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FULL-SCALE CRASH TEST OF A TWO-BAR METAL BRIDGE RAIL

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16. Abstract

The North Carolina Department of Transportation (NCDOT) frequently uses a two-bar metal bridge rail in scenic locations to preserve observational integrity. NCDOT had previously evaluated this system under National Cooperative Highway Research Program (NCHRP) Report No. 350 safety performance criteria, but recent updates to the American Association of State Highway Transportation Officials' *Manual for Assessing Safety Hardware (MASH)* necessitated further testing to ensure continued compliance with the latest safety standards. A 90-ft long, 30-in. tall vertical concrete parapet was constructed at Midwest Roadside Safety Facility's Outdoor Test Site. The top face of the parapet supported posts attached to two longitudinal elliptical rails offset from the front face of the parapet by 1 in.

The bridge rail was evaluated through two full-scale crash tests in accordance with Test Level 3 (TL-3) of MASH 2016. In test no. NCBR-1 (test designation no. 3-10), an 1100C small car impacted the downstream end of the barrier at 63.2 mph and an angle of 25.2 deg. In test no. NCBR-2 (test designation no. 3-11), a 2270P quad cab pickup truck impacted the upstream end of the barrier at 61.9 mph and an angle of 24.9 deg. In both tests, the two-bar metal bridge rail successfully contained and redirected the vehicle and did not penetrate or show potential for debris to penetrate the occupant compartment. All occupant risk measurements were below the maximum threshold. Thus, the NCDOT two-bar metal bridge rail was determined to be crashworthy according to MASH 2016 TL-3 standards.

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This report was completed with funding from the North Carolina Department of Transportation. 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 North Carolina Department of Transportation nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

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

INDEPENDENT APPROVING AUTHORITY

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

ACKNOWLEDGEMENTS

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North Carolina Department of Transportation
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1 INTRODUCTION

1.1 Background

The North Carolina Department of Transportation's (NCDOT) two-bar metal bridge rail was developed for use on scenic bridges to allow for enhanced viewing of the surroundings. An example of an installed configuration is shown in Figure 1. NCDOT's standard drawings of the two-bar metal bridge rail are shown in Appendix A.

Figure 1. NCDOT Two-Bar Metal Bridge Rail Installation

The crashworthiness of this bridge rail was previously recognized as meeting National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* [1] safety performance standards. NCHRP Report No. 350 has since been superseded by the American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware* (MASH 2016) [2]. Thus, it was desired to evaluate the bridge rail to MASH 2016 standards.

NCDOT solicited the help of researchers at the University of North Carolina–Charlotte (UNCC) and the Midwest Roadside Safety Facility (MwRSF) to evaluate the crashworthiness of the NCDOT two-bar combination bridge rail system. The research study consisted of an investigation of critical impact points (CIPs), evaluation of vehicle snag and occupant interaction with roadside structures, and barrier capacity and impact loading using finite element analysis (FEA) and full-scale crash testing according to MASH Test-Level (TL-3) test designation nos. 3-10 and 3-11 impact conditions.

1.2 Objectives

The objective of this study was to evaluate the NCDOT two-bar metal bridge rail according to the TL-3 safety performance criteria set forth in MASH 2016.

1.3 Scope

In order to complete the research objective, researchers conducted the following tasks:

1. Developed NCDOT-approved CAD drawings of the NCDOT two-bar metal bridge rail, and constructed the system at the MwRSF Outdoor Test Site.

2. Conducted two full-scale crash tests at the MwRSF Outdoor Test Site, according to MASH 2016 test designation nos. 3-10 and 3-11.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as the NCDOT two-bar metal bridge rail, 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. Note that there is no difference between MASH 2009 [3] and MASH 2016 for longitudinal barriers, such as the system tested in this project, except additional occupant compartment deformation measurements, photographs, and documentation are required by MASH 2016. According to TL-3 of MASH 2016, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 1.

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

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

[1] Evaluation criteria explained in Table 2

2.2 Evaluation Criteria

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

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), 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 2. MASH 2016 Evaluation Criteria for Longitudinal Barrier

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

3 DESIGN DETAILS

The test installation consisted of a 90-ft long concrete parapet with top-mounted aluminum posts and elliptical rails. Schematics of the test installation are shown in Figures 2 through 28. Photographs of the test installation are shown in Figures 29 through 33. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix B.

The concrete parapet consisted of three 30-ft long concrete barrier segments with 1-in. long, unfilled gaps to replicate bridge expansion joints in between segments. NCDOT typically installs a joint filler between expansion joints, but this material erodes over time. Thus, this material was omitted in construction to ensure a "worst practical case" impact scenario, maximizing the risk that snag could occur. The overall length and width of the concrete parapet were 90 ft and 14 in., respectively. The concrete parapets consisted of tapered buttress ends at the upstream and downstream end of the system, and 30-in. tall prismatic concrete parapet segments. The concrete end buttresses were 56 in. tall and were vertically tapered to 32¾ in. above the roadway at the outer faces over a longitudinal distance of 39 in. All edges of the concrete faces had ½-in. x ½-in. chamfers. Construction joints, consisting of ½-in. wide, saw-cut grooves extending on the front, back, and top faces, were installed in equally-spaced, 10-ft increments and at the interior faces of the concrete buttresses. Photos of the rail parapet construction are shown in Figure 29, and the parapet is shown in Figure 30.

Typical internal concrete reinforcement consisted of two vertically-staggered, #5 U-shaped stirrups tied together and spaced 12 in. apart on center, with eight #5 longitudinal rebar extending from end to end of each parapet segment. The internal rebar cages for the buttress ends consisted of a mesh of vertical #7 bars which followed the contour of the vertically-tapered ends, diagonal #7 bars parallel to the surface of the taper, and #6 longitudinal bars above the typical #5 longitudinal bars. All rebar were Grade 60 and had a minimum clear cover of 2 in. Concrete reinforcement details are shown in Figures 16 through 23.

The rail system consisted of 16 vertical post and base plate assemblies attached to two elliptical rail segments, as shown in Figures 5 through 8. Posts consisted of welded aluminum plates measuring 23½ in. tall, 5¾ in. wide, and 4¼ in. deep at the base, mounted to the top of a two-piece, cast aluminum base plate assembly, as shown in Figures 6 through 8. The posts were riveted through the front face of the base plate assembly with ¾-in. diameter, 1-in. long aluminum rivets. The posts were installed with the front flange offset 5¾ in. from the traffic-side face of the rail. As a result, there was a 1-in. lateral offset between the front face of the concrete parapet and the leading edge of the aluminum rail.

Post nos. 1 and 16 were spaced 16 in. from the upstream and downstream edges of the parapet, respectively, in compliance with NCDOT design specifications [4]. Post nos. 1 through 3 and 14 through 16 were spaced 38 in. apart. Post nos. 3 through 6, where impact for test no. NCBR-2 occurred, were spaced 78 in. apart. Post nos. 6 through 13, where impact for test no. NCBR-1 occurred, were spaced 72 in. apart. Post nos. 13 and 14 were spaced 68 in. apart. NCDOT state standards permit the post spacing for the two-bar bridge rail system to be up to 6 ft – 6 in. apart. In addition, there are minimum allowable distances between the expansion gaps and the vertical post-to-parapet connections. The tested post configuration was selected to maximize the loading on the rail splices by placing posts on the downstream sides of the expansion joints, and the post spacing was selected to be consistent with NCDOT standards for rail end sections and expansion joint offsets. This was deemed a critical construction scenario to maximize the likelihood of a vehicle stiff element, such as a hood or quarter panel, protruding above the top surface of the concrete parapet and engaging with the upstream vertical edge of a post flange, and also to increase the possibility of vehicle snag at the expansion gap. Real-world installations of the NCBR 2-bar bridge rail were examined and the test setup was determined to be comparable to rail spacings for previously-constructed systems.

Two elliptical rail segments were mounted on the front side of each aluminum post, as shown in Figures 3, 4, and 31. The elliptical rails were 4¾ in. wide and 4 in. tall, with a grooved back slot, as shown in Figure 12. At each post location, clamp bars and shim plates (as needed for alignment) were bolted to the posts with ½-in.-13 UNC, 1-in. long, ASTM F593 stainless steel cap screws, as shown in Figures 3, 9, and 10. Shaped splice bars measuring 36 in. long with dimpled back plates were inserted into the elliptical rails at every expansion joint, which provided rail shear and bending connectivity. Post-to-rail attachment details are shown in Figure 32.

The post base assemblies were attached to the top surface of the concrete parapet using four ¾-in. diameter by 2½-in. long, ASTM A3125 bolts threaded into steel ferrules, as shown in Figures 3, 15, and 16. The ferrules were welded to a wire cage and cast into the concrete parapets. The upstream and downstream ends of the aluminum rail were bolted to ½-in. thick, L-angle brackets which connected the back side of the elliptical aluminum rails to the interior vertical face of the concrete buttress, as shown in Figures 13 and 14. The L-angle brackets were bolted to the concrete buttress ends using a ¾-in. diameter, 7-in. long threaded rod with washer and nut epoxied into the buttress face to a minimum depth of 5 in., as shown in Figure 4. The epoxy was Adhesive Technologies (ATC) Ultrabond 1 with a minimum bond strength of 1,100 psi. Post-to-parapet and rail end anchorage attachment details are shown in Figures 32 and 33.

The NCDOT two-bar bridge rail system is typically installed on a reinforced box girder bridge deck system, but based on feedback from NCDOT, the strengths of the barrier-to-deck connection and the stiffness of the bridge deck were deemed sufficient to install the parapet directly to the top surface of the concrete tarmac at the MwRSF Outdoor Test Site to represent typical installation on an NCDOT bridge deck. Vertical attachment of the concrete parapet to the concrete tarmac surface consisted of #5 rebar embedded 6 in. into the tarmac on the front and back sides of the system and spaced 12 in. apart on centers, as shown in Figures 16 through 23. The end buttresses were anchored to the concrete tarmac using #7 bars epoxied to the tarmac surface, also with an embedment depth of 6 in. to ensure full development of the bars.

A field test of a threaded anchor rod epoxied into the barrier was conducted prior to full-scale testing. The 6.4 kip achieved exceeded the 5 kip requirement. The load-force plot for the test is shown in Figure 34. The critical impact point for test no. NCBR-1 was $54^{9}/_{16}$ in. upstream from post no. 11, 43.2 in. upstream from the expansion joint between post nos. 10 and 11. The critical impact point for test no. NCBR-2 was $61^{15}/_{16}$ in. upstream from post no. 6, 51.6 in. upstream from the expansion joint between post nos. 5 and 6. Both critical impact points were selected based on CIP simulation results from UNCC and verified by NCDOT. The impact side of the rail was painted white to clearly delineate marks produced during impact. Impact points for test nos. NCBR-1 and NCBR-2 are shown in Figures 27 and 28, respectively. Photographs of the constructed system are shown in Figures 30 through 33.

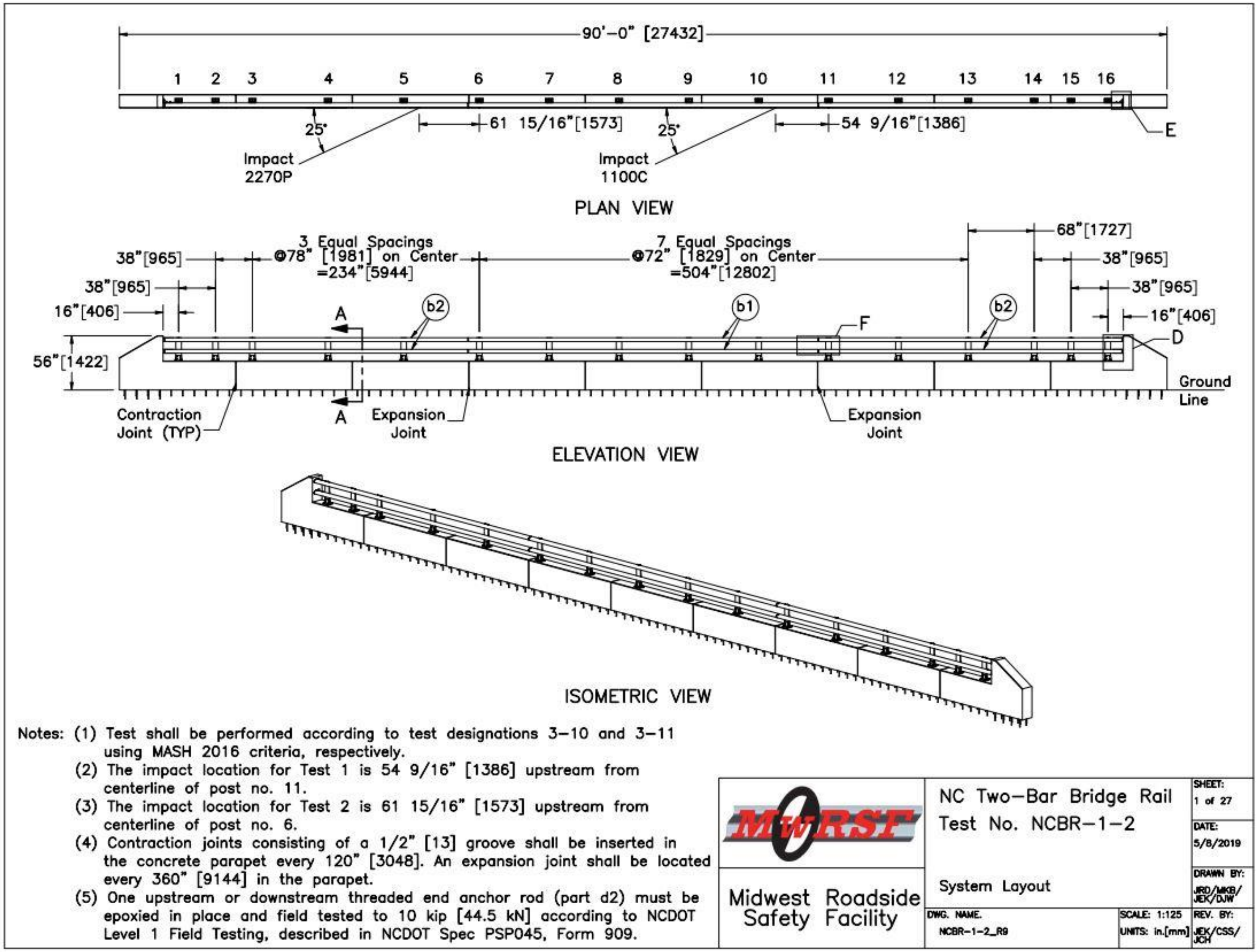


Figure 2. System Layout, Test Nos. NCBR-1 and NCBR-2

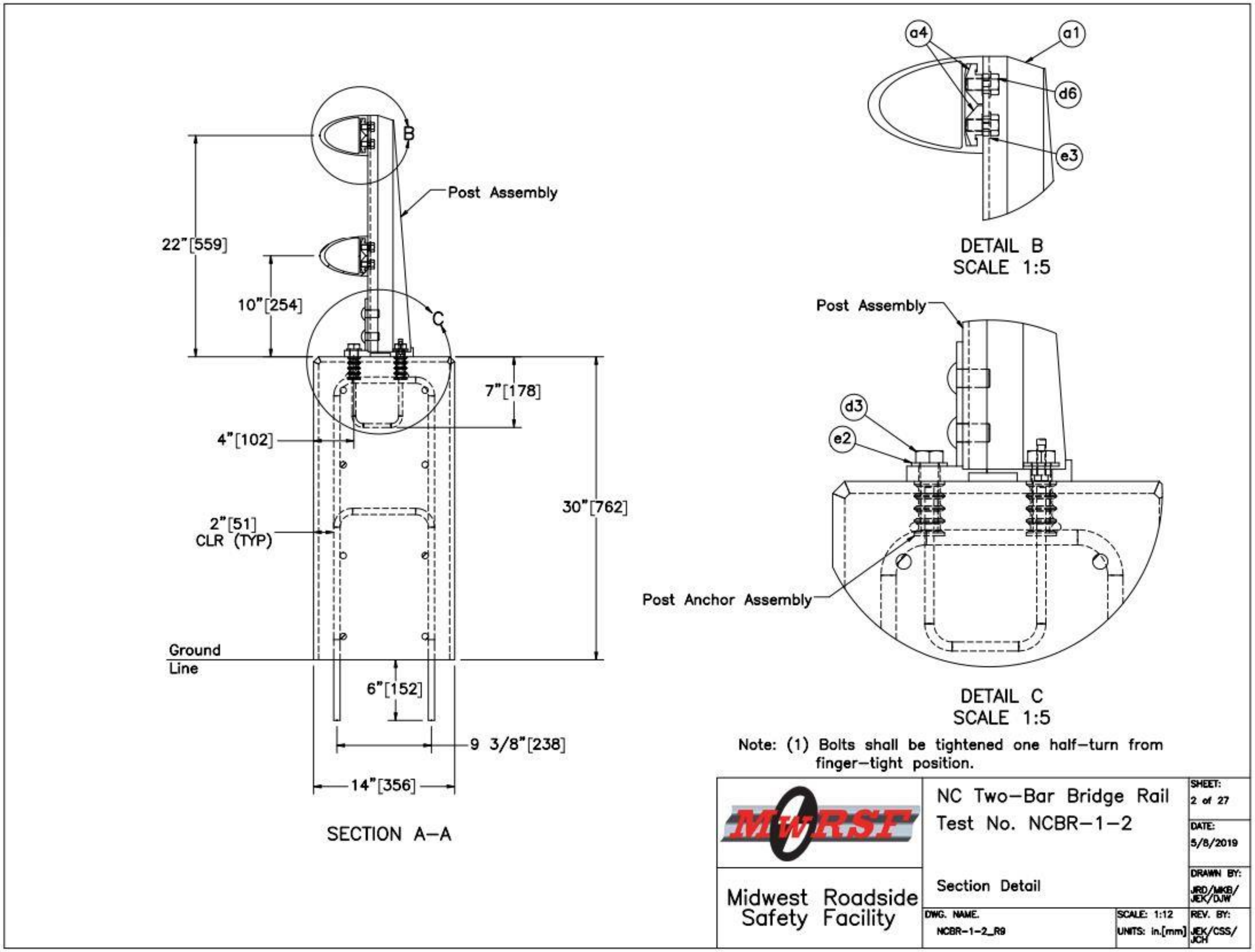


Figure 3. Section Detail, Test Nos. NCBR-1 and NCBR-2

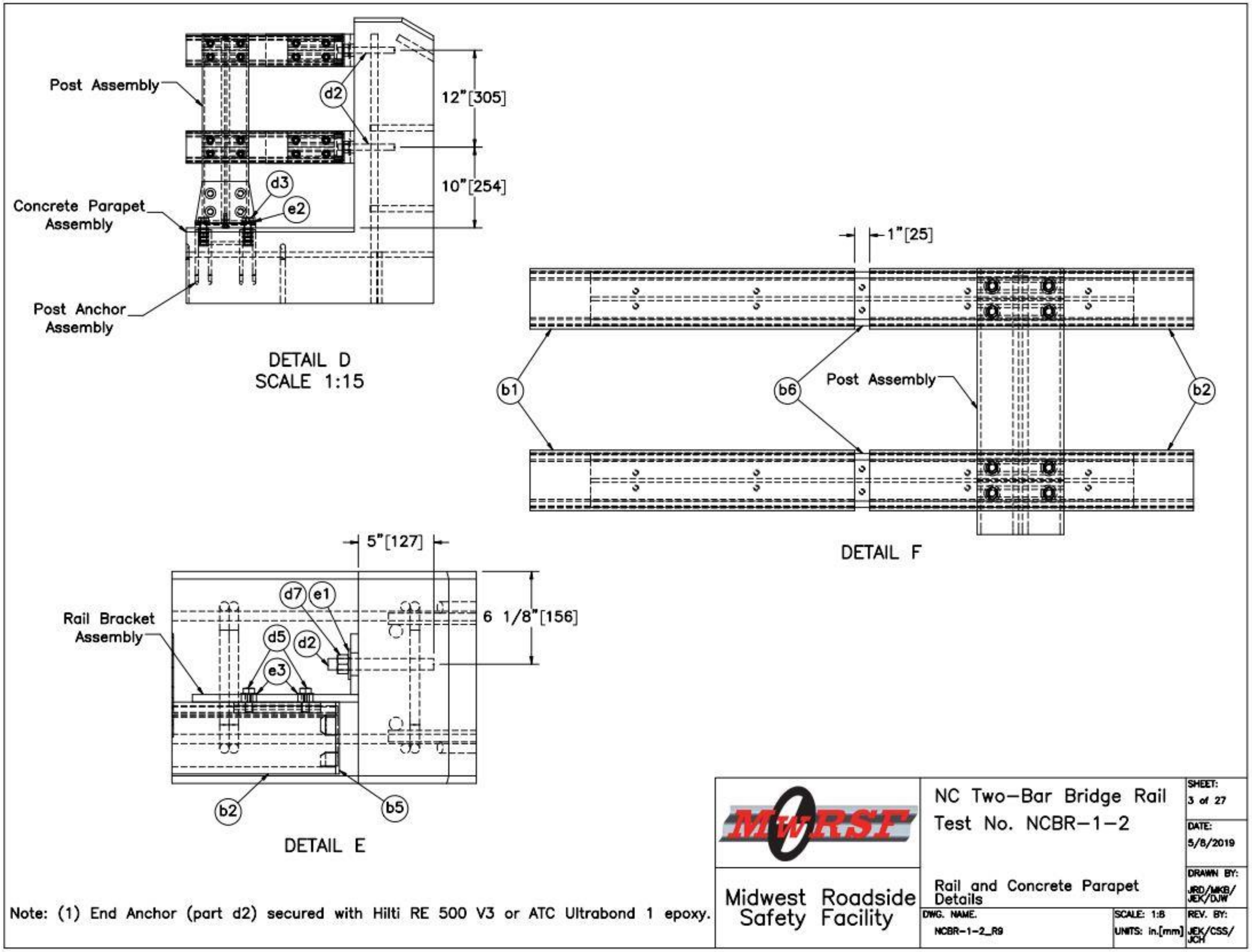
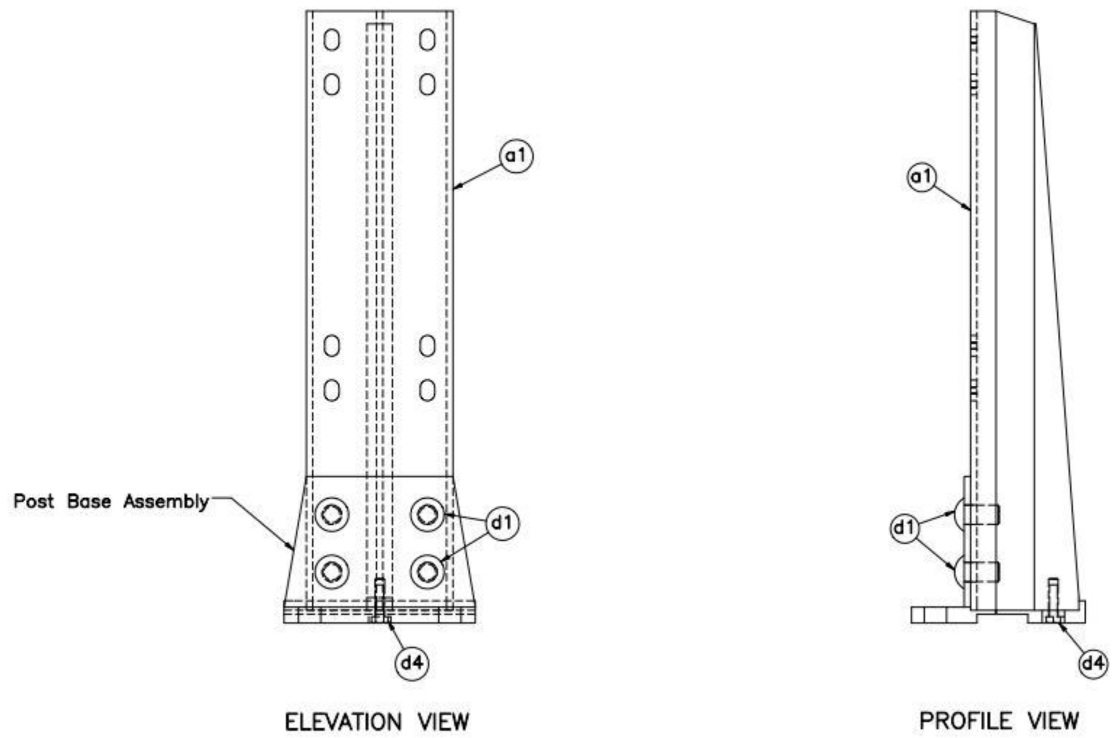


Figure 4. Rail and Concrete Parapet Details, Test Nos. NCBR-1 and NCBR-2



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	16	Post Assembly	–	–
–	1	Post Base Assembly	–	–
a1	1	5 3/4"x 4 1/4" [146x108], 23 1/2" [597] Long Post	ASTM B221 Alloy 6061–T6	–
d1	4	3/4" [19] Dia., 1 3/8" Long Rivet	ASTM B316 Alloy 6061–T6	–
d4	1	3/8"–16 UNC [M10x1.5], 1 1/2" [38] Long Cap Screw	ASTM F593 Alloy 305 Stainless Steel	–

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Midwest Roadside Safety Facility

NC Two–Bar Bridge Rail
Test No. NCBR–1–2

Post Assembly

SHEET: 4 of 27
DATE: 5/8/2019
DRAWN BY: JRD/MKB/JEK/DJW
DWG. NAME. NCBR–1–2_R9
SCALE: 1:6
UNITS: in.[mm]
REV. BY: JEK/CSS/JCH

Figure 5. Post Assembly, Test Nos. NCBR-1 and NCBR-2

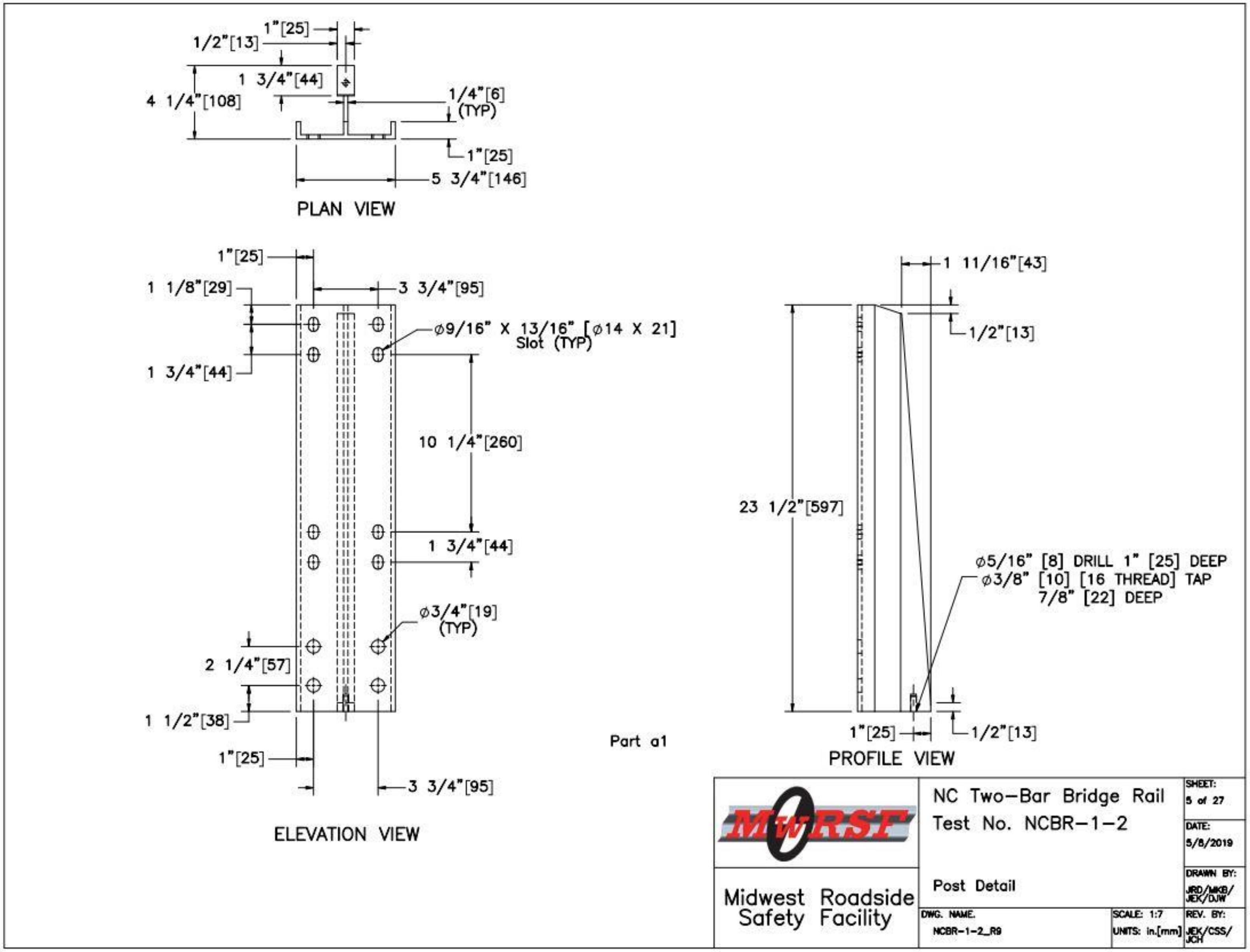
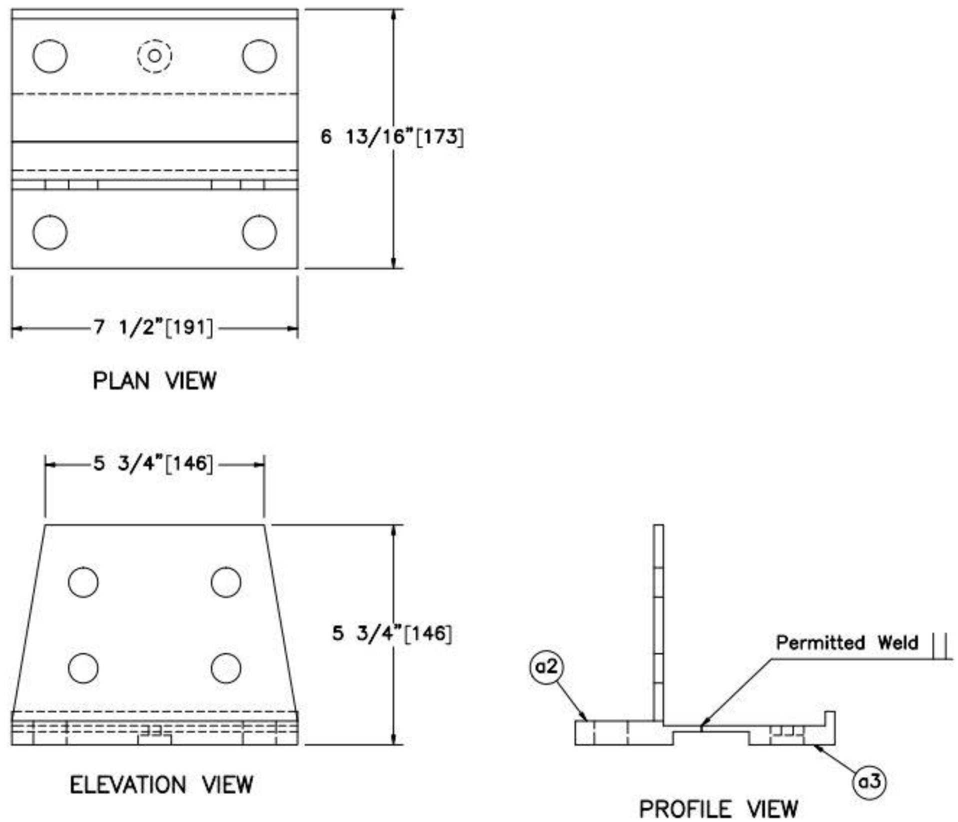


Figure 6. Post Detail, Test Nos. NCBR-1 and NCBR-2



Note: (1) Base can be supplied as one extrusion or two extrusions welded together.

Item No.	QTY.	Description	Material Specification	Treatment Specification
–	16	Post Base Assembly	–	–
a2	1	7 1/2"x3 5/16"x5 3/4" [191x84x146] Post Plate	ASTM B221 Alloy 6061–T6	-
a3	1	7 1/2"x3 1/4"x7/8" [181x83x22] Post Plate	ASTM B221 Alloy 6061–T6	-

Midwest Roadside Safety Facility	NC Two–Bar Bridge Rail Test No. NCBR–1–2		SHEET: 6 of 27 DATE: 5/8/2019
	Post Base Assembly		DRAWN BY: JRD/MKB/JEK/DJW
	DWG. NAME. NCBR–1–2_R9	SCALE: 1:4 UNITS: in.[mm]	REV. BY: JEK/CSS/JCH

Figure 7. Post Base Assembly, Test Nos. NCBR-1 and NCBR-2

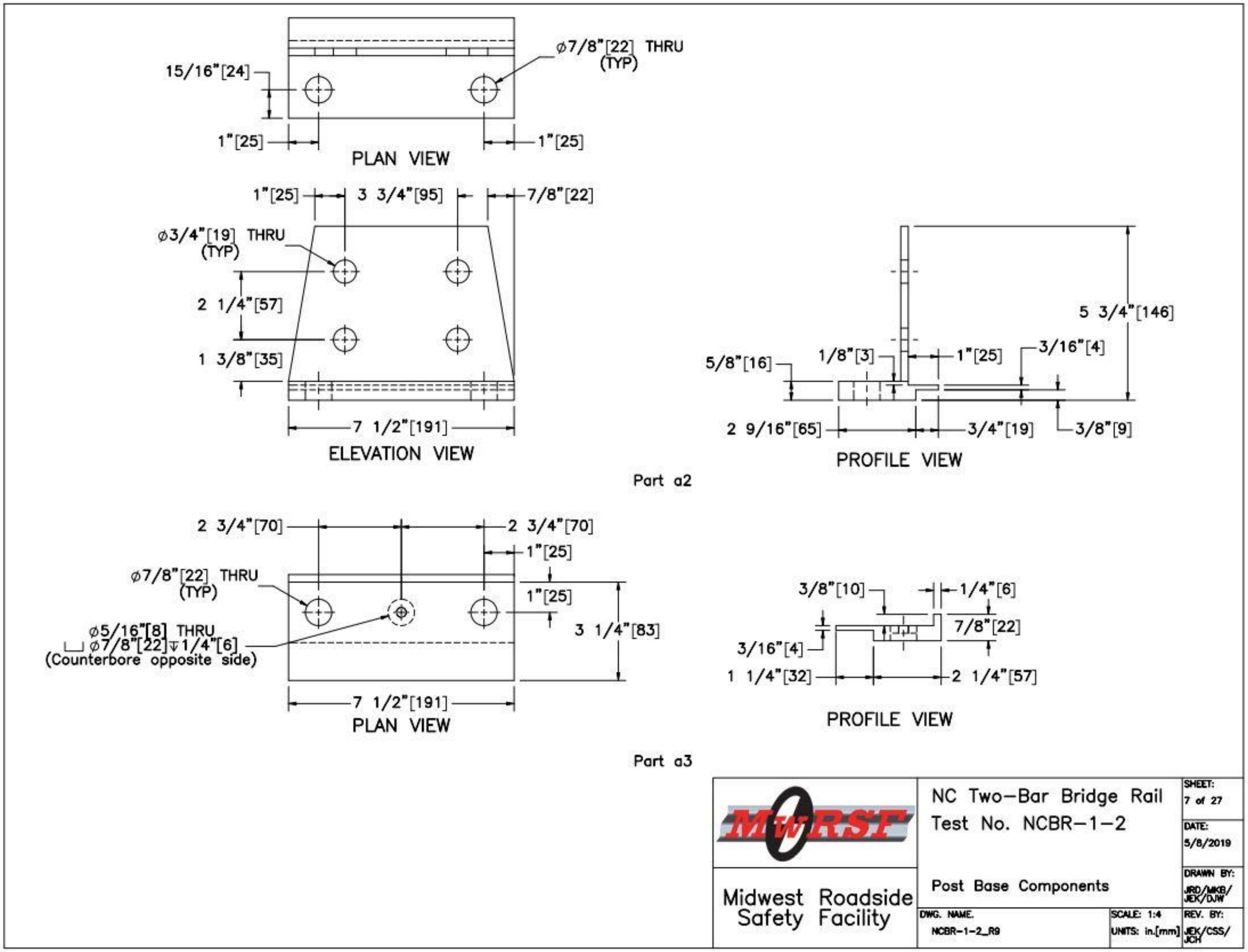


Figure 8. Post Base Components, Test Nos. NCBR-1 and NCBR-2

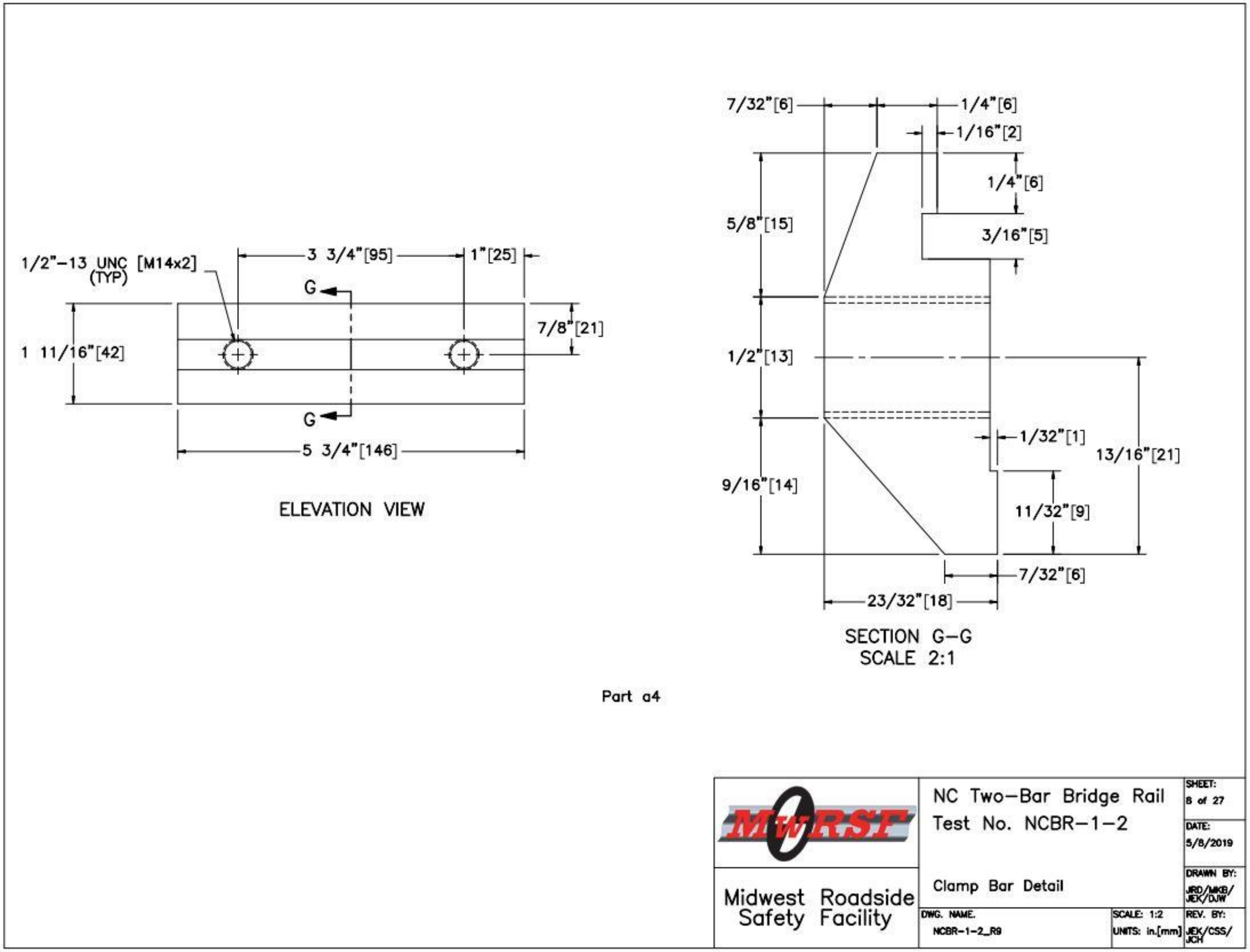


Figure 9. Clamp Bar Detail, Test Nos. NCBR-1 and NCBR-2

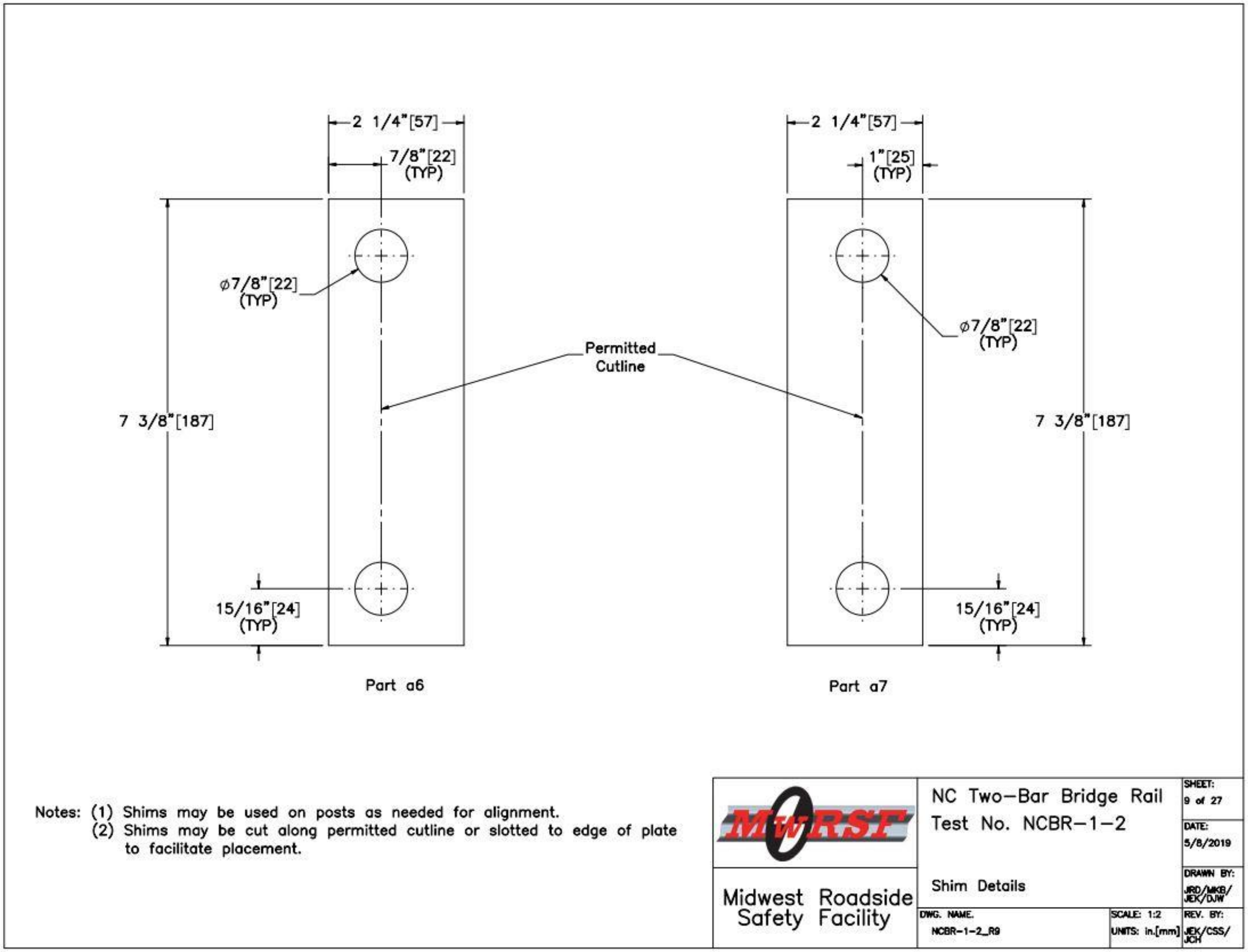


Figure 10. Shim Details, Test Nos. NCBR-1 and NCBR-2

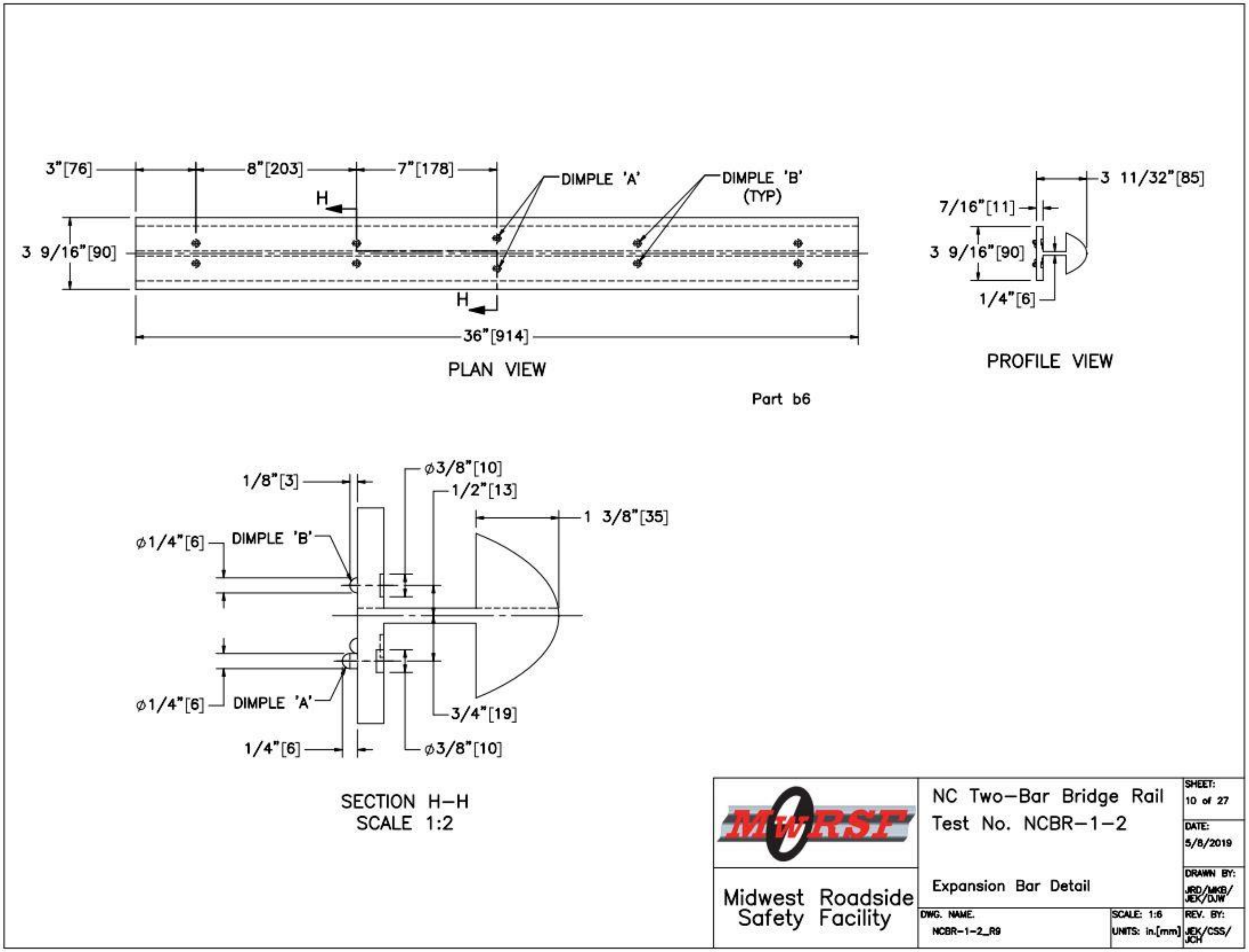


Figure 11. Expansion Bar Detail, Test Nos. NCBR-1 and NCBR-2

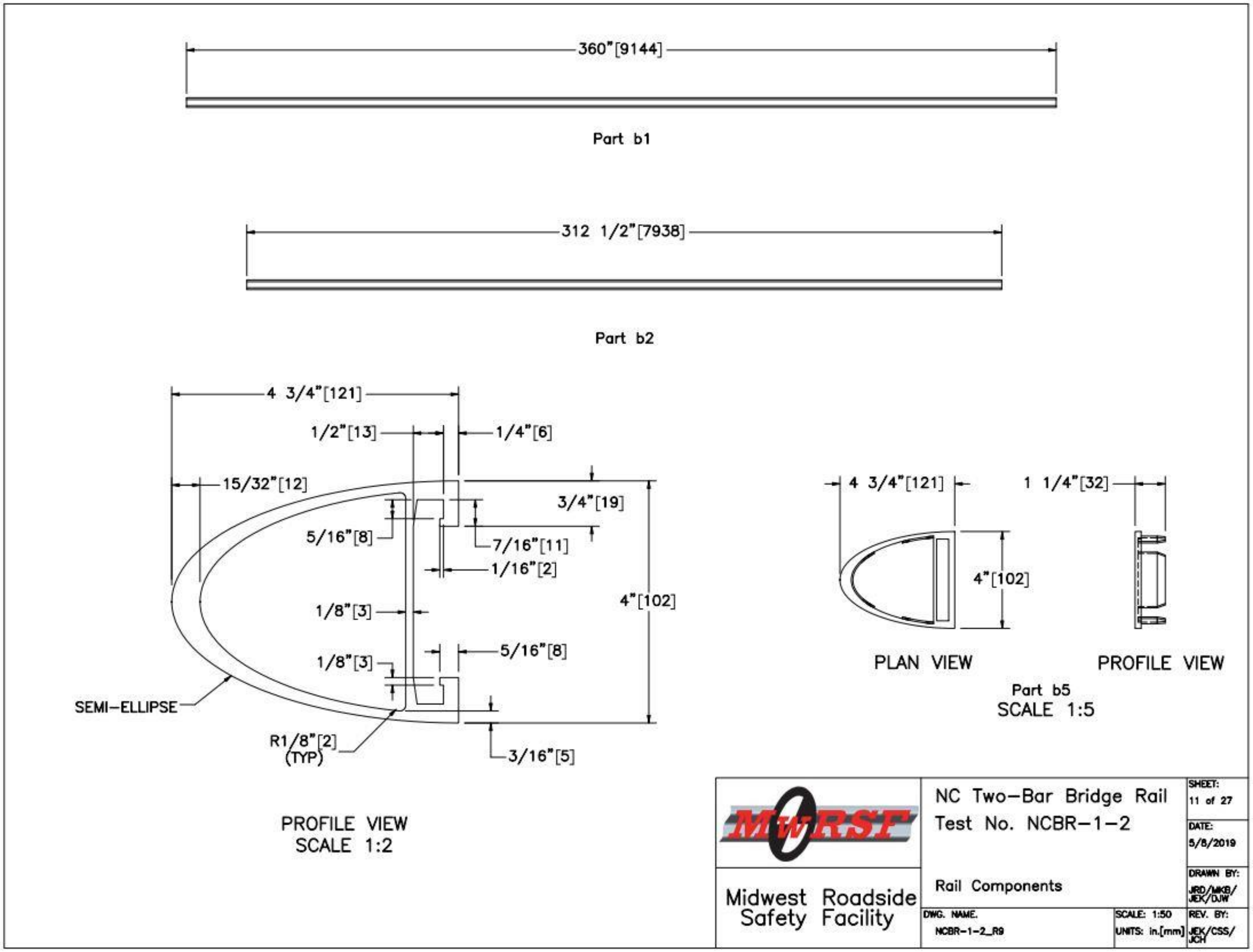
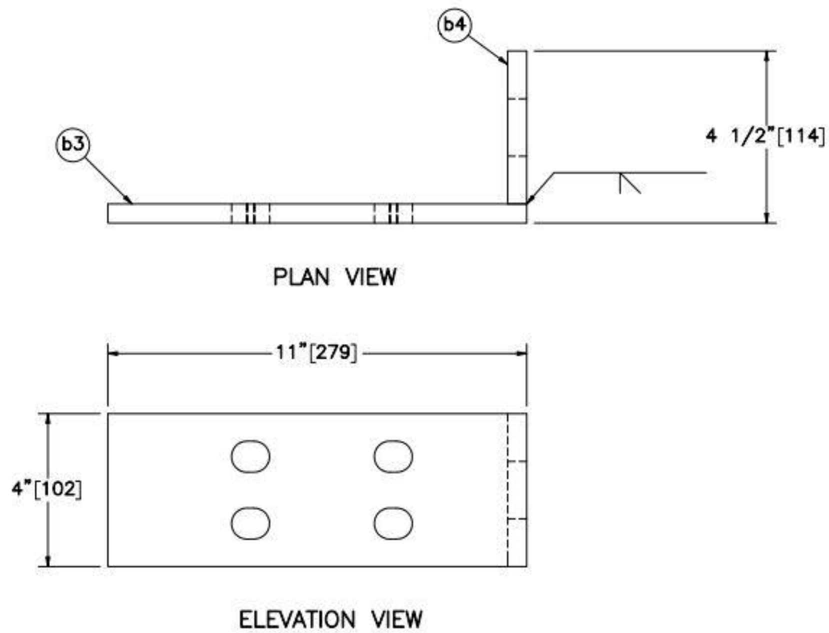


Figure 12. Rail Components, Test Nos. NCBR-1 and NCBR-2



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	4	Rail Bracket Assembly	–	ASTM A123
b3	1	11"x4"x1/2" [279x102x13] Plate	ASTM A36	See Assembly
b4	1	4"x4"x1/2" [102x102x13] Plate	ASTM A36	See Assembly

Midwest Roadside Safety Facility

NC Two-Bar Bridge Rail
Test No. NCBR-1-2

Rail Bracket Assembly

SHEET: 12 of 27
DATE: 5/8/2019
DRAWN BY: JRD/MKB/JEK/DJW
REV. BY: JEK/CSS/JCH
DWG. NAME. NCBR-1-2_R9
SCALE: 1:4
UNITS: in.[mm]

Figure 13. Rail Bracket Assembly, Test Nos. NCBR-1 and NCBR-2

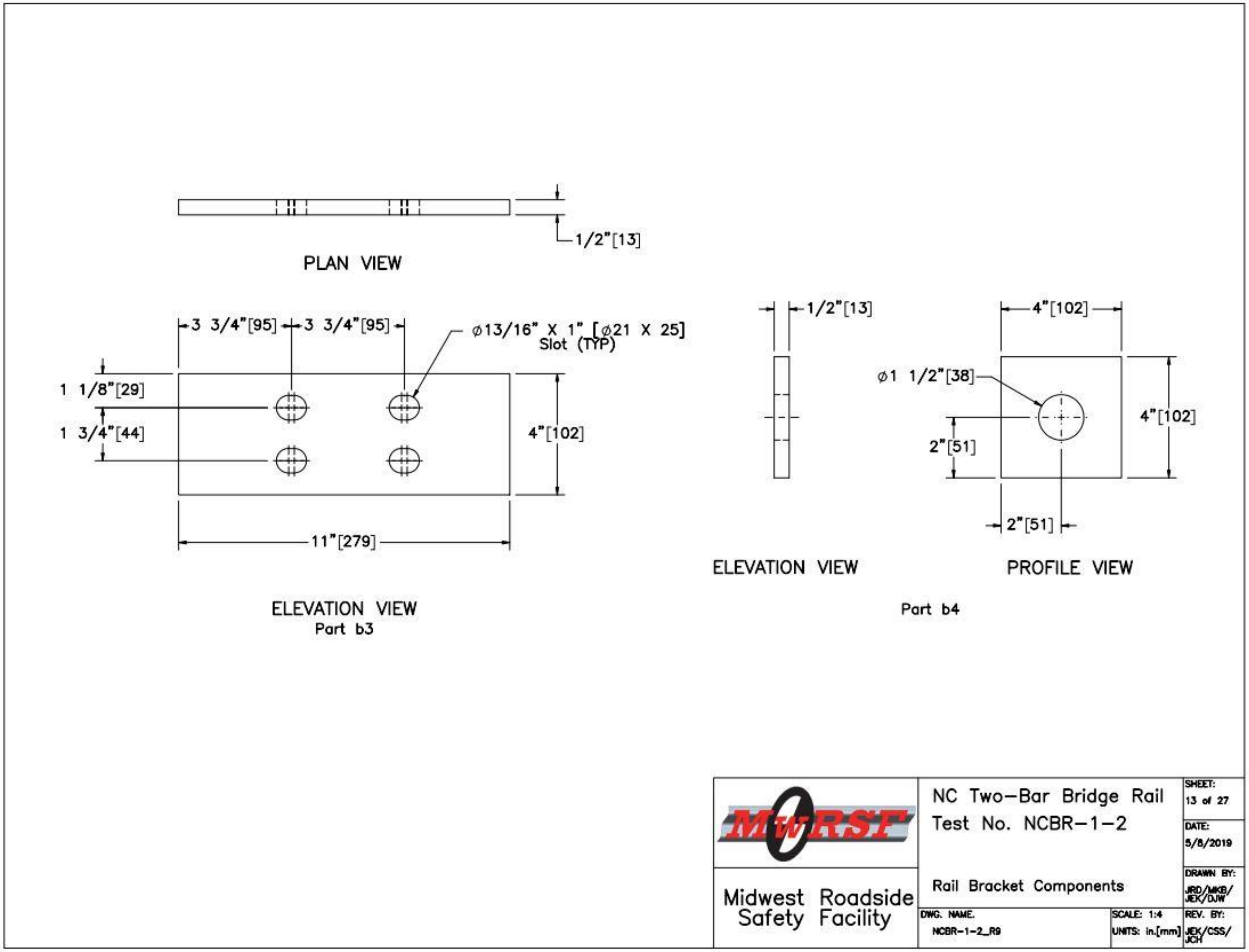
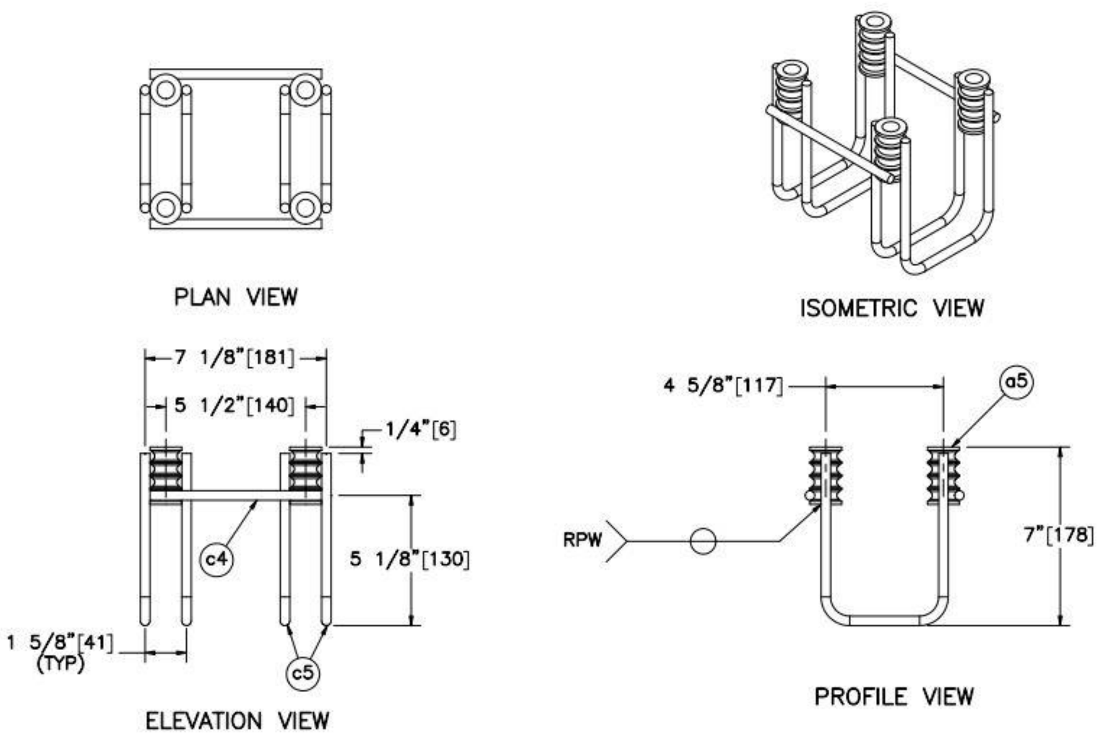


Figure 14. Rail Bracket Components, Test Nos. NCBR-1 and NCBR-2



Note: (1) Bolts shall be tightened one half-turn from finger-tight position.

Item No.	QTY.	Description	Material Specification	Treatment Specification
–	16	Post Anchor Assembly	–	–
a5	4	3/4" [19] Threaded Ferrule	ASTM A108 Gr. 12L14	ASTM A123
c4	2	3/8" [10] Dia. Wire Strut, 6 3/4" [171] Long	Min. Tensile Strength = 100,000 psi [690 MPa]	AASHTO M111
c5	4	3/8" [10] Dia. Wire Strut, 15 15/16" [405] Long Unbent	Min. Tensile Strength = 100,000 psi [690 MPa]	AASHTO M111

Midwest Roadside Safety Facility

NC Two-Bar Bridge Rail
Test No. NCBR-1-2

Post Anchor Assembly

SHEET:	14 of 27
DATE:	5/8/2019
DRAWN BY:	JRD/MKB/JEK/DJW
REV. BY:	JEK/CSS/JCH
DWG. NAME.	NCBR-1-2_R9
SCALE:	1:6
UNITS:	in.[mm]

Figure 15. Post Anchor Assembly, Test Nos. NCBR-1 and NCBR-2

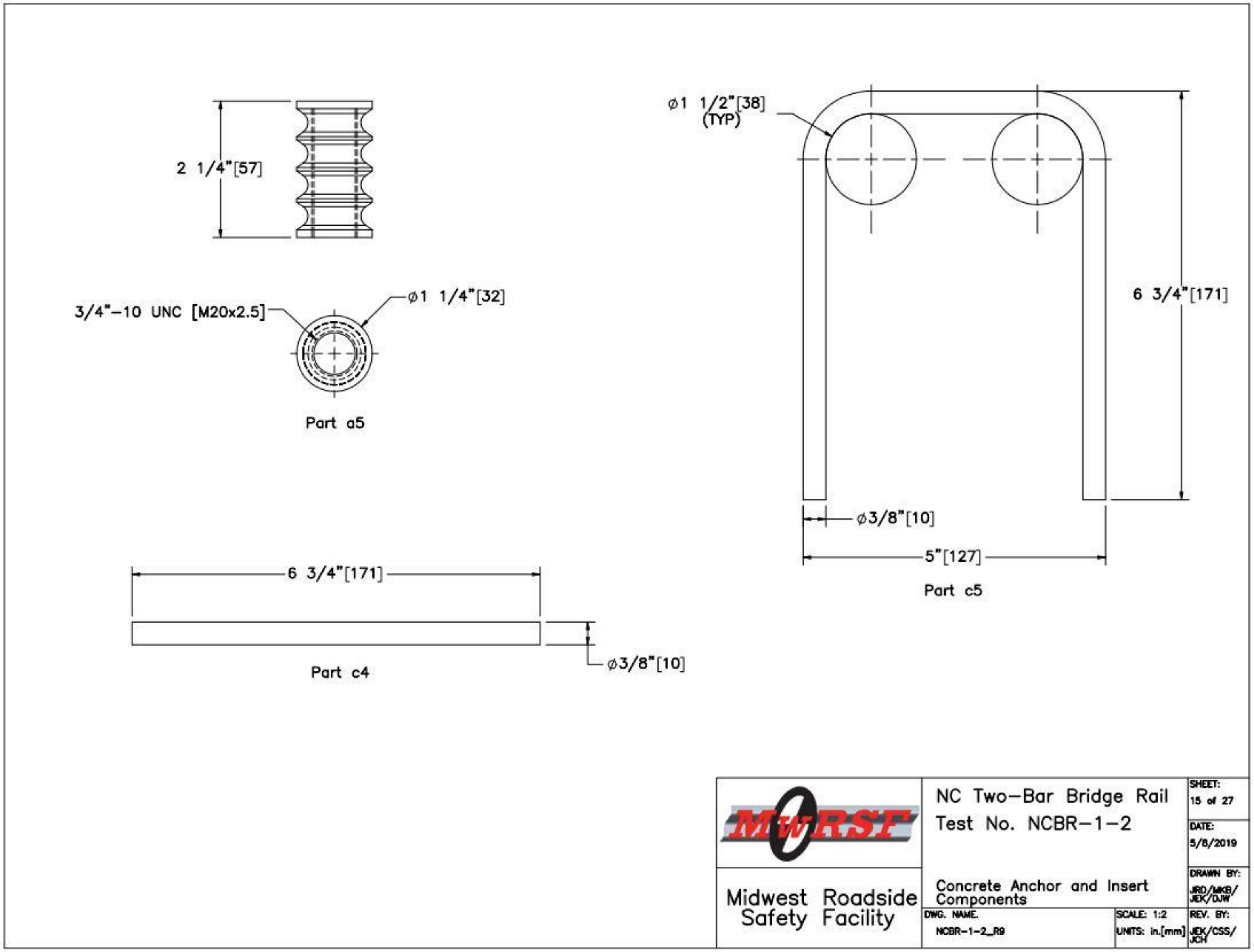
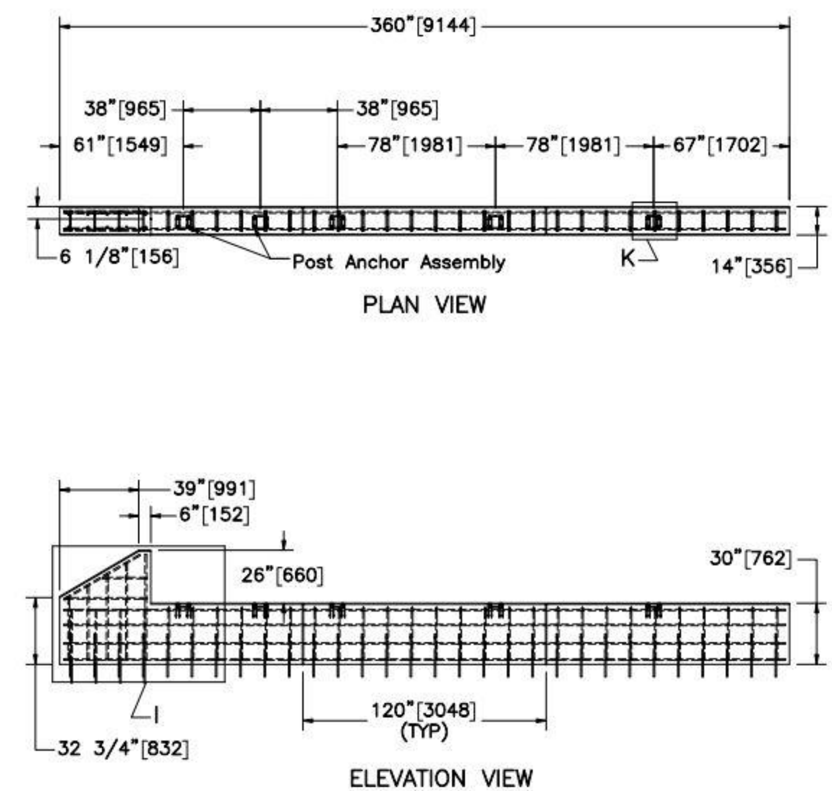


Figure 16. Concrete Anchor and Insert Components, Test Nos. NCBR-1 and NCBR-2



Notes: (1) Grooved contraction joints, 1/2" [13] in depth, shall be tooled in all exposed faces of the parapet at each third point between expansion joints.

Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Upstream Parapet Assembly	–	–
–	5	Post Anchor Assembly		
c1	1	Concrete	–	–
c6	26	#5 [16] Bar, 59 1/2" [1,511] Long Unbent	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c8	8	#5 [16] Bar, 356" [9,042] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c9	8	#5 [16] Bar, 36" [914] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c10	30	#5 [16] Bar, 49 1/2" [1,257] Long Unbent	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c11	2	#6 [19] Bar, 22" [559] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c12	2	#6 [19] Bar, 40" [1,016] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c13	2	#6 [19] Bar, 43 1/4" [1,099] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c14	2	#7 [22] Bar, 31" [787] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c15	2	#7 [22] Bar, 36 1/2" [927] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c16	2	#7 [22] Bar, 42" [1,067] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c17	2	#7 [22] Bar, 47 1/2" [1,207] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c18	2	#7 [22] Bar, 52" [1,321] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)

Midwest Roadside Safety Facility

NC Two–Bar Bridge Rail
Test No. NCBR–1–2

Upstream Concrete Parapet Assembly

SHEET: 16 of 27
DATE: 5/8/2019
DRAWN BY: JRD/MKB/JEK/DJW
DWG. NAME. NCBR–1–2_R9
SCALE: 1:75
UNITS: in.[mm]
REV. BY: JEK/CSS/JCH

Figure 17. Upstream Concrete Parapet Assembly, Test Nos. NCBR-1 and NCBR-2

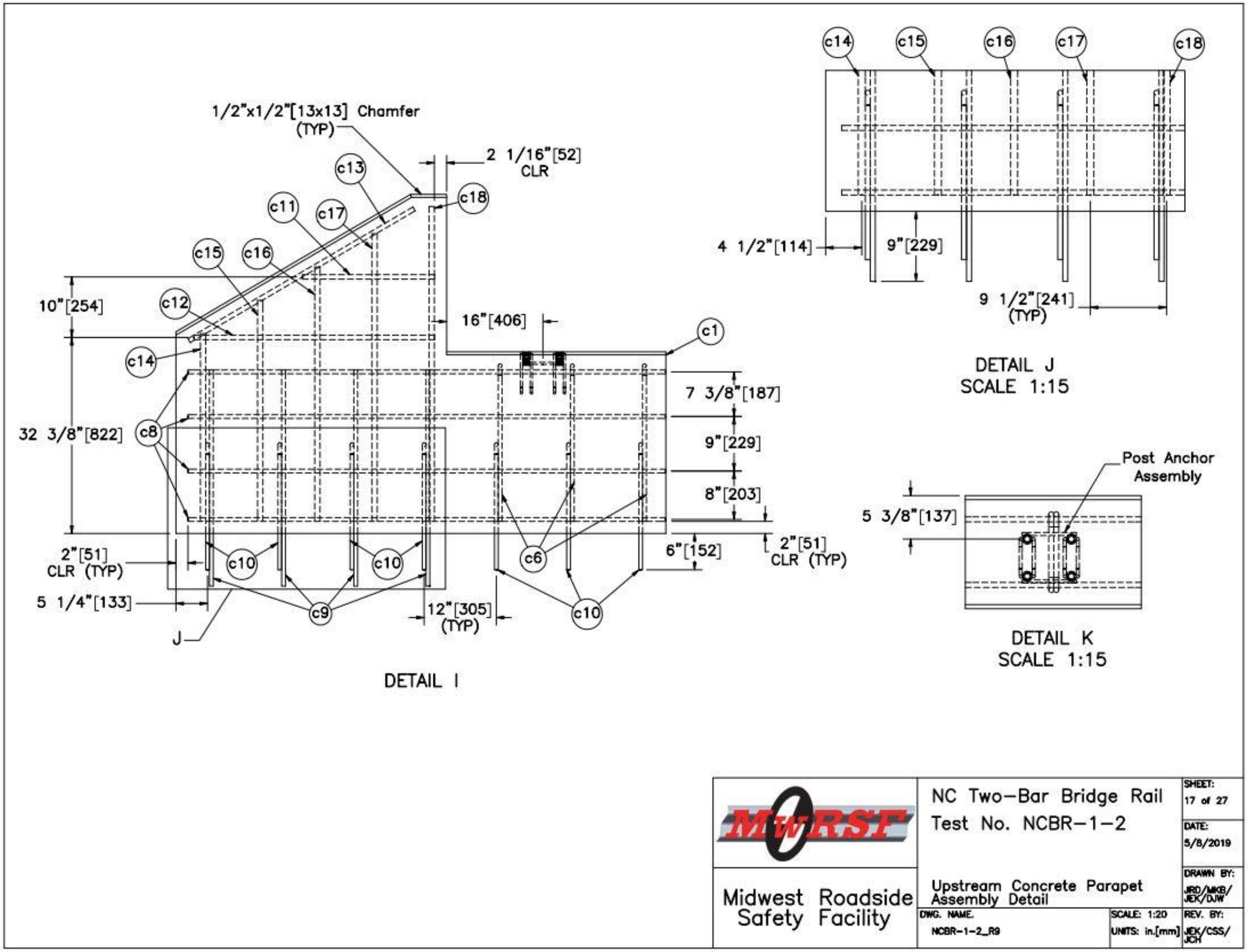
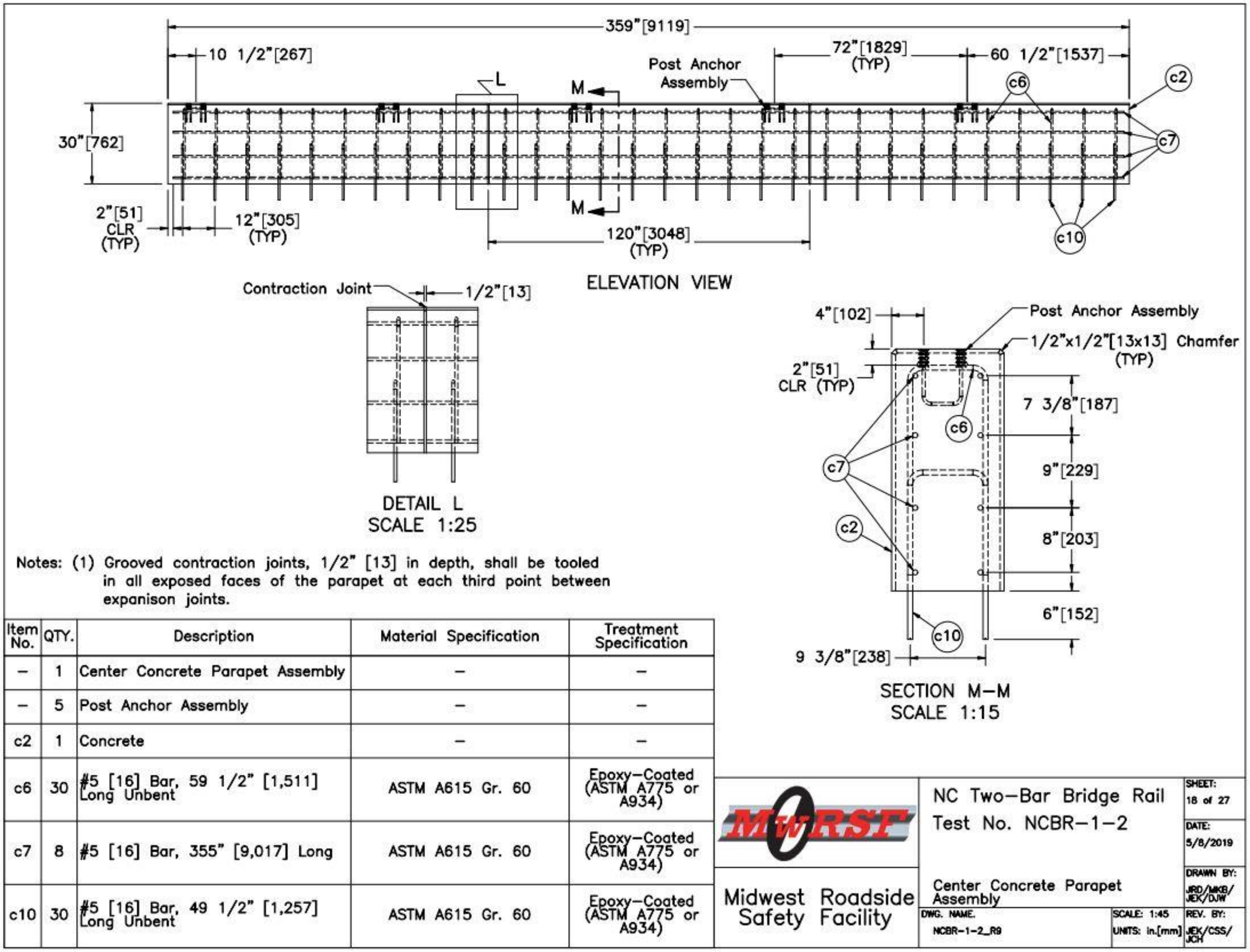
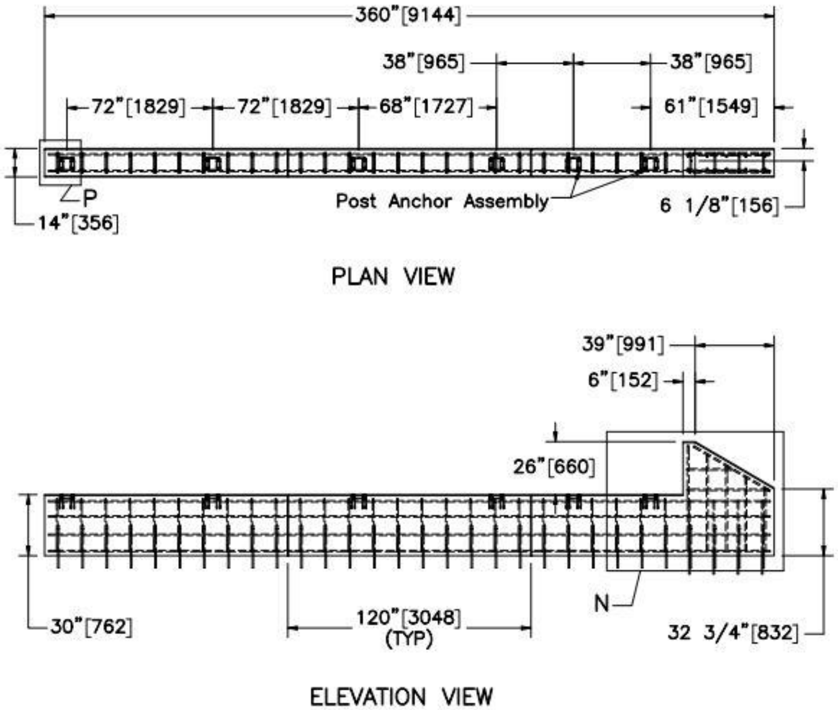


Figure 18. Upstream Concrete Parapet Assembly Detail, Test Nos. NCBR-1 and NCBR-2



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Center Concrete Parapet Assembly	–	–
–	5	Post Anchor Assembly	–	–
c2	1	Concrete	–	–
c6	30	#5 [16] Bar, 59 1/2" [1,511] Long Unbent	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c7	8	#5 [16] Bar, 355" [9,017] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
c10	30	#5 [16] Bar, 49 1/2" [1,257] Long Unbent	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)

Figure 19. Center Concrete Parapet Assembly, Test Nos. NCBR-1 and NCBR-2



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Downstream Parapet Assembly	–	–
–	6	Post Anchor Assembly		
c3	1	Concrete	–	–
c6	26	#5 [16] Bar, 59 1/2" [1,511] Long Unbent	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c8	8	#5 [16] Bar, 356" [9,042] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c9	8	#5 [16] Bar, 36" [914] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c10	30	#5 [16] Bar, 49 1/2" [1,257] Long Unbent	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c11	2	#6 [19] Bar, 22" [559] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c12	2	#6 [19] Bar, 40" [1,016] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c13	2	#6 [19] Bar, 43 1/4" [1,099] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c14	2	#7 [22] Bar, 31" [787] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c15	2	#7 [22] Bar, 36 1/2" [927] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c16	2	#7 [22] Bar, 42" [1,067] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c17	2	#7 [22] Bar, 47 1/2" [1,207] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c18	2	#7 [22] Bar, 52" [1,321] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)

Midwest Roadside Safety Facility

NC Two-Bar Bridge Rail
Test No. NCBR-1-2

Downstream Concrete Parapet Assembly

SHEET: 19 of 27
DATE: 5/8/2019
DRAWN BY: JRD/MKB/JEK/DJW
DWG. NAME. NCBR-1-2_R9
SCALE: 1:75
UNITS: in.[mm]
REV. BY: JEK/CSS/JCH

Notes: (1) Grooved contraction joints, 1/2" [13] in depth, shall be tooled in all exposed faces of the parapet at each third point between expanison joints.

Figure 20. Downstream Concrete Parapet Assembly, Test Nos. NCBR-1 and NCBR-2

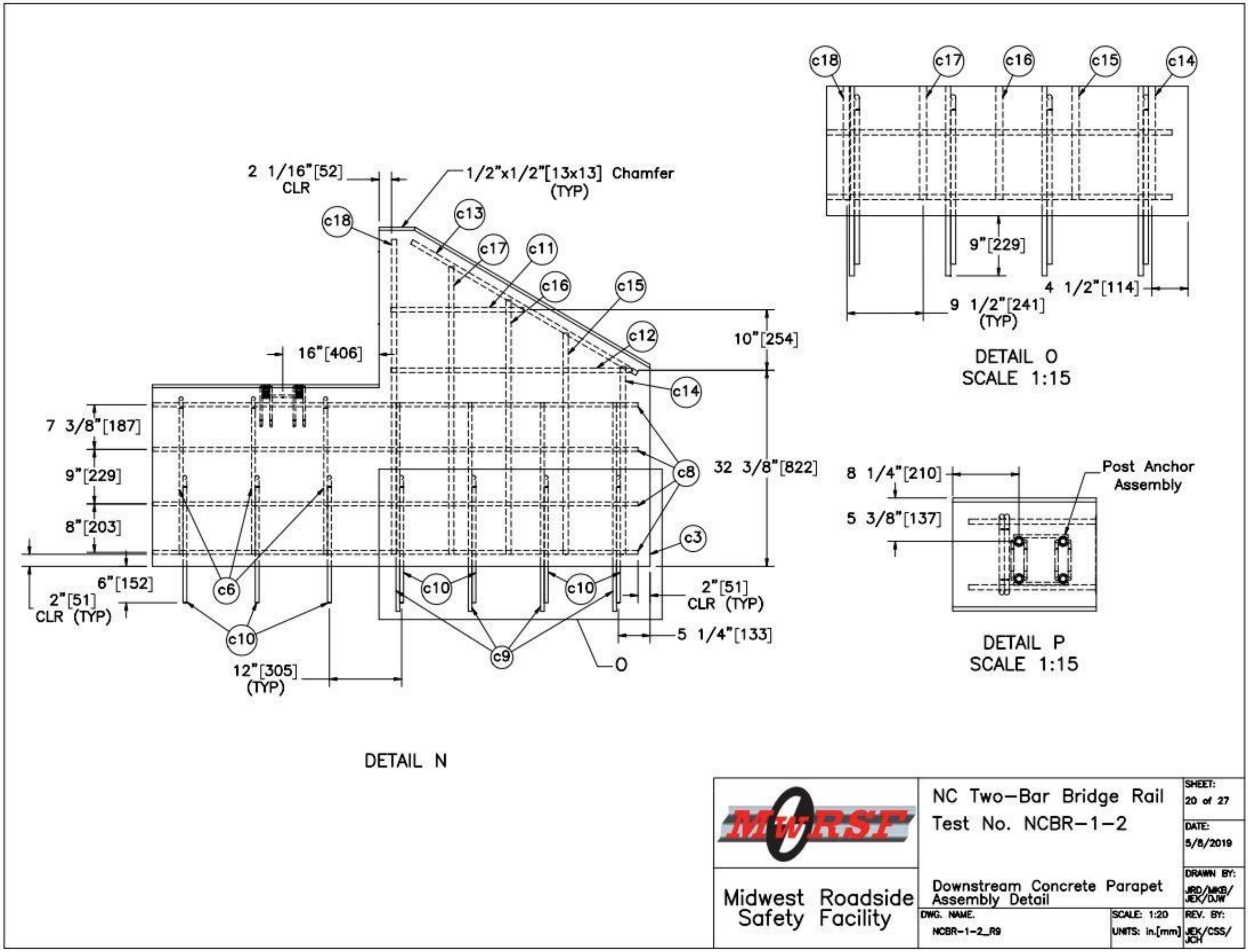
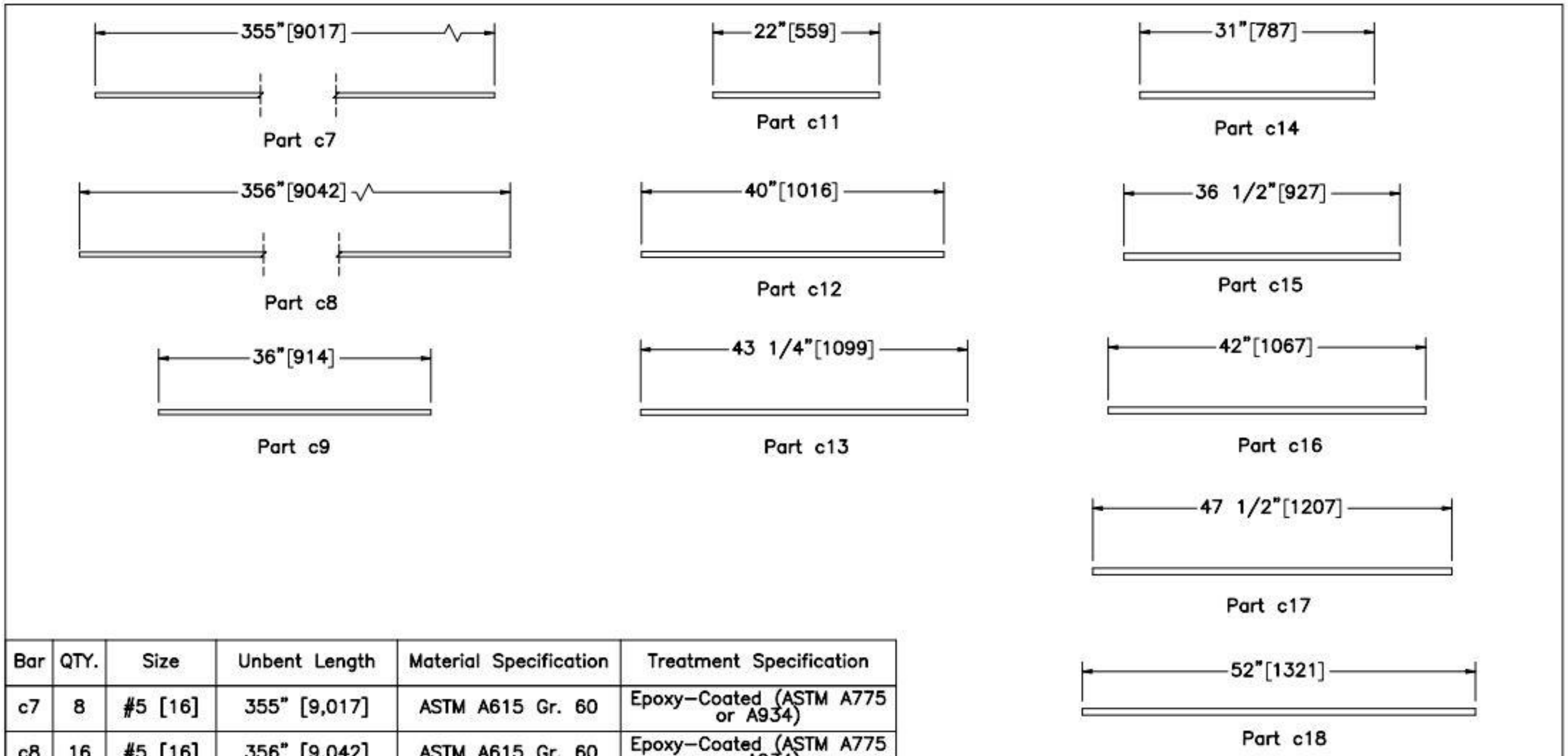


Figure 21. Downstream Concrete Parapet Assembly, Test Nos. NCBR-1 and NCBR-2



Bar	QTY.	Size	Unbent Length	Material Specification	Treatment Specification
c7	8	#5 [16]	355" [9,017]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c8	16	#5 [16]	356" [9,042]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c9	16	#5 [16]	36" [914]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c11	4	#6 [19]	22" [559]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c12	4	#6 [19]	40" [1,016]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c13	4	#6 [19]	43 1/4" [1,099]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c14	4	#7 [22]	31" [787]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c15	4	#7 [22]	36 1/2" [927]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c16	4	#7 [22]	42" [1,067]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c17	4	#7 [22]	47 1/2" [1,207]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c18	4	#7 [22]	52" [1,321]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)

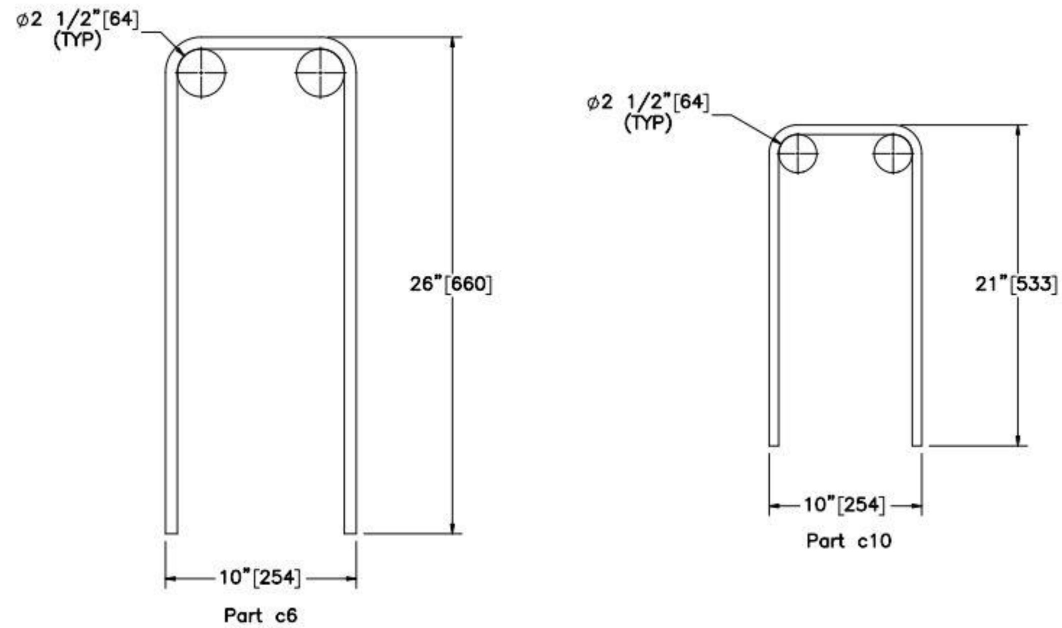
Midwest Roadside Safety Facility

NC Two-Bar Bridge Rail
Test No. NCBR-1-2

System Rebar

SHEET: 21 of 27
DATE: 5/8/2019
DRAWN BY: JRD/MKB/JEK/DJW
DWG. NAME. NCBR-1-2_R9
SCALE: 1:20
UNITS: in.[mm]
REV. BY: JEK/CSS/JCH

Figure 22. System Rebar, Test Nos. NCBR-1 and NCBR-2



Bar	QTY.	Size	Unbent Length	Material Specification	Treatment Specification
c6	82	#5 [16]	59 1/2" [1,511]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)
c10	90	#5 [16]	49 1/2" [1,257]	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)

Midwest Roadside Safety Facility

NC Two-Bar Bridge Rail
Test No. NCBR-1-2

System Rebar

SHEET: 22 of 27
DATE: 5/8/2019
DRAWN BY: JRD/MKB/JEK/DJW
DWG. NAME. NCBR-1-2_R9
SCALE: 1:10
UNITS: in.[mm]
REV. BY: JEK/CSS/JCH

Figure 23. System Rebar, Test Nos. NCBR-1 and NCBR-2

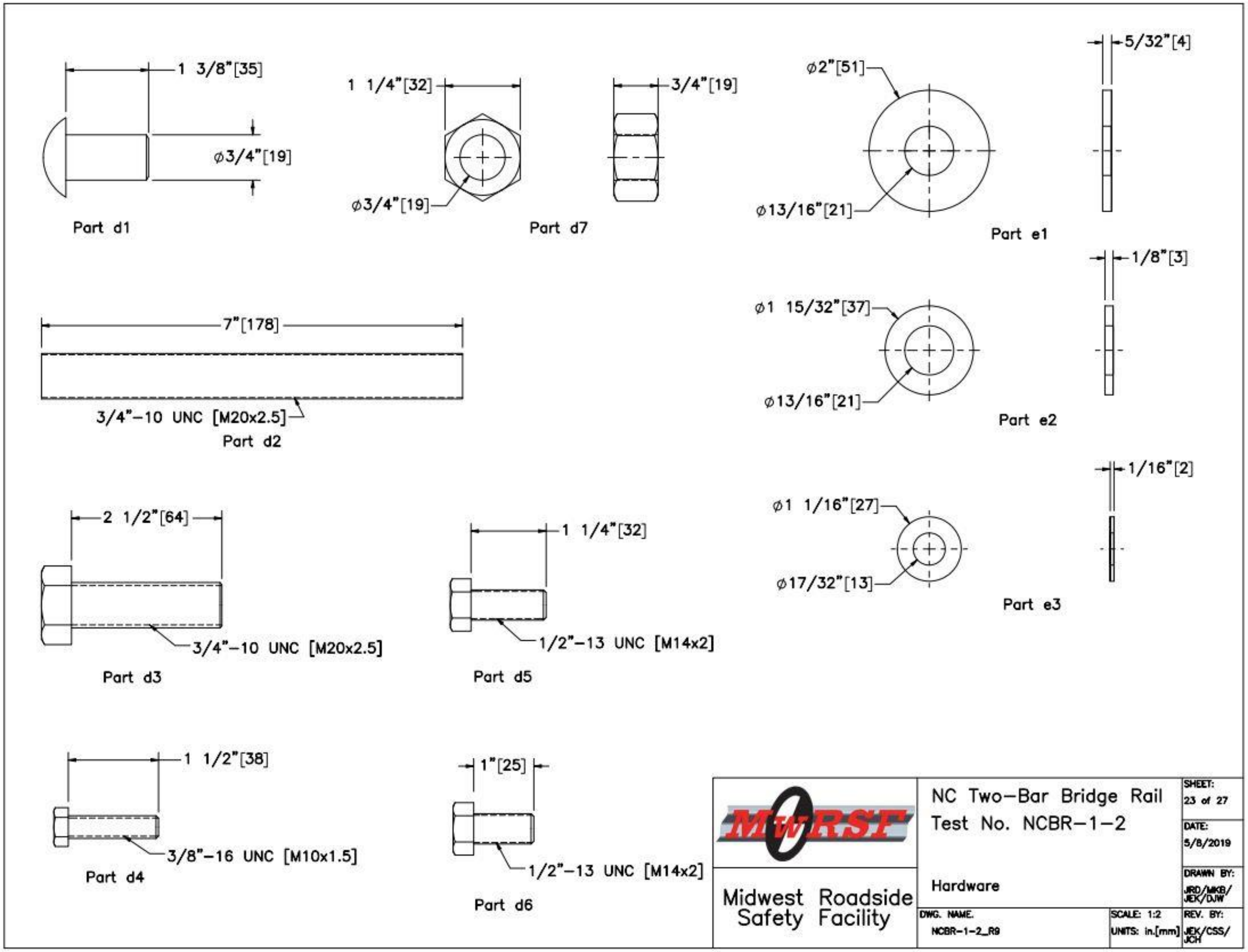


Figure 24. Hardware, Test Nos. NCBR-1 and NCBR-2

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	17	5 3/4"x 4 1/4" [146x108], 23 1/2" [597] Long Post	ASTM B221 Alloy 6061–T6	–	–
a2	17	7 1/2"x3 5/16"x5 3/4" [191x84x146] Post Plate	ASTM B221 Alloy 6061–T6	–	PAB02
a3	17	7 1/2"x3 1/4"x7/8" [181x83x22] Post Plate	ASTM B221 Alloy 6061–T6	–	PAB02
a4	76	5 3/4"x1 11/16"x3/4" [146x43x19] Clamp Bar	ASTM B221 Alloy 6061–T6	–	FPC01–02
a5	64	3/4" [19] Threaded Ferrule	ASTM A108 Gr. 12L14	ASTM A123	–
a6	–	7 3/8"x2 1/4" [187x57] Front Shim	ASTM B209 Alloy 6061–T6	–	–
a7	–	7 3/8"x2 1/4" [187x57] Rear Shim	ASTM B209 Alloy 6061–T6	–	–
b1	2	360" [9,144] Long Elliptical Rail	ASTM B221 Alloy 6061–T6	–	RAM06
b2	4	312 1/2" [7,938] Long Elliptical Rail	ASTM B221 Alloy 6061–T6	–	RAM06
b3	4	11"x4"x1/2" [279x102x13] Plate	ASTM A36	See Assembly	–
b4	4	4"x4"x1/2" [102x102x13] Plate	ASTM A36	See Assembly	–
b5	4	4 1/4"x4"x1 1/4" [108x102x32] Rail Cap	ASTM B221 Alloy 6061–T6	–	–
b6	4	36"x3 9/16"x3 5/8" [914x90x92] Expansion Bar	ASTM B221 Alloy 6061–T6	–	RAS06
c1	1	Concrete	–	–	–
c2	1	Concrete	–	–	–
c3	1	Concrete	–	–	–
c4	32	3/8" [10] Dia. Wire Strut, 6 3/4" [171] Long	Min. Tensile Strength = 100,000 psi [690 MPa]*	AASHTO M111	–
c5	64	3/8" [10] Dia. Wire Strut, 15 15/16" [405] Long Unbent	Min. Tensile Strength = 100,000 psi [690 MPa]*	AASHTO M111	–
c6	82	#5 [16] Bar, 59 1/2" [1,511] Long Unbent	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)	–
c7	8	#5 [16] Bar, 355" [9,017] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)	–
c8	16	#5 [16] Bar, 356" [9,042] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)	–
c9	16	#5 [16] Bar, 36" [914] Long	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)	–

Notes: (1) Alloy 6351–T5 may be substituted for alloy 6061–T6 where applicable.

*A 7/16" [11] wire strut with a minimum tensile strength of 90,000 psi [621 MPa] is acceptable.

Midwest Roadside Safety Facility

NC Two–Bar Bridge Rail
Test No. NCBR–1–2

Bill of Materials

SHEET: 24 of 27
DATE: 5/8/2019
DRAWN BY: JRD/MKB/JEK/DJW
DWG. NAME. NCBR–1–2_R9
SCALE: NONE
UNITS: in.[mm]
REV. BY: JEK/CSS/JCH

Figure 25. Bill of Materials, Test Nos. NCBR-1 and NCBR-2

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
c10	90	#5 [16] Bar, 49 1/2" [1,257] Long Unbent	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
c11	4	#6 [19] Bar, 22" [559] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
c12	4	#6 [19] Bar, 40" [1,016] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
c13	4	#6 [19] Bar, 43 1/4" [1,099] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
c14	4	#7 [22] Bar, 31" [787] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
c15	4	#7 [22] Bar, 36 1/2" [927] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
c16	4	#7 [22] Bar, 42" [1,067] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
c17	4	#7 [22] Bar, 47 1/2" [1,207] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
c18	4	#7 [22] Bar, 52" [1,321] Long	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
d1	68	3/4" [19] Dia., 1 3/8" Long Rivet	ASTM B316 Alloy 6061-T6	–	–
d2	4	3/4"-10 UNC [M20x2.5], 7" [178] Long Fully Threaded Rod	Alloy 304 Stainless Steel	–	FRR20b
d3	68	3/4"-10 UNC [M20x2.5], 2 1/2" [64] Long Hex Bolt	ASTM F3125 Gr. A325 Type I	ASTM A153 or B695 Class 55 or F1941 or F2329 or F1136 Gr. 3 or F2833 Gr. 1	FBX20b
d4	17	3/8"-16 UNC [M10x1.5], 1 1/2" [38] Long Cap Screw	ASTM F593 Alloy 305 Stainless Steel	–	–
d5	16	1/2"-13 UNC [M14x2], 1 1/4" [32] Long Hex Head Cap Screw	ASTM F593 Alloy 305 Stainless Steel	–	FBS14
d6	136	1/2"-13 UNC [M14x2], 1" [25] Long Hex Head Cap Screw	ASTM F593 Alloy 305 Stainless Steel	–	FBS14
d7	4	3/4"-10 UNC [M20x2.5] Heavy Hex Nut	Alloy 304 Stainless Steel	–	FNX20b
e1	4	3/4" [19] Dia. Plain USS Washer	Alloy 304 Stainless Steel	–	–
e2	68	3/4" [19] Dia. Plain SAE Washer	ASTM F436*	ASTM A153 or B695 Class 55 or FI136 Gr. 3 or F2329	FWC20b
e3	152	1/2" [13] Dia. Plain SAE Washer	ASTM F844 Alloy 304 Stainless Steel	–	–
–**	–	Hilti RE 500 V3 or ATC Ultrabond 1 Epoxy	ASTM C881 Type I, II, IV & V Gr. 3, Class A, B & C	–	–

*At the contractor's option, stainless steel bolt and washer may be used as an alternative.
**Epoxy for part d2 must have a minimum bond strength of 1,100 psi [7.6 MPa]. Bond strength of 1,300 psi [9.0 Mpa] or greater is preferred.

Midwest Roadside Safety Facility

NC Two-Bar Bridge Rail
Test No. NCBR-1-2

Bill of Materials

SHEET: 25 of 27
DATE: 5/8/2019
DRAWN BY: JRD/MKB/JEK/DJW
REV. BY: JEK/CSS/JCH
DWG. NAME. NCBR-1-2_R9
SCALE: NONE
UNITS: in.[mm]

Figure 26. Bill of Materials, Test Nos. NCBR-1 and NCBR-2

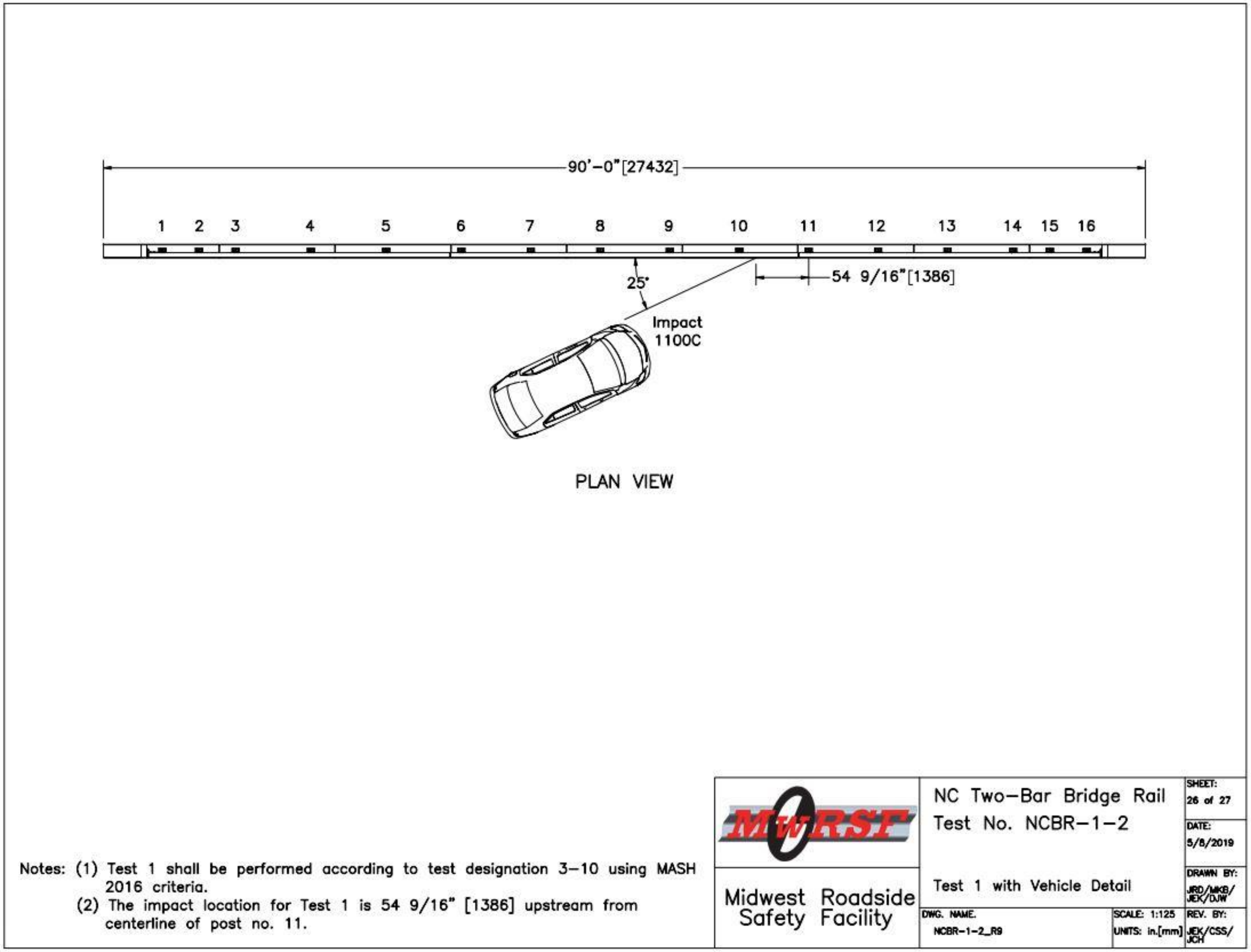


Figure 27. Test No. NCBR-1 with Vehicle Detail

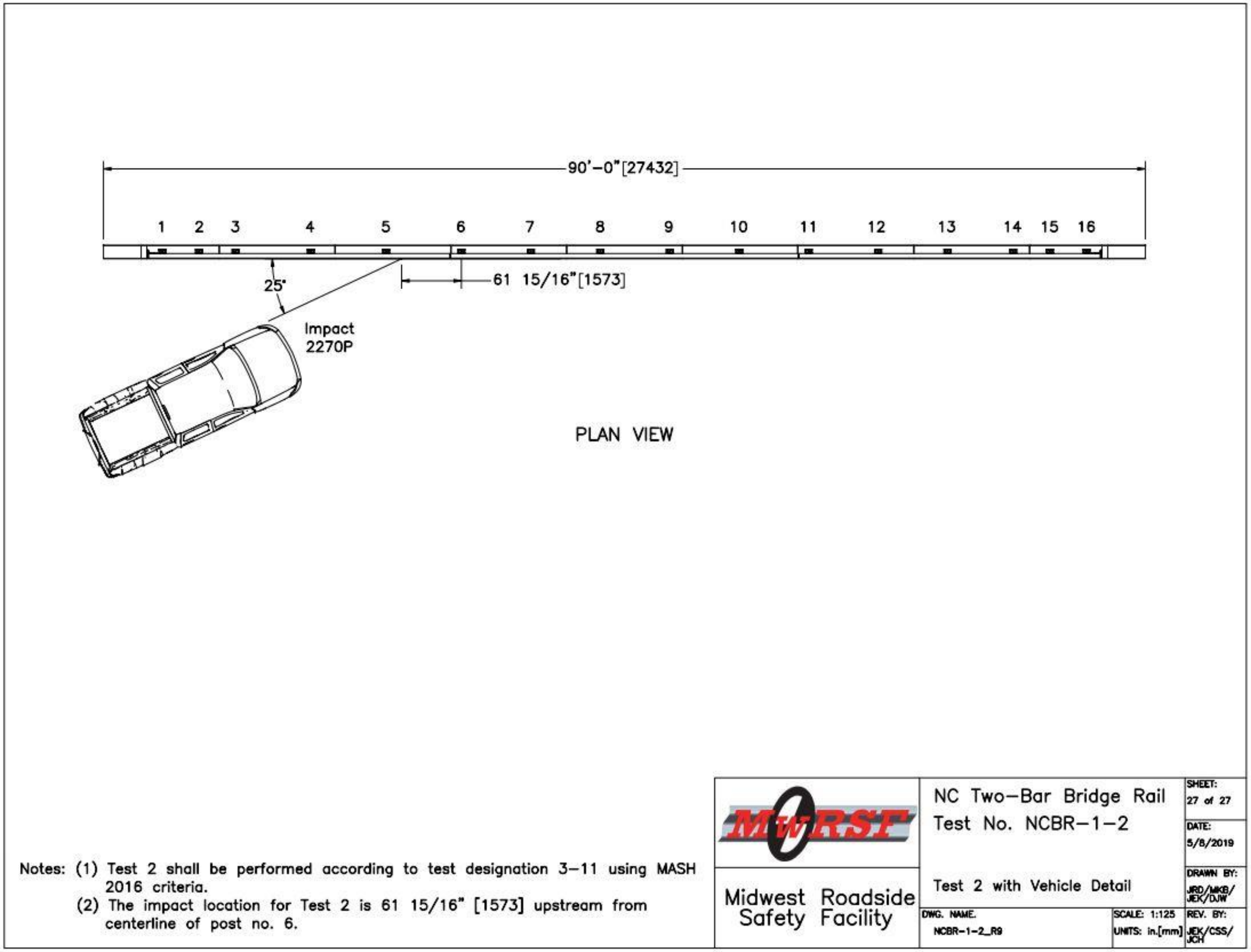


Figure 28. Test No. NCBR-2 with Vehicle Detail

Figure 29. Construction Photographs, Test Nos. NCBR-1 and NCBR-2

Figure 30. System Installation Photographs, Test Nos. NCBR-1 and NCBR-2

Figure 31. Post and Rail Assembly, Test Nos. NCBR-1 and NCBR-2

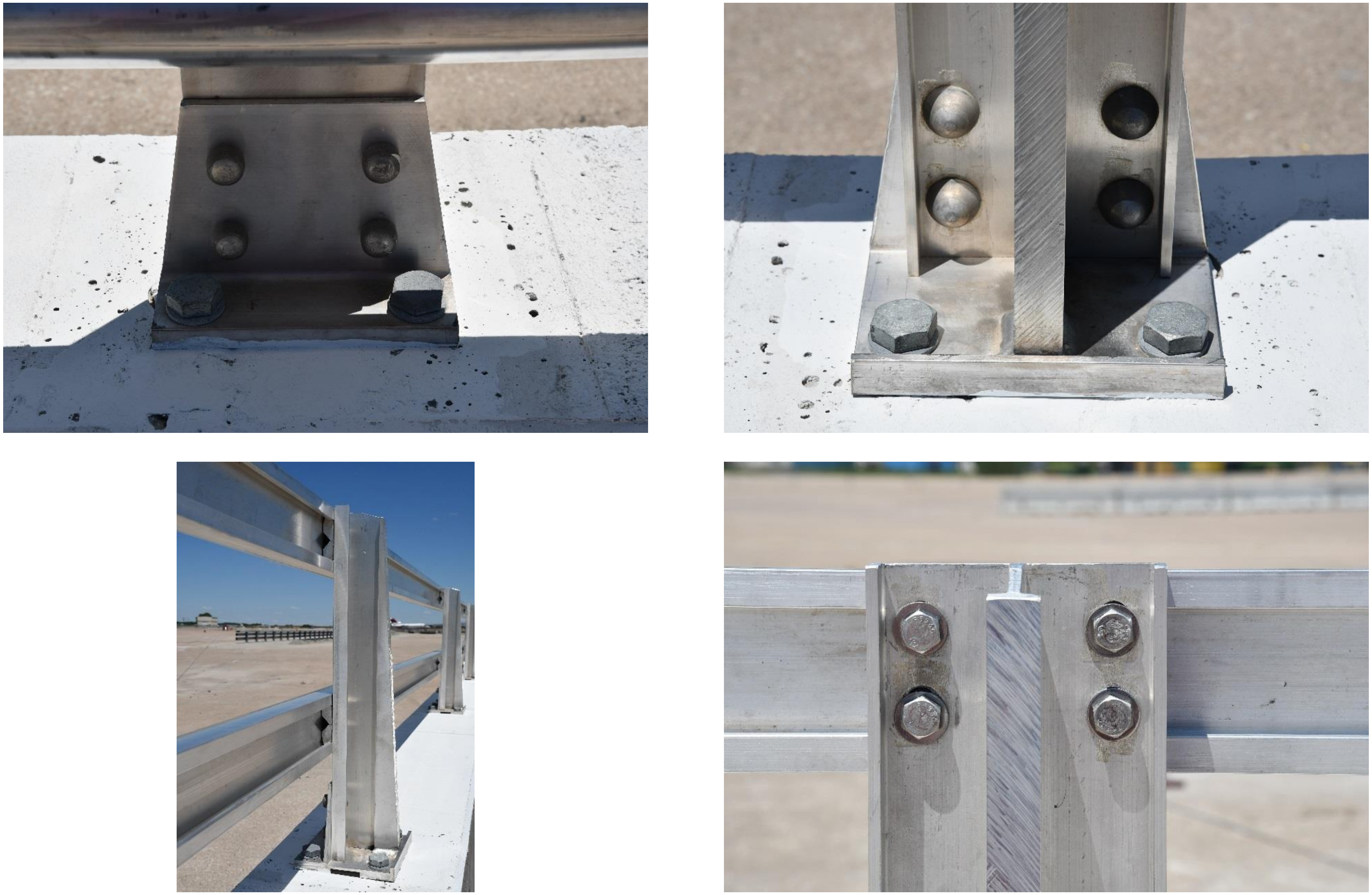


Figure 32. Post-to-Parapet and Post-to-Rail Attachment Details, Test Nos. NCBR-1 and NCBR-2

Figure 33. Rail End Anchorage Details, Test Nos. NCBR-1 and NCBR-2

Load Cell Setup Parameters

Calibration Factor:	2.1475	mV/V
Excitation:	10.01	V
Gain:	400	mV/mV
Full Load:	50	kips
Load Cell Data Output:	1.1	V
Load:	6.396	kips
Calibration Factor:	5.815	kip/V

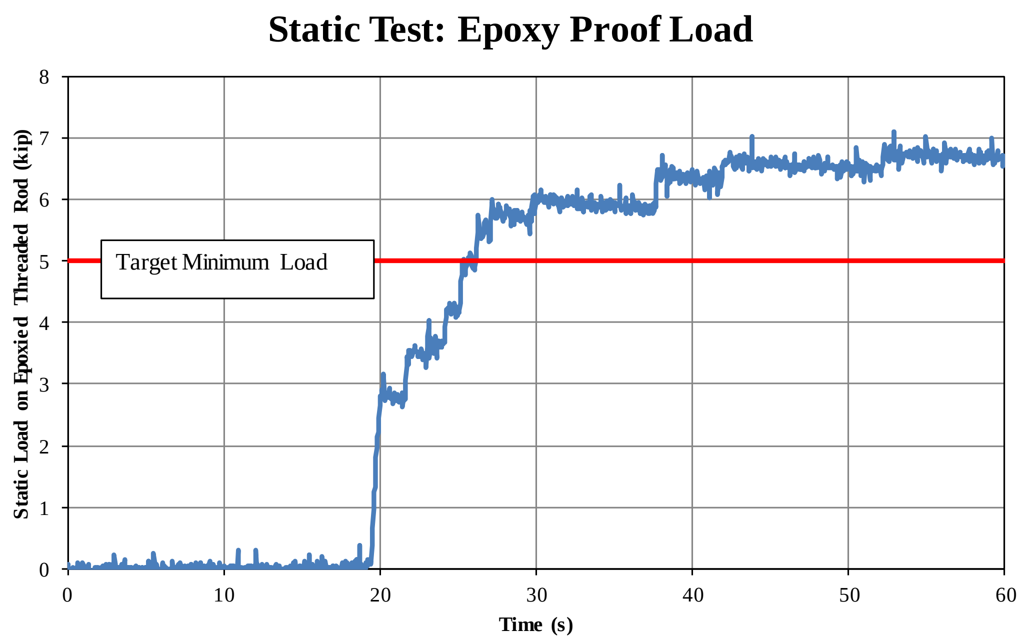


Figure 34. Load-Time Plot for Threaded Rod Proof Testing, Test Nos. NCBR-1 and NCBR-2

4 TEST CONDITIONS

4.1 Test Facility

Both full-scale crash test nos. NCBR-1 and NCBR-2 were conducted at the MwRSF Outdoor Test Site. The MwRSF 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.

4.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [5] was used to steer the test vehicle. A guide flag, attached to the right-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. 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.

4.3 Test Vehicles

For test no. NCBR-1, a 2010 Hyundai Accent was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,505 lb, 2,425 lb, and 2,585 lb, respectively. The test vehicle is shown in Figures 35 and 36, and vehicle dimensions are shown in Figure 37. MASH 2016 requires that test vehicles used in crash testing be no more than six model years old. However, a 2010 model was used for test no. NCBR-1 per a joint agreement with NCDOT to select a small car with geometry that complied with recommended vehicle dimension ranges specified in Table 4.1 of MASH 2016. Note that the computer simulation vehicle used to predict the vehicle engagement with the system during test no. NCBR-1 was a Toyota Yaris produced by the National Crash Analysis Center (NCAC) [6], but no Toyota Yaris test vehicles were found which could be purchased and shipped to the MwRSF Outdoor Test Site within the specified contract time and budget limits.

For test no. NCBR-2, a 2015 Chevrolet Silverado quad cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,015 lb, 5,018 lb, and 5,183 lb, respectively. The test vehicle is shown in Figures 38 and 39 and vehicle dimensions are shown in Figure 40. The 2015 Chevrolet Silverado was selected for testing because it was believed to have similar properties to the simulation vehicle model, a 2007 Silverado C1500 quad cab initially developed at NCAC [6] and modified at UNCC.

The longitudinal components of the center of gravity (c.g.) were determined using the measured axle weights. The vertical component of the c.g. for the 1100C vehicle was determined using a procedure published by SAE [7]. The location of the final c.g. is shown in Figure 41. The Suspension Method [8] was used to determine the vertical component of the c.g. for the 2270P vehicle. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The pickup truck was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The location of the final c.g. is shown in Figure 42. Data used to calculate the locations of the c.g. and ballast information are shown in Appendix C.

Square, black- and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in video analysis, as shown in Figures 41 and 42. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

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

Figure 35. Test Vehicle, Test No. NCBR-1

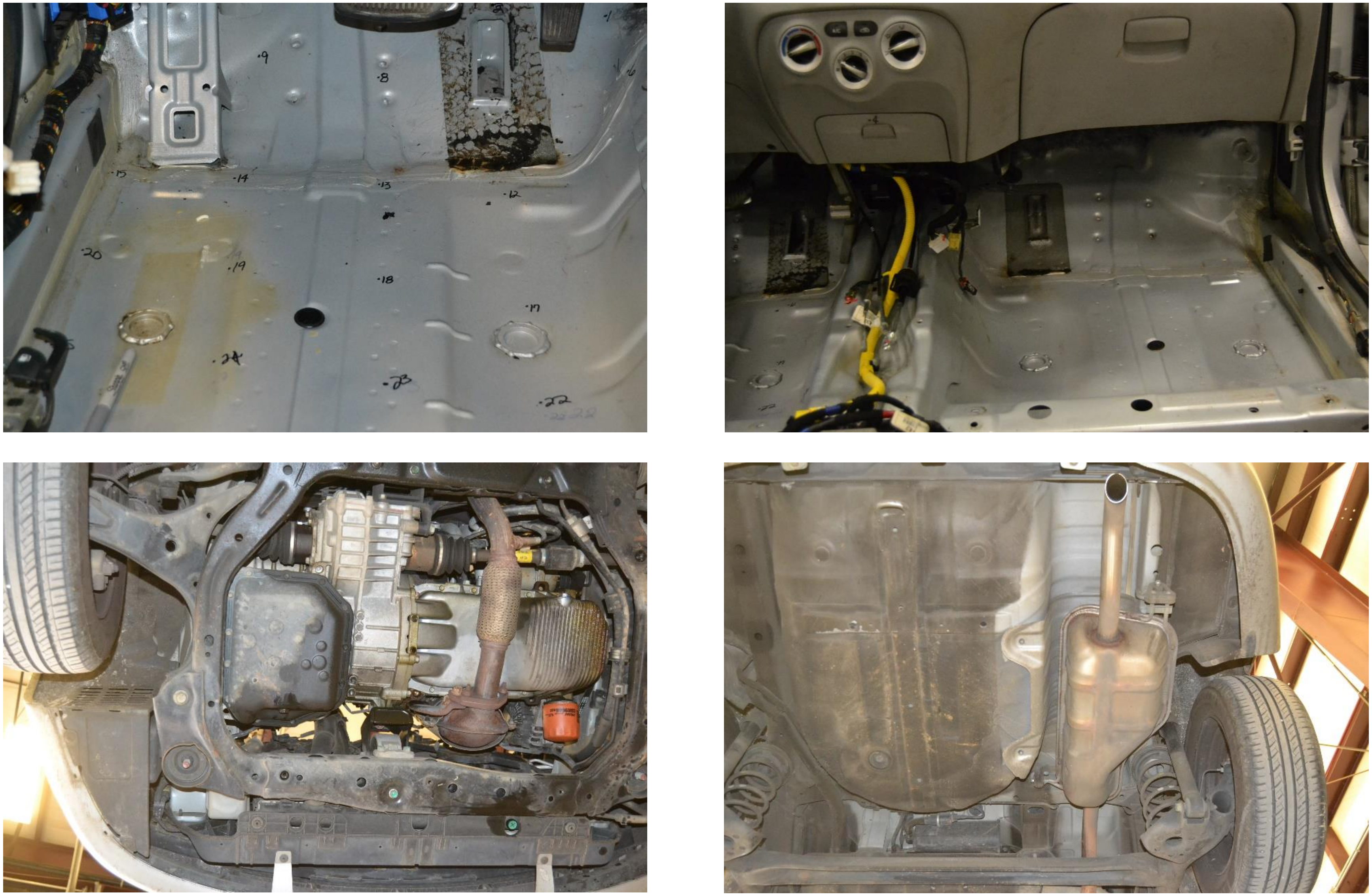
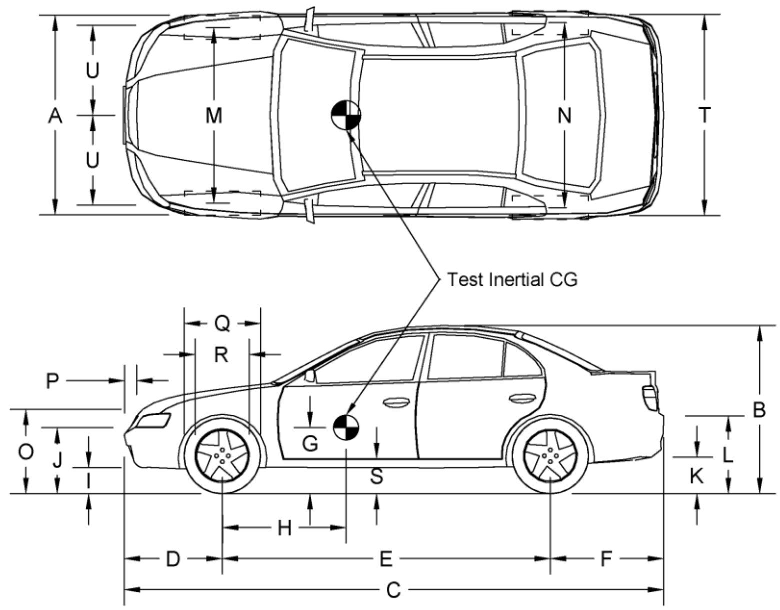


Figure 36. Test Vehicle’s Interior Floorboards and Undercarriage, Test No. NCBR-1

Date:	5/13/2019	**Test Name:**	NCBR-1	**VIN No:**	kmhcn4ac1au467917
Year:	2010	**Make:**	Hyundai	**Model:**	Accent
Tire Size:	185/65 r14	**Tire Inflation Pressure:**	32 psi	**Odometer:**	195823



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

A:	66 7/8 (1699) 65±3 (1650±75)	**B:**	57 5/8 (1464)
C:	168 4/9 (4278) 169±8 (4300±200)	**D:**	32 3/8 (822) 35±4 (900±100)
E:	99 (2515) 98±5 (2500±125)	**F:**	37 (940)
G:	22 5/8 (575)	**H:**	35 1/2 (902) 39±4 (990±100)
I:	8 (203)	**J:**	21 1/2 (546)
K:	12 3/4 (324)	**L:**	23 1/4 (591)
M:	57 7/8 (1470) 56±2 (1425±50)	**N:**	57 1/4 (1454) 56±2 (1425±50)
O:	27 1/2 (699) 24±4 (600±100)	**P:**	3 1/2 (89)
Q:	15 3/8 (391)	**R:**	23 (584)
S:	6 (152)	**T:**	64 7/8 (1648)

U (impact width):	29 1/4 (743)
Top of radiator core support:	29 1/2 (749)
Wheel Center Height (Front):	10 2/3 (271)
Wheel Center Height (Rear):	11 (279)
Wheel Well Clearance (Front):	25 3/4 (654)
Wheel Well Clearance (Rear):	25 5/8 (651)
Bottom Frame Height (Front):	8 (203)
Bottom Frame Height (Rear):	16 (406)
Engine Type:	Gasoline
Engine Size:	1.4L 4 Cyl
Transmission Type:	Automatic
Drive Type:	FWD

Mass Distribution - lb (kg)

Gross Static	**LF**	845 (383)	**RF**	793 (360)
	LR	478 (217)	**RR**	469 (213)

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	1596 (724)	1555 (705)	1638 (743)
W-rear	909 (412)	870 (395)	947 (430)
W-total	2505 (1136)	2425 (1100) 2420±55 (1100±25)	2585 (1173) 2585±55 (1175±50)

GVWR Ratings lb

Front	1918
Rear	1874
Total	3638

Surrogate Occupant Data

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

Note any damage prior to test:

Figure 37. Vehicle Dimensions, Test No. NCBR-1

Figure 38. Test Vehicle, Test No. NCBR-2

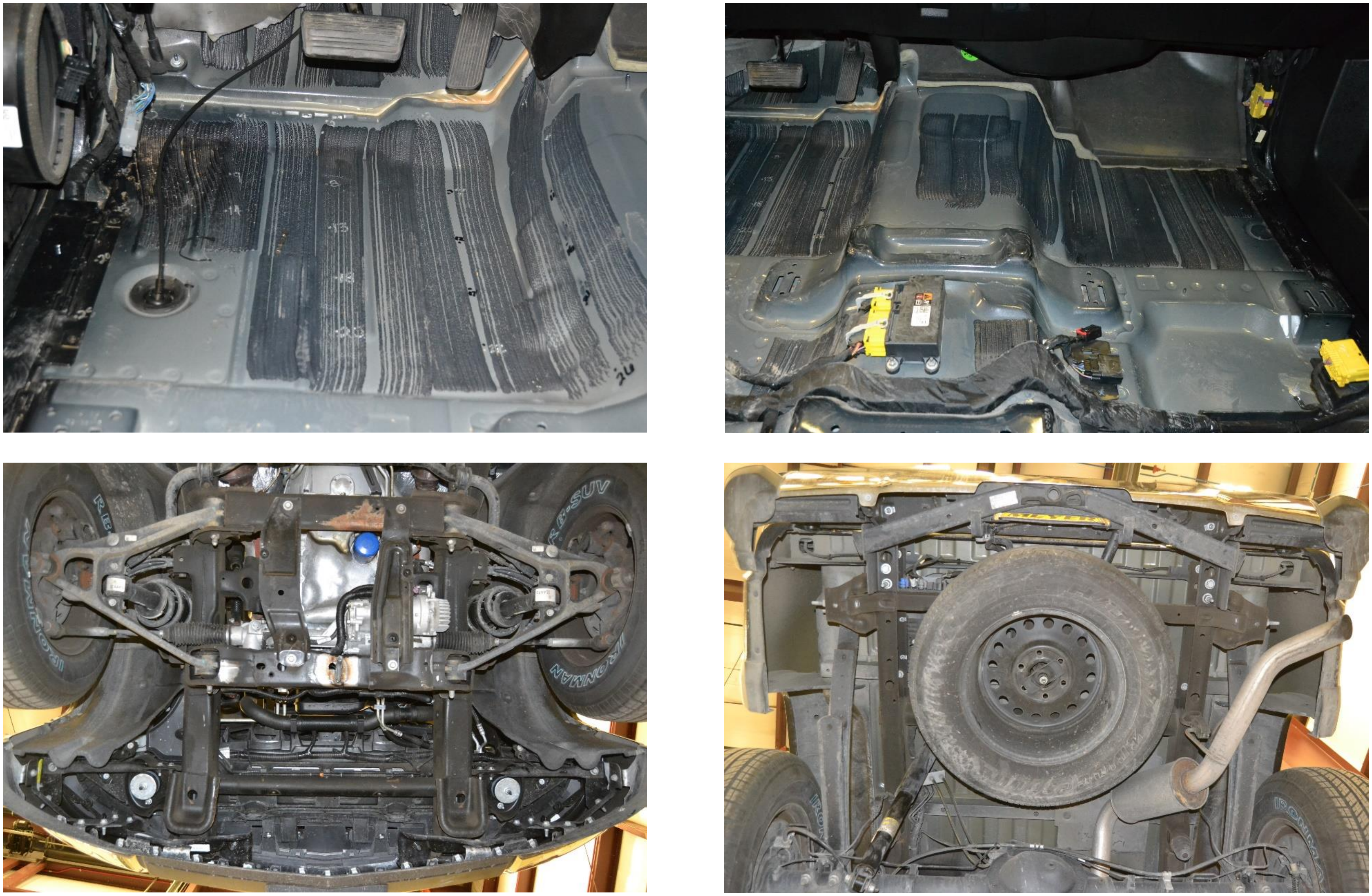
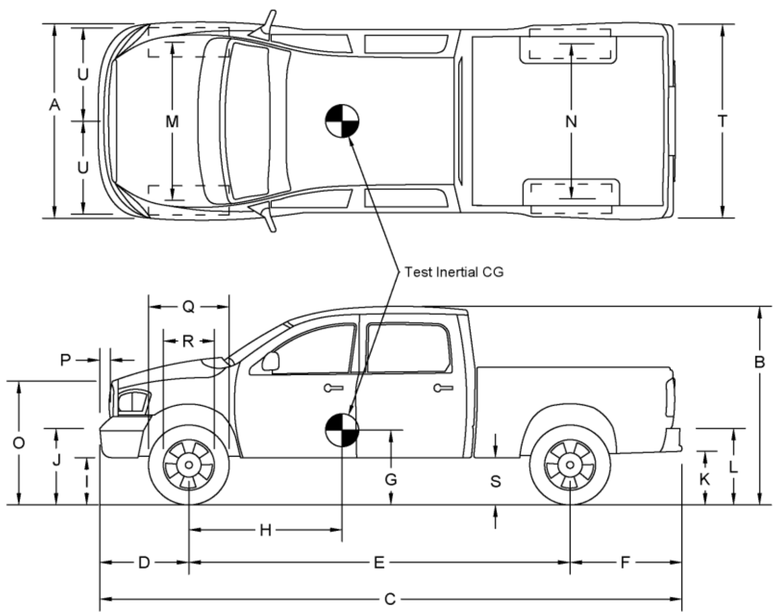


Figure 39. Test Vehicle’s Interior Floorboards and Undercarriage, Test No. NCBR-2

Date:	6/11//2019	**Test Name:**	NCBR-2	**VIN No:**	1GCRCPEH6FZ173614
Year:	2015	**Make:**	Chevrolet	**Model:**	Silverado
Tire Size:	255/70R17	**Tire Inflation Pressure:**	35 psi	**Odometer:**	83730



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

A:	79 3/4 (2026) 78±2 (1950±50)	**B:**	73 (1854)
C:	229 (5817) 237±13 (6020±325)	**D:**	38 (965) 39±3 (1000±75)
E:	144 (3658) 148±12 (3760±300)	**F:**	47 (1194)
G:	28 5/16 (719) min: 28 (710)	**H:**	61 3/8 (1559) 63±4 (1575±100)
I:	18 3/4 (476)	**J:**	25 (635)
K:	20 1/4 (514)	**L:**	28 1/2 (724)
M:	68 (1727) 67±1.5 (1700±38)	**N:**	67 1/2 (1715) 67±1.5 (1700±38)
O:	44 3/8 (1127) 43±4 (1100±75)	**P:**	1 3/4 (44)
Q:	30 1/2 (775)	**R:**	18 5/8 (473)
S:	16 (406)	**T:**	77 1/2 (1969)

U (impact width):	38 1/8 (968)
Wheel Center Height (Front):	14 1/2 (368)
Wheel Center Height (Rear):	14 5/8 (371)
Wheel Well Clearance (Front):	35 3/4 (908)
Wheel Well Clearance (Rear):	38 (965)
Bottom Frame Height (Front):	9 1/2 (241)
Bottom Frame Height (Rear):	12 (305)
Engine Type:	Gasoline
Engine Size:	4.3L
Transmission Type:	Auto
Drive Type:	RWD
Cab Style:	Quad Cab
Bed Length:	67"

Mass Distribution - lb (kg)

Gross Static	**LF**	1519 (689)	**RF**	1464 (664)
	LR	1095 (497)	**RR**	1105 (501)

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	2931 (1329)	2879 (1306)	2983 (1353)
W-rear	2084 (945)	2139 (970)	2200 (998)
W-total	5015 (2275)	5018 (2276) 5000±110 (2270±50)	5183 (2351) 5165±110 (2343±50)

GVWR Ratings - lb

Front	3600
Rear	3950
Total	6900

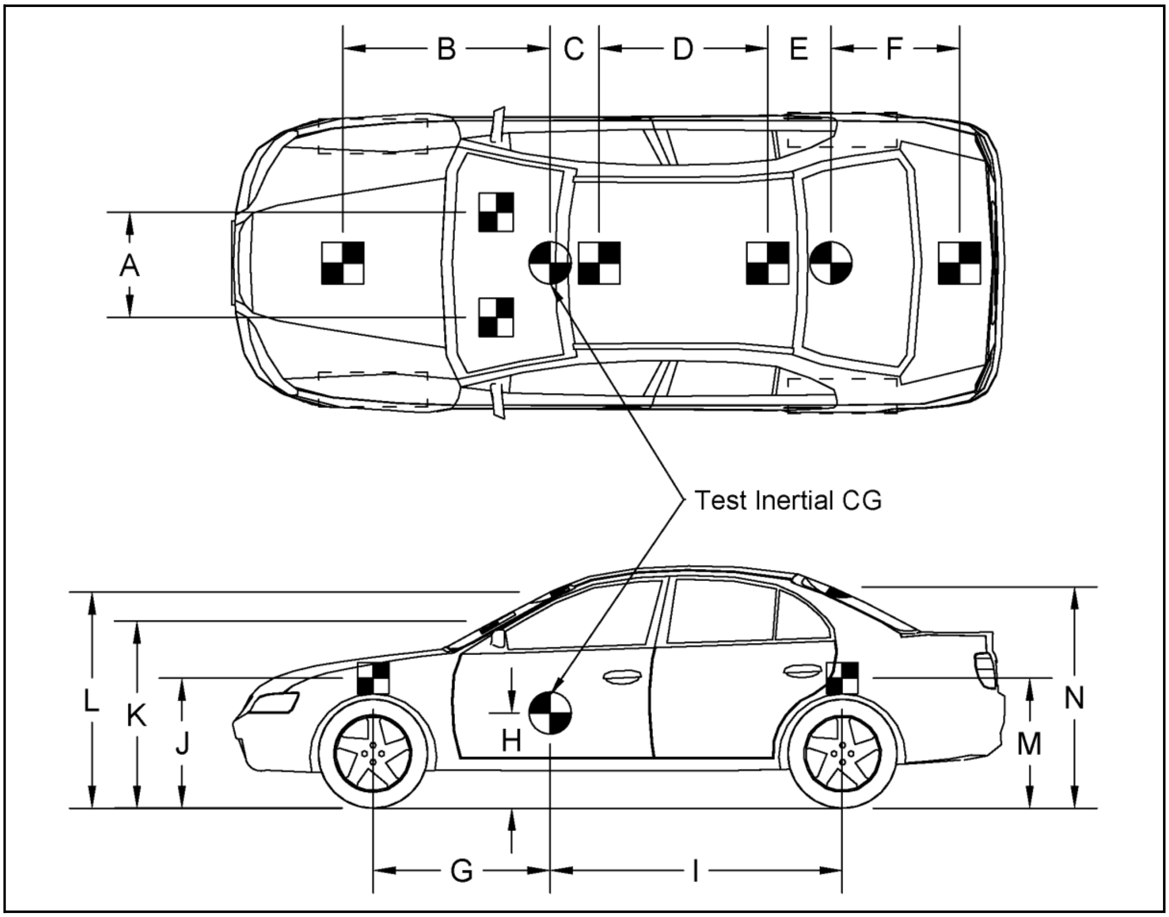
Surrogate Occupant Data

Type:	Hybrid II
Mass:	165 lb
Seat Position:	Left/Driver

Note any damage prior to test: None

Figure 40. Vehicle Dimensions, Test No. NCBR-2

Date:	**5/13/2019**	**Test Name:**	**NCBR-1**	**VIN:**	**kmhcn4ac1au467917**
Year:	**2010**	**Make:**	**Hyundai**	**Model:**	**Accent**



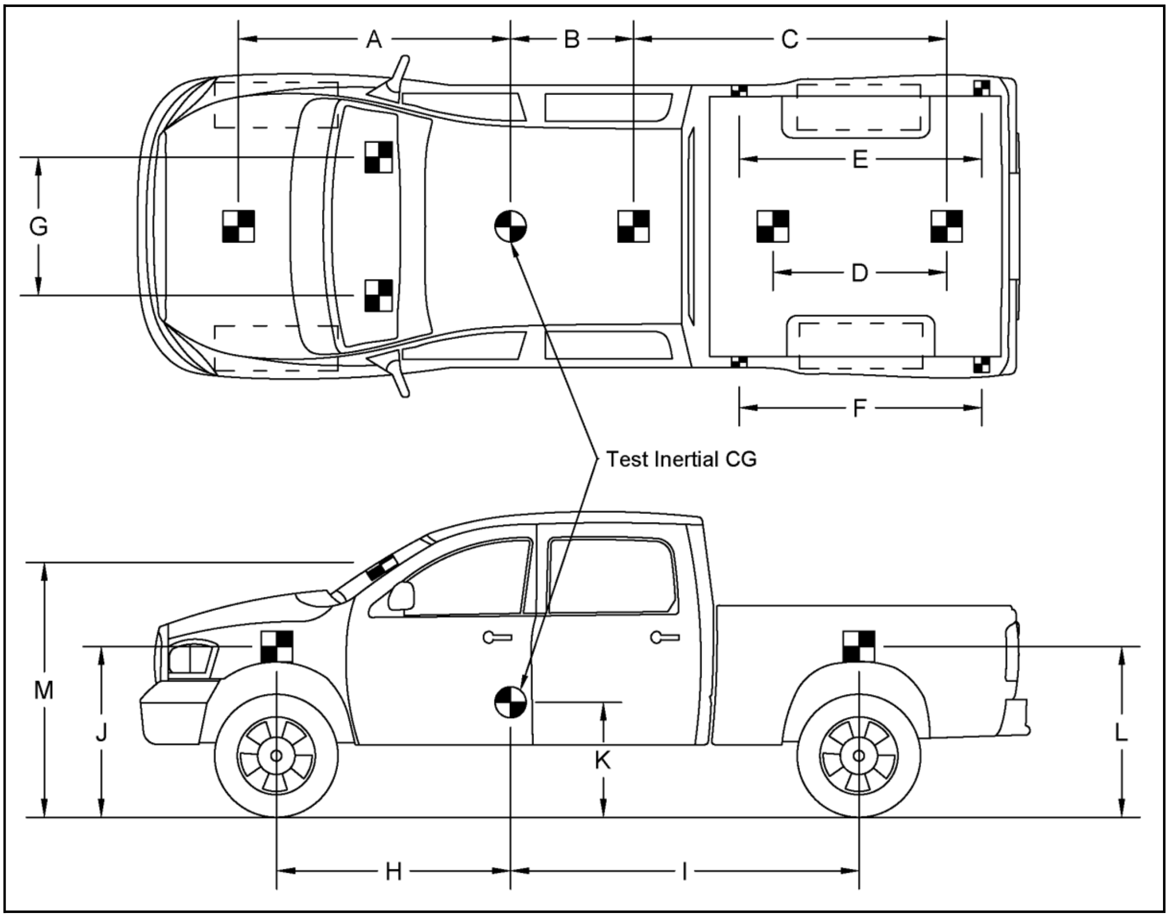
TARGET GEOMETRY-- in. (mm)

A:	**24 7/8**	**(632)**	**F:**	**21 1/2**	**(546)**	**K:**	**48 15/16**	**(1243)**
						Windshield Target		
B:	**46 1/4**	**(1175)**	**G:**	**35 5/8**	**(905)**	**L:**	**52 1/4**	**(1327)**
						Front round CG target		
C:	**14 15/16**	**(379)**	**H:**	**22 9/16**	**(573)**	**M:**	**29**	**(737)**
D:	**34 1/4**	**(870)**	**I:**	**63 7/16**	**(1611)**	**N:**	**52 3/16**	**(1326)**
						Rear Round target		
E:	**15 1/8**	**(384)**	**J:**	**28 3/4**	**(730)**			

Figure 41. Target Geometry, Test No. NCBR-1

Date: 6/11//2019 **Test Name:** NCBR-2 **VIN:** 1GCRCPEH6FZ173614

Year: 2015 **Make:** Chevrolet **Model:** Silverado



TARGET GEOMETRY-- in. (mm)

A:	73 1/2 (1867)	E:	67 3/8 (1711)	J:	39 3/4 (1010)
B:	25 3/8 (645)	F:	67 3/8 (1711)	K:	28 (711)
C:	83 1/2 (2121)	G:	31 3/8 (797)	L:	42 (1067)
D:	46 (1168)	H:	61 3/8 (1559)	M:	60 1/2 (1537)
		I:	83 1/4 (2115)		

Figure 42. Target Geometry, Test No. NCBR-2

4.4 Simulated Occupant

For test nos. NCBR-1 and NCBR-2, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the left-front seat of the test vehicle with the seat belt fastened. The dummy had a final weight of 160 lb for test no. NCBR-1 and 165 for test no. NCBR-2. As recommended by MASH 2016, the dummy was not included when calculating c.g. locations.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

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

The SLICE-1 and SLICE-2 units were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SLICE-1 unit was designated as the primary system for both tests. 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. Both SLICE 6DX systems were configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The SLICEWare computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

Two identical angular rate sensor systems mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders were used to measure the rates of rotation of the test vehicles. 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 then downloaded, converted to the proper Euler angles for analysis, and plotted. The SLICEWare computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

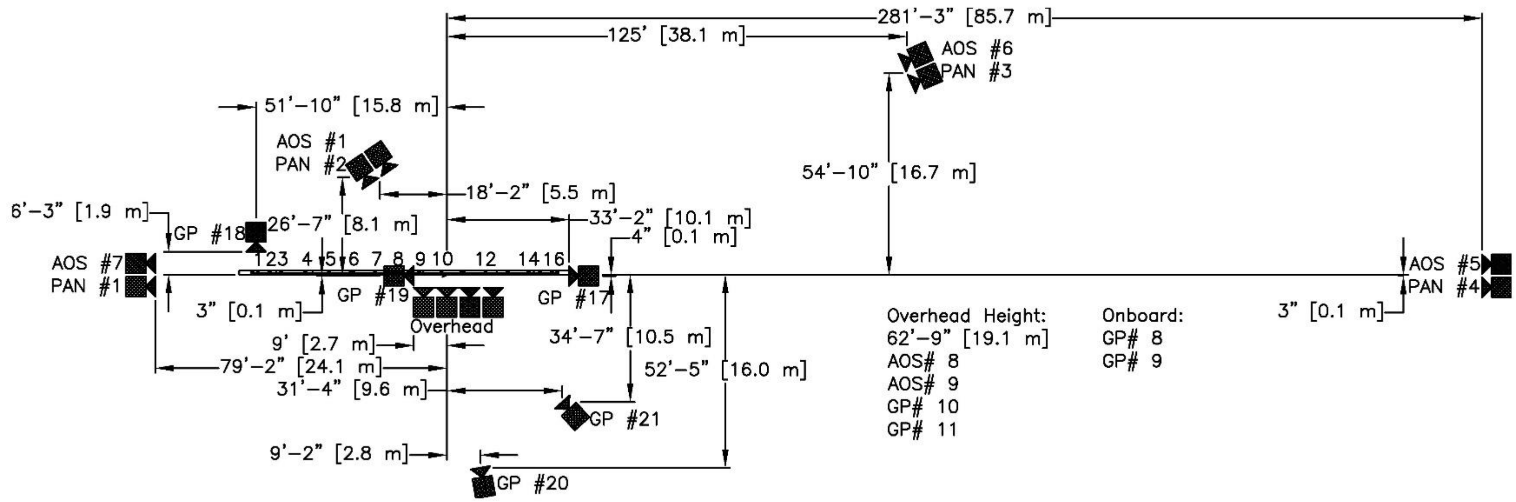
4.5.3 Retroreflective Optic Speed Trap

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

4.5.4 Digital Photography

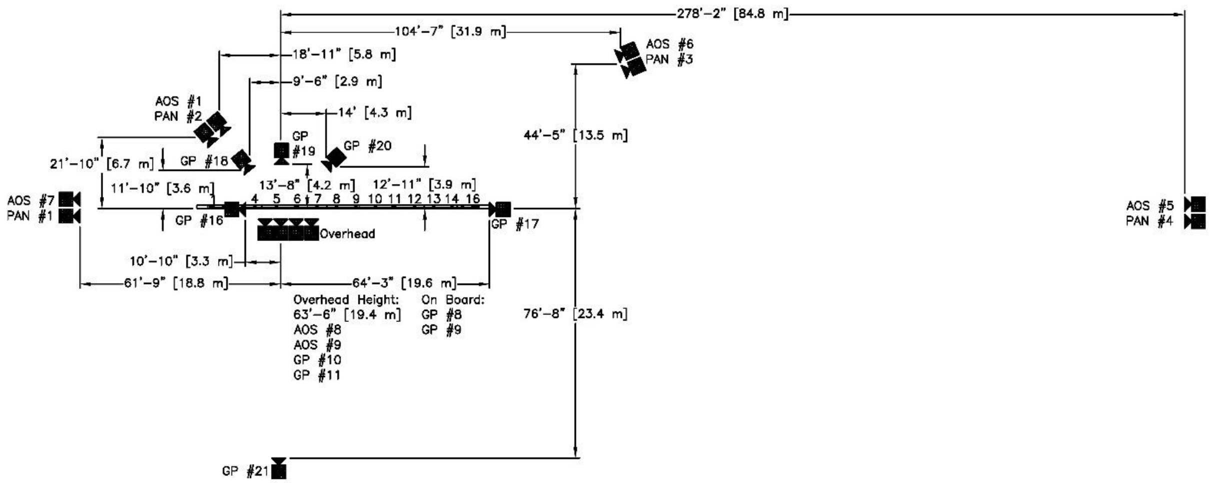
Six AOS high-speed digital video cameras, nine GoPro digital video cameras, and four Panasonic digital video cameras were used to film test no. NCBR-1. Six AOS high-speed digital video cameras, ten GoPro digital video cameras, and four Panasonic digital video cameras were used to film test no. NCBR-2. Camera details and operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figures 43 and 44.

The high-speed videos were analyzed using TEMA Motion and Redlake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A Nikon digital still camera was used to document pre- and post-test conditions for the tests.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam	500	Kowa 25 mm	
AOS-5	AOS X-PRI	500	100 mm	
AOS-6	AOS X-PRI	500	Fujinon 35 mm	
AOS-7	AOS X-PRI	500	Fujinon 50 mm	
AOS-8	AOS S-VIT 1531	500	Kowa 16 mm	
AOS-9	AOS TRI-VIT 2236	500	Kowa 12 mm	
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	120		
GP-11	GoPro Hero 4	240		
GP-17	GoPro Hero 4	240		
GP-18	GoPro Hero 6	240		
GP-19	GoPro Hero 6	240		
GP-20	GoPro Hero 6	240		
GP-21	GoPro Hero 6	240		
PAN-1	Panasonic HC-V770	120		
PAN-2	Panasonic HC-V770	120		
PAN-3	Panasonic HC-V770	120		
PAN-4	Panasonic HC-V770	120		

Figure 43. Camera Locations, Speeds, and Lens Settings, Test No. NCBR-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam	500	Kowa 25 mm	
AOS-5	AOS X-PRI	500	100 mm fixed	
AOS-6	AOS X-PRI	500	Fujinon 35 mm fixed	
AOS-7	AOS X-PRI	500	Fujinon 50 mm fixed	
AOS-8	AOS S-VIT 1531	500	Kowa 16 mm	
AOS-9	AOS TRI-VIT 2236	500	Kowa 12 mm	
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	120		
GP-11	GoPro Hero 4	240		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	240		
GP-18	GoPro Hero 6	240		
GP-19	GoPro Hero 6	240		
GP-20	GoPro Hero 6	240		
GP-21	GoPro Hero 6	240		
PAN-1	Panasonic HC-V770	120		
PAN-2	Panasonic HC-V770	120		
PAN-3	Panasonic HC-V770	120		
PAN-4	Panasonic HC-V770	120		

Figure 44. Camera Locations, Speeds, and Lens Settings, Test No. NCBR-2

5 FULL-SCALE CRASH TEST NO. NCBR-1

5.1 Weather Conditions

Test no. NCBR-1 was conducted on May 13, 2019 at approximately 2:00 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

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

Temperature	72 deg. F
Humidity	46 percent
Wind Speed	13 mph
Wind Direction	180 deg. from True North
Sky Conditions	Clear
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.33 in.
Previous 7-Day Precipitation	1.68 in.

5.2 Test Description

Initial vehicle impact was to occur 54$^{9}/_{16}$ in. upstream from post no. 11, as shown in Figure 45, which was selected by UNCC from simulation results and verified by NCDOT as the point that maximized the loading on the rail splices. The 2,425-lb small car impacted the NCDOT two-bar metal bridge rail at a speed of 63.2 mph and an angle of 25.2 deg. The actual point of impact was 51.1 in. upstream from post no. 11. The vehicle came to rest 164 ft – 8 in. downstream and 60 ft – 7 in. laterally behind the traffic side of the barrier after the brakes were applied.

A detailed description of the sequential impact events is contained in Table 4. High-speed footage of the test is shown in Figures 46 and 47. Sequential photographs are shown in Figures 48 and 49. Documentary photographs of the crash test are shown in Figures 50 through 52. The vehicle trajectory and final position are shown in Figure 53.

Figure 45. Impact Location, Test No. NCBR-1

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

TIME (sec)	EVENT
0.000	Vehicle's front bumper contacted concrete parapet 51.1 in. upstream from post no. 11.
0.004	Vehicle's left headlight contacted concrete parapet.
0.006	Vehicle's left-front tire and left-front fender contacted concrete parapet.
0.008	Vehicle's left headlight shattered. Vehicle's hood contacted concrete parapet.
0.028	Vehicle's left-side mirror contacted rail.
0.034	Vehicle's left-front door contacted concrete parapet.
0.044	Vehicle's hood contacted post no. 11.
0.046	Vehicle's windshield cracked.
0.074	Vehicle’s left-front window shattered due to contact from simulated occupant's head.
0.078	Simulated occupant head passed through left-front window.
0.088	Vehicle's right-rear tire became airborne.
0.128	Simulated occupant head reentered through left-front window.
0.134	Vehicle's left-rear door contacted concrete parapet.
0.138	Vehicle's right-front tire became airborne.
0.162	Vehicle's left quarter panel contacted concrete parapet. Vehicle became parallel to system at 44.8 mph.
0.170	Vehicle's rear bumper contacted concrete parapet.
0.178	Vehicle's left quarter panel contacted rail.
0.182	Vehicle's left taillight contacted rail.
0.200	Vehicle's left-side mirror became disengaged.
0.330	Vehicle exited system at 42.8 mph and an 8.5 deg. angle.
0.372	Vehicle's right-front tire regained contact with ground.
0.446	Vehicle's right-rear tire regained contact with ground.

Figure 46. Downstream High-Speed Footage, Test No. NCBR-1

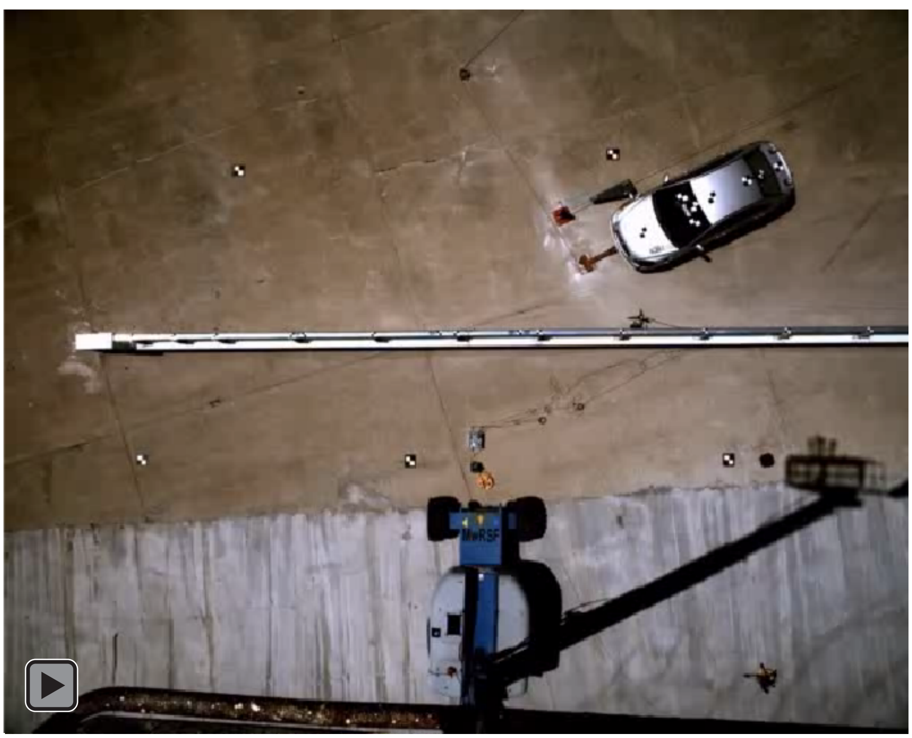


Figure 47. Overhead High-Speed Footage, Test No. NCBR-1

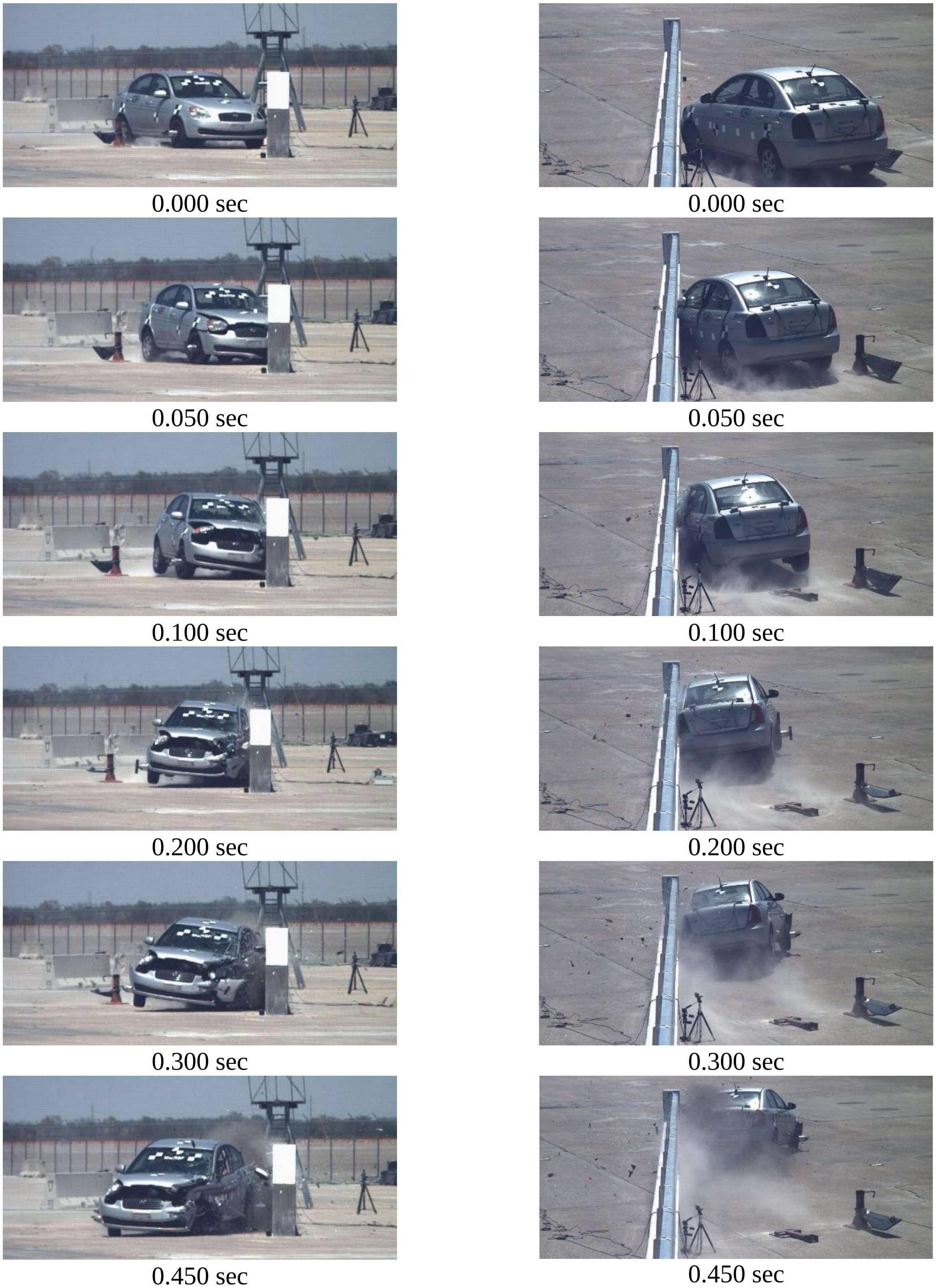


Figure 48. Sequential Photographs, Test No. NCBR-1

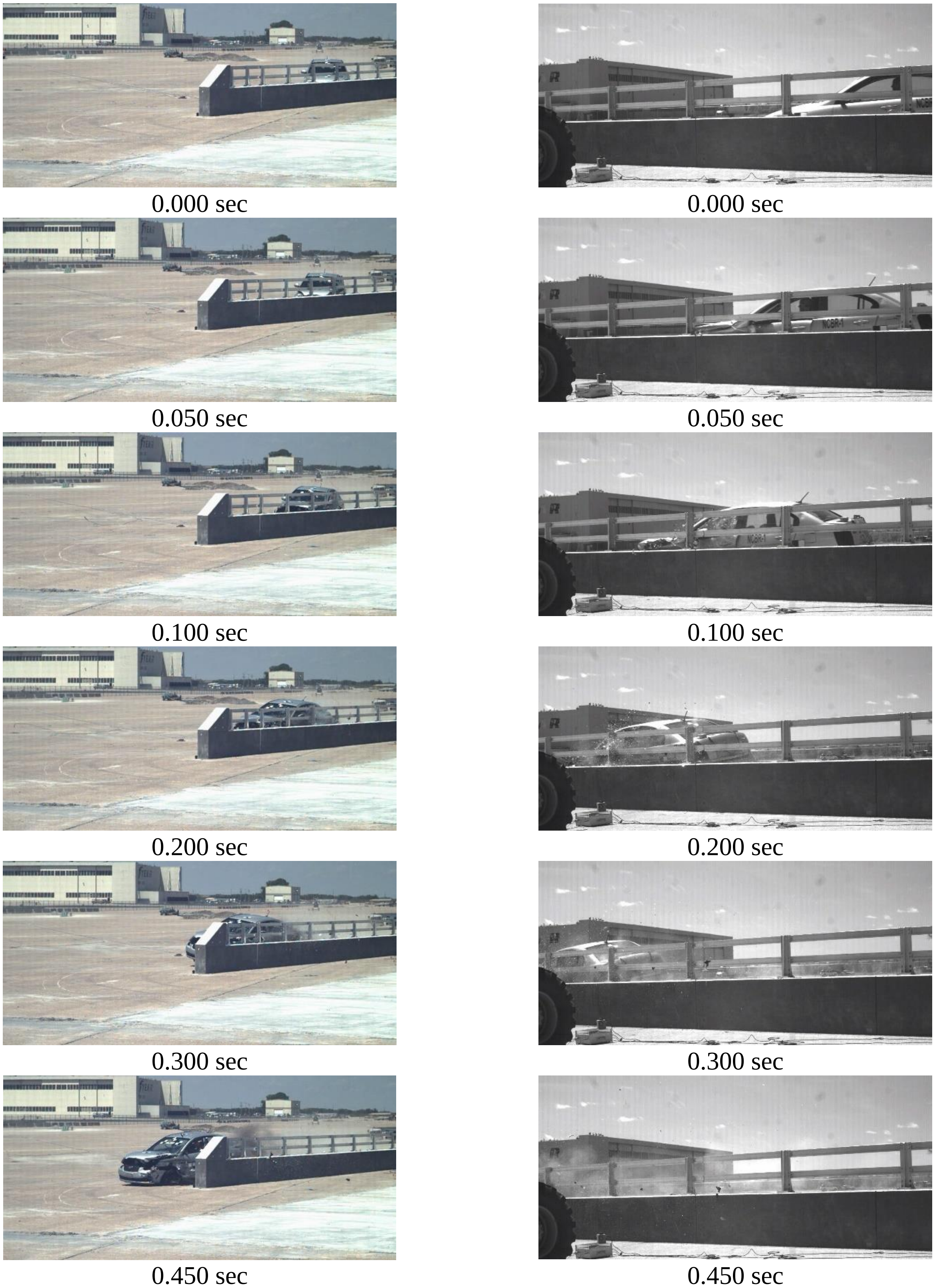


Figure 49. Sequential Photographs, Test No. NCBR-1

Figure 50. Documentary Photographs, Test No. NCBR-1

Figure 51. Documentary Photographs, Test No. NCBR-1

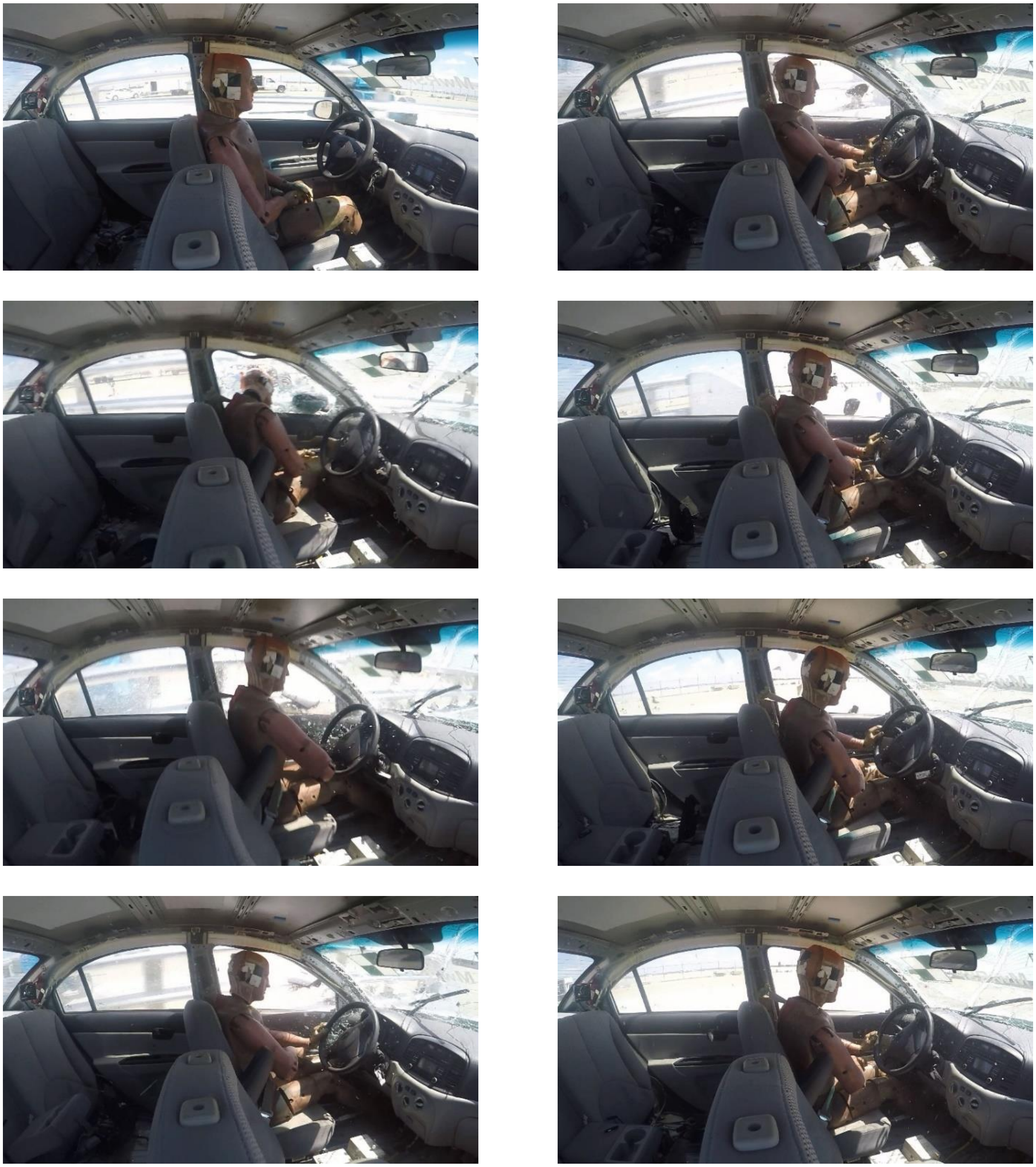


Figure 52. Documentary Photographs, Test No. NCBR-1

Figure 53. Vehicle Final Position and Trajectory Marks, Test No. NCBR-1

5.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 54 through 57. Barrier damage consisted of contact marks and concrete gouging across the front face of the parapet. Note that all cracking visible in the system photographs was documented beforehand and not a result of test no. NCBR-1. The length of vehicle contact along the concrete parapet was 134¾ in., which spanned from 53¾ in. upstream from the splice between post nos. 10 and 11 to 71 in. downstream from the splice.

Tire marks were visible on the front face of the parapet. Scuff marks were on the front and top faces of the barrier. A ½-in. wide x 1-in. tall x ½-in. deep piece of concrete was removed from the top corner of the upstream edge of the expansion gap between post nos. 10 and 11.

Two small, parallel gouges beginning 14½ and 16 in. upstream from the expansion gap on parapet segment no. 2 extended to the expansion gap. A 3½-in. long, ¼-in. tall gouge was centered 27½ in. upstream from the expansion gap and 19¼ in. above the tarmac. A 1-in. wide x 1-in. tall x ¼-in. deep rounded gouge was located 16 in. upstream from the expansion gap and 14 in. above the tarmac. Gouging occurred on the top edge of the front face of the parapet, starting 44 in. upstream from the expansion gap, extending downstream for 14 in., and measuring 1¼ in. thick. A gouge occurred in the surface of the parapet 4¼ in. downstream from the expansion gap, measuring ¾ in. in both height and width.

A contact mark on the front face of the lower rail began 67½ in. upstream from and extended to the splice between post nos. 10 and 11. An additional 51½-in. long, 1¼-in. wide contact mark on the front face of the lower rail began 1½ in. upstream from the splice. A 32¼-in. long contact mark was located on the bottom face of the lower rail, beginning 1¾ in. upstream from the splice. Surface scratches, likely from the shattered left-front window, were located across the front face of both rails, beginning 16 in. upstream from the splice and extending to 53 in. downstream.

A 5½-in. long contact mark was observed on the upstream edge of the base plate of post no. 11, and contact was observed on the base plate and bolts extending 6½ in. downstream along the traffic-side face. Minor splice movement was observed between post nos. 10 and 11, such that the traffic-side gap was $^{13}/_{16}$ in. and the back-side gap was ¾ in. for the lower rail. Both front- and back-side gaps were ¾ in. for the upper rail between all posts.

Orange paint splatter was observed on post no. 11 and both rails, beginning 9½ in. upstream from the splice and extending to 16½ in. downstream, as seen in Figure 57. Paint splatter was also found on the front face and upstream edge of post no. 11. Note that the dummy had recently been painted, and the wet paint caused splatter when the dummy's head contacted the side window. The dummy's head did not contact the system. Surface scratches were found across the entire width of the front face of post no. 11 between both rails.

Figure 54. System Damage, Test No. NCBR-1

Figure 55. System Damage, Test No. NCBR-1

Figure 56. Concrete Gouging, Test No. NCBR-1

Figure 57. Rail and Post No. 11 Damage, Test No. NCBR-1

The maximum lateral permanent set of the barrier system was -0.2 in., as measured in the field, which was 0.2 in. forward from its initial position. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 0.3 in. at post no. 15, as determined from high-speed digital video analysis. The working width of the system was found to be 14.0 in., also determined from high-speed digital video analysis. Barrier deflections are shown schematically in Figure 58.

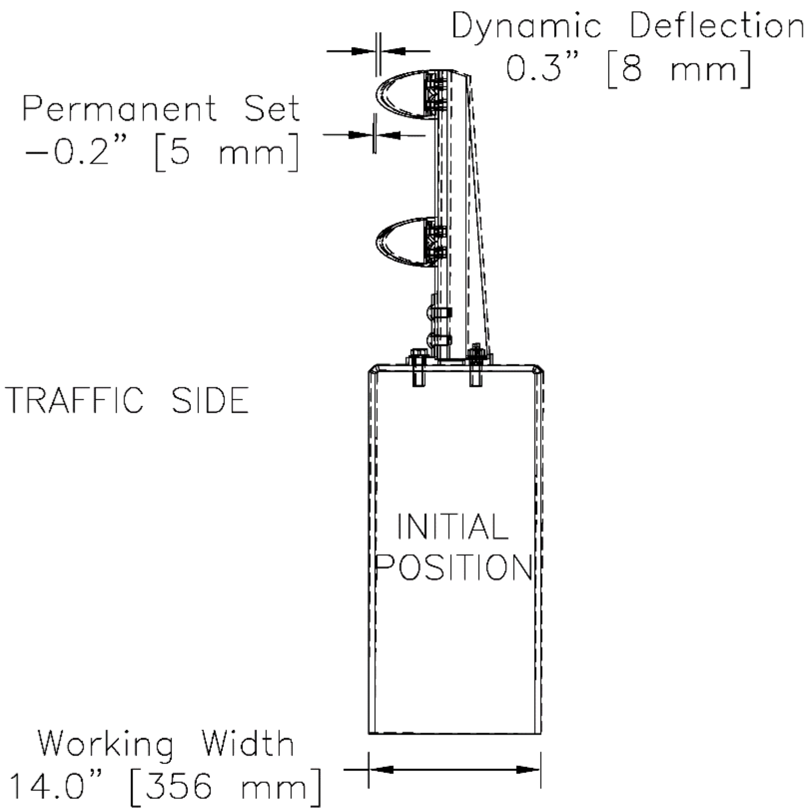


Figure 58. Barrier Deflections, Test No. NCBR-1

5.4 Vehicle Damage

Damage to the vehicle was moderate, as shown in Figures 59 through 63. The majority of the damage was concentrated on the left-front corner and left side of the vehicle where impact had occurred. The left side of the bumper was deformed and torn in front of the wheel. The left-front fender was pushed inward near the door panel and torn around the left-front wheel. The left-front steel rim was deformed with tears and crushing. The left-front tire was torn and deformed. The left-side headlight and fog light were disengaged from the vehicle. The left side of the radiator was pushed backward. Denting and scraping were observed across the entire left side. The top of the left-front door was slightly ajar and the bottom was pushed inward. The bottom of the left-rear door was dented and scuffed. The fuel hatch was ajar. The left-rear wheel assembly was deformed inward. The left-rear steel rim and tire were scuffed. The left side of the rear bumper was dented and scuffed. The hood was crushed inward, separated from the bumper entirely, and the left edge was torn. The right side of the bumper was pushed downward. The left side of the windshield was cracked and deformed, and the upper-right side had minor cracking. The left-front side window disengaged from the vehicle after contact with the dummy's head. The remaining window glass was undamaged. The spring perch on the left side was cracked. The left-side control arm was bent backward. The transmission mounts shifted toward the right side. The left-side frame rail compressed and bent upward. The rear cross member bent inward on both ends. The front cross member was bent and crushed upward. The frame horn was bent upward on the left side. The floor pan was opened at the seam across the whole left side. The front exhaust mount folded inward.

The maximum occupant compartment intrusions are listed in Table 5, along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment and none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D. It should be noted that a large tear was visible in the vehicle windshield. Review of the high-speed video revealed that tearing of the windshield was formed due to crushing of the back left corner of the hood, resulting in a vertical crack which propagated through the windshield to the roof. Neither the barrier nor any vehicle component contacted the windshield except at the bottom left corner. The displacement of the vehicle's "A"-pillar and hood were minimal. No deformations occurred to the roof panel. After the test, the windshield displacements were measured and compared against an exemplary vehicle. However, windshield deformations were artificially high due to settling that occurred in between testing and measurement. Therefore, windshield displacements were deemed acceptable according to MASH, and none of the MASH criteria for windshield contact, protrusion, or deformation were violated.

Figure 59. Vehicle Damage, Test No. NCBR-1

Figure 60. Vehicle Damage, Test No. NCBR-1

Figure 61. Occupant Compartment Damage, Test No. NCBR-1

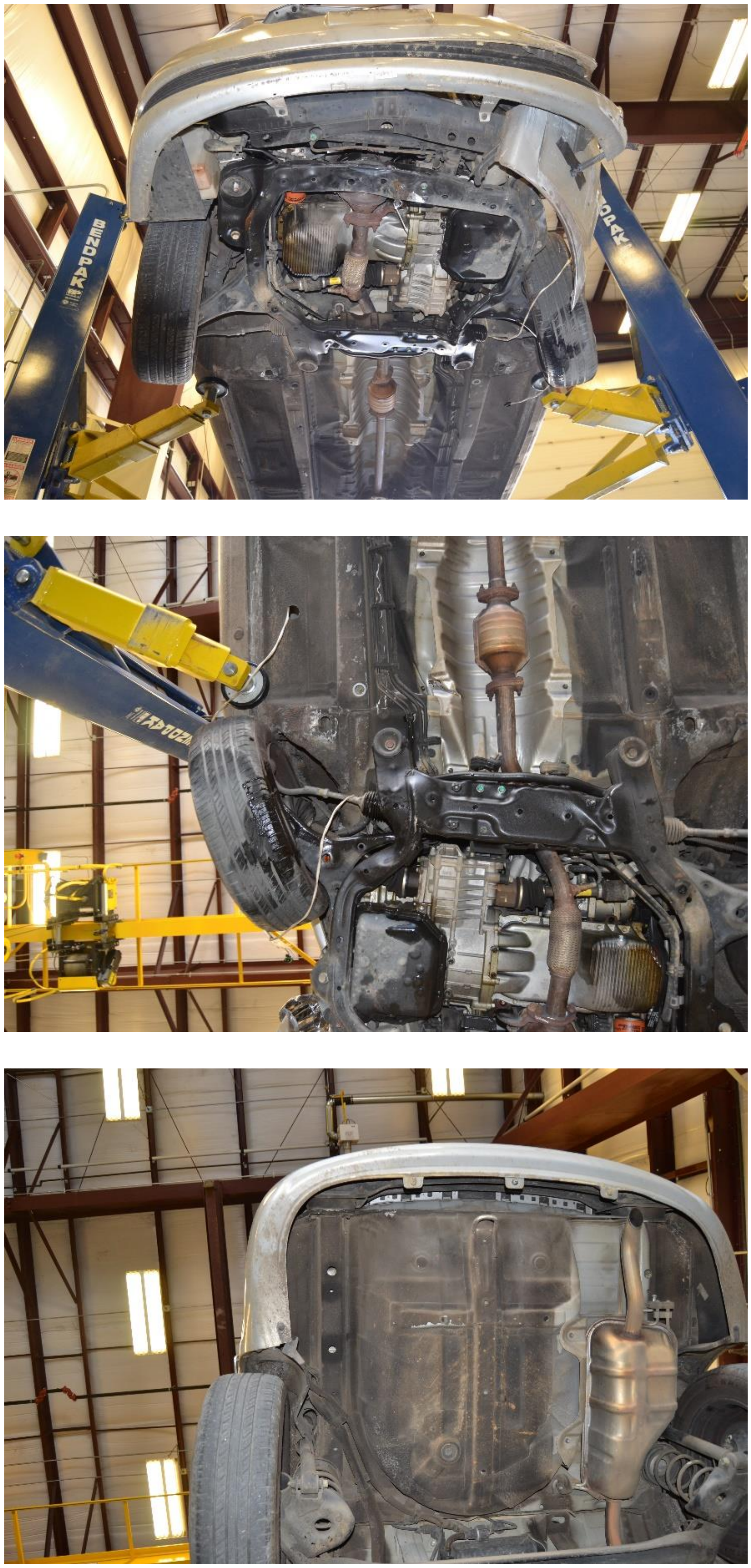


Figure 62. Undercarriage Damage, Test No. NCBR-1

Figure 63. Windshield Damage (Pre- and Post-Test), Test No. NCBR-1

Table 5. Maximum Occupant Compartment Intrusions by Location, Test No. NCBR-1

LOCATION	MAXIMUM INTRUSION in.	MASH 2016 ALLOWABLE INTRUSION in.
Toe Pan – Wheel Well	2.7	≤ 9
Floor Pan	1.9	≤ 12
A-Pillar	1.0	≤ 5
B-Pillar	0.4	≤ 5
A-Pillars (lateral)	1.0	≤ 3
B-Pillar (lateral)	1.0	≤ 3
Side Front Panel	2.9	≤ 12
Side Door (above seat)	0.8	≤ 9
Side Door (below seat)	0.5	≤ 12
Roof	–0.3	N/A[2]
Windshield	5.0*	≤ 3
Side Window	Shattered due to contact with dummy's head	Test article did not cause window shatter
Dash	1.5	N/A[1]

Note: Negative values denote outward deformation
* Windshield crush was measured three days after the test and during that time frame settling of the damaged windshield occurred. Thus, the measured value is not believed to be realistic
N/A[1] – Not applicable
N/A[2] – MASH 2016 criteria is not applicable when deformation is outward

5.5 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, as determined from the accelerometer data, are shown in Table 6. Note that the OIVs and ORAs were within the suggested limits provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 6. Recorded data from the accelerometers and rate transducers are shown graphically in Appendix E.

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

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 (primary)	SLICE-2	
OIV ft/s	Longitudinal	-24.46	-24.49	±40
	Lateral	30.78	28.60	±40
ORA g's	Longitudinal	-3.65	-2.86	±20.49
	Lateral	10.20	12.79	±20.49
MAX. ANGULAR DISPL. deg.	Roll	-12.6	-8.2	±75
	Pitch	-4.0	-5.0	±75
	Yaw	39.9	39.3	not required
THIV ft/s		38.74	35.75	not required
PHD g's		10.39	12.99	not required
ASI		2.51	2.34	not required

5.6 Barrier Loads

The longitudinal and lateral vehicle accelerations, as measured at the vehicle's c.g., were processed using an SAE CFC-60 filter and a 50-msec moving average. The 50-msec moving average vehicle accelerations were then combined with the uncoupled yaw angle versus time data in order to estimate the vehicular loading applied to the barrier system. The results of the barrier load estimate are shown in Figure 64. A peak load of 57.7 kip was noted at 0.031 s after impact, with a peak longitudinal wall force of approximately 14.8 kip. The average overall estimated vehicle-barrier sliding friction coefficient was 0.547 over the first 0.1 s of impact. The vehicle exhibited a "tail slap" effect in which two separate peaks were observed, the first corresponding to the redirection of the front of the vehicle, and the second corresponding to the tail end of the vehicle contacting the barrier system. The initial redirection load was approximately five times as large as the tail slap load.

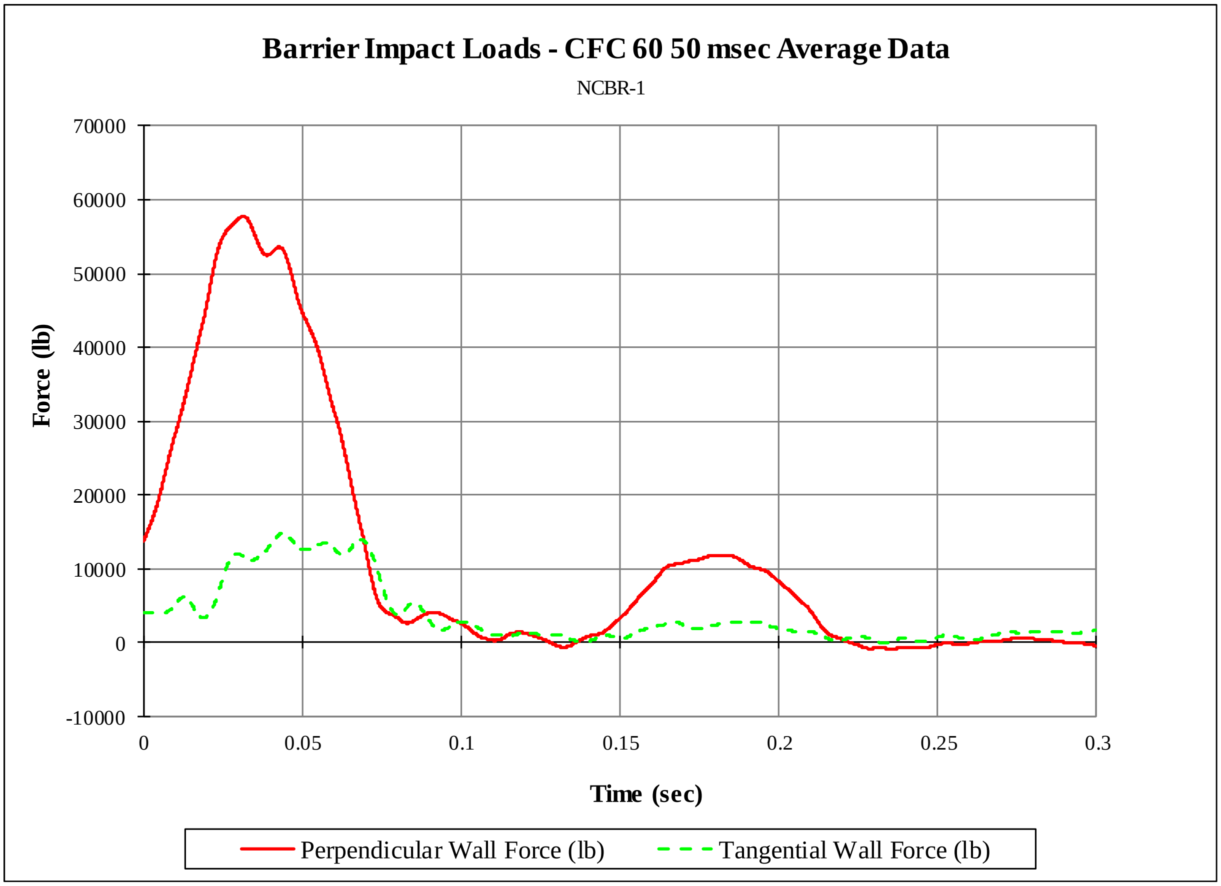


Figure 64. Estimated Barrier Impact and Friction Loads, Test No. NCBR-1

5.7 Discussion

Analysis of the test results for test no. NCBR-1 showed that the system adequately contained and redirected the 1100C vehicle with minimal barrier damage and displacement. A summary of the test results and sequential photographs are shown in Figure 65. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. Windshield deformation was measured three days after testing, and in that time settling and buckling of the windshield occurred. The measured deformation of 5.0 in. is not believed to be realistic, and is therefore not considered a violation of MASH 2016 safety performance criteria. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after impact. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 8.5 deg., and its trajectory did not violate the bounds of the exit box. Therefore, test no. NCBR-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-10.

During the test, the dummy’s head protruded out of the left-side window and nearly entered the ZOI without contacting the system. This behavior is associated with an increased occupant risk. Further evaluation of dummy movement is provided in Chapter 7.

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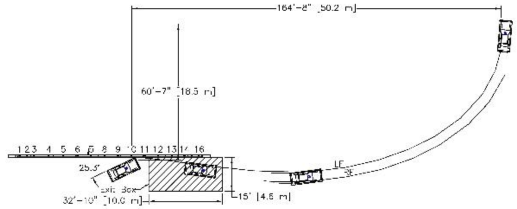

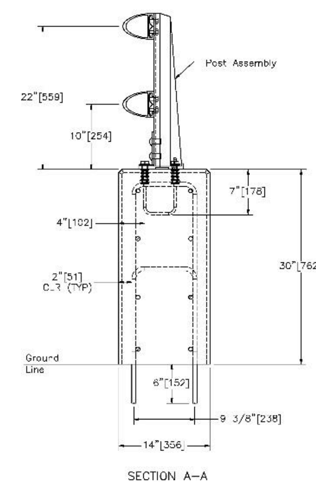

Test Agency .... MwRSF

- Test Number NCBR-1
- Date .... May 13, 2019
- MASH 2016 Test Designation No. 3-10
- Test Article .... NCDOT Two-Bar Metal Bridge Rail
- Total Length .... 90 ft
- Key Component – Elliptical Aluminum Rail
  - Length .... 30 ft
  - Width .... 4 in.
  - Depth .... 4¾ in.
- Key Component – Aluminum Post
  - Height .... 23½ in.
  - Length .... 5¾ in.
  - Width .... 4¼ in.
  - Spacing .... 72 in.
- Vehicle Make / Model .... 2010 Hyundai Accent
  - Curb .... 2,505 lb
  - Test Inertial .... 2,425 lb
  - Gross Static .... 2,585 lb
- Impact Conditions
  - Speed .... 63.2 mph
  - Angle .... 25.2 deg.
  - Impact Location .... 51.1 in. upstream from post no. 11
- Impact Severity .... 59.0 kip-ft > 51 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed .... 42.8 mph
  - Angle .... 8.5 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 164 ft – 8 in. downstream, 60 ft – 7 in. laterally behind
- Vehicle Damage .... Moderate
  - VDS [10] 11-LFQ-4
  - CDC [11] 11-LFEW-3
  - Maximum Interior Deformation .... 2.9 in.

- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... -0.2 in.
  - Dynamic .... 0.3 in.
  - Working Width .... 14.0 in.
- Transducer Data

Evaluation Criteria		Transducer SLICE-1 (primary)	Transducer SLICE-2	MASH 2016 Limit
OIV ft/s	Longitudinal	-24.46	-24.49	±40
	Lateral	30.78	28.60	±40
ORA g's	Longitudinal	-3.65	-2.86	±20.49
	Lateral	10.20	12.79	±20.49
MAX ANGULAR DISP. deg.	Roll	-12.6	-8.2	±75
	Pitch	-4.0	-5.0	±75
	Yaw	39.9	39.3	not required
THIV – ft/s		38.74	35.75	not required
PHD – g's		10.39	12.99	not required
ASI		2.51	2.34	not required

Figure 65. Summary of Test Results and Sequential Photographs, Test No. NCBR-1

6 FULL-SCALE CRASH TEST NO. NCBR-2

6.1 Weather Conditions

Test no. NCBR-2 was conducted on June 11, 2019 at approximately 12:00 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 7.

Table 7. Weather Conditions, Test No. NCBR-2

Temperature	75 deg. F
Humidity	37 percent
Wind Speed	11 mph
Wind Direction	230 deg. from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.15 in.
Previous 7-Day Precipitation	0.43 in.

6.2 Test Description

Initial vehicle impact was to occur 61 $^{15}/_{16}$ in. upstream from post no. 6, as shown in Figure 66, which was selected by UNCC from simulation results and verified by NCDOT as the point that maximized loading on the rail splices. The 5,018-lb quad cab pickup truck impacted the NCDOT two-bar metal bridge rail at a speed of 61.9 mph and an angle of 24.9 deg. The actual point of impact was 61 $^{7}/_{8}$ in. upstream from post no. 6. The vehicle came to rest 200 ft – 2 in. downstream and 25 ft – 10 in. laterally in front of the traffic side of the barrier after the brakes were applied.

A detailed description of the sequential impact events is contained in Table 8. High-speed footage of the test is shown in Figure 67. Sequential photographs are shown in Figures 69 and 70. Documentary photographs of the crash test are shown in Figures 71 through 73. The vehicle trajectory and final position are shown in Figure 74.

Figure 66. Impact Location, Test No. NCBR-2

Table 8. Sequential Description of Impact Events, Test No. NCBR-2

TIME (msec)	EVENT
0.0	Vehicle's front bumper contacted the parapet 61 $^{7}/_{8}$ in. upstream from post no. 6.
6.0	Vehicle's left headlight contacted rail.
8.0	Vehicle's left headlight deformed, vehicle's right fender contacted rail.
10.0	Vehicle's left fender deformed, vehicle's left-front tire contacted the parapet.
24.0	Vehicle's hood contacted post no. 6 and deformed.
30.0	Vehicle's left-front door deformed, vehicle's left headlight shattered.
34.0	Vehicle yawed away from system.
36.0	Vehicle's left-front tire became airborne.
38.0	Vehicle pitched downward.
42.0	Vehicle's left-front tire deformed.
46.0	Post no. 6 deflected downstream.
48.0	Vehicle's left-front door contacted the parapet and opened.
58.0	Vehicle rolled toward system.
62.0	Vehicle’s left-side mirror shattered.
68.0	Vehicle's left-front tire regained contact with ground.
70.0	Post no. 6 deflected backward.
72.0	Post no. 7 deflected backward.
92.0	Vehicle's left fender became disengaged.
94.0	Vehicle’s left-front window shattered.
104.0	Vehicle's right-front tire became airborne.
114.0	Vehicle's left-rear door deformed.
140.0	Vehicle's right-rear tire became airborne.
186.0	Vehicle's left-rear door contacted the parapet.
192.0	Vehicle’s left quarter panel contacted the parapet and vehicle became parallel to system at 49.9 mph.
194.0	Vehicle's left quarter panel deformed.
202.0	Vehicle's rear bumper contacted the parapet.
206.0	Vehicle's rear bumper deformed.
208.0	Post no. 5 deflected backward.
212.0	Post no. 5 deflected forward, vehicle's left taillight contacted rail.
214.0	Vehicle's left taillight deformed.
218.0	Vehicle's left taillight shattered.
222.0	Post no. 6 deflected backward.
306.0	Vehicle exited system at 46.6 mph and an 8.83 deg. angle.
376.0	Vehicle's right-front tire regained contact with ground.
430.0	Vehicle's right-rear tire regained contact with ground.

Figure 67. Downstream High-Speed Footage, Test No. NCBR-2

Figure 68. Overhead High-Speed Footage, Test No. NCBR-2

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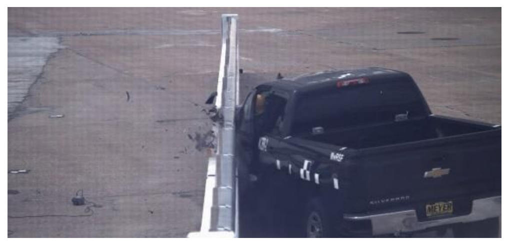

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Figure 69. Sequential Photographs, Test No. NCBR-2

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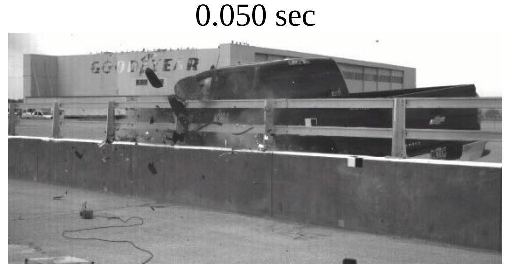

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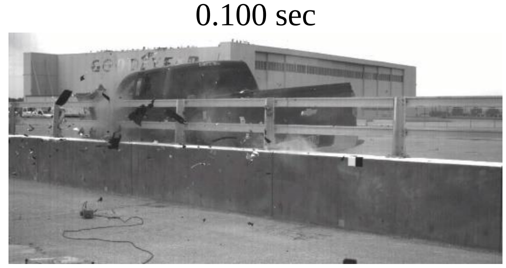

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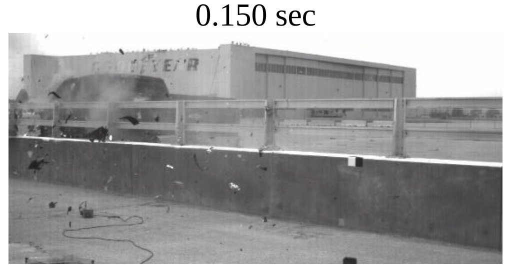

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Figure 70. Sequential Photographs, Test No. NCBR-2

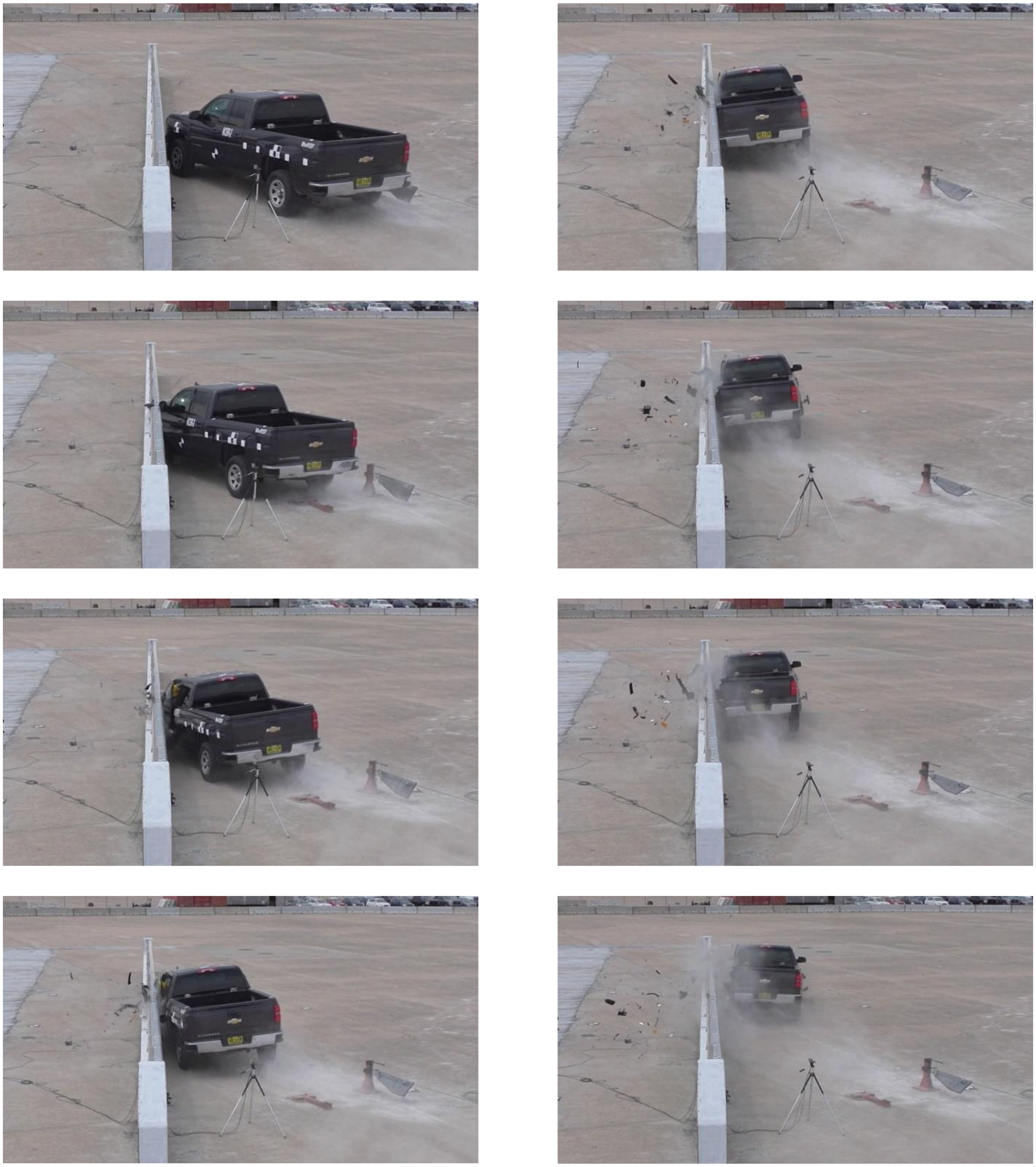


Figure 71. Documentary Photographs, Test No. NCBR-2

Figure 72. Documentary Photographs, Test No. NCBR-2

Figure 73. Documentary Photographs, Test No. NCBR-2

Figure 74. Vehicle Final Position and Trajectory Marks, Test No. NCBR-2

6.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 75 through 79. Barrier damage consisted of contact marks and concrete gouging across the front face of the parapet, and minor concrete breakout on the upstream edge of the second parapet segment at the expansion joint. Note that any cracking visible in the system photographs was documented beforehand and not a result of test no. NCBR-2.

Contact marks on the lower rail were observed 16 in. downstream from post no. 5 and extending 150½ in. downstream. Contact marks on the upper rail were observed starting 10 in. downstream of the impact point and extending 164 in. downstream. A separate contact mark was observed on the underside of the upper rail, starting 33 in. upstream from post no. 8, measuring 21 in. long and ½ in. wide. The splices between the first and second rail segments experienced minor elongation, measuring $^{7}/_{8}$ in. at both the front and back of both rails.

Minor concrete breakout measuring up to 3 in. wide x 15 in. long x 1½ in. deep, extending vertically between 9 and 24 in. above the ground line, occurred on the upstream edge of the second concrete parapet at the expansion gap between post nos. 5 and 6. Gouging was observed 20 in. downstream from post no. 5 and 14 in. below the top surface of the parapet, measuring 16 in. long and 7 in. tall. Gouging also occurred along the top edge of the front face of the parapet, located 13 in. downstream from the impact point and measuring 22 in. long and 1 in. wide. A 17-in. circular gouge occurred 17½ in. downstream from post no. 5. Small scratches were located throughout the impact region across the front face of the parapet.

An 8¼-in. contact mark began 4¼ in. from the top of post no. 6 on its upstream flange. An additional 1½-in. contact mark, beginning 5¼ in. from the bottom of post no. 6, was observed on the upstream flange. Contact marks extended 2¾ in. downstream from the upstream edge of the post-mounting bracket at post no. 6. Contact marks were observed on the back side of the upstream flange beginning 3 in. from the top of the flange and extending down 5 in. downstream. Contact marks were also observed along the entire upstream front flange edge, front post-to-parapet attachment bolts, and front edge of the base plate at post no. 6. A ¼-in. contact mark began 4¾ in. from the top of post no. 7 on its upstream flange. Minor contact marks, measuring 7 in. in height, began 2 in. from the bottom of the upstream flange of post no. 7 and along the front edge and top surface of the base plate and the front post-to-parapet attachment bolts.

Figure 75. System Damage, Test No. NCBR-2

Figure 76. System Damage, Test No. NCBR-2

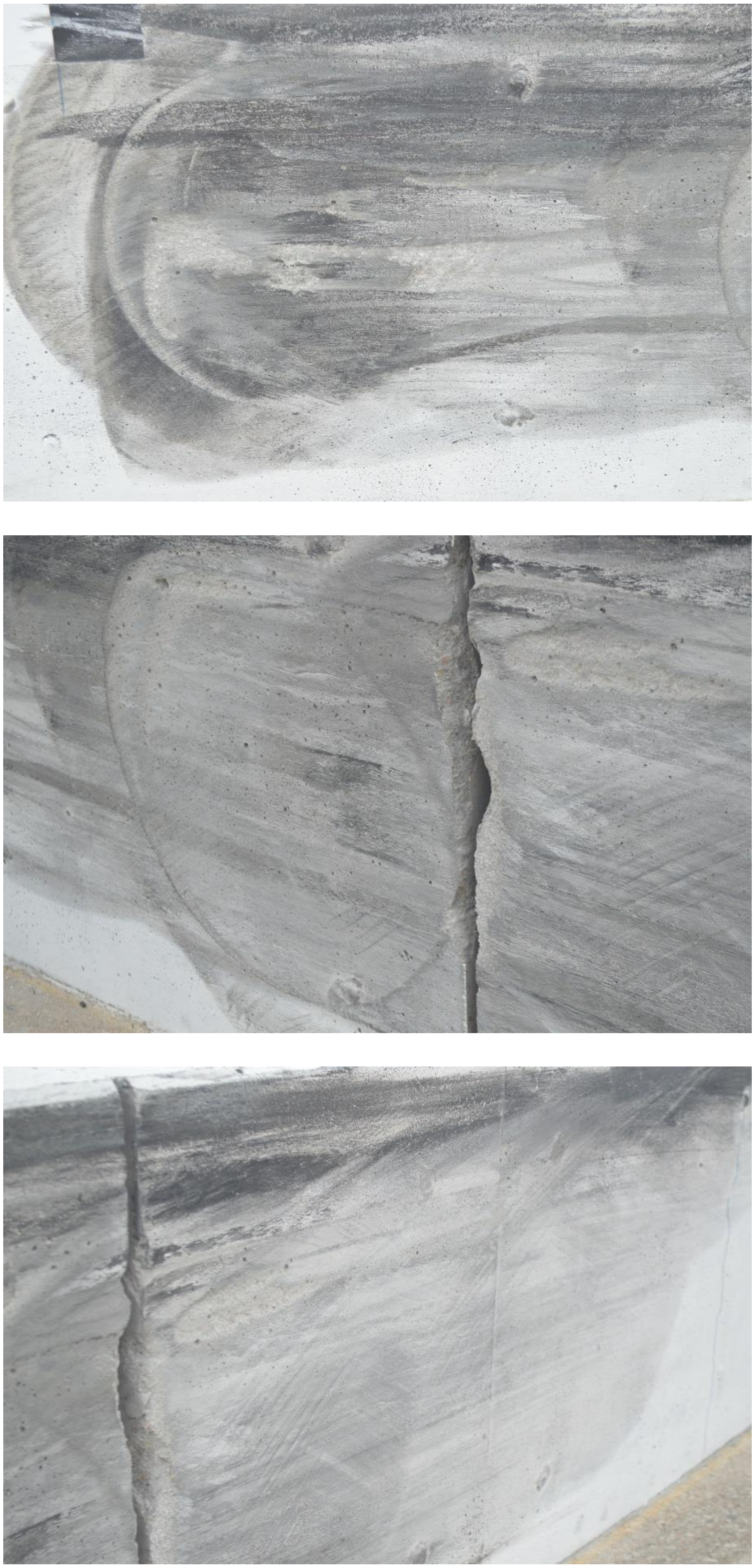


Figure 77. Concrete Gouging, Test No. NCBR-2

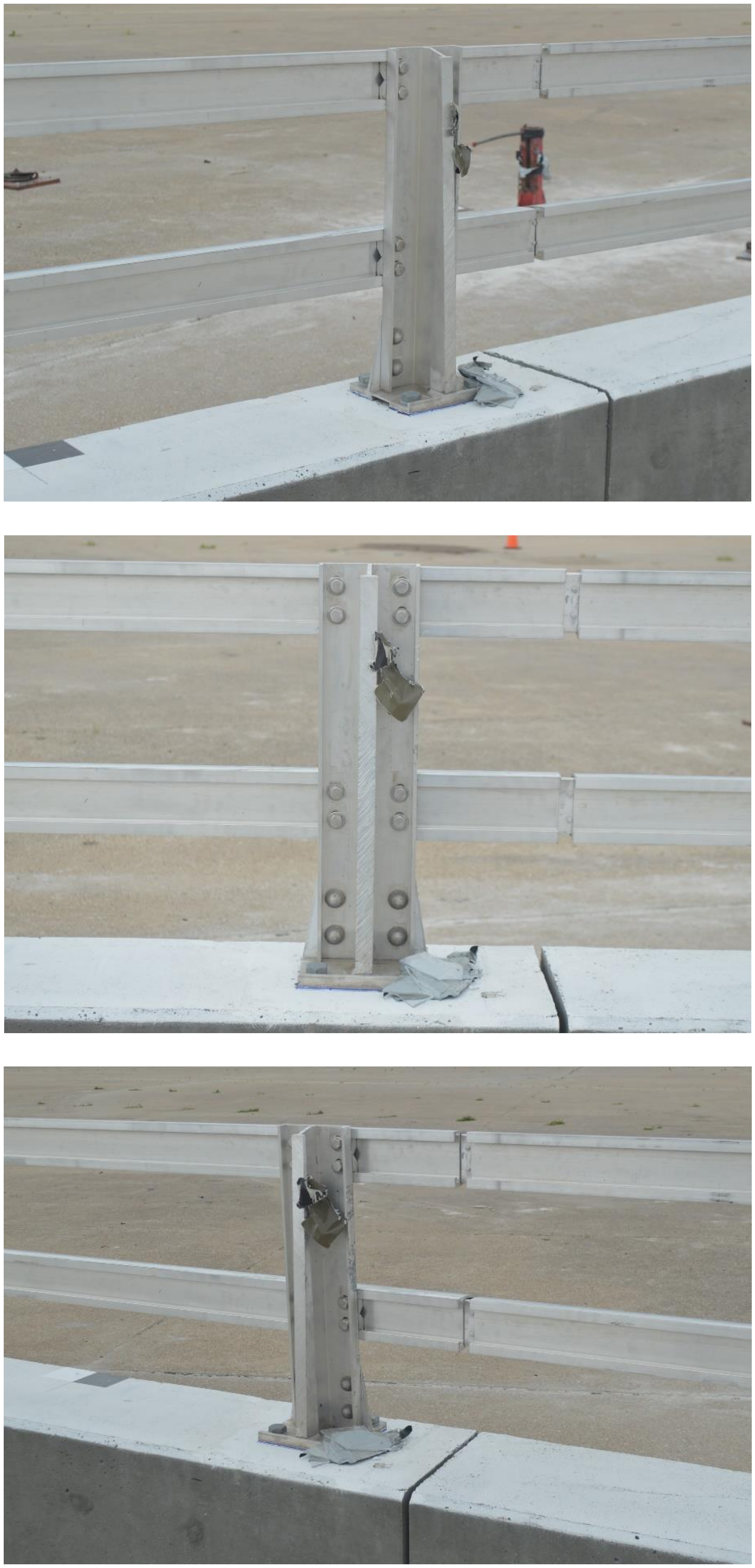


Figure 78. Post No. 6 Backside Damage, Test No. NCBR-2

Figure 79. Rail and Post No. 6 Damage, Test No. NCBR-2

The maximum lateral permanent set of the barrier system was 0.7 in. between post nos. 5 and 6, as measured in the field. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 0.8 in. on the upper rail, as determined from high-speed digital video analysis. The working width of the system was found to be 15.5 in., also determined from high-speed digital video analysis. Barrier deflections are shown schematically in Figure 80.

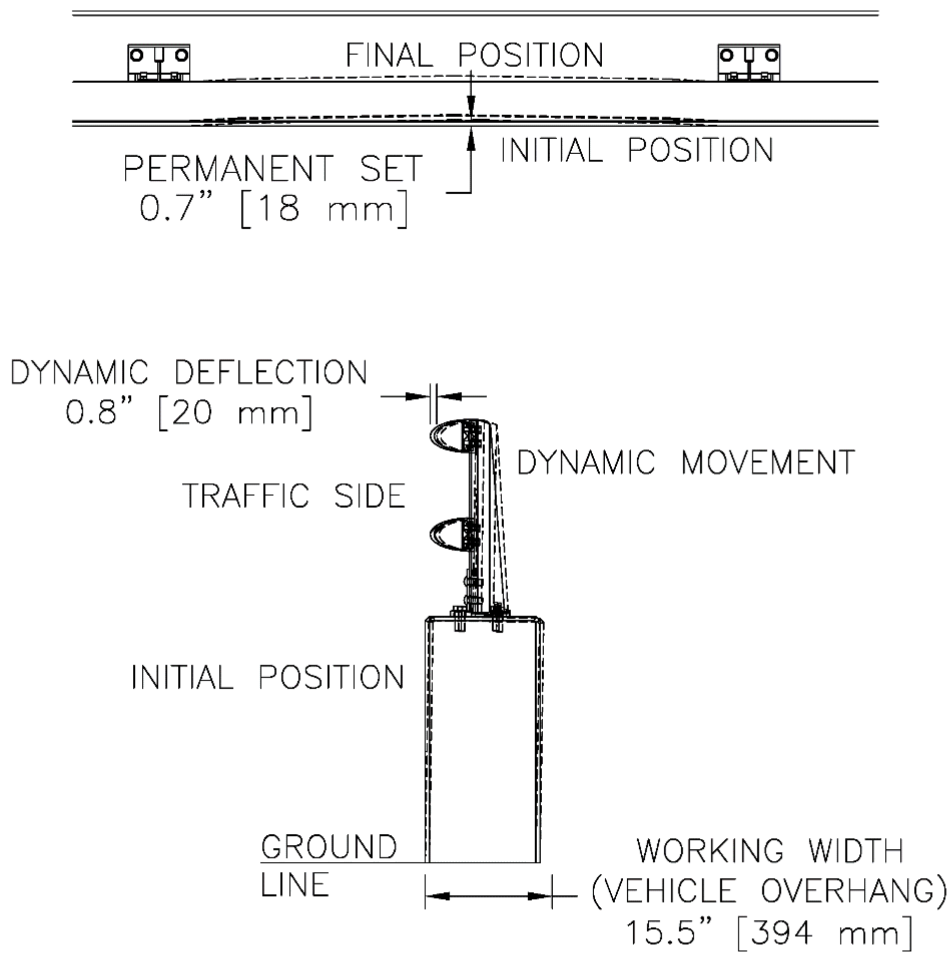


Figure 80. Barrier Deflections, Test No. NCBR-2

6.4 Vehicle Damage

Damage to the vehicle was moderate, as shown in Figures 81 through 85. The majority of the damage was concentrated on the left-front corner and left side of the vehicle where the impact occurred. The left side of the bumper was crushed inward. The left-front fender was pushed upward near the door panel and dented and torn behind the left-front wheel. The left-front steel rim and tire were scuffed and deformed. The grille was pushed backward around the left-side headlight assembly. The left-side headlight and fog light were disengaged from the vehicle. Denting and scraping were observed across the entire left side. The left-front door was slightly ajar and deformed inward at the bottom. The left-rear door was dented. The left side of the truck bed was dented and the fuel hatch was ajar. The left-rear tire was scuffed. The left taillight was disengaged from the vehicle. The left side of the rear bumper was torn and pushed downward. The right side of the front bumper was pushed downward. The vehicle's aluminum hood was deformed across its entirety and the left edge was torn from front to back. A piece of the hood was torn off the left side. The left side window was ejected from the vehicle after impact with the dummy's head. The remaining window glass remained undamaged. The anti-roll bar shifted toward the right side and the left-side end link connector was bent. The left-side bottom control arm joint was torn out of the frame. The left-side outer tie rod was bent and the left-side upper mount of the steering rack was dented. The front left side of the oil pan had a 2.5 in. x 3.5 in. puncture. The left side of the frame at the impact point was caved inward and bent at the middle of the left-front door. The right side of the frame bent inward at the midpoint of the right-front door. The middle cross member bent where it connected to the frame. The left-side frame horn bent inward. The right-front passenger cab mount was disengaged. The floor pan was wrinkled. The tail pipe came out of the rear hanging mount.

The maximum occupant compartment intrusions are listed in Table 9 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment and none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D. Note that set 1 interior and floor pan deformation data was compromised and is not listed in Appendix D. Note there is no NASS crush information due to incomplete pretest profile information.

Figure 81. Vehicle Damage, Test No. NCBR-2

Figure 82. Vehicle Damage, Test No. NCBR-2

Figure 83. Occupant Compartment Damage, Test No. NCBR-2

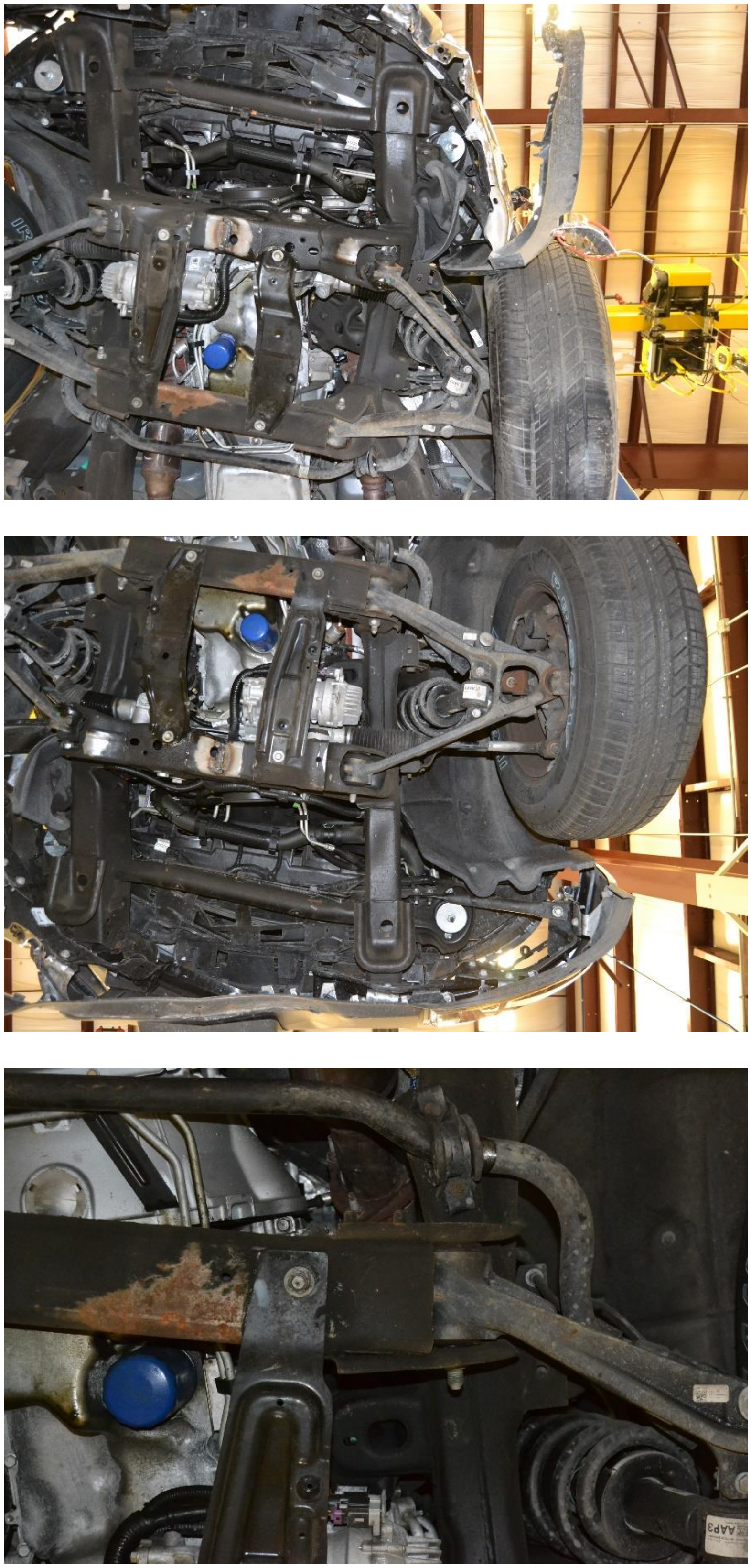


Figure 84. Undercarriage Damage, Test No. NCBR-2

Figure 85. Windshield Damage (Pre- and Post-Test), Test No. NCBR-2

Table 9. Maximum Occupant Compartment Intrusions by Location, Test No. NCBR-2

LOCATION	MAXIMUM INTRUSION in.	MASH 2016 ALLOWABLE INTRUSION in.
Toe Pan – Wheel Well	1.3	≤ 9
Floor Pan	0.5	≤ 12
A-Pillar	1.2	≤ 5
B-Pillar	1.4	≤ 5
A-Pillar (lateral)	1.2	≤ 3
B-Pillar (lateral)	1.4	≤ 3
Side Front Panel	1.6	≤ 12
Side Door (above seat)	1.6	≤ 9
Side Door (below seat)	0.5	≤ 12
Roof	0.2	≤ 4
Windshield	N/A	≤ 3
Side Window	Shattered due to contact with dummy's head	Test article did not cause window shatter
Dash	0.0	N/A[1]

N/A[1] – Not applicable

6.5 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, as determined from the accelerometer data, are shown in Table 10. Note that the OIVs and ORAs were within the suggested limits provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 10. Recorded data from the accelerometers and rate transducers are shown graphically in Appendix F.

Table 10. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. NCBR-2

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 (primary)	SLICE-2	
OIV ft/s	Longitudinal	-21.49	-20.66	±40
	Lateral	27.89	26.20	±40
ORA g’s	Longitudinal	-5.09	-5.06	±20.49
	Lateral	10.78	13.36	±20.49
MAX. ANGULAR DISPL. deg.	Roll	-9.3	-6.1	±75
	Pitch	3.0	2.4	±75
	Yaw	32.1	31.5	not required
THIV ft/s		36.41	34.48	not required
PHD g’s		11.26	13.74	not required
ASI		1.91	1.84	not required

6.6 Barrier Loads

The longitudinal and lateral vehicle accelerations, as measured at the vehicle’s c.g., were processed using an SAE CFC-60 filter and a 50-msec moving average. The 50-msec moving average vehicle accelerations were then combined with the uncoupled yaw angle versus time data in order to estimate the vehicular loading applied to the barrier system. The results of the barrier load estimate are shown in Figure 86. A peak load of 89.9 kip was noted at 0.052 s after impact, with a peak longitudinal wall force of approximately 30.6 kip. The resulting average overall estimated vehicle-barrier sliding friction coefficient was 0.237 measured over the first 0.1 s of impact. The vehicle exhibited a “tail slap” effect in which two separate peaks were observed, the first corresponding to the redirection of the front of the vehicle, and the second corresponding to the tail end of the vehicle contacting the barrier system. The initial redirection load was more than twice as large as the tail slap load.

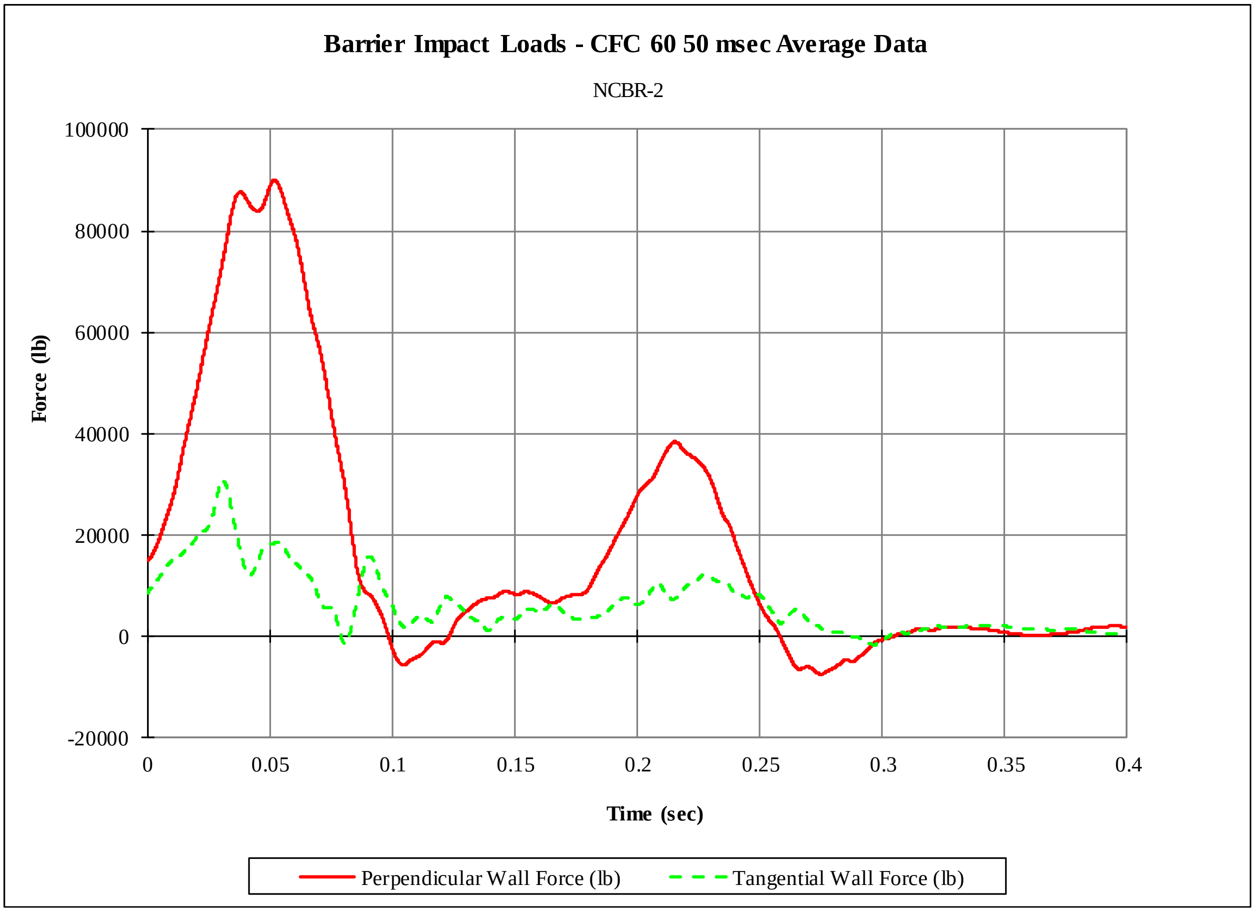
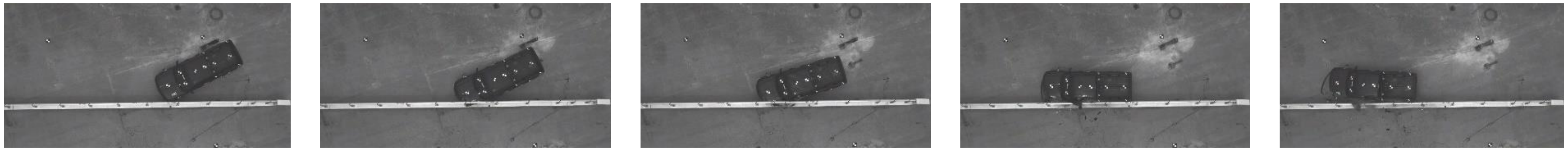


Figure 86. Estimated Barrier Impact and Friction Loads, Test No. NCBR-2

6.7 Discussion

Analysis of the test results for test no. NCBR-2 showed that the system adequately contained and redirected the 2270P vehicle with minimal barrier damage and displacement. A summary of the test results and sequential photographs are shown in Figure 87. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after impact. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix F, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 6.3 deg., and its trajectory did not violate the bounds of the exit box. Therefore, test no. NCBR-2 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.

During the test, the dummy’s head protruded out of the left-side window and extended into the ZOI but did not contact the system. This behavior is associated with an increased occupant risk. Further evaluation of the dummy movement is provided in Chapter 7.



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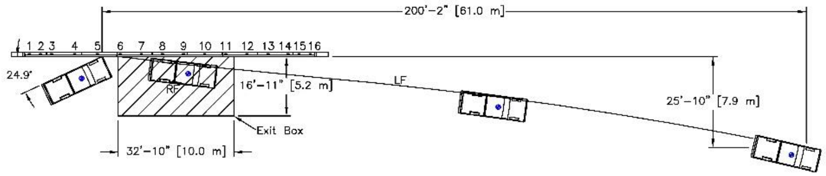
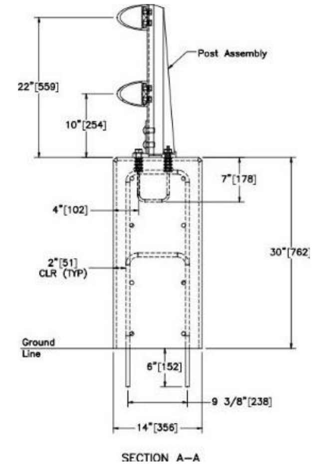




- Test Agency .... MwRSF
- Test Number NCBR-2
- Date .... June 11, 2019
- MASH 2016 Test Designation No. 3-11
- Test Article .... NCDOT Two-Bar Metal Bridge Rail
- Total Length .... 90 ft
- Key Component – Elliptical Aluminum Rail
  - Length .... 26 ft – ½ in.
  - Width .... 4 in.
  - Depth .... 4¾ in.
- Key Component – Aluminum Post
  - Height .... 23½ in.
  - Length .... 5¾ in.
  - Width .... 4¼ in.
  - Spacing .... 78 in.
- Vehicle Make / Model .... 2015 Chevrolet Silverado
  - Curb .... 5,015 lb
  - Test Inertial .... 5,018 lb
  - Gross Static .... 5,183 lb
- Impact Conditions
  - Speed .... 61.9 mph
  - Angle .... 24.9 deg.
  - Impact Location .... $61^7/_8$ in. upstream from post no. 6
- Impact Severity .... 113.5 kip-ft > 106 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed .... 46.6 mph
  - Angle .... 8.8 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 200 ft – 2 in. downstream, 25 ft – 10 in. laterally in front
- Vehicle Damage .... Moderate
  - VDS [10] 11-LFQ-4
  - CDC [11] 11-LFEW-3
  - Maximum Interior Deformation .... 1.6 in.
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... 0.7 in.
  - Dynamic .... 0.8 in.
  - Working Width .... 15.5 in.
- Transducer Data

Evaluation Criteria		Transducer SLICE-1 (primary)	Transducer SLICE-2	MASH 2016 Limit
OIV ft/s	Longitudinal	-21.49	-20.66	±40
	Lateral	27.89	26.20	±40
ORA g's	Longitudinal	-5.09	-5.06	±20.49
	Lateral	10.78	13.36	±20.49
MAX ANGULAR DISP. deg.	Roll	-9.3	-6.1	±75
	Pitch	3.0	2.4	±75
	Yaw	32.1	31.5	not required
THIV – ft/s		36.42	34.48	not required
PHD – g's		11.26	13.74	not required
ASI		1.91	1.84	not required

Figure 87. Summary of Test Results and Sequential Photographs, Test No. NCBR-2

7 HEAD EJECTION ANALYSIS

During test nos. NCBR-1 and NCBR-2, the dummy shifted laterally during impact, resulting in head contact with the side window. For both tests, the window glass disengaged from the door panel and was ejected laterally into the barrier system. Subsequently, the dummy's head extended outside of the occupant compartment and toward the aluminum railing on top of the concrete parapet. It was noted that for MASH 2016 occupant risk evaluation criteria, no shattering of a side window from direct contact with a structural member of the test article should occur. By extension, this requirement is because direct contact between a test article and the side window is believed to place an occupant's head at significantly elevated risk of contacting the test article, increasing potential for serious injury, even if an impact does not violate any other MASH 2016 evaluation criteria. Thus, occupant head ejection out of the occupant compartment resulting in direct contact between the occupant's head and a test article or structurally-stiff element should also be considered a pass/fail test evaluation criterion. Based on this conservative interpretation and extension of MASH 2016, MwRSF and UNCC researchers evaluated high-speed video, onboard digital video, and dummy kinesthetics to determine if the dummy's head impacted the test article during the full-scale tests.

Available video views rendered head ejection extent difficult to measure. Overhead, upstream, and downstream views were partially obscured because of light reflection and shadows, dust and paint fragments from point of impact (POI), and test debris. Using available views, the lateral head extension was estimated to be approximately 2 in. for test no. NCBR-1 and 6 in. for test no. NCBR-2.

Onboard high-speed footage for test nos. NCBR-1 and NCBR-2 is shown in Figures 88 through 91. Onboard camera views of the occupant's head movement are shown in Figures 92 through 95. For test no. NCBR-1, the maximum head protrusion occurred at 0.109 s, and a close-up view of maximum head extension is shown in Figure 94. For test no. NCBR-2, the maximum head protrusion occurred at 0.142 s, and is shown in Figure 95.

Video analysis of the velocity profile and positioning of the dummy's head during both tests suggested that head contact did not occur. The velocity profiles, taken from onboard views, were smooth and lacked any abrupt transitions in speed or position, which would have indicated an impact. Vehicle positions at 0.109 sec for test no. NCBR-1 and 0.142 sec for test no. NCBR-2 are shown in Figure 96. Although significant head protrusion was visible in the overhead video, the protrusion did not appear to overlap the rail in either test. It was concluded that the dummy did not contact the test article in either of test nos. NCBR-1 or NCBR-2. Therefore, both tests were deemed to have successfully passed MASH 2016 evaluation criteria, using a stringent interpretation of the occupant risk criteria.

Figure 88. Onboard High-Speed Footage, Test No. NCBR-1

Figure 89. Onboard High-Speed Footage, Test No. NCBR-1

Figure 90. Onboard High-Speed Footage, Test No. NCBR-2

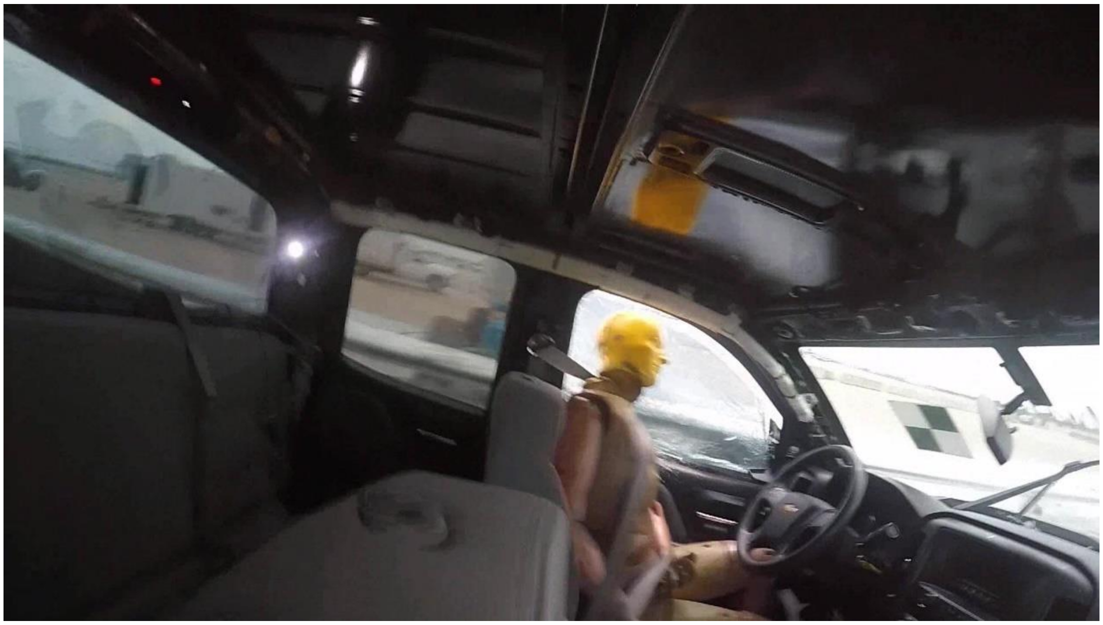


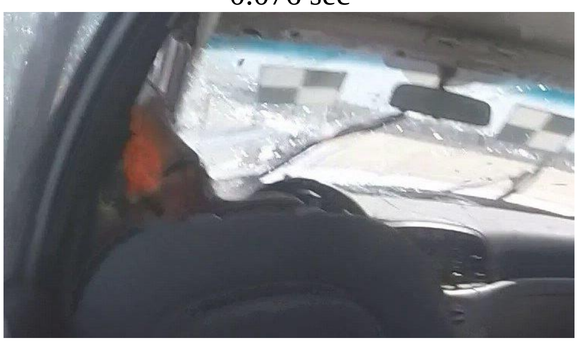
Figure 91. Onboard High-Speed Footage, Test No. NCBR-2

0.000 sec

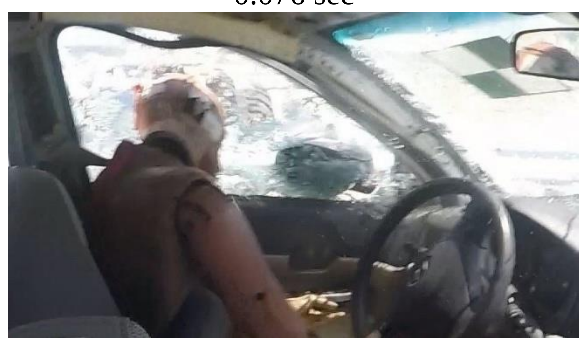
0.000 sec

0.076 sec

0.076 sec



0.109 sec



0.109 sec

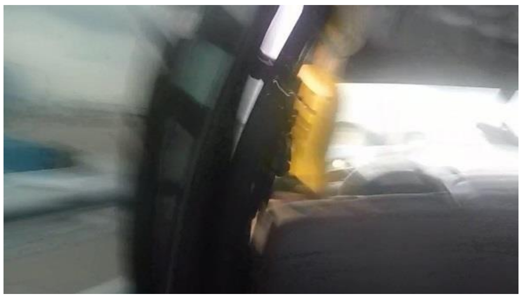
0.160 sec

0.160 sec

Figure 92. Occupant Head Movement, Test No. NCBR-1


0.000 sec


0.000 sec


0.092 sec

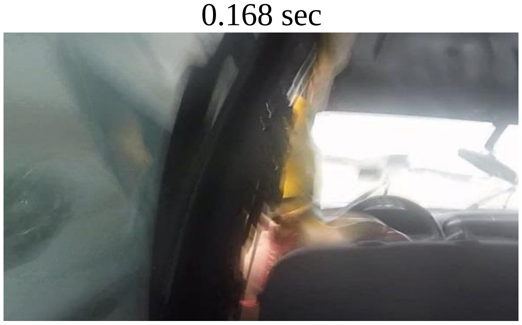

0.092 sec


0.142 sec


0.142 sec


0.168 sec


0.168 sec

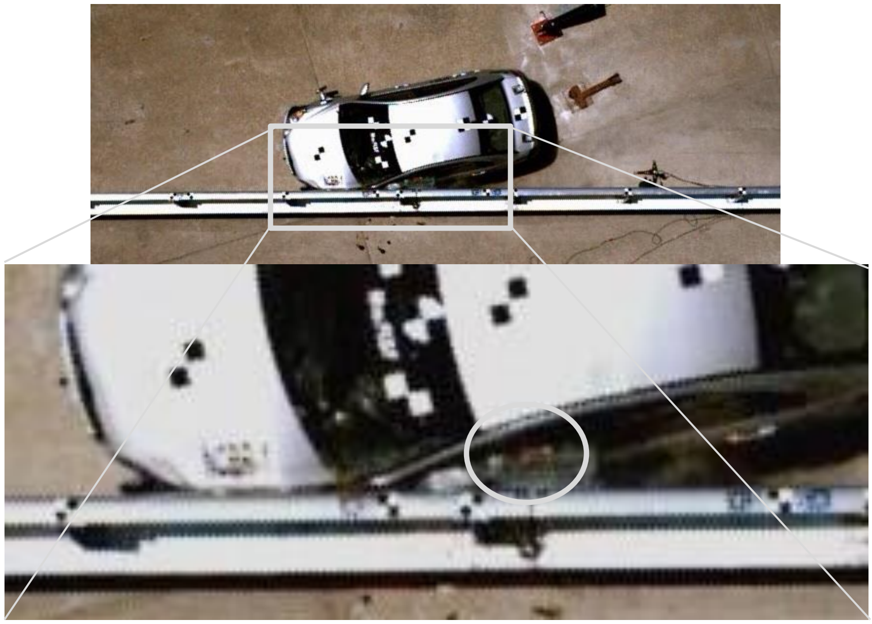

0.210 sec


0.210 sec

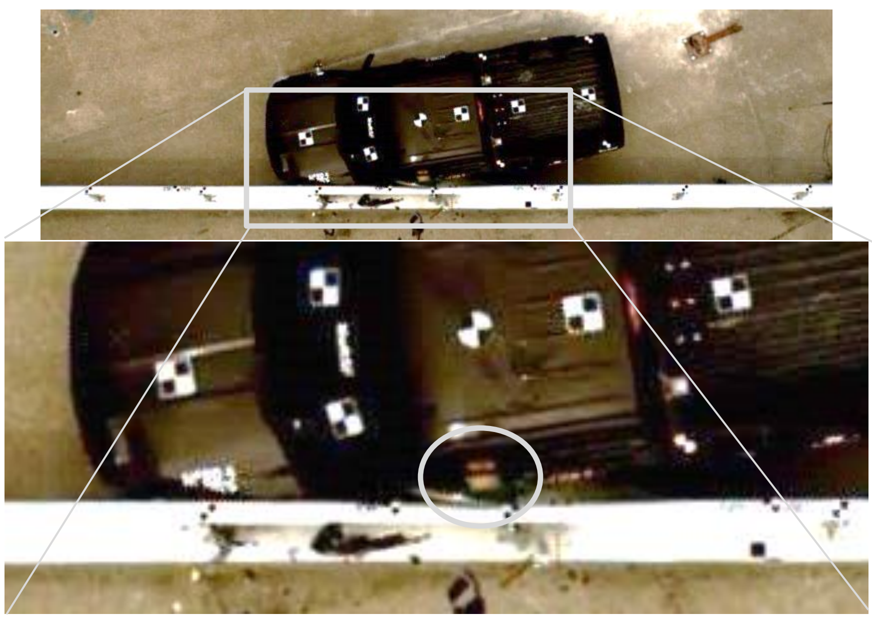
Figure 93. Occupant Head Movement, Test No. NCBR-2

Figure 94. Maximum Occupant Head Protrusion, Test No. NCBR-1

Figure 95. Maximum Occupant Head Protrusion, Test No. NCBR-2



Test No. NCBR-1: 0.110 s



Test No. NCBR-2: 0.142 s

Figure 96. Vehicle Position and Dummy Head Protrusion at Maximum Dummy Movement, Test Nos. NCBR-1 and NCBR-2

8 SUMMARY AND CONCLUSIONS

In test no. NCBR-1, a 2,425-lb small car impacted the NCDOT two-bar metal rail system at 63.2 mph and an angle of 25.2 deg., resulting in an impact severity of 59.0 kip-ft and an estimated peak load of 57.7 kip on the system. Impact occurred 51.1 in. upstream from post no. 11, and the vehicle exited the system at 42.8 mph and an 8.5 deg. angle. The vehicle was successfully contained and smoothly redirected with minor damage to the barrier system and moderate damage to the vehicle. Windshield deformation was extreme, but not believed to violate MASH 2016 safety performance criteria, as it was measured several days after testing, allowing for settling to occur. All vehicle accelerations, ORAs, and OIVs fell within the recommended safety limits established in MASH 2016. Therefore, test no. NCBR-1 was successful according to the safety criteria of MASH 2016 test designation no. 3-10.

In test no. NCBR-2, a 5,018-lb quad cab pickup truck impacted the NCDOT two-bar metal rail system at 61.9 mph and a 24.9 deg. angle, resulting in an impact severity of 113.5 kip-ft and an estimated peak load of 89.9 kip on the system. Impact occurred $61^7/_8$ in. upstream from post no. 6, and the vehicle exited the system at 44.6 mph and an 8.8 deg. angle. The vehicle was successfully contained and smoothly redirected with minor damage to the barrier system and moderate damage to the vehicle. All vehicle accelerations, ORAs, and OIVs fell within the recommended safety limits established in MASH 2016. Therefore, test no. NCBR-2 was successful according to the safety criteria of MASH 2016 test designation no. 3-11. A summary of the test evaluations for test nos. NCBR-1 and NCBR-2 are shown in Table 8.

The bridge rail did not deflect, exhibit structural cracking, nor experience significant permanent set in the top-mounted aluminum rail. However, the bridge ends and upstream and downstream rail transitions were not evaluated in this project. At each end of the bridge rail, the longitudinal aluminum rails were terminated using ½-in. thick, L-shaped brackets bolted to the concrete parapet, and the rails were offset from the traffic-side face by 1 in. During both test nos. NCBR-1 and NCBR-2, contact was observed on the aluminum rail segments, indicating that vehicle components engaged the posts after extending over the top of the 30-in. tall concrete parapet. As a result, impacts near the downstream end of the bridge rail system could result in increased vehicle engagement with the vertical concrete buttress, which could contribute to increased occupant compartment crush. Further research may be required to evaluate the ends of the system. A MASH 2016-approved, TL-3 approach guardrail transition which is compatible and approved for use in combination with the end of the concrete buttresses is recommended.

Table 11. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. NCBR-1</th><th>Test No. NCBR-2</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation, although controlled lateral deflection of the test article is acceptable.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="5">Occupant Risk</td><td rowspan="2">D.</td><td>1. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</td><td>S</td><td>S</td></tr>
<tr><td>2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>S</td><td>S</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 deg.</td><td>S</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits</th></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s</td><td>40 ft/s</td></tr>
</table></td><td>S</td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g's</td><td>20.49 g's</td></tr>
</table></td><td>S</td><td>S</td></tr>
<tr><td colspan="3">MASH 2016 Test Designation No.</td><td>3-10</td><td>3-11</td></tr>
<tr><td colspan="3">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

9 MASH EVALUATION

The objective of this research was to evaluate the safety performance of NCDOT's two-bar metal bridge rail system. The system was tested at MASH 2016-compliant critical impact points selected by UNCC through simulation and verified by NCDOT. Test nos. NCBR-1 and NCBR-2 were conducted according to MASH 2016 test designation nos. 3-10 and 3-11, respectively. In both tests, the test vehicle was contained and smoothly redirected with minimal roll and pitch angular displacements. Damage to the system was minor and all ORA and OIV values were within MASH 2016 safety limits. The vehicle in test no. NCBR-1 experienced extreme windshield deformation, but this value was exaggerated due to settling in the time in between testing and measurement. No other occupant deformation limits were violated in either test.

Due to the success of test nos. NCBR-1 and NCBR-2, it was determined that impacts within the Length of Need (LON) of the two-bar bridge rail were crashworthy according to MASH 2016 TL-3 impact conditions.

10 REFERENCES

1. 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.

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

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

4. *Structures Management Unit Manual: Chapter 6, Superstructures*, North Carolina Department of Transportation.

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

6. Singh, H., Ganesan, V., Davies, J., Paramasuwom, M., and Gradischnig, L., *Vehicle Interior and Restraints Modeling Development of Full Vehicle Finite Element Model Including Vehicle Interior and Occupant Restraints Systems For Occupant Safety Analysis Using THOR Dummies*, National Highway Traffic Safety Administration, May 2018.

7. 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.

8. *Center of Gravity Test Code* - SAE J874 March 1981, SAE Handbook Vol. 4, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1986.

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

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

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

12. Gutierrez, D., Bielenberg, R.W., Faller, R.K., Reid, J.D., and Lechtenberg, K.A., *Development of MASH TL-3 Transition Between Guardrail and Portable Concrete Barriers*, Report No. TRP-03-300-14, Midwest Roadside Safety Facility, University of Nebraska–Lincoln, Lincoln, Nebraska, June 2014.

11 APPENDICES

Appendix A. NCDOT Standard Plans

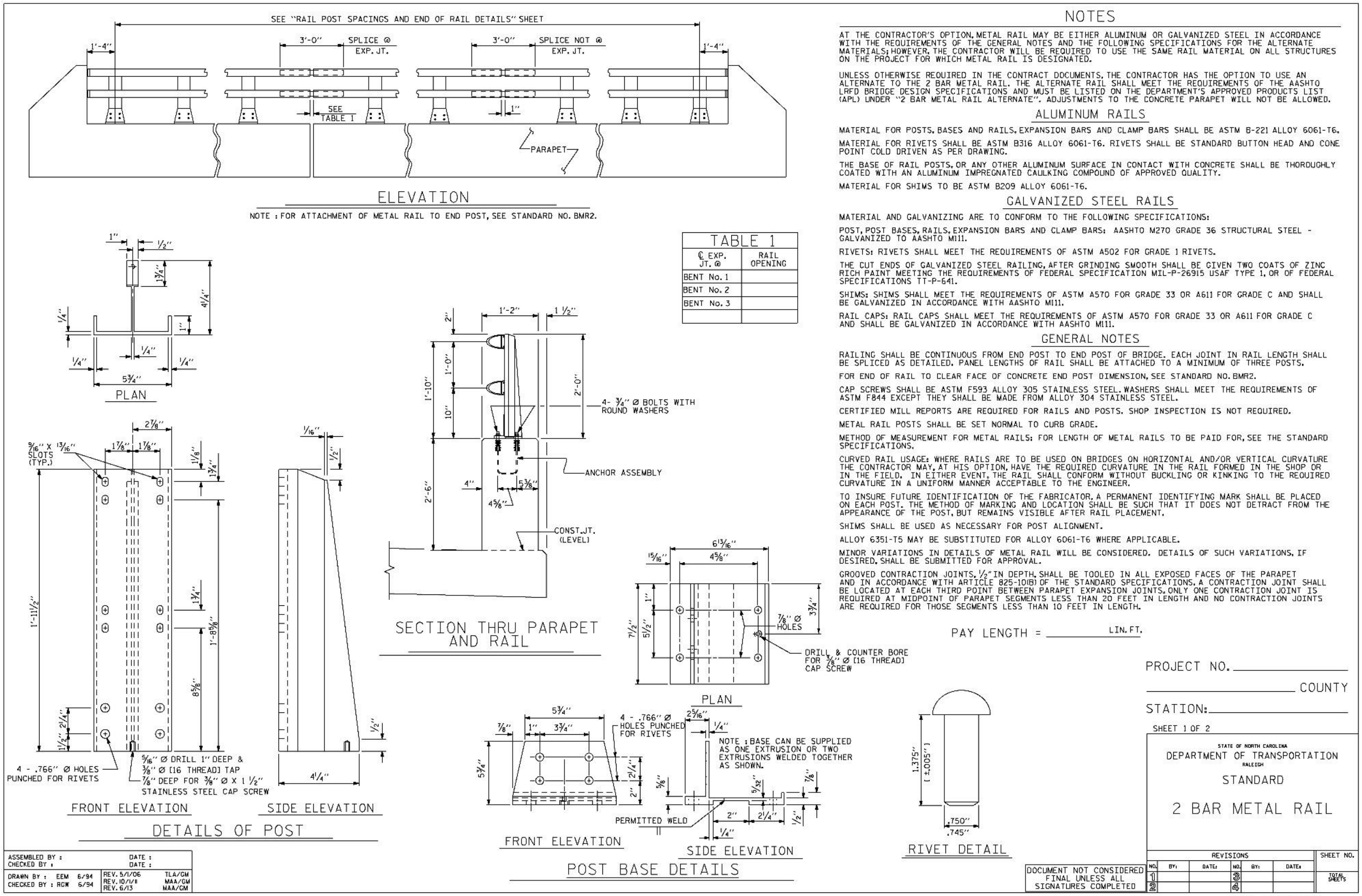


Figure A-1. NCDOT Design Standards of Two-Bar Metal Bridge Rail

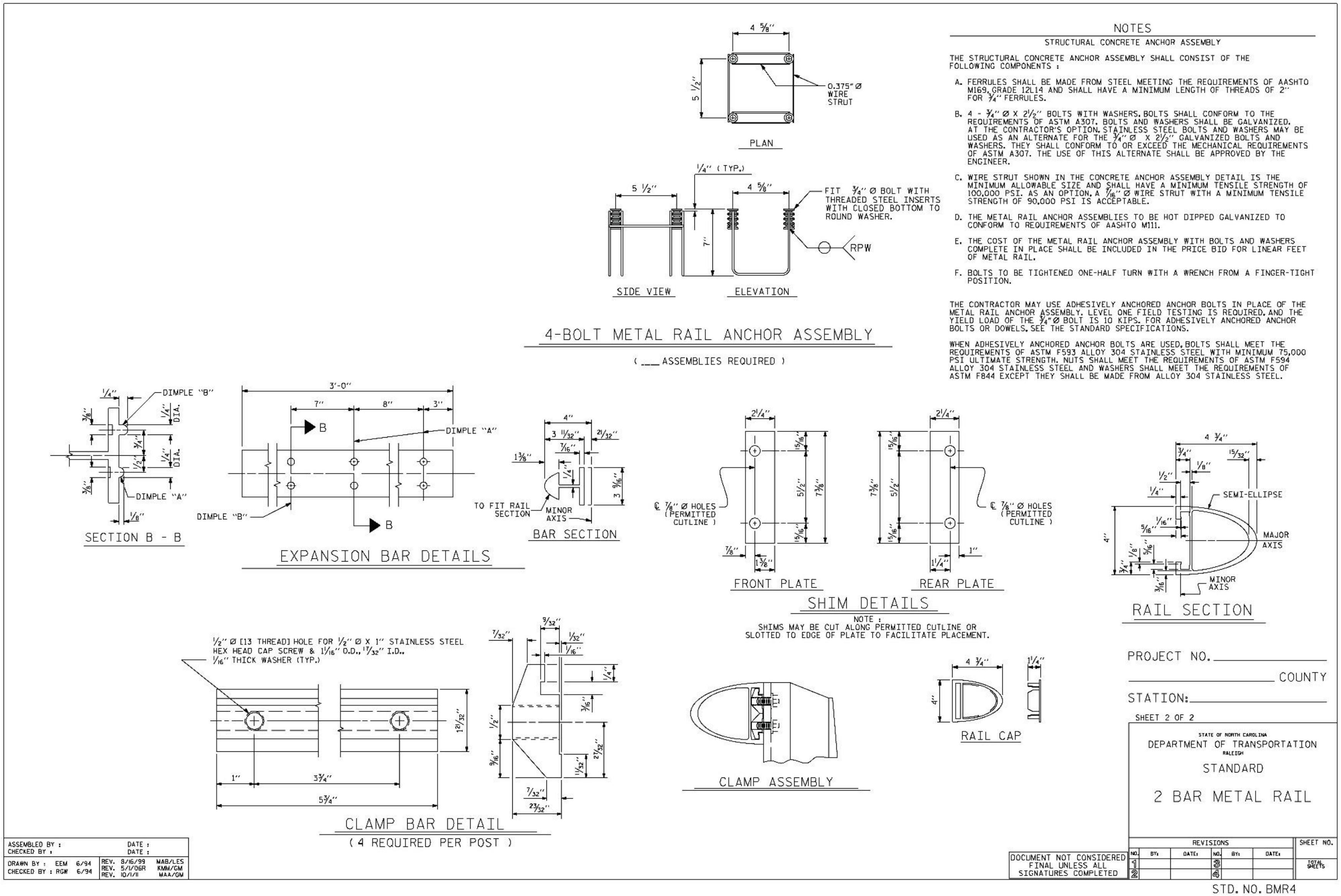


Figure A-2. NCDOT Design Standards of Two-Bar Metal Bridge Rail

Appendix B. Material Specifications

Table B-1. Bill of Materials, Test Nos. NCBR-1 and NCBR-2

Item No.	Description	Material Specification	Certification
a1	5¾ in. x 4¼ in. x 23½ in. Long Post	ASTM B221 Alloy 6061-T6	H#1802056 or H#1801031 or H#1801065
a2	7½ in. x 3$^5/_{16}$ x 5¾ in. Post Plate	ASTM B221 Alloy 6061-T6	H#1802056 or H#1801031 or H#1801065
a3	7½ in. x 3¼ in. x $^7/_8$ in. Post Plate	ASTM B221 Alloy 6061-T6	H#1802056 or H#1801031 or H#1801065
a4	5¾ in. x 1$^{11}/_{16}$ in. x ¾ in. Clamp Bar	ASTM B221 Alloy 6061-T6	H#1802056 or H#1801031 or H#1801065
a5	¾ in. Threaded Ferrule	ASTM A108 Gr. 12L14	H#1820400
a6	7$^3/_8$ in. x 2¼ in. Front Shim	ASTM B209 Alloy 6061-T6	H#1802056 or H#1801031 or H#1801065
a7	7$^3/_8$ in. x 2¼ in. Rear Shim	ASTM B209 Alloy 6061-T6	H#1802056 or H#1801031 or H#1801065
b1	360 in. Long Elliptical Rail	ASTM B221 Alloy 6061-T6	H#1902024
b2	312½ in. Long Elliptical Rail	ASTM B221 Alloy 6061-T6	H#1902024
b3	11 in. x 4 in. x ½ in. Plate	ASTM A36	021137497
b4	4 in. x 4 in. x ½ in. Plate	ASTM A36	021137497
b5	4¼ in. x 4 in. x 1¼ in. Rail Cap	ASTM B221 Alloy 6061-T6	H#1802056 or H#1801031 or H#1801065
b6	36 in. x 3$^9/_{16}$ in. x 3 $^5/_8$ in. Expansion Bar	ASTM B221 Alloy 6061-T6	H#1802056 or H#1801031 or H#1801065
c1	Concrete	-	
c2	Concrete	-	
c3	Concrete	-	
c4	$^3/_8$ in. Dia. Wire Strut, 6¾ in. Long	Min. Tensile Strength = 100,000 psi	-
c5	$^3/_8$ in. Dia. Wire Strut, 15$^{15}/_{16}$ in. Long Unbent	Min. Tensile Strength = 100,000 psi	-
c6	#5 Bar, 59½ in. Long Unbent	ASTM A615 Gr. 60	H#57177640
c7	#5 Bar, 355 in. Long	ASTM A615 Gr. 60	H#57177640

Table B-1. Bill of Materials, Test Nos. NCBR-1 and NCBR-2, Cont.

Item No.	Description	Material Specification	Certification
c8	#5 Bar, 356 in. Long	ASTM A615 Gr. 60	H#57177640
c9	#5 Bar, 36 in. Long	ASTM A615 Gr. 60	H#1810025501
c10	#5 Bar, 49½ in. Long Unbent	ASTM A615 Gr. 60	H#57177640
c11	#6 Bar, 22 in. Long	ASTM A615 Gr. 60	H#KN17101898
c12	#6 Bar, 40 in. Long	ASTM A615 Gr. 60	H#KN17101898
c13	#6 Bar, 43¼ in. Long	ASTM A615 Gr. 60	H#KN17101898
c14	#7 Bar, 31 in. Long	ASTM A615 Gr. 60	H#57165810
c15	#7 Bar, 36½ in. Long	ASTM A615 Gr. 60	H#57165810
c16	#7 Bar, 42 in. Long	ASTM A615 Gr. 60	H#57165810
c17	#7 Bar, 47½ in. Long	ASTM A615 Gr. 60	H#57165810
c18	#7 Bar, 52 in. Long	ASTM A615 Gr. 60	H#57165810
d1	¾ in. Dia., 1 $^3/_8$ in. Long Rivet	ASTM B316 Alloy 6061-T6	H#1801065
d2	¾ in. Dia., 6½ in. Long Hex Head Drill-In Anchor	ASTM A36	COC
d3	¾ in.-10 UNC, 2½ in. Long Hex Bolt	ASTM F3125 Gr. A325 Type I	Lot 798156
d4	$^3/_8$ in.-16 UNC, 1½ in. Long Cap Screw	ASTM F593 Alloy 305 Stainless Steel	H#205Y Certificate#60221G
d5	½ in.-13 UNC, 1¼ in. Long Hex Head Cap Screw	ASTM F593 Alloy 305 Stainless Steel	H#205Y Certificate#60221G
d6	½ in.-13 UNC, 1 in. Long Hex Head Cap Screw	ASTM F593 Alloy 305 Stainless Steel	H#205Y Certificate #60221G
e1	¾ in. Dia. Plain USS Washer	ASTM F436	H#281047
e2	¾ in. Dia. Plain SAE Washer	ASTM F436	H#A56620
e3	½ in. Dia. Plain SAE Washer	ASTM F844 Alloy 304 Stainless Steel	Coil 037VM5 H#7VM9
-	Ultrabond 1 Adhesive	ASTM C881 Type I, II, IV & V Gr. 3, Class A, B & C	Lot 1881003027

Alexandria INDUSTRIES

PHONE 317.545.1221
TOLL FREE 800.560.6601
FAX 317.545.3613

www.AlexandriaIndustries.com

Cert Stamp
LBF PO# M01018
Job/Item #
Page 1 of 6

ALEXANDRIA EXTRUSION MID-AMERICA HEREBY CERTIFIES THAT SAMPLES OF THE MATERIALS THAT WERE ORDERED DESCRIBED IN THIS REPORT HAVE THE PROPERTIES SHOWN.
Representative

19391

PS01

CERTIFIED TEST REPORT

Customer	LB Foster
Customer PO	
Bill of Lading	
Qty Shipped	
Date Shipped	3/2/2018

CO Number	Die Number
604795	3540

Heat Number	Alloy	Ultimate Strength	Yield Strength	Elongation	Hardness
1802056	6061-T6	41100	37300	10	96
1801031	6061-T6	41715	37385	8	93
1801031	6061-T6	42835	37696	10	95
1801031	6061-T6	43466	39179	9.5	96

ASTM B221

Cert Stamp
LBF PO# 4094
Job/Item # 19391
Page 1 of 3

Figure B-1. Aluminum Parts, Test Nos. NCBR-1 and NCBR-2

Alexandria INDUSTRIES

4925 Aluminum Drive • Indianapolis, IN 46218
www.AlexandriaIndustries.com
sales@AlexandriaIndustries.com

Cert Stamp
LBF PO# M01018
Job/Item #
Page 4 of 6

ALEXANDRIA EXTRUSION MID-AMERICA HEREBY CERTIFIES THAT SAMPLES OF THE MATERIALS THAT WERE ORDERED DESCRIBED IN THIS REPORT HAVE THE PROPERTIES SHOWN.
Representative:

19378
PB02

CERTIFIED TEST REPORT

Customer	L.B FOSTER
Customer PO	4094
Bill of Lading	55480
Qty Shipped	
Date Shipped	2/28/2018

CO Number	Die Number
604795	51450

Test Counter	Heat Number	Alloy	Ultimate Strength	Yield Strength	Elongation	Hardness
33439	1801065	6061	46900	44300	10	94

Cert Stamp
LBF PO# 4094
Job/Item # 19378
Page 1 of 2

ASTM B221

Figure B-2. Additional Aluminum Parts, Test Nos. NCBR-1 and NCBR-2

MeadowBurke
A CRH COMPANY

Certificate of Origin

Sold to: L. B. FOSTER CO.

Shipped to: L. B. FOSTER CO.

BEDFROD, PA 15522

Purchase Order: 4578

MB Order Number: S480432

This document certifies that all products listed in the table below are manufactured by Meadow Burke, LLC in the United States, using steel manufactured in the United States from domestically produced billets.

Part Number	Description
MB432127303	GRD RL IN(4) 3/4" X 2.5" .02 FERRULES SPECIAL
	H=7" D=4-5/8" W=5-1/2" HDG RETAP

VP of Operations – Jason Tebeau

12-10-18

Date

VP of Engineering – Michael Recker

Meadow Burke, LLC

Cert Stamp
LBF PO# 4578
Job/Item # 31478
Page 1 of 3

Figure B-3. ¾ in. Threaded Ferrule, Test Nos. NCBR-1 and NCBR-2

ALEXANDRIA EXTRUSION MID-AM
4925 ALUMINUM DRIVE
INDIANAPOLIS, IN 46218
(317) 545-1221

Packing list number 408010 Page 2
3/28/19 14:50:29

Shipped from:
Company . . . : 6 ALEX EXT MID-AM
Warehouse . . : 6

Ship Date . . . : 3/28/19
Shipment number : 19255

Ship to . : Midwest Roadside Safety Facility
4630 NW 36TH Street
LINCOLN NE 68524
United States of America

Carrier/pro number	Truck/trailer number	Gross weight	U/M
CPU		723.176	LB

Shipping instructions : CPU

AR1164

ALL BUNDLES MUST BE
MARKED WITH PO 269157 AND
AR1164

Item number	Rel	Item description	Packed qty/ Backorder qty	U/M
00654034	1	BARRIER RAIL SEMI-EL	2.000	EA
654-30'		BARRIER RAIL SEMI-EL	.000	EA
00654209	1	BARRIER RAIL SEMI-EL	4.000	EA
654-26'-0 1/2"		BARRIER RAIL SEMI-EL	.000	EA

** End of list **

Figure B-4. Longitudinal Elliptical Rails, Test Nos. NCBR-1 and NCBR-2

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

NCBR
2611130129001 Truck 1

Customer's Signature: ____________

PLANT	TRUCK	DRIVER	CUSTOMER	PROJECT	TAX	PO NUMBER	DATE	TIME	TICKET
01	240	3609	62461				4/8/19	10:35 AM	1234810

Customer: UNL-MIDWEST ROADSIDE SAFETY

Delivery Address: 4630 NW 36TH ST

Special Instructions: AIRPARK / NW 36TH ST & W CUMINGSST / NORTH OF OLD GOODYEAR HANGARS

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
9.00	9.00	11.50	470031PF	47BD (1PF)	yd	$122.91	$1,106.19

Water Added On Job At Customer's Request: ____________

SLUMP: 4.00 in

Notes:

TICKET SUBTOTAL	$1,106.19
SALES TAX	$0.00
TICKET TOTAL	$1,106.19
PREVIOUS TOTAL	
GRAND TOTAL	$1,106.19

CAUTION FRESH CONCRETE

KEEP CHILDREN AWAY

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

Terms & Conditions

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

MATERIAL	DESCRIPTION	DESIGN QTY	REQUIRED	BATCHED	% VAR	% MOISTURE	ACTUAL WATER
CEM1PF	DURACEM	658 lb	5922 lb	5895 lb	-0.46%		
G47B	47B GRAVEL	1975 lb	17926 lb	17920 lb	-0.03%	0.85% A	18 gl
L47B	47B ROCK	840 lb	7623 lb	7700 lb	+0.30%	0.83% A	8 gl
LRWR	POZZ 322N LOW	20.00 oz	180.00 oz	179.00 oz	-0.56%		
AIR	MICRO AIR 200	5.00 oz	45.00 oz	45.00 oz	0.00%		
WATER	WATER	31.5 GL	266.9 GL	265.5 GL	-0.51%		265.5 gl

Actual   Num Batches: 1   Manual 10:35:05

Load: 33745 lb   Design W/C: 0.40   Water/Cement: 0.41 A   Design Water: 283.5 gl   Actual: 291.2 gl

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

Actual W/C Ratio 0.41   Actual Water: 291 gl   Batched Cement: 5895 lb   Allowable Water: 0 lb   To Add: 0.0 gl

Figure B-5. Concrete, Test Nos. NCBR-1 and NCBR-2

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

NCBR
26111 30 129001
Truck 2

Customer's Signature:

PLANT	TRUCK	DRIVER	CUSTOMER	PROJECT	TAX	PO NUMBER	DATE	TIME	TICKET
01	130	9921	62461				4/8/19	10:48 AM	1234813

Customer: UNL-MIDWEST ROADSIDE SAFETY
Delivery Address: 4330 NW 36TH ST
Special Instructions: AIRPARK / NW 36TH ST & W CUMINGSST / NORTH OF OLD GOODYEAR HANGARS

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
2.50	11.50	11.50	470031PF	47BD (1PF)	yd	$122.91	$307.28

Water Added On Job At Customer's Request:

SLUMP: 4.00 in

Notes:

TICKET SUBTOTAL	$307.28
SALES TAX	$0.00
TICKET TOTAL	**$307.28**
PREVIOUS TOTAL	$1,106.19
GRAND TOTAL	**$1,413.47**

CAUTION FRESH CONCRETE

KEEP CHILDREN AWAY

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

Terms & Conditions

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

MATERIAL	DESCRIPTION	DESIGN QTY	REQUIRED	BATCHED	% VAR	% MOISTURE	ACTUAL WATER
CEM1PF	DURACEM	658 lb	1645 lb	1625 lb	-1.22%		
G47B	47B GRAVEL	1975 lb	4980 lb	4980 lb	0.01%	0.86% E	5 gl
L47B	47B ROCK	840 lb	2117 lb	2120 lb	0.04%	0.82% A	2 gl
LRWR	POZZ 322N LOV	20.00 oz	50.00 oz	50.00 oz	0.00%		
AIR	MICRO AIR 200	5.00 oz	12.50 oz	13.00 oz	4.00%		
WATER	WATER	[illegible] GL	74.1 GL	73.3 GL	-0.42%		73.8 gl

Actual
Load 9345 lb | Num Batches: 1 | Design W/C: 0.40 | Water/Cement: 0.42 A | Design Water: 78.8 gl | Manual 10:48:01 | Actual 80.9 gl
Slump: 4.00 in # | Water in Truck: 0.0 GL | Adjust Water: 0.0 GL / Load | Trim Water: 0.0 GL / CYDS | Note: Manual feed occured
Actual W/C Ratio 0.42 | Actual Water: 81 gl | Batched Cement: 1625 lb | Allowable Water: 0 lb | To Add: 0.0 gl

Figure B-6. Concrete, Test Nos. NCBR-1 and NCBR-2

Simcote, Inc
1645 Red Rock Road
Saint Paul, MN 55119-
Phone: (651) 735-9660

JOB NUMBER	RELEASE NUMBER	REQ. DELIVERY DATE	PAGE
51639	18		1 of 2

JOB NAME	CC
2018 ORDERS	RNS

CUSTOMER	BY
CONCRETE INDUSTRIES,INC.	MEB

MATERIAL TYPE	REFERENCE	DRAWING ID	DESCRIPTION
Rebar, Grade 60, Epoxy	EPOXY	PO# 133797	72" CITY CURB INLETS & #5 X 40-0

CITY CURB INLETS & STOCK
PO# 133797
NE CERTS REQUIRED
SHIP TO: CONCRETE INDUSTRIES
6300 CORNHUSKER HWY
LINCOLN, NE 68507
CONTACT: DAVE B. (402)434-1824

**TEST BARS REQUIRED - 2 BARS PER HEAT # **

Description
(245) 72" CURB INLET TOPS

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
1	2450	4	4-06	B	3	7365		0-08	1-00	2-102				0-082		0-082		B01
2	490	4	2-11	E	S12	956	0-09	1-051					0-09	0-08		0-08	0-032	104
3	1470	4	1-10	A	3	1797		0-08	1-00	0-02				0-082		0-082		B01
4	1960	4	8-09	C		11456												O
5	490	4	7-00	D		2291												O
	6860.					23865.												

Description
STOCK #5 X 40-0

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
6	573	5	40-00			23906												O
	573.					23906.												

Description
TEST BARS

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
7	2	5	6-00	TEST5		13												O
	2.					13.												
8	2	4	6-00	TEST4		8												O
9	2	4	6-00	TEST3		8												O
10	2	4	6-00	TEST2		8												O
11	2	4	6-00	TEST1		8												O
	8.					32.												

Total Weight: 47,816 Lbs

Longest Length: 40-00

INSPECT EPOXY COATING FOR DAMAGE, TOUCH UP, PADDING, & PLACING OF DUNNAGE

INITIALS:____________

Figure B-7. #5 Bar, Test Nos. NCBR-1 and NCBR-2

ABC COATING CO. OF ILLINOIS, INC.

1160 N. BOUDREAU ROAD
MANTENO, IL 60950
(708) 258-9633

AN ACUÑA CO.

DATE:	3/5/2018	CONTRACTOR:	Carroll Distributing
OUR JOB NO:	IL-8185	COUNTY:	
CUSTOMER:	Adelphia Metals, LLC	PROJECT NO:	SO# 222984
CUSTOMER PO NO:	822859/822844/5180	JOB NO:	2018 Stock

We certify that the following described bar material has been cleaned, coated with 3 M #413 or Nap-gard 7-2719, 7-2750 or Valspar 720A009 Powder inspected in accordance with and meets the specification requirements of the Iowa Department of Transportation and ASTM A775-17 AASHTO M284-06, ASTM D3963-01. Manufacturer's Certifications for the bar material and epoxy resin used are on file.

Mill	Lot/Heat	Powder	Size	Weight
Nucor GR 60	KN1810000601	3777133B	4/13	11,904
Nucor GR 60	KN1810025501	3804648	5/18	28,912
Nucor GR 60	KN1710201402	3649393	8/25	6,168
				45,984

Certifications for the listed material and resin are attached

STATE OF ILLINOIS)
COUNTY OF COOK)

Thomas Greenfield, Vice President
SUBSCRIBED AND SWORN BEFORE ME, a Notary Public in and for Cook County, Illinois, on this 5th day of March 2018

OFFICIAL SEAL
FREDDIE ROCHA
NOTARY PUBLIC, STATE OF ILLINOIS
COOK COUNTY
MY COMMISSION EXPIRES 03/31/2018

My commission expires 03-31-2018

Notary Public in and for Chicago, Illinois

EPOXY COATING PLANT CERTIFICATION TM CONCRETE REINFORCING STEEL INSTITUTE

CRSI MEMBER

Figure B-8. #5 Bar, 36 in. Long, Test Nos. NCBR-1 and NCBR-2

Simcote, Inc
1645 Red Rock Road
Saint Paul, MN 55119-
Phone: (651) 735-9660

JOB NUMBER	RELEASE NUMBER	REQ. DELIVERY DATE	PAGE
51639	16		1 of 2

JOB NAME: 2018 ORDERS — CC: QDM
CUSTOMER: CONCRETE INDUSTRIES,INC. — BY: Jud

MATERIAL TYPE	REFERENCE	DRAWING ID	DESCRIPTION
Rebar, Grade 60, Epoxy	EPOXY STOCK	PO# 133016	#3, 4, 5, & 6 STOCK STRAIGHT BAR

#3, 4 & 5 X 20' & #6 X 40' EPOXY STRAIGHT BAR
PO# 133016
NE CERTS REQUIRED
SHIP TO: CONCRETE INDUSTRIES
6300 CORNHUSKER HWY
LINCOLN, NE 68507
CONTACT: DAVE BORCHERS (402)434-1824

**TEST BARS REQUIRED - 2 BARS PER HEAT # **

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
1	256	6	40-00			15380												0
	256.					15380.												
2	1000	5	20-00			20860												0
	1000.					20860.												
3	600	4	20-00			8016												0
	600.					8016.												
4	500	3	20-00			3760												0
	500.					3760.												

Description
TEST BARS

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
5	2	6	6-00	TEST6		18												0
	2.					18.												
6	2	5	6-00	TEST5		13												0
	2.					13.												
7	2	4	6-00	TEST4		8												0
	2.					8.												
8	2	3	6-00	TEST3		5												0
	2.					5.												

Total Weight: 48,060 Lbs

Longest Length: 40-00

INSPECT EPOXY COATING FOR DAMAGE, TOUCH UP, PADDING, & PLACING OF DUNNAGE

INITIALS:____________

Figure B-9. #6 Bar, Test Nos. NCBR-1 and NCBR-2

Simcote, Inc
1645 Red Rock Road
Saint Paul, MN 55119-
Phone: (651) 735-9660

JOB NUMBER	RELEASE NUMBER	REQ. DELIVERY DATE	PAGE
51639	17		1 of 1

JOB NAME	CT
2018 ORDERS	QNU

CUSTOMER	BY
CONCRETE INDUSTRIES,INC.	Jud

MATERIAL TYPE	REFERENCE	DRAWING ID	DESCRIPTION
Rebar, Grade 60, Epoxy	EPOXY	PO# 133211	#7 X 60'-0" STRAIGHT STOCK

#7 X 60'-0" EPOXY STRAIGHT BAR
PO# 133211
NE CERTS REQUIRED
SHIP TO: 6300 CORNHUSKER HWY
LINCOLN, NE 68507
CONTACT: DAVE SLAMA (402)434-1837

**TEST BARS REQUIRED - 2 BARS PER HEAT # **

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
1	390	7	60-00			47830												0
	390.					47830.												

Description
TEST BARS

Itm	Qty	Size	Length	Mark	Shape	Lbs	A	B	C	D	E	F/R	G	H	J	K	O	BC
2	2	7	6-00	TEST7		25												0
	2.					25.												

Total Weight: 47,855 Lbs

Longest Length: 60-00

INSPECT EPOXY COATING FOR DAMAGE, TOUCH UP, PADDING, & PLACING OF DUNNAGE

INITIALS:____________

WEIGHT SUMMARY

SIZE	TOTAL ITEMS	TOTAL PIECES	TOTAL LBS	STRAIGHT ITEMS	STRAIGHT PIECES	STRAIGHT LBS	LIGHT BENDING ITEMS	LIGHT BENDING PIECES	LIGHT BENDING LBS	HEAVY BENDING ITEMS	HEAVY BENDING PIECES	HEAVY BENDING LBS
Rebar, Grade 60, Epoxy												
7	2	392	47,855	2	392	47,855	0	0	0	0	0	0
	2	392	47,855	2	392	47,855	0	0	0	0	0	0

Total Weight: 47,855 Lbs

Longest Length: 60-00

V16.02.080 (T) (SMN) ©2018 aSa UNAUTHORIZED REPRODUCTION PROHIBITED Tuesday, September 25, 2018 10:08 AM

Figure B-10. #7 Bar, Test Nos. NCBR-1 and NCBR-2

PrecisionForm, Inc. - 148 W Airport Rd - Lititz, PA 17543

CERTIFIED INSPECTION REPORT AND TEST RESULTS

Cert Stamp
LBF PO# M01018
Job/Item #
Page 6 of 6

SHIP TO
L.B. FOSTER CO
202 WEBER LANE
BEDFORD PA 15522-

SOLD TO
L.B. FOSTER CO
202 WEBER LANE
BEDFORD PA 15522-

Product Information

CUSTOMER PURCHASE ORDER NO: 4427
PFI ORDER NO: C-015728
PACKLIST NO: PL039677
PART DESCRIPTION: 6061-T6 III-BUT-RAD-END .750 X1.375 PLN
FINISH: PLAIN
ALLOY: 6061
TEMPER: T6
CUSTOMER PART / DWG: 19418
REV LEVEL:
PFI PART NO: PR-4199-000
DATE SHIPPED: 8/13/2018
WEIGHT SHIPPED: 616.8
QUANTITY: 6000 EA

CERTIFIED TO
ISO/TS 16949:2009
ISO 9001:2008

AUTHORIZED SIGNATURE QUALITY ASSURANCE MANAGER

We hereby certify that the material covered by this report has been inspected in accordance with, and has been found to meet, the applicable requirements described herein, including any specifications forming a part of the description, and that samples representative of the material met the composition limits and had the mechanical properties shown on this sheet.

Physical Test results

WORK ORDER		# of tests	TRACE ID min	max		TRACE QTY	MILL/HEAT LOT NO
X0076739			TFO-00062310			3000	213004
	Double Shear	1	29.66	29.66	KSI	Pass	
X0077276			TFG-00062366			1000	213004
	Double Shear	1	29.09	29.09	KSI	Pass	
X0077277			TFG-00062357			2000	213004
	Double Shear	1	30.28	30.28	KSI	Pass	

Comments

This is to certify that the material used in production of these parts is in accordance with ASTM B316

Cert Stamp
LBF PO# 4427
Job/Item # 19418
Page 1 of 1

-PROCUREMENT SPEC NASM5674 REV NEW, AS APPLICABLE
-ANODIZED COATINGS PER MIL-A-8625, AS APPLICABLE CONVERSION COATINGS PER MIL-DTL-5541, AS APPLICABLE
*KIPS PER SQUARE INCH, ONE KIP EQUALS ONE THOUSAND POUNDS
-NO MATERIALS PROHIBITED UNDER SPOC 184.1 WERE USED IN MANUFACTURE OF THIS PRODUCT
-NO MERCURY WAS USED IN THE MANUFACTURE OF THIS PRODUCT
-PARTS ARE MADE IN THE USA
-CHEMICAL COMPOSITION OF RAW MATERIAL MEETS APPLICABLE INDUSTRY STANDARD PER MANUFACTURER'S CERTIFICATE OF ANALYSIS. COPY AVAILABLE UPON REQUEST.

Page 1 of 1

Figure B-11. ¾ in.-Diameter, $1^3/_8$-in. Long Rivet, Test Nos. NCBR-1 and NCBR-2

Kelken Construction Systems
550 Hartle Street, STE C
Sayreville, NJ 08872
P: 732-416-6730 F: 732-416-6733

CERTIFICATION COVER SHEET

COMPANY: L.B. FOSTER COMPANY
SHIPPED TO: L.B. FOSTER COMPANY
P.O. NUMBER: 4584
REFERENCE: 218327
SALES ORDER: 0105913
INVOICE NUMBER: 00006046

HEAT/LOT NUMBER	QUANTITY	ITEM	DESCRIPTION
3076378	521	4H650A363	3/4 X 6 1/2" HDG A36 KELIBOLT(FABHEAD) WITH 1 FLAT WASHER PRECOATED WITH KELISLIP

Cert Stamp
LBF PO# 4584
Job/Item # 28420
Page 1 of 8

NAME: MARILYN MONTELEONE DATE: 12/19/2018

SIGNATURE:

Figure B-12. ¾-in. Diameter, 6½-in. Long Hex Head Drill-In Anchor, Test Nos. NCBR-1 and NCBR-2

32345

NUCOR
Nucor Steel Nebraska

Mill Certification
03/30/2018

MTR#: 45828
Lot #:10089087120
2911 E NUCOR ROAD
PO BOX 309
NORFOLK, NE 68701 US
402-644-0200
Fax: 402-644-0329

Sold To: FASTENER IN
PO BOX 6100
SAINT JOE, IN 46785-6100 US

Ship To: FASTENER IN2
6730 CR 60
SAINT JOE, IN 46785 US

Customer P.O	191303	Sales Order #	10009347 - 10.28
Product Group	Hot Roll - Engineered Bar	Product #	3099656
Grade	1030ML1	Lot #	10089087120
Size	0.7656"	Heat #	100890871
BOL #	BOL-143772	Load #	45828
Description	Hot Roll - Engineered Bar Round 49/64" 1030ML1 COIL 6200 lbs	Customer Part #	005012
Production Date	03/08/2018	Qty Shipped LBS	42335
Product Country Of Origin	United States	Qty Shipped EA	8
Original Item Description		Original Item Number	

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

Melt Country of Origin : United States — Melting Date: 03/02/2018

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	Cu (%)	Ti (%)	V (%)	B (%)
0.41	0.80	0.008	0.012	0.23	0.05	0.08	0.01	0.12	0.031	0.053	0.000
Nb (%)	**N (PPM)**	**Sn (%)**	**Al (%)**	**Pb (%)**	**Ca (%)**						
0.002	89	0.012	0.00	0.000	0.001						

Reduction Ratio 95.33 : 1

Comments:

Coarse Grain Practice
Selenium,Tellurium,Lead,Bismuth or Boron were not intentionally added to this heat.
All manufacturing processes of the steel materials in this product, including melting, have been performed in the United States.
All products produced are weld free.
Mercury, in any form, has not been used in the production or testing of this material.
Test conform to ASTM A29-15, ASTM E415 and ASTM E1019-resulphurized grades or applicable customer requirements.
All material melted at Nucor Steel Nebraska is produced in an Electric Arc Furnace.
Strand Cast
ISO-17025 LAB accreditation cert available upon request.
Exporting Country-USA
Sales@nucorne.com
California Proposition 65: This product contains chemicals known to the State of California to cause cancer, birth defects and other reproductive harm. The list of chemicals are available upon request. For more information, please call 402-644-0200.

Cert Stamp
LBF PO# 4214
Job/Item # 30150
Page 6 of 7

Chemistry Verification Checks

Part# 5012 HN# 32345

	Checked By	Date
Receiving OK:	29-1	4-2-18
Certifications OK:	3 7 5	4-9-15

Jim Hill, Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 1

Figure B-13. ¾ in.-10 UNC, 2½ in. Long Hex Bolt, Test Nos. NCBR-1 and NCBR-2

ROBBINS

BOX 2047150 · 1300 AIRPORT ROAD · FALL RIVER, MASSACHUSETTS 02722 · 508-675-2555 · FAX 508-677-0091

MANUFACTURERS OF STAINLESS STEEL, NON-FERROUS BOLTS, SCREWS, NUTS & SPECIAL COLD FORMED PARTS

CERTIFICATE OF COMPLIANCE - GENERAL

2/27/18

L.B. FOSTER COMPANY
C/O ACCOUNTS PAYABLE
202 REBER LANE
BEDFORD
PA 15522

CUSTOMER NO.	01604800		
PURCHASE ORDER NO.	4008		
LINE ITEM NO.			
THREAD CLASS	UNC 2A		
REPORT/CERTIFICATE NO.	60221G	DATE OF MFG.:	2/23/18

COMPANY NO.	01	MATERIAL	304L STAINLESS
INVOICE NO.		HEAT/LOT NO.	05Y
ITEM NUMBER	50001312500AK		
ITEM	1/2-13 X 1-1/4 HEX CAP 304		
ROBBINS LOT NO.	L56204	SHOP ORDER NO.	C132257
QUANTITY SHIPPED	1,524		

THIS REPORT MUST NOT BE REPRODUCED EXCEPT IN FULL, AND RELATES ONLY TO THE ITEM(S) TESTED.

SPECIFICATION(S) INVOKED:

MATERIAL	ASTM-F-593-09 304L	HEAD MARKINGS	F593C & R
MECH. PROP.	ASTM-F-593-09 GROUP 1 CW	COMMENTS	
DIMENSIONAL	ANSI B18.2.1		
NDT TESTING	N/A		
NDT ACCEPTANCE	N/A		

Cert Stamp
LBF PO# 4008
Job/Item # 22936
Page 3 of 3

THE UNDERSIGNED HEREBY CERTIFIES THAT:

ALL ITEMS FURNISHED IN THIS SHIPMENT ARE IN FULL COMPLIANCE WITH ALL PURCHASE ORDER AND SPECIFICATION REQUIREMENTS.

WHEN THE ABOVE CITED PURCHASE ORDER REQUIRES MATERIAL TEST REPORTS, THE UNDERSIGNED FURTHER CERTIFIES THAT:

THE TEST REPORTS SUPPLIED REPRESENT THE ACTUAL ATTRIBUTES OF THE ITEMS FURNISHED AND THE TEST RESULTS ARE IN FULL COMPLIANCE WITH ALL APPLICABLE SPECIFICATIONS AND PURCHASE ORDER REQUIREMENTS.

COMMONWEALTH OF MASS. COUNTY OF BRISTOL
SUBSCRIBED AND SWORN TO BEFORE ME
THIS 27th DAY OF Feb 2018
NOTARY PUBLIC Mabel E. Moxet
MY COMMISSION EXPIRES 06.18.2021

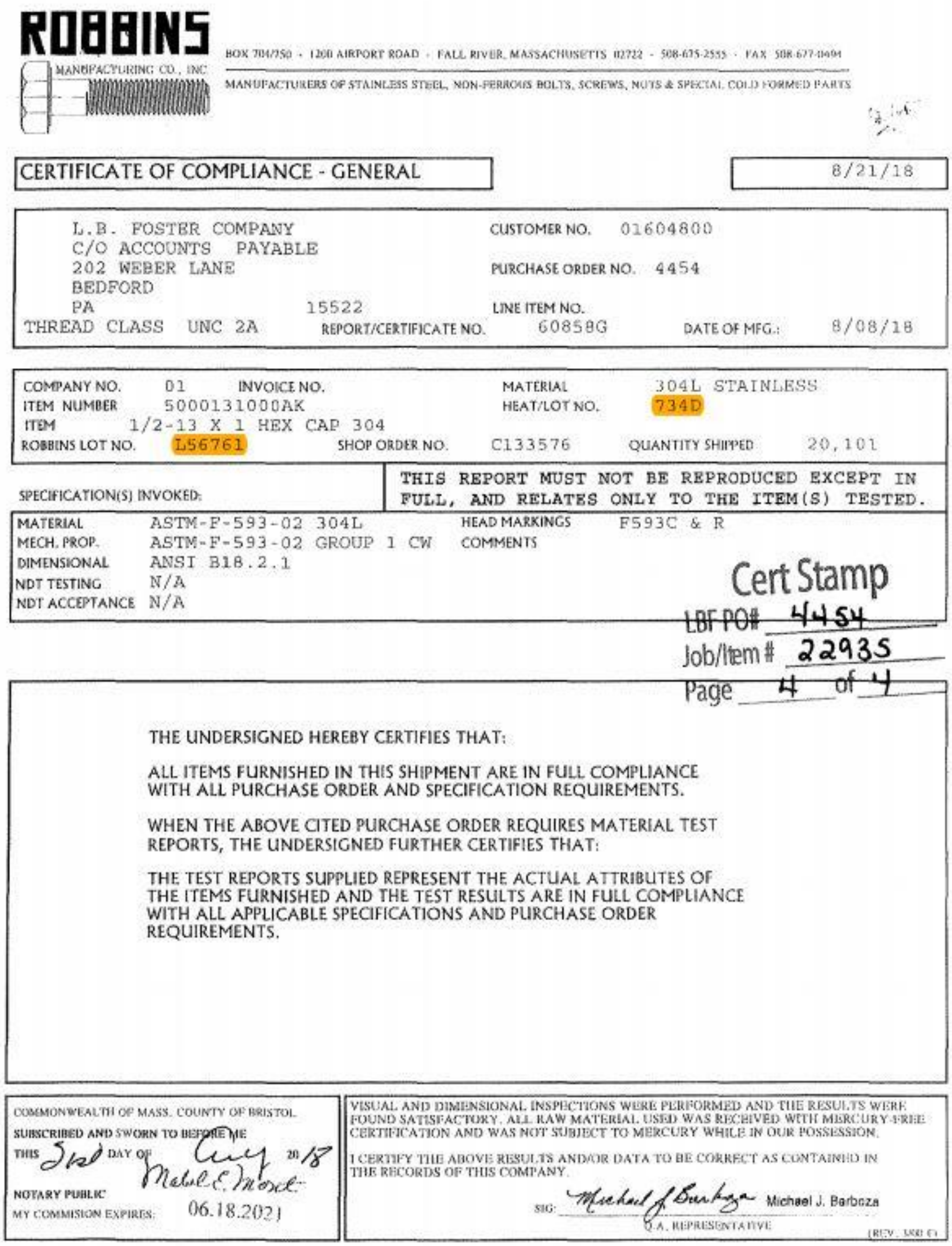
VISUAL AND DIMENSIONAL INSPECTIONS WERE PERFORMED AND THE RESULTS WERE FOUND SATISFACTORY. ALL RAW MATERIAL USED WAS RECEIVED WITH MERCURY-FREE CERTIFICATION AND WAS NOT SUBJECT TO MERCURY WHILE IN OUR POSSESSION.

I CERTIFY THE ABOVE RESULTS AND/OR DATA TO BE CORRECT AS CONTAINED IN THE RECORDS OF THIS COMPANY.

SIG
Q.A. REPRESENTATIVE

(REV. 4/03)

Figure B-14. ½ in.-13 UNC, 1¼ in. Long Hex Head Cap Screw, Test Nos. NCBR-1 and NCBR-2



ROBBINS MANUFACTURING CO., INC.

BOX 704/750 · 1200 AIRPORT ROAD · FALL RIVER, MASSACHUSETTS 02722 · 508-675-2555 · FAX 508-677-0494

MANUFACTURERS OF STAINLESS STEEL, NON-FERROUS BOLTS, SCREWS, NUTS & SPECIAL COLD FORMED PARTS

CERTIFICATE OF COMPLIANCE - GENERAL | 8/21/18

L.B. FOSTER COMPANY
C/O ACCOUNTS PAYABLE
202 WEBER LANE
BEDFORD
PA 15522

CUSTOMER NO. 01604800
PURCHASE ORDER NO. 4454
LINE ITEM NO.

THREAD CLASS UNC 2A | REPORT/CERTIFICATE NO. 60858G | DATE OF MFG.: 8/08/18

COMPANY NO.	01	INVOICE NO.	
ITEM NUMBER	5000131000AK	MATERIAL	304L STAINLESS
ITEM	1/2-13 X 1 HEX CAP 304	HEAT/LOT NO.	734D
ROBBINS LOT NO.	L56761	SHOP ORDER NO.	C133576
QUANTITY SHIPPED	20,101		

SPECIFICATION(S) INVOKED:

THIS REPORT MUST NOT BE REPRODUCED EXCEPT IN FULL, AND RELATES ONLY TO THE ITEM(S) TESTED.

MATERIAL	ASTM-F-593-02 304L
MECH. PROP.	ASTM-F-593-02 GROUP 1 CW
DIMENSIONAL	ANSI B18.2.1
NDT TESTING	N/A
NDT ACCEPTANCE	N/A

HEAD MARKINGS F593C & R
COMMENTS

Cert Stamp
LBF PO# 4454
Job/Item # 22935
Page 4 of 4

THE UNDERSIGNED HEREBY CERTIFIES THAT:

ALL ITEMS FURNISHED IN THIS SHIPMENT ARE IN FULL COMPLIANCE WITH ALL PURCHASE ORDER AND SPECIFICATION REQUIREMENTS.

WHEN THE ABOVE CITED PURCHASE ORDER REQUIRES MATERIAL TEST REPORTS, THE UNDERSIGNED FURTHER CERTIFIES THAT:

THE TEST REPORTS SUPPLIED REPRESENT THE ACTUAL ATTRIBUTES OF THE ITEMS FURNISHED AND THE TEST RESULTS ARE IN FULL COMPLIANCE WITH ALL APPLICABLE SPECIFICATIONS AND PURCHASE ORDER REQUIREMENTS.

COMMONWEALTH OF MASS. COUNTY OF BRISTOL
SUBSCRIBED AND SWORN TO BEFORE ME
THIS 21st DAY OF Aug 2018
NOTARY PUBLIC Mabel E. Morel
MY COMMISION EXPIRES: 06.18.2021

VISUAL AND DIMENSIONAL INSPECTIONS WERE PERFORMED AND THE RESULTS WERE FOUND SATISFACTORY. ALL RAW MATERIAL USED WAS RECEIVED WITH MERCURY-FREE CERTIFICATION AND WAS NOT SUBJECT TO MERCURY WHILE IN OUR POSSESSION.

I CERTIFY THE ABOVE RESULTS AND/OR DATA TO BE CORRECT AS CONTAINED IN THE RECORDS OF THIS COMPANY.

SIG: Michael J. Barboza Michael J. Barboza
Q.A. REPRESENTATIVE

(REV. 3/00 C)

Figure B-15. ½ in.-13 UNC, 1 in. Long Hex Head Cap Screw, Test Nos. NCBR-1 and NCBR-2

AZZ GALVANIZING ROCKFORD

AUGUST 29, 2018

Technical Stamping
50600 E. Russell Schmidt
Chesterfield TWP, MI 48051

To Whom It May Concern:

This is to certify that the hot dip galvanizing of the following washers on your Purchase Order number 1638 conforms to specification ASTM A-153. The following sizes and lot numbers comply with the coating, workmanship, finish, and appearance requirements of ASTM F2329 specifications. The hot dip galvanizing is ROHS compliant. The galvanizing process was conducted in a temperature range of 830F to 855F.

PIECES	PART# & SIZE	LOT NUMBER	AVERAGE ZINC COATING IN MILS.
314,174	#F0034 3/4" WASHER	0618-882	4.09

This certification in no way implies anything other than the quality of our hot dip galvanizing as it pertains to your order.

This product was galvanized in Rockford, IL USA

Yours very truly,

AZZ Galvanizing Rockford, IL

Peggy Doering

Peggy Doering
Office Manager

PD: bd

Cert Stamp
LBF PO# 4572
Job/Item # 14800
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Figure B-16. ¾ in. Dia. Plain Washers, Test Nos. NCBR-1 and NCBR-2

Certsdoc2, v1.0

PO Number: None

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

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

TOMMY HEWITT
Quality Assurance Manager

HEAT NO.:3076378 SECTION: ROUND .680 x 20'0" A36/52950 GRADE: ASTM A36-14/A529-14 Gr 50 ROLL DATE: 12/24/2017 MELT DATE: 12/08/2017 Cert. No.: 82374792 / 076378A901	SOLD TO: Unique Industries Inc 13488 Highway 25 Calera AL US 35040-5017 T 2056680490 O 2056680431	SHIP TO: Unique Industr Inc Highway 25 Calera AL US 35040-0000 T 2056680490 O 2056680431

Delivery#: 82374792
BOL#: 72461237
CUST PO#: 325046
CUST P/N:
DLVRY LBS / HEAT: 17958.000 LB
DLVRY PCS / HEAT: 727 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.16%	Reduction of Area test 1	57%		
Mn	0.72%	Yield Strength test 2	53.2ksi		
P	0.011%	Tensile Strength test 2	76.5ksi		
S	0.030%	Elongation test 2	39%		
Si	0.23%	Elongation Gage Lgth test 2	2IN		
Cu	0.30%	Reduction of Area test 2	58%		
Cr	0.09%	BHN @ Surface test 1	156BHN		
Ni	0.08%				
Mo	0.028%				
V	0.003%				
Cb	0.001%				
Sn	0.012%				
Al	0.002%				
Carbon Eq F1554	0.30%				
Carbon Eq A529	0.37%				
Yield Strength test 1	52.4ksi				
Tensile Strength test 1	75.8ksi				
Elongation test 1	27%				
Elongation Gage Lgth test 1	8IN				

The Following is true of the material represented by this MTR:
- *Material is fully killed
- *100% melted and rolled in the USA
- *EN10204:2004 3.1 compliant
- *Contains no weld repair
- *Contains no Mercury contamination
- *Manufactured in accordance with the latest version of the plant quality manual
- *Meets the "Buy America" requirements of 23 CFR635.410

REMARKS :

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Job/Item # 28420
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Figure B-17. ½ in. Dia. Plain SAE Washer, Test Nos. NCBR-1 and NCBR-2

Appendix C. Vehicle Center of Gravity Determination

Date:	5/13/2019	Test Name:	NCBR-1	VIN:	kmhcn4ac1au467917
Year:	2010	Make:	Hyundai	Model:	Accent

Vehicle CG Determination

	Vehicle Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Car (Curb)	2505	22.761875	57018.497
+	Hub	19	10.6875	203.0625
+	Brake activation cylinder & frame	7	16.625	116.375
+	Pneumatic tank (Nitrogen)	30	13.75	412.5
+	Strobe/Brake Battery	5	20.25	101.25
+	Brake Receiver/Wires	6	43	258
+	CG Plate including DAQ	13	17.25	224.25
-	Battery	-31	27	-837
-	Oil	-8	11	-88
-	Interior	-82	24	-1968
-	Fuel	-21	15	-315
-	Coolant	-4	21	-84
-	Washer fluid	-1	18	-18
+	Water Ballast (In Fuel Tank)	0	0	0
+	Onboard Supplemental Battery	0	0	0
-	Spare Tire	-21	14.5	-304.5
				0
	Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle			54719.434

Estimated Total Weight (lb) 2417

Vehicle Dimensions for C.G. Calculations

Wheel Base:	99.0	in.	Front Track Width:	57.875	in.
Roof Height:	57.625	in.	Rear Track Width:	57.25	in.

Center of Gravity	**1100C MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)	2420 ± 55	2425	5.0
Longitudinal CG (in.)	39 ± 4	35.518	-3.482
Lateral CG (in.)	NA	0.154	NA
Vertical CG (in.)	NA	22.639	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	823	773
Rear	447	462
FRONT	1596	lb
REAR	909	lb
TOTAL	2505	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	778	777
Rear	428	442
FRONT	1555	lb
REAR	870	lb
TOTAL	2425	lb

Figure C-1. Vehicle Mass Distribution, Test No. NCBR-1

Date:	**6/11//2019**	**Test Name:**	**NCBR-2**
VIN:	**1GCRCPEH6FZ173614**		
Year:	**2015**	**Make:**	**Chevrolet**
Model:	**Silverado**		

Vehicle CG Determination

	Vehicle Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	5015	27.8561	139698.34
+	Hub	31	14.5	449.5
+	Brake activation cylinder & frame	7	29 1/4	204.75
+	Pneumatic tank (Nitrogen)	31	26	806
+	Strobe/Brake Battery	5	26	130
+	Brake Receiver/Wires	6	54 1/4	325.5
+	CG Plate including DAQ	17	30	510
-	Battery	-40	41	-1640
-	Oil	-9	13	-117
-	Interior	-98	34 3/8	-3368.75
-	Fuel	-172	19 1/8	-3289.5
-	Coolant	-11	36 3/4	-404.25
-	Washer fluid	-10	35	-350
+	Water Ballast (In Fuel Tank)	0	0	0
+	Onboard Supplemental Battery	13	25 1/8	326.625
+	Boggie Plates in Bed	233	37 3/4	8795.75
				0
	Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle			142076.97

Estimated Total Weight (lb)	5018
Vertical CG Location (in.)	28.3135

Vehicle Dimensions for C.G. Calculations

Wheel Base:	144 in.	Front Track Width:	68 in.
		Rear Track Width:	67.5 in.

Center of Gravity	**2270P MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)	5000 ± 110	5018	18.0
Longitudinal CG (in.)	63 ± 4	61.382224	-1.61778
Lateral CG (in.)	NA	0.3240335	NA
Vertical CG (in.)	28 or greater	28.31	0.31347

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	1498	1433
Rear	1026	1058
FRONT	2931 lb	
REAR	2084 lb	
TOTAL	5015 lb	

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1433	1446
Rear	1052	1087
FRONT	2879 lb	
REAR	2139 lb	
TOTAL	5018 lb	

Figure C-2. Vehicle Mass Distribution, Test No. NCBR-2

Appendix D. Vehicle Deformation Record

Date: 5/13/2019 Test Name: NCBR-1 VIN: kmhcn4ac1au467917
Year: 2010 Make: Hyundai Model: Accent

VEHICLE DEFORMATION
DRIVER SIDE FLOOR PAN - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	64.0274	-11.5483	3.2591	64.1974	-10.3416	3.6540	-0.1700	1.2067	-0.3949	1.2810	0.0000	NA
	2	64.6351	-16.5250	3.1292	63.7302	-14.7847	2.6246	0.9049	1.7403	0.5046	2.0254	1.0361	X, Z
	3	64.8974	-21.7437	2.9131	63.8423	-19.9651	2.3591	1.0551	1.7786	0.5540	2.1409	1.1917	X, Z
	4	64.3931	-26.4336	1.3919	63.1575	-24.6474	1.0098	1.2356	1.7862	0.3821	2.2053	1.2933	X, Z
	5	61.7510	-31.4146	-1.1101	59.4663	-28.7906	-2.0034	2.2847	2.6240	0.8933	3.5921	2.4531	X, Z
	6	59.0730	-11.0782	3.5884	59.2986	-10.2164	3.6139	-0.2256	0.8618	-0.0255	0.8912	0.0000	NA
	7	60.2708	-16.4297	5.6631	59.6192	-14.7234	5.2611	0.6516	1.7063	0.4020	1.8702	0.7656	X, Z
	8	61.1665	-21.4484	5.1542	60.1708	-19.6748	4.8751	0.9957	1.7736	0.2791	2.0530	1.0341	X, Z
	9	61.9780	-26.8999	4.6677	60.9246	-25.1494	4.2631	1.0534	1.7505	0.4046	2.0827	1.1284	X, Z
	10	61.0537	-32.4899	1.9164	58.5324	-29.8840	1.0263	2.5213	2.6059	0.8901	3.7336	2.6738	X, Z
FLOOR PAN (Z)	11	53.2300	-10.9749	3.7162	53.4260	-10.7013	3.3939	-0.1960	0.2736	0.3223	0.4660	0.3223	Z
	12	55.1058	-15.9885	7.2470	54.0004	-15.1133	5.4782	1.1054	0.8752	1.7688	2.2620	1.7688	Z
	13	55.5284	-21.0545	7.2127	54.6932	-19.5202	7.1765	0.8352	1.5343	0.0362	1.7473	0.0362	Z
	14	55.5219	-27.1438	7.1926	55.0523	-25.5461	7.1084	0.4696	1.5977	0.0842	1.6674	0.0842	Z
	15	55.7073	-32.3551	7.1905	55.3910	-30.7451	6.9768	0.3163	1.6100	0.2137	1.6546	0.2137	Z
	16	48.3041	-10.9495	3.9244	48.4938	-10.6745	3.6553	-0.1897	0.2750	0.2691	0.4290	0.2691	Z
	17	48.8649	-15.2732	8.1615	48.4345	-15.7473	6.2476	0.4304	-0.4741	1.9139	2.0182	1.9139	Z
	18	49.1990	-20.7498	7.4283	48.4212	-19.5030	7.6493	0.7778	1.2468	-0.2210	1.4860	-0.2210	Z
	19	49.7707	-26.4426	7.6167	49.2818	-25.1902	7.8852	0.4889	1.2524	-0.2685	1.3710	-0.2685	Z
	20	50.2633	-32.1848	7.3800	49.9777	-30.8038	7.2975	0.2856	1.3810	0.0825	1.4126	0.0825	Z
	21	43.9165	-11.0497	4.2558	44.1234	-10.7755	3.9853	-0.2069	0.2742	0.2705	0.4372	0.2705	Z
	22	43.7170	-15.0540	8.2341	43.5988	-15.3588	6.9757	0.1182	-0.3048	1.2584	1.3002	1.2584	Z
	23	43.5466	-20.2315	7.6024	42.7523	-19.3082	7.9960	0.7943	0.9233	-0.3936	1.2800	-0.3936	Z
	24	44.4389	-26.1266	7.7253	44.0242	-25.1900	7.9113	0.4147	0.9366	-0.1860	1.0411	-0.1860	Z
	25	44.8518	-32.0431	7.5374	44.5744	-30.9144	7.6274	0.2774	1.1287	-0.0900	1.1658	-0.0900	Z
	26	38.1365	-10.6718	4.1612	38.3080	-10.4644	3.9909	-0.1715	0.2074	0.1703	0.3185	0.1703	Z
	27	38.5846	-14.5991	7.6906	38.4484	-14.2982	7.4967	0.1362	0.3009	0.1939	0.3830	0.1939	Z
	28	38.4376	-19.8256	7.6991	37.9346	-19.3825	7.8834	0.5030	0.4431	-0.1843	0.6952	-0.1843	Z
	29	42.4426	-21.9910	7.4207	38.0959	-25.2240	8.0212	4.3467	-3.2330	-0.6005	5.4504	-0.6005	Z
	30	42.9251	-26.2127	7.3468	38.1640	-29.5026	7.9888	4.7611	-3.2899	-0.6420	5.8227	-0.6420	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan	Posttest Floor Pan
	

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

Date: 5/13/2019 Test Name: NCBR-1 VIN: kmhcn4ac1au467917
Year: 2010 Make: Hyundai Model: Accent

VEHICLE DEFORMATION
DRIVER SIDE INTERIOR CRUSH - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	48.3238	-7.8324	-21.3445	48.6934	-6.4954	-21.8201	-0.3696	1.3370	-0.4756	1.4664	1.4664	X, Y, Z
	2	45.8878	-21.0222	-23.8189	46.2913	-19.7597	-24.3967	-0.4035	1.2625	-0.5778	1.4459	1.4459	X, Y, Z
	3	48.6044	-32.7687	-20.3852	49.0532	-31.3955	-20.8723	-0.4488	1.3732	-0.4871	1.5246	1.5246	X, Y, Z
	4	46.1260	-7.3155	-7.8768	46.3417	-6.2013	-8.2821	-0.2157	1.1142	-0.4053	1.2051	1.2051	X, Y, Z
	5	49.5810	-20.4721	-7.9093	49.8150	-19.1896	-8.3691	-0.2340	1.2825	-0.4598	1.3824	1.3824	X, Y, Z
	6	50.1209	-32.8981	-6.2997	49.7728	-31.4706	-6.6387	0.3481	1.4275	-0.3390	1.5079	1.5079	X, Y, Z
SIDE PANEL (Y)	7	53.5008	-34.3532	-1.4248	57.3967	-31.6191	-4.6482	-3.8959	2.7341	-3.2234	5.7484	2.7341	Y
	8	53.0566	-35.2060	2.5527	53.1255	-32.8226	2.2732	-0.0689	2.3834	-0.2795	2.4007	2.3834	Y
	9	57.9878	-34.9209	2.3493	58.0120	-32.0129	2.0861	-0.0242	2.9080	-0.2632	2.9200	2.9080	Y
IMPACT SIDE DOOR (Y)	10	45.8849	-35.5520	-16.8144	45.4089	-34.7546	-17.0097	0.4760	0.7974	-0.1953	0.9490	0.7974	Y
	11	36.7441	-35.4969	-17.5026	36.4055	-36.0685	-17.4648	0.3386	-0.5716	0.0378	0.6654	-0.5716	Y
	12	23.4699	-35.0620	-17.8750	23.1864	-36.9928	-17.6961	0.2835	-1.9308	0.1789	1.9597	-1.9308	Y
	13	42.8548	-35.7492	0.3252	42.7252	-35.2114	0.1346	0.1296	0.5378	-0.1906	0.5851	0.5378	Y
	14	36.7392	-35.5761	0.4717	36.6647	-35.7927	0.2877	0.0745	-0.2166	-0.1840	0.2938	-0.2166	Y
	15	27.6878	-35.2851	-0.0494	27.8023	-35.7695	-0.0665	-0.1145	-0.4844	-0.0171	0.4980	-0.4844	Y
ROOF - (Z)	16	32.6583	-7.8115	-36.6100	32.4933	-7.8914	-36.7103	0.1650	-0.0799	-0.1003	0.2090	-0.1003	Z
	17	32.6026	-12.0061	-36.4645	32.4894	-12.0717	-36.5983	0.1132	-0.0656	-0.1338	0.1871	-0.1338	Z
	18	31.8841	-17.4721	-36.2639	31.8570	-17.6244	-36.4221	0.0271	-0.1523	-0.1582	0.2213	-0.1582	Z
	19	31.4441	-22.3242	-35.9222	31.4076	-22.4147	-36.1395	0.0365	-0.0905	-0.2173	0.2382	-0.2173	Z
	20	30.7194	-27.0002	-35.4670	30.6927	-27.0954	-35.6907	0.0267	-0.0952	-0.2237	0.2446	-0.2237	Z
	21	29.0641	-7.7411	-38.5900	29.0553	-7.8807	-38.6921	0.0088	-0.1396	-0.1021	0.1732	-0.1021	Z
	22	28.6750	-12.0386	-38.5791	28.5624	-12.1592	-38.7228	0.1126	-0.1206	-0.1437	0.2188	-0.1437	Z
	23	28.2005	-17.1802	-38.4157	28.0912	-17.2486	-38.5588	0.1093	-0.0684	-0.1431	0.1926	-0.1431	Z
	24	27.6345	-22.1418	-38.1107	27.6281	-22.2806	-38.2296	0.0064	-0.1388	-0.1189	0.1829	-0.1189	Z
	25	26.8783	-26.6085	-37.7269	26.8762	-26.7872	-37.8142	0.0021	-0.1787	-0.0873	0.1989	-0.0873	Z
	26	25.1323	-7.8011	-39.1537	25.1308	-7.8983	-39.2351	0.0015	-0.0972	-0.0814	0.1268	-0.0814	Z
	27	24.8951	-12.0728	-39.1036	24.6865	-12.2473	-39.2200	0.2086	-0.1745	-0.1164	0.2958	-0.1164	Z
	28	24.3697	-17.0971	-38.9292	24.2862	-17.2384	-39.0247	0.0835	-0.1413	-0.0955	0.1899	-0.0955	Z
	29	23.8617	-22.0619	-38.6004	23.8728	-22.1855	-38.6750	-0.0111	-0.1236	-0.0746	0.1448	-0.0746	Z
	30	23.8026	-24.0776	-38.3837	23.4223	-24.3003	-38.4969	0.3803	-0.2227	-0.1132	0.4550	-0.1132	Z
A-PILLAR Maximum (X, Y, Z)	31	53.5472	-33.5715	-22.1561	53.7143	-32.5343	-22.6128	-0.1671	1.0372	-0.4567	1.1455	1.0372	Y
	32	49.4033	-32.7635	-25.0236	49.6958	-31.9488	-25.6378	-0.2925	0.8147	-0.6142	1.0614	0.8147	Y
	33	44.6571	-31.6196	-28.4963	45.0208	-31.1998	-29.0821	-0.3637	0.4198	-0.5858	0.8073	0.4198	Y
	34	41.6262	-30.8608	-30.3546	41.8181	-30.5637	-30.8675	-0.1919	0.2971	-0.5129	0.6230	0.2971	Y
	35	38.7291	-30.1760	-31.6508	38.8147	-29.9808	-32.1070	-0.0856	0.1952	-0.4562	0.5035	0.1952	Y
	36	35.1562	-29.3169	-33.5556	35.1852	-29.3084	-33.8720	-0.0290	0.0085	-0.3164	0.3178	0.0085	Y
A-PILLAR Lateral (Y)	31	53.5472	-33.5715	-22.1561	53.7143	-32.5343	-22.6128	-0.1671	1.0372	-0.4567	1.1455	1.0372	Y
	32	49.4033	-32.7635	-25.0236	49.6958	-31.9488	-25.6378	-0.2925	0.8147	-0.6142	1.0614	0.8147	Y
	33	44.6571	-31.6196	-28.4963	45.0208	-31.1998	-29.0821	-0.3637	0.4198	-0.5858	0.8073	0.4198	Y
	34	41.6262	-30.8608	-30.3546	41.8181	-30.5637	-30.8675	-0.1919	0.2971	-0.5129	0.6230	0.2971	Y
	35	38.7291	-30.1760	-31.6508	38.8147	-29.9808	-32.1070	-0.0856	0.1952	-0.4562	0.5035	0.1952	Y
	36	35.1562	-29.3169	-33.5556	35.1852	-29.3084	-33.8720	-0.0290	0.0085	-0.3164	0.3178	0.0085	Y
B-PILLAR Maximum (X, Y, Z)	37	13.2863	-28.0516	-34.3184	13.4028	-28.1925	-34.2184	-0.1165	-0.1409	0.1000	0.2084	0.1000	Z
	38	11.3043	-30.0839	-30.0338	11.4471	-30.1761	-29.8444	-0.1428	-0.0922	0.1894	0.2545	0.1894	Z
	39	15.1543	-31.0625	-27.8373	15.2340	-31.1552	-27.6123	-0.0797	-0.0927	0.2250	0.2561	0.2250	Z
	40	12.2434	-32.3109	-23.2984	12.3723	-32.3534	-22.9696	-0.1289	-0.0425	0.3288	0.3557	0.3288	Z
B-PILLAR Lateral (Y)	37	13.2863	-28.0516	-34.3184	13.4028	-28.1925	-34.2184	-0.1165	-0.1409	0.1000	0.2084	-0.1409	Y
	38	11.3043	-30.0839	-30.0338	11.4471	-30.1761	-29.8444	-0.1428	-0.0922	0.1894	0.2545	-0.0922	Y
	39	15.1543	-31.0625	-27.8373	15.2340	-31.1552	-27.6123	-0.0797	-0.0927	0.2250	0.2561	-0.0927	Y
	40	12.2434	-32.3109	-23.2984	12.3723	-32.3534	-22.9696	-0.1289	-0.0425	0.3288	0.3557	-0.0425	Y

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

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

Date:	5/13/2019	Test Name:	NCBR-1	VIN:	kmhcn4ac1au467917
Year:	2010	Make:	Hyundai	Model:	Accent

VEHICLE DEFORMATION
DRIVER SIDE INTERIOR CRUSH - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	48.4610	-7.5315	-21.2792	48.6934	-6.4954	-21.8201	-0.2324	1.0361	-0.5409	1.1917	1.1917	X, Y, Z
	2	46.1351	-20.7418	-23.7506	46.2913	-19.7597	-24.3967	-0.1562	0.9821	-0.6461	1.1859	1.1859	X, Y, Z
	3	48.9412	-32.4643	-20.3069	49.0532	-31.3955	-20.8723	-0.1120	1.0688	-0.5654	1.2143	1.2143	X, Y, Z
	4	46.2389	-7.0257	-7.8151	46.3417	-6.2013	-8.2821	-0.1028	0.8244	-0.4670	0.9530	0.9530	X, Y, Z
	5	49.7999	-20.1541	-7.8359	49.8150	-19.1896	-8.3691	-0.0151	0.9645	-0.5332	1.1022	1.1022	X, Y, Z
	6	50.4376	-32.5745	-6.2192	49.7728	-31.4706	-6.6387	0.6648	1.1039	-0.4195	1.3552	1.3552	X, Y, Z
SIDE PANEL (Y)	7	53.8219	-33.9999	-1.3385	57.3967	-31.6191	-4.6482	-3.5748	2.3808	-3.3097	5.4223	2.3808	Y
	8	53.3786	-34.8543	2.6388	53.1255	-32.8226	2.2732	0.2531	2.0317	-0.3656	2.0798	2.0317	Y
	9	58.3077	-34.5295	2.4426	58.0120	-32.0129	2.0861	0.2957	2.5166	-0.3565	2.5589	2.5166	Y
IMPACT SIDE DOOR (Y)	10	46.2389	-35.2677	-16.7388	45.4089	-34.7546	-17.0097	0.8300	0.5131	-0.2709	1.0127	0.5131	Y
	11	37.0990	-35.2867	-17.4407	36.4055	-36.0685	-17.4648	0.6935	-0.7818	-0.0241	1.0453	-0.7818	Y
	12	23.8223	-34.9590	-17.8332	23.1864	-36.9928	-17.6961	0.6359	-2.0338	0.1371	2.1353	-2.0338	Y
	13	43.1848	-35.4809	0.3963	42.7252	-35.2114	0.1346	0.4596	0.2695	-0.2617	0.5936	0.2695	Y
	14	37.0678	-35.3570	0.5337	36.6647	-35.7927	0.2877	0.4031	-0.4357	-0.2460	0.6425	-0.4357	Y
	15	28.0152	-35.1393	-0.0011	27.8023	-35.7695	-0.0665	0.2129	-0.6302	-0.0654	0.6684	-0.6302	Y
ROOF - (Z)	16	32.8186	-7.6445	-36.5681	32.4933	-7.8914	-36.7103	0.3253	-0.2469	-0.1422	0.4324	-0.1422	Z
	17	32.7966	-11.8393	-36.4206	32.4894	-12.0717	-36.5983	0.3072	-0.2324	-0.1777	0.4242	-0.1777	Z
	18	32.1219	-17.3108	-36.2183	31.8570	-17.6244	-36.4221	0.2649	-0.3136	-0.2038	0.4583	-0.2038	Z
	19	31.7205	-22.1662	-35.8748	31.4076	-22.4147	-36.1395	0.3129	-0.2485	-0.2647	0.4793	-0.2647	Z
	20	31.0328	-26.8477	-35.4184	30.6927	-27.0954	-35.6907	0.3401	-0.2477	-0.2723	0.5012	-0.2723	Z
	21	29.2270	-7.6041	-38.5536	29.0553	-7.8807	-38.6921	0.1717	-0.2766	-0.1385	0.3538	-0.1385	Z
	22	28.8725	-11.9046	-38.5410	28.5624	-12.1592	-38.7228	0.3101	-0.2546	-0.1818	0.4405	-0.1818	Z
	23	28.4393	-17.0497	-38.3758	28.0912	-17.2486	-38.5588	0.3481	-0.1989	-0.1830	0.4407	-0.1830	Z
	24	27.9128	-22.0156	-38.0691	27.6281	-22.2806	-38.2296	0.2847	-0.2650	-0.1605	0.4208	-0.1605	Z
	25	27.1921	-26.4881	-37.6842	26.8762	-26.7872	-37.8142	0.3159	-0.2991	-0.1300	0.4540	-0.1300	Z
	26	25.2966	-7.6960	-39.1230	25.1308	-7.8983	-39.2351	0.1658	-0.2023	-0.1121	0.2846	-0.1121	Z
	27	25.0939	-11.9695	-39.0711	24.6865	-12.2473	-39.2200	0.4074	-0.2778	-0.1489	0.5151	-0.1489	Z
	28	24.6087	-16.9978	-38.8950	24.2862	-17.2384	-39.0247	0.3225	-0.2406	-0.1297	0.4227	-0.1297	Z
	29	24.1403	-21.9664	-38.5645	23.8728	-22.1855	-38.6750	0.2675	-0.2191	-0.1105	0.3630	-0.1105	Z
	30	24.0971	-23.9824	-38.3468	23.4223	-24.3003	-38.4969	0.6748	-0.3179	-0.1501	0.7609	-0.1501	Z
A-PILLAR Maximum (X, Y, Z)	31	53.8930	-33.2281	-22.0700	53.7143	-32.5343	-22.6128	0.1787	0.6938	-0.5428	0.8988	0.7164	X, Y
	32	49.7470	-32.4549	-24.9442	49.6958	-31.9488	-25.6378	0.0512	0.5061	-0.6936	0.8601	0.5087	X, Y
	33	44.9969	-31.3511	-28.4245	45.0208	-31.1998	-29.0821	-0.0239	0.1513	-0.6576	0.6752	0.1513	Y
	34	41.9628	-30.6176	-30.2877	41.8181	-30.5637	-30.8675	0.1447	0.0539	-0.5798	0.6000	0.1544	X, Y
	35	39.0622	-29.9569	-31.5885	38.8147	-29.9808	-32.1070	0.2475	-0.0239	-0.5185	0.5750	0.2475	X
	36	35.4853	-29.1276	-33.4992	35.1852	-29.3084	-33.8720	0.3001	-0.1808	-0.3728	0.5116	0.3001	X
A-PILLAR Lateral (Y)	31	53.8930	-33.2281	-22.0700	53.7143	-32.5343	-22.6128	0.1787	0.6938	-0.5428	0.8988	0.6938	Y
	32	49.7470	-32.4549	-24.9442	49.6958	-31.9488	-25.6378	0.0512	0.5061	-0.6936	0.8601	0.5061	Y
	33	44.9969	-31.3511	-28.4245	45.0208	-31.1998	-29.0821	-0.0239	0.1513	-0.6576	0.6752	0.1513	Y
	34	41.9628	-30.6176	-30.2877	41.8181	-30.5637	-30.8675	0.1447	0.0539	-0.5798	0.6000	0.0539	Y
	35	39.0622	-29.9569	-31.5885	38.8147	-29.9808	-32.1070	0.2475	-0.0239	-0.5185	0.5750	-0.0239	Y
	36	35.4853	-29.1276	-33.4992	35.1852	-29.3084	-33.8720	0.3001	-0.1808	-0.3728	0.5116	-0.1808	Y
B-PILLAR Maximum (X, Y, Z)	37	13.6071	-28.0391	-34.2952	13.4028	-28.1925	-34.2184	0.2043	-0.1534	0.0768	0.2668	0.2183	X, Z
	38	11.6352	-30.0852	-30.0126	11.4471	-30.1761	-29.8444	0.1881	-0.0909	0.1682	0.2682	0.2523	X, Z
	39	15.4896	-31.0316	-27.8099	15.2340	-31.1552	-27.6123	0.2556	-0.1236	0.1976	0.3459	0.3231	X, Z
	40	12.5821	-32.3012	-23.2747	12.3723	-32.3534	-22.9696	0.2098	-0.0522	0.3051	0.3739	0.3703	X, Z
B-PILLAR Lateral (Y)	37	13.6071	-28.0391	-34.2952	13.4028	-28.1925	-34.2184	0.2043	-0.1534	0.0768	0.2668	-0.1534	Y
	38	11.6352	-30.0852	-30.0126	11.4471	-30.1761	-29.8444	0.1881	-0.0909	0.1682	0.2682	-0.0909	Y
	39	15.4896	-31.0316	-27.8099	15.2340	-31.1552	-27.6123	0.2556	-0.1236	0.1976	0.3459	-0.1236	Y
	40	12.5821	-32.3012	-23.2747	12.3723	-32.3534	-22.9696	0.2098	-0.0522	0.3051	0.3739	-0.0522	Y

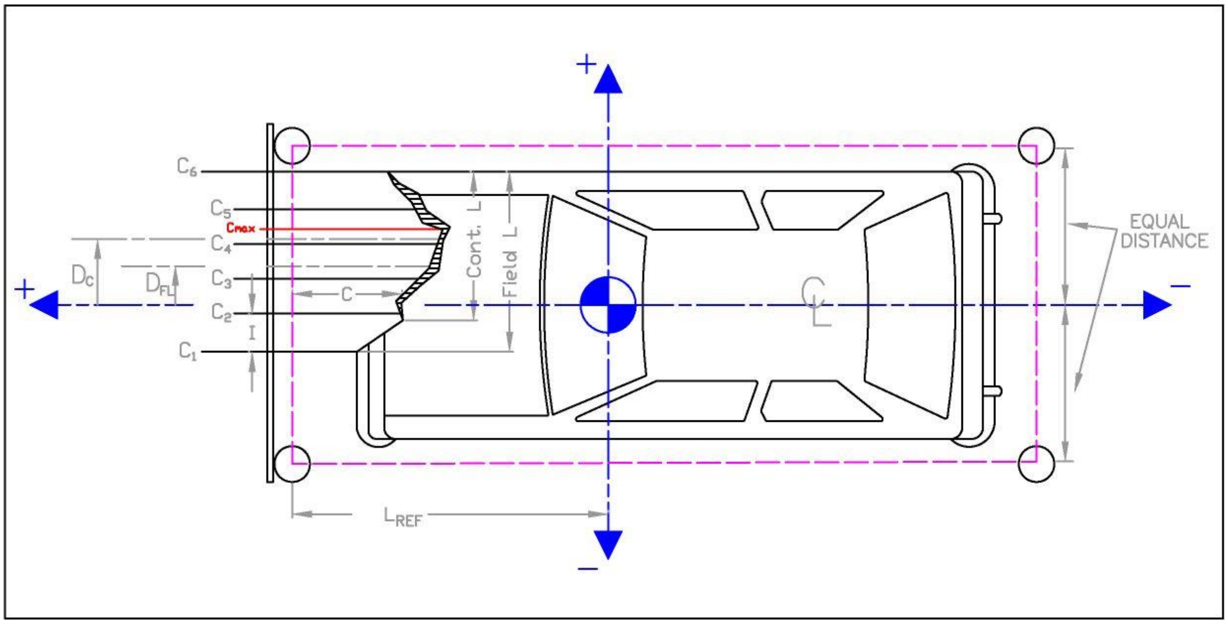
[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure D-3. Occupant Compartment Deformation Data – Set 2, Test No. NCBR-1

Date:	5/13/2019	Test Name:	NCBR-1	VIN:	kmhcn4ac1au467917
Year:	2010	Make:	Hyundai	Model:	Accent



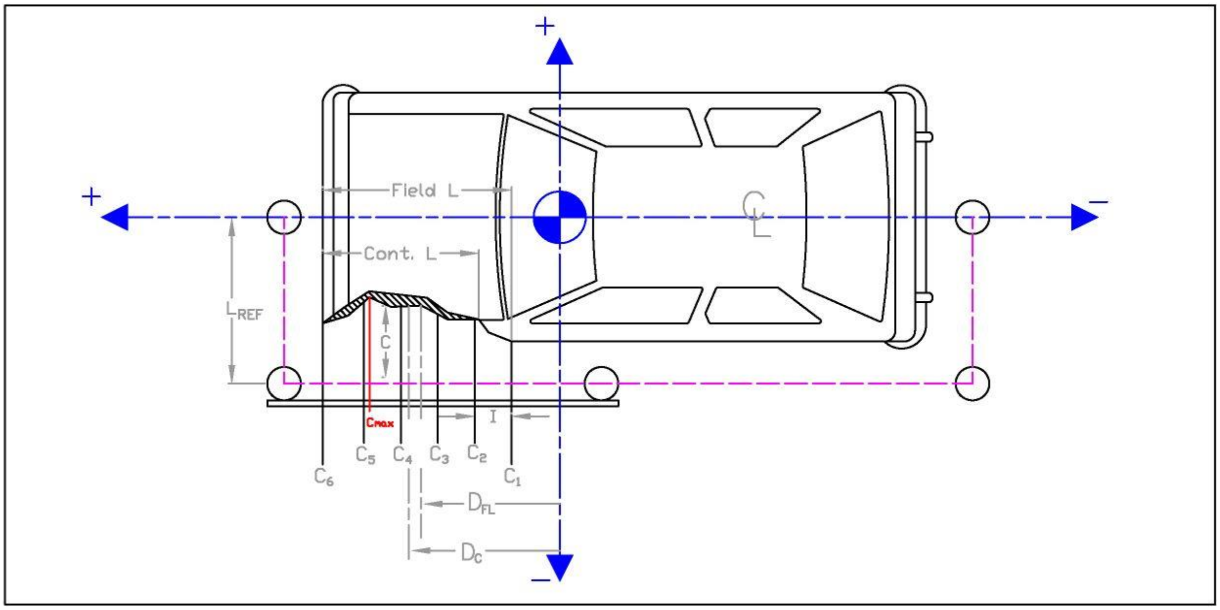
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	86	(2184)
Total Width of Vehicle:	66 7/8	(1699)
Width of contact and induced crush - Field L:	66 7/8	(1699)
Crush measurement spacing interval (L/5) - I:	13 3/8	(340)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	15	(381)
Distance from center of vehicle to center of contact damage - D_C:	-22 3/4	-(578)

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

Crush Measurement			Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	N/A	NA	-33 1/2	-(851)	20 1/4	(514)	15 3/4	(400)	NA	NA
C_2	20	(508)	-20 1/8	-(511)	5	(127)			- 3/4	-(19)
C_3	16 1/4	(413)	-6 3/4	-(171)	2 3/8	(60)			-1 7/8	-(48)
C_4	16	(406)	6 5/8	(168)	2 3/8	(60)			-2 1/8	-(54)
C_5	18 3/8	(467)	20	(508)	4 7/8	(124)			-2 1/4	-(57)
C_6	n/a	NA	33 3/8	(848)	19 7/8	(505)			NA	NA
C_{MAX}	23	(584)	-23 1/2	-(597)	6 3/8	(162)			7/8	(22)

Figure D-4. Exterior Vehicle Crush (NASS) - Front, Test No. NCBR-1

Date:	5/13/2019	**Test Name:**	NCBR-1	**VIN:**	kmhcn4ac1au467917
Year:	2010	**Make:**	Hyundai	**Model:**	Accent



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	45	(1143)
Total Vehicle Length:	168 4/9	(4278)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-11 5/7	-(298)
Width of contact and induced crush - Field L:	168 4/9	(4278)
Crush measurement spacing interval (L/5) - I:	33 3/4	(857)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-11 5/7	-(298)
Width of Contact Damage:	168 4/9	(4278)
Distance from vehicle c.g. to center of contact damage - D_C:	11 5/7	(298)

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

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	18 1/2	(470)	-95 7/8	-(2435)	11 1/8	(283)	9	(229)	-1 5/8	-(41)
C_2	n/a	NA	-62 1/8	-(1578)	4	(102)			NA	NA
C_3	12	(305)	-28 3/8	-(721)	3 3/8	(86)			- 3/8	-(10)
C_4	12 3/4	(324)	5 3/8	(137)	3 1/4	(83)			1/2	(13)
C_5	n/a	NA	39 1/8	(994)	3 1/2	(89)			NA	NA
C_6	n/a	NA	72 7/8	(1851)	36	(914)			NA	NA
C_{MAX}	29 1/4	(743)	54	(1372)	5 1/2	(140)			14 3/4	(375)

Figure D-5. Exterior Vehicle Crush (NASS) - Side, Test No. NCBR-1

Date: 5/13/2019 Test Name: NCBR-1 VIN: kmhcn4ac1au467917
Year: 2010 Make: Hyundai Model: Accent

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	5 3/4	Top	1 3/8	Driver	6 7/8	6 7/8	0
	2	1 3/4	Top	14	Driver	5 5/8	5 3/4	0.125
	3	6 3/4	Top	28	Driver	5 3/4	5 3/5	-0.15
	4	13 1/2	Top	5 1/2	Driver	6 1/4	9 3/8	3.125
	5	15	Top	21	Driver	5 1/4	8 1/4	3
	6	18 7/8	Top	2 1/4	Driver	7 1/8	7 1/4	0.125
	7	19 3/4	Top	14 1/4	Driver	5 1/2	10	4.5
	8	21 1/4	Top	17 1/8	Driver	5 1/8	10 1/8	5
	9	24	Top	3 1/8	Driver	6 7/8	7	0.125
	10	25 3/4	Top	15 1/2	Driver	5	8 1/4	3.25
	11	29 1/8	Top	24 1/8	Driver	5	6	1
	12	29 1/2	Top	31 1/2	Driver	4 7/8	5	0.125

[A] Length to vertical reference, typically the top or bottom of the windshield frame.
[B] 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: 2010 Make: Hyundai Model: Accent VIN: KMHCN4AC8BU608788

Windshield Deformation Notes:

The windshield deformation measurement were taken three days after the test and the windshield settled and deteriorated during this time. The values represented in these measurements do not reflect the test day values. It is likely the values were much less signifcant on the day of the test.

Figure D-6. Windshield Deformation, Test No. NCBR-1

Date: 6/11//2019 Test Name: NCBR-2 VIN: 1GCRCPEH6FZ173614
Year: 2015 Make: Chevrolet Model: Silverado

VEHICLE DEFORMATION
DRIVER SIDE INTERIOR CRUSH - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	55.2501	1.0252	-27.0936	55.3392	1.8708	-27.1193	-0.0891	-0.8456	-0.0257	0.8507	0.8507	X, Y, Z
	2	54.4103	-12.8645	-28.6392	54.3516	-11.9644	-29.1708	0.0587	0.9001	-0.5316	1.0470	1.0470	X, Y, Z
	3	54.4008	-29.0954	-26.7884	54.1430	-28.2785	-27.8652	0.2578	0.8169	-1.0768	1.3760	1.3760	X, Y, Z
	4	52.3038	1.4892	-16.5682	52.1158	2.0333	-16.6987	0.1880	-0.5441	-0.1305	0.5903	0.5903	X, Y, Z
	5	53.5830	-10.9189	-15.6419	53.2104	-10.3771	-16.1068	0.3726	0.5418	-0.4649	0.8053	0.8053	X, Y, Z
	6	52.4798	-29.3149	-15.3242	52.0496	-28.8210	-16.4757	0.4302	0.4939	-1.1515	1.3247	1.3247	X, Y, Z
SIDE PANEL (Y)	7	62.8151	-30.1859	-2.5010	62.2271	-28.6163	-3.2717	0.5880	1.5696	-0.7707	1.8448	1.5696	Y
	8	62.8769	-30.4575	1.5594	62.3305	-28.8729	0.9052	0.5464	1.5846	-0.6542	1.7993	1.5846	Y
	9	65.7132	-30.5027	2.0845	64.9462	-29.6573	1.3833	0.7670	0.8454	-0.7012	1.3397	0.8454	Y
IMPACT SIDE DOOR (Y)	10	28.1099	-30.9029	-20.7366	27.4268	-33.0617	-21.6000	0.6831	-2.1588	-0.8634	2.4233	-2.1588	Y
	11	40.7207	-31.6412	-20.0000	51.3589	-32.0855	-20.9713	-10.6382	-0.4443	-0.9713	10.6917	-0.4443	Y
	12	52.4889	-32.0649	-20.2124	27.7161	-30.5042	-0.9721	24.7728	1.5607	19.2403	31.4057	1.5607	Y
	13	28.1514	-31.0400	0.1349	41.7035	-31.4817	1.9557	-13.5521	-0.4417	1.8208	13.6810	-0.4417	Y
	14	42.3773	-31.9046	2.8951	50.6662	-31.9092	0.8253	-8.2889	-0.0046	-2.0698	8.5434	-0.0046	Y
	15	51.4193	-32.4455	1.6364	50.7002	-31.9055	0.8745	0.7191	0.5400	-0.7619	1.1786	0.5400	Y
ROOF - (Z)	16	48.8298	1.8323	-40.7430	49.1068	3.0193	-40.5743	-0.2770	-1.1870	0.1687	1.2305	0.1687	Z
	17	48.5125	-3.6603	-40.5928	48.7080	-2.5601	-40.6756	-0.1955	1.1002	-0.0828	1.1205	-0.0828	Z
	18	47.7721	-9.4783	-40.4618	47.9521	-8.2193	-40.7851	-0.1800	1.2590	-0.3233	1.3123	-0.3233	Z
	19	46.5598	-15.3907	-40.3241	46.7312	-14.2314	-40.8822	-0.1714	1.1593	-0.5581	1.2980	-0.5581	Z
	20	44.6083	-22.4867	-39.6231	44.7011	-21.2309	-40.5284	-0.0928	1.2558	-0.9053	1.5509	-0.9053	Z
	21	35.8812	2.4063	-45.0365	36.0437	3.7955	-44.9124	-0.1625	-1.3892	0.1241	1.4042	0.1241	Z
	22	35.9027	-1.6925	-45.0069	36.1695	-0.3276	-45.0471	-0.2668	1.3649	-0.0402	1.3913	-0.0402	Z
	23	35.1446	-7.6870	-44.9151	35.3680	-6.3126	-45.1948	-0.2234	1.3744	-0.2797	1.4203	-0.2797	Z
	24	34.9991	-14.1551	-44.5858	35.0952	-12.7480	-45.1237	-0.0961	1.4071	-0.5379	1.5095	-0.5379	Z
	25	34.1141	-20.6301	-44.0403	34.3312	-19.2077	-44.7954	-0.2171	1.4224	-0.7551	1.6250	-0.7551	Z
	26	23.8209	2.6692	-45.2462	24.1081	4.1513	-45.2206	-0.2872	-1.4821	0.0256	1.5099	0.0256	Z
	27	23.9674	-1.6014	-45.4793	24.1915	-0.1259	-45.6101	-0.2241	1.4755	-0.1308	1.4981	-0.1308	Z
	28	23.9821	-6.9333	-45.3496	24.2233	-5.4108	-45.6775	-0.2412	1.5225	-0.3279	1.5760	-0.3279	Z
	29	23.8083	-13.3864	-45.0622	23.9572	-11.8773	-45.5844	-0.1489	1.5091	-0.5222	1.6038	-0.5222	Z
	30	23.9543	-19.7926	-44.5101	24.1543	-18.2834	-45.2715	-0.2000	1.5092	-0.7614	1.7022	-0.7614	Z
A-PILLAR Maximum (X, Y, Z)	31	60.9411	-28.9676	-28.6246	60.7588	-28.1686	-29.3921	0.1823	0.7990	-0.7675	1.1228	0.8195	X, Y
	32	58.6922	-28.2467	-30.5574	58.5625	-27.4006	-31.4067	0.1297	0.8461	-0.8493	1.2058	0.8560	X, Y
	33	55.6269	-27.2601	-32.8968	55.5911	-26.3243	-33.7690	0.0358	0.9358	-0.8722	1.2797	0.9365	X, Y
	34	52.3517	-26.2625	-35.3927	52.3796	-25.2049	-36.2504	-0.0279	1.0576	-0.8577	1.3620	1.0576	Y
	35	49.3367	-25.2682	-37.1460	49.4750	-24.1724	-38.1381	-0.1383	1.0958	-0.9921	1.4846	1.0958	Y
	36	45.9482	-24.2197	-38.9812	46.0031	-23.0431	-39.9411	-0.0549	1.1766	-0.9599	1.5195	1.1766	Y
A-PILLAR Lateral (Y)	31	60.9411	-28.9676	-28.6246	60.7588	-28.1686	-29.3921	0.1823	0.7990	-0.7675	1.1228	0.7990	Y
	32	58.6922	-28.2467	-30.5574	58.5625	-27.4006	-31.4067	0.1297	0.8461	-0.8493	1.2058	0.8461	Y
	33	55.6269	-27.2601	-32.8968	55.5911	-26.3243	-33.7690	0.0358	0.9358	-0.8722	1.2797	0.9358	Y
	34	52.3517	-26.2625	-35.3927	52.3796	-25.2049	-36.2504	-0.0279	1.0576	-0.8577	1.3620	1.0576	Y
	35	49.3367	-25.2682	-37.1460	49.4750	-24.1724	-38.1381	-0.1383	1.0958	-0.9921	1.4846	1.0958	Y
	36	45.9482	-24.2197	-38.9812	46.0031	-23.0431	-39.9411	-0.0549	1.1766	-0.9599	1.5195	1.1766	Y
B-PILLAR Maximum (X, Y, Z)	37	16.4402	-23.2793	-40.2397	16.5729	-21.8820	-41.1058	-0.1327	1.3973	-0.8661	1.6493	1.3973	Y
	38	20.4870	-24.8650	-35.3611	20.5738	-23.6054	-36.2127	-0.0868	1.2596	-0.8516	1.5229	1.2596	Y
	39	17.4111	-26.3015	-30.6973	17.5832	-25.1478	-31.6876	-0.1721	1.1537	-0.9903	1.5301	1.1537	Y
	40	21.7709	-27.5253	-25.6436	21.8154	-26.5194	-26.6254	-0.0445	1.0059	-0.9818	1.4063	1.0059	Y
B-PILLAR Lateral (Y)	37	16.4402	-23.2793	-40.2397	16.5729	-21.8820	-41.1058	-0.1327	1.3973	-0.8661	1.6493	1.3973	Y
	38	20.4870	-24.8650	-35.3611	20.5738	-23.6054	-36.2127	-0.0868	1.2596	-0.8516	1.5229	1.2596	Y
	39	17.4111	-26.3015	-30.6973	17.5832	-25.1478	-31.6876	-0.1721	1.1537	-0.9903	1.5301	1.1537	Y
	40	21.7709	-27.5253	-25.6436	21.8154	-26.5194	-26.6254	-0.0445	1.0059	-0.9818	1.4063	1.0059	Y

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure D-7. Occupant Compartment Deformation Data – Set 1, Test No. NCBR-2

Date: 6/11//2019 Test Name: NCBR-2 VIN: 1GCRCPEH6FZ173614
Year: 2015 Make: Chevrolet Model: Silverado

VEHICLE DEFORMATION
DRIVER SIDE FLOOR PAN - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	65.7826	-6.7257	1.9658	65.2176	-6.1431	2.1822	0.5650	0.5826	-0.2164	0.8399	0.5650	X
	2	67.2944	-12.0827	3.8956	66.6721	-10.9022	4.1189	0.6223	1.1805	-0.2233	1.3530	0.6223	X
	3	67.1760	-17.7259	4.7118	66.4678	-16.5001	4.8170	0.7082	1.2258	-0.1052	1.4196	0.7082	X
	4	66.8693	-23.0059	4.6670	65.8689	-21.7271	4.3436	1.0004	1.2788	0.3234	1.6555	1.0514	X, Z
	5	66.4526	-28.4145	4.6743	65.2647	-27.2452	4.1340	1.1879	1.1693	0.5403	1.7522	1.3050	X, Z
	6	61.8738	-6.1300	2.0986	61.2565	-5.6104	2.2749	0.6173	0.5196	-0.1763	0.8259	0.6173	X
	7	61.9620	-10.4525	5.8226	61.4424	-9.4999	6.1361	0.5196	0.9526	-0.3135	1.1295	0.5196	X
	8	61.7329	-17.2578	5.7325	61.3269	-16.1662	5.7489	0.4060	1.0916	-0.0164	1.1648	0.4060	X
	9	61.7157	-22.5748	5.5794	61.3362	-21.5553	5.4113	0.3795	1.0195	0.1681	1.1008	0.4151	X, Z
	10	61.1678	-28.7171	5.6615	60.8499	-27.5347	5.7910	0.3179	1.1824	-0.1295	1.2312	0.3179	X
FLOOR PAN (Z)	11	57.7543	-6.1302	2.6139	57.2132	-6.1565	2.6589	0.5411	-0.0263	-0.0450	0.5436	-0.0450	Z
	12	57.4014	-10.1253	5.8242	56.7406	-9.2719	6.2348	0.6608	0.8534	-0.4106	1.1548	-0.4106	Z
	13	57.5449	-16.8248	5.7356	57.1099	-15.8869	5.8257	0.4350	0.9379	-0.0901	1.0378	-0.0901	Z
	14	57.9708	-22.2480	5.5311	57.5942	-21.2730	5.4007	0.3766	0.9750	0.1304	1.0533	0.1304	Z
	15	57.4050	-27.9534	5.7129	57.1624	-26.9793	5.5990	0.2426	0.9741	0.1139	1.0103	0.1139	Z
	16	53.7852	-5.9175	2.9711	53.2015	-6.3335	2.7644	0.5837	-0.4160	0.2067	0.7460	0.2067	Z
	17	53.6126	-9.8724	5.8382	53.0299	-8.9538	6.3428	0.5827	0.9186	-0.5046	1.1992	-0.5046	Z
	18	53.4002	-16.2354	5.7261	52.9158	-15.4493	5.8941	0.4844	0.7861	-0.1680	0.9385	-0.1680	Z
	19	53.3403	-21.7337	5.7509	52.9399	-20.9099	5.6540	0.4004	0.8238	0.0969	0.9211	0.0969	Z
	20	52.9929	-27.6989	5.6228	52.6697	-26.7328	5.1903	0.3232	0.9661	0.4325	1.1067	0.4325	Z
	21	49.8679	-5.6045	3.2917	49.3528	-5.4406	3.2025	0.5151	0.1639	0.0892	0.5479	0.0892	Z
	22	49.7153	-9.4776	5.8337	49.1109	-8.6363	6.5108	0.6044	0.8413	-0.6771	1.2376	-0.6771	Z
	23	49.5921	-16.0232	5.7432	49.1120	-15.2128	5.9570	0.4801	0.8104	-0.2138	0.9659	-0.2138	Z
	24	49.3420	-21.5986	5.7846	48.9440	-20.8376	5.6941	0.3980	0.7610	0.0905	0.8635	0.0905	Z
	25	48.9220	-27.4278	5.6648	48.6344	-26.5834	5.1297	0.2876	0.8444	0.5351	1.0402	0.5351	Z
	26	45.8123	-5.2014	3.2632	45.5023	-5.2401	2.9382	0.3100	-0.0387	0.3250	0.4508	0.3250	Z
	27	45.0866	-9.0025	4.5605	44.6145	-8.5995	5.0186	0.4721	0.4030	-0.4581	0.7715	-0.4581	Z
	28	44.8299	-15.5699	4.6878	44.4236	-14.8021	4.8467	0.4063	0.7678	-0.1589	0.8831	-0.1589	Z
	29	44.6703	-21.2235	4.8297	44.2647	-20.3959	4.7187	0.4056	0.8276	0.1110	0.9283	0.1110	Z
	30	44.4349	-26.6620	4.8885	44.0832	-25.8000	4.4612	0.3517	0.8620	0.4273	1.0244	0.4273	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan	Posttest Floor Pan
	

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

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

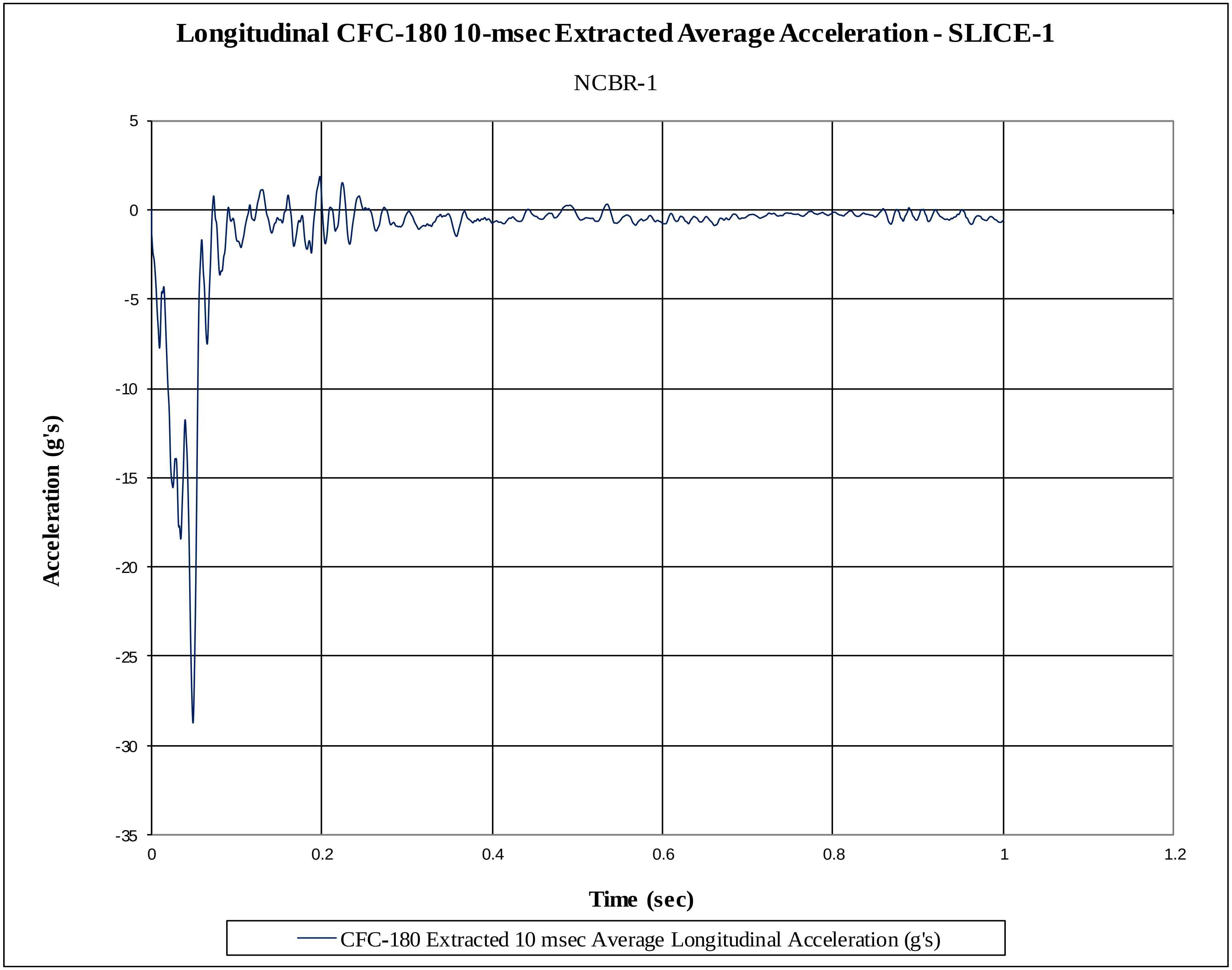


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. NCBR-1

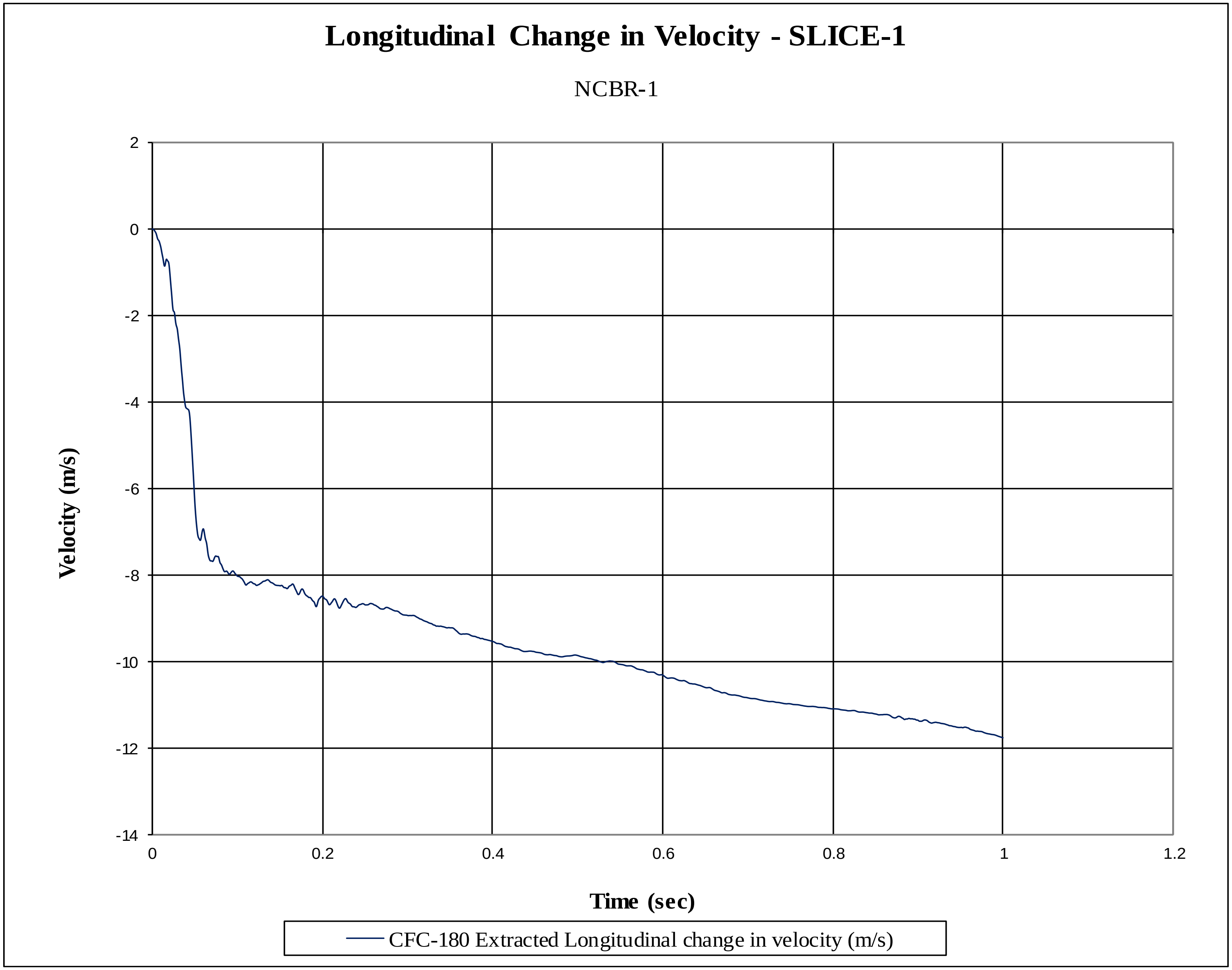


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. NCBR-1

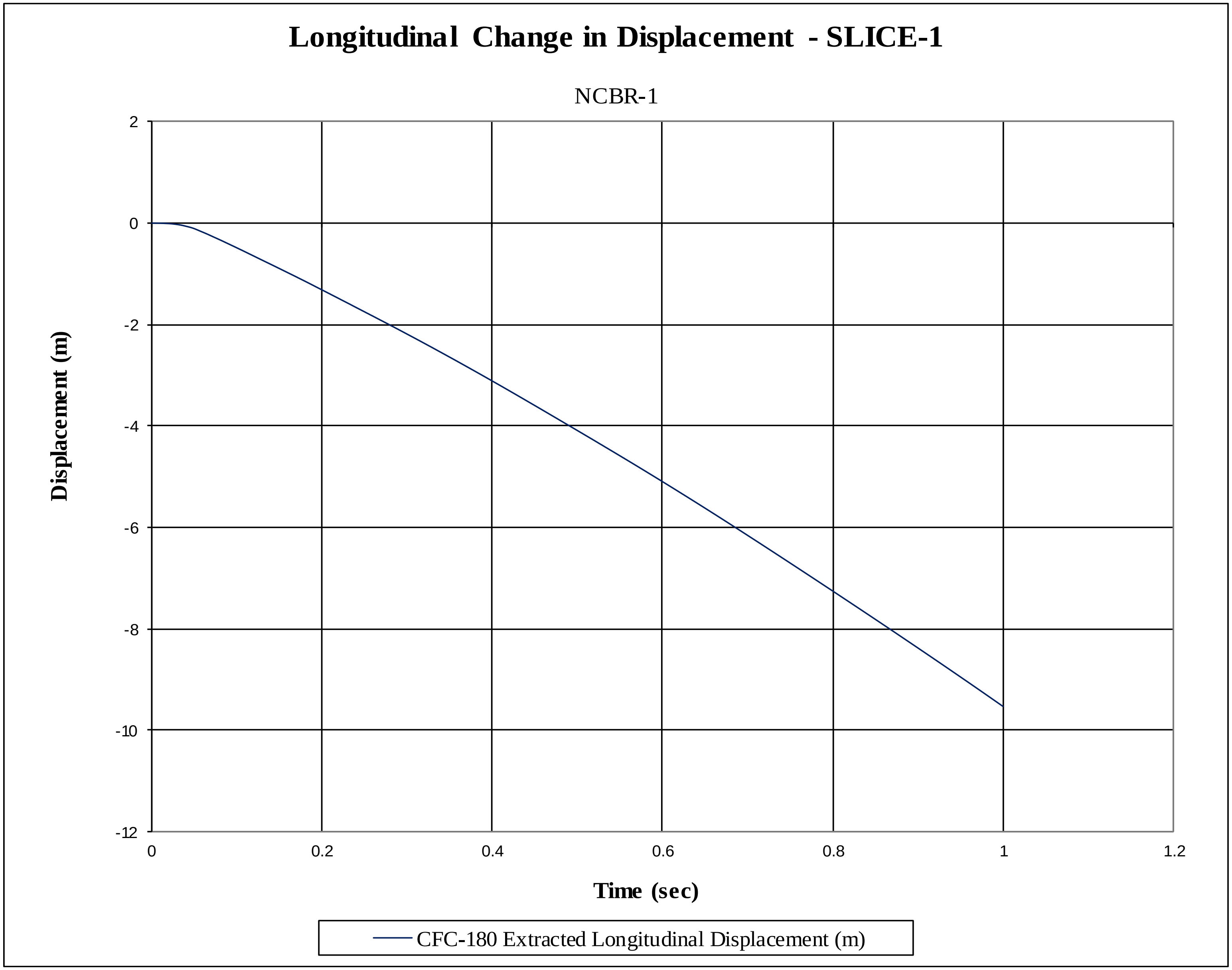


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. NCBR-1

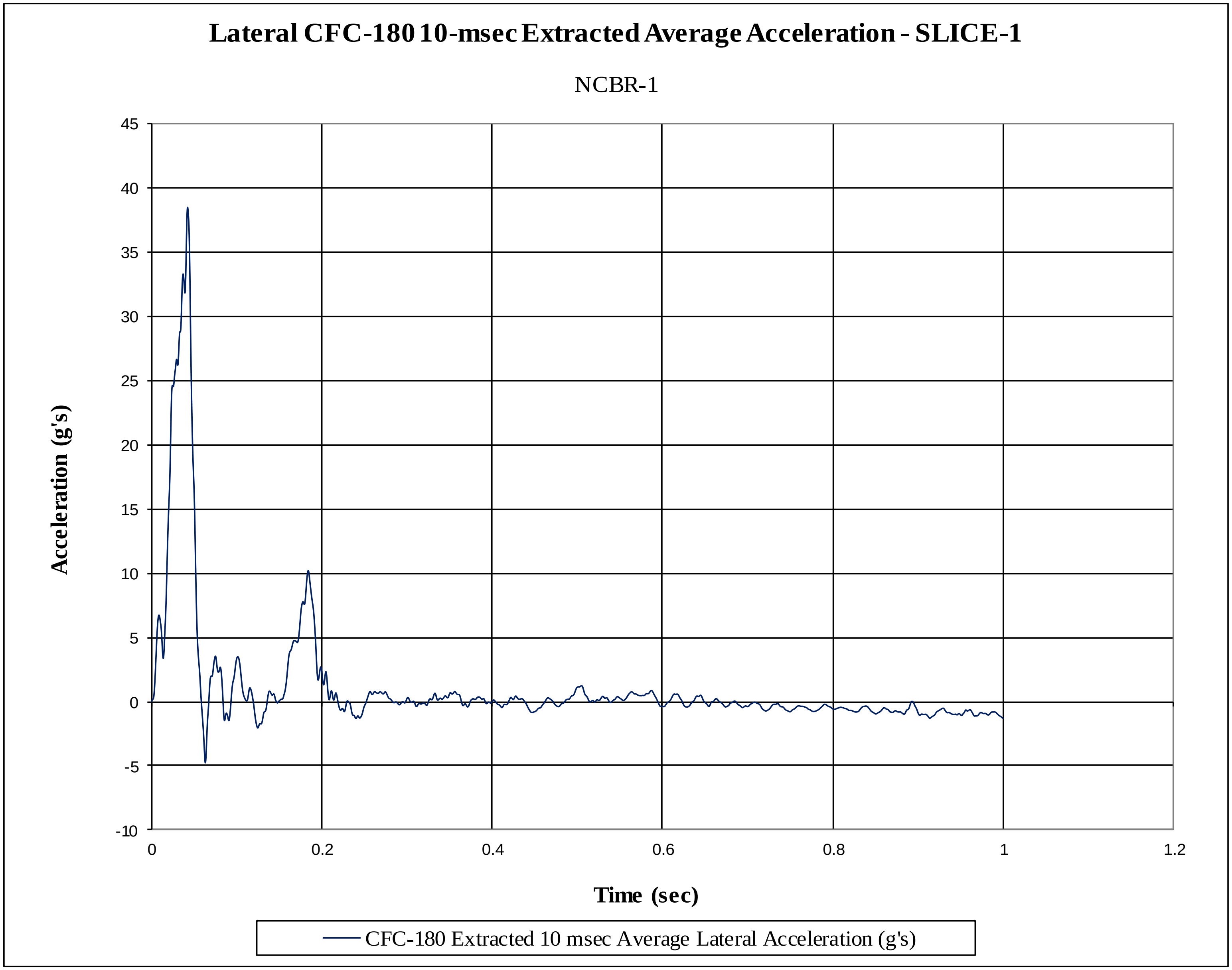


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. NCBR-1

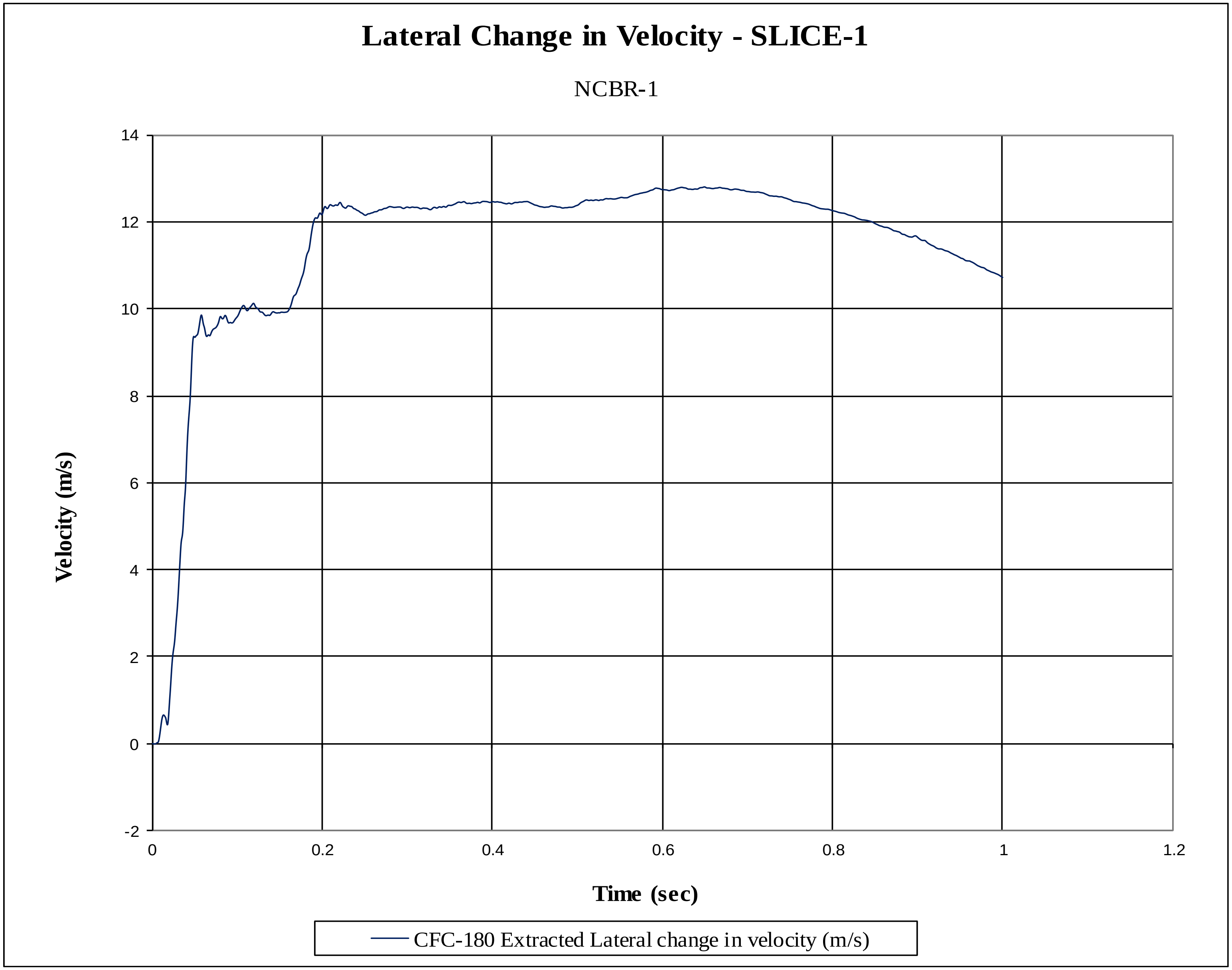


Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. NCBR-1

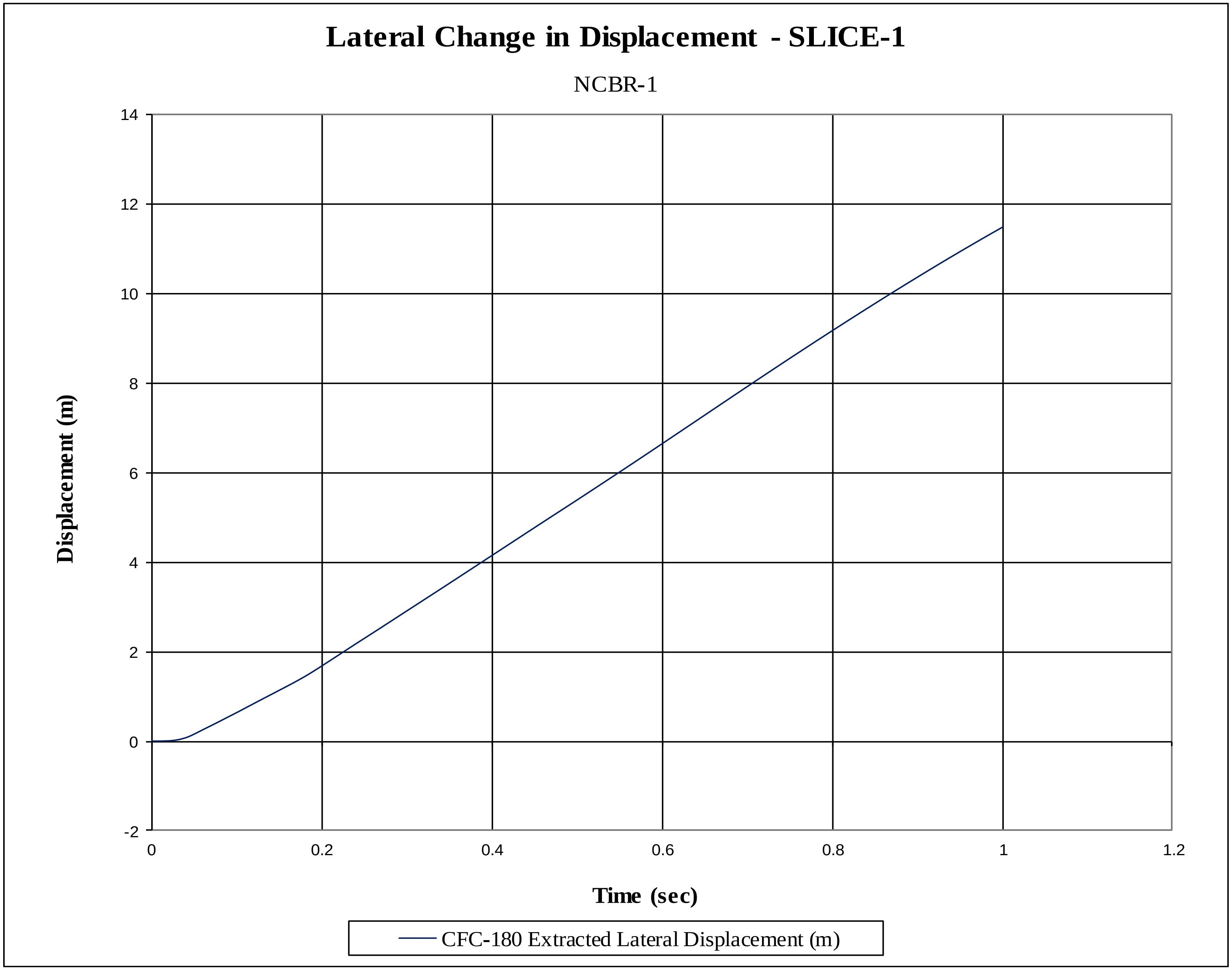


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. NCBR-1

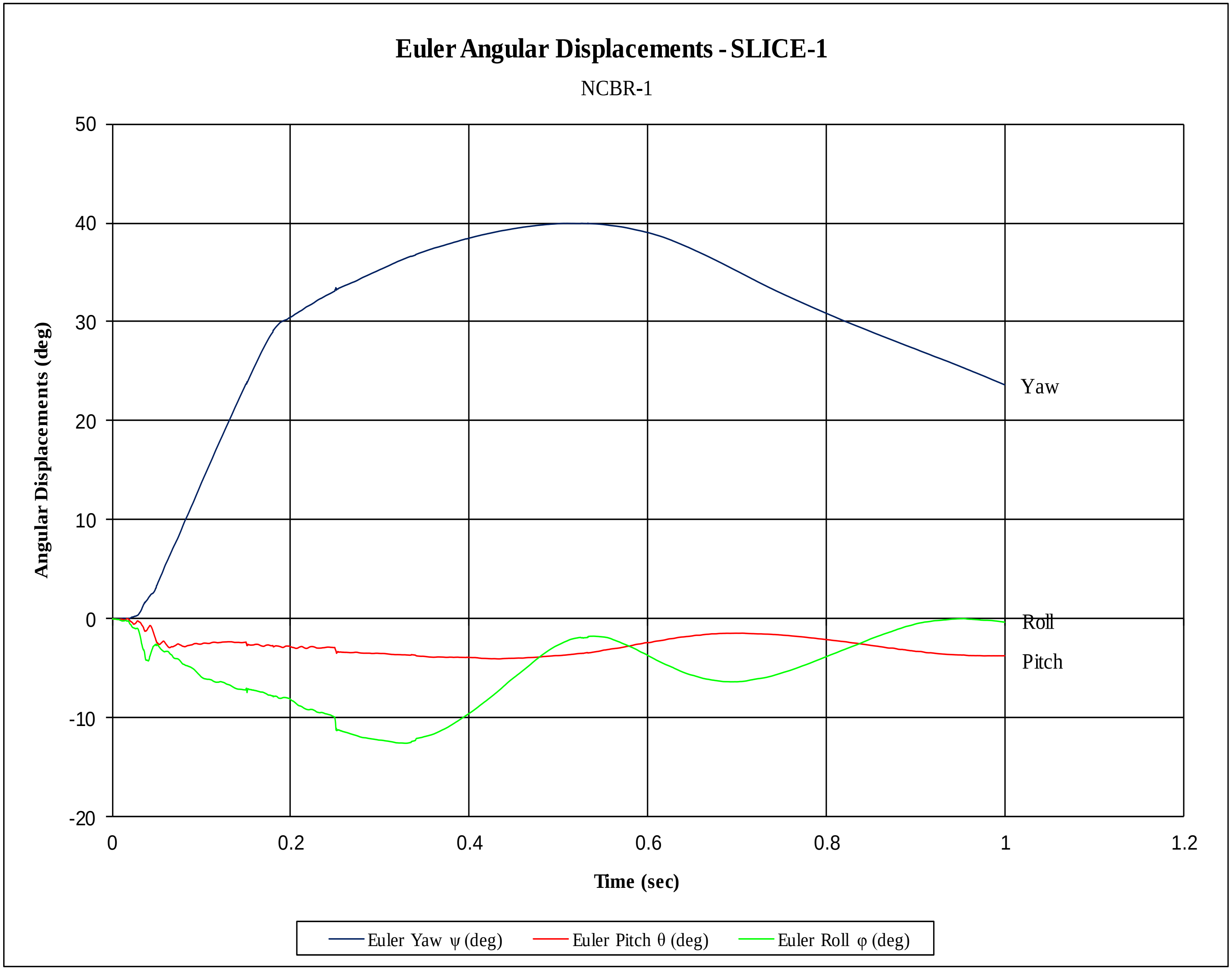


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. NCBR-1

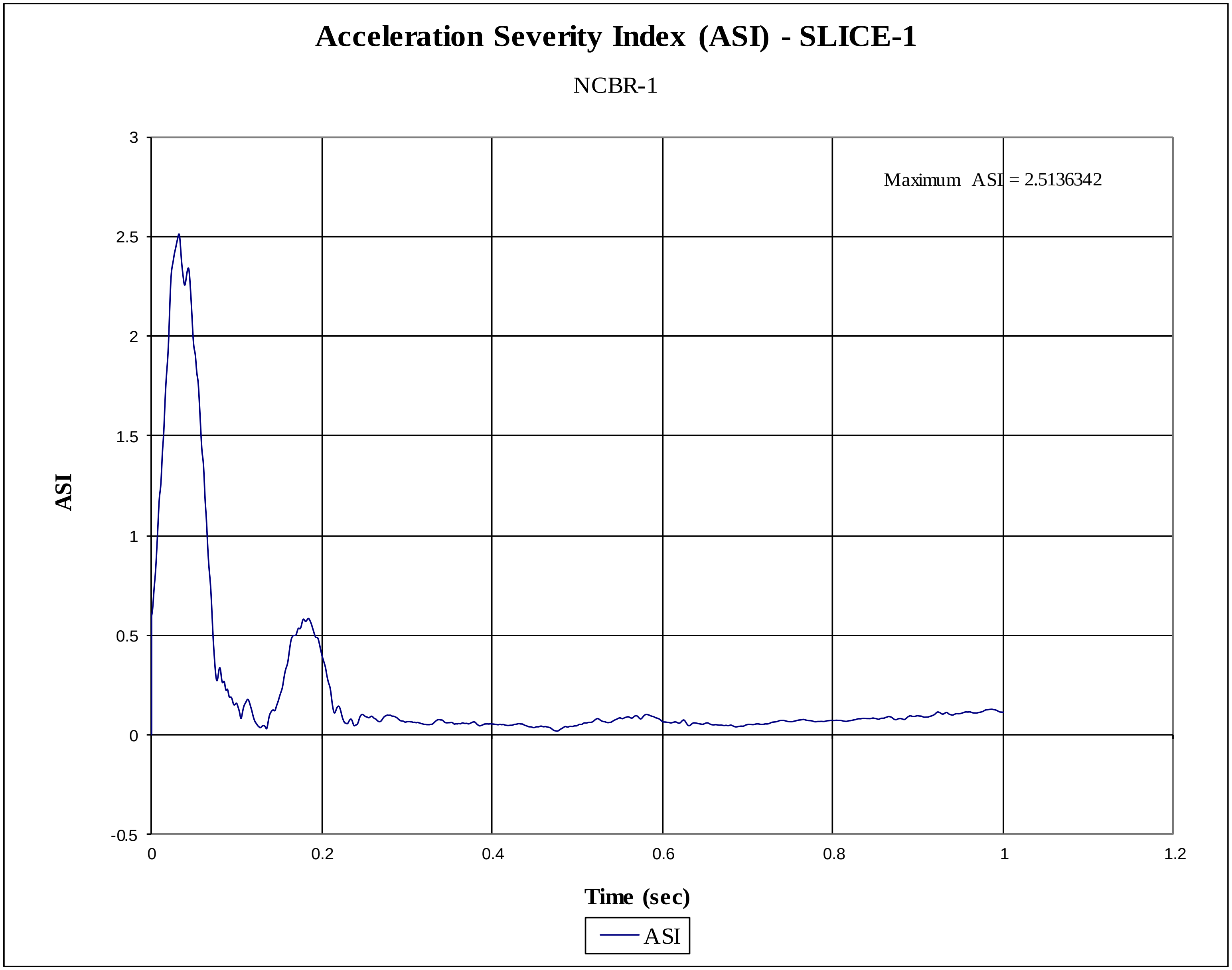


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. NCBR-1

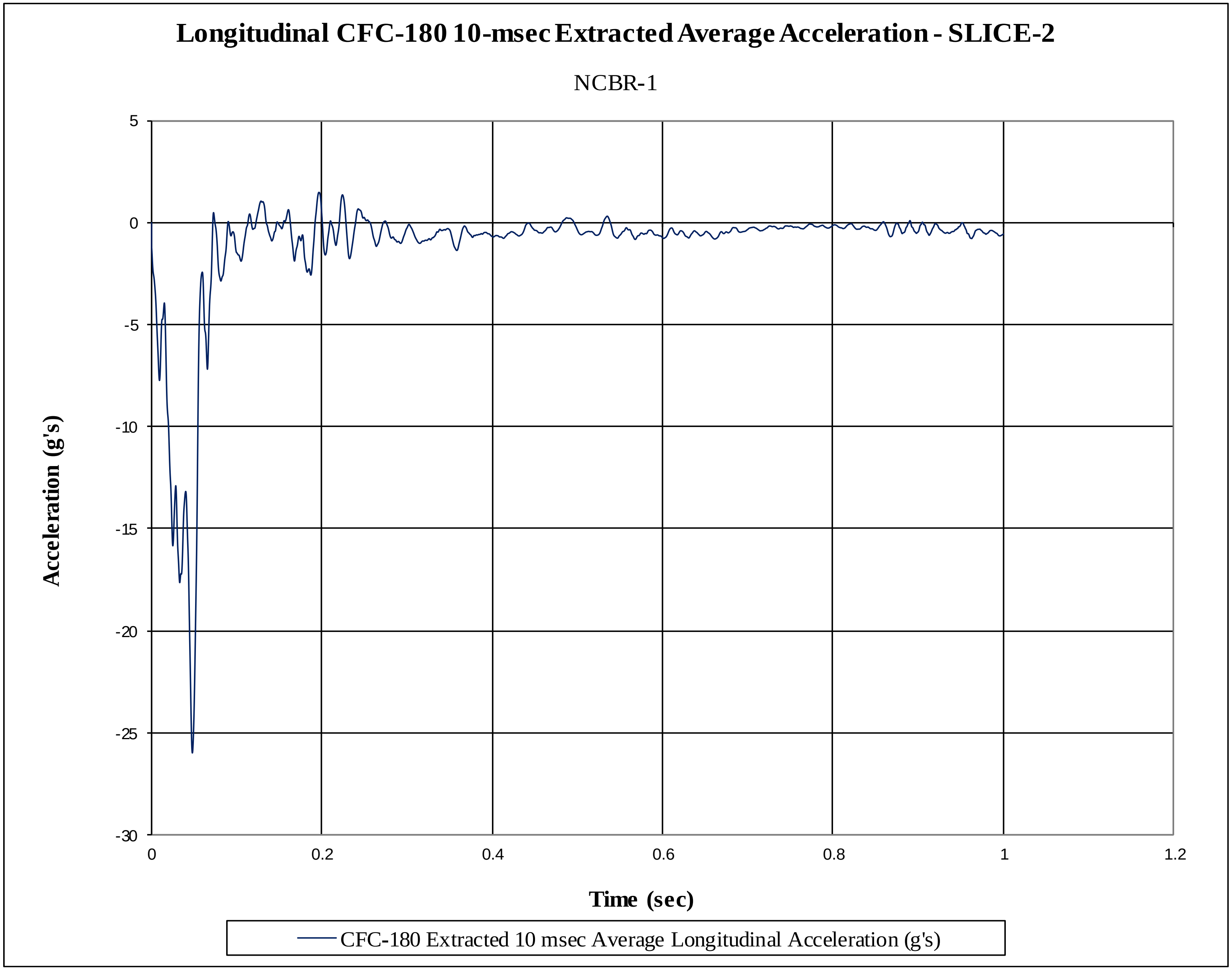


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. NCBR-1

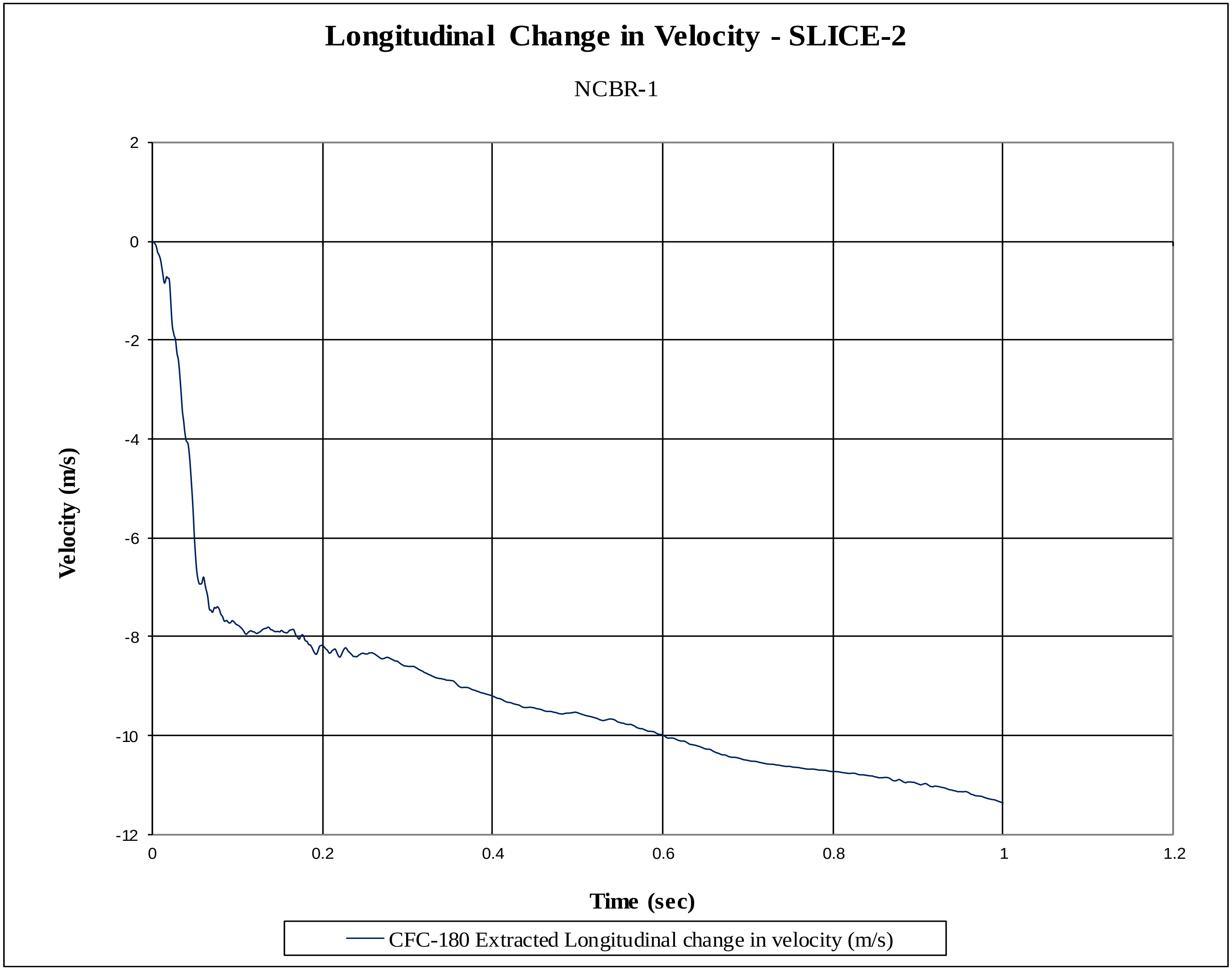


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. NCBR-1

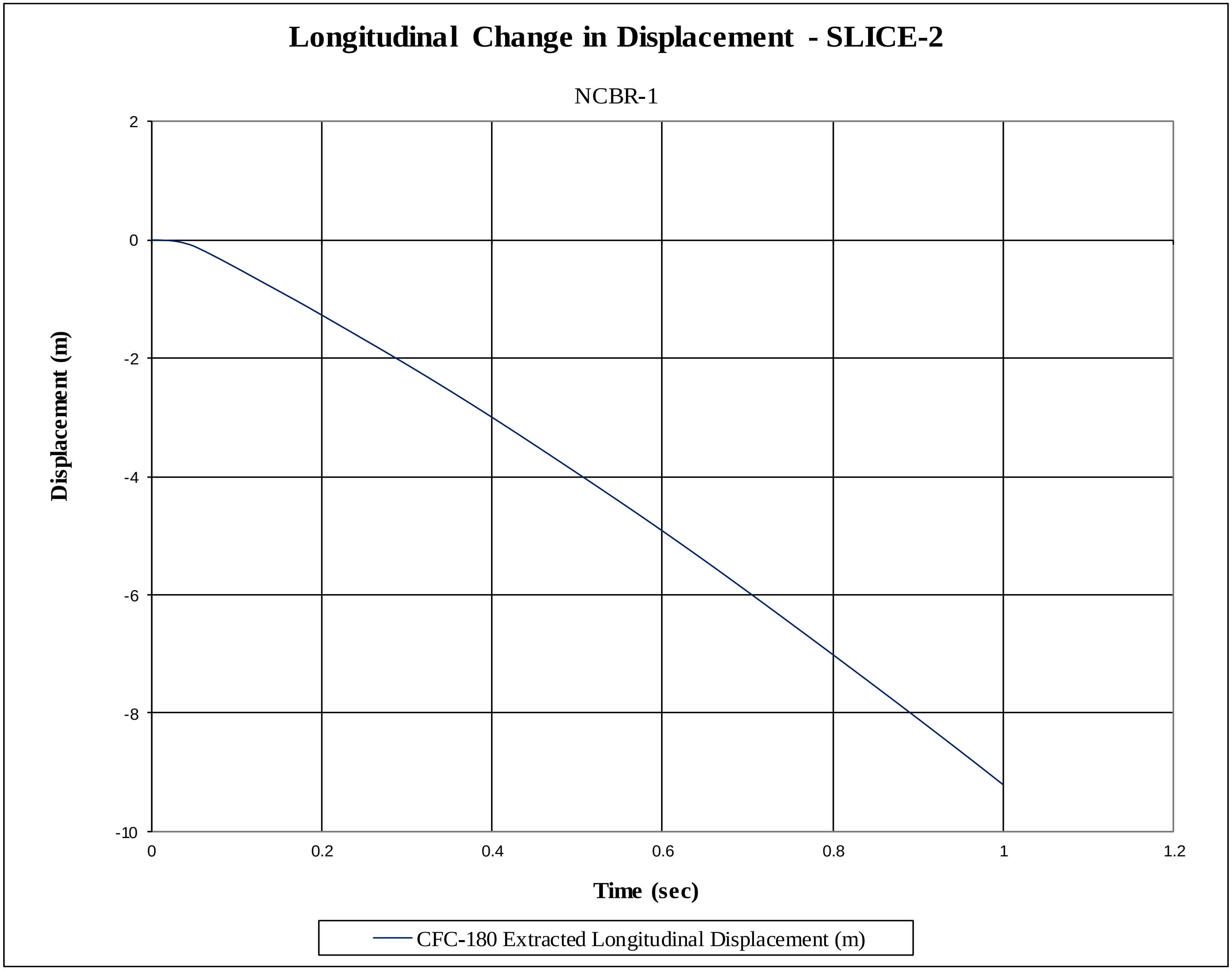


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. NCBR-1

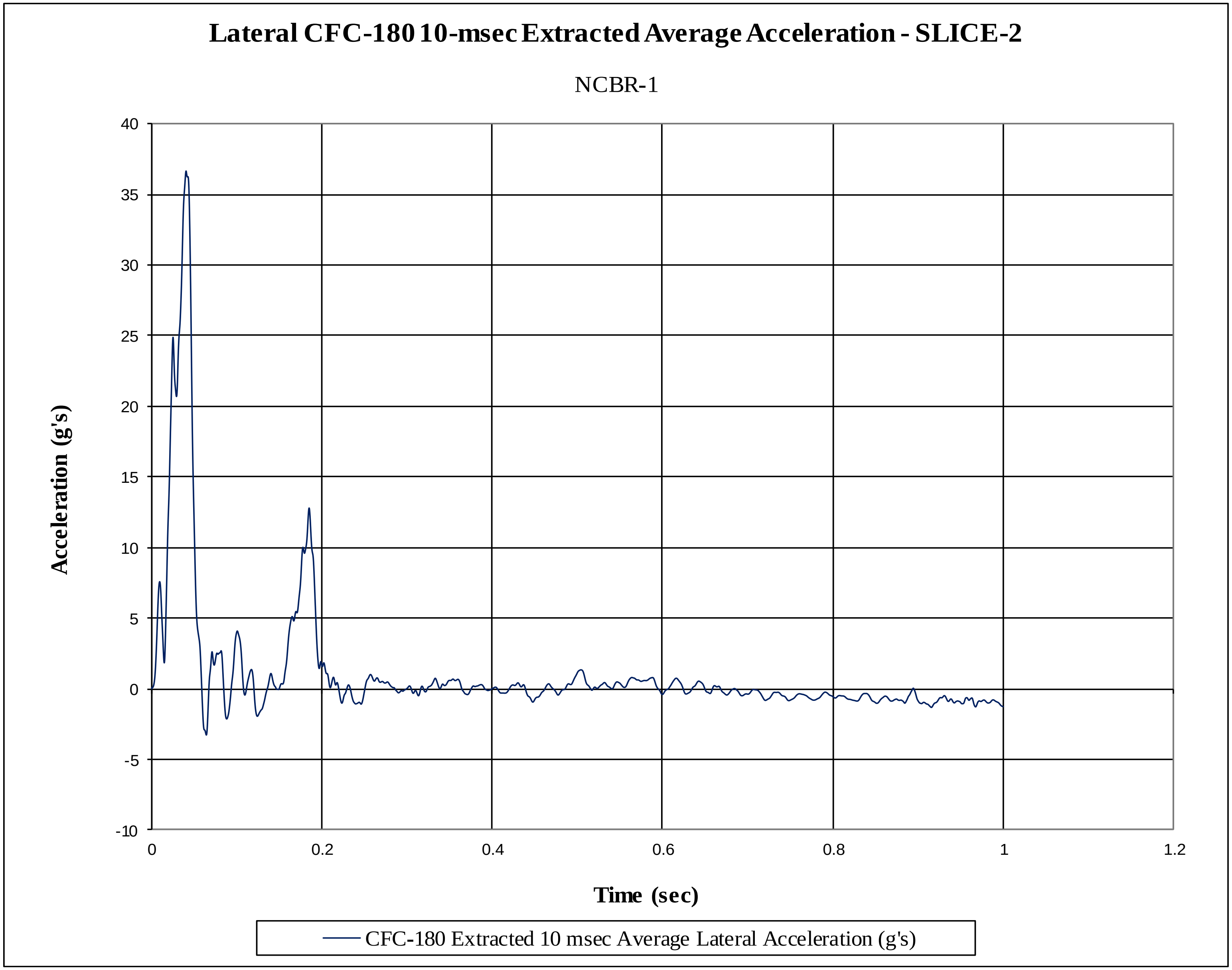


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. NCBR-1

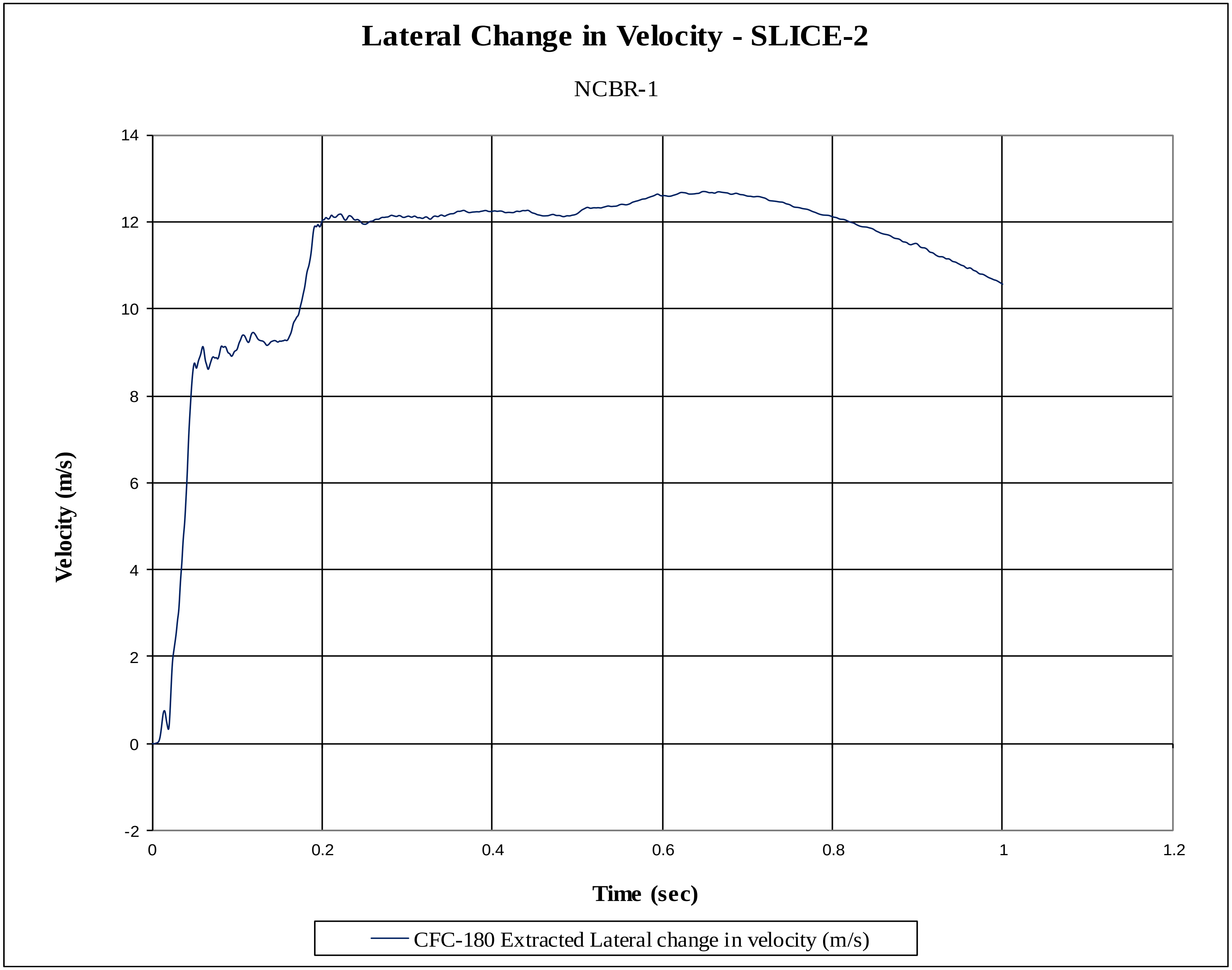


Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. NCBR-1

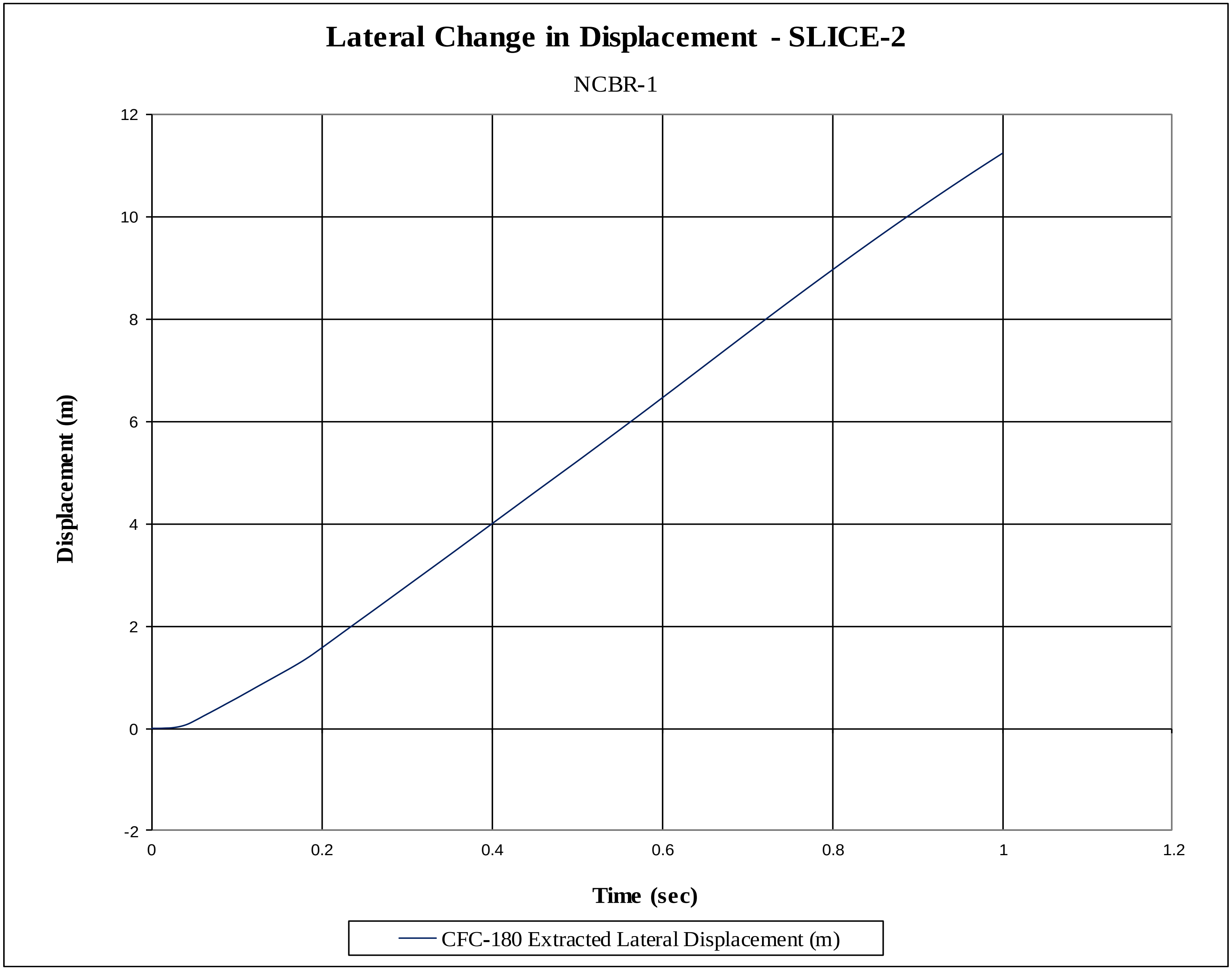


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. NCBR-1

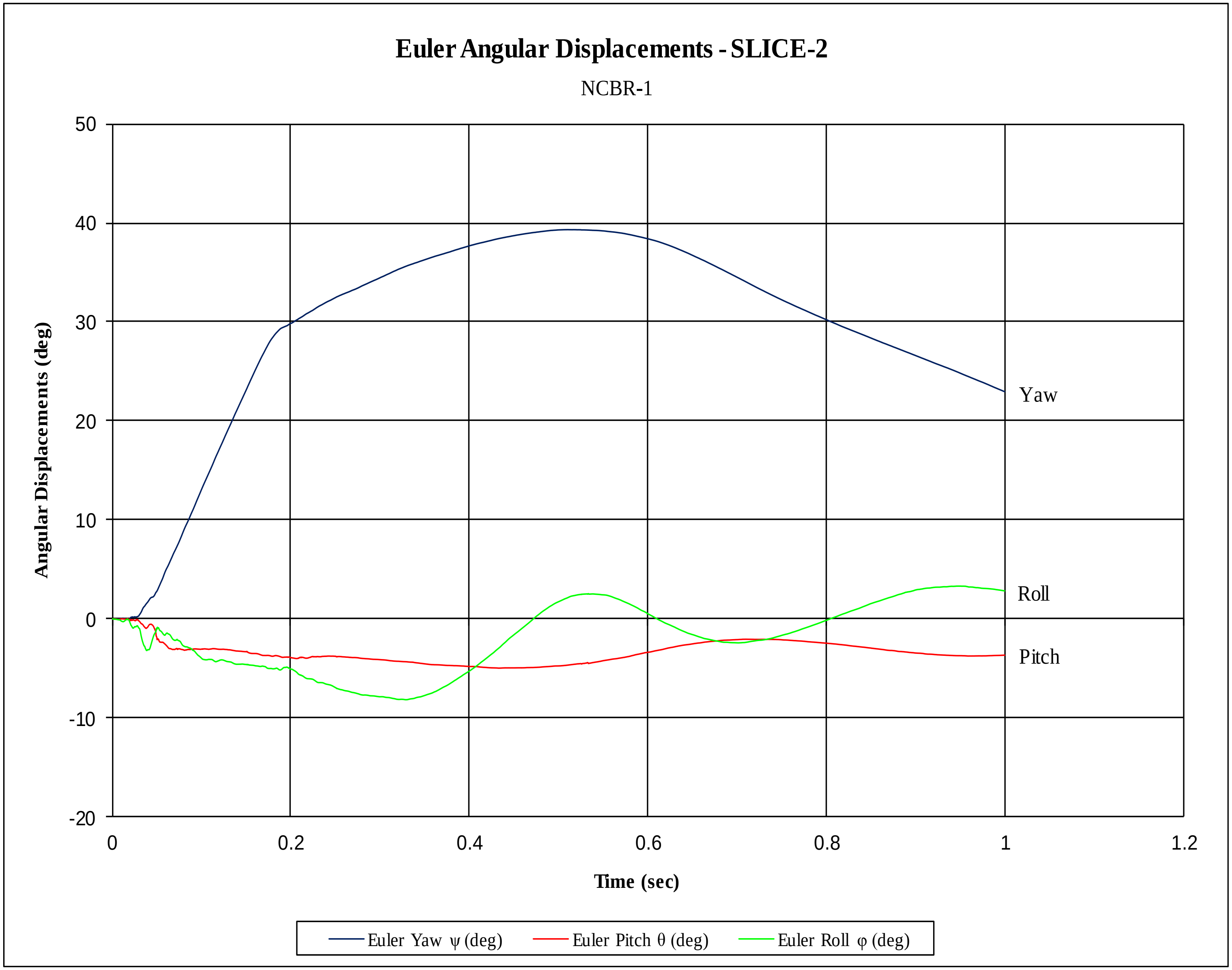


Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. NCBR-1

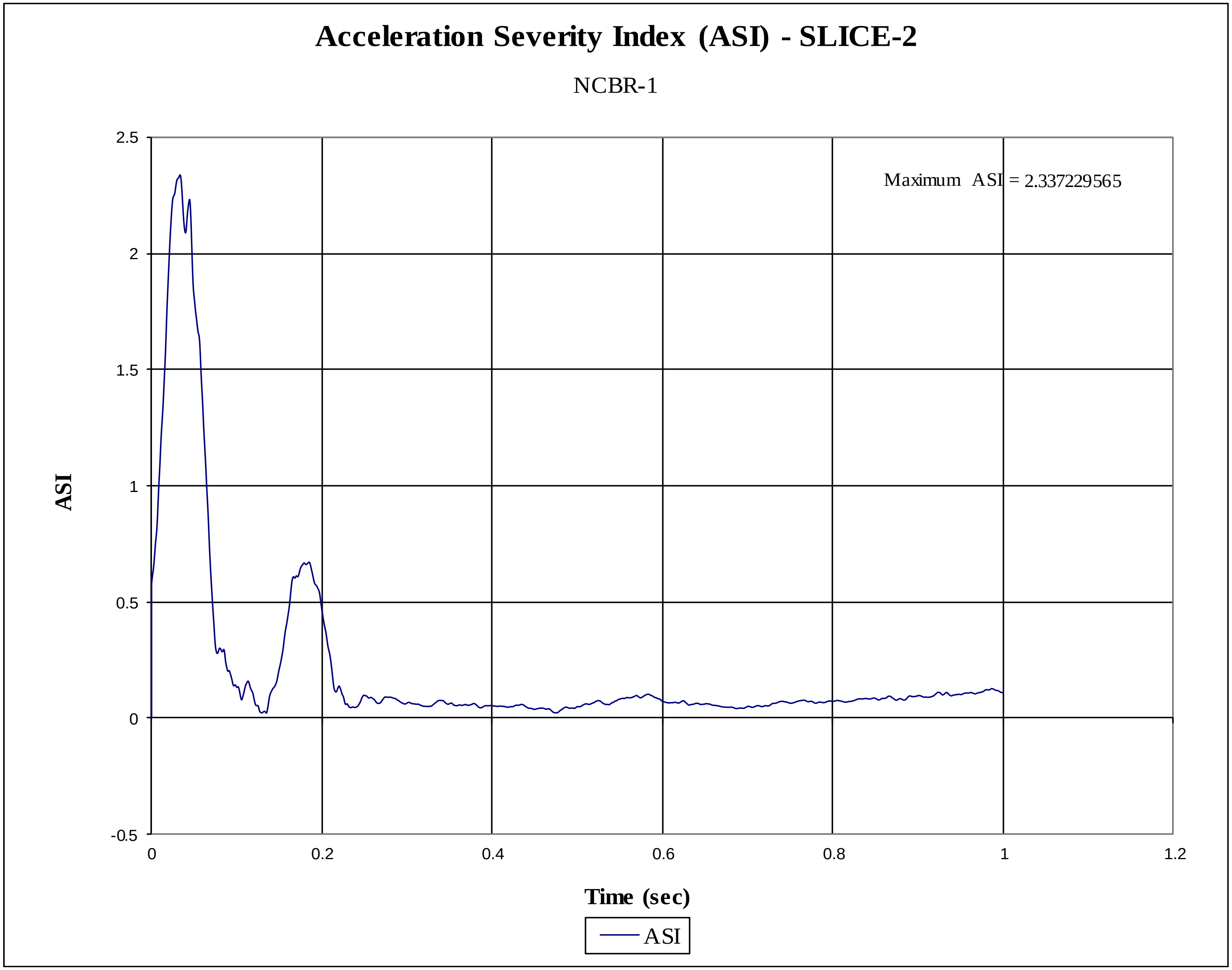


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. NCBR-1

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

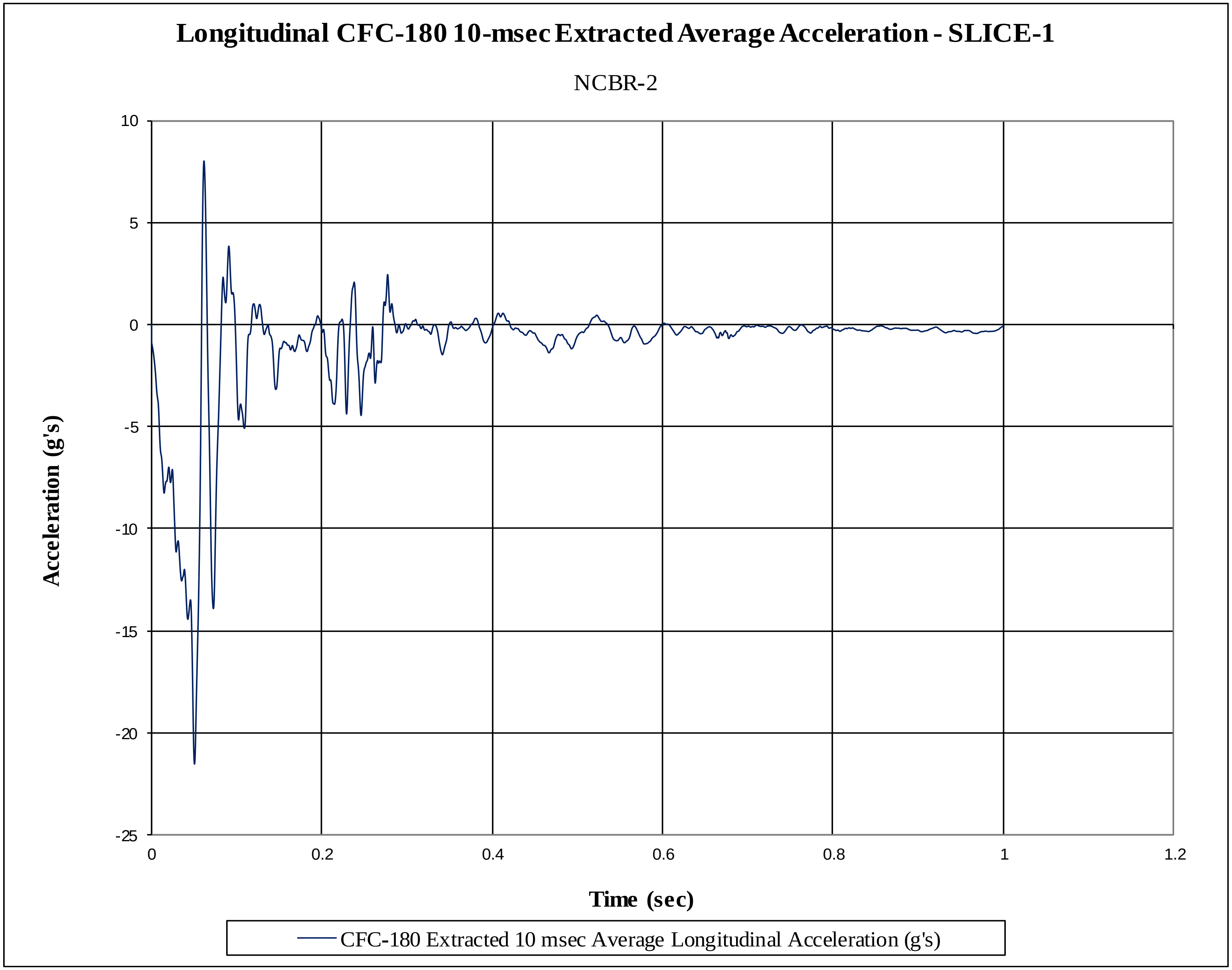


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. NCBR-2

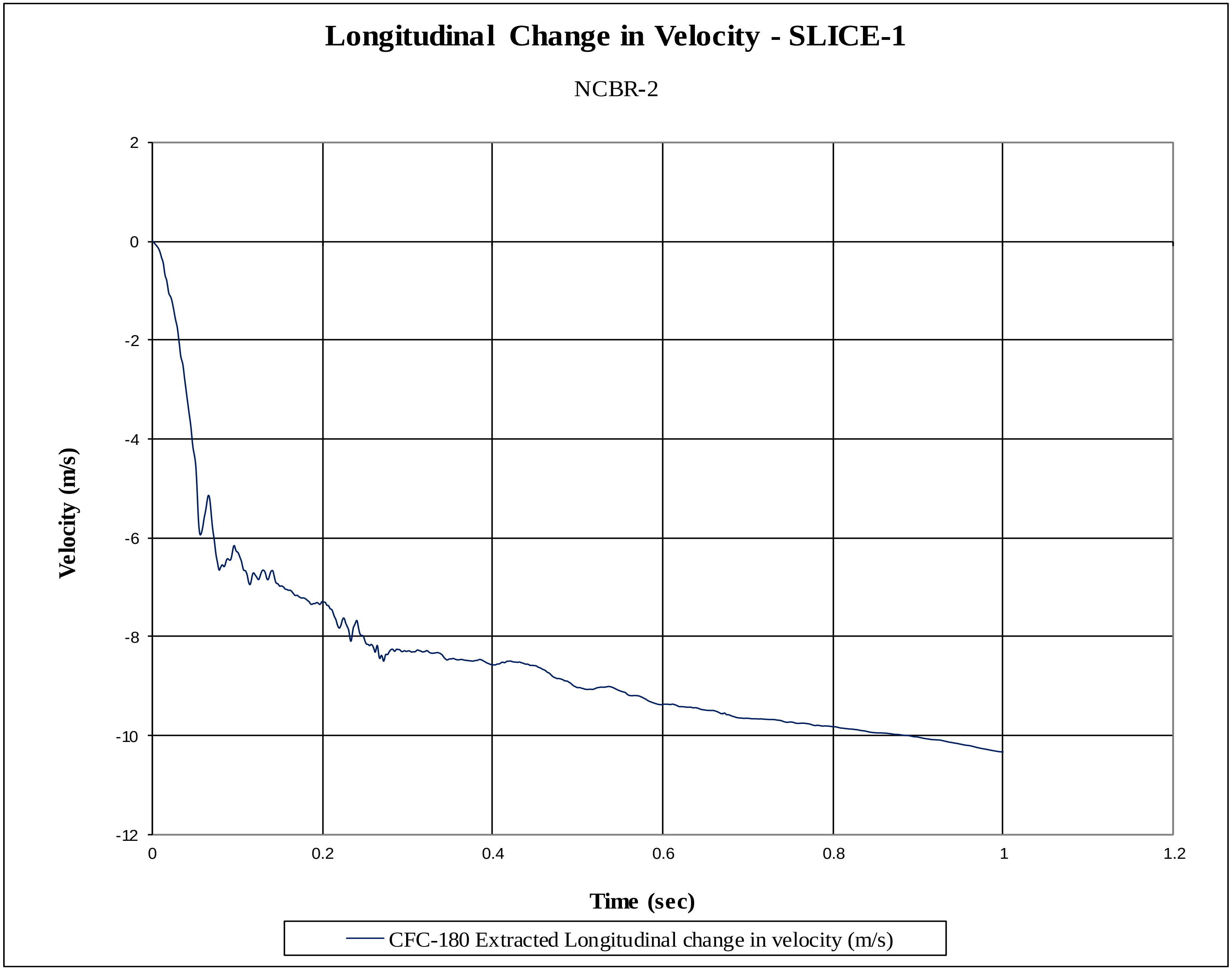


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. NCBR-2

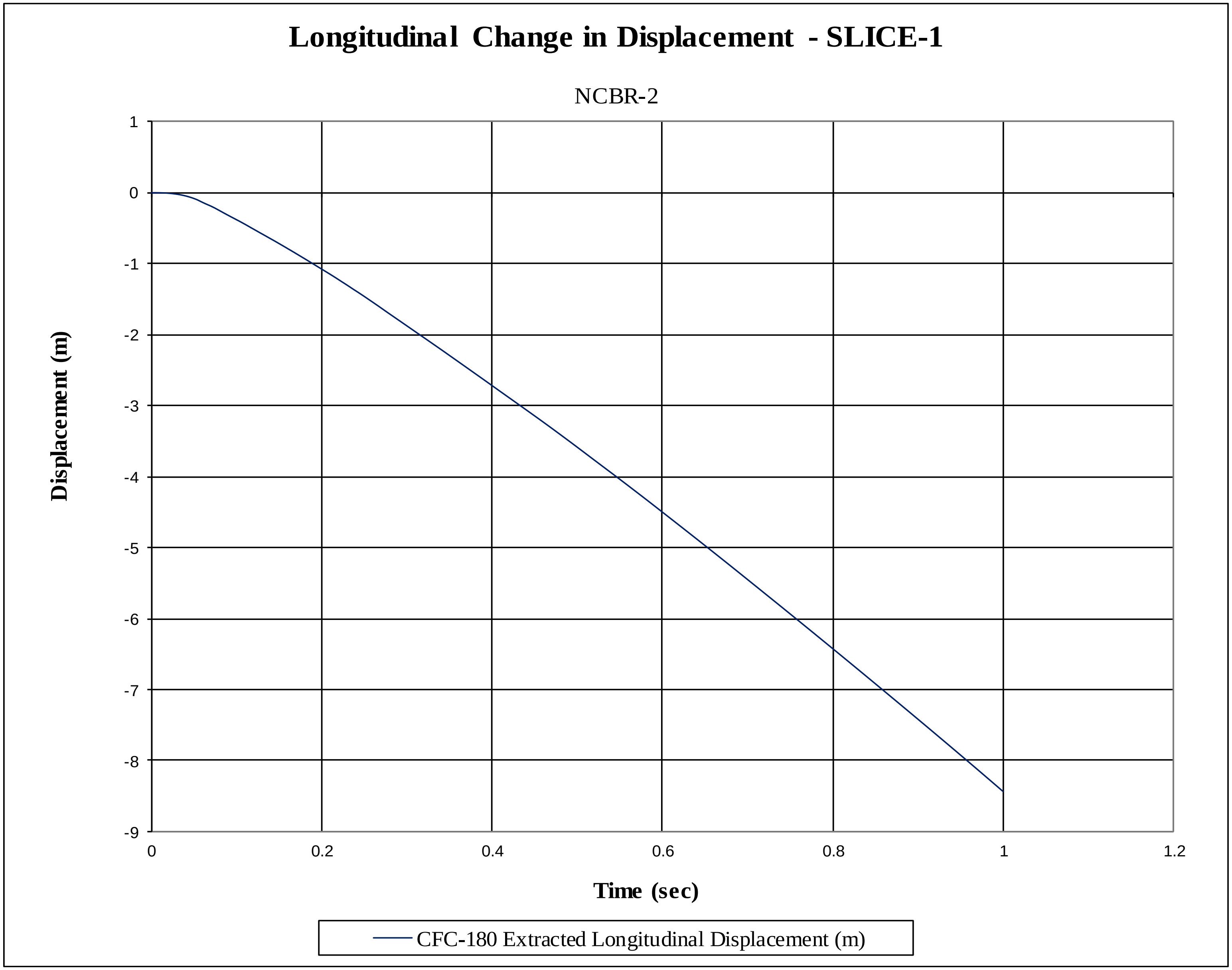


Figure F-3. Longitudinal Occupant Displacement (SLICE-1), Test No. NCBR-2

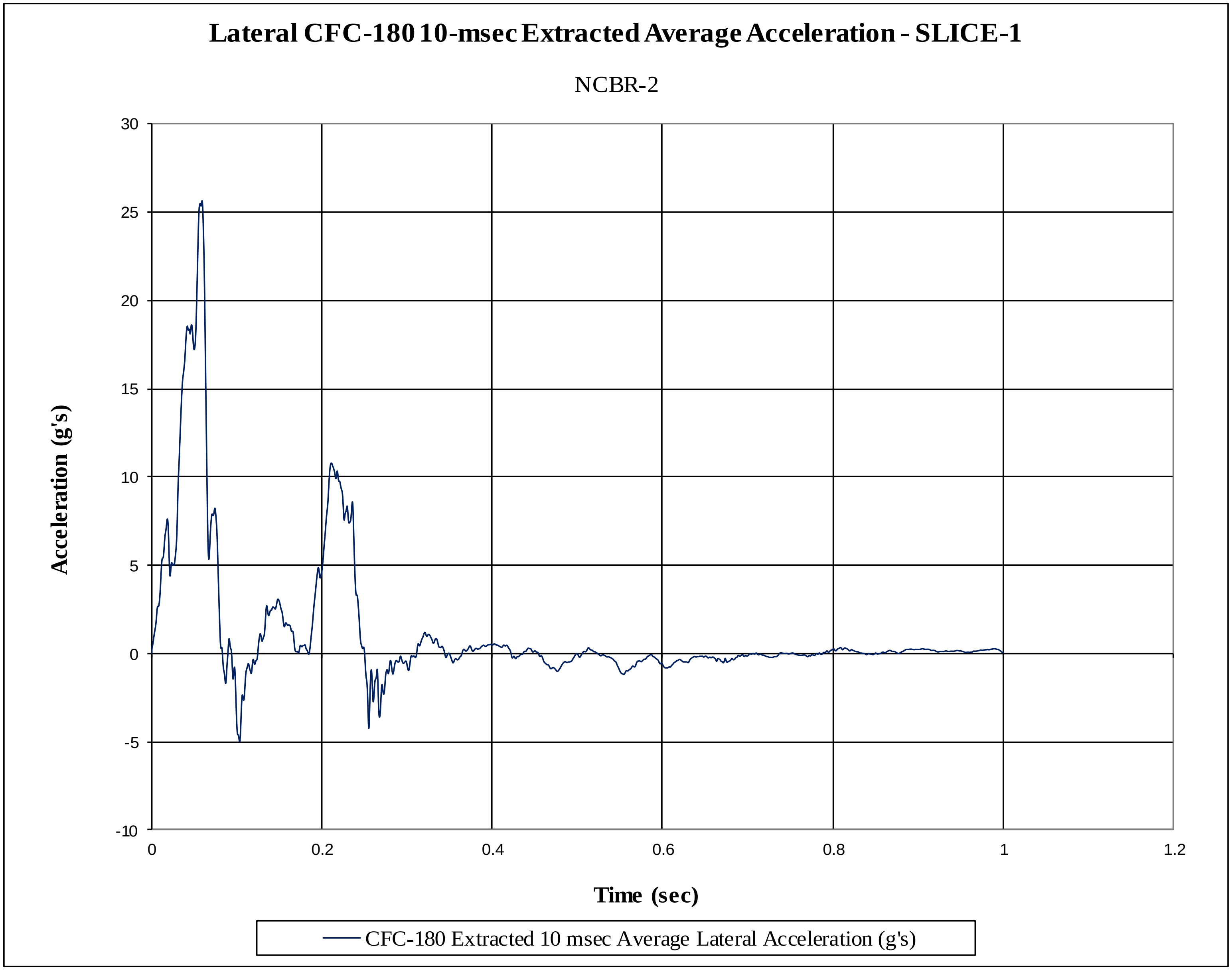


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. NCBR-2

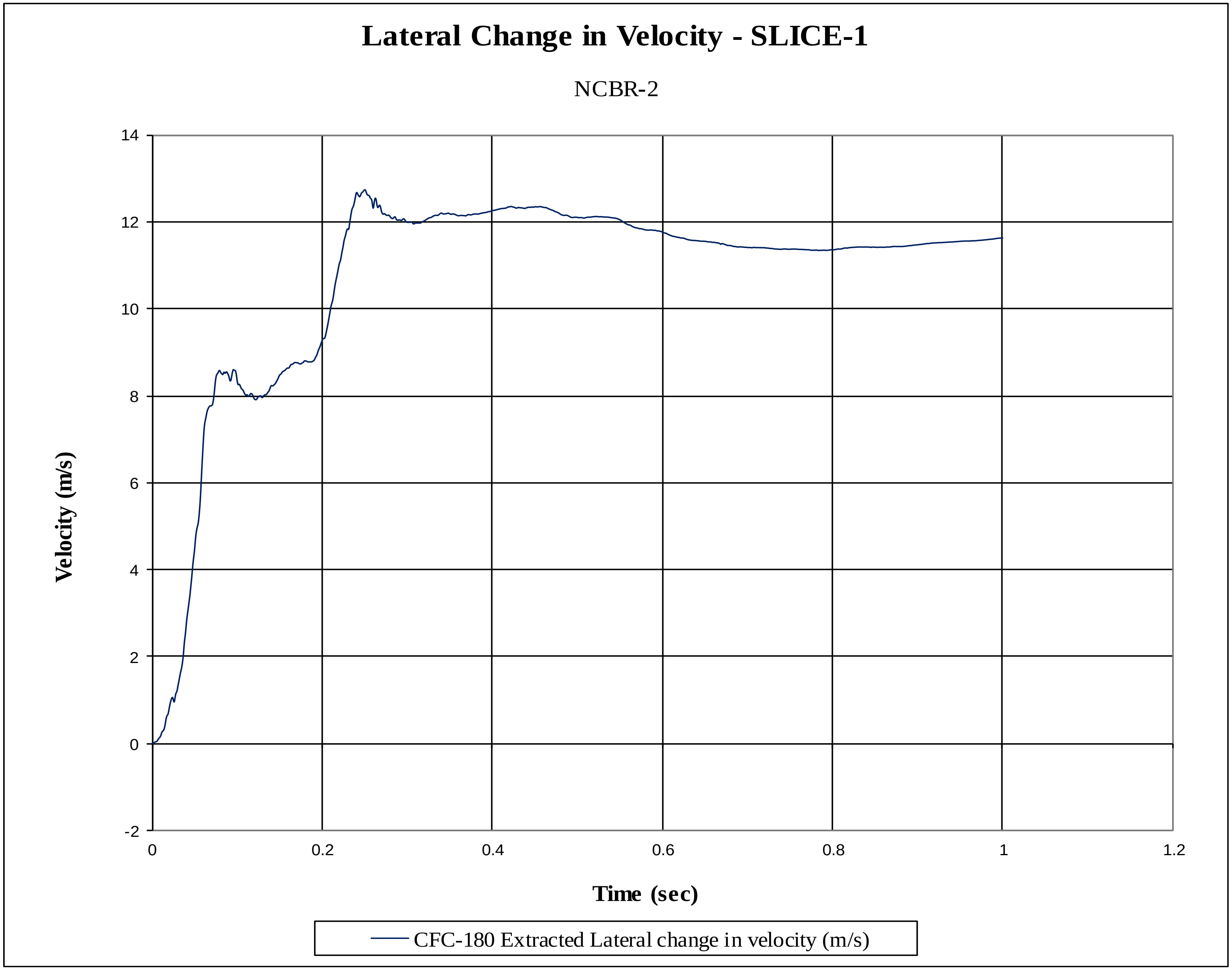


Figure F-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. NCBR-2

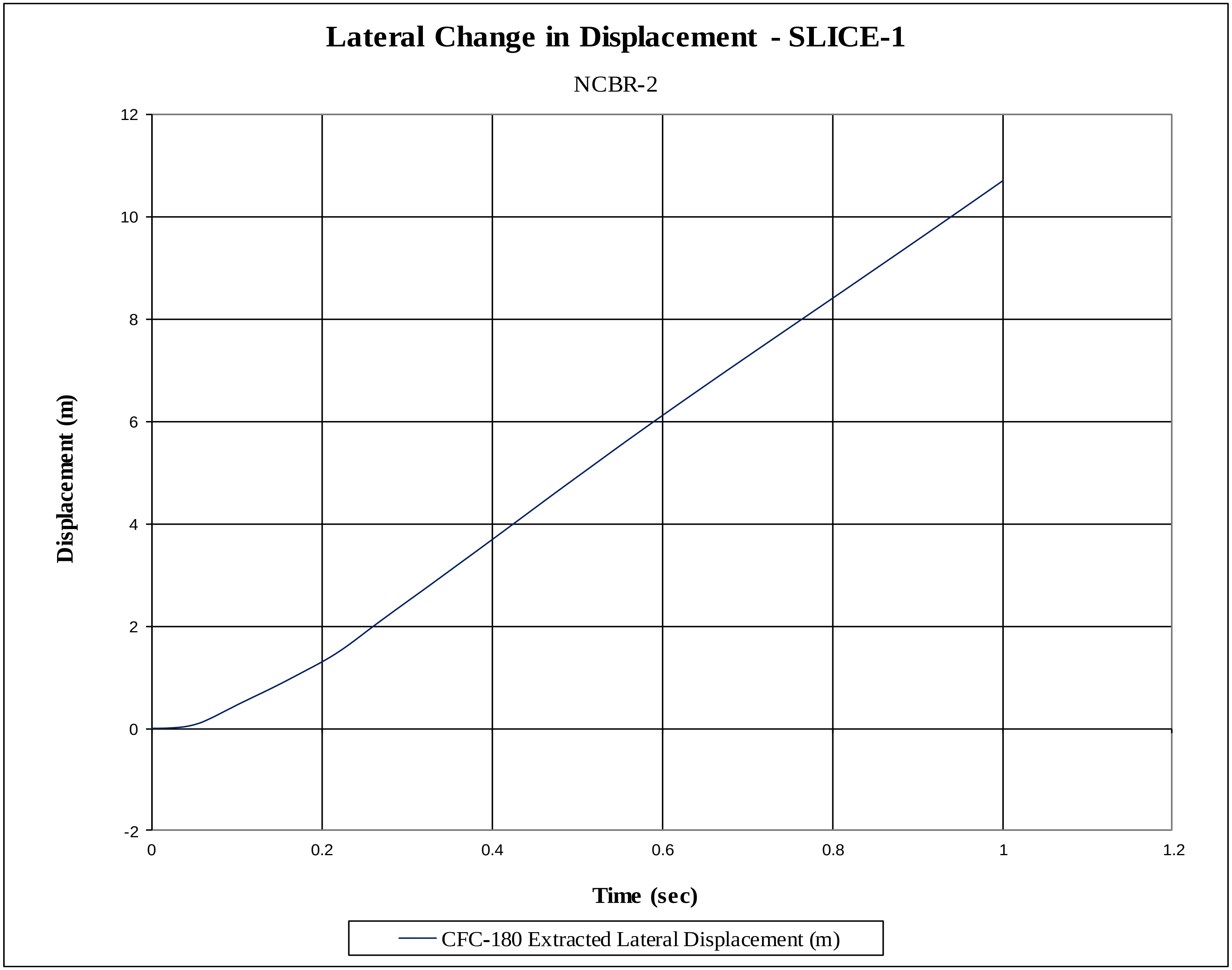


Figure F-6. Lateral Occupant Displacement (SLICE-1), Test No. NCBR-2

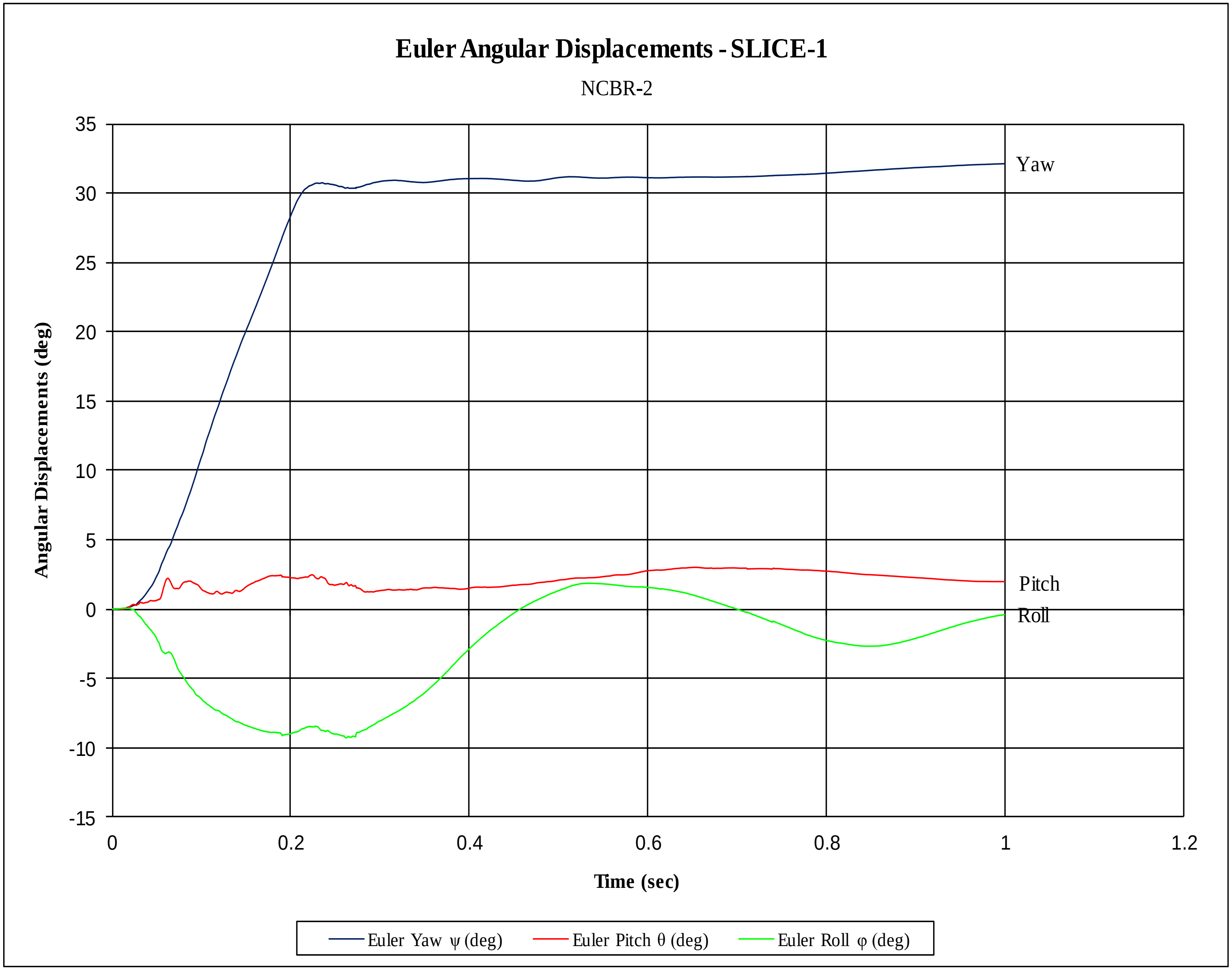


Figure F-7. Vehicle Angular Displacements (SLICE-1), Test No. NCBR-2

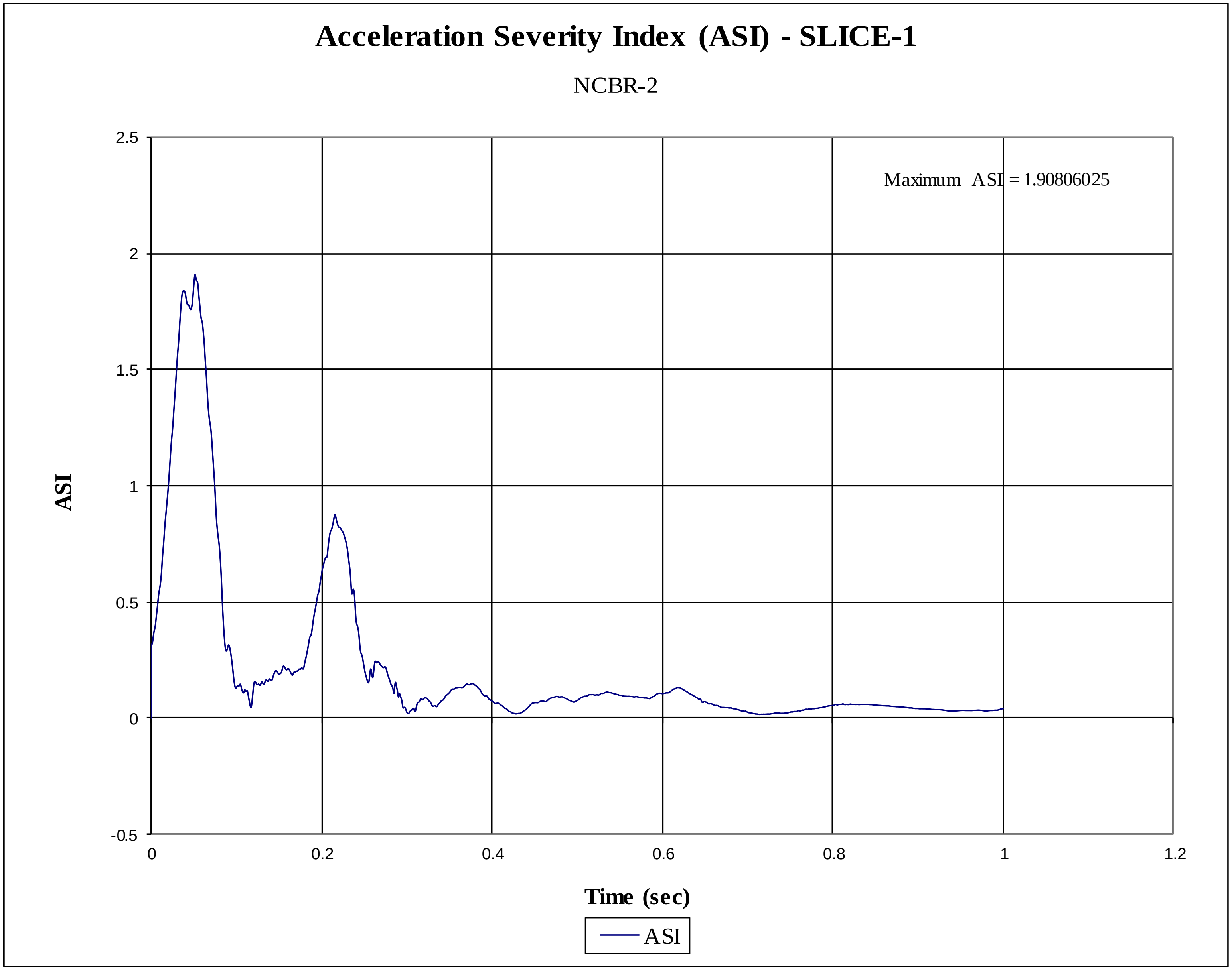


Figure F-8. Acceleration Severity Index (SLICE-1), Test No. NCBR-2

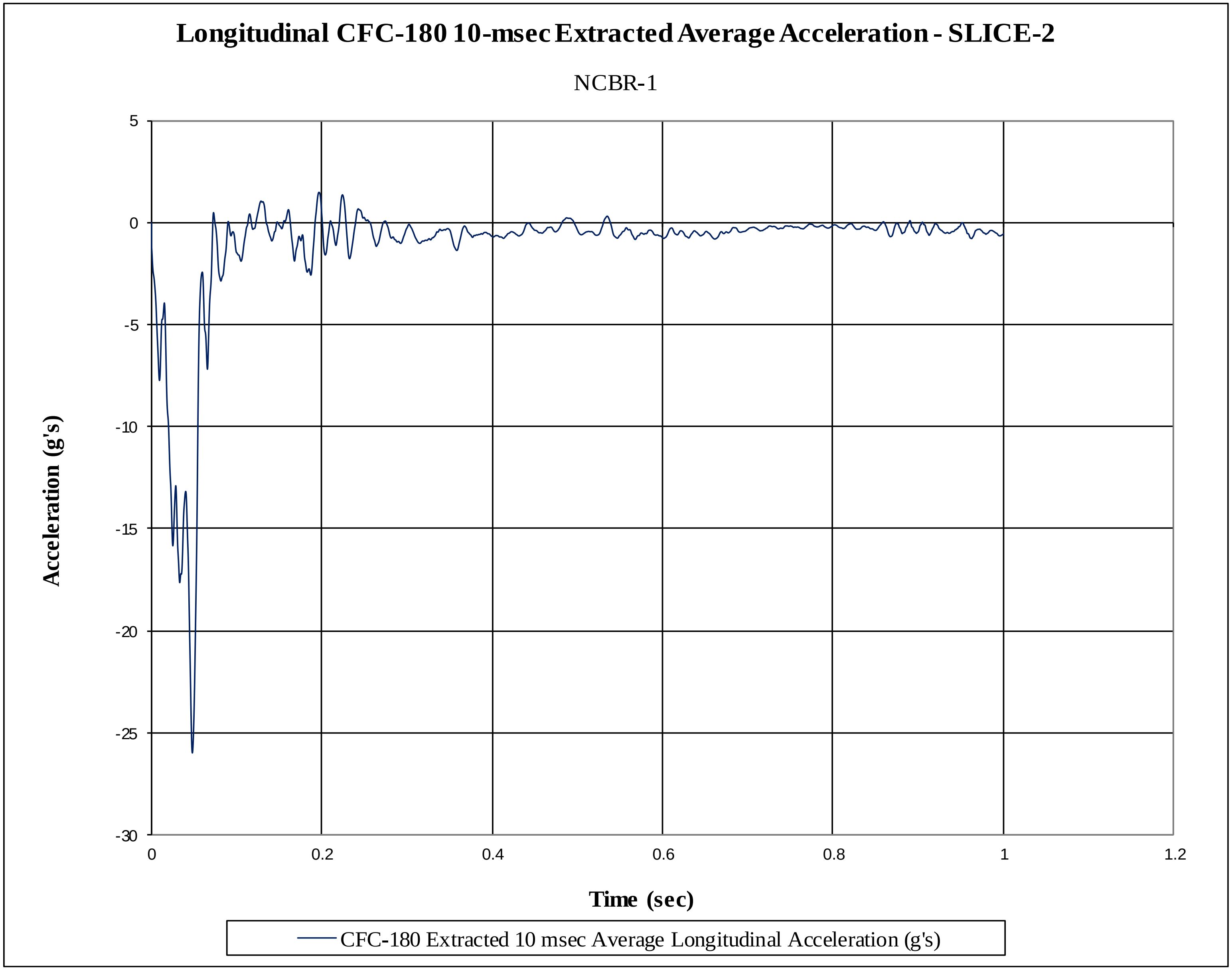


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. NCBR-2

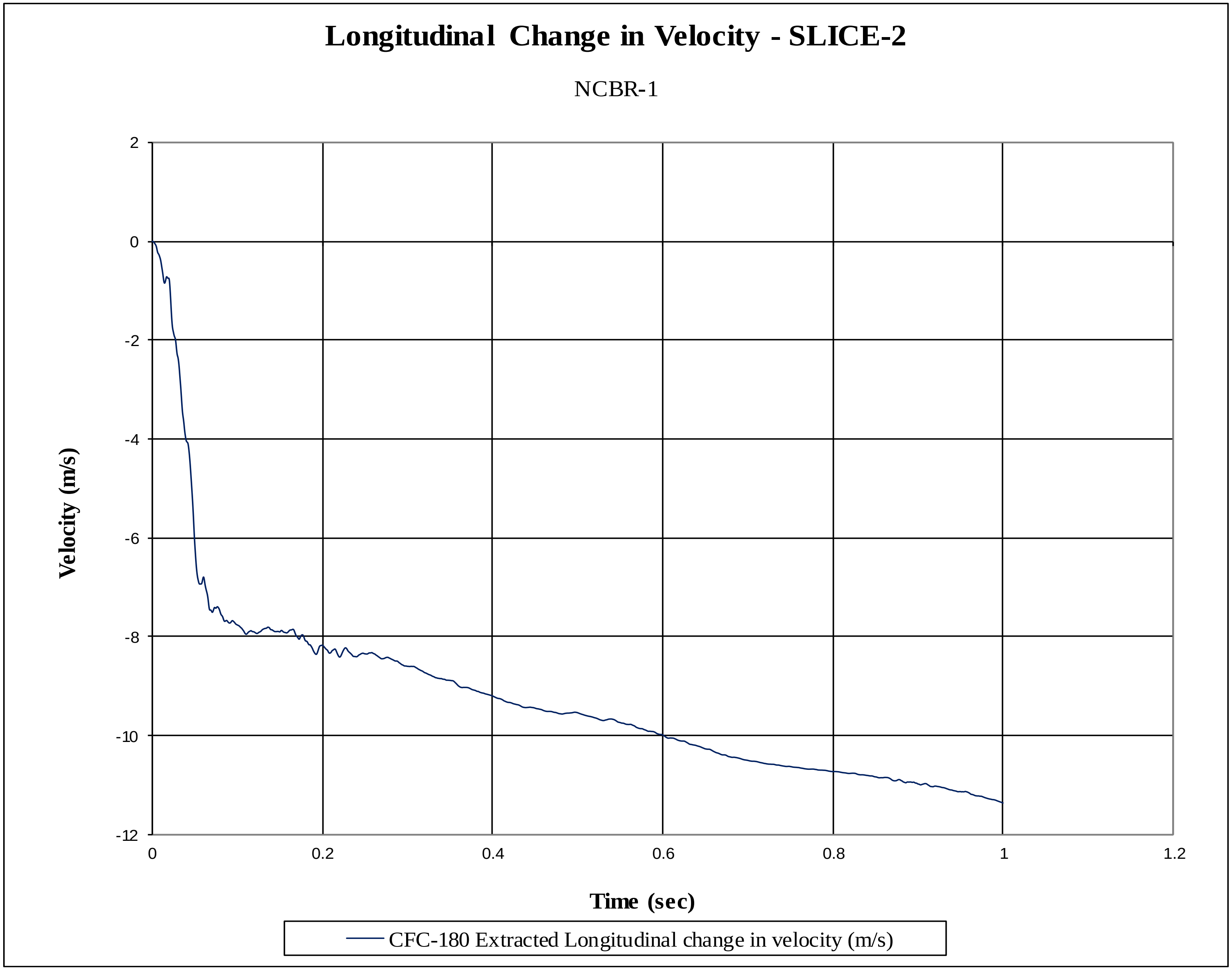


Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. NCBR-2

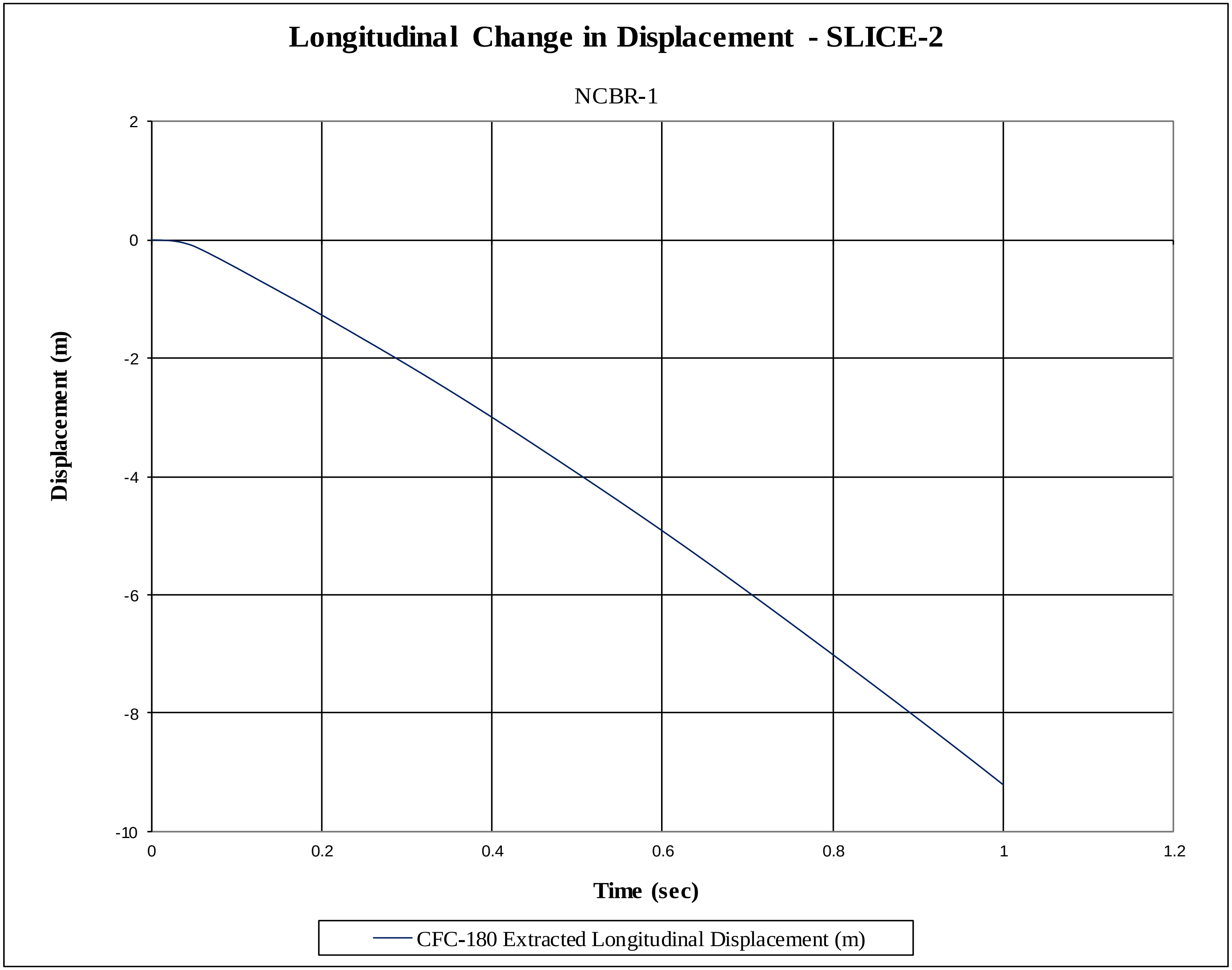


Figure F-11. Longitudinal Occupant Displacement (SLICE-2), Test No. NCBR-2

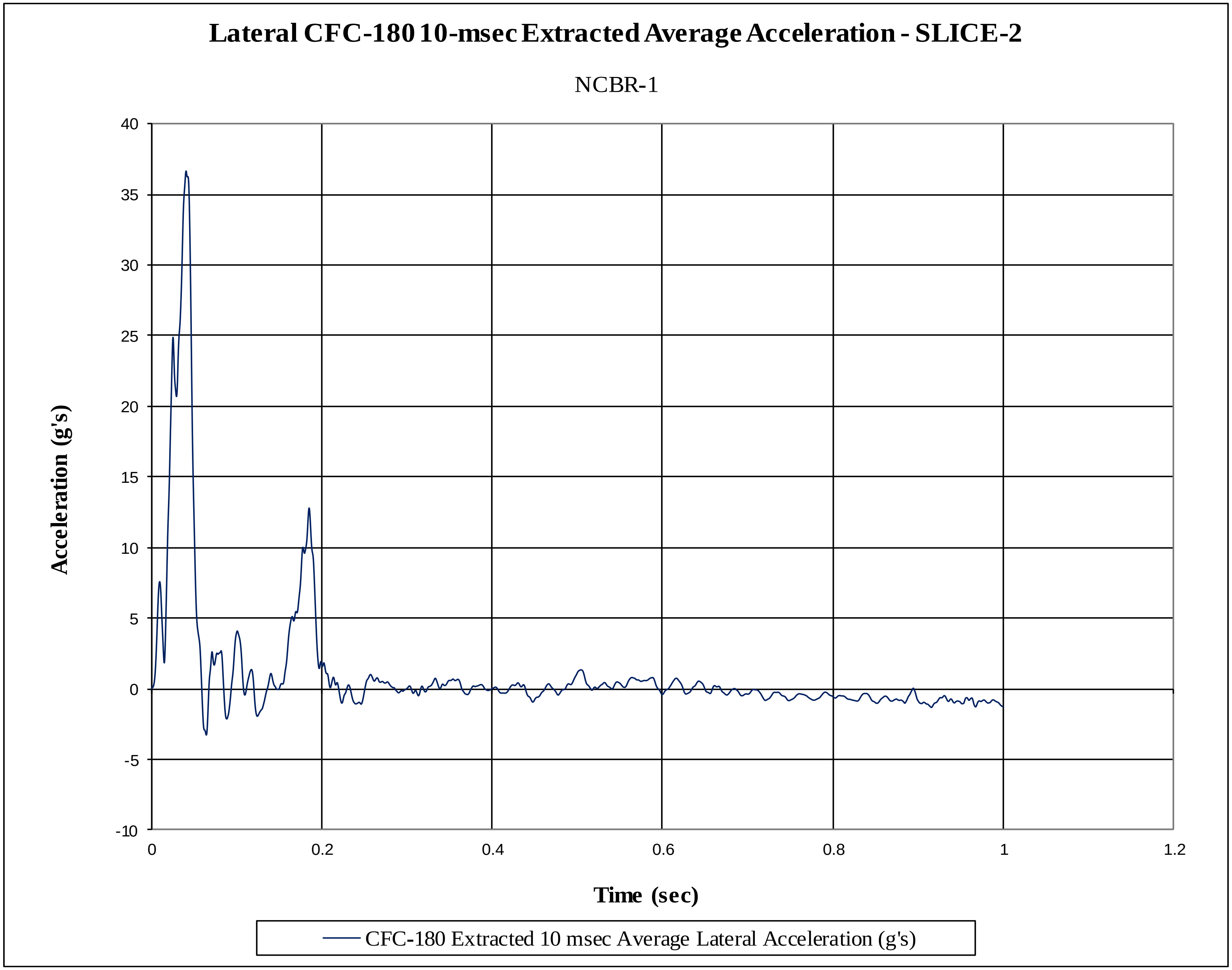


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. NCBR-2

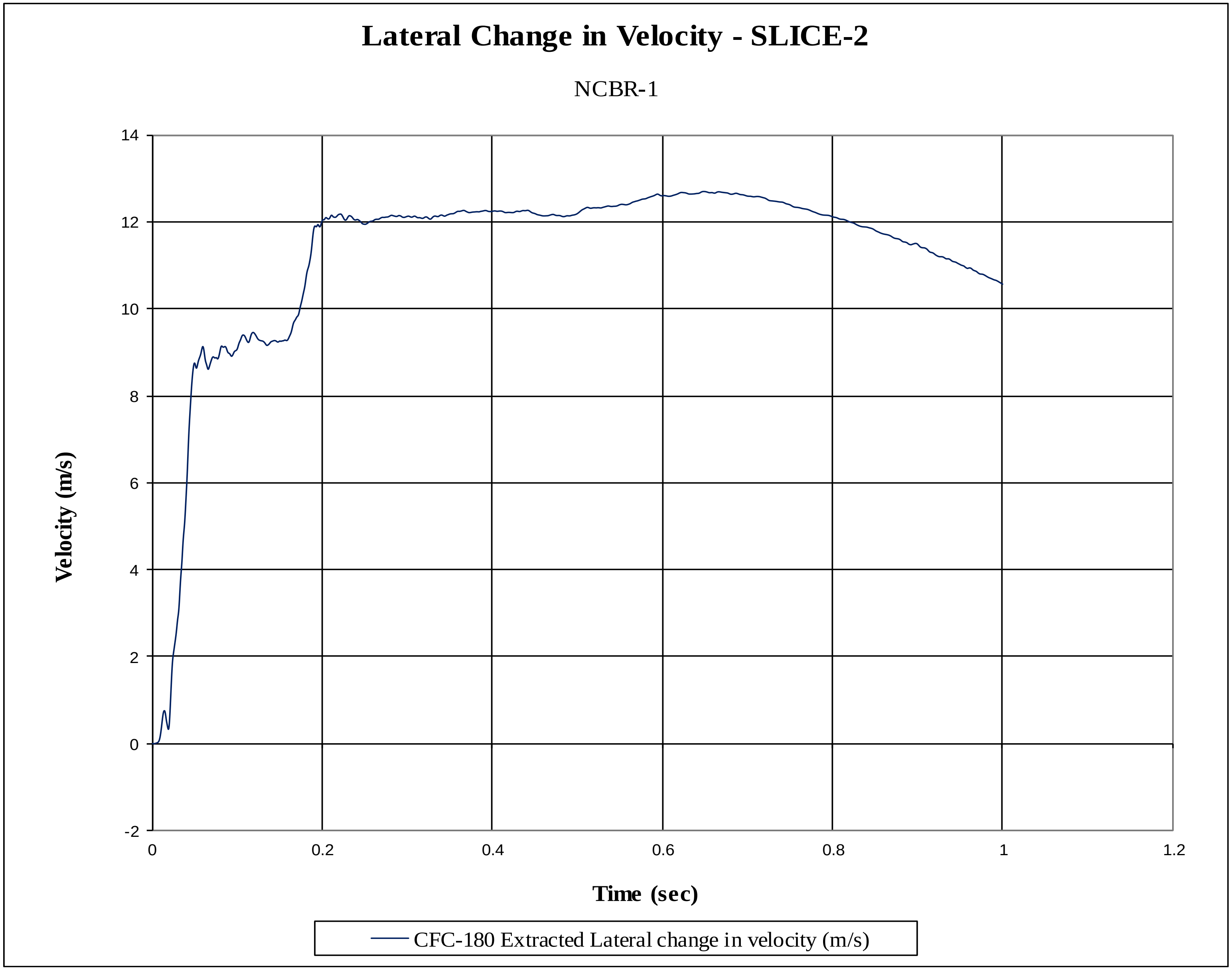


Figure F-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. NCBR-2

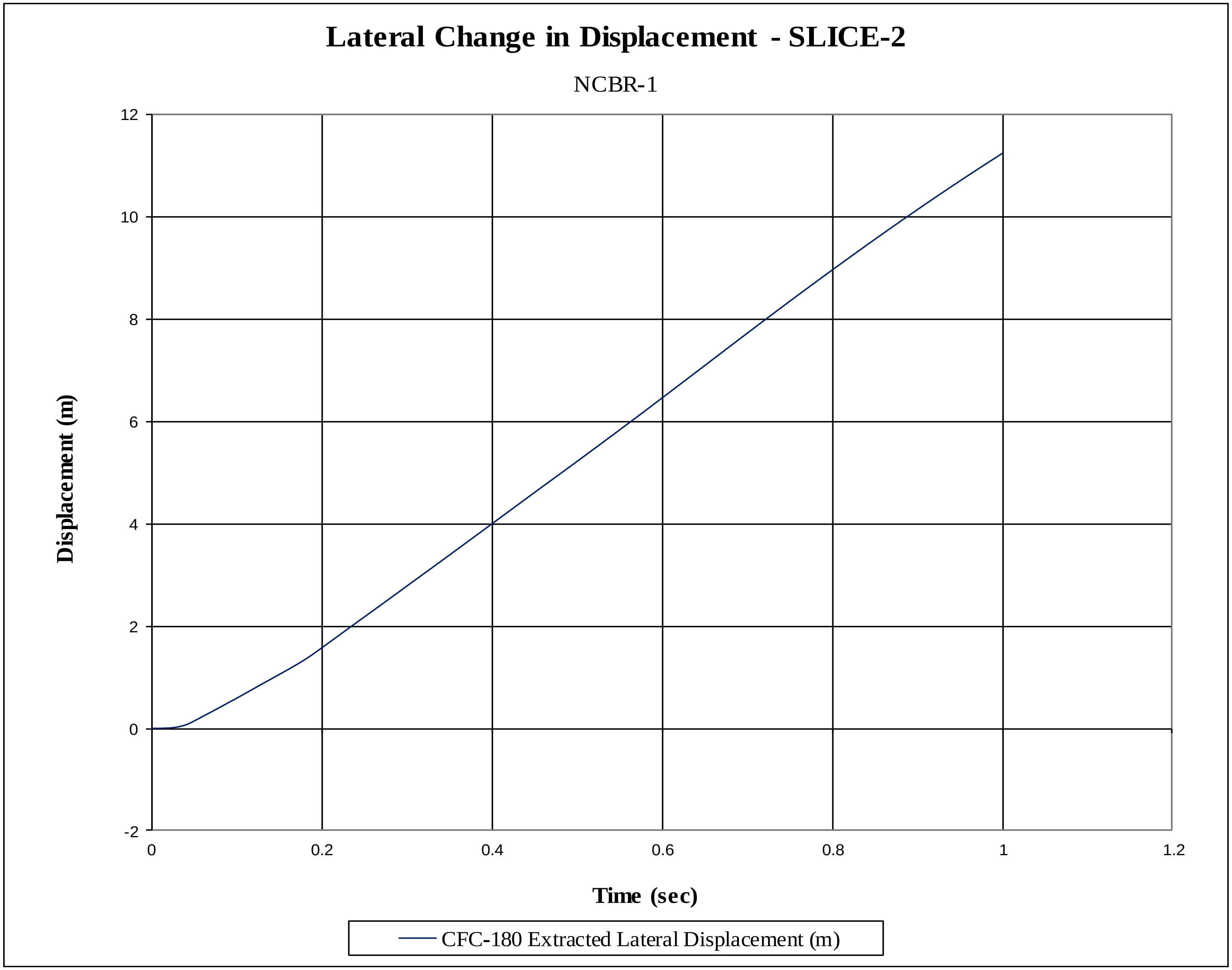


Figure F-14. Lateral Occupant Displacement (SLICE-2), Test No. NCBR-2

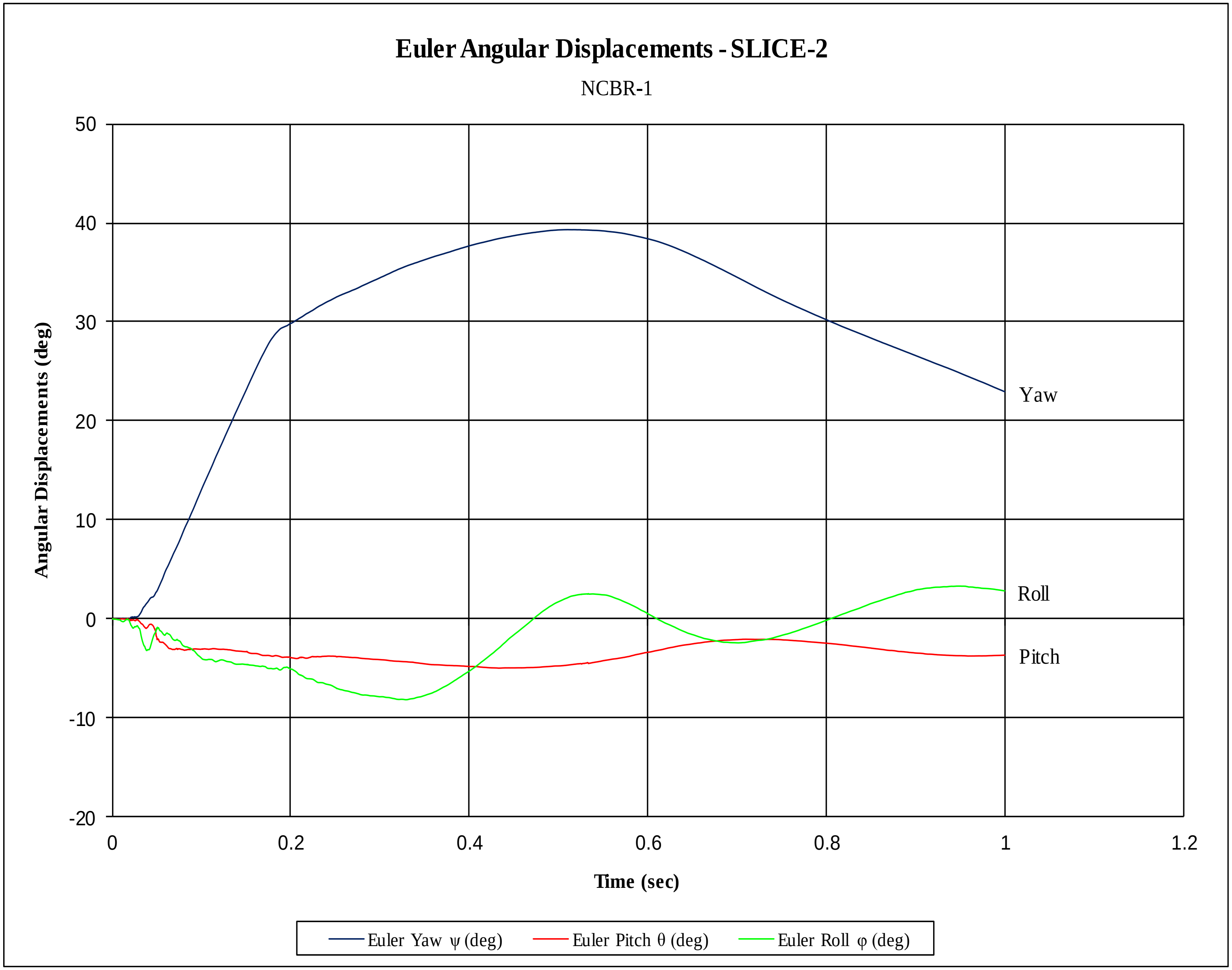


Figure F-15. Vehicle Angular Displacements (SLICE-2), Test No. NCBR-2

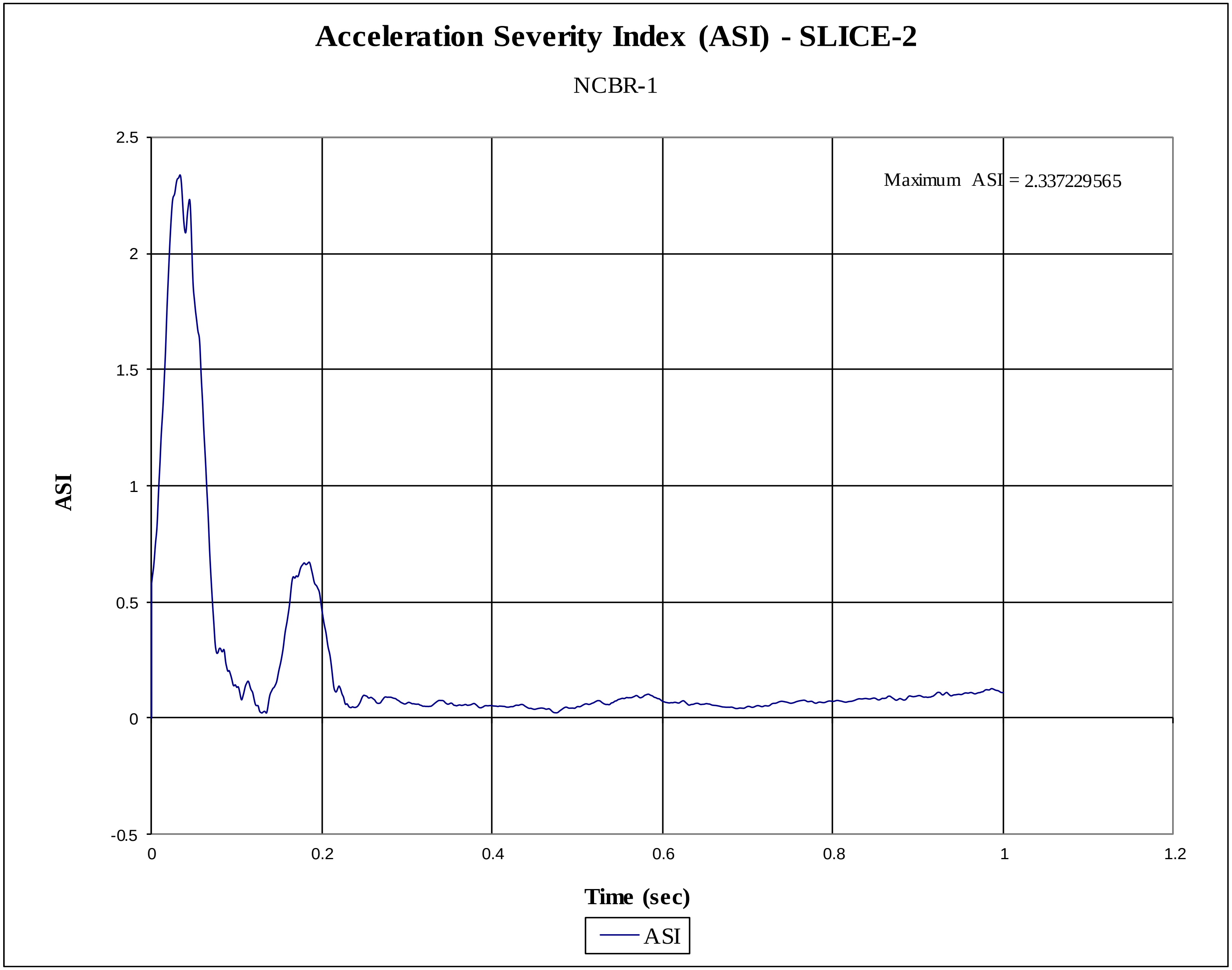


Figure F-16. Acceleration Severity Index (SLICE-2), Test No. NCBR-2

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