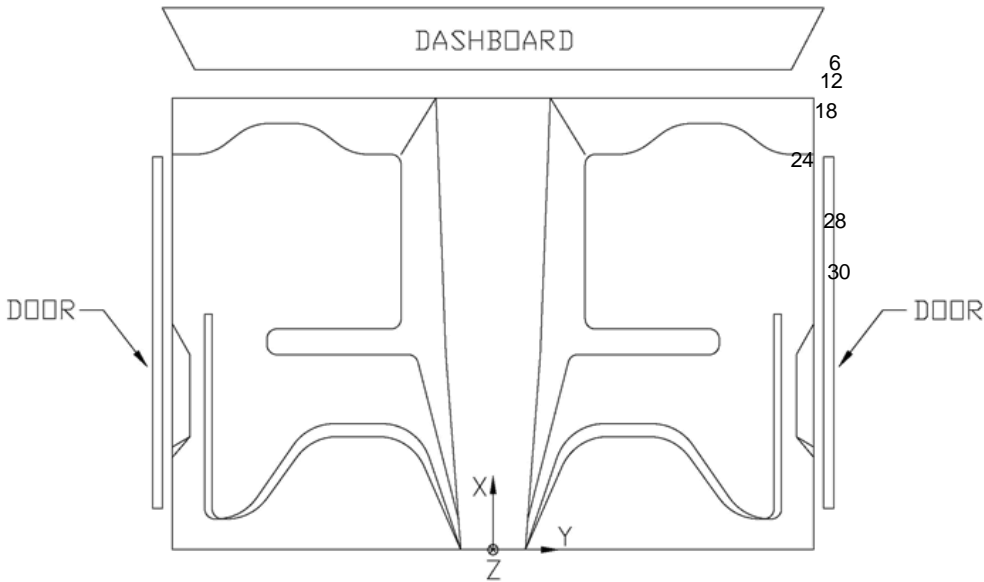


Figure D-7. Floor Pan Deformation Data – Set 1, Test No. CMGS-2

Date: 2/14/2018 Test Name: CMGS-2 VIN: 1D7RB1CTXAS115553
Year: 2010 Make: DODGE Model: RAM 1500 CREW CAB

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 | 62.959 | 26.617 | 3.121 | 62.630 | 26.661 | 2.831 | -0.329 | 0.044 | -0.290 | 0.441 |
| 2 | 63.707 | 24.663 | 2.236 | 63.578 | 24.822 | 1.968 | -0.128 | 0.159 | -0.268 | 0.337 |
| 3 | 64.143 | 22.835 | 1.554 | 64.110 | 23.018 | 1.276 | -0.033 | 0.184 | -0.278 | 0.335 |
| 4 | 63.913 | 20.007 | 1.615 | 63.794 | 20.221 | 1.217 | -0.119 | 0.213 | -0.398 | 0.467 |
| 5 | 62.243 | 17.368 | 2.678 | 62.125 | 17.664 | 2.397 | -0.118 | 0.296 | -0.281 | 0.425 |
| 6 | 60.744 | 15.212 | 3.744 | 60.630 | 15.538 | 3.498 | -0.114 | 0.326 | -0.247 | 0.425 |
| 7 | 59.977 | 28.183 | -0.407 | 59.793 | 28.183 | -0.795 | -0.184 | 0.000 | -0.388 | 0.430 |
| 8 | 60.189 | 25.306 | -1.028 | 60.166 | 25.402 | -1.517 | -0.023 | 0.096 | -0.489 | 0.499 |
| 9 | 60.006 | 21.430 | -1.056 | 59.964 | 21.552 | -1.474 | -0.042 | 0.122 | -0.418 | 0.437 |
| 10 | 59.979 | 17.926 | -0.238 | 59.922 | 18.141 | -0.624 | -0.058 | 0.215 | -0.386 | 0.446 |
| 11 | 59.020 | 15.847 | 2.437 | 58.849 | 16.131 | 2.101 | -0.171 | 0.284 | -0.336 | 0.472 |
| 12 | 58.389 | 14.090 | 3.452 | 58.271 | 14.418 | 3.127 | -0.119 | 0.328 | -0.324 | 0.476 |
| 13 | 55.912 | 27.643 | -3.073 | 55.801 | 27.810 | -3.499 | -0.110 | 0.167 | -0.425 | 0.470 |
| 14 | 56.030 | 25.116 | -2.993 | 55.965 | 25.247 | -3.409 | -0.065 | 0.131 | -0.416 | 0.441 |
| 15 | 56.058 | 22.630 | -2.990 | 56.034 | 22.792 | -3.399 | -0.024 | 0.162 | -0.410 | 0.441 |
| 16 | 56.180 | 19.125 | -3.006 | 56.141 | 19.301 | -3.416 | -0.039 | 0.176 | -0.410 | 0.448 |
| 17 | 55.303 | 16.809 | -0.856 | 55.263 | 17.052 | -1.290 | -0.041 | 0.243 | -0.434 | 0.499 |
| 18 | 54.528 | 13.537 | 1.496 | 54.426 | 13.703 | 1.208 | -0.102 | 0.166 | -0.288 | 0.348 |
| 19 | 49.184 | 28.682 | -4.839 | 49.125 | 28.903 | -5.284 | -0.059 | 0.221 | -0.445 | 0.500 |
| 20 | 49.124 | 26.117 | -4.715 | 49.119 | 26.320 | -5.161 | -0.005 | 0.202 | -0.446 | 0.490 |
| 21 | 49.214 | 22.741 | -4.725 | 49.150 | 22.867 | -5.161 | -0.064 | 0.126 | -0.435 | 0.458 |
| 22 | 49.252 | 19.636 | -4.749 | 49.239 | 19.763 | -5.161 | -0.013 | 0.127 | -0.412 | 0.431 |
| 23 | 49.216 | 16.871 | -4.743 | 49.170 | 17.039 | -5.138 | -0.046 | 0.167 | -0.395 | 0.432 |
| 24 | 48.099 | 10.857 | -1.696 | 48.074 | 10.967 | -2.055 | -0.025 | 0.110 | -0.359 | 0.377 |
| 25 | 40.473 | 26.438 | -5.102 | 40.340 | 26.537 | -5.464 | -0.133 | 0.099 | -0.362 | 0.399 |
| 26 | 40.438 | 22.327 | -5.064 | 40.347 | 22.544 | -5.427 | -0.091 | 0.217 | -0.364 | 0.433 |
| 27 | 40.307 | 18.636 | -5.061 | 40.240 | 18.786 | -5.412 | -0.067 | 0.150 | -0.351 | 0.387 |
| 28 | 40.174 | 14.416 | -5.067 | 40.129 | 14.528 | -5.391 | -0.045 | 0.112 | -0.324 | 0.346 |
| 29 | 33.606 | 23.870 | -1.058 | 33.639 | 23.988 | -1.277 | 0.033 | 0.118 | -0.219 | 0.251 |
| 30 | 33.537 | 14.757 | -1.045 | 33.551 | 14.932 | -1.314 | 0.014 | 0.174 | -0.269 | 0.321 |

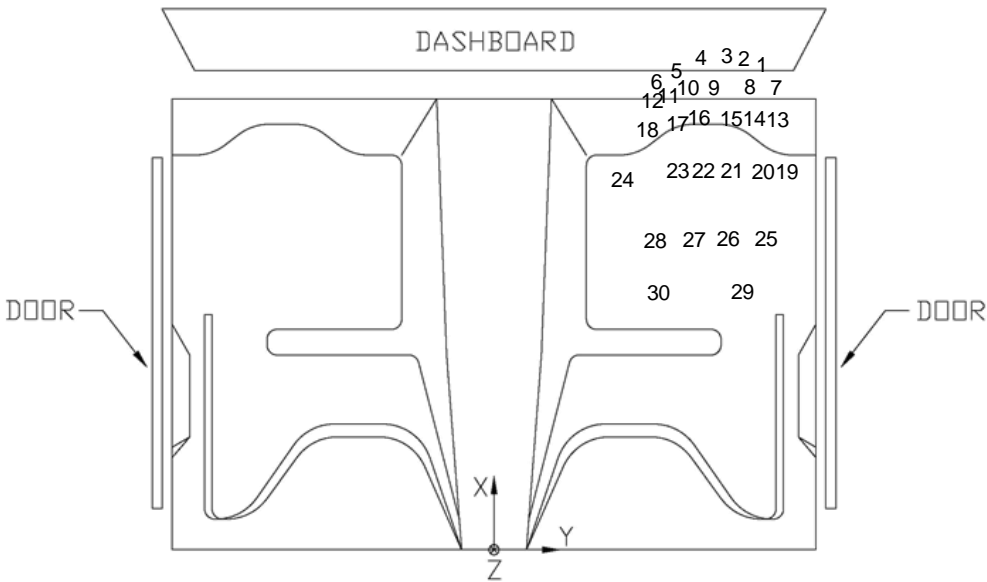


Figure D-8. Floor Pan Deformation Data – Set 2, Test No. CMGS-2

Date: 2/14/2018
Year: 2010

Test Name: CMGS-2
Make: DODGE

VIN: 1D7RB1CTXAS115553
Model: RAM 1500 CREW CAB

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

| | POINT | X (in.) | Y (in.) | Z (in.) | X' (in.) | Y' (in.) | Z' (in.) | ΔX (in.) | ΔY (in.) | ΔZ (in.) | Total Δ (in.) |
|---------------------|-------|------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|------------------|
| DASH | 1 | -47.020 | -48.357 | 20.164 | -46.983 | -48.392 | 20.202 | 0.037 | -0.035 | 0.038 | 0.064 |
| | 2 | -49.089 | -38.210 | 14.643 | -49.020 | -38.132 | 14.673 | 0.069 | 0.078 | 0.030 | 0.109 |
| | 3 | -46.019 | -30.678 | 20.914 | -46.018 | -30.621 | 20.963 | 0.002 | 0.056 | 0.049 | 0.075 |
| | 4 | -50.950 | -38.078 | 31.061 | -50.938 | -38.099 | 31.102 | 0.012 | -0.021 | 0.041 | 0.048 |
| | 5 | -46.930 | -20.267 | 30.796 | -46.917 | -20.305 | 30.740 | 0.014 | -0.038 | -0.056 | 0.069 |
| | 6 | -44.026 | -19.878 | 19.478 | -44.013 | -19.977 | 19.459 | 0.013 | -0.099 | -0.019 | 0.102 |
| SIDE PANEL | 7 | -56.089 | -52.035 | 8.971 | -55.987 | -51.153 | 8.956 | 0.102 | 0.881 | -0.015 | 0.887 |
| | 8 | -59.068 | -51.996 | 6.653 | -58.963 | -51.312 | 6.622 | 0.105 | 0.683 | -0.031 | 0.692 |
| | 9 | -60.646 | -51.882 | 4.010 | -60.590 | -51.374 | 4.095 | 0.056 | 0.508 | 0.086 | 0.518 |
| IMPACT SIDE DOOR | 10 | -21.856 | -54.031 | 26.435 | -21.450 | -54.944 | 26.673 | 0.406 | -0.913 | 0.238 | 1.027 |
| | 11 | -34.469 | -53.794 | 26.323 | -34.095 | -54.301 | 26.556 | 0.373 | -0.506 | 0.233 | 0.671 |
| | 12 | -44.396 | -53.586 | 26.211 | -44.043 | -53.756 | 26.433 | 0.353 | -0.170 | 0.222 | 0.451 |
| | 13 | -26.279 | -54.789 | 16.281 | -25.834 | -55.314 | 16.569 | 0.445 | -0.525 | 0.288 | 0.746 |
| | 14 | -37.165 | -54.656 | 16.671 | -36.746 | -54.849 | 16.890 | 0.419 | -0.193 | 0.219 | 0.510 |
| | 15 | -36.791 | -55.196 | 6.792 | -36.310 | -55.184 | 6.938 | 0.481 | 0.012 | 0.146 | 0.503 |
| ROOF | 16 | -35.177 | -41.318 | 47.536 | -35.093 | -41.328 | 47.664 | 0.084 | -0.010 | 0.128 | 0.153 |
| | 17 | -36.527 | -36.395 | 47.912 | -36.507 | -36.424 | 47.985 | 0.021 | -0.029 | 0.073 | 0.081 |
| | 18 | -37.515 | -31.014 | 48.080 | -37.485 | -31.127 | 48.133 | 0.030 | -0.113 | 0.053 | 0.128 |
| | 19 | -37.980 | -26.873 | 48.110 | -37.964 | -26.897 | 48.138 | 0.016 | -0.023 | 0.028 | 0.040 |
| | 20 | -29.773 | -41.267 | 49.564 | -29.843 | -41.375 | 49.630 | -0.071 | -0.108 | 0.066 | 0.145 |
| | 21 | -31.020 | -35.266 | 49.936 | -31.029 | -35.339 | 49.979 | -0.009 | -0.073 | 0.043 | 0.086 |
| | 22 | -32.010 | -28.878 | 50.160 | -32.143 | -28.834 | 50.179 | -0.133 | 0.044 | 0.019 | 0.141 |
| | 23 | -32.165 | -23.898 | 50.306 | -32.274 | -23.946 | 50.304 | -0.108 | -0.047 | -0.002 | 0.118 |
| | 24 | -23.272 | -39.694 | 50.229 | -23.297 | -39.715 | 50.314 | -0.025 | -0.022 | 0.085 | 0.091 |
| | 25 | -23.503 | -35.851 | 50.422 | -23.507 | -35.932 | 50.504 | -0.004 | -0.081 | 0.082 | 0.115 |
| | 26 | -22.978 | -29.390 | 50.791 | -23.018 | -29.467 | 50.834 | -0.040 | -0.077 | 0.043 | 0.097 |
| | 27 | -22.738 | -25.268 | 50.939 | -22.802 | -25.234 | 50.978 | -0.063 | 0.034 | 0.038 | 0.081 |
| | 28 | -18.962 | -39.319 | 50.441 | -19.060 | -39.324 | 50.528 | -0.098 | -0.005 | 0.087 | 0.131 |
| | 29 | -19.021 | -34.949 | 50.734 | -19.086 | -34.956 | 50.801 | -0.065 | -0.007 | 0.067 | 0.094 |
| | 30 | -18.967 | -28.866 | 51.039 | -19.105 | -28.911 | 51.085 | -0.138 | -0.045 | 0.045 | 0.152 |
| A PILLAR | 31 | -54.374 | -50.505 | 33.075 | -54.379 | -50.520 | 33.079 | -0.005 | -0.015 | 0.003 | 0.017 |
| | 32 | -51.087 | -49.824 | 36.231 | -51.023 | -49.862 | 36.270 | 0.064 | -0.038 | 0.039 | 0.084 |
| | 33 | -45.252 | -48.770 | 40.803 | -45.086 | -48.788 | 40.885 | 0.166 | -0.017 | 0.082 | 0.186 |
| | 34 | -39.014 | -47.418 | 44.440 | -38.913 | -47.453 | 44.565 | 0.101 | -0.035 | 0.126 | 0.165 |
| B PILLAR | 35 | -11.043 | -47.050 | 46.038 | -11.038 | -47.084 | 46.234 | 0.005 | -0.034 | 0.196 | 0.199 |
| | 36 | -14.083 | -47.060 | 45.925 | -14.116 | -47.105 | 46.145 | -0.033 | -0.046 | 0.221 | 0.228 |
| | 37 | -11.824 | -48.626 | 41.371 | -11.754 | -48.680 | 41.575 | 0.070 | -0.054 | 0.204 | 0.222 |
| | 38 | -14.797 | -49.032 | 40.268 | -14.775 | -49.139 | 40.485 | 0.023 | -0.107 | 0.216 | 0.243 |
| | 39 | -12.980 | -51.436 | 32.920 | -12.899 | -51.515 | 33.134 | 0.080 | -0.079 | 0.215 | 0.243 |
| | 40 | -14.321 | -52.268 | 29.284 | -14.273 | -52.382 | 29.539 | 0.048 | -0.114 | 0.256 | 0.284 |

Figure D-9. Occupant Compartment Deformation Data – Set 1, Test No. CMGS-2

Date: 2/14/2018
Year: 2010

Test Name: CMGS-2
Make: DODGE

VIN: 1D7RB1CTXAS115553
Model: RAM 1500 CREW CAB

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 | 44.453 | 28.840 | 16.384 | 44.457 | 28.947 | 16.172 | 0.004 | 0.107 | -0.212 | 0.237 |
| | 2 | 46.629 | 18.681 | 10.818 | 46.579 | 18.722 | 10.611 | -0.050 | 0.041 | -0.207 | 0.217 |
| | 3 | 43.600 | 11.105 | 17.077 | 43.657 | 11.166 | 16.885 | 0.057 | 0.061 | -0.192 | 0.209 |
| | 4 | 48.436 | 18.536 | 27.233 | 48.525 | 18.662 | 27.036 | 0.089 | 0.126 | -0.197 | 0.250 |
| | 5 | 44.574 | 0.655 | 26.858 | 44.669 | 0.832 | 26.632 | 0.095 | 0.177 | -0.227 | 0.302 |
| | 6 | 41.708 | 0.301 | 15.539 | 41.749 | 0.509 | 15.355 | 0.040 | 0.207 | -0.184 | 0.280 |
| SIDE PANEL | 7 | 53.492 | 32.644 | 5.245 | 53.415 | 31.823 | 4.918 | -0.077 | -0.821 | -0.327 | 0.887 |
| | 8 | 56.492 | 32.640 | 2.887 | 56.385 | 32.016 | 2.579 | -0.106 | -0.625 | -0.308 | 0.704 |
| | 9 | 58.065 | 32.555 | 0.292 | 58.007 | 32.099 | 0.050 | -0.058 | -0.456 | -0.242 | 0.519 |
| IMPACT SIDE DOOR | 10 | 19.306 | 34.257 | 22.609 | 18.875 | 35.245 | 22.705 | -0.431 | 0.988 | 0.095 | 1.082 |
| | 11 | 31.927 | 34.127 | 22.533 | 31.526 | 34.719 | 22.564 | -0.401 | 0.592 | 0.032 | 0.715 |
| | 12 | 41.813 | 33.993 | 22.495 | 41.478 | 34.267 | 22.423 | -0.335 | 0.273 | -0.072 | 0.439 |
| | 13 | 23.607 | 35.109 | 12.535 | 23.238 | 35.683 | 12.594 | -0.369 | 0.574 | 0.059 | 0.685 |
| | 14 | 34.586 | 35.060 | 12.917 | 34.155 | 35.318 | 12.896 | -0.431 | 0.258 | -0.021 | 0.503 |
| | 15 | 34.201 | 35.651 | 2.996 | 33.698 | 35.676 | 2.945 | -0.502 | 0.026 | -0.051 | 0.506 |
| ROOF | 16 | 32.621 | 21.554 | 43.688 | 32.680 | 21.698 | 43.634 | 0.060 | 0.144 | -0.053 | 0.165 |
| | 17 | 33.991 | 16.588 | 44.130 | 34.140 | 16.806 | 43.940 | 0.149 | 0.218 | -0.190 | 0.325 |
| | 18 | 34.988 | 11.296 | 44.244 | 35.168 | 11.518 | 44.071 | 0.180 | 0.222 | -0.173 | 0.334 |
| | 19 | 35.512 | 7.116 | 44.172 | 35.686 | 7.293 | 44.064 | 0.174 | 0.177 | -0.108 | 0.270 |
| | 20 | 27.109 | 21.424 | 45.745 | 27.434 | 21.690 | 45.610 | 0.325 | 0.266 | -0.135 | 0.441 |
| | 21 | 28.505 | 15.531 | 46.058 | 28.676 | 15.665 | 45.940 | 0.172 | 0.134 | -0.118 | 0.248 |
| | 22 | 29.681 | 9.032 | 46.238 | 29.851 | 9.170 | 46.120 | 0.170 | 0.138 | -0.118 | 0.249 |
| | 23 | 29.797 | 4.126 | 46.357 | 30.027 | 4.283 | 46.231 | 0.230 | 0.157 | -0.126 | 0.305 |
| | 24 | 20.575 | 19.806 | 46.373 | 20.905 | 19.969 | 46.300 | 0.329 | 0.162 | -0.073 | 0.374 |
| | 25 | 20.998 | 16.062 | 46.549 | 21.150 | 16.187 | 46.480 | 0.152 | 0.125 | -0.069 | 0.209 |
| | 26 | 20.507 | 9.518 | 46.879 | 20.722 | 9.717 | 46.793 | 0.214 | 0.199 | -0.086 | 0.304 |
| | 27 | 20.329 | 5.381 | 47.006 | 20.545 | 5.481 | 46.925 | 0.215 | 0.100 | -0.081 | 0.251 |
| | 28 | 16.439 | 19.410 | 46.570 | 16.672 | 19.538 | 46.520 | 0.234 | 0.128 | -0.050 | 0.271 |
| | 29 | 16.518 | 15.011 | 46.841 | 16.739 | 15.169 | 46.782 | 0.221 | 0.159 | -0.059 | 0.279 |
| | 30 | 16.544 | 9.011 | 47.116 | 16.815 | 9.124 | 47.049 | 0.271 | 0.113 | -0.068 | 0.301 |
| A PILLAR | 31 | 51.855 | 31.004 | 29.426 | 51.855 | 31.109 | 29.042 | 0.000 | 0.104 | -0.384 | 0.398 |
| | 32 | 48.521 | 30.252 | 32.414 | 48.511 | 30.411 | 32.237 | -0.010 | 0.159 | -0.177 | 0.238 |
| | 33 | 42.648 | 29.109 | 36.979 | 42.592 | 29.268 | 36.859 | -0.056 | 0.160 | -0.120 | 0.207 |
| | 34 | 36.408 | 27.675 | 40.557 | 36.439 | 27.866 | 40.546 | 0.031 | 0.191 | -0.011 | 0.194 |
| B PILLAR | 35 | 8.446 | 27.089 | 42.149 | 8.571 | 27.234 | 42.262 | 0.126 | 0.145 | 0.113 | 0.223 |
| | 36 | 11.502 | 27.106 | 42.096 | 11.649 | 27.285 | 42.168 | 0.147 | 0.178 | 0.072 | 0.242 |
| | 37 | 9.243 | 28.685 | 37.532 | 9.264 | 28.850 | 37.606 | 0.022 | 0.166 | 0.074 | 0.183 |
| | 38 | 12.286 | 29.119 | 36.449 | 12.278 | 29.341 | 36.512 | -0.007 | 0.221 | 0.063 | 0.230 |
| | 39 | 10.398 | 31.570 | 29.058 | 10.368 | 31.719 | 29.172 | -0.029 | 0.150 | 0.114 | 0.190 |
| | 40 | 11.740 | 32.409 | 25.482 | 11.728 | 32.608 | 25.577 | -0.013 | 0.199 | 0.094 | 0.220 |

Figure D-10. Occupant Compartment Deformation Data – Set 2, Test No. CMGS-2

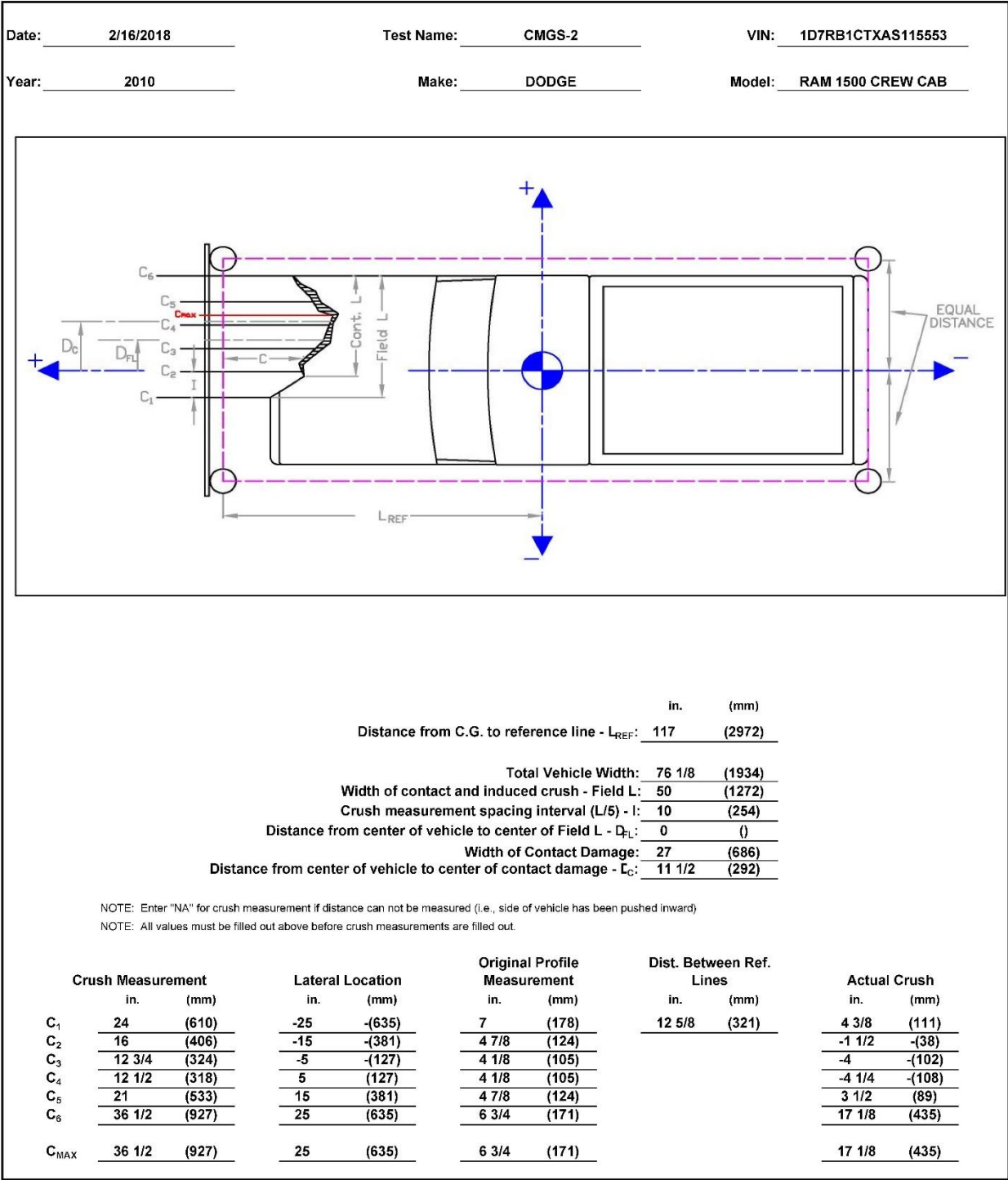


Figure D-11. Exterior Vehicle Crush (NASS) - Front, Test No. CMGS-2

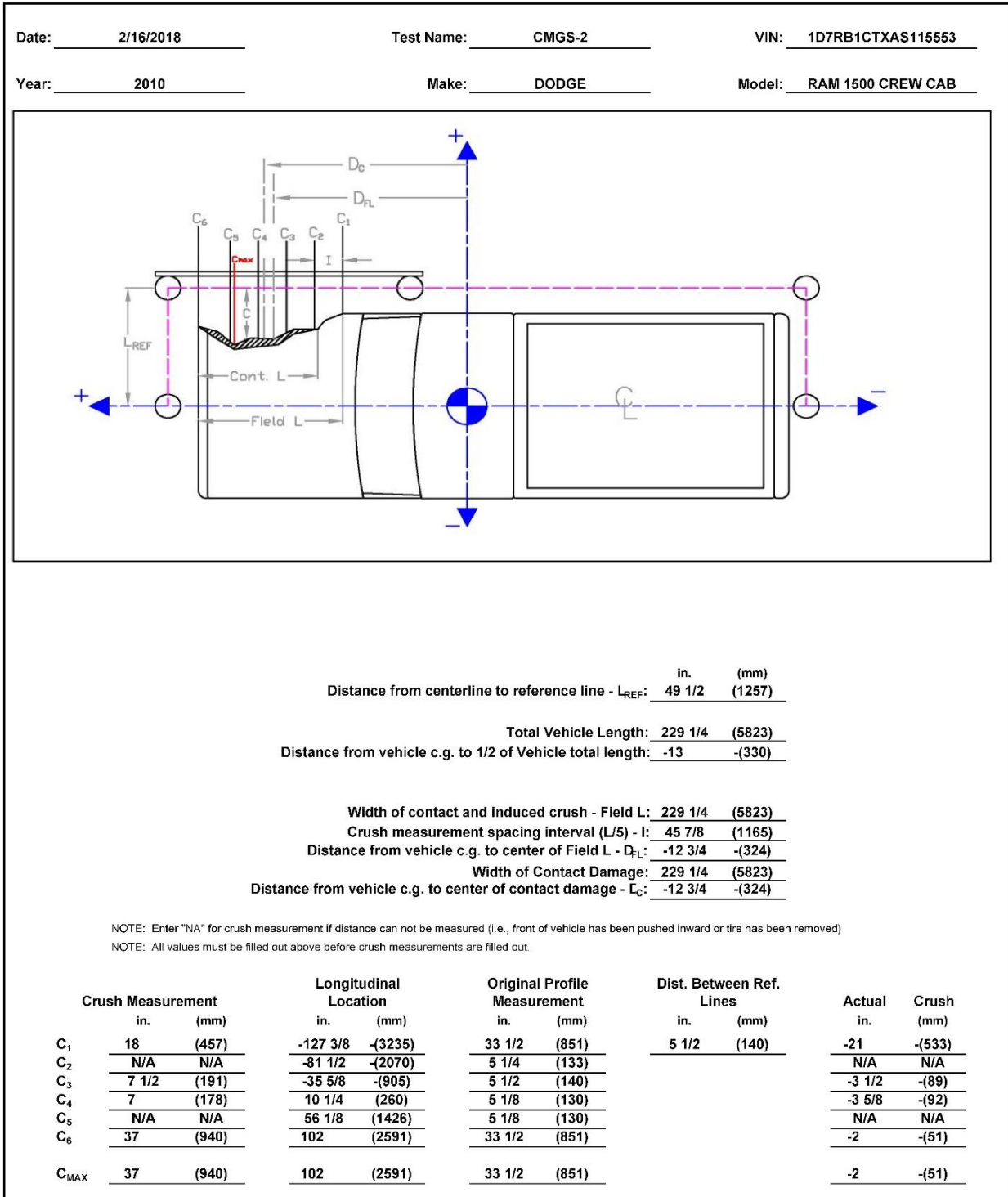


Figure D-12. Exterior Vehicle Crush (NASS) - Side, Test No. CMGS-2

Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. CMGS-1

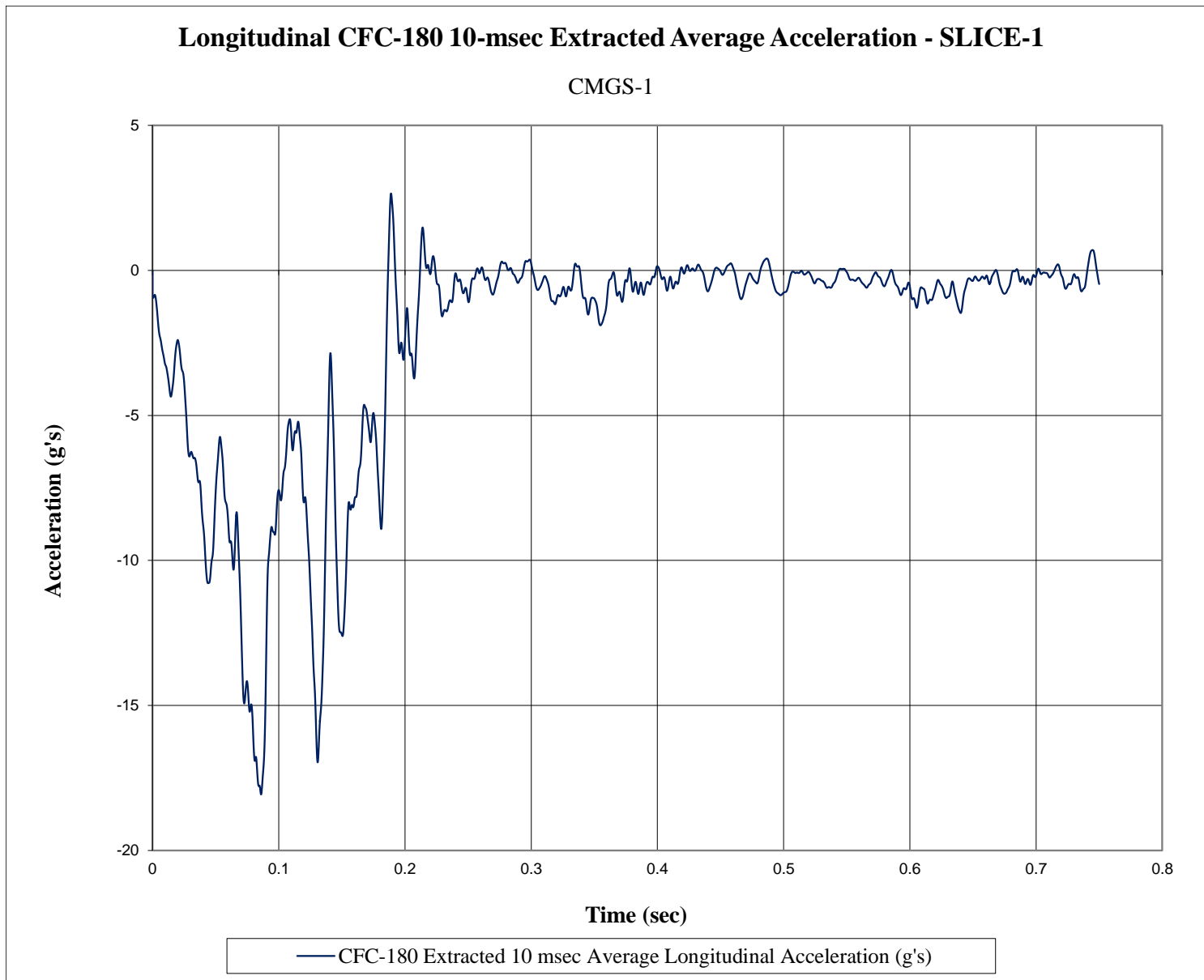


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. CMGS-1

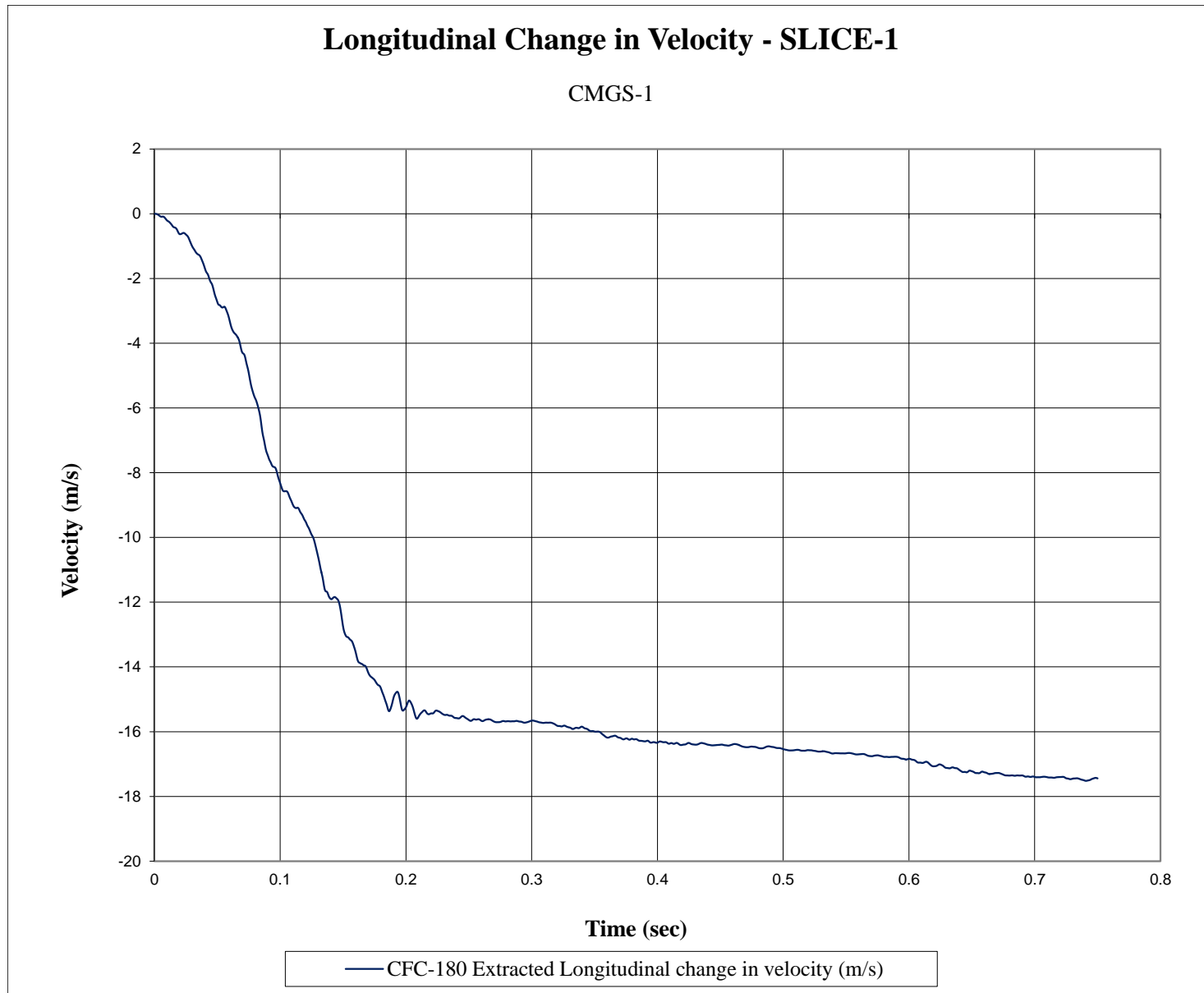


Figure E-2. Longitudinal Change in Velocity (SLICE-1), Test No. CMGS-1

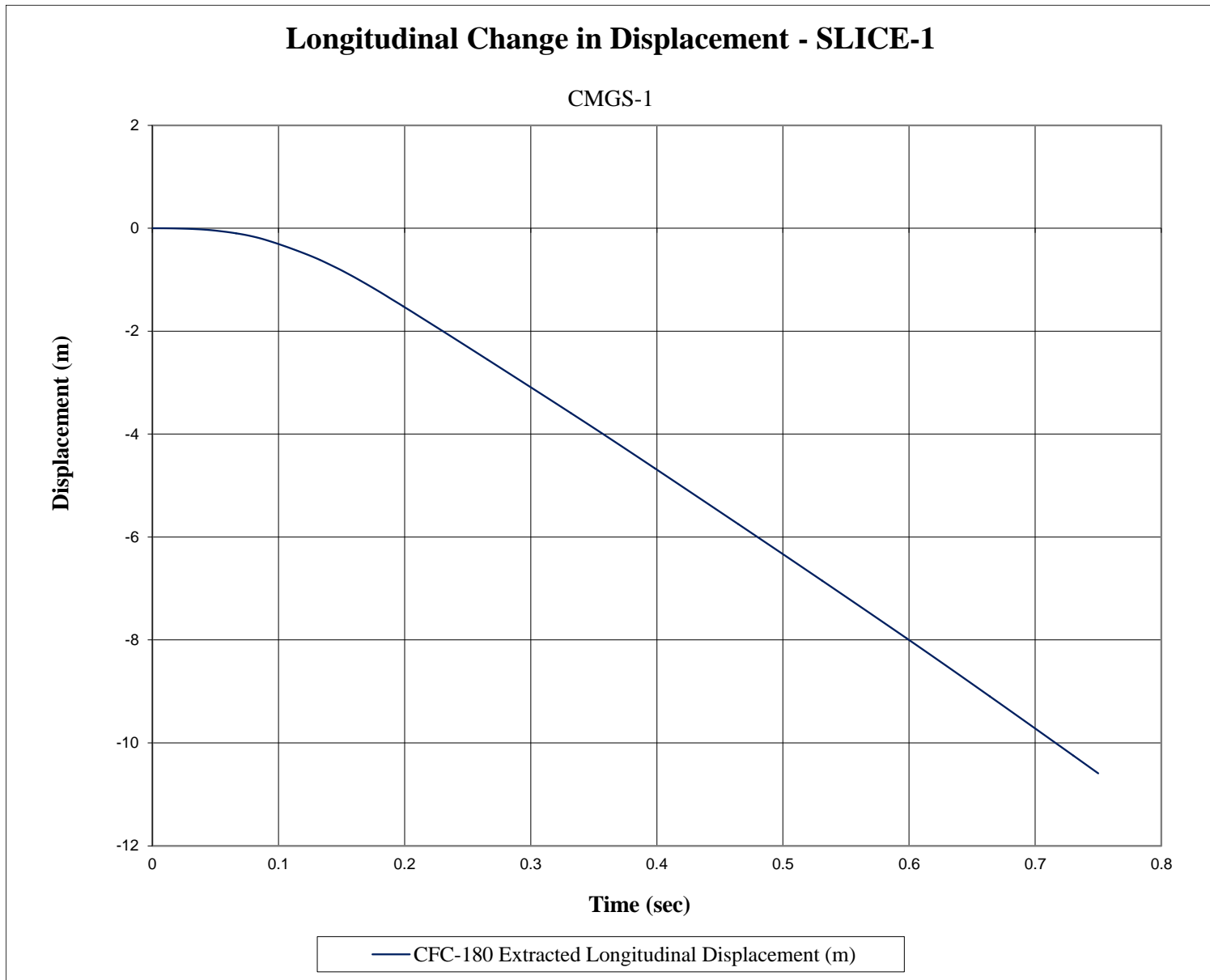


Figure E-3. Longitudinal Change in Displacement (SLICE-1), Test No. CMGS-1

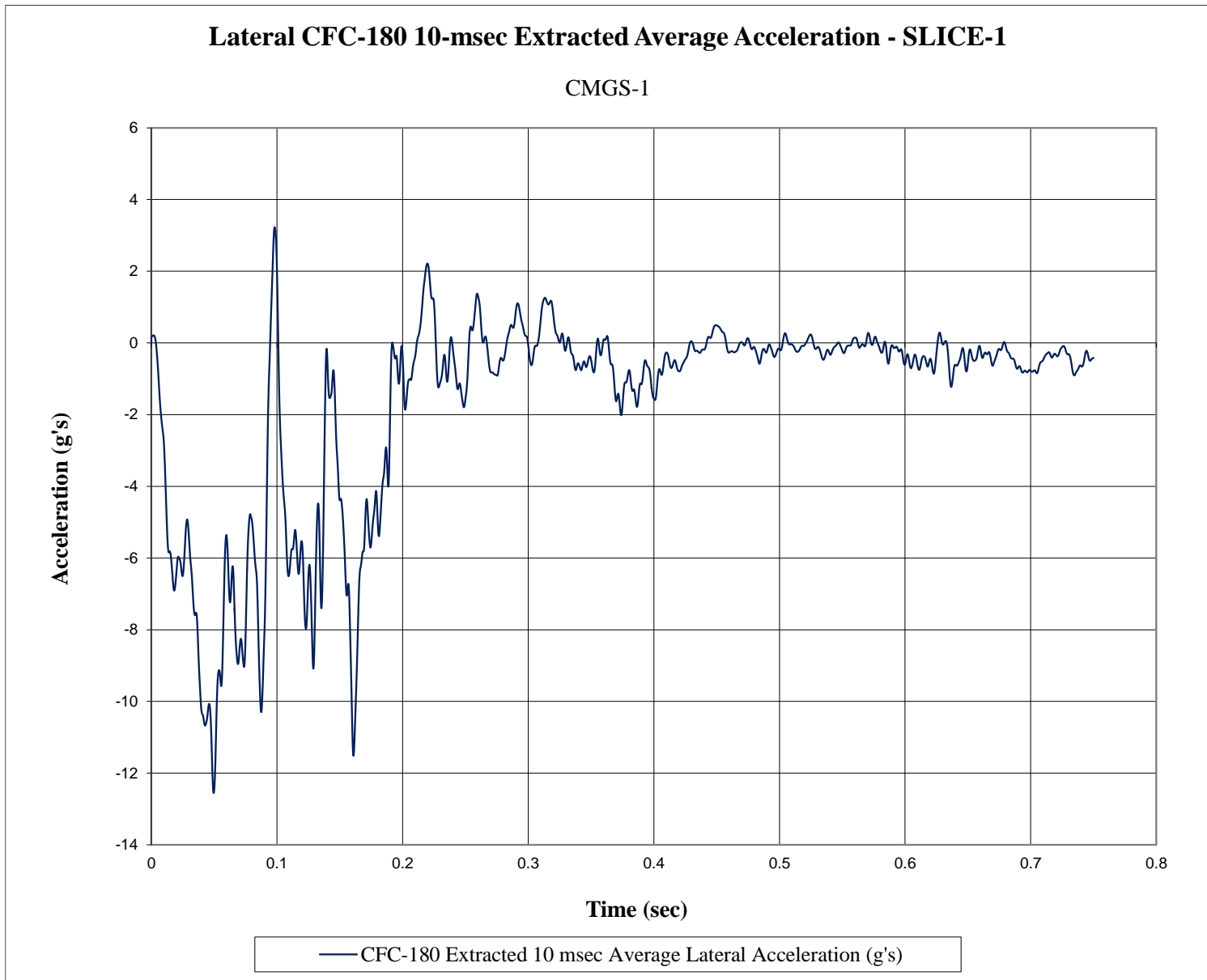


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. CMGS-1

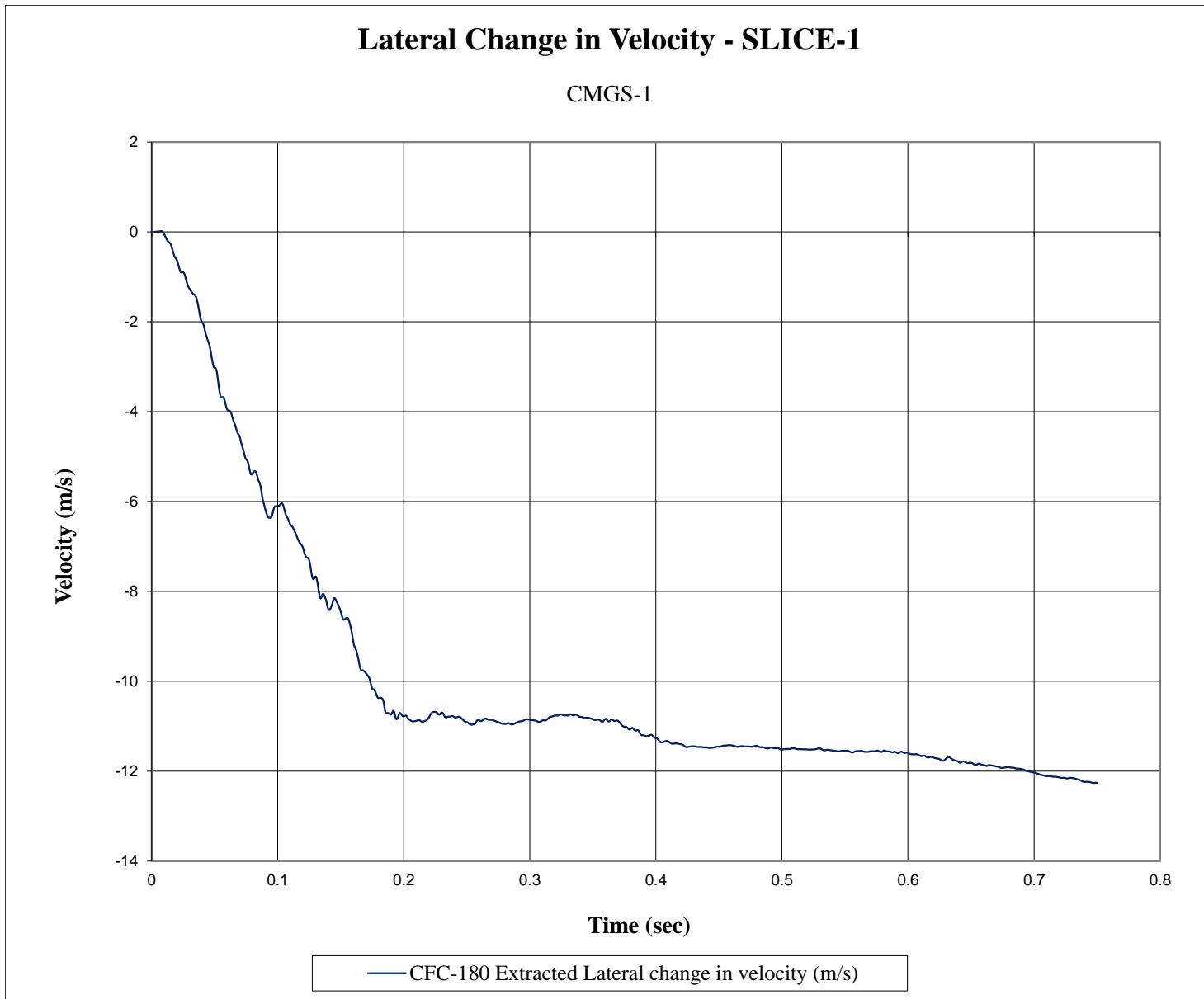


Figure E-5. Lateral Change in Velocity (SLICE-1), Test No. CMGS-1

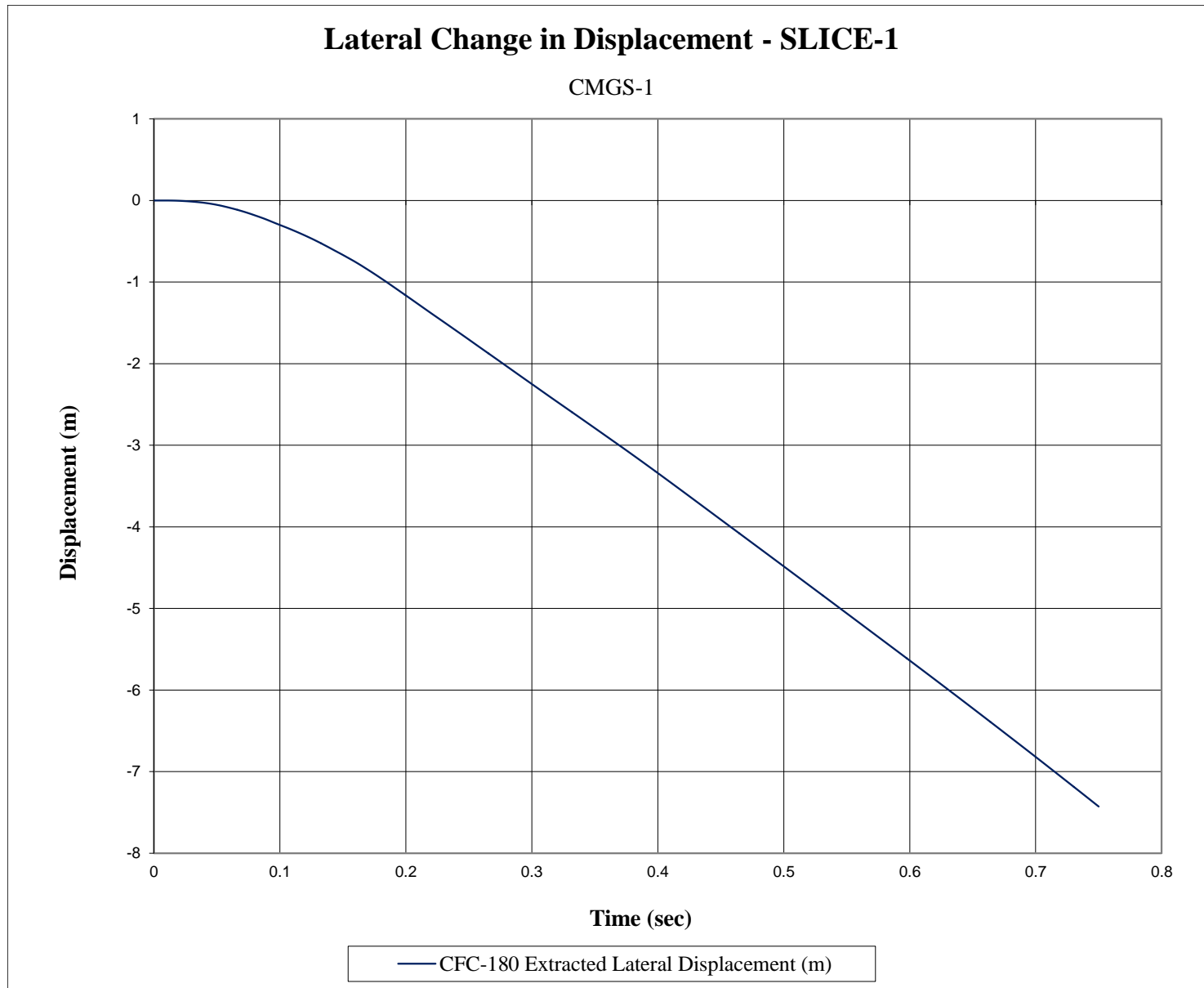


Figure E-6. Lateral Change in Displacement (SLICE-1), Test No. CMGS-1

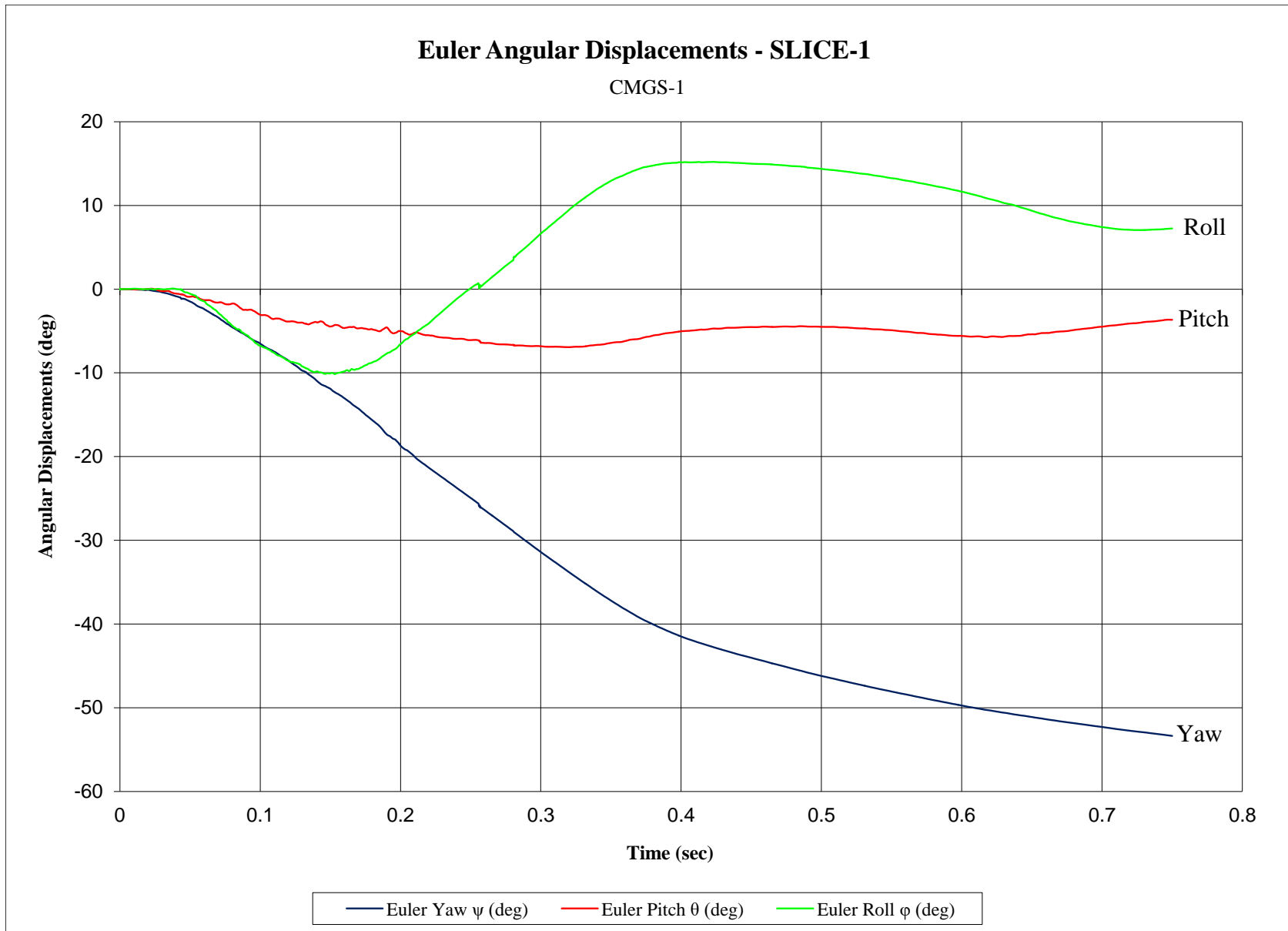


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. CMGS-1

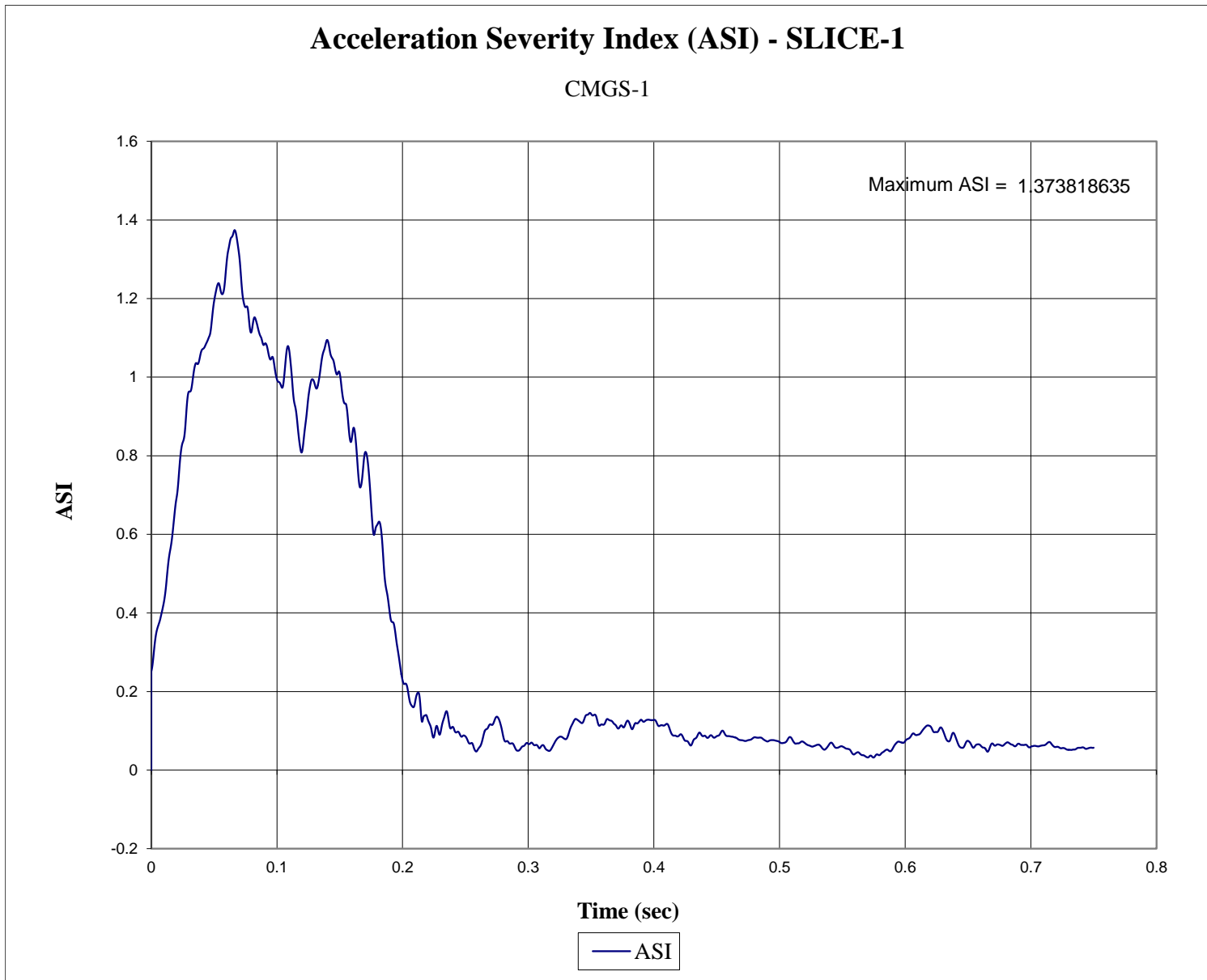


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. CMGS-1

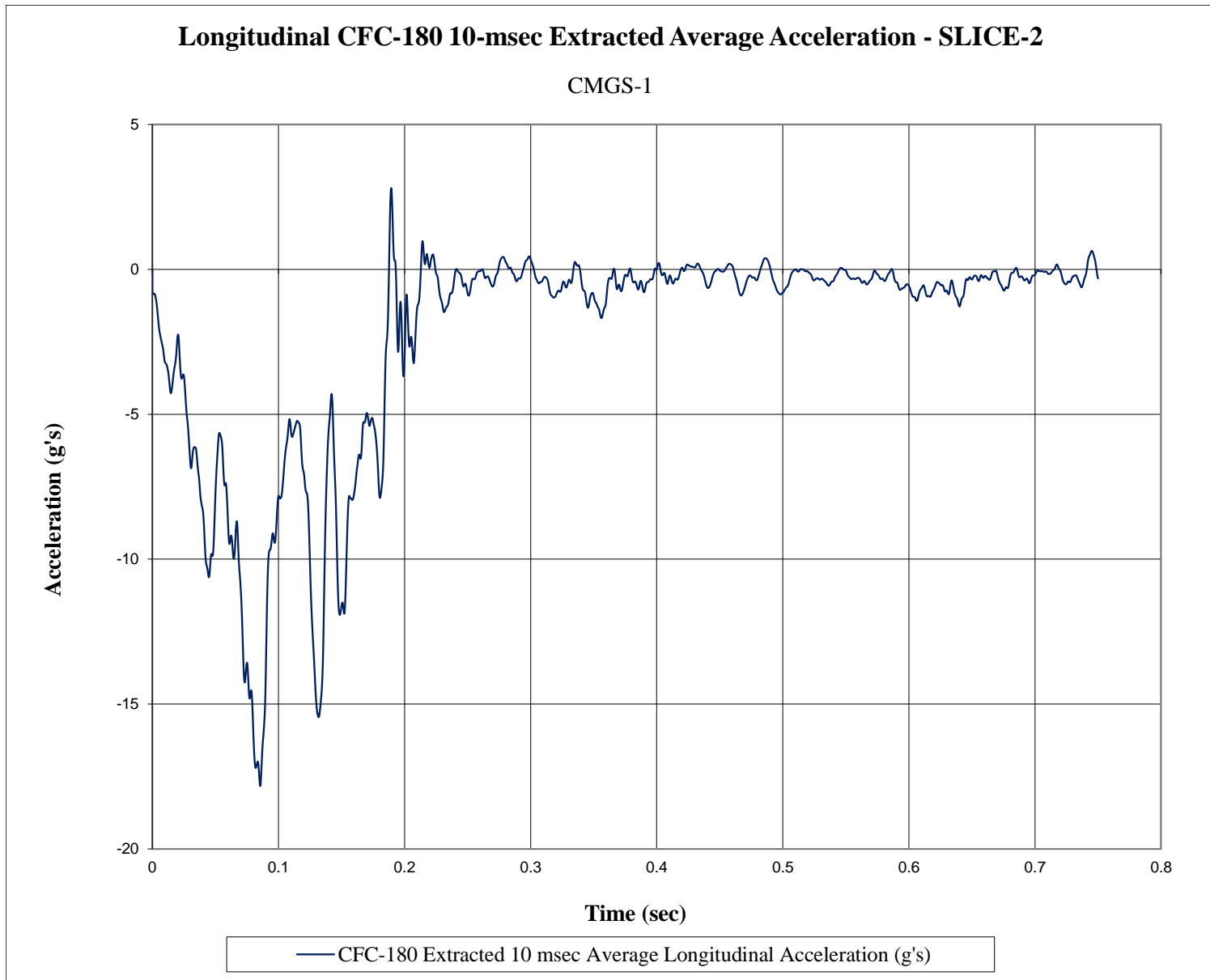


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. CMGS-1

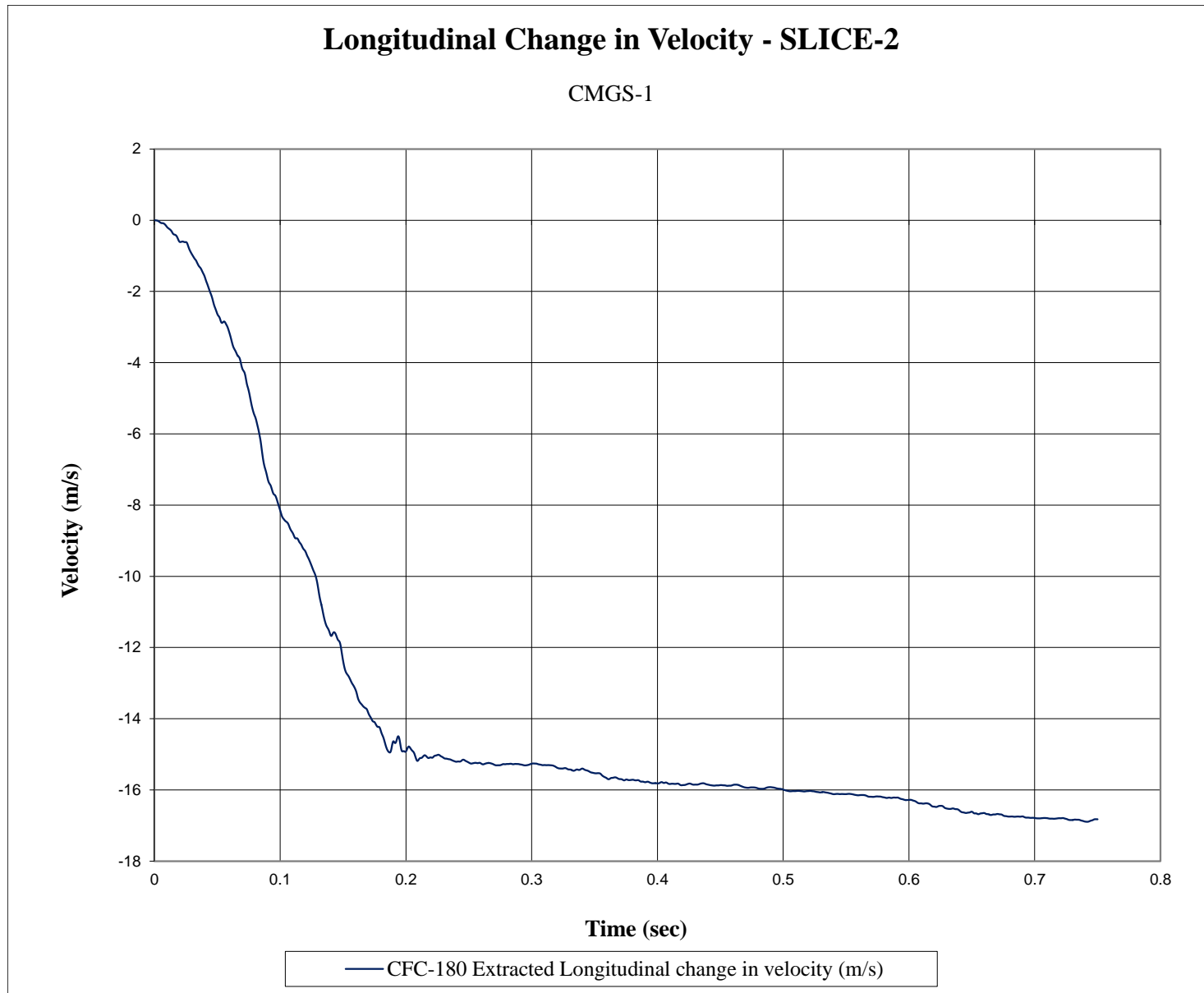


Figure E-10. Longitudinal Change in Velocity (SLICE-2), Test No. CMGS-1

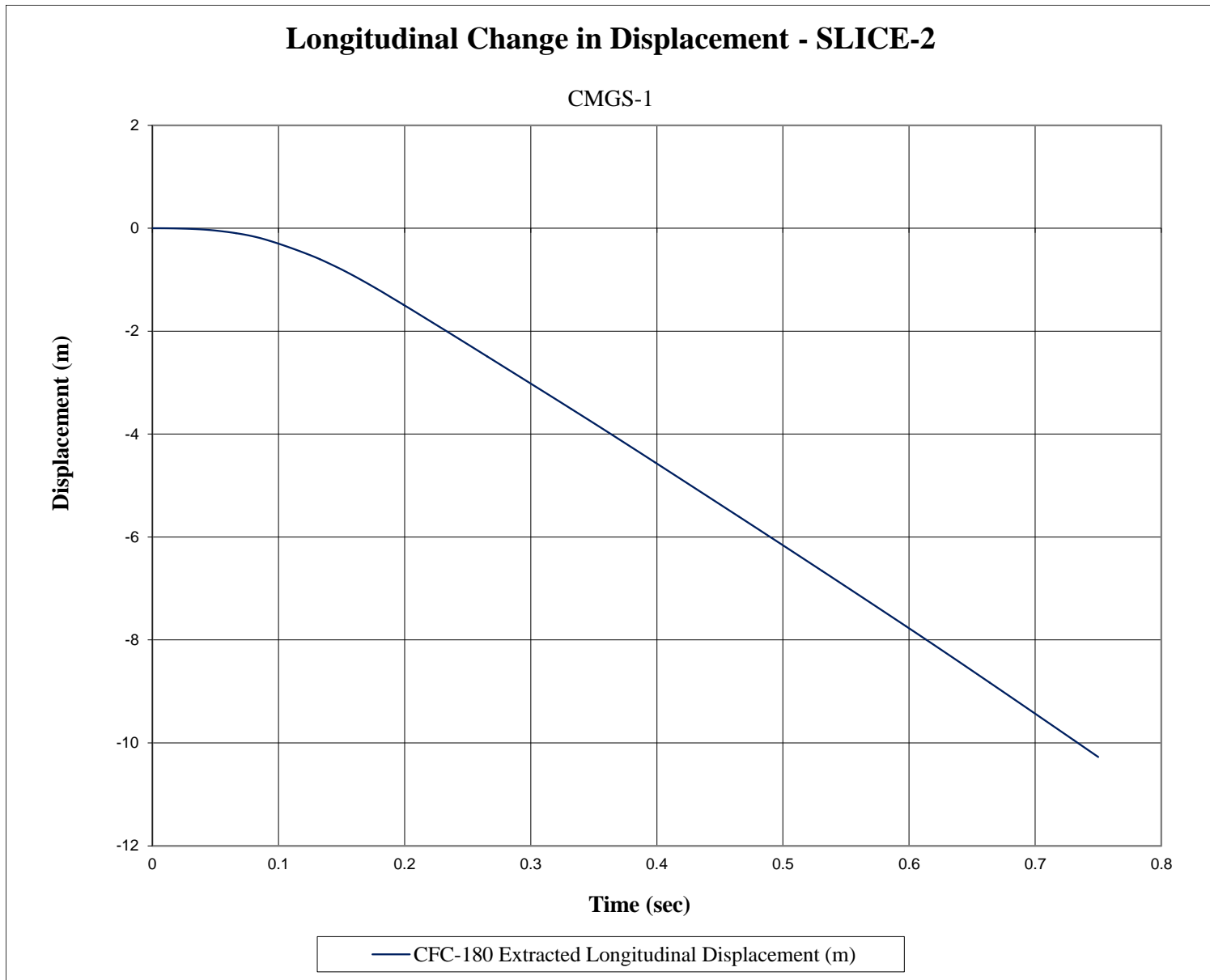


Figure E-11. Longitudinal Change in Displacement (SLICE-2), Test No. CMGS-1

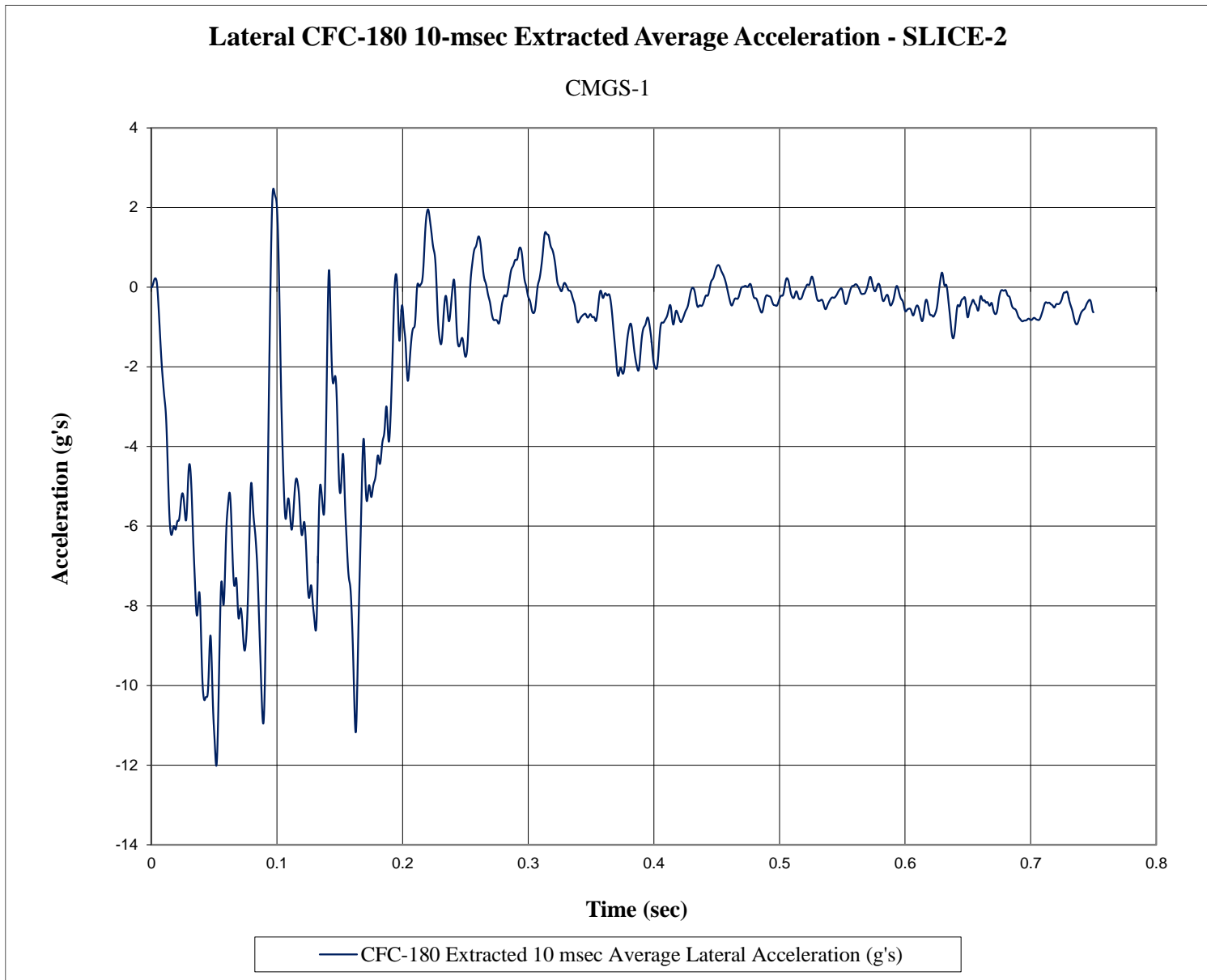


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. CMGS-1

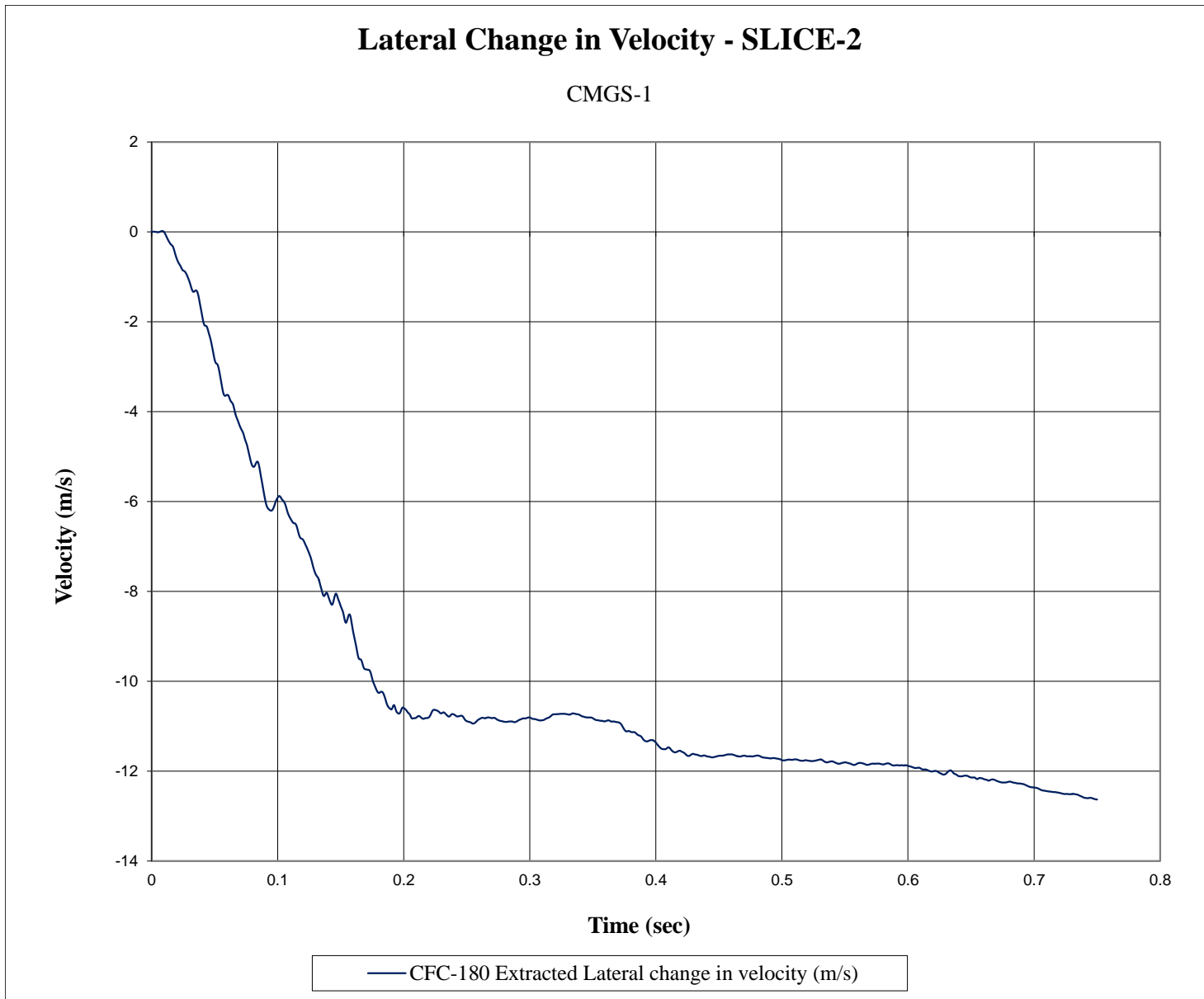


Figure E-13. Lateral Change in Velocity (SLICE-2), Test No. CMGS-1

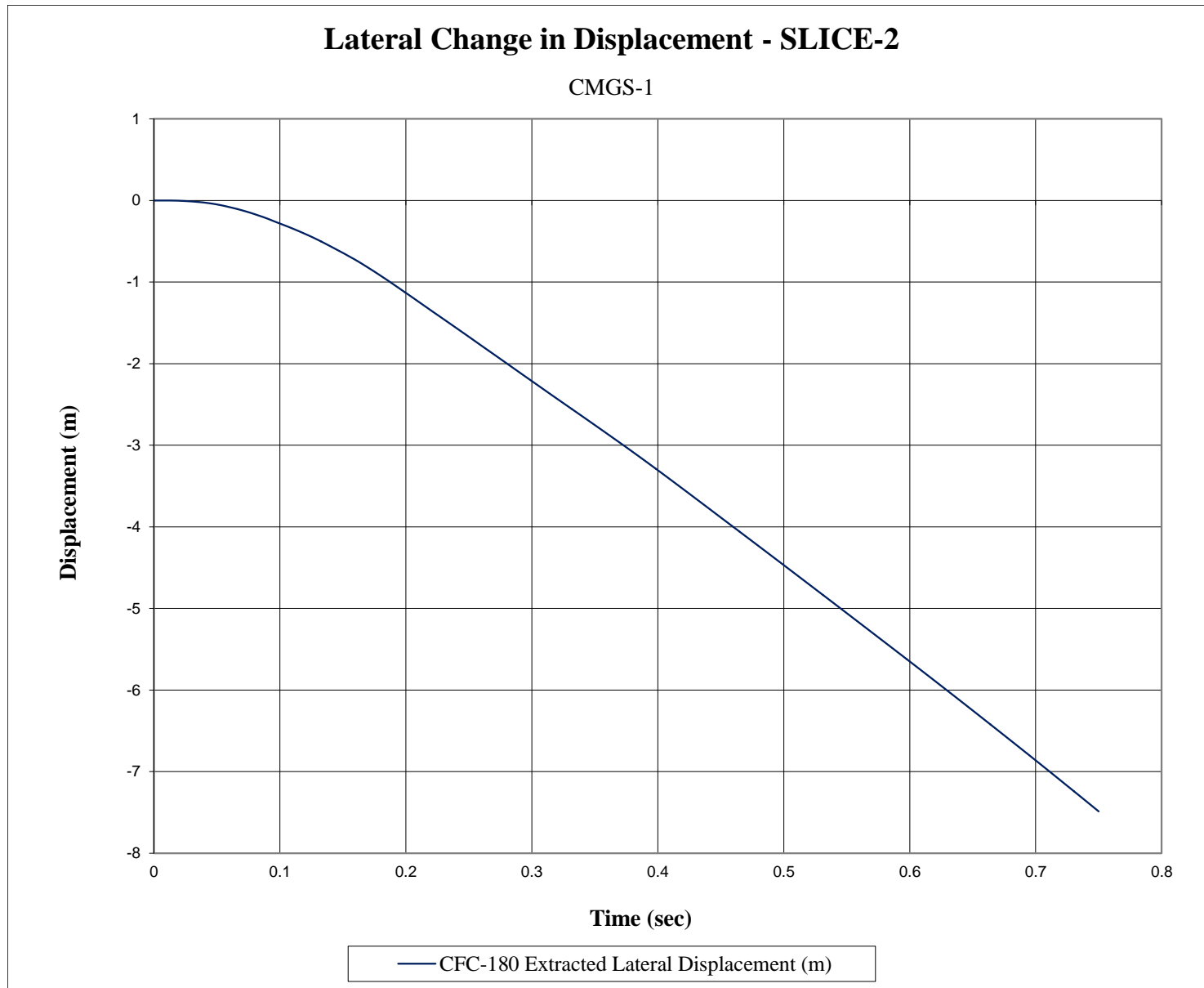


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. CMGS-1

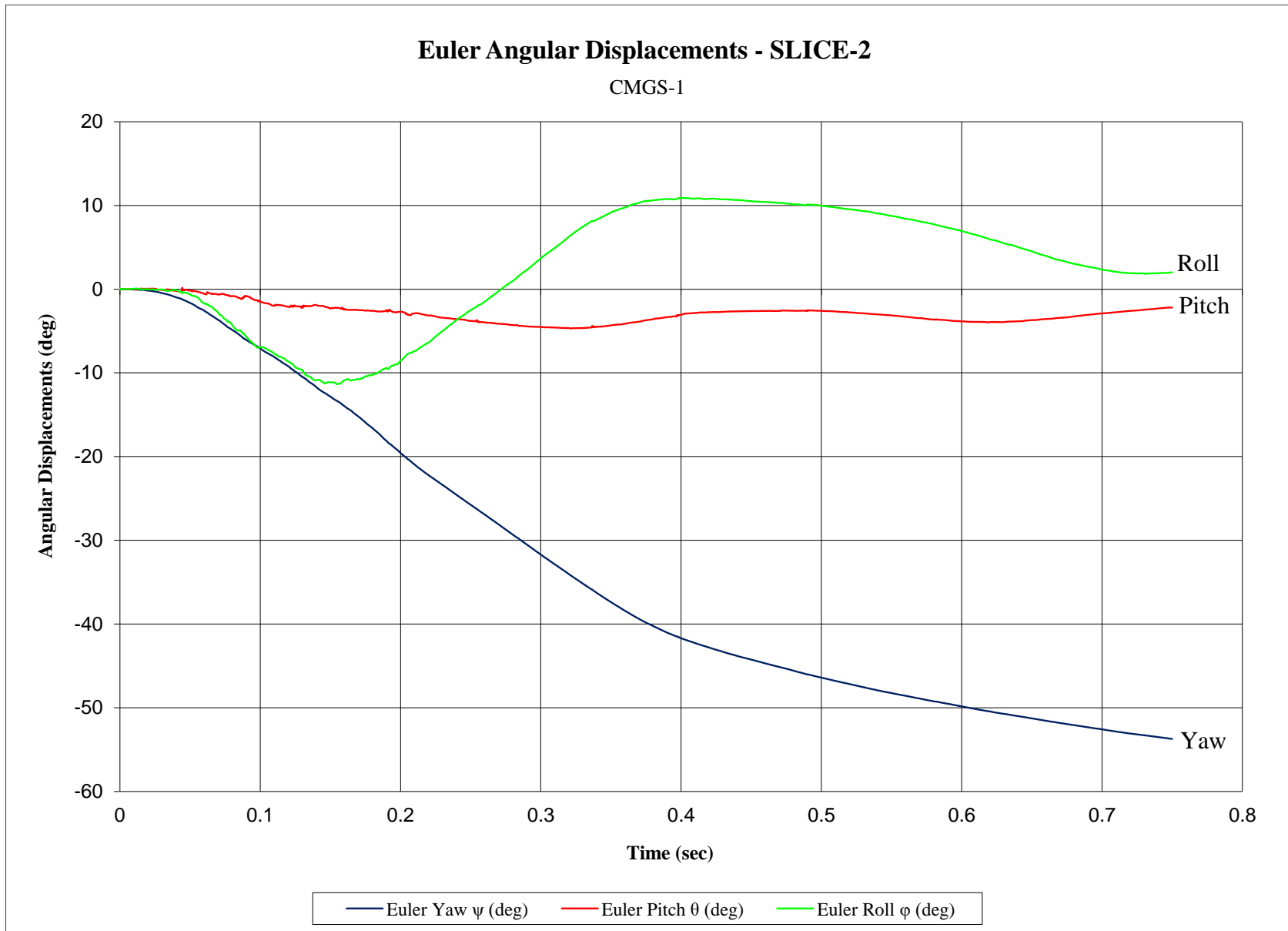


Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. CMGS-1

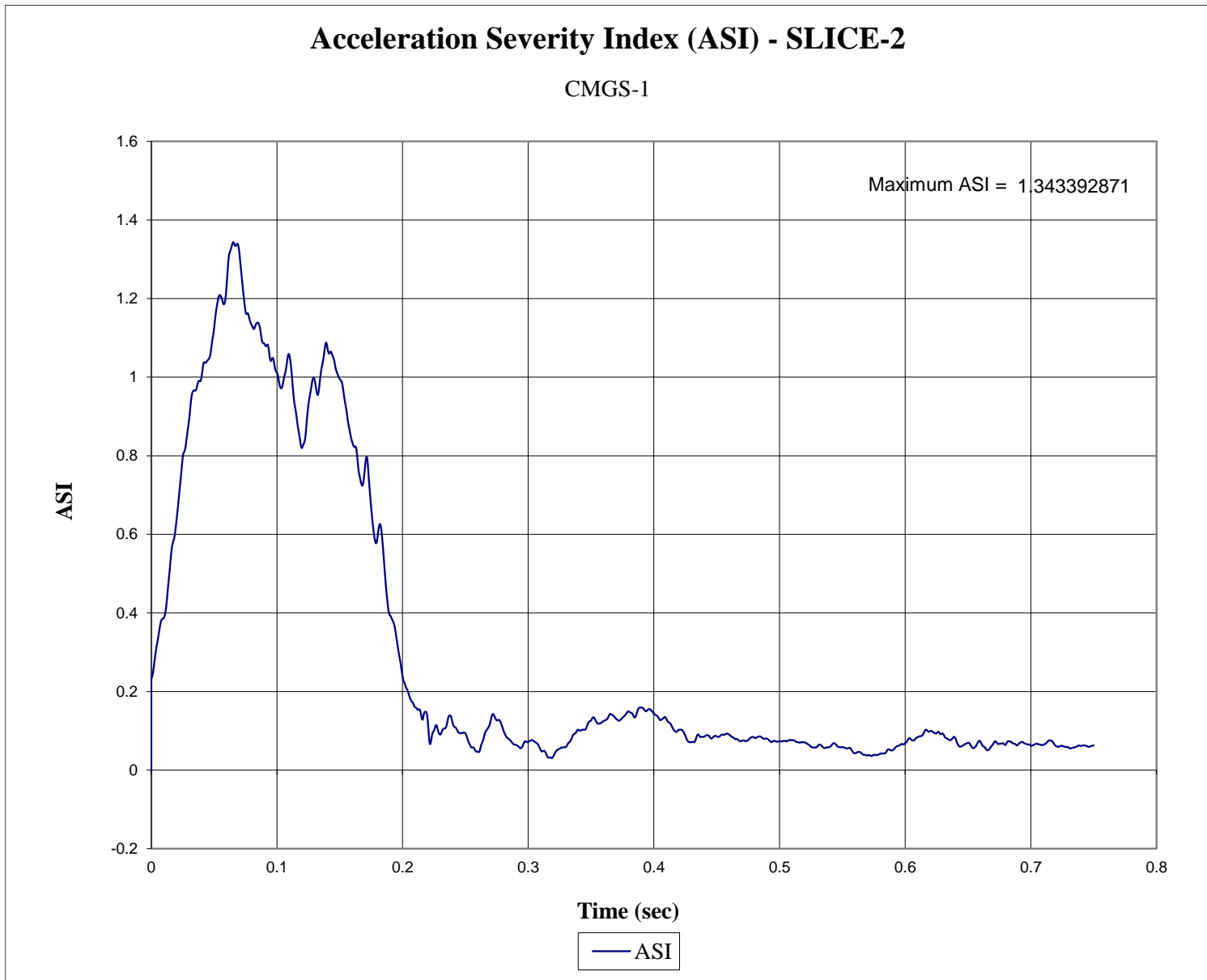


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. CMGS-1

Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. CMGS-2

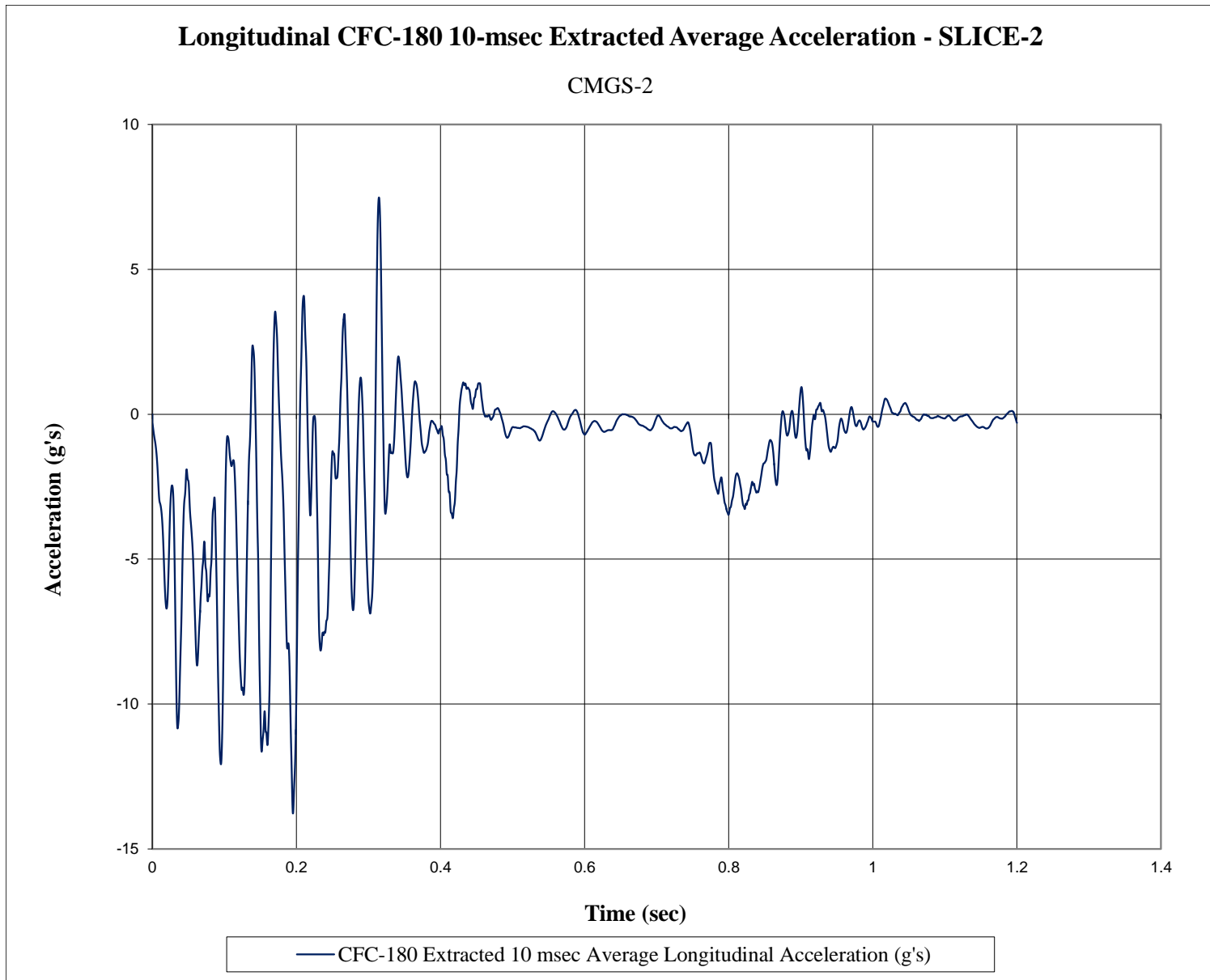


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. CMGS-2

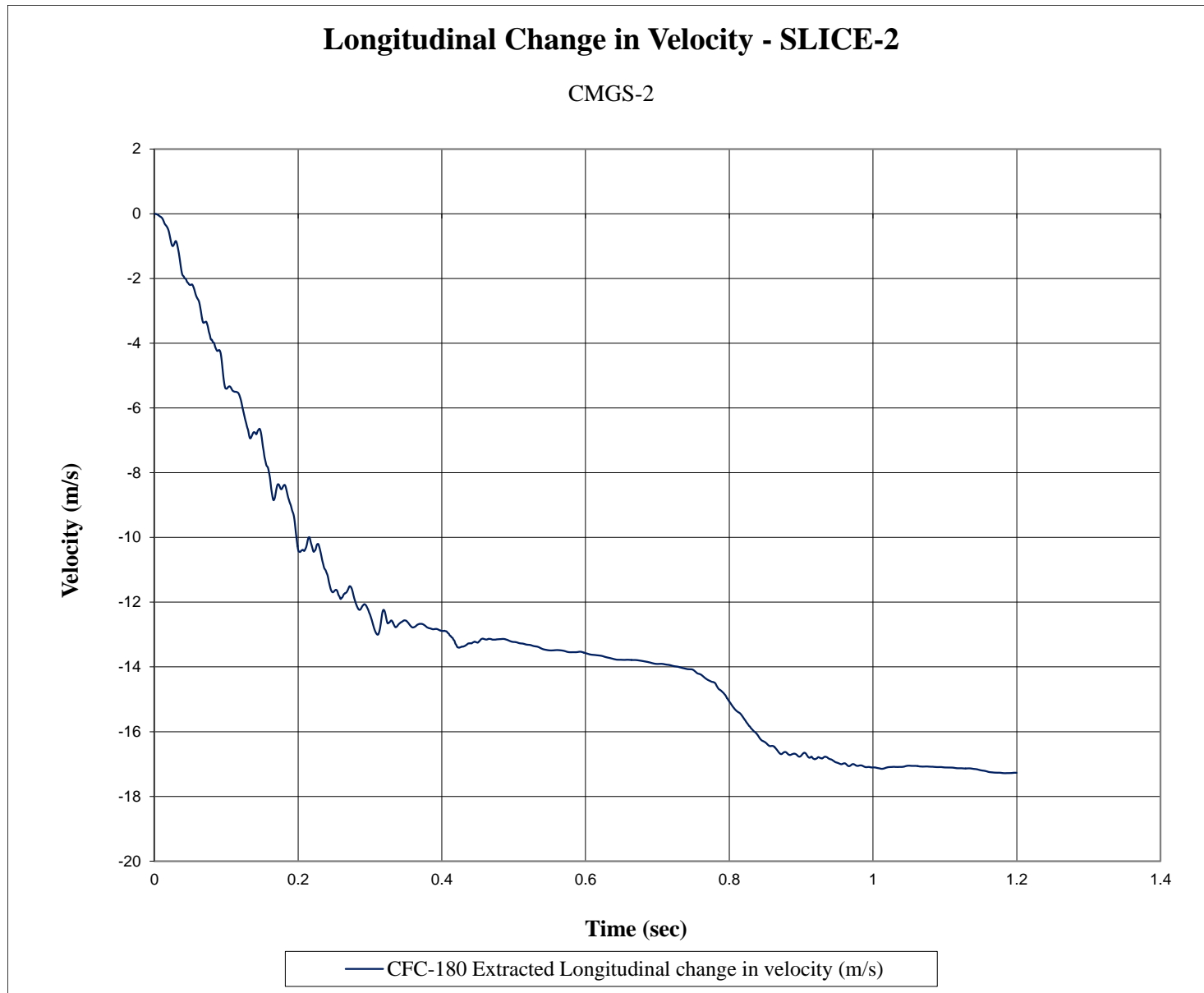


Figure F-2. Longitudinal Change in Velocity (SLICE-2), Test No. CMGS-2

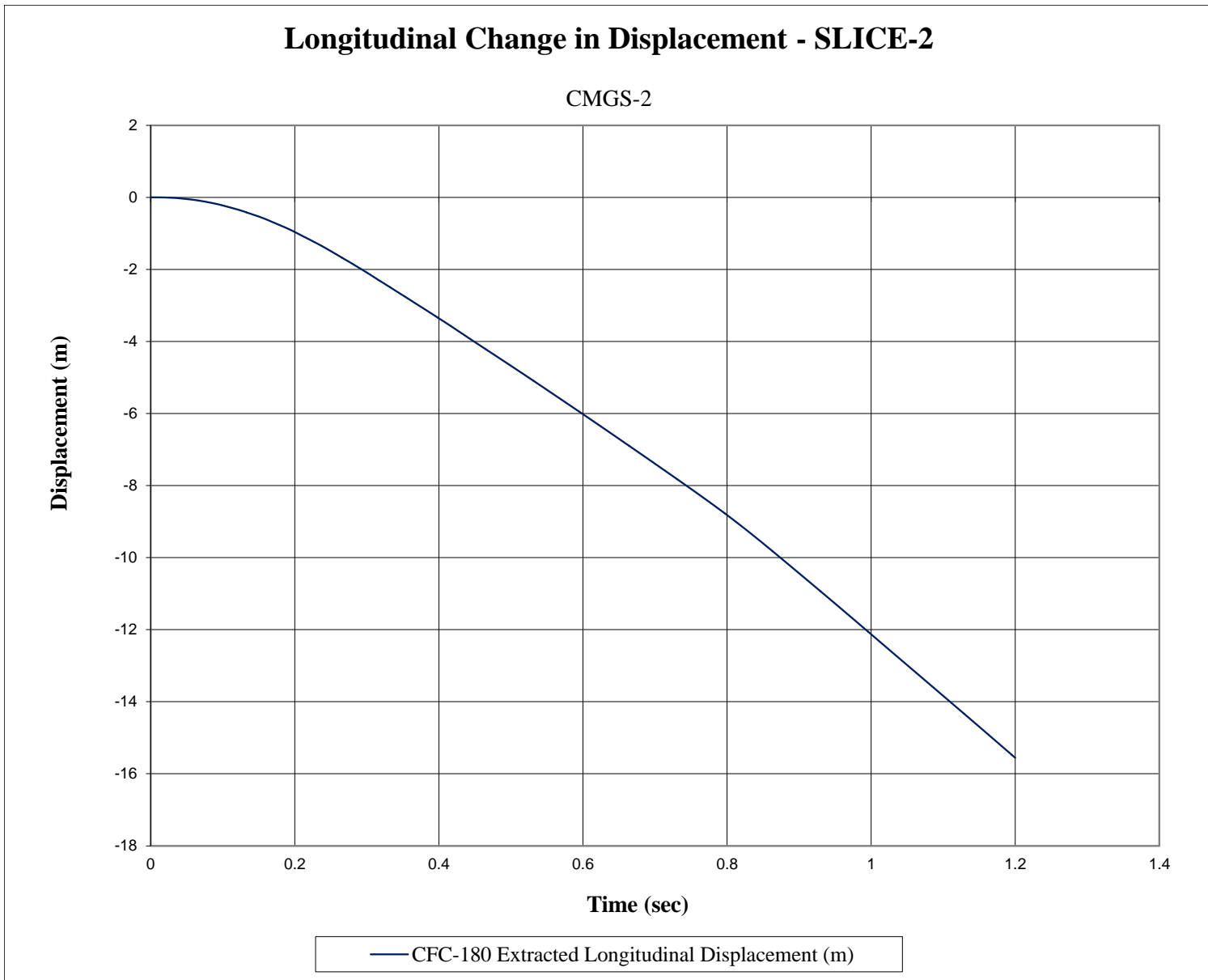


Figure F-3. Longitudinal Change in Displacement (SLICE-2), Test No. CMGS-2

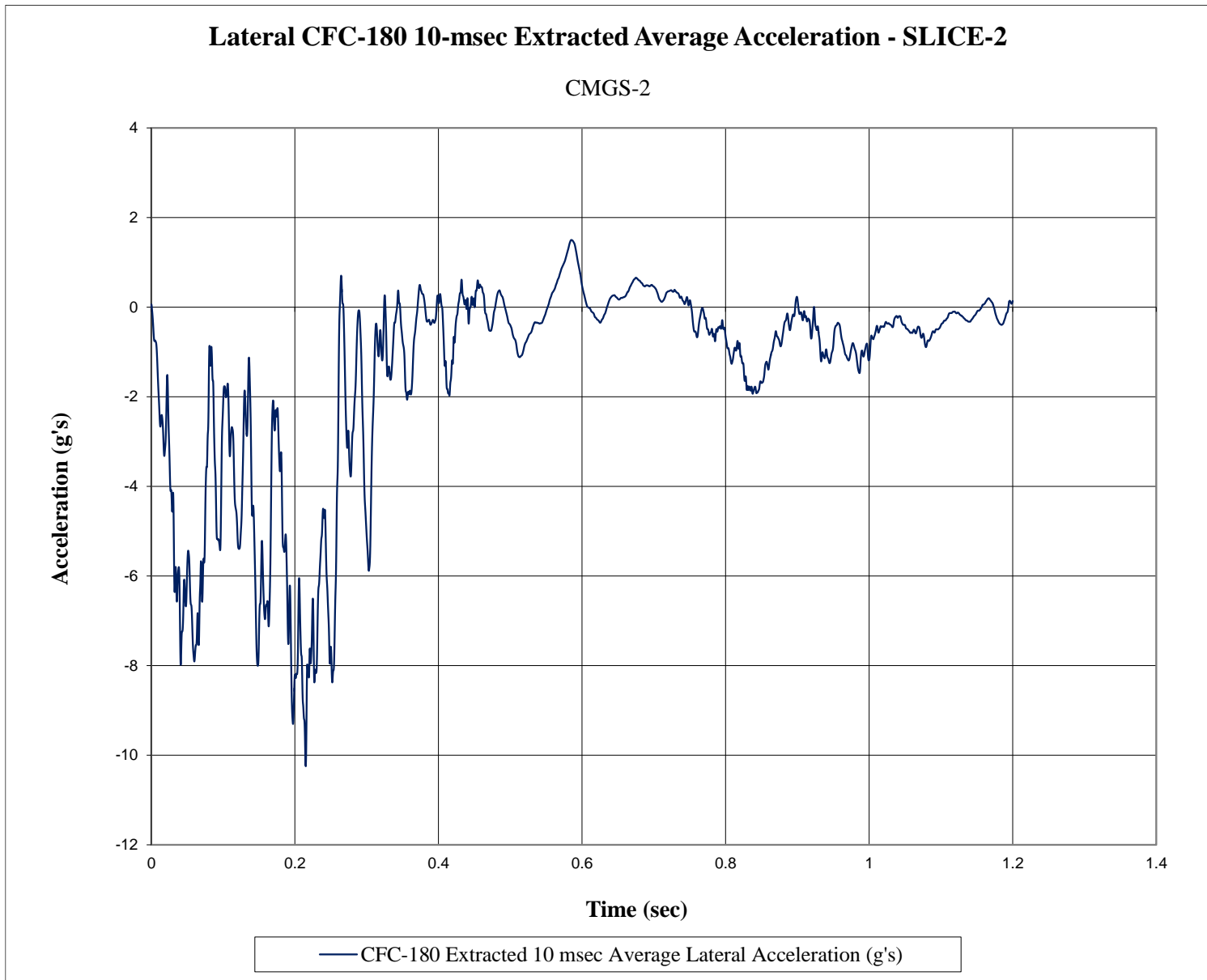


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. CMGS-2

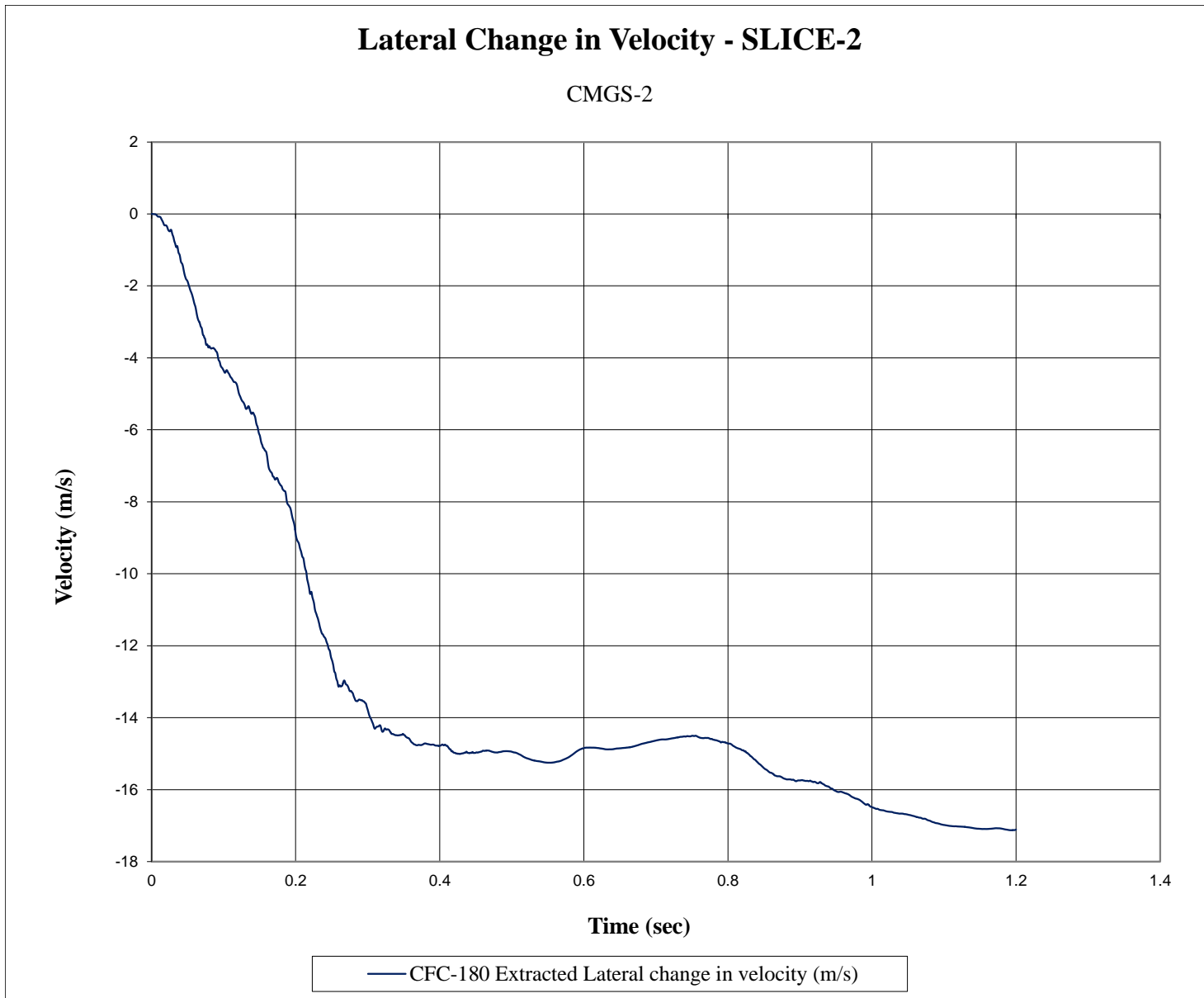


Figure F-5. Lateral Change in Velocity (SLICE-2), Test No. CMGS-2

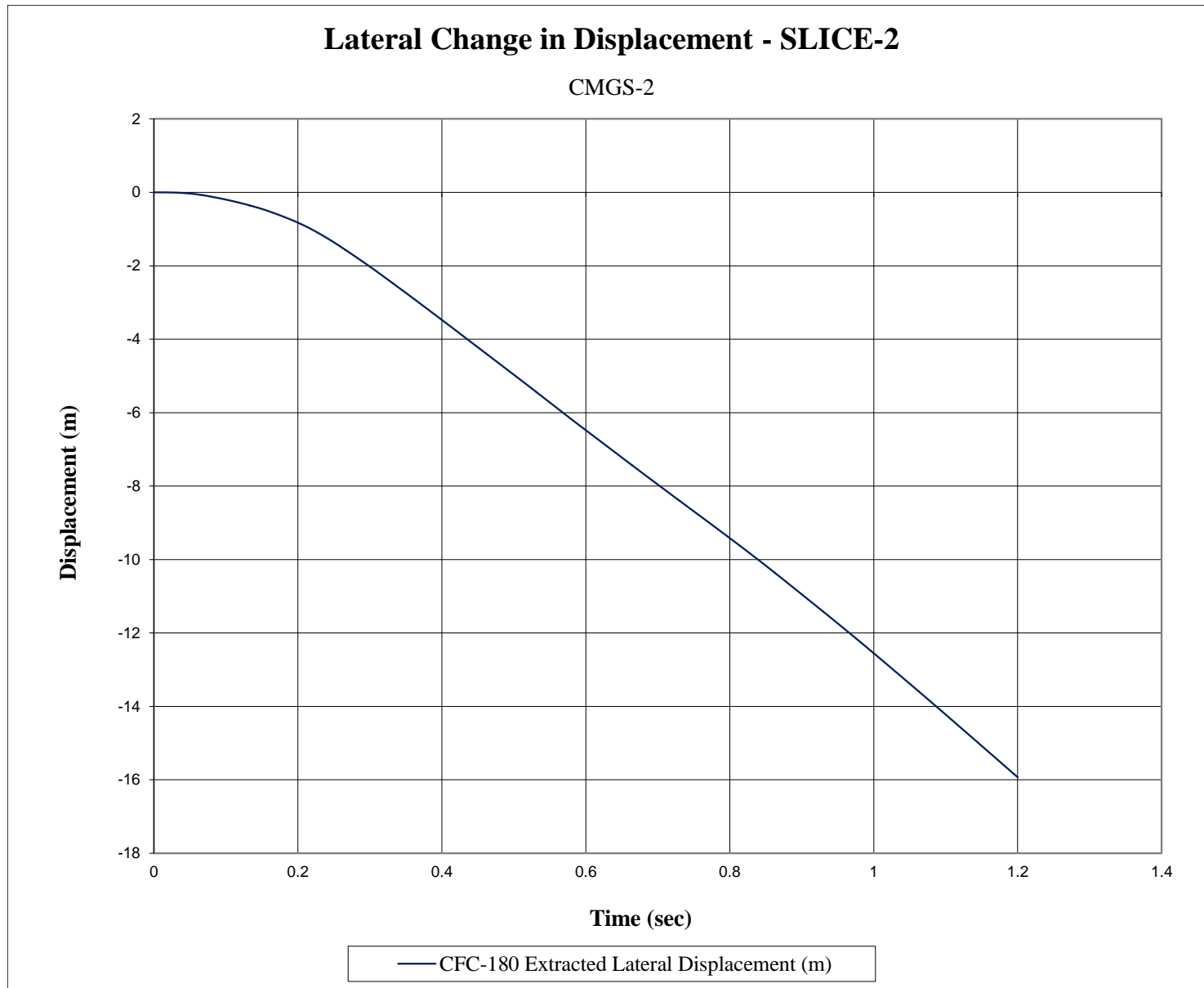


Figure F-6. Lateral Change in Displacement (SLICE-2), Test No. CMGS-2

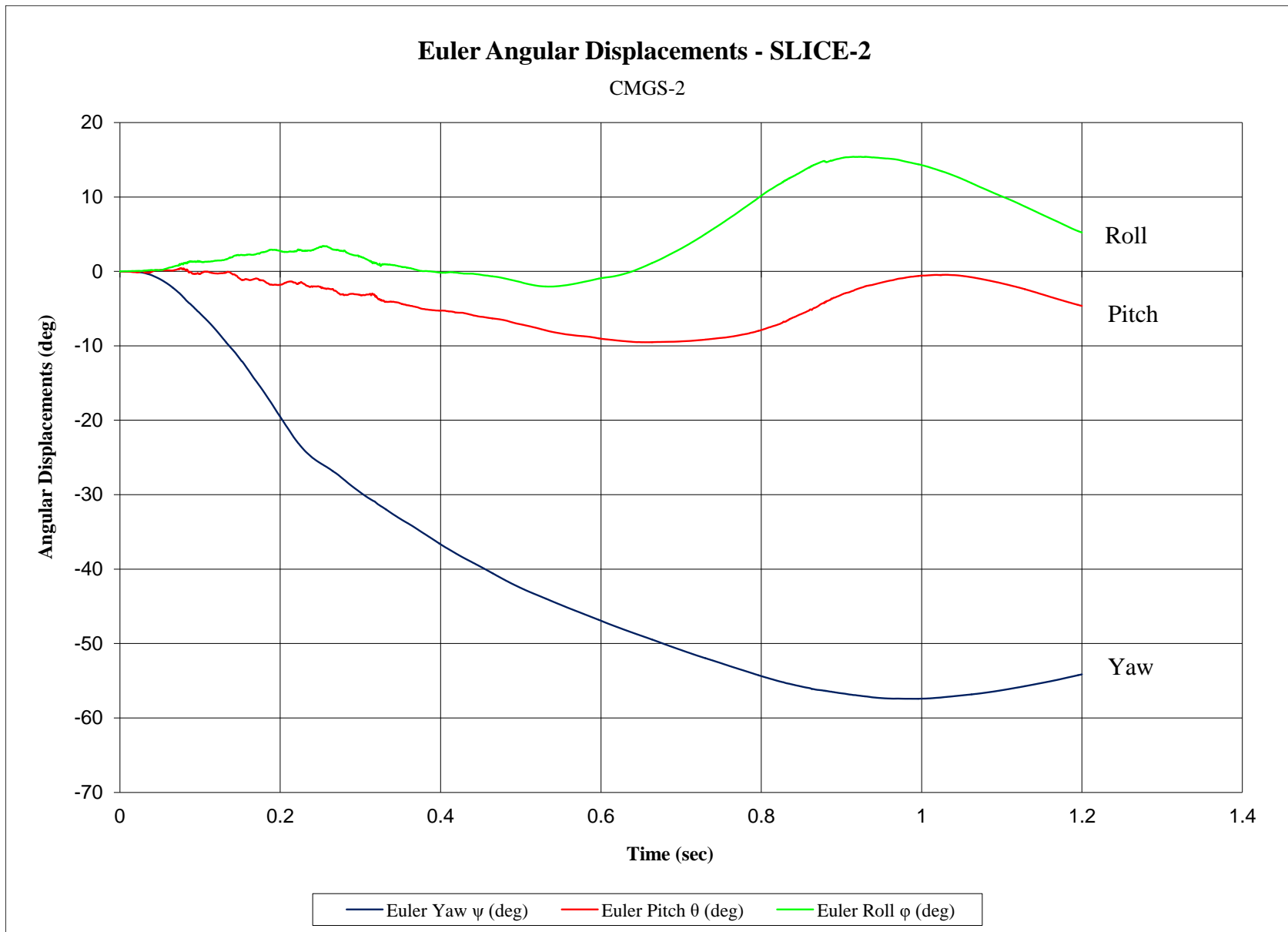


Figure F-7. Vehicle Angular Displacements (SLICE-2), Test No. CMGS-2

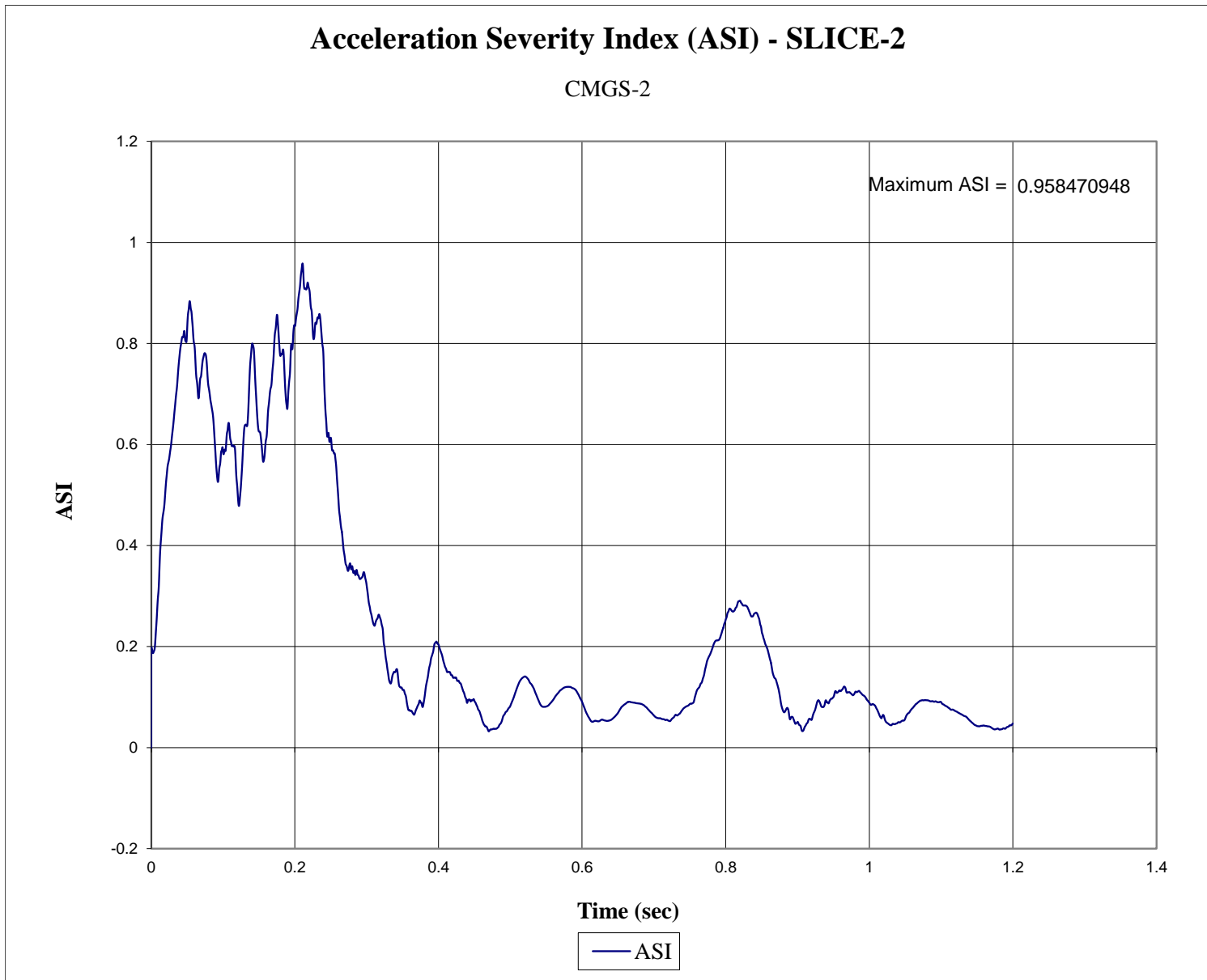


Figure F-8. Acceleration Severity Index (SLICE-2), Test No. CMGS-2

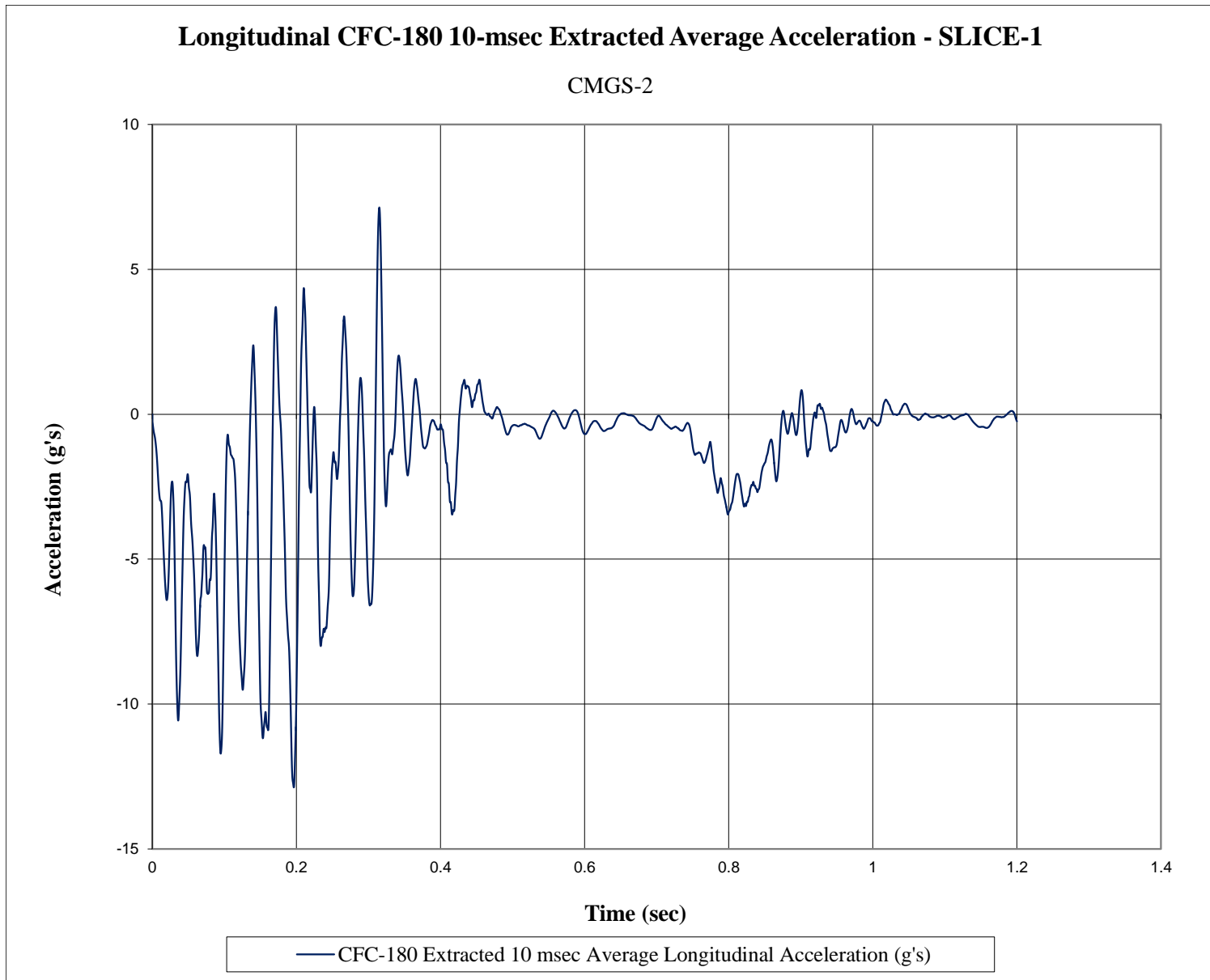


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. CMGS-2

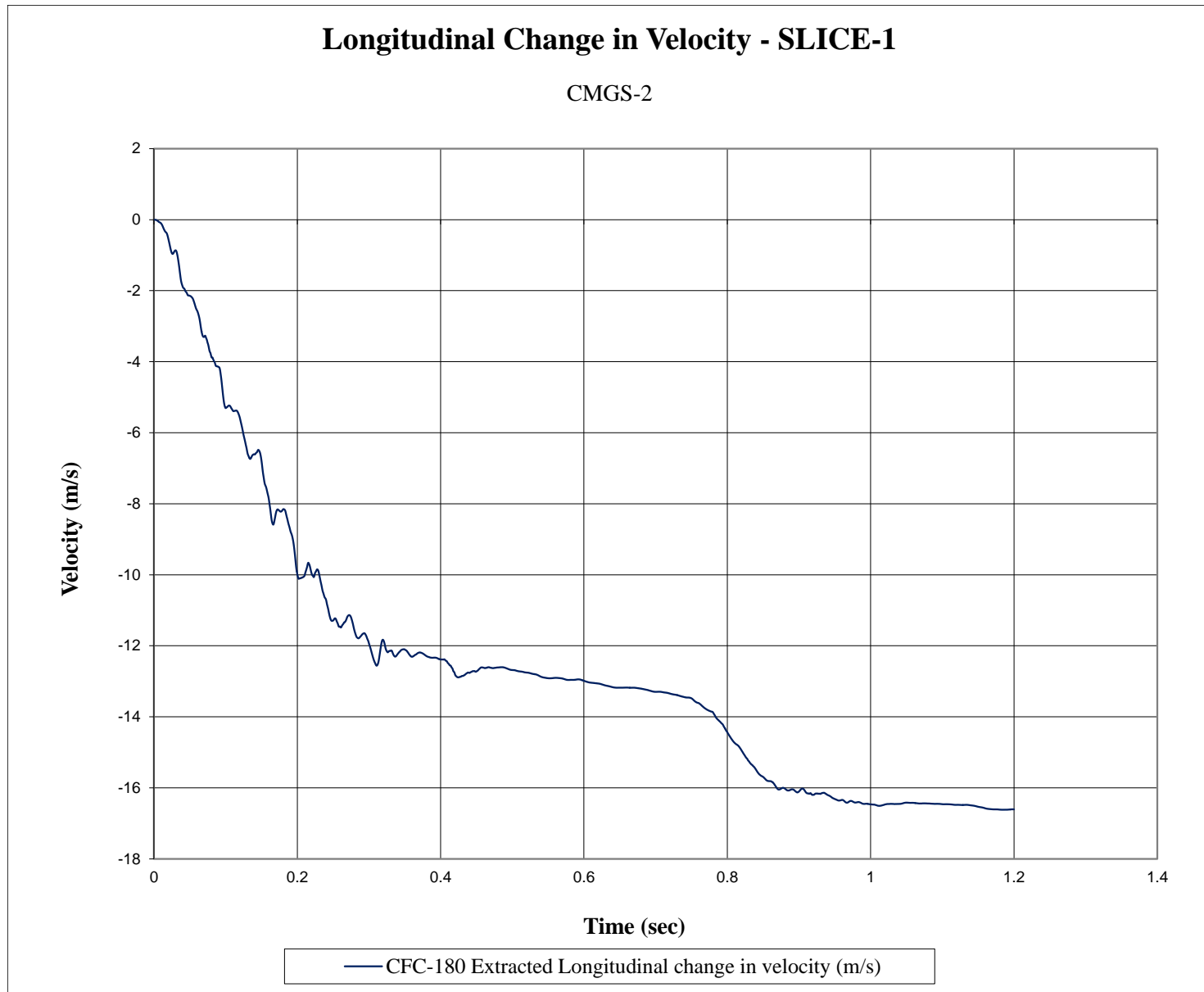


Figure F-10. Longitudinal Change in Velocity (SLICE-1), Test No. CMGS-2

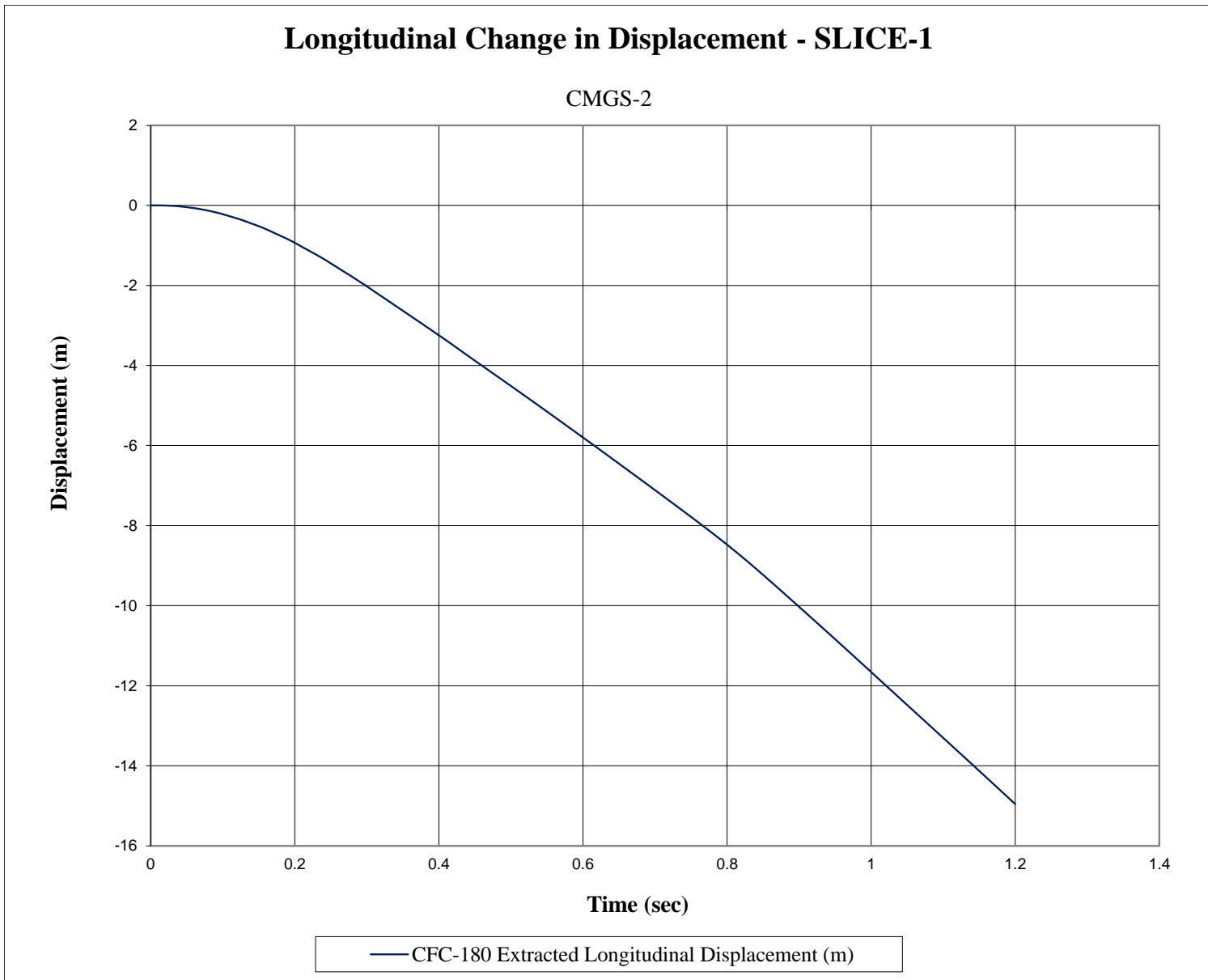


Figure F-11. Longitudinal Change in Displacement (SLICE-1), Test No. CMGS-2

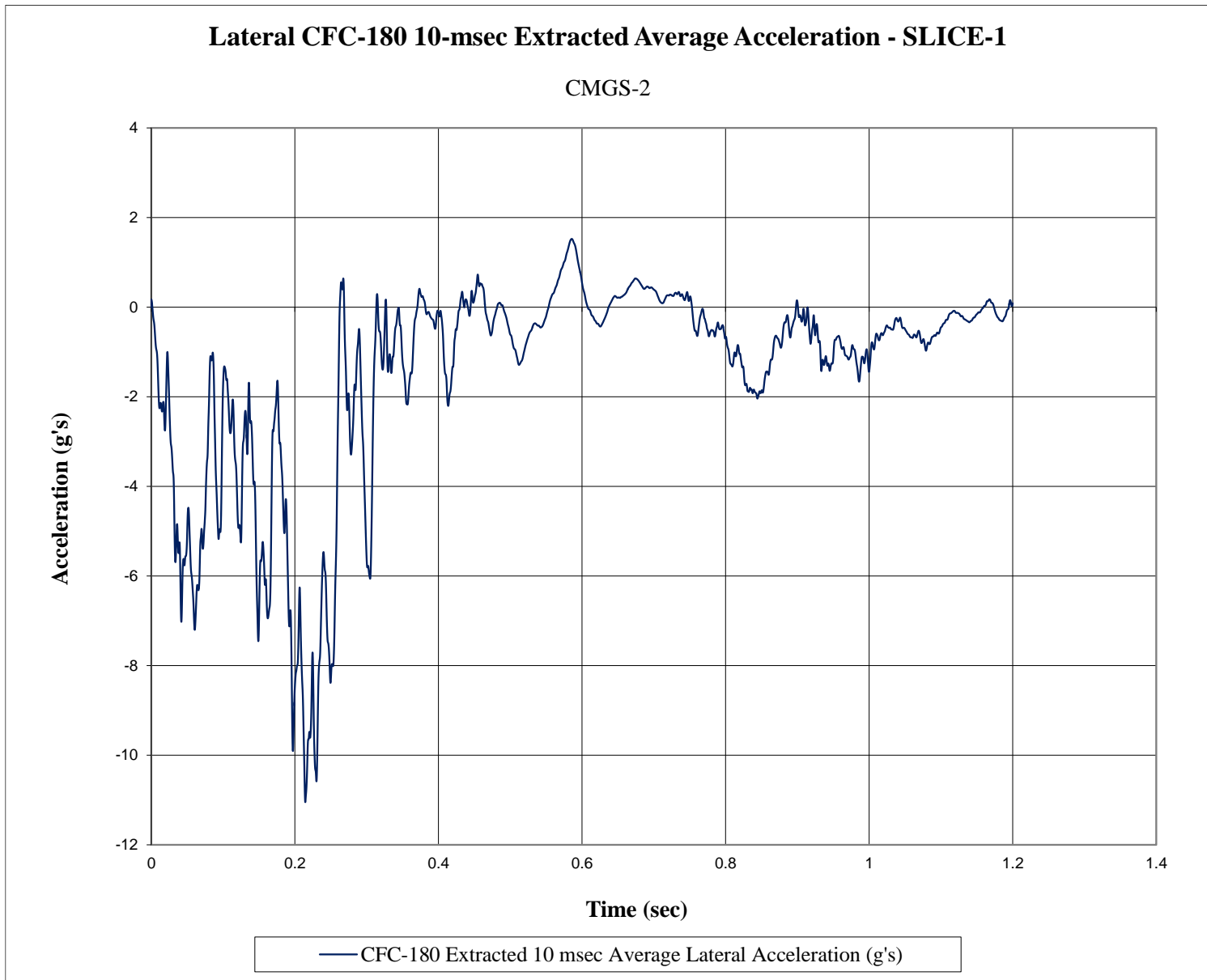


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-1), Test No. CMGS-2

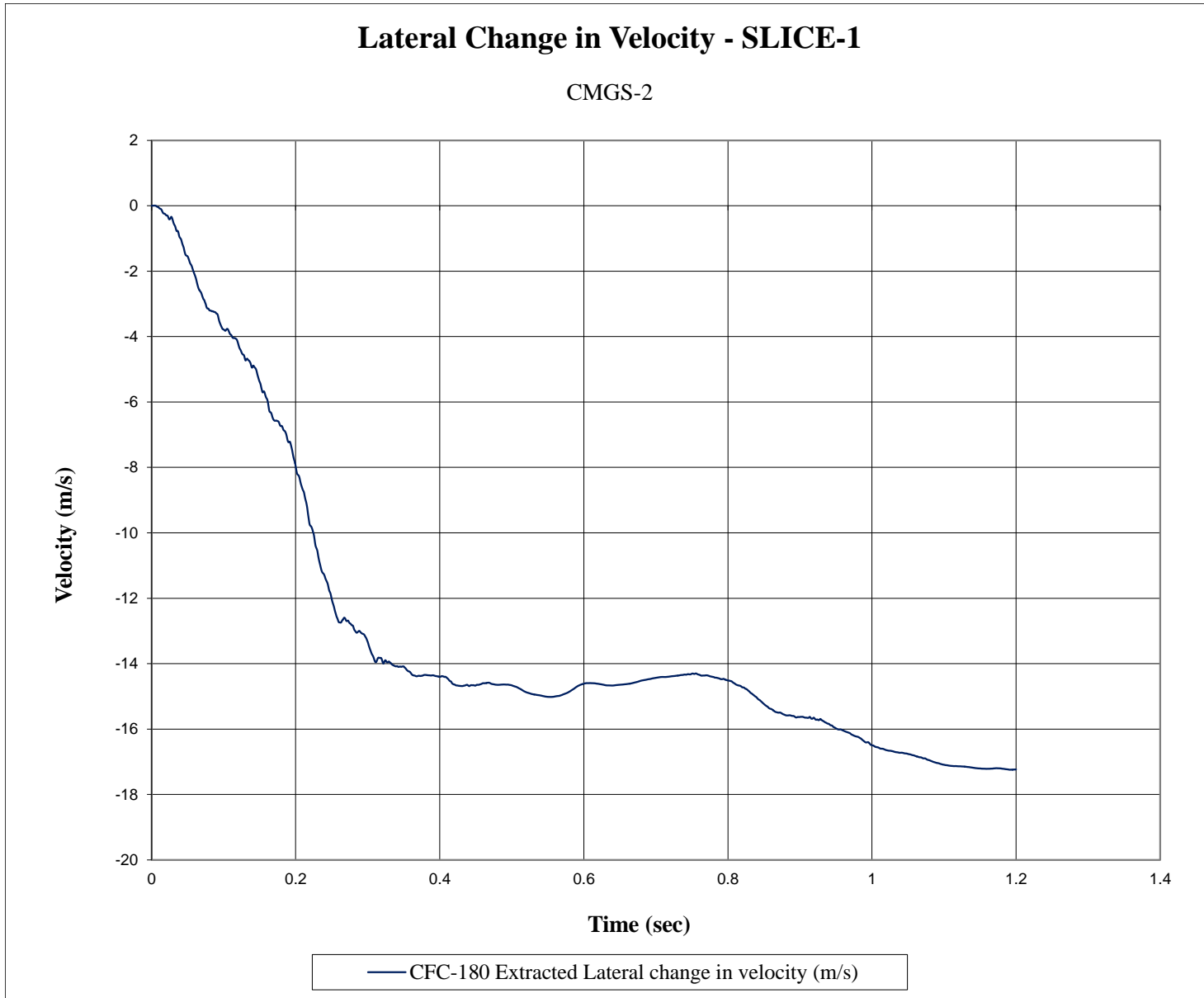


Figure F-13. Lateral Change in Velocity (SLICE-1), Test No. CMGS-2

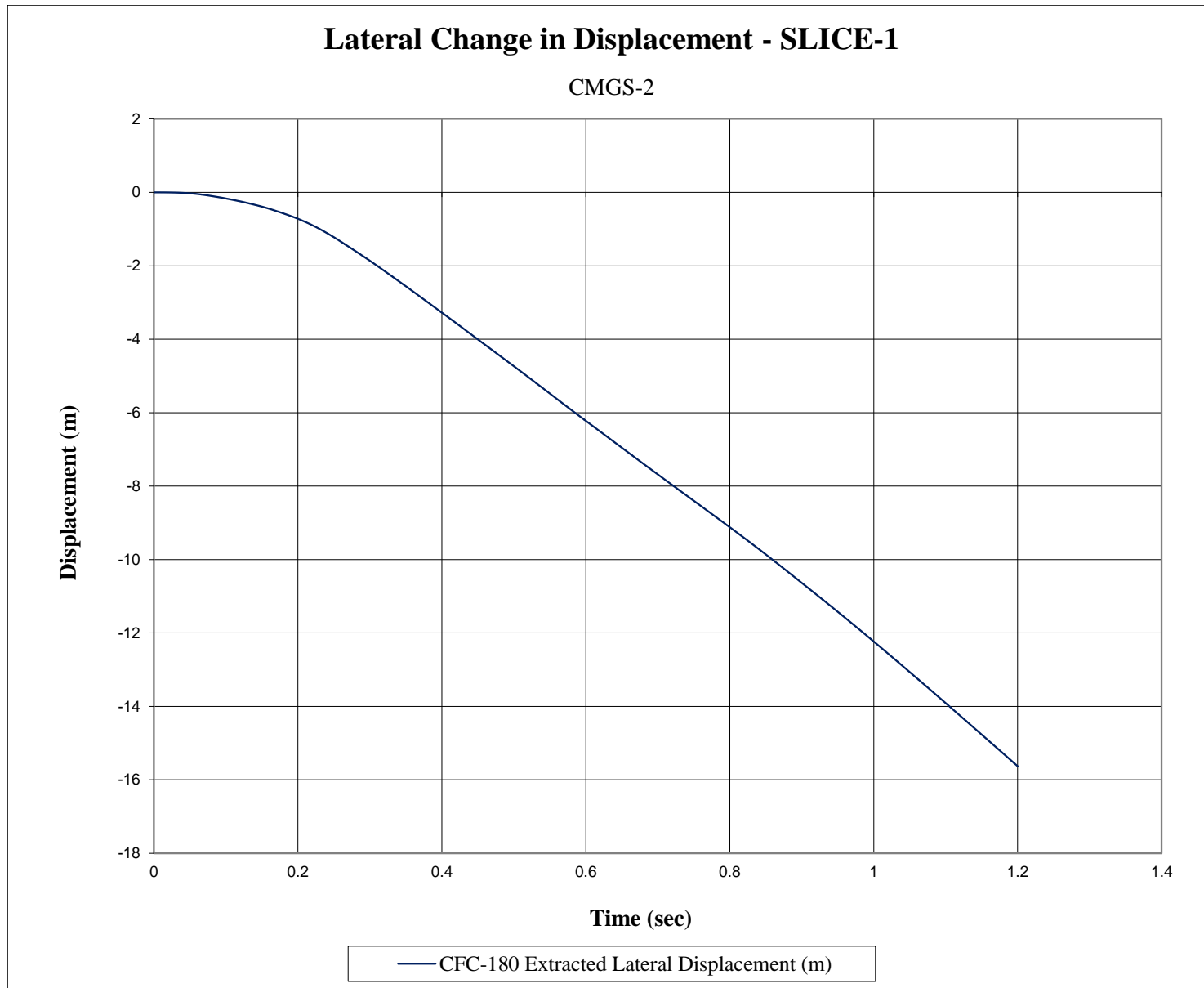


Figure F-14. Lateral Change in Displacement (SLICE-1), Test No. CMGS-2

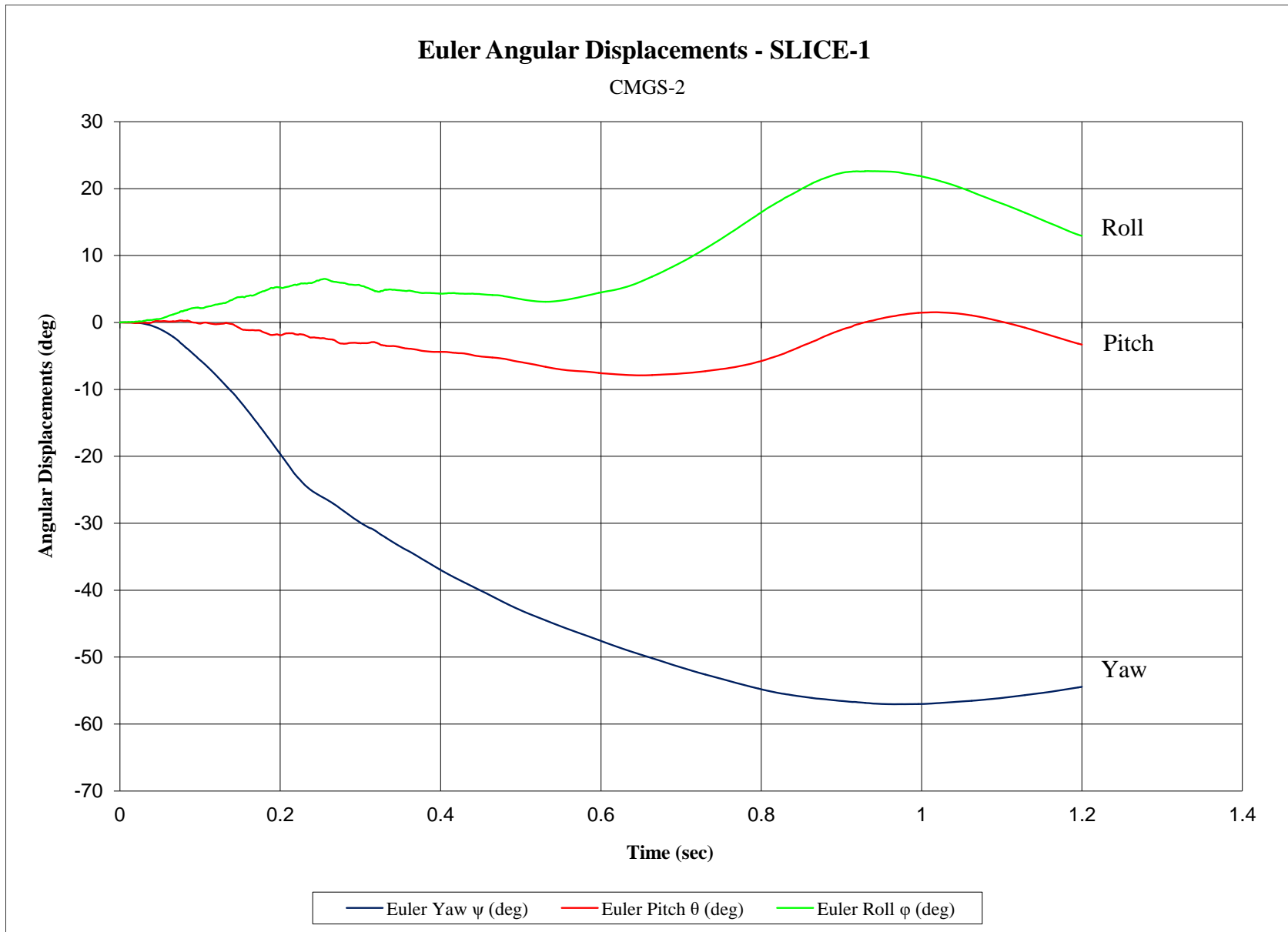


Figure F-15. Vehicle Angular Displacements (SLICE-1), Test No. CMGS-2

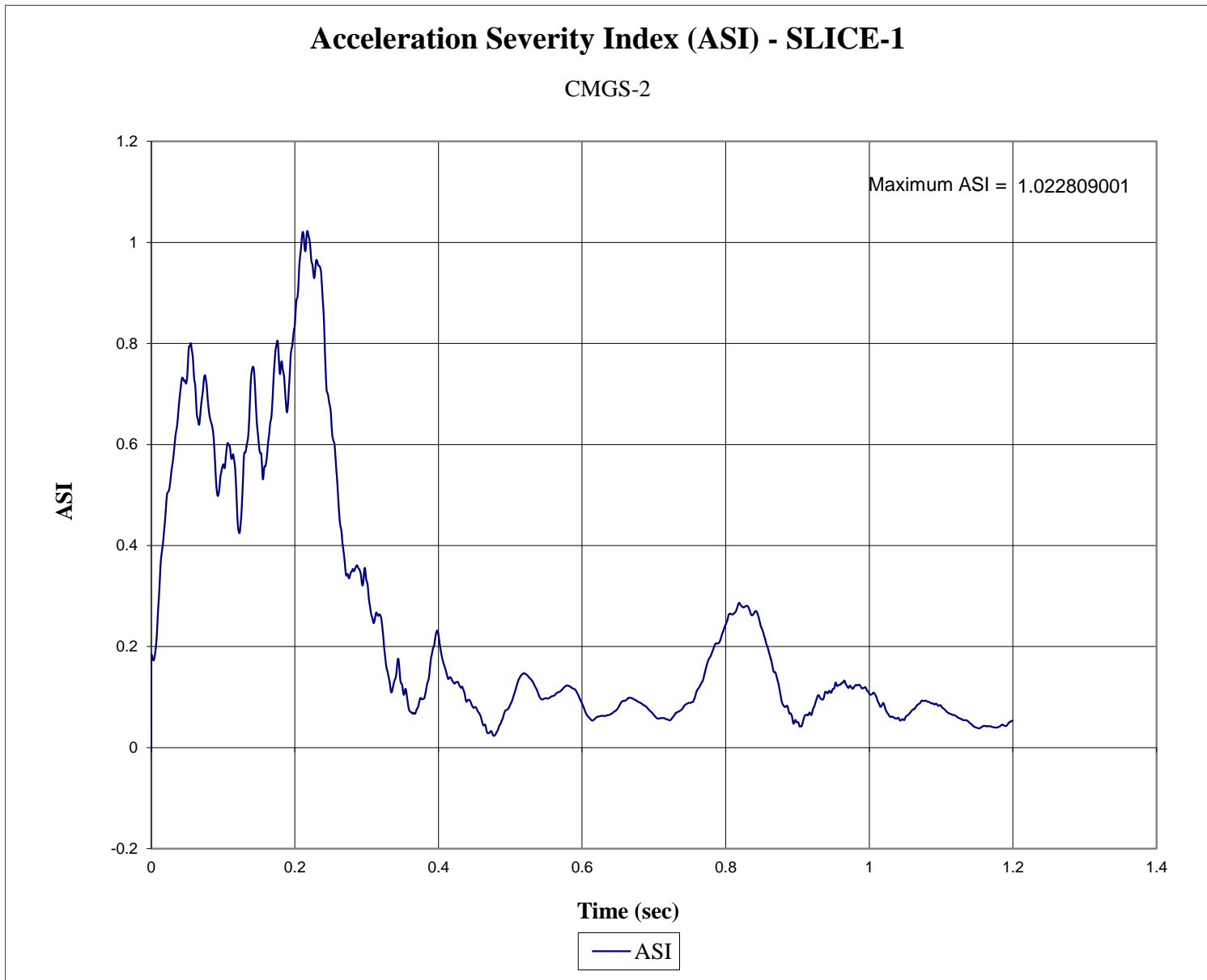


Figure F-16. Acceleration Severity Index (SLICE-1), Test No. CMGS-2

END OF DOCUMENT

November 2020 ADDENDUM / ERRATA

to MwRSF Report No. TRP-03-383-20

“Dynamic Testing and Evaluation of Culvert-Mounted, Strong-Post MGS to TL-3 Guidelines of
MASH 2016”

Published October 26, 2020

| <u>Page</u> | <u>Revision</u> |
|-------------|--|
| 90 | Test no. CMGS-1 impact location changed from 76 in. to 92 in. upstream from post no. 19. |
| 143 | Test no. CMGS-1 impact location changed from 76 in. to 92 in. upstream from post no. 19. |