ISO 17025 LABORATORY
TESTING CERT # 2937.01

Midwest Pooled Fund Research Program
Fiscal Years 2018-2019 (Year 28)
Research Project Number TPF-5(193) Supplement #122
NDOT Sponsoring Agency Code RPFP-18-SIGN-1

MASH FULL-SCALE TESTING OF SINGLE-POST, U-CHANNEL SIGN SUPPORTS

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MwRSF Research Report No. TRP-03-440-20

December 17, 2020

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. TRP-03-440-20	2.	3. Recipient's Accession No.
4. Title and Subtitle MASH Full-Scale Testing of Single-Post, U-Channel Sign Supports		5. Report Date December 17, 2020
		6.
7. Author(s) Rasmussen, J.D., Faller, R.K., Lechtenberg, K.A., Bielenberg, R.W., Dowler, N., Bayingana, A., and Markvicka, C.		8. Performing Organization Report No. TRP-03-440-20
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 #122
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: 2018-2020
		14. Sponsoring Agency Code RPFP-18-SIGN-1

15. Supplementary Notes
Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

Single-post, U-channel sign supports are used across the country for small signs, chevrons, and mile delineators. Despite their wide use, many U-channel sign supports have not been fully evaluated to current American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware* (MASH) Test Level 3 (TL-3) criteria.

The objective of this research effort was to evaluate the MASH crashworthiness of select U-channel sign supports. The project sponsors were surveyed to identify common post and sign configurations. In addition, previous full-scale crash testing and dynamic component testing of various U-channel supports were reviewed to help identify critical sign configurations. Full-scale crash testing was used to evaluate three sign configurations to MASH test designation no. 3-61. System A had a 1.12-lb/ft U-channel support with a 36-in. tall x 12-in. wide sign mounted at 4 ft above the ground line. System B had a 4-lb/ft U-channel support with a 36-in. tall x 36-in. wide sign mounted at 7 ft above the ground line, with a lap splice near the ground line. System C had a 4-lb/ft U-channel support with a 36-in. tall x 36-in. wide sign mounted at 5 ft above the ground line, with a lap splice near the ground line. System A contacted at the centerline of the vehicle, and Systems B and C contacted the right- and left-quarter points of the test vehicle, respectively.

In test no. UCSS-1, an 1100C small car, initially traveling at 67.1 mph, impacted three U-channel systems in succession at a 0-degree impact angle, or head-on to the signs. Systems A and C met all MASH test designation no. 3-61 evaluation criteria, but the performance of System B was inconclusive due to interference from System A prior to impact.

17. Document Analysis/Descriptors Highway Safety, Crash Test, Roadside Appurtenances, Compliance Test, MASH 2016, Test Designation 3-61, U-Channel Sign Supports, and Breakaway Supports		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 147	22. Price

DISCLAIMER STATEMENT

This material is based upon work supported by the Federal Highway Administration, U.S. Department of Transportation and the Midwest Pooled Fund Program under TPF-5(193) Supplement #122. 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 University of Nebraska-Lincoln, 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, or regulation. Trade or manufacturers' names, which may appear in this report, are cited only because they are considered essential to the objectives of the report. The United States (U.S.) government and the State of Nebraska do not endorse products or 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 Dr. Cody Stolle, Research Assistant Professor.

ACKNOWLEDGEMENTS

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, Georgia Department of Transportation, Hawaii 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 contributed to the completion of this research project.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in.	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short ton (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE & PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in.
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliter	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or “metric ton”)	1.103	short ton (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE & PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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1 INTRODUCTION

1.1 Background

Single-post, U-channel sign supports are used by many agencies for a variety of small signs and delineators, including mile delineators and object markers. These signs are generally mounted between 4 ft and 7 ft above the ground and placed in close proximity to the roadway. Despite the wide use of U-channel sign supports, their crashworthiness has not been fully evaluated to current *Manual for Assessing Safety Hardware* (MASH 2016) [1] safety criteria. With the impending MASH implementation dates agreed upon by the Federal Highway Administration (FHWA) and American Association of State Highway and Transportation Officials' (AASHTO), single-post, U-channel sign supports need to be evaluated to MASH 2016 Test Level 3 (TL-3) safety criteria.

Numerous studies and full-scale crash tests have been conducted on U-channel sign supports over the past four decades. These tests may help identify critical configurations for evaluation prior to MASH testing. However, several of these projects were conducted under previous evaluation criteria, the National Cooperative Highway Research Program (NCHRP) Report Nos. 230, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*) [2], and 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* [3]; and no U-channel sign supports completed the full testing matrix required by MASH. NCHRP Project 03-119 [4] is currently evaluating luminaire poles, sign supports, and work zone devices to MASH 2016 standards, but U-channel supports will only be partially evaluated during this project, and it is unknown if any of these systems will be full-scale crash tested to MASH standards.

1.2 Objective and Scope

The objective of this study was to evaluate single-post, U-channel sign supports according to the TL-3 safety performance criteria set forth in MASH 2016, as shown in Table 1. The study included a literature review of past testing, survey of sponsoring agencies, and dynamic component testing to identify critical sign configurations and evaluation parameters, including mounting height, sign size, and post splice configuration. Additionally, one full-scale crash test was conducted to evaluate the crashworthiness of three systems. The research scope included the development of a bogie vehicle to be utilized in the MASH compliance evaluation of the selected sign configurations. Thus, a full-scale MASH test designation no. 3-61 crash test was conducted to provide baseline data to validate the bogie vehicle. The background and full-scale crash test are detailed herein. MASH test designation nos. 3-60 and 3-62 were not conducted as part of the initial research effort. For a complete evaluation of the sign systems according to MASH TL-3, the full test matrix should be conducted, as shown in Table 1.

Table 1. MASH 2016 TL-3 Test Matrix

Test No.	Vehicle Designation	Vehicle Weight, lb	Impact Speed, mph	Impact Point	Impact Angle, degrees
3-60	1100C	2,420	19	Vehicle Quarterpoint	CIA[1]
3-61	1100C	2,420	62		
3-62	2270P	5,000	62		

[1]Critical Impact Angle from 0 to 25 deg., which is to be determined

2 LITERATURE REVIEW

A total of 22 full-scale crash tests were found on single U-channel sign supports, as described below. Additional data can be found in Appendix A.

2.1 Small Sign Support Analysis (1988)

In 1988, Texas A&M Transportation Institute (TTI) conducted a series of full-scale small car crash tests to evaluate the impact performance of small sign supports used by the Arizona Department of Transportation (ADOT) [5]. While the testing covered more than just single-post U-channels, it was determined that both 3-lb/ft and 4-lb/ft U-channel posts met performance criteria set forth by NCHRP Report No. 230 and the 1985 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals* [6].

The sign panels measured 2 ft x 2½ ft and were positioned so the lower edge was 5 ft above the ground. Two low-speed tests and one high-speed test were used to validate the system. In all three tests, the sign support fractured at bumper height and lost contact with the front of the vehicle, and the sign panel impacted the vehicle's roof. Roof deformation was within safety standards. A summary of the impact data and properties of each sign support test is shown in Table 2.

Table 2. Summary of U-Channel Sign Support Tests for ADOT, 1988

Test No. (Designation)	Post Weight, lb/ft	Post Yield Strength, ksi	Test Inertial Weight, lb	Impact Speed, mph	Impact Location	Max. Compartment Deformation and Location, in.	Pass/ Fail
7024-7 (63)	3	102	1,800	60.5	15 in. left of centerline	2 (Roof)	Pass
7024-8 (62)	3	102	1,800	19.9	15 in. right of centerline	0	Pass
7024-13 (63)	4	84.1	1,795	20.3	15 in. left of centerline	2 (Roof)	Pass

2.2 Florida Thin-Walled Aluminum Tube and Steel U-Channel Sign Supports (1992)

In 1992, TTI conducted a series of full-scale 1,800-lb small car crash tests to evaluate the impact performance of 4-lb/ft steel U-channel sign supports used by the Florida Department of Transportation (FDOT) in strong and weak soil [7]. The sign panels measured 2 ft x 3 ft and were mounted so the lower end of the panel was 7 ft above the ground. Some of the crash tests involved sign systems with normal splice orientation where the sign post is nested behind the base stub, while others had a reverse splice orientation with the sign post nested in front of the base stub. Two of these sixteen tests failed due to occupant risk because the signs struck the vehicle's roof and caused large deformations. One of these failing systems had a normal spice orientation, while the other one had a reverse orientation. The project adhered to performance criteria set forth by NCHRP Report No. 230. A schematic of the system is shown in Figure 1. A summary of the testing is shown in Table 3.

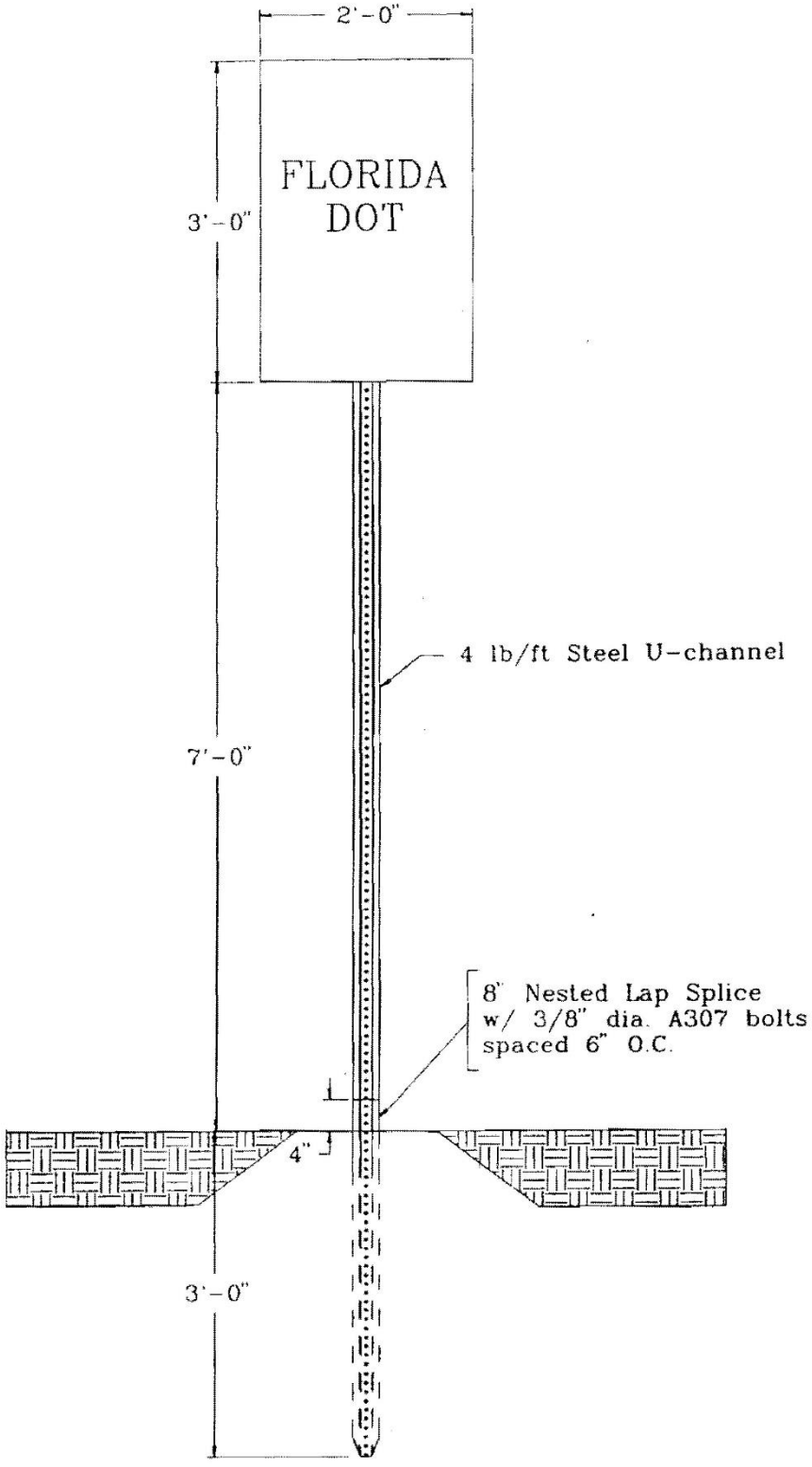


Figure 1. FDOT U-Channel Schematic, Test Nos. 7185-3 through 7185-18 [7]

Table 3. Summary of U-Channel Sign Support Tests for FDOT, 1992 [7]

Test No. (Designation)	Splice Orientation	Post Yield Strength, ksi	Soil Type	Impact Speed, mph	Impact Location	Max. Compartment Deformation Location[1]	Pass/ Fail
7185-3 (62)	Reverse	80	Weak	18.4	Left quarterpoint	N/A	Pass
7185-4 (63)	Reverse	80	Weak	61.8	Right quarterpoint	N/A	Pass
7185-5 (62)	Reverse	80	Standard	19.3	Left quarterpoint	N/A	Pass
7185-6 (63)	Reverse	80	Standard	61.1	Right quarterpoint	N/A	Pass
7185-7 (62)	Reverse	60	Weak	20.3	Left quarterpoint	N/A	Pass
7185-8 (63)	Reverse	60	Weak	61.5	Right quarterpoint	N/A	Pass
7185-9 (62)	Reverse	60	Standard	17.0	Right quarterpoint	N/A	Pass
7185-10 (63)	Reverse	60	Standard	60.8	Left quarterpoint	Roof over driver compartment area	Fail[2]
7185-11 (62)	Normal	80	Weak	19.2	Left quarterpoint	N/A	Pass
7185-12 (63)	Normal	80	Weak	61.9	Right quarterpoint	N/A	Pass
7185-13 (62)	Normal	80	Standard	20.1	Left quarterpoint	N/A	Pass
7185-14 (63)	Normal	80	Standard	61.8	Right quarterpoint	N/A	Pass
7185-15 (62)	Normal	60	Standard	19.4	Left quarterpoint	N/A	Pass
7185-16 (63)	Normal	60	Standard	62.4	Right quarterpoint	N/A	Pass
7185-17 (62)	Normal	60	Weak	20.0	Left quarterpoint	N/A	Pass
7185-18 (63)	Normal	60	Weak	62.4	Right quarterpoint	Roof over driver compartment area	Fail[3]

[1]Exact deformation values not available
[2]Test failed due to driver compartment intrusion
[3]Test failed because occupant compartment deformation was too large

2.3 Impact Performance Evaluation of Work-Zone Traffic Control Devices (2000)

In 2000, TTI conducted a series of full-scale small car crash tests to evaluate the impact performance of selected work zone sign supports [8]. The project adhered to performance criteria set forth by NCHRP Report No. 350. Among the selected systems was a U-channel sign support with a 2 ft x 3 ft sign panel mounted 4 ft above the ground. For test no. 417929-3, it should be noted that the test vehicle simultaneously impacted two identical U-channel supports on the right and left quarter points. After impact, one of the U-channel sign posts split and fractured at bumper height. The sign panel impacted and cut the vehicle's windshield before losing contact with the vehicle. Due to the sign panel showing potential to penetrate the occupant compartment, this test failed. The test on second sign support was acceptable. A schematic of the U-channel system is shown in Figure 2. A summary of the impact data and properties of the sign support is shown in Table 4.

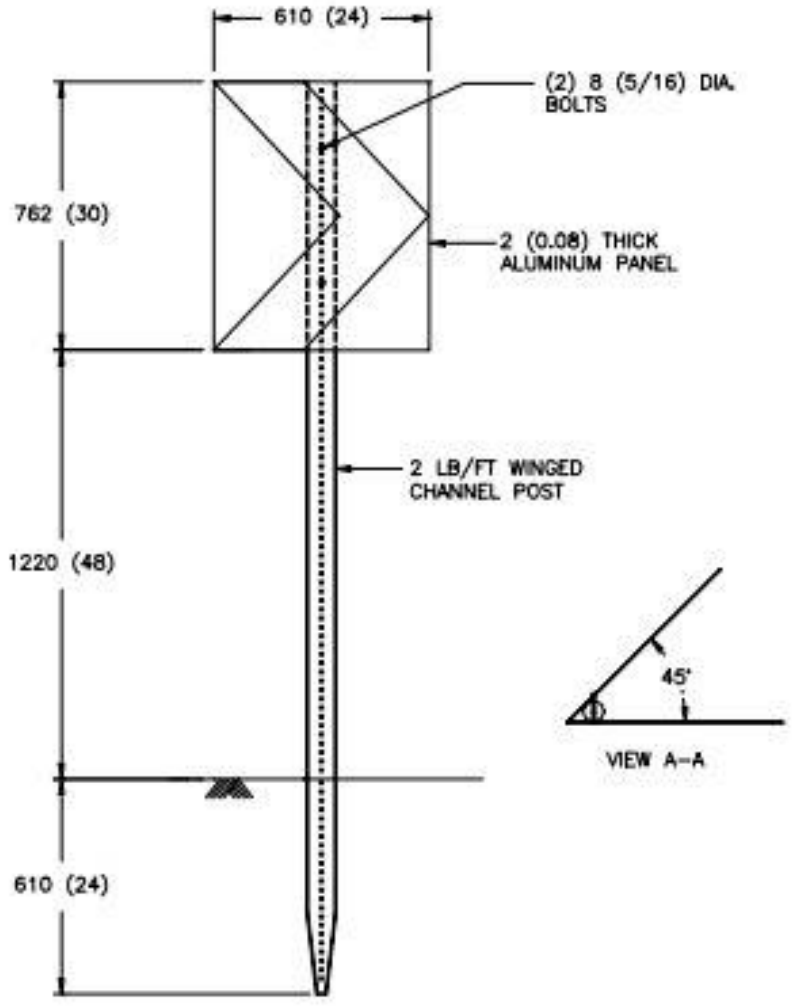


Figure 2. U-Channel Schematic, Test No. 417929-3 [8]

Table 4. Summary of U-Channel Sign Support Test, 2000 [8]

Test No. (Designation)	Support Size, lb/ft	U-Channel Type	Test Inertial Weight, lb	Impact Speed, mph	Impact Location	Max. Compartment Deformation, in.	Pass/ Fail
417929-3 (3-71)	2	Winged	1,806	62	Right and left quarter points	3.0	Fail[1]

[1]Test failed because sign panel showed potential to penetrate occupant compartment

2.4 Compliance Test of U-Channel Sign Support System (2009)

In 2009, New Zealand-based Holmes Solutions conducted a single-post full-scale 2270P crash test to evaluate the impact performance of the Nucor Lap Splice U-Channel Sign Support system [9]. The project adhered to performance criteria set forth by MASH 2009 [10]. Test no. 2-362 was conducted with a 1 ft x 1 ft sign panel mounted 5 ft – 11 in. above the ground and a 3 ft x 3 ft sign panel mounted 7 ft above the ground on a single post. After a head-on impact, the support bent slightly before breaking just above the splice. The sign panel impacted the vehicle's windshield, fracturing the glass. The sign post contacted the left side of the vehicle until it passed over the A-pillar, where it lost contact. The test failed because occupant compartment deformation exceeded maximum limits. The test results are shown in Table 5.

Table 5. Summary of U-Channel Sign Support Test for Nucor Compliance Test, 2009 [9]

Test No. (Designation)	Post Weight, lb/ft	Test Inertial Weight, lb	Lower Panel Height(s)	Impact Speed, mph	Impact Location	Max. Compartment Deformation and Location, in.	Pass/ Fail
2-362 (3-62)	4	4,991	5 ft –11 in. 7 ft	61	Centerline	5.5 (Right side of roof above windshield)	Fail[1]

[1]Test failed because occupant compartment deformation was too large

2.5 Evaluation of Existing Roadside Safety Hardware Using MASH (2010)

In 2010, TTI conducted a full-scale 2270P crash test to evaluate the impact performance of a 4-lb/ft steel U-channel support with a 3 ft x 3 ft plywood sign mounted 7 ft above the ground [11]. The project adhered to performance criteria set forth by MASH 2009. After primary impact with the U-channel support, the test vehicle impacted a Perforated Square Steel Tube (PSST) support. The sign post broke away at the splice location, and the sign panel rotated around the leading edge of the vehicle's hood, contacting the roof near the top of the windshield and overriding the vehicle. Contact with the roof was minor and caused slight deformations. A schematic of the system is shown in Figure 3. A summary of the impact data and sign support properties is shown in Table 6.

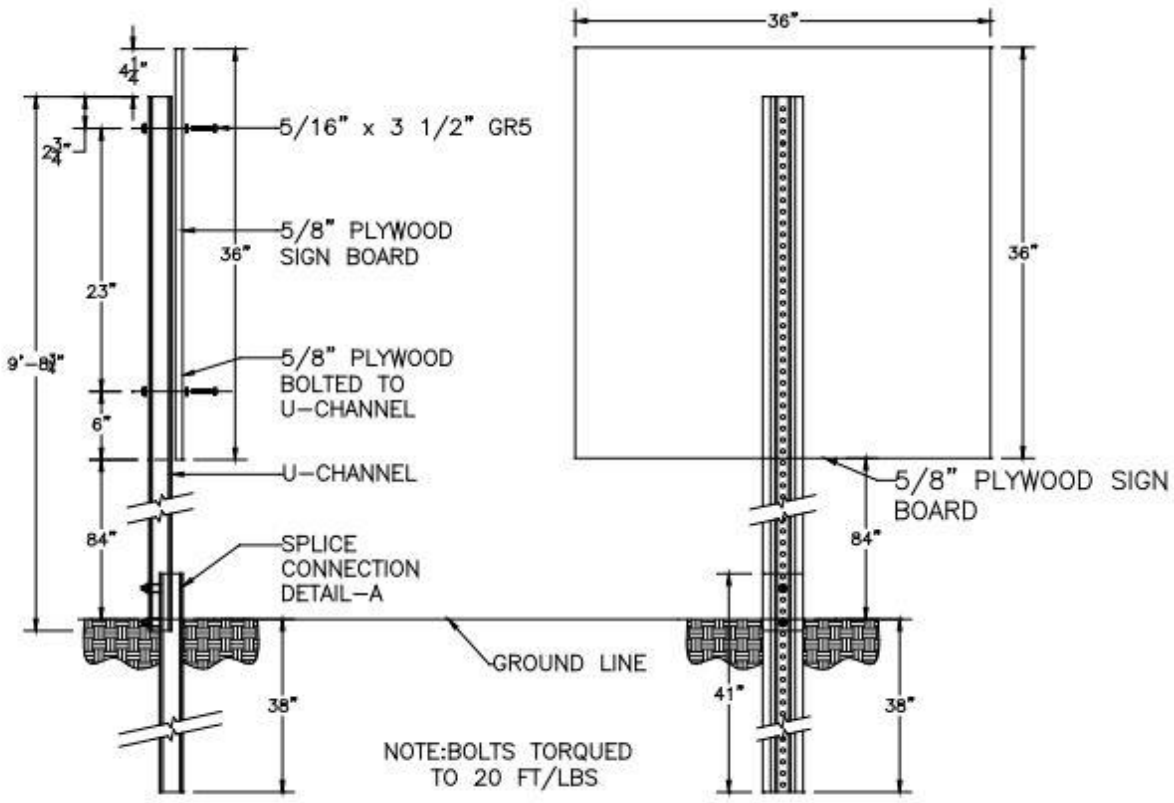


Figure 3. U-Channel Schematic, Test No. RF476460-1-2 [11]

Table 6. Summary of U-Channel Sign Support Test for NCHRP Project 22-14(03), 2010 [11]

Test No. (Designation)	Post Weight, lb/ft	Test Inertial Weight, lb	Impact Speed, mph	Impact Location	Max. Compartment Deformation and Location, in.	Pass/ Fail
RF476460-1-2 (3-62)	4	4,958	63.3	Left quarterpoint	2.1[1] (Roof)	Pass

[1]It is believed most of the vehicle damage was due to the secondary impact with the PSST support

3 SIGN SUPPORT DESIGN AND ANALYSIS

In order to determine critical sign configurations, MwRSF researchers reviewed reports, photographs, and video footage of previous testing to estimate the likelihood of success with MASH 2016 performance criteria. Each test was graded on a scale of one (very unlikely to pass) to five (very likely to pass). This scale was subjective and does not indicate a definite pass or failure. This information is summarized in Table 7 for the 22 tests described in the literature review.

Most of the systems would likely comply with MASH criteria for the low-speed test designation no. 3-60. However, researchers were less optimistic about MASH test designation nos. 3-61 and 3-62, where the heavy sign panels would impact the test vehicle at higher speeds and potentially cause excessive deformation or intrude into the passenger compartment. Generally, the systems that were predicted to have a higher chance of passing had higher minimum steel yield strengths. A panel mounting height of 5 ft or less above the ground and a smaller post weight was associated with a lower chance of passing MASH test designation no. 3-60 than the system with a panel mounting height of 7 ft and a heavier post.

Midwest Roadside Safety Facility (MwRSF) researchers surveyed the Midwest Pooled Fund Program member states to gain a full understanding of current U-channel sign support usage. MwRSF used the results, as shown in Figure 4, to determine which sign support configurations were desired by state transportation departments. Fourteen states responded to the survey, which is shown in its entirety in Appendix B.

All fourteen states currently use U-channel sign supports for small delineators with sign panels, and thirteen states planned to use them in the future. Generally, 1.12-lb/ft and 2-lb/ft weight U-channel sign supports are used for small delineator applications. While many different sign panel sizes are used, the mounting height to the bottom of the sign panel for small delineators was typically 4 ft. Some states did not attach sign panels and only attached a reflective marker at the top of the sign support. Every state mounted these supports in soil, and six states mounted them in both soil and concrete.

Nine of the thirteen states that responded used U-channel sign supports for a purpose other than small delineators. Specifications for these applications varied widely in several aspects, including U-channel weight and sign panel size. Every state mounted these supports in soil, and three states mounted them in both soil and concrete.

Based on the results of the survey, several systems were identified as a priority for evaluation with this project, as shown in Table 8. The yield strength and splice configurations could be variable and would be further evaluated throughout the project.

Table 7. MASH 2016 Estimates of Previous Testing

Test No.	Designation	Vehicle Type	Post Weight, lb/ft	Lower Panel Height(s), ft	Impact Location	Actual Test Result	MASH 3-60 Prediction	MASH 3-61 Prediction	MASH 3-62 Prediction
7024-7	NCHRP 230 63	1800S	3	5	15 in. left of centerline	Pass	2	4	2
7024-8	NCHRP 230 62	1800S	3	5	15 in. right of centerline	Pass	2	4	2
7024-13	NCHRP 230 63	1800S	4	5	15 in. left of centerline	Pass	2	4	2
7185-3	NCHRP 230 62	1800S	4	7	Left quarterpoint	Pass	5	4	4
7185-4	NCHRP 230 63	1800S	4	7	Right quarterpoint	Pass	5	4	4
7185-5	NCHRP 230 62	1800S	4	7	Left quarterpoint	Pass	5	4	4
7185-6	NCHRP 230 63	1800S	4	7	Right quarterpoint	Pass	5	4	4
7185-7	NCHRP 230 62	1800S	4	7	Left quarterpoint	Pass	5	1	2
7185-8	NCHRP 230 63	1800S	4	7	Right quarterpoint	Pass	5	1	2
7185-9	NCHRP 230 62	1800S	4	7	Right quarterpoint	Pass	5	1	2
7185-10	NCHRP 230 63	1800S	4	7	Left quarterpoint	Fail	5	1	2
7185-11	NCHRP 230 62	1800S	4	7	Left quarterpoint	Pass	5	4	4
7185-12	NCHRP 230 63	1800S	4	7	Right quarterpoint	Pass	5	4	4
7185-13	NCHRP 230 62	1800S	4	7	Left quarterpoint	Pass	5	4	4
7185-14	NCHRP 230 63	1800S	4	7	Right quarterpoint	Pass	5	4	4
7185-15	NCHRP 230 62	1800S	4	7	Left quarterpoint	Pass	5	1	2
7185-16	NCHRP 230 63	1800S	4	7	Right quarterpoint	Pass	5	1	2
7185-17	NCHRP 230 62	1800S	4	7	Left quarterpoint	Pass	5	1	2
7185-18	NCHRP 230 63	1800S	4	7	Right quarterpoint	Fail	5	1	2
417292-3	NCHRP 350 3-71	820C	2	4	Right quarterpoint	Fail	4	1	2
2-362	MASH 3-62	2270P	4	5 ft –11 in.	Centerline	Fail	4	3	1
RF476460-1-2	MASH 3-62	2270P	4	7	Left quarterpoint	Pass	5	5	Pass[1]

[1]Full-scale crash test was conducted to MASH
Scale: 1 unlikely to pass and 5 likely to pass

	Question	No. Resp.	Results	
Usage	1. Are you currently using U-Channel Sign Supports?	14	**Yes** - 14 **No** - 0	
	2. Are you interested in using U-Channel Sign Supports in the future?	14	**Yes** - 13 **No** - 1	
	3. Do you want to provide input on which sign supports will be evaluated with this Pooled Fund project?	14	**Yes** - 13 **No** - 1	
Small Delineators	4. Do you use U-channel sign support for small delineators?	13	**Yes** - 13 **No** - 0	
	5. What supplier do you purchase U-channel delineators from?	12	**Nucor Steel Marion** - 4 **Franklin Industries** - 3 **Chicago Heights Steel** - 1	**MD Solutions** - 1 **Vulcan Signing** - 1 **Unknown** - 6
	6. What weight U-channel do you utilize for delineators?	13	**1.12 lb/ft** - 5 **2 lb/ft** - 6 **2.2 lb/ft** - 1 **2.5 lb/ft** - 2	**3 lb/ft**- 3 **4 lb/ft**- 1 **0.93-in. A36/A36m steel** - 1
	7. Do you use sign panels with U-channel delineators?	13	**Yes** - 13 **No** - 0	
	7a. What is the typical height to bottom of sign panel for U-channel delineators?	12	**2 ft** - 1 **4 ft** - 9 **5 ft** - 2	
	7b. What is the typical sign panel size for U-channel delineators?	13	**6 in. x 12 in.** - 3 **10 in. x 36 in.** - 3 **12 in. x 24 in.** - 4 **12 in. x 36 in.** - 8	**12 in. x 48 in.** - 3 **18 in. x 18 in.** - 3 **None (reflector only)** - 3
	8. Do you use spliced U-channel with delineators?	12	**Yes** - 3 **No** - 9	
	9. Do you mount U-channel delineators in concrete or soil?	13	**Soil** - 7 **Concrete** - 0 **Both** - 6	
Other Sign Supports	10. Do you use U-channel sign support for other sign supports?	13	**Yes** - 9 **No** - 4	
	11. What supplier do you purchase other U-channel sign supports from?	10	**Nucor Steel Marion** - 5 **Franklin Industries** - 4 **Chicago Heights Steel** - 2	**MD Solutions** - 1 **Vulcan Signing** - 1 **Unknown** - 2
	12. What weight U-channel do you utilize for other sign supports?	9	**1.12 lb/ft** - 3 **2 lb/ft** - 2 **2.5 lb/ft** - 3	**3 lb/ft**- 5 **4 lb/ft**- 3
	13. What is the typical bottom of sign panel height for other U-channel sign supports?	9	**5 ft** - 5 **6 ft** - 1 **7 ft** - 8 **> 7 ft** - 1	
	14. What is the typical single sign panel size or total clustered panel size (w x h) for other U-channel sign supports?	8	**18 in. x 18 in.** - 4 **18 in. x 24 in.** - 4 **24 in. x 24 in.** - 6 **24 in. x 30 in.** - 5 **24 in. x 36 in.** - 4 **24 in. x 48 in.** - 2 **30 in. x 30 in.** - 6	**30 in. x 36 in.** - 4 **36 in. x 24 in.** - 2 **36 in. x 36 in.** - 4 **36 in. x 48 in.** - 2 **42 in. x 30 in.** - 2 **48 in. x 48 in.** - 2
	15. Do you use spliced U-channel with other small U-channel sign supports?	9	**Yes** - 7 **No** - 2	
	16. Do you mount other small U-channel signs in concrete or soil?	9	**Soil** - 6 **Concrete** - 0 **Both** - 3	

Figure 4. U-Channel Sign Support Survey Results

Table 8. Sign Systems Prioritized for Testing

Post Weight, lb/ft	Sign Panel Size	Lower Panel Height, ft	Post Yield Strength, ksi	Splice Configuration
1.12	Reflector only	4	60	None
1.12	8 in. x 2 ft x 0.08 in.	4	60	None
3	3 ft x 3 ft x 0.1 in.	7	60	8-in. overlap at ground line
4	3 ft x 3 ft x 0.1 in.	7	80+	None
4	3 ft x 3 ft x 0.1 in.	7	60	8-in. overlap at ground line
4	3 ft x 3 ft x 0.1 in.	5	60	8-in. overlap at ground line

4 DESIGN DETAILS

The test installation consisted of three separate U-channel sign supports, schematics of which are shown in Figures 5 through 16. Photographs of the test installation are shown in Figures 17 and 18. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix C.

The U-channel sign supports were made of A499 steel with a powder-coated finish. System A (test no. UCSS-1A) was a single post embedded in the ground without any splices, while Systems B and C (test nos. UCSS-1B and UCSS-1C, respectively) were comprised of an upper post support attached to an embedded ground stub foundation with a lap splice. The lap splices consisted of Gr. 9 hex bolts and heavy hex nuts, flat washers, and lock washers. The systems were placed 30 ft apart, with a slight offset so that Systems B and C contacted the right and left quarter points of the test vehicle, respectively.

The 1.12-lb/ft U-channel support for System A was 96 in. tall, including 24 in. below the ground line. The weight of the support was confirmed to be 1.12 lb/ft. The sign panel was 36 in. tall, 12 in. wide, and 0.08 in. thick. The bottom of the sign panel was 48 in. above the ground line. The mounting points for the sign panel were 6 in. above the bottom edge of the sign panel and 2 in. below the top edge of the U-channel support.

The 4-lb/ft U-channel support for System B was 120 in. tall, which overlapped 8 in. with a ground stub that extended 38 in. below the ground line. The weight of the support was confirmed to be 4 lb/ft. The sign panel for System B was 36 in. tall, 36 in. wide, and 0.08 in. thick. The bottom of the sign panel was 84 in. above the ground line. The mounting points for the sign panel were 6 in. above the bottom edge of the sign panel and 2 in. below the top edge of the U-channel support.

The 4-lb/ft U-channel support for System C was 96 in. tall, which overlapped 8 in. with a ground stub that extended 38 in. below the ground line. The weight of the support was confirmed to be 4 lb/ft. The sign panel for System C was 36 in. tall, 36 in. wide, and 0.08 in. thick. The bottom of the sign panel was 60 in. above the ground line. The mounting points for the sign panel were 6 in. above the bottom edge of the sign panel and 2 in. below the top edge of the U-channel support.

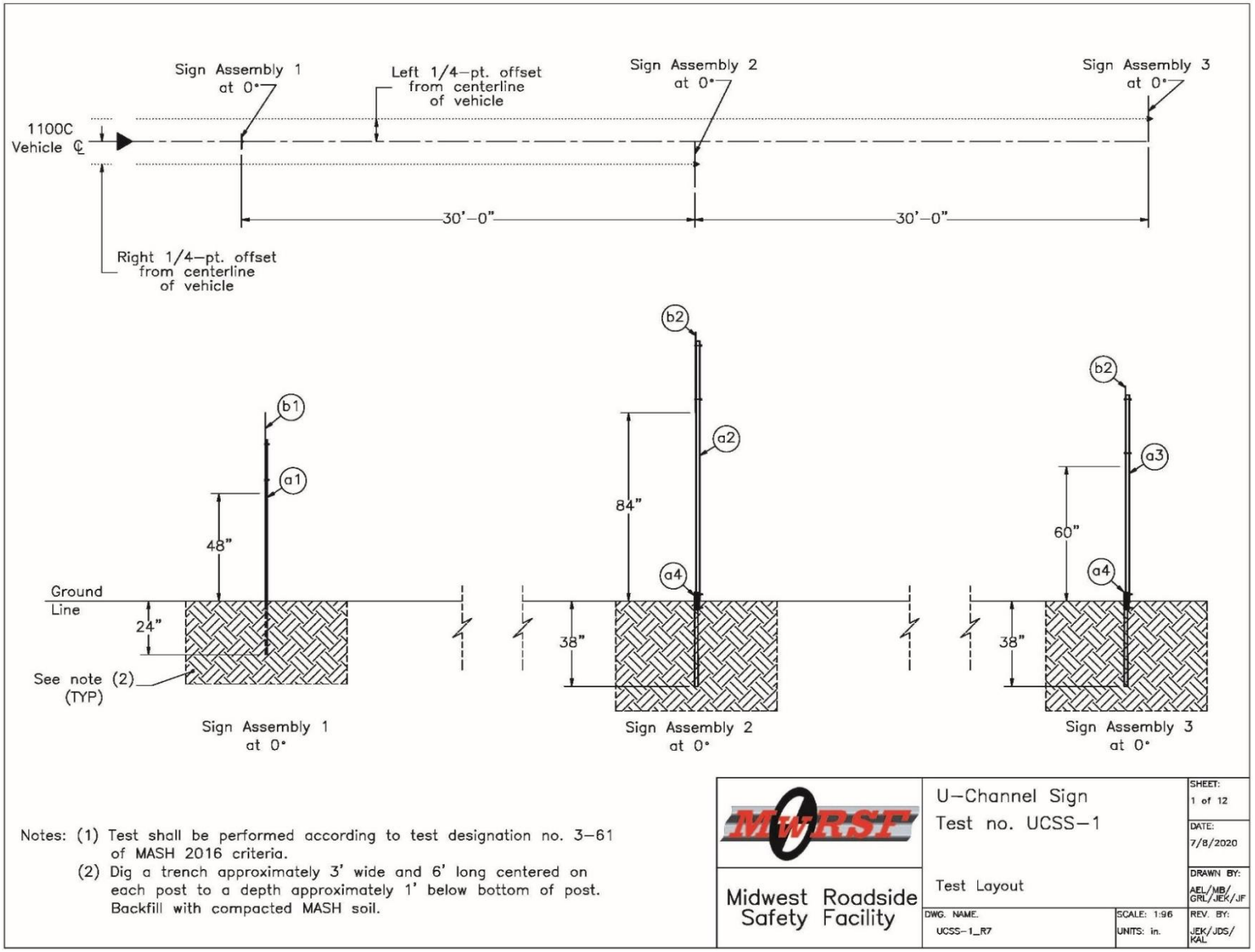


Figure 5. Test Installation Layout, Test No. UCSS-1

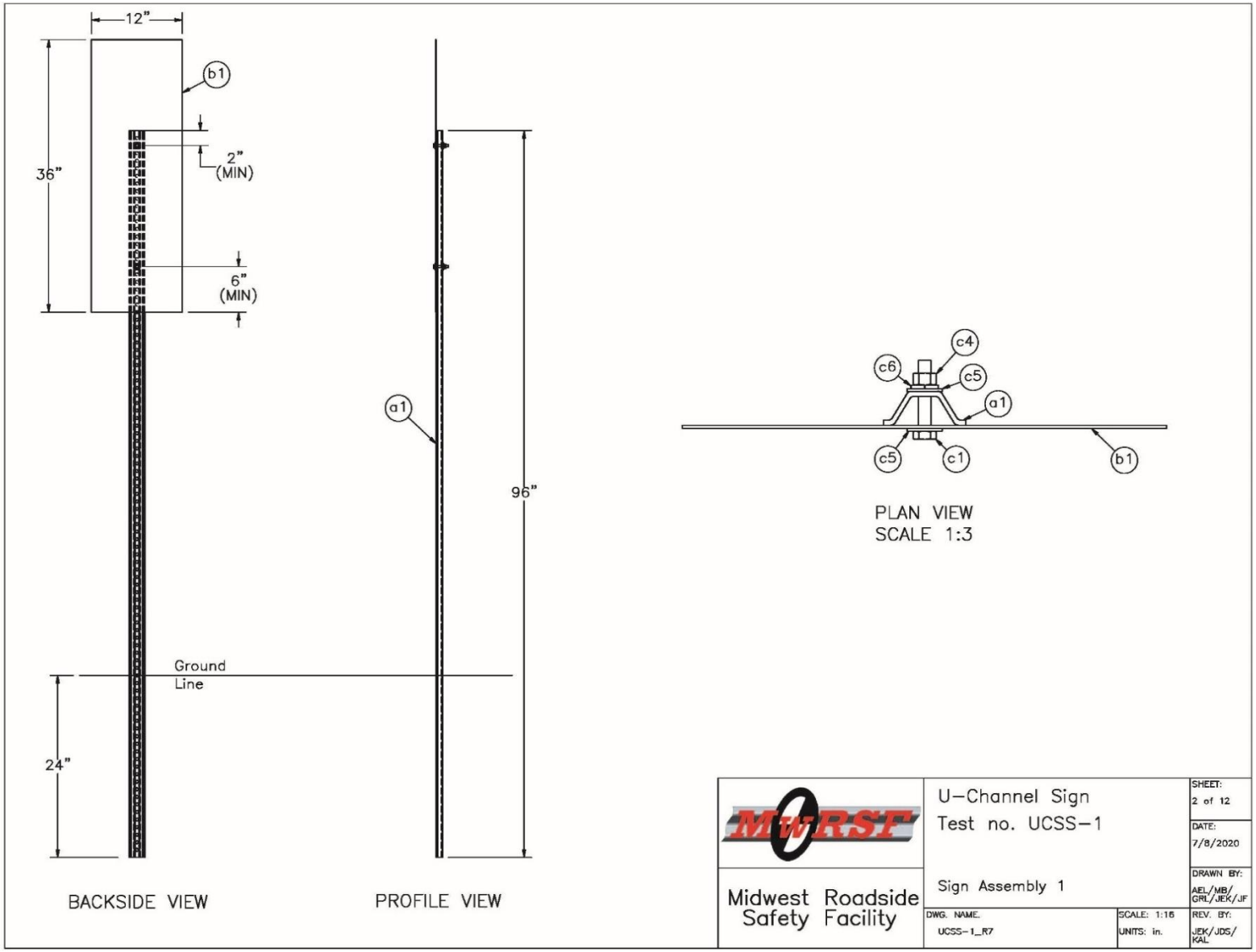


Figure 6. Sign Assembly, Test No. UCSS-1A

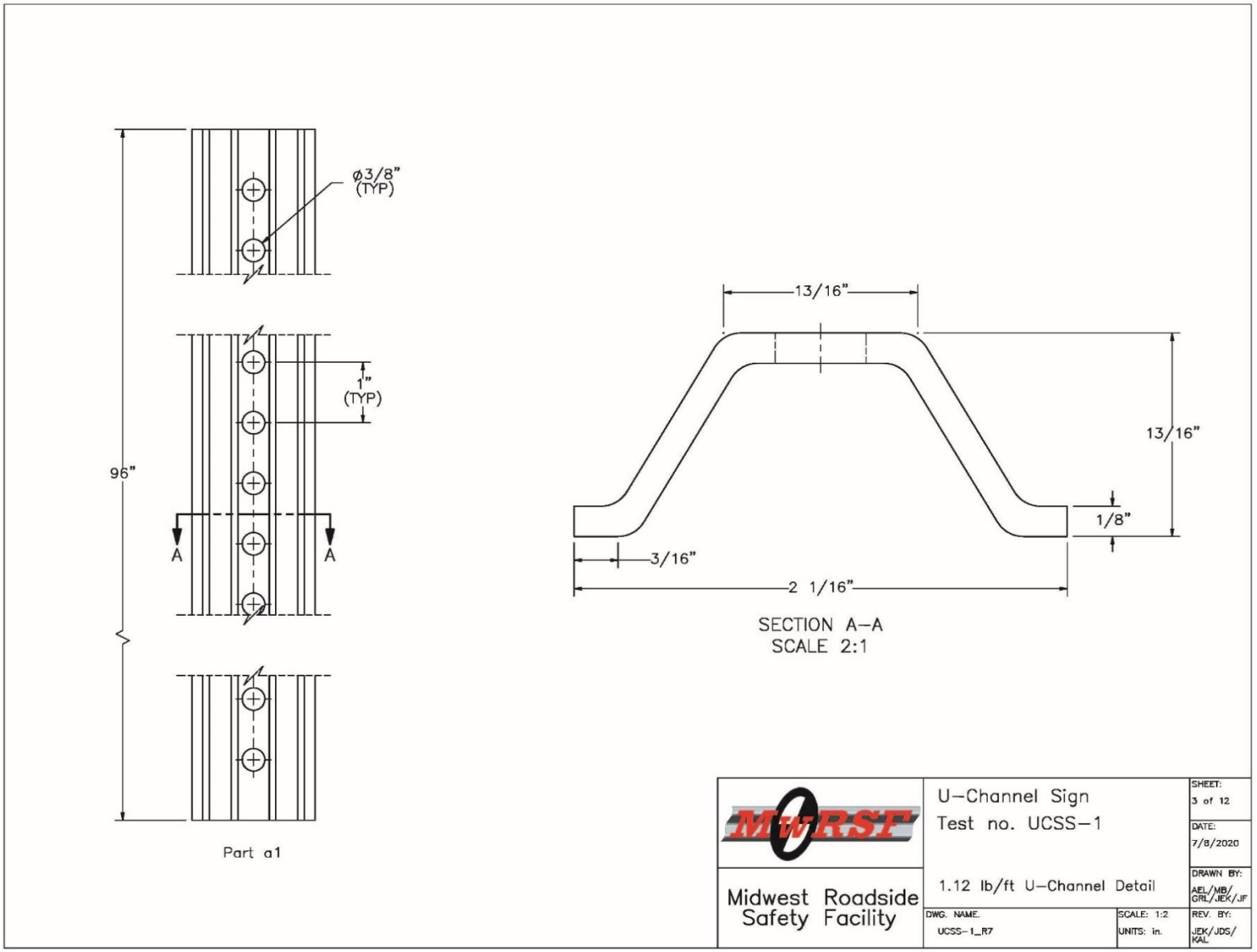


Figure 7. U-Channel Base Detail, Test No. UCSS-1A

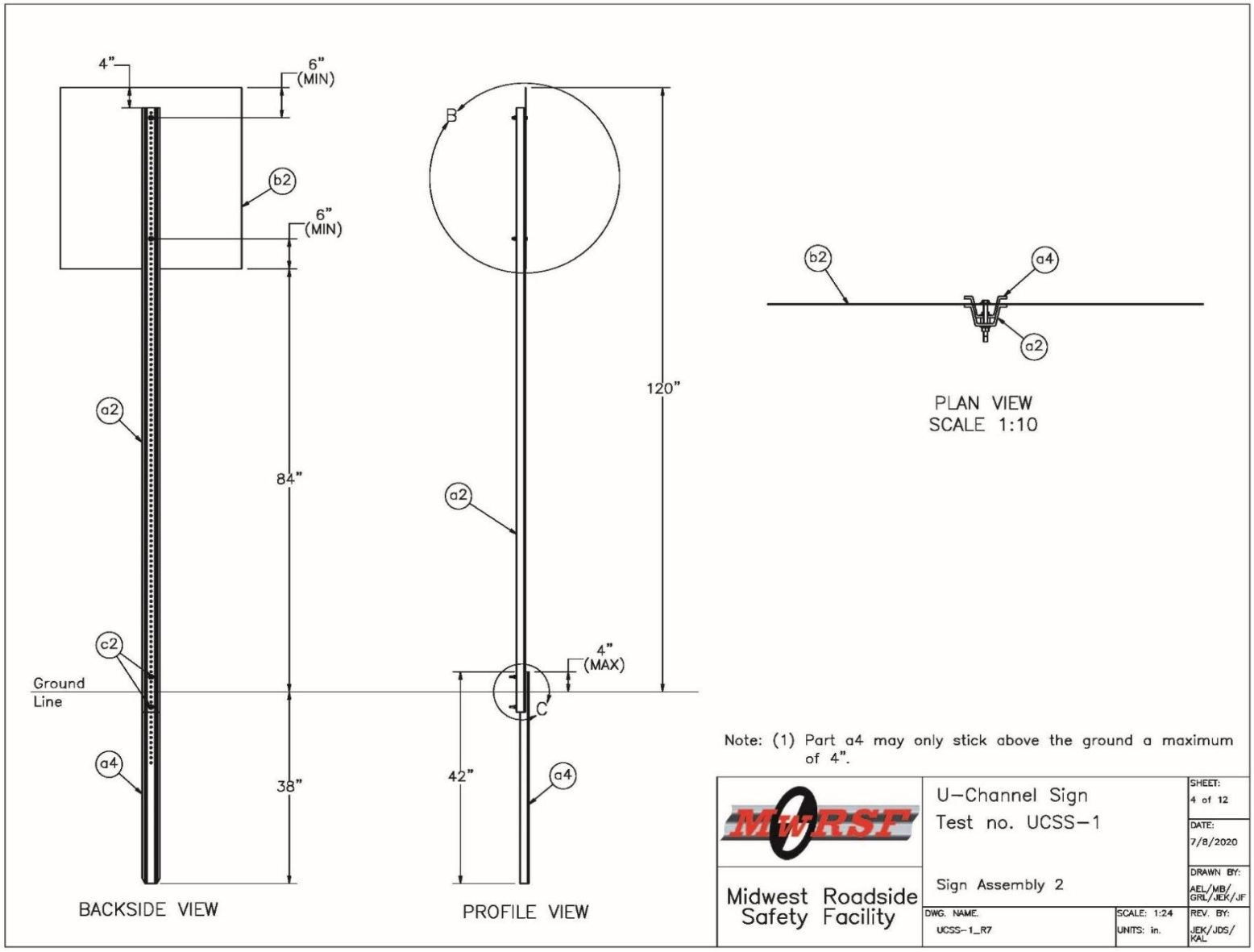


Figure 8. Sign Assembly, Test No. UCSS-1B

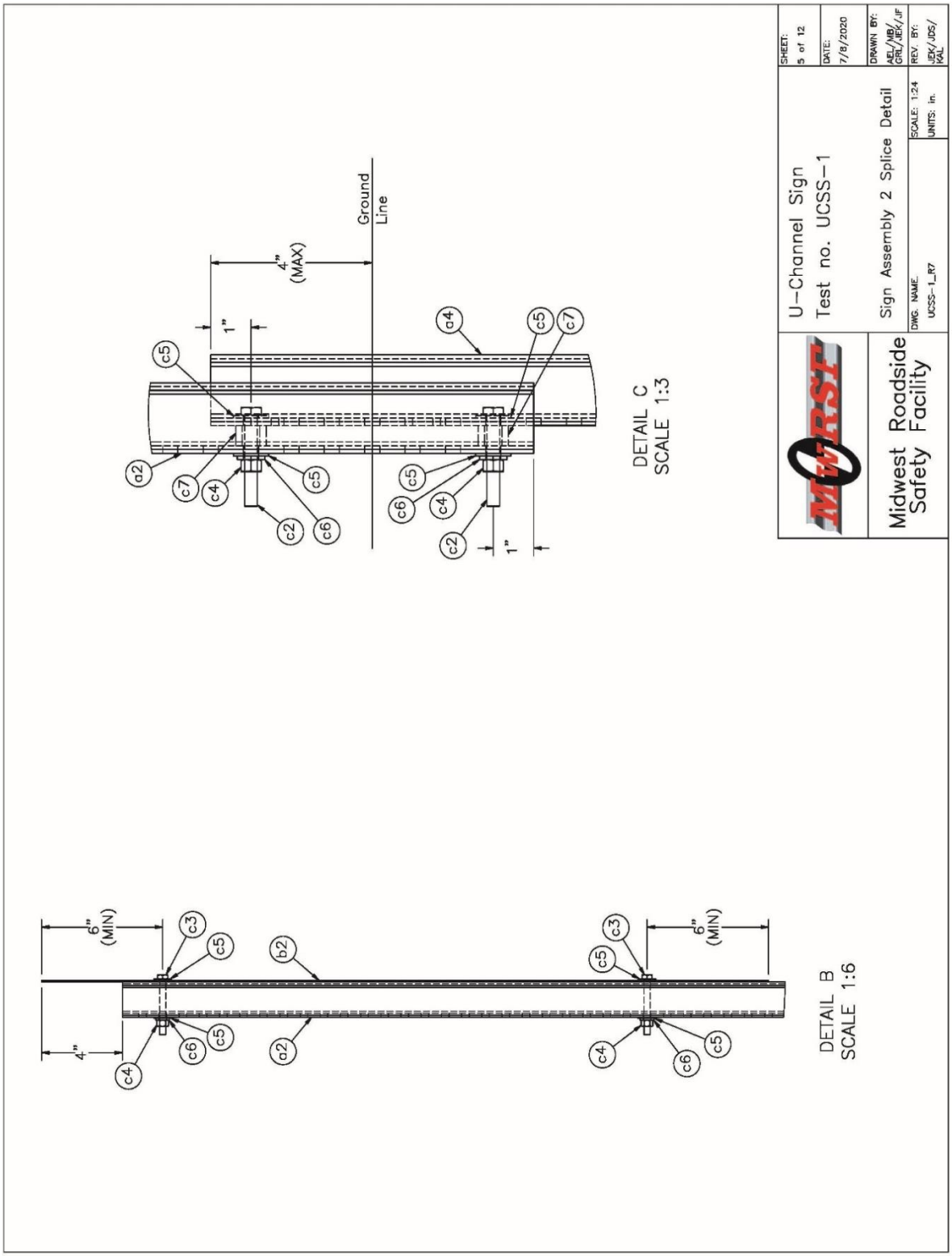


Figure 9. Splice Detail, Test No. UCSS-1B

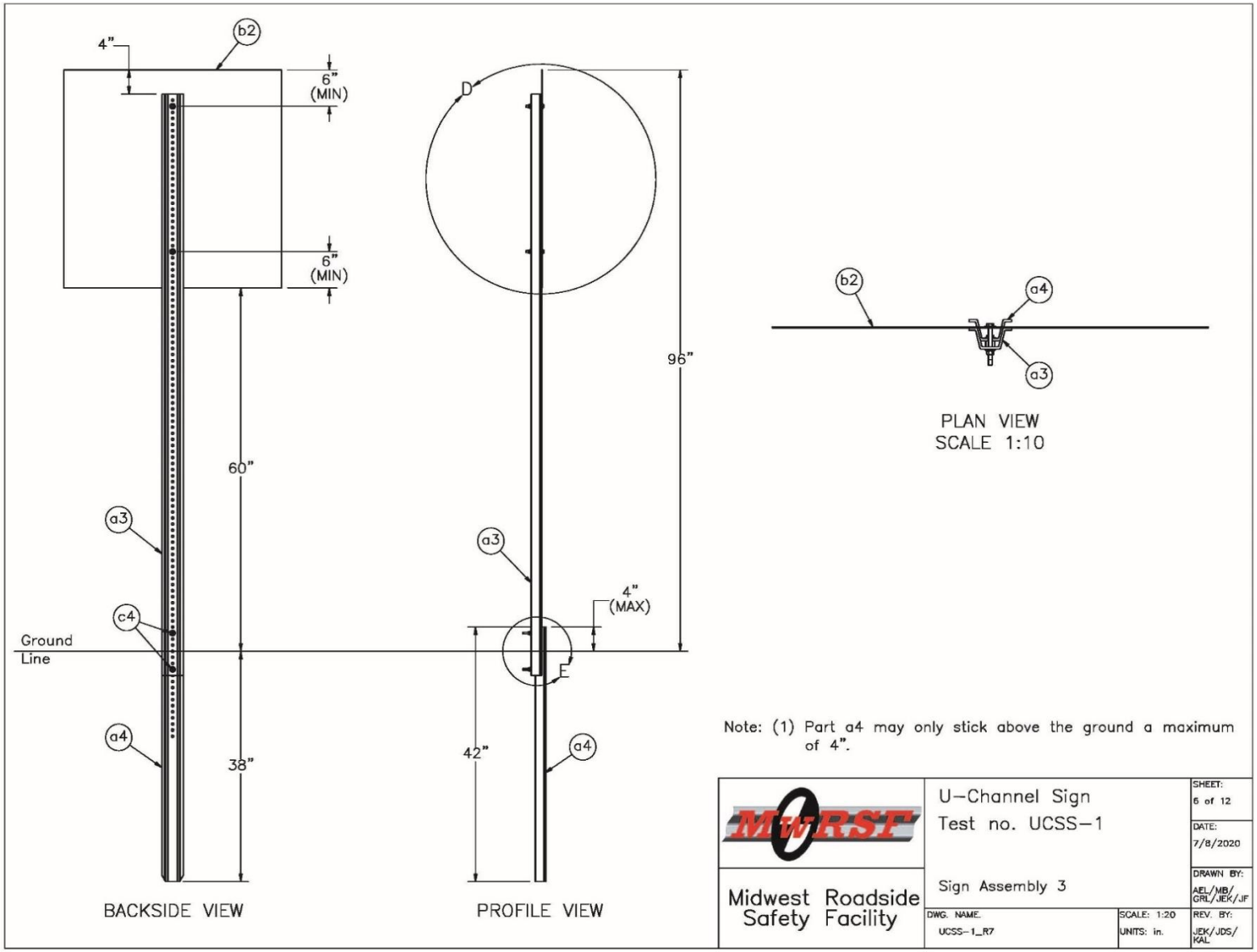


Figure 10. Sign Assembly, Test No. UCSS-1C

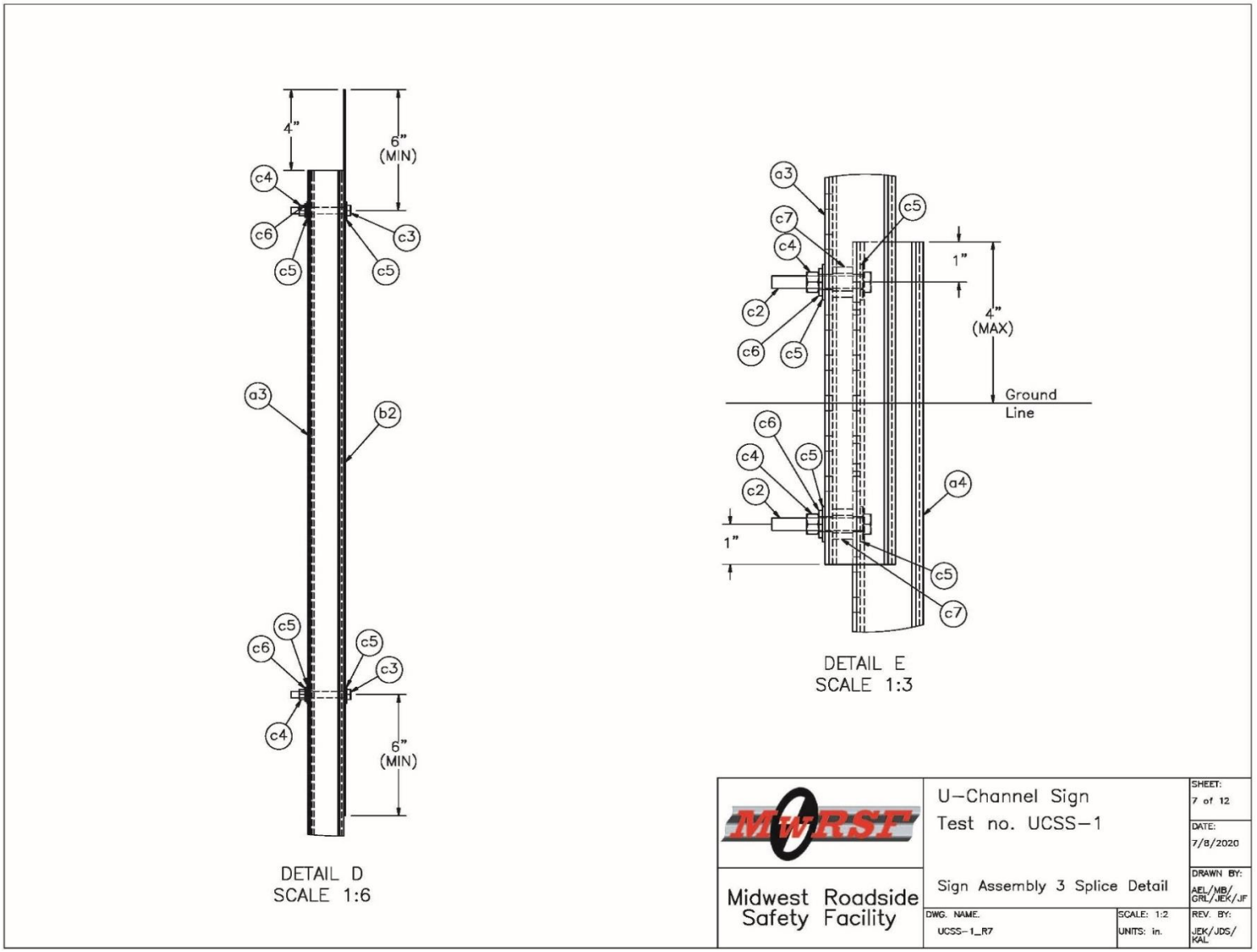


Figure 11. Splice Detail, Test No. UCSS-1C

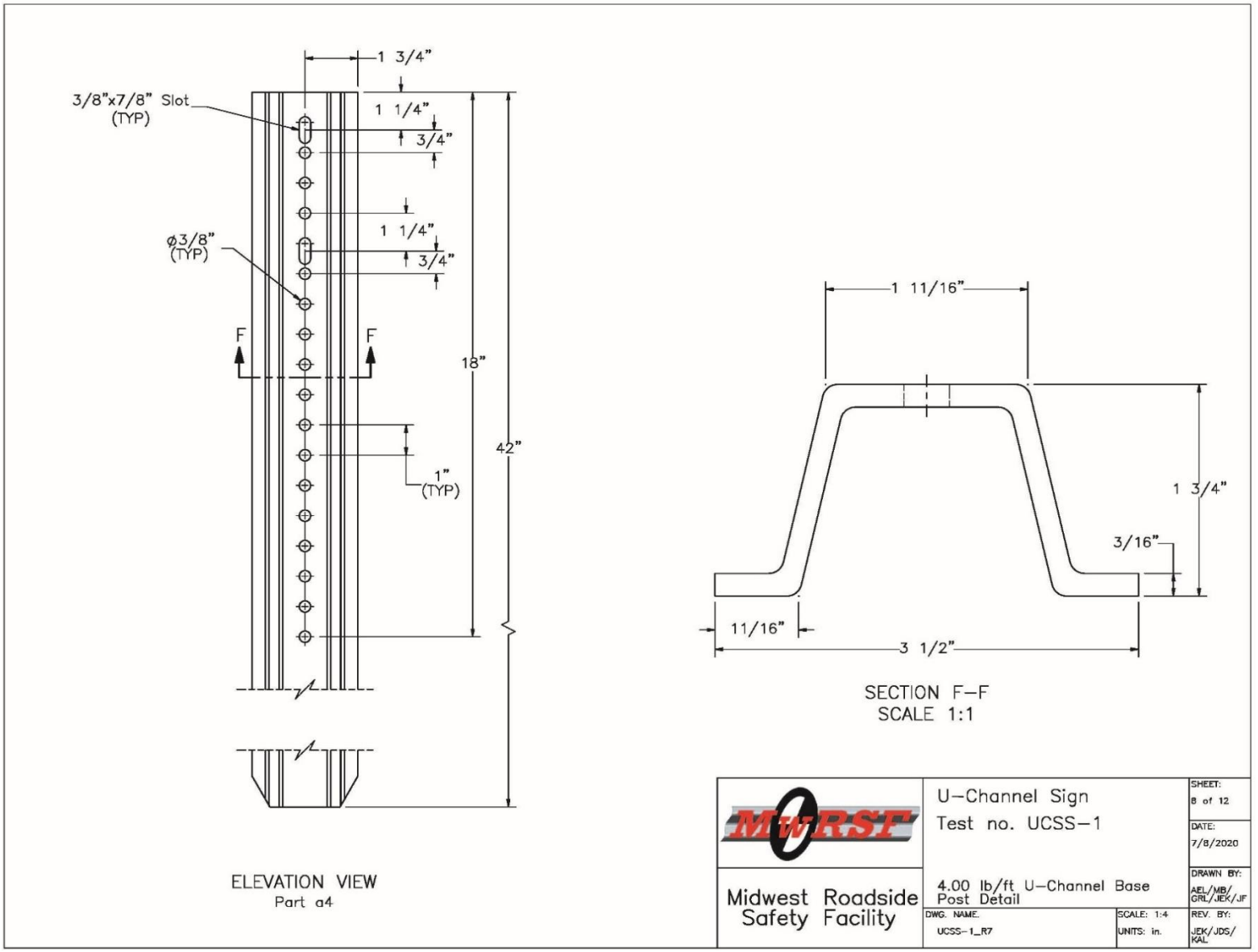


Figure 12. U-Channel Base Detail, Test Nos. UCSS-1B and UCSS-1C

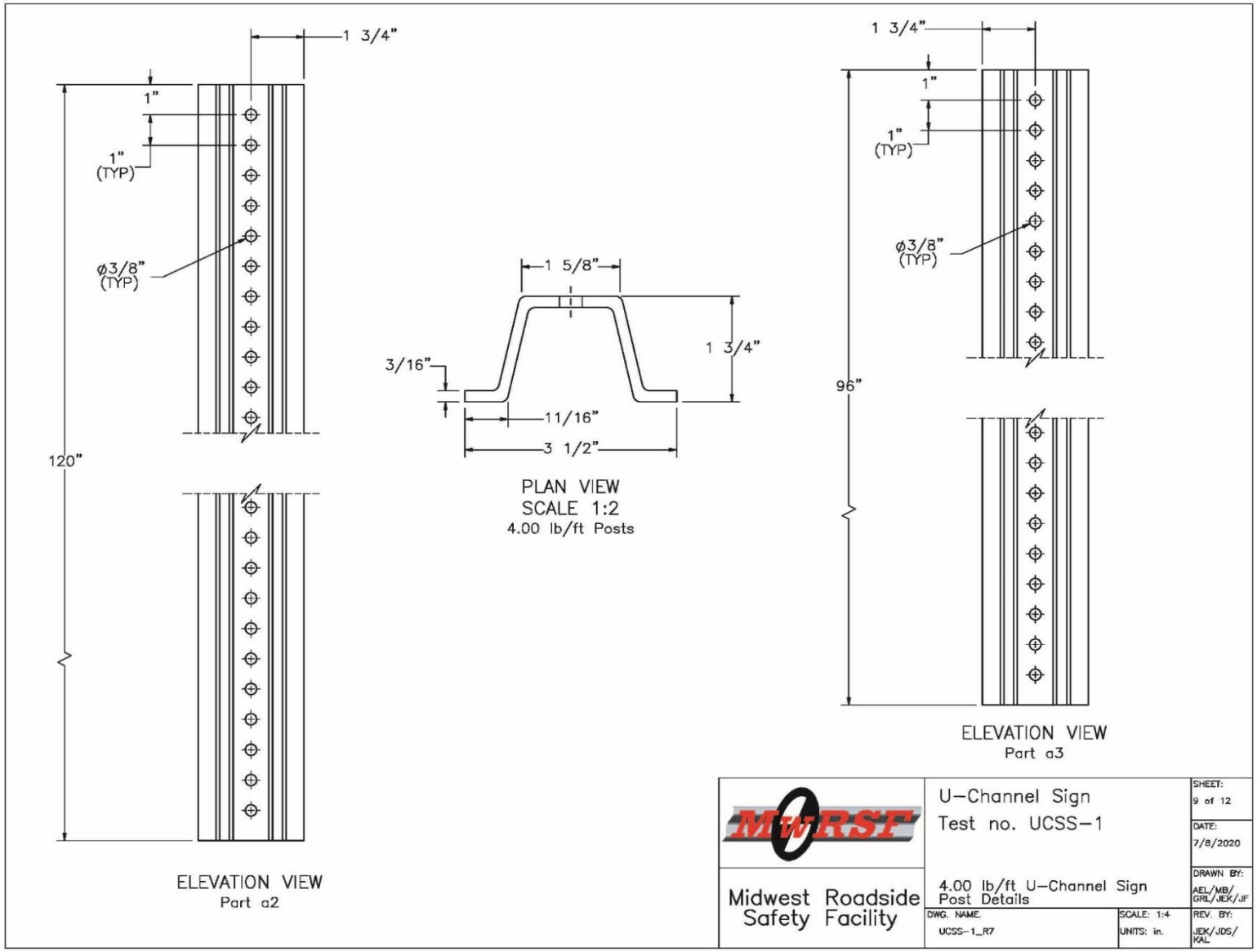


Figure 13. U-Channel Post Detail, Test Nos. UCSS-1B and UCSS-1C

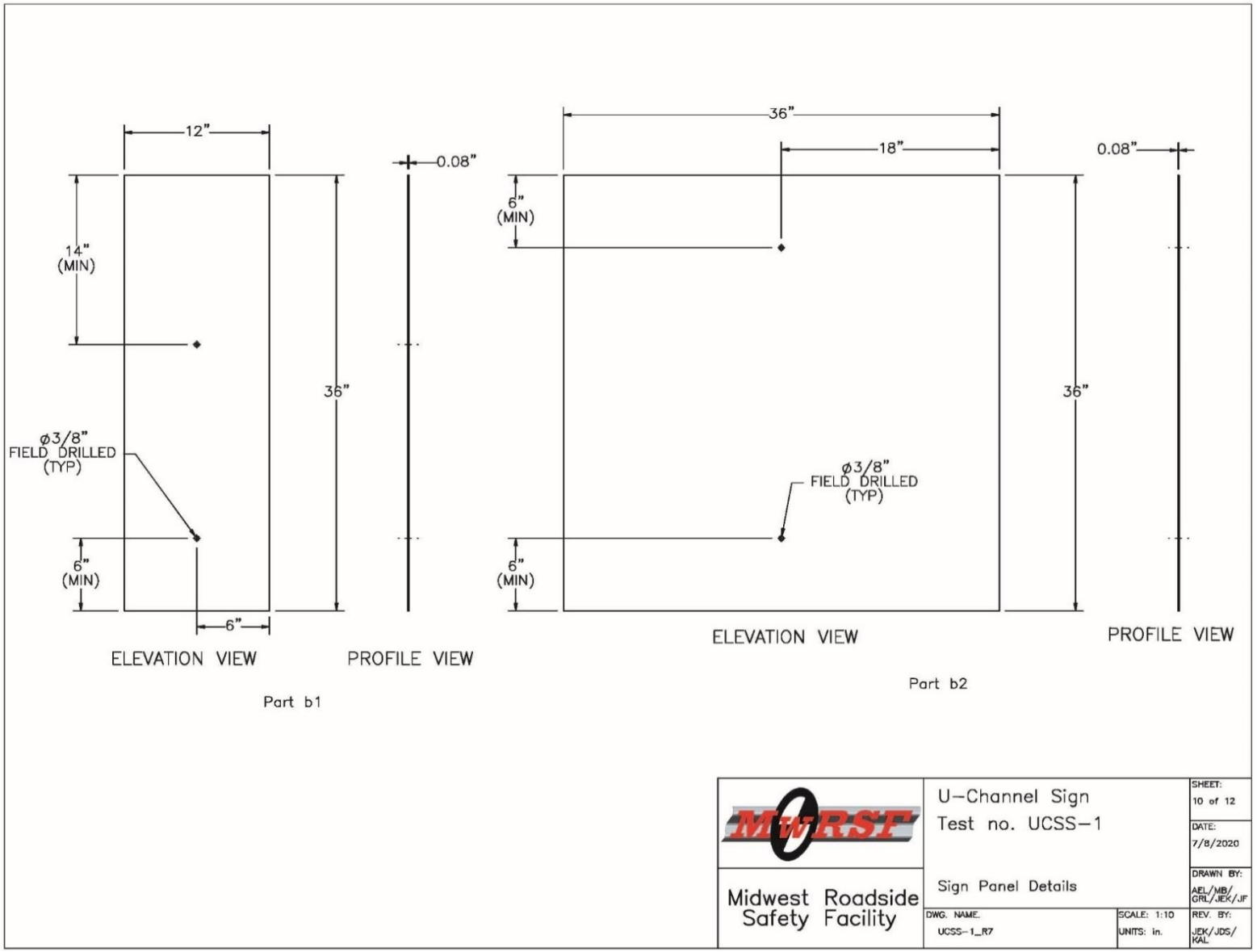


Figure 14. Sign Panel Detail, Test No. UCSS-1

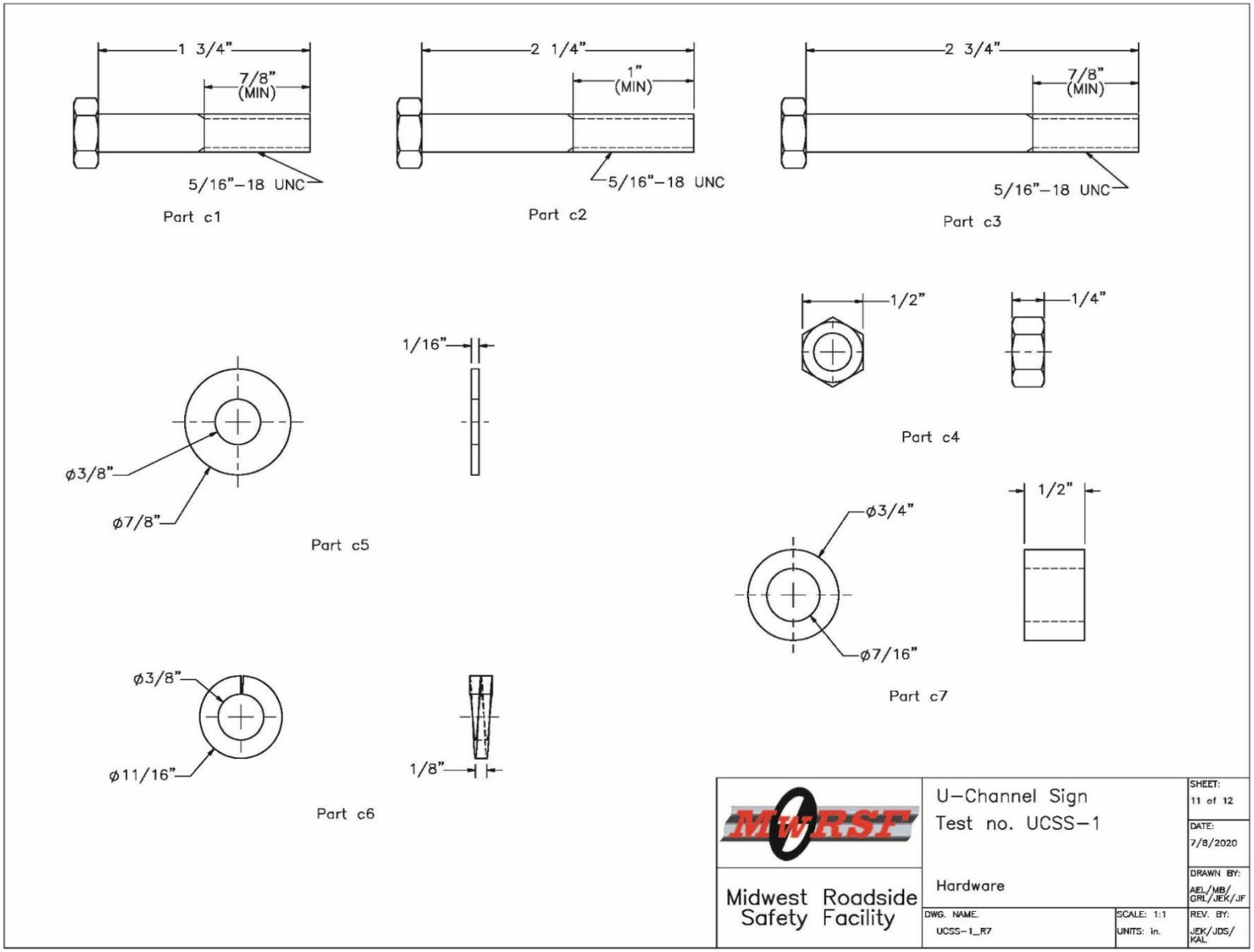


Figure 15. Sign Support and Ground Stub Splice Attachment Hardware Detail, Test No. UCSS-1

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	1	1.12 lb/ft U–Channel Sign Post, 96" Long	ASTM A499 Gr. 60 Min. Yield = 80 ksi	ASTM A123	–
a2	1	4.00 lb/ft U–Channel Sign Post, 120" Long	ASTM A499 Gr. 60 Min. Yield = 60 ksi	ASTM A123	–
a3	1	4.00 lb/ft U–Channel Sign Post, 96" Long	ASTM A499 Gr. 60 Min. Yield = 60 ksi	ASTM A123	–
a4	2	4.00 lb/ft U–Channel Sign Post, 42" Long	ASTM A499 Gr. 60 Min. Yield = 60 ksi	ASTM A123	–
b1	1	36"x12"x0.08" Sign with Reflective Sheeting	Aluminum Alloy 5052 or Similar	–	–
b2	2	36"x36"x0.08" Sign with Reflective Sheeting	Aluminum Alloy 5052 or Similar	–	–
c1	2	5/16"–18 UNC, 1 3/4" Long Hex Bolt	SAE J429 Gr. 5 or 9	Fe/Zn 3AN per ASTM F1941	FBX08b
c2	4	5/16"–18 UNC, 2 1/4" Long Hex Bolt	SAE J429 Gr. 9	Zinc–Plated	–
c3	4	5/16"–18 UNC , 2 3/4" Long Hex Bolt	SAE J429 Gr. 5 or 9	Fe/ZN 3AN per ASTM F1941	FBX08b
c4	10	5/16"–18 UNC Heavy Hex Nut	SAE J995 Gr. 5 or 9	Fe/Zn 3AN per ASTM F1941	FNX08b
c5	20	5/16" Dia. Plain Round Washer	Low Carbon Steel	Fe/Zn 3AN per ASTM F1941	FWC08a
c6	10	3/8" Dia. Lock Washer	Low Carbon Steel	Fe/Zn 3AN per ASTM F1941	–
c7	4	1/2" Thick Spacer with 7/16" Hole	–	–	–

Midwest Roadside Safety Facility

U–Channel Sign
Test no. UCSS–1

Bill of Materials

SHEET: 12 of 12
DATE: 7/8/2020
DRAWN BY: AEL/MB/GRL/JEK/JF
REV. BY: JEK/JDS/KAL
DWG. NAME. UCSS–1_R7
SCALE: None
UNITS: in.

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

Figure 17. Test Installation, Test No. UCSS-1

Figure 18. Test Installation, Test No. UCSS-1

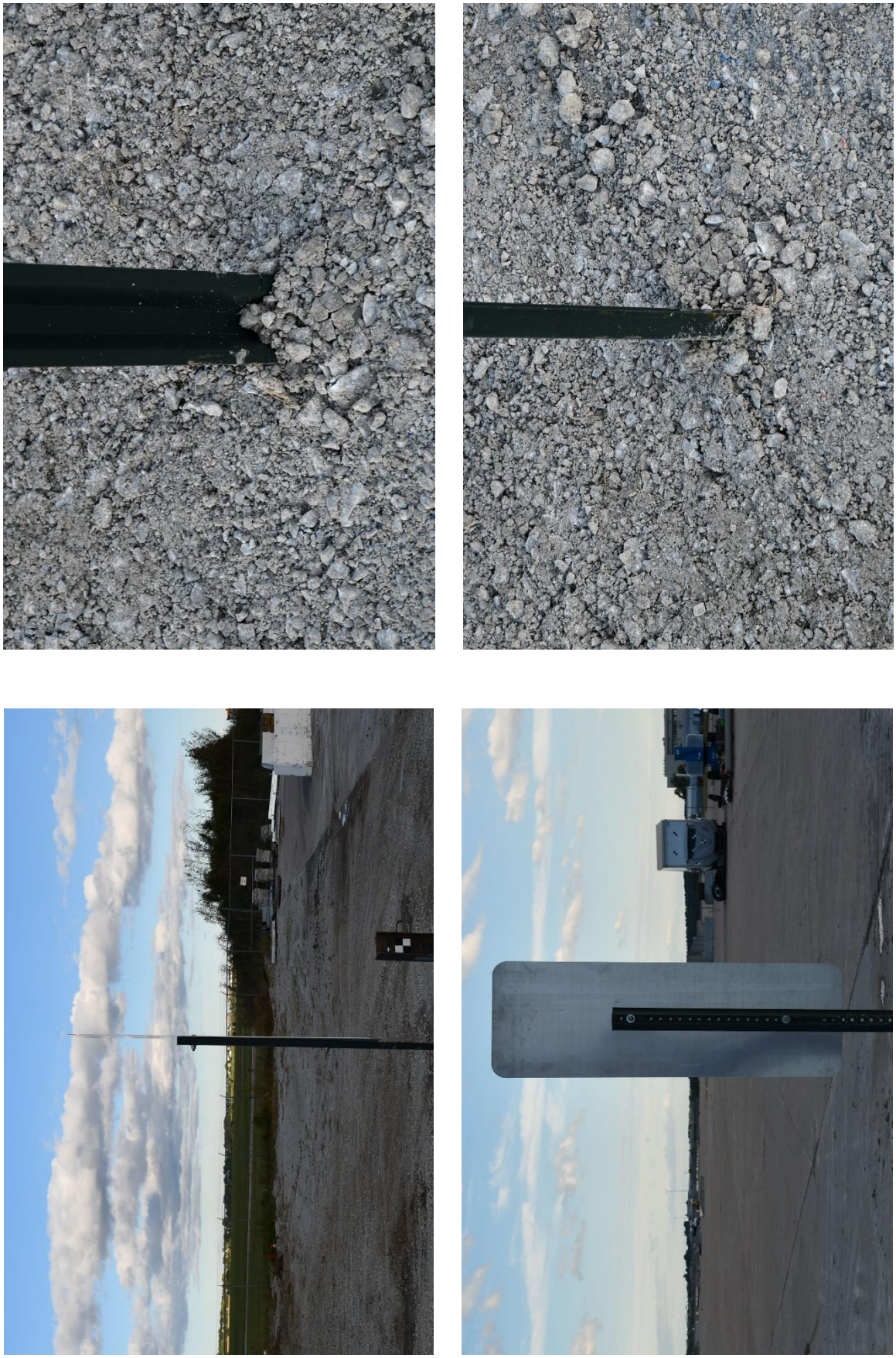


Figure 19. Test Installation, Test No. UCSS-1A

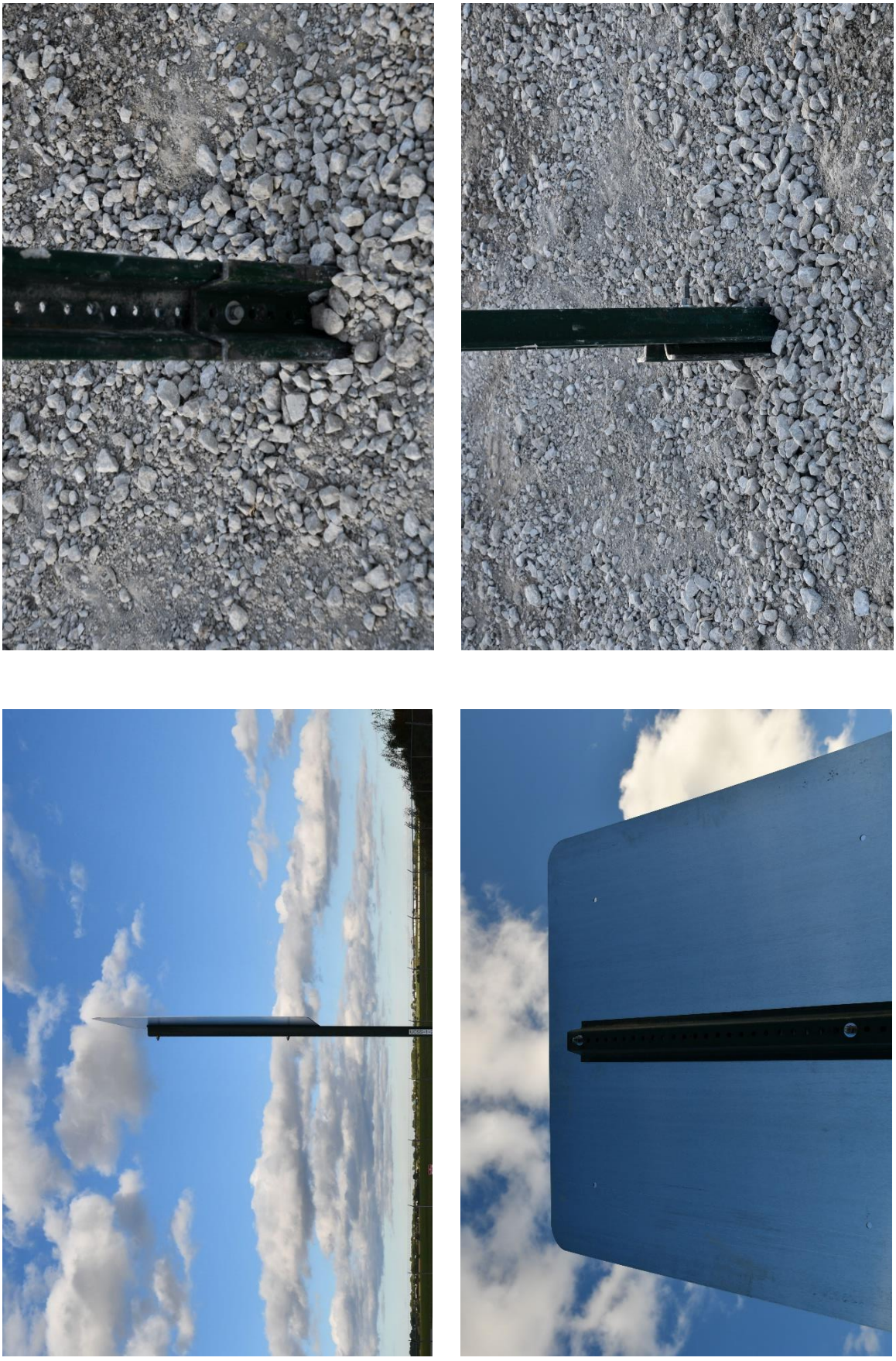


Figure 20. Test Installation, Test No. UCSS-1B

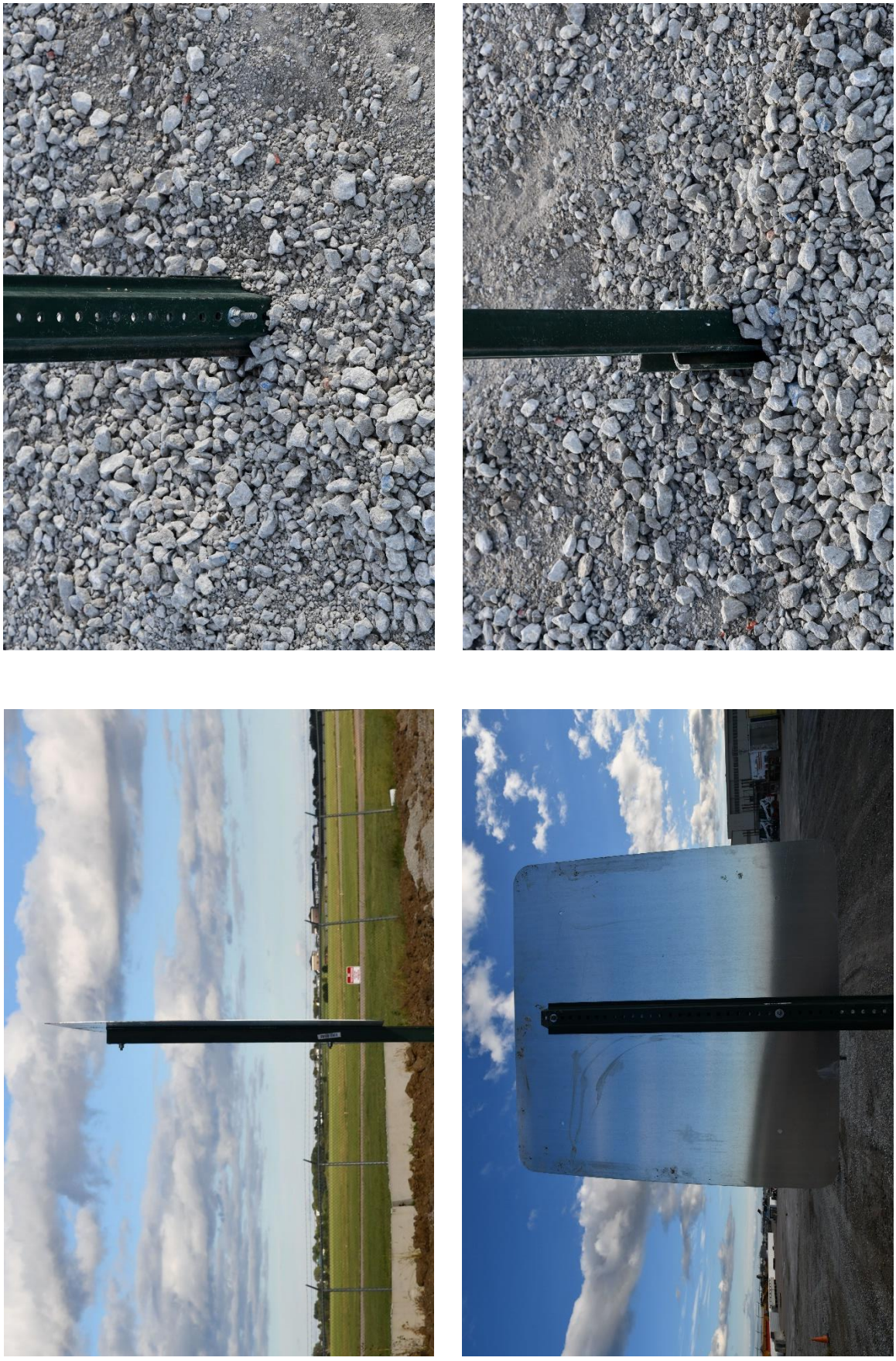


Figure 21. Test Installation, Test No. UCSS-1C

5 TEST REQUIREMENTS AND EVALUATION CRITERIA

5.1 Test Requirements

Support structures, such as U-channel sign supports, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the 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. According to TL-3 criteria, support structures must be subjected to three full-scale vehicle crash tests, as summarized in Table 9.

Table 9. MASH 2016 TL-3 Crash Test Conditions for Support Structures

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb	Impact Conditions		Evaluation Criteria[1]
				Speed, mph	Angle, degrees	
Support Structures	3-60	1100C	2,420	19	CIA	B,D,F,H,I,N
	3-61	1100C	2,420	62	CIA	B,D,F,H,I,N
	3-62	2270P	5,000	62	CIA	B,D,F,H,I,N

[1]Evaluation criteria explained in Table 10

Test designation no. 3-61, reported herein, was conducted for three sign supports simultaneously. The selected devices, termed Systems A, B, and C, corresponded to test nos. UCSS-1A, UCSS-1B, and UCSS-1C, respectively. The systems were installed 30 ft apart and contacted by the test vehicle at a 0-degree angle. MASH notes that the critical impact angle (CIA) should be selected to represent the highest risk for the system to fail any of the recommended evaluation criteria. Since these permanent sign supports will not be typically installed 90 degrees from the normal direction of travel, a critical impact angle between 0 and 25 degrees is recommended. Impacting the sign systems at a 0-degree impact angle was believed to be most critical in terms of maximizing the potential area of contact of the sign panels with the windshield and roof. The initial impact point of System A was the centerline of the vehicle's front bumper, while Systems B and C were impacted at the vehicle's right- and left-side quarter points, respectively.

Only one full-scale MASH test designation no. 3-61 crash test was conducted, as reported herein. MASH test designation nos. 3-60 and 3-62 were not conducted as part of the initial research effort. For a complete evaluation of the sign systems according to MASH TL-3, the full test matrix should be conducted, as shown in Table 9.

5.2 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 is that the test article should readily activate in a predicable manner by breaking away, fracturing, or yielding. 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 10 and are defined in greater detail in MASH 2016.

It is important to note that in tests of breakaway features, the impulse on the vehicle may be relatively small and of short duration. It is not unusual for *x* and *y* in the flail-space model to be less than 2 ft and 1 ft, respectively, during the period in which accelerations are recorded or up to the time brakes are applied to the test vehicle. As specified in Section A5.5.2 of MASH 2016, in such cases, it is recommended that the OIV be set equal to the vehicle's change in velocity that occurs during contact with the test article, or parts thereof [1]. If parts of the test article remain with the vehicle after impact, the vehicle's change in velocity should be computed at the time the vehicle clears the footing or foundation of the test article.

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

Table 10. MASH 2016 Evaluation Criteria for Support Structures

<table>
<tr><td>Structural Adequacy</td><td>B.</td><td colspan="4">The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td></tr>
<tr><td rowspan="5">Occupant Risk</td><td>D.</td><td colspan="4">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="4">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="3">H.</td><td colspan="4">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="4">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td rowspan="3">I.</td><td>Longitudinal</td><td>10 ft/s</td><td>16 ft/s</td></tr>
<tr><td colspan="4">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="4">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>Post-Impact Vehicular Response</td><td>N.</td><td colspan="4">Vehicle trajectory behind the test article is acceptable.</td></tr>
</table>

5.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH 2016, foundation soil strength must be verified. During the installation of a soil dependent system, a W6x16 post is installed near the impact region using the same installation procedures as the system itself. Prior to full-scale testing, a dynamic impact test is conducted to verify a minimum dynamic soil resistance of 7.5 kips at post deflections between 5 and 20 in. at a height of 25 in. If dynamic testing near the system is not desired, MASH 2016 permits a static test to be conducted and compared against a previously established baseline. In this situation, the soil must provide a resistance of at least 90 percent of the static baseline test at deflections of 5, 10, and 15 in. Further details can be found in Appendix B of MASH 2016.

6 TEST CONDITIONS

6.1 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 five miles northwest of the University of Nebraska–Lincoln.

6.2 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 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 measurement accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch [12] 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 system. The ⅜-in. diameter guide cable was tensioned to approximately 3,500 lb and supported both laterally and vertically every 100 ft 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.

6.3 Test Vehicles

A 2009 Toyota Yaris subcompact four-door car was used as the test vehicle for test no. UCSS-1. The curb, test inertial, and gross static vehicle weights were 2,312 lb, 2,395 lb, and 2,557 lb, respectively. The test vehicle is shown in Figures 22 through 24, and vehicle dimensions are shown in Figure 25. MASH recommends using test vehicles within 6 model years on the day the test is conducted. Regardless of age, test vehicles should adhere to the properties specified in MASH [13]. While the test vehicle utilized was older than 6 years from the test date, the properties of the test vehicle met the requirements in MASH, and the test vehicle was geometrically similar to newer 1100C test vehicles. Note, MASH recommends that, when practical, the test vehicle should be selected to conform to all the parameters shown in MASH Tables 4-1 and 4-2. The hood height was measured to be 32⅞ in., and MASH recommends 24 +/- 4 in. for the 1100C hood height. This difference was noted. Since, the overall front geometry of the Toyota Yaris was similar to other 1100C test vehicles, which was the primary contact area for the test article, it was not considered to be an issue. The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The vertical component of the c.g. was determined using a procedure published by SAE [14]. The location of the final c.g. is shown in Figures 25 and 26. Data used to calculate the location of the c.g. and ballast information are shown in Appendix D.

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

Figure 22. Test Vehicle, Test No. UCSS-1

Figure 23. Test Vehicle's Interior Floorboards, Test No. UCSS-1

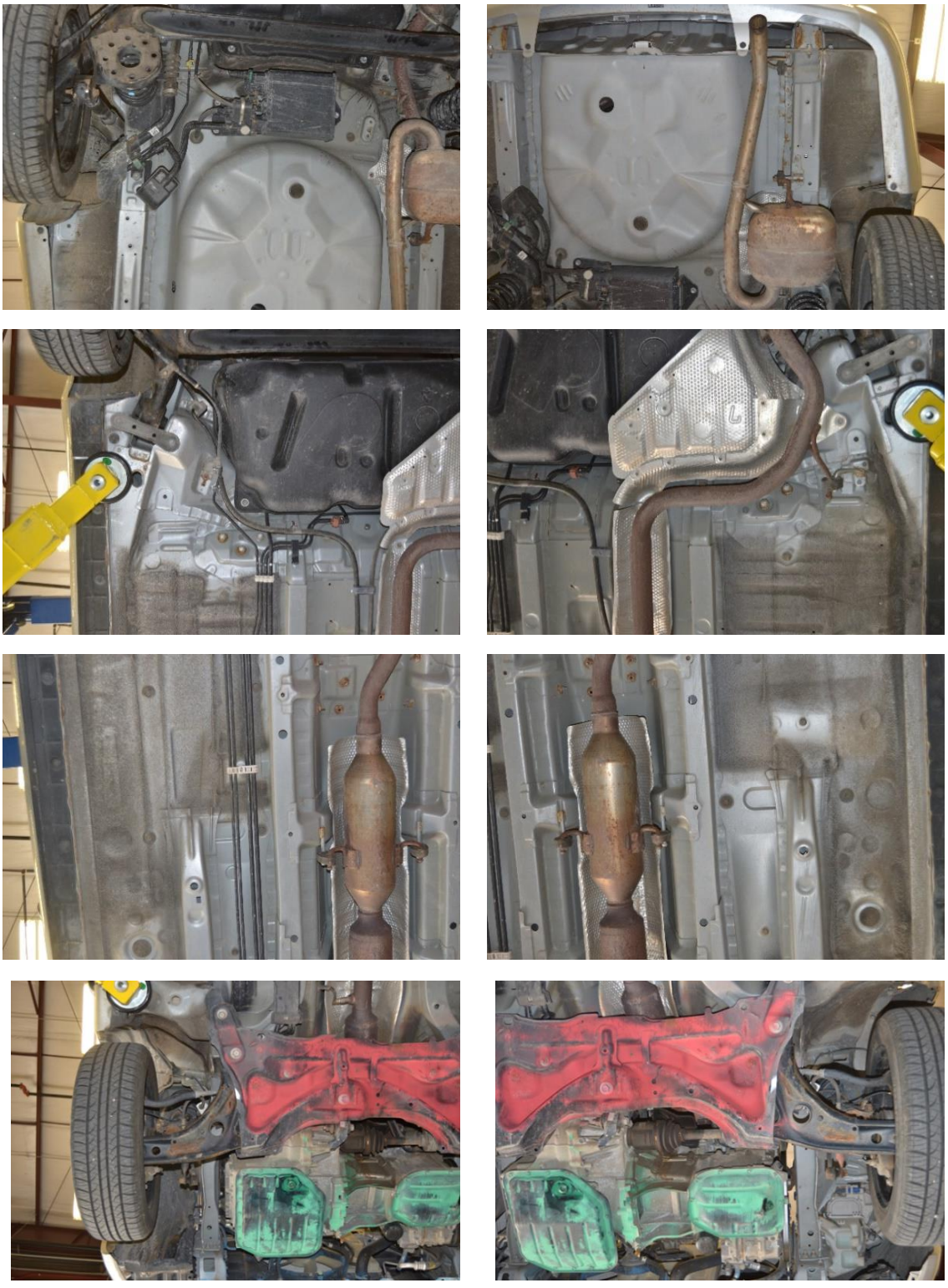
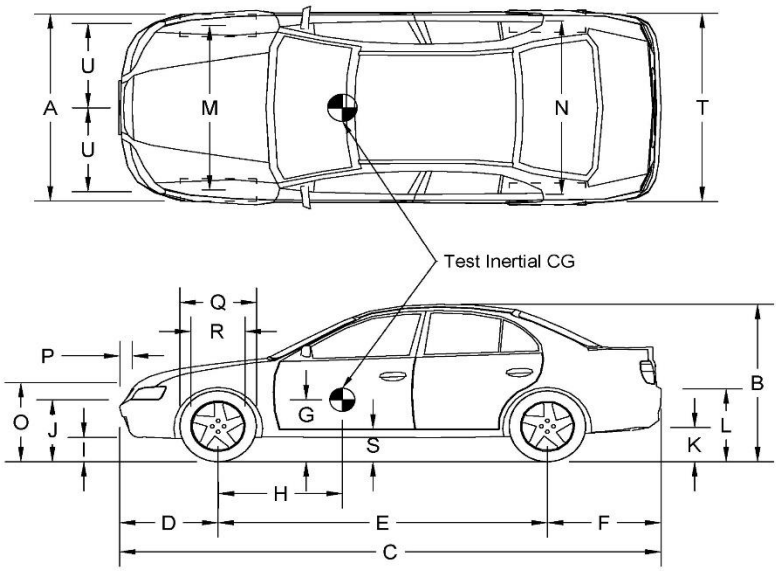


Figure 24. Test Vehicle's Undercarriage, Test No. UCSS-1

Date:	9/26/2018	**Test Name:**	UCSS-1	**VIN No:**	jtdbt903194056758
Year:	2009	**Make:**	Toyota	**Model:**	Yaris
Tire Size:	p185/60	**Tire Inflation Pressure:**	32 Psi	**Odometer:**	147873



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

A:	66 3/8 (1686) 65±3 (1650±75)	**B:**	56 3/8 (1432)
C:	168 3/4 (4286) 169±8 (4300±200)	**D:**	37 1/8 (943) 35±4 (900±100)
E:	100 5/8 (2556) 98±5 (2500±125)	**F:**	31 3/8 (797)
G:	22 1/2 (572)	**H:**	40 7/8 (1038) 39±4 (990±100)
I:	7 1/4 (184)	**J:**	19 3/8 (492)
K:	13 3/8 (340)	**L:**	25 1/8 (638)
M:	57 7/8 (1470) 56±2 (1425±50)	**N:**	57 3/8 (1457) 56±2 (1425±50)
O:	32 7/8 (835) 24±4 (600±100)	**P:**	1 1/4 (32)
Q:	23 1/4 (591)	**R:**	16 3/8 (416)
S:	8 1/4 (210)	**T:**	65 (1651)

U (impact width): 33 1/8 (841)

Mass Distribution lb (kg)

Gross Static	**LF**	728 (330)	**RF**	777 (352)
	LR	517 (235)	**RR**	535 (243)

Top of radiator core support:	31 1/2 (800)
Wheel Center Height (Front):	11 1/4 (286)
Wheel Center Height (Rear):	11 1/2 (292)
Wheel Well Clearance (Front):	26 1/4 (667)
Wheel Well Clearance (Rear):	26 1/4 (667)
Bottom Frame Height (Front):	15 3/4 (400)
Bottom Frame Height (Rear):	16 1/2 (419)

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	1430 (649)	1422 (645)	1505 (683)
W-rear	882 (400)	973 (441)	1052 (477)
W-total	2312 (1049)	2395 (1086) 2420±55 (1100±25)	2557 (1160) 2585±55 (1175±50)

Engine Type: Gasoline
Engine Size: VVT-i 1.5L 4 Cy
Transmission Type: Automatic
Drive Type: FWD

GVWR Ratings lb

Front	1840
Rear	1820
Total	3300

Surrogate Occupant Data

Type:	Hybrid II
Mass:	162 lb
Seat Position:	right

Note any damage prior to test: Previously used for CHIC-4 Repaired near suspension.

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

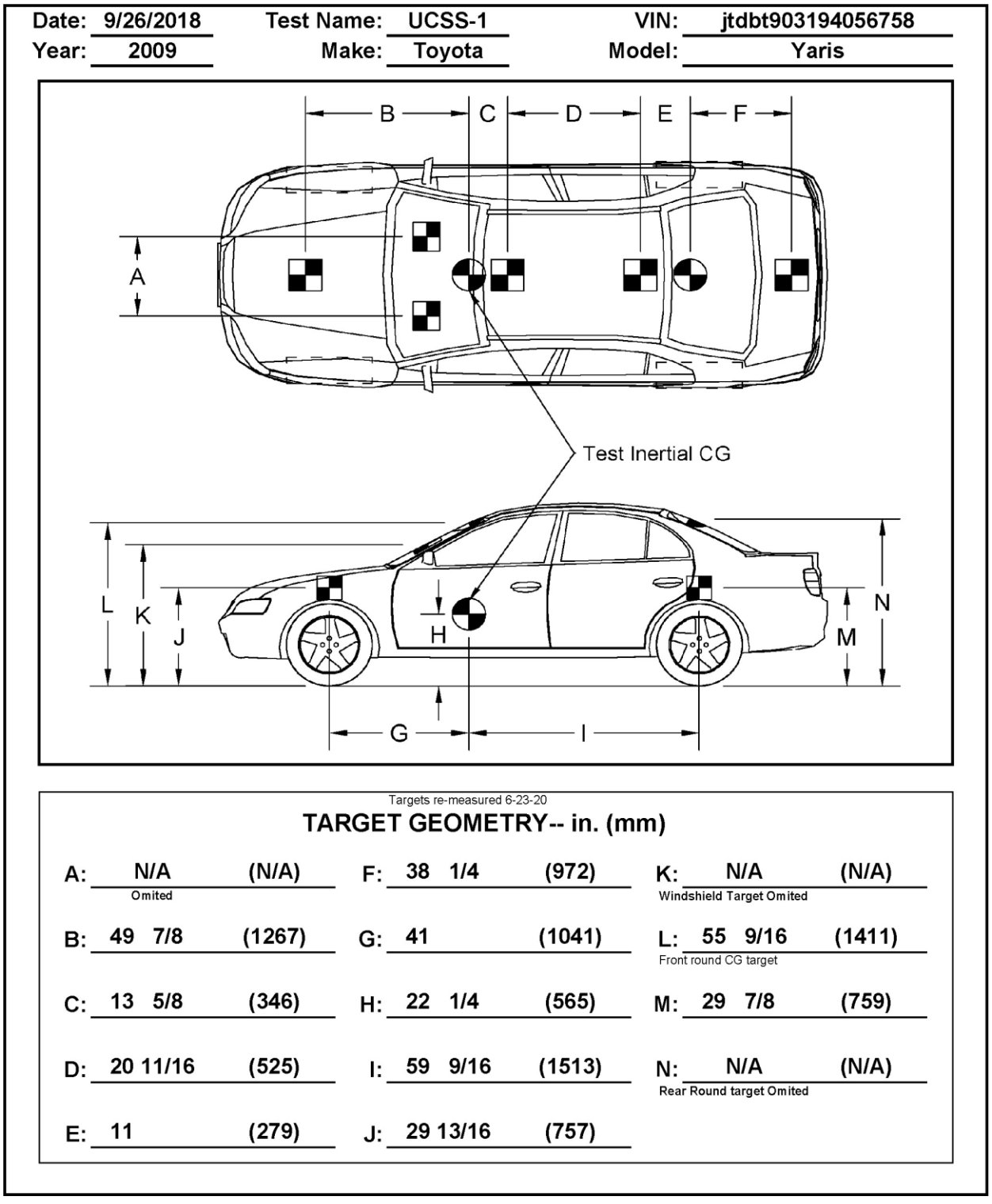


Figure 26. Target Geometry, Test No. UCSS-1

The front wheels of the test vehicle were aligned to vehicle standards, except for the toe-in value, which was adjusted to zero so the vehicle would track properly along the guide cable. Three 5B flash bulbs were mounted under the windshield wipers on the right, left, and center of the windshield, and were fired by a pressure tape switch mounted at each quarter point and centerline of the front bumper. The flash bulb was fired upon initial impact with the test articles to create a visual indicator of the precise time of impact. A remote-controlled brake system was installed so the vehicle could be brought safely to a stop.

6.4 Simulated Occupant

A Hybrid II 50th-Percentile, Adult Male Dummy, equipped with footwear, was placed in the right-front seat of the test vehicle with the seat belt fastened. The dummy had a final weight of 162 lb. As recommended by MASH 2016, the dummy was not included in calculating the c.g. location.

6.5 Data Acquisition Systems

6.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometer systems were mounted near the c.g. of the test vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [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-2 unit was designated as the primary system. Note that the SLICE-2 unit did not record data during test no. UCSS-1 due to triggering issues. 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.

6.5.2 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. Note again that the SLICE-2 unit did not record this data due to triggering issues. Each SLICE MICRO Triax ARS had a range of 1,500 deg./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 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.

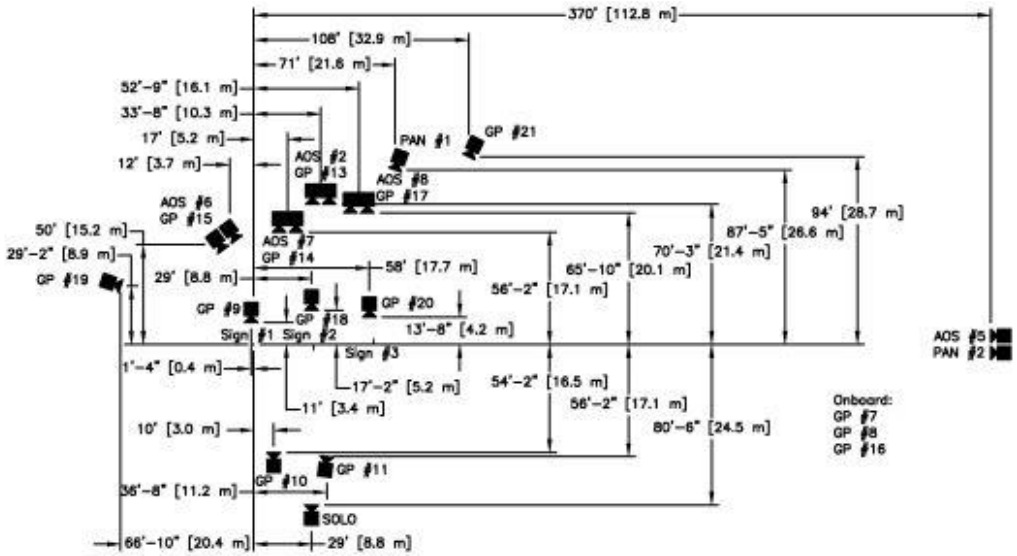
6.5.3 Retroreflective Optic Speed Trap

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

6.5.4 Digital Photography

Five AOS high-speed digital video cameras, fourteen GoPro digital video cameras, two Panasonic digital video cameras, and one SoloShot digital video camera were used to film test no. UCSS-1. Camera details and operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 27.

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 digital still camera was used to document pre- and post-test conditions.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam CTM	500	KOWA 16mm Fixed	-
AOS-5	AOS X-PRI Gigabit	500	100 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	Sigma 28-70 #2	70
AOS-7	AOS X-PRI Gigabit	500	Sigma 28-70 #1	70
AOS-8	AOS S-VIT 1531	500	Fujinon 75 mm Fixed	-
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	120		
GP-11	GoPro Hero 4	120		
GP-13	GoPro Hero 4	120		
GP-14	GoPro Hero 4	120		
GP-15	GoPro Hero 4	120		
GP-16	GoPro Hero 4	120		
GP-17	GoPro Hero 4	120		
GP-18	GoPro Hero 6	120		
GP-19	GoPro Hero 6	120		
GP-20	GoPro Hero 6	120		
GP-21	GoPro Hero 6	120		
PAN-1	Panasonic HC-V770	60		
PAN-2	Panasonic HC-V770	60		
SOLO	SoloShot	120		

Figure 27. Camera Locations, Speeds, and Lens Settings, Test No. UCSS-1

7 FULL-SCALE CRASH TEST NO. UCSS-1 (UCSS-1A, UCSS-1B, UCSS-1C)

7.1 Static Soil Test

Before conducting full-scale crash test no. UCSS-1, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The results, as shown in Appendix E, demonstrated a soil resistance above 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. UCSS-1 was conducted on September 26, 2018 at approximately 02:00 p.m. The weather conditions, as per the National Oceanic and Atmospheric Administration (station 14939/LNK), are shown in Table 11.

Table 11. Weather Conditions, Test No. UCSS-1

Temperature	70°F
Humidity	25 percent
Wind Speed	7 mph
Wind Direction	300 deg. from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.07 in.
Previous 7-Day Precipitation	0.71 in.

7.3 Test Description

The 2,395-lb car impacted System A at 67.1 mph and an angle of 0 degrees. System B was impacted at 65.5 mph and an angle of 0 degrees. System C was impacted at 61.5 mph and an angle of 0 degrees The impact location is shown in Figures 28 and 29. Overhead cameras were not present to verify the impact angle with each system. However, the angles appeared very close to nominal. A detailed sequential description of the impact events is contained in Tables 12 through 14. Sequential photographs are shown in Figures 30 through 32. Vehicle trajectory and final position are shown in Figure 34.

MASH 2016 does not provide specific guidance about alignment between the test vehicle and test article for U-channel sign supports, so a centerline impact was selected for System A. In order to distinguish damage between different test articles, Systems B and C were aligned with the right and left quarter points of the front bumper, respectively. System A remained in contact with the vehicle throughout the entire impact event. The vehicle was determined to have exited each system when the vehicle cleared the footings of the signs. The vehicle came to rest 246 ft – 6 in. downstream and 5 ft – 5 in. to the left of System A.

Table 12. Sequential Description of Impact Events, Test No. UCSS-1A

TIME (sec)	EVENT
0.000	Vehicle's front bumper contacted bottom of System A sign support.
0.030	Sign support pulled from ground, buckled, and bent downward toward vehicle's hood.
0.060	Sign support fully pulled from ground and lower portion of sign support lodged into vehicle's right-lower A-arm. Sign support's middle lower half bent.
0.090	Lower portion of sign support lodged into vehicle's A-arm. Sign support's top section pulled toward ground.
0.120	Sign panel and sign support bent and buckled toward right side of vehicle.
0.146	Vehicle cleared the footing of system A.

Table 13. Sequential Description of Impact Events, Test No. UCSS-1B

TIME (sec)	EVENT
0.000	System A and vehicle's front bumper on right corner point contacted bottom of System B sign support.
0.040	Lower portion of sign support sheared off at top attachment point of ground stub by attachment hardware.
0.080	Sign support on the sign panel side moved toward vehicle's roof.
0.120	Top portion of sign support, where sign panel is attached, contacted right-rear of vehicle's roof.
0.154	Vehicle cleared the footing of system B.
0.160	Sign support deflected off vehicle's roof.

Table 14. Sequential Description of Impact Events, Test No. UCSS-1C

TIME (sec)	EVENT
0.000	Vehicle's left-front bumper contacted bottom of System C sign support.
0.024	U-channel sign support and ground stub section attachment hardware sheared off, and the sign support sheared off about 12 in. from attachment hardware. Lower portion of sign support (where the shearing occurred) stayed in ground and bent approximately 45 deg. to the rear.
0.048	Sign support rotated clockwise with the end with the sign panel moving toward vehicle's roof.
0.072	Sign support continued to rotate clockwise and became horizontal with ground.
0.096	Top portion of sign support where sign panel was attached contacted vehicle's roof.
0.120	Sign support deflected off vehicle's roof.
0.156	Vehicle cleared the footing of System C.

Figure 28. Impact Location, Test No. UCSS-1A

Figure 29. Impact Location, Test Nos. UCSS-1B and UCSS-1C


0.000 sec


0.080 sec


0.160 sec


0.240 sec


0.320 sec


0.400 sec


0.480 sec


0.560 sec


0.720 sec


0.800 sec


0.880 sec


0.960 sec

Figure 30. Sequential Photographs, Test No. UCSS-1

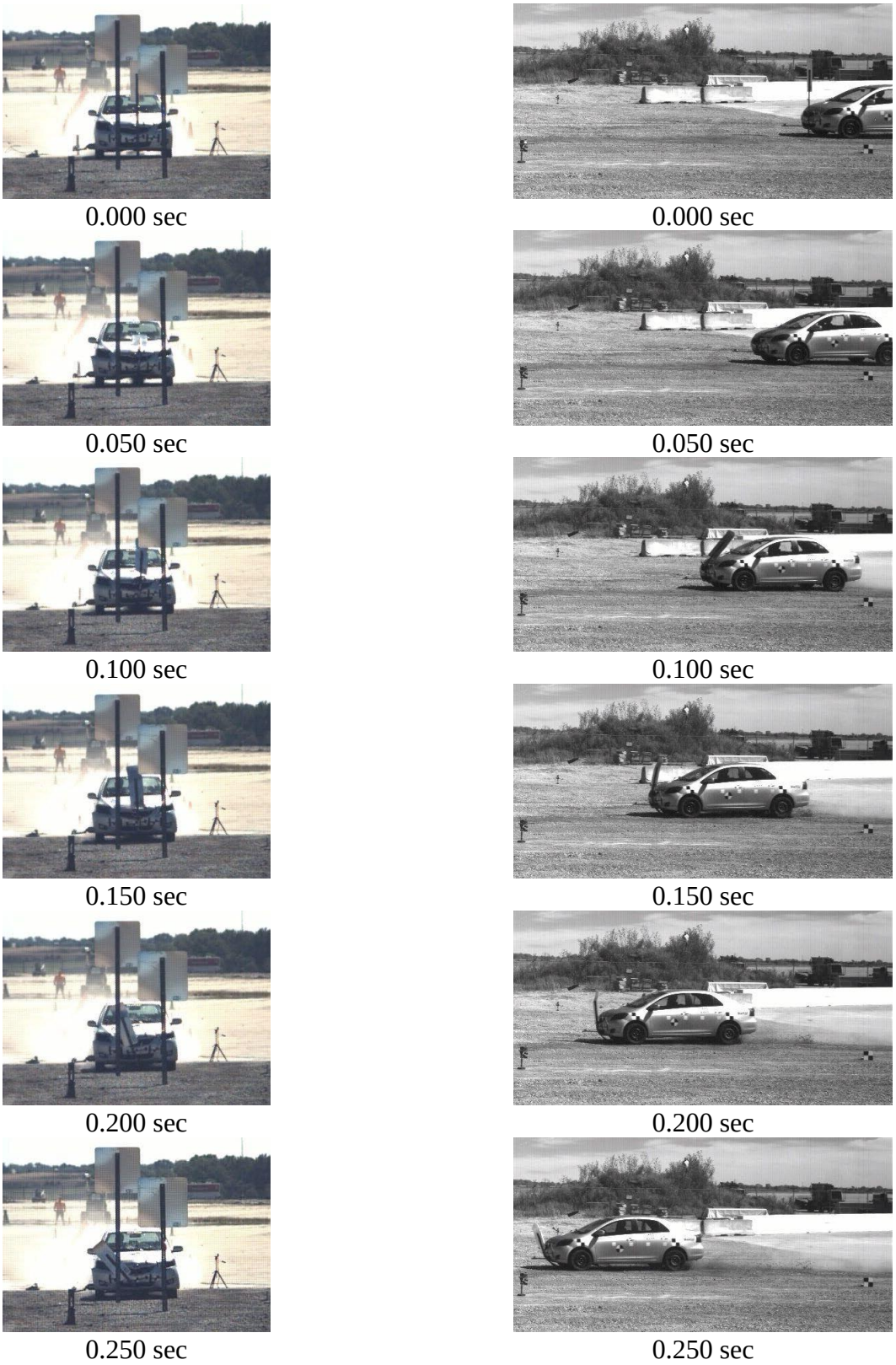


Figure 31. Sequential Photographs, Test No. UCSS-1A


0.000 sec


0.000 sec


0.050 sec


0.050 sec


0.100 sec


0.100 sec


0.150 sec


0.150 sec


0.200 sec


0.200 sec


0.250 sec


0.250 sec

Figure 32. Sequential Photographs, Test No. UCSS-1B


0.000 sec


0.000 sec


0.040 sec

0.040 sec


0.080 sec

0.080 sec


0.120 sec

0.120 sec


0.160 sec

0.160 sec


0.200 sec

0.200 sec

Figure 33. Sequential Photographs, Test No. UCSS-1C

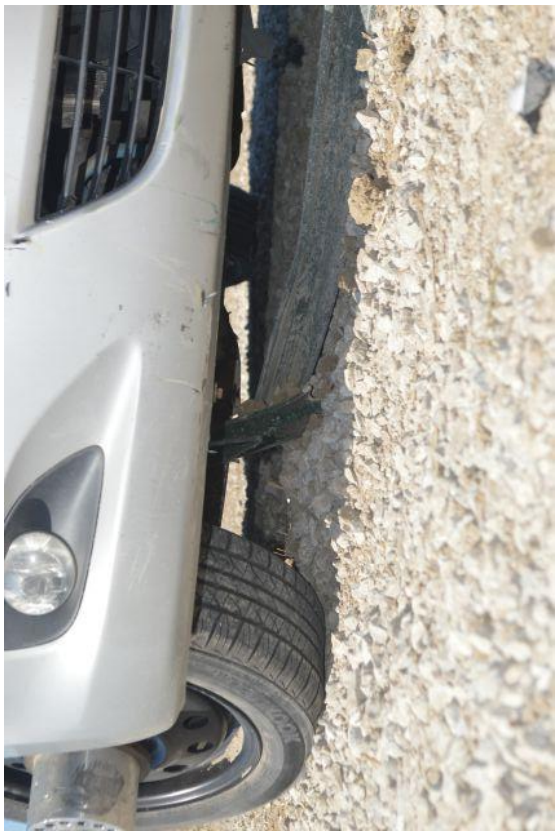
Figure 34. Vehicle Trajectory, Test No. UCSS-1

7.4 System Damage

System damage is shown in Figures 35 through 37 for Systems A, B, and C, respectively. System A was initially impacted 14.5 in. above the ground. The sign support was pulled out of the ground and bent around the vehicle's hood and undercarriage. The lower end of the sign support was lodged in the vehicle's right-side lower A-arm. The sign support and sign panel were bent and buckled toward the right side of the vehicle.

System B was initially impacted by System A's sign support, which was wrapped around the front bumper. Damage to the system included deformation of the sign panel, sign support, and support stub. The bottom of the U-channel sign support fractured, and the support-to-stub attachment hardware fractured. The top of the sign support and sign panel contacted the vehicle's roof. The ground stub did not rotate through the soil or experience uplift, and the stub height (top of the ground stub) remained approximately 4 in. above the ground level, as shown in Figure 36.

System C was initially impacted 14.5 in. above the ground. The sign support deflected backward and fractured 10 in. above the top of the stub. The lower portion of the fractured sign support remained in contact with the ground. The upper portion of the sign support and sign panel contacted the vehicle's roof. The ground stub did not rotate through the soil or experience uplift, and the stub height (top of the ground stub) remained approximately 4 in. above the ground level, as shown in Figure 37. Although a portion of the upper sign support remained attached to the ground tub, this portion of the post was loose after the test and could be moved easily by hand. Thus, this portion of the post was not considered a hazard and not included in the ground stub measurement.



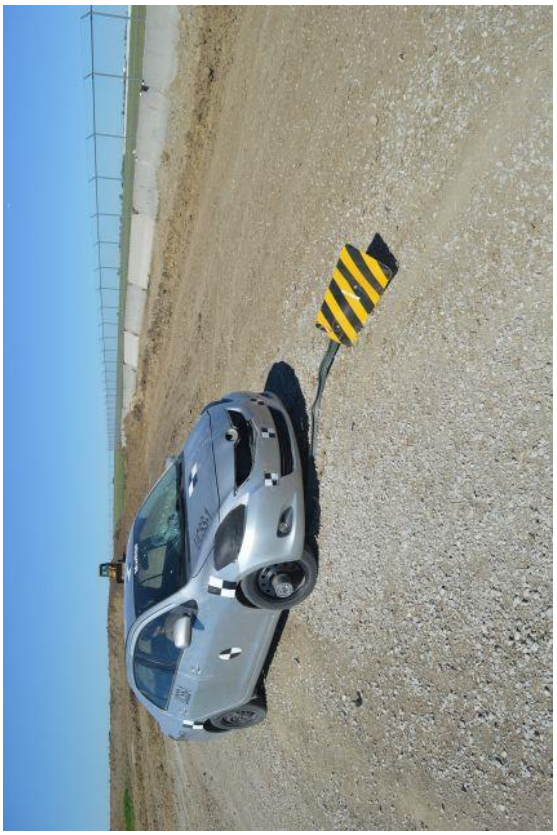


Figure 35. System Damage, Test No. UCSS-1A

Figure 36. System Damage, Test No. UCSS-1B

Figure 37. System Damage, Test No. UCSS-1C

7.5 Vehicle Damage

Damage to the vehicle was minor, as shown in Figures 38 through 43. The maximum occupant compartment deformations are listed in Table 15 along with the deformation limits established in MASH 2016 for various areas of the occupant compartment. Note that none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix F. The windshield damage occurred from System A. The roof damage occurred from Systems B and C.

Contact marks were found across the front bumper and hood from impact with all three systems. The rear of the vehicle's roof was moderately deformed after impact with Systems B and C. The lower center portion of the front windshield was cracked and slightly deformed. Minor scrapes were found on the leading edge of the lower control arms. The bottom portion of the sign support of System A was lodged in the right-side lower A-arm. The transmission and oil pan housings were scraped. Part of one of the U-channel supports was lodged in the suspension on the right side. The lower radiator support was damaged on the leading edge.

Figure 38. Vehicle Damage, Test No. UCSS-1

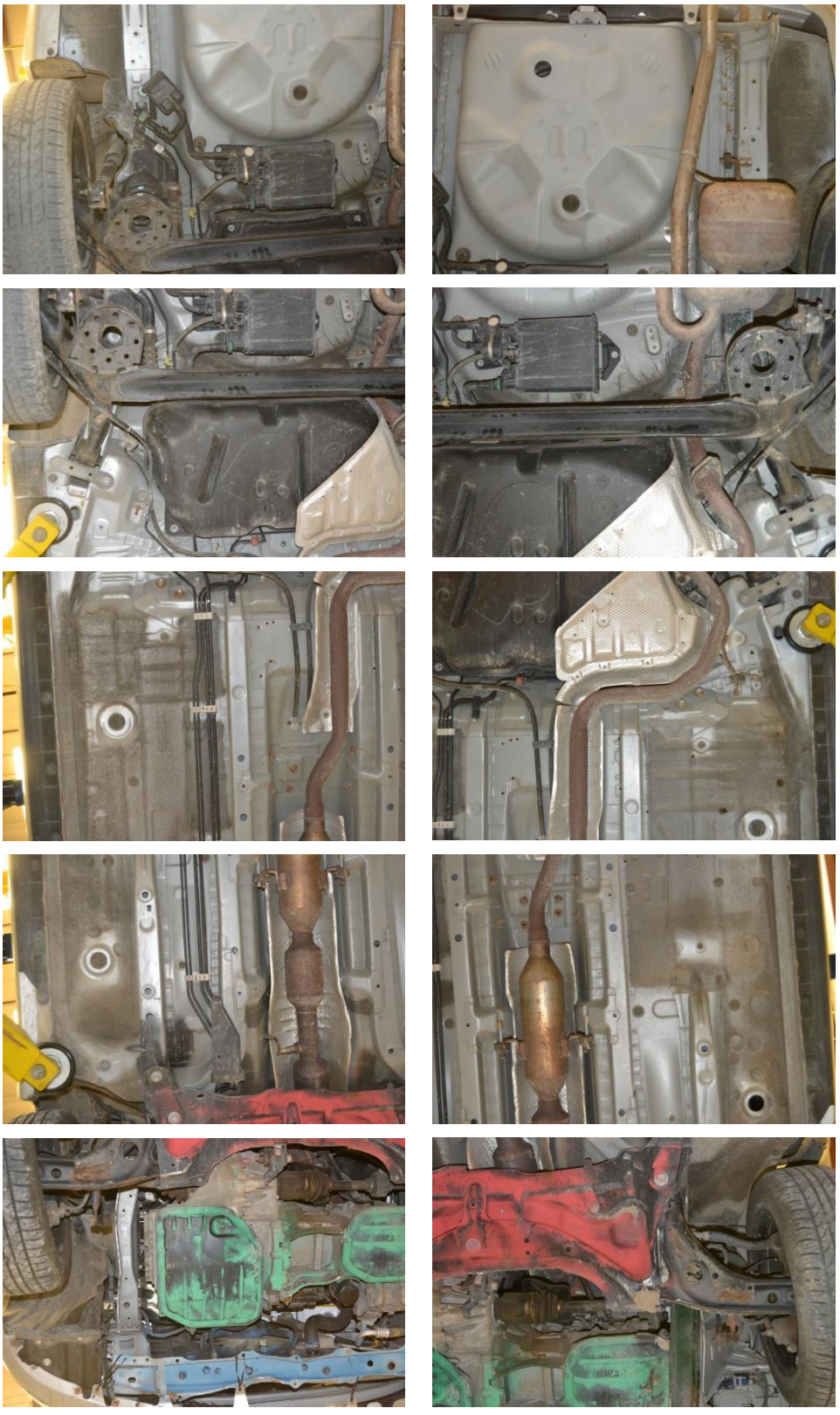


Figure 39. Undercarriage Damage, Test No. UCSS-1

Figure 40. Undercarriage Damage, Test No. UCSS-1

Figure 41. Right-Side Lower A-Arm Damage, Test No.UCSS-1

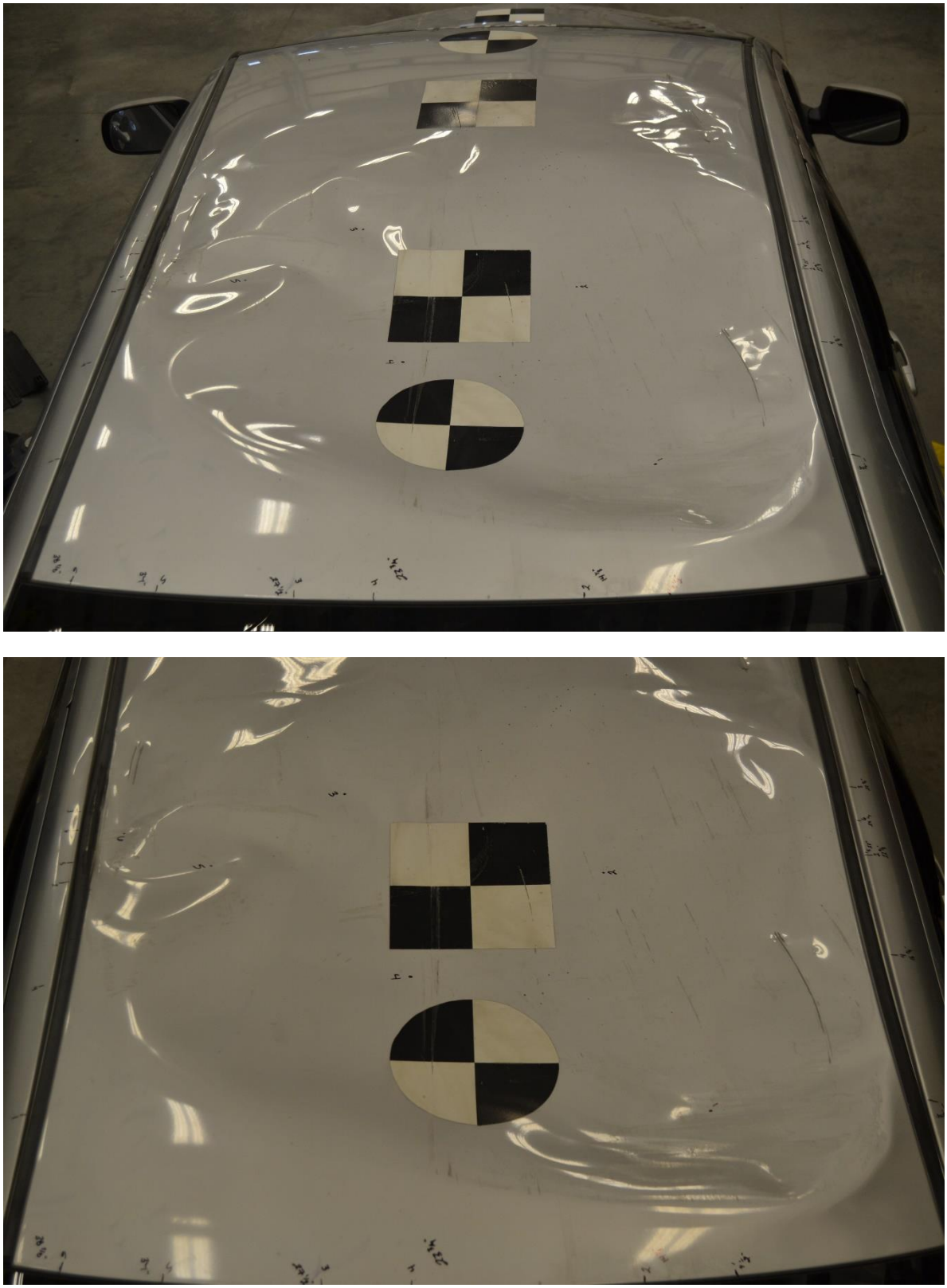


Figure 42. Roof Damage, Test No. UCSS-1

Pre-test

Post-test

Figure 43. Windshield Damage, Test No. UCSS-1

Table 15. Maximum Occupant Compartment Deformations by Location, Test No. UCSS-1

LOCATION	MAXIMUM INTRUSION in.	MASH 2016 ALLOWABLE INTRUSION in.
Wheel Well & Toe Pan	N/A	≤ 9
Floor Pan & Transmission Tunnel	N/A	≤ 12
A-Pillar	N/A	≤ 5
A-Pillar (Lateral)	N/A	≤ 3
B-Pillar	N/A	≤ 5
B-Pillar (Lateral)	N/A	≤ 3
Side Front Panel (in Front of A-Pillar)	N/A	≤ 12
Side Door (Above Seat)	N/A	≤ 9
Side Door (Below Seat)	N/A	≤ 12
Roof	2.375	≤ 4
Windshield	0.375	≤ 3
Side Window	Intact	No shattering resulting from contact with structural member of test article
Dash	N/A	N/A

N/A – Not applicable

7.6 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 16. It is important to note that in these tests, the impulse on the vehicle was relatively small and of short duration. Thus, *x* and *y* in the flail-space model were less than 2 ft and 1 ft, respectively, during the period when the vehicle was in contact with each system. As specified in Section A5.5.2 of MASH 2016, in such cases, it was recommended that the OIV be set equal to the vehicle's change in velocity that occurs during contact with the test article, or parts thereof [1]. If parts of the test article remain with the vehicle after impact, the vehicle's change in velocity should be computed at the time the vehicle clears the footing or foundation of the test article. For each of the three tests, the OIV, or in this case, the vehicle change in velocity, was reported at the time in which the vehicle cleared the footings.

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 16. The results of the occupant risk analysis, as determined from accelerometer data, are summarized in Figures 44 through 46. The recorded data from the accelerometers and rate transducers are shown graphically in Appendix G.

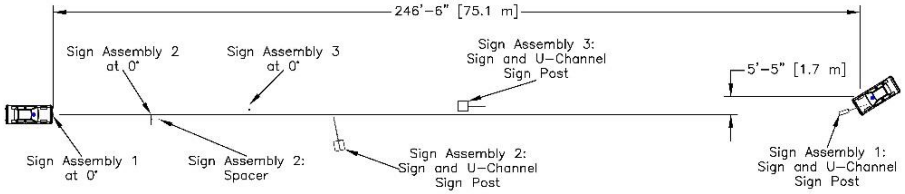
Table 16. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. UCSS-1

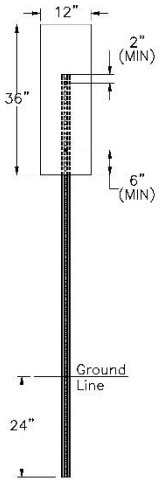
Evaluation Criteria		Transducer Data			MASH 2016 Limits
		Test No. UCSS-1A	Test No. UCSS-1B	Test No. UCSS-1C	
OIV ft/s	Longitudinal	-1.70	-4.47	-2.41	±16
	Lateral	0.05	0.10	-0.46	not required
ORA g's	Longitudinal	N/A	N/A	N/A	±20.49
	Lateral	N/A	N/A	N/A	±20.49
MAX. ANGULAR DISPL. deg.	Roll	0.7	-0.5	-1.9	±75
	Pitch	-0.3	0.9	-0.4	±75
	Yaw	-0.1	1.4	-0.7	not required
THIV ft/s		9.87	11.39	11.02	not required
PHD g's		0.29	0.26	0.69	not required
ASI		0.08	0.13	0.11	not required

Note: SLICE-2 was the designated primary transducer for test no. UCSS-1, but its equipment did not trigger. Data is from SLICE-1. The vehicle cleared the footings at 0.146 sec, 0.154 sec, and 0.156 sec after impact for test nos. UCSS-1A, UCSS-1B, and UCSS-1C, respectively, which was used to determine vehicle change in velocity, denoted as OIV.
N/A – Not Applicable

7.7 Discussion

Analysis of the results for test no. UCSS-1 showed that the systems readily activated in a predictable manner when impacted by the 1100C vehicle. A summary of the test results and sequential photographs are shown in Figures 44 through 46. Detached elements, fragments, or other debris from the test articles 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 remained upright during and after impacts. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix G, were deemed acceptable because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle traversed the foundations and continued forward until it stopped downstream of the systems. Therefore, test nos. UCSS-1A and UCSS-1C were determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-61. However, since System A contacted and interfered with System B prior to the test vehicle contact, test no. UCSS-1B was ruled inconclusive.



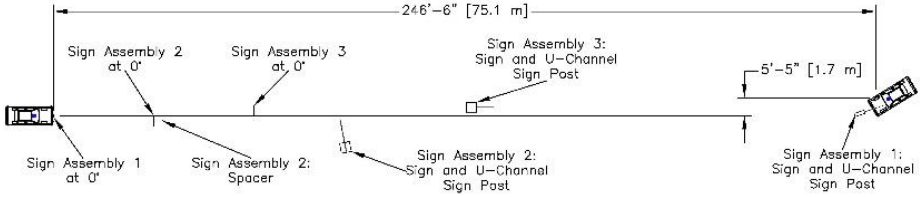


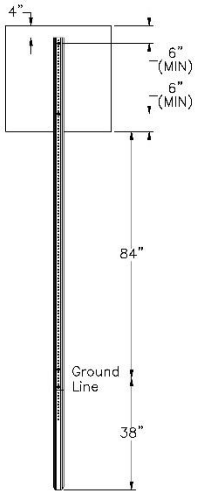
- Test Agency ..... MwRSF
- Test Number UCSS-1A
- Date ..... September 26, 2018
- MASH 2016 Test Designation No. 3-61
- Test Article ..... 4-ft Tall Object Marker
- Key Component – U-channel Sign Support
  - Weight ..... 1.12 lb/ft
  - Length ..... 96 in.
  - Height to Bottom of Sign ..... 4 ft
- Key Component – Aluminum Sign
  - Length ..... 36 in.
  - Width ..... 12 in.
  - Depth ..... 0.08 in.
- Soil Type
- Vehicle Make /Model ..... 2009 Toyota Yaris
  - Curb ..... 2,312 lb
  - Test Inertial ..... 2,395 lb
  - Gross Static ..... 2,557 lb
- Impact Conditions
  - Speed ..... 67.1 mph
  - Angle ..... 0 deg.
  - Impact Location ..... Centerline of front bumper
- Kinetic Energy ..... 360.1 kip-ft > 286.1 kip-ft
- Exit Conditions
  - Speed ..... 65.9 mph
  - Angle ..... 0 deg.
- Vehicle Stability ..... Satisfactory
- Vehicle Stopping Distance ..... 246.5 ft
- Vehicle Damage ..... Minimal
  - VDS [16] 12-FC-1
  - CDC [17] 12FCEN5
  - Maximum Interior Deformation ..... 0.375 in.
- Test Article Damage ..... Severe
- Transducer Data

Evaluation Criteria		Transducer SLICE-1	MASH 2016 Limit
OIV ft/s	Longitudinal	-1.70	±16
	Lateral	0.05	Not required
ORA g's	Longitudinal	N/A	±20.49
	Lateral	N/A	±20.49
MAX ANGULAR DISP. deg.	Roll	0.7	±75
	Pitch	-0.3	±75
	Yaw	-0.1	Not required
THIV – ft/s		3.01	Not required
PHD – g's		0.29	Not required
ASI		0.08	Not required

N/A – Not Applicable

Figure 44. Summary of Test Results and Sequential Photographs, Test No. UCSS-1A





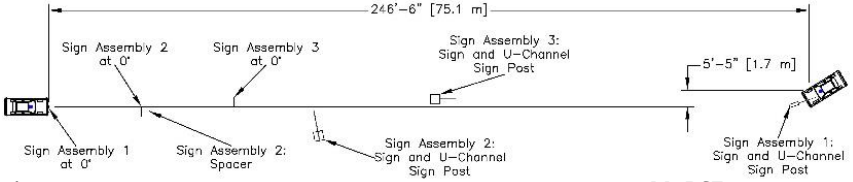
- Test Agency ..... MwRSF
- Test Number UCSS-1B
- Date ..... September 26, 2018
- MASH 2016 Test Designation No. 3-61
- Test Article ..... 7-ft Tall Warning Sign
- Key Component – U-channel Sign Support
  - Weight ..... 4 lb/ft
  - Length ..... 120 in.
  - Height to Bottom of Sign ..... 7 ft
- Key Component – Aluminum Sign
  - Length ..... 36 in.
  - Width ..... 36 in.
  - Depth ..... 0.08 in.
- Soil Type
- Vehicle Make /Model ..... 2009 Toyota Yaris
  - Curb ..... 2,312 lb
  - Test Inertial ..... 2,395 lb
  - Gross Static ..... 2,557 lb
- Impact Conditions
  - Speed ..... 65.5 mph
  - Angle ..... 0 deg.
  - Impact Location ..... Right quarter point of front bumper
- Kinetic Energy ..... 343.8 kip-ft > 286.1 kip-ft
- Exit Conditions
  - Speed ..... 62.4 mph
  - Angle ..... 0 deg.
- Vehicle Stability ..... Satisfactory
- Vehicle Stopping Distance ..... 246.5 ft
- Vehicle Damage ..... Minimal
  - VDS [16] 12-FC-1
  - CDC [17] 12FCEN5
  - Maximum Interior Deformation ..... 2.375 in.
- Test Article Damage ..... Severe
- Transducer Data

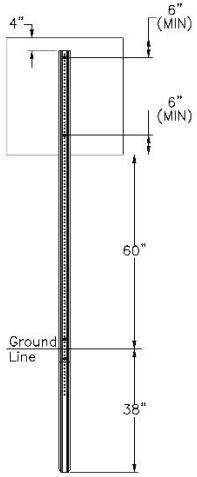
Evaluation Criteria		Transducer SLICE-1	MASH 2016 Limit
OIV ft/s	Longitudinal	-4.47	±16
	Lateral	-0.10	Not required
ORA g's	Longitudinal	N/A	±20.49
	Lateral	N/A	±20.49
MAX ANGULAR DISP. deg.	Roll	-0.5	±75
	Pitch	0.9	±75
	Yaw	1.4	Not required
THIV – ft/s		11.39	Not required
PHD – g's		0.26	Not required
ASI		0.13	Not required

N/A – Not Applicable

Figure 45. Summary of Test Results and Sequential Photographs, Test No. UCSS-1B

0.000 sec 0.030 sec 0.060 sec 0.090 sec 0.120 sec





- Test Agency ..... MwRSF
- Test Number UCSS-1C
- Date ..... September 26, 2018
- MASH 2016 Test Designation No. 3-61
- Test Article ..... 5-ft Tall Warning Sign
- Key Component – U-Channel Sign Support
  - Weight ..... 4 lb/ft
  - Length ..... 96 in.
  - Height to Bottom of Sign ..... 5 ft
- Key Component – Aluminum Sign
  - Length ..... 36 in.
  - Width ..... 36 in.
  - Depth ..... 0.08 in.
- Soil Type
- Vehicle Make /Model ..... 2009 Toyota Yaris
  - Curb ..... 2,312 lb
  - Test Inertial ..... 2,395 lb
  - Gross Static ..... 2,557 lb
- Impact Conditions
  - Speed ..... 61.5 mph
  - Angle ..... 0 deg.
  - Impact Location ..... Left quarter point of front bumper
- Kinetic Energy ..... 302.9 kip-ft > 286.1 kip-ft
- Exit Conditions
  - Speed ..... 59.9 mph
  - Angle ..... 0 deg.
- Vehicle Stability ..... Satisfactory
- Vehicle Stopping Distance ..... 246.5 ft
- Vehicle Damage ..... Minimal
  - VDS [16] 12-FC-1
  - CDC [17] 21FCEN5
  - Maximum Interior Deformation ..... 2.375 in.
- Test Article Damage ..... Severe
- Transducer Data

Evaluation Criteria		Transducer SLICE-1	MASH 2016 Limit
OIV ft/s	Longitudinal	-2.41	±16
	Lateral	-0.46	Not required
ORA g's	Longitudinal	N/A	±20.49
	Lateral	N/A	±20.49
MAX ANGULAR DISP. deg.	Roll	-1.9	±75
	Pitch	-0.4	±75
	Yaw	-0.7	Not required
THIV – ft/s		11.02	Not required
PHD – g's		0.69	Not required
ASI		0.11	Not required

N/A – Not Applicable

Figure 46. Summary of Test Results and Sequential Photographs, Test No. UCSS-1C

8 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Previous full-scale crash testing and dynamic component testing of various U-channel support configurations were reviewed to help identify critical sign configurations. Testing was conducted on systems with various panel mounting heights and post weights and included head-on impacts as well as impacts to the right or left quarter points. Out of these 22 tests, four of them failed due to the excessive deformation to the vehicle's roof and excessive occupant risk. Based on a survey from fourteen states, some common system configurations were prioritized for this test, with the primary features summarized in Table 8.

The research scope included the development of a bogie vehicle to be utilized in the MASH compliance evaluation of the selected sign configurations. Thus, a full-scale MASH test designation no. 3-61 crash test was conducted to provide baseline data to validate the bogie vehicle. The background and full-scale crash test are detailed herein.

Test no. UCSS-1 was conducted with three U-channel sign supports in accordance with MASH 2016 test designation no. 3-61. System A had a 1.12-lb/ft U-channel support with a 36-in. tall x 12-in. wide sign mounted at 4 ft above the ground line. System B had a 4-lb/ft U-channel support with a 36-in. tall x 36-in. wide sign mounted at 7 ft above the ground line, with a lap splice near the ground line. System C had a 4-lb/ft U-channel support with a 36-in. tall x 36-in. wide sign mounted at 5 ft above the ground line, with a lap splice near the ground line. System A contacted the vehicle at its centerline, System B was impacted by the vehicle at its right-front bumper, and System C was impacted by the vehicle's left-front bumper. A summary of the test results is shown in Table 17. The systems were installed 30 ft apart in compacted crushed limestone, alternatively classified as well-graded gravel, on level terrain. During the test, a 2,395-lb small car impacted and disengaged all support structures from the ground. Detached elements and fragments did not show potential for penetrating the occupant compartment nor present an undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle remained upright during and after the collisions. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix G, were deemed acceptable as they did not adversely influence occupant risk nor cause rollover. Therefore, test nos. UCSS-1A and UCSS-1C were determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-61. However, since System A contacted and interfered with System B prior to the test vehicle contact, test no. UCSS-1B was ruled inconclusive. All other testing criteria for test no. UCSS-1B was satisfactory. However, it is recommended that this test be repeated to obtain conclusive test results.

The stub height remaining after an impact is of potential concern for vehicle override and undercarriage contact. For both systems B and C, the ground stub did not rotate or experience uplift. Thus, the stub height (top of the ground stub) was not changed from approximately 4 in. This result within the LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals [18] 4 in. recommendation for sign supports after an impact. As well, the impact configurations selected for systems B and C were selected because they represented the most common configuration for U-channel sign supports on roadsides, such that the post flanges were on the upstream side of impact. This configuration is also the standard, recommended orientation. Previous research has indicated that the sign supports perform approximately the same in both orientations, fracturing near the top of the ground stub.

MASH 2016 requires three full-scale crash tests to fully verify a sign support system. MASH test designation no. 3-60 is a 19-mph, small car impact used to determine if the support will activate the breakaway, fracture, or yielding mechanism in the support. MASH test designation nos. 3-61 and 3-62 are 62-mph impacts used to evaluate the behavior of the system during high-speed collisions by 1100C small car and 2270P pickup truck, respectively. MASH test designation no. 3-61 was conducted successfully on Systems A and C. MASH test designation nos. 3-60 and 3-62 should be conducted to complete the TL-3 testing matrix for these sign supports. Dynamic bogie tests will be completed on additional U-channel sign supports and will be reported in a forthcoming report.

Table 17. Summary of Safety Performance Evaluation

Evaluation Factors	Evaluation Criteria	Test No. UCSS-1A	Test No. UCSS-1B	Test No. UCSS-1C
Structural Adequacy	B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	S	S	S
Occupant Risk	D. 1. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	S	S	S
	2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.	S	S	S
	F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 deg.	S	S	S
	H. Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:	S	S	S
	Occupant Impact Velocity Limits			
	Component / Preferred / Maximum			
	Longitudinal / 10 ft/s / 16 ft/s			
	I. The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:	S	S	S
	Occupant Ridedown Acceleration Limits			
	Component / Preferred / Maximum			
	Longitudinal and Lateral / 15.0 g's / 20.49 g's			
Post-Impact Vehicular Response	N. Vehicle trajectory behind the test article is acceptable.	S	S	S
MASH 2016 Test Designation No.		3-61	3-61	3-61
Final Evaluation (Pass/Fail)		Pass	Inconclusive*	Pass

S – Satisfactory U – Unsatisfactory N/A – Not Applicable *Inconclusive due to interference from System A

9 REFERENCES

1. *Manual for Assessing Safety Hardware (MASH), Second Edition*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2016.

2. Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program (NCHRP) Report No. 230, Transportation Research Board, Washington, D.C., March 1981.

3. Ross, H.E., Sicking, D.L., Zimmer, R.A., and Michie, J.D., *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features*, TRB, National Research Council, Washington, D.C., 1993.

4. Bush, M.S., Marzougui, D., *NCHRP Project 03-119: Application of MASH Test Criteria to Breakaway Sign and Luminaire Supports and Crashworthy Work-Zone Traffic Control Devices*, George Mason University, 2019.

5. Ross, H.E., Sicking, D.L., Campise, W.L., Zimmer, R.A., *Small Sign Support Analysis*, Texas Transportation Institute, College Station, Texas, August 1988.

6. American Association of State Highway and Transportation Officials (AASHTO), *Standard Specifications/or Structural Supports/or Highway Signs, Luminaires, and Traffic Signals*, 1994.

7. Bullard, D.L., *Evaluation of the Crash Worthiness of the Florida Thin Walled Aluminum Tube and Steel U-Channel Sign Supports*, Texas Transportation Institute, College Station, Texas, February 1992.

8. Bligh, R.P., Bullard, D.L., Menges, W.L., and Schoenman, S.K., *Impact Performance Evaluation of Work Zone Traffic Control Devices*, Texas Transportation Institute, College Station, Texas, December 2000.

9. Allington, C. and Williamson, C., *NCHRP 350 Compliance Test 3-62 on Nucor Lap Splice U-Channel Support System*, Holmes Solutions, Christchurch, New Zealand, February 2009.

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

11. Bullard, D.L., *NCHRP Project 22-14(03): Evaluation of Existing Roadside Safety Hardware Using Manual for Assessing Safety Hardware (MASH)*, Texas A&M Research Foundation, 2010.

12. Hinch, J., Yang, T.L., and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, Virginia, 1986.

13. AASHTO, "Clarifications on Implementing the AASHTO *Manual for Assessing Safety Hardware*, 2016", March 24, 2020. https://design.transportation.org/wp-content/uploads/sites/21/2020/03/Clarifications-on-Implementing-MASH-2016-aka-MASH-QA-Updated-Mar-24-2020.pdf

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

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

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

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

18. AASHTO, *LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, 2015 with updates in 2017, 2018, and 2019.

10 APPENDICES

Appendix A. Data from Previous U-Channel Testing

Table A-1. Data from Previous U-Channel Testing

Test No.	Designation	Vehicle Designation	Post Weight, lb/ft	Sign Panel Dimensions, ft	Lower Panel Height(s), in.	Impact Location	Stub Orientation	Soil Type	Pass/ Fail
7024-7	NCHRP 230 63	1800S	3	2 x 2½	5	15 in. left of centerline	Reverse	Standard	Pass
7024-8	NCHRP 230 62	1800S	3	2 x 2½	5	15 in. right of centerline	Reverse	Standard	Pass
7024-13	NCHRP 230 63	1800S	4	2 x 2½	5	15 in. left of centerline	Reverse	Standard	Pass
7185-3	NCHRP 230 62	1800S	4	2 x 3	7	Left quarterpoint	Reverse	Weak	Pass
7185-4	NCHRP 230 63	1800S	4	2 x 3	7	Right quarterpoint	Reverse	Weak	Pass
7185-5	NCHRP 230 62	1800S	4	2 x 3	7	Left quarterpoint	Reverse	Standard	Pass
7185-6	NCHRP 230 63	1800S	4	2 x 3	7	Right quarterpoint	Reverse	Standard	Pass
7185-7	NCHRP 230 62	1800S	4	2 x 3	7	Left quarterpoint	Reverse	Weak	Pass
7185-8	NCHRP 230 63	1800S	4	2 x 3	7	Right quarterpoint	Reverse	Weak	Pass
7185-9	NCHRP 230 62	1800S	4	2 x 3	7	Right quarterpoint	Reverse	Standard	Pass
7185-10	NCHRP 230 63	1800S	4	2 x 3	7	Left quarterpoint	Reverse	Standard	Fail
7185-11	NCHRP 230 62	1800S	4	2 x 3	7	Left quarterpoint	Normal	Weak	Pass
7185-12	NCHRP 230 63	1800S	4	2 x 3	7	Right quarterpoint	Normal	Weak	Pass
7185-13	NCHRP 230 62	1800S	4	2 x 3	7	Left quarterpoint	Normal	Standard	Pass
7185-14	NCHRP 230 63	1800S	4	2 x 3	7	Right quarterpoint	Normal	Standard	Pass
7185-15	NCHRP 230 62	1800S	4	2 x 3	7	Left quarterpoint	Normal	Standard	Pass
7185-16	NCHRP 230 63	1800S	4	2 x 3	7	Right quarterpoint	Normal	Standard	Pass
7185-17	NCHRP 230 62	1800S	4	2 x 3	7	Left quarterpoint	Normal	Weak	Pass
7185-18	NCHRP 230 63	1800S	4	2 x 3	7	Right quarterpoint	Normal	Weak	Fail
417292-3	NCHRP 350 3-71	820C	2	2 x 3	4	Right quarterpoint	N/A	Standard	Fail
2-362	MASH 3-62	2270P	4	1 x 1 3 x 3	5 ft –11 in. 7 ft	Centerline	Normal	Standard	Fail
RF476460-1-2	MASH 3-62	2270P	4	3 x 3	7	Left quarterpoint	Normal	Standard	Pass

Appendix B. U-Channel Sign Support Survey

Name: _____

State: _____

Email Address: _____

The Midwest Pooled Fund Program sponsored a project in Year 28 (2017-2020) to evaluate single, steel, U-Channel Sign Supports to MASH TL-3 (60 mph speeds). We have categorized these sign supports into two general categories:

(1) delineators [such as mile marker and reference location signs, object markers, or reflectors (without a sign) that have a typical minimum bottom of sign panel height around 4 ft] and

(2) other smaller signs [such as speed limit or highway designator signs and may include clustered sign panels that have a typical minimum bottom of sign panel height of 5 to 7 ft].

Examples of these systems are shown below.

1. Are you currently using U-Channel Sign Supports (delineators, mile markers, or other smaller signs such as speed limit or highway designator signs)?
   - ☐ Yes
   - ☐ No
2. Are you interested in using U-Channel Sign Supports (delineators, mile markers, or other smaller signs such as speed limit or highway designator signs) in the future?
   - ☐ Yes
   - ☐ No
3. Do you want to provide input on which sign supports will be evaluated with this Pooled Fund project?
   - ☐ Yes, I want to provide input for this Pooled Fund project. Please continue with survey
   - ☐ No, I do not want to provide input for this Pooled Fund project. Please stop here and submit

Figure B-1. U-Channel Sign Support Survey Questions, Page 1

SMALL DELINEATORS (SUCH AS MILE MARKERS OR REFLECTORS, TYPICALLY 4 FT TO BOTTOM OF SIGN OR REFLECTOR)

4. Do you use U-channel sign support for small delineators?
   - ☐ Yes, please answer questions 5-9
   - ☐ No, please skip questions 5-9
5. What supplier do you purchase from for U-channel delineators? You may select multiple.
   - ☐ Franklin Industries
   - ☐ Nucor Steel Marion (Rib-bak)
   - ☐ Chicago Heights Steel
   - ☐ Other _____
   - ☐ Unknown
6. What weight/foot U-channel do you utilize for delineators? You may select multiple.
   - ☐ 1.12 lb/ft ☐ 3 lb/ft
   - ☐ 2 lb/ft ☐ 4 lb/ft
   - ☐ 2.5 lb/ft
   - ☐ Other _____
   - ☐ Unknown
7. Do you use sign panels (such as mile marker or object marker signs) with U-channel delineators?
   - ☐ Yes. Please answer 7a and 7b.
     - 7a. If yes, What is the typical height to bottom of sign panel for U-channel delineators?
       - ☐ 4 ft
       - ☐ 5 ft
       - ☐ Other _____
     - 7b. If yes, What is the typical sign panel size for U-channel delineators? You may select multiple.
       - ☐ 10 in. x 24 in. ☐ 12 in. x 24 in.
       - ☐ 10 in. x 36 in. ☐ 12 in. x 36 in.
       - ☐ 10 in. x 48 in. ☐ 12 in. x 48 in.
       - ☐ 6 in. x 12 in. ☐ 18 in. x 18 in.
   - ☐ No, it only has a reflector
8. Do you use spliced U-channel (lapped, slipbase, etc.) with delineators?
   - ☐ Yes, lapped near groundline
   - ☐ Yes, lapped near middle of post or bottom of sign
   - ☐ No
   - ☐ Other: _____
   - ☐ Unknown
9. Do you mount U-channel delineators in concrete or soil?
   - ☐ Only soil
   - ☐ Only concrete
   - ☐ Both

OTHER SIGN SUPPORTS (SUCH AS SPEED LIMIT OR HIGHWAY DESIGNATOR SIGNS, TYPICALLY 5 FT OR 7 FT TO BOTTOM OF SIGN PANEL)

10. Do you use U-channel sign support for other sign supports?
    - ☐ Yes, please answer questions 11-16
    - ☐ No, please skip questions 11-16
11. What supplier do you purchase from for other U-channel sign supports? You may select multiple.
    - ☐ Franklin Industries
    - ☐ Nucor Steel Marion (Rib-bak)
    - ☐ Chicago Heights Steel
    - ☐ Other _____
    - ☐ Unknown
12. What weight/foot U-channel do you utilize for other sign supports? You may select multiple.
    - ☐ 1.12 lb/ft ☐ 3 lb/ft
    - ☐ 2 lb/ft ☐ 4 lb/ft
    - ☐ 2.5 lb/ft
    - ☐ Other _____
    - ☐ Unknown
13. What is the typical bottom of sign panel height for other U-channel sign supports? You may select multiple.
    - ☐ 5 ft
    - ☐ 7 ft
    - ☐ Greater than 7 ft
    - ☐ Other _____
    - ☐ Unknown
14. What is the typical single sign panel size or total clustered panel size (width x height) for other U-channel sign supports? You may select multiple.
    - ☐ 18 in. x 18 in. ☐ 30 in. x 30 in. ☐ 42 in. x 30 in.
    - ☐ 18 in. x 24 in. ☐ 30 in. x 36 in. ☐ 48 in. x 48 in.
    - ☐ 24 in. x 24 in. ☐ 36 in. x 24 in. ☐ 48 in. x 60 in.
    - ☐ 24 in. x 30 in. ☐ 36 in. x 36 in. ☐ 54 in. x 18 in.
    - ☐ 24 in. x 36 in. ☐ 36 in. x 48 in. ☐ 60 in. x 60 in.
    - ☐ Other _____
15. Do you use spliced U-channel (lapped, slipbase, etc.) with other small U-channel sign supports?
    - ☐ Yes, lapped near groundline
    - ☐ Yes, lapped near middle of post or bottom of sign
    - ☐ No
    - ☐ Other: _____
    - ☐ Unknown
16. Do you mount other small U-channel signs in concrete or soil?
    - ☐ Only soil
    - ☐ Only concrete
    - ☐ Both

Figure B-2. U-Channel Sign Support Survey Questions, Page 2

17. Please provide two single, U-channel sign configuration that is the highest need for your state:

1st Sign Configuration

U-channel weight per foot: _____

Height to bottom of sign: _____

Sign panel size: _____

Splice Used?: ☐ Yes, Please Describe: _____

☐ No, directly buried in ground

2nd Sign Configuration

U-channel weight per foot: _____

Height to bottom of sign: _____

Sign panel size: _____

Splice Used?: ☐ Yes, Please Describe: _____

☐ No, directly buried in ground

18. Please provide any additional comments that you feel would be important to the project.

Figure B-3. U-Channel Sign Support Survey Questions, Page 3

Appendix C. Material Specifications

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

Item No.	Description	Material Specification	Reference
a1	1.12 lb/ft Franklin U-Channel Sign Post, 96 in. Long	ASTM A499 Gr. 60	PO#E000562398 Grainger COC
a2	4.00 lb/ft Franklin U-Channel Sign Post, 120 in. Long	ASTM A499 Gr. 60	PO#1543 Franklin Industries COC
a3	4.00 lb/ft Franklin U-Channel Sign Post, 96 in. Long	ASTM A499 Gr. 60	PO#1543 Franklin Industries COC
a4	4.00 lb/ft Franklin U-Channel Sign Post, 42 in. Long	ASTM A499 Gr. 60	PO#1543 Franklin Industries COC
b1	36 in. x 12 in. x 0.08 in. Sign with Reflective Sheeting	3M Engineer Grade Reflective Alum	Smart Sign COC RTS-143048
b2	36 in. x 36 in. x 0.08 in. Sign with Reflective Sheeting	3M Engineer Grade Reflective Alum	Smart Sign COC RTS-143551
c1	$^{5}/_{16}$ in.-18 UNC, 1¾ in. Long Hex Bolt	SAE J429 Gr. 9	P#11540782 C#486338 H#10449870
c2	$^{5}/_{16}$ in.-18 UNC, 2¼ in. Long Hex Bolt	SAE J429 Gr. 9	H#10242060 P#11540736 C#469737
c3	$^{5}/_{16}$ in.-18 UNC, 2¾ in. Long Hex Bolt	SAE J429 Gr. 9	P#464179 C#11540737 H#10229550
c4	$^{5}/_{16}$ in.-18 UNC Heavy Hex Nut	SAE J995 Gr. 9	P.O.#110233073 P#11541092 H#10463770
c5	$^{5}/_{16}$-in. Dia. Plain Round Washer	ASME B18.18-2017	P#1133006 C#210149350 COC
c6	⅜-in. Dia. Lock Washer	ASME B 18.21.1-2009	P#1133620 C#210150709 H#F790006793
c7	Round Spacer, Steel, Zinc Plated Finish, ⅜ in. Screw Size, ¾ in. OD, 0.38 in. ID, ½ in. Length	Steel	ASIN: B009YLXKQC

GRAINGER
FOR THE ONES WHO GET IT DONE

Certificate of Conformance

W.W. Grainger, Inc.
100 Grainger Parkway
Lake Forest, IL. 60045-5201

September 17 2018

Attn: SHAUN M TIGHE
SHAUN M TIGHE
CANFIELD ADMINISTRATION
BLDG
LINCOLN, NE, 68588-0439

Fax #

Grainger Sales Order #: 1331380123
Customer PO #: E000562398

Dear SHAUN M TIGHE
As you requested, we are providing you with the following information. We certify that, to the best of Grainger's actual knowledge, the products described below conform to the respective manufacturer's specifications as described and approved by the manufacturer.

Item #	Description	Vendor Part #	Catalog Page #	Order Quantity
39F187	Post,U Channel,Green,8 ft.	054-00014	1834	2.000

Shea Gallup
Process Management Analyst
Compliance Team
Grainger Industrial Supply

Figure C-1. 96-in. Long Franklin U-Channel Sign Post, Test No. UCSS-1

Franklin Industries

CERTIFICATE OF COMPLIANCE

July 12, 2018

Sanbar Construction
9101 Broadway SE
Albuquerque, NM 87105

RE: Customer Purchase Order No: 1543
Franklin Industries' Folio No: H5018
Franklin Industries' Product: 7', 1.12lb. per ft. 10', 11', 3'6, 3lb. per ft. green u channel post.

We hereby certify that all posts manufactured by Franklin Industries Co are hot rolled and fabricated in Franklin, Pennsylvania and have been produced from recycled Standard T rails weighing 91 lbs. / yard or heavier, complying with ASTM specification A499-89, Grade 60. Standard T rails used for products subject to "Buy America" requirements were produced according to ASTM A1 from rails melted and rolled in the United States of America.

Yours truly,

Darlene Suttle
Customer Service/Sales

PO Box 671 Franklin, PA 16323
Sales Office 814.437.3726
Fax 814.432.7556

Figure C-2. 120-in. Long Franklin U-Channel Sign Post, Test No. UCSS-1

Franklin Industries

CERTIFICATE OF COMPLIANCE

July 12, 2018

Sanbar Construction
9101 Broadway SE
Albuquerque, NM 87105

RE: Customer Purchase Order No: 1543
Franklin Industries' Folio No: H5018
Franklin Industries' Product: 7', 1.12lb. per ft. 10', 11', 3'6, 3lb. per ft. green u channel post.

We hereby certify that all posts manufactured by Franklin Industries Co are hot rolled and fabricated in Franklin, Pennsylvania and have been produced from recycled Standard T rails weighing 91 lbs. / yard or heavier, complying with ASTM specification A499-89, Grade 60. Standard T rails used for products subject to "Buy America" requirements were produced according to ASTM A1 from rails melted and rolled in the United States of America.

Yours truly,

Darlene Suttle
Customer Service/Sales

PO Box 671 Franklin, PA 16323
Sales Office 814.437.3726
Fax 814.432.7556

Figure C-3. 96-in. Long Franklin U-Channel Sign Post, Test No. UCSS-1

Franklin Industries

CERTIFICATE OF COMPLIANCE

July 12, 2018

Sanbar Construction
9101 Broadway SE
Albuquerque, NM 87105

RE: Customer Purchase Order No: 1543
Franklin Industries' Folio No: H5018
Franklin Industries' Product: 7', 1.12lb. per ft. 10', 11', 3'6, 3lb. per ft. green u channel post.

We hereby certify that all posts manufactured by Franklin Industries Co are hot rolled and fabricated in Franklin, Pennsylvania and have been produced from recycled Standard T rails weighing 91 lbs. / yard or heavier, complying with ASTM specification A499-89, Grade 60. Standard T rails used for products subject to "Buy America" requirements were produced according to ASTM A1 from rails melted and rolled in the United States of America.

Yours truly,

Darlene Suttle
Customer Service/Sales

PO Box 671 Franklin, PA 16323
Sales Office 814.437.3726
Fax 814.432.7556

Figure C-4. 42-in. Long Franklin U-Channel Sign Post, Test No. UCSS-1

SmartSign

300 Cadman Plaza West, ste 1303
Brooklyn NY 11201
Phone: 1-800-952-1457

9/11/18

CERTIFICATE OF COMPLIANCE

Smartsign hereby certifies that all materials supplied against purchase order RTS-143048 shipped on 9/10/18 conforms to the material and/ or manufacturing specifications as called on this said purchase order without expectations.

Item #
X-OM-3L

Description:
Type 3 Object Marker

Sincerely,

Tahyna Colon
Call Center Manager
tahyna@smartsign.com
800-952-1457 x 7140

Figure C-5. 36-in. x 12-in. x 0.08-in. Sign with Reflective Sheeting, Test No. UCSS-1

SmartSign

300 Cadman Plaza West, ste 1303
Brooklyn NY 11201
Phone: 1-800-952-1457

9/18/18

CERTIFICATE OF COMPLIANCE

Smartsign hereby certifies that all materials supplied against purchase order PO: RTS-143551, shipped on 9/17/18 conforms to the material and/ or manufacturing specifications as called on this said purchase order without expectations.

Item #
X-R5-1

Description: Do not Enter, [Engineer Grade Reflective Aluminum Sign, 80 mil

Sincerely,

Tahyna Colon
Call Center Manager
tahyna@smartsign.com
800-952-1457 x 7140

Figure C-6. 36-in. x 36-in. x 0.08-in. Sign with Reflective Sheeting, Test No. UCSS-1

61 Barnes Industrial Park North
Wallingford, Connecticut 06492
(203) 284-7023

CERTIFIED MATERIAL TEST REPORT : EN 10204 3.1

Certified Number	:	486338	**Date Issued**	:	September 19, 2018
Customer	:	Fastenal,	**Manufacturing date**	:	August 25, 2017
		4730 Service Drive	**SHOP Part Number**	:	11540782
		Winona, MN 57987	**Purchase Order**	:	350020074
			Holo Code	:	N/A
Manufacturer	:	Holo-Krome	**Grade**	:	9
		61 Barnes Industrial Park North	**Material**	:	8640
		Wallingford, CT 06492	**Finish**	:	ECOGUARD®
			Order Quantity	:	5,000 Pcs
Customer Part Number	:	11540782	**Production Lot Size**	:	5,000 Pcs
Description	:	5/16"-18 x 1-3/4" Holo-Krome® Hex Cap Screw			
Thread Designation	:	UNRC-2A	**Marking**	:	H-K ; G9 ; '9 radial lines'

CHEMISTRY – Heat Number: 10449870
Heat Composition (WT% Heat Analysis)

Element:	C	P	S	Cr	Mn	Mo	Ni	Si
Result:	0.39	0.010	0.010	0.42	0.84	0.22	0.42	0.21

MACROETCH (if required): N/A

SURFACE QUALITY: In accordance with ASTM F788/F788M-13	PASS
COATING: ECOGUARD®	PASS

Heat Treat Method:	Quenched and Tempered				
Mechanical Properties: In accordance with ASTM A574-17					
Attribute	**Test Method**	**Sample Size**	**Requirement**	**Result**	**Acceptance**
Core Hardness	ASTM F606/F606M-16	4	38 – 42 HRC	41 – 42 HRC	PASS
Proof Load	ASTM F606/F606M-16	3	Min : 140,650 PSI	PASS	PASS
6° Wedge Tensile	ASTM F606/F606M-16	3	Min : 180,000 PSI	189,126 – 190,025 PSI	PASS
Decarburization/Carburization	ASTM F2328-17	3	NO COLOR	PASS	PASS

January 6, 2016

Figure C-7. $^{5}/_{16}$-in.-18 UNC, 1¾-in. Long Hex Bolt, Page 1, Test No. UCSS-1

61 Barnes Industrial Park North
Wallingford, Connecticut 06492
(203) 284-7023

DIMENSIONAL INSPECTION: Per H-K Dimension Inspection Drawing Plan : S12150-3 REV B
SAMPLING PLAN : Per ASME B18.18-17

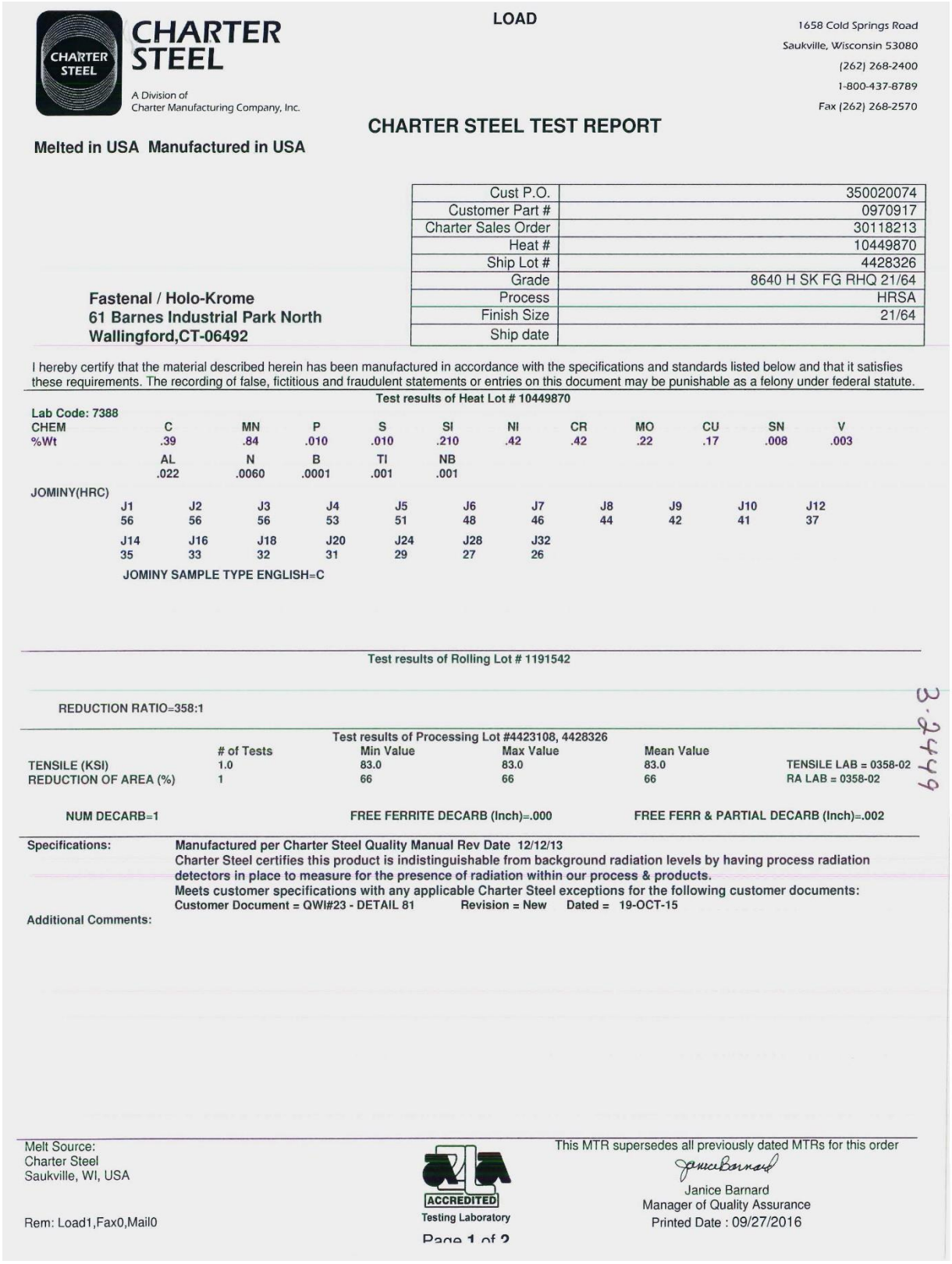
Characteristics	DIMENSION DATA		UNIT	SAMPLE SIZE	RESULT		ACCEPTANCE
	MIN	MAX			MIN	MAX	
Width Across Flat	0.489	0.499	INCH	3	0.492	0.493	PASS
Width Across Corner	0.557	-	INCH	3	0.562	0.565	PASS
Head Height	0.227	0.241	INCH	7	0.228	0.234	PASS
Washer Diameter	0.450	0.499	INCH	3	0.472	0.474	PASS
Washer Height	0.015	0.025	INCH	7	0.019	0.020	PASS
Body Length	0.600	-	INCH	7	0.738	0.739	PASS
Grip Length	-	0.875	INCH	7	0.850	0.852	PASS
Total Length	1.710	1.750	INCH	7	1.726	1.730	PASS
Major Diameter	0.3026	0.3113	INCH	7	0.3070	0.3084	PASS
Thread	5/16"-18 UNRC-2A		INCH	7	PASS	PASS	PASS

Compliancy Statement:
All products as indicated in the test report above, conforms to the above requirement.
All manufacturing Operations & Processes performed in the United States of America.
Products meets RoHs & DFARS requirement, Mercury was not used during the manufacture of this product.

Comments:

Muhammad Luqman Azmi
Quality Assurance Dept.

Figure C-8. $^{5}/_{16}$-in.-18 UNC, 1¾-in Long Hex Bolt, Page 2, Test No. UCSS-1



CHARTER STEEL
A Division of
Charter Manufacturing Company, Inc.

LOAD

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

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Cust P.O.	350020074
Customer Part #	0970917
Charter Sales Order	30118213
Heat #	10449870
Ship Lot #	4428326
Grade	8640 H SK FG RHQ 21/64
Process	HRSA
Finish Size	21/64
Ship date	

Fastenal / Holo-Krome
61 Barnes Industrial Park North
Wallingford,CT-06492

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

Test results of Heat Lot # 10449870

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.39	.84	.010	.010	.210	.42	.42	.22	.17	.008	.003
	AL	N	B	TI	NB						
	.022	.0060	.0001	.001	.001						

JOMINY(HRC)

J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J12
56	56	56	53	51	48	46	44	42	41	37

J14	J16	J18	J20	J24	J28	J32
35	33	32	31	29	27	26

JOMINY SAMPLE TYPE ENGLISH=C

Test results of Rolling Lot # 1191542

REDUCTION RATIO=358:1

3.2449

Test results of Processing Lot #4423108, 4428326

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE (KSI)	1.0	83.0	83.0	83.0	TENSILE LAB = 0358-02
REDUCTION OF AREA (%)	1	66	66	66	RA LAB = 0358-02

NUM DECARB=1 FREE FERRITE DECARB (Inch)=.000 FREE FERR & PARTIAL DECARB (Inch)=.002

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 12/12/13
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = QWI#23 - DETAIL 81 Revision = New Dated = 19-OCT-15

Additional Comments:

Melt Source:
Charter Steel
Saukville, WI, USA

Rem: Load1,Fax0,Mail0

ACCREDITED
Testing Laboratory

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
Printed Date : 09/27/2016

Page 1 of 2

Figure C-9. $^{5}/_{16}$-in.-18 UNC, 1¾-in. Long Hex Bolt, Page 1, Test No. UCSS-1

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFARS compliance, LEEDS compliance, REACH compliance, ROHS-WEEE compliance, and Conflict Materials Restrictions.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	**CSSM**	Charter Steel Melting Division	1658 Cold Springs Road, Saukville, WI 53080
0358-02	8171	**CSSR/ CSSP**	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	**CSFP**	Charter Steel Ohio Processing Division	6255 US Highway 23, Rising Sun, OH 43457
0358-04	125544	**CSCM/ CSCR**	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
*	*	--	Subcontracted test performed by laboratory not in Charter Steel System	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Specifications	CSSM	CSSR/ CSSP	CSFP	CSCM/ CSCR
Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwelll Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
Inclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 03/31/17. All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specification, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

A2LA ACCREDITED
Testing Laboratory

Page 2 of 2

Figure C-10. $^{5}/_{16}$-in.-18 UNC, 1¾-in. Long Hex Bolt, Page 2, Test No. UCSS-1

CERTIFICATE OF MATERIAL AND PROCESSING REQUIREMENTS COMPLIANCE

We certify that this shipment consisting of the purchase order numbers, part numbers and ship to location listed below were coated to our agreed upon coating processing requirements and the material manufacture's requirements.

Allegheny Coatings
224 River Road Ridgway, PA 15853 USA
Ph: (814) 772-3850 Fax (814) 772-2336
Contact: Christina McClelland

Direct Ship Reference Nbr:

PL ID	14696
SHIP DATE	01-Sep-2017
SHIP TERMS	Third Party Collect
SHIP VIA	XPO
CAR TRAILER NBR:	

BILL TO: MNWINONA-B2171 OurSupplier ID
FASTENAL COMPANY
PO BOX 1225
WINONA,MN 55987
USA Supplier Code
Attn: Ph (507) 453-8921

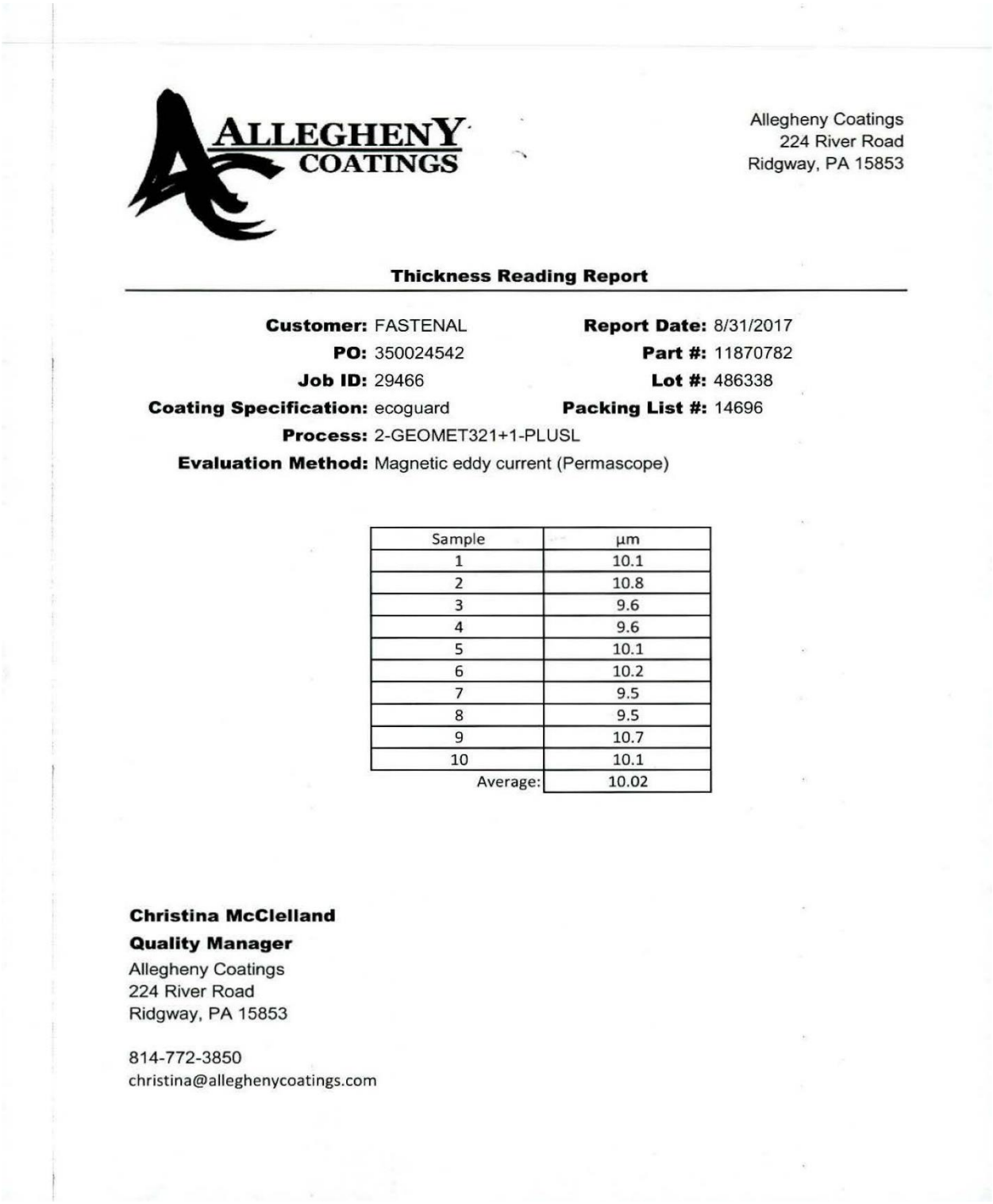
SHIP TO CTWALLING-S3871 OurSupplier I
FASTENAL COMPANY, HOLO-KROME COMPANY
61 BARNES INDUSTRIAL PARK NORTH
WALLINGFORD,CT 06492
USA Supplier Code
Attn: Ph: (203) 284-7028

CustomerPartNbr	CustomerPO	WO#-REL#	OurJobID	ShipToPartNbr	Lot Nbr		ShipCode
	Eng.DrawingNbr	Specification Name		SaltSprayTest	Salt Hrs	Net Wgt	Pieces
10309013	350024475	350024475	29404		781686-1		
		NA		ASTM B-117	1000	258	4724
DIPSPIN/AKC+GB/2-GEOMET321+1-PLUSL/;							
11540782	350024542	350024542	29466		486338		
		ECOGUARD		ASTM B-117	1000	247	5335
DIPSPIN/AKC+GB/2-GEOMET321+1-PLUSL/THICKNESS READING							
Coating meets the adhesion requirements of ASTM F1136							
11540785	350024544	350024544	29464		486340		
		ECOGUARD		ASTM B-117	1000	828	11427
DIPSPIN/AKC+GB/2-GEOMET321+1-PLUSL/THICKNESS READING							
Coating meets the adhesion requirements of ASTM F1136							
GEOA760004880	350024481	350024481	29381		485886		
		NA		ASTM B-117	0	565	462
DIPSPIN/AKC+GB/2-GEOMET500/HANDLOAD/UNLOAD							

Signature:

Page 1 of 1

Figure C-11. $^{5}/_{16}$-in.-18 UNC, 1¾-in. Long Hex Bolt, Test No. UCSS-1



ALLEGHENY COATINGS

Allegheny Coatings
224 River Road
Ridgway, PA 15853

Thickness Reading Report

Customer: FASTENAL
Report Date: 8/31/2017
PO: 350024542
Part #: 11870782
Job ID: 29466
Lot #: 486338
Coating Specification: ecoguard
Packing List #: 14696
Process: 2-GEOMET321+1-PLUSL
Evaluation Method: Magnetic eddy current (Permascope)

Sample	µm
1	10.1
2	10.8
3	9.6
4	9.6
5	10.1
6	10.2
7	9.5
8	9.5
9	10.7
10	10.1
Average:	10.02

Christina McClelland
Quality Manager
Allegheny Coatings
224 River Road
Ridgway, PA 15853

814-772-3850
christina@alleghenycoatings.com

Figure C-12. $^{5}/_{16}$-in.-18 UNC, 1¾-in. Long Hex Bolt, Test No. UCSS-1

Sep. 18. 2018 3:52PM Fastenal-NELIN No. 5628 P. 2

FASTENAL®

Certificate of Compliance

Sold To:	**Purchase Order:**	U-Channel YR28
UNL TRANSPORTATION	**Job:**	U-Channel YR28
	Invoice Date:	09/18/2018

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

100 PCS 5/16" Zinc Finish Medium Split Lock Washer SUPPLIED UNDER OUR TRACE NUMBER 210150709 AND UNDER PART NUMBER 1133620

100 PCS 5/16" x 0.875" OD Low Carbon Zinc Finish Steel USS General Purpose Flat Washer SUPPLIED UNDER OUR TRACE NUMBER 210149350 AND UNDER PART NUMBER 1133006

16 PCS 5/16"-18 x 1-3/4" Grade 9 Holo-Krome[REG] ECOGUARD[REG] Finish Hex Cap Screw SUPPLIED UNDER OUR TRACE NUMBER 486338 AND UNDER PART NUMBER 11540782

24 PCS 5/16"-18 x 2-3/4" Grade 9 Holo-Krome[REG] ECOGUARD[REG] Finish Hex Cap Screw SUPPLIED UNDER OUR TRACE NUMBER 464179 AND UNDER PART NUMBER 11540737

40 PCS 5/16"-18 FNL[REG] ECOGUARD[REG] Finish High Hex Nut for Grade 9 Applications SUPPLIED UNDER OUR TRACE NUMBER 110233073 AND UNDER PART NUMBER 11541092

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

J Morgan

Fastenal Account Representative Signature

Sean Morgan

Printed Name

9/18/18

Date

Please check current revision to avoid using obsolete copies.

This document was printed on 09/18/2018 and was current at that time.

Fastenal Store Location/Address

3201 N. 23rd Street STE 1
LINCOLN, NE 68521
Phone #: (402)476-7900
Fax #: 402/476-7958

Page 1 of 1

Figure C-13. $^{5}/_{16}$-in.-18 UNC, 1¾-in. Long Hex Bolt, Test No. UCSS-1

61 Barnes Industrial Park North
Wallingford, Connecticut 06492
(203) 284-7023

CERTIFIED MATERIAL TEST REPORT : EN 10204 3.1

Certified Number	:	469737	**Date Issued**	:	September 26, 2018
Customer	:	Fastenal,	**Manufacturing date**	:	October 10, 2014
		4730 Service Drive	**SHOP Part Number**	:	11540736
		Winona, MN 57987	**Purchase Order**	:	350007110
			Holo Code	:	N/A
Manufacturer	:	Holo-Krome	**Grade**	:	9
		61 Barnes Industrial Park North	**Material**	:	8640
		Wallingford, CT 06492	**Finish**	:	ECOGUARD®
			Order Quantity	:	11,500 Pcs
Customer Part Number	:	11540736	**Production Lot Size**	:	11,500 Pcs
Description	:	5/16"-18 x 2-1/4" Holo-Krome® Hex Cap Screw			
Thread Designation	:	UNRC-2A	**Marking**	:	H-K ; G9 ; '9 radial lines'

CHEMISTRY – Heat Number: 10242060
Heat Composition (WT% Heat Analysis)

Element:	C	P	S	Cr	Mn	Mo	Ni	Si
Result:	0.38	0.010	0.007	0.42	0.86	0.21	0.46	0.22

MACROETCH (if required): N/A

SURFACE QUALITY: In accordance with ASTM F788/F788M-13	PASS
COATING: ECOGUARD®	PASS

Heat Treat Method:	Quenched and Tempered				
Mechanical Properties: In accordance with ASTM A574-17					
Attribute	**Test Method**	**Sample Size**	**Requirement**	**Result**	**Acceptance**
Core Hardness	ASTM F606/F606M-16	4	38 – 42 HRC	42 HRC	PASS
Proof Load	ASTM F606/F606M-16	3	Min : 140,650 PSI	PASS	PASS
6° Wedge Tensile	ASTM F606/F606M-16	3	Min : 180,000 PSI	197,932 – 199,998 PSI	PASS
Decarburization/Carburization	ASTM F2328-17	3	NO COLOR	PASS	PASS

January 6, 2016

Figure C-14. $^{5}/_{16}$-in.-18 UNC, 2¼-in. Long Hex Bolt, Page 1, Test No. UCSS-1

61 Barnes Industrial Park North
Wallingford, Connecticut 06492
(203) 284-7023

DIMENSIONAL INSPECTION: Per H-K Dimension Inspection Drawing Plan : S12150-3 REV B
SAMPLING PLAN : Per ASME B18.18-17

Characteristics	DIMENSION DATA		UNIT	SAMPLE SIZE	RESULT		ACCEPTANCE
	MIN	MAX			MIN	MAX	
Width Across Flat	0.489	0.500	INCH	3	0.493	0.494	PASS
Width Across Corner	0.557	-	INCH	3	0.563	0.564	PASS
Head Height	0.227	0.242	INCH	6	0.234	0.235	PASS
Washer Diameter	0.450	0.500	INCH	3	0.475	0.477	PASS
Washer Height	0.015	0.025	INCH	6	0.018	0.019	PASS
Body Length	1.100	-	INCH	6	1.228	1.230	PASS
Grip Length	-	1.375	INCH	6	1.320	1.350	PASS
Total Length	2.210	2.250	INCH	6	2.225	2.228	PASS
Major Diameter	0.3026	0.3113	INCH	6	0.305	0.307	PASS
Thread	5/16"-18 UNRC-2A		INCH	6	PASS	PASS	PASS

Compliancy Statement:
All products as indicated in the test report above, conforms to the above requirement.
All manufacturing Operations & Processes performed in the United States of America.
Products meets RoHs & DFARS requirement, Mercury was not used during the manufacture of this product.

Comments:

Muhammad Luqman Azmi
Quality Assurance Dept.

Figure C-15. $^{5}/_{16}$-in.-18 UNC, 2¼-in. Long Hex Bolt, Page 2, Test No. UCSS-1

LOAD

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

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

Fastenal-West Hartford
61 Barnes Industrial Park North
Wallingford,CT-06492
Kind Attn :Mark Leone

Cust P.O.	350007110
Customer Part #	0970917
Charter Sales Order	30054252
Heat #	10242060
Ship Lot #	4199470
Grade	8640 R SK FG RHQ 3/8
Process	SA+SAFS
Finish Size	0.3265

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 10242060

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.38	.86	.010	.007	.220	.46	.42	.21	.17	.009	.003

	AL	N	B	TI	NB
	.026	.0070	.0001	.001	.002

JOMINY(HRC)	JOM01	JOM02	JOM03	JOM04	JOM05	JOM06	JOM07	JOM08	JOM09	JOM10	JOM12
	55	55	55	53	50	47	45	43	41	40	37

	JOM14	JOM16	JOM18	JOM20	JOM24	JOM28	JOM32
	35	33	32	30	28	27	26

JOMINY SAMPLE TYPE ENGLISH = C
CHEM. DEVIATION EXT.-GREEN =

3.2366

Test Results of Rolling Lot# 1090751

REDUCTION RATIO = 274:1

Test Results of Processing Lot# 4195387,4199470

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE	1.0	72.2	72.2	72.2	TENSILE LAB = 0358-02
REDUCTION OF AREA	1	78	78	78	RA LAB = 0358-02
ROCKWELL B	1	77	77	77	RB LAB = 0358-02

NUM DECARB = 1 FREE FERRITE DECARB = .000 FREE FERR & PARTIAL DECARB = .002

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = QWI#23 - DETAIL 55 Revision = New Dated = 02-MAR-12

Additional Comments:

Charter Steel
Saukville, WI, USA

Rem: Load1,Fax0,Mail0

ACCREDITED
Testing Laboratory

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
04/02/2013

Figure C-16. $^{5}/_{16}$-in.-18 UNC, 2¼-in. Long Hex Bolt, Page 1, Test No. UCSS-1

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFAR's compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	CSSM	Charter Steel Melting Division	1653 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
*	*	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Specification	CSSM	CSSR/CSSP	CSFP	CSCM/CSCR
Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwell Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
Inclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/13.
All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specifiction, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

ACCREDITED
Testing Laboratory

Figure C-17. $^{5}/_{16}$-in.-18 UNC, 2¼-in. Long Hex Bolt, Page 2, Test No. UCSS-1

ALLEGHENY COATINGS
P•E•N•N•S•Y•L•V•A•N•I•A

Test Report For Fastenal

Date: 10/20/14

PO: 350013919
Job ID: 41732

PART# 11540736
LOT # 469737

THICKNESS: ASTM B-499

Test: Average Coating Thickness
Meaurements done in microns

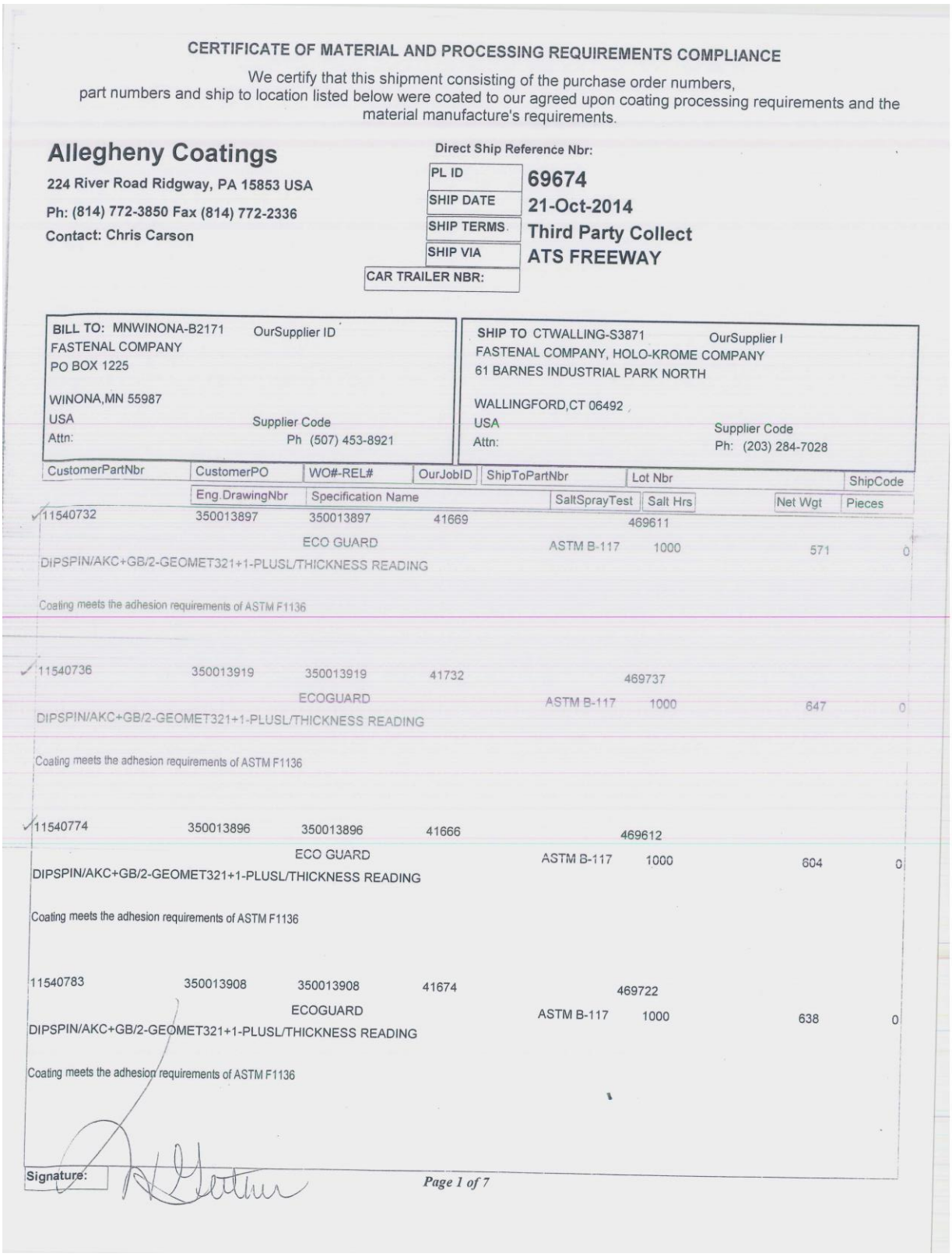
Specification:

Part #	Average Microns
1	11.9
2	12.2
3	8.1
4	8.2
5	6.4
6	6.9
7	12.4
8	9.5
9	11.4
10	11.6

Average thickness= 9.86
6-12 microns minimum per Control Plan

Donna Tripodi
QA Manager
Allegheny Coatings
Ridgway, PA

Figure C-18. $^{5}/_{16}$-in.-18 UNC, 2¼-in. Long Hex Bolt, Page 1, Test No. UCSS-1



CERTIFICATE OF MATERIAL AND PROCESSING REQUIREMENTS COMPLIANCE

We certify that this shipment consisting of the purchase order numbers, part numbers and ship to location listed below were coated to our agreed upon coating processing requirements and the material manufacture's requirements.

Allegheny Coatings
224 River Road Ridgway, PA 15853 USA
Ph: (814) 772-3850 Fax (814) 772-2336
Contact: Chris Carson

Direct Ship Reference Nbr:

PL ID	69674
SHIP DATE	21-Oct-2014
SHIP TERMS	Third Party Collect
SHIP VIA	ATS FREEWAY
CAR TRAILER NBR:	

BILL TO: MNWINONA-B2171 OurSupplier ID
FASTENAL COMPANY
PO BOX 1225
WINONA,MN 55987
USA
Attn: Supplier Code Ph (507) 453-8921

SHIP TO CTWALLING-S3871 OurSupplier I
FASTENAL COMPANY, HOLO-KROME COMPANY
61 BARNES INDUSTRIAL PARK NORTH
WALLINGFORD,CT 06492
USA
Attn: Supplier Code Ph: (203) 284-7028

CustomerPartNbr	CustomerPO	WO#-REL#	OurJobID	ShipToPartNbr	Lot Nbr	ShipCode
	Eng.DrawingNbr	Specification Name		SaltSprayTest	Salt Hrs	Net Wgt	Pieces
✓11540732	350013897	350013897	41669	469611		
		ECO GUARD		ASTM B-117	1000	571	0
DIPSPIN/AKC+GB/2-GEOMET321+1-PLUSL/THICKNESS READING							
Coating meets the adhesion requirements of ASTM F1136							
✓11540736	350013919	350013919	41732	469737		
		ECOGUARD		ASTM B-117	1000	647	0
DIPSPIN/AKC+GB/2-GEOMET321+1-PLUSL/THICKNESS READING							
Coating meets the adhesion requirements of ASTM F1136							
✓11540774	350013896	350013896	41666	469612		
		ECO GUARD		ASTM B-117	1000	604	0
DIPSPIN/AKC+GB/2-GEOMET321+1-PLUSL/THICKNESS READING							
Coating meets the adhesion requirements of ASTM F1136							
11540783	350013908	350013908	41674	469722		
		ECOGUARD		ASTM B-117	1000	638	0
DIPSPIN/AKC+GB/2-GEOMET321+1-PLUSL/THICKNESS READING							
Coating meets the adhesion requirements of ASTM F1136							

Signature:

Page 1 of 7

Figure C-19. $^{5}/_{16}$-in.-18 UNC, 2¼-in. Long Hex Bolt, Page 2, Test No. UCSS-1

ISO 9001 Certified
Certificate Number: US11/82236

61 Barnes Industrial Park North
Wallingford, CT 06492
(203)-284-7023

CERTIFICATE OF CONFORMANCE

July 8, 2015

This certifies the Grade 9 Hex Head Bolt samples submitted were randomly selected from the lot identified and tested to the specifications listed. The samples were found to conform to the specifications listed below. The original test data is on file at Holo-Krome.

Quantity:	10,000
Fastenal Part Number:	11540737
H-K Part Number:	11540737
Description:	5/16"-18 X 2-3/4" HCS G9 ECO
Lot No.:	464179
Mill Heat:	10229550
H-K Lab Number:	3-2359

SPECIFICATIONS

Dimensional per ASME 18.2.1				
Hardness per ASTM E18:	40 /	40 /	40	Rc
Proof Load (Length) per ASTM A574-2012:		PASS		
Tensile per ASTM F606 / USA.HCS.GR9.ECO:	185,802 /	187,913 /	188,093	PSI
Decarburization (Microscopic) per ASTM F2328-2005:		PASS		
Surface Discontinuities per ASTM F788-12:		PASS		

Product was heat treated in accordance to ASTM A574.

Heat treat was performed at the Holo-Krome facility.
Product meets DFARs requirements.
Material was melted and processed in the United States of America.
Product meets RoHS requirements.
Mercury was not used during the manufacture of this product.
Raw Material Certificate is Attached.

COMMENTS

Angel Perez Morales

Angel Perez Morales

Quality Assurance Technician

MADE IN THE USA

Figure C-20. $^{5}/_{16}$-in.-18 UNC, 2¾-in. Long Hex Bolt, Test No. UCSS-1

LOAD

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

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

Fastenal-West Hartford
61 Barnes Industrial Park North
Wallingford,CT-06492
Kind Attn :Mark Leone

Cust P.O.	350006957
Customer Part #	0970917
Charter Sales Order	30053773
Heat #	10229550
Ship Lot #	4182846
Grade	8640 R SK FG RHQ 3/8
Process	SA+SAFS
Finish Size	0.3265

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 10229550

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.39	.85	.010	.007	.230	.44	.43	.22	.13	.009	.003

	AL	N	B	TI	NB
	.025	.0060	.0001	.002	.002

JOMINY(HRC)	JOM01	JOM02	JOM03	JOM04	JOM05	JOM06	JOM07	JOM08	JOM09	JOM10	JOM12
	56	56	56	53	52	48	46	44	43	41	38

	JOM14	JOM16	JOM18	JOM20	JOM24	JOM28	JOM32
	36	34	33	32	30	28	27

JOMINY SAMPLE TYPE ENGLISH = C
CHEM. DEVIATION EXT.-GREEN =

3.359

Test Results of Rolling Lot# 1084924

REDUCTION RATIO = 274:1

Test Results of Processing Lot# 4182487,4182846

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE	1.0	72.6	72.6	72.6	TENSILE LAB = 0358-02
REDUCTION OF AREA	1	76	76	76	RA LAB = 0358-02
ROCKWELL B	1	76	76	76	RB LAB = 0358-02

NUM DECARB = 1 FREE FERRITE DECARB = .000 FREE FERR & PARTIAL DECARB = .002

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = QWI#23 - DETAIL 55 Revision = New Dated = 02-MAR-12

Additional Comments:

Charter Steel
Saukville, WI, USA

Rem: Load1,Fax0,Mail0

ACCREDITED
Testing Laboratory

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
01/08/2013

Figure C-21. $^{5}/_{16}$-in.-18 UNC, 2¾-in. Long Hex Bolt, Page 1, Test No. UCSS-1

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFAR's compliance.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	CSSM	Charter Steel Melting Division	1653 Cold Springs Road, Saukville, WI 53080
0358-02	8171	CSSR/ CSSP	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	CSFP	Charter Steel Ohio Processing Division	6255 US Highway 23, Risingsun, OH 43457
0358-04	125544	CSCM/ CSCR	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
*	*	--	Subcontracted test performed by laboratory not in Charter Steel system	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Specification	CSSM	CSSR/CSSP	CSFP	CSCM/CSCR
Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwell Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
Inclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 01/31/13.
All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specifiction, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

ACCREDITED
Testing Laboratory

Figure C-22. $^{5}/_{16}$-in.-18 UNC, 2¾-in. Long Hex Bolt, Page 2, Test No. UCSS-1

Sep. 18. 2018 3:52PM Fastenal-NELIN No. 5628 P. 2

FASTENAL®

Certificate of Compliance

Sold To:

UNL TRANSPORTATION

Purchase Order: U-Channel YR28

Job: U-Channel YR28

Invoice Date: 09/18/2018

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

100 PCS 5/16" Zinc Finish Medium Split Lock Washer SUPPLIED UNDER OUR TRACE NUMBER 210150709 AND UNDER PART NUMBER 1133620

100 PCS 5/16" x 0.875" OD Low Carbon Zinc Finish Steel USS General Purpose Flat Washer SUPPLIED UNDER OUR TRACE NUMBER 210149350 AND UNDER PART NUMBER 1133006

16 PCS 5/16"-18 x 1-3/4" Grade 9 Holo-Krome[REG] ECOGUARD[REG] Finish Hex Cap Screw SUPPLIED UNDER OUR TRACE NUMBER 486338 AND UNDER PART NUMBER 11540782

24 PCS 5/16"-18 x 2-3/4" Grade 9 Holo-Krome[REG] ECOGUARD[REG] Finish Hex Cap Screw SUPPLIED UNDER OUR TRACE NUMBER 464179 AND UNDER PART NUMBER 11540737

40 PCS 5/16"-18 FNL[REG] ECOGUARD[REG] Finish High Hex Nut for Grade 9 Applications SUPPLIED UNDER OUR TRACE NUMBER 110233073 AND UNDER PART NUMBER 11541092

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

J Morgan

Fastenal Account Representative Signature

Sean Morgan

Printed Name

9/18/18

Date

Please check current revision to avoid using obsolete copies.

This document was printed on 09/18/2018 and was current at that time.

Fastenal Store Location/Address

3201 N. 23rd Street STE 1
LINCOLN, NE 68521
Phone #: (402)476-7900
Fax #: 402/476-7958

Page 1 of 1

Figure C-23. $^{5}/_{16}$-in.-18 UNC, 2¾-in. Long Hex Bolt, Test No. UCSS-1

ELGIN FASTENER GROUP

MATERIAL CERTIFICATION

Customer: FASTENAL COMPANY 2001 THEURER BLVD. WINONA MN 55987		Date: 11/13/2017
	Customer P.O. Number:	110233073
	Customer Part Number:	11541092
	Invoice Number:	62068
	Lot Number:	0072385-129135-129136
Description: NUT THICK HEX 5/16-18 FNL9 ORG	Ship Quantity: 12000	Ship Date: 7/6/2017
	Material: 1038	Heat Number: 10463770
Specification:		

C	Mn	P	S	Si	Ni	Cr	Mo	Al
0.380	0.750	0.008	0.010	0.200	0.040	0.080	0.010	0.033

Hardness	C 36.1
Proof Load:	4 passed at 180,000 psi min
Plating	Geomet 321 + L - Pass

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 laboratory. Statistical process control data is on file. All manufacturing processes for these parts occurred in the United States of America.
* Processed Mercury Free using material that is Free of Welds.

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

Joe Kilpatrick
Quality Technician

Figure C-24. $^{5}/_{16}$-in.-18 UNC Heavy Hex Nut, Test No. UCSS-1

ERIEVIEW METAL TREATING
4465 JOHNSTON PARKWAY
CLEVELAND, OHIO 44128
PHONE: (216) 663-2765
FAX: (216) 663-7782

page 1

ERIEVIEW METAL TREATING CO.
4465 JOHNSTON PARKWAY
CLEVELAND, OH 44128

CERTIFICATION

CUSTOMER: T00033
TELEFAST IND.
ap@elginfasteners.com
1415 S. BENHAM ROAD
VERSAILLES, IN 47042

DATE: 06/22/2017

We certify that this lot of material has been processed to your specification and/or instructions. Records are maintained on file for your examination upon request

ORDER NO: 129136
PART NO: T0963/00
DESC: 5/16-18 THICK HEX NUT
LOT NO: 0072385 BINS 10438
CONTAINERS: 1 BIN

EMT NO: 478664-0001
WEIGHT: 345
PIECES: 26360

SPECIFICATION: Geomet 321 "XL"

RECEIVED

CERTIFIED BY:

PACKING LIST - FILE COPY

Figure C-25. $^{5}/_{16}$-in.-18 UNC Heavy Hex Nut, Test No. UCSS-1

USA HEAT TREATING INC.
ISO 9001 Registered Company

OrderDate:	Order#:
6/8/2017	127037

Original Order:

CERTIFICATION

Company Name
EFG Berea Plant Telefast Industries

Ship Name
ERIEVIEW

PO	Lot	Heat	BinNumber
129135	0072385	C-10463770	10438

ProductName: **T0963-H-P**
ProductDescription: **NUT THICK HEX 5/16-18**
Containers: **1** Bin(s)
Quantity/Weight: **345** LBS. **26360** PCS:
Material: **1035**
PreProcess: **PreWash**
Process: **Neutral Harden** **Certification/Pass Slip Req.**

PostProcess: **Dry Finish**

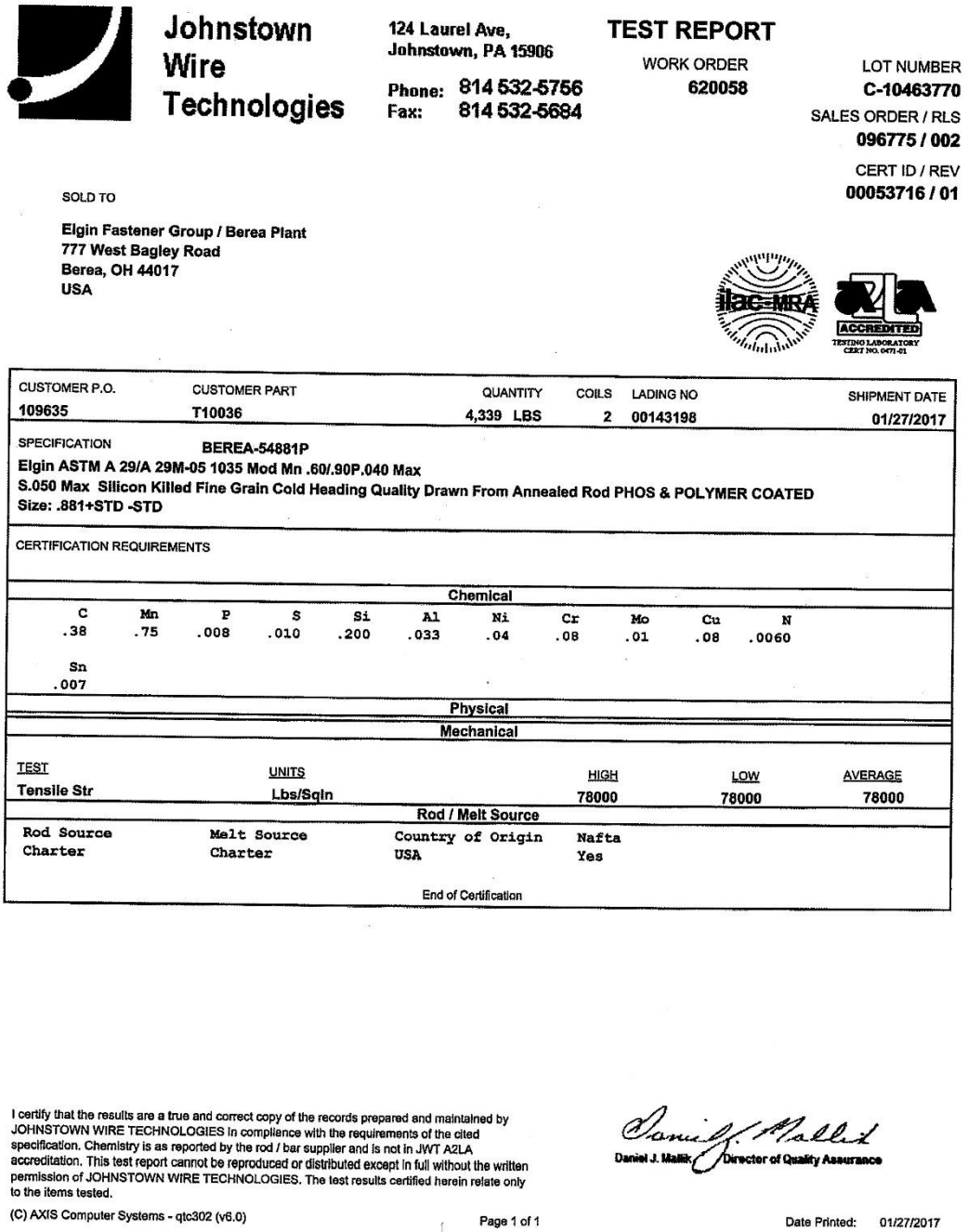
Test Results:
Specification RC 32/38
RC 36.1-35.0-35.3-36.9-36.1-36.9-35.9-36.4-35.5-36.6

The above order has been processed and inspected. All samples tested were within the above stated results.

Approved By: DELANEY Date: **6/13/2017**
Quality Manager

Proudly processed in the United States of America

Figure C-26. $^{5}/_{16}$-in.-18 UNC Heavy Hex Nut, Test No. UCSS-1



Johnstown Wire Technologies

124 Laurel Ave,
Johnstown, PA 15906

Phone: 814 532-5756
Fax: 814 532-5684

TEST REPORT

WORK ORDER
620058

LOT NUMBER
C-10463770

SALES ORDER / RLS
096775 / 002

CERT ID / REV
00053716 / 01

SOLD TO

Elgin Fastener Group / Berea Plant
777 West Bagley Road
Berea, OH 44017
USA

ACCREDITED
TESTING LABORATORY
CERT NO. 0471.01

CUSTOMER P.O.	CUSTOMER PART	QUANTITY	COILS	LADING NO	SHIPMENT DATE
109635	T10036	4,339 LBS	2	00143198	01/27/2017

SPECIFICATION BEREA-54881P

Elgin ASTM A 29/A 29M-05 1035 Mod Mn .60/.90P.040 Max
S.050 Max Silicon Killed Fine Grain Cold Heading Quality Drawn From Annealed Rod PHOS & POLYMER COATED
Size: .881+STD -STD

CERTIFICATION REQUIREMENTS

Chemical

C	Mn	P	S	Si	Al	Ni	Cr	Mo	Cu	N	Sn
.38	.75	.008	.010	.200	.033	.04	.08	.01	.08	.0060	.007

Physical

Mechanical

TEST	UNITS	HIGH	LOW	AVERAGE
Tensile Str	Lbs/Sqin	78000	78000	78000

Rod / Melt Source

Rod Source	Melt Source	Country of Origin	Nafta
Charter	Charter	USA	Yes

End of Certification

I certify that the results are a true and correct copy of the records prepared and maintained by JOHNSTOWN WIRE TECHNOLOGIES in compliance with the requirements of the cited specification. Chemistry is as reported by the rod / bar supplier and is not in JWT A2LA accreditation. This test report cannot be reproduced or distributed except in full without the written permission of JOHNSTOWN WIRE TECHNOLOGIES. The test results certified herein relate only to the items tested.

Daniel J. Mallik, Director of Quality Assurance

(C) AXIS Computer Systems - qtc302 (v6.0)

Page 1 of 1

Date Printed: 01/27/2017

Figure C-27. $^{5}/_{16}$-in.-18 UNC Heavy Hex Nut, Test No. UCSS-1

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

EMAIL

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

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Cust P.O.	91626
Customer Part #	FXA38CD-31/64
Charter Sales Order	30122857
Heat #	10463770
Ship Lot #	1198506
Grade	1038 R SK FG RHQ 31/64
Process	HR
Finish Size	31/64
Ship date	

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

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

Test results of Heat Lot # 10463770

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.38	.75	.008	.010	.200	.04	.08	.01	.08	.007	.003
	AL	N	B	TI	NB						
	.033	.0060	.0001	.002	.001						

JOMINY(HRC)

J1	J2	J3	J4	J5	J6	J7
55	49	38	27	23	21	20

JOMINY SAMPLE TYPE ENGLISH=C **CAT DI=1.06**

Test results of Rolling Lot # 1198506

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE (KSI)	1	93.1	93.1	93.1	TENSILE LAB = 0358-02
REDUCTION OF AREA (%)	1	44	44	44	RA LAB = 0358-02

NUM DECARB=1 **AVE DECARB (Inch)=.002**
REDUCTION RATIO=164:1

Specifications: **Manufactured per Charter Steel Quality Manual Rev Date 12/12/13**
Charter Steel certifies this product is indistinguishable from background radiation levels by having process radiation detectors in place to measure for the presence of radiation within our process & products.
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = RW007-RW100 Revision = Dated = 08-NOV-13

Additional Comments:

Melt Source:
Charter Steel
Saukville, WI, USA

Rem: Load1,Fax0,Mail0

ACCREDITED
Testing Laboratory

This MTR supersedes all previously dated MTRs for this order

Janice Barnard Division Mgr. of Quality Assurance
barnardJ@chartersteel.com
Printed Date : 11/28/2016

Page 1 of 2

Figure C-28. $^{5}/_{16}$-in.-18 UNC Heavy Hex Nut, Page 1, Test No. UCSS-1

The following statements are applicable to the material described on the front of this Test Report:

1. Except as noted, the steel supplied for this order was melted, rolled, and processed in the United States meeting DFARS compliance, LEEDS compliance, REACH compliance, ROHS-WEEE compliance, and Conflict Materials Restrictions.
2. Mercury was not used during the manufacture of this product, nor was the steel contaminated with mercury during processing.
3. Unless directed by the customer, there are no welds in any of the coils produced for this order.
4. The laboratory that generated the analytical or test results can be identified by the following key:

Certificate Number	Lab Code	Laboratory		Address
0358-01	7388	**CSSM**	Charter Steel Melting Division	1658 Cold Springs Road, Saukville, WI 53080
0358-02	8171	**CSSR/ CSSP**	Charter Steel Rolling/ Processing Division	1658 Cold Springs Road, Saukville, WI 53080
0358-03	123633	**CSFP**	Charter Steel Ohio Processing Division	6255 US Highway 23, Rising Sun, OH 43457
0358-04	125544	**CSCM/ CSCR**	Charter Steel Cleveland	4300 E. 49th St., Cuyahoga Heights, OH 44125-1004
*	*	--	Subcontracted test performed by laboratory not in Charter Steel System	

5. When run by a Charter Steel laboratory, the following tests were performed according to the latest revisions of the specifications listed below, as noted in the Charter Steel Laboratory Quality Manual:

Test	Specifications	CSSM	CSSR/ CSSP	CSFP	CSCM/ CSCR
Chemistry Analysis	ASTM E415; ASTM E1019	X			X
Macroetch	ASTM E381	X			X
Hardenability (Jominy)	ASTM A255; SAE J406; JIS G0561	X			X
Grain Size	ASTM E112	X	X	X	X
Tensile Test	ASTM E8; ASTM A370		X	X	X
Rockwelll Hardness	ASTM E18; ASTM A370	X	X	X	X
Microstructure (spheroidization)	ASTM A892		X	X	
Inclusion Content (Methods A, E)	ASTM E45		X		X
Decarburization	ASTM E1077		X	X	X

Charter Steel has been accredited to perform all of the above tests by the American Association for Laboratory Accreditation (A2LA). These accreditations expire 03/31/17. All other test results associated with a Charter Steel laboratory that appear on the front of this report, if any, were performed according to documented procedures developed by Charter Steel and are not accredited by A2LA.

6. The test results on the front of this report are the true values measured on the samples taken from the production lot. They do not apply to any other sample.
7. This test report cannot be reproduced or distributed except in full without the written permission of Charter Steel. The primary customer whose name and address appear on the front of this form may reproduce this test report subject to the following restrictions:
   - It may be distributed only to their customers
   - Both sides of all pages must be reproduced in full
8. This certification is given subject to the terms and conditions of sale provided in Charter Steel's acknowledgement (designated by our Sales Order number) to the customer's purchase order. Both order numbers appear on the front page of this Report.
9. Where the customer has provided a specification, the results on the front of this test report conform to that specification unless otherwise noted on this test report.

A2LA ACCREDITED
Testing Laboratory

Page 2 of 2

Figure C-29. $^{5}/_{16}$-in.-18 UNC Heavy Hex Nut, Page 2, Test No. UCSS-1

Sep. 18. 2018 3:52PM Fastenal-NELIN No. 5628 P. 2

FASTENAL®

Certificate of Compliance

Sold To:

UNL TRANSPORTATION

Purchase Order: U-Channel YR28

Job: U-Channel YR28

Invoice Date: 09/18/2018

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

100 PCS 5/16" Zinc Finish Medium Split Lock Washer SUPPLIED UNDER OUR TRACE NUMBER 210150709 AND UNDER PART NUMBER 1133620

100 PCS 5/16" x 0.875" OD Low Carbon Zinc Finish Steel USS General Purpose Flat Washer SUPPLIED UNDER OUR TRACE NUMBER 210149350 AND UNDER PART NUMBER 1133006

16 PCS 5/16"-18 x 1-3/4" Grade 9 Holo-Krome[REG] ECOGUARD[REG] Finish Hex Cap Screw SUPPLIED UNDER OUR TRACE NUMBER 486338 AND UNDER PART NUMBER 11540782

24 PCS 5/16"-18 x 2-3/4" Grade 9 Holo-Krome[REG] ECOGUARD[REG] Finish Hex Cap Screw SUPPLIED UNDER OUR TRACE NUMBER 464179 AND UNDER PART NUMBER 11540737

40 PCS 5/16"-18 FNL[REG] ECOGUARD[REG] Finish High Hex Nut for Grade 9 Applications SUPPLIED UNDER OUR TRACE NUMBER 110233073 AND UNDER PART NUMBER 11541092

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

J Morgan

Fastenal Account Representative Signature

Sean Morgan

Printed Name

9/18/18

Date

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Fastenal Store Location/Address

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LINCOLN, NE 68521
Phone #: (402)476-7900
Fax #: 402/476-7958

Page 1 of 1

Figure C-30. $^{5}/_{16}$-in.-18 UNC Heavy Hex Nut, Test No. UCSS-1

FASTWELL INDUSTRY CO., LTD.

TEL:(86)21 53964567 HEAD OFFICE :6TH FLOOR,NO.227.SEC.1. FU-SHENG S.RD.,
64813702 TAIPEI ,TAIPEDI,TAIWAN
FAX: 64811848 SHANGHAI OFFICE:SUITE A,11F,HAILI BUIL DING ,NO.88 DAPU ROAD.
SHANGHAI CHINA ZIP CODE :200023

CERTIFICATE OF INSPECTION

CUSTOMER NAME: FASTENAL COMPANY PURCHASING-IMPORT TRAFFIC

REPORT NO.	:20180424001	HEAT NO.	:/
INSPECTION DATE	: 2018.04.24	LOT. NO.	: /
FINISH	: ZINC PLATED CR3+	MATERIALS	: /
MANUFACTURING DATE	: 2018.02	P.O.NO.	:210149350
DESCRIPTION	:USS FLAT WASHER	PART NUMBER	:1133006
SIZE	: 5/16	MANUFACTUREDQUANTITY:862500PCS	
MARK	:/	SHIPQUANTITY:862500PCS	
INVOICE NO .	:FS18040042	Sampling plan:	ASME B18.18-2017

1、DIMENSIONS INSPECTION

SPECIFICATION:ASME B18.21.1 - 2009

CHARACTERISTIC	SPECIFICATION	INSPECTION RESULTS	SAMPLING	AC	RE
OUTSIDE DIA.	0.868 - 0.905	0.876 - 0.881	8PCS	8	0
INSIDE DIA.	0.370 - 0.390	0.384 - 0.385	8PCS	8	0
THICKNESS	0.064 - 0.104	0.069 - 0.075	8PCS	8	0

2、MECHANICAL INSPECTION:

SPECIFICATION :

CHARACTERISTIC	TEST METHOD	STANDARD	RESULTS	SAMPLING	AC	RE

3、 FINISH INSPECTION

SPECIFICATION： ASTM F1941-2015

CHARACTERISTIC	TEST METHOD	STANDARD	RESULTS	SAMPLING	AC	RE
THICKNESS OF COATING	ASTM B487	3UM min.	3.22 - 3.58	29PCS	29	0
SALT SPRAY TEST	ASTM B117-2016	6H NO WHITE RUST,12H NO RED RUST	OK	15PCS	15	0

4、APPEARANCE INSPECTION

SPECIFICATION:ASME B18.21.1-2009

CHARACTERISTIC	TEST METHOD	STANDARD	RESULTS	SAMPLING	AC	RE
GENERAL WORKMANSHIP	ASME B18.21.1-2009	VISUAL	OK	29PCS	29	0

5、CHEMICAL ANALYSIS

HEAT NO	C-X100	Mn-x100	P-x1000	S-x1000	Si-x100	Cu-x100	Ni-x100	Cr-x100	Mo-x100	Al-x1000	B-x10000	V-x100
STANDARD												

QC MANAGER

Alice miao

Remark :1.This cortificate is valid with signature of

2.This test report only relates to the items listed and tested ,it's not allowed to be partially used.

3.Samples testing conform to the requirements of specification.

4. This test report is responsible for designated samples only.

5.The above composition is quoted from original mill certs which is not in the scope of Lab Accreditation.

6.Quality System conforms to ISO 9001 requirements.

7.All fasteners meet the requirements of the (FQA)and records of compliance are on file.

8.Sampling Data is according to ASME B18.18.

9.Parts are manufactured and tested according to above specification and compliance with order， we certify that this is a ture representation of information provided by manufacturer and laboratory.

Figure C-31. $^{5}/_{16}$-in. Dia. Plain Round Washer, Test No. UCSS-1

Sep. 18. 2018 3:52PM Fastenal-NELIN No. 5628 P. 2

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Purchase Order: U-Channel YR28

Job: U-Channel YR28

Invoice Date: 09/18/2018

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

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24 PCS 5/16"-18 x 2-3/4" Grade 9 Holo-Krome[REG] ECOGUARD[REG] Finish Hex Cap Screw SUPPLIED UNDER OUR TRACE NUMBER 464179 AND UNDER PART NUMBER 11540737

40 PCS 5/16"-18 FNL[REG] ECOGUARD[REG] Finish High Hex Nut for Grade 9 Applications SUPPLIED UNDER OUR TRACE NUMBER 110233073 AND UNDER PART NUMBER 11541092

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

J Morgan

Fastenal Account Representative Signature

Sean Morgan

Printed Name

9/18/18

Date

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Page 1 of 1

Figure C-32. $^{5}/_{16}$-in. Dia. Plain Round Washer, Test No. UCSS-1

HANGZHOU SPRING WASHER CO.,LTD

QUALITY TEST CERTIFICATE OF SPRING LOCK WASHER

Standard: ASME B 18.21.1-2009 Contract No.: 17HZW12599

Order No.: PO 210150709 Invoice No.:

Chemical Composition (%)	C	Si	Mn	P	S	Cr	Ni	Cu
	0.67	0.19	0.53	0.008	0.01	0.06	0.03	0.09
Heat No.	F790006793							
Specification	5/16" MECH							
Quantity	405 M							
Lot No.	1801058							
Part No.	1133620							

Testing Item	Ac/n	Norm	Result	Reject	Norm	Result	Reject
Inside Diameter	2/100	7.98-8.18	8.02-8.18	0			
Outside Diameter	1/32	Max15.01	Max14.75	0			
Width	1/32	Min3.26	Min3.23	0			
Thickness	1/32	2.06-2.35	2.04-2.08	0			
Height							
Section							
Surface Defects	2/100	None	None	0			
Hardness	0/8	HRC38-46	HRC40-41.5	0			
Springing							
Toughness	0/8	Qualified	Qualified	0			

General:

The spring lock washers are conformed with the standard of ASME B 18.21.1-2009. QUALIFI

杭州弹簧垫圈有限公司 质检专用章

Inspector: Shiweiqing Quality Inspection Chief: Date: 2019.09.20

Figure C-33. ⅜-in. Dia. Lock Washer, Test No. UCSS-1

Sep. 18. 2018 3:52PM Fastenal-NELIN No. 5628 P. 2

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UNL TRANSPORTATION

Purchase Order: U-Channel YR28

Job: U-Channel YR28

Invoice Date: 09/18/2018

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24 PCS 5/16"-18 x 2-3/4" Grade 9 Holo-Krome[REG] ECOGUARD[REG] Finish Hex Cap Screw SUPPLIED UNDER OUR TRACE NUMBER 464179 AND UNDER PART NUMBER 11540737

40 PCS 5/16"-18 FNL[REG] ECOGUARD[REG] Finish High Hex Nut for Grade 9 Applications SUPPLIED UNDER OUR TRACE NUMBER 110233073 AND UNDER PART NUMBER 11541092

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J Morgan

Fastenal Account Representative Signature

Sean Morgan

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9/18/18

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Page 1 of 1

Figure C-34. ⅜-in. Dia. Lock Washer, Test No. UCSS-1

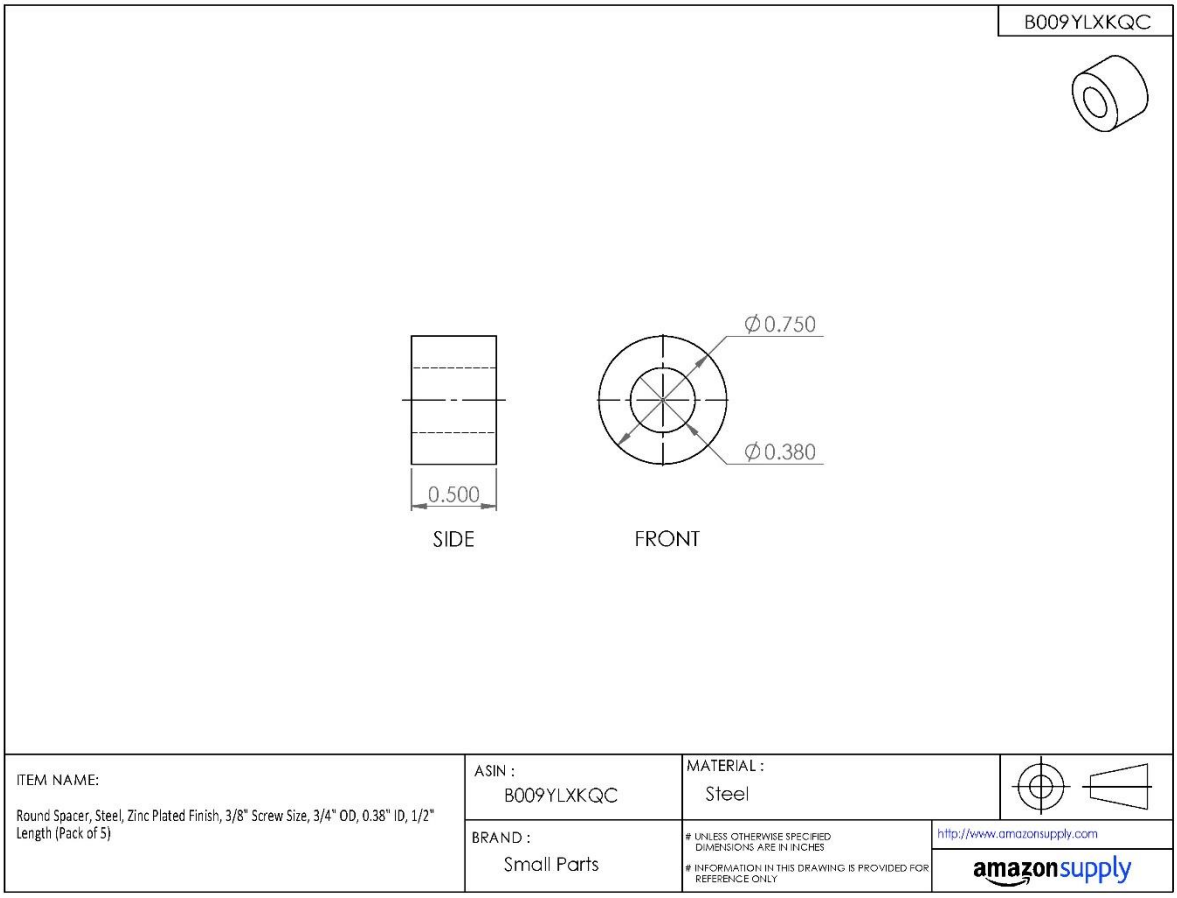


Figure C-35. Round Spacer, Steel, Zinc Plated Finish, ⅜-in. Screw Size, ¾-in. OD, 0.38 in.-ID, ½-in. Length, Test No. UCSS-1

Appendix D. Vehicle Center of Gravity Determination

Date:	9/26/2018	Test Name:	UCSS-1	VIN:	jtdbt903194056758
Year:	2009	Make:	Toyota	Model:	Yaris

Vehicle CG Determination

	Vehicle Equipment	Weight (lb.)
+	Unballasted Car (Curb)	2312
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	22
+	Strobe/Brake Battery	5
+	Brake Receiver/Wires	6
+	CG Plate including DAS	14
-	Battery	-35
-	Oil	-11
-	Interior	-6
-	Fuel	-19
-	Coolant	-7
-	Washer fluid	0
+	Water Ballast (In Fuel Tank)	83
+	Onboard Supplemental Battery	5
+	Smart Barrier	0

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

Estimated Total Weight (lb.) 2395

Vehicle Dimensions for C.G. Calculations

Wheel Base:	100.625	in.	Front Track Width:	57.875	in.
Roof Height:	56.375	in.	Rear Track Width:	57.375	in.

Center of Gravity	1100C MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb.)	2420 ± 55	2395	-25.0
Longitudinal CG (in.)	39 ± 4	40.88	1.88
Lateral CG (in.)	NA	-0.18	NA
Vertical CG (in.)	NA	22.469	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	730	700	
Rear	445	437	
FRONT	1430		lb.
REAR	882		lb.
TOTAL	2312		lb.

TEST INERTIAL WEIGHT (lb.)

	Left	Right	
Front	712	710	
Rear	493	480	
FRONT	1422		lb.
REAR	973		lb.
TOTAL	2395		lb.

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

Date:	9/26/2018	Test Name:	UCSS-1	VIN:	jtdbt903194056758
Year:	2009	Make:	Toyota	Model:	Yaris

Vehicle CG Determination

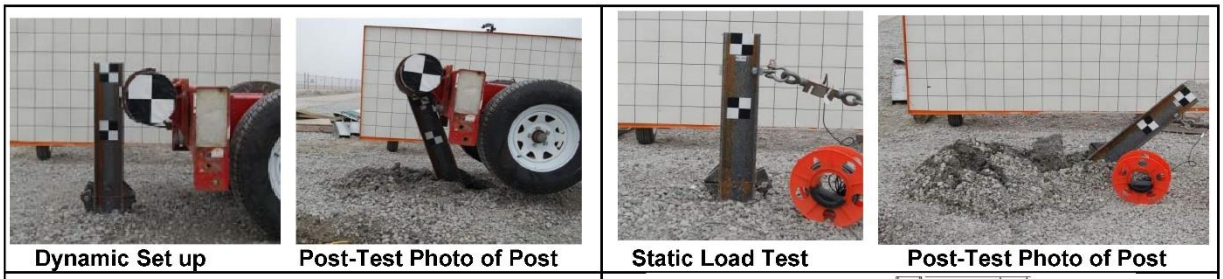
	Vehicle Equipment	Long CG (in.)	Lat CG (in.)	Vertical CG (in.)	Long M (lb.-in.)	Lat M (lb.-in.)	Vertical M (lb.-in.)
+	Unballasted Car (Curb)	38.387	-0.474	22.268	88751.25	########	51483.905
+	Hub	0	20.5	11.25	0	389.5	213.75
+	Brake activation cylinder & frame	32.125	-12.25	16.0	224.875	-85.75	112.0
+	Pneumatic tank (Nitrogen)	65.5	-12.75	13.25	1441.0	-280.5	291.5
+	Strobe/Brake Battery	85.25	17.125	20.0	426.25	85.625	100.0
+	Brake Receiver/Wires	131.625	0	35.5	789.75	0	213.0
+	CG Plate including DAS	39.875	0	15.25	558.25	0	213.5
-	Battery	31.0	-7.5	-13.5	-1085.0	262.5	472.5
-	Oil	24.0	-5.0	7.0	-264.0	55.0	-77.0
-	Interior	40.625	0	21.75	-243.75	0	-130.5
-	Fuel	80.0	0	12.5	-1520.0	0	-237.5
-	Coolant	20.0	-19.0	-3.0	-140.0	133.0	21.0
-	Washer fluid	22.0	-13.0	20.5	0	0	0
+	Water Ballast (In Fuel Tank)	80.0	0	12.5	6640.0	0	1037.5
+	Onboard Supplemental Battery	31.0	0	20.0	155.0	0	100.0
+	Smart Barrier	0	0	0	0	0	0
					0	0	0
Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle					#########	-535.5	53813.655
				Estimated CG Location (in.)	39.972	-0.224	22.469

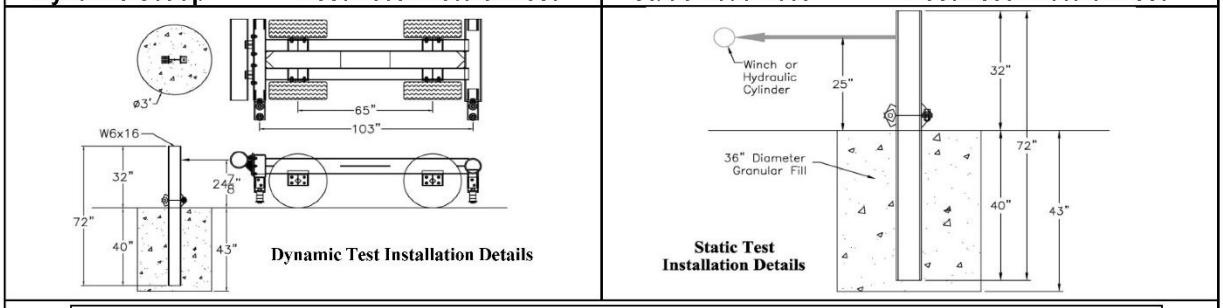
Calibrated Scales Used

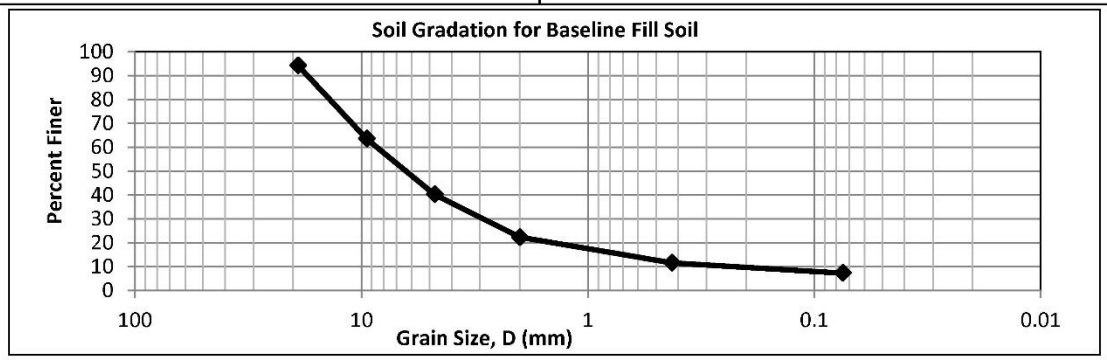
Equipment Type	Manufacturer	Serial #	Capacity
Pad Scale	Pennsylvania Scale	95-228908	5000 lbs.
Pad Scale	Pennsylvania Scale	95-228909	5000 lbs.
Race Wheel Scales	Intercomp	22033056	1500/pad

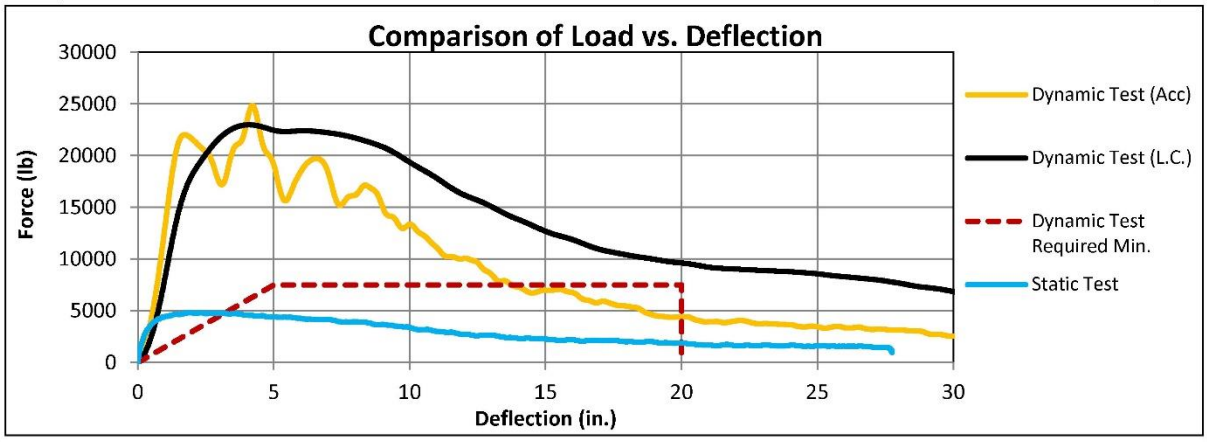
Figure D-2. Vehicle Mass Distribution, Test No. UCSS-1

Appendix E. Static Soil Tests



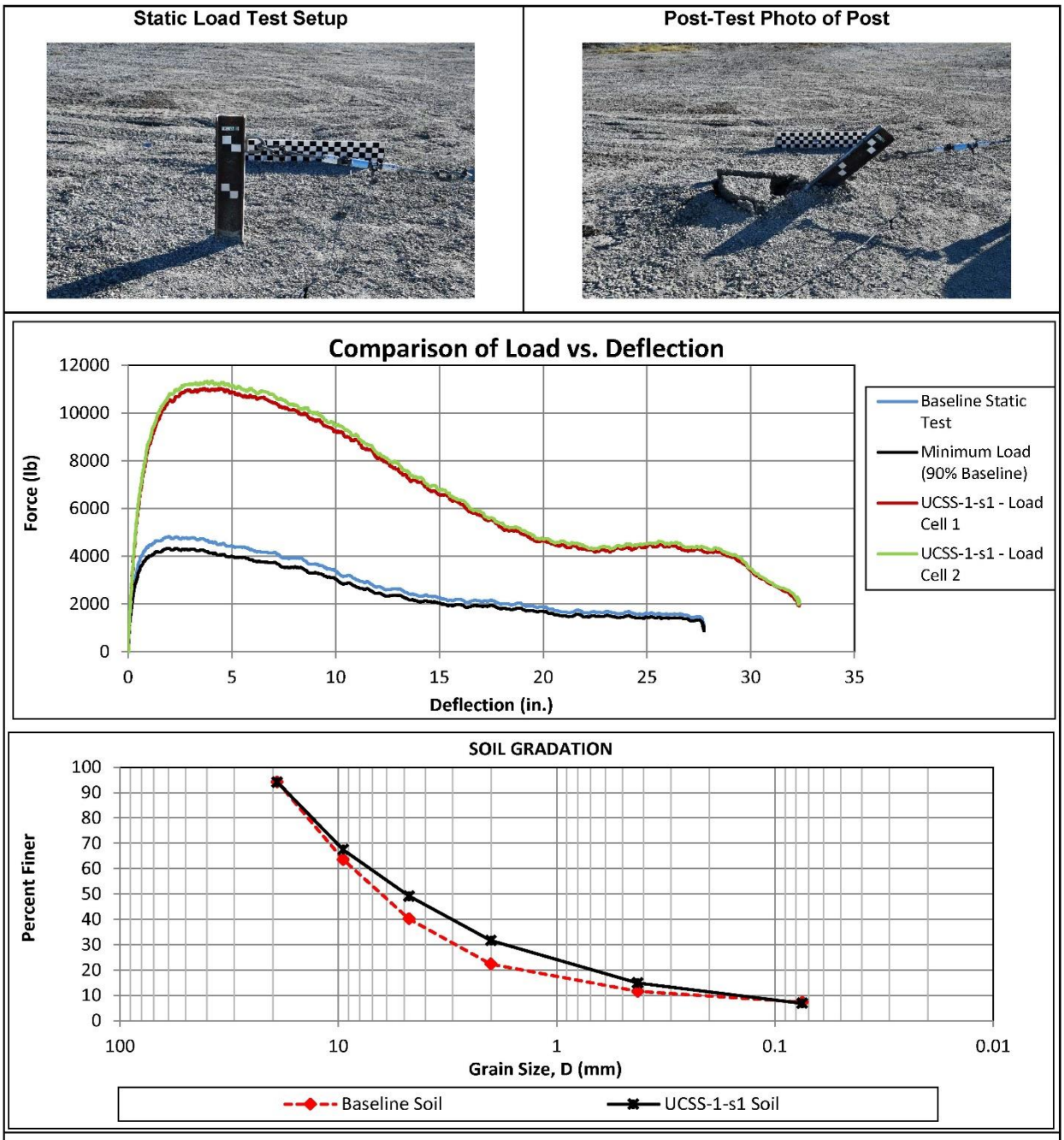






Date	2/16/2018		
Test Facility & Site Location	Midwest Roadside Safety Facility		
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)		
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)		
Description of fill placement procedure	H.E.-8		
Bogie Weight	1786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

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



Date	9/26/2018
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Low Plasticity Silt (ML)
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	8-inch lifts tamped with a pneumatic compactor

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

Appendix F. Vehicle Deformation Records

Date: 9/26/2018 Test Name: UCSS-1 VIN: jtdbt903194056758
Year: 2009 Make: Toyota Model: Yaris

VEHICLE DEFORMATION
ROOF

	POINT	Vertical Reference Length[A]	Vertical Reference Side[B] (Top or Bottom)	Lateral Referece Length[C]	Lateral Reference Side[B] (Driver or Pass.)	Examplar Vehicle Measurement	Test Vehicle Measurment	Crush[D] (in.)
WINDSHIELD	1	6 3/4	Top of back Glass	9 1/2	Pass.	5 1/2	7 1/8	1.625
	2	22 7/8	Top of back Glass	14 1/8	Pass.	5 1/2	7 7/8	2.375
	3	28 3/4	Top of back Glass	27 1/2	Pass.	5 1/2	6 3/4	1.25
	4	16 3/4	Top of back Glass	23 3/4	Pass.	5 3/8	7 3/4	2.375
	5	23	Top of back Glass	34	Pass.	6	7 1/4	1.25
	6	25 1/4	Top of back Glass	38 3/8	Pass.	6 3/8	7	0.625

[A] Length to vertical reference, typically the top or bottom of the windshield frame.
[B] C Side of windshield frame, top, bottom, passenger, or driver, in which the reference was measured from.
[C] Length to lateral referene either the driver or passenger side windshield frame.
[D] Crush is the difference between the test vehcile and examplar vehicle that is the intrusion of the windshield deformation. The intrusion is perpendicular to the plane of the windshield which is a resultant of the X & Z directions.

Examplar Vehicle Description

Year: 2008 Make: Toyota Model: Yaris VIN: jtdbt923384017665

Windshield Deformation Notes:

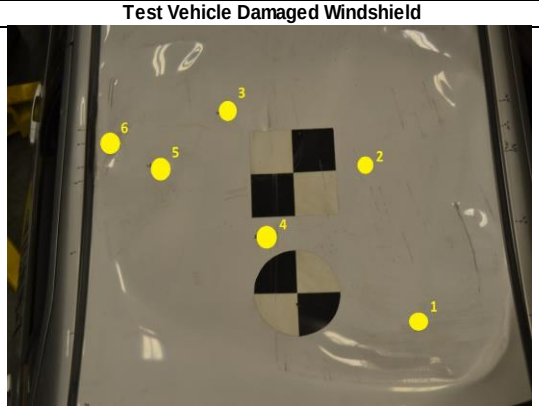
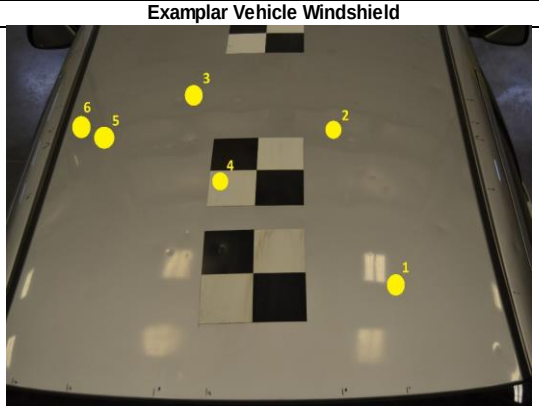
Test Vehicle Damaged Windshield	Examplar Vehicle Windshield
	

Figure F-1. Roof Deformation Data, Test No. UCSS-1

Date: 9/26/2018 Test Name: UCSS-1 VIN: jtdbt903194056758
Year: 2009 Make: Toyota Model: Yaris

VEHICLE DEFORMATION
WINDSHIELD

	POINT	Vertical Reference Length[A]	Vertical Reference Side[B] (Top or Bottom)	Lateral Referece Length[C]	Lateral Reference Side[B] (Driver or Pass.)	Examplar Vehicle Measurement	Test Vehicle Measurment	Crush[D] (in.)
WINDSHIELD	1	23 1/8	Top	21 7/8	Driver	5 1/8	4 3/4	-0.375
	2	27 1/2	Top	16 5/8	Driver	5 1/8	4 3/4	-0.375
	3	29	Top	25 3/4	Driver	5 1/8	5	-0.125

[A] Length to vertical reference, typically the top or bottom of the windshield frame.
[B] C Side of windshield frame, top, bottom, passenger, or driver, in which the reference was measured from.
[C] Length to lateral referene either the driver or passenger side windshield frame.
[D] Crush is the difference between the test vehcile and examplar vehicle that is the intrusion of the windshield deformation. The intrusion is perpendicular to the plane of the windshield which is a resultant of the X & Z directions.

Examplar Vehicle Description

Year: 2008 Make: Toyota Model: Yaris VIN: jtdbt923384017665

Windshield Deformation Notes:

Test Vehicle Damaged Windshield	Examplar Vehicle Windshield
	

Figure F-2. Windshield Deformation Data, Test No. UCSS-1

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

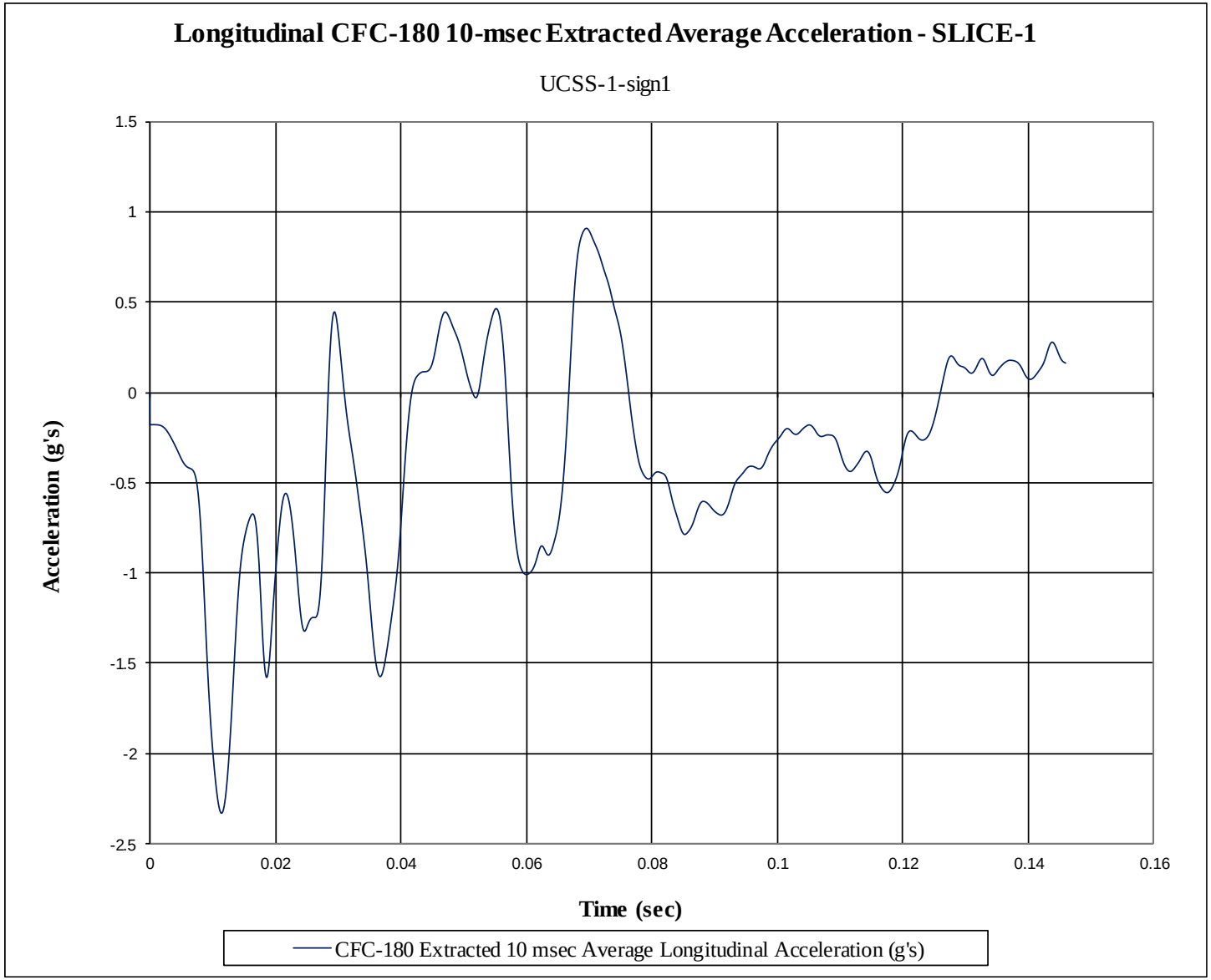


Figure G-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. UCSS-1A

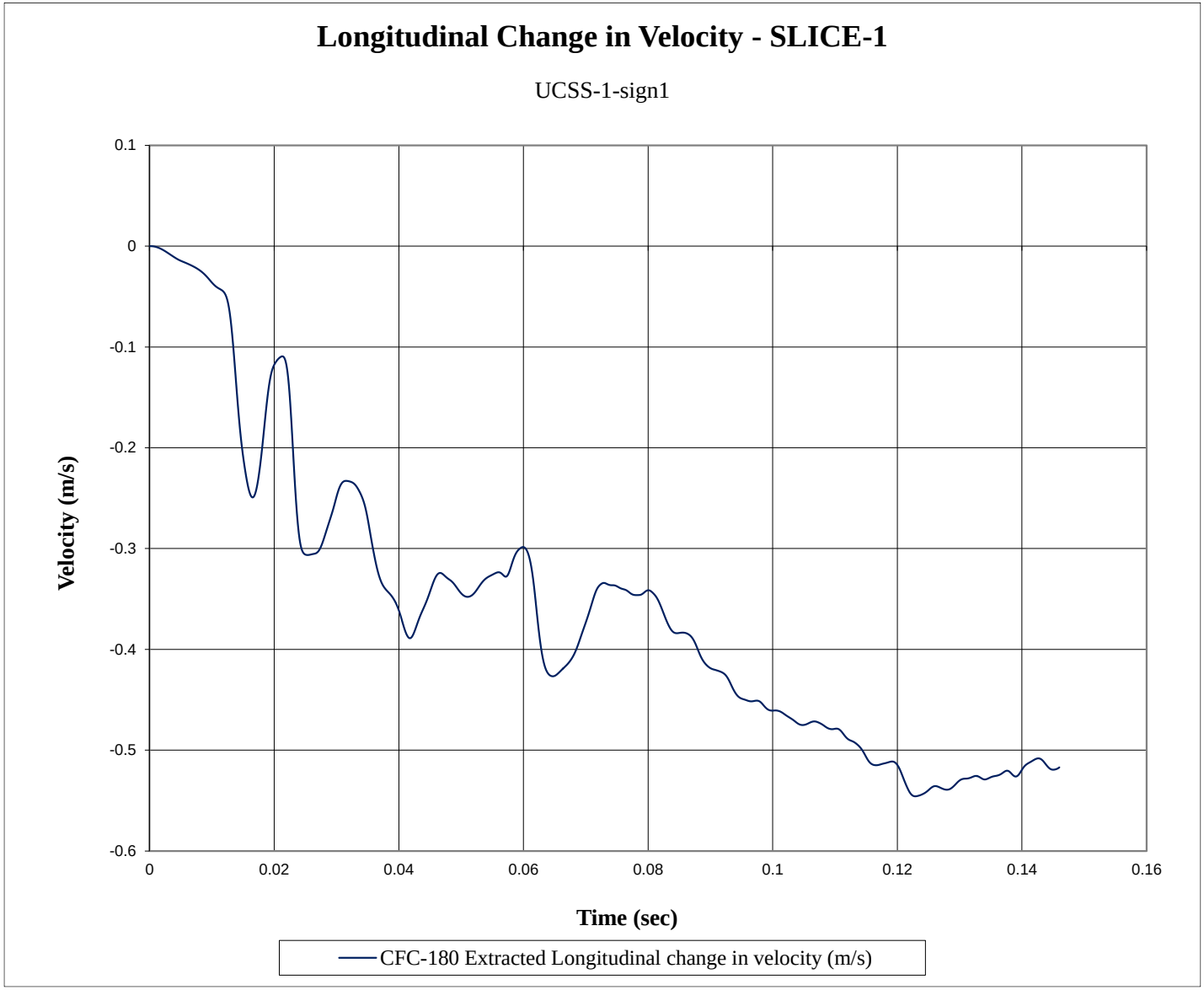


Figure G-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. UCSS-1A

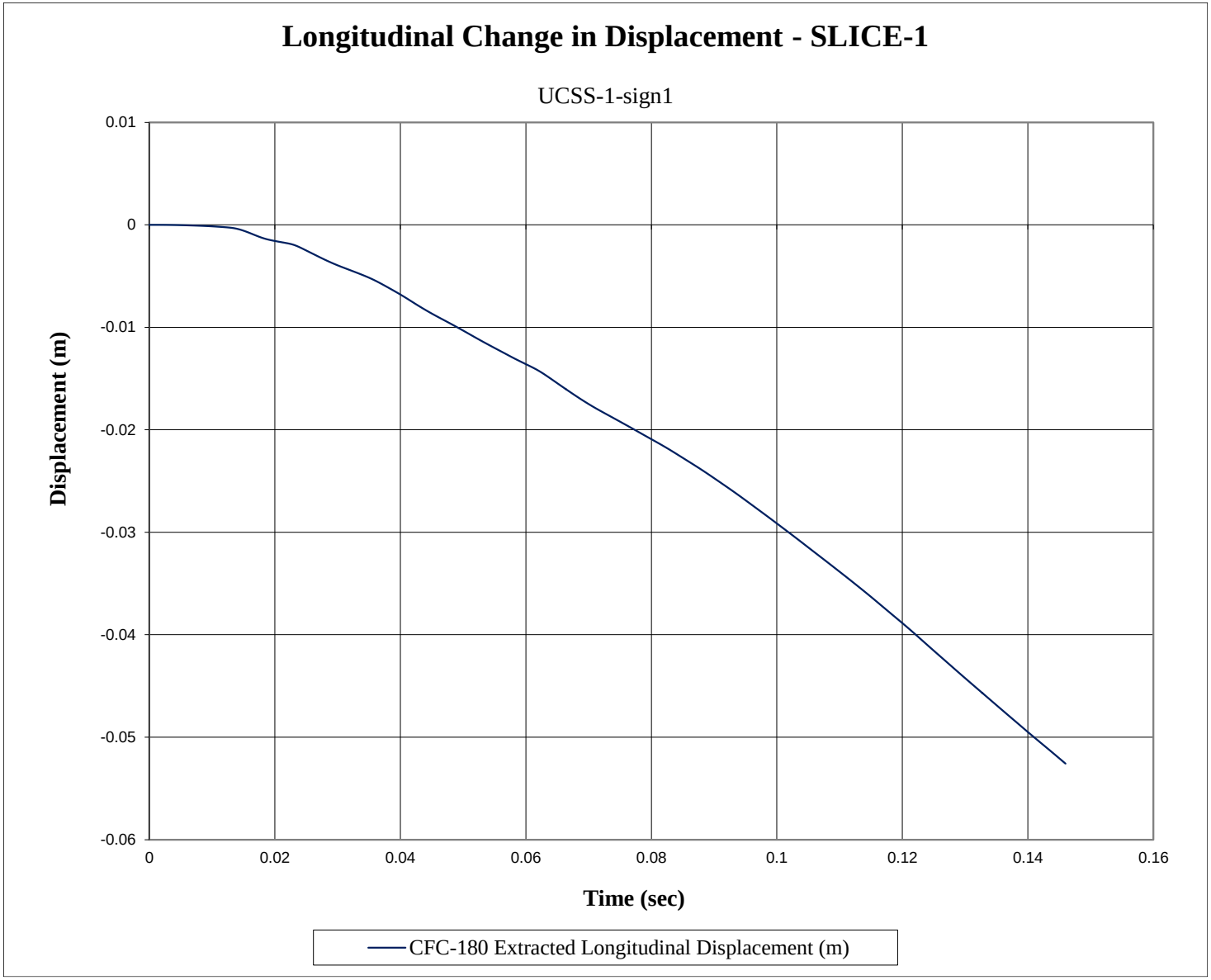


Figure G-3. Longitudinal Occupant Displacement (SLICE-1), Test No. UCSS-1A

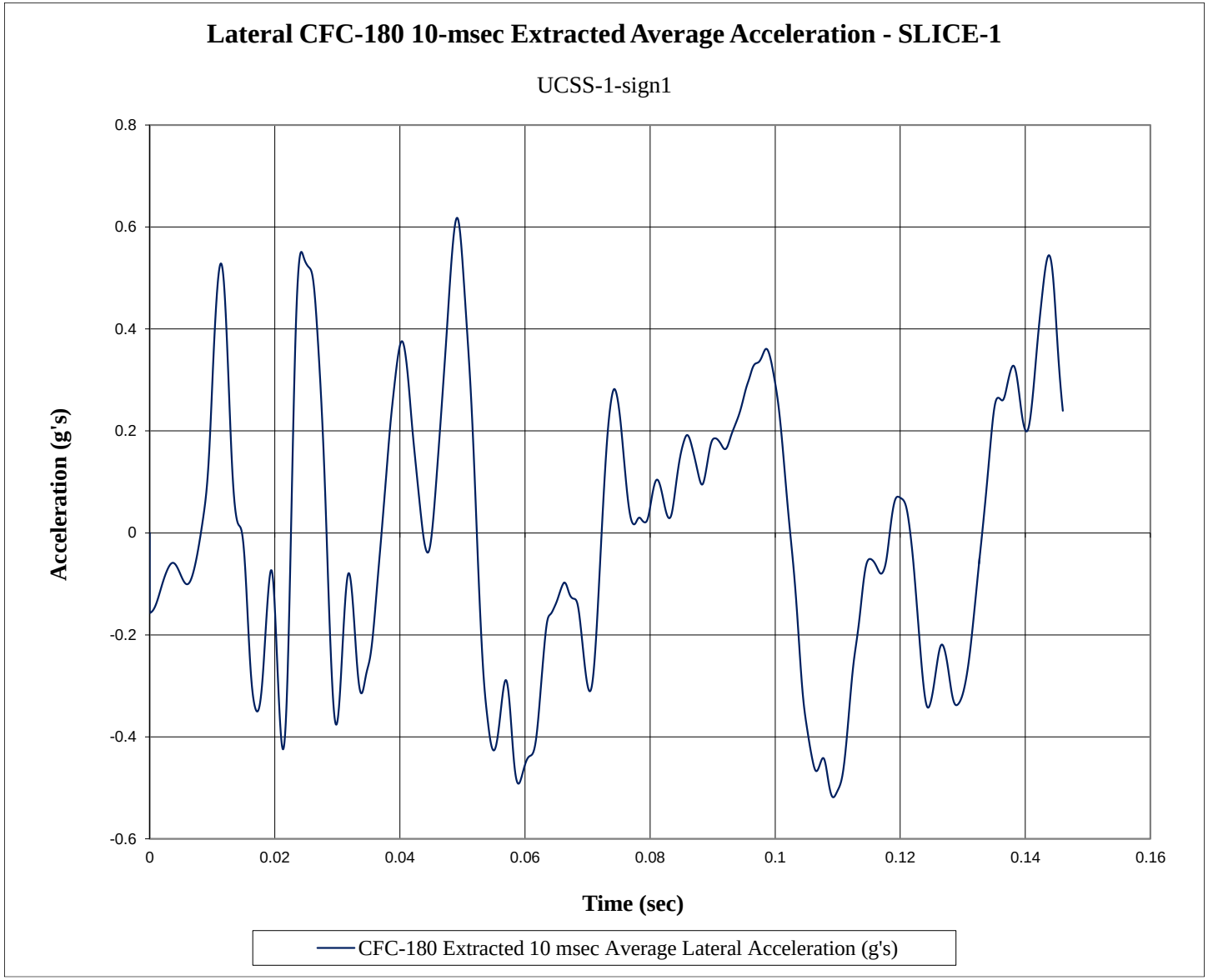


Figure G-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. UCSS-1A

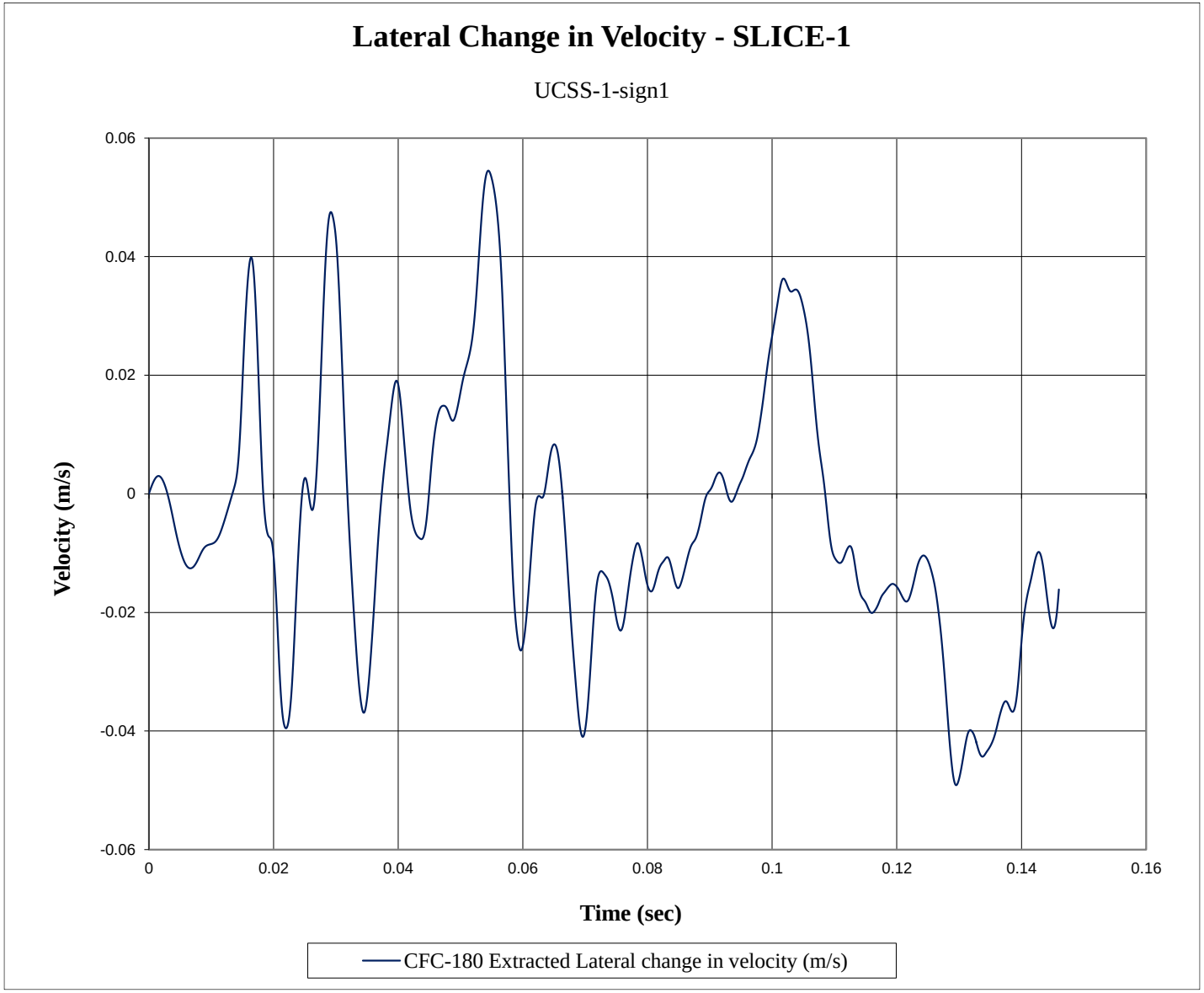


Figure G-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. UCSS-1A

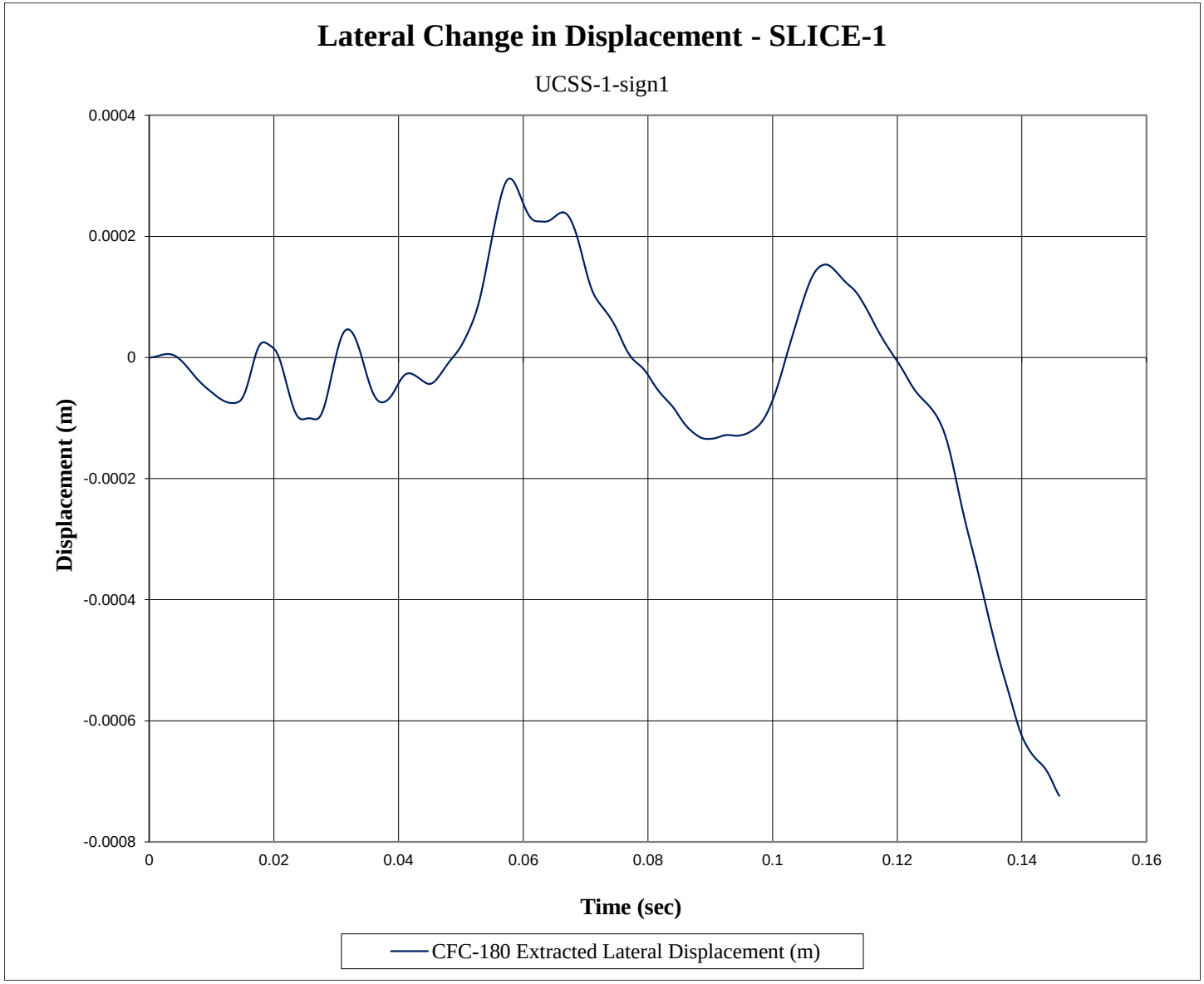


Figure G-6. Lateral Occupant Displacement (SLICE-1), Test No. UCSS-1A

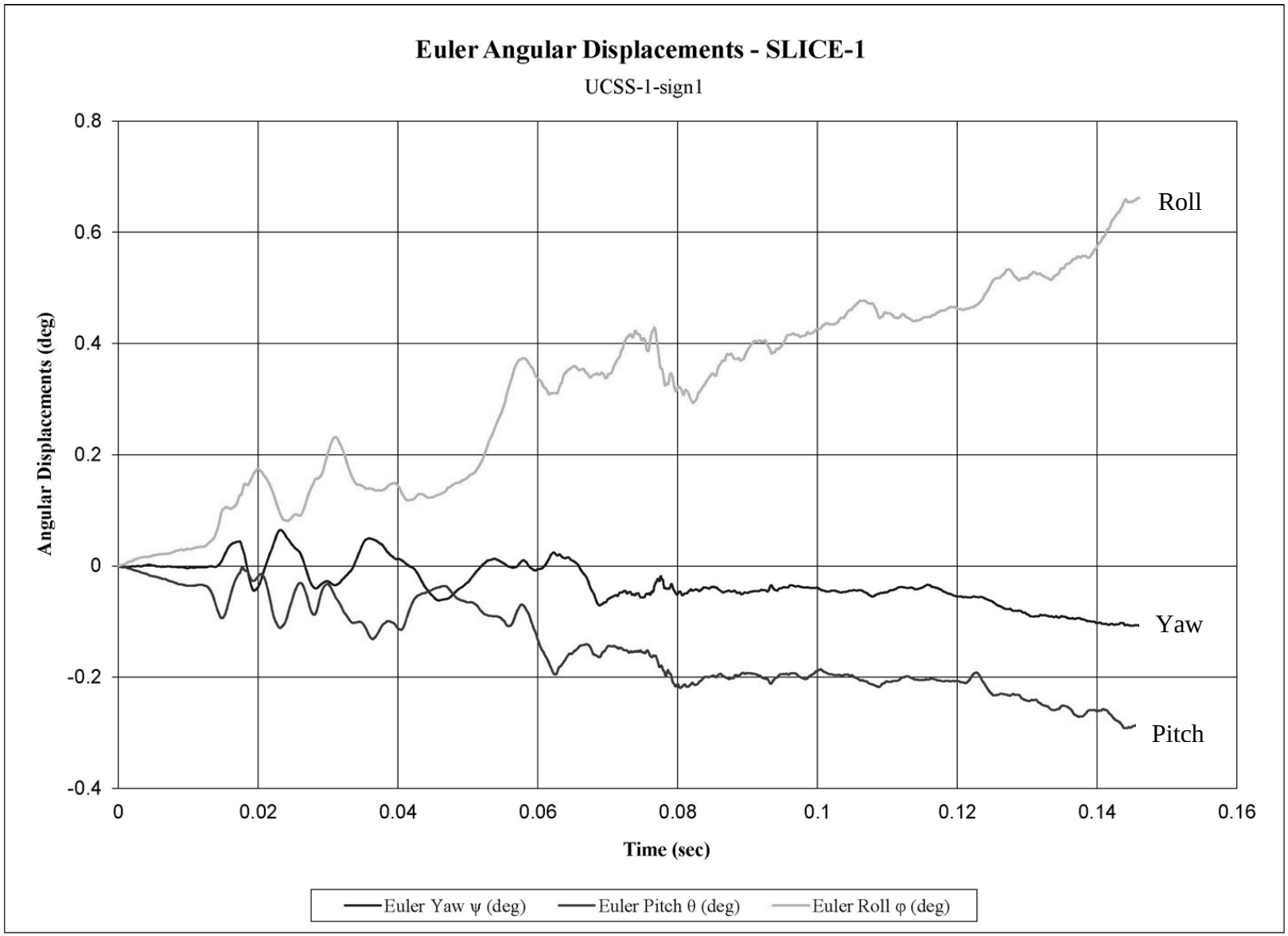


Figure G-7. Vehicle Angular Displacements (SLICE-1), Test No. UCSS-1A

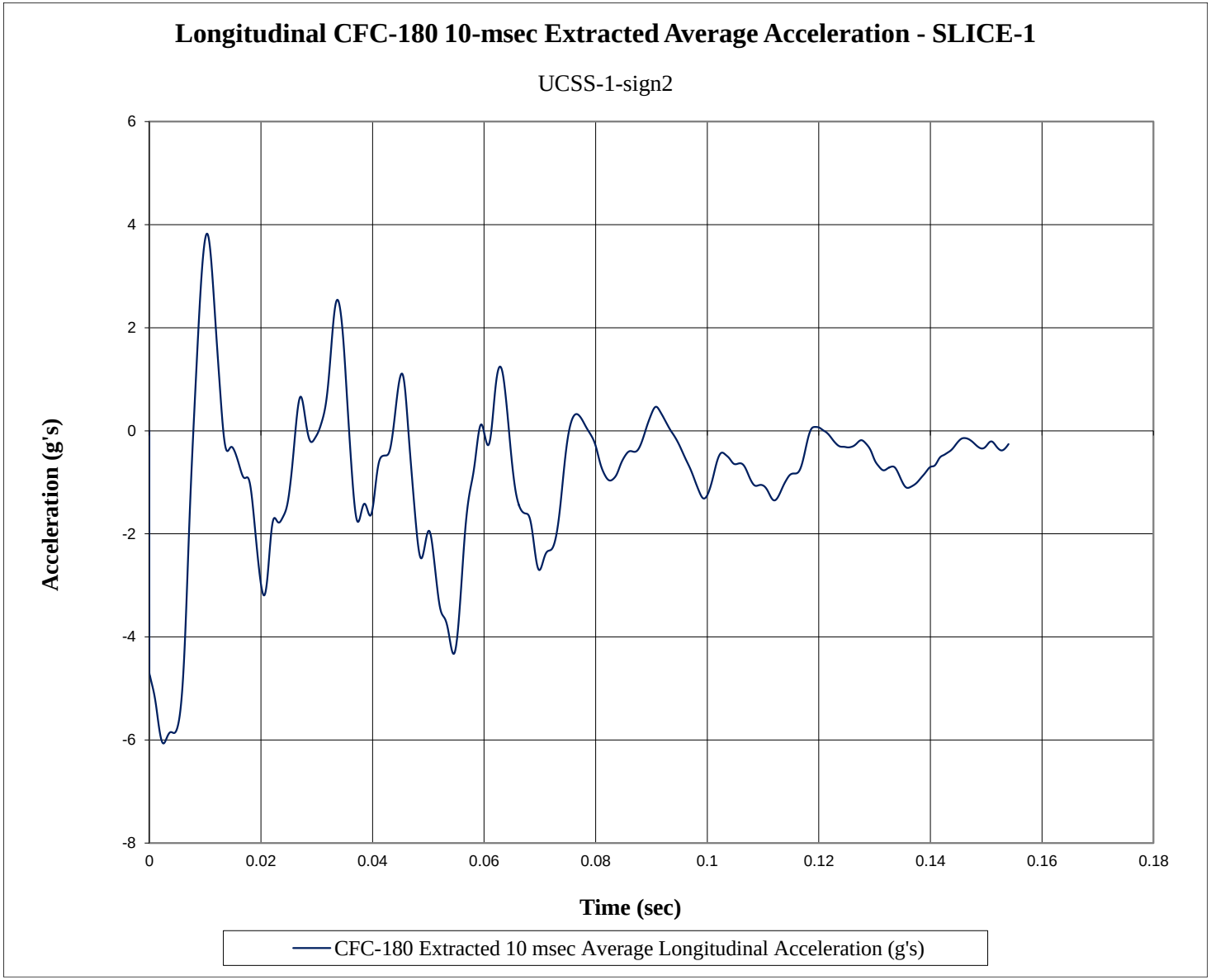


Figure G-8. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. UCSS-1B

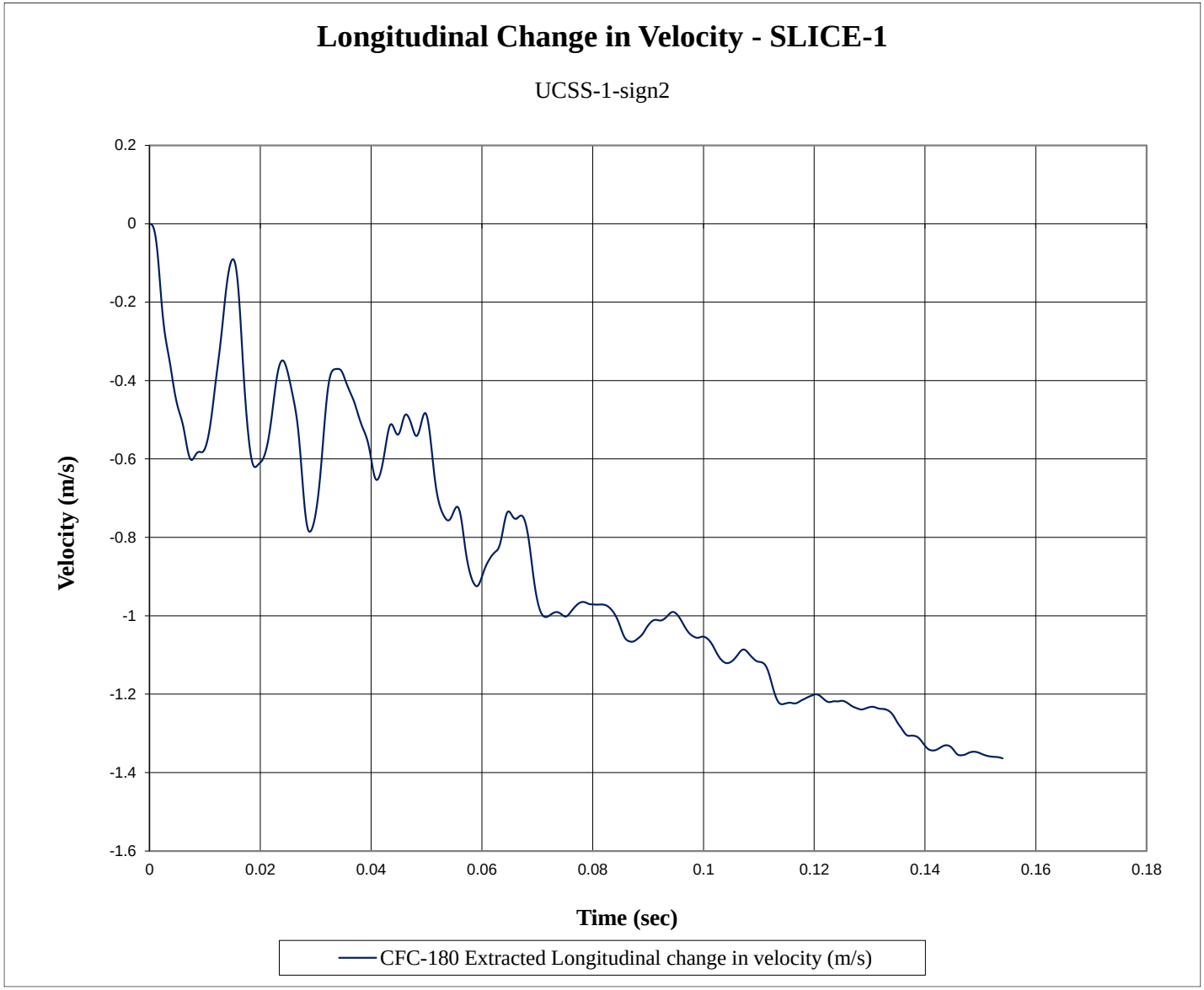


Figure G-9. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. UCSS-1B

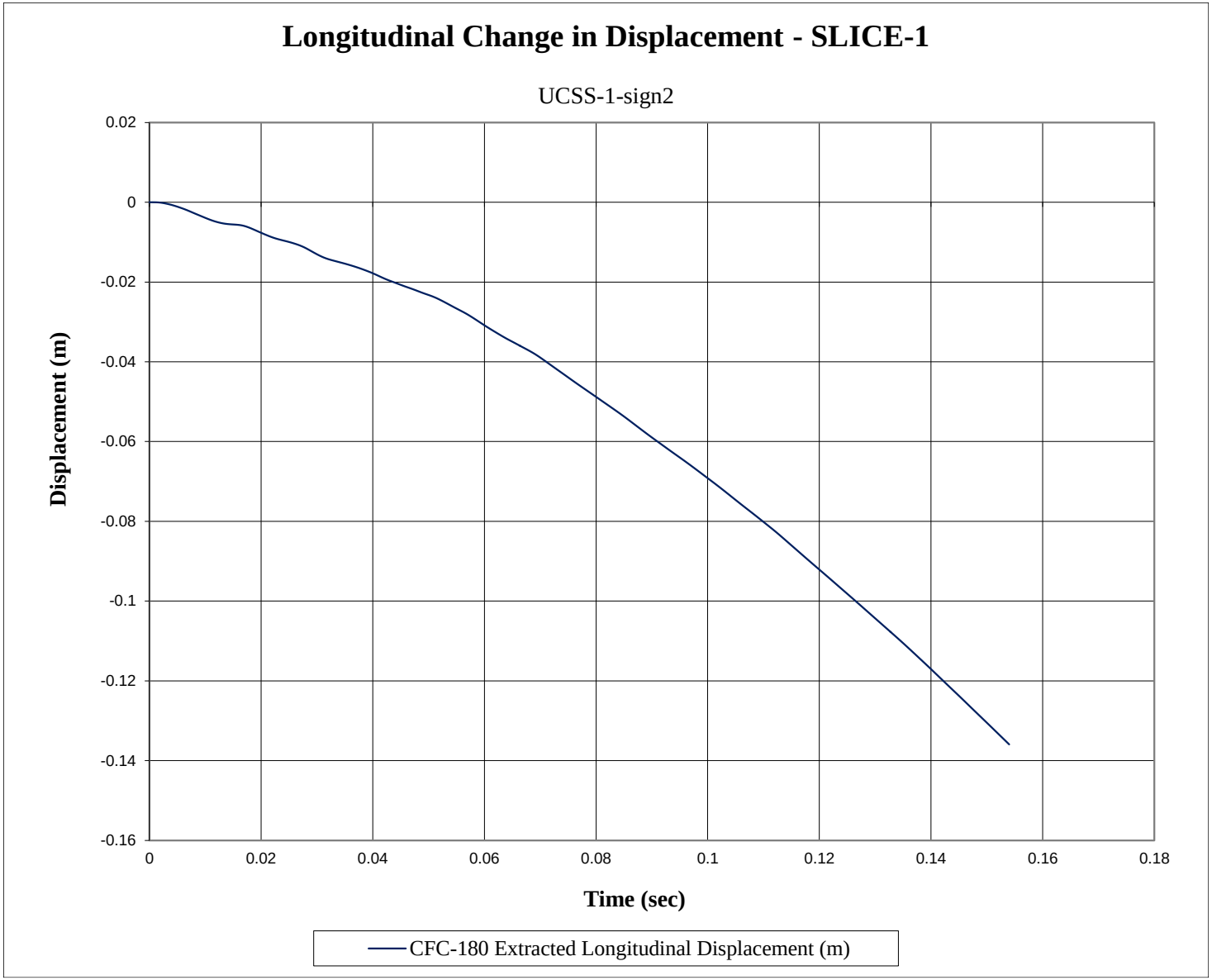


Figure G-10. Longitudinal Occupant Displacement (SLICE-1), Test No. UCSS-1B

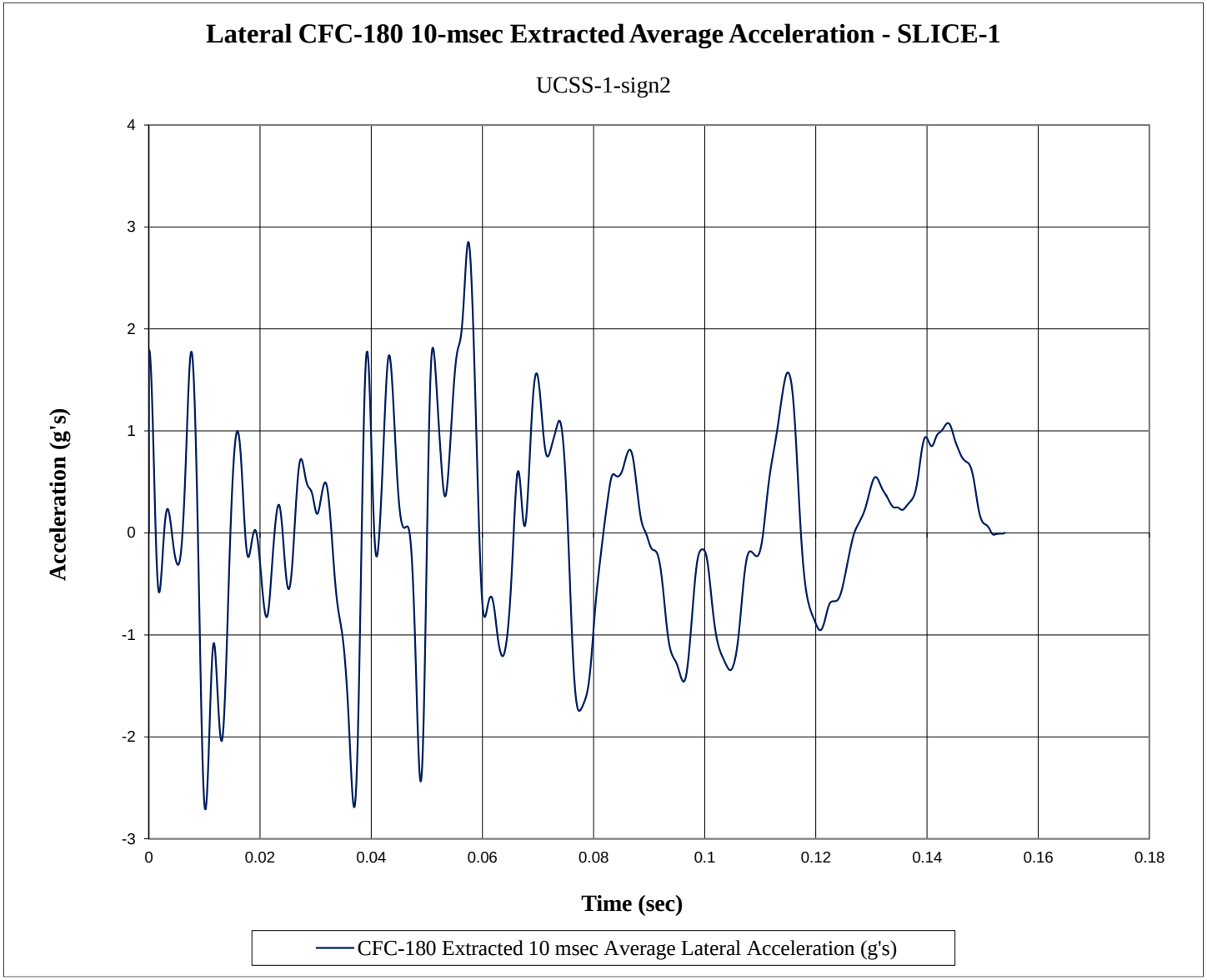


Figure G-11. 10-ms Average Lateral Deceleration (SLICE-1), Test No. UCSS-1B

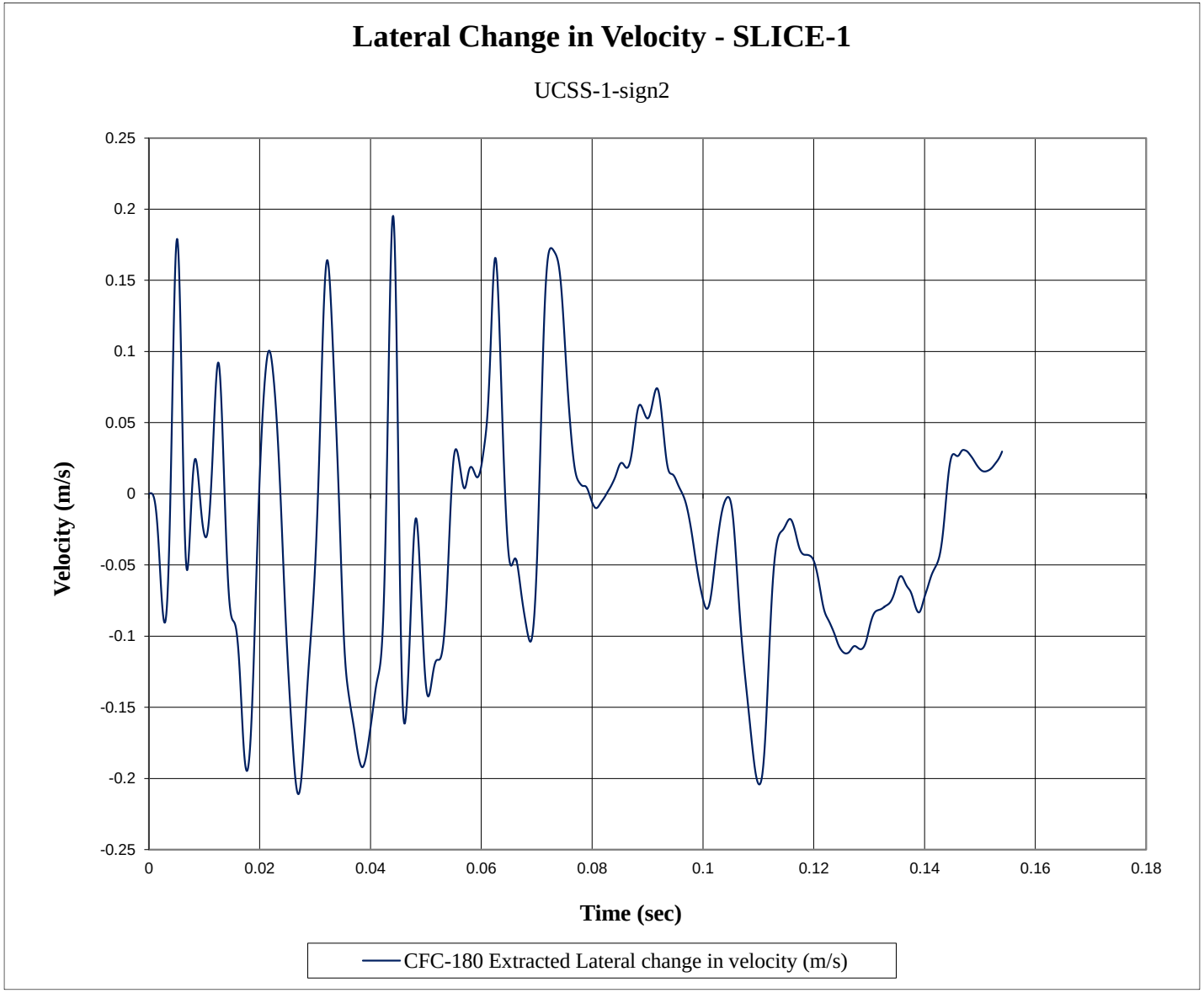


Figure G-12. Lateral Occupant Impact Velocity (SLICE-1), Test No. UCSS-1B

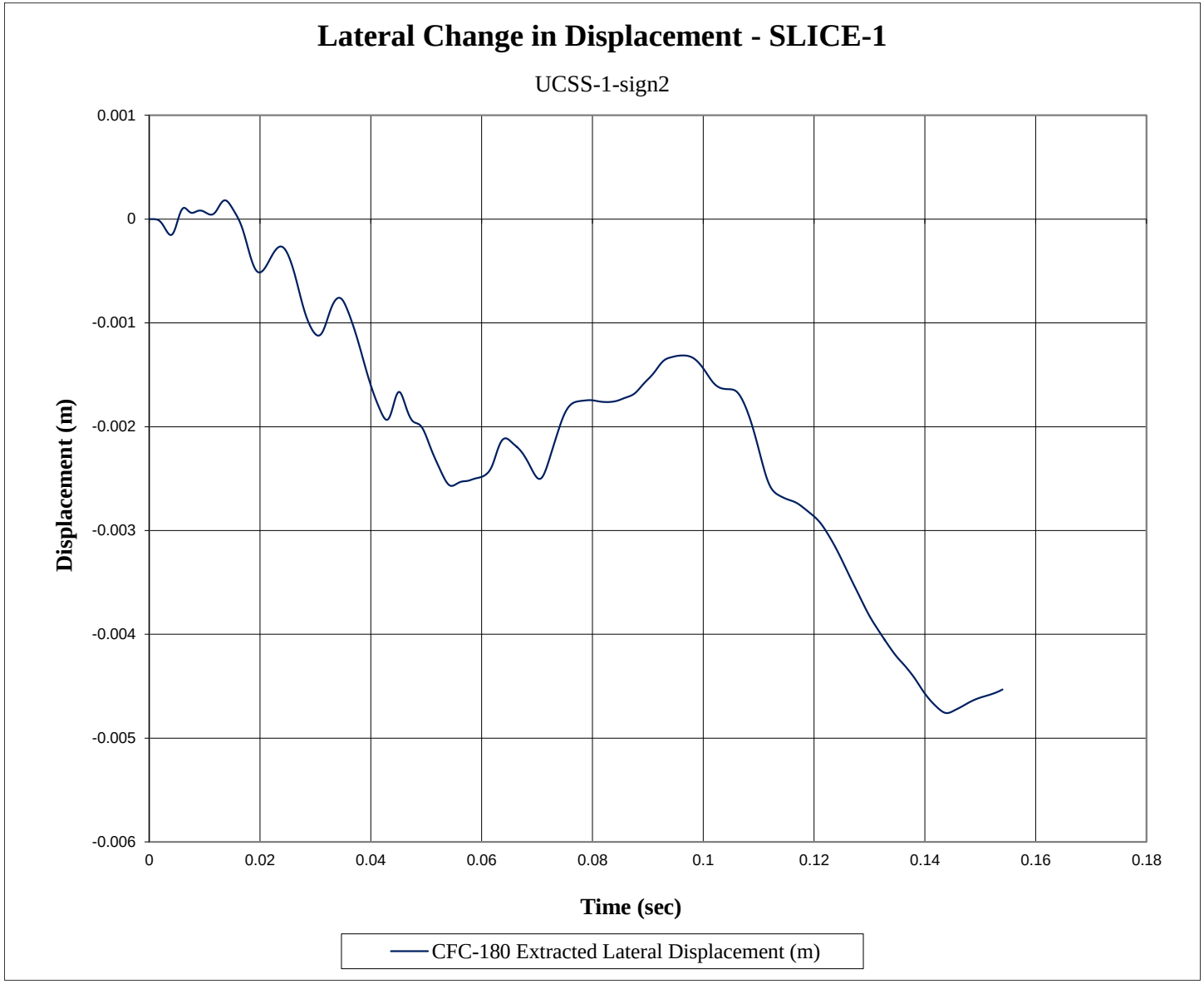


Figure G-13. Lateral Occupant Displacement (SLICE-1), Test No. UCSS-1B

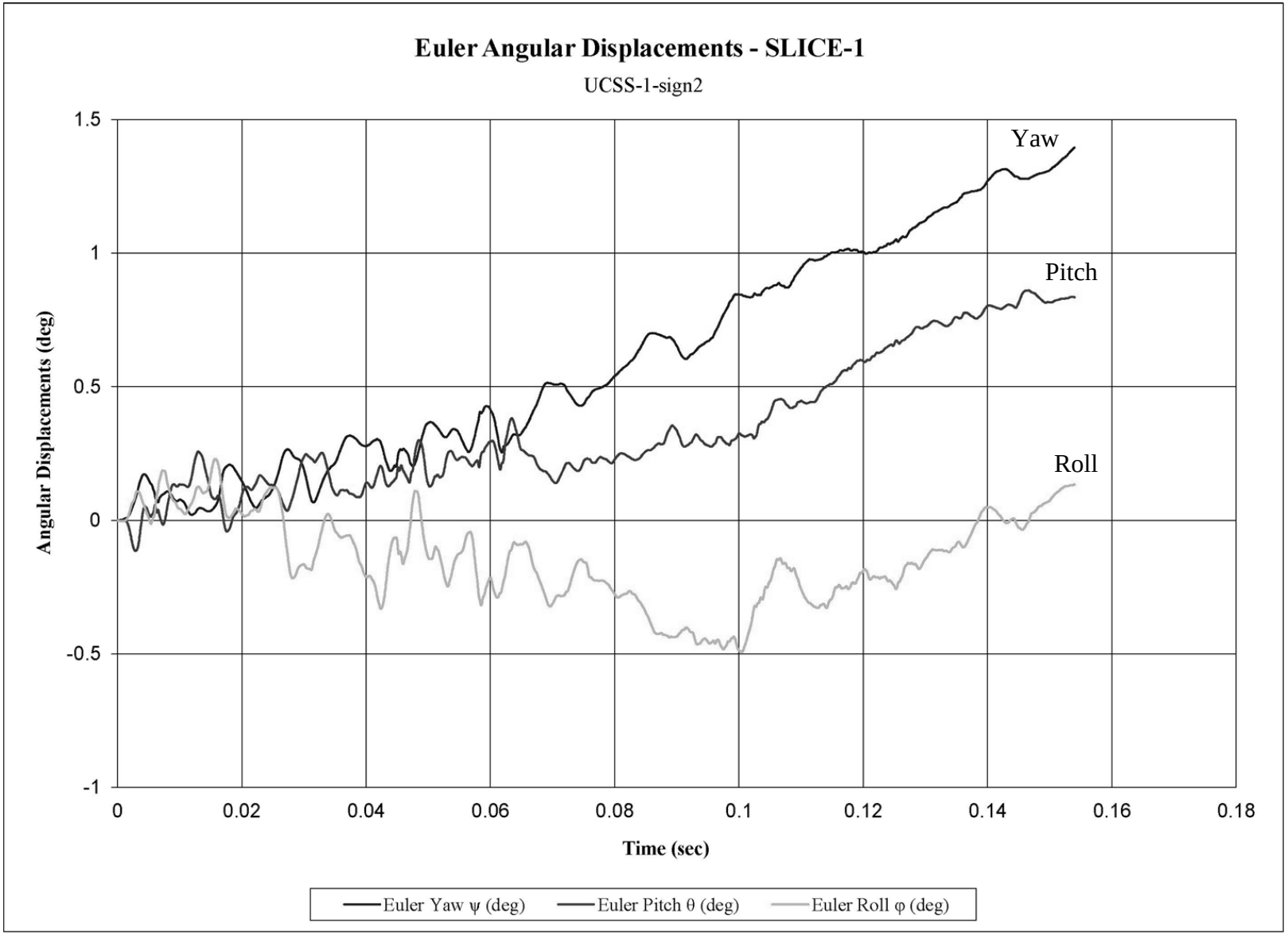


Figure G-14. Vehicle Angular Displacements (SLICE-1), Test No. UCSS-1B

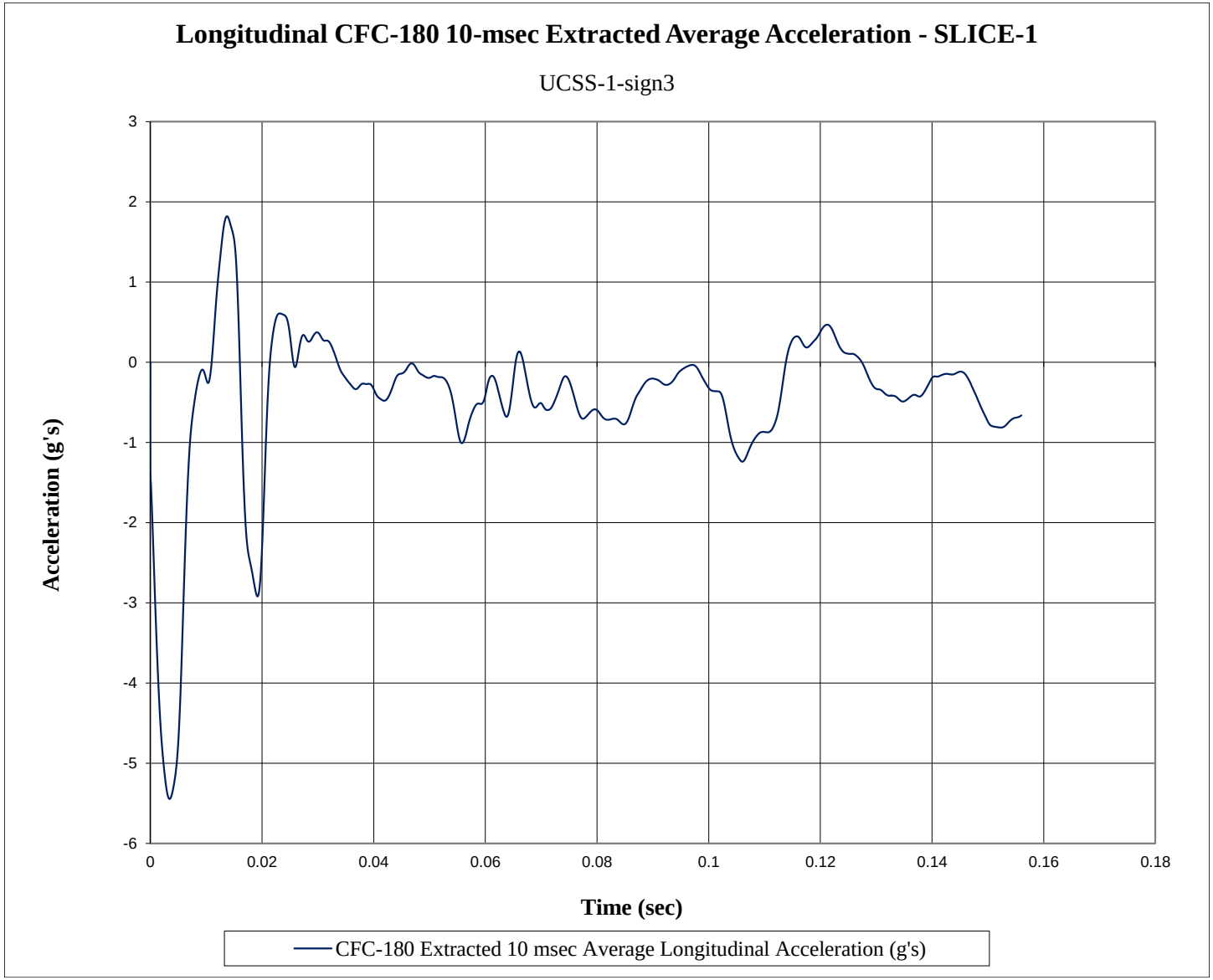


Figure G-15. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. UCSS-1C

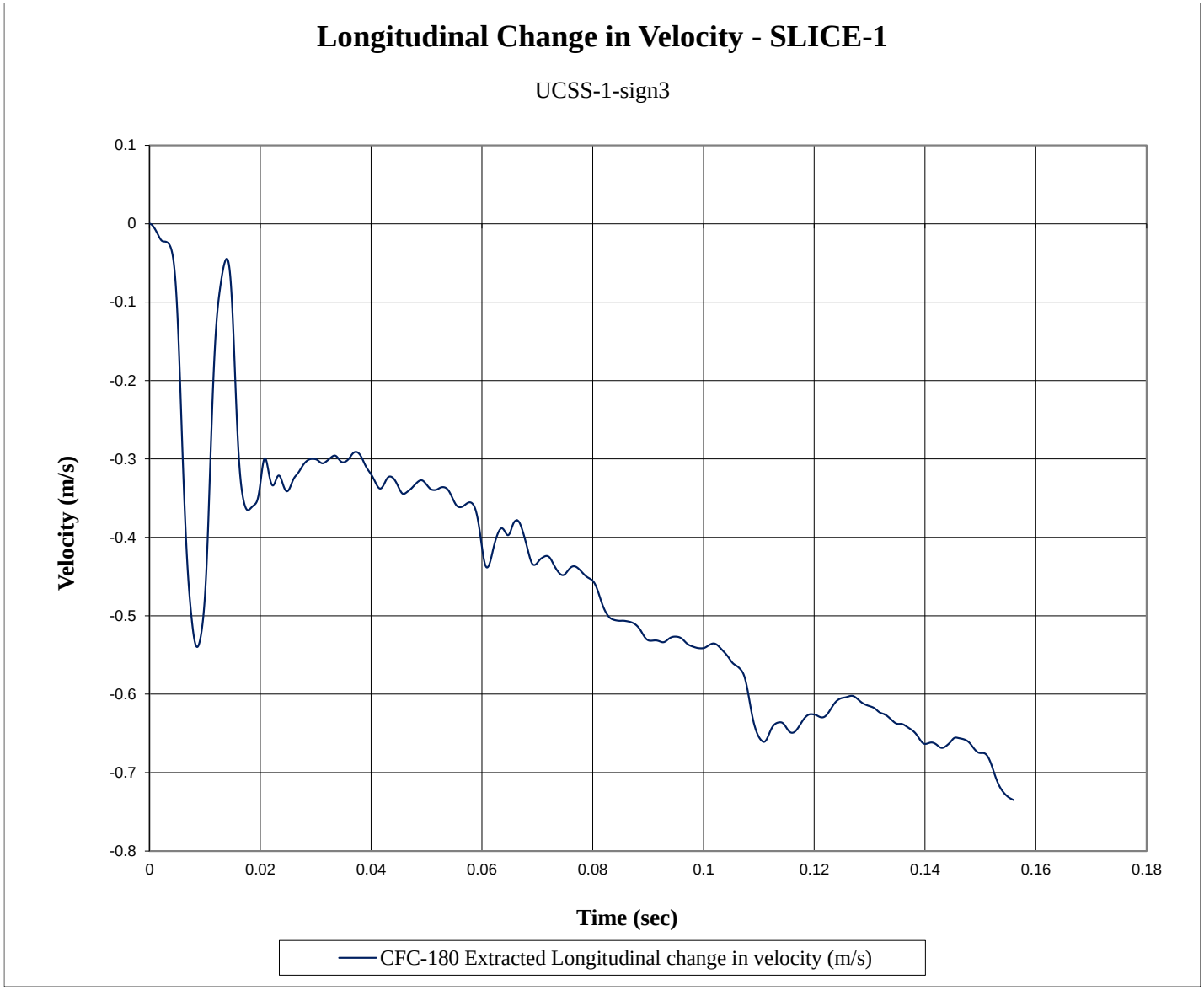


Figure G-16. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. UCSS-1C

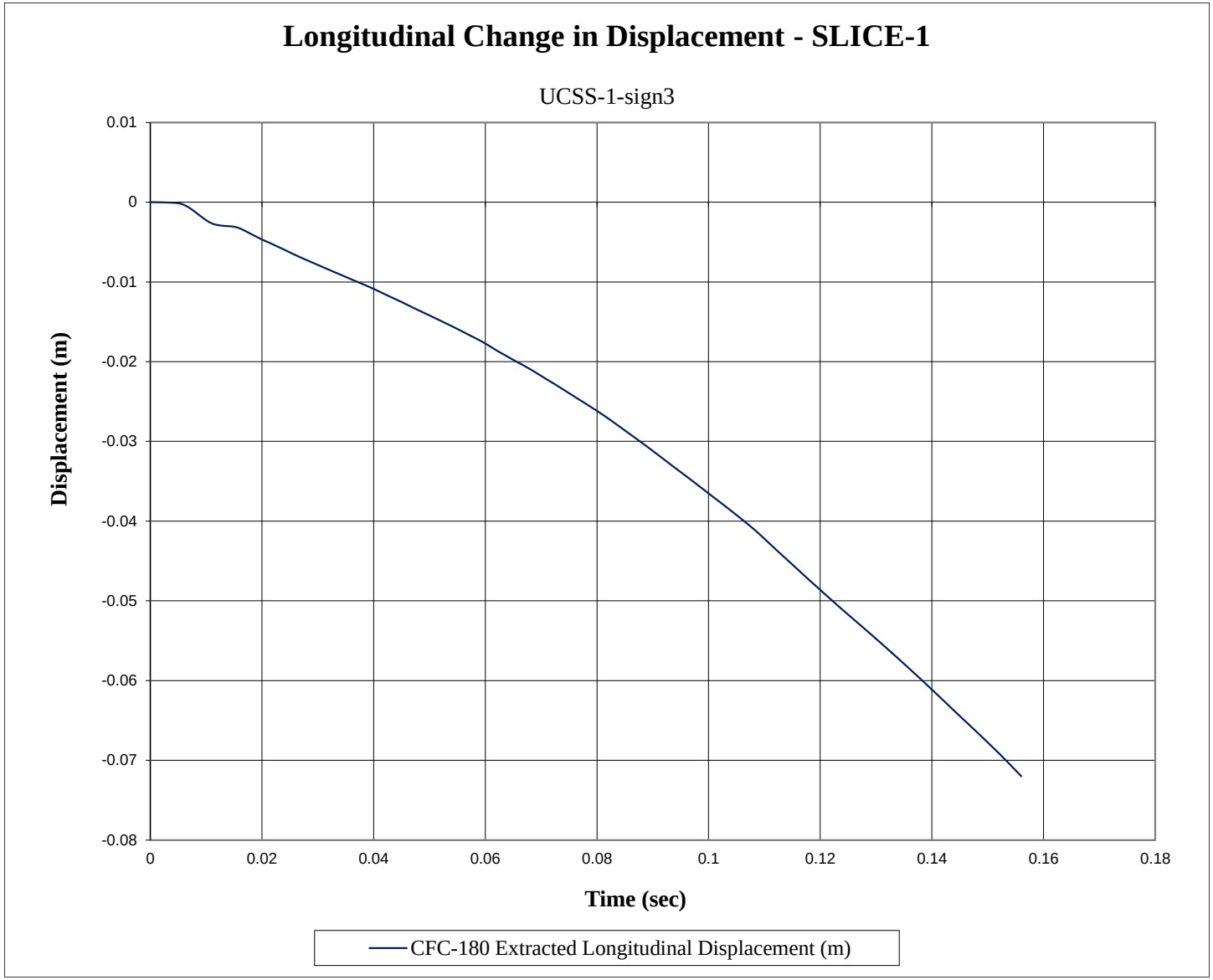


Figure G-17. Longitudinal Occupant Displacement (SLICE-1), Test No. UCSS-1C

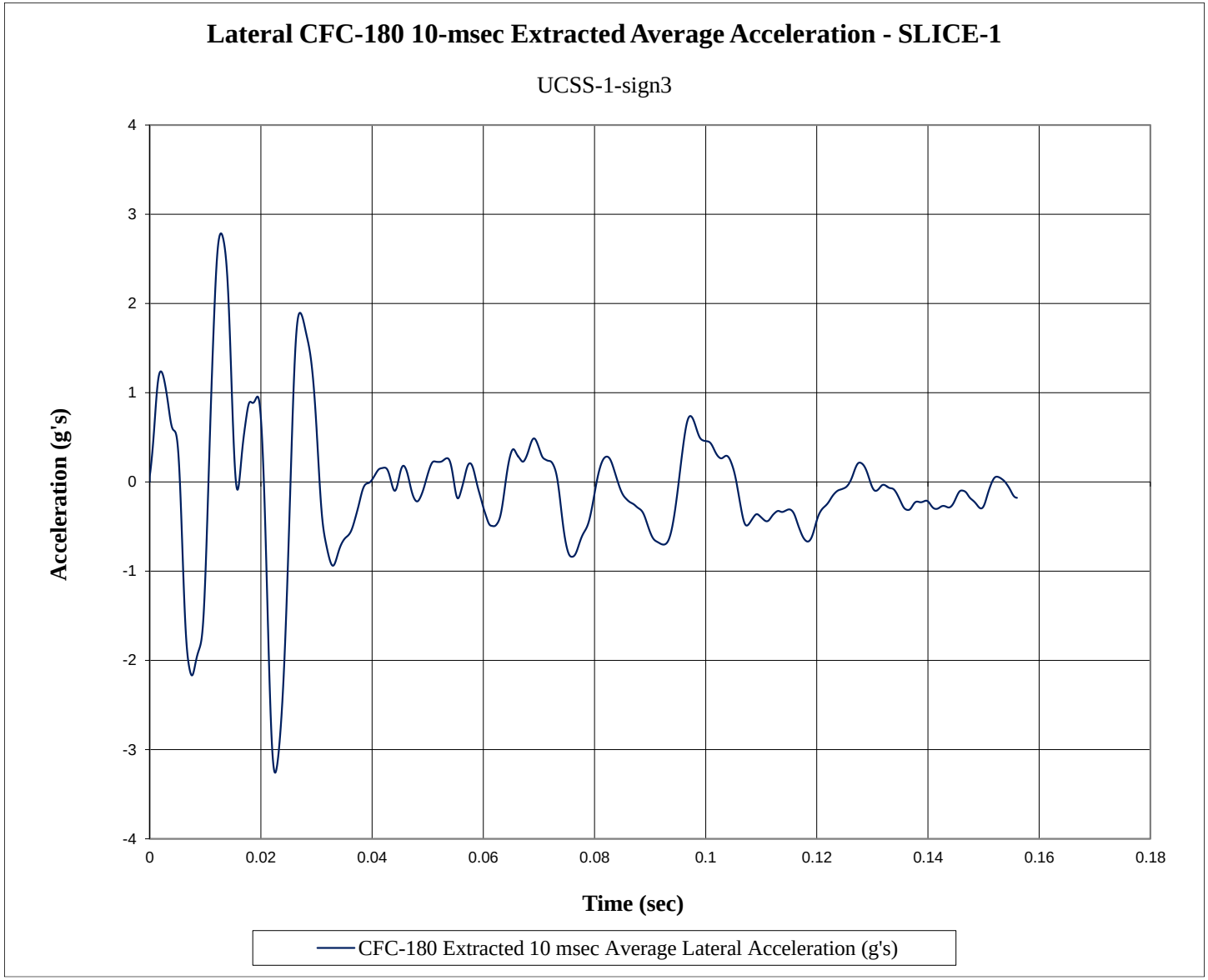


Figure G-18. 10-ms Average Lateral Deceleration (SLICE-1), Test No. UCSS-1C

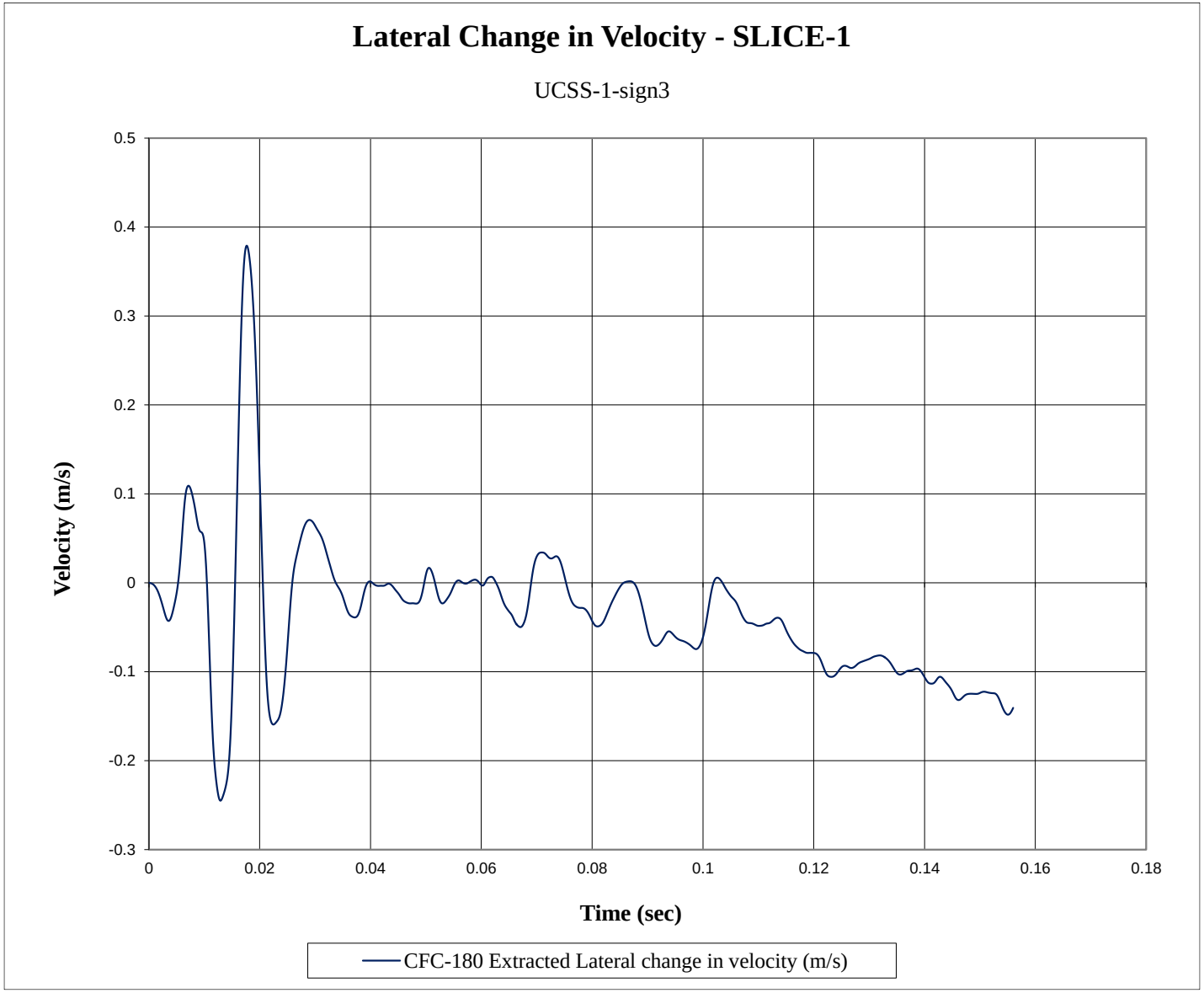


Figure G-19. Lateral Occupant Impact Velocity (SLICE-1), Test No. UCSS-1C

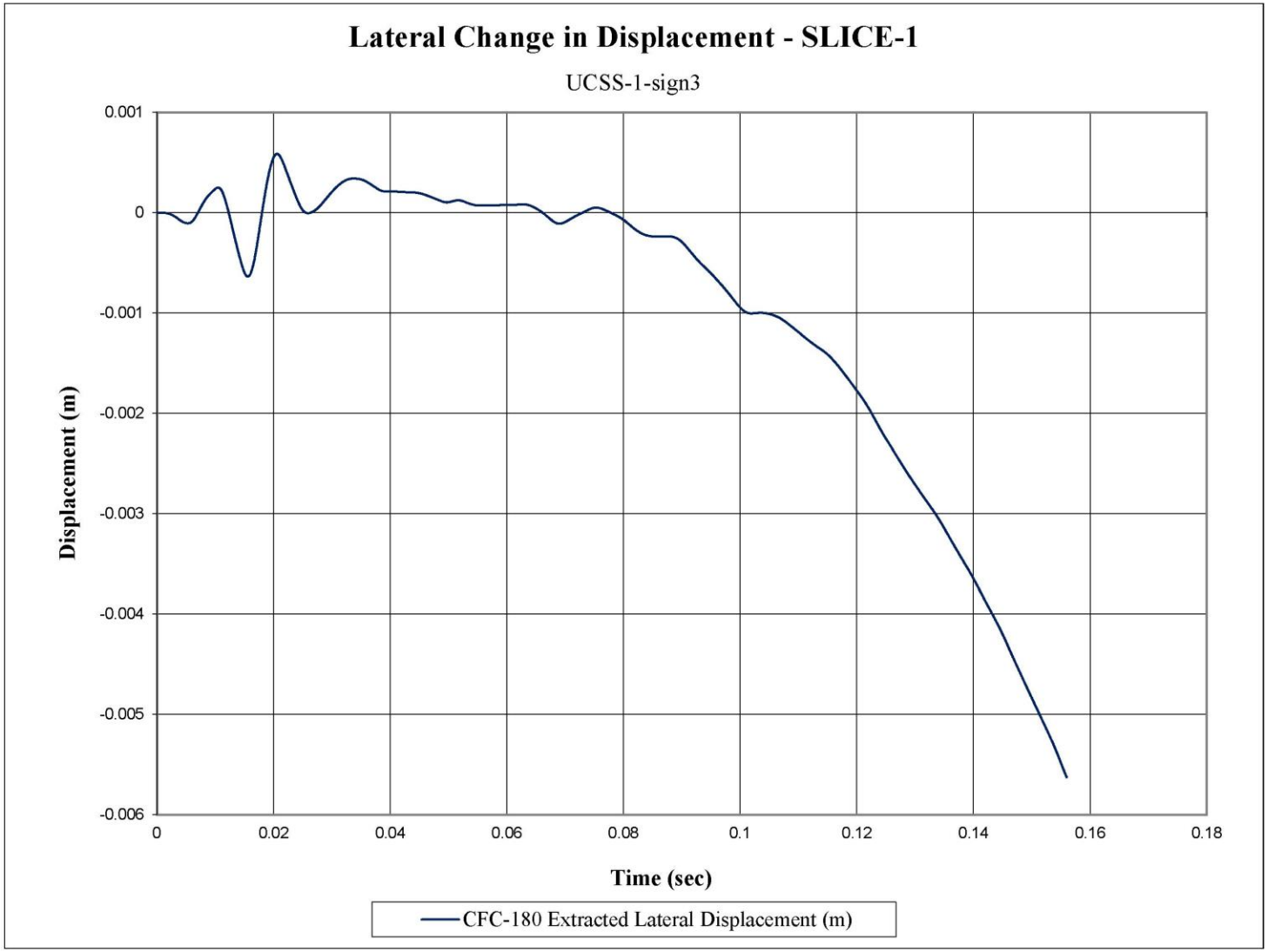


Figure G-20. Lateral Occupant Displacement (SLICE-1), Test No. UCSS-1C

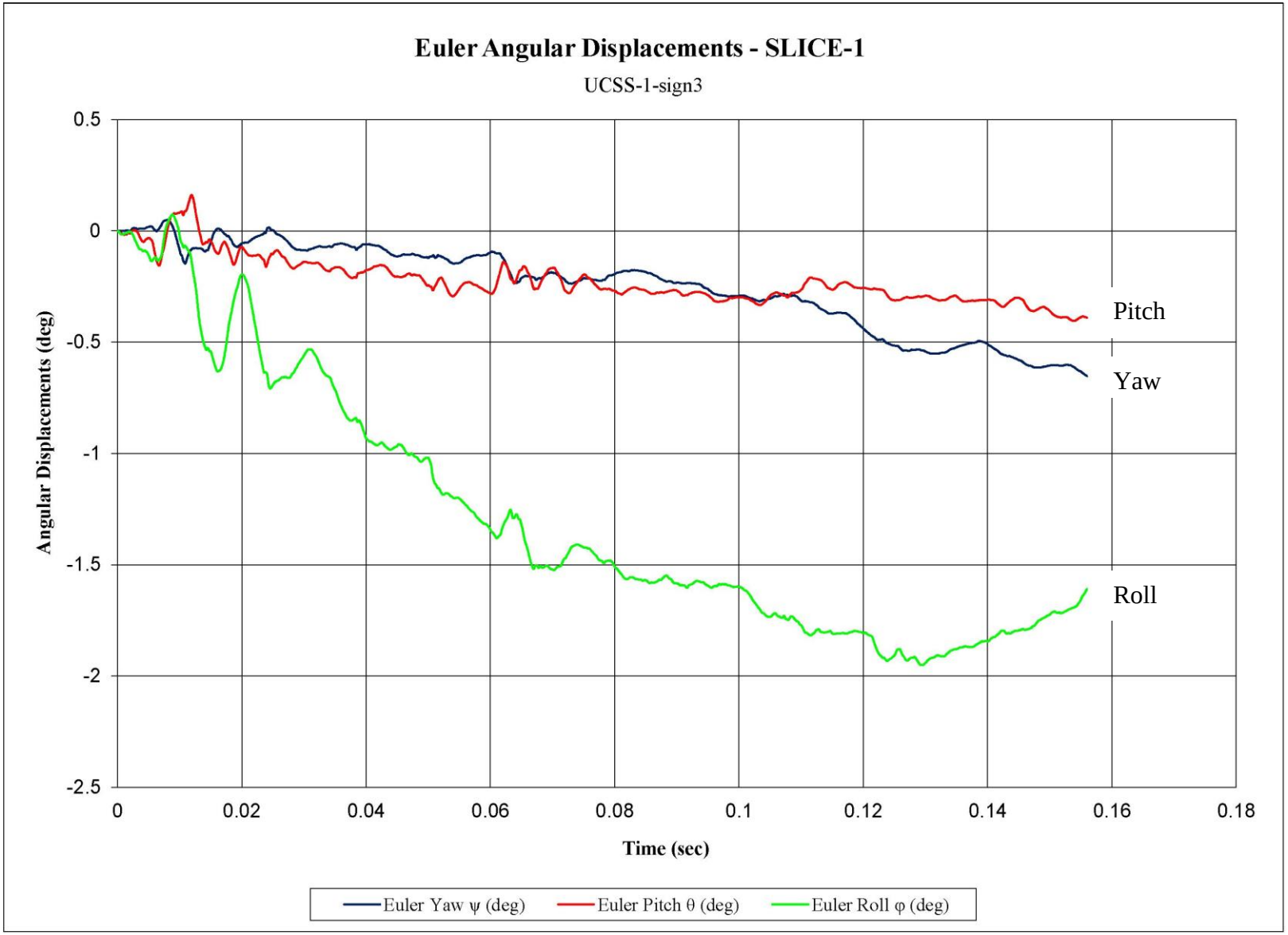


Figure G-21. Vehicle Angular Displacements (SLICE-1), Test No. UCSS-1C

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