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MASH 2016 TEST LEVEL 4 EVALUATION OF MNDOT CONCRETE PARAPET WITH BRUSH CURB AND UPPER BEAM AND POST RAIL WITH NEW TAPERED END SECTION

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16. Abstract

The Minnesota Department of Transportation (MnDOT) desires to use a concrete parapet with a brush curb, upper beam and post rail, and a new tapered end section along high-speed highways and roadways when bridge structures are encountered. The MnDOT combination bridge railing system was full-scale crash tested according to the Test Level 4 (TL-4) procedures described in the *Manual for Assessing Safety Hardware* (MASH 2016). The combination bridge railing system consisted of a 21-in. tall concrete parapet with a 6-in. tall and 2-in. wide brush curb at the lower front face and eight rail and post assemblies, which consisted of one steel rail welded onto two or three steel posts with their own welded base plates. The steel assemblies were anchored to the top face of the concrete parapet.

In full-scale crash test nos. MNCBR-1, MNCBR-2, and MNCBR-3, the bridge railing system was evaluated according to MASH 2016 test designation nos. 4-12, 4-11, and 4-10, respectively. The 2013 International Durastar 4300 SBA single-unit truck impacted the system $60\frac{1}{8}$ in. upstream from the centerline of the splice between post nos. 6 and 7 with a speed of 57.4 mph at an angle of 15.4 degrees. The 2014 Dodge Ram 1500 crew cab pickup truck impacted the system 69.9 in. upstream from the centerline of post no. 23 with a speed of 63.9 mph at an angle of 25.1 degrees. The 2009 Kia Rio small car impacted the system $70\frac{7}{16}$ in. upstream from the centerline of post no. 23 with a speed of 62.5 mph at an angle of 25.5 degrees. The vehicles were successfully contained and redirected, resulting in minimal plastic deformation to the upper steel railing and moderate to minimal scraping and gouging of the concrete parapet. The combination bridge railing system was found to meet the AASHTO MASH 2016 TL-4 impact safety criteria.

17. Key Words
Highway Safety, Crash Test, Roadside Appurtenances, Compliance Test, MASH 2016, Test Level 4, TL-4, High-Speed Highways and Roadways, Concrete Parapet, Brush Curb, Beam and Post, Hybrid Bridge Rail, and Combination Bridge Rail

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UNCERTAINTY OF MEASUREMENT STATEMENT

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

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Dr. Cheng Feng, Post-Doctoral Research Associate.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

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1 INTRODUCTION

1.1 Background

The Minnesota Department of Transportation (MnDOT) currently uses a combination bridge railing system that is configured with a concrete parapet, a lower brush curb, and an upper steel beam and post railing structure, as shown in Figure 1. The crashworthiness of this bridge railing system was previously recognized as meeting the National Cooperative Highway Research Program (NCHRP) Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* [1], Test-Level 4 (TL-4) safety performance standards. NCHRP Report 350 has since been superseded by the American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware* (MASH 2009 [2] and MASH 2016 [3]). Thus, it was desired to evaluate the bridge railing system to the MASH 2016 impact safety standards. In an effort to encourage state departments of transportation (DOTs) and hardware developers to advance their designs, the Federal Highway Administration (FHWA) and AASHTO developed an implementation policy that included sunset dates for various categories of roadside safety hardware. The new policy recommended that all bridge rails installed on federal-aid roadways were to be evaluated under MASH 2016 by December 31, 2019 [4]. MNDOT began to plan for this crash testing effort in 2018.

Figure 1. Typical Concrete Parapet with Brush Curb and Upper Beam and Post Rail

MnDOT plans to use the combination bridge railing system with a new, tapered concrete end section between the top of the parapet and the bottom of the steel tube rail while incorporating a standardized concrete end post at each end. Two different end region scenarios would be considered: (1) the combination bridge railing system with a 2-in. long expansion joint on the roadway, as shown in Figures 2 and 3 and (2) the combination bridge railing system with a ¼-in. long saw cut joint on the roadway, as shown in Figures 4 and 5. The combination bridge railing system shown in Figures 2 through 5 (MnDOT's Standard Plan FIG.5–397.157(A)) would be the focus of the research study reported herein.

In 1995, MwRSF conducted a crash testing program for MnDOT on the original bridge railing system consisting of a concrete parapet, a lower brush curb, and an upper steel beam and post rail [5]. Through the effort, three design variations were tested and evaluated according to TL-4 safety performance standards under NCHRP Report 350 [1]. Results from these full-scale vehicle crash tests were described in MwRSF's report entitled *Test Level 4 Evaluation of Minnesota Combination Bridge Rail* [5].

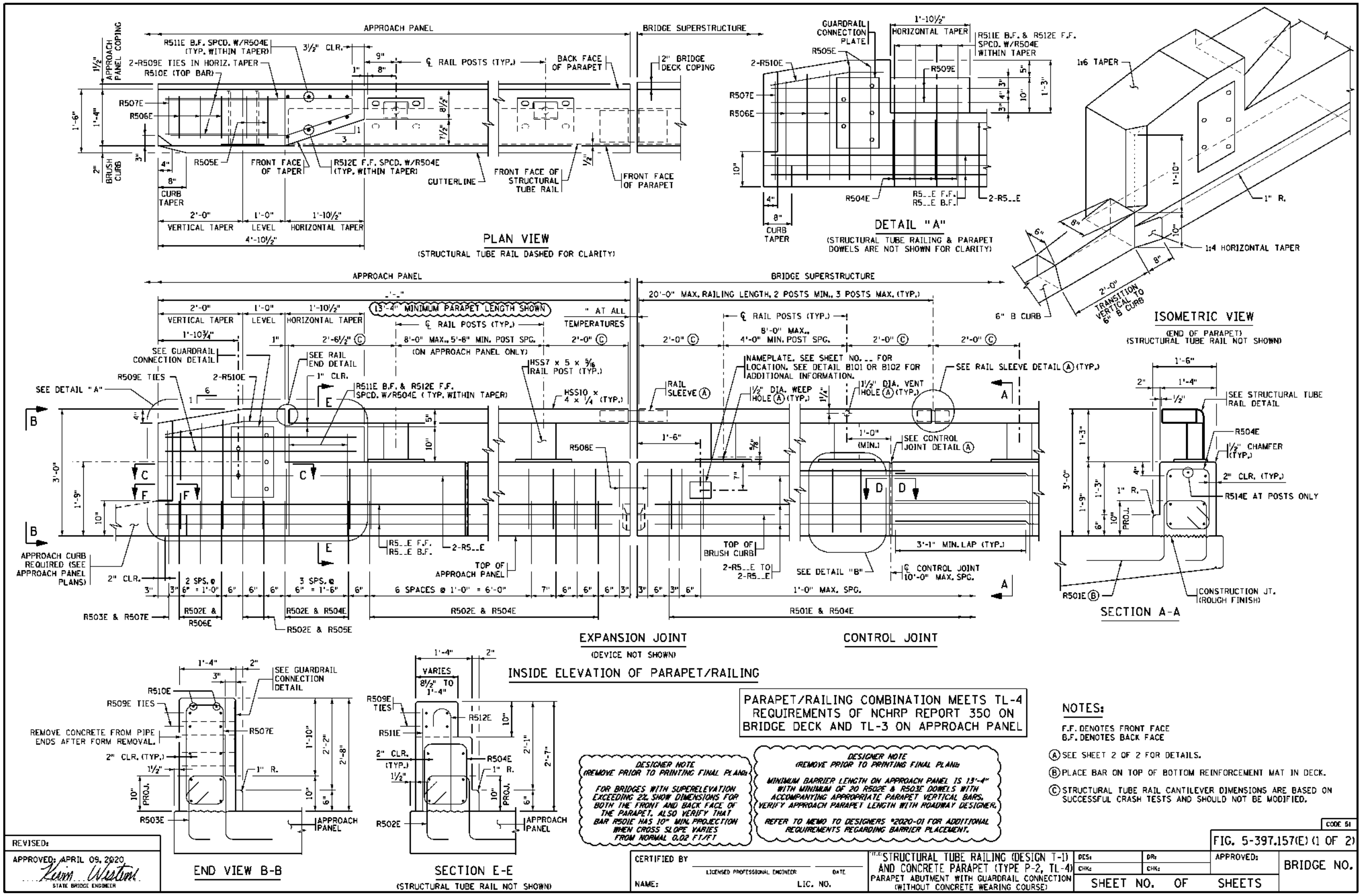


Figure 2. 2020 MnDOT Standard Plans FIG.5–397.157(E) Sheets 1 of 2 [6]

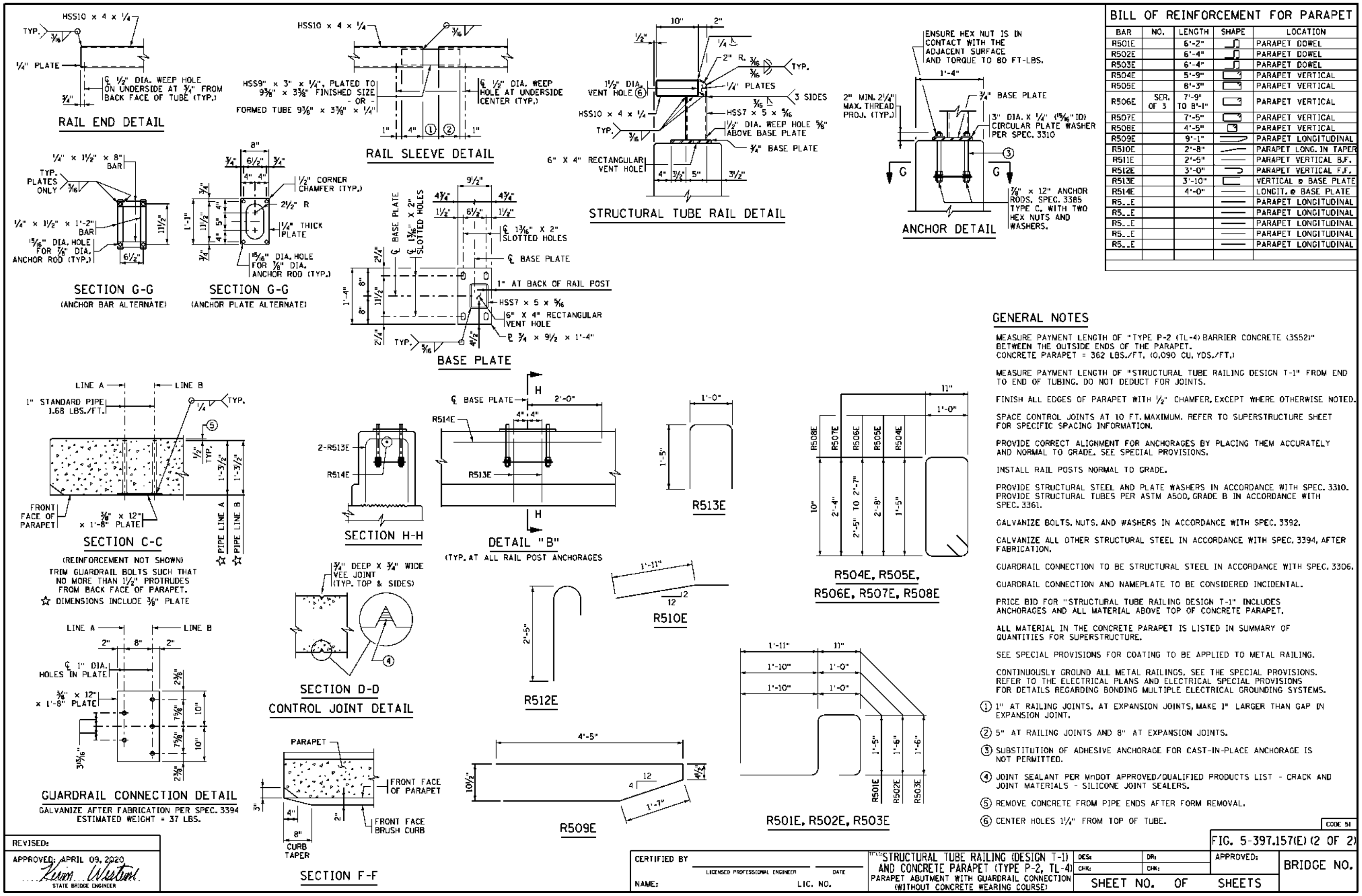


Figure 3. 2020 MnDOT Standard Plans FIG.5–397.157(E) Sheets 2 of 2 [6]

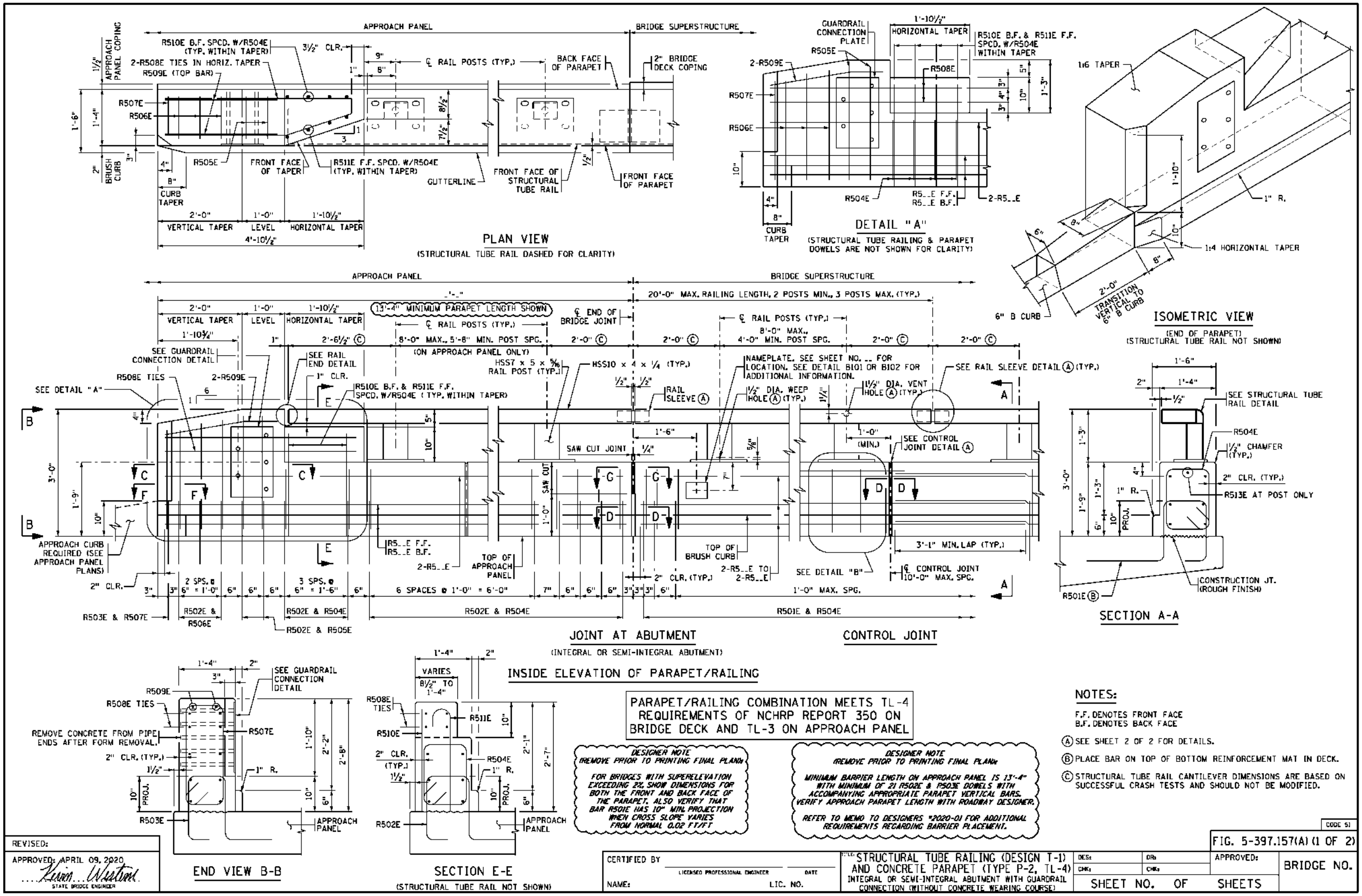


Figure 4. 2020 MnDOT Standard Plans FIG.5–397.157(A) Sheets 1 of 2 [7]

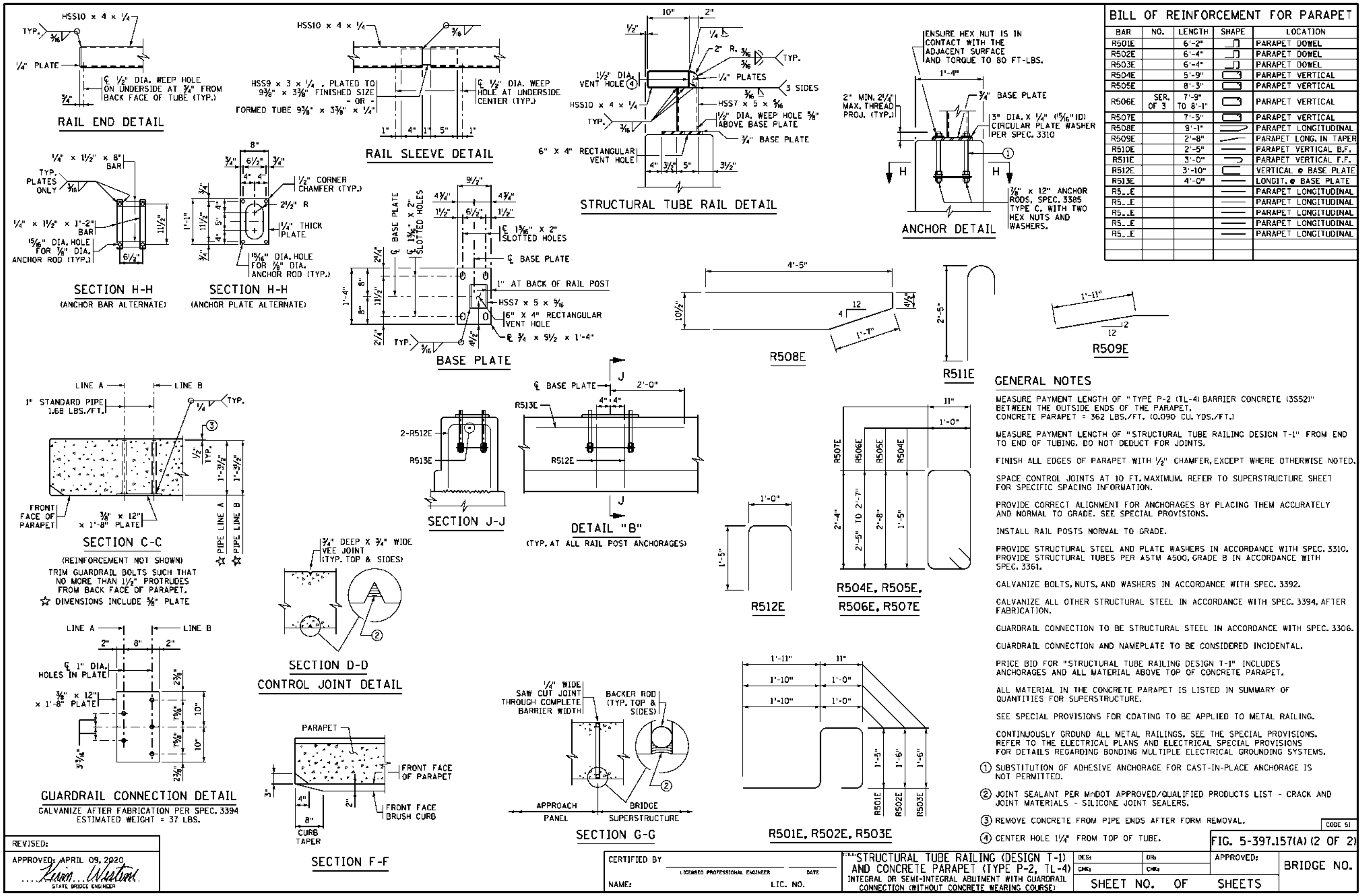


Figure 5. 2020 MnDOT Standard Plans FIG.5–397.157(A) Sheets 2 of 2 [7]

For the testing conducted in 1995, design no. 1 consisted of a TS 6-in. x 3-in. x ¼-in. steel structural tube rail mounted on 10¼-in. tall, TS 6-in. x 6-in. x ¼-in. vertical steel posts that were anchored on a 20-in. tall by 12-in. wide concrete parapet with a 6-in. tall by 6-in. wide brush curb [5], as shown in Figure 6. The steel post was welded to an ASTM A709 Grade 50 post base plate with round oversized holes for the anchor bolts measuring 11 in. x 9½ in. x ¾ in. and with a ⅜-in. 3-way pass weld around all edges [5], as shown in Figure 6. Test no. MN-1 consisted of a 1987 Ford F600 single-unit truck impacting the combination bridge rail (design no. 1) at 50.8 mph and 16.2 degrees, as shown in Figure 6. The impact point was located 5 ft upstream from the splice between post nos. 4 and 5. The performance of test no. MN-1 was determined to be satisfactory according to NCHRP Report 350 [5].

For test no. MN-2 on design no. 1, a 1986 Ford F250 pickup truck impacted the combination bridge railing system at 60.6 mph and 25.5 degrees. The critical impact point was located 4 ft – 11 in. upstream from the splice between post nos. 8 and 9. The post-test investigation on the combination bridge railing system revealed that the pickup truck's wheel climbed the 6-in. tall brush curb, causing the vehicle's front bumper to rise up and extend between the concrete parapet and the upper steel railing system. This extension allowed the front bumper to snag on the steel base plate, steel nuts, anchor bolt ends, and structural steel tube post. Further, the post-test investigation into the vehicle's damage confirmed the snagging evidence observed on the bridge railing hardware. The pickup truck's front bumper contacted the right-front tire, which then was pushed backward into the right-side floorboard, which caused the right-side door and lower body to buckle. Significant undercarriage damage and deformation to the frame was observed due to the vehicle's front bumper contact on the upper railing system. As a result of this occupant compartment deformation, the performance of test no. MN-2 was determined to be unsatisfactory according to the occupant risk criteria set forth in NCHRP Report 350 [5, 1].

Following test no. MN-2, several retrofit options were considered to reduce the potential for vehicle snagging on the vertical steel posts. A retrofit option was chosen to continue the research effort, which consisted of extending the structural steel tube rail forward and expanding the concrete barrier by 4 in. toward the roadway. This option would also reduce the width of the brush curb in front of the concrete barrier, thereby reducing the potential for the brush curb to cause vehicle instabilities during wheel ride up on the curb [5].

Design no. 2 consisted of a 20-in. tall by 16-in. wide concrete parapet. The upper steel railing system was extended by welding a TS 4-in. x 3-in. x ¼-in. steel rail to the front face of the existing TS 6-in. x 3-in. x ¼-in. steel structural tube that was mounted on 10¼-in. tall, TS 6-in. x 6-in. x ¼-in. steel posts, as shown in Figure 7. For test no. MN-3, a 1986 Ford F250 pickup truck impacted the modified combination bridge railing system (design no. 2) at 62.5 mph and 25.9 degrees. The critical impact point was located 4 ft – 11 in. upstream from the splice between post nos. 8 and 9. Although the test vehicle's front bumper snagged on the steel posts, the occupant compartment deformation criteria was judged to be marginally acceptable. All occupant risk evaluation criteria for test no. MN-3 were well below recommended limits. Hence, test no. MN-3 was determined to be acceptable to the criteria set forth in NCHRP Report 350 [5, 1].

For test no. MN-4 on design no. 2, a 1988 Ford Festiva small car impacted the modified combination bridge railing system at 61.0 mph and 20.6 degrees. The critical impact point was located 3 ft – 7¼ in. upstream from the centerline of post no. 8. There was virtually no damage to the upper steel railing system, and the vehicle damage was deemed to be relatively minor. The performance of test no. MN-4 on the MnDOT combination bridge railing system was determined to be satisfactory according to the criteria set forth in NCHRP Report 350 [5, 1].

Following the completion of the crash testing program, MwRSF worked with MnDOT to develop design no. 3 as a recommendation. Design no. 3 consisted of a TS 10-in. x 4-in. x ¼-in. steel tube rail mounted across the TS 7-in. x 5-in. x 5⁄16-in. steel posts, which were anchored on a 20-in. tall by 16-in. wide reinforced concrete parapet [5], as shown in Figure 8.

Since the 1995 study and during the planning of the MASH crash testing program, MnDOT, in consultation with MwRSF, made further modifications to the bridge railing system. Some of these updates included: (1) the brush curb geometry changed from an inclined slope to a vertical front face, measuring 6 in. tall and 2 in. wide with a 1-in. radius at the top, as shown in Figure 4; (2) a new concrete end post was incorporated in combination with a tapered end section between the parapet and upper metal rail, as shown in Figure 4; (3) the post assembly and anchorage hardware was updated; and (4) the anchor holes were updated from oversized to slotted holes. The slotted holes for the anchor bolts were designed to facilitate the construction tolerances at the bridge site. For the last modification, the post was fabricated with a TS 7-in. x 5-in. x 5⁄16-in. steel post that was welded to the post base plate with a ⅜-in. three pass weld, as shown in Figure 8. The new detail used an HSS 7x5x5⁄16 steel structural tube that was welded to the post base plate with a 5⁄16-in. fillet weld, as shown in Figures 3 and 5. The threaded anchor rod length was updated from 10 in. to 12 in. long. The 16-in. x 9½-in. x ¾-in. post base plate was fabricated with a 2-in. diameter vent hole, while the new detail specified a 6-in. by 4-in. rectangular vent hole. MnDOT's prior design set the ¾-in. thick steel post base plate on top of a 1-in. thick epoxy grout pad, while the new revision did not use the epoxy grout pad for the anchorage assembly.

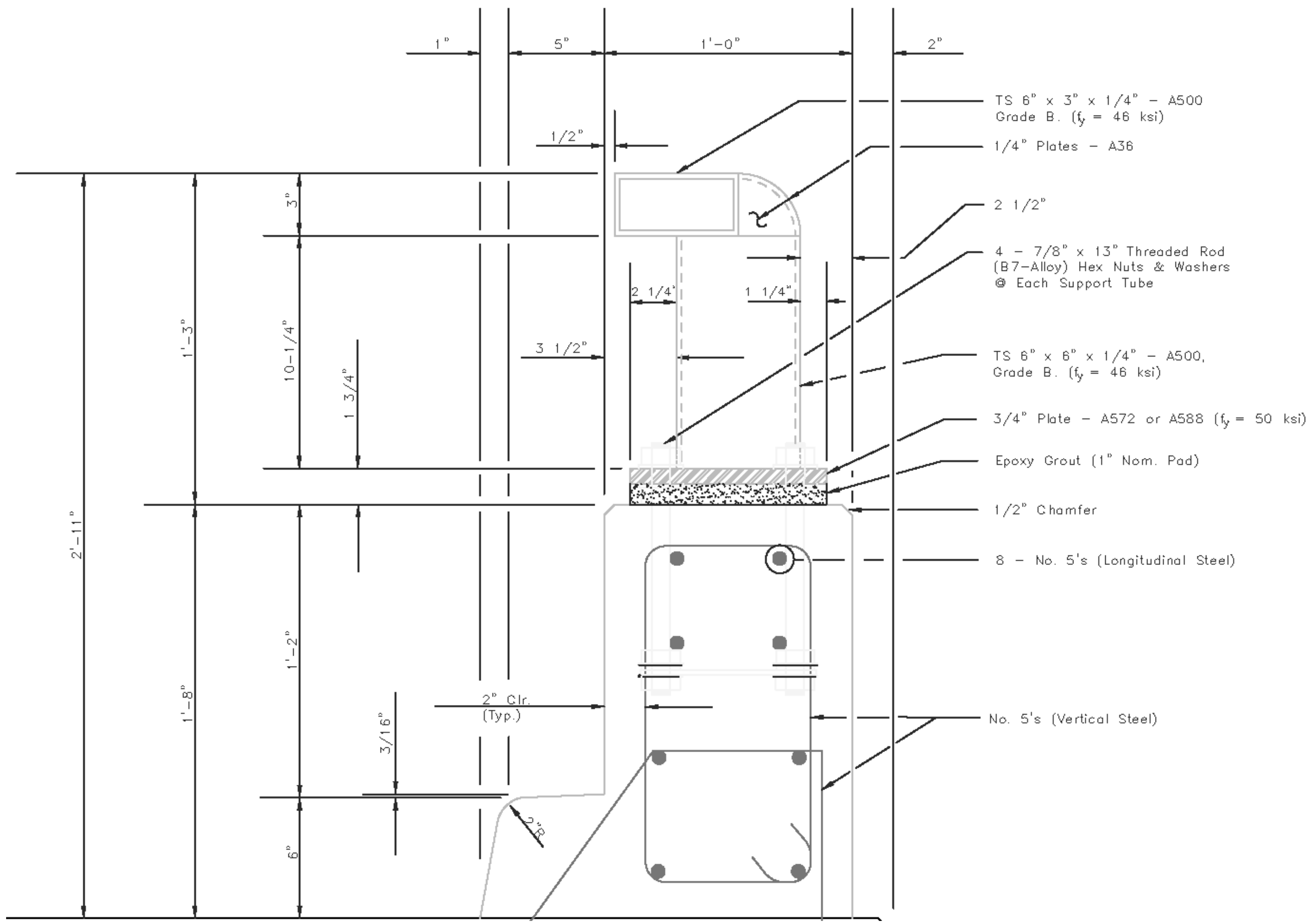


Figure 6. 1995 MnDOT Detail Design No. 1 [5], Test Nos. MN-1 and MN-2

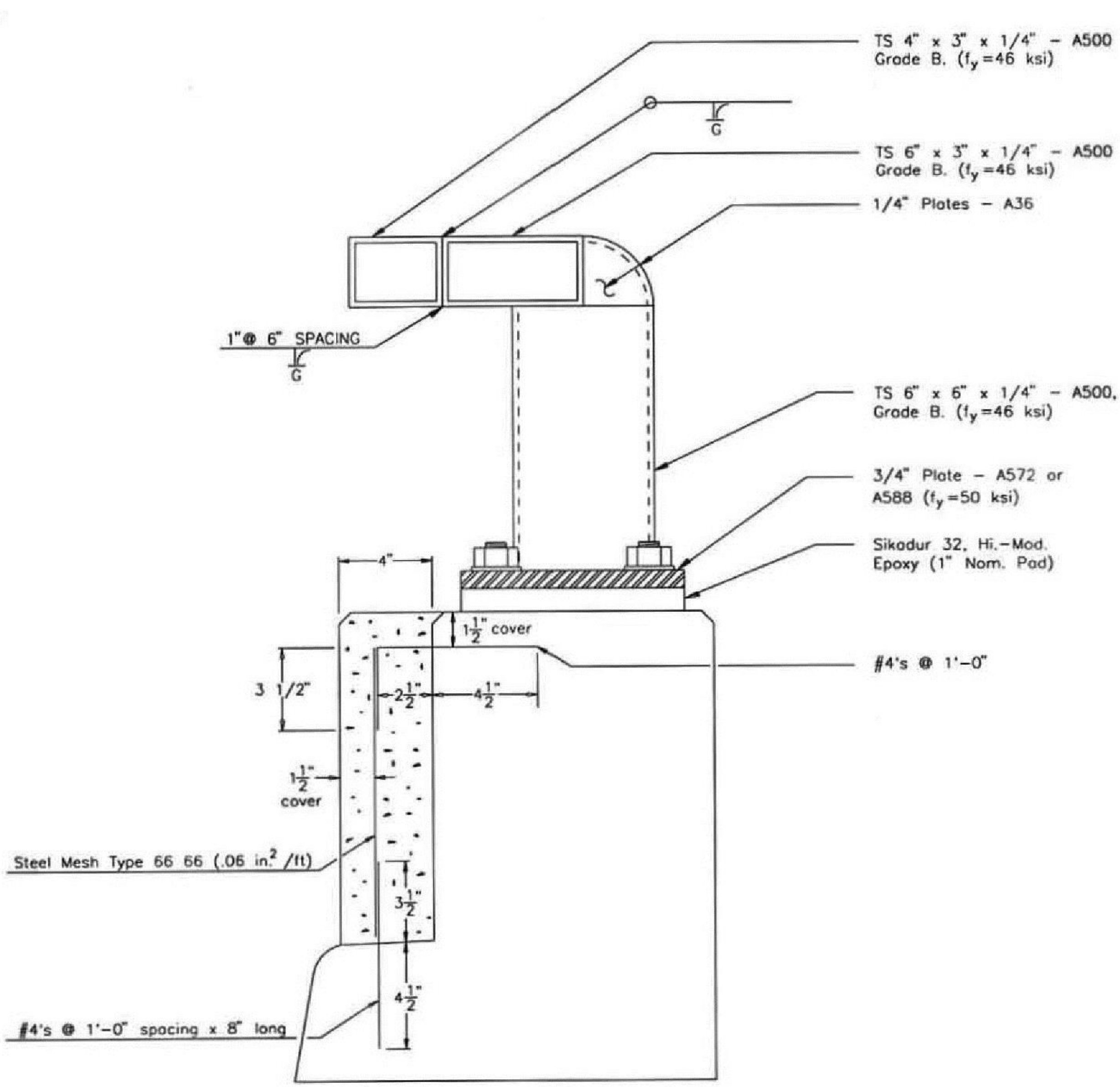


Figure 7. 1995 MnDOT Details Design No. 2 [5], Test No. MN-3 and MN-4

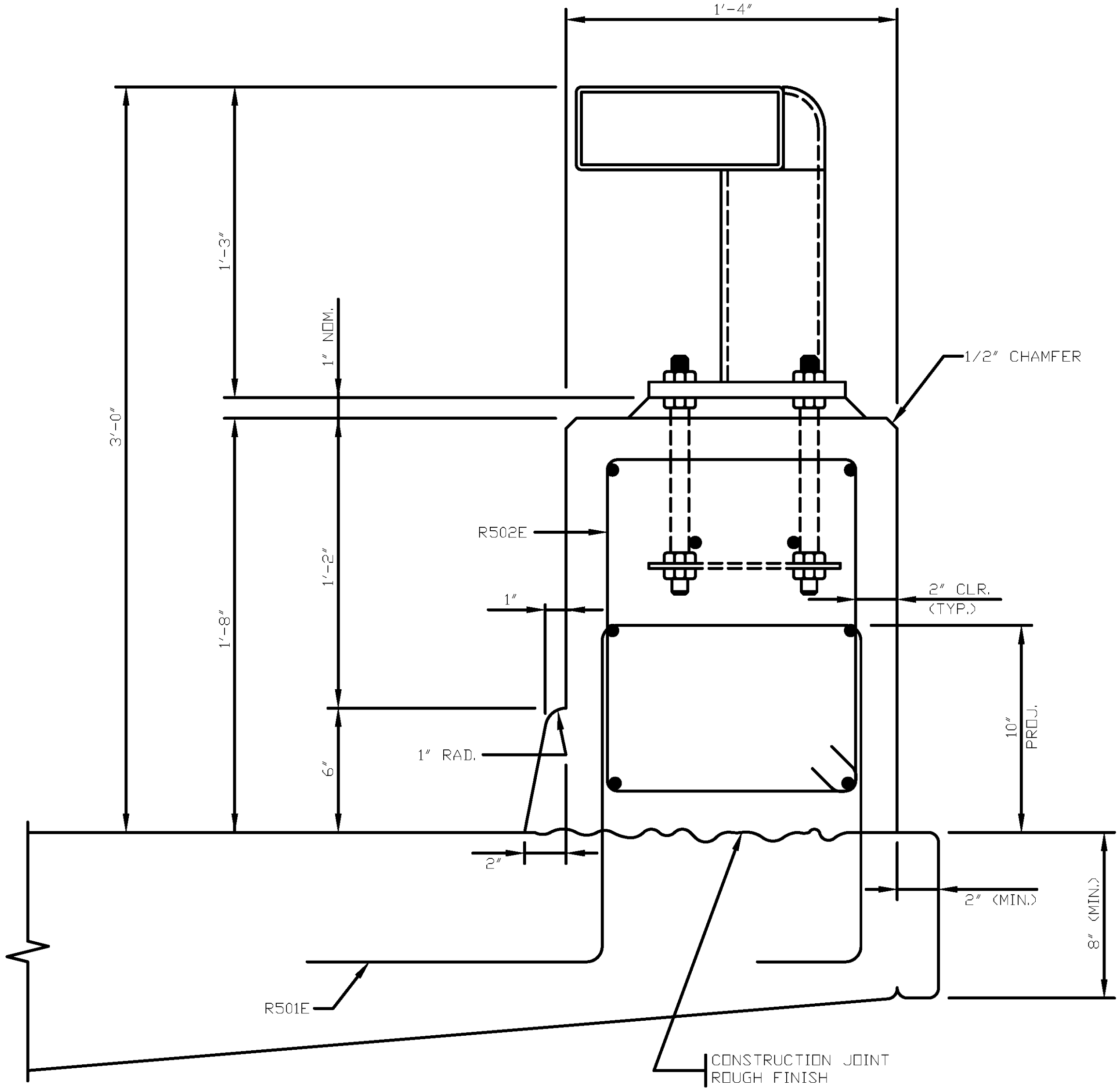


Figure 8. 1995 MnDOT-MwRSF Design No. 3 [5]

1.2 Research Objective

The objective of this research effort was to conduct an AASHTO MASH 2016 TL-4 safety performance evaluation on MnDOT's modified concrete parapet with a brush curb, an upper steel beam and post railing, and a new tapered concrete end section adjacent to a concrete end post.

1.3 Scope

The research objectives included the construction of a test installation consisting of a concrete parapet with a brush curb, an upper steel beam and post railing, and a new tapered concrete end section adjacent to a concrete end post. The test installation was full-scale crash tested and evaluated according to TL-4 safety performance criteria, as published in MASH 2016 [3]. The full-scale vehicle crash tests were conducted in accordance with MASH 2016 test designation nos. 4-10, 4-11, 4-12 with an 1100C small car sedan, a 2270P pickup truck, and a 10000S single-unit truck, respectively [3]. The critical impact points were selected using MASH guidance [3]. A summary of test results was provided herein, along with summary and conclusions.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as rigid barriers, 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 AASHTO MASH 2016 [3]. According to TL-4 of MASH 2016, longitudinal barrier systems must be subjected to three full-scale vehicle crash tests, as summarized in Table 1. Note that there is no difference between MASH 2009 [2] and MASH 2016 [3] for longitudinal barriers, except that additional occupant compartment deformation measurements, photographs, and documentation are required by MASH 2016 [3].

Table 1. MASH 2016 TL-4 Crash Test Conditions for Longitudinal Barriers

Hardware Type	Test Designation No.	Test Vehicle	Vehicle Weight, lb	Target Impact Conditions		Evaluation Criteria [1]
				Speed, mph	Angle, deg.	
Longitudinal Barrier	4-10	1100C	2,420	62	25	A,D,F,H,I
	4-11	2270P	5,000	62	25	A,D,F,H,I
	4-12	10000S	22,000	56	15	A,D,G

[1] Evaluation criteria are explained in Table 2.

Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barriers

<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="12">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td>G.</td><td colspan="3">It is preferable, although not essential, that the vehicle remain upright during and after collision.</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>

2.2 Critical Impact Point

In MASH 2016 [3], the impact point refers to the location at which the test vehicle first contacts the test article. The impact point for a redirective, longitudinal barrier can affect its overall safety performance. The potential for vehicle instability, rollover, snag, pocketing, excessive interior occupant deformation, elevated occupant risk, test article penetration, and structural failure is often associated with the selection of the impact point, used to evaluate the barrier system. Within practical limits, the impact location should be selected to represent the point along the barrier system that will maximize the risk for test failure. The impact location that maximizes the risk of test failure is known as the critical impact point (CIP).

MnDOT's combination bridge railing system is configured with a lower, rigid, reinforced-concrete parapet along with an upper metal beam and post railing. MASH 2016 specifies that post-and-beam longitudinal barriers may have two potential critical CIPs, one associated with wheel snagging and pocketing on a post (i.e., hard point) and another that induces maximum loading to a critical portion of the system, such as a rail splice [3]. For the MnDOT combination bridge railing system, wheel snag on lower posts would not be a concern, as no openings exist within the 21-in. tall concrete parapet. As such, maximum loading to the rigid concrete barrier may more likely be associated with an increase in vehicle deformation. At the time of maximum loading, one may begin to observe the engine hood, front bumper, and front fender panel extending over the top of the rigid concrete parapet, where vehicle-to-barrier contact may occur if the metal railing system is located near the front face of the barrier. If the upper metal railing is located farther away from the front face of the rigid concrete barrier, then additional longitudinal distance and time may be appropriate to allow the vehicle to maximize its lateral extent over the top of the parapet. At this point, the vehicle's upper structure may be able to contact the metal structure, snag on vertical elements, interact with horizontal elements, and laterally load elements at splice locations.

When splices are coincident with a hard point, such as at a vertical support post, a single test can be conducted to evaluate both critical points. If splices are spaced away from a hard point, it may be necessary to conduct two full-scale crash tests with a particular vehicle to properly evaluate CIPs. Due to the fact that rail splices within the new combination bridge railing system are located near vertical support posts, it was believed that vehicle snagging on a post, which is near a splice, as well as maximum loading on a post or splice above the parapet could be evaluated with one test per vehicle type. Before selecting the CIPs, it should be noted that the new combination bridge railing system installed along roads would include a standardized, reinforced-concrete end post at each end along with a lateral tapered end section extending toward the interior and located between the upper railing and the lower parapet. Each lateral tapered end section has a blunt end facing toward the interior bridge rail. This tapered end section and blunt end pose a snag risk to passenger vehicles, similar to the risk posed by the vertical support posts and was therefore evaluated as part of the test program.

For the 10000S single-unit truck, it was determined that one test would be conducted within the upstream interior region to impart maximum loading to the upper beam and post railing near a splice location while providing sufficient bridge rail length to evaluate vehicle containment and redirection without override of the barrier. Note that the tapered end section with a blunt end and vertical support posts provide similar snag risk for the bumpers, engine hoods, and quarter panels of passenger vehicles. Therefore, the 1100C and the 2270P pickup truck crash tests were targeted for the downstream end region, where all of the snag risks could be evaluated with a single test with each passenger vehicle type.

The CIP for a rigid barrier under test designation nos. 4-10, 4-11, and 4-12 are 43.3 in. (1,100 mm), 51.2 in. (1,300 mm), and 59.1 in. (1,500 mm), respectively, as provided in Table 2.7 of MASH 2016 [3]. Each metal rail, post, and mounting plate assembly was attached to the top vertical face of the concrete parapet, which provided a lateral offset of 7½ in. between the front barrier face (excluding brush curb) and the front face of each post. As noted above, it may be prudent to provide additional longitudinal distance and time for the vehicle to maximize its lateral extent over the top of the 21-in. tall concrete parapet. Using a 25-degree impact angle in combination with a 7½-in. lateral post offset, the additional longitudinal distance required to maximize lateral vehicle extent over the top of the parapet would be approximately 16.1 in. When combining the two initial CIP lengths of 43.3 in. (test designation no. 4-10) and 51.2 in. (test designation no. 4-11) with the additional longitudinal distance of 16.1 in., one would obtain modified CIP distances of approximately 59.4 in. and 67.3 in., which would be measured upstream from the upstream face of a vertical support post. Since each vertical support post is 7 in. wide, the modified CIP distances to the centerline of a post for passenger vehicles would be approximately 62.9 in. and 70.8 in. for test designation nos. 4-10 and 4-11, respectively. Based on approximate calculations for the passenger vehicle CIPs early in the project, the target CIPs were selected to be 63½ in. and 70$^{11}/_{16}$ in. for test designation nos. 4-10 and 4-11, respectively, which were measured upstream from the centerline of post no. 23.

In comparison, test nos. MN-2, MN-3, and MN-4 [5] were conducted by MwRSF on the original combination bridge railing system [5] according to TL-4 of the NCHRP Report 350 impact safety standards [1]. For test nos. MN-2 and MN-3, which used a 2000P pickup truck (test designation no. 4-11), the CIP was 59 in. upstream from the second expansion splice, or 35 in. upstream from the centerline of post no. 8. For test no. MN-4, which used an 820C small car (test designation no. 4-10), the CIP was 67¼ in. upstream from the second expansion splice, or 43¼ in. upstream from the centerline of post no. 8.

2.3 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 bridge railing to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH 2016. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in MASH 2016.

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

3 DESIGN DETAILS

The test installation consisted of a 154-ft long concrete parapet with a brush curb, an upper steel beam and post railing system, a downstream concrete end post, and a new tapered end section beyond the last bridge post under the tube rail and above the parapet. The test plan and construction drawings are shown in Figures 9 through 36. Photographs of the construction process and test installation are shown in Figures 37 through 45. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The reinforced concrete parapet consisted of a 21-in. tall by 16-in. wide vertical wall with a lower brush curb on the front face, measuring approximately 6 in. tall by 2 in. wide. A new tapered end section was constructed on the interior side of the downstream concrete end post. The tapered end section was positioned above the concrete barrier and below the tube rail and was anchored to the concrete end post and concrete parapet. Details for the reinforced concrete sections are shown in Figures 9 through 17. All steel reinforcing bars conformed to ASTM A615 Grade 60 and were epoxy-coated according to ASTM A775.

The 154-ft long reinforced, concrete barrier consisted of two different sections called the parapet approach and the concrete barrier. The parapet approach section consisted of the end post with a vertical taper and the new tapered end section with a lateral taper. This section included the downstream end of the combination bridge railing system and extended 13 ft – 4 in. upstream to the saw cut and triangular control joint combination, as shown in Figures 9 through 11, 13, 14, and 16. The vertical taper section started at the end post and consisted of a 32-in. tall reinforced concrete barrier with a vertical taper of 4 in. over 24 in. upstream and ending at a height of 36 in. The vertical concrete taper was reinforced with five rebar sections, as shown in Figures 10 and 16, which consisted of twelve ASTM A615 Grade 60 #5 longitudinal rebar spaced at 11 in. at various heights and ASTM A615 Grade 60 #5 U-shape stirrups measuring 17 in. x 12 in. and embedded 10 in. into the concrete tarmac, as shown in Figure 17. The 10-in. tall, lateral concrete tapered section started with a width of 16 in. and laterally tapered to an 8½ in. width, which extended over 22½ in. It was reinforced with two rebar sections, as shown in Figures 11 and 14, which consisted of ten ASTM A615 Grade 60 #5 longitudinal rebar spaced at 11 in. at various heights, as shown in Figure 17. The lateral tapered end section of the parapet approach was reinforced with four types of stirrups tied together: (1) ASTM A615 Grade 60 #5 vertical stirrups measuring 27 in. long, as shown in Figure 33; (2) ASTM A615 Grade 60 #5 square-shape stirrups measuring 17 in. x 12 in.; (3) ASTM A615 Grade 60 #5 vertical bent stirrups measuring 27 in. long and bent with a 3¾ in. radius, as shown in Figure 33; and (4) ASTM A615 Grade 60 #5 U-shape stirrups measuring 17 in. x 12 in. and embedded 10 in. into the concrete tarmac, as shown in Figure 17.

The concrete barrier section started at the saw cut joint and extended 140 ft upstream. The 140 ft – 8 in. long reinforced-concrete barrier section consisted of a 21-in. tall by 16-in. wide vertical wall with a 2-in. wide by 6-in. tall brush curb, which was cast using a Nebraska 47BD concrete mix with a minimum compressive strength of 4,000 psi. This section was reinforced with six ASTM A615 Grade 60 #5 longitudinal rebar spaced at 11 in. at heights of 4 in., 12⁵⁄₁₆ in., and 17⅛ in., as shown in Figure 17. This section was reinforced with two stirrup types tied together, an ASTM A615 Grade 60 #5 square-shape stirrup measuring 17 in. x 12 in. and an ASTM A615 Grade 60 #5 U-shape stirrup embedded 10 in. into the concrete tarmac, as shown in Figures 12 and 17. Although the barrier may be anchored to various foundations, such as bridge decks, the vertical steel was anchored into existing concrete tarmac for testing purposes, as shown in Figure 37 [8].

All steel reinforcing bars were epoxy-coated according to ASTM A775. The overall height of the system with the parapet and the steel railing was 36 in.

The combination bridge railing system utilized a total of eight rail and post assemblies, which consisted of one rail and post assembly anchored to the top face of the concrete parapet near the new tapered end section. This rail and post assembly consisted of: (1) one 122½-in. long ASTM A500 Grade B HSS 10x4x¼ steel tube; (2) one ASTM A709 Grade 50 rail end plate, measuring 10 in. x 4 in. x ¼ in., which was welded to the downstream end of the rail with a 3/16-in. fillet weld on the sides; (3) two ASTM A500 Grade B HSS 7x5x5/16 steel tubes; (4) four ASTM A709 Grade 50 post plates, measuring 4 in. x 2 in. x ¼ in.; (5) two ASTM A709 Grade 50 post base plates, measuring 16 in. x 9½ in. x ¾ in.; (6) two ASTM A709 Grade 50 post bent plates, measuring 6½ in. x 4⅞ in. x 5/16 in.; and (7) one ASTM A500 Grade B rail sleeve, measuring 9⅜ in. x 3⅜ in. x ¼ in. on the upstream end of the assembly with a 3/16-in. fillet weld on the sides and a 6-in. long overhang that is used to connect the next rail and post assembly with a 1-in. gap between rail ends. All components for rail and post assemblies were treated according to ASTM A123 hot-dip galvanizing, as shown in Figure 21.

The post and rail assemblies for the next seven assemblies used: (1) 239-in. long ASTM A500 Grade B HSS 10x4x¼ posts; (2) three ASTM A500 Grade B HSS 7x5x5/16 posts; (3) six ASTM A709 Grade 50 post plates, measuring 4 in. x 2 in. x ¼ in.; (4) three ASTM A709 Grade 50 post base plates, measuring 16 in. x 9½ in. x ¾ in.; (5) three ASTM A709 Grade 50 post bent plates, measuring 6½ in. x 4⅞ in. x 5/16 in.; and (6) one ASTM A500 Grade B rail sleeve, measuring 9⅜ in. x 3⅜ in. x ¼ in. on the upstream end of the assembly with a 3/16-in. fillet weld on the sides and a 6-in. overhang that is used to connect the next rail and post assembly with a 1-in. gap between rail ends. All components for rail and post assemblies were treated according to ASTM A123 hot-dip galvanizing, as shown in Figure 23.

The post attachment consisted of ASTM A500 Grade B HSS 7x5x5/16 posts, which was welded to an ASTM A709 Grade 50 post base plates, measuring 16 in. x 9½ in. x ¾ in. with a 5/16-in. fillet weld around all edges. An ASTM A709 Grade 50 post bent plate, measuring 6½ in. x 4⅞ in. x 5/16 in., was welded to the back side of the top of the steel tubing. The back side of the rail consisted of an ASTM A500 Grade B HSS 10x4x¼ with two weld options, as shown in Figures 22, 29, and 30.

Four fabrication methods were developed for the 9⅜-in. x 3⅜-in. x ¼-in. rail sleeve assembly. Option 1 consisted of two ASTM A709 Grade 50 plates, each measuring 10 in. x 8⅞ in. x ¼ in., which were welded at the corners with a ¼-in. fillet weld to two ASTM A709 Grade 50 plates, each measuring 10 in. x 2⅞ in. x ¼ in., as shown in Figure 25. Option 2 consisted of an HSS 9x3x¼ with a 10-in. x 8-in. x 3/16-in. ASTM A709 Grade 50 plate welded to the top and bottom faces of the HSS tube with a ¼-in. fillet weld on all sides, as shown in Figure 26. A 10-in. x 2-in. x 3/16-in. ASTM A709 Grade 50 plate was welded to each of the side faces of the HSS tube with a ¼-in. fillet weld on all sides, as shown in Figure 26. Option 3 consisted of two ASTM A709 Grade 50 plates, each bent to an L-shape and measuring 9⅛ in. x 3⅛ in. x ¼ in., which were welded at two corners with a ¼-in. fillet weld to comply with the rail sleeve dimensions of 9⅜ in. x 3⅜ in. x ¼ in., as shown in Figure 27. Option 4 consisted of two ASTM A709 Grade 50 plates, each bent to an C-shape with a radius of ½ in. at the corners and measuring 9⅜ in. x 1 11/16 in. x ¼ in., which were welded together along the side corners with a ¼-in. fillet weld to comply with the rail sleeve dimensions of 9⅜ in. x 3⅜ in. x ¼ in., as shown in Figure 28.

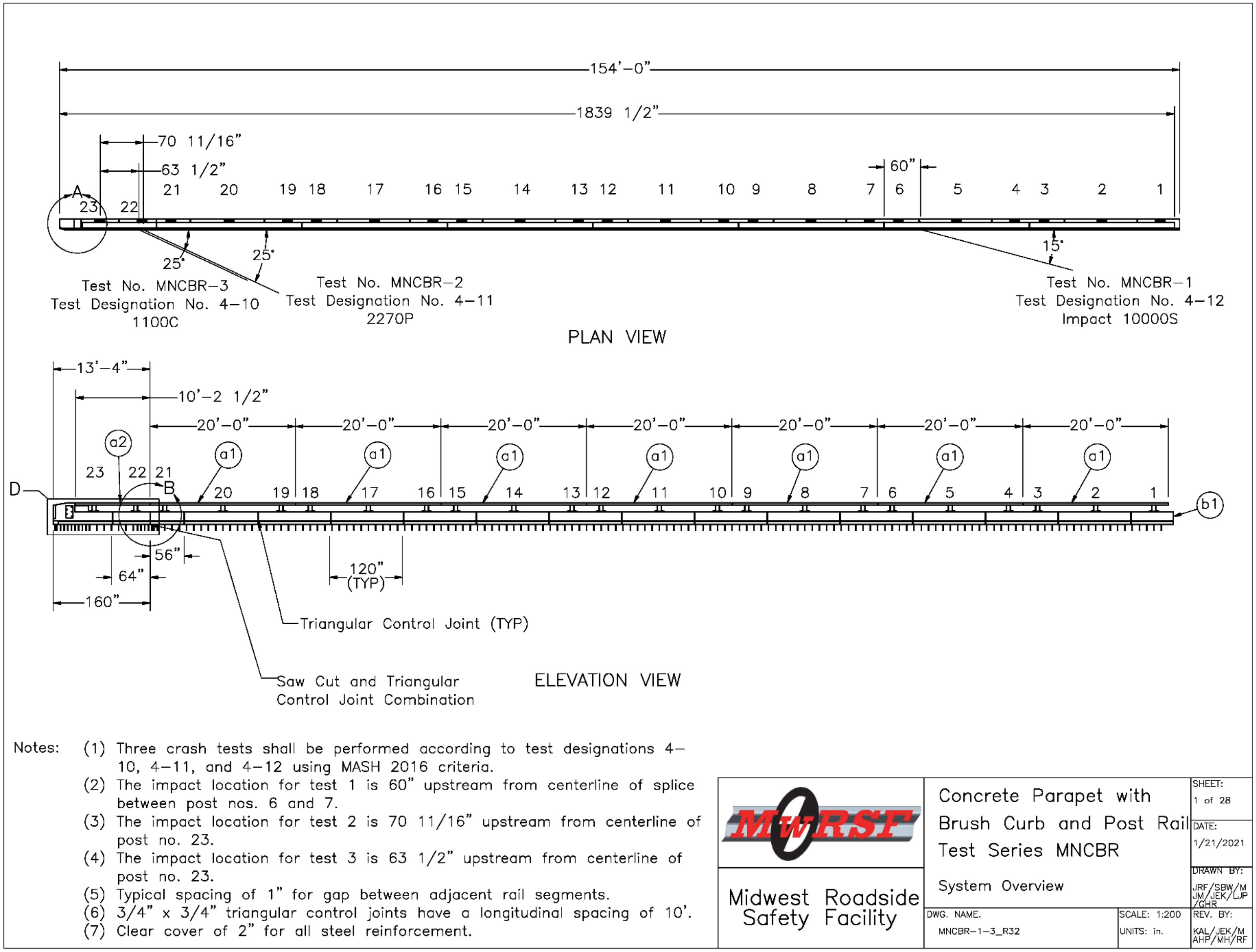


Figure 9. System Layout, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

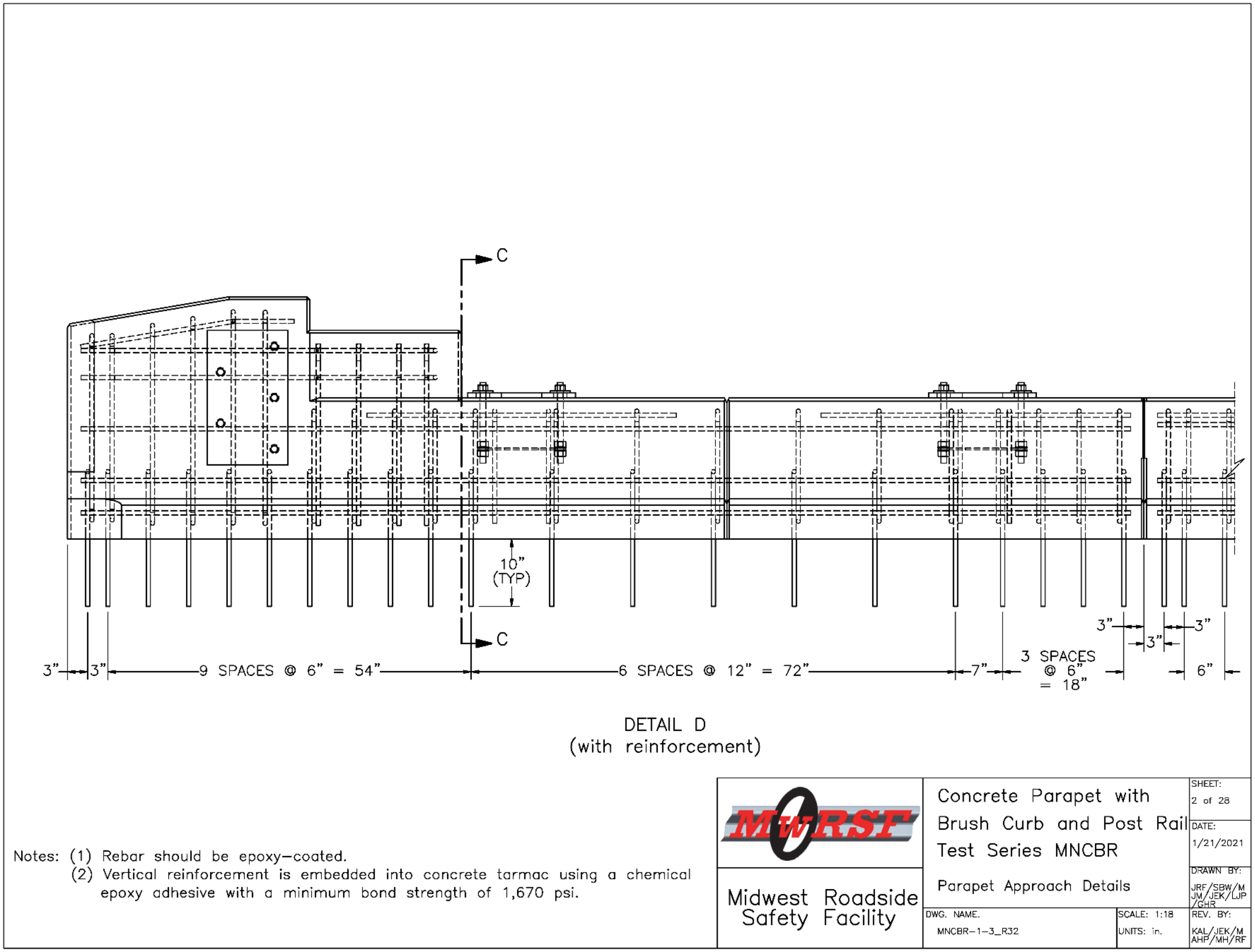


Figure 10. Parapet Approach Details, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

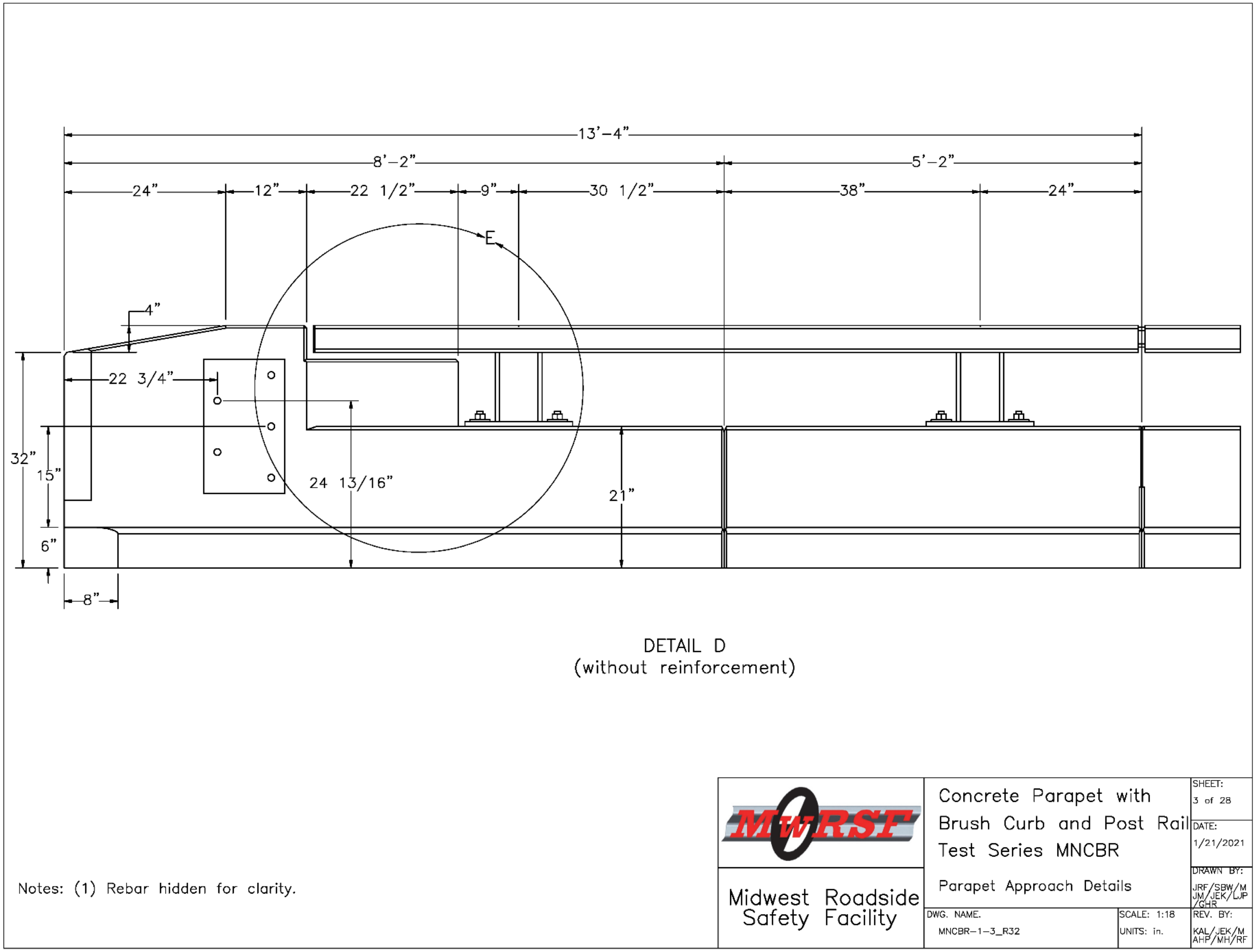
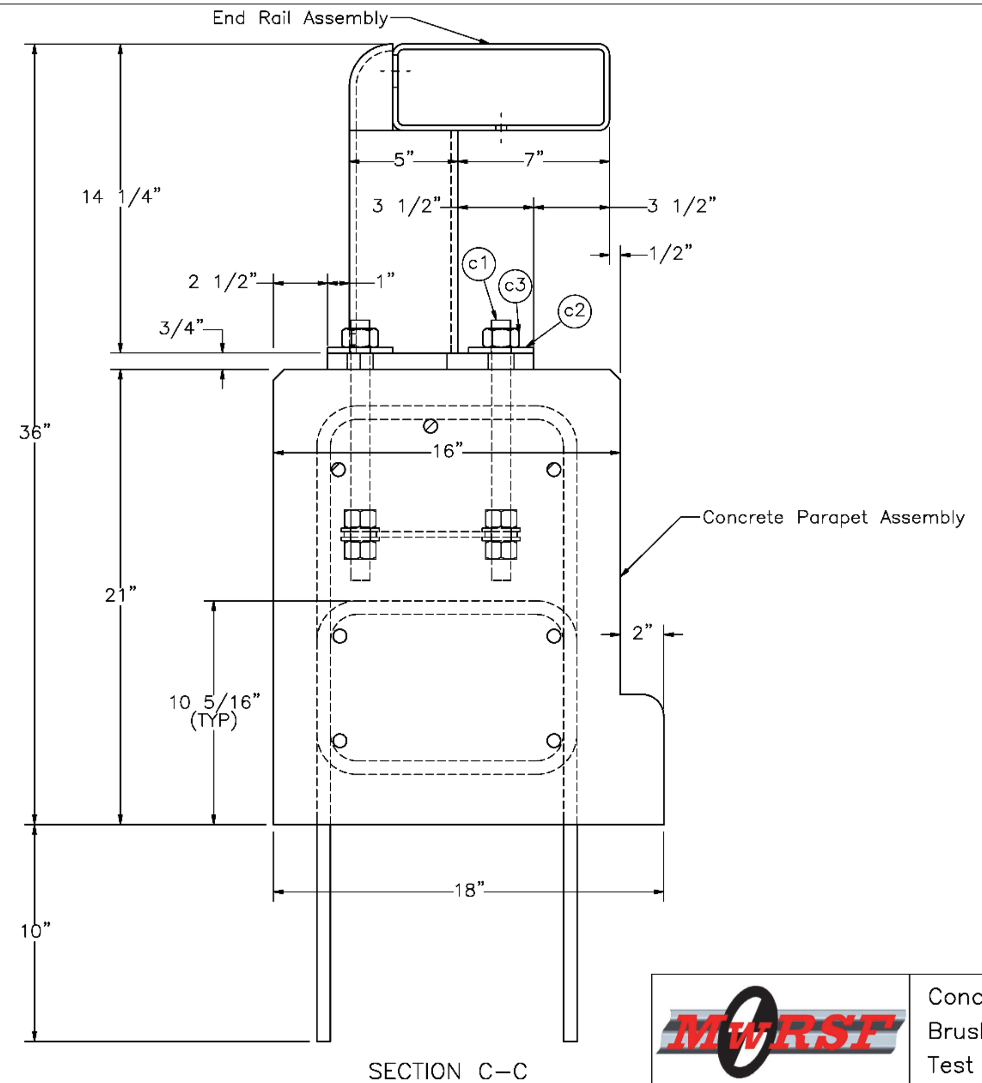


Figure 11. Parapet Approach Details, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Notes: (1) Rebar should be epoxy–coated.
(2) Vertical reinforcement is embedded into concrete tarmac using a chemical epoxy adhesive with a minimum bond strength of 1,670 psi.

Midwest Roadside Safety Facility	Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR Profile View	SHEET: 4 of 28 DATE: 1/21/2021 DRAWN BY: JRF/SBW/M JM/JEK/LJP /GHR
	DWG. NAME. MNCBR–1–3_R32	SCALE: 1:7 UNITS: in. / REV. BY: KAL/JEK/M AHP/MH/RF

Figure 12. Profile View, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

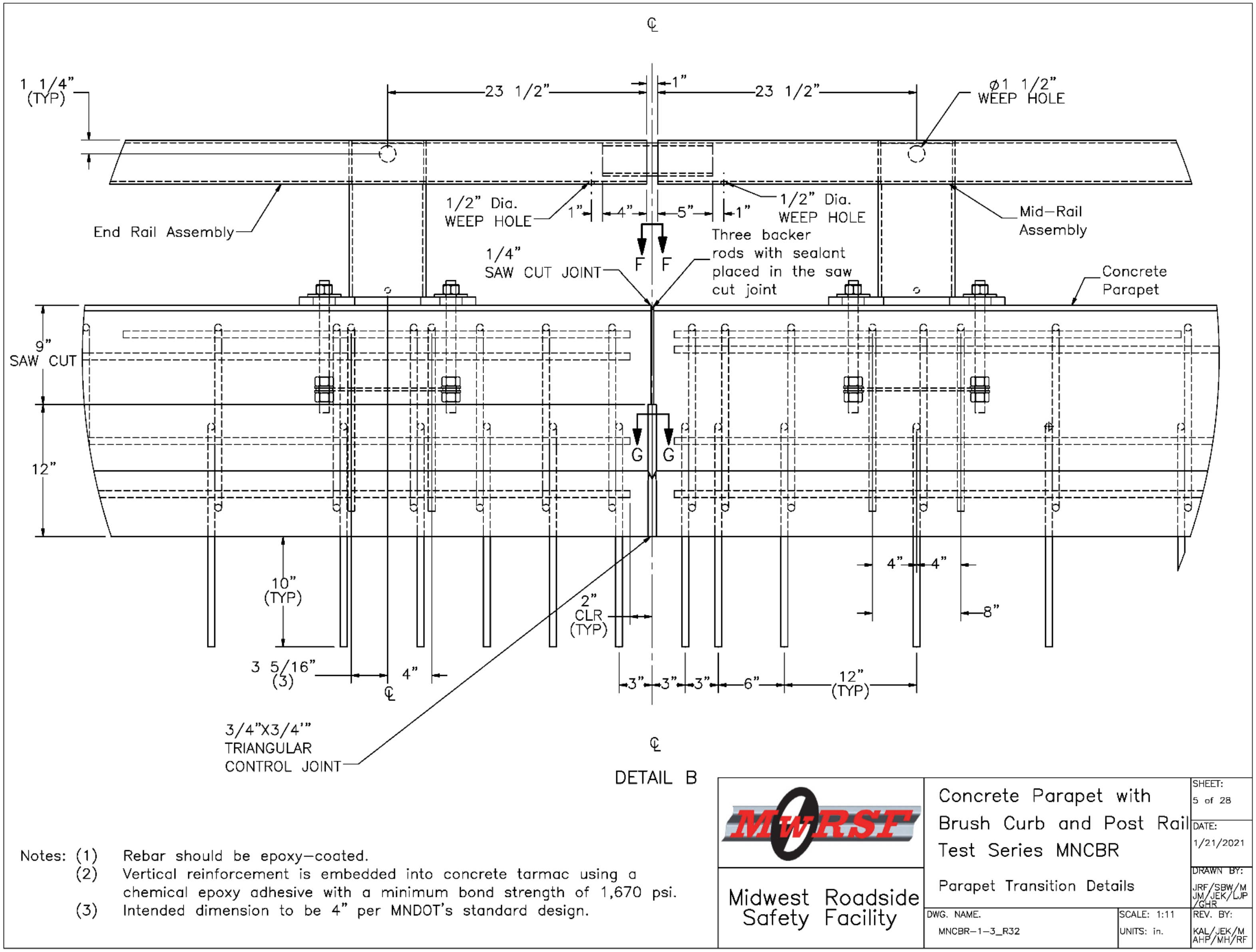


Figure 13. Parapet Transition, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

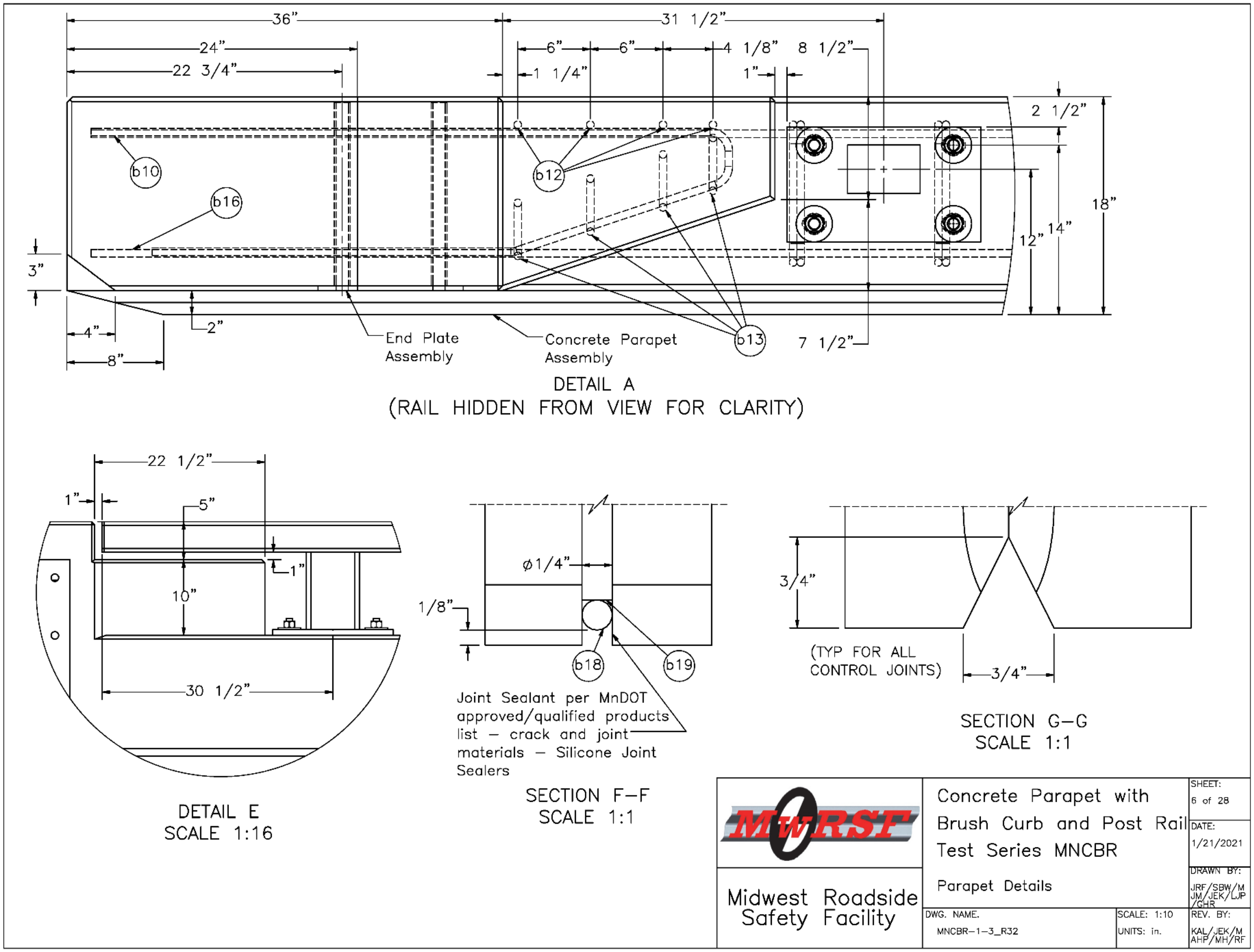
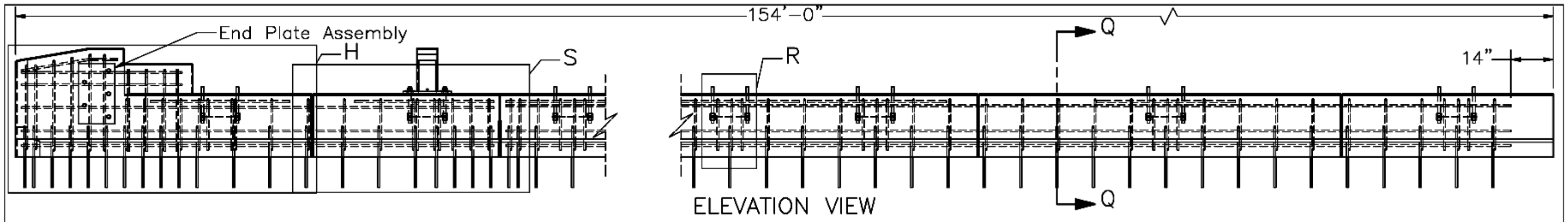


Figure 14. New Taper End Section, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Concrete Parapet Assembly	–	–
–	1	End Plate Assembly	–	ASTM A123
b1	1	Concrete	Min. f'c = 4000 psi	–
b2	160	#5 Rebar, 50" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b3	1	#5 Rebar, 48" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b4	2	#5 Rebar, 46 3/4" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b5	156	#5 Rebar, 70" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b6	2	#5 Rebar, 100" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b7	1	#5 Rebar, 98" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b8	1	#5 Rebar, 96" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b9	2	#5 Rebar, 90" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b10	2	#5 Rebar, 109 5/16" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b11	2	#5 Rebar, 32" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b12	4	#5 Rebar, 27" Total Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b13	4	#5 Rebar, 33 7/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b14	46	#5 Rebar, 45 3/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b15	22	#5 Rebar, 46" Total Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b16	6	#5 Rebar, 156" Total Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b17	6	#5 Rebar, 1672" Total Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b18	2	1/4" Dia., 8 5/8" Long Vertical Backer Rod	–	Not Needed
b19	1	1/4" Dia., 15 1/4" Long Horizontal Backer Rod	ASTM D5249 Type 3	Not Needed
c1	92	7/8"–9 UNC, 12" Long Vertical Anchor Rod	ASTM F1554 Gr. 105	ASTM A153
c3	152	7/8"–9 UNC Heavy Hex Nut	ASTM A563DH	ASTM A153
c4	23	13"x8"x1/4" Anchor Plate	ASTM A709 Gr. 50	ASTM A123
c5	184	7/8" Dia. SAE Washer	ASTM A709 Gr. 50	ASTM A153

Notes: (1) Rebar should be epoxy–coated.
(2) Vertical reinforcement is embedded into concrete tarmac using a chemical epoxy adhesive with a minimum bond strength of 1,670 psi.

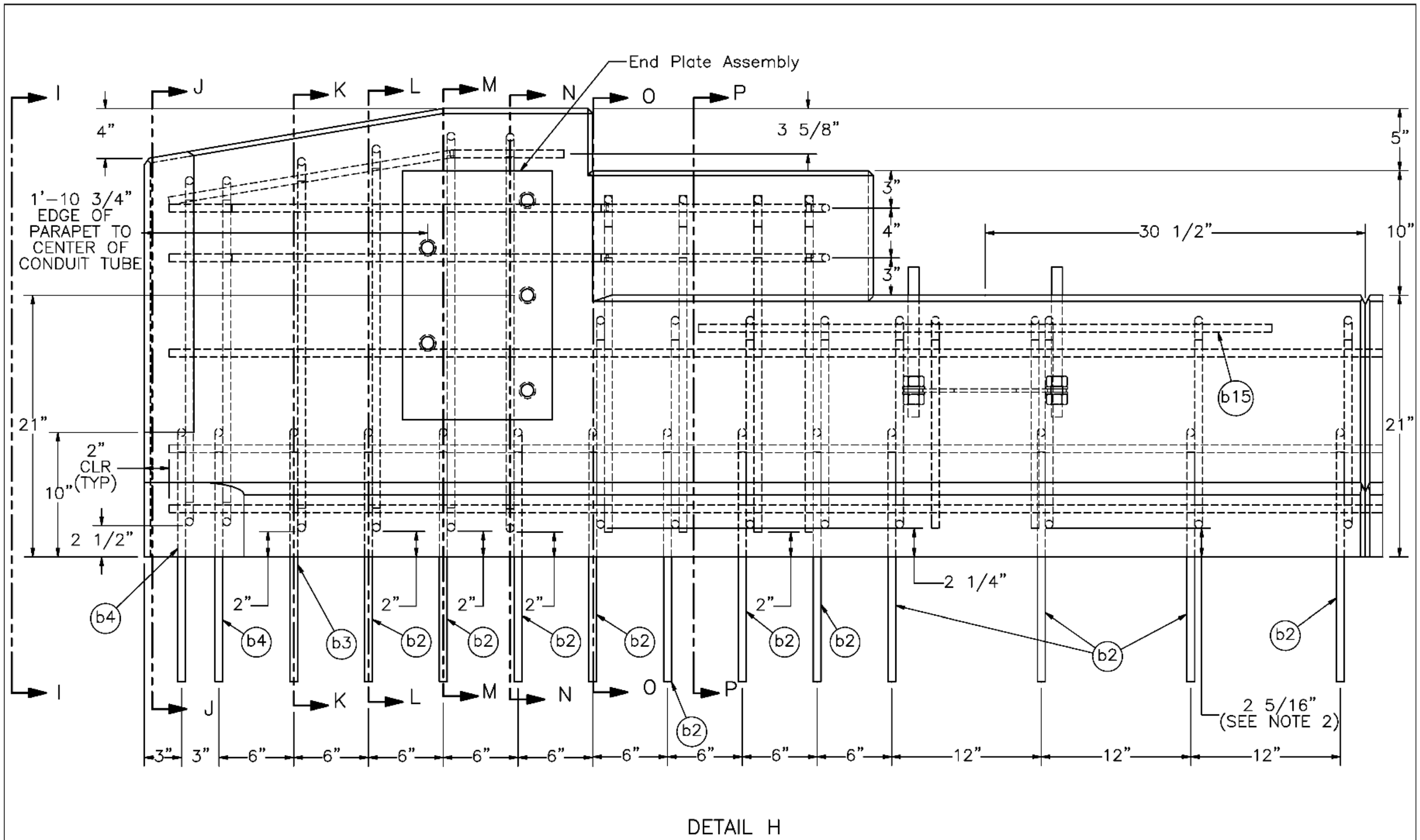
Midwest Roadside Safety Facility

Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

Concrete Parapet Assembly

SHEET: 7 of 28
DATE: 1/21/2021
DRAWN BY: JRF/SBW/MJM/JEK/LJP/GHR
REV. BY: KAL/JEK/MAHP/MH/RF
DWG. NAME. MNCBR–1–3_R32
SCALE: 1:50
UNITS: in.

Figure 15. Concrete Parapet, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Notes:

(1) All edges are finished with a 1/2" chamfer except where otherwise noted.

(2) Clear cover on barrier bottom varies according to provided bar dimensions.

(3) Rebar should be epoxy-coated.

(4) Vertical reinforcement is embedded into concrete tarmac using a chemical epoxy adhesive with a minimum bond strength of 1,670 psi.

Midwest Roadside Safety Facility	Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR Parapet Details	SHEET: 8 of 28 DATE: 1/21/2021 DRAWN BY: JRF/SBW/MJM/JEK/LJP/CHR
	DWG. NAME. MNCBR-1-3_R32 · SCALE: 1:11 UNITS: in.	REV. BY: KAL/JEK/MAHP/MH/RF

Figure 16. New Taper End Section Rebar Details, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

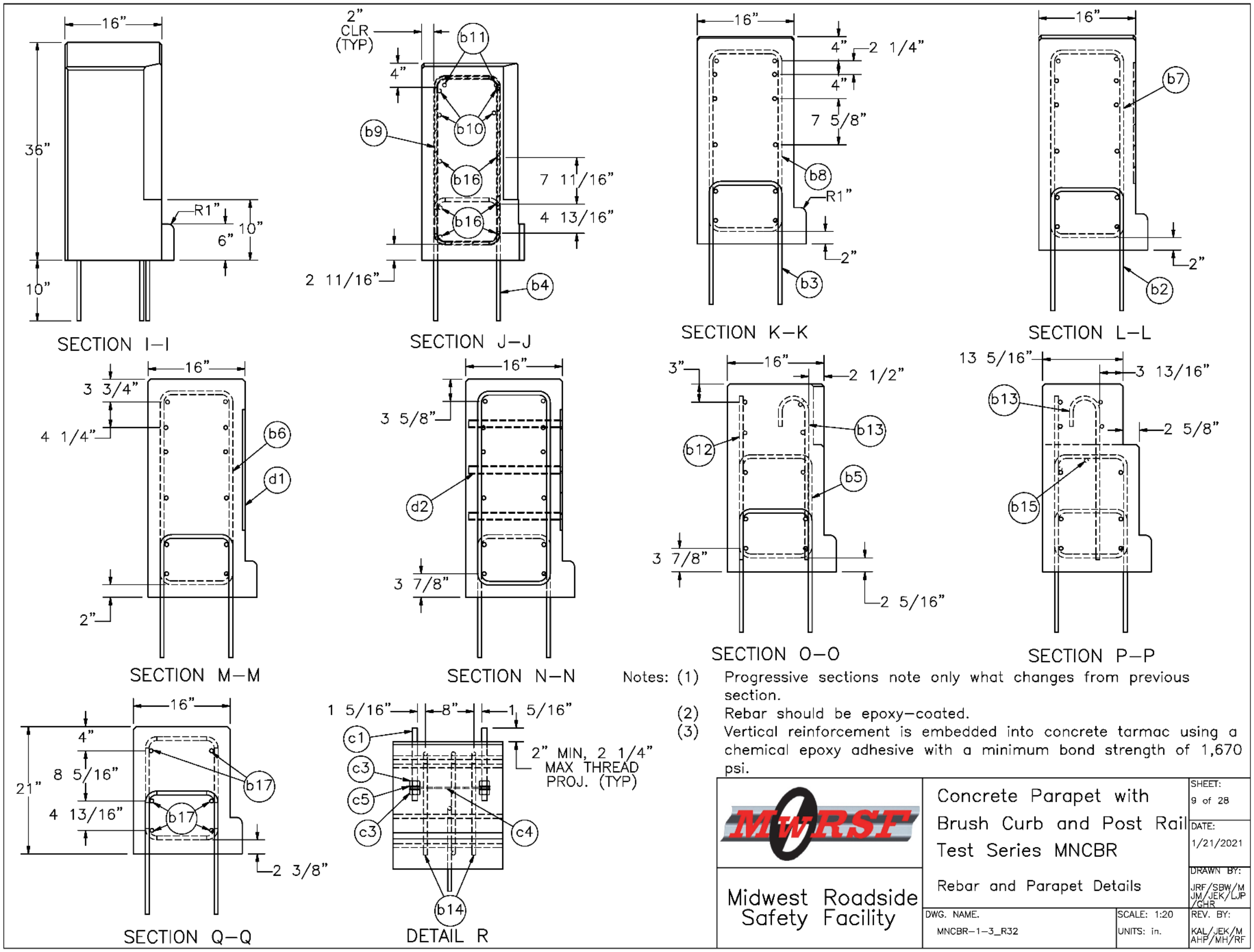


Figure 17. Rebar Details, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

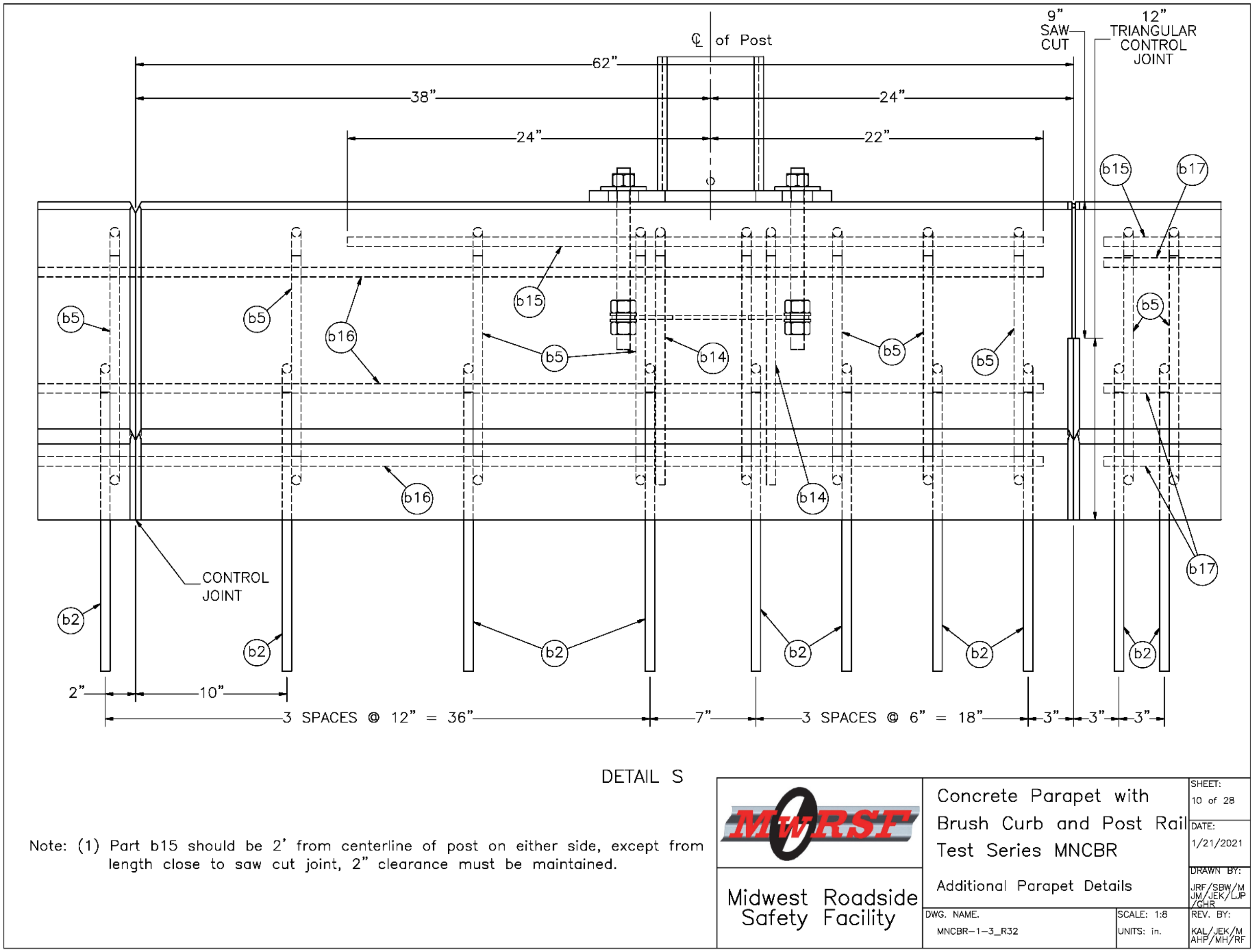
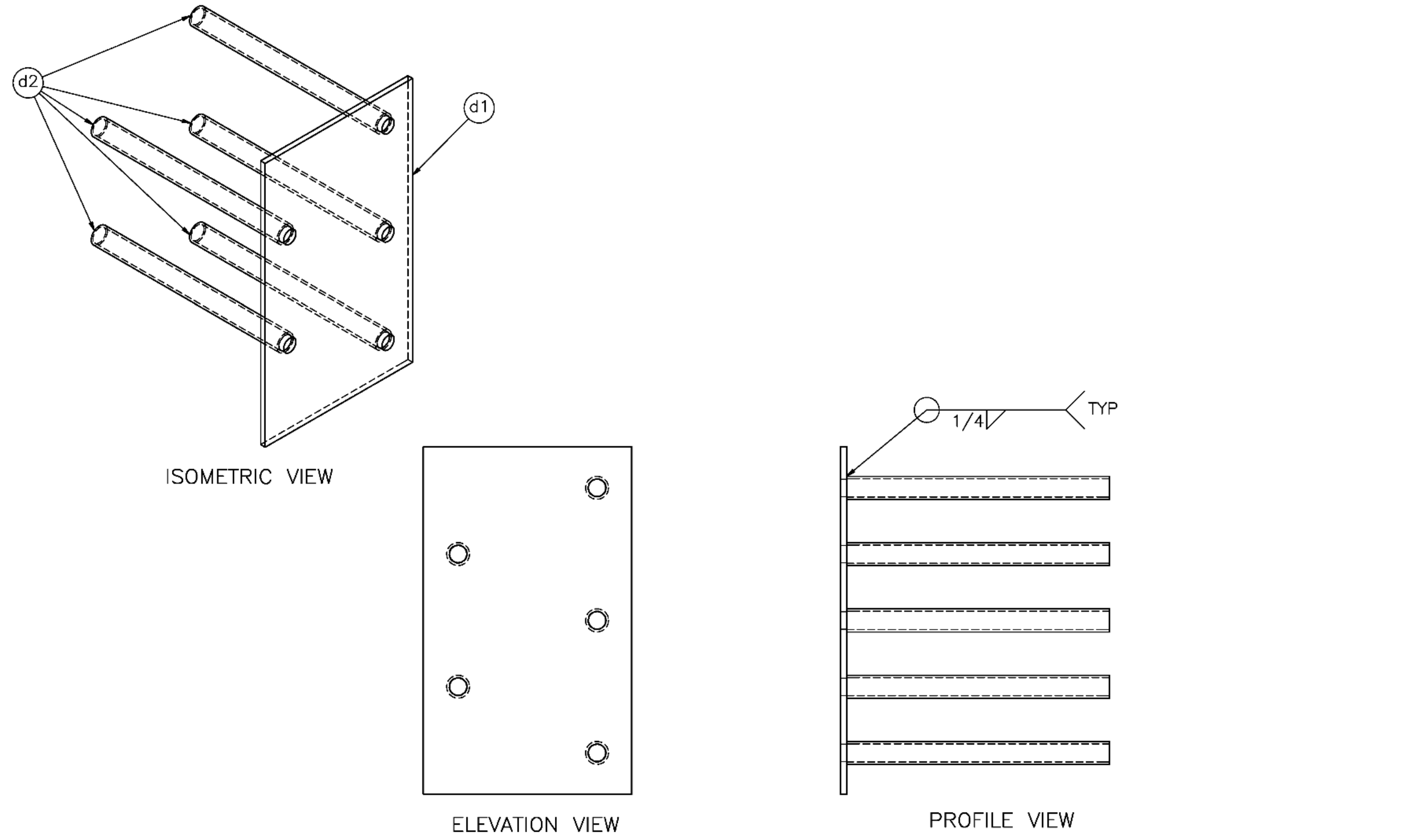


Figure 18. Additional Rebar Details, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	End Plate Assembly	–	ASTM A123
d1	1	12"x20"x3/8" End Plate	ASTM A709 Gr. 50	See Assembly
d2	5	1.049" ID 1.68 lb/ft Standard Pipe, 15 1/8" Long	ASTM A53 Schedule 40	See Assembly

MwRSF
Midwest Roadside Safety Facility

Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

End Plate Assembly

SHEET: 11 of 28	DATE: 1/21/2021	DRAWN BY: JRF/SBW/M JM/JEK/LJP /GHR	REV. BY: KAL/JEK/M AHP/MH/RF
DWG. NAME. MNCBR-1-3_R32	SCALE: 1:8	UNITS: in.	

Figure 19. End Plate Assembly, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

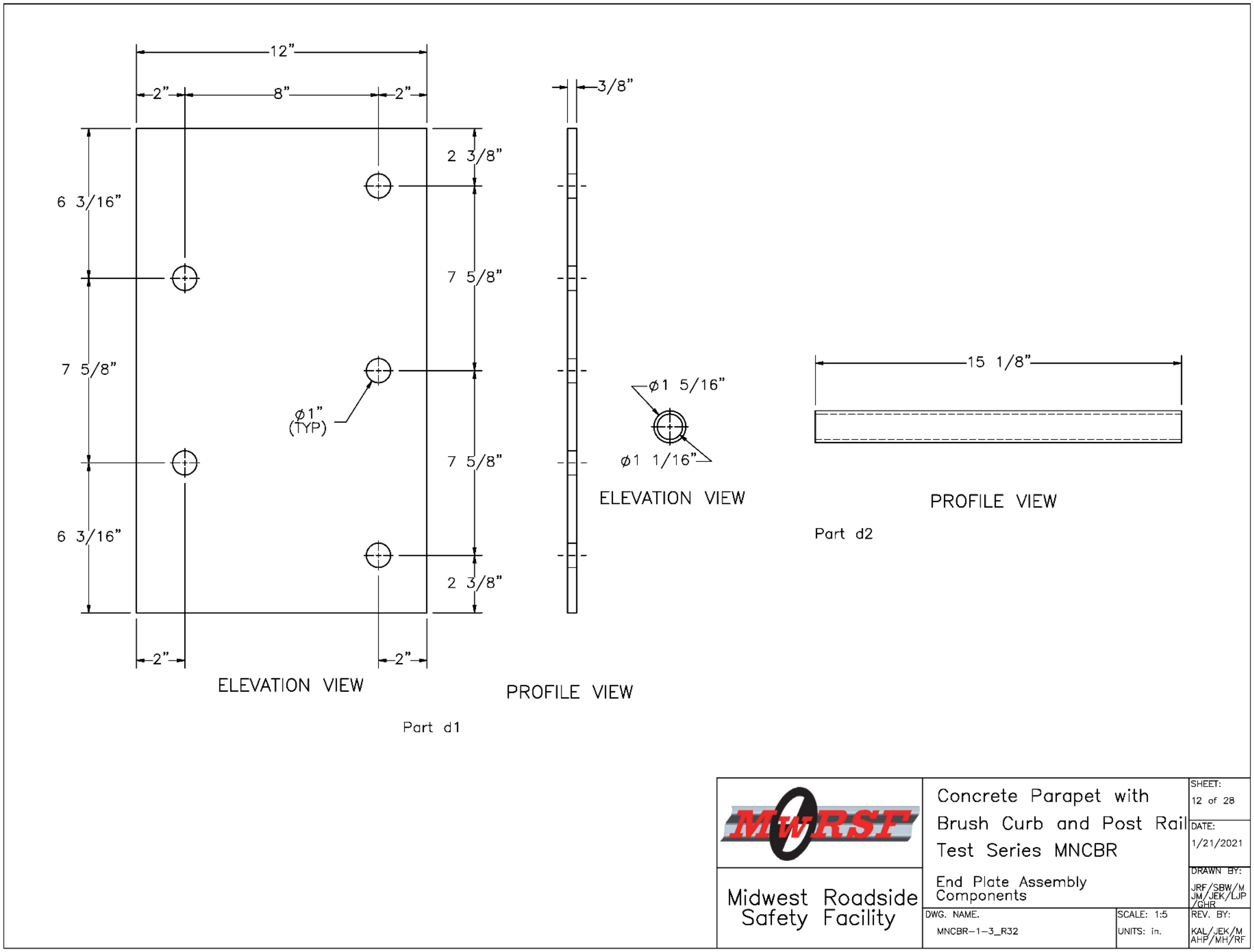
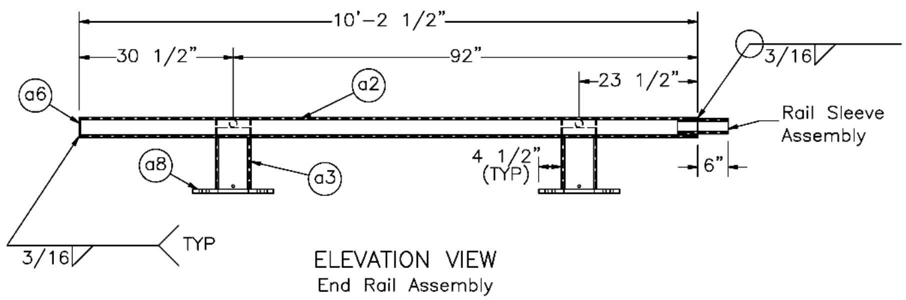
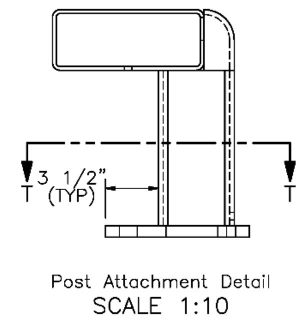
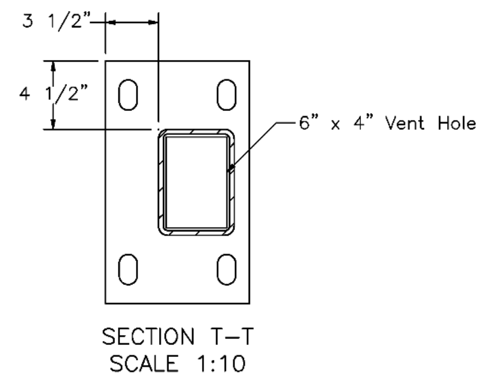


Figure 20. End Plate Assembly Components, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3







Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	End Rail Assembly	–	ASTM A123
a2	1	HSS10"x4"x1/4", 10'–2 1/2" Long Tube Rail	ASTM A500 Gr. B	See Assembly
a3	2	HSS 7"x5"x5/16", 10 1/4" Long Tube Post	ASTM A500 Gr. B	See Assembly
a5	4	4"x2"x1/4" Post Plate	ASTM A709 Gr. 50	See Assembly
a6	1	10"x4"x1/4" Rail End Plate	ASTM A709 Gr. 50	See Assembly
a7	2	16"x9 1/2"x3/4" Post Base Plate	ASTM A709 Gr. 50	See Assembly
a8	2	6 1/2"x4 7/8"x5/16" Post Bent Plate	ASTM A709 Gr. 50	See Assembly
a13	1	9"x3"x1/4", 10" Long Rail Sleeve	ASTM A500 Gr. B	See Assembly

Midwest Roadside Safety Facility

Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

Rail and Post Assemblies State Standard Drawing

SHEET:	13 of 28
DATE:	1/21/2021
DRAWN BY:	JRF/SBW/M JM/JEK/LJP /CHR
DWG. NAME.	MNCBR–1–3_R32
SCALE:	1:30
UNITS:	in.
REV. BY:	KAL/JEK/M AHP/MH/RF

Figure 21. Rail and Post Assemblies, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

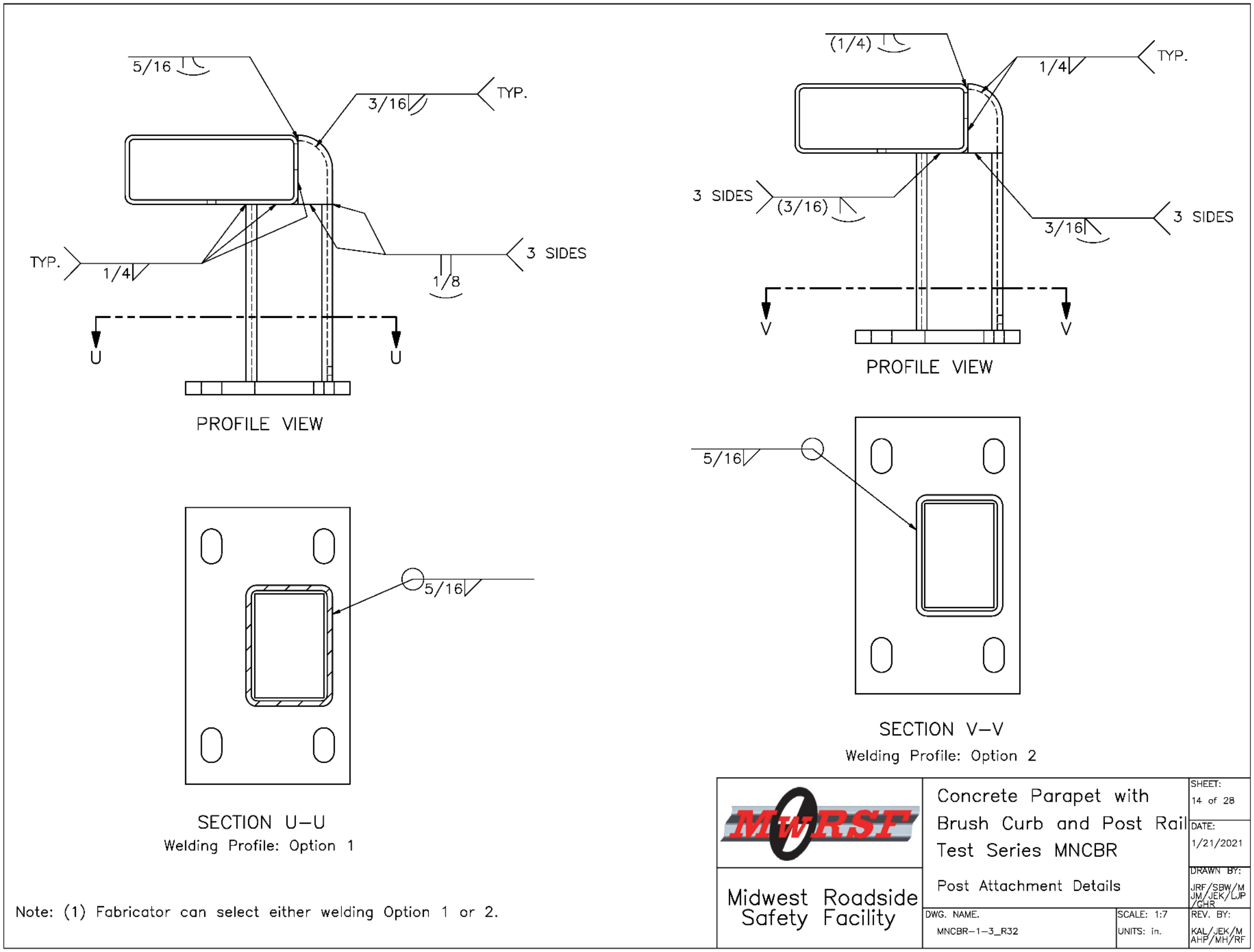
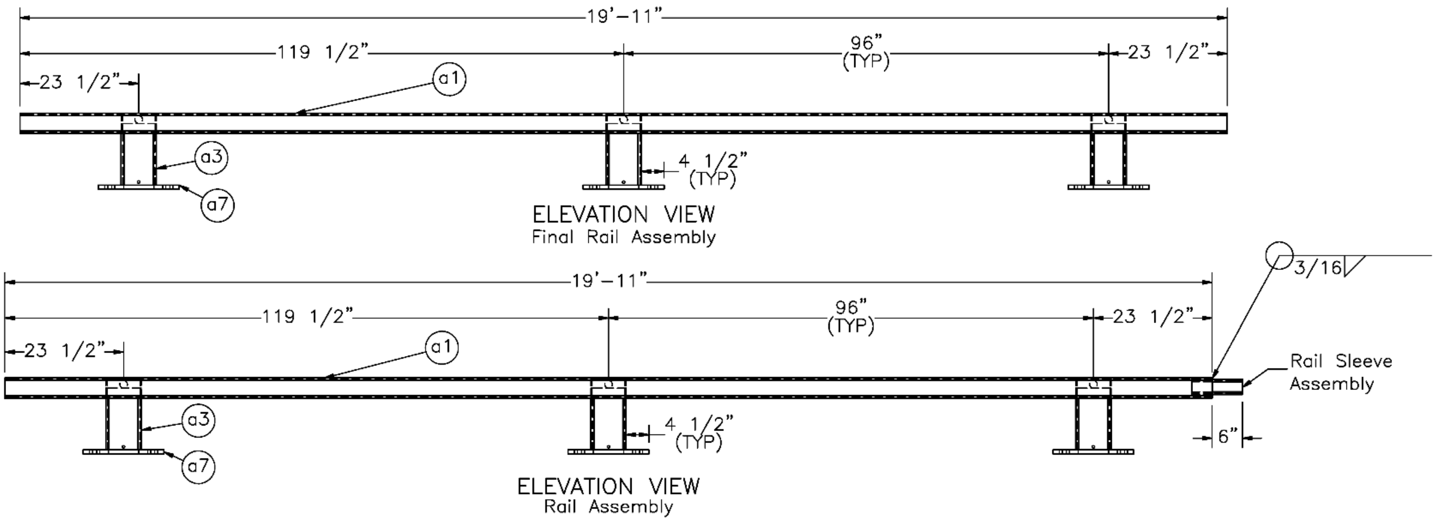


Figure 22. Post Attachment Details, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Final Rail Assembly	–	ASTM A123
a1	1	HSS10"x4"x1/4", 19' 11" Long Tube Rail	ASTM A500 Gr. B	See Assembly
a3	3	HSS 7"x5"x5/16", 10 1/4" Long Tube Post	ASTM A500 Gr. B	See Assembly
a5	6	4"x2"x1/4" Post Plate	ASTM A709 Gr. 50	See Assembly
a7	3	16"x9 1/2"x3/4" Post Base Plate	ASTM A709 Gr. 50	See Assembly
a8	3	6 1/2"x4 7/8"x5/16" Post Bent Plate	ASTM A709 Gr. 50	See Assembly

Item No.	QTY.	Description	Material Specification	Treatment Specification
–	6	Rail Assembly	–	ASTM A123
a1	1	HSS10"x4"x1/4", 19' 11" Long Tube Rail	ASTM A500 Gr. B	See Assembly
a3	3	HSS 7"x5"x5/16", 10 1/4" Long Tube Post	ASTM A500 Gr. B	See Assembly
a5	6	4"x2"x1/4" Post Plate	ASTM A709 Gr. 50	See Assembly
a7	3	16"x9 1/2"x3/4" Post Base Plate	ASTM A709 Gr. 50	See Assembly
a8	3	6 1/2"x4 7/8"x5/16" Post Bent Plate	ASTM A709 Gr. 50	See Assembly
a13	1	HSS 9"x3"x1/4", 10" Long Rail Sleeve	ASTM A500 Gr. B	See Assembly

Midwest Roadside Safety Facility

Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

Rail Assemblies

SHEET: 15 of 28
DATE: 1/21/2021
DRAWN BY: JRF/SBW/MJM/JEK/LJP/GHR
DWG. NAME. MNCBR-1-3_R32
SCALE: 1:30
UNITS: in.
REV. BY: KAL/JEK/MAHP/MH/RF

Figure 23. Rail Assemblies, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

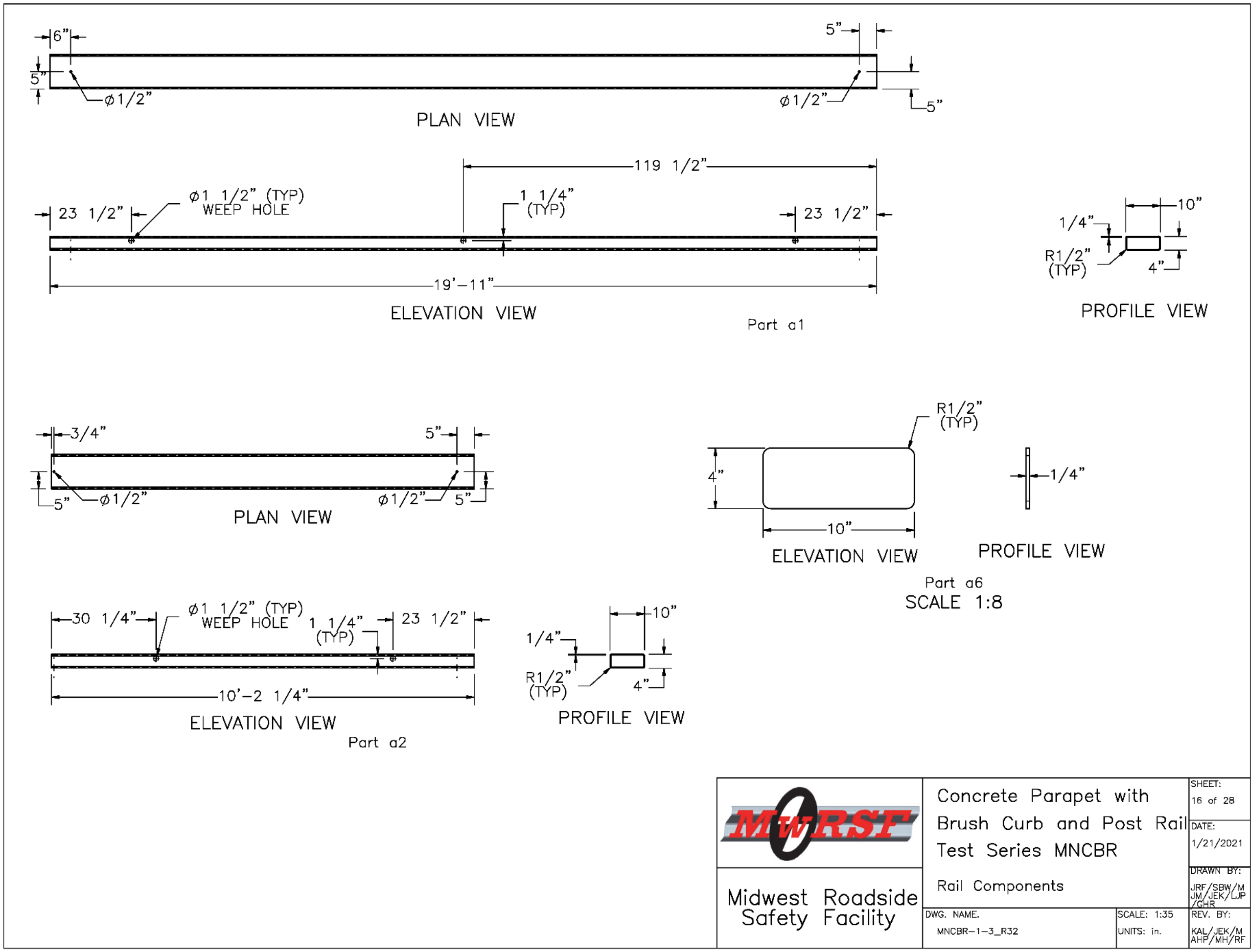
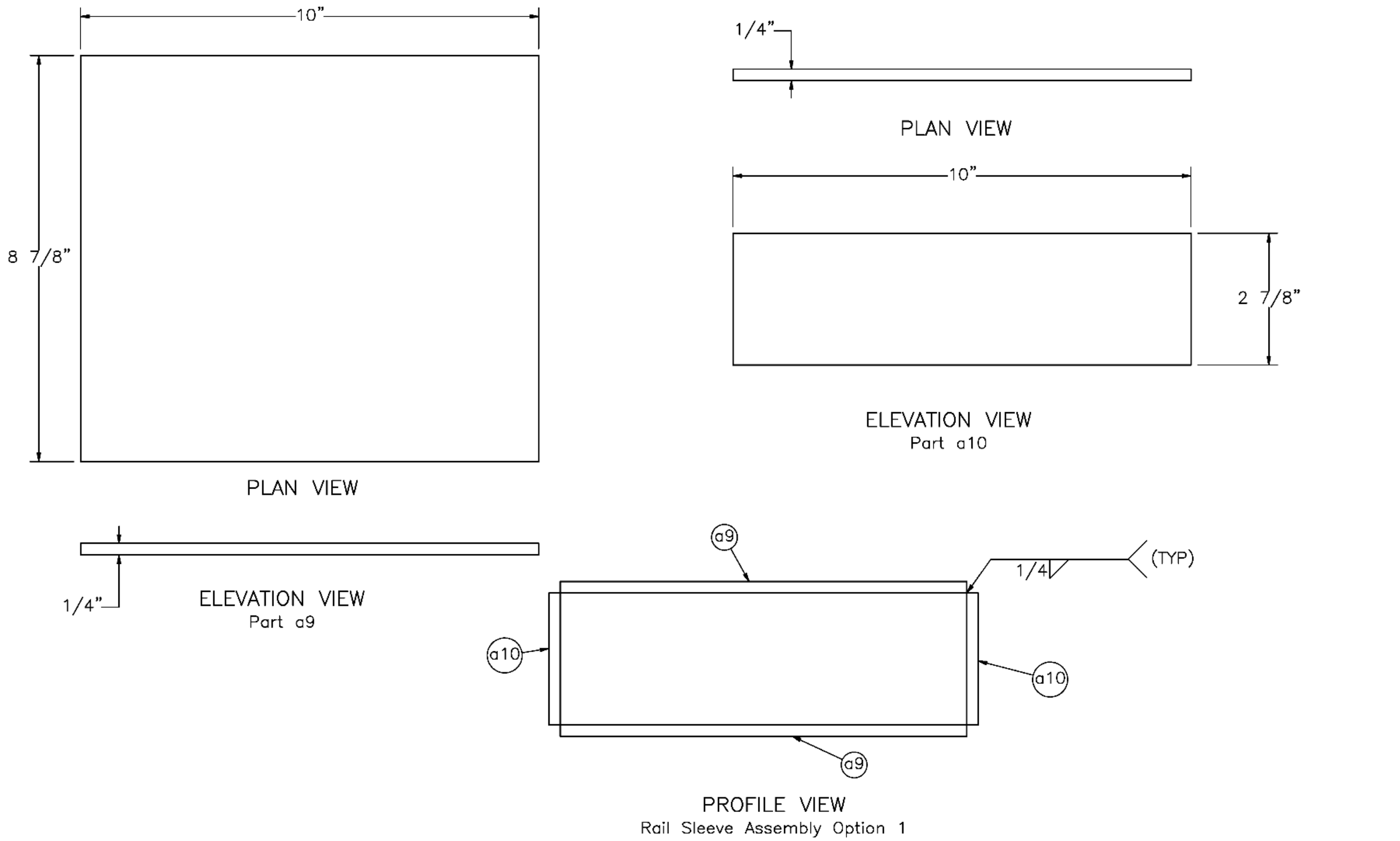


Figure 24. Rail Components, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
a4	7	Rail Sleev Assembly (Option 1)	–	ASTM A123
a9	2	10"x8 7/8"x1/4" Plate	ASTM A709 Gr. 50	See Assembly
a10	2	10"x2 7/8"x1/4" Plate	ASTM A709 Gr. 50	See Assembly

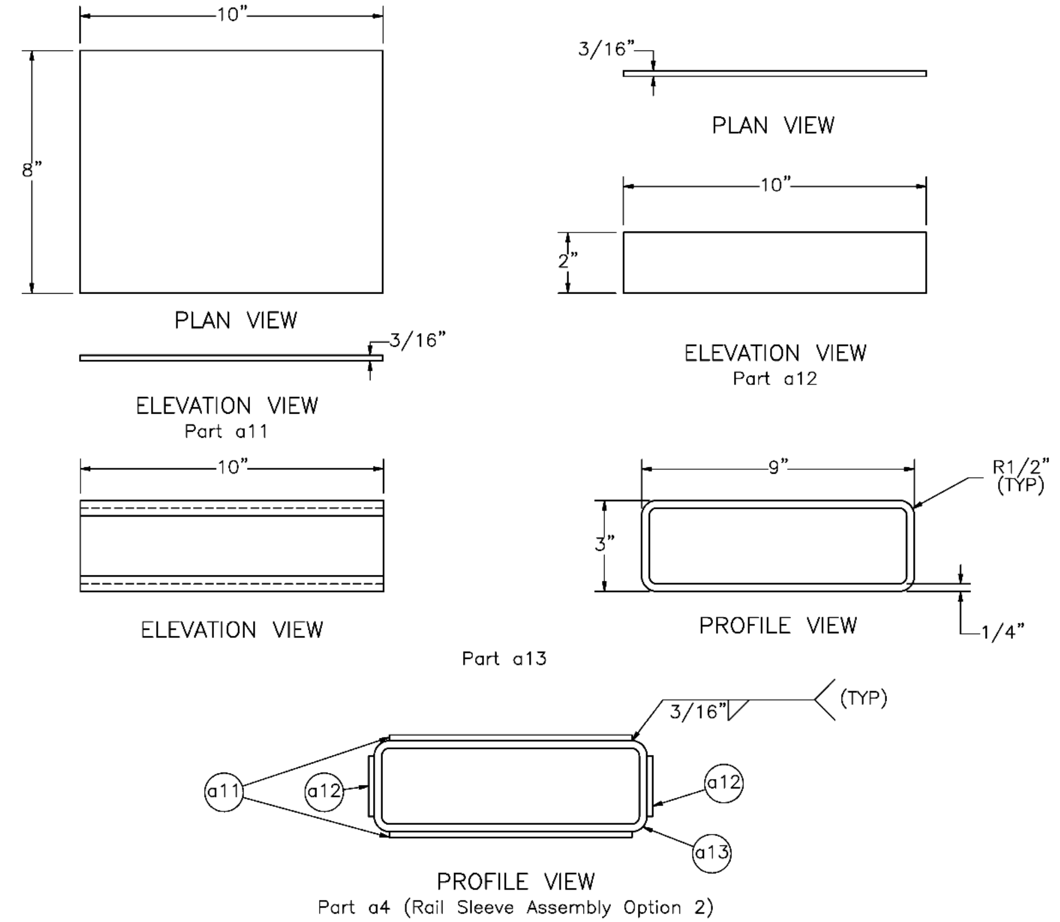
Midwest Roadside Safety Facility

Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

Rail Sleeve Assembly Option 1

SHEET: 17 of 28
DATE: 1/21/2021
DRAWN BY: JRF/SBW/M JM/JEK/LJP /GHR
REV. BY: KAL/JEK/M AHP/MH/RF
DWG. NAME. MNCBR-1-3_R32
SCALE: 1:3
UNITS: in.

Figure 25. Rail Sleeve Assembly Option 1, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
a4	7	Rail Sleeve Assembly (Option 2)	–	ASTM A123
a11	2	10"x8"x3/16" Plate	ASTM A709 Gr. 50	See Assembly
a12	2	10"x2"x3/16" Plate	ASTM A709 Gr. 50	See Assembly
a13	1	HSS 9"x3"x1/4", 10" Long Rail Sleeve	ASTM A500 Gr. B	See Assembly

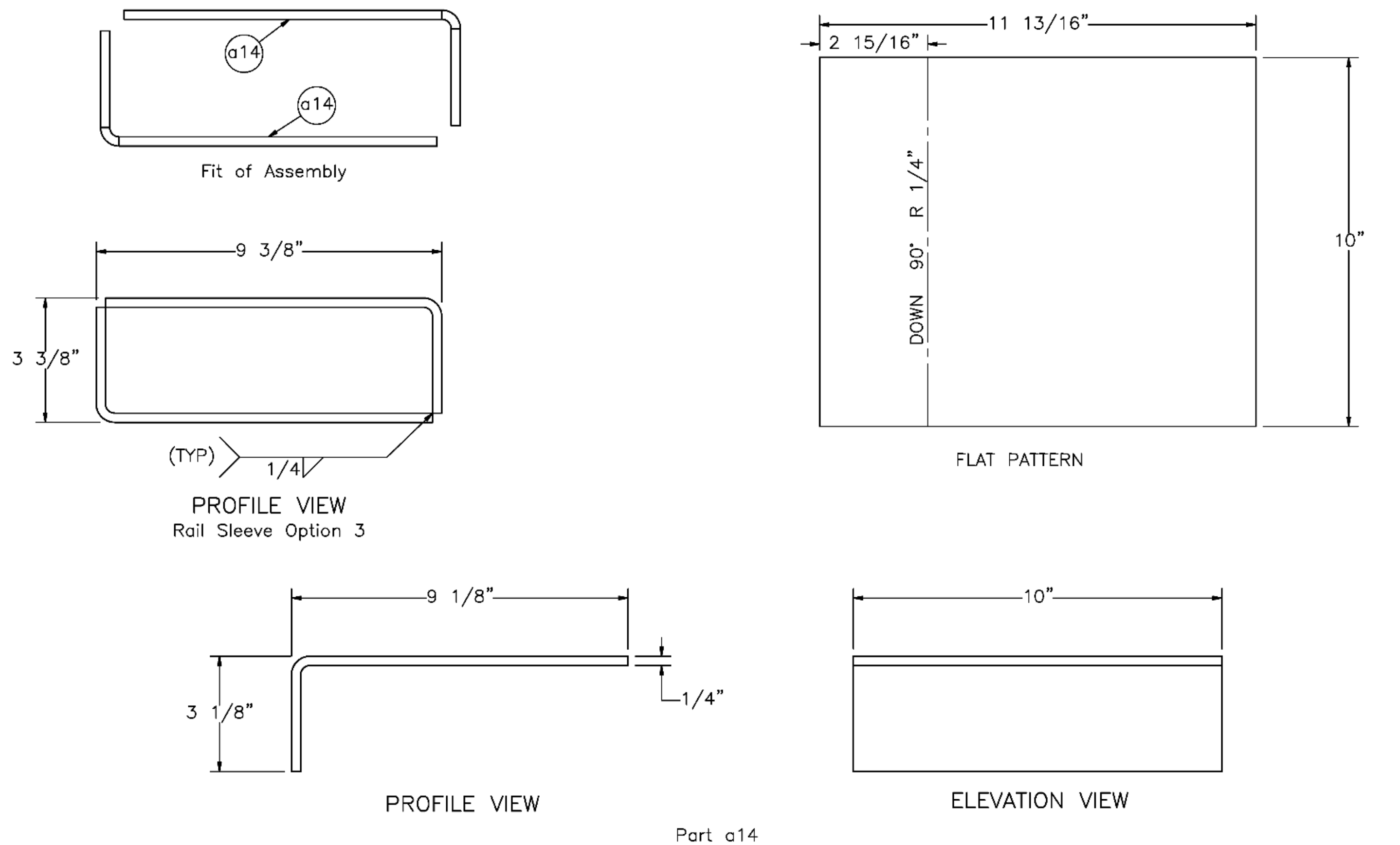
Midwest Roadside Safety Facility

Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

Rail Sleeve Assembly Option 2

SHEET:	18 of 28
DATE:	1/21/2021
DRAWN BY:	JRF/SBW/M JM/JEK/LJP /GHR
DWG. NAME.	MNCBR-1-3_R32
SCALE:	1:5
UNITS:	in.
REV. BY:	KAL/JEK/M AHP/MH/RF

Figure 26. Rail Sleeve Option 2, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
a4	7	Rail Sleeve Assembly (Option 3)	–	ASTM A123
a14	2	10"x11 13/16"x1/4" Rail Sleeve Bent Plate	ASTM A709 Gr. 50	See Assembly

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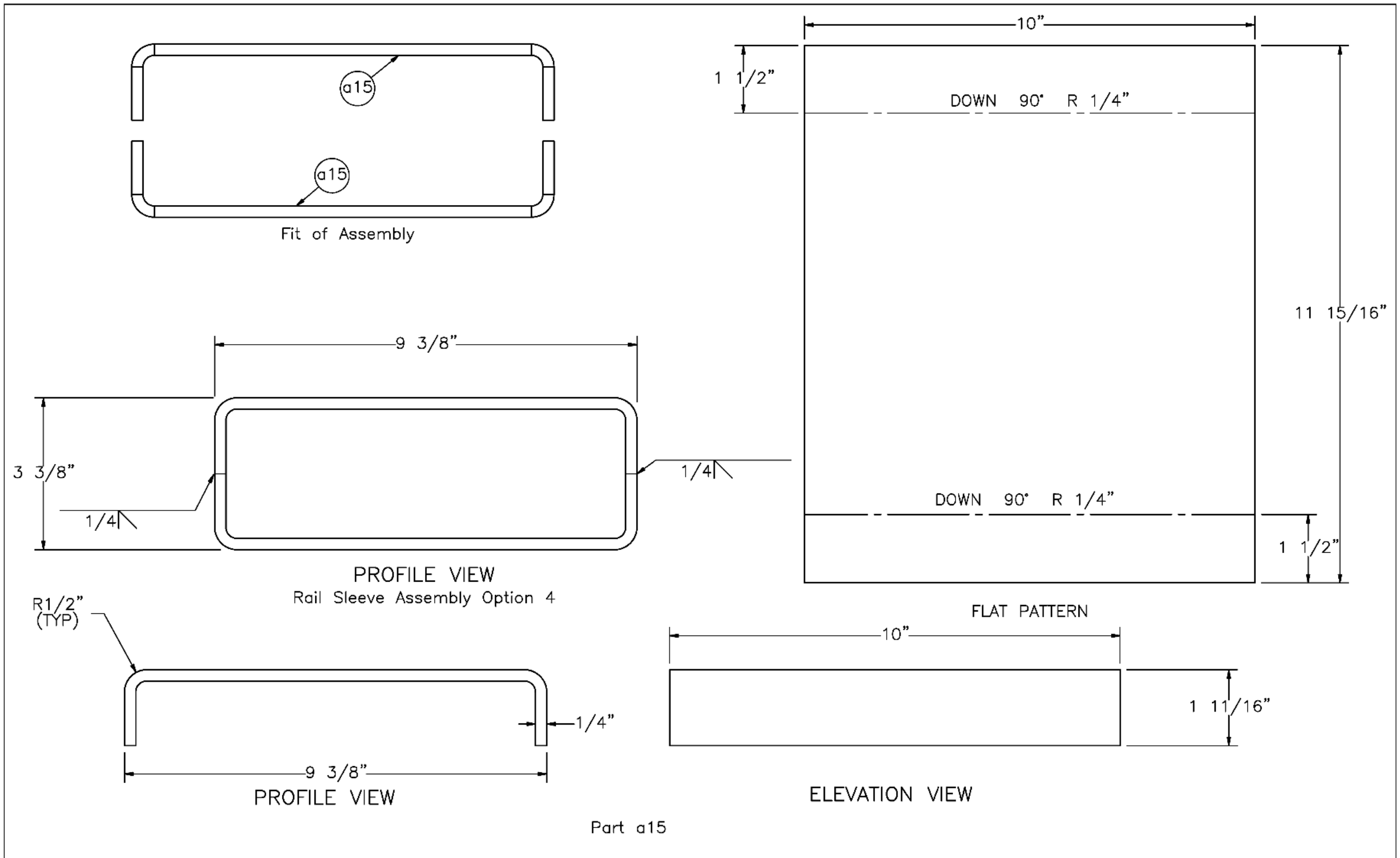
Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

Rail Sleeve Assembly Option 3

SHEET: 19 of 28
DATE: 1/21/2021
DRAWN BY: JRF/SBW/MJM/JEK/LJP/GHR
DWG. NAME. MNCBR-1-3_R32
SCALE: 1:4
UNITS: in.
REV. BY: KAL/JEK/MAHP/MH/RF

Figure 27. Rail Sleeve Assembly Option 3, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Note: (1) Bevel welds to be ground smooth.

Item No.	QTY.	Description	Material Specification	Treatment Specification
a4	7	Rail Sleeve Assembly (Option 4)	–	ASTM A123
a15	2	10"x11 15/16"x1/4" Rail Sleeve Bent Plate	ASTM A709 Gr. 50	See Assembly

MwRSF Midwest Roadside Safety Facility	Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR Rail Sleeve Assembly Option 4		SHEET: 20 of 28 DATE: 1/21/2021 DRAWN BY: JRF/SBW/M JM/JEK/LJP /GHR
	DWG. NAME. MNCBR-1-3_R32	SCALE: 1:3 UNITS: in.	REV. BY: KAL/JEK/M AHP/MH/RF

Figure 28. Rail Sleeve Assembly Option 4, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

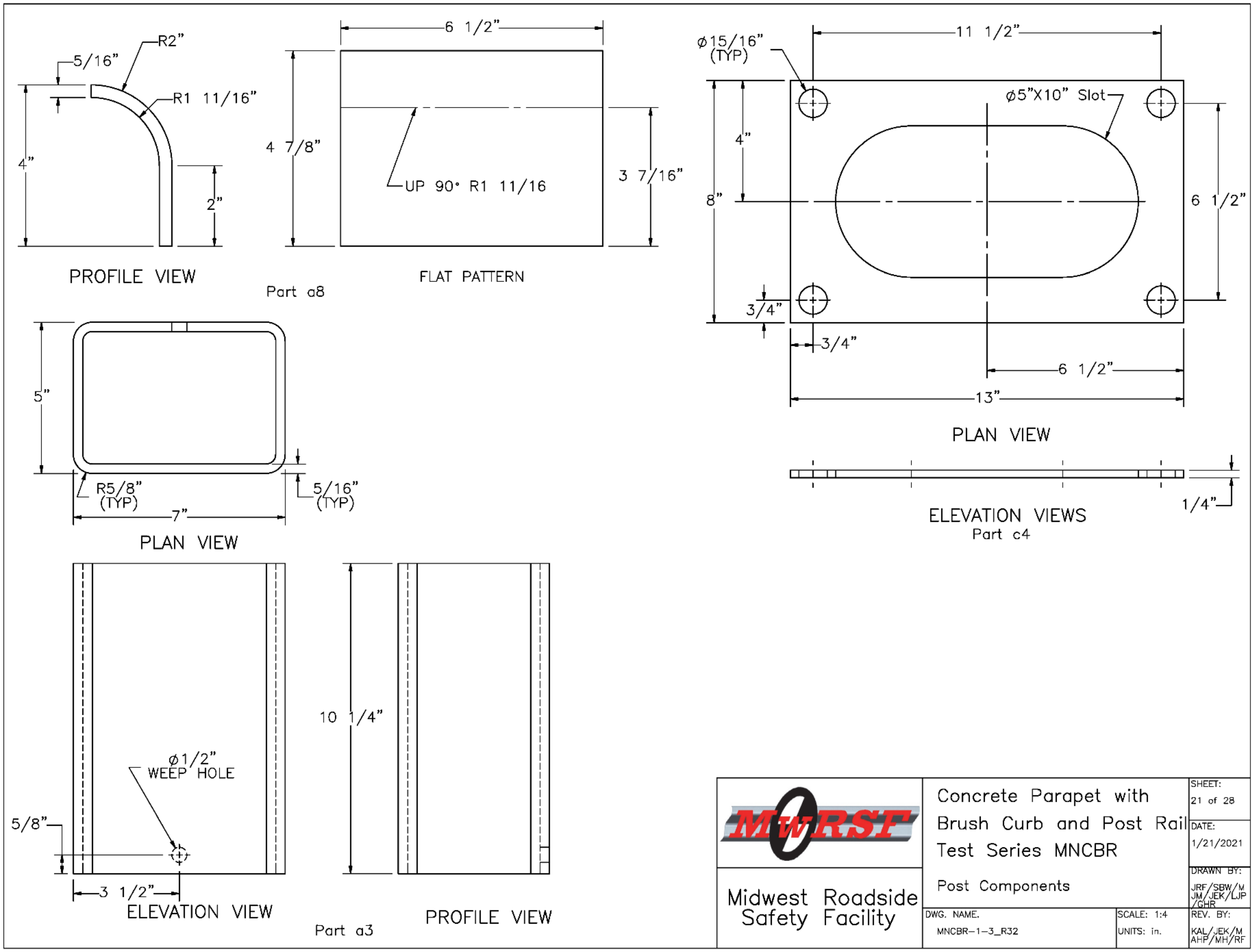


Figure 29. Post Components, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

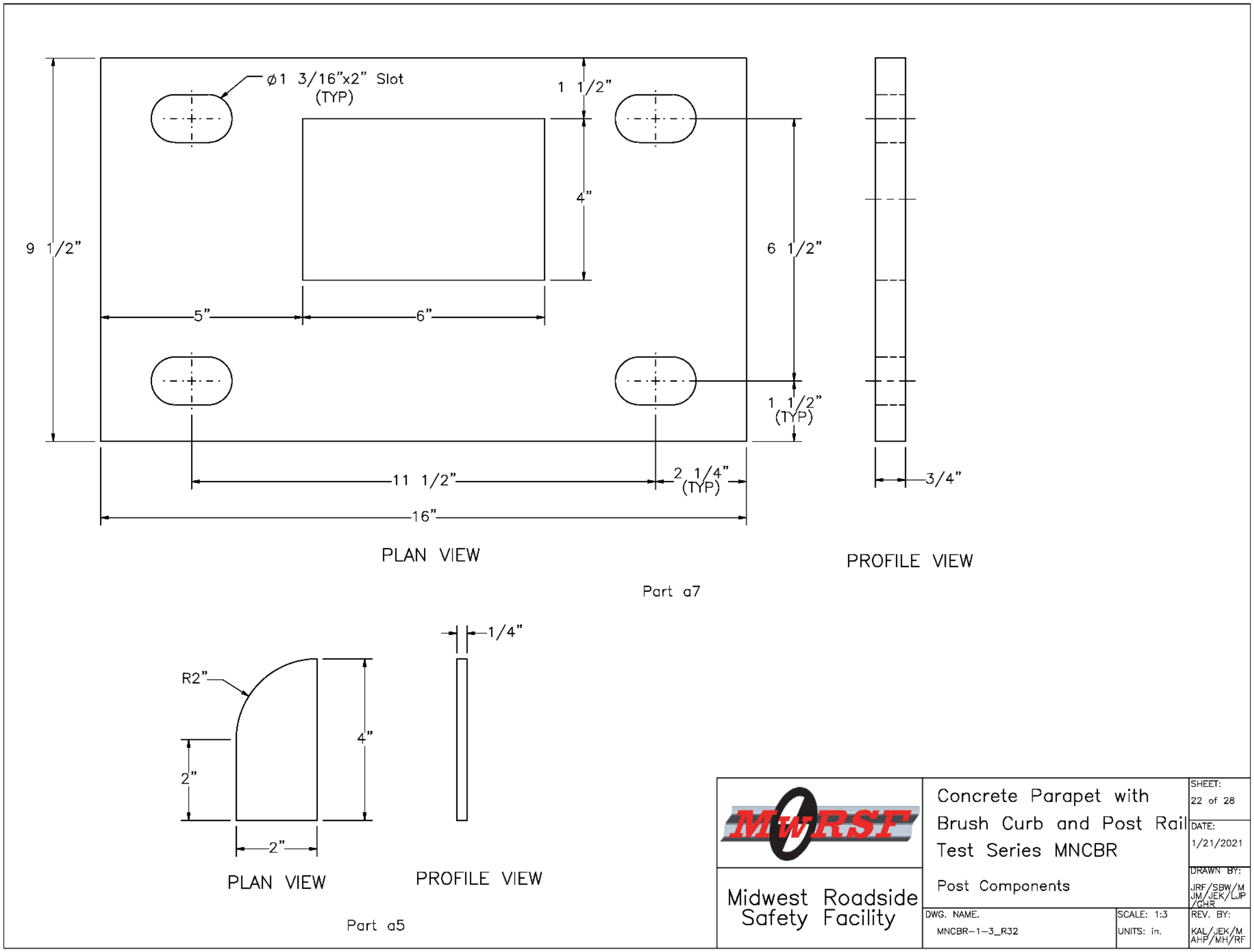
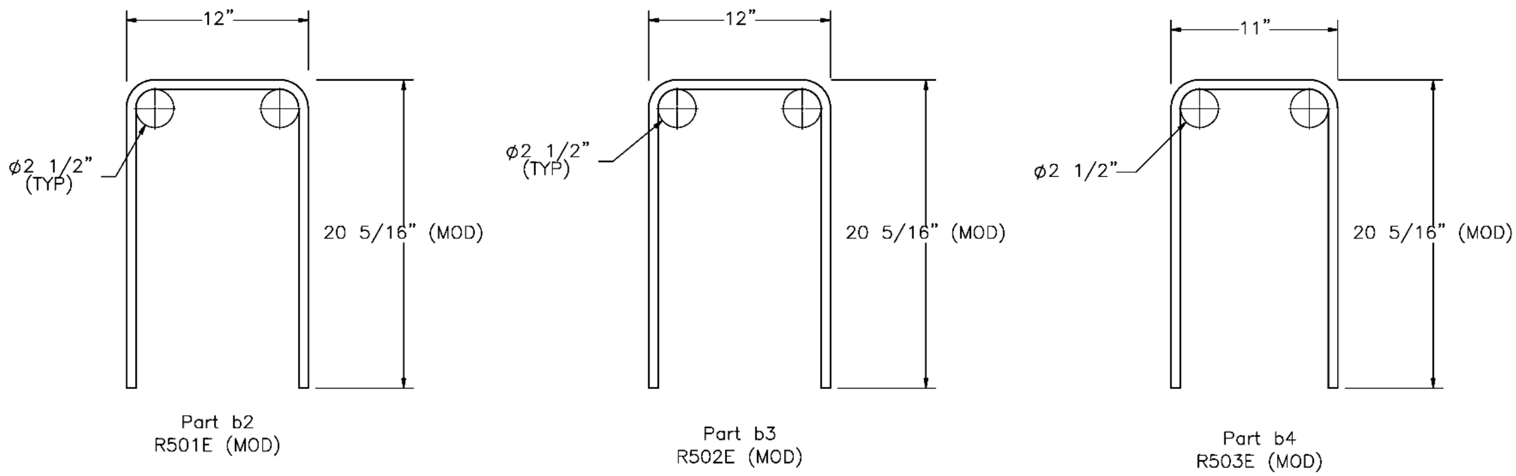


Figure 30. Post Components, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Bar	QTY.	Size	Total Unbent Length	Material Specification	Treatment Specification
b2	160	#5	50"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b3	1	#5	50"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b4	2	#5	49"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)

Midwest Roadside Safety Facility

Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

System Rebar

SHEET: 23 of 28

DATE: 1/21/2021

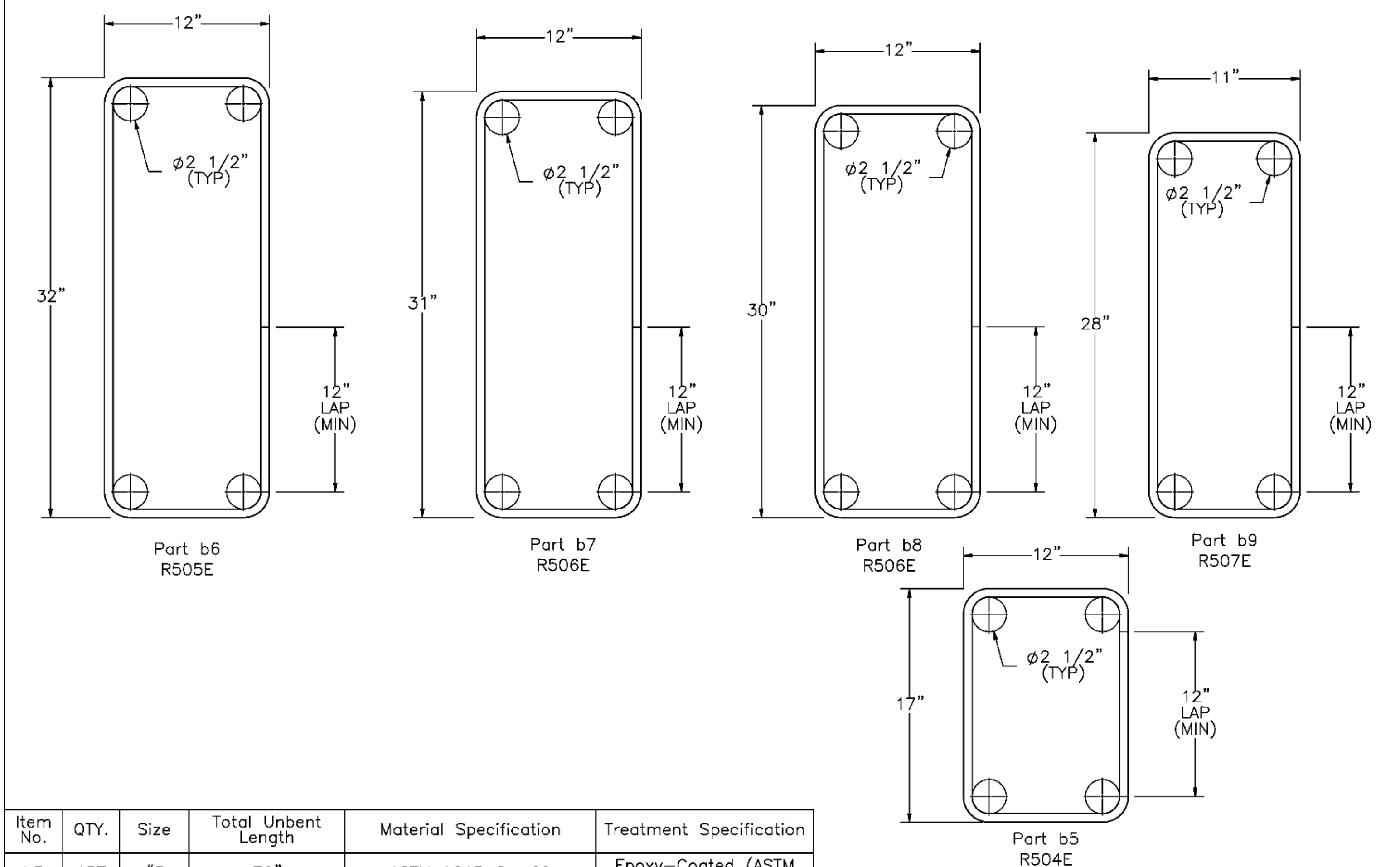
DRAWN BY: JRF/SBW/MJM/JEK/LJP/GHR

DWG. NAME. MNCBR–1–3_R32

SCALE: 1:10
UNITS: in.

REV. BY: KAL/JEK/MAHP/MH/RF

Figure 31. System Rebar, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Item No.	QTY.	Size	Total Unbent Length	Material Specification	Treatment Specification
b5	157	#5	70"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b6	2	#5	100"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b7	1	#5	98"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b8	1	#5	96"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b9	2	#5	90"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)

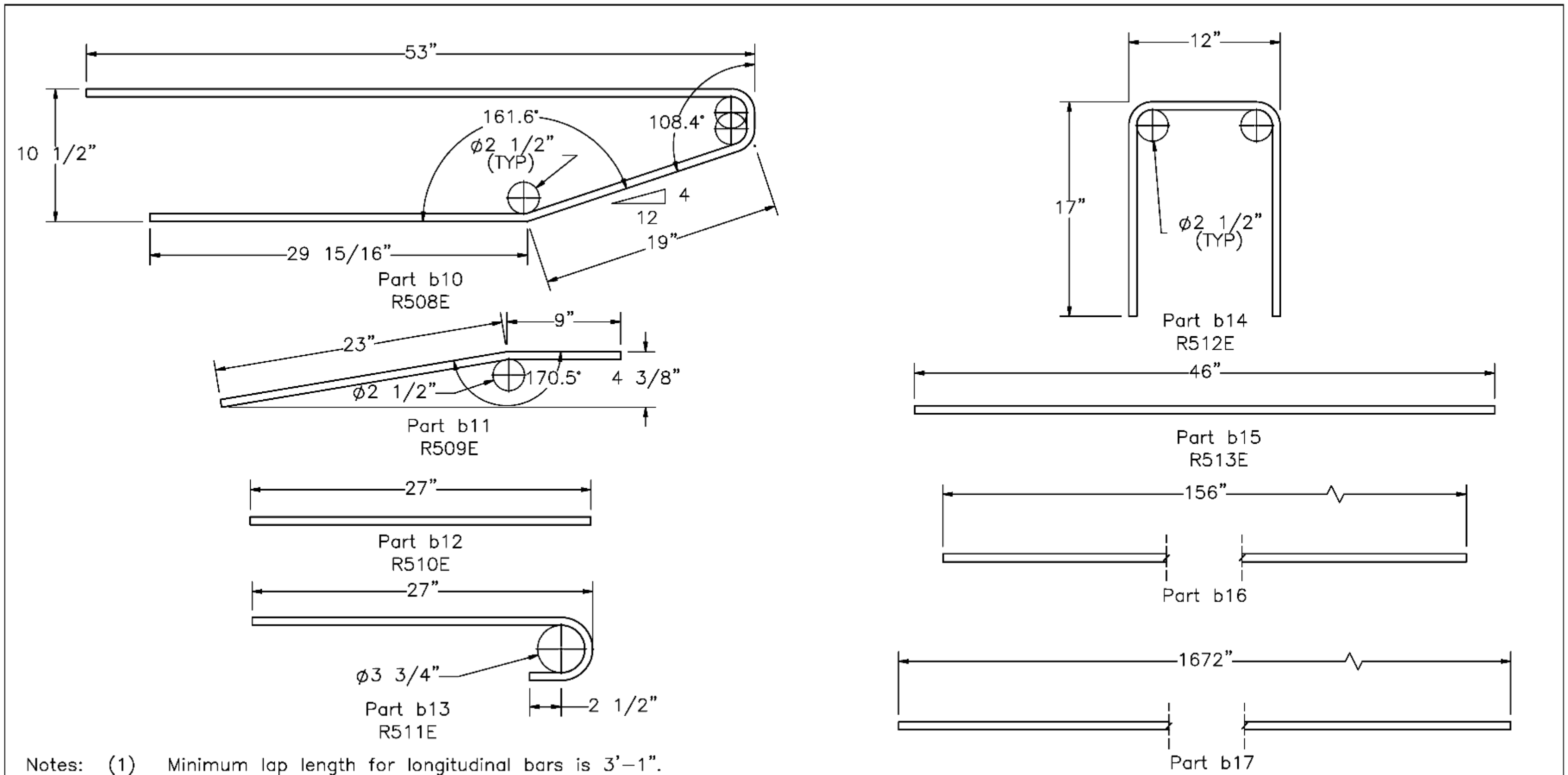
Midwest Roadside Safety Facility

Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

System Rebar

SHEET: 24 of 28
DATE: 1/21/2021
DRAWN BY: JRF/SBW/MJM/JEK/LJP/GHR
DWG. NAME. MNCBR–1–3_R32
SCALE: 1:10
UNITS: in.
REV. BY: KAL/JEK/MAHP/MH/RF

Figure 32. System Rebar, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3



Notes: (1) Minimum lap length for longitudinal bars is 3'–1".

Bar	QTY.	Size	Total Unbent Length	Material Specification	Treatment Specification
b10	2	#5	104 1/4"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b11	2	#5	32"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b12	4	#5	27"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b13	4	#5	33 7/8"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b14	46	#5	43 3/8"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b15	22	#5	48"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b16	6	#5	156"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)
b17	6	#5	1672"	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)

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Midwest Roadside Safety Facility

Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

System Rebar

SHEET: 25 of 28
DATE: 1/21/2021
DRAWN BY: JRF/SBW/MJM/JEK/LJP/GHR
DWG. NAME. MNCBR–1–3_R32
SCALE: 1:12
UNITS: in.
REV. BY: KAL/JEK/MAHP/MH/RF

Figure 33. System Rebar, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

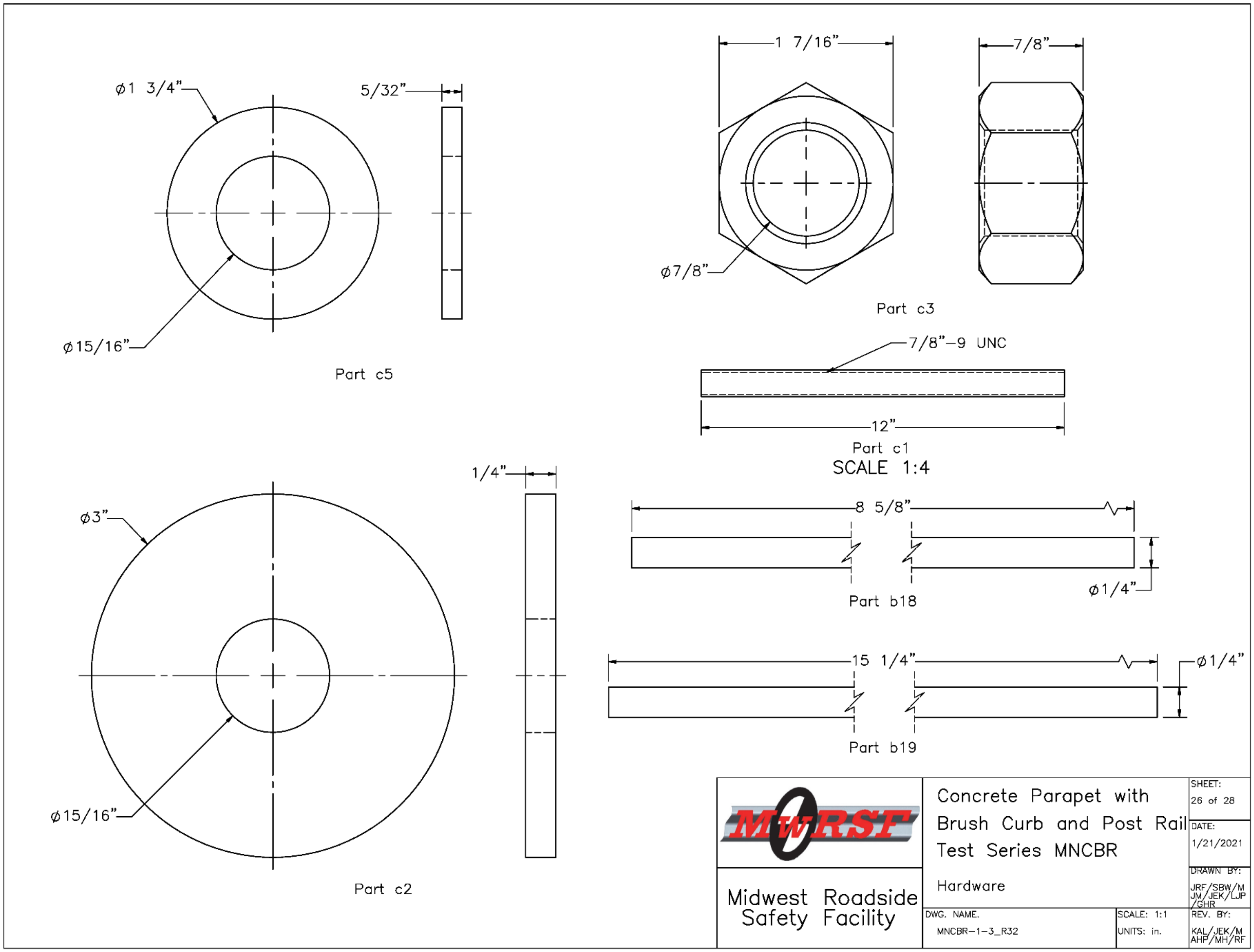


Figure 34. Hardware, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	7	HSS10"x4"x1/4", 19' 11" Long Tube Rail	ASTM A500 Gr. B	See Assembly	–
a2	1	HSS10"x4"x1/4", 10'–2 1/4" Long Tube Rail	ASTM A500 Gr. B	See Assembly	–
a3	23	HSS 7"x5"x5/16", 10 1/4" Long Tube Post	ASTM A500 Gr. B	See Assembly	–
a4[1]	7	HSS 9"x3"x1/4" x10" Rail Sleeve	See Assembly	ASTM A123	–
a5	46	4"x2"x1/4" Post Plate	ASTM A709 Gr. 50	See Assembly	–
a6	1	10"x4"x1/4" Rail End Plate	ASTM A709 Gr. 50	See Assembly	–
a7	23	16"x9 1/2"x3/4" Post Base Plate	ASTM A709 Gr. 50	See Assembly	–
a8	23	6 1/2"x4 7/8"x5/16" Post Bent Plate	ASTM A709 Gr. 50	See Assembly	–
a9[2]	14	10"x8 7/8"x1/4" Plate	ASTM A709 Gr. 50	See Assembly	–
a10[2]	14	10"x2 7/8"x1/4" Plate	ASTM A709 Gr. 50	See Assembly	–
a11[3]	14	10"x8"x3/16" Plate	ASTM A709 Gr. 50	See Assembly	–
a12[3]	14	10"x2"x3/16" Plate	ASTM A709 Gr. 50	See Assembly	–
a13[3]	7	9"x3"x1/4", 10" Long Rail Sleeve	ASTM A500 Gr. B	See Assembly	–
a14[4]	14	10"x11 13/16"x1/4" Rail Sleeve Bent Plate	ASTM A709 Gr. 50	See Assembly	–
a15[5]	14	10"x11 15/16"x1/4" Rail Sleeve Bent Plate	ASTM A709 Gr. 50	See Assembly	–
b1	1	Concrete	Min. f'c = 4000 psi	–	–
b2	160	#5 Rebar, 50" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b3	1	#5 Rebar, 48" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b4	2	#5 Rebar, 49" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b5	157	#5 Rebar, 70" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b6	2	#5 Rebar, 100" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b7	1	#5 Rebar, 98" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b8	1	#5 Rebar, 96" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b9	2	#5 Rebar, 90" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b10	2	#5 Rebar, 104 1/4" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–

Note: (1) Rail sleeve assembly will be fabricated using only one option out of the four contained herein.
(2) Rail sleeve assembly option 1 will use parts a9 and a10.
(3) Option 2 will use parts a11, a12, and a13.
(4) Option 3 will use part a14.
(5) Option 4 will use part a15.

Midwest Roadside Safety Facility

Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

Bill of Materials

SHEET: 27 of 28
DATE: 1/21/2021
DRAWN BY: JRF/SBW/MJM/JEK/LJP/GHR
DWG. NAME. MNCBR–1–3_R32
SCALE: None
UNITS: in.
REV. BY: KAL/JEK/MAHP/MH/RF

Figure 35. Bill of Materials, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
b11	2	#5 Rebar, 32" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b12	4	#5 Rebar, 27" Total Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b13	4	#5 Rebar, 33 7/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b14	46	#5 Rebar, 43 3/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b15	22	#5 Rebar, 46" Total Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b16	6	#5 Rebar, 156" Total Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b17	6	#5 Rebar, 1672" Total Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b18	2	1/4" Dia., 8 5/8" Long Vertical Backer Rod	ASTM D5249 Type 3	Not Needed	–
b19	1	1/4" Dia., 15 1/4" Long Horizontal Backer Rod	ASTM D5249 Type 3	Not Needed	–
c1	92	7/8"–9 UNC, 12" Long Vertical Anchor Rod	ASTM F1554 Gr. 105	ASTM A153	–
c2	92	3" Dia. x 1/4" Circular Plate Washer	ASTM A709 Gr. 50	ASTM A153	–
c3	276	7/8"–9 UNC Heavy Hex Nut	ASTM A563DH	ASTM A153	FNX22b
c4	23	13"x8"x1/4" Anchor Plate	ASTM F436 TYPE 1	ASTM A153 or B695 CLASS 55	–
c5	184	7/8" Dia. SAE Washer	ASTM A709 Gr. 50	ASTM A153	–
d1	1	12"x20"x3/8" End Plate	ASTM A709 Gr. 50	See Assembly	–
d2	5	1.049" ID 1.68 lb/ft Standard Pipe, 15 1/8" Long	ASTM A53 Schedule 40	See Assembly	–
e1	–	Chemical Adhesive	Min. Bond Strength = 1,670 psi	–	–
e2	–	Joint Sealant	ASTM D5893	–	–

Midwest Roadside Safety Facility

Concrete Parapet with Brush Curb and Post Rail Test Series MNCBR

Bill of Materials

SHEET: 28 of 28
DATE: 1/21/2021
DRAWN BY: JRF/SBW/MJM/JEK/LJP/GHR
DWG. NAME. MNCBR–1–3_R32
SCALE: None
UNITS: in.
REV. BY: KAL/JEK/MAHP/MH/RF

Figure 36. Bill of Materials, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

Figure 37. New Concrete Tapered End Rebar Installation, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

Figure 38. New Concrete Tapered End Rebar Installation, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

Figure 39. New Concrete Tapered End Installation, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

Figure 40. System Installation, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

Figure 41. Downstream End, Post Nos. 23, 22, 23, and Upper Rail, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

Figure 42. Downstream and Upstream Ends, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

Figure 43. Splice Connection, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

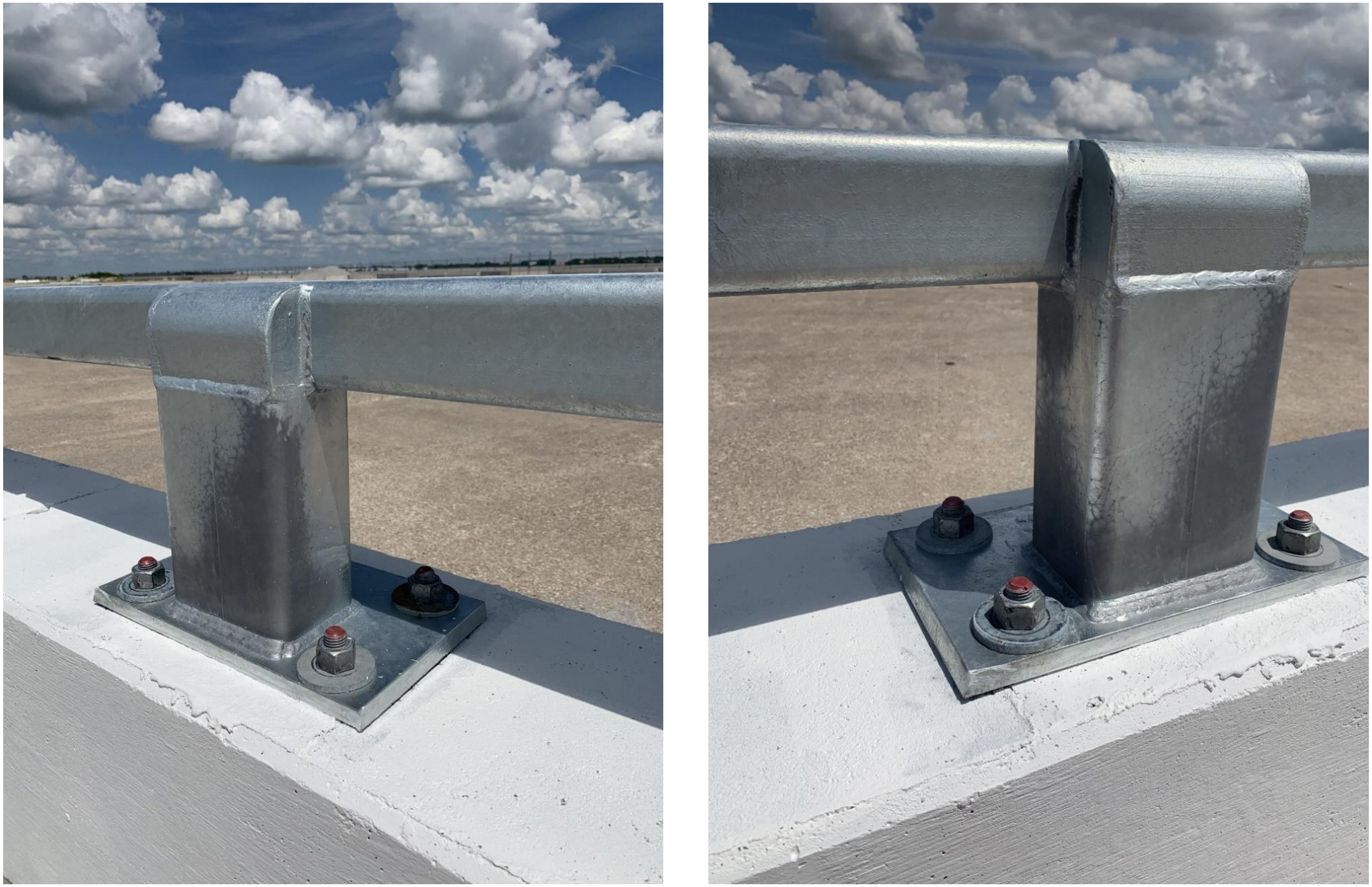


Figure 44. Post Assembly, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

Figure 45. Post Assembly, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3

4 TEST CONDITIONS

4.1 Test Facility

The Outdoor Test Site is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles 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, located on the tow vehicle, was used to increase the accuracy of the test vehicle's impact speed.

A vehicle guidance system developed by Hinch [9] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. 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. MNCBR-1, a 2013 International Durastar 4300 SBA 4x2 single-unit truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 14,852 lb, 22,042 lb, and 22,202 lb, respectively. The test vehicle is shown in Figures 46 and 47, and vehicle dimensions are shown in Figures 48 and 49.

For test no. MNCBR-2, a 2014 Dodge Ram 1500 quad cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,134 lb, 5,003 lb, and 5,162 lb, respectively. The test vehicle is shown in Figures 50 and 51, and vehicle dimensions are shown in Figures 52 and 53.

For test no. MNCBR-3, a 2009 Kia Rio small sedan was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,448 lb, 2,442 lb, and 2,600 lb, respectively. The test vehicle is shown in Figures 54 and 55, and vehicle dimensions are shown in Figures 56 and 57. MASH 2016 requires test vehicles used in crash testing to be no more than six model years old. A 2009 model was used for this test because the vehicle geometry of newer models did not comply with recommended vehicle dimension ranges specified in Table 4.1 of MASH 2016. The use of older test vehicles due to recent small car vehicle properties falling outside of MASH 2016 recommendations was allowed by FHWA and AASHTO in MASH implementation guidance dated May 2018 [10].

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights for all three vehicle types. The Elevated Axle Method [11] was used to determine the vertical component of the c.g. for the 10000S vehicle. This method converted measured wheel weights at different elevations to the location of the vertical component of the c.g. The Suspension Method [12] was used to determine the vertical component of the c.g. for the pickup truck. 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 vehicle 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 vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [13]. The location of the final c.g. for test no. MNCBR-1 is shown in Figures 48 and 49. The location of the final c.g. for test no. MNCBR-2 is shown in Figures 52 and 53. The location of the final c.g. for test no. MNCBR-3 is shown in Figures 56 and 57. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 49, 53, and 57. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

The front wheels of the test vehicles were aligned to vehicle standards, except the toe-in value was adjusted to zero such that the vehicle would track properly along the guide cable. For test no. MNCBR-1, a 5B flash bulb was mounted under the vehicle’s left-side windshield wiper. For test nos. MNCBR-2 and MNCBR-3 a 5B flash bulb was mounted under the vehicle’s right-side windshield wiper. The 5B flash bulb was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed digital videos. A radio-controlled brake system was installed in the test vehicles so the vehicles could be brought safely to a stop after the tests.

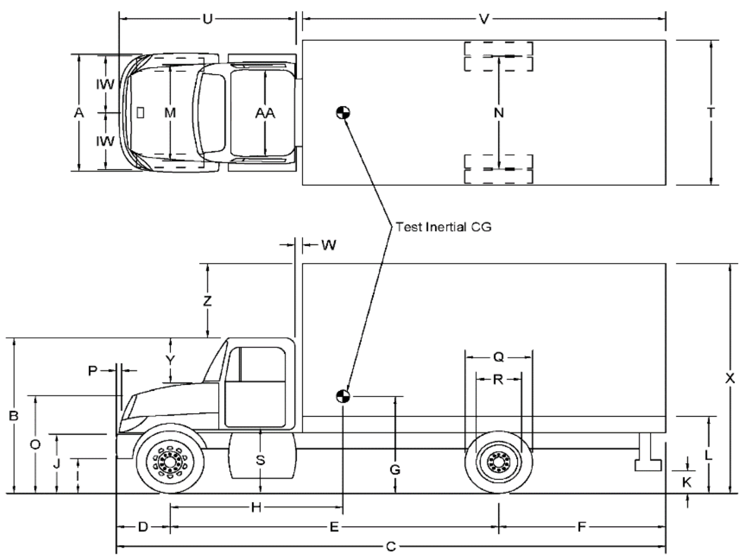
Figure 46. Test Vehicle, Test No. MNCBR-1

Figure 47. Test Vehicle's Interior Floorboards and Undercarriage, Test No. MNCBR-1

Test Name: MNCBR-1 **VIN No:** 1HTMMAAM7DH105190

Model Year: 2013 **Make:** International **Model:** Durastar 4300 SBA 4x2

Tire Size: 11R22.5 **Tire Inflation Pressure:** 105 psi **Odometer:** 207303



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

A:	90 5/8	(2302)	B:	98 7/8	(2511)
C:	378 2/3	(9619) Max: 394 (10000)	D:	43 1/2	(1105)
E:	236 3/4	(6013) Max: 240 (6100)	F:	98	(2489)
G:	50 3/16	(1275)	H:	143 1/16	(3634)
I:	21 3/4	(552)	J:	34 7/8	(886)
K:	15 3/8	(391)	L:	47 1/2	(1207) 49±2 (1245±50)
M:	79 3/8	(2016)	N:	74	(1880)
O:	60 3/8	(1534)	P:	4 1/2	(114)
Q:	41 1/4	(1048)	R:	23 1/4	(591)
S:	37 3/4	(959)	T:	95 3/4	(2432)
U:	107 3/4	(2737)	V:	256	(6502)
W:	2 1/2	(64)	X:	146	(3708)
Y:	31	(787)	Z:	45	(1143)
IW (Impact Width):	91	(2311)	AA:	70 1/2	(1791)

Ballast

Weight lb (kg): 7860 (3565)

CG height in. (mm): 63 (1601)
63±2 (1600±50)

Mass Distribution - lb (kg)

Gross Static	LF	4454	(2020)	RF	4404	(1998)
	LR	6556	(2974)	RR	6788	(3079)

Wheel Center Height (Front):	19 3/4	(502)
Wheel Center Height (Rear):	20 1/8	(511)
Wheel Well Clearance (Front):	46 3/8	(1178)
Wheel Well Clearance (Rear):	42 1/5	(1072)
Bottom Frame Height (Front):	26 1/4	(667)
Bottom Frame Height (Rear):	27 3/4	(705)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	7338 (3328)	8722 (3956)	8858 (4018)
W-rear	7514 (3408)	13320 (6042)	13344 (6053)
W-total	14852 (6737) 13200±2200 (6000±1000)	22042 (9998) 22046±660 (10000±300)	22202 (10071)

GVWR Ratings - lb

Front	10000
Rear	17500
Total	25999

Surrogate Occupant Data

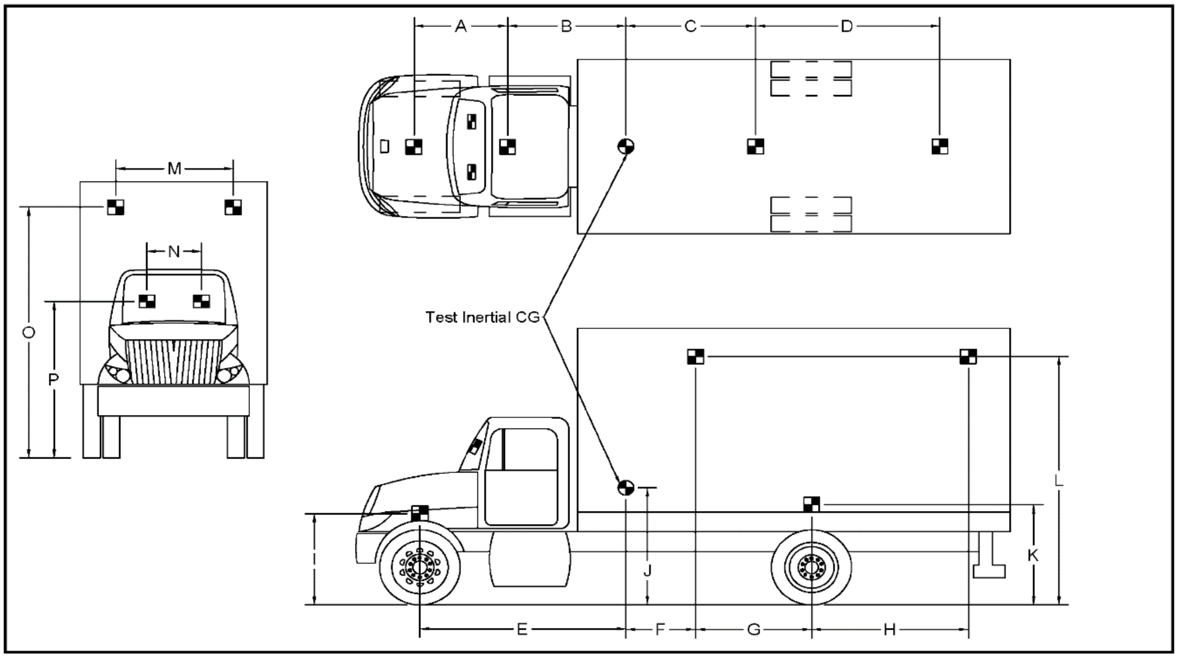
Type:	Hybrid II
Mass:	160 lb
Seat Position:	Right/Passenger

Engine Type:	Diesel
Engine Size:	7.6L L6
Transmission Type:	Automatic
Drive Type:	RWD

Note any damage prior to test: None

Figure 48. Vehicle Dimensions, Test No. MNCBR-1

	Test Name: MNCBR-1	VIN: 1HTMMAAM7DH105190	
Model Year: 2013	Make: International	Model: Durastar 4300 SBA 4x2	



TARGET GEOMETRY-- in. (mm)

A: 58 1/8 (1476)	F: 25 3/16 (640)	L: 139 5/8 (3546)
B: 94 1/8 (2391)	G: 68 11/16 (1745)	M: 61 5/8 (1565)
C: 71 (1803)	H: 59 3/8 (1508)	N: 51 3/4 #VALUE!
D: 75 3/16 (1910)	I: 50 3/8 (1280)	O: 121 11/16 (3091)
E: 142 15/16 (3631)	J: 50 1/8 (1273)	P: 83 1/2 (2121)
	K: 46 3/8 (1178)	

Figure 49. Target Geometry, Test No. MNCBR-1

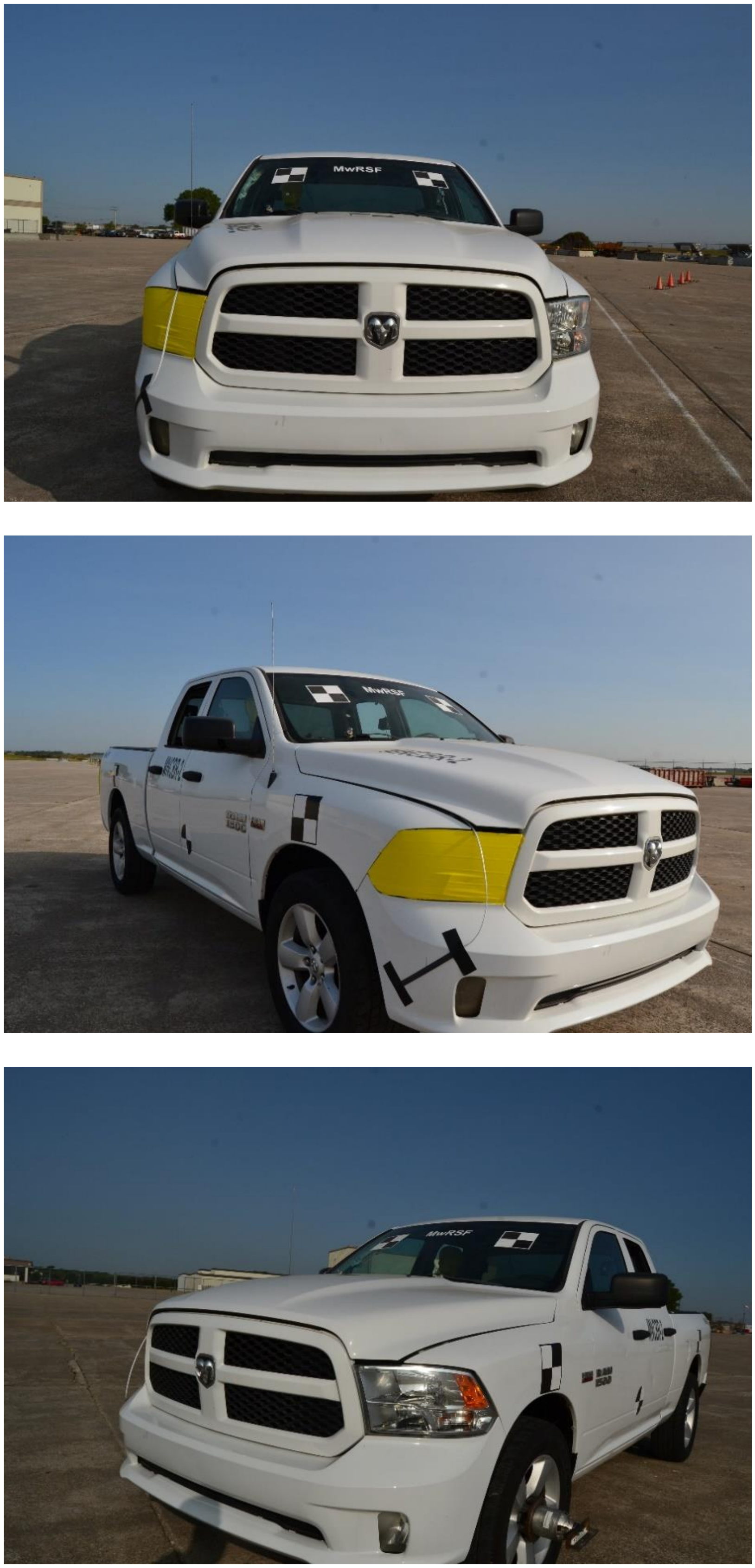


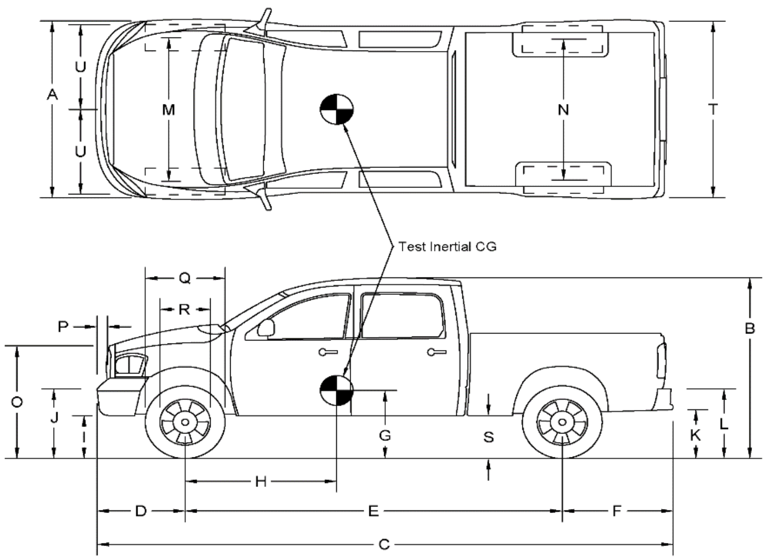
Figure 50. Test Vehicle, Test No. MNCBR-2

Figure 51. Test Vehicle's Interior Floorboards and Undercarriage, Test No. MNCBR-2

Test Name: MNCBR-2 **VIN No:** 1C6RR6FT2ES278435

Model Year: 2014 **Make:** Dodge **Model:** Ram 1500

Tire Size: 275/60R20 **Tire Inflation Pressure:** 39 psi **Odometer:** 216437



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

A:	77 1/4 (1962) 78±2 (1950±50)	B:	75 1/4 (1911)
C:	229 (5817) 237±13 (6020±325)	D:	38 (965) 39±3 (1000±75)
E:	140 1/4 (3562) 148±12 (3760±300)	F:	47 1/2 (1207)
G:	29 5/8 (752) min: 28 (710)	H:	60 3/8 (1534) 63±4 (1575±100)
I:	12 5/8 (321)	J:	25 (635)
K:	20 5/8 (524)	L:	29 1/2 (749)
M:	68 1/4 (1734) 67±1.5 (1700±38)	N:	68 1/5 (1732) 67±1.5 (1700±38)
O:	46 (1168) 43±4 (1100±75)	P:	4 (102)
Q:	32 1/2 (826)	R:	21 1/2 (546)
S:	14 3/4 (375)	T:	76 (1930)

U (impact width): 36 1/2 (927)

Wheel Center Height (Front):	15 5/8 (397)
Wheel Center Height (Rear):	15 7/8 (403)
Wheel Well Clearance (Front):	36 1/4 (921)
Wheel Well Clearance (Rear):	38 1/2 (978)
Bottom Frame Height (Front):	13 5/8 (346)
Bottom Frame Height (Rear):	26 (660)
Engine Type:	Gasoline
Engine Size:	5.7L V8
Transmission Type:	Automatic
Drive Type:	RWD
Cab Style:	Quad Cab
Bed Length:	76"

Mass Distribution - lb (kg)

Gross Static				
	LF	1477 (670)	RF	1470 (667)
	LR	1098 (498)	RR	1117 (507)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2926 (1327)	2850 (1293)	2947 (1337)
W-rear	2208 (1002)	2153 (977)	2215 (1005)
W-total	5134 (2329)	5003 (2269) 5000±110 (2270±50)	5162 (2341) 5165±110 (2343±50)

GVWR Ratings - lb

Front	3700
Rear	3900
Total	6900

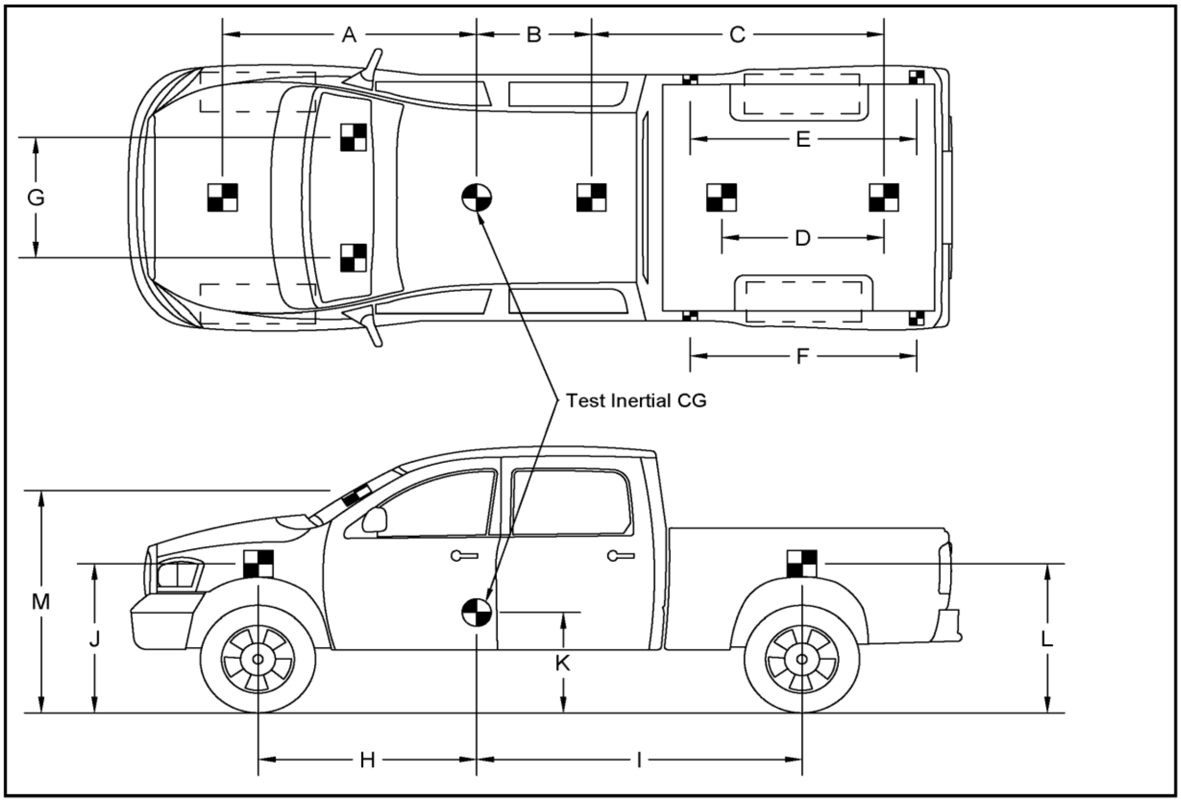
Surrogate Occupant Data

Type:	Hybrid II
Mass:	159 lb
Seat Position:	Right/Passenger

Note any damage prior to test: None

Figure 52. Vehicle Dimensions, Test No. MNCBR-2

		Test Name:	**MNCBR-2**	**VIN:**	**1C6RR6FT2ES278435**
Model Year:	**2014**	**Make:**	**Dodge**	**Model:**	**Ram 1500**



TARGET GEOMETRY-- in. (mm)

A:	**67 1/2**	**(1715)**	**E:**	**66 3/4**	**(1695)**	**J:**	**40 3/4**	**(1035)**
B:	**27 15/16**	**(710)**	**F:**	**66 3/4**	**(1695)**	**K:**	**29 5/8**	**(752)**
C:	**77 7/8**	**(1978)**	**G:**	**35 1/4**	**(895)**	**L:**	**43 1/16**	**(1094)**
D:	**47 5/8**	**(1210)**	**H:**	**60 5/8**	**(1540)**	**M:**	**65 1/8**	**(1654)**
			I:	**80**	**(2032)**			

Figure 53. Target Geometry, Test No. MNCBR-2

Figure 54. Test Vehicle, Test No. MNCBR-3

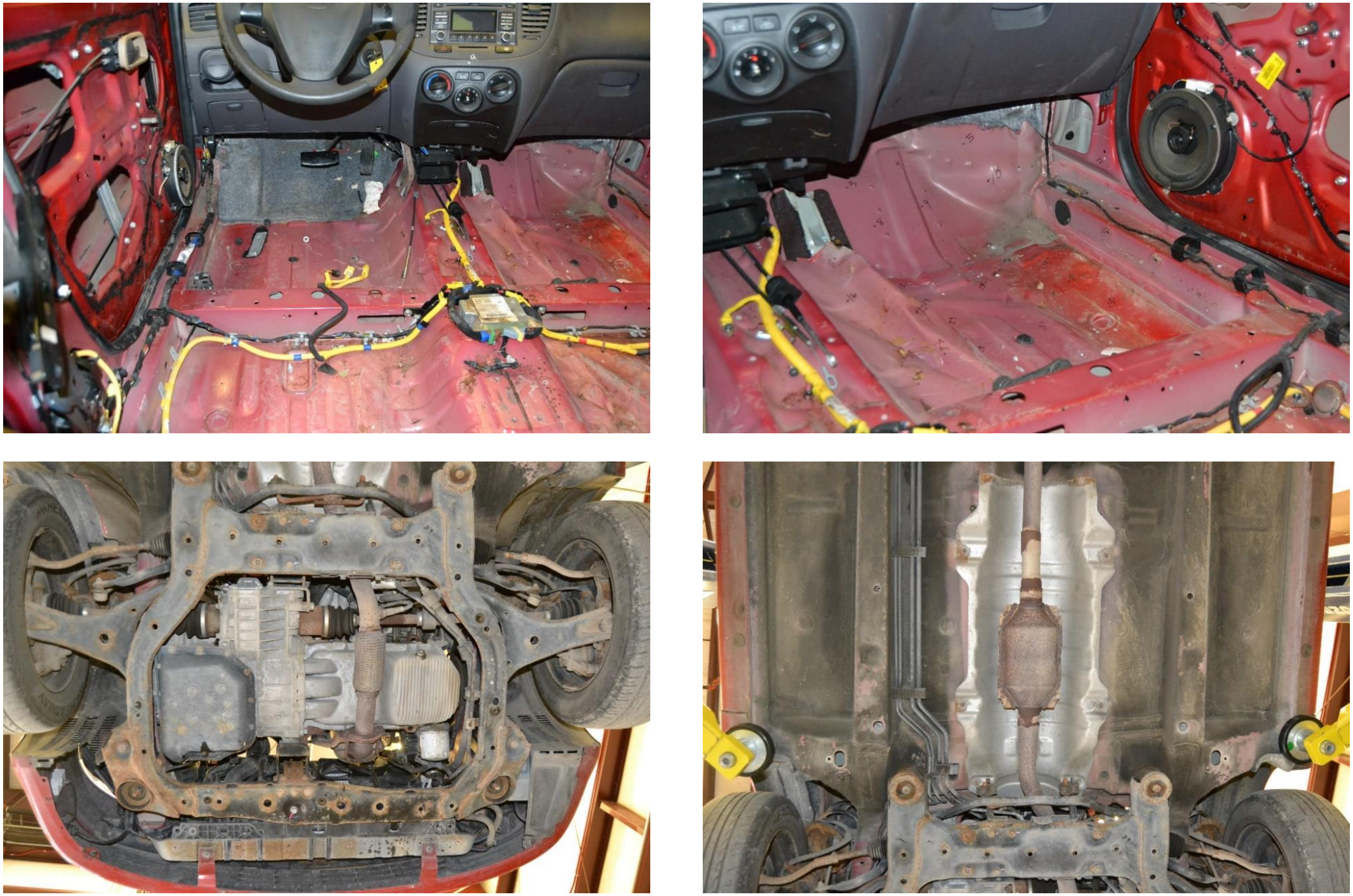
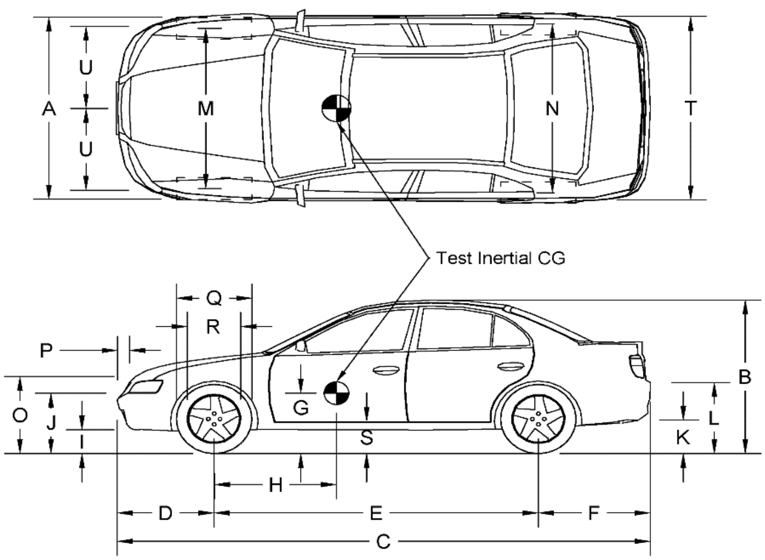


Figure 55. Test Vehicle's Interior Floorboards and Undercarriage, Test No. MNCBR-3

		Test Name:	MNCBR-3	VIN No:	KNADE223196557772
Model Year:	2009	Make:	Kia	Model:	Rio
Tire Size:	185/65R14	Tire Inflation Pressure:	32 psi	Odometer:	105814



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

A:	65 4/7 (1665) 65±3 (1650±75)	B:	57 3/8 (1457)
C:	167 (4242) 169±8 (4300±200)	D:	32 (813) 35±4 (900±100)
E:	98 1/2 (2502) 98±5 (2500±125)	F:	36 1/2 (927)
G:	22 5/16 (567)	H:	36 7/8 (937) 39±4 (990±100)
I:	8 5/8 (219)	J:	22 (559)
K:	12 3/4 (324)	L:	25 (635)
M:	57 3/8 (1457) 56±2 (1425±50)	N:	57 1/8 (1451) 56±2 (1425±50)
O:	27 1/4 (692) 24±4 (600±100)	P:	1 1/4 (32)
Q:	22 3/4 (578)	R:	15 1/4 (387)
S:	11 1/4 (286)	T:	64 5/8 (1641)

U (impact width):	28 1/2 (724)
Top of radiator core support:	28 (711)
Wheel Center Height (Front):	10 1/2 (267)
Wheel Center Height (Rear):	11 (279)
Wheel Well Clearance (Front):	24 3/4 (629)
Wheel Well Clearance (Rear):	24 4/5 (630)
Bottom Frame Height (Front):	5 1/2 (140)
Bottom Frame Height (Rear):	15 5/8 (397)
Engine Type:	Gasoline
Engine Size:	1.4L 4 Cyl
Transmission Type:	Automatic
Drive Type:	FWD

Mass Distribution - lb (kg)

Gross Static	LF	814 (369)	RF	794 (360)
	LR	471 (214)	RR	521 (236)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	1564 (709)	1528 (693)	1608 (729)
W-rear	884 (401)	914 (415)	992 (450)
W-total	2448 (1110)	2442 (1108) 2420±55 (1100±25)	2600 (1179) 2585±55 (1175±50)

GVWR Ratings lb	
Front	1918
Rear	1874
Total	3638

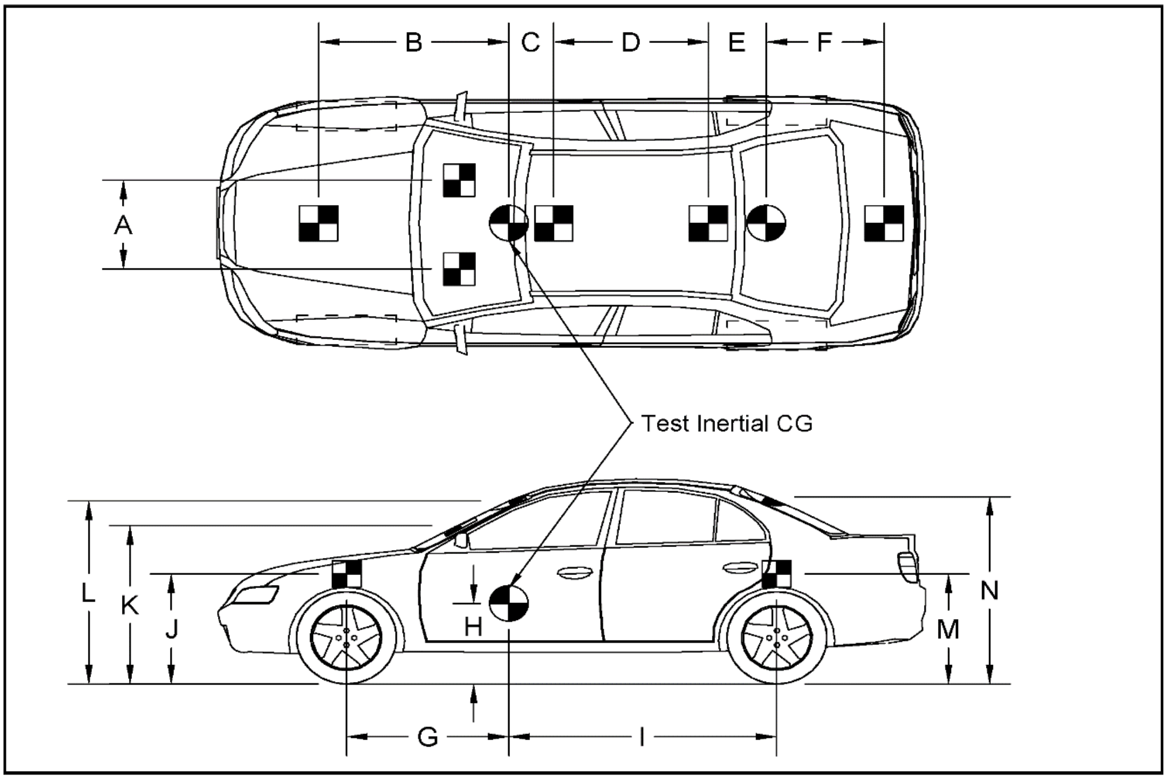
Surrogate Occupant Data

Type:	Hybrid II
Mass:	158 lb
Seat Position:	Right/Passenger

Note any damage prior to test: Dent in leading edge of hood, left fender, right rocker panel.

Figure 56. Vehicle Dimensions, Test No. MNCBR-3

		Test Name:	MNCBR-3	VIN:	KNADE223196557772
Model Year:	2009	Make:	Kia	Model:	Rio



TARGET GEOMETRY-- in. (mm)

A:	24 3/4	(629)	F:	34 7/8	(886)	K:	47 5/8	(1210)
						Windshield Target		
B:	44 3/16	(1122)	G:	36 15/16	(938)	L:	52 5/8	(1337)
						Front round CG target		
C:	13 1/4	(337)	H:	22 1/16	(560)	M:	29	(737)
D:	34 1/16	(865)	I:	61 3/4	(1568)	N:	53 1/4	(1353)
						Rear Round target		
E:	12 13/16	(325)	J:	28 15/16	(735)			

Figure 57. Target Geometry, Test No. MNCBR-3

4.4 Simulated Occupant

For test nos. MNCBR-1, MNCBR-2, and MNCBR-3, a Hybrid II 50th-Percentile, Adult Male Dummy equipped with footwear was placed in the right-front seat of the test vehicle with the seat belt fastened. The simulated occupant had a final weight of 160 lb, 159 lb, and 158 lb for test nos. MNCBR-1, MNCBR-2, and MNCBR-3, respectively. As recommended by MASH 2016, the simulated occupant was not included in calculating the c.g. location.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Accelerometer systems used in the full-scale crash testing were the SLICE-1, SLICE-2, and TDAS systems described below. Test no. MNCBR-1 used all three systems and test nos. MNCBR-2 and MNCBR-3 used only the SLICE-1 and SLICE-2 units. 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 [14].

The SLICE-1 and SLICE-2 units were environmental shock and vibration sensor/recorder systems used to measure the accelerations in the longitudinal, lateral, and vertical directions. The units were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. of Seal Beach, California. The acceleration sensors were mounted inside the body of custom-built, SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

The TDAS unit was a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California. The unit was configured to record two sets of triaxial data along with roll and yaw data. Two sets of accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. The accelerometers were configured and controlled using a system developed and manufactured by Diversified Technical Systems, Inc. of Seal Beach, California. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. The SIM was configured with 16 MB SRAM and eight sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

For test no. MNCBR-1, the SLICE-1 unit was mounted near the c.g., the SLICE-2 unit was mounted in the cab, and the TDAS unit was mounted on the rear axle of the single-unit truck. The SLICE-1 unit was designated as the primary unit. For test nos. MNCBR-2 and MNCBR-3, the SLICE-1 and SLICE-2 units were mounted near the c.g. of the test vehicles. SLICE-2 was designated as the primary unit for test no. MNCBR-2 and SLICE-1 was the primary unit for test no. MNCBR-3.

4.5.2 Rate Transducers

Two identical angular rate sensor systems mounted inside the body of the SLICE-1 and SLICE-2 event data recorders were used to measure the rates of rotation of the test vehicles. The units were positioned as described in Section 4.5.1. Each SLICE MICRO Triax ARS had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessors. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

For test no. MNCBR-1, a third angular rate sensor, the ARS-1500, with a range of 1,500 degrees/sec was configured to measure the rates of rotation of the test vehicle in two directions (roll and yaw). The angular rate sensor was mounted on an aluminum block at the rear axle of the single-unit truck and recorded data at 10,000 Hz to the DTS SIM. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data. Normally, triaxial rate transducer data is required to determine Euler angles in all three directions (roll, pitch, and yaw). The pitch rate and angle of the vehicle were assumed to be low at the time of peak lateral loading to the bridge railing. Therefore, when determining Euler angles, a pitch rate equal to zero was assumed for the third rotational axis at the rear-axle rate sensor location. Then, the modified Euler angles for all three axes were combined with the accelerations from the two TDAS sets of triaxial accelerometers at the rear axle to determine barrier loading.

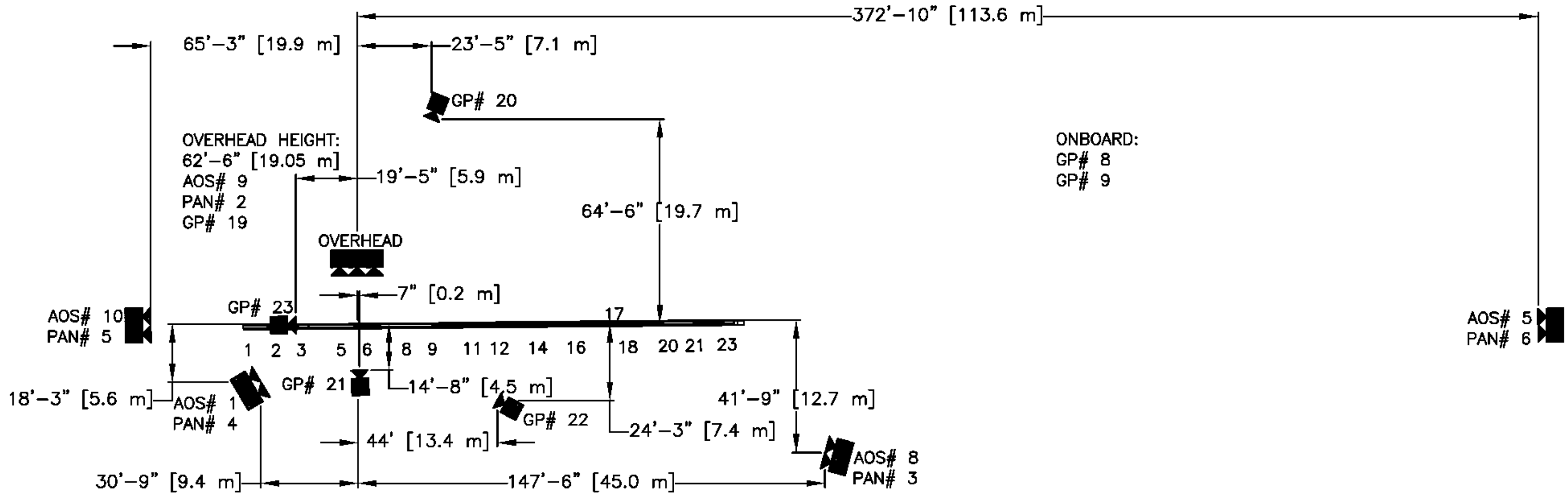
4.5.3 Retroreflective Optic Speed Trap

A 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 right side of all test 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 used as a backup if vehicle speeds cannot be determined from the electronic data.

4.5.4 Digital Photography

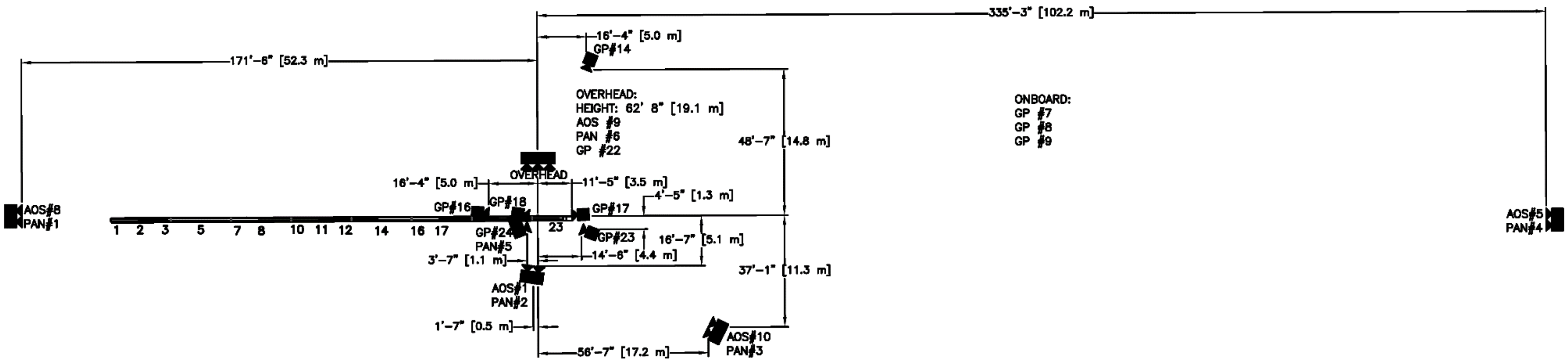
Five AOS high-speed digital video cameras, seven GoPro digital video cameras, and five Panasonic digital video cameras were utilized to film test no. MNCBR-1. Five AOS high-speed digital video cameras, ten GoPro digital video cameras, and six Panasonic digital video cameras were utilized to film test no. MNCBR-2. Five AOS high-speed digital video cameras, ten GoPro digital video cameras, and five Panasonic digital video cameras were utilized to film test no. MNCBR-3. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the systems are shown in Figures 58 through 60.

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



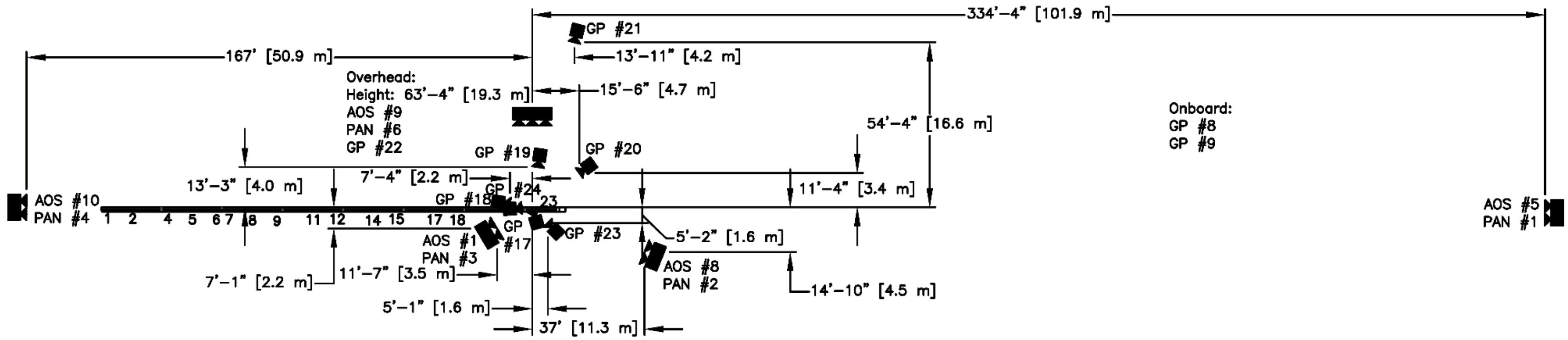
No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam CTM	500	Kowa 16 mm	
AOS-5	AOS X-PRI Gigabit	500	100 mm	
AOS-8	AOS S-VIT 1531	500	Kowa 25 mm	
AOS-9	AOS TRI-VIT 2236	1000	Kowa 12 mm	
AOS-10	AOS Vitcam CTM	500	Fujinon 50 mm	
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-19	GoPro Hero 6	240		
GP-20	GoPro Hero 6	240		
GP-21	GoPro Hero 6	240		
GP-22	GoPro Hero 7	240		
GP-23	GoPro Hero 7	240		
PAN-2	Panasonic HC-V770	120		
PAN-3	Panasonic HC-V770	120		
PAN-4	Panasonic HC-V770	120		
PAN-5	Panasonic HC-VX981	120		
PAN-6	Panasonic HC-VX981	120		

Figure 58. Camera Locations, Speeds, and Lens Settings, Test No. MNCBR-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam CTM	500	Kowa 16 mm	
AOS-5	AOS X-PRI Gigabit	500	100 mm	
AOS-8	AOS S-VIT 1531	500	75 mm	
AOS-9	AOS TRI-VIT 2236	1000	Kowa 12 mm	
AOS-10	AOS Vitcam CTM	500	50 mm	
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-14	GoPro Hero 4	120		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	240		
GP-18	GoPro Hero 6	240		
GP-22	GoPro Hero 7	240		
GP-23	GoPro Hero 7	240		
GP-24	GoPro Hero 7	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		
PAN-5	Panasonic HC-VX981	120		
PAN-6	Panasonic HC-VX981	120		

Figure 59. Camera Locations, Speeds, and Lens Settings, Test No. MNCBR-2



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam CTM	500	Fujinon 50mm	
AOS-5	AOS X-PRI Gigabit	500	100 mm	
AOS-8	AOS S-VIT 1531	500	75 mm	
AOS-9	AOS TRI-VIT 2236	1000	Kowa 12 mm	
AOS-10	AOS TRI-VIT 2236	500	Nikor M86 mm	
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
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		
GP-22	GoPro Hero 7	240		
GP-23	GoPro Hero 7	240		
GP-24	GoPro Hero 7	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		
PAN-6	Panasonic HC-V770	120		

Figure 60. Camera Locations, Speeds, and Lens Settings, Test No. MNCBR-3

5 FULL-SCALE CRASH TEST NO. MNCBR-1

5.1 Weather Conditions

Test no. MNCBR-1 was conducted on September 2, 2020 at approximately 2:00 p.m. The weather conditions as reported by the National Oceanic and Atmospheric Administration (station 14939/LNK) are shown in Table 3.

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

Temperature	87°F
Humidity	23%
Wind Speed	10 mph
Wind Direction	230° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.06 in.
Previous 7-Day Precipitation	0.09 in.

5.2 Test Description

Test no. MNCBR-1 was conducted on a concrete parapet with a brush curb and upper beam and post rail with a new tapered end section under MASH 2016 TL-4 guidelines for test designation no. 4-12, which involved an impact with a 10000S vehicle at 56 mph and 15 degrees. The CIP for this system was selected to impart significant lateral loading into the upper railing system as well as increase the potential for vehicle interaction and snag on the vertical support posts and upper metal tube rail.

Initial vehicle impact was to occur 60 in. upstream from the centerline of splice between post nos. 6 and 7, as shown in Figure 61, which was selected as discussed in Chapter 2.2. The 22,042-lb single-unit box truck impacted the concrete parapet with a brush curb and upper beam and post rail with a new tapered end section at a speed of 57.4 mph and at an angle of 15.4 degrees. The actual point of impact was 60⅛ in. upstream from the target impact location. In the test, the vehicle was captured and redirected by the concrete parapet with brush curb and upper beam and post rail with new tapered end section.

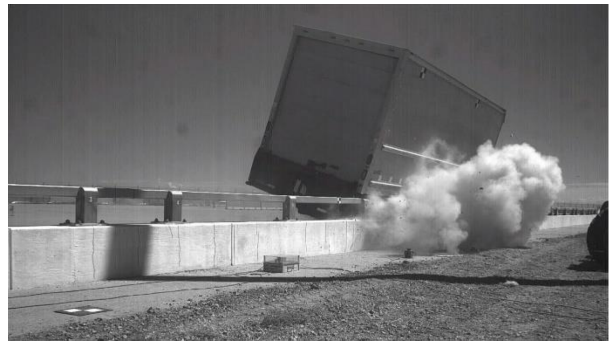
A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 62 through 65. Documentary photographs of the crash test are shown in Figure 66. The vehicle trajectory and final position are shown in Figure 67.

Figure 61. Impact Location, Test No. MNCBR-1

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

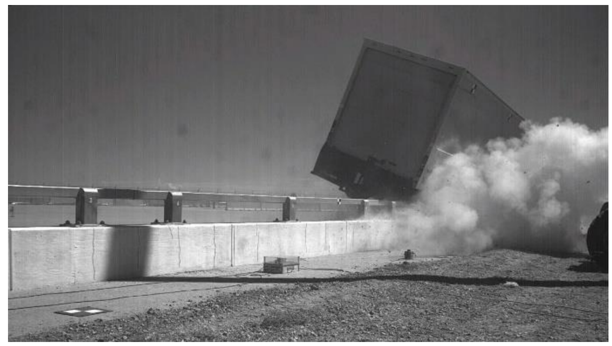
Time (sec)	Event
0.000	Vehicle's right-front bumper impacted concrete barrier 60⅛ in. upstream from centerline of splice between post nos. 6 and 7.
0.006	Vehicle’s right-front tire contacted concrete parapet.
0.014	Vehicle's right-front wheel contacted concrete barrier, and concrete barrier was gouged and spalled on front side.
0.024	Vehicle's right step plates deformed.
0.032	Vehicle's right mudguards deformed.
0.038	Vehicle's right mudguard contacted upper steel rail.
0.047	Vehicle yawed away from system.
0.048	Vehicle right step plates contacted upper steel rail.
0.056	Vehicle's right-front door deformed.
0.078	Vehicle rolled toward system.
0.082	Vehicle’s right-front door contacted upper steel rail. Vehicle pitched upward.
0.098	Vehicle's right-side box contacted upper steel rail and deformed.
0.180	Vehicle's left-front tire became airborne.
0.264	Vehicle's right-rear tire contacted concrete barrier.
0.294	Vehicle’s rear bumper contacted concrete barrier.
0.308	Vehicle’s left-rear tire became airborne.
0.316	Vehicle was parallel to system at a speed of 50.5 mph.
0.406	Vehicle's left-front tire regained contact with ground.
0.458	Vehicle's left-front tire became airborne.
1.262	Vehicle's left-rear tire regained contact with ground.
1.270	Vehicle’s left-front tire regained contact with ground.
1.906	Vehicle's right-front tire became airborne. Vehicle exited system at a speed of 38.7 mph and at an angle of 12 degrees.
2.114	Vehicle’s right-front tire regained contact with ground.
2.196	System came to rest.
2.274	Vehicle pitched upward.
2.460	Vehicle yawed away from system.
2.486	Vehicle pitched downward.
9.908	Vehicle came to rest 330 ft downstream and 11 ft – 2 in. laterally in front of system.

0.000 sec



0.200 sec

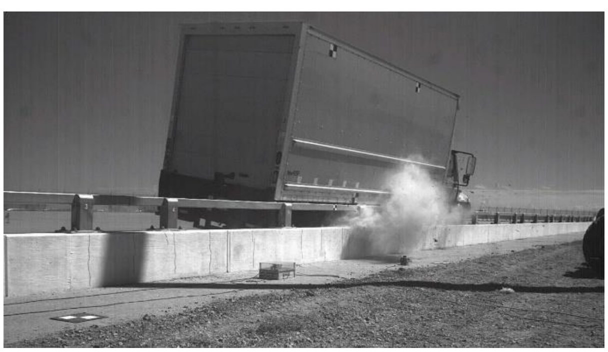
0.050 sec



0.250 sec

0.100 sec

0.350 sec



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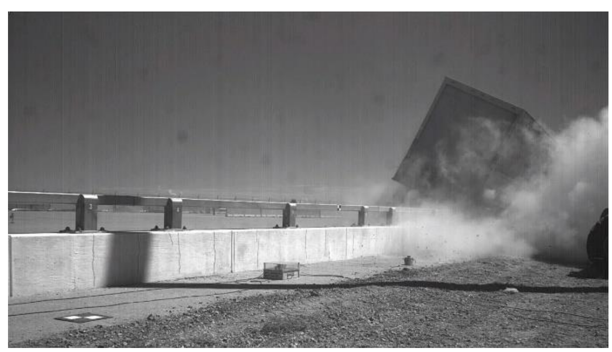

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Figure 62. Sequential Photographs, Test No. MNCBR-1

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Figure 63. Sequential Photographs, Test No. MNCBR-1

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Figure 64. Sequential Photographs, Test No. MNCBR-1

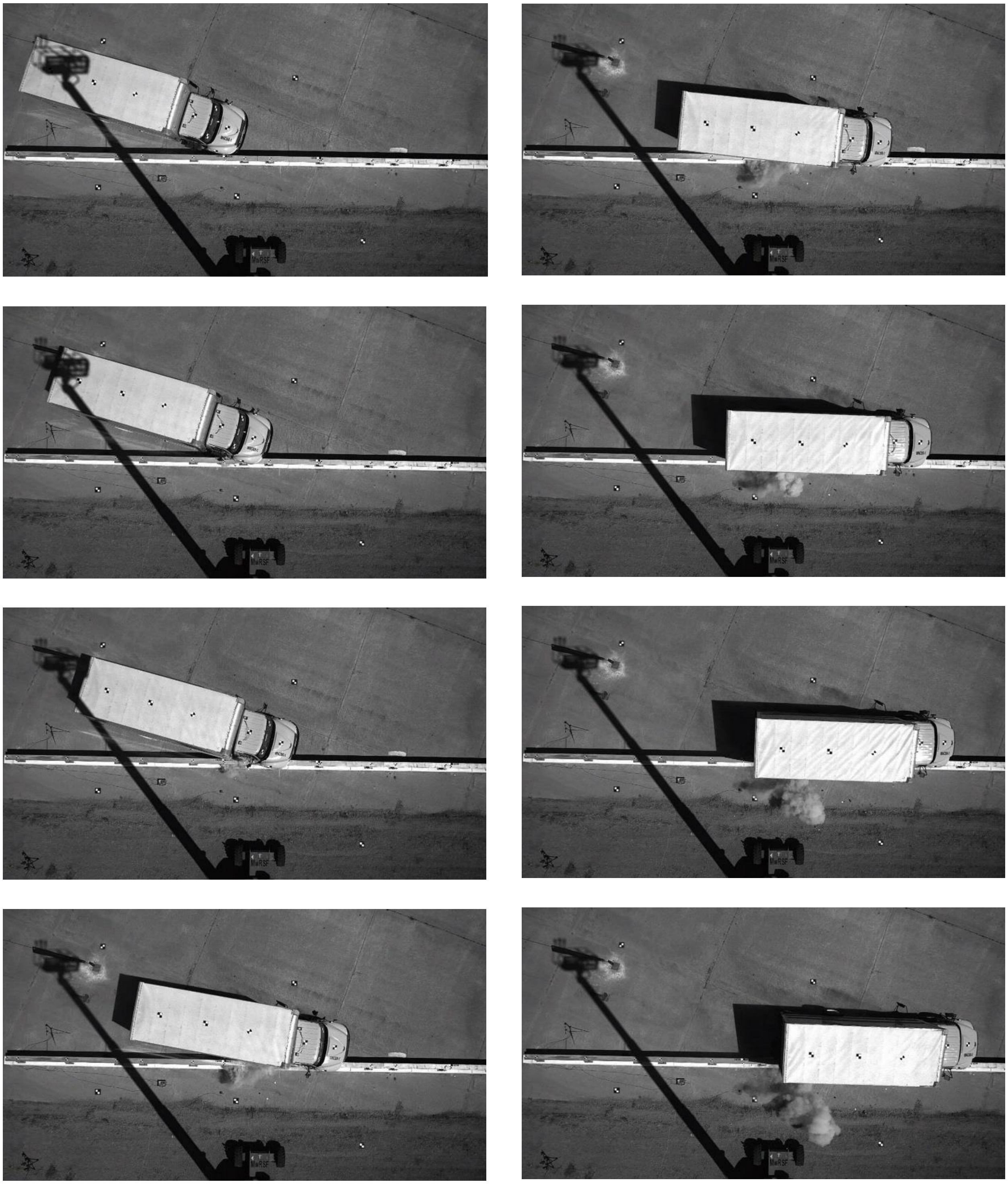

Figure 65. Documentary Photographs, Test No. MNCBR-1

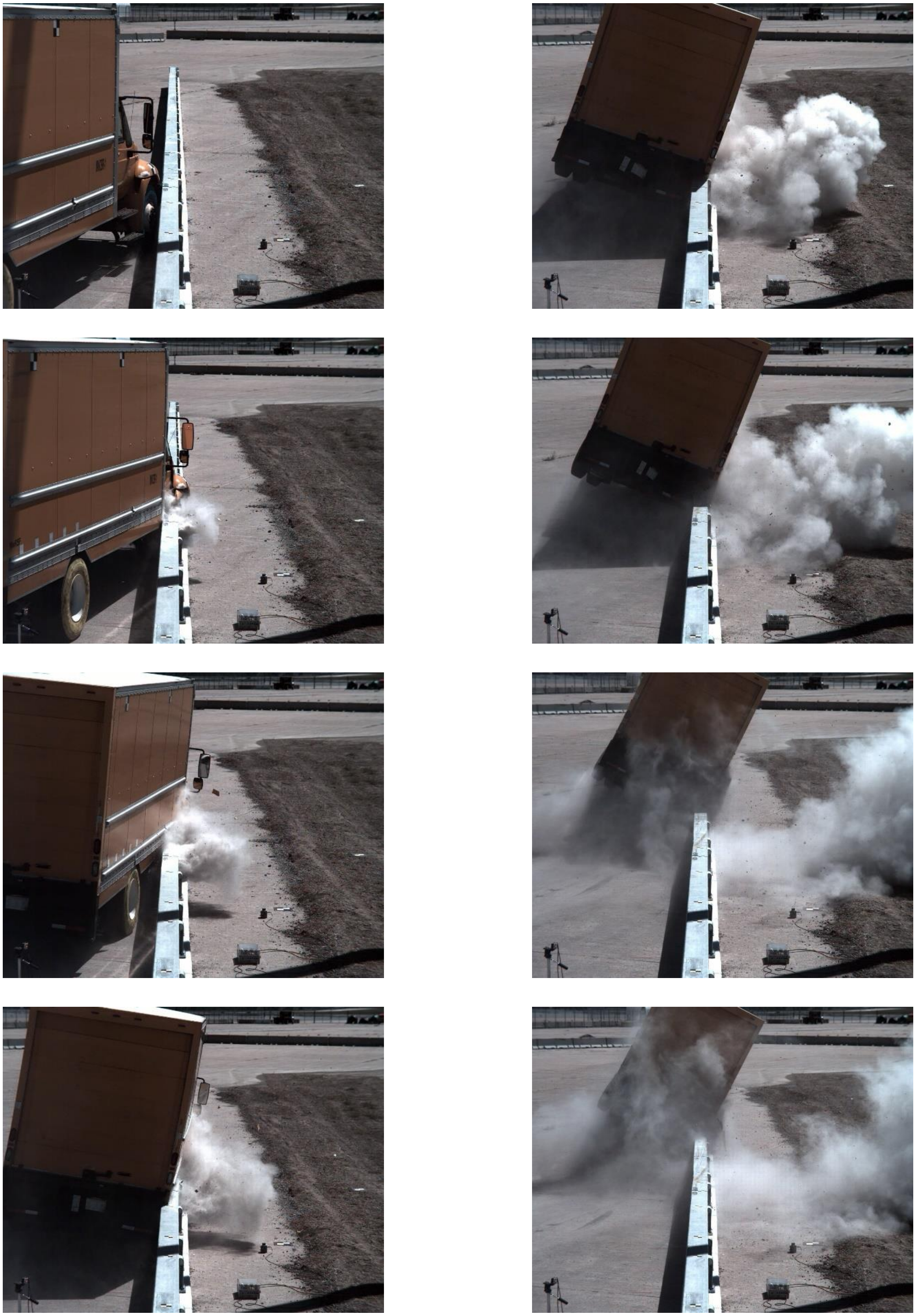

Figure 66. Documentary Photographs, Test No. MNCBR-1

Figure 67. Vehicle Final Position and Trajectory Marks, Test No. MNCBR-1.

5.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 68 through 84. Barrier damage largely consisted of contact marks on the front face of the concrete barrier, gouging and spalling of the concrete, and contact marks on the upper steel rail. Note that the cracking shown in the system photographs was identified before the test and was related to shrinkage, which was not a result of test no. MNCBR-1. The length of vehicle contact along the barrier extended downstream approximately 122 ft – 3½ in., starting 8½ in. upstream from the centerline of post no. 5.

Contact marks measuring 5 in. wide were found across the front face of the brush curb, starting 5 in. upstream from the impact point and extending 158 in. downstream. Contact marks 4 in. wide were found across the front face of the brush curb, starting 15 in. upstream from the centerline of post no. 9 and extending 152 in. downstream. Contact marks 2½ in. wide were found across the front face of the brush curb, starting 75 in. upstream from the centerline of post no. 18 and extending 122 in. downstream. Contact marks were found on across the entire top face of the upper steel rail, starting 24 in. upstream from the impact point and extending 98 ft – 2½ in. downstream. Contact marks were found across the entire front face of the upper steel rail, starting 8½ in. upstream from the centerline of post no. 5 and extending 82 ft – 4½ in. downstream. Contact marks were found across the entire front face of the upper steel rail, starting 97¼ in. downstream from the centerline of splice between post nos. 15 and 16 and extending 115 in. downstream from the centerline of splice between post nos. 18 and 19. Contact marks were found on the front face of the bridge railing system, starting 20½ in. upstream from the centerline of splice between post nos. 21 and 22 and extending 40 in. upstream. Contact marks were found on the front face of the bridge railing system, starting 28 in. downstream from the centerline of the splice between post nos. 21 and 22 and extending 11½ in. downstream. Contact marks were found across the entire front face of the upper steel rail, starting 1 in. upstream from the downstream side of the new tapered end and extending 44½ in. downstream. Contact marks 1 in. wide were found on the bottom face of the upper steel rail, starting 15¾ in. downstream from the impact point and extending 32½ in. downstream from the centerline of post no. 7. Contact marks 6¼ in. wide were found on the bottom face of the upper steel rail, starting 16¼ in. downstream from the centerline of post no. 8 and extending 15 in. downstream from the centerline of post no. 12.

Tire marks were visible on the front face of the 21-in. tall concrete barrier, starting 62 in. upstream from the impact point and extending 118 ft – 6 in. downstream across the traffic side of the concrete barrier. Contact marks 1¼ in. wide were found on the top face of base plate of post no. 7, starting 2½ in. from the traffic-side edge and extending 12½ in. downstream. Contact marks 2½ in. wide were found across the entire length of the traffic side of post no. 10. A 3½-in. tall contact mark was found across the entire traffic side of post no. 10, starting 4 in. above the base plate. Contact marks 6½ in. wide were found on the traffic side of post no. 11, starting 1 in. above the base plate and extending 6½ in. downstream from the upstream corner. Contact marks 1 in. wide were found on the non-traffic side of post no. 12, starting 6 in. from the top of post and extending downward. Contact marks 3 in. wide were found on top of the traffic side of post no. 13 and extended across the entire length of post. Contact marks 2½ in. wide were found on the top of traffic side on post no. 18, starting on the upstream edge and extending 7 in. downstream.

Scuff marks were also found along the length of vehicle contact. Gouging, measuring ¼ in. wide by 77 in. long, was found on the front face of the concrete parapet and located 21 in. upstream from post no. 6 and 15 in. above the ground. Gouging, measuring 25 in. wide by 34 in. long, was located 33 in. upstream from post no. 20. Gouging, measuring 2½ in. wide by 28 in. long, was located 90 in. upstream from post no. 21. Gouging, measuring ½ in. wide by 19½ in. long, was located 46 in. upstream from post no. 21. Concrete chipping, measuring 9½ in. wide by 9 in. long, was located 36 in. upstream from the new tapered end and 26 in. above the ground.

Figure 68. System Damage, Test No. MNCBR-1

Figure 69. System Damage, Test No. MNCBR-1

Figure 70. Concrete Gouging and Spalling, Test No. MNCBR-1

Figure 71. Concrete Gouging and Spalling, Test No. MNCBR-1

Figure 72. Rail and Post Damage, Test No. MNCBR-1

Figure 73. Rail and Post Damage, Test No. MNCBR-1

Figure 74. Rail and Post Damage, Post No. 8, Test No. MNCBR-1

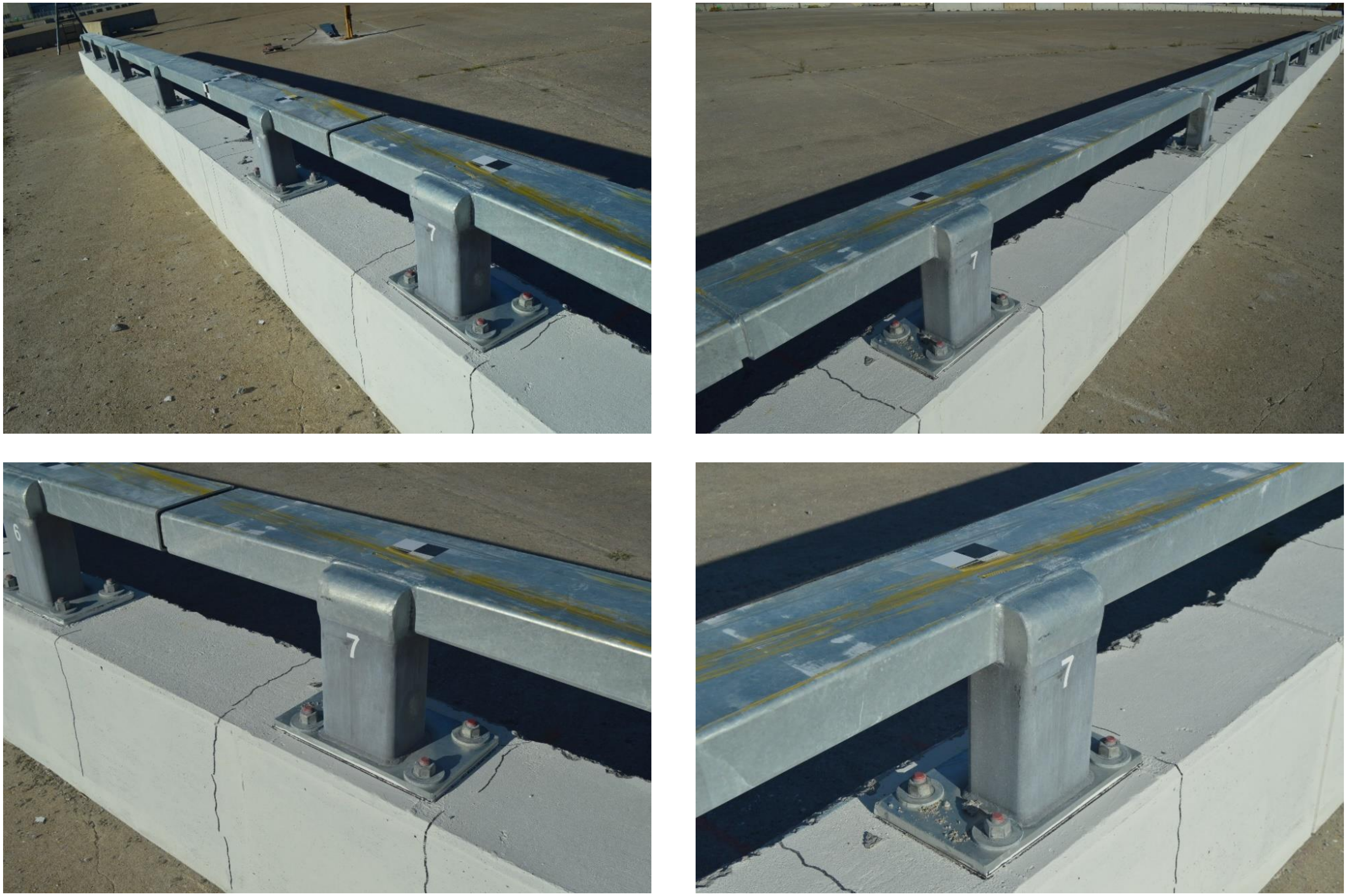

Figure 75. Rail and Post Damage, Post No. 7, Test No. MNCBR-1

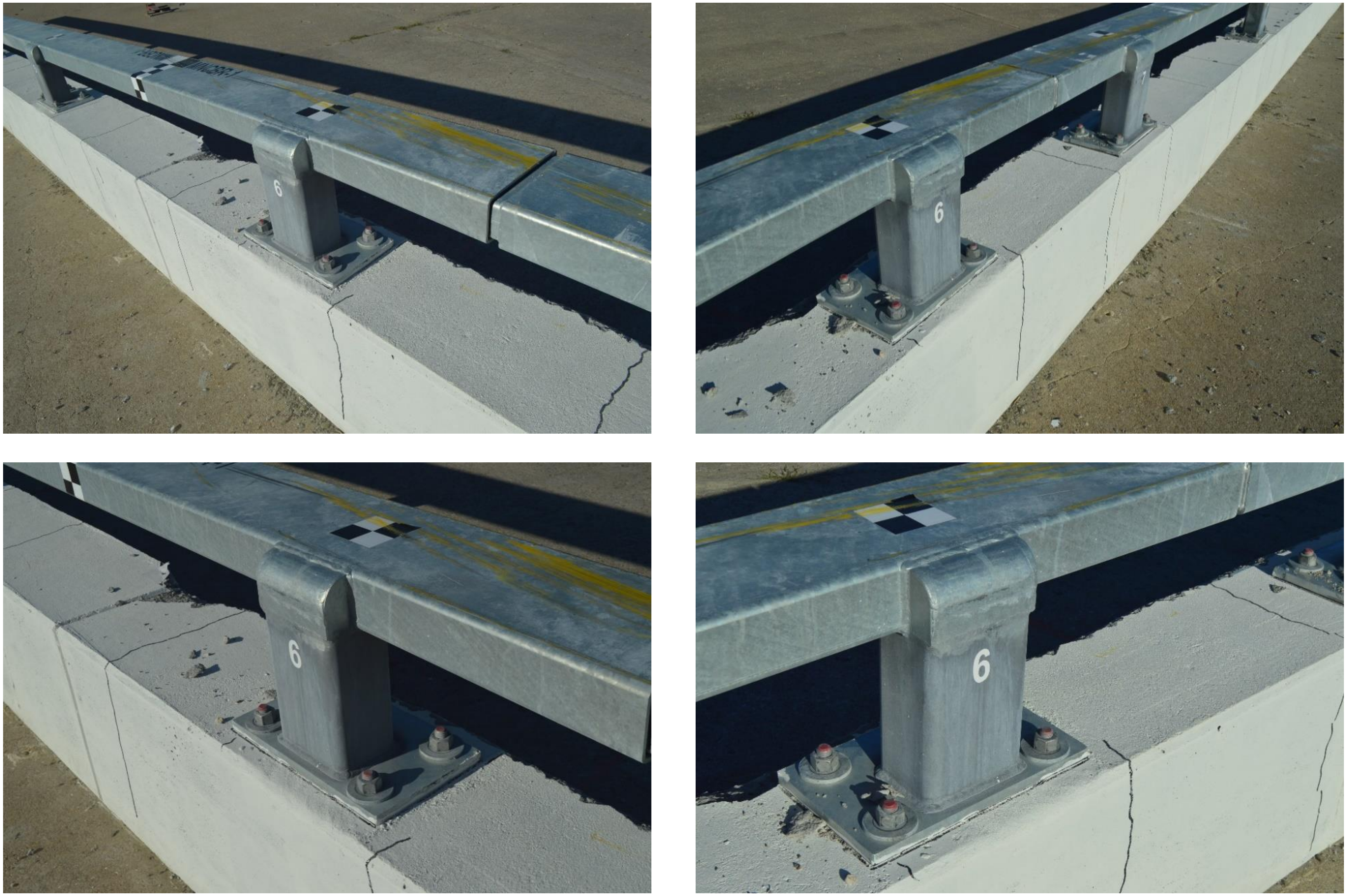

Figure 76. Rail and Post Damage, Post No. 6, Test No. MNCBR-1

Figure 77. Vehicle Final Position and Trajectory Marks, Test No. MNCBR-1

Figure 78. Upstream View of End of Rail, Test No. MNCBR-1

Figure 79. Vehicle Debris on Bridge Railing, Test No. MNCBR-1

Figure 80. Non-Traffic Side Rail and Post Damage, Post No. 14, Test No. MNCBR-1

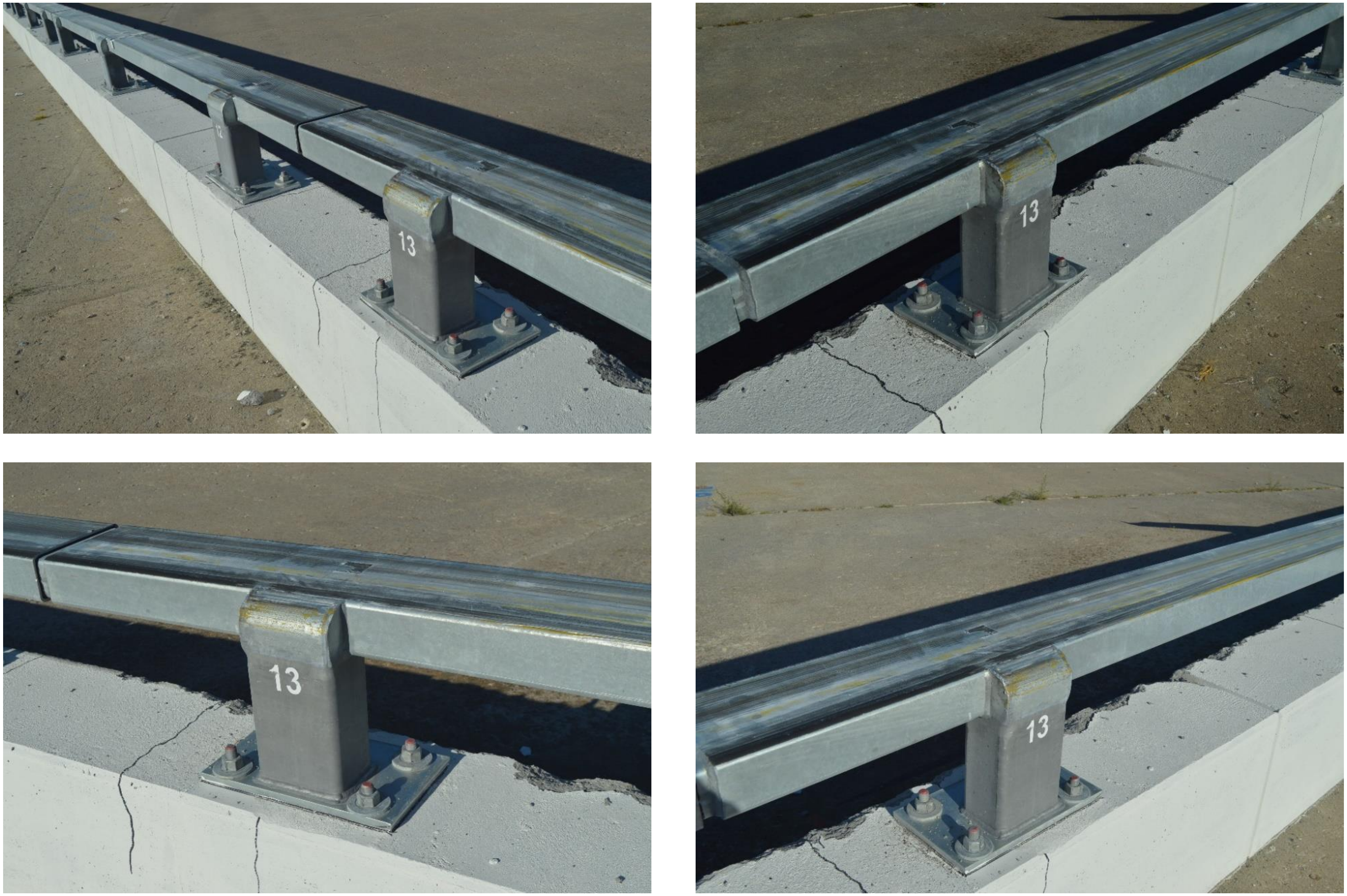

Figure 81. Rail and Post Damage, Post No. 13, Test No. MNCBR-1

Figure 82. Rail and Post Damage, Post Nos. 12 and 11, Test No. MNCBR-1

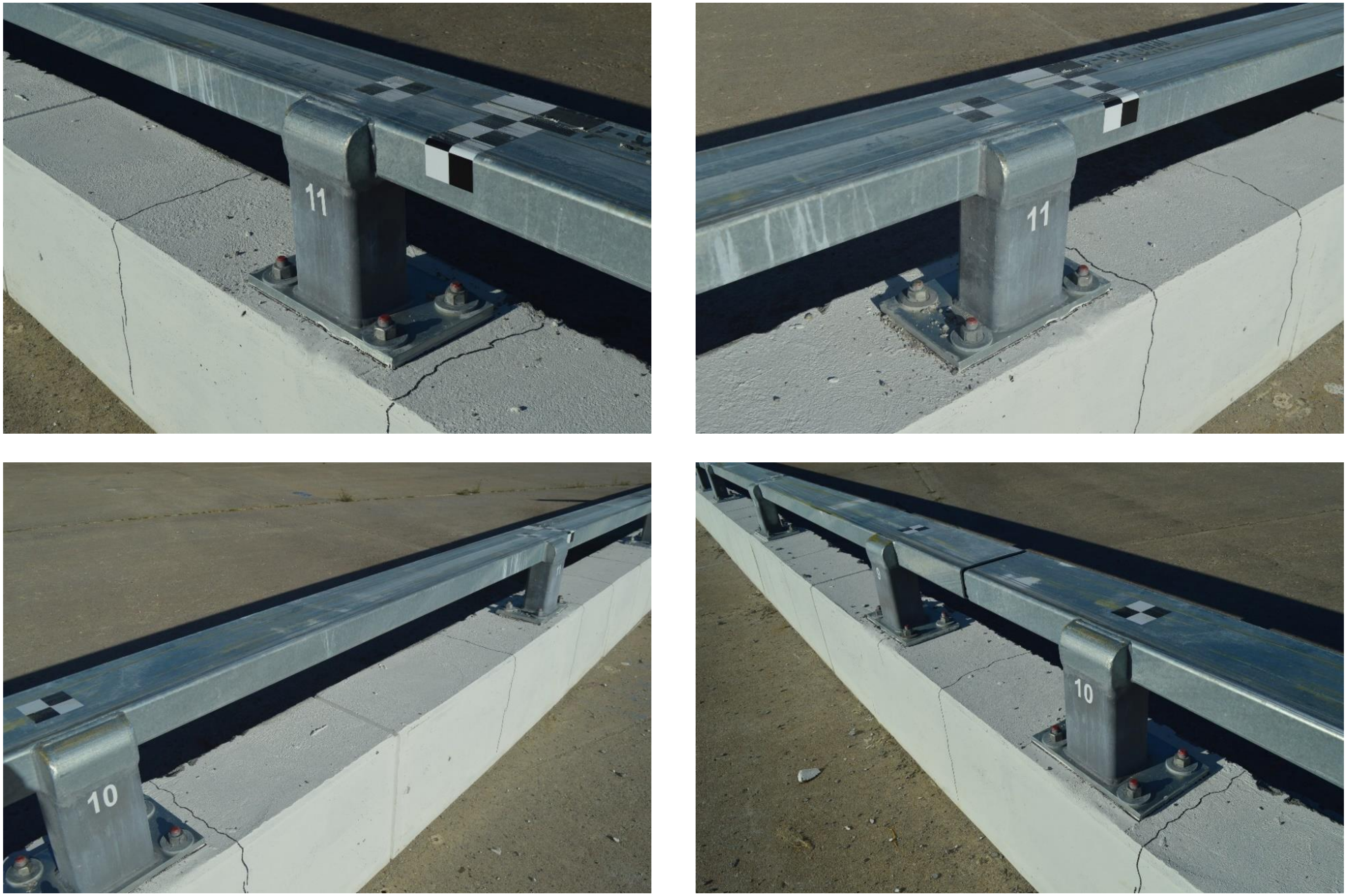

Figure 83. Rail and Post Damage, Post Nos. 11 and 10, Test No. MNCBR-1

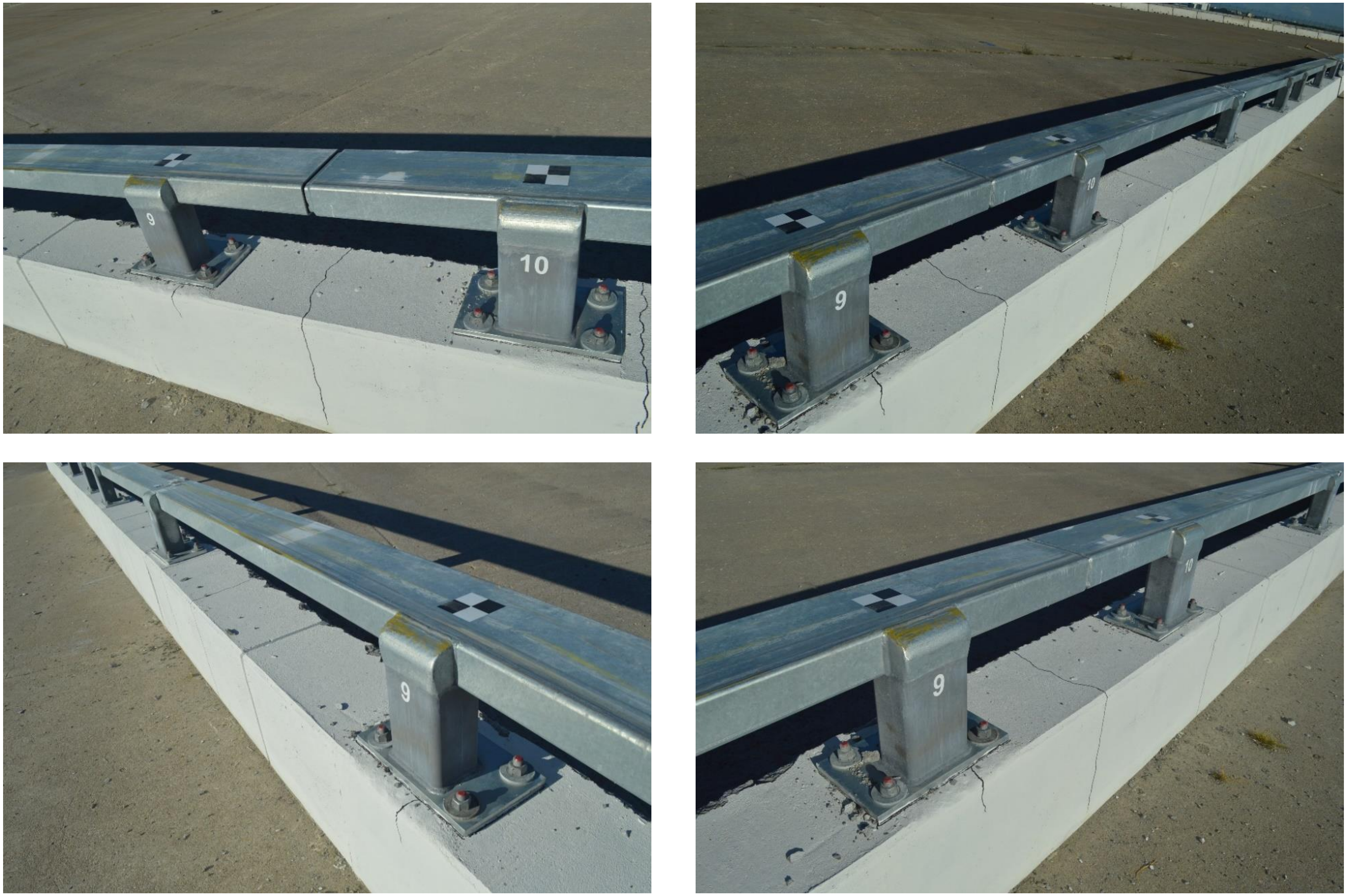

Figure 84. Rail and Post Damage, Post Nos. 10 and 9, Test No. MNCBR-1

The maximum lateral permanent set of the barrier system was 0.2 in. at post no. 9, as measured in the field. The maximum lateral dynamic barrier deflection, including tipping of the upper metal rail along the top surface, was 0.9 in., as determined from high-speed digital video analysis. The working width of the system was found to be 51.6 in., also determined from high-speed digital video analysis. The Zone of Intrusion (ZOI) was determined to be 49.6 in. Barrier deflections are shown schematically in Figure 85.

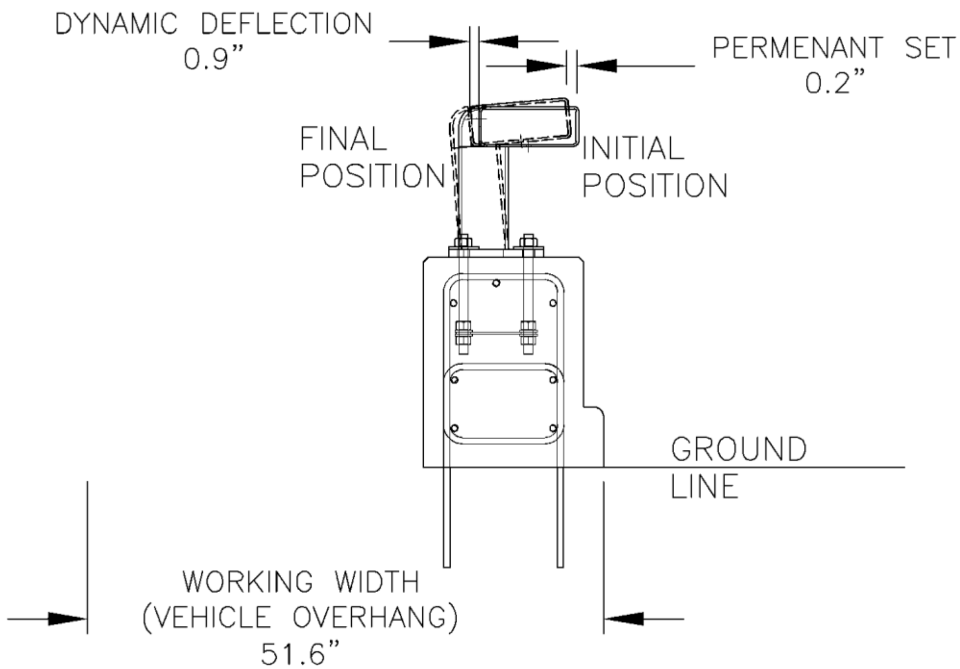

Figure 85. Permanent Set, Dynamic Deflection, and Working Width, Test No. MNCBR-1

5.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 86 through 91. 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. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix C. 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.

The majority of the damage was concentrated on the right-front corner and right side of the vehicle, where impact had occurred, as shown in Figure 86. The left side of the front bumper was crushed inward due to the vehicle impact into a downstream portable concrete barrier far beyond the bridge railing system. The right side of the bumper was crushed inward. The right-front fender was pushed upward near the door panel and torn behind the right-front wheel, as shown in Figure 87. The right-side upper control arm was bent. The right-front steel rim was moderately deformed with concentrated crushing along the edge, as shown in Figure 87.

Denting and scraping were observed across the entire right side. The right-front door was slightly ajar, and creases were found in the door's sheet metal. The right-side window glass shattered, as shown in Figures 87 through 90. The right-rear door was dented and ajar. The right side of the truck bed was dented, and the fuel hatch was ajar. The right-rear wheel detached, as shown in Figures 87 through 90. The right side of the rear bumper was torn and pushed downward. The roof and remaining window glass remained undamaged. The undercarriage and the box were scraped, as shown in Figure 91.

The right-side edge or seam of the floor pan released, as shown in Figures 88 and 89. The right-front wheel and/or rubber tire pushed on the supporting member and the floor pan was held in place at the edge until the partially-rusted spot welds along the seam failed. As such, the spot-weld region was pulled downward along this seam in more of a tensile loading manner, where the spot welds eventually tore out of the fabricated holes. Based on a review of the post-test results, researchers confirmed that the right-front wheel and/or rubber tire did not penetrate at the floor edge or seam since the floor did not reveal upward bending (prying up) at the edge but rather downward bending (tension down with tear out) at the edge, as shown in Figures 88 and 89. The maximum measured floor pan deformation was 5.6 in., which is within AASHTO MASH 2016 [3] occupant compartment deformation limits. The doorsill remained intact and did not show evidence of vehicle components prying through the edge opening at the doorsill region.

Figure 86. Vehicle Damage, Test No. MNCBR-1

Figure 87. Vehicle Damage, Test No. MNCBR-1

Figure 88. Undercarriage Damage, Test No. MNCBR-1

Figure 89. Vehicle Floor Pan Damage, Test No. MNCBR-1

Figure 90. Vehicle Floor Pan Damage, Test No. MNCBR-1

Figure 91. Undercarriage Damage, Test No MNCBR-1

Table 5. Maximum Occupant Compartment Intrusion by Location, Test No. MNCBR-1

Location	Maximum Intrusion in.	MASH 2016 Allowable Intrusion in.
Wheel Well & Toe Pan	5.5	≤ 9
Floor Pan & Transmission Tunnel	5.6	≤ 12
A-Pillar	1.4	≤ 5
A-Pillar (Lateral)	1.4	≤ 3
B-Pillar	1.4	≤ 5
B-Pillar (Lateral)	1.4	≤ 3
Side Front Panel (in Front of A-Pillar)	0.7	≤ 12
Side Door (Above Seat)	0.7	≤ 9
Side Door (Below Seat)	0.5	≤ 12
Roof	0.8	≤ 4
Windshield	0.0	≤ 3
Side Window	Shattered due to contact with simulated occupant's head	No shattering resulting from contact with structural member of test article
Dash	1.4	N/A

N/A – Not Applicable

5.5 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ride down accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 6. Although not required for TL-4 crash testing with 10000S vehicle, the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 6. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix D.

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

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 at c.g. (primary)	SLICE-2 in cab	
OIV ft/s	Longitudinal	-6.54	-3.58	not required
	Lateral	-13.47	-15.12	not required
ORA g's	Longitudinal	-6.36	-6.60	not required
	Lateral	-18.08	-15.14	not required
Maximum Angular Displacement deg.	Roll	25.8	21.0	not required
	Pitch	2.6	-3.8	not required
	Yaw	-14.9	-17.2	not required
THIV – ft/s		19.33	26.97	not required
PHD – g's		18.10	9.70	not required
ASI		0.68	0.85	not required

5.6 Barrier Loads

The longitudinal and lateral vehicle accelerations, as measured at the vehicle's c.g. and at the rear axle, were also processed using a 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. From the data analysis, the perpendicular impact forces were determined for the bridge rail, as shown in Figures 92 through 94. The maximum perpendicular (i.e., lateral) loads imparted to the barrier were 133.8, 119.5, and 106.1 kips, as determined by the SLICE-1 (primary) unit and the two data sets from the TDAS unit, TDAS-1 and TDAS-2. The two lateral barrier load estimates from the TDAS system at the rear axle of the single-unit truck used modified Euler angles based on the assumptions described in Section 4.5.2.

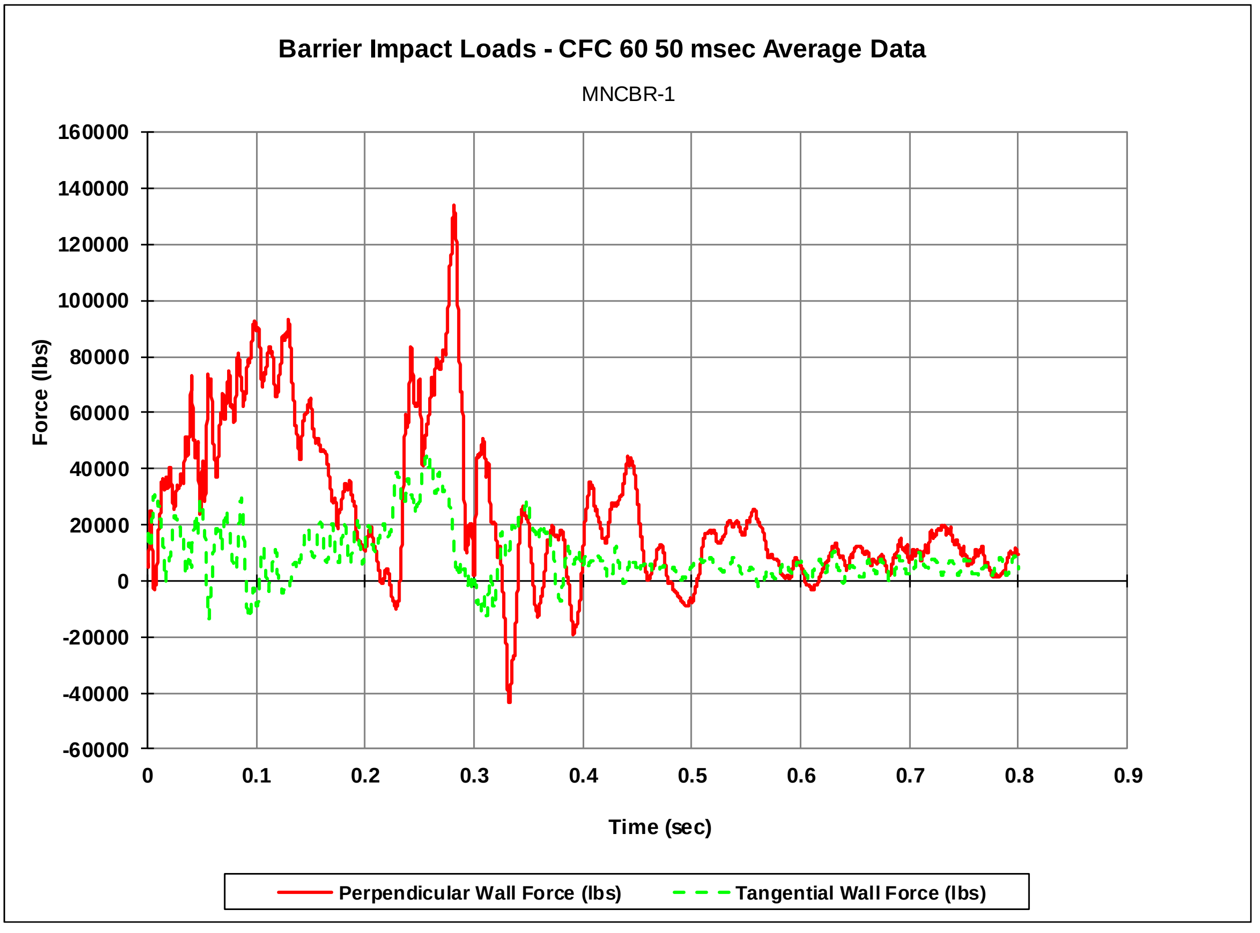

Figure 92. Perpendicular and Tangential Forces Imparted to the Barrier System (SLICE-1) Located at c.g., Test No. MNCBR-1

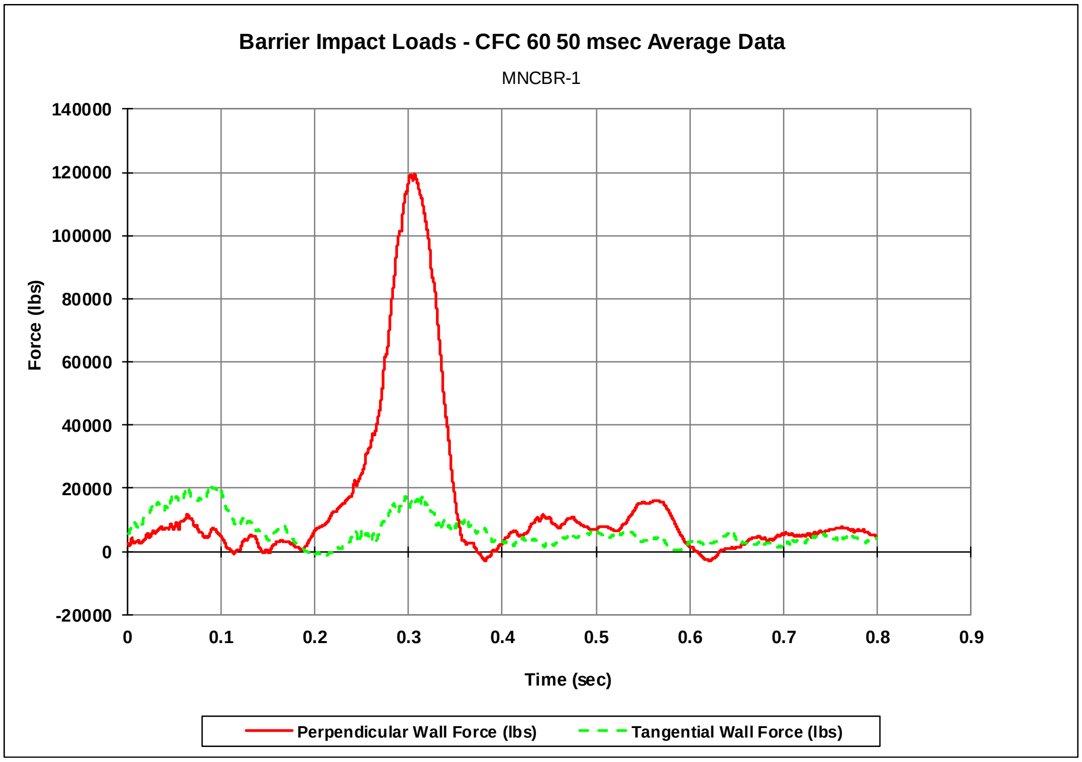

Figure 93. Perpendicular and Tangential Forces Imparted to the Barrier System (TDAS-1) Located at Rear Axle, Test No. MNCBR-1

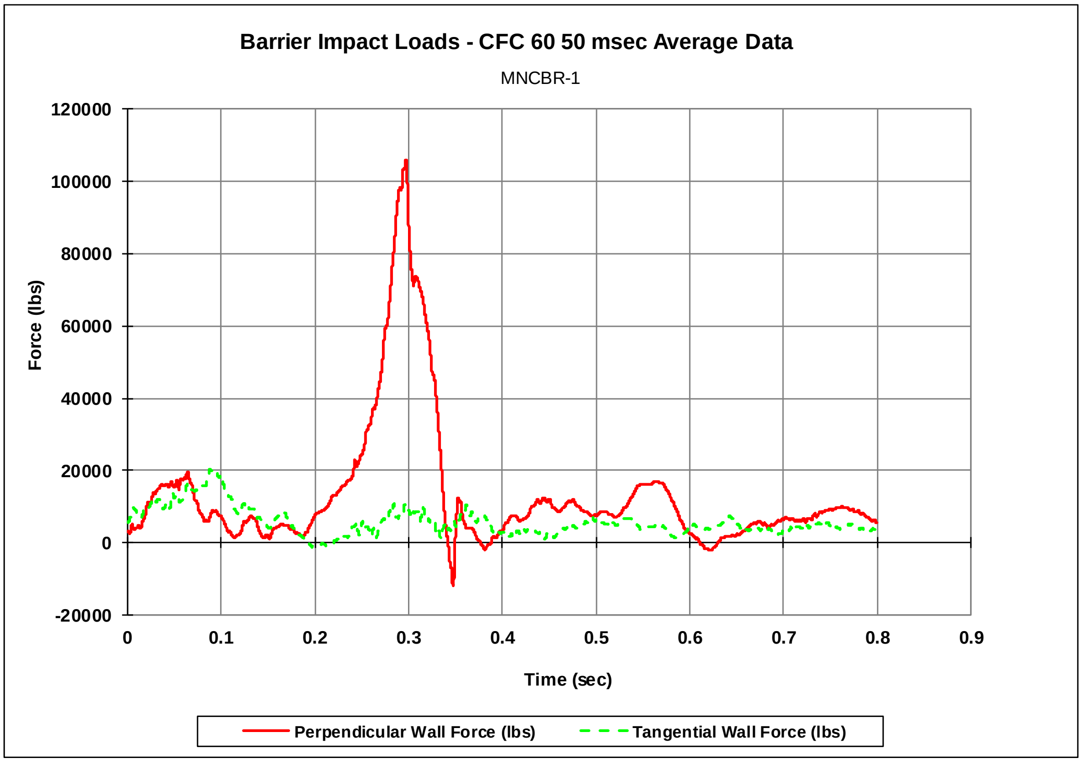

Figure 94. Perpendicular and Tangential Forces Imparted to the Barrier System (TDAS-2) Located at Rear Axle, Test No. MNCBR-1

5.7 Discussion

The analysis of the results for test no. MNCBR-1 showed that the bridge railing system adequately contained and redirected the 10000S vehicle with negligible displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 95. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix D, were deemed acceptable because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle approximated to be 12 degrees, and its trajectory did not violate the bounds of the exit box. During the test, the ZOI was measured to be 49.6 in. Therefore, test no. MNCBR-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 4-12.

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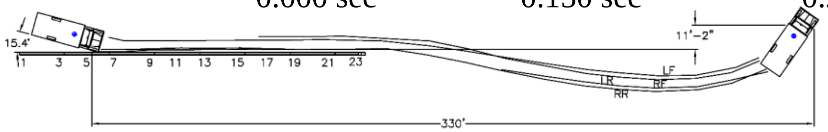

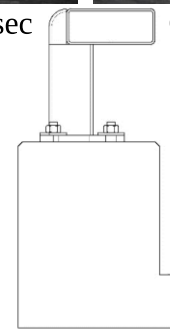

- Test Agency .... MwRSF
- Test Number MNCBR-1
- Date 9/2/2020
- MASH 2016 Test Designation No. 4-12
- Test Article .... Minnesota Combination Bridge Rail
- Total System Length .... 154 ft
- Total Bridge Rail Height .... 36 in.
- Bridge Rail Elements .... HSS 10x4x¼ Tube
  - Length .... 150 ft – 2½ in.
- Bridge Post Assembly (Main Components)
  - Post .... HSS 7x5x5⁄16 by 10¼ in. long
  - Base Plate (Welded) .... 16 in. x 9½ in. x ¾ in.
- Concrete Parapet
  - Length .... 140 ft – 8 in.
  - Width .... 16 in.
  - Height .... 21 in.
- Concrete Tapered End Section (Excluding End Post)
  - Length .... 22½ in.
  - Height .... 10 in.
  - Width .... 16 in. at downstream end and 8½ in. wide at the upstream end
- Brush Curb
  - Width .... 2 in.
  - Height .... 6 in.
- Vehicle Make /Model .... 2013 International Durastar 4300 SBA SUT
  - Curb .... 14,852 lb
  - Test Inertial .... 22,042 lb
  - Gross Static .... 22,202 lb
- Impact Conditions
  - Speed .... 57.4 mph
  - Angle Point .... 15.4 deg.
  - Impact Location. 60⅛ in. upstream from splice centerline between post nos. 6 and 7
  - Impact Severity (IS) .... 171.2 kip-ft > 142 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed .... 38.7 mph
  - Angle Approximation .... 12 deg.
- Exit Box Criterion .... Pass

  Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 330 ft downstream

  11 ft – 2 in. laterally in front
- Vehicle Damage .... Moderate
  - VDS [15] 01-RFQ-5
  - CDC [16] 01-RYEW-5
  - Maximum Interior Deformation .... 5.6 in.
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... 0.2 in.
  - Dynamic .... 0.9 in.
  - Working Width .... 51.6 in.
  - ZOI .... 49.6 in.
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1 at c.g. (primary)	SLICE-2 in cab	
OIV ft/s	Longitudinal	-6.54	-3.58	not required
	Lateral	-13.47	-15.12	not required
ORA g's	Longitudinal	-6.36	-6.60	not required
	Lateral	-18.08	-15.14	not required
Maximum Angular Displacement deg.	Roll	25.8	21.0	not required
	Pitch	2.6	-3.8	not required
	Yaw	-14.9	-17.2	not required
THIV – ft/s		19.33	26.97	not required
PHD – g's		18.10	9.70	not required
ASI		0.68	0.85	not required

Figure 95. Summary of Test Results and Sequential Photographs, Test No. MNCBR-1

6 FULL-SCALE CRASH TEST NO. MNCBR-2

6.1 Weather Conditions

Test no. MNCBR-2 was conducted on September 16, 2020 at approximately 1:45 p.m. The weather conditions as reported by the National Oceanic and Atmospheric Administration (station 14939/LNK) are shown in Table 7.

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

Temperature	79°F
Humidity	45%
Wind Speed	22 mph
Wind Direction	360° from True North
Sky Conditions	Sunny
Visibility	6.0 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.00 in.

6.2 Test Description

Test no. MNCBR-2 was conducted on a concrete parapet with brush curb and upper beam and post rail with new tapered end section under the MASH 2016 TL-4 guidelines for test designation no. 4-11, which involved an impact with a 2270P pickup truck at 62 mph and 25 degrees. The CIP for this system was selected to maximize the potential for vehicle interaction and snag on the vertical support posts, the upper metal tube rail, and the tapered end section.

Initial vehicle impact was to occur 70¹¹⁄₁₆ in. upstream from the centerline of post no. 23, as shown in Figure 96, which was selected as discussed in Chapter 2.2. The 5,003-lb crew cab pickup truck impacted the concrete parapet with a brush curb and upper beam and post rail with a new tapered end section at a speed of 63.9 mph and at an angle of 25.1 degrees. The actual point of impact was 0.78 in. downstream from the target impact point. In the test, the vehicle was captured and redirected by the concrete parapet with brush curb and upper beam and post rail with new tapered end section.

A detailed description of the sequential impact events is contained in Table 8. Sequential photographs are shown in Figures 97 through 98. Documentary photographs of the crash test are shown in Figure 99. The vehicle trajectory and final position are shown in Figure 100.

Figure 96. Impact Location, Test No. MNCBR-2

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

Time (sec)	Event
0.000	Vehicle's front bumper impacted concrete barrier 69.9 in. upstream from post no. 23.
0.002	Vehicle’s front bumper cover deformed.
0.006	Vehicle's right headlight contacted upper steel rail at post no. 22 and deformed.
0.012	Vehicle's right fender contacted upper steel rail and deformed.
0.024	Vehicle's grille deformed.
0.038	Vehicle's engine hood deformed, and vehicle’s right-front door contacted upper steel rail.
0.046	Vehicle's right-front door contacted concrete barrier and deformed.
0.048	Vehicle grille contacted upper steel rail.
0.054	Vehicle's front bumper contacted post no. 23.
0.066	Barrier’s traffic-side face spalled near post no. 23. Vehicle's right headlight shattered.
0.084	Vehicle’s left headlight became disengaged.
0.090	Vehicle's right-front window shattered and simulated occupant's head passed through right-front window.
0.092	Vehicle's left-front tire became airborne.
0.140	Vehicle's left-rear tire became airborne.
0.144	Vehicle's right-rear door contacted upper steel rail and deformed.
0.172	Vehicle's right quarter panel contacted upper steel rail and deformed.
0.178	Simulated occupant's head reentered through right-front window. Vehicle was parallel to system at a speed of 46.5 mph.
0.198	Vehicle's rear bumper contacted concrete barrier and deformed. Vehicle’s right-rear tire contacted concrete barrier.
0.200	Vehicle pitched downward.
0.362	Vehicle exited system at a speed of 45.1 mph and at an angle of 5.1 degrees.
0.364	System came to rest.
0.660	Vehicle's left-front tire regained contact with ground.
0.908	Vehicle's left-rear tire regained contact with ground.
1.110	Vehicle's left-rear tire became airborne.
1.354	Vehicle rolled away from system.
1.418	Vehicle left-rear tire regained contact with ground.
3.700	Vehicle came to rest 176 ft – 3 in. downstream and 12 ft – 6 in. laterally in front of system.

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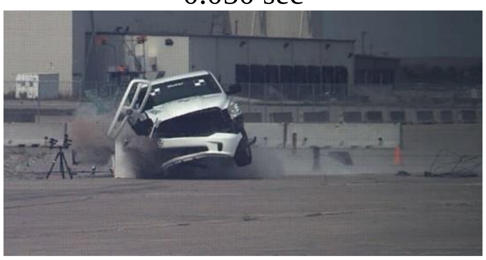

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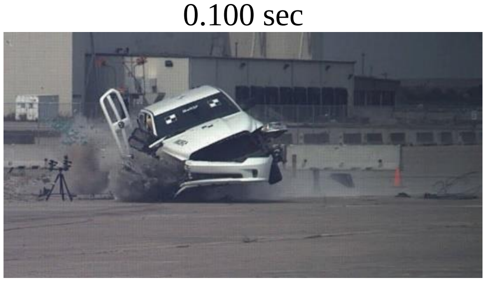

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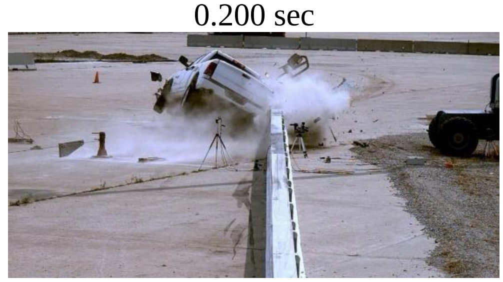

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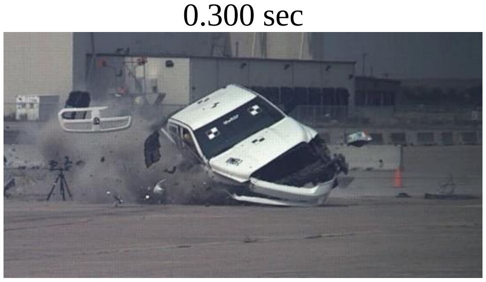

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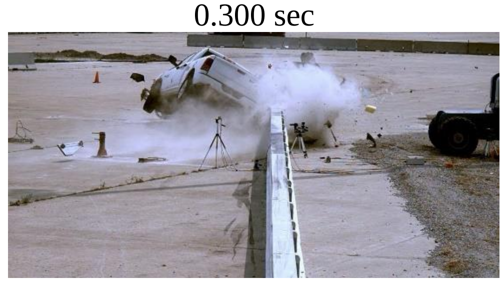

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Figure 97. Sequential Photographs, Test No. MNCBR-2


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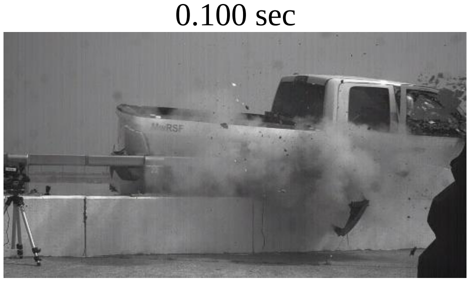
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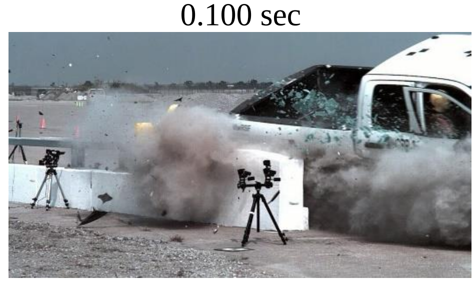
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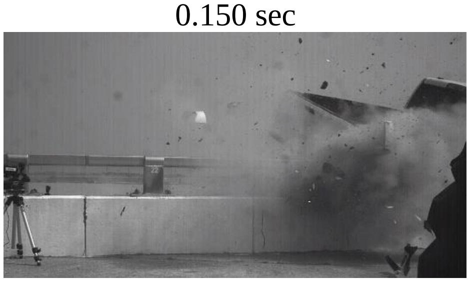
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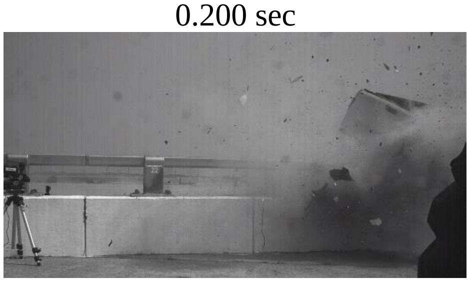
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Figure 98. Sequential Photographs, Test No. MNCBR-2

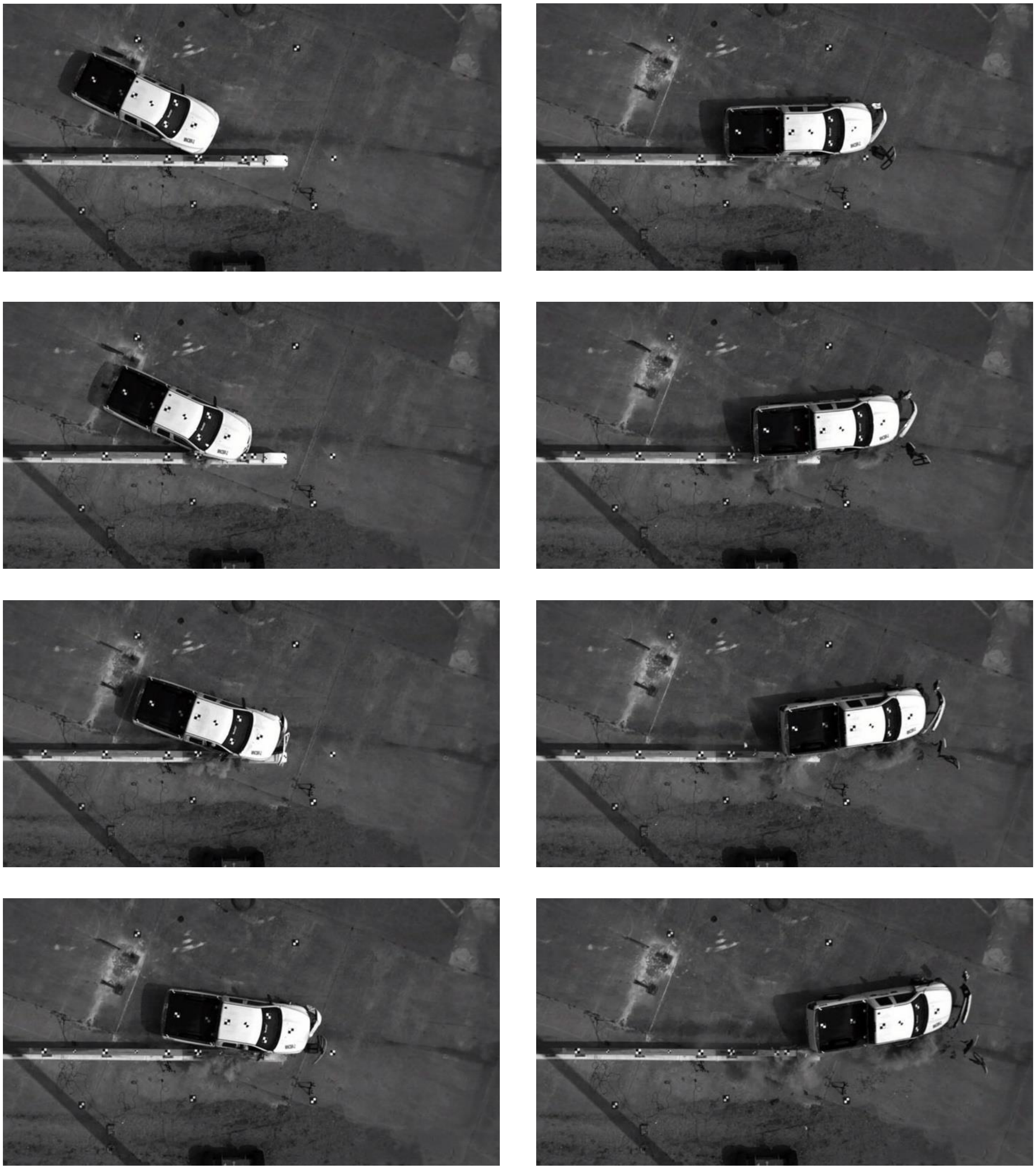

Figure 99. Documentary Photographs, Test No. MNCBR-2

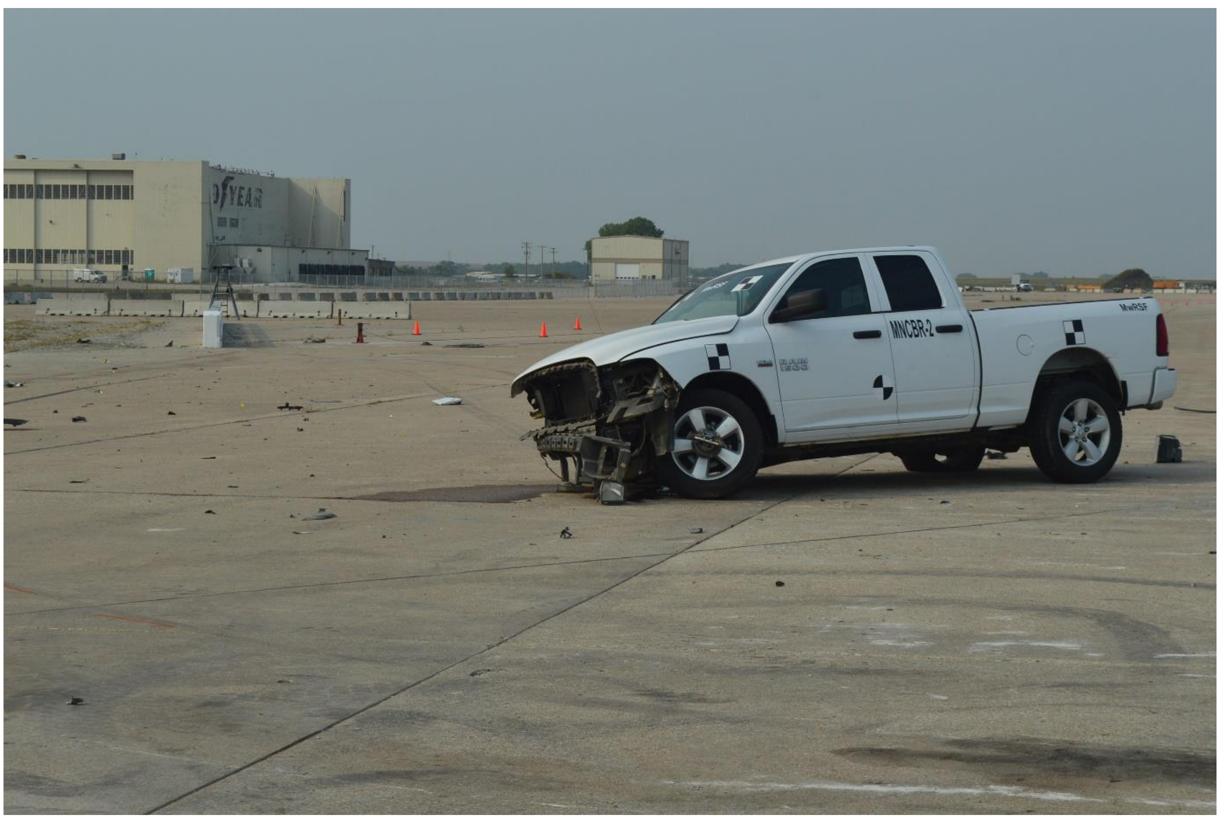

Figure 100. Vehicle Final Position and Trajectory Marks, Test No. MNCBR-2

6.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 101 through 111. Barrier damage largely consisted of contact marks on the front face of the concrete barrier and spalling of the concrete. Note that the cracking shown in the system photographs was identified before the test as being related to shrinkage, and was not a result of test no. MNCBR-2. The length of vehicle contact along the barrier extended downstream approximately 12 ft – 10 in., starting at 21½ in. upstream from post no. 22.

Tire marks were visible on the front face of the 21-in. tall concrete barrier, starting 16 in. upstream from the centerline of post no. 22 and extending 9 ft – 9 in. downstream across the traffic side of the barrier. Contact marks 15 in. wide were found across the front face of the concrete barrier above the brush curb, starting 21½ in. upstream from the centerline of post no. 22 and extending 9 ft – 11 in. downstream. Contact marks 15 in. wide were found across the entire length of the front face of the end post, including the horizontal tapered end, starting 9 in. downstream from the centerline of post no. 23 and extending 56 in. downstream. Contact marks measuring 4 in. wide were found on front face of the steel upper rail, starting 6½ in. downstream from the centerline of the splice between post nos. 21 and 22 and extending 9 ft – 9 in. downstream. Contact marks measuring 8½ in. wide were found on the top face of the steel upper rail, starting 7 in. downstream from the centerline of splice between post nos. 21 and 22 and extending 9 ft – 8 in. downstream. Contact marks measuring 5½ in. wide were found on the front face of the steel upper rail, starting 13 in. downstream from the centerline of the splice between post nos. 21 and 22 and extending 8 ft – 8½ in. downstream. Contact marks measuring ⅛ in. wide were found on the upstream face of post no. 22, starting 12 in. from the top of plate and extending 1 in. downward. Contact marks measuring 1 in. wide were found on the upstream face of post no. 23, starting 6½ in. from the top of the plate and extending 2 in. upward. Contact marks measuring 6½ in. were found on the front face of post no. 23, starting ½ in. from the top of the plate and extending 8½ in. upward. Contact marks measuring ½ in. wide were found on the upstream corner of the front face of post no. 23, starting at the post base plate and extending across the entire height of the post. The vehicle's lateral overlap/contact distance at the upstream end of the tapered end section was 1 in. The vehicle's overlap/contact distance at the upstream corner of the front face of post no. 23 was ½ in.

Scuff marks were also found along the length of vehicle contact. Gouging was found on the top corner of the front face of the concrete parapet, measuring 75 in. long and located 2 in. upstream from post no. 22 with a width of 7 in. Gouging with a width of 3 in. and measuring 25 in. long was located 48 in. upstream from post no. 23. Gouging was found on the upstream face of the mid horizontal tapered section measuring ¾ in. long located 8 in. from the top front corner of the upstream face. Gouging was found on the upstream face of the mid horizontal tapered section measuring ½ in. long located 3½ in. from the top front corner of the upstream face. Gouging with a width of 1½ in. and measuring 10 in. long was located 20 in. upstream from post no. 23. Gouging with a width of 1½ in. and measuring 17½ in. long was located 11½ in. upstream from post no. 23. Concrete chipping, measuring 21½ in. long, was located at upstream edge of end post with a width of 9 in.

Figure 101. System Damage, Test No. MNCBR-2

Figure 102. System Damage, Test No. MNCBR-2

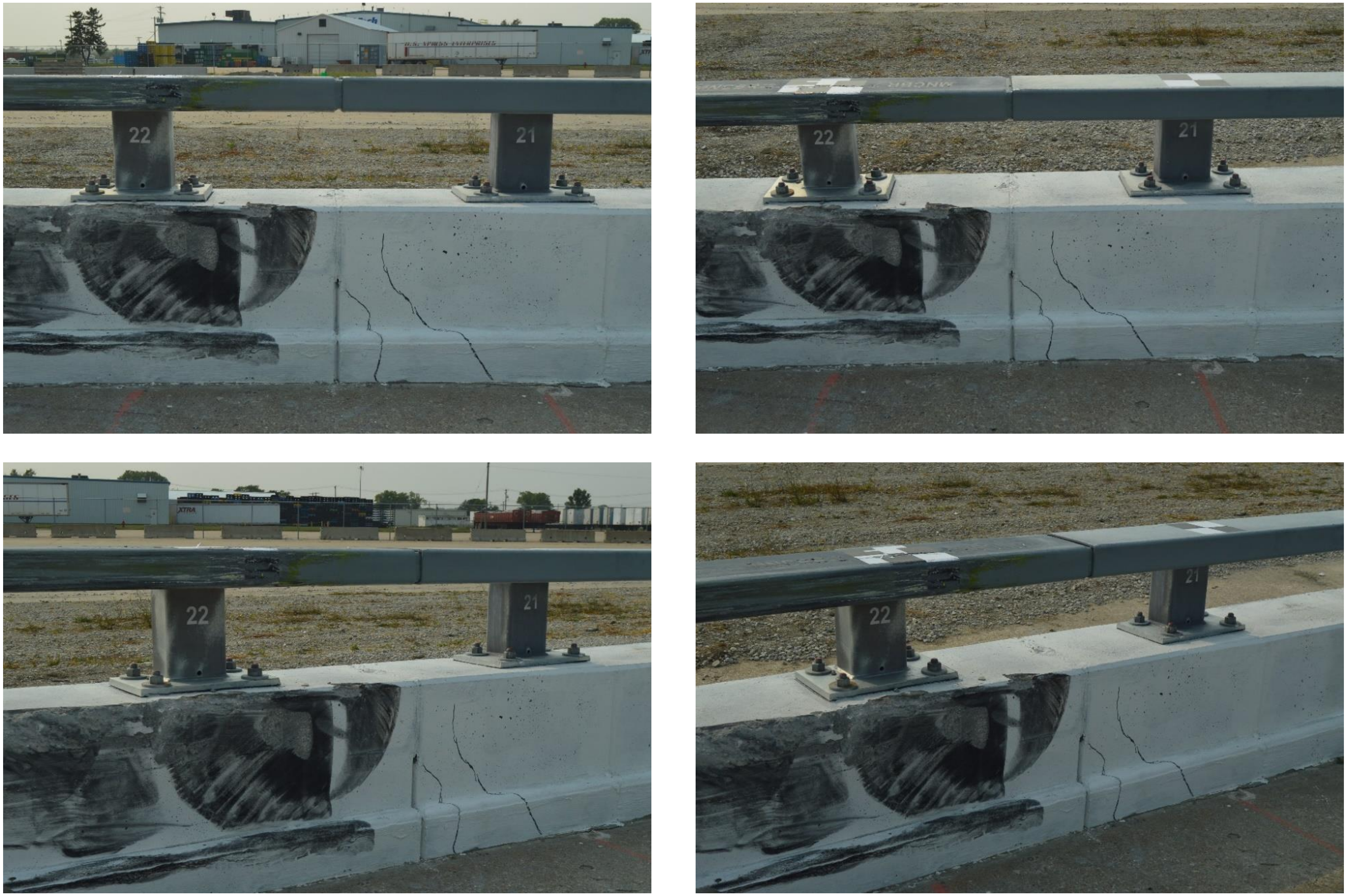

Figure 103. Damage on Splice between Post Nos. 22 and 21, Test No. MNCBR-2

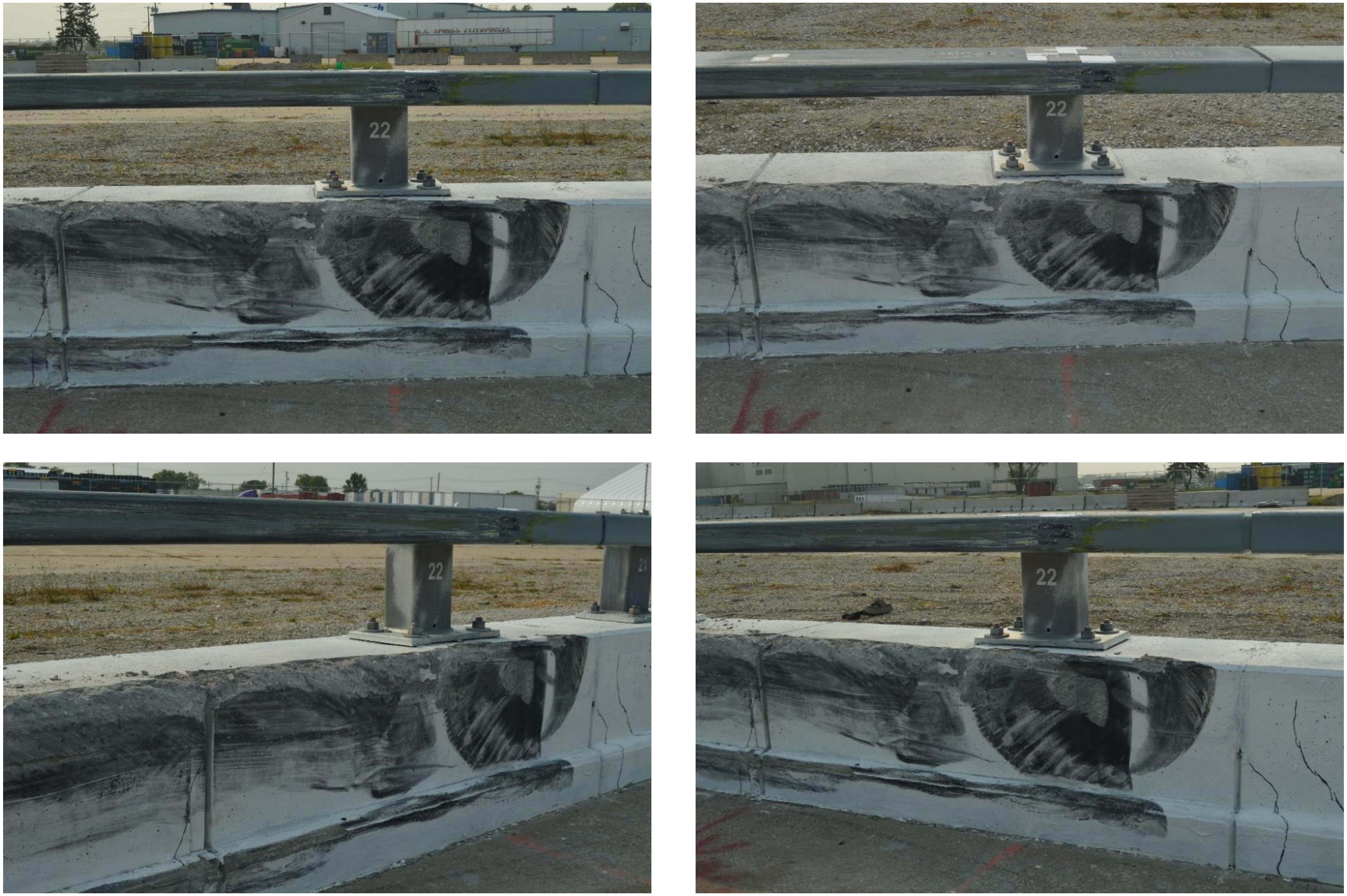

Figure 104. Concrete Gouging and Spalling, Test No. MNCBR-2

Figure 105. Rail and Post No. 22 Damage, Test No. MNCBR-2

Figure 106. Rail and Post No. 22 Damage, Test No. MNCBR-2

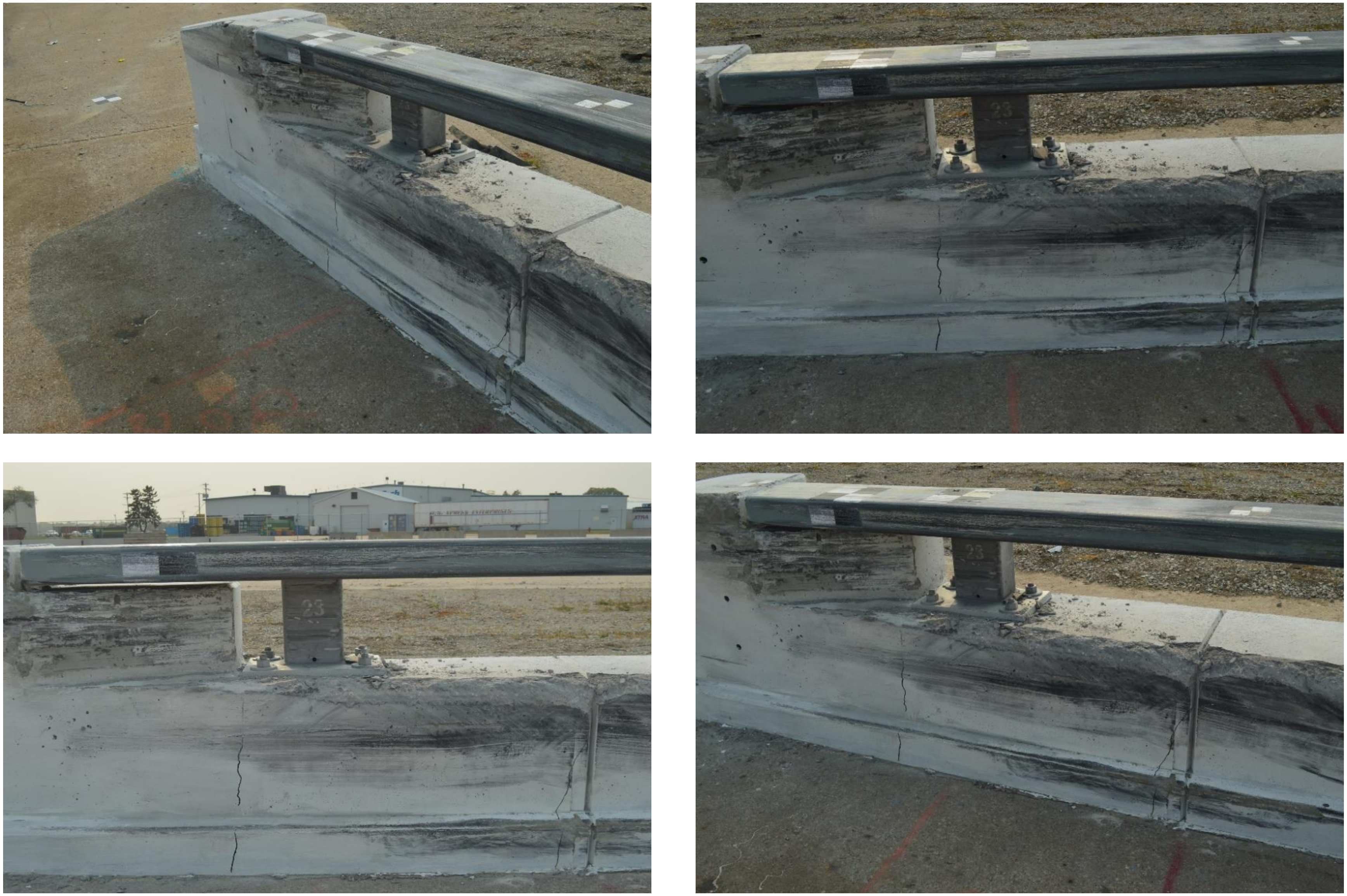

Figure 107. Rail and Post No. 23 Damage, Test No. MNCBR-2

Figure 108. Rail and Post No. 23 Damage, Test No. MNCBR-2

Figure 109. End Post, Tapered End, and Rail and Post No. 23 Damage, Test No. MNCBR-2

Figure 110. Post No. 23 Damage, Test No. MNCBR-2

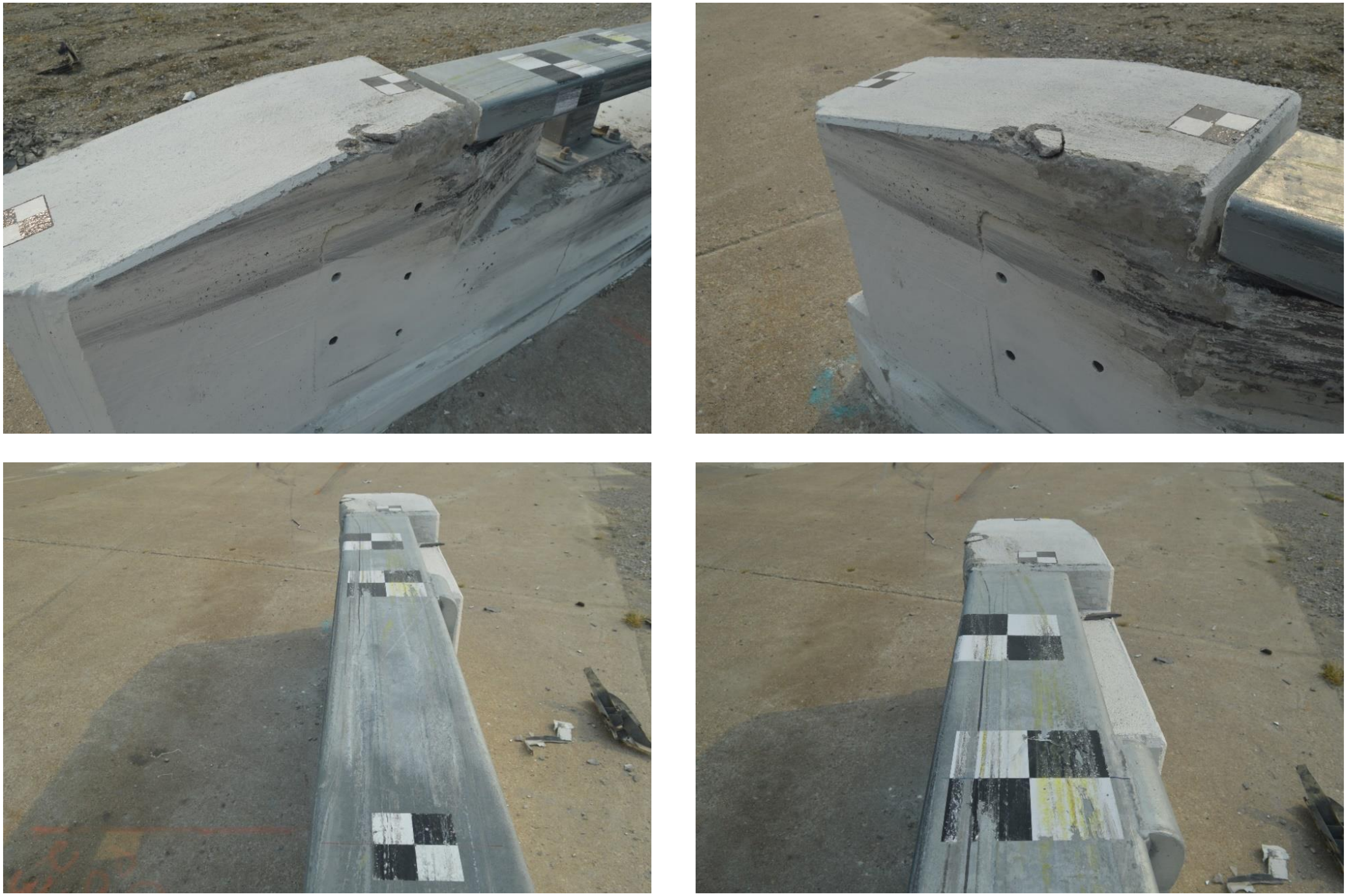

Figure 111. End Post, Tapered End, and Rail Damage, Test No. MNCBR-2

The maximum lateral permanent set of the barrier system was 0.3 in. between post nos. 22 and 23, as measured in the field. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 0.4 in. on the upper rail, as determined from high-speed digital video analysis. The working width of the system was found to be 18 in., also determined from high-speed digital video analysis. The ZOI was found to be 16 in. Barrier deflections are shown schematically in Figure 112.

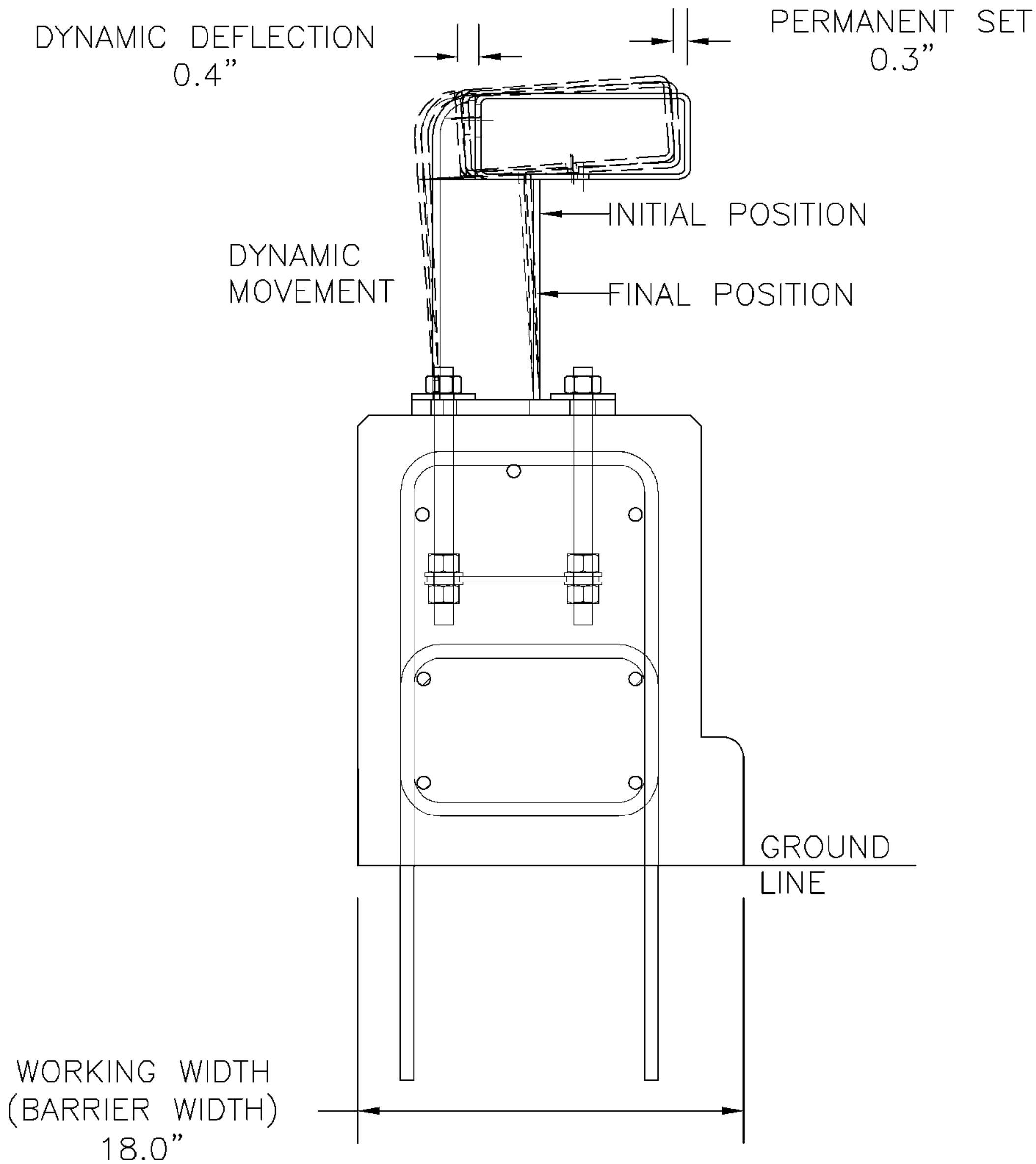

Figure 112. Permanent Set, Dynamic Deflection, and Working Width, Test No. MNCBR-2

6.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 113 through 121. 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. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix C. 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. Outward deformations, which are denoted as negative numbers in Appendix C, are not considered crush toward the occupant, and are not evaluated by MASH 2016 criteria.

The majority of the damage was concentrated on the right-front corner and right side of the vehicle, where impact had occurred, as shown in Figure 113. The right side of the front bumper plastic cover was shattered after impact, and the entire front bumper detached soon thereafter. The right-front fender was pushed inward and dented and torn behind the right-front wheel, as shown in Figure 114. The right-front cast aluminum rim was severely deformed with tears and significant crushing, as shown in Figures 114 and 116. The grille disengaged and fractured soon after impact. Both headlights were disengaged from the vehicle, as shown in Figure 115. The right side of the radiator was pushed backward. Denting and scraping were observed across the entire right side. The right-front door was slightly ajar, and creases were found in the door's sheet metal. The right-side window glass shattered, as shown in Figure 117. The right-rear door was dented and ajar. The right side of the truck bed was dented, and the fuel hatch was ajar, as shown in Figure 118. The right side of the rear bumper was scraped and pushed downward. The roof and remaining window glass remained undamaged. The floor pan was pushed inward, as shown in Figure 119. The right-side upper control arm was fractured, and undercarriage was scraped, as shown in Figure 121 and Figure 122.

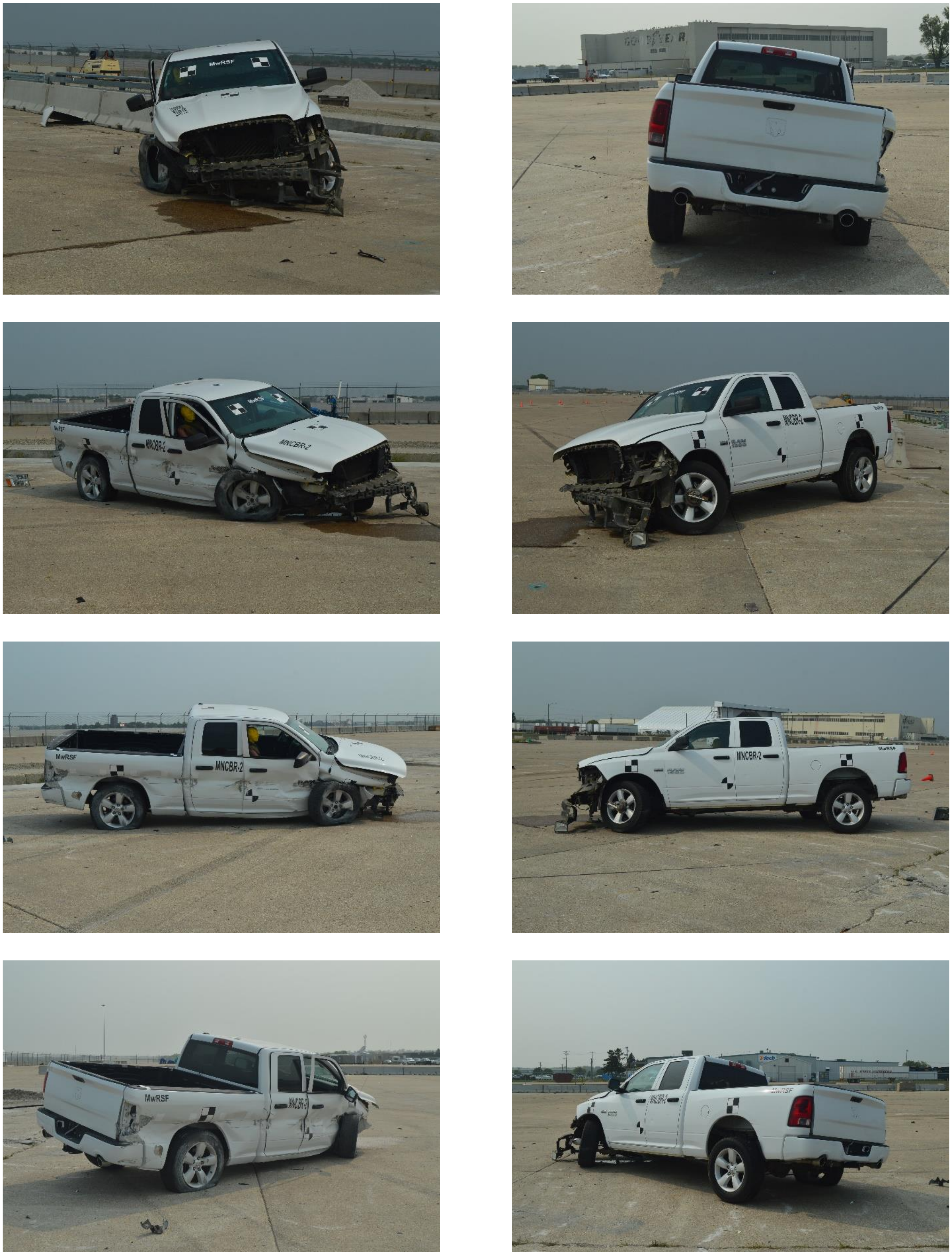

Figure 113. Vehicle Damage, Test No. MNCBR-2

Figure 114. Vehicle Damage, Test No. MNCBR-2

Figure 115. Vehicle Damage, Test No. MNCBR-2

Figure 116. Vehicle Damage, Test No. MNCBR-2

Figure 117. Vehicle Damage, Test No. MNCBR-2

Figure 118. Vehicle Damage, Test No. MNCBR-2

Figure 119. Vehicle Floor Pan Damage, Test No. MNCBR-2

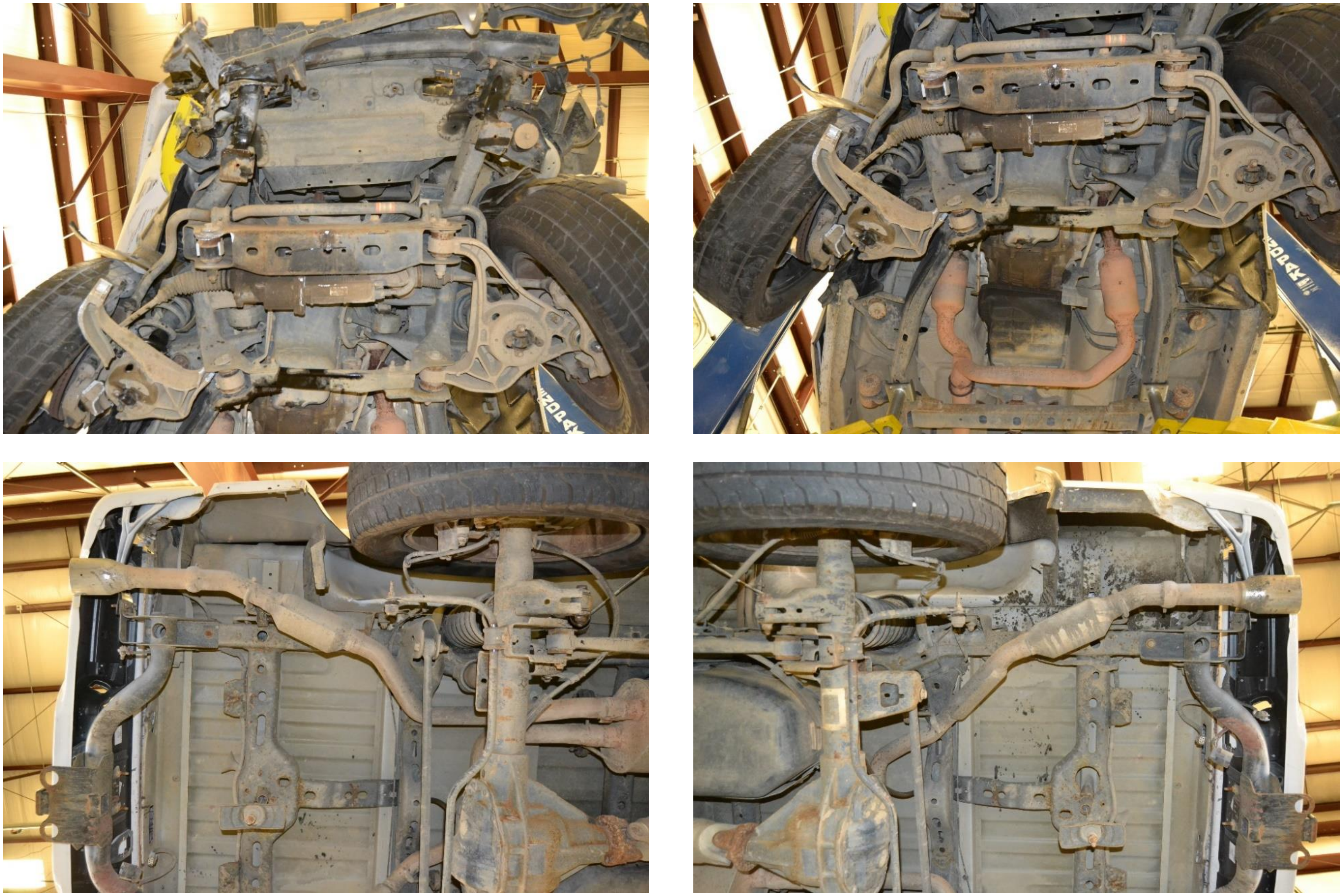

Figure 120. Undercarriage Damage, Test No. MNCBR-2

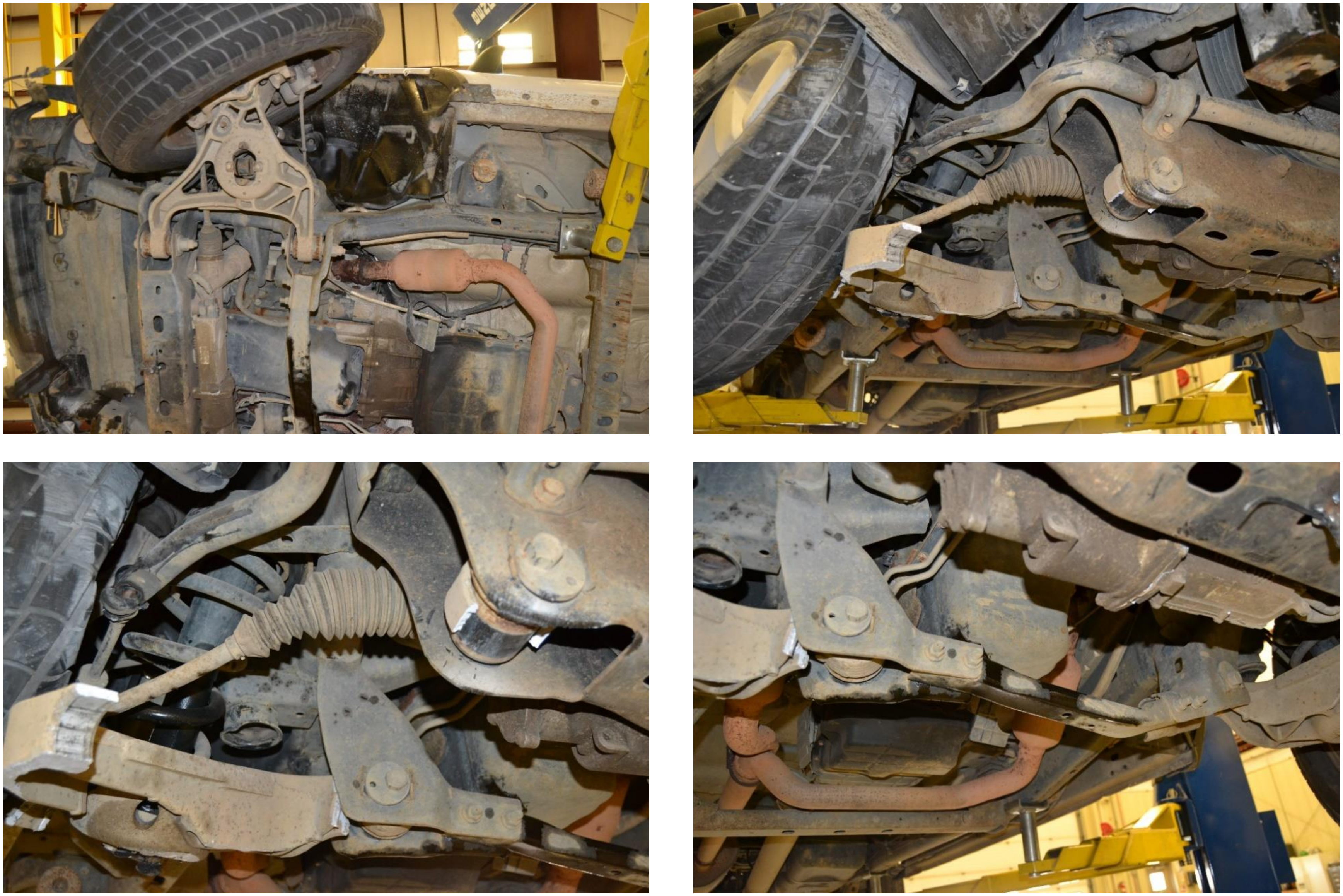

Figure 121. Undercarriage Damage, Test No. MNCBR-2

Table 9. Maximum Occupant Compartment Intrusion by Location, Test No. MNCBR-2

Location	Maximum Intrusion in.	MASH 2016 Allowable Intrusion in.
Wheel Well & Toe Pan	4.1	≤ 9
Floor Pan & Transmission Tunnel	0.7	≤ 12
A-Pillar	0.2	≤ 5
A-Pillar (Lateral)	0.2	≤ 3
B-Pillar	0.5	≤ 5
B-Pillar (Lateral)	0.5	≤ 3
Side Front Panel (in Front of A-Pillar)	5.8	≤ 12
Side Door (Above Seat)	0.7	≤ 9
Side Door (Below Seat)	1.9	≤ 12
Roof	0.0	≤ 4
Windshield	0.0	≤ 3
Side Window	Shattered due to contact with simulated occupant's head	No shattering resulting from contact with structural member of test article
Dash	1.6	N/A

N/A – Not Applicable

6.5 Head Ejection

It is noted in MASH 2016 under the occupant risk evaluation criteria that no shattering of a side window from direct contact with a structural member of the test article should occur. This requirement is believed to extend to direct contact between a test article and the side window as an occupant's head would be considered to be at elevated risk of contacting the test article, thus increasing the 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 should be tracked for tall barriers and considered a pass/fail test evaluation criterion.

High-speed footage with camera views of the occupant's head movement for test no. MNCBR-2 are shown in Figures 122 and 123. Video analysis of the positioning of the dummy's head during test no. MNCBR-2 showed that head contact did not occur, as shown in Figures 123 and 124. Therefore, the test was deemed to have successfully passed MASH 2016 evaluation criteria using a stringent interpretation of the occupant risk criteria.

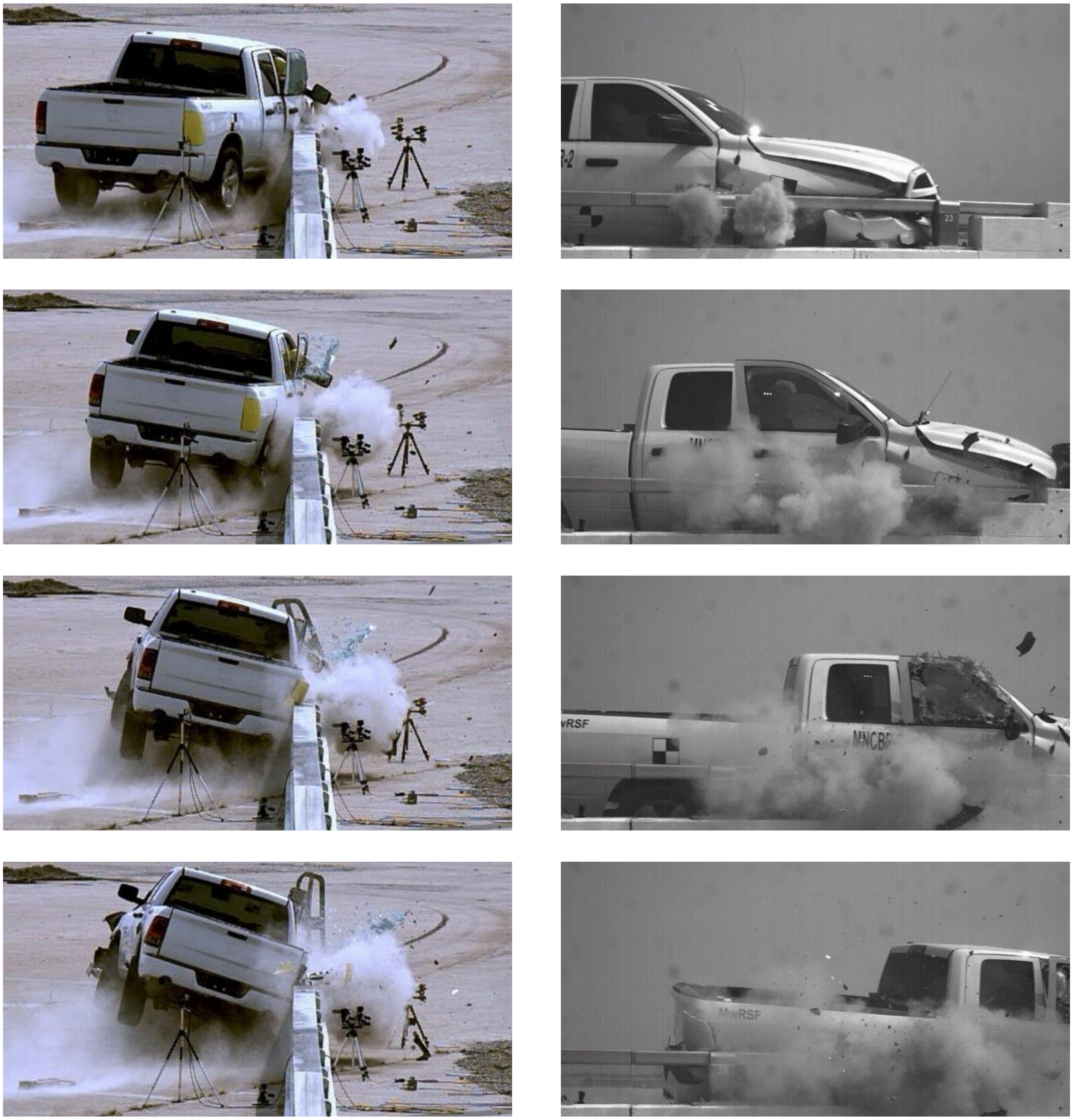

Figure 122. Documentary Photographs, Test No. MNCBR-2

Figure 123. Overhead View of Head Ejection During Impact Event, Test No. MNCBR-2

Figure 124. Downstream Behind View of Head Ejection During Impact Event, Test No. MNCBR-2

6.6 Occupant Risk

The calculated OIVs and maximum 0.010-sec average ORAs in both the longitudinal and lateral directions are shown in Table 10. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 10. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

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

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s	Longitudinal	-21.33	-21.20	±40
	Lateral	-23.04	-25.28	±40
ORA g's	Longitudinal	-8.98	-9.80	±20.49
	Lateral	-9.03	-7.34	±20.49
Maximum Angular Displacement deg.	Roll	33.3	29.8	±75
	Pitch	-7.0	-8.7	±75
	Yaw	-48.1	-47.9	not required
THIV – ft/s		30.70	32.36	not required
PHD – g's		9.23	10.03	not required
ASI		1.48	1.64	not required

6.7 Barrier Loads

The longitudinal and lateral vehicle accelerations, as measured at the vehicle's c.g., were also processed using a 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. From the data analysis, the perpendicular impact forces were determined for the bridge rail, as shown in Figure 125. The maximum perpendicular (i.e., lateral) load imparted to the barrier was 76.5 kips, as determined by the SLICE-2 (primary) unit.

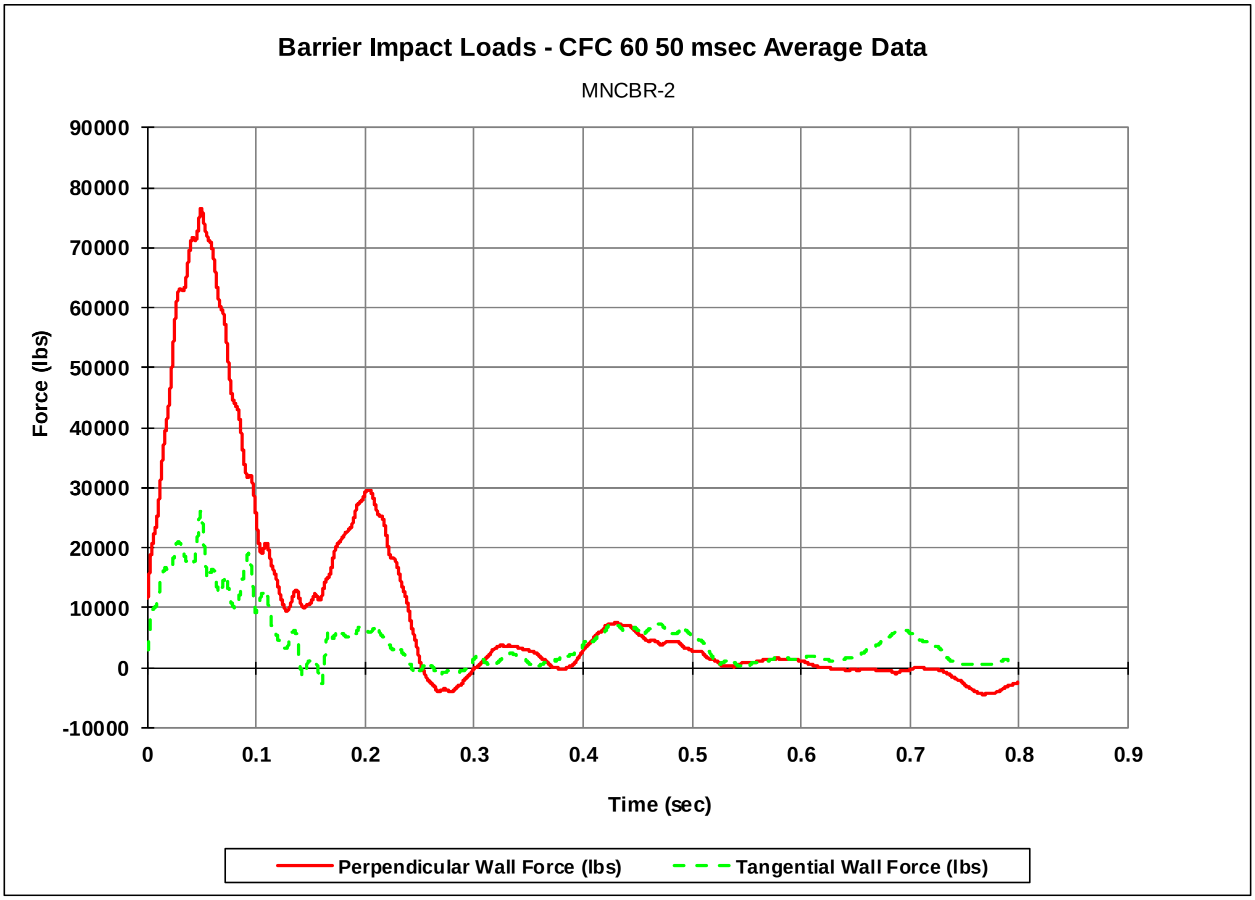

Figure 125. Perpendicular and Tangential Forces Imparted to the Barrier System (SLICE-2), Test No. MNCBR-2

6.8 Discussion

The analysis of the results for test no. MNCBR-2 showed that the bridge railing system adequately contained and redirected the 2270P vehicle with negligible displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 126. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix 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 5.1 degrees, and its trajectory did not violate the bounds of the exit box. During the test, the simulated occupant's head protruded from the right-side window and extended into the ZOI but did not contact the metal railing system. Therefore, test no. MNCBR-2 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 4-11.

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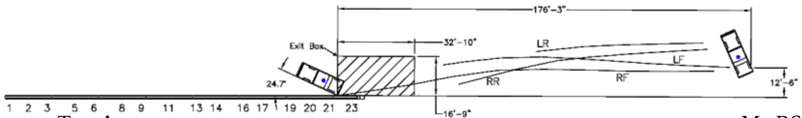
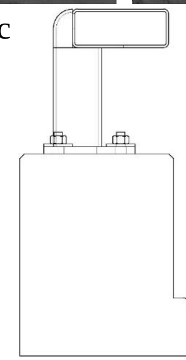


- Test Agency .... MwRSF
- Test Number MNCBR-2
- Date 9/16/2020
- MASH 2016 Test Designation No. 4-11
- Test Article .... Minnesota Combination Bridge Rail
- Total System Length .... 154 ft
- Total Bridge Rail Height .... 36 in.
- Bridge Rail Elements .... HSS 10x4x¼ Tube
  - Length .... 150 ft – 2½ in.
- Bridge Post Assembly (Main Components)
  - Post .... HSS 7x5x5⁄16 by 10¼ in. long
  - Base Plate (Welded) .... 16 in. x 9½ in. x ¾ in.
- Concrete Parapet
  - Length .... 140 ft – 8 in.
  - Width .... 16 in.
  - Height .... 21 in.
- Concrete Tapered End Section (Excluding End Post)
  - Length .... 22½ in.
  - Height .... 10 in.
  - Width .... 16 in. at downstream end and 8½ in. wide at the upstream end
- Brush Curb
  - Width .... 2 in.
  - Height .... 6 in.
- Vehicle Make /Model .... 2014 Dodge Ram 1500 Quad Cab Pickup Truck
  - Curb .... 5,134 lb
  - Test Inertial .... 5,003 lb
  - Gross Static .... 5,162 lb
- Impact Conditions
  - Speed .... 63.9 mph
  - Angle .... 25.1 deg.
  - Impact Location .... 69.9 in. upstream from post no. 23
- Impact Severity (IS) .... 122.9 kip-ft > 106 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed .... 45.1 mph
  - Angle .... 5.1 deg.
- Exit Box Criterion .... Pass
  Vehicle Stability .... Satisfactory



- Vehicle Stopping Distance .... 176 ft – 3 in. downstream
  12 ft – 6 in. laterally in front
- Vehicle Damage .... Moderate
  - VDS [15] 01-RFQ-5
  - CDC [16] 01-RYEW-5
  - Maximum Interior Deformation .... 5.8 in.
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... 0.3 in.
  - Dynamic .... 0.4 in.
  - Working Width .... 18 in.
  - ZOI .... 16 in.
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s	Longitudinal	-21.33	-21.20	±40 (12.2)
	Lateral	-23.04	-25.28	±40 (12.2)
ORA g's	Longitudinal	-8.98	-9.80	±20.49
	Lateral	-9.03	-7.34	±20.49
Maximum Angular Displacement deg.	Roll	33.3	29.8	±75
	Pitch	-7.0	-8.7	±75
	Yaw	-48.1	-47.9	not required
THIV – ft/s		30.70	32.36	not required
PHD – g's		9.23	10.03	not required
ASI		1.48	1.64	not required

Figure 126. Summary of Test Results and Sequential Photographs, Test No. MNCBR-2

7 FULL-SCALE CRASH TEST NO. MNCBR-3

7.1 Weather Conditions

Test no. MNCBR-3 was conducted on September 29, 2020 at approximately 1:30 p.m. The weather conditions as reported by the National Oceanic and Atmospheric Administration (station 14939/LNK) are shown in Table 11.

Table 11. Weather Conditions, Test No. MNCBR-3

Temperature	79°F
Humidity	51%
Wind Speed	15 mph
Wind Direction	260° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.12 in.
Previous 7-Day Precipitation	0.03 in.

7.2 Test Description

Test no. MNCBR-3 was conducted on a concrete parapet with a brush curb and upper beam and post rail with a new tapered end section under the MASH 2016 TL-4 guidelines for test designation no. 4-10, which involved an impact with a 1100C small car vehicle at 62 mph and 25 degrees. The CIP for this system was selected to maximize the potential for vehicle interaction and snag on the vertical support posts, the upper metal tube rail, and the tapered end section.

Initial vehicle impact was to occur 63½ in. upstream from the centerline of post no. 23, as shown in Figure 127, which was selected as discussed in Chapter 2.2. The 2,442-lb small car vehicle impacted the concrete parapet with brush curb and upper beam and post rail with new tapered end section at a speed of 62.5 mph and at an angle of 25.5 degrees. The actual point of impact was 6.9 in. upstream from target impact point. In the test, the vehicle was captured and redirected by the concrete parapet with brush curb and upper beam and post rail with new tapered end section.

A detailed description of the sequential impact events is contained in Table 12. Sequential photographs are shown in Figures 128 through Figure 129. Documentary photographs of the crash test are shown in Figure 130. The vehicle trajectory and final position are shown in Figure 131.

Figure 127. Impact Location, Test No. MNCBR-3

Table 12. Sequential Description of Impact Events, Test No. MNCBR-3

Time (sec)	Event
0.000	Vehicle's front bumper impacted post no. 22.
0.002	Vehicle’s front bumper deformed.
0.004	Vehicle's right-front tire contacted barrier near post no. 22.
0.012	Vehicle's right fender contacted concrete barrier near post no. 22, and vehicle’s engine hood contacted upper steel rail.
0.014	Vehicle's engine hood and right fender deformed.
0.020	Vehicle pitched downward.
0.030	Vehicle's roof experienced flexure.
0.034	Vehicle’s top-left door deformed outward. Vehicle’s door became ajar.
0.044	Vehicle's right-front door contacted post no. 22, and vehicle’s right-side mirror contacted upper steel rail.
0.046	Vehicle's right-front door and right-side mirror deformed.
0.056	Vehicle’s right headlight contacted post no. 23.
0.060	Vehicle's right headlight shattered.
0.068	Simulated occupant’s head exited cabin and shattered right-front window. Vehicle's right fender snagged on tapered end.
0.138	Vehicle's left-rear tire became airborne.
0.149	Vehicle was parallel to system at a speed of 47.5 mph.
0.150	Vehicle’s right quarter panel contacted post no. 22.
0.152	Vehicle's right quarter panel deformed.
0.154	Simulated occupant's head reentered through right-front window. Vehicle's rear bumper contacted post no. 22.
0.158	Vehicle's right tailgate contacted upper steel rail.
0.180	Vehicle’s right tailgate cover shattered.
0.278	Vehicle exited system at a speed of 46.0 mph and at an angle of 5.8 degrees.
0.389	Vehicle's left-rear tire regained contact with ground.
0.396	Vehicle pitched upward.
0.628	Vehicle rolled away from system.
4.849	Vehicle came to rest 190 ft – 7 in. downstream and 36 ft – 3 in. laterally in front from system.

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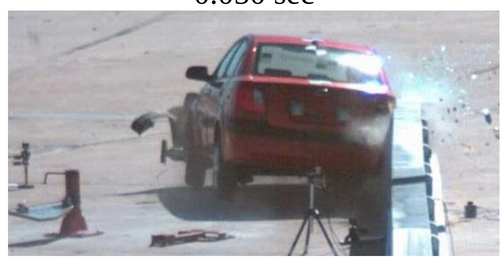

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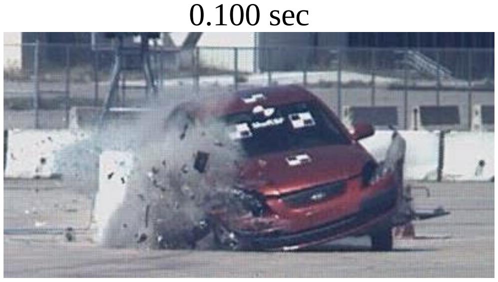

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Figure 128. Sequential Photographs, Test No. MNCBR-3


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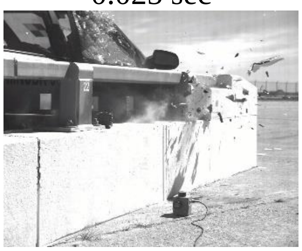
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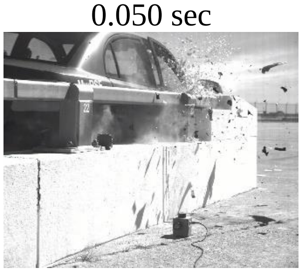
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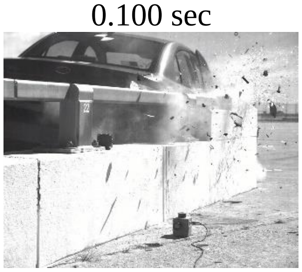
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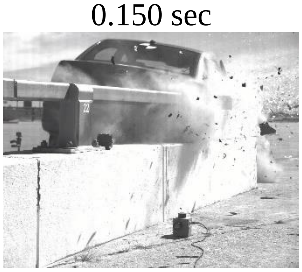
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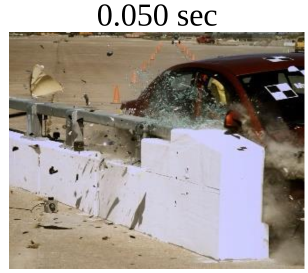
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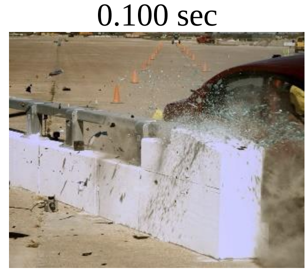
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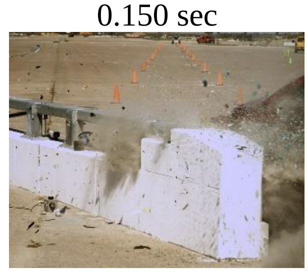

0.225 sec

Figure 129. Sequential Photographs, Test No. MNCBR-3

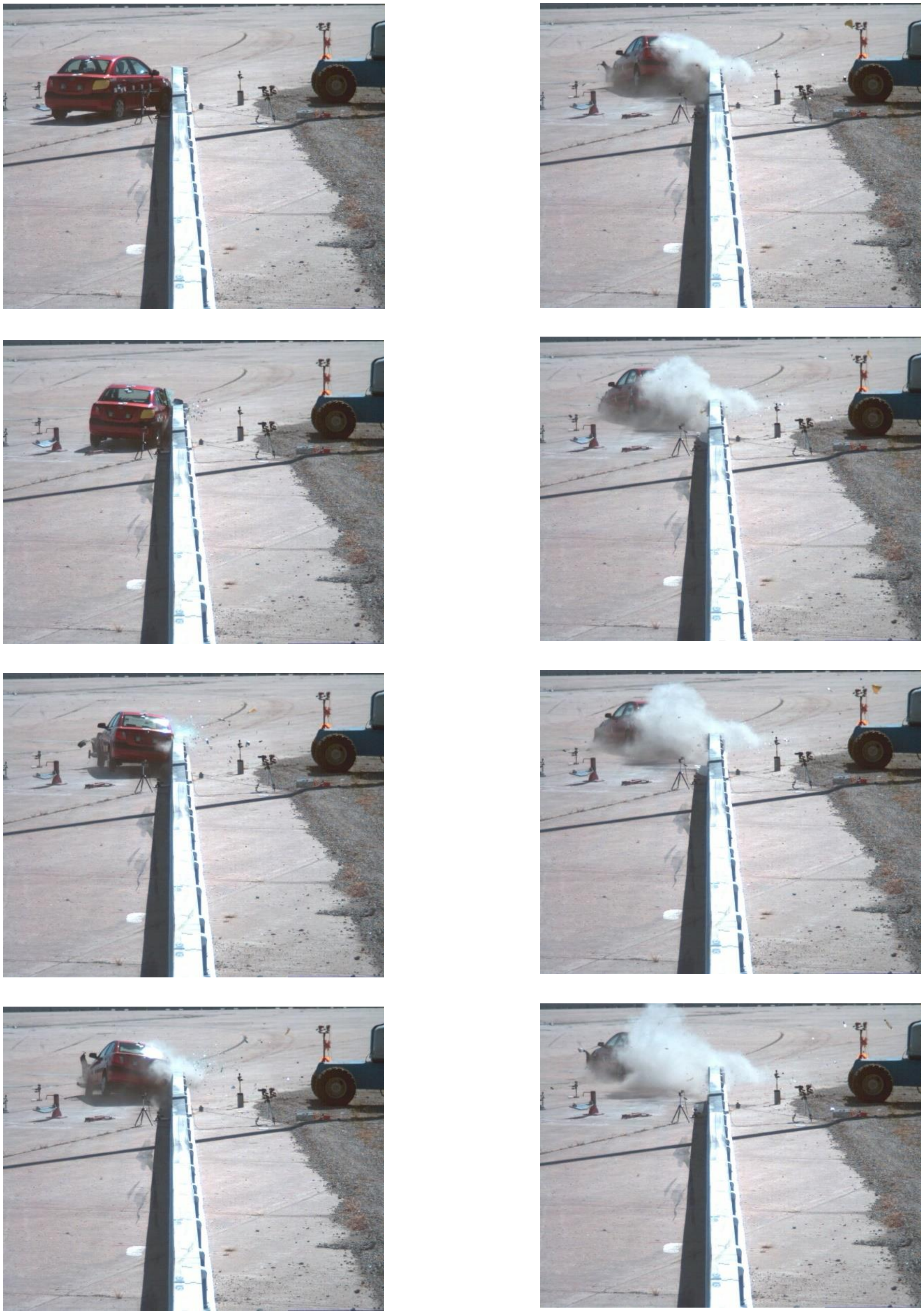


Figure 130. Documentary Photographs, Test No. MNCBR-3

Figure 131. Vehicle Final Position and Trajectory Marks, Test No. MNCBR-3.

7.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 132 through 138. Barrier damage largely consisted of contact marks on the front face of the concrete barriers and spalling of the concrete. Note that the cracking shown in the system photographs was identified before the test as being related to shrinkage, and was not a result of test no. MNCBR-3. The length of vehicle contact along the barrier extended downstream approximately 10 ft starting at 18 in. upstream from the impact point.

Tire marks were visible on the front face of the 21-in. tall concrete barrier, starting 18 in. upstream from the centerline of post no. 22 and extending 110 in. downstream across the traffic side of the barrier. Contact marks 15 in. wide were found across the front face of the concrete barrier above the brush curb, starting 18 in. upstream from the impact point and extending 102 in. downstream. Contact marks 9 in. wide were found across the entire length of the front face of mid-horizontal taper section of end post, starting 95 in. downstream from the impact point and extending 24 in. downstream. Contact marks measuring 9½ in. wide were found on front face of steel upper rail, starting 98 in. downstream from the impact point and extending 12 in. downstream. Contact marks measuring 4½ in. wide were found on the front face of steel upper rail, starting 9½ in. downstream from the impact point and extending 100½ in. downstream. Contact marks measuring 1 in. wide were found on the top face of the steel upper rail, starting 70½ in. downstream from the impact point and extending 6 in. downstream. Contact marks measuring ½ in. wide were found on the bottom face of the upper steel rail, starting 67 in. downstream from the impact point and extending 24½ in. downstream. Contact marks measuring 7¾ in. wide were found on the front face of post no. 23 and extending 5½ in. downward. Contact marks measuring 8 in. were found on the upstream front corner of the upstream face of post no. 23 and extending 1 in. downward. Contact marks measuring 1 in. wide were found on the upstream face of post no. 23 and extended 8 in. upward from the post base plate. The vehicle’s lateral overlap/contact distance at the upstream end of the tapered end section was 1½ in. The vehicle’s lateral overlap/contact distance at the upstream corner of the front face of post no. 23 was 2½ in.

Scuff marks were also found along the length of vehicle contact. Gouging was found on the front face of the concrete parapet measuring 36½ in. long and located 32 in. upstream from the impact point with a width of 2 in. Gouging, measuring 2 in. wide by 28 in. long, was located 64½ in. downstream from the impact point. Gouging was found on the upstream face of the middle horizontal tapered end section, measuring ¼ in. long and located 2 in. from the top front corner of the upstream face. Gouging, measuring 9½ in. wide by 24 in. long, was located 95 in. upstream from the impact point. Gouging, measuring 2½ in. wide by 18 in. long, was located 6½ in. upstream from the impact point.

Figure 132. System Damage, Test No. MNCBR-3

Figure 133. System Damage, Test No. MNCBR-3

Figure 134. Concrete Gouging, Test No. MNCBR-3

Figure 135. Concrete Gouging, Test No. MNCBR-3

Figure 136. Rail and Post No. 4 Damage, Test No. MNCBR-3

Figure 137. Rail and Post No. 4 Damage, Test No. MNCBR-3

Figure 138. Rail and Post No. 4 Damage, Test No. MNCBR-3

The maximum lateral permanent set of the barrier system was 0.1 in. between post nos. 22 and 23, as measured in the field. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 0.3 in. on the upper rail, as determined from high-speed digital video analysis. The working width of the system was found to 18 in., also determined from high-speed digital video analysis. The ZOI was found to be 10 in. Barrier deflections are shown schematically in Figure 139.

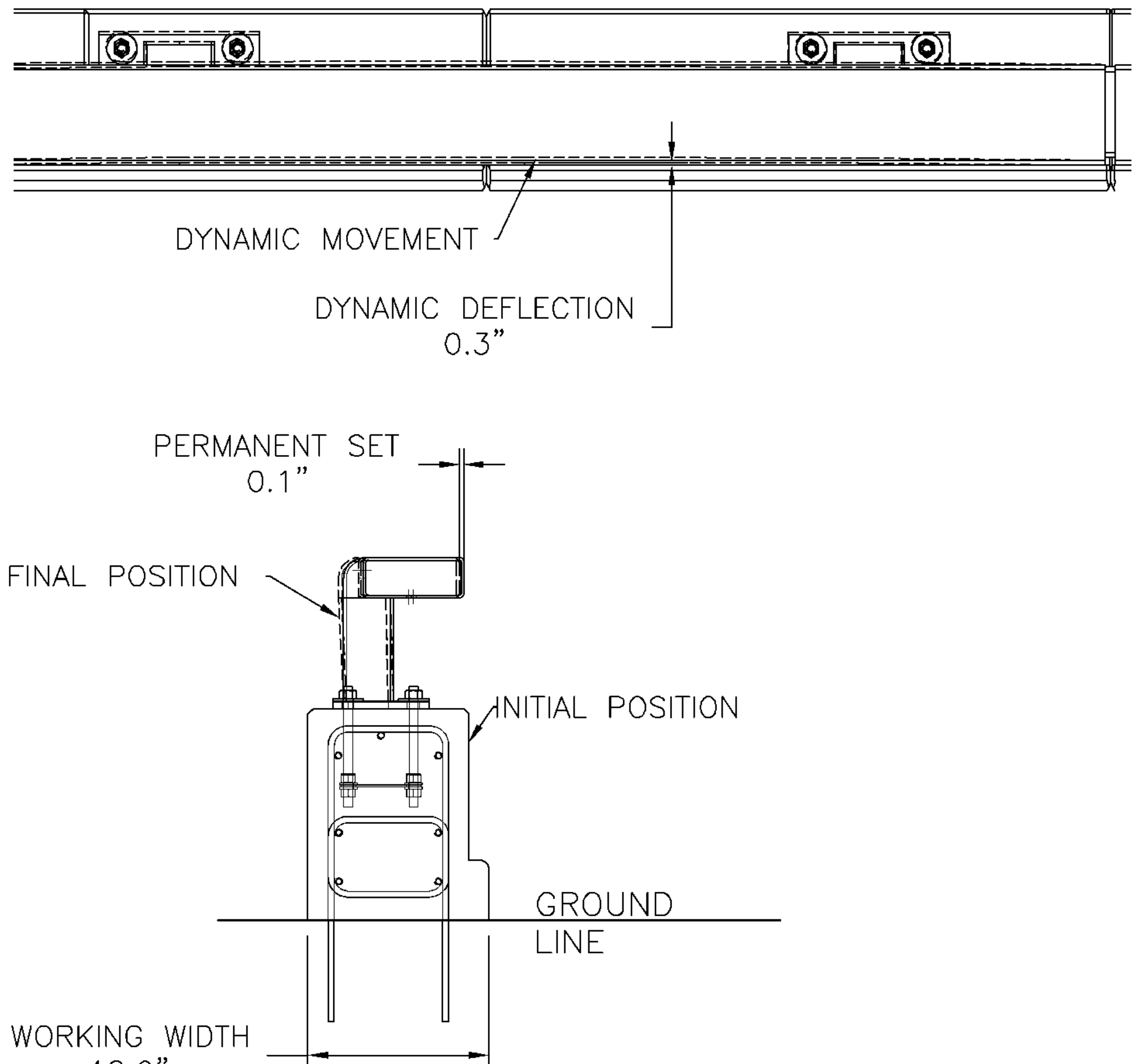


Figure 139. Permanent Set, Dynamic Deflection, and Working Width, Test No. MNCBR-3

7.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 140 through 145. The maximum occupant compartment intrusions are listed in Table 13 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix C. 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. Outward deformations, which are denoted as negative numbers in Appendix C, are not considered crush toward the occupant, and are not evaluated by MASH 2016 criteria.

The majority of the damage was concentrated on the right-front corner and right side of the vehicle, where impact had occurred, as shown in Figure 140. The vehicle's steel engine hood was deformed across its entirety, and the right edge was torn from front to back. The left side of the front bumper was pushed downward. The right side of the bumper was torn and crushed inward. The right-front fender was pushed upward near the door panel, and torn behind the right-front wheel, as shown in Figure 141. The right-front steel rim was deformed with significant crushing, as shown in Figure 142. The right-side headlight was disengaged from the vehicle, as shown in Figure 141. Denting and scraping were observed across the entire right side. The right-front door was crushed inward at the leading edge, and it was slightly ajar. The right-side front window glass was shattered by the simulated occupant's head, as shown in Figure 142. The right-rear door was scraped along its entirety and dented at the door handle. The right-side quarter panel was slightly crushed inward and scraped across its entire length, as shown in Figure 142. The floor panel was crushed inward, as shown in Figure 143. The right side of the rear bumper was slightly scraped. The right side of the windshield had a various hairline cracks, as shown in Figure 145. The roof and remaining window glass remained undamaged.

Figure 140. Vehicle Damage, Test No. MNCBR-3

Figure 141. Vehicle Damage, Test No. MNCBR-3

Figure 142. Vehicle Damage, Test No. MNCBR-3

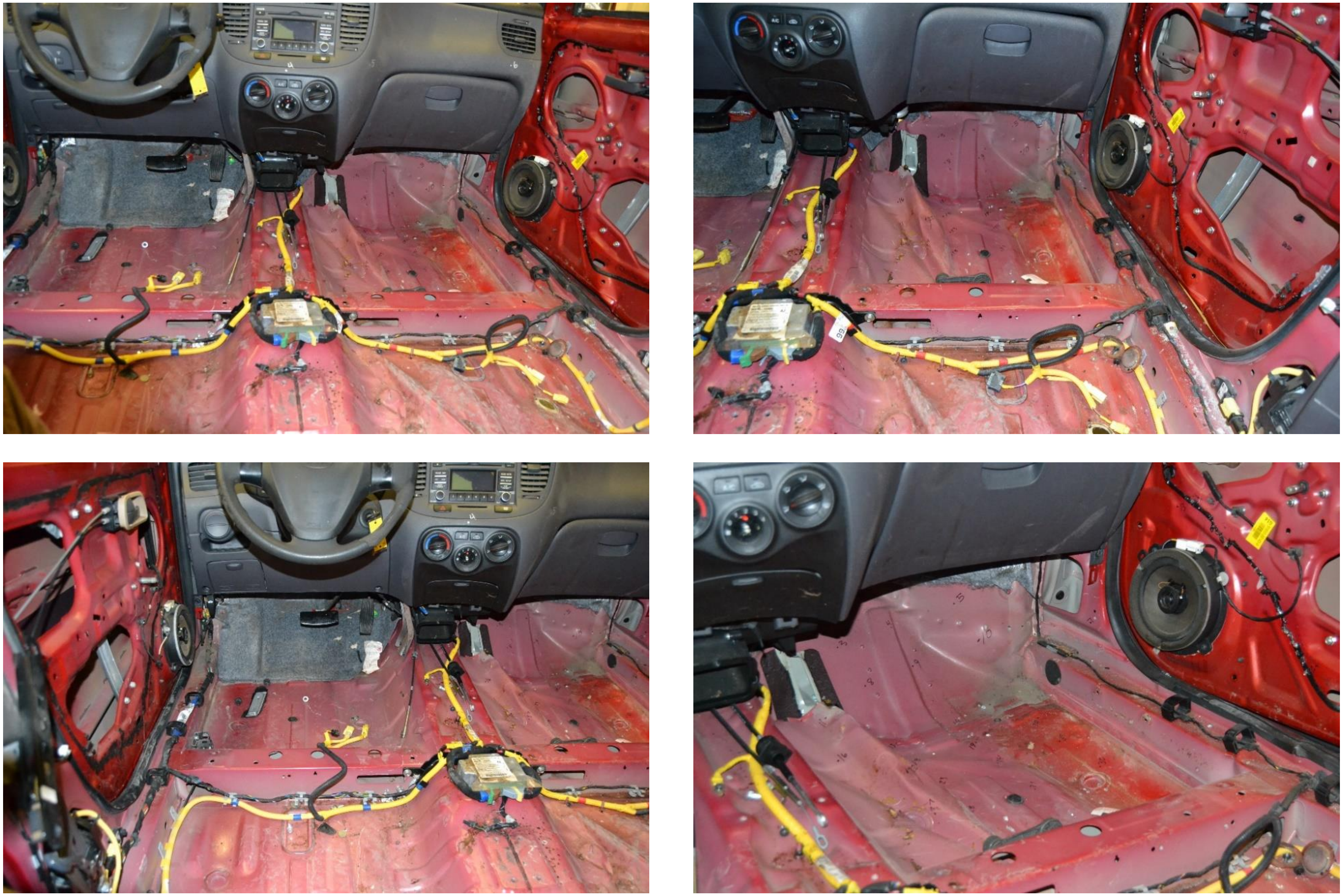


Figure 143. Vehicle Floor Pan Damage, Test No. MNCBR-3

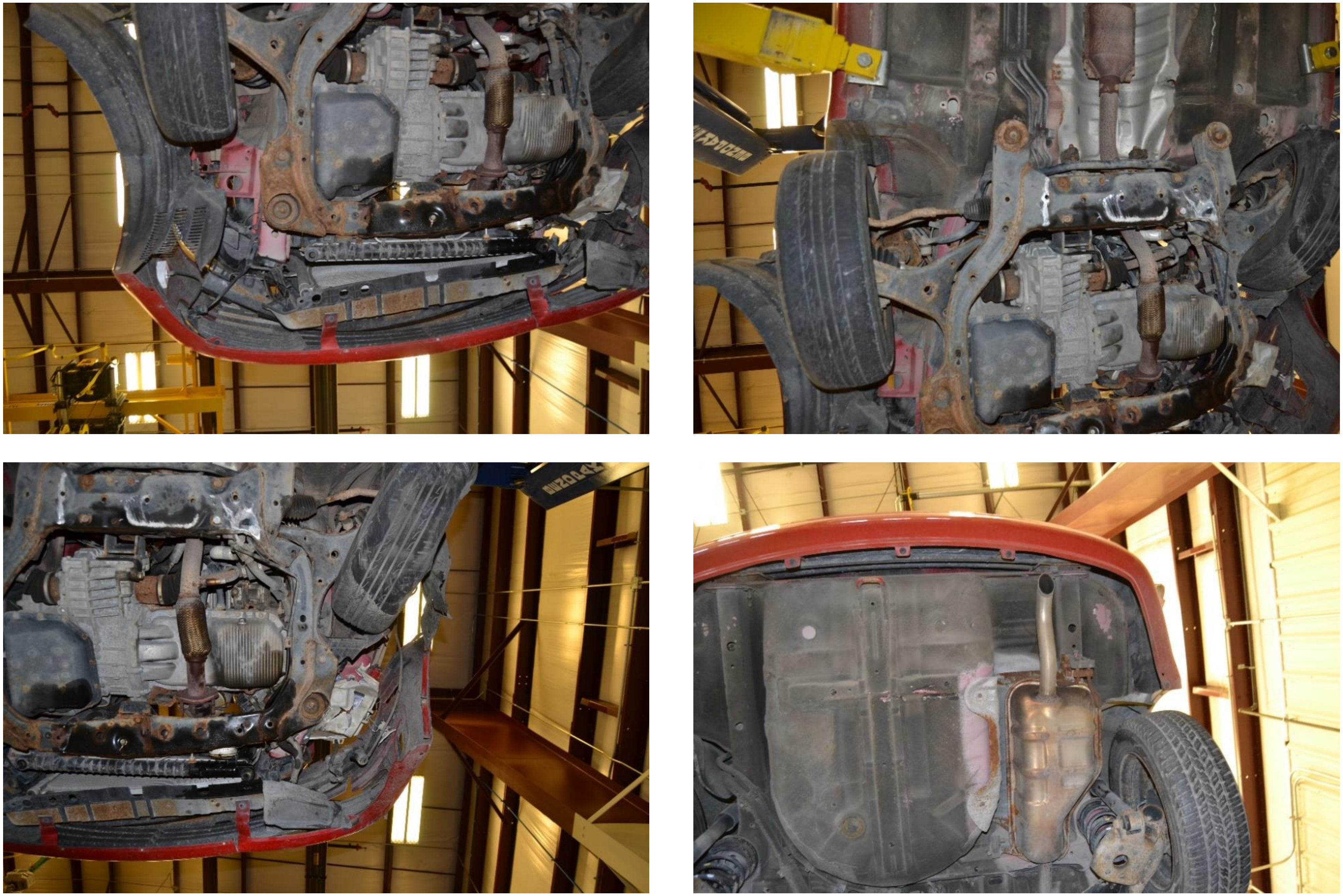


Figure 144. Undercarriage Damage, Test No. MNCBR-3

Figure 145. Windshield Damage (Post-Test), Test No. MNCBR-3

Table 13. Maximum Occupant Compartment Intrusion by Location, Test No. MNCBR-3

Location	Maximum Intrusion in.	MASH 2016 Allowable Intrusion in.
Wheel Well & Toe Pan	1.7	≤ 9
Floor Pan & Transmission Tunnel	2.2	≤ 12
A-Pillar	0.8	≤ 5
A-Pillar (Lateral)	0.2	≤ 3
B-Pillar	0.4	≤ 5
B-Pillar (Lateral)	0.0	≤ 3
Side Front Panel (in Front of A-Pillar)	2.5	≤ 12
Side Door (Above Seat)	0.1	≤ 9
Side Door (Below Seat)	0.5	≤ 12
Roof	0.4	≤ 4
Windshield	0.0	≤ 3
Side Window	Shattered due to contact with simulated occupant's head	No shattering resulting from contact with structural member of test article
Dash	0.7	N/A

N/A – Not Applicable

7.5 Head Ejection

It is noted in MASH 2016 under the occupant risk evaluation criteria that no shattering of a side window from direct contact with a structural member of the test article should occur. This requirement is believed to extend to direct contact between a test article and the side window as an occupant's head would be considered to be at elevated risk of contacting the test article, thus increasing the 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 should be tracked for tall barriers and considered a pass/fail test evaluation criterion.

Onboard high-speed footage with camera views of the occupant's head movement for test no. MNCBR-3 are shown in Figures 146 and 147. Video analysis of the positioning of the dummy's head during test no. MNCBR-3 showed that head contact did not occur, as shown in Figures 148 and 151. Therefore, the test was deemed to have successfully passed MASH 2016 evaluation criteria using a stringent interpretation of the occupant risk criteria.

Figure 146. Documentary Photographs, Test No. MNCBR-3

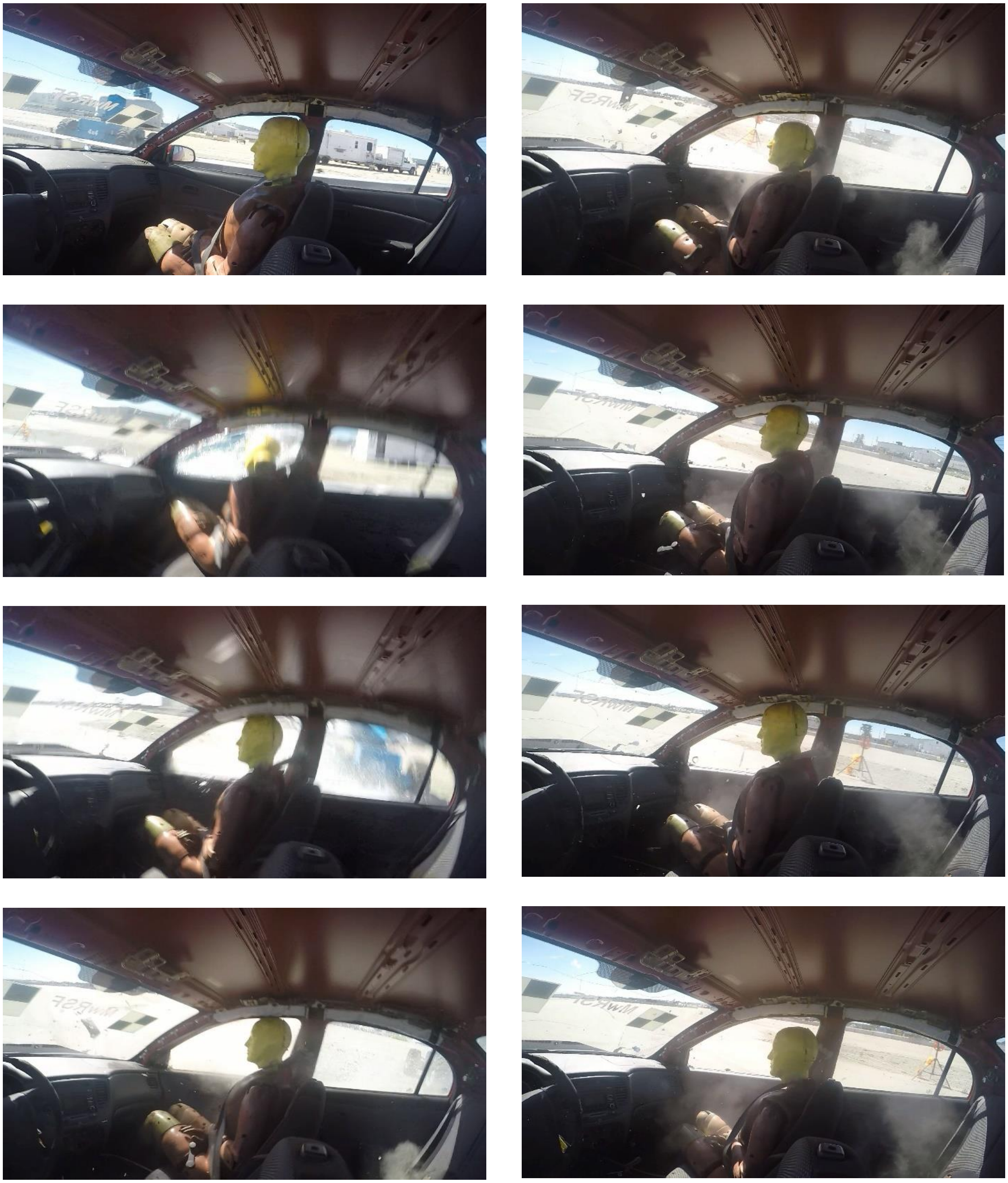


Figure 147. Documentary Photographs, Test No. MNCBR-3

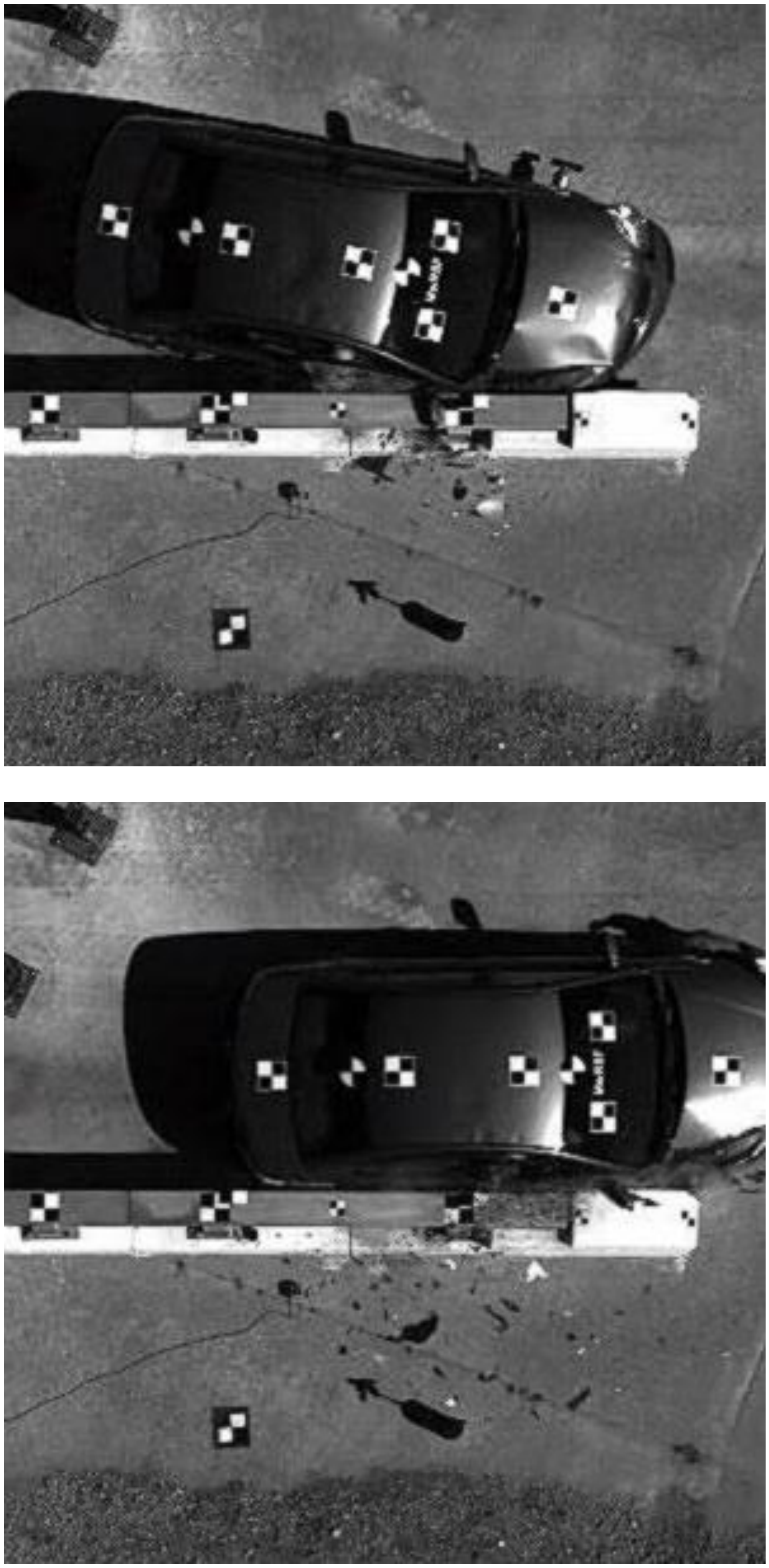


Figure 148. Overhead View of Head Ejection During Impact Event, Test No. MNCBR-3

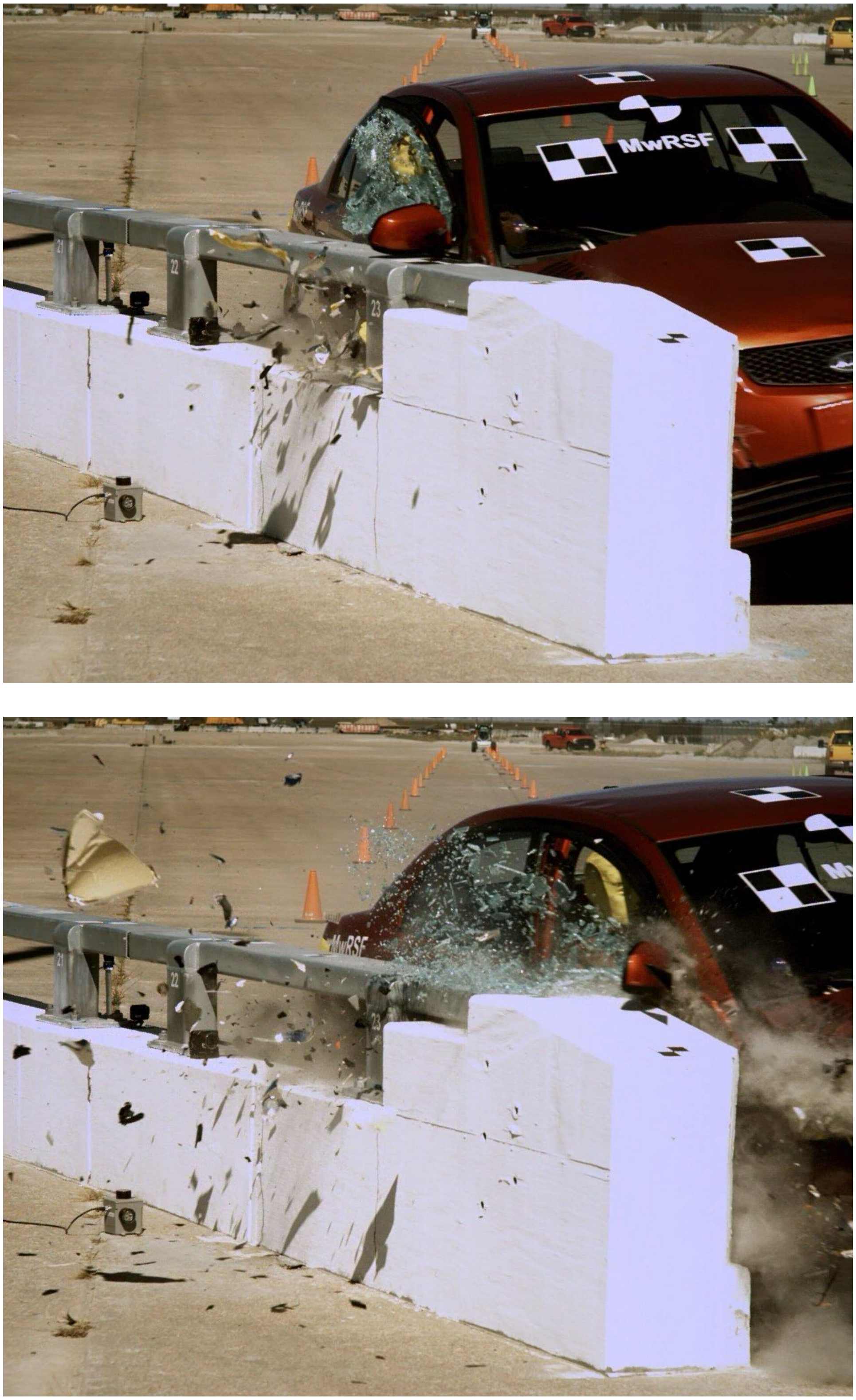


Figure 149. Downstream Behind View of Head Ejection During Impact Event, Test No. MNCBR-3

Figure 150. Upstream View of Head Ejection During Impact Event, Test No. MNCBR-3

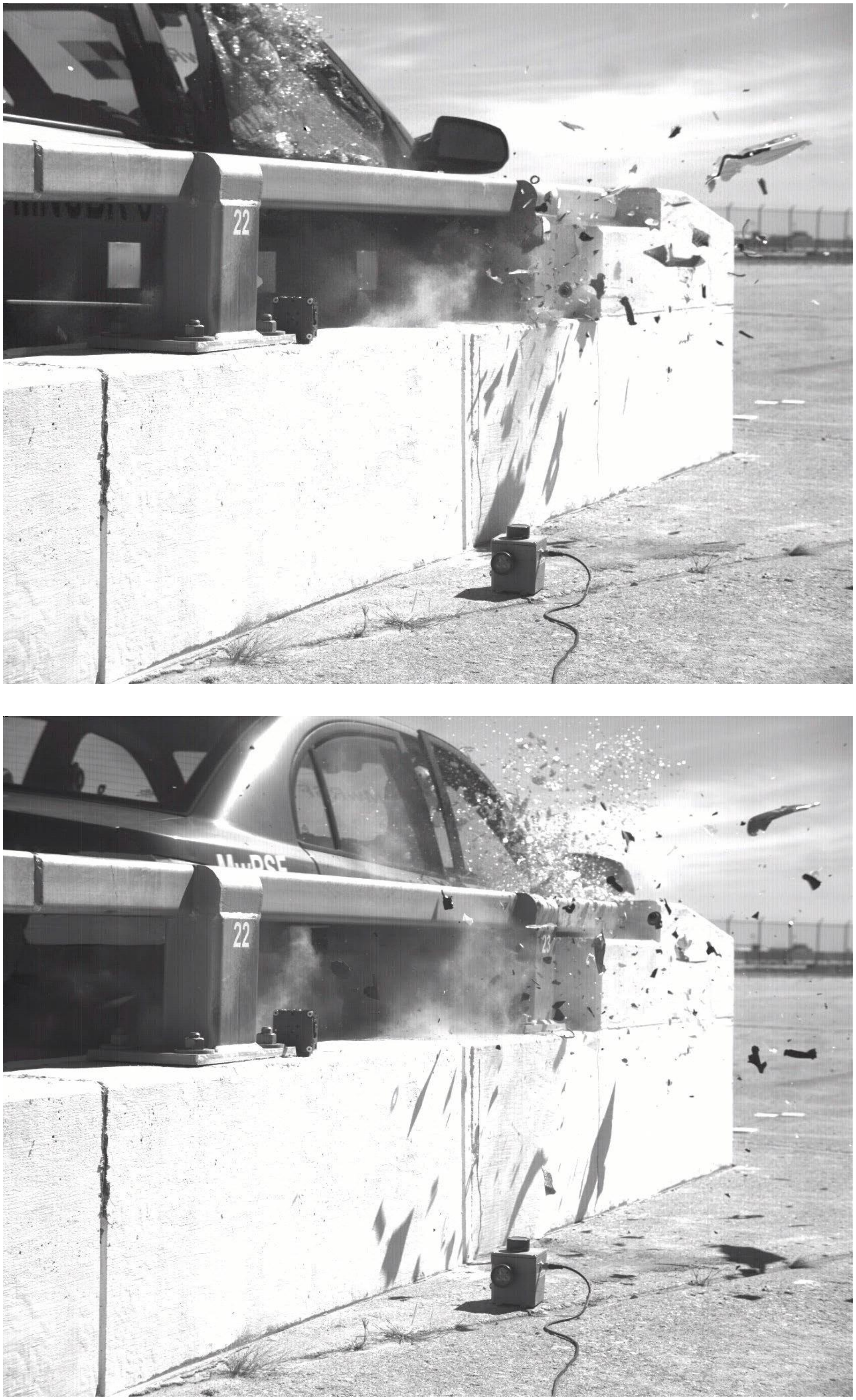


Figure 151. Upstream Behind View of Head Ejection During Impact Event, Test No. MNCBR-3

7.6 Occupant Risk

The calculated OIVs and maximum 0.010-sec average ORAs in both the longitudinal and lateral directions are shown in Table 14. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 14. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix F.

Table 14. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MNCBR-3

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 (primary)	SLICE-2	
OIV ft/s	Longitudinal	-19.58	-20.67	±40
	Lateral	-34.25	-31.47	±40
ORA g's	Longitudinal	-4.53	2.83	±20.49
	Lateral	-10.87	-12.05	±20.49
Maximum Angular Displacement deg.	Roll	12.9	9.8	±75
	Pitch	-7.0	-7.9	±75
	Yaw	-45.2	-45.3	not required
THIV – ft/s		0.28	0.18	not required
PHD – g's		37.20	38.51	not required
ASI		2.47	2.33	not required

7.7 Barrier Loads

The longitudinal and lateral vehicle accelerations, as measured at the vehicle's c.g., were also processed using a 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. From the data analysis, the perpendicular impact forces were determined for the bridge rail, as shown in Figure 152. The maximum perpendicular (i.e., lateral) load imparted to the barrier was 56.5 kips, as determined by the SLICE-1 (primary) unit.

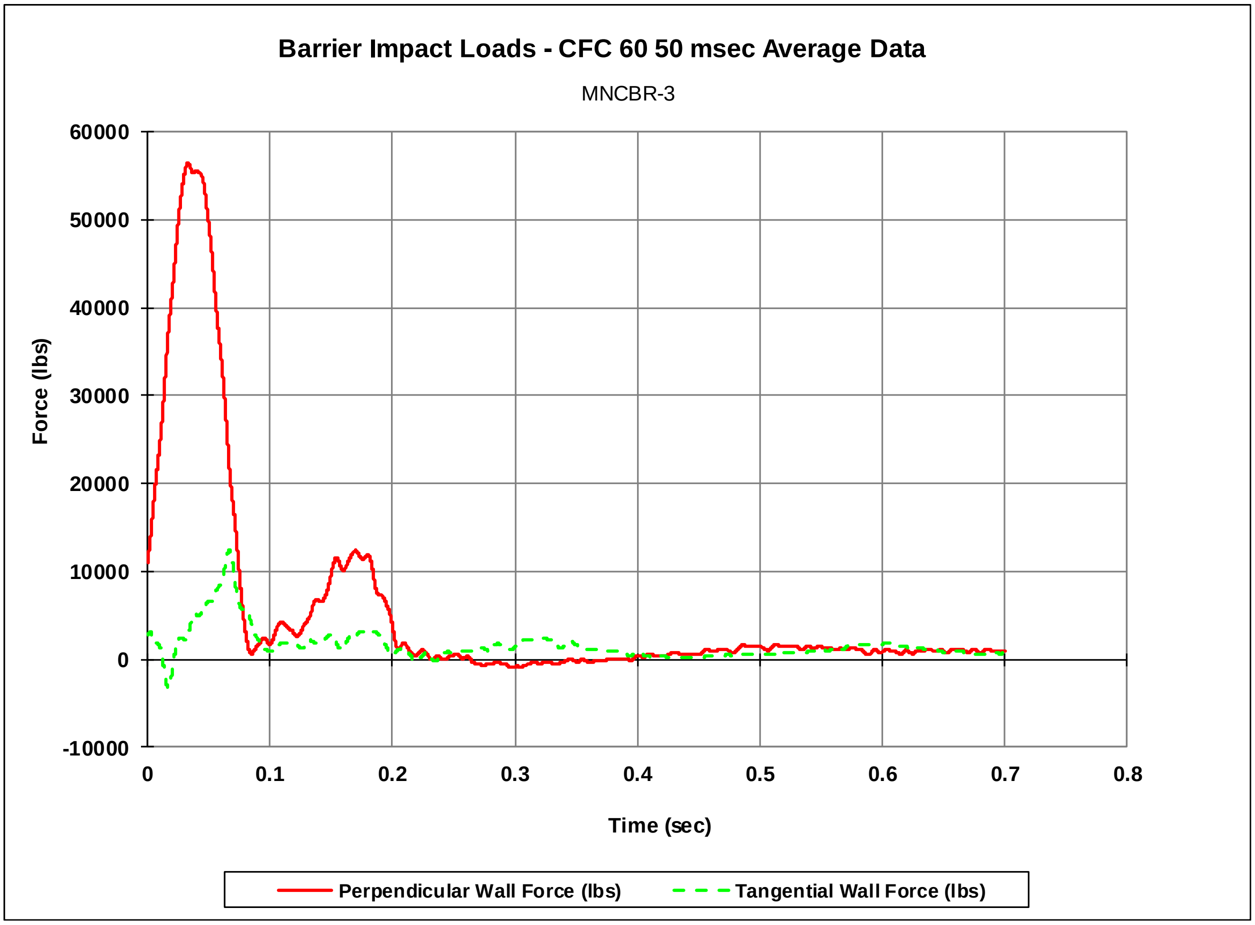
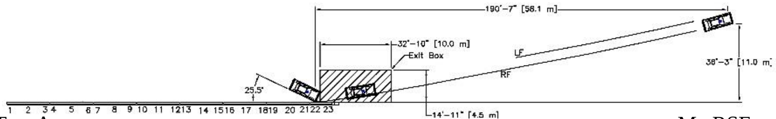


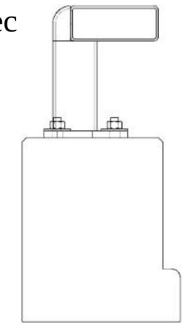
Figure 152. Perpendicular and Tangential Forces Imparted to the Barrier System (SLICE-1), Test No. MNCBR-3

7.8 Discussion

The analysis of the results for test no. MNCBR-3 showed that the bridge railing system adequately contained and redirected the 1100C small car vehicle with negligible displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 153. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix F, were deemed acceptable because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at a speed of 46.0 mph and at an angle of 5.8 degrees, and its trajectory did not violate the bounds of the exit box. During the test, the simulated occupant's head protruded out of the right-side window and extended into the ZOI but did not contact the metal railing system. Therefore, test no. MNCBR-3 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 4-10.

0.000 sec | 0.100 sec | 0.200 sec | 0.300 sec | 0.400 sec





- Test Agency .... MwRSF
- Test Number MNCBR-3
- Date 9/29/2020
- MASH 2016 Test Designation No. 4-10
- Test Article .... Minnesota Combination Bridge Rail
- Total System Length .... 154 ft
- Total Bridge Rail Height .... 36 in.
- Bridge Rail Elements .... HSS 10x4x¼ Tube
  - Length .... 150 ft – 2½ in.
- Bridge Post Assembly (Main Components)
  - Post .... HSS 7x5x5⁄16 by 10¼ in. long
  - Base Plate (Welded) .... 16 in. x 9½ in. x ¾ in.
- Concrete Parapet
  - Length .... 140 ft – 8 in.
  - Width .... 16 in.
  - Height .... 21 in.
- Concrete Tapered End Section (Excluding End Post)
  - Length .... 22½ in.
  - Height .... 10 in.
  - Width .... 16 in. at downstream end and 8½ in. wide at the upstream end
- Brush Curb
  - Width .... 2 in.
  - Height .... 6 in.
- Vehicle Make /Model .... 2009 Kia Rio
  - Curb .... 2,448 lb
  - Test Inertial .... 2,442 lb
  - Gross Static .... 2,600 lb
- Impact Conditions
  - Speed .... 62.5 mph
  - Angle .... 25.5 deg.
  - Impact Location .... 70 7⁄16 in. upstream from post no. 23
- Impact Severity (IS) .... 59.1 kip-ft > 51 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed .... 46.0 mph
  - Angle .... 5.8 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 190 ft – 7 in. downstream
  36 ft – 3 in. laterally in front
- Vehicle Damage .... Moderate
  - VDS [15] 01-RFQ-5
  - CDC [16] 01-RYEW-5
  - Maximum Interior Deformation .... 2.5 in.
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... 0.1 in.
  - Dynamic .... 0.3 in.
  - Working Width .... 18 in.
  - ZOI .... 10 in.
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1 (primary)	SLICE-2	
OIV ft/s	Longitudinal	-19.58	-20.67	±40 (12.2)
	Lateral	-34.25	-31.47	±40 (12.2)
ORA g's	Longitudinal	-4.53	2.83	±20.49
	Lateral	-10.87	-12.05	±20.49
Maximum Angular Displacement deg.	Roll	12.9	9.8	±75
	Pitch	-6.9	-7.9	±75
	Yaw	-45.2	-45.3	not required
THIV – ft/s		0.28	0.18	not required
PHD – g's		37.20	38.51	not required
ASI		2.47	2.33	not required

Figure 153. Summary of Test Results and Sequential Photographs, Test No. MNCBR-3

8 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

8.1 Summary

The objective of this study was to crash test and evaluate a concrete parapet with brush curb, an upper beam and post rail, and a new tapered end section system according to MASH 2016 TL-4 safety performance criteria. An early variation of the MnDOT combination bridge railing system was previously crash tested by MwRSF according to NCHRP Report 350 impact safety standards [1]. Thus, MnDOT desired to have its combination bridge railing system, with a few design modifications, crash tested according to MASH 2016 TL-4 impact safety standards. The combination bridge railing system was evaluated using three full-scale vehicle crash tests according to MASH 2016 test designation nos. 4-12 (MNCBR-1), 4-11 (MNCBR-2), and 4-10 (MNCBR-3), which involved a 10000S single-unit box truck, a 2270P pickup truck, and a 1100C small car sedan, respectively. The critical impact point for each impact scenario was selected using the critical impact point analysis and guidance found in MASH 2016 [3], which is detailed in Section 2.2.

For test no. MNCBR-1, the 22,042-lb single-unit box truck impacted the combination bridge railing system at a speed of 57.4 mph and at an angle of 15.4 degrees. The initial vehicle impact was to occur 60 in. upstream from the centerline of splice between post nos. 6 and 7, as shown in Figure 61. The actual point of impact was 0.15 in. upstream from the target impact location. The vehicle was captured and safely redirected by the bridge railing. During vehicle redirection, the right-side edge or seam of floor pan released, as shown in Figures 88 and 89. The right-front wheel and/or rubber tire pushed on the supporting member and floor pan was held in place at the edge until the partially-rusted spot welds along the seam failed. As such, the spot-weld region was pulled downward along this seam in more of a tensile loading manner, where the spot welds eventually tore out of the fabricated holes. Based on a review of the post-test results, researchers confirmed that the right-front wheel and/or rubber tire did not penetrate at the floor edge or seam since the floor did not reveal upward bending (prying up) at the edge but rather downward bending (tension down with tear out) at the edge, as shown in Figures 88 and 89. The maximum measured floor pan deformation was 5.6 in., which is within MASH 2016 [3] occupant compartment deformation limits. The vehicle snag did not pose a risk to the occupant compartment and did not result in elevated occupant risk measures. The vehicle exited the barrier in a stable manner and came to rest 330 ft downstream and 11 ft – 2 in. laterally behind the barrier. The maximum lateral permanent set, dynamic deflection, and working width of the barrier was 0.2 in., 0.9 in., and 51.6 in., respectively. The ZOI was found to be 49.6 in. All occupant risk values were found to be within evaluation limits, and the occupant compartment deformations were also deemed acceptable. Subsequently, test no. MNCBR-1 was determined to satisfy the safety performance criteria for MASH 2016 test designation no. 4-12. A summary of the test evaluation is shown in Table 15.

For test no. MNCBR-2, the 5,003-lb crew cab pickup truck impacted the combination bridge railing system at a speed of 63.9 mph and at an angle of 25.1 degrees. The initial vehicle impact was to occur 70 11/16 in. upstream from the centerline of post no. 23, as shown in Figure 96. The actual point of impact was 0.78 in. upstream from the target impact location. The vehicle was captured and safely redirected by the bridge railing. During vehicle redirection, the right-front fender and right-front corner of the engine hood contacted the upstream side of the post downstream from the impact point. This contact resulted in sufficient snag to crush the entire right-front fender inward. However, the vehicle snag did not pose a risk to the occupant compartment and did not result in elevated occupant risk measures. The vehicle exited the barrier in a stable manner and came to rest 176 ft – 3 in. downstream from impact point and 12 ft – 6 in. laterally in front of the barrier. The maximum lateral permanent set, dynamic deflection, and working width of the barrier was 0.3 in., 0.4 in., and 18 in., respectively. The ZOI was found to be 16 in. All occupant risk values were found to be within evaluation limits, and the occupant compartment deformations were also deemed acceptable. Subsequently, test no. MNCBR-2 was determined to satisfy the safety performance criteria for MASH 2016 test designation no. 4-11. A summary of the test evaluation is shown in Table 16.

For test no. MNCBR-3, the 2,442-lb small car sedan impacted the combination bridge railing system at a speed of 62.5 mph and at an angle of 25.5 degrees. Initial vehicle impact was to occur 63½ in. upstream from the centerline of post no. 23, as shown in Figure 127. The actual point of impact was 6.9 in. upstream from the target impact location. The vehicle was captured and safely redirected by the bridge railing. During vehicle redirection, the right-front fender and right-front corner of the engine hood contacted the upstream side of the post downstream from the impact point. This contact resulted in sufficient snag to peel back the entire right-front fender and tear the hood of the vehicle. However, the vehicle snag did not pose a risk to the occupant compartment and did not result in elevated occupant risk measures. The vehicle exited the barrier in a stable manner and came to rest 190 ft – 7 in. downstream from impact point and 36 ft – 3 in. laterally in front of the barrier. The maximum lateral permanent set, dynamic deflection, and working width of the barrier was 0.1 in., 0.3 in., and 18 in., respectively. The ZOI was found to be 10 in. All occupant risk values were found to be within evaluation limits, and the occupant compartment deformations were also deemed acceptable. Subsequently, test no. MNCBR-3 was determined to satisfy the safety performance criteria for MASH 2016 test designation no. 4-10. A summary of the test evaluation is shown in Table 16.

8.2 Conclusions

MnDOT's concrete parapet with brush curb, an upper beam and post rail, and a new tapered end section was evaluated through three full-scale vehicle crash tests, test designation nos. 4-10, 4-11, and 4-12, according to the MASH 2016 TL-4 [3] safety criteria. MnDOT's concrete parapet with brush curb, an upper beam and post rail, and a new tapered end section was found to satisfy all evaluation criteria for MASH 2016 test designation nos. 4-10, 4-11, and 4-12.

Table 15. Summary of Safety Performance Evaluation, Test No. MNCBR-1

Evaluation Factors	Evaluation Criteria	Test No. MNCBR-1
Structural Adequacy	A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	S
Occupant Risk	D. 1. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.	S
	2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.	S
	G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	S
MASH 2016 Test Designation No.		4-12
Final Evaluation (Pass or Fail)		Pass

S – Satisfactory U – Unsatisfactory N/A – Not Applicable

Table 16. Summary of Safety Performance Evaluation, Test Nos. MNCBR-2 and MNCBR-3

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. MNCBR-2</th><th>Test No. MNCBR-3</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 degrees.</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><th>Component</th><th>Preferred</th><th>Maximum</th></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><th>Component</th><th>Preferred</th><th>Maximum</th></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>4-11</td><td>4-10</td></tr>
<tr><td colspan="3">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory   U – Unsatisfactory   N/A – Not Applicable

8.3 Recommendations

Based on the successful MASH 2016 crash testing under TL-4 impact conditions, MnDOT's bridge railing denoted in Figures 2 and 3 would similarly be deemed to be crashworthy. For scenarios where future 3-in. thick pavement overlays may be expected, the parapet height could be increased by 3 in. to an overall height of 24 in. This modification would also result in an overall bridge railing height of 39 in. This configuration would be expected to meet MASH TL-4 conditions both before and after the pavement overlay with corresponding top rail heights of 39 in. and 36 in., respectively. Under the pavement overlay scenario, the vertical taper at the end of the concrete end post would need to continue to 39 in. using the same slope.

9 MASH EVALUATION

The objective of this research effort was to evaluate the safety performance of MnDOT's modified concrete parapet with brush curb, an upper steel beam and post railing, and a new tapered concrete end section adjacent to a concrete end post. The combination bridge railing system consisted of a 154-ft long concrete parapet with a brush curb, an upper steel beam and post railing system, a downstream concrete end post, and a new tapered end section beyond the last bridge post under the tube rail and above the parapet. The combination bridge railing system utilized a total of eight rail and post assemblies, which consisted of eight rail and post assemblies anchored to the top face of the concrete parapet.

According to TL-4 evaluation criteria in MASH 2016, three tests are required for evaluation of longitudinal barrier systems: (1) test designation no. 4-10 – an 1100C small car, (2) test designation no. 4-11 – a 2270P pickup truck, and (3) test designation no. 4-12 – a 10000S single-unit box truck.

During test no. MNCBR-1, a 22,042-lb single-unit box truck with a simulated occupant seated in the right-front passenger seat impacted the combination bridge railing system at a speed of 57.4 mph and at an angle of 15.4 degrees, resulting in an impact severity of 171.2 kip-ft. At 0.316 sec after impact, the vehicle became parallel to the system at a speed of 50.5 mph. At 1.906 sec, the vehicle exited the system at a speed of 38.7 mph and at an angle of 12 degrees. The vehicle was successfully contained and smoothly redirected.

Exterior vehicle damage was moderate. Interior occupant compartment deformations were moderate with a maximum of 5.6 in., which did not violate the limits established in MASH 2016. Damage to the barrier was also moderate, consisting of contact marks on the front face of the concrete parapet as well as concrete gouging and scuff marks along the length of vehicle contact which, extended downstream approximately 122 ft – 3½ in., starting 8½ in. upstream from the centerline of post no. 5. The maximum lateral permanent set, dynamic deflection, and working width of the barrier was 0.2 in., 0.9 in., and 51.6 in., respectively. The ZOI was found to be 49.6 in. All occupant risk values were found to be within evaluation limits, and the occupant compartment deformations were also deemed acceptable. Therefore, MnDOT’s modified concrete parapet with brush curb, an upper steel beam and post railing, and a new tapered concrete end section adjacent to a concrete end post successfully met all the safety performance criteria of MASH 2016 test designation no. 4-12.

During test no. MNCBR-2, a 5,003-lb crew cab pickup truck with a simulated occupant seated in the right-front passenger seat impacted the combination bridge railing system at a speed of 63.9 mph and at an angle of 25.1 degrees, resulting in an impact severity of 122.9 kip-ft. At 0.178 sec after impact, the vehicle became parallel to the system at a speed of 46.5 mph. At 0.362 sec, the vehicle exited the system at a speed of 45.1 mph and at an angle of 5.1 degrees. The vehicle was successfully contained and smoothly redirected.

Exterior vehicle damage was moderate. Interior occupant compartment deformations were moderate with a maximum of 5.8 in., which did not violate the limits established in MASH 2016. Damage to the barrier was also moderate, consisting of contact marks on the front face of the concrete parapet as well as concrete gouging and scuff marks along the length of vehicle contact which, extended downstream approximately 12 ft – 10 in., starting 1 ft – 9½ in. upstream from post no. 22. The maximum lateral permanent set, dynamic deflection, and working width of the barrier was 0.3 in., 0.4 in., and 18 in., respectively. The ZOI was found to be 16 in. All occupant risk values were found to be within evaluation limits, and the occupant compartment deformations were also deemed acceptable. Therefore, MnDOT's modified concrete parapet with brush curb, an upper steel beam and post railing, and a new tapered concrete end section adjacent to a concrete end post successfully met all the safety performance criteria of MASH 2016 test designation no. 4-11.

During test no. MNCBR-3, a 2,442-lb small car sedan with a simulated occupant seated in the right-front passenger seat impacted the combination bridge railing system at a speed of 62.5 mph and at an angle of 25.5 degrees, resulting in an impact severity of 59.1 kip-ft. At 0.149 sec after impact, the vehicle became parallel to the system at a speed of 47.5 mph. At 0.278 sec, the vehicle exited the system at a speed of 46.0 mph and at an angle of 5.8 degrees. The vehicle was successfully contained and smoothly redirected.

Exterior vehicle damage was moderate. Interior occupant compartment deformations were moderate with a maximum of 2.5 in., which did not violate the limits established in MASH 2016. Damage to the barrier was also moderate, consisting of contact marks on the front face of the concrete parapet as well as concrete gouging and scuff marks along the length of vehicle contact, which extended downstream approximately 10 ft starting 18 in. upstream from the impact point. The maximum lateral permanent set, dynamic deflection, and working width of the barrier was 0.1 in., 0.3 in., and 18 in., respectively. The ZOI was found to be 10 in. All occupant risk values were found to be within evaluation limits, and the occupant compartment deformations were also deemed acceptable. Therefore, MnDOT's modified concrete parapet with brush curb, an upper steel beam and post railing, and a new tapered concrete end section adjacent to a concrete end post successfully met all the safety performance criteria of MASH 2016 test designation no. 4-10.

MnDOT's modified concrete parapet with brush curb, an upper steel beam and post railing, and a new tapered concrete end section adjacent to a concrete end post was successfully crash tested and evaluated according to the AASHTO MASH 2016 TL-4 criteria.

10 REFERENCES

1. Ross, H.E., Sicking, D.l., Zimmer, R.A., and Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program (NCHRP) Report 350, Transportation Research Board, Washington, D.C., 1993.

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

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

4. *AASHTO/FHWA Joint Implementation Agreement for the AASHTO Manual for Assessing Safety Hardware,* American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2015.

5. Pfeifer B.G., Holloway J.C., Faller R.K, and Rosson B.T., *TL-4 Evaluation of the Minnesota Combination Bridge Rail*, Research Report No. TRP-03-53-96, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, 1995.

6. Minnesota Department of Transportation (DOT), Design – *Structural Tube Railing (Design T-2)*, Fig. 5-397.157e(E), https://www.dot.state.mn.us/bridge/bridgedetails2.html, October 15, 2020.

7. Minnesota Department of Transportation (DOT), Design – *Structural Tube Railing (Design T-2)*, Fig. 5-397.157e(A), https://www.dot.state.mn.us/bridge/bridgedetails2.html, October 15, 2020.

8. Bielenberg, R.W., Reid, J.D., Rosenbaugh, S.K., Haase, A.J., and Faller, R.K., *Attachment of a Combination Bridge Rail to Concrete Parapet Utilizing Epoxy Adhesive Anchors*, Research Report No. TRP-03-325-15, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, November 3, 2015.

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

10. *Clarifications on Implementing the AASHTO Manual for Assessing Safety Hardware*, 2016, FHWA and AASHTO, https://design.transportation.org/wp-content/uploads/sites/21/2019/11/Clarifications-on-Implementing-MASH-2016-aka-MASH-QA-Updated-Nov-19-2019.pdf, November 2019.

11. Taborck, J.J., Mechanics of Vehicle – 7, Machine Design Journal, May 30, 1957

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

13. 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.

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

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

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

11 APPENDICES

Appendix A. Material Specifications

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

Item No.	Description	Material Specification	Reference
a1	HSS10"x4"x¼", 19' 11" Long Tube Rail	ASTM A500 Gr. B	H#2101855
a2	HSS10"x4"x¼", 10'-2½" Long Tube Rail	ASTM A500 Gr. B	H#2101855
a3	HSS 7"x5"x5⁄16", 10¼" Long Tube Post	ASTM A500 Gr. B	H#SC5168
a4	Rail Sleeve Assembly	MnDOT - ASTM A709 Gr 50 Supplied - ASTM A1018 Gr.50 σ_y = 69 ksi, σ_u= 77.7 ksi, % elong = 30 in 2" ,	H#NLK1756788
a5	4"x2"x¼" Post Plate	MnDOT - ASTM A709 Gr 50 Supplied - ASTM A1018 Gr.50 σ_y = 69 ksi, σ_u= 77.7 ksi, % elong = 30 in 2" ,	H#NLK1756788
a6	10"x4"x¼" Rail End Plate	MnDOT - ASTM A709 Gr 50 Supplied - ASTM A1018 Gr.50 σ_y = 69 ksi, σ_u= 77.7 ksi, % elong = 30 in 2" ,	H#NLK1756788
a7	16"x9½"x¾" Post Base Plate	MnDOT - ASTM A709 Gr 50 Supplied - ASTM A1018 Gr.50 σ_y = 63 ksi, σ_u= 73 ksi, % elong = 50 in 2" ,	H#4129785
a8	6½"x4⅞"x5⁄16" Post Bent Plate	MnDOT - ASTM A709 Gr 50 Supplied - ASTM A1018 Gr.50 σ_y = 62.1 ksi, σ_u= 69 ksi, % elong = 36 in 2" ,	H#Y0171
b1	Concrete	Min. f'c = 4000 psi	Ticket#1253155 Benesch Concrete Sample Test Reports
b2	#5 Rebar, 50" Total Unbent Length	ASTM A615 Gr. 60	H#62150950 H#62150922
b3	#5 Rebar, 48" Total Unbent Length	ASTM A615 Gr. 60	H#62150950 H#62150922
b4	#5 Rebar, 46¾" Total Unbent Length	ASTM A615 Gr. 60	H#62150922
b5	#5 Rebar, 70" Total Unbent Length	ASTM A615 Gr. 60	H#62150950
b6	#5 Rebar, 100" Total Unbent Length	ASTM A615 Gr. 60	H#62150950

Table A-2. Bill of Materials, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3, Cont.

Item No.	Description	Material Specification	Reference
b7	#5 Rebar, 98" Total Unbent Length	ASTM A615 Gr. 60	H#62150950
b8	#5 Rebar, 96" Total Unbent Length	ASTM A615 Gr. 60	H#62150950
b9	#5 Rebar, 90" Total Unbent Length	ASTM A615 Gr. 60	H#62150950
b10	#5 Rebar, 109⁵⁄₁₆" Total Unbent Length	ASTM A615 Gr. 60	H#62150950
b11	#5 Rebar, 32" Total Unbent Length	ASTM A615 Gr. 60	H#62150950
b12	#5 Rebar, 27" Total Length	ASTM A615 Gr. 60	H#62150950
b13	#5 Rebar, 33⅞" Total Unbent Length	ASTM A615 Gr. 60	H#62150950
b14	#5 Rebar, 45⅜" Total Unbent Length	ASTM A615 Gr. 60	H#62150950
b15	#5 Rebar, 46" Total Length	ASTM A615 Gr. 60	H#62150950
b16	#5 Rebar, 156" Total Length	ASTM A615 Gr. 60	H#62150950
b17	#5 Rebar, 1672" Total Length	ASTM A615 Gr. 60	H#62150950
b18	¼" Dia., 8⅝" Long Vertical Backer Rod	ASTM D5249 Type 3	FillPro Standard Backer Rod
b19	¼" Dia., 15¼" Long Horizontal Backer Rod	ASTM D5249 Type 3	FillPro Standard Backer Rod
c1	⅞"-9 UNC, 12" Long Vertical Anchor Rod	ASTM F1554 Gr. 105	H#10551610

Table A-3. Bill of Materials, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3, Cont.

Item No.	Description	Material Specification	Reference
c2	3" Dia. x ¼" Circular Plate Washer	ASTM A709 Gr. 50	H#B9L648
c3	⅞"-9 UNC Heavy Hex Nut	ASTM A563 Gr. DH	H#G7310000508
c4	13"x8"x¼" Anchor Plate	ASTM A709 Gr. 50	H#B9L648
c5	⅞" Dia. SAE Washer	ASTM F436, Type I	H#63019 P#0156031 PO#210201802
d1	12"x20"x⅜" End Plate	ASTM A709 Gr. 50	H#B9G672
d2	1.049" ID 1.68 lb/ft Standard Pipe, 15⅛" Long	ASTM A53 Schedule 40	H#A1808219
e1	Epoxy	Min. Bond Strength = 1670 psi	Hilti Tech Data available online
e2	Joint Sealant	ASTM D5893	301NS Expansion Joint Sealant Pecora #LI061687

18Jun20 21:10 TEST CERTIFICATE No: MAR 352817

NUCOR TUBULAR PRODUCTS INC.
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 01031798
Rel
S/O No MAR 394796-001
B/L No MAR 233465-003 Shp 18Jun20
Inv No Inv

Sold To: (1403)
NORFOLK IRON & METAL
P.O. BOX 1129
NORFOLK, NE 68701

Ship To: (1)
NORFOLK IRON & METAL
3001 NORTH VICTORY RD
NORFOLK, NE 68702

Tel: 402-371-1810 Fax: 402 379-5409

CERTIFICATE of ANALYSIS and TESTS Cert. No: MAR 352817
08Jun20

Part No 01233
TUBING A500 GRADE B(C)
10" X 4" X 1/4" X 20'

		Pcs	Wgt
TUBING A500 GRADE B(C) 10" X 4" X 1/4" X 20'		18	8,070
Heat Number	**Tag No**	**Pcs**	**Wgt**
2101855	399852	6	2,690
	YLD=54040/TEN=68640/ELG=34.4		
2101855	399853	6	2,690
2101855	399854	6	2,690

Heat Number
2101855

*** Chemical Analysis ***
C=0.2100 Mn=0.7800 P=0.0080 S=0.0015 Si=0.0300 Al=0.0300
Cu=0.0800 Cr=0.0300 Mo=0.0100 V=0.0030 Ni=0.0300 Nb=0.0000
Cb=0.0000 Sn=0.0030 N=0.0060 B=0.0000 Ti=0.0020 Sb=0.0000
Ca=0.0010
MELTED AND MANUFACTURED IN THE USA

THE SPECIFICATIONS LISTED BELOW REPRESENT THE CURRENT ISSUED DATES OF THESE STANDARDS. THIS DOES NOT INDICATE THAT THE MATERIAL ABOVE CONFORMS TO EACH OR ALL OF THE STANDARDS. WE CERTIFY THE MATERIAL ABOVE TO THE SPECIFICATION LISTED IN THE LINE DESCRIPTION.

CURRENT STANDARDS:
A252-19
A500/A500M-18
A513/A513M-19
ASTM A53/A53M-18| ASME SA-53/SA-53M-18
A847/A847M-14
A1085/A1085M-15
IN COMPLIANCE WITH EN 10204 SECTION 4.1
INSPECTION CERTIFICATE TYPE 3.1

Page: 1 .... Last

Figure A-1. HSS 10x4x¼, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item Nos. a1 and a2)

TUBULAR STEEL INC Fax:3148519336 Oct 20 2014 21:16 P.01

Independence Tube

6226 W. 74th St
Chicago, IL 60638
708-496-0380
Fax: 708-563-1950

independencetube.com
itctube.com
Certificate Number: DCR 222398

Sold By:
INDEPENDENCE TUBE CORPORATION
6226 W. 74th St.
Chicago, IL 60638
Tel: 708-496-0380
Fax: 708-563-1950

Purchase Order No: PO-045396
Sales Order No: DCR 62616 - 2
Bill of Lading No: DCR 41642 - 3
Invoice No: DCR 88455 - 2

Shipped: 10/17/2014
Invoiced: 10/17/2014

Sold To:
4008 - TUBULAR STEEL
7440 DEER TRAIL LANE
LORAIN, OH 44053

Ship To:
1 - TUBULAR STEEL
7440 DEER TRAIL LANE
LORAIN, OH 44053

CERTIFICATE of ANALYSIS and TESTS

Customer Part No:

Certificate No: DCR 222398
Test Date: 10/15/2014

TUBING A500 GRADE B(C)
7" X 5" X 5/16"

Total Pieces	Total Weight
9	10,083

* DO NOT SWITCH TAGS * OLD STOCK

Heat #: SC5168 Yield: 69,300 psi Tensile: 75,600 psi Elongation: 23.50 % Y/T Ratio: 0.9167 Carbon Eq: 0.1402

C	Mn	P	S	Si	Al	Cu	Cr	Mo	V	Ni
0.0500	0.4000	0.0100	0.0010	0.2480	0.0230	0.1300	0.0500	0.0100	0.0010	0.0400

Bundle Tag	Pieces	Weight
779265	9	10,083

MELTED & MFG USA

Certification:

I certify that the above results are a true and correct copy of records prepared and maintained by Independence Tube Corporation. Sworn this day, 10/15/2014

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

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

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

Jose Martinez, QMS Manager

Page - 1

Figure A-2. HSS 7x5x5⁄16, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. a3)

LMK Indiana

NLMK INDIANA
6500 SOUTH BOUNDARY ROAD
PORTAGE, IN 46368
PHONE: 219.787.8200

11/20/2017 13:35
CSTM8105
Page 2 of 5

CERTIFICATE OF TEST FOR COIL 5205560 HEAT# NLK1756788

: RATNER STEEL SUPPLY COMPANY
2500 WEST COUNTY ROAD B
ROSEVILLE, MN 55113

RATNER STEEL SUPPLY COMPANY
655 GEORGE NELSON DRIVE
PORTAGE, IN 46368

ORDER SPECIFICATIONS

CUSTOMER PO: 302989-1 | ORDER: 3043272 | ITEM: 41207775

RESULTS FOR COIL: 5205560
PRODUCT TYPE: HR
PRODUCT CATEGORY: A1018 HSLA GR 50 F
ORDERED GRADE: C050
ORDERED GAUGE: 0.2400 MIN
GAUGE TOL: +0.0160/-0.0000
ORDERED WIDTH: 48.0000 MIN
WIDTH TOL: +1.1250/-0.0000

EDGE: MILL
FINISH: BLACK
HARDNESS: NA
HARDNESS RANGE: NA
YIELD: 50000
TENSILE: 60000
ELONGATION: 22%
BEND:

INDUSTRY SPEC: ASTM A1018 HSLAS-F GR 50
CUSTOMER SPEC: NA
CUSTOMER PART #:
CERT #: 14
CUSTOMER NOTE:

	COIL #	SIZE	WGT	YIELD	TENSILE	ELONGATION
)1	5205560	0.2400 x 48.0000	45860	69,000	77,700	30.0

NLK1756788 (Country of Origin: RUSSIA)

C: .09 - MN: .87 - P: .007 - S: .004 - SI: .01 - AL: .040 - CU: .03 - NI: .02 - CR: .02 - MO: * - SN: * - TI: .001 - V: .003 - NB: .037 - N: .005 - B: .0002 - CA: .0025 - CE: * - ZR: * - AS: * - SB: *

	COIL #	SIZE	WGT	YIELD	TENSILE	ELONGATION
)1	5205563	0.2400 x 48.0000	46940	70,100	78,900	25.0

NLK1756788 (Country of Origin: RUSSIA)

C: .09 - MN: .87 - P: .007 - S: .004 - SI: .01 - AL: .040 - CU: .03 - NI: .02 - CR: .02 - MO: * - SN: * - TI: .001 - V: .003 - NB: .037 - N: .005 - B: .0002 - CA: .0025 - CE: * - ZR: * - AS: * - SB: *

9923001

:tured in the United States of America - 'BUY AMERICAN' Compliant.

s with a reported value of " * " were undetected, and thus are less than .001%.
IDIANA certifies that the material listed herein has been tested in accordance with the methods prescribed in the governing specifications. Based upon lts of such testing, the material conforms to the specifications. All testing has been performed using the current revision of the testing specifications.

Robert M Chace
Robert M Chace
Applications Engineer

Figure A-3. Rail Sleeve Assembly and ¼-in. Plate, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item Nos. a4, a5, and a6)

AM/NS Calvert LLC

1 AM/NS Way
Calvert, Al. 36513 USA

AM/NS CALVERT

CUSTOMER ORIGINAL

Mill Certificate

Order - Item	Certificate Number	Delivery No	Ship Date	Page
188542-10	1190888740	82490193-10	03/16/2020	1 of 1

Customer No: 10779 | Cust PO: 01030558

Customer Part No: 31982

Customer Sold to:	Customer Ship to:	Contact - Stan Bevans
Norfolk Iron & Metal Company 3001 North Victory Rd. NORFOLK NE 68701 USA	Norfolk Iron & Metal Company 3003 North Victory Rd. West Pit NORFOLK NE 68701 USA	AM/NS Calvert LLC 1 AM/NS Way CALVERT AL 36513 USA Email: Stanley.Bevans@ArcelorMittal.com Ph : 1-251-289-3000

Steel Grade / Customer Specification
Hot Roll Black Coil Conv GR50 ASA572ASA656 Typ7 MM / 0.7490 " X 60.0000 " ACCORDING TO A1018 {Hvy 0.230"(6)-1"(25.4)}-Hot Roll Base

Type of Product/Surface
Hot Roll Black Coil Dry Exposed LASER CUT PARTS/ EXP PAINTED

TEST METHOD | Melted in USA | Manufactured in USA

ASTM

MATERIAL DESCRIPTION

	ORDERED	Heat No.	Coil No.	Weight Net LB	Weight Gross LB
(mm)	19.025	4129785	1190888740	44,114.000	44,114.000
(in)	0.7490				

CHEMICAL COMPOSITION OF THE COIL *

Heat No.	C	Si	Mn	P	S	Al	Cr	Cu	Mo	N
4129785	0.0660	0.01	0.85	0.011	0.007	0.047	0.04	0.026	0.005	0.0048

Ni	Nb	Ti	B	V	Ca
0.016	0.031	0.001	0.0000	0.001	0.0000

TENSILE TEST

Test Direction	Yield Strength	Tensile Strength	% Total Elong.
T	63 ksi	73 ksi	50

AM/NS Calvert LLC certify that the material herein described has been manufactured, sampled, tested and inspected in accordance with the contract requirements and is fully in compliance.

* - This test is not covered by our current A2LA accreditation

Yasunori Iwasa
Quality Management Director
AM/NS Calvert

Rev.

Figure A-4. Post Base Plate, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. a7)

NLMK Indiana

6500 SOUTH BOUNDARY ROAD
PORTAGE, IN 46368
PHONE: 219.787.8200

CSTM8105
Page 2 of 2

CERTIFICATE OF TEST FOR COIL 5285823 HEAT# Y0171

ɪLD TO: NORFOLK IRON & METAL COMPANY
PO BOX 1129
3001 NORTH VICTORY ROAD
NORFOLK, NE 68702

ɪIP TO: NORFOLK IRON & METAL COMPANY
3003 N VICTORY ROAD
WEST PIT
NORFOLK, NE 68702

ORDER SPECIFICATIONS

CUSTOMER PO: 01030477-14 **ORDER:** 3060751 **ITEM:** 41232536

RESULTS FOR COIL:	5285823	EDGE:	MILL	INDUSTRY SPEC:	ASTM A1018 GR 50 F CONV TO A656/SA656 GR50 TY 7
PRODUCT TYPE:	HR	FINISH:	BLACK	CUSTOMER SPEC:	FOR CONV TO A572/SA572 GR 50
PRODUCT CATEGORY:	A1018/CONV TO A572	HARDNESS:	NA	CUSTOMER PART #:	22966
ORDERED GRADE:	C572	HARDNESS RANGE:	NA	CERT #:	14
ORDERED GAUGE:	0.3090 MIN	YIELD:	50000	CUSTOMER NOTE:	
GAUGE TOL:	+0.0180/-0.0000	TENSILE:	65000		
ORDERED WIDTH:	60.0000 MIN	ELONGATION:	23%		
WIDTH TOL:	+1.5000/-0.0000	BEND:			

B #	COIL #	SIZE	WGT	YIELD	TENSILE	ELONGATION
ɪ0751-01	5285823	0.3090 x 60.0000	47500	62,100	69,000	36.0

ɪEAT# Y0171 (Country of Origin: MELT & MFG IN USA) C: .05 - MN: .65 - P: .015 - S: .005 - SI: .02 - AL: .028 - CU: .15 - NI: .05 - CR: .11 - MO: .01 - SN: .03 - TI: .002 - V: .002 - NB: .021 - N: .007 - B: .0001 - CA: .0032 - CE: * - ZR: * - AS: * - SB: .001

5/16" Plate

ɪnufactured in the United States of America - 'BUY AMERICAN' Compliant.

ɪments with a reported value of " * " were undetected, and thus are less than .001%.
.MK INDIANA certifies that the material listed herein has been tested in accordance with the methods prescribed in the governing specifications. Based upon ɪ results of such testing, the material conforms to the specifications. All testing has been performed using the current revision of the testing specifications.

Robert M Chace

Robert M Chace
Applications Engineer

Figure A-5. Post Bent Plate, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. a8)

7/17

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

Customer's Signature: ____________

PLANT	TRUCK	DRIVER	CUSTOMER	PROJECT	TAX	PO NUMBER	DATE	TIME	TICKET
1	239	3978	62461			MNCBR	7/2/20	11:44 AM	1253155

Customer	Delivery Address	Special Instructions
UNL-MIDWEST ROADSIDE SAFETY	4630 NW 36TH ST	NORTH OF OLD GOODYEAR HANGERS

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
8.25	16.50	16.50	NL324424	47BD1PF4000	yd	$124.00	$1,023.00

Water Added On Job At Customer's Request: ____________

SLUMP	Notes:
4.00 in	

TICKET SUBTOTAL	$1,023.00
SALES TAX	$0.00
TICKET TOTAL	**$1,023.00**
PREVIOUS TOTAL	$1,023.00
GRAND TOTAL	**$2,046.00**

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.

MNCBR R#21-101

Figure A-6. Concrete Mix, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. b1)

benesch

Concrete Sample Test Report
Cylinder Compressive Strength

Project Name:	Midwest Roadside Safety - Misc Testing
Project Number:	00110546.00
Client:	Midwest Roadside Safety Facility
Location:	MNPD
Sample:	003
Description:	T1-S-C

Field Data (ASTM C172, C143, C173/C231, C138, C1064)

		Property	Test Result
Supplier:		Slump (in):	
Mix Name:		Air Content (%):	
Ticket Number:		Unit Weight (lb/ft^3):	
Truck Number:		Air Temp (°F):	
Load Volume (yd^3):		Mix Temp (°F):	
Mold Date:	07/02/2020		
Molded By:	MNCBR		

Laboratory Test Data (ASTM C39)

Sample Number:	003				
Set Number:	001				
Specimen Number:	1				
Age:	62				
Length (in):	12				
Diameter (in):	6.02				
Area (in^2):	28.46				
Test Date:	09/02/2020				
Break Type:	6				
Max Load (lbf):	149,316				
Strength (psi):	5,250				
Spec Strength (psi):					

Remarks:
Set 001, Specimen 1, 62-day Compressive Strength (psi): **5,250**

Concrete test specimens along with documentation and test data were submitted by the Midwest Roadside Safey. Test results presented relate to the concrete specimens as received.

Date received: 09/02/2020
Curing: [x] Standard [ ] Field
ASTM C511
Submitted by: Matt Roesler

Distribution:

Report Date: 9/2/20

This report shall not be reproduced, except in full, without prior approval of Alfred Benesch & Company. Results relate only to items tested.

825 M Street Suite 100
Lincoln, NE 68508

Alfred Benesch & Company

https://forneytools.forneyvault.com/Report?id=505fd6bb-f45c-411f-acde-7198b8a62a36

Figure A-7. Concrete Compression Test, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. b1)

benesch

Page 1 of 1

Concrete Sample Test Report
Cylinder Compressive Strength

Project Name:	Midwest Roadside Safety - Misc Testing
Project Number:	00110546.00
Client:	Midwest Roadside Safety Facility
Location:	MNPD
Sample:	004
Description:	t1-N-C

Field Data (ASTM C172, C143, C173/C231, C138, C1064)

Supplier:	
Mix Name:	
Ticket Number:	
Truck Number:	
Load Volume (yd³):	
Mold Date:	07/02/2020
Molded By:	MNCBR

Property	Test Result
Slump (in):	
Air Content (%):	
Unit Weight (lb/ft³):	
Air Temp (°F):	
Mix Temp (°F):	

Laboratory Test Data (ASTM C39)

Sample Number:	004				
Set Number:	001				
Specimen Number:	1				
Age:	62				
Length (in):	12				
Diameter (in):	6.01				
Area (in²):	28.37				
Test Date:	09/02/2020				
Break Type:	3				
Max Load (lbf):	160,647				
Strength (psi):	5,660				
Spec Strength (psi):					

Remarks:
Set 001, Specimen 1, 62-day Compressive Strength (psi): **5,660**

Concrete test specimens along with documentation and test data were submitted by the Midwest Roadside Safey. Test results presented relate to the concrete specimens as received.

Date received: 09/02/2020
Curing: ☒ Standard ☐ Field
ASTM C511
Submitted by:

Distribution:

Report Date: 9/2/20

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Figure A-8. Concrete Compression Test, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. b1)

benesch

Concrete Sample Test Report
Cylinder Compressive Strength

Project Name:	Midwest Roadside Safety - Misc Testing
Project Number:	00110546.00
Client:	Midwest Roadside Safety Facility
Location:	MNPD
Sample:	005
Description:	T2-S-C

Field Data (ASTM C172, C143, C173/C231, C138, C1064)

Supplier:	
Mix Name:	
Ticket Number:	
Truck Number:	
Load Volume (yd³):	
Mold Date:	07/02/2020
Molded By:	MNCBR

Property	Test Result
Slump (in):	
Air Content (%):	
Unit Weight (lb/ft³):	
Air Temp (°F):	
Mix Temp (°F):	

Laboratory Test Data (ASTM C39)

Sample Number:	005				
Set Number:	001				
Specimen Number:	1				
Age:	62				
Length (in):	12				
Diameter (in):	6				
Area (in²):	28.27				
Test Date:	09/02/2020				
Break Type:	6				
Max Load (lbf):	111,302				
Strength (psi):	3,940				
Spec Strength (psi):					

Remarks:
Set 001, Specimen 1, 62-day Compressive Strength (psi): **3,940**

Concrete test specimens along with documentation and test data were submitted by the Midwest Roadside Safey. Test results presented relate to the concrete specimens as received.

Date received: 09/02/2020
Curing: ☒ Standard ☐ Field
ASTM C511
Submitted by: Matt Roesler

Distribution:

Report Date: 9/2/20

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Figure A-9. Concrete Compression Test, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. b1)

benesch

Concrete Sample Test Report
Cylinder Compressive Strength

Project Name:	Midwest Roadside Safety - Misc Testing
Project Number:	00110546.00
Client:	Midwest Roadside Safety Facility
Location:	MNPD
Sample:	006
Description:	T2-N-C

Field Data (ASTM C172, C143, C173/C231, C138, C1064)

Supplier:	
Mix Name:	
Ticket Number:	
Truck Number:	
Load Volume (yd³):	
Mold Date:	07/02/2020
Molded By:	MNCBR

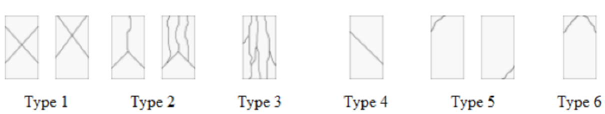
Property	Test Result
Slump (in):	
Air Content (%):	
Unit Weight (lb/ft³):	
Air Temp (°F):	
Mix Temp (°F):	

Laboratory Test Data (ASTM C39)

Sample Number:	006			
Set Number:	001			
Specimen Number:	1			
Age:	62			
Length (in):	12			
Diameter (in):	6.01			
Area (in²):	28.37			
Test Date:	09/02/2020			
Break Type:	6			
Max Load (lbf):	130,298			
Strength (psi):	4,590			
Spec Strength (psi):				

Remarks:
Set 001, Specimen 1, 62-day Compressive Strength (psi): **4,590**

Concrete test specimens along with documentation and test data were submitted by the Midwest Roadside Safey. Test results presented relate to the concrete specimens as received.



Date received: 09/02/2020
Curing: ☒ Standard ☐ Field
ASTM C511
Submitted by: Matt Roesler

Distribution:

Report Date: 9/2/20

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Alfred Benesch & Company

https://forneytools.forneyvault.com/Report?id=e0b00211-71de-4c11-8070-feccd63e9f9c

Figure A-10. Concrete Compression Test, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. b1)

GERDAU

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

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
SIMCOTE INC 1645 RED ROCK RD SAINT PAUL,MN 55119 USA	SIMCOTE INC 1645 RED ROCK ROAD SAINT PAUL,MN 55119-6014 USA	60 (420)	Rebar / #5 (16MM)	0000036750

LENGTH	WEIGHT	HEAT / BATCH
40'00"	8,594 LB	62150922/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
8328518/000050		ASTM A615/A615M-16

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
MN-3734	1332-0000075667	11/21/2019

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %
0.42	1.09	0.009	0.021	0.23	0.29	0.12	0.19	0.029	0.012	0.004	0.002

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
68545	473	107801	743	8.000	203.2

MECHANICAL PROPERTIES

Elong. %	BendTest
13.80	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
1.75	0.380	0.131	0.419

COMMENTS / NOTES

Material 100% melted and rolled in the USA. Manufacturing processes for this steel, which may include scrap melted in an electric arc furnace and hot rolling, have been performed at Gerdau St. Paul Mill, 1678 Red Rock Road, Saint Paul, Minnesota, USA. All product produced from strand cast billets. Silicon killed (deoxidized) steel. No weld repairment performed. Steel not exposed to mercury or any liquid alloy which is liquid at ambient temperatures during processing or while in Gerdau St. Paul Mills possession. Any modification to this certification as provided by Gerdau-St. Paul Mill without the expressed written consent of Gerdau St. Paul Mill negates the validity of this test report. This report shall not be reproduced except in full, without the expressed written consent of Gerdau St. Paul Mill. Gerdau St. Paul Mill is not responsible for the inability of this material to meet specific applications.
Roll batch 62150922/02 roll date 8/26/2019

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. Weld repair has not been performed on this material. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

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QUALITY DIRECTOR
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ALEA BRANDENBURG
QUALITY ASSURANCE MGR.
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Figure A-11. #5 Rebar, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item Nos. b2, b3, and b4)

GERDAU

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

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
SIMCOTE INC 1645 RED ROCK ROAD SAINT PAUL,MN 55119-6014 USA	SIMCOTE INC 1645 RED ROCK ROAD SAINT PAUL,MN 55119-6014 USA	60 (420)	Rebar / #5 (16MM)	0000034231

LENGTH	WEIGHT	HEAT / BATCH
60'00"	8,636 LB	62150950/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
8050886/000020		ASTM A615/A615M-16

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
MN-3726		09/10/2019

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %
0.45	1.02	0.010	0.027	0.22	0.34	0.12	0.20	0.025	0.012	0.004	0.002

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
72026	497	110043	759	8.000	203.2

MECHANICAL PROPERTIES

Elong. %	BendTest
15.00	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
1.50	0.038	0.180	0.415

COMMENTS / NOTES

Material 100% melted and rolled in the USA. Manufacturing processes for this steel, which may include scrap melted in an electric arc furnace and hot rolling, have been performed at Gerdau St. Paul Mill, 1678 Red Rock Road, Saint Paul, Minnesota, USA. All product produced from strand cast billets. Silicon killed (deoxidized) steel. No weld repairment performed. Steel not exposed to mercury or any liquid alloy which is liquid at ambient temperatures during processing or while in Gerdau St. Paul Mills possession. Any modification to this certification as provided by Gerdau-St. Paul Mill without the expressed written consent of Gerdau St. Paul Mill negates the validity of this test report. This report shall not be reproduced except in full, without the expressed written consent of Gerdau St. Paul Mill. Gerdau St. Paul Mill is not responsible for the inability of this material to meet specific applications.
Roll batch 62150950/02 roll date 8/23/2019
ASTM A615-MN-DOT-SPEC-3302

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. Weld repair has not been performed on this material. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

Bhaskar
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Figure A-12. #5 Rebar, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item Nos. b2, b3, b5, b6, b7, b8, b9, b10, b11, b12, b13, b14, b15, b16, and b17)

Technical Data: FillPro™ Standard Backer Rod (Formerly ITP Standard)

Description: Flexible, gray or white, extruded round, closed-cell polyethylene foam backer rod in continuous coils or 6 foot lengths.

Typical Properties

Property	Value	Test Methods
Density (nominal)	> 1.5	ASTM D1622
Outgassing (# of bubbles)	> 1	ASTM C1253
Tensile Strength psi (kPa)	> 24	ASTM D1623
Compression Recovery, %, min	> 96	ASTM D5249
Compression Deflection @ 25%	7 PSI minimum	ASTM D5249
Water Absorption	0.03 gm/cc	ASTM C1016 –Procedure B
Temperature Range	-90°F to 210°F	–
Classification	Type 3	ASTM D5249

Sizes

Diameter	Shipping Format	Feet per Carton	Metric Diameter	Meters per Carton	Color
*1/4"	2 Spools	4000	6 mm	1219	Gray
*3/8"	1 Spool	2100	9 mm	640	Gray
1/2"	2 Spools	2500	12 mm	762	Gray
5/8"	2 Spools	1550	15 mm	472	Gray
3/4"	1 Spool	1100	19 mm	335	Gray
7/8"	1 Spool	850	22 mm	259	Gray
1"	1 Spool	600	25 mm	182	Gray
1-1/4"	1 Spool	400	31 mm	121	Gray
1-1/2"	6' Lengths	396	38 mm	121	Gray
2"	6' Lengths	228	50 mm	70	Gray
2-1/2"	6' Lengths	144	63 mm	44	White
3"	6' Lengths	102	76 mm	31	White
4"	6' Lengths	48	101 mm	15	White
5"	6' Lengths	90	127 mm	27	White
6"	6' Lengths	60	152 mm	18	White

Size and lengths per spool are those at times of packaging and may vary with climatic condition after manufacture.

Carton Sizes & Weights

Rod Diameter	Weight / Carton	Carton Measurement
1/4" - 3/8" 6 mm to 9 mm	6 lbs 2.7 kgs	18" x 18" x 15" 457 mm x 457 mm x 381 mm
1/2" - 1-1/4" 12 mm to 31 mm	11 lbs 5 kgs	18" x 18" x 30" 457 mm x 457 mm x 762 mm
1-1/2" - 4" 38 mm to 101 mm	14 lbs 6.4 kgs	17" x 10" x 74" 432 mm x 254 mm x 1880 mm
5" - 6" 127 mm to 152 mm	35 lbs 15.9 kgs	17" x 23" x 74" 432 mm x 584 mm x 1880 mm

Shipping Information

- Rectangular cartons with convenient hand holes for carrying, are ideal for warehousing and handling.
- Most other express services will accept all cartons for reshipment.
- Truckload quantities furnished on pallets and may be warehoused 2 pallets high to maximize space.

Proper Sizing Chart (Size to Joint Width)

Joint Width	Use Rod Diameter
1/8" - 3/16"	1/4"
3/16" - 1/4"	3/8"
1/4" - 3/8"	1/2"
3/8" - 1/2"	5/8"
1/2" - 5/8"	3/4"
5/8" - 3/4"	7/8"
3/4" - 7/8"	1"
7/8" - 1"	1 1/4"
1" - 1 1/4"	1 1/2"
1 1/4" - 1 1/2"	2"
1 1/2" - 2"	2 1/2"
2" - 2 1/2"	3"
2 1/2" - 3"	4"
3" - 4 3/4"	5"
4 3/4" - 5 3/4"	6"

armacell®

Armacell Canada Inc.

153 Van Kirk Drive
Brampton, ON L7A 1A4
TOLL FREE: 800-387-3847 ext. 161401
TEL: 905.846.3666
Fax: 905.846.0363

Web: www.tundrafoam.com | www.armacell.us

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FillPro-Standard	Data Sheet	5430	Eng/US	9/2017

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Figure A-13. Backer Rod, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item Nos. b18 and b19)

Job Material Certification

Page 5 of 16

Vulcan THREADED PRODUCTS, INC.

Vulcan Threaded Products
10 Cross Creek Trail
Pelham, AL 35124
Tel (205) 620-5100
Fax (205) 620-5150

JOB MATERIAL CERTIFICATION

Job No: 590453 **Job Information** **Certified Date:** 8/31/18

Containers: S14697464

Customer: Conklin and Conklin

Ship To: 34201 Seventh Street
Union City, CA 94587

Vulcan Part No: BAR B7 .7987x144 SC

Customer Part No: RAWSTEEL-.796-B

Customer PO No: 19136

Shipped Qty: 3105 lbs

Order No: 368176

Line No: 1

Note:

Applicable Specifications

Type	Specification	Rev	Amend	Option
-	ASTM F1554 Gd 105 S4	2015		
Heat Treat	ASME SA-193/SA-193M B7	2013		
	ASTM A193 B7	2016		
Quality	EN 10204 3.1	2004		

Test Results

See following pages for tests

Certified Chemical Analysis

Heat No: 10551610 Origin: USA

C	Mn	P	S	Si	Cr	Mo	Ni	V	Cu
0.41	0.87	0.007	0.024	0.29	0.91	0.21	0.05	0.003	0.14
Al	**Nb**	**Sn**	**Ti**	**N**	**B**	**DI**	**RR**	**G.S.**	**Macro S**
0.028	0.002	0.006	0.003	0.0060	0.0002	5.23	54:1	Fine	2
Macro R	**Macro C**	**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**	**J8**
2	2	57	57	57	57	57	57	56	55
J9	**J10**	**J12**	**J14**	**J16**	**J18**	**J20**	**J24**	**J28**	**J32**
54	52	50	48	46	46	45	42	40	38

Notes

Material was manufactured, tested and inspected as required by the product standard and in accordance with Vulcan's ISO 9001:2015 Quality Management System registered June 30th, 2017. Processed material is Tempered - Stress Free. No weld repair performed on the material. No Mercury used in the production of this material. Melted and Manufactured in the USA.
Document is in accordance with EN 10204 - 3.1B of 2004 (3.1).

Plex 8/31/18 10:22 AM vulc.joco Page 1 of 2

19665 7/8 6 B7 ATR

PORTLAND BOLT
PO# 41910
INV# 078677
50 7/8" X 144" B7 ATR, HDG
AUGUST 5, 2019

41910-01

https://www.plexonline.com/b7e2cf83-6155-4673-8f8b-c1fc57a3338b/Sales/Report_Job_Cert.asp?Mode=... 3/8/2019

Figure A-14. Anchor Rod, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. c1)

1/4

SSAB

1770 Bill Sharp Boulevard, Muscatine, IA 52761-9412, US

Test Certificate

⚠ **WARNING:** This product can expose you to chemicals including nickel and nickel compounds, which are known to the State of California to cause cancer. For more information go to www.P65Warnings.ca.gov.

Form TC1: Revision 4: Date 6 Feb 2019

Customer:
STEEL & PIPE SUPPLY
P.O. BOX 1688

MANHATTAN
KS 66502

Customer P.O.No.:4500338793

Mill Order No. 41-587716-02

Shipping Manifest: MR393684

Product Description: ASTM A572-50/M345(18)/A709-50/M345(18)
MAX SILICON 0.05%, CEV 0.45%
COIL FOR CONVERSION

Ship Date: 18 Dec 19
Cert Date: 18 Dec19

Cert No: 061810556
(Page 1 of 1)

Size: 0.240(MIN) X 96.00 X COIL (IN)

Tested Pieces:				Tensiles:						Charpy Impact Tests						
Heat Id	Piece Id	Piece Dimensions	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1 2 3 Avg	% Shear 1 2 3 Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp %Shr
B9L648	0416	0.313		54	75		28	T							

Heat Id	C	Mn	P	S	Si	Tot Al	Cu	Ni	Cr	Mo	Cb	V	Ti	IIW	ORGN
B9L648	.16	.84	.010	.003	.04	.035	.33	.15	.13	.04	.001	.018	.006	.36	USA

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
HOT-ROLLED COIL INTENDED FOR CONVERSION TO GRADE. CERTIFIED TO CHEMISTRY ONLY.
COIL END PHYSICAL TEST RESULTS, IF REPORTED, ARE FOR INFORMATION ONLY.
CEV (IIW) = C + MN/6 + (CR+MO+V)/5 + (NI+CU)/15
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED AND MANUFACTURED IN THE USA
PRODUCTS SHIPPED:
B9L648 0434 PCES: 1, LBS: 49400

(P) Cust Part #: 72896999A2

WE HEREBY CERTIFY THAT THIS MATERIAL WAS TESTED IN ACCORDANCE WITH, AND MEETS THE REQUIREMENTS OF, THE APPROPRIATE SPECIFICATION

Brian Wales
SENIOR METALLURGIST - PRODUCT

Figure A-15. Anchor Plate and Plate Washer, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item Nos. c2 and c4)

2017.03.32

SG03B-1914E

江苏沙钢集团有限公司
Jiangsu Shagang Group CO., LTD.
高速线材质量证明书
High-speed Wire Rod Quality Certificate

沙钢

江苏省张家港市锦丰镇 邮编：215625
Jinfeng, Zhangjiagang, Jiangsu, P. R. CHINA
TEL: (0512) 58568866, 58568829
FAX: (0512) 58550366, 58550818

订货单位CUSTOMER	浙江沙钢物资贸易有限公司	用户代码CUSTOMER CODE		合同号CONTRACT NO.	X71W0008Q008
牌号STEEL GRADE	SWRCH35K	提货单号DELIVERY	U23161	发货日期DATE OF DELIVERY	20170218
交货标准 SPECIFICATION	Q/320582 SGY303-2014	质证书号CERTIFICATE NO.	U231610003 X71W0008Q008 6	签发日期DATE OF ISSUE	20170218
		用途USE		精炼方式REFINING MATHOD	炉外精炼

序号 NO	炉批号 HEAT NO.	直径 Dia. mm.	盘数 Coils	重量 Kg	化学成分CHEMICAL COMPOSITION % C	Si	Mn	P	S	Cr	Ni	Cu	N		拉伸试验TENSILE TEST Rm	ReL	A	A11.3	Z	顶端试验 H. T.	硬度试验 HRB	脱碳层 D. of. D	晶粒度 Micro-Grade	索氏体 Sorbite %	备注 REMARKS
					2	2	2	3	3	2	2	2	4		MPa		%								
					1=×10 2=×100 3=×1000 4=×10000 5=×100000																				
1	G731000508	34.0	21	48750	35	13	74	16	4	1	1	1	34		552	309			34.0	完好		0.01	8		
															554	320			36.0			0.01	8		
2	G731000510	30.0	19	44179	36	14	72	14	5	1	1	1	50		592	355			38.0	完好		0.01	8		
															594	362			43.0			0.01	8		
3	G731000510	30.0	12	27865	36	14	72	14	5	1	1	1	50		592	355			38.0	完好		0.01	8		
															594	362			43.0			0.01	8		
4	G731000510	30.0	12	27224	36	14	72	14	5	1	1	1	50		592	355			38.0	完好		0.01	8		
															594	362			43.0			0.01	8		
5	G731000511	30.0	21	48306	36	13	72	12	5	1	1	2	55		579	349			33.0	完好		0.01	8		
															587	359			35.0			0.01	8		
6	G731000511	30.0	1	2228	36	13	72	12	5	1	1	2	55		579	349			33.0	完好		0.01	8		
															587	359			35.0			0.01	8		
合计 Total			86	198552																					

说明 NOTES: 本质量证明书适用于合金类线材；本产品不含有任何辐射元素。It is guaranteed that the products don't contain radiochemical imparities.
*1. H. T.—Head-colding Test; *2 D. of D.—Depth of Decarburization;

综合判定 FINAL RESULT: 合格 PASS

注意事项 ATTENTIVE ITEMS:
1. 质量证明书复印件不作有效证明文件，除非盖章；The copy of this Certificate is not valid except stamped.
2. 用户验货后使用如有异议应及时告知炉号、牌号，并保留实物及标志。Please inform us the steel grade and the heat number of under quanlified material(s) found in inspection on time, and keep the material(s) and the marking card
3. 高扎丝纽结处近端为轧制成品头部。The coil head is marked by the binding

质检印章 SEAL

签证人 VISA

质检专用章

第6页，共9页

Figure A-16. Heavy Hex Nut, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. c3)

Stamping The Future

Wrought Washer Mfg., Inc
1901 Chicory Road
Mount Pleasant, WI 53403

Certificate Of Conformance

Date:
Certification To: Fastenal Company
9911 Woodend Road
Edwardsville, KS 66111
USA

Part Info

PO No Revision:
Customer Part No: 0156031
Part Name: 7/8 F436 S MARK HDG
Quantity: 2,000
Supplier:
Master Unit No(s): M006605

Customer Part Rev Level:
Customer PO No: 210201802
Line No: 3

Piece List:
Wrought Washer Mfg., Inc. Part No: 017305
Heat Code(s): 63019
Shipper No: WW01813
Job No(s): 317722 HT 314372

Revision:

Supplier	Heat No	Attachment
	63019	19

We hereby certify that the subject parts conform to the purchase order and any applicable specification indicated above. We further certify that all hardening and/or plating meet full purchase order specification requirements.

We hereby certify that all statutory requirements as to American Production and Labor Standards and all conditions of purchase applicable to the transaction have been complied with and that the subject parts were manufactured in the USA.

Paul J. Seggelink

Signature Date

Figure A-17. SAE Washer, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. c5)

3/8

SSAB Test Certificate

1770 Bill Sharp Boulevard, Muscatine, IA 52761-9412, US

⚠ **WARNING:** This product can expose you to chemicals including nickel and nickel compounds, which are known to the State of California to cause cancer. For more information go to www.P65Warnings.ca.gov.

Form TC1: Revision 4: Date 6 Feb 2019

Customer:
STEEL & PIPE SUPPLY
P.O. BOX 1688

MANHATTAN
KS 66502

Customer P.O.No.:4500331744
Mill Order No. 41-575276-01
Shipping Manifest: MR381892

Product Description: ASTM A572-50/M345(18)/A709-50/M345(18)
MAX SILICON 0.05%, CEV 0.45%
COIL FOR CONVERSION

Ship Date: 22 Jul 19
Cert Date: 22 Jul19
Cert No: 061786073
(Page 1 of 1)

Size: 0.365(MIN) X 96.00 X COIL (IN)

Tested Pieces:				Tensiles:						Charpy Impact Tests					
Heat Id	Piece Id	Piece Dimensions	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1 2 3 Avg	% Shear 1 2 3 Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp %Shr
B9G672	0422	0.500		50	71		44	T							

Chemical Analysis

Heat Id	C	Mn	P	S	Si	Tot Al	Cu	Ni	Cr	Mo	Cb	V	Ti	IIW	ORGN
B9G672	.15	.87	.009	.002	.04	.028	.29	.09	.14	.02	.001	.018	.007	.36	USA

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
HOT-ROLLED COIL INTENDED FOR CONVERSION TO GRADE. CERTIFIED TO CHEMISTRY ONLY.
COIL END PHYSICAL TEST RESULTS, IF REPORTED, ARE FOR INFORMATION ONLY.
CEV (IIW) = C + MN/6 + (CR+MO+V)/5 + (NI+CU)/15
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED AND MANUFACTURED IN THE USA.
PRODUCTS SHIPPED:
B9G672 0426 PCES: 1, LBS: 49450

(P) Cust Part #: 721296999A2

WE HEREBY CERTIFY THAT THIS MATERIAL WAS TESTED IN ACCORDANCE WITH, AND MEETS THE REQUIREMENTS OF, THE APPROPRIATE SPECIFICATION

Brian Wales
SENIOR METALLURGIST - PRODUCT

Figure A-18. End Plate, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. d1)

ORIGINAL

Jazeera Steel حديد الجزيرة

AL JAZEERA STEEL PRODUCTS COMPANY SAOG

PO BOX 40, PC 327, Suhar Industrial Estate
SULTANATE OF OMAN
Phone : 968 26751763/4/5 Fax 968 26751766

PAGE : 1/1

MILL TEST CERTIFICATE

MTC NO. :216/08/2018 DATED 14/08/2018
INVOICE NO. : AJSPC/EXP/172 DATED 14/08/2018
CUSTOMER'S NAME :SUNBELT GROUP LP
ADDRESS SUITE 950,POST OAK BOULEVARD
HOUSTON,TX 77056-3817
USA

P.O. NO. : 23,704

SR NO.	NPS (Inch)	NPS (MM)	WT (Inch)	LENGTH (Feet)	TYPE	Lb / Ft	HEAT NO.	BUNDLES	PCS	TOTAL (FEET)	NET WT. (MT)	MECHANICAL TESTING: UTS (psi)	YS (psi)	% EL IN GL 2"	FLATTENING / BEND TEST	HYADRAULIC TEST (psi)	CHEMICAL ANALYSIS (%): C / Cu	Mn / Ni	P / Cr	S / Mo	Si / V	Zinc Coating (Oz/Ft²)
							ERW STEEL PIPE CONFORMING TO THE SPECIFICATION ASTM A53 -12 GRA SCH 40															
1	1" (UL+FM)	1.315	0.133	21.0	BPE	1.68	A1808219	146	8760	183960	140.186	63802/64532	46720/47596	38/40	OK	700	0.154 / 0.013	0.795 / 0.027	0.013 / 0.009	0.005 / 0.001	0.012 / 0.002	–
2	1" (UL+FM)	1.315	0.133	21.0	BPE	1.68	A1807217	8	480	10080	7.681	63364/64240	45552/46428	38/40	OK	700	0.146 / 0.009	0.793 / 0.026	0.009 / 0.007	0.006 / 0.002	0.008 / 0.004	–
3	1" (UL+FM)	1.315	0.133	21.0	BPE	1.68	A1804209	1	60	1260	0.960	59015/59885	41470/42340	34/35	OK	700	0.149 / 0.005	0.822 / 0.007	0.006 / 0.010	0.004 / 0.001	0.014 / 0.001	–
4	6" (UL+FM)	6.625	0.280	21.0	BPE	18.99	A1808436	80	560	11760	101.298	63510/64386	41464/42340	35/37	OK	1520	0.143 / 0.022	0.770 / 0.003	0.006 / 0.011	0.009 / 0.002	0.007 / 0.001	–
5	1/2" (UL)	0.840	0.109	21.0	BPE	0.85	A1806312	18	2160	45360	17.489	63656/64386	47450/48326	35/37	OK	700	0.159 / 0.004	0.516 / 0.012	0.009 / 0.006	0.012 / 0.001	0.025 / 0.001	–
6	1" (UL+FM)	1.315	0.133	21.0	GPE	1.68	A1808219	19	1140	23940	18.244	63802/64532	46720/47596	38/40	OK	700	0.154 / 0.013	0.795 / 0.027	0.013 / 0.009	0.005 / 0.001	0.012 / 0.002	1.87/1.89
7	1" (UL+FM)	1.315	0.133	21.0	GPE	1.68	A1807217	13	780	16380	12.482	63364/64240	45552/46428	38/40	OK	700	0.146 / 0.009	0.793 / 0.026	0.009 / 0.007	0.006 / 0.002	0.008 / 0.004	1.88/1.90
8	1.1/4" (UL+FM)	1.660	0.140	21.0	GPE	2.27	A1805212	3	126	2646	2.724	63218/63948	45990/46866	35/37	OK	1200	0.153 / 0.009	0.824 / 0.012	0.009 / 0.005	0.006 / 0.003	0.011 / 0.002	1.88/1.90
9	3" (UL+FM)	3.500	0.216	21.0	GTC	7.68	A1805115	1	14	294	1.024	63510/64386	48910/49640	37/39	OK	2220	0.148 / 0.003	0.792 / 0.013	0.005 / 0.008	0.005 / 0.002	0.015 / 0.001	1.87/1.89
10	3" (UL+FM)	3.500	0.216	21.0	GTC	7.68	A1807431	3	42	882	3.073	63364/64094	43800/44676	34/36	OK	2220	0.143 / 0.008	0.822 / 0.021	0.010 / 0.007	0.003 / 0.001	0.007 / 0.003	1.86/1.88
11	3" (UL+FM)	3.500	0.216	21.0	GTC	7.68	A1802405	1	14	294	1.024	63364/64240	46866/47596	36/38	OK	2220	0.145 / 0.004	0.897 / 0.006	0.020 / 0.012	0.006 / 0.001	0.015 / 0.001	1.87/1.89
						GRAND TOTAL		293	14136	296856	306.185											

THIS IS TO CERTIFY THAT THE MATERIAL CONFORMS TO THE SPECIFICATION ASTM A53 -12 GRA
ALL THE PIPES ARE TESTED NON DESTRUCTIVELY BY EDDY CURRENT METHOD AND HYDROSTATICALLY TESTED AT THE PRESSURE MENTIONED ABOVE.

For Al Jazeera Steel Products Company SAOG

AL-JAZEERA STEEL PRODUCTS CO. (SAOG) P.O. Box : 40 Sohar Postal Code : 327 S. of Oman

Authorized Signatory
Quality Control

Figure A-19. Standard Pipe, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. d2)

P.O. Box 21148
Tulsa, OK 74121
Phone (918) 252-6000
Fax No. (918) 252-6520

Certified Quality and Environmental Systems
SQS
ISO 9001 / ISO 14001
Reg. No. 12455-03

Date: 12/13/2016

Subject: Certificate of Conformance

Product: HIT RE-500 V3 Adhesive

To Whom it May Concern:

This is to certify that the HIT-RE 500 V3 is a high-strength, slow cure two-part epoxy adhesive contained in two cartridges separating the resin from the hardener.

Additionally, this certifies that the product has been seismically and cracked concrete qualified as represented in ICC-ES report ESR- 3814.

Sincerely,

Hilti, Inc.

5400 South 122 East Avenue

Tulsa, Oklahoma 74146

800-879-8000

800-879-7000 fax

US-Sales@hilti.com

Figure A-20. Epoxy, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. e1)

Pecora 301 NS

Specification Data Sheet

PECORA CORPORATION®
Architectural Weatherproofing Products
U.S.A. • since 1862

Non-Sag Silicone Highway & Pavement Joint Sealant

1. BASIC USES

Sealing of transverse contraction and expansion joints, longitudinal, centerline and shoulder joints in Portland cement concrete (PCC) and asphalt.

2. MANUFACTURER

Pecora Corporation
165 Wambold Road
Harleysville, PA 19438

Phone: 215-723-6051
800-523-6688
Fax: 215-721-0286
Website: www.pecora.com

3. PRODUCT DESCRIPTION

Pecora 301 NS Silicone Pavement Sealant is a one part, ultra low modulus product designed for sealing joints in concrete or asphalt pavement. It has excellent unprimed adhesion to concrete, metal and asphalt substrates, superior weather resistance and remains flexible at extremely low temperatures.

Pecora 301 NS Silicone Pavement Sealant is a non-sag product designed for applications on flat and sloped surfaces.

Advantages:

- Reduces pavement deterioration by restricting surface water penetration into underlying base and sub base layers.
- Convenient one component, neutral moisture curing system.
- Ultra low modulus resulting in high movement capability.
- Ease of application with standard automated bulk dispensing equipment such as Graco or Pyles.
- VOC compliant.
- Primerless adhesion to concrete and asphalt.
- Aids in elimination of non-compressables entering expansion joints.

Limitations:

Pecora 301 NS Silicone Pavement Sealant should not be used:

- for continuous water immersion conditions.
- when ambient temperatures is below 40°F (4°C) or above 120°F (49°C).
- flush with traffic surface. **(Sealant must be recessed below surface.)**
- for applications requiring support of hydrostatic pressures.
- with solvents for dilution purposes.
- with concrete that is cured less than 7 days.
- with newly applied asphalt until cooled to ambient temperature (usually 24-48 hours).
- as a structural component or in longitudinal joints greater than 3/4" in width that are intended to be used as a constant travelling surface.

PACKAGING

- 30 fl. oz. (887ml) cartridges
- 20 fl. oz. (592ml) sausages
- 4.5 gallon pails (17.0L)
- 50 gallon drum (188.9L)

Color: pavement gray

SEALANT COVERAGE CHART RECESS GUIDELINES

Joint Width (inches)	Sealant Depth (inches)	Recess (inches)	Backer Rod Diameter (in)	Minimum Joint Depth (in)	Linear ft./gal
1/4	1/4	1/8	3/8	3/4	308
3/8	1/4	1/8	1/2	7/8	205
1/2	1/4	1/8	5/8	1-1/4	154
3/4	3/8	1/4	7/8	1-1/4	68
1.0	1/2	1/4	1-1/4	2	38

TABLE 1: TYPICAL UNCURED PROPERTIES

Test Property	Value	Test Procedure
Cure Through (days)	7	0.5" cross section
Extrusion Rate (grams/min)	90-250	Mil-S-8802
Rheological Properties	non-sag	
Tack Free Time (mins)	60	ASTM C679
VOC Content (g/L)	50	ASTM D3960

TABLE 2: TYPICAL CURED PROPERTIES (After 7 days cure at 77°F (25°C), 50% RH)

Test Property	Value	Test Procedure
Adhesion, minimum elongation		ASTM D5329*
Asphalt	500	
Concrete	500	
Metal	500	
Elongation (%)	>1400	ASTMD412
Resilience (%)	>95	ASTM D5329
Stress @ 150% Elongation (psi)	22	ASTMD412
Hardness, maximum 21 day cure (Shore 00) Joint	60	ASTM C661
Movement Capability +100/-50%; 10 cycles	Pass	ASTM C719

*modified section 14

Since Pecora architectural sealants are applied to varied substrates under diverse environmental conditions and construction situations it is recommended that substrate testing be conducted prior to application.

Figure A-21. Concrete Joint Sealant, Test Nos. MNCBR-1, MNCBR-2, and MNCBR-3 (Item No. e2)

Appendix B. Vehicle Center of Gravity Determination

	Test Name: MNCBR-1	VIN:	1HTMMAAM7DH105190
Model Year: 2013	Make: International	Model:	Durastar 4300 SBA 4x2

Vehicle CG Determination

		Vehicle Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
	+	Unballasted Truck (Curb)	14852	42.601	632703.156
	+	Hub	34	19.75	671.5
	+	Brake activation cylinder & frame	9	44.5	400.5
	+	Pneumatic tank (Nitrogen)	30	43.5	1305.0
	+	Strobe/Brake Battery	5	43.0	215.0
	+	Tow Pin Plate	9	13.5	121.5
	+	Brake Receiver/Wires	6	99.5	597.0
	+	Cab DAQ Unit & Mouting Plate	11	43.313	476.438
	+	CG DAQ Units & Enclosure	6	31.5	189.0
	+	Rear Axle DAQ Unit and Enclosure/Tc	30	50.0	1500.0
	-	Battery	-184	28.5	-5244.0
	-	Oil	-51	21.0	-1071.0
	-	Interior	-66	70.0	-4620.0
	-	Fuel	-368	25.5	-9384.0
	-	Coolant	-57	52.0	-2964.0
	-	Washer fluid	-6	27.0	-162.0
	+	Pump battery	40	53.0	2120.0
	+	Tdas	10	50.0	500.0
BALLAST	+	PCB	5100	69.25	353175.0
	+	Hardware	178	47.0	8366.0
	+	Concrete Blocks	1286	51.25	65907.5
	+	Steel Blocks	875	50.25	43968.75
	+	Foam 8" thick under PCB only	18	51.75	931.5
	+	Steal plates	403	57.25	23071.75
		Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle			1112774.593

Estimated Total Weight (lb)	22170	290	Total Ballast Weight (lb)	7860
Vertical CG Location (in.)	50.193		Ballast Vertical CG Location (in.)	63.031

Vehicle Dimensions for C.G. Calculations

Wheel Base: 236.75 in. Front Track Width: 79.375 in.
Rear Track Width: 74.0 in.

Center of Gravity	10000S MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	22046 ± 660	22042	-4.0
Longitudinal CG (in.)	NA	143.068	NA
Lateral CG (in.)	NA	0.129	NA
Vertical CG (in.)	NA	50.193	NA
Ballast Vertical CG (in.)	63 ± 2	63.031	0.03060

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	3708	3630
Rear	3778	3736

FRONT	7338	lb
REAR	7514	lb
TOTAL	14852	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	4400	4322
Rear	6584	6736

FRONT	8722	lb
REAR	13320	lb
TOTAL	22042	lb

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

Model Year: **2014**	**Test Name:** **MNCBR-2**	**VIN:**	**1C6RR6FT2ES278435**
	Make: **Dodge**	**Model:**	**Ram 1500**

Vehicle CG Determination

	Vehicle Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	5134	29.702401	152492.13
+	Hub	19	15.625	296.875
+	Brake activation cylinder & frame	7	30.25	211.75
+	Pneumatic tank (Nitrogen)	30	27.5	825
+	Strobe/Brake Battery	5	27 1/2	137.5
+	Brake Receiver/Wires	7	52 3/4	369.25
+	CG Plate including DAQ	30	32	960
-	Battery	-44	44	-1936
-	Oil	-12	19	-228
-	Interior	-87	32	-2784
-	Fuel	-155	21	-3255
-	Coolant	-12	34	-408
-	Washer fluid	0	36	0
+	Water Ballast (In Fuel Tank)	73	17	1241
+	Onboard Supplemental Battery	5	27 1/2	137.5
				0
				0
				148060

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

Estimated Total Weight (lb)	5000
Vertical CG Location (in.)	29.612

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140.25 in. Front Track Width: 68.25 in.
Rear Track Width: 68.1875 in.

Center of Gravity	**2270P MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)	5000 ± 110	5003	3.0
Longitudinal CG (in.)	63 ± 4	60.355437	-2.64456
Lateral CG (in.)	NA	-0.511334	NA
Vertical CG (in.)	28 or greater	29.61	1.61200

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	1499	1427
Rear	1099	1109

FRONT	2926	lb
REAR	2208	lb
TOTAL	5134	lb

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1468	1382
Rear	1071	1082

FRONT	2850	lb
REAR	2153	lb
TOTAL	5003	lb

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

		Test Name:	MNCBR-3	VIN:	KNADE223196557772
Model Year:	2009	Make:	Kia	Model:	Rio

Vehicle CG Determination

	Vehicle Equipment	Weight (lb)
+	Unballasted Car (Curb)	2448
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	30
+	Strobe/Brake Battery	5
+	Brake Receiver/Wires	5
+	CG Plate including DAQ	22
-	Battery	-31
-	Oil	-14
-	Interior	-60
-	Fuel	-19
-	Coolant	-5
-	Washer fluid	0
+	Water Ballast (In Fuel Tank)	41
+	Onboard Supplemental Battery	

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

Estimated Total Weight (lb) 2448

Vehicle Dimensions for C.G. Calculations

Wheel Base:	98.5	in.	Front Track Width:	57.375	in.
Roof Height:	57.375	in.	Rear Track Width:	57.125	in.

Center of Gravity	**1100C MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)	2420 ± 55	2442	22.0
Longitudinal CG (in.)	39 ± 4	36.867	-2.133
Lateral CG (in.)	NA	-0.61	NA
Vertical CG (in.)	NA	22.292	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	797	767
Rear	442	442

FRONT	1564	lb
REAR	884	lb
TOTAL	2448	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	804	724
Rear	443	471

FRONT	1528	lb
REAR	914	lb
TOTAL	2442	lb

Figure B-3. Vehicle Mass Distribution, Test No. MNCBR-3

Appendix C. Vehicle Deformation Records

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

Model Year: 2013

Test Name: MNCBR-1
Make: International

VIN: 1HTMMAAM7DH105190
Model: Durastar 4300 SBA 4x2

VEHICLE DEFORMATION
FLOOR PAN - SET 1

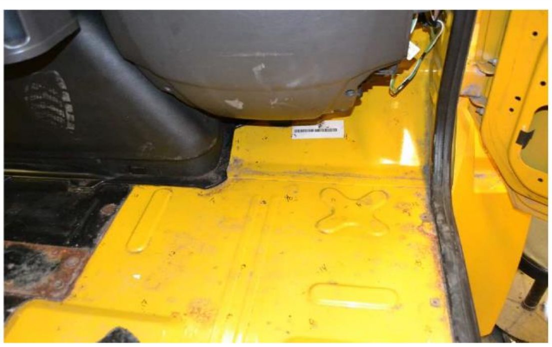
	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	45.3773	22.7163	1.5856	44.9116	23.4973	1.8776	0.4657	-0.7810	-0.2920	0.9550	0.4657	X
	2	45.7548	25.3638	1.4524	45.3522	26.0994	1.8770	0.4026	-0.7356	-0.4246	0.9399	0.4026	X
	3	46.0788	28.0969	1.3148	45.7067	28.7276	1.3692	0.3721	-0.6307	-0.0544	0.7343	0.3721	X
	4	46.2555	33.0143	1.2006	45.4123	32.7961	-1.1784	0.8432	0.2182	2.3790	2.5334	2.5240	X, Z
	5	46.5288	37.9063	-0.1314	45.7760	37.9168	-1.9812	0.7528	-0.0105	1.8498	1.9971	1.9971	X, Z
	6	37.2702	14.7691	2.4503	37.0401	15.3884	2.4576	0.2301	-0.6193	-0.0073	0.6607	0.2301	X
	7	37.1153	22.0681	2.4309	36.7704	22.6878	2.2770	0.3449	-0.6197	0.1539	0.7257	0.3777	X, Z
	8	37.1334	26.5479	2.4968	36.6613	27.0843	1.8242	0.4721	-0.5364	0.6726	0.9813	0.8217	X, Z
	9	37.8188	32.4162	2.4986	36.9737	31.4865	-1.8225	0.8451	0.9297	4.3211	4.5000	4.4030	X, Z
	10	37.5818	38.9384	2.4628	36.2617	37.9743	-2.4670	1.3201	0.9641	4.9298	5.1938	5.1035	X, Z
FLOOR PAN (Z)	11	30.8657	14.4853	2.4803	30.6129	15.0102	2.4484	0.2528	-0.5249	0.0319	0.5835	0.0319	Z
	12	30.2719	20.4875	2.5402	29.9209	21.0089	2.0929	0.3510	-0.5214	0.4473	0.7715	0.4473	Z
	13	29.6180	26.2601	2.5182	29.1949	26.7618	2.0558	0.4231	-0.5017	0.4624	0.8028	0.4624	Z
	14	29.9033	31.8148	2.5114	29.1112	30.8777	-0.9361	0.7921	0.9371	3.4475	3.6593	3.4475	Z
	15	30.7756	39.0982	2.4151	29.6670	37.9395	-2.7544	1.1086	1.1587	5.1695	5.4125	5.1695	Z
	16	25.4710	14.4625	2.4426	25.2552	14.9475	2.3496	0.2158	-0.4850	0.0930	0.5389	0.0930	Z
	17	25.3494	20.2029	2.4396	25.0960	20.6774	2.2264	0.2534	-0.4745	0.2132	0.5786	0.2132	Z
	18	25.1065	26.1782	2.5060	24.7243	26.4399	1.5256	0.3822	-0.2617	0.9804	1.0843	0.9804	Z
	19	25.0364	31.7371	2.4149	24.5327	31.2747	0.1259	0.5037	0.4624	2.2890	2.3889	2.2890	Z
	20	25.1953	39.0610	2.3636	24.4819	38.2501	-0.4719	0.7134	0.8109	2.8355	3.0342	2.8355	Z
	21	20.4677	14.0926	1.8780	20.2080	14.5586	1.7495	0.2597	-0.4660	0.1285	0.5487	0.1285	Z
	22	20.4135	19.5750	1.9397	20.1722	19.9791	1.5744	0.2413	-0.4041	0.3653	0.5958	0.3653	Z
	23	20.4419	26.1515	2.4659	20.0205	26.3054	1.5824	0.4214	-0.1539	0.8835	0.9909	0.8835	Z
	24	20.3995	31.6733	1.8480	19.8649	31.5012	0.4309	0.5346	0.1721	1.4171	1.5243	1.4171	Z
	25	20.2059	39.0033	2.3549	19.7635	38.6056	1.2478	0.4424	0.3977	1.1071	1.2568	1.1071	Z
	26	14.9978	13.8292	1.8667	14.7318	14.2632	1.6927	0.2660	-0.4340	0.1740	0.5379	0.1740	Z
	27	14.7644	19.6311	2.4166	14.4309	20.0413	2.1427	0.3335	-0.4102	0.2739	0.5954	0.2739	Z
	28	14.5492	26.1734	2.4474	14.1952	26.4536	2.1928	0.3540	-0.2802	0.2546	0.5183	0.2546	Z
	29	14.4994	31.7299	2.3907	14.1706	31.8659	1.4138	0.3288	-0.1360	0.9769	1.0397	0.9769	Z
	30	14.1383	39.1785	2.3339	13.8572	39.1529	1.9596	0.2811	0.0256	0.3743	0.4688	0.3743	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 C-1. Floor Pan Deformation Data – Set 1, Test No. MNCBR-1

Model Year: 2013 | Test Name: MNCBR-1 | VIN: 1HTMMAAM7DH105190
Make: International | Model: Durastar 4300 SBA 4x2

VEHICLE DEFORMATION
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	45.1532	-1.5484	-0.9212	44.9319	-1.5903	-0.8439	0.2213	-0.0419	-0.0773	0.2381	0.2213	X
	2	45.5411	1.0963	-1.0785	45.4027	1.0049	-0.9366	0.1384	0.0914	-0.1419	0.2183	0.1384	X
	3	45.8759	3.8268	-1.2403	45.7781	3.6109	-1.5354	0.0978	0.2159	0.2951	0.3785	0.3109	X, Z
	4	46.0733	8.7423	-1.3942	45.4831	7.5990	-4.2070	0.5902	1.1433	2.8128	3.0931	2.8741	X, Z
	5	46.3554	13.6227	-2.7664	45.8912	12.6865	-5.1811	0.4642	0.9362	2.4147	2.6311	2.4589	X, Z
	6	37.0196	-9.4522	0.0821	36.9789	-9.5794	0.1429	0.0407	-0.1272	-0.0608	0.1467	0.0407	X
	7	36.8969	-2.1528	0.0077	36.7909	-2.2868	-0.2679	0.1060	-0.1340	0.2756	0.3243	0.2953	X, Z
	8	36.9355	2.3272	0.0389	36.7244	2.0940	-0.8602	0.2111	0.2332	0.8991	0.9525	0.9235	X, Z
	9	37.6468	8.1922	-0.0112	37.0192	6.3730	-4.6521	0.6276	1.8192	4.6409	5.0241	4.6831	X, Z
	10	37.4383	14.7150	-0.0951	36.3707	12.8450	-5.4922	1.0676	1.8700	5.3971	5.8108	5.5017	X, Z
FLOOR PAN (Z)	11	30.6146	-9.7069	0.1753	30.5487	-9.8789	0.2649	0.0659	-0.1720	-0.0896	0.2048	-0.0896	Z
	12	30.0479	-3.7017	0.1945	29.9200	-3.8866	-0.2710	0.1279	-0.1849	0.4655	0.5169	0.4655	Z
	13	29.4193	2.0734	0.1341	29.2605	1.8706	-0.4802	0.1588	0.2028	0.6143	0.6661	0.6143	Z
	14	29.7292	7.6265	0.0817	29.1682	5.8893	-3.6012	0.5610	1.7372	3.6829	4.1105	3.6829	Z
	15	30.6328	14.9050	-0.0792	29.7718	12.8818	-5.6562	0.8610	2.0232	5.5770	5.9948	5.5770	Z
	16	25.2196	-9.7057	0.1892	25.1896	-9.8791	0.2674	0.0300	-0.1734	-0.0782	0.1926	-0.0782	Z
	17	25.1234	-3.9650	0.1430	25.0949	-4.1546	-0.0376	0.0285	-0.1896	0.1806	0.2634	0.1806	Z
	18	24.9077	2.0117	0.1656	24.7772	1.5866	-0.9168	0.1305	0.4251	1.0824	1.1702	1.0824	Z
	19	24.8613	7.5700	0.0322	24.6156	6.3761	-2.4680	0.2457	1.1939	2.5002	2.7815	2.5002	Z
	20	25.0522	14.8925	-0.0773	24.6348	13.3289	-3.2893	0.4174	1.5636	3.2120	3.5967	3.2120	Z
	21	20.2096	-10.0574	-0.3248	20.1278	-10.2251	-0.2263	0.0818	-0.1677	-0.0985	0.2110	-0.0985	Z
	22	20.1803	-4.5745	-0.3049	20.1518	-4.8131	-0.5754	0.0285	-0.2386	0.2705	0.3618	0.2705	Z
	23	20.2428	2.0057	0.1701	20.0741	1.5117	-0.7687	0.1687	0.4940	0.9388	1.0742	0.9388	Z
	24	20.2189	7.5227	-0.4900	19.9573	6.6694	-2.0840	0.2616	0.8533	1.5940	1.8269	1.5940	Z
	25	20.0627	14.8572	-0.0379	19.9542	13.7971	-1.4949	0.1085	1.0601	1.4570	1.8051	1.4570	Z
	26	14.7388	-10.2963	-0.2820	14.6485	-10.4551	-0.1721	0.0903	-0.1588	-0.1099	0.2132	-0.1099	Z
	27	14.5363	-4.4893	0.2253	14.4235	-4.6624	0.0967	0.1128	-0.1731	0.1286	0.2434	0.1286	Z
	28	14.3504	2.0540	0.2077	14.2635	1.7507	-0.0556	0.0869	0.3033	0.2633	0.4109	0.2633	Z
	29	14.3247	7.6100	0.1085	14.2873	7.1352	-1.0081	0.0374	0.4748	1.1166	1.2139	1.1166	Z
	30	13.9960	15.0595	-0.0024	14.0691	14.4393	-0.6919	-0.0731	0.6202	0.6895	0.9303	0.6895	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 C-2. Floor Pan Deformation Data – Set 2, Test No. MNCBR-1

Model Year: 2013 | Test Name: MNCBR-1 | VIN: 1HTMMAAM7DH105190
Make: International | Model: Durastar 4300 SBA 4x2

VEHICLE DEFORMATION
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	40.8163	4.7562	-29.6452	41.5513	4.2320	-28.9944	-0.7350	0.5242	0.6508	1.1129	1.1129	X, Y, Z
	2	40.2042	20.2526	-28.8919	41.0925	19.7820	-28.1591	-0.8883	0.4706	0.7328	1.2440	1.2440	X, Y, Z
	3	40.6330	35.8507	-28.2587	41.6701	35.3461	-27.5366	-1.0371	0.5046	0.7221	1.3607	1.3607	X, Y, Z
	4	37.4469	4.5573	-17.6939	37.9510	4.1724	-17.1325	-0.5041	0.3849	0.5614	0.8470	0.8470	X, Y, Z
	5	36.8129	21.1665	-18.6266	37.2620	20.7330	-18.0588	-0.4491	0.4335	0.5678	0.8438	0.8438	X, Y, Z
	6	37.3599	35.9356	-18.6069	38.2152	35.5039	-17.8535	-0.8553	0.4317	0.7534	1.2188	1.2188	X, Y, Z
SIDE PANEL (Y)	7	46.3166	41.0728	-8.8266	46.9524	40.4955	-8.0505	-0.6358	0.5773	0.7761	1.1575	0.5773	Y
	8	44.3118	41.0333	-8.6149	44.9764	40.4649	-7.8503	-0.6646	0.5684	0.7646	1.1616	0.5684	Y
	9	44.8740	41.0407	-6.0275	45.4532	40.2973	-5.2566	-0.5792	0.7434	0.7709	1.2175	0.7434	Y
IMPACT SIDE DOOR (Y)	10	35.5780	42.1179	-22.0413	36.4067	41.7730	-21.3076	-0.8287	0.3449	0.7337	1.1593	0.3449	Y
	11	21.0728	41.0649	-23.1598	22.0170	40.9535	-22.7196	-0.9442	0.1114	0.4402	1.0477	0.1114	Y
	12	10.1096	41.0466	-23.4906	11.0340	41.0629	-23.2167	-0.9244	-0.0163	0.2739	0.9643	-0.0163	Y
	13	36.3909	41.1242	-0.8497	36.9172	40.5892	-0.2108	-0.5263	0.5350	0.6389	0.9856	0.5350	Y
	14	23.9826	41.0836	-0.5021	24.5013	40.6829	-0.0083	-0.5187	0.4007	0.4938	0.8206	0.4007	Y
	15	11.5742	40.4132	-1.6080	12.0960	40.1810	-1.4045	-0.5218	0.2322	0.2035	0.6063	0.2322	Y
ROOF - (Z)	16	39.7173	4.8139	-51.7581	40.7447	4.4577	-51.0981	-1.0274	0.3562	0.6600	1.2720	0.6600	Z
	17	39.5238	11.5617	-51.6903	40.6995	11.2112	-50.9608	-1.1757	0.3505	0.7295	1.4273	0.7295	Z
	18	38.9594	17.7563	-51.6710	40.1413	17.4465	-50.9671	-1.1819	0.3098	0.7039	1.4101	0.7039	Z
	19	37.9309	25.5403	-51.5249	39.2499	25.2126	-50.8056	-1.3190	0.3277	0.7193	1.5377	0.7193	Z
	20	36.9317	30.8830	-51.3303	38.2601	30.5223	-50.6429	-1.3284	0.3607	0.6874	1.5386	0.6874	Z
	21	35.6104	4.9428	-54.1590	36.6435	4.6421	-53.5965	-1.0331	0.3007	0.5625	1.2141	0.5625	Z
	22	35.0429	11.1666	-54.3886	36.1727	10.7636	-53.8121	-1.1298	0.4030	0.5765	1.3309	0.5765	Z
	23	34.2891	17.6245	-54.4266	35.4822	17.3084	-53.8514	-1.1931	0.3161	0.5752	1.3617	0.5752	Z
	24	33.2887	24.4764	-54.1178	34.5656	24.1306	-53.5246	-1.2769	0.3458	0.5932	1.4498	0.5932	Z
	25	32.0377	30.1195	-54.0485	33.3472	29.8004	-53.5076	-1.3095	0.3191	0.5409	1.4523	0.5409	Z
	26	27.9474	4.5640	-55.7076	29.0958	4.3747	-55.2275	-1.1484	0.1893	0.4801	1.2590	0.4801	Z
	27	26.2750	10.8574	-54.6945	27.4222	10.6336	-54.2235	-1.1472	0.2238	0.4710	1.2602	0.4710	Z
	28	26.3541	16.6925	-55.8935	27.6373	16.4384	-55.3974	-1.2832	0.2541	0.4961	1.3990	0.4961	Z
	29	25.5198	23.8700	-55.6392	26.7638	23.6582	-55.1539	-1.2440	0.2118	0.4853	1.3520	0.4853	Z
	30	25.1425	30.3174	-54.7529	26.5491	30.0503	-54.2046	-1.4066	0.2671	0.5483	1.5331	0.5483	Z
A-PILLAR Maximum (X, Y, Z)	31	43.1109	40.3533	-28.9439	44.2611	39.8772	-28.0845	-1.1502	0.4761	0.8594	1.5127	0.9825	Y, Z
	32	41.5897	40.3256	-32.7931	42.7796	39.8534	-31.9449	-1.1899	0.4722	0.8482	1.5357	0.9708	Y, Z
	33	40.3439	40.1353	-35.7254	41.5173	39.6863	-35.0232	-1.1734	0.4490	0.7022	1.4393	0.8335	Y, Z
	34	38.8186	39.7812	-39.1281	40.0779	39.4187	-38.4223	-1.2593	0.3625	0.7058	1.4884	0.7934	Y, Z
	35	37.0198	39.4323	-43.1417	38.3174	39.0672	-42.4319	-1.2976	0.3651	0.7098	1.5234	0.7982	Y, Z
	36	35.2744	38.9226	-46.8289	36.5920	38.5749	-46.1677	-1.3176	0.3477	0.6612	1.5146	0.7470	Y, Z
A-PILLAR Lateral (Y)	31	43.1109	40.3533	-28.9439	44.2611	39.8772	-28.0845	-1.1502	0.4761	0.8594	1.5127	0.4761	Y
	32	41.5897	40.3256	-32.7931	42.7796	39.8534	-31.9449	-1.1899	0.4722	0.8482	1.5357	0.4722	Y
	33	40.3439	40.1353	-35.7254	41.5173	39.6863	-35.0232	-1.1734	0.4490	0.7022	1.4393	0.4490	Y
	34	38.8186	39.7812	-39.1281	40.0779	39.4187	-38.4223	-1.2593	0.3625	0.7058	1.4884	0.3625	Y
	35	37.0198	39.4323	-43.1417	38.3174	39.0672	-42.4319	-1.2976	0.3651	0.7098	1.5234	0.3651	Y
	36	35.2744	38.9226	-46.8289	36.5920	38.5749	-46.1677	-1.3176	0.3477	0.6612	1.5146	0.3477	Y
B-PILLAR Maximum (X, Y, Z)	37	4.5827	39.2625	-47.7652	5.9180	39.2440	-47.3874	-1.3353	0.0185	0.3778	1.3878	0.3783	Y, Z
	38	-1.3289	39.6606	-41.4639	-0.0876	39.6376	-41.1879	-1.2413	0.0230	0.2760	1.2718	0.2770	Y, Z
	39	4.2486	40.3807	-35.5437	5.3578	40.3299	-35.2048	-1.1092	0.0508	0.3389	1.1609	0.3427	Y, Z
	40	-1.0188	40.6182	-31.7011	-0.0088	40.5620	-31.4786	-1.0100	0.0562	0.2225	1.0357	0.2295	Y, Z
B-PILLAR Lateral (Y)	37	4.5827	39.2625	-47.7652	5.9180	39.2440	-47.3874	-1.3353	0.0185	0.3778	1.3878	0.0185	Y
	38	-1.3289	39.6606	-41.4639	-0.0876	39.6376	-41.1879	-1.2413	0.0230	0.2760	1.2718	0.0230	Y
	39	4.2486	40.3807	-35.5437	5.3578	40.3299	-35.2048	-1.1092	0.0508	0.3389	1.1609	0.0508	Y
	40	-1.0188	40.6182	-31.7011	-0.0088	40.5620	-31.4786	-1.0100	0.0562	0.2225	1.0357	0.0562	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 C-3. Occupant Compartment Deformation Data – Set 1, Test No. MNCBR-1

Model Year: 2013 | Test Name: MNCBR-1 | VIN: 1HTMMAAM7DH105190
Make: International | Model: Durastar 4300 SBA 4x2

VEHICLE DEFORMATION
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	40.2186	-19.9373	-31.9520	40.5189	-20.9205	-31.2357	-0.3003	-0.9832	0.7163	1.2530	1.2530	X, Y, Z
	2	39.6715	-4.4334	-31.3108	39.9576	-5.3537	-30.9693	-0.2861	-0.9203	0.3415	1.0225	1.0225	X, Y, Z
	3	40.1644	11.1673	-30.8006	40.4270	10.2264	-30.9418	-0.2626	0.9409	-0.1412	0.9870	0.9870	X, Y, Z
	4	36.9640	-20.0328	-19.9676	37.2135	-20.5611	-19.2935	-0.2495	-0.5283	0.6741	0.8921	0.8921	X, Y, Z
	5	36.3829	-3.4289	-21.0206	36.3705	-4.0520	-20.8188	0.0124	-0.6231	0.2018	0.6551	0.6551	X, Y, Z
	6	36.9850	11.3378	-21.1186	37.2114	10.7225	-21.1879	-0.2264	0.6153	-0.0693	0.6593	0.6593	X, Y, Z
SIDE PANEL (Y)	7	46.0547	16.5149	-11.4644	46.1484	16.1388	-11.7992	-0.0937	0.3761	-0.3348	0.5122	0.3761	Y
	8	44.0520	16.4846	-11.2331	44.1783	16.1019	-11.5487	-0.1263	0.3827	-0.3156	0.5119	0.3827	Y
	9	44.6391	16.5095	-8.6514	44.7203	16.0349	-8.9633	-0.0812	0.4746	-0.3119	0.5737	0.4746	Y
IMPACT SIDE DOOR (Y)	10	35.1930	17.5006	-24.5827	35.2684	16.8451	-24.8269	-0.0754	0.6555	-0.2442	0.7036	0.6555	Y
	11	20.6739	16.4942	-25.5536	20.8552	15.8726	-25.8472	-0.1813	0.6216	-0.2936	0.7110	0.6216	Y
	12	9.7081	16.5150	-25.7786	9.8627	15.8864	-26.0733	-0.1546	0.6286	-0.2947	0.7113	0.6286	Y
	13	36.2068	16.6645	-3.3929	36.3097	16.4557	-3.7200	-0.1029	0.2088	-0.3271	0.4015	0.2088	Y
	14	23.8024	16.6736	-2.9257	23.9022	16.4701	-3.2109	-0.0998	0.2035	-0.2852	0.3643	0.2035	Y
	15	11.3814	16.0420	-3.9070	11.4706	15.8295	-4.2768	-0.0892	0.2125	-0.3698	0.4357	0.2125	Y
ROOF - (Z)	16	38.9064	-20.0430	-54.0531	39.1643	-21.5284	-53.3054	-0.2579	-1.4854	0.7477	1.6828	0.7477	Z
	17	38.7387	-13.2942	-54.0348	39.0690	-14.7750	-53.4187	-0.3303	-1.4808	0.6161	1.6375	0.6161	Z
	18	38.1976	-7.0975	-54.0572	38.4614	-8.5483	-53.6434	-0.2638	-1.4508	0.4138	1.5315	0.4138	Z
	19	37.1995	0.6912	-53.9605	37.5128	-0.7880	-53.7492	-0.3133	1.4792	0.2113	1.5267	0.2113	Z
	20	36.2221	6.0390	-53.7970	36.4853	4.5170	-53.7598	-0.2632	1.5220	0.0372	1.5450	0.0372	Z
	21	34.7770	-19.9167	-56.4152	35.0013	-21.4663	-55.7057	-0.2243	-1.5496	0.7095	1.7190	0.7095	Z
	22	34.2305	-13.6927	-56.6867	34.4768	-15.3606	-56.1374	-0.2463	-1.6679	0.5493	1.7732	0.5493	Z
	23	33.5004	-7.2325	-56.7666	33.7337	-8.8269	-56.4032	-0.2333	-1.5944	0.3634	1.6518	0.3634	Z
	24	32.5286	-0.3747	-56.5004	32.7714	-2.0038	-56.3081	-0.2428	-1.6291	0.1923	1.6583	0.1923	Z
	25	31.2993	5.2734	-56.4621	31.5089	3.6540	-56.4719	-0.2096	1.6194	-0.0098	1.6329	-0.0098	Z
	26	27.0981	-20.2781	-57.8871	27.4180	-21.8474	-57.1364	-0.3199	-1.5693	0.7507	1.7688	0.7507	Z
	27	25.4589	-13.9709	-56.9059	25.7202	-15.5672	-56.3248	-0.2613	-1.5963	0.5811	1.7188	0.5811	Z
	28	25.5483	-8.1455	-58.1500	25.8601	-9.8091	-57.7192	-0.3118	-1.6636	0.4308	1.7465	0.4308	Z
	29	24.7432	-0.9631	-57.9424	24.9357	-2.5915	-57.7231	-0.1925	-1.6284	0.2193	1.6543	0.2193	Z
	30	24.3984	5.4922	-57.1015	24.6938	3.8300	-57.0075	-0.2954	1.6622	0.0940	1.6909	0.0940	Z
A-PILLAR Maximum (X, Y, Z)	31	42.6524	15.6552	-31.5439	42.9677	14.7519	-31.7227	-0.3153	0.9033	-0.1788	0.9733	0.9033	Y
	32	41.0940	15.6041	-35.3779	41.3915	14.5731	-35.5413	-0.2975	1.0310	-0.1634	1.0854	1.0310	Y
	33	39.8192	15.3962	-38.2966	40.0548	14.2821	-38.5787	-0.2356	1.1141	-0.2821	1.1732	1.1141	Y
	34	38.2599	15.0222	-41.6816	38.5340	13.8773	-41.9284	-0.2741	1.1449	-0.2468	1.2028	1.1449	Y
	35	36.4211	14.6497	-45.6750	36.6777	13.3636	-45.8768	-0.2566	1.2861	-0.2018	1.3269	1.2861	Y
	36	34.6383	14.1187	-49.3412	34.8644	12.7197	-49.5475	-0.2261	1.3990	-0.2063	1.4321	1.3990	Y
A-PILLAR Lateral (Y)	31	42.6524	15.6552	-31.5439	42.9677	14.7519	-31.7227	-0.3153	0.9033	-0.1788	0.9733	0.9033	Y
	32	41.0940	15.6041	-35.3779	41.3915	14.5731	-35.5413	-0.2975	1.0310	-0.1634	1.0854	1.0310	Y
	33	39.8192	15.3962	-38.2966	40.0548	14.2821	-38.5787	-0.2356	1.1141	-0.2821	1.1732	1.1141	Y
	34	38.2599	15.0222	-41.6816	38.5340	13.8773	-41.9284	-0.2741	1.1449	-0.2468	1.2028	1.1449	Y
	35	36.4211	14.6497	-45.6750	36.6777	13.3636	-45.8768	-0.2566	1.2861	-0.2018	1.3269	1.2861	Y
	36	34.6383	14.1187	-49.3412	34.8644	12.7197	-49.5475	-0.2261	1.3990	-0.2063	1.4321	1.3990	Y
B-PILLAR Maximum (X, Y, Z)	37	3.9405	14.5680	-49.9847	4.1654	13.1279	-50.0240	-0.2249	1.4401	-0.0393	1.4581	1.4401	Y
	38	-1.9085	15.0363	-43.6299	-1.6881	13.7114	-43.6953	-0.2204	1.3249	-0.0654	1.3447	1.3249	Y
	39	3.7285	15.7801	-37.7694	3.8978	14.6653	-37.8802	-0.1693	1.1148	-0.1108	1.1330	1.1148	Y
	40	-1.5007	16.0666	-33.8782	-1.3766	14.9992	-34.0322	-0.1241	1.0674	-0.1540	1.0856	1.0674	Y
B-PILLAR Lateral (Y)	37	3.9405	14.5680	-49.9847	4.1654	13.1279	-50.0240	-0.2249	1.4401	-0.0393	1.4581	1.4401	Y
	38	-1.9085	15.0363	-43.6299	-1.6881	13.7114	-43.6953	-0.2204	1.3249	-0.0654	1.3447	1.3249	Y
	39	3.7285	15.7801	-37.7694	3.8978	14.6653	-37.8802	-0.1693	1.1148	-0.1108	1.1330	1.1148	Y
	40	-1.5007	16.0666	-33.8782	-1.3766	14.9992	-34.0322	-0.1241	1.0674	-0.1540	1.0856	1.0674	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 C-4. Occupant Compartment Deformation Data – Set 2, Test No. MNCBR-1

Model Year: 2013	Test Name: MNCBR-1	VIN: 1HTMMAAM7DH105190
	Make: International	Model: Durastar 4300 SBA 4x2

Reference Set 1			
Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Roof	0.7	≤ 4	Z
Windshield[D]	0.0	≤ 3	X, Z
A-Pillar Maximum	1.0	≤ 5	Y, Z
A-Pillar Lateral	0.5	≤ 3	Y
B-Pillar Maximum	0.4	≤ 5	Y, Z
B-Pillar Lateral	0.1	≤ 3	Y
Toe Pan - Wheel Well	5.1	≤ 9	X, Z
Side Front Panel	0.7	≤ 12	Y
Side Door (above seat)	0.3	≤ 9	Y
Side Door (below seat)	0.5	≤ 12	Y
Floor Pan	5.2	≤ 12	Z
Dash - no MASH requirement	1.4	NA	X, Y, Z

Reference Set 2			
Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Roof	0.8	≤ 4	Z
Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	1.4	≤ 5	Y
A-Pillar Lateral	1.4	≤ 3	Y
B-Pillar Maximum	1.4	≤ 5	Y
B-Pillar Lateral	1.4	≤ 3	Y
Toe Pan - Wheel Well	5.5	≤ 9	X, Z
Side Front Panel	0.5	≤ 12	Y
Side Door (above seat)	0.7	≤ 9	Y
Side Door (below seat)	0.2	≤ 12	Y
Floor Pan	5.6	≤ 12	Z
Dash - no MASH requirement	1.4	NA	X, Y, Z

[A] Items highlighted in red do not meet MASH allowable deformations.
[B] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.
[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment. If direction of deformation is "NA" then no intrusion is recorded and deformation will be 0.
[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle interior crush:

Figure C-5. Maximum Occupant Compartment Deformations by Location, Test No. MNCBR-1

Model Year: 2014 | Test Name: MNCBR-2 | VIN: 1C6RR6FT2ES278435
Make: Dodge | Model: Ram 1500

VEHICLE DEFORMATION
PASSENGER 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	52.1773	13.7646	-4.5310	51.9404	13.8186	-4.4275	0.2369	-0.0540	-0.1035	0.2641	0.2369	X
	2	52.9073	18.2150	-2.4018	52.5653	18.0372	-1.9417	0.3420	0.1778	-0.4601	0.6002	0.3420	X
	3	54.2706	21.9100	1.0319	53.9472	21.4364	1.7808	0.3234	0.4736	-0.7489	0.9433	0.3234	X
	4	54.5203	27.4797	1.8887	52.5358	25.1568	1.6928	1.9845	2.3229	0.1959	3.0615	1.9941	X, Z
	5	54.2390	34.5082	1.8008	50.9416	29.7399	-0.1778	3.2974	4.7683	1.9786	6.1257	3.8455	X, Z
	6	49.0155	12.7330	-3.1789	48.6994	12.9284	-3.3788	0.3161	-0.1954	0.1999	0.4220	0.3740	X, Z
	7	49.8575	17.8431	-0.4917	49.5469	17.5115	-0.0782	0.3106	0.3316	-0.4135	0.6143	0.3106	X
	8	51.2601	21.9570	3.1923	50.9377	21.2205	3.9698	0.3224	0.7365	-0.7775	1.1184	0.3224	X
	9	51.3843	27.8628	3.6635	50.8386	26.4335	4.6320	0.5457	1.4293	-0.9685	1.8107	0.5457	X
	10	51.0839	34.4333	3.9547	49.1803	30.1552	3.7289	1.9036	4.2781	0.2258	4.6879	1.9169	X, Z
FLOOR PAN (Z)	11	45.2096	12.0235	-1.9716	45.1544	11.8390	-2.0483	0.0552	0.1845	0.0767	0.2073	0.0767	Z
	12	46.6351	17.1764	1.9545	46.4046	16.5085	2.3344	0.2305	0.6679	-0.3799	0.8022	-0.3799	Z
	13	47.4182	22.0629	5.0603	47.0717	21.3109	5.7427	0.3465	0.7520	-0.6824	1.0730	-0.6824	Z
	14	47.7087	28.1150	5.0730	47.6397	27.3312	6.5814	0.0690	0.7838	-1.5084	1.7013	-1.5084	Z
	15	47.8079	33.6835	5.1701	46.8218	31.0404	5.0921	0.9861	2.6431	0.0780	2.8221	0.0780	Z
	16	41.7545	12.1052	-1.3069	41.6871	12.0531	-1.3180	0.0674	0.0521	0.0111	0.0859	0.0111	Z
	17	43.2427	16.5419	4.9795	42.9959	16.0008	5.2258	0.2468	0.5411	-0.2463	0.6437	-0.2463	Z
	18	43.8743	21.9455	5.1095	43.6798	21.3165	6.0089	0.1945	0.6290	-0.8994	1.1146	-0.8994	Z
	19	43.9326	28.1358	5.1019	43.8252	27.4788	7.0468	0.1074	0.6570	-1.9449	2.0557	-1.9449	Z
	20	44.1431	33.6381	5.1972	43.4780	31.5929	6.2026	0.6651	2.0452	-1.0054	2.3740	-1.0054	Z
	21	36.3943	11.8485	-0.8747	36.3134	11.8983	-0.9230	0.0809	-0.0498	0.0483	0.1066	0.0483	Z
	22	37.9499	16.1266	5.2027	37.7139	15.6690	5.3213	0.2360	0.4576	-0.1186	0.5284	-0.1186	Z
	23	38.2901	21.9529	5.2329	38.1294	21.4397	5.8260	0.1607	0.5132	-0.5931	0.8006	-0.5931	Z
	24	38.3424	28.5864	5.2191	38.3917	27.9556	6.9176	-0.0493	0.6308	-1.6985	1.8125	-1.6985	Z
	25	38.1664	33.9425	5.2252	37.8954	32.9436	7.1978	0.2710	0.9989	-1.9726	2.2276	-1.9726	Z
	26	33.0720	11.9619	-0.4713	32.9820	12.0200	-0.5599	0.0900	-0.0581	0.0886	0.1390	0.0886	Z
	27	32.7877	15.6129	4.4946	32.5992	15.2392	4.5009	0.1885	0.3737	-0.0063	0.4186	-0.0063	Z
	28	32.7582	21.6652	4.4742	32.6813	21.3077	4.9193	0.0769	0.3575	-0.4451	0.5761	-0.4451	Z
	29	32.8645	29.2295	4.4689	32.8465	28.8144	5.5539	0.0180	0.4151	-1.0850	1.1618	-1.0850	Z
	30	32.5406	33.7921	4.2299	32.6511	33.4088	6.0508	-0.1105	0.3833	-1.8209	1.8641	-1.8209	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 C-6. Floor Pan Deformation Data – Set 1, Test No. MNCBR-2

Model Year: 2014 | Test Name: MNCBR-2 | Make: Dodge | VIN: 1C6RR6FT2ES278435 | Model: Ram 1500

VEHICLE DEFORMATION
PASSENGER 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	53.6649	33.7952	-8.2509	53.6049	33.7817	-8.6399	0.0600	0.0135	0.3890	0.3938	0.3936	X, Z
	2	54.3499	38.2552	-6.1268	54.1974	38.0394	-6.2134	0.1525	0.2158	0.0866	0.2781	0.1754	X, Z
	3	55.6630	41.9668	-2.6915	55.5497	41.5004	-2.5372	0.1133	0.4664	-0.1543	0.5042	0.1133	X
	4	55.8702	47.5400	-1.8460	54.1144	45.2098	-2.6811	1.7558	2.3302	0.8351	3.0348	1.9443	X, Z
	5	55.5440	54.5664	-1.9527	52.4944	49.7553	-4.6201	3.0496	4.8111	2.6674	6.2898	4.0516	X, Z
	6	50.4996	32.7463	-6.9205	50.3676	32.8856	-7.5848	0.1320	-0.1393	0.6643	0.6915	0.6773	X, Z
	7	51.2881	37.8679	-4.2391	51.1788	37.5207	-4.3484	0.1093	0.3472	0.1093	0.3801	0.1546	X, Z
	8	52.6359	41.9993	-0.5542	52.5373	41.2962	-0.3512	0.0986	0.7031	-0.2030	0.7384	0.0986	X
	9	52.7183	47.9069	-0.0960	52.4031	46.5173	0.2363	0.3152	1.3896	-0.3323	1.4631	0.3152	X
	10	52.3732	54.4760	0.1773	50.7226	50.2149	-0.7232	1.6506	4.2611	0.9005	4.6575	1.8803	X, Z
FLOOR PAN (Z)	11	46.6893	32.0149	-5.7405	46.8271	31.7922	-6.2457	-0.1378	0.2227	0.5052	0.5690	0.5052	Z
	12	48.0515	37.1860	-1.8158	48.0381	36.5319	-1.9278	0.0134	0.6541	0.1120	0.6638	0.1120	Z
	13	48.7793	42.0846	1.2843	48.6672	41.3867	1.4128	0.1121	0.6979	-0.1285	0.7184	-0.1285	Z
	14	49.0306	48.1385	1.2849	49.1945	47.4219	2.1664	-0.1639	0.7166	-0.8815	1.1478	-0.8815	Z
	15	49.0930	53.7077	1.3696	48.3555	51.1041	0.6227	0.7375	2.6036	0.7469	2.8072	0.7469	Z
	16	43.2287	32.0757	-5.1022	43.3570	31.9942	-5.5253	-0.1283	0.0815	0.4231	0.4496	0.4231	Z
	17	44.6404	36.5365	1.1847	44.6269	36.0433	0.9640	0.0135	0.4932	0.2207	0.5405	0.2207	Z
	18	45.2359	41.9443	1.3068	45.2748	41.3740	1.6723	-0.0389	0.5703	-0.3655	0.6785	-0.3655	Z
	19	45.2542	48.1349	1.2850	45.3782	47.5514	2.6223	-0.1240	0.5835	-1.3373	1.4643	-1.3373	Z
	20	45.4284	53.6387	1.3689	45.0060	51.6507	1.7187	0.4224	1.9880	-0.3498	2.0623	-0.3498	Z
	21	37.8672	31.7852	-4.7102	37.9836	31.8100	-5.1384	-0.1164	-0.0248	0.4282	0.4444	0.4282	Z
	22	39.3487	36.0874	1.3687	39.3470	35.6786	1.0539	0.0017	0.4088	0.3148	0.5160	0.3148	Z
	23	39.6510	41.9159	1.3877	39.7241	41.4585	1.4769	-0.0731	0.4574	-0.0892	0.4717	-0.0892	Z
	24	39.6606	48.5495	1.3586	39.9420	47.9909	2.4758	-0.2814	0.5586	-1.1172	1.2804	-1.1172	Z
	25	39.4498	53.9043	1.3508	39.4128	52.9790	2.6837	0.0370	0.9253	-1.3329	1.6230	-1.3329	Z
	26	34.5413	31.8780	-4.3323	34.6508	31.9153	-4.7835	-0.1095	-0.0373	0.4512	0.4658	0.4512	Z
	27	34.1955	35.5386	0.6226	34.2368	35.2039	0.2299	-0.0413	0.3347	0.3927	0.5176	0.3927	Z
	28	34.1270	41.5905	0.5877	34.2788	41.2781	0.5617	-0.1518	0.3124	0.0260	0.3483	0.0260	Z
	29	34.1844	49.1553	0.5654	34.3941	48.7941	1.0892	-0.2097	0.3612	-0.5238	0.6699	-0.5238	Z
	30	33.8329	53.7152	0.3131	34.1679	53.3937	1.5201	-0.3350	0.3215	-1.2070	1.2932	-1.2070	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 C-7. Floor Pan Deformation Data – Set 2, Test No. MNCBR-2

Model Year: 2014

Test Name: MNCBR-2
Make: Dodge

VIN: 1C6RR6FT2ES278435
Model: Ram 1500

VEHICLE DEFORMATION
PASSENGER 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	40.3868	4.3516	-26.7493	40.6251	4.1188	-26.9425	-0.2383	0.2328	-0.1932	0.3851	0.3851	X, Y, Z
	2	42.9359	17.6157	-25.9579	43.1139	17.3743	-26.3408	-0.1780	0.2414	-0.3829	0.4864	0.4864	X, Y, Z
	3	43.9984	32.4775	-25.9597	44.0197	32.2949	-26.5761	-0.0213	0.1826	-0.6164	0.6432	0.6432	X, Y, Z
	4	37.4926	4.0588	-14.5862	37.4209	3.9424	-14.8768	0.0717	0.1164	-0.2906	0.3212	0.3212	X, Y, Z
	5	39.4168	18.0963	-16.2979	39.3156	17.6365	-16.7983	0.1012	0.4598	-0.5004	0.6871	0.6871	X, Y, Z
	6	40.2157	32.5233	-16.5392	39.6498	32.0784	-17.4165	0.5659	0.4449	-0.8773	1.1348	1.1348	X, Y, Z
SIDE PANEL (Y)	7	49.1208	36.9021	0.2072	47.6138	31.7527	-0.4335	1.5070	5.1494	-0.6407	5.4035	5.1494	Y
	8	49.1010	36.9198	-3.9484	47.4154	31.6268	-4.7104	1.6856	5.2930	-0.7620	5.6069	5.2930	Y
	9	52.2469	36.8778	-2.4814	50.2409	31.0969	-3.3223	2.0060	5.7809	-0.8409	6.1766	5.7809	Y
IMPACT SIDE DOOR (Y)	10	38.0420	39.2446	-15.2157	37.0317	38.5501	-15.5685	1.0103	0.6945	-0.3528	1.2757	0.6945	Y
	11	27.8355	39.4462	-15.5492	26.9140	40.3809	-15.6879	0.9215	-0.9347	-0.1387	1.3199	-0.9347	Y
	12	17.5886	39.6879	-15.5914	16.7174	40.7953	-15.4684	0.8712	-1.1074	0.1230	1.4144	-1.1074	Y
	13	36.8431	39.4289	-2.6551	35.9308	37.5051	-3.0228	0.9123	1.9238	-0.3677	2.1607	1.9238	Y
	14	28.6010	40.0569	-2.2728	27.8513	39.1081	-2.3708	0.7497	0.9488	-0.0980	1.2132	0.9488	Y
	15	19.4514	39.2800	-3.0905	18.6640	39.4793	-3.0547	0.7874	-0.1993	0.0358	0.8130	-0.1993	Y
ROOF - (Z)	16	29.9957	3.5169	-45.4280	30.4191	3.6168	-45.3849	-0.4234	-0.0999	0.0431	0.4372	0.0431	Z
	17	29.6601	9.3410	-45.4536	29.9949	9.4650	-45.4288	-0.3348	-0.1240	0.0248	0.3579	0.0248	Z
	18	29.0031	14.4120	-45.4217	29.3471	14.5449	-45.3967	-0.3440	-0.1329	0.0250	0.3696	0.0250	Z
	19	27.7937	20.2135	-45.3091	28.1145	20.3980	-45.2829	-0.3208	-0.1845	0.0262	0.3710	0.0262	Z
	20	25.7173	26.1884	-45.1437	26.1407	26.3413	-45.1042	-0.4234	-0.1529	0.0395	0.4519	0.0395	Z
	21	23.9549	3.8249	-46.4084	24.3197	3.9888	-46.4362	-0.3648	-0.1639	-0.0278	0.4009	-0.0278	Z
	22	23.1913	9.3737	-46.3669	23.5399	9.5019	-46.3903	-0.3486	-0.1282	-0.0234	0.3722	-0.0234	Z
	23	23.6701	14.0782	-46.1928	24.0201	14.2368	-46.2032	-0.3500	-0.1586	-0.0104	0.3844	-0.0104	Z
	24	23.8915	20.0633	-45.8651	24.3142	20.2382	-45.8554	-0.4227	-0.1749	0.0097	0.4576	0.0097	Z
	25	22.5378	25.8136	-45.6309	22.8757	26.0280	-45.6121	-0.3379	-0.2144	0.0188	0.4006	0.0188	Z
	26	16.7851	4.3753	-46.9015	17.0897	4.4531	-46.9684	-0.3046	-0.0778	-0.0669	0.3214	-0.0669	Z
	27	15.6659	9.9320	-46.8946	16.0818	10.1054	-46.9348	-0.4159	-0.1734	-0.0402	0.4524	-0.0402	Z
	28	14.8446	15.6686	-46.7603	15.2883	15.8429	-46.7840	-0.4437	-0.1743	-0.0237	0.4773	-0.0237	Z
	29	15.1061	21.5659	-46.4429	15.4885	21.6983	-46.4683	-0.3824	-0.1324	-0.0254	0.4055	-0.0254	Z
	30	14.8619	26.0746	-46.1374	15.2845	26.1803	-46.1472	-0.4226	-0.1057	-0.0098	0.4357	-0.0098	Z
A-PILLAR Maximum (X, Y, Z)	31	50.0926	35.9301	-28.2867	50.3714	36.1955	-28.2172	-0.2788	-0.2654	0.0695	0.3911	0.0695	Z
	32	46.0575	35.0848	-31.6615	46.4812	35.2766	-31.7651	-0.4237	-0.1918	-0.1036	0.4765	0.0000	NA
	33	42.2284	34.2030	-34.2818	42.6756	34.3602	-34.3720	-0.4472	-0.1572	-0.0902	0.4825	0.0000	NA
	34	38.3966	33.3727	-36.9399	38.8215	33.5159	-36.9862	-0.4249	-0.1432	-0.0463	0.4508	0.0000	NA
	35	34.8170	32.6529	-39.4893	35.2178	32.7902	-39.5650	-0.4008	-0.1373	-0.0757	0.4304	0.0000	NA
	36	31.8966	31.8418	-41.1579	32.2759	31.9520	-41.2206	-0.3793	-0.1102	-0.0627	0.3999	0.0000	NA
A-PILLAR Lateral (Y)	31	50.0926	35.9301	-28.2867	50.3714	36.1955	-28.2172	-0.2788	-0.2654	0.0695	0.3911	-0.2654	Y
	32	46.0575	35.0848	-31.6615	46.4812	35.2766	-31.7651	-0.4237	-0.1918	-0.1036	0.4765	-0.1918	Y
	33	42.2284	34.2030	-34.2818	42.6756	34.3602	-34.3720	-0.4472	-0.1572	-0.0902	0.4825	-0.1572	Y
	34	38.3966	33.3727	-36.9399	38.8215	33.5159	-36.9862	-0.4249	-0.1432	-0.0463	0.4508	-0.1432	Y
	35	34.8170	32.6529	-39.4893	35.2178	32.7902	-39.5650	-0.4008	-0.1373	-0.0757	0.4304	-0.1373	Y
	36	31.8966	31.8418	-41.1579	32.2759	31.9520	-41.2206	-0.3793	-0.1102	-0.0627	0.3999	-0.1102	Y
B-PILLAR Maximum (X, Y, Z)	37	8.1518	31.6943	-41.2354	8.5103	31.7758	-41.1770	-0.3585	-0.0815	0.0584	0.3723	0.0584	Z
	38	5.6584	35.1211	-31.8257	5.9735	34.9146	-31.7409	-0.3151	0.2065	0.0848	0.3862	0.2232	Y, Z
	39	9.5694	36.1473	-26.5761	9.7705	35.8815	-26.3864	-0.2011	0.2658	0.1897	0.3835	0.3266	Y, Z
	40	6.2754	36.6055	-20.6716	6.4007	36.1319	-20.5334	-0.1253	0.4736	0.1382	0.5090	0.4934	Y, Z
B-PILLAR Lateral (Y)	37	8.1518	31.6943	-41.2354	8.5103	31.7758	-41.1770	-0.3585	-0.0815	0.0584	0.3723	-0.0815	Y
	38	5.6584	35.1211	-31.8257	5.9735	34.9146	-31.7409	-0.3151	0.2065	0.0848	0.3862	0.2065	Y
	39	9.5694	36.1473	-26.5761	9.7705	35.8815	-26.3864	-0.2011	0.2658	0.1897	0.3835	0.2658	Y
	40	6.2754	36.6055	-20.6716	6.4007	36.1319	-20.5334	-0.1253	0.4736	0.1382	0.5090	0.4736	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 C-8. Occupant Compartment Deformation Data – Set 1, Test No. MNCBR-2

Model Year: 2014 | Test Name: MNCBR-2 | VIN: 1C6RR6FT2ES278435
Make: Dodge | Model: Ram 1500

VEHICLE DEFORMATION
PASSENGER 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	42.0834	24.0424	-30.5813	42.4100	23.6859	-31.0192	-0.3266	0.3565	-0.4379	0.6523	0.6523	X, Y, Z
	2	44.5358	37.3254	-29.8015	44.8130	36.9642	-30.5995	-0.2772	0.3612	-0.7980	0.9188	0.9188	X, Y, Z
	3	45.4959	52.1941	-29.8282	45.6245	51.8855	-31.0439	-0.1286	0.3086	-1.2157	1.2608	1.2608	X, Y, Z
	4	39.1095	23.7553	-18.4373	39.1778	23.6597	-18.9597	-0.0683	0.0956	-0.5224	0.5354	0.5354	X, Y, Z
	5	40.9485	37.8021	-20.1664	40.9900	37.3370	-21.0705	-0.0415	0.4651	-0.9041	1.0176	1.0176	X, Y, Z
	6	41.6497	52.2337	-20.4335	41.2339	51.7707	-21.8924	0.4158	0.4630	-1.4589	1.5861	1.5861	X, Y, Z
SIDE PANEL (Y)	7	50.4115	56.7091	-3.6370	49.1585	51.7360	-4.8880	1.2530	4.9731	-1.2510	5.2789	4.9731	Y
	8	50.4196	56.7180	-7.7927	48.9713	51.5484	-9.1631	1.4483	5.1696	-1.3704	5.5408	5.1696	Y
	9	53.5557	56.7008	-6.3045	51.7967	51.0563	-7.7610	1.7590	5.6445	-1.4565	6.0890	5.6445	Y
IMPACT SIDE DOOR (Y)	10	39.4209	58.9427	-19.1391	38.5701	58.2509	-20.1423	0.8508	0.6918	-1.0032	1.4862	0.6918	Y
	11	29.2157	59.0731	-19.5415	28.4414	60.0151	-20.3113	0.7743	-0.9420	-0.7698	1.4420	-0.9420	Y
	12	18.9680	59.2441	-19.6530	18.2418	60.3674	-20.1215	0.7262	-1.1233	-0.4685	1.4173	-1.1233	Y
	13	38.1363	59.1452	-6.5872	37.4455	57.3765	-7.5857	0.6908	1.7687	-0.9985	2.1453	1.7687	Y
	14	29.8877	59.7172	-6.2617	29.3543	58.9369	-6.9753	0.5334	0.7803	-0.7136	1.1843	0.7803	Y
	15	20.7493	58.8754	-7.1391	20.1666	59.2396	-7.6859	0.5827	-0.3642	-0.5468	0.8782	-0.3642	Y
ROOF - (Z)	16	31.8243	23.0966	-49.3276	32.2522	22.8578	-49.4765	-0.4279	0.2388	-0.1489	0.5121	-0.1489	Z
	17	31.4488	28.9182	-49.3679	31.7909	28.7020	-49.6042	-0.3421	0.2162	-0.2363	0.4686	-0.2363	Z
	18	30.7567	33.9845	-49.3514	31.1107	33.7775	-49.6456	-0.3540	0.2070	-0.2942	0.5047	-0.2942	Z
	19	29.5067	39.7778	-49.2595	29.8407	39.6237	-49.6175	-0.3340	0.1541	-0.3580	0.5133	-0.3580	Z
	20	27.3881	45.7386	-49.1209	27.8287	45.5562	-49.5276	-0.4406	0.1824	-0.4067	0.6267	-0.4067	Z
	21	25.7883	23.3608	-50.3491	26.1531	23.1759	-50.5472	-0.3648	0.1849	-0.1981	0.4544	-0.1981	Z
	22	24.9862	28.9043	-50.3248	25.3382	28.6840	-50.5811	-0.3520	0.2203	-0.2563	0.4880	-0.2563	Z
	23	25.4314	33.6124	-50.1576	25.7878	33.4241	-50.4600	-0.3564	0.1883	-0.3024	0.5039	-0.3024	Z
	24	25.6094	39.5995	-49.8413	26.0429	39.4315	-50.1965	-0.4335	0.1680	-0.3552	0.5851	-0.3552	Z
	25	24.2147	45.3409	-49.6286	24.5670	45.2149	-50.0386	-0.3523	0.1260	-0.4100	0.5551	-0.4100	Z
	26	18.6183	23.8607	-50.8916	18.9217	23.5864	-51.1028	-0.3034	0.2743	-0.2112	0.4603	-0.2112	Z
	27	17.4608	29.4095	-50.9042	17.8778	29.2320	-51.1515	-0.4170	0.1775	-0.2473	0.5163	-0.2473	Z
	28	16.5992	35.1407	-50.7877	17.0473	34.9659	-51.0839	-0.4481	0.1748	-0.2962	0.5649	-0.2962	Z
	29	16.8180	41.0403	-50.4814	17.2096	40.8263	-50.8506	-0.3916	0.2140	-0.3692	0.5792	-0.3692	Z
	30	16.5407	45.5478	-50.1872	16.9763	45.3110	-50.5935	-0.4356	0.2368	-0.4063	0.6410	-0.4063	Z
A-PILLAR Maximum (X, Y, Z)	31	51.5818	55.6837	-32.1217	51.9551	55.8030	-32.7252	-0.3733	-0.1193	-0.6035	0.7196	0.0000	NA
	32	47.5754	54.8035	-35.5217	48.0795	54.8092	-36.2689	-0.5041	-0.0057	-0.7472	0.9014	0.0000	NA
	33	43.7701	53.8898	-38.1657	44.2862	53.8317	-38.8714	-0.5161	0.0581	-0.7057	0.8762	0.0581	Y
	34	39.9621	53.0275	-40.8477	40.4439	52.9258	-41.4824	-0.4818	0.1017	-0.6347	0.8033	0.1017	Y
	35	36.4048	52.2776	-43.4195	36.8511	52.1407	-44.0590	-0.4463	0.1369	-0.6395	0.7918	0.1369	Y
	36	33.5014	51.4429	-45.1059	33.9187	51.2604	-45.7095	-0.4173	0.1825	-0.6036	0.7562	0.1825	Y
A-PILLAR Lateral (Y)	31	51.5818	55.6837	-32.1217	51.9551	55.8030	-32.7252	-0.3733	-0.1193	-0.6035	0.7196	-0.1193	Y
	32	47.5754	54.8035	-35.5217	48.0795	54.8092	-36.2689	-0.5041	-0.0057	-0.7472	0.9014	-0.0057	Y
	33	43.7701	53.8898	-38.1657	44.2862	53.8317	-38.8714	-0.5161	0.0581	-0.7057	0.8762	0.0581	Y
	34	39.9621	53.0275	-40.8477	40.4439	52.9258	-41.4824	-0.4818	0.1017	-0.6347	0.8033	0.1017	Y
	35	36.4048	52.2776	-43.4195	36.8511	52.1407	-44.0590	-0.4463	0.1369	-0.6395	0.7918	0.1369	Y
	36	33.5014	51.4429	-45.1059	33.9187	51.2604	-45.7095	-0.4173	0.1825	-0.6036	0.7562	0.1825	Y
B-PILLAR Maximum (X, Y, Z)	37	9.7593	51.1314	-45.3426	10.1546	50.9329	-45.7189	-0.3953	0.1985	-0.3763	0.5807	0.1985	Y
	38	7.1790	54.5608	-35.9573	7.5750	54.1885	-36.3342	-0.3960	0.3723	-0.3769	0.6614	0.3723	Y
	39	11.0474	55.6251	-30.6837	11.3528	55.2553	-30.9851	-0.3054	0.3698	-0.3014	0.5664	0.3698	Y
	40	7.7107	56.0730	-24.8025	7.9673	55.5669	-25.1440	-0.2566	0.5061	-0.3415	0.6623	0.5061	Y
B-PILLAR Lateral (Y)	37	9.7593	51.1314	-45.3426	10.1546	50.9329	-45.7189	-0.3953	0.1985	-0.3763	0.5807	0.1985	Y
	38	7.1790	54.5608	-35.9573	7.5750	54.1885	-36.3342	-0.3960	0.3723	-0.3769	0.6614	0.3723	Y
	39	11.0474	55.6251	-30.6837	11.3528	55.2553	-30.9851	-0.3054	0.3698	-0.3014	0.5664	0.3698	Y
	40	7.7107	56.0730	-24.8025	7.9673	55.5669	-25.1440	-0.2566	0.5061	-0.3415	0.6623	0.5061	Y

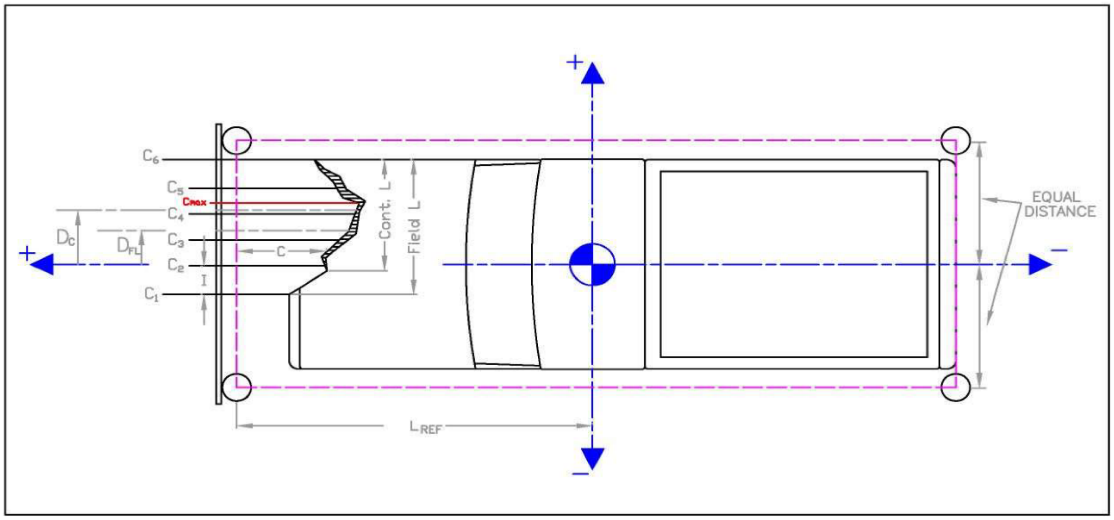
[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[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 C-9. Occupant Compartment Deformation Data – Set 2, Test No. MNCBR-2

Date Measured:	9/18/2020	Test Name:	MNCBR-2	VIN:	1C6RR6FT2ES278435
Model Year:	2014	Make:	Dodge	Model:	Ram 1500



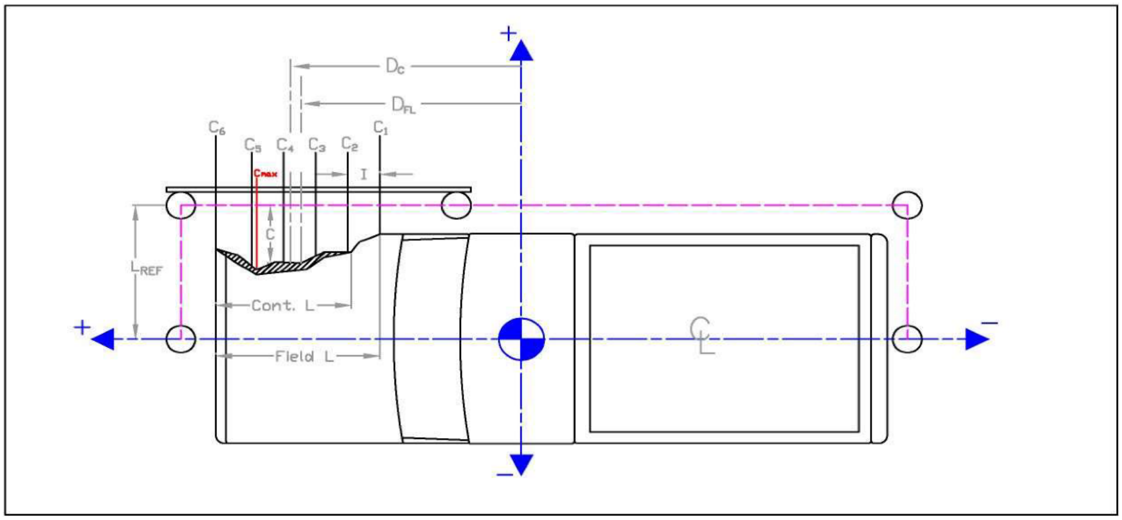
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	109	(2769)
Total Vehicle Width:	77 1/4	(1962)
Width of contact and induced crush - Field L:	77 1/4	(1962)
Crush measurement spacing interval (L/5) - I:	15 1/2	(394)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	28 5/8	(727)
Distance from center of vehicle to center of contact damage - D_C:	24 1/3	(618)

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	16 1/2	(419)	-38 5/8	-(981)	22 1/2	(572)	4 3/8	(111)	-10 3/8	-(264)
C_2	10	(254)	-23 1/8	-(587)	6 1/2	(165)			- 7/8	-(22)
C_3	7 3/4	(197)	-7 5/8	-(194)	4 1/4	(108)			- 7/8	-(22)
C_4	13	(330)	7 7/8	(200)	4 1/4	(108)			4 3/8	(111)
C_5	37 1/2	(953)	23 3/8	(594)	6 1/4	(159)			26 7/8	(683)
C_6	NA	N/A	38 7/8	(987)	20 1/2	(521)			N/A	N/A
C_{MAX}	37 1/2	(953)	23 3/8	(594)	6 1/4	(159)			26 7/8	(683)

Figure C-10. Exterior Vehicle Crush (NASS) – Front, Test No. MNCBR-2

Date Measured:	9/18/2020	Test Name:	MNCBR-2	VIN:	1C6RR6FT2ES278435
Model Year:	2014	Make:	Dodge	Model:	Ram 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	45 1/2	(1156)
Total Vehicle Length:	229	(5817)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-6 5/8	-(168)
Width of contact and induced crush - Field L:	229	(5817)
Crush measurement spacing interval (L/5) - I:	45 3/4	(1162)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-16 1/8	-(410)
Width of Contact Damage:	229	(5817)
Distance from vehicle c.g. to center of contact damage - D_C:	-16 1/8	-(410)

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	N/a	N/A	-130 5/8	-(3318)	33 1/2	(851)	1 1/2	(38)	N/A	N/A
C_2	N/a	N/A	-84 7/8	-(2156)	5 1/2	(140)			N/A	N/A
C_3	7 3/4	(197)	-39 1/8	-(994)	5 3/4	(146)			1/2	(13)
C_4	6 3/4	(171)	6 5/8	(168)	5	(127)			1/4	(6)
C_5	N/a	N/A	52 3/8	(1330)	5 5/8	(143)			N/A	N/A
C_6	N/a	N/A	98 1/8	(2492)	8 3/8	(213)			N/A	N/A
C_{MAX}	28	(711)	84	(2134)	5 3/4	(146)			20 3/4	(527)

Figure C-11. Exterior Vehicle Crush (NASS) – Side, Test No. MNCBR-2

Test Name: MNCBR-2 | VIN: 1C6RR6FT2ES278435

Model Year: 2014 | Make: Dodge | Model: Ram 1500

Passenger Side Maximum Deformation							
Reference Set 1				Reference Set 2			
Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]	Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Roof	0.0	≤ 4	Z	Roof	-0.4	≤ 4	Z
Windshield[D]	0.0	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	0.1	≤ 5	Z	A-Pillar Maximum	0.2	≤ 5	Y
A-Pillar Lateral	-0.3	≤ 3	Y	A-Pillar Lateral	0.2	≤ 3	Y
B-Pillar Maximum	0.5	≤ 5	Y, Z	B-Pillar Maximum	0.5	≤ 5	Y
B-Pillar Lateral	0.5	≤ 3	Y	B-Pillar Lateral	0.5	≤ 3	Y
Toe Pan - Wheel Well	3.8	≤ 9	X, Z	Toe Pan - Wheel Well	4.1	≤ 9	X, Z
Side Front Panel	5.8	≤ 12	Y	Side Front Panel	5.6	≤ 12	Y
Side Door (above seat)	0.7	≤ 9	Y	Side Door (above seat)	0.7	≤ 9	Y
Side Door (below seat)	1.9	≤ 12	Y	Side Door (below seat)	1.8	≤ 12	Y
Floor Pan	0.1	≤ 12	Z	Floor Pan	0.7	≤ 12	Z
Dash - no MASH requirement	1.1	NA	X, Y, Z	Dash - no MASH requirement	1.6	NA	X, Y, Z

[A] Items highlighted in red do not meet MASH allowable deformations.

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

[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment. If direction of deformation is "NA" then no intrusion is recorded and deformation will be 0.

[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle interior crush:

Figure C-12. Maximum Occupant Compartment Deformations by Location, Test No. MNCBR-2

Model Year: 2009 | Test Name: MNCBR-3 | Make: Kia | VIN: KNADE223196557772 | Model: Rio

VEHICLE DEFORMATION
PASSENGER 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	63.2198	16.2464	5.3295	62.6456	14.5414	5.7370	0.5742	1.7050	-0.4075	1.8447	0.5742	X
	2	63.4692	19.6365	5.0723	N/a	N/a	N/a	#VALUE!	#VALUE!	#VALUE!	NA	NA	#VALUE!
	3	63.9940	22.9386	4.9041	62.6009	20.6156	4.4876	1.3931	2.3230	0.4165	2.7405	1.4540	X, Z
	4	64.2975	27.1587	4.3955	63.1207	24.9007	4.0347	1.1768	2.2580	0.3608	2.5717	1.2309	X, Z
	5	62.9921	31.4277	2.6012	61.5721	28.9663	2.6745	1.4200	2.4614	-0.0733	2.8426	1.4200	X
	6	60.0949	16.2992	7.1882	59.9862	14.4223	7.9352	0.1087	1.8769	-0.7470	2.0230	0.1087	X
	7	60.5448	20.2787	6.7084	N/a	N/a	N/a	#VALUE!	#VALUE!	#VALUE!	NA	NA	#VALUE!
	8	61.0561	23.5632	6.6248	59.8067	21.3602	6.4821	1.2494	2.2030	0.1427	2.5366	1.2575	X, Z
	9	61.6785	27.5755	6.2173	60.7790	25.3179	6.2486	0.8995	2.2576	-0.0313	2.4304	0.8995	X
	10	61.2778	32.7577	4.8449	59.7399	29.8764	5.0088	1.5379	2.8813	-0.1639	3.2702	1.5379	X
FLOOR PAN (Z)	11	55.9498	16.5655	8.1713	55.4134	16.7448	5.9287	0.5364	-0.1793	2.2426	2.3128	2.2426	Z
	12	55.9491	20.1525	8.3303	54.7271	18.5885	7.5873	1.2220	1.5640	0.7430	2.1193	0.7430	Z
	13	56.2127	23.4489	8.3313	55.3505	21.3715	8.7685	0.8622	2.0774	-0.4372	2.2913	-0.4372	Z
	14	56.4304	28.4875	8.3004	55.8510	26.4295	8.8775	0.5794	2.0580	-0.5771	2.2145	-0.5771	Z
	15	57.4055	33.0155	8.2518	57.1046	30.9149	8.7886	0.3009	2.1006	-0.5368	2.1889	-0.5368	Z
	16	52.9326	16.2782	8.2760	52.8388	16.4767	7.5214	0.0938	-0.1985	0.7546	0.7859	0.7546	Z
	17	53.2351	19.5061	8.5903	52.2494	19.0988	6.6202	0.9857	0.4073	1.9701	2.2403	1.9701	Z
	18	53.3966	22.9100	8.3634	52.5138	21.0577	9.0267	0.8828	1.8523	-0.6633	2.1565	-0.6633	Z
	19	53.9170	28.0066	8.3528	53.3404	26.1463	9.0522	0.5766	1.8603	-0.6994	2.0694	-0.6994	Z
	20	54.2097	33.1385	8.1732	53.8728	31.1851	8.8000	0.3369	1.9534	-0.6268	2.0790	-0.6268	Z
	21	49.8862	16.6314	8.6955	50.0619	16.7840	8.4291	-0.1757	-0.1526	0.2664	0.3537	0.2664	Z
	22	50.1596	20.0628	8.9347	49.2150	19.4514	7.4464	0.9446	0.6114	1.4883	1.8658	1.4883	Z
	23	50.6587	23.4175	8.3867	49.7932	21.7594	9.2445	0.8655	1.6581	-0.8578	2.0577	-0.8578	Z
	24	51.2861	27.9650	8.3932	50.6741	26.2577	9.3847	0.6120	1.7073	-0.9915	2.0670	-0.9915	Z
	25	51.6846	33.0949	8.7121	51.3876	31.3628	9.4684	0.2970	1.7321	-0.7563	1.9132	-0.7563	Z
	26	46.4491	17.2189	9.0066	46.5388	17.3890	8.4152	-0.0897	-0.1701	0.5914	0.6219	0.5914	Z
	27	46.8760	20.2812	9.0664	46.1902	19.4708	8.7447	0.6858	0.8104	0.3217	1.1093	0.3217	Z
	28	47.0329	23.3150	8.4157	46.1903	21.8753	9.4178	0.8426	1.4397	-1.0021	1.9460	-1.0021	Z
	29	47.4484	28.1406	8.4094	46.9253	26.6343	9.5395	0.5231	1.5063	-1.1301	1.9544	-1.1301	Z
	30	47.9970	33.5448	9.0159	47.7484	32.0266	9.8845	0.2486	1.5182	-0.8686	1.7667	-0.8686	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.

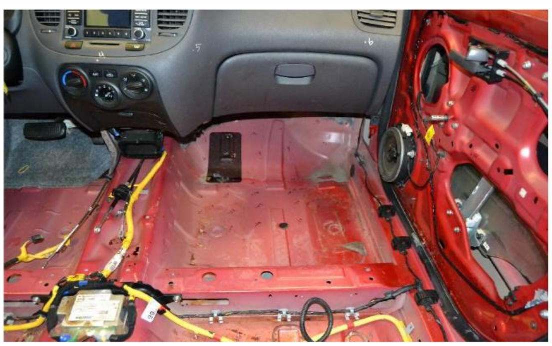
Pretest Floor Pan	Posttest Floor Pan
	

Figure C-13. Floor Pan Deformation Data – Set 1, Test No. MNCBR-3

Model Year: 2009 | Test Name: MNCBR-3 | VIN: KNADE223196557772
Make: Kia | Model: Rio

VEHICLE DEFORMATION
PASSENGER SIDE FLOOR PAN - SET 2

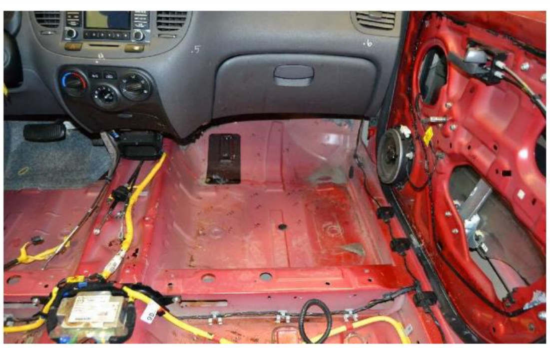
	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	63.0829	-1.3344	5.0463	62.4029	-2.6711	5.9981	0.6800	-1.3367	-0.9518	1.7763	0.6800	X
	2	63.3506	2.0547	4.7946	N/a	N/a	N/a	#VALUE!	#VALUE!	#VALUE!	NA	NA	#VALUE!
	3	63.8935	5.3541	4.6305	62.3920	3.4094	4.7791	1.5015	1.9447	-0.1486	2.4614	1.5015	X
	4	64.2190	9.5733	4.1287	62.9314	7.6949	4.3530	1.2876	1.8784	-0.2243	2.2884	1.2876	X
	5	62.9301	13.8533	2.3485	61.4106	11.7728	2.9985	1.5195	2.0805	-0.6500	2.6570	1.5195	X
	6	59.9666	-1.2674	6.9189	59.7220	-2.7917	8.1698	0.2446	-1.5243	-1.2509	1.9870	0.2446	X
	7	60.4371	2.7104	6.4449	N/a	N/a	N/a	#VALUE!	#VALUE!	#VALUE!	NA	NA	#VALUE!
	8	60.9669	5.9921	6.3653	59.5813	4.1541	6.7502	1.3856	1.8380	-0.3849	2.3337	1.3856	X
	9	61.6104	10.0015	5.9629	60.5699	8.1093	6.5463	1.0405	1.8922	-0.5834	2.2368	1.0405	X
	10	61.2333	15.1887	4.6023	59.5591	12.6777	5.3196	1.6742	2.5110	-0.7173	3.1020	1.6742	X
FLOOR PAN (Z)	11	55.8274	-0.9793	7.9208	55.1771	-0.4426	6.1310	0.6503	0.5367	1.7898	1.9785	1.7898	Z
	12	55.8480	2.6072	8.0868	54.4814	1.3951	7.7921	1.3666	1.2121	0.2947	1.8503	0.2947	Z
	13	56.1305	5.9021	8.0931	55.1032	4.1699	8.9934	1.0273	1.7322	-0.9003	2.2060	-0.9003	Z
	14	56.3768	10.9394	8.0710	55.6206	9.2255	9.1329	0.7562	1.7139	-1.0619	2.1534	-1.0619	Z
	15	57.3776	15.4619	8.0268	56.8910	13.7067	9.0789	0.4866	1.7552	-1.0521	2.1034	-1.0521	Z
	16	52.8091	-1.2496	8.0383	52.5862	-0.7095	7.6973	0.2229	0.5401	0.3410	0.6765	0.3410	Z
	17	53.1315	1.9759	8.3576	52.0150	1.9193	6.8037	1.1165	0.0566	1.5539	1.9143	1.5539	Z
	18	53.3115	5.3792	8.1365	52.2630	3.8651	9.2226	1.0485	1.5141	-1.0861	2.1381	-1.0861	Z
	19	53.8610	10.4728	8.1335	53.1074	8.9504	9.2819	0.7536	1.5224	-1.1484	2.0505	-1.1484	Z
	20	54.1823	15.6033	7.9626	53.6602	13.9885	9.0604	0.5221	1.6148	-1.0978	2.0212	-1.0978	Z
	21	49.7668	-0.8799	8.4719	49.8019	-0.3967	8.5796	-0.0351	0.4832	-0.1077	0.4963	-0.1077	Z
	22	50.0608	2.5494	8.7166	48.9740	2.2786	7.6023	1.0868	0.2708	1.1143	1.5799	1.1143	Z
	23	50.5767	5.9023	8.1729	49.5429	4.5754	9.4175	1.0338	1.3269	-1.2446	2.0925	-1.2446	Z
	24	51.2301	10.4461	8.1855	50.4385	9.0698	9.5891	0.7916	1.3763	-1.4036	2.1192	-1.4036	Z
	25	51.6594	15.5730	8.5125	51.1693	14.1718	9.7056	0.4901	1.4012	-1.1931	1.9045	-1.1931	Z
	26	46.3345	-0.2733	8.7994	46.2811	0.2211	8.5347	0.0534	0.4944	0.2647	0.5633	0.2647	Z
	27	46.7791	2.7864	8.8632	45.9368	2.3024	8.8713	0.8423	0.4840	-0.0081	0.9715	-0.0081	Z
	28	46.9506	5.8205	8.2177	45.9390	4.7035	9.5566	1.0116	1.1170	-1.3389	2.0159	-1.3389	Z
	29	47.3936	10.6436	8.2190	46.6896	9.4592	9.7095	0.7040	1.1844	-1.4905	2.0298	-1.4905	Z
	30	47.9758	16.0434	8.8335	47.5286	14.8466	10.0898	0.4472	1.1968	-1.2563	1.7918	-1.2563	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 C-14. Floor Pan Deformation Data – Set 2, Test No. MNCBR-3

Model Year: 2009 | Test Name: MNCBR-3 | Make: Kia | VIN: KNADE223196557772 | Model: Rio

VEHICLE DEFORMATION
PASSENGER 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	49.3046	11.0021	-20.3862	49.2928	10.7565	-20.4242	0.0118	0.2456	-0.0380	0.2488	0.2488	X, Y, Z
	2	48.2593	18.3952	-20.1496	48.2574	18.1060	-20.2212	0.0019	0.2892	-0.0716	0.2979	0.2979	X, Y, Z
	3	50.2530	32.9068	-19.5840	50.1592	32.6504	-19.5276	0.0938	0.2564	0.0564	0.2788	0.2788	X, Y, Z
	4	44.3632	10.4563	-12.7286	44.3277	10.1838	-12.7947	0.0355	0.2725	-0.0661	0.2826	0.2826	X, Y, Z
	5	45.1397	18.0799	-13.3966	45.0968	17.8243	-13.4041	0.0429	0.2556	-0.0075	0.2593	0.2593	X, Y, Z
	6	47.2714	32.4559	-13.7849	46.8679	32.1621	-13.8483	0.4035	0.2938	-0.0634	0.5031	0.5031	X, Y, Z
SIDE PANEL (Y)	7	54.0048	37.1548	2.3133	53.6342	35.3724	2.4940	0.3706	1.7824	0.1807	1.8295	1.7824	Y
	8	58.9394	37.2595	2.8352	58.4894	34.7530	2.8253	0.4500	2.5065	-0.0099	2.5466	2.5065	Y
	9	55.3407	36.9881	-2.1094	54.5450	35.2233	-2.0478	0.7957	1.7648	0.0616	1.9369	1.7648	Y
IMPACT SIDE DOOR (Y)	10	48.0393	38.1142	-17.7190	47.4237	38.0103	-17.4457	0.6156	0.1039	0.2733	0.6815	0.1039	Y
	11	36.9046	38.1008	-18.4900	36.4317	39.2744	-18.1556	0.4729	-1.1736	0.3344	1.3087	-1.1736	Y
	12	25.1931	38.1693	-18.9522	24.7545	40.1223	-18.7291	0.4386	-1.9530	0.2231	2.0140	-1.9530	Y
	13	49.1182	38.3010	-6.5091	48.4152	37.8123	-6.2190	0.7030	0.4887	0.2901	0.9040	0.4887	Y
	14	36.6071	38.6757	-7.9149	36.2294	40.5730	-7.6870	0.3777	-1.8973	0.2279	1.9479	-1.8973	Y
	15	26.8320	38.4635	-8.6014	26.4801	41.0337	-8.2667	0.3519	-2.5702	0.3347	2.6157	-2.5702	Y
ROOF - (Z)	16	35.1168	10.5473	-35.1558	35.1416	10.7610	-35.2242	-0.0248	-0.2137	-0.0684	0.2257	-0.0684	Z
	17	34.8869	15.1928	-35.1723	34.9302	15.3869	-35.2177	-0.0433	-0.1941	-0.0454	0.2040	-0.0454	Z
	18	34.8484	19.1196	-35.0225	34.9782	19.2846	-35.0313	-0.1298	-0.1650	-0.0088	0.2101	-0.0088	Z
	19	34.6755	22.9708	-34.8223	34.7752	23.1905	-34.8268	-0.0997	-0.2197	-0.0045	0.2413	-0.0045	Z
	20	34.3499	28.2854	-34.4933	34.4815	28.4609	-34.4780	-0.1316	-0.1755	0.0153	0.2199	0.0153	Z
	21	29.9383	10.2313	-38.0086	30.0169	10.4094	-38.0494	-0.0786	-0.1781	-0.0408	0.1989	-0.0408	Z
	22	29.1099	14.9408	-38.1125	29.1221	15.1526	-38.1456	-0.0122	-0.2118	-0.0331	0.2147	-0.0331	Z
	23	28.6932	18.4076	-38.0681	28.8048	18.5951	-38.0693	-0.1116	-0.1875	-0.0012	0.2182	-0.0012	Z
	24	28.2566	22.0956	-37.9366	28.3424	22.3269	-37.9211	-0.0858	-0.2313	0.0155	0.2472	0.0155	Z
	25	27.9846	26.7677	-37.5997	28.0215	26.9596	-37.5671	-0.0369	-0.1919	0.0326	0.1981	0.0326	Z
	26	27.4023	10.2575	-38.4611	27.4577	10.4333	-38.5079	-0.0554	-0.1758	-0.0468	0.1902	-0.0468	Z
	27	26.2309	15.0193	-38.5793	26.3188	15.2454	-38.5951	-0.0879	-0.2261	-0.0158	0.2431	-0.0158	Z
	28	26.0813	18.3090	-38.4845	26.0894	18.5007	-38.4994	-0.0081	-0.1917	-0.0149	0.1924	-0.0149	Z
	29	26.0563	21.8598	-38.2997	26.1075	22.1045	-38.2816	-0.0512	-0.2447	0.0181	0.2507	0.0181	Z
	30	25.2822	26.5539	-38.0339	25.4010	26.7195	-37.9875	-0.1188	-0.1656	0.0464	0.2090	0.0464	Z
A-PILLAR Maximum (X, Y, Z)	31	53.6170	36.0142	-22.1950	53.6736	35.7740	-22.0315	-0.0566	0.2402	0.1635	0.2960	0.2906	Y, Z
	32	49.6069	35.2268	-25.0218	49.8483	35.0696	-25.1186	-0.2414	0.1572	-0.0968	0.3039	0.1572	Y
	33	46.7177	34.6007	-26.9124	46.9888	34.6274	-26.9791	-0.2711	-0.0267	-0.0667	0.2805	0.0000	NA
	34	43.2535	33.8539	-28.8932	43.4652	33.8695	-28.9282	-0.2117	-0.0156	-0.0350	0.2151	0.0000	NA
	35	39.8763	33.1576	-30.6156	40.0629	33.1939	-30.6341	-0.1866	-0.0363	-0.0185	0.1910	0.0000	NA
	36	36.2629	32.3997	-32.3551	36.4182	32.5052	-32.3264	-0.1553	-0.1055	0.0287	0.1899	0.0287	Z
A-PILLAR Lateral (Y)	31	53.6170	36.0142	-22.1950	53.6736	35.7740	-22.0315	-0.0566	0.2402	0.1635	0.2960	0.2402	Y
	32	49.6069	35.2268	-25.0218	49.8483	35.0696	-25.1186	-0.2414	0.1572	-0.0968	0.3039	0.1572	Y
	33	46.7177	34.6007	-26.9124	46.9888	34.6274	-26.9791	-0.2711	-0.0267	-0.0667	0.2805	-0.0267	Y
	34	43.2535	33.8539	-28.8932	43.4652	33.8695	-28.9282	-0.2117	-0.0156	-0.0350	0.2151	-0.0156	Y
	35	39.8763	33.1576	-30.6156	40.0629	33.1939	-30.6341	-0.1866	-0.0363	-0.0185	0.1910	-0.0363	Y
	36	36.2629	32.3997	-32.3551	36.4182	32.5052	-32.3264	-0.1553	-0.1055	0.0287	0.1899	-0.1055	Y
B-PILLAR Maximum (X, Y, Z)	37	15.0062	32.4612	-33.5172	15.1622	32.6574	-33.2938	-0.1560	-0.1962	0.2234	0.3358	0.2234	Z
	38	13.0116	34.6028	-28.9947	13.1795	34.7661	-28.6914	-0.1679	-0.1633	0.3033	0.3832	0.3033	Z
	39	17.2731	36.0575	-24.5615	17.3735	36.1275	-24.2915	-0.1004	-0.0700	0.2700	0.2964	0.2700	Z
	40	18.6125	37.2690	-15.2307	18.6808	37.2477	-14.9680	-0.0683	0.0213	0.2627	0.2723	0.2636	Y, Z
B-PILLAR Lateral (Y)	37	15.0062	32.4612	-33.5172	15.1622	32.6574	-33.2938	-0.1560	-0.1962	0.2234	0.3358	-0.1962	Y
	38	13.0116	34.6028	-28.9947	13.1795	34.7661	-28.6914	-0.1679	-0.1633	0.3033	0.3832	-0.1633	Y
	39	17.2731	36.0575	-24.5615	17.3735	36.1275	-24.2915	-0.1004	-0.0700	0.2700	0.2964	-0.0700	Y
	40	18.6125	37.2690	-15.2307	18.6808	37.2477	-14.9680	-0.0683	0.0213	0.2627	0.2723	0.0213	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 C-15. Occupant Compartment Deformation Data – Set 1, Test No. MNCBR-3

Model Year: 2009 | Test Name: MNCBR-3 | Make: Kia | VIN: KNADE223196557772 | Model: Rio

VEHICLE DEFORMATION
PASSENGER 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	49.0394	-6.4814	-20.6029	49.3337	-6.4904	-20.2203	-0.2943	-0.0090	0.3826	0.4828	0.4828	X, Y, Z
	2	48.0448	0.9180	-20.3425	48.3348	0.8620	-19.9506	-0.2900	0.0560	0.3919	0.4907	0.4907	X, Y, Z
	3	50.1381	15.4142	-19.7473	50.3053	15.3879	-19.0831	-0.1672	0.0263	0.6642	0.6854	0.6854	X, Y, Z
	4	44.1269	-7.0144	-12.9259	44.2844	-7.1166	-12.6504	-0.1575	-0.1022	0.2755	0.3334	0.3334	X, Y, Z
	5	44.9517	0.6056	-13.5772	45.1001	0.5256	-13.1708	-0.1484	0.0800	0.4064	0.4400	0.4400	X, Y, Z
	6	47.1781	14.9680	-13.9367	46.9511	14.8576	-13.4446	0.2270	0.1104	0.4921	0.5531	0.5531	X, Y, Z
SIDE PANEL (Y)	7	54.0109	19.5789	2.1450	53.5592	17.8595	3.0018	0.4517	1.7194	0.8568	1.9734	1.7194	Y
	8	58.9482	19.6492	2.6462	58.4072	17.2106	3.3780	0.5410	2.4386	0.7318	2.6029	2.4386	Y
	9	55.3269	19.4150	-2.2838	54.5177	17.7532	-1.5314	0.8092	1.6618	0.7524	1.9956	1.6618	Y
IMPACT SIDE DOOR (Y)	10	47.9673	20.6314	-17.8592	47.5759	20.7403	-16.9738	0.3914	-0.1089	0.8854	0.9742	-0.1089	Y
	11	36.8296	20.6946	-18.5829	36.5990	22.0707	-17.7871	0.2306	-1.3761	0.7958	1.6063	-1.3761	Y
	12	25.1169	20.8428	-18.9952	24.9331	22.9871	-18.4756	0.1838	-2.1443	0.5196	2.2140	-2.1443	Y
	13	49.0948	20.7813	-6.6535	48.4464	20.4189	-5.7399	0.6484	0.3624	0.9136	1.1775	0.3624	Y
	14	36.5807	21.2434	-8.0052	36.2917	23.2602	-7.3080	0.2890	-2.0168	0.6972	2.1534	-2.0168	Y
	15	26.8015	21.0985	-8.6508	26.5516	23.7792	-7.9864	0.2499	-2.6807	0.6644	2.7731	-2.6807	Y
ROOF - (Z)	16	34.7866	-6.8020	-35.3134	35.3416	-6.2543	-35.1689	-0.5550	0.5477	0.1445	0.7930	0.1445	Z
	17	34.5878	-2.1550	-35.3167	35.1544	-1.6277	-35.1158	-0.5666	0.5273	0.2009	0.7997	0.2009	Z
	18	34.5763	1.7716	-35.1564	35.2208	2.2675	-34.8877	-0.6445	-0.4959	0.2687	0.8564	0.2687	Z
	19	34.4301	5.6233	-34.9453	35.0362	6.1721	-34.6440	-0.6061	-0.5488	0.3013	0.8714	0.3013	Z
	20	34.1415	10.9391	-34.6010	34.7664	11.4399	-34.2427	-0.6249	-0.5008	0.3583	0.8773	0.3583	Z
	21	29.5941	-7.0757	-38.1450	30.2455	-6.5488	-38.0520	-0.6514	0.5269	0.0930	0.8430	0.0930	Z
	22	28.7968	-2.3605	-38.2329	29.3767	-1.8001	-38.1075	-0.5799	0.5604	0.1254	0.8161	0.1254	Z
	23	28.4036	1.1089	-38.1777	29.0767	1.6431	-37.9982	-0.6731	-0.5342	0.1795	0.8779	0.1795	Z
	24	27.9923	4.7994	-38.0346	28.6323	5.3756	-37.8155	-0.6400	-0.5762	0.2191	0.8886	0.2191	Z
	25	27.7531	9.4723	-37.6843	28.3320	10.0059	-37.4160	-0.5789	-0.5336	0.2683	0.8318	0.2683	Z
	26	27.0565	-7.0313	-38.5866	27.6915	-6.5063	-38.5374	-0.6350	0.5250	0.0492	0.8254	0.0492	Z
	27	25.9166	-2.2615	-38.6874	26.5789	-1.6875	-38.5857	-0.6623	0.5740	0.1017	0.8823	0.1017	Z
	28	25.7893	1.0289	-38.5833	26.3656	1.5678	-38.4581	-0.5763	-0.5389	0.1252	0.7989	0.1252	Z
	29	25.7889	4.5793	-38.3890	26.4003	5.1690	-38.2020	-0.6114	-0.5897	0.1870	0.8698	0.1870	Z
	30	25.0475	9.2778	-38.1076	25.7150	9.7843	-37.8667	-0.6675	-0.5065	0.2409	0.8719	0.2409	Z
A-PILLAR Maximum (X, Y, Z)	31	53.5118	18.5060	-22.3644	53.8627	18.5188	-21.5163	-0.3509	-0.0128	0.8481	0.9179	0.8481	Z
	32	49.4846	17.7530	-25.1762	50.0669	17.8674	-24.6512	-0.5823	-0.1144	0.5250	0.7923	0.5250	Z
	33	46.5833	17.1513	-27.0561	47.2251	17.4602	-26.5466	-0.6418	-0.3089	0.5095	0.8757	0.5095	Z
	34	43.1059	16.4330	-29.0241	43.7187	16.7416	-28.5409	-0.6128	-0.3086	0.4832	0.8392	0.4832	Z
	35	39.7168	15.7638	-30.7340	40.3313	16.1023	-30.2899	-0.6145	-0.3385	0.4441	0.8303	0.4441	Z
	36	36.0911	15.0347	-32.4601	36.7013	15.4510	-32.0280	-0.6102	-0.4163	0.4321	0.8558	0.4321	Z
A-PILLAR Lateral (Y)	31	53.5118	18.5060	-22.3644	53.8627	18.5188	-21.5163	-0.3509	-0.0128	0.8481	0.9179	-0.0128	Y
	32	49.4846	17.7530	-25.1762	50.0669	17.8674	-24.6512	-0.5823	-0.1144	0.5250	0.7923	-0.1144	Y
	33	46.5833	17.1513	-27.0561	47.2251	17.4602	-26.5466	-0.6418	-0.3089	0.5095	0.8757	-0.3089	Y
	34	43.1059	16.4330	-29.0241	43.7187	16.7416	-28.5409	-0.6128	-0.3086	0.4832	0.8392	-0.3086	Y
	35	39.7168	15.7638	-30.7340	40.3313	16.1023	-30.2899	-0.6145	-0.3385	0.4441	0.8303	-0.3385	Y
	36	36.0911	15.0347	-32.4601	36.7013	15.4510	-32.0280	-0.6102	-0.4163	0.4321	0.8558	-0.4163	Y
B-PILLAR Maximum (X, Y, Z)	37	14.8305	15.2417	-33.5319	15.4579	15.7274	-33.2195	-0.6274	-0.4857	0.3124	0.8527	0.3124	Z
	38	12.8695	17.3846	-28.9953	13.4373	17.7981	-28.6164	-0.5678	-0.4135	0.3789	0.7981	0.3789	Z
	39	17.1594	18.7989	-24.5764	17.5911	19.0907	-24.1581	-0.4317	-0.2918	0.4183	0.6682	0.4183	Z
	40	18.5463	19.9766	-15.2482	18.8046	20.1057	-14.8099	-0.2583	-0.1291	0.4383	0.5249	0.4383	Z
B-PILLAR Lateral (Y)	37	14.8305	15.2417	-33.5319	15.4579	15.7274	-33.2195	-0.6274	-0.4857	0.3124	0.8527	-0.4857	Y
	38	12.8695	17.3846	-28.9953	13.4373	17.7981	-28.6164	-0.5678	-0.4135	0.3789	0.7981	-0.4135	Y
	39	17.1594	18.7989	-24.5764	17.5911	19.0907	-24.1581	-0.4317	-0.2918	0.4183	0.6682	-0.2918	Y
	40	18.5463	19.9766	-15.2482	18.8046	20.1057	-14.8099	-0.2583	-0.1291	0.4383	0.5249	-0.1291	Y

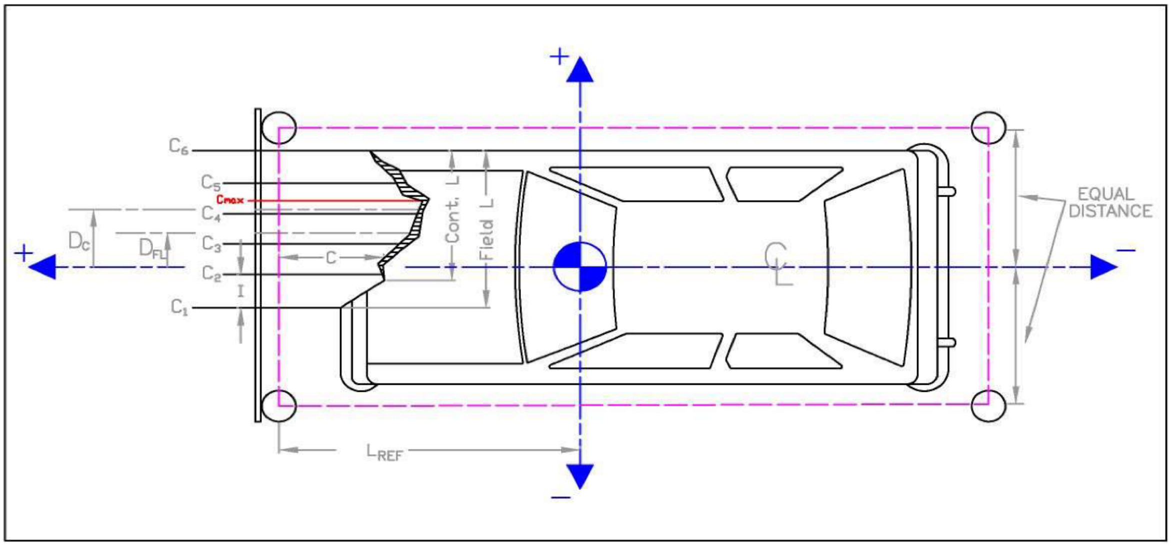
[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[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 C-16. Occupant Compartment Deformation Data – Set 2, Test No. MNCBR-3

Date Measured	10/6/20	MNCBR-3	VIN:	KNADE223196557772
Model Year:	2009	Make: Kia	Model:	Rio



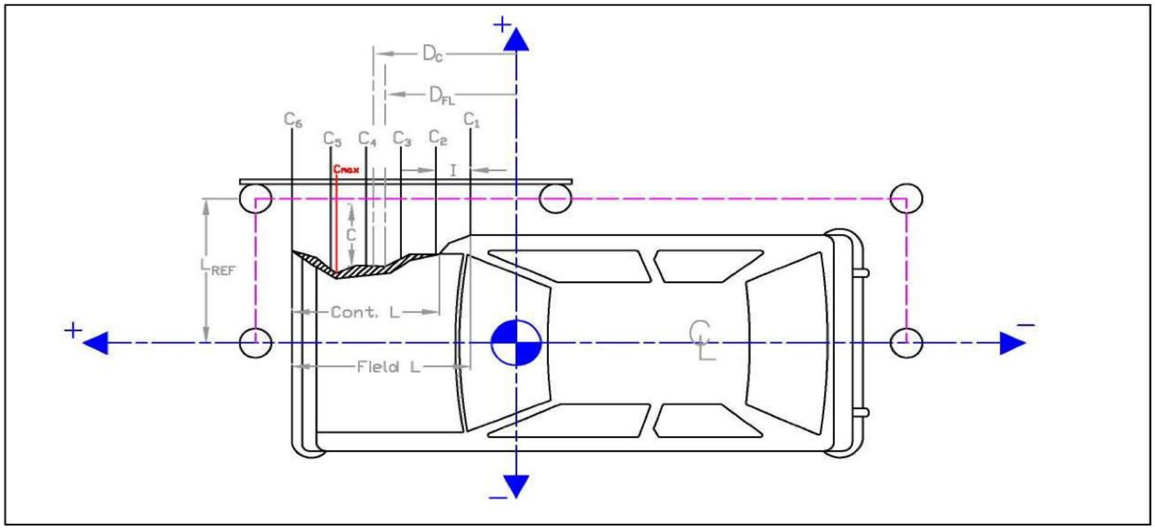
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	74 7/8	(1902)
Total Width of Vehicle:	65 4/7	(1665)
Width of contact and induced crush - Field L:	21 7/9	(553)
Crush measurement spacing interval (L/5) - I:	4 3/8	(111)
Distance from center of vehicle to center of Field L - D_{FL}:	21 8/9	(556)
Width of Contact Damage:	21 7/9	(553)
Distance from center of vehicle to center of contact damage - D_C:	21 8/9	(556)

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	7	(178)	11	(279)	6 5/8	(168)	-1	-(25)	1 3/8	(35)
C_2	9 1/2	(241)	15 3/8	(391)	7 1/4	(184)			3 1/4	(83)
C_3	11 5/8	(295)	19 3/4	(502)	8 1/2	(216)			4 1/8	(105)
C_4	14 7/8	(378)	24 1/8	(613)	10 3/8	(264)			5 1/2	(140)
C_5	26 5/8	(676)	28 1/2	(724)	13 7/8	(352)			13 3/4	(349)
C_6	NA	NA	32 7/8	(835)	24	(610)			NA	NA
C_{MAX}	26 5/8	(676)	28 1/2	(724)	13 7/8	(352)			13 3/4	(349)

Figure C-17. Exterior Vehicle Crush (NASS) – Front, Test No. MNCBR-3

Date Measured	10/6/20	Test Name:	MNCBR-3	VIN:	KNADE223196557772
Model Year:	2009	Make:	Kia	Model:	Rio



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	38 3/4	(984)
Total Vehicle Length:	167	(4242)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-10 1/8	-(257)
Width of contact and induced crush - Field L:	167	(4242)
Crush measurement spacing interval (L/5) - I:	33 3/8	(848)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-14 3/4	-(375)
Width of Contact Damage:	167	(4242)
Distance from vehicle c.g. to center of contact damage - D_C:	-14 3/4	-(375)

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	N/a	NA	-98 1/4	-(2496)	26	(660)	2 3/4	(70)	NA	NA
C_2	N/a	NA	-64 7/8	-(1648)	4	(102)			NA	NA
C_3	5 1/2	(140)	-31 1/2	-(800)	3 5/8	(92)			- 7/8	-(22)
C_4	5 5/8	(143)	1 7/8	(48)	3 3/4	(95)			- 7/8	-(22)
C_5	N/a	NA	35 1/4	(895)	3 1/4	(83)			NA	NA
C_6	N/a	NA	68 5/8	(1743)	20 1/4	(514)			NA	NA
C_{MAX}	12 3/8	(314)	58 1/2	(1486)	6	(152)			3 5/8	(92)

Figure C-18. Exterior Vehicle Crush (NASS) – Side, Test No. MNCBR-3

Test Name: MNCBR-3 VIN: KNADE223196557772

Model Year: 2009 Make: Kia Model: Rio

Passenger Side Maximum Deformations							
Reference Set 1				**Reference Set 2**			
Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]	Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Roof	0.0	≤ 4	Z	Roof	0.4	≤ 4	Z
Windshield[D]	0.0	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	0.3	≤ 5	Y, Z	A-Pillar Maximum	0.8	≤ 5	Z
A-Pillar Lateral	0.2	≤ 3	Y	A-Pillar Lateral	-0.4	≤ 3	Y
B-Pillar Maximum	0.3	≤ 5	Z	B-Pillar Maximum	0.4	≤ 5	Z
B-Pillar Lateral	0.0	≤ 3	Y	B-Pillar Lateral	-0.5	≤ 3	Y
Toe Pan - Wheel Well	1.5	≤ 9	X	Toe Pan - Wheel Well	1.7	≤ 9	X
Side Front Panel	2.5	≤ 12	Y	Side Front Panel	2.4	≤ 12	Y
Side Door (above seat)	0.1	≤ 9	Y	Side Door (above seat)	-2.1	≤ 9	Y
Side Door (below seat)	0.5	≤ 12	Y	Side Door (below seat)	0.4	≤ 12	Y
Floor Pan	2.2	≤ 12	Z	Floor Pan	1.8	≤ 12	Z
Dash - no MASH requirement	0.5	NA	X, Y, Z	Dash - no MASH requirement	0.7	NA	X, Y, Z

[A] Items highlighted in red do not meet MASH allowable deformations.

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

[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment. If direction of deformation is "NA" then no intrusion is recorded and deformation will be 0.

[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle crush:

Points 2 and 7 on the floor pan were comprimised and we deleted the points.

Figure C-19. Maximum Occupant Compartment Deformations by Location, Test No. MNCBR-3

Appendix D. Accelerometer and Rate Transducer Data Plots, Test No. MNCBR-1

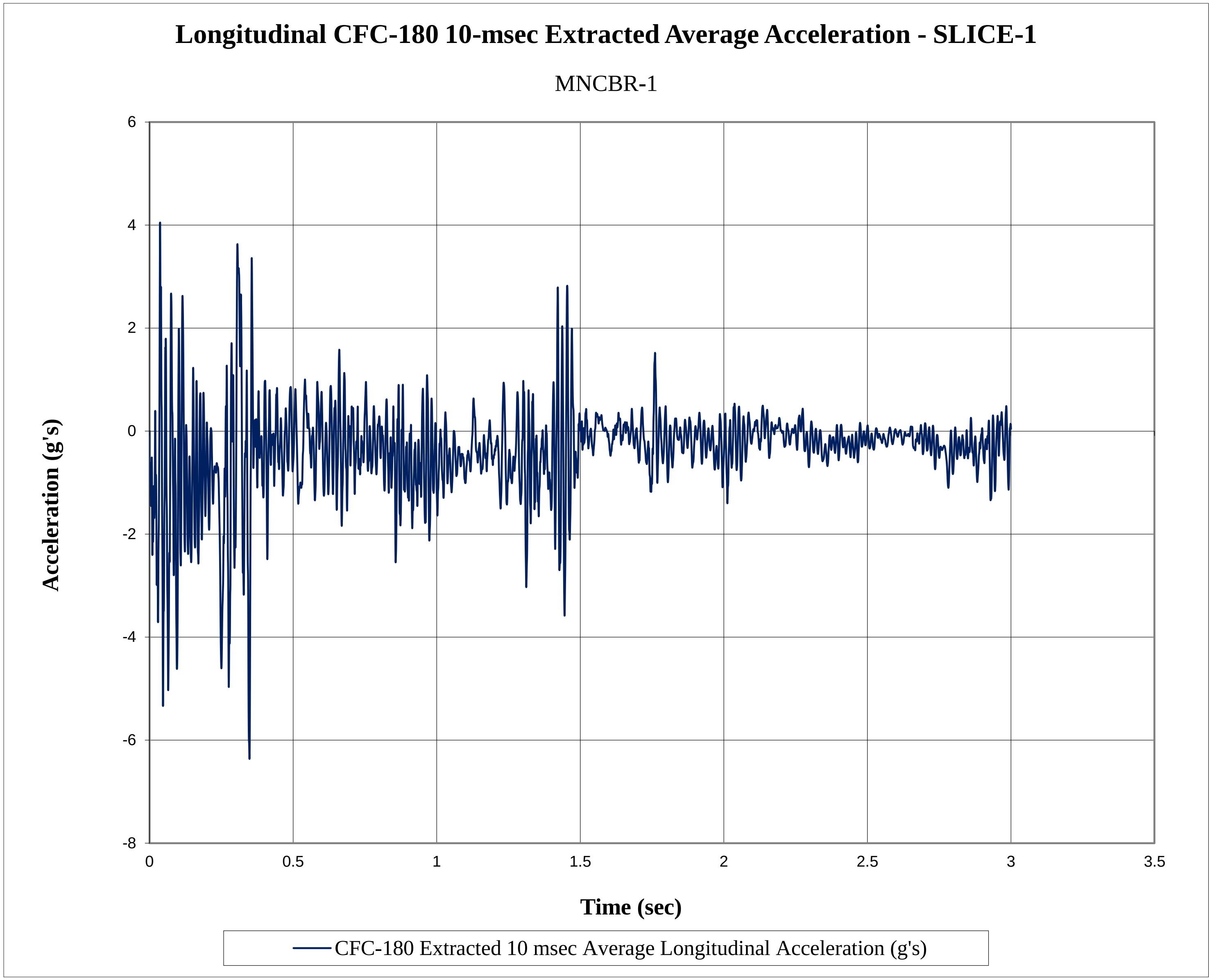


Figure D-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MNCBR-1

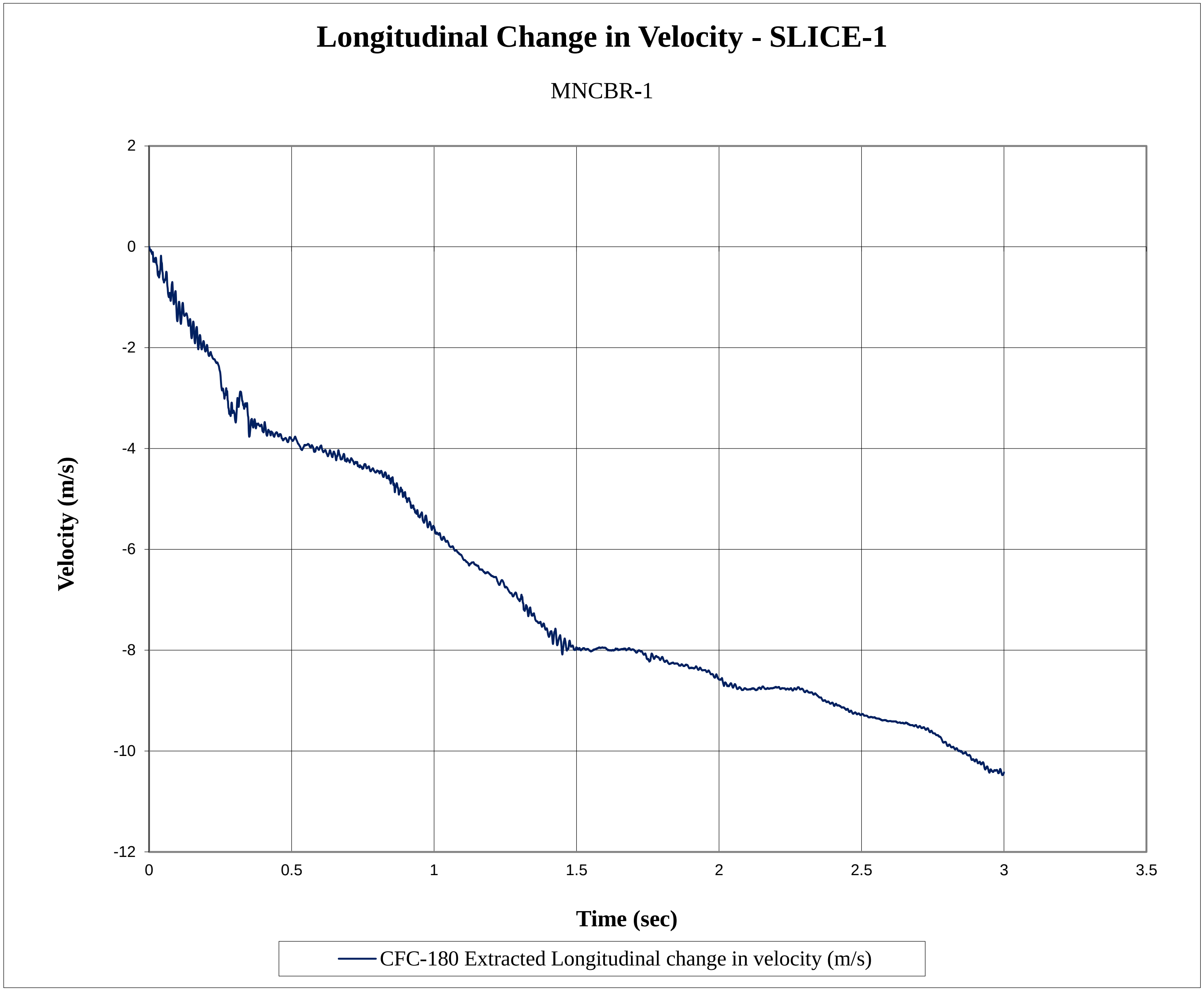


Figure D-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MNCBR-1

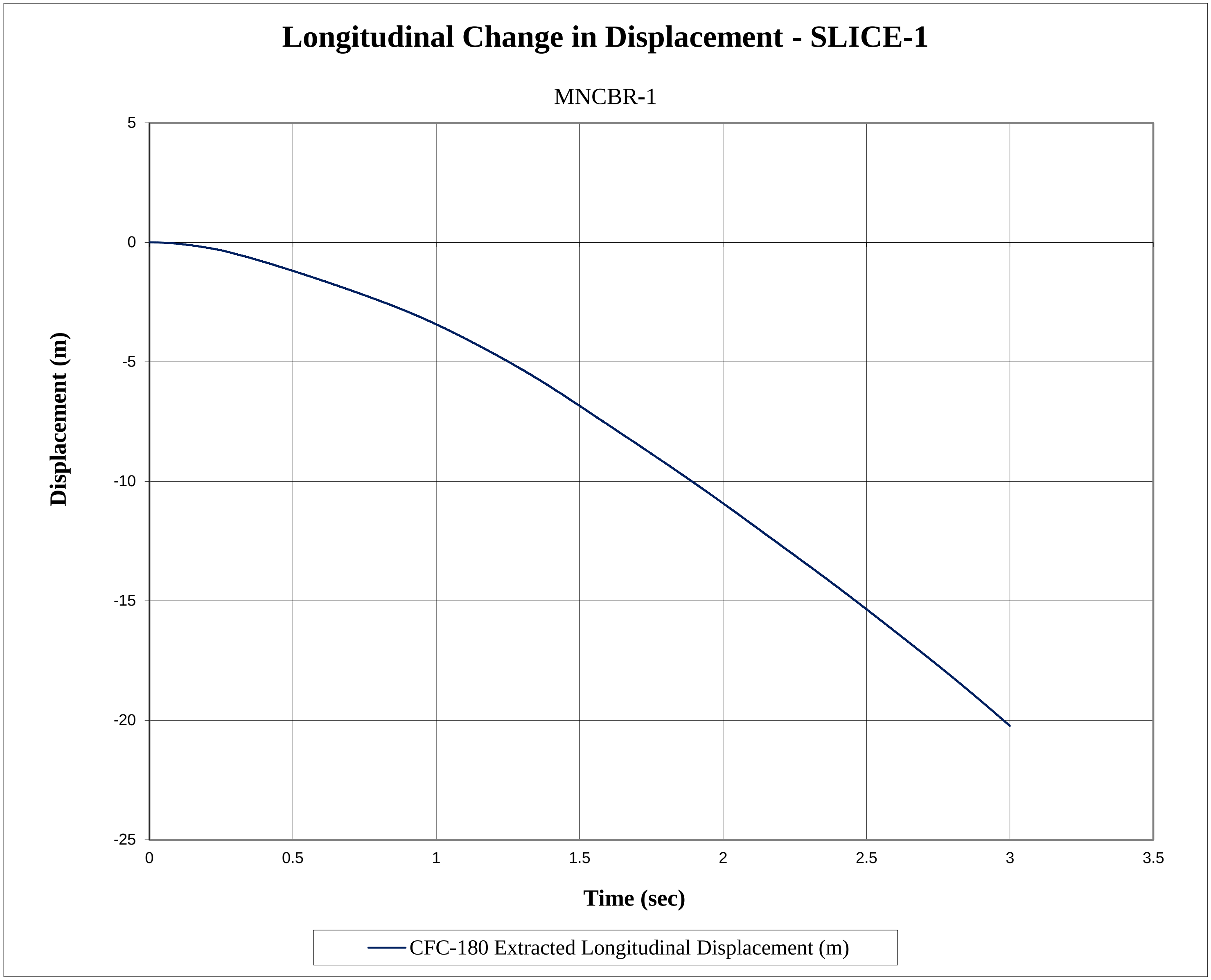


Figure D-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MNCBR-1

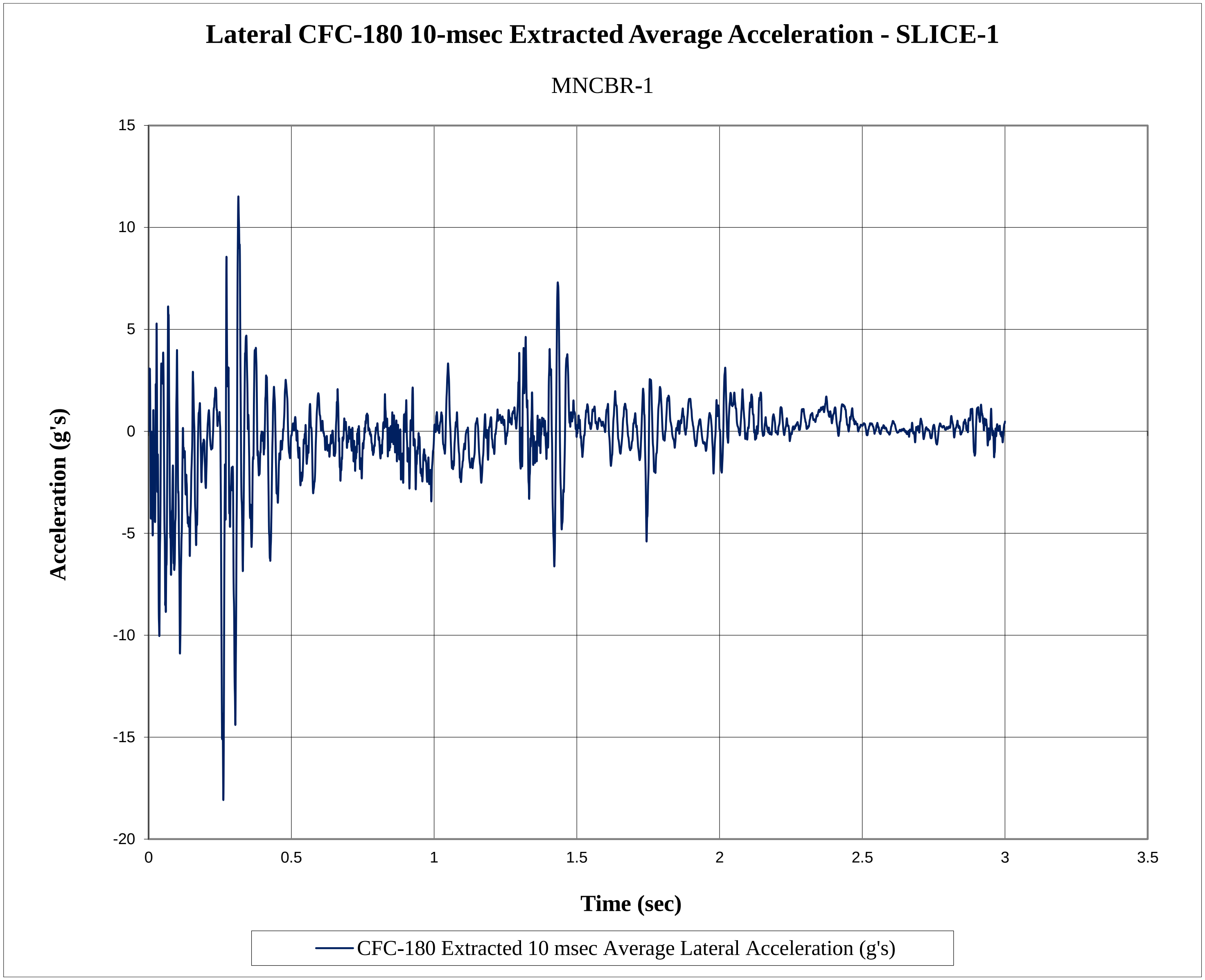


Figure D-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MNCBR-1

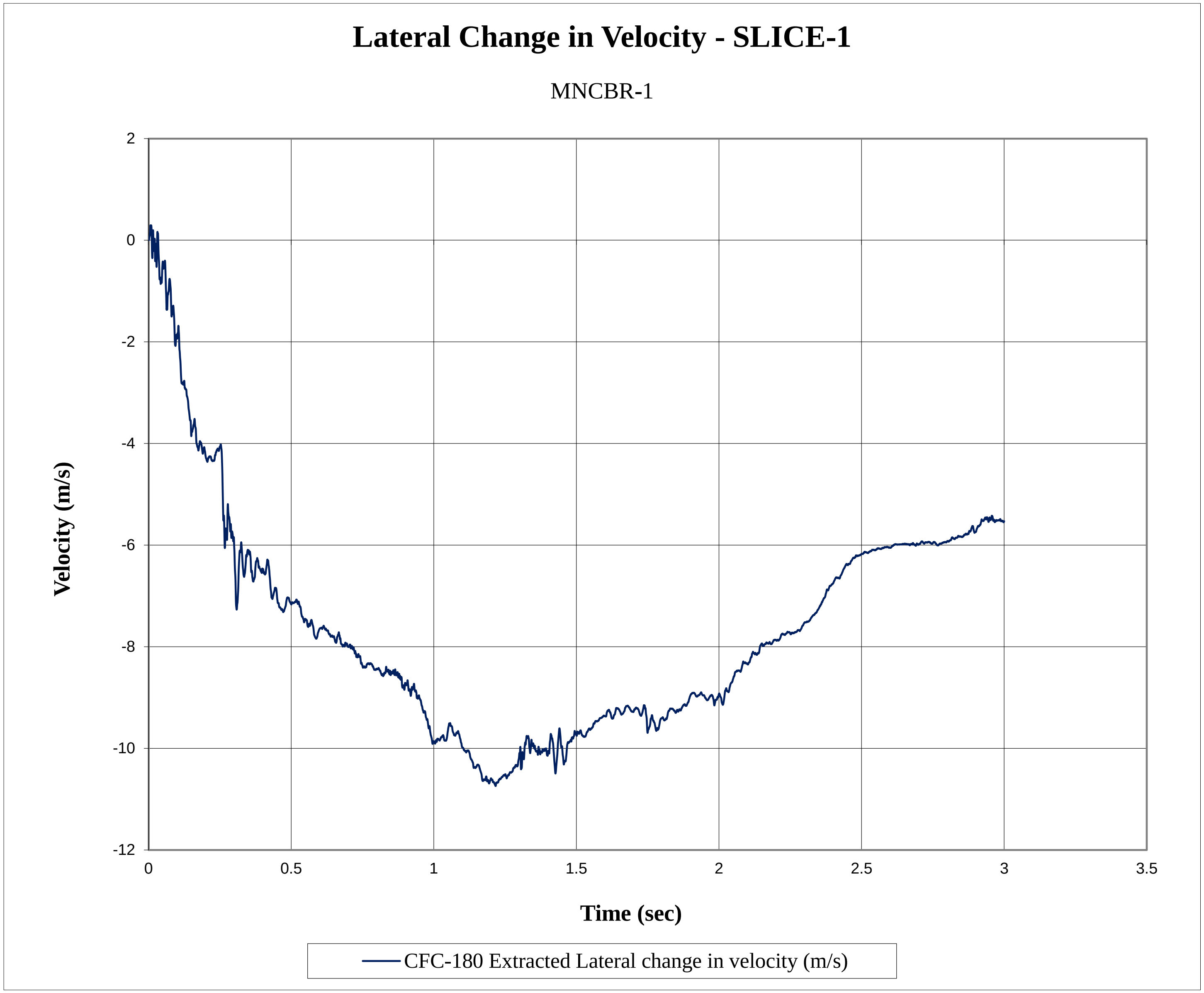


Figure D-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MNCBR-1

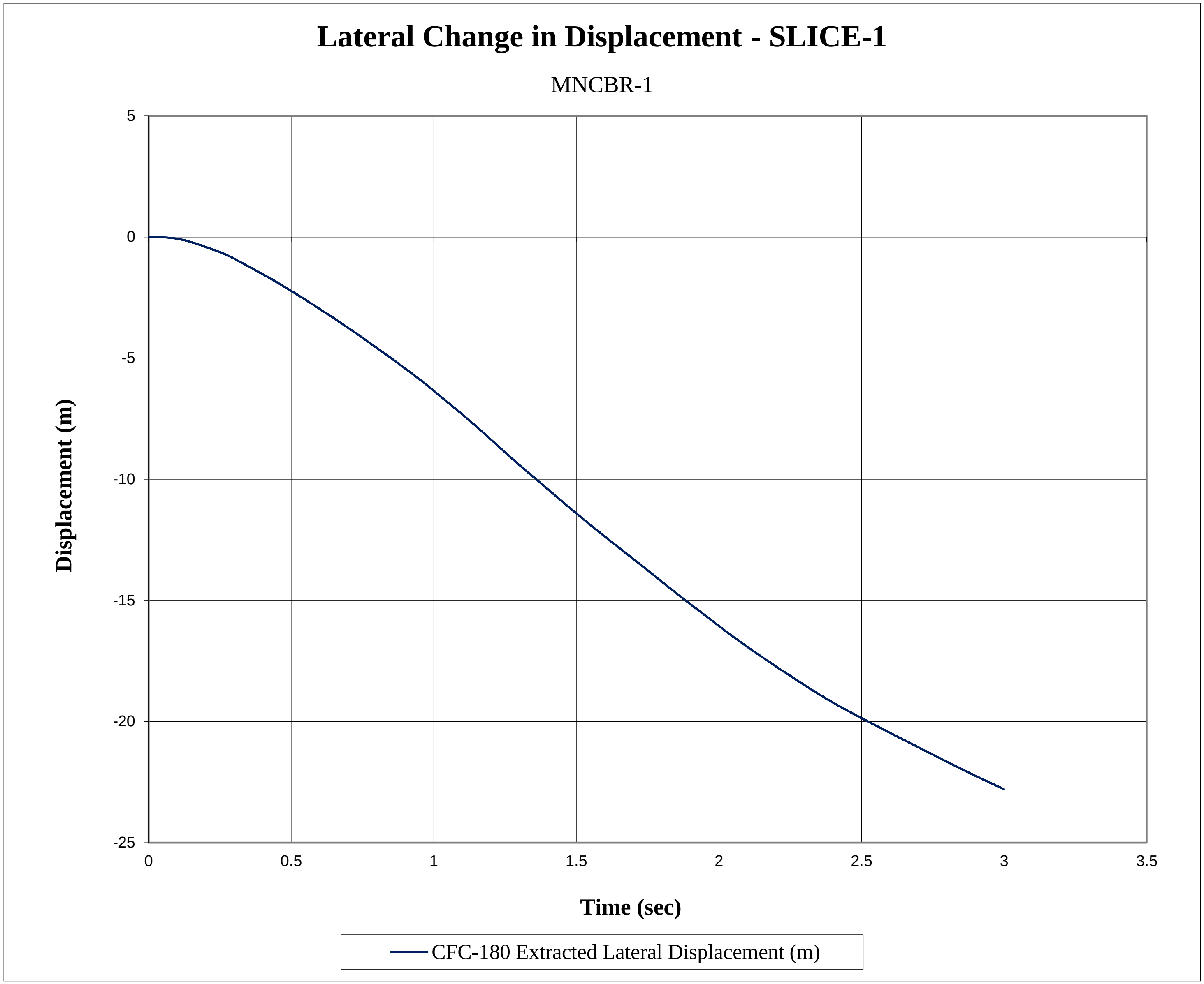


Figure D-6. Lateral Occupant Displacement (SLICE-1), Test No. MNCBR-1

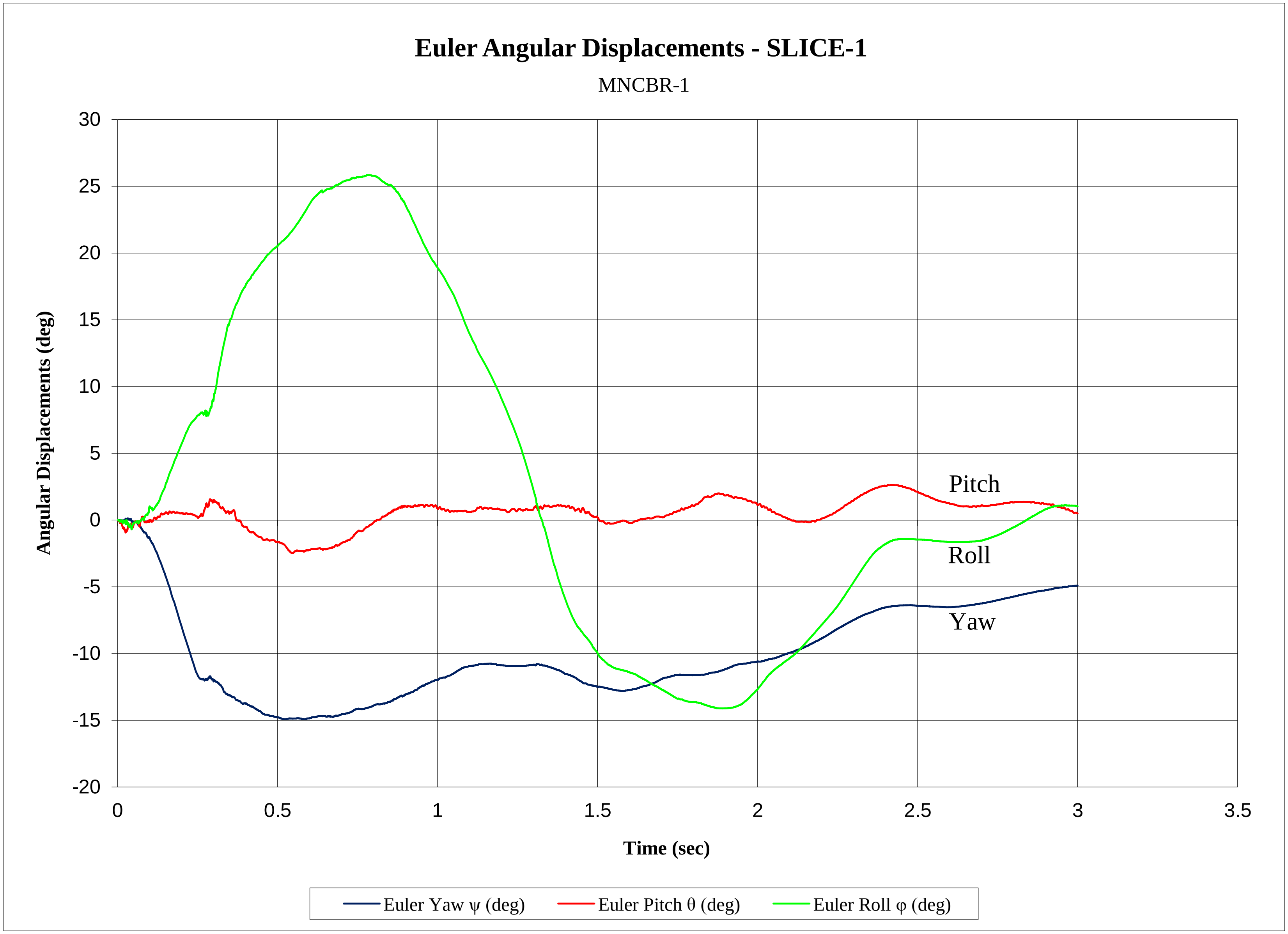


Figure D-7. Vehicle Angular Displacements (SLICE-1), Test No. MNCBR-1

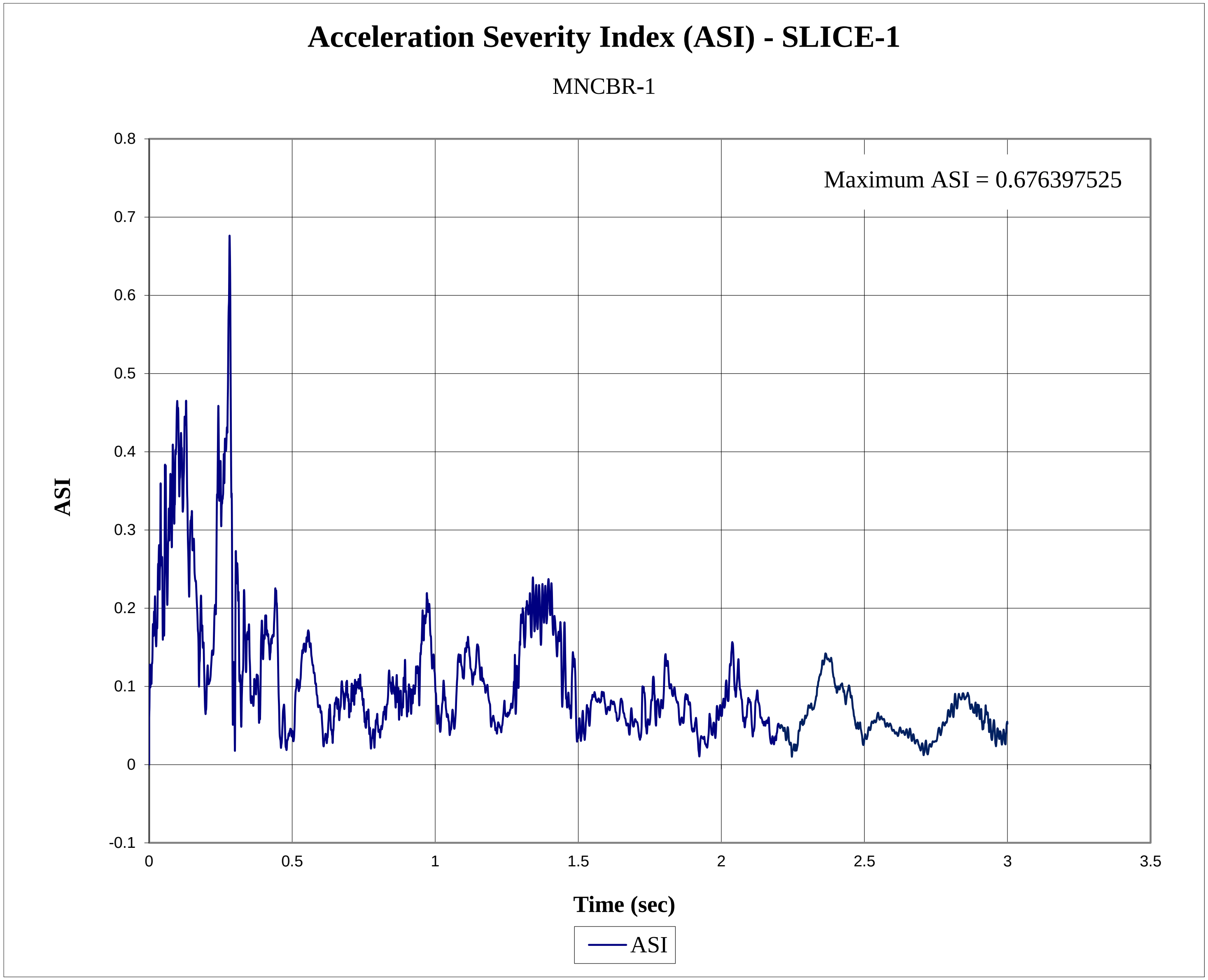


Figure D-8. Acceleration Severity Index (SLICE-1), Test No. MNCBR-1

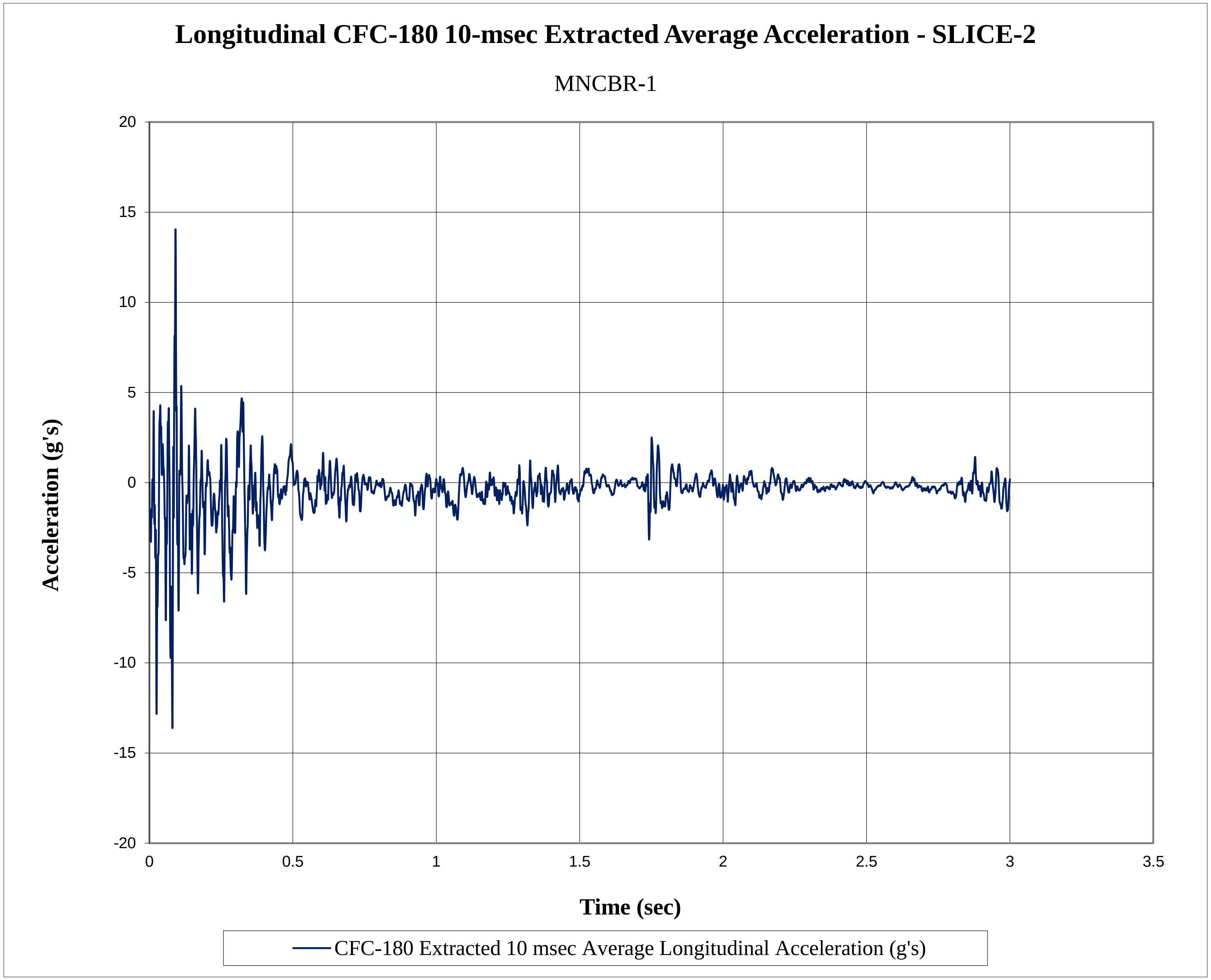


Figure D-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MNCBR-1

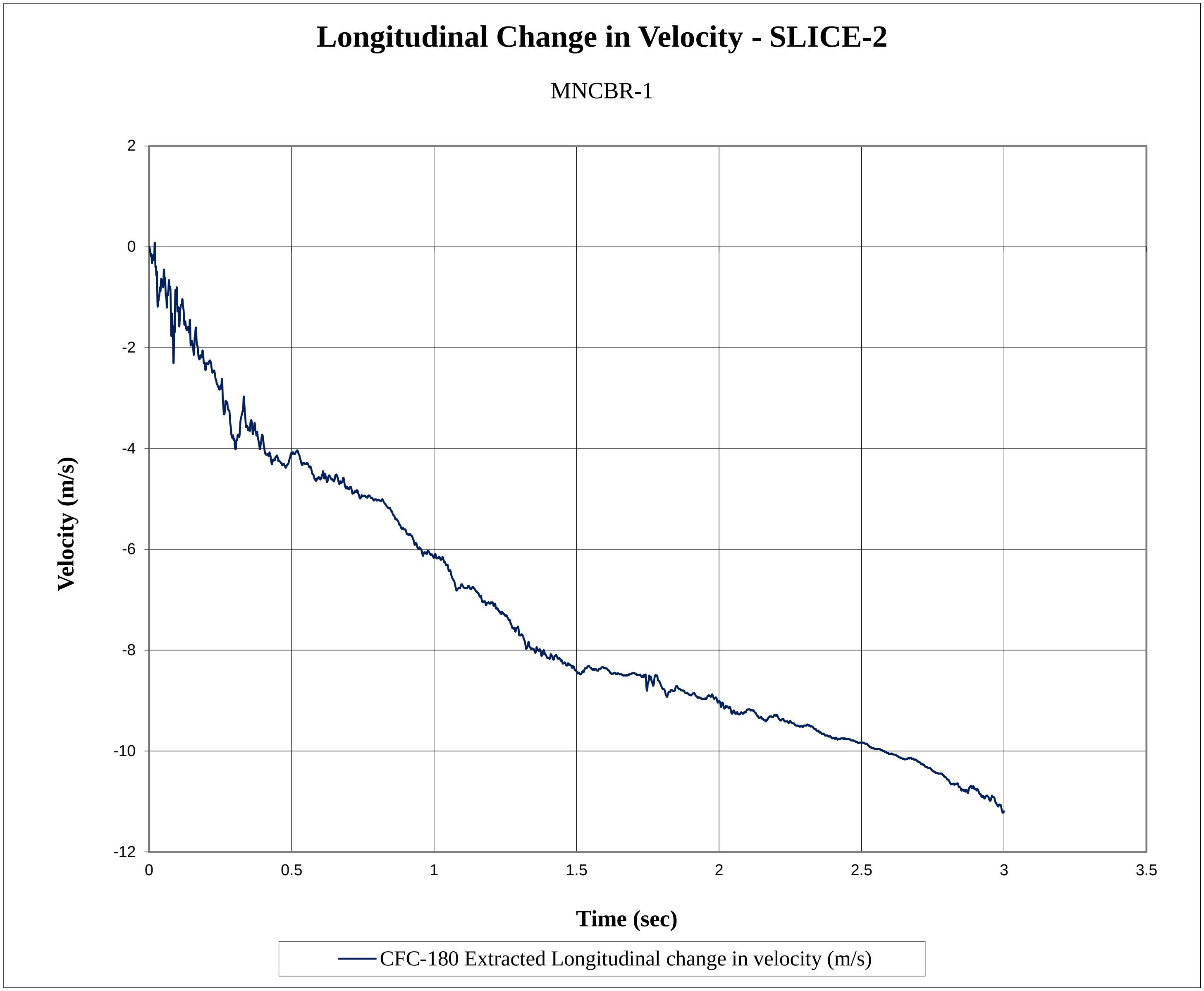


Figure D-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MNCBR-1

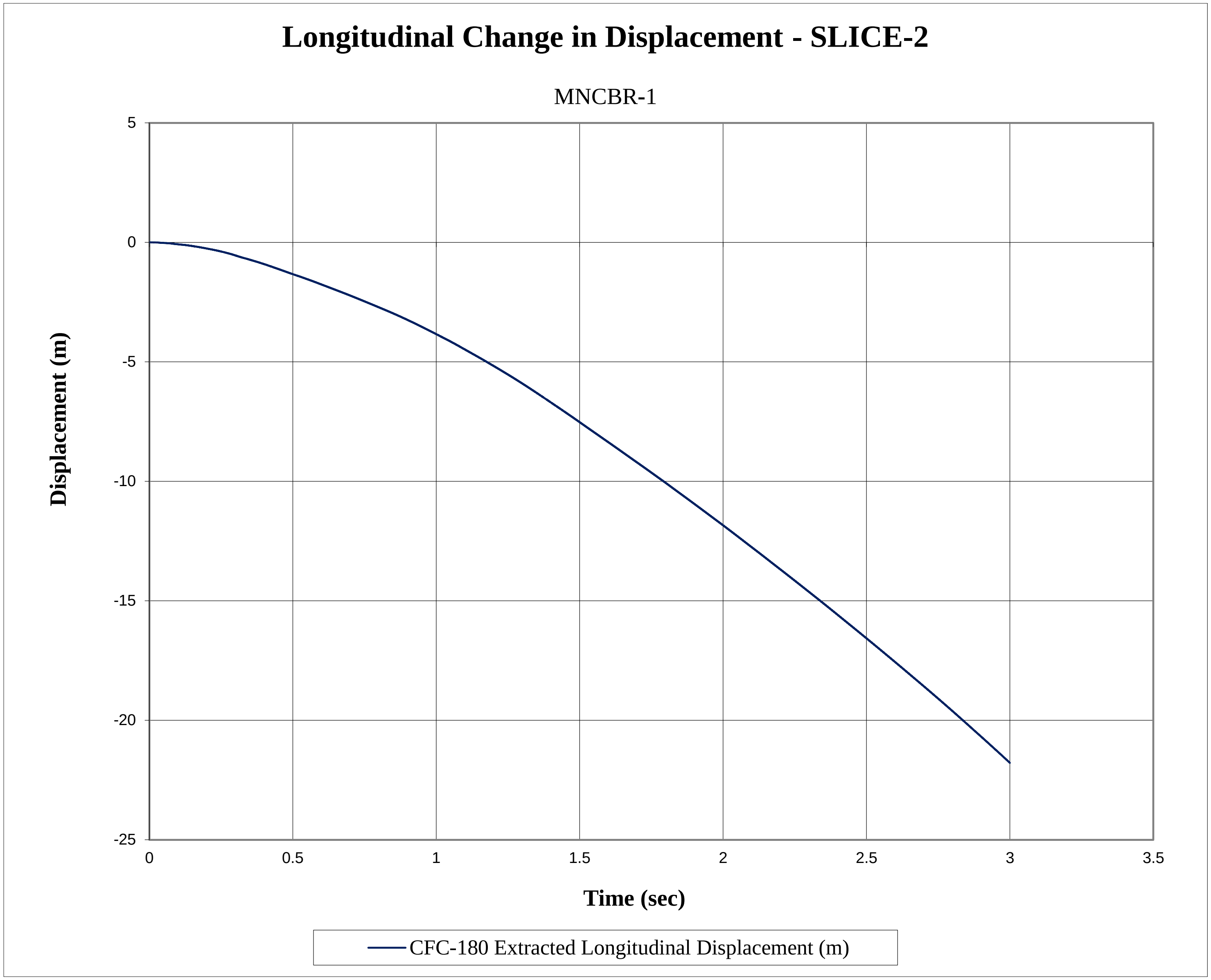


Figure D-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MNCBR-1

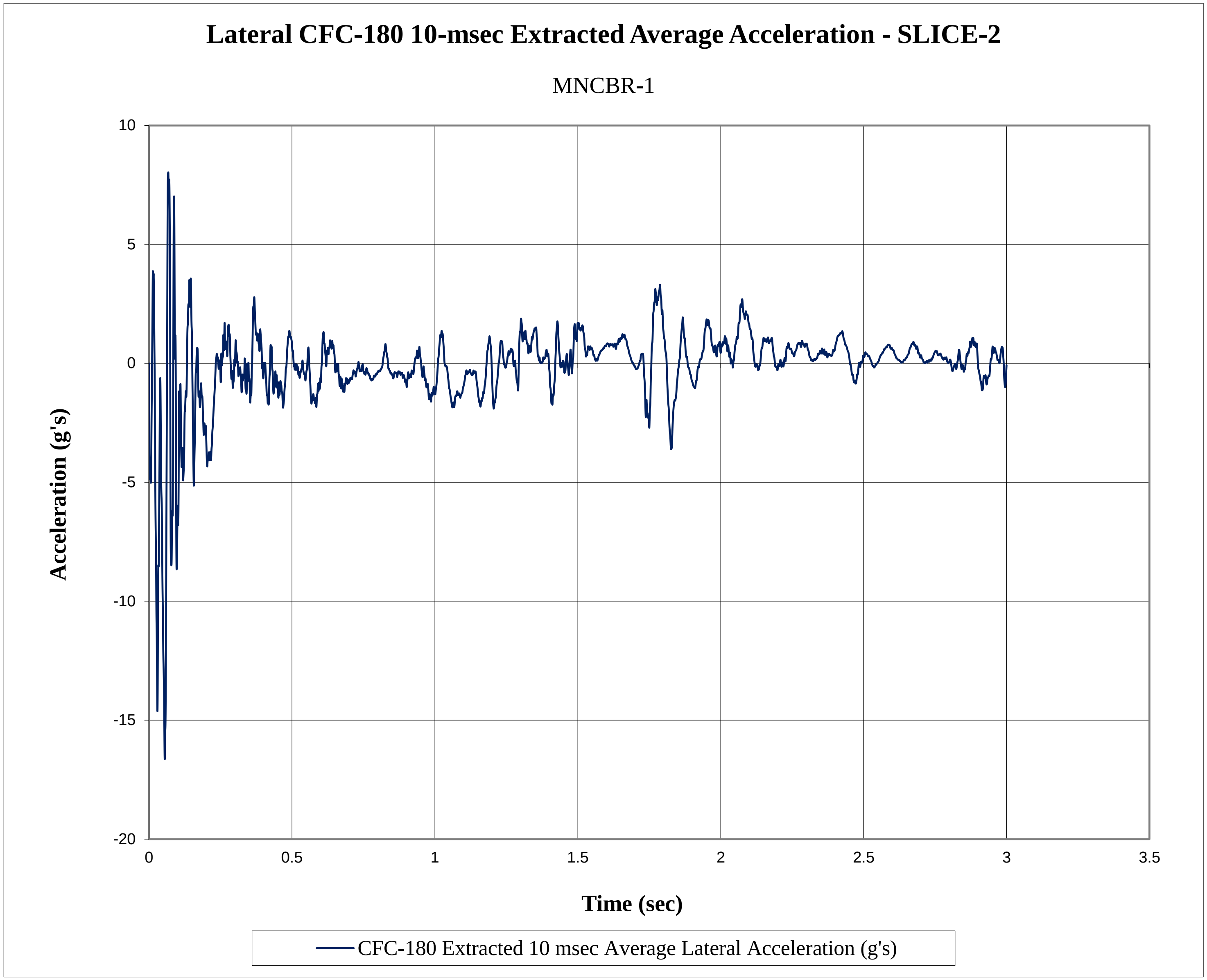


Figure D-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MNCBR-1

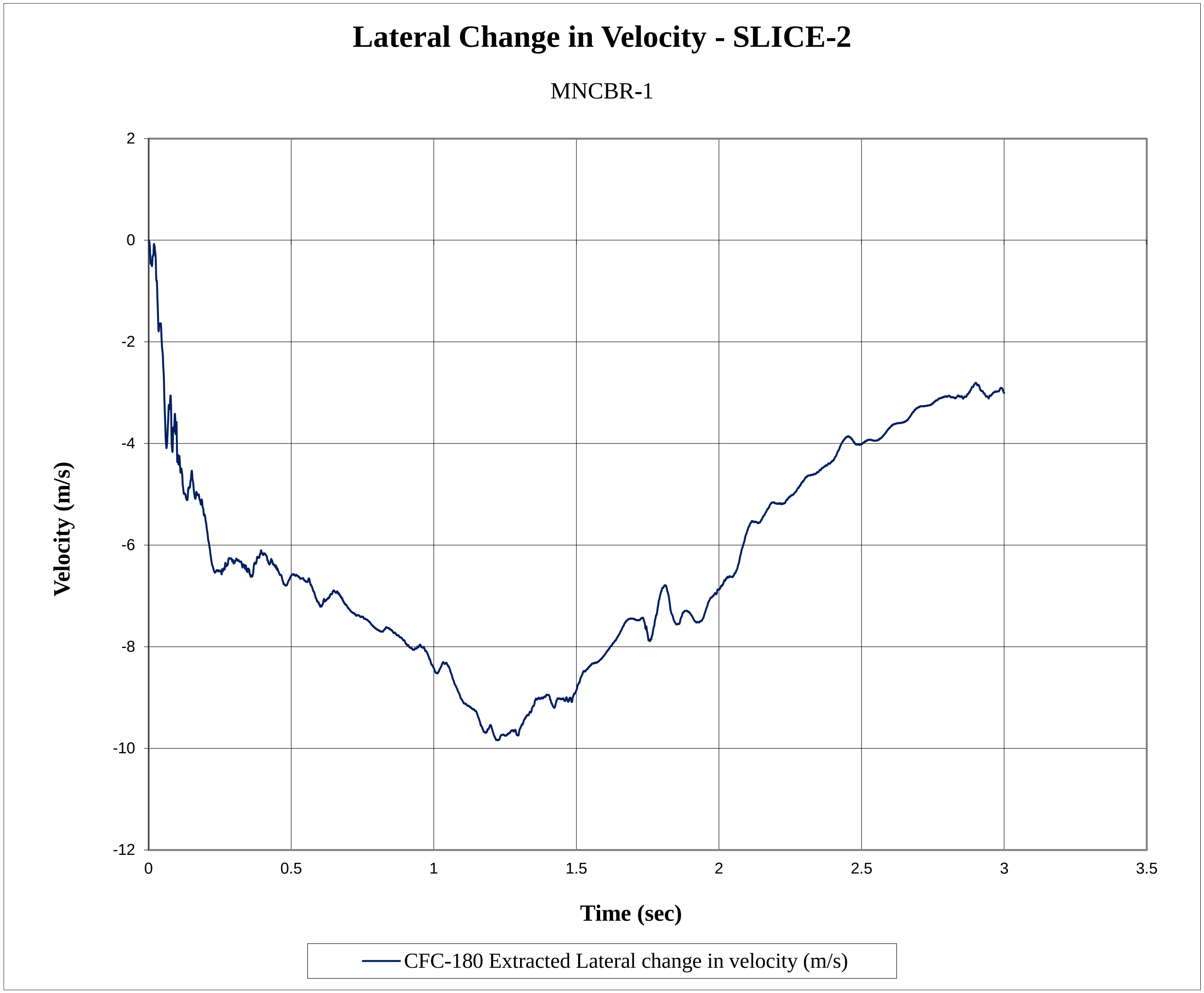


Figure D-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MNCBR-1

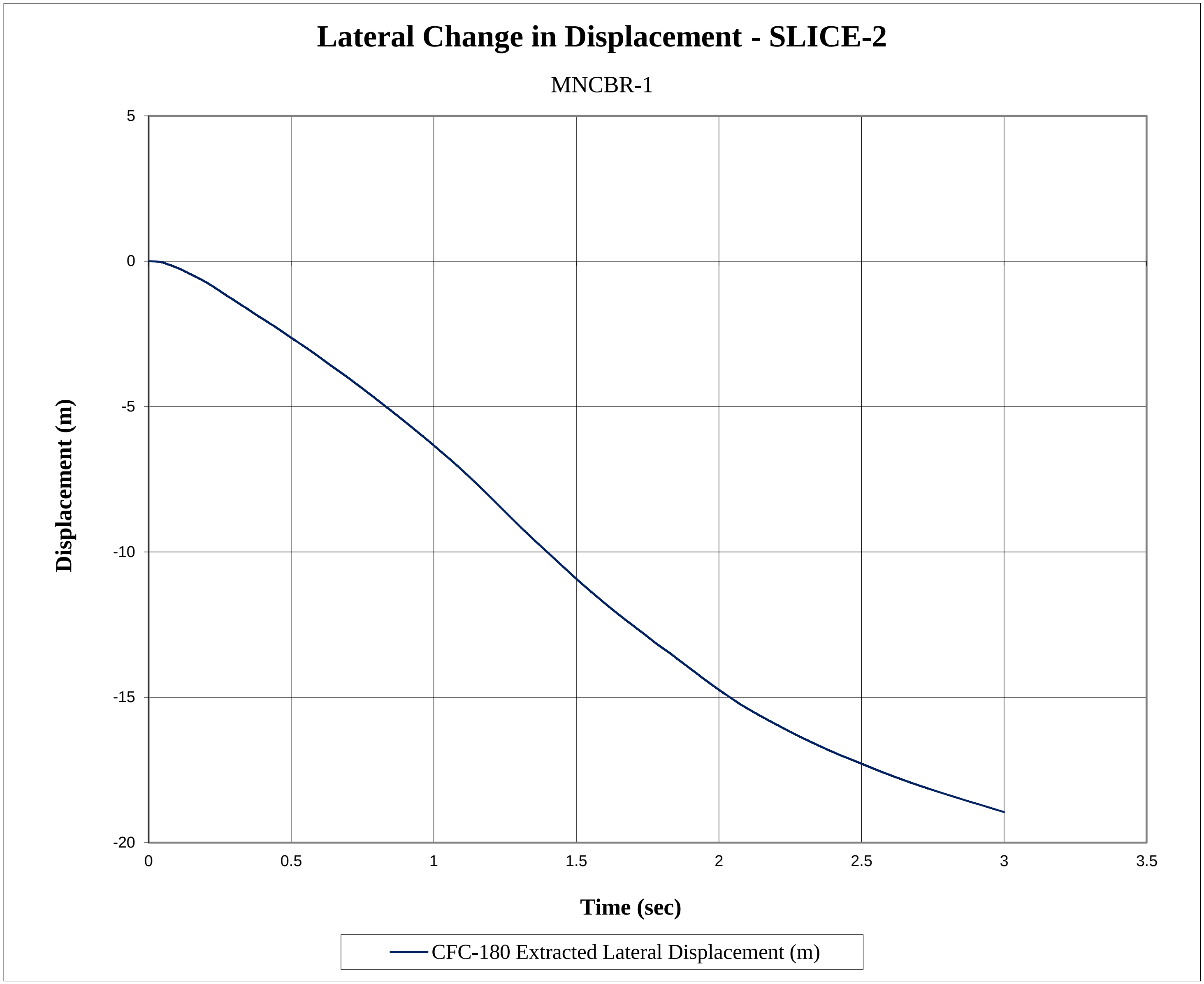


Figure D-14. Lateral Occupant Displacement (SLICE-2), Test No. MNCBR-1

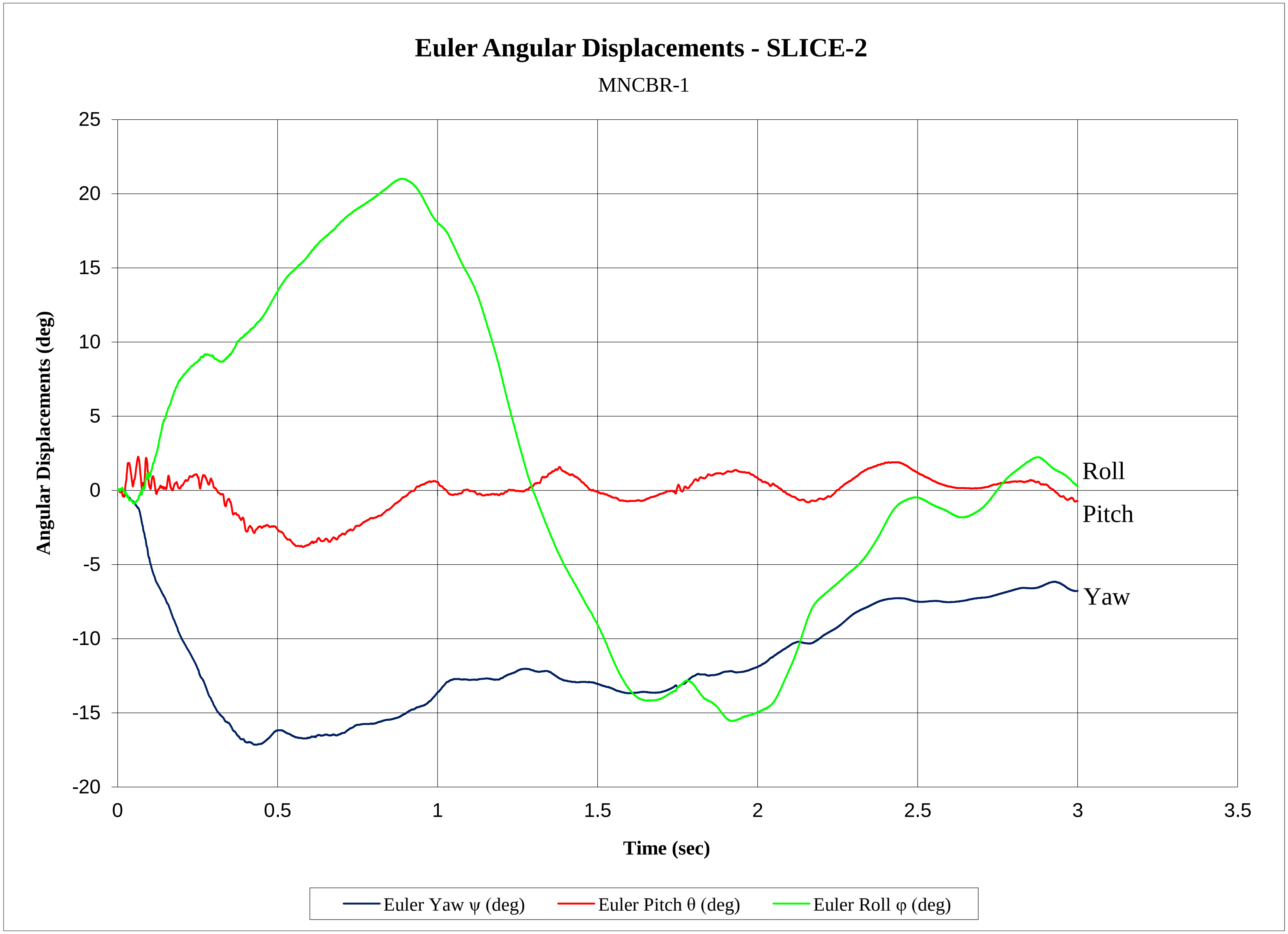


Figure D-15. Vehicle Angular Displacements (SLICE-2), Test No. MNCBR-1

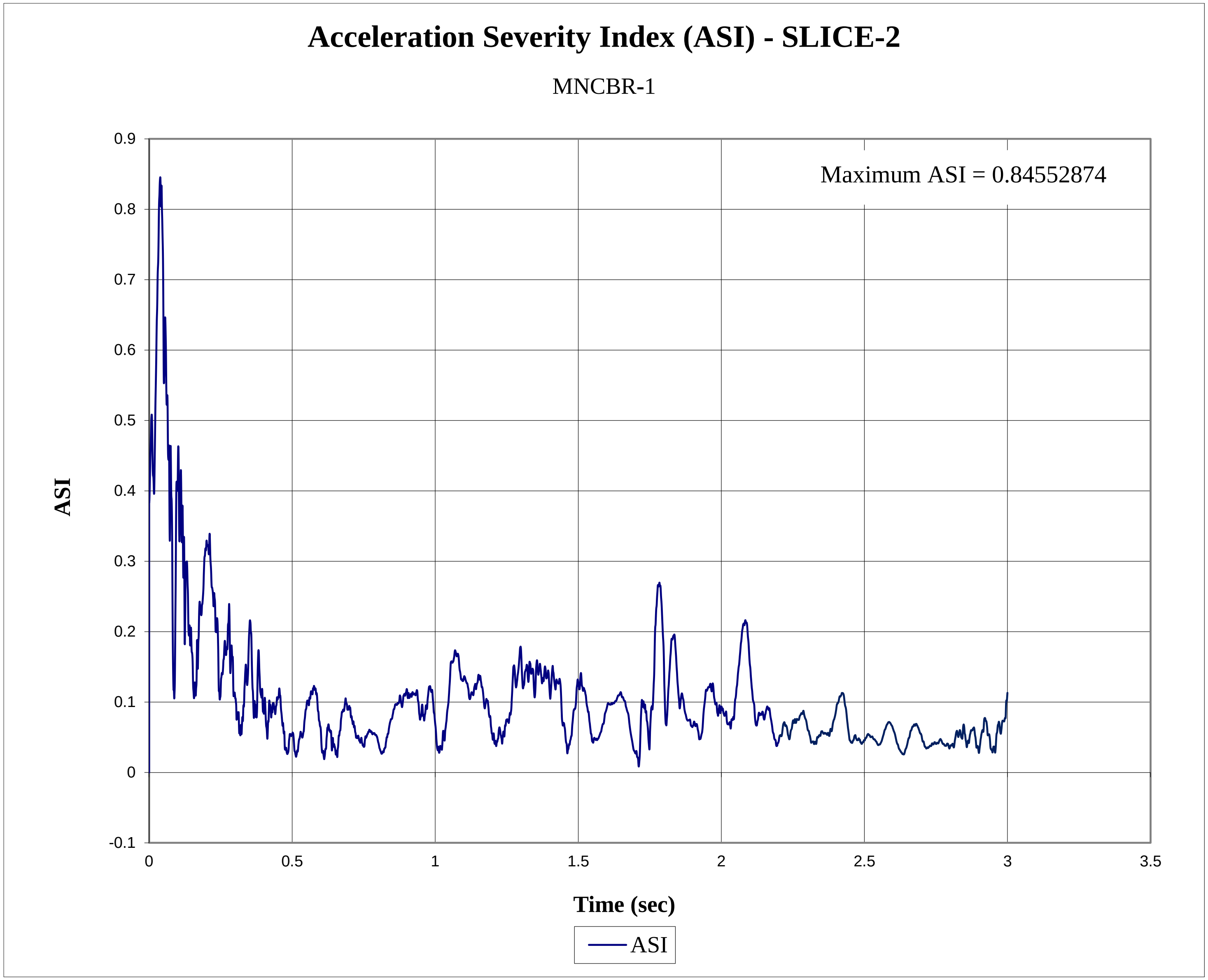


Figure D-16. Acceleration Severity Index (SLICE-2), Test No. MNCBR-1

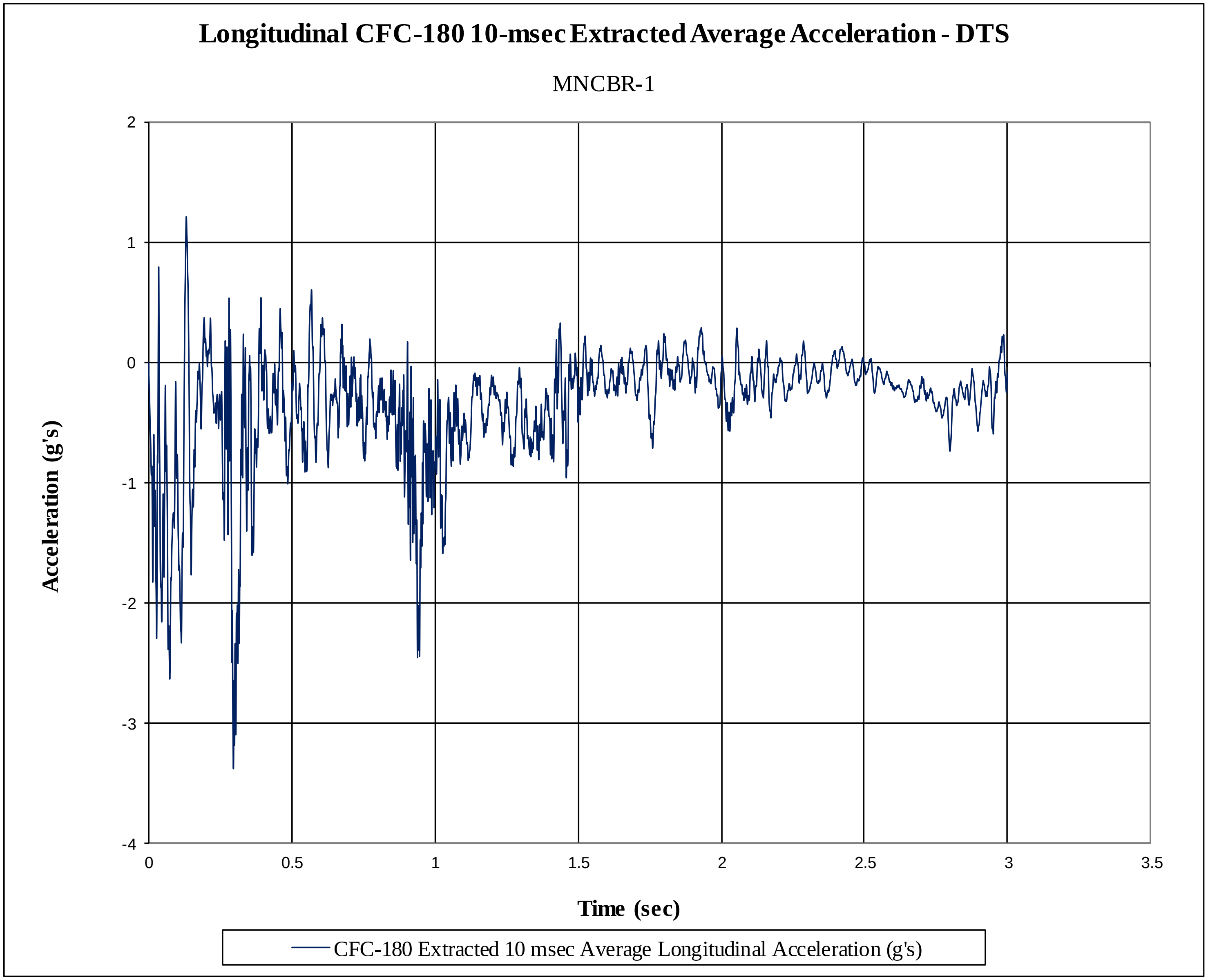


Figure D-17. 10-ms Average Longitudinal Deceleration (TDAS-1), Test No. MNCBR-1

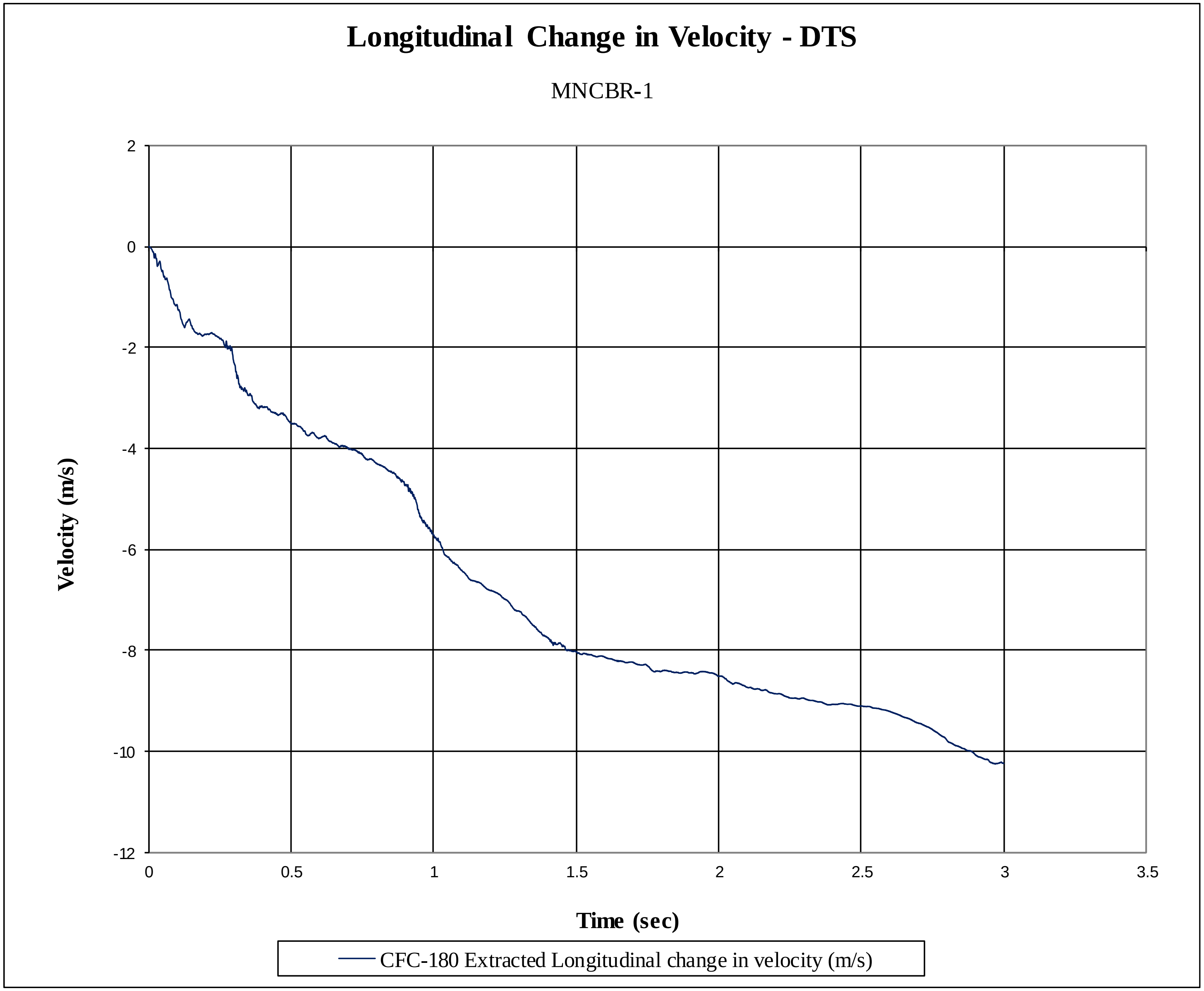


Figure D-18. Longitudinal Occupant Impact Velocity (TDAS-1), Test No. MNCBR-1

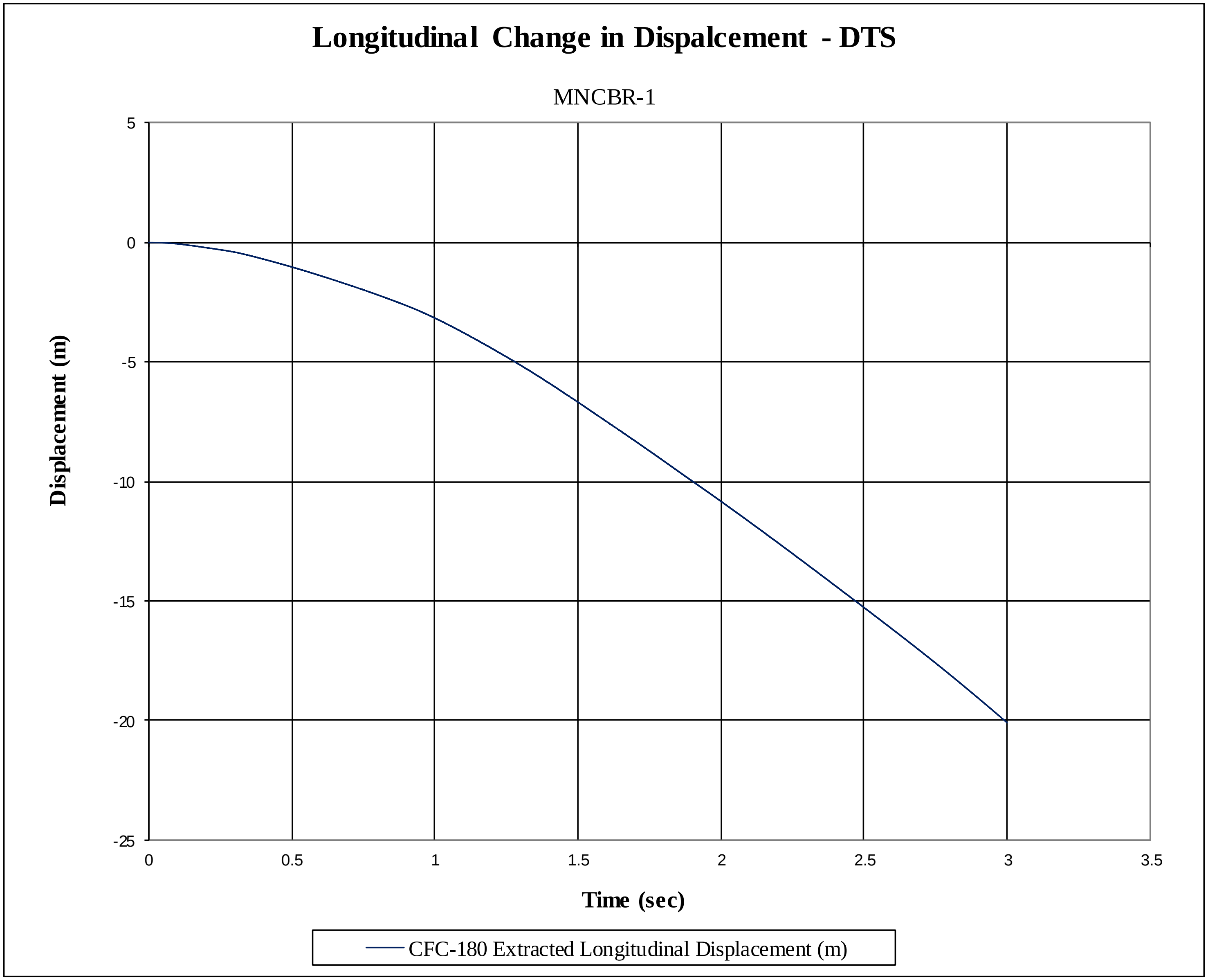


Figure D-19. Longitudinal Occupant Displacement (TDAS-1), Test No. MNCBR-1

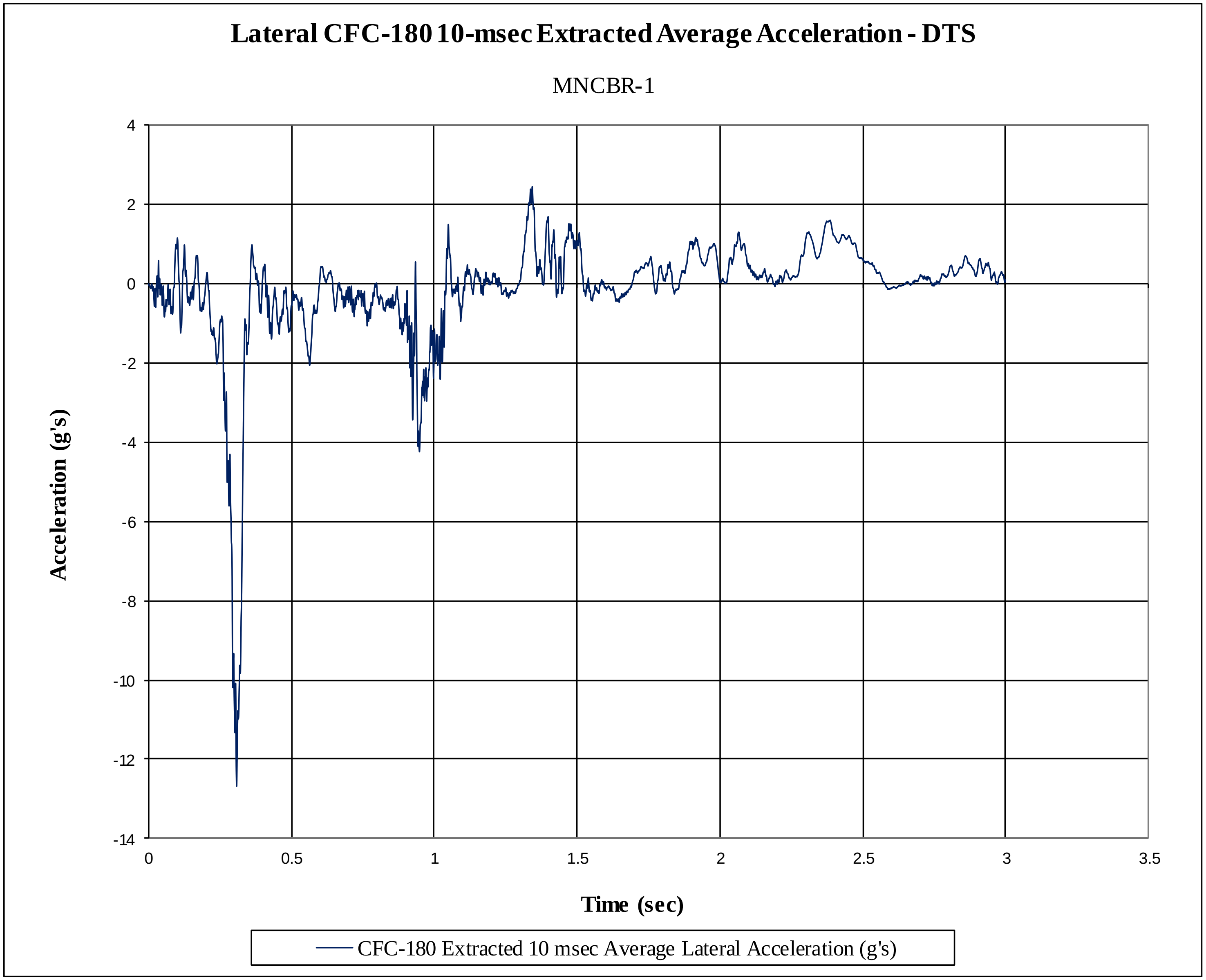


Figure D-20. 10-ms Average Lateral Deceleration (TDAS-1), Test No. MNCBR-1

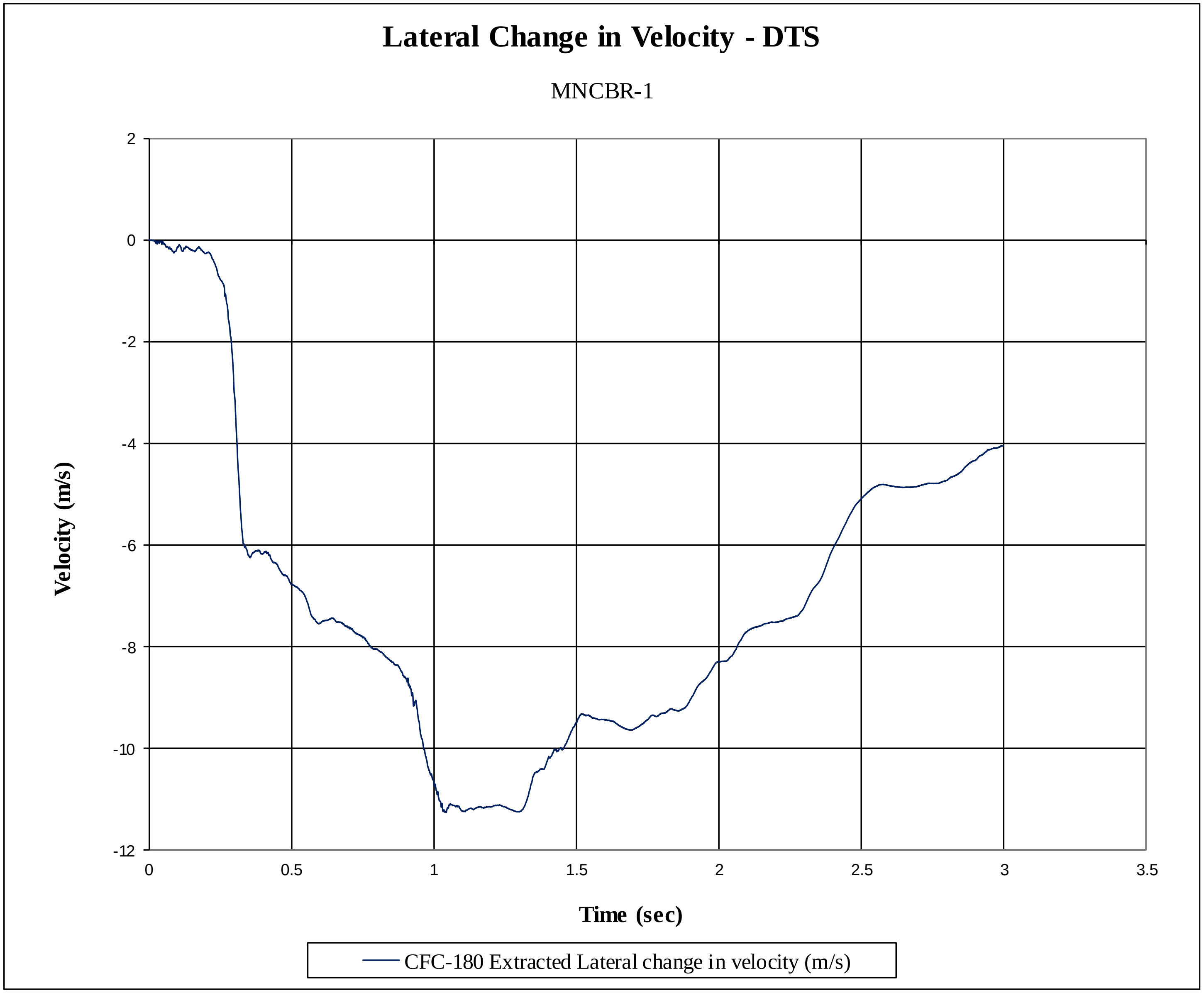


Figure D-21. Lateral Occupant Impact Velocity (TDAS-1), Test No. MNCBR-1

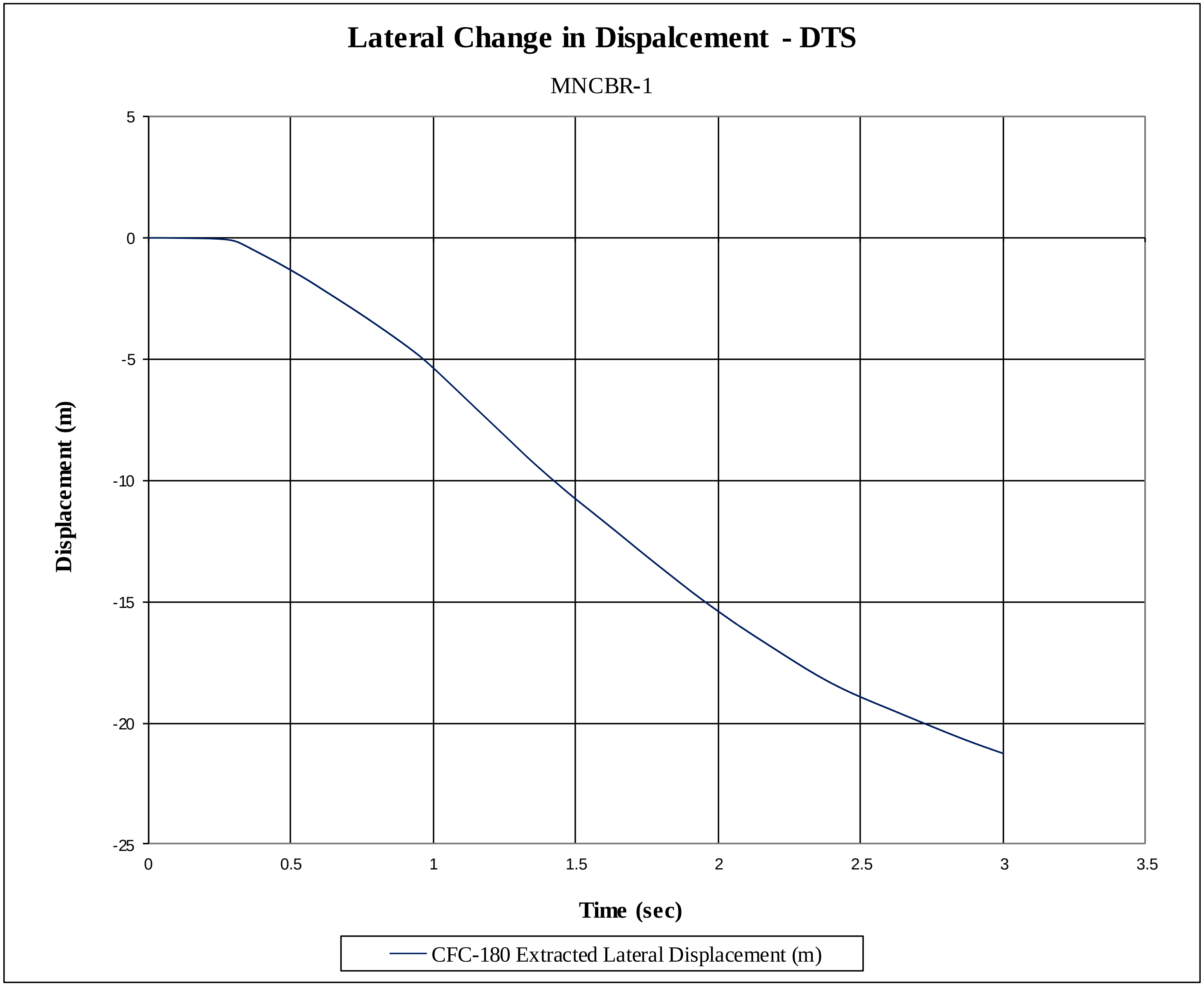


Figure D-22. Lateral Occupant Displacement (TDAS-1), Test No. MNCBR-1

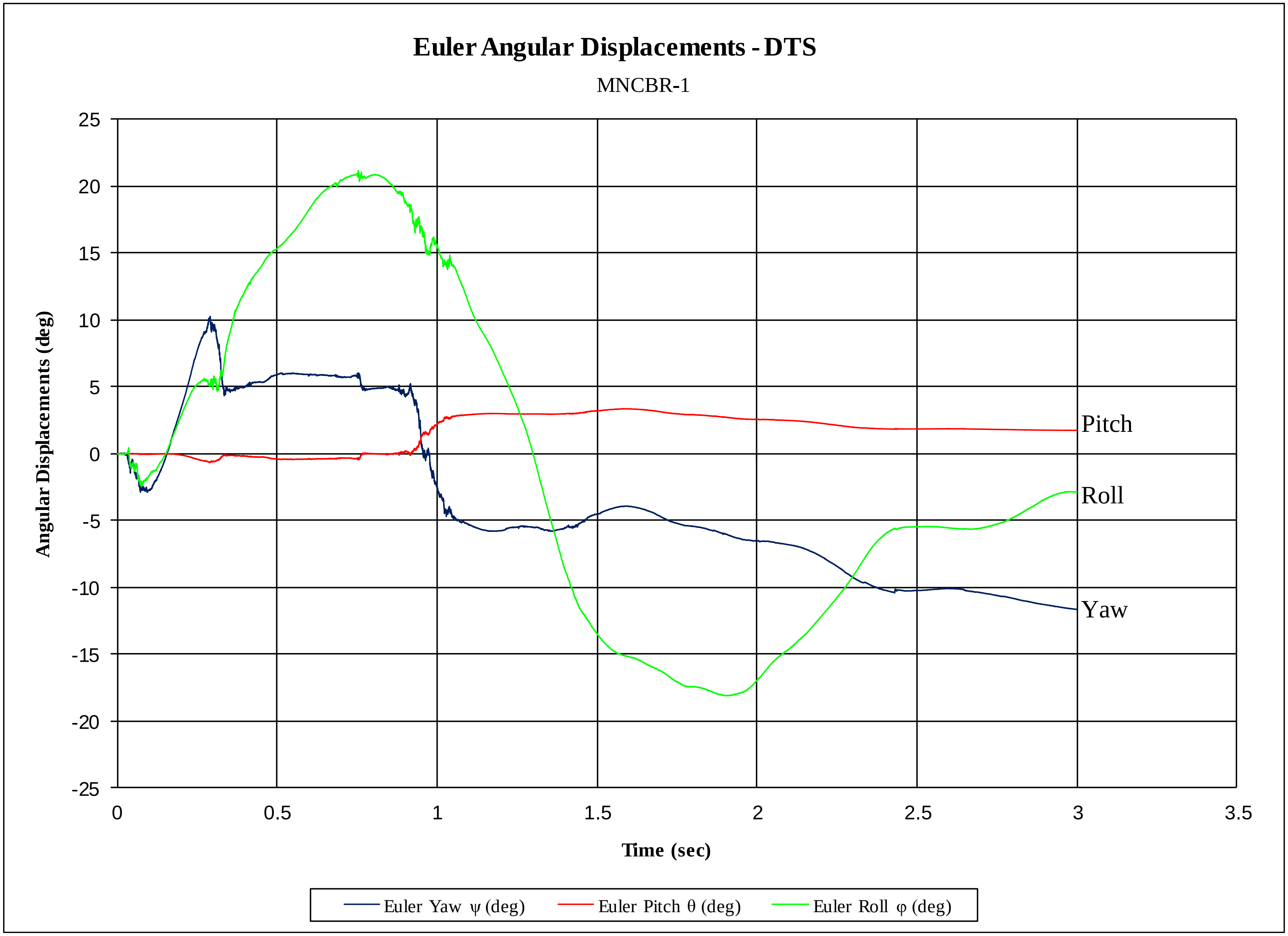


Figure D-23. Vehicle Angular Displacements (TDAS-1), Test No. MNCBR-1

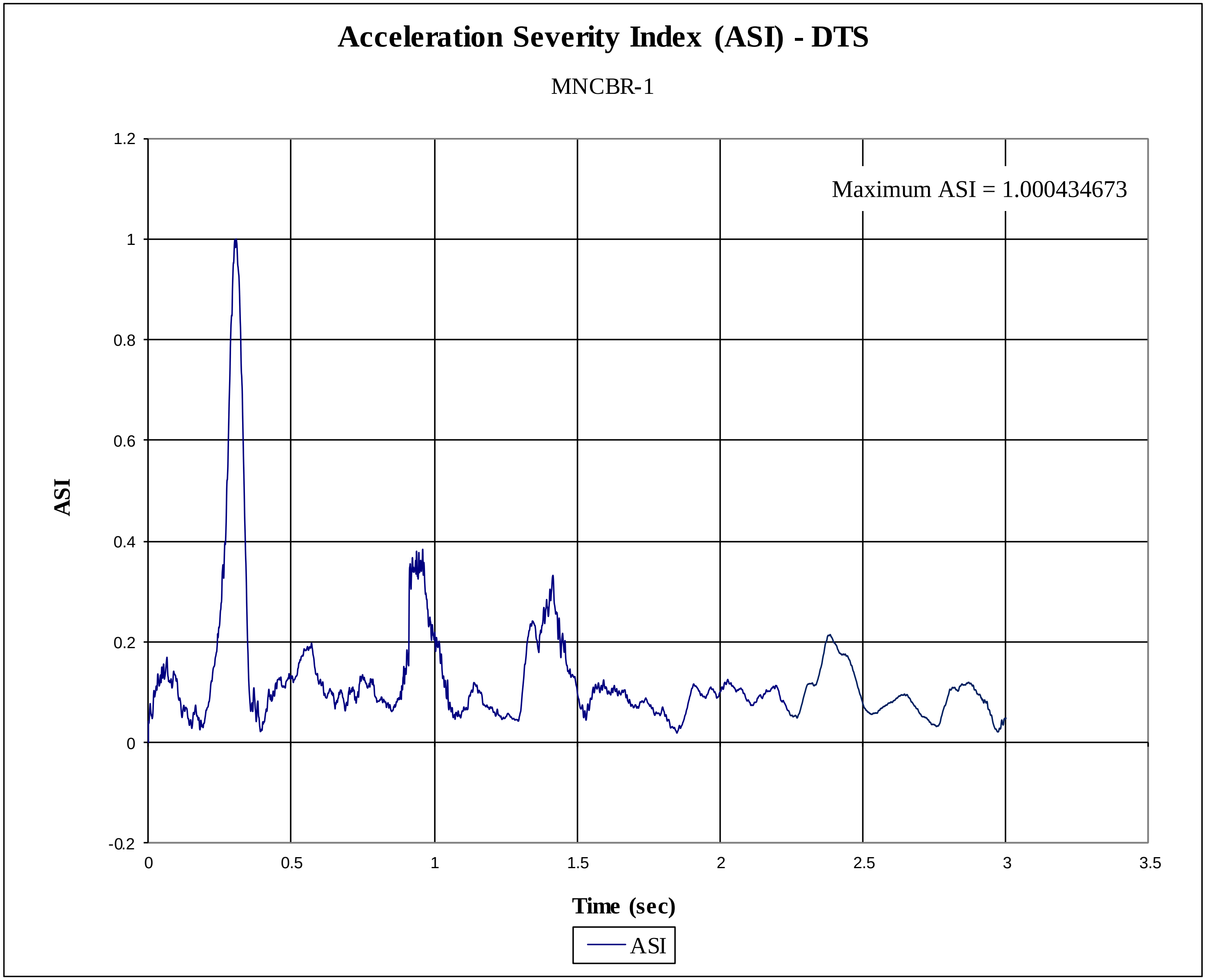


Figure D-24. Acceleration Severity Index (TDAS-1), Test No. MNCBR-1

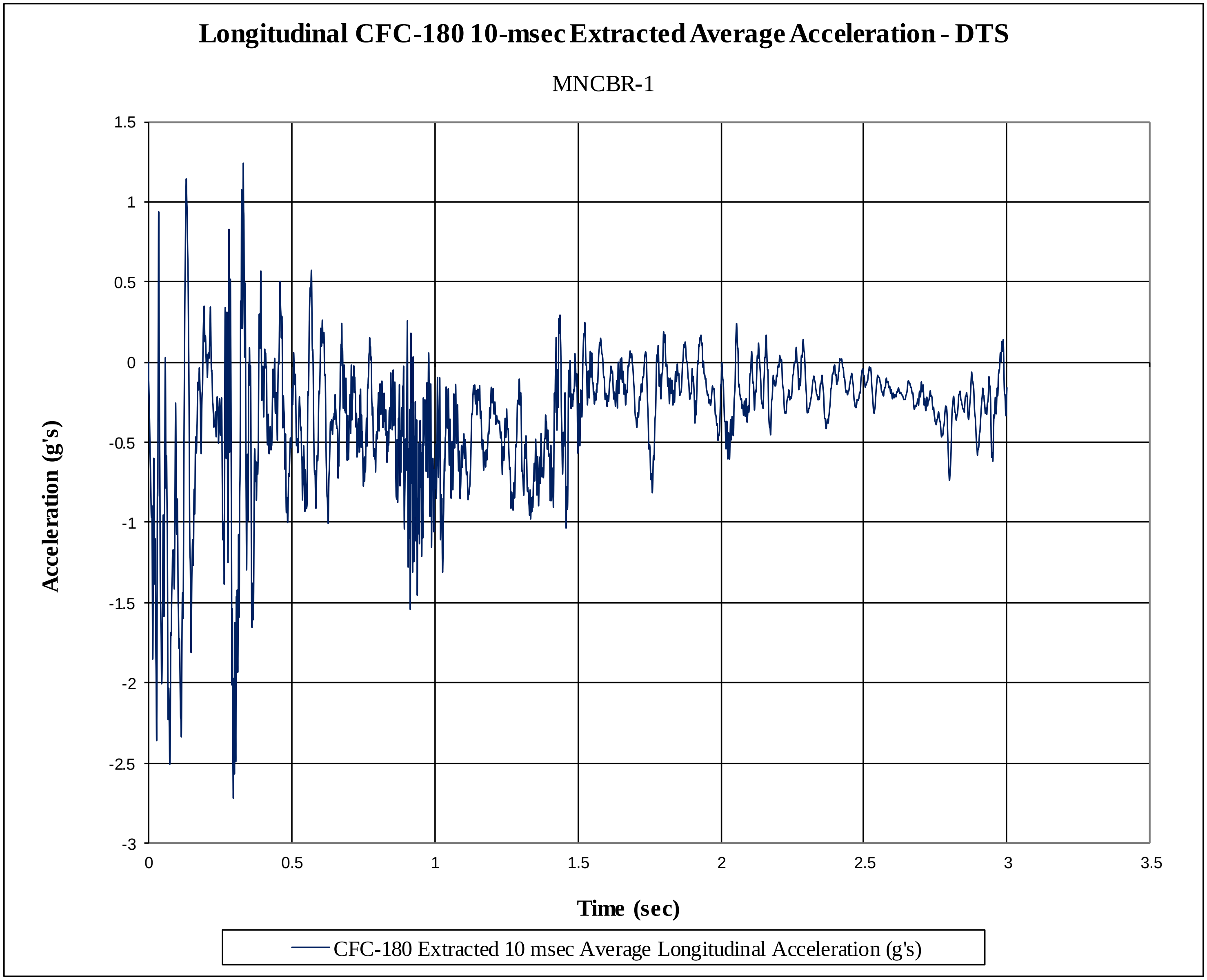


Figure D-25. 10-ms Average Longitudinal Deceleration (TDAS-2), Test No. MNCBR-1

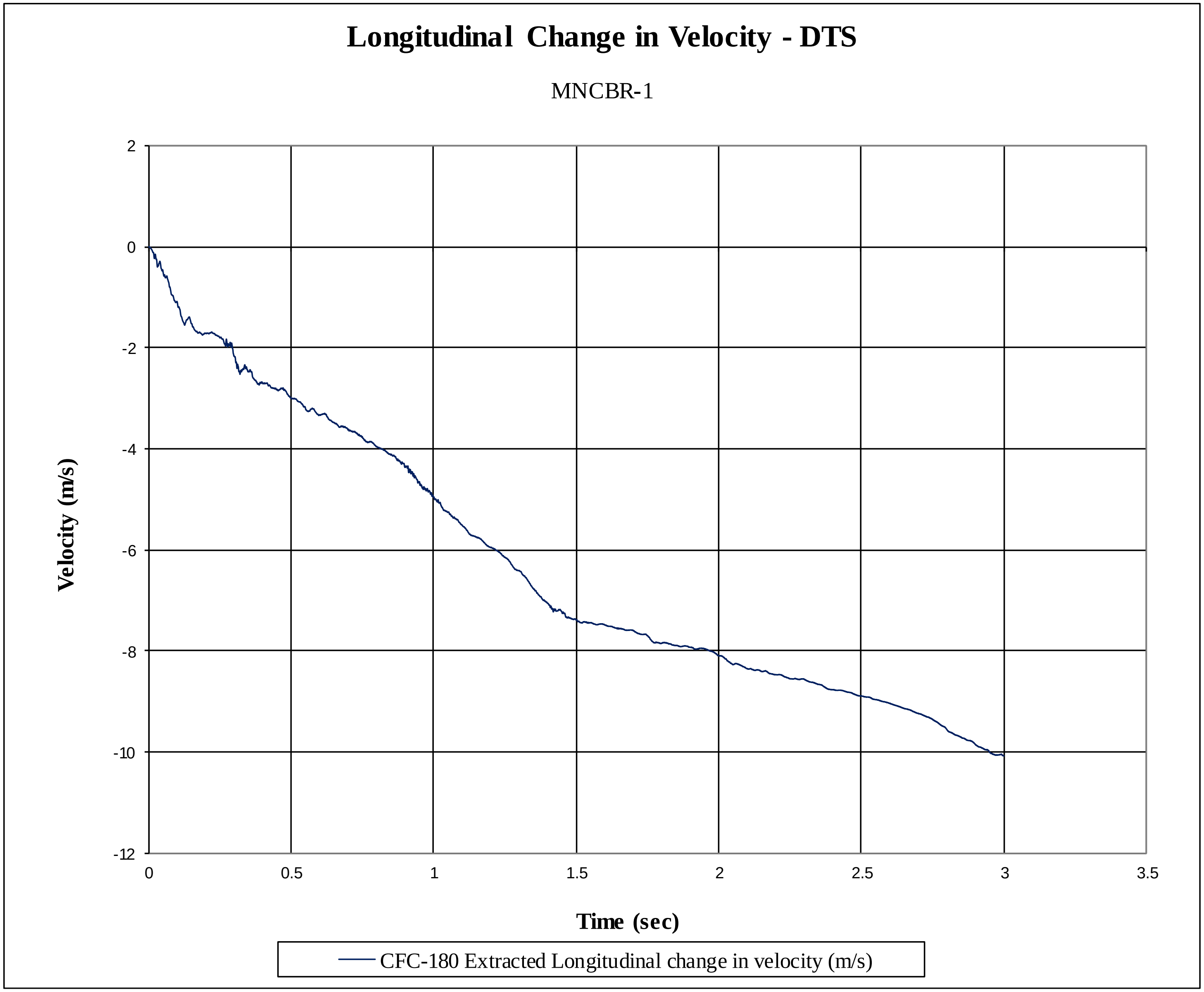


Figure D-26. Longitudinal Occupant Impact Velocity (TDAS-2), Test No. MNCBR-1

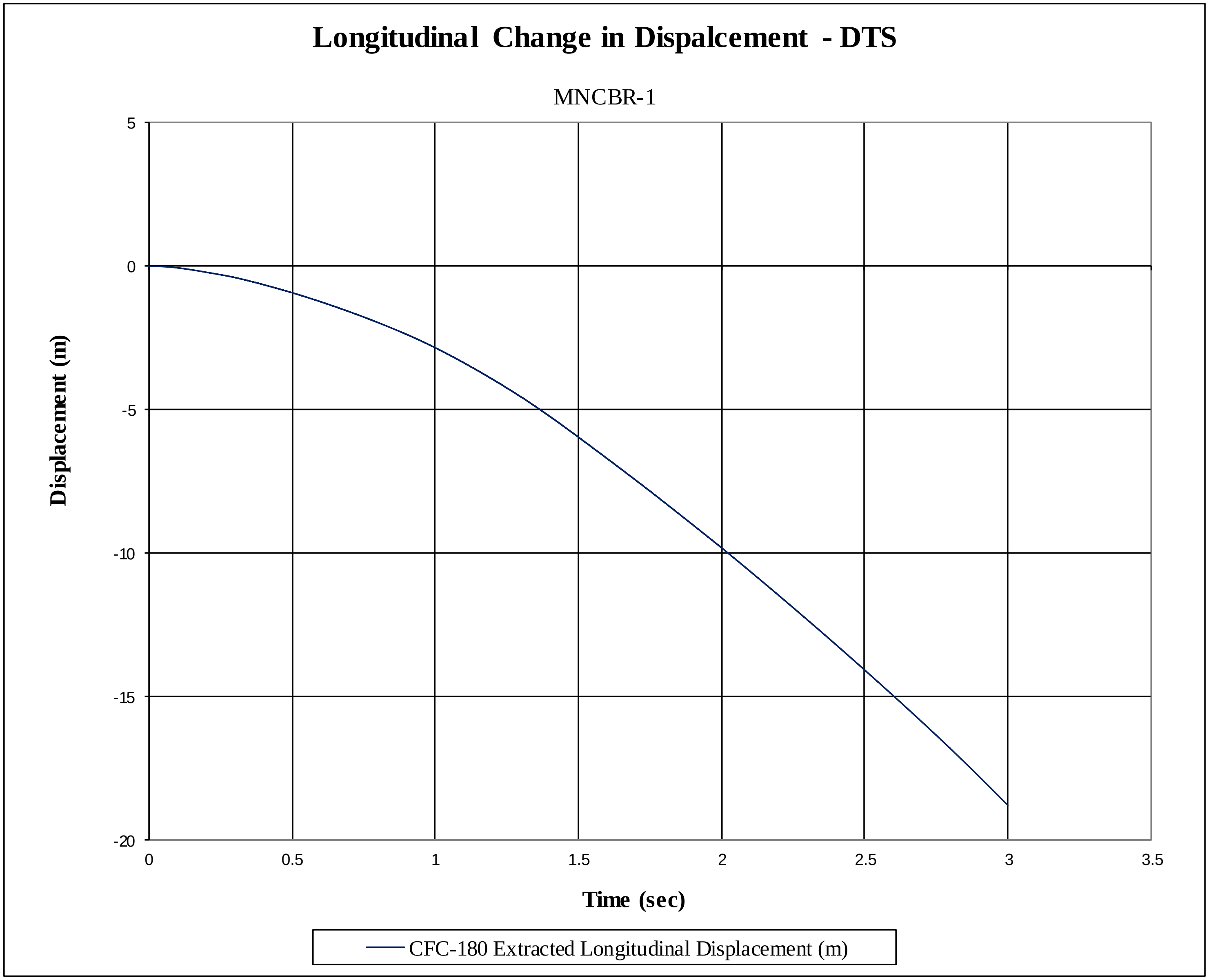


Figure D-27. Longitudinal Occupant Displacement (TDAS-2), Test No. MNCBR-1

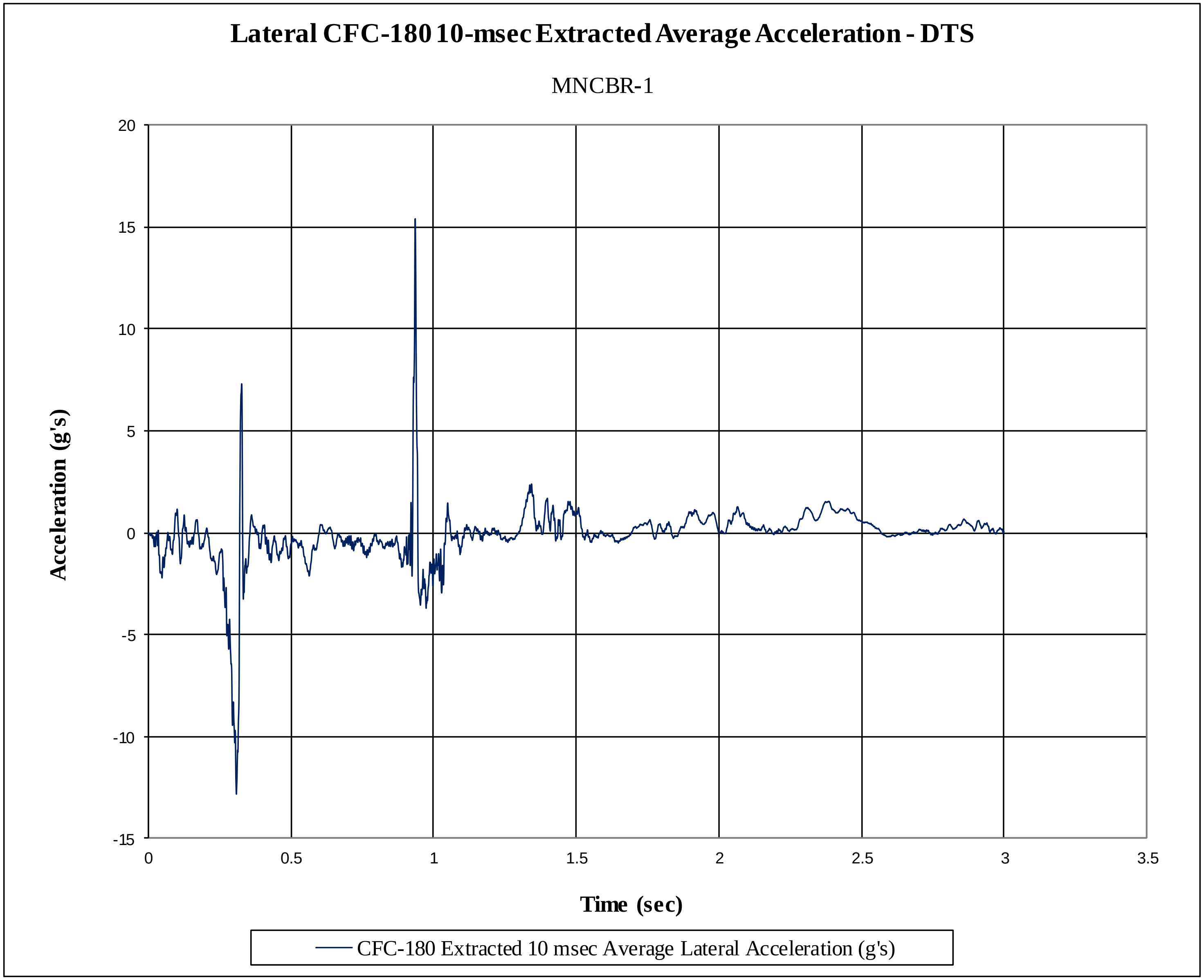


Figure D-28. 10-ms Average Lateral Deceleration (TDAS-2), Test No. MNCBR-1

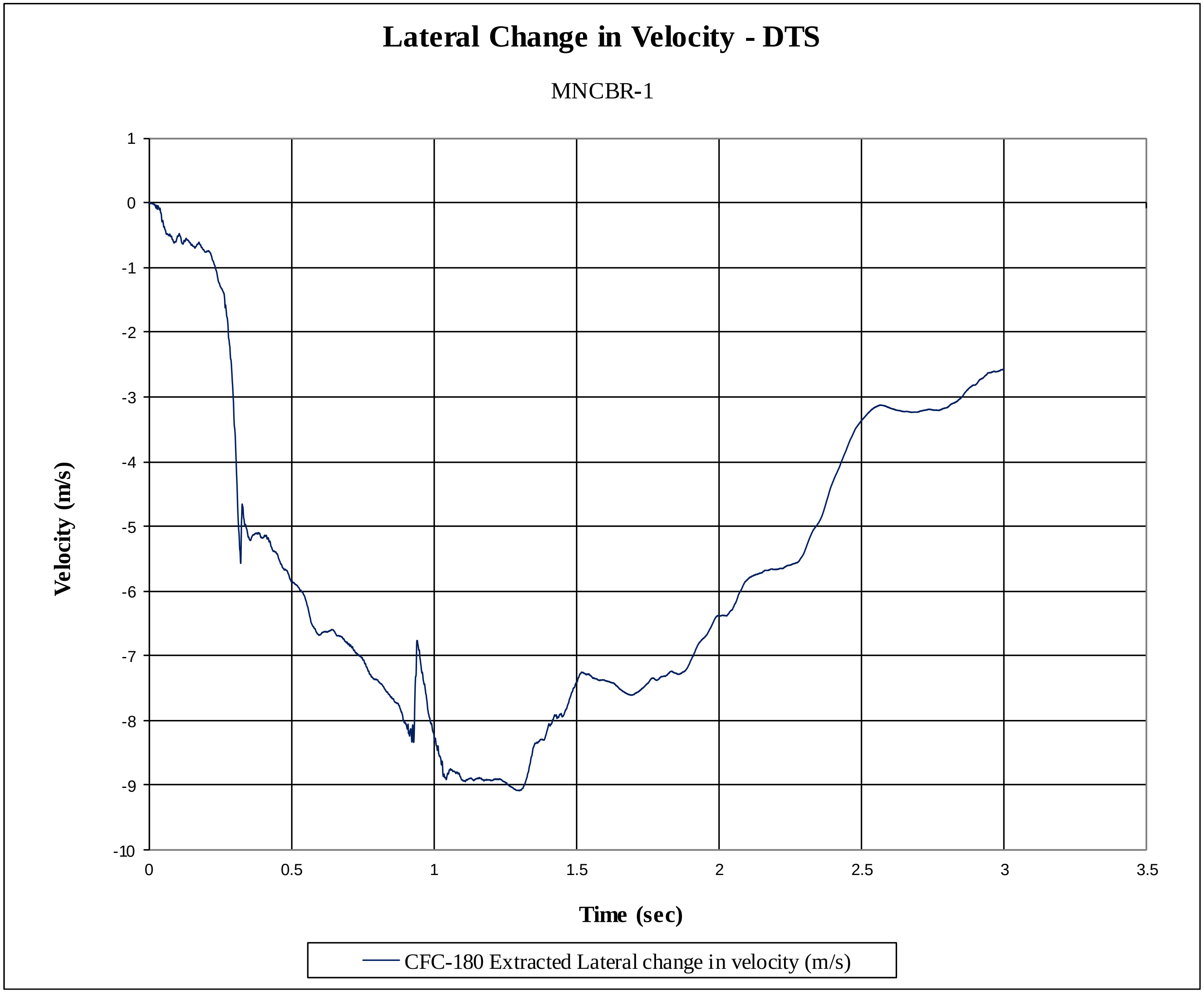


Figure D-29. Lateral Occupant Impact Velocity (TDAS-2), Test No. MNCBR-1

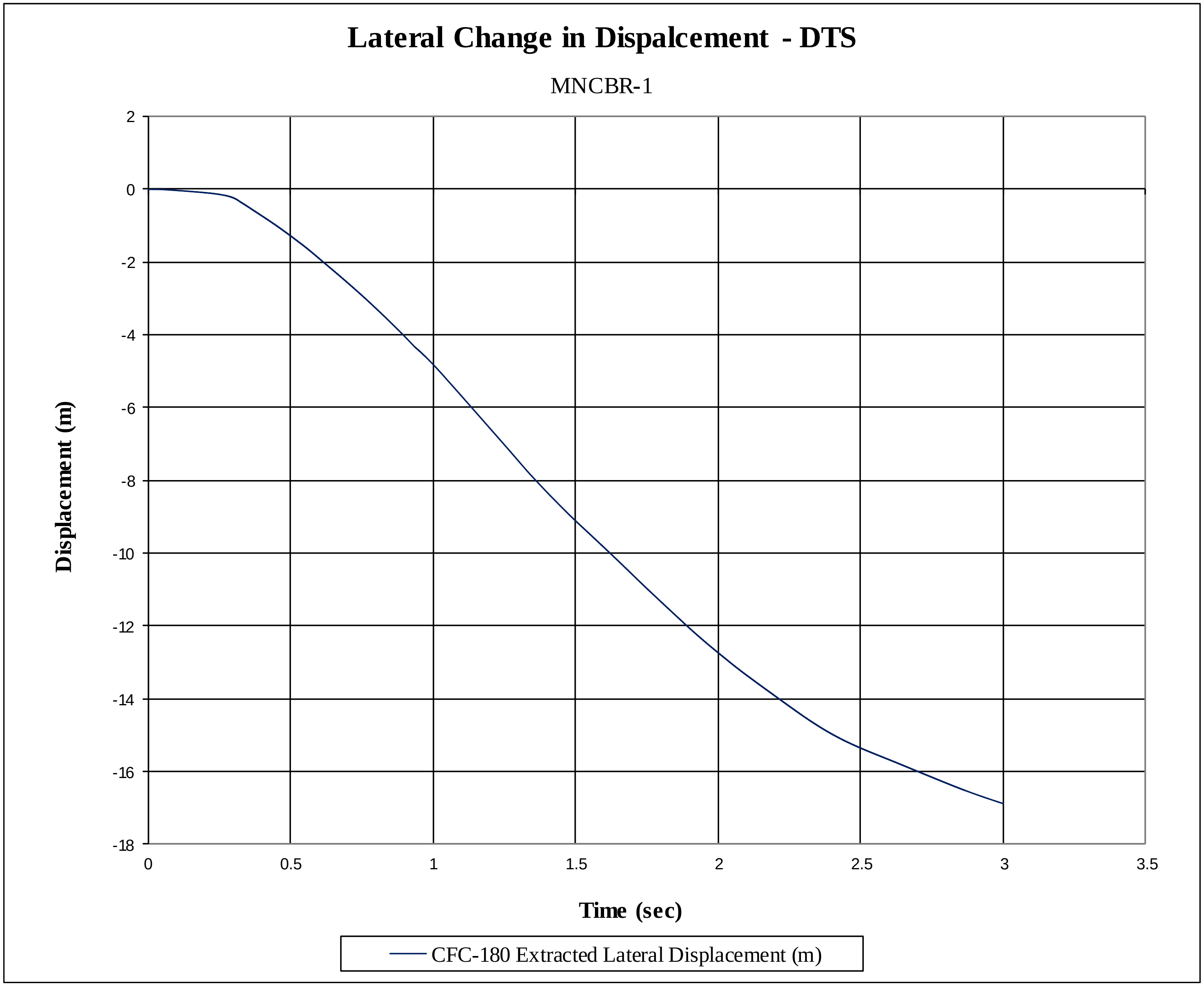


Figure D-30. Lateral Occupant Displacement (TDAS-2), Test No. MNCBR-1

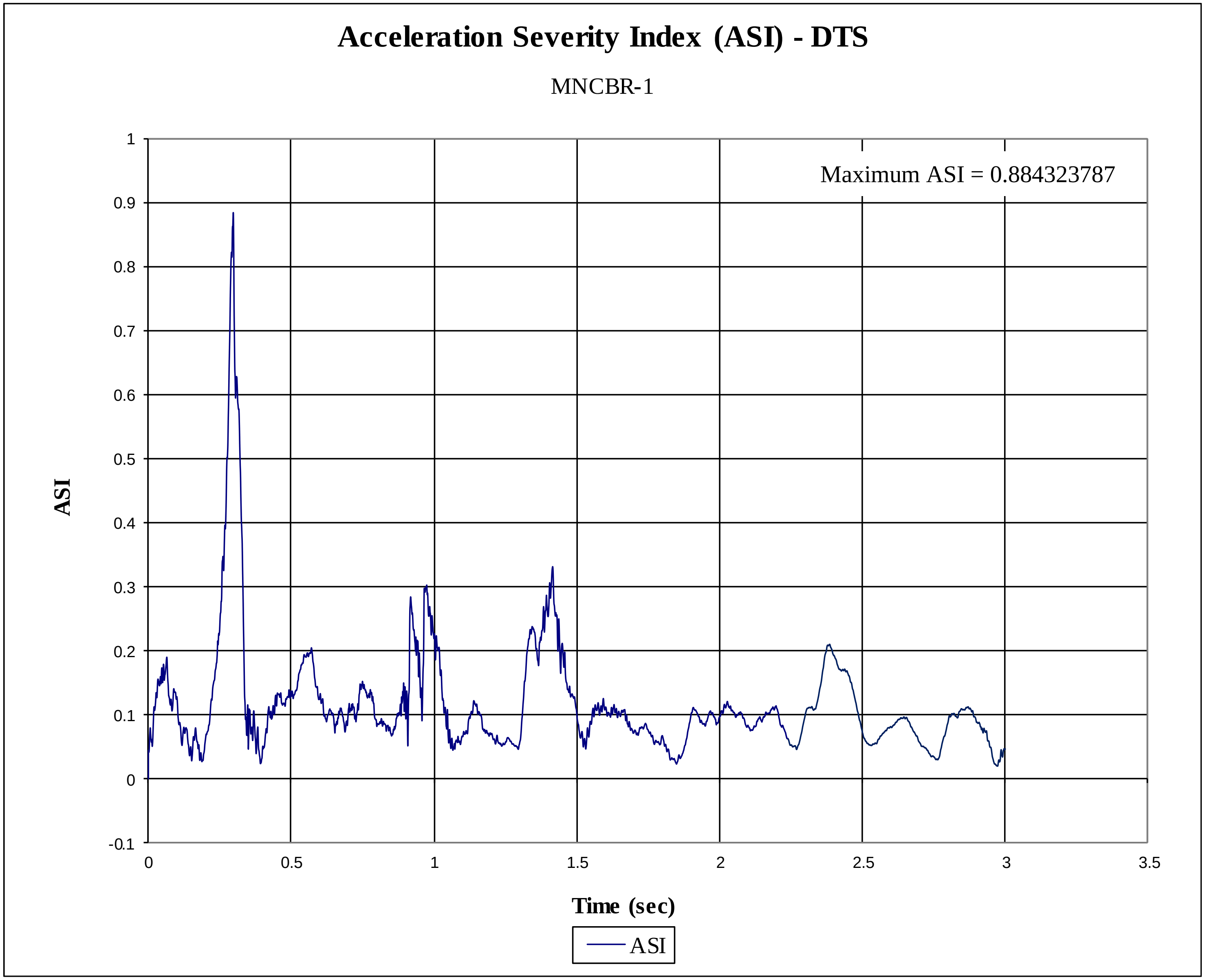


Figure D-31. Acceleration Severity Index (TDAS-2), Test No. MNCBR-1

Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. MNCBR-2

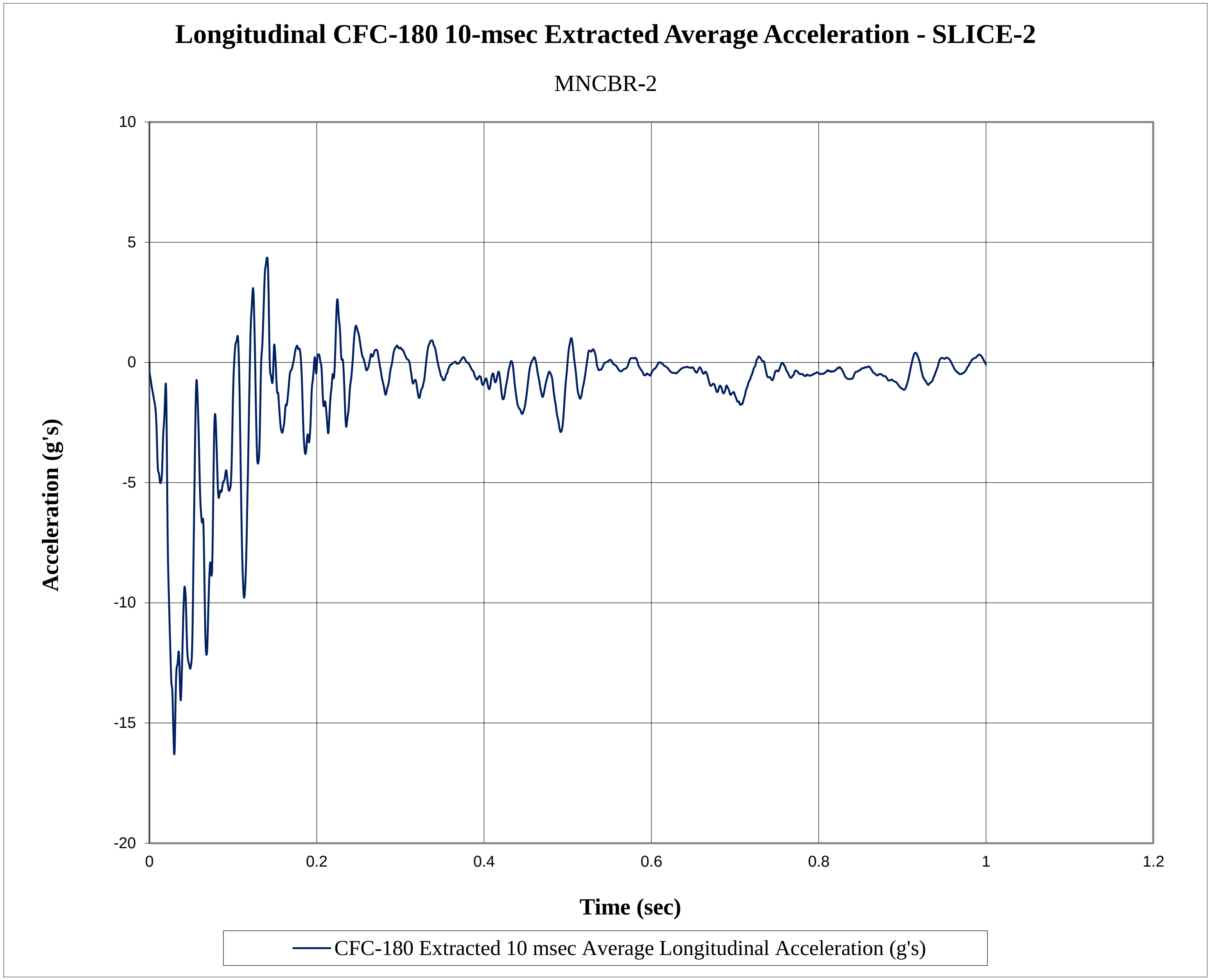


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MNCBR-2

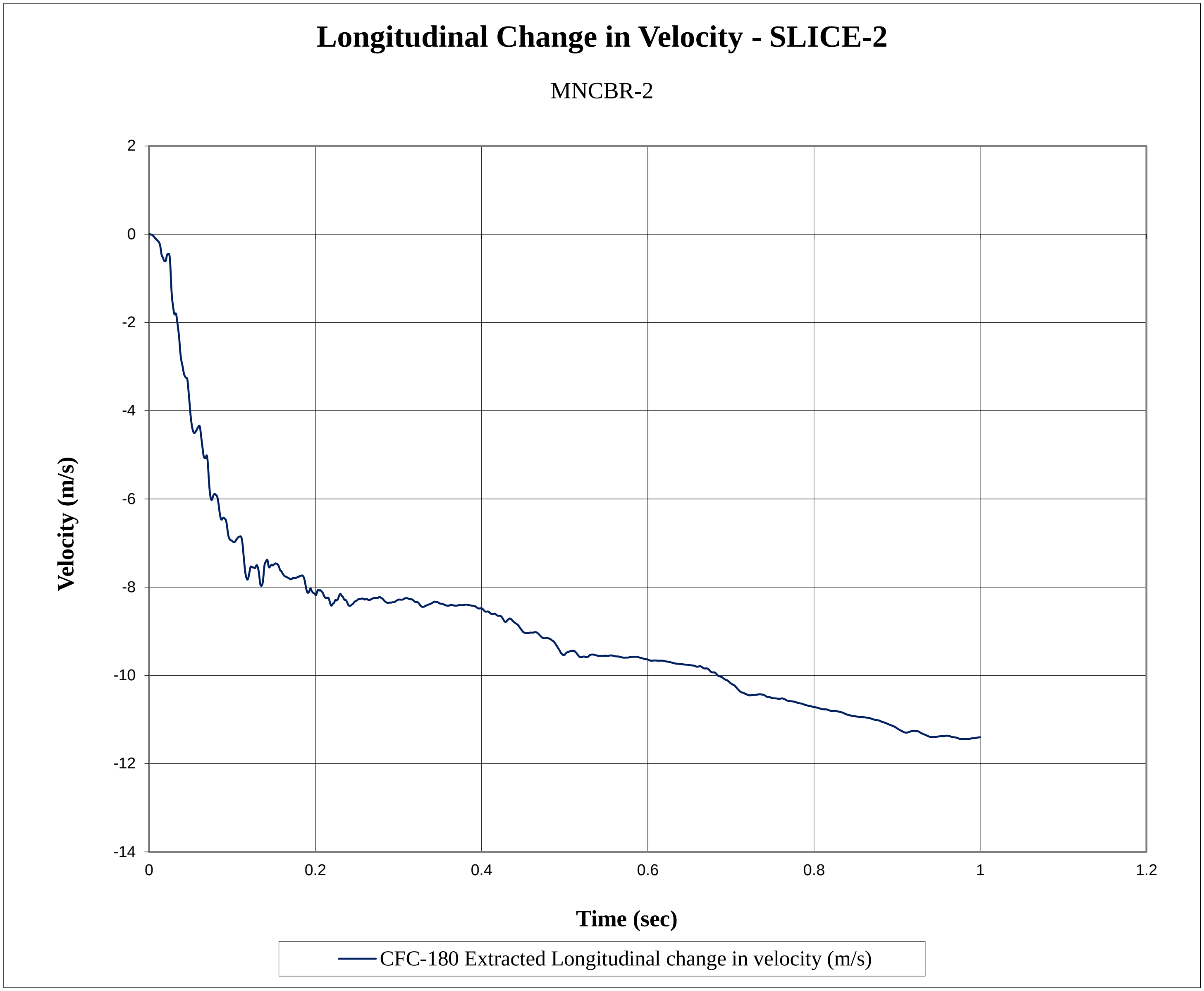


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MNCBR-2

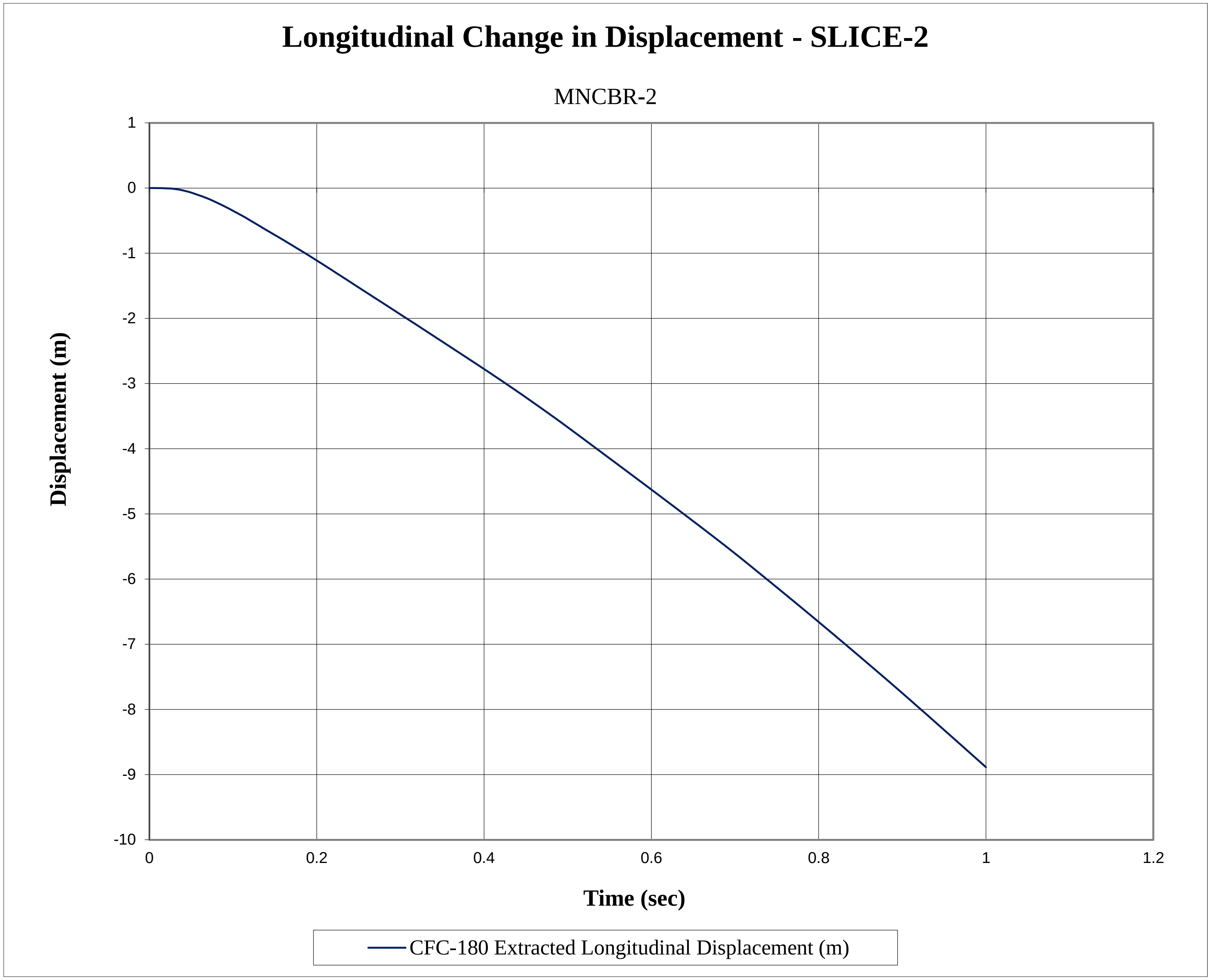


Figure E-3. Longitudinal Occupant Displacement (SLICE-2), Test No. MNCBR-2

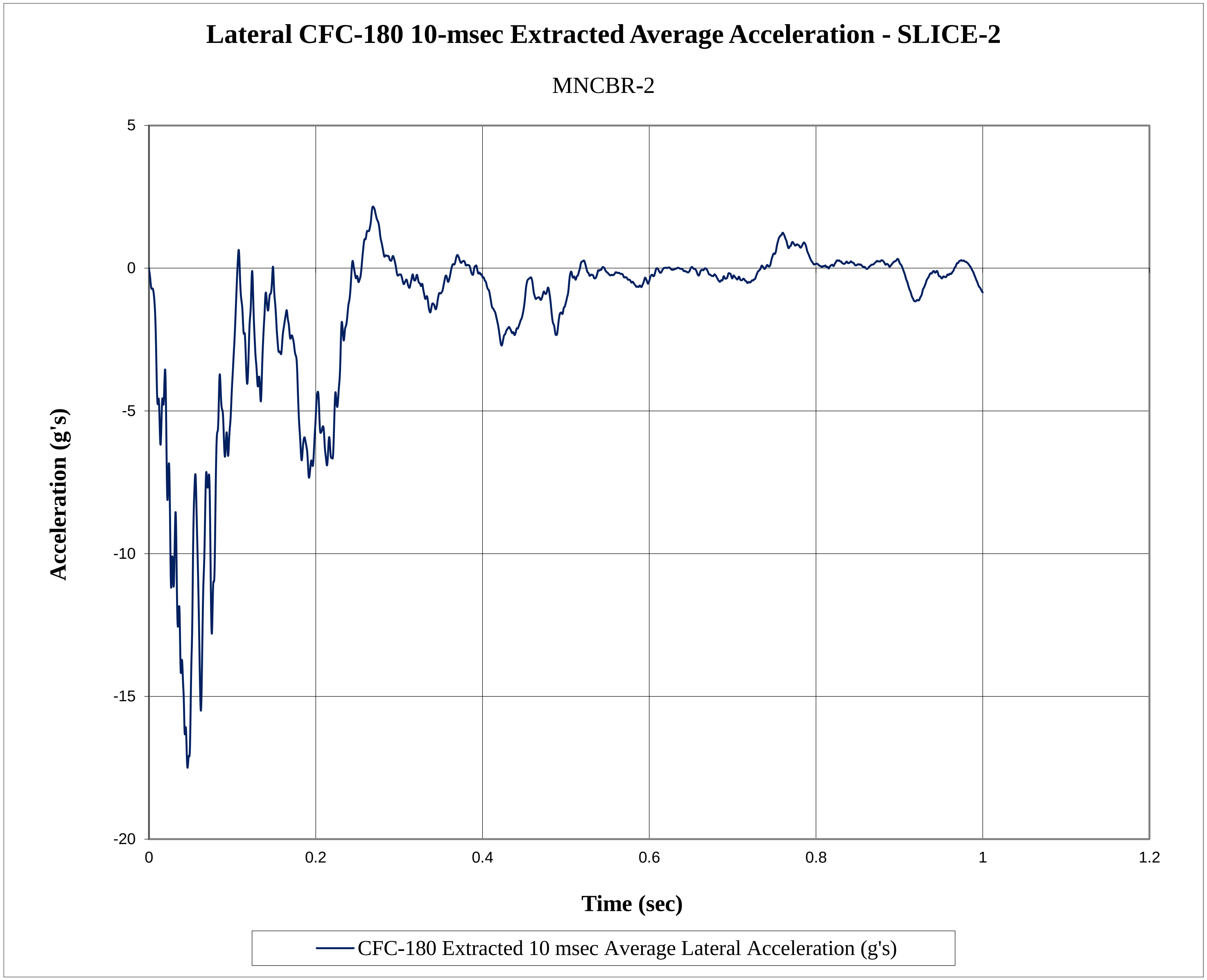


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MNCBR-2

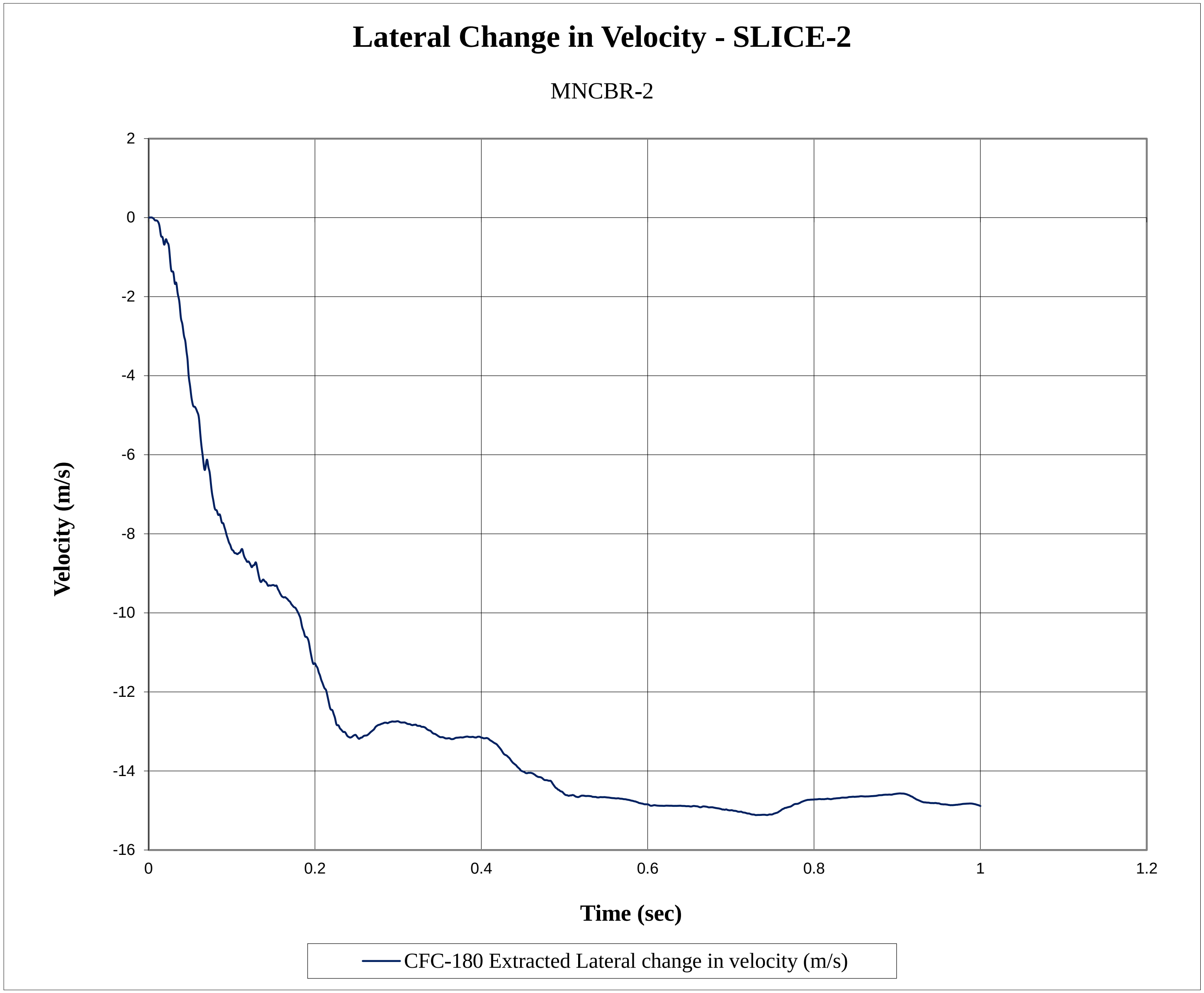


Figure E-5. Lateral Occupant Impact Velocity (SLICE-2), Test No. MNCBR-2

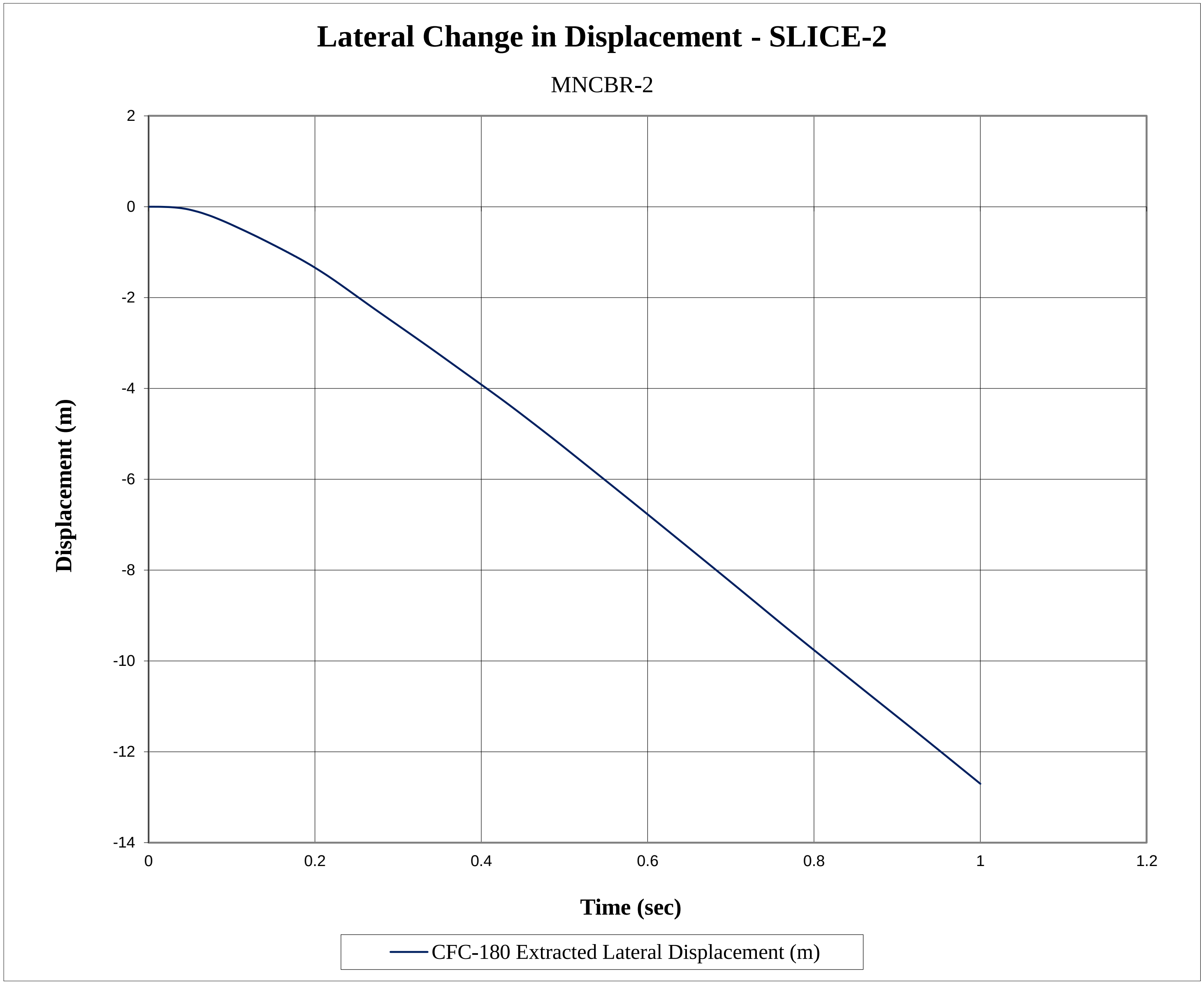


Figure E-6. Lateral Occupant Displacement (SLICE-2), Test No. MNCBR-2

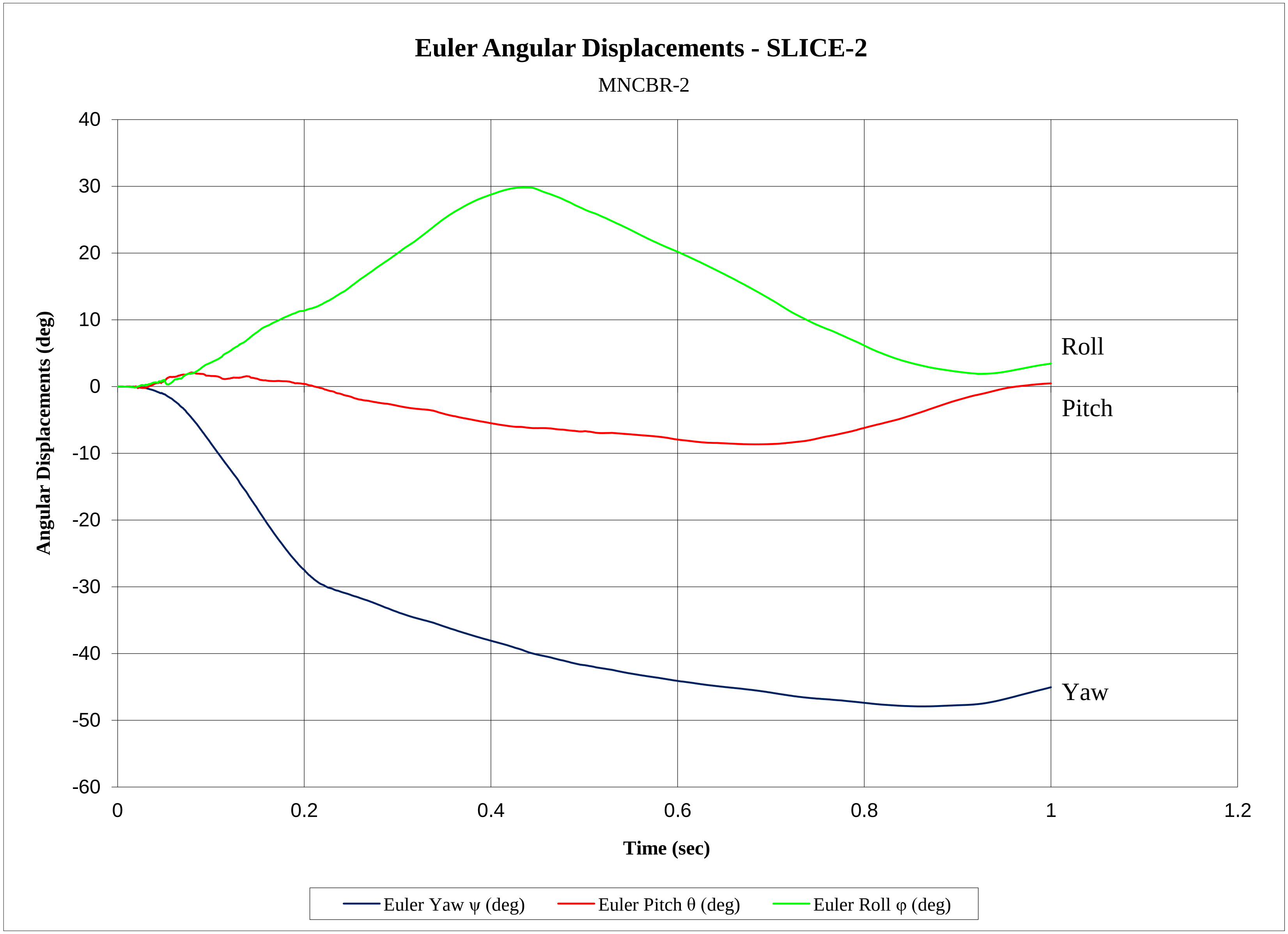


Figure E-7. Vehicle Angular Displacements (SLICE-2), Test No. MNCBR-2

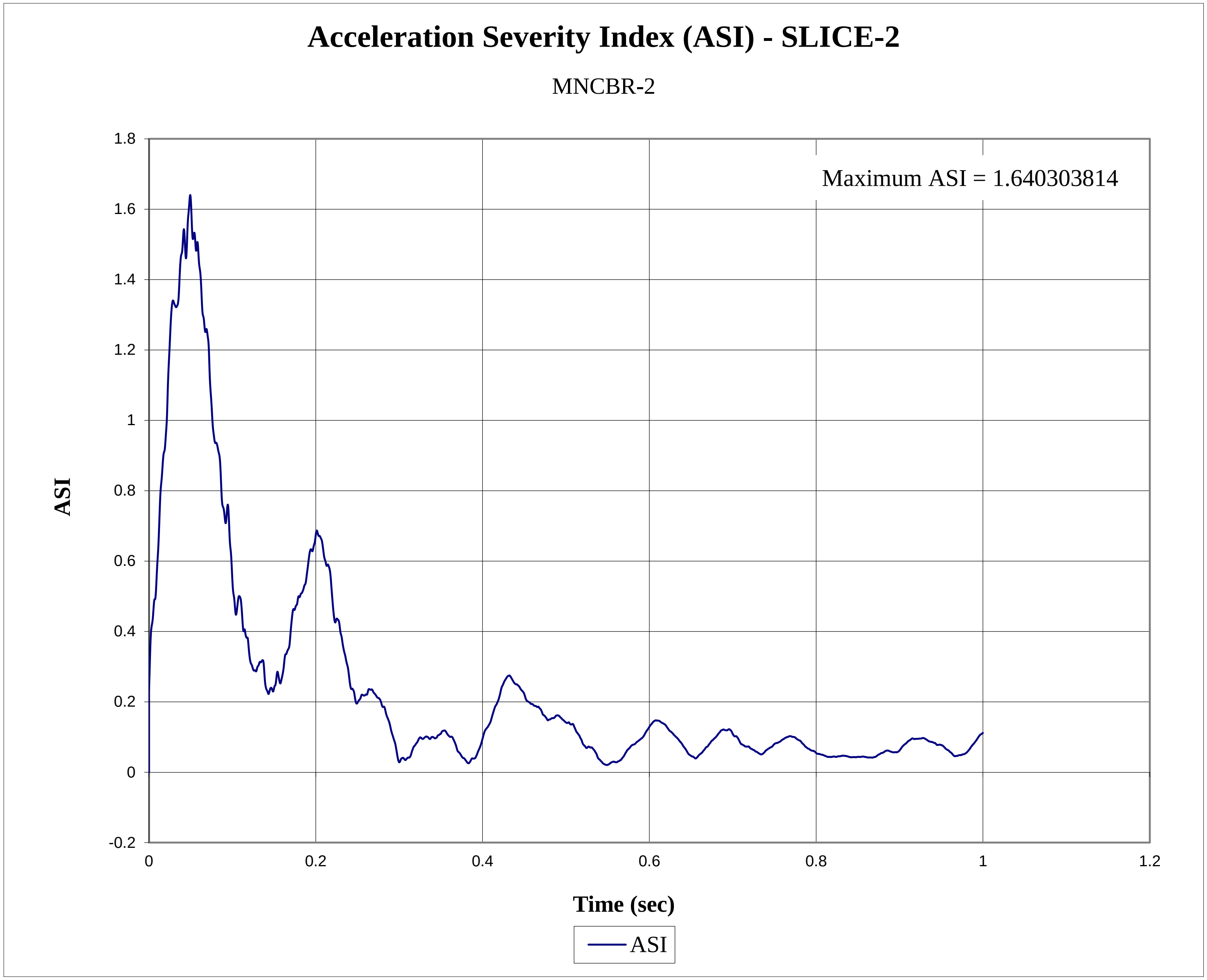


Figure E-8. Acceleration Severity Index (SLICE-2), Test No. MNCBR-2

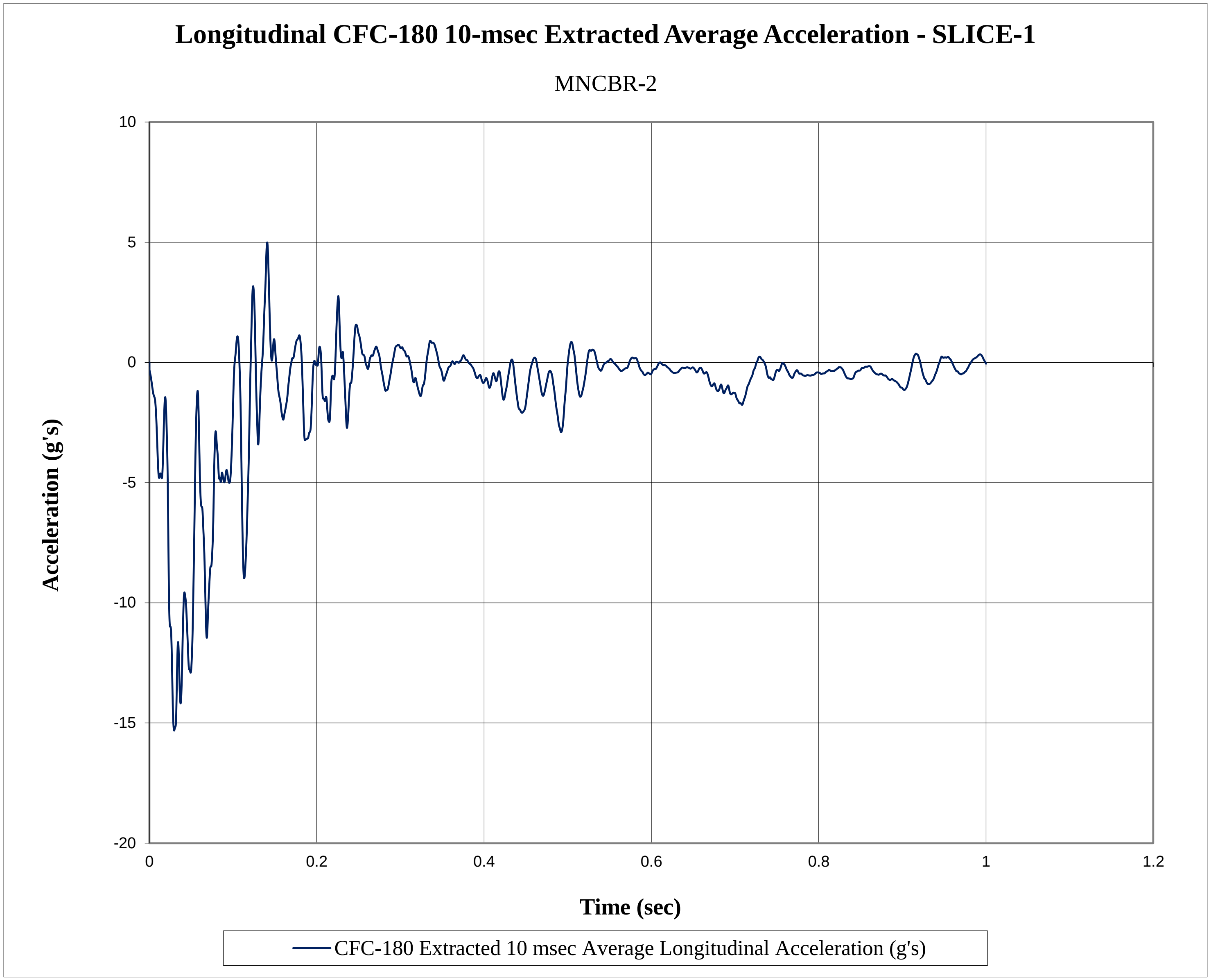


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MNCBR-2

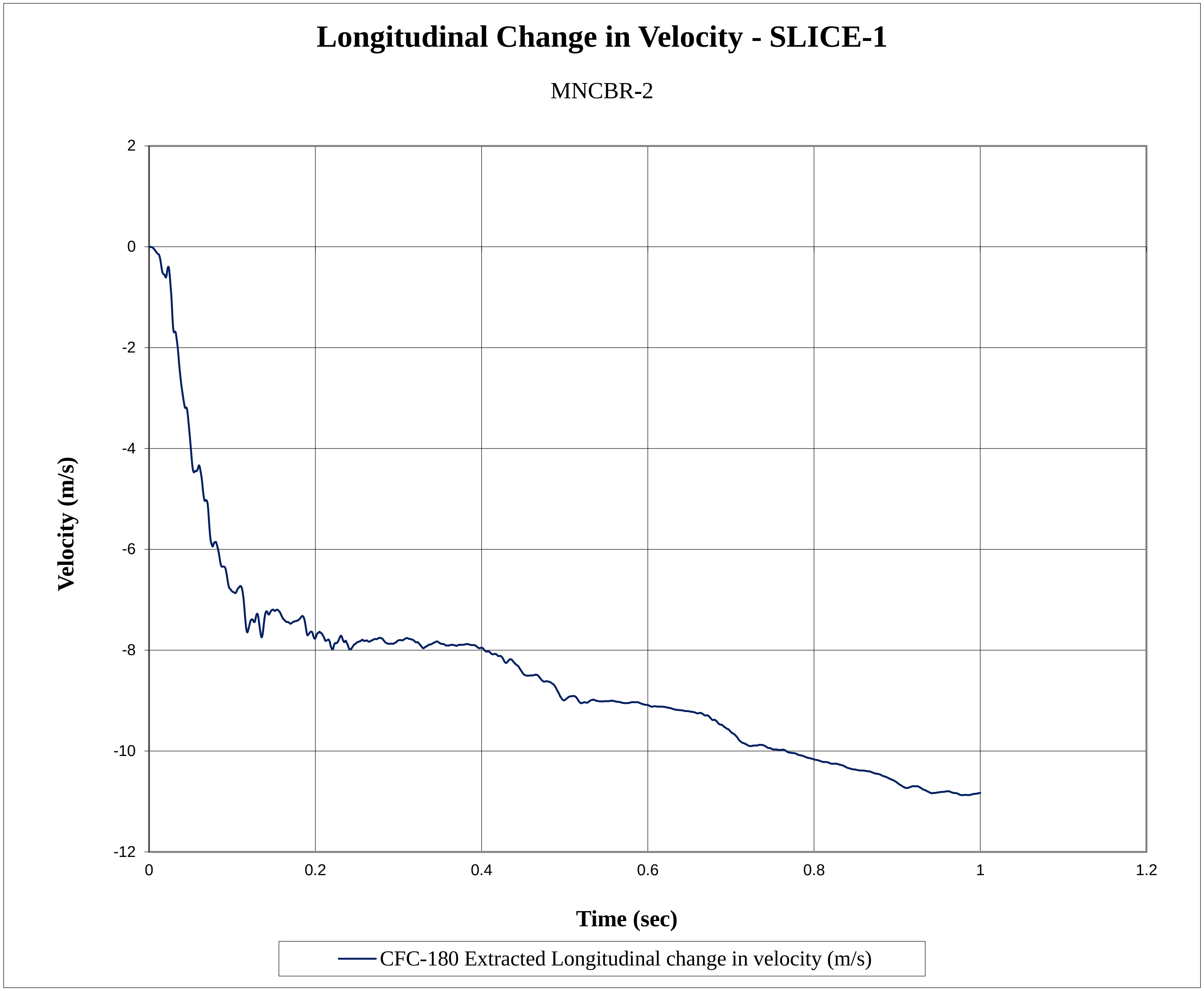


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MNCBR-2

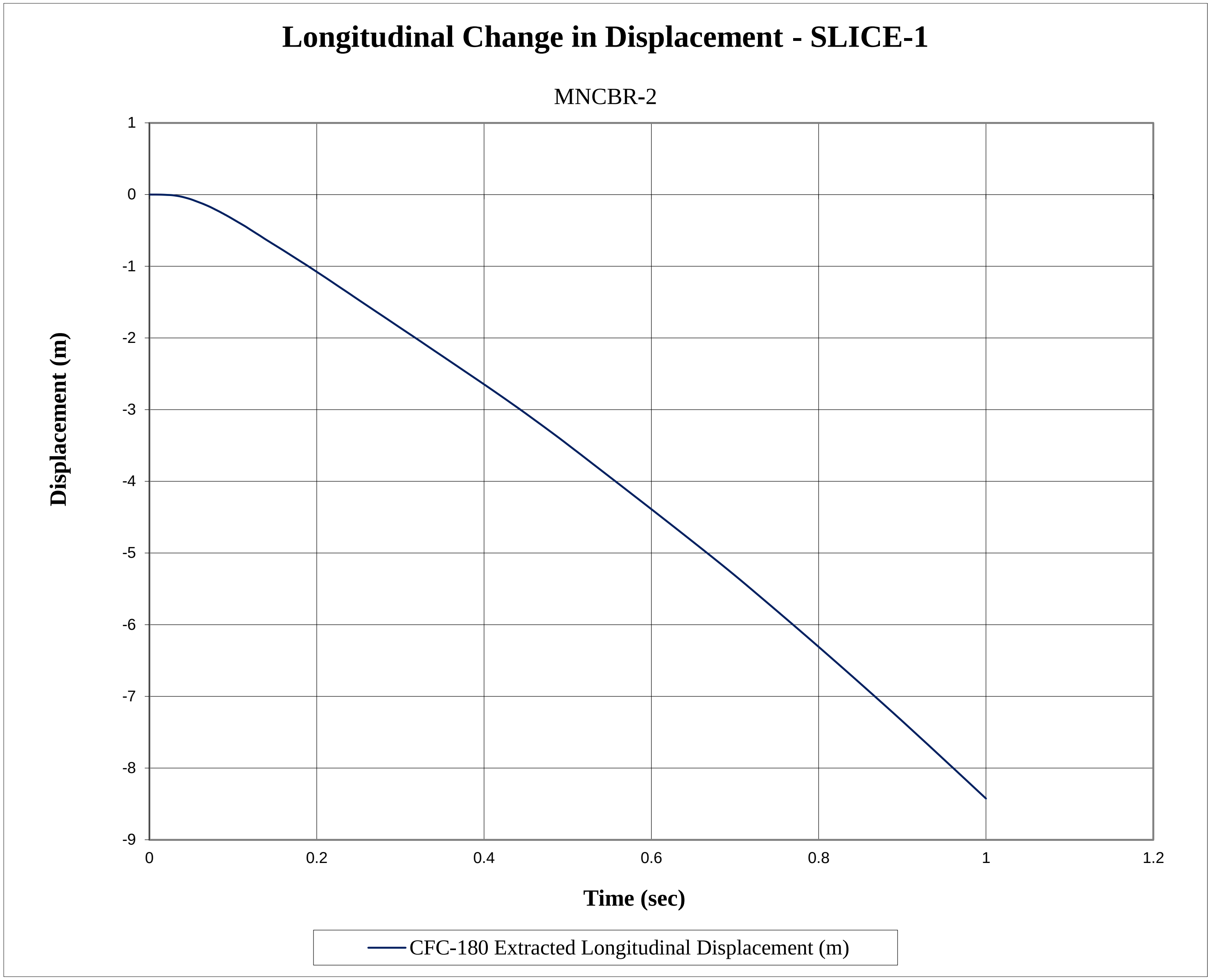


Figure E-11. Longitudinal Occupant Displacement (SLICE-1), Test No. MNCBR-2

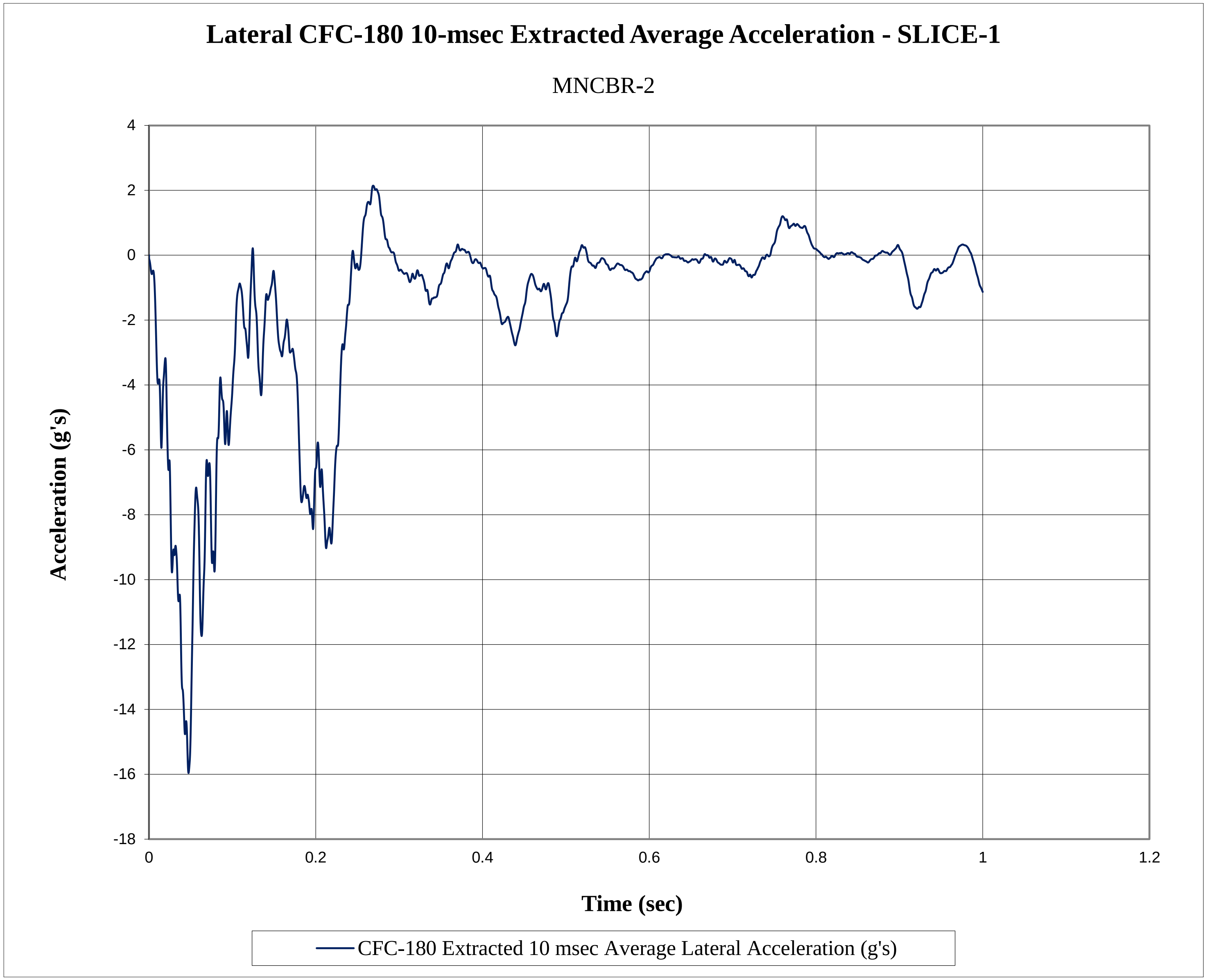


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MNCBR-2

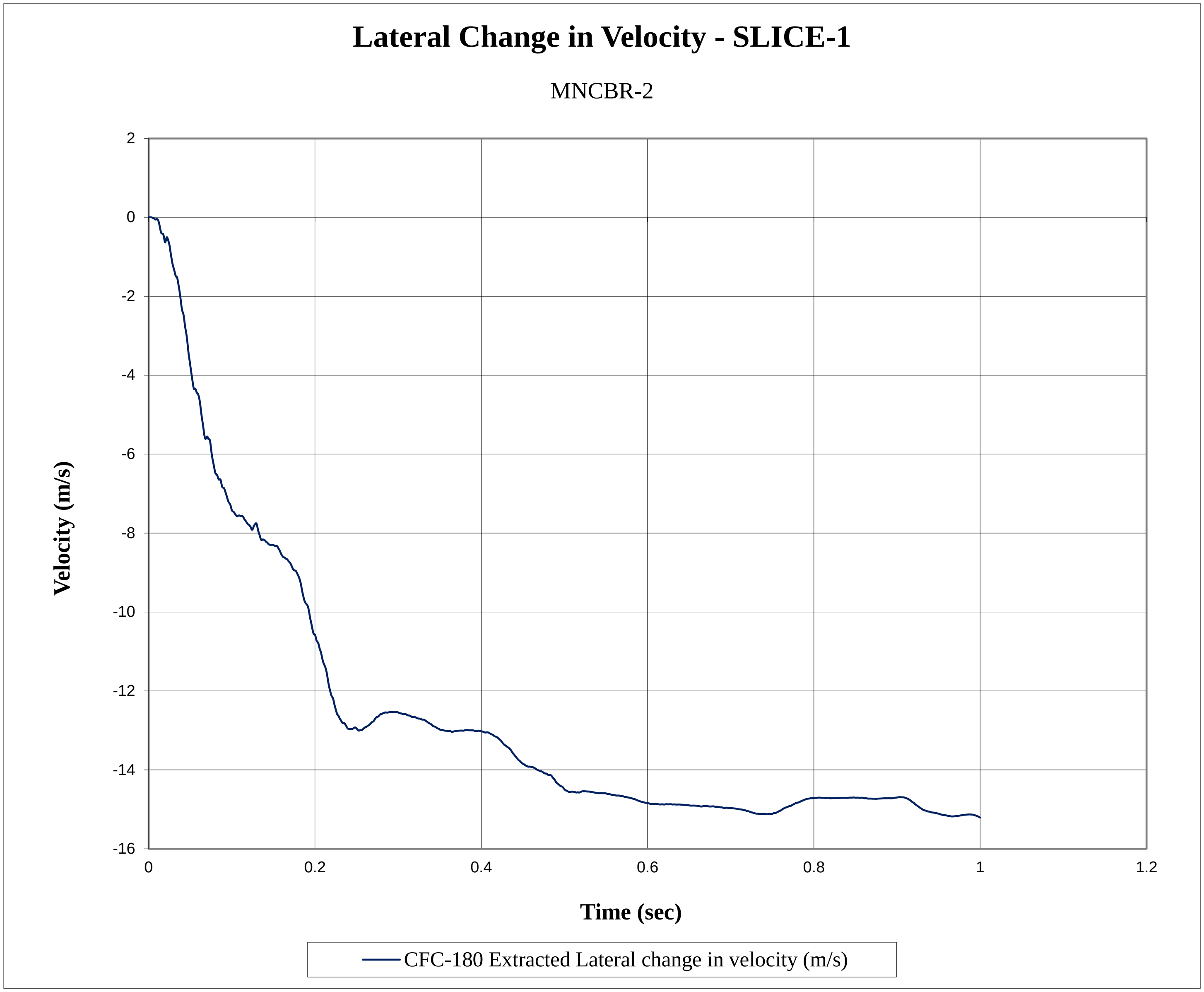


Figure E-13. Lateral Occupant Impact Velocity (SLICE-1), Test No. MNCBR-2

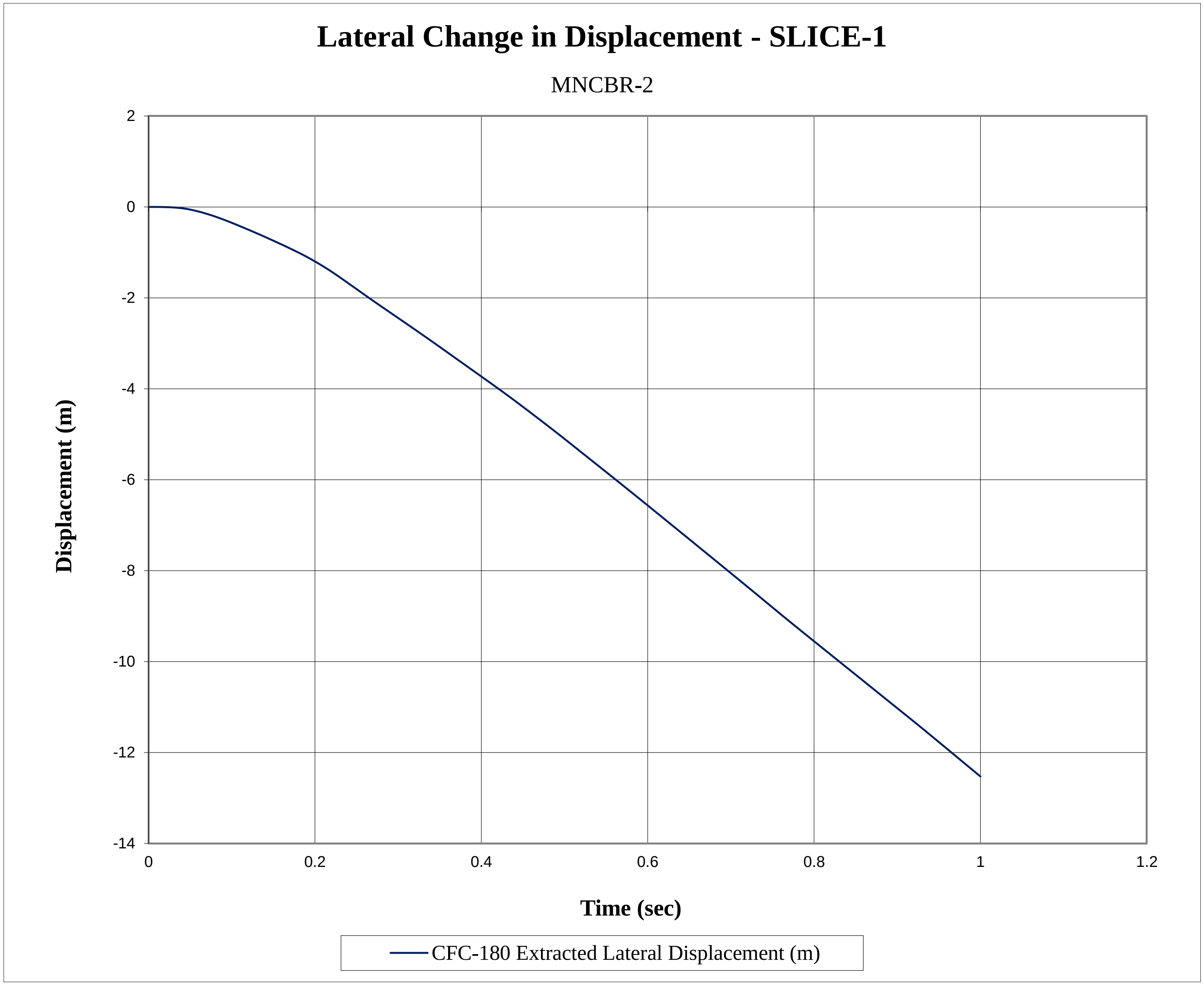


Figure E-14. Lateral Occupant Displacement (SLICE-1), Test No. MNCBR-2

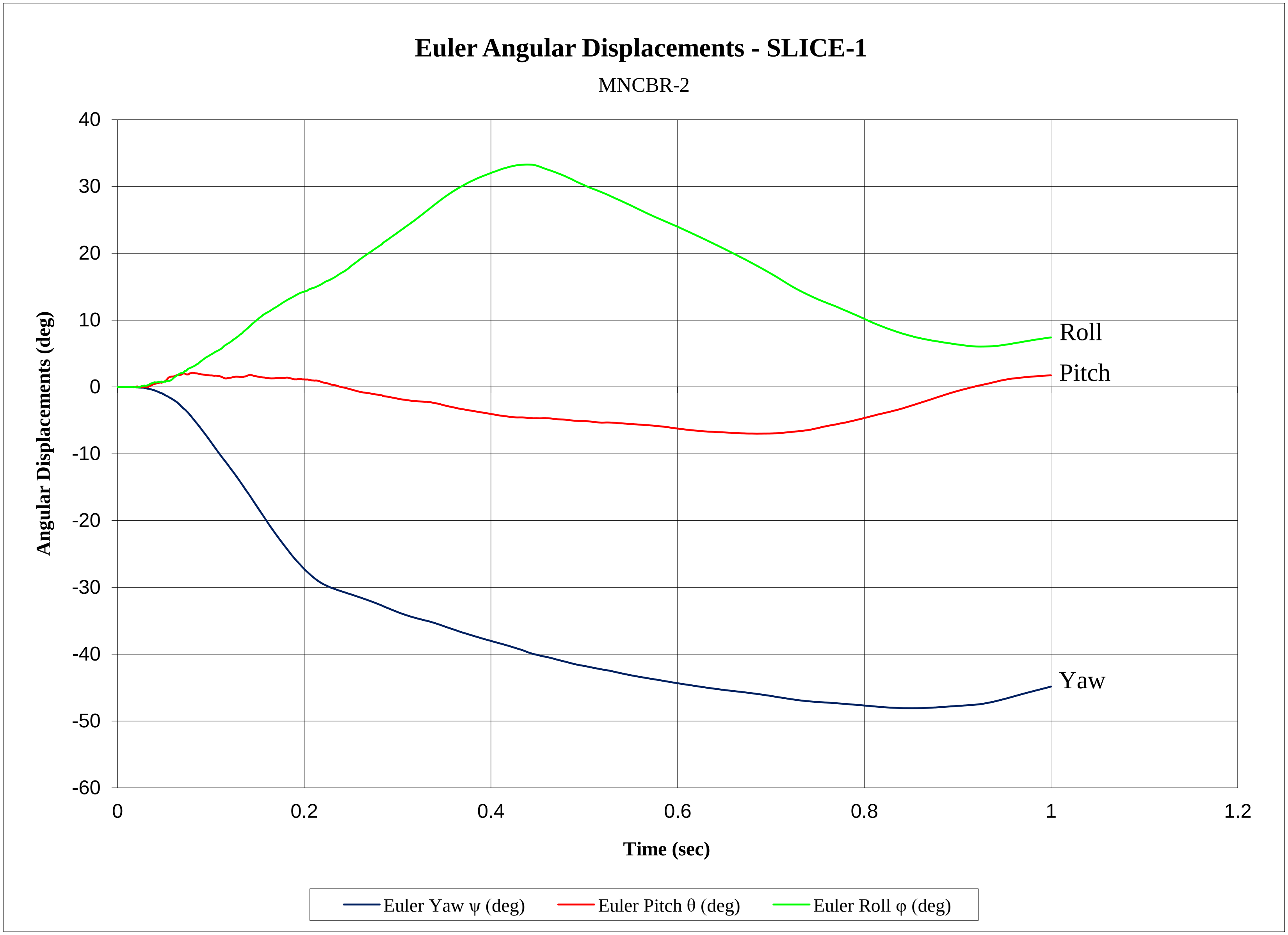


Figure E-15. Vehicle Angular Displacements (SLICE-1), Test No. MNCBR-2

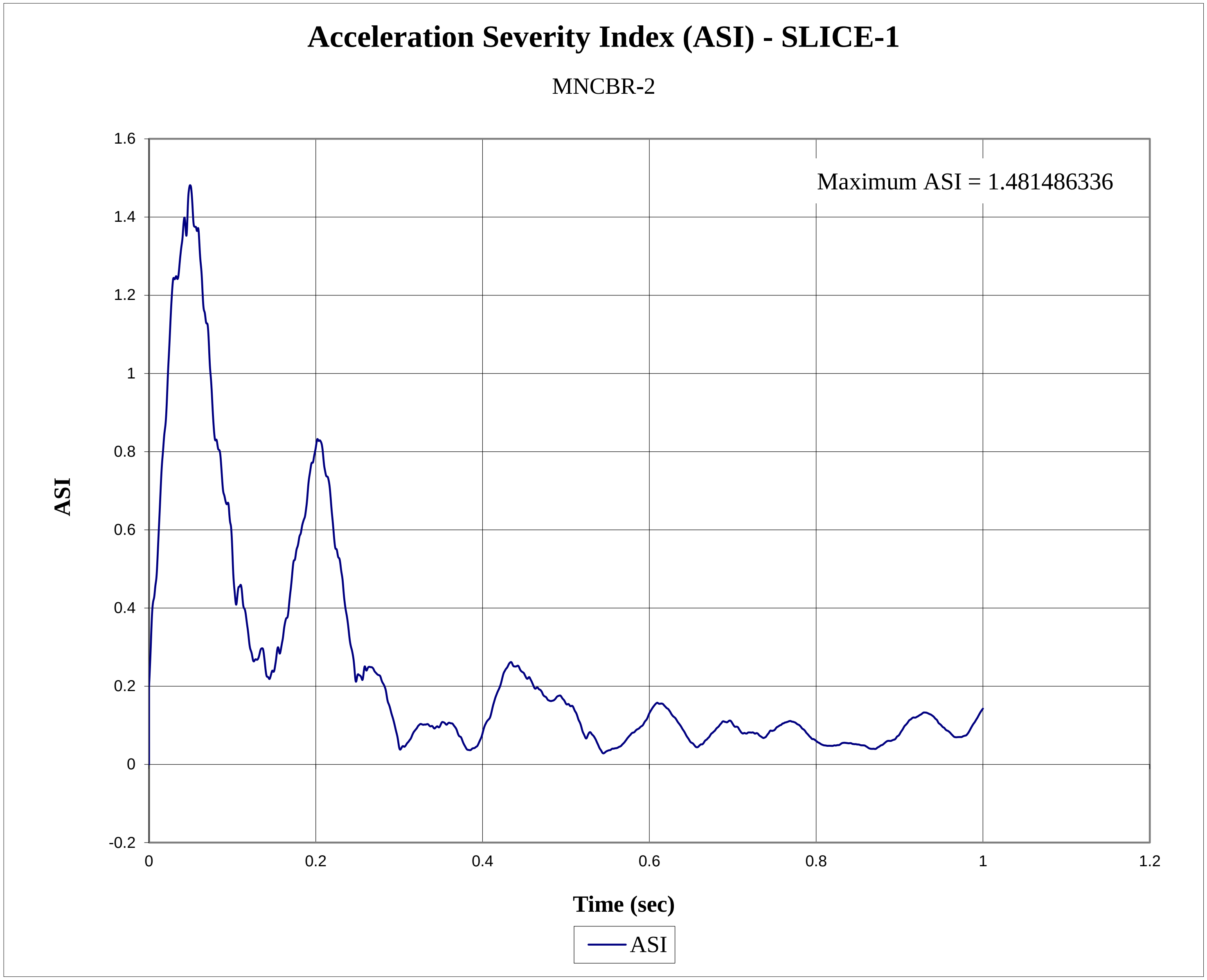


Figure E-16. Acceleration Severity Index (SLICE-1), Test No. MNCBR-2

Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. MNCBR-3

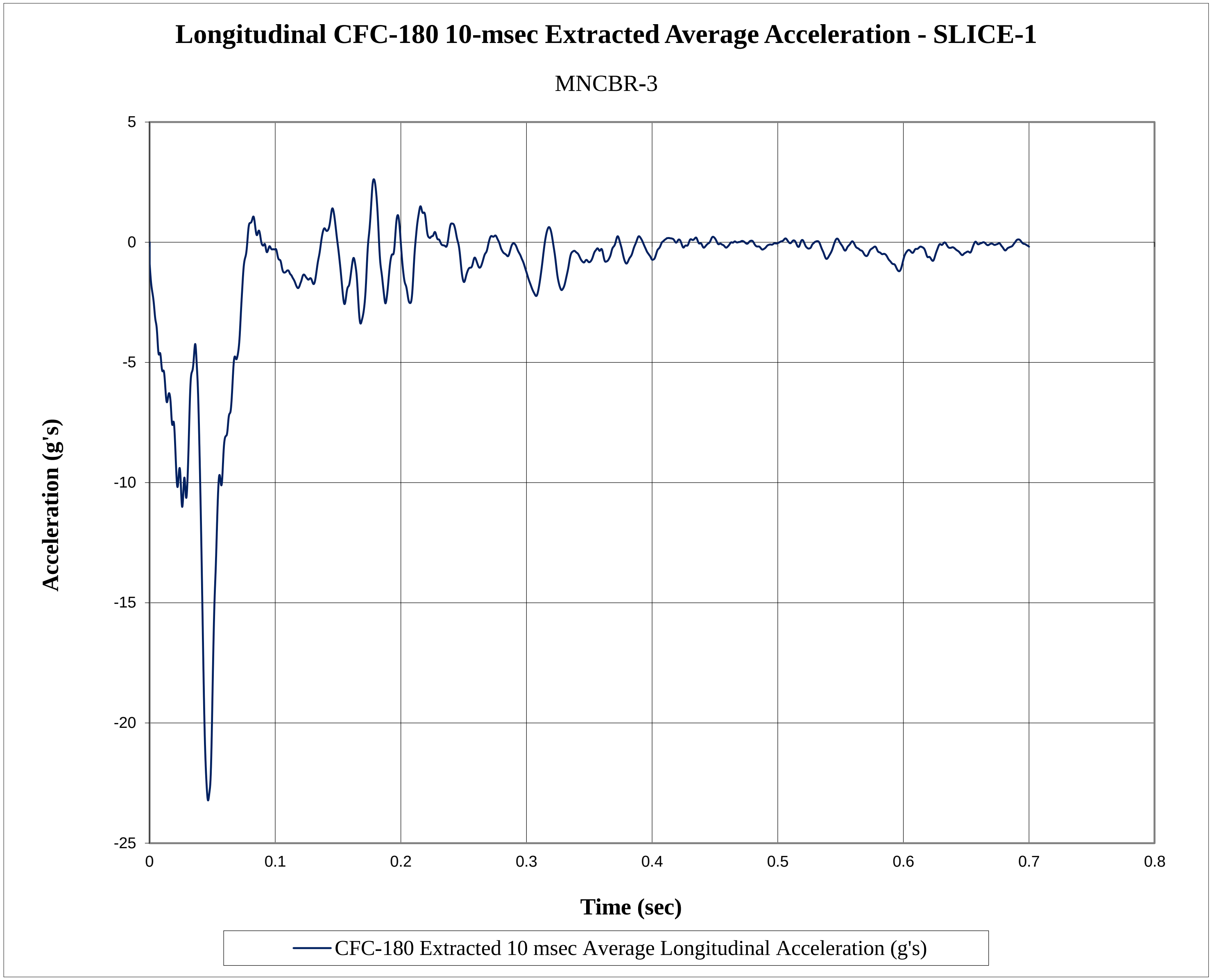


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MNCBR-3

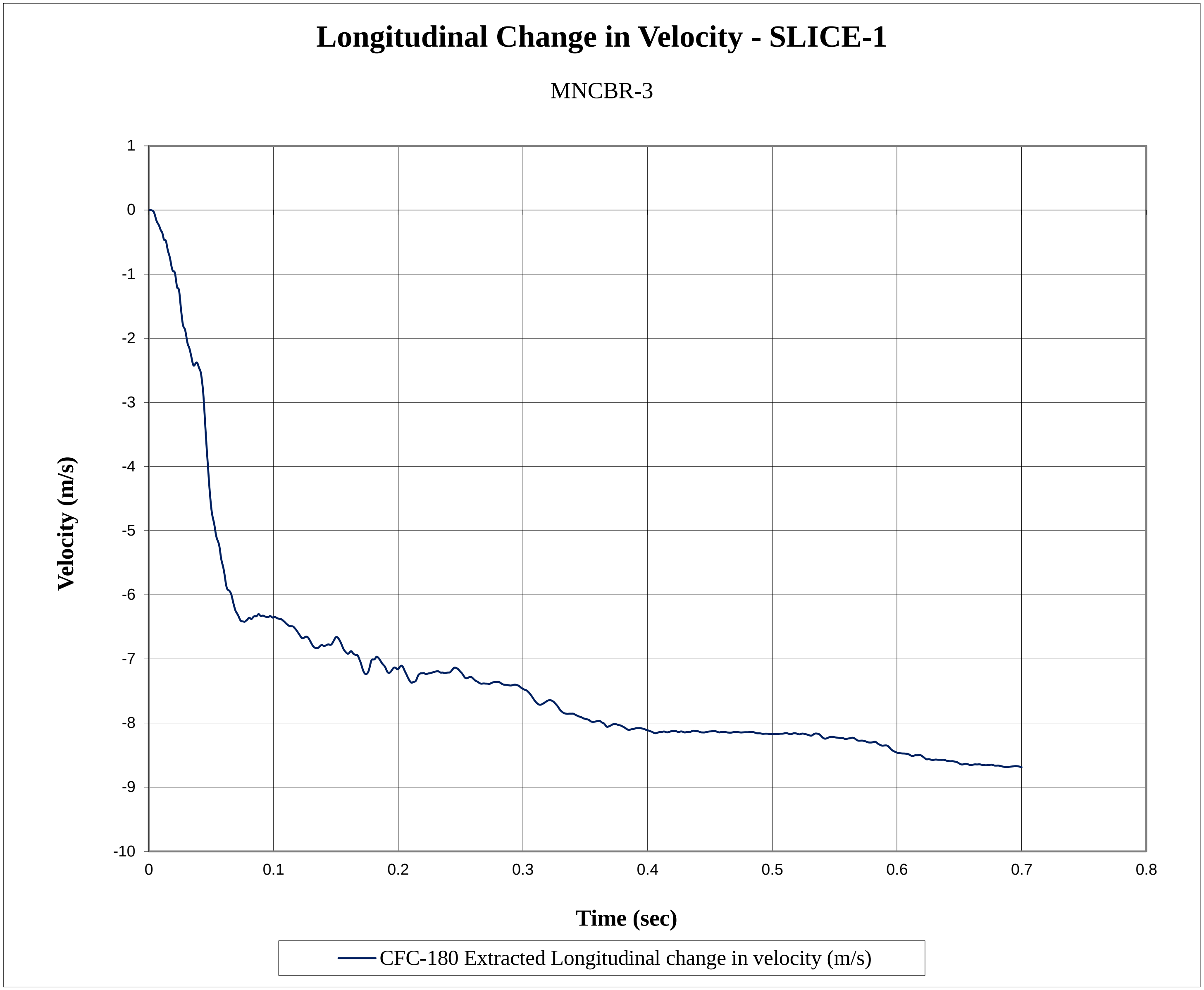


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MNCBR-3

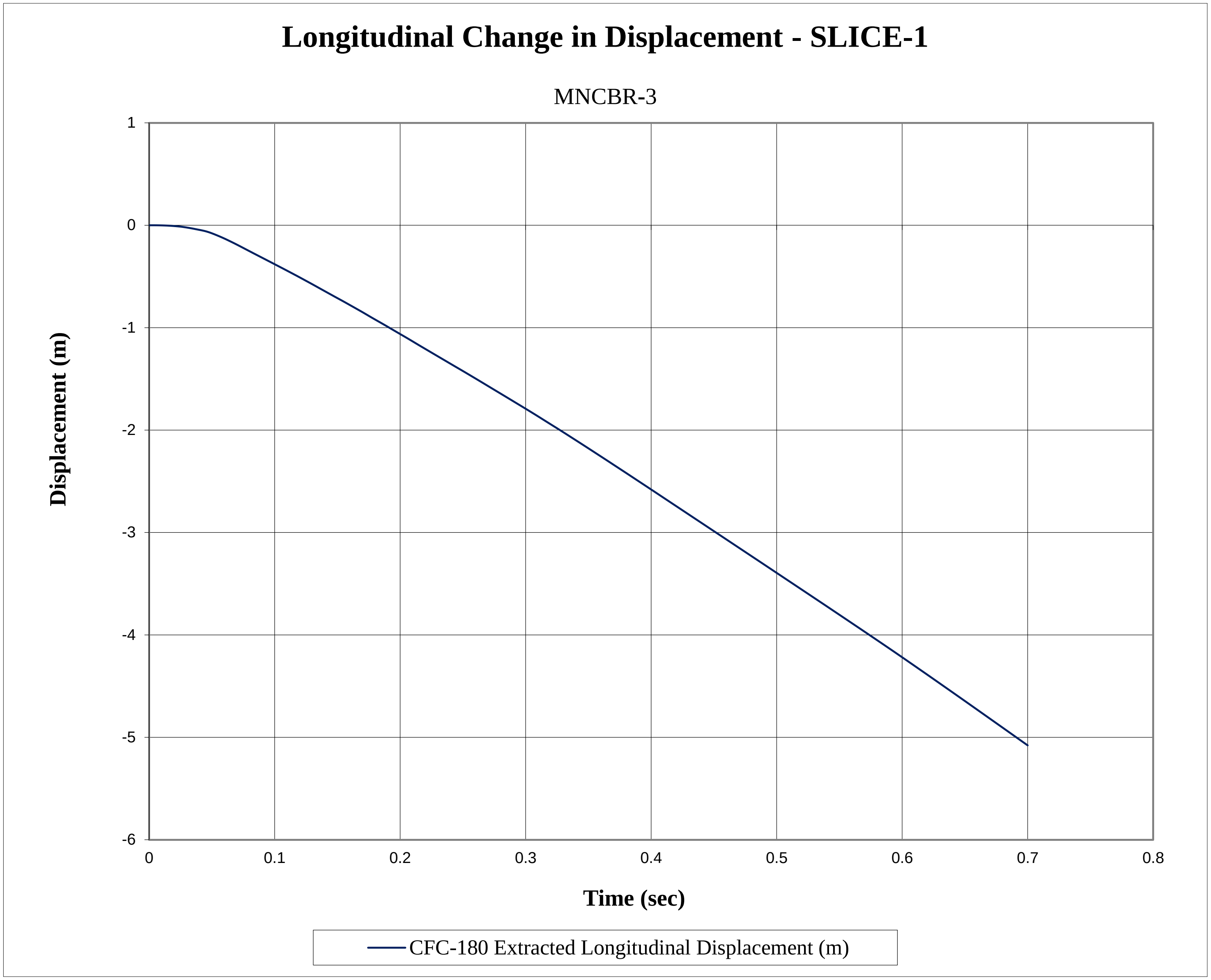


Figure F-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MNCBR-3

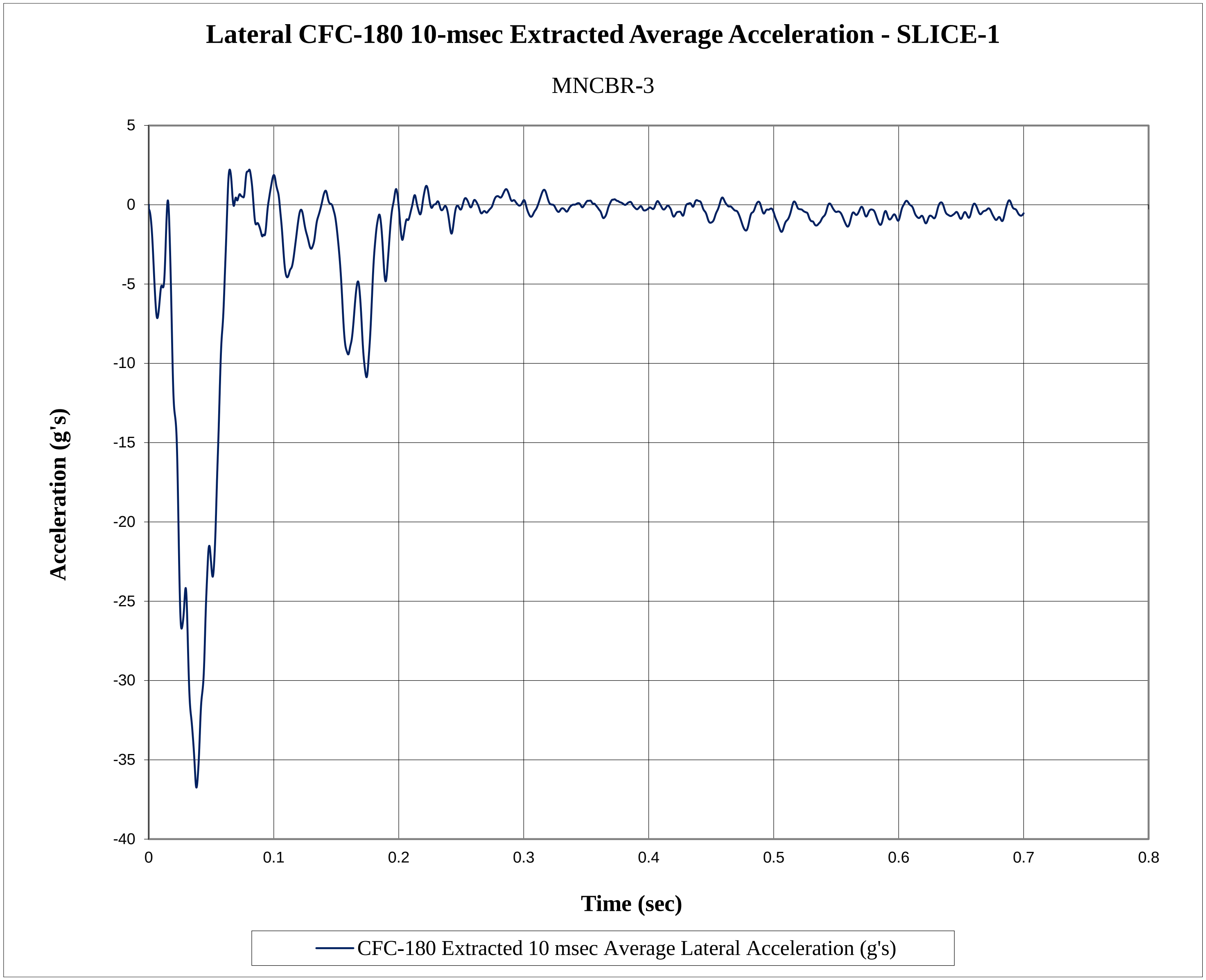


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MNCBR-3

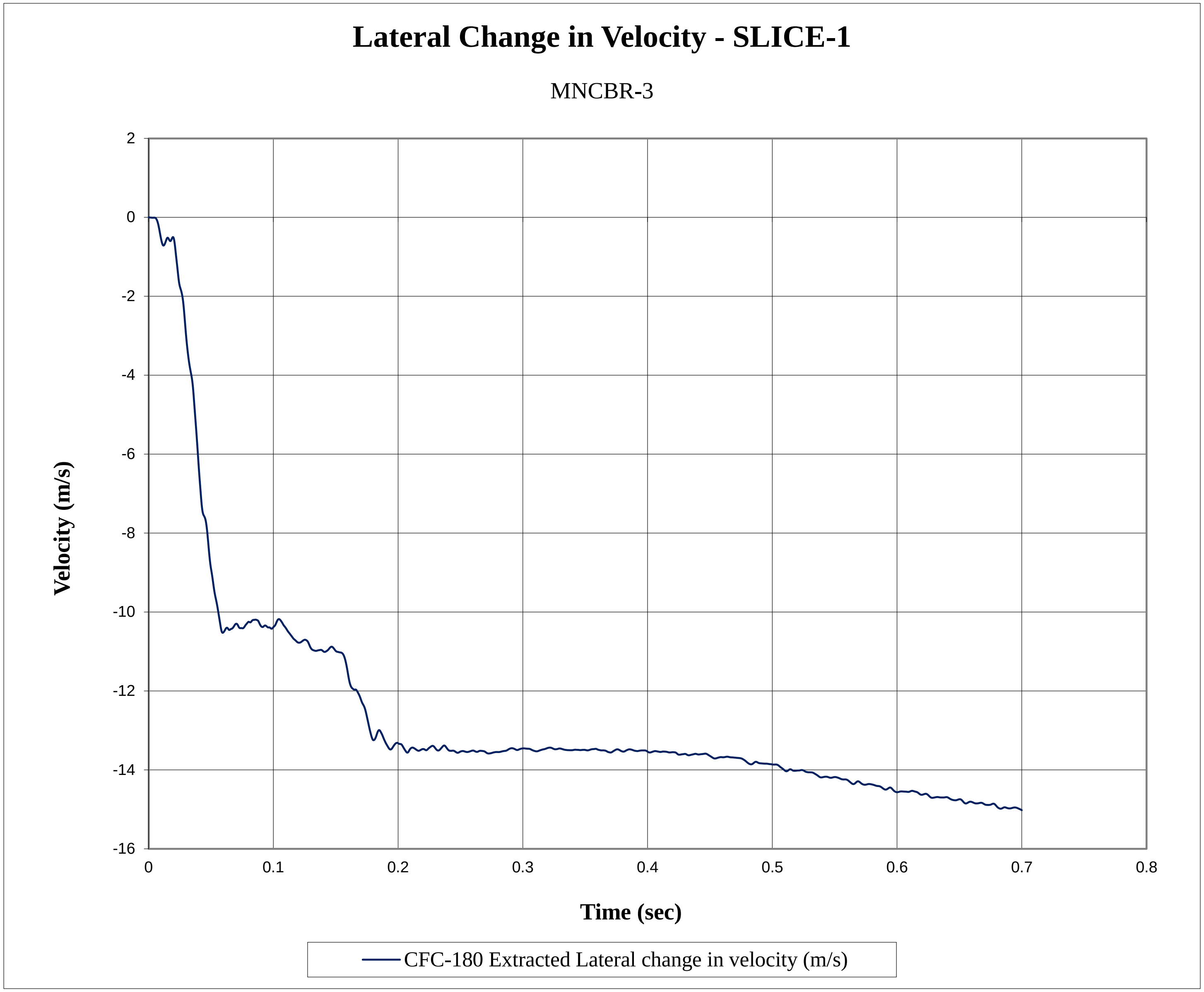


Figure F-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MNCBR-3

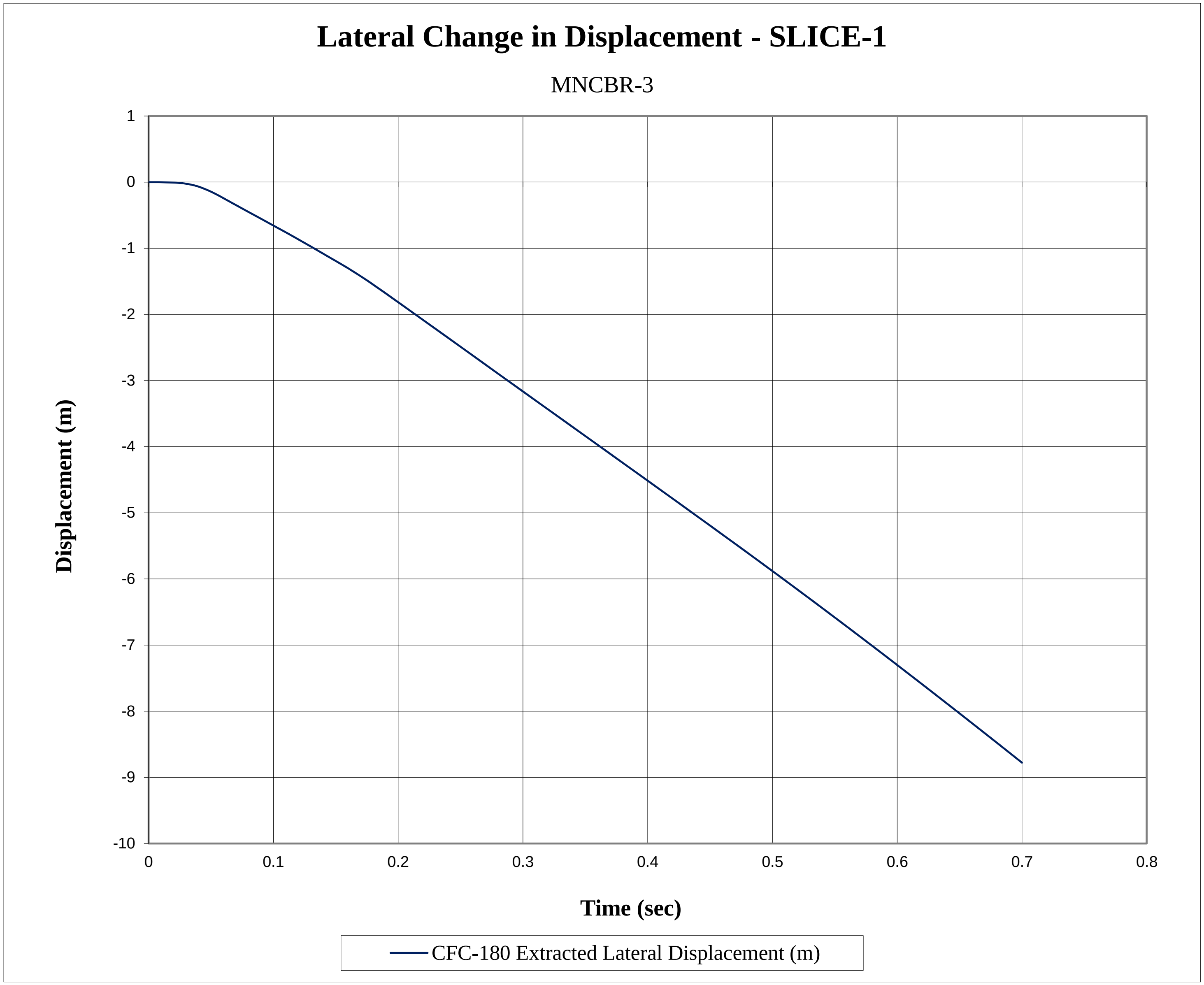


Figure F-6. Lateral Occupant Displacement (SLICE-1), Test No. MNCBR-3

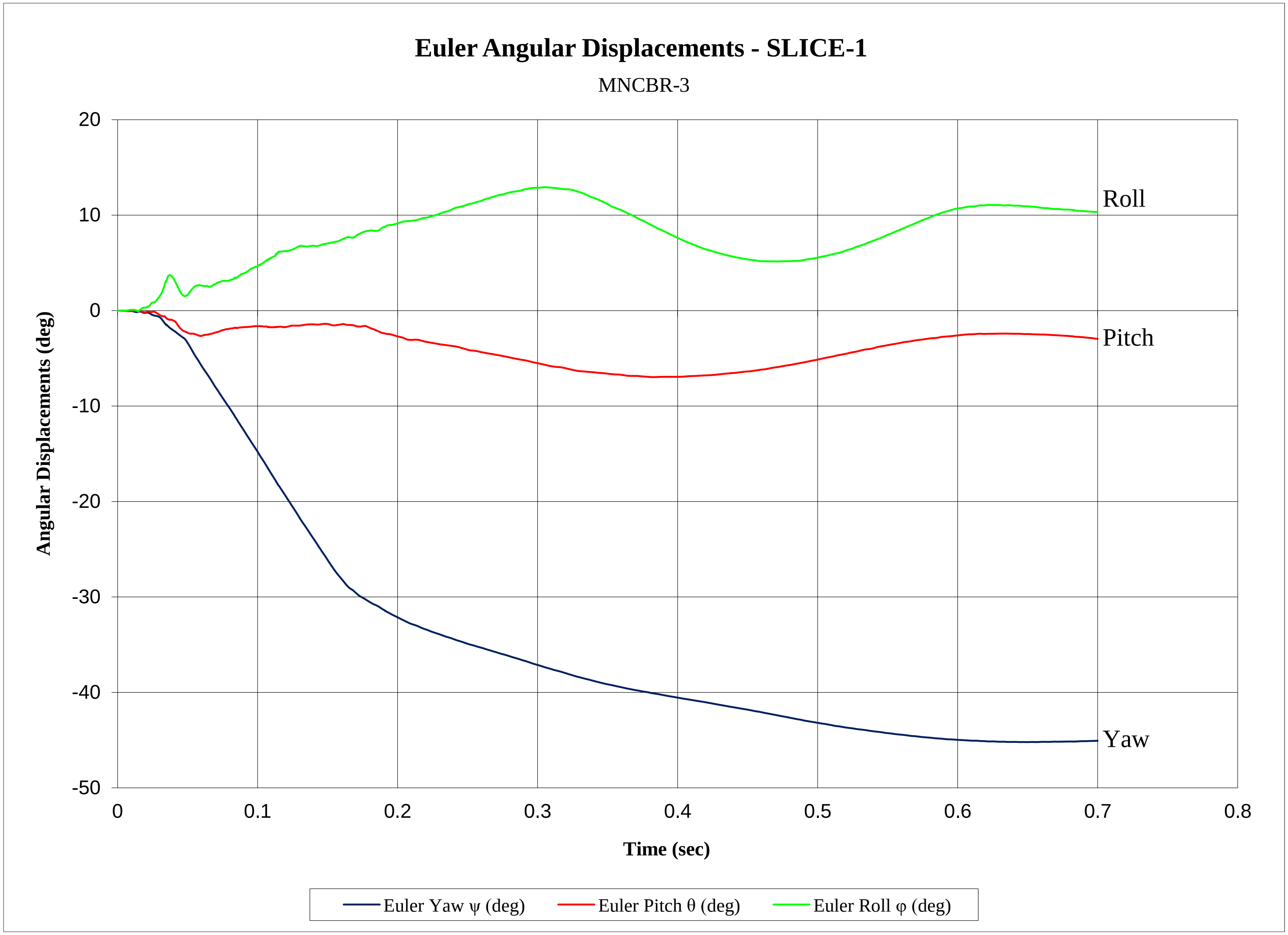


Figure F-7. Vehicle Angular Displacements (SLICE-1), Test No. MNCBR-3

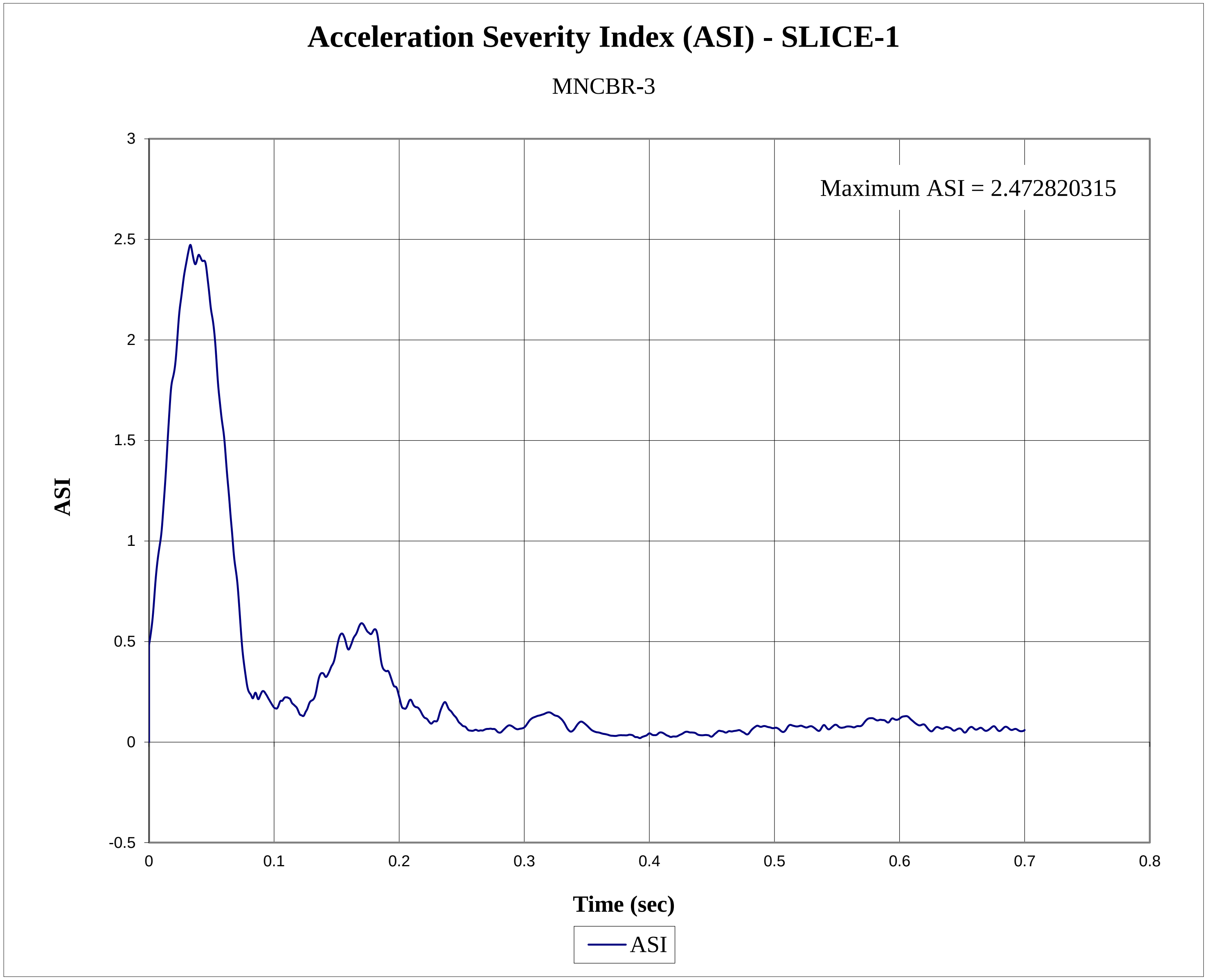


Figure F-8. Acceleration Severity Index (SLICE-1), Test No. MNCBR-3

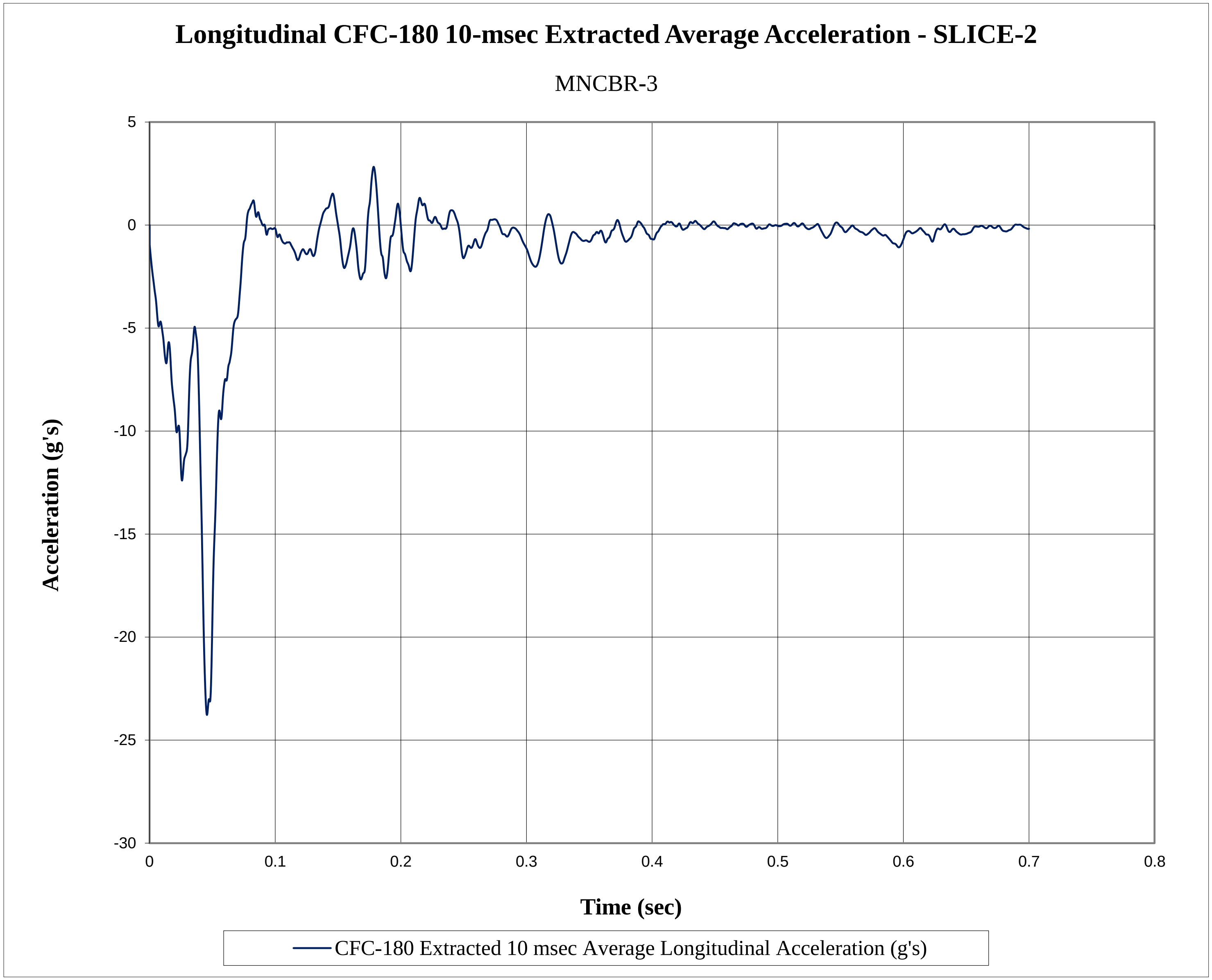


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MNCBR-3

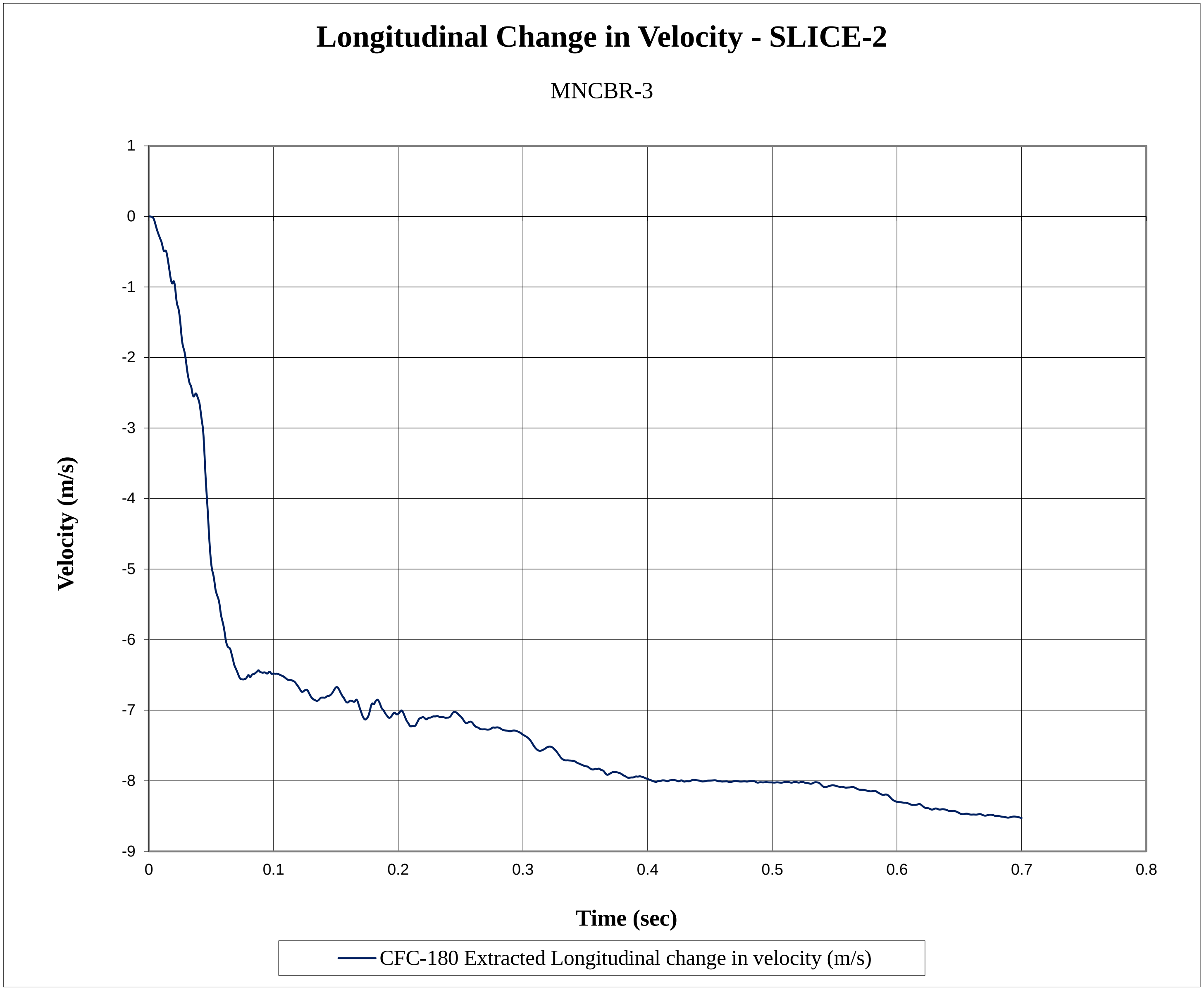


Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MNCBR-3

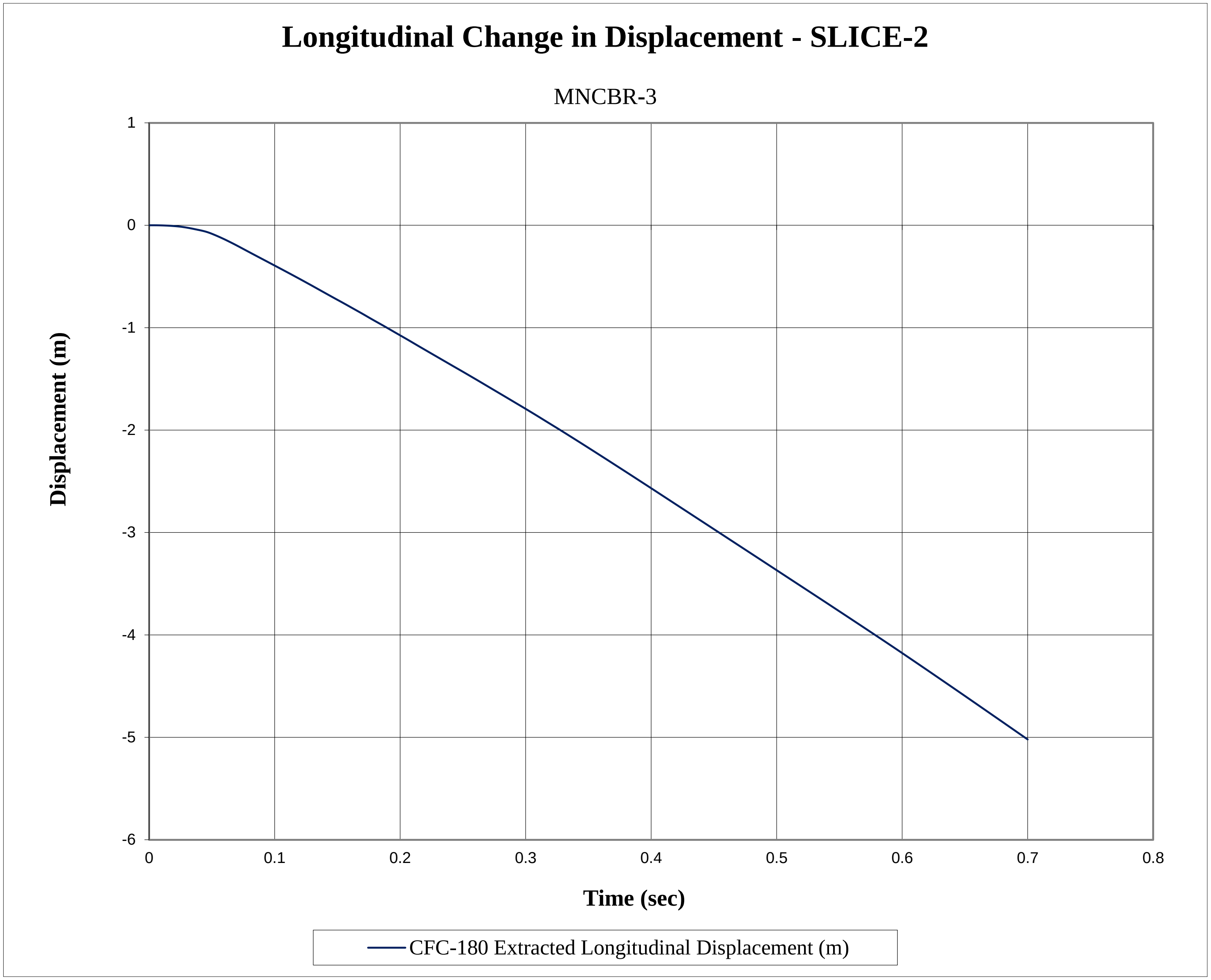


Figure F-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MNCBR-3

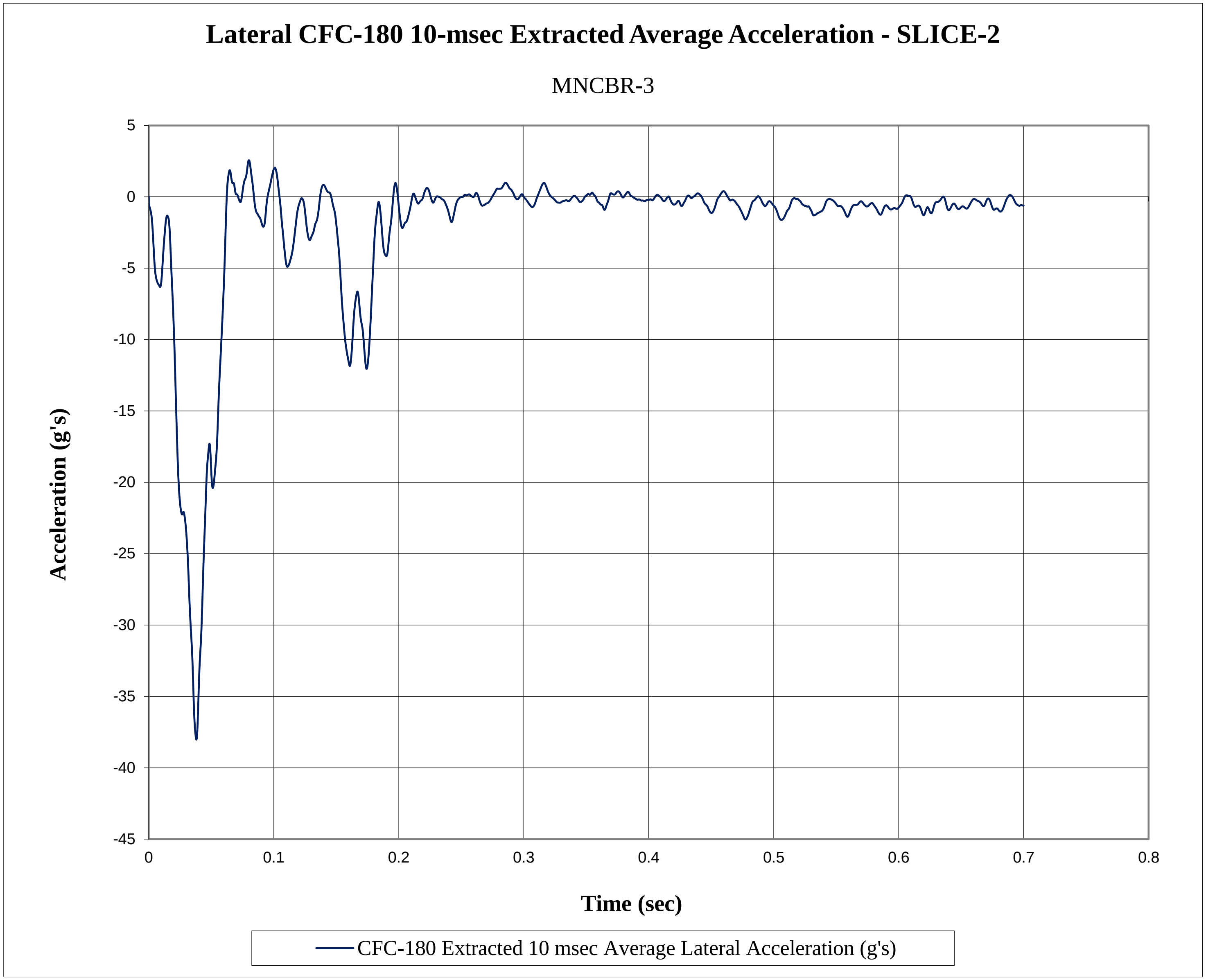


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MNCBR-3

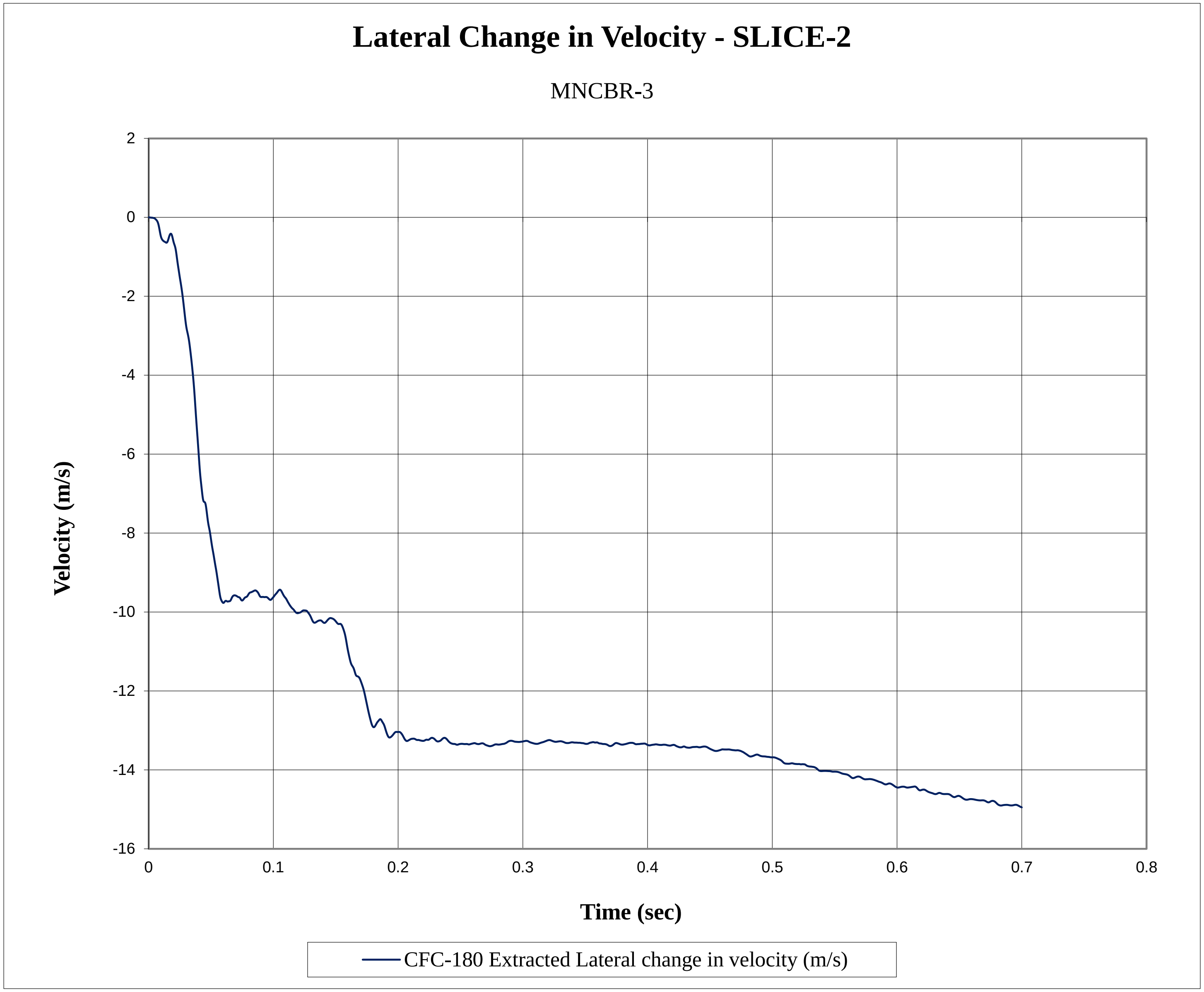


Figure F-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MNCBR-3

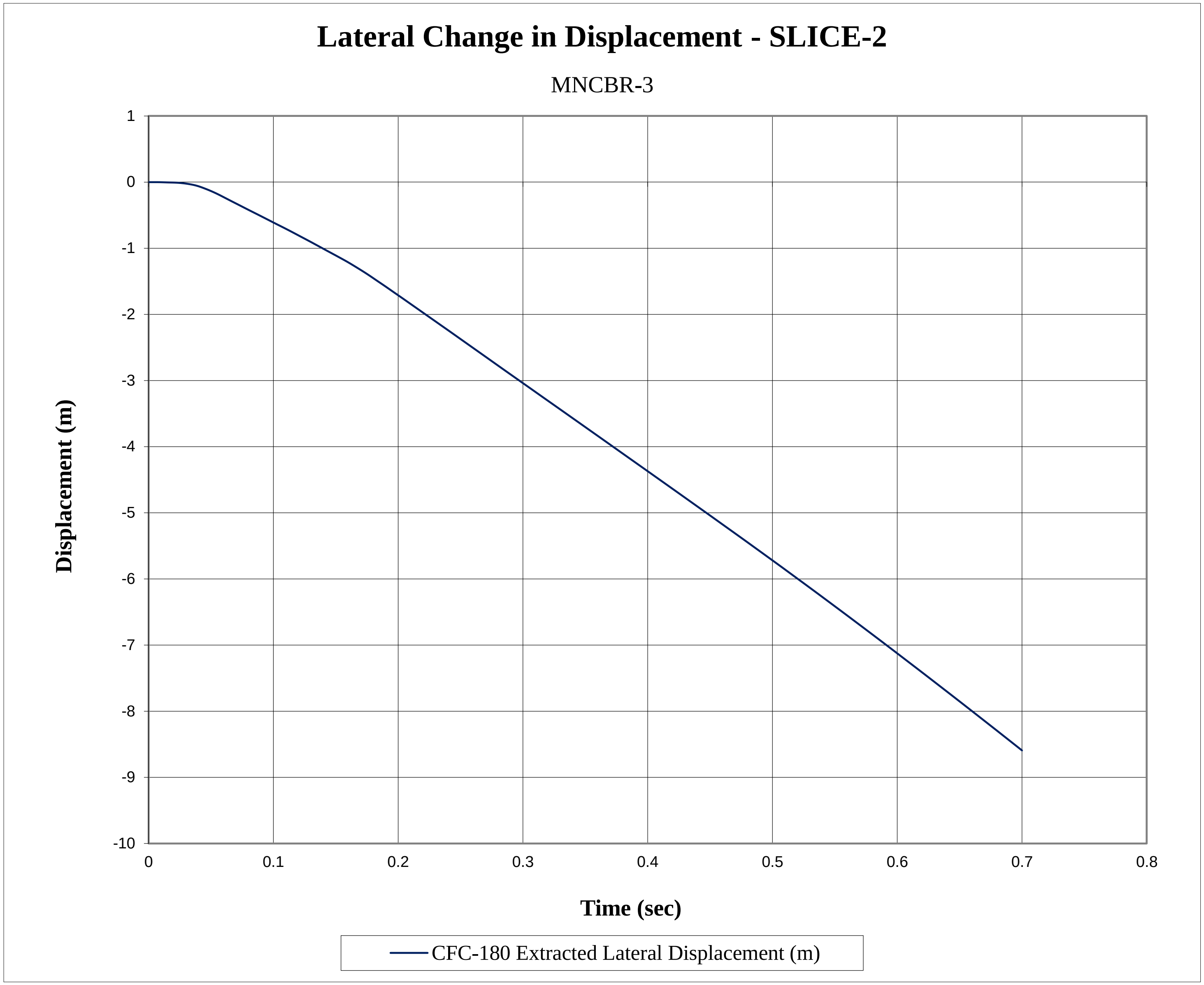


Figure F-14. Lateral Occupant Displacement (SLICE-2), Test No. MNCBR-3

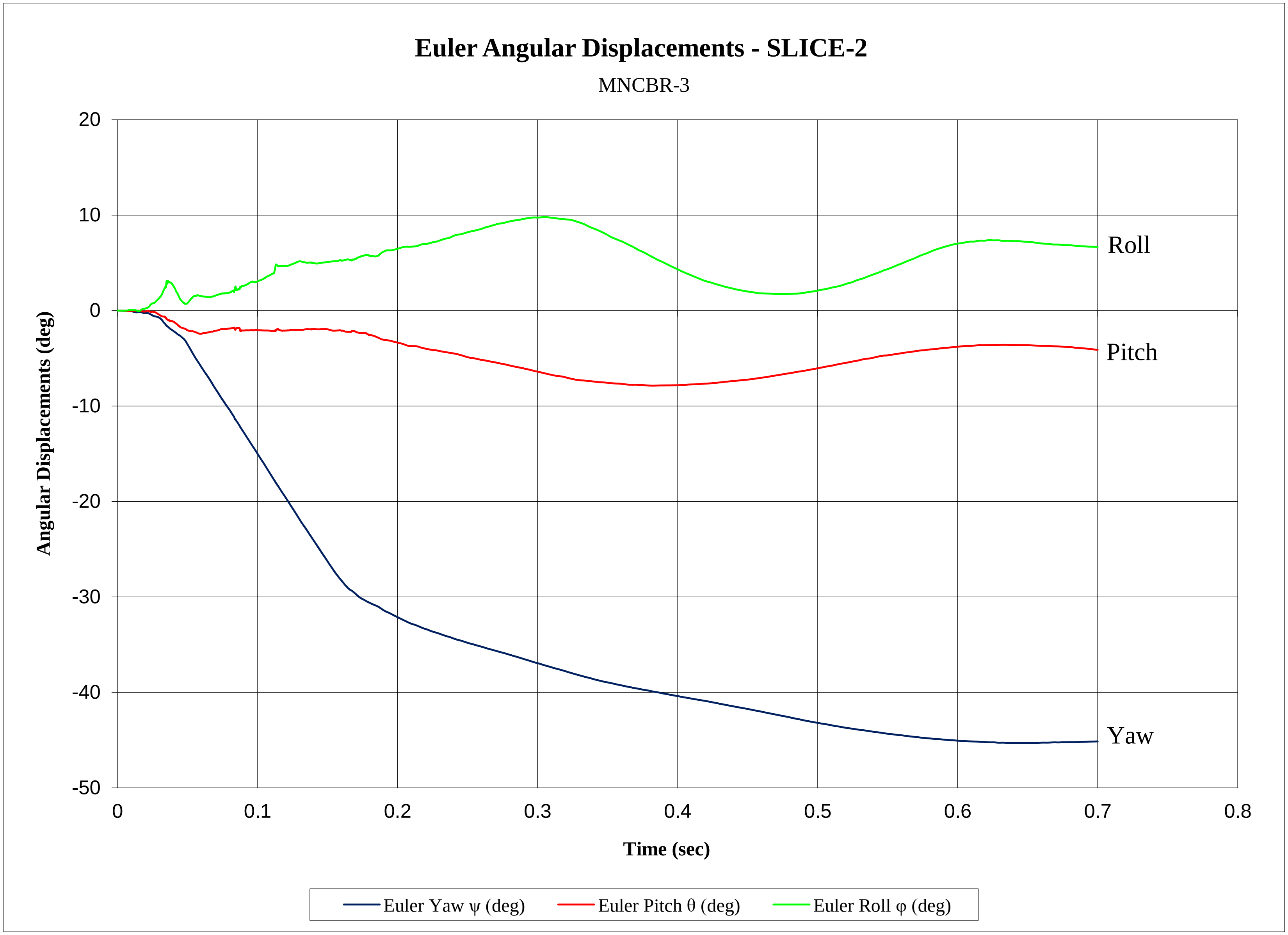


Figure F-15. Vehicle Angular Displacements (SLICE-2), Test No. MNCBR-3

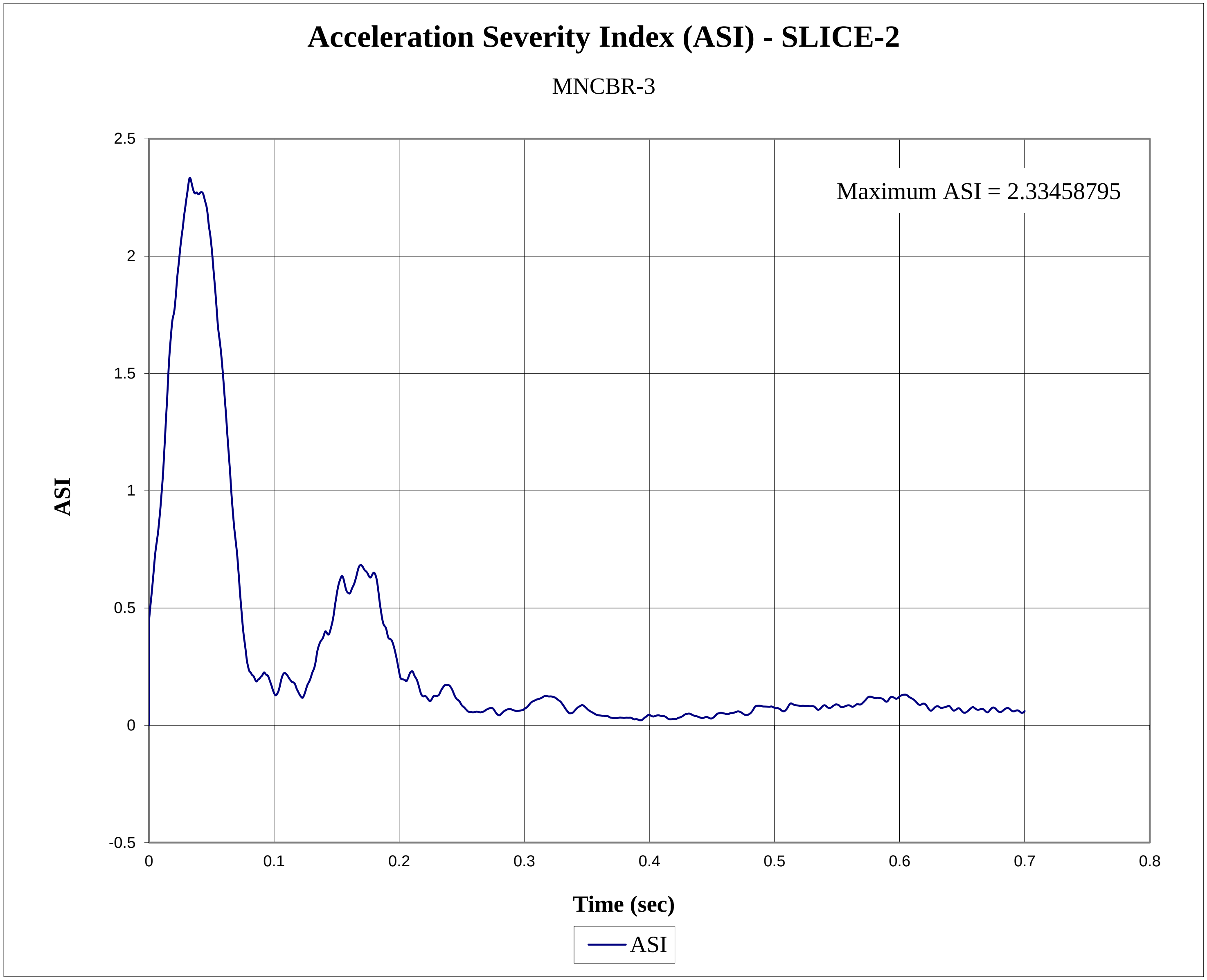


Figure F-16. Acceleration Severity Index (SLICE-2), Test No. MNCBR-3

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