Midwest Pooled Fund Research Program
Fiscal Years 2017-2019 (Years 27 through 29)
Research Project Number TPF-5(193) Supplement #105
NDOT Sponsoring Agency Code RPFP-17-MGS-1

MGS WITH CURB AND OMITTED POST: EVALUATION TO MASH 2016 TEST DESIGNATION NO. 3-10

Submitted by

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MwRSF Research Report No. TRP-03-393-19

April 12, 2019

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. TRP-03-393-19	2.	3. Recipient's Accession No.
4. Title and Subtitle MGS with Curb and Omitted Post: Evaluation to MASH 2016 Test Designation No. 3-10		5. Report Date April 12, 2019 6.
7. Author(s) Rosenbaugh, S.K., Stolle, C.S., and Ronspies, K.B.		8. Performing Organization Report No. TRP-03-393-19
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) Nebraska Transportation Center University of Nebraska-Lincoln Main Office: Prem S. Paul Research Center at Whittier School Room 130, 2200 Vine Street Lincoln, Nebraska 68583-0853 Outdoor Test Site: 4630 N.W. 36th Street Lincoln, Nebraska 68524		10. Project/Task/Work Unit No. 11. Contract © or Grant (G) No. TPF-5 (193) Supplement #105
12. Sponsoring Organization Name and Address Midwest Pooled Fund Program Nebraska Department of Transportation 1500 Nebraska Highway 2 Lincoln, Nebraska 68502		13. Type of Report and Period Covered Final Report: 2015 – 2019 14. Sponsoring Agency Code RPFP-17-MGS-1
15. Supplementary Notes Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration.		

16. Abstract

The use of curbs along roads is often required for certain functions such as drainage control, right-of-way reduction and sidewalk separation. However, curbs along roadways can adversely affect the interaction of errant vehicles with roadside barriers. When curbs are placed near guardrail systems, the propensity for vehicle underride, override, and instability increases. Additionally, the presence of drainage features often prevent the placement of guardrail posts, thus requiring a post to be omitted. Thus, the test installation evaluated herein consisted of the Midwest Guardrail System (MGS) placed with the front face of the guardrail located 6 in. (152 mm) behind a 6-in. (152-mm) tall, AASHTO Type B curb and one post omitted near the middle of the system, resulting in a 12.5-ft (3.8 m) span between two posts.

Test no. MGSCO-1 was conducted on standard MGS with the rail mounted 32 in. (813 mm) above the roadway. During test no. MGSCO-1, the W-beam ruptured at the splice located within the unsupported span, and the test vehicle penetrated behind the system and eventually rolled over. To strengthen the system, 37.5 ft (11.4 m) of nested rail was recommended for placement around the location of the omitted post. During test no. MGSCO-2, the vehicle was successfully contained and redirected without any evidence of rail tearing. The vehicle remained stable, and all of the vehicle decelerations met the allowable limits. Thus, test MGSCO-2 passed the safety criteria of MASH 2016 test designation no. 3-10. Additional testing according to MASH 2016 test designation no. 3-11 is recommended to complete the MASH 2016 testing matrix prior to the implementation of the system on roadways.

17. Document Analysis/Descriptors Highway Safety, Crash Test, Roadside Appurtenances, Compliance Test, MASH 2016, Test Level 3, Curb, Guardrail, Omitted Post, Nested W-Beam, MGS		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 185	22. Price

DISCLAIMER STATEMENT

This report was completed with funding from the Federal Highway Administration, U.S. Department of Transportation and the Midwest Pooled Fund Program. The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the state highway departments participating in the Midwest Pooled Fund Program nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

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

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Jennifer Schmidt, Research Assistant Professor.

ACKNOWLEDGMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) the Midwest Pooled Fund Program funded by the California Department of Transportation, Florida Department of Transportation, Illinois Department of Transportation, Indiana Department of Transportation, Iowa Department of Transportation, Kansas Department of Transportation, Kentucky Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Nebraska Department of Transportation, New Jersey Department of Transportation, North Carolina Department of Transportation, Ohio Department of Transportation, South Carolina Department of Transportation, South Dakota Department of Transportation, Utah Department of Transportation, Virginia Department of Transportation, Wisconsin Department of Transportation, and Wyoming Department of Transportation for sponsoring this project; and (2) MwRSF personnel for constructing the barriers and conducting the crash tests.

Acknowledgement is also given to the following individuals who made a contribution to the completion of this research project.

Midwest Roadside Safety Facility
R.K. Faller, Ph.D., P.E., Research Professor & MwRSF Director
J.D. Reid, Ph.D., Professor
J.C. Holloway, M.S.C.E., E.I.T., Assistant Director –Physical Testing Division
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R.W. Bielenberg, M.S.M.E., E.I.T., Research Engineer
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Federal Highway Administration
David Mraz, Division Bridge Engineer, Nebraska Division Office

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1 INTRODUCTION

1.1 Background

The use of curbs along roads is often required for certain functions such as drainage control, right-of-way reduction and sidewalk separation. However, curbs along roadways can adversely affect the interaction of errant vehicles with roadside barriers. When curbs are placed near guardrail systems, the propensity for vehicle underride, override, and instability increases. The Midwest Guardrail System (MGS) installed behind curbs is a common hardware configuration used by state departments of transportation (DOT) that had not yet been evaluated to the *Manual for Assessing Safety Hardware* (MASH 2016) Test Level 3 (TL-3) conditions [1-2]. During the early development of the MGS, the guardrail system was successfully crash tested in combination with a curb to National Cooperative Highway Research Program (NCHRP) Report No. 350 TL-3 requirements [3-5]. The curb was placed at a 6-in. (152-mm) offset from the front face of the guardrail, as shown in Figure 1. However, only the small pickup truck test 3-11 was conducted to verify the crashworthiness of the system installed adjacent to a curb.

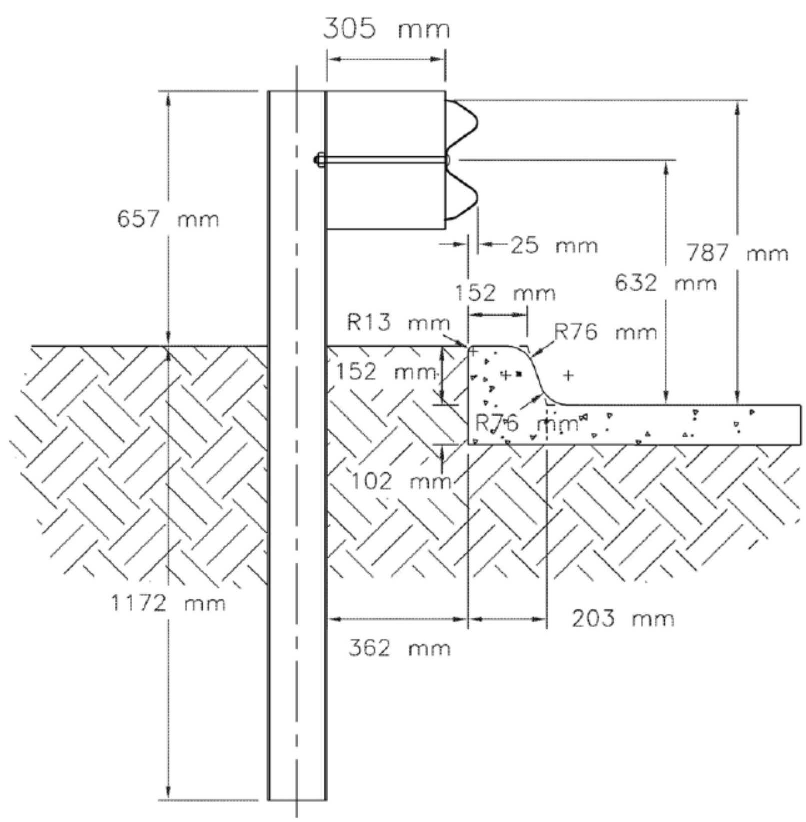


Figure 1. MGS Offset 6 in. (152 mm) from 6-in. (152-mm) AASHTO Type B Curb [3-5]

Roadside obstructions sometimes prevent proper post placement within a run of guardrail. To avoid obstacles, one approved alternative is to install a long-span system for an unsupported span up to 25 ft wide (7.6 m). However, the MGS long-span system developed at the Midwest Roadside Safety Facility (MwRSF) requires the use of three CRT posts adjacent to the unsupported span to prevent pocketing and high rail tension [6].

Previously, the MGS with an omitted post without the use of CRT posts was crash tested to MASH 2016 TL-3 test no. 3-11 and adequately redirected the 2270P pickup truck when installed on level terrain and in a tangent configuration [7]. Concerns existed that the omission of a single post within a standard length of MGS guardrail would lead to high rail loads, barrier pocketing, and vehicle instability. In order to evaluate the performance of the MGS with a single omitted post, a full-scale crash test was performed according to the TL-3 safety performance criteria defined in MASH 2016, test designation no. 3-11 [7]. Test no. MGSMP-1 consisted of a 4,934-lb (2,238-kg) pickup truck impacting the MGS with an omitted post at a speed of 63.4 mph (102.1 km/h) and an angle of 25.3 degrees. The vehicle was contained and smoothly redirected, and test no. MGSMP-1 met the MASH 2016 safety criteria.

Following the evaluation of the MGS with an omitted post, MwRSF considered the application of an omitted post when a curb was present. The MGS in combination with curbs has never been evaluated with a small car or to the safety performance criteria of MASH 2016. Recent MASH 2016 small car testing of the MGS stiffness transition with curb resulted in W-beam rail rupture due to partial vehicle underride and a vertical load being imparted to the rail [8]. An omitted post within an MGS installation with curb may cause similar results as the vehicle would be allowed to travel farther into the system and impart vertical loads to the W-beam rail and splices. There is also potential for the combination of an omitted post and curb to increase rail loading, rail pocketing, and vehicle instability when impacted with the 2270P vehicle. Therefore, the Midwest Pooled Fund member states funded a research study to evaluate the performance of the MGS installed with an omitted post and in conjunction with a 6-in. (152-mm) tall AASHTO Type B curb.

1.2 Objective

The objective of this research was to evaluate the performance of the MGS installed with the face of the rail offset 6-in. (152-mm), as measured from the face at mid-height of the 6-in. (152-mm) tall AASHTO Type B curb with a single omitted post according to MASH 2016 TL-3 safety criteria. Both MASH 2016 test designation nos. 3-10 and 3-11 were originally to be included in the evaluation. However, due to the failure observed during test no. MGSCO-1, a MASH 2016 test designation no. 3-10, the system was modified and retested to MASH 2016 test designation no. 3-10 criteria. As such, MASH 2016 test designation no. 3-11 was not conducted during this research study.

1.3 Scope

The research objective was achieved through the completion of several tasks. The MGS with a 6-in. (152-mm) offset from a 6-in. (152-mm) tall, AASHTO Type B curb was designed and drawn in CAD. Barrier VII was used to identify the critical impact point of the system based on stiffness and the likelihood for rail rupture or release. A full-scale test was conducted according to MASH 2016 test designation no. 3-10, which resulted in a failure. After the test failure, the system was redesigned by nesting the 12-gauge metric W-beam rail around the omitted post location. An additional full-scale test was conducted according to MASH 2016 test designation no. 3-10. Following the successful completion of the second test, test results were analyzed, evaluated and documented. Conclusions and recommendations were then made pertaining to the safety performance of the MGS with a curb and an omitted post.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as W-beam guardrails, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [1]. Note that there is no difference between MASH 2009 [2] and MASH 2016 for longitudinal barriers, such as the system tested in this project, except that additional occupant compartment deformation measurements 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. Note, both crash tests described herein were conducted in accordance with MASH 2016 test designation no. 3-10. Evaluation of the system according to MASH 2016 test designation no. 3-11 will need to be completed in a separate project in order to complete the testing matrix.

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

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed mph (km/h)	Angle deg.	
Longitudinal Barrier	3-10	1100C	2,420 (1,100)	62 (100)	25	A,D,F,H,I
	3-11	2270P	5,000 (2,270)	62 (100)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

It should be noted that the test matrix detailed herein represents the researchers' best engineering judgement with respect to the MASH 2016 safety requirements and their internal evaluation of critical tests necessary to evaluate the crashworthiness of the barrier system.

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 MGS installed 6 in. (152 mm) behind the face at mid-height of an AASHTO Type B curb to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH 2016. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in MASH 2016.

Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barrier

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

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

2.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH 2016, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, W6x16 (W152x23.8) posts are installed near the impact region utilizing the same installation procedures are the system itself. Prior to full-scale testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips (33.4 kN) at post deflections between 5 and 20 in. (127 and 508 mm) measured at a height of 25 in. (635 mm). If dynamic testing near the system is not desired, MASH 2016 permits a static test to be conducted 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 – TEST NO. MGSCO-1

The test installation consisted of 12-gauge (2.7-mm) AASHTO M180 standard W-beam guardrail, W6x8.5 steel posts with timber blockouts, and MGS end anchorages. The total system length was 182 ft – 3½ in. (55.6 m). The system was installed with the face of the guardrail located 6 in. (152 mm) behind the face of a 6-in. (152-mm) tall AASHTO Type B curb at mid-height, as shown in Figures 2 through 14. Photographs of the test installation are shown Figures 15 and 16. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The test installation was constructed using twenty-eight guardrail posts. Post nos. 3 through 26 were standard 72-in. (1,829-mm) long W6x8.5, ASTM A992 steel guardrail posts. Post nos. 3-26 were each embedded to a depth of 45 in. (1,143 mm), and post nos. 1, 2, 27, and 28 were embedded to a depth of 39 in. (991 mm). All posts were embedded in well-graded gravel (GW) and were spaced 75 in. (1,905 mm) on center. One post was omitted between post nos. 13 and 14, which created an unsupported span length of 150 in. (3,810 mm) between these posts. Timber blockouts measuring 6 in. x 12 in. x 14¼ in. long (152 mm x 305 mm x 362 mm) were used to block the rail away from the front face of each steel post. The W-beam guardrail was mounted with a top-rail height of 32 in. (813 mm) measured from the surface of the roadway. The system was raised 1 in. (25 mm) from its nominal 31-in. (787-mm) rail height to evaluate the potential of the small car to extend under the rail under standard construction tolerances. Splice joints, which were oriented to prevent vehicle snag, were used between posts to connect the guardrail where necessary, as shown in Figure 4.

A 6-in. (152-mm) tall, AASHTO Type B curb spanned from post nos. 9 through 19. The curb was located 6 in. (152 mm) in front of the face of the rail, as measured from the face of curb at mid-height. Soil was backfilled behind the curb flush to the top surface of the curb. The soil backfill extended a minimum of 5 ft (1.5 m) behind the curb. A replica concrete gutter was created by casting a 4-in. (102-mm) deep by 48-in. (1,219-mm) wide concrete slab in front of the curb. The concrete used to cast the curb and gutter had a minimum compressive strength of 4,000 psi (27.6 MPa). The curb was reinforced by a single no. 4 rebar extending longitudinally.

The upstream and downstream ends of the guardrail installation were configured with a non-proprietary end anchorage system [9-12]. The guardrail anchorage system had a comparable strength to other crashworthy end terminals. The anchorage system consisted of timber posts, foundation tubes, anchor cables, bearing plates, rail brackets, and channel struts.

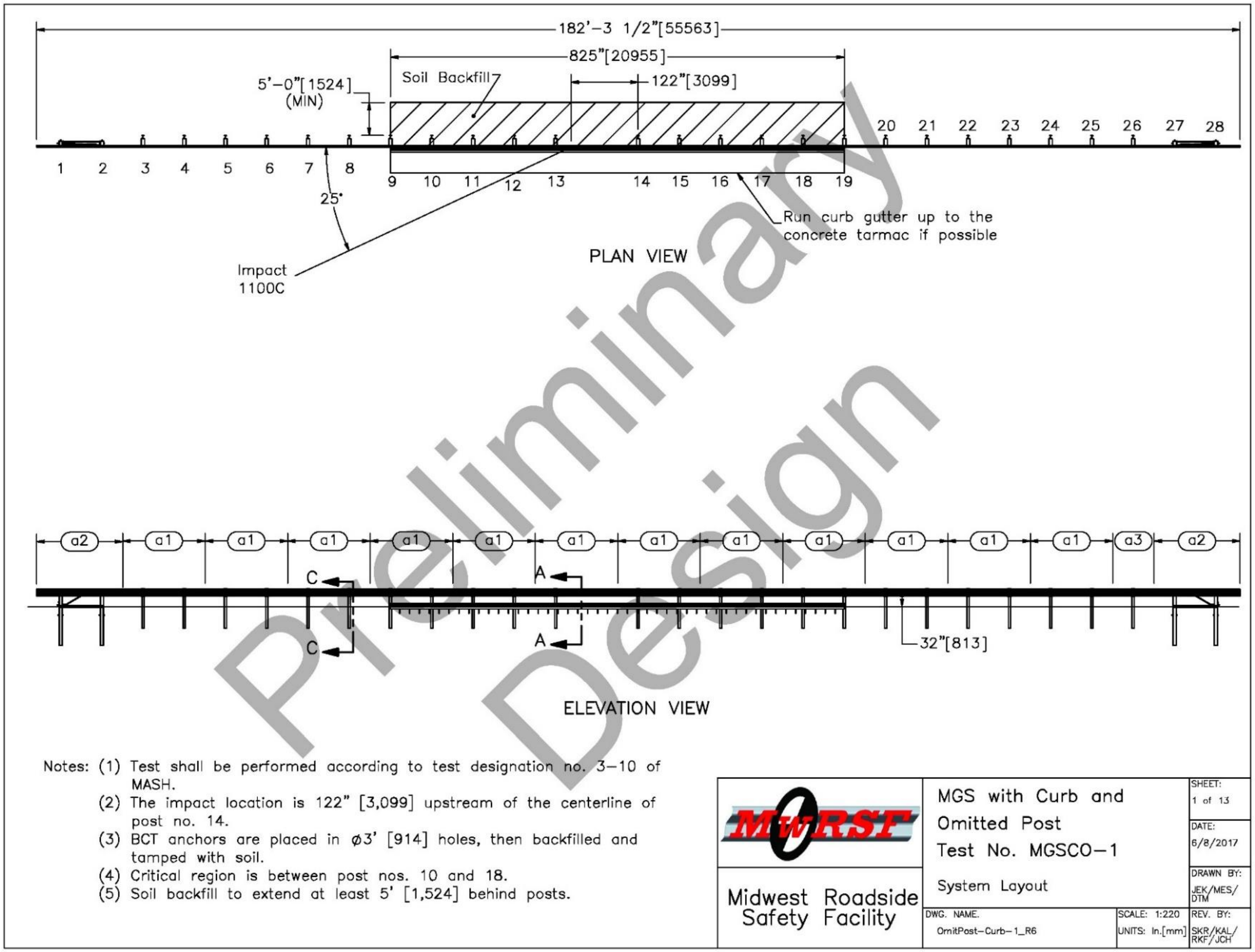


Figure 2. System Layout, Test No. MGSCO-1

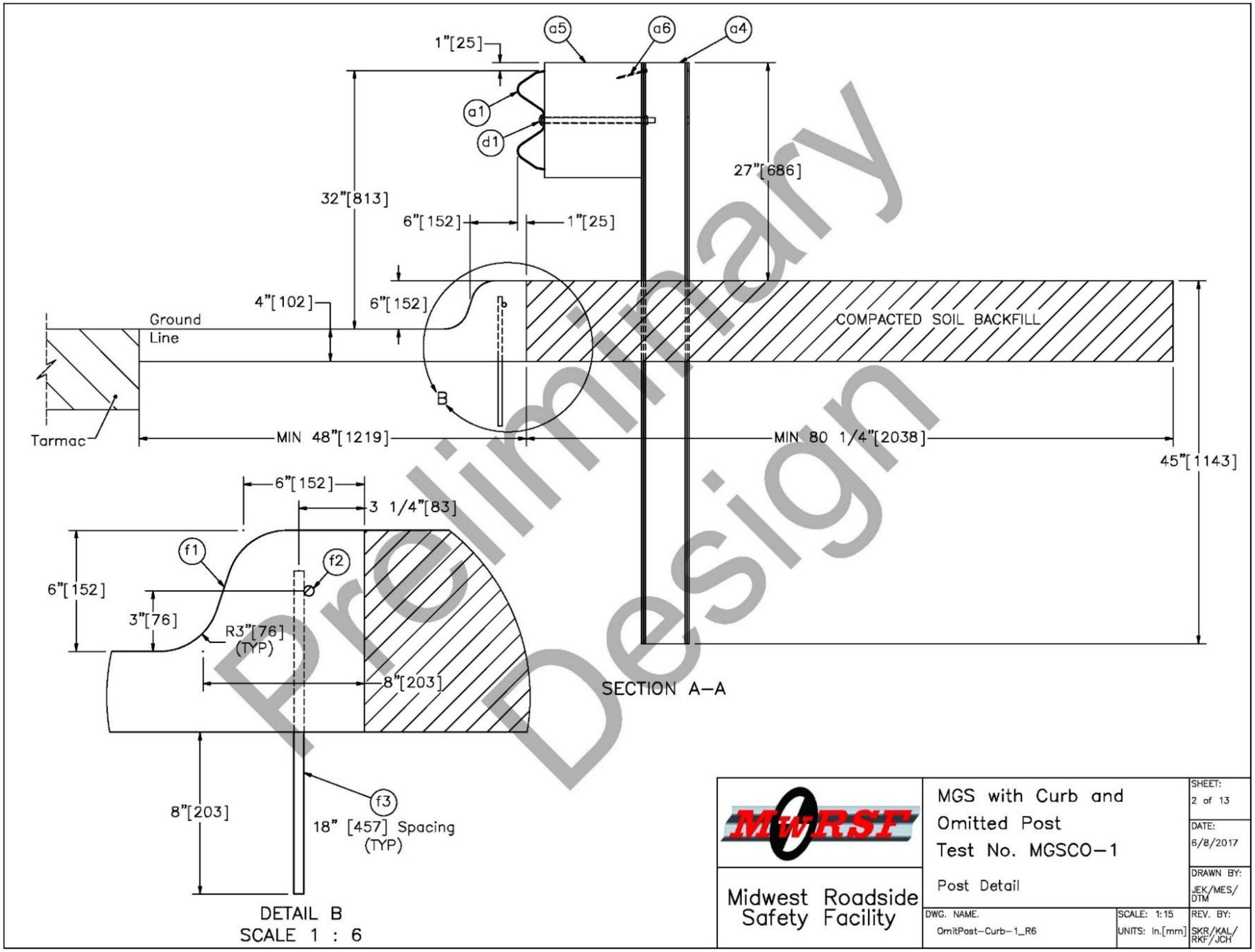


Figure 3. System Profile, Curb Geometry, and Reinforcement Details, Test No. MGSCO-1

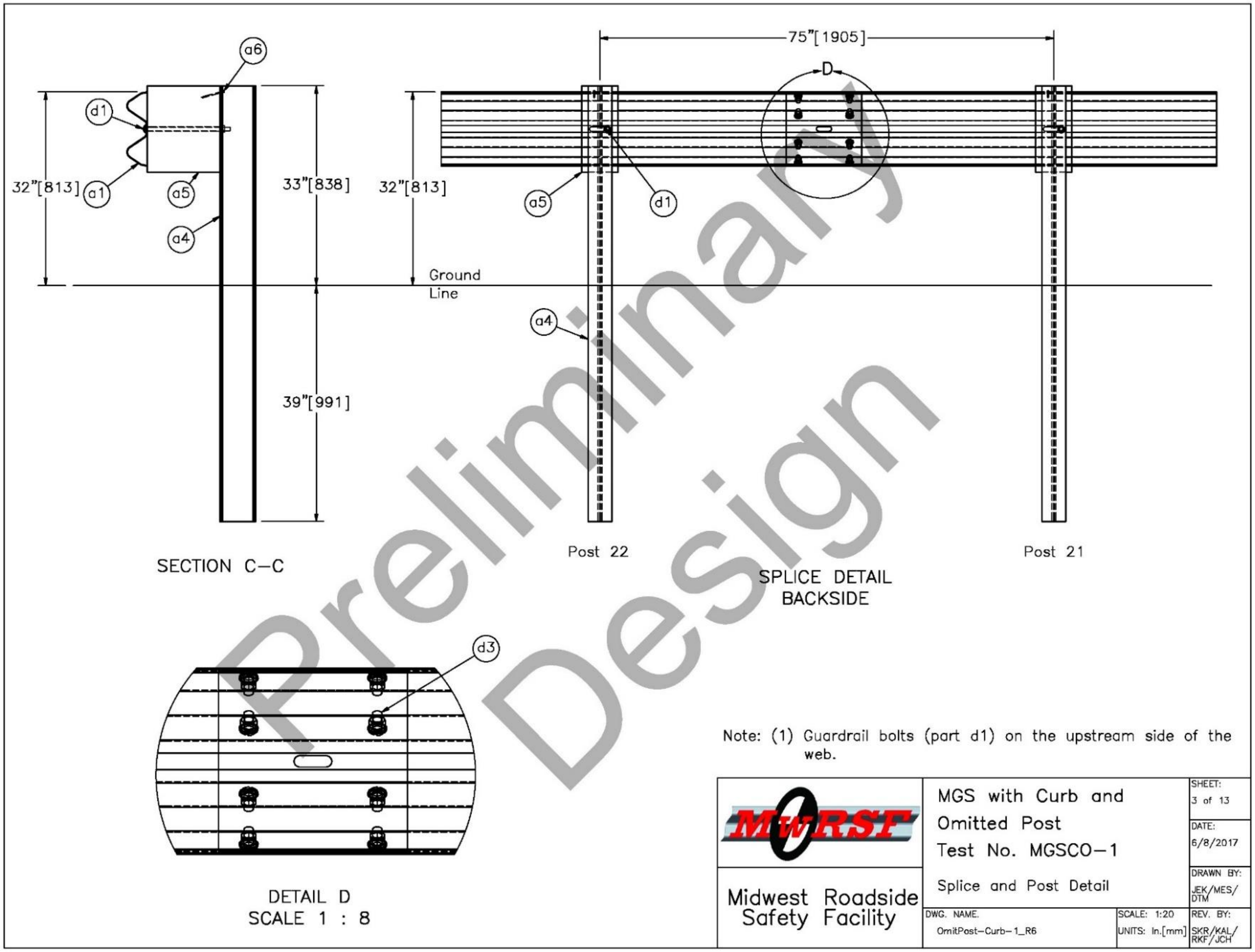


Figure 4. Splice and Post Detail, Test No. MGSCO-1

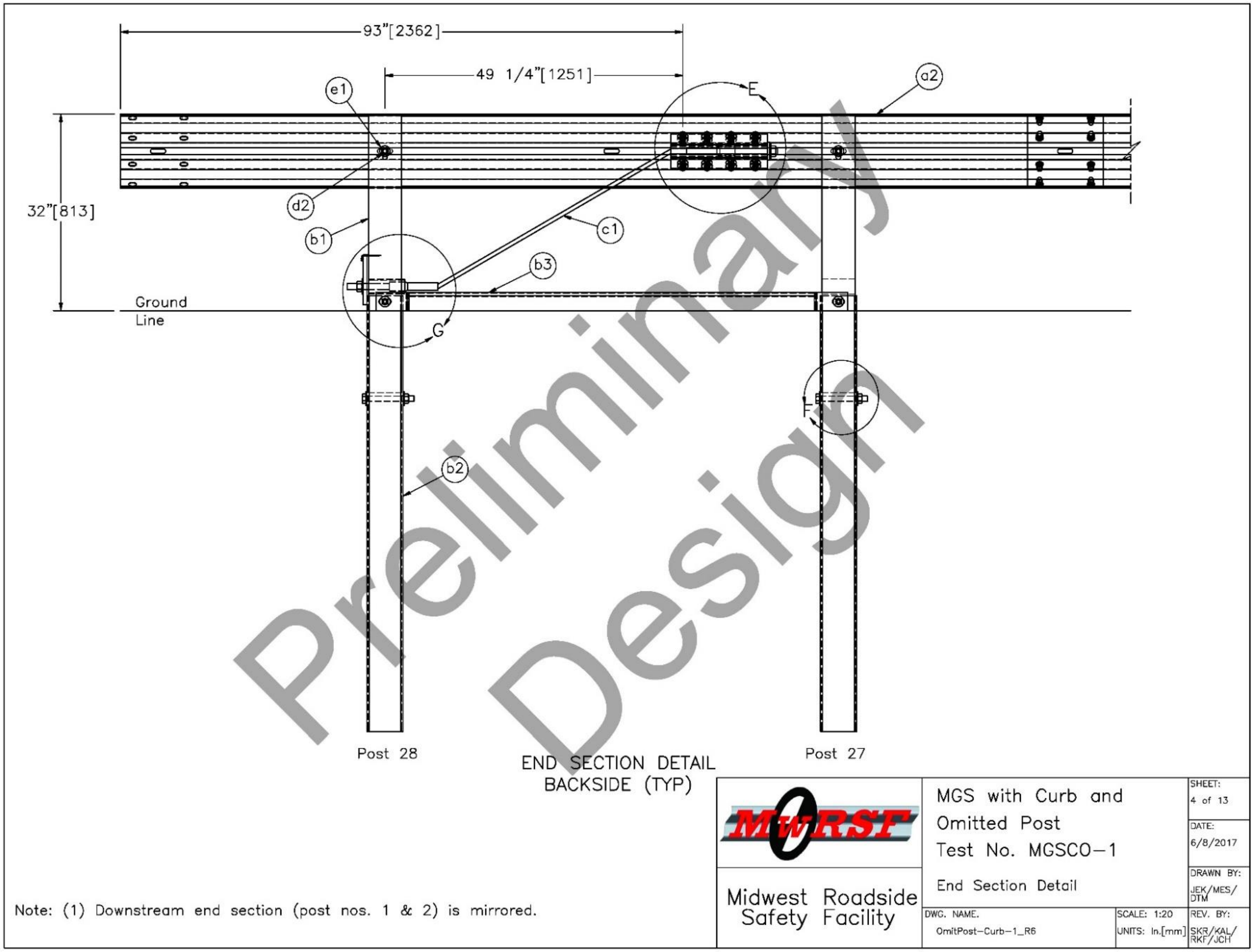


Figure 5. End Anchorage Detail, Test No. MGSCO-1

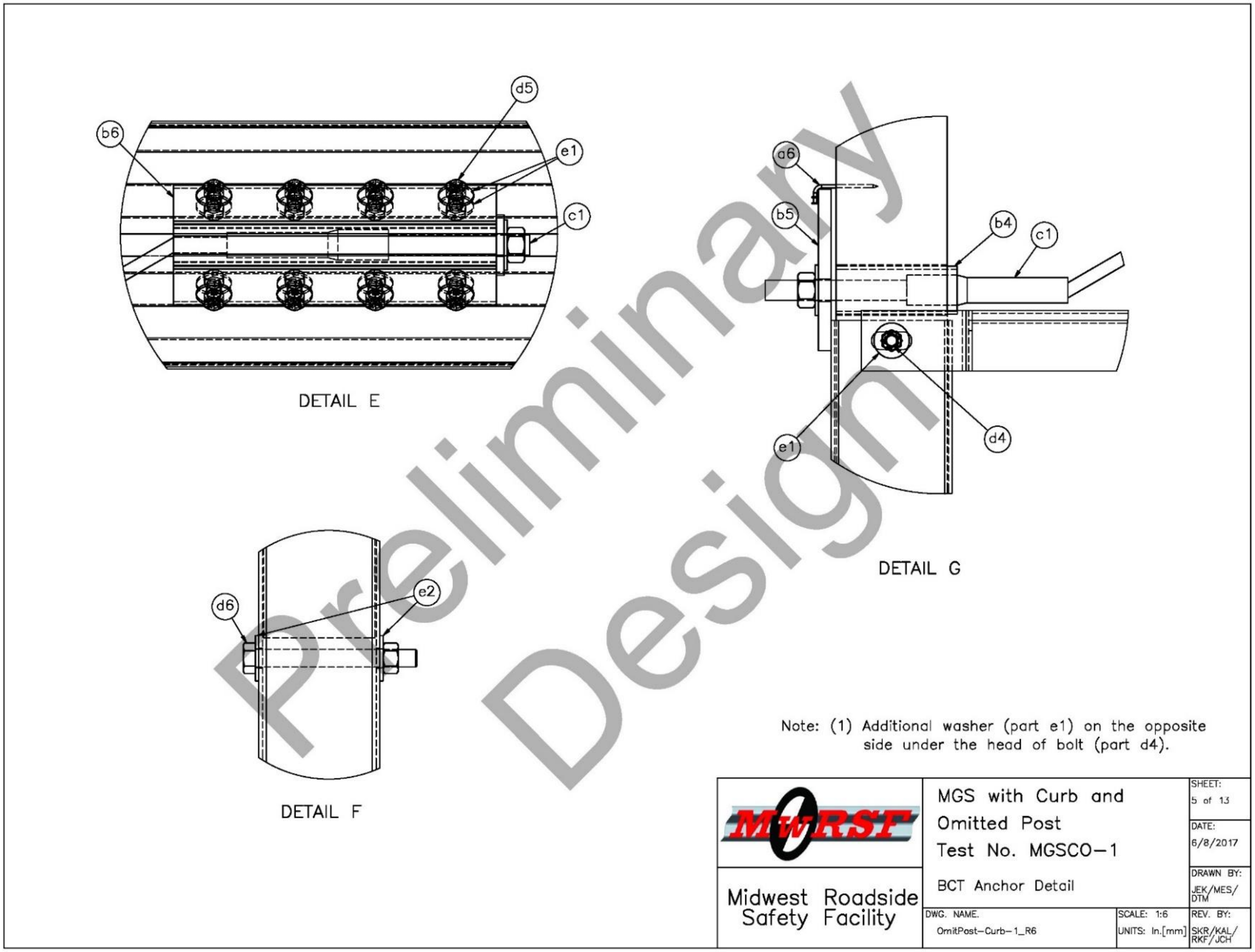


Figure 6. MGS End Anchorage Detail, Test No. MGSCO-1

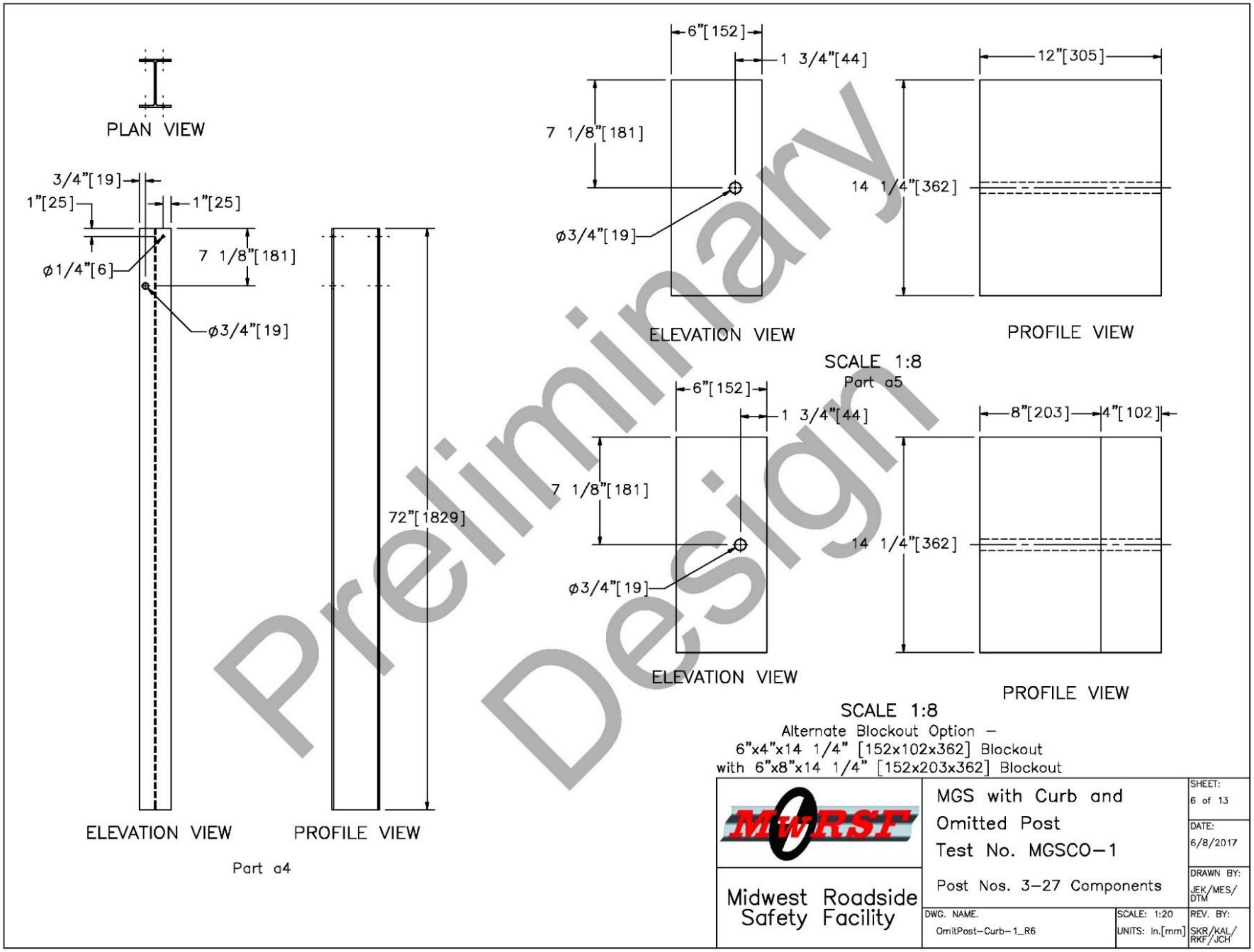


Figure 7. Post Nos. 3 through 27 Component Details, Test No. MGSCO-1

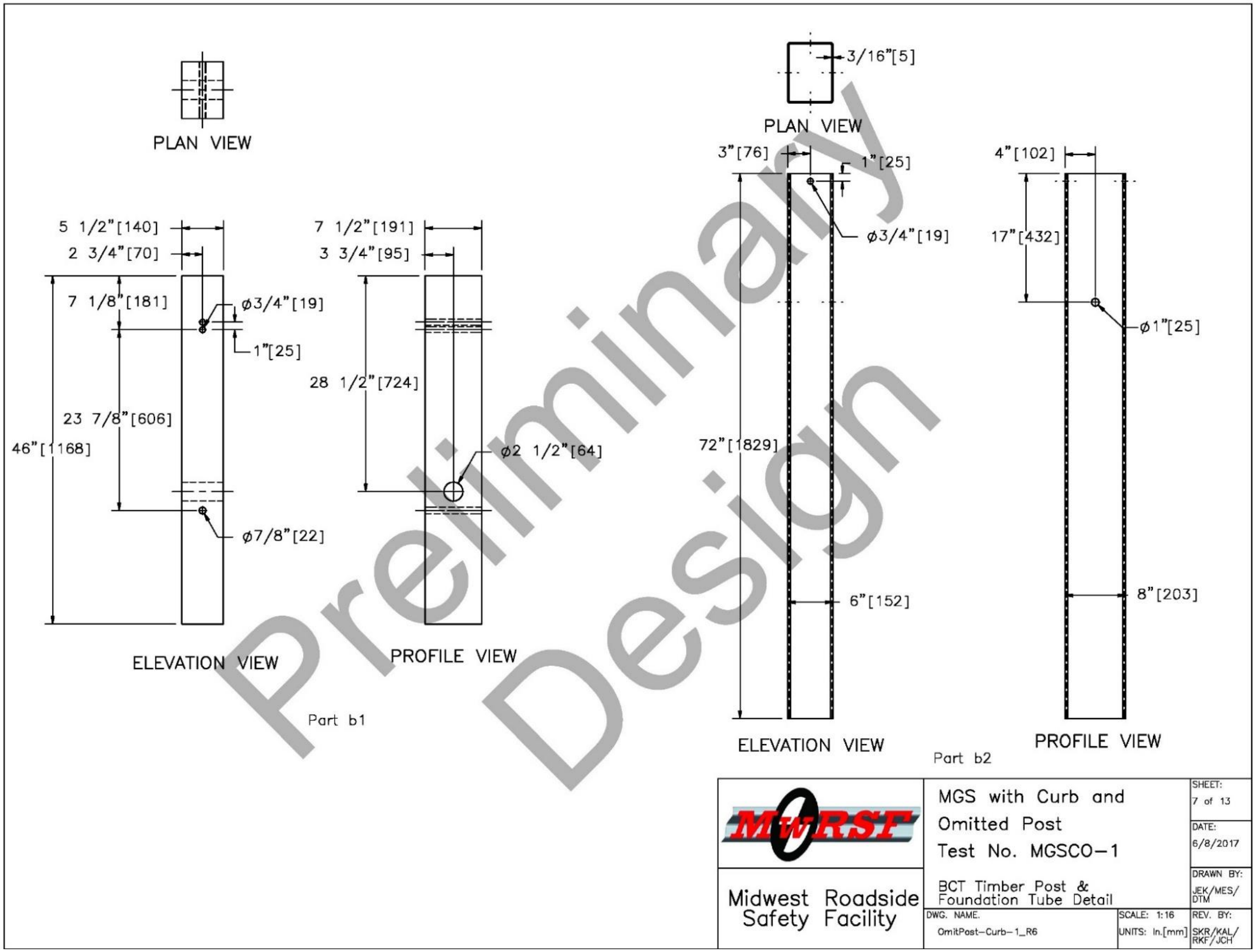


Figure 8. MGS BCT Timber Post and Foundation Tube Detail, Test No. MGSCO-1

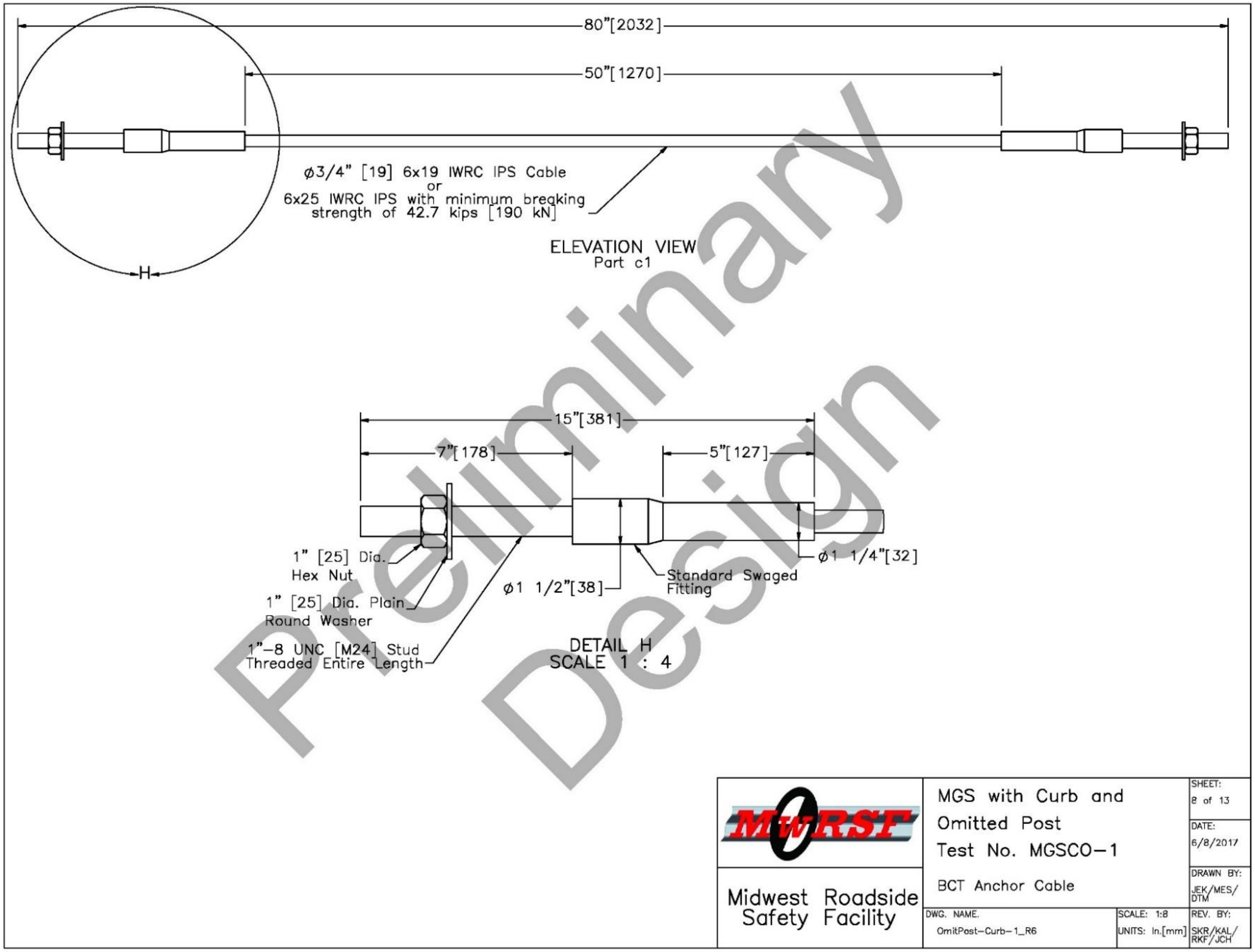


Figure 9. MGS BCT Anchor Cable, Test No. MGSCO-1

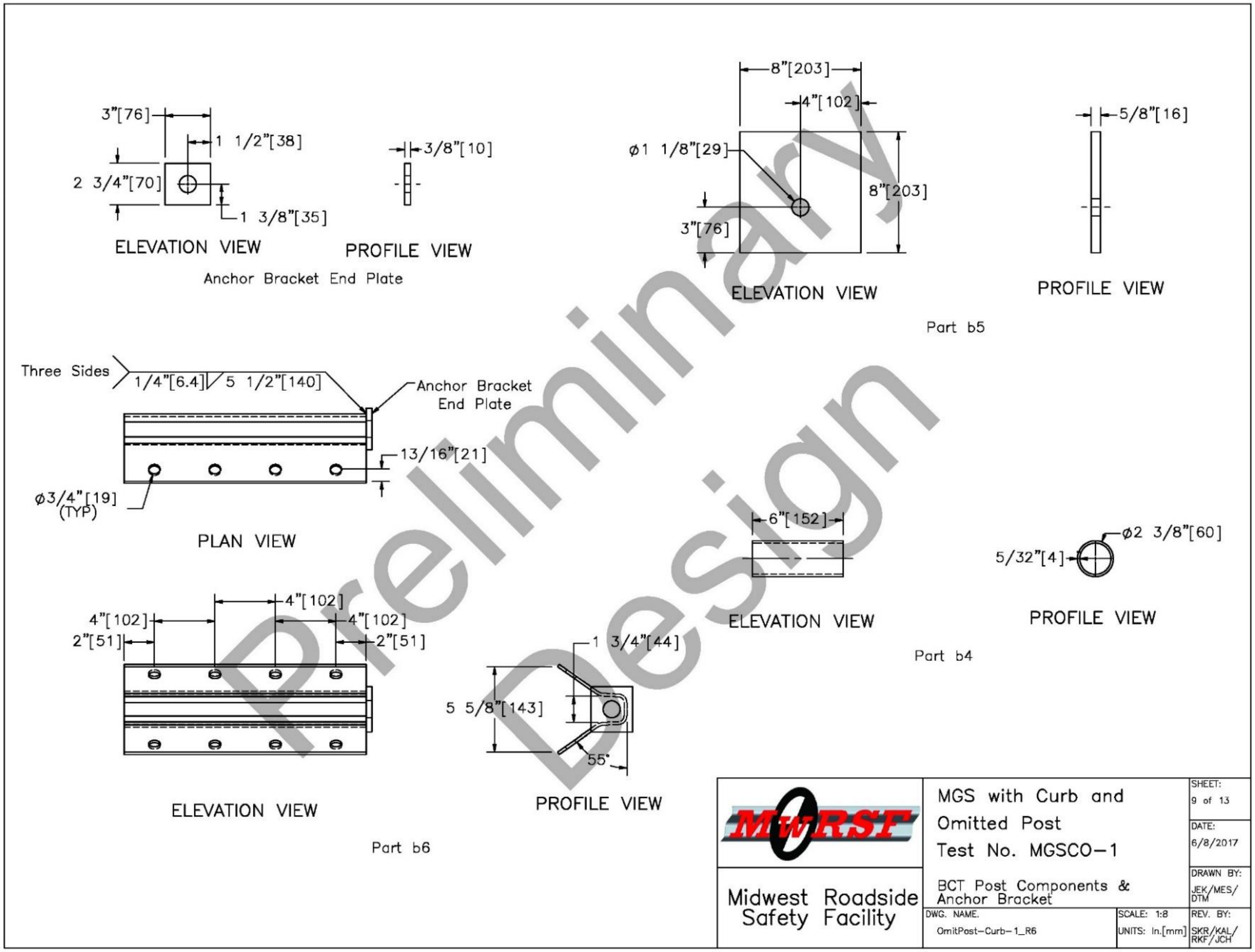


Figure 10. MGS BCT Post Components and Anchor Bracket, Test No. MGSCO-1

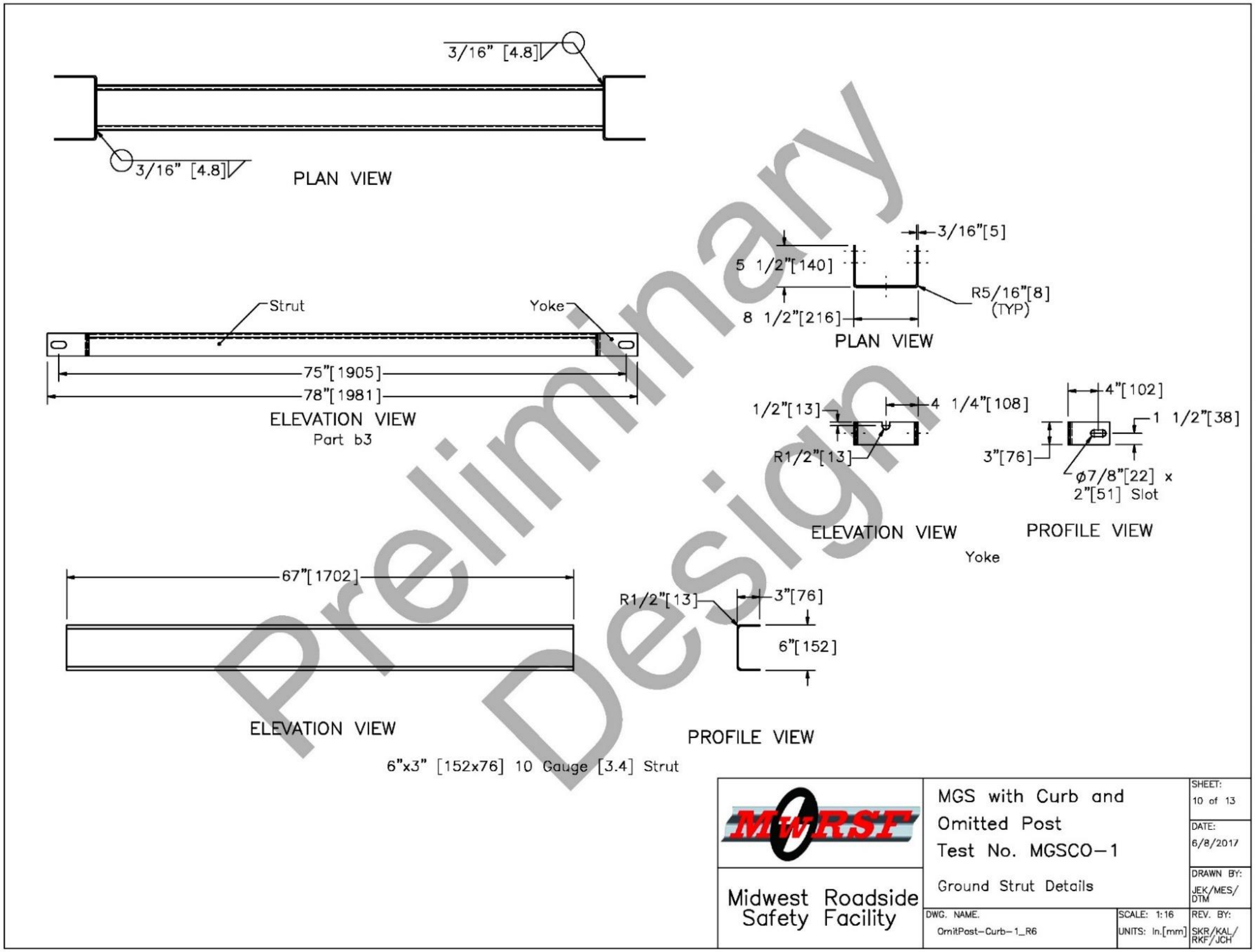


Figure 11. Groundline Strut Details, Test No. MGSCO-1

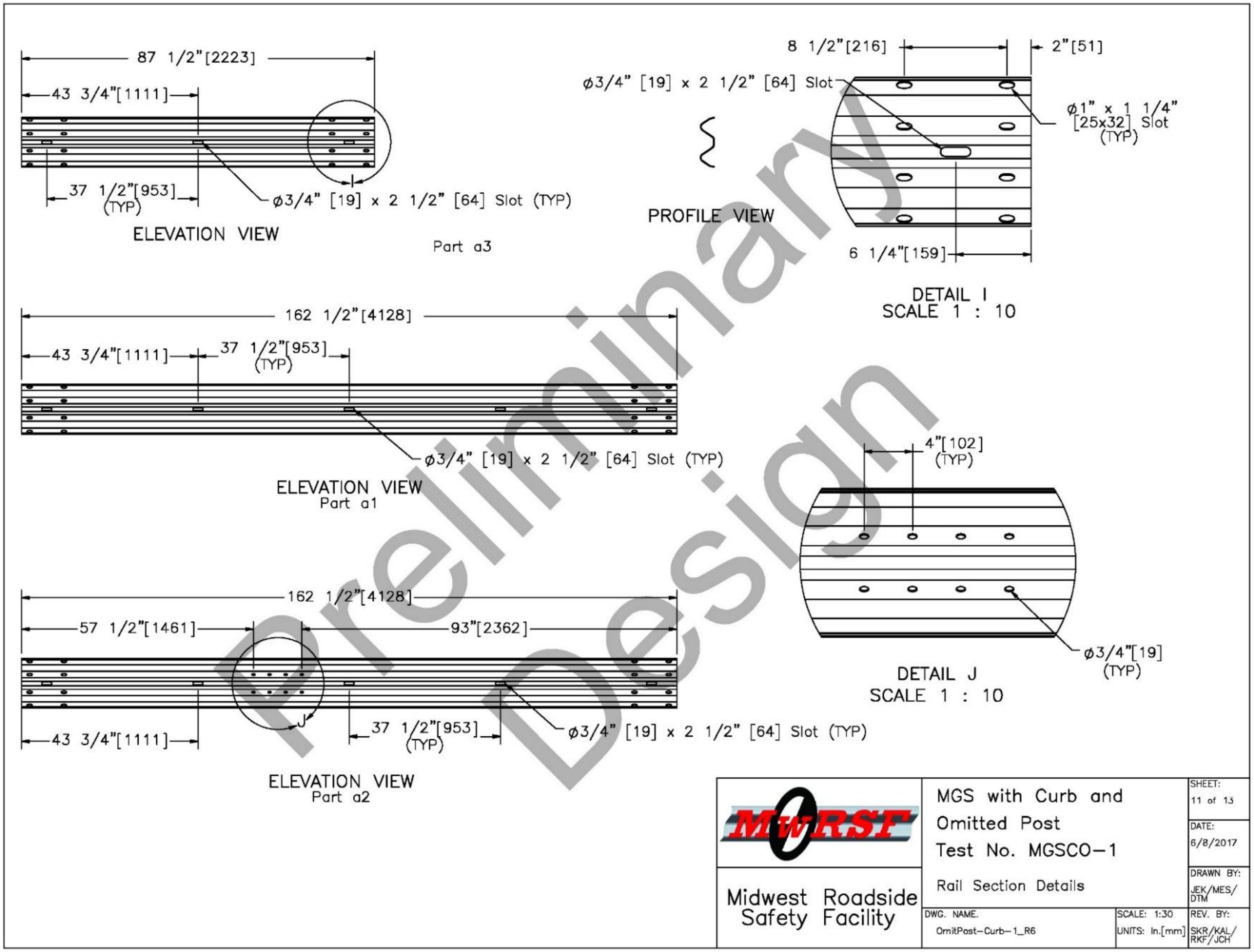


Figure 12. Rail Details, Test No. MGSCO-1

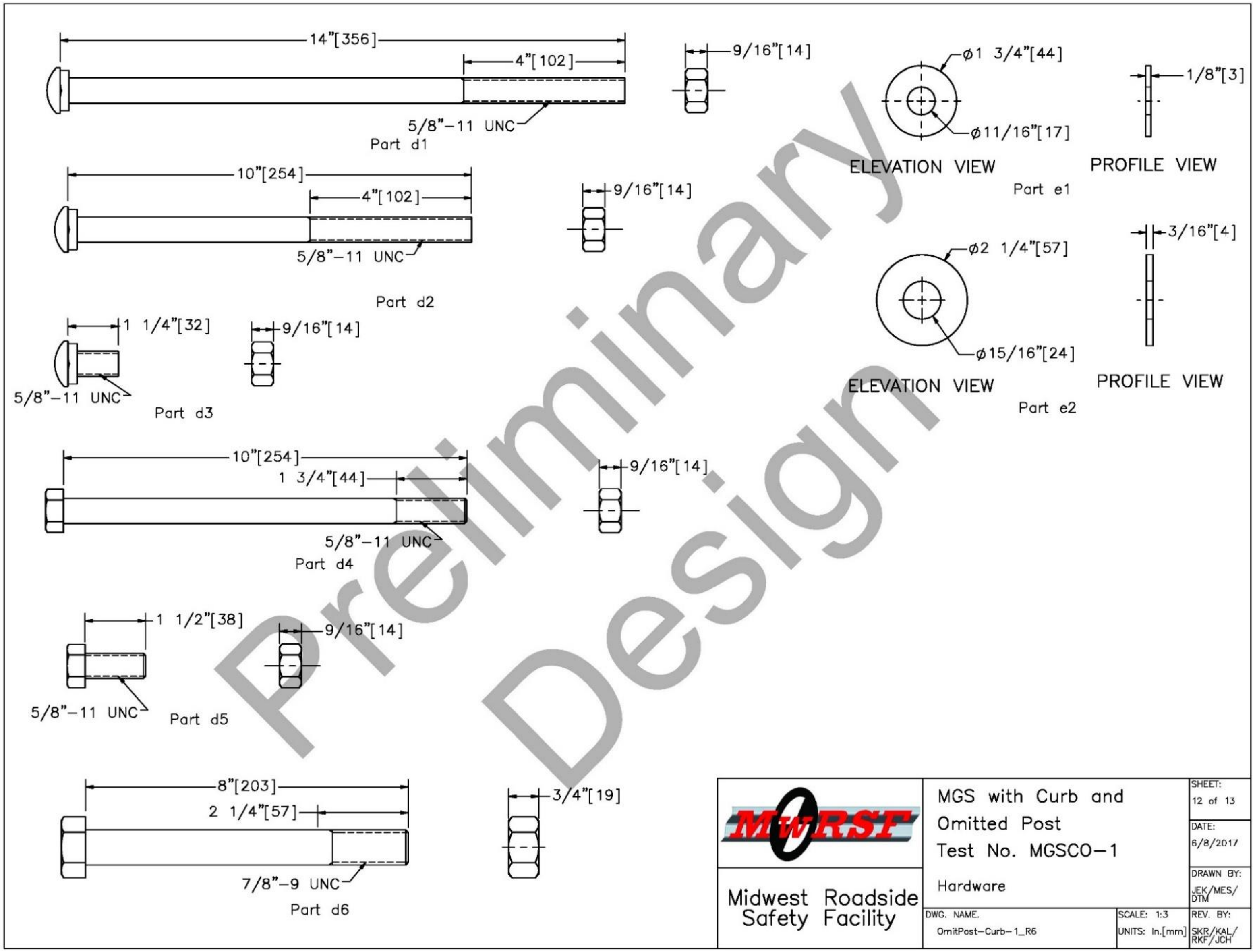


Figure 13. Attachment and Connection Hardware, Test No. MGSCO-1

Item No.	QTY.	Description	Material Spec	Galvanization Spec	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
a4	24	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa]	ASTM A123	PWE06
a5	24	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–	PDB10a
a6	26	16D Double Head Nail	–	–	–
b1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face)	–	PDF01
b2	4	72" [1829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123	PTE06
b3	2	Ground Strut Assembly	ASTM A36	ASTM A123	PFP02
b4	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	FMM02
b5	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
b6	2	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
c1	2	BCT Anchor Cable	–	–	FCA01
d1	24	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
d2	4	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB03
d3	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
d4	4	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
d5	16	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
d6	4	7/8" [22] Dia. UNC, 8" [203] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	–
e1	44	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
e2	8	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
f1	1	Curb	f'c = 4,000 psi [27.6 MPa]	–	–
f2	1	#4 Rebar 819" [20,803] Long	ASTM A615 Gr. 60	–	–
f3	45	#4 Rebar 16" [406] Long	ASTM A615 Gr. 60	–	–

MwRSF

Midwest Roadside Safety Facility

MGS with Curb and Omitted Post

Test No. MGSCO–1

Bill of Materials

SHEET: 13 of 13

DATE: 6/8/2017

DRAWN BY: JEK/MES/DTM

DWG. NAME. OmitPost–Curb–1_R6

SCALE: None

UNITS: In.[mm]

REV. BY: SKR/KAL/RKF/JCH

Figure 14. Bill of Materials, Test No. MGSCO-1

Figure 15. Test Installation Photographs, Test No. MGSCO-1

Figure 16. Test Installation Photographs, Test No. MGSCO-1

4 TEST CONDITIONS

4.1 Test Facility

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

4.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [13] 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 ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, 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. MGSCO-1, 2009 Hyundai Accent was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,458 lb (1,115 kg), 2,438 lb (1,106 kg), and 2,604 lb (1,181 kg), respectively. The test vehicle is shown in Figure 17, and vehicle dimensions are shown in Figure 18. Pre-test photographs of the vehicle’s interior floorboards and undercarriage for test no. MGSCO-1 are not available.

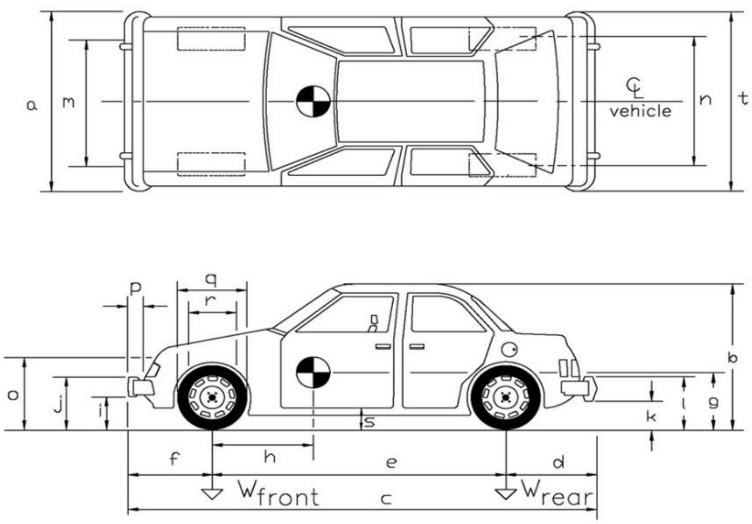
For test no. MGSCO-2, a 2011 Hyundai Accent was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,440 lb (1,107 kg), 2,404 lb (1,090 kg), and 2,566 lb (1,164 kg), respectively. The test vehicle is shown in Figures 19 and 20, and vehicle dimensions are shown in Figure 21.

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 [14]. The location of the final c.g. for test no. MGSCO-1 is shown in Figures 18 and 22. The location of the final c.g. for test no. MGSCO-2 is shown in Figures 21 and 23. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 22 and 23. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

Figure 17. Test Vehicle, Test No. MGSCO-1

Date:	8/28/2017	Test Number:	MGSCO-1	VIN:	KMHCN4AC1AU480683
Year:	2009	Make:	Hyundai	Model:	Accent
Tire Size:	185/65 R14	Tire Inflation Pressure:	32 Psi	Odometer:	125370



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

a: 64 7/8 (1648) 65±3 (1650±75)	b: 58 (1473)		
c: 168 1/4 (4274) 169±8 (4300±200)	d: 35 3/4 (908)		
e: 98 7/8 (2511) 98±5 (2500±125)	f: 33 5/8 (854) 35±4 (900±100)		
g: 22 7/8 (581)	h: 37 1/16 (941) 39±4 (990±100)		
i: 16 1/2 (419)	j: 20 3/4 (527)		
k: 16 1/4 (413)	l: 20 3/4 (527)		
m: 56 1/2 (1435) 56±2 (1425±50)	n: 57 1/8 (1451) 56±2 (1425±50)		
o: 28 (711) 24±4 (600±100)	p: 2 (51)		
q: 24 1/8 (613)	r: 15 3/8 (391)		
s: 12 1/8 (308)	t: 64 3/4 (1645)		

Mass Distribution lb (kg)

Gross Static	LF	820 (372)	RF	795 (361)
	LR	515 (234)	RR	474 (215)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	1560 (708)	1524 (691)	1615 (733)
W-rear	898 (407)	914 (415)	989 (449)
W-total	2458 (1115)	2438 (1106) 2420±55 (1100±25)	2604 (1181) 2585±55 (1175±50)

Top of radiator core support:	29 1/2 (749)
Wheel Center Height (Front):	10 3/4 (273)
Wheel Center Height (Rear):	11 (279)
Wheel Well Clearance (Front):	25 7/8 (657)
Wheel Well Clearance (Rear):	25 (633)
Bottom Frame Height (Front):	8 3/8 (213)
Bottom Frame Height (Rear):	7 1/4 (184)
Engine Type:	Gasoline
Engine Size:	1.6L
Transmission Type:	Automatic
Drive Type:	FWD

GVWR Ratings lb

Front:	1918
Rear:	1874
Total:	3638

Dummy Data

Type:	Hybrid II
Mass:	166 lb
Seat Position:	Driver

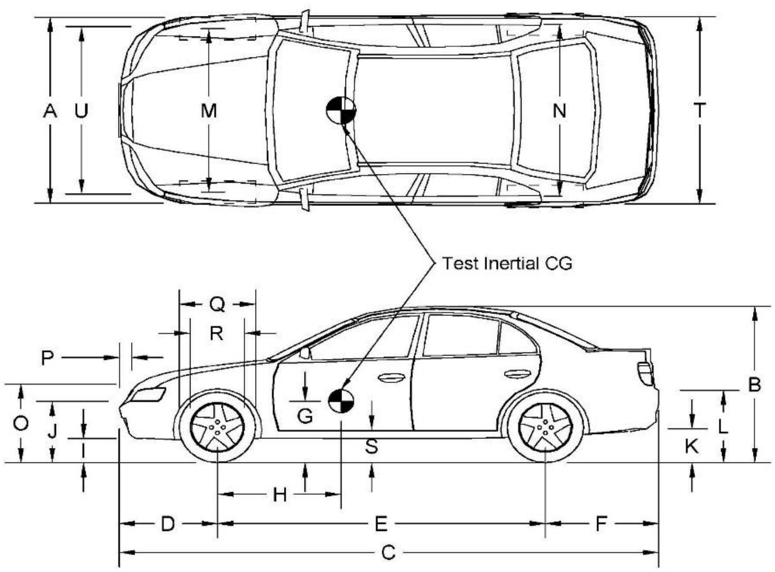
Note any damage prior to test: NONE

Figure 18. Vehicle Dimensions, Test No. MGSCO-1

Figure 19. Test Vehicle, Test No. MGSCO-2

Figure 20. Test Vehicle’s Undercarriage and Interior Floorboards, Test No. MGSCO-2

Date:	2/6/2018	Test Name:	MGSCO-2	VIN No:	KMHCN4AC1BU614772
Year:	2011	Make:	Hyundai	Model:	Accent
Tire Size:	P185/65 R14	Tire Inflation Pressure:	32 Psi	Odometer:	126220



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

A:	65 1/4 (1657) 65±3 (1650±75)	B:	58 (1473)
C:	168 1/4 (4274) 169±8 (4300±200)	D:	33 1/4 (845) 35±4 (900±100)
E:	98 1/2 (2502) 98±5 (2500±125)	F:	37 1/4 (946)
G:	22 13/16 (579)	H:	35 5/8 (905) 39±4 (990±100)
I:	8 1/2 (216)	J:	23 1/2 (597)
K:	12 (305)	L:	23 (584)
M:	58 1/8 (1476) 56±2 (1425±50)	N:	57 1/2 (1461) 56±2 (1425±50)
O:	27 5/8 (702) 24±4 (600±100)	P:	2 3/4 (70)
Q:	24 (610)	R:	15 1/2 (394)
S:	12 (305)	T:	64 (1626)

U (impact width):	58 (1473)
Top of radiator core support:	28 3/4 (730)
Wheel Center Height (Front):	10 7/8 (276)
Wheel Center Height (Rear):	11 1/4 (286)
Wheel Well Clearance (Front):	24 7/8 (632)
Wheel Well Clearance (Rear):	24 7/8 (632)
Bottom Frame Height (Front):	6 (152)
Bottom Frame Height (Rear):	16 (406)
Engine Type:	Gasoline
Engine Size:	1.6L
Transmission Type:	Automatic
Drive Type:	FWD

Mass Distribution lb. (kg)

Gross Static				
LF	834 (378)	RF	782 (355)
LR	478 (217)	RR	472 (214)

Weights lb. (kg)	Curb	Test Inertial	Gross Static
W-front	1567 (711)	1535 (696)	1616 (733)
W-rear	873 (396)	869 (394)	950 (431)
W-total	2440 (1107)	2404 (1090) 2420±55 (1100±25)	2566 (1164) 2585±55 (1175±50)

GVWR Ratings lb.

Front	1918
Rear	1874
Total	3638

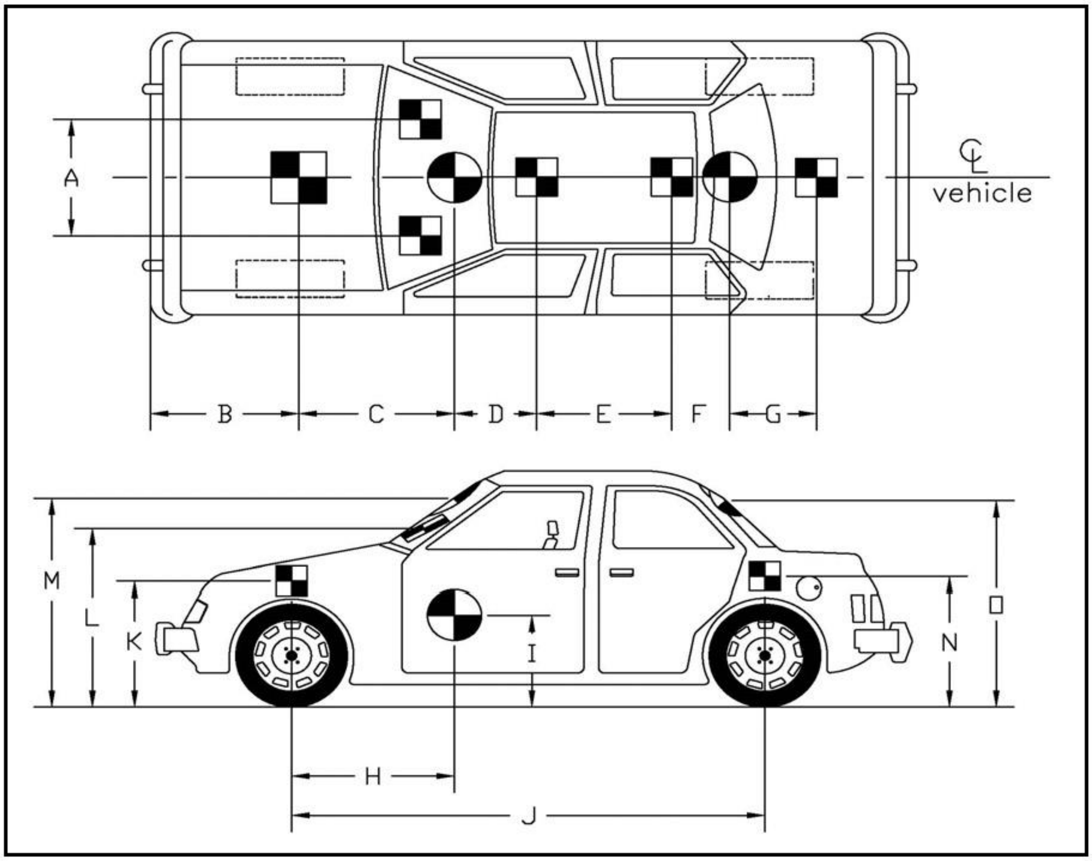
Surrogate Occupant Data

Type:	Hybrid II
Mass:	161 lbs.
Seat Position:	Left

Note any damage prior to test: None

Figure 21. Vehicle Dimensions, Test No. MGSCO-2

Date:	8/28/2017	Test Name:	MGSCO-1	VIN:	KMHCN4AC1AU480683
Year:	2009	Make:	Hyundai	Model:	Accent

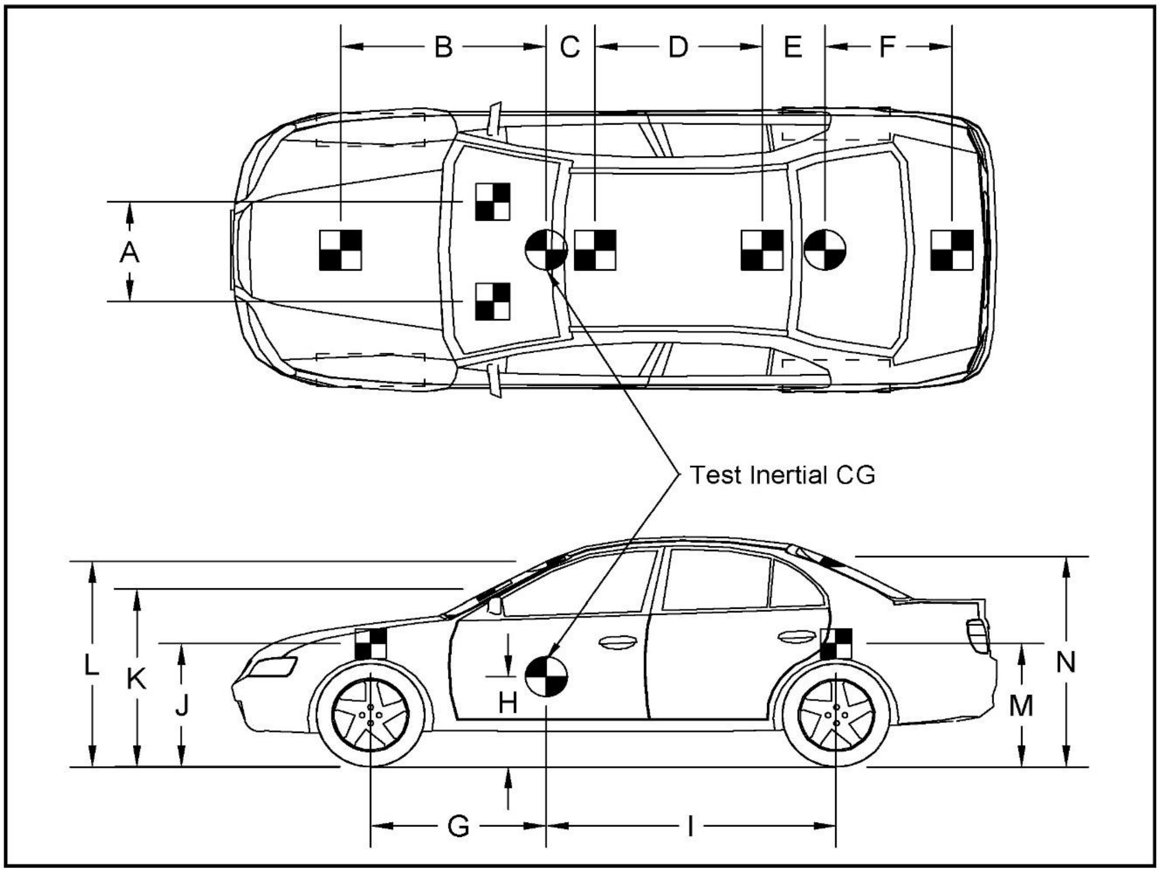


TARGET GEOMETRY - in. (mm)

A	23 4/7	(598)	F	18 3/4	(476)	K	29 3/4	(756)
B	19 1/2	(495)	G	23 7/8	(606)	L	49 3/8	(1254)
C	49 1/2	(1257)	H	37	(938)	M	52 7/8	(1343)
D	11 1/2	(292)	I	22 7/8	(581)	N	29	(737)
E	31 1/2	(800)	J	98 1/3	(2497)	O	53 1/4	(1353)

Figure 22. Target Geometry, Test No. MGSCO-1

Date:	2/2/2018	**Test Name:**	MGSCO-2	**VIN:**	KMHCN4AC1BU614772
Year:	2011	**Make:**	Hyundai	**Model:**	Accent



TARGET GEOMETRY-- in. (mm)

A:	16	(406)	**F:**	23	(584)	**K:**	47 1/4 Windshield Target	(1200)
B:	42 3/4	(1086)	**G:**	35 5/8	(905)	**L:**	51 3/4 Front round CG target	(1314)
C:	11	(279)	**H:**	22 3/4	(578)	**M:**	29	(737)
D:	38	(965)	**I:**	62 7/8	(1597)	**N:**	51 3/4 Rear Round target	(1314)
E:	17 3/4	(451)	**J:**	28 7/8	(733)			

Figure 23. Target Geometry, Test No. MGSCO-2

The front wheels of the test vehicles were aligned to vehicle standards except the toe-in value was adjusted to zero such that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted to the dashes of both vehicles. Each bulb 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 vehicles so the vehicles could be brought safely to a stop after the test.

4.4 Simulated Occupant

For test nos. MGSCO-1 and MGSCO-2, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the left-front seat of the test vehicles with the seat belt fastened. The dummy, which had a weight of 166 lb (75 kg) and 161 lb (73 kg) for test nos. MGSCO-1 and MGSCO-2, respectively, was manufactured by Android Systems of Carson, California. As recommended by MASH 2016, the dummy was not included in calculating the c.g. location.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometers systems were mounted near the c.g. of the test vehicles. 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 [15].

The SLICE-1 and SLICE-2 units were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SLICE-1 unit was designated as the primary system for test no. MGSCO-1, and the SLICE-2 unit was designated as the primary system for test no. MGSCO-2. 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.

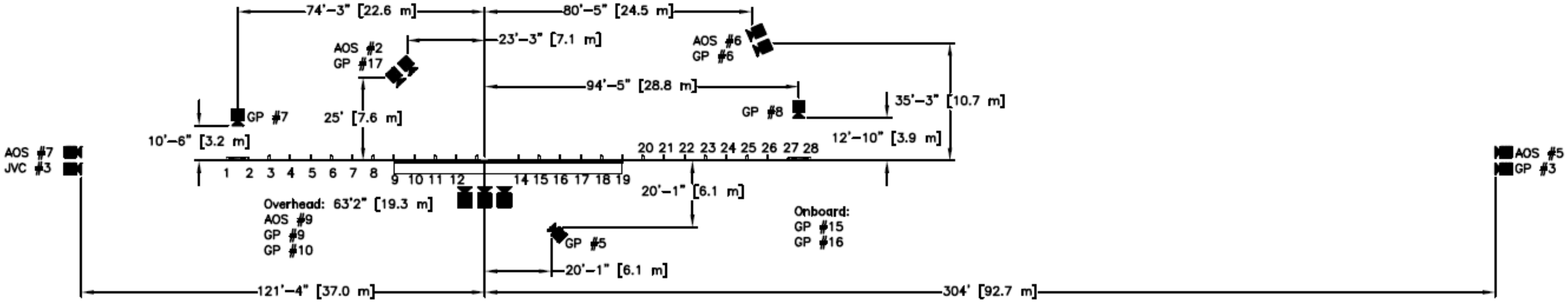
4.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the test vehicles before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the vehicles. 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

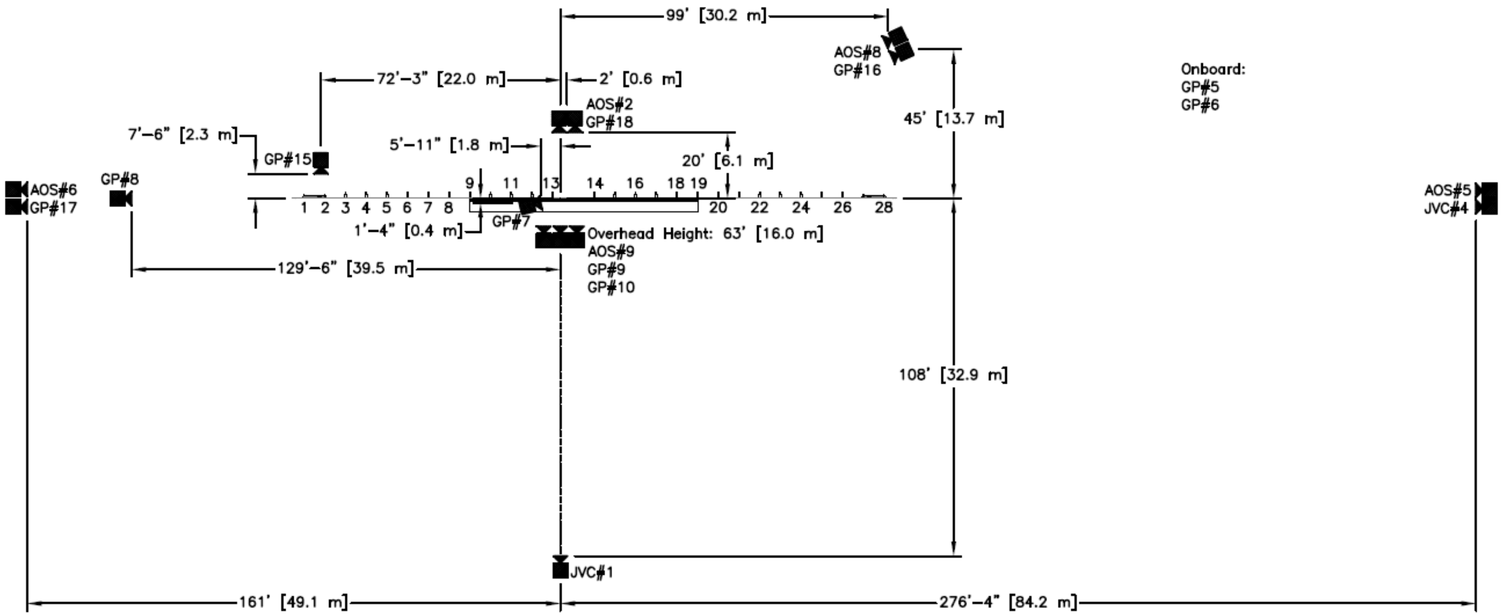
Five AOS high-speed digital video cameras, ten GoPro digital video cameras, and one JVC digital video camera were utilized to film test no. MGSCO-1. Five AOS high-speed digital video cameras, ten GoPro digital video cameras, and two JVC digital video cameras were utilized to film test no. MGSCO-2.Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figures 24 and 25.

The high-speed 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 Nikon digital still camera was also used to document pre- and post-test conditions for both tests.



No.	Type	Operating Speed (frames/sec)	Lens
AOS-2	AOS Vitcam	500	KOWA 25 mm Fixed
AOS-5	AOS X-PRI	500	VIVITAR 135 mm Fixed
AOS-6	AOS X-PRI	500	FUJINON 35 mm Fixed
AOS-7	AOS X-PRI	500	FUJINON 50 mm Fixed
AOS-9	AOS TRI-VIT 2236	500	KOWA 12 mm Fixed
GP-3	GoPro Hero 3	60	
GP-5	GoPro Hero 3+	120	
GP-6	GoPro Hero 3+	120	
GP-7	GoPro Hero 4	240	
GP-8	GoPro Hero 4	240	
GP-9	GoPro Hero 4	120	
GP-10	GoPro Hero 4	240	
GP-15	GoPro Hero 4	120	
GP-16	GoPro Hero 4	120	
GP-17	GoPro Hero 4	240	
JVC-3	JVC – GZ-MG27u (Everio)	29.97	

Figure 24. Camera Locations, Speeds, and Lens Settings, Test No. MGSCO-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam CTM	500	KOWA 16 mm	
AOS-5	AOS X-PRI Gigabit	500	TELESAR 135 mm	
AOS-6	AOS X-PRI Gigabit	500	FUJINON 50 mm	
AOS-8	AOS S-VIT 1531	500	SIGMA 28-70 DG	70
AOS-9	AOS TRI-VIT	1000	KOWA 12 mm	
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
GP-15	GoPro Hero 4	120		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	120		
GP-18	GoPro Hero 4	120		
JVC-1	JVC – GZ-MC500 (Everio)	29		
JVC-4	JVC – GZ-MG27u (Everio)	29		

Figure 25. Camera Locations, Speeds, and Lens Settings, Test No. MGSCO-2

5 FULL-SCALE CRASH TEST NO. MGSCO-1

5.1 Selection of the Critical Impact Point

The BARRIER VII computer program [16] was utilized to select the critical impact point for the test, as recommended in Section 2.3.1 of MASH 2016. An MGS model with a single omitted post and the same length as the test installation was created and validated against test no. MGSMP-1, which was the full-scale test previously conducted on the MGS with an omitted post [7]. After the model was validated, the strength of the posts were increased to reflect the increased embedment depth and decreased effective rail height caused by the soil backfill behind the curb of the test installation described herein. Impacts were then simulated on the MGS with curb and omitted post model according to the impact conditions of MASH 2016 test designation no. 3-10, an 1100C small car impacting at 62 mph (100 km/hr) and 25 degrees. Simulated impacts were conducted at 9.375-in. (238-mm) intervals along the length of the barrier system. The results of this analysis are shown in Table 3 where the impact point is identified as a distance upstream from post no. 14, or the first post downstream from the omitted post.

For each simulated impact point, the maximum dynamic deflection, extent of the snag on post no. 14, maximum pocketing angle, and the maximum rail force was documented. Pocketing occurs when a flexible barrier deflects sufficiently to allow the front of the vehicle to engage the blunt end of the stiffer barrier. The risk of a high-deceleration pocketing event has been correlated to the maximum angle between the deflected guardrail and the downstream section of rail. Vehicle snag was measured as the lateral extent of the front tire beyond the face of the post at the time of tire-to-post contact, and pocketing angles were measured over 37.5-in. (953-mm) segments of rail. The maximum rail deflections were all similar and only varied by a couple of inches. Vehicle snag and maximum pocketing angle were the highest for impacts near the upstream end of the elongated span, while rail forces peaked during impacts near the middle of the elongated span. Ultimately, the critical impact point was identified as 121.875 in. (3,096 mm) upstream from post no. 14, which was located at the upstream end of the elongated span, due to this impact point having the highest snag potential, second highest pocketing angle, and a rail force within 5 percent of the recorded maximum force. The distance to the critical impact point was rounded to 122 in. (3,099 mm) upstream of post no. 14 for the physical crash test.

Table 3. BARRIER VII Simulation Results

Impact Point Distance US from Post No. 14 (in.)	Maximum Rail Deflection (in.)	Vehicle Snag on Post No. 14 (in.)	Maximum Pocketing Angle (deg.)	Maximum Rail Force (kip)
225	22.03	-	12.38	58.38
215.625	23.05	-	13.52	61.87
206.25	24.37	-	14.64	65.28
196.875	24.79	-	15.18	65.94
187.5	22.85	-	14.11	66.16
178.125	23.01	-	14.56	68.52
168.75	22.70	0.98	14.89	67.94
159.375	22.66	2.08	15.09	68.64
150	22.85	2.67	15.25	69.12
140.625	23.15	4.18	15.37	68.19
131.25	23.8	5.00	15.64	68.52
121.875	24.31	5.41	15.86	68.63
112.5	24.66	5.31	16	67.74
103.125	24.82	5.12	15.73	68.75
93.75	25.49	4.65	15.09	71.7
84.375	25.87	3.99	14.05	71.53
75	25.97	3.21	12.32	70.19
65.625	26.06	2.00	9.86	68.63
56.25	26.13	0.39	6.59	66.82
46.875	25.92	-	3.12	67.58
37.5	25.35	-	1.3	68.05

5.2 Static Soil Test

Before full-scale crash test no. MGSCO-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.

5.3 Weather Conditions

Test no. MGSCO-1 was conducted on August 28, 2017 at approximately 3:00 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 4.

Table 4. Weather Conditions, Test No. MGSCO-1

Temperature	78° F
Humidity	52%
Wind Speed	7 mph
Wind Direction	30° from True North
Sky Conditions	Partly Cloudy
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.09 in.
Previous 7-Day Precipitation	0.09 in.

5.4 Test Description

Initial vehicle impact was to occur 122 in. (3,099 mm) upstream from the centerline of post no. 14, as shown in Figure 26, which was selected using BARRIER VII analysis. The 2,438-lb (1,106-kg) vehicle impacted the MGS with curb and an omitted post at a speed of 64.1 mph (103 km/h) and at an angle of 25.7 degrees. The actual point of impact was 2.7 in. (69 mm) upstream from target impact. Initially, the guardrail captured the front of the vehicle and began to redirect it. At around 0.130 s after impact, the rail ruptured at the splice located within the elongated span while the vehicle was in contact with this region of the barrier. The tear in the upstream (front) rail segment went through the upstream-bottom splice bolt hole and extended up through the center of the splice. Subsequently, the vehicle penetrated the system and eventually rolled over behind the barrier. The vehicle came to rest 91 ft (28 m) downstream from impact and 15 ft – 6 in. (4.7 m) laterally behind the barrier system.

A detailed description of the sequential impact events is contained in Table 5. Sequential photographs are shown in Figures 27 and 28. Documentary photographs of the crash test are shown in Figures 29 and 30. The vehicle trajectory and final position are shown in Figure 31.

5.5 Barrier Damage

Damage to the barrier was extensive, as shown in Figures 32 through 36. Barrier damage consisted of contact marks, deformed and torn W-beam rail, bent and twisted posts, and deformed post-to-rail attachment hardware and blockouts. The length of vehicle contact along the barrier was approximately 29 ft – 1 in. (8.8 m) which spanned from point of impact downstream to post no. 17.

Damage to the curb consisted of tire marks and minor scrapes. Post nos. 11 through 13 were twisted to face downstream, and the back flange of post nos. 12 and 13 had minor buckling of their back flanges near the ground line. Soil heaves and craters formed at the base of post nos. 14 through 18. Post nos. 14 and 15 were bent backward and downstream, contained several contact marks along their front flanges, and were disengaged from their blockouts, as shown in Figure 33. Post no. 16 was bent backward and downstream, twisted to face downstream, and contained contact marks on the upstream edges of both flanges. Post no. 17 was bent backward and downstream, but to a lesser degree than the adjacent upstream posts. Post no. 18 was bent slightly downstream and twisted to face downstream.

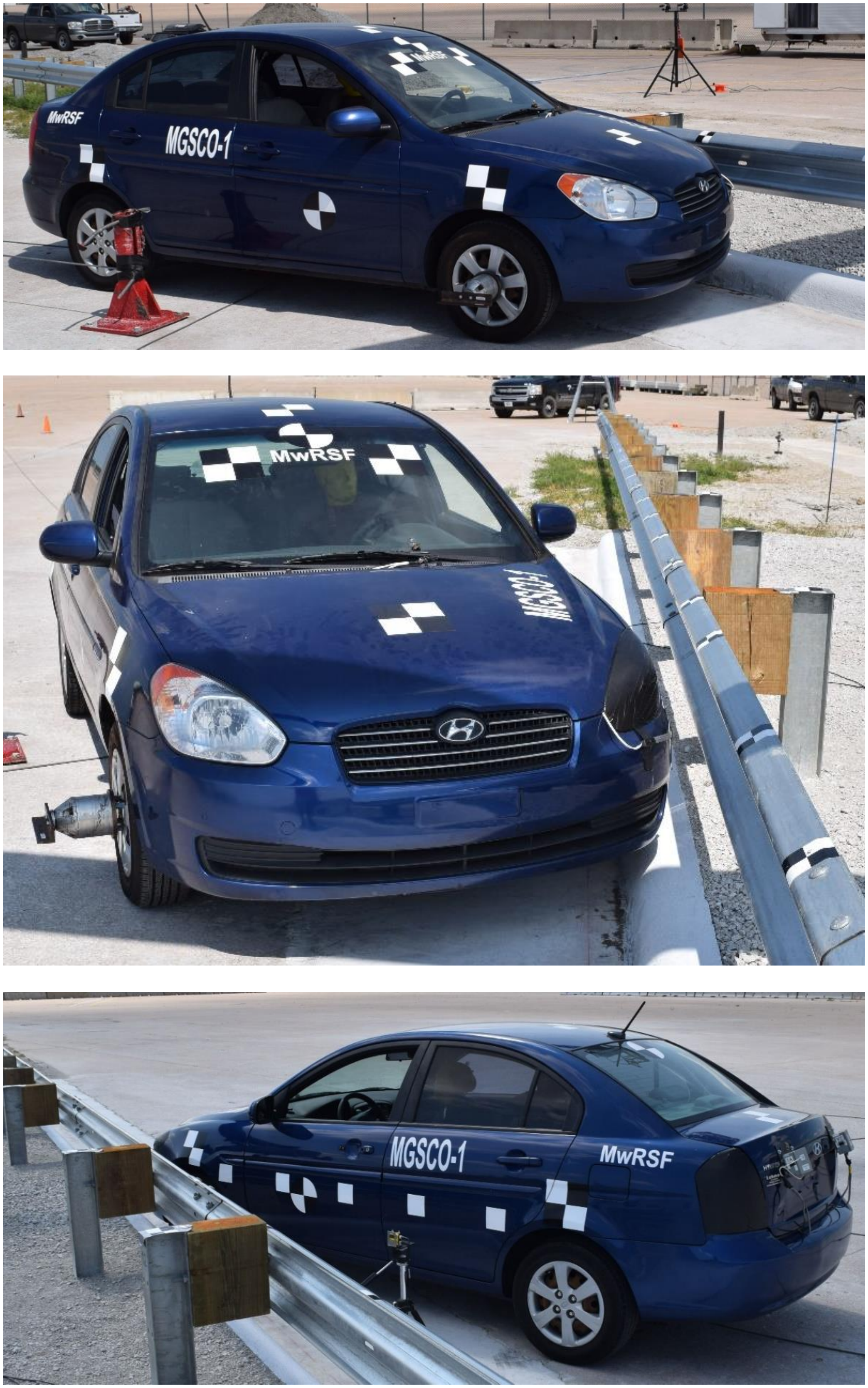


Figure 26. Impact Location, Test No. MGSCO-1

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

TIME (s)	EVENT
0.000	Vehicle's left-front tire contacted curb 124.7 in. (3,167 mm) upstream from the centerline of post no. 14.
0.004	Vehicle's front bumper contacted rail between post nos. 13 and 14 and deformed.
0.014	Vehicle's hood contacted rail and began to override the rail.
0.018	Post no. 14 deflected downstream. Vehicle rolled away from barrier.
0.026	Post no. 13 deflected backward.
0.032	Post no. 14 deflected backward.
0.036	Post no. 13 twisted counterclockwise.
0.048	Vehicle's left-front door contacted rail.
0.072	Vehicle pitched upward.
0.094	Soil heave formed on downstream side of post no. 14. Vehicle's right fender deformed. Vehicle's left-rear tire contacted curb. Vehicle's front bumper contacted post no. 14.
0.102	Rail disengaged from bolt at post no. 14.
0.104	Post no. 14 bent backward and downstream. Post no. 15 deflected downstream.
0.114	Post no. 15 twisted clockwise and deflected backward.
0.116	Blockout disengaged from post no. 14.
0.132	Rail ruptured at the splice between post nos. 13 and 14 (upstream segment tore). Vehicle penetrated system.
0.152	Vehicle's left-front tire became airborne.
0.166	Vehicle's right-front tire contacted curb. Vehicle's front bumper contacted post no. 15.
0.180	Vehicle's hood was unlatched and extended over the rail.
0.186	Blockout disengaged from post no. 15. Vehicle's right fender contacted rail. Blockout at post no. 15 split vertically through bolt hole.
0.190	Rail disengaged from bolt at post no. 16.
0.206	Rail disengaged from bolt at post no. 15.
0.216	Vehicle's windshield cracked due to contact with hood.
0.256	Rail disengaged from bolt at post no. 17. Vehicle rolled toward barrier
0.284	Vehicle's right-front tire contacted post no. 16. Vehicle's left-rear tire regained contact with ground.
0.840	Vehicle rolled onto its left side.
1.300	Vehicle rolled onto its roof.
2.500	Vehicle was upright with all four wheels on the ground.
3.500	Vehicle came to rest behind barrier.

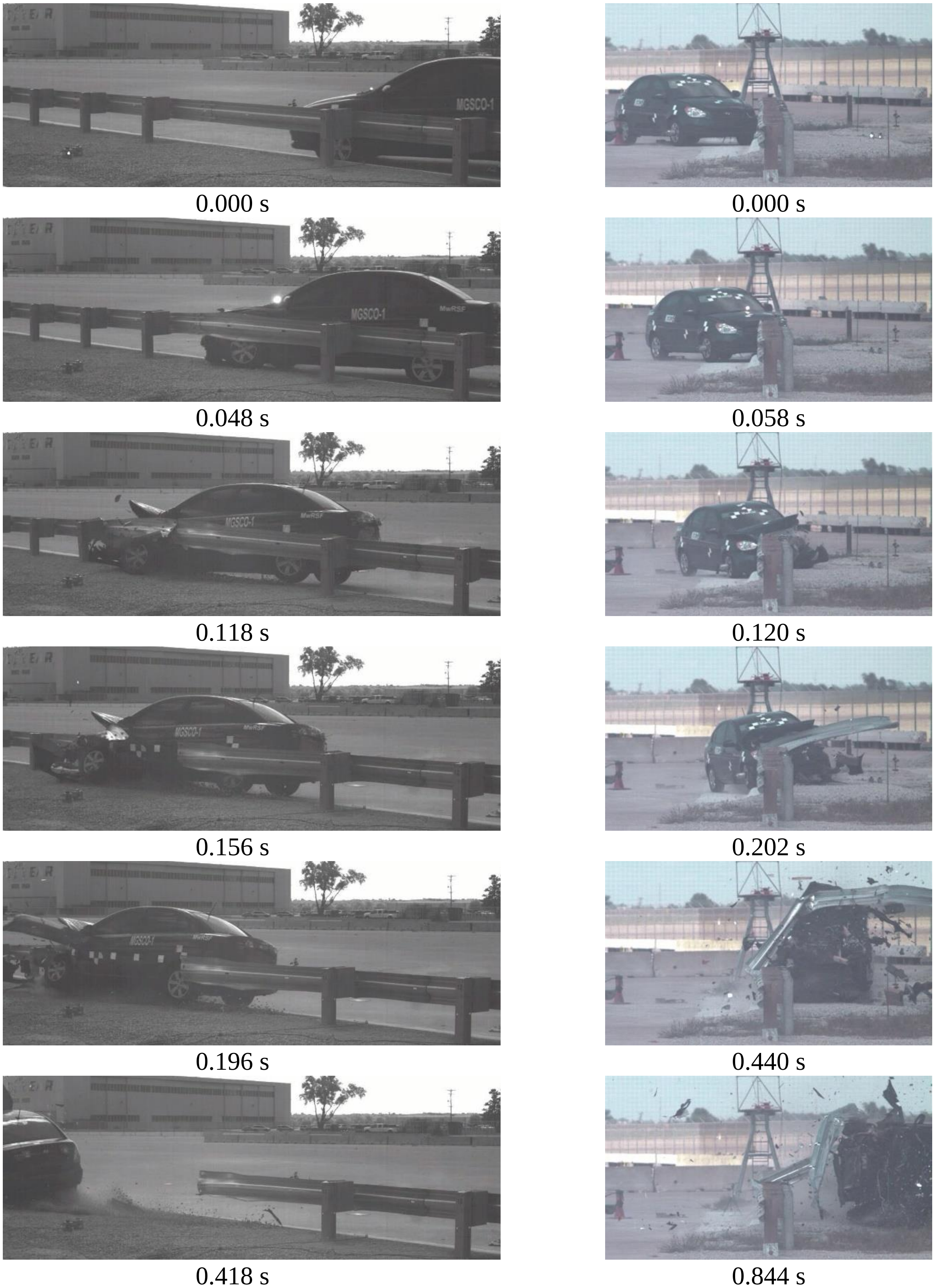


Figure 27. Sequential Photographs, Test No. MGSCO-1

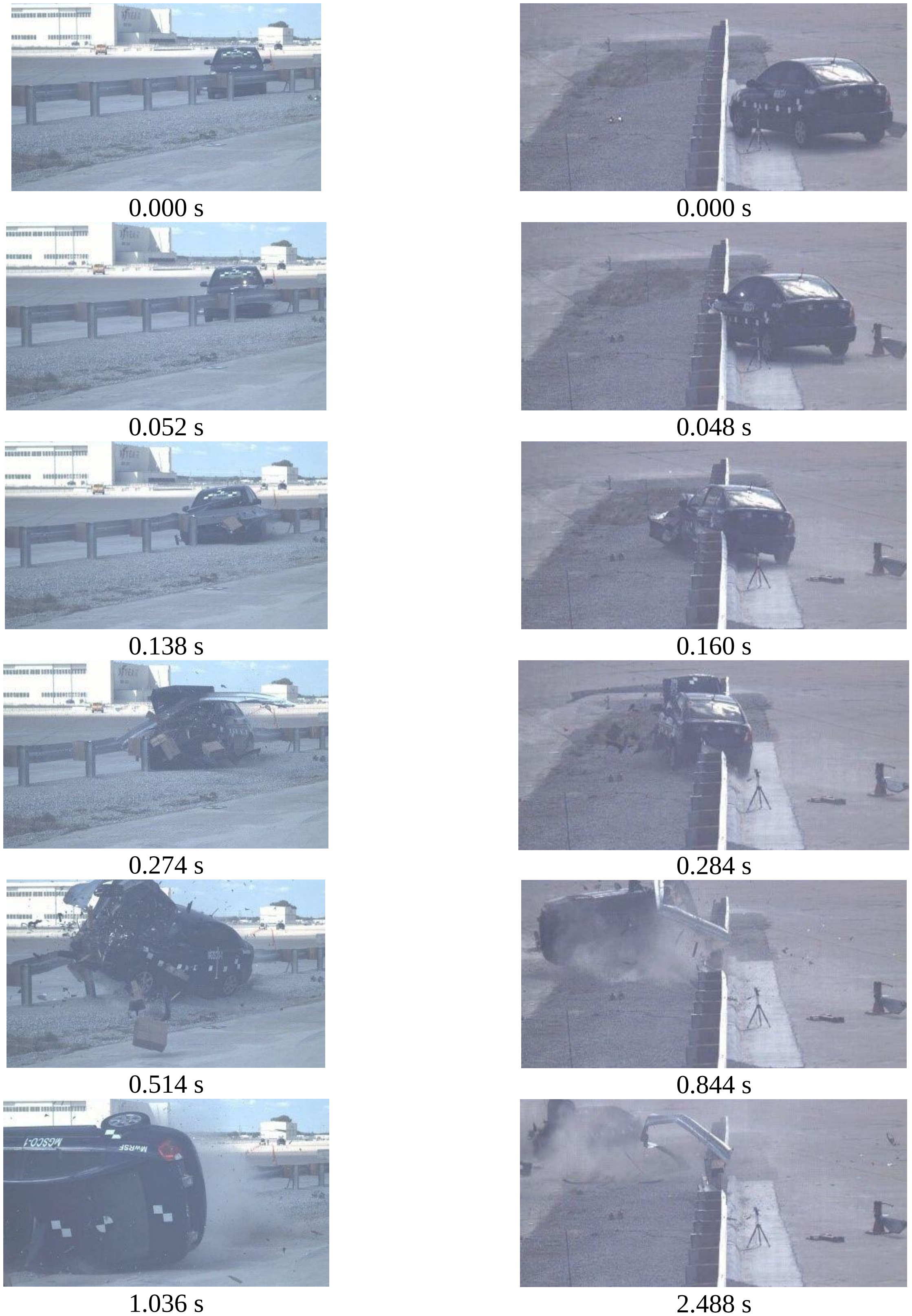


Figure 28. Additional Sequential Photographs, Test No. MGSCO-1

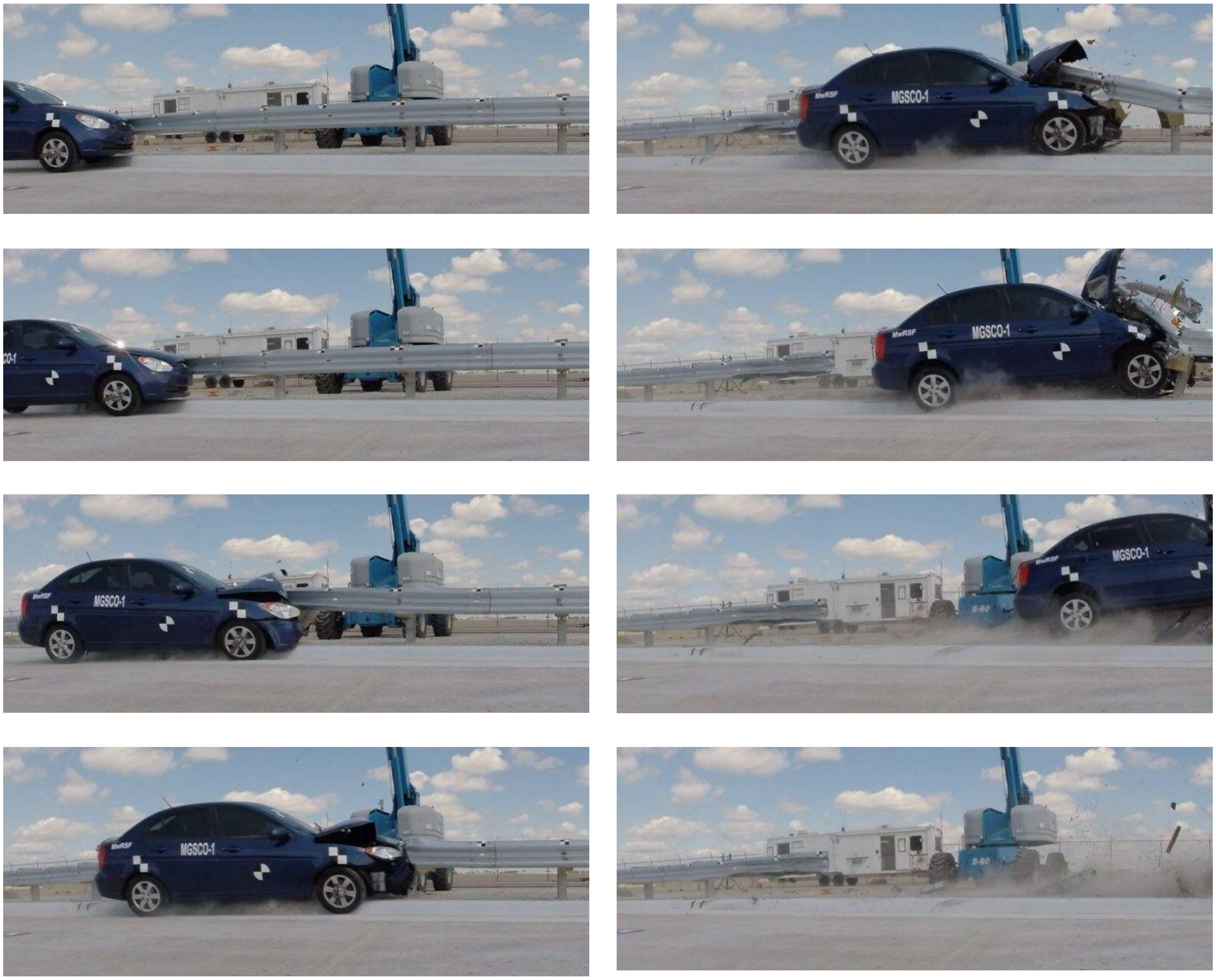


Figure 29. Documentary Photographs, Test No. MGSCO-1

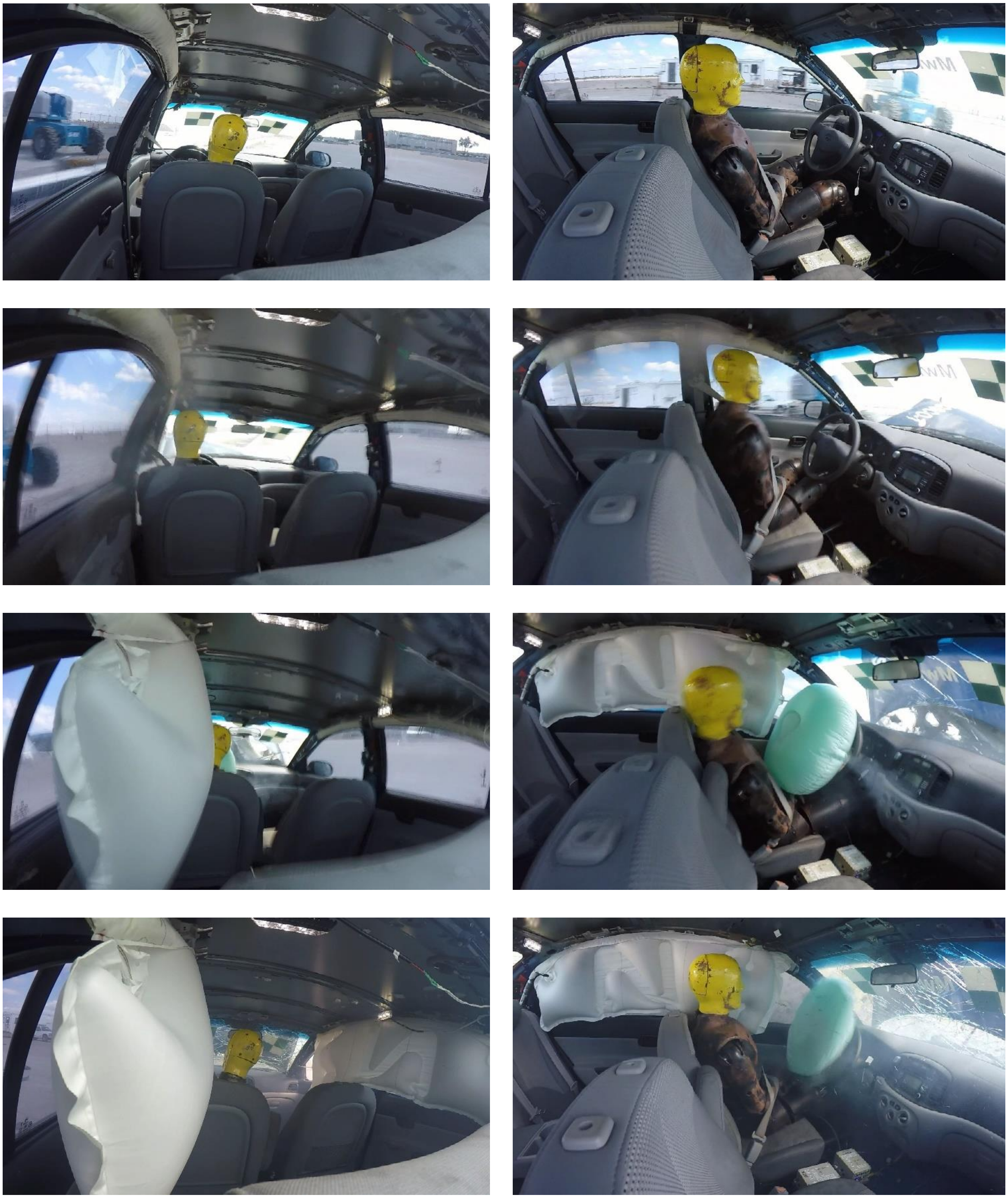


Figure 30. On-Board Documentary Photographs, Test No. MGSCO-1

Figure 31. Vehicle Final Position, Test No. MGSCO-1

Figure 32. System Damage, Test No. MGSCO-1

Figure 33. System Damage, Post Nos. 14 through 18, Test No. MGSCO-1

Figure 34. Rail Damage, Upstream from Rupture, Test No. MGSCO-1

Figure 35. Rail Damage, Downstream from Rupture, Test No. MGSCO-1

Figure 36. Rail Rupture at Splice, Test No. MGSCO-1

The guardrail experienced various degrees of bending, flattening, denting, kinking, and scraping extending from 2 in. (51 mm) downstream from post no. 12 and extending 1 in. (25 mm) upstream from post no. 20, as shown in Figures 34 through 36. The rail was detached from post nos. 13 through 18. The rail was completely torn at the splice located between post nos. 13 and 14, which placed it within the elongated span length. The tear on the upstream rail segment (front side of splice) went through the lower-upstream bolt hole, through the bolt slot located at the center of the splice, and continued up through between the columns of splice bolt holes, as shown in Figure 36. Partial rail tears were found at the attachment bolt slots for post nos. 14 through 16 where the guardrail bolts pulled through the rail. The maximum deflection and permanent set of the barrier system were not defined due to rail tearing and system failure.

5.6 Vehicle Damage

The damage to the vehicle was severe, as shown in Figures 37 through 40. The maximum occupant compartment intrusion 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 windshield intrusion was found to exceed the MASH 2016 intrusion limits. Additionally, the right-front and left-front side windows were shattered, but this was the result of the vehicle rolling over and not from contact with the system. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Damage consisting of crushing, denting, scrapes, and gouges was spread across the front, sides, and top of the vehicle. The front bumper cover was disengaged from the vehicle. The hood was unlatched, buckled, and deformed. The frame horns of the chassis were bent to the left side. The engine cradle was crushed along the leading edge, and the rear section was dented and crushed in the center. Scrapes were observed on the right-side floor pan. The largest scrape measured 17 in. (432 mm) long and ½ in. (13 mm) deep. The lower radiator support was crushed along its leading edge along its width. Slight scraping was found along the spare tire well, but the brake lines were undamaged.

The left-front fender panel was buckled, partially disengaged, and contained a 30-in. (762-mm) by 6-in. (152-mm) gouge. The left-side mirror was disengaged, and the door handle was torn off of the left-rear side door. The left-rear side panel was dented behind the rear door. The left-rear fender panel was dented. The roof was deformed due to rollover during the crash. The windshield was cracked, and the left-front and right-front side windows were shattered. Undercarriage damage consisted of damage to the left-front shock and spring, which included a slight bend in the shock and a 1-in. (25-mm) long scrape on the spring. The right-front spring had two 2-in. (51-mm) long scrapes. Both the left-rear and right-rear springs and bump stops were undamaged, and both rear shocks experienced a ½-in. x ½-in. (13-mm x 13-mm) scrape as a result of wheel rub. The left-side control arm was damaged, and the right-side control arm was scraped. The rear suspension was undamaged; however, each shock had a ½-in. x ½-in. (13-mm x 13-mm) scrape due to wheel rub. The left-front anti-roll bar link and the left steering knuckle joint were bent. The left-lower control arm wheel joint was damaged, and the right-lower control arm was scraped. Both the transmission and oil pan experienced minor scraping.

Figure 37. Vehicle Damage, Test No. MGSCO-1

Figure 38. Additional Vehicle Damage, Test No. MGSCO-1

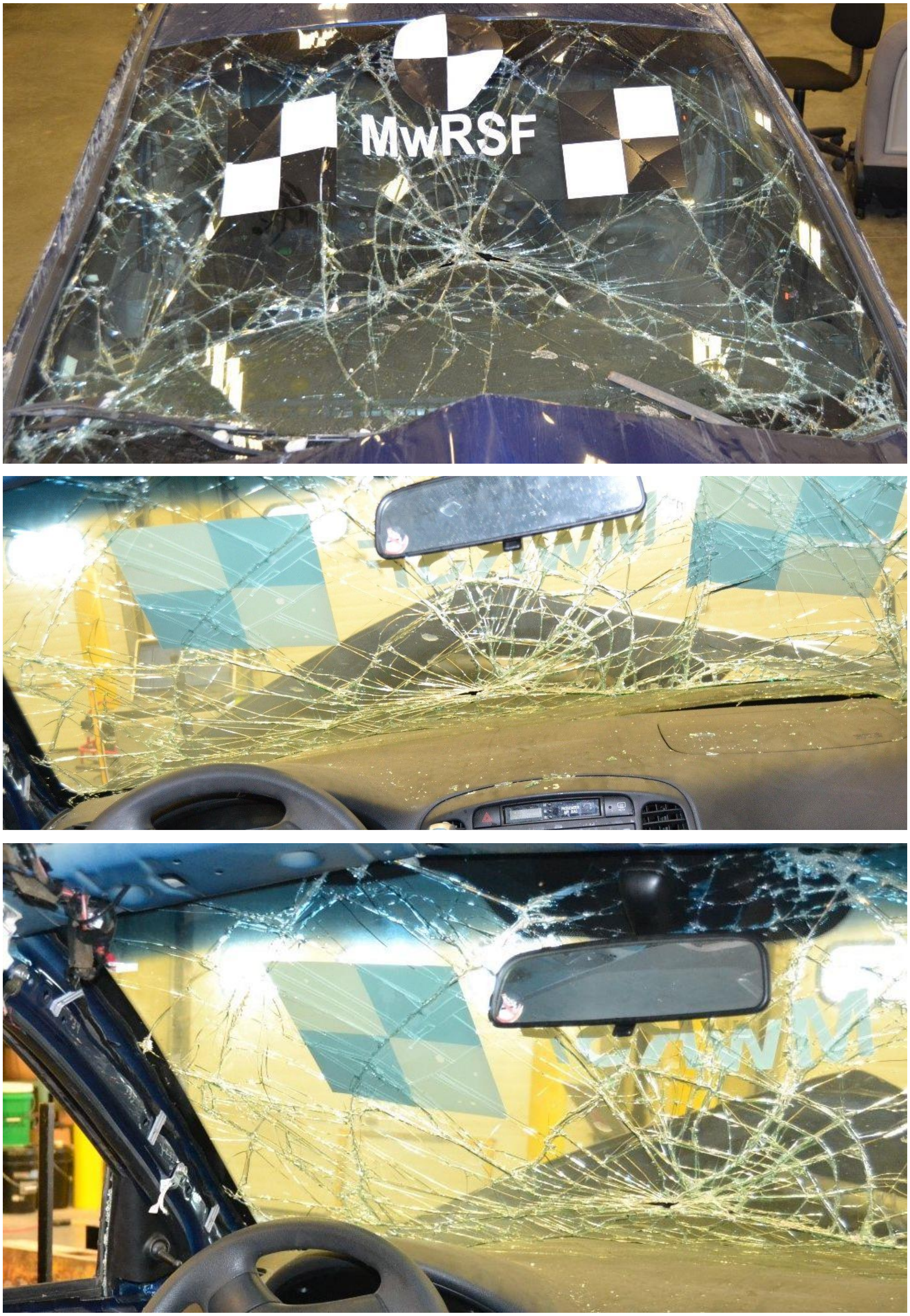


Figure 39. Vehicle Windshield Damage, Test No. MGSCO-1

Figure 40. Occupant Compartment and Undercarriage Damage, Test No. MGSCO-1

Table 6. Maximum Occupant Compartment Intrusion by Location

LOCATION	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	½ (13)	≤ 9 (229)
Floor Pan & Transmission Tunnel	½ (13)	≤ 12 (305)
A- and B-Pillars	⅜ (10)	≤ 5 (127)
A- and B-Pillars (Lateral)	⅛ (3)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	⅜ (10)	≤ 12 (305)
Side Door (Above Seat)	⅜ (10)	≤ 9 (229)
Side Door (Below Seat)	⅝ (16)	≤ 12 (305)
Roof	1½ (38)	≤ 4 (102)
Windshield	4 (102)	≤ 3 (76)
Side Windows	Both front side windows shattered*	No shattering resulting from contact with structural member of test article
Dash	⅜ (10)	N/A

N/A – Not applicable
*Side windows were shattered as a result of contact with the ground during vehicle rollover, not contact with the system.

5.7 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 10-ms average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 7. Vehicle pitch and yaw angular displacements were deemed acceptable because they did not adversely influence occupant risk, however, the roll angular displacements exceeded the limit set forth in MASH 2016 due to vehicle rollover. The calculated THIV, PHD, and ASI values are also shown in Table 7. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

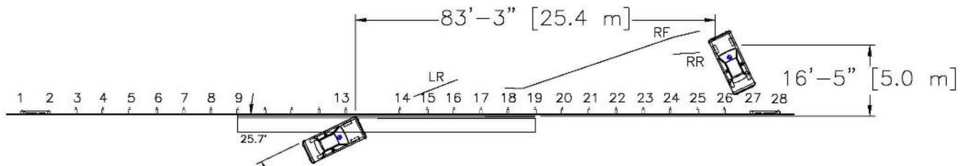
5.8 Discussion

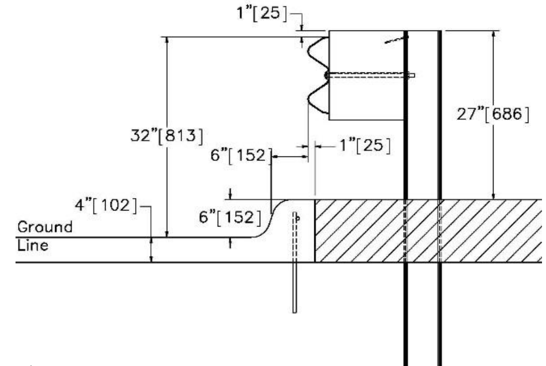
A summary of the test results and sequential photographs are shown in Figure 41. The analysis of the test results for test no. MGSCO-1 showed that the system did not adequately contain and redirect the 1100C vehicle. The rail completely tore at the splice located within the elongated span length. Subsequently, the test vehicle penetrated the barrier and eventually rolled over. Additionally, the windshield crush of 4 in. (102 mm) exceeded the MASH 2016 limits for occupant compartment crush. Due to these three failures, test no. MGSCO-1 did not satisfy the MASH 2016 safety performance criteria for test designation no. 3-10.

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

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 (primary)	SLICE-2	
OIV ft/s (m/s)	Longitudinal	-23.62 (-7.20)	-23.54 (-7.17)	±40 (12.2)
	Lateral	13.84 (4.22)	12.53 (3.82)	±40 (12.2)
ORA g's	Longitudinal	-13.37	-12.23	±20.49
	Lateral	-9.20	-10.55	±20.49
MAX. ANGULAR DISPL. deg.	Roll	-368.0	-367.6	±75
	Pitch	-11.0	15.1	±75
	Yaw	271.0	268.6	not required
THIV ft/s (m/s)		24.87 (7.58)	25.26 (7.70)	not required
PHD g's		14.70	13.59	not required
ASI		1.03	0.99	not required

0.000 s | 0.034 s | 0.094 s | 0.202 s | 0.790 s





- Test Agency .... MwRSF
- Test Number MGSCO-1
- Date .... August 28, 2017
- MASH 2016 Test Designation No. 3-10
- Test Article .... MGS with Curb and Omitted Post
- Total Length .... 182 ft - 3½ in. (55.6 m)
- Key Component – Steel W-Beam Guardrail
  - Thickness .... 12 gauge (2.7 mm)
  - Top Mounting Height .... 32 in. (813 mm) from roadway surface
- Key Component – Steel Post
  - Shape .... W6x8.5 or W6x9
  - Length .... 72 in. (1,829 mm)
  - Post Nos. 1-12, 15-28 Spacing .... 75 in. (1,905 mm)
  - Post Nos. 13-14 Spacing .... 150 in. (3,810 mm)
  - Embedment Depth .... 45 in. (1,143 mm)
- Key Component – Wood Blockout
  - Post Nos. 3-26 .... 6 x 12 x 14¼ (152 x 305 x 362 mm)
- Soil Type .... Well-Graded Gravel (GW)
- Vehicle Make /Model .... 2009 Hyundai Accent
  - Curb .... 2,458 lb (1,115 kg)
  - Test Inertial .... 2,438 lb (1,106 kg)
  - Gross Static .... 2,604 lb (1,181 kg)
- Impact Conditions
  - Speed .... 64.1 mph (103 km/h)
  - Angle .... 25.7 deg.
  - Impact Location .... 124.7 in. (3,167 mm) US from centerline of post no. 14
- Impact Severity .... 62.9 kip-ft (85 kJ) > 51 kip-ft (69.7 kJ) limit from MASH 2016
- Exit Conditions .... Vehicle did not exit system
- Exit Box Criterion .... N/A
- Vehicle Stability .... Unsatisfactory
- Vehicle Stopping Distance .... 91 ft (27.7 m) DS from impact location
  15 ft – 6 in. (4.7 m) laterally behind system

- Vehicle Damage .... Severe
  - VDS [17] .... 11-LFQ-5 and 11-L&T-2
  - CDC [18] 11-LDAO-3
  - Maximum Interior Deformation .... 4 in. (102 mm)
- Test Article Damage .... Extensive
- Maximum Test Article Deflections
  - Permanent Set .... N/A
  - Dynamic .... N/A
  - Working Width .... N/A
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1 (primary)	SLICE-2	
OIV ft/s (m/s)	Longitudinal	-23.62 (-7.20)	-23.54 (-7.17)	±40 (12.2)
	Lateral	13.84 (4.22)	12.53 (3.82)	±40 (12.2)
ORA g's	Longitudinal	-13.37	-12.23	±20.49
	Lateral	-9.20	-10.55	±20.49
MAX ANGULAR DISP. deg.	Roll	-368.0	-367.6	±75
	Pitch	-11.0	15.1	±75
	Yaw	271.0	268.6	Not required
THIV – ft/s (m/s)		24.87 (7.58)	25.26 (7.70)	Not required
PHD – g's		14.70	13.59	Not required
ASI		1.03	0.99	Not required

Figure 41. Summary of Test Results and Sequential Photographs, Test No. MGSCO-1

6 DESIGN DETAILS – TEST NO. MGSCO-2

After the failure of test no. MGSCO-1, the system needed to be modified to improve its crashworthiness. Through discussions with the project sponsors, the selected modification was to incorporate nested W-beam rail around the omitted post location to increase the rail strength and prevent premature failure. The rails were nested such that the two upstream rails were placed in front of the two downstream rails. This option was desired most because it did not require a change to the curb geometry nor the use of specialized parts. To ensure adequate rail strength around the omitted post, nested rail was recommended to extend at least two posts beyond each side of the elongated span length. In other words, nested rail was recommended to encompass the elongated span and the two adjacent 75-in. (1,905-mm) spans on each side. Thus, the MGS in combination with a curb and an omitted post was modified to include 37.5 ft (11.4 m) of nested rail at the location of the omitted post.

The test article from the previous test was repaired and modified for test no. MGSCO-2. The upstream and downstream anchorages were reinstalled, and post nos. 13 through 20 were replaced. The only unique design feature for test no. MGSCO-2 was the addition of three W-beam rail sections creating nested guardrail that extended from the splice between post nos. 10 and 11 to the splice between post nos. 15 and 16. Details of the installation can be seen in Figures 42 through 54. Photographs of the test installation are shown in Figure 55. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

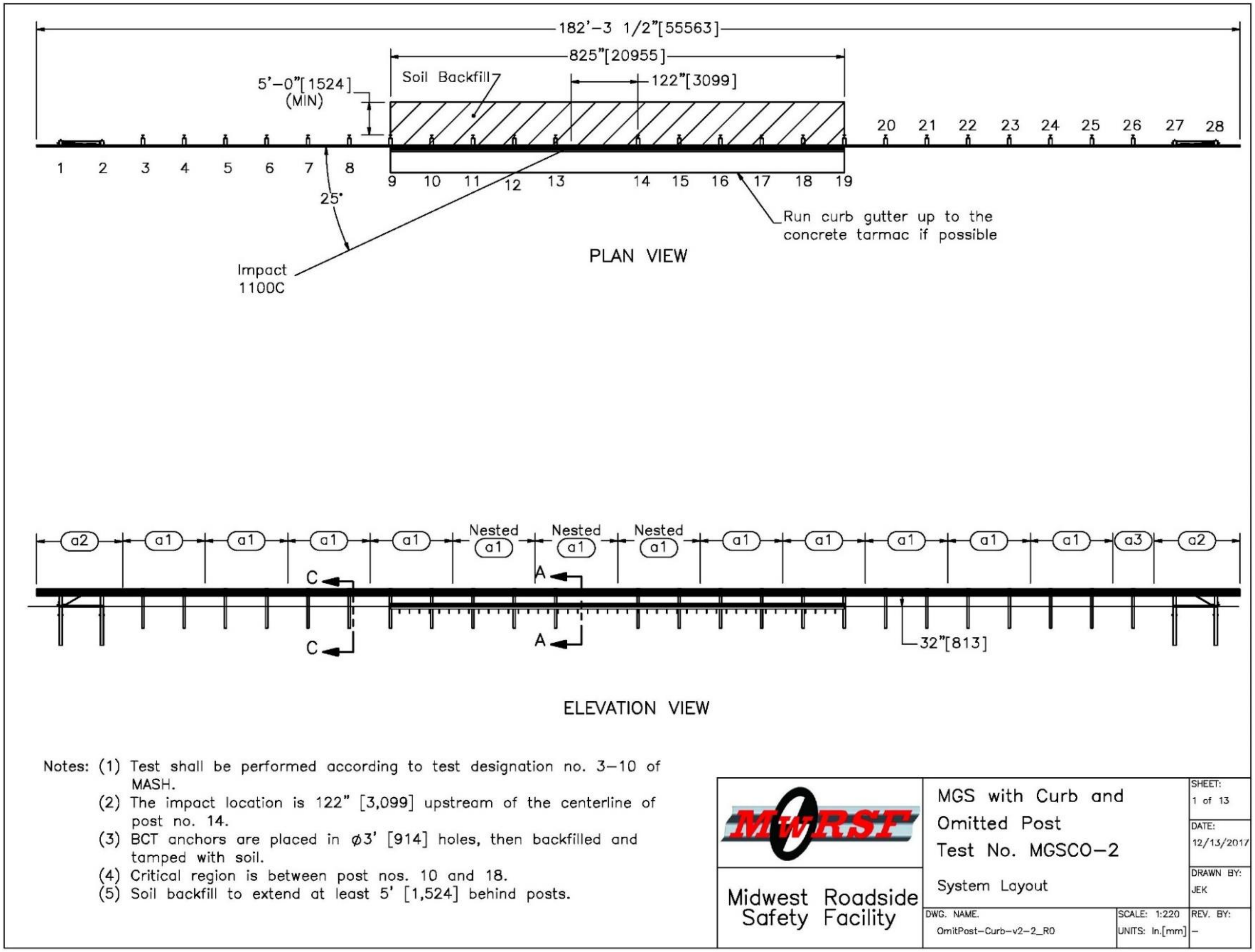


Figure 42. System Layout, Test No. MGSCO-2

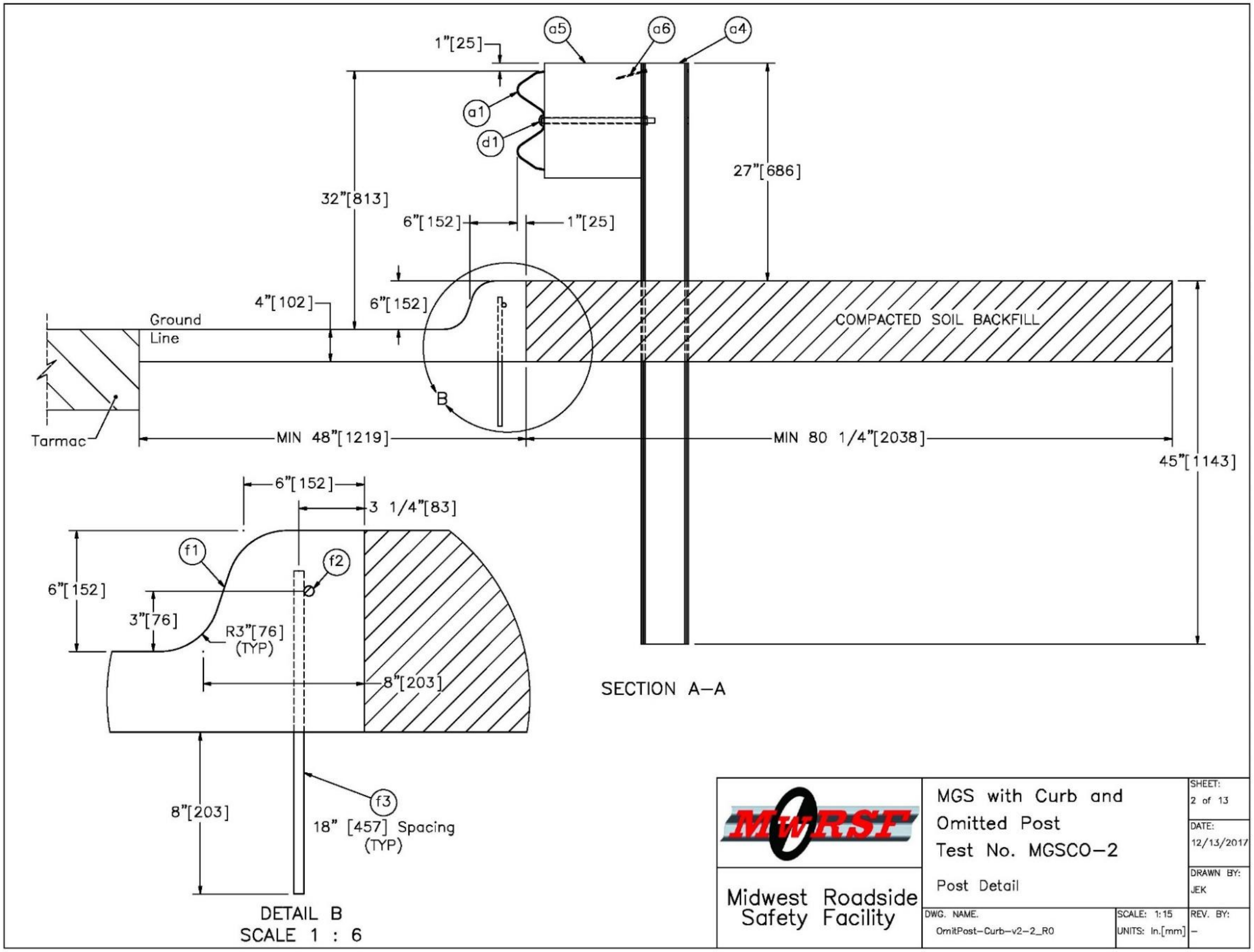


Figure 43. System Profile, Curb Geometry and Reinforcement Details, Test No. MGSCO-2

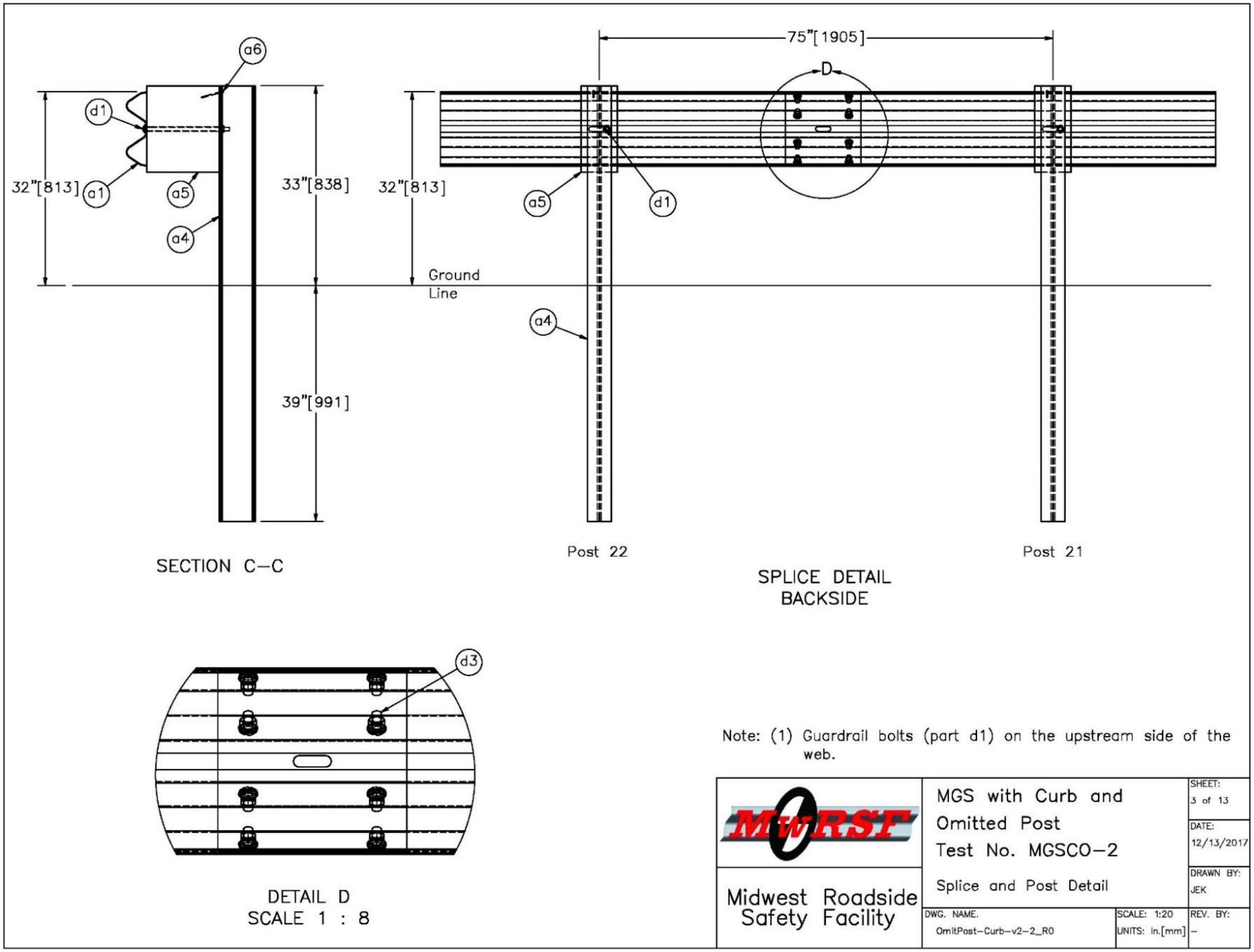


Figure 44. Splice and Post Detail, Test No. MGSCO-2

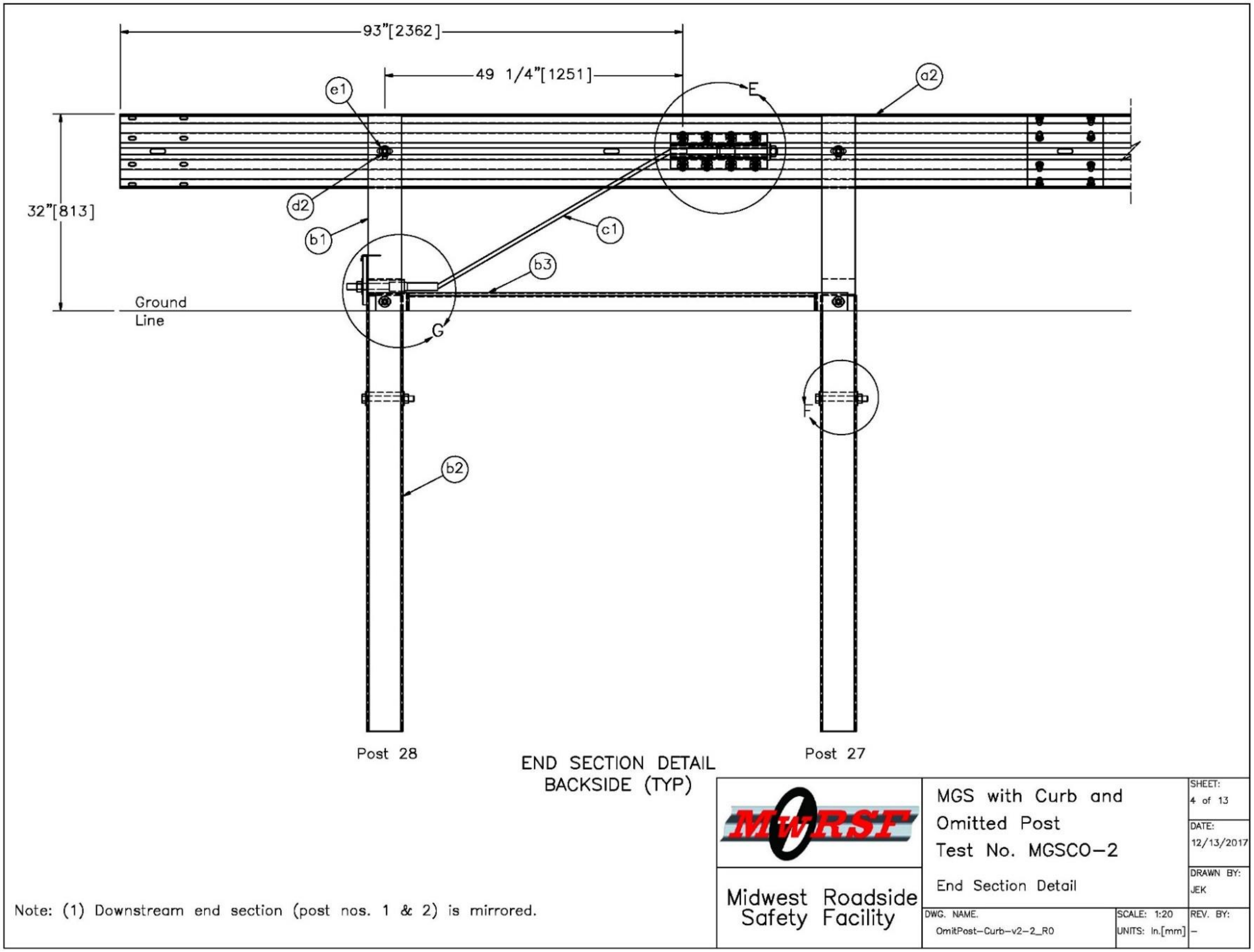


Figure 45. End Anchorage Detail, Test No. MGSCO-2

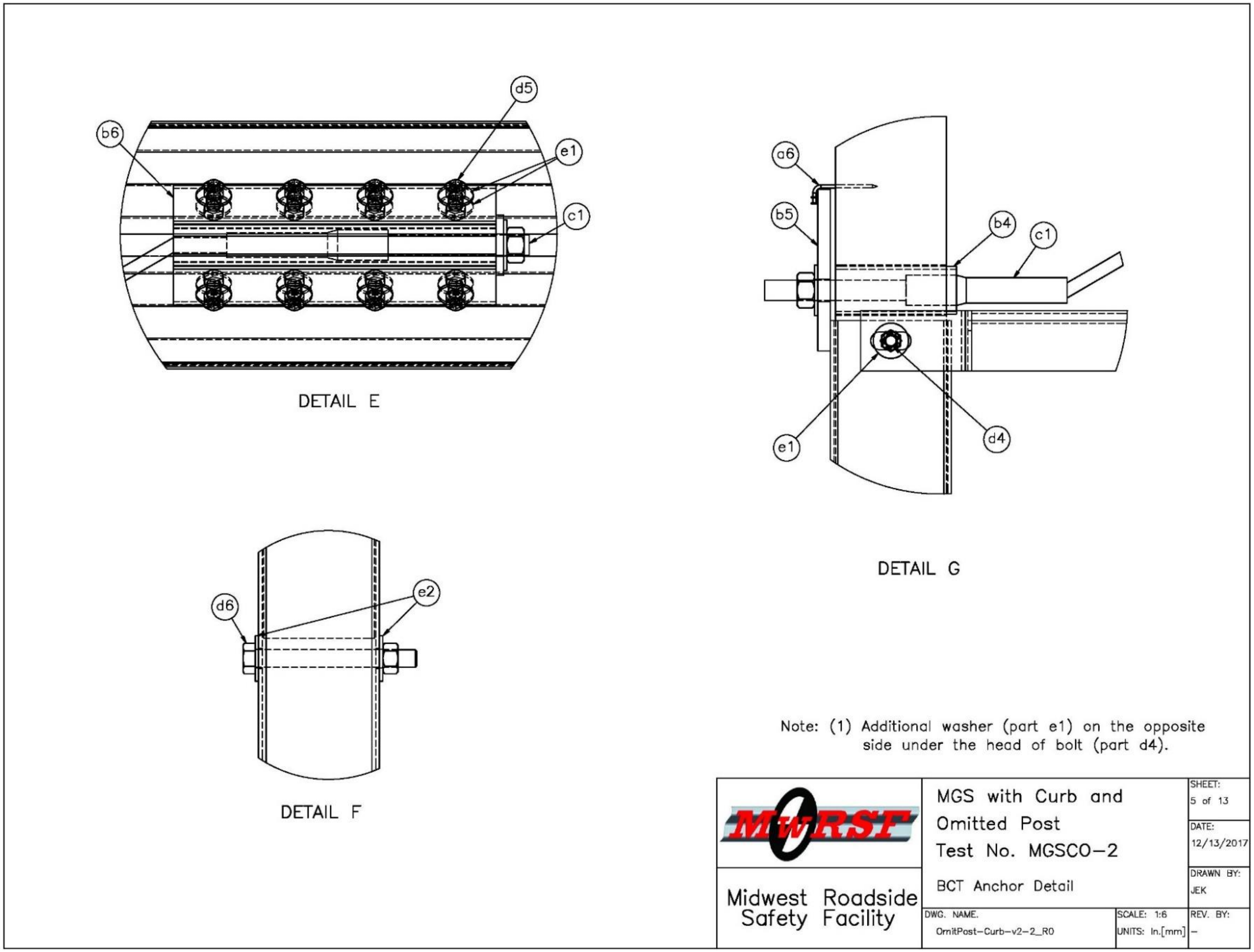


Figure 46. MGS End Anchorage Detail, Test No. MGSCO-2

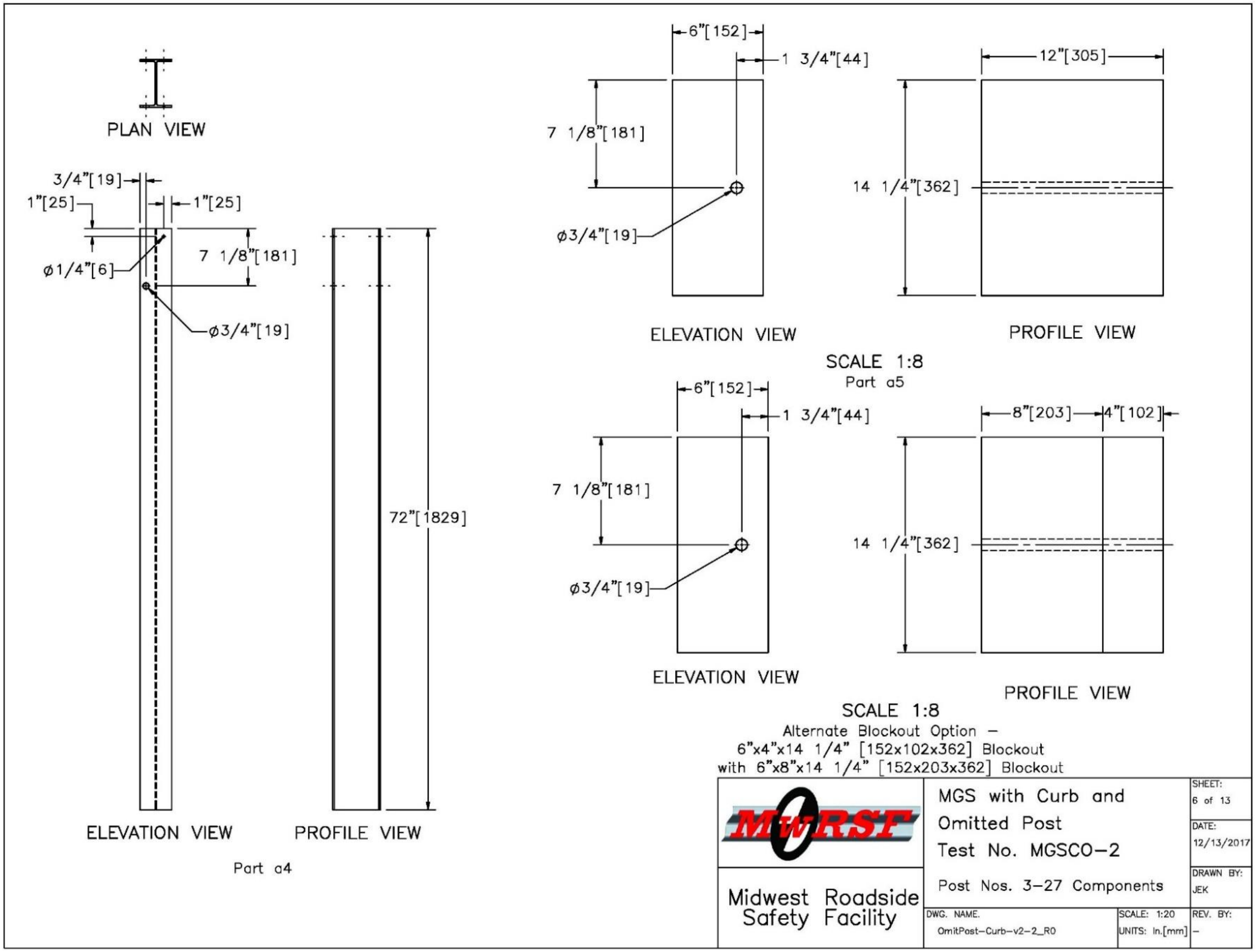


Figure 47. Post Nos. 3 through 27 Component Details, Test No. MGSCO-2

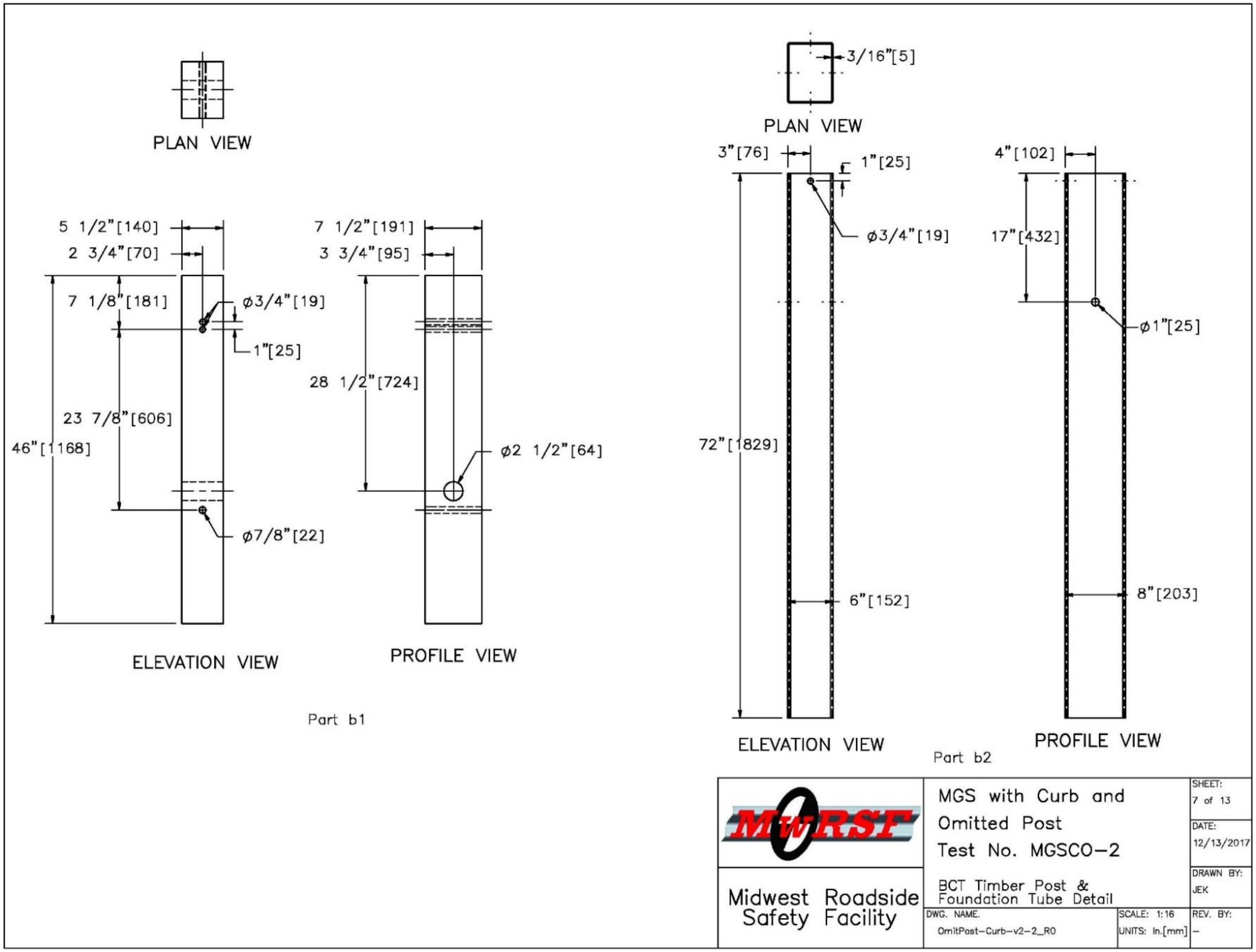


Figure 48. MGS BCT Timber Post and Foundation Tube Detail, Test No. MGSCO-2

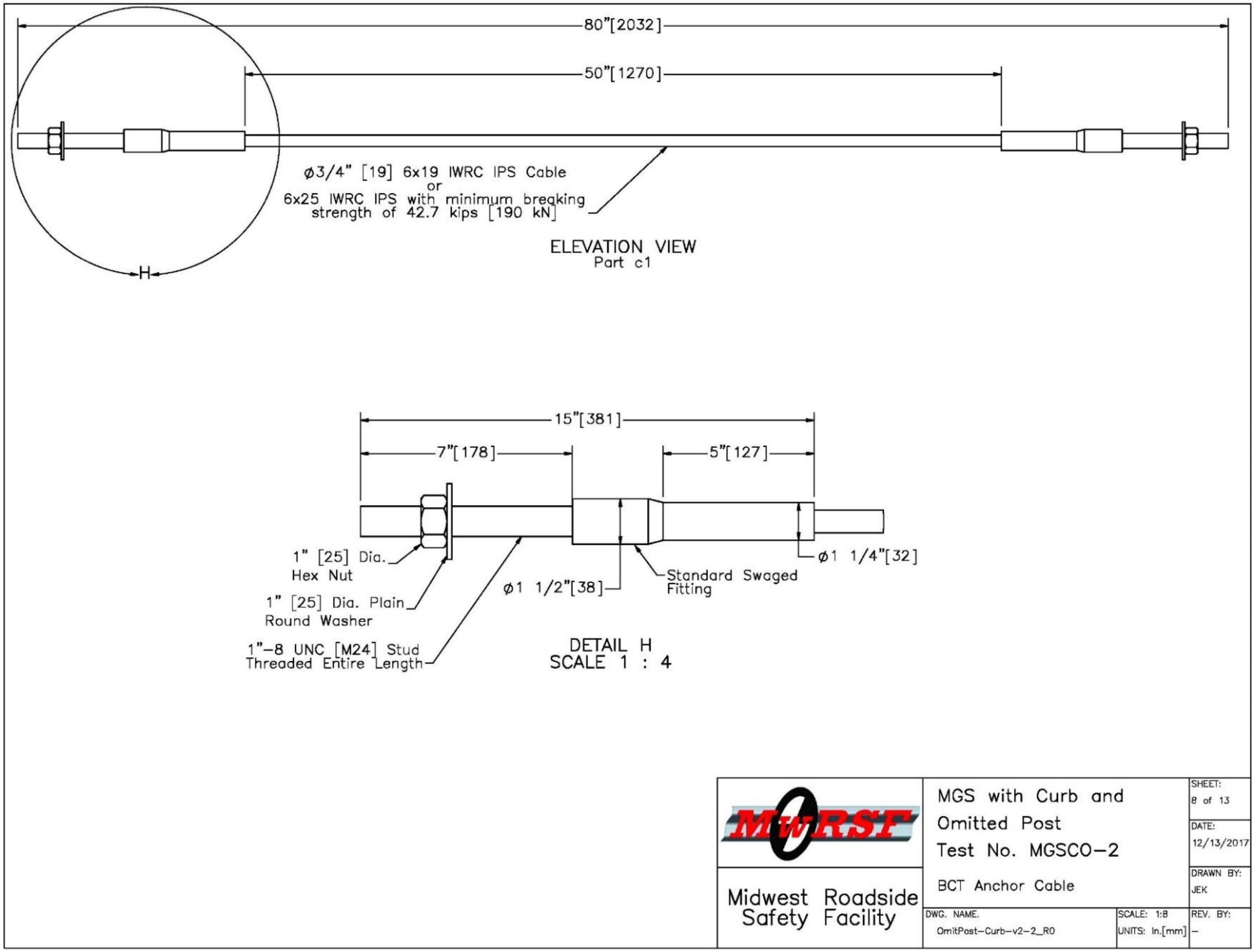


Figure 49. MGS BCT Anchor Cable, Test No. MGSCO-2

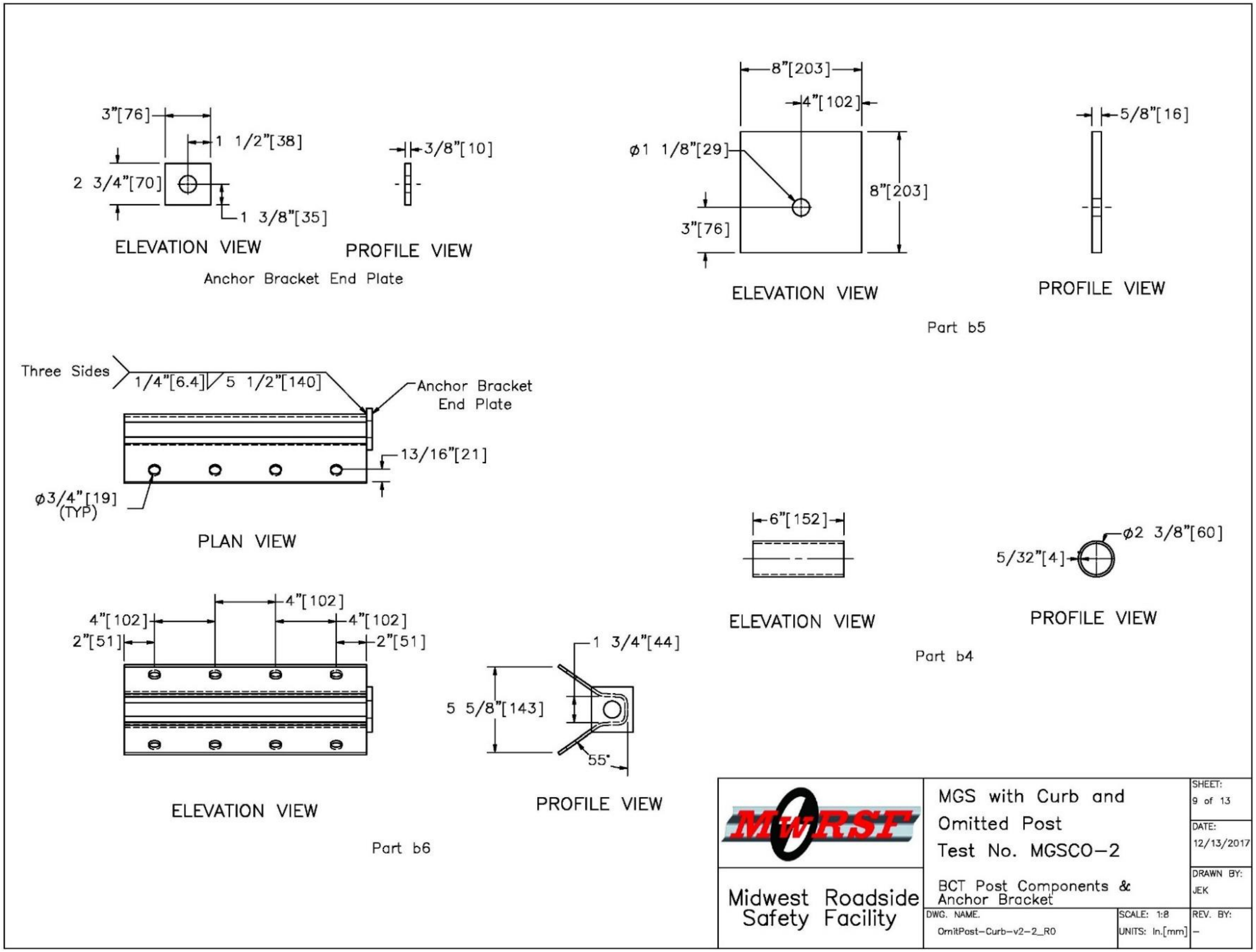


Figure 50. MGS BCT Post Components and Anchor Bracket, Test No. MGSCO-2

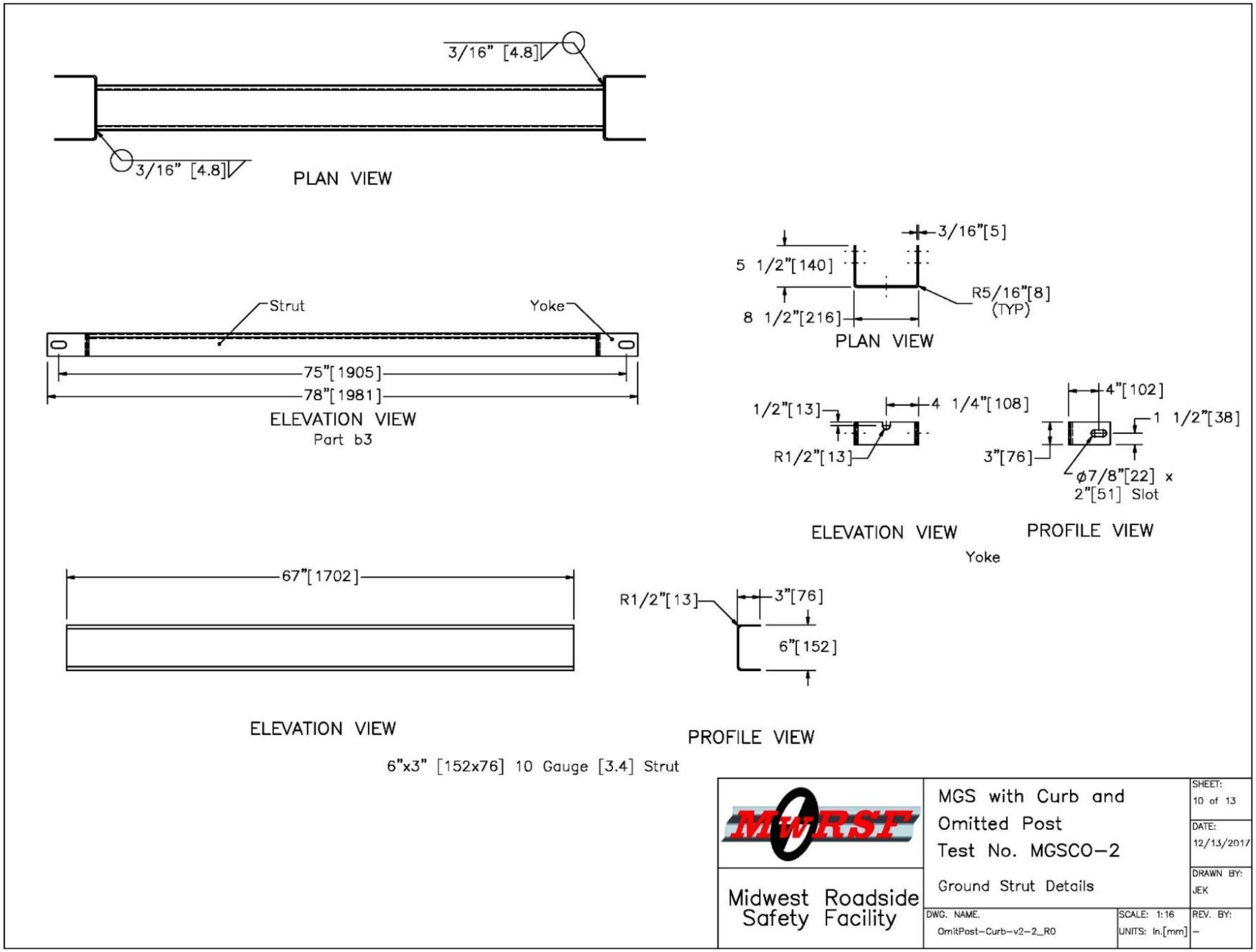


Figure 51. Groundline Strut Details, Test No. MGSCO-2

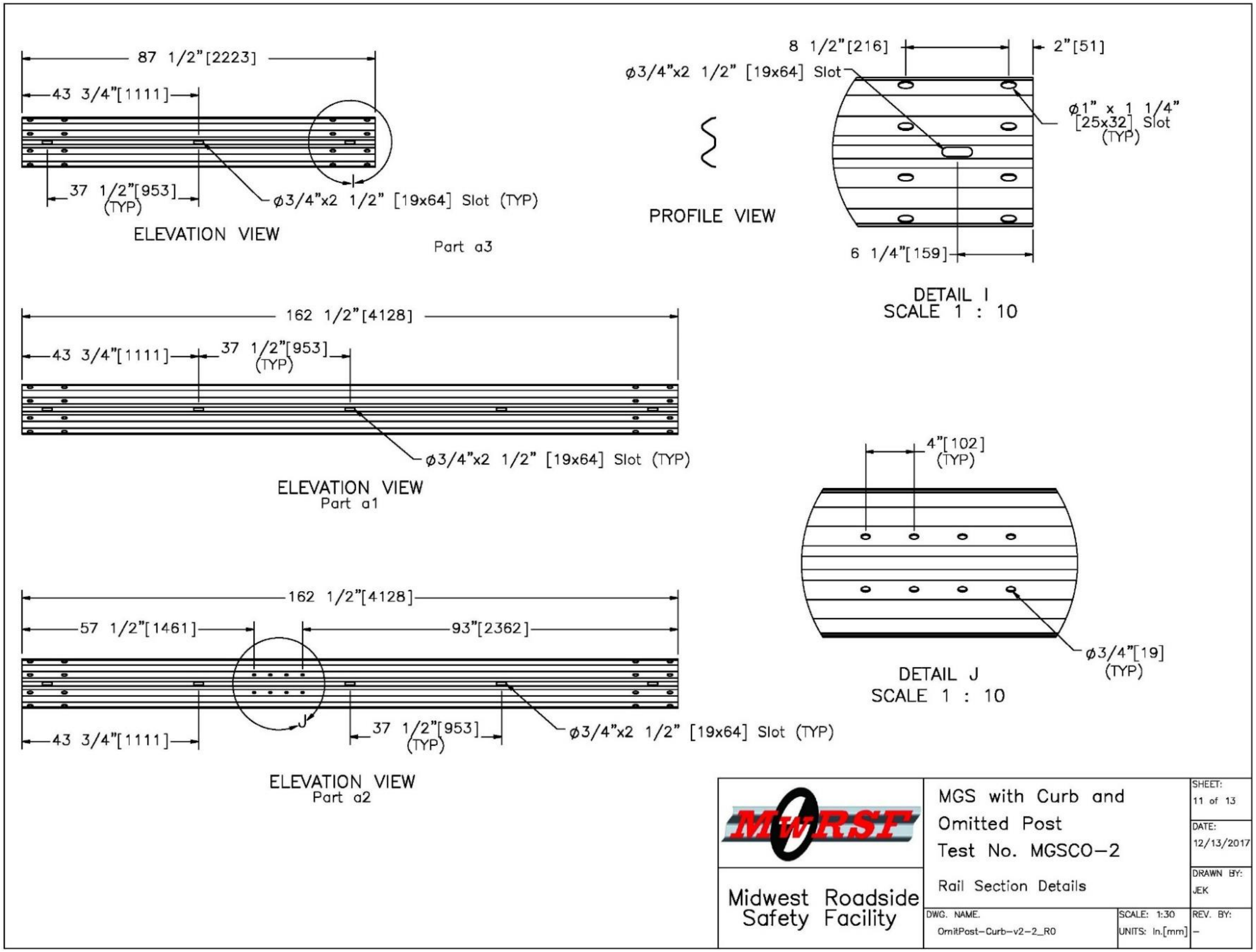


Figure 52. Rail Details, Test No. MGSCO-2

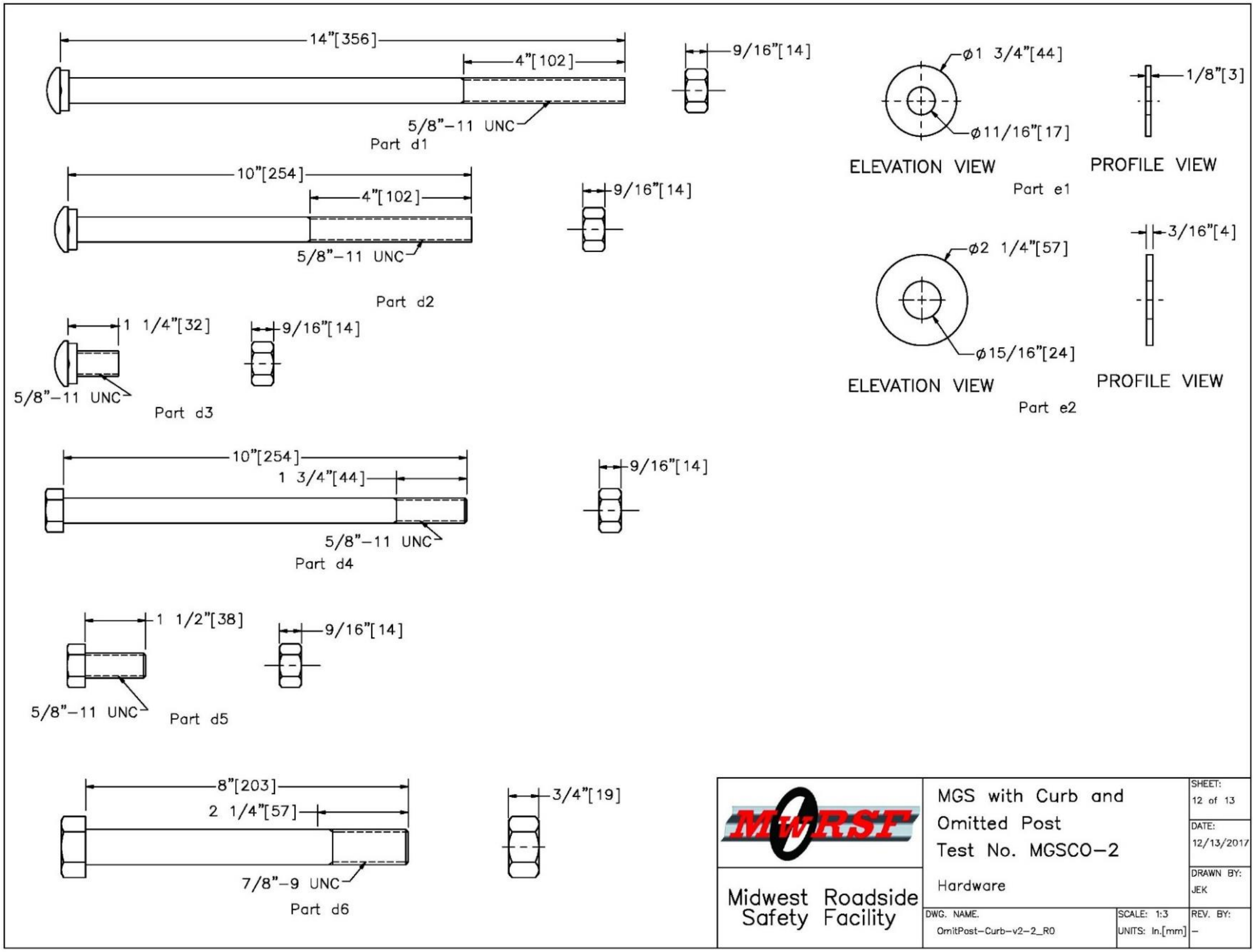


Figure 53. Attachment and Connection Hardware, Test No. MGSCO-2

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	15	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
a2	2	12'–6" [3,810] 12 gauge [2.7] W–Beam MGS End Section	AASHTO M180	ASTM A123 or A653	RWM14a
a3	1	6'–3" [1,905] 12 gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
a4	24	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 Min. 50 ksi [345 MPa]	ASTM A123	PWE06
a5	24	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–	PDB10a
a6	26	16D Double Head Nail	–	–	–
b1	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face)	–	PDF01
b2	4	72" [1829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123	PTE06
b3	2	Ground Strut Assembly	ASTM A36	ASTM A123	PFP02
b4	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	FMM02
b5	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
b6	2	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
c1	2	BCT Anchor Cable	–	–	FCA01
d1	24	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
d2	4	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB03
d3*	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
d4	4	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
d5	16	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX16a
d6	4	7/8" [22] Dia. UNC, 8" [203] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	–
e1	44	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
e2	8	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
f1	1	Curb	f'c = 4,000 psi [27.6 MPa]	–	–
f2	1	#4 Rebar 819" [20,803] Long	ASTM A615 Gr. 60	–	–
f3	45	#4 Rebar 16" [406] Long	ASTM A615 Gr. 60	–	–

* 2" [51] Long Guardrail Bolts (FBB02) may be used in place of part d3 at nested splice locations.

Midwest Roadside Safety Facility

MGS with Curb and Omitted Post
Test No. MGSCO–2

Bill of Materials

SHEET: 13 of 13
DATE: 12/13/2017
DRAWN BY: JEK
DWG. NAME. OmitPost–Curb–v2–2_R0
SCALE: None
UNITS: in.[mm]
REV. BY: –

Figure 54. Bill of Materials, Test No. MGSCO-2

Figure 55. Test Installation Photographs, Test No. MGSCO-2

7 FULL-SCALE CRASH TEST NO. MGSCO-2

7.1 Static Soil Test

Before full-scale crash test no. MGSCO-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.

7.2 Weather Conditions

Test no. MGSCO-2 was conducted on February 2, 2018 at approximately 3:15 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. MGSCO-2

Temperature	37° F
Humidity	39%
Wind Speed	24 mph
Wind Direction	200° 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.

7.3 Test Description

Initial vehicle impact was to occur 122 in. (3,099 mm) upstream from the centerline of post no. 14, as shown in Figure 56, which was selected from the BARRIER VII analysis and remained the same as in test no. MGSCO-1. The 2,404-lb (1,090-kg) vehicle impacted the MGS with curb and omitted post at a speed of 63.2 mph (102 km/h) and at an angle of 24.7 degrees. The actual point of impact was 3.2 in. (81 mm) upstream from the targeted location. During the impact event, the vehicle was captured and redirected without any evidence of rail tearing. The vehicle snagged on and overrode post nos. 14 and 15, the first two posts downstream from impact, which caused the vehicle to not become parallel to the system and yaw back toward the barrier as it was exiting the system. However, the vehicle remained stable throughout impact and came to rest 56 ft – 8 in (17.3 m) downstream from impact and 11 ft – 7 in. (3.5 m) in front of the barrier after brakes were applied.

A detailed description of the sequential impact events is contained in Table 9. Sequential photographs are shown in Figures 57 and 58. Documentary photographs of the crash test are shown in Figures 59 through 60. The vehicle trajectory and final position are shown in Figure 61.

Figure 56. Impact Location, Test No. MGSCO-2

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

TIME (s)	EVENT
0.000	Vehicle's left-front tire contacted curb.
0.004	Vehicle's front bumper contacted rail 119.8 in. (3,042 mm) upstream from post no. 14.
0.014	Vehicle's left fender contacted rail.
0.020	Post no. 13 deflected backward. Vehicle's hood contacted rail.
0.034	Post no. 14 deflected backward.
0.078	Post no. 14 deflected downstream. Vehicle's left-front door contacted rail.
0.092	Vehicle's left-rear tire contacted curb.
0.100	Vehicle's front bumper cover contacted curb.
0.104	Post no. 14 bent downstream.
0.106	Post no. 15 deflected backward.
0.110	Vehicle's front bumper contacted post no. 14.
0.118	Vehicle's left-rear tire became airborne.
0.120	Section of vehicle's front bumper cover disengaged.
0.122	Rail disengaged from bolt at post no. 14.
0.126	Blockout at post no. 14 fractured.
0.135	Post no. 16 deflected backward.
0.173	Post no. 15 deflected downstream.
0.192	Post no. 15 bent downstream.
0.210	Vehicle’s front bumper contacted post no. 15
0.224	Rail disengaged from bolt at post no. 15.
0.270	Vehicle yawed toward barrier.
0.316	Post no. 16 deflected downstream.
0.322	Vehicle's left-rear tire regained contact with ground.
0.402	Rail disengaged from bolt at post no. 16.
0.504	Rail disengaged from bolt at post no. 17.
0.558	Vehicle exited system at 26.5 mph (42.6 km/h) and angle of 9.3 degrees while yawing toward the barrier.
1.144	Vehicle’s front bumper contacted rail between post nos. 20 and 21.
1.302	Vehicle's front bumper cover disengaged.
1.800	Vehicle exited system at 20.8 mph (33.5 km/h).
4.000	Vehicle came to rest facing the barrier.

*Unable to determine the moment the vehicle came to rest

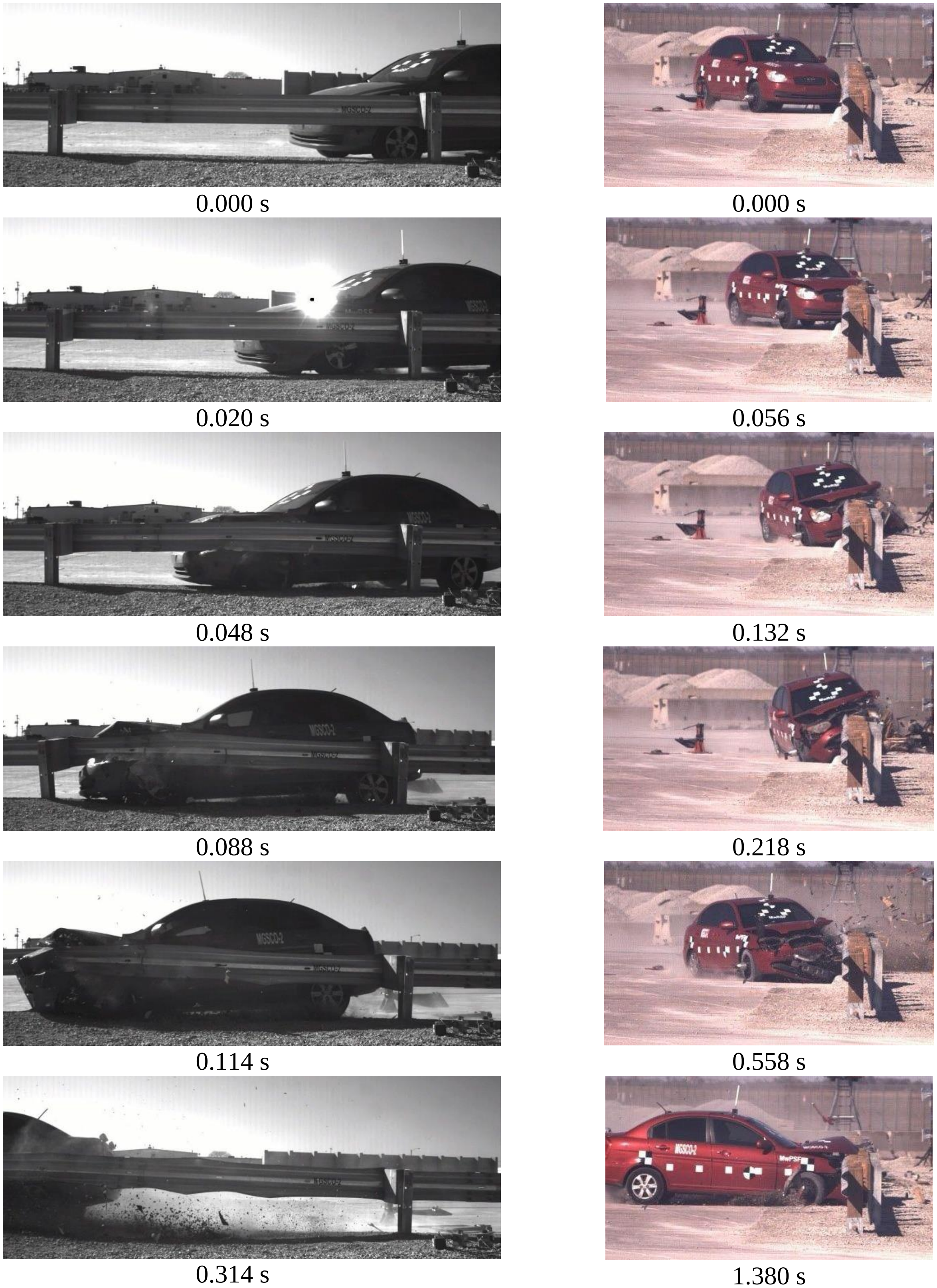


Figure 57. Sequential Photographs, Test No. MGSCO-2

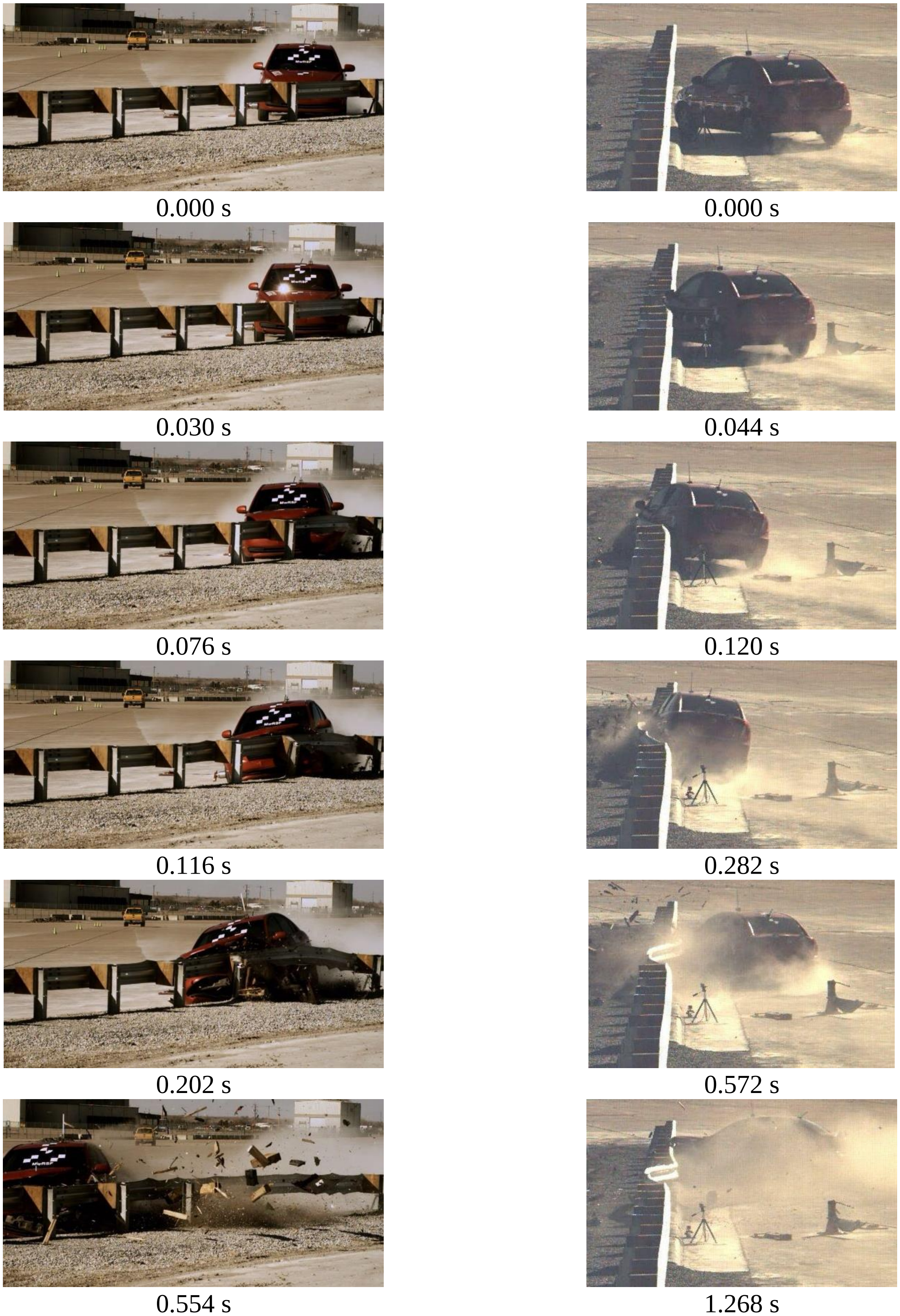


Figure 58. Additional Sequential Photographs, Test No. MGSCO-2

Figure 59. Additional Documentary Photographs, Test No. MGSCO-2

Figure 60. Additional Documentary Photographs, Test No. MGSCO-2

Figure 61. Vehicle Final Position and Trajectory Marks, Test No. MGSCO-2

7.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 62 through 65. Barrier damage consisted of contact marks, bent and deformed posts, fractured blockouts, and deformed W-beam guardrail. The length of vehicle contact along the barrier was approximately 29 ft – 2.2 in. (8.9 m) which spanned from 10 ft – 5.2 in. (3.2 m) upstream from the centerline of post no. 14 downstream to post no. 17. Contact marks and video analysis indicated the vehicle briefly re-contacted the rail approximately 17 in. (432 mm) downstream from post no. 20 before rebounding off of post no. 21 and coming to rest.

Tire marks were found on the curb near the point of impact and on the top of the curb in front of post no. 14. The rail experienced bending, kinking, and flattening at multiple locations spanning from post nos. 13 to 17. The rail was disengaged from the guardrail bolts at post nos. 14 through 17. The maximum lateral splice separation was measured to be ⅜ in. (10 mm) at the splice between post nos. 15 and 16. There was no evidence of rail tearing.

Post nos. 14 and 15 were bent backward and downstream as they had been overridden by the vehicle. Post nos. 13 and 16 were only slightly deflected backward. The guardrail bolt tore out of the bolt hole on post no. 14, while the guardrail bolt at post no. 15 was bent approximately 90 degrees. The blockouts from post nos. 14 and 15 were fractured and disengaged, and the blockout on post no. 16 was vertically split near its back-downstream corner. The majority of the posts outside of the contact region were twisted to face the impacted area.

The maximum lateral permanent set of the barrier system, including guardrail and post deflection, was 16¾ in. (425 mm) which occurred 37.5 in. (953 mm) upstream from post no. 14, as measured in the field. The maximum lateral dynamic barrier deflection, including deformation of the MGS along the top surface, was 23.4 in. (594 mm) at post no. 14. The lateral post dynamic deflection was 20.2 in. (513 mm), and the lateral rail dynamic deflection was 23.4 in. (594 mm). The rail and post dynamic deflections were determined from high-speed digital video analysis. The working width of the system was found to be 39.4 in. (1,001 mm), also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 66.

7.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 67 through 69. The maximum occupant compartment intrusions are listed in Table 10 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. There were no penetrations into the occupant compartment and none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

The majority of the damage was concentrated on the front and the front-left corner of the vehicle. The front bumper cover disengaged from the vehicle. The left side of the front bumper was dented inward approximately 8 in. (203 mm) and down approximately 10 degrees. The right frame horn was separated from the front bumper at the weld. The radiator was crushed in 2½ in. (64 mm) from the top, and the condenser was dented 2½ in. (64 mm) from the top. The upper support for the radiator was ripped off its attachment mounts. The left side of the hood crumpled and the right side of the hood was dented and deflected. The vehicle's headlights were crushed and disengaged. The left-front fender was crushed inward toward the engine bay. The left-front wheel rim was dented along the edge, and a 3-in. (76-mm) gouge was found on the inside of the tire's side wall. The vehicle's windshield was cracked near the center toward the left side. The roof and remaining window glass remained undamaged.

Figure 62. System Damage, Test No. MGSCO-2

Figure 63. Additional System Damage, Test No. MGSCO-2

Figure 64. System Damage, Post Nos. 13 and 14, Test No. MGSCO-2

Figure 65. System Damage, Post Nos. 15 through 18, Test No. MGSCO-2

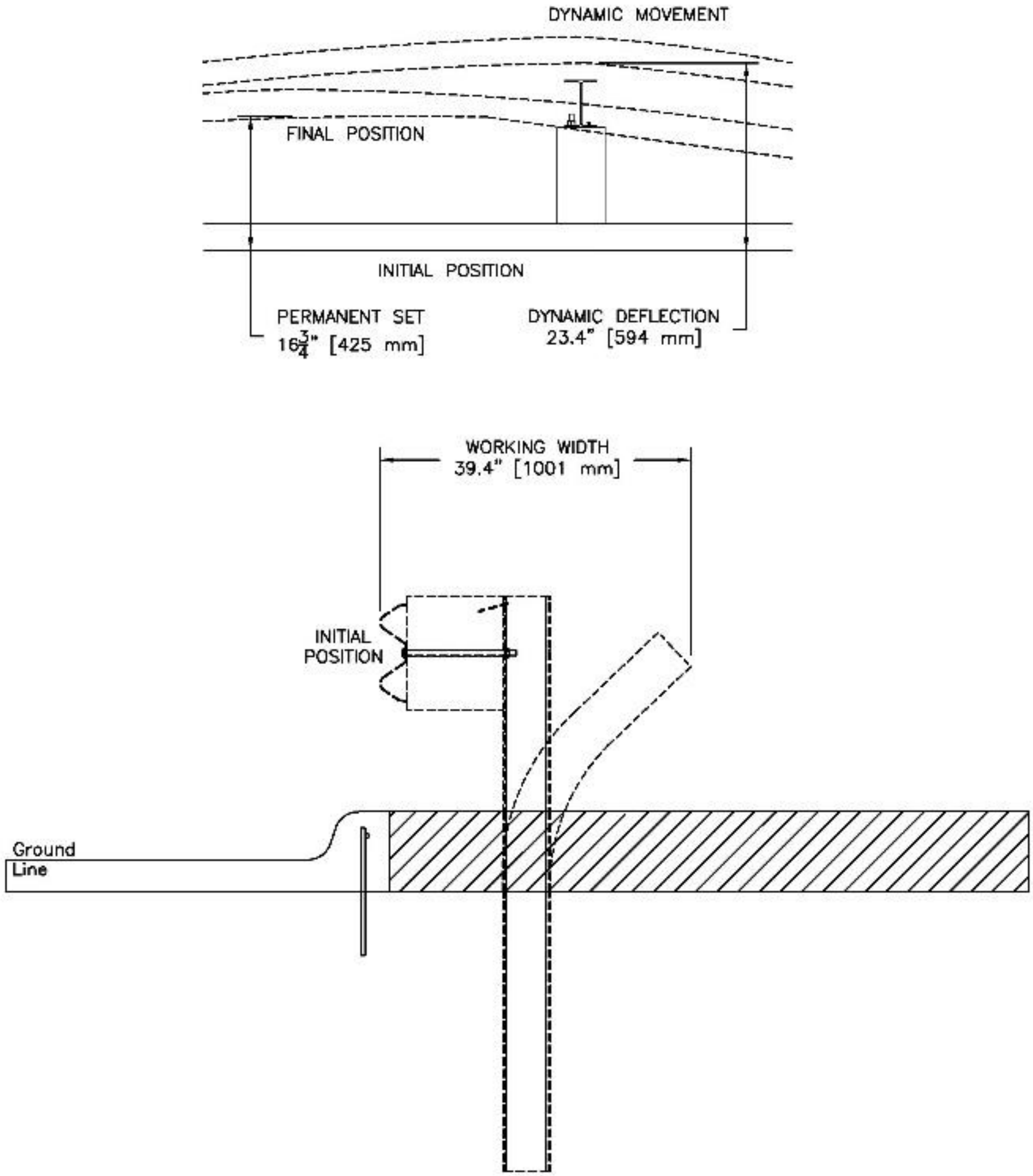


Figure 66. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. MGSCO-2

Figure 67. Vehicle Damage, Test No. MGSCO-2

Figure 68. Additional Vehicle Damage, Test No. MGSCO-2

Figure 69. Occupant Compartment and Undercarriage Damage, Test No. MGSCO-2

Table 10. Maximum Occupant Compartment Intrusion by Location

LOCATION	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	½ (13)	≤ 9 (229)
Floor Pan & Transmission Tunnel	⅛ (3)	≤ 12 (305)
A- and B-Pillars	¼ (6)	≤ 5 (127)
A- and B-Pillars (Lateral)	⅛ (3)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	½ (13)	≤ 12 (305)
Side Door (Above Seat)	⅜ (10)	≤ 9 (229)
Side Door (Below Seat)	⅜ (10)	≤ 12 (305)
Roof	⅛ (3)	≤ 4 (102)
Windshield	0	≤ 3 (76)
Side Window	Intact	No shattering resulting from contact with structural member of test article
Dash	¼ (6)	N/A

N/A – Not applicable

Damage to the vehicle's undercarriage included bending of the middle of the left-front strut. No additional damage to the suspension was observed. A dent was observed on the front of the transmission pan, and the oil pan was scratched. Gouges were observed on the bottom of the lower-front engine mount. The left-side frame horn was crushed inward and down, and the right-front corner of the engine and transmission cradle bent in and up at the point of initial impact. Scrapes and gouges were found along the back section of the cradle.

7.6 Occupant Risk

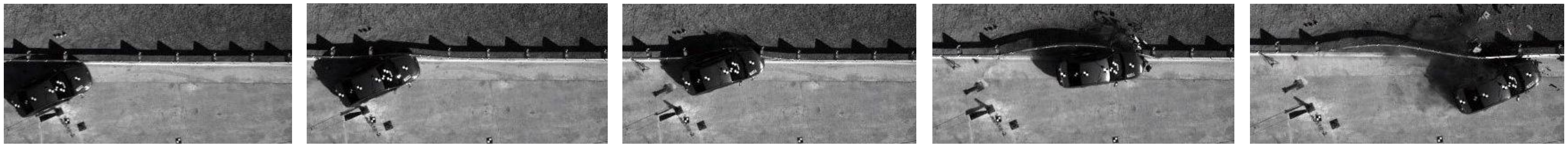
The calculated occupant impact velocities (OIVs) and maximum 10-ms average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 11. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 11. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix F.

Table 11. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MGSCO-2

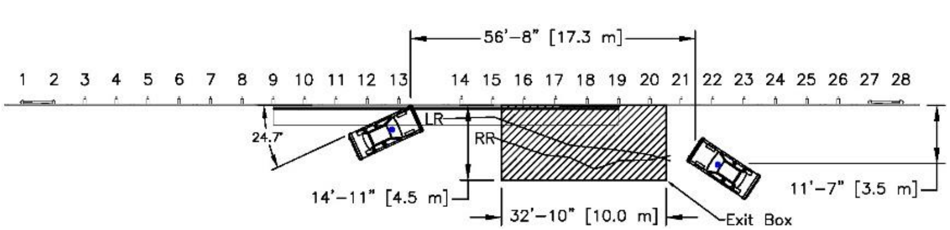
Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1	**SLICE-2 (Primary)**	
OIV ft/s (m/s)	Longitudinal	-33.40 (-10.18)	-33.25 (-10.13)	±40 (12.2)
	Lateral	20.65 (6.29)	19.95 (6.08)	±40 (12.2)
ORA g's	Longitudinal	-10.96	-10.04	±20.49
	Lateral	10.31	9.58	±20.49
MAX. ANGULAR DISPL. deg.	Roll	12.6	14.1	±75
	Pitch	-3.8	-4.1	±75
	Yaw	-31.1	-30.3	not required
THIV ft/s (m/s)		28.64 (8.73)	29.63 (9.03)	not required
PHD g's		15.01	13.71	not required
ASI		1.11	1.08	not required

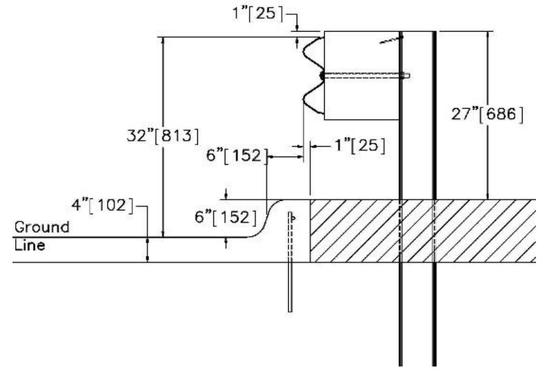
7.7 Discussion

The analysis of the test results for test no. MGSCO-2 showed that the system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 70. 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. 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 F, were deemed acceptable, as they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 16.4 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. MGSCO-2 was determined to satisfy the MASH 2016 safety performance criteria for test designation no. 3-10.



0.000 s | 0.040 s | 0.106 s | 0.278 s | 0.554 s





- Test Agency .... MwRSF
- Test Number MGSCO-2
- Date .... February 2, 2018
- MASH 2016 Test Designation No. 3-10
- Test Article .... MGS with Curb and Omitted Post
- Total Length .... 182 ft - 3½ in. (55.6 m)
- Key Component – Steel W-beam Guardrail
  - Thickness .... 12 gauge (2.7 mm)
  - Top Mounting Height .... 32 in. (813 mm) from roadway surface
- Key Component – Steel Post
  - Shape .... W6x8.5 (W152x12.6) or W6x9 (W152x13.4)
  - Length .... 72 in. (1,829 mm)
  - Post Nos. 1-12, 15-28 Spacing .... 75 in. (1,905 mm)
  - Post Nos. 13-14 Spacing .... 150 in. (3,810 mm)
  - Embedment Depth .... 45 in. (1,143 mm)
- Key Component – Wood Blockout
  Post Nos. 3-26 .... 6 x 2 x 14¼ (152 x 305 x 362 mm)
- Soil Type .... Well-Graded Gravel (GW)
- Vehicle Make /Model .... 2011 Hyundai Accent
  Curb .... 2,440 lb (1,107 kg)
  Test Inertial .... 2,404 lb (1,090 kg)
  Gross Static .... 2,566 lb (1,164 kg)
- Impact Conditions
  Speed .... 63.2 mph (102 km/h)
  Angle .... 24.7 deg.
  Impact Location .... 125.2 in. (3,180 mm) US from centerline of post no. 14
- Impact Severity .... 56.1 kip-ft (76 kJ) > 51 kip-ft (69.7 kJ) limit from MASH 2016
- Exit Conditions
  Speed .... 26.5 mph (42.6 km/h)
  Angle .... 9.3 deg. facing the front of the barrier
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory

- Vehicle Stopping Distance .... 56 ft - 8 in. (17.3 m) DS from Impact Location
  11 ft – 7 in. (3.5 m) laterally in front
- Vehicle Damage .... Moderate
  VDS [17] 11-FL-4
  CDC [18] 11-FLEW-3
  Maximum Interior Deformation .... ½ in. (13 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  Permanent Set .... 16¾ in. (425 mm)
  Dynamic .... 23.4 in. (594 mm)
  Working Width .... 39.4 in. (1,001 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (Primary)	
OIV ft/s (m/s)	Longitudinal	-33.40 (-10.18)	-33.25 (-10.13)	±40 (12.2)
	Lateral	20.65 (6.29)	19.95 (6.08)	±40 (12.2)
ORA g's	Longitudinal	-10.96	-10.04	±20.49
	Lateral	10.31	9.58	±20.49
MAX ANGULAR DISP. deg.	Roll	12.6	14.1	±75
	Pitch	-3.8	-4.1	±75
	Yaw	-31.1	-30.3	not required
THIV – ft/s (m/s)		28.64 (8.73)	29.63 (9.03)	not required
PHD – g's		15.01	13.71	not required
ASI		1.11	1.08	not required

Figure 70. Summary of Test Results and Sequential Photographs, Test No. MGSCO-2

8 SUMMARY AND CONCLUSIONS

The objective of this project was to evaluate the MGS in combination with a curb and an omitted post in accordance with MASH 2016 TL-3 criteria. The test article utilized for full-scale crash testing consisted of the MGS placed with the face of the rail offset 6 in. (152 mm) behind a 6-in (152-mm) tall AASHTO Type B curb. Additionally, one post was omitted from the middle of the barrier system creating a single elongated rail span of 150 in. (3,810 mm).

In test no. MGSCO-1, the 2,438-lb (1,106-kg) small car impacted the MGS with a curb and omitted post at a speed of 64.1 mph (103 km/h) an angle of 25.7 degrees, at a location 124.7 in. (3,167 mm) upstream from the centerline of post no. 14, thus resulting in an impact severity of 62.9 kip-ft (85 kJ). During the impact event, the W-beam rail ruptured at the splice located within the elongated span length, and the vehicle penetrated the system and eventually rolled over. Additionally, the windshield crush of 4 in. (102mm) exceeded the allowable limits for occupant compartment deformation. Thus, test no. MGSCO-1 failed to satisfy safety performance criteria for MASH 2016 test no. 3-10. Rail rupture was believed to be related to the concentrated loading of the bumper on the rail, the increased stiffness of the post with the additional embedment, and the vertical and twisting forces applied by the small car bumper wedging under the rail.

To strengthen the rail and prevent premature failure, the system was modified to incorporate 37.5 ft (11.4 m) of nested guardrail encompassing the elongated rail span and the two adjacent 75-in. (1,905-mm) spans on each side. The modified system was then retested according to MASH 2016 test designation no. 3-10. In test no. MGSCO-2 the 2,404-lb (1,090-kg) small car impacted the MGS with a curb and an omitted post at a speed of 63.2 mph (102 km/h) an angle of 24.7 degrees, at a location 125.2 in. (3,180 mm) upstream from the centerline of post no. 14, thus resulting in an impact severity of 56.1 kip-ft (76 kJ). The vehicle was captured and redirected without any evidence of rail tearing. The vehicle remained upright and stable through the test, and all vehicle decelerations and occupant compartment deformations were within the allowable MASH 2016 limits. Therefore, test no. MGSCO-2 was determined to satisfy the safety performance criteria for MASH 2016 test designation no. 3-10. A summary of both test evaluations is shown in Table 12.

The project was originally intended to include both tests within the MASH 2016 TL-3 matrix, test designation nos. 3-10 and 3-11 with the small car and pickup truck, respectively. However, the failure experienced during test no. MGSCO-1 required a design modification and retesting to MASH 2016 test designation no. 3-10 impact conditions. Although test no. MGSCO-2 passed the safety performance criteria of MASH 2016 test designation no. 3-10, the system must also be tested to MASH 2016 test no. 3-11 criteria in order to complete the MASH 2016 TL-3 evaluation matrix and be deemed crashworthy. Subsequently, an additional project containing a MASH 3-11 test on the system was funded as part of the 2018 Midwest Pooled Fund Program and is scheduled to be completed in 2020.

Table 12. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. MGSCO-1</th><th>Test No. MGSCO-2</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>U</td><td>S</td></tr>
<tr><td rowspan="12">Occupant Risk</td><td rowspan="2">D</td><td colspan="3">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.</td><td>S</td><td>S</td></tr>
<tr><td colspan="3">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.</td><td>U</td><td>S</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>U</td><td>S</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
<tr><td colspan="5">MASH 2016 Test Designation No.</td><td>3-10</td><td>3-10</td></tr>
<tr><td colspan="5">Final Evaluation (Pass or Fail)</td><td>Fail</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

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10 APPENDICES

Appendix A. Material Specifications

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

Item No.	Description	Material Spec	Reference No.
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	H#515691
a4	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long Steel Post	ASTM A992 Min. 50 ksi [345 MPa]	H#55044258 H#55044251
a5	6" x 12" x 14¼" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No. 1 or better	Ch#21327 Ch#18379 Part#GR61214BLK
a6	16D Double Head Nail	-	Order#E000357170
b1	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension force)	Ch#22927 Part#GS6846PST
b2	72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	H#0173175
b3	Ground Strut Assembly	ASTM A1011	H#163375
b4	2⅜" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	H#A79999
b5	8" x 8" x ⅝" [203x203x16] Anchor Bearing Plate	ASTM A36	H#DL15103543
b6	Anchor Bracket Assembly	ASTM A36	H#JK16101488
c1	BCT Anchor Cable	-	Part#3012G
d1	⅝" [16] Dia. UNC, 14" [356] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolts: H#NF16100453 H#6600679 Nuts: H#10446960
d2	⅝" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolts: H#20351510 H#20297970 Nuts: H#10446960
d3	⅝" [16] Dia. UNC, 1¼" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolts: H#20337380 L#005377 Nuts: H#10446960
d4	⅝" [16] Dia. UNC, 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolts: H#DL15107048 Nuts: Part#36713
d5	⅝" [16] Dia. UNC, 1½" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	Bolts: H#816070039 Nuts: Part#36713
d6	⅞" [22] Dia. UNC, 8" [203] Long Hex Head Bolt and Nut	Bolt – ASTM A36 Gr. A Nut – ASTM A563A	Bolts: H#2038622 Nuts: H#12101054
e1	⅝" [16] Dia. Plain Round Washer	ASTM F844	n/a
e2	⅞" [22] Dia. Plain Round Washer	ASTM F844	L#16H-168236-30
f1	Curb	f'c = 4,000 psi [27.6 MPa]	Ticket#1215828
f2	#4 Rebar 819" [20,803] Long	ASTM A615 Gr. 60	H#JW16104719
f3	#4 Rebar 16" [406] Long	ASTM A615 Gr. 60	H#58028856

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

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 July 2015

Notary Public, State of Ohio

NOTARIAL SEAL
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. (3.8-m) W-Beam MGS Section and End Section, Test Nos. MGSCO-1 and MGSCO-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

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
			M-180	A	2	515664	64,600	74,600	25.0	0.067	0.740	0.009	0.008	0.010	0.019	0.000	0.022	0.000	4
			M-180	A	2	515665	64,300	73,800	27.0	0.063	0.750	0.012	0.008	0.007	0.018	0.000	0.027	0.000	4
			M-180	A	2	515666	64,700	74,200	27.0	0.067	0.740	0.009	0.008	0.010	0.031	0.000	0.023	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	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	515691	64,000	72,300	27.0	0.060	0.740	0.009	0.008	0.010	0.021	0.000	0.032	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	515701	64,300	74,200	28.0	0.064	0.800	0.013	0.010	0.010	0.030	0.000	0.029	0.000	4
			M-180	A	2	515701	65,200	73,700	28.0	0.064	0.800	0.013	0.010	0.010	0.030	0.000	0.029	0.000	4
			M-180	A	2	521448	65,400	75,600	28.0	0.074	0.078	0.014	0.012	0.010	0.060	0.000	0.058	0.000	4
			M-180	A	2	616037	67,800	78,000	26.0	0.065	0.830	0.014	0.007	0.016	0.023	0.000	0.026	0.000	4
			M-180	A	2	616038	65,500	73,700	24.0	0.070	0.740	0.009	0.006	0.015	0.014	0.000	0.018	0.000	4
			M-180	A	2	616041	63,700	74,300	28.0	0.065	0.760	0.013	0.008	0.009	0.028	0.000	0.029	0.000	4
			M-180	A	2	616043	62,700	71,800	27.0	0.067	0.740	0.013	0.008	0.010	0.034	0.000	0.031	0.000	4
			M-180	A	2	616043	64,900	77,000	25.0	0.067	0.740	0.013	0.008	0.010	0.034	0.000	0.031	0.000	4
			M-180	A	2	616067	63,200	73,300	28.0	0.063	0.750	0.013	0.010	0.012	0.035	0.000	0.032	0.000	4
			M-180	A	2	616069	62,600	73,100	26.0	0.064	0.750	0.008	0.007	0.011	0.026	0.000	0.022	0.000	4
			M-180	A	2	616070	62,800	73,000	29.0	0.060	0.730	0.014	0.008	0.012	0.021	0.000	0.032	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
			M-180	A	2	621267	65,000	74,800	29.0	0.066	0.780	0.015	0.013	0.009	0.068	0.000	0.055	0.000	4
22	12365G	T12/12'6/8@1'6.75/S	M-180	A	2	151877	58,680	77,470	26.0	0.190	0.720	0.013	0.004	0.010	0.120	0.00	0.050	0.002	4

2 of 4

Figure A-2. 6-ft – 3-in. (1.9-m) W-Beam MGS Section, Test Nos. MGSCO-1 and MGSCO-2

CERTIFIED MATERIAL TEST REPORT Page 1/1

GERDAU

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

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

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

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

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

CHEMICAL COMPOSITION

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

MECHANICAL PROPERTIES

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

COMMENTS / NOTES

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

Bhaskar
BHASKAR YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

Figure A-3. 72-in. (1,829-mm) Long Steel Post, Test Nos. MGSCO-1 and MGSCO-2

CERTIFIED MATERIAL TEST REPORT

Page 1/1

GERDAU

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

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
HIGHWAY SAFETY CORP 473 W FAIRGROUND ST MARION,OH 43302-1701 USA	HIGHWAY SAFETY CORP GLASTONBURY,CT 06033-0358 USA	A992/A709-36	Wide Flange Beam / 6 X 8.5# / 150 X 13.0	0000006197

LENGTH	WEIGHT	HEAT / BATCH
42'00"	44,982 LB	55044251/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
3399484/000010	IB-B0600800	ASTM A6-14 ASTM A709-13A ASTM A992-11 CSA G40.21-13 345WM

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
000167 PO#1677003	1323-0000066391	03/16/2016

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	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 0.2% PSI	UTS PSI	YS MPa	UTS MPa	G/L Inch	Elong. %
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. CMTR complies with EN 10204 3.1.

Bhaskar

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

Figure A-4. 72-in. (1,829-mm) Long Steel Post, Test Nos. MGSCO-1 and MGSCO-2

CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 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# 18052937

Customer PO# 3161 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
	6x12 – 14" OCD Blok	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.

GM
Nick Sowl, General Counsel

10/29/15
Date

Figure A-5. Timber Blockout for Steel Posts, Test Nos. MGSCO-1 and MGSCO-2

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

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

CWNP Invoice 10048570
Shipped To MIDWEST-MILFORD
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, 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-6. Timber Blockout for Steel Posts, Test Nos. MGSCO-1 and MGSCO-2

CENTRAL
NEBRASKA
WOOD PRESERVERS, INC.

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

6x12x14 B/O
Orange Paint
R#17-395
Purchased for Thrie Buttress

Date: 7/26/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10054605

Customer PO# 3292 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
40756	6x8-14" BLK	126	22416	.676
GR61214BLK	6x12-14" OCD BLK	84	21292	.623
⎫	⎫	84	22397	.607
⎭	⎭	168	22421	.733

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

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

Nick Sowl, General Counsel

7/26/16
Date

Figure A-7. Timber Blockout for Steel Posts, Test Nos. MGSCO-1 and MGSCO-2

McMASTER-CARR

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

Figure A-8. Double-Headed Nails, Test Nos. MGSCO-1 and MGSCO-2

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

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

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

Date: 11/11/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10055387

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

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GR6806.5PST	6x8-6.5" PST	35	22973	.679
GR6806.5CRT	6x8-6.5" CRT	35	22973	.679
GS6846PST	5.5-7.5-46" BCT	42	22927	.638
6R61214BLK	6x12-14" OCD	168	22927	.638

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

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

Nick Sowl, General Counsel

11/11/16
Date

Figure A-9. BCT Timber Post, Test Nos. MGSCO-1 and MGSCO-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 3/4X6'6/DBL	HW			99692													
25	4063B	WD 6'0 POST 6X8 CRT	HW			43360													
15	4147B	WD 3'9 POST 5.5"X7.5"	HW			2401													
20	15000G	6'0 SYT PST/8.5/31" GR HT	A-36			34940	46,000	66,000	25.3	0.130	0.640	0.012	0.043	0.220	0.310	0.001	0.100	0.002	4
10	19948G	.135(10Ga)X1.75X1.75	HW			P34744													
2	33795G	SYT-3"AN STRT 3-HL 6'6	A-36			JJ6421	53,600	73,400	31.3	0.140	1.050	0.009	0.028	0.210	0.280	0.000	0.100	0.022	4
4	34053A	SRT-31 TRM UP PST 2'6.625	A-36			JJ5463	56,300	77,700	31.3	0.170	1.070	0.009	0.016	0.240	0.220	0.002	0.080	0.020	4

1 of 3

Figure A-10. Foundation Tube, Test Nos. MGSCO-1 and MGSCO-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 Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

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

1 of 2

Figure A-11. Ground Strut Assembly, Test Nos. MGSCO-1 and MGSCO-2

425 E. O'Connor
Lima, OH

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

LINCOLN, NE 68501-1097

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

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

Trinity Highway Products. LLC

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

NCHRP Report 350 Compliant

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

MGSBR

Ground Strut

090453-8

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

402-761-3288

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

06/04/2009 16:36

Notary Public:
Commission Expires

Trinity Highway Products, LLC
Certified By:

2 of 4

Figure A-12. Ground Strut Assembly, Test Nos. MGSCO-1 and MGSCO-2

EXLTUBE

1000 BURLINGTON STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

Certified Test Report

Customer:	Size:	Customer Order No:	Date:
SPS - New Century 401 New Century Parkway NEW CENTURY KS 66031-1127	02.375	4500269918	07/25/2016
	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 KSI	Tensile KSI	Elongation % 2 inch
A79999	63.2	67.3	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 tiles 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-13. BCT Post Sleeve, Test Nos. MGSCO-1 and MGSCO-2

NUCOR
NUCOR CORPORATION
NUCOR STEEL SOUTH CAROLINA

Mill Certification
7/30/2015

MTR #: 0000087896
300 Steel Mill Road
DARLINGTON, SC 29540
(843) 393-5841
Fax: (843) 395-8701

Sold To: TRINITY INDUSTRIES INC
ROLLFORM ACCOUNTING-4TH FLOOR
PO BOX 568887
DALLAS, TX 75356-8887
(214) 689-0847
Fax: (214) 589-8535

Ship To: TRINITY INDUSTRIES LIMA
550 E. ROBB AVENUE
PLANT 55
LIMA, OH 45801-0000
(214) 589-8407
Fax: (214) 589-8420

Customer P.O.	171075	Sales Order	229472.1
Product Group	Merchant Bar Quality	Part Number	5362580024010W0
Grade	NUCOR MULTIGRADE	Lot #	DL1510354303
Size	5/8x8" Flat	Heat #	DL15103543
Product	5/8x8" Flat 20' NUCOR MULTIGRADE	B.L. Number	C1-668702
Description	NUCOR MULTIGRADE	Load Number	C1-347435
Customer Spec		Customer Part #	100395B

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: 6/22/2015 Melt Date: 6/18/2015 Qty Shipped LBS: 45,929 Qty Shipped Pcs: 135

Melt Date: 6/18/2015

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.15%	0.75%	0.013%	0.025%	0.20%	0.36%	0.09%	0.09%	0.021%	0.0500%	0.003%	0.016%
Ti	CE4020										
0.001%	0.34%										

CE4020: C. E. CSA G4020, AASHTO M270

Roll Date: 6/22/2015

Yield 1: 58,000psi	Tensile 1: 74,000psi	Elongation: 25% in 8"(% in 203.3mm)
Yield 2: 58,000psi	Tensile 2: 74,000psi	Elongation 25% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/A36M-12, A529/529M-05(2009) GR50(345), A572/572M-13A GR50(345), A709/709M-13A GR36(250) & GR50(345), CSA G40.21-04 GR44W(300W) & GR50W(350W) AASHTO M270/M270M-10 GR36(270) & GR50(345), ASME SA36/SA36M-07, QQ-S-741D, KILLED FG PRACTICE

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

James H. Blew
Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 1

Figure A-14. Anchor Bearing Plate, Test Nos. MGSCO-1 and MGSCO-2

NUCOR
NUCOR STEEL JACKSON, INC.

Mill Certification
7/27/2016

MTR #: M1-150903
NUCOR STEEL JACKSON, INC.
3630 Fourth Street
Flowood, MS 39232
(601) 939-1623
Fax: (601) 936-6202

Sold To: O'NEAL STEEL INC
ATTN ACCOUNTS PAYABLE
PO BOX 98
BIRMINGHAM, AL 35202-0098
(205) 599-8000
Fax: (205) 599-8052

Ship To: O'NEAL STEEL INC
4530 MESSER-AIRPORT HWY
BIRMINGHAM, AL 35222
(205) 599-8000
Fax: (205) 599-8052

Customer P.O.	00771356	Sales Order	343125.5
Product Group	Merchant Bar Quality	Part Number	5350030024010W0
Grade	NUCOR MULTIGRADE	Lot #	JK1610148801
Size	1/2x3" Flat	Heat #	JK16101488
Product	1/2x3" Flat 20' NUCOR MULTIGRADE	B.L. Number	M1-429898
Description	NUCOR MULTIGRADE	Load Number	M1-150903
Customer Spec		Customer Part #	00777557

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: 4/5/2016 Melt Date: 3/30/2016 Qty Shipped LBS: 4,900 Qty Shipped Pcs: 48

Melt Date: 3/30/2016

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.16%	0.78%	0.017%	0.028%	0.20%	0.28%	0.09%	0.14%	0.020%	0.0280%	0.001%	0.010%
CE4020	CEA529										
0.35%	0.39%										

CE4020: C. E. CSA G4020, AASHTO M270
CEA529: A529 CARBON EQUIVALENT

Roll Date: 4/5/2016

Yield 1: 56,172psi	Tensile 1: 75,460psi	Elongation: 25% in 8"(% in 203.3mm)
Yield 2: 56,126psi	Tensile 2: 76,500psi	Elongation 25% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/36M, ASTM A529/529M GR50 ASTM A572/572M GR50 ASTM709/709M GR36/GR50 CSA G40.21 GR44W(300W)/GR50W(350W) AASHTO M270/M270M GR36/GR50 ASME SA36/SA36M MEETS EN10204 SEC 3.1 REPORTING REQUIREMENTS

ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT, INCLUDING MELTING, HAVE OCCURRED WITHIN THE UNITED STATES. ALL PRODUCTS PRODUCED ARE WELD FREE. MERCURY, IN ANY FORM, HAS NOT BEEN USED IN THE PRODUCTION OR TESTING OF THIS MATERIAL.

QA Approved
SI# 777557

Christopher Smith
Christopher Smith
Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 1

Figure A-15. Anchor Bracket Assembly, Test Nos. MGSCO-1 and MGSCO-2

COMMERCIAL GROUP LIFTING PRODUCTS

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

Figure A-16. BCT Anchor Cable, Test Nos. MGSCO-1 and MGSCO-2

R#16-692 5/8"x14"GR Bolt
Orange Paint H#16100453 L#28667-B
June2016 SMT

CERTIFICATE OF COMPLIANCE

3540G

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

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 176703

SHIPPER #: 057716
DATE SHIPPED: 05/17/2016

LOT#: 28667-B

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE: SPEC: 60,000 psi*min RESULTS: 78,080
76,544

HARDNESS: 100 max 82.10
83.50

*Pounds Per Square Inch.

COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
ROGERS GALVANIZE: 28667-B

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si
NUCOR	1010	NF16100453	.12	.56	.006	.030	.19

QUANTITY AND DESCRIPTION:

5,950 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 CERIFY 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
17th DAY OF May 2016
Merry F Shane

Linda Melomas
APPROVED SIGNATORY

5/17/16
DATE

OFFICIAL SEAL
MERRY F. SHANE
NOTARY PUBLIC – STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Figure A-17. 14-in. (356-mm) Long Guardrail Bolt, Test Nos. MGSCO-1 and MGSCO-2

FASTENERS & FITTINGS INC.

901 STEELES AVENUE EAST
MILTON, ONTARIO L9T 5H3
PHONE: (905) 670-2503 FAX: (905) 670-2506, TOLL FREE: 1-800-613-4094

ISO 9001 REGISTERED COMPANY

CERTIFICATE OF CONFORMANCE

CUSTOMER	: ROLL FORM GROUP	OUR PACKING SLIP NO:	: 66192
CUSTOMER PO NO	: 18329	OUR INVOICE NO:	: ---
ITEM	: GUARDRAIL BOLT	SUPPLIER INVOICE NO	: HSW07046
SIZE	: 5/8" - 11 x 14" H.D.G	BULK LOT NO / PO No.	: 1017
HEAT NO	: 6600679	DATE	: 12-Jun-07

No	Test Item	Specs / Standards / Criteria	Result
1	Appearance	Per ASTM F 812-95	OK
2	Thread	Go & No Go and P.D & M.D	OK
3	Mark		307 A N
4	Coating Thickness	CSA-CSAG-164-M Class 5(Min 65um or 2.54 mills)Avg.	70.8
5	Mass of Coating	CSA-CSAG-164-M Class 5(Min 460g/m2 or 1.5 oz/ft2)Avg.	505.3
6	Dimensions	Head Diameter(31.80-34.85)	32.36-33.51
		Head Height(7.20-10.26)	8.62-9.39
		Shoulder Width O(22.25-23.77)	22.68-23.21
		Shoulder Width V(15.08-16.66)	15.76-16.33
		Shoulder Depth P(4.78-6.29)	5.61-6.01
		Length(351.03-359.15)	353.77-355.20
7	Tensile Strength	Min 60,000 PSI	61,500-64,000 PSI
8	Material	Per ASTM (A307)	OK

Material Chemical Composition:

C	Si	Mn	P	S
%	%	%	%	%
0.12	0.18	0.46	0.028	0.02

Hot Dip Galvanizing Inspection Certificate: (Test Standard CSAG-164-M class 5)

Test of No.	Weight of coating test							G/m² over
1	70	73	70	69	72	72	71.0	506.9
2	72	68	72	72	68	72	70.7	504.6
3	69	72	70	68	72	72	70.5	503.4
4	71	70	71	72	69	71	70.7	504.6
5	72	70	72	72	71	69	71.0	506.9
Average of The Average							70.8	505.3

Muhammad Ashraf
905-670-2503 ext 328
16 Aug 2011

2-0063-11X1400"SGUG (HSW07046) WO# 11165 PPS# 66192 CustPO# 18329 Aug16-2011

Figure A-18. 14-in. (356-mm) Long Guardrail Bolt, Test Nos. MGSCO-1 and MGSCO-2

CERTIFICATION

ELGIN FASTENER GROUP
BEREA PLANT

DATE: 10/28/2016

CUSTOMER
Trinity Highway Plant #55
550 E. Robb Ave.
Attn: Phil Speck
Lima, OH 45801

DESCRIPTION
Nut Guard Rail 5/8-11 A563
GRA HDG + .031

EFG PART NUMBER: 221914

CUSTOMER P.O.
177002

LOT NUMBER
0055551-116146

MATERIAL
1018

CUSTOMER PART NUMBER
003340G

INVOICE
46048

SHIP DATE
10/28/2016

HEAT NUMBER
10446960

QUANTITY
26000

HARDNESS: B 89.5
PROOF LOAD: 5 samples passed at 75,000 psi min.
PLATING: Hot Dip Galvanized - Pass

All parts processed Mercury free and without Welds.

We hereby certify that to our actual knowledge the information contained herein is correct. We also certify that all parts substantially conform to SAE, ASTM, or customer specifications as agreed upon. The product has been manufactured and tested in accordance with our Quality Assurance manual. The above data accurately represents values provided by our suppliers or values generated in the EFG – Berea Plant laboratory. All manufacturing processes for these parts occurred in the United States of America.

This document may only be reproduced without alteration and only for the purpose of certifying the same or lesser quantity of the product specified here.

The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal Statutes.

Joe Kilpatrick

Joe Kilpatrick

Quality Technician

777 Bagley Road ★ Berea, OH 44017 ★ 440 826 0811 ★ elginfasteners.com

ENGINEERED FASTENING SOLUTIONS

Figure A-19. ⅝-in. (16-mm) Diameter Nut, Test Nos. MGSCO-1 and MGSCO-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

FEB 25 2016

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 / Mils) 2.52 (2.0 Mils 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.

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 12-17-15

NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 419-227-1296

NOTARIAL SEAL STATE OF OHIO

MONIQUE HOLMES
Notary Public, State of Ohio
My Commission Expires
July 5, 2020

Figure A-20. 10-in. (254-mm) Long Guardrail Bolt, Test Nos. MGSCO-1 and MGSCO-2

R#15-0627 H#20297970 L#140530L
5/8x10" Guardrail Bolt
June 2015 SMT White Paint

35006

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

7/31/14

MATERIAL CERTIFICATION

Customer: Stock
Date: June 25,2014
Invoice Number:
Lot Number: 140530L
Part Number: 3500G
Quantity: 17,173 Pcs.
Description: 5/8" x 10" G.R. Bolt

Heat Numbers:	
20297970	17,173

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
20297970	.09	.33	.006	.001	.06	.03	.04	.01	.06	.002	.001	.026	.008	.0001	.001	.002

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.54 (2.0 Mils 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.

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 11th day of July 2014

Sherri Braun NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 45801 419-227-1296.

NOTARIAL SEAL STATE OF OHIO
SHERRI BRAUN
Notary Public, State of Ohio
My Commission Expires
April 20, 2019

RECEIVED
JUL 11 2014
Trinity Highway Products, LLC
Dallas, Texas. Plant 99

Figure A-21. 10-in. (254-mm) Long Guardrail Bolt, Test Nos. MGSCO-1 and MGSCO-2

Customer:	Bennett Bolt Works, Inc.	Date:	11/7/2014
Description:	5/8-11 x 1-1/4 Guard Rail Bolt A307 HDG-A153 Class C	P/N:	62C125BSP3
Order No:	827556	Lot #:	0090480-KD

Physical Test

Sample	Hardness 69-100HRB	Plating	Stress Area	Proof Load	Ultimate Tensile		
Required				LBS.	PSI	LBS. ≥13,560	PSI ≥60,000
1	88		0.226			18,100	80,002
2	93		0.226			18,050	79,781
3	93		0.226			17,995	79,538
4	92		0.226			18,030	79,693
5	94		0.226			17,950	79,339

Chemistry

Heat #	C	MN	P	S	SI	NI	CR	MO	PB	V	B	AL	CU	Other
20337380	.14	.35	.008	.002	.070	.03	.06	.01	-	.001	.0001	.050	.05	-

Dimensional Check

Head Height:	.293	Thread Length:	.971
.292/.332	.305	Full Thread	.973
Body Diameter:	.621		.980
.594/.656	.635		
Length:	1.281	Point:	IN THE DIE
1.188/1.312	1.276	Total Volume:	224,113 pcs
	1.271	Pc Wt:	178.84/1,000 Pcs.

SILO FASTENERS

1415 S BENHAM ROAD

VERSAILLES IND 47042

Name: TERRY ELKINS

Terry Elkins

Title: QUALITY MANAGER

Date: 10/7/2014

Figure A-22. 1¼-in. (32-mm) Long Guardrail Bolt, Test Nos. MGSCO-1 and MGSCO-2

Customer:	Trinity Highway Products	Date:	10-28-16
Description:	5/8-11 x 1-1/4 Guard Rail Bolt A307 HDG-A153 Class C	P/N:	003360G
Order No:	40563	Lot #:	0053777-AAJ

Physical Test

Sample	Hardness 69-100HRB	Plating	Stress Area	Proof Load	Ultimate Tensile		
Required				LBS.	PSI	LBS. ≥13,560	PSI ≥60,000
1	84		0.226			21,500	95,200
2	85		0.226			21,400	94,700
3	86		0.226			21,500	95,100
4	84		0.226			22,400	94,600
5	85		0.226			21,300	94,300

Chemistry

Heat #	C	MN	P	S	SI	NI	CR	MO	PB	V	B	AL	CU	Other
0435580	.16	.68	.007	.013	.220	.04	.07	.01	-	.002	.0001	.023	.07	-

Dimensional Check

Head Height:	.230	Thread Length:	1.031
.220/.250	.234	Full Thread	1.033
Body Diameter:	.618	1.00 MIN	1.034
.594/.656	.621		
Length:	1.244	Point:	IN THE DIE
1.188/1.312	1.250	Total Volume:	224,000 pcs
	1.269	Pc Wt:	178.84/1,000 Pcs.

SILO FASTENERS

1415 S BENHAM ROAD

VERSAILLES IND 47042

Name: JOE KILPATRICK

Title: QUALITY TECHNICIAN

Date: 10-28-16

Figure A-23. 1¼-in. (32-mm) Long Guardrail Bolt, Test Nos. MGSCO-1 and MGSCO-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) 395-8701

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

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

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

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

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

Melt Date: 12/5/2015

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

CE1554: CE per F1554 GR55, S1

Roll Date: 1/28/2016

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

Specification Comments:

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

James H. Blew

James H. Blew
Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 2

Figure A-24. 10-in. (254-mm) Long Hex Head Bolt, Test Nos. MGSCO-1 and MGSCO-2

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

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

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

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

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

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

David Biss
Quality Manager

December 07, 2015

Page 1 of 1

Figure A-25. ⅝-in. (16-mm) Diameter Hex Nuts, Test Nos. MGSCO-1 and MGSCO-2

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

FACTORY: NINGBO ECONOMIC & TECHNICAL DEVELOPMENT ZONE YONGGANG FASTENERS CO., LTD.
REPORT DATE:2016/12/29
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:	C %*100	Mn%*100	P %*1000	S %*1000
Grade A ASTM A307-12	0.29max	1.20 max	0.04max	0.15max
TEST:	0.07	0.28	0.016	0.003

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

COATINGS OF ZINC: SPECIFIATION:ASTM F2329-2013

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
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 Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

Figure A-26. 1½-in. (38-mm) Long Hex Head Bolt, Test Nos. MGSCO-1 and MGSCO-2

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

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

CMC

1SERIES-BPS®

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

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

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

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

REMARKS :

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

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

Figure A-27. 8-in. (203-mm) Long Hex Head Bolt, Test Nos. MGSCO-1 and MGSCO-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 (%)

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

Mechanical Property Inspection

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

Shape & Dimension	
Inspection	ANSI B18.2.2 GOOD
Thread Precision Inspection	ANSI B1.1 CLASS 2B GOOD
Appearance Inspection	GOOD
Remarks:	"DH U"
	Production Quantity 22,391 pcs.
	BCT Foundation Tube Keeper Bolt Nuts R#15-0600 June 2015 SMT

OFFICIAL SEAL
JEAN MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/18/13
07-10-12

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

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

Chief of Quality Assurance Section

Figure A-28. ⅞-in. (22-mm) Diameter Nuts, Test Nos. MGSCO-1 and MGSCO-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
INVOICE NBR: TD16680155
PART NBR.: 33188
LOT NO.: 16H-168236-30

DATE: 2016-10-08
ORDER NBR. 210114135
QUANTITY:3240PCS

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:

IFI & MORGAN LTD.
检验专用章
QUANLITY CONTROL

Figure A-29. ⅞-in. (22-mm) Diameter Washer, Test Nos. MGSCO-1 and MGSCO-2

benesch
engineers · scientists · planners

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
Date 10-Aug-17
Project Name: Omitted Post
Placement Location: Curb A

Mix Designation: N/A
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
MMO- 3	A	8/4/2017	8/10/2017	8/10/2017	6	0	6	12	6.00	28.27	120,650	4,270		6	C 1231

1 cc: Midwest Roadside Safety Facility

Remarks:

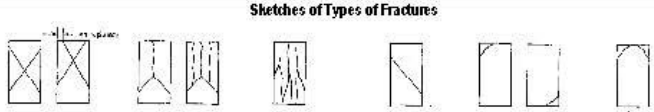
Concrete test specimens along with documentation and test data were submitted by Midwest Roadside Safety Facility.

Test results presented relate only to the concrete specimens as received from Midwest Roadside Safety

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

Report Number 2147369392
Page 1

Sketches of Types of Fractures



Type 1
Reasonably well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps

Type 2
Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end

Type 3
Columnar vertical cracking through both ends, no well-formed cones

Type 4
Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type 1

Type 5
Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6
Similar to Type 5 but end of cylinder is pointed

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By
Brant Wells, Field/Lab Operations Manager

Figure A-30. Curb Concrete, Test Nos. MGSCO-1 and MGSCO-2

NUCOR
NUCOR CORPORATION
NUCOR STEEL TEXAS

Mill Certification
8/2/2016

MTR #: J1-347424
8812 Hwy 79 W
Jewett, TX 75846
(903) 626-4461
Fax: (903) 626-6290

Sold To: ADELPHIA METALS I LLC
1930 E MARLTON PIKE M-66
CHERRY HILL, NJ 08003
(856) 988-8889
Fax: (856) 988-8090

Ship To: ADELPHIA METALS-CUST PU
N/A
JEWETT, TX 75846
(856) 988-8889
Fax: (856) 988-8163

Customer P.O.	818359	Sales Order	236478.5
Product Group	Rebar	Part Number	900000132404200
Grade	ASTM A615/A615M-14 GR 60[420] AASHTO M31-07	Lot #	JW1610471901
Size	13/#4 Rebar	Heat #	JW16104719
Product	13/#4 Rebar 20' A615M GR420 (Gr60)	B.L. Number	J1-745944
Description	A615M GR 420 (Gr60)	Load Number	J1-347424
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: 6/22/2016 Melt Date: 6/18/2016 Qty Shipped LBS: 48,096 Qty Shipped Pcs: 3,600

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb
0.38%	0.98%	0.011%	0.021%	0.19%	0.30%	0.15%	0.16%	0.042%	0.0032%	0.000%

Yield 1: 63,900psi Tensile 1: 101,000psi Elongation: 15% in 8"(% in 203.3mm)

Bend OK

Specification Comments:

Comments: E-mail: websales@nstexas.com

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

Bgla R Vantari

Bhargava R Vantari
Division Metallurgist

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NBMG-10 January 1, 2012

Figure A-31. 819-in. (20,803-mm) Long Rebar, Test Nos. MGSCO-1 and MGSCO-2

CERTIFIED MATERIAL TEST REPORT Page 1/1

GERDAU

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

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
NEBCO INC STEEL DIVISION HAVELOCK,NE 68529 USA	CONCRETE INDUSTRIES INC LINCOLN,NE 68529-0529 USA	60 (420)	Rebar / #4 (13MM)	0000000000

LENGTH	WEIGHT	HEAT / BATCH
60'00"	46,534 LB	58028856/02

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
4777299/000010		ASTM A615/A615M-15 E1

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
123808	1327-0000226793	02/28/2017

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.46	0.91	0.016	0.031	0.26	0.31	0.12	0.20	0.026	0.006	0.004	0.000	0.003

CHEMICAL COMPOSITION

CEqyA706 %
0.65

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
69462	479	110140	759	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
13.90	OK

COMMENTS / NOTES

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

Bhaskar

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

Phone: (409) 769-1014 Email: Bhaskar.Yalamanchili@gerdau.com

Tom L Harrington

TOM HARRINGTON
QUALITY ASSURANCE MGR.

Phone: 972-779-1872 Email: Tommy.Harrington@gerdau.com

Figure A-32. 16-in. (406-mm) Long Rebar, Test Nos. MGSCO-1 and MGSCO-2

Appendix B. Vehicle Center of Gravity Determination

Date:	9/4/2017	Test Name:	MGSCO-1	VIN:	KMHCN4AC1AU480683
Year:	2009	Make:	Hyundai	Model:	Accent

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)
+	Unbalasted Car (Curb)	2458
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	22
+	Strobe/Brake Battery	6
+	Brake Reciever/Wires	4
+	CG Plate including DAS	13
-	Battery	-30
-	Oil	-13
-	Interior	-57
-	Fuel	-14
-	Coolant	-5
-	Washer fluid	-1
+	Water Ballast (In Fuel Tank)	0
+	Onboard Battery	14

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

Estimated Total Weight (lb) 2423

Vehicle Dimensions for C.G. Calculations

Roof Height:	58	in.	Front Track Width:	56 1/2	in.
Wheel Base:	98 7/8	in.	Rear Track Width:	57 1/8	in.

Center of Gravity	1100C MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	2420 ± 55	2438	18
Longitudinal CG (in.)	39 ± 4	37.06799	-1.9320139
Lateral CG (in.)	NA	0.419452	NA
Vertical CG (in.)	NA	22.88543	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	803	757
Rear	435	463

FRONT	1560	lb
REAR	898	lb
TOTAL	2458	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	767	757
Rear	434	480

FRONT	1524	lb
REAR	914	lb
TOTAL	2438	lb

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

Date:	2/6/2018	Test Name:	MGSCO-2	VIN:	KMHCN4AC1BU614772
Year:	2011	Make:	Hyundai	Model:	Accent

Vehicle CG Determination

Vehicle Equipment		Weight (lb)
+	Unballasted Car (Curb)	2440
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	28
+	Strobe/Brake Battery	5
+	Brake Receiver/Wires	5
+	CG Plate including DAS	13
-	Battery	-30
-	Oil	-6
-	Interior	-63
-	Fuel	-21
-	Coolant	-7
-	Washer fluid	0
+	Water Ballast (In Fuel Tank)	0
+	Onboard Supplemental Battery	14

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

Estimated Total Weight (lb) 2404

Vehicle Dimensions for C.G. Calculations

Wheel Base:	98 1/2	in.	Front Track Width:	58 1/8	in.
Roof Height:	58	in.	Rear Track Width:	57 1/2	in.

Center of Gravity	1100C MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	2420 ± 55	2404	-16.0
Longitudinal CG (in.)	39 ± 4	35.605865	-3.39413
Lateral CG (in.)	NA	0.1923877	NA
Vertical CG (in.)	NA	22.80	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	808	759
Rear	425	448

FRONT	1567	lb
REAR	873	lb
TOTAL	2440	lb

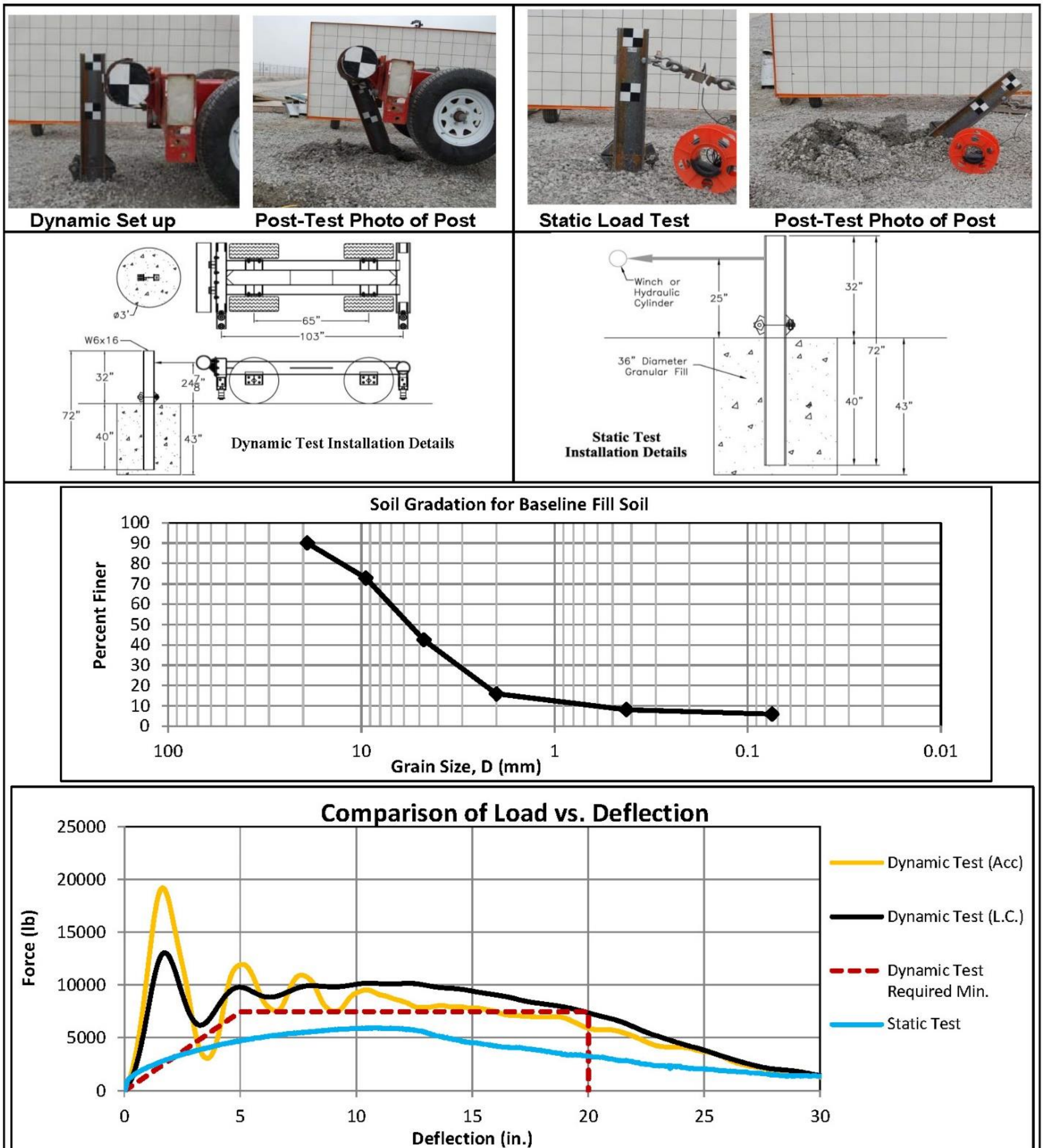
TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	771	764
Rear	423	446

FRONT	1535	lb
REAR	869	lb
TOTAL	2404	lb

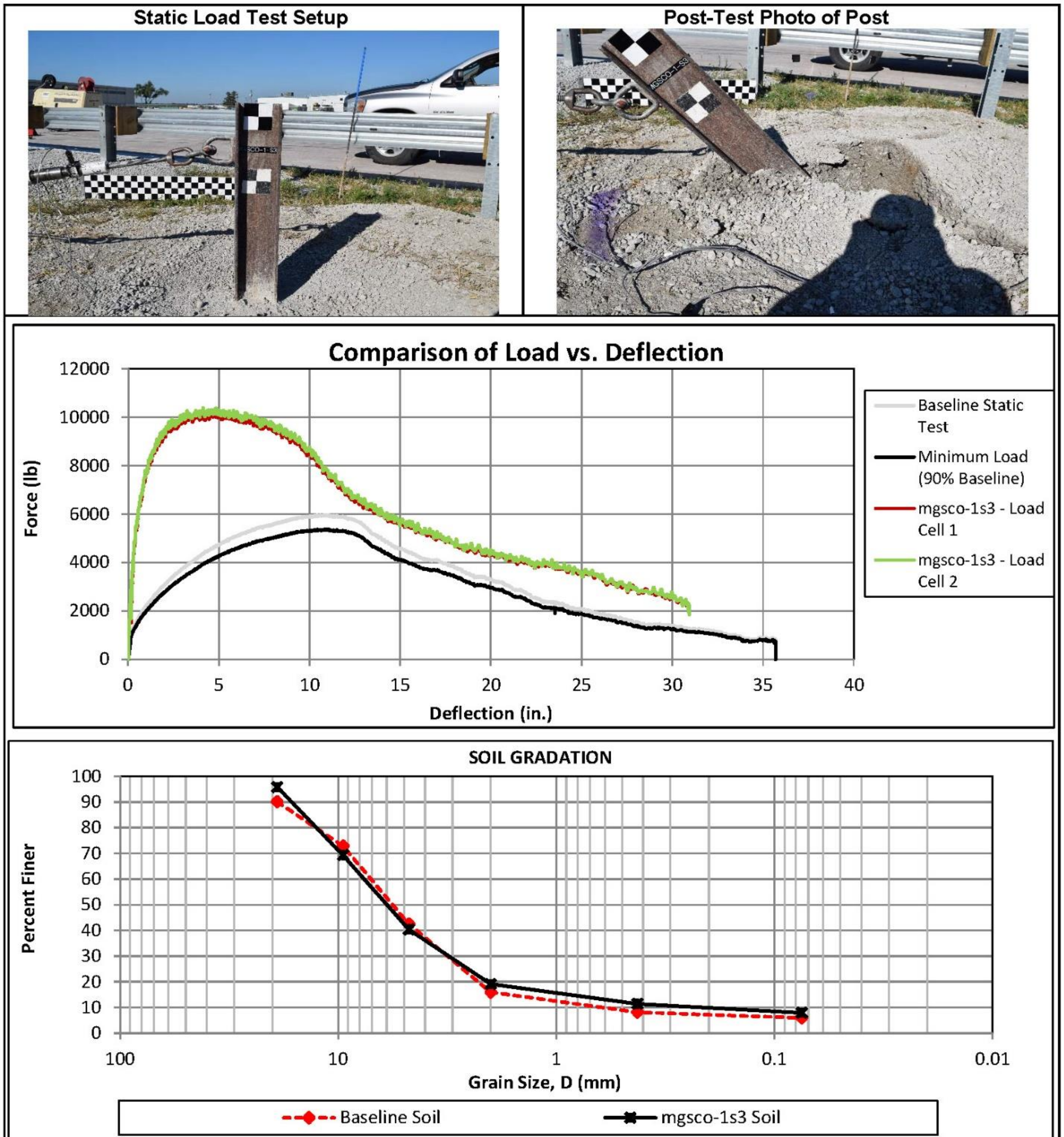
Figure B-2. Vehicle Mass Distribution, Test No. MGSCO-2

Appendix C. Static Soil Tests



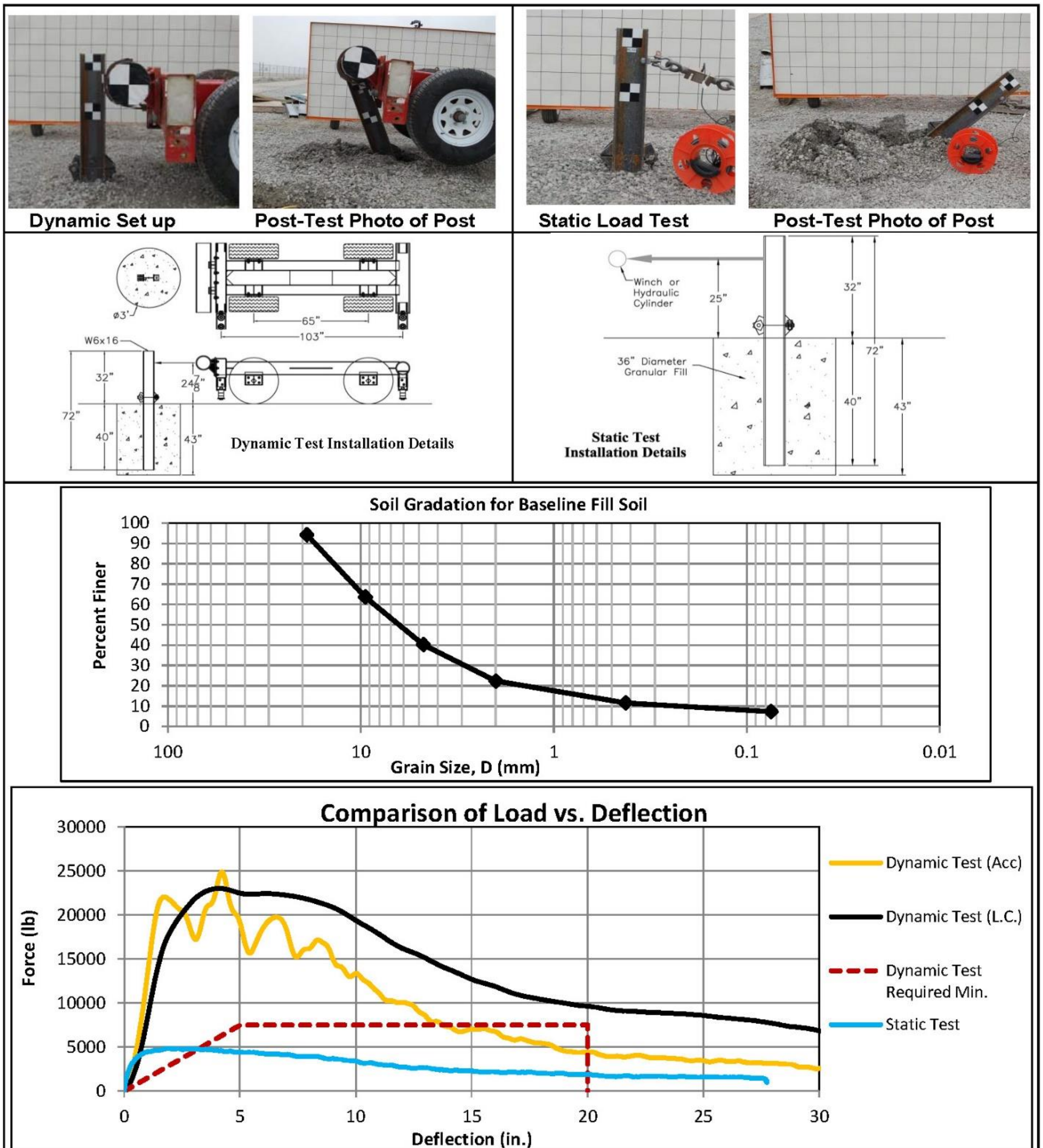
Date	3/20/2012		
Test Facility & Site Location	Midwest Roadside Safety Facility		
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)		
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)		
Description of fill placement procedure	8" lift 3-4 passes		
Bogie Weight	1843	lb	836 kg
Impact Velocity	20.0	mph	32.2 km/h

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



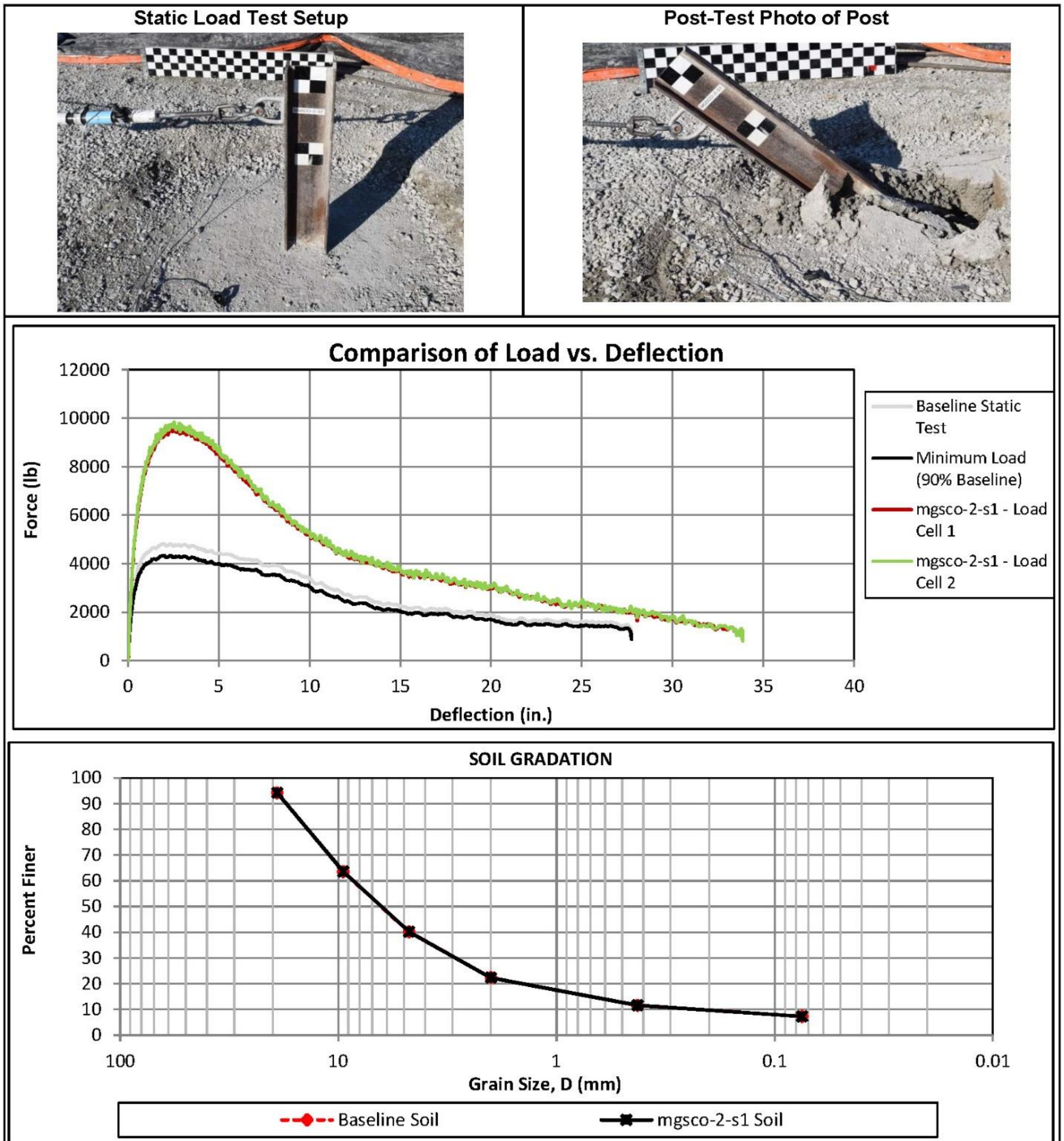
Date..	8/28/2017
Test Facility & Site Location......................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)...........	Well-Graded Gravel (GW)
Fill material description (ASTM D2487).........	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure........	8-inch lifts tamped with a pneumatic compactor

Figure C-2. Static Soil Test, Test No. MGSCO-1



Date	2/16/2018		
Test Facility & Site Location	Midwest Roadside Safety Facility		
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)		
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)		
Description of fill placement procedure	H.E.-8		
Bogie Weight	1786	lb	810 kg
Impact Velocity	20.9	mph	33.7 km/h

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



Date..	3/2/2018
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-4. Static Soil Test, Test No. MGSCO-2

Appendix D. Vehicle Deformation Records

Date: 9/4/2017 Test Name: MGSCO-1 VIN: KMHCN4AC1AU480683
Year: 2009 Make: Hyundai 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	27.710	-21.212	2.223	27.329	-21.347	2.187	-0.381	-0.136	-0.037	0.407
2	28.571	-17.583	-1.997	28.278	-17.770	-1.990	-0.293	-0.187	0.007	0.347
3	27.495	-11.986	-2.602	27.257	-12.289	-2.515	-0.238	-0.303	0.087	0.395
4	27.217	-5.808	-2.761	27.013	-6.114	-2.674	-0.204	-0.305	0.087	0.377
5	25.350	-19.114	-3.832	25.176	-19.363	-3.778	-0.174	-0.249	0.054	0.309
6	24.764	-14.943	-3.703	24.503	-15.098	-3.690	-0.261	-0.156	0.013	0.304
7	24.880	-11.745	-3.881	24.637	-11.950	-3.844	-0.243	-0.205	0.038	0.320
8	24.439	-5.960	-4.105	24.267	-6.235	-4.052	-0.172	-0.275	0.053	0.329
9	20.665	-19.019	-5.072	20.503	-19.283	-5.093	-0.162	-0.264	-0.021	0.310
10	20.212	-15.113	-4.822	19.946	-15.275	-4.825	-0.266	-0.162	-0.003	0.311
11	19.752	-11.093	-5.024	19.543	-11.213	-5.009	-0.210	-0.119	0.015	0.242
12	19.065	-5.846	-4.805	18.852	-6.055	-4.785	-0.213	-0.209	0.020	0.299
13	15.419	-22.319	-5.197	15.216	-22.614	-5.202	-0.203	-0.295	-0.005	0.358
14	14.661	-16.901	-4.655	14.416	-17.124	-4.666	-0.246	-0.223	-0.012	0.332
15	14.397	-11.651	-4.632	14.156	-11.895	-4.620	-0.241	-0.244	0.013	0.344
16	14.098	-6.486	-5.176	13.875	-6.662	-5.161	-0.223	-0.176	0.015	0.284
17	11.325	-23.018	-4.925	11.083	-23.238	-4.941	-0.243	-0.220	-0.016	0.328
18	11.026	-17.395	-4.376	10.799	-17.584	-4.397	-0.227	-0.188	-0.021	0.296
19	10.632	-11.522	-4.355	10.352	-11.710	-4.359	-0.280	-0.188	-0.003	0.337
20	10.515	-6.661	-5.047	10.244	-6.806	-5.023	-0.271	-0.144	0.024	0.308
21	6.970	-22.350	-4.509	6.813	-22.651	-4.524	-0.157	-0.300	-0.015	0.339
22	7.010	-17.259	-4.056	6.847	-17.449	-4.084	-0.163	-0.190	-0.028	0.252
23	7.211	-11.043	-4.122	6.958	-11.366	-4.142	-0.253	-0.322	-0.020	0.410
24	6.874	-6.473	-4.569	6.595	-6.648	-4.565	-0.280	-0.175	0.004	0.330
25	0.457	-23.167	0.052	0.256	-23.457	0.047	-0.202	-0.291	-0.006	0.354
26	0.435	-17.773	-0.024	0.202	-18.052	-0.033	-0.233	-0.279	-0.009	0.364
27	0.403	-12.263	-0.048	0.213	-12.437	-0.069	-0.190	-0.174	-0.021	0.258
28	0.230	-6.430	-0.103	0.039	-6.735	-0.127	-0.191	-0.305	-0.024	0.361

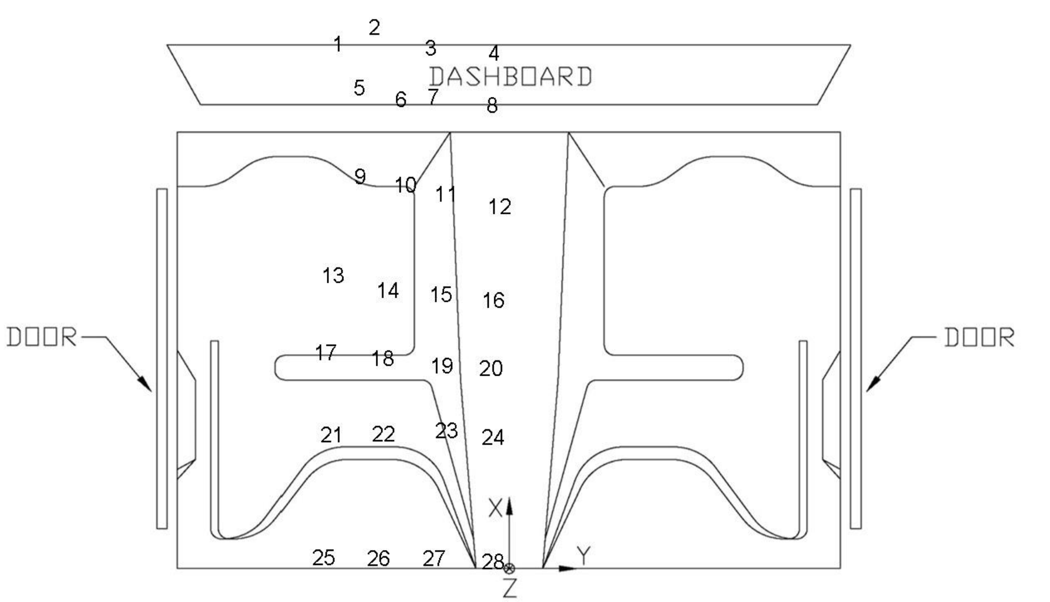


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. MGSCO-1

Date: 9/4/2017 Test Name: MGSCO-1 VIN: KMHCN4AC1AU480683
Year: 2009 Make: Hyundai 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	66.865	-33.365	-19.261	67.009	-33.460	-19.043	0.145	-0.096	0.218	0.279
2	66.893	-29.436	-23.287	67.243	-29.571	-22.993	0.350	-0.135	0.293	0.476
3	65.924	-23.811	-23.190	66.202	-24.004	-22.874	0.278	-0.194	0.316	0.463
4	65.702	-17.544	-22.755	66.028	-17.797	-22.447	0.326	-0.253	0.309	0.515
5	63.487	-30.776	-24.617	63.783	-31.017	-24.363	0.296	-0.241	0.254	0.458
6	62.910	-26.592	-24.043	63.255	-26.695	-23.758	0.345	-0.103	0.285	0.459
7	63.098	-23.380	-23.945	63.407	-23.579	-23.660	0.309	-0.199	0.285	0.465
8	62.727	-17.642	-23.583	63.079	-17.841	-23.298	0.353	-0.199	0.285	0.495
9	58.652	-30.532	-24.991	59.017	-30.806	-24.788	0.365	-0.274	0.203	0.499
10	58.212	-26.658	-24.283	58.553	-26.825	-24.067	0.341	-0.166	0.216	0.437
11	57.830	-22.534	-24.058	58.173	-22.772	-23.818	0.344	-0.237	0.240	0.481
12	57.315	-17.476	-23.285	57.615	-17.699	-23.030	0.301	-0.223	0.255	0.453
13	53.395	-33.820	-24.425	53.721	-34.021	-24.242	0.326	-0.200	0.183	0.424
14	52.827	-28.465	-23.287	53.134	-28.635	-23.094	0.307	-0.170	0.193	0.401
15	52.627	-23.175	-22.745	53.000	-23.393	-22.544	0.373	-0.217	0.201	0.476
16	52.351	-18.035	-22.788	52.711	-18.263	-22.587	0.361	-0.229	0.202	0.472
17	49.428	-34.561	-23.471	49.739	-34.672	-23.323	0.311	-0.111	0.148	0.362
18	49.268	-28.961	-22.383	49.575	-29.140	-22.217	0.307	-0.179	0.166	0.392
19	48.955	-23.108	-21.774	49.254	-23.306	-21.594	0.299	-0.197	0.179	0.401
20	48.766	-18.185	-21.988	49.120	-18.370	-21.803	0.354	-0.185	0.186	0.440
21	45.238	-33.880	-22.221	45.618	-34.126	-22.098	0.380	-0.246	0.123	0.470
22	45.425	-28.867	-21.335	45.805	-29.070	-21.215	0.381	-0.202	0.120	0.447
23	45.675	-22.780	-20.892	46.023	-22.982	-20.764	0.348	-0.203	0.128	0.422
24	45.293	-18.072	-20.850	45.670	-18.266	-20.712	0.377	-0.194	0.138	0.447
25	39.619	-35.092	-16.615	39.911	-35.287	-16.480	0.292	-0.195	0.135	0.376
26	39.678	-29.780	-16.231	39.956	-29.990	-16.110	0.278	-0.210	0.121	0.368
27	39.697	-24.153	-15.752	40.029	-24.453	-15.653	0.332	-0.300	0.099	0.458
28	39.686	-18.472	-15.304	39.909	-18.702	-15.161	0.223	-0.230	0.143	0.351

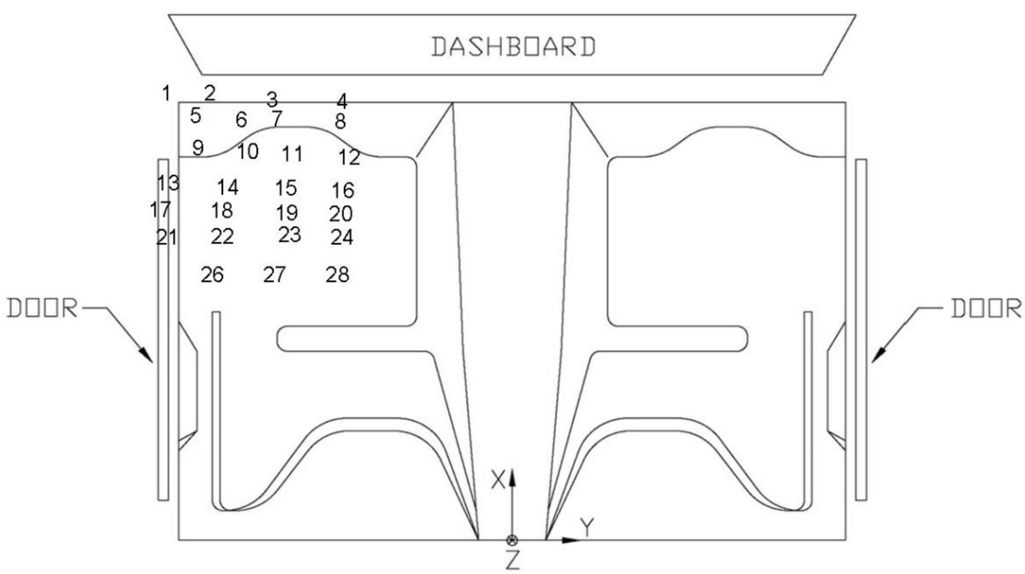


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. MGSCO-1

Date: 9/4/2017 Test Name: MGSCO-1 VIN: KMHCN4AC1AU480683
Year: 2009 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	16.054	-21.670	22.597	15.785	-21.868	22.588	-0.269	-0.199	-0.010	0.334
	2	12.622	-12.950	26.432	12.314	-13.159	26.441	-0.308	-0.210	0.009	0.372
	3	14.345	1.261	24.016	14.041	1.094	24.031	-0.303	-0.167	0.015	0.347
	4	14.601	-20.492	12.695	14.295	-20.708	12.690	-0.305	-0.216	-0.005	0.374
	5	15.546	-11.964	10.506	15.193	-12.028	10.559	-0.354	-0.064	0.053	0.363
	6	10.672	0.924	11.824	10.335	0.753	11.857	-0.337	-0.171	0.033	0.380
SIDE PANEL	7	19.119	-25.920	3.176	18.874	-26.122	3.203	-0.245	-0.202	0.027	0.319
	8	23.068	-25.782	6.554	22.877	-25.945	6.507	-0.191	-0.163	-0.047	0.255
	9	25.441	-26.175	3.151	25.136	-26.367	3.137	-0.306	-0.192	-0.014	0.361
IMPACT SIDE DOOR	10	-8.699	-27.438	24.981	-8.886	-27.606	25.022	-0.186	-0.168	0.040	0.254
	11	3.177	-27.137	23.332	2.957	-27.202	23.378	-0.220	-0.066	0.046	0.234
	12	14.806	-26.943	21.533	14.555	-26.926	21.464	-0.252	0.017	-0.069	0.262
	13	-9.011	-28.293	10.287	-9.229	-28.610	10.282	-0.218	-0.317	-0.005	0.384
	14	6.924	-27.875	7.820	6.766	-28.404	7.744	-0.158	-0.530	-0.076	0.558
	15	15.601	-27.023	9.621	15.409	-27.267	9.594	-0.192	-0.244	-0.027	0.311
ROOF	16	3.555	-18.144	39.756	3.393	-18.201	39.950	-0.161	-0.057	0.194	0.259
	17	3.971	-14.041	40.002	3.933	-14.213	40.503	-0.039	-0.172	0.502	0.532
	18	4.279	-9.958	40.165	4.376	-10.186	40.975	0.097	-0.228	0.809	0.846
	19	4.424	-4.112	40.309	4.554	-4.334	41.483	0.130	-0.222	1.174	1.202
	20	4.442	0.439	40.274	4.543	0.207	41.408	0.101	-0.232	1.134	1.162
	21	-2.282	-16.783	42.607	-2.509	-17.001	42.582	-0.227	-0.218	-0.025	0.315
	22	-1.974	-13.294	42.823	-2.150	-13.424	43.158	-0.176	-0.130	0.334	0.400
	23	-1.770	-9.264	43.012	-1.812	-9.516	43.487	-0.042	-0.252	0.474	0.539
	24	-1.661	-3.850	43.143	-1.789	-3.948	43.760	-0.128	-0.097	0.617	0.638
	25	-1.675	0.123	43.148	-1.715	-0.091	43.757	-0.040	-0.213	0.610	0.647
	26	-7.427	-16.116	43.918	-7.734	-16.265	43.835	-0.308	-0.149	-0.083	0.352
	27	-7.292	-13.097	44.132	-7.467	-13.302	44.409	-0.175	-0.205	0.277	0.386
	28	-6.973	-9.366	44.292	-7.204	-9.474	44.713	-0.231	-0.108	0.421	0.492
	29	-6.867	-4.249	44.436	-7.022	-4.467	44.881	-0.155	-0.218	0.444	0.519
	30	-6.789	-0.262	44.435	-6.918	-0.395	44.875	-0.129	-0.134	0.440	0.478
A PILLAR	31	21.956	-24.974	24.826	21.775	-25.115	24.755	-0.181	-0.141	-0.071	0.240
	32	16.175	-23.984	29.685	15.987	-24.064	29.617	-0.188	-0.080	-0.068	0.215
	33	11.851	-23.105	32.801	11.652	-23.161	32.713	-0.199	-0.056	-0.088	0.225
	34	6.677	-22.032	36.115	6.514	-22.075	36.029	-0.164	-0.043	-0.087	0.190
B PILLAR	35	-18.869	-26.551	23.389	-18.972	-26.671	23.413	-0.103	-0.120	0.024	0.160
	36	-15.240	-26.381	24.211	-15.389	-26.511	24.198	-0.149	-0.130	-0.013	0.198
	37	-19.309	-25.740	29.957	-19.462	-25.845	29.919	-0.153	-0.105	-0.038	0.189
	38	-15.339	-25.502	30.110	-15.500	-25.591	30.145	-0.161	-0.089	0.035	0.187
	39	-19.617	-23.224	37.340	-19.711	-23.300	37.305	-0.094	-0.076	-0.035	0.126
	40	-16.524	-22.883	37.606	-16.581	-22.925	37.613	-0.057	-0.042	0.007	0.071

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

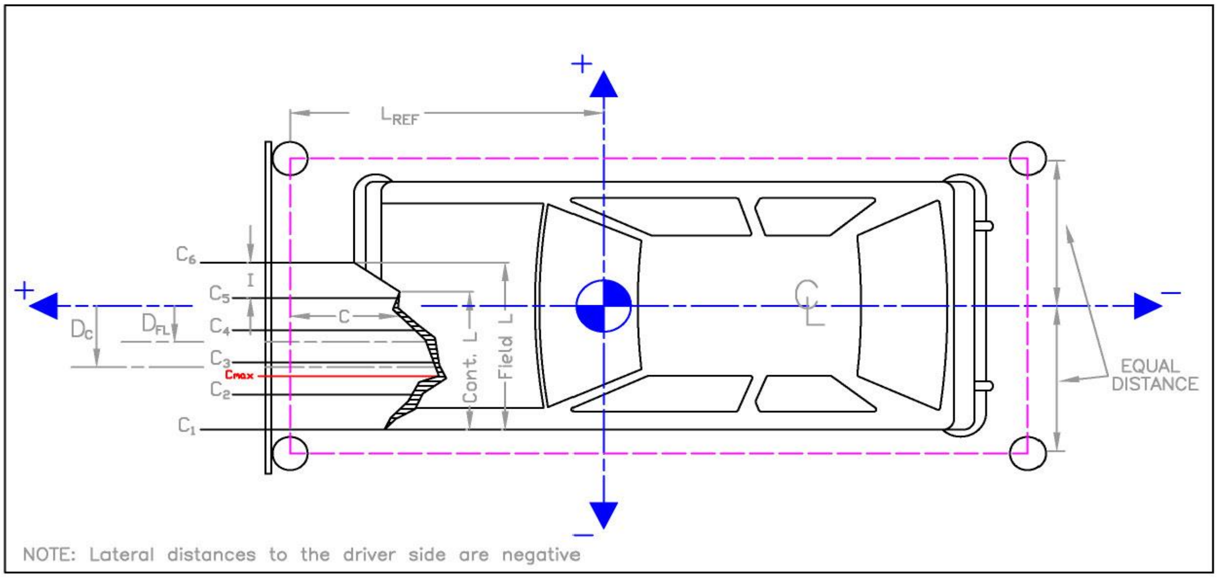
Date: 9/4/2017 Test Name: MGSCO-1 VIN: KMHCN4AC1AU480683
Year: 2009 Make: Hyundai Model: Accent

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	59.091	-35.651	2.734	59.271	-35.760	2.956	0.180	-0.109	0.223	0.306
	2	56.504	-27.250	7.791	56.655	-27.445	8.070	0.151	-0.195	0.278	0.372
	3	57.995	-12.864	6.430	58.115	-13.115	6.655	0.119	-0.251	0.225	0.358
	4	55.854	-33.575	-6.665	56.090	-33.725	-6.510	0.236	-0.150	0.155	0.319
	5	56.527	-24.828	-8.193	56.725	-25.027	-7.939	0.198	-0.199	0.254	0.378
	6	52.174	-12.187	-4.864	52.259	-12.445	-4.546	0.085	-0.258	0.318	0.418
SIDE PANEL	7	58.489	-38.135	-17.233	58.804	-38.284	-17.036	0.314	-0.149	0.197	0.400
	8	63.013	-38.296	-14.600	63.044	-38.404	-14.536	0.031	-0.108	0.064	0.130
	9	64.670	-38.388	-18.394	64.978	-38.523	-18.150	0.308	-0.135	0.244	0.415
IMPACT SIDE DOOR	10	35.071	-41.580	9.107	35.325	-41.733	9.231	0.254	-0.153	0.125	0.321
	11	46.453	-41.128	5.406	46.678	-41.177	5.574	0.225	-0.050	0.168	0.285
	12	57.582	-40.773	1.401	57.713	-40.725	1.677	0.132	0.048	0.276	0.310
	13	32.096	-41.126	-5.311	32.334	-41.426	-5.185	0.238	-0.300	0.125	0.403
	14	47.372	-40.488	-10.617	47.648	-41.001	-10.501	0.276	-0.513	0.116	0.593
	15	56.198	-39.798	-10.391	56.528	-39.994	-10.237	0.330	-0.195	0.154	0.413
ROOF	16	49.983	-33.681	22.098	50.225	-33.657	22.491	0.242	0.025	0.394	0.463
	17	50.541	-29.558	22.598	50.892	-29.680	23.320	0.351	-0.122	0.721	0.811
	18	50.953	-25.510	23.045	51.438	-25.691	24.086	0.485	-0.181	1.041	1.162
	19	51.109	-19.790	23.731	51.849	-20.038	24.975	0.740	-0.249	1.244	1.469
	20	51.226	-15.193	24.086	51.939	-15.503	25.275	0.714	-0.310	1.188	1.420
	21	44.787	-32.591	26.074	44.929	-32.654	26.222	0.142	-0.063	0.148	0.214
	22	45.148	-29.019	26.578	45.428	-29.288	26.995	0.280	-0.269	0.417	0.570
	23	45.510	-25.084	27.033	45.870	-25.261	27.637	0.360	-0.177	0.604	0.725
	24	45.652	-19.668	27.658	45.983	-19.943	28.379	0.331	-0.275	0.721	0.840
	25	45.729	-15.740	27.995	46.182	-16.007	28.684	0.453	-0.267	0.689	0.867
	26	39.922	-31.981	28.392	40.016	-32.085	28.421	0.094	-0.104	0.030	0.143
	27	40.153	-29.011	28.837	40.390	-29.164	29.214	0.237	-0.153	0.376	0.471
	28	40.547	-25.232	29.278	40.858	-25.456	29.750	0.310	-0.225	0.472	0.608
	29	40.802	-20.201	29.821	41.013	-20.371	30.384	0.211	-0.170	0.562	0.624
	30	40.998	-16.176	30.138	41.295	-16.439	30.665	0.297	-0.263	0.527	0.659
A PILLAR	31	65.228	-39.100	3.500	65.508	-39.209	3.736	0.280	-0.109	0.236	0.382
	32	60.397	-38.543	9.472	60.598	-38.583	9.750	0.200	-0.040	0.279	0.345
	33	56.858	-37.961	13.327	57.021	-37.987	13.446	0.163	-0.027	0.119	0.204
	34	52.301	-37.179	17.621	52.489	-37.187	17.809	0.188	-0.008	0.188	0.266
B PILLAR	35	24.815	-40.555	9.482	25.127	-40.671	9.535	0.312	-0.115	0.053	0.337
	36	28.552	-40.457	9.609	28.860	-40.577	9.734	0.309	-0.120	0.125	0.354
	37	25.622	-40.326	16.042	25.870	-40.420	16.086	0.248	-0.094	0.043	0.269
	38	29.431	-40.108	15.506	29.728	-40.187	15.623	0.296	-0.079	0.117	0.328
	39	26.677	-38.485	23.514	26.824	-38.543	23.660	0.147	-0.058	0.146	0.215
	40	29.843	-38.157	23.259	29.936	-38.187	23.406	0.093	-0.030	0.147	0.177

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

Date:	8/31/2017	Test Number:	MGSCO-1		
Year:	2009	Make:	Hyundai	Model:	Accent



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	74	(1880)
Total Width of Vehicle:	64 7/8	(1648)
Width of contact and induced crush - Field L:	64 7/8	(1648)
Crush measurement spacing interval (L/5) - I:	13	(330)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	64 7/8	(1648)
Distance from center of vehicle to center of contact damage - D_C:	0	()

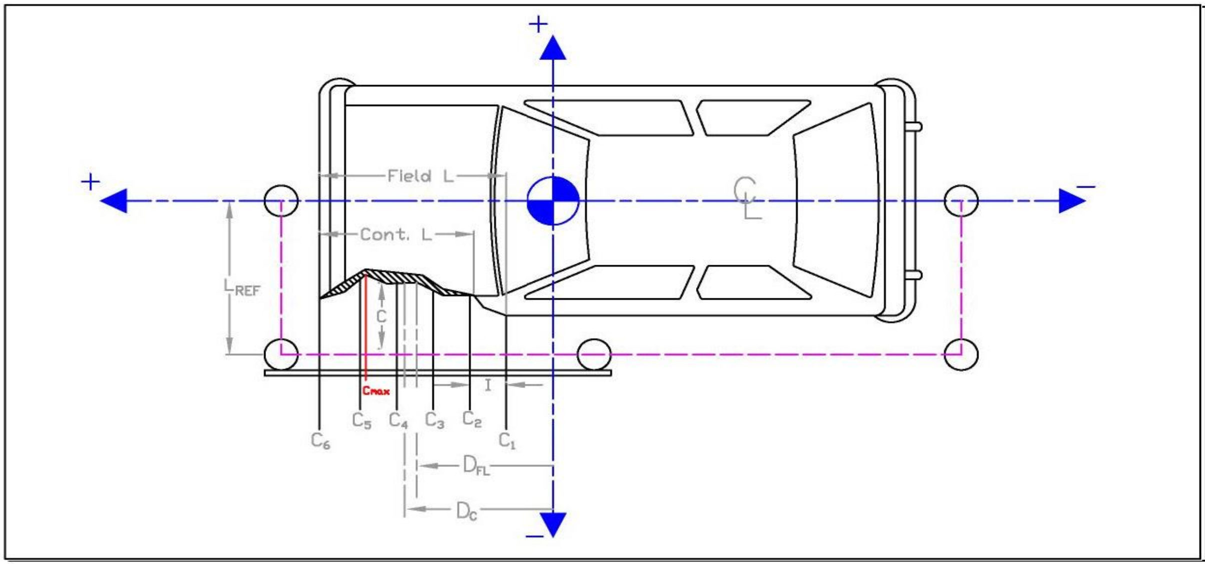
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

Crush Measurement			Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-32 1/2	-(826)	20 1/4	(514)	2	(52)	NA	NA
C_2	10 3/4	(273)	-19 1/2	-(495)	4 3/4	(121)			4	(100)
C_3	14 1/2	(368)	-6 1/2	-(165)	2 3/8	(60)			10	(256)
C_4	13	(330)	6 1/2	(165)	2 3/8	(60)			8 4/7	(217)
C_5	10 3/4	(273)	19 1/2	(495)	4 3/4	(121)			4	(100)
C_6	na	NA	32 1/2	(826)	19 7/8	(505)			NA	NA
C_{MAX}	15	(381)	-12	-(305)	3	(76)			10	(252)

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

Date: 42978 Test Number: MGSCO-1

Year: 2009 Make: Hyundai Model: Accent



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	34	(864)
Total Vehicle Length:	168 1/4	(4274)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-13 4/9	-(341)
Width of contact and induced crush - Field L:	168 1/4	(4274)
Crush measurement spacing interval (L/5) - I:	33 5/8	(854)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-13 4/9	-(341)
Width of Contact Damage:	168 1/4	(4274)
Distance from vehicle c.g. to center of contact damage - D_C:	-13 4/9	-(341)

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

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	na	NA	-97 5/8	-(2480)	36	(914)	-2	-(51)	NA	NA
C_2	3	(76)	-64	-(1626)	4	(102)			1	(25)
C_3	1 3/4	(44)	-30 3/8	-(772)	3 3/8	(86)			3/8	(10)
C_4	1 1/8	(29)	3 1/4	(83)	3 1/4	(83)			- 1/8	-(3)
C_5	na	NA	36 7/8	(937)	3 1/2	(89)			NA	NA
C_6	na	NA	70 1/2	(1791)	31 7/8	(810)			NA	NA
C_{MAX}	14	(356)	55	(1397)	4 3/4	(121)			11 1/4	(286)

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

Date: 2/6/2018 Test Name: MGSCO-2 VIN: KMHCN4AC1BU614772
Year: 2011 Make: Hyundai 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.)	Crush (in.)
TOE PAN - WHEEL WELL	1	62.409	-32.063	1.173	62.222	-31.405	0.989	0.187	0.658	-0.184	0.263
	2	64.516	-29.208	-0.442	64.248	-28.510	-0.628	0.268	0.698	-0.186	0.327
	3	64.989	-24.266	-2.630	65.094	-23.932	-2.662	-0.105	0.334	-0.032	0.110
	4	64.023	-17.155	-3.246	64.214	-16.874	-3.215	-0.192	0.281	0.032	0.194
	5	61.071	-31.588	-3.735	61.226	-31.254	-3.887	-0.156	0.334	-0.152	0.218
	6	61.813	-26.985	-4.147	62.006	-26.717	-4.137	-0.192	0.268	0.010	0.192
	7	61.422	-22.272	-4.639	61.631	-22.009	-4.655	-0.209	0.263	-0.016	0.209
	8	61.468	-16.655	-4.849	61.708	-16.436	-4.776	-0.240	0.218	0.072	0.250
FLOOR PAN	9	54.744	-33.088	-6.937	55.036	-32.767	-6.953	-0.292	0.322	-0.016	-0.016
	10	54.962	-28.334	-7.128	55.206	-28.058	-7.159	-0.244	0.276	-0.031	-0.031
	11	54.698	-22.695	-7.179	54.869	-22.434	-7.199	-0.171	0.260	-0.020	-0.020
	12	54.306	-17.525	-7.060	54.516	-17.193	-7.008	-0.211	0.332	0.052	0.052
	13	50.711	-33.402	-7.637	50.978	-33.138	-7.654	-0.267	0.264	-0.018	-0.018
	14	50.601	-28.146	-7.265	50.813	-27.851	-7.295	-0.212	0.295	-0.031	-0.031
	15	50.253	-22.577	-7.331	50.442	-22.225	-7.292	-0.189	0.352	0.038	0.038
	16	50.181	-17.567	-7.864	50.442	-17.303	-7.823	-0.261	0.264	0.041	0.041
	17	47.308	-34.062	-7.740	47.531	-33.755	-7.763	-0.223	0.307	-0.023	-0.023
	18	47.322	-28.233	-7.357	47.479	-27.973	-7.388	-0.158	0.260	-0.030	-0.030
	19	47.143	-22.502	-7.406	47.381	-22.230	-7.386	-0.238	0.272	0.020	0.020
	20	47.644	-17.348	-8.027	47.899	-17.161	-8.039	-0.255	0.187	-0.012	-0.012
	21	44.221	-34.347	-7.690	44.435	-34.018	-7.724	-0.214	0.328	-0.033	-0.033
	22	44.075	-28.623	-7.426	44.250	-28.338	-7.458	-0.175	0.285	-0.032	-0.032
	23	44.476	-22.739	-7.460	44.688	-22.484	-7.484	-0.212	0.255	-0.024	-0.024
	24	44.740	-17.348	-8.089	44.969	-17.102	-8.070	-0.230	0.245	0.019	0.019
	25	40.875	-32.452	-7.780	41.128	-32.381	-7.800	-0.253	0.071	-0.020	-0.020
	26	40.708	-29.101	-7.504	40.928	-28.791	-7.527	-0.220	0.310	-0.023	-0.023
	27	40.797	-22.932	-7.535	41.013	-22.596	-7.577	-0.216	0.336	-0.042	-0.042
	28	41.371	-17.406	-7.938	41.531	-17.181	-7.971	-0.161	0.224	-0.033	-0.033
	29	35.208	-29.568	-4.059	35.454	-29.331	-4.081	-0.246	0.237	-0.021	-0.021
	30	35.125	-21.349	-4.132	35.407	-21.096	-4.164	-0.282	0.253	-0.031	-0.031

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

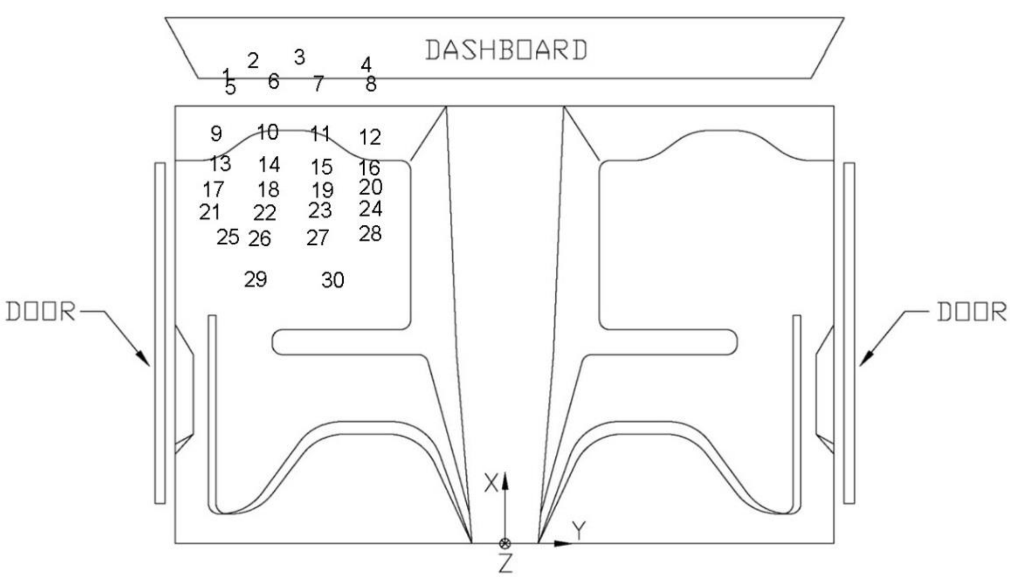


Figure D-7. Floor Pan Deformation Data – Set 1, Test No. MGSCO-2

Date: 2/6/2018 Test Name: MGSCO-2 VIN: KMHCN4AC1BU614772
Year: 2011 Make: Hyundai 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.)	Crush (in.)
TOE PAN - WHEEL WELL	1	52.782	-20.211	5.724	52.317	-19.890	5.561	0.465	0.321	-0.164	0.493
	2	54.915	-17.369	4.121	54.378	-17.001	3.979	0.536	0.368	-0.142	0.555
	3	55.442	-12.402	2.002	55.288	-12.398	2.031	0.154	0.005	0.029	0.157
	4	54.593	-5.267	1.508	54.537	-5.315	1.637	0.056	-0.048	0.129	0.140
	5	51.378	-19.637	0.846	51.264	-19.617	0.702	0.114	0.019	-0.143	0.183
	6	52.196	-15.042	0.493	52.128	-15.092	0.537	0.069	-0.050	0.045	0.082
	7	51.881	-10.316	0.078	51.837	-10.368	0.123	0.044	-0.052	0.045	0.063
	8	52.024	-4.697	-0.047	52.020	-4.796	0.117	0.003	-0.099	0.164	0.164
FLOOR PAN	9	44.979	-20.976	-2.282	45.008	-20.947	-2.314	-0.030	0.029	-0.033	-0.033
	10	45.278	-16.224	-2.403	45.266	-16.239	-2.424	0.012	-0.015	-0.021	-0.021
	11	45.113	-10.581	-2.364	45.037	-10.610	-2.342	0.076	-0.029	0.023	0.023
	12	44.814	-5.408	-2.161	44.788	-5.368	-2.037	0.026	0.039	0.124	0.124
	13	40.931	-21.209	-2.924	40.936	-21.226	-2.971	-0.005	-0.017	-0.047	-0.047
	14	40.920	-15.958	-2.471	40.877	-15.945	-2.499	0.042	0.012	-0.029	-0.029
	15	40.669	-10.383	-2.447	40.615	-10.315	-2.374	0.055	0.068	0.073	0.073
	16	40.678	-5.366	-2.903	40.703	-5.384	-2.802	-0.025	-0.019	0.101	0.101
	17	37.515	-21.808	-2.985	37.476	-21.775	-3.048	0.039	0.032	-0.063	-0.063
	18	37.638	-15.986	-2.514	37.540	-16.003	-2.551	0.098	-0.017	-0.037	-0.037
	19	37.560	-10.253	-2.473	37.553	-10.260	-2.428	0.007	-0.007	0.045	0.045
	20	38.143	-5.099	-3.023	38.160	-5.189	-2.981	-0.017	-0.090	0.042	0.042
	21	34.425	-22.039	-2.893	34.376	-21.980	-2.974	0.048	0.058	-0.082	-0.082
	22	34.384	-16.318	-2.539	34.304	-16.304	-2.588	0.080	0.014	-0.049	-0.049
	23	34.889	-10.442	-2.489	34.854	-10.461	-2.497	0.035	-0.019	-0.007	-0.007
	24	35.238	-5.047	-3.041	35.232	-5.074	-2.974	0.006	-0.027	0.067	0.067
	25	31.112	-20.084	-2.902	31.100	-20.279	-2.974	0.011	-0.195	-0.072	-0.072
	26	31.008	-16.736	-2.573	30.974	-16.692	-2.623	0.035	0.044	-0.050	-0.050
	27	31.206	-10.569	-2.512	31.177	-10.500	-2.545	0.030	0.069	-0.034	-0.034
	28	31.872	-5.049	-2.840	31.795	-5.089	-2.832	0.077	-0.041	0.007	0.007
	29	25.554	-17.160	0.949	25.534	-17.201	0.881	0.020	-0.041	-0.067	-0.067
	30	25.615	-8.941	1.002	25.644	-8.967	0.971	-0.028	-0.026	-0.031	-0.031

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

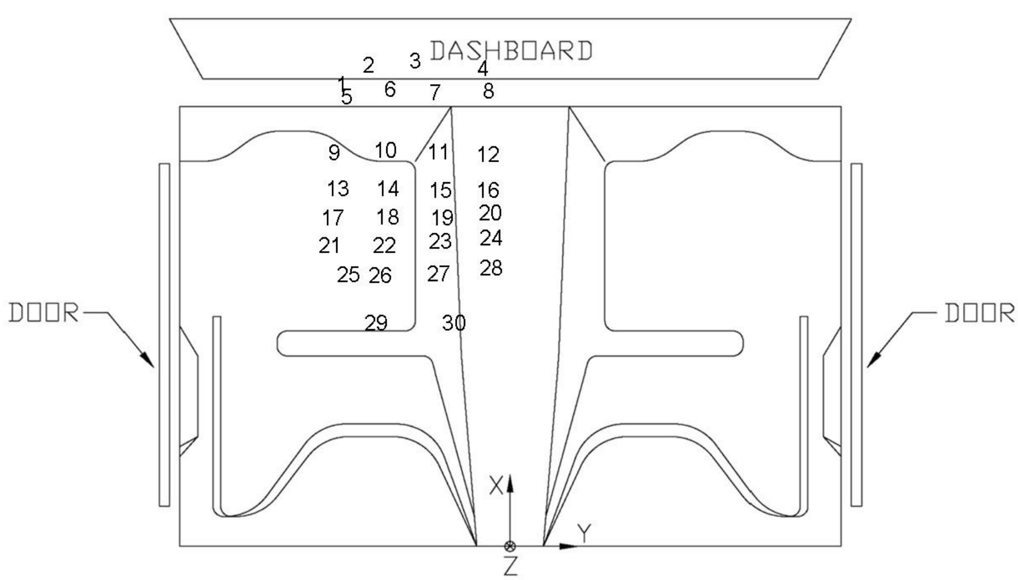


Figure D-8. Floor Pan Deformation Data – Set 2, Test No. MGSCO-2

Date: 2/6/2018 Test Name: MGSCO-2 VIN: KMHCN4AC1BU614772
Year: 2011 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.)	Crush (in.)
DASH	1	48.280	-9.292	21.248	48.241	-9.059	21.331	0.039	0.233	0.082	0.250
	2	49.289	-19.812	23.162	49.298	-19.612	23.250	-0.009	0.200	0.088	0.218
	3	49.624	-28.640	22.302	49.681	-28.441	22.359	-0.057	0.200	0.057	0.215
	4	44.194	-9.615	14.435	44.199	-9.408	14.563	-0.005	0.206	0.128	0.243
	5	47.160	-22.079	9.493	47.098	-21.823	9.602	0.062	0.256	0.109	0.285
	6	46.716	-32.394	15.177	46.690	-32.175	15.257	0.027	0.218	0.080	0.234
SIDE PANEL	7	53.170	-36.805	-0.659	53.181	-36.589	-0.630	-0.011	0.216	0.029	0.216
	8	58.650	-36.853	-0.916	58.610	-36.597	-0.904	0.040	0.255	0.012	0.255
	9	57.541	-36.748	3.581	57.868	-36.284	3.642	-0.326	0.464	0.061	0.464
IMPACT SIDE DOOR	10	21.294	-37.293	19.935	20.985	-37.298	20.090	0.309	-0.005	0.155	-0.005
	11	33.585	-37.368	19.344	33.423	-37.178	19.377	0.161	0.191	0.032	0.191
	12	47.026	-37.504	18.689	46.753	-37.069	18.797	0.273	0.434	0.108	0.434
	13	23.173	-37.859	9.399	22.992	-38.023	9.524	0.181	-0.163	0.124	-0.163
	14	33.497	-37.922	9.315	33.341	-38.018	9.330	0.157	-0.096	0.015	-0.096
	15	46.922	-37.974	8.439	46.729	-37.639	8.495	0.193	0.335	0.056	0.335
ROOF	16	34.644	-28.106	35.837	34.611	-27.960	35.958	0.033	0.146	0.121	0.121
	17	35.599	-19.976	36.264	35.635	-19.811	36.325	-0.036	0.165	0.061	0.061
	18	36.012	-10.771	36.366	36.055	-10.525	36.388	-0.043	0.245	0.021	0.021
	19	30.270	-27.587	37.150	30.293	-27.477	37.268	-0.023	0.110	0.118	0.118
	20	31.175	-20.484	37.459	31.191	-20.382	37.585	-0.015	0.103	0.126	0.126
	21	32.216	-10.055	36.872	32.196	-9.997	36.916	0.020	0.057	0.043	0.043
	22	28.081	-27.482	38.087	28.129	-27.414	38.172	-0.048	0.068	0.084	0.084
	23	28.789	-20.705	38.504	28.739	-20.559	38.594	0.049	0.146	0.090	0.090
	24	29.064	-15.706	38.659	29.126	-15.597	38.713	-0.061	0.109	0.054	0.054
	25	29.156	-10.205	38.699	29.227	-10.116	38.737	-0.071	0.088	0.038	0.038
	26	25.787	-27.336	38.451	25.830	-27.280	38.531	-0.044	0.057	0.080	0.080
	27	26.291	-23.717	38.701	26.325	-23.595	38.784	-0.034	0.122	0.082	0.082
	28	26.556	-19.002	38.950	26.573	-18.903	39.022	-0.017	0.099	0.072	0.072
	29	27.085	-14.479	39.019	27.064	-14.357	39.088	0.021	0.121	0.069	0.069
	30	27.153	-10.058	39.035	27.149	-9.971	39.087	0.004	0.087	0.052	0.052
A PILLAR	31	52.310	-35.506	24.223	52.350	-35.362	24.276	-0.041	0.145	0.054	0.160
	32	47.116	-34.400	27.621	47.043	-34.253	27.725	0.073	0.147	0.105	0.195
	33	41.622	-33.141	30.724	41.690	-33.022	30.814	-0.068	0.119	0.091	0.164
	34	35.442	-31.704	34.208	35.579	-31.613	34.124	-0.137	0.091	-0.084	0.184
B PILLAR	35	11.131	-32.381	32.667	11.050	-32.233	32.851	0.081	0.148	0.184	0.250
	36	15.725	-34.068	27.982	15.752	-33.968	28.076	-0.027	0.100	0.094	0.140
	37	12.130	-35.771	24.390	12.110	-35.679	24.554	0.019	0.092	0.164	0.189
	38	17.192	-35.842	20.847	17.231	-35.774	20.895	-0.039	0.068	0.048	0.092
	39	13.392	-36.119	17.878	13.419	-36.046	17.990	-0.026	0.072	0.112	0.136
	40	18.197	-36.205	13.994	18.211	-36.147	14.118	-0.014	0.058	0.125	0.138

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

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

Date: 2/6/2018 Test Name: MGSCO-2 VIN: KMHCN4AC1BU614772
Year: 2011 Make: Hyundai Model: Accent

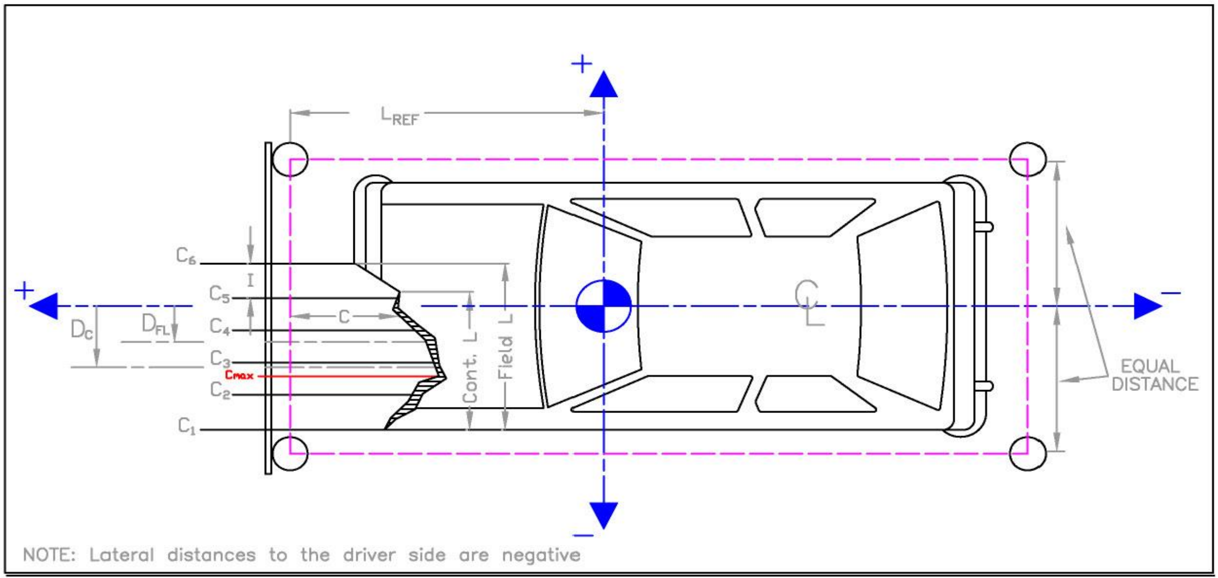
VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Crush (in.)
DASH	1	39.112	2.273	26.358	39.006	2.250	26.561	0.106	0.023	0.203	0.230
	2	39.960	-8.289	28.112	39.879	-8.361	28.237	0.081	-0.072	0.126	0.166
	3	40.122	-17.109	27.126	40.078	-17.174	27.151	0.043	-0.065	0.024	0.082
	4	34.918	2.119	19.605	34.878	2.128	19.838	0.040	-0.009	0.232	0.236
	5	37.583	-10.327	14.448	37.475	-10.229	14.573	0.108	0.098	0.125	0.192
	6	37.039	-20.710	19.996	36.931	-20.693	20.006	0.108	0.017	0.010	0.109
SIDE PANEL	7	43.169	-25.014	4.003	43.146	-24.881	3.949	0.023	0.133	-0.055	0.133
	8	48.643	-25.156	3.661	48.570	-24.988	3.608	0.074	0.168	-0.053	0.168
	9	47.605	-25.094	8.175	47.888	-24.760	8.168	-0.283	0.334	-0.007	0.334
IMPACT SIDE DOOR	10	11.607	-25.220	25.080	11.190	-25.424	25.042	0.418	-0.204	-0.038	-0.204
	11	23.884	-25.506	24.298	23.619	-25.527	24.179	0.265	-0.021	-0.119	-0.021
	12	37.309	-25.873	23.432	36.940	-25.664	23.438	0.369	0.209	0.005	0.209
	13	13.315	-25.672	14.509	13.057	-25.954	14.439	0.258	-0.282	-0.071	-0.282
	14	23.634	-25.919	14.264	23.401	-26.146	14.117	0.233	-0.227	-0.147	-0.227
	15	37.040	-26.198	13.180	36.783	-26.006	13.127	0.257	0.192	-0.053	0.192
ROOF	16	25.361	-16.496	40.898	25.183	-16.702	40.941	0.178	-0.205	0.043	0.043
	17	26.470	-8.391	41.420	26.371	-8.584	41.472	0.100	-0.193	0.051	0.051
	18	27.051	0.803	41.643	26.973	0.689	41.731	0.078	0.114	0.089	0.089
	19	21.018	-15.917	42.285	20.891	-16.164	42.314	0.127	-0.247	0.029	0.029
	20	22.057	-8.837	42.677	21.931	-9.096	42.774	0.125	-0.259	0.097	0.097
	21	23.277	1.580	42.217	23.131	1.279	42.318	0.146	0.300	0.101	0.101
	22	18.847	-15.786	43.257	18.740	-16.079	43.245	0.106	-0.293	-0.012	-0.012
	23	19.682	-9.030	43.755	19.489	-9.248	43.809	0.194	-0.219	0.054	0.054
	24	20.051	-4.039	43.975	19.974	-4.298	44.031	0.077	-0.259	0.056	0.056
	25	20.243	1.459	44.089	20.182	1.178	44.172	0.061	0.281	0.084	0.084
	26	16.561	-15.605	43.658	16.449	-15.908	43.636	0.112	-0.304	-0.022	-0.022
	27	17.134	-11.999	43.950	17.018	-12.240	43.962	0.116	-0.242	0.012	0.012
	28	17.488	-7.293	44.260	17.361	-7.560	44.300	0.127	-0.267	0.040	0.040
	29	18.100	-2.781	44.382	17.941	-3.028	44.458	0.159	-0.246	0.076	0.076
	30	18.248	1.637	44.458	18.112	1.355	44.552	0.136	0.282	0.094	0.094
A PILLAR	31	42.712	-24.048	28.911	42.634	-24.185	28.884	0.077	-0.137	-0.027	0.160
	32	37.591	-22.896	32.404	37.391	-23.050	32.421	0.200	-0.154	0.017	0.253
	33	32.169	-21.583	35.608	32.100	-21.785	35.602	0.069	-0.202	-0.006	0.213
	34	26.070	-20.085	39.207	26.058	-20.332	39.016	0.012	-0.246	-0.191	0.312
B PILLAR	35	1.729	-20.305	38.033	1.507	-20.449	38.031	0.222	-0.144	-0.002	0.265
	36	6.220	-22.008	33.255	6.118	-22.169	33.162	0.103	-0.161	-0.093	0.213
	37	2.541	-23.596	29.696	2.402	-23.732	29.648	0.139	-0.136	-0.047	0.200
	38	7.547	-23.709	26.074	7.476	-23.846	25.925	0.071	-0.137	-0.149	0.214
	39	3.698	-23.875	23.161	3.625	-23.980	23.063	0.073	-0.105	-0.098	0.161
	40	8.440	-23.994	19.202	8.368	-24.088	19.131	0.072	-0.095	-0.071	0.138

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

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

Date:	2/6/2018	Test Name:	MGSCO-2	VIN:	KMHCN4AC1BU614772
Year:	2011	Make:	Hyundai	Model:	Accent



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	93 5/8	(2378)
Total Width of Vehicle:	65 1/4	(1657)
Width of contact and induced crush - Field L:	65 1/4	(1657)
Crush measurement spacing interval (L/5) - I:	13	(330)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	65 1/4	(1657)
Distance from center of vehicle to center of contact damage - D_C:	0	()

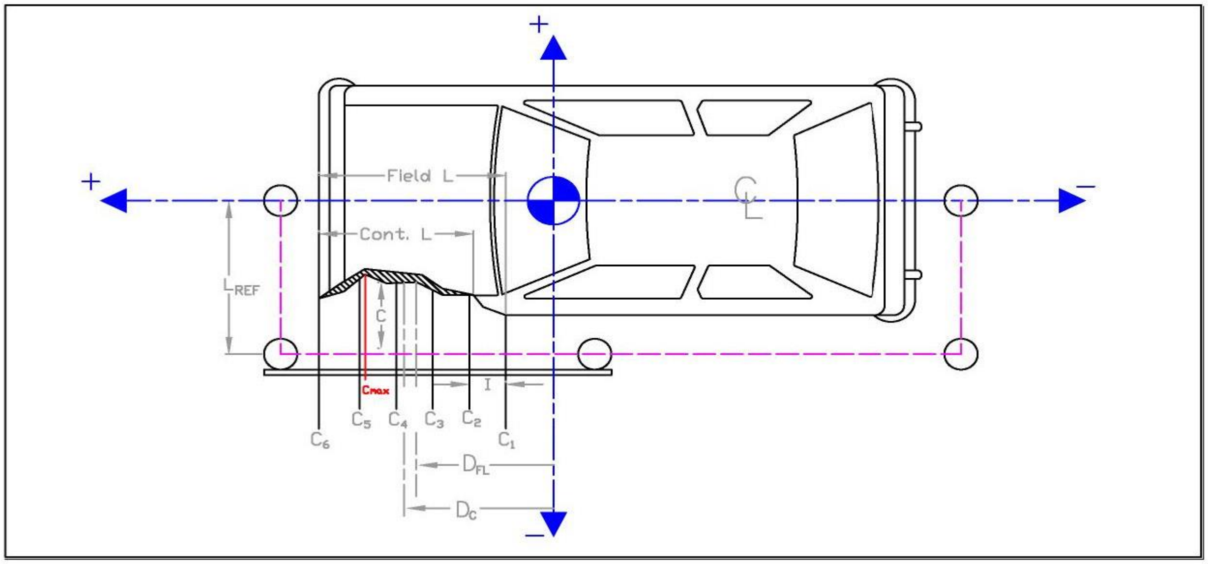
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	NA	NA	-32 5/8	-(829)	20 1/4	(514)	22 3/4	(578)	NA	NA
C_2	35	(889)	-19 5/8	-(498)	4 3/4	(121)			7 1/2	(191)
C_3	30 1/2	(775)	-6 5/8	-(168)	2 3/8	(60)			5 3/8	(137)
C_4	28 1/2	(724)	6 3/8	(162)	2 1/4	(57)			3 1/2	(89)
C_5	30 1/4	(768)	19 3/8	(492)	4 5/8	(117)			2 7/8	(73)
C_6	NA	NA	32 3/8	(822)	19 7/8	(505)			NA	NA
C_{MAX}	35	(889)	-19 5/8	-(498)	4 3/4	(121)			7 1/2	(191)

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

Date: 2/6/2018 | Test Name: MGSCO-2 | VIN: KMHCN4AC1BU614772

Year: 2011 | Make: Hyundai | Model: Accent



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	55	(1397)
Total Vehicle Length:	168 1/4	(4274)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-11 1/4	-(286)
Width of contact and induced crush - Field L:	66	(1676)
Crush measurement spacing interval (L/5) - I:	13 1/4	(337)
Distance from vehicle c.g. to center of Field L - D_{FL}:	38	(965)
Width of Contact Damage:	66	(1676)
Distance from vehicle c.g. to center of contact damage - D_C:	38	(965)

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

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	19 1/2	(495)	5	(127)	3 1/4	(83)	19	(483)	-2 3/4	-(70)
C_2	17 1/2	(445)	18 1/4	(464)	3 1/4	(83)			-4 3/4	-(121)
C_3	25	(635)	31 1/2	(800)	3 3/8	(86)			2 5/8	(67)
C_4	30	(762)	44 3/4	(1137)	3 7/8	(98)			7 1/8	(181)
C_5	38 3/4	(984)	58	(1473)	6 5/8	(168)			13 1/8	(333)
C_6	NA	NA	71 1/4	(1810)	36	(914)			NA	NA
C_{MAX}	38 3/4	(984)	58	(1473)	6 5/8	(168)			13 1/8	(333)

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

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

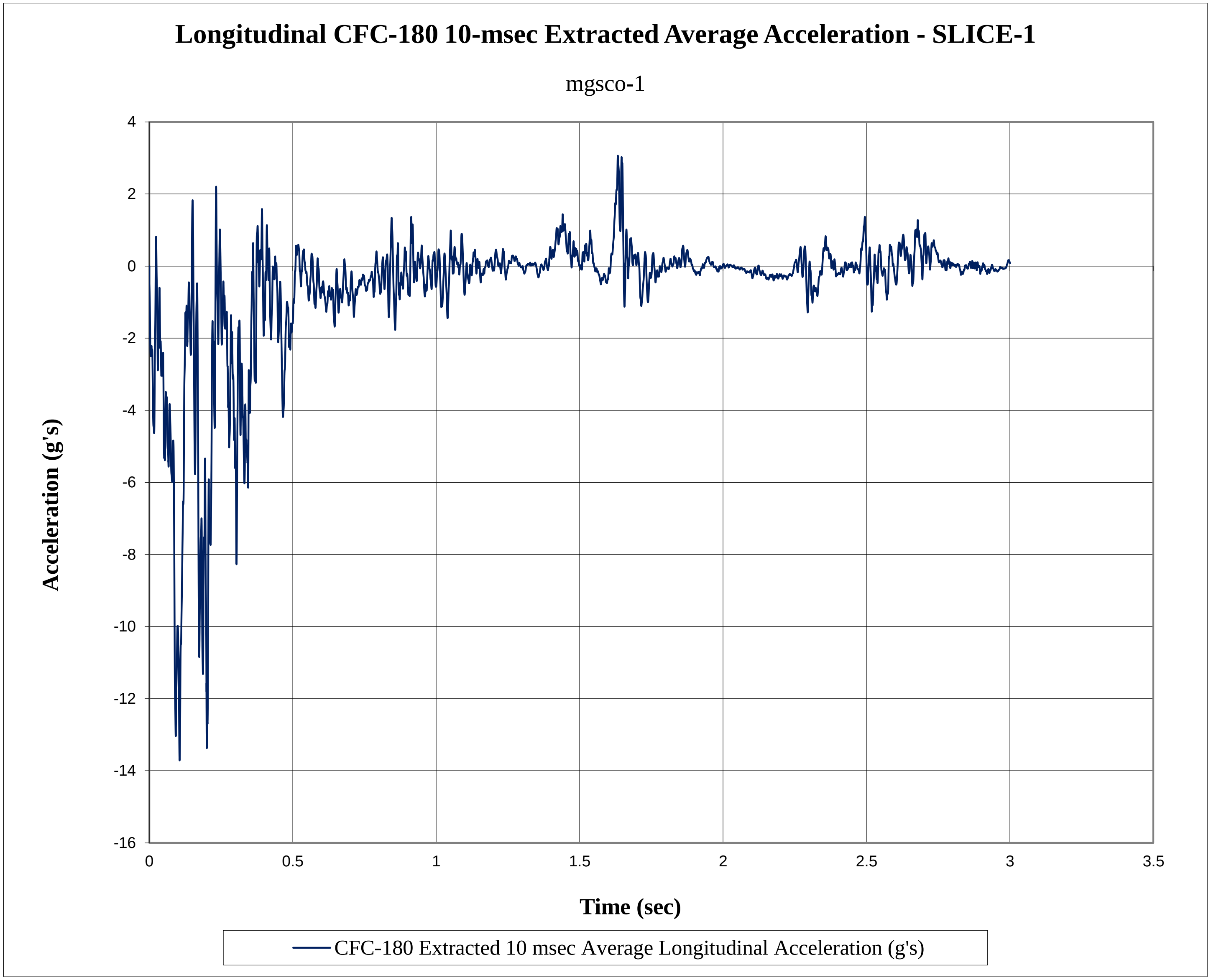


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSCO-1

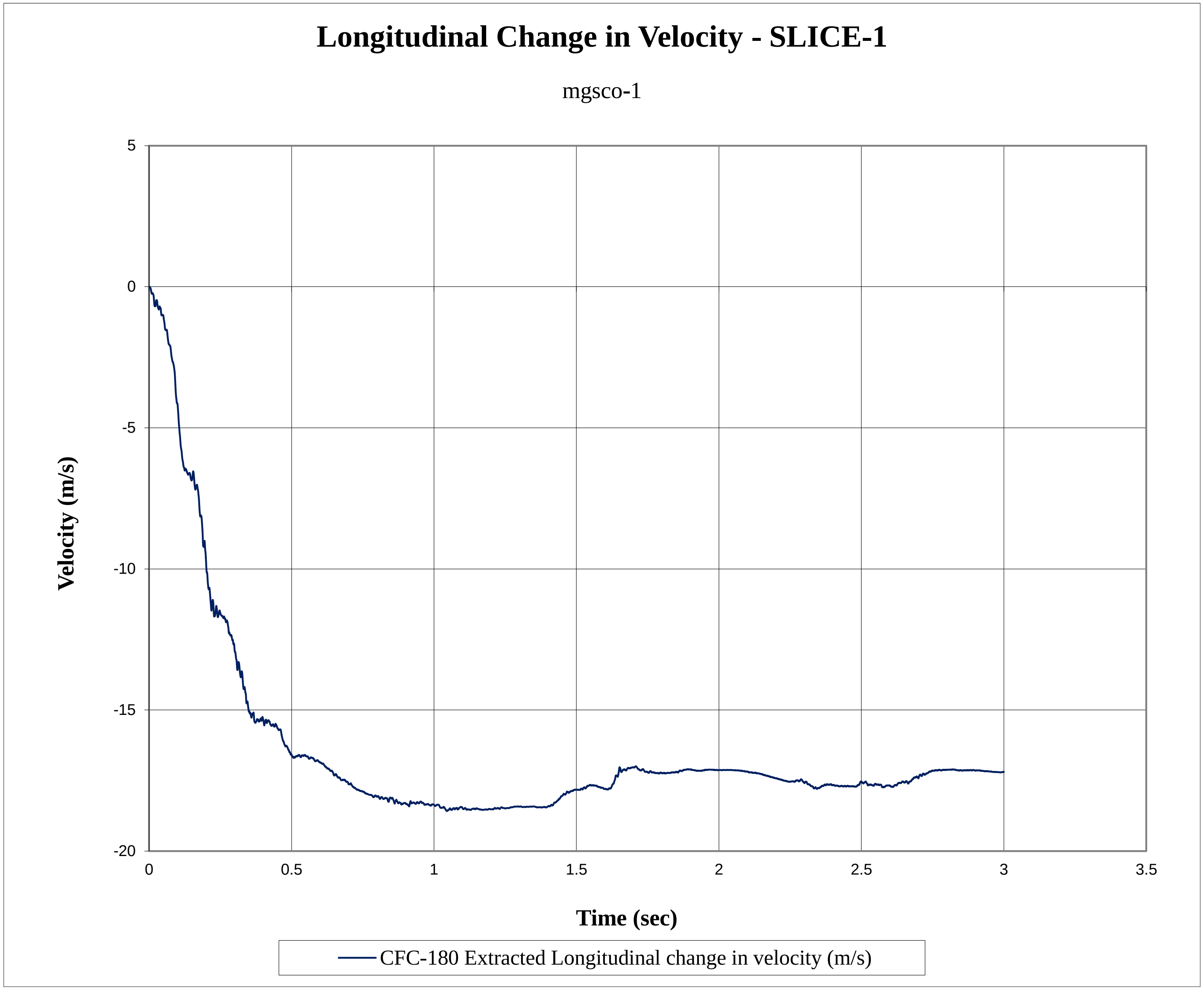


Figure E-2. Longitudinal Occupant Velocity (SLICE-1), Test No. MGSCO-1

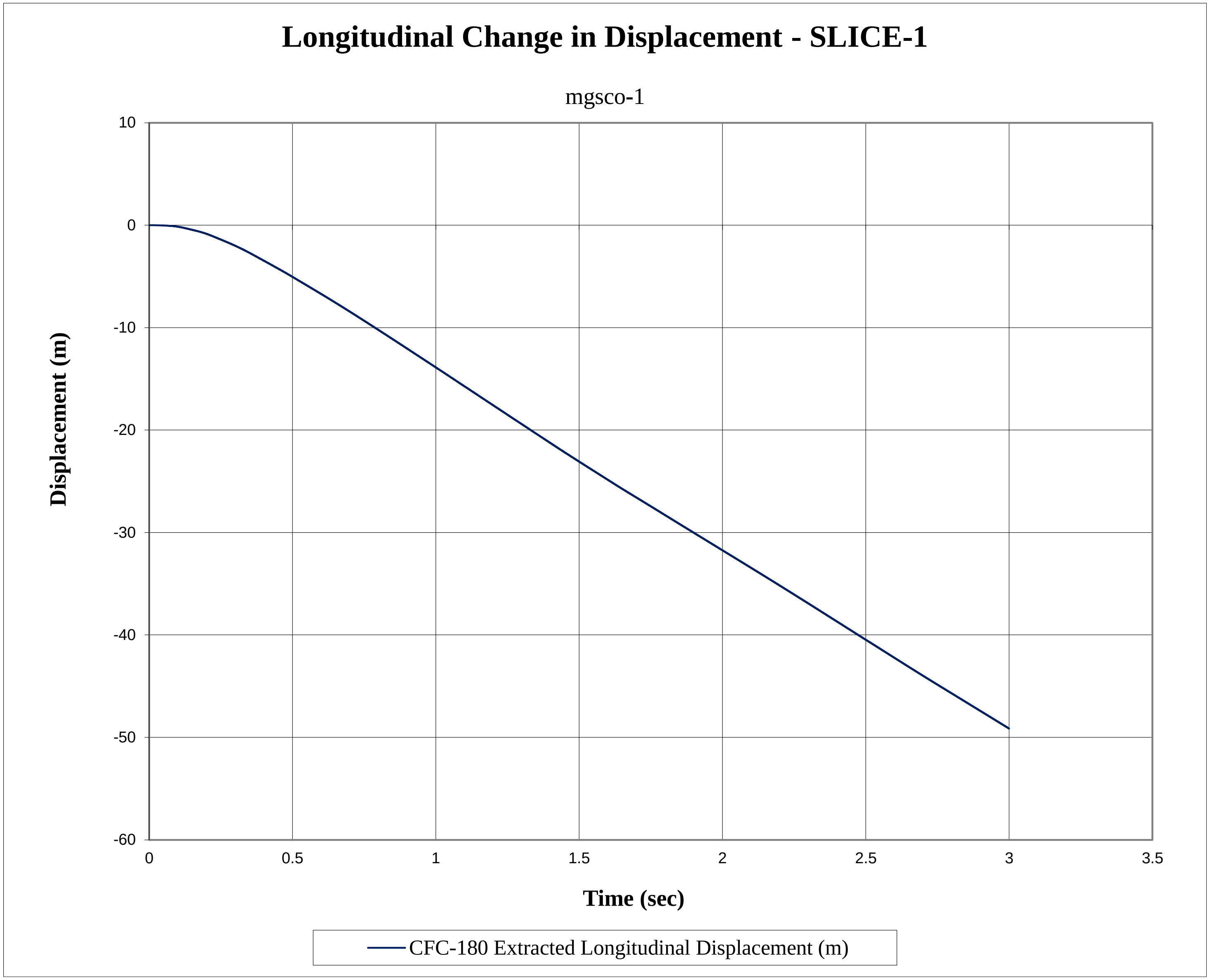


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSCO-1

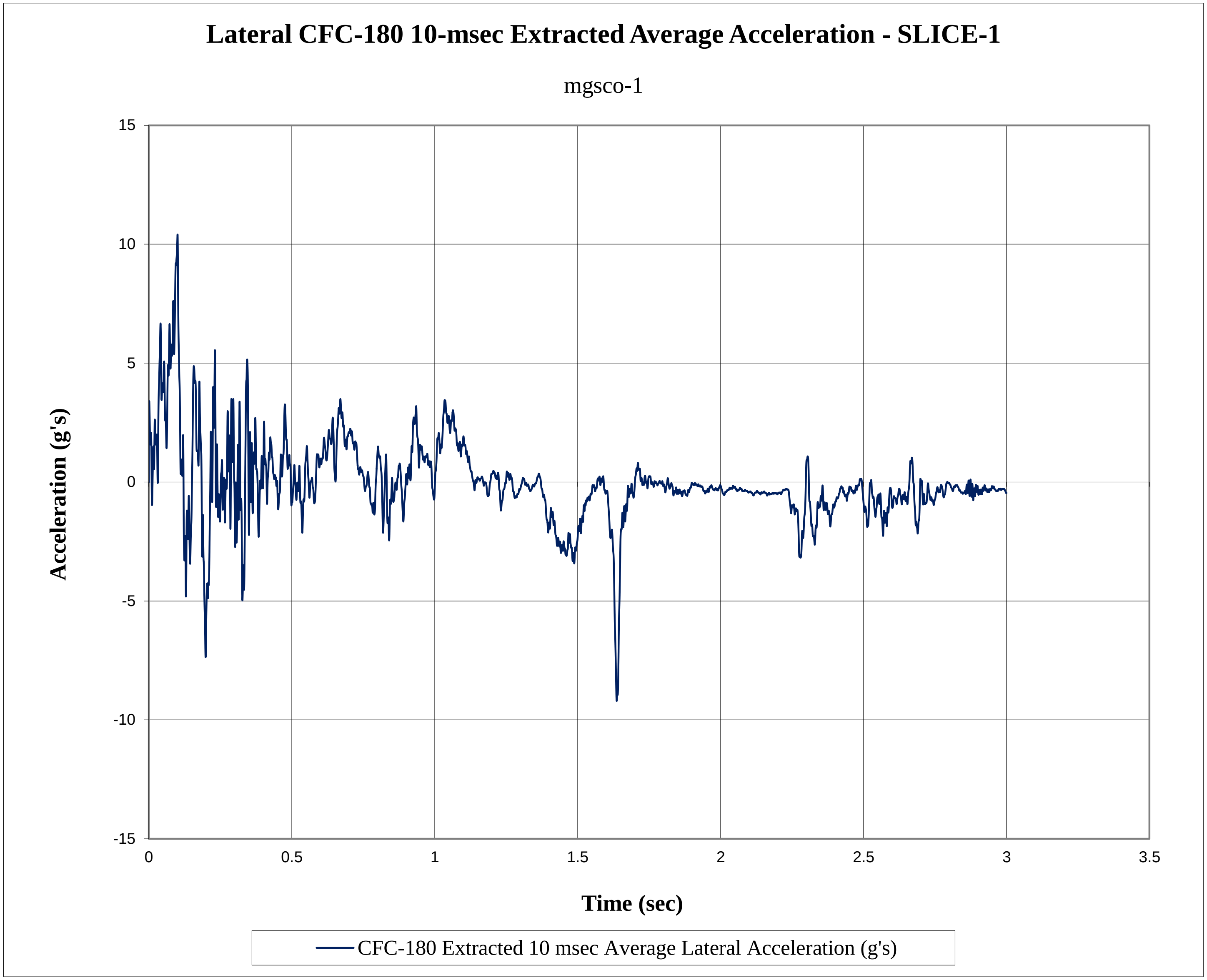


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSCO-1

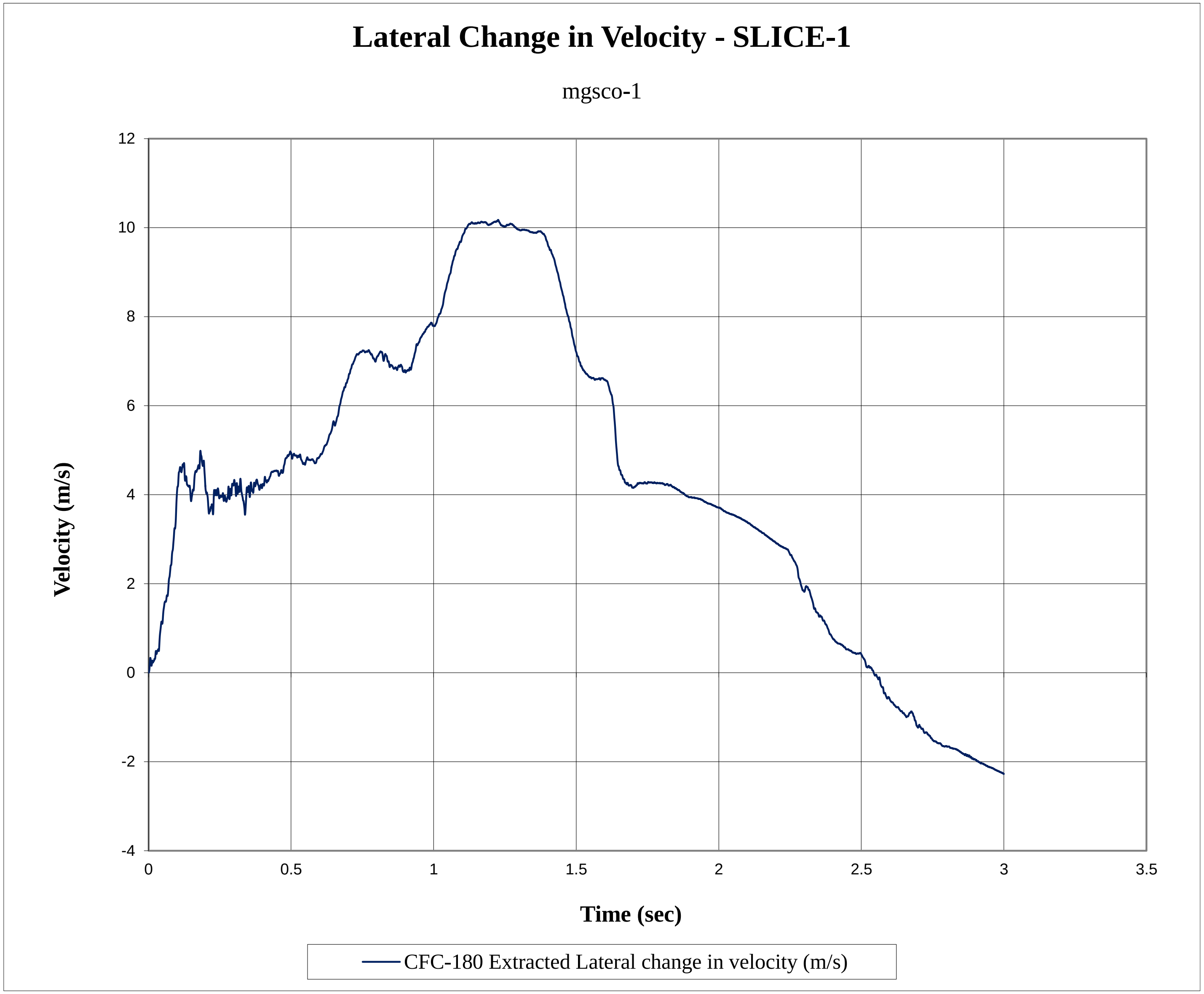


Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MGSCO-1

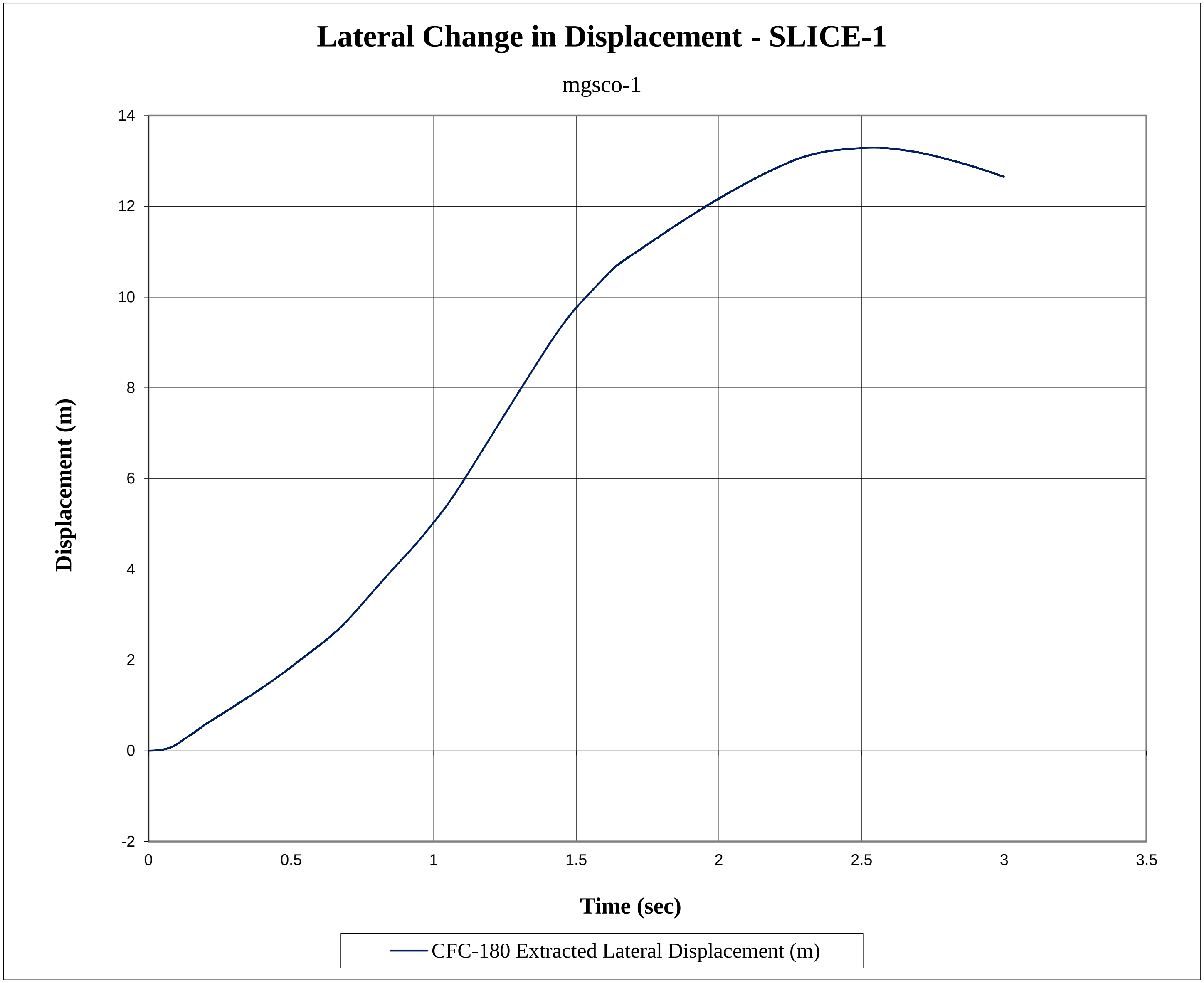


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. MGSCO-1

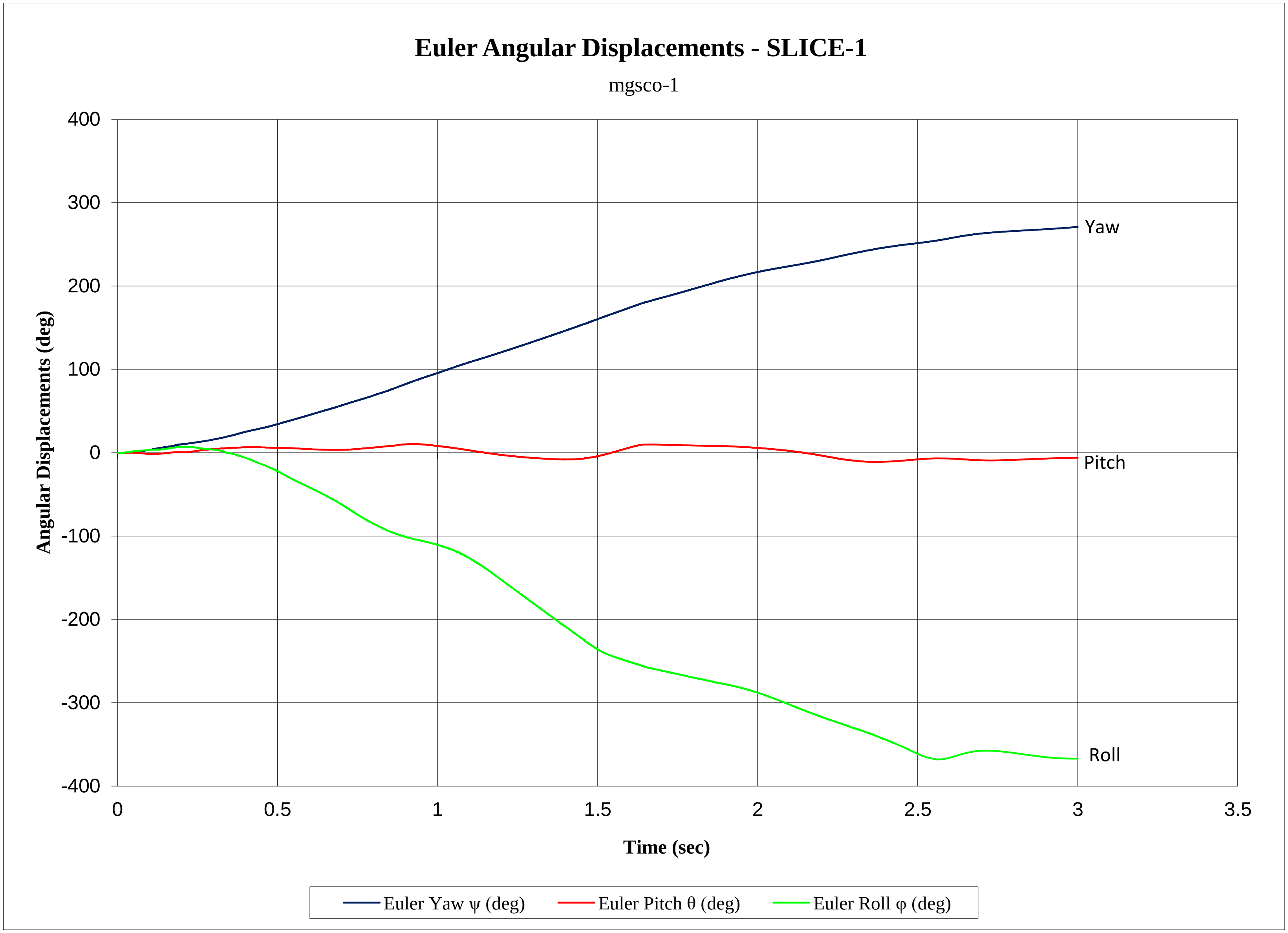


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. MGSCO-1

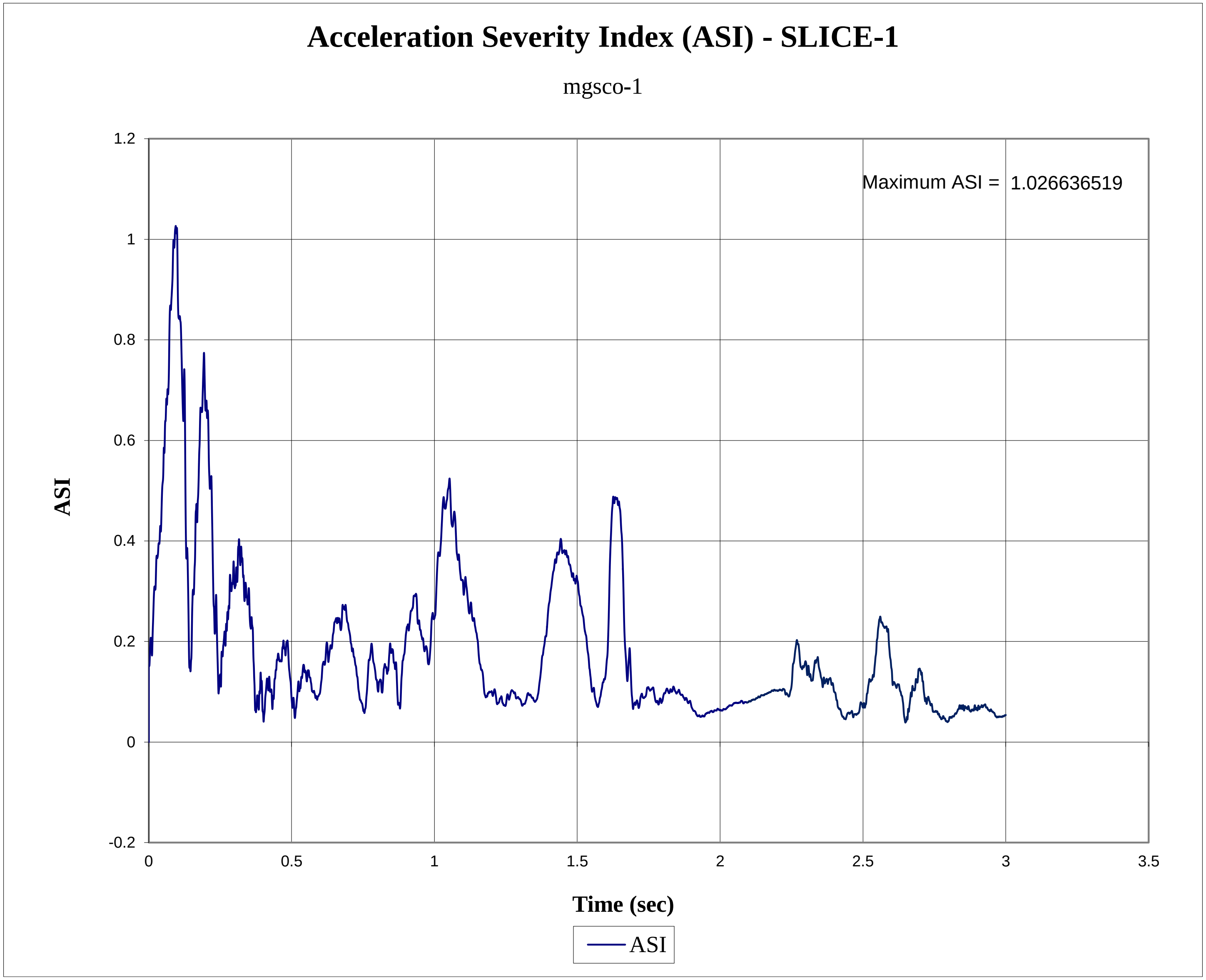


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. MGSCO-1

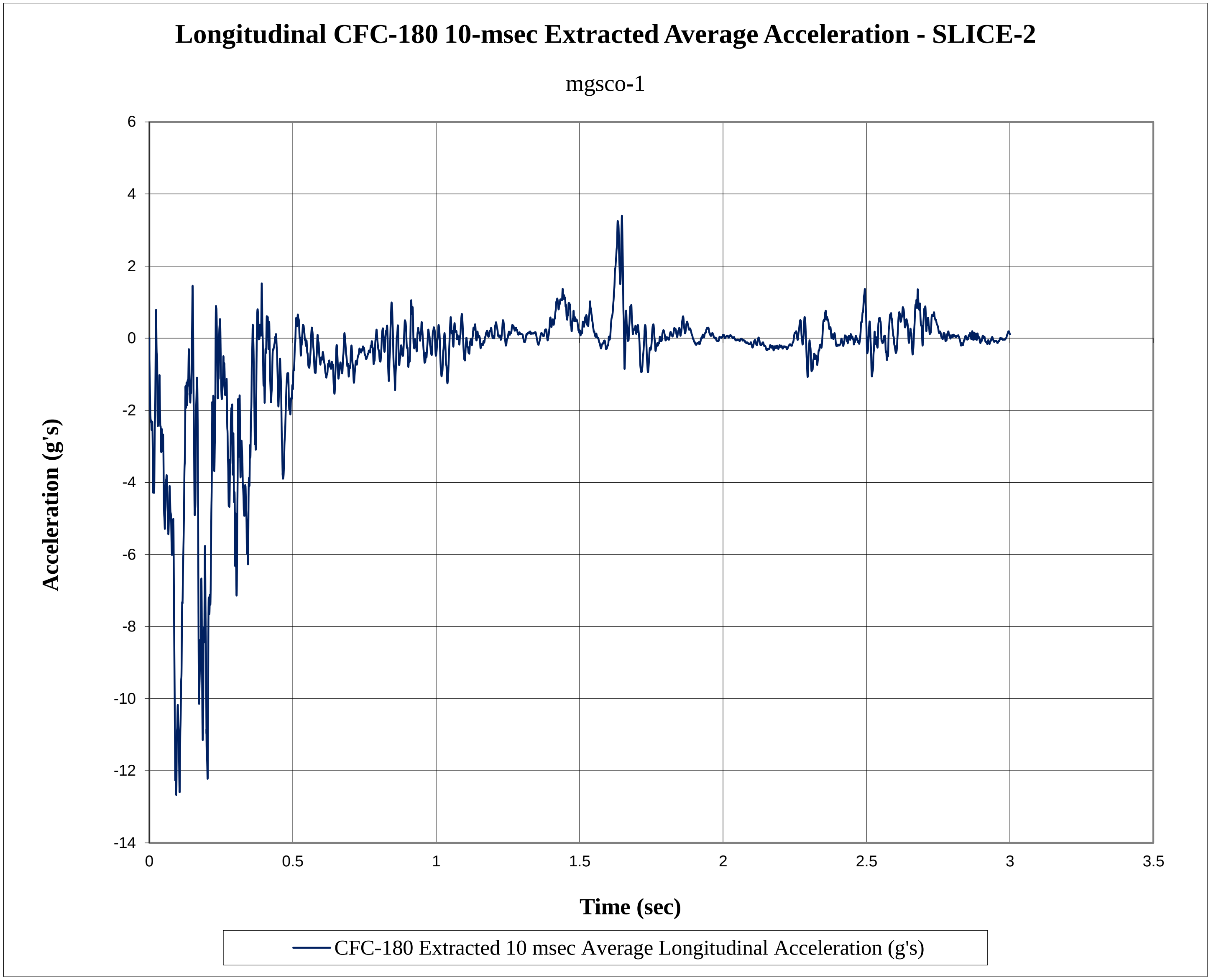


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSCO-1

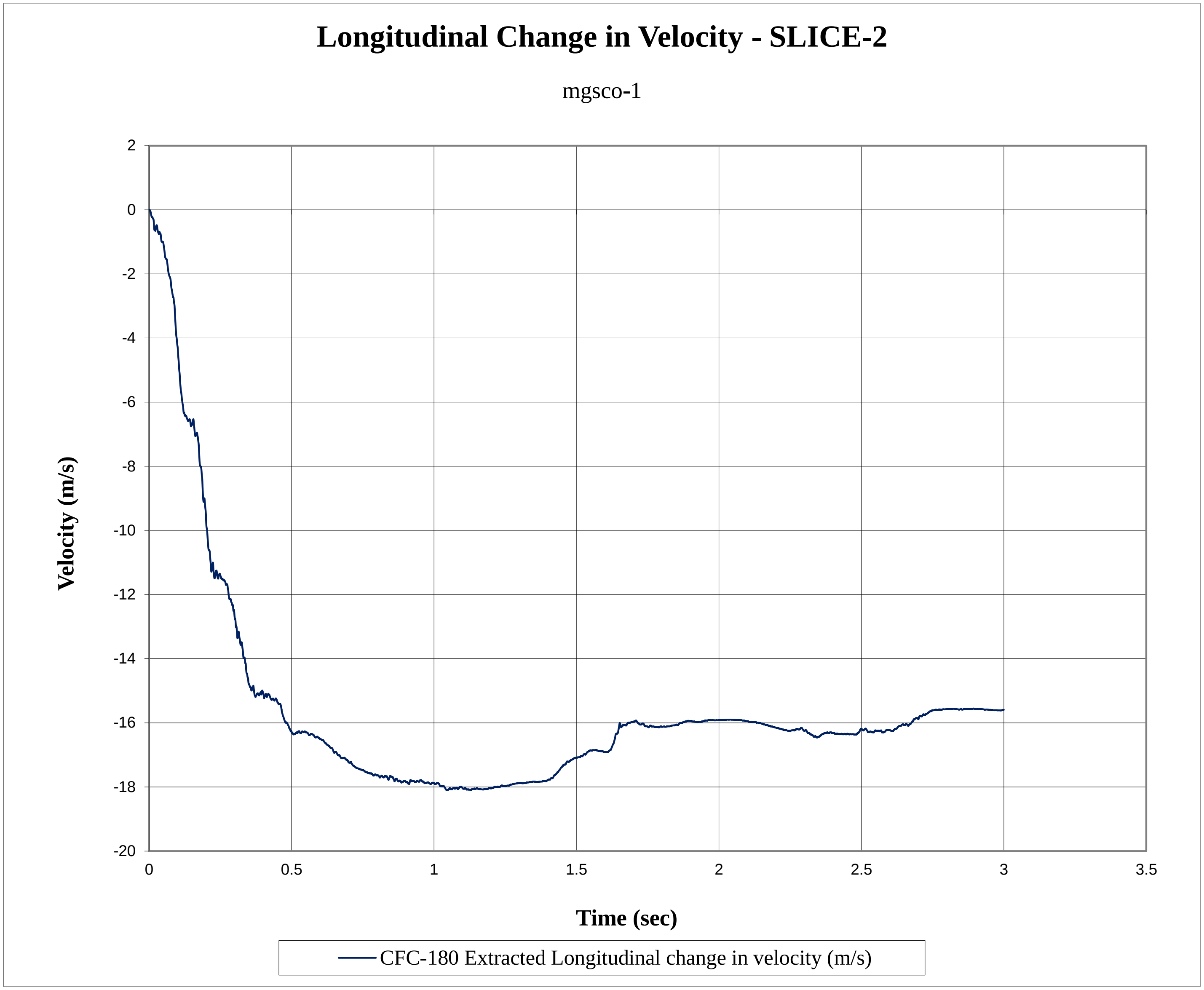


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MGSCO-1

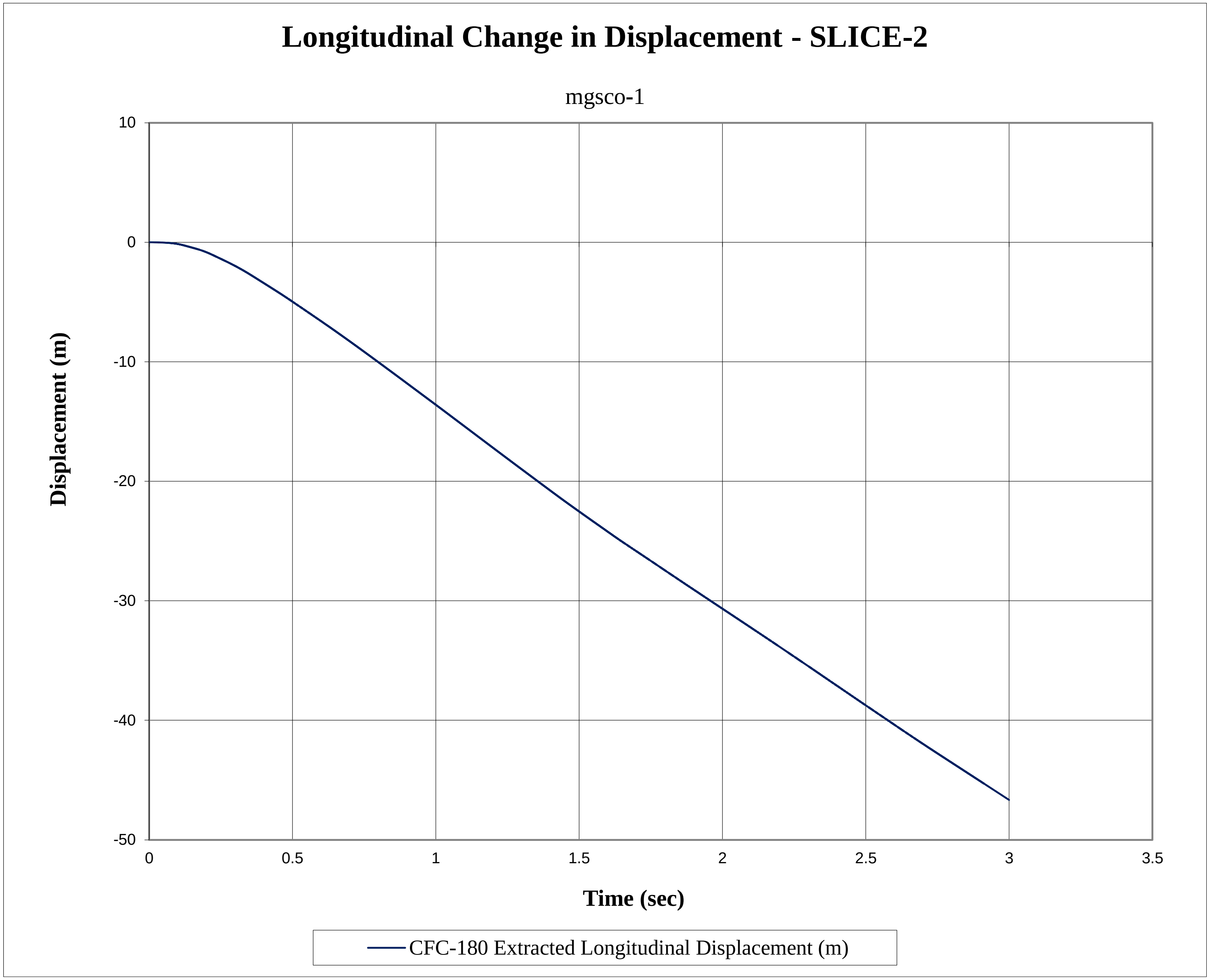


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSCO-1

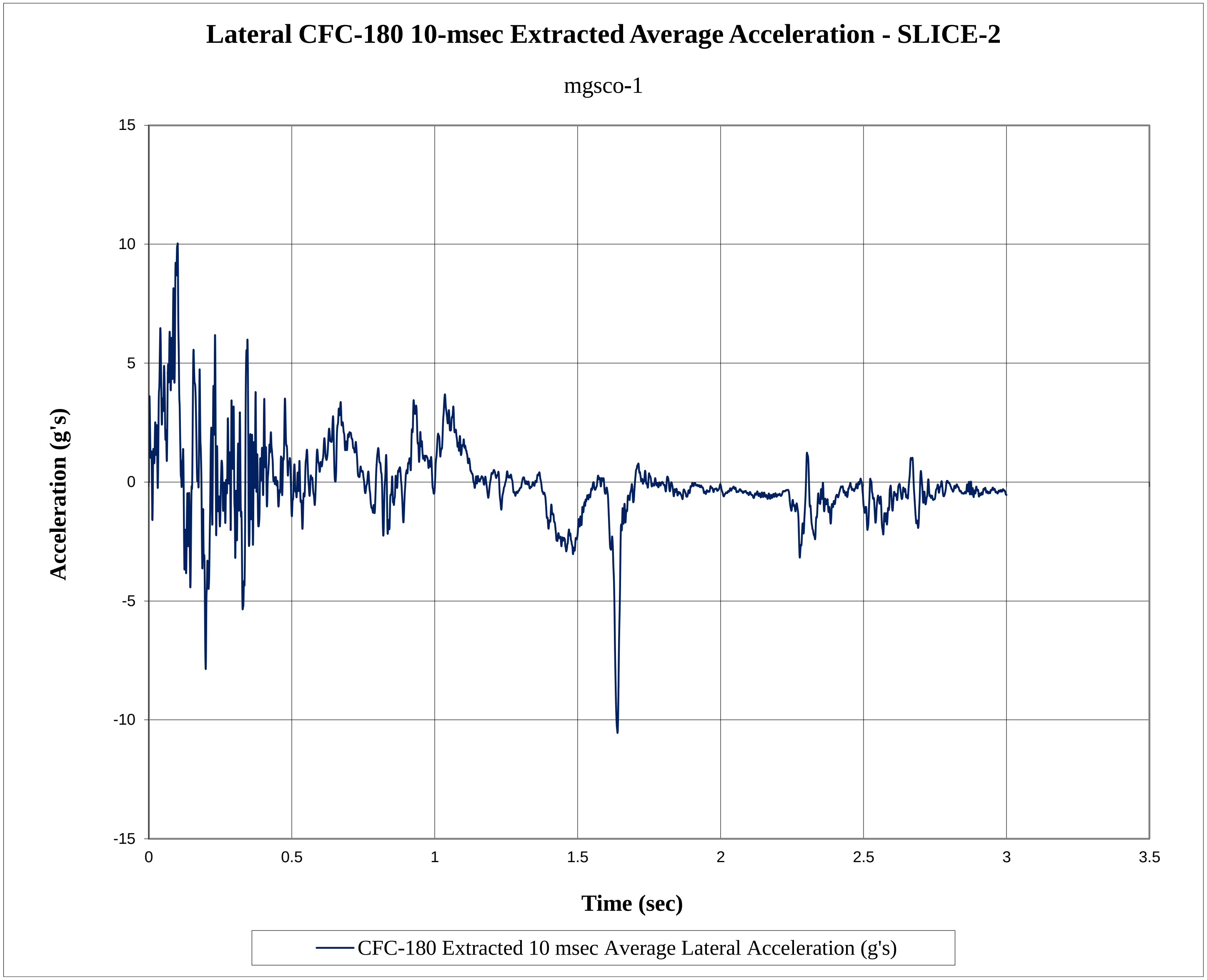


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSCO-1

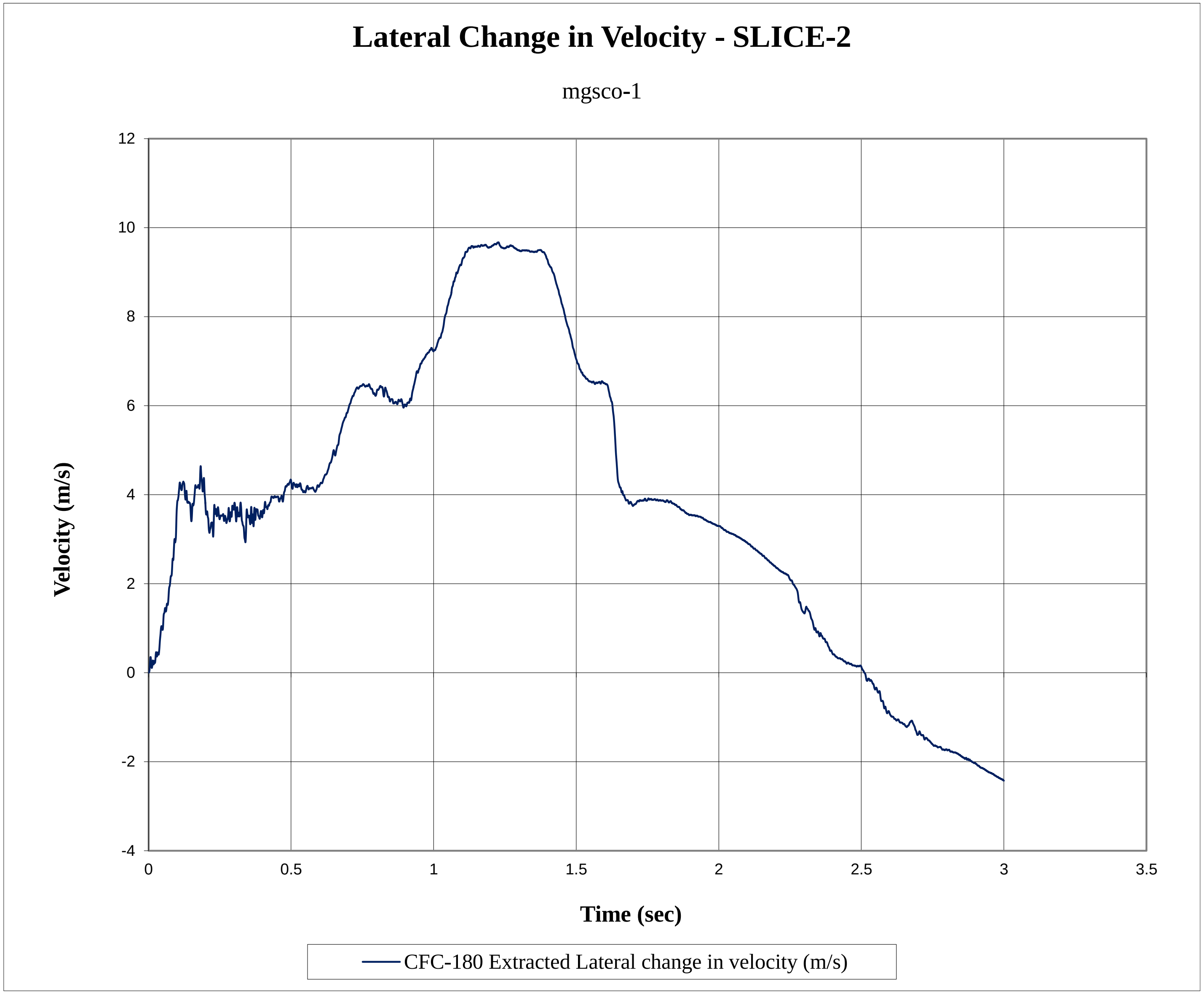


Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MGSCO-1

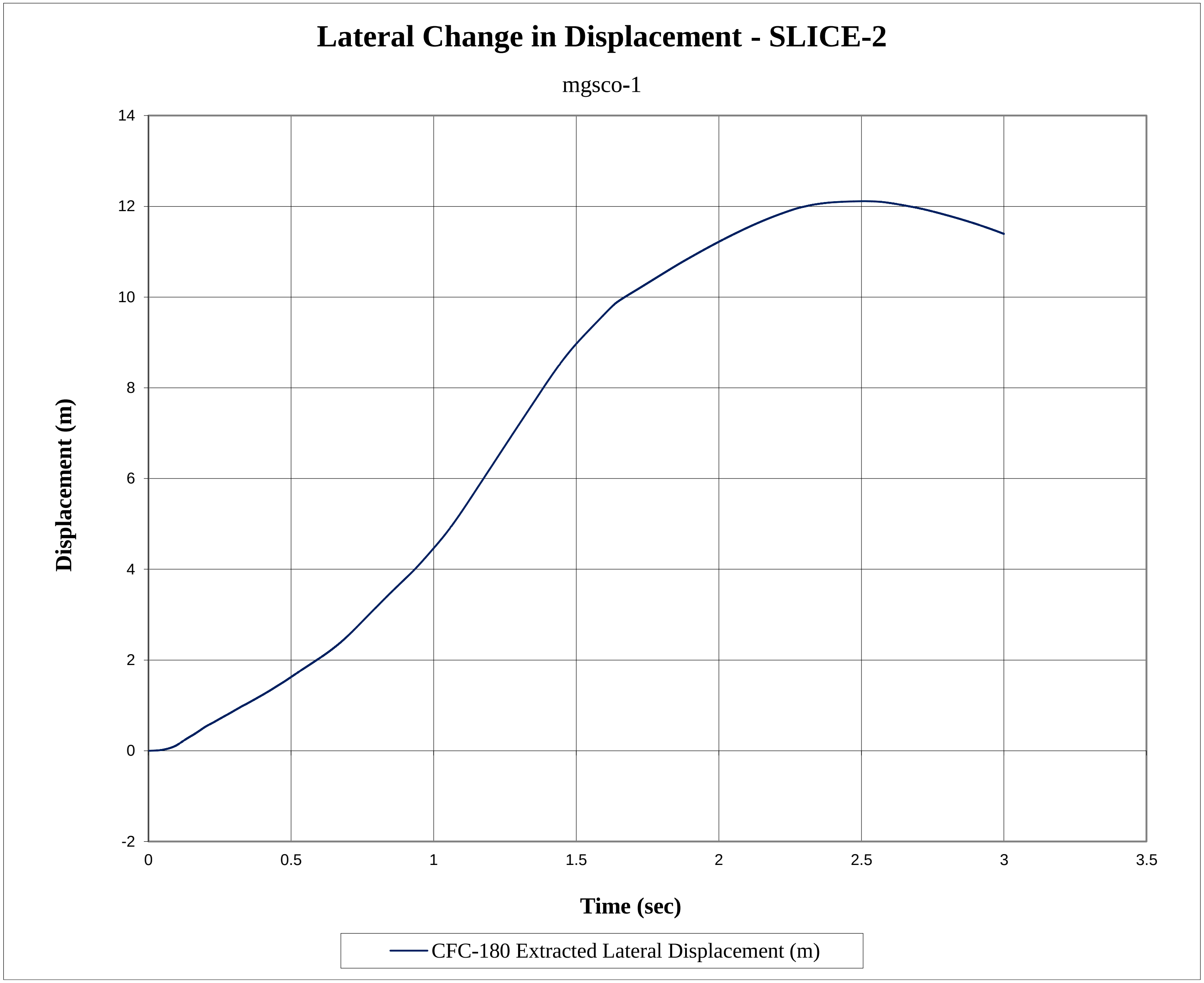


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. MGSCO-1

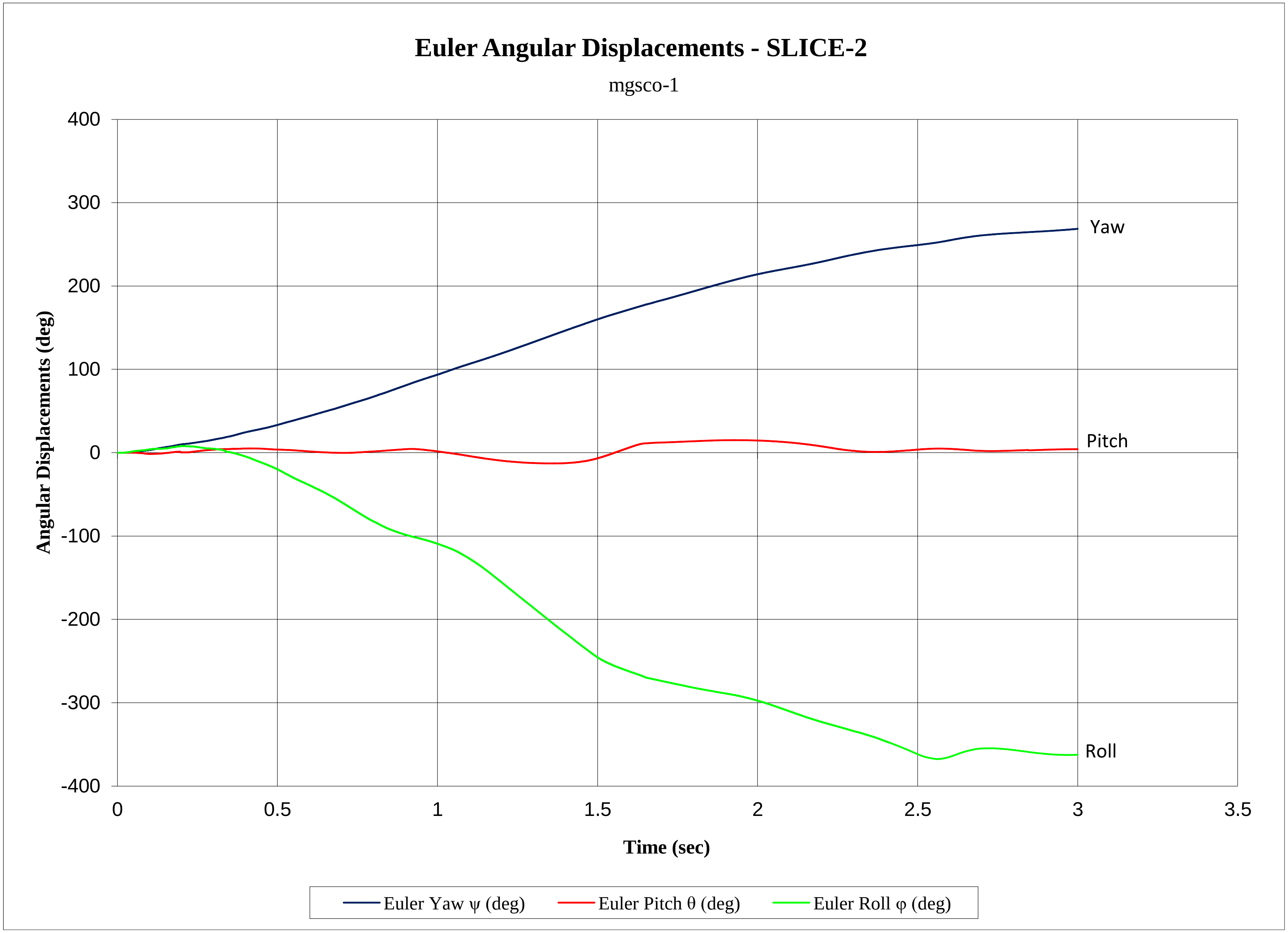


Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. MGSCO-1

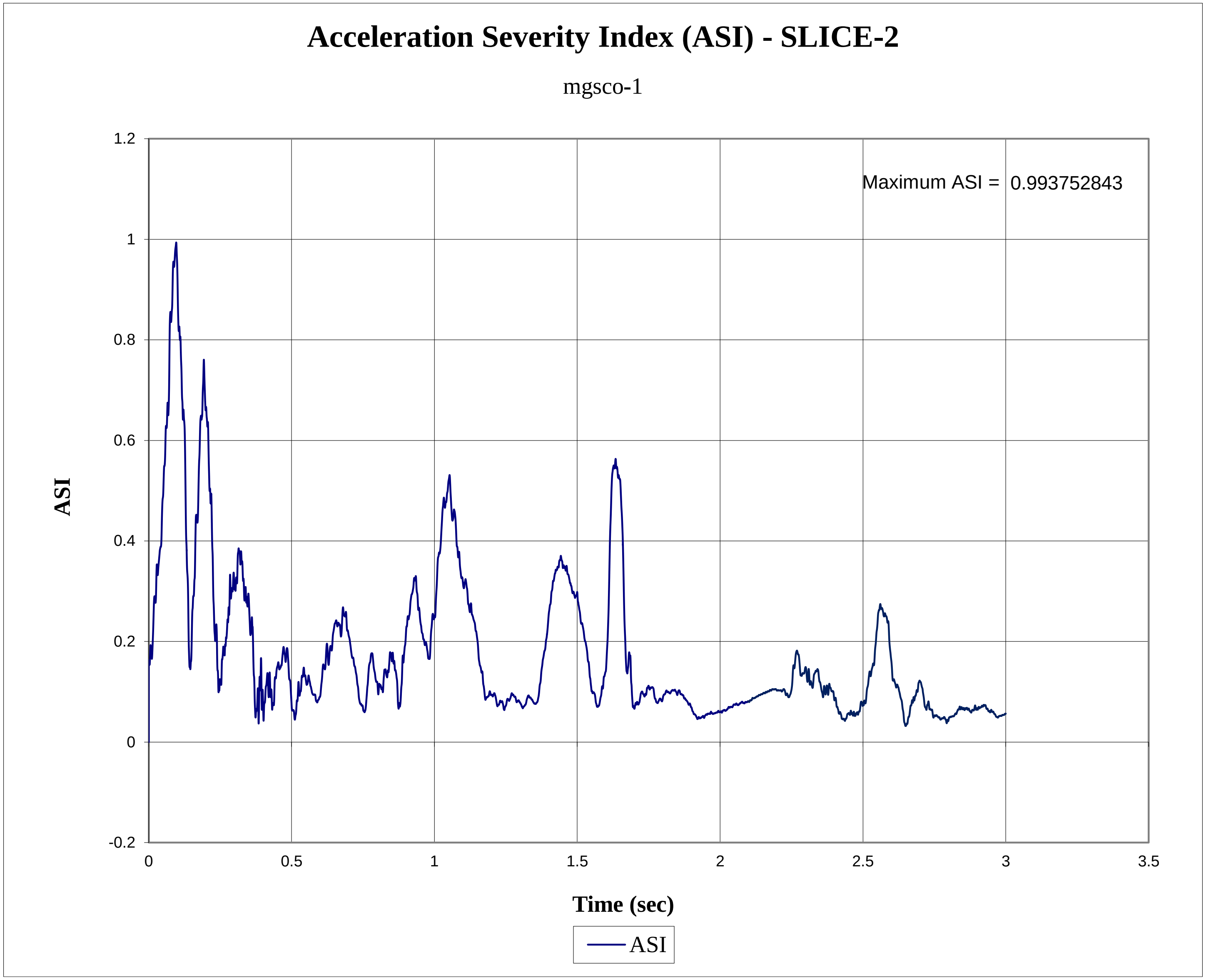


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. MGSCO-1

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

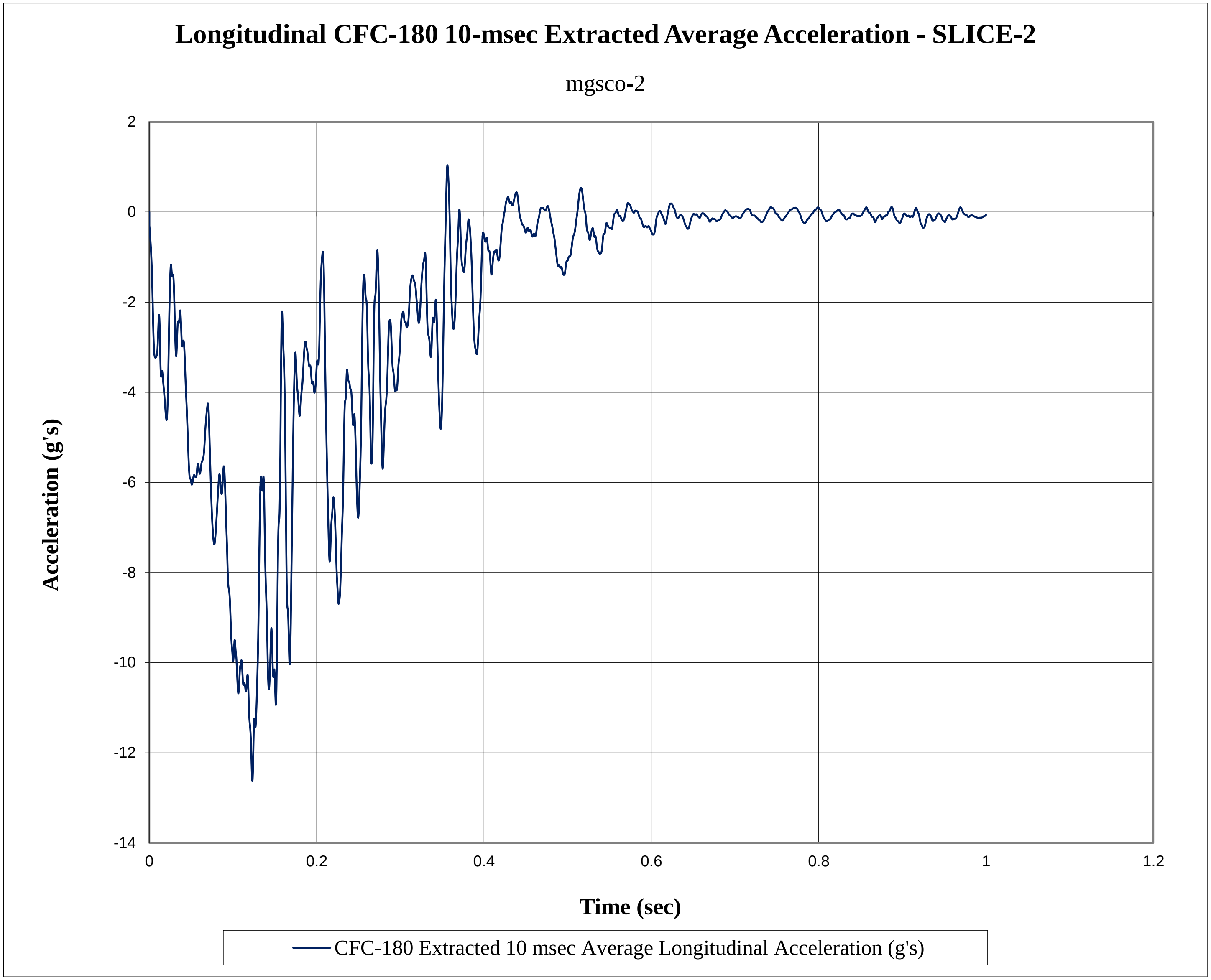


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MGSCO-2

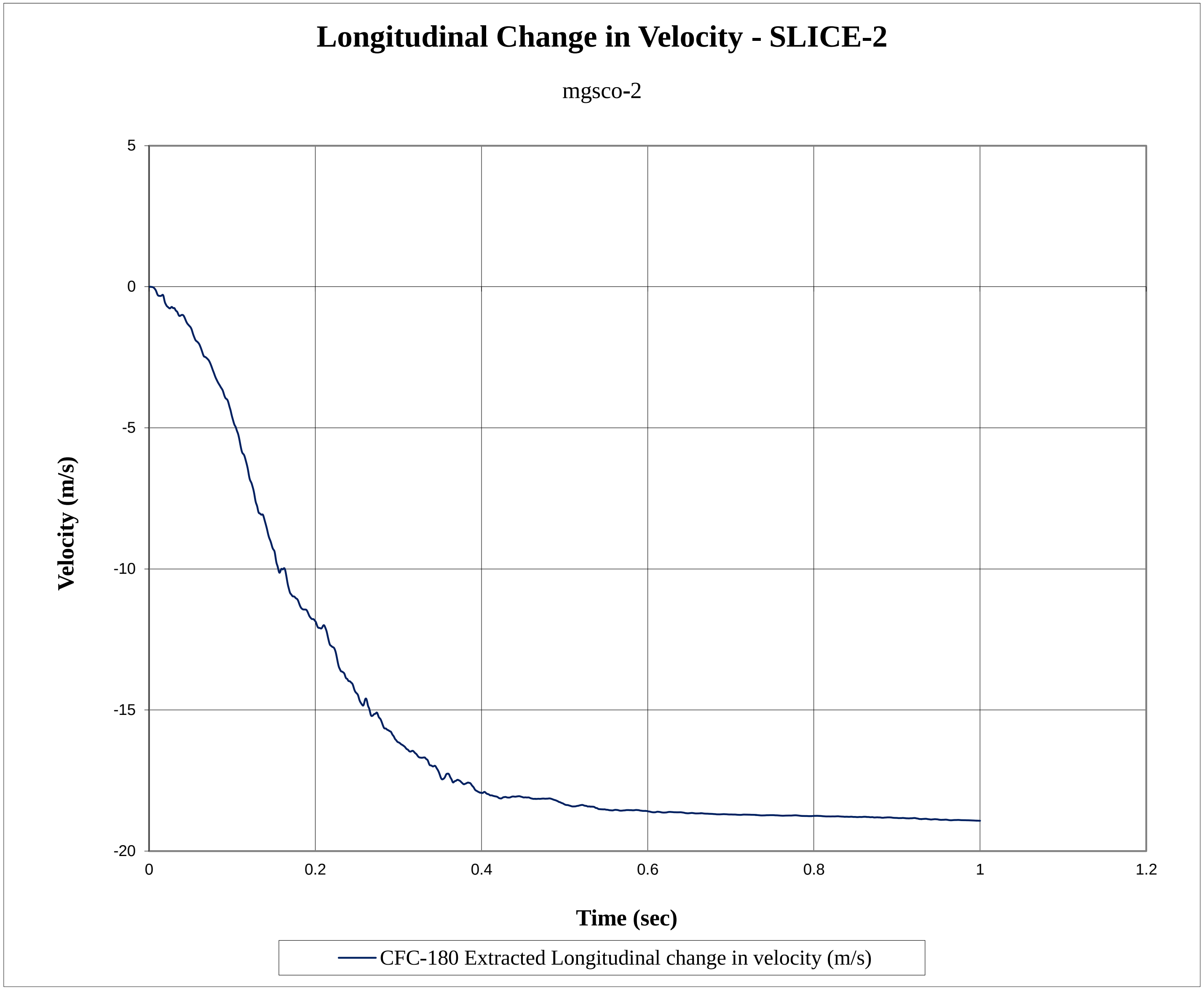


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MGSCO-2

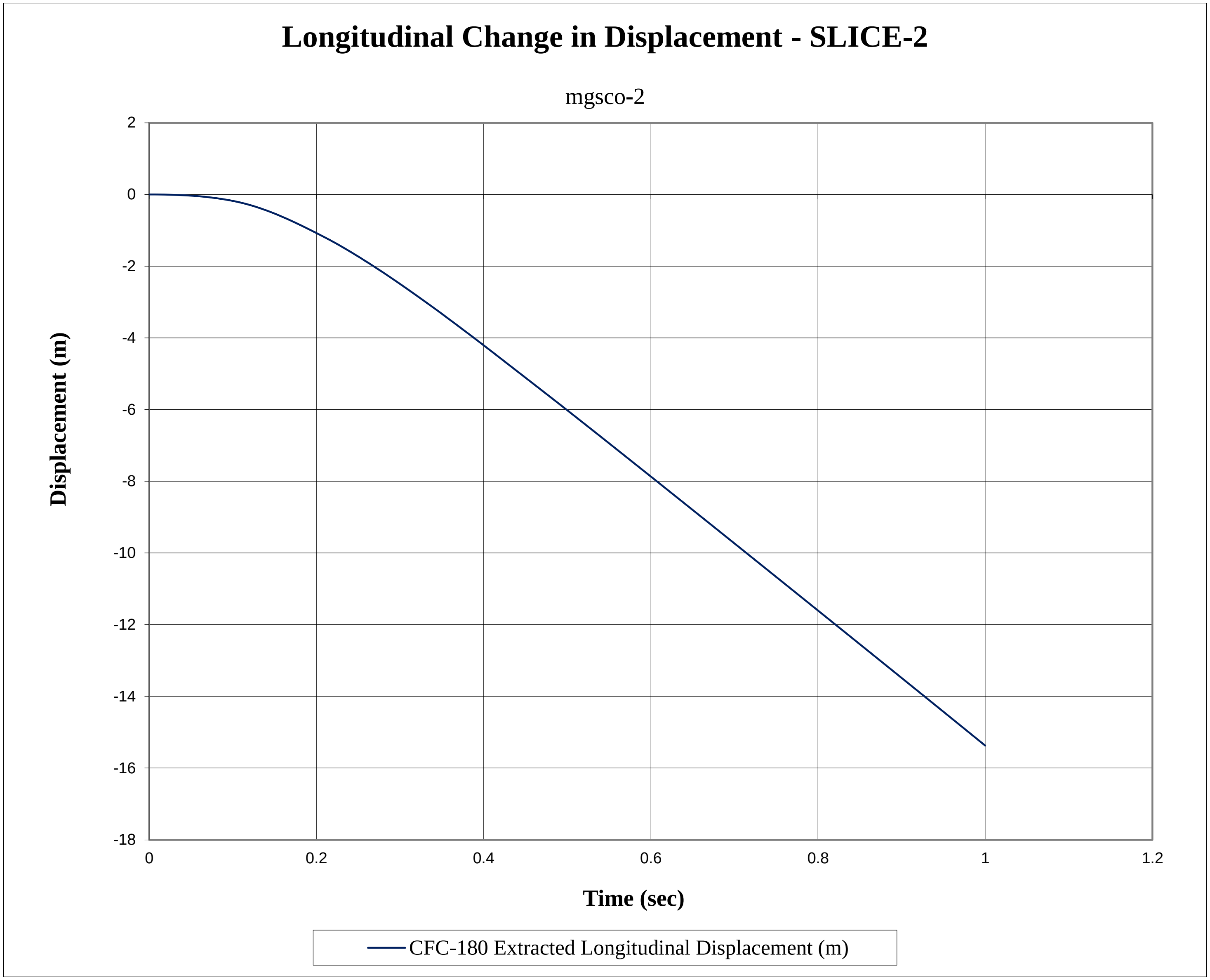


Figure F-3. Longitudinal Occupant Displacement (SLICE-2), Test No. MGSCO-2

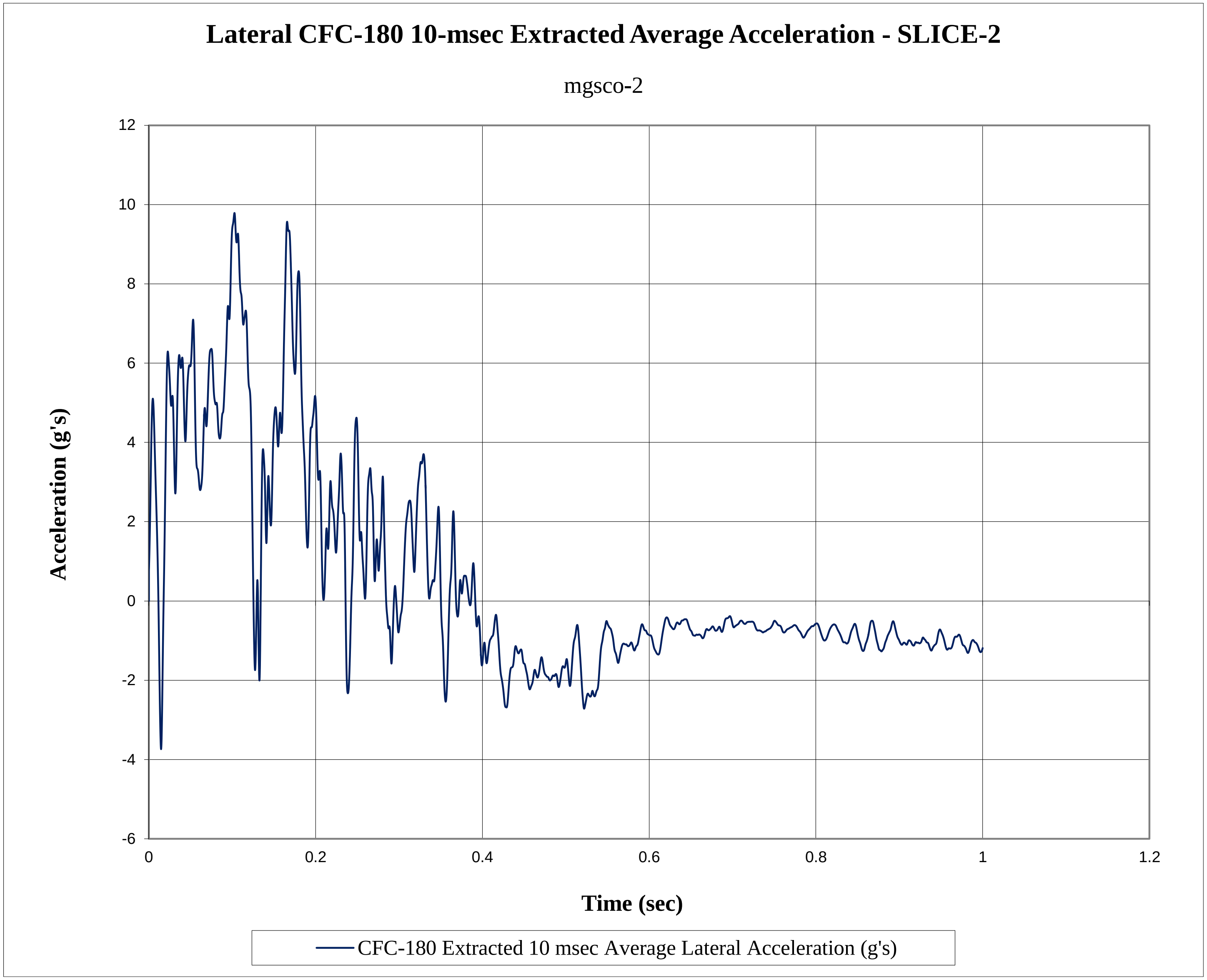


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MGSCO-2

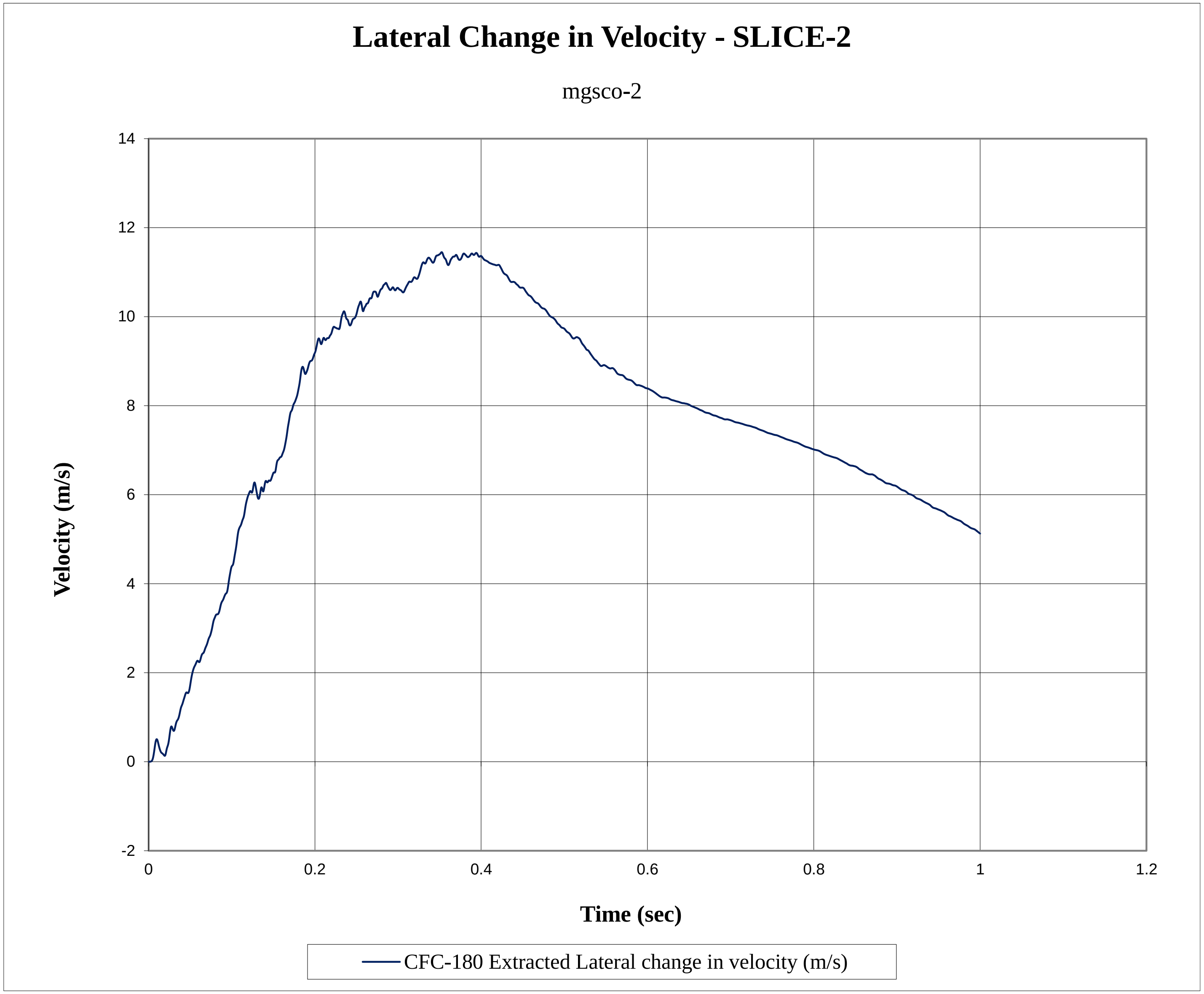


Figure F-5. Lateral Occupant Impact Velocity (SLICE-2), Test No. MGSCO-2

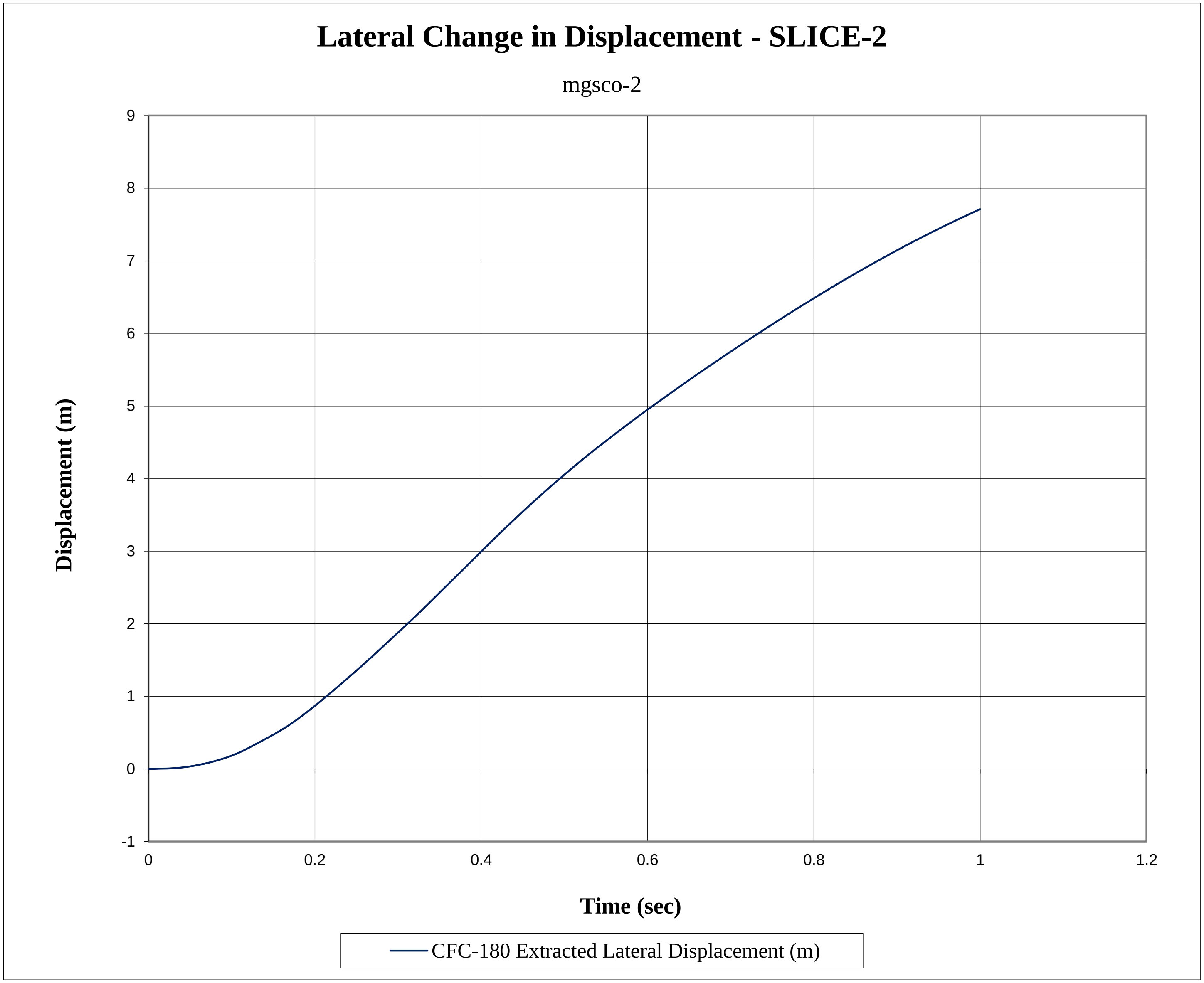


Figure F-6. Lateral Occupant Displacement (SLICE-2), Test No. MGSCO-2

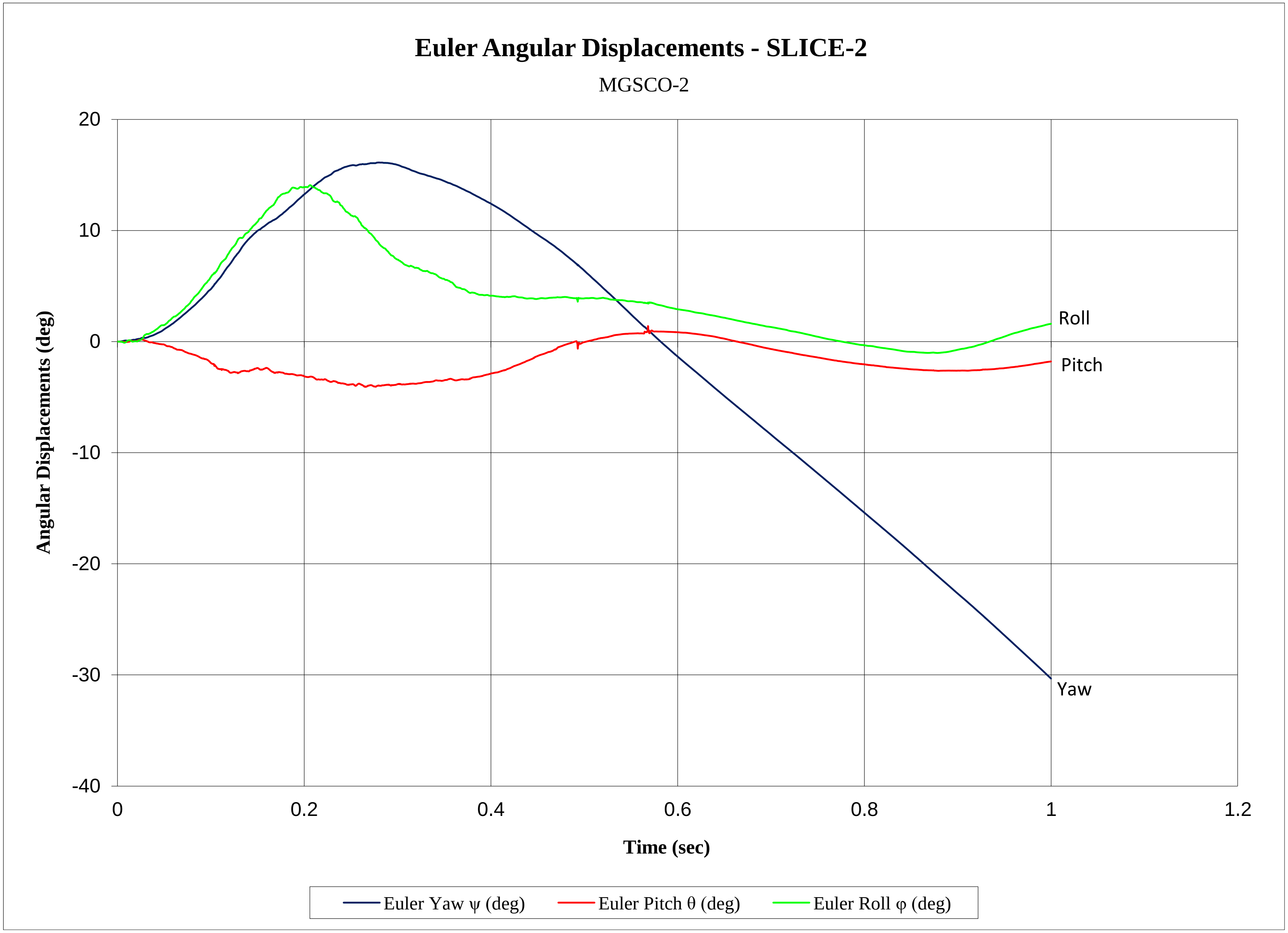


Figure F-7. Vehicle Angular Displacements (SLICE-2), Test No. MGSCO-2

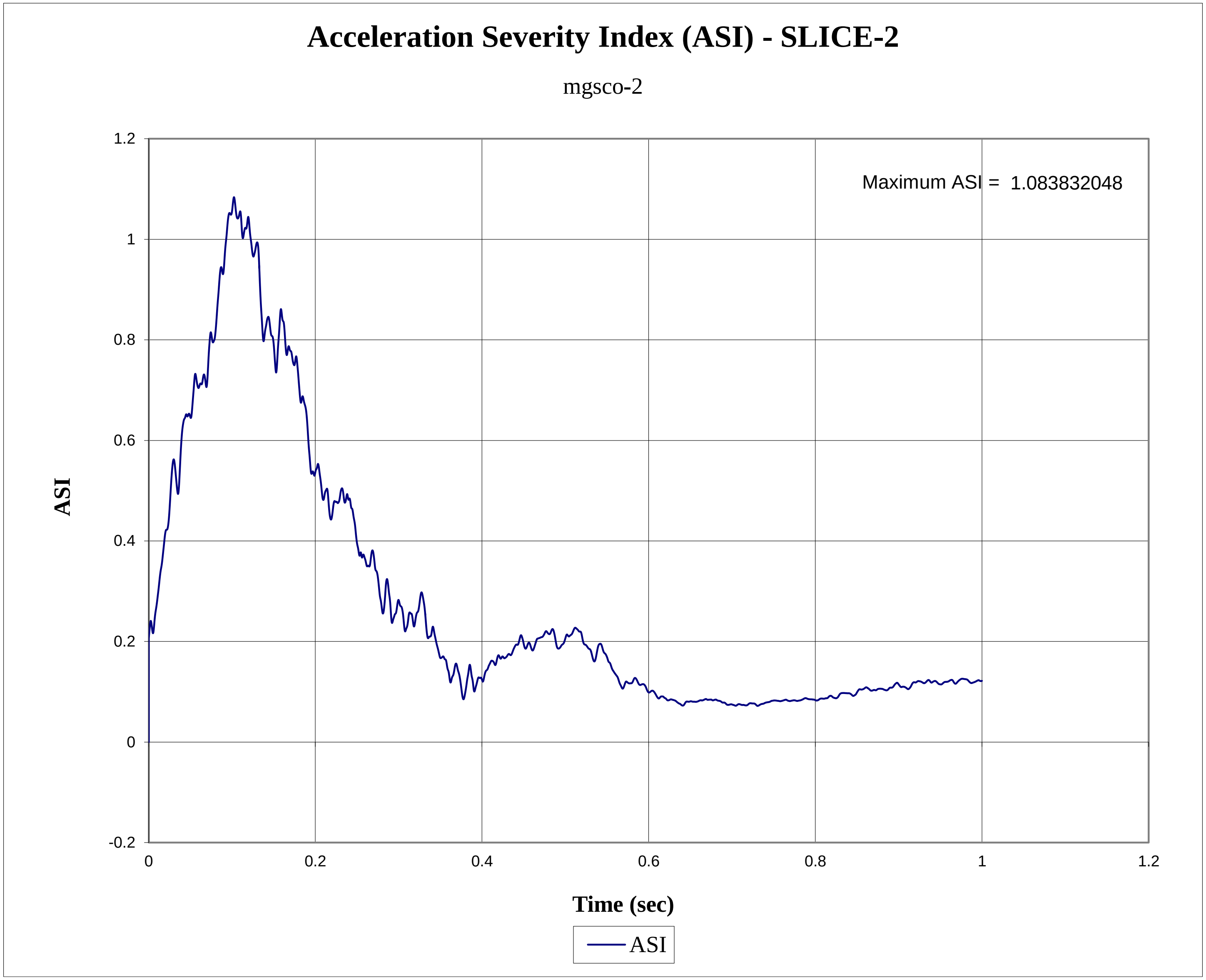


Figure F-8. Acceleration Severity Index (SLICE-2), Test No. MGSCO-2

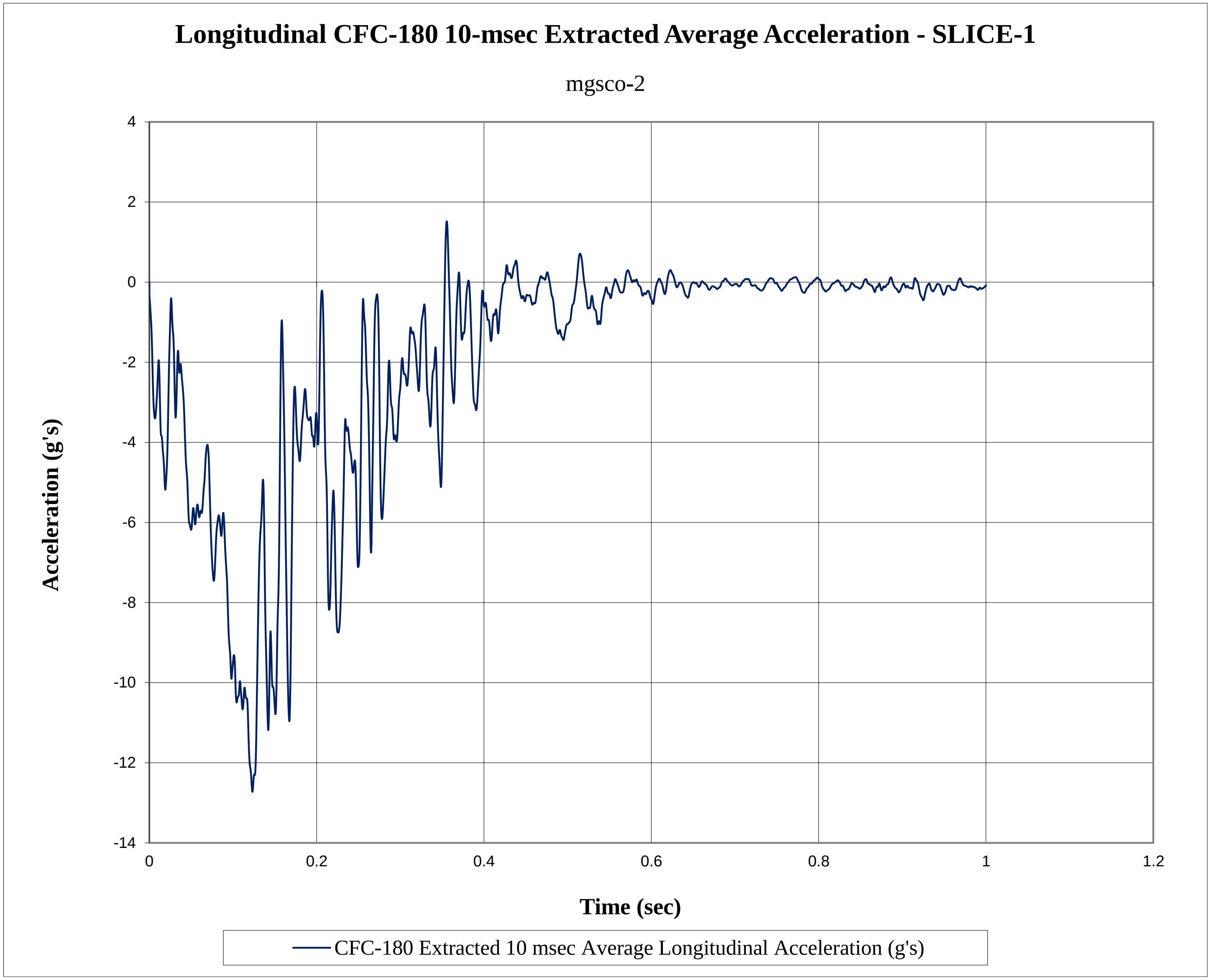


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MGSCO-2

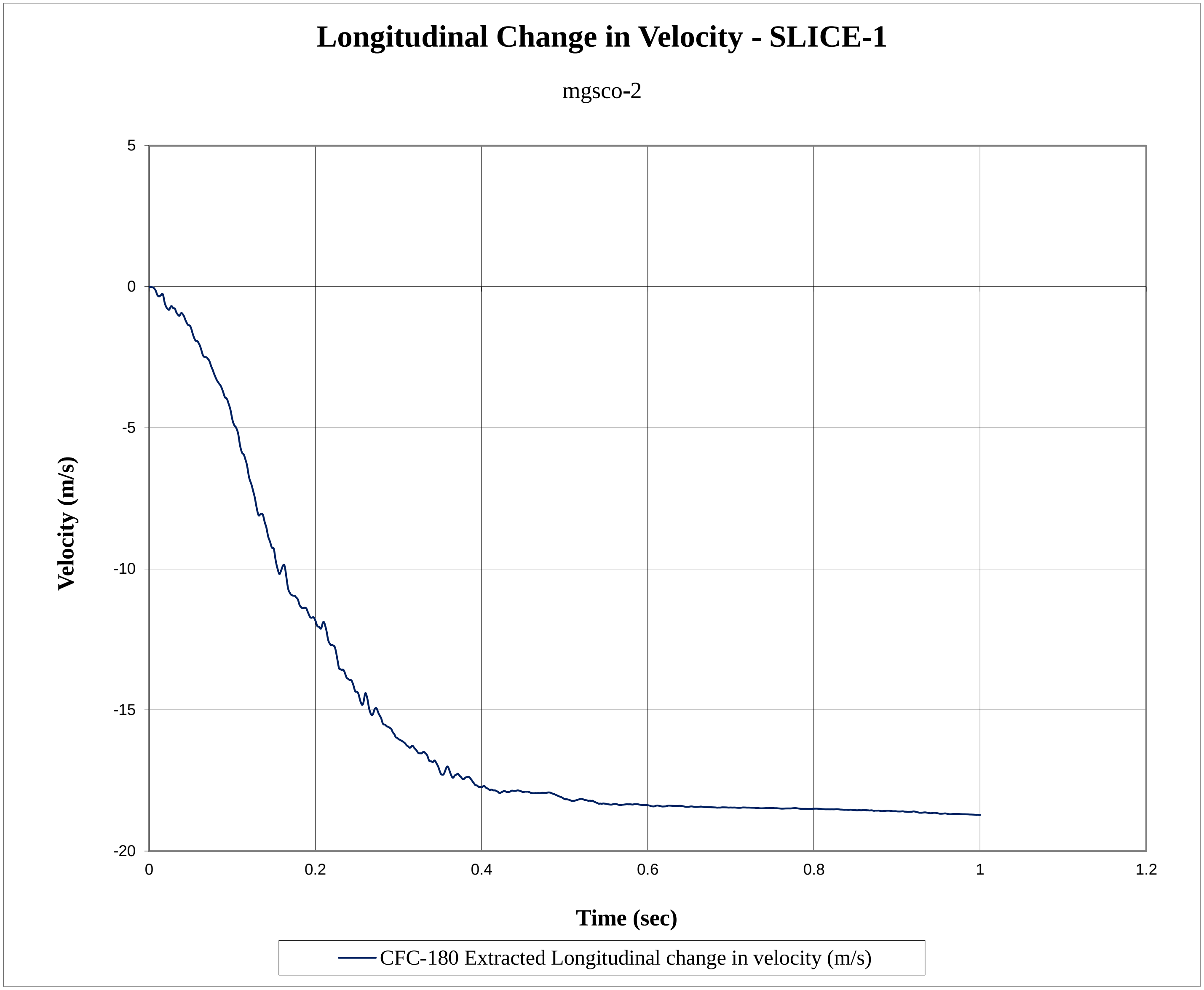


Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MGSCO-2

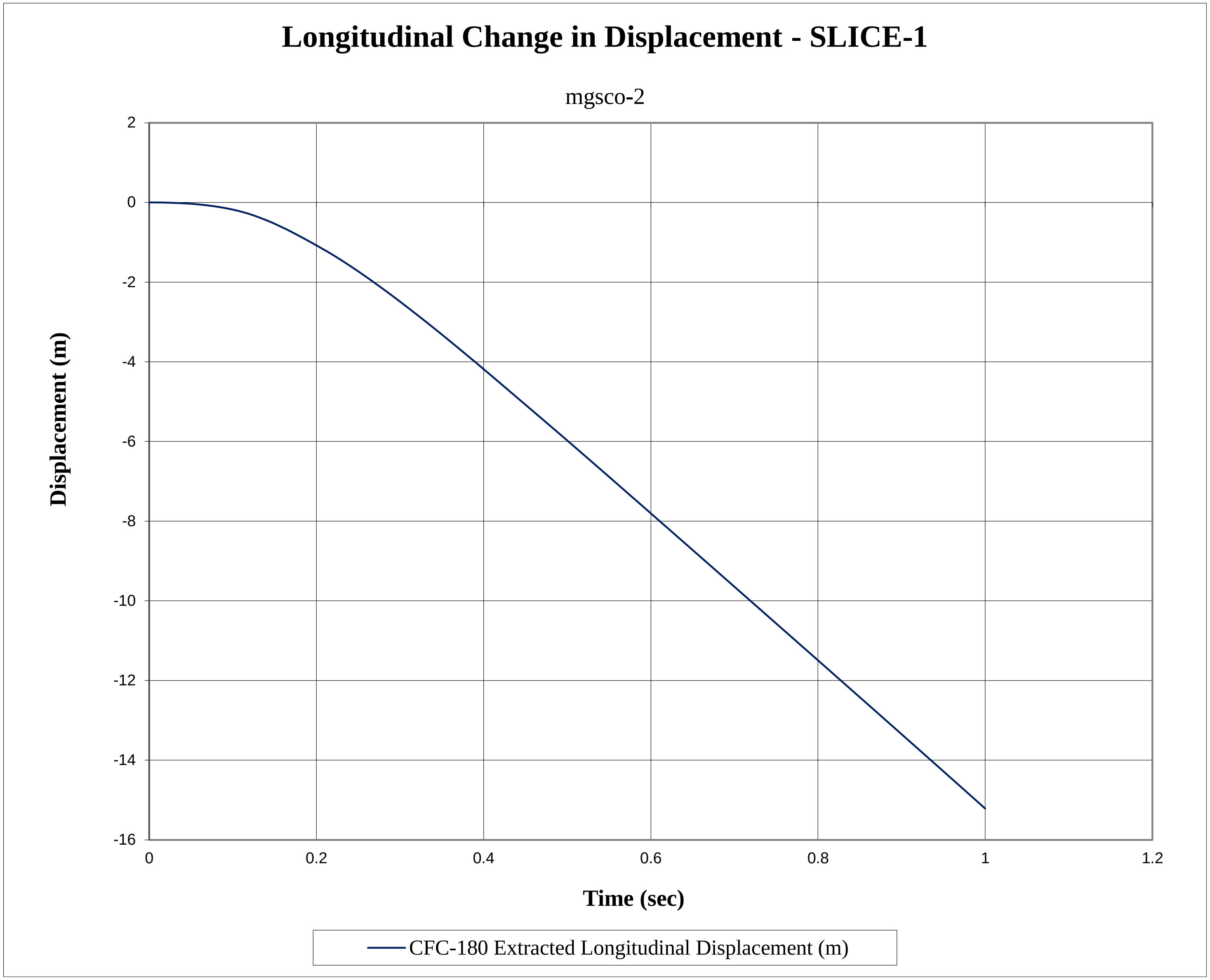


Figure F-11. Longitudinal Occupant Displacement (SLICE-1), Test No. MGSCO-2

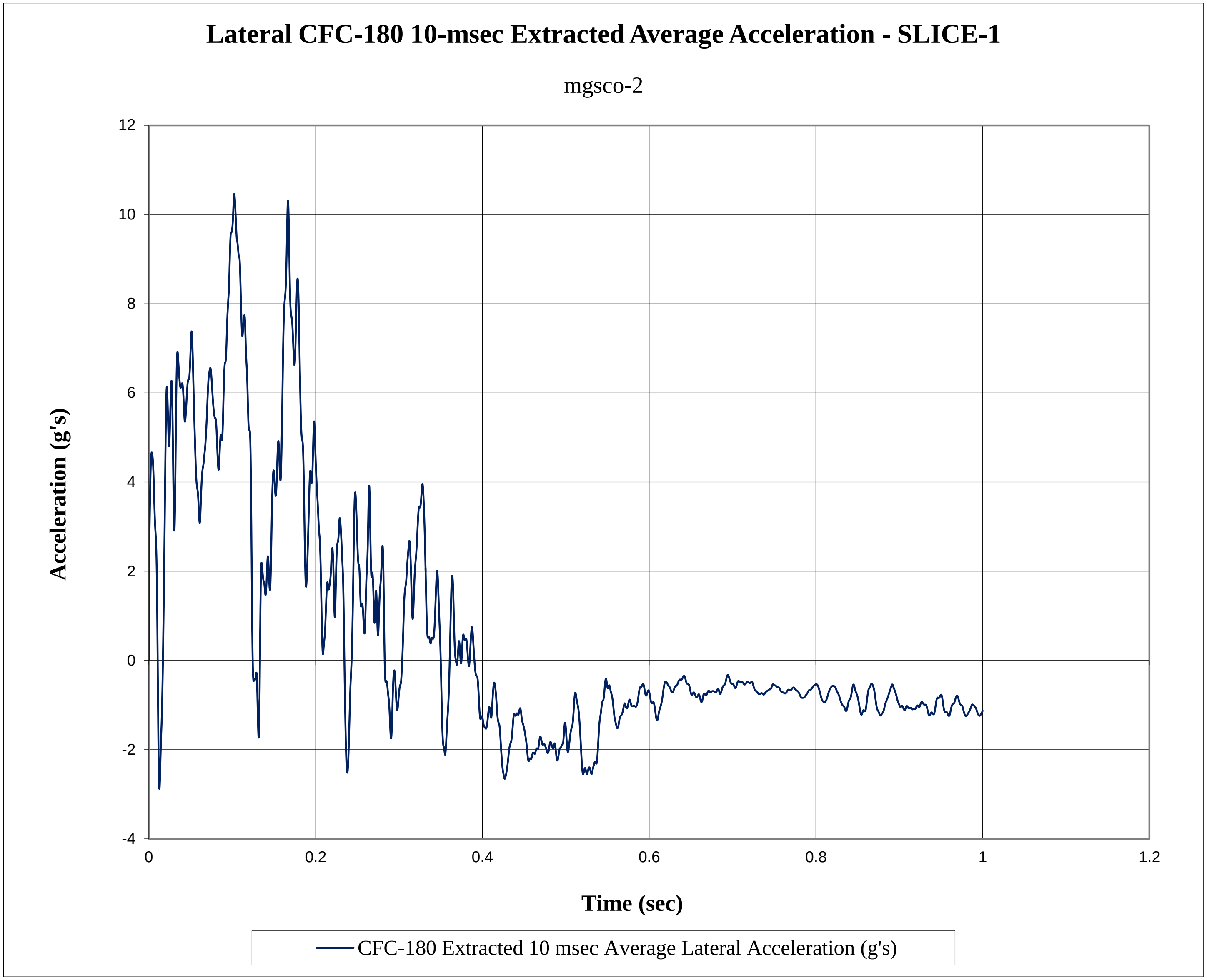


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MGSCO-2

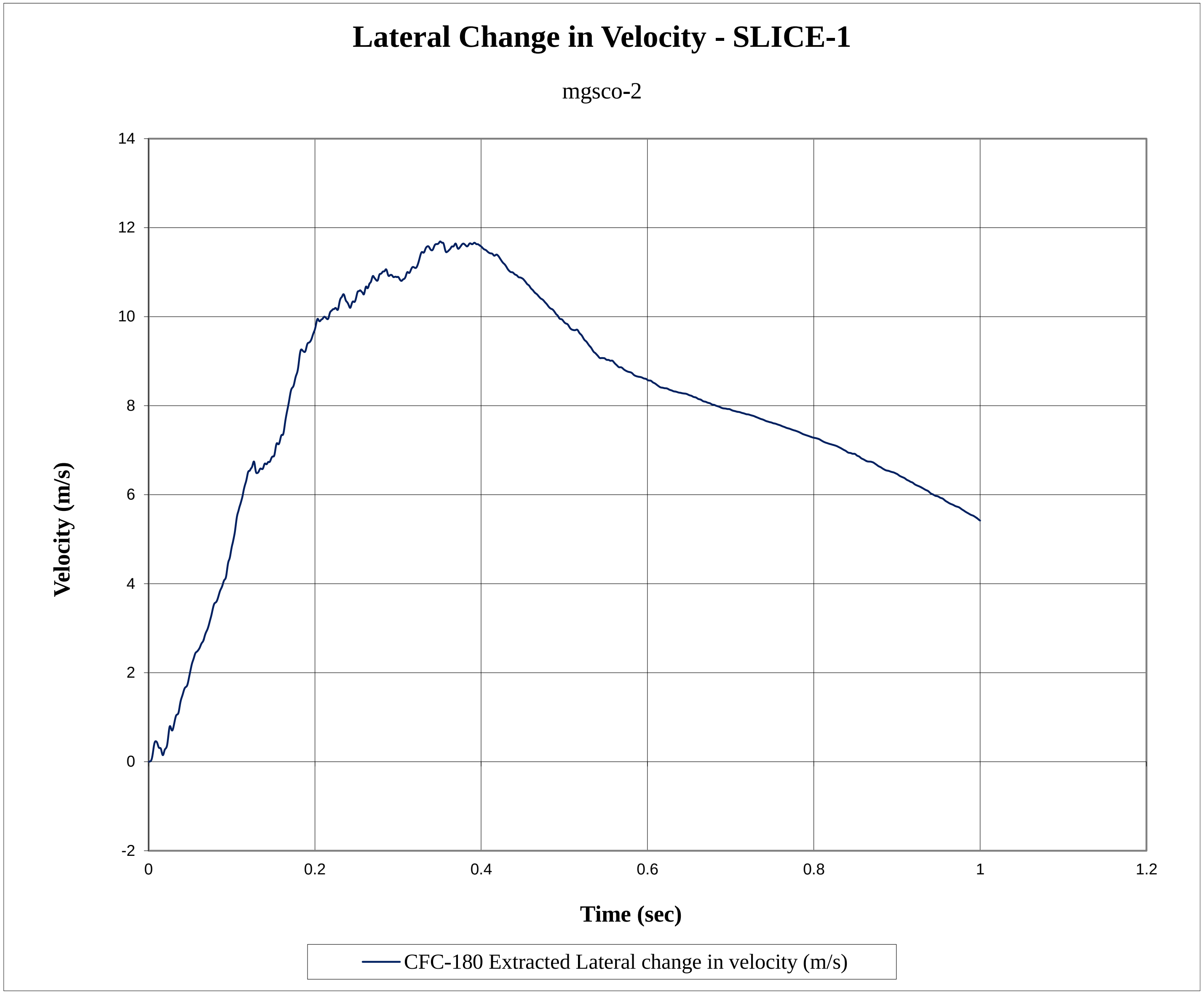


Figure F-13. Lateral Occupant Impact Velocity (SLICE-1), Test No. MGSCO-2

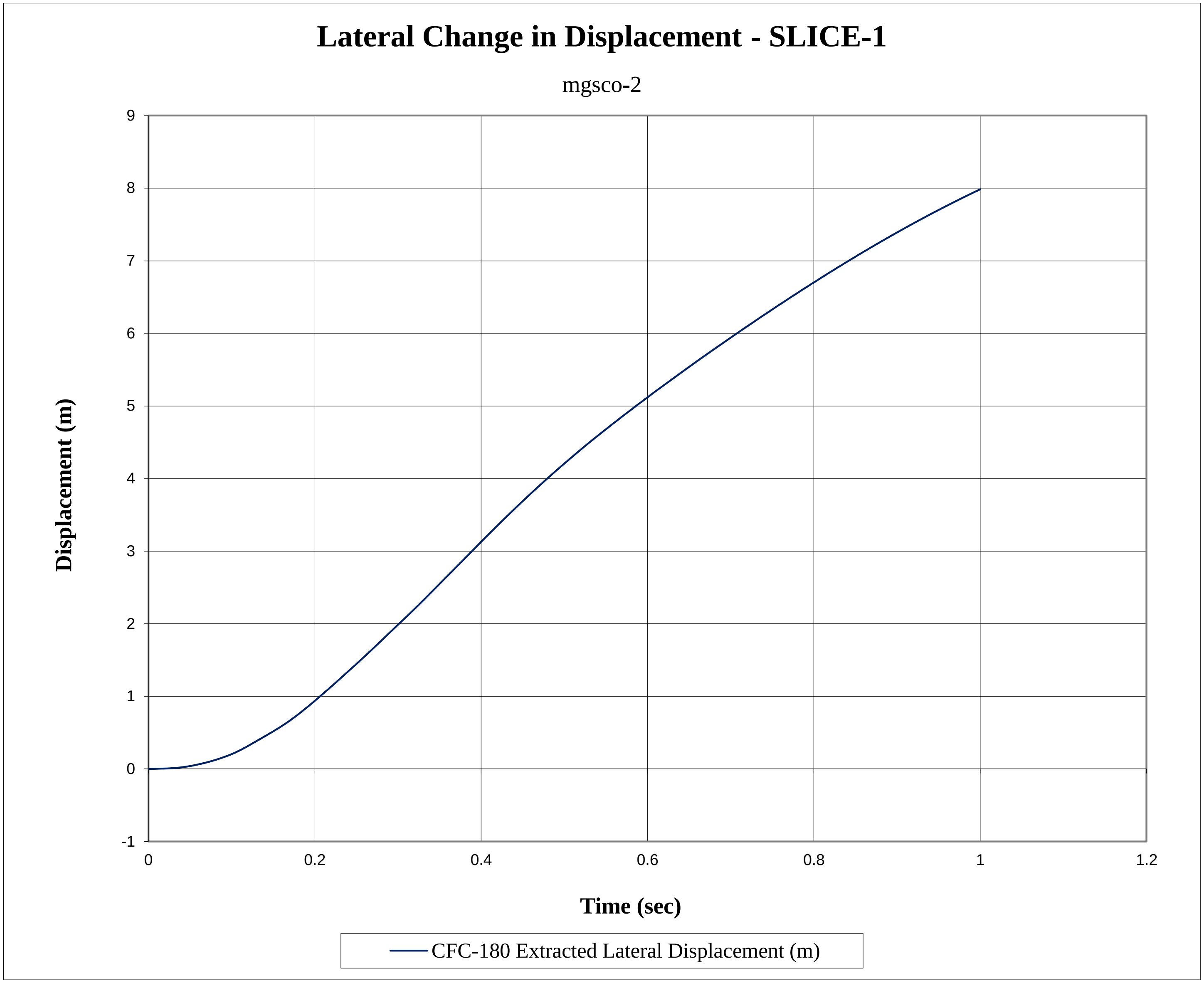


Figure F-14. Lateral Occupant Displacement (SLICE-1), Test No. MGSCO-2

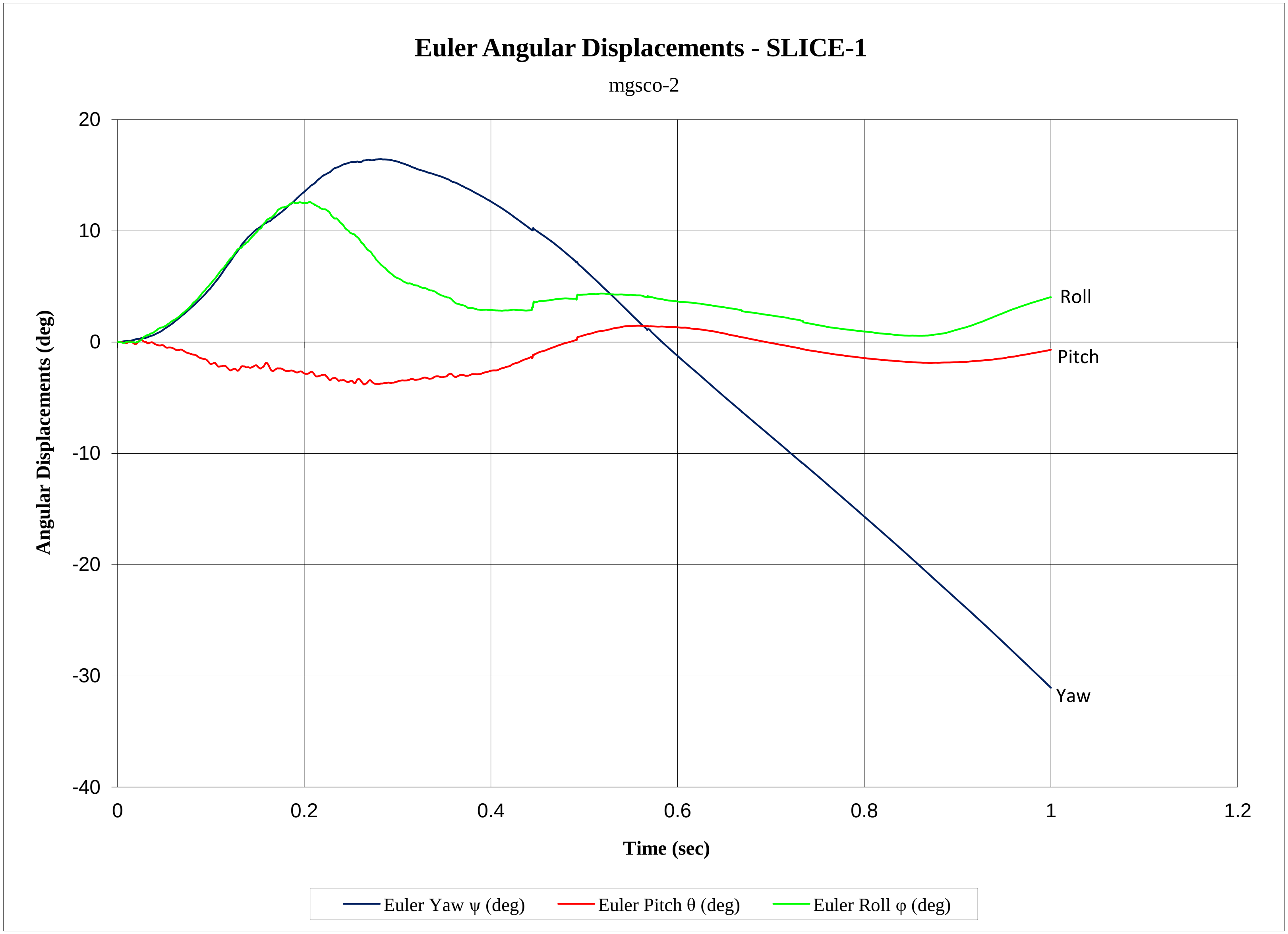


Figure F-15. Vehicle Angular Displacements (SLICE-1), Test No. MGSCO-2

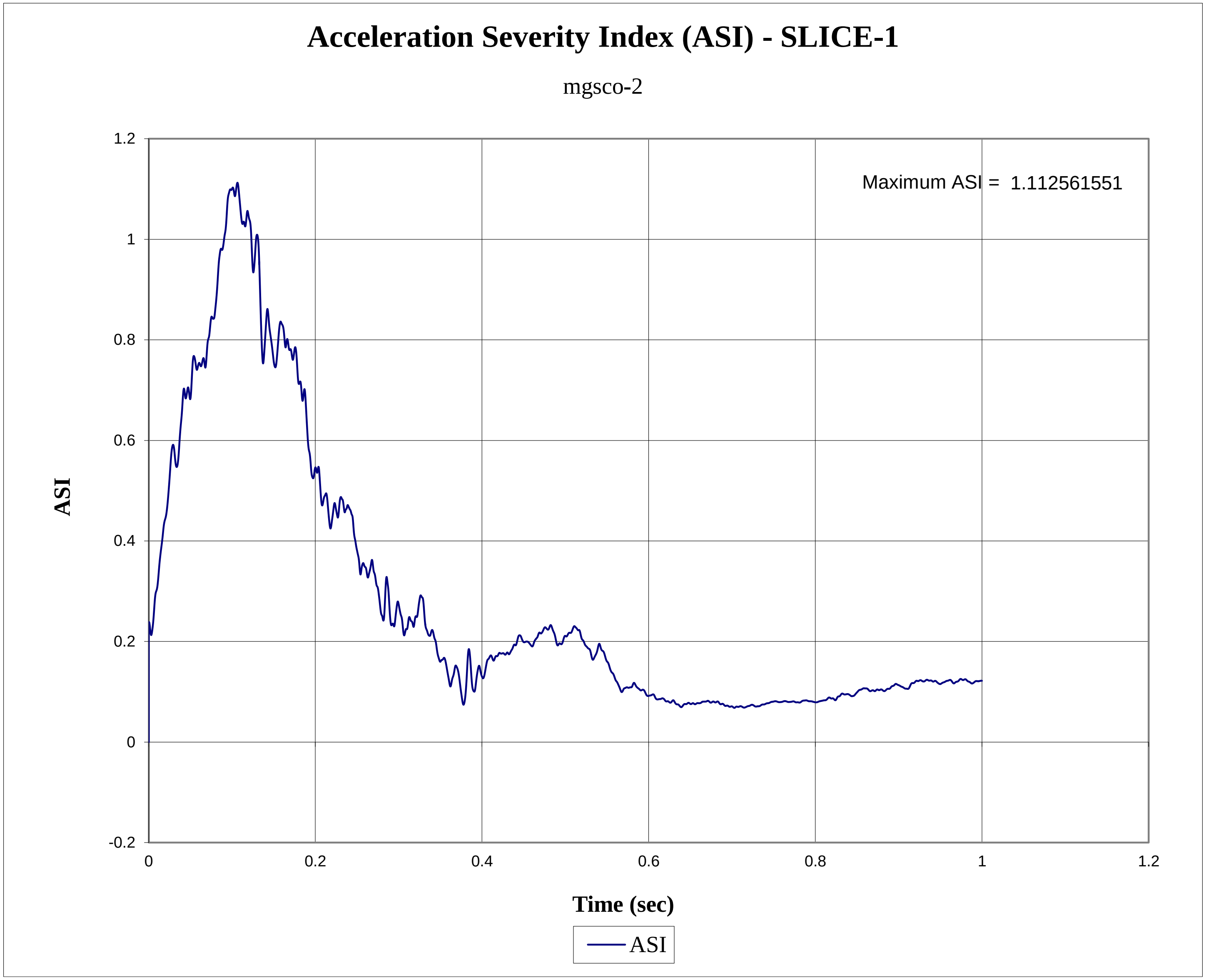


Figure F-16. Acceleration Severity Index (SLICE-1), Test No. MGSCO-2

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