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CRASH TESTING AND EVALUATION OF AN OPEN CONCRETE BRIDGE RAILING

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16. Abstract

This report documents three full-scale vehicle crash tests that were conducted to investigate the safety performance of an open concrete bridge rail according to American Association of State Highway and Transportation Officials' *Manual for Assessing Safety Hardware 2016* (MASH 2016) Test Level 4 (TL-4) evaluation criteria. The barrier system test installation consisted of a 39-in. tall by 132-ft long open concrete bridge rail supported by 15 concrete posts. The interior posts were 36 in. long by 10 in. wide and 72-in. long by 10-in. wide posts were utilized at the upstream end section. All posts were 12 in. tall and were spaced at 108 in. on center. Test nos. OCBR-1, OCBR-2, and OCBR-3 were conducted according to test designation nos. 4-10, 4-11, and 4-12, respectively.

In test no. OCBR-1, an 1100C small car impacted the barrier at speed of 64.2 mph and an angle of 25.2 degrees. In test no OCBR-2, a 2270P pickup truck impacted the barrier at a speed of 61.8 mph and an angle of 24.7 degrees. In test no. OCBR-3, a 10000S single-unit truck impacted the barrier at a speed of 56.6 mph and an angle of 15.2 degrees. In all tests, the bridge rail successfully contained and redirected the vehicles. Tests nos. OCBR-1, OCBR-2, and OCBR-3 successfully met the TL-4 safety performance criteria defined in MASH 2016.

17. Key Words
Highway Safety, Crash Test, Roadside Appurtenances, Compliance Test, MASH 2016, Test Level 4, Bridge Rail, Open Concrete 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 for the data contained herein was Brandon Perry, Research Engineer.

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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.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

To prevent errant motorists traversing bridge structures from leaving the roadway, bridge rails are installed along the edges of the bridge deck. One type of bridge rail is a concrete beam-and-post system, also known as an open concrete bridge rail. Open concrete bridge rails typically consist of rectangular or tapered trapezoidal posts with vertical-faced rails on top. Many transportation agencies prefer open concrete bridge rails for their aesthetics and drainage capabilities. When impacting open concrete bridge rails, vehicle components such as bumpers and wheels (including tires and rims) have the potential to extend beneath the rail and contact a post, potentially resulting in vehicle snag, which can result in excessive occupant compartment deformation or occupant deceleration. Open concrete bridge rails can also be designed with a lower curb which may mitigate the potential for vehicle components to extend under the rail and snag on the posts. However, systems without curbs allow for improved aesthetics and easier snow removal and water drainage directly away from the bridge edge.

The Kansas Department of Transportation (KDOT) currently utilizes a National Cooperative Highway Research Program (NCHRP) Report 350 [1] Test Level 4 (TL-4) compliant 32-in. tall open concrete corral rail on many of its bridges [2], as shown in Figures 1 through 5. The KDOT corral rail, or a similar variation, is also used to some extent across over 22 states, including Nebraska, Illinois, Virginia, Indiana, Iowa, Ohio, Minnesota, Missouri, Texas, and Wisconsin. However, there are concerns as to whether KDOT's corral rail meets the current roadside hardware criteria in the American Association of State Highway and Transportation Officials' (AASHTO's) *Manual for Assessing Safety Hardware* (MASH) [3] due to modifications of the test vehicles and impact conditions in MASH relative to NCHRP Report 350. First, MASH test designation no. 4-10 with the 1100C small car requires an impact at 62 mph and an angle of 25 degrees, while the previous NCHRP Report 350 small car test required an impact angle of only 20 degrees. The increase in the small car impact angle may potentially increase vehicle snag, vehicle instability, and occupant risk, especially with respect to open concrete rail post geometry. Second, similar wheel snag and instability concerns exist with respect to open concrete rails during impacts with the 2270P pickup truck vehicle. Third, the mass of the 2270P pickup truck and 10000S single-unit truck (SUT) vehicles were increased in MASH to 5,000 lb and 22,000 lb, respectively, and the impact speed for test designation no. 4-12 with the SUT was increased from 49.7 mph to 56 mph. These changes in vehicle mass and impact conditions have increased the impact loads imparted to roadside bridge rails. Analysis of NCHRP Report 350 and MASH tests of rigid barrier systems have shown increases in impact loading between 14 to 50 percent for the pickup truck and 11 to 54 percent for the SUT. Finally, the increased speed and mass of the 10000S vehicle test in MASH has indicated a need for increased rail height as compared to TL-4 bridge rails evaluated under NCHRP Report 350 due to the SUT's propensity to roll over the bridge rail. Currently, the minimum height of a rigid, concrete barrier evaluated to MASH TL-4 with the 10000S vehicle has been identified as 36 in. in multiple successful crash tests [4].

At the time of this research, only one open concrete bridge rail had been evaluated under MASH criteria. Texas A&M Transportation Institute (TTI) recently completed MASH testing of a 42-in. tall open concrete bridge rail system, shown in Figure 6 [5]. This system was successfully evaluated to MASH TL-5, and was successfully tested with both the 2270P pickup truck and

1100C small car. While this open concrete bridge rail has some similar features to the KDOT design, the TTI bridge rail differs significantly in that it incorporated a 9-in. tall curb at the base, was 10 in. taller, and had different post and joint details. The inclusion of the curb at the base of the rail may mitigate some of the wheel snag and vehicle stability concerns posed by an open concrete bridge rail without a curb.

Five state DOTs, which included Kansas, Iowa, Nebraska, South Dakota, and Virginia, desired the development of a modified version of the KDOT open concrete bridge rail system that was MASH TL-4 compliant. In addition to potential modifications to the bridge rail in order to meet MASH TL-4 standards, the states desired that the bridge rail design consider 3-in. asphalt overlays while maintaining safety performance. Finally, the Midwest Pooled Fund has developed a MASH TL-3 standardized concrete end buttress for the attachment of thrie beam approach guardrail transitions. The objective of this buttress design was to allow the attachment of any MASH TL-3 compliant thrie beam approach guardrail transition to a standard parapet design that could accommodate approach guardrail transitions with or without curbs and at various post spacings and post configurations. This standardized concrete end buttress recently completed MASH TL-3 evaluation for both a standard 31-in. tall thrie beam approach guardrail transition and a 34-in. tall thrie beam approach guardrail transition that allows for pavement overlays. It was desired that the MASH TL-4 corral rail design be developed with appropriate transitions to interface with the standardized concrete end buttress.

Previous research on the development of the MASH TL-4 open concrete bridge rail system was detailed in a Phase I design report [6-7]. The proposed design for the new open concrete bridge rail was a 27-in. tall by 14-in. wide concrete rail supported by 36-in. long by 10-in. wide concrete posts. This report documents three full-scale crash tests conducted to evaluate the new MASH TL-4 open concrete bridge rail system.

1.2 Objective

The objective of this research effort was to develop a MASH-compliant TL-4 open concrete corral railing based on the existing KDOT NCHRP Report 350 TL-4 corral rail. The railing was designed for strength, vehicle stability, and to accommodate pavement overlays. Efforts were also made to optimize load transfer into the deck, thereby minimizing the risk of damage to the bridge deck. Details were developed for both interior and end regions/discontinuities of the bridge rail. Geometric and structural transitions between the bridge rail design and the standardized end buttress were provided for the simple and consistent attachment of approach guardrail transitions. The system was evaluated according to MASH TL-4 criteria through full-scale crash testing.

1.3 Scope

The research objective was achieved through the completion of several tasks detailed in this report. Three full-scale crash tests were conducted on the open concrete bridge rail according to MASH test designation nos. 4-10, 4-11, and 4-12. Then the full-scale vehicle crash test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made pertaining to the safety performance of the open concrete bridge rail. Guidance was also provided relative to geometric and structural transitions between the bridge rail design and the standardized end buttress for attachment of approach guardrail transitions.

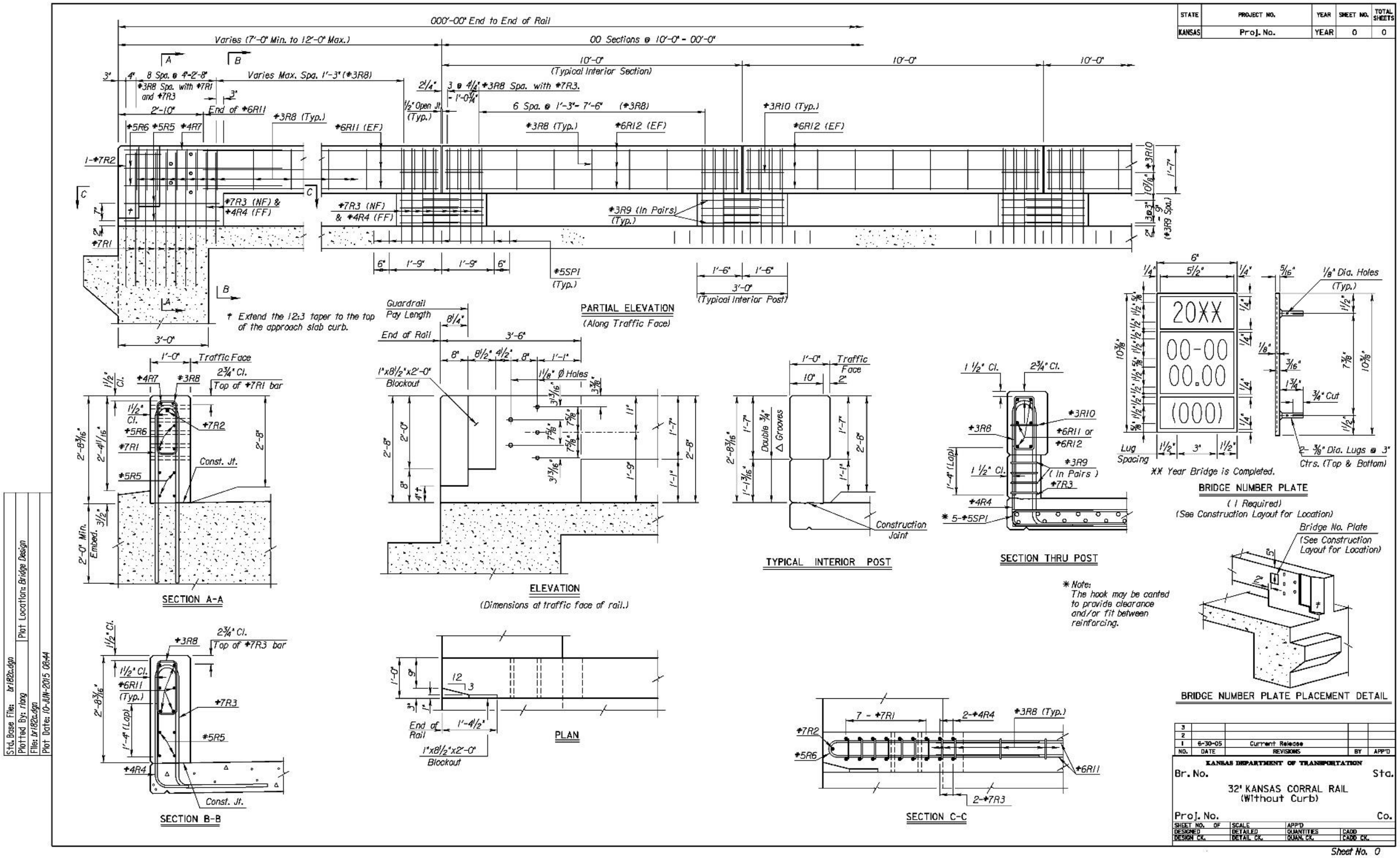


Figure 1. KDOT Open Concrete Corral Rail Details [8]

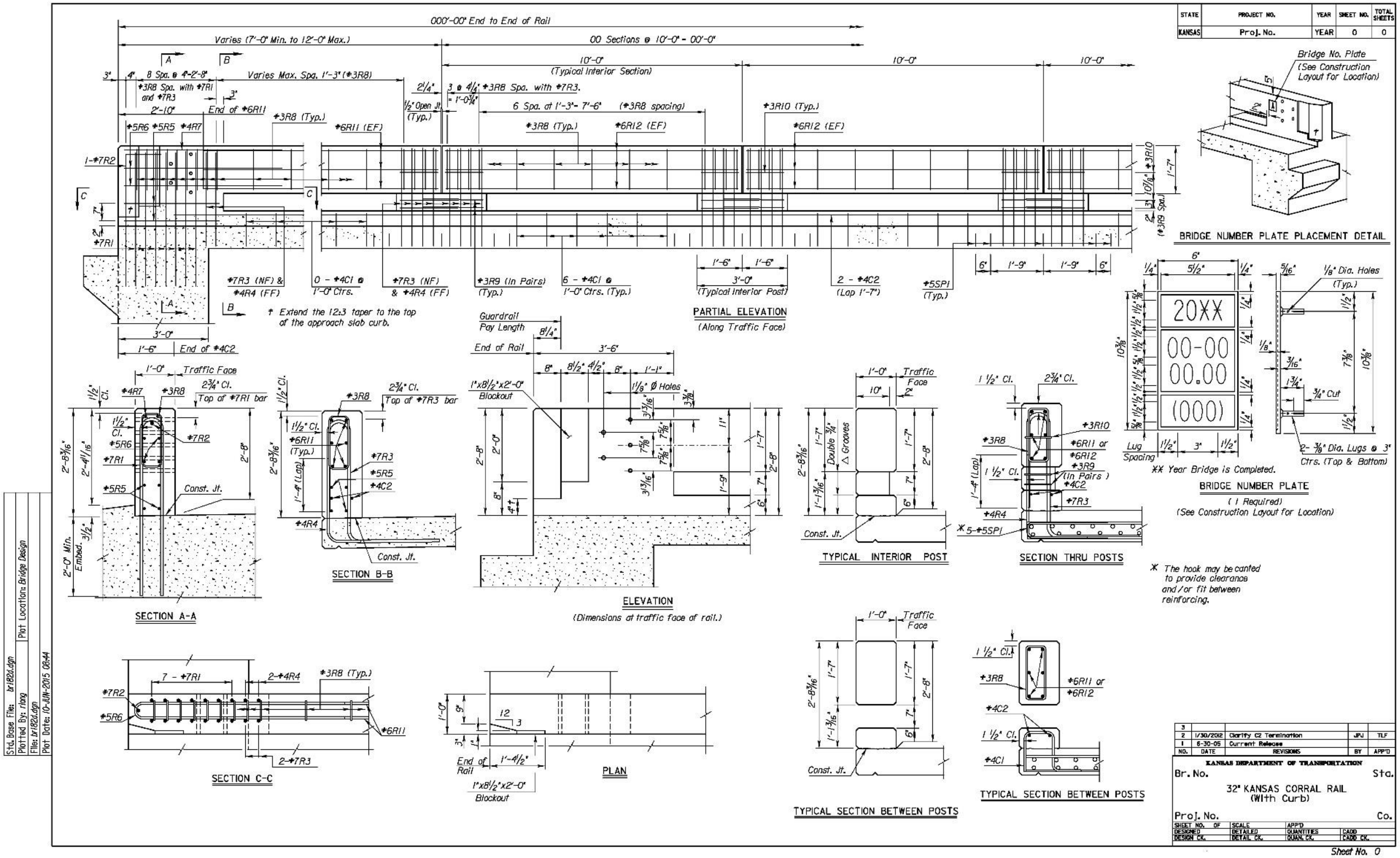


Figure 2. KDOT Open Concrete Corral Rail Details [8]

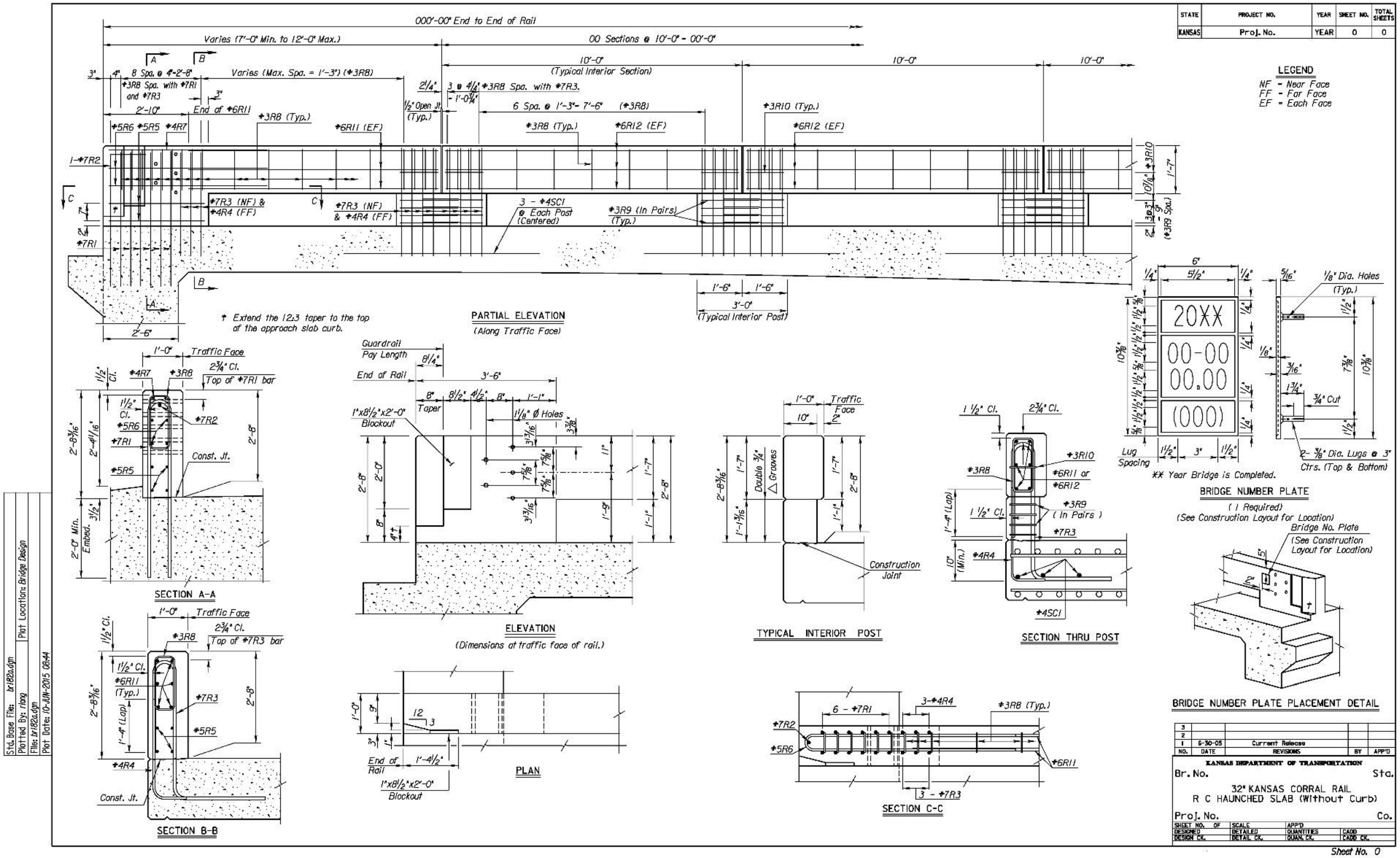


Figure 3. KDOT Open Concrete Corral Rail Details [8]

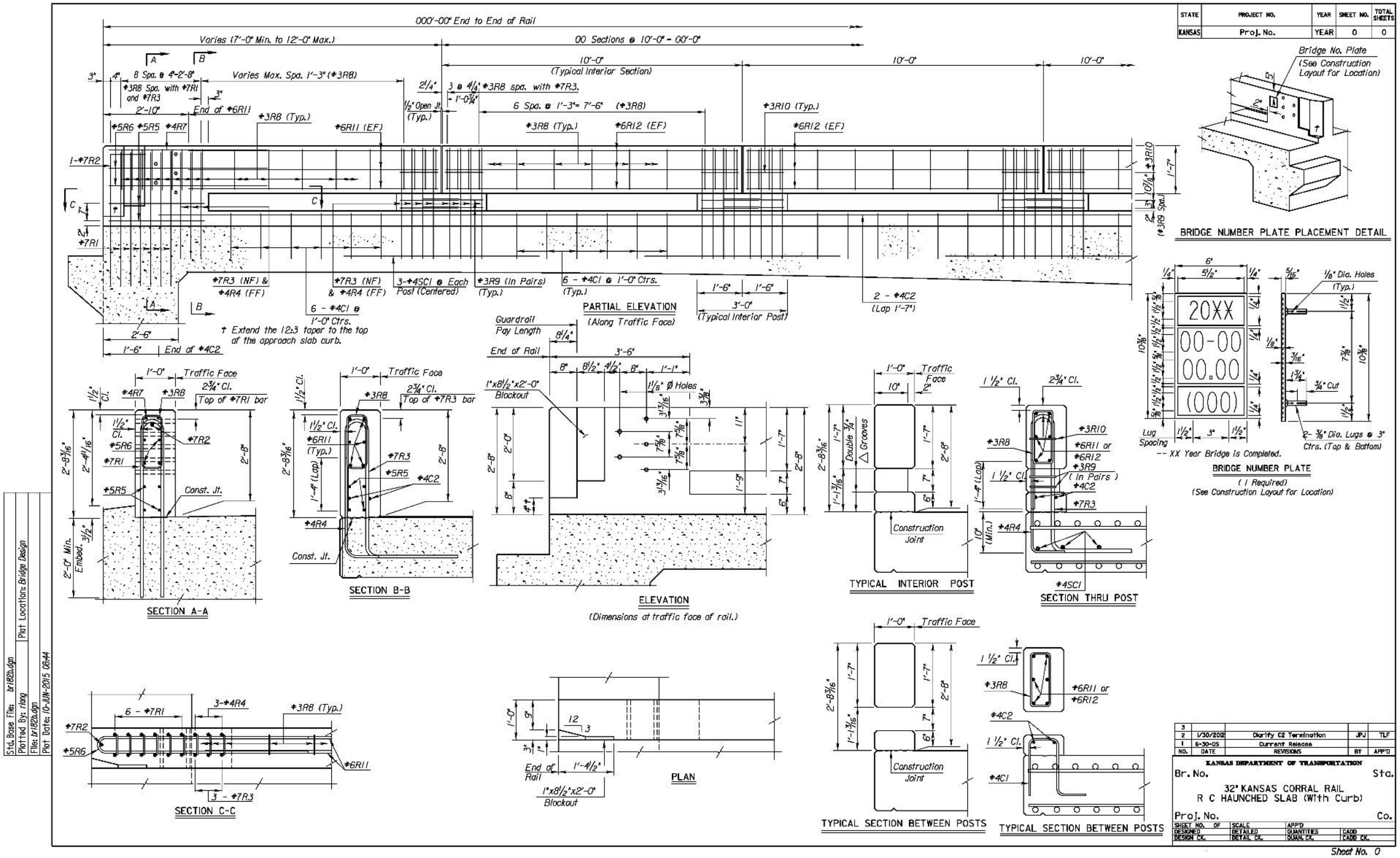


Figure 4. KDOT Open Concrete Corral Rail Details [8]

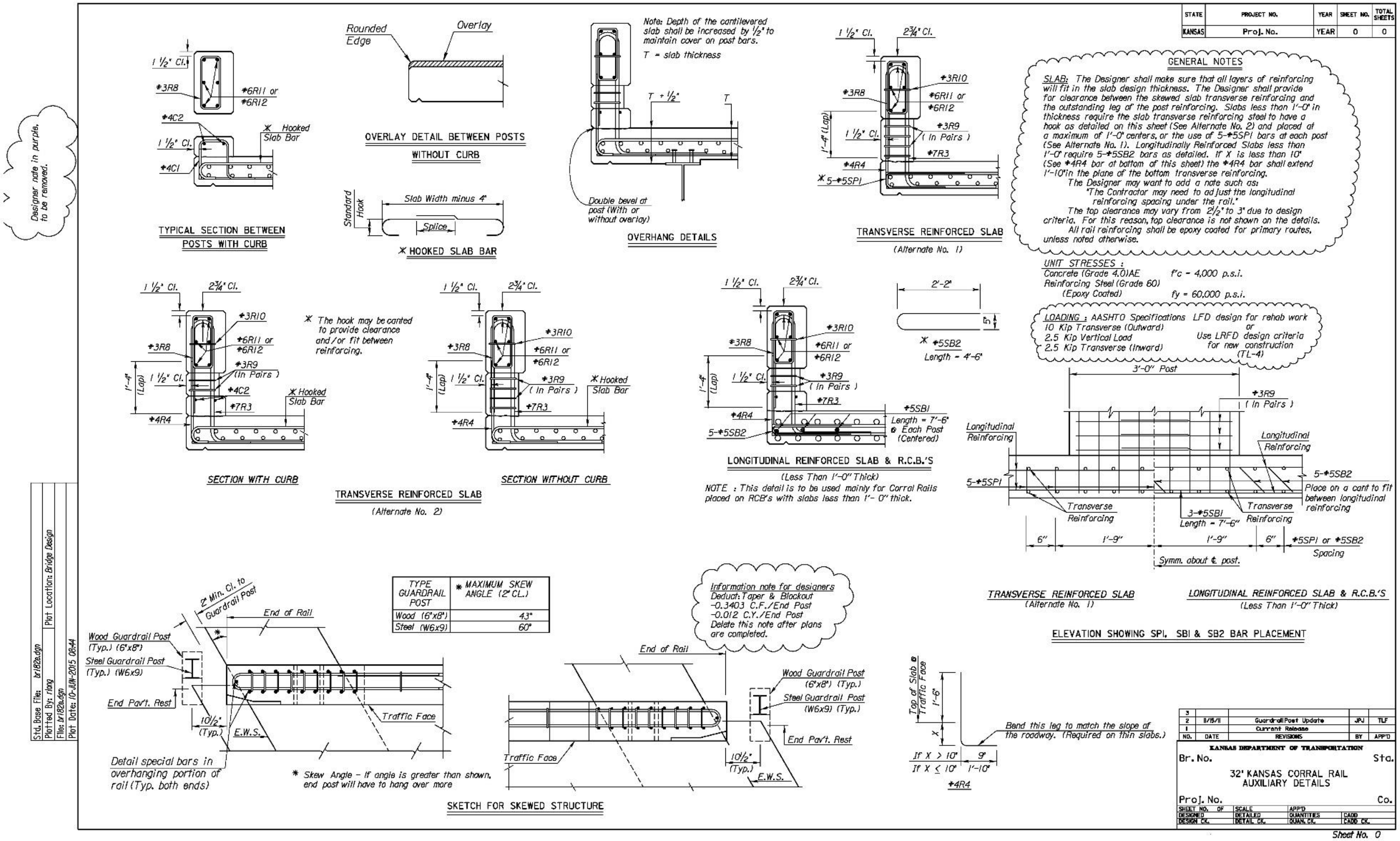


Figure 5. KDOT Open Concrete Corral Rail Details [8]

Figure 6. TTI TL-5 Open Concrete Bridge Rail [5]

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as open concrete bridge rails, must satisfy impact safety standards to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System. For new hardware, these safety standards consist of the guidelines and procedures published in MASH. According to TL-4 of MASH, longitudinal barrier systems must be subjected to three full-scale vehicle crash tests, as summarized in Table 1.

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

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight lb	Impact Conditions		Evaluation Criteria [1]
				Speed mph	Angle degrees	
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 explained in Table 2.

Test designation no. 4-10 with the 1100C vehicle was required to evaluate occupant risk measures and the potential for vehicle snag on the upstream end of the posts. Test designation no. 4-11 with the 2270P vehicle was required to evaluate concerns for increased bridge rail loading, potential vehicle snag at joints and posts, and vehicle instability. Test designation no. 4-12 with the 10000S vehicle was required to evaluate the overall structural capacity of the bridge rail and its ability to contain and redirect SUTs. Full evaluation of the open concrete bridge rail design would likely require multiple tests of each test designation to evaluate design differences between the end and interior sections of the bridge rail. However, it was believed that selection of a critical configuration for each test could be combined with conservative bridge rail design to limit the number of required tests.

Note that the test matrix detailed herein represents the researchers' best engineering judgement of which tests were necessary to assess system crashworthiness according to MASH safety requirements. However, any tests deemed non-critical in this research effort might require future evaluation due to revisions to the MASH criteria or additional knowledge gained over time.

Table 2. MASH Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="11">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.</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 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 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 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three factors: (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. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in MASH.

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.

3 CRITICAL IMPACT POINT SELECTION

Evaluation of the critical impact points (CIPs) for the TL-4 open concrete bridge rail required consideration of several factors, including occupant risk, vehicle capture, and critical structural loading of the barrier at interior and end sections. First, test designation nos. 4-10 and 4-11 with passenger vehicles were designed primarily to evaluate occupant risk during impact with the bridge rail. As such, CIPs for test designation nos. 4-10 and 4-11 corresponded to the location on a bridge rail where vehicle snagging was maximized. MASH states that CIPs for the 1100C and 2270P vehicles for longitudinal barriers should be 3.6 ft and 4.3 ft upstream from a reference post, respectively. Thus, the CIPs for test nos. OCBR-1 and OCBR-2 were selected as 43 3/16 in. upstream from the upstream edge of post no. 11 and 51⅝ in. upstream from the upstream edge of post no. 7, respectively. Because the TL-4 open concrete bridge rail was designed with an increased rail height to accommodate 3-in. tall paving overlays, the critical height of the rail also had to be specified for the passenger vehicle tests. The researchers determined that evaluation of the TL-4 open concrete bridge rail at its maximum rail height would provide the largest opening between the rail element and the road surface, and the corresponding greatest potential for the vehicle wheels to extend under the rail and snag on the system posts.

Test designation no. 4-12 with the 10000S SUT was intended to evaluate the structural capacity of the barrier and the containment of the heavy truck. MASH states that the CIP for test designation no. 4-12 with the 10000S vehicle should be selected to generate the maximum lateral loading of the bridge rail components and connections. To evaluate the CIP for the TL-4 open concrete bridge rail, the researchers selected an impact point that would maximize the loading at the midspan of the rail as this would generate the highest beam moments as well as impart critical loading to the posts and deck components. The design of the open concrete bridge rail had previously identified a midspan impact as the critical location for loading of the bridge rail based on inelastic beam and post analysis with a three-span failure mode [6-7]. Research conducted during NCHRP Project 22-20(2) [9] had previously shown that the maximum loading from SUT impacts occurs as a result of the rear tandem impacting the bridge rail as the vehicle is redirected.

To select the CIP for the SUT used in the open concrete bridge rail crash test, it was necessary to investigate previous SUT full-scale crash tests and determine approximately where the rear tandem impacted the system in relation to the initial impact point. Through examination of videos and photographs of full-scale crash tests, it was determined that the rear tandem of the SUT consistently impacted the barrier downstream from the initial impact point. Additionally, it was observed that as the wheelbase of the SUT increased, the impact point of the rear tandem moved farther upstream, closer to the initial impact point. Based on the previously observed impact locations, SUTs with wheelbases consistent with that used in test no. OCBR-3 corresponded to a rear tandem impact located approximately 16 to 19 in. downstream from the initial impact location. Thus, the CIP for test no. OCBR-3 was selected 18 in. upstream from the midspan between post nos. 3 and 4, as this impact location would result in the rear tandem impacting at approximately the mid-span of the rail. It should also be noted that the researchers considered both interior and end section impact locations as part of the CIP selection. During the design of the open concrete bridge rail, the end sections of the bridge rail and deck were designed with greater capacity than the interior sections. As such, the impact was conducted on an interior region of the bridge rail.

Finally, because the TL-4 open concrete bridge rail system had two potential top rail heights dependent on whether the system was installed with an overlay 36 in. and 39 in., the researchers had to select the critical height of the bridge rail for test designation no. 4-12. Typically, MASH TL-4 full-scale crash tests have been conducted at the lower height to ensure adequate capture and containment of the 10000S vehicle, and previous MASH TL-4 crash testing has established the lower height for containment of the 10000S vehicle as 36 in. [9]. Because the lower rail height of the TL-4 open concrete bridge rail with the overlay was planned to be 36 in., which coincided with the rail height of multiple previous full-scale crash tests, it was not believed that the lower bound rail height was critical for evaluation of the system. The highest rail height of the bridge rail without the overlay in place, 39 in., was selected for test designation no. 4-12 because this height increased the effective load height of the vehicle on the bridge rail and would produce more critical loads and moments in the posts and deck.

4 DESIGN DETAILS

The TL-4 open concrete bridge rail system test installation consisted of a 39-in. tall by 132-ft long open concrete bridge rail supported by 15 concrete posts, as shown in Figures 7 through 26. Photographs of the test installation are shown in Figures 27 through 29. Material specifications, mill certifications, and certificates of conformity for the system materials are in Appendix A.

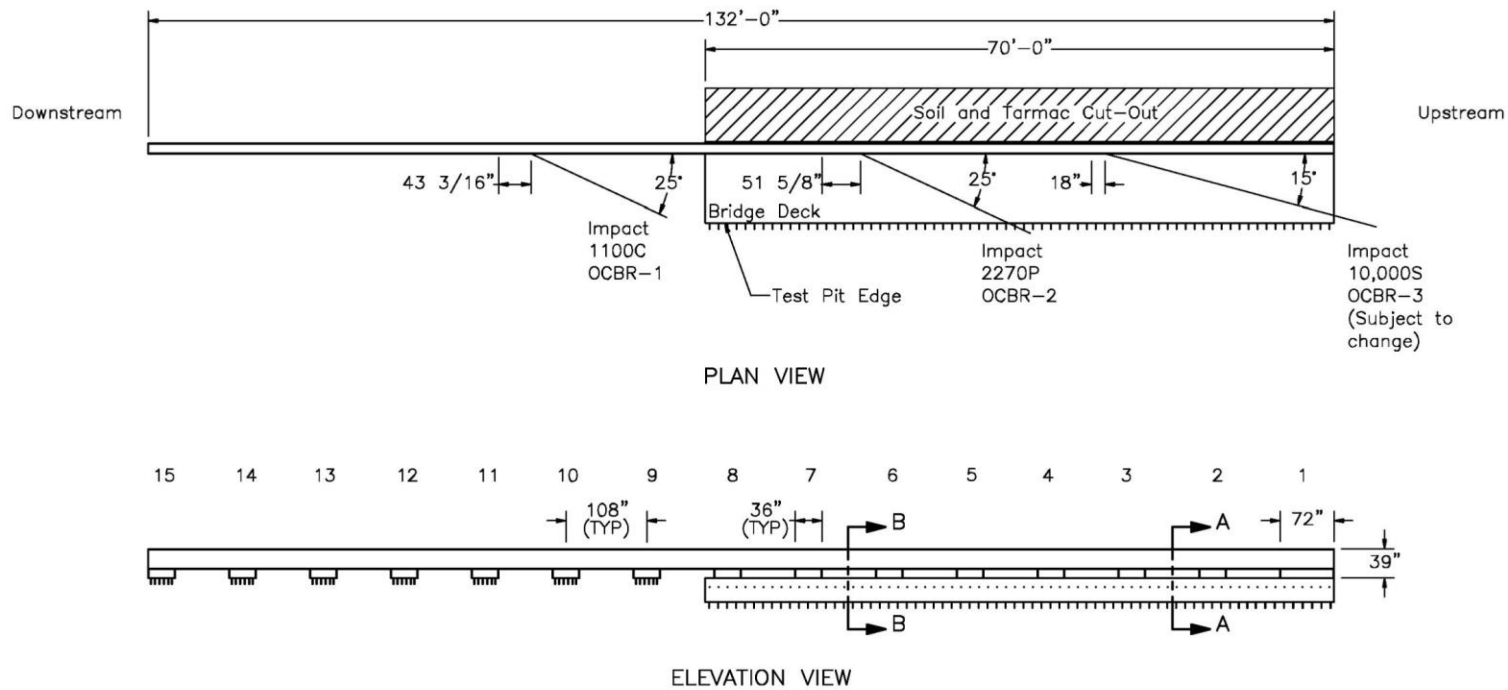
The open concrete bridge rail was supported by 14 36-in. long by 10-in. wide rectangular posts in the interior section, and a 72-in. long by 10-in. wide rectangular end post at the upstream end of the system. All posts were 12 in. tall and spaced at 108 in. center to center. The backs of the posts were offset 2 in. from the deck edge. Vertical reinforcement in the interior section posts consisted of 12 No. 5 rebars, 6 on each face of the post, spaced at 6 in. The vertical reinforcement at the end section post consisted of 28 No. 5 rebars, 14 on each face of the post, longitudinally spaced at 5 in. Post shear reinforcement in each of the concrete posts consisted of 3 No. 4 rebar stirrups vertically spaced at 4 in. The reinforcement for the interior posts and end section post is shown in Figures 11 through 13.

A 27-in. tall by 14-in. wide concrete rail was supported by posts, as shown in Figure 27. The rail was installed with a 4-in. post setback measured from the traffic-side face of the rail to the traffic-side face of the posts. The longitudinal rail reinforcement in the interior section of rail consisted of 8 No. 6 rebars, 4 on each face of the rail, vertically spaced at 6½ in. on center, as shown in Figure 9. The longitudinal rail reinforcement in the end section of rail consisted of 14 No. 6 rebars, 7 on each face of the rail, vertically spaced at 3¼ in. on center, as shown in Figures 12 and 13.

The upstream 70 ft of the test installation was installed on an 8-in. thick simulated bridge deck, which extended 60 in. laterally past the reinforced concrete grade beam, as shown in Figure 17. The remaining downstream portion of the open concrete bridge rail was anchored to the existing concrete tarmac. The bridge rail, bridge deck, and grade beam were all constructed utilizing 4,000-psi concrete.

Reinforcement for the bridge deck consisted of no. 4 transverse U-bars, no. 4 longitudinal bars, and no. 5 lateral U-bars that wrapped around the vertical post reinforcement of both the interior and end section posts to satisfy the area of steel requirement in this section. Lateral U-bars were included to provide additional flexural reinforcement as well as tension reinforcement. Clear cover from the top of the bridge deck to the top layer of reinforcement was 2½ in., and clear cover from the bottom of the bridge deck to the bottom layer of reinforcement was 1½ in. Lateral and longitudinal clear cover from the edge of the bridge deck to the end of the lateral and longitudinal deck reinforcement was 2 in. In interior sections of the deck at posts, no. 4 transverse U-bars were spaced at 3 in., as this spacing aligned with the vertical post reinforcement. At interior deck sections between posts, the no. 4 transverse U-bars were spaced at 12 in. In the region of the deck at the end post, no. 4 transverse U-bars were laterally spaced at 2½ in. Lateral no. 5 U-bars spaced at 10 in. were wrapped around two vertical post bars in the end post region. The no. 4 transverse U-bars in the transition region between the end post and the interior post were laterally spaced at 9 in. Longitudinal bridge deck reinforcement was placed adjacent to vertical post bars to reduce the possibility of reinforcement pulling out of the concrete, and the remaining bars were spaced at 12 in. in the top and bottom reinforcement layers.

It should be noted that three deck reinforcement options were provided during the design phase of this project [6-7]. The deck reinforcement selected for full-scale crash testing was chosen as it would be the easiest to construct. However, the other options listed in the design report would be expected to perform similarly.



Notes: (1) Test no. OCBR–1 shall be performed according to test designation no. 4–10 using MASH 2016 criteria.
(2) The impact location for test no. OCBR–1 is 43 3/16 in. upstream of the upstream edge of post 11.
(3) Test no. OCBR–2 shall be performed according to test designation no. 4–11 using MASH 2016 criteria.
(4) The impact location for test no. OCBR–2 is 51 5/8 in. upstream of the upstream edge of post 7.
(5) Test no. OCBR–3 shall be performed according to test designation no. 4–12 using MASH 2016 criteria.
(6) The impact location for test no. OCBR–3 is 18" upstream from the midspan between posts 3 and 4.
(7) System should be adjusted for west to east tarmac slope when constructed. Tarmac rail and bridge rail are to be aligned.

MwRSF
Midwest Roadside Safety Facility

Open Concrete Bridge Rail
Test Nos. OCBR–1–3
Overall View

SHEET: 1 of 20
DATE: 8/20/2021
DRAWN BY: MJM/LJP/SBW/GHR
DWG. NAME. OCBR–1–3_R18
SCALE: 1:200
UNITS: in.
REV. BY: JD/JEK/SKR/JDR/KAL/JCH/RWB

Figure 7. Test Installation Layout, Test Nos. OCBR-1, OCBR-2, and OCBR-3

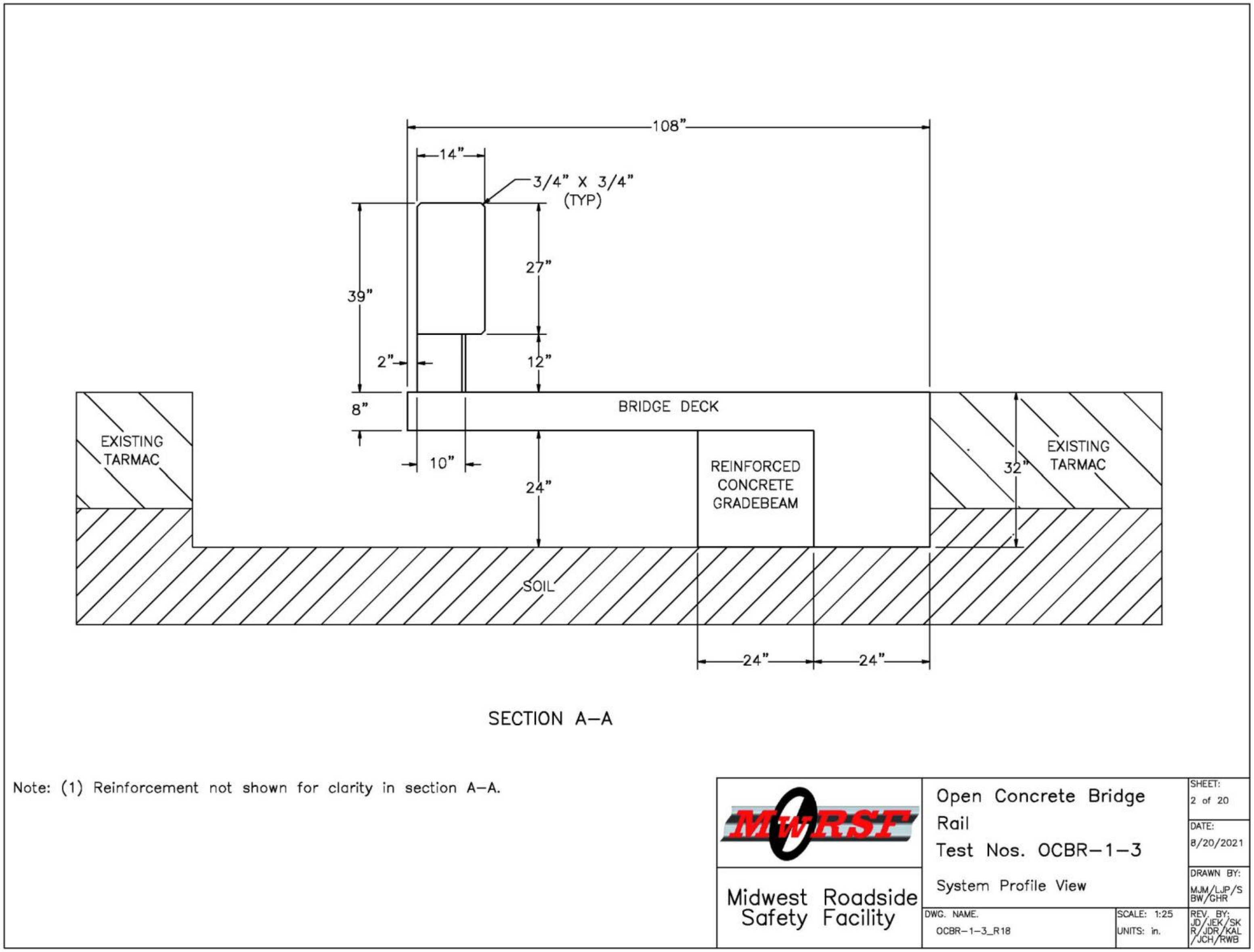
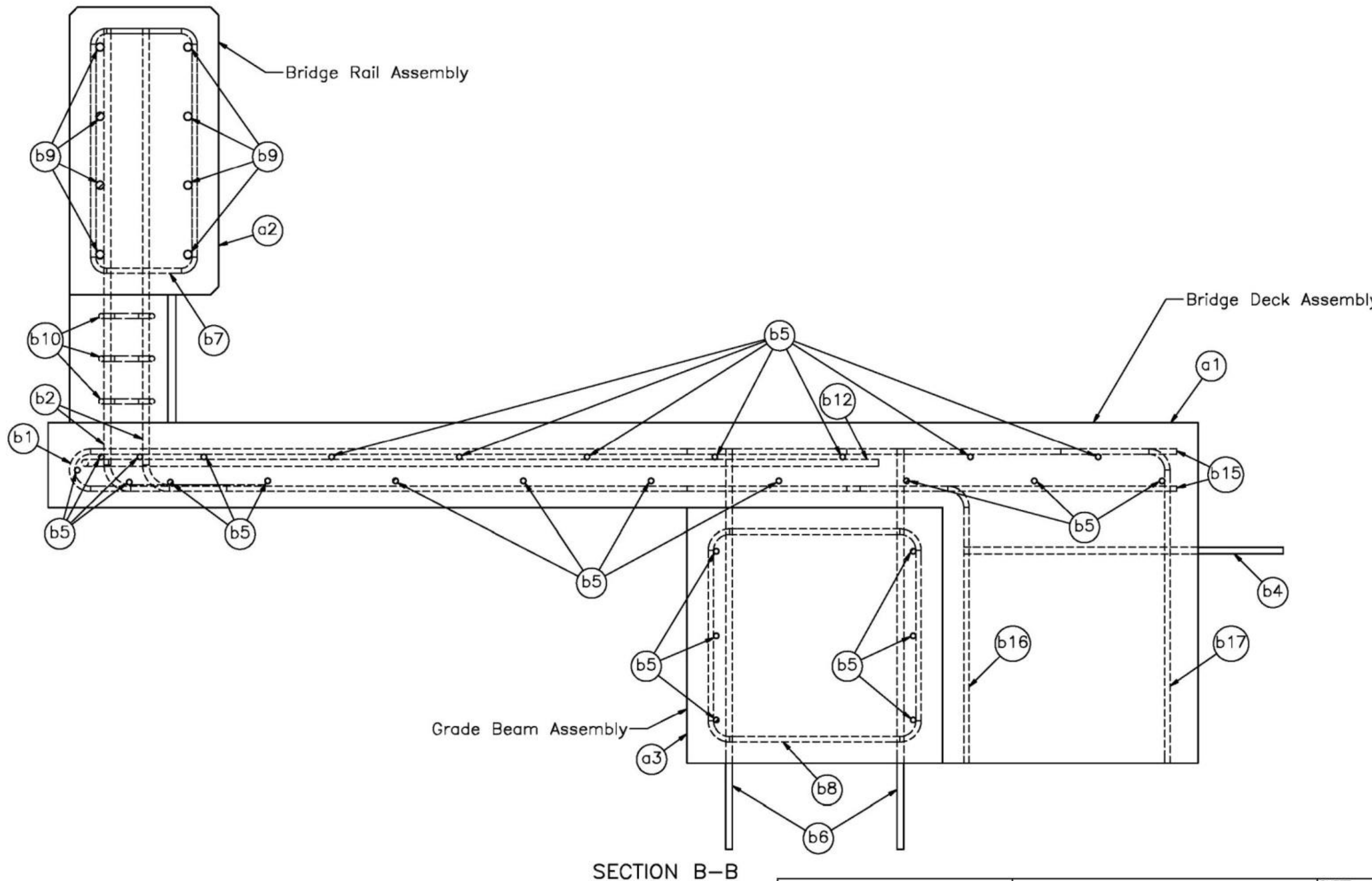


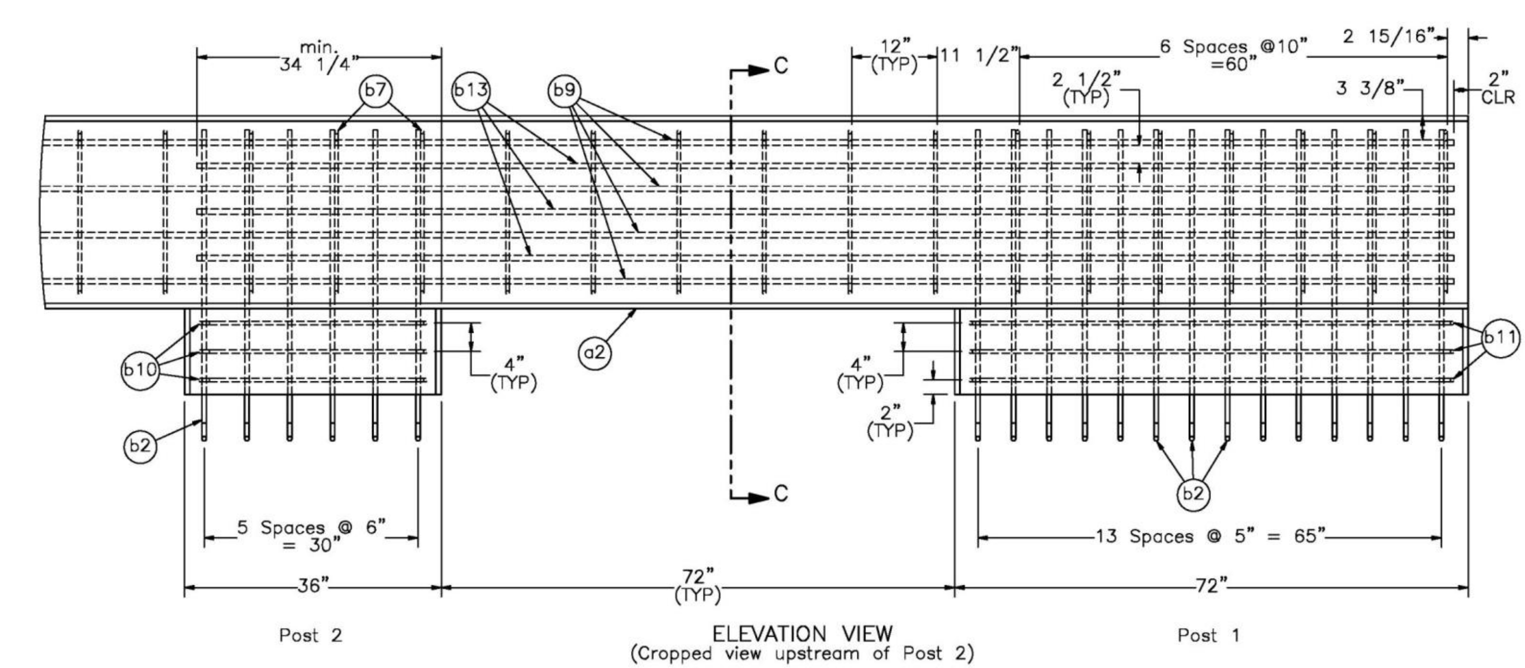
Figure 8. System Profile View, Test Nos. OCBR-1, OCBR-2, and OCBR-3



Notes:
(1) Reinforcement bar no. b6 is driven into soil.
(2) Reinforcement bar nos. b4 are anchored into the existing tarmac with chemical epoxy adhesive with a minimum bond strength of 1,450 psi.
(3) Bar nos. b2 will be cast in place with deck.
(4) Bar nos. b11 are used instead of bar nos. b10 in end section.
(5) Bar nos. b3 are used in place of bar nos. b12 in end section.
(6) Bar nos. b13 are added to end sections in between bar nos. 9.

MwRSF — Midwest Roadside Safety Facility	Open Concrete Bridge Rail Test Nos. OCBR–1–3 Concrete Rail, Deck, and Box Beam Assembly. Interior Section	SHEET: 3 of 20 DATE: 8/20/2021 DRAWN BY: MJM/LJP/S BW/GHR
	DWG. NAME. OCBR–1–3_R18	SCALE: 1:13 UNITS: in.
		REV. BY: JD/JEK/SK R/JDR/KAL /JCH/RWB

Figure 9. Concrete Rail, Deck, and Box Beam Assembly, Interior Section, Test Nos. OCBR-1, OCBR-2, and OCBR-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Modified Bridge Rail Assembly	–	–
a2	–	Bridge Rail Concrete	Min. f'c = 4,000 psi	–
b2	112	#5 Rebar, 53 7/16" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b7	133	#4 Bent Rebar, 73 7/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b9	8	#6 Rebar, 1580" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b10	42	#4 Bent Rebar, 82 3/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b11	3	#4 Bent Rebar, 154 3/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b13	6	#6 Rebar, 176 1/4" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b14	84	#5 Rebar, 45" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)

Notes:
(1) Reinforcement bar nos. b7 have lateral spacings of 12", except at end sections, as detailed above throughout the entire bridge rail.
(2) Reinforcement bar nos. b2 have lateral spacings of 6" as detailed above in all interior post sections throughout the bridge deck.
(3) Bar nos. b2 will be cast in place with deck.
(4) Bar nos. b2 are shown in both the bridge rail assembly and ht ebridge deck assembly.

MwRSF Midwest Roadside Safety Facility	Open Concrete Bridge Rail Test Nos. OCBR-1-3	SHEET: 4 of 20 DATE: 8/20/2021
	Modified Bridge Rail Assembly: Post Nos. 1-2	DRAWN BY: MJM/LJP/S BW/GHR
	DWG. NAME. OCBR-1-3_R18 | SCALE: 1:21 UNITS: in.	REV. BY: JD/JEK/SK R/JDR/KAL /JCH/RWB

Figure 10. Modified Bridge Rail Assembly, Post Nos. 1 and 2, Test Nos. OCBR-1, OCBR-2, and OCBR-3

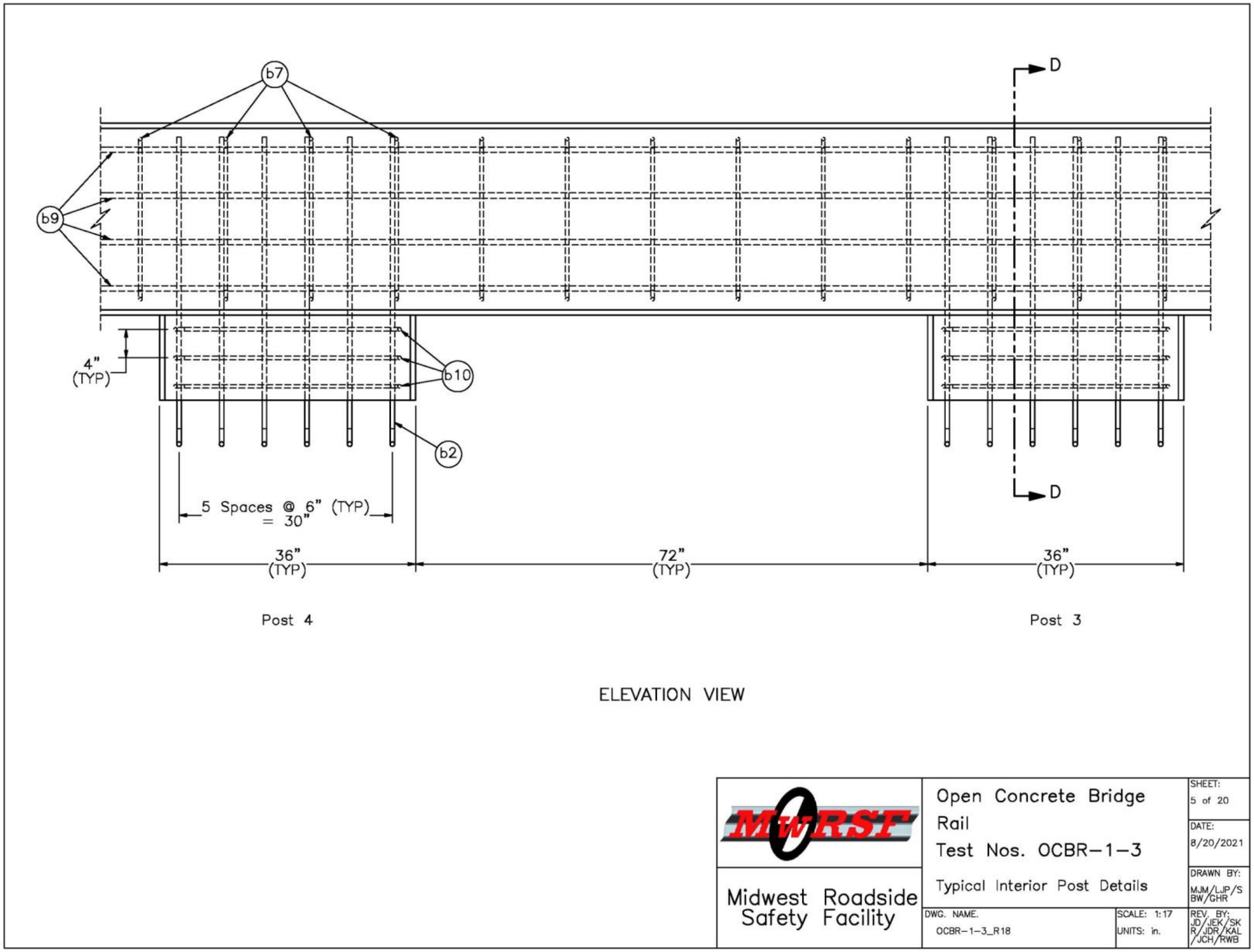


Figure 11. Typical Interior Post Details, Test Nos. OCBR-1, OCBR-2, and OCBR-3

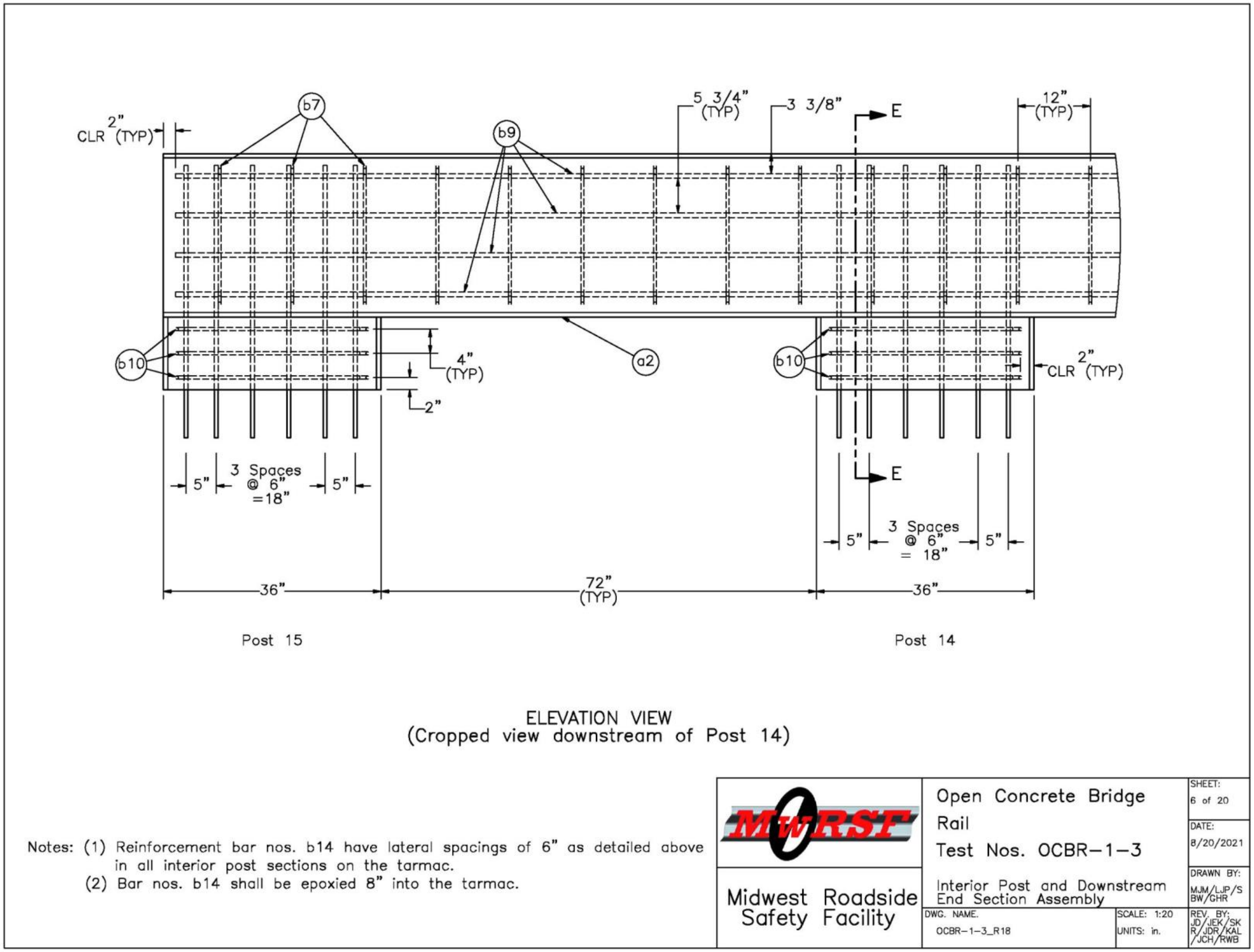


Figure 12. Interior Post and Downstream End Section Assembly, Test Nos. OCBR-1, OCBR-2, and OCBR-3

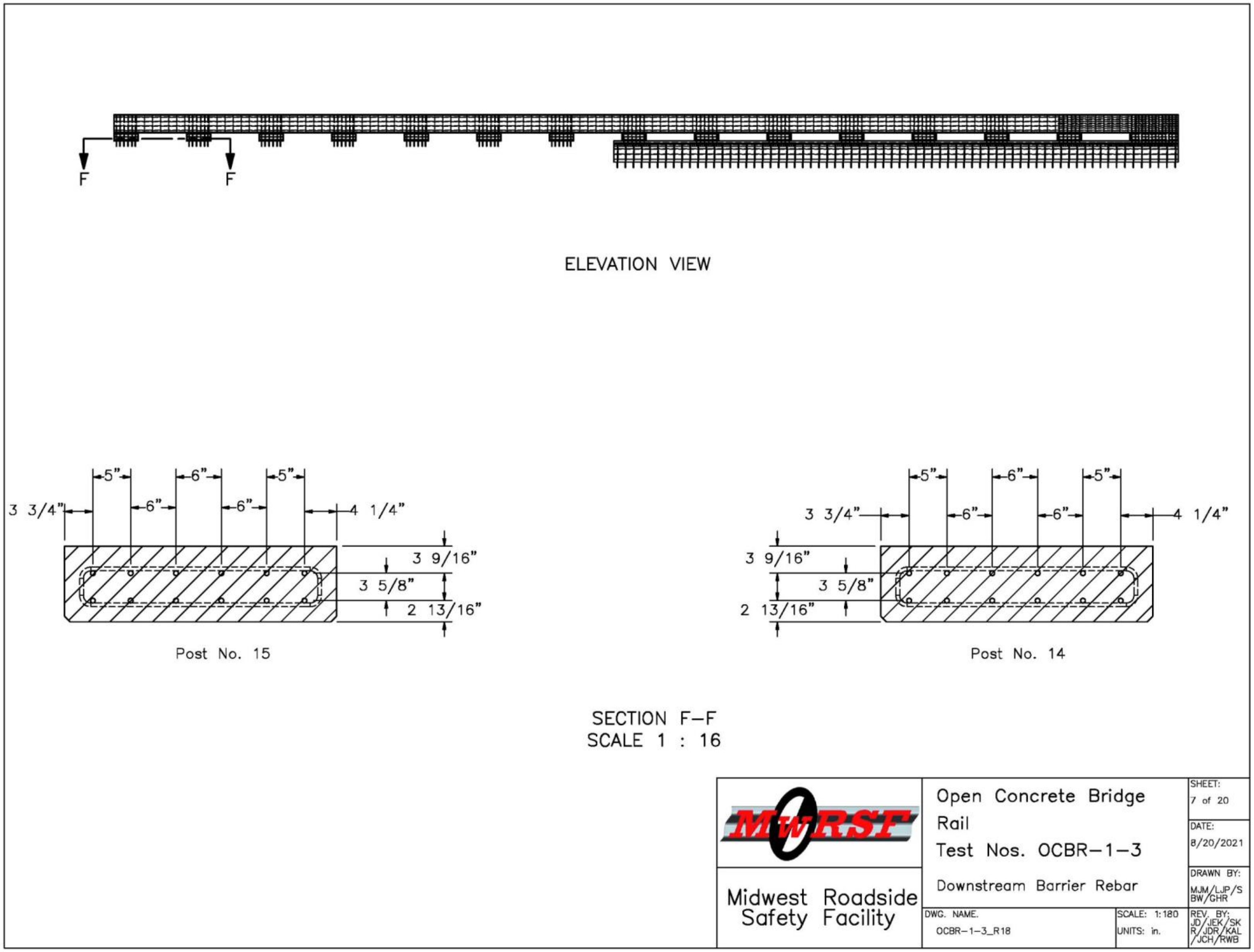


Figure 13. Downstream Barrier Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3

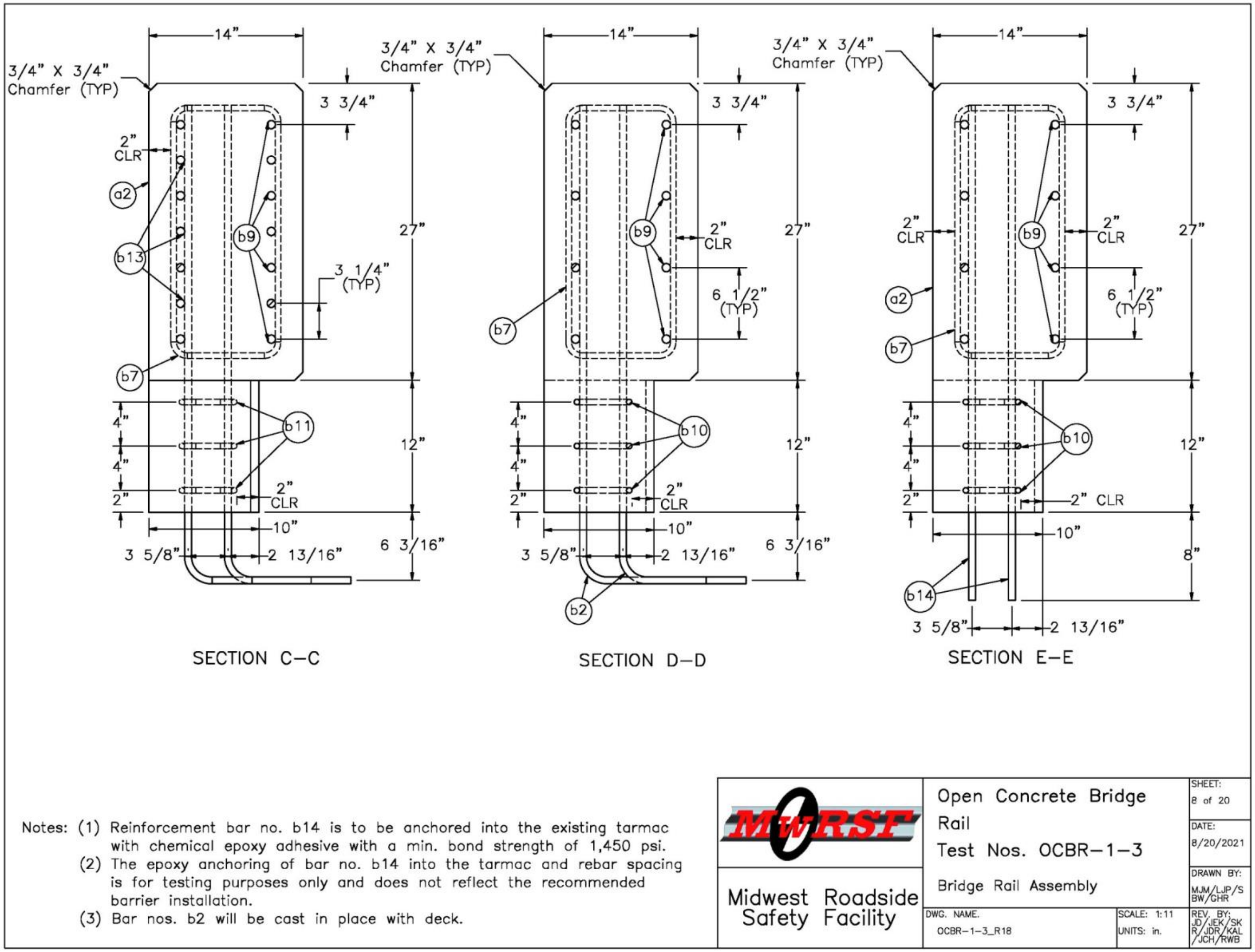
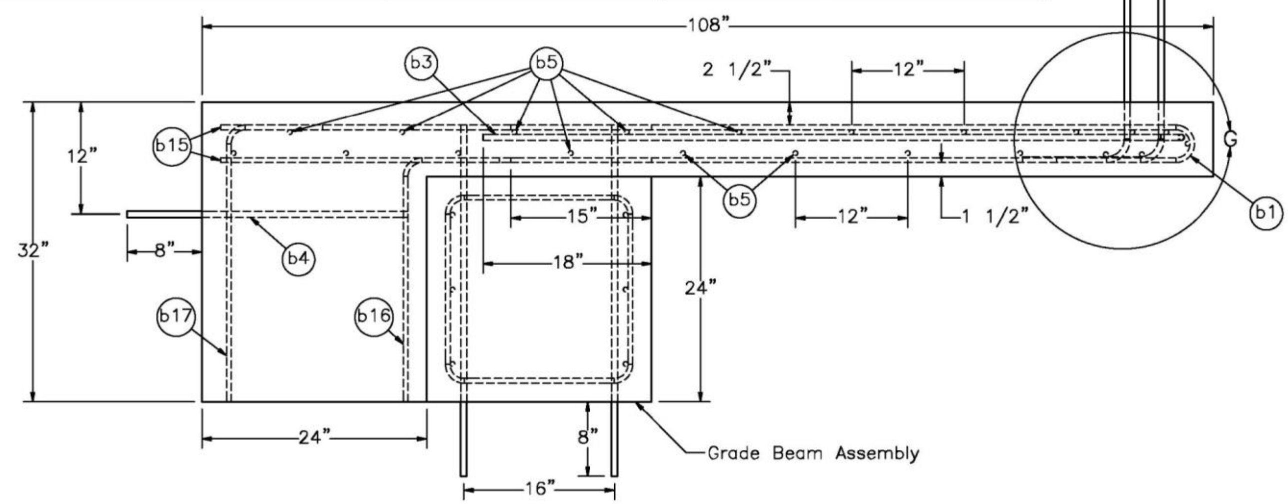


Figure 14. Bridge Rail Assembly, Test Nos. OCBR-1, OCBR-2, and OCBR-3

Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Concrete Bridge Deck Assembly	–	–
a1	–	Bridge Deck Concrete	Min. f'c = 4,000 psi	–
b1	189	#4 Rebar, 147 1/2" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b2	112	#5 Rebar, 53 7/16" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b3	7	#5 Rebar, 154 3/4" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b4	70	#5 Rebar, 30" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b5	27	#4 Rebar, 836" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b12	21	#5 Rebar, 155 5/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b15	140	#4 Rebar, 46" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b16	70	#4 Bent Rebar, 35" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b17	70	#4 Bent Rebar, 38 1/2" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)



Notes: (1) Reinforcement bar nos. b4 are anchored into the existing tarmac with chemical epoxy adhesive with a minimum bond strength of 1,450 psi.
(2) Bar nos. b12 should extend a minimum of 18" past the edge of the grade beam.
(3) Bar nos. b1 should extend a minimum of 15" past the edge of the grade beam.
(4) Bar nos. b2 may be slightly angled to prevent interference with each other in the deck. Rotation angles are to be about the vertical axis of the bars. The upper portion of the bars should not be offset. Only the lower horizontal hooks of the bar nos. b2 should be moved/angled.
(5) Bar nos. b12 are not shown in this view as they are behind bar nos. b3.
(6) Bar nos. b2 are shown in both the bridge rail assembly and the bridge deck assembly.

Midwest Roadside Safety Facility

Open Concrete Bridge Rail
Test Nos. OCBR-1-3
Bridge Deck Assembly

SHEET: 9 of 20
DATE: 8/20/2021
DRAWN BY: MJM/LJP/SBW/GHR
DWG. NAME. OCBR-1-3_R18
SCALE: 1:16
UNITS: in.
REV. BY: JD/JEK/SKR/JDR/KAL/JCH/RWB

Figure 15. Bridge Deck Assembly, Test Nos. OCBR-1, OCBR-2, and OCBR-3

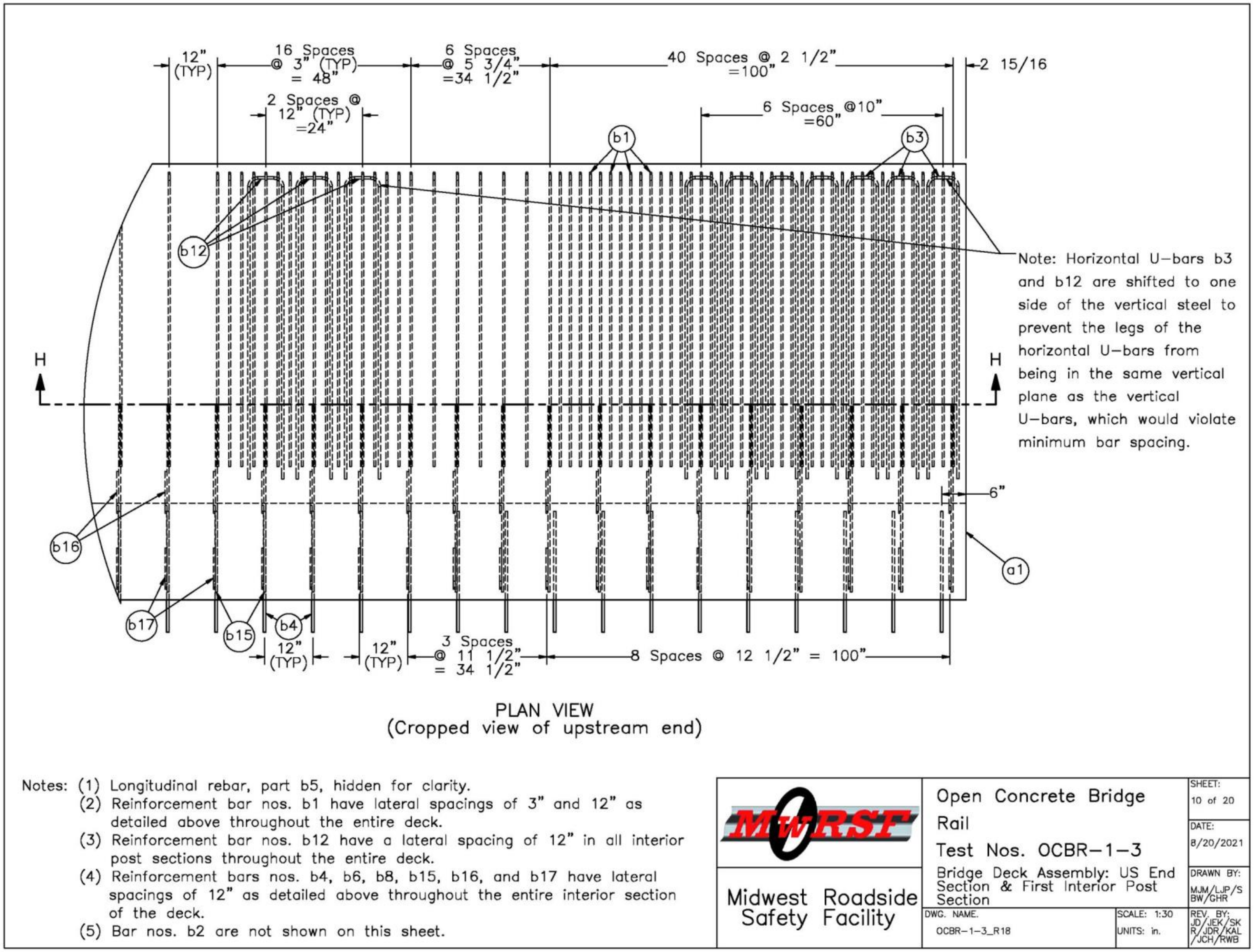


Figure 16. Bridge Deck Assembly: Upstream End Section and First Interior Post Section, Test Nos. OCBR-1, OCBR-2, and OCBR-3

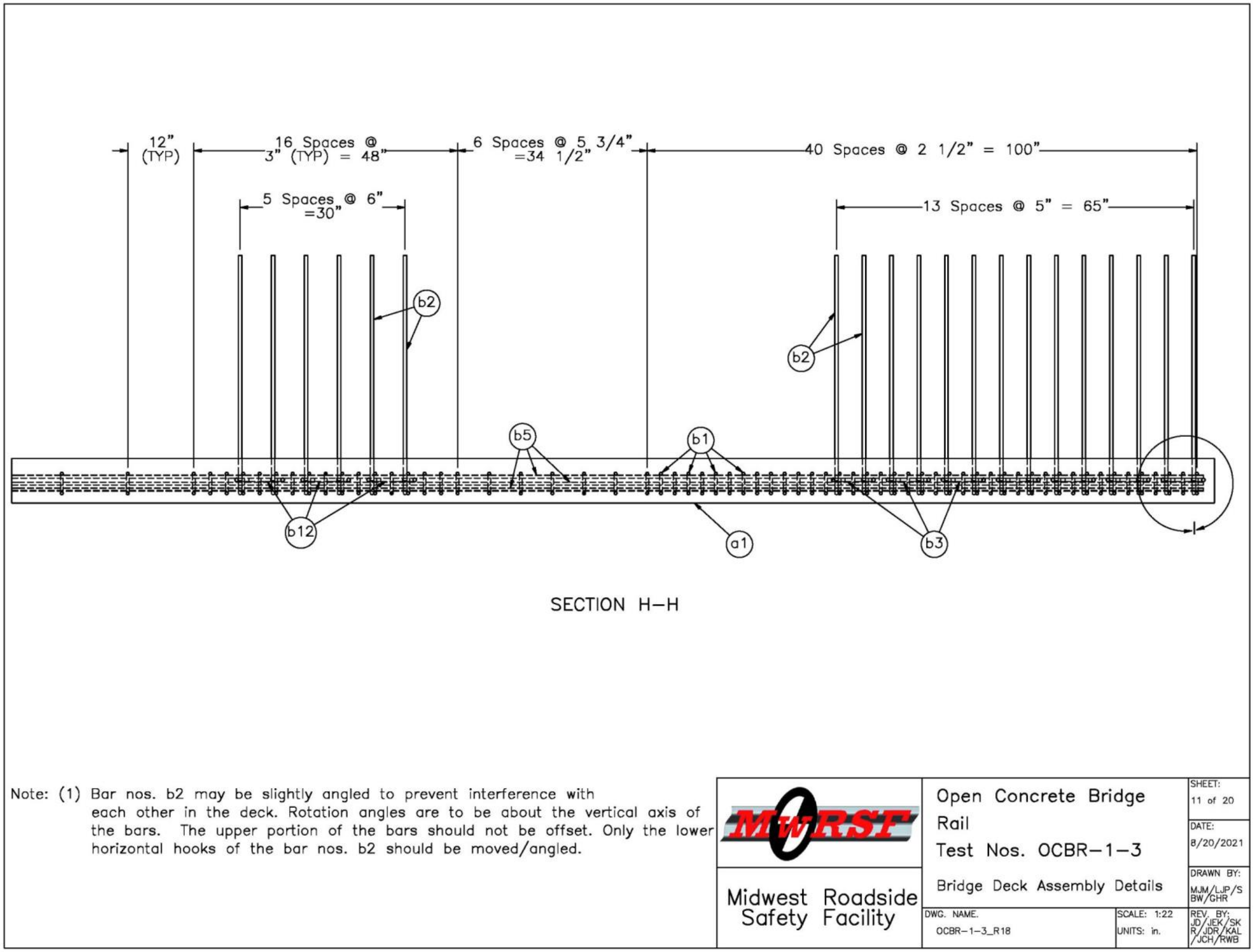


Figure 17. Bridge Deck Assembly Details, Test Nos. OCBR-1, OCBR-2, and OCBR-3

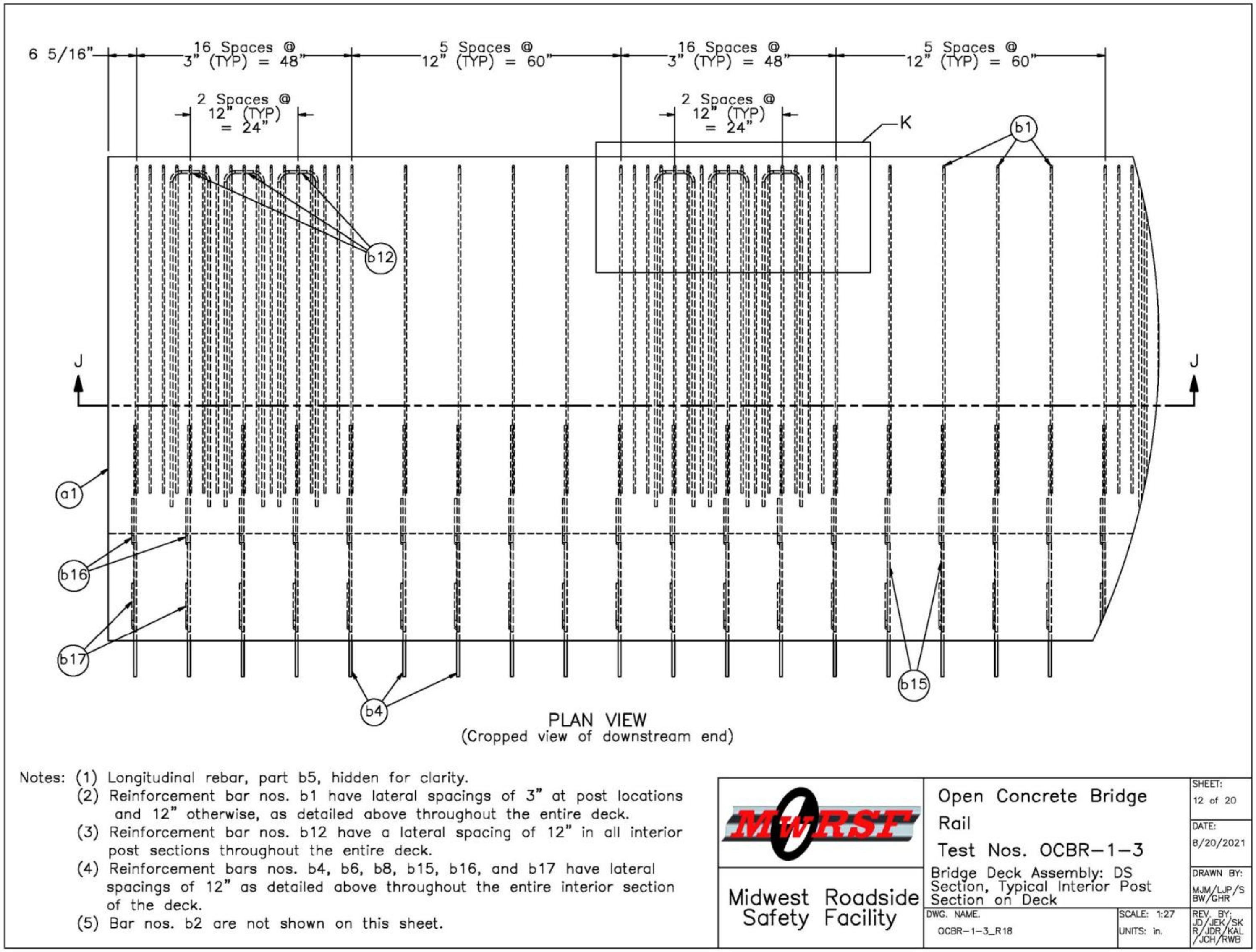


Figure 18. Bridge Deck Assembly: Downstream Section, Typical Interior Post Section on Deck, Test Nos. OCBR-1, OCBR-2, and OCBR-3

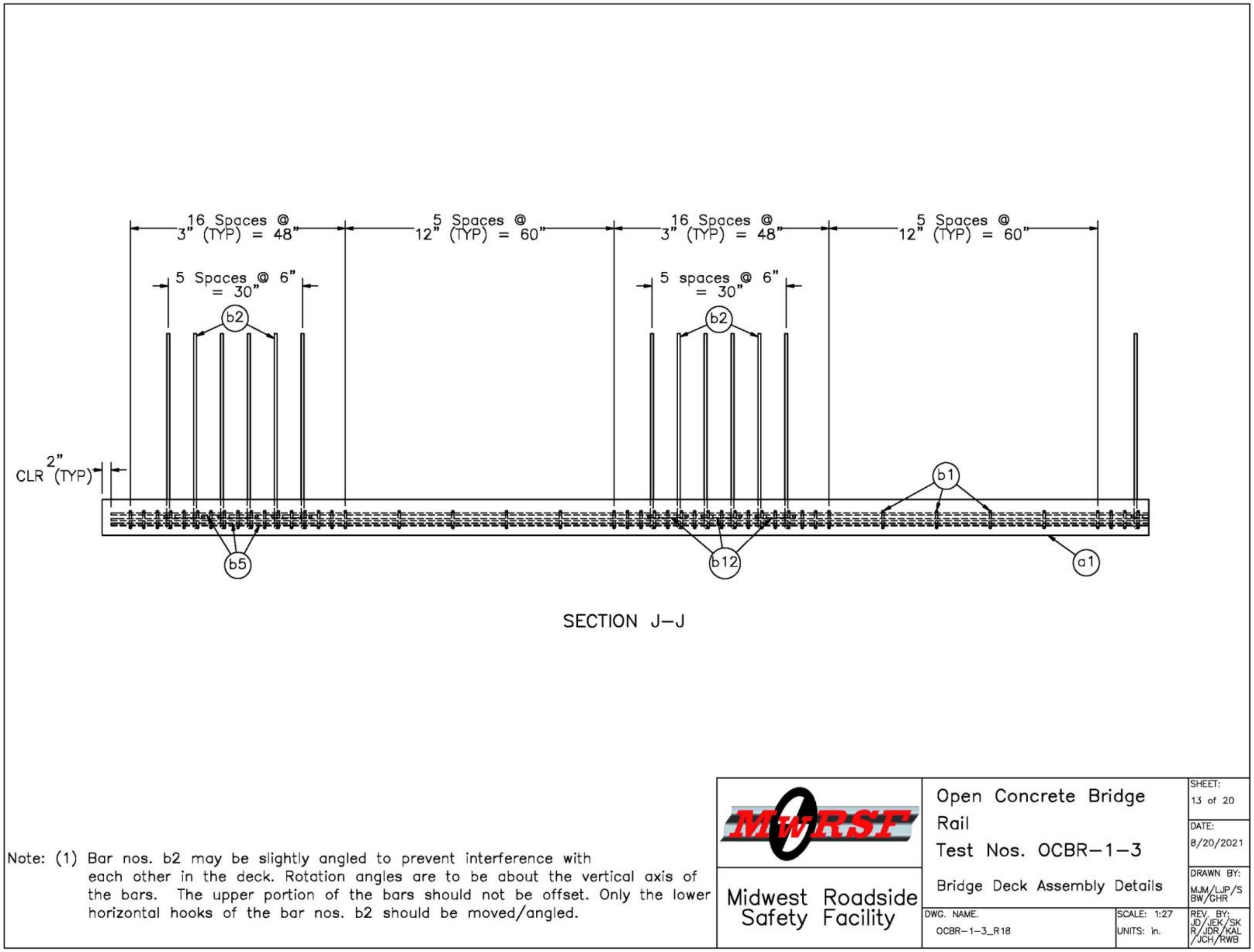


Figure 19. Bridge Deck Assembly Details, Test Nos. OCBR-1, OCBR-2, and OCBR-3

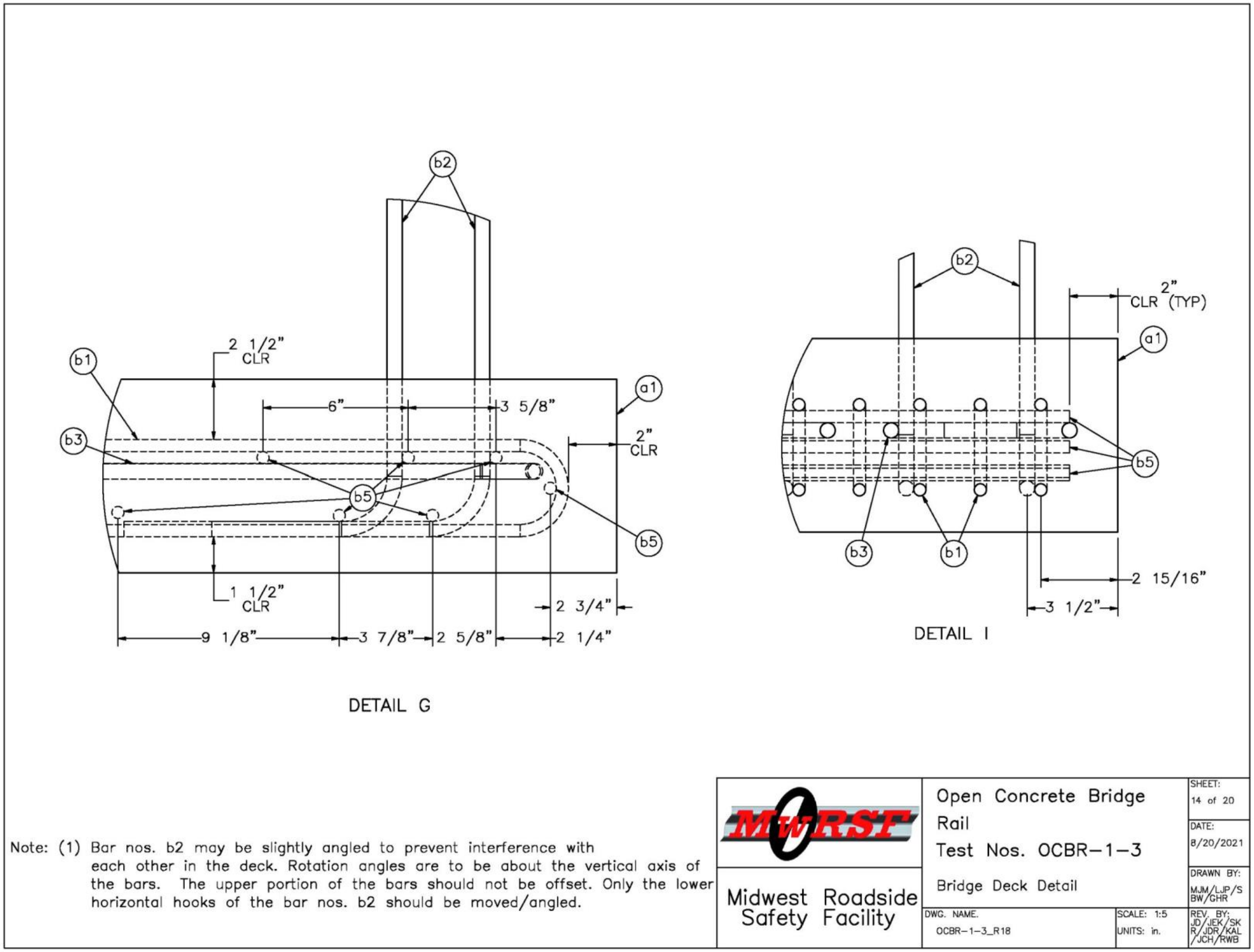


Figure 20. Bridge Deck Detail, Test Nos. OCBR-1, OCBR-2, and OCBR-3

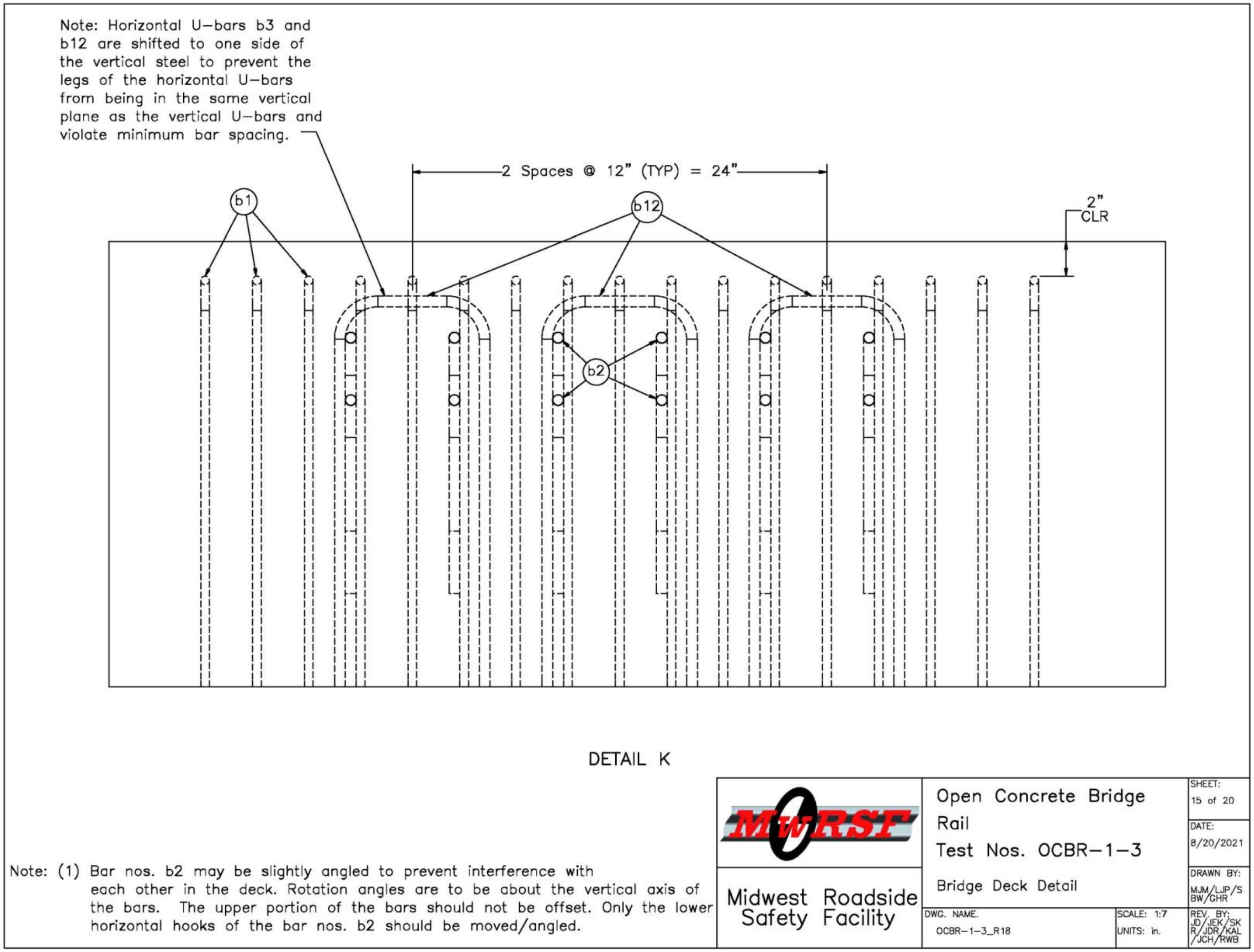
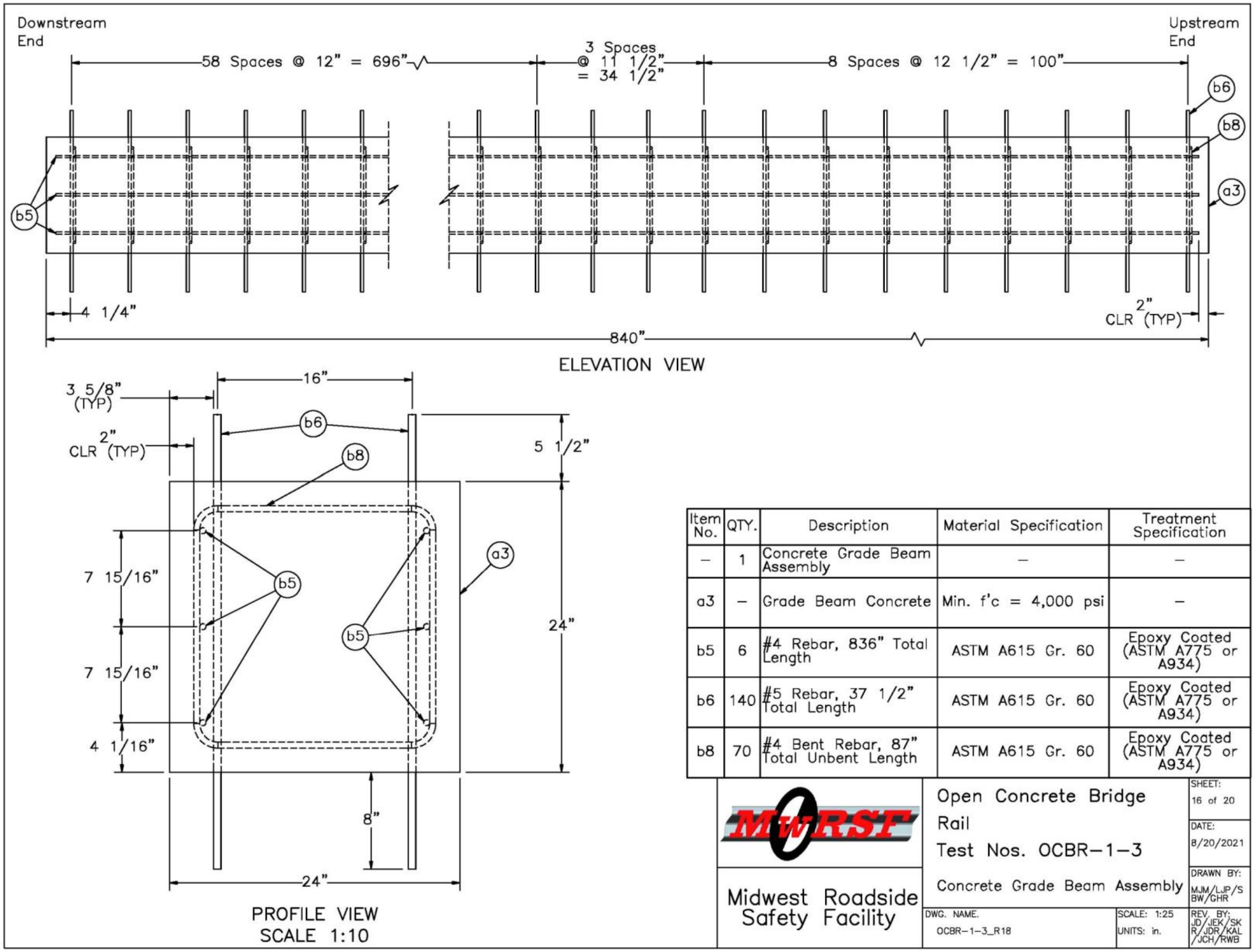
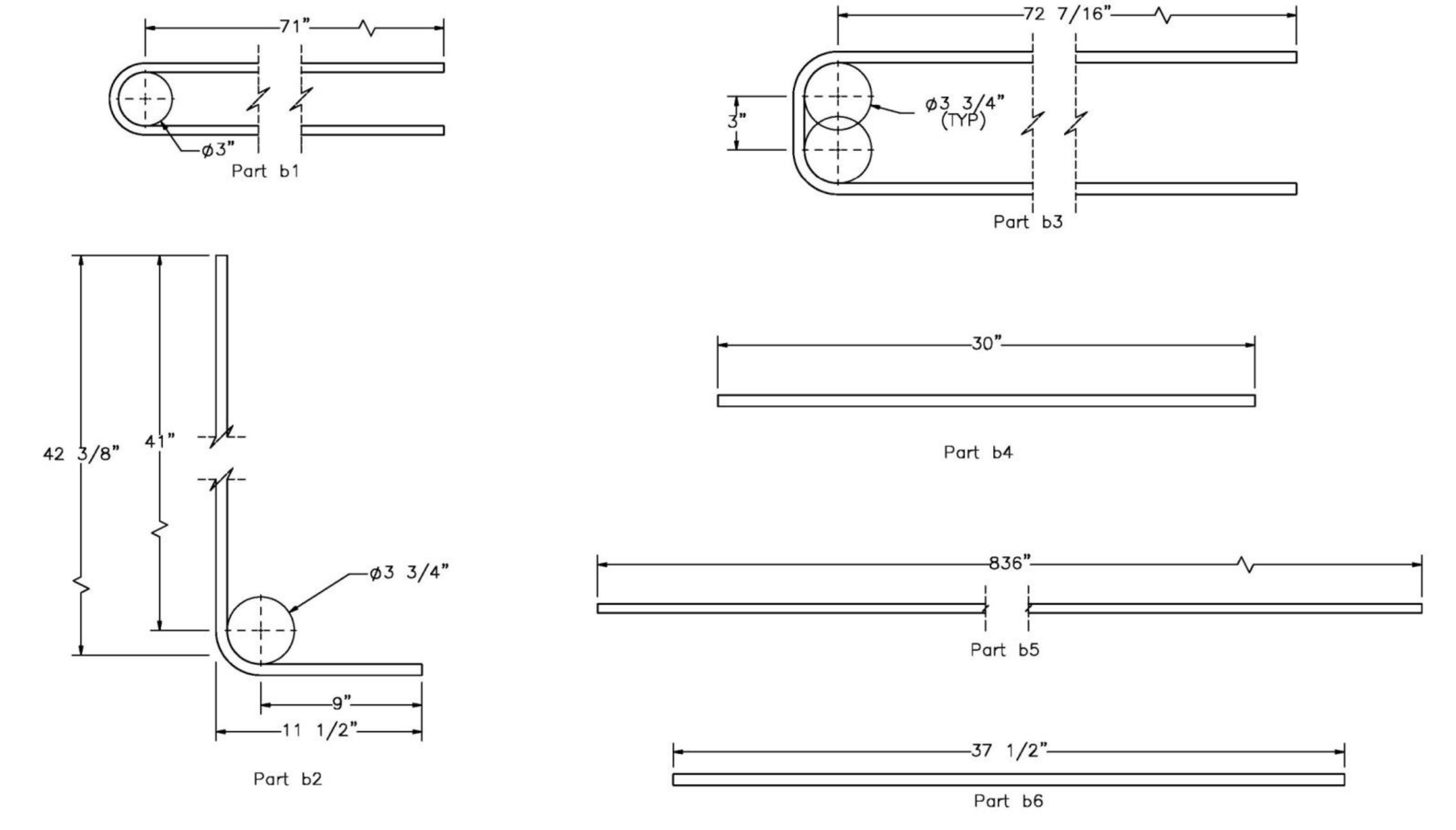


Figure 21. Bridge Deck Detail, Test Nos. OCBR-1, OCBR-2, and OCBR-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Concrete Grade Beam Assembly	–	–
a3	–	Grade Beam Concrete	Min. f'c = 4,000 psi	–
b5	6	#4 Rebar, 836" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b6	140	#5 Rebar, 37 1/2" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b8	70	#4 Bent Rebar, 87" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)

Figure 22. Concrete Grade Beam Assembly, Test Nos. OCBR-1, OCBR-2, and OCBR-3



Bill of Bars

Bar	QTY.	Size	Total Length	Min. Lap Length	Material
b1	189	#4	147 1/2"	Epoxy Coated (ASTM A775 or A934)	ASTM A615 Gr. 60
b2	112	#5	53 7/16"	–	ASTM A615 Gr. 60
b3	7	#5	154 3/4"	Epoxy Coated (ASTM A775 or A934)	ASTM A615 Gr. 60
b4	70	#5	30"	–	ASTM A615 Gr. 60
b5	27	#4	836"	19"	ASTM A615 Gr. 60
b6	140	#5	37 1/2"	–	ASTM A615 Gr. 60

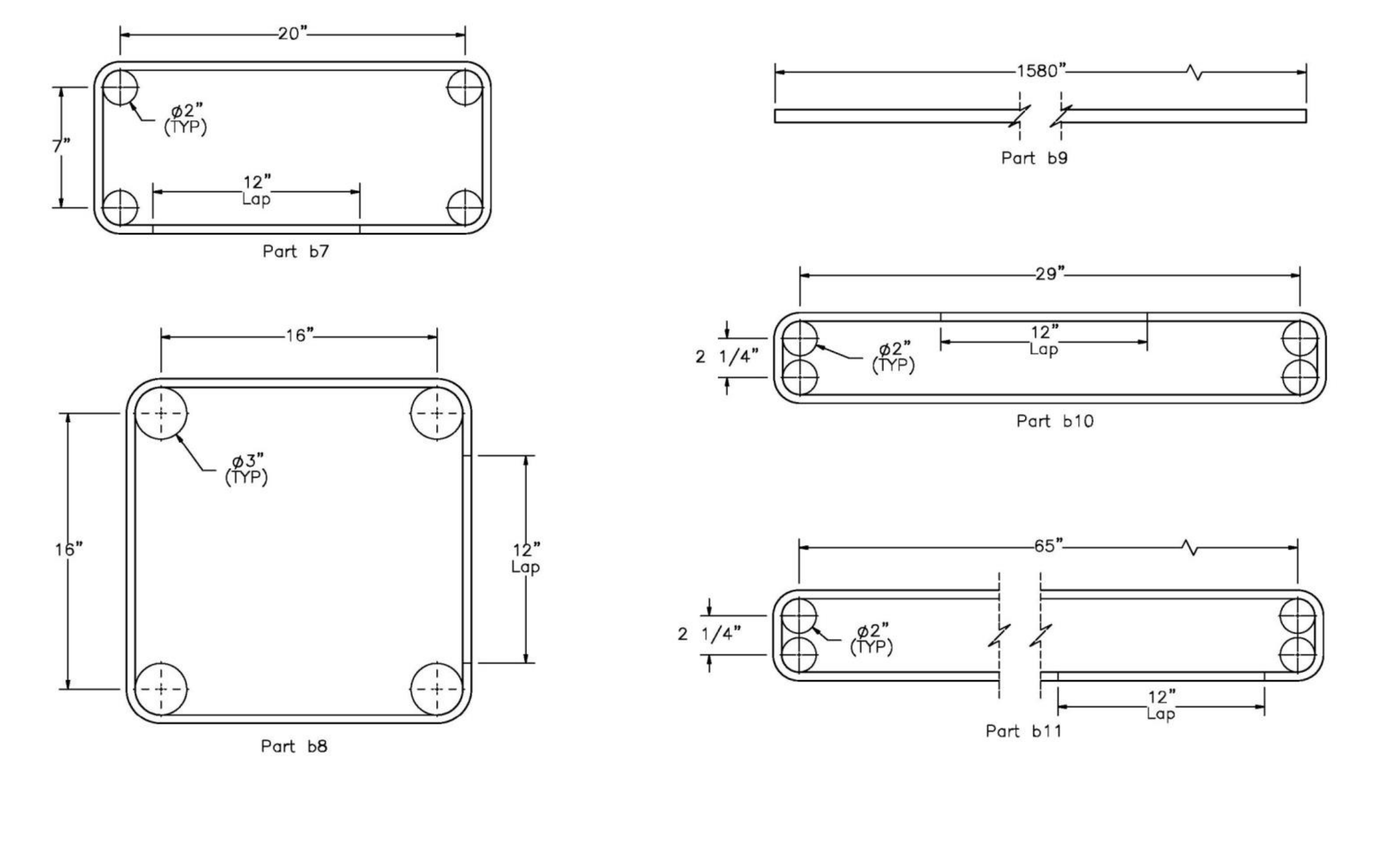
MwRSF
Midwest Roadside Safety Facility

Open Concrete Bridge Rail
Test Nos. OCBR-1-3

System Rebar

SHEET: 17 of 20
DATE: 8/20/2021
DRAWN BY: MJM/LJP/SBW/GHR
DWG. NAME. OCBR-1-3_R18
SCALE: 1:8
UNITS: in.
REV. BY: JD/JEK/SKR/JDR/KAL/JCH/RWB

Figure 23. System Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3



Bill of Bars					
Bar	QTY.	Size	Total Length	Min. Lap Length	Material
b7	133	#4	73 7/8"	–	ASTM A615 Gr. 60
b8	70	#4	87	–	ASTM A615 Gr. 60
b9	8	#6	1580"	29"	ASTM A615 Gr. 60
b10	42	#4	82 3/8"	–	ASTM A615 Gr. 60
b11	3	#4	154 3/8"	–	ASTM A615 Gr. 60

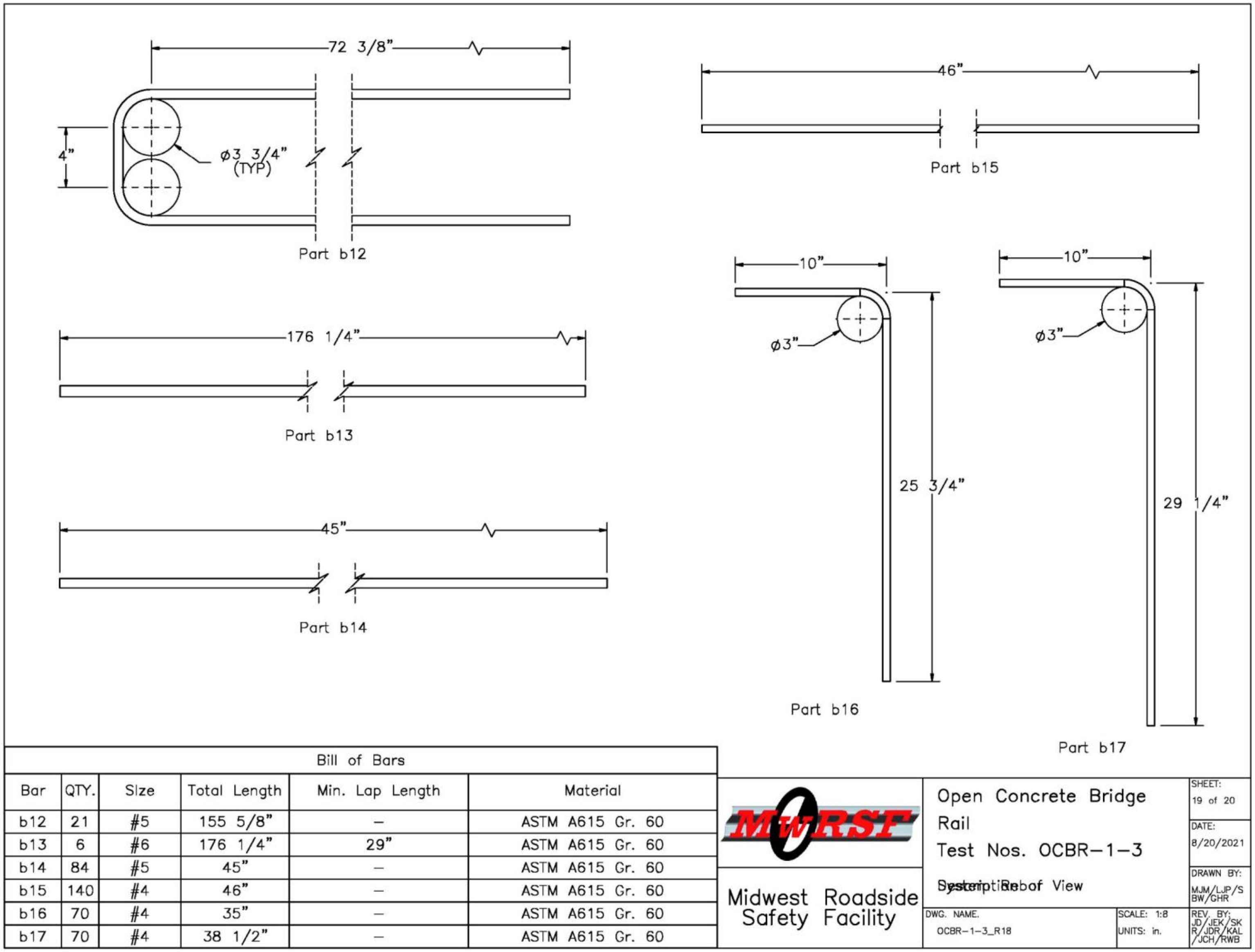
Midwest Roadside Safety Facility

Open Concrete Bridge Rail
Test Nos. OCBR-1-3

System Rebar

SHEET: 18 of 20
DATE: 8/20/2021
DRAWN BY: MJM/LJP/SBW/GHR
DWG. NAME. OCBR-1-3_R18
SCALE: 1:8
UNITS: in.
REV. BY: JD/JEK/SKR/JDR/KAL/JCH/RWB

Figure 24. System Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3



Bill of Bars

Bar	QTY.	Size	Total Length	Min. Lap Length	Material
b12	21	#5	155 5/8"	–	ASTM A615 Gr. 60
b13	6	#6	176 1/4"	29"	ASTM A615 Gr. 60
b14	84	#5	45"	–	ASTM A615 Gr. 60
b15	140	#4	46"	–	ASTM A615 Gr. 60
b16	70	#4	35"	–	ASTM A615 Gr. 60
b17	70	#4	38 1/2"	–	ASTM A615 Gr. 60

Figure 25. System Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3

Item No.	QTY.	Description	Material Specification	Treatment Specification
a1	1	Bridge Deck Concrete*	Min. f'c = 4,000 psi	–
a2	1	Bridge Rail Concrete*	Min. f'c = 4,000 psi	–
a3	1	Grade Beam Concrete*	Min. f'c = 4,000 psi	–
b1	189	#4 Rebar, 147 1/2" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b2	112	#5 Rebar, 53 7/16" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b3	7	#5 Rebar, 154 3/4" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b4	70	#5 Rebar, 30" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b5	27	#4 Rebar, 836" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b6	140	#5 Rebar, 37 1/2" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b7	133	#4 Bent Rebar, 73 7/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b8	70	#4 Bent Rebar, 87" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b9	8	#6 Rebar, 1580" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b10	42	#4 Bent Rebar, 82 3/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b11	3	#4 Bent Rebar, 154 3/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b12	21	#5 Rebar, 155 5/8" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b13	6	#6 Rebar, 176 1/4" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b14	84	#5 Rebar, 45" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b15	140	#4 Rebar, 46" Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b16	70	#4 Bent Rebar, 35" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
b17	70	#4 Bent Rebar, 38 1/2" Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)

* NE Mix 47B1S/1PF4000HW was used for testing purposes.

Midwest Roadside Safety Facility

Open Concrete Bridge Rail
Test Nos. OCBR-1-3
Bill of Materials

SHEET: 20 of 20
DATE: 8/20/2021
DRAWN BY: MJM/LJP/SBW/GHR
DWG. NAME. OCBR-1-3_R18
SCALE: None
UNITS: in.
REV. BY: JD/JEK/SKR/JDR/KAL/JCH/RWB

Figure 26. Bill of Materials, Test Nos. OCBR-1, OCBR-2, and OCBR-3

Figure 27. Test Installation Photos, Test Nos. OCBR-1, OCBR-2, and OCBR-3

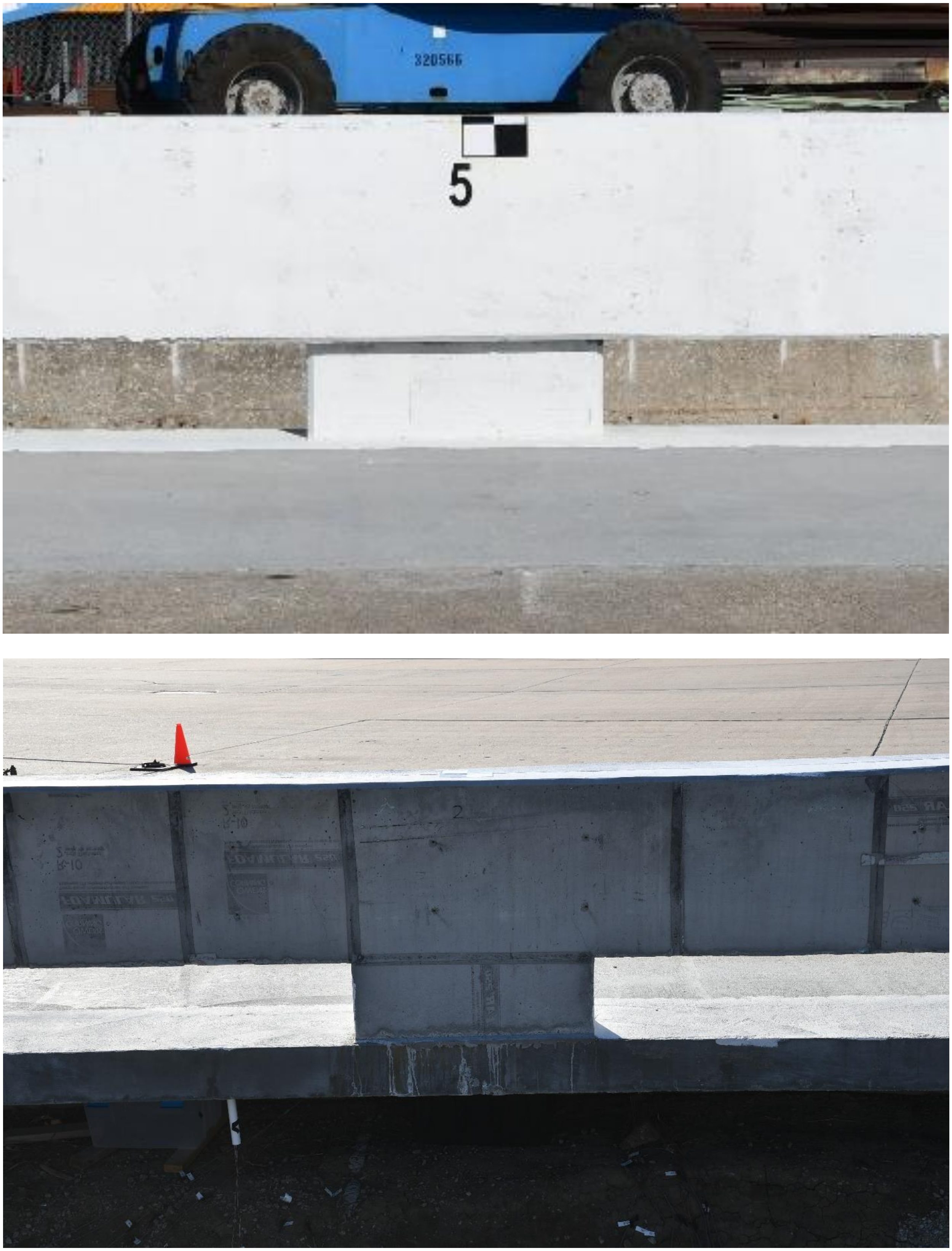


Figure 28. Typical Post Installation, Test Nos. OCBR-1, OCBR-2, and OCBR-3

Figure 29. Bridge Deck Installation, Test Nos. OCBR-1, OCBR-2, and OCBR-3

5 TEST CONDITIONS

5.1 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.

5.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [10] 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.

5.3 Test Vehicles

For test no. OCBR-1, a 2015 Hyundai Accent small car was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,460 lb, 2,431 lb, and 2,590 lb, respectively. The test vehicle is shown in Figures 30 and 31 , and vehicle dimensions are shown in Figure 32.

For test no. OCBR-2, a 2015 Dodge Ram 1500 pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 4,921 lb, 5,002 lb, and 5,116 lb, respectively. The test vehicle is shown in Figures 33 and 34, and vehicle dimensions are shown in Figure 35. Note that the vehicle width, measurement A in Figure 35, has a value of 75⅝ in. (1,920 mm), which is outside of the MASH recommended limits for 2270P overall vehicle width of 78 ± 2 in. (1,950 ± 50 mm). This value was deemed acceptable for four reasons: first, the value is outside of recommended limits when comparing standard units, however it falls within MASH recommendations when comparing metric units. The authors acknowledge that there are flaws in the MASH limits when comparing standard and metric recommendations. For example, 78 in. is 1,981 mm, and not 1,950 mm, a difference of nearly 1¼ in. Second, the rear vehicle width, measurement T in Figure 35, has a value of 76¼ in., which is within the MASH recommended limits for 2270P overall vehicle width of 78 ± 2 in. Note that MASH does not specify the location in which overall vehicle width should be measured. Third, Dodge Ram 1500 pickup trucks have been the primary 2270P make and model for full-scale crash test vehicles for several years. As such this vehicle was deemed acceptable for consistency. Lastly, MASH states that vehicles should conform to vehicle properties when practical.

For test no. OCBR-3, an International Durastar 4300 SBA 4X2 Single-Unit Truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 16,784 lb; 21,906 lb; and 22,052 lb; respectively. The test vehicle is shown in Figures 36 and 37, and vehicle dimensions are shown in Figure 38. Note that the total curb weight was 16,784 lb, outside of the MASH recommended limit of 13,200 ± 1,400 lb. This vehicle was deemed acceptable as the test inertial weight was within MASH recommended limits, there was insufficient time to locate a vehicle with a lower curb weight prior to the test, and MASH states that vehicles should conform to vehicle properties when practical.

The vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [13]. The final c.g. location is shown in Figure 32. The Suspension Method [12] was used to determine the vertical component of the c.g. for the 2270P vehicle. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The 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 final c.g. location is shown in Figure 35. 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 was used to determine the vertical component of the c.g. for the 10000S vehicle [11]. This method converted measured wheel weights at different elevations to the location of the vertical component of the c.g. The final c.g. location is shown in Figure 38. Ballast information and data used to calculate the location of the vehicles' c.g. are shown in Appendix B.

Square, black-and-white checkered targets were placed on the vehicles, as shown in Figures 39 through 41, to serve as a reference in the high-speed digital video and aid in the video analysis. 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 vehicles would track properly along the guide cable. A 5B flash bulb was mounted under the vehicle's left-side windshield wiper for test no. OCBR-1, right-side windshield wiper for test nos. OCBR-2 and OCBR-3, and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed digital videos. A radio-controlled brake system was installed in the test vehicles so they could be brought safely to a stop after the test.

Figure 30. Test Vehicle, Test No. OCBR-1

Figure 31. Test Vehicle’s Interior Floorboards and Undercarriage, Test No. OCBR-1

Test Name: OCBR-1

VIN No: KMHCT4AF5FU879644

Model Year: 2015

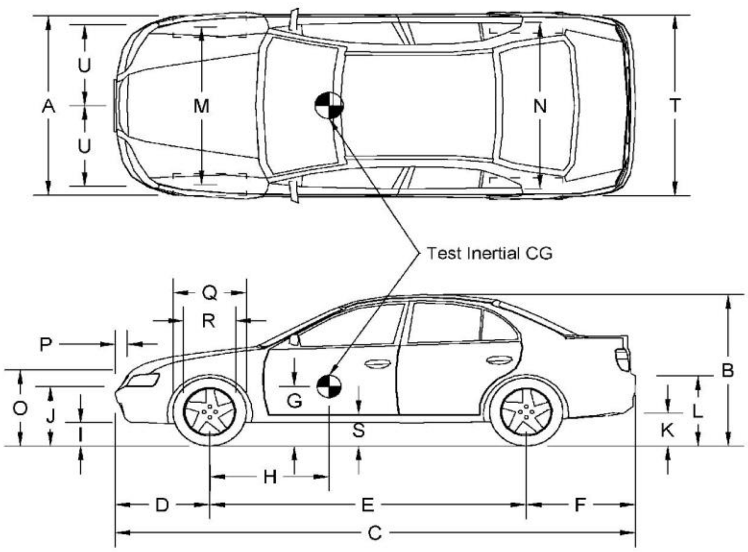
Make: Hyundai

Model: Accent

Tire Size: 175/70R14

Tire Inflation Pressure: 33 psi

Odometer: 129357



Vehicle Geometry - in. (mm)

Target Ranges listed below

A: 66 (1676)	65±3 (1650±75)	B: 56 1/4 (1429)	
C: 167 3/4 (4261)	169±8 (4300±200)	D: 31 3/4 (806)	35±4 (900±100)
E: 101 (2565)	98±5 (2500±125)	F: 35 (889)	
G: 21 3/4 (552)		H: 38 3/4 (984)	39±4 (990±100)
I: 8 (203)		J: 22 (559)	
K: 11 (279)		L: 25 1/8 (638)	
M: 59 1/4 (1505)	59±2 (1498±50)	N: 59 3/8 (1508)	59±2 (1425±50)
O: 29 (737)	28±4 (711±100)	P: 1 (25)	
Q: 23 (584)		R: 15 1/4 (387)	
S: 10 1/2 (267)		T: 67 (1702)	

U (impact width): 30 1/2 (775)

Top of radiator core support: 27 1/2 (699)

Wheel Center Height (Front): 11 (279)

Wheel Center Height (Rear): 11 (279)

Wheel Well Clearance (Front): 24 3/4 (629)

Wheel Well Clearance (Rear): 25 (635)

Bottom Frame Height (Front): 5 1/4 (133)

Bottom Frame Height (Rear): 16 (406)

Engine Type: Gasoline

Engine Size: 1.6L 4 cyl

Transmission Type: Automatic

Drive Type: FWD

Mass Distribution - lb (kg)

Gross Static	LF	810 (367)	RF	770 (349)
	LR	487 (221)	RR	523 (237)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	1550 (703)	1498 (679)	1580 (717)
W-rear	910 (413)	933 (423)	1010 (458)
W-total	2460 (1116)	2431 (1103) 2420±55 (1100±25)	2590 (1175) 2585±55 (1175±50)

GVWR Ratings lb

Front	1874
Rear	1852
Total	3527

Surrogate Occupant Data

Type: Hybrid II

Mass: 161 lb

Seat Position: Right/Passenger

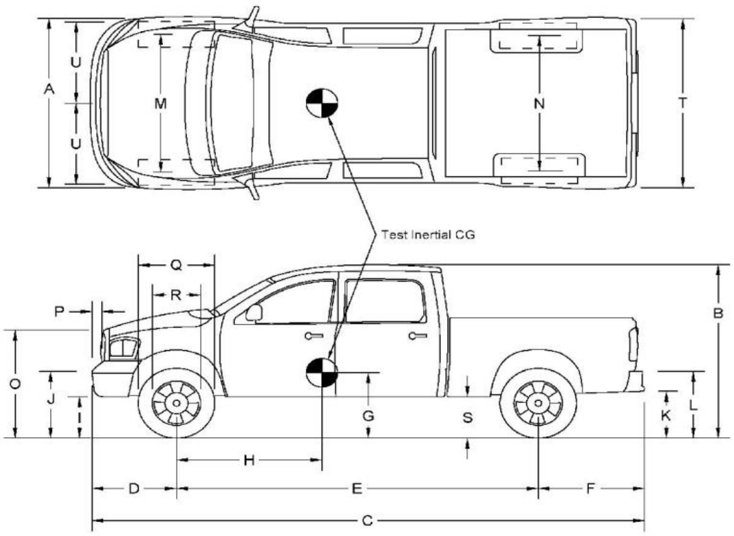
Note any damage prior to test: None

Figure 32. Vehicle Dimensions, Test No. OCBR-1

Figure 33. Test Vehicle, Test No. OCBR-2

Figure 34. Test Vehicle’s Interior Floorboards and Undercarriage, Test No. OCBR-2

		Test Name:	OCBR-2	VIN No:	1C6RR6FG6FS720783
Model Year:	2015	Make:	Dodge	Model:	Ram 1500
Tire Size:	p265/70/R17	Tire Inflation Pressure:	40 psi	Odometer:	203907



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

	in.	(mm)	Target		in.	(mm)	Target
A:	75 5/8	1920 7/8	78±2 (1950±50)	B:	74 3/8	1889 1/8	
C:	229 1/4	5822 19/20	237±13 (6020±325)	D:	42	1066 4/5	39±3 (1000±75)
E:	140 1/4	3562 7/20	148±12 (3760±300)	F:	47	1193 4/5	
G:	28 3/4	730 1/4	min: 28 (710)	H:	66 1/8	1679 23/40	63±4 (1575±100)
I:	12 3/4	323 17/20		J:	26	660 2/5	
K:	20	508		L:	28 3/4	730 1/4	
M:	67 7/8	1724 1/40	67±1.5 (1700±38)	N:	67 3/4	1720 17/20	67±1.5 (1700±38)
O:	45	1143	43±4 (1100±75)	P:	4 3/4	120 13/20	
Q:	30 1/2	774 7/10		R:	18 1/2	469 9/10	
S:	13	330 1/5		T:	76 1/4	1936 3/4	

U (impact width):	36	914 2/5
Wheel Center Height (Front):	14 3/4	374 13/20
Wheel Center Height (Rear):	15	381
Wheel Well Clearance (Front):	34 3/4	882 13/20
Wheel Well Clearance (Rear):	37 1/4	946 3/20
Bottom Frame Height (Front):	18	457 1/5
Bottom Frame Height (Rear):	24 5/8	625 19/40
Engine Type:	Gasoline	
Engine Size:	3.6L V6	
Transmission Type:	Automatic	
Drive Type:	RWD	
Cab Style:	Quad Cab	
Bed Length:	76"	

Mass Distribution - lb (kg)

Gross Static	LF	1403	(636)	RF	1339	(607)
	LR	1189	(539)	RR	1235	(560)

Weights lb (kg)	Curb		Test Inertial		Gross Static	
W-front	2694	(1222)	2643	(1199)	2742	(1244)
W-rear	2227	(1010)	2359	(1070)	2424	(1100)
W-total	4921	(2232)	5002	(2269)	5166	(2343)
			5000±110 (2270±50)		5165±110 (2343±50)	

GVWR Ratings - lb		Surrogate Occupant Data	
Front	3700	Type:	Hybrid II
Rear	3900	Mass:	164 lb
Total	6800	Seat Position:	Passenger

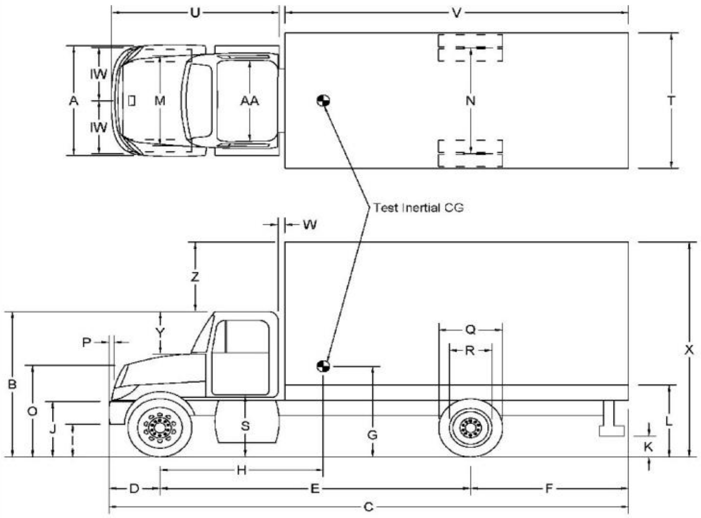
Note any damage prior to test: Roof dents/scrape, right side front door dent by door handle.

Figure 35. Vehicle Dimensions, Test No. OCBR-2

Figure 36. Test Vehicle, Test No. OCBR-3

Figure 37. Test Vehicle's Interior Floorboards and Undercarriage, Test No. OCBR-3

	Test Name: OCBR-3	VIN No: 1HTMMAAPXDH412511	
Model Year: 2013	Make: International	Model: 4300 SBA 4X2	
Tire Size: 265/75R22.5G	Tire Inflation Pressure: 110 psi	Odometer: 350002	



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

	in.	mm		in.	mm
A:	92	2336 4/5	B:	98	2489 1/5
C:	391 5/8 (Max: 394 (10000))	9947 11/40	D:	39 3/8	1000 1/8
E:	236 3/8 (Max: 240 (6100))	6003 37/40	F:	115 7/8	2943 9/40
G:	48	1219 1/5	H:	147 13/16	3754 7/16
I:	21	533 2/5	J:	35	889
K:	24 20/93	615 5/82	L:	48 (49±2 (1245±50))	1219 1/5
M:	80 1/4	2038 7/20	N:	73	1854 1/5
O:	59	1498 3/5	P:	4 1/2	114 3/10
Q:	40	1016	R:	23 1/2	596 9/10
S:	37	939 4/5	T:	102	2590 4/5
U:	107	2717 4/5	V:	270 1/2	6870 7/10
W:	3 1/2	88 9/10	X:	147 1/4	3740 3/20
Y:	31	787 2/5	Z:	46 3/4	1187 9/20
IW (Impact Width):	45 1/2	1155 7/10	AA:	70 1/2	1790 7/10

Ballast

Weight lb (kg): 6534 (2964)

CG height in. (mm): 62 1/2 (1588)
63±2 (1600±50)

Mass Distribution - lb (kg)

Gross Static				
	LF	4226 (1917)	RF	4096 (1858)
	LR	6830 (3098)	RR	6900 (3130)

Wheel Center Height (Front):	18 3/4	476 1/4
Wheel Center Height (Rear):	20	508
Wheel Well Clearance (Front):	45 3/4	1162 1/20
Wheel Well Clearance (Rear):	43 3/4	1111 1/4
Bottom Frame Height (Front):	25	635
Bottom Frame Height (Rear):	27 7/8	708 1/40

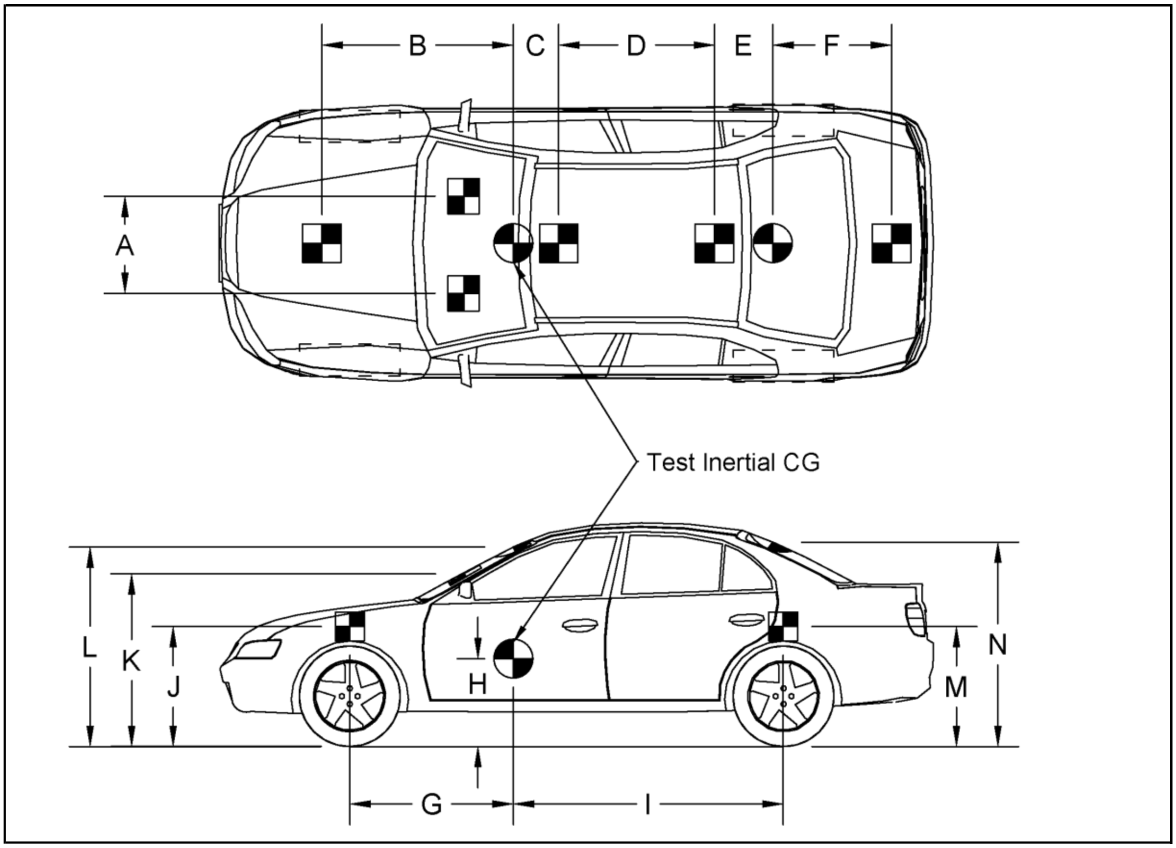
Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	8284 (3758)	8206 (3722)	8322 (3775)
W-rear	8500 (3856)	13700 (6214)	13730 (6228)
W-total	16784 (7613) 13200±2200 (6000±1000)	21906 (9936) 22046±660 (10000±300)	22052 (10003)

GVWR Ratings - lb		Surrogate Occupant Data			
Front	4535	Type:	Hybrid II	Engine Type:	Diesel
Rear	8618	Mass:	146 lb	Engine Size:	7.6L V6
Total	13164	Seat Position:	Right/Passenger	Transmission Type:	Manual
				Drive Type:	RWD

Note any damage prior to test: None

Figure 38. Vehicle Dimensions, Test No. OCBR-3

		Test Name:	OCBR-1	VIN:	KMHCT4AF5FU879644
Model Year:	2015	Make:	Hyundai	Model:	Accent

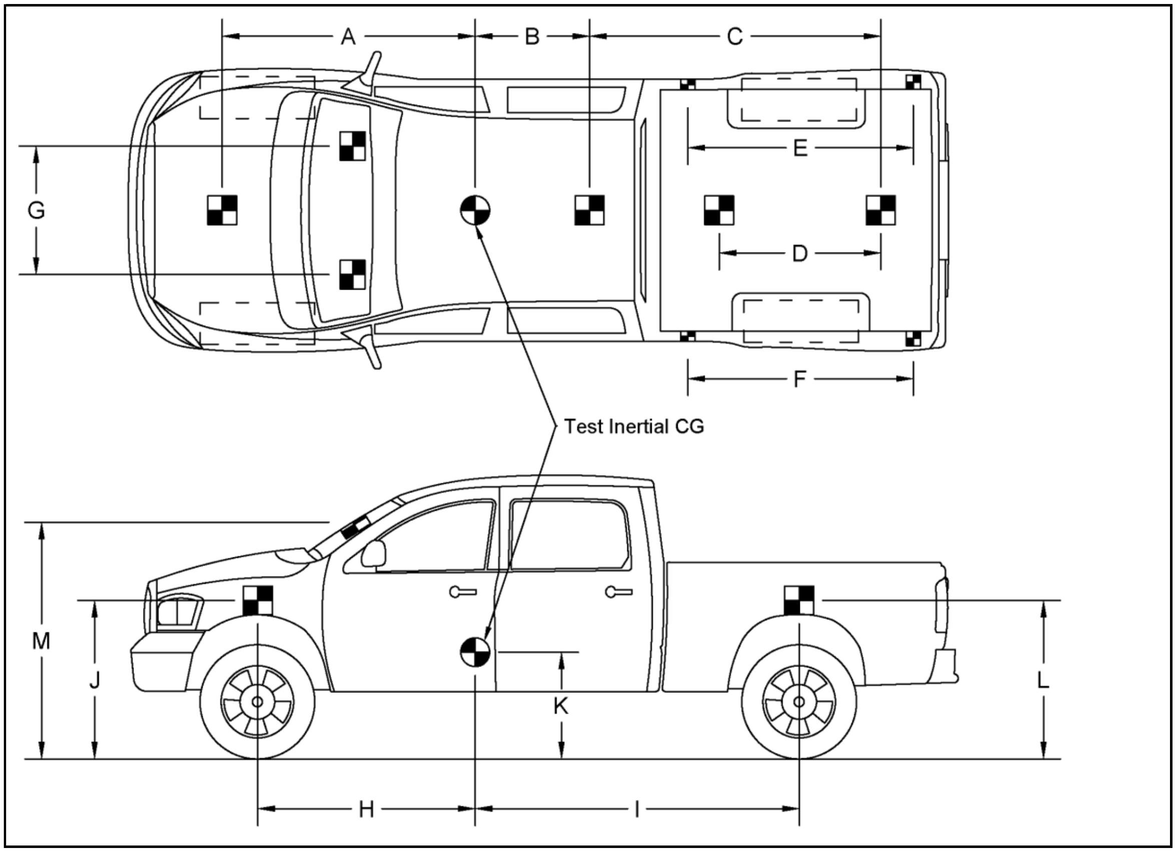


TARGET GEOMETRY-- in. (mm)

A:	26 3/8 (670)	F:	32 1/4 (819)	K:	46 3/4 (1187) Windshield Target
B:	47 3/4 (1213)	G:	38 3/4 (984)	L:	53 (1346) Front round CG target
C:	11 1/4 (286)	H:	21 11/16 (551)	M:	29 (737)
D:	31 (787)	I:	62 3/8 (1584)	N:	53 (1346) Rear Round target
E:	15 (381)	J:	28 1/2 (724)		

Figure 39. Target Geometry, Test No. OCBR-1

		Test Name:	**OCBR-2**	**VIN:**	**1C6RR6FG6FS720783**
Model Year:	**2015**	**Make:**	**Dodge**	**Model:**	**Ram 1500**



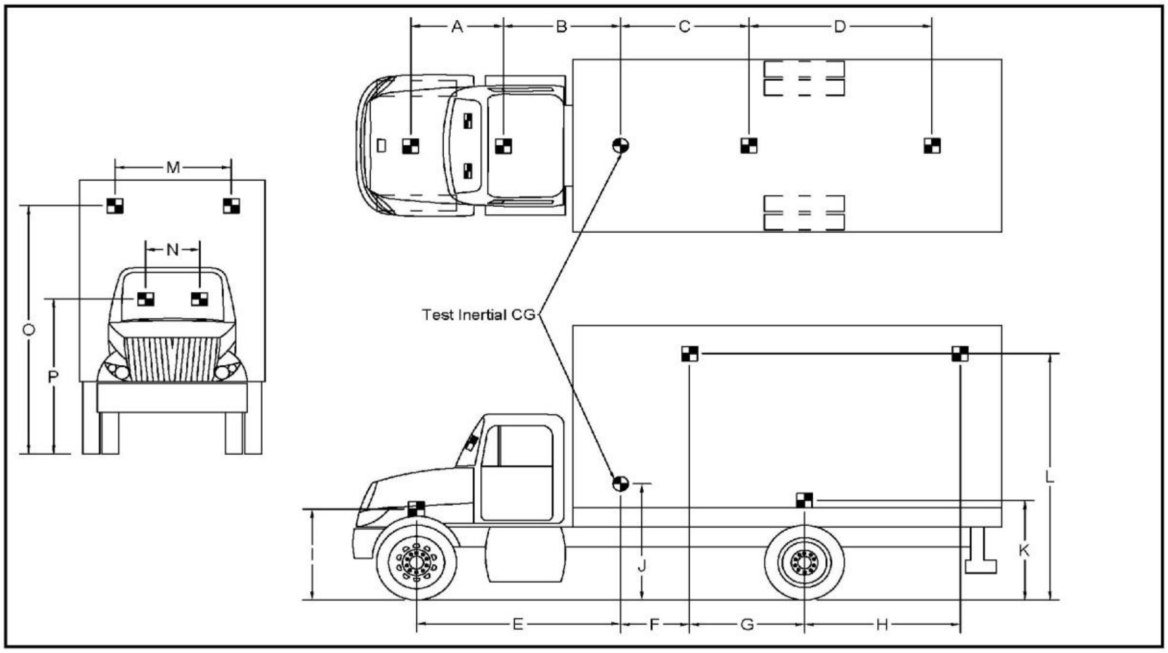
TARGET GEOMETRY-- in. (mm)

A:	**75 3/4**	**(1924)**	**E:**	**63 1/4**	**(1607)**	**J:**	**38 5/8**	**(981)**
B:	**22**	**(559)**	**F:**	**63 1/4**	**(1607)**	**K:**	**28 3/4**	**(730)**
C:	**71 7/8**	**(1826)**	**G:**	**36**	**(914)**	**L:**	**41 1/8**	**(1045)**
D:	**38 1/4**	**(972)**	**H:**	**66 1/16**	**(1678)**	**M:**	**63**	**(1600)**
			I:	**74 3/16**	**(1884)**			

Figure 40. Target Geometry, Test No. OCBR-2

Test Name: OCBR-3 **VIN:** 1HTMMAAPXDH412511

Model Year: 2013 **Make:** International **Model:** 4300 SBA 4X2



TARGET GEOMETRY-- in. (mm)

A:	58 3/8	(1483)	F:	36 1/8	(918)	L:	128 5/8	(3267)
B:	50 3/4	(1289)	G:	88 1/2	(2248)	M:	55 1/2	(1410)
C:	51 1/2	(1308)	H:	51 1/4	(1302)	N:	43 5/8	(1108)
D:	165 3/4	(4210)	I:	49 7/16	(1256)	O:	125 1/8	(3178)
E:	147 13/16	(3754)	J:	47 7/8	(1216)	P:	83 7/8	(2130)
			K:	53 3/8	(1356)			

Note, the orintation of distance "F" and "C" is inverse, the CG target is behind the leading square target on the box side and roof.
The values for F and C are correct.

Figure 41. Target Geometry, Test No. OCBR-3

5.4 Simulated Occupant

For test nos. OCBR-1, OCBR-2, and OCBR-3, a Hybrid II 50th-Percentile, Adult Male Dummy equipped with footwear was placed in the right-front seat of the test vehicles with the seat belt fastened. The simulated occupant had a final weight of 161 lb, 164 lb and 146 lb for test nos. OCBR-1, OCBR-2, and OCBR-3, respectively. As recommended by MASH, the simulated occupant weight was not included in calculating the c.g. location.

5.5 Data Acquisition Systems

5.5.1 Accelerometers and Rate Transducers

The accelerometer and rate transducer units used in the full-scale crash testing were the SLICE-1, SLICE-2, and TDAS units described below. SLICE-1 and SLICE-2 units were used in test nos. OCBR-1 and OCBR-2 while all three units were used in test no. OCBR-3. For test nos. OCBR-1 and OCBR-2, SLICE-1 and SLICE-2 units were mounted near the c.g. of the test vehicles. SLICE-1 was the primary unit for test no. OCBR-1 and SLICE-2 was the primary unit for test no. OCBR-2. For test no. OCBR-3, the SLICE-1 unit was mounted near the c.g., the TDAS unit was mounted in the cab, and the SLICE-2 unit was mounted on the rear axle of the SUT. Data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAEJ211/1 specifications [14].

The SLICE-1 and SLICE-2 units were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. of Seal Beach, California. Triaxial acceleration and angular rate sensor modules were mounted inside the bodies of custom-built SLICE 6DX event data recorders equipped with 7GB of non-volatile flash memory and recorded data at 10,000 Hz to the onboard microprocessor. The accelerometers had a range of ±500g's in each of three directions (longitudinal, lateral, and vertical) and a 1,650 Hz (CFC 1000) anti-aliasing filter. The SLICE MICRO Triax ARS had a range of 1,500 degrees/sec in each of three directions (roll, pitch, and yaw). The raw angular rate measurements were downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" software program and a customized Microsoft Excel worksheet were used to analyze and plot both the accelerometer and angular rate sensor data.

The TDAS unit was a data acquisition system developed and manufactured by Diversified Technical Systems, Inc. of Seal Beach, California. Sensor data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M mounted on the TDAS3-R4 module rack. The SIM was configured with 16 MB SRAM and eight sensor input channels with 250kB SRAM/channel. 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 unit was configured to record one set of triaxial acceleration data and one set of triaxial angular rate data. The two-arm piezo resistive accelerometer module manufactured by Endevco of San Juan Capistrano, California had a range of ±500 g's and measured longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. The ARS-1500 angular rate sensors with a range of 1,500 degrees/sec measured the rates of rotation of the test vehicle in three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the DTS SIM. The raw data measurements were downloaded, converted to the proper Euler angles for analysis and plotted. The "DTS TDAS Control" computer software program and a custom Microsoft Excel worksheet were used to analyze and plot both the accelerometer and angular rate sensor data.

5.5.2 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 side of the vehicles. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are used as a backup if vehicle speeds cannot be determined from the electronic data.

5.5.3 String Potentiometers

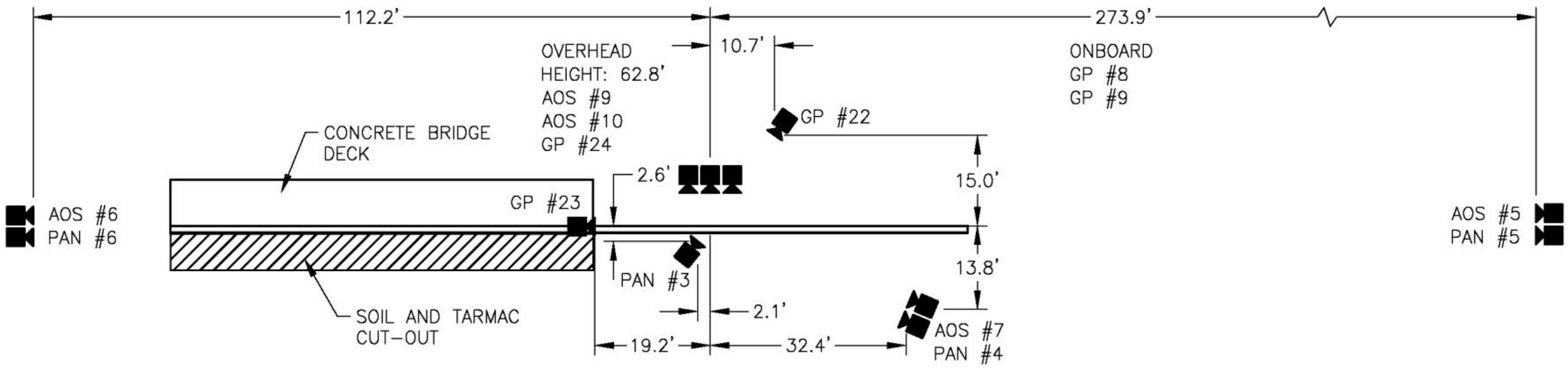
String potentiometers were attached to the system at post nos. 3, 4 and the mid-span between posts nos. 3 and 4 for test no. OCBR-3. The string potentiometers used were Unimeasure model nos. PA-50-70124 and PA-80 with a displacement range up to 50 and 80 in., respectively. Two PA-50-70124 units and one PA-80 unit were used. During testing, output voltage signals were sent from the transducers to a National Instruments PCI-6071E data acquisition board, acquired with LabView software, and stored on a personal computer at a sample rate of 10,000 Hz. The positioning and setup of the transducers are shown in Figure 42.

Figure 42. Location of String Potentiometers, Test No. OCBR-3

5.5.4 Digital Photography

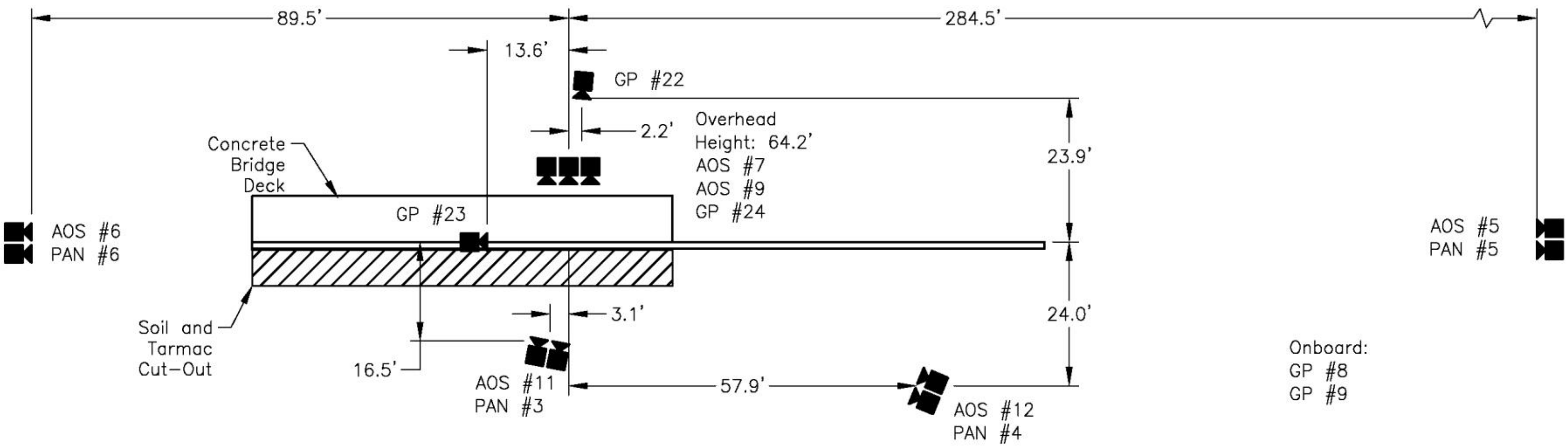
Five AOS high-speed digital video cameras, five GoPro digital video cameras, and four Panasonic digital video cameras were utilized to film test no. OCBR-1. Six AOS high-speed digital video cameras, five GoPro digital video cameras, and four Panasonic digital video cameras were utilized to film test no. OCBR-2. Due to technical difficulties, cameras GP-24 and PAN-5 did not record the impact event for test no. OCBR-2. Seven AOS high-speed digital video cameras, eight GoPro digital video cameras, and six Panasonic digital video cameras were utilized to film test no. OCBR-3. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figures 43 through 45.

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-5	AOS X-PRI Gigabit	500	100 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	Fujinon 75 mm Fixed	-
AOS-7	AOS X-PRI Gigabit	500	Fujinon 35 mm Fixed	-
AOS-9	AOS TRI-VIT 2236	500	Kowa 12 mm Fixed	-
AOS-10	AOS TRI-VIT 2236	500	Kowa 16 mm Fixed	-
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-22	GoPro Hero 7	240		
GP-23	GoPro Hero 7	240		
GP-24	GoPro Hero 7	240		
PAN-3	Panasonic HC-V770	120		
PAN-4	Panasonic HC-V770	120		
PAN-5	Panasonic HC-VX981	120		
PAN-6	Panasonic HC-VX981	120		

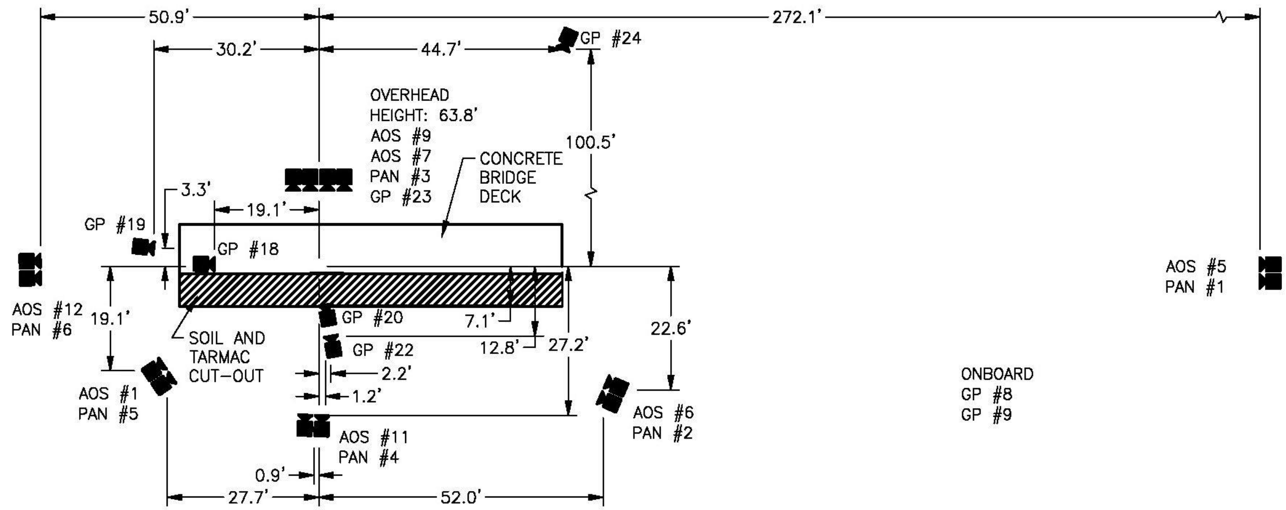
Figure 43. Camera Locations, Speeds, and Lens Settings, Test No. OCBR-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI Gigabit	500	100 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	Fujinon 50 mm Fixed	-
AOS-7	AOS X-PRI Gigabit	500	Kowa 16 mm Fixed	-
AOS-9	AOS TRI-VIT 2236	500	Kowa 12 mm Fixed	-
AOS-11	AOS J-PRI	500	Sigma 24 – 135	24
AOS-12	AOS J-PRI	500	Sigma 28 – 70	28
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-22	GoPro Hero 7	240		
GP-23	GoPro Hero 7	240		
GP-24*	GoPro Hero 7	240		
PAN-3	Panasonic HC-V770	120		
PAN-4	Panasonic HC-V770	120		
PAN-5*	Panasonic HC-VX981	120		
PAN-6	Panasonic HC-VX981	120		

*Camera did not record impact event due to technical difficulties.

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



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam CTM	500	Fujinon 50 mm Fixed	-
AOS-5	AOS X-PRI Gigabit	500	100 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	Sigma 24 – 135	-
AOS-7	AOS X-PRI Gigabit	500	Kowa 16 mm	-
AOS-9	AOS TRI-VIT 2236	500	Kowa 12 mm	-
AOS-11	AOS J-PRI	500	Sigma 17 – 50	17
AOS-12	AOS J-PRI	500	Nikon 50 mm Fixed	-
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-18	GoPro Hero 6	240		
GP-19	GoPro Hero 6	240		
GP-20	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		

*Camera did not record impact event due to technical difficulties.

Figure 45. Camera Locations, Speeds, and Lens Settings, Test No. OCBR-3

6 FULL-SCALE CRASH TEST NO. OCBR-1

6.1 Weather Conditions

Test no. OCBR-1 was conducted on October 6, 2021 at approximately 2:00 p.m. The weather conditions as reported by the National Oceanic and Atmospheric Administration (station 14939/KLNK) are shown in Table 3.

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

Temperature	76°F
Humidity	48%
Wind Speed	7 mph
Wind Direction	Variable
Sky Conditions	Cloudy
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.01 in.

6.2 Test Description

Initial vehicle impact was to occur $43^{3}/_{16}$ in. upstream from the upstream edge of post no. 11, as shown in Figure 46, which was selected using Table 2.7 of MASH 2016. The 2,431-lb small car impacted the open concrete bridge rail at a speed of 64.2 mph and at an angle of 25.2 degrees. The actual point of impact was 45.3 in. upstream from the upstream edge of post no. 11, which was 2.1 in. upstream from the targeted impact location. The right-front wheel of the vehicle extended beneath the rail and impacted post no. 11 of the system. Wheel and tire overlap at post no. 11 was approximately 5¼ in. from the face of the post. As the vehicle was redirected, loading of the right-front fender, right-front door, and the bottom of the A-pillar caused fracture of the driver-side window and deformation and cracking of the windshield. This damage to the vehicle glass was not due to the windshield or side window contacting the barrier but was attributed to the loading and deformation of the vehicle body. It was also noted that the simulated occupant's head extended out of the window, but did not contact the test article. The vehicle exited the barrier and continued downstream in a stable manner until brakes were applied. After brakes were applied, the vehicle came to rest 186.2 ft downstream of the impact target and 16.5 ft laterally in front of the system, facing downstream and toward the non-traffic side of the barrier.

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

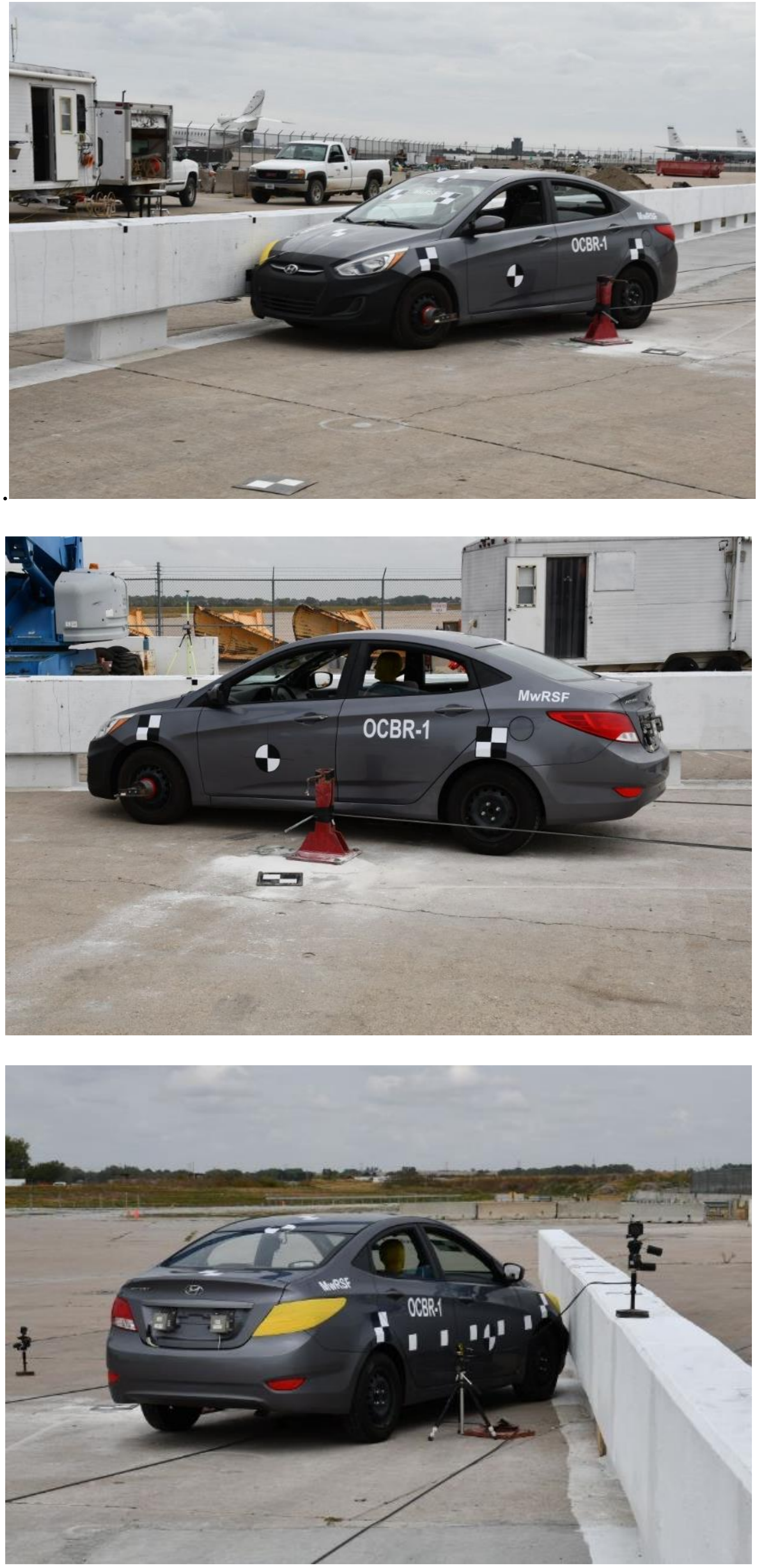


Figure 46. Target Impact Location, Test No. OCBR-1

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

Time (sec)	Event
0.000	Vehicle's front bumper and right headlight contacted system 2.1 in. upstream from targeted impact location between post nos. 10 and 11 and deformed.
0.010	Vehicle's right fender contacted barrier and deformed. Vehicle's right-front tire contacted barrier. Vehicle's right headlight shattered.
0.022	Vehicle's left fender deformed. Vehicle's hood contacted barrier and deformed. Vehicle yawed away from barrier.
0.034	Vehicle's right mirror and right-front door contacted barrier and deformed. Vehicle's roof deformed. Vehicle pitched downward.
0.044	Vehicle's front bumper and right mirror detached. Vehicle’s right A-pillar and right-front door frame deformed. Vehicle’s windshield cracked.
0.060	Vehicle rolled toward barrier. Vehicle's right-front window shattered and right-front tire deflated.
0.200	Vehicle was parallel to system at a speed of 42.1 mph.
0.222	Vehicle's right-rear door, rear bumper, and right quarter panel contacted barrier and deformed.
0.238	Vehicle pitched upward.
0.258	Vehicle exited system at a speed of 40.8 mph and an angle of 2.4 degrees.
0.548	Vehicle's left headlight disengaged.
4.908	Vehicle came to rest.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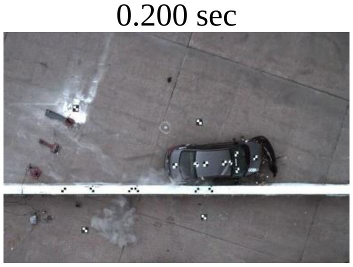
0.000 sec


0.100 sec


0.100 sec


0.200 sec


0.200 sec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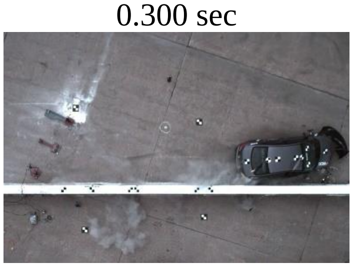
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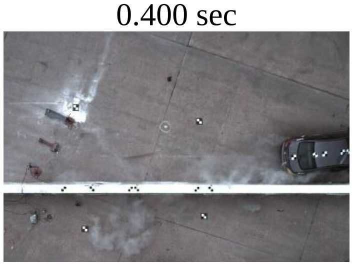
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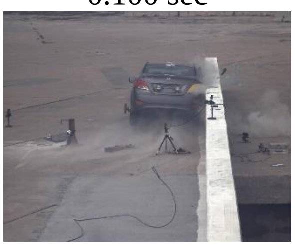
Figure 47. Sequential Photographs, Test No. OCBR-1

0.000 sec

0.100 sec



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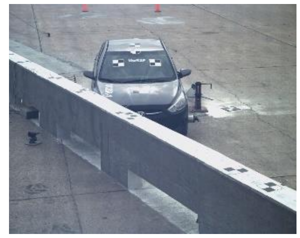

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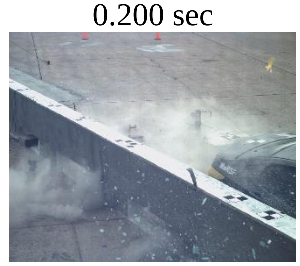

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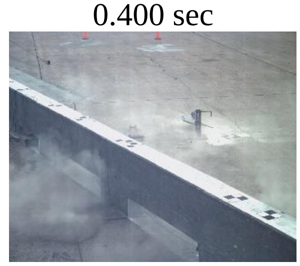

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Figure 48. Sequential Photographs, Test No. OCBR-1

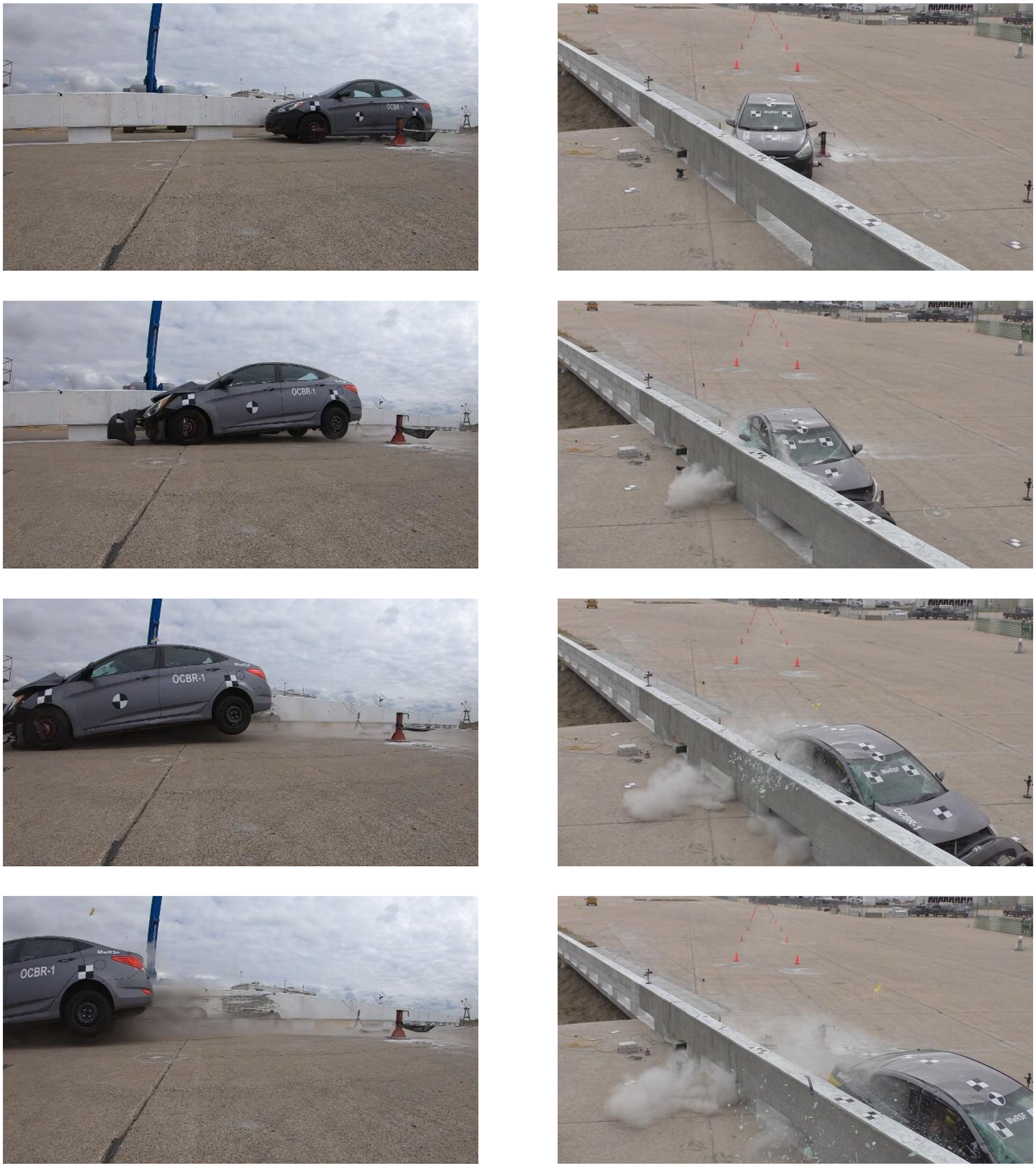

Figure 49. Documentary Photographs, Test No. OCBR-1

Figure 50. Vehicle Final Position and Trajectory Marks, Test No. OCBR-1

6.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 51 through 54. Barrier damage consisted of contact marks on the front face of the concrete segments and spalling and gouging of the concrete. Vehicle contact along the barrier began 10 in. upstream from the impact point and spanned 13 ft – 11 in. downstream.

The longest contact mark started 10 in. upstream from the impact point and spanned 160 in. downstream. Contact marks were found on the bottom-front face of the concrete barrier between 21 in. and 143 in. from the impact point with lengths between 3½ in. and 38½ in. Contact marks were found on the front face of post nos. 11 and 12. Tire contact marks on the upstream face of post no. 11 indicated 5¼ in. of overlap of the wheel and tire on the face of the post. A tire contact mark started 24 in. upstream from the impact point and extended 133½ in. downstream.

Minor spalling with lengths between 2 in. and 3¼ in. were present between 1½ in. and 19¼ in. from the impact point. Minor gouging was present between 33¼ in. and 44½ in. from the impact point. Gouges of lengths between 20¼ in. and 34 in. were present between the centerline of the impact point and 57¾ in. from the impact point. Major gouges of over 100 ft in length were present between 22½ ft downstream and 55½ ft downstream from the impact point. Post nos. 11 and 12 had gouges on their upstream faces. No cracking or structural damage to the bridge rail beam or posts was noted.

Figure 51. Overall System Damage, Test No. OCBR-1

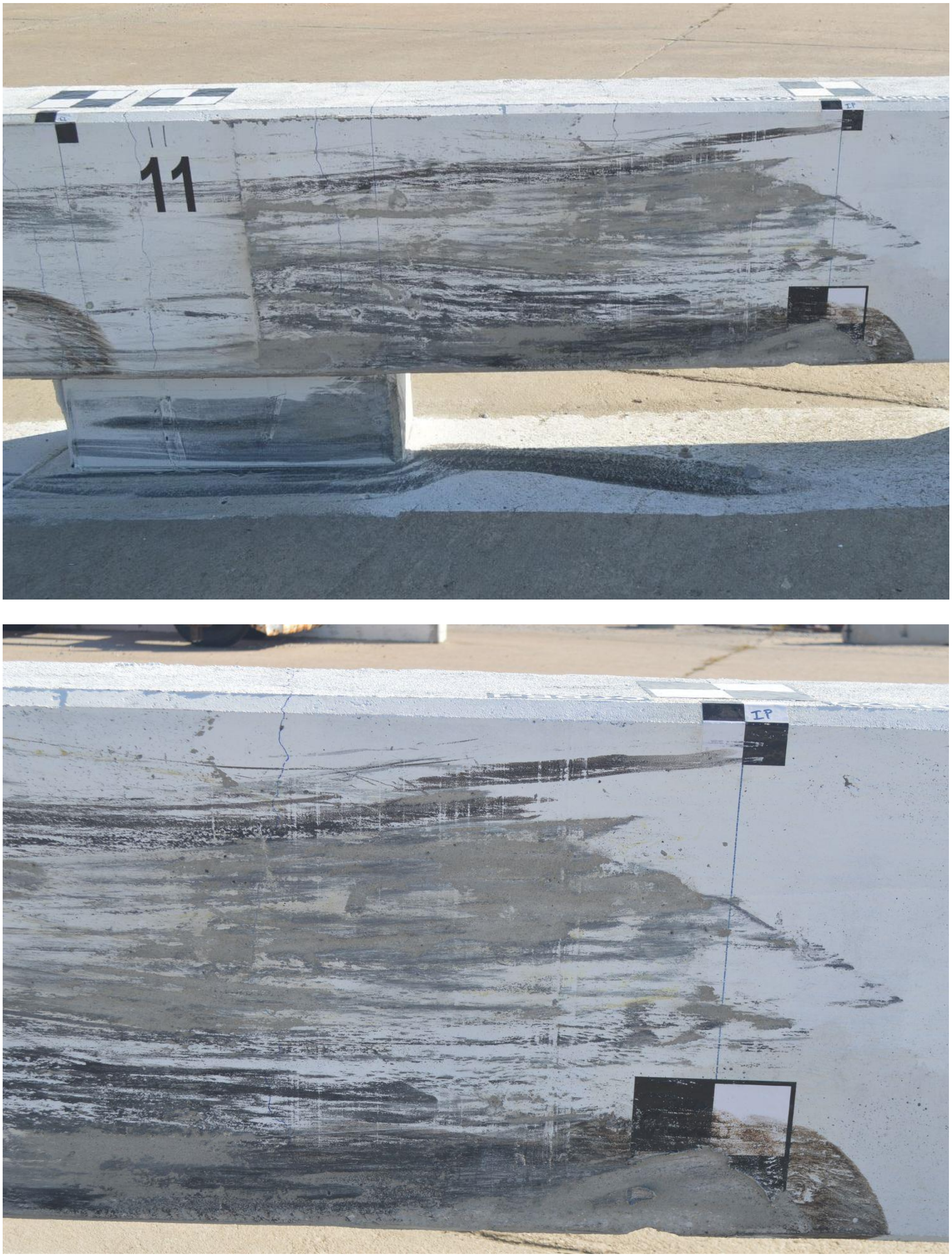

Figure 52. Concrete Beam Damage, Impact, Test No. OCBR-1

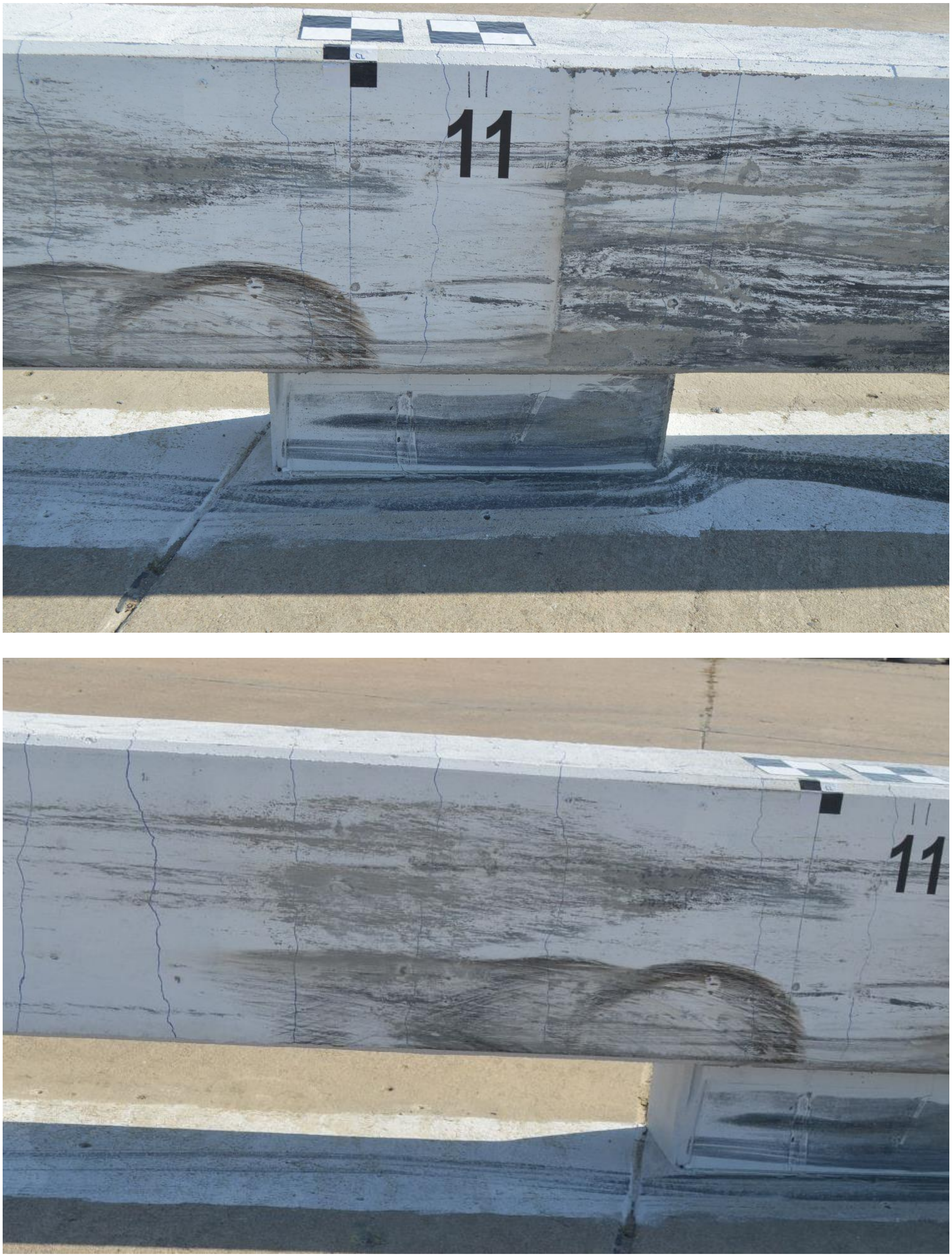

Figure 53. Concrete Beam Damage near Post No. 11, Test No. OCBR-1

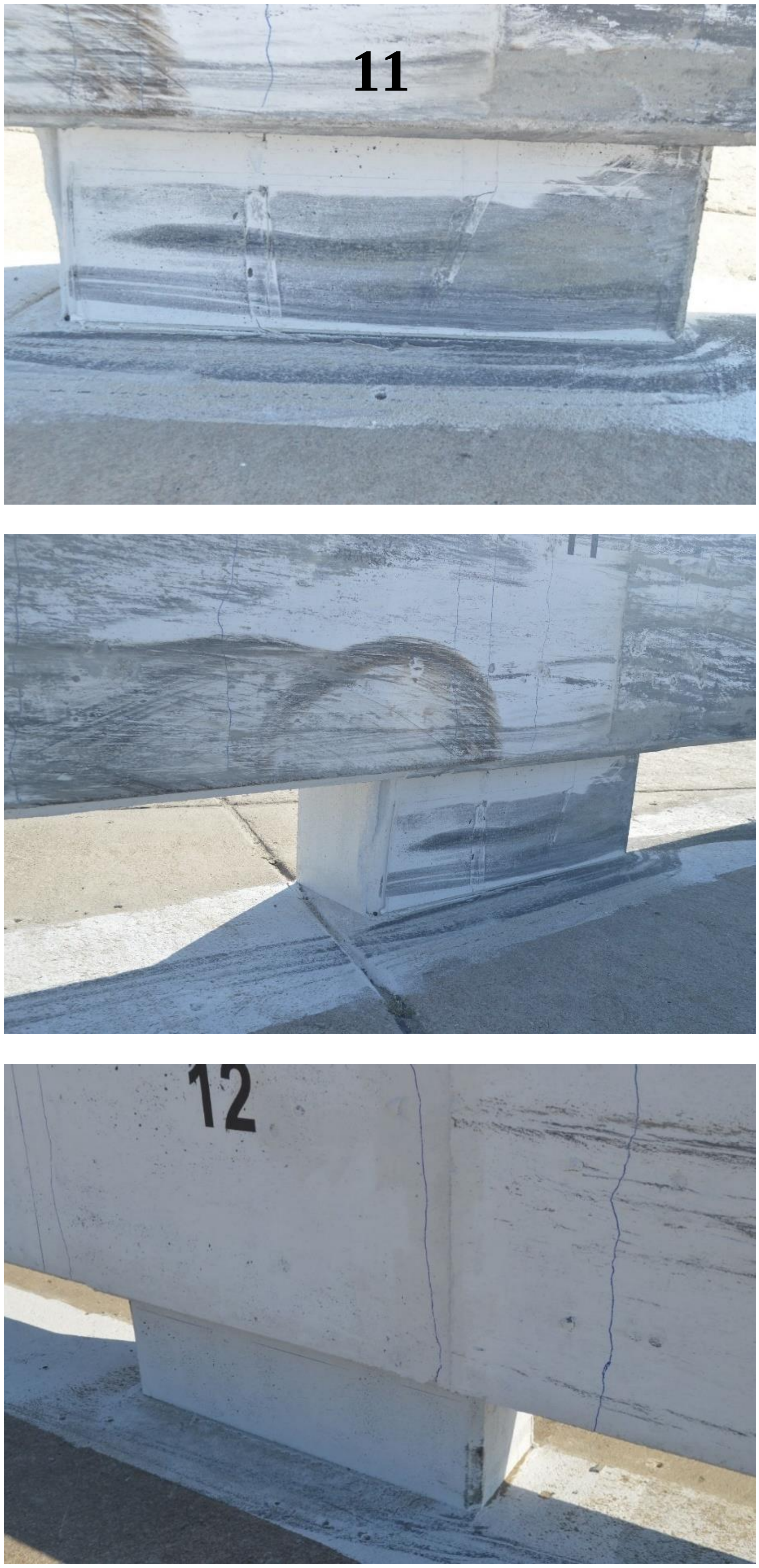

Figure 54. Concrete Post Damage, Post Nos. 11 and 12, Test No. OCBR-1

The maximum lateral permanent set of the barrier system was 0.3 in., as measured in the field. The maximum lateral dynamic barrier deflection was 0.3 in., as determined from high-speed digital video analysis. The working width of the system was found to be 14.3 in., also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 55.

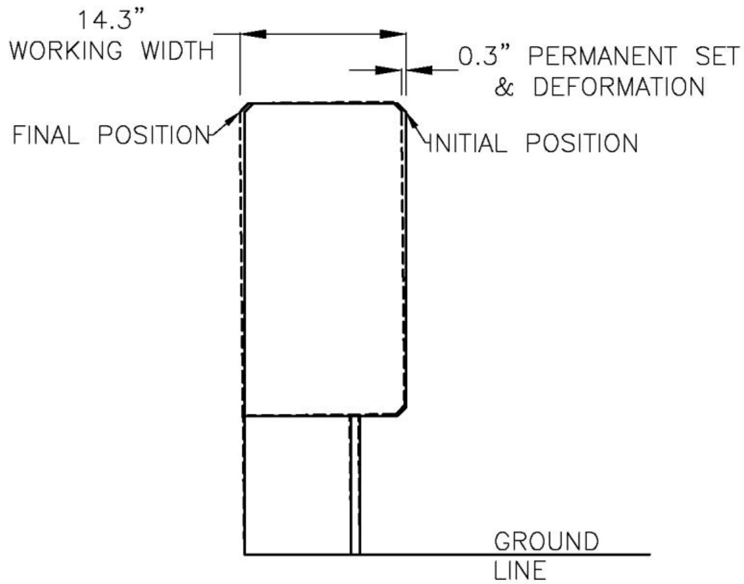

Figure 55. Permanent Set, Dynamic Deflection, and Working Width, Test No. OCBR-1

6.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 56 through 58. The maximum occupant compartment intrusions are listed in Table 5, along with the intrusion limits established in MASH for various areas of the occupant compartment. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix C. MASH 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 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 criteria.

Majority of the damage was concentrated on the right-front corner and right side of the vehicle where the impact had occurred. The bumper cover detached from the impact side of the vehicle. The bumper was crushed inward on the right side of the vehicle. The left side of the radiator detached from the frame. As for the hood, the right side was crushed inward due to impact and significant dents were found across the right half of the hood and the rooftop. The left fender was bent inward toward the left side of the vehicle. Deformation of the fender, bumper, A-pillar, and door areas was observed. Additionally, the loading of the body structure caused deformation of the windshield and tearing of the windshield liner. The windshield deformation and windshield tearing were not an issue with respect to the MASH occupant criteria as the deformation and tearing was not caused by direct loading of the glass by the test article.

The entire right quarter panel had scrapes and was crushed toward the middle, and the right-rear door had scrapes at the rear of the door. The right-front door had scrapes throughout and was crushed at the front which caused the door to bend outward from its frame. The entire right fender experienced major scrapes and was crushed inward at the front of the fender.

Damage to the undercarriage was concentrated on the right-front area. The right side of the frame horn experienced a significant inward crush. The vehicle’s right-side sprocket was slightly twisted. The right-side upper control arm sheared off from the steering knuckle. The right steering knuckle was crushed inward while the left side was undamaged. The lower control arm was still connected but bent severely. The right side of the sway bar was bent forward, bending the connecting rod. The right-side tie rod was bent at the connection with the wheel, and the front-end engine mounts were pushed slightly inward.

Figure 56. Vehicle Damage, Test No. OCBR-1

Figure 57. Vehicle Damage, Test No. OCBR-1

Figure 58. Interior and Undercarriage Damage, Test No. OCBR-1

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

Location	Maximum Intrusion in.	MASH Allowable Intrusion in.
Wheel Well & Toe Pan	0.6	≤ 9
Floor Pan & Transmission Tunnel	0.0*	≤ 12
A-Pillar	2.3	≤ 5
A-Pillar (Lateral)	1.9	≤ 3
B-Pillar	0.1	≤ 5
B-Pillar (Lateral)	0.0*	≤ 3
Side Front Panel (in Front of A-Pillar)	2.8	≤ 12
Side Door (Above Seat)	0.0*	≤ 9
Side Door (Below Seat)	0.0*	≤ 12
Roof	1.3	≤ 4
Windshield	1.4†	≤ 3
Side Window	Shattered due to induced damage**	No shattering resulting from contact with structural member of test article
Dash	2.1	N/A

N/A – No MASH criteria exist for this location.
*Negative value reported as 0.0. See Appendix C for further information.
**See Section 6.4 for further explanation.
†Right side A-pillar was too deformed to provide accurate windshield measurements. Deformation measurement was determined based on laser scan and comparison with exemplar vehicle.

6.5 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 6. Note that the OIVs and ORAs were within suggested limits, as provided in MASH. Although the SLICE-2 unit provided a lateral ORA that exceeded MASH limits, the SLICE-1 unit was the primary transducer and located closer to the vehicle c.g., therefore the lateral ORA was deemed acceptable. The calculated THIV, PHD, and ASI values are also shown in Table 6. The recorded data from the accelerometers and the rate transducers is shown graphically in Appendix D.

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

Evaluation Criteria		Transducer		MASH Limits
		SLICE-1 (primary)	SLICE-2	
OIV ft/s	Longitudinal	-29.18	-29.50	±40
	Lateral	-32.52	-32.77	±40
ORA g's	Longitudinal	-7.18	6.95	±20.49
	Lateral	-12.72	22.08	±20.49
Maximum Angular Displacement deg.	Roll	6.3	-4.9	±75
	Pitch	-6.4	-6.6	±75
	Yaw	-30.8	-31.2	not required
THIV – ft/s		41.71	41.76	not required
PHD – g's		14.28	21.57	not required
ASI		2.57	2.55	not required

6.6 Discussion

The analysis of the test results for test no. OCBR-1 showed that the system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 59. 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.

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 6. Note that the OIVs and ORAs were within suggested limits, as provided in MASH. Although the SLICE-2 unit provided a lateral ORA that exceeded MASH 2016 limits, the SLICE-1 unit was the primary transducer and located closer to the vehicle c.g.; therefore, the lateral ORA was deemed acceptable. After impact, the vehicle exited the barrier at an angle of 2.4 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. OCBR-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 4-10.

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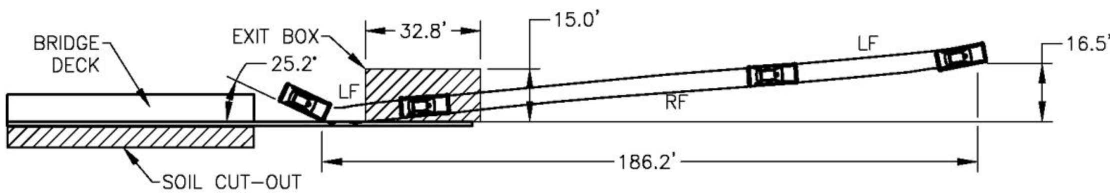

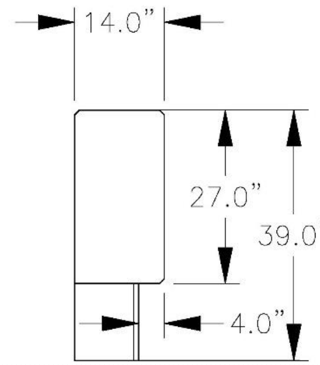

- Test Agency .... MwRSF
- Test Number OCBR-1
- Date 10/6/2021
- MASH Test Designation No. 4-10
- Test Article .... TL-4 Open Concrete Bridge Rail
- Total Length .... 132 ft
- Key Component - Beam
  - Length .... 1,584 in.
  - Width .... 14 in.
  - Depth .... 27 in.
- Key Component - Post
  - Length .... 36 in.
  - Width .... 10 in.
  - Spacing .... 108 in.
- Vehicle Make /Model .... 2015 Hyundai Accent
  - Curb .... 1,550 lb
  - Test Inertial .... 2,431 lb (MASH Limit 2420 ± 55 lb)
  - Gross Static .... 2,590 lb
- Impact Conditions
  - Speed .... 64.2 mph (MASH Limit 62 ± 2.5 mph)
  - Angle .... 25.2 deg. (MASH Limit 25 ± 1.5 degrees)
  - Impact Location .... 45.3 in. upstream of the upstream edge of post no. 11
- Impact Severity .... 60.7 kip-ft > 51 kip-ft MASH limit
- Exit Conditions
  - Speed .... 40.8 mph
  - Angle .... 2.4 degrees
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 186.2 ft downstream, 16.5 ft laterally in front
- Vehicle Damage .... Moderate
  - VDS [16] 1-RFQ-5
  - CDC [17] 01RFAW3
  - Maximum Interior Deformation .... 2.8 in. ≤ 12 in. Side-Front Panel MASH limit
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... 0.3 in.
  - Dynamic .... 0.3 in.
  - Working Width .... 14.4 in.
- Transducer Data

Evaluation Criteria		Transducer		MASH Limits
		SLICE-1 (primary)	SLICE-2	
OIV ft/s	Longitudinal	-29.18	-29.50	±40
	Lateral	-7.18	6.95	±40
ORA g’s	Longitudinal	-7.18	6.95	±20.49
	Lateral	-12.72	22.08*	±20.49
Maximum Angular Displacement deg.	Roll	6.3	-4.9	±75
	Pitch	30.8	-6.6	±75
	Yaw	-30.8	-31.2	not required
THIV – ft/s		41.71	41.76	not required
PHD – g’s		14.28	21.57	not required
ASI		2.57	2.55	not required

*Note: although the SLICE-2 lateral ORA exceeded MASH 2016 limits, the SLICE-1 unit was the primary transducer and located closer to the vehicle c.g.; therefore, the lateral ORA was deemed acceptable.

Figure 59. Summary of Test Results and Sequential Photographs, Test No. OCBR-1

7 FULL-SCALE CRASH TEST NO. OCBR-2

7.1 Weather Conditions

Test no. OCBR-2 was conducted on December 16, 2021 at approximately 1:45 p.m. The weather conditions as reported by the National Oceanic and Atmospheric Administration (station 14939/KLNK) are shown in Table 7.

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

Temperature	45°F
Humidity	42%
Wind Speed	13 mph
Wind Direction	240° from True North
Sky Conditions	Clear
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.20 in.
Previous 7-Day Precipitation	0.25 in.

7.2 Test Description

Initial vehicle impact was to occur 51⅝ in. upstream from the upstream edge of post no. 7, as shown in Figure 60, which was selected using Table 2.7 of MASH 2016. The 5,002-lb quad cab pickup truck impacted the open concrete bridge rail at a speed of 61.8 mph and at an angle of 24.7 degrees. The actual point of impact was 53.2 in. upstream from the upstream edge of post no. 7. Wheel snag on the bridge rail posts was not observed. As the vehicle was redirected, loading of the right-front fender, right-front door, and the bottom of the A-pillar caused fracture of the right-side window and minor deformation and cracking of the windshield. It was also noted that the simulated occupant's head extended out of the window, but did not contact the test article. The vehicle exited the barrier and continued downstream in a stable manner until brakes were applied. After brakes were applied, the vehicle came to rest 204.5 ft downstream and 35.2 ft laterally behind the system with the vehicle facing downstream and away from the system.

A detailed description of the sequential impact events is contained in Table 8. Sequential photographs are shown in Figures 61 and 62. Documentary photographs of the crash test are shown in Figure 63 and 64. The vehicle trajectory and final position are shown in Figure 65.

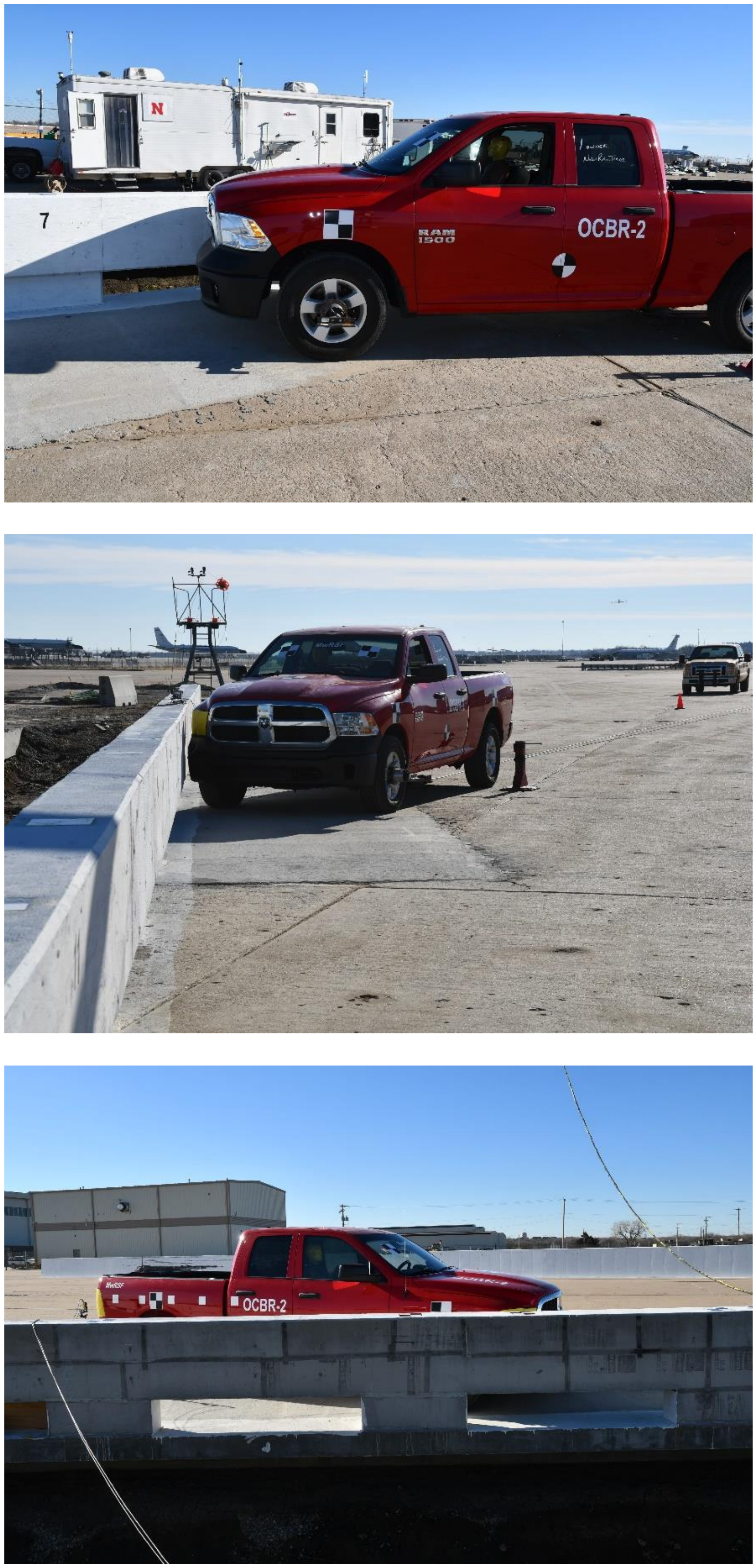

Figure 60. Target Impact Location, Test No. OCBR-2

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

Time (sec)	Event
0.000	Vehicle's front bumper contacted barrier 53.2 in. upstream from upstream edge of post no. 7 and deformed. Vehicle's right headlight contacted barrier and shattered.
0.008	Vehicle's right fender contacted barrier and crushed inward.
0.020	Vehicle's grille and right edge of vehicle’s hood deformed. Vehicle yawed away from barrier.
0.032	Vehicle's left fender deformed. Vehicle's right-front door contacted barrier and deformed. Vehicle rolled toward barrier.
0.042	Vehicle's roof deformed. Vehicle's grille disengaged. Top of vehicle’s right-front door became ajar.
0.064	Vehicle's left headlight disengaged.
0.092	Simulated occupant’s head contacted right-front window and window shattered. Vehicle's front radiator support disengaged. Vehicle's left-front tire became airborne.
0.133	Vehicle's left-rear tire became airborne.
0.148	Vehicle's right-rear door contacted barrier.
0.172	Vehicle's right quarter panel contacted barrier. Vehicle's right taillight contacted barrier and shattered. Vehicle's rear bumper contacted barrier and crushed inward.
0.173	Vehicle was parallel to system at a speed of 47.9 mph.
0.326	Vehicle exited system at a speed of 45.9 mph and an angle of 5.9 degrees. Vehicle rolled away from barrier.
0.394	Vehicle's left-front tire contacted ground.
0.448	Vehicle's left-rear tire contacted ground.
4.908	Vehicle came to rest.

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0.350 sec

0.400 sec

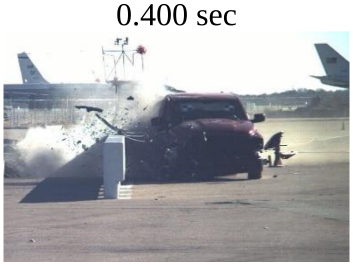

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Figure 61. Sequential Photographs, Test No. OCBR-2

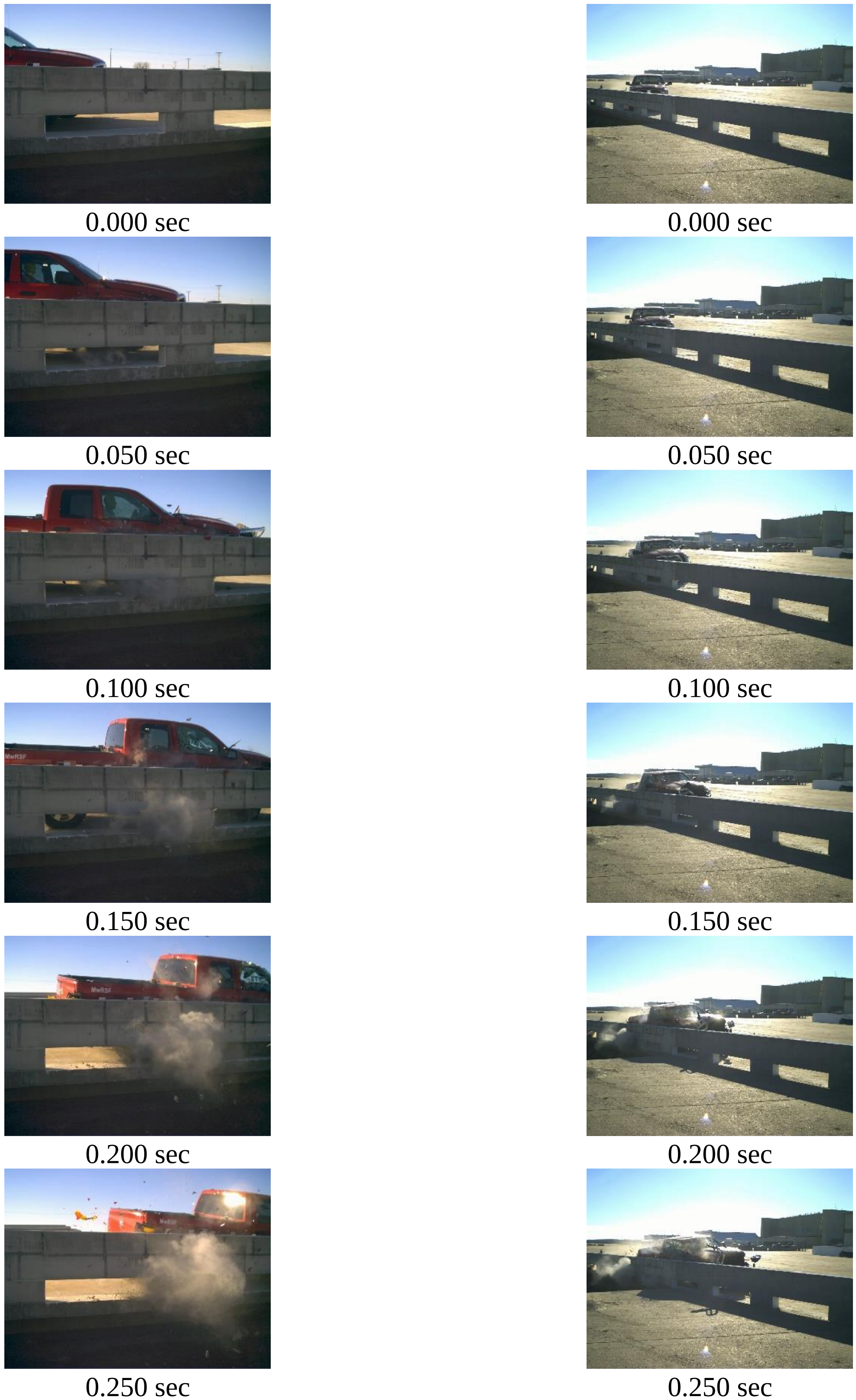


Figure 62. Sequential Photographs, Test No. OCBR-2

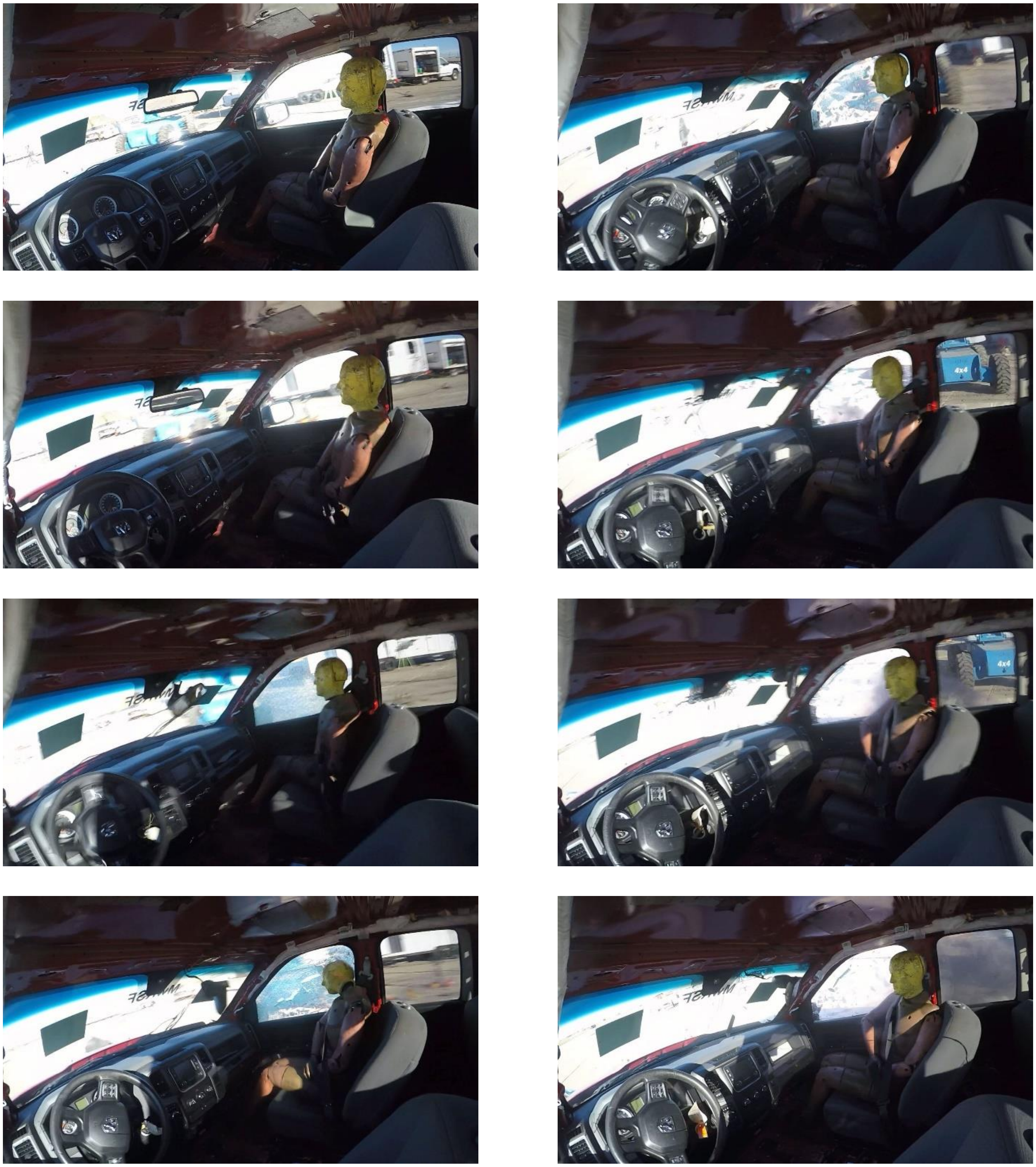


Figure 63. Documentary Photographs, Test No. OCBR-2

Figure 64. Documentary Photographs, Test No. OCBR-2

Figure 65. Vehicle Final Position and Trajectory Marks, Test No. OCBR-2

7.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 66 and 67. Barrier damage consisted of contact marks on the front face of the concrete segments and cracking. The length of vehicle contact along the barrier was approximately 12 ft – 3 in. which started 14¾ in. downstream from the centerline of post no. 6.

A contact mark was found on the top face of the barrier beginning 28½ in. downstream from the centerline of post no. 6 and extending 120 in. Various gouges were observed along the bottom edge of the beam between post nos. 6 and 7 where vehicle impact occurred, the most severe beginning 49 in. downstream of the centerline of post no. 6 and extending 34 in. downstream at a maximum depth of 2 in. Cracking of the bridge rail beam was observed 6 in. upstream from the centerline of post no. 6 and 49 in. upstream from post no. 8, with the cracks measuring 7 in. and 13 in. in length, respectively. The top of the bridge deck cracked at the upstream corner of post no. 7 and the downstream corner of post no. 6, but the cracks did not extend through to the bottom face of the deck. Cracks were also found at the post-to-deck interface areas at the edge of post nos. 6 and 7. Finally, post no. 6 was cracked at its base by the downstream corner and post no. 7 was cracked at its base by the upstream corner.

Figure 66. Overall System and Post No. 6 Damage, Test No. OCBR-2

Figure 67. Post Nos. 7 and 8 Damage, Test No. OCBR-2

The maximum lateral permanent set of the barrier system was 0.3 in. at the rail at post no. 7, as measured in the field. The maximum lateral dynamic barrier deflection was 1.3 in. at the rail at post no. 7, as determined from high-speed digital video analysis. The working width of the system was found to be 15.3 in. at the rail at post no. 7, also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 68.

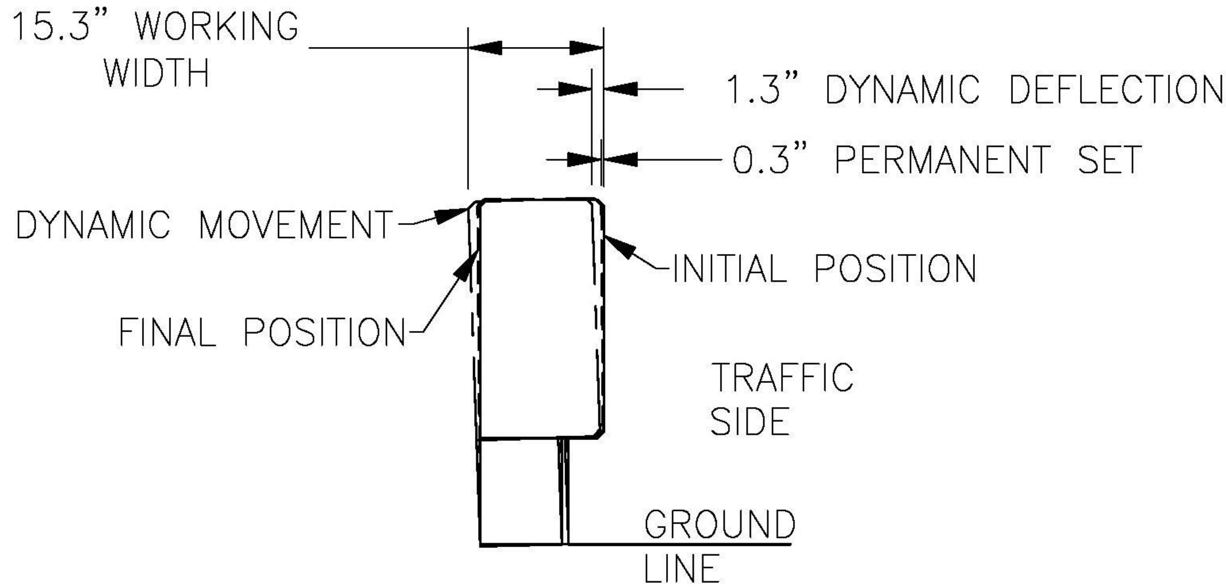


Figure 68. Permanent Set, Dynamic Deflection, and Working Width, Test No. OCBR-2

7.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 69 and 70. The maximum occupant compartment intrusions are listed in Table 9, along with the intrusion limits established in MASH for various areas of the occupant compartment. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix C. MASH 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 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 criteria.

Majority of the damage was concentrated on the right-front corner and right side of the vehicle where the impact had occurred. The right corner of the hood had a slight dent and the grille disengaged from the vehicle. The right side of the front bumper was scraped and bent rearward, while the whole bumper moved laterally to the left. The right fender experienced major crushing and scraping along the entire length of the panel. The leading and rear edges of the right-front door panel were crushed inward while the center of the door panel bowed outward. Scraping occurred along all areas of contact. Minor crushing occurred around the midpoint of the right-rear door panel. Crush occurred on the entire length of the right box side. The right taillight disengaged. The right end of the rear bumper was scraped and crushed inward. The left fender was bent toward the left slightly. The lower-right corner of the windshield slightly cracked, and the front-right window shattered due to contact with the simulated occupant's head. The remaining window glass remained undamaged.

On the undercarriage, the right-side shock was bent to the right and rear slightly. The bump stop on the right showed evidence of contact with the spring. The right-front end link was detached from the lower control arm and bent rearward. The right-side lower control arm was detached from the inner mounts. The right-side upper control arm was bent severely rearward. The right-side inner tie rod and the second engine cross were bent slightly. The right-side horn was bent inward 4 in. inward at the leading edge. The second mounts from the front of the vehicle were bent slightly. The front strap was detached and the gas tank was hanging low at the front edge.

Figure 69. Vehicle Damage, Test No. OCBR-2

Figure 70. Interior and Undercarriage Damage, Test No. OCBR-2

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

Location	Maximum Intrusion in.	MASH Allowable Intrusion in.
Wheel Well & Toe Pan	1.4	≤ 9
Floor Pan & Transmission Tunnel	0.2	≤ 12
A-Pillar	0.3	≤ 5
A-Pillar (Lateral)	0.1	≤ 3
B-Pillar	0.1	≤ 5
B-Pillar (Lateral)	0.1	≤ 3
Side Front Panel (in Front of A-Pillar)	2.1	≤ 12
Side Door (Above Seat)	0.1	≤ 9
Side Door (Below Seat)	0.0*	≤ 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	0.5	N/A

N/A – No MASH criteria exist for this location.
*Negative value reported as 0.0. See Appendix C for further information.

7.5 Occupant Risk

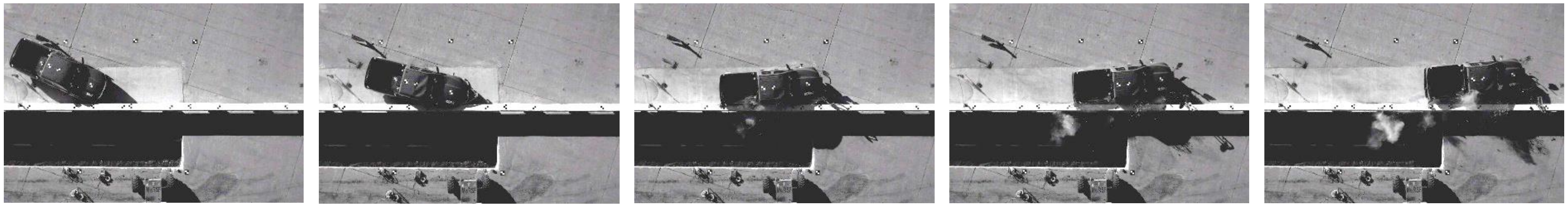
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 10. Note that the OIVs and ORAs were within suggested limits, as provided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

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

Evaluation Criteria		Transducer		MASH Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s	Longitudinal	-18.34	-18.77	±40
	Lateral	-28.24	-25.17	±40
ORA g's	Longitudinal	-4.72	-4.81	±20.49
	Lateral	-10.87	-12.15	±20.49
Maximum Angular Displacement deg.	Roll	9.44	11.75	±75
	Pitch	-2.34	-2.06	±75
	Yaw	-30.10	-30.92	not required
THIV – ft/s		34.06	32.41	not required
PHD – g's		11.11	12.38	not required
ASI		1.91	1.79	not required

7.6 Discussion

The analysis of the test results for test no. OCBR-2 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 71. 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 5.9 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. OCBR-2 was determined to be acceptable according to the MASH safety performance criteria for test designation no. 4-11.



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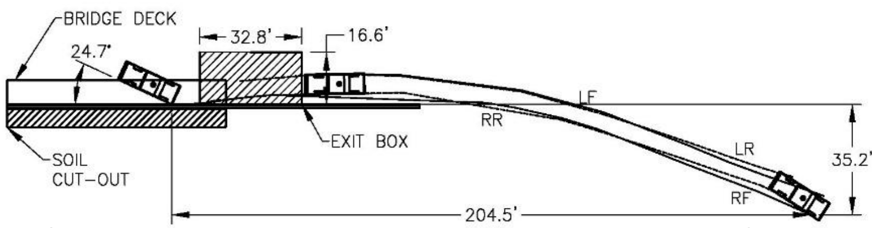

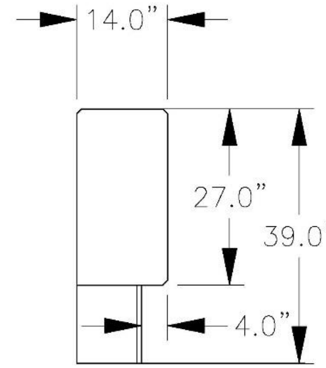

- Test Agency .... MwRSF
- Test Number OCBR-2
- Date 12/16/2021
- MASH Test Designation No. 4-11
- Test Article .... TL-4 Open Concrete Bridge Rail
- Total Length .... 132 ft
- Key Component - Beam
  - Length .... 1,584 in.
  - Width .... 14 in.
  - Depth .... 27 in.
- Key Component - Post
  - Length .... 36 in.
  - Width .... 10 in.
  - Spacing .... 108 in.
- Vehicle Make /Model .... 2015 Dodge Ram 1500
  - Curb .... 4,921 lb
  - Test Inertial .... 5,002 lb (MASH Limit 5,000 ± 110 lb)
  - Gross Static .... 5,166 lb
- Impact Conditions
  - Speed .... 61.8 mph (MASH Limit 62 ± 2.5 mph)
  - Angle .... 24.7 deg. (MASH Limit 25 ± 1.5 deg.)
  - Impact Location .... 53.2 in upstream from the upstream edge of post no. 7
- Impact Severity .... 115.5 kip-ft > 106 kip-ft MASH 2016 limit
- Exit Conditions
  - Speed .... 45.9 mph
  - Angle .... 5.9 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 204.5 ft downstream, 35.2 ft laterally behind
- Vehicle Damage .... Moderate
  - VDS [16] 1-RFQ-4
  - CDC [17] 01RFAW3
  - Maximum Interior Deformation .... 2.1 in. ≤ 12 in. Side-Front Panel MASH 2016 limit
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... 0.3 in.
  - Dynamic .... 1.3 in.
  - Working Width .... 15.3 in.
- Transducer Data

Evaluation Criteria		Transducer SLICE-1	Transducer SLICE-2 (primary)	MASH Limits
OIV ft/s	Longitudinal	-18.34	-18.77	±40
	Lateral	-28.24	-25.17	±40
ORA g's	Longitudinal	-4.72	-4.81	±20.49
	Lateral	-10.87	-12.15	±20.49
Maximum Angular Displacement deg.	Roll	9.44	11.75	±75
	Pitch	-2.34	-2.06	±75
	Yaw	-30.10	-30.92	not required
THIV – ft/s		34.06	32.41	not required
PHD – g's		11.11	12.38	not required
ASI		1.91	1.79	not required

Figure 71. Summary of Test Results and Sequential Photographs, Test No. OCBR-2

8 FULL-SCALE CRASH TEST NO. OCBR-3

8.1 Weather Conditions

Test no. OCBR-3 was conducted on March 4th, 2022 at approximately 3:00 p.m. The weather conditions as reported by the National Oceanic and Atmospheric Administration (station 14939/KLNK) are shown in Table 11.

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

Temperature	70°F
Humidity	32%
Wind Speed	23 mph
Wind Direction	170° from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.5 in.
Previous 7-Day Precipitation	0.5 in.

8.2 Test Description

Initial vehicle impact was to occur 18 in. upstream from the midspan between post nos. 3 and 4, as shown in Figure 72, which was selected using Table 2.7 of MASH 2016. The 22,052-lb single-unit truck impacted the open concrete bridge rail at a speed of 56.6 mph and at an angle of 15.2 degrees. The actual point of impact was 11 in. upstream from the midspan between post nos. 3 and 4. Wheel snag on the bridge rail posts was not observed, but there was engagement of the wheel lugs with the face of the rail beam and gouging of the lugs in the concrete. The right-front wheel turned into/toward the barrier after impact and displaced rearward. As the vehicle was redirected, the box of the vehicle extended over the top of the 39-in. tall bridge rail and the box rode along the top of the rail throughout the redirection. The rear tandem axle and the box lift on the rear of the box impacted the rail at 282 msec after initial impact. The impact of the rear of the vehicle produced the highest of the barrier loading and corresponded with the peak barrier loading, peak dynamic deflections, and majority of the damage observed to the barrier and deck. The vehicle became parallel with the barrier at 300 msec after initial impact. Vehicle stability and roll were good throughout the impact. The vehicle exited the barrier and continued downstream in a stable manner until the right-front corner of the vehicle impacted a downstream concrete parapet that was part of a separate barrier installation. This secondary impact was at a relatively high impact angle (estimated at 40 degrees or more) and resulted in a more severe impact for the 10000S than the original impact with the bridge rail. As such, a significant amount of the front-end damage to the vehicle was likely incurred during the secondary impact. After brakes were applied, the vehicle came to rest 254.9 ft downstream and 32.3 ft laterally behind the system.

A detailed description of the sequential impact events is contained in Table 12. Sequential photographs are shown in Figures 73 and 74. Documentary photographs of the crash test are shown in Figure 75. The vehicle trajectory and final position are shown in Figure 76.

Figure 72. Target Impact Location, Test No. OCBR-3

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

Time (sec)	Event
0.000	Vehicle's front bumper contacted barrier 11 in. upstream from the midspan between post nos. 3 and 4 and deformed.
0.006	Vehicle's right fender contacted barrier and deformed.
0.012	Vehicle's right-front tire and right headlight contacted barrier.
0.024	Vehicle's right headlight shattered.
0.030	Vehicle's right-front tire and right fender pushed back into vehicle's right fuel tank.
0.036	Vehicle's right fuel tank deformed.
0.080	Vehicle's right door deformed. Vehicle rolled toward barrier.
0.142	Vehicle yawed away from barrier.
0.152	Vehicle's left-front tire became airborne. Occupant’s head contacted left-side window.
0.164	Vehicle box's bottom right-front corner contacted top of barrier.
0.222	Vehicle's left-rear tires became airborne.
0.282	Vehicle's rear bumper/lift mechanism contacted barrier near post no. 3. Barrier between post nos. 2 and 3 deflected backward. Vehicle’s box door opened and deformed.
0.300	Vehicle’s box deformed. Vehicle was parallel to barrier at a speed of 49.1 mph.
0.326	Vehicle pitched downward.
0.486	Vehicle yawed toward barrier.
0.610	Vehicle's hood opened.
0.694	Vehicle rolled away from barrier.
0.864	Vehicle's left-rear tires and left-front tire contacted ground.
0.871	Vehicle’s box door and frame disengaged.
1.030	Vehicle rolled toward barrier. Vehicle's right-front wheel scraped barrier from post nos. 11 through 15.
1.458	Vehicle rolled away from barrier.
1.810	Vehicle exited system at an approximate speed of 40.2 mph.
1.860	Vehicle rolled toward barrier.
6.379	Vehicle came to a rest against secondary barrier system.


0.000 sec


0.000 sec


0.200 sec


0.200 sec


0.400 sec


0.400 sec


0.600 sec


0.600 sec


0.800 sec


0.800 sec


1.000 sec

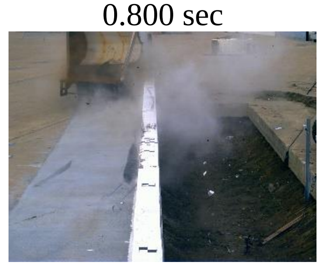
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Figure 73. Sequential Photographs, Test No. OCBR-3


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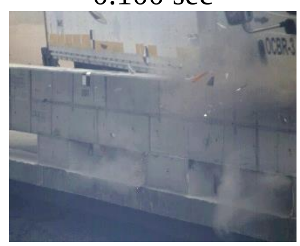
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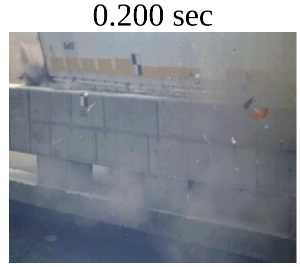
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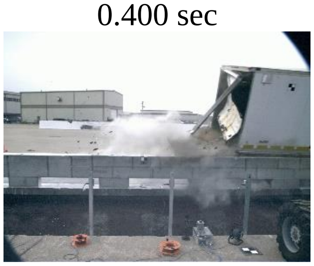
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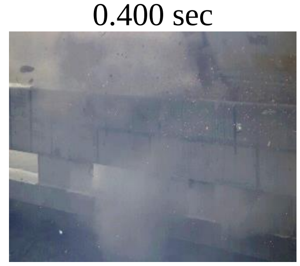
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Figure 74. Sequential Photographs, Test No. OCBR-3

Figure 75. Documentary Photographs, Test No. OCBR-3

Figure 76. Vehicle Final Position and Trajectory Marks, Test No. OCBR-3

8.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 77 through 80. Barrier damage consisted of contact marks, spalling, cracking, and gouging of the bridge rail beam and concrete cracking on deck. The length of vehicle contact along the barrier was approximately 64 ft – 10½ in., starting 3 ft – 10½ in. downstream from post no. 2.

Multiple contact marks of various heights and lengths were present on the front and top face of the bridge rail beam. Two contact marks measuring over 300 in. in length were present on the front face of the bridge rail beam starting 2 in. downstream from post nos. 3 and 18 in. downstream from post no. 11. Another contact mark was found on the top face of the bridge rail beam with a length of 62 ft starting 27 in. upstream from post no. 3. Additional contact marks were present between post no. 3 and the downstream end of the bridge rail beam.

Spalling and gouging were noted on the face of the bridge rail beam due to interaction of the wheel lugs with the face of the beam. A total of seven gouges on the top face and front edge of the bridge rail beam with lengths between 4 and 111 in. were found between post nos. 2 through 5. Another set of gouges with lengths between 9½ in. and 70½ in. spanned from post no. 11 to the downstream end of the bridge rail beam. Spalling was observed 38½ in. upstream from post no. 14 spanning 20 in. downstream.

Hairline cracks with lengths between 9 in. and 36 in. were observed on the front face of the concrete beam spanning 31 in. downstream from post no. 1 to 36 in. upstream from post no. 3. Minor cracks on the front face of the concrete beam ranging from 1 in. to 59 in. long were present starting 40 in. downstream from post no. 2 and ending 63 in. upstream from post no. 6. Another set of cracks were present on the backside of the concrete beam with lengths between 1 in. and 31 in. spanning between post no. 2 and 82 in. upstream from post no. 5. Cracks were also present on the back side of concrete post nos. 3 and 4 with lengths between 6½ in. and 17 in. As for the concrete deck, cracks were found on the front, top, and bottom surfaces of the deck at the downstream and upstream edge of concrete posts no. 1 through 5; these cracks measured between 1 in. and 36 in. long. The deck surface at post nos. 2 through 4 all had deck-post interface cracks. The upstream edge of the deck overhang had a 3-in. tall vertical crack. Another overhang crack and tarmac joint crack spanned across the entire deck with a length of 70 ft. A schematic of the cracking observed in the beam and posts is shown in Figure 81.

Figure 77. Overall System Damage, Test No. OCBR-3

Figure 78. Concrete Beam and Deck Damage, Test No. OCBR-3

Figure 79. Concrete Beam and Post Damage, Post Nos. 3 and 4, Test No. OCBR-3

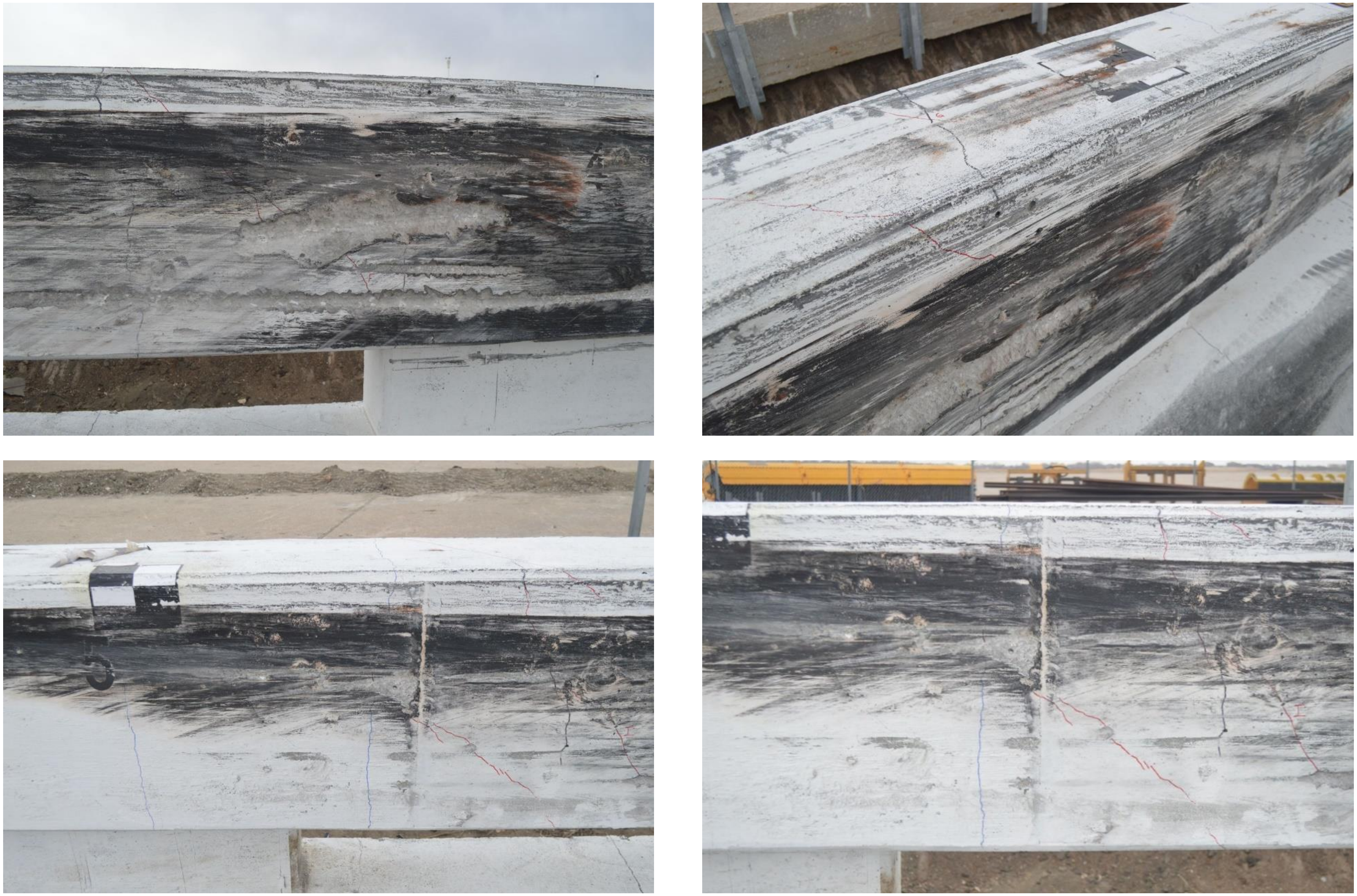


Figure 80. Concrete Beam Damage from Post Nos. 4 through 6, Test No. OCBR-3

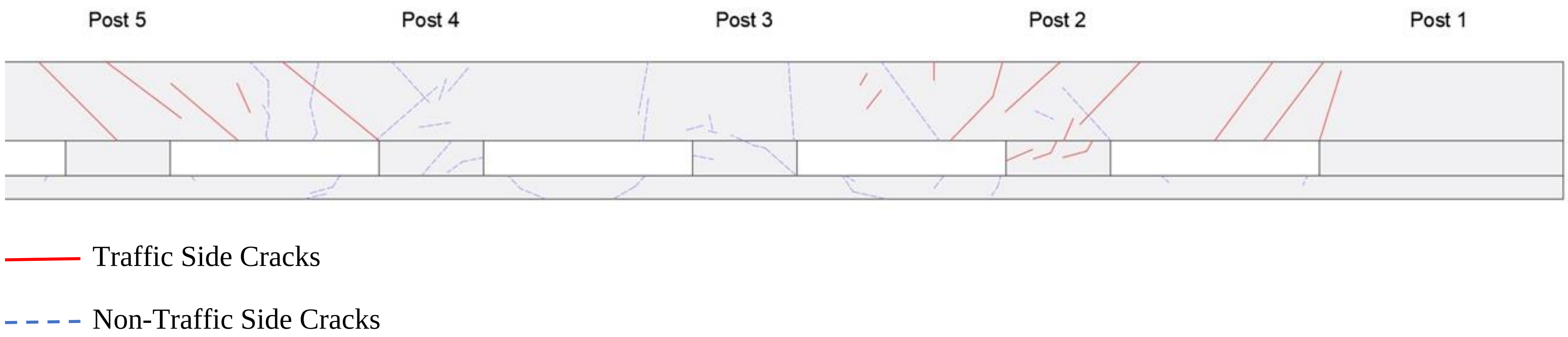


Figure 81. Schematic of Bridge Rail Cracks, Test No. OCBR-3

The maximum lateral permanent set of the barrier system, including barrier and deck panel shift, was 0.9 in., as measured in the field. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 1.5 in., as determined from high-speed digital video analysis. The working width of the system was found to be 50.8 in., which included the vehicle box trailer's protrusion behind the barrier, also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 82.

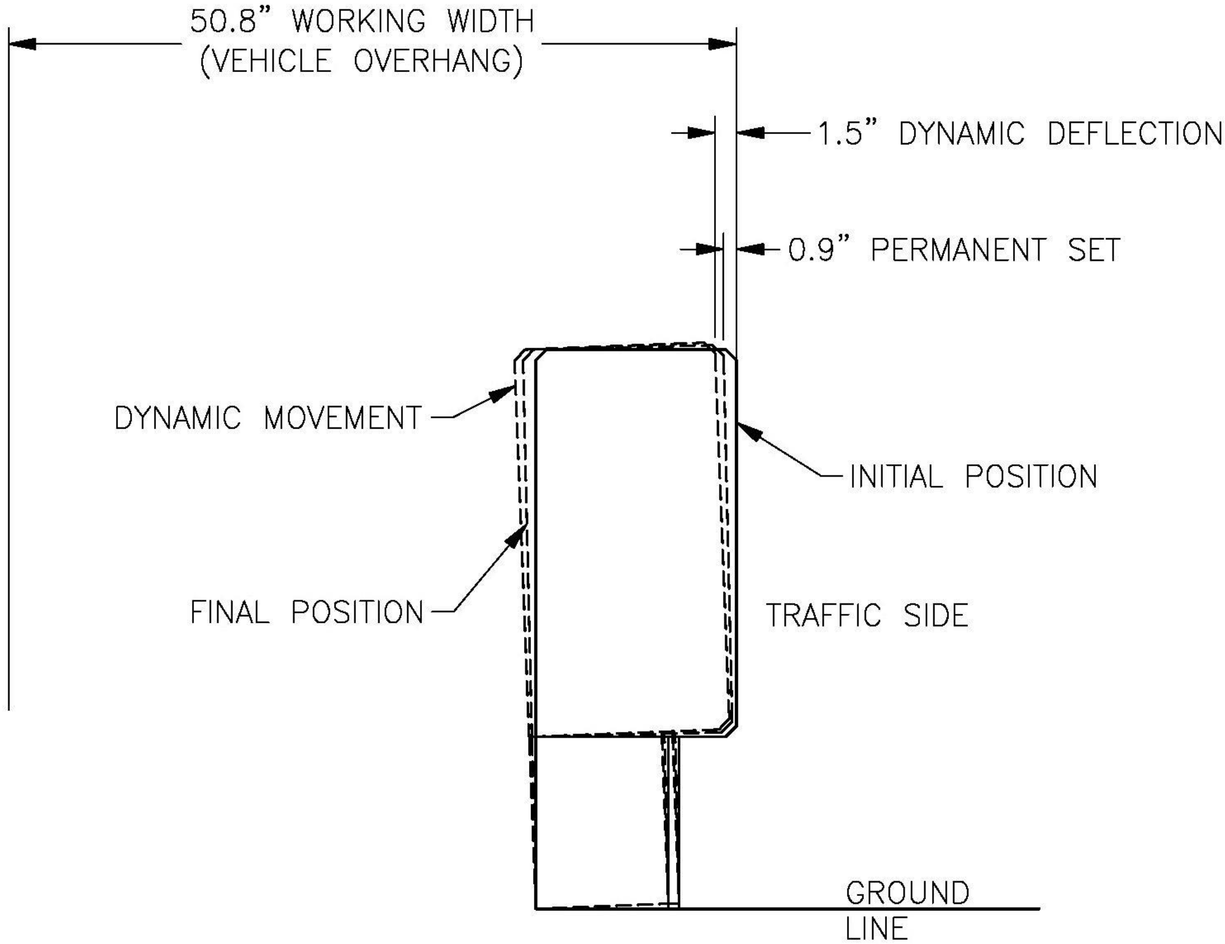


Figure 82. Permanent Set, Dynamic Deflection, and Working Width, Test No. OCBR-3

8.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 83 and 84. The maximum occupant compartment intrusions are listed in Table 13 along with the intrusion limits established in MASH for various areas of the occupant compartment. Note that the reference sets for occupant compartment intrusion were compromised so the standard occupant compartment measurements were not taken. However, comparisons were made to an exemplar vehicle with the same cab and interior configuration. Measurements were taken at the maximum area of deformation of the interior occupant compartment. The occupant compartment deformation was within MASH limits.

Majority of the damage was concentrated on the right-front corner and right side of the vehicle where the impact had occurred. The front bumper was dented and crushed on the right side of the vehicle. A tear was observed on the right side of the bumper where the tow hook was located. The entire front end of the vehicle was crushed rearward and inward on the right side. The hood was disengaged from the vehicle. The right-front door was wrinkled and scraped, and the steps were crushed backward due to the tire shifting the entire fuel tank rearward.

A small dent and scrape were found at the leading edge of the right side of the box. Smaller wrinkles were observed throughout the side of the box. The vehicle's rear bumper detached and the rolling door was disengaged. The left side of the cab had a small wrinkle at the back side of the door, and the back side of the cab was crushed from the impact of the box sliding forward.

It should be noted that there was a secondary impact event during the crash test due to a high angle impact of the right-front corner of the 10000S vehicle into a downstream concrete parapet after exiting the bridge rail. Review of the acceleration data from the vehicle found that this event produced very large lateral and longitudinal accelerations and a correspondingly high change in velocity that brought the vehicle to a stop. This impact likely accounted for a significant amount of damage to the right-front corner of the vehicle and the front wheels and suspension.

Further, review of the damage to the vehicle occupant compartment found right-side floor pan deformation due to the right-front wheel being pushed into the vehicle floorboard and opening a seam in the vehicle floor, as shown in Figure 85. This resulted in a maximum floor pan deformation of 4.5 in., which was within the MASH limits. Several observations were made regarding this floor pan damage.

1. As noted previously, there was a significant secondary event during the crash test due to a high angle impact with the right-front corner of the vehicle on a downstream concrete parapet. This impact generated large lateral and longitudinal accelerations and a correspondingly high change in velocity.

2. Review of the wheel motion during the initial impact with the bridge rail showed that the right-front wheel experienced only minor climb on the face of the bridge rail. The wheel also turned into or toward the bridge rail during the impact and was pushed back longitudinally. While the push back of the wheel was consistent with the floor pan deformation observed, the turn in or rotation of the front wheel was not. The floor pan deformation and wheel position were more consistent with the final position of the wheel when it impacted the downstream parapet during the secondary impact.

3. These two factors would suggest that it is most likely that the floor pan deformation observed was due to the secondary impact event. However, some degree of floor pan deformation due to the initial impact cannot be ruled out.

4. Review of previous MASH TL-4 bridge rail testing identified very similar levels of deformation and side seam deformations in existing full-scale crash tests. These tests were all deemed acceptable under MASH. Examples of these deformations and the relevant full-scale crash testing are provided in Figures 86 through 91.

In terms of evaluation of the crash test, the researchers reviewed MASH guidance regarding occupant compartment deformation. The floor pan deformation was within MASH deformation limits. Thus, the only remaining issue was the opening of the seam on the side of the floor pan. As noted previously, the researcher believed that floor pan deformation was most likely due to the secondary impact with a concrete barrier system downstream of the tested bridge rail, MASH provides the follow relevant guidance related to the opening of seams in the floor.

> "Note that some vehicles now incorporate glued seams on the floor board as well as other areas. In the presence of significant deformation, these bonded seams can separate and create an opening into the occupant compartment. There is no available data to relate occupant injury severity to the opening of seams in the floor pan area. However, it is generally believed that an opening in the occupant compartment by and of itself does not necessarily result in injury to the occupants unless it is accompanied by an object moving toward the occupant. Therefore, a seam separation by itself is not considered a test failure unless (1) a component of the safety device protrudes through the opening or (2) the deformation limits of 12 in. (305 mm) is exceeded."

In test no. OCBR-3, the wheel loaded the floor pan and separated the seam the at the edge of the vehicle floor pan. However, the wheel/tire did not protrude through the seam opening and the deformation was lower than the MASH limits. Thus, the floor pan deformation and opening observed in the test would not be grounds for failure of test no. OCBR-3. The researchers plan to discuss this issue with other accredited test labs as this behavior appears to be somewhat common, and it is desirable to ensure that test labs are documenting and evaluating this behavior consistently.

Figure 83. Vehicle Damage, Test No. OCBR-3

Figure 84. Vehicle Damage, Test No. OCBR-3

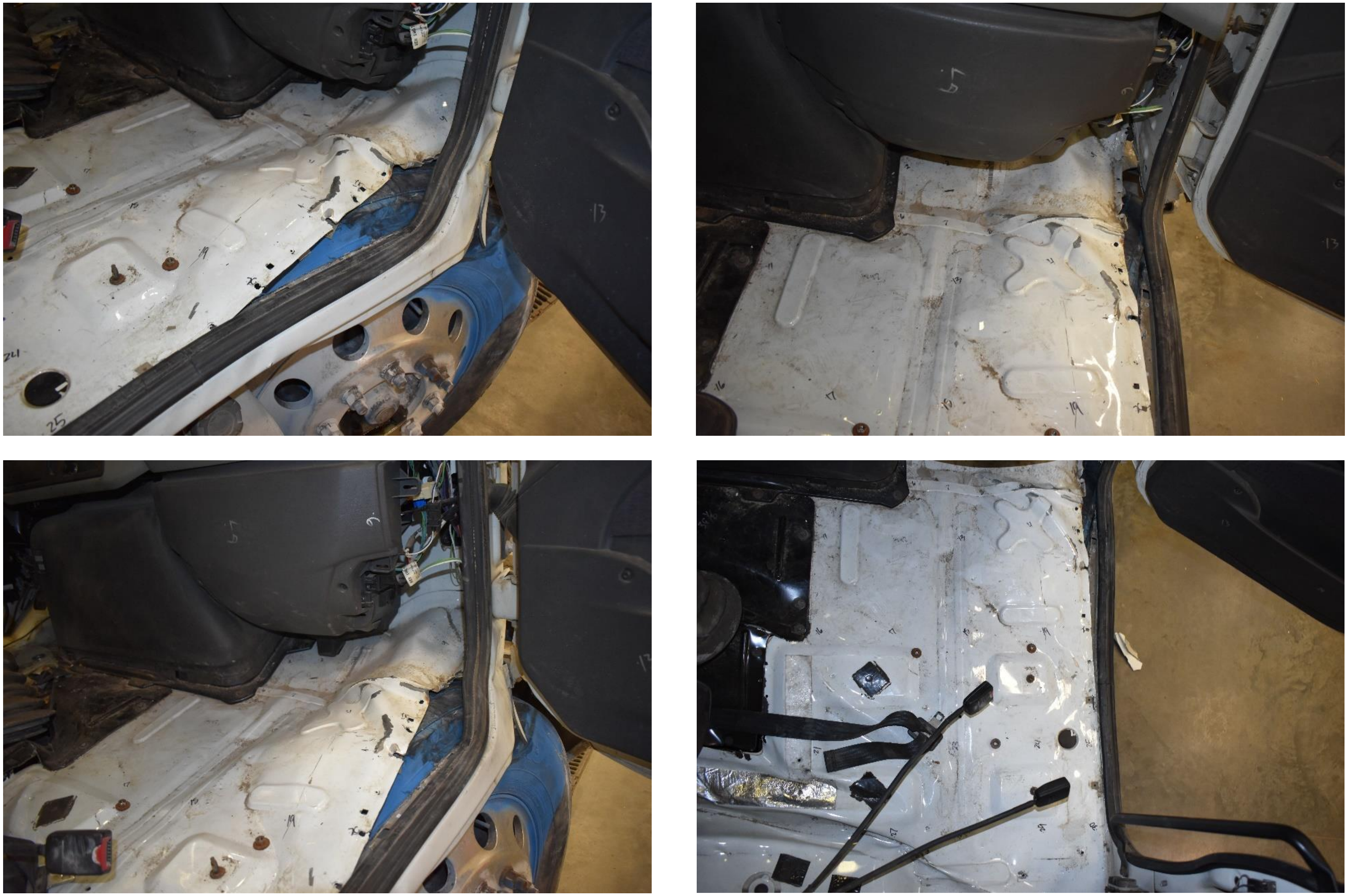


Figure 85. Vehicle Damage, Occupant Compartment Deformation Test No. OCBR-3

Figure 86. Vehicle Floor Pan Separation, MASH TL-4 Flared Concrete Barrier, Test No. 611901-05-1 [18]

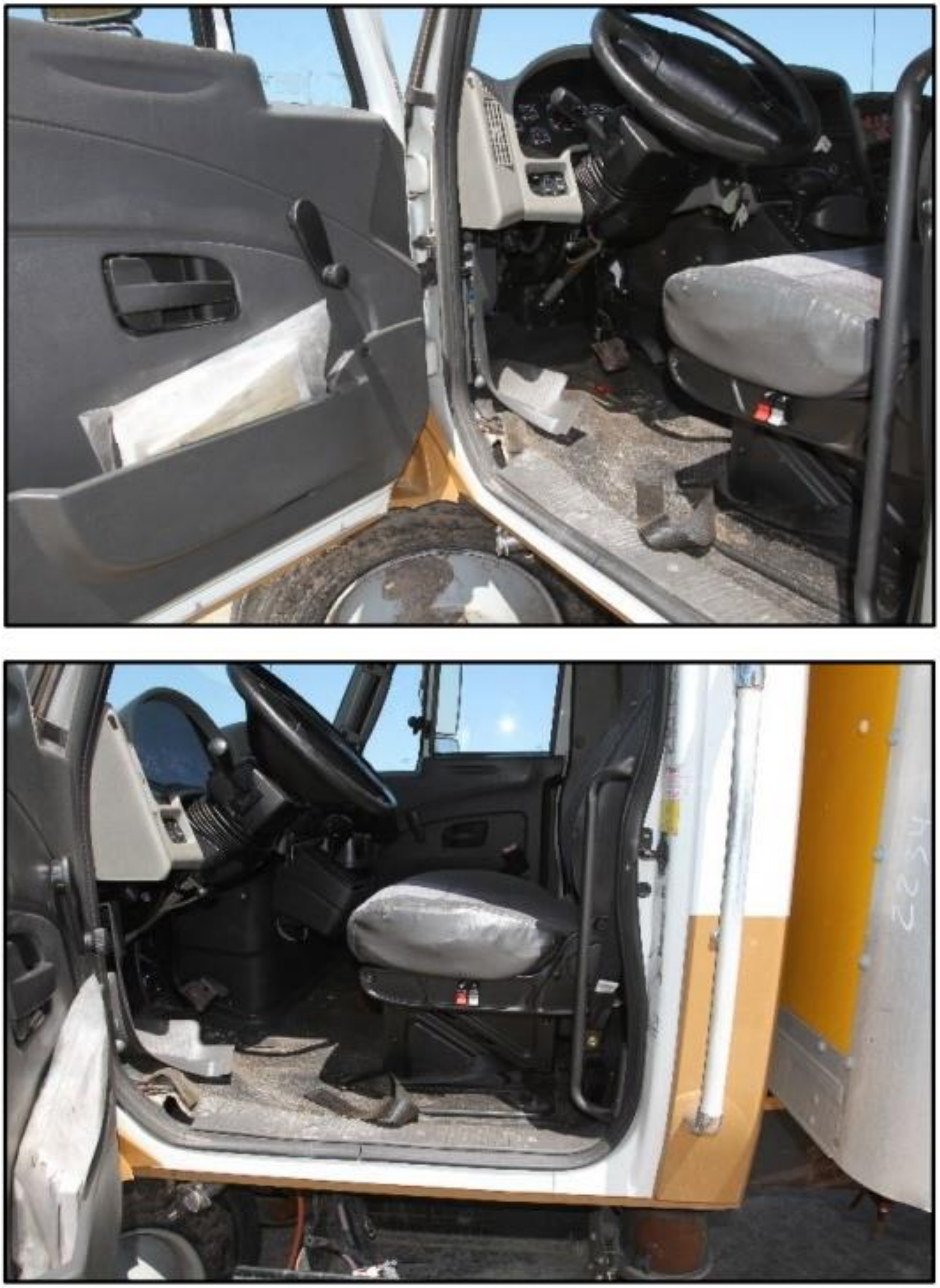


Figure 87. Vehicle Floor Pan Separation, C1W Bridge Rail, Test No. 469469-1 [19]

Figure 88. Vehicle Floor Pan Separation, TL-4 Barrier on Rubber Posts, Test No. 468958-3 [20]

Figure 89. Vehicle Floor Pan Separation, 42-in. Tall Single Slope Barrier, Test No. 469467-1 [21]

Figure 90. Vehicle Floor Pan Separation, Minnesota Combination Bridge Rail, Test No. MNCBR-1 [22]

Figure 91. Vehicle Floor Pan Separation, Optimized TL-4 Concrete Bridge Rail, Test No. 4CBR-1 [23]

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

Location	Maximum Intrusion in.	MASH Allowable Intrusion in.
Wheel Well & Toe Pan	4.5	≤ 9
Floor Pan & Transmission Tunnel	*	≤ 12
A-Pillar	*	≤ 5
A-Pillar (Lateral)	*	≤ 3
B-Pillar	*	≤ 5
B-Pillar (Lateral)	*	≤ 3
Side Front Panel (in Front of A-Pillar)	*	≤ 12
Side Door (Above Seat)	*	≤ 9
Side Door (Below Seat)	*	≤ 12
Roof	*	≤ 4
Windshield	*	≤ 3
Side Window	Intact	No shattering resulting from contact with structural member of test article
Dash	*	N/A

N/A – No MASH criteria exist for this location.
*No measurements taken due to compromised reference points.

8.5 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 14. Note that while OIV and ORA values are not required for test designation no. 4-12, the OIVs and ORAs were within suggested limits, as provided in MASH. The calculated THIV, PHD, and ASI values are also shown in Table 14. The recorded data from the accelerometers and the rate transducers is shown graphically in Appendix F.

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

Evaluation Criteria		Transducer			MASH Limits
		SLICE-1 (C.G.)	SLICE-2 (Rear-Axle)	TDAS (Cab)	
OIV ft/s	Longitudinal	N/A	N/A	-5.40	not required
	Lateral	N/A	N/A	-16.17	not required
ORA g's	Longitudinal	N/A	N/A	-3.78	not required
	Lateral	N/A	N/A	-5.71	not required
Maximum Angular Displacement deg.	Roll	15.3	16.52	23.0	<¼ roll
	Pitch	-1.9	2.15	8.7	not required
	Yaw	-15.7	-16.69	17.0	not required
THIV – ft/s		N/A	N/A	13.77	not required
PHD – g's		N/A	N/A	3.23	not required
ASI		0.58	1.72	0.79	not required

N/A – OIV, ORA, PHD, and THIV values were only calculated for the vehicle cab accelerometer.

8.6 Barrier Loads

The longitudinal and lateral vehicle accelerations, as measured at the vehicle's c.g. and at the rear axle, were 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 and 93. The maximum perpendicular (i.e., lateral) loads imparted to the barrier were 102.1 kips and 203.9 kips, as determined by the SLICE-1 (primary) unit and SLICE-2, respectively. It should be noted that the impact loading indicated by the SLICE-2 transducer was significantly higher than those calculated from previous MASH TL-4 SUT truck impacts. This increase in load may be partially due to the presence of a mechanical lift installed on the rear of the SUT in test no. OCBR-3 that may have increased the accelerations imparted to the SLICE-2 unit which was mounted at the rear tandem axle.

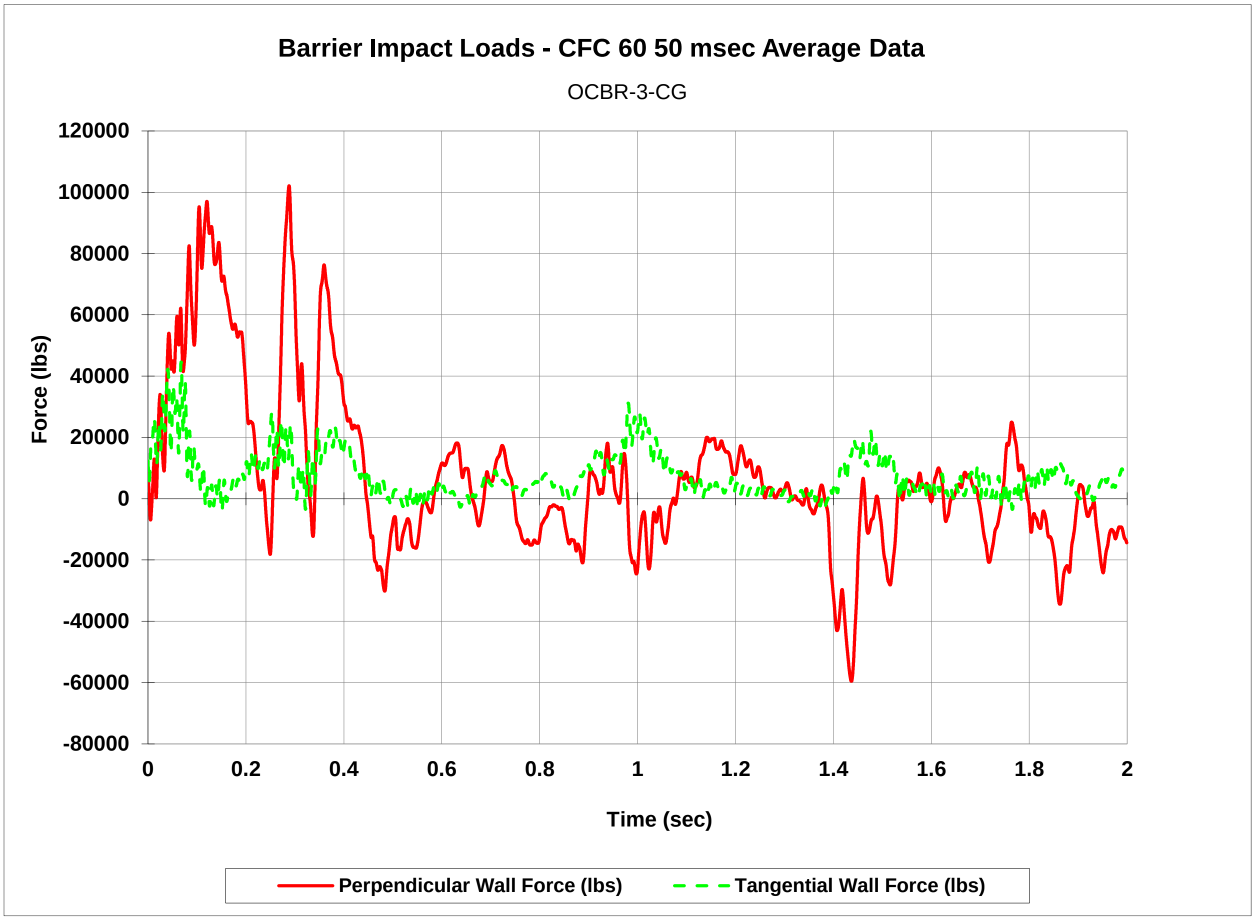


Figure 92. Perpendicular and Tangential Forces Imparted to the Barrier System (SLICE-1) Located at Vehicle c.g., Test No. OCBR-3

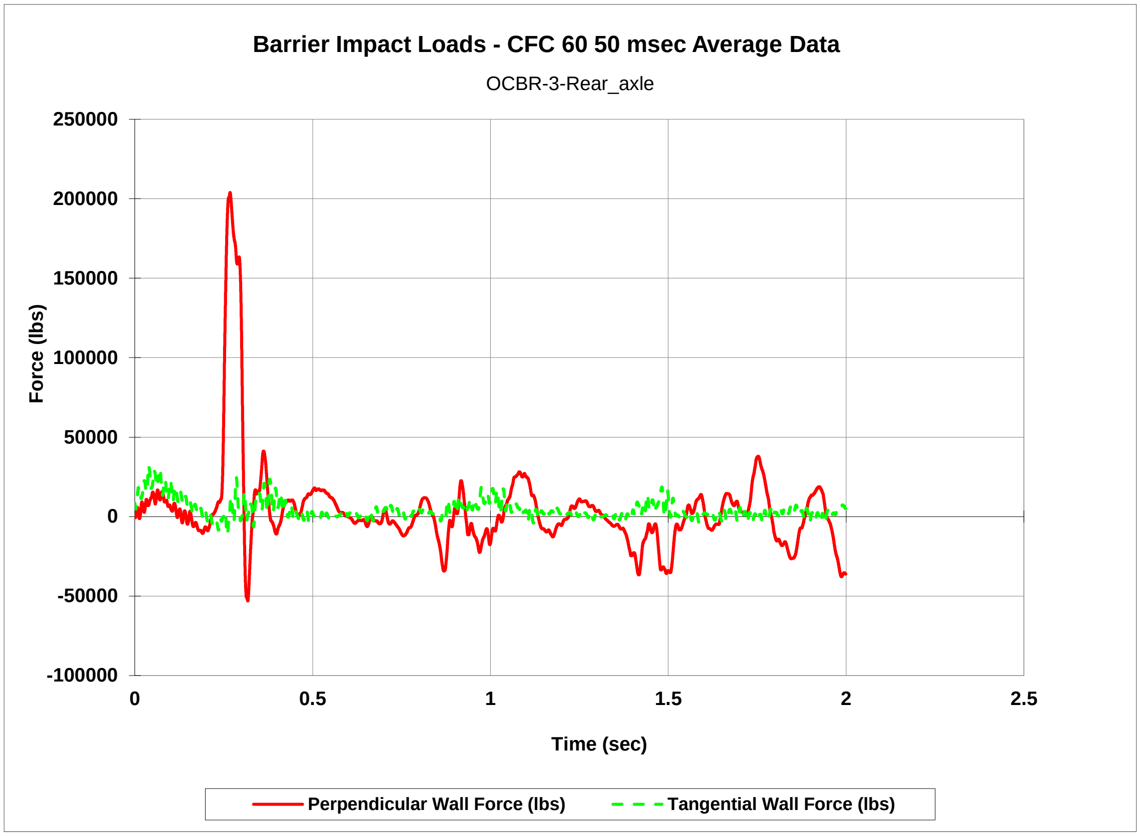
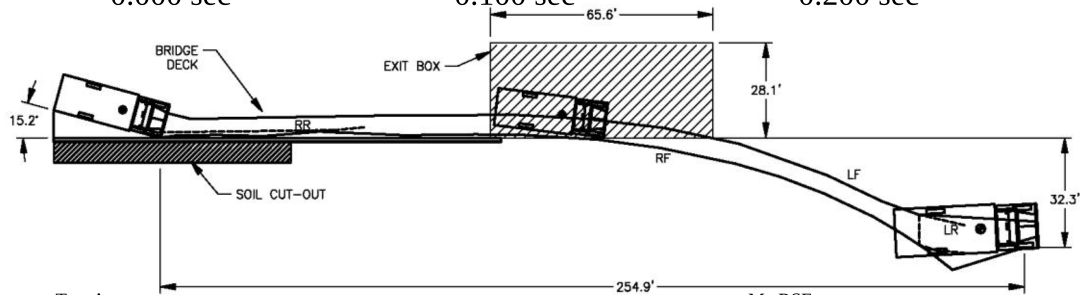


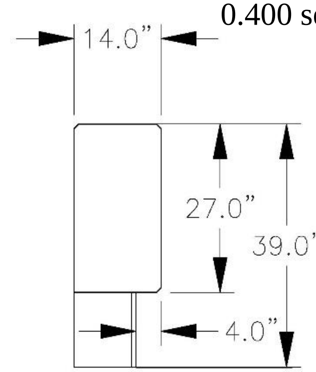
Figure 93. Perpendicular and Tangential Forces Imparted to the Barrier System (SLICE-2) Located at Rear Axle, Test No. OCBR-3

8.7 Discussion

The analysis of the test results for test no. OCBR-3 showed that the system adequately contained and redirected the 10000S vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 94. 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 and its trajectory did not violate the bounds of the exit box. Therefore, test no. OCBR-3 was determined to be acceptable according to the MASH safety performance criteria for test designation no. 4-12.

0.000 sec 0.100 sec 0.200 sec 0.300 sec 0.400 sec





- Test Agency .... MwRSF
- Test Number OCBR-3
- Date 03/04/2022
- MASH Test Designation No. 4-12
- Test Article .... TL-4 Open Concrete Bridge Rail
- Total Length .... 132 ft
- Key Component - Beam
  - Length .... 1,584 in.
  - Width .... 14 in.
  - Depth .... 27 in.
- Key Component - Post
  - Length .... 36 in.
  - Width .... 10 in.
  - Spacing .... 108 in.
- Vehicle Make /Model .... International 4300 SBA 4X2
  - Curb .... 16,784 lb (MASH Limit 13,200 ± 2,200 lb)
  - Test Inertial .... 21,906 lb (MASH Limit 22,046 ± 660 lb)
  - Gross Static .... 22,052 lb
- Impact Conditions
  - Speed .... 56.6 mph (MASH Limit 56 ± 2.5 mph)
  - Angle .... 15.2 deg. (MASH Limit 15 ± 1.5 degrees)
  - Impact Location .... 11.02 in. US from midspan of post nos. 3 and 4
- Impact Severity .... 161.3 kip-ft > 142 kip-ft MASH limit
- Exit Conditions
  - Speed .... approximately 40.2 mph
  - Angle .... N/A
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 254.9 ft downstream, 32.3 ft in front
- Vehicle Damage .... Moderate
  - VDS [16] 1-RFQ-5
  - CDC [17] 01RFAW4
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 0.9 in.
  - Dynamic .... 1.5 in.
  - Working Width .... 50.8 in.
- Transducer Data

Evaluation Criteria		Transducer			MASH Limits
		SLICE-1 (C.G.)	SLICE-2 (Rear Axle)	TDAS (Cab)	
OIV ft/s	Longitudinal	N/A	N/A	-5.40	not required
	Lateral	N/A	N/A	-16.17	not required
ORA g's	Longitudinal	N/A	N/A	-3.78	not required
	Lateral	N/A	N/A	-5.71	not required
Maximum Angular Displacement deg.	Roll	15.3	16.52	23.0	<¼ Roll
	Pitch	-1.9	2.15	8.7	not required
	Yaw	-15.7	-16.69	17.0	not required
THIV – ft/s		N/A	N/A	13.77	not required
PHD – g's		N/A	N/A	3.23	not required
ASI		0.58	1.72	0.79	not required

N/A – OIV, ORA, PHD and THIV values were only calculated for the vehicle cab accelerometer.

Figure 94. Summary of Test Results and Sequential Photographs, Test No. OCBR-3

9 END BUTTRESS OPTIONS FOR AGT ATTACHMENT

9.1 Overview

Approach guardrail transitions (AGTs) are typically required to connect guardrail to the ends of bridge rails like the TL-4 open concrete bridge rail detailed herein. MwRSF has previously designed 31-in. and 34-in. tall thrie beam AGTs connected to a standardized end buttress [24-25]. It was desired that end buttress options be developed with shape transitions between the open concrete bridge rail and the standardized end buttress in order to facilitate attachment of both 31-in. and 34-in. tall thrie beam AGTs. End buttress options were designed to connect a 31-in. tall thrie beam approach guardrail transition to the 36-in. tall bridge rail configurations. Additionally, it was desired that the 39-in. tall bridge configuration have end buttress options to connect to a 34-in. tall AGT. A geometrical transition was required between the concrete bridge rail and the buttress to limit vehicle snag and maintain vehicle stability. Various options for the end buttress were considered, including a stand-alone concrete buttress and incorporating the prior crashworthy buttress geometry directly into the end post of the bridge rail. These options are presented in the subsequent sections.

9.2 Thrie Beam Approach Guardrail Transitions

Multiple AGT designs have been developed and tested to MASH TL-3 over the years with varying configurations to attach approach guardrail to rigid bridge rail designs. In recent years, the Midwest Pooled Fund Program and MwRSF developed a standardized end buttress design for concrete bridge rails that facilitates safe attachment of a wide variety of AGTs to existing bridge rails [15, 24]. The standardized buttress was designed with a dual taper on its front upstream edge. A longer lower taper was designed to mitigate tire snag below the rail, while a shorter upper taper was designed to prevent vehicle snag and limit the unsupported span length of the rail, as shown in Figure 95. This buttress design was evaluated in combination with a critically weak AGT without a curb, which represented the worst-case scenario. Since the buttress proved crashworthy in this critical configuration, the standardized buttress should remain crashworthy when utilized with other AGTs as the stiffer systems would only reduce vehicle snag. Therefore, the standardized buttress can be used in combination with any thrie beam AGT system that has previously been successfully tested to either NCHRP Report 350 or MASH criteria. These AGTs may be either ¼-post or ½-post spacings (i.e., 18¾-in. and 37½-in. post spacings, respectively). Further, since the standardized buttress was tested without a curb, and curbs tend to reduce tire snag, the standardized buttress can be utilized with these AGTs in either a curbed or non-curbed installation. Finally, a variation of the standardized end buttress has been developed for use with a 34-in. tall AGT to facilitate future overlays. This version of the standardized buttress is identical to the 31-in. tall AGT version other than an increase in the height of the lower taper and the overall buttress, as shown in Figure 96.

For illustrative purposes, the shape transitions between the open concrete bridge rail and the standardized end buttress are presented herein with the two AGT designs previously tested to MASH TL-3 with the standardized buttress. The first thrie beam AGT was a 31-in. tall thrie beam AGT with W6x9 posts at ¼ post spacing connected to a 36-in. tall, standardized buttress configuration, which was successfully crash tested according to MASH TL-3 test designation no. 3-21 [15]. The first post upstream from the end buttress (W6x9) was spaced 8 in. from the edge of the buttress and incorporated an 11-in. tall vertical opening between the thrie beam rail and the ground. The second thrie-beam AGT was the 34-in. tall thrie-beam AGT with W6x15 posts at ½ post spacing connected to a 39-in. tall buttress, which was successfully tested according to MASH TL-3 test designation no. 3-21 [24]. The first post (W6x15) was spaced 25 in. upstream from the upstream edge of the end buttress. The MGS-to-thrie beam transition incorporated a symmetrical W-beam-to-thrie beam transition, and the vertical opening between the rail and ground was 14 in. tall. The 34-in. tall AGT allowed end users to maintain a 31-in. tall AGT when a 3-in. tall wearing surface was implemented.

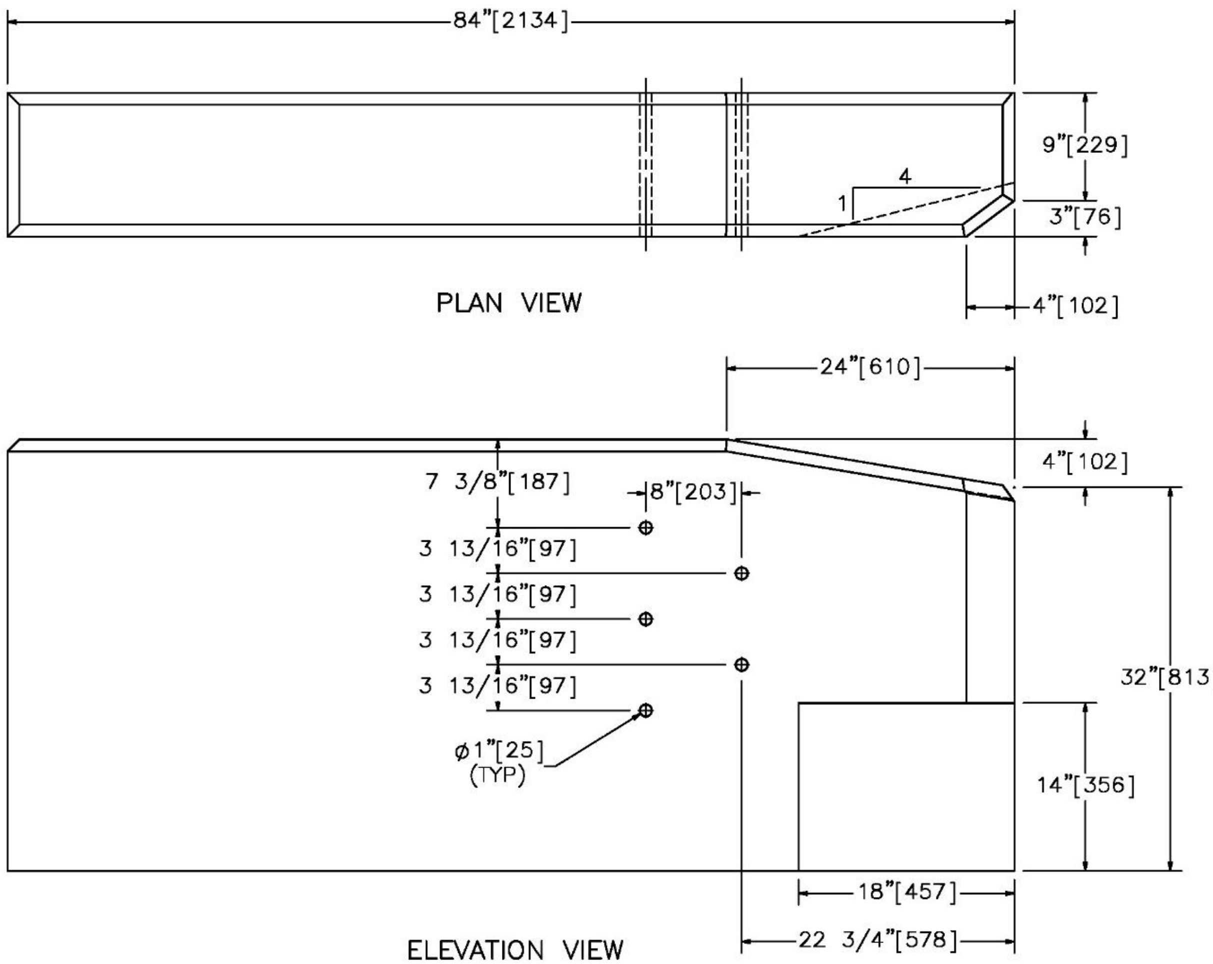
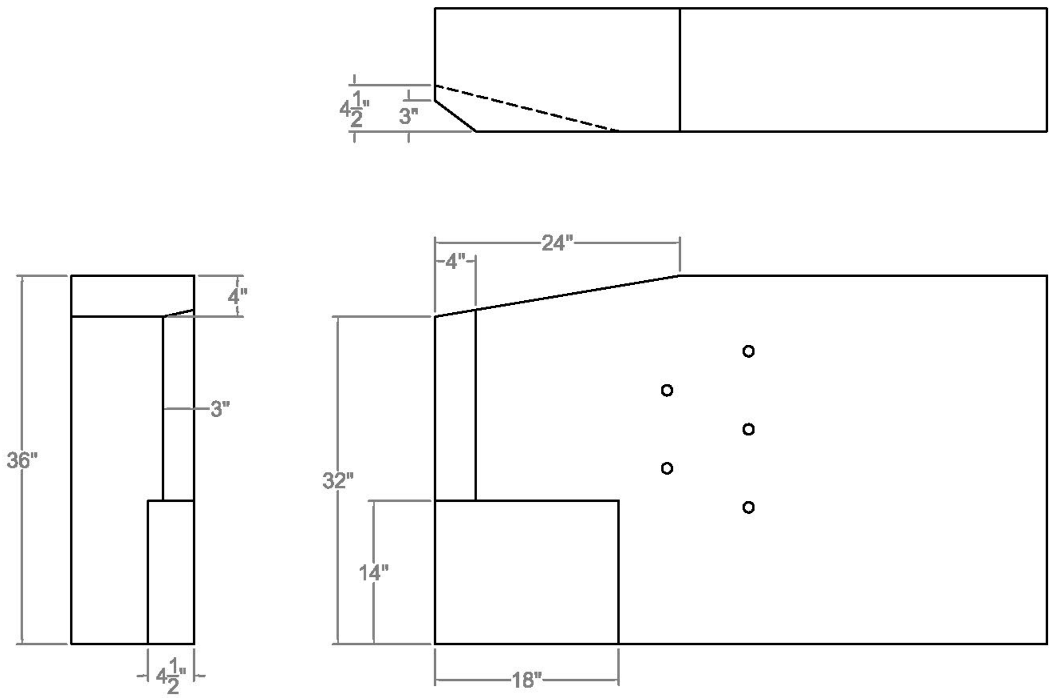
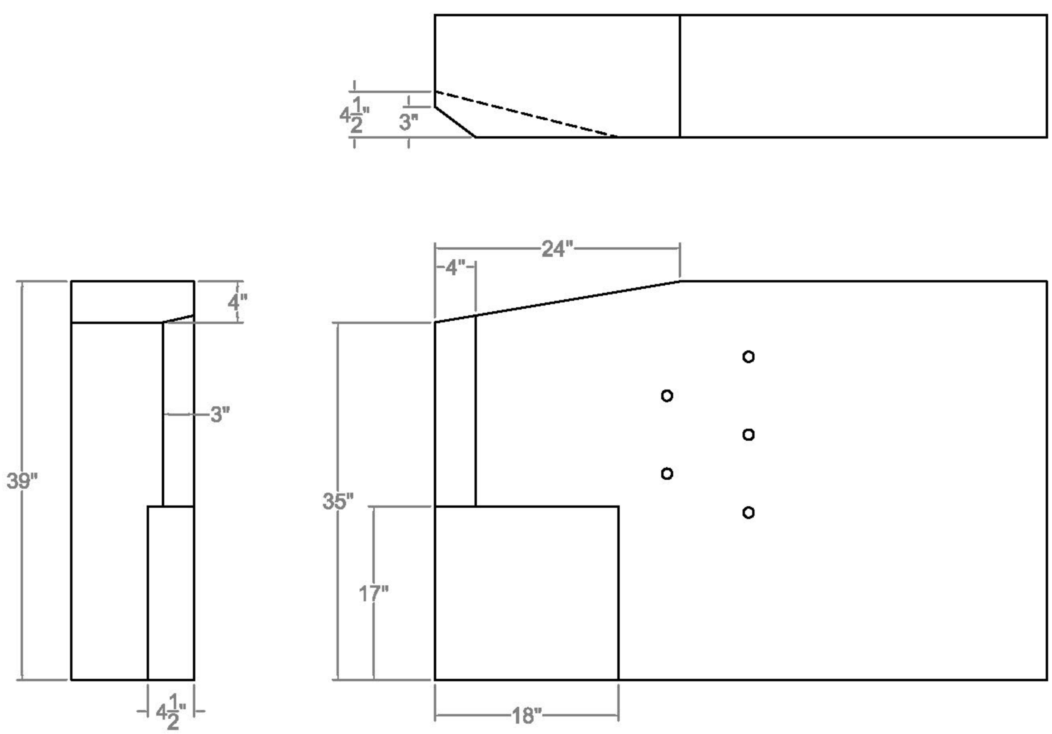


Figure 95. Standardized Buttress AGT System Layout, 31-in. Tall AGT



(a) Standardized Transition Buttress



(b) Modified Transition Buttress for use with the 34-in. Tall AGT

Figure 96. General Shape and Dimensions for (a) the Standardized Transition Buttress and (b) the Modified Buttress for Use with the 34-in. Tall AGT

9.3 Design Loads

Although the end section of the bridge rail was designed to withstand MASH TL-4 design loads, the AGT was designed to withstand MASH TL-3 design loads. It was desired that the AGT attachment be able to withstand at least MASH TL-3 impact loads. Previous research efforts have recommended a MASH TL-3 design load of 70 kips, applied at an effective height of 24 in. [29].

The capacities of the new end buttress configurations were determined by calculating the overturning moment and shear load required to cause failure of the end buttress. A 70-kip design load applied at a height of 24 in. was utilized, resulting in a minimum required moment capacity of 140 kip-ft and shear capacity of 70 kips. The minimum area of steel required to resist moment loads was 6 in.^{2}, and the minimum area of steel required to resist shear loads was only 0.3 in.^{2}, as the large length of the concrete end buttress allowed the concrete to resist majority of the shear load. For end buttress configurations that were designed to be integrated with the end post of the open concrete bridge rail, vertical and longitudinal reinforcement was left the same, but spacings were adjusted as necessary to not interfere with bolt holes of the thrie beam attachment. As the length of the end buttress increases, it is possible that the end buttress will behave similar to a closed concrete parapet and exhibit a yield line failure mechanism. None of the variants designed were of sufficient length to cause this failure, and thus were only designed to resist overturning moment and shear loads.

9.4 End Buttress Foundation

The stand-alone end buttress configurations will each require sufficient anchorage to transfer the impact loads and to prevent overturning of the buttress. The foundation can be provided through an independent concrete foundation or by attaching it to the bridge deck. The transitions with the geometrical transitions incorporated into the bridge rail end post will be anchored directly to the bridge deck ore reinforced concrete approach slab.

9.5 Open Concrete Bridge Rail End Buttress Shape Transition

The end buttress options for the TL-4 open concrete bridge rail applied the same geometry for the upstream end of the buttress as the previously developed standardized end buttress in order to ensure similar performance when the AGT was impacted upstream of the buttress. Thus, the upstream end was configured with a similar 6:1 vertical taper to bring the height of the end buttress down to 1 in. above the thrie beam rail height on the upstream end. The horizontal tapers on the upstream end of the buttress utilized a 4:1 taper on the lower section of the buttress to mitigate wheel snag and a 3-in. deep by 4-in. long chamfer on the upper section of the buttress to mitigate vehicle structure snag and bending of the thrie beam rail element about a sharp corner.

On the downstream end of the open concrete bridge rail end buttress, the buttress geometry was modified to match up with the end post of the concrete bridge rail and mitigate snag and maintain vehicle stability for both oncoming and reverse direction traffic. The vertical height of the downstream end of the end buttress was selected to match the height of the bridge rail beam. The upper face of the end buttress was set in the same plane as the front of the bridge rail beam. The lower section of the downstream end of the buttress was tapered horizontally to match the 4-in. deep post offset from the face of the rail used for the bridge rail post.

To achieve this geometry, horizontal and vertical tapers were applied to the end buttress. A vertical taper of 6:1 was used to transition the buttress height from the AGT attachment end up to the height of the open concrete bridge rail in order to be consistent with the original, crash tested, standardized end buttress geometry. The Roadside Design Guide [26] recommends utilizing lateral flare rates flatter than 20:1 for rigid barrier systems. However, these barrier system flare rates were thought to be extremely conservative when applied to barrier shape changes as many transition buttresses have successfully utilized much steeper lateral tapers. A recent computer simulation study on concrete barrier transitions indicated that lateral slopes up to 6:1 may be crashworthy according to MASH. However, the simulations indicated that both OIV values and occupant compartment deformations to passenger vehicles were approaching the MASH limits. Thus, the study recommended utilizing lateral slopes of 10:1 for rigid barrier shape changes [27]. Based on that research, lateral tapers applied to the end buttress options were limited to 10:1. Finally, it should be noted that the end buttress options were intended for use with a maximum longitudinal gap from the bridge rail of 4 in.

9.6 End Buttress Option 1

End buttress option 1 consisted of an 84-in. long by 12-in. wide standalone end buttress. The upstream end of the buttress matched the standardized end buttress, while the downstream end of the buttress incorporated a 10:1 lateral taper on the lower section of the buttress to match the 4-in. deep offset of the open concrete bridge rail posts. Two versions of the option 1 end buttress were developed to accommodate both the 31-in. tall and 34-in. tall AGT systems discussed previously. The only difference between these two variations was the overall buttress height and the height of the lower tapered sections on the upstream and downstream ends of the buttress. Schematics of end buttress option 1 are shown in Figure 97 through Figure 102.

9.7 End Buttress Option 2

End buttress option 2 consisted of an 88-in. long by 14-in. wide standalone end buttress. This buttress was different from option 1 in that it carried the 4-in. post offset from the bridge rail all the way across the front of the buttress. This eliminated the need for a flare on the downstream end of the buttress adjacent to the bridge rail. Additionally, only a limited portion of the lower portion of the upstream end of buttress had to be flared at a 4:1 slope to match the standardized end buttress geometry. Note that the narrowing of the base of the buttress for option 2 required increasing the width and length of the buttress to meet the design loads. However, the details provided herein are intended as examples, and end users may develop sections with a different length and width that would have the required strength. The critical characteristic is providing the appropriate geometry for the traffic-side face of the buttress that matches the standardized end buttress for AGTs and the open concrete bridge rail. Two versions of the option 2 end buttress were developed to accommodate both the 31-in. tall and 34-in. tall AGT systems discussed previously. The only difference between these two variations was the overall buttress height and the height of the lower offset section of the buttress. Schematics of end buttress option 2 are shown in Figures 103 through 109.

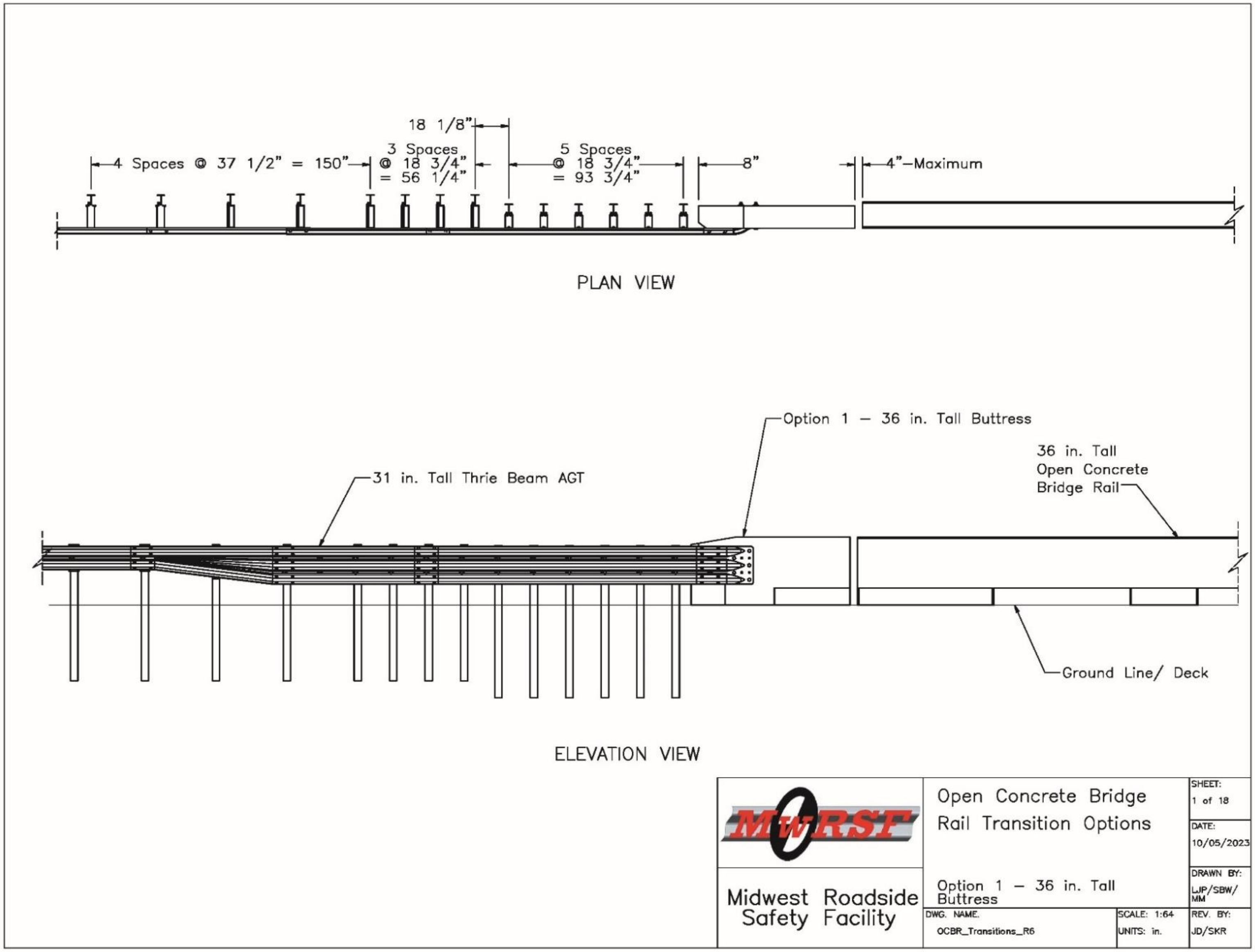


Figure 97. End Buttress Shape Transition, Option 1

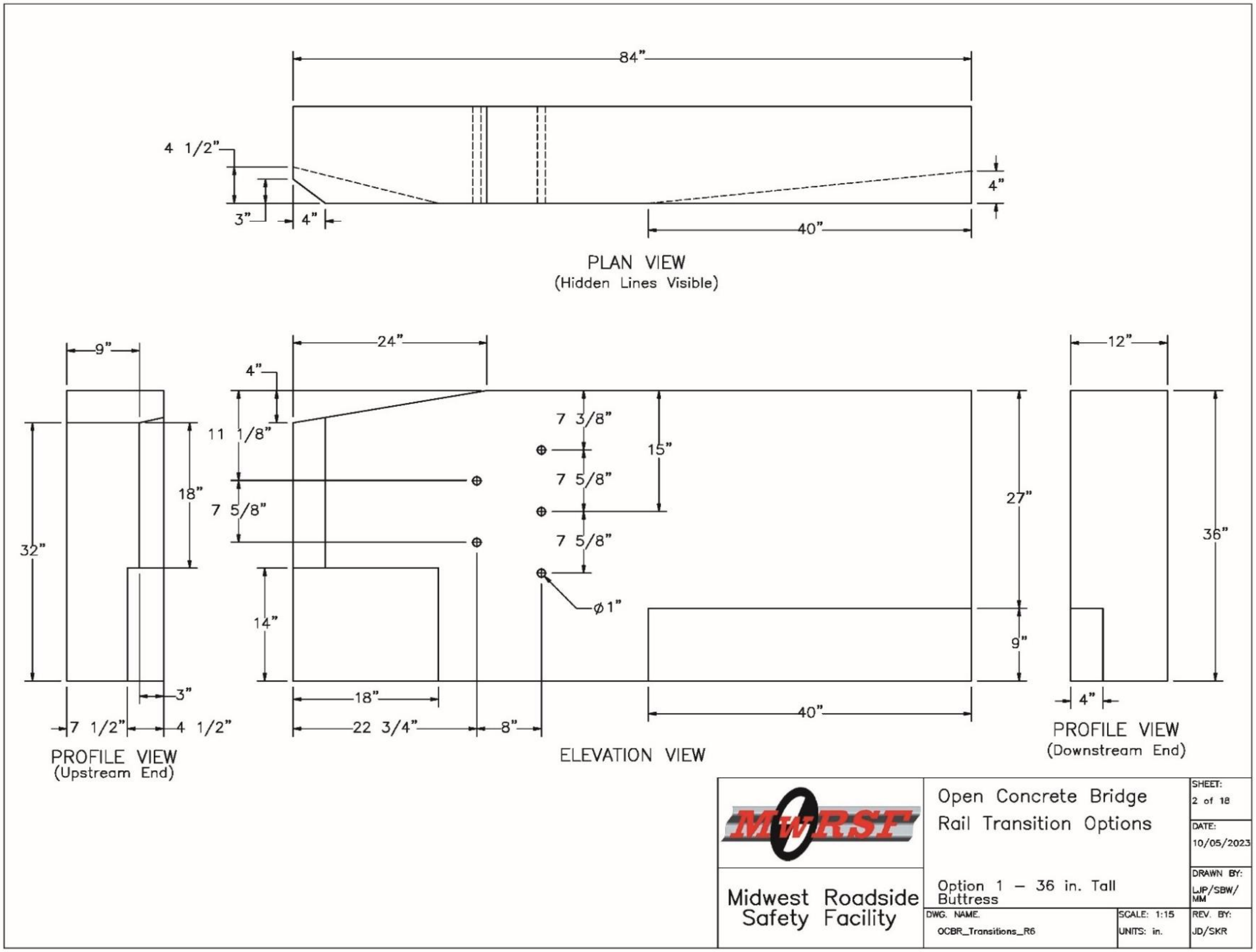


Figure 98. End Buttress Shape Transition, Option 1

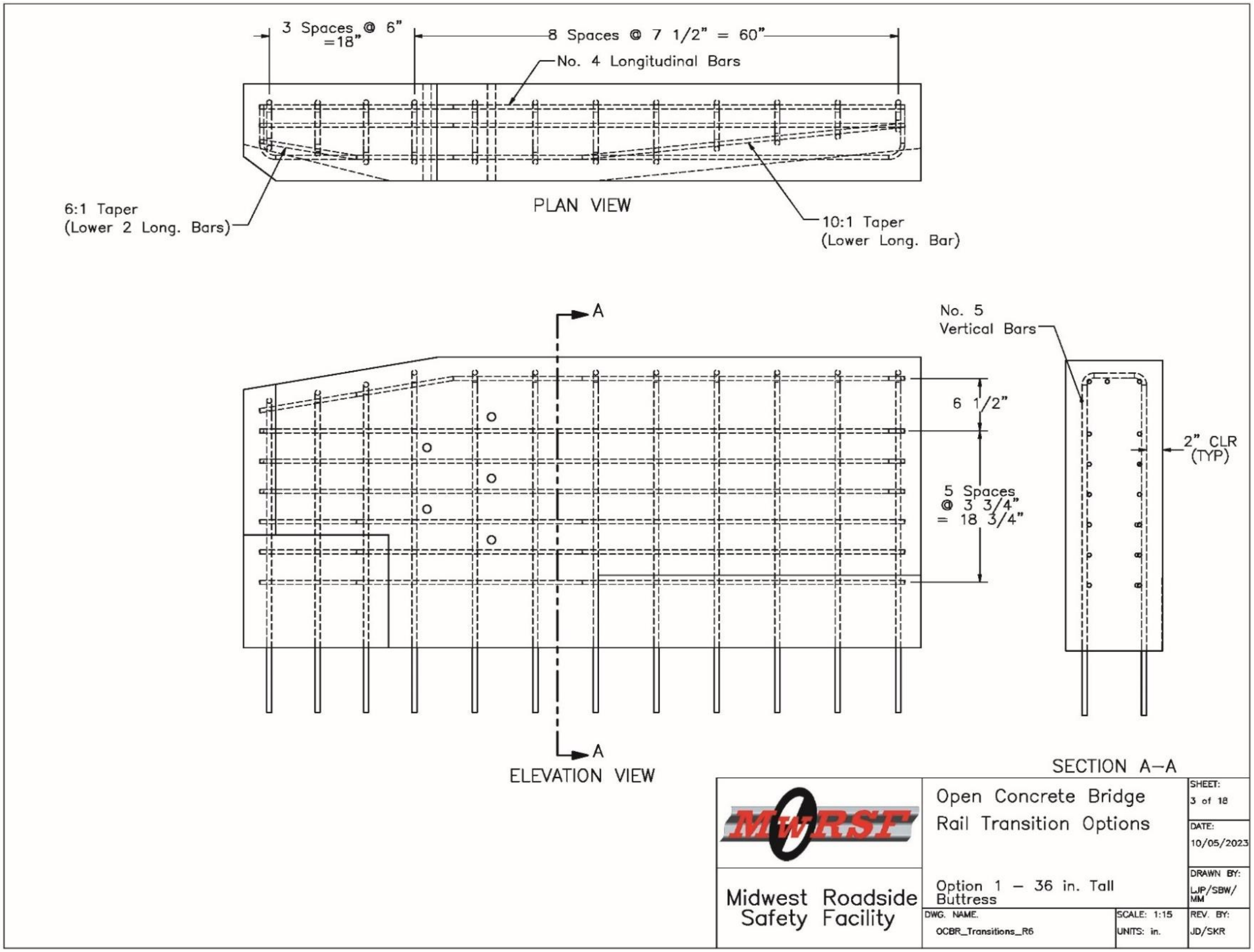


Figure 99. End Buttress Shape Transition, Option 1

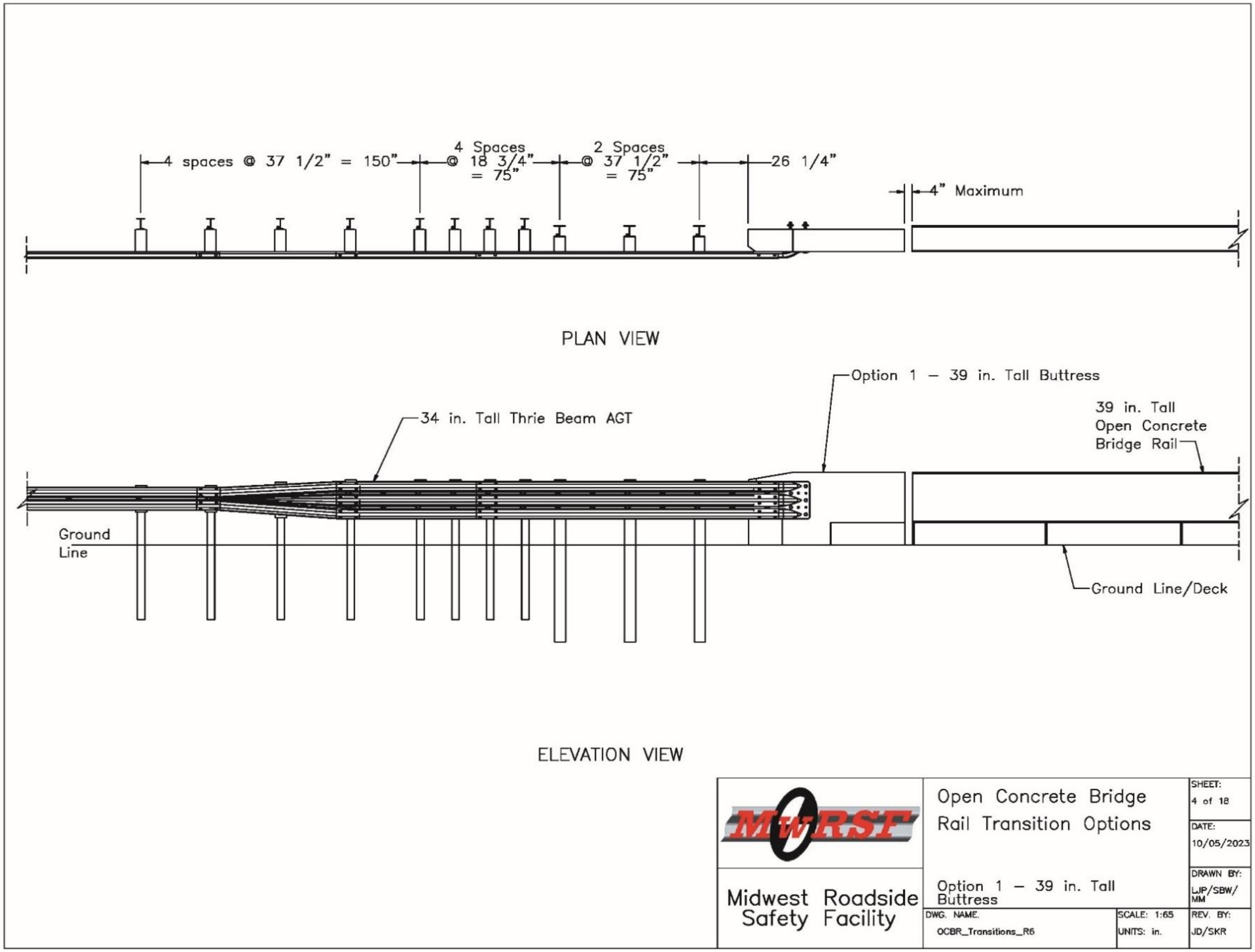


Figure 100. End Buttress Shape Transition, Option 1

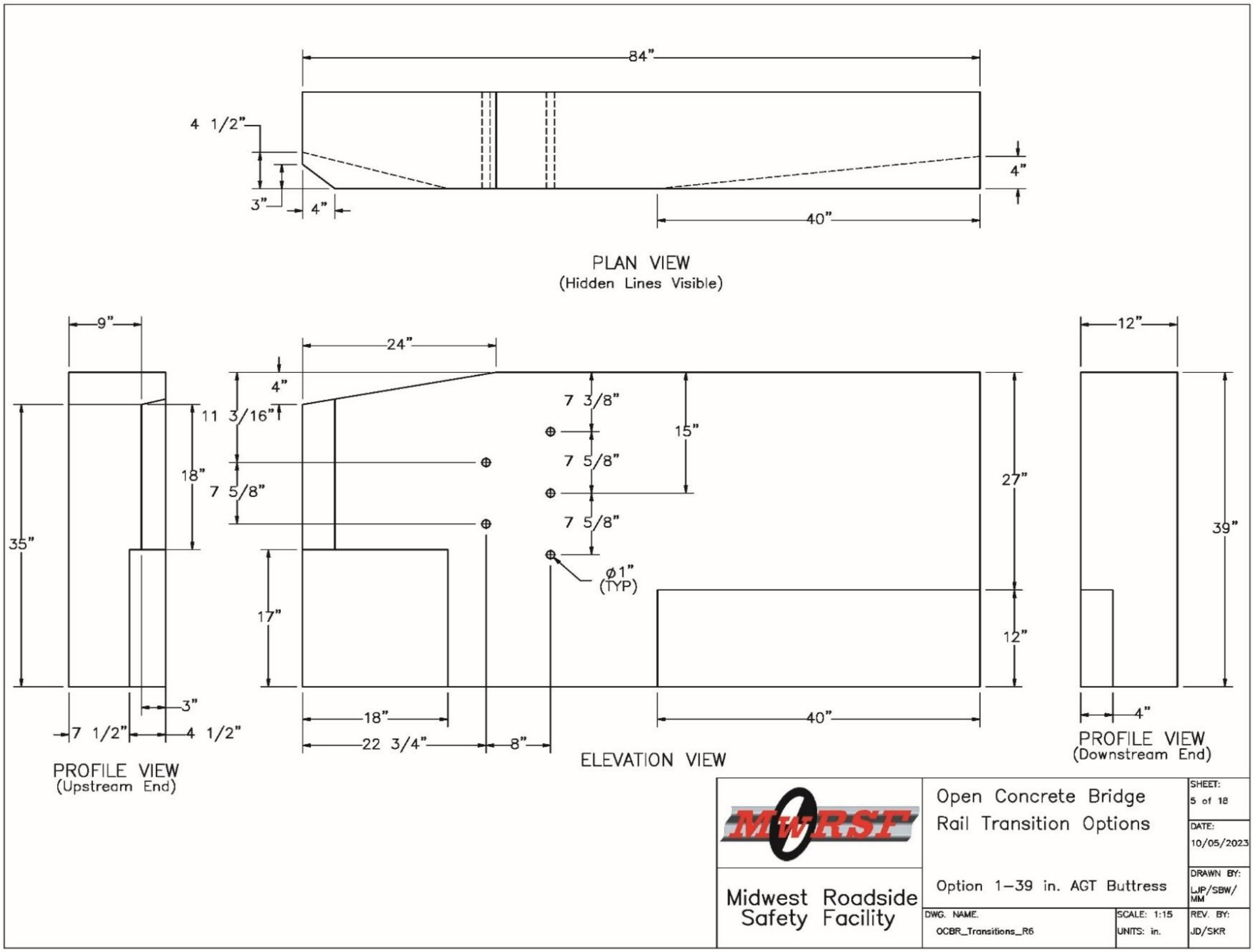


Figure 101. End Buttress Shape Transition, Option 1

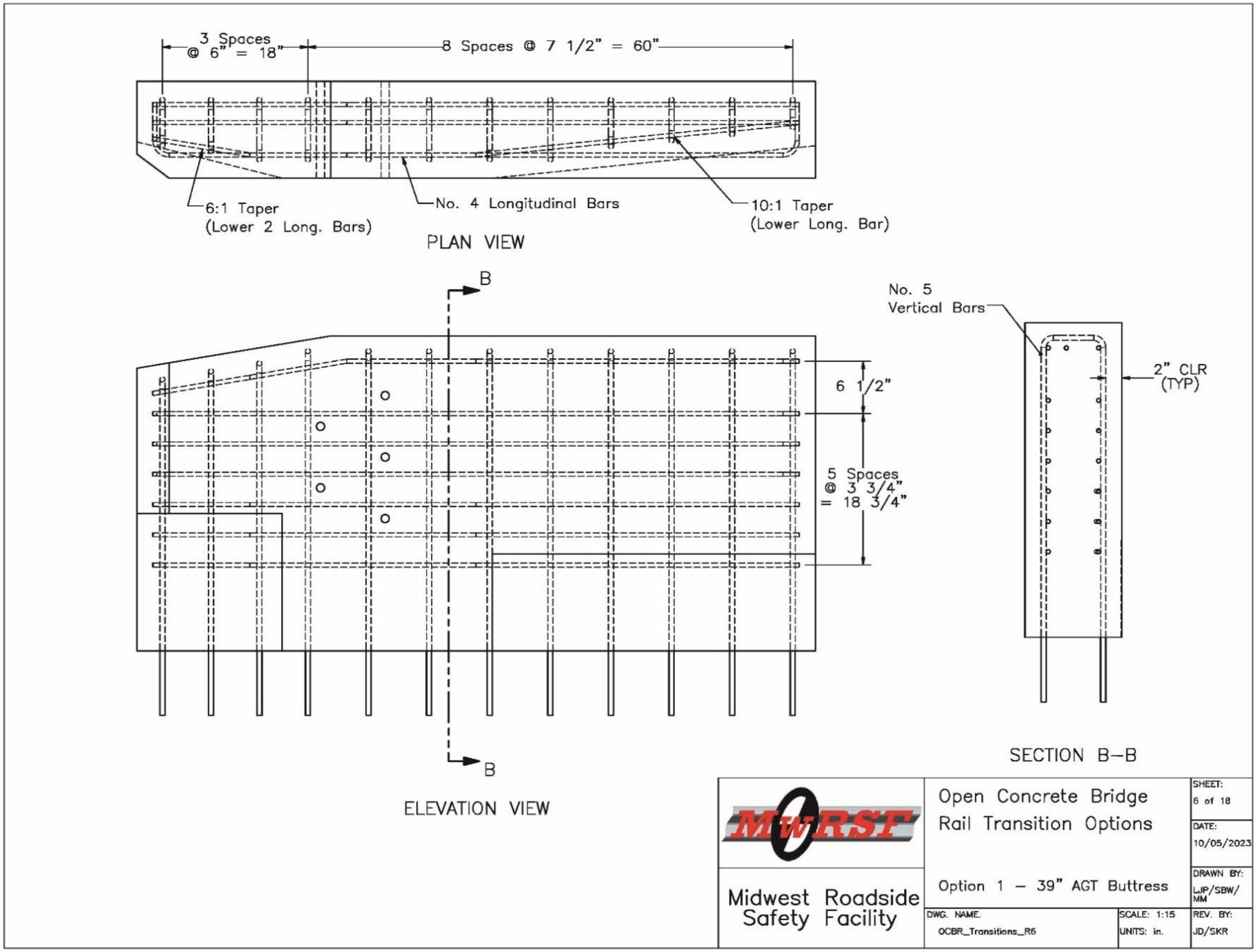


Figure 102. End Buttress Shape Transition, Option 1

9.8 End Buttress Option 3

End buttress option 3 consisted of integrating the standardized end buttress geometry into the end post of the open concrete bridge rail by modification of the upstream end of the of the bridge rail end post to match the standardized end buttress geometry. This required placement of a vertical taper on the upper portion of the upstream end of the bridge rail end post to bring the height of the end post down to match the AGT and reduce the potential for vehicle snag. The length of the post remained 72 in., and the post setback was 4 in. A 4:1 taper section was incorporated above the post setback to match the geometry of the standardized end buttress. Two versions of the option 3 end buttress were developed to accommodate both the 31-in. tall and 34-in. tall AGT systems discussed previously. The only difference between these two variations was the overall buttress height and the height of the lower tapered section on the upstream end of the buttress. Schematics of end buttress option 3 are shown in Figures 110 through Figure 114.

9.9 Summary

Three end buttress options were developed that could be utilized with the new open concrete bridge rail, and each configuration provides examples of the basic geometry and reinforcement configurations that end users could potentially utilize. Lengths and widths of the end buttresses, as well as reinforcement sizes and spacings can be varied, provided the geometric requirements and strength requirements are satisfied. A foundation for the end buttress must be designed or considered into the bridge deck design.

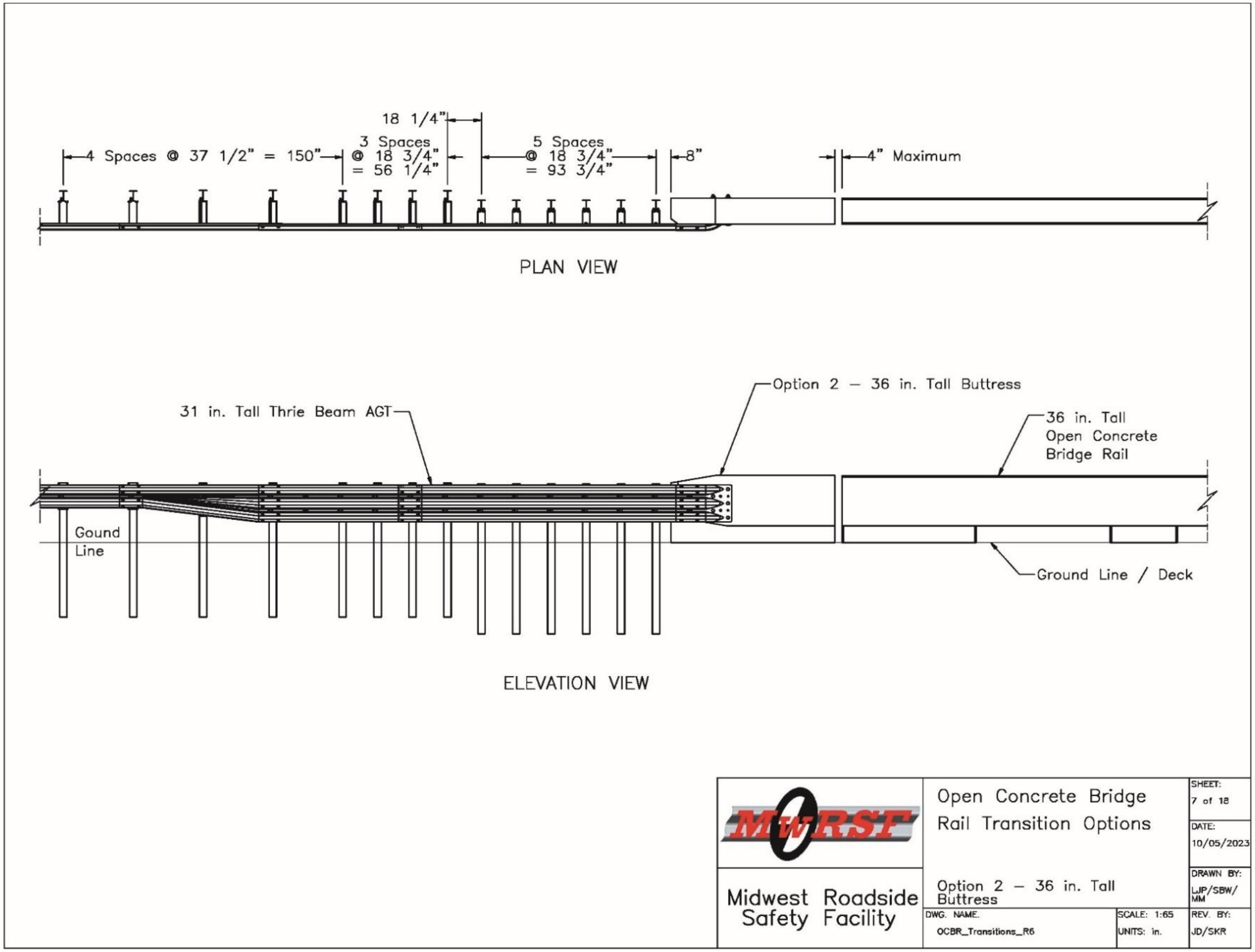


Figure 103. End Buttress Shape Transition, Option 2

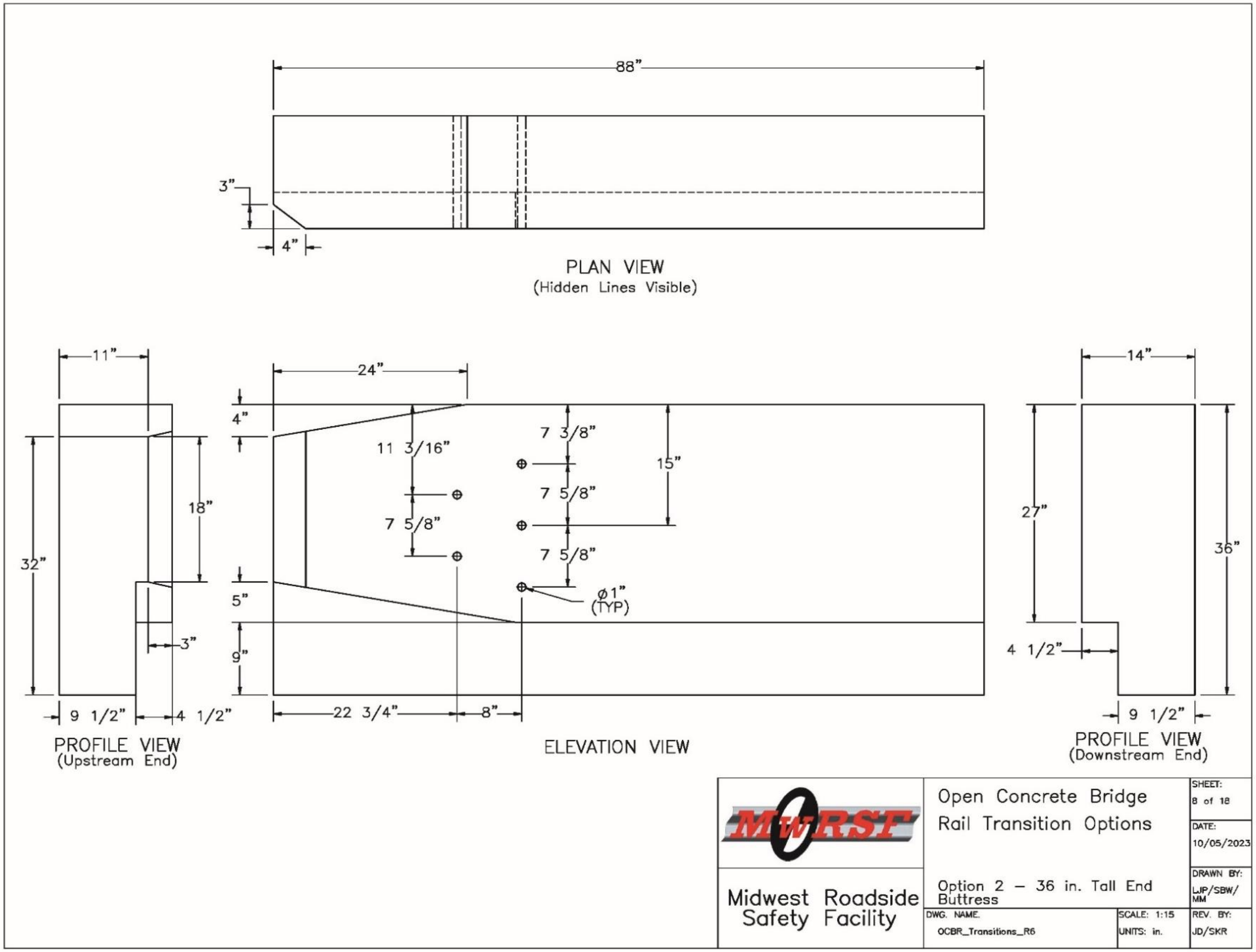


Figure 104. End Buttress Shape Transition, Option 2

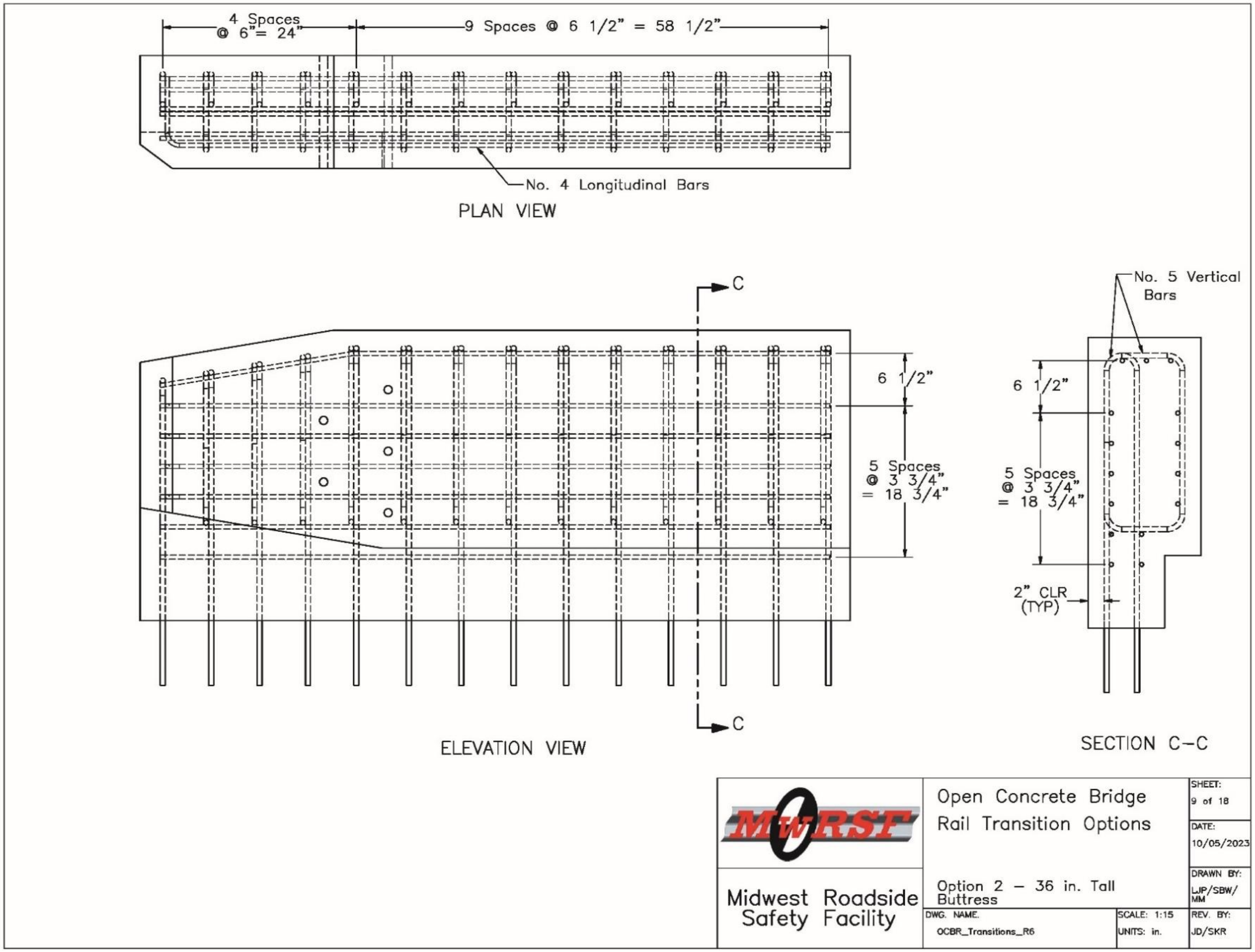


Figure 105. End Buttress Shape Transition, Option 2

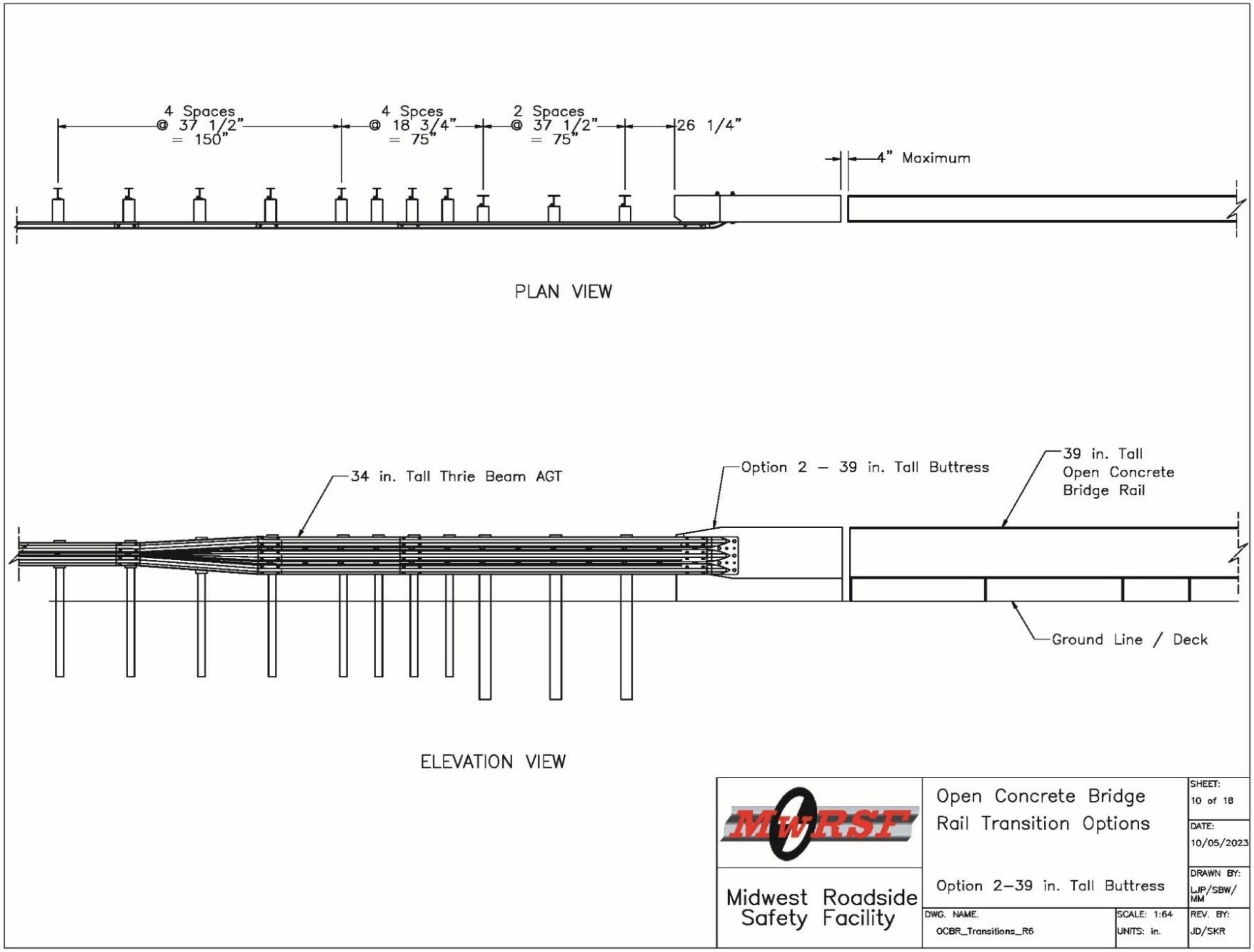


Figure 106. End Buttress Shape Transition, Option 2

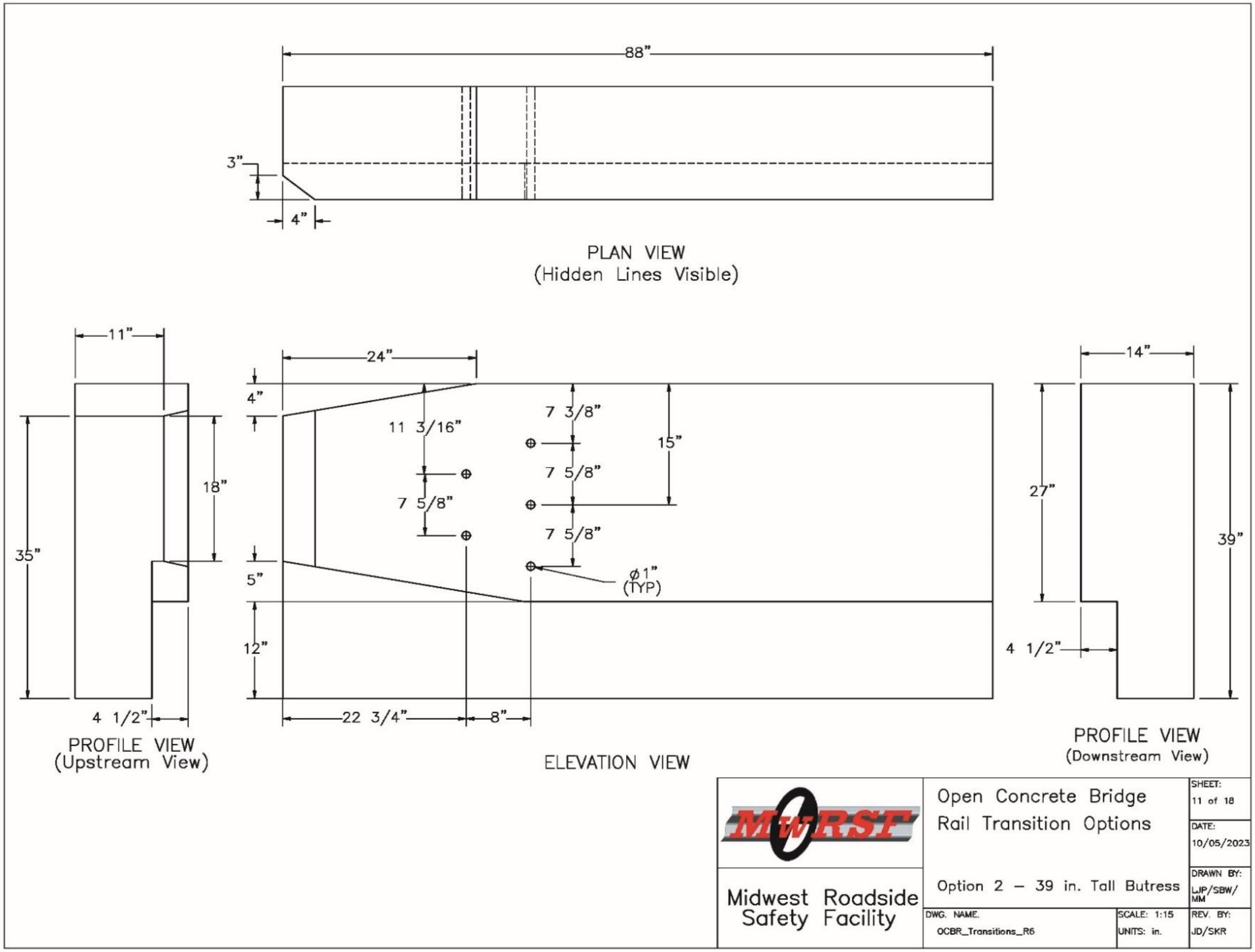


Figure 107. End Buttress Shape Transition, Option 2

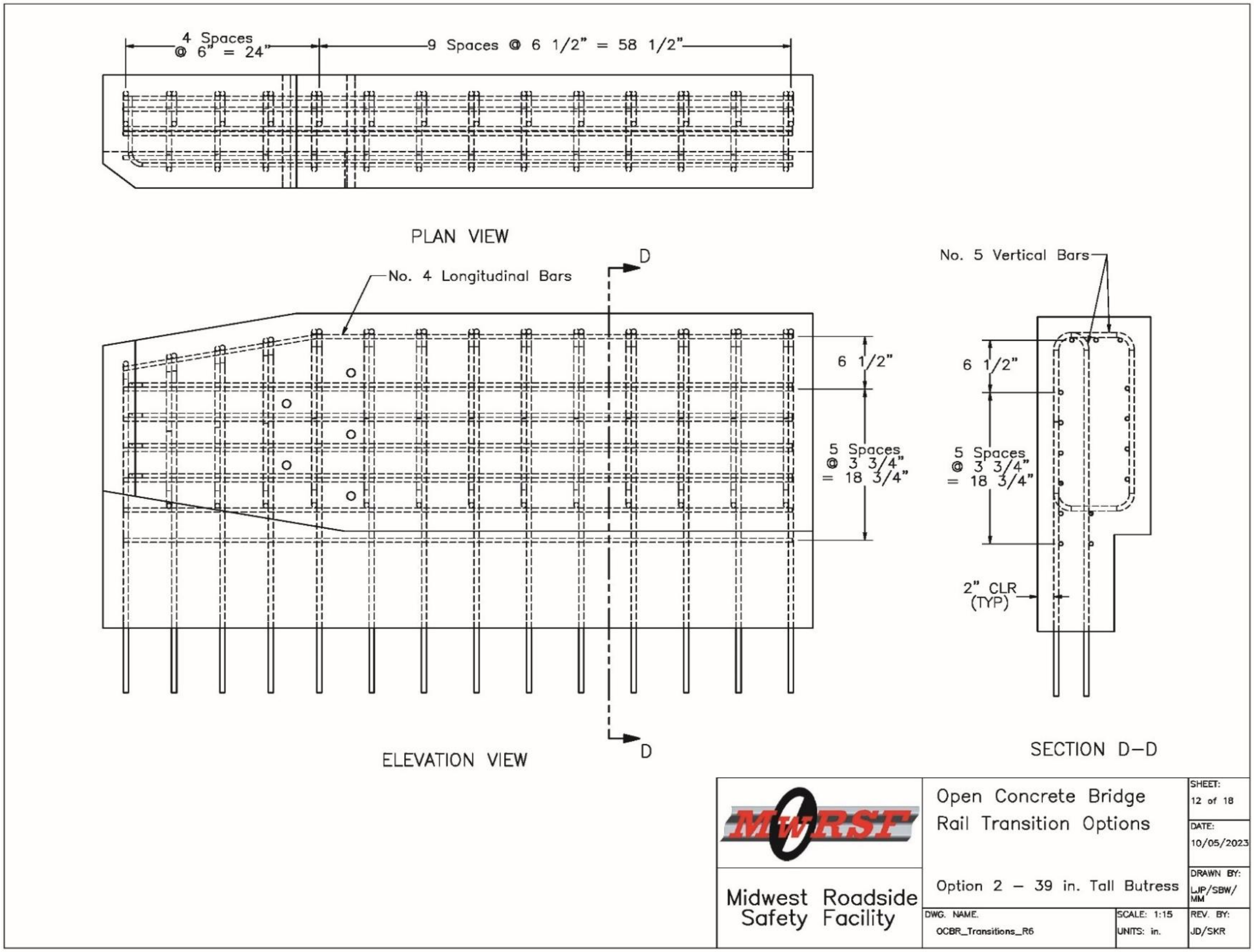


Figure 108. End Buttress Shape Transition, Option 2

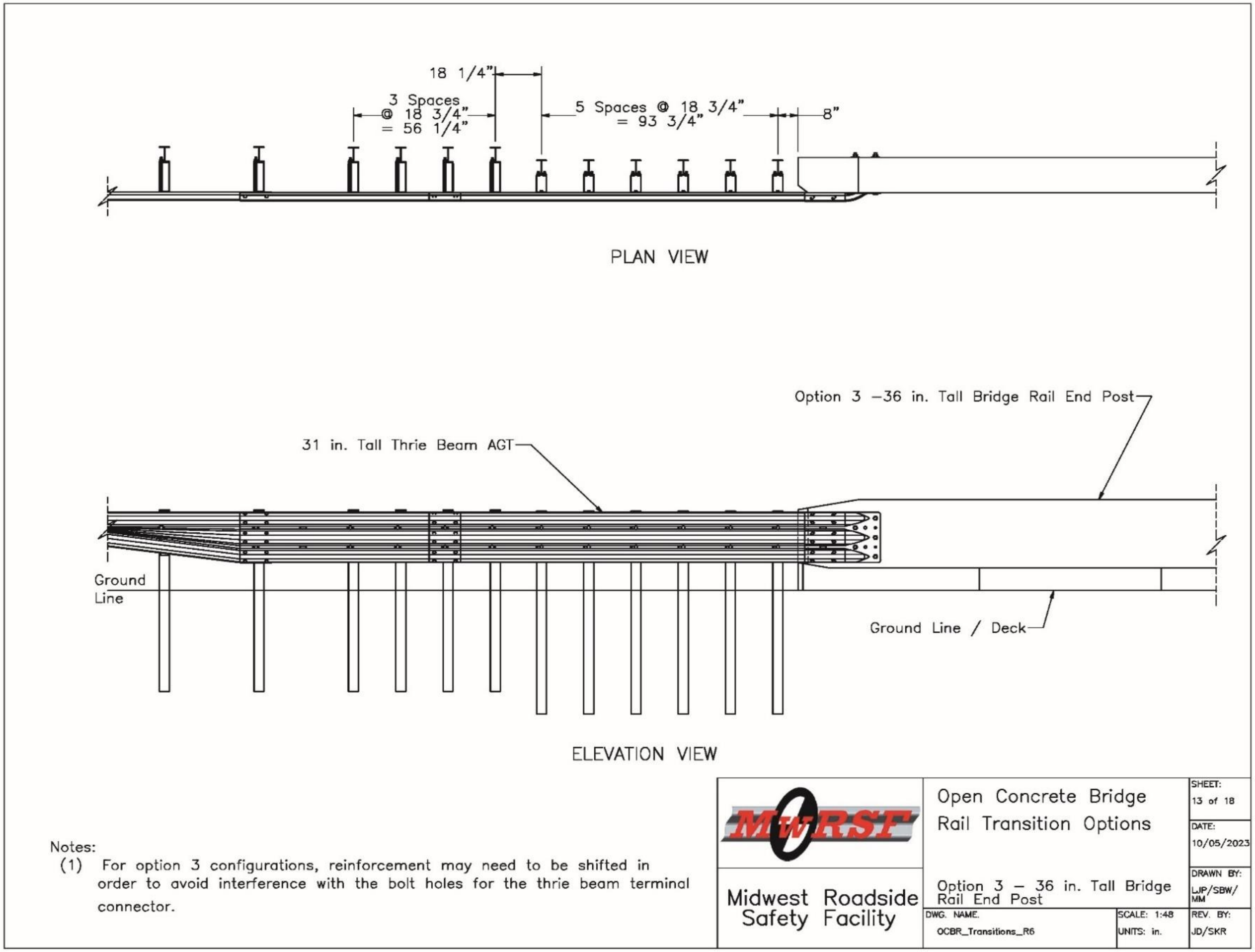


Figure 109. End Buttress Shape Transition, Option 3

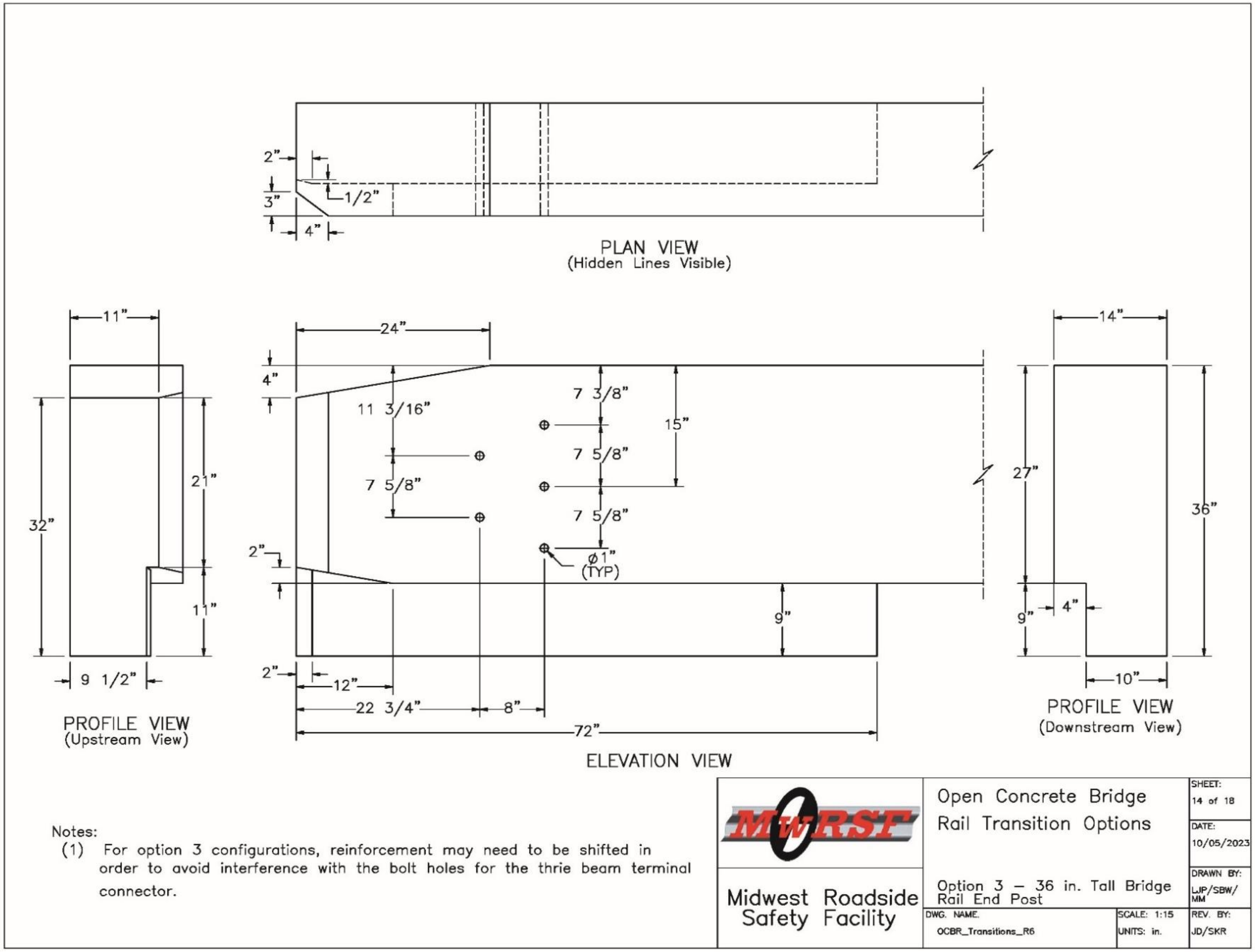


Figure 110. End Buttress Shape Transition, Option 3

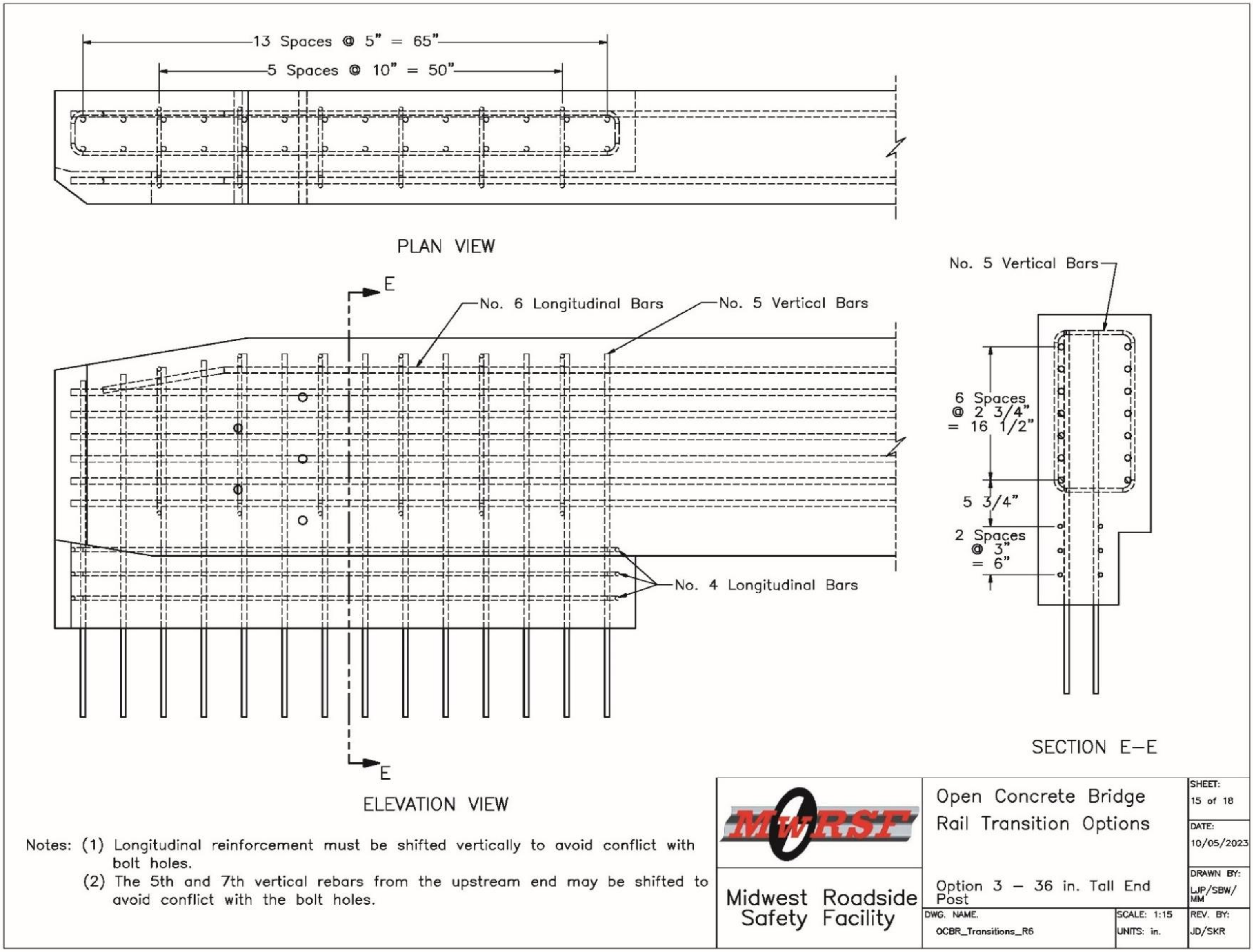


Figure 111. End Buttress Shape Transition, Option 3

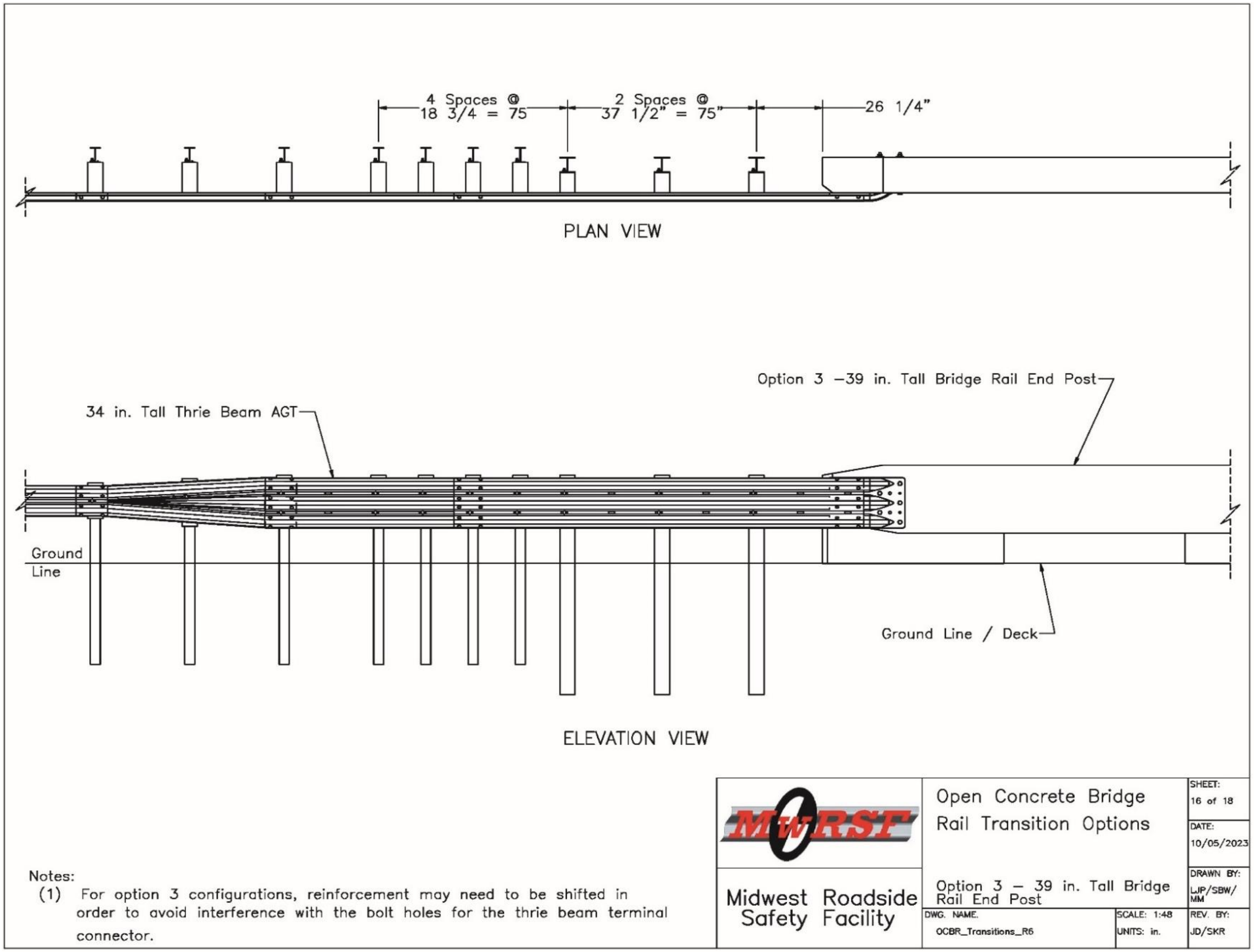


Figure 112. End Buttress Shape Transition, Option 3

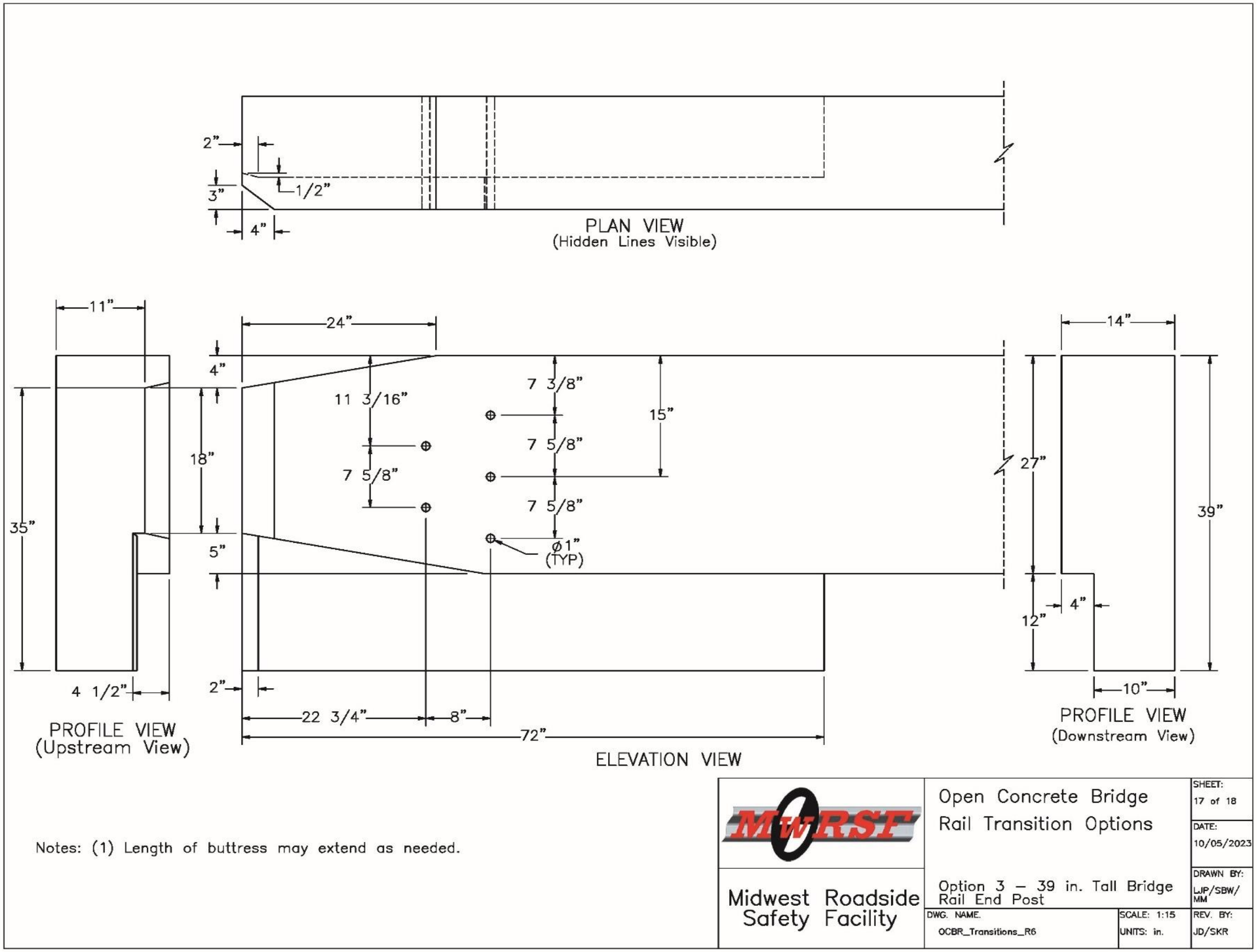


Figure 113. End Buttress Shape Transition, Option 3

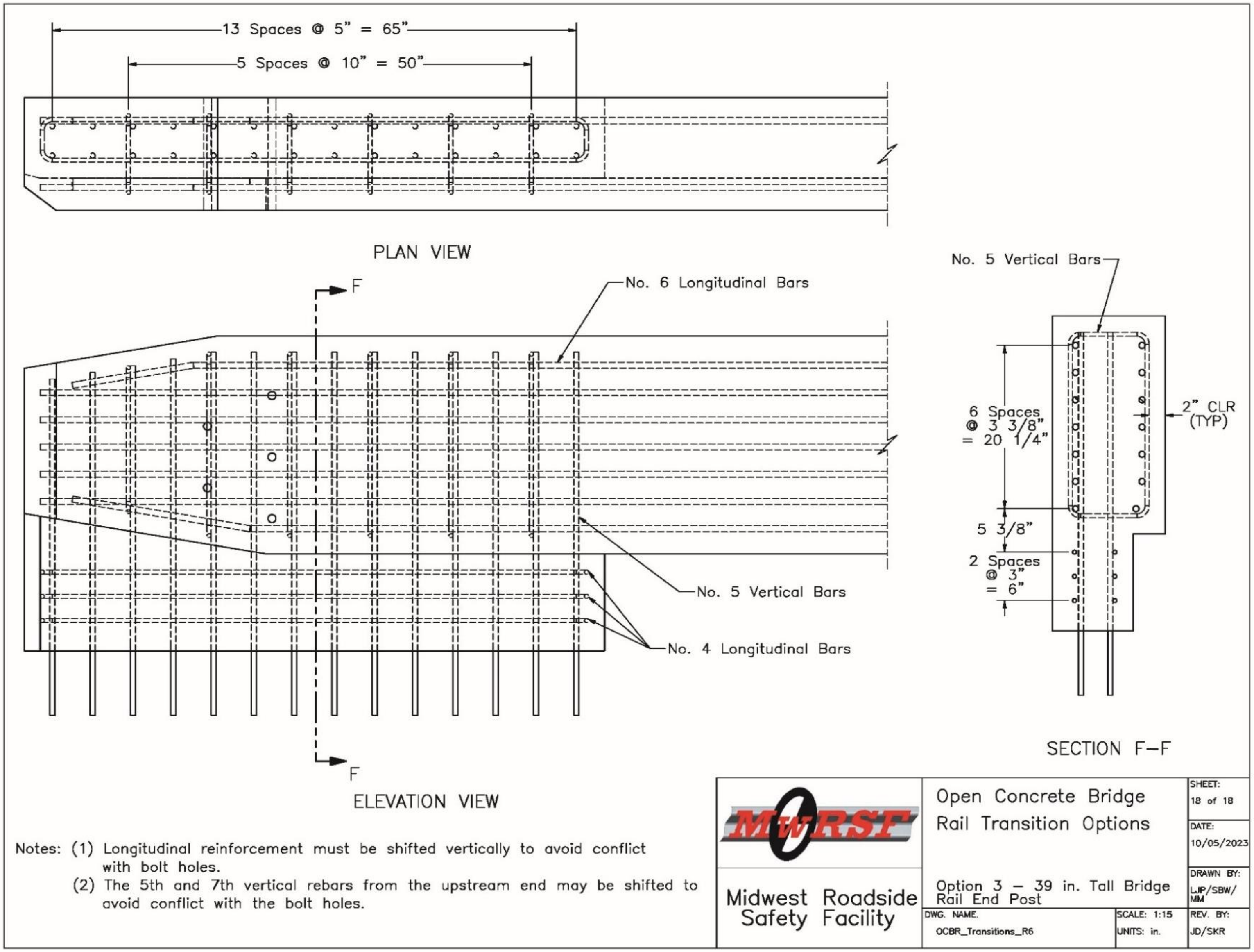


Figure 114. End Buttress Shape Transition, Option 3

10 SUMMARY AND CONCLUSIONS

The focus of this research effort was the MASH TL-4 evaluation of a new open concrete bridge rail design. The proposed design for the new open concrete bridge rail was a 39-in. tall bridge rail system comprised of a 27-in. tall by 14-in. wide concrete rail supported by 36-in. long by 10-in. wide by 12-in. tall concrete posts. The 39-in. rail height was selected to allow for future 3-in. paving overlays while still maintaining MASH TL-4 compliance. The barrier system was designed for a minimum bridge deck thickness of 8 in. and a maximum 5-ft long cantilevered overhang. Design details were developed for the interior and end section reinforcement for both the bridge rail and the deck. Three full-scale crash tests were conducted on the open concrete bridge rail according to MASH test designation nos. 4-10, 4-11, and 4-12.

Test no. OCBR-1 was conducted according to MASH test designation no. 4-10. In test no. OCBR-1, an 1100C vehicle impacted the open concrete bridge rail system at a speed of 64.2 mph, an angle of 25.2 degrees, and at a location 45.3 in. upstream from post no. 11. The vehicle was successfully contained and redirected with moderate damage to the vehicle and minimal damage to the barrier. All occupant risk measures fell within the recommended safety limits established in MASH. Therefore, test no. OCBR-1 was successful according to the safety criteria of MASH test designation no. 4-10.

Test no. OCBR-2 was conducted according to MASH test designation no. 4-11. In test no. OCBR-2, a 2270P vehicle impacted the open concrete bridge rail system at a speed of 61.8 mph, an angle of 24.7 degrees, and at a location 53.2 in. upstream from the upstream edge of post no. 7. The vehicle was successfully contained and redirected with moderate damage to the vehicle and minimal damage to the barrier. All occupant risk measures fell within the recommended safety limits established in MASH. Therefore, test no. OCBR-2 was successful according to the safety criteria of MASH test designation no. 4-11.

Test no. OCBR-3 was conducted according to MASH test designation no. 4-12. In test no. OCBR-3, a 10000S vehicle impacted the open concrete bridge rail system at a speed of 56.6 mph, an angle of 15.2 degrees, and at a location 11 in. upstream from the midspan of posts 3 and 4. The vehicle was successfully contained and redirected with moderate damage to the vehicle and the barrier. All occupant risk measures fell within the recommended safety limits established in MASH. Therefore, test no. OCBR-3 was successful according to the safety criteria of MASH test designation no. 4-12.

Although the full-scale crash test was conducted on the bridge railing interior section, the end section of the open concrete bridge rail was designed with an increased post length and increased reinforcement of the bridge rail and corresponding bridge deck. The strength of this end section design was shown to be greater than that of the tested interior section using AASHTO recommended evaluation methods [7, 28]. As such, the open concrete bridge rail end sections should also be considered MASH TL-4 crashworthy. Note that end section geometry and reinforcement should be used adjacent to any railing discontinuity or expansion/contraction gap.

Finally, the new bridge railing was developed with a nominal height of 39 in. to account for future roadway overlays up to 3 in. thick and still satisfy the 36-in. minimum height requirement for MASH TL-4 barriers. The bridge rail was tested and evaluated in a critical configuration without a 3-in. overlay placed on the deck in order to maximize loading and moment demands on the system and increase the potential for passenger vehicle snag on the bridge rail posts. Based on the successful full-scale crash tests of the open concrete bridge rail at the upper range of the rail height, it is believed that the railing should be considered crashworthy at heights between 36 and 39 in. Therefore, the new concrete bridge rail was determined to be crashworthy to MASH TL-4 standards at its nominal height of 39 in. and after roadway overlays up to 3 in. thick. The researchers provided options for end buttresses at the end of the bridge rail for the attachment of AGTs for both bridge rail height options.

Table 15. Summary of Safety Performance Evaluation.

Evaluation Factors		Evaluation Criteria			Test No. OCBR-1	Test No. OCBR-2	Test No. OCBR-3
Structural Adequacy	A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.			S	S	S
Occupant Risk	D.	1. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.			S	S	S
		2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.			S	S	S
	F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.			S	S	S
	H.	Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:			S	S	S
		Occupant Impact Velocity Limits					
		Component	Preferred	Maximum			
		Longitudinal and Lateral	30 ft/s	40 ft/s			
	I.	The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:			S	S	S
		Occupant Ridedown Acceleration Limits					
		Component	Preferred	Maximum			
		Longitudinal and Lateral	15.0 g's	20.49 g's			
MASH 2016 Test Designation No.					4-10	4-11	4-12
Final Evaluation (Pass or Fail)					Pass	Pass	Pass

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

11 MASH EVALUATION

A new open concrete bridge rail was evaluated according to MASH TL-4 performance criteria. The open concrete bridge rail system was a 39-in. tall bridge rail system comprised of a 27-in. tall by 14-in. wide concrete rail supported by 36-in. long by 10-in. wide by 12-in. tall concrete posts. The 39-in. rail height was selected to allow for future 3-in. paving overlays while still maintaining a 36-in. nominal height for MASH TL-4 compliance. The barrier system was designed for a minimum bridge deck thickness of 8 in. and a maximum 5-ft long cantilevered overhang. Design details were developed for the interior and end section reinforcement for both the bridge rail and the deck.

11.1 Test Matrix

The open concrete bridge rail system is classified as a longitudinal barrier for the purposes of evaluation. According to TL-4 of MASH, longitudinal barrier systems must be subjected to three full-scale vehicle crash tests, as summarized in Table 16.

Table 16. MASH TL-4 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight lb	Impact Conditions		Evaluation Criteria [1]
				Speed mph	Angle deg.	
Longitudinal Barrier	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 explained in Table 2.

Test designation no. 4-10 with the 1100C vehicle was conducted to evaluate occupant risk measures and the potential for vehicle snag on the upstream end of posts. Test designation no. 4-11 with the 2270P vehicle was conducted to evaluate concerns for increased bridge rail loading, potential vehicle snag at joints and posts, and vehicle instability. Test designation no. 4-12 with the 10000S vehicle was conducted to evaluate the overall structural capacity of the bridge rail and its ability to contain and redirect the single-unit truck. Due to the variable height of the bridge rail between 36 in. and 39 in., the bridge rail configuration utilized for testing was selected to be critical for each test. Thus, the 39-in. rail height without a 3-in. overlay was selected for all crash tests to maximize loading and moment demands on the system during the single-unit truck test and to increase the potential for passenger vehicle snag on the bridge rail posts. It should also be noted that the researchers considered both interior and end section impact locations as part of the critical impact point selection. During the design of the open concrete rail, the end sections of the bridge rail and deck were designed with greater capacity than the interior sections. As such, the critical impact was conducted on an interior region of the bridge rail. Finally, critical impact points for the two passenger vehicle tests were selected to maximize the potential for vehicle snag on the exposed bridge rail posts, while the critical impact point for the single-unit truck test was selected to maximize the loading of the bridge rail.

11.2 Full-Scale Crash Test Results

The results of the MASH TL-3 full-scale crash testing of the open concrete bridge rail system are summarized below. A summary of the full-scale crash testing is provided in Table 17. A plan and elevation view of the final system and a system photo are shown in Figure 115.

1. Test no. OCBR-1 - Test no. OCBR-1 was conducted according to MASH test designation no. 4-10. In test no. OCBR-1, an 1100C vehicle impacted the open concrete bridge rail system at a speed of 64.2 mph and an angle of 25.2 degrees, and at a location 45.3 in. upstream from post no. 11. The vehicle was successfully contained and redirected with moderate damage to the vehicle and minimal damage to the barrier. All occupant risk measures fell within the recommended safety limits established in MASH. Therefore, test no. OCBR-1 was successful according to the safety criteria of MASH test designation no. 4-10.

2. Test on. OCBR-2 - Test no. OCBR-2 was conducted according to MASH test designation no. 4-11. In test no. OCBR-2, a 2270P vehicle impacted the open concrete bridge rail system at a speed of 61.8 mph and an angle of 24.7 degrees, and at a location 53.2 in. upstream from the upstream edge of post no. 7. The vehicle was successfully contained and redirected with moderate damage to the vehicle and minimal damage to the barrier. All occupant risk measures fell within the recommended safety limits established in MASH. Therefore, test no. OCBR-2 was successful according to the safety criteria of MASH test designation no. 4-11.

3. Test no. OCBR-3 - Test no. OCBR-3 was conducted according to MASH test designation no. 4-12. In test no. OCBR-3, a 10000S vehicle impacted the open concrete bridge rail system at a speed of 56.6 mph and an angle of 15.2 degrees, and at a location 11 in. upstream from the midspan of posts 3 and 4. The vehicle was successfully contained and redirected with moderate damage to the vehicle and the barrier. All occupant risk measures fell within the recommended safety limits established in MASH. Therefore, test no. OCBR-3 was successful according to the safety criteria of MASH test designation no. 4-12.

Table 17. MASH TL-4 Crash Test Summary for Open Concrete Bridge Rail

MwRSF Test No.	MASH Test Designation No.	MwRSF Report No.	Date of Test	Pass/Fail	System Version
OCBR-1	4-10	TRP-03-389-20	10/06/21	Pass	39-in. Tall Bridge Rail
OCBR-2	4-11	TRP-03-389-20	12/16/21	Pass	39-in. Tall Bridge Rail
OCBR-3	4-12	TRP-03-389-20	03/04/22	Pass	39-in. Tall Bridge Rail

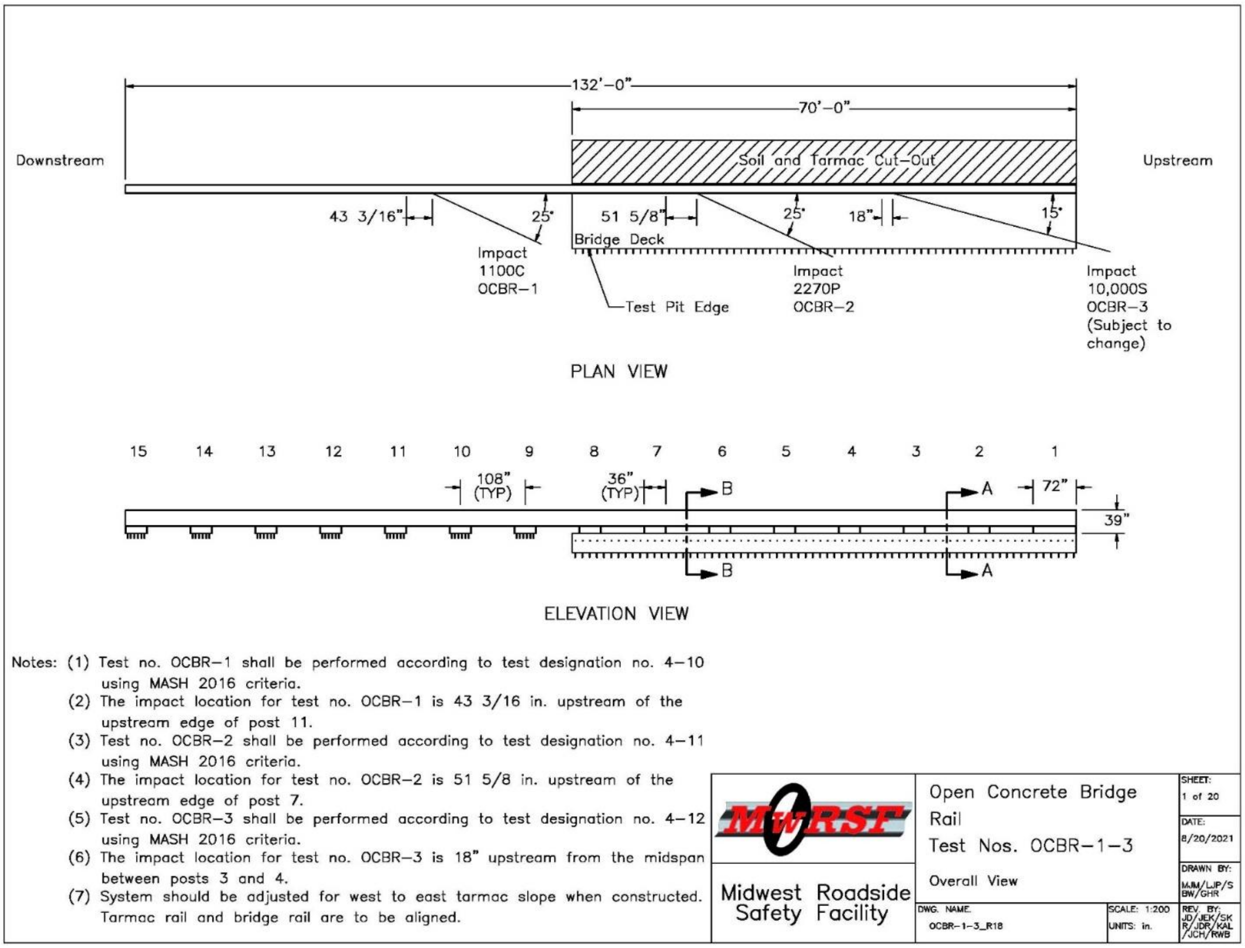


Figure 115. MASH TL-4 Open Concrete Bridge Rail

11.3 MASH 2016 Evaluation

Based on the results of the three successful full-scale crash tests conducted in this research effort, the open concrete bridge rail system meets all the safety requirements for MASH TL-4.

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13 APPENDICES

Appendix A. Material Specifications

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

Item No.	Description	Material Specification	Reference
a1	Bridge Deck Concrete	Min. f'c = 4,000 psi NE Mix 47B1S/1PF4000HW	Ticket No. #1267134, #1267135, #1267132
a2	Bridge Rail Concrete	Min. f'c = 4,000 psi NE Mix 47B1S/1PF4000HW	Ticket No #1270201, #1270204, #1270203
a3	Grade Beam Concrete	Min. f'c = 4,000 psi NE Mix 47B1S/1PF4000HW	Inv #HI-600351
b1	#4 Rebar, 147½" Total Unbent Length	ASTM A615 Gr. 60	H#3600014739
b2	#5 Rebar, 53 7/16" Total Unbent Length	ASTM A615 Gr. 60	H#62150922
b3	#5 Rebar, 154¾" Total Unbent Length	ASTM A615 Gr. 60	H#62150922
b4	#5 Rebar, 30" Total Length	ASTM A615 Gr. 60	H#62150922
b5	#4 Bent Rebar, 836" Total Unbent Length	ASTM A615 Gr. 60	H#6015833
b6	#6 Rebar, 37½" Total Length	ASTM A615 Gr. 60	H#62150922
b7	#4 Bent Rebar, 73⅞" Total Unbent Length	ASTM A615 Gr. 60	H#7006848
b8	#4 Bent Rebar, 87" Total Unbent Length	ASTM A615 Gr. 60	H#3600012482
b9	#6 Rebar, 1580" Total Length	ASTM A615 Gr. 60	H#3600013486
b10	#4 Bent Rebar, 82⅜" Total Unbent Length	ASTM A615 Gr. 60	H#7006848
b11	#4 Bent Rebar, 154⅜" Total Unbent Length	ASTM A615 Gr. 60	H#3600014740
b12	#5 Rebar, 155⅝" Total Unbent Length	ASTM A615 Gr. 60	H#62150922
b13	#6 Rebar, 176¼" Total Length	ASTM A615 Gr. 60	H#3600013486
b14	#5 Rebar, 45" Total Length	ASTM A615 Gr. 60	H#9700006936
b15	#4 Rebar, 46" Total Length	ASTM A615 Gr. 60	H#7006848
b16	#4 Bent Rebar, 35" Total Unbent Length	ASTM A615 Gr. 60	H#7006848
b17	#4 Bent Rebar, 38½" Total Unbent Length	ASTM A615 Gr. 60	H#7006848

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	240	9419	62461		NTE	OCBR	7/12/21	9 40 AM	1267132

Customer	Delivery Address	Special Instructions
UNL-MIDWEST ROADSIDE SAFETY	4630 NW 36TH ST	AIRPARK / NORTH OF OLD GOODYEARHANGERS

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
9.00	9.00	27.00	QL324504	LNK47B1PF4000HW	yd	$132.50	$1,192.50

Water Added On Job At Customer's Request:	SLUMP	Notes:		
	4.00 in		TICKET SUBTOTAL	$1,192.50
			SALES TAX	$0.00
			TICKET TOTAL	$1,192.50
			PREVIOUS TOTAL	
			GRAND TOTAL	**$1,192.50**

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.

Figure A-1. Bridge Deck Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a1)

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	251	9827	62461		NTE	OCBR	7/12/21	9 55 AM	1267134

Customer
UNL-MIDWEST ROADSIDE SAFETY

Delivery Address
4630 NW 36TH ST

Special Instructions
AIRPARK / NORTH OF OLD GOODYEARHANGERS

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
9.00	18.00	27.00	QL324504	LNK47B1PF4000HW	yd	$132.50	$1 192.50

Water Added On Job At Customer's Request: ________

SLUMP: 4.00 in

Notes:

TICKET SUBTOTAL	$1 192.50
SALES TAX	$0.00
TICKET TOTAL	**$1,192.50**
PREVIOUS TOTAL	$1 192 50
GRAND TOTAL	**$2 385.00**

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.

Figure A-2. Bridge Deck Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a1)

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	284	8520	62461		NTE	OCBR	7/12/21	10:00 AM	1267135

Customer: UNL-MIDWEST ROADSIDE SAFETY

Delivery Address: 4630 NW 36TH ST

Special Instructions: AIRPARK / NORTH OF OLD GOODYEARHANGERS

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
9.00	27.00	27.00	QL324504	LNK47B1PF4000HW	yd	$132.50	$1,192.50

Water Added On Job At Customer's Request:

SLUMP: 4.00 in

Notes:

TICKET SUBTOTAL	$1,192.50
SALES TAX	$0.00
TICKET TOTAL	**$1,192.50**
PREVIOUS TOTAL	$2,385.00
GRAND TOTAL	**$3,577.50**

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.

Figure A-3. Bridge Deck Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a1)

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:	024
Description:	OCBR (Deck)

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

		Property	Test Result
Supplier:		Slump (in):	
Mix Name:		Air Content (%):	
Ticket Number:		Unit Weight (lb/ft³):	
Truck Number:		Air Temp (°F):	
Load Volume (yd³):		Mix Temp (°F):	
Mold Date:	07/12/2021	Min Temp (°F):	
Molded By:		MaxTemp (°F):	
Initial Cure Method:			

Laboratory Test Data (ASTM C39)

Sample Number:	024	024				
Set Number:	Truck #2	Truck #3				
Specimen Number:	1	1				
Age:	21	21				
Length (in):	12	12				
Diameter (in):	6	5.99				
Area (in²):	28.27	28.18				
Test Date:	08/02/2021	08/02/2021				
Break Type:	6	6				
Max Load (lbf):	134,654	111,790				
Strength (psi):	4,760	3,970				
Spec Strength (psi):						
Excl in Avg Strength:	☐	☐	☐	☐	☐	☐

Remarks:
Average 21-day Compressive Strength (psi): **4,360**

Date received: 08/02/2021
Curing: ☒ Standard ☐ Field
ASTM C511
Submitted by: Matt Roesler

Type 1 Type 2 Type 3 Type 4 Type 5 Type 6

Distribution:

Report Date: 8/2/21

825 M Street Suite 100
Lincoln, NE 68508

Alfred Benesch & Company

Figure A-4. Bridge Deck Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a1)

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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:	027
Description:	OCBR

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

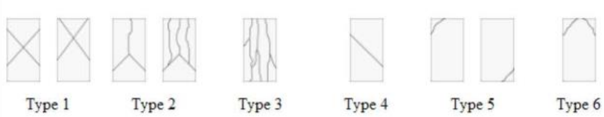
		Property	Test Result
Supplier:			
Mix Name:		Slump (in):	
Ticket Number:		Air Content (%):	
Truck Number:		Unit Weight (lb/ft³):	
Load Volume (yd³):		Air Temp (°F):	
Mold Date:	09/16/2021	Mix Temp (°F):	
Molded By:		Min Temp (°F):	
Initial Cure Method:		MaxTemp (°F):	

Laboratory Test Data (ASTM C39)

Sample Number:	027	027				
Set Number:	OCBR-1	OCBR-2				
Specimen Number:	1	1				
Age:	14	14				
Length (in):	12	12				
Diameter (in):	5.96	5.95				
Area (in²):	27.90	27.81				
Test Date:	09/30/2021	09/30/2021				
Break Type:	6	6				
Max Load (lbf):	96,378	108,018				
Strength (psi):	3,450	3,880				
Spec Strength (psi):						
Excl in Avg Strength:	☐	☐	☐	☐	☐	☐

Remarks:
Average 14-day Compressive Strength (psi): **3,670**

Date received: 09/30/2021
Curing: ☒ Standard ☐ Field
ASTM C511
Submitted by: [signature]



Distribution:

Report Date: 9/30/21

825 M Street Suite 100
Lincoln, NE 68508

Alfred Benesch & Company

Figure A-5. Bridge Rail Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a2)

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	147	11014	62461		N01	OCBR-H34S	9/16/21	10:30 AM	1270201

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

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
8.00	8.00	24.00	QL324504	LNK47B1PF4000HW	yd	$132.50	$1,060.00

Water Added On Job At Customer's Request:	SLUMP	Notes:		
	4.00 in		TICKET SUBTOTAL	$1,060.00
			SALES TAX	$0.00
			TICKET TOTAL	$1,060.00
			PREVIOUS TOTAL	
			GRAND TOTAL	$1,060.00

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.

Figure A-6. Bridge Rail Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a2)

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	133	7142	62461		N01	OCBR-H34S	9/16/21	10:48 AM	1270204

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

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
8.00	24.00	24.00	QL324504	LNK47B1PF4000HW	yd	$132.50	$1,060.00

Water Added On Job At Customer's Request:

SLUMP: 4.00 in

Notes:

TICKET SUBTOTAL	$1,060.00
SALES TAX	$0.00
TICKET TOTAL	**$1,060.00**
PREVIOUS TOTAL	$2,120.00
GRAND TOTAL	**$3,180.00**

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.

Figure A-7. Bridge Rail Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a2)

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	056	056	62461		N01	OCBR-H34S	9/16/21	10:43 AM	1270203

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

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
8.00	16.00	24.00	QL324504	LNK47B1PF4000HW	yd	$132.50	$1,060.00

Water Added On Job At Customer's Request:	SLUMP	Notes:		
	4.00 in		TICKET SUBTOTAL	$1,060.00
			SALES TAX	$0.00
			TICKET TOTAL	**$1,060.00**
			PREVIOUS TOTAL	$1,060.00
			GRAND TOTAL	**$2,120.00**

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.

Figure A-8. Bridge Rail Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a2)

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:	027
Description:	OCBR

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

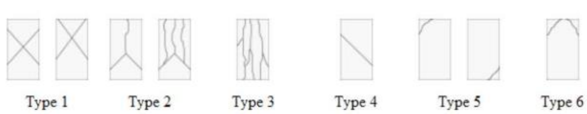
		Property	Test Result
Supplier:			
Mix Name:		Slump (in):	
Ticket Number:		Air Content (%):	
Truck Number:		Unit Weight (lb/ft³):	
Load Volume (yd³):		Air Temp (°F):	
Mold Date:	09/16/2021	Mix Temp (°F):	
Molded By:		Min Temp (°F):	
Initial Cure Method:		MaxTemp (°F):	

Laboratory Test Data (ASTM C39)

Sample Number:	027	027				
Set Number:	OCBR-1	OCBR-2				
Specimen Number:	1	1				
Age:	14	14				
Length (in):	12	12				
Diameter (in):	5.96	5.95				
Area (in²):	27.90	27.81				
Test Date:	09/30/2021	09/30/2021				
Break Type:	6	6				
Max Load (lbf):	96,378	108,018				
Strength (psi):	3,450	3,880				
Spec Strength (psi):						
Excl in Avg Strength:	☐	☐	☐	☐	☐	☐

Remarks:
Average 14-day Compressive Strength (psi): **3,670**

Date received: 09/30/2021
Curing: ☒ Standard ☐ Field
ASTM C511
Submitted by:



Distribution:

Report Date: 9/30/21

825 M Street Suite 100
Lincoln, NE 68508
Alfred Benesch & Company

Figure A-9. Bridge Rail Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a2)

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:	027
Description:	OCBR

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

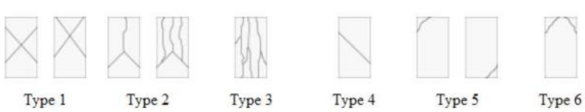
		Property	Test Result
Supplier:		Slump (in):	
Mix Name:		Air Content (%):	
Ticket Number:		Unit Weight (lb/ft³):	
Truck Number:		Air Temp (°F):	
Load Volume (yd³):		Mix Temp (°F):	
Mold Date:	09/16/2021	Min Temp (°F):	
Molded By:		MaxTemp (°F):	
Initial Cure Method:			

Laboratory Test Data (ASTM C39)

Sample Number:	027	027				
Set Number:	OCBR-1	OCBR-2				
Specimen Number:	1	1				
Age:	14	14				
Length (in):	12	12				
Diameter (in):	5.96	5.95				
Area (in²):	27.90	27.81				
Test Date:	09/30/2021	09/30/2021				
Break Type:	6	6				
Max Load (lbf):	96,378	108,018				
Strength (psi):	3,450	3,880				
Spec Strength (psi):						
Excl in Avg Strength:	☐	☐	☐	☐	☐	☐

Remarks:
Average 14-day Compressive Strength (psi): **3,670**

Date received: 09/30/2021
Curing: ☒ Standard ☐ Field
ASTM C511
Submitted by: Matt Roesler



Distribution:

Report Date: 9/30/21

825 M Street Suite 100
Lincoln, NE 68508

Alfred Benesch & Company

Figure A-10. Bridge Rail Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a2)

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:	020
Description:	OCBR

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

		Property	Test Result
Supplier:		Slump (in):	
Mix Name:		Air Content (%):	
Ticket Number:		Unit Weight (lb/ft³):	
Truck Number:		Air Temp (°F):	
Load Volume (yd³):		Mix Temp (°F):	
Mold Date:	08/31/2020	Min Temp (°F):	
Molded By:	MwRSF	MaxTemp (°F):	
Initial Cure Method:			

Laboratory Test Data (ASTM C39)

Sample Number:	020	020				
Set Number:	1	2				
Specimen Number:	1	1				
Age:	193	193				
Length (in):	12	12				
Diameter (in):	6	6				
Area (in²):	28.27	28.27				
Test Date:	03/12/2021	03/12/2021				
Break Type:	2	2				
Max Load (lbf):	179,475	198,020				
Strength (psi):	6,350	7,000				
Spec Strength (psi):						

Remarks:

Average 193-day Compressive Strength (psi): **6,680**

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

Date received: 03/12/2021

Curing: ☒ Standard ☐ Field

ASTM C511

Submitted by:

Type 1 Type 2 Type 3 Type 4 Type 5 Type 6

Distribution:

Report Date: 3/12/21

825 M Street Suite 100
Lincoln, NE 68508

Alfred Benesch & Company

Figure A-11. Grade Beam Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a3)

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

INVOICE

Remit to: P.O. Box 80268
Lincoln, NE 68501

Job: 4630 NW 36TH ST
LINCOLN

Bill To: UNL-MIDWEST ROADSIDE SAFETY
ATTN VALERIE SWARTZ
130 WHITTIER RESEARCH CENTER
UNIVERSITY OF NEBRASKA LINCOLN
LINCOLN NE 68583

Page	1
Account Number	62461
Invoice Date	08/31/20
Invoice Amount	1,702.59
Invoice Number	HI 600351
Amount Paid	

Invoice Terms: Net 30

To insure proper credit, please detach and return top portion of invoice with remittance.

Invoice No.: HI 600351 | Invoice Date: 08/31/20 | PO No.JIM4506250 | Order: | Ship#:

Line	Item Description	Quantity	Unit Price	Misc.	Extension
1	LNK47B1PF4500STR QL32D423 CONC TKTS: 1255881 1255889 1255879	12.50 CY	127.00	0.00	1,587.50

Account: 62461 UNL-MIDWEST ROADSIDE SAFETY
Job: 4630 NW 36TH ST
Tax Code: RMN01 Lincoln Sales Tax

Sub Total	1,587.50
Sales Tax	115.09
Total Amount	1,702.59

Terms: All invoices must be paid within 30 days of invoice. Past due accounts will be charged an interest rate of 1.33% per month which is 16% per year.

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

Invoice – Customer Copy

Reprint

Figure A-12. Grade Beam Concrete, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. a3)

SIMCOTE, INC.

Date: November 5, 2020

CERTIFICATE OF COMPLIANCE

To: Concrete Industries, Inc.

Re: PO# 144607-1

Project No: #4 & #5 x 40'-0" Epoxy Straight Bar

County:

Contractor:

To Whom It May Concern:

The representative samples of the coated bars have been coated and tested. They conform to the requirements of the State of *Nebraska* Department of Roads Specification.

Sincerely,

SIMCOTE, INC.

Adam Simmet
President

1645 Red Rock Road, St. Paul, MN 55119
Phone: (651) 735-9660 Fax: (651) 735-9664

250 N. Greenwood St., Marion, OH 43302
Phone: (740) 382-5000 Fax: (740) 383-1167

Figure A-13. #4 Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. b1)

SUMMARY SHEET 11/5/2020

JOB/ORDER NUMBER 52249

CUSTOMER NAME CONCRETE INDUSTRIES

CONTRACTOR

TICKET/RELEASE # (S) 9

SIZE	HEAT	LOT	DATE
4	55064958	0K06	11-03-20A
4	3600014739	69479	10-19-20C
5	58042433	0K07	11-02-20A

Figure A-14. #4 Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. b1)

GERDAU

CERTIFIED MATERIAL TEST REPORT

Page 1/1

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

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.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR
Phone: (409) 267-1071 Email: Bhaskar.Yalamanchili@gerdau.com

ALSA BRANDENBURG
QUALITY ASSURANCE MGR.
Phone: (651) 731-5662 Email: Alea.Brandenburg@gerdau.com

Figure A-15. #5 Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item Nos. b2 through b4, b6, and b12)

CMC STEEL OKLAHOMA
584 Old Highway 70
Durant OK 74701-0000

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

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

Robert Booth
Quality Assurance Manager

HEAT NO.:6015833 SECTION: SPOOL REBAR 13MM (#4) A615/A706-60 3.5T GRADE: ASTM A615 GR A706-60 Dual Gr ROLL DATE: 06/19/2020 MELT DATE: 06/19/2020 Cert. No.: 83139931 / 015833J051	SOLD TO: Concrete Industries Inc 6300 Cornhusker Hwy Lincoln NE US 68529-0529 4024341899 4024341899	SHIP TO: Concrete Industries Inc 6300 Cornhusker Hwy Lincoln NE US 68529-0529 4024341899 4024341899	Delivery#: 83139931 BOL#: 73665794 CUST PO#: 142456 CUST P/N: DLVRY LBS / HEAT: 6864.000 LB DLVRY PCS / HEAT: 1 EA

Characteristic	Value	Characteristic	Value
C	0.29%	Elongation Gage Lgth test 1	8IN
Mn	1.22%	Tensile to Yield ratio test1	1.41
P	0.009%	Bend Test 1	Passed
S	0.023%	Rebar Deformation Avg. Spaci	0.334IN
Si	0.26%	Rebar Deformation Avg. Heigh	0.028IN
Cu	0.28%	Rebar Deformation Max. Gap	0.117IN
Cr	0.16%	Bend Test Diameter	1.500IN
Ni	0.16%	Strain at Peak Stress test 1	11.3%
Mo	0.051%		
V	0.008%		
Sn	0.009%		
Al	0.004%		
N	0.0124%		
Carbon Eq A706	0.53%		
Yield Strength test 1	73.9ksi		
Yield Strength test 1 (metri	510MPa		
Tensile Strength test 1	103.8ksi		
Tensile Strength 1 (metric)	716MPa		
Elongation test 1	15%		

The Following is true of the material represented by this MTR:
*Material is fully killed
*100% melted and rolled in the USA
*EN10204:2004 3.1 compliant
*Contains no weld repair
*Contains no Mercury contamination
*Manufactured in accordance with the latest version of the plant quality manual
*Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661
*Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

REMARKS : ALSO MEETS AASHTO M31

Page 1 OF 1 07/13/2020 13:55:16

Figure A-16. #4 Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. b5)

CMC STEEL TENNESSEE
1919 Tennessee Avenue
Knoxville TN 37921-2686

CERTIFIED MILL TEST REPORT
For additional copies call

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

Jim Hall
Quality Assurance Manager

HEAT NO.:7006848 SECTION: REBAR 13MM (#4) 60'0" 420/60 GRADE: ROLL DATE: MELT DATE: 01/05/2020 Cert. No.: 82944733 / 006848L265	SOLD TO	ABC Coating Co - Tulsa 2236 S Yukon Ave Tulsa OK US 74107-2765 9185852587 9185858131	SHIP TO	CPU Chicago Depot 13535 S Torrence Ave Chicago IL US 60633-2164 7736466363	Delivery#: 82944733 BOL#: 1865847 CUST PO#: 010620-Minn CUST P/N: DLVRY LBS / HEAT: 26932.000 LB DLVRY PCS / HEAT: 672 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.27%	Rebar Deformation Avg. Spaci	0.329IN		
Mn	0.59%	Rebar Deformation Avg. Heigh	0.034IN		
P	0.008%	Rebar Deformation Max. Gap	0.106IN		
S	0.048%				
Si	0.20%				
Cu	0.33%				
Cr	0.17%				
Ni	0.11%				
Mo	0.014%				
V	0.002%				
Sn	0.007%				
Yield Strength test 1	85.9ksi				
Yield Strength test 1 (metri	592MPa				
Tensile Strength test 1	99.1ksi				
Tensile Strength 1 (metric)	684MPa				
Elongation test 1	13%				
Elongation Gage Lgth test 1	8IN				
Elongation Gage Lgth 1(metri	200mm				
Bend Test 1	Passed				

The Following is true of the material represented by this MTR:
*Material is fully killed
*100% melted and rolled in the USA
*EN10204:2004 3.1 compliant
*Contains no weld repair
*Contains no Mercury contamination
*Manufactured in accordance with the latest version of the plant quality manual
*Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661
*Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov

REMARKS :

Page 1 OF 1 01/21/2020 09:09:21

Figure A-17. #4 Bent Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item Nos. b7, b8, b10, b15 through b17)

NUCOR®

Mill Certification

07/14/2020

MTR#:451286-2
Lot #:360001348621
ONE NUCOR WAY
BOURBONNAIS, IL 60914 US
815 937-3131
Fax: 815 939-5599

Sold To: SIMCOTE INC
1645 RED ROCK RD
ST PAUL, MN 55119 US

Ship To: SIMCOTE INC
1645 RED ROCK RD
ST PAUL, MN 55119 US

Customer PO	MN-3748	Sales Order #	36013225 - 4.1
Product Group	Rebar	Product #	2110264
Grade	A615 Gr 60/AASHTO M31	Lot #	360001348621
Size	#6	Heat #	3600013486
BOL #	BOL-533793	Load #	451286
Description	Rebar #6/19mm A615 Gr 60/AASHTO M31 40' 0" [480"] 6001-10000 lbs	Customer Part #	
Production Date	06/14/2020	Qty Shipped LBS	38390
Product Country Of Origin	United States	Qty Shipped EA	639
Original Item Description		Original Item Number	

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

Melt Country of Origin : United States   Melting Date: 06/12/2020

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	Cu (%)	V (%)	Nb (%)	Sn (%)
0.38	0.86	0.015	0.046	0.180	0.26	0.20	0.07	0.35	0.003	0.001	0.013

Other Test Results

Yield (PSI) : 66200
Tensile (PSI) : 104100
Average Deformation Height (IN) : 0.052
Elongation in 8" (%) : 16.1
Bend Test : Pass
Weight Percent Variance (%) : -3.70

Comments:

All manufacturing processes of the steel materials in this product, including melting, have occurred within the United States. Products produced are weld free. Mercury, in any form, has not been used in the production or testing of this material.

Zach Sprintz

Zachary Sprintz, Chief Metallurgist

Page 1 of 1

Figure A-18. #6 Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item Nos. b9 and b13)

NUCOR

Mill Certification

09/02/2020

MTR#:458890-2
Lot #:360001474020
ONE NUCOR WAY
BOURBONNAIS, IL 60914 US
815 937-3131
Fax: 815 939-5599

Sold To: SIMCOTE INC
1645 RED ROCK RD
ST PAUL, MN 55119 US

Ship To: SIMCOTE INC
1645 RED ROCK RD
ST PAUL, MN 55119 US

Customer PO	MN-3748	Sales Order #	36013225 - 1.31
Product Group	Rebar	Product #	2110206
Grade	A615 Gr 60/AASHTO M31	Lot #	360001474020
Size	#4	Heat #	3600014740
BOL #	BOL-567414	Load #	458890
Description	Rebar #4/13mm A615 Gr 60/AASHTO M31 60' 0" [720"] 6001-10000 lbs	Customer Part #	
Production Date	08/12/2020	Qty Shipped LBS	22725
Product Country Of Origin	United States	Qty Shipped EA	567
Original Item Description		Original Item Number	

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

Melt Country of Origin : United States — Melting Date: 08/07/2020

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	Cu (%)	V (%)	Nb (%)
0.34	0.90	0.015	0.043	0.198	0.18	0.23	0.06	0.40	0.012	0.002

Other Test Results

Yield (PSI) : 66100
Tensile (PSI) : 99200
Average Deformation Height (IN) : 0.036
Elongation in 8" (%) : 14.5
Bend Test : Pass
Weight Percent Variance (%) : -4.00

Comments:

All manufacturing processes of the steel materials in this product, including melting, have occurred within the United States. Products produced are weld free. Mercury, in any form, has not been used in the production or testing of this material.

Zachary Sprintz, Chief Metallurgist

Page 1 of 1

Figure A-19. #4 Bent Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. b11)

NUCOR®

Mill Certification

05/04/2021

MTR#:685135-1
Lot #:970000693620
500 REBAR RD
SEDALIA, MO 65301 US
660 951-1679
Fax: 660 951-1698

Sold To: SIMCOTE INC
1645 RED ROCK RD
ST PAUL, MN 55119 US

Ship To: SIMCOTE INC
1645 RED ROCK RD
ST PAUL, MN 55119 US

Customer PO	MN-3766	Sales Order #	97003933 - 3.2
Product Group	Rebar	Product #	2110230
Grade	A615 Gr 60/AASHTO M31	Lot #	970000693620
Size	#5	Heat #	9700006936
BOL #	BOL-765190	Load #	685135
Description	Rebar #5/16mm A615 Gr 60/AASHTO M31 40' 0" [480"] 4001-8000 lbs	Customer Part #	
Production Date	04/17/2021	Qty Shipped LBS	47563.2
Product Country Of Origin	United States	Qty Shipped EA	1140
Original Item Description		Original Item Number	

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

Melt Country of Origin : United States — Melting Date: 04/17/2021

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	V (%)	Nb (%)
0.26	0.83	0.011	0.023	0.239	0.10	0.15	0.02	0.005	0.001

Mechanical

	Average Deformation Height (IN)	Bend Test
(1)	0.037	Pass

Tensile testing

	Yield (PSI)	Tensile (PSI)	Elongation in 8" (%)
(1)	82200	98100	14.3

Comments:
1. All manufacturing processes of the steel materials in this product, including melting, casting and rolling were performed in the USA.
2. Mercury, Radium, Hexavalent Chrome or Alpha source materials in any form have not been used in the production and testing of this material.
3. Weld repair was not performed on this material.

Lauren Jellison, Division Metallurgist

Page **1** of **1**

Figure A-20. #5 Rebar, Test Nos. OCBR-1, OCBR-2, and OCBR-3 (Item No. b14)

Appendix B. Vehicle Center of Gravity Determination

		Test Name:	**OCBR-1**	**VIN:**	**KMHCT4AF5FU879644**
Model Year:	**2015**	**Make:**	**Hyundai**	**Model:**	**Accent**

Vehicle CG Determination

	Vehicle Equipment	Weight (lb)
+	Unballasted Car (Curb)	2460
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	30
+	Strobe/Brake Battery	5
+	Brake Receiver/Wires	5
+	CG Plate including DAQ	20
-	Battery	-35
-	Oil	-14
-	Interior	-80
-	Fuel	0
-	Coolant	-7
-	Washer fluid	-4
+	Water Ballast (In Fuel Tank)	0
+	Onboard Supplemental Battery	0
+	Spare Tire	24

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

Estimated Total Weight (lb) 2430

Vehicle Dimensions for C.G. Calculations

Wheel Base:	101.0	in.	Front Track Width:	59.25	in.
Roof Height:	56.25	in.	Rear Track Width:	59.375	in.

Center of Gravity	**1100C MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)	2420 ± 55	2431	11.0
Longitudinal CG (in.)	39 ± 4	38.763	-0.237
Lateral CG (in.)	NA	-0.988	NA
Vertical CG (in.)	NA	21.743	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	827	723
Rear	427	483

FRONT	1550	lb
REAR	910	lb
TOTAL	2460	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	792	706
Rear	464	469

FRONT	1498	lb
REAR	933	lb
TOTAL	2431	lb

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

	Test Name: OCBR-2	VIN:	1C6RR6FG6FS720783
Model Year: 2015	Make: Dodge	Model:	Ram 1500

Vehicle CG Determination

Vehicle Equipment		Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	4921	28.458628	140044.91
+	Hub	19	14.75	280.25
+	Brake activation cylinder & frame	7	27	189
+	Pneumatic tank (Nitrogen)	30	26	780
+	Strobe/Brake Battery	10	24	240
+	Brake Receiver/Wires	6	50	300
+	CG Plate including DAQ	30	29 3/4	892.5
-	Battery	-44	39	-1716
-	Oil	-12	14	-168
-	Interior	-107	29	-3103
-	Fuel	-171	6	-1026
-	Coolant	-13	35	-455
-	Washer fluid	-4	34	-136
+	Water Ballast (In Fuel Tank)	231	18	4158
+	Onboard Supplemental Battery	0	0	0
+	Ballast Plates	100	34 1/4	3425
				0
				143705.66

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

Estimated Total Weight (lb)	5003
Vertical CG Location (in.)	28.7239

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140.25 in. Front Track Width: 67.875 in.
Rear Track Width: 67.75 in.

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	5002	2.0
Longitudinal CG (in.)	63 ± 4	66.143493	3.14349
Lateral CG (in.)	NA	-0.759196	NA
Vertical CG (in.)	28 or greater	28.72	0.72390

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	1389	1305
Rear	1103	1124

FRONT	2694	lb
REAR	2227	lb
TOTAL	4921	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	1390	1253
Rear	1167	1192

FRONT	2643	lb
REAR	2359	lb
TOTAL	5002	lb

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

	Test Name: OCBR-3	VIN:	1HTMMAAPXDH412511
Model Year: 2013	Make: International	Model:	4300 SBA 4X2

Vehicle CG Determination

		Vehicle Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
	+	Unballasted Truck (Curb)	16784	40.887	686241.648
	+	Hub	43	18.75	806.25
	+	Brake activation cylinder & frame	7	44.0	308.0
	+	Pneumatic tank (Nitrogen)	31	44.0	1364.0
	+	Strobe/Brake Battery	5	42.25	211.25
	+	Tow Pin Plate	9	12.5	112.5
	+	Brake Receiver/Wires	6	98.75	592.5
	+	C.G DAQ Unit & Mouting Plate	32	30.5	976.0
	+	Rear axle DAQ Units & Enclosure	16	32.625	522.0
	-	Battery	-112	26.5	-2968.0
	-	Oil	-51	23.0	-1173.0
	-	Interior	0	70.0	0
	-	Fuel	-938	23.5	-22043.0
	-	Coolant	-60	47.0	-2820.0
	-	Washer fluid	-6	27.5	-165.0
	+	Tdas	17	41.5	705.5
					0
BALLAST	+	PCB	5100	64.75	330225.0
	+	Concrete blocks	1286	55.5	71373.0
	+	Hardware	148	47.0	6956.0
	+				0
	+				0
					0
		Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle			1071224.648

Estimated Total Weight (lb)	22317	Total Ballast Weight (lb)	6534
Vertical CG Location (in.)	48.0	Ballast Vertical CG Location (in.)	62.527

Vehicle Dimensions for C.G. Calculations

Wheel Base: 236.375 in. Front Track Width: 80.25 in.
Rear Track Width: 73.0 in.

Center of Gravity	10000S MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	22046 ± 660	21906	-140.0
Longitudinal CG (in.)	NA	147.829	NA
Lateral CG (in.)	NA	-0.241	NA
Vertical CG (in.)	NA	48.0	NA
Ballast Vertical CG (in.)	63 ± 2	62.527	-0.47260

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	4156	4128
Rear	4390	4110

FRONT	8284	lb
REAR	8500	lb
TOTAL	16784	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	4182	4024
Rear	6840	6860

FRONT	8206	lb
REAR	13700	lb
TOTAL	21906	lb

Figure B-3. Vehicle Mass Distribution, Test No. OCBR-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 detailed herein. MASH 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 criteria. Reference Set 2 from test no. OCBR-1 was omitted due to visually compromised reference points. Both interior crush reference sets for test no. OCBR-3 were compromised so no measurements were taken. However, comparisons were made to an exemplar vehicle with the same cab and interior configuration and is shown below.

Model Year: 2015 | Test Name: OCBR-1 | VIN: KMHCT4AF5FU879644
Make: Hyundai | Model: Accent

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	71.9441	10.2557	3.5959	72.7122	10.0360	5.0444	-0.7681	0.2197	-1.4485	1.6542	0.0000	NA
	2	72.9457	14.6304	4.3707	73.6055	14.2291	5.6412	-0.6598	0.4013	-1.2705	1.4868	0.0000	NA
	3	73.3937	19.8557	3.9433	74.0722	19.1186	5.2554	-0.6785	0.7371	-1.3121	1.6508	0.0000	NA
	4	72.9870	24.8710	3.9610	73.6522	24.0702	4.9859	-0.6652	0.8008	-1.0249	1.4609	0.0000	NA
	5	71.1586	29.2851	2.9016	70.6067	27.1330	3.6748	0.5519	2.1521	-0.7732	2.3524	0.5519	X
	6	66.9852	10.2093	5.4931	67.6358	10.0600	6.6409	-0.6506	0.1493	-1.1478	1.3278	0.0000	NA
	7	68.0857	15.2843	7.1931	68.5682	14.8037	8.2673	-0.4825	0.4806	-1.0742	1.2719	0.0000	NA
	8	68.7042	19.9590	6.6747	69.2753	19.4681	7.7862	-0.5711	0.4909	-1.1115	1.3426	0.0000	NA
	9	68.3321	24.4353	6.7466	69.0256	23.8749	7.7270	-0.6935	0.5604	-0.9804	1.3252	0.0000	NA
	10	68.7276	29.5767	6.2565	69.6804	28.9239	7.3640	-0.9528	0.6528	-1.1075	1.6002	0.0000	NA
FLOOR PAN (Z)	11	62.8065	10.2624	6.1425	63.3998	10.1724	7.1103	-0.5933	0.0900	-0.9678	1.1387	-0.9678	Z
	12	63.4636	14.6168	8.6054	63.9643	14.4121	9.5058	-0.5007	0.2047	-0.9004	1.0504	-0.9004	Z
	13	63.3138	19.4472	8.6426	63.8970	19.1448	9.7096	-0.5832	0.3024	-1.0670	1.2530	-1.0670	Z
	14	63.8230	24.5330	8.4590	64.4918	24.1330	9.4394	-0.6688	0.4000	-0.9804	1.2524	-0.9804	Z
	15	63.3454	29.3372	8.5367	64.0837	28.8861	9.2620	-0.7383	0.4511	-0.7253	1.1290	-0.7253	Z
	16	58.7081	9.9085	6.0341	59.3314	9.8711	6.7633	-0.6233	0.0374	-0.7292	0.9600	-0.7292	Z
	17	58.3647	14.4147	8.6193	58.9422	14.3610	9.4073	-0.5775	0.0537	-0.7880	0.9784	-0.7880	Z
	18	58.7378	19.2604	8.6501	59.3237	19.1295	9.4421	-0.5859	0.1309	-0.7920	0.9938	-0.7920	Z
	19	58.1555	24.2437	8.6406	58.8492	24.0029	9.5284	-0.6937	0.2408	-0.8878	1.1521	-0.8878	Z
	20	58.2014	28.8952	8.3550	58.9697	28.6012	9.2659	-0.7683	0.2940	-0.9109	1.2274	-0.9109	Z
	21	53.5824	9.5204	5.9798	54.1503	9.5997	6.5096	-0.5679	-0.0793	-0.5298	0.7807	-0.5298	Z
	22	53.4674	14.4358	8.7803	54.0050	14.4279	9.3838	-0.5376	0.0079	-0.6035	0.8083	-0.6035	Z
	23	53.1592	19.4071	8.6723	53.7570	19.3018	9.5183	-0.5978	0.1053	-0.8460	1.0412	-0.8460	Z
	24	53.1400	24.3317	8.6686	54.2435	24.0370	9.4633	-1.1035	0.2947	-0.7947	1.3914	-0.7947	Z
	25	52.8953	28.6540	8.3681	53.6763	28.5999	9.3328	-0.7810	0.0541	-0.9647	1.2424	-0.9647	Z
	26	49.0031	9.2601	6.1381	49.6225	9.3950	6.4354	-0.6194	-0.1349	-0.2973	0.7002	-0.2973	Z
	27	48.8391	13.7829	8.7138	49.3388	13.8379	9.1217	-0.4997	-0.0550	-0.4079	0.6474	-0.4079	Z
	28	48.3460	18.7378	8.7397	48.9654	18.7696	9.3142	-0.6194	-0.0318	-0.5745	0.8454	-0.5745	Z
	29	48.2266	24.1064	8.7457	48.9176	24.2083	9.4673	-0.6910	-0.1019	-0.7216	1.0043	-0.7216	Z
	30	48.2480	28.6081	8.7132	48.9986	28.6447	9.5956	-0.7506	-0.0366	-0.8824	1.1590	-0.8824	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. OCBR-1

Model Year: 2015 | Test Name: OCBR-1 | Make: Hyundai | VIN: KMHCT4AF5FU879644 | Model: Accent

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	61.6559	30.6222	-18.9985	60.1462	29.4760	-19.1462	1.5097	1.1462	-0.1477	1.9013	1.9013	X, Y, Z
	2	62.2120	21.1847	-18.5688	61.2815	20.0371	-18.5179	0.9305	1.1476	0.0509	1.4783	1.4783	X, Y, Z
	3	61.0405	6.8792	-20.0687	61.0547	5.6606	-19.6168	-0.0142	1.2186	0.4519	1.2998	1.2998	X, Y, Z
	4	58.2226	29.6148	-15.3661	56.6576	28.2599	-15.6757	1.5650	1.3549	-0.3096	2.0930	2.0930	X, Y, Z
	5	58.7340	21.0828	-14.9269	57.6599	19.7983	-15.0239	1.0741	1.2845	-0.0970	1.6772	1.6772	X, Y, Z
	6	55.9515	6.4802	-11.1883	55.3311	5.3544	-10.4731	0.6204	1.1258	0.7152	1.4710	1.4710	X, Y, Z
SIDE PANEL (Y)	7	66.5846	32.9619	-2.0583	64.9880	30.1291	-2.1879	1.5966	2.8328	-0.1296	3.2543	2.8328	Y
	8	63.7748	32.8605	2.6973	63.3570	31.0810	3.3697	0.4178	1.7795	0.6724	1.9476	1.7795	Y
	9	69.3248	33.0636	2.3826	67.7190	30.6301	2.7066	1.6058	2.4335	0.3240	2.9335	2.4335	Y
IMPACT SIDE DOOR (Y)	10	52.6828	33.4759	-14.6947	51.1126	35.0653	-14.1060	1.5702	-1.5894	0.5887	2.3105	-1.5894	Y
	11	45.5988	34.0319	-15.5872	44.4011	36.7107	-15.1557	1.1977	-2.6788	0.4315	2.9659	-2.6788	Y
	12	38.0558	33.7390	-16.9074	36.8229	37.1370	-16.3762	1.2329	-3.3980	0.5312	3.6536	-3.3980	Y
	13	54.3163	34.2559	-1.0777	53.1108	34.6920	-0.6487	1.2055	-0.4361	0.4290	1.3518	-0.4361	Y
	14	44.0029	34.1725	0.1080	42.7665	35.4371	0.6253	1.2364	-1.2646	0.5173	1.8427	-1.2646	Y
	15	36.2120	33.2923	-1.2067	35.4876	34.8797	-0.9855	0.7244	-1.5874	0.2212	1.7588	-1.5874	Y
ROOF - (Z)	16	47.9351	23.0837	-35.0479	48.1926	23.4539	-36.2693	-0.2575	-0.3702	-1.2214	1.3020	-1.2214	Z
	17	49.5915	16.1825	-35.1964	49.6055	16.5278	-35.4996	-0.0140	-0.3453	-0.3032	0.4597	-0.3032	Z
	18	50.5307	5.6132	-35.2413	50.5096	5.9548	-34.6625	0.0211	-0.3416	0.5788	0.6724	0.5788	Z
	19	39.5760	21.5175	-37.9582	39.5529	21.5368	-38.5923	0.0231	-0.0193	-0.6341	0.6348	-0.6341	Z
	20	39.9676	14.7513	-38.3270	40.0692	14.8396	-37.4833	-0.1016	-0.0883	0.8437	0.8544	0.8437	Z
	21	40.5917	4.8294	-38.4675	40.8743	5.0894	-38.1810	-0.2826	-0.2600	0.2865	0.4791	0.2865	Z
	22	27.0850	19.9311	-39.3558	27.2467	20.0647	-39.2375	-0.1617	-0.1336	0.1183	0.2408	0.1183	Z
	23	27.3993	13.7428	-39.6946	27.6686	13.9081	-39.5532	-0.2693	-0.1653	0.1414	0.3462	0.1414	Z
	24	27.6335	4.6926	-39.8844	27.9036	4.7523	-39.6540	-0.2701	-0.0597	0.2304	0.3600	0.2304	Z
	25	11.1610	18.3816	-39.3004	11.3357	18.3128	-39.2688	-0.1747	0.0688	0.0316	0.1904	0.0316	Z
	26	12.1578	12.0430	-39.6752	12.4033	12.0383	-39.6102	-0.2455	0.0047	0.0650	0.2540	0.0650	Z
	27	12.2291	3.3869	-39.8083	12.4606	3.3891	-39.7039	-0.2315	-0.0022	0.1044	0.2540	0.1044	Z
	28	-2.4031	17.3846	-37.6124	-2.1858	17.3430	-37.6372	-0.2173	0.0416	-0.0248	0.2226	-0.0248	Z
	29	-2.1357	11.1634	-37.9945	-1.9177	11.1094	-38.0037	-0.2180	0.0540	-0.0092	0.2248	-0.0092	Z
	30	-1.8166	4.9037	-38.1557	-1.5833	4.8691	-38.1591	-0.2333	0.0346	-0.0034	0.2359	-0.0034	Z
A-PILLAR Maximum (X, Y, Z)	31	65.7401	32.0179	-22.4687	64.5434	30.0970	-22.1724	1.1967	1.9209	0.2963	2.2825	2.2825	X, Y, Z
	32	62.8755	31.2305	-25.1024	62.0112	29.6823	-25.1527	0.8643	1.5482	-0.0503	1.7738	1.7731	X, Y
	33	58.2096	30.0682	-27.5361	57.7227	29.0012	-28.3571	0.4869	1.0670	-0.8210	1.4316	1.1728	X, Y
	34	55.0210	29.3838	-29.4706	54.9598	28.6541	-30.7503	0.0612	0.7297	-1.2797	1.4744	0.7323	X, Y
	35	51.9718	28.3563	-31.1581	52.2205	27.9024	-32.9883	-0.2487	0.4539	-1.8302	1.9020	0.4539	Y
	36	47.6586	27.7613	-32.9522	48.2190	27.1713	-35.1263	-0.5604	0.5900	-2.1741	2.3214	0.5900	Y
A-PILLAR Lateral (Y)	31	65.7401	32.0179	-22.4687	64.5434	30.0970	-22.1724	1.1967	1.9209	0.2963	2.2825	1.9209	Y
	32	62.8755	31.2305	-25.1024	62.0112	29.6823	-25.1527	0.8643	1.5482	-0.0503	1.7738	1.5482	Y
	33	58.2096	30.0682	-27.5361	57.7227	29.0012	-28.3571	0.4869	1.0670	-0.8210	1.4316	1.0670	Y
	34	55.0210	29.3838	-29.4706	54.9598	28.6541	-30.7503	0.0612	0.7297	-1.2797	1.4744	0.7297	Y
	35	51.9718	28.3563	-31.1581	52.2205	27.9024	-32.9883	-0.2487	0.4539	-1.8302	1.9020	0.4539	Y
	36	47.6586	27.7613	-32.9522	48.2190	27.1713	-35.1263	-0.5604	0.5900	-2.1741	2.3214	0.5900	Y
B-PILLAR Maximum (X, Y, Z)	37	25.6722	26.6206	-33.9782	25.9267	26.8408	-33.9369	-0.2545	-0.2202	0.0413	0.3391	0.0413	Z
	38	23.3988	27.8357	-31.0246	23.6549	27.9673	-30.9508	-0.2561	-0.1316	0.0738	0.2972	0.0738	Z
	39	26.4970	29.4917	-27.1641	26.7125	29.5875	-27.0840	-0.2155	-0.0958	0.0801	0.2491	0.0801	Z
	40	23.7396	30.3923	-23.5992	23.9449	30.4110	-23.4962	-0.2053	-0.0187	0.1030	0.2304	0.1030	Z
B-PILLAR Lateral (Y)	37	25.6722	26.6206	-33.9782	25.9267	26.8408	-33.9369	-0.2545	-0.2202	0.0413	0.3391	-0.2202	Y
	38	23.3988	27.8357	-31.0246	23.6549	27.9673	-30.9508	-0.2561	-0.1316	0.0738	0.2972	-0.1316	Y
	39	26.4970	29.4917	-27.1641	26.7125	29.5875	-27.0840	-0.2155	-0.0958	0.0801	0.2491	-0.0958	Y
	40	23.7396	30.3923	-23.5992	23.9449	30.4110	-23.4962	-0.2053	-0.0187	0.1030	0.2304	-0.0187	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-2. Occupant Compartment Deformation Data – Set 1, Test No. OCBR-1

Test Name:	OCBR-1	VIN:	KMHCT4AF5FU879644
Model Year: 2015	Make: Hyundai	Model:	Accent

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	0.8	≤ 4	Z	Roof	0.0	≤ 4	Z
Windshield[D]	0.0	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	2.3	≤ 5	X, Y, Z	A-Pillar Maximum	0.0	≤ 5	NA
A-Pillar Lateral	1.9	≤ 3	Y	A-Pillar Lateral	0.0	≤ 3	Y
B-Pillar Maximum	0.1	≤ 5	Z	B-Pillar Maximum	0.0	≤ 5	NA
B-Pillar Lateral	-0.2	≤ 3	Y	B-Pillar Lateral	0.0	≤ 3	Y
Toe Pan - Wheel Well	0.6	≤ 9	X	Toe Pan - Wheel Well	0.0	≤ 9	NA
Side Front Panel	2.8	≤ 12	Y	Side Front Panel	0.0	≤ 12	Y
Side Door (above seat)	-3.4	≤ 9	Y	Side Door (above seat)	0.0	≤ 9	Y
Side Door (below seat)	-1.6	≤ 12	Y	Side Door (below seat)	0.0	≤ 12	Y
Floor Pan	-1.1	≤ 12	Z	Floor Pan	0.0	≤ 12	Z
Dash - no MASH requirement	2.1	NA	X, Y, Z	Dash - no MASH requirement	0.0	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.

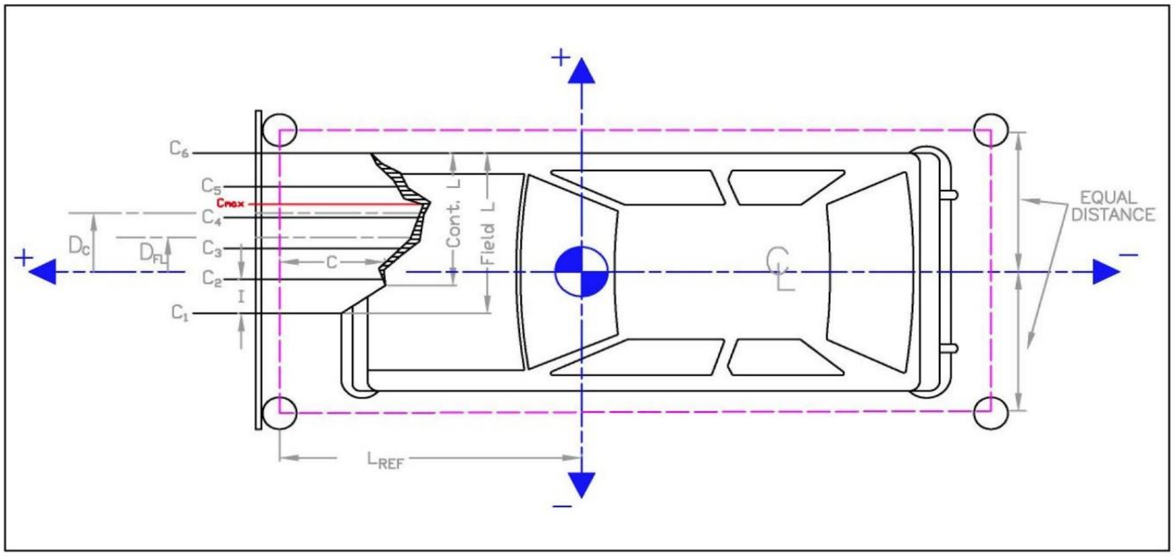
[D] If deformation is observed for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle crush:

The secondary set of points was omited due to visually compromised reference points.

Figure C-3. Maximum Occupant Compartment Deformation by Location, Test No. OCBR-1

Test Name:	OCBR-1	VIN:	KMHCT4AF5FU879644
Model Year: 2015	Make: Hyundai	Model:	Accent



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	88	(2235)
Total Width of Vehicle:	66	(1676)
Width of contact and induced crush - Field L:	66	(1676)
Crush measurement spacing interval (L/5) - I:	13 1/4	(337)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	66	(1676)
Distance from center of vehicle to center of contact damage - D_C:	0	()

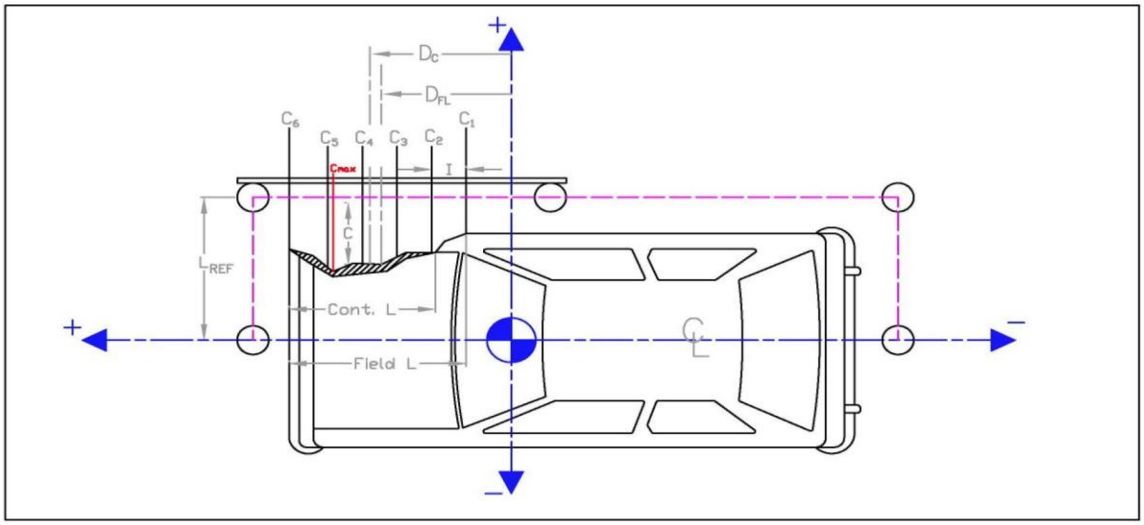
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	N/A	NA	-33	-(838)	15 5/8	(397)	12 3/4	(324)	NA	NA
C_2	25 1/8	(638)	-19 3/4	-(502)	6 3/4	(171)			5 5/8	(143)
C_3	25 1/8	(638)	-6 1/2	-(165)	4 3/8	(111)			8	(203)
C_4	23 1/2	(597)	6 3/4	(171)	4 1/2	(114)			6 1/4	(159)
C_5	31 5/8	(803)	20	(508)	6 7/8	(175)			12	(305)
C_6	N/A	NA	33 1/4	(845)	15 5/8	(397)			NA	NA
C_{MAX}	41 3/4	(1060)	23	(584)	8 1/4	(210)			20 3/4	(527)

Figure C-4. Exterior Vehicle Crush (NASS) – Front, Test No. OCBR-1

Test Name: OCBR-1 **VIN:** KMHCT4AF5FU879644

Model Year: 2015 **Make:** Hyundai **Model:** Accent



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	40	(1016)
Total Vehicle Length:	167 3/4	(4261)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-13 3/8	-(340)
Width of contact and induced crush - Field L:	167 3/4	(4261)
Crush measurement spacing interval (L/5) - I:	33 1/2	(851)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-13 3/8	-(340)
Width of Contact Damage:	167 3/4	(4261)
Distance from vehicle c.g. to center of contact damage - D_C:	-13 3/8	-(340)

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	-97 1/4	-(2470)	24	(610)	-1 1/4	-(32)	NA	NA
C_2	N/A	NA	-63 3/4	-(1619)	7	(178)			NA	NA
C_3	6 1/8	(156)	-30 1/4	-(768)	8 1/8	(206)			- 3/4	-(19)
C_4	6 1/4	(159)	3 1/4	(83)	8 1/4	(210)			- 3/4	-(19)
C_5	N/A	NA	36 3/4	(933)	7	(178)			NA	NA
C_6	N/A	NA	70 1/4	(1784)	25 5/8	(651)			NA	NA
C_{MAX}	23 3/4	(603)	62 1/2	(1588)	10	(254)			15	(381)

Figure C-5. Exterior Vehicle Crush (NASS) – Side, Test No. OCBR-1

Model Year: 2015 | Test Name: OCBR-2 | VIN: 1C6RR6FG6FS720783
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	54.8010	29.3599	-7.9976	54.6491	29.3942	-7.9910	0.1519	-0.0343	-0.0066	0.1559	0.1519	X
	2	55.6835	33.3055	-5.9341	55.4589	33.2923	-5.6872	0.2246	0.0132	-0.2469	0.3340	0.2246	X
	3	56.9143	36.5973	-2.5067	56.8333	36.3894	-2.1188	0.0810	0.2079	-0.3879	0.4475	0.0810	X
	4	57.2738	40.9300	-2.1646	56.6720	40.4628	-2.1734	0.6018	0.4672	0.0088	0.7619	0.6019	X, Z
	5	57.2859	47.1416	-2.0552	55.9178	45.8561	-2.3734	1.3681	1.2855	0.3182	1.9041	1.4046	X, Z
	6	51.5505	28.0366	-6.7562	51.3383	28.0208	-6.8448	0.2122	0.0158	0.0886	0.2305	0.2300	X, Z
	7	52.6806	33.2207	-3.8716	52.4954	33.0094	-3.6627	0.1852	0.2113	-0.2089	0.3501	0.1852	X
	8	53.8577	36.6731	-0.5334	53.6887	36.3620	-0.1317	0.1690	0.3111	-0.4017	0.5355	0.1690	X
	9	54.1860	41.5081	-0.3937	53.9191	41.0820	0.0878	0.2669	0.4261	-0.4815	0.6962	0.2669	X
	10	54.2568	47.5080	-0.3529	53.7694	46.7032	0.0665	0.4874	0.8048	-0.4194	1.0301	0.4874	X
FLOOR PAN (Z)	11	48.1461	27.1894	-5.6314	48.1229	26.9325	-5.4845	0.0232	0.2569	-0.1469	0.2968	-0.1469	Z
	12	49.6589	32.6946	-1.4346	49.5145	32.3190	-1.1891	0.1444	0.3756	-0.2455	0.4714	-0.2455	Z
	13	50.6951	36.9795	1.0445	50.5399	36.6527	1.4654	0.1552	0.3268	-0.4209	0.5550	-0.4209	Z
	14	50.8504	41.8867	1.0448	50.7374	41.3764	1.8270	0.1130	0.5103	-0.7822	0.9408	-0.7822	Z
	15	51.0027	47.6332	1.0233	50.8186	47.1697	1.9463	0.1841	0.4635	-0.9230	1.0491	-0.9230	Z
	16	44.7411	27.3128	-4.5005	44.6419	27.0896	-4.4328	0.0992	0.2232	-0.0677	0.2535	-0.0677	Z
	17	46.7698	31.9069	0.9140	46.6161	31.6218	1.1014	0.1537	0.2851	-0.1874	0.3742	-0.1874	Z
	18	46.9944	37.2805	1.0979	46.8764	36.9897	1.5702	0.1180	0.2908	-0.4723	0.5671	-0.4723	Z
	19	47.1740	42.2376	1.0789	47.0785	41.8981	2.0336	0.0955	0.3395	-0.9547	1.0178	-0.9547	Z
	20	47.1772	47.7017	1.0896	47.1018	47.2542	2.1251	0.0754	0.4475	-1.0355	1.1306	-1.0355	Z
	21	39.0604	27.7172	-3.6461	38.9977	27.7973	-3.7948	0.0627	-0.0801	0.1487	0.1802	0.1487	Z
	22	40.8558	32.2481	1.1454	40.7448	32.0129	1.2902	0.1110	0.2352	-0.1448	0.2977	-0.1448	Z
	23	40.8929	37.0442	1.1175	40.7907	36.7282	1.4663	0.1022	0.3160	-0.3488	0.4816	-0.3488	Z
	24	41.1342	42.6995	1.0988	41.0808	42.3063	2.0058	0.0534	0.3932	-0.9070	0.9900	-0.9070	Z
	25	41.2370	47.9690	1.0959	41.2691	47.6269	2.1388	-0.0321	0.3421	-1.0429	1.0980	-1.0429	Z
	26	35.0681	27.9657	-3.1699	35.0106	28.0637	-3.3575	0.0575	-0.0980	0.1876	0.2193	0.1876	Z
	27	35.2234	32.4693	0.3679	35.1313	32.1885	0.4183	0.0921	0.2808	-0.0504	0.2998	-0.0504	Z
	28	35.3603	36.9954	0.3400	35.3252	36.7665	0.5227	0.0351	0.2289	-0.1827	0.2950	-0.1827	Z
	29	35.3545	41.6382	0.3223	35.3511	41.4204	0.6496	0.0034	0.2178	-0.3273	0.3932	-0.3273	Z
	30	35.5231	46.6965	0.3090	35.5552	46.5394	0.7518	-0.0321	0.1571	-0.4428	0.4709	-0.4428	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. OCBR-2

Model Year: 2015 | Test Name: OCBR-2 | VIN: 1C6RR6FG6FS720783
Make: Dodge | 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	51.2332	15.8477	-4.0429	51.1587	15.8172	-3.7210	0.0745	0.0305	-0.3219	0.3318	0.0745	X
	2	51.9851	19.8129	-1.9655	51.8286	19.7400	-1.4142	0.1565	0.0729	-0.5513	0.5777	0.1565	X
	3	53.1155	23.1310	1.4711	53.0890	22.8813	2.1577	0.0265	0.2497	-0.6866	0.7311	0.0265	X
	4	53.3220	27.4722	1.8317	52.7856	26.9467	2.1048	0.5364	0.5255	-0.2731	0.7990	0.5364	X
	5	53.1132	33.6797	1.9701	51.8438	32.3104	1.9062	1.2694	1.3693	0.0639	1.8683	1.2710	X, Z
	6	48.0384	14.4036	-2.7916	47.8963	14.3284	-2.5803	0.1421	0.0752	-0.2113	0.2655	0.1421	X
	7	48.9979	19.6118	0.1116	48.8740	19.3527	0.6058	0.1239	0.2591	-0.4942	0.5716	0.1239	X
	8	50.0684	23.0889	3.4600	49.9444	22.7430	4.1402	0.1240	0.3459	-0.6802	0.7731	0.1240	X
	9	50.2248	27.9318	3.6207	50.0096	27.4682	4.3622	0.2152	0.4636	-0.7415	0.9006	0.2152	X
	10	50.0819	33.9302	3.6893	49.6636	33.0806	4.3434	0.4183	0.8496	-0.6541	1.1509	0.4183	X
FLOOR PAN (Z)	11	44.6722	13.4305	-1.6537	44.7190	13.1278	-1.2250	-0.0468	0.3027	-0.4287	0.5269	-0.4287	Z
	12	46.0094	18.9672	2.5613	45.9155	18.5573	3.0749	0.0939	0.4099	-0.5136	0.6638	-0.5136	Z
	13	46.9050	23.2751	5.0551	46.7852	22.9228	5.7329	0.1198	0.3523	-0.6778	0.7732	-0.6778	Z
	14	46.8853	28.1847	5.0777	46.8170	27.6504	6.0970	0.0683	0.5343	-1.0193	1.1529	-1.0193	Z
	15	46.8326	33.9330	5.0824	46.6956	33.4429	6.2191	0.1370	0.4901	-1.1367	1.2454	-1.1367	Z
	16	41.2708	13.4273	-0.5051	41.2331	13.1626	-0.1783	0.0377	0.2647	-0.3268	0.4222	-0.3268	Z
	17	43.1624	18.0664	4.9206	43.0399	17.7582	5.3608	0.1225	0.3082	-0.4402	0.5512	-0.4402	Z
	18	43.1963	23.4437	5.1285	43.1119	23.1316	5.8326	0.0844	0.3121	-0.7041	0.7748	-0.7041	Z
	19	43.1990	28.4041	5.1318	43.1418	28.0438	6.2986	0.0572	0.3603	-1.1668	1.2225	-1.1668	Z
	20	43.0074	33.8648	5.1681	42.9779	33.3974	6.3927	0.0295	0.4674	-1.2246	1.3111	-1.2246	Z
	21	35.5839	13.6249	0.3795	35.5667	13.6725	0.4519	0.0172	-0.0476	-0.0724	0.0883	-0.0724	Z
	22	37.2413	18.1954	5.1832	37.1583	17.9439	5.5414	0.0830	0.2515	-0.3582	0.4455	-0.3582	Z
	23	37.1072	22.9898	5.1775	37.0392	22.6578	5.7198	0.0680	0.3320	-0.5423	0.6395	-0.5423	Z
	24	37.1467	28.6501	5.1841	37.1336	28.2424	6.2623	0.0131	0.4077	-1.0782	1.1528	-1.0782	Z
	25	37.0616	33.9200	5.2054	37.1357	33.5662	6.3981	-0.0741	0.3538	-1.1927	1.2463	-1.1927	Z
	26	31.5877	13.7287	0.8768	31.5721	13.7993	0.8836	0.0156	-0.0706	-0.0068	0.0726	-0.0068	Z
	27	31.6007	18.2190	4.4349	31.5434	17.9238	4.6614	0.0573	0.2952	-0.2265	0.3765	-0.2265	Z
	28	31.5760	22.7472	4.4275	31.5771	22.5057	4.7683	-0.0011	0.2415	-0.3408	0.4177	-0.3408	Z
	29	31.4046	27.3868	4.4316	31.4403	27.1576	4.8974	-0.0357	0.2292	-0.4658	0.5204	-0.4658	Z
	30	31.3927	32.4479	4.4411	31.4653	32.2805	5.0024	-0.0726	0.1674	-0.5613	0.5902	-0.5613	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. OCBR-2

Model Year: 2015 | Test Name: OCBR-2 | VIN: 1C6RR6FG6FS720783
Make: Dodge | 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	48.0048	48.2788	-30.7616	48.1675	48.1532	-31.0327	-0.1627	0.1256	-0.2711	0.3402	0.3402	X, Y, Z
	2	46.3174	34.1099	-31.0191	46.4252	33.9940	-31.3162	-0.1078	0.1159	-0.2971	0.3366	0.3366	X, Y, Z
	3	42.6833	18.5294	-30.8412	42.8269	18.3609	-31.0184	-0.1436	0.1685	-0.1772	0.2836	0.2836	X, Y, Z
	4	43.3084	48.6263	-20.2775	43.1286	48.3861	-20.6270	0.1798	0.2402	-0.3495	0.4606	0.4606	X, Y, Z
	5	42.2390	36.5923	-20.8576	42.2915	36.3632	-21.2404	-0.0525	0.2291	-0.3828	0.4492	0.4492	X, Y, Z
	6	39.7393	18.6579	-20.1431	39.8168	18.5481	-20.4171	-0.0775	0.1098	-0.2740	0.3052	0.3052	X, Y, Z
SIDE PANEL (Y)	7	52.0636	50.9181	-4.3059	51.7025	49.2602	-4.3863	0.3611	1.6579	-0.0804	1.6987	1.6579	Y
	8	52.0528	50.9280	-8.7097	51.5371	48.7977	-8.7783	0.5157	2.1303	-0.0686	2.1929	2.1303	Y
	9	54.9277	50.8414	-6.6212	54.4811	49.3025	-6.8567	0.4466	1.5389	-0.2355	1.6196	1.5389	Y
IMPACT SIDE DOOR (Y)	10	19.6130	53.7280	-17.9955	19.0914	54.9637	-17.9696	0.5216	-1.2357	0.0259	1.3415	-1.2357	Y
	11	32.4776	53.7330	-17.9626	31.8476	54.5093	-18.1488	0.6300	-0.7763	-0.1862	1.0170	-0.7763	Y
	12	39.7079	53.3830	-18.3973	39.0212	53.2768	-18.5441	0.6867	0.1062	-0.1468	0.7102	0.1062	Y
	13	19.1846	53.7773	-8.0521	18.6760	54.7787	-8.2805	0.5086	-1.0014	-0.2284	1.1461	-1.0014	Y
	14	31.9737	54.4488	-8.3579	31.3932	54.9300	-8.5618	0.5805	-0.4812	-0.2039	0.7811	-0.4812	Y
	15	38.7510	53.8806	-7.8567	38.1500	53.9089	-8.0138	0.6010	-0.0283	-0.1571	0.6218	-0.0283	Y
ROOF - (Z)	16	35.8008	40.2969	-46.4626	35.8892	40.2995	-46.9812	-0.0884	-0.0026	-0.5186	0.5261	-0.5186	Z
	17	37.8657	31.4838	-46.6295	37.9308	31.5253	-47.0339	-0.0651	-0.0415	-0.4044	0.4117	-0.4044	Z
	18	38.5481	22.7994	-46.7991	38.6800	22.7570	-47.0434	-0.1319	0.0424	-0.2443	0.2809	-0.2443	Z
	19	29.8042	39.8941	-49.0653	29.8401	39.8907	-49.4940	-0.0359	0.0034	-0.4287	0.4302	-0.4287	Z
	20	31.7433	31.0269	-49.4018	31.8187	31.0118	-49.5930	-0.0754	0.0151	-0.1912	0.2061	-0.1912	Z
	21	32.3924	16.5553	-49.4790	32.3935	22.9247	-49.8289	-0.0011	-6.3694	-0.3499	6.3790	-0.3499	Z
	22	12.3581	40.0702	-50.5109	12.3110	40.0176	-50.5947	0.0471	0.0526	-0.0838	0.1096	-0.0838	Z
	23	12.4528	31.3988	-51.2167	12.5062	31.4104	-51.2723	-0.0534	-0.0116	-0.0556	0.0780	-0.0556	Z
	24	12.0733	23.1981	-51.3627	12.0902	23.1397	-51.4459	-0.0169	0.0584	-0.0832	0.1030	-0.0832	Z
	25	-1.0675	40.2695	-50.9046	-0.9850	40.2541	-51.1034	-0.0825	0.0154	-0.1988	0.2158	-0.1988	Z
	26	-1.4773	31.6226	-51.3297	-1.4119	31.5306	-51.4548	-0.0654	0.0920	-0.1251	0.1685	-0.1251	Z
	27	-1.3055	23.0382	-51.5097	-1.2045	22.9280	-51.6133	-0.1010	0.1102	-0.1036	0.1819	-0.1036	Z
	28	-17.2215	40.4583	-50.7377	-17.1739	40.4130	-50.8963	-0.0476	0.0453	-0.1586	0.1717	-0.1586	Z
	29	-17.2998	31.2036	-51.0998	-17.2926	31.0722	-51.2284	-0.0072	0.1314	-0.1286	0.1840	-0.1286	Z
	30	-16.9010	22.9490	-51.1642	-16.8986	22.8309	-51.2654	-0.0024	0.1181	-0.1012	0.1555	-0.1012	Z
A-PILLAR Maximum (X, Y, Z)	31	52.9143	49.6806	-32.0992	52.6550	49.6767	-32.3529	0.2593	0.0039	-0.2537	0.3628	0.2593	X, Y
	32	49.1742	48.8822	-34.8223	48.9983	48.7927	-35.2256	0.1759	0.0895	-0.4033	0.4490	0.1974	X, Y
	33	44.1173	47.7466	-38.5762	44.0425	47.6910	-39.1227	0.0748	0.0556	-0.5465	0.5544	0.0932	X, Y
	34	41.0589	47.3256	-41.1915	40.9881	47.2943	-41.7426	0.0708	0.0313	-0.5511	0.5565	0.0774	X, Y
	35	37.7320	46.7258	-43.6713	37.7987	46.7908	-44.3325	-0.0667	-0.0650	-0.6612	0.6677	0.0000	NA
	36	34.3580	45.7166	-45.0573	34.3653	45.8555	-45.6991	-0.0073	-0.1389	-0.6418	0.6567	0.0000	NA
A-PILLAR Lateral (Y)	31	52.9143	49.6806	-32.0992	52.6550	49.6767	-32.3529	0.2593	0.0039	-0.2537	0.3628	0.0039	Y
	32	49.1742	48.8822	-34.8223	48.9983	48.7927	-35.2256	0.1759	0.0895	-0.4033	0.4490	0.0895	Y
	33	44.1173	47.7466	-38.5762	44.0425	47.6910	-39.1227	0.0748	0.0556	-0.5465	0.5544	0.0556	Y
	34	41.0589	47.3256	-41.1915	40.9881	47.2943	-41.7426	0.0708	0.0313	-0.5511	0.5565	0.0313	Y
	35	37.7320	46.7258	-43.6713	37.7987	46.7908	-44.3325	-0.0667	-0.0650	-0.6612	0.6677	-0.0650	Y
	36	34.3580	45.7166	-45.0573	34.3653	45.8555	-45.6991	-0.0073	-0.1389	-0.6418	0.6567	-0.1389	Y
B-PILLAR Maximum (X, Y, Z)	37	10.9874	46.2645	-45.7876	10.9398	46.1973	-46.0421	0.0476	0.0672	-0.2545	0.2675	0.0824	X, Y
	38	8.5032	49.4340	-37.4506	8.4703	49.3368	-37.6477	0.0329	0.0972	-0.1971	0.2222	0.1026	X, Y
	39	11.9323	50.1442	-34.7965	11.9163	50.0557	-34.9587	0.0160	0.0885	-0.1622	0.1855	0.0899	X, Y
	40	9.2654	51.1208	-28.9069	9.2421	51.0054	-29.0374	0.0233	0.1154	-0.1305	0.1758	0.1177	X, Y
B-PILLAR Lateral (Y)	37	10.9874	46.2645	-45.7876	10.9398	46.1973	-46.0421	0.0476	0.0672	-0.2545	0.2675	0.0672	Y
	38	8.5032	49.4340	-37.4506	8.4703	49.3368	-37.6477	0.0329	0.0972	-0.1971	0.2222	0.0972	Y
	39	11.9323	50.1442	-34.7965	11.9163	50.0557	-34.9587	0.0160	0.0885	-0.1622	0.1855	0.0885	Y
	40	9.2654	51.1208	-28.9069	9.2421	51.0054	-29.0374	0.0233	0.1154	-0.1305	0.1758	0.1154	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. OCBR-2

Test Name: OCBR-2 VIN: 1C6RR6FG6FS720783

Model Year: 2015 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	43.6446	34.5734	-26.7318	44.0516	34.3503	-26.7768	-0.4070	0.2231	-0.0450	0.4663	0.4663	X, Y, Z
	2	42.4608	20.3544	-27.0287	42.8067	20.1388	-27.0673	-0.3459	0.2156	-0.0386	0.4094	0.4094	X, Y, Z
	3	39.3840	4.6540	-26.8851	39.7577	4.3892	-26.7793	-0.3737	0.2648	0.1058	0.4701	0.4701	X, Y, Z
	4	38.9940	34.7200	-16.2226	38.9949	34.4025	-16.3772	-0.0009	0.3175	-0.1546	0.3531	0.3531	X, Y, Z
	5	38.3501	22.6575	-16.8381	38.5801	22.3579	-16.9958	-0.2300	0.2996	-0.1577	0.4093	0.4093	X, Y, Z
	6	36.4935	4.6433	-16.1716	36.7299	4.4668	-16.1817	-0.2364	0.1765	-0.0101	0.2952	0.2952	X, Y, Z
SIDE PANEL (Y)	7	47.7460	37.2705	-0.2886	47.5130	35.5701	-0.1256	0.2330	1.7004	0.1630	1.7240	1.7004	Y
	8	47.7118	37.2942	-4.6922	47.3693	35.1038	-4.5179	0.3425	2.1904	0.1743	2.2239	2.1904	Y
	9	50.5989	37.3032	-2.6188	50.2915	35.7106	-2.5926	0.3074	1.5926	0.0262	1.6222	1.5926	Y
IMPACT SIDE DOOR (Y)	10	15.1445	38.9681	-13.8016	14.7388	40.1332	-13.7473	0.4057	-1.1651	0.0543	1.2349	-1.1651	Y
	11	28.0008	39.4307	-13.8348	27.5033	40.1260	-13.9109	0.4975	-0.6953	-0.0761	0.8583	-0.6953	Y
	12	35.2366	39.3395	-14.3079	34.7161	39.1456	-14.2977	0.5205	0.1939	0.0102	0.5555	0.1939	Y
	13	14.7669	38.9703	-3.8560	14.3183	39.9301	-4.0588	0.4486	-0.9598	-0.2028	1.0787	-0.9598	Y
	14	27.5223	40.0973	-4.2253	27.0227	40.5267	-4.3243	0.4996	-0.4294	-0.0990	0.6662	-0.4294	Y
	15	34.3181	39.7689	-3.7608	33.8105	39.7427	-3.7683	0.5076	0.0262	-0.0075	0.5083	0.0262	Y
ROOF - (Z)	16	31.6498	26.2128	-42.3969	32.0754	26.0776	-42.7431	-0.4256	0.1352	-0.3462	0.5650	-0.3462	Z
	17	34.0258	17.4793	-42.6043	34.4232	17.3803	-42.7964	-0.3974	0.0990	-0.1921	0.4524	-0.1921	Z
	18	35.0157	8.8253	-42.8068	35.4790	8.6436	-42.8079	-0.4633	0.1817	-0.0011	0.4977	-0.0011	Z
	19	25.6577	25.6053	-44.9701	26.0474	25.4581	-45.2636	-0.3897	0.1472	-0.2935	0.5096	-0.2935	Z
	20	27.9091	16.8138	-45.3466	28.3359	16.6540	-45.3632	-0.4268	0.1598	-0.0166	0.4560	-0.0166	Z
	21	29.0719	2.3747	-45.4763	29.1939	8.5921	-45.6012	-0.1220	-6.2174	-0.1249	6.2199	-0.1249	Z
	22	8.2090	25.1653	-46.3254	8.5260	24.9715	-46.3860	-0.3170	0.1938	-0.0606	0.3765	-0.0606	Z
	23	8.6083	16.5051	-47.0611	9.0234	16.3767	-47.0662	-0.4151	0.1284	-0.0051	0.4345	-0.0051	Z
	24	8.5198	8.2965	-47.2330	8.8976	8.0965	-47.2433	-0.3778	0.2000	-0.0103	0.4276	-0.0103	Z
	25	-5.2170	24.8881	-46.6494	-4.7694	24.7424	-46.9111	-0.4476	0.1457	-0.2617	0.5386	-0.2617	Z
	26	-5.3214	16.2335	-47.1017	-4.8901	16.0095	-47.2659	-0.4313	0.2240	-0.1642	0.5130	-0.1642	Z
	27	-4.8454	7.6613	-47.3118	-4.3814	7.4195	-47.4272	-0.4640	0.2418	-0.1154	0.5358	-0.1154	Z
	28	-21.3665	24.5016	-46.3989	-20.9542	24.3341	-46.7240	-0.4123	0.1675	-0.3251	0.5511	-0.3251	Z
	29	-21.1176	15.2512	-46.7919	-20.7453	14.9950	-47.0594	-0.3723	0.2562	-0.2675	0.5252	-0.2675	Z
	30	-20.4258	7.0162	-46.8864	-20.0628	6.7726	-47.0987	-0.3630	0.2436	-0.2123	0.4860	-0.2123	Z
A-PILLAR Maximum (X, Y, Z)	31	48.4940	36.1532	-28.0900	48.4847	36.0305	-28.0909	0.0093	0.1227	-0.0009	0.1231	0.1231	X, Y
	32	44.7705	35.2310	-30.7964	44.8646	35.0201	-30.9684	-0.0941	0.2109	-0.1720	0.2880	0.2109	Y
	33	39.7374	33.9283	-34.5281	39.9553	33.7471	-34.8721	-0.2179	0.1812	-0.3440	0.4457	0.1812	Y
	34	36.6823	33.4072	-37.1291	36.9199	33.2446	-37.4958	-0.2376	0.1626	-0.3667	0.4662	0.1626	Y
	35	33.3658	32.6973	-39.5938	33.7532	32.6307	-40.0899	-0.3874	0.0666	-0.4961	0.6330	0.0666	Y
	36	30.0226	31.5732	-40.9659	30.3563	31.5763	-41.4610	-0.3337	-0.0031	-0.4951	0.5971	0.0000	NA
A-PILLAR Lateral (Y)	31	48.4940	36.1532	-28.0900	48.4847	36.0305	-28.0909	0.0093	0.1227	-0.0009	0.1231	0.1227	Y
	32	44.7705	35.2310	-30.7964	44.8646	35.0201	-30.9684	-0.0941	0.2109	-0.1720	0.2880	0.2109	Y
	33	39.7374	33.9283	-34.5281	39.9553	33.7471	-34.8721	-0.2179	0.1812	-0.3440	0.4457	0.1812	Y
	34	36.6823	33.4072	-37.1291	36.9199	33.2446	-37.4958	-0.2376	0.1626	-0.3667	0.4662	0.1626	Y
	35	33.3658	32.6973	-39.5938	33.7532	32.6307	-40.0899	-0.3874	0.0666	-0.4961	0.6330	0.0666	Y
	36	30.0226	31.5732	-40.9659	30.3563	31.5763	-41.4610	-0.3337	-0.0031	-0.4951	0.5971	-0.0031	Y
B-PILLAR Maximum (X, Y, Z)	37	6.6437	31.2917	-41.5742	6.9336	31.0976	-41.8329	-0.2899	0.1941	-0.2587	0.4343	0.1941	Y
	38	4.0924	34.3441	-33.2138	4.3454	34.1455	-33.4406	-0.2530	0.1986	-0.2268	0.3936	0.1986	Y
	39	7.5079	35.1673	-30.5749	7.7608	34.9836	-30.7470	-0.2529	0.1837	-0.1721	0.3568	0.1837	Y
	40	4.8389	36.0296	-24.6685	5.0478	35.8367	-24.8287	-0.2089	0.1929	-0.1602	0.3264	0.1929	Y
B-PILLAR Lateral (Y)	37	6.6437	31.2917	-41.5742	6.9336	31.0976	-41.8329	-0.2899	0.1941	-0.2587	0.4343	0.1941	Y
	38	4.0924	34.3441	-33.2138	4.3454	34.1455	-33.4406	-0.2530	0.1986	-0.2268	0.3936	0.1986	Y
	39	7.5079	35.1673	-30.5749	7.7608	34.9836	-30.7470	-0.2529	0.1837	-0.1721	0.3568	0.1837	Y
	40	4.8389	36.0296	-24.6685	5.0478	35.8367	-24.8287	-0.2089	0.1929	-0.1602	0.3264	0.1929	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. OCBR-2

Test Name: OCBR-2 VIN: 1C6RR6FG6FS720783

Model Year: 2015 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	-0.5	≤ 4	Z	Roof	-0.3	≤ 4	Z
Windshield[D]	0.0	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	0.3	≤ 5	X, Y	A-Pillar Maximum	0.2	≤ 5	Y
A-Pillar Lateral	0.1	≤ 3	Y	A-Pillar Lateral	0.2	≤ 3	Y
B-Pillar Maximum	0.1	≤ 5	X, Y	B-Pillar Maximum	0.2	≤ 5	Y
B-Pillar Lateral	0.1	≤ 3	Y	B-Pillar Lateral	0.2	≤ 3	Y
Toe Pan - Wheel Well	1.4	≤ 9	X, Z	Toe Pan - Wheel Well	1.3	≤ 9	X, Z
Side Front Panel	2.1	≤ 12	Y	Side Front Panel	2.2	≤ 12	Y
Side Door (above seat)	0.1	≤ 9	Y	Side Door (above seat)	0.2	≤ 9	Y
Side Door (below seat)	-1.0	≤ 12	Y	Side Door (below seat)	0.0	≤ 12	Y
Floor Pan	0.2	≤ 12	Z	Floor Pan	-1.2	≤ 12	Z
Dash - no MASH requirement	0.5	NA	X, Y, Z	Dash - no MASH requirement	0.5	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.

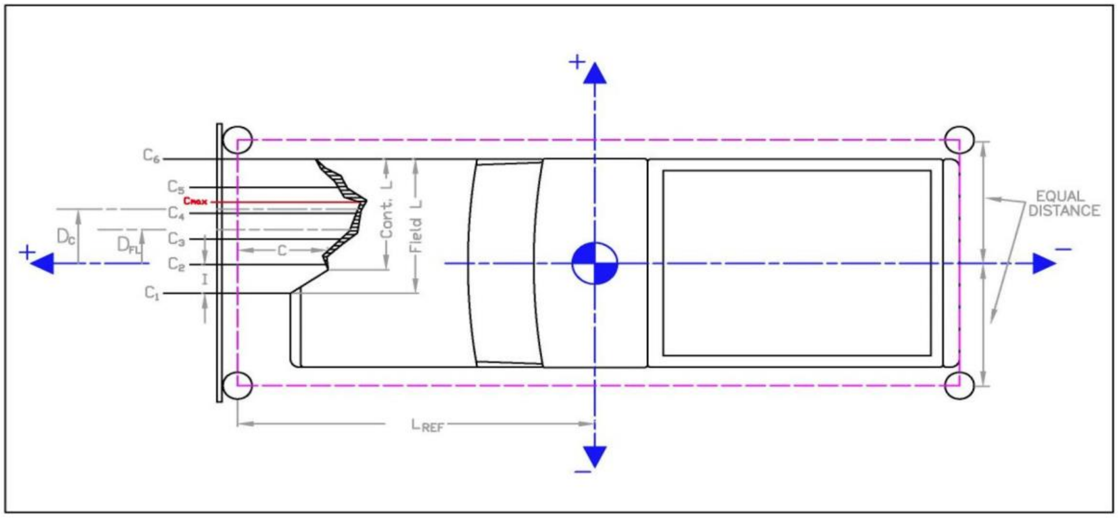
[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle interior crush:

Figure C-10. Maximum Occupant Compartment Deformation by Location, Test No. OCBR-2

Test Name: OCBR-2 **VIN:** 1C6RR6FG6FS720783

Model Year: 2015 **Make:** Dodge **Model:** Ram 1500



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	123	(3124)
Total Vehicle Width:	75 5/8	(1921)
Width of contact and induced crush - Field L:	75 5/8	(1921)
Crush measurement spacing interval (L/5) - I:	15 1/8	(384)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	21 1/3	(541)
Distance from center of vehicle to center of contact damage - D_C:	21 1/6	(537)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

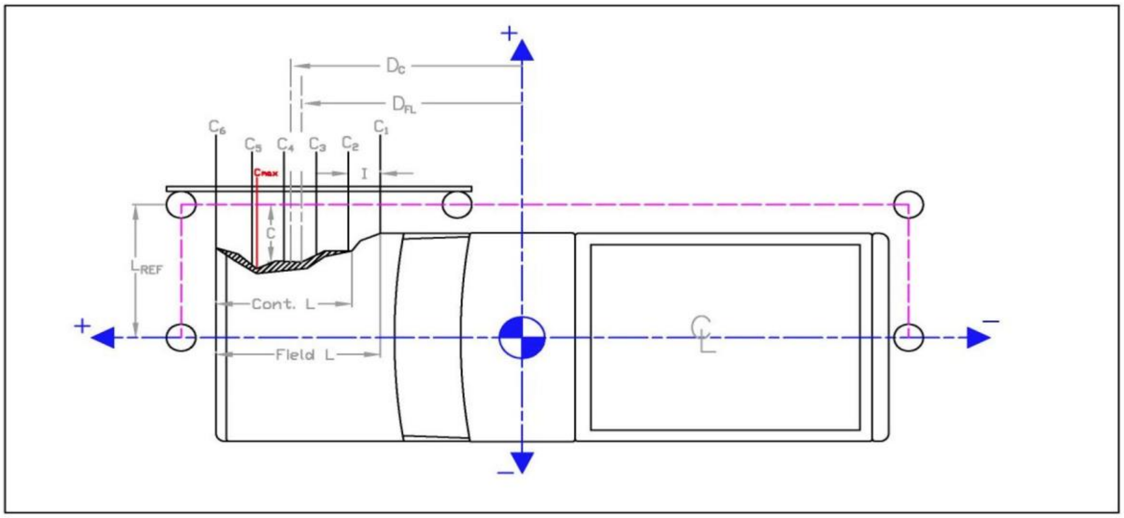
NOTE: All values must be filled out above before crush measurements are filled out.

	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	29 3/4	(756)	-37 7/8	-(962)	22 1/2	(572)	12 5/8	(321)	-5 3/8	-(137)
C_2	17 1/2	(445)	-22 3/4	-(578)	6 3/8	(162)			-1 1/2	-(38)
C_3	16	(406)	-7 5/8	-(194)	4 1/4	(108)			- 7/8	-(22)
C_4	16 3/8	(416)	7 1/2	(191)	4 1/4	(108)			- 1/2	-(13)
C_5	34 1/8	(867)	22 5/8	(575)	6	(152)			15 1/2	(394)
C_6	N/A	N/A	37 3/4	(959)	19 7/8	(505)			N/A	N/A
C_{MAX}	34 1/8	(867)	22 5/8	(575)	6	(152)			15 1/2	(394)

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

Test Name: OCBR-2 **VIN:** 1C6RR6FG6FS720783

Model Year: 2015 **Make:** Dodge **Model:** Ram 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	48 5/8	(1235)
Total Vehicle Length:	229 1/4	(5823)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-6 1/2	-(165)
Width of contact and induced crush - Field L:	229 1/4	(5823)
Crush measurement spacing interval (L/5) - I:	45 7/8	(1165)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-6 1/2	-(165)
Width of Contact Damage:	229 1/4	(5823)
Distance from vehicle c.g. to center of contact damage - D_C:	-6 1/2	-(165)

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	14	(356)	-121 1/8	-(3077)	33 1/2	(851)	4 5/8	(117)	-24 1/8	-(613)
C_2	N/A	N/A	-75 1/4	-(1911)	5 1/2	(140)			N/A	N/A
C_3	9 1/2	(241)	-29 3/8	-(746)	5 7/8	(149)			-1	-(25)
C_4	9 3/8	(238)	16 1/2	(419)	5	(127)			- 1/4	-(6)
C_5	N/A	N/A	62 3/8	(1584)	5 5/8	(143)			N/A	N/A
C_6	N/A	N/A	108 1/4	(2750)	14	(356)			N/A	N/A
C_{MAX}	29 3/8	(746)	94	(2388)	6	(152)			18 3/4	(476)

Figure C-12. Exterior Vehicle Crush (NASS) – Side, Test No. OCBR-2

Test Name: OCBR-3 VIN: 1HTMMAAPXDH412511

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

MAXIMUM COMPARATIVE INTERIOR VEHICLE DEFORMATION

	POINT	Floor pan location	Upper reference location	Lateral Referece Length	Lateral Reference Side (Driver or Pass.)	Examplar Vehicle Measurement	Test Vehicle Measurment	Crush (in.)
WINDSHIELD	1	2.5" from right side door seal, along lateral body seam.	Left most mounting hole for right side visor.	2.5	Passenger	54 1/2	50	4.5
								.

Examplar Vehicle Description

Year: 2005 Make: International Model: 4300 SBA 4x2 VIN: 1HTMMAAL65H681961

Deformation Notes:

The point that was measured in the reference vehicle had the floor covering peeled back to reveal the steel floor pan beneath. The referenced visor bolt hole was also void of visor and hardware at the time of measurement. Also note the model year of reference vehicle is 2005, not 2013 as is the tested vehicle. However, the cabs are idenical.

Test Vehicle Damage	Examplar Vehicle
	

Figure C-13. Comparative Occupant Compartment Crush Measurement, Test No. OCBR-3

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

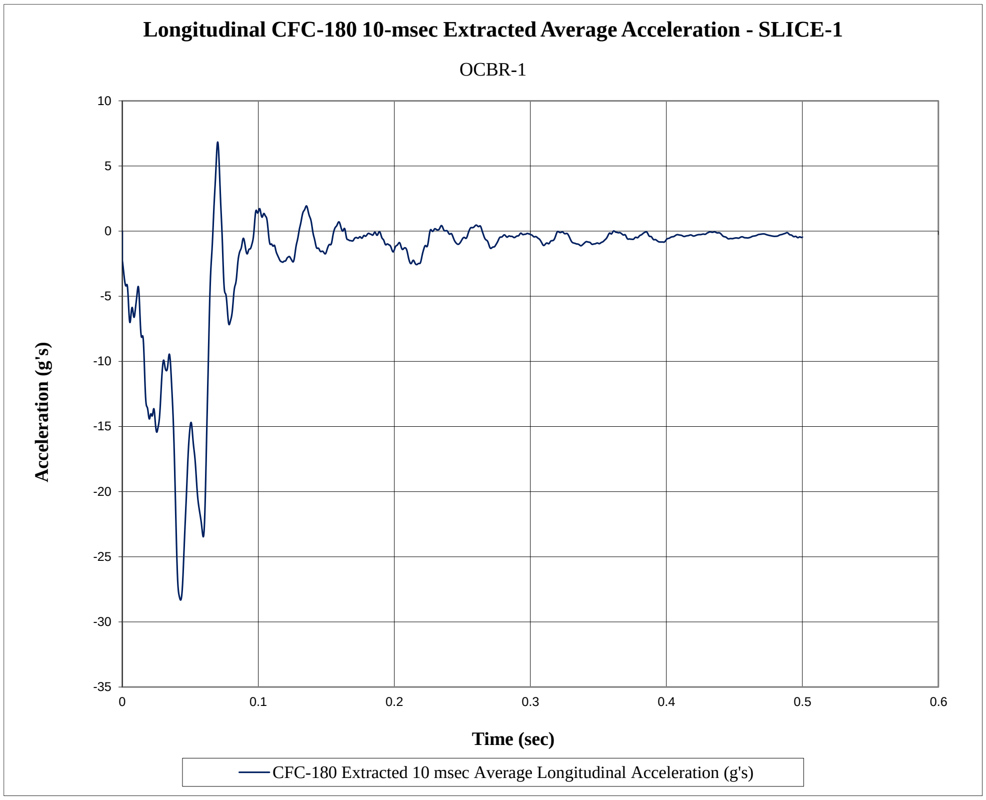


Figure D-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. OCBR-1

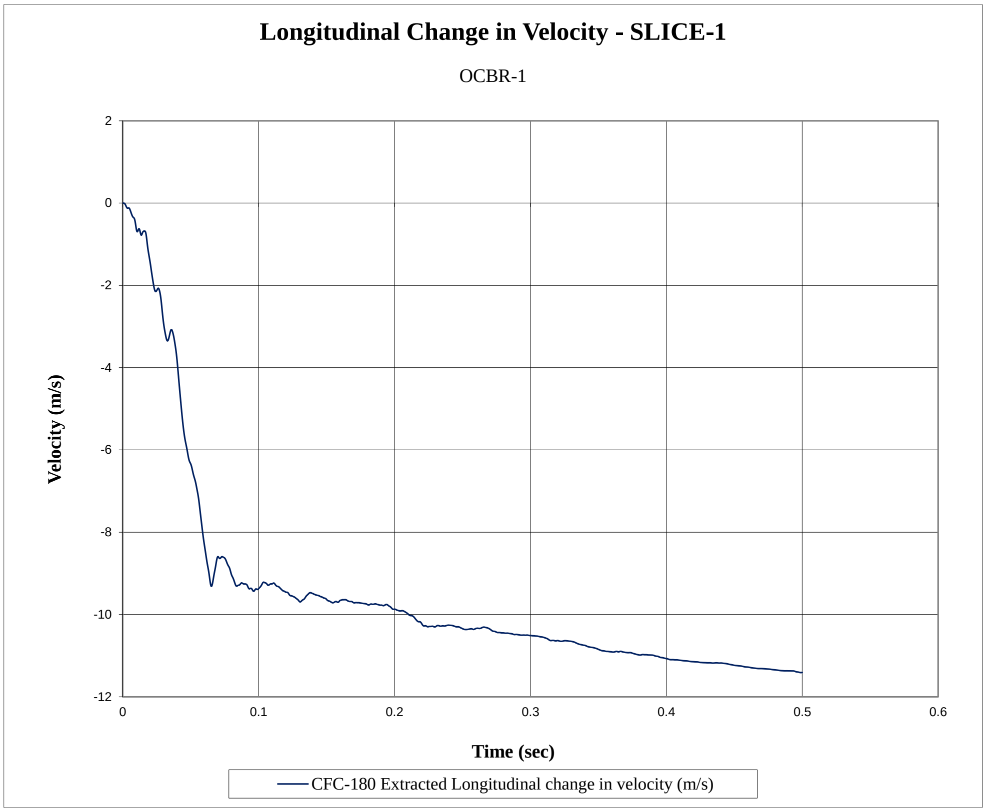


Figure D-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. OCBR-1

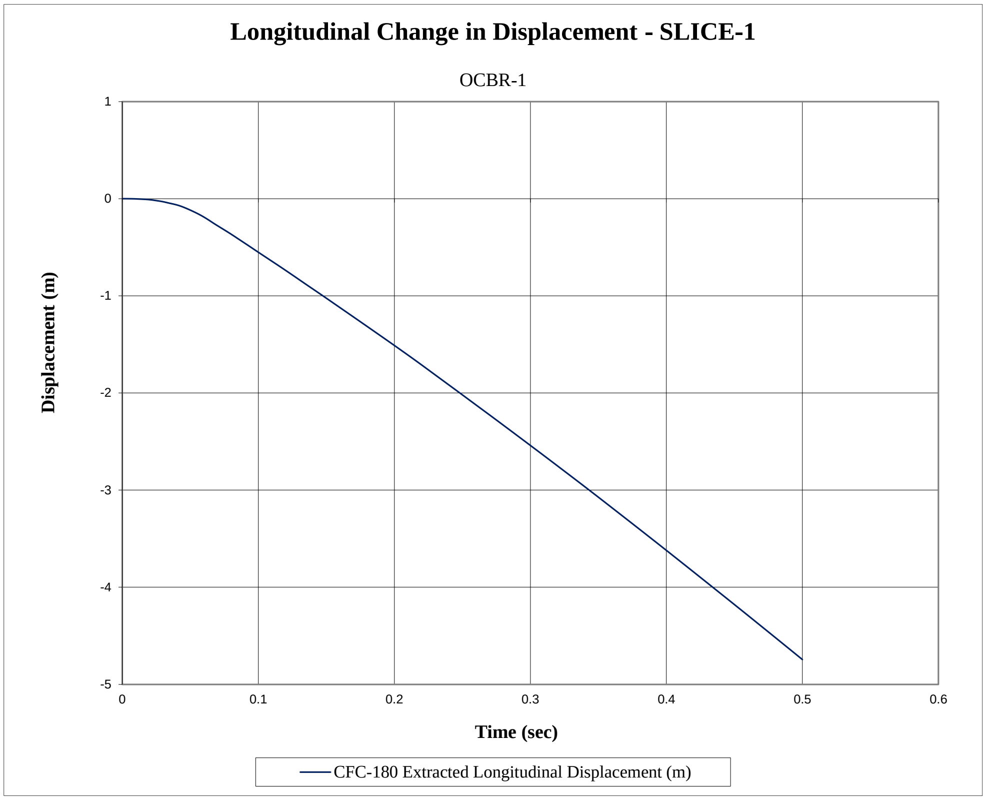


Figure D-3. Longitudinal Occupant Displacement (SLICE-1), Test No. OCBR-1

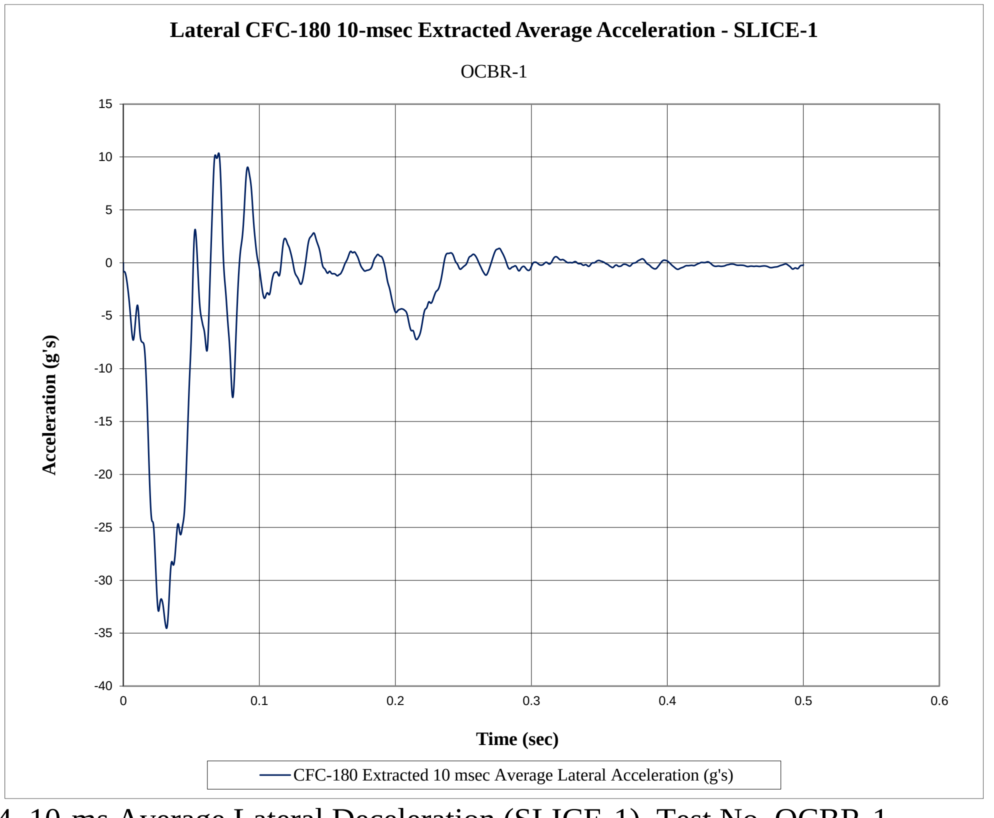


Figure D-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. OCBR-1

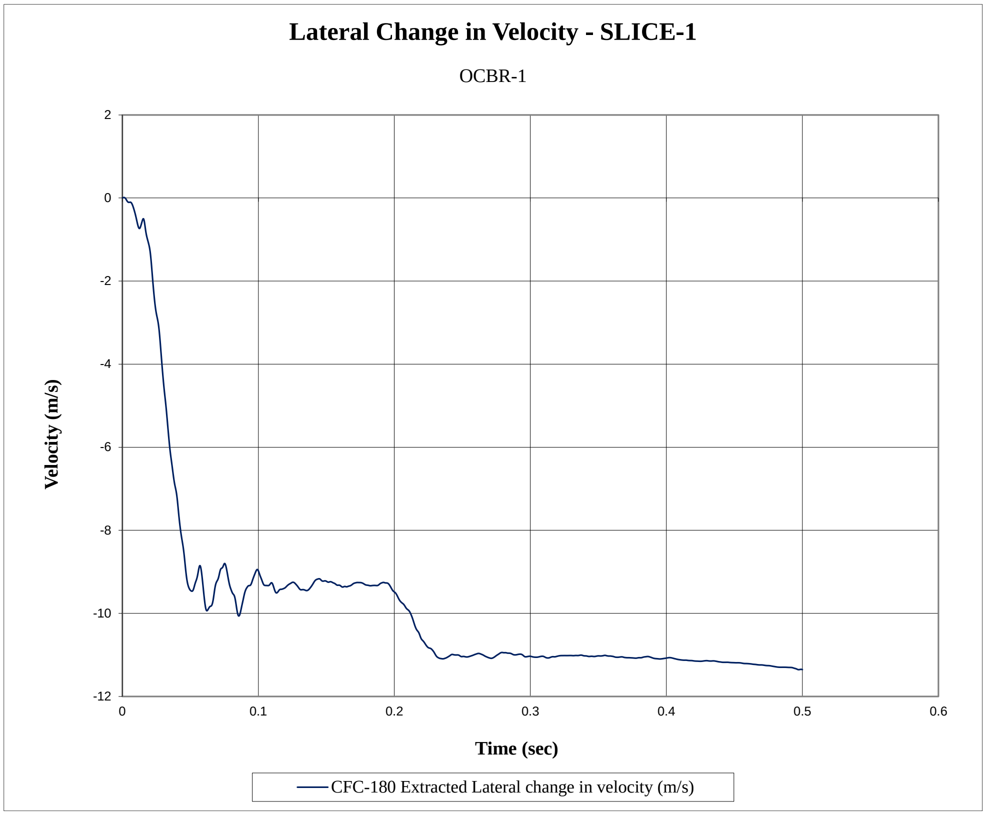


Figure D-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. OCBR-1

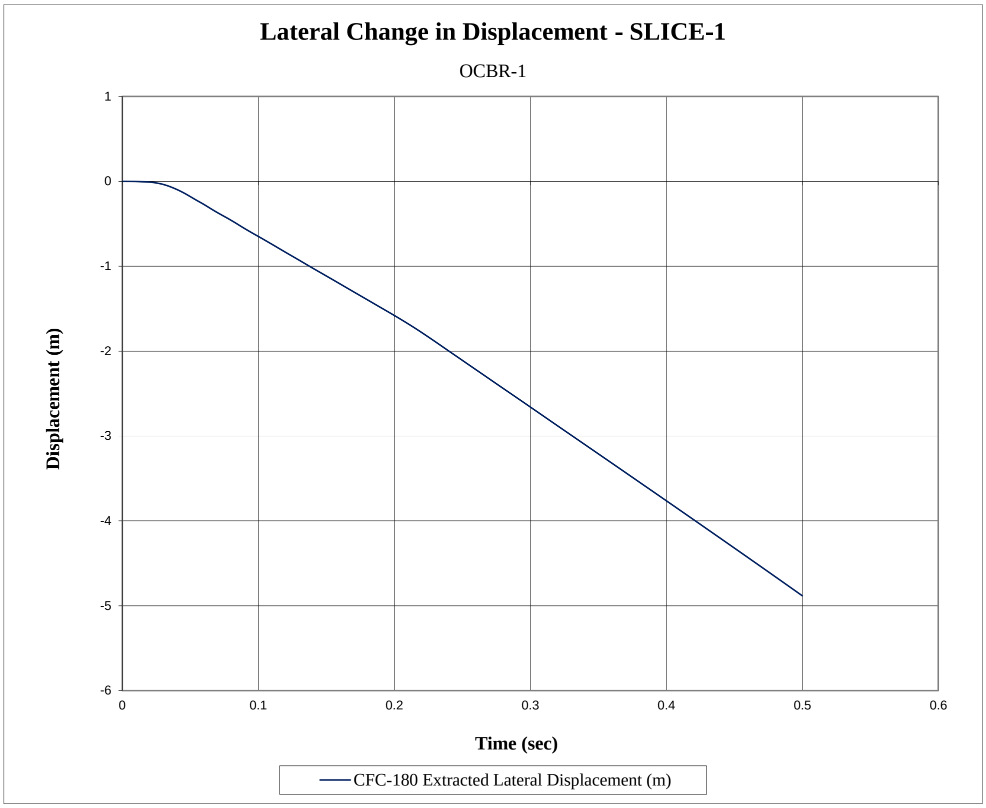


Figure D-6. Lateral Occupant Displacement (SLICE-1), Test No. OCBR-1

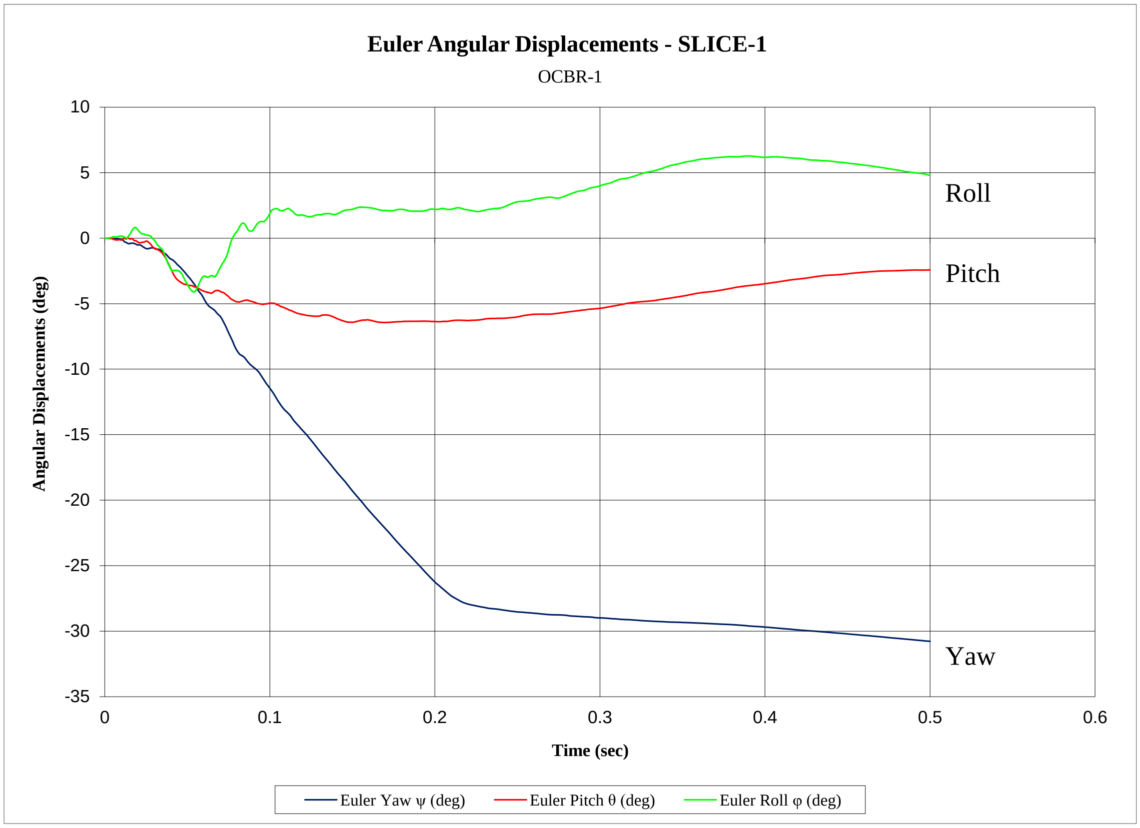


Figure D-7. Vehicle Angular Displacements (SLICE-1), Test No. OCBR-1

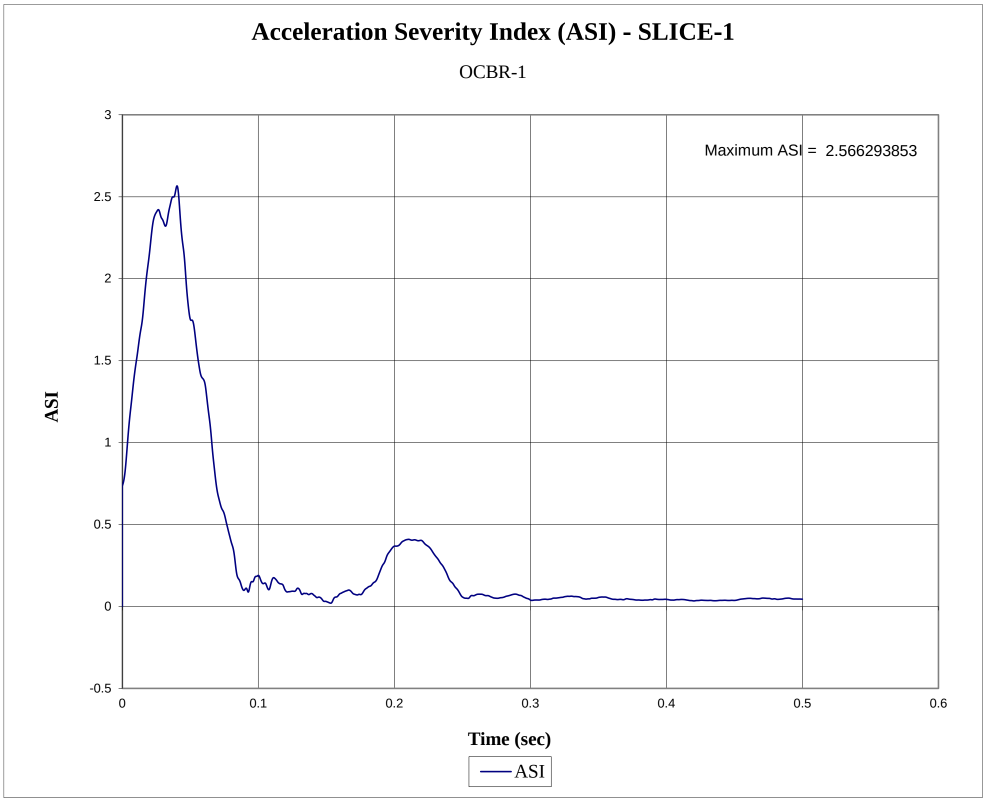


Figure D-8. Acceleration Severity Index (SLICE-1), Test No. OCBR-1

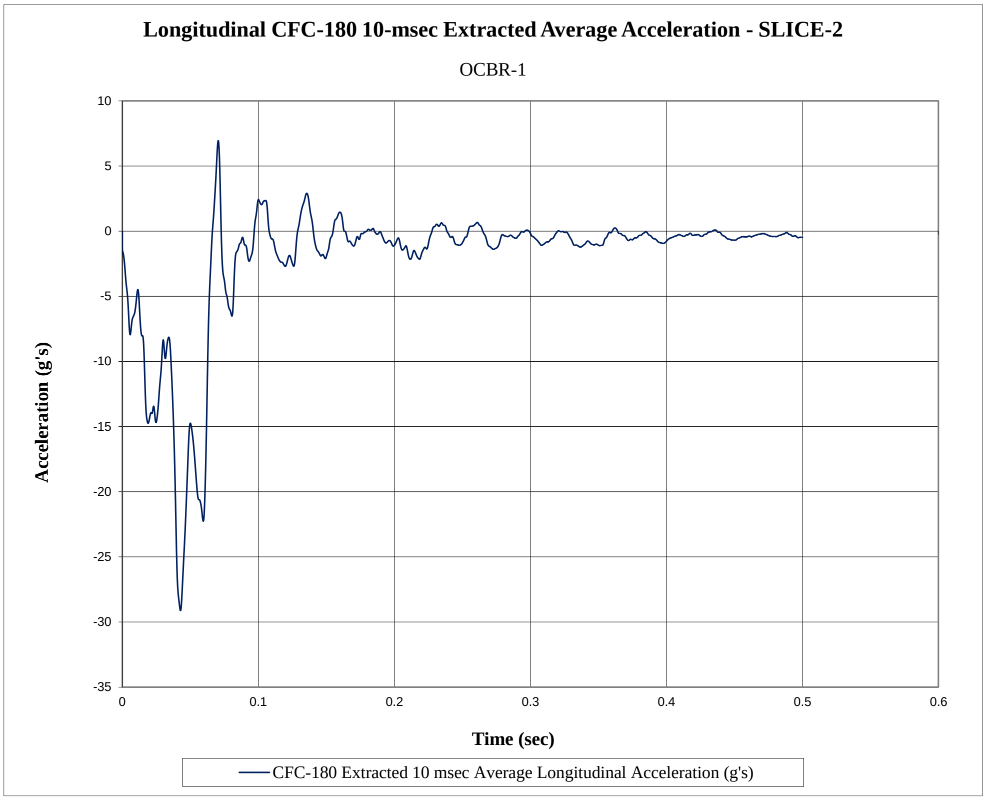


Figure D-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. OCBR-1

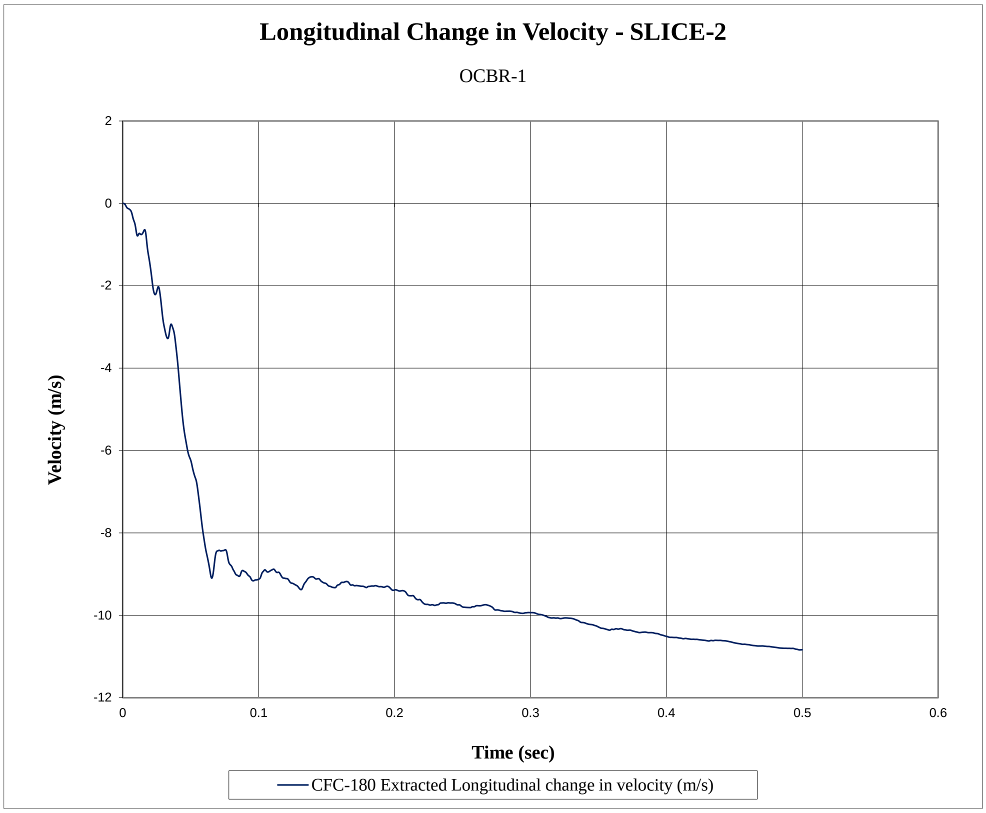


Figure D-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. OCBR-1

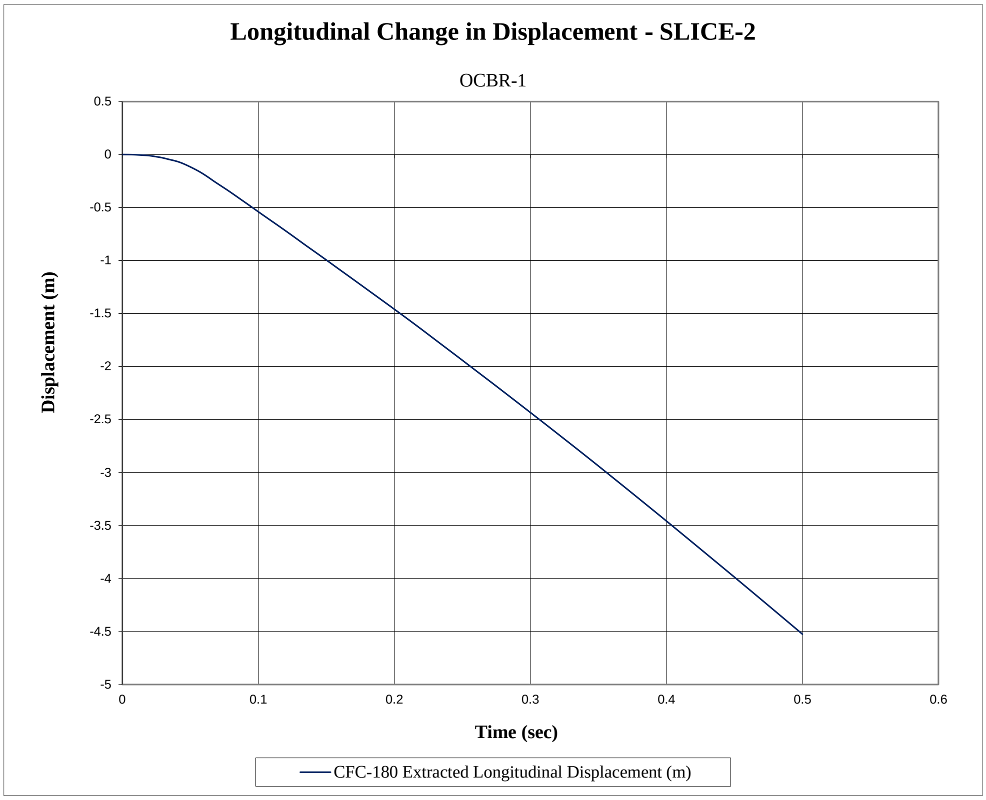


Figure D-11. Longitudinal Occupant Displacement (SLICE-2), Test No. OCBR-1

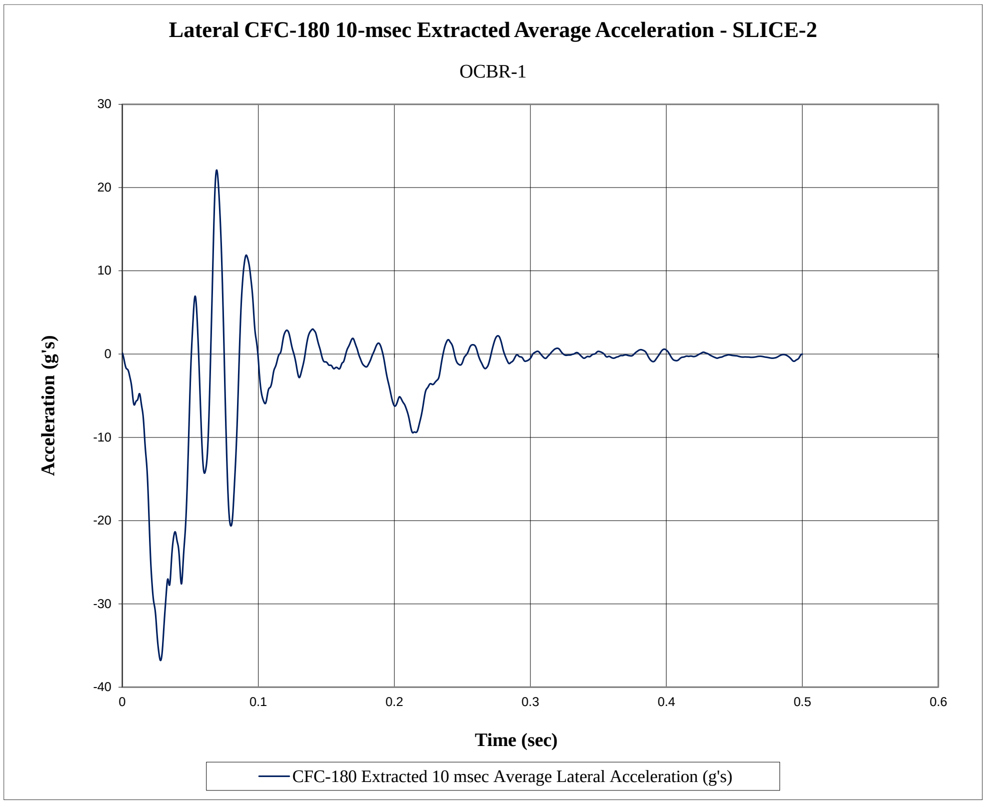


Figure D-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. OCBR-1

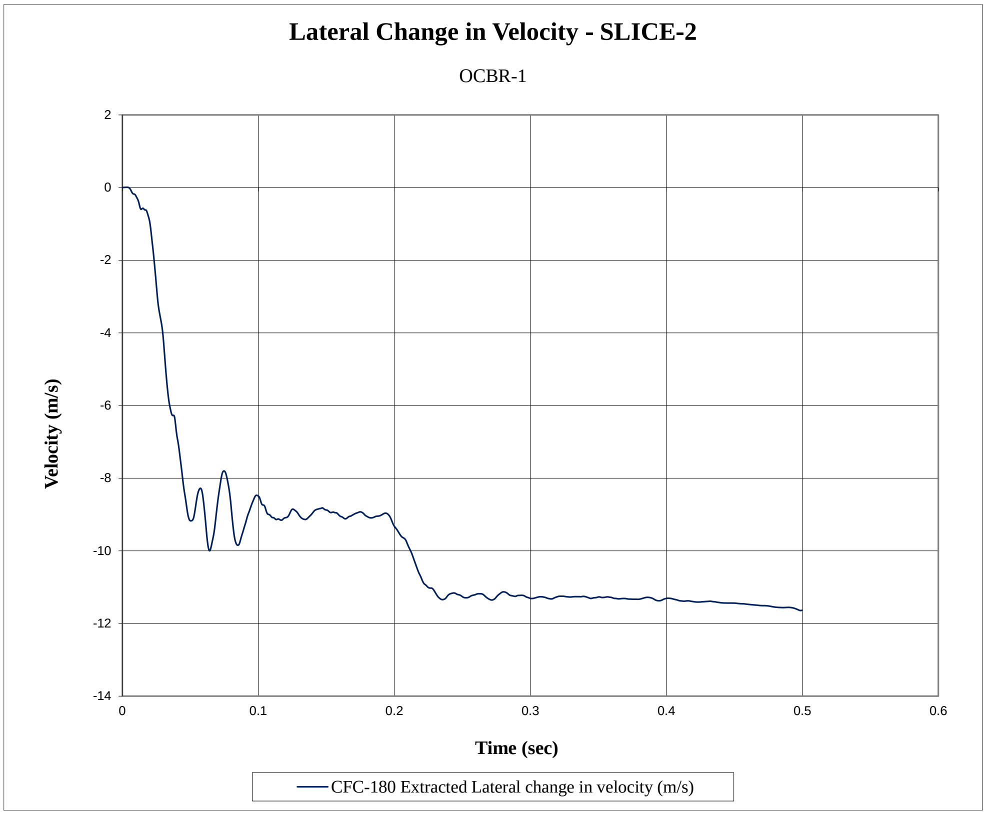


Figure D-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. OCBR-1

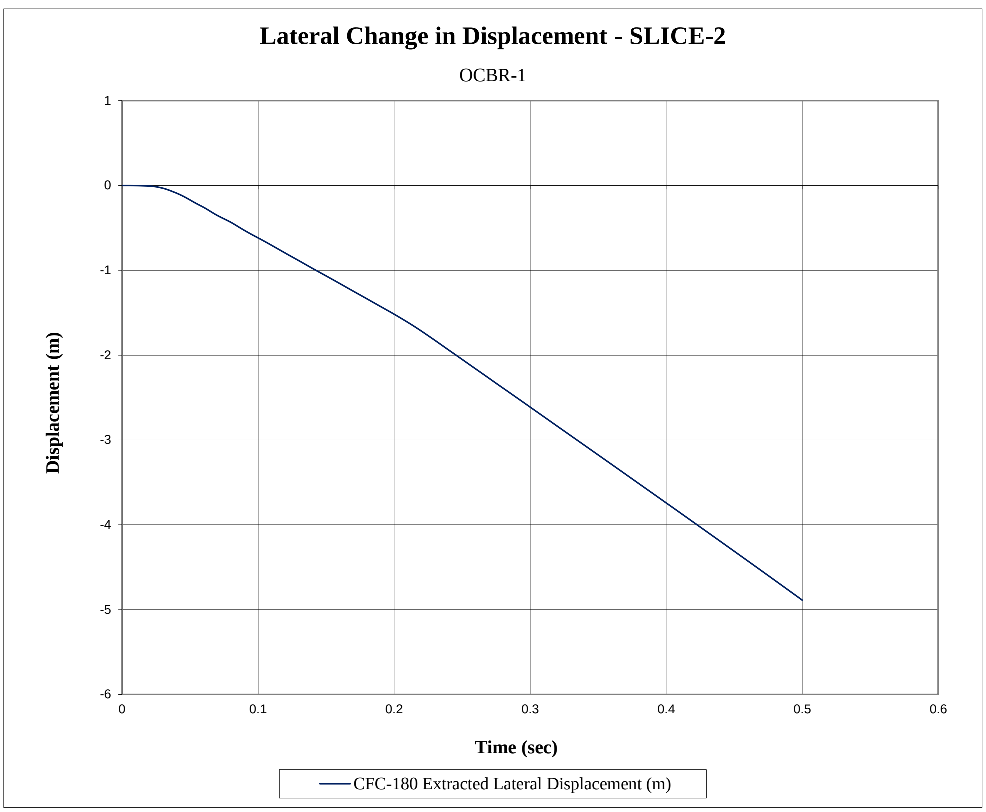


Figure D-14. Lateral Occupant Displacement (SLICE-2), Test No. OCBR-1

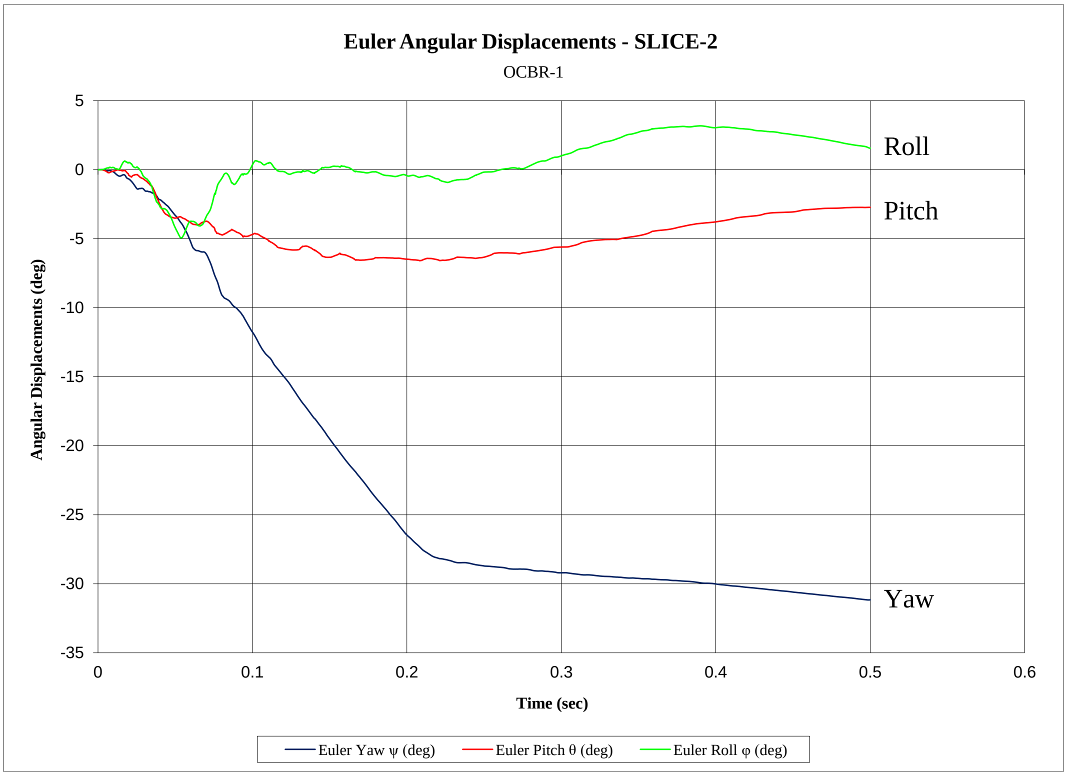


Figure D-15. Vehicle Angular Displacements (SLICE-2), Test No. OCBR-1

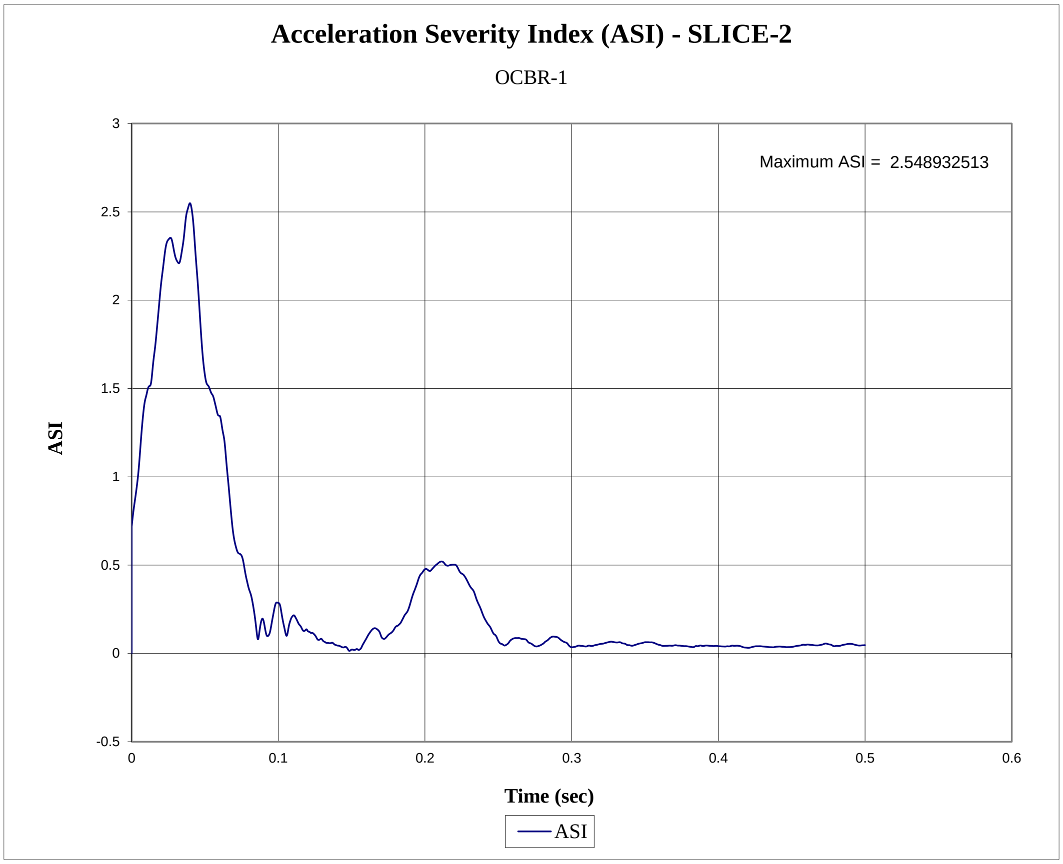


Figure D-16. Acceleration Severity Index (SLICE-2), Test No. OCBR-1

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

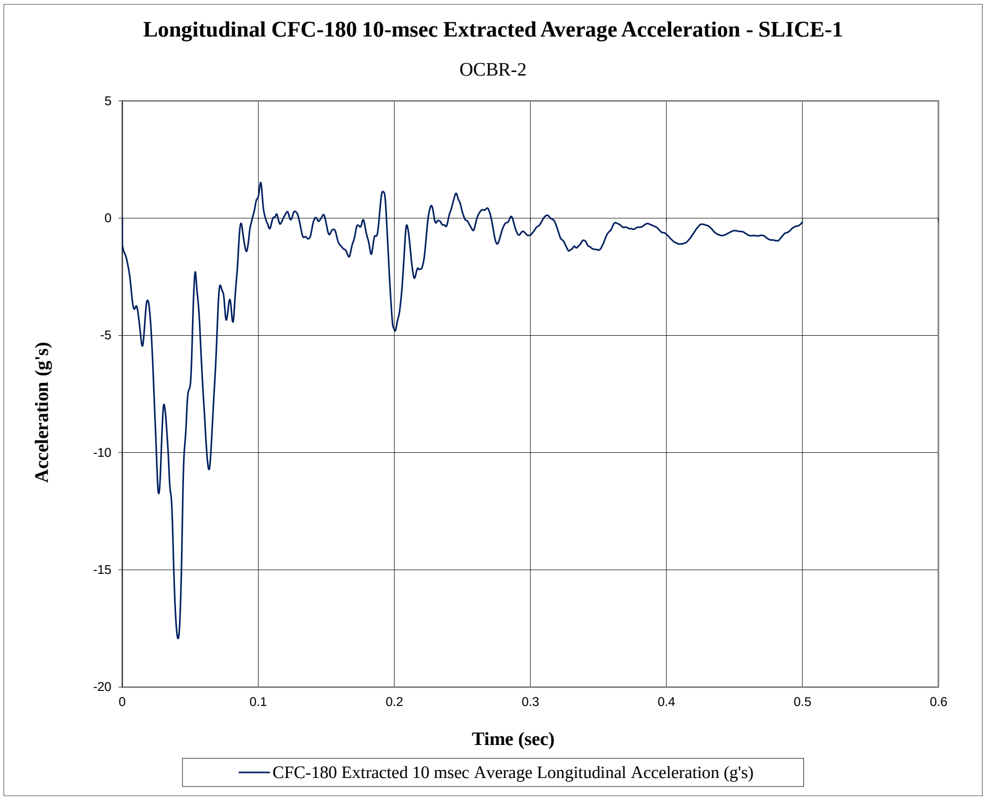


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. OCBR-2

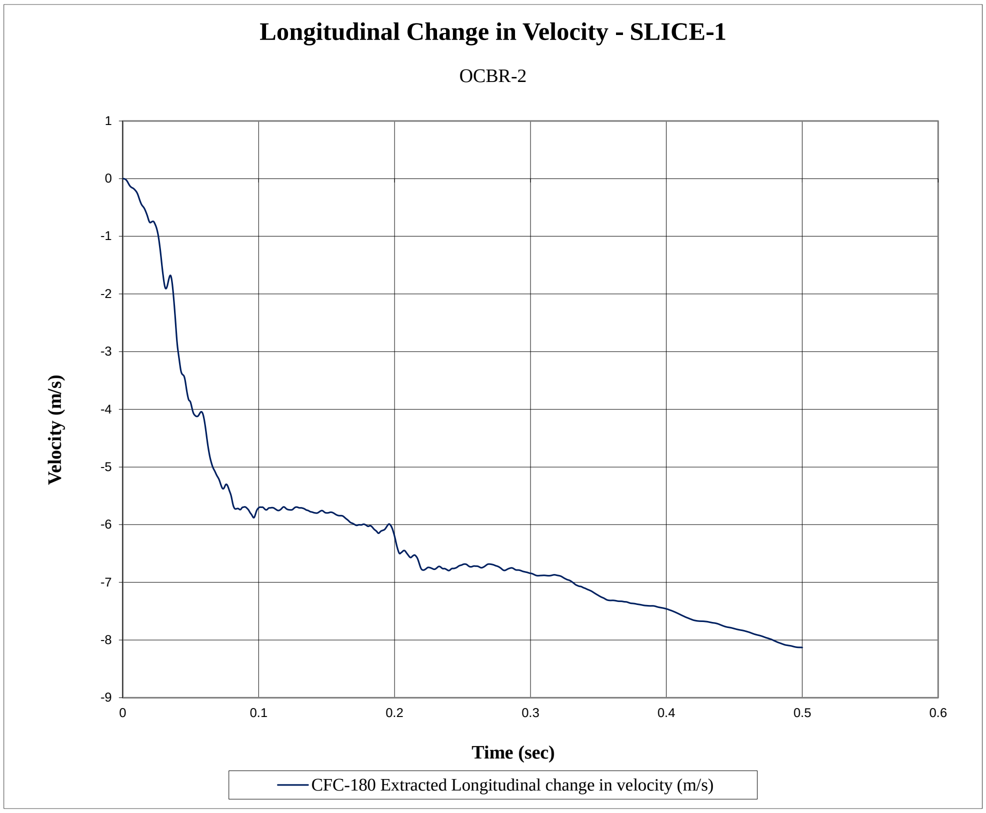


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. OCBR-2

Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No.OCBR-2

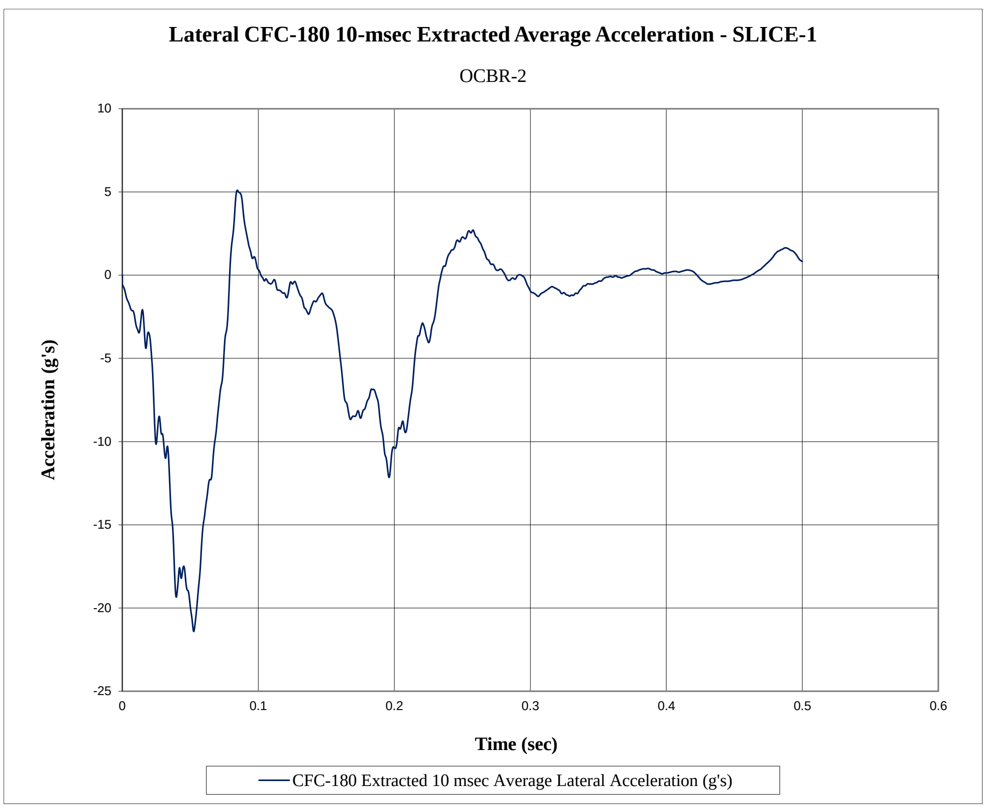


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. OCBR-2

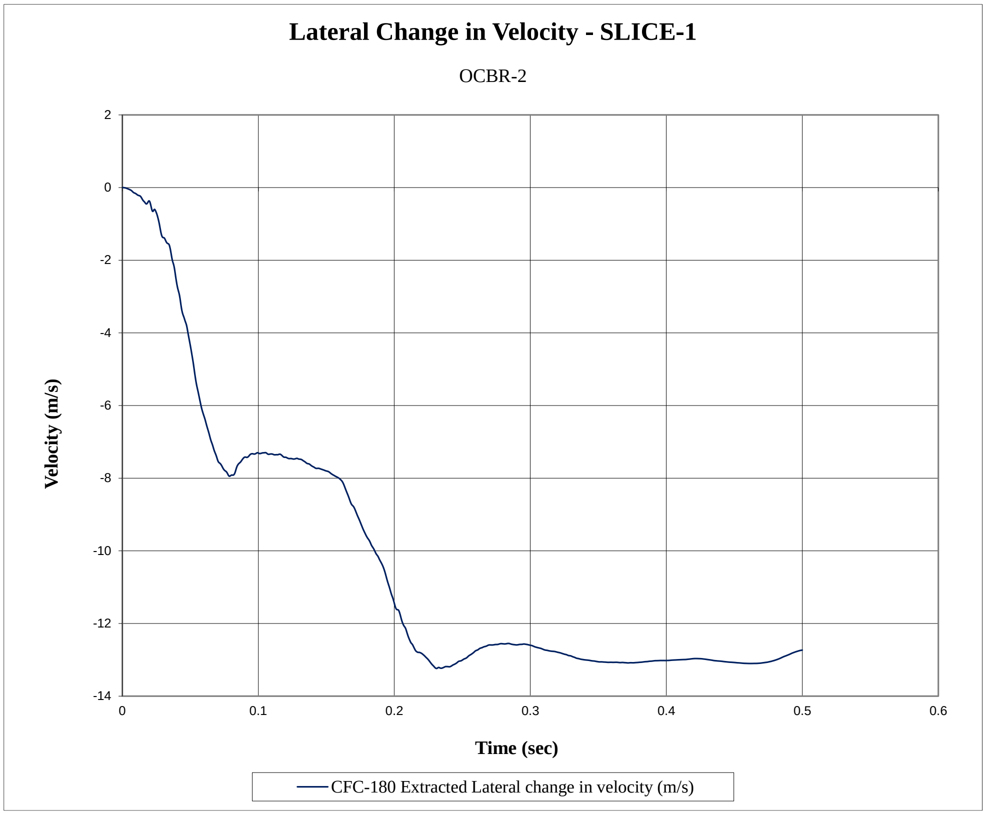


Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. OCBR-2

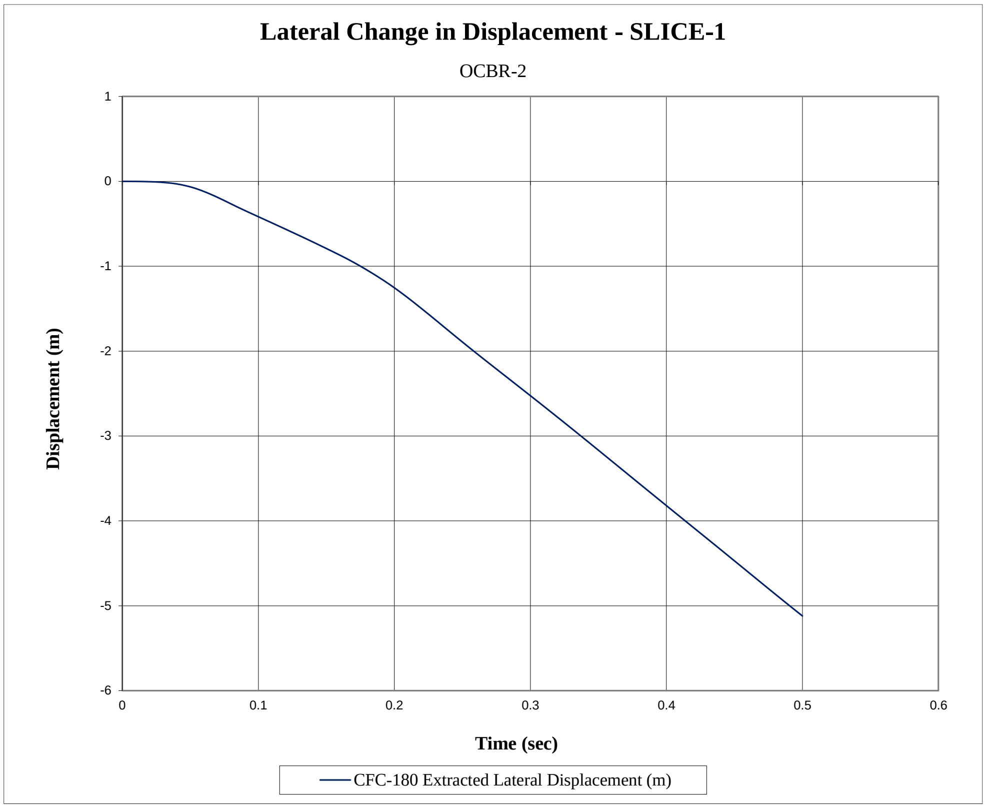


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. OCBR-2

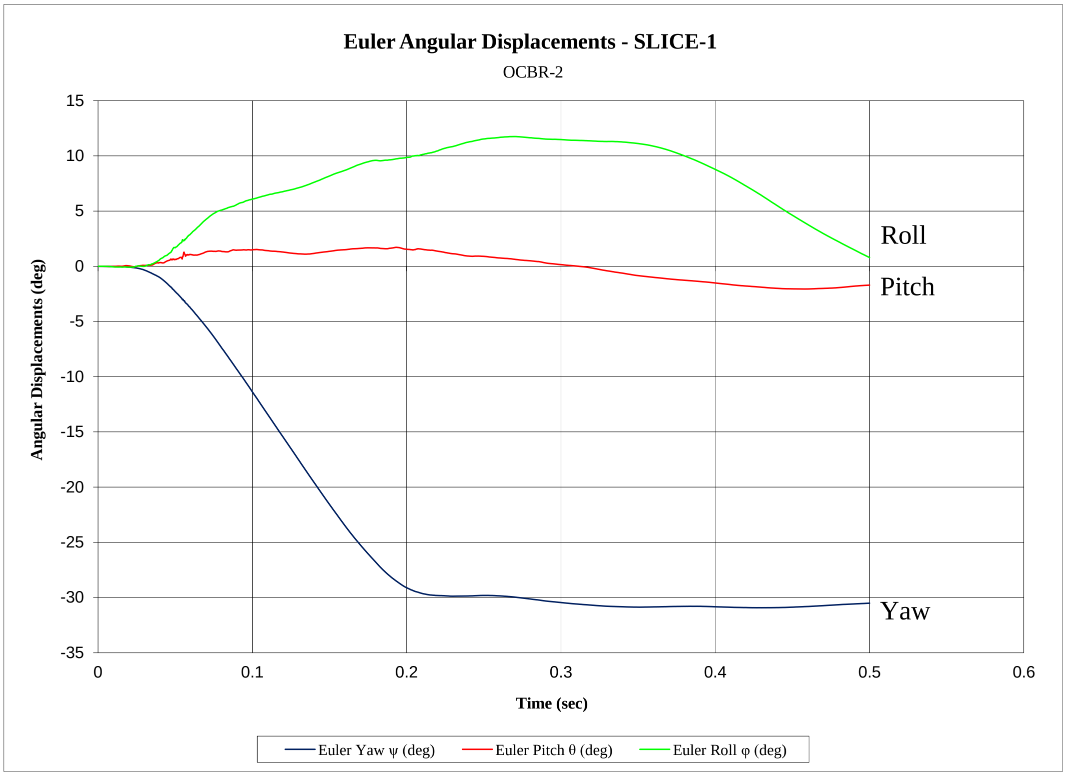


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. OCBR-2

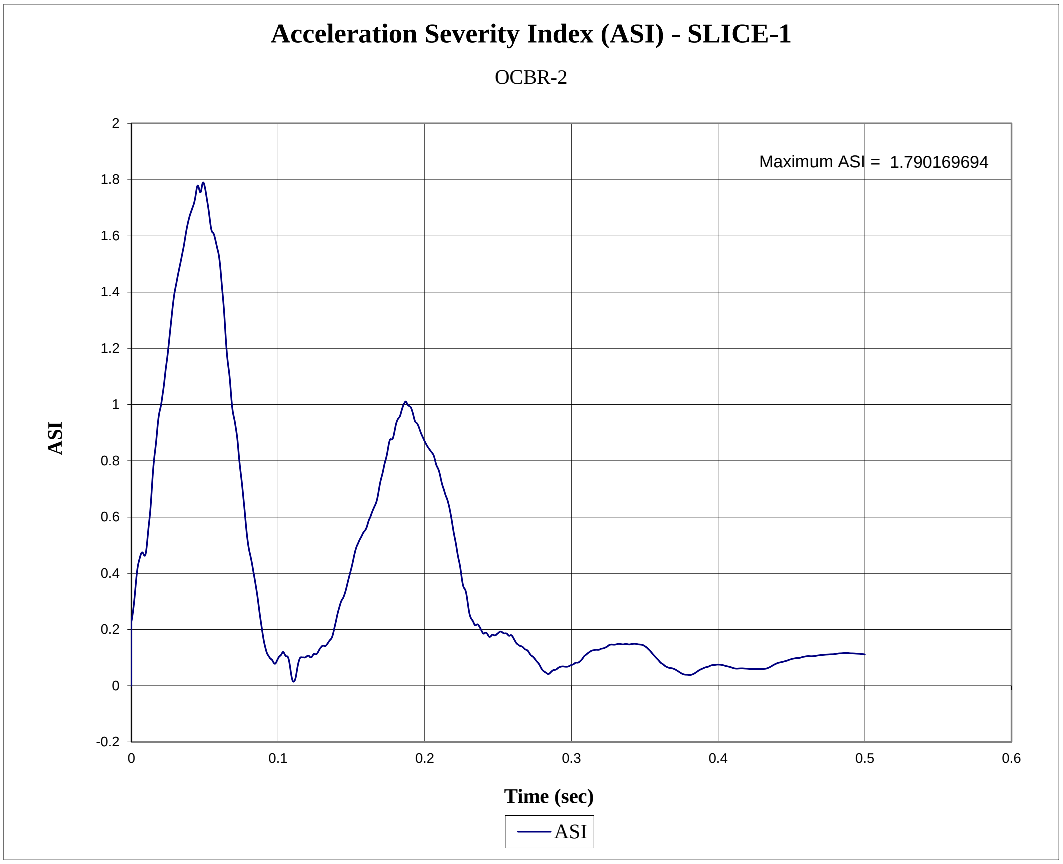


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. OCBR-2

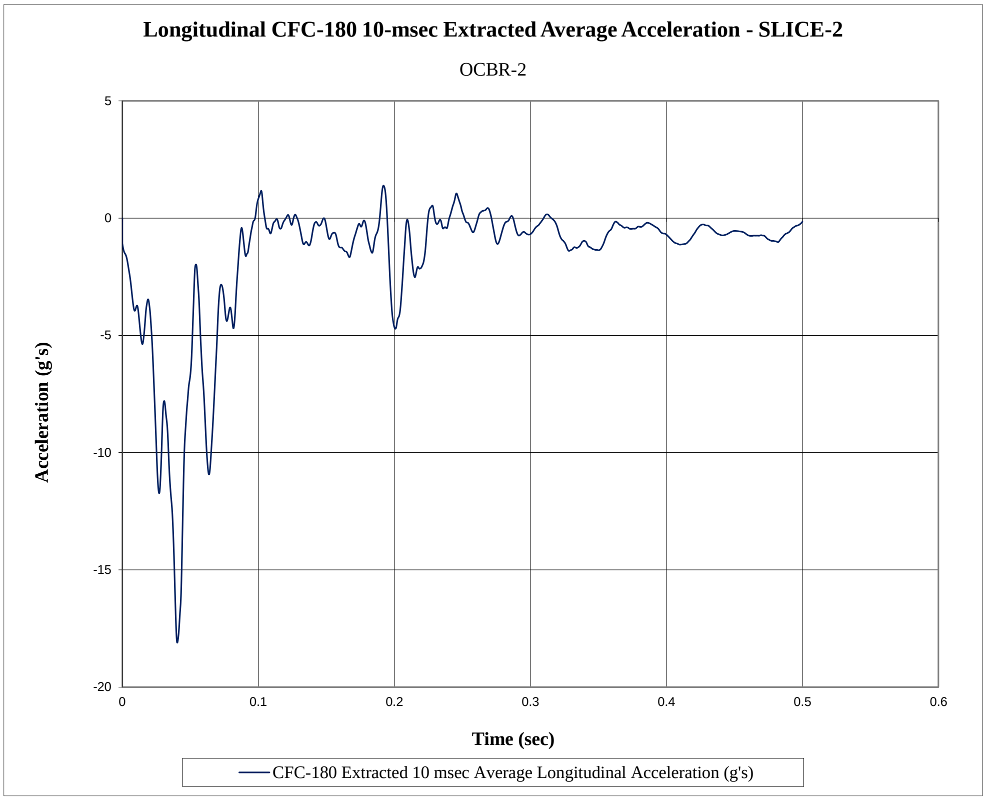


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. OCBR-2

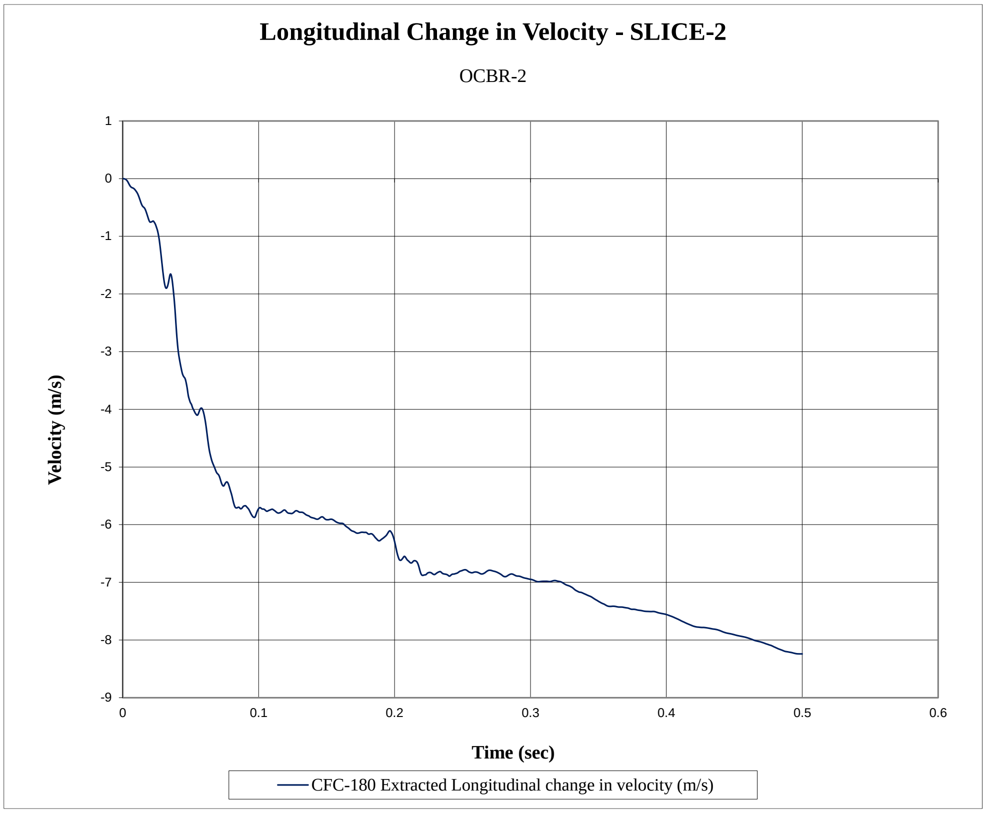


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. OCBR-2

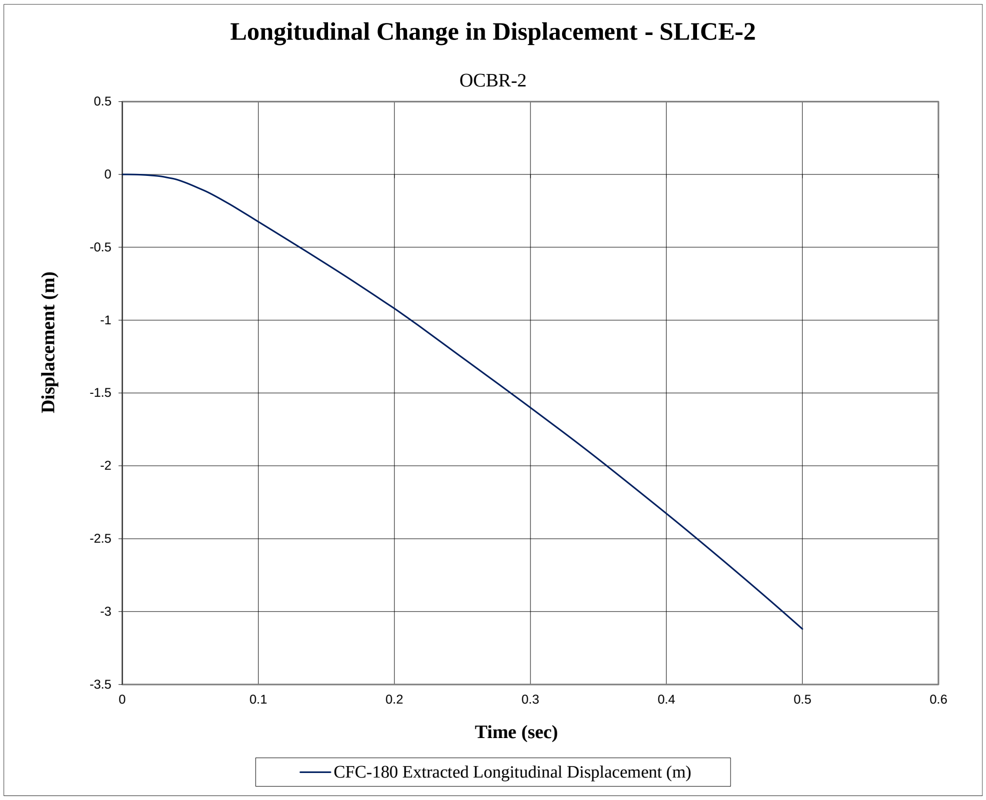


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. OCBR-2

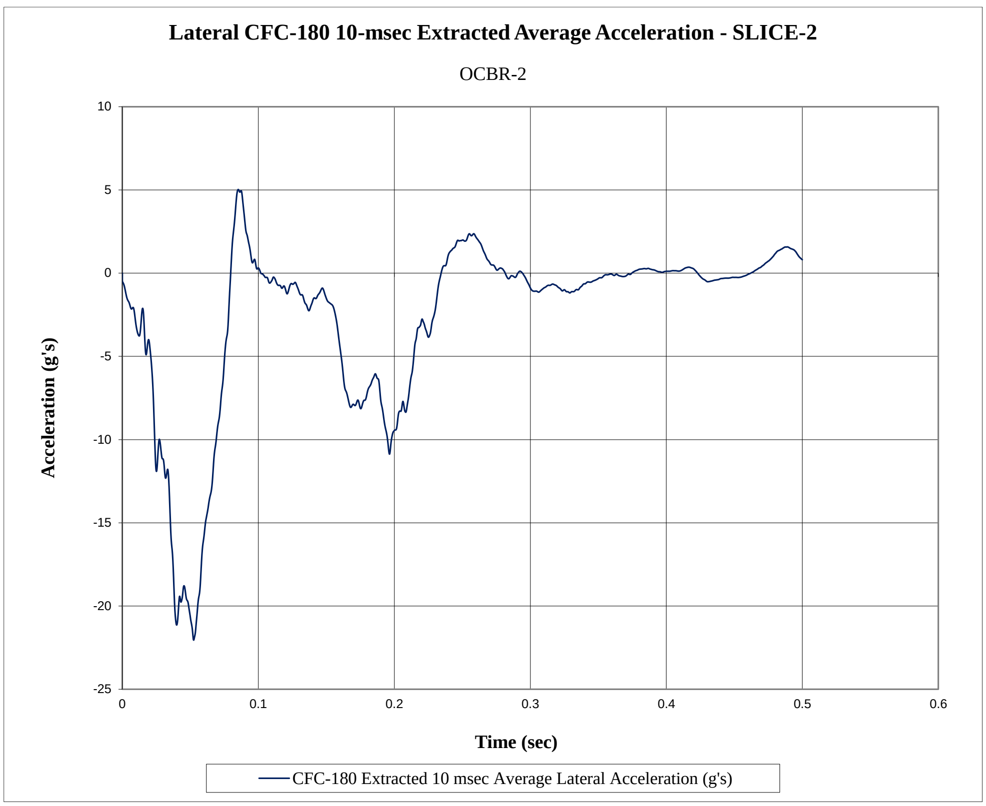


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. OCBR-2

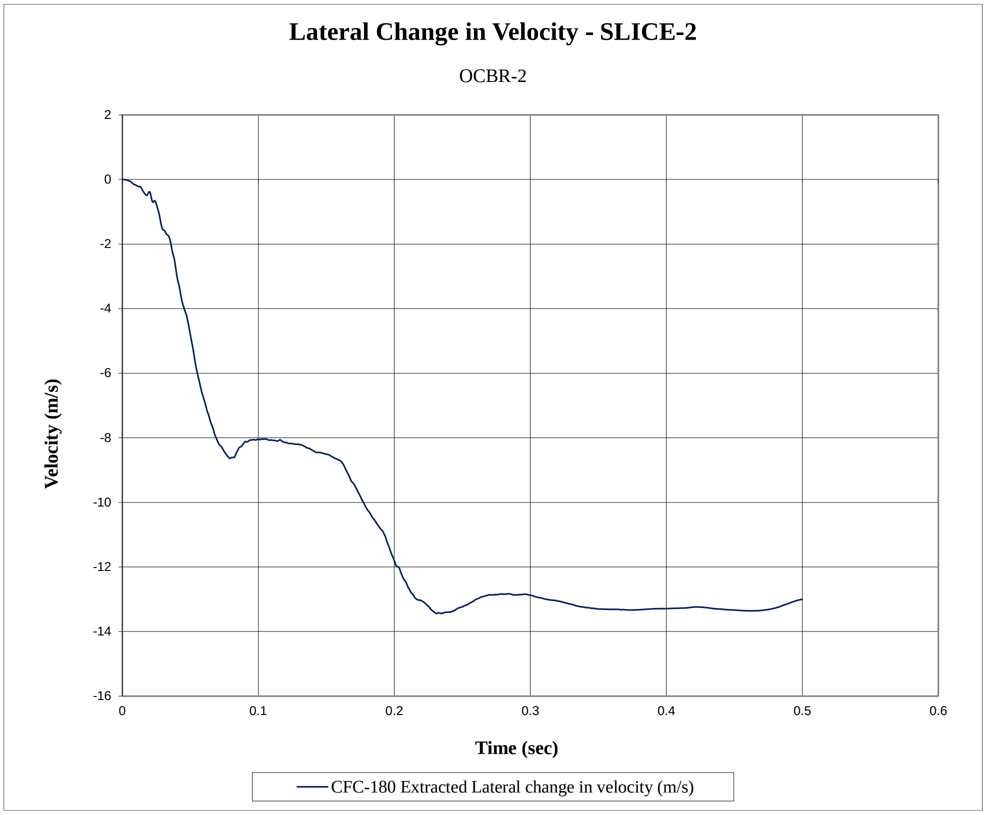


Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. OCBR-2

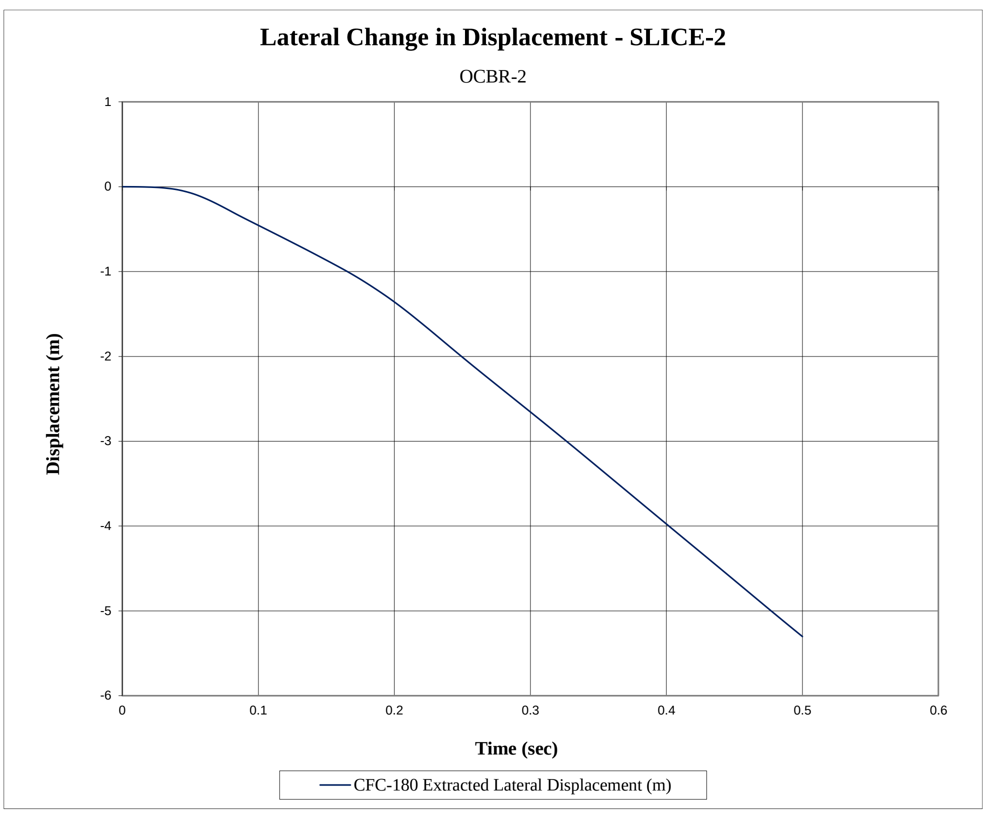


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. OCBR-2

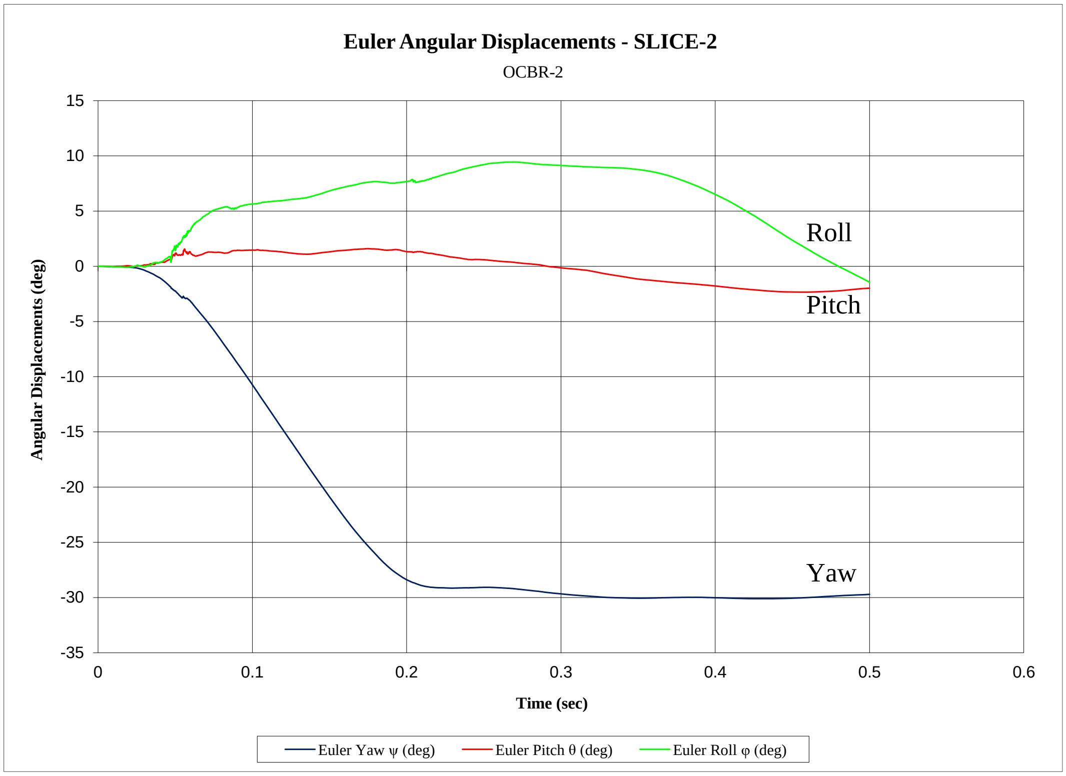


Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. OCBR-2

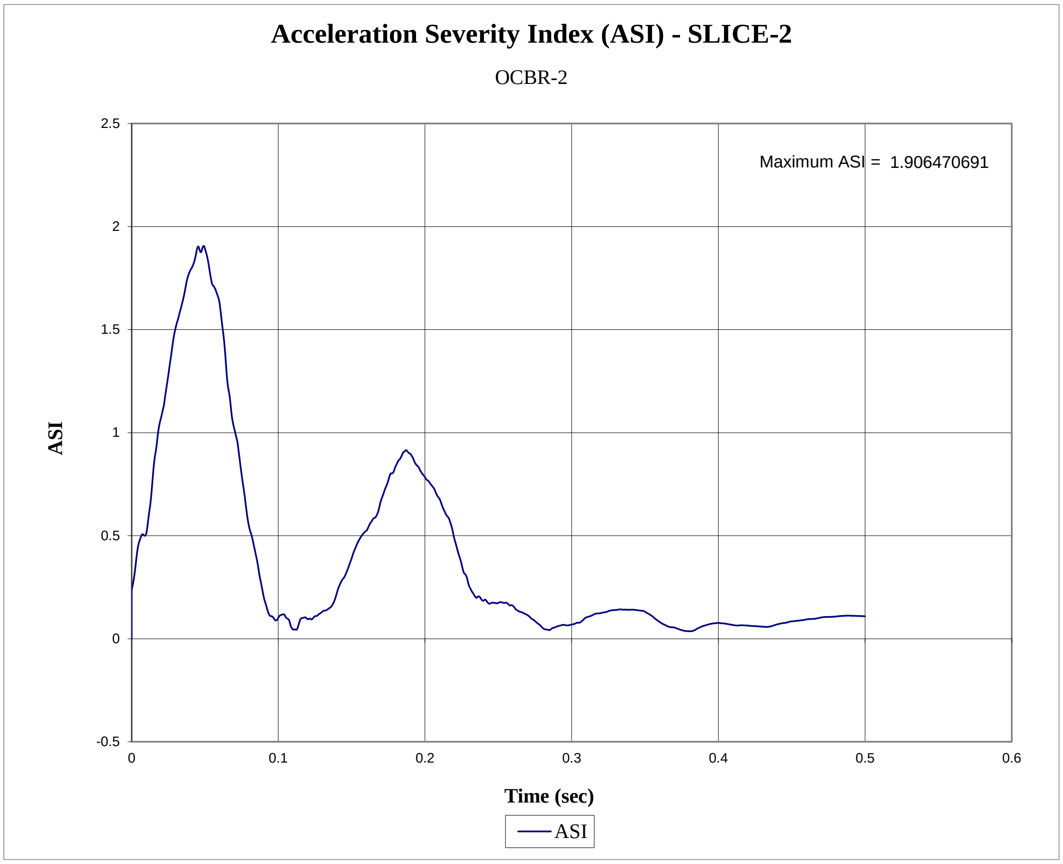


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. OCBR-2

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

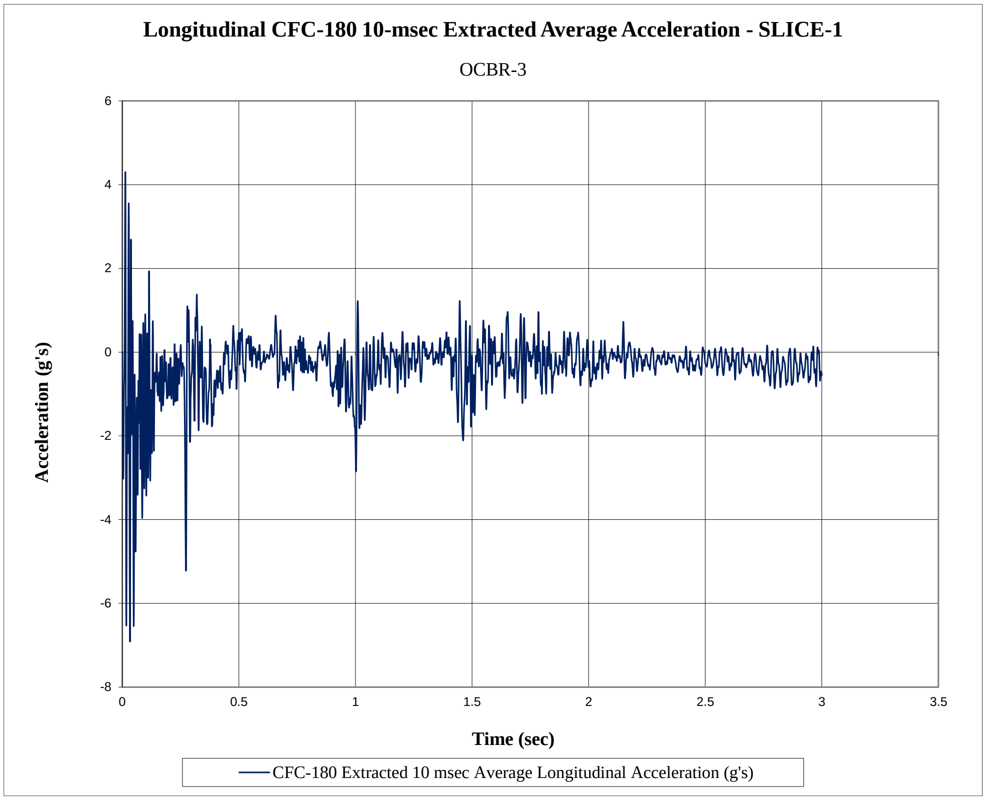


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. OCBR-3

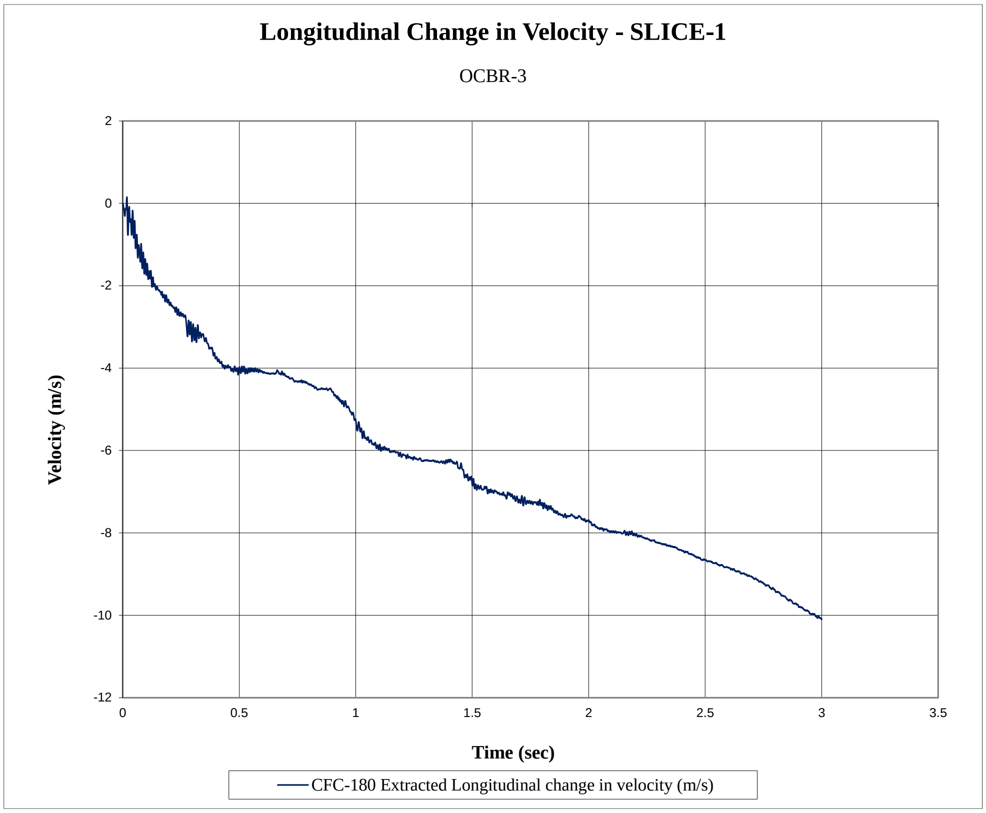


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. OCBR-3

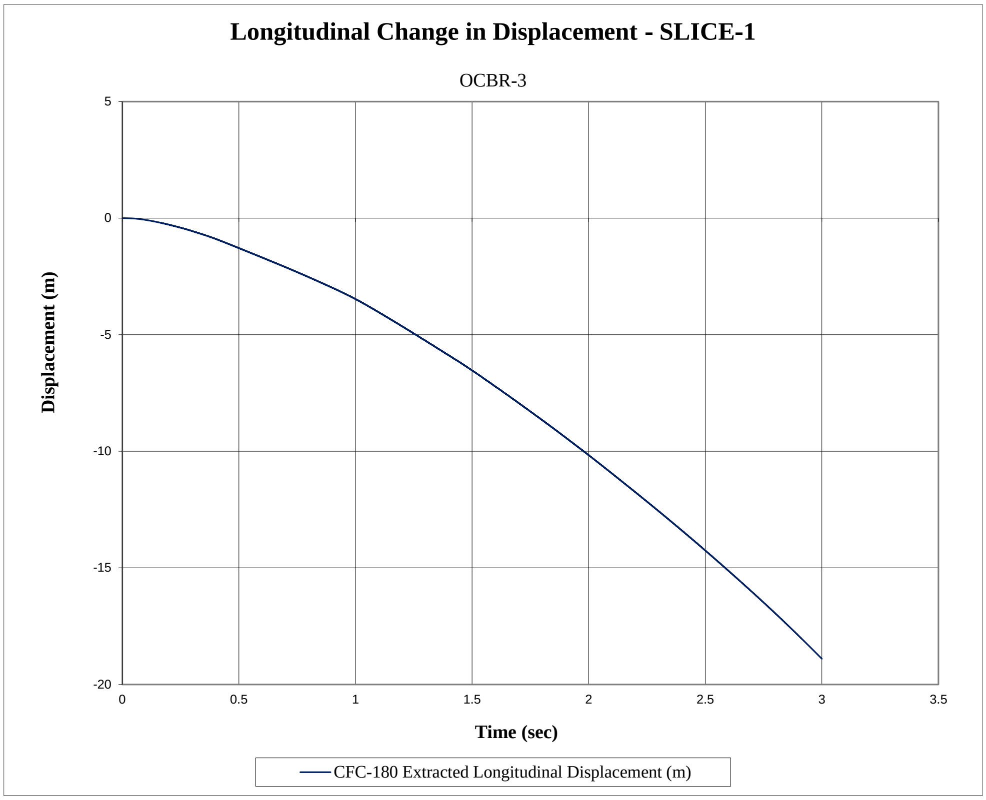


Figure F-3. Longitudinal Occupant Displacement (SLICE-1), Test No. OCBR-3

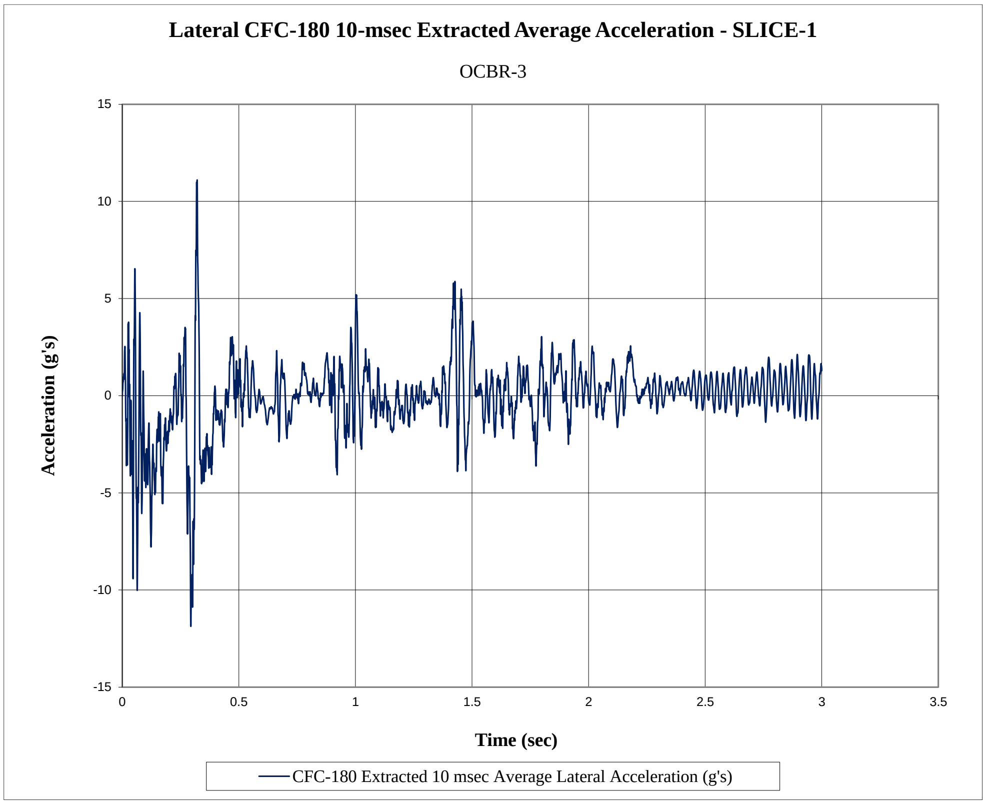


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. OCBR-3

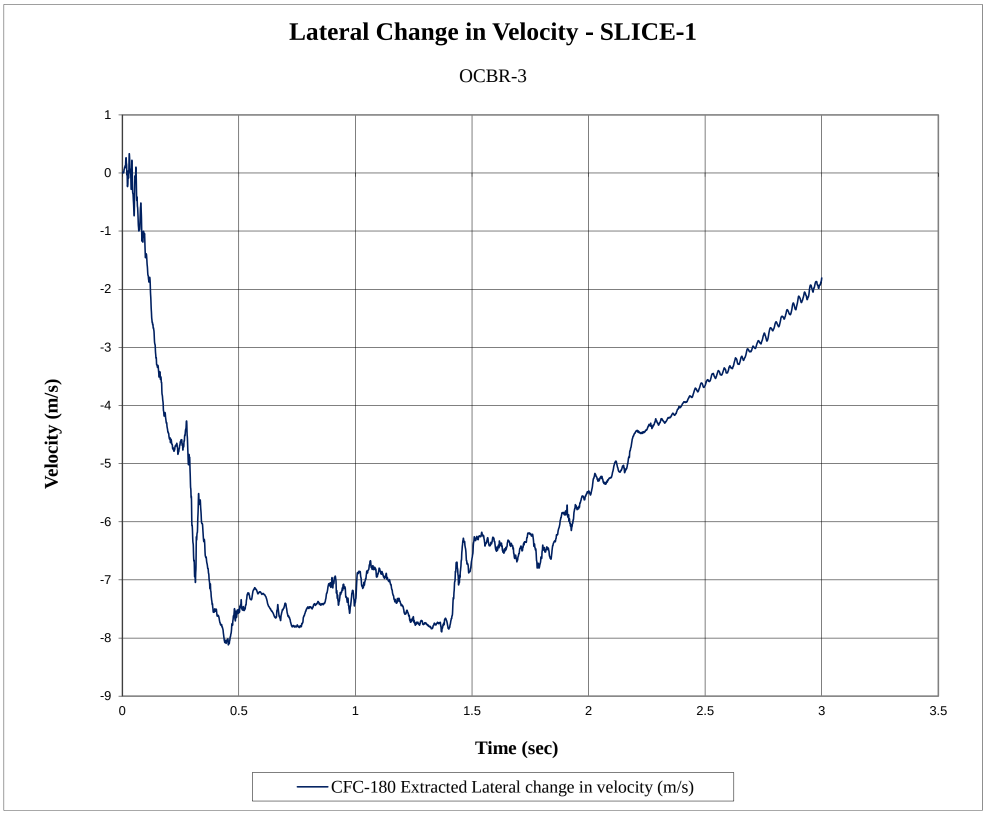


Figure F-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. OCBR-3

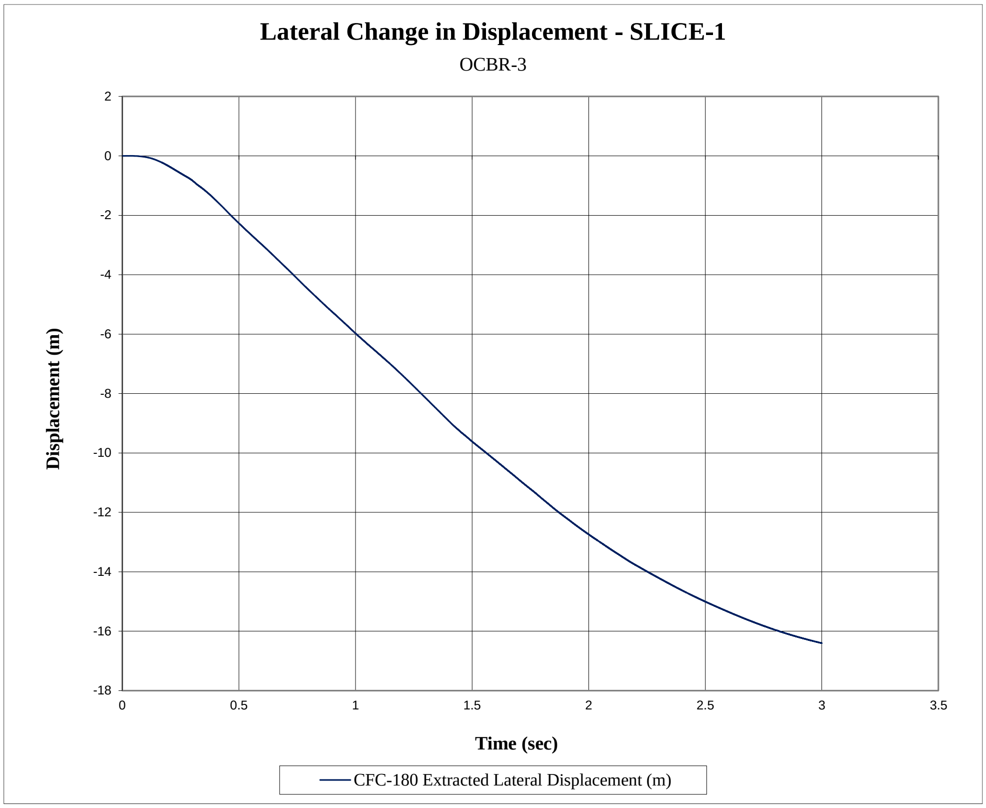


Figure F-6. Lateral Occupant Displacement (SLICE-1), Test No. OCBR-3

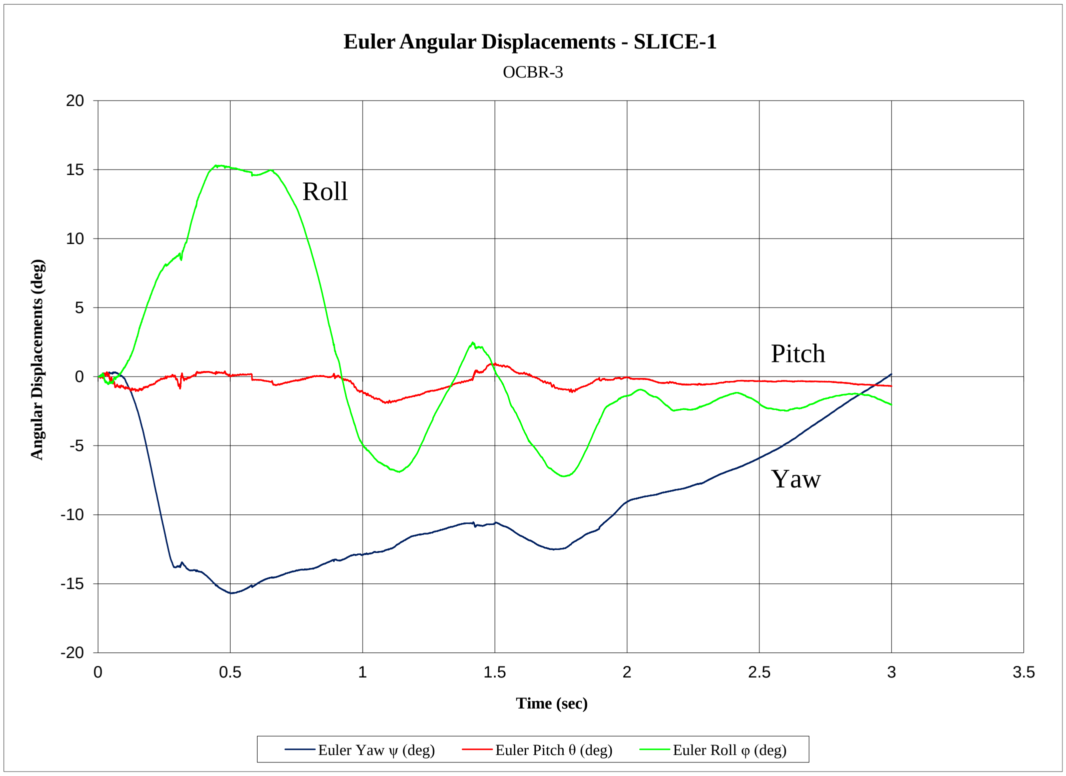


Figure F-7. Vehicle Angular Displacements (SLICE-1), Test No. OCBR-3

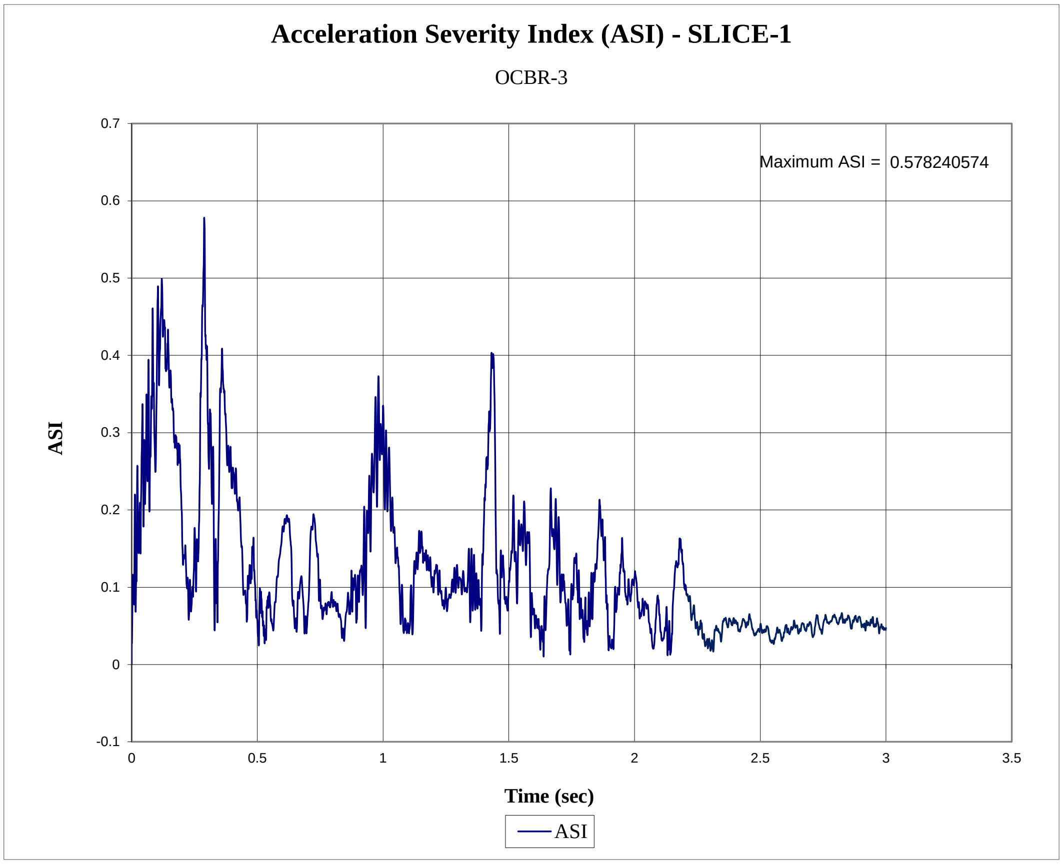


Figure F-8. Acceleration Severity Index (SLICE-1), Test No. OCBR-3

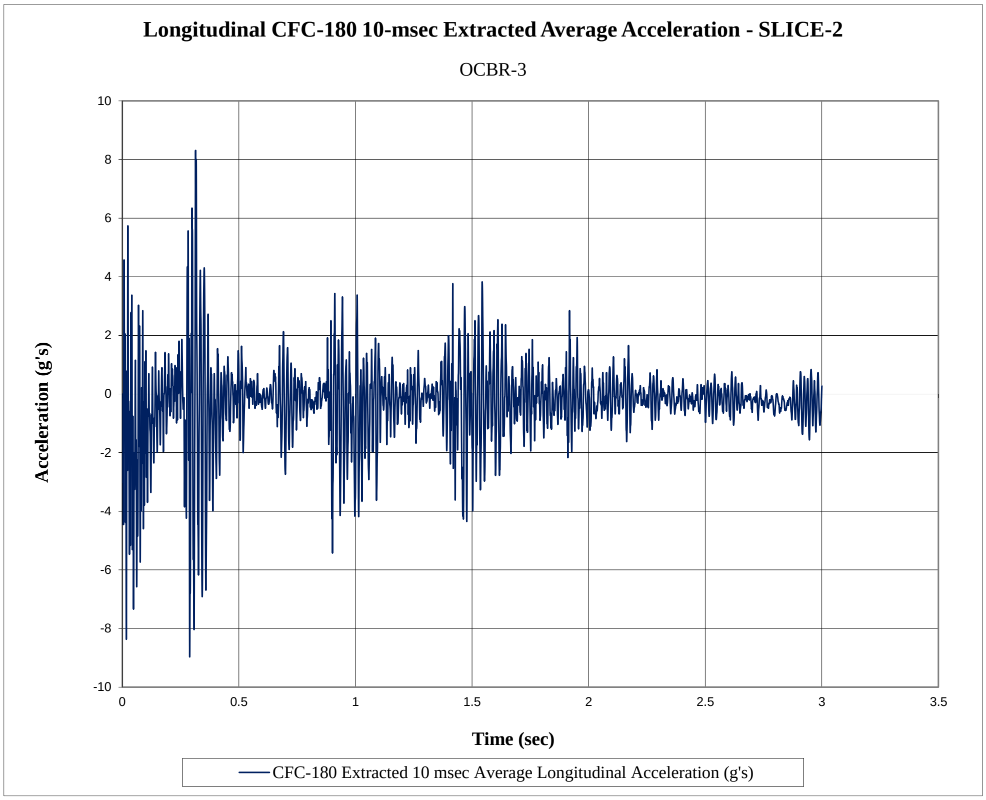


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. OCBR-3

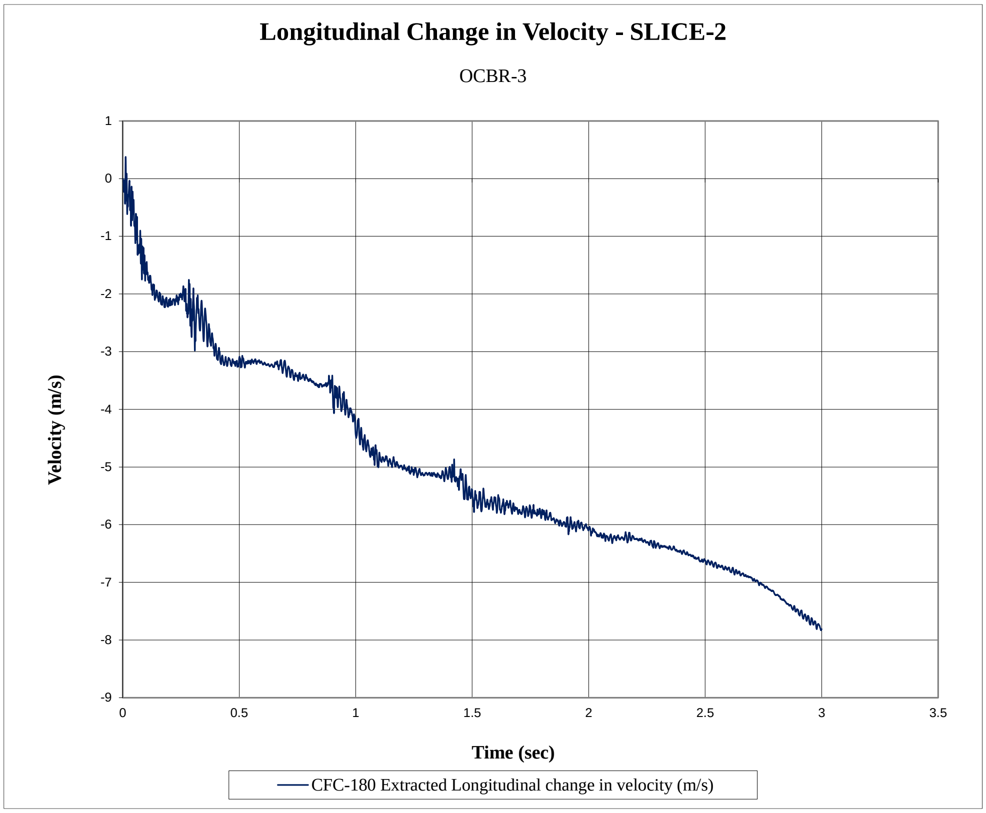


Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. OCBR-3

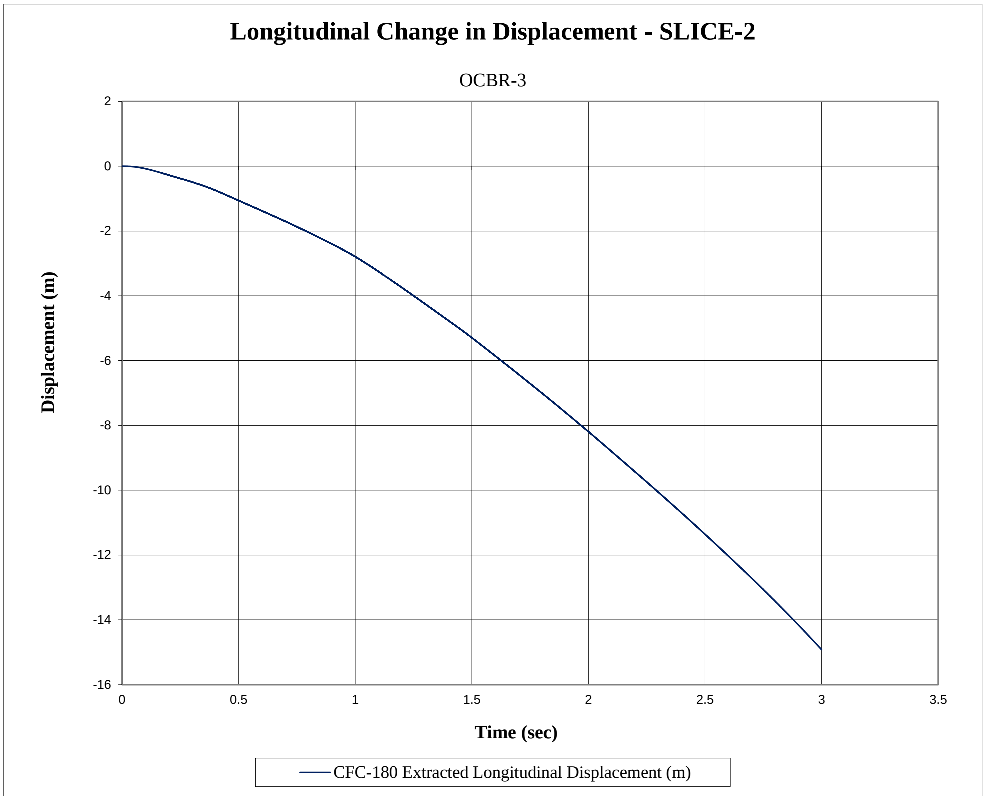


Figure F-11. Longitudinal Occupant Displacement (SLICE-2), Test No. OCBR-3

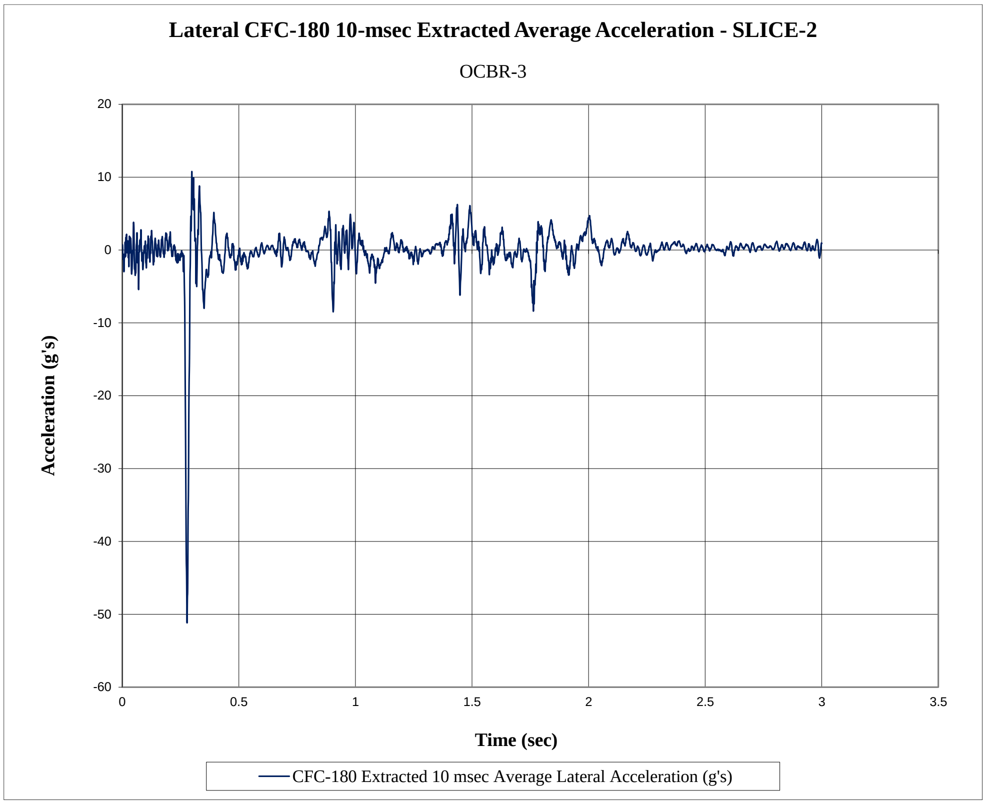


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. OCBR-3

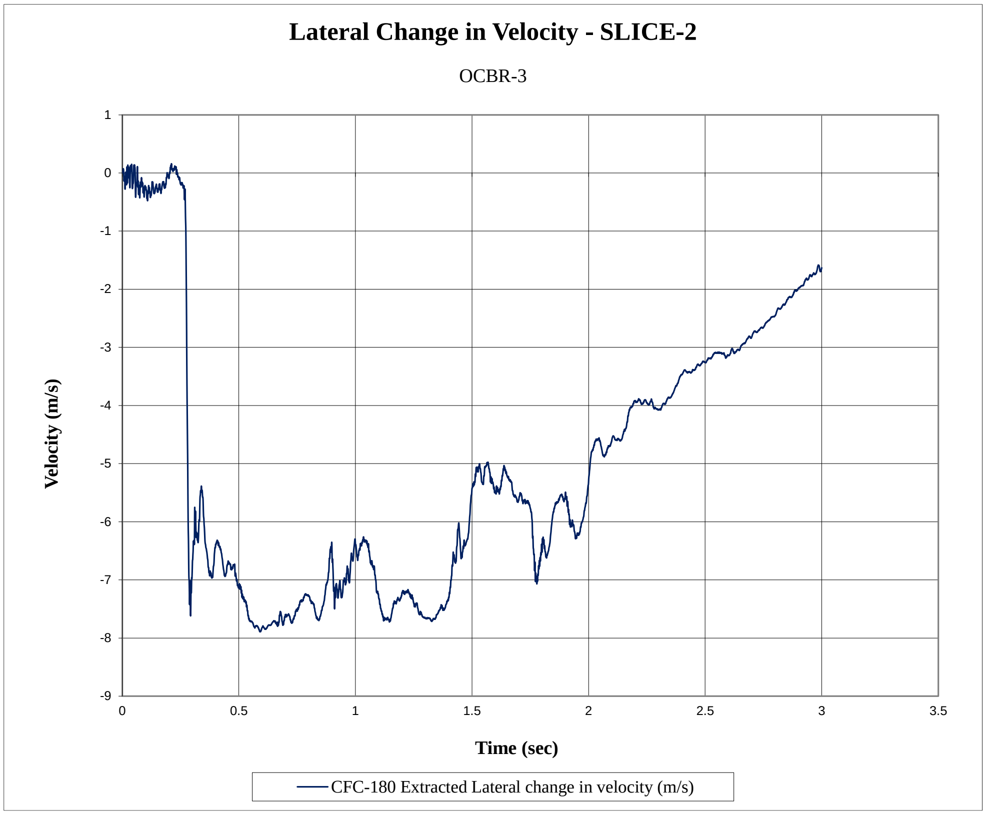


Figure F-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. OCBR-3

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

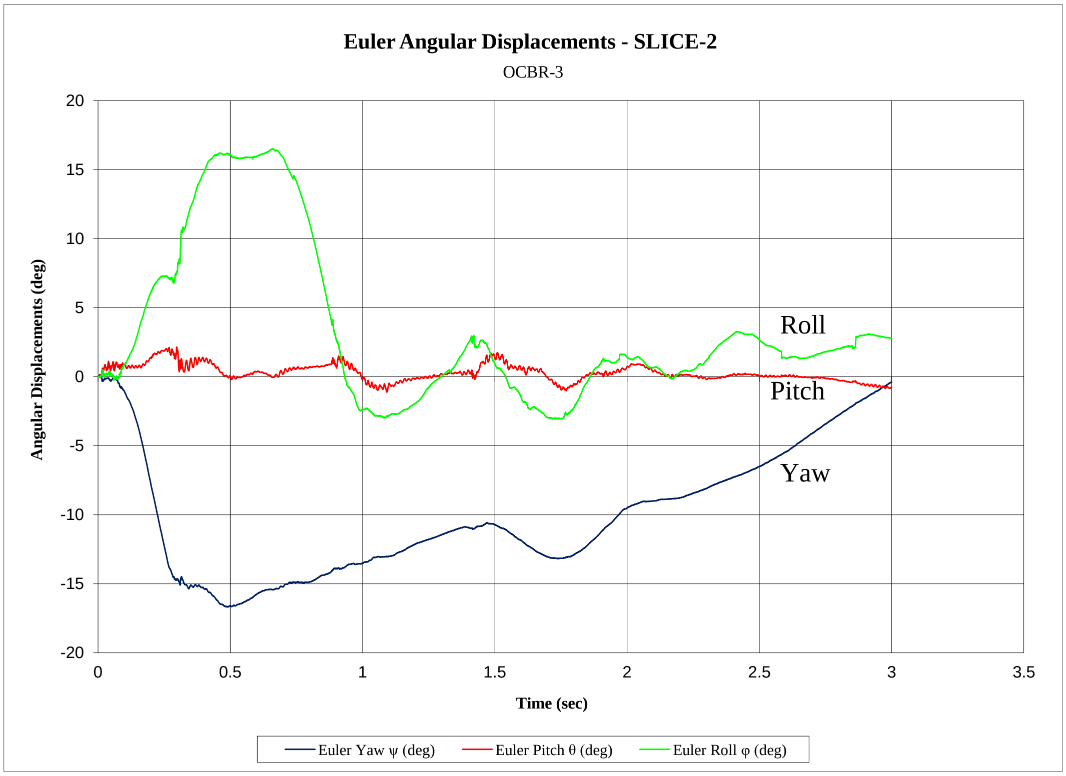


Figure F-15. Vehicle Angular Displacements (SLICE-2), Test No. OCBR-3

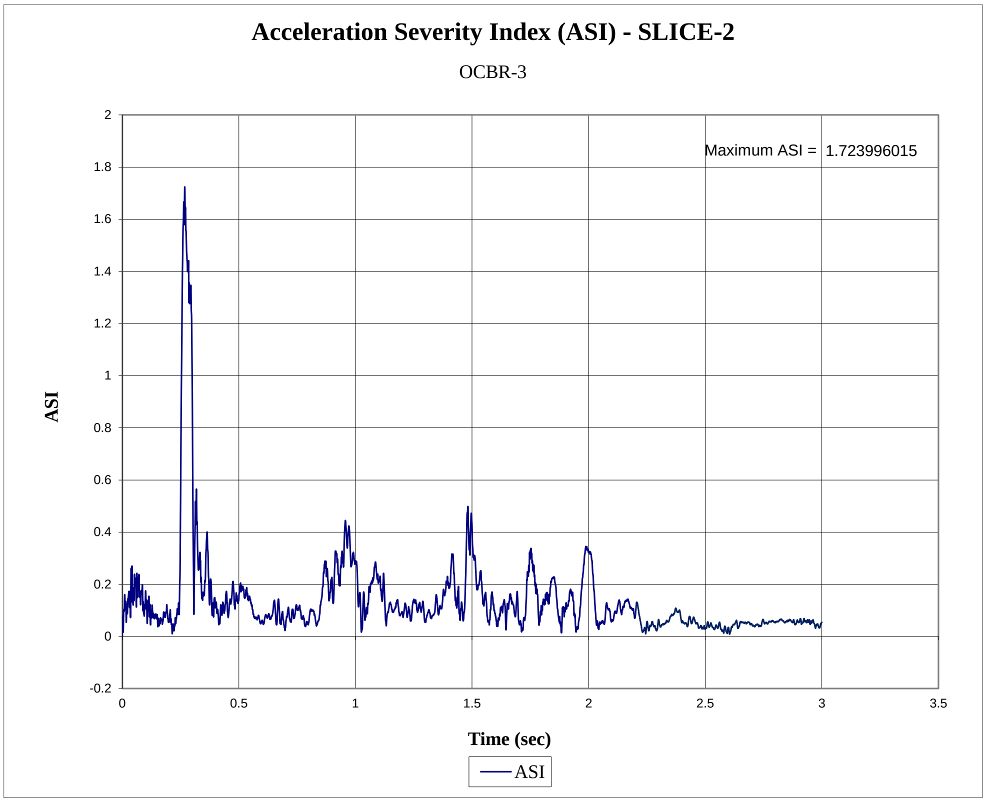


Figure F-16. Acceleration Severity Index (SLICE-2), Test No. OCBR-3

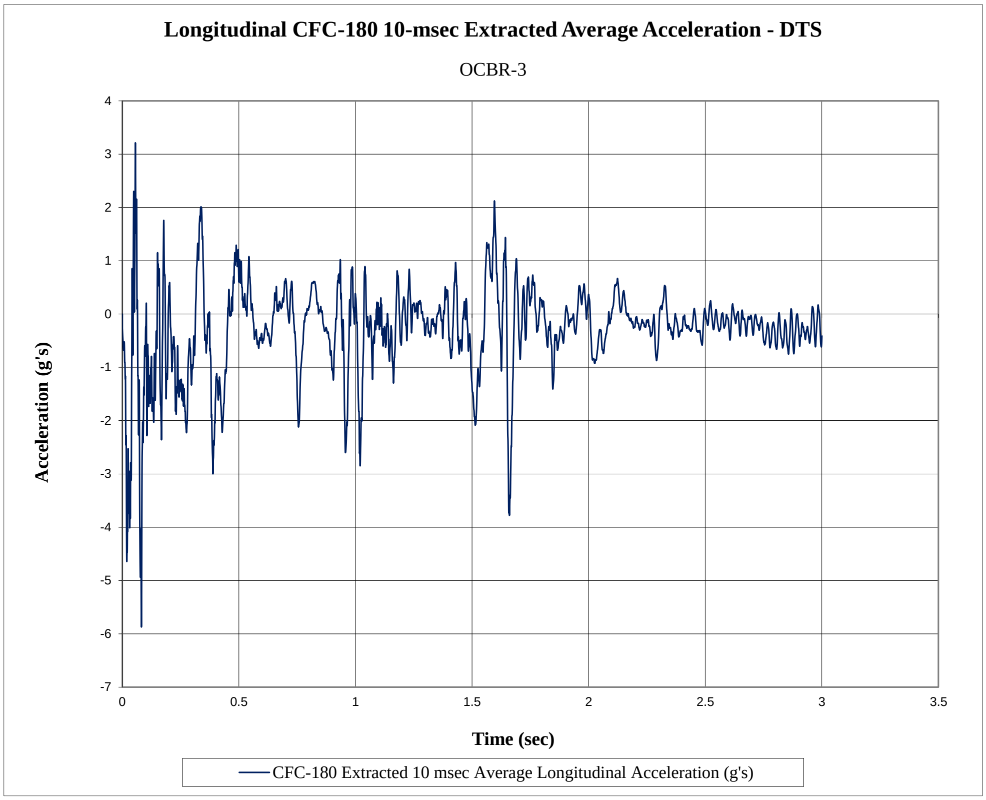


Figure F-17. 10-ms Average Longitudinal Deceleration (DTS), Test No. OCBR-3

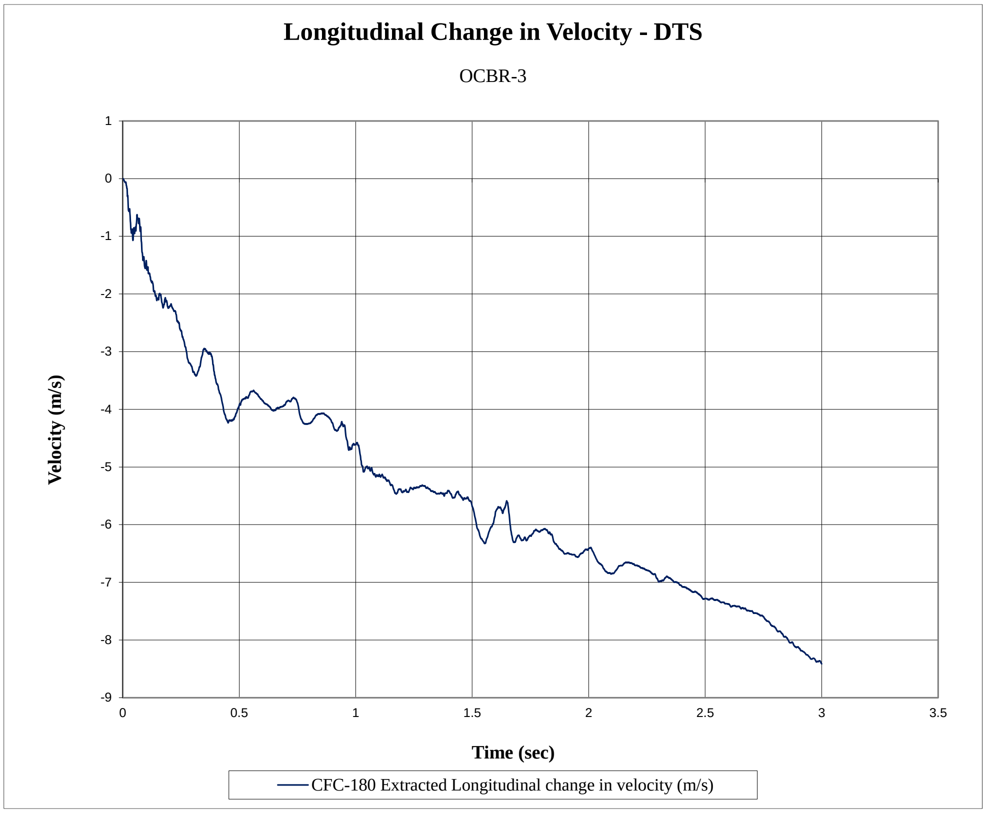


Figure F-18. Longitudinal Occupant Impact Velocity (DTS), Test No. OCBR-3

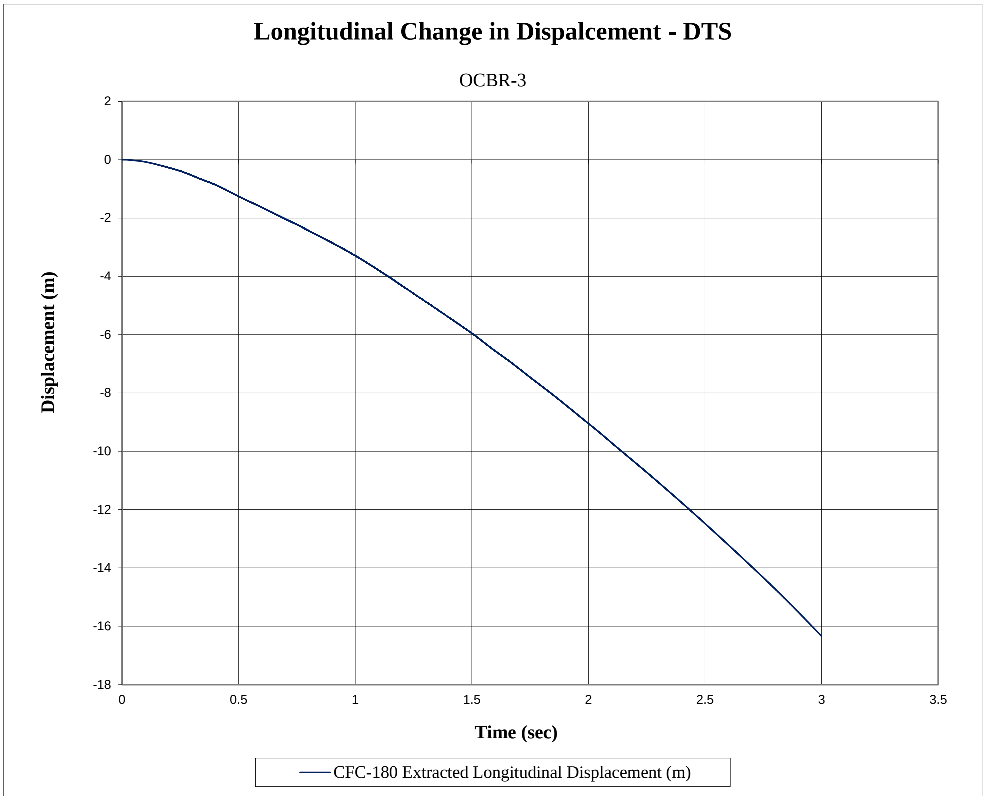


Figure F-19. Longitudinal Occupant Displacement (DTS), Test No. OCBR-3

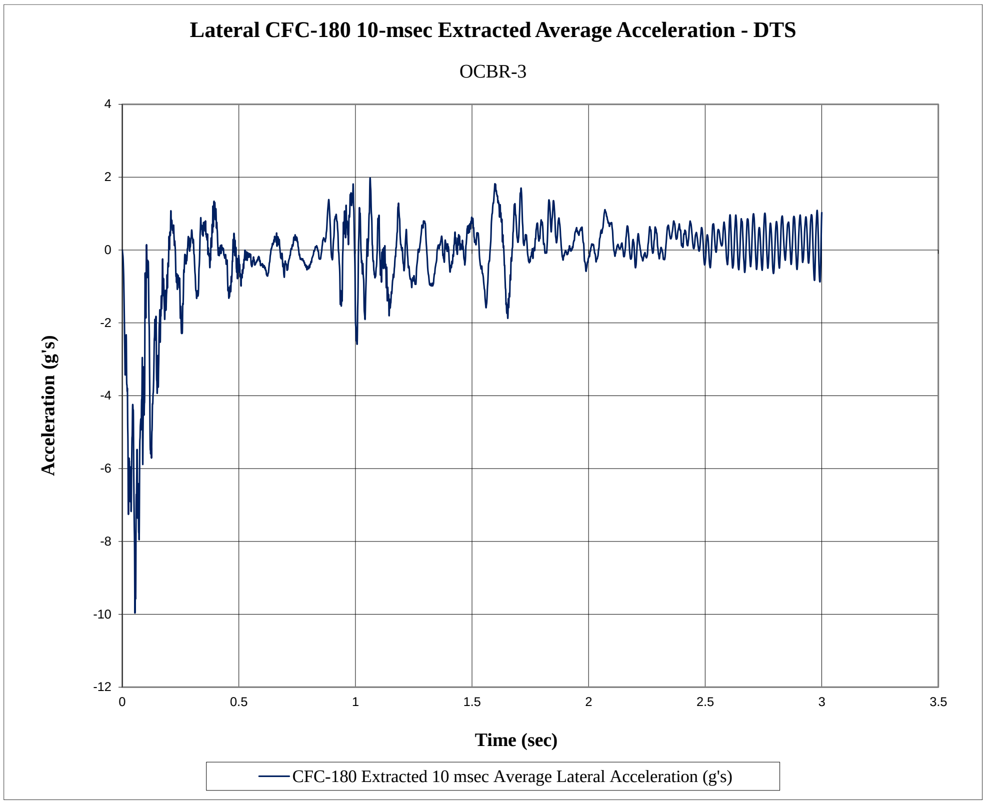


Figure F-20. 10-ms Average Lateral Deceleration (DTS), Test No. OCBR-3

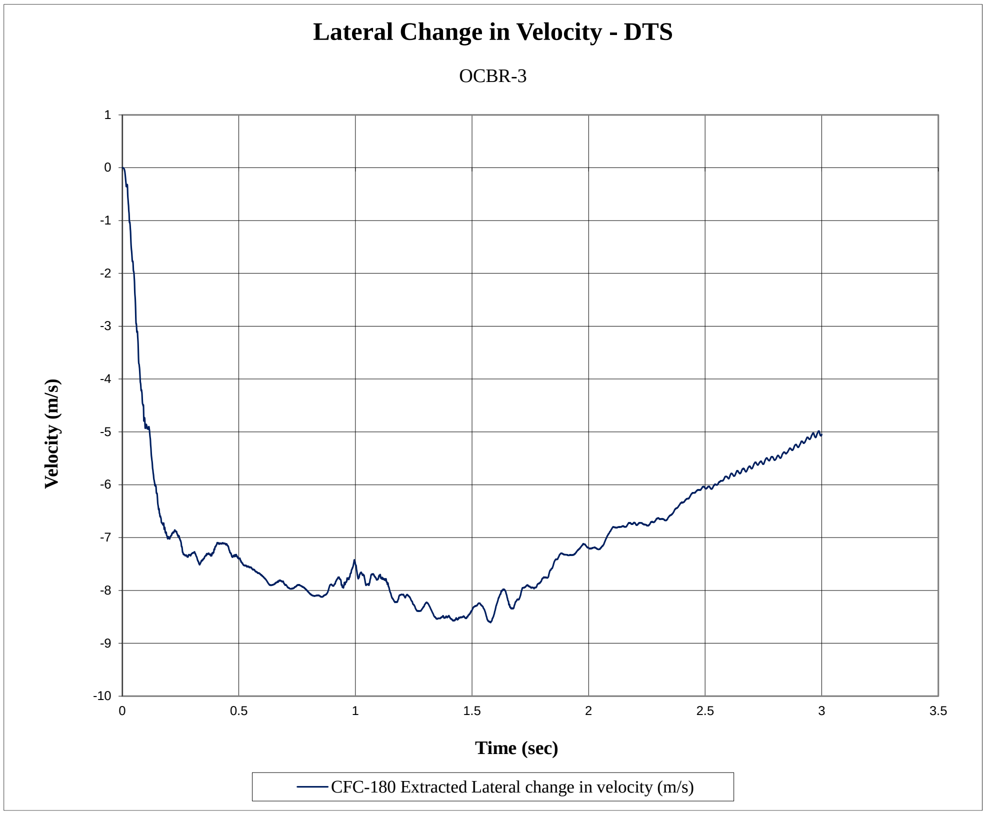


Figure F-21. Lateral Occupant Impact Velocity (DTS), Test No. OCBR-3

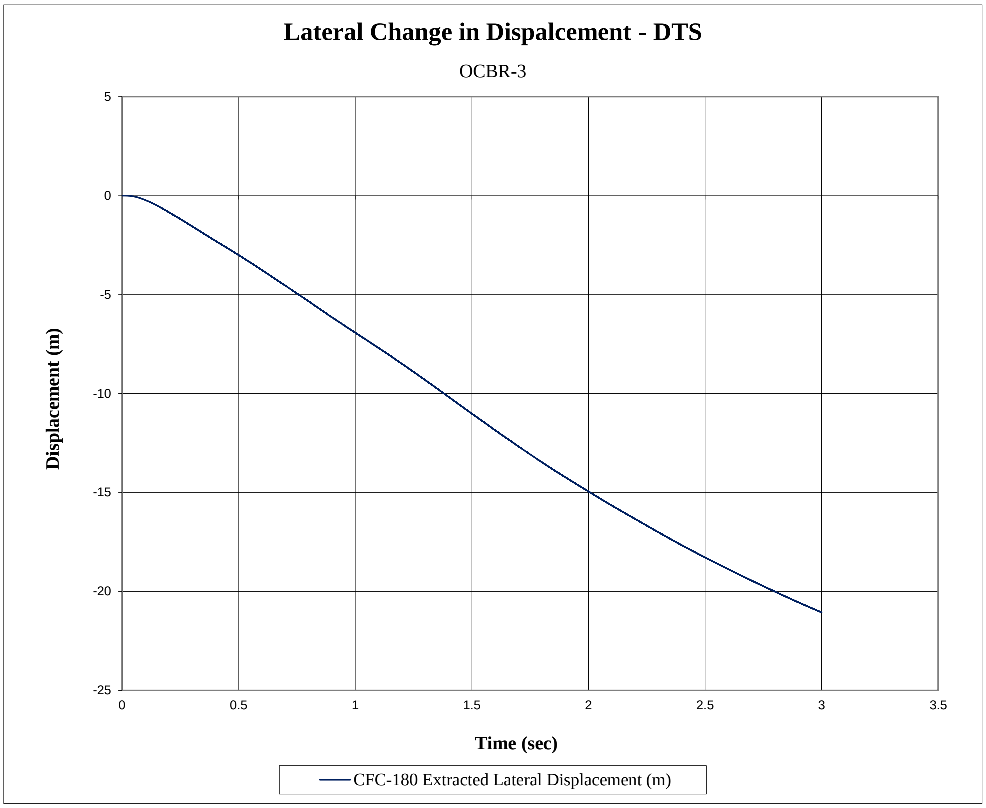


Figure F-22. Lateral Occupant Displacement (DTS), Test No. OCBR-3

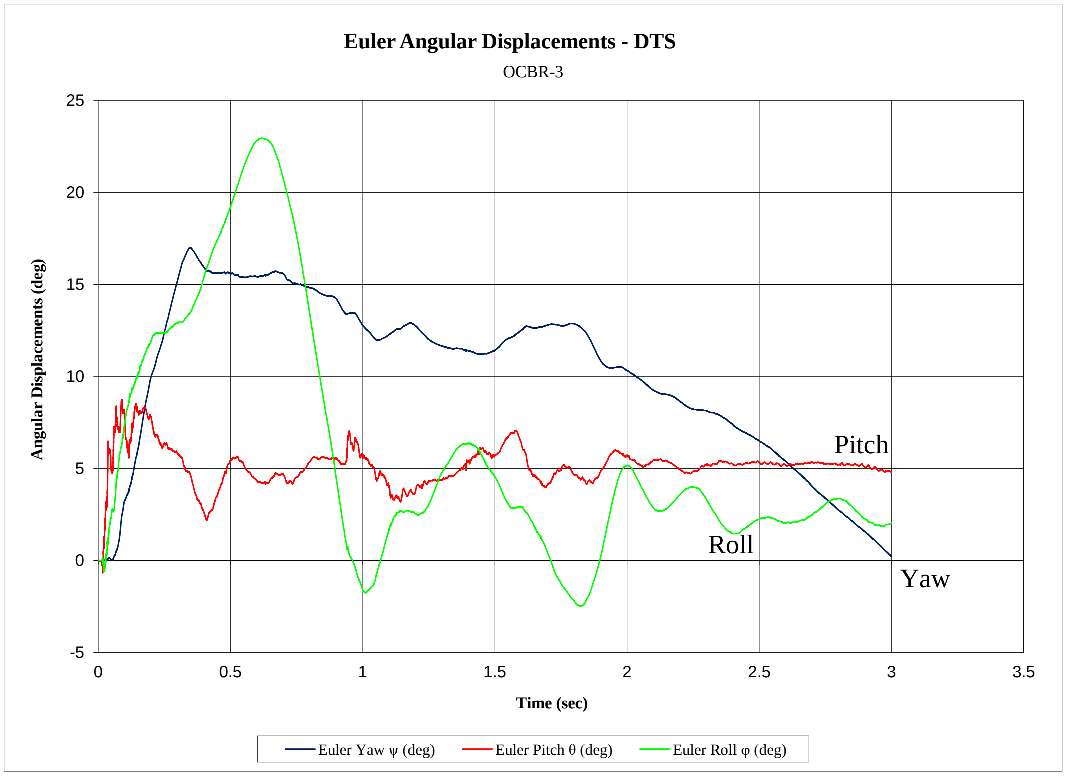


Figure F-23. Vehicle Angular Displacements (DTS), Test No. OCBR-3

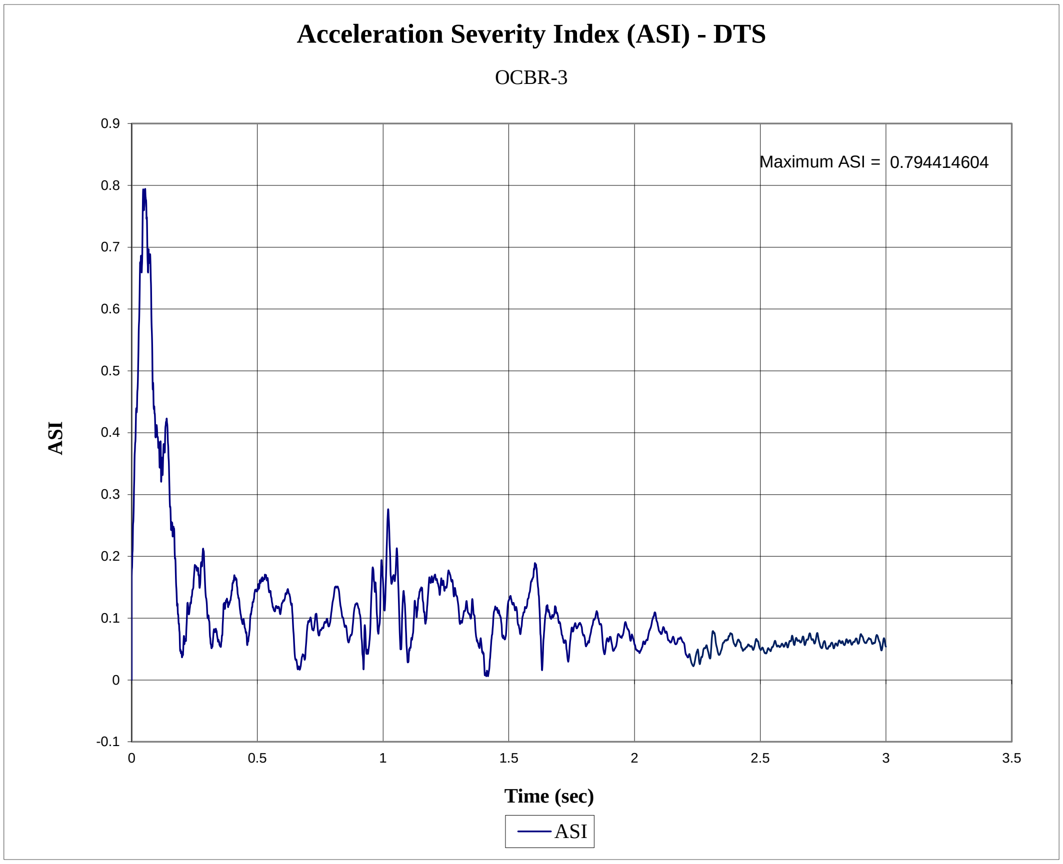


Figure F-24. Acceleration Severity Index (DTS), Test No. OCBR-3

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