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DEVELOPMENT OF IOWA DOT COMBINATION BRIDGE SEPARATION BARRIER WITH BICYCLE RAILING – PHASE II

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16. Abstract

A combination bridge rail was designed and crash tested for Iowa Department of Transportation (Iowa DOT) for use alongside a pedestrian/bicycle bridge pathway that would satisfy *Manual for Assessing Safety Hardware* (MASH) 2016 Test Level 2 (TL-2) criteria. Currently, Iowa DOT employs a combination bridge rail that utilizes a concrete parapet that had previously been successfully evaluated according to National Cooperative Highway Research Program (NCHRP) Report No. 350 TL-4 criteria. While the parapet had been successfully evaluated, the combination bridge rail system as a whole had not been evaluated to any crash test standards. Thus, Iowa DOT desired that researchers at Midwest Roadside Safety Facility (MwRSF) test the new combination bridge separation barrier to current MASH 2016 TL-2 standards to use in place of their current, untested system.

The new combination bridge rail system consisted of a pedestrian/bicycle railing mounted atop a vertical concrete parapet. The pedestrian/bicycle railing featured spliced longitudinal rails welded atop structural steel tube posts with welded steel base plates for attachment atop the parapet. In full-scale crash test no. IBBR-1, the 2270P vehicle was successfully redirected, resulting in minimal damage to the rail from plastic deformation and minimal damage to the parapet. This combination bridge rail design minimized the concrete parapet height that could be used in order to safely redirect the impacting vehicle, thus providing many advantages such as reduced dead weight on bridges, decreased construction costs, and improved sight lines.

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DISCLAIMER STATEMENT

This material is based upon work supported by the Federal Highway Administration, U.S. Department of Transportation and the Iowa Department of Transportation under TPF-5(193) Supplement #101. The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the University of Nebraska-Lincoln, Iowa Department of Transportation nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names, which may appear in this report, are cited only because they are considered essential to the objectives of the report. The United States (U.S.) government and the State of Iowa do not endorse products or manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

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

INDEPENDENT APPROVING AUTHORITY

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

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

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1 INTRODUCTION

1.1 Background

Roadway designers are often faced with the challenge of providing pedestrian or bicycling railings on crashworthy traffic barriers in order to meet current guidance for vulnerable users. Current American Association of State Highway and Transportation Officials (AASHTO) *LRFD Bridge Design Specifications* [1] are imprecise regarding when a pedestrian or bicycle railing attached to a crashworthy traffic barrier would require crash testing to evaluate performance. The AASHTO *Roadside Design Guide*, 4th Edition [2], states that hardware attachments should not be placed within a barrier's Zone of Intrusion (ZOI) if practical alternate locations exist. The location and geometric configuration of these railing attachments can affect the safety performance of the barrier system. The Iowa Department of Transportation (DOT) currently has no complete vehicle/pedestrian separation barrier system that is documented as fully crashworthy in accordance with National Cooperative Highway Research Program (NCHRP) *Report No. 350* [3] or AASHTO's *Manual for Assessing Safety Hardware (MASH)* [4-5].

Iowa DOT typically builds separation barriers between vehicle and pedestrian/bicycle facilities when sidewalks or trails are present on vehicular bridges. In order to meet AASHTO *LRFD Bridge Design Specifications*, Iowa DOT must typically attach steel railings to crashworthy traffic barriers to achieve a minimum total system height above the trail surface of 42 in. (1,067 mm) for bicyclists. In some cases, public demands have encouraged Iowa DOT to attach such steel railings to separators when no bicycle facility exists and only a pedestrian sidewalk is present. Subsequently, most recently constructed separation barriers have included bicycle railing hardware since it is assumed that bicyclists will use sidewalks that do not meet minimum criteria required in the design of "official" bike facilities.

For urban applications, average travel speeds may warrant lower-cost, Test Level 2 (TL-2) crashworthy railing systems. Since 1999, Iowa DOT has preferred the use of vertical-face concrete barriers for low-speed (45 mph or less) roadway bridges as separation barriers between vehicles and pedestrian facilities in and near urban areas. A 34-in. (864-mm) tall, 10-in. (254-mm) wide vertical-face concrete barrier shape is typically used on these projects, as shown in Figure 1, though the existing roadway conditions that the barrier is typically installed on would allow for a lower height, MASH TL-2 barrier system. Improved vehicle stability and reduced lateral loading associated with TL-2 impact conditions suggest that top barrier height could be significantly reduced without compromising safety performance, which will lead to reduced dead weight on bridges, decreased construction costs, and improved sight lines. Vertical-face barriers are favored by the Federal Highway Administration (FHWA) and researchers because of performance benefits like decreased vehicle roll and reduced vehicle climbing potential. As such, Iowa DOT desired to determine a minimum crashworthy height for a MASH TL-2 vertical bridge parapet.

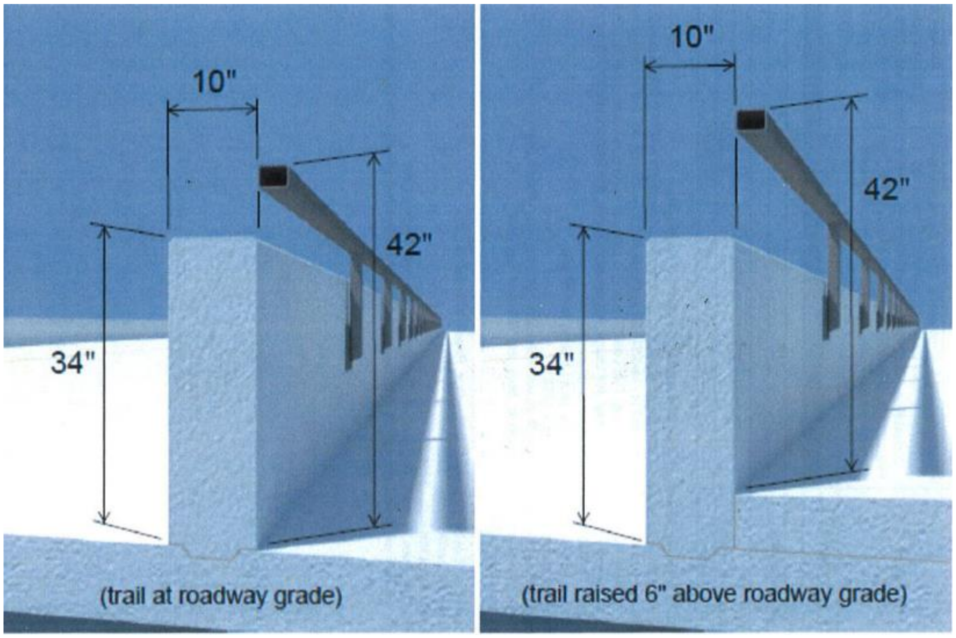


Figure 1. Iowa DOT Alternate Separation Barrier (in service)

It is Iowa DOT policy to place the vehicle barrier between the roadway and a pedestrian facility on a vehicular bridge. As noted previously, the use of such a separation barrier usually involves the addition of a steel railing to a concrete barrier in order to reach the minimum pedestrian/bicycle height. Exceptions occur only when there is no official bicycle facility and/or when sight distance concerns outweigh the safety implications of omitting the railing attachment. Iowa DOT steel railing attachments for pedestrians or bicyclists are designed to resist pedestrian loading and not vehicle impact loading.

Section 13 of AASHTO's *LRFD Bridge Design Specifications* describes the design requirements for railings. Specifically, sections 13.8 through 13.10 describe the design requirements for pedestrian, bicycle, and combination rails. With respect to geometry of the system, the railing was required to have an overall height of at least 42 in. (1,067 mm) above the top of the walkway or bicycle path. The design specifications also defined the maximum clear opening space for the railing. Clear space is defined as the space between horizontal and/or vertical elements. For the lower 27 in. (686 mm) of the railing, any clear space must be small enough to prevent a 6-in. (152-mm) diameter sphere from passing through. For any part of the railing above 27 in. (686 mm), the clear space must prevent pass-through of an 8-in. (203-mm) diameter sphere. However, the opening size recommendations for pedestrian/bicycle railings are only specified for railings on the outer edge of a bikeway when highway traffic is separated from the pathway by a traffic railing. Iowa DOT was concerned with the pedestrian/bicycle railing on the separator barrier only. Thus, the combination pedestrian/bicycle railing was not subject to the pass-through specifications, but still needed to meet the 42-in. (1,067 mm) height relative to the surface of the sidewalk or bikeway and the structural loading requirement. The location and design of the railing attachments also play a crucial role in the safety performance of the total barrier system. Poorly placed and/or designed railing attachments could lead to excessive vehicle snag, which could lead to vehicle instability or occupant risk concerns.

Additionally, current Iowa DOT policy for bicycle rail attachments is based on the 1989 AASHTO *Guide Specifications for Bridge Railings* [6]. In section G2.7.1.2.2, the guide states:

> "When a traffic railing is located between the roadway and a sidewalk or bikeway, the minimum height of the railing above the surface of the sidewalk or bikeway should be 24 inches and the railing should have a smooth surface to avoid snag points for pedestrians and cyclists."

As such, the separation bridge rail must have a minimum height of 24 in. (610 mm) relative to the sidewalk or bikeway. Thus, for sidewalks ranging in height from 0 to 6 in. (0 to 152 mm) relative to the roadway, the combination bicycle railing would need to have a minimum bridge rail parapet height ranging from 24 in. to 30 in. (610 mm to 762 mm) tall relative to the roadway and provide for a combination bicycle railing extending 42 in. (1,067 mm) above the surface of the sidewalk or bikeway.

In order to address the need for a crashworthy combination bridge separation barrier, Iowa DOT funded a research project to design and evaluate such a barrier. The objective of this study was to develop a MASH TL-2 combination bridge separation barrier with an upper bicycle railing for Iowa DOT. The new system could be used when sidewalks or trails are present on vehicular bridges. In Phase I of this effort, Midwest Roadside Safety Facility (MwRSF) designed a combination rail consisting of a 24-in. (610-mm) tall by 10-in. (254-mm) wide concrete parapet with a 24-in. (610-mm) tall tubular steel combination rail mounted on top [7]. The Phase I study also used LS-DYNA computer simulation to evaluate the feasibility of the system for MASH TL-2 impacts with both 1100C and 2270P vehicles and determine critical impact points (CIPs) for full-scale crash testing. The research detailed herein describes the full-scale crash testing and evaluation of that barrier design to MASH TL-2.

1.2 Objective

The objective of the research project was to develop a MASH 2016 TL-2 crashworthy, low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing. It was desired that the barrier be usable in standard applications as well as allow for the crashworthy bicycle railing to be added as needed. The design was to minimize the height of the concrete parapet portion of the system while providing improved visibility and sightlines. In addition, the new railing system was to comply with current AASHTO LRFD guidance for bicycle railings with respect to the parapet and combination railing.

1.3 Scope

The research objective was achieved through the completion of several tasks. The combination bridge separation barrier was constructed at the MwRSF Outdoor Test Facility based on the design details developed in Phase I. In order to evaluate the barrier systems, test designation no. 2-11 was conducted on the combination bridge separation barrier at the CIP determined in Phase I of the research. The test results were analyzed, evaluated, and documented, and conclusions and recommendations were made pertaining to the safety performance of the system. Specific recommendations were also be made regarding termination of the combination railing on the bridge parapet.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing detailed herein, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the FHWA for use on the National Highway System. For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [4]. Note that there is no difference between MASH 2009 [5] and MASH 2016 for longitudinal barriers such as the system tested in this project, except that additional occupant compartment deformation measurements, photographs, and documentation are required by MASH 2016. According to TL-2 of MASH 2016, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 1.

Table 1. MASH 2016 TL-2 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed mph (km/h)	Angle deg.	
Longitudinal Barrier	2-10	1100C	2,420 (1,100)	44 (70)	25	A,D,F,H,I
	2-11	2270P	5,000 (2,270)	44 (70)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

The researchers deemed test designation no. 2-11 as the critical test for the evaluation of the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing. Test designation no. 2-11 was deemed critical as the height of the 2270P vehicle would provide the maximum potential for vehicle instability due to the low-height parapet design used in the system and provide for the maximum extension of the vehicle over the parapet for vehicle engagement and snag on the bicycle rail. Both behaviors could adversely affect occupant safety. The CIP was determined through the simulation of the vehicle impacting the barrier system model at multiple impact points in the first phase of this research [7]. Due to the nature of the system, snag severity was considered to be the most important factor in determining the CIP. Several other parameters, such as vehicle damage, system damage, vehicle accelerations and velocities, and vehicle overlap of the system were observed and measured. From this process, it was concluded that an impact 3.8 ft (1.2 m) upstream from the face of a post, or 46⅝ in. (1,184 mm) upstream from the centerline of a post, would provide the highest probability of snag and the highest snag severity for all of the impact points simulated based on observed overlap. Thus, this impact point was chosen as the CIP to be used in full-scale crash testing.

Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barrier

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

Test designation no. 2-10 was deemed non-critical for the evaluation of the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing. Previous MASH crash testing with the 1100C vehicle at TL-3 on taller vertical parapets has shown that occupant risk measures were not exceeded for small car impacts, even when conducted at higher speeds [8-9]. Vehicle stability on the low-height parapet was also deemed not critical as redirection of the taller 2270P vehicle in test designation no. 2-11 would be a more critical test of vehicle stability. As such, the final remaining concern for test designation no. 2-10 was the potential for vehicle snag on the bicycle rail. During the previous phase of this research, simulations were conducted with the 1100C vehicle on the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing to evaluate the potential for vehicle snag [7]. The interaction between the 1100C vehicle and the attached bicycle rail was relatively minor. The vehicle’s front-right headlight assembly contacted post no. 4 in the simulation, but no permanent deformation of the post occurred, suggesting a minor snag event. Further, no contact between the side passenger windows and the attached bicycle rail was observed during simulation. Thus, the simulation effort confirmed that MASH 2016 test designation no. 2-11 would provide a more severe impact scenario than MASH 2016 test designation no. 2-10.

It should be noted that the test matrix detailed herein represents the researchers' best engineering judgement with respect to the MASH 2016 safety requirements and their internal evaluation of critical tests necessary to evaluate the crashworthiness of the w-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing. However, these opinions may change in the future due to the development of new knowledge (crash testing, real-world performance, etc.) or changes to the evaluation criteria. Thus, any tests within the evaluation matrix deemed non-critical may eventually need to be evaluated based on additional knowledge gained over time or revisions to the MASH 2016 criteria.

2.2 Evaluation Criteria

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

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

3 DESIGN DETAILS – TEST NO. IBBR-1

The test installation consisted of 100 ft – 4½ in. (30.6 m) of pedestrian/bicycle railing mounted atop a concrete parapet, as shown in Figures 2 through 15. Photographs of the test installation are shown in Figures 16 through 19. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The bicycle rail consisted of tubular steel, longitudinal rails, tubular steel posts, and fabricated steel splice sections. The longitudinal rails were fabricated with HSS3x2x⅛ ASTM A500 Grade C structural steel tubing. Each of the longitudinal rails consisted of 20-ft (6,096-mm) long sections spliced at the quarter-span between two posts. The rails were welded on top of the posts using ⅛-in. (3-mm) fillet welds around the entire post section.

The 28¼-in. long x 2⅝-in. deep x 1⅝-in. wide (718-mm x 67-mm x 41-mm) rail splices were fabricated with two 28¼-in. x 1¼-in. x $^{5}/_{16}$-in. (718-mm x 32-mm x 8-mm) ASTM A572 Grade 50 plates and two 28¼-in. x 2-in. x $^{5}/_{16}$-in. (718-mm x 51-mm x 8-mm) ASTM A572 Grade 50 plates welded together using $^{3}/_{16}$-in. (5-mm) fillet welds, as shown in Figures 6 and 7. The splices were inserted into the bicycle rail tubes and held in place with four ½-in. (13-mm) diameter, 3-in. (76-mm) long bolts placed vertically with two in the upstream tube section and two in the downstream tube section.

The 21⅜-in. (543-mm) long steel posts were fabricated with HSS2x2x⅛ ASTM A500 Grade C structural steel tubing. A 9¼-in. x 7-in. x $^{5}/_{8}$-in. (235-mm x 178-mm x 16-mm) ASTM A572 Grade 50 steel plate was welded to the bottom of each post in order to attach it to the top face of the barrier. For each post attachment location to the parapet, two ¾-in. (19-mm) diameter, 14-in. (356-mm) long ASTM F1554 Grade 105 threaded rods were anchored 12 in. (305 mm) into the parapet using epoxy adhesive with a minimum bond strength of 1,560 psi (10.8 MPa), as shown in Figures 3 and 5. All connection hardware was coated using the appropriate ASTM galvanization process and specification as stated in the Bill of Materials, shown in Figure 15. The posts were spaced 10 ft (3 m) apart on center.

The 24-in. tall x 10-in. wide (610-mm x 254-mm) concrete parapet consisted of NE mix 47BD with a minimum compressive strength of 4,000 psi (27.6 MPa). The parapet was reinforced with four ASTM A615 Grade 60 #4 longitudinal rebar spaced at 10¼ in. (260 mm) and ASTM A615 Grade 60 #4 shear stirrups spaced at 24 in. (610 mm), as shown in Figures 11 and 12. Although the barrier may be anchored to various foundations, such as bridge decks, the vertical steel was anchored into existing concrete tarmac for testing purposes, as shown in Figure 3. The overall height of the system with the parapet and the bicycle railing was 48 in. (1,219 mm).

The upstream and downstream ends of the bicycle railing did not utilize an anchored termination to the parapet for the full-scale crash testing. Recommended termination configurations for the bicycle railing are provided in Section 6.3 of this report.

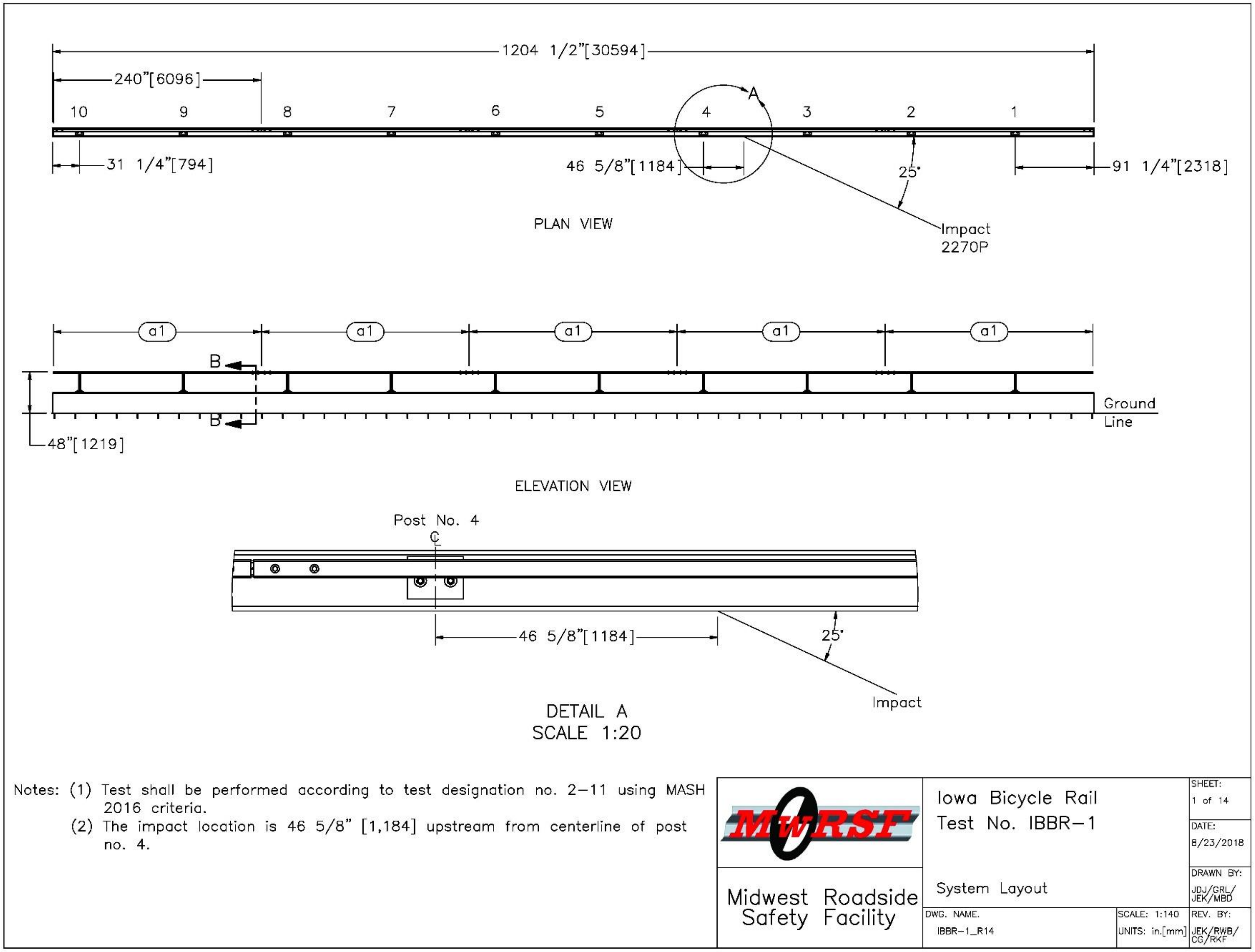
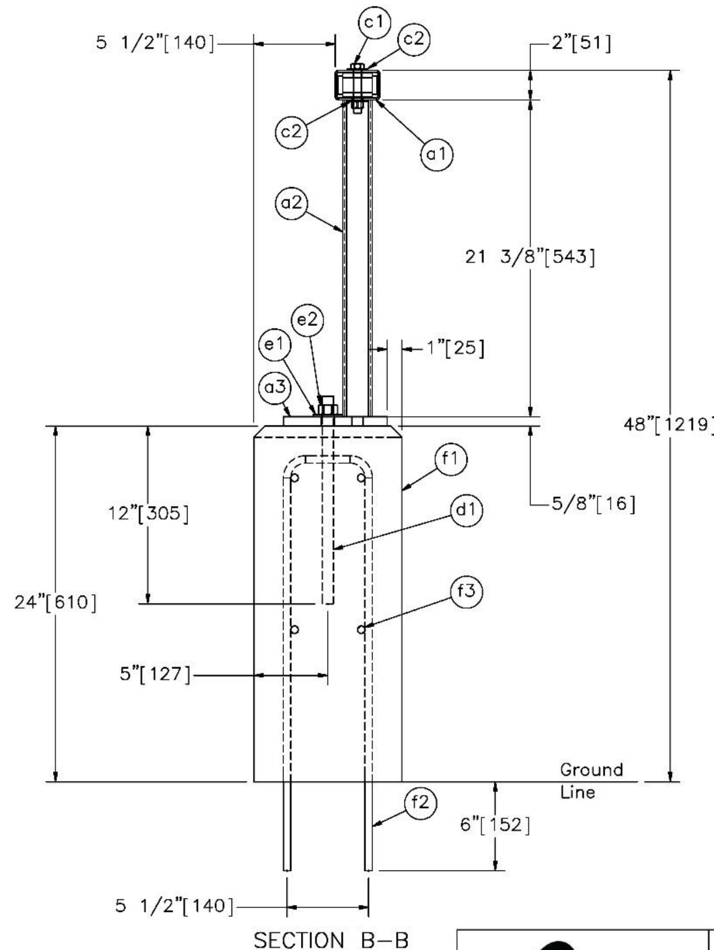


Figure 2. System Layout, Test No. IBBR-1



Notes: (1) Reinforcement bar no. f2 is anchored into the exisiting tarmac with Hilti HIT–RE 500 V3 epoxy with a minimum bond strength of 1,560 psi [10.8 MPa].
(2) Threaded rod (part d1) is anchored into the concrete barrier with Hilti HIT–RE 500 V3 epoxy with a minimum bond strength of 1,560 psi [10.8 MPa].

MwRSF Midwest Roadside Safety Facility	Iowa Bicycle Rail Test No. IBBR–1		SHEET: 2 of 14
			DATE: 8/23/2018
	System Cross Section		DRAWN BY: JDJ/GRL/JEK/MBD
	DWG. NAME. IBBR–1_R14	SCALE: 1:10 UNITS: in.[mm]	REV. BY: JEK/RWB/CC/RKF

Figure 3. System Cross Section Layout, Test No. IBBR-1

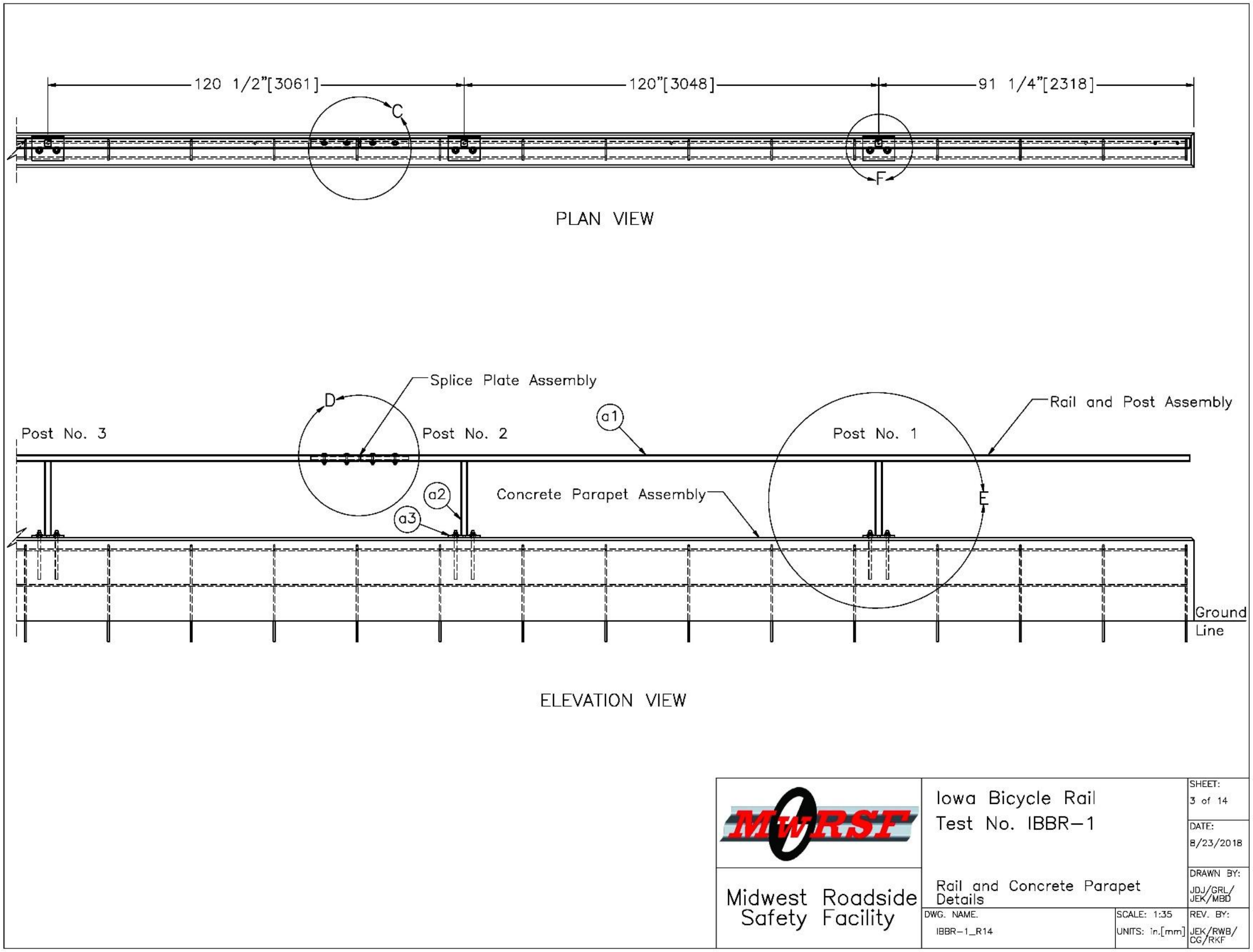


Figure 4. Rail and Concrete Parapet Overview, Test No. IBBR-1

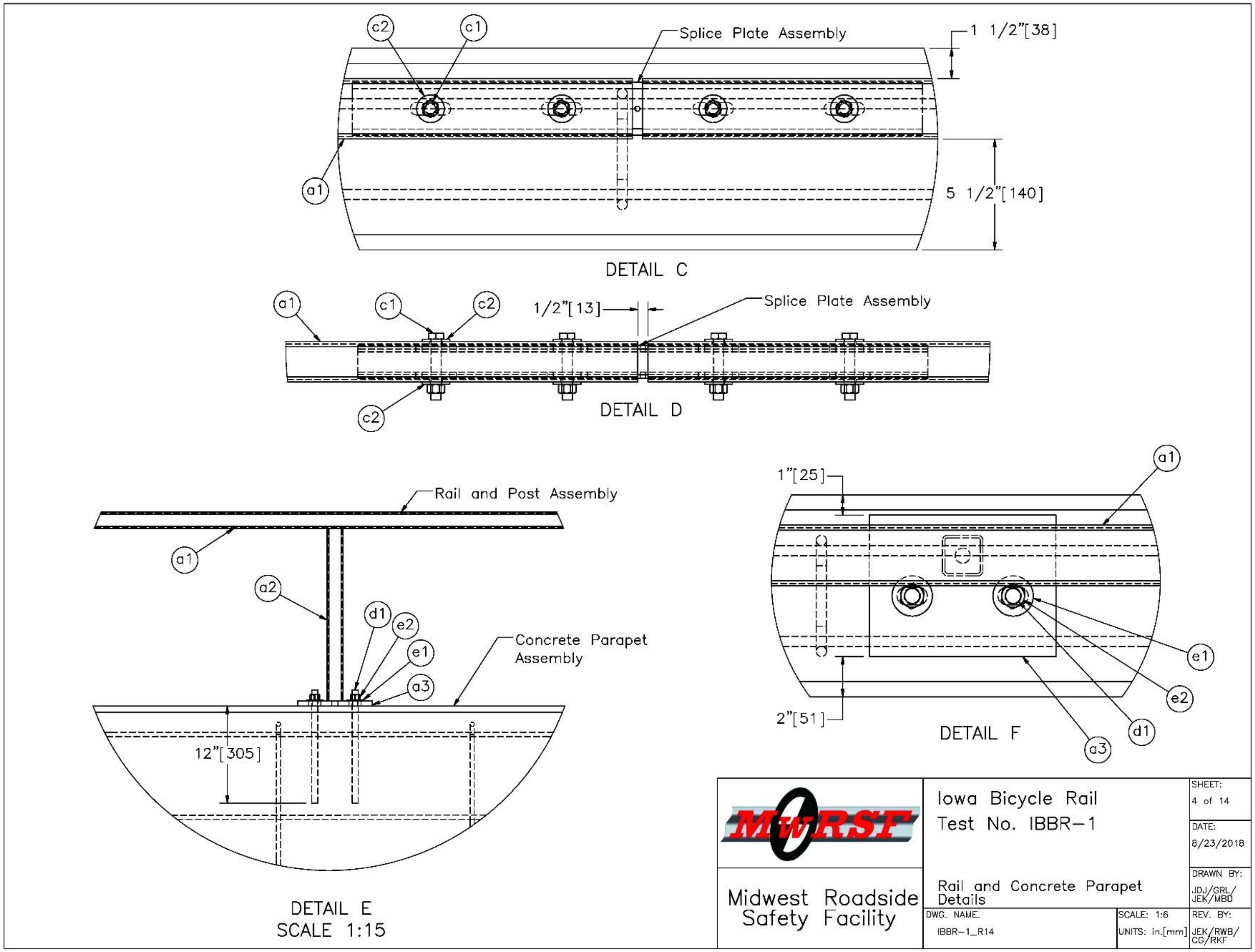
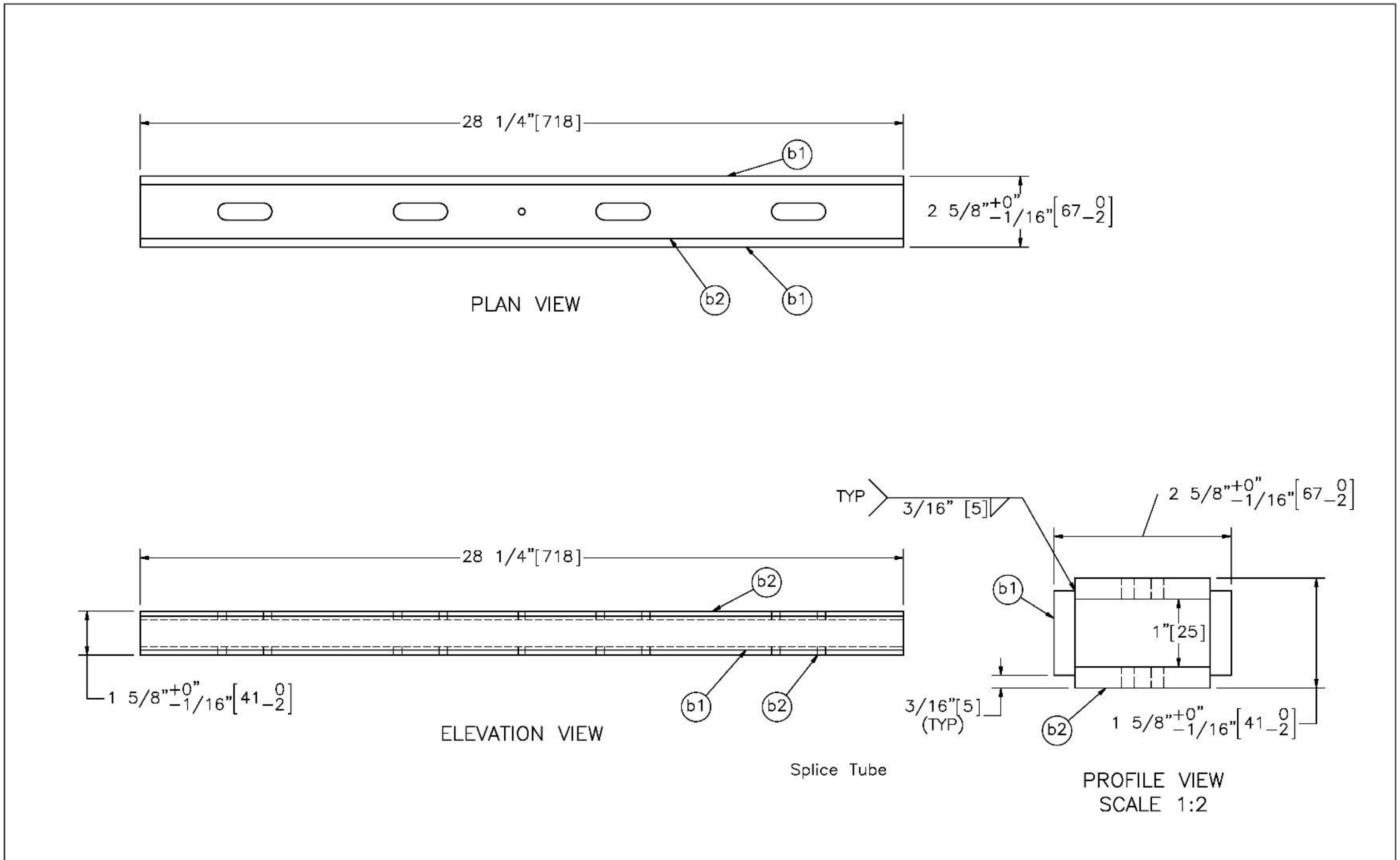


Figure 5. Rail and Concrete Parapet Details, Test No. IBBR-1



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	4	Splice Plate Assembly	–	ASTM A123
b1	2	28 1/4"x1 1/4"x5/16" [718x32x8] Plate	ASTM A572 Gr. 50	–
b2	2	28 1/4"x2"x5/16" [718x51x8] Plate	ASTM A572 Gr. 50	–

Midwest Roadside Safety Facility

Iowa Bicycle Rail
Test No. IBBR−1

Splice Plate Assembly

SHEET: 5 of 14
DATE: 8/23/2018
DRAWN BY: JDJ/GRL/JEK/MBD
DWG. NAME. IBBR−1_R14
SCALE: 1:5
UNITS: in.[mm]
REV. BY: JEK/RWB/CG/RKF

Figure 6. Splice Plate Assembly, Test No. IBBR-1

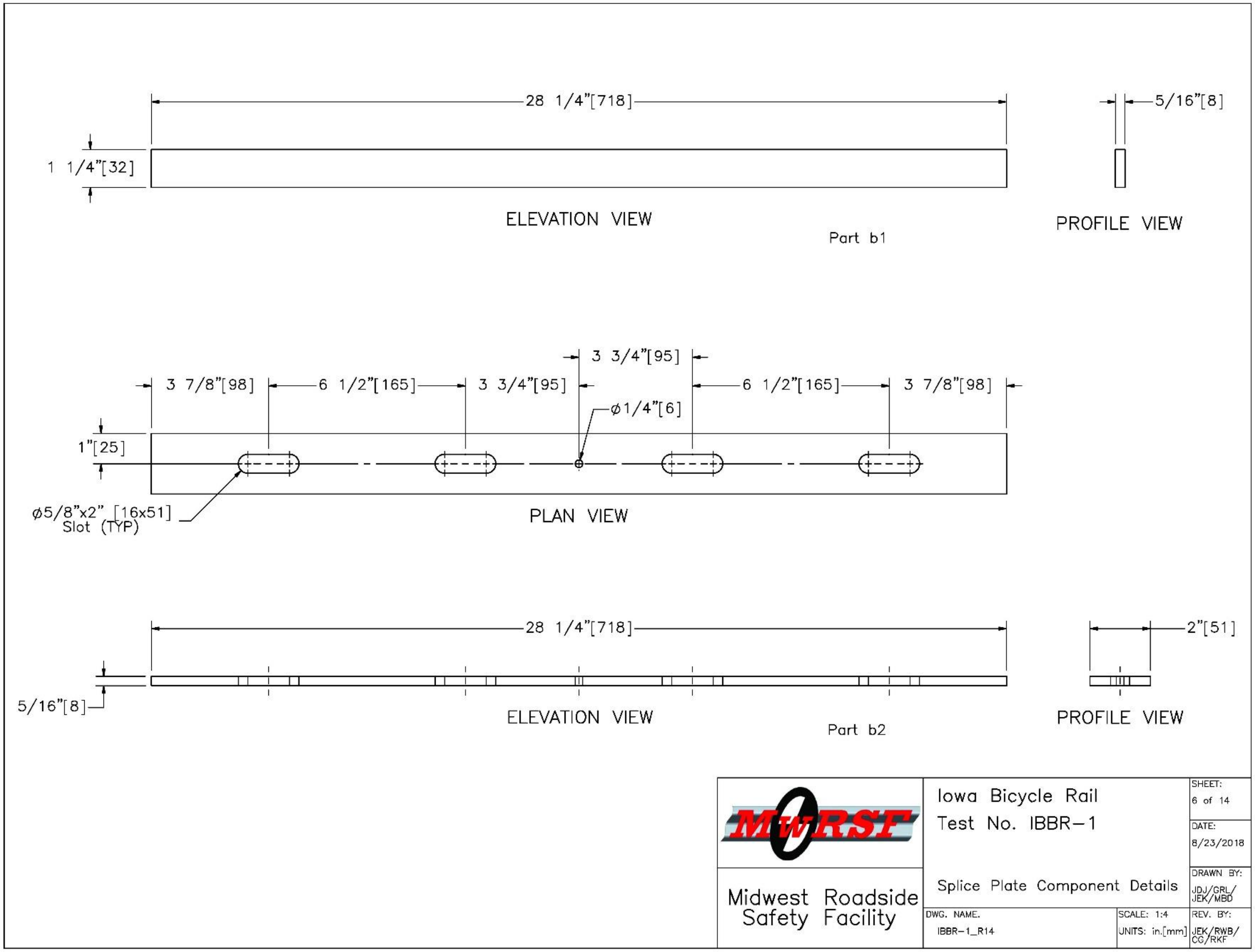
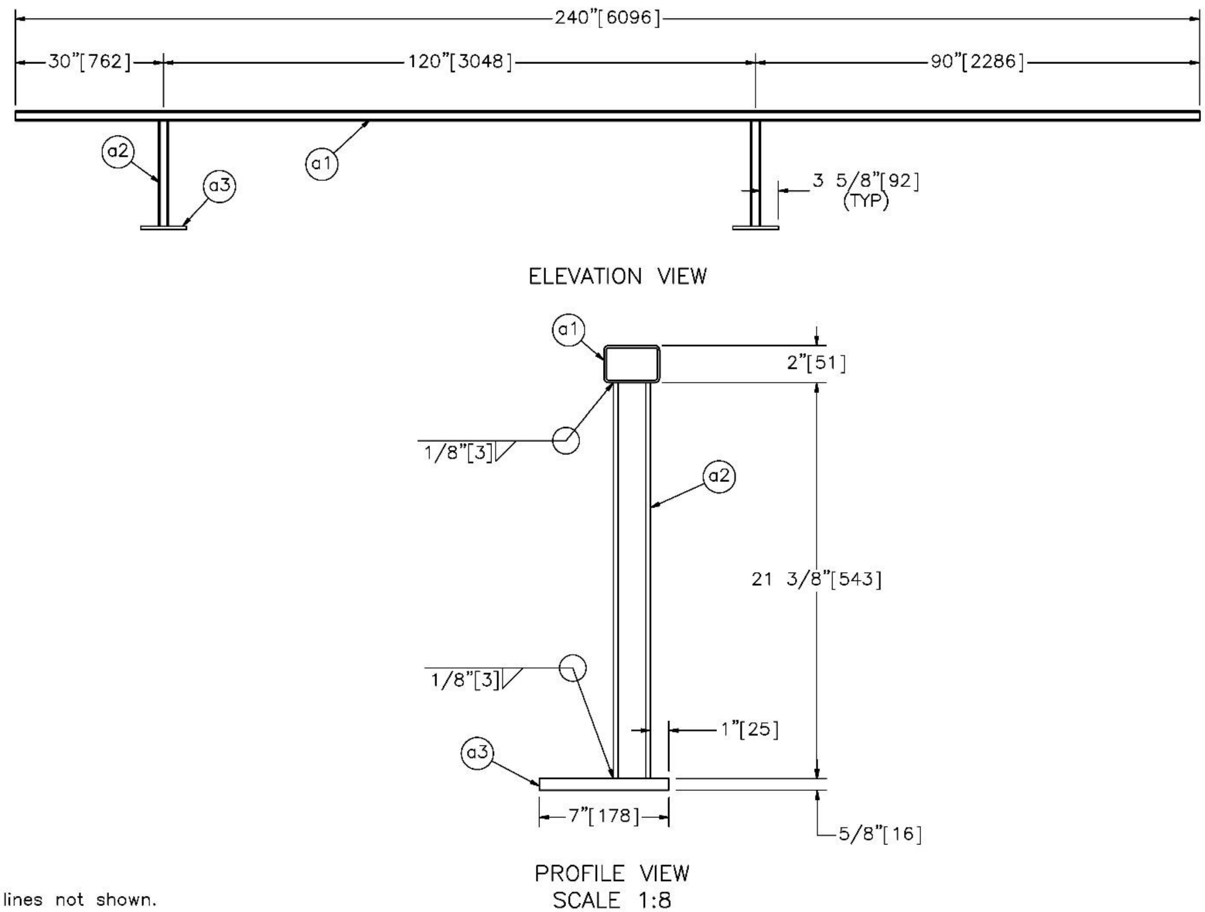


Figure 7. Splice Plate Component Details, Test No. IBBR-1



Note: Hidden lines not shown.

Item No.	QTY.	Description	Material Specification	Treatment Specification
–	5	Rail and Post Assembly	–	ASTM A123
a1	1	HSS 3"x2"x1/8" [76x51x3], 240" [6,096] Long Tube	ASTM A500 Gr. C	–
a2	2	HSS 2"x2"x1/8" [51x51x3], 21 3/8" [543] Long Tube	ASTM A500 Gr. C	–
a3	2	9 1/4"x7"x5/8" [235x178x16] Plate	ASTM A572 Gr. 50	–

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Iowa Bicycle Rail
Test No. IBBR-1

Rail and Post Assembly

SHEET: 7 of 14
DATE: 8/23/2018
DRAWN BY: JDJ/GRL/JEK/MBD
DWG. NAME. IBBR-1_R14
SCALE: 1:30
UNITS: in.[mm]
REV. BY: JEK/RWB/CG/RKF

Figure 8. Rail and Post Assembly, Test No. IBBR-1

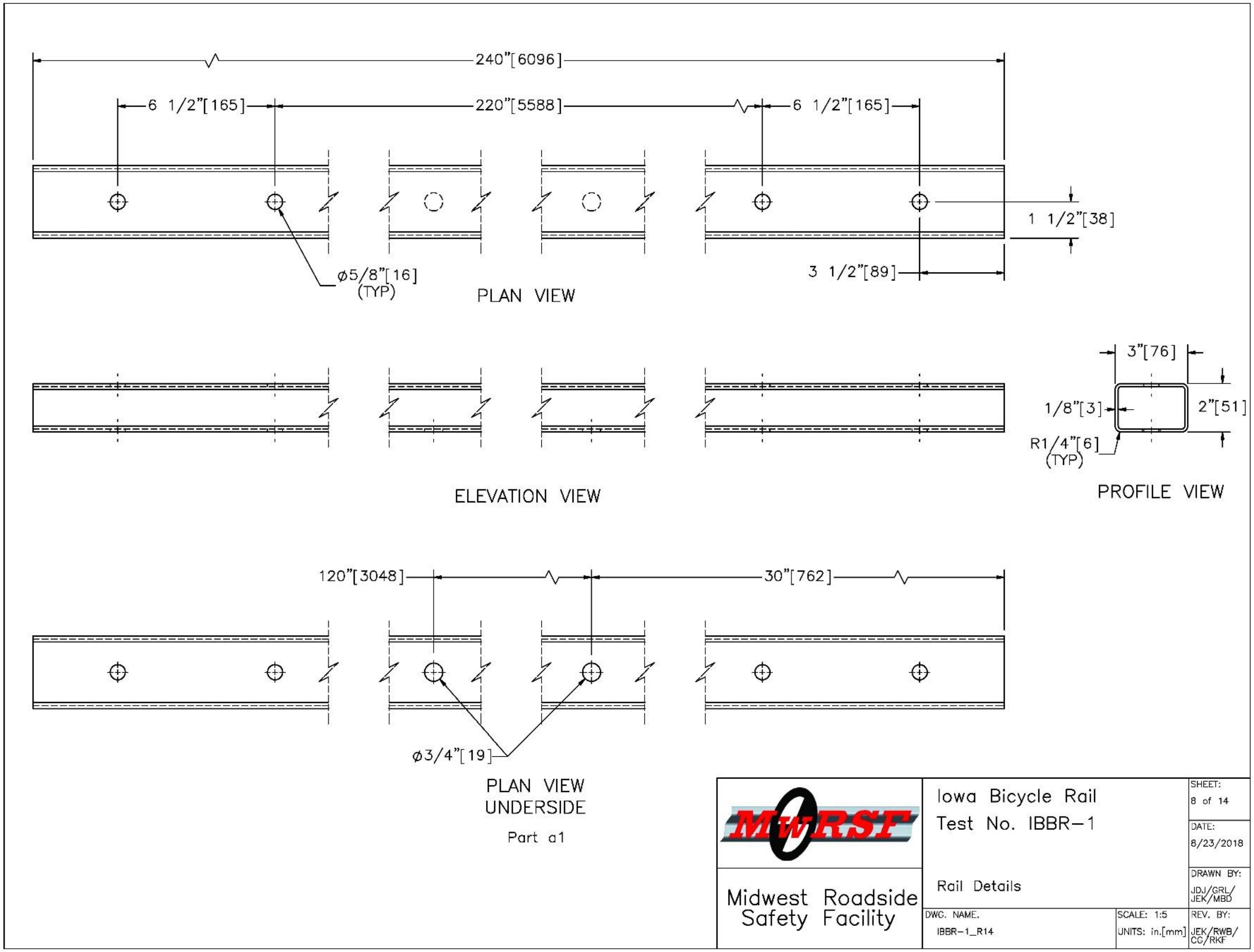


Figure 9. Rail Details, Test No. IBBR-1

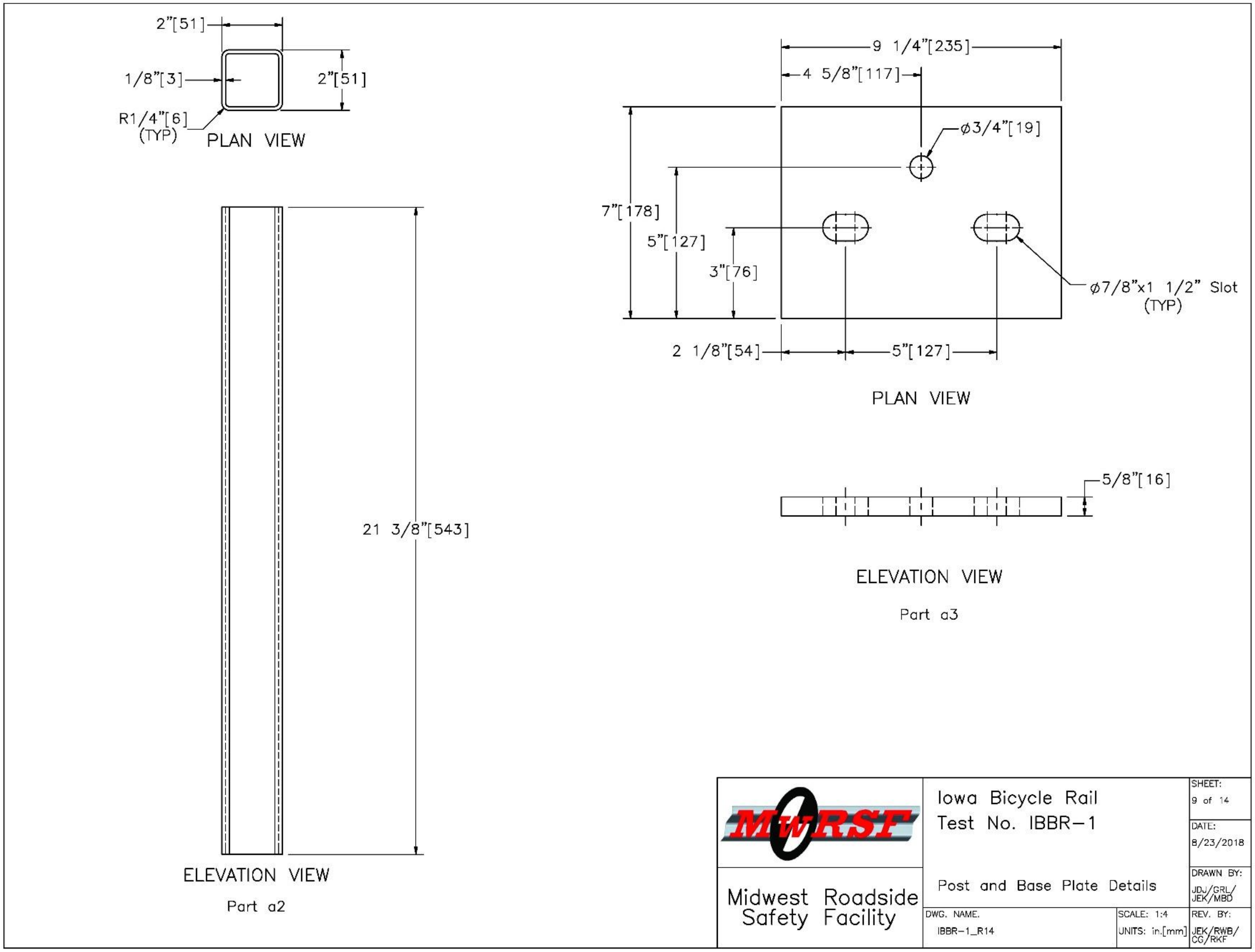


Figure 10. Post and Base Plate Details, Test No. IBBR-1

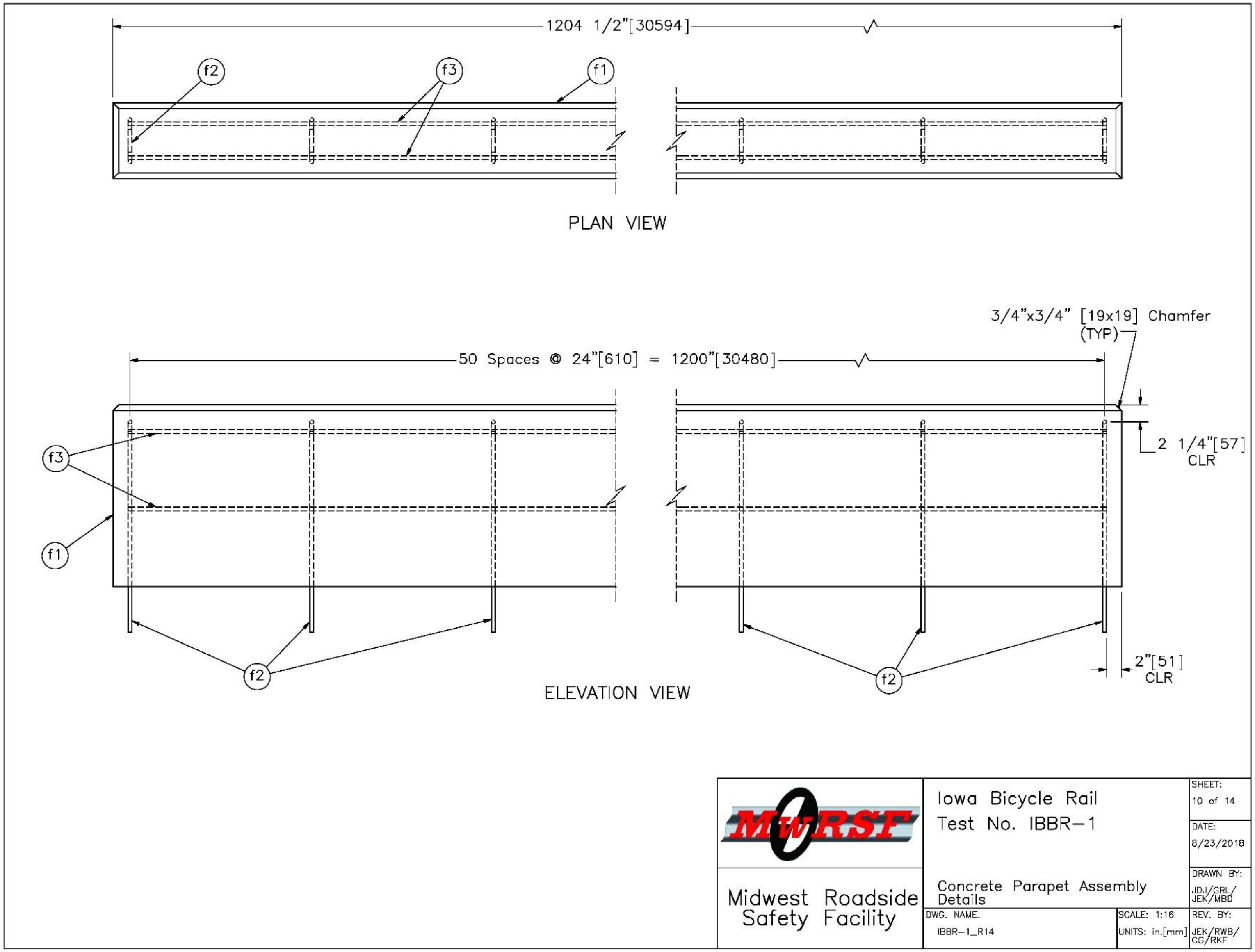
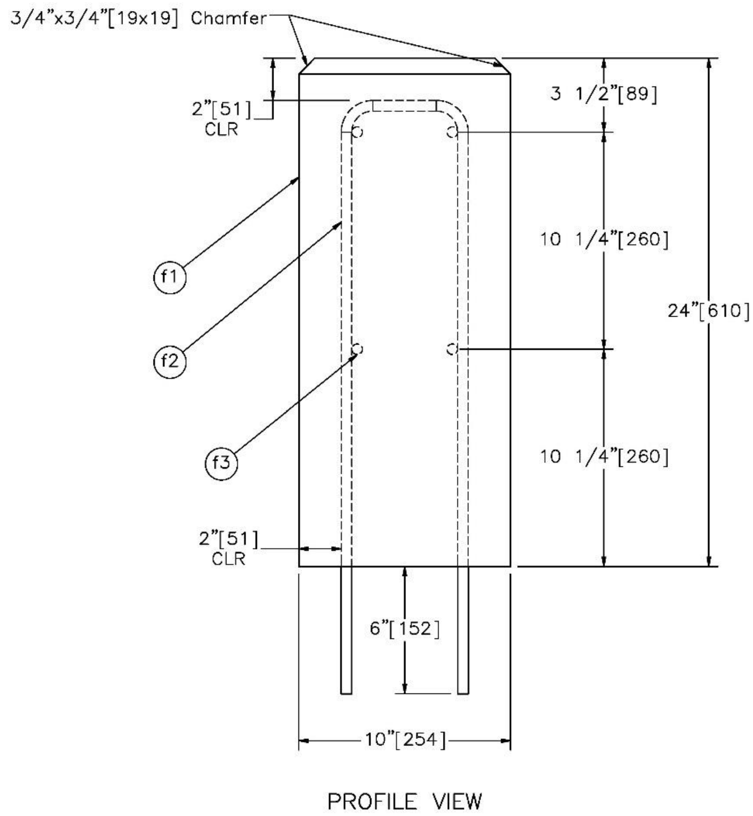


Figure 11. Concrete Parapet Assembly Details, Test No. IBBR-1



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Concrete Parapet Assembly	–	–
f1	1	Concrete	Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD	–
f2	51	#4 [13] Rebar, 59 15/16" [1,522] Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
f3	4	#4 [13] Rebar, 1,200 1/2" [30,493] Total Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)

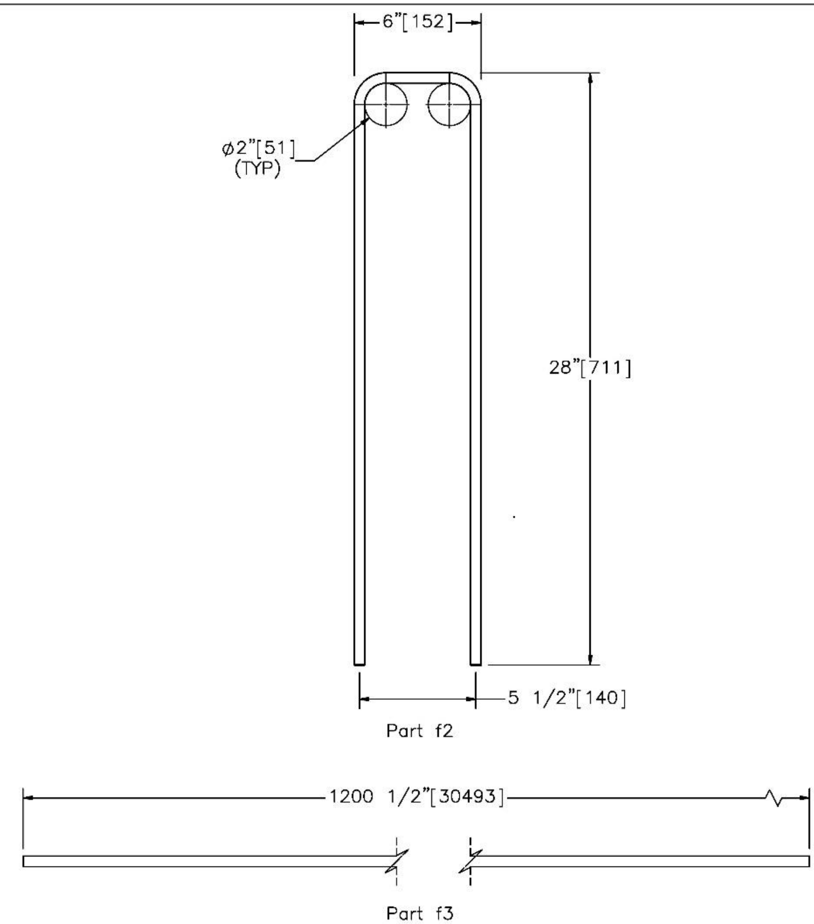
Midwest Roadside Safety Facility

Iowa Bicycle Rail
Test No. IBBR–1

Concrete Parapet Assembly Details

SHEET: 11 of 14
DATE: 8/23/2018
DRAWN BY: JDJ/GRL/JEK/MBD
DWG. NAME. IBBR–1_R14
SCALE: 1:7
UNITS: in.[mm]
REV. BY: JEK/RWB/CG/RKF

Figure 12. Concrete Parapet Assembly Details, Test No. IBBR-1



Bill of Bars

Bar	QTY.	Size	Total Unbent Length	Material Specification	Treatment Specification
f2	51	#4 [13]	59 15/16" [1,522]	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)
f3	4	#4 [13]	1,200 1/2" [30,493]	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775 or A934)

MwRSF
Midwest Roadside Safety Facility

Iowa Bicycle Rail
Test No. IBBR–1
Concrete Parapet Reinforcement

SHEET: 12 of 14
DATE: 8/23/2018
DRAWN BY: JDJ/GRL/JEK/MBD
DWG. NAME. IBBR–1_R14
SCALE: 1:7
UNITS: in.[mm]
REV. BY: JEK/RWB/CG/RKF

Figure 13. Concrete Parapet Reinforcement, Test No. IBBR-1

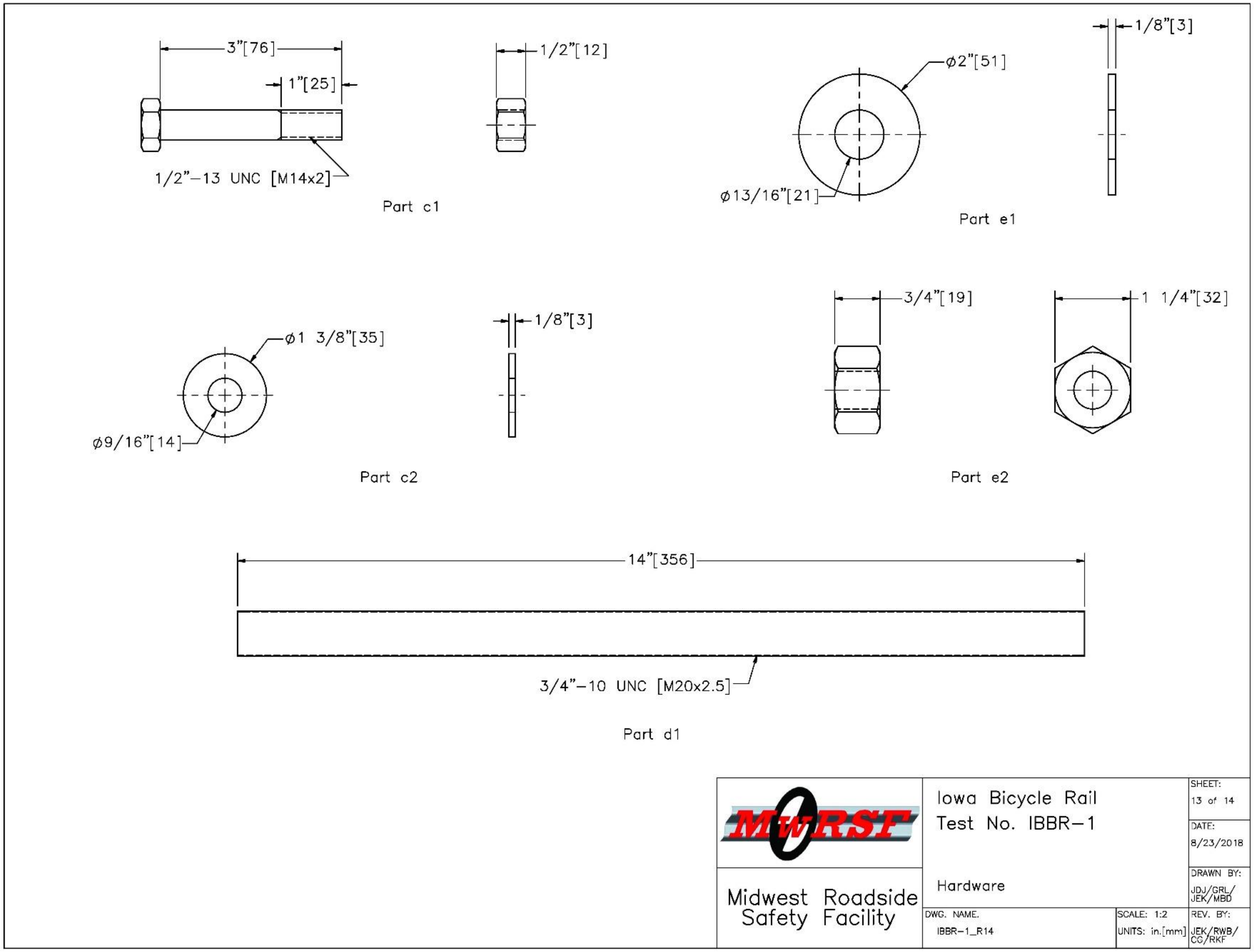


Figure 14. Hardware, Test No. IBBR-1

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	5	HSS 3"x2"x1/8" [76x51x3], 240" [6,096] Long Tube	ASTM A500 Gr. C	–	–
a2	10	HSS 2"x2"x1/8" [51x51x3], 21 3/8" [543] Long Tube	ASTM A500 Gr. C	–	–
a3	10	9 1/4"x7"x5/8" [235x178x16] Plate	ASTM A572 Gr. 50	–	–
b1	8	28 1/4"x1 1/4"x5/16" [718x32x8] Plate	ASTM A572 Gr. 50	–	–
b2	8	28 1/4"x2"x5/16" [718x51x8] Plate	ASTM A572 Gr. 50	–	–
c1	16	1/2"-13 UNC [M14x2], 3" [76] Long Heavy Hex Head Bolt and Nut	Bolt- ASTM F3125 Gr. A325 Type 1 or equivalent Nut – ASTM A563DH or equivalent	ASTM A153 or B695 Class 55 or F1136 Gr.3 or F2329 or F2833 Gr. 1	FBX14b
c2	32	1/2" [13] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC14a
d1	20	3/4"-10 UNC [M20x2.5], 14" [356] Long Fully Threaded Rod	ASTM F1554 Gr. 105	ASTM A123 or B695 Class 55 or F2329	FRR20b
e1	20	3/4" [19] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC20a
e2	20	3/4"-10 UNC [M20x2.5] Heavy Hex Nut	ASTM A563DH	ASTM A153 or B695 Class 55 or F2329	FBX20a
f1	1	Concrete	Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD	–	–
f2	51	#4 [13] Rebar, 59 15/16" [1,522] Total Unbent Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
f3	4	#4 [13] Rebar, 1,200 1/2" [30,493] Total Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775 or A934)	–
–	1	Epoxy	Min. bond strength = 1,560 psi [10.8 MPa] (Hilti HIT-RE 500 V3)	–	–

Midwest Roadside Safety Facility	Iowa Bicycle Rail Test No. IBBR-1		SHEET: 14 of 14 DATE: 8/23/2018
	Bill of Materials		DRAWN BY: JDJ/GRL/JEK/MBD
	DWG. NAME. IBBR-1_R14	SCALE: None UNITS: in.[mm]	REV. BY: JEK/RWB/CG/RKF

Figure 15. Bill of Materials, Test No. IBBR-1

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

Figure 17. Test Installation Photographs, Test No. IBBR-1

Figure 18. Test Installation Photographs, Test No. IBBR-1

Figure 19. Test Installation Photographs, Test No. IBBR-1

4 TEST CONDITIONS

4.1 Test Facility

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

4.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [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. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

4.3 Test Vehicle

For test no. IBBR-1, a 2011 Dodge Ram 1500 Quad Cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 4,986 lb (2,262 kg), 4,980 lb (2,259 kg), and 5,138 lb (2,331 kg), respectively. The test vehicle is shown in Figures 20 and 21, and vehicle dimensions are shown in Figure 22. It should be noted that the front overhang distance is ½ in. over the recommended MASH dimension, but it was not believed that this would affect the crash test results.

MASH 2016 describes that test vehicles used in crash testing should be no more than six model years old. Although a 2011 Dodge Ram 1500 Quad Cab pickup truck was used for the full crash test in 2018, it was acceptable because the vehicle model was within six years of the project start date.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [11] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The location of the final c.g. is shown in Figures 22 and 23. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure

23. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicle.

The front wheels of the test vehicle 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 right-side windshield wiper 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 remote-controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

Figure 20. Test Vehicle, Test No. IBBR-1

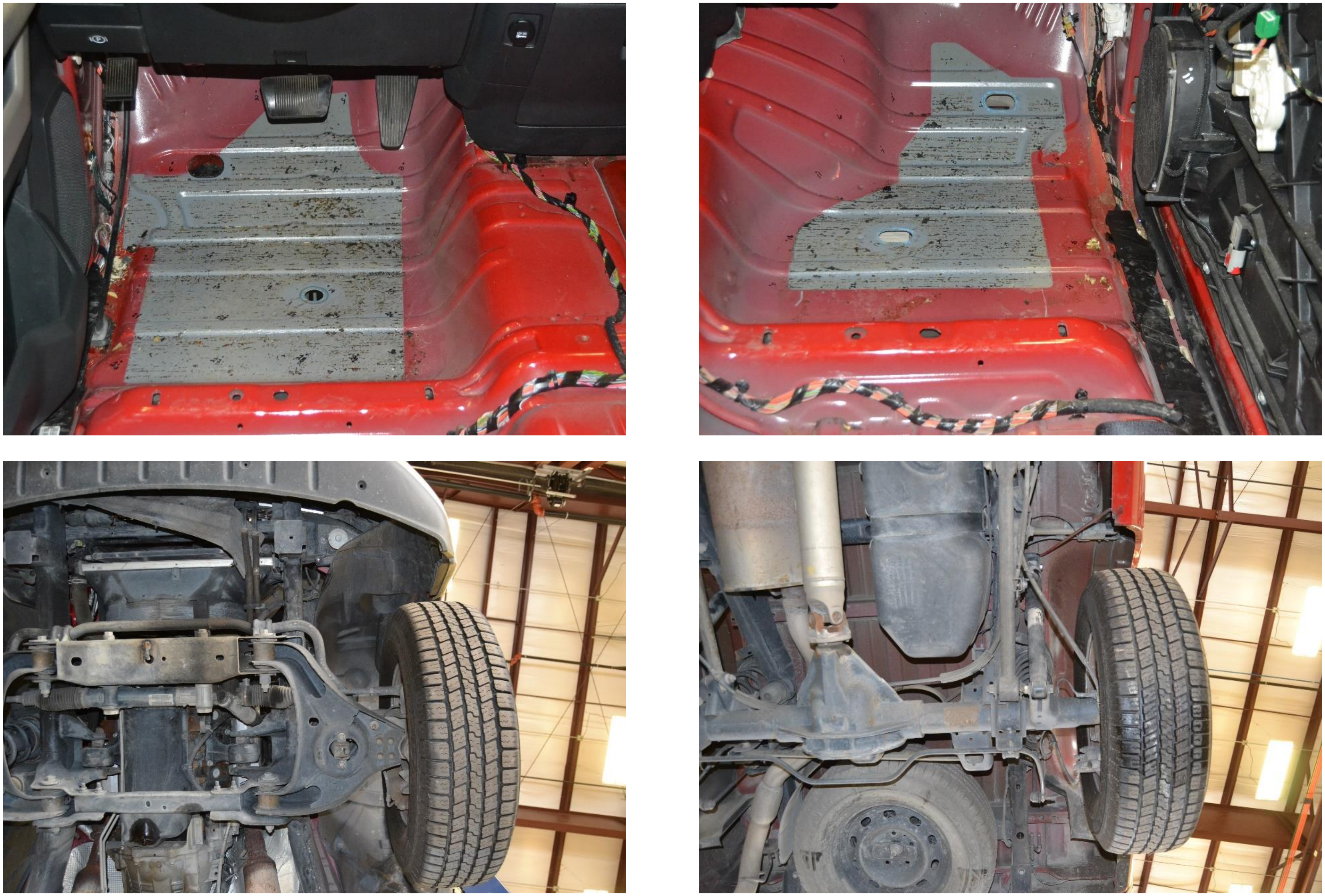
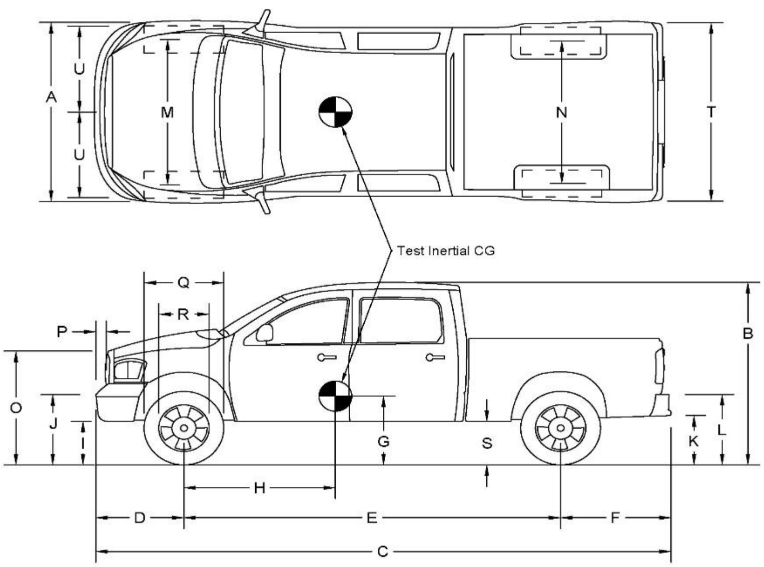


Figure 21. Test Vehicle’s Interior Floorboards and Undercarriage

Date:	9/13/2018	Test Name:	IBBR-1	VIN No:	1D7RB1GPXBS586259
Year:	2011	Make:	Dodge	Model:	Ram 1500
Tire Size:	P265/70R17	Tire Inflation Pressure:	40 Psi	Odometer:	210216



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

A:	77 1/2 (1969) 78±2 (1950±50)	B:	74 1/8 (1883)		
C:	229 1/4 (5823) 237±13 (6020±325)	D:	42 1/2 (1080) 39±3 (1000±75)		
E:	140 3/4 (3575) 148±12 (3760±300)	F:	47 1/8 (1197)		
G:	28 1/16 (713) min: 28 (710)	H:	61 15/16 (1573) 63±4 (1575±100)		
I:	12 (305)	J:	25 (635)		
K:	20 3/4 (527)	L:	29 1/4 (743)		
M:	67 1/2 (1715) 67±1.5 (1700±38)	N:	67 3/8 (1711) 67±1.5 (1700±38)		
O:	44 (1118) 43±4 (1100±75)	P:	4 7/8 (124)		
Q:	31 1/4 (794)	R:	18 1/2 (470)		
S:	15 (381)	T:	77 1/2 (1969)		

U (impact width):	71 1/4 (1810)
Wheel Center Height (Front):	15 1/4 (387)
Wheel Center Height (Rear):	15 1/2 (394)
Wheel Well Clearance (Front):	34 3/4 (883)
Wheel Well Clearance (Rear):	37 3/4 (959)
Bottom Frame Height (Front):	9 1/2 (241)
Bottom Frame Height (Rear):	19 1/2 (495)
Engine Type:	Gasoline
Engine Size:	4.7L V8
Transmission Type:	Automatic
Drive Type:	RWD
Cab Style:	Quad Cab
Bed Length:	76"

Mass Distribution lb (kg)

Gross Static	LF	1446 (656)	RF	1440 (653)
	LR	1116 (506)	RR	1136 (515)

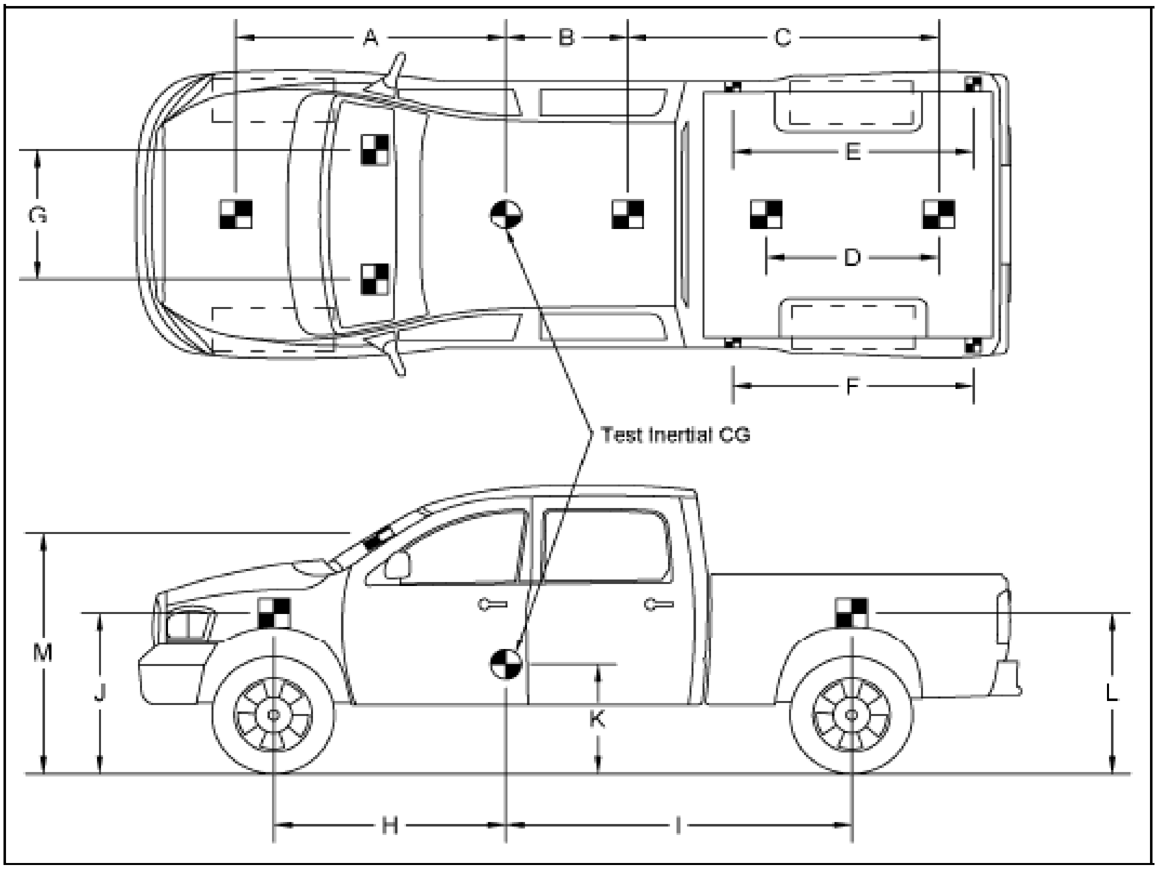
Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2834 (1285)	2788 (1265)	2886 (1309)
W-rear	2152 (976)	2192 (994)	2252 (1021)
W-total	4986 (2262)	4980 (2259) 5000±110 (2270±50)	5138 (2331) 5165±110 (2343±50)

GVWR Ratings lb		Surrogate Occupant Data	
Front	3700	Type:	Hybrid II
Rear	3900	Mass:	158 lb
Total	6700	Seat Position:	Right/Passenger

Note any damage prior to test: Left front fender small dent.

Figure 22. Vehicle Dimensions, Test No. IBBR-1

Date:	9/13/2018	Test Name:	IBBR-1	VIN:	1D7RB1GPXBS586259
Year:	2011	Make:	Dodge	Model:	Ram 1500



TARGET GEOMETRY-- in. (mm)

A:	79	(2007)	E:	63 1/4	(1607)	J:	39	(991)
B:	27 3/8	(695)	F:	63 3/8	(1610)	K:	28	(711)
C:	68	(1727)	G:	32 1/2	(826)	L:	41 7/8	(1064)
D:	37 7/8	(962)	H:	62	(1575)	M:	63 3/4	(1619)
			I:	78 1/4	(1988)			

Figure 23. Target Geometry, Test No. IBBR-1

4.4 Simulated Occupant

For test no IBBR-1, a Hybrid II 50th-Percentile, Adult Male Dummy equipped with footwear was placed in the right-front seat of the test vehicle with the seat belt fastened. The dummy had a final weight of 158 lb (72 kg). As recommended by MASH 2016, the dummy was not included in calculating the c.g. location.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometers systems were mounted near the c.g. of the test vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [12].

The two systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SLICE-2 unit was designated as the primary system. The acceleration sensors were mounted inside the bodies of custom-built, SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

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

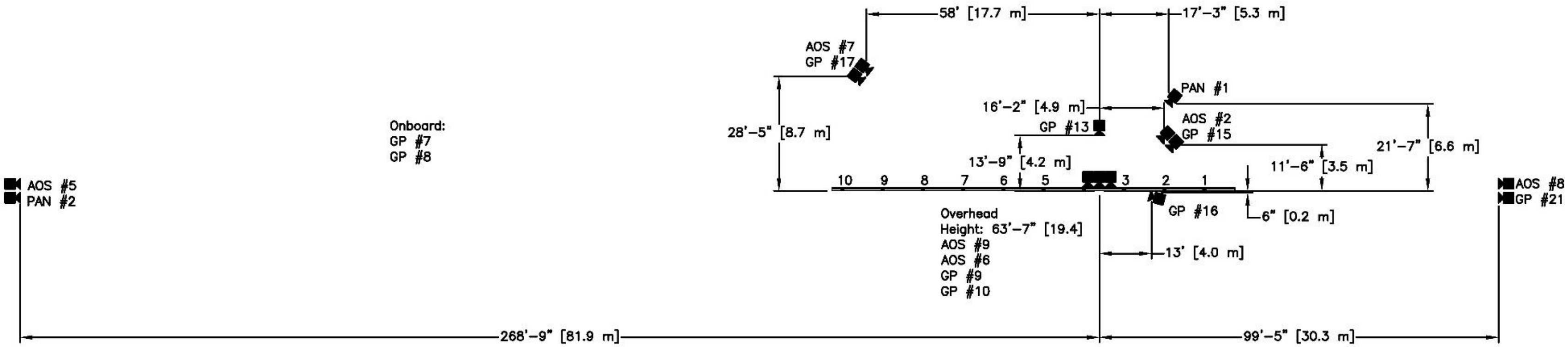
4.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the test vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the vehicle. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

4.5.4 Digital Photography

Six AOS high-speed digital video cameras, nine GoPro digital video cameras, and two Panasonic digital video cameras were utilized to film test no. IBBR-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 24.

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 the test.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam CTM	500	Sigma 28-70 #2	28
AOS-5	AOS X-PRI Gigabit	500	100mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	KOWA 16mm Fixed	-
AOS-7	AOS X-PRI Gigabit	500	KOWA 25mm Fixed	-
AOS-8	AOS S-VIT 1531	500	Sigma 28-70 #1	70
AOS-9	AOS TRI-VIT 2236	1000	KOWA 12mm Fixed	-
GP-7	GoPro Hero 4	120	-	-
GP-8	GoPro Hero 4	120	-	-
GP-9	GoPro Hero 4	240	-	-
GP-10	GoPro Hero 4	240	-	-
GP-13	GoPro Hero 4	240	-	-
GP-15	GoPro Hero 4	240	-	-
GP-16	GoPro Hero 4	240	-	-
GP-17	GoPro Hero 4	240	-	-
GP-21	GoPro Hero 6	120	-	-
PAN-1	Panasonic HC-V770	60	-	-
PAN-2	Panasonic HC-V770	60	-	-

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

5 FULL-SCALE CRASH TEST NO. IBBR-1

5.1 Weather Conditions

Test no. IBBR-1 was conducted on September 13, 2018 at approximately 1:45 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

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

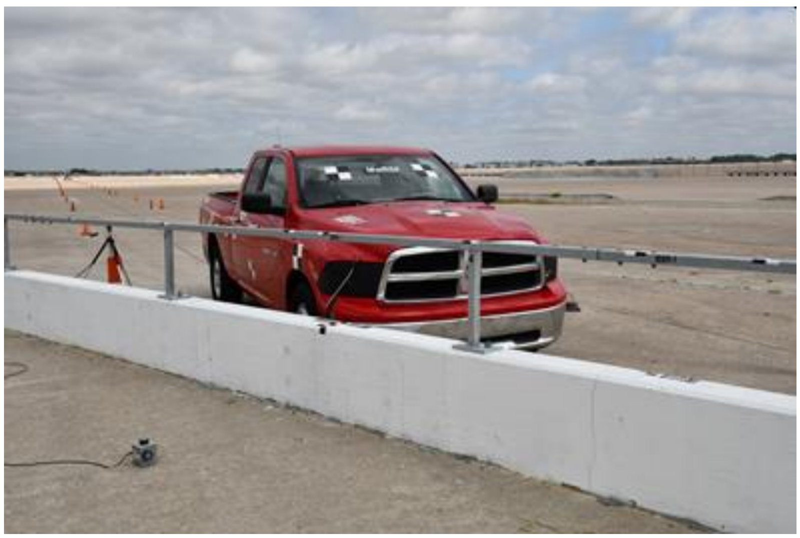
Temperature	73° F
Humidity	63 %
Wind Speed	22 mph
Wind Direction	10° from True North
Sky Conditions	Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.02 in.

5.2 Test Description

Test no. IBBR-1 was conducted on the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle under the MASH TL-2 guidelines for test designation no. 2-11. Test designation no. 2-11 is an impact of the 2270P vehicle at 44 mph (70.8 km/h) and 25 degrees on the system. The CIP for this test was selected to maximize the potential for vehicle interaction and snag on the support posts of the bicycle railing

Initial vehicle impact was to occur 46⅝ in. (1,184 mm) upstream from post no. 4, as shown in Figure 25. The 4,980-lb (2,259-kg) quad cab pickup truck impacted the barrier at a speed of 45.3 mph (72.8 km/h) and at an angle of 25.6 degrees. The actual point of impact was 49⅜ in. (1,254 mm) upstream from post no. 4. In the test, the vehicle was captured and redirected by the 24-in. (610-mm) tall parapet and bicycle railing. During the redirection of the vehicle, the right-front fender and right corner of the vehicle hood snagged on the vertical support post downstream of impact. The snag was sufficient to peel back and disengage the entire right-front fender and deform and tear the hood of the vehicle. However, the snag of the vehicle components did not pose a risk to the vehicle occupant compartment nor did it pose a hazard due to the velocity change or deceleration of the vehicle. Vehicle redirection was primarily facilitated by the parapet, and the only contact, outside of post snag, between the 2270P vehicle and the bicycle railing occurred when the vehicle’s hood and the right-rear corner of the truck box made minor contact with the upper tube rail during tail slap. The vehicle came to rest 39 ft – 11 in. (12.2 m) downstream and 8 ft – 7 in. (2.6 m) laterally behind the barrier after brakes were applied.

A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 26 through 28. Documentary photographs of the crash test are shown in Figure 29. The vehicle trajectory and final position are shown in Figure 30.



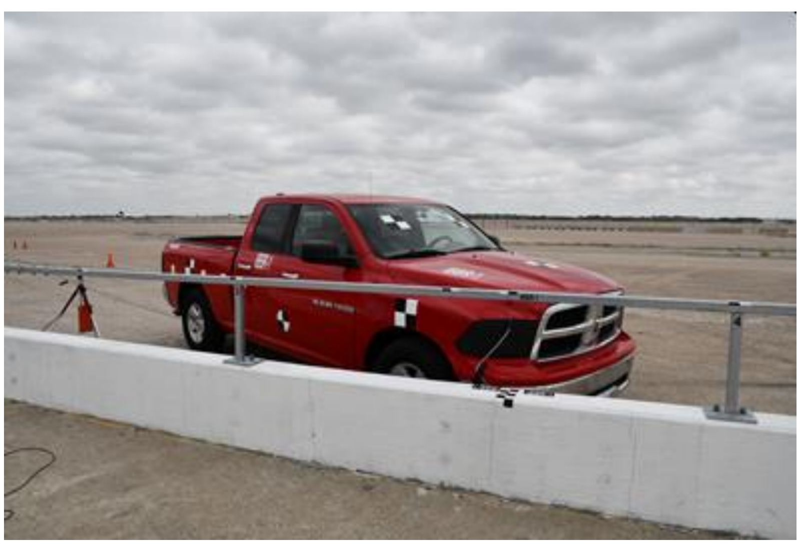


Figure 25. Impact Location, Test No. IBBR-1

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

TIME (sec)	EVENT
0.000	Vehicle's front bumper impacted the concrete barrier 49⅜ in. (1,254 mm) upstream from post no. 4.
0.002	Vehicle's front bumper deformed and vehicle's plastic fascia contacted concrete barrier.
0.010	Vehicle's right-front tire contacted concrete barrier.
0.038	Vehicle's right-front tire ruptured and plastic fascia contacted post no. 4 mounting plate.
0.052	Vehicle's hood deformed, post no. 4 was impacted by vehicle's right headlight and grille, and vehicle rolled toward system and pitched downward.
0.058	Vehicle's grille disengaged.
0.062	Vehicle's right fender contacted post no. 4 and plastic fascia partially detached.
0.064	Vehicle's right fender deformed.
0.072	Vehicle's right-front door deformed.
0.084	Post no. 4 deformed and was snagged by vehicle.
0.094	Post no. 4 became partially disengaged on top due to failure of the base material of the horizontal tube. Post no. 4 disengaged from mounting plate on bottom due to weld failure.
0.098	Vehicle's left-front tire became airborne.
0.126	Vehicle's left-rear tire became airborne.
0.184	Vehicle's detached grille contacted post no. 5.
0.230	Vehicle's right-rear door contacted concrete barrier.
0.254	Vehicle was parallel to the system at 34.0 mph (54.8 km/h).
0.262	Vehicle's right quarter panel deformed.
0.266	Vehicle's rear bumper deformed.
0.272	Vehicle's right quarter panel contacted the bicycle rail.
0.340	Vehicle yawed toward system.
0.350	Vehicle's right fender became disengaged.
0.383	Vehicle exited the system at a speed of 32.2 mph (51.8 km/h) and at an angle of 6.2 degrees.
0.396	Vehicle rolled away from system.
0.582	Vehicle's left-front tire regained contact with ground.
0.682	Vehicle pitched upward and left-rear tire regained contact with ground.
0.744	Vehicle's plastic fascia became disengaged.
3.983	Vehicle came to rest 39 ft – 11 in. downstream and 8 ft – 7 in. laterally behind the barrier.

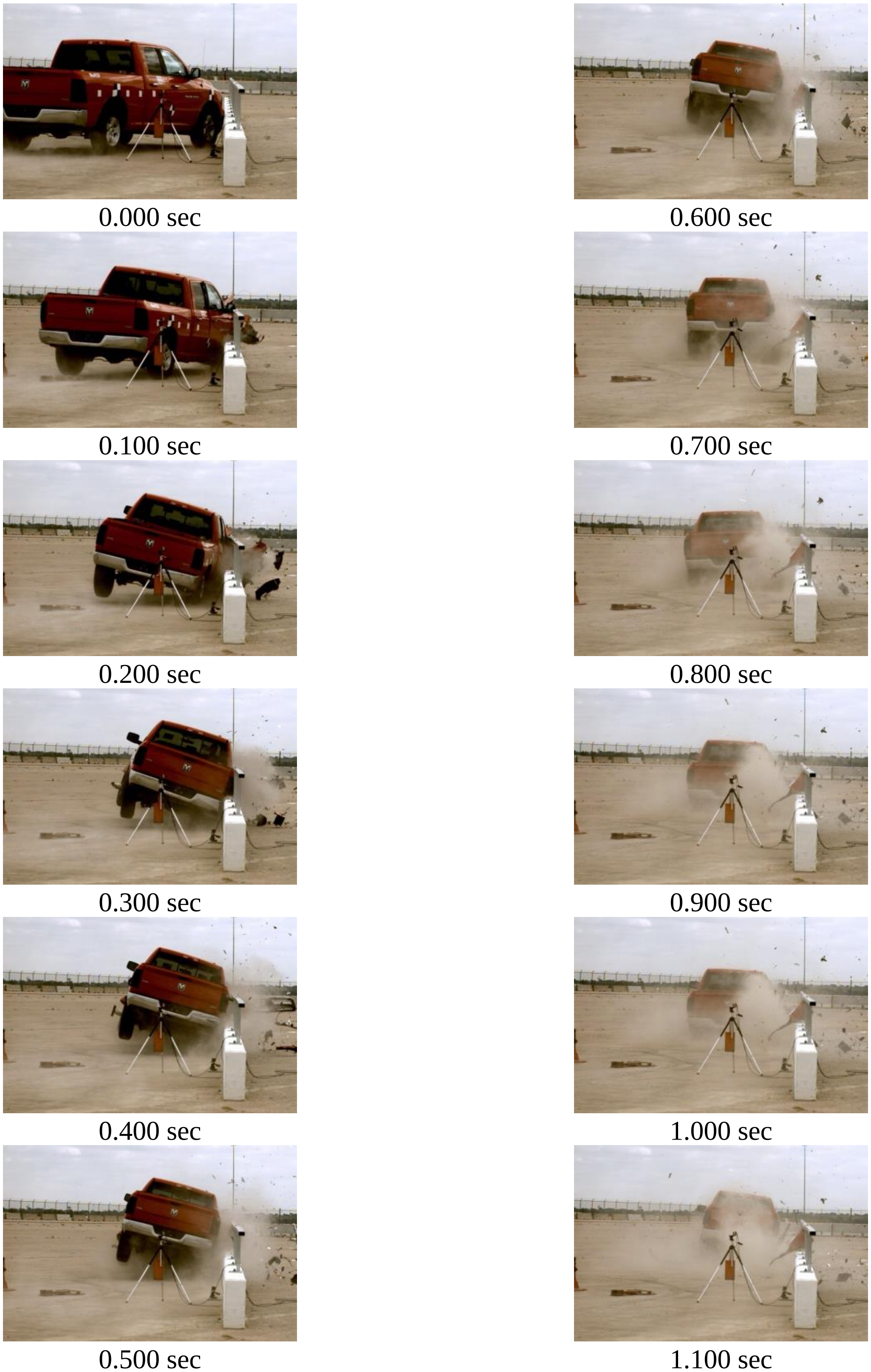


Figure 26. Sequential Photographs, Test No. IBBR-1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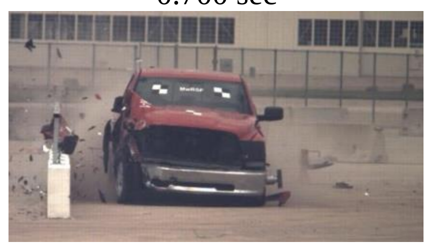
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Figure 27. Additional Sequential Photographs, Test No. IBBR-1

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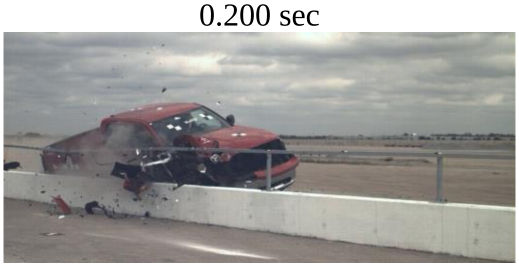

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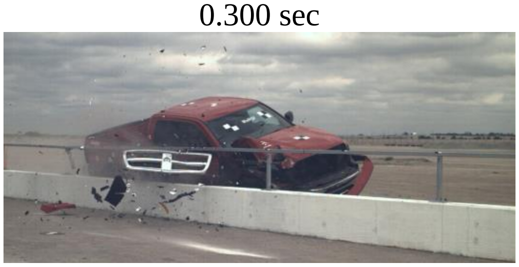

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Figure 28. Additional Sequential Photographs, Test No. IBBR-1

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

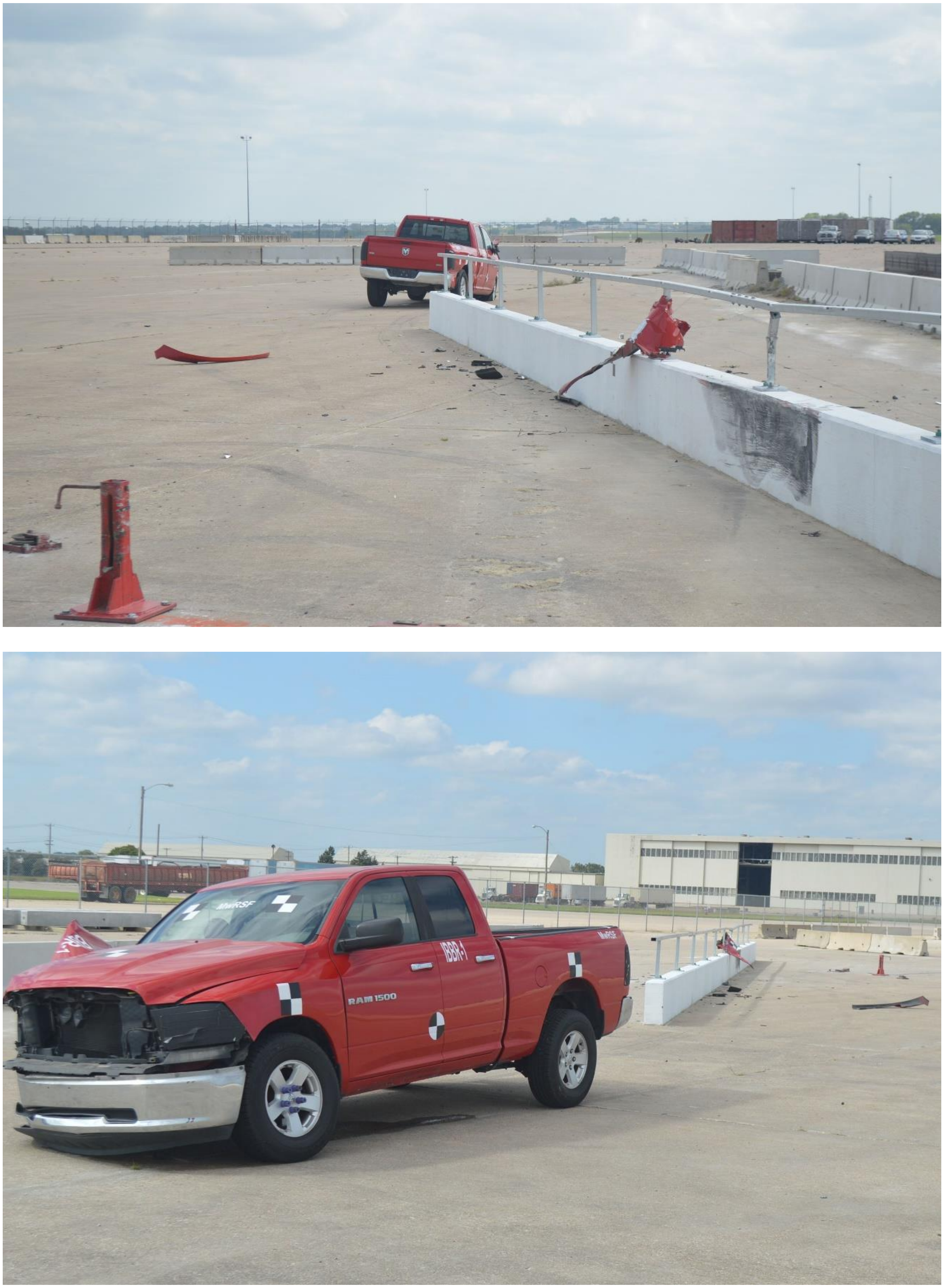

Figure 30. Vehicle Final Position and Trajectory Marks, Test No. IBBR-1

5.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 31 through 34. Barrier damage consisted of contact marks on the front face of the concrete parapet, concrete spalling, and deformation of the bicycle rail. The length of vehicle contact along the barrier was approximately 15 ft – 1½ in. (4.6 m) which spanned from 4 ft – 10½ in. (1.5 m) downstream from the center of post no. 3 to the right-front fender contact with post no. 5.

Tire marks were visible on the front face of the concrete barrier between post nos. 3 and 5. Scuff marks were also found on the front and top face of the concrete barrier between post nos. 3 and 5 as well as on the bicycle rail in that region. Concrete spalling started 5 in. (127 mm) upstream from the impact point and continued downstream along the top front corner of the barrier for 65 in. (1,651 mm). A small 3-in. x 3¾-in. (76-mm x 95-mm) gouge in the concrete was found 7½ in. (191 mm) from the top of the barrier at the impact point. A 26-in. (660-mm) long contact mark was visible on the bicycle rail located 52½ in. (1,334 mm) upstream from the center of post no. 4. An 11½-in. (292-mm) long contact mark beginning 1 in. (25 mm) upstream from the center of post no. 4 was also found.

The bicycle railing section at post no. 4 was slightly bent downward and contact marks were visible on the bicycle rail on post nos. 4 and 5. Contact marks on the rail splice in between post nos. 4 and 5 and downstream from post no. 4 were also observed. Post no. 4 was fractured and deflected downstream. Post no. 4 had a fracture of the weld at the baseplate and fractured at the base material of the horizontal tube at the post to rail connection. A hinge in post no. 4 was located 13 in. (330 mm) from the bottom of the post. A 3-in. (76-mm) wide contact mark was visible on the top face of the base plate at post no. 4 that extended across the length of the plate. The anchor hardware at the base plate of post no. 4 was undamaged. Contact marks were visible on all faces of post no. 4, but only on the back and upstream faces for post no. 5. Note that post no. 5 was not permanently deformed. The right-front quarter panel of the vehicle snagged on post no. 5 and was removed from the vehicle. No impact damage or cracking was observed on the parapet. Additionally, no damage or cracking was observed at or adjacent to the anchor rods of the system.

Figure 31. Front Side System Damage, Test No. IBBR-1

Figure 32. Back Side System Damage, Test No. IBBR-1

Figure 33. Post No. 4 Damage, Test No. IBBR-1

Figure 34. System Damage, Test No. IBBR-1

The maximum lateral permanent set of the barrier system was ½ in. (13 mm) including barrier and post deflection, which occurred at post no. 4, as measured in the field. The maximum lateral dynamic barrier deflection was 3.8 in. (97 mm) at post no. 4, as determined from high-speed digital video analysis. The working width of the system was found to be 38.8 in. (986 mm), also determined from high-speed digital video analysis. The extension of working width behind the barrier was due to fender snag. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 35.

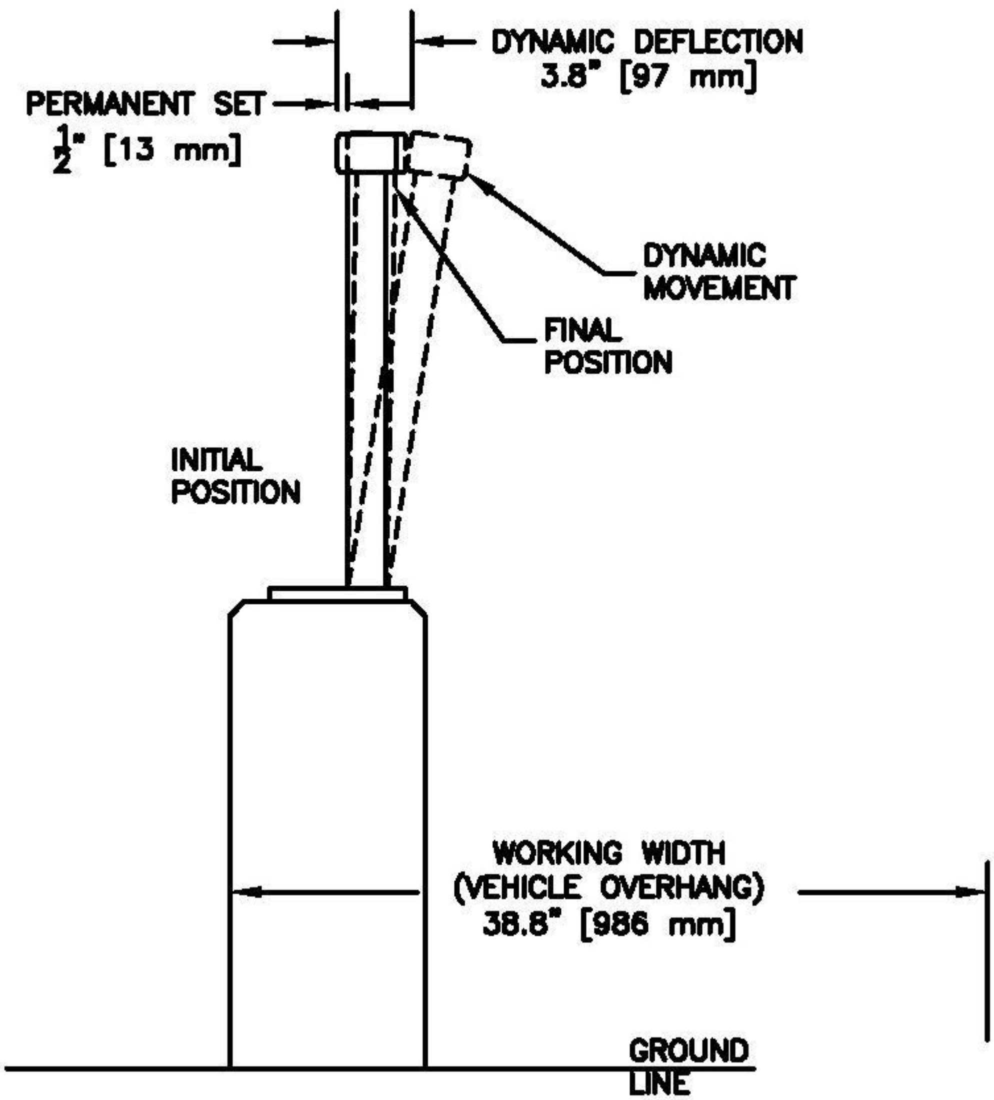

Figure 35. Permanent Set Deflection, Dynamic Deflection and Working Width, Test No. IBBR-1

5.4 Vehicle Damage

The damage to the vehicle was moderate and consisted mainly of crushing of the right-front vehicle structure, disengagement of the right-front fender, crushing and tearing of the vehicle hood, and contact marks along the side of the vehicle, as shown in Figures 36 through 39.

Figure 36. Vehicle Damage, Test No. IBBR-1

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

Figure 38. Undercarriage Damage, Test No. IBBR-1

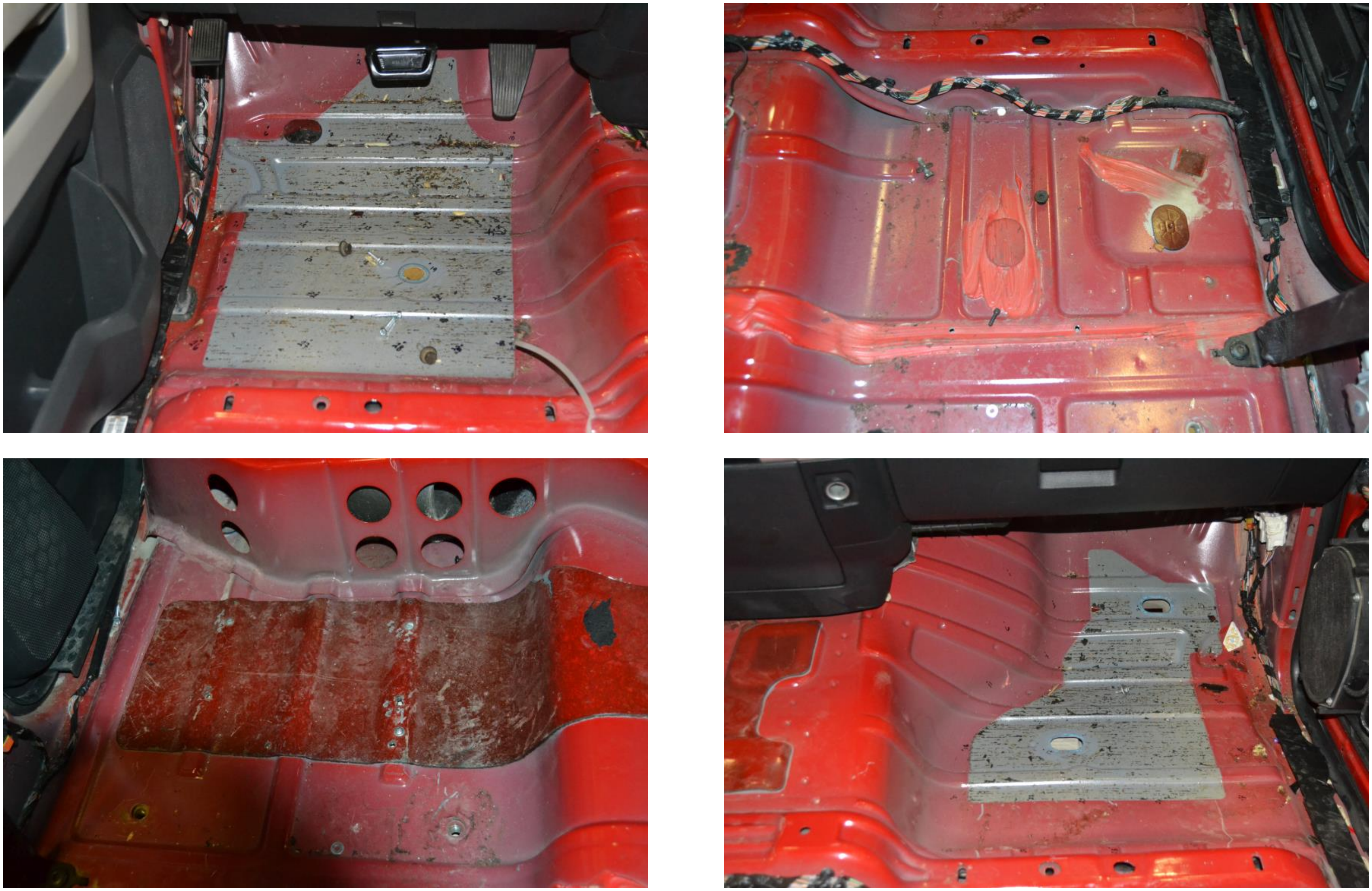

Figure 39. Vehicle Floor Pan, Test No. IBBR-1

The maximum occupant compartment intrusion values are listed in Table 5 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment and none of the established MASH 2016 deformation limits were violated. The entire A-pillar (lateral), side door above seat, and floor pan deformed slightly outward, which is not considered crush toward the occupant, is denoted as negative numbers in Table 5, and is not evaluated by MASH 2016 criteria. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix C.

Table 5. Maximum Occupant Compartment Intrusion by Location

LOCATION	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	0.3 (7.6)	≤ 9 (229)
Floor Pan & Transmission Tunnel	-0.4 (-10.2)	N/A
A-Pillar	0.3 (7.6)	≤ 5 (127)
A-Pillar (Lateral)	0.1 (2.5)	N/A
B-Pillar	0.2 (5.1)	≤ 5 (127)
B-Pillar (Lateral)	0.1 (2.5)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	0.1 (2.5)	≤ 12 (305)
Side Door (Above Seat)	-0.5 (12.7)	N/A
Side Door (Below Seat)	0.1 (2.5)	≤ 12 (305)
Roof	0.1 (2.5)	≤ 4 (102)
Windshield	0.0 (0.0)	≤ 3 (76)
Side Window	Intact	No shattering resulting from contact with structural member of test article
Dash	0.4 (10.2)	N/A

Note: Negative values denote outward deformation
N/A – Not applicable

The majority of damage was concentrated on the right-front corner and right side of the vehicle where the impact had occurred. Denting and scraping were observed on the entire right side of the vehicle. The right-side mirror and casing were shattered and bent backward. The right side of hood was torn and folded up toward the windshield. The right side of the bumper was crushed inward and back. The grille was fractured and removed from the vehicle. The right-side headlight and fog light were removed from the vehicle. The right-front quarter panel snagged on post no. 4, impacted post no. 5, and was removed from the vehicle. The sub-body frame behind the right-front quarter panel was crushed into the engine area. The right-front tire was torn and deflated, and the right-front steel rim was deformed and had significant tearing. The right upper control arm was bent and pushed off its bushing and the right side of the radiator was pushed backward. Scuff marks were found on the right-rear tire, but the wheel assembly remained intact. The right side of the rear bumper was dented and scuffed. The left-front quarter panel was dented in behind the door. The right side of the windshield had minor cracking and subsequent hairline cracks. The roof and remaining window glass remained undamaged.

5.5 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined by accelerometer data, are shown in Table 6. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 6. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix D.

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

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1	**SLICE-2 (primary)**	
OIV ft/s (m/s)	Longitudinal	-15.20 (-4.63)	-15.08 (-4.60)	±40 (12.2)
	Lateral	-16.02 (-4.88)	-18.32 (-5.58)	±40 (12.2)
ORA g's	Longitudinal	3.01	-2.79	±20.49
	Lateral	-11.10	-8.57	±20.49
MAX. ANGULAR DISPL. deg.	Roll	17.57	14.76	±75
	Pitch	-3.28	-3.76	±75
	Yaw	-29.50	-30.08	not required
THIV ft/s (m/s)		21.69 (6.61)	23.16 (7.06)	not required
PHD g's		11.22	8.72	not required
ASI		1.17	1.27	not required

5.6 Discussion

The analysis of the test results for test no. IBBR-1 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 40. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix D, were deemed acceptable because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 6.2 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. IBBR-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 2-11.

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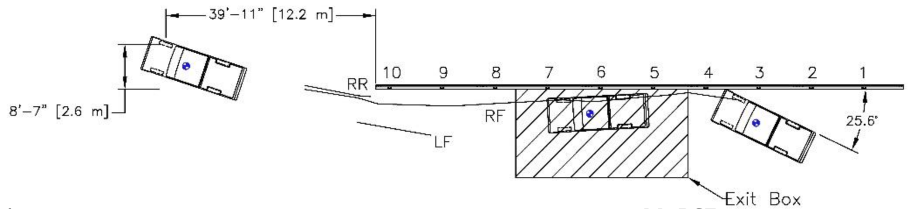

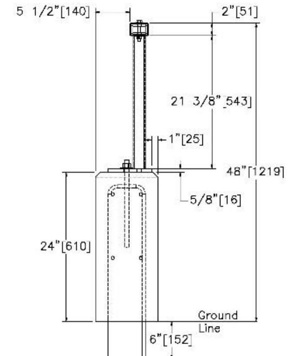

- Test Agency .... MwRSF
- Test Number IBBR-1
- Date 9/13/2018
- MASH 2016 Test Designation No. 2-11
- Test Article .... Iowa Bicycle Bridge Rail
- Total Length .... 100 ft – 4½ in. (30.6 m)
- Key Component - Rail
  - Length .... 100 ft – 4½ in. (30.6 m)
  - Height .... 2 in. (51 mm)
  - Depth .... 3 in. (76 mm)
- Key Component - Post
  - Height .... 21⅜ in. (543 mm)
  - Width .... 2 in. (51 mm)
  - Spacing .... 10 ft (3.05 m)
- Key Component – Concrete Parapet
  - Length .... 100 ft – 4½ in. (30.6 m)
  - Width .... 10 in. (254 mm)
  - Height .... 24 in. (610 mm)
- Type of Support Surface
  - Anchor .... Vertical rebar anchored to concrete tarmac and epoxied
- Vehicle Make /Model .... 2011 Dodge Ram 1500 Crew Cab
  - Curb .... 4,986 lb (2,262 kg)
  - Test Inertial .... 4,980 lb (2,259 kg)
  - Gross Static .... 5,138 lb (2,331 kg)
- Impact Conditions
  - Speed .... 45.3 mph (72.8 km/h)
  - Angle .... 25.6 deg.
  - Impact Location .... 49⅜ in. (1,254 mm) upstream from post no. 4
- Impact Severity .... 63.8 kip-ft (86.5 kJ) > 52 kip-ft (70.5 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 32.2 mph (51.8 km/h)
  - Angle .... 6.2 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 39 ft – 11 in. (12.2 m) downstream
  8 ft – 7 in. (2.6 m) laterally behind
- Vehicle Damage .... Moderate
  - VDS [13] 01-RFQ-5
  - CDC [14] 01-RYEW-5
  - Maximum Interior Deformation .... 0.4 in. (10 mm)
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... ½ in. (13 mm)
  - Dynamic .... 3.8 in. (97 mm)
  - Working Width .... 38.8 in. (986 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-15.20 (-4.63)	-15.08 (-4.60)	±40 (12.2)
	Lateral	-16.02 (-4.88)	-18.32 (-5.58)	±40 (12.2)
ORA g's	Longitudinal	3.01	-2.79	±20.49
	Lateral	-11.10	-8.57	±20.49
MAX ANGULAR DISP. deg.	Roll	17.57	14.76	±75
	Pitch	-3.28	-3.76	±75
	Yaw	-29.50	-30.08	not required
THIV – ft/s (m/s)		21.69 (6.61)	23.16 (7.06)	not required
PHD – g's		11.22	8.72	not required
ASI		1.17	1.27	not required

Figure 40. Summary of Test Results and Sequential Photographs, Test No. IBBR-1

6 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 Summary

The objective of this study was to evaluate a low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing to MASH TL-2. The system could be used when sidewalks or trails are present on vehicular bridges. Existing combination barrier systems utilized by Iowa DOT were not previously crash tested to any impact safety standards. Thus, it was desired to have the barrier system meet MASH 2016 TL-2 standards and be used on new construction projects. The barrier system was evaluated through full-scale crash testing for MASH 2016 test designation no. 2-11, which involves a 2270P truck impacting the system with at a speed of 44 mph (70 km/h) at an angle of 25 degrees. This test designation was selected due to the 2270P vehicle height being more critical to evaluate capture by the low-height parapet, potential for vehicle-to-rail interaction, and system loading. Test designation no. 2-10, which involves the 1100C vehicle, was not deemed critical due to the 1100C vehicle's improved capture and redirection with the low-height parapet, previous TL-3 testing of vertical parapets indicating that occupant risk values would not be an issue, and previous simulation analysis indicating that the 1100C vehicle would only have minimal interaction with the bicycle railing.

Test no. IBBR-1 was conducted to evaluate a low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing. The critical impact point for test no. IBBR-1 was selected as 46⅝ in. (1,184 mm) upstream from the centerline of post no. 4 to maximize vehicle snag. The 4,980-lb (2,259-kg) quad cab pickup truck impacted the barrier at a speed of 45.3 mph (72.8 km/h) and at an angle of 25.6 degrees. The vehicle was captured and redirected by the 24-in. (610-mm) tall parapet and bicycle railing. During the redirection of the vehicle, the right-front fender and right corner of the vehicle hood snagged on the vertical support post downstream from impact. This snag was predicted in the simulation modeling. The snag was sufficient to peel back and disengage the entire right-front fender and deform and tear the hood of the vehicle. However, the snag of the vehicle component did not pose a risk to the vehicle occupant compartment nor did it pose a hazard due to the velocity change or deceleration of the vehicle. The vehicle exited the barrier in a stable manner and came to rest 39 ft – 11 in. (12.2 m) downstream from and 8 ft – 7 in. (2.6 m) laterally behind the barrier. A dynamic deflection of 3.8 in. (97 mm) and a system working width of 38.8 in. (986 mm) were observed during the test. All occupant risk values were found to be within evaluation limits, and the occupant compartment deformations were also deemed acceptable. Subsequently, test no. IBBR-1 was determined to satisfy the safety performance criteria for MASH 2016 test designation no. 2-11. A summary of the test evaluation is shown in Table 7.

6.2 Conclusions

The proposed low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing was evaluated through a full-scale crash test, test designation no. 2-11, to MASH 2016 TL-2 criteria. The low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing system satisfied vehicle trajectory requirements and was within acceptable limits of all evaluation criterion for MASH 2016 test designation no. 2-11.

It should be noted that during test no. IBBR-1 vehicle redirection was primarily facilitated by the parapet, and the only contact, outside of post snag, between the 2270P vehicle and the bicycle railing occurred when the vehicle's hood and the right-rear corner of the truck box made minor contact with the horizontal tube rail during tail slap. The researchers believed that vehicle redirection would have occurred successfully on the 24-in. (610-mm) tall parapet without the presence of the bicycle railing. Thus, it is believed that the 24-in. (610-mm) tall vertical parapet evaluated in this research would also meet MASH TL-2 without the combination rail attached.

Table 7. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. IBBR-1</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td></tr>
<tr><td rowspan="5">Occupant Risk</td><td rowspan="2">D.</td><td>1. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</td><td>S</td></tr>
<tr><td>2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>S</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:
<table><tr><th colspan="3">Occupant Impact Velocity Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr></table></td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:
<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15.0 g's</td><td>20.49 g's</td></tr></table></td><td>S</td></tr>
<tr><td colspan="3">MASH 2016 Test Designation No.</td><td>2-11</td></tr>
<tr><td colspan="3">Final Evaluation (Pass or Fail)</td><td>Pass</td></tr>
</table>

S – Satisfactory   U – Unsatisfactory   NA - Not Applicable

6.3 Recommendations

The MASH TL-2 low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing system detailed herein was evaluated using a basic length of need configuration. Real-world installations will have other considerations for the application of the design that should be considered. The following sections provide recommendations for implementation of the traffic barrier.

6.3.1 Vertical Parapet End Sections

The vertical parapet evaluated herein as part of the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing was designed with reinforcement for containment of MASH TL-2 impact loads. The reinforcement used in the full-scale crash test represented the reinforcement recommended for the interior sections of the parapet. End sections of the concrete parapet would represent a free end of the concrete barrier and would lack the continuity required to develop similar capacity without increased barrier reinforcement near the barrier ends. In order to adequately reinforce the ends of the concrete parapet to have similar capacity as the interior sections, it is recommended that the stirrup spacing in the parapet be reduced from 24 in. (610 mm) to 12 in. (305 mm) for 5 ft (1.83 m) adjacent to the parapet end.

6.3.2 Vertical Parapet End Section Design and Termination

The vertical parapet evaluated herein as part of the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing was designed with reinforcement for containment of MASH TL-2 impact loads. The reinforcement used in the full-scale crash test represented the reinforcement recommended for the interior sections of the parapet. End sections of the concrete parapet would represent a free end of the concrete barrier and would lack the continuity required to develop similar capacity without increased barrier reinforcement near the barrier ends. In order to adequately reinforce the ends of the concrete parapet to have a similar capacity as the interior sections, it is recommended that the stirrup spacing in the parapet be reduced from 24 in. (610 mm) to 12 in. (305 mm) for 5 ft (1.8 m) adjacent to the parapet end.

A variety of options are potentially available for safely terminating or shielding the end of the vertical parapet. State DOTs typically have their own polices for hardware and methods for shielding the ends of concrete parapets. Additionally, the focus of this research was the development and evaluation of the length-of-need for the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing. As such, the researchers did not design or specify specific end treatments for the parapet. Methods or concepts for the terminating the bicycle railing on the parapet were devised and are discussed in a subsequent section.

With that said, there are some comments that can be made regarding termination of the vertical parapet used in this system. It is generally recommended that the ends of the parapet be shielded by a MASH TL-2 crashworthy crash cushion or an approach guardrail transition and end terminal. Connection of a crash cushion or an approach guardrail transition to the 24-in. (610-mm) tall vertical parapet will likely require adjustment of the geometry of the end of the parapet. For example, the parapet may need to have an increased height and/or a modified end geometry for the proper attachment of typical crash cushion designs. Similarly, crashworthy attachment of typical thrie beam approach guardrail transitions would require increasing the parapet height to 32 in. (813 mm) and adjusting the end of the parapet to an end buttress geometry that mitigates vehicle snag. Appropriate parapet end geometries for the attachment of approach guardrail transitions would require using a geometry that matches the end parapet geometry used in the crash testing of the individual approach guardrail transition or one could employ the standardized end buttress geometry developed through the Midwest Pooled Fund that accommodates all crashworthy thrie beam approach guardrail transitions [15-16]. Transition from the low-height vertical parapet to the appropriate end buttress geometry for either application should be done using 10:1 or flatter lateral tapers and 6:1 or flatter vertical tapers.

It is also noted that sloped concrete end treatments may be desired as a parapet termination option for certain applications, such as urban installation where space is limited. The safety performance of sloped concrete end terminals has varied in previous research efforts and limited recommendations are available for their use. Previous evaluation of sloped concrete ends for 32-in. (813-mm) tall safety-shape barriers under NCHRP Report No. 230 [17] and NCHRP Report No. 350 [18] safety criteria identified potential vehicle stability issues with concrete sloped end treatments. During some of these tests, vehicles experienced high roll angles, instability, or rollover, and some vehicles came to rest on the non-traffic side of the sloped end treatment. Although sloped end treatments are not traditionally defined as gating terminals, vehicle traversal to the non-traffic side face of the system was nonetheless deemed acceptable.

In NCHRP Report No. 358 [19], which was published in 1994, a series of work zone and temporary barrier applications were evaluated. Full-scale crash tests and simulations were conducted on two types of concrete barrier sloped end treatments: a conventional sloped end treatment (CSET) and the New York sloped end treatment (NYSET). Both designs attached to 32-in. (813-mm) tall safety-shape parapets and had lengths of approximately 20 ft (6.1 m). Full-scale crash tests were performed with small cars weighing approximately 1,970 lb (894 kg) due to their greater instability compared to larger cars. Four of the six tests resulted in vehicle rollover. The remaining two tests, nos. 7110-5 and 7110-8, both of which impacted the sloped end treatment end-on, resulted in marginally stable vehicles. After reviewing these tests, it was found that the guide plate attached to the right-front wheel contacted the pavement before the wheel, which reduced the likelihood of rollover. Simulations were utilized to determine the validity of this finding: simulations with the guide plate predicted no rollover and those without predicted rollover. Researchers concluded that an end-on impact at 45 mph (72.4 km/h) with a sloped end treatment would result in vehicle rollover.

Researchers conducted computer simulations using additional impact conditions for the CSET model because it was simpler than the NYSET model but had similar test outcomes. A 1,800-lb (816-kg) test vehicle was simulated impacting CSETs of varying taper lengths at varying impact angles, locations, and speeds for a total of 84 simulations, as summarized in Table 8. All simulations which involved the vehicle impacting the sloped end treatment at 30 degrees resulted in vehicle rollover, and all simulations utilizing a 15-degree impact angle were deemed unstable. Head-on impacts resulted in stable vehicles at 30 and 37 mph (48.2 and 59.5 km/h) when the taper length was 20 and 25 ft (6.1 and 7.6 m) long. From simulation results, it was recommended that sloped end treatments be at least 20 ft (6.1 m) long and be used on roadways with speed limits less than or equal to 45 mph (72.4 km/h).

Table 8. Summary of Simulations Conducted for NCHRP Report No. 358

Impact Angle deg	Impact Location: Distance from Leading End	Impact Speed mph	Vehicle Action at Taper Length (L)			
			10 ft	15 ft	20 ft	25 ft
0	0	30	Overturn	Overturn	Stable	Stable
0	0	37	Overturn	Overturn	Stable	Stable
0	0	45	Overturn	Overturn	Overturn	Stable
15	0.1L	30	Climbs	Rides	Rides	Ran Over
15	0.1L	37.5	Climbs	Ran Over	Overturn	Overturn
15	0.1L	45	Ran Over	Ran Over	Overturn	Overturn
15	0.2L	30	Climbs	Rides	Redirects	Redirects
15	0.2L	37.5	Rides	Overturn	Rides	Climbs
15	0.2L	45	Climbs	Rides	Rides	Rides
15	0.3L	30	Rides	Redirects	Redirects	Redirects
15	0.3L	37.5	Overturn	Overturn	Climbs	Climbs
15	0.3L	45	Overturn	Overturn	Ran Over	Rides
30	0.1L	30	Overturn	Overturn	Overturn	Overturn
30	0.1L	37.5	Overturn	Overturn	Overturn	Overturn
30	0.1L	45	Overturn	Overturn	Overturn	Overturn
30	0.2L	30	Overturn	Overturn	Overturn	Overturn
30	0.2L	37.5	Overturn	Overturn	Overturn	Overturn
30	0.2L	45	Overturn	Overturn	Overturn	Overturn
30	0.3L	30	Overturn	Overturn	Overturn	Overturn
30	0.3L	39.5	Overturn	Overturn	Overturn	Overturn
30	0.3L	45	Overturn	Overturn	Overturn	Overturn

The research from NCHRP Report No. 358 was utilized to provide the current guidance in the *Roadside Design Guide* [2]. This guidance notes that the use of sloped concrete ends is sometimes necessary even though the treatment has not met acceptable crash testing criteria. It also recommends that this type of treatment only be used in locations where vehicle speed is less than 40 mph (64.3 km/h) and space is limited by right-of-way constraints or other roadside features that preclude using a crashworthy end treatment.

Additional research has been conducted on sloped concrete ends for use with low-height TL-2 portable concrete barriers that have heights closer to the 24-in. (610-mm) tall parapet evaluated herein. TTI developed a low-profile concrete barrier and associated low-profile sloped end treatment (LPSET) for the Texas Department of Transportation (TxDOT) in the early 1990s

[20]. The barrier was 20 in. (508 mm) tall, utilized a rectangular profile, and is shown in Figure 41.

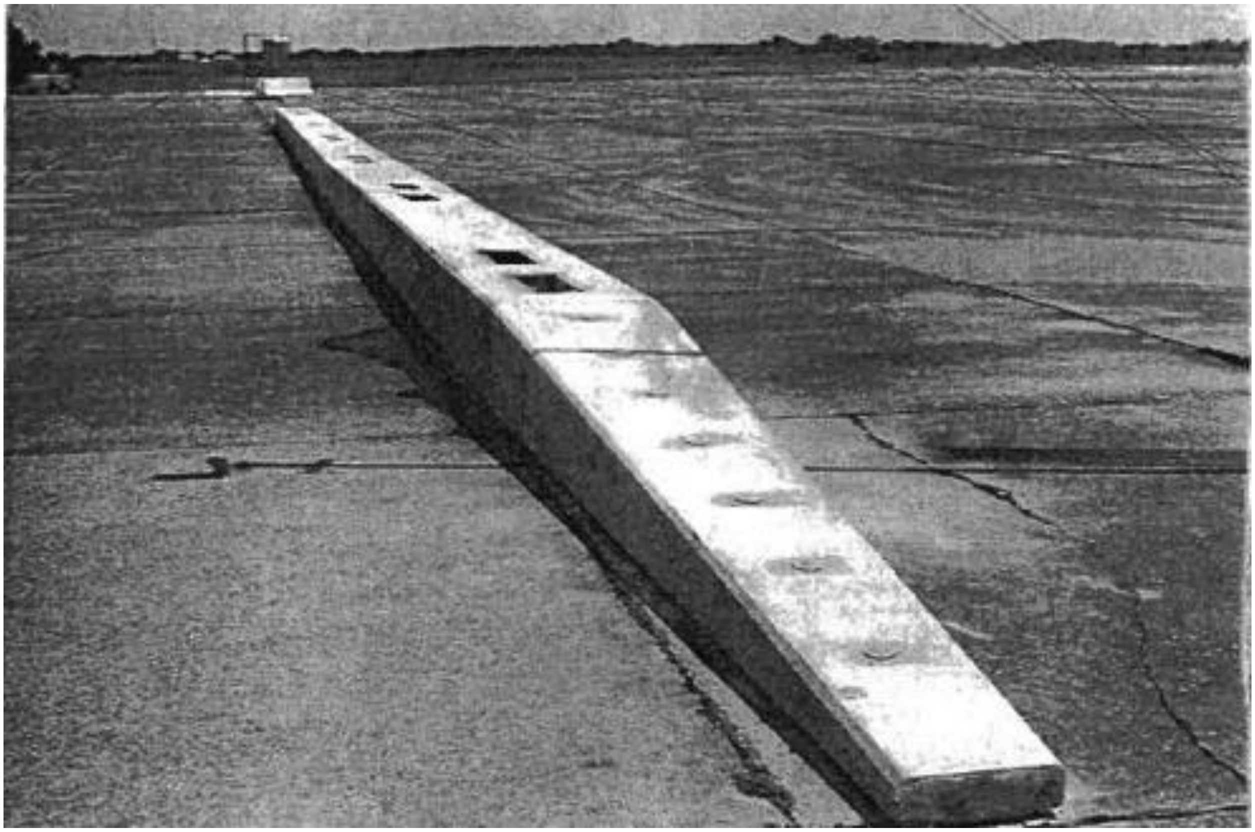

Figure 41. Low-Profile Sloped End Treatment

Three full-scale crash tests were performed on the LPSET according to crash test conditions consistent with NCHRP Report No. 230 at "work zone speeds" of 45 mph (72.4 km/h). Test no. 1949A-1 impacted the sloped end treatment 6.5 ft (2.0 m) from the end of the treatment at an angle of 16.3 degrees and a speed of 44.7 mph (71.9 km/h). The sloped end treatment redirected the vehicle and the vehicle exited the system at a speed of 37.4 mph (60.2 km/h) and an angle of 6.1 degrees. Test no. 1949A-2 impacted the sloped end treatment end-on at a speed of 45.1 mph (72.6 km/h) with the centerline of the right wheels aligned with the centerline of the sloped end treatment. The right-side wheels of the vehicle rode along the top of the concrete barrier, and the vehicle eventually lost contact with the barrier and exited the system. Test no. 1949A-3 impacted the sloped end treatment end-on at a speed of 46.5 mph (74.3 km/h) with the centerline of the vehicle aligned with the centerline of the sloped end treatment. The vehicle rode atop the barrier before coming to rest. Thus, the sloped end treatment was determined to be successful according to NCHRP Report No. 230 test criteria.

TTI re-evaluated the LPSET according to NCHRP Report No. 350 TL-2 criteria in 1998 [21]. Test no. 414038-1 was performed with a 1990 Ford Festiva impacting the sloped end treatment 3 ft (0.9 m) from the end at a speed of 44.1 mph (71.0 km/h) and an angle of 15.8 degrees. During the test, the right rear tire became trapped on the non-impact side of the barrier. The vehicle eventually came to rest on the traffic side of the barrier. Test no. 414038-2 consisted of a 1990

Ford Festiva impacting the leading end of the LPSET at an angle of 15.1 degrees and a speed of 42.8 mph (68.9 km/h). The vehicle traveled up the end treatment and came to rest on the non-traffic side of the concrete barrier. Thus, the low-profile sloped end treatment was determined to be successful according to NCHRP Report No. 350 TL-2 test criteria.

In 2013, TTI re-tested a modified, non-pinned version of the sloped end treatment according to MASH TL-2 impact conditions [22]. Test no. 490023-5 was performed with the car impacting the sloped end treatment 33 in. (838 mm) from the end at a speed of 43.9 mph (70.9 km/h) and an angle of 15.2 degrees. During this test, the vehicle rode up the end treatment and came to rest on the non-traffic side of the barrier. Test no. 490023-7 was performed with a 2270P pickup truck impacting the sloped end treatment at a speed of 45.0 mph (72.4 km/h) and an angle of 25.3 degrees. The impact location was 78.0 in. (1,981 mm) upstream from the splice location, coinciding with where the sloped end treatment reached a height of 18 in. (457 mm). The vehicle was successfully redirected and came to rest on the traffic side of the barrier. Thus, the low-profile sloped end treatment was determined to be successful according to MASH impact conditions.

This previous research at TTI regarding sloped concrete end treatment testing for the 20-in. (508-mm) tall low-profile portable concrete barrier suggests that sloped concrete end treatments have improved safety performance when used with low-height barriers as the potential for vehicle instability is reduced. However, no evaluation of sloped concrete ends has been conducted at the 24-in. (610-mm) height used for the parapet detailed herein. While the safety performance for the increased barrier heights cannot be adequately determined without further research and testing, the best guidance for the use sloped concrete end treatments for the Iowa DOT low-height parapet detailed herein would be to use a slope configuration similar to the TTI slope end system. This would require that the system use a 4-in. (102-mm) initial height and taper to the 24-in. (610-mm) parapet height at a taper of 11.25:1 for a length of 225 in. (5,715 mm).

6.3.3 Parapet Anchorage

For full-scale testing purposes, the low-height vertical parapet evaluated in this research was anchored directly to the concrete tarmac at the MwRSF Outdoor Test Facility. The vertical steel in the barrier was epoxied into the tarmac at a depth sufficient to develop the full-shear and tensile capacity of the vertical bars. Real-world installations may use different methods to anchor the parapet such as tying into an existing bridge deck slab. However, it is recommended that the anchorage be capable of developing the shear and tensile capacity of the vertical bars regardless of the anchoring configuration.

6.3.4 Attachment to Other Parapet Types

The MASH TL-2 crashworthy bicycle railing system detailed herein was evaluated with a 24-in. (610-mm) tall, vertical parapet. There may be a desire to apply the bicycle railing design to other MASH TL-2 compliant concrete parapets. The main concerns for attachment of the crashworthy bicycle railing system to alternative concrete parapets or barriers are increased vehicle snag on the bicycle railing, adequate attachment and anchoring of the bicycle railing, and the capacity of the alternative parapet. Based on these concerns, the use of an alternative parapet design with the bicycle railing detailed herein should follow the recommendations below.

1. The alternative parapet design should have similar or greater capacity to the 24-in. (610-mm) tall, vertical parapet design evaluated in this study to ensure that the alternative parapet has the capacity to redirect errant vehicles.

2. The use of taller vertical parapets should be allowable as a taller parapet would serve to reduce vehicle interaction and snag on the bicycle railing. Similarly, it would be acceptable to use a 26-in. (660-mm) tall parapet to accommodate future pavement overlays that reduce the functional height of the barrier to its original 24 in. (610 mm). The use of increased parapet heights would still follow the parapet end termination recommendations made in Section 6.3.2.

3. The use of equal or greater height single-slope and safety-shape barriers may be allowable as well. Previous research into the zone of intrusion (ZOI) for rigid barriers has suggested that single-slope and safety shape barriers have lower lateral ZOI values as compared to vertical shapes [23]. In impacts with permanent, sloped-face, concrete barriers, the front impact-side wheel will begin to climb the barrier face and result in both vertical rise and roll away from the barrier. This tends to reduce lateral extension over the top of the barrier as compared to vertical-face barriers. In vertical barrier impacts, the reduced climb and roll tend to accentuate the extension of the engine hood and fender panel over the parapet. However, the increased vehicle climb generated by single-slope and safety-shape barriers may create a concern in terms of vehicle capture and override. No minimum height has been established for MASH TL-2 impact conditions aside from the vertical parapet evaluated in this research. As such, it is not possible to recommend single-slope and safety-shape parapets between heights of 24 in. (610 mm) and 32 in. (813 mm) for use with the bicycle rail detailed herein. Single-slope and safety-shape parapets 32 in. (813 mm) or taller should be acceptable as this height has been found to be acceptable at MASH TL-3 and would have no concerns with vehicle capture or increased vehicle interaction with the bicycle railing.

4. Any alternative parapet design would need to have sufficient top width to allow for proper installation of the bicycle rail mounting plate and anchors as well as provide for equal or greater offset from the top front corner of the barrier to the bicycle rail post as the full-scale crash tested system. The bicycle rail attachment designed and evaluated in this research offset the post toward the rear of the base plate and offset the baseplate relative to the traffic face of the parapet to reduce vehicle snag on the post. Thus, narrowing of the parapet height below the current 10 in. (254 mm) parapet width would likely induce increased vehicle snag. Reduction of the width of the top of the parapet may also cause issues with the alignment of the vertical base plate anchors with the parapet steel, provide reduced support for the post base plate, and reduce the shear capacity of the epoxy anchors. As such, it is not recommended to install the bicycle rail evaluated herein on alternative parapets with a top width less than 10 in. (254 mm) without further evaluation. Increased top barrier width would be acceptable. It is recommended to offset the post and rail assembly at the as-tested offset to the back face of the parapet on a wider parapet which would serve to provide reduced vehicle interaction and snag on the bicycle rail.

Note that the recommendations for attachment of the bicycle railing to alternative parapets are only relevant for MASH TL-2 impact conditions. Attachment of the bicycle railing to parapets warranted for MASH TL-3 is not recommended without further study.

6.3.5 Termination of the Combination Bicycle Railing

The final implementation recommendation for the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing is the termination of the bicycle railing. For full-scale testing purposes, the barrier system was evaluated along its length of need, and the barrier system length was sufficient to remove concerns for end effects for the bicycle rail, such that end terminations were not installed in the as-tested system. However, real-world installations will require end terminations in order to safely attach and anchor the ends of the bicycle rail to the parapet. To date, little to no research or full-scale crash testing has been conducted related to the design and evaluation of end terminations for combination railing or bicycle railings.

In order to safely terminate the ends of the bicycle rail, several concerns must be addressed. First, the horizontal tube rail must be angled or tapered, brought down to the top of the parapet, and connected to the parapet to provide anchorage for the railing and to eliminate a free tube end that could spear an impacting vehicle or detach and impact other vehicles and/or pedestrians. The railing must be brought down to the top of the parapet over a reasonable longitudinal distance to limit the space needed for the bicycle rail termination. Finally, the potential for vehicle snag on the end termination for the rail must be considered for both oncoming and reverse direction traffic impacts.

The researchers considered both the applied vertical taper for the end termination and the method for connection of the horizontal rail to the parapet in order to develop the safest and most effective end termination possible.

6.3.5.1 Vertical Taper

In order to determine a vertical taper rate for termination of the horizontal tube of the bicycle rail, the researchers looked at the geometry of the rail taper, the performance of the vertical posts in the as-tested system, and previously tested systems with tapered horizontal rails.

In terms of the end termination geometry, steeper vertical tapers posed an advantage as they reduced the length and complexity of the overall end termination section. Any end termination would require bringing the horizontal tube rail down 24 in. (610 mm) from its nominal mounting height to the top of the parapet. Additionally, the bicycle rail was designed with support posts at 10-ft (3.05-m) spacing. Thus, it would be advantageous to bring the horizontal rail down to the parapet in less than 10 ft (3.05 m) to eliminate the need for intermediate posts in the tapered end section of the terminal. It was also desired that the end termination connect directly to the splice location used on existing rail sections.

Review of previously tested barriers with vertical tapers found that tapers as steep as 2H:1V have performed acceptably when used in other types of tube rail terminations. Texas A&M Transportation Institute (TTI) evaluated a thrie beam transition to the Wisconsin Type M tubular steel bridge rail under NCHRP Report No. 350 test designation no. 3-21 [24]. The top tube of the Type M tubular bridge rail had a top mounting height of 42 in. (1,067 mm) and was tapered downward at a 2H:1V slope to extend below the 31.5 in. (800 mm) tall thrie beam AGT, as shown in Figure 42. In test no. 401021-3, a 2000P vehicle impacted the transition upstream from the tapered tube attachment at a speed of 62.6 mph (100.7km/h) and an angle of 25.2 degrees. The pickup truck traversed across the sloped bridge rail tube with both the left-front fender and hood contacting the tube, as shown in Figure 43. However, this contact did not adversely affect vehicle redirection by the transition nor post an occupant risk hazard. The 2000P vehicle was safely redirected and test no. 401021-3 was deemed acceptable under NCHRP Report No. 350 TL-3.

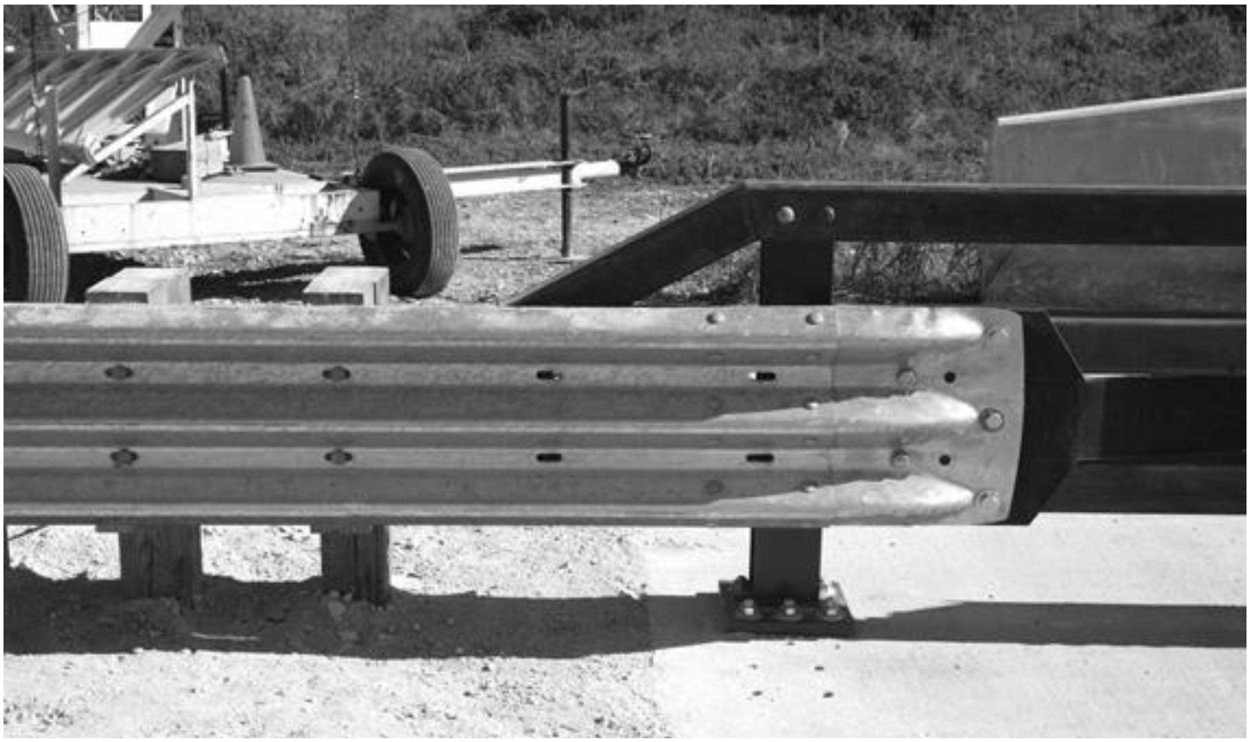

Figure 42. Thrie Beam Transition to Wisconsin Type M Tubular Steel Bridge Rail [24]

Figure 43. Tapered Tubular Rail Contact, Test No. 401021-3 [24]

TTI also performed testing and evaluation of a New York State Department of Transportation (NYSDOT) box-beam transition to four-tube bridge rail under NCHRP Report No. 350 test designation no. 3-21 [24]. The top tube of the four-tube bridge rail had a top mounting height of 42 in. (1,067 mm) and was tapered downward at a 2H:1V slope to attach to the top of the third tube of the bridge rail near the end of the bridge rail prior to the box beam approach transition, as shown in Figure 44. The third tube of the bridge rail had a top height of 32.7 in. (830 mm). In test no. 401021-7, a 2000P vehicle impacted the transition upstream from the tapered tube attachment at a speed of 62.1 mph (100.0km/h) and an angle of 24.4 degrees.

Figure 44. Box Beam Transition to Four-Tube Steel Bridge Rail [24]

During the test, the pickup truck traversed the sloped bridge rail tube with both the left-front fender and hood contacting the tube, as shown in Figure 45. However, this contact did not adversely affect vehicle redirection by the transition nor pose an occupant risk hazard. The 2000P vehicle was safely redirected and test no. 401021-7 was deemed acceptable under NCHRP Report No. 350 TL-3.

Figure 45. Tapered Tubular Rail Contact, Test No. 401021-7 [24]

These two previous transition tests suggest that a 2H:1V slope for a vertical tube transition is capable of being crashworthy under NCHRP Report No. 350 TL-3. Thus, it was necessary to compare these installations to the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing and determine if a similar slope could be applied. The two crash tested transitions had several differences when comparing them to the bicycle railing designed herein. The transitions had smaller lateral offsets between the tapered rail and the face of the adjacent thrie beam or tube rails than the system evaluated in test no. IBBR-1. The transitions were also tested at NCHRP Report No. 350 TL-3 rather than MASH TL-2. These two factors would tend to produce less vehicle interaction and snag on a 2H:1V sloped end tube for termination of the bicycling railing developed herein as compared to the two transition tests. Alternatively, the adjacent barrier height for the box beam transition and the thrie beam transition used in the TTI tests was at least 7.5 in. (191 mm) taller than the low-height parapet used in test no. IBBR-1. The height of the sloped tube end for the bicycle rail developed herein was 24 in. (610 mm) above the parapet, which is 9.3 in. to 10.5 in. (236 mm to 267 mm) vertically more exposed sloped rail than the previously tested TTI systems. These two factors would tend to produce more vehicle interaction and snag on a 2H:1V sloped end tube for termination of the bicycling railing developed herein as compared to the two transition tests. However, it was expected that the severity of the interaction of the vehicle with the vertically tapered end tube was more dependent on the 2H:1V slope than it was on the variation in exposed rail height. Thus, because the use of 2H:1V vertical tapers for termination of tubular rails was successful under NCHRP Report No. 350 TL-3, they would seem reasonable for use in the termination of the bicycling railing design herein under MASH TL-2 impact conditions.

The researchers also reviewed the snag and vehicle contact with the vertical support posts in test no. IBBR-1. During test no. IBBR-1, the vehicle fender and hood directly contacted the vertical support posts of the bicycle rail, which caused deformation and disengagement of the right-front fender of the pickup truck and disengagement of the post, as shown in Figure 46. This degree of vehicle snag on the vertical post did not cause an occupant risk or vehicle stability problem during the full-scale crash test. It seems reasonable that contact of an oncoming vehicle on a similarly anchored end termination tube sloped at a 2H:1V slope would pose similar or less concern for occupant risk and vehicle instability. While the vertically tapered termination tube would have a slightly increased cross section and slightly reduced lateral offset due to the size of the horizontal tube compared to the post used in the bicycle rail, the much lower slope of the tube (2H:1V versus vertical) would be expected to be safely traversable by an oncoming vehicle.

Based on the geometry data, the previous vertical tube transition slopes evaluated at TTI, and the results of the vehicle interaction the vertical post in test no. IBBR-1, the researchers believed that the use of a 2H:1V slope would be acceptable for termination of the bicycle railing. The 2H:1V slope would allow attachment of the horizontal top rail over a reasonable longitudinal distance. Additionally, the previous crash tests conducted at TTI under NCHRP Report No. 350 TL-3 suggested that a 2H:1V taper for vertical tube terminations was crashworthy and could potentially be applied to a slightly different scenario for a MASH TL-2 bicycling railing termination. Finally, the vehicle snag on traversal of the vertical post support post in test no. IBBR-1 suggested that a 2H:1V vertically tapered end rail would likely be traversable as well. It should be noted that for reverse direction traffic impacts or impacts on a downstream end termination, the sloped rail poses a risk due to the vehicle structure becoming wedged between the sloped rail and the top of the parapet. This will be further addressed in the subsequent section regarding the connection of the sloped rail to the parapet.

Figure 46. Vertical Support Post Contact, Test No. IBBR-1

6.3.5.2 End Termination and Connection to Parapet

Once a vertical taper of 2H:1V was selected for the end termination of the bicycle rail, the design of the end termination was further developed in terms of the geometry of the overall end termination section and the connection of the end termination to the existing bicycle rail and parapet. As noted previously, it was desired to attach the end termination to the bicycle rail using the existing splice connections in the system. Further, it was desired to maintain a maximum 10-ft (3.05-m) spacing between the attachment of any vertical posts or tapered tubes to the concrete parapet in order to keep support spacing similar to the as-tested bicycle rail. Finally, it was noted in the previous section that reverse direction traffic impacts or impacts on a downstream end termination for the bicycle rail may have the potential to wedge the vehicle between the sloped rail and the top of the parapet. Thus, concepts for mitigating that contact were developed.

Three end termination concepts were developed for the end termination based on these criteria and are described in subsequent sections. The end termination concepts are described schematically herein as it is not known which concept Iowa DOT would prefer. Final termination designs may be further refined. Additional details can be provided if Iowa DOT selects a particular concept for use with the system. Note that none of the end termination concepts shown have been full-scale crash tested or evaluated as compliant with MASH TL-2. Instead, they represent the researchers' best engineering judgment at this time with respect to the end termination of parapet-mounted bicycle railings.

It should be noted that the location of the attachment of the tapered down tube section to the parapet relative to the end of the parapet could affect performance for all the concepts detailed below. Recall that termination of the end of the low-height parapet adjacent to crash cushions or approach guardrail transitions requires raising the height of the end of the parapet to 32 in. (813 mm) and potentially modifying its shape. It is recommended that the end of the sloped tube be placed a minimum of 12 in. (305 mm) from the vertical and/or lateral shape transitions from the low-height parapet to the end buttress. This spacing should limit vehicle interaction and snag on the sloped tube for oncoming traffic and provide for sufficient room for the sloped tube to release when impacted in the reverse direction as required by some of the concepts. A safe termination offset for the sloped tube end adjacent to a sloped concrete end treatment is more difficult to define. The existing crash testing of a sloped concrete end treatment for low-height portable concrete barrier noted previously showed the potential for the vehicle to ride up onto and on top of the barrier for significant distances that exceeded 50 ft (15.2 m). If similar behavior occurred with the Iowa DOT low-height parapet with a sloped concrete end treatment, the potential exists for the vehicle to be on top of the low-height parapet and subsequently interact with the sloped tube termination. This may induce increased vehicle instability. Because the potential distance that impacting vehicles may travel along the top of the low-height parapet with a sloped concrete end treatment is unknown, and the potential for further vehicle instability exists, the offset for the sloped tube terminations from the end of the low-height parapet when used with a sloped concrete end treatment cannot be defined at this time.

6.3.5.3 Partially-Welded Tube End Termination

The partially-welded tube end termination concept is shown in Figures 47 and 48. The end termination attached to the bicycle rail at a standard splice location. Following the splice, a vertical support post was placed in the end termination such that the termination could be attached to a splice on either end of the system while maintaining a maximum of 10-ft (3.05-m) post spacing in the system. Note that this configuration creates a spacing less than the standard 10-ft (3.05-m) post spacing on one end of the system. This reduced post spacing was not expected to adversely affect the performance of the barrier as the bicycling railing was full-scale crash tested at a critical impact point to maximize vehicle snag on an individual post. As such, a reduced post spacing would not be expected to pose an increase in vehicle snag and any additional contact with a subsequent post at reduced spacing would be considered to be less severe snag than what was evaluated in full-scale crash testing.

The horizontal tube was tapered vertically to the top of the parapet at a 2H:1V slope. The tube was then welded to a modified base plate that was slightly larger than the standard post base plate to account for the attachment of the sloped tube end and allowing attachment to the anchor rods. This required increasing the size of the base plate and the end of the tube termination to 14½ in. x 7 in. (368 mm x 178 mm) and widening the anchor slots by an additional 5¼ in. (133 mm). The remaining system components, including the horizontal tube that slopes down to the parapet, the vertical post tube, the vertical post base plate, and anchor rods, use the same section and parts used in the as-tested bicycle rail.

In order to mitigate concerns for reverse direction impacts wedging the vehicle between the sloped top tube and the parapet, the sloped tube was welded to the end base plate with ⅛-in. (3.2-mm) fillet welds on only the front and back sides of the tube. These welds should adequately anchor the sloped tube to the base plate during vehicle impacts on the length of need of the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing and during vehicle impacts near the approach to the end termination. During a reverse direction traffic impact or impact near a downstream end termination, these welds should unzip and allow the post to disengage from the base plate and limit the wedging of the vehicle between the sloped rail and the parapet.

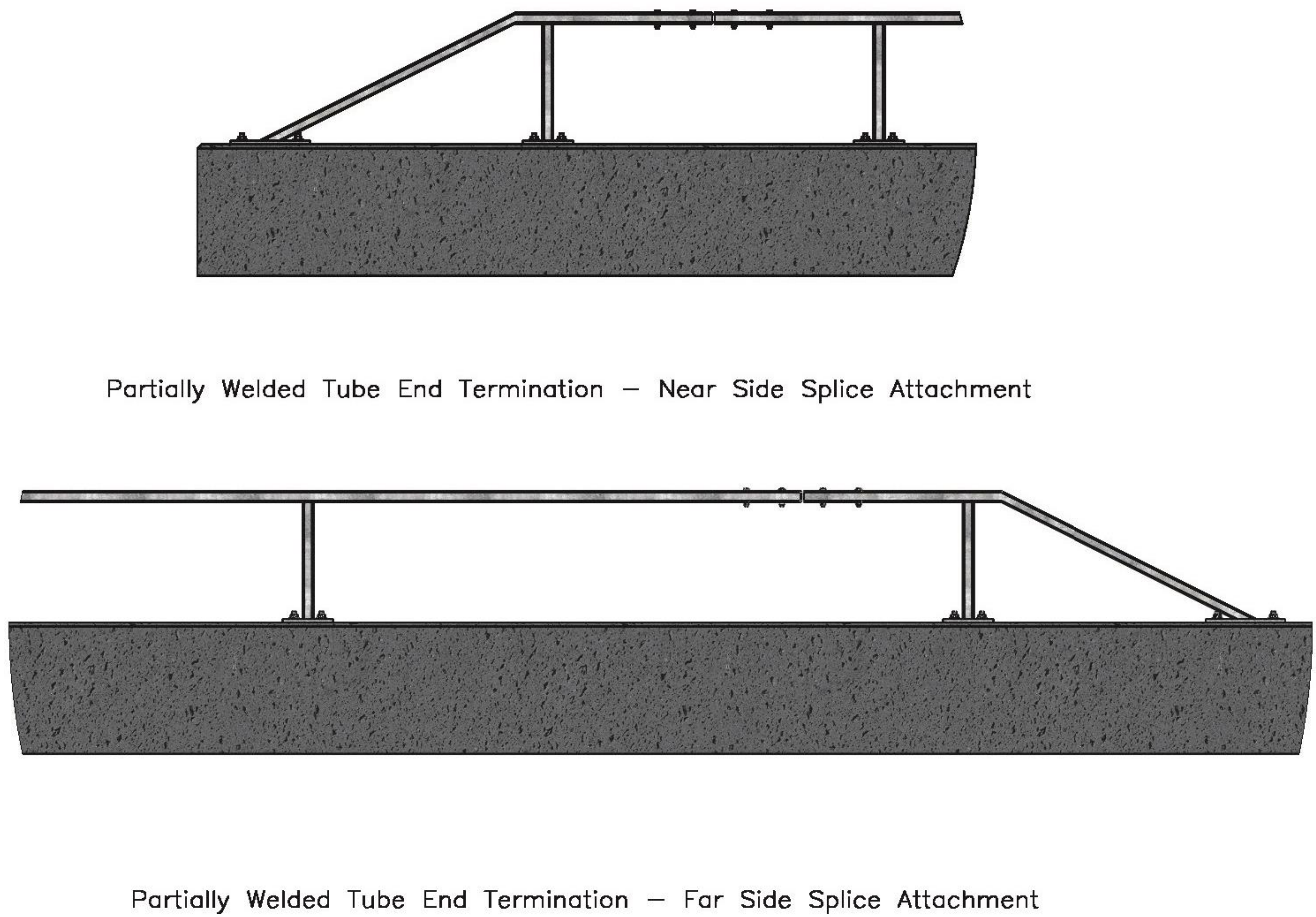

Figure 47. Partially-Welded Tube End Termination

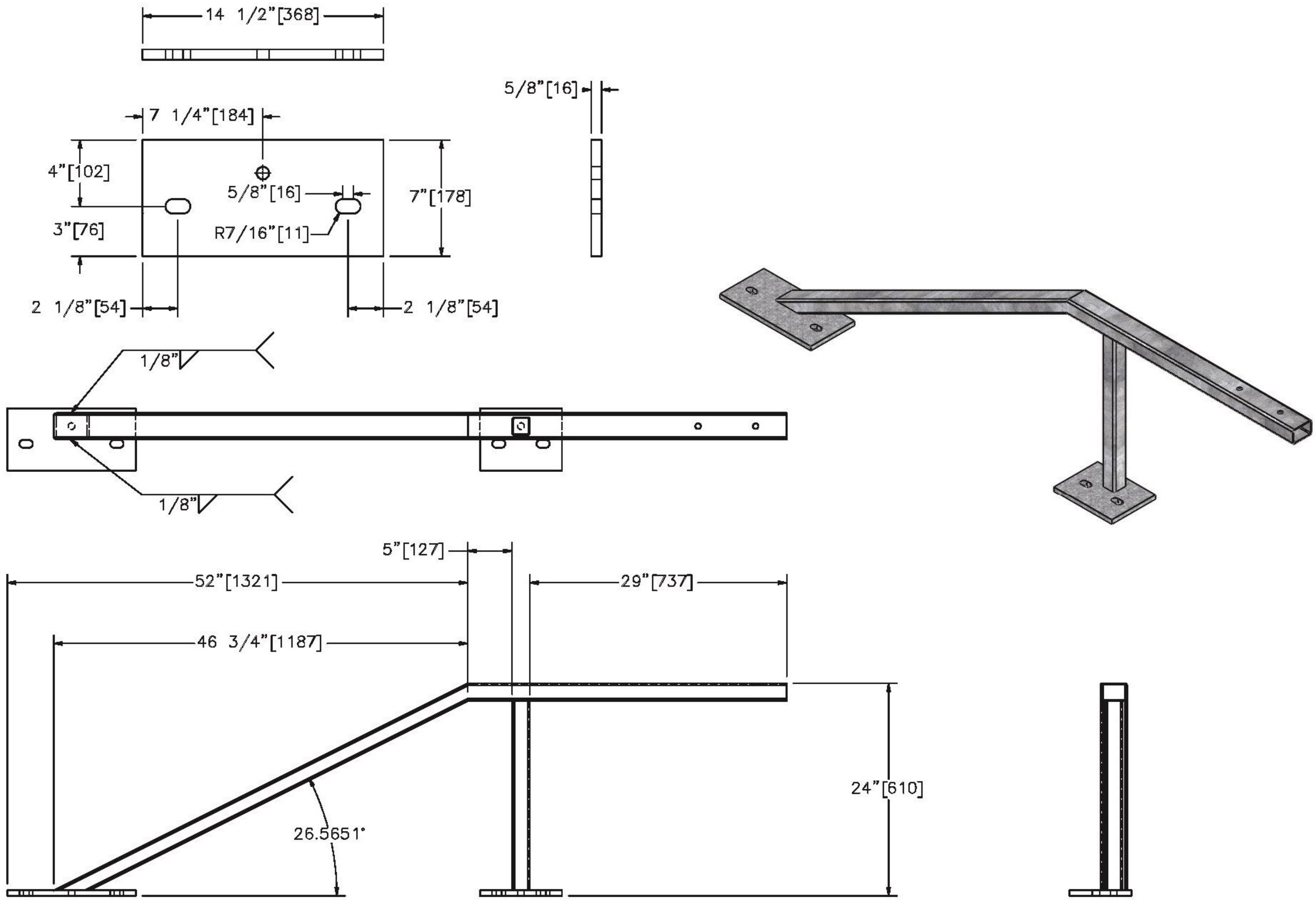

Figure 48. Partially-Welded Tube End Termination

6.3.5.4 Bolted Tube End Termination

The bolted tube end termination concept was nearly identical to the partially welded tube end termination described previously. The main difference between the first and second concepts is that in the second concept the sloped tube was connected to the end termination base plate with a single $^{3}/_{16}$-in. (4.8-mm) diameter, A307 bolt that passed through the tube and a C-shaped, bent plate welded to the base plate, as shown in Figure 49.

The C-shaped, bent plate was 7 in. long x 6½ in. wide x ¼ in. thick (178 mm x 165 mm x 6.4 mm), and the outer edge was chamfered to match the slope of the tube rail. The single bolt connecting the tube rail to the base plate served a similar function as the welds in the previous concept in that the bolt would anchor the sloped tube to the base plate during vehicle impacts on the length of need of the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing and during vehicle impacts near the approach to the end termination. During a reverse direction traffic impact or impact near a downstream end termination, the bolt should fracture and allow the post to disengage from the base plate and limit the wedging of the vehicle between the sloped rail and the parapet.

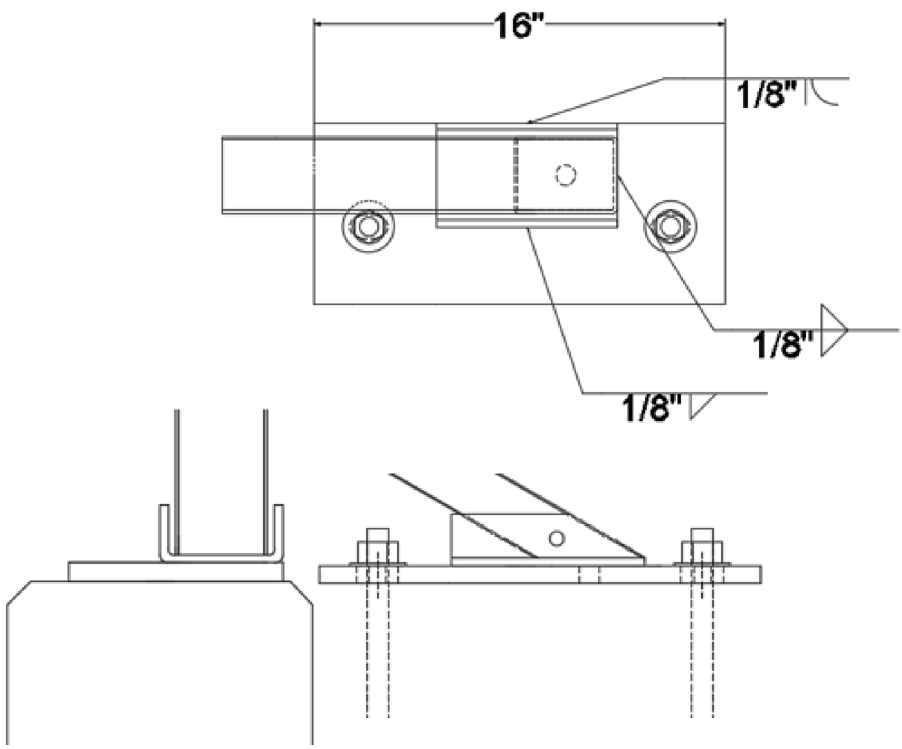

Figure 49. Bolted Tube End Termination

6.3.5.5 Laterally-Tapered End Termination

The third end termination concept consisted of tapering the rail laterally to the back side of the parapet and then tapering vertically, as shown in Figures 50 and 51. In the laterally-tapered end termination concept, the horizontal tube rail was tapered laterally at a 10:1 slope until the front face of the tube was flush with the back side of the parapet. Then, the tube was tapered downward at a 2H:1V slope until it was safely below the top of the parapet. The tube was then welded to a base plate which could be anchored to the back side of the parapet.

This concept reduced the potential for wedging the vehicle between the slope rail and the parapet by increasing the lateral offset of the slope tube. This offset should minimize the degree of vehicle snag and allow for safe vehicle redirection during a reverse direction traffic impact or impact near a downstream end termination. It should be noted that this concept may be less preferred by Iowa DOT, as they desired that the bicycle rail be mounted to the top of the parapet to reduce hardware on the back of the system that may be engaged by bicyclists and pedestrians. However, if this railing termination were to occur beyond the point at which the rail alignment pulls away from the back of the barrier system, engagement of this termination by bicyclists or pedestrians could be minimized or eliminated. Reduction of rail clear width by the back-mounted railing would also not be a concern in these circumstances.

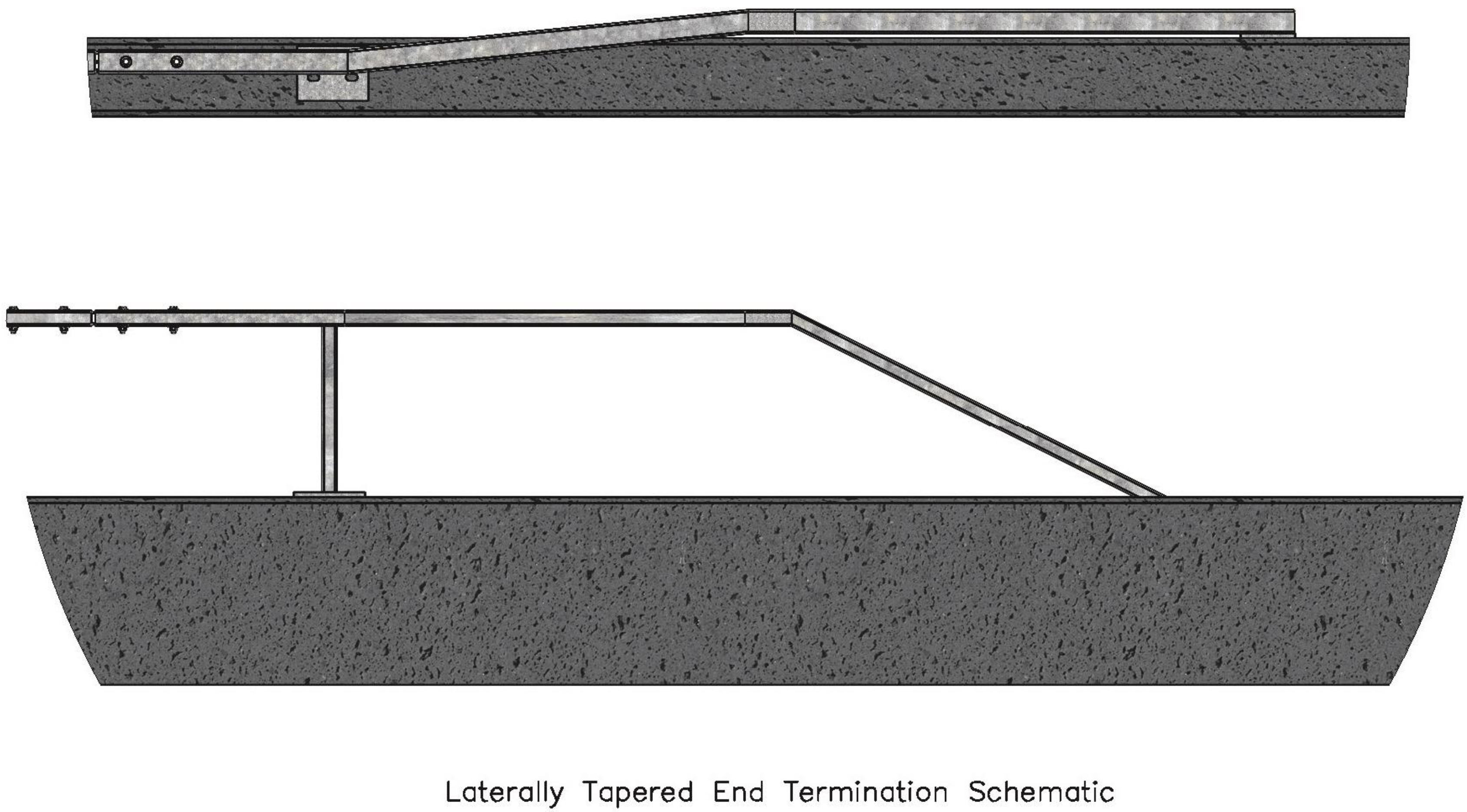

Figure 50. Laterally-Tapered End Termination

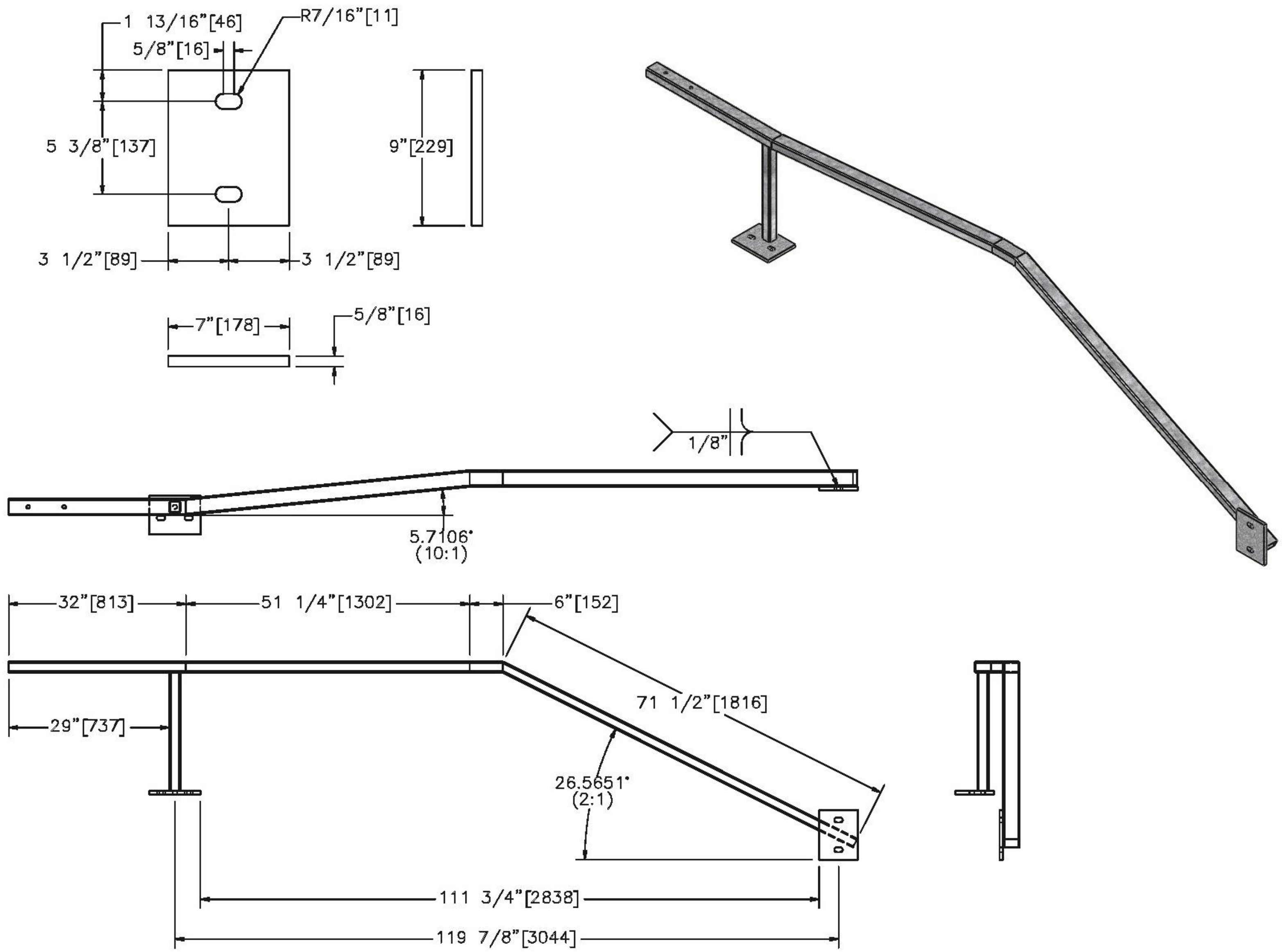

Figure 51. Laterally-Tapered End Termination

7 MASH EVALUATION

A low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing was evaluated to determine its compliance with MASH 2016 TL-2 evaluation criteria. The barrier system comprised a bicycle railing mounted atop a 24-in. tall x 10-in. wide (610-mm x 254-mm) concrete parapet. The overall height of the system with the parapet and the bicycle railing was 48 in. (1,219 mm). The bicycle rail consisted of a tubular steel longitudinal rail, tubular steel posts, and fabricated steel splice sections. The longitudinal rail was fabricated with HSS3x2x⅛ ASTM A500 Grade C structural steel tubing. Each rail segment was 20-ft (6.1-m) long and spliced at the quarter-span between two posts. The longitudinal rail was supported by HSS2x2x⅛ ASTM A500 Grade C structural steel tube posts mounted on 9¼-in. x 7-in. x 5/8-in. (235-mm x 178-mm x 16-mm) ASTM A572 Grade 50 steel base plates at 10-ft (3.05-m) spacing. For each post attachment location to the parapet, two ¾-in. (19-mm) diameter, 14-in. (356-mm) long ASTM F1554 Grade 105 threaded rods were anchored 12 in. (305 mm) into the parapet using epoxy adhesive with a minimum bond strength of 1,560 psi (10.8 MPa)

7.1 Test Matrix

Longitudinal barriers, such as the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing detailed herein, must satisfy the safety evaluation guidelines published in MASH 2016 [4]. According to TL-2 of MASH 2016, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 9.

Table 9. MASH 2016 TL-2 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed mph (km/h)	Angle deg.	
Longitudinal Barrier	2-10	1100C	2,420 (1,100)	44 (70)	25	A,D,F,H,I
	2-11	2270P	5,000 (2,270)	44 (70)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

The researchers deemed test designation no. 2-11 as the critical test for the evaluation of the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing. Test designation no. 2-11 was deemed critical as the height of the 2270P vehicle would provide the maximum potential for vehicle instability due to the low-height parapet design used in the system and provide for the maximum extension of the vehicle over the parapet for vehicle engagement and snag on the bicycle rail. Both behaviors could adversely affect occupant safety. The critical impact point (CIP) was determined through the simulation of the vehicle impacting the barrier system model at multiple impact points in the first phase of this research [7]. Due to the nature of the system, snag severity was considered the most important factor in determining the CIP. Several other parameters, such as vehicle damage, system damage, vehicle accelerations and velocities, and vehicle overlap of the system were observed and measured. From this process, it was concluded that an impact 3.8 ft (1.2 m) upstream from the face of a post or 46⅝ in. (1,184 mm) upstream from the centerline of a post would provide the highest probability of snag and the highest snag severity for all of the impact points simulated. Thus, this impact point was chosen as the CIP to be used in full-scale crash testing.

Test designation no. 2-10 was deemed non-critical for the evaluation of the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing. Previous MASH crash testing with the 1100C vehicle at TL-3 on taller vertical parapets has shown that occupant risk measures were not exceeded for small car impacts even when conducted at higher speeds [8-9]. Vehicle stability on the low-height parapet was also deemed not critical as redirection of the taller 2270P vehicle in test designation no. 2-11 would be a more critical test of the vehicle stability. As such, the final remaining concern for test designation no. 2-10 was the potential for vehicle snag on the bicycle rail. During the previous phase of this research, simulations were conducted with the 1100C vehicle on the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing to evaluate the potential for vehicle snag [7]. The interaction between the 1100C vehicle and the attached bicycle rail was relatively minor. The vehicle's front-right headlight assembly contacted post no. 4 in the simulation, but no permanent deformation of the post occurred suggesting a minor snag event. Further, no contact between the side passenger windows and the attached bicycle rail was observed during simulation. Thus, the simulation effort confirmed that MASH 2016 test designation no. 2-11 would provide a more severe impact scenario than MASH 2016 test designation no. 2-10.

7.2 Full-Scale Crash Test Results

The results of the MASH TL-3 full-scale crash testing of the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing are summarized below.

1. Test no. IBBR-1 was conducted on the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle under the MASH TL-2 guidelines for test designation no. 2-11. Test designation no. 2-11 is an impact of the 2270P vehicle into the system at 44 mph (70 km/h) and 25 degrees. The CIP for this test was selected to maximize the potential for vehicle interaction and snag on the support posts of the bicycle railing. The 4,980-lb (2,259-kg) quad cab pickup truck impacted the barrier at a speed of 45.3 mph (72.8 km/h) and at an angle of 25.6 degrees. In the test, the vehicle was captured and redirected by the 24-in. (610-mm) tall concrete parapet with bicycle railing. During the redirection of the vehicle, the right-front fender and right corner of the vehicle hood snagged on the vertical support post downstream from impact. The snag was sufficient to peel back and disengage the entire right-front fender and deform and tear the hood of the vehicle. However, the snag of the vehicle components did not pose a risk to the vehicle occupant compartment nor did it pose a hazard due to the velocity change or deceleration of the vehicle. Vehicle redirection was primarily facilitated by the parapet, and the only contact, outside of post snag, between the 2270P vehicle and the bicycle railing occurred when the vehicle's hood and the right-rear corner of the truck box made minor contact with the upper tube rail during tail slap. It was believed that vehicle redirection would have occurred successfully on the 24-in. (610-mm) tall parapet without the presence of the bicycle railing. The vehicle came to rest 39 ft – 11 in. (12.2 m) downstream and 8 ft – 7 in. (2.6 m) laterally behind the barrier after brakes

were applied. Test no. IBBR-1 met all safety requirements for MASH 2016 test designation no. 2-11.

7.3 MASH Evaluation

Based on the results of the successful full-scale crash test conducted in this study, the low-height, vertical-face, traffic barrier with an attached crashworthy bicycle railing meets all safety requirements for MASH TL-2.

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9 APPENDICES

Appendix A. Material Specifications

Table A-1. Bill of Materials, Test No. IBBR-1

Item No.	Description	Material Specification	Reference
a1	HSS 3"x2"x⅛" [76x51x3], 240" [6,096] Long Tube	ASTM A500 Gr. C	H#A805360
a2	HSS 2"x2"x⅛" [51x51x3], 21⅜" [543] Long Tube	ASTM A500 Gr. C	H#17167161
a3	9¼"x7"x⅝" [235x178x16] Plate	ASTM A572 Gr. 50	H#A8C385
b1	28¼"x1¼"x5/16" [718x32x8] Plate	ASTM A572 Gr. 50	H#63180629
b2	28¼"x2"x5/16" [718x51x8] Plate	ASTM A572 Gr. 50	H#63180629
c1	½"-13 UNC [M14x2], 3" [76] Long Heavy Hex Head Bolt and Nut	Bolt- ASTM F3125 Gr. A325 Type 1 or equivalent Nut - ASTM A563DH or equivalent	BOLT: H#HD02754 NUT: H#HJ07110
c2	½" [13] Dia. Plain Round Washer	ASTM F844	P#33184 PO#170081147
d1	¾"-10 UNC [M20x2.5], 14" [356] Long Fully Threaded Rod	ASTM F1554 Gr. 105	H#10520660
e1	¾" [19] Dia. Plain Round Washer	ASTM F844	P#33186 PO#170081886
e2	¾"-10 UNC [M20x2.5] Heavy Hex Nut	ASTM A563DH	H#DL17106524
f1	Concrete	Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD	R#2147370338, 2147370339 LabID#URR-64, URR-65
f2	#4 [13] Rebar, 59 15/16" [1,522] Total Unbent Length	ASTM A615 Gr. 60	H#57169166
f3	#4 [13] Rebar, 1,200½" [30,493] Total Length	ASTM A615 Gr. 60	H#57169166
-	Epoxy	Min. bond strength = 1,560 psi [10.8 MPa] (Hilti HIT-RE 500 V3)	Hilti Tech Data Sheets: R#19-989

EXLTUBE

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

STEEL VENTURES, LLC dba EXLTUBE

Certified Test Report

Customer:	Size:	Customer Order No:	Date:
SPS - New Century 401 New Century Parkway NEW CENTURY KS 66031-1127	02.00X03.00	4500310508	06/28/2018
	Gauge: 11	Delivery No: 83183759 Load No: 4035074	
	Specification: ASTM A500-13 Gr.B/C		

Heat No	Yield KSI	Tensile KSI	Elongation % 2 Inch
A805360	55.4	65.9	26.50

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
A805360	0.0600	0.8200	0.0060	0.0020	0.0200	0.1100	0.0400	0.0600	0.0200	0.0020

This material was melted & manufactured in the U.S.A.
Coil Producing Mill: STEEL DYNAMICS COLUMBUS, COLUMBUS, MS

We hereby certify that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above. This product was manufactured in accordance with your purchase order requirements.

This material has not come into direct contact with mercury, any of its compounds, or any mercury bearing devices during our manufacturing process, testing, or inspections.

This material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

Tensile test completed using test specimen with 3/4" reduced area.

STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe
Quality Assurance Manager

Figure A-1. HSS 3-in. x 2-in. x ⅛-in. (76-mm x 51-mm x 3-mm) Square Steel Tubing for Rails, Test No. IBBR-1

Atlas Tube (Arkansas) Inc.
5039N County Road 1015
Blytheville, Arkansas, USA
72315
Tel: 870-838-2000
Fax: 870-762-6630

Atlas Tube A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80816793
Date: 04.12.2018
Customer: 179

MATERIAL TEST REPORT

Sold to

Steel & Pipe Supply Compan
PO Box 1688
MANHATTAN KS 66505
USA

Shipped to

Steel & Pipe Supply Compan
401 New Century Parkway
NEW CENTURY KS 66031
USA

Material: 2.0x2.0x125x20'0"0(10x5). Material No: 200201252000 Made in: USA Melted in: USA

Sales order: 1277265 Purchase Order: C452002299 Cust Material #: 6520012020

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
17167161	0.220	0.450	0.006	0.002	0.030	0.028	0.100	0.002	0.016	0.040	0.040	0.003	0.001	0.000	0.007

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M400121054	50	069570 Psi	076040 Psi	24 %	ASTM A500-13 GRADE B&C	0.32

Material Note:
Sales Or.Note:

Material: 2.0x2.0x125x20'0"0(10x5). Material No: 200201252000 Made in: USA Melted in: USA

Sales order: 1277265 Purchase Order: C452002299 Cust Material #: 6520012020

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
17167161	0.220	0.450	0.006	0.002	0.030	0.028	0.100	0.002	0.016	0.040	0.040	0.003	0.001	0.000	0.007

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M400121053	50	069570 Psi	076040 Psi	24 %	ASTM A500-13 GRADE B&C	0.32

Material Note:
Sales Or.Note:

Material: 2.0x2.0x188x24'0"0(10x5). Material No: 200201882400 Made in: USA Melted in: USA

Sales order: 1277271 Purchase Order: C452002299 Cust Material #: 6520018824

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
1181327	0.200	0.770	0.007	0.001	0.020	0.030	0.070	0.001	0.010	0.030	0.030	0.003	0.001	0.000	0.006

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M400120938	50	076540 Psi	084510 Psi	24 %	ASTM A500-13 GRADE B&C	0.35

Material Note:
Sales Or.Note:

Jason Richard

Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 1 Of 4

Metals Service Center Institute

Figure A-2. HSS 2-in. x 2-in. x ⅛-in. (751-mm x 51-mm x 3-mm) Square Steel Tubing for Posts, Test No. IBBR-1

SSAB

Preliminary Test Certificate

Form TC1: Revision 3: Date 7 Feb 2018

1770 Bill Sharp Boulevard, Muscatine, IA 52761-9412, US **Official copy to follow**

Customer: STEEL & PIPE SUPPLY P.O. BOX 1688 MANHATTAN KS 66502	Customer P.O. No.: 4500304234	Mill Order No.: 41-534059-01	Shipping Manifest : MT343422
	Product Description: ASTM A572-50/M345(15)/A709-50/M345(17)	Ship Date: 10 Apr 18 Cert Date: 10 Apr 18	Cert No: 061702221 (Page 1 of 1)
	Size: 0.625 X 96.00 X 240.0 (IN)		

Tested Pieces				Tensiles						Charpy Impact Tests					
Heat Id	Piece Id	Tested Thickness	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1 2 3 Avg	% Shear 1 2 3 Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp %Shr
A8C385	C01	0.627 (DISCRT)	L	57	72		37	T							

Chemical Analysis

Heat Id	C	Mn	P	S	Si	Tot Al	Cu	Ni	Cr	Mo	Cb	V	Ti	ORGN
A8C385	.06	1.23	.012	.002	.22	.031	.34	.15	.16	.05	.002	.045	.002	USA

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED AND MANUFACTURED IN THE USA.
PRODUCTS SHIPPED:
A8C385 C01 PCES: 9, LBS: 36756

(II) Cust Part # : 722096240A2

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

SENIOR METALLURGIST - PRODUCT

Figure A-3. Steel Mounting Plate for Post, Test No. IBBR-1

CERTIFIED MATERIAL TEST REPORT — Page 1/1

GERDAU

US-ML-JACKSON TN
801 GERDAU AMERISTEEL ROAD
JACKSON, TN 38305
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
STEEL AND PIPE SUPPLY CO INC JONESBURG INDUSTRIAL PARK JONESBURG,MO 63351 USA	STEEL AND PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	GGMULTI	Flat Bar / 5/16 X 3	0000000000

LENGTH	WEIGHT	HEAT / BATCH
20'00"	9,698 LB	**63180629**/03

SALES ORDER	CUSTOMER MATERIAL N°
6400437/000010	000000000101030020

SPECIFICATION / DATE or REVISION
ASTM A529-14, A572-15
ASTM A6-17,A36-14, ASME SA-36
ASTM A709-17, AASHTO M270-15
CSA G40.20-13/G40.21-13

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500308001	1333-0000107435	05/11/2018

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Al %	Sn %
0.16	0.75	0.012	0.031	0.21	0.31	0.11	0.12	0.028	0.024	0.000	0.001	0.010

MECHANICAL PROPERTIES

Elong. %	G/L Inch	G/L mm	UTS PSI	UTS MPa	YS PSI
25.00	8.000	200.0	75270	519	57130
24.00	8.000	200.0	75370	520	56390

MECHANICAL PROPERTIES

YS MPa
394
389

GEOMETRIC CHARACTERISTICS

R:R
29.15

COMMENTS / NOTES

This grade meets the requirements for the following grades:
ASTM Grades: A36; A529-50; A572-50; A709-36; A709-50
CSA Grades: 44W; 50W
AASHTO Grades: M270-36; M270-50
ASME Grades: SA36

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

BHASKAR YALAMANCHILI
QUALITY DIRECTOR
Phone: (409) 769-1014 Email: Bhaskar.Yalamanchili@gerdau.com

BEN LOVELL
QUALITY ASSURANCE MGR.
Phone: (731) 423-5213 Email: benjamin.lovell@gerdau.com

Figure A-4. 1¼-in. (32-mm) Splice Plate and 2-in. (51-mm) Splice Plate, Test No. IBBR-1

INSPECTION CERTIFICATE

KPF FACTORY : 50, CHUNGJUSANDAN 5-RO, CHUNGJU-SI
CHUNGCHEONGBUK-DO, KOREA 380-250
TEL : (043)849 - 1114 FAX : (043)849 - 1234

FIELD OF TESTING : MECHANICAL TESTING
LAB. ID. : 111983
CERT. NO. : 0882.01

STANDARD OF CERTIFIED : IATF 16949, ISO 9001, ISO 14001
CERTIFICATE NO. : TS-01899, AC-01899, EAC-01899

STANDARD OF CERTIFIED : EN 14399-1,2,3,4,5,6,10
CERTIFICATE NO. : 1020 - CPR - 070038467

STANDARD OF CERTIFIED : EN 15048-1
CERTIFICATE NO. : 1020 - CPR - 070048404

Certificate No. : J420180110053
P/O No. : 120294334
L/C No. : FASTENAL(INDIANAPOLIS)
Date issued : 2018.01.10
Date Shipped : 2017.12.31
Date Tested : 2017.11.09
Date Manufactured : 2017.10.02
Specifications : Set : ASTM F3125 - 15
Bolt : ASTM F3125 - 15
Nut : ASTM A563 - 15
Washer :

Customer : FASTENAL(INDIANAPOLIS)
Description : STR H/H B N I F3125_A325 TY1 DH HDG_B
Size : 1/2-13UNCx3
Surface Condition : HDG_B
Set Lot No. : 2018328300
Q'ty Shipped : 4,500 SETS
Marking : Bolt : A325,KPF LOGO
Nut : DH,KPF LOGO
Washer :

1. Chemical Composition (%)

Division			C x100	Si x100	Mn x100	P x1000	S x1000	Cr x100	Mo x100	Ni x100	B x10000	Cu X100
Bolt	Spec.	Min.	30	15	60							
		Max.	52	30		35	40				30	
Heat No.	HD02754		36	21	81	15	6	33		1	19	1
Nut	Spec.	Min.	20		60							
		Max.	55			40	50					
Heat No.	HJ07110		46	21	72	15	4				16	1
Washer	Spec.	Min.										
		Max.										
Heat No.												

1.1 Steel Grade : - Bolt : 10B33 - Nut : S45C

2. Mechanical Properties

2.1 Bolt
- Lot No : 2018328200
- Grade : F3125_A325 TY1

Division		Hardness Surface	Hardness Core (n = 4)	Specimen Tensile Yield Strength	Specimen Tensile Tensile Strength	Specimen Tensile Elongation	Specimen Tensile Reduction of Area	Proof Load Load (n = 3)	Proof Load Elongation (n = 3)	Wedge Tensile Load (n = 3)
Unit	Min.							LBF		LBF
	Max.		HRC						in	
Spec.	Min.							12,050		17,050
	Max.		34						0.0005	
Results	Min.		HRC 31					12,050	0.0002	19,482
	Max.		32					12,050	0.0003	19,843
	Avg.		32					12,050	0.0003	19,713
	Wedge Angele									10 °
Tested By			B.S.KANG					B.S.KANG		B.S.KANG
Spec. of Test Method			ASTM F606/F606M-14a					ASTM F606/F606M-14a		ASTM F606/F606M-14a

2.2 Nut
- Lot No : 2018787800
- Grade : GR.DH

Division		Hardness (n = 2)	Proof Load (n = 2)
Unit	Min.	HRC	LBF
	Max.	HRC	
Spec.	Min.	24	21,290
	Max.	38	
Results	Min.	HRC 31	21,290
	Max.	32	21,290
	Avg.	32	21,290
Tested By		B.S.KANG	B.S.KANG
Spec. of Test Method		ASTM A370-16	ASTM A370-16

2.3 Washer
- Lot No :
- Grade :

Division		Hardness
Unit	Min.	
	Max.	
Spec.	Min.	
	Max.	
Results	Min.	
	Max.	
	Avg.	
Tested By		
Spec. of Test Method		

3. Rotational Capacity Test

Division	Unit Min.	Unit Max.	Spec. Min.	Spec. Max.	Results (n = 3) Min.	Results (n = 3) Max.
Initial Tension	kips	kips	1	3	2	2
Torque		ft.lb		125	68	73
Rotation Degree		°		360	360	360
Design Tension	kips		12		12	12
Full Rotation Tension	kips		14		16	17
Tested By	B.S.KANG					
Spec. of Test Method	ASTM F3125-15					

4. Visual & Thread Inspection

Division	Appearance	Thread
Bolt	OK	OK
Nut	OK	OK
Washer	OK	-

Reference :
1. PART NO:11134587
2. MECHANICAL SAMPLING PLAN - ASTM F1470-2012
3. ALL FASTENERS MEET THE REQUIREMENTS OF THE (FQA) AND RECORDS OF COMPLIANCE ARE ON FILE
4. THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER
5. HEATS HAVE THE ELEMENTS LISTED IN 5.4 INTENTIONALLY ADDED WERE NOT USED
6. NUT LUBRICATION : OK
7. EN10204-3.1

This is to certify that the above results are true and correct in every details

Youn o Choi

YOUN - O CHOI
Chief of Quality Management Dept.

KPF

Figure A-5. Heavy Hex Bolt and Nut, Test No. IBBR-1

INSPECTION CERTIFICATE

KPF FACTORY : 50, CHUNGJUSANDAN 5-RO, CHUNGJU-SI
CHUNGCHEONGBUK-DO, KOREA 380-250
TEL : (043)849-1114 FAX : (043)849-1234

FIELD OF TESTING : MECHANCICAL TESTING
LAB. ID. : 111983
CERT. NO. : 0882.01

STANDARD OF CERTIFIED : IATF 16949, ISO 9001, ISO 14001
CERTIFICAT NO. : TS-01899, AC-01899, EAC-01899

STANDARD OF CERTIFIED : EN 14399-1,2,3,4,5,6,10
CERTIFICAT NO. : 1020-CPR-070038467

STANDARD OF CERTIFIED : EN 15048-1
CERTIFICAT NO. : 1020-CPR-070048404

Customer	FASTENAL(INDIANAPOLIS)	Surface Condition	HDG_B
Lot No.	2018328300	Q'ty Shipped	4,500 Sets
Description	STR H/H B N I F3125_A325 TY1 DH HDG_B	Date issued	Jan. 10. 2018
Size	1/2-13UNCx3	Specification	ASTM F2329 - 2015
Sampling Method	ASTM F1470-2012	PO No.	120294334

Contents		Spec.	Test Method	Results						Judgement	Remarks
				MIN		MAX		standard deviation	AVG		
Appearance		ASTM F2329 - 2015	Visual	Pass		Pass				pass	
BOLT	Individual Coating Thickness	MIN 43.0μm	ASTM E376-2011	66		75		3.806	-	pass	
	Average Coating Thickness	MIN 53.7μm		-	-	-	-	-	71		
NUT	Individual Coating Thickness	MIN 43.0μm	ASTM E376-2011	66		76		4.214	-	pass	
	Average Coating Thickness	MIN 53.7μm		-	-	-	-	-	72		

This is to certify that the above results are true and correct in every details

Youn o Choi

YOUN - O CHOI
Chief of Quality Management Dept.

Figure A-6. Heavy Hex Bolt and Nut, Test No. IBBR-1

CERTIFIED MATERIAL TEST REPORT
FOR USS FLAT WASHERS HDG

FACTORY: IFI & Morgan Ltd REPORT DATE: 26/4/2018
ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan,Zhejiang, China

SAMPLING PLAN PER ASME B18.18-11 PO NUMBER: 170081147
SIZE: USS 1/2 HDG QNTY(Lot size): 64800PCS
HEADMARKS: NO MARK PART NO: 33184

DIMENSIONAL INSPECTIONS SPECIFICATION: ASTM B18.21.1-2011

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	***********************************	******************	********	********
APPEARANCE	ASTM F844	PASSED	100	0
OUTSIDE DIA	1.368-1.405	1.370-1.378	10	0
INSIDE DIA	0.557-0.577	0.567-0.575	10	0
THICKNESS	0.086-0.132	0.086-0.102	10	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
********************	******************	******************	******************	********	********
HOT DIP GALVANIZED	ASTM F2329-13	Min 0.0017"	0.0017-0.0020 in	8	0

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD. 检验专用章 QUANLITY CONTROL

(SIGNATURE OF Q.A. LAB MGR.)

Figure A-7. ½-in. (13-mm) Diameter Plain Round Washer, Test No. IBBR-1

Job Material Certification

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

JOB MATERIAL CERTIFICATION

Job No: 557599 **Job Information** **Certified Date:** 12/18/17

Containers: S13372865

Customer: Portland Bolt & Mfg., Inc.

Ship To: 3441 NW Guam Street
Portland, OR 97210

Vulcan Part No: ATR B7 3/4x12

Customer Part No: ATR B7 3/4x12

Customer PO No: 34040

Shipped Qty: 203 pcs

Order No: 337036

Line No: 1

Note:

19570 3/4 B7/G105 ATR

Applicable Specifications

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

Test Results

See following pages for tests

Certified Chemical Analysis

Heat No: 10520660 Origin: USA

C	Mn	P	S	Si	Cr	Mo	Ni	V	Cu
0.410	0.89	0.009	0.024	0.29	0.92	0.21	0.05	0.003	0.10
Al	**Cb**	**Sn**	**Ti**	**N**	**B**	**DI**	**RR**	**G.S.**	**Macro S**
0.026	0.001	0.007	0.002	0.0060	0.0001	5.31	68:1	Fine	2
Macro R	**Macro C**	**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**	**J8**
2	2	57	57	57	57	57	57	57	55
J9	**J10**	**J12**	**J14**	**J16**	**J18**	**J20**	**J24**	**J28**	**J32**
54	52	50	48	46	46	45	43	40	38

Notes

Material was manufactured, tested and inspected in accordance with Vulcan Threaded Products Inc. Quality Assurance Program and Manual Rev. A, dated 8/23/11. Processed material is Quenched and Tempered - Stress Free. No weld repair performed on the material. No Mercury used in the production of this material. Melted and Manufactured in the USA.
Depth of decarburization meets ASTM A962/A962M-17 spec requirements
Document is in accordance with EN 10204 - 3.1B of 2004 (3.1).

Plex 12/18/17 9:07 AM vulc.mgri Page 1 of 2

Figure A-8. ¾-in. (19-mm) Threaded Rod, Test No. IBBR-1

Job Material Certification

Page 6 of 6

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

VULCAN THREADED PRODUCTS, INC.

JOB MATERIAL CERTIFICATION

Job No: 557599 **Job Information** **Certified Date:** 12/18/17

Containers: S13372865

Test Results

Part No: BAR B7 .6813x292 HT

Test No: 45971 **Test:** Quench & Temper Information (Lbs)

Description	Austenitizing Temp (F)	Tempering Temp (F)	Run Speed (Ft/min)	Quench Water Temp (F)	Note
Results	1,704	1,341	38	94	

Test No: 45974 **Test:** F1554-105 FB Requirements

Description	Tensile (ksi) (ksi)	Yield 0.2% Offset (ksi) (ksi)	Elongation (%)	Elongation Gage Length (8in)	ROA (%)	Note
	139	128	14	8in	60	

Test No: 45972 **Test:** A193 B7, F1554-105 Requirements

Description	Tensile (ksi)	Yield 0.2% Offset (ksi)	Elongation (%)	Elongation Gage Length	ROA (%)	Midradius Hardness	Surface Hardness	Center Hardness	Hardness Test Type	Note
	141	130	19	4D	63	30	31		HRC	
	138	126	21	4D	56	30	29		HRC	
	140	129	19	4D	62	30	30		HRC	
	139	127	19	4D	60	30	30		HRC	
	143	131	18	4D	62	29	29		HRC	
	143	131	20	4D	60	30	29		HRC	

Test No: 45973 **Test:** F1554-15 gd105 S4 Charpy ft/lbs Requirements

Description	Container	Test Temp (F)	Test1 (ft/lbs)	Test2 (ft/lbs)	Test3 (ft/lbs)	Results Avg (ft/lbs)	Note
		-20	109	119	114	114	

Griffin, Mitchell - Certification Engineer 12/18/17 Date

Plex 12/18/17 9:07 AM vulc.mgri Page 2 of 2

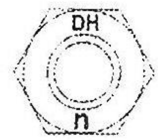
Figure A-9. ¾-in. (19-mm) Threaded Rod, Test No. IBBR-1

NUCOR
FASTENER DIVISION

LOT NO.
401431B

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
143 CORDOVA BOLT INC   NUCOR ORDER # 59543
TEST REPORT SERIAL# FB557503   CUST PART #
TEST REPORT ISSUE DATE 2/26/18
DATE SHIPPED 3/23/18   CUSTOMER P.O. # 066050
NAME OF LAB SAMPLER: RYAN UNGER, LAB TECHNICIAN



****************CERTIFIED MATERIAL TEST REPORT****************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175657	8100	401431B	3/4-10 GR DH HV H.D.G. HEX NUT HDG/GREEN LUBE

MANUFACTURE DATE 12/04/17

--CHEMISTRY   MATERIAL GRADE -1045L
**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER   NUCOR STEEL - SOUTH CAROL

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM031943	DL17106524	.44	.64	.004	.022	.21

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-15

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 50100 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	31.0	PASS	N/A	N/A
N/A	31.2	PASS	N/A	N/A
N/A	29.8	PASS	N/A	N/A
N/A	29.9	PASS	N/A	N/A
N/A	29.0	PASS	N/A	N/A

AVERAGE VALUES FROM TESTS
30.2
PRODUCTION LOT SIZE 200000 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-07a   160 PCS. SAMPLED   LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-13 - GALVANIZING PERFORMED IN THE U.S.A.

1. 0.00254	2. 0.00319	3. 0.00226	4. 0.00315	5. 0.00210	6. 0.00279	7. 0.00344
8. 0.00266	9. 0.00338	10. 0.00289	11. 0.00277	12. 0.00292	13. 0.00222	14. 0.00241
15. 0.00246						

AVERAGE THICKNESS FROM 15 TESTS .00275

--HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.404	1.413
Thickness	32	0.736	0.751

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO INTENTIONAL ADDITIONS OF BISMUTH, SELENIUM, TELLURIUM, OR LEAD WERE USED IN THE STEEL USED TO PRODUCE THIS PRODUCT.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/19

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

BOB HAYWOOD
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

Figure A-10. ¾-in. (19-mm) Heavy Hex Nut, Test No. IBBR-1

benesch
engineers · scientists · planners

LINCOLN OFFICE
825 "M" Street Suite 100
Lincoln, NE 68508
Phone: (402) 479-2200
Fax: (402) 479-2276

COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 6x12

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility **Date** 09-Jul-18
Project Name: Miscellaneous Concrete Testing
Placement Location: IBBR-1

Mix Designation: **Required Strength:**

Field Test Data

Sampled in accordance with ASTM C172-90; Tested in accordance with ASTM C143-90a, ASTM C 1064-86, ASTM C138-92, and ASTM C 231-97

Slump, in. **Concrete Temp.** °F **Initial Cure Method** **Final Cure Method** **Ticket No:**
Air Content, % **Unit Weight, lb/ cu. ft.** **Initial Cure Temp. Min/Max** **Final Cure Temp.**

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area, sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
URR- 64	1	7/2/2018	7/9/2018	7/9/2018	7	0	7	12	6.01	28.41	112,537	3,960		5	C 1231

1 cc: Ms. Karla Lechtenberg
Midwest Roadside Safety Facility

Remarks:

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

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

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Report Number 2147370338
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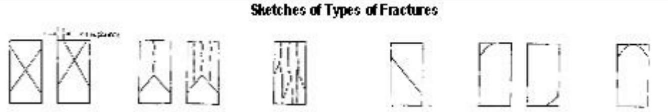
Sketches of Types of Fractures



ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By Brant Wells
Brant Wells, Field/Lab Operations Manager

Figure A-11. Barrier Concrete, Test No. IBBR-1

benesch
engineers · scientists · planners

LINCOLN OFFICE
825 "M" Street Suite 100
Lincoln, NE 68508
Phone: (402) 479-2200
Fax: (402) 479-2276

COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 6x12

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility **Date** 09-Jul-18
Project Name: Miscellaneous Concrete Testing
Placement Location: IBBR-9 (4 GAL)

Mix Designation: **Required Strength:**

Field Test Data

Sampled in accordance with ASTM C172-90; Tested in accordance with ASTM C143-90a, ASTM C 1064-86, ASTM C138-92, and ASTM C 231-97

Slump, in. **Concrete Temp.** °F **Initial Cure Method** **Final Cure Method** **Ticket No:**
Air Content, % **Unit Weight, lb/ cu. ft.** **Initial Cure Temp. Min/Max** **Final Cure Temp.**

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area, sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
URR- 65	1	7/2/2018	7/9/2018	7/9/2018	7	0	7	12	6.00	28.30	114,566	4,050		5	C 1231

1 cc: Ms. Karla Lechtenberg
Midwest Roadside Safety Facility

Remarks: 4 gallons of Water

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

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

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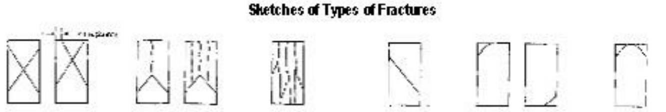
Report Number 2147370339
Page 1

Sketches of Types of Fractures



ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By [signature]
Brant Wells, Field/Lab Operations Manager

Figure A-12. Barrier Concrete, Test No. IBBR-1

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
4	212	9264	3	3		BUNKY 5601716	7/2/18	8:01 AM	4206575

Customer: CIA---MWRSS

Delivery Address: 4630 NW 36TH ST

Special Instructions: MIDWEST ROADSIDE SAFETY / NORTHOF GOODYEAR HANGERS

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
6.75	6.75	6.75	470031PF	47BD (1PF)	yd	$122.91	$829.64
				MINIMUM HAUL			$2.50

Water Added On Job At Customer's Request: ______

SLUMP: 3.00 in

Notes:

TICKET SUBTOTAL	$832.14
SALES TAX	$0.00
TICKET TOTAL	**$832.14**
PREVIOUS TOTAL	
GRAND TOTAL	**$832.14**

CAUTION FRESH CONCRETE

KEEP CHILDREN AWAY

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

Terms & Conditions

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

MATERIAL	DESCRIPTION	DESIGN QTY	REQUIRED	BATCHED	% VAR	% MOISTURE	ACTUAL WATER
CEM1PF	1PF CEMENT	658.0 lb	4441.5 lb	4430.0 lb	-0.26%		
G47B	47B GRAVEL	1975.0 lb	13574.4 lb	13520.0 lb	-0.40%	1.82% A	29.0 gl
L47B	47B ROCK	840.0 lb	5843.5 lb	5820.0 lb	-0.12%	3.06% A	20.7 gl
LRWR	POZZ 322N LOV	20.0 oz	135.0 oz	135.0 oz	0.00%		
AIR	MB AE 200 air e	5.4 oz	36.5 oz	36.0 oz	-1.23%		
WATER	WATER	31.4 gl	162.0 gl	161.3 gl	-0.45%		161.3 gl

Actual	Num Batches: 1			Manual
Load: 25127 lb	**Design W/C: 0.40**	Water/Cement: 0.40 T	Design Water: 212.0 gl	Actual: 211.0 gl
Slump: 3.00 in	Water in Truck: 0.0 gl	Adjust Water: 0.0 gl / Load	Trim Water: 0.0 gl / CYDS	
Actual W/C Ratio 0.40	Actual Water: 211 gl	Batched Cement: 4430 lb	Allowable Water: 3 lb	To Add: 0.9 gl

Figure A-13. Barrier Concrete, Test No. IBBR-1

CERTIFIED MATERIAL TEST REPORT

Page 1/1

GERDAU

US-ML-KNOXVILLE
1919 TENNESSEE AVENUE N. W.
KNOXVILLE, TN 37921
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
SIMCOTE INC 1645 RED ROCK SAINT PAUL,MN 55119 USA	SIMCOTE INC 1645 RED ROCK ROAD SAINT PAUL,MN 55119-6014 USA	60 (420) TMX	Rebar / #4 (13MM)	0000000000

LENGTH	WEIGHT	HEAT / BATCH
60'00"	94,262 LB	57169166/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
5749568/000090		ASTM A615/A615M-15 E1

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
MN-3676	1326-0000074465	11/10/2017

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.26	0.57	0.006	0.040	0.21	0.32	0.10	0.13	0.009	0.011	0.002	0.38

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
83730	577	98580	680	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
10.60	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
4.49	0.032	0.115	0.320

COMMENTS / NOTES

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

Bhaskar
BHASKAR YALAMANCHILI
QUALITY DIRECTOR
Phone: (409) 769-1014 Email: Bhaskar.Yalamanchili@gerdau.com

Jim Hall
JIM HALL
QUALITY ASSURANCE MGR.
Phone: 865-202-5972 Email: Jim.hall@gerdau.com

Figure A-14. #4 Rebar, Test No. IBBR-1

HILTI

Hilti Inc.
5400 South 122nd East Ave.
TULSA, OK 74146

Bill-To Address

UNIVERSITY OF NEBRASKA-LINCOLN
942 N 22ND ST
LINCOLN NE 68588

Delivery Address

UNIVERSITY OF NEBRASKA-LINCOLN
MWRSF
4630 NW 36TH ST
LINCOLN NE 68524-1802

CS Cash Sale 26274597

Page 1(1)

Order Type:	CS Cash Sale 06/08/2018	**Customer Number:**	19884583
		Purchase Order No.:	
Order Date:	06/08/2018	**Your Reference:**	
Our Contact:	PI Order Integration	**Your Main Contact:**	Shaun Tighe
		Your Main Contact Tel.:	402-472-4800

Item No.	Description	Ordered Quantity	Net Price/Unit	Net Value
2123404	Epoxy adh RE 500-V3 16.9oz/500ml	1 BOX of 20 EA = 20 EA	1,000.31 BOX	1,000.31
	Line Total			**1,000.31**
	FREIGHT			**10.00**
		Final Total	**USD**	**1,010.31**

All Sales Subject to Hilti Terms and Conditions. Price subject to change without notice. Phone 1-800-879-8000 Fax 1-800-879-7000

Figure A-15. Hilti Epoxy, Test No. IBBR-1

Appendix B. Vehicle Center of Gravity Determination

Date:	9/13/2018	Test Name:	IBBR-1	VIN:	1D7RB1GPXBS586259
Year:	2011	Make:	Dodge	Model:	Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	4986	28.377983	141492.63
+	Hub	19	15.25	289.75
+	Brake activation cylinder & frame	8	29 3/8	235
+	Pneumatic tank (Nitrogen)	30	27 1/4	817.5
+	Strobe/Brake Battery	5	27 1/2	137.5
+	Brake Receiver/Wires	5	52	260
+	CG Plate including DAS	42	30	1260
-	Battery	-42	41	-1722
-	Oil	-3	18.5	-55.5
-	Interior	-84	36	-3024
-	Fuel	-101	17 7/8	-1805.375
-	Coolant	-8	34 1/4	-274
-	Washer fluid	-3	39.125	-117.375
+	Water Ballast (In Fuel Tank)	130	19	2470
+	Onboard Supplemental Battery	12	26	312
+	Smart Barrier	9	24 1/2	220.5
				0
Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle				140496.63

Estimated Total Weight (lb)	5005
Vertical CG Location (in.)	28.0713

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140.75 in.
Front Track Width: 67.5 in.
Rear Track Width: 67.375 in.

Center of Gravity	**2270P MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)	5000 ± 110	4980	-20.0
Longitudinal CG (in.)	63 ± 4	61.95261	-1.04739
Lateral CG (in.)	NA	-0.56875	NA
Vertical CG (in.)	28 or greater	28.07	0.07125

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	1438	1396
Rear	1075	1077

FRONT	2834	lb
REAR	2152	lb
TOTAL	4986	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	1434	1354
Rear	1098	1094

FRONT	2788	lb
REAR	2192	lb
TOTAL	4980	lb

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

Appendix C. Vehicle Deformation Records

Date: 9/13/2018 Test Name: IBBR-1 VIN: 1D7RB1GPXBS586259
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
FLOOR PAN - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	49.2797	22.0575	-1.2691	49.2454	22.1470	-1.1492	0.0343	-0.0895	-0.1199	0.1535	0.0343	X
	2	50.3954	25.2465	1.9173	50.4246	25.2597	2.0369	-0.0292	-0.0132	-0.1196	0.1238	0.0000	NA
	3	50.2940	29.1656	2.3921	50.2139	29.0956	2.4718	0.0801	0.0700	-0.0797	0.1329	0.0801	X
	4	50.0282	31.1602	2.4637	49.9311	31.1145	2.6132	0.0971	0.0457	-0.1495	0.1840	0.0971	X
	5	49.9543	35.5317	2.3538	49.9645	35.5117	2.6554	-0.0102	0.0200	-0.3016	0.3024	0.0000	NA
	6	46.2436	21.6135	0.8640	46.2108	21.6536	1.0089	0.0328	-0.0401	-0.1449	0.1539	0.0328	X
	7	46.8567	24.3322	3.8010	46.8465	24.3419	3.9572	0.0102	-0.0097	-0.1562	0.1568	0.0102	X
	8	46.7268	28.8781	4.4194	46.6495	28.8896	4.5376	0.0773	-0.0115	-0.1182	0.1417	0.0773	X
	9	46.4515	32.3955	4.4730	46.3229	32.3067	4.6387	0.1286	0.0888	-0.1657	0.2278	0.1286	X
	10	46.2561	35.6373	4.4721	46.2179	35.6155	4.7209	0.0382	0.0218	-0.2488	0.2527	0.0382	X
FLOOR PAN (Z)	11	43.2769	20.3086	3.3748	43.2110	20.2928	3.5771	0.0659	0.0158	-0.2023	0.2133	-0.2023	Z
	12	43.2850	23.8333	5.1366	43.2514	23.8534	5.2628	0.0336	-0.0201	-0.1262	0.1321	-0.1262	Z
	13	42.9985	27.7677	5.1471	42.9719	27.7651	5.3095	0.0266	0.0026	-0.1624	0.1646	-0.1624	Z
	14	42.4824	31.9030	5.1482	42.4722	31.9241	5.4016	0.0102	-0.0211	-0.2534	0.2545	-0.2534	Z
	15	42.5275	35.0606	5.1524	42.4859	35.0376	5.4948	0.0416	0.0230	-0.3424	0.3457	-0.3424	Z
	16	38.9378	18.5190	5.0759	38.8633	18.5400	5.1756	0.0745	-0.0210	-0.0997	0.1262	-0.0997	Z
	17	38.5888	23.3311	5.1851	38.5818	23.3178	5.2940	0.0070	0.0133	-0.1089	0.1099	-0.1089	Z
	18	37.9455	27.0560	5.1754	37.9302	27.0370	5.3431	0.0153	0.0190	-0.1677	0.1695	-0.1677	Z
	19	37.8748	30.8802	5.2110	37.8002	30.8586	5.5304	0.0746	0.0216	-0.3194	0.3287	-0.3194	Z
	20	37.7788	35.0530	5.1994	37.7203	34.9764	5.6279	0.0585	0.0766	-0.4285	0.4392	-0.4285	Z
	21	34.7938	17.8347	5.0671	34.7571	17.7831	5.1342	0.0367	0.0516	-0.0671	0.0923	-0.0671	Z
	22	34.4063	22.0106	5.2098	34.3725	22.0092	5.2983	0.0338	0.0014	-0.0885	0.0947	-0.0885	Z
	23	34.2368	24.7062	5.1874	34.1685	24.6462	5.3203	0.0683	0.0600	-0.1329	0.1610	-0.1329	Z
	24	33.9443	29.0799	5.2164	33.9476	29.0374	5.5274	-0.0033	0.0425	-0.3110	0.3139	-0.3110	Z
	25	33.7089	33.9922	5.2345	33.7485	33.9226	5.6228	-0.0396	0.0696	-0.3883	0.3965	-0.3883	Z
	26	30.5758	17.3493	4.5530	30.5330	17.2846	4.5991	0.0428	0.0647	-0.0461	0.0902	-0.0461	Z
	27	30.1407	21.2148	4.3622	30.1147	21.1534	4.4621	0.0260	0.0614	-0.0999	0.1201	-0.0999	Z
	28	29.5848	25.7230	4.2462	29.5989	25.7104	4.4035	-0.0141	0.0126	-0.1573	0.1584	-0.1573	Z
	29	29.4790	29.9346	4.2933	29.5044	29.9070	4.5062	-0.0254	0.0276	-0.2129	0.2162	-0.2129	Z
	30	29.1056	33.8025	4.4717	29.0462	33.8419	4.7191	0.0594	-0.0394	-0.2474	0.2575	-0.2474	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. IBBR-1

Date: 9/13/2018 Test Name: IBBR-1 VIN: 1D7RB1GPXBS586259
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
FLOOR PAN - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	53.0022	0.0074	-5.0005	52.7625	0.0327	-4.8043	0.2397	-0.0253	-0.1962	0.3108	0.2397	X
	2	54.2525	3.1419	-1.8100	54.0683	3.1006	-1.6241	0.1842	0.0413	-0.1859	0.2649	0.1842	X
	3	54.3472	7.0620	-1.3425	54.0535	6.9450	-1.2147	0.2937	0.1170	-0.1278	0.3410	0.2937	X
	4	54.1828	9.0678	-1.2764	53.8750	8.9769	-1.0885	0.3078	0.0909	-0.1879	0.3719	0.3078	X
	5	54.3328	13.4371	-1.3940	54.1375	13.3666	-1.0724	0.1953	0.0705	-0.3216	0.3828	0.1953	X
	6	49.9298	-0.2769	-2.8922	49.6833	-0.2875	-2.6772	0.2465	-0.0106	-0.2150	0.3273	0.2465	X
	7	50.6563	2.4130	0.0453	50.4267	2.3833	0.2618	0.2296	0.0297	-0.2165	0.3170	0.2296	X
	8	50.7532	6.9609	0.6552	50.4612	6.9388	0.8126	0.2920	0.0221	-0.1574	0.3325	0.2920	X
	9	50.6571	10.4879	0.7008	50.3124	10.3689	0.8896	0.3447	0.1190	-0.1888	0.4106	0.3447	X
	10	50.6273	13.7354	0.6929	50.3794	13.6791	0.9508	0.2479	0.0563	-0.2579	0.3621	0.2479	X
FLOOR PAN (Z)	11	46.8796	-1.4237	-0.4044	46.5891	-1.4731	-0.1342	0.2905	-0.0494	-0.2702	0.3998	-0.2702	Z
	12	47.0528	2.0996	1.3517	46.7971	2.0915	1.5303	0.2557	0.0081	-0.1786	0.3120	-0.1786	Z
	13	46.9672	6.0435	1.3534	46.7218	6.0127	1.5505	0.2454	0.0308	-0.1971	0.3163	-0.1971	Z
	14	46.6626	10.1997	1.3434	46.4390	10.1926	1.6121	0.2236	0.0071	-0.2687	0.3496	-0.2687	Z
	15	46.8687	13.3509	1.3428	46.6142	13.3018	1.6867	0.2545	0.0491	-0.3439	0.4306	-0.3439	Z
	16	42.4409	-2.9863	1.2631	42.1388	-2.9863	1.4264	0.3021	0.0000	-0.1633	0.3434	-0.1633	Z
	17	42.3369	1.8376	1.3616	42.1059	1.8004	1.5129	0.2310	0.0372	-0.1513	0.2786	-0.1513	Z
	18	41.8845	5.5903	1.3403	41.6488	5.5488	1.5326	0.2357	0.0415	-0.1923	0.3070	-0.1923	Z
	19	42.0085	9.4132	1.3692	41.7166	9.3731	1.6954	0.2919	0.0401	-0.3262	0.4396	-0.3262	Z
	20	42.1255	13.5854	1.3499	41.8508	13.4900	1.7673	0.2747	0.0954	-0.4174	0.5087	-0.4174	Z
	21	38.2677	-3.4585	1.2206	37.9994	-3.5283	1.3440	0.2683	-0.0698	-0.1234	0.3035	-0.1234	Z
	22	38.0925	0.7320	1.3533	37.8342	0.7131	1.4784	0.2583	0.0189	-0.1251	0.2876	-0.1251	Z
	23	38.0608	3.4327	1.3250	37.7679	3.3573	1.4824	0.2929	0.0754	-0.1574	0.3410	-0.1574	Z
	24	37.9914	7.8156	1.3444	37.7744	7.7552	1.6606	0.2170	0.0604	-0.3162	0.3882	-0.3162	Z
	25	38.0067	12.7335	1.3526	37.8296	12.6447	1.7244	0.1771	0.0888	-0.3718	0.4213	-0.3718	Z
	26	34.0349	-3.7294	0.6719	33.7610	-3.8093	0.7650	0.2739	-0.0799	-0.0931	0.3001	-0.0931	Z
	27	33.7990	0.1529	0.4712	33.5467	0.0750	0.6002	0.2523	0.0779	-0.1290	0.2939	-0.1290	Z
	28	33.4747	4.6834	0.3431	33.2703	4.6522	0.5085	0.2044	0.0312	-0.1654	0.2648	-0.1654	Z
	29	33.5834	8.8949	0.3824	33.3939	8.8487	0.5849	0.1895	0.0462	-0.2025	0.2812	-0.2025	Z
	30	33.4062	12.7772	0.5514	33.1396	12.8034	0.7692	0.2666	-0.0262	-0.2178	0.3453	-0.2178	Z

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

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

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

Pretest Floor Pan

Posttest Floor Pan

Figure C-2. Floor Pan Deformation Data – Set 2, Test No. IBBR-1

Date: 9/13/2018 Test Name: IBBR-1 VIN: 1D7RB1GPXBS586259
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
INTERIOR CRUSH - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	40.9387	32.2525	-26.7464	41.1496	32.5392	-26.5191	-0.2109	-0.2867	0.2273	0.4223	0.4223	X, Y, Z
	2	41.0729	17.2307	-27.8066	41.3291	17.4065	-27.7111	-0.2562	-0.1758	0.0955	0.3251	0.3251	X, Y, Z
	3	42.6965	5.8355	-28.2397	42.9671	6.0909	-28.1907	-0.2706	-0.2554	0.0490	0.3753	0.3753	X, Y, Z
	4	36.2253	36.7498	-16.1619	36.4056	36.8899	-15.8909	-0.1803	-0.1401	0.2710	0.3544	0.3544	X, Y, Z
	5	36.0759	21.3187	-16.5548	36.3138	21.5658	-16.3970	-0.2379	-0.2471	0.1578	0.3776	0.3776	X, Y, Z
	6	34.9054	6.2631	-17.3722	35.1771	6.4431	-17.3170	-0.2717	-0.1800	0.0552	0.3306	0.3306	X, Y, Z
SIDE PANEL (Y)	7	45.2930	39.2680	0.0527	45.4028	39.2492	0.4130	-0.1098	0.0188	0.3603	0.3771	0.0188	Y
	8	45.1747	39.2866	-4.7318	45.2475	39.2856	-4.3631	-0.0728	0.0010	0.3687	0.3758	0.0010	Y
	9	47.3379	39.3654	-1.9133	47.4989	39.3852	-1.5775	-0.1610	-0.0198	0.3358	0.3729	-0.0198	Y
IMPACT SIDE DOOR (Y)	10	33.9829	41.0561	-16.0770	33.9701	41.3342	-15.8975	0.0128	-0.2781	0.1795	0.3312	-0.2781	Y
	11	23.1953	40.6964	-15.7707	23.2108	41.2349	-15.6296	-0.0155	-0.5385	0.1411	0.5569	-0.5385	Y
	12	12.1568	40.3852	-15.5797	12.2426	40.8710	-15.3990	-0.0858	-0.4858	0.1807	0.5254	-0.4858	Y
	13	34.7953	39.7419	-6.5125	34.8233	39.6974	-6.3583	-0.0280	0.0445	0.1542	0.1629	0.0445	Y
	14	24.5898	41.4128	-3.8588	24.5738	41.5711	-3.6156	0.0160	-0.1583	0.2432	0.2906	-0.1583	Y
	15	14.0423	40.0508	-3.0621	14.1026	40.2347	-2.8772	-0.0603	-0.1839	0.1849	0.2677	-0.1839	Y
ROOF - (Z)	16	21.2440	27.1759	-45.2457	21.4366	27.4443	-45.1213	-0.1926	-0.2684	0.1244	0.3530	0.1244	Z
	17	22.0284	21.3810	-45.6962	22.2602	21.6276	-45.5966	-0.2318	-0.2466	0.0996	0.3528	0.0996	Z
	18	23.1428	15.6361	-45.9058	23.3024	15.9044	-45.8392	-0.1596	-0.2683	0.0666	0.3192	0.0666	Z
	19	24.5205	10.3882	-45.9194	24.8396	10.6220	-45.8565	-0.3191	-0.2338	0.0629	0.4006	0.0629	Z
	20	25.5178	5.3943	-45.8607	25.7037	5.7395	-45.8430	-0.1859	-0.3452	0.0177	0.3925	0.0177	Z
	21	15.4752	26.5834	-45.8864	15.6874	26.7662	-45.7720	-0.2122	-0.1828	0.1144	0.3025	0.1144	Z
	22	15.7360	21.5164	-46.2121	16.0641	21.7217	-46.1089	-0.3281	-0.2053	0.1032	0.4006	0.1032	Z
	23	16.1047	15.6520	-46.4965	16.2722	15.9291	-46.4240	-0.1675	-0.2771	0.0725	0.3318	0.0725	Z
	24	16.6524	10.9192	-46.6916	16.8868	11.2269	-46.6365	-0.2344	-0.3077	0.0551	0.3907	0.0551	Z
	25	16.6621	5.4451	-46.7756	16.8861	5.7212	-46.7477	-0.2240	-0.2761	0.0279	0.3566	0.0279	Z
	26	7.4931	24.9915	-46.3237	7.7658	25.2250	-46.2274	-0.2727	-0.2335	0.0963	0.3717	0.0963	Z
	27	8.1583	20.0023	-46.6291	8.4255	20.2540	-46.5537	-0.2672	-0.2517	0.0754	0.3747	0.0754	Z
	28	8.7019	13.7108	-46.9025	8.9800	13.9433	-46.8391	-0.2781	-0.2325	0.0634	0.3680	0.0634	Z
	29	9.2630	8.5520	-47.0174	9.4664	8.7987	-46.9691	-0.2034	-0.2467	0.0483	0.3234	0.0483	Z
	30	9.4065	3.5669	-47.0483	9.6580	3.8062	-47.0251	-0.2515	-0.2393	0.0232	0.3479	0.0232	Z
A-PILLAR Maximum (X, Y, Z)	31	43.3904	37.7314	-30.0823	43.5020	37.9194	-29.8357	-0.1116	-0.1880	0.2466	0.3296	0.2466	Z
	32	41.1618	37.1246	-31.7551	41.3304	37.3105	-31.4735	-0.1686	-0.1859	0.2816	0.3772	0.2816	Z
	33	37.1784	35.9562	-34.7160	37.3195	36.1256	-34.4990	-0.1411	-0.1694	0.2170	0.3093	0.2170	Z
	34	33.8663	35.1757	-37.1809	34.0811	35.3682	-36.9695	-0.2148	-0.1925	0.2114	0.3576	0.2114	Z
	35	31.2859	34.5099	-39.0257	31.5147	34.7008	-38.7974	-0.2288	-0.1909	0.2283	0.3754	0.2283	Z
	36	28.7069	33.7562	-40.1291	28.9695	33.9694	-39.9840	-0.2626	-0.2132	0.1451	0.3681	0.1451	Z
A-PILLAR Lateral (Y)	31	43.3904	37.7314	-30.0823	43.5020	37.9194	-29.8357	-0.1116	-0.1880	0.2466	0.3296	-0.1880	Y
	32	41.1618	37.1246	-31.7551	41.3304	37.3105	-31.4735	-0.1686	-0.1859	0.2816	0.3772	-0.1859	Y
	33	37.1784	35.9562	-34.7160	37.3195	36.1256	-34.4990	-0.1411	-0.1694	0.2170	0.3093	-0.1694	Y
	34	33.8663	35.1757	-37.1809	34.0811	35.3682	-36.9695	-0.2148	-0.1925	0.2114	0.3576	-0.1925	Y
	35	31.2859	34.5099	-39.0257	31.5147	34.7008	-38.7974	-0.2288	-0.1909	0.2283	0.3754	-0.1909	Y
	36	28.7069	33.7562	-40.1291	28.9695	33.9694	-39.9840	-0.2626	-0.2132	0.1451	0.3681	-0.2132	Y
B-PILLAR Maximum (X, Y, Z)	37	3.5936	32.1709	-40.5666	3.7872	32.3189	-40.5077	-0.1936	-0.1480	0.0589	0.2507	0.0589	Z
	38	1.4078	34.8703	-32.9735	1.5859	34.9998	-32.8523	-0.1781	-0.1295	0.1212	0.2514	0.1212	Z
	39	4.7000	36.2257	-28.3076	4.8444	36.3215	-28.2148	-0.1444	-0.0958	0.0928	0.1966	0.0928	Z
	40	1.2295	36.4658	-24.8735	1.3758	36.5625	-24.7527	-0.1463	-0.0967	0.1208	0.2129	0.1208	Z
B-PILLAR Lateral (Y)	37	3.5936	32.1709	-40.5666	3.7872	32.3189	-40.5077	-0.1936	-0.1480	0.0589	0.2507	-0.1480	Y
	38	1.4078	34.8703	-32.9735	1.5859	34.9998	-32.8523	-0.1781	-0.1295	0.1212	0.2514	-0.1295	Y
	39	4.7000	36.2257	-28.3076	4.8444	36.3215	-28.2148	-0.1444	-0.0958	0.0928	0.1966	-0.0958	Y
	40	1.2295	36.4658	-24.8735	1.3758	36.5625	-24.7527	-0.1463	-0.0967	0.1208	0.2129	-0.0967	Y

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

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

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

Figure C-3. Occupant Compartment Deformation Data – Set 1, Test No. IBBR-1

Date:	9/13/2018	Test Name:	IBBR-1	VIN:	1D7RB1GPXBS586259
Year:	2011	Make:	Dodge	Model:	Ram 1500

VEHICLE DEFORMATION
INTERIOR CRUSH - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	45.6472	10.5921	-30.5217	45.4959	10.6926	-30.2872	0.1513	-0.1005	0.2345	0.2966	0.2966	X, Y, Z
	2	45.0250	-4.4176	-31.5795	44.9018	-4.4357	-31.3976	0.1232	-0.0181	0.1819	0.2204	0.2204	X, Y, Z
	3	46.0697	-15.8808	-31.9979	45.9546	-15.8237	-31.7990	0.1151	0.0571	0.1989	0.2368	0.2368	X, Y, Z
	4	41.0797	15.3291	-19.9778	40.8661	15.3458	-19.7371	0.2136	-0.0167	0.2407	0.3222	0.3222	X, Y, Z
	5	40.1478	-0.0745	-20.3707	39.9834	0.0444	-20.1638	0.1644	0.1189	0.2069	0.2898	0.2898	X, Y, Z
	6	38.2189	-15.0515	-21.1968	38.0724	-15.0039	-21.0173	0.1465	0.0476	0.1795	0.2365	0.2365	X, Y, Z
SIDE PANEL (Y)	7	50.1266	17.3905	-3.6872	49.7909	17.3299	-3.3438	0.3357	0.0606	0.3434	0.4840	0.0606	Y
	8	50.0498	17.4126	-8.4725	49.6912	17.3465	-8.1215	0.3586	0.0661	0.3510	0.5061	0.0661	Y
	9	52.1903	17.3826	-5.6358	51.9134	17.3453	-5.3108	0.2769	0.0373	0.3250	0.4286	0.0373	Y
IMPACT SIDE DOOR (Y)	10	39.0589	19.7440	-19.9123	38.6651	19.9105	-19.7950	0.3938	-0.1665	0.1173	0.4434	-0.1665	Y
	11	28.2648	19.9345	-19.6973	27.9128	20.3715	-19.6499	0.3520	-0.4370	0.0474	0.5631	-0.4370	Y
	12	17.2235	20.1859	-19.5997	16.9387	20.5790	-19.5431	0.2848	-0.3931	0.0566	0.4887	-0.3931	Y
	13	39.7224	18.3951	-10.3411	39.3254	18.2873	-10.2382	0.3970	0.1078	0.1029	0.4240	0.1078	Y
	14	29.5932	20.5849	-7.7741	29.1572	20.7066	-7.6230	0.4360	-0.1217	0.1511	0.4772	-0.1217	Y
	15	18.9837	19.7624	-7.0666	18.6231	19.9201	-6.9977	0.3606	-0.1577	0.0689	0.3996	-0.1577	Y
ROOF - (Z)	16	25.8765	6.5158	-49.1866	25.7539	6.5196	-49.0872	0.1226	-0.0038	0.0994	0.1579	0.0994	Z
	17	26.3686	0.6883	-49.6301	26.2792	0.6654	-49.5224	0.0894	0.0229	0.1077	0.1418	0.1077	Z
	18	27.1907	-5.1061	-49.8297	27.0251	-5.1055	-49.7231	0.1656	0.0006	0.1066	0.1969	0.1066	Z
	19	28.2993	-10.4173	-49.8313	28.2857	-10.4606	-49.6950	0.0136	-0.0433	0.1363	0.1437	0.1363	Z
	20	29.0404	-15.4556	-49.7637	28.8946	-15.3813	-49.6460	0.1458	0.0743	0.1177	0.2016	0.1177	Z
	21	20.0907	6.2175	-49.8762	19.9848	6.1372	-49.8002	0.1059	0.0803	0.0760	0.1531	0.0760	Z
	22	20.0958	1.1437	-50.1992	20.1025	1.0781	-50.1062	-0.0067	0.0656	0.0930	0.1140	0.0930	Z
	23	20.1678	-4.7321	-50.4800	20.0127	-4.7192	-50.3885	0.1551	0.0129	0.0915	0.1805	0.0915	Z
	24	20.4753	-9.4867	-50.6700	20.3843	-9.4482	-50.5692	0.0910	0.0385	0.1008	0.1412	0.1008	Z
	25	20.2069	-14.9541	-50.7536	20.0987	-14.9469	-50.6516	0.1082	0.0072	0.1020	0.1489	0.1020	Z
	26	12.0418	5.0341	-50.3809	11.9994	5.0067	-50.3383	0.0424	0.0274	0.0426	0.0661	0.0426	Z
	27	12.4546	0.0173	-50.6802	12.4033	0.0064	-50.6309	0.0513	0.0109	0.0493	0.0720	0.0493	Z
	28	12.6793	-6.2939	-50.9486	12.6322	-6.3261	-50.8768	0.0471	-0.0322	0.0718	0.0917	0.0718	Z
	29	12.9779	-11.4746	-51.0582	12.8519	-11.4897	-50.9742	0.1260	-0.0151	0.0840	0.1522	0.0840	Z
	30	12.8676	-16.4605	-51.0876	12.7843	-16.4857	-51.0018	0.0833	-0.0252	0.0858	0.1222	0.0858	Z
A-PILLAR Maximum (X, Y, Z)	31	48.4029	15.9374	-33.8371	48.1618	15.9240	-33.6048	0.2411	0.0134	0.2323	0.3351	0.3351	X, Y, Z
	32	46.1605	15.4440	-35.5287	45.9799	15.4191	-35.2643	0.1806	0.0249	0.2644	0.3212	0.3212	X, Y, Z
	33	42.1479	14.4785	-38.5231	41.9469	14.4265	-38.3292	0.2010	0.0520	0.1939	0.2841	0.2841	X, Y, Z
	34	38.8214	13.8664	-41.0159	38.7013	13.8238	-40.8327	0.1201	0.0426	0.1832	0.2232	0.2232	X, Y, Z
	35	36.2261	13.3320	-42.8824	36.1243	13.2799	-42.6863	0.1018	0.0521	0.1961	0.2270	0.2270	X, Y, Z
	36	33.6214	12.7100	-44.0076	33.5578	12.6747	-43.8982	0.0636	0.0353	0.1094	0.1314	0.1314	X, Y, Z
A-PILLAR Lateral (Y)	31	48.4029	15.9374	-33.8371	48.1618	15.9240	-33.6048	0.2411	0.0134	0.2323	0.3351	0.0134	Y
	32	46.1605	15.4440	-35.5287	45.9799	15.4191	-35.2643	0.1806	0.0249	0.2644	0.3212	0.0249	Y
	33	42.1479	14.4785	-38.5231	41.9469	14.4265	-38.3292	0.2010	0.0520	0.1939	0.2841	0.0520	Y
	34	38.8214	13.8664	-41.0159	38.7013	13.8238	-40.8327	0.1201	0.0426	0.1832	0.2232	0.0426	Y
	35	36.2261	13.3320	-42.8824	36.1243	13.2799	-42.6863	0.1018	0.0521	0.1961	0.2270	0.0521	Y
	36	33.6214	12.7100	-44.0076	33.5578	12.6747	-43.8982	0.0636	0.0353	0.1094	0.1314	0.0353	Y
B-PILLAR Maximum (X, Y, Z)	37	8.4646	12.4057	-44.6575	8.3312	12.3309	-44.7019	0.1334	0.0748	-0.0444	0.1593	0.1529	X, Y
	38	6.3551	15.2168	-37.0834	6.1869	15.1672	-37.0864	0.1682	0.0496	-0.0030	0.1754	0.1754	X, Y
	39	9.6724	16.4051	-32.3900	9.4577	16.3450	-32.4189	0.2147	0.0601	-0.0289	0.2248	0.2230	X, Y
	40	6.1897	16.8235	-28.9854	5.9678	16.7860	-28.9981	0.2219	0.0375	-0.0127	0.2254	0.2250	X, Y
B-PILLAR Lateral (Y)	37	8.4646	12.4057	-44.6575	8.3312	12.3309	-44.7019	0.1334	0.0748	-0.0444	0.1593	0.0748	Y
	38	6.3551	15.2168	-37.0834	6.1869	15.1672	-37.0864	0.1682	0.0496	-0.0030	0.1754	0.0496	Y
	39	9.6724	16.4051	-32.3900	9.4577	16.3450	-32.4189	0.2147	0.0601	-0.0289	0.2248	0.0601	Y
	40	6.1897	16.8235	-28.9854	5.9678	16.7860	-28.9981	0.2219	0.0375	-0.0127	0.2254	0.0375	Y

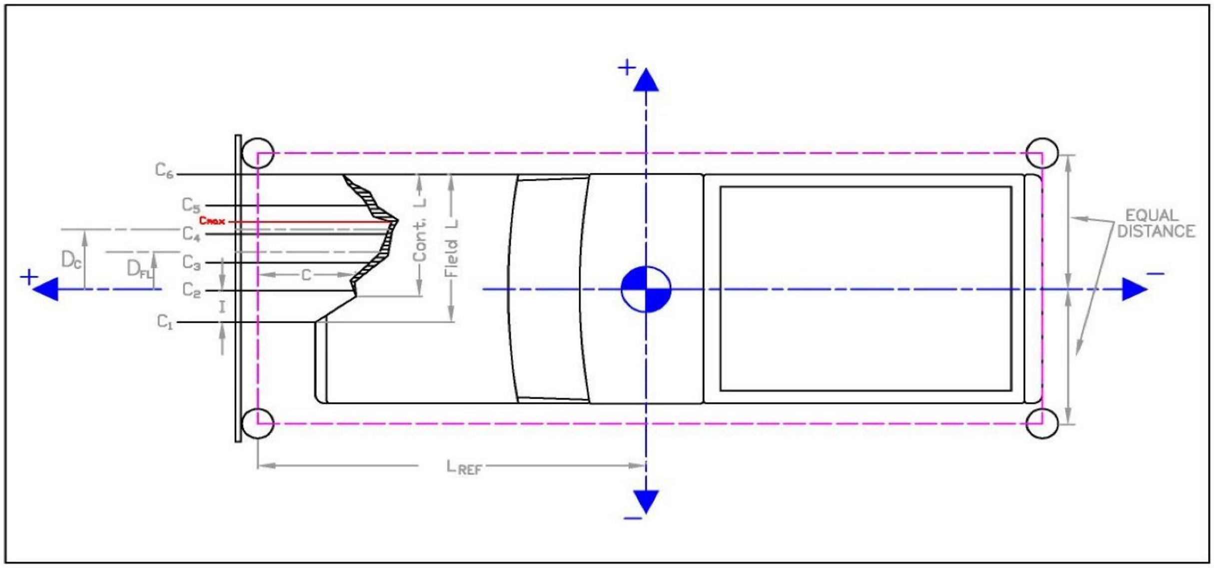
[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

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

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

Figure C-4. Occupant Compartment Deformation Data – Set 2, Test No. IBBR-1

Date:	9/13/2018	Test Name:	IBBR-1	VIN:	1D7RB1GPXBS586259
Year:	2011	Make:	Dodge	Model:	Ram 1500



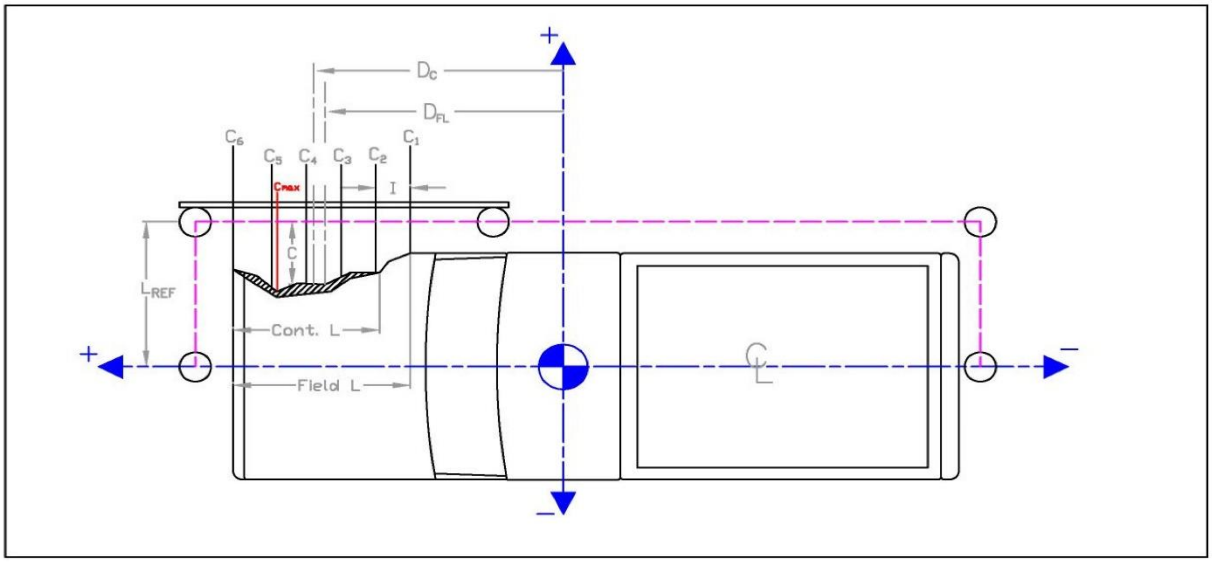
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	109	(2769)
Total Vehicle Width:	77 1/2	(1969)
Width of contact and induced crush - Field L:	32	(813)
Crush measurement spacing interval (L/5) - I:	6 3/8	(162)
Distance from center of vehicle to center of Field L - D_{FL}:	20 1/2	(521)
Width of Contact Damage:	18	(457)
Distance from center of vehicle to center of contact damage - D_C:	29	(737)

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	6 3/4	(171)	4 1/2	(114)	4	(102)	3 1/3	(84)	- 4/7	-(14)
C_2	7	(178)	10 7/8	(276)	4 1/2	(114)			- 4/5	-(21)
C_3	9 1/4	(235)	17 1/4	(438)	5 1/8	(130)			4/5	(21)
C_4	24 1/2	(622)	23 5/8	(600)	6 1/4	(159)			15	(379)
C_5	n/a	#VALUE!	30	(762)	9 1/4	(235)			#VALUE!	#VALUE!
C_6	n/a	#VALUE!	36 3/8	(924)	15 7/8	(403)			#VALUE!	#VALUE!
C_{MAX}	24 1/2	(622)	23 5/8	(600)	6 1/4	(159)			15	(379)

Figure C-5. Exterior Vehicle Crush (NASS) - Front, Test No. IBBR-1

Date:	9/13/2018	Test Name:	IBBR-1	VIN:	1D7RB1GPXBS586259
Year:	2011	Make:	Dodge	Model:	Ram 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	45	(1143)
Total Vehicle Length:	229 1/4	(5823)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-5 4/7	-(141)
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}:	-10 1/5	-(259)
Width of Contact Damage:	229 1/4	(5823)
Distance from vehicle c.g. to center of contact damage - D_C:	-10 1/5	-(259)

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	9 1/4	(235)	-124 7/8	-(3172)	33 1/2	(851)	1	(25)	-25 1/4	-(641)
C_2	n/a	#VALUE!	-79	-(2007)	5 1/2	(140)			#VALUE!	#VALUE!
C_3	5 1/8	(130)	-33 1/8	-(841)	5 7/8	(149)			-1 3/4	-(44)
C_4	3 7/8	(98)	12 3/4	(324)	5	(127)			-2 1/8	-(54)
C_5	n/a	#VALUE!	58 5/8	(1489)	5 3/8	(137)			#VALUE!	#VALUE!
C_6	n/a	#VALUE!	104 1/2	(2654)	14	(356)			#VALUE!	#VALUE!
C_{MAX}	20	(508)	81	(2057)	5 3/8	(137)			13 5/8	(346)

Figure C-6. Exterior Vehicle Crush (NASS) - Side, Test No. IBBR-1

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

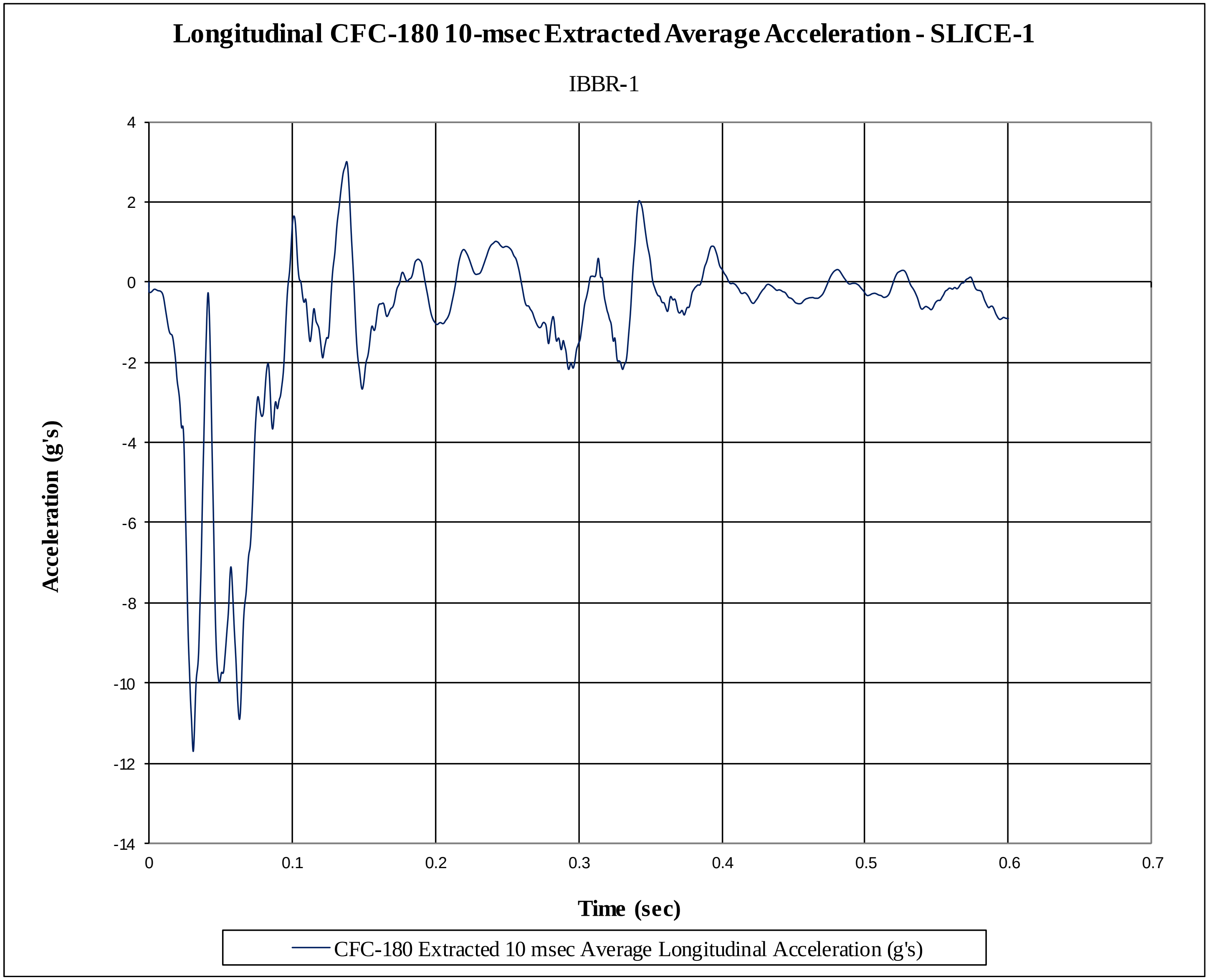


Figure D-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. IBBR-1

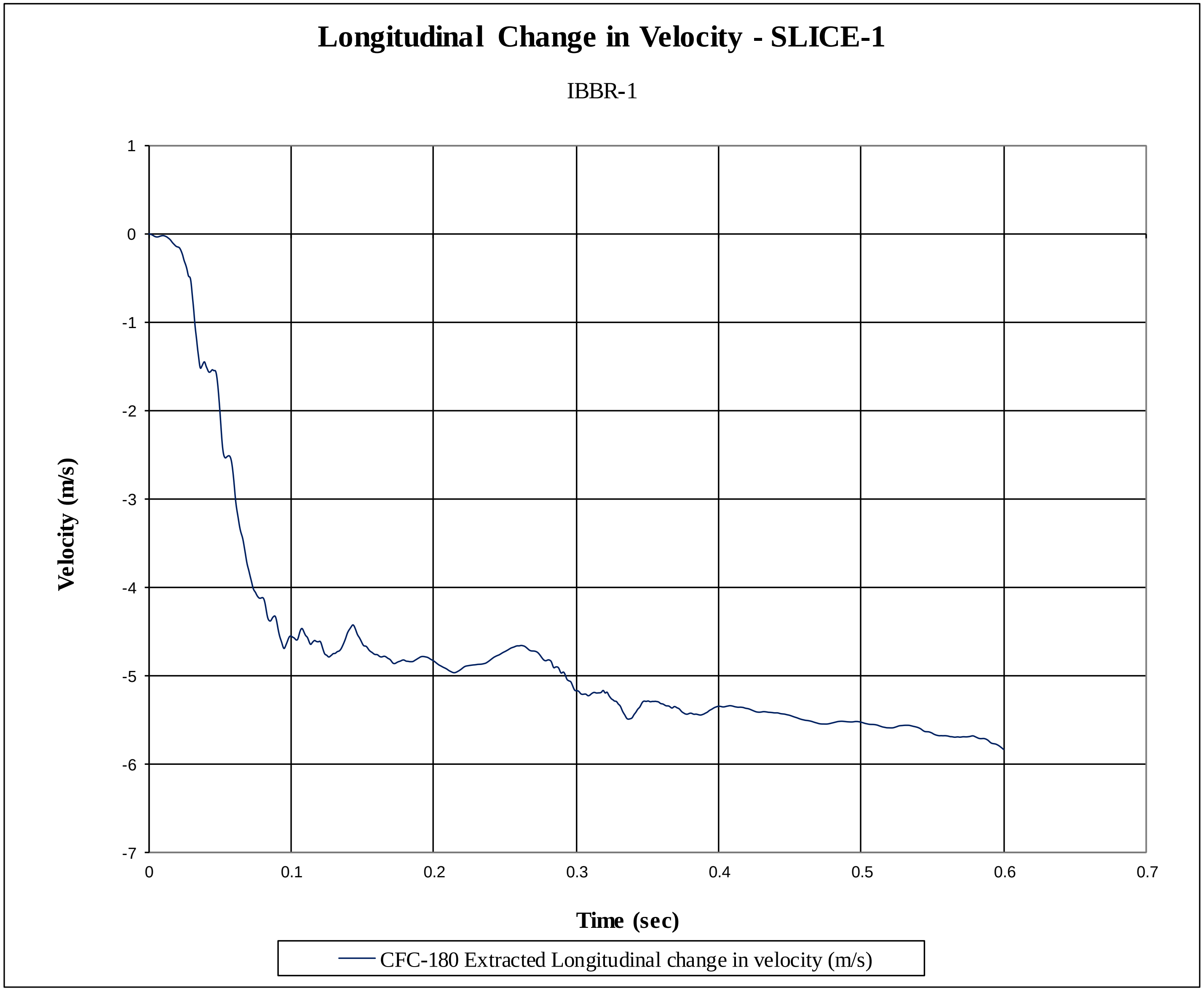


Figure D-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. IBBR-1

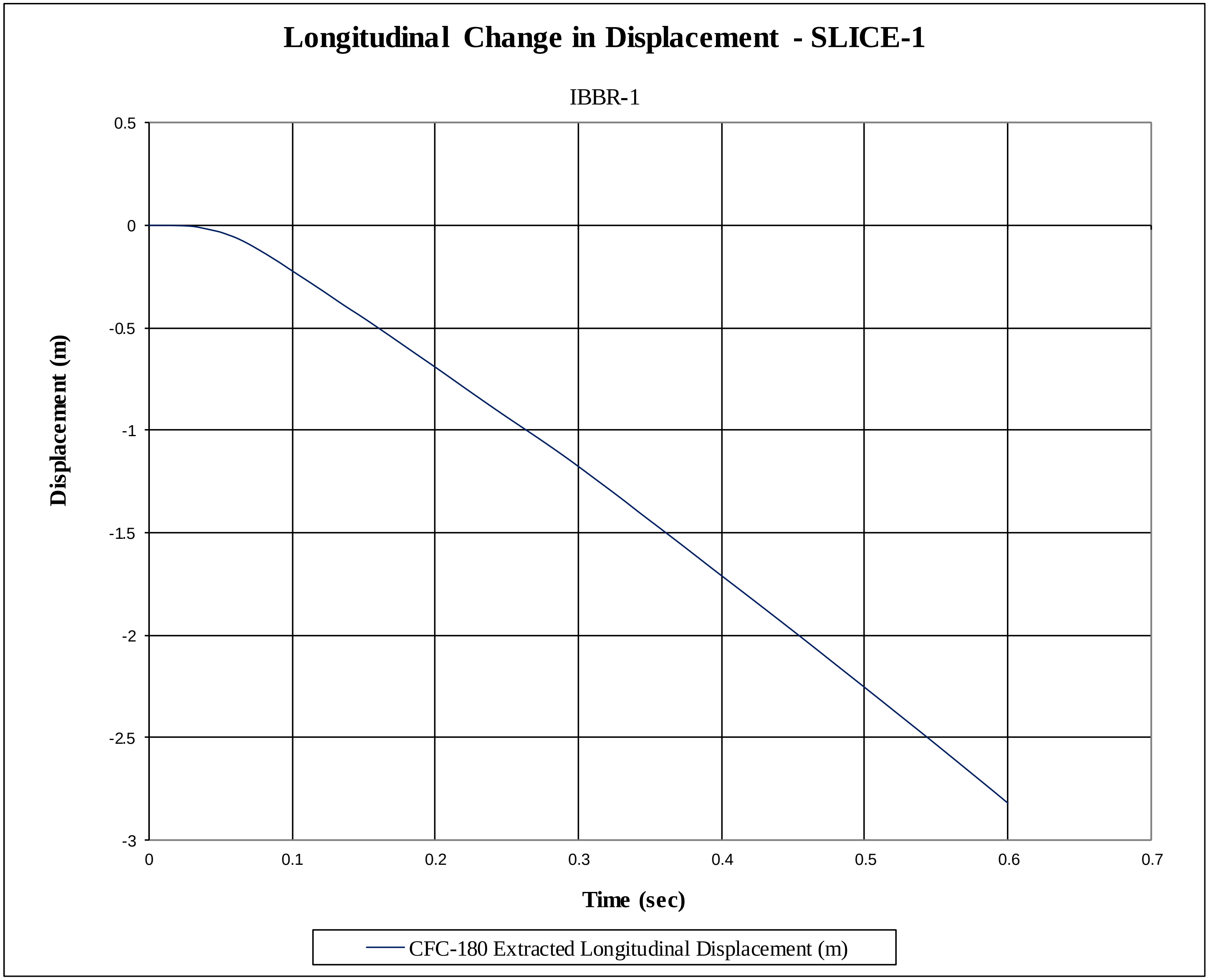


Figure D-3. Longitudinal Occupant Displacement (SLICE-1), Test No. IBBR-1

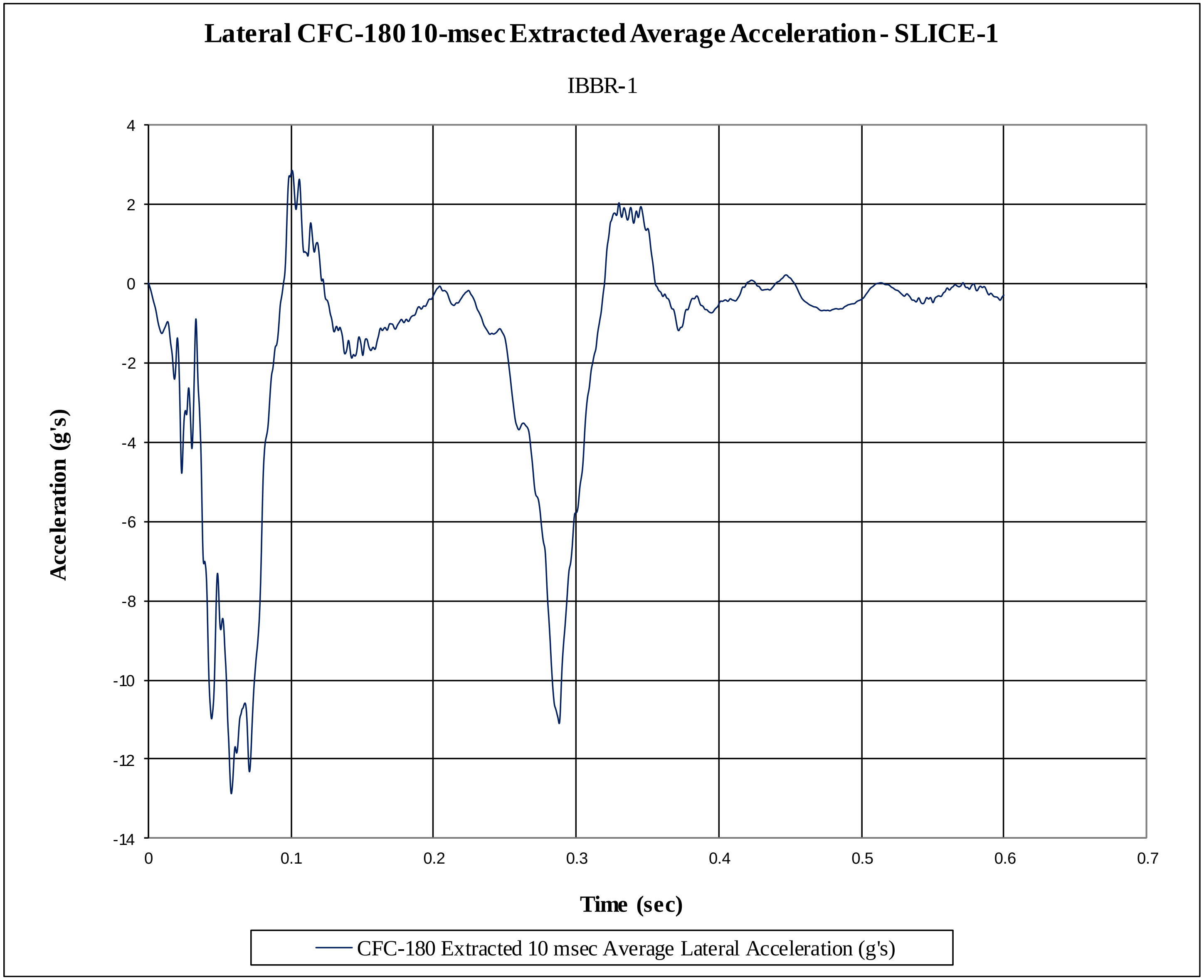


Figure D-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. IBBR-1

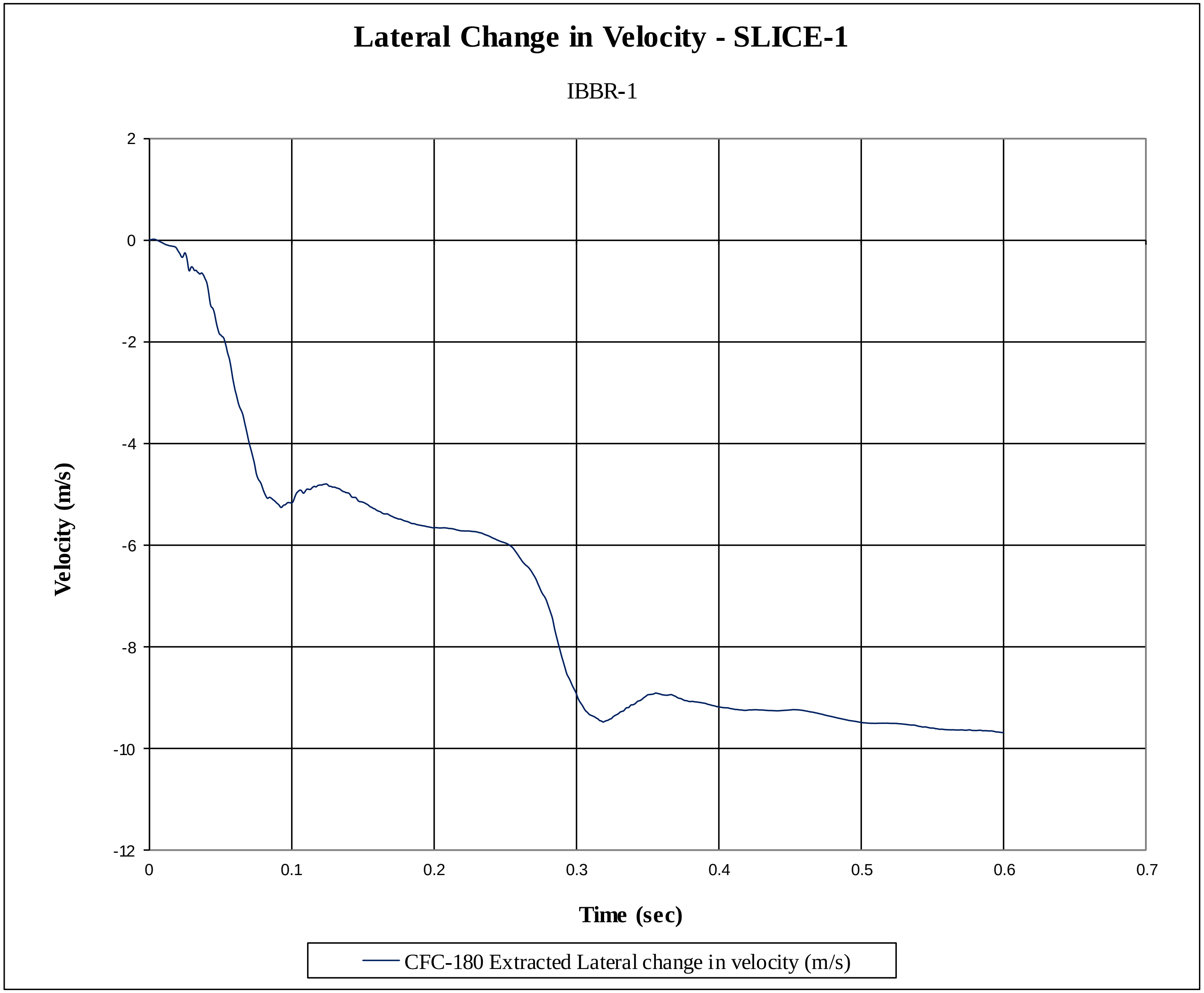


Figure D-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. IBBR-1

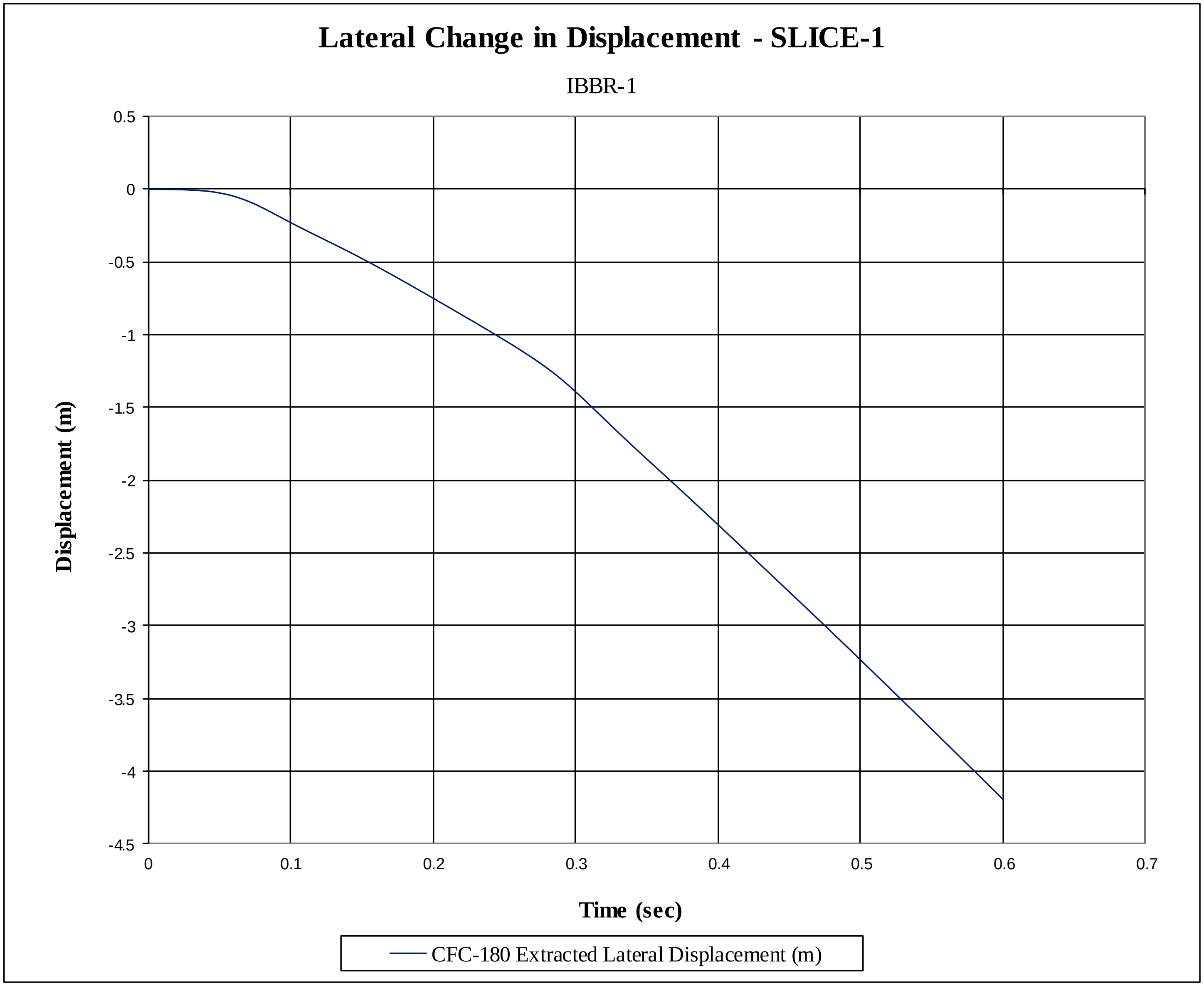


Figure D-6. Lateral Occupant Displacement (SLICE-1), Test No. IBBR-1

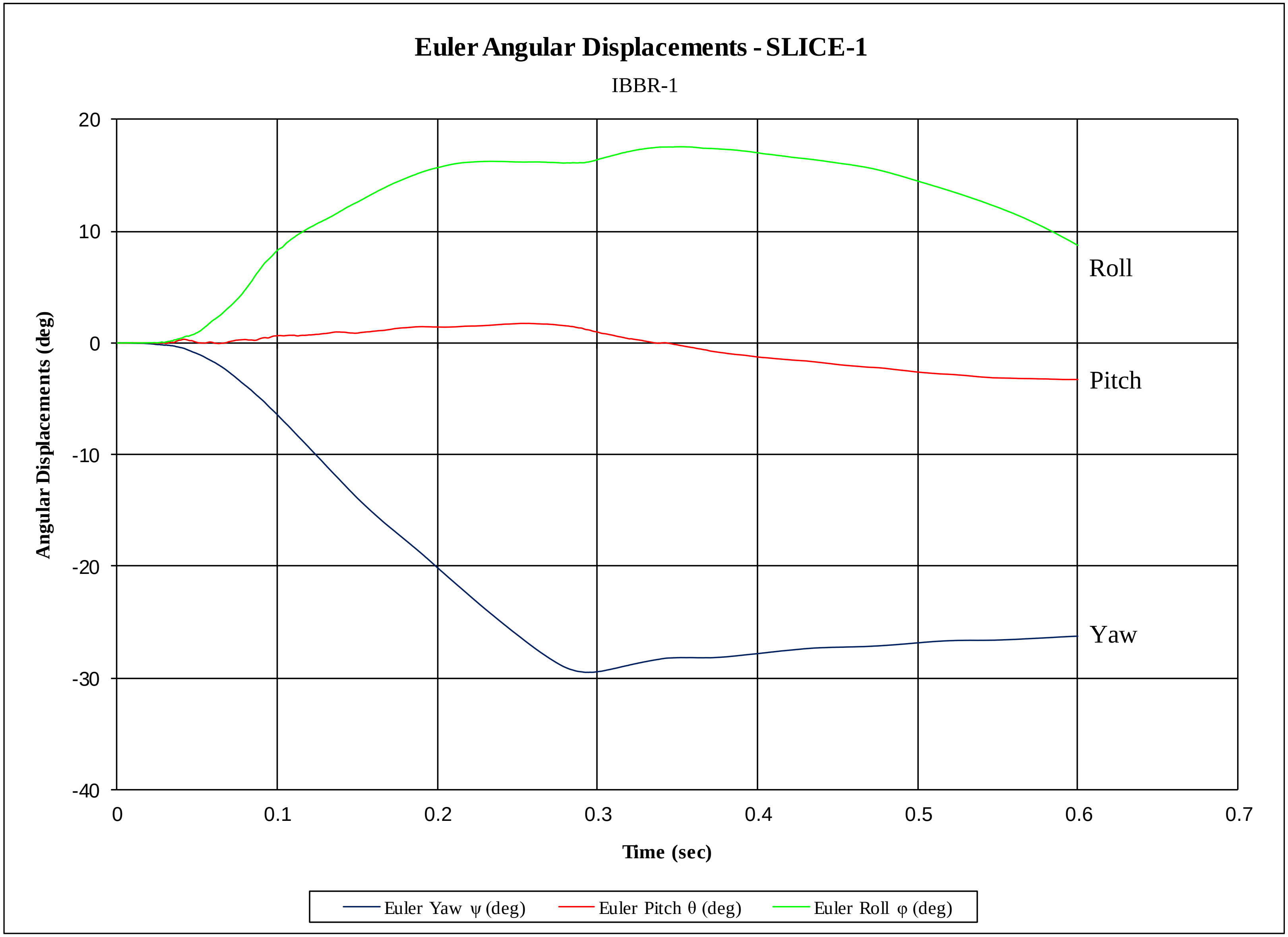


Figure D-7. Vehicle Angular Displacements (SLICE-1), Test No. IBBR-1

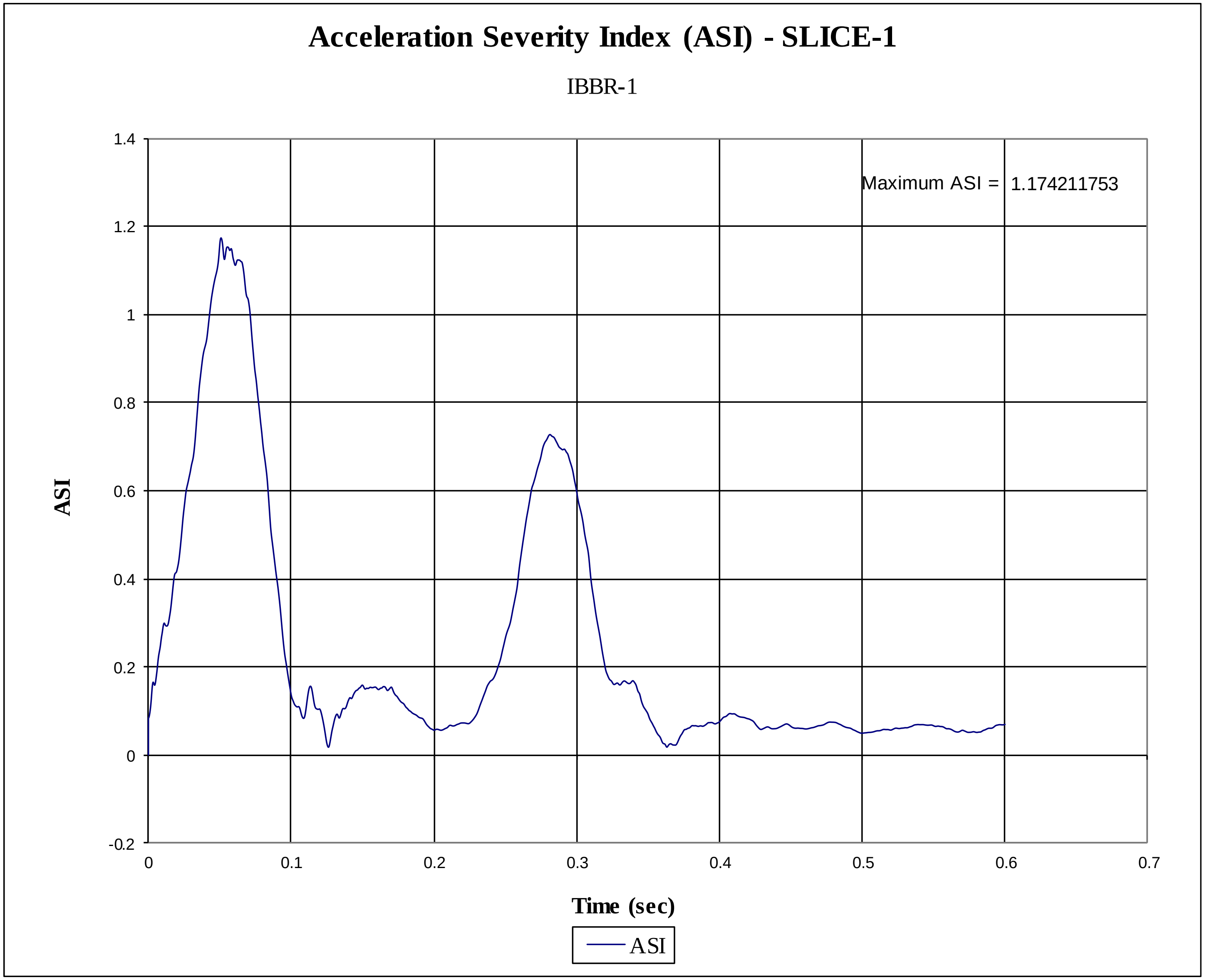


Figure D-8. Acceleration Severity Index (SLICE-1), Test No. IBBR-1

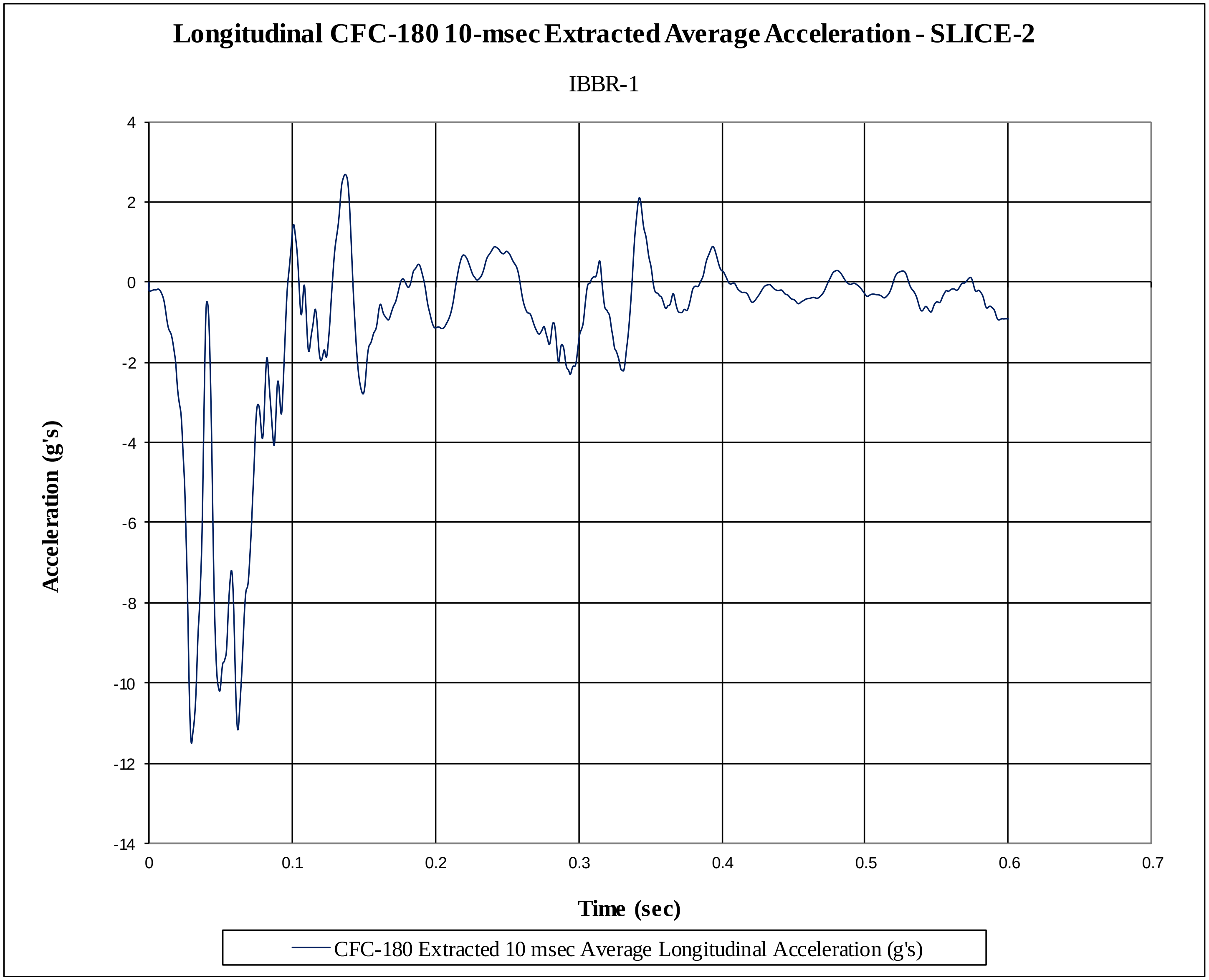


Figure D-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. IBBR-1

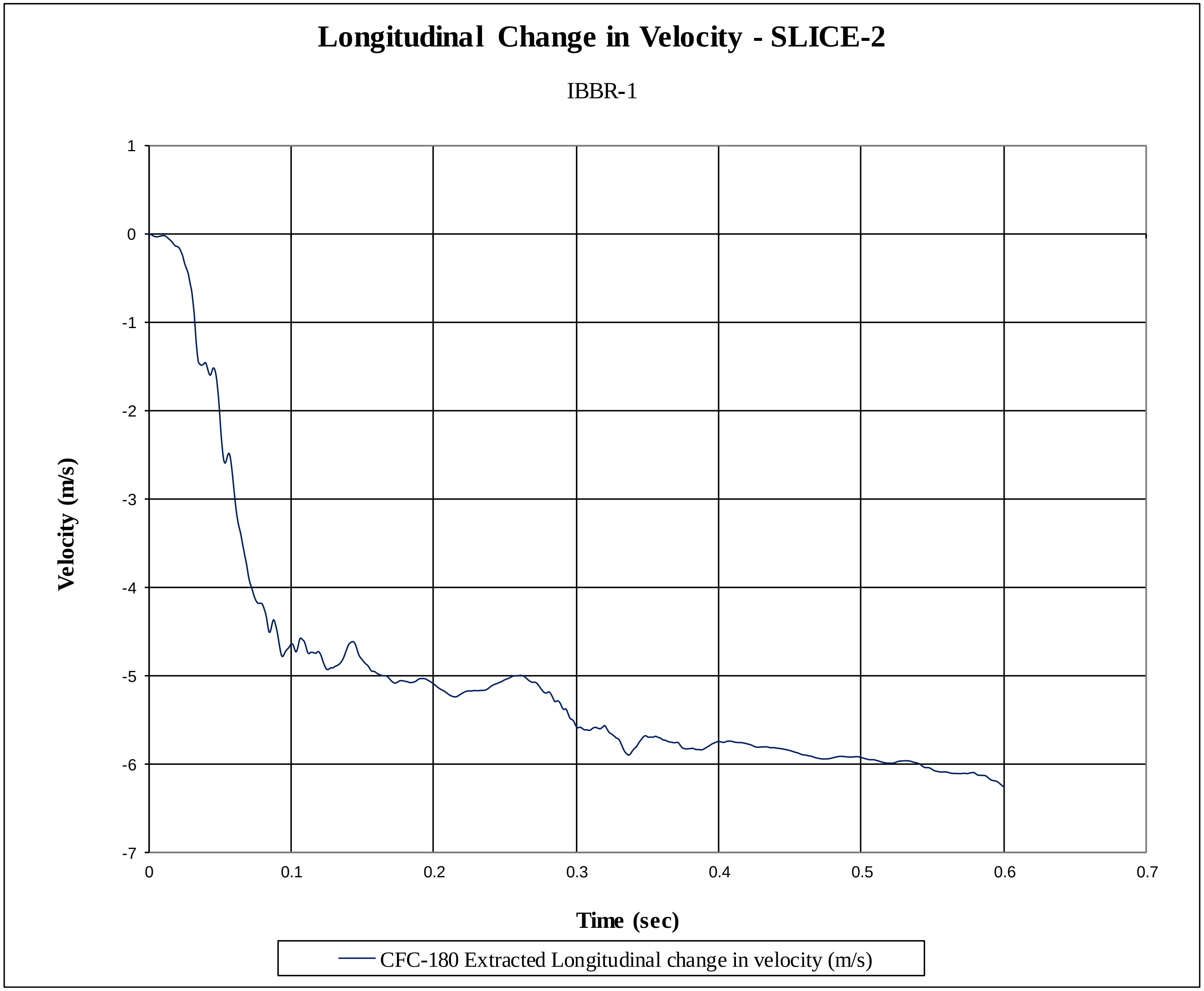


Figure D-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. IBBR-1

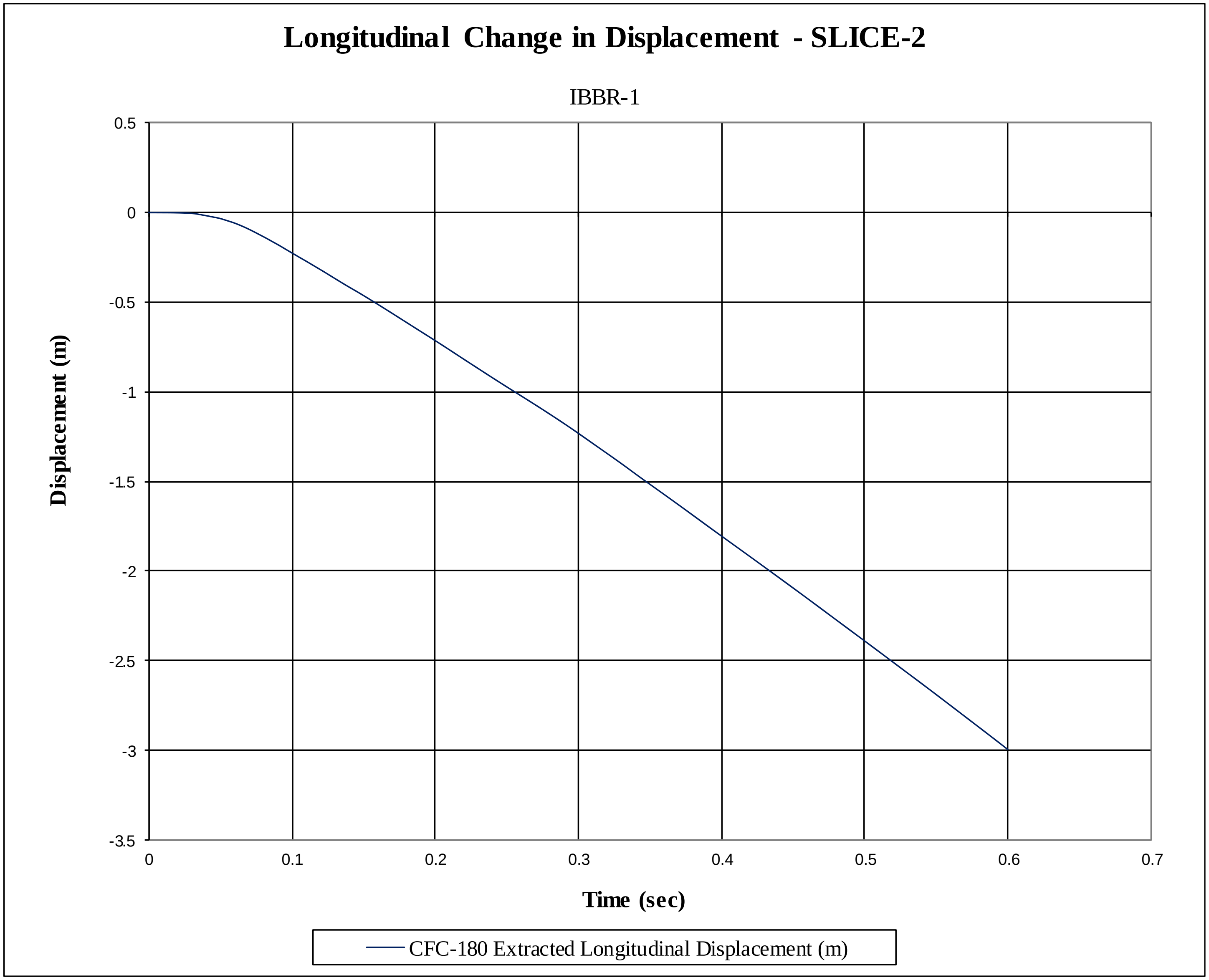


Figure D-11. Longitudinal Occupant Displacement (SLICE-2), Test No. IBBR-1

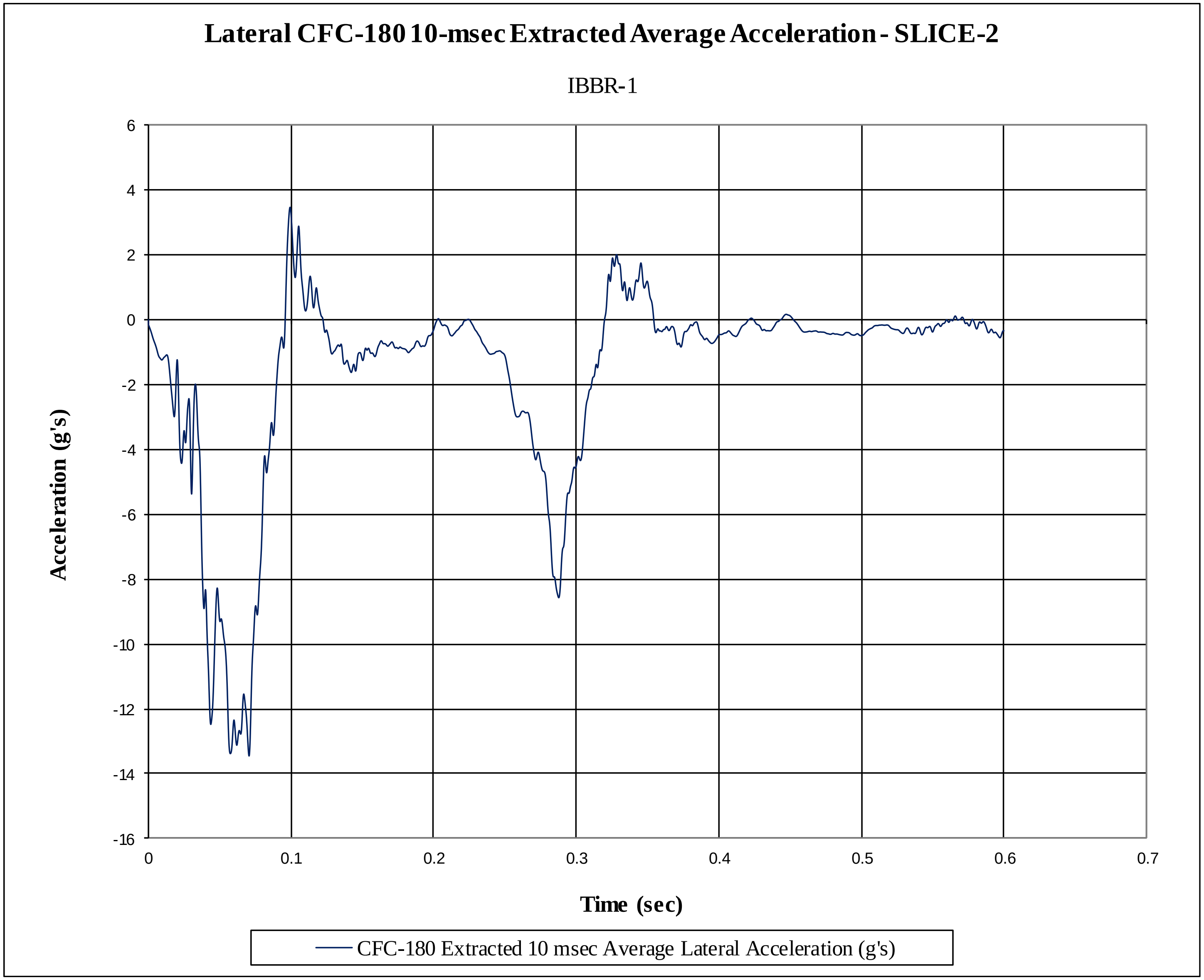


Figure D-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. IBBR-1

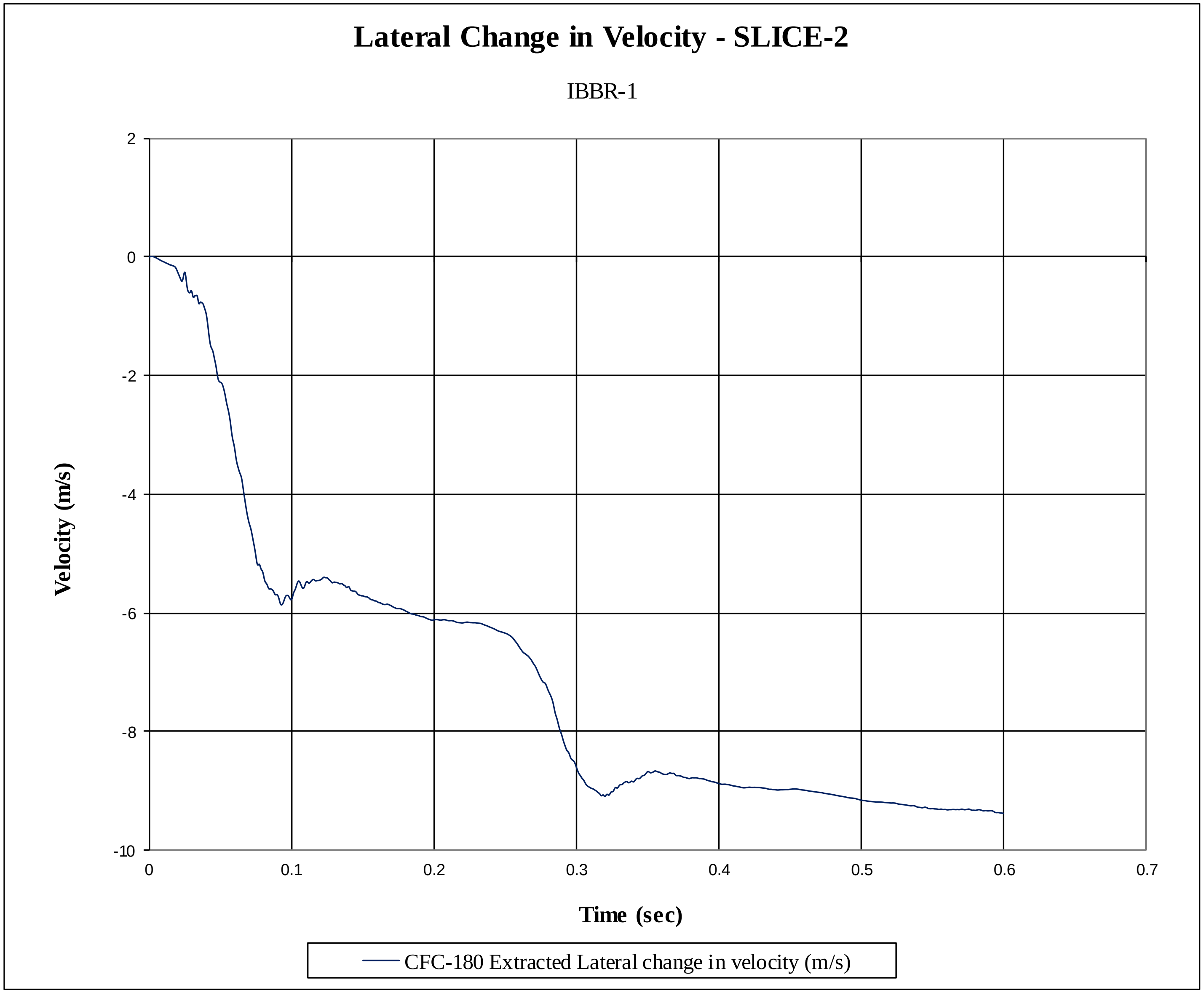


Figure D-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. IBBR-1

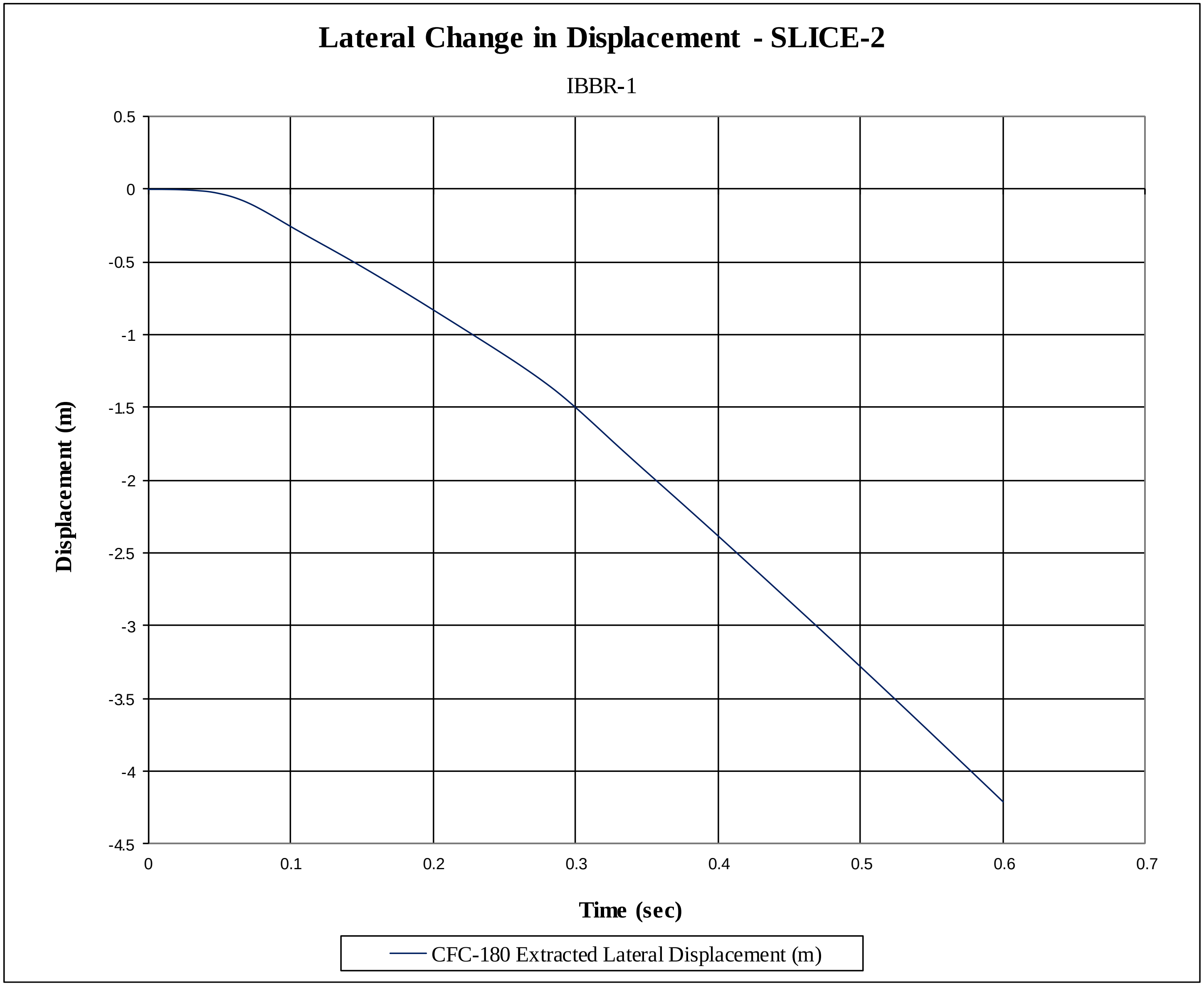


Figure D-14. Lateral Occupant Displacement (SLICE-2), Test No. IBBR-1

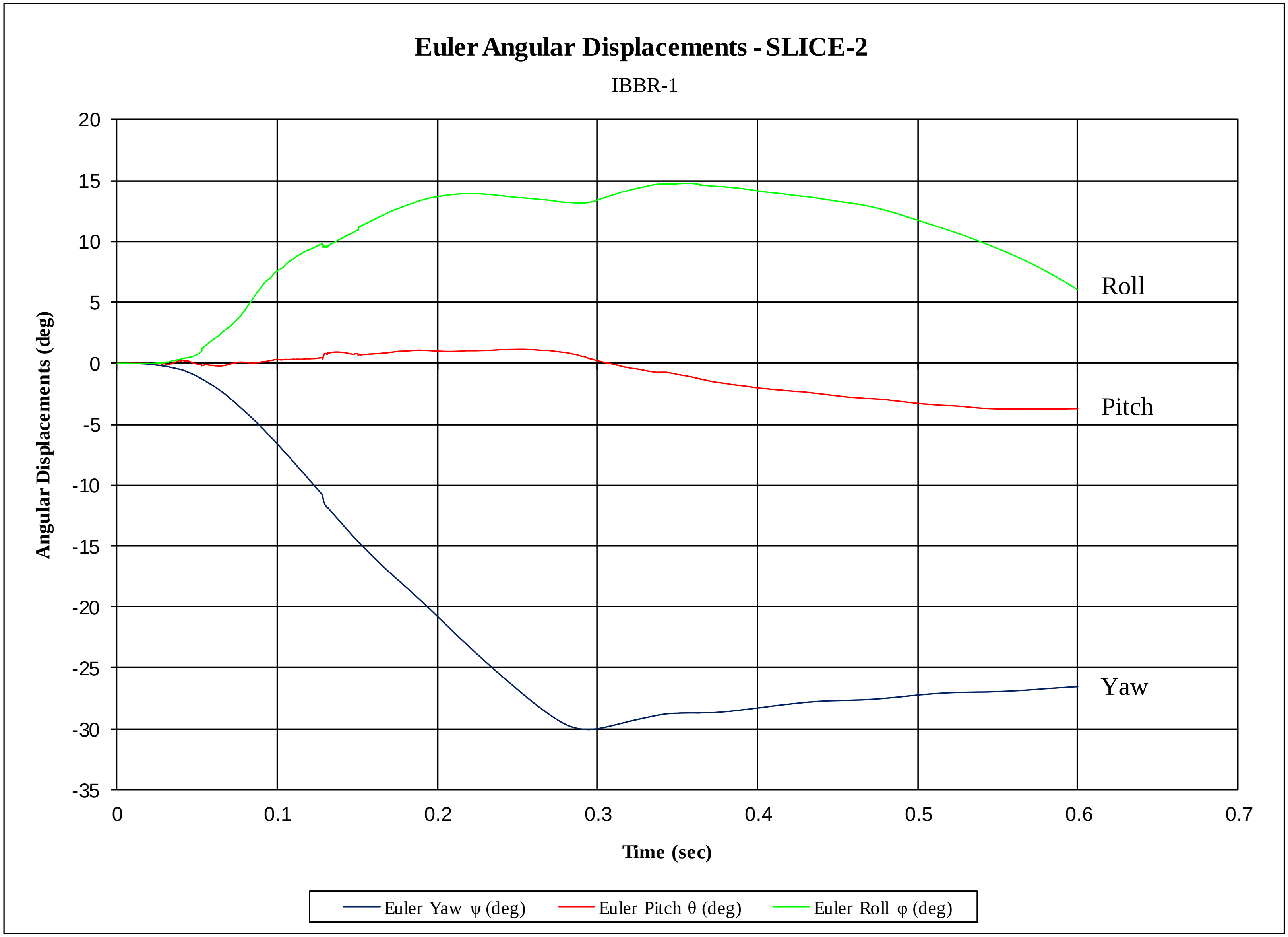


Figure D-15. Vehicle Angular Displacements (SLICE-2), Test No. IBBR-1

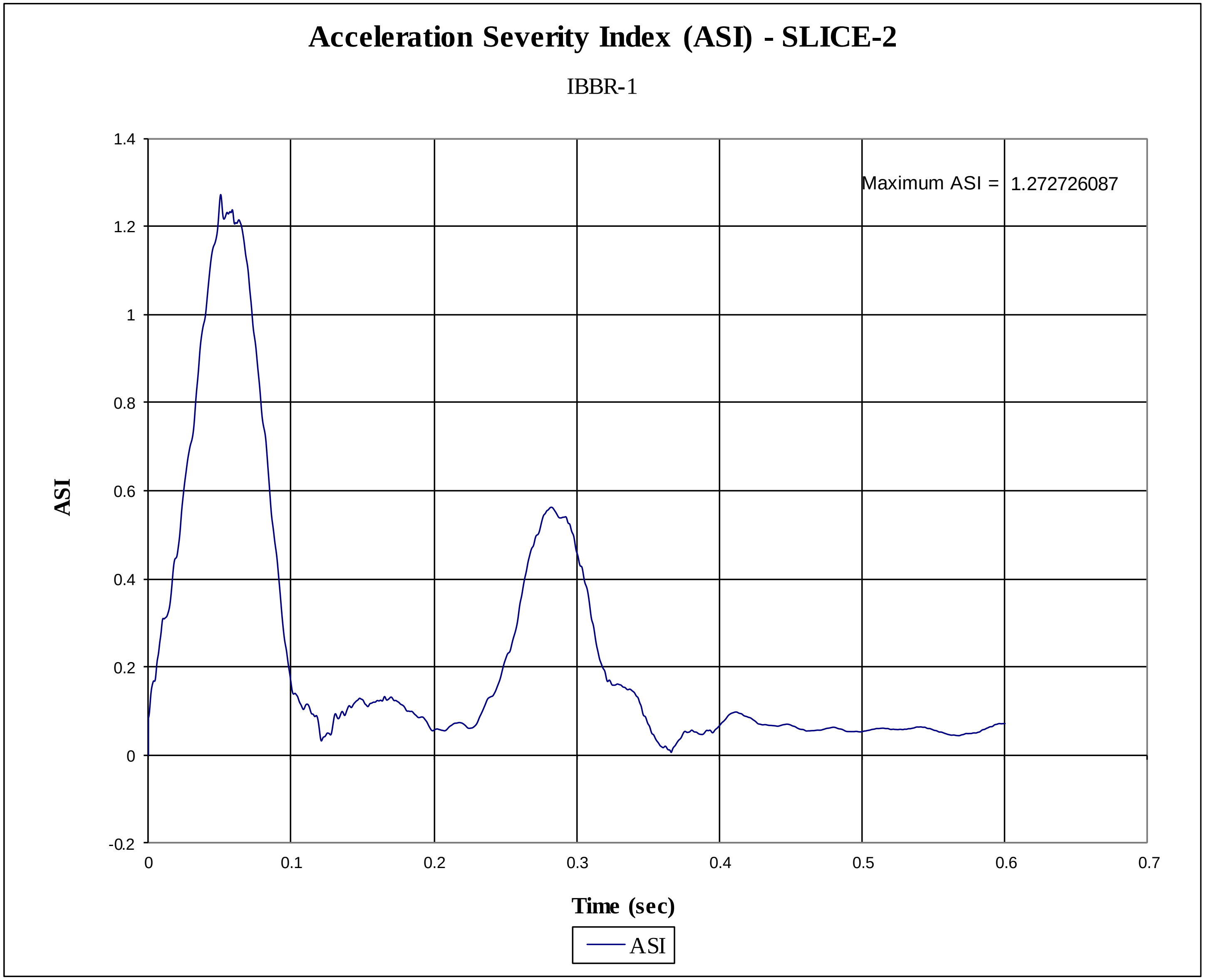


Figure D-16. Acceleration Severity Index (SLICE-2), Test No. IBBR-1

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