Hawaii Department of Transportation
Research Project Number 67167

CRASH TESTING AND EVALUATION OF THE HDOT 42-IN. TALL, AESTHETIC CONCRETE BRIDGE RAIL: MASH TEST DESIGNATION NOS. 3-10 AND 3-11

Submitted by

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<tr><td colspan="3">16. Abstract
This report documents two full-scale crash tests conducted in support of a study to investigate the safety performance of the Hawaii Department of Transportation's (HDOT's) 42-in. Tall, Aesthetic Concrete Bridge Rail system. The barrier system was 88 ft long and consisted of two 11-ft long concrete parapets and three 22-ft long concrete parapets anchored to the concrete tarmac. Expansion joints between each segment consisted of 24-in. long, No. 8 ASTM A615 Grade 60 steel bars cast into the concrete and inserted into a PVC pipe on the upstream side of the expansion joint. Test nos. H42BR-1 and H42BR-2 were conducted according to Manual for Assessing Safety Hardware 2016 (MASH 2016) criteria using Test-Level 3 (TL-3) test designation nos. 3-10 and 3-11, respectively.

In test no. H42BR-1, an 1100C small car impacted the barrier at a speed of 63.2 mph and an angle of 24.9 degrees. In test no. H42BR-2, a 2270P quad cab pickup truck impacted the barrier at a speed of 62.7 mph and an angle of 25.1 degrees. In both tests, the bridge rail successfully contained and redirected the vehicle, and it did not penetrate or show potential for debris to penetrate the occupant compartment. All occupant risk measurements were below the maximum thresholds. Thus, test nos. H42BR-1 and H42BR-2 successfully met the TL-3 safety performance criteria defined in MASH 2016.</td></tr>
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DISCLAIMER STATEMENT

This report was completed with funding from the Federal Highway Administration, U.S. Department of Transportation and the Hawaii Department of Transportation. The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Hawaii Department of Transportation nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

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

INDEPENDENT APPROVING AUTHORITY

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

ACKNOWLEDGEMENTS

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1 INTRODUCTION

1.1 Background

The Hawaii Department of Transportation (HDOT) uses several concrete bridge rails with aesthetic treatments. However, the crashworthiness of these bridge railings under current impact safety standards has not been demonstrated. This report documents two full-scale crash tests conducted in support of a study to evaluate the safety performance of HDOT's 42-in. Tall, Aesthetic Concrete Bridge Rail with aesthetic recessed panels added to its traffic-side and back-side surfaces. The recessed panels for the system were 6 in. wide, 14 in. tall, and ½ in. deep with an inclination angle of 60 degrees. The bridge rail is typically anchored to a concrete bridge deck with a 2-in. thick concrete finishing surface applied on the traffic-side face of the barrier. Expansion joints with smooth dowels were located at 22-ft intervals in the rail. End sections measuring 3 ft – 6 in. long are normally placed at the ends of the bridge rail adjacent to an end buttress structure. However, only the length-of-need (LON) of the barrier was evaluated in this study. The original standard plans of the HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail are shown in Figures 1 through 3.

In 2006, researchers at the Texas A&M Transportation Institute (TTI) published National Cooperative Highway Research Program (NCHRP) Report No. 554 [1], which developed design guidelines for aesthetic treatments for safety shape concrete roadway barriers using a series of Finite Element Modeling (FEM) simulations in conjunction with physical crash testing. The computer simulation effort examined the effect of asperity width and depth as well as the angle of inclination of asperity surface. A parametric FEM analyses was performed for asperity angles of 30, 45, and 90 degrees, and the simulation outcomes were categorized as acceptable, marginal/unknown, and unacceptable. NCHRP Report No. 554 provided final design guidelines for safety shape barriers based on simulation and crash testing results, as shown in Figure 4.

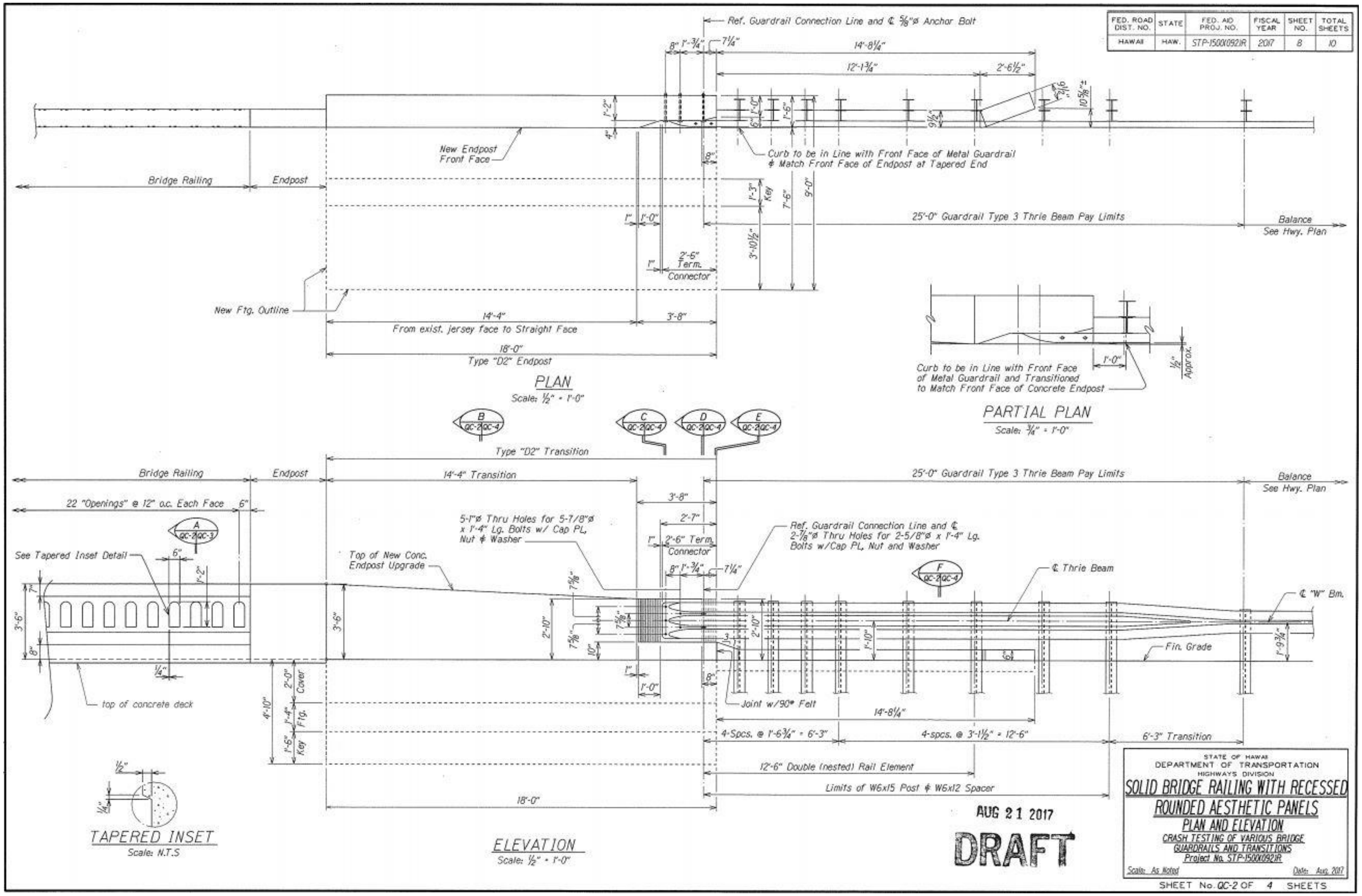


Figure 1. HDOT Standard Detail for the 42-in. Tall, Aesthetic Concrete Bridge Rail

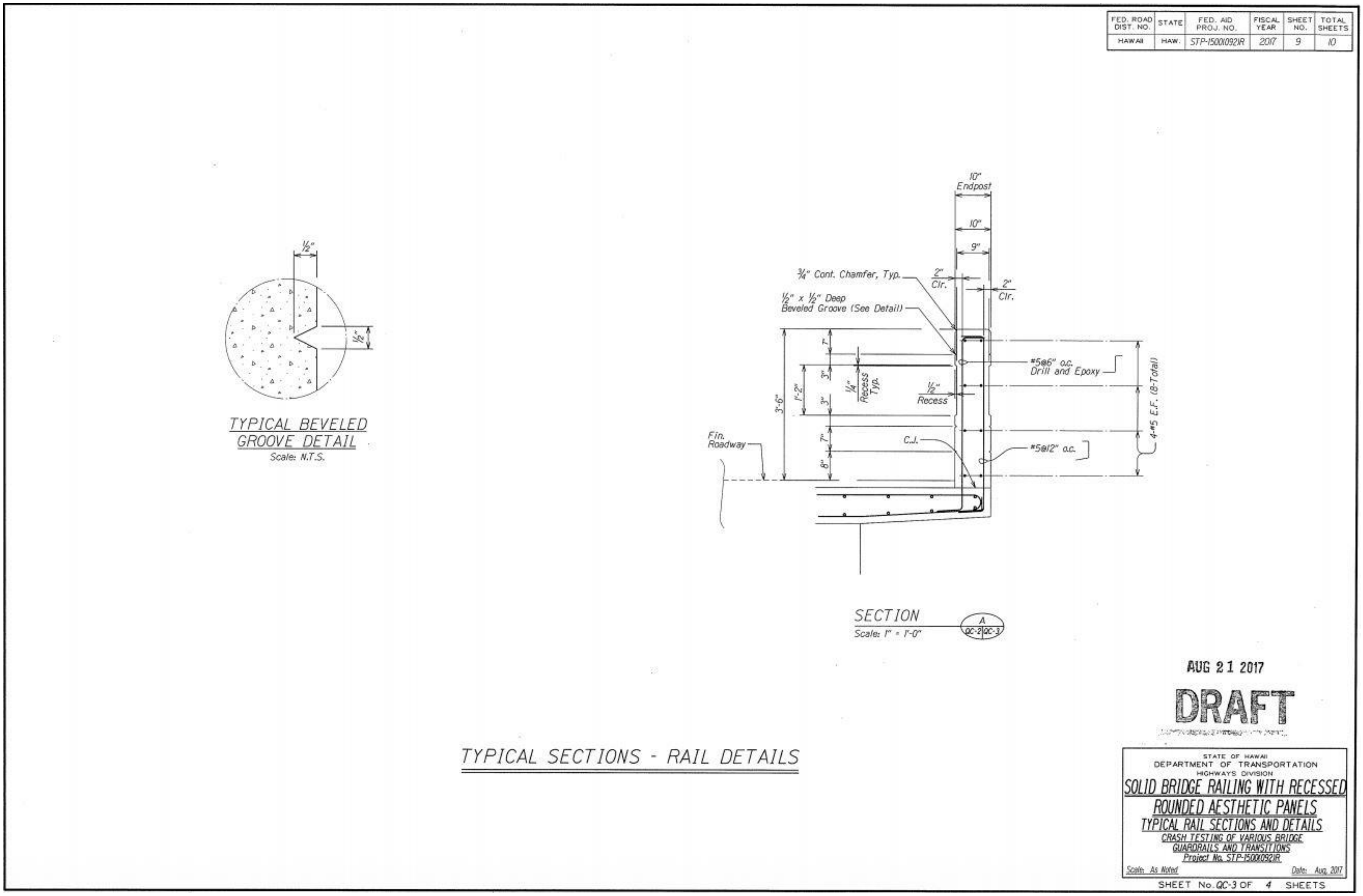


Figure 2. HDOT Standard Detail for the 42-in. Tall, Aesthetic Concrete Bridge Rail

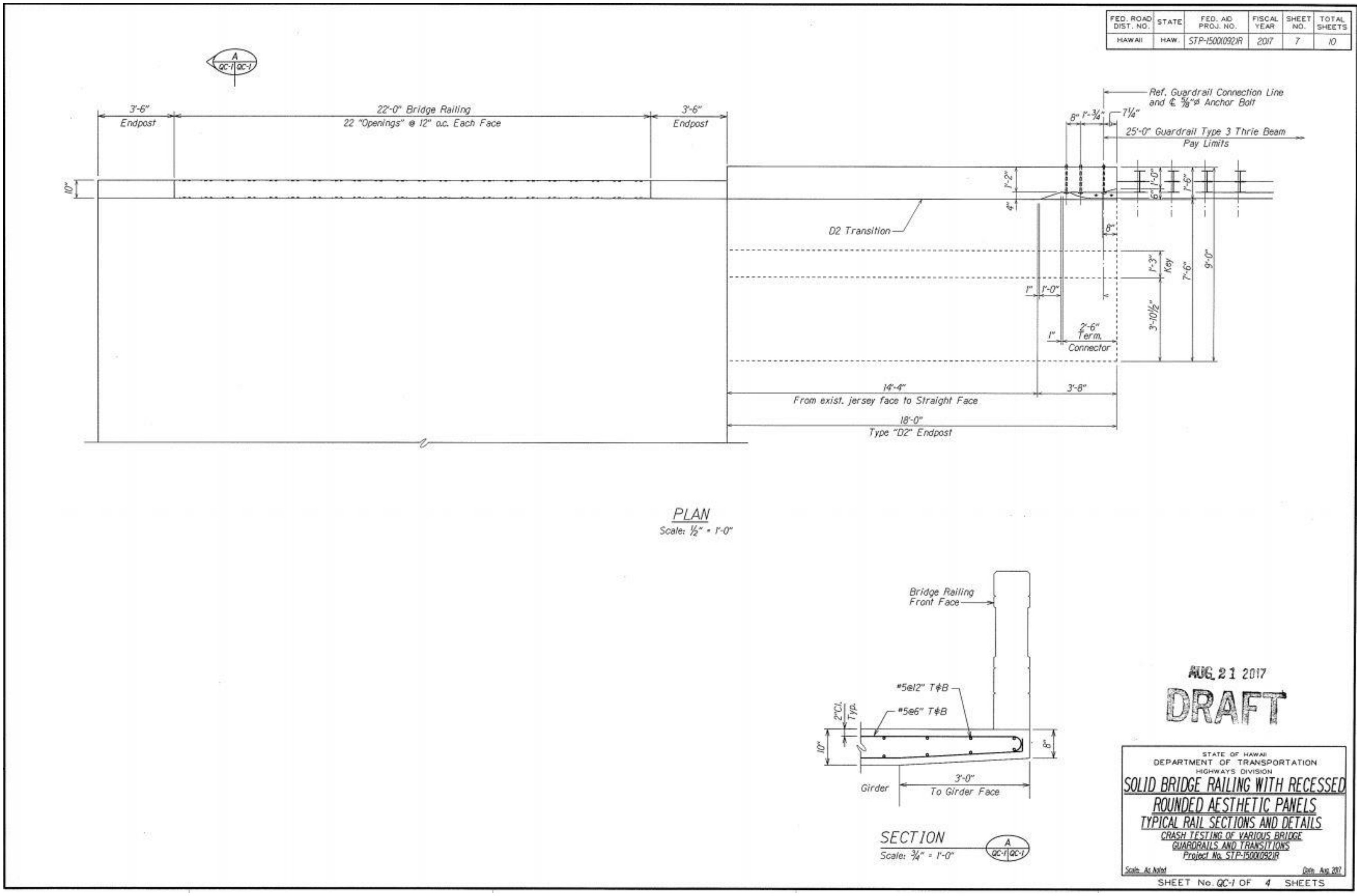


Figure 3. HDOT Standard Detail for the 42-in. Tall, Aesthetic Concrete Bridge Rail

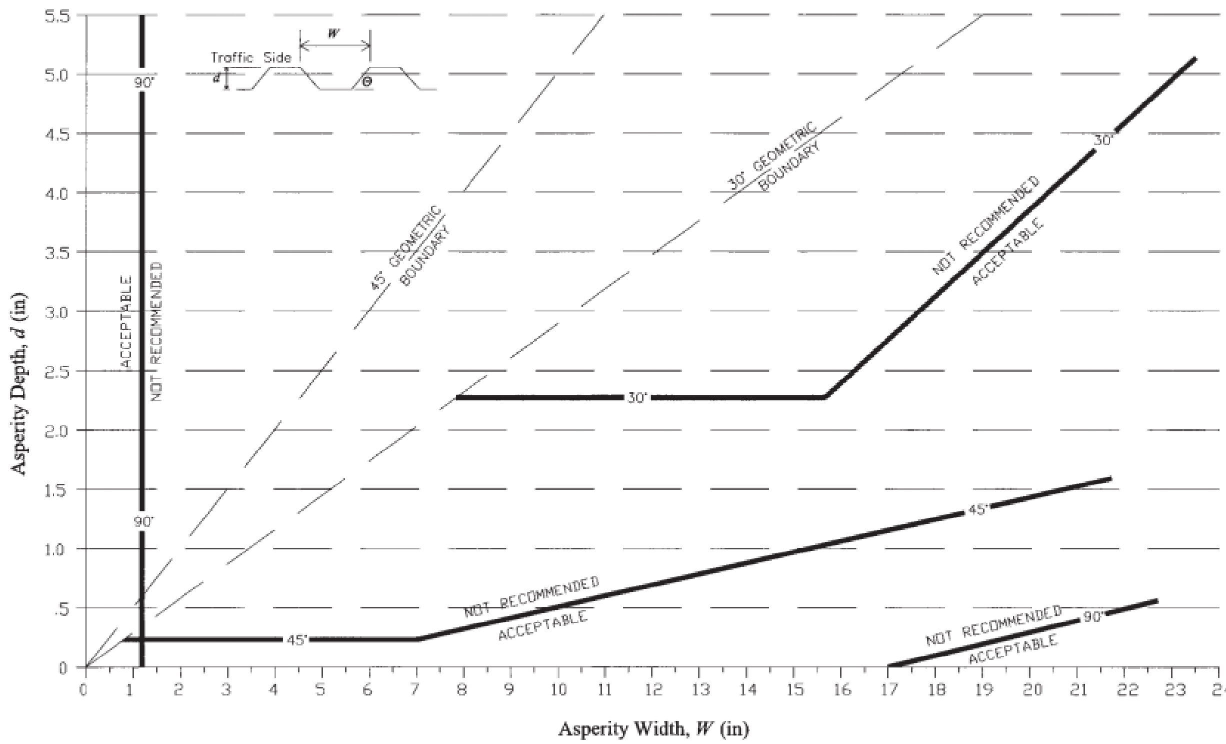


Figure 4. Final Design Guidelines for Aesthetic Surface Treatments of Safety Shape Concrete Barriers

NCHRP Report No. 554 also provided guidelines for single-slope and vertical-face barriers that were developed by the California Department of Transportation (Caltrans) [2] in 2002 and approved by the Federal Highway Administration (FHWA) in acceptance letter B-110 [3]. Caltrans conducted crash testing on single-slope barriers with various architectural treatments in order to develop guidelines for evaluating crashworthiness of barriers with wide-ranging patterns and textures. Six recommendations for single-slope or vertical-face barriers were developed after full-scale crash testing in accordance with NCHRP Report No. 350, Test Level 3 (TL-3) [4] criteria. As reported in NCHRP Report No. 554, the following types of surface treatment are permitted:

1. Sandblasted textures with a maximum relief of 9.5 mm ($^3/_8$ in.).

2. Images or geometric patterns cut into the face of the barrier 25 mm (1 in.) or less and having 45-degrees or flatter chamfered or beveled edges to minimize vehicular sheet metal or wheel snagging.

3. Textures or patterns of any shape and length inset into the face of the barrier up to 13 mm (½ in.) deep and 25 mm (1 in.) wide.

4. Any pattern or texture with gradual undulation that has a maximum relief of 20 mm (¾ in.) over a distance of 300 mm ($11^{13}/_{16}$ in.).

5. Gaps, slots, grooves, or joints of any depth with a maximum width of 20 mm (¾ in.) and a maximum surface differential across these features of 5 mm ($^3/_{16}$ in.).

6. Any pattern or texture with a maximum relief of 64 mm (2½ in.), if such a pattern begins 610 mm (24 in.) or more above the base of the barrier and if all leading edges are rounded or sloped to minimize any vehicle snagging potential.

After comparing the HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail to the NCHRP Report No. 554 design guidelines, the research team anticipated that existing bridge rail would likely provide acceptable safety performance under current impact safety standards for passenger vehicles. However, full-scale crash testing was needed to evaluate the bridge rail to the safety criteria in the American Association of State Highway and Transportation (AASHTO) *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) [5].

1.2 Objectives

The objective of this report was to conduct a safety performance evaluation of the LON of HDOT's 42-in. Tall, Aesthetic Concrete Bridge Rail system. The system was evaluated according to TL-3 criteria found in MASH 2016.

1.3 Scope

Two full-scale crash tests were conducted on the HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail according to MASH 2016 test designation nos. 3-10 and 3-11. The crash test results were analyzed, evaluated, and documented, and conclusions and recommendations were made pertaining to the safety performance of the system. A final report was published discussing the results and findings of the crash tests.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Aesthetic concrete bridge rails must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the FHWA for use on the National Highway System (NHS). The current safety standards consist of the guidelines and procedures published in MASH 2016. Note that there is no difference between MASH 2009 [6] and MASH 2016 for longitudinal barriers, such as bridge rails, except that additional occupant compartment deformation measurements, photographs, and documentation are required by MASH 2016. According to TL-3 of MASH 2016, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 1. An evaluation of the bridge railing system is discussed herein.

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

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

[1] Evaluation criteria explained in Table 2

It should be noted that the test matrix detailed herein represents a practical worst-case condition with respect to the MASH 2016 safety requirements and a crashworthiness evaluation of the barrier system. According to MASH 2016, the HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail should be evaluated at a location that evaluates the greatest propensity for vehicle snag and a location that maximizes structural loading of the bridge rail at a critical section. For the HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail, the critical impact point for both impact locations occurred upstream from an expansion joint in the bridge rail. The system has a transition from the recessed panel to the main face of the bridge rail $2^3/_4$ in. upstream from each expansion joint in the rail. Thus, impacting upstream from this point provided an evaluation of vehicle snag on both the recessed panel edge and the expansion joint. Additionally, the critical structural section in the rail is at the expansion joint because the bridge rail design does not reduce the transverse reinforcement near the expansion joint, and smooth dowel bars are used to transfer shear loading across the opening. As such, the critical impact points specified for test designation nos. 3-10 and 3-11 for rigid barrier testing by MASH 2016 were applied upstream from an expansion joint to evaluate vehicle snag and structural loading of the system.

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="9">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 deg.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s</td><td>40 ft/s</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

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 rail to contain and safely 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 tests documented herein were conducted and reported in accordance with the procedures provided in MASH 2016.

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

3 DESIGN DETAILS

The test installation consisted of a reinforced concrete bridge rail anchored to the concrete tarmac at MwRSF's Outdoor Test Site, rather than a simulated bridge deck and overhang. Previous testing of a MASH 2016 TL-4 bridge rail on similar 8-in. thick concrete bridge deck displayed no deck damage [7], indicating the potential for deck damage or deflection that would affect the outcome of the full-scale crash test was minimal under MASH 2016 TL-3 impact conditions. The HDOT Aesthetic Concrete Bridge Rail was constructed with a 44-in. height in a 2-in. deep trench, resulting in an effective rail height of 42 in. relative to the tarmac surface to simulate the correct height of the rail relative to the bridge deck in the HDOT standard plans. A concrete fill was then applied to the trench in front of the traffic-side face of the rail to simulate the 2-in. tall finished grade used by HDOT. Design details for the installation are shown in Figures 5 through 14. Photographs of the installation are shown in Figures 15 through 17. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The reinforced concrete bridge rail had a total length of 88 ft and measured 42 in. tall and 10 in. wide, as shown in Figures 5 and 7. The barrier had a vertical front face with aesthetic recessed panels spaced 12 in. apart, measuring 6 in. wide and 14 in. tall with a 3-in. top-edge radius. Three ½-in. tall x ½-in. deep V-shaped horizontal bevel cuts were etched into each face, 8, 15, and 35 in. above the tarmac, as shown in Figure 10. The top edge of the barrier on each side was chamfered at a 45-degree angle, measuring ¾ in. wide.

The barrier system consisted of five distinct segments separated with ½-in. wide expansion joints, as shown in Figure 5. Expansion joints were spaced 22 ft apart, and the upstream expansion joint between segment nos. 1 and 2 was located 10 ft – 11¾ in. from the upstream end of the barrier system. The spacing between the expansion joints was limited to 22 ft, which was the smallest rail segment length between joints noted by HDOT. Larger rail segment lengths between expansion joints were considered less critical. Filler and sealant compounds were used to fill the gap between segments at expansion joints. The concrete mix for the bridge rail sections required a minimum 28-day compressive strength of 4,000 psi. Two concrete cylinder compression tests were conducted, with 21-day compressive strength results of 4,870 psi and 4,500 psi.

Steel reinforcement consisted of ASTM A615 Gr. 60 rebar, as shown in Figure 12. Eight No. 5 longitudinal rebars were located $2^{15}/_{16}$ in. from the outer surface of each segment, with four on each side. The longitudinal rebar were 259½ in. long for the longer barrier segments, 127¾ in. long for the shorter barrier segments, and were located 2⅛, 14⅛, 26⅛, and 38⅛ in. above the tarmac. Vertical stirrups were also provided using No. 5 rebar, which were spaced on 12-in. centers on the back-side face and on 6-in. centers on the traffic-side face. Vertical reinforcement bars were anchored to an existing concrete tarmac on both the traffic-side and backside faces to a depth of 8 in. and epoxied with Hilti HIT RE-500 V3 in order to develop the full tensile strength of the bar. All rebar had a 2-in. concrete clear cover.

The barrier was constructed to be consistent with a 2-in. deep wearing surface, as shown in Figure 7. To represent the wearing surface, the tarmac was milled to a width of 16 in. and depth of 2 in. The barrier system was constructed with a 44-in. height relative to the milled depth and 2 in. of low-strength concrete fill was added to the front side of the barrier to produce a rail height of 42 in. on the traffic-side face, while keeping the overall height of the rail consistent with construction on a bridge deck as in the HDOT standard plans. No concrete fill was added to the back side of the barrier.

At each expansion joint, shear continuity was maintained using a pin-and-receiver casting, 12-in. long x 1¼-in. diameter, Schedule 80 PVC pipe with a 1¼-in. diameter along the vertical centerline of one barrier segment. Then, four No. 8 smooth rebar pins were inserted into each PVC tube, which were subsequently cast into adjacent concrete barrier segments. The pins were spaced $10^{11}/_{16}$ in. apart, and the top pin was located 6 in. from the top surface along the midplane of the barrier.

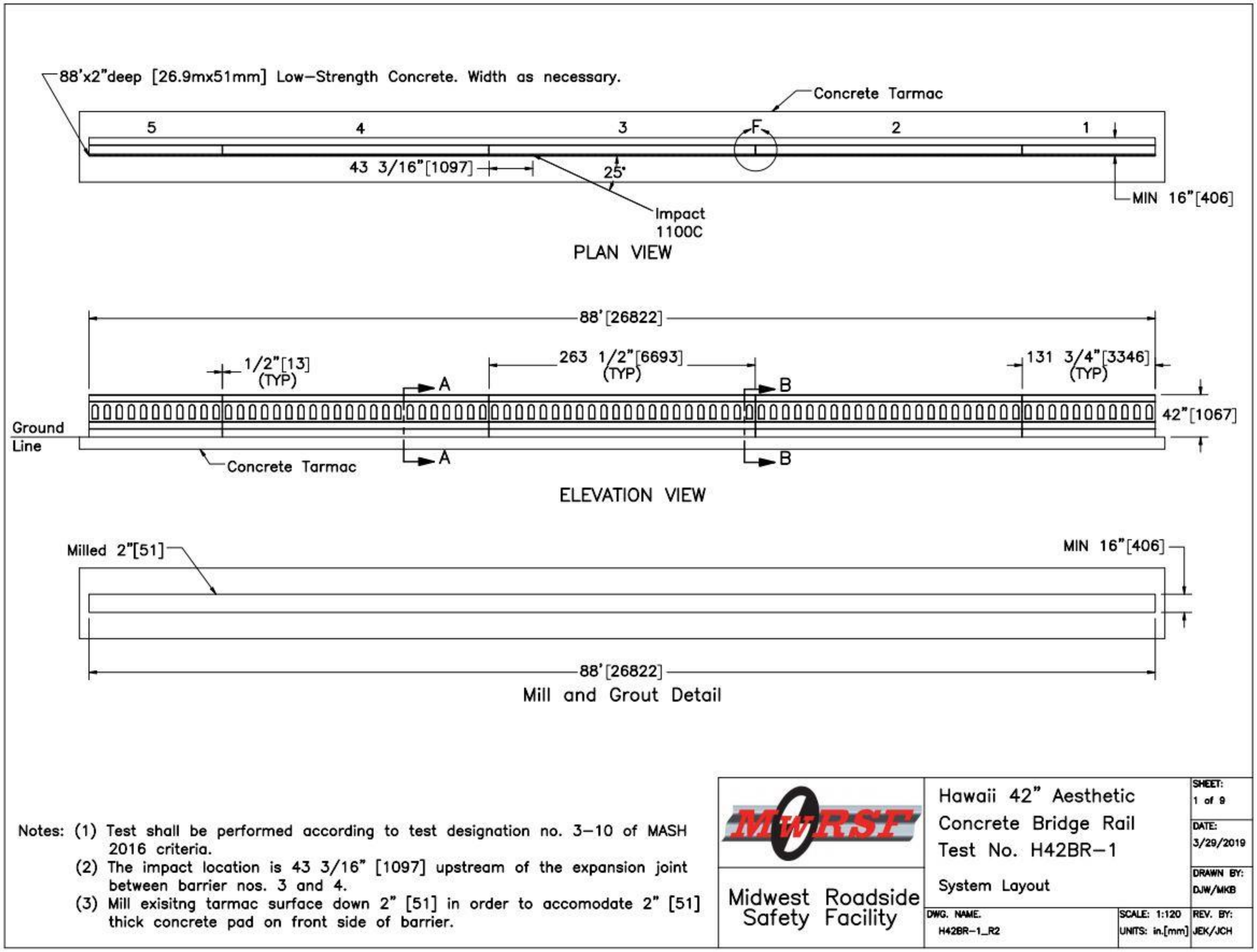


Figure 5. System Layout, Test Nos. H42BR-1

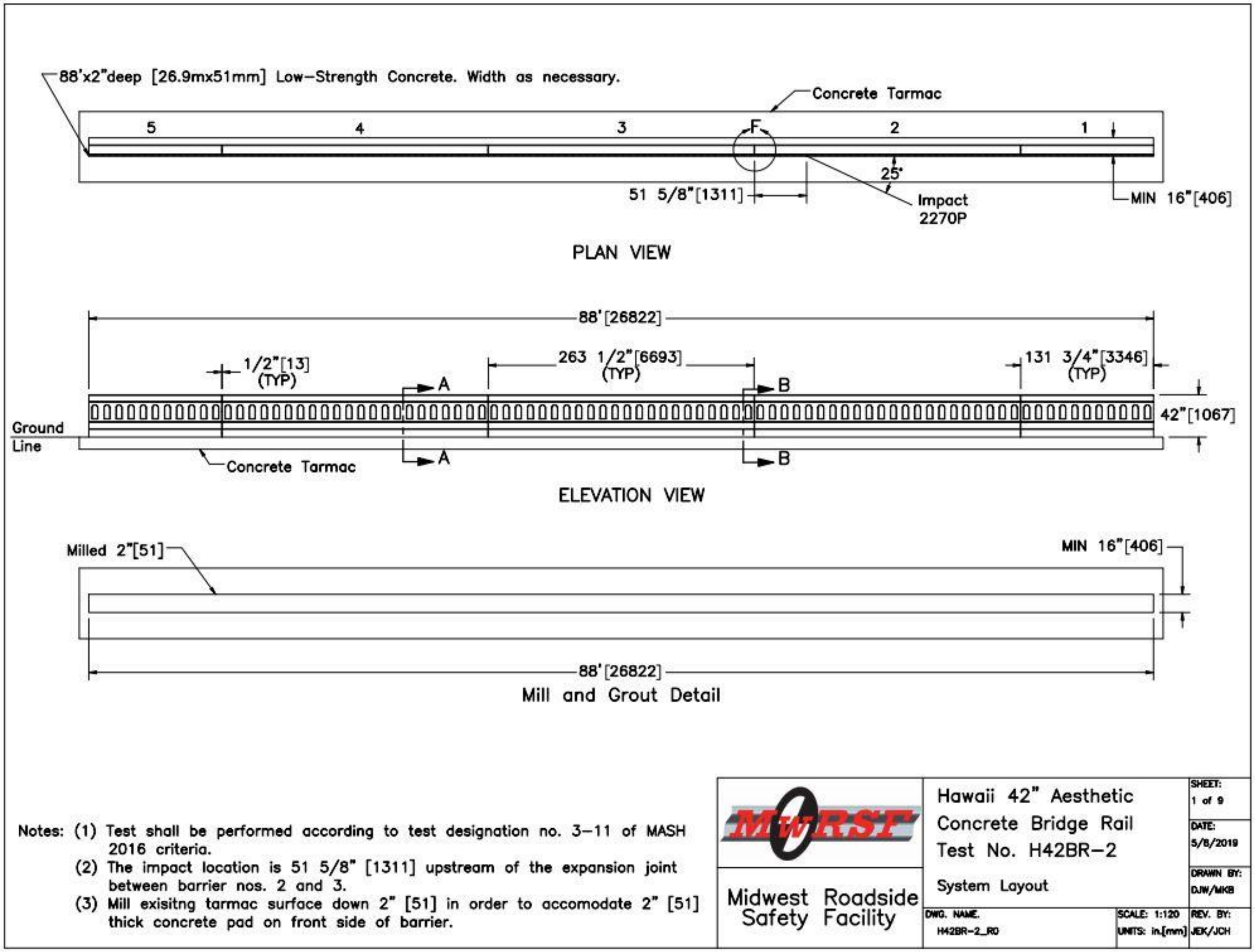


Figure 6. System Layout, Test Nos. H42BR-2

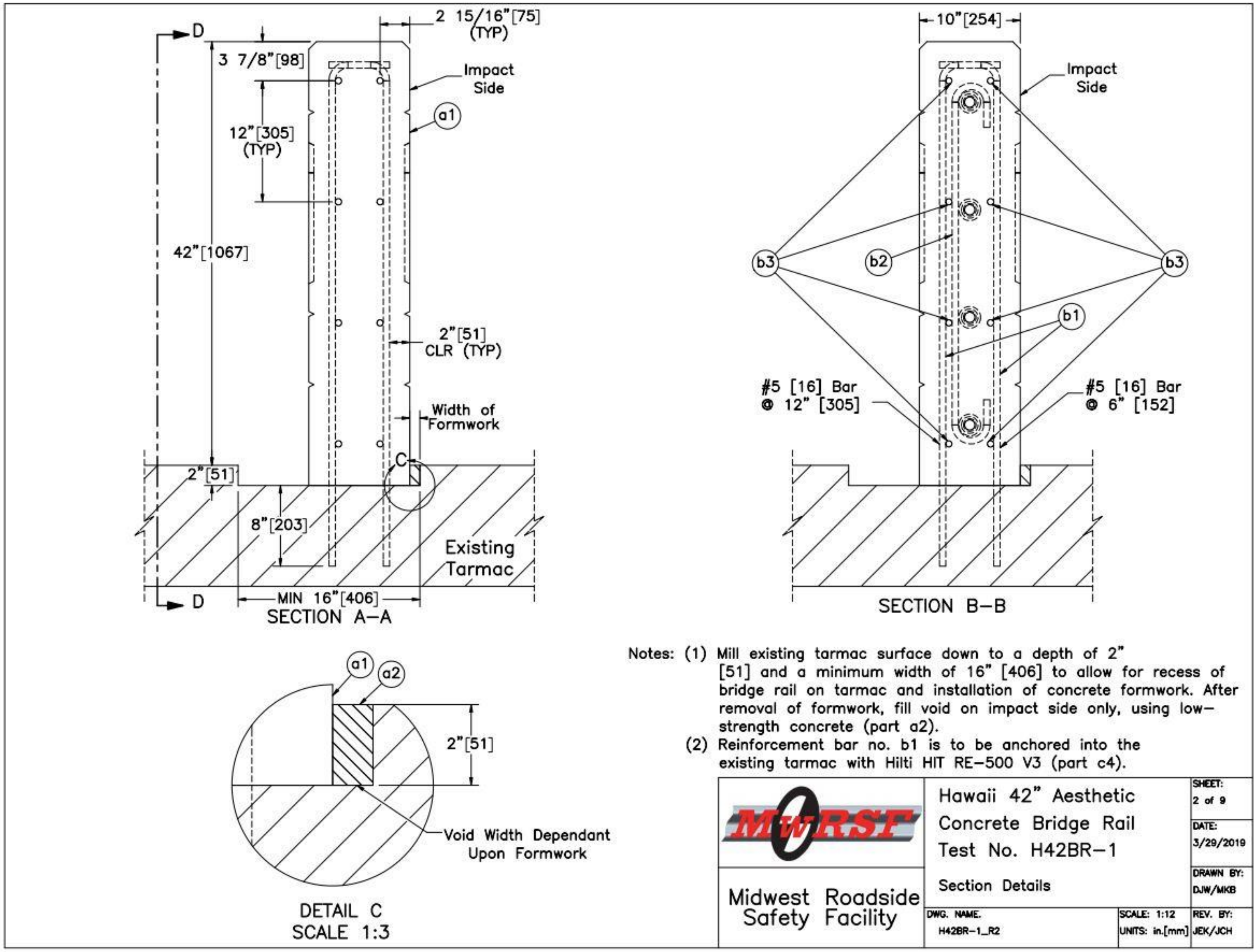


Figure 7. Section Details, Test Nos. H42BR-1 and H42BR-2

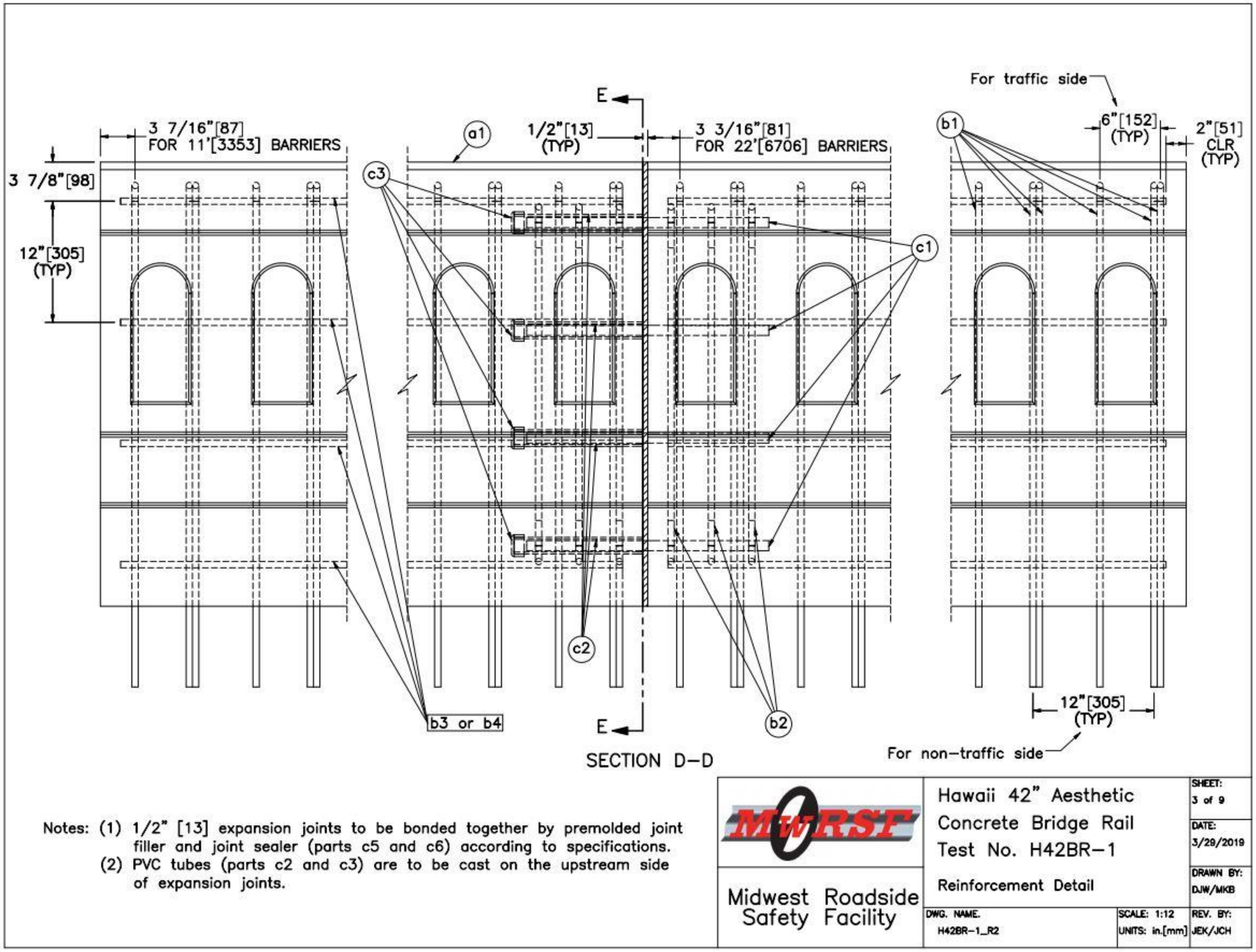


Figure 8. Reinforcement Detail, Test Nos. H42BR-1 and H42BR-2

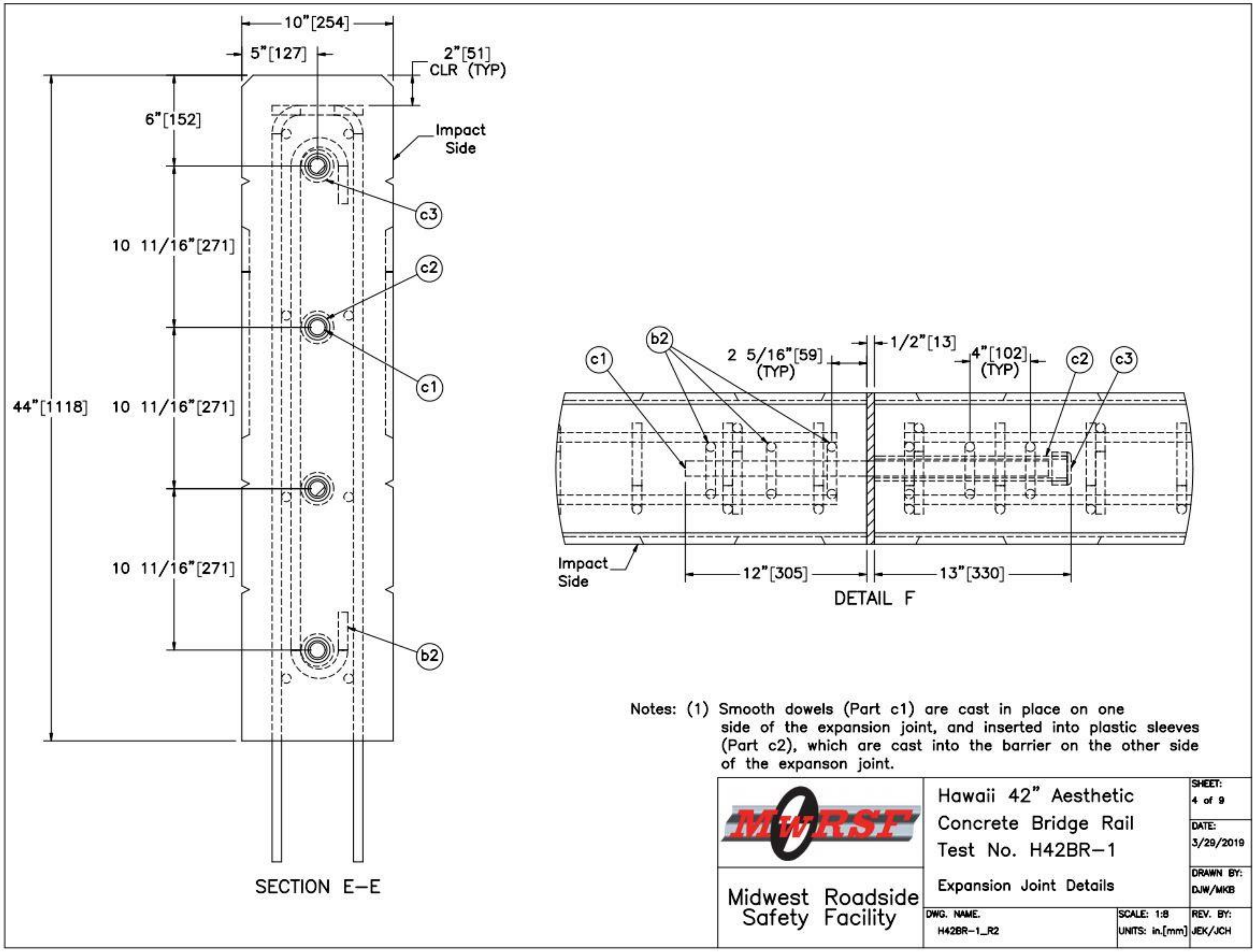


Figure 9. Expansion Joint Details, Test Nos. H42BR-1 and H42BR-2

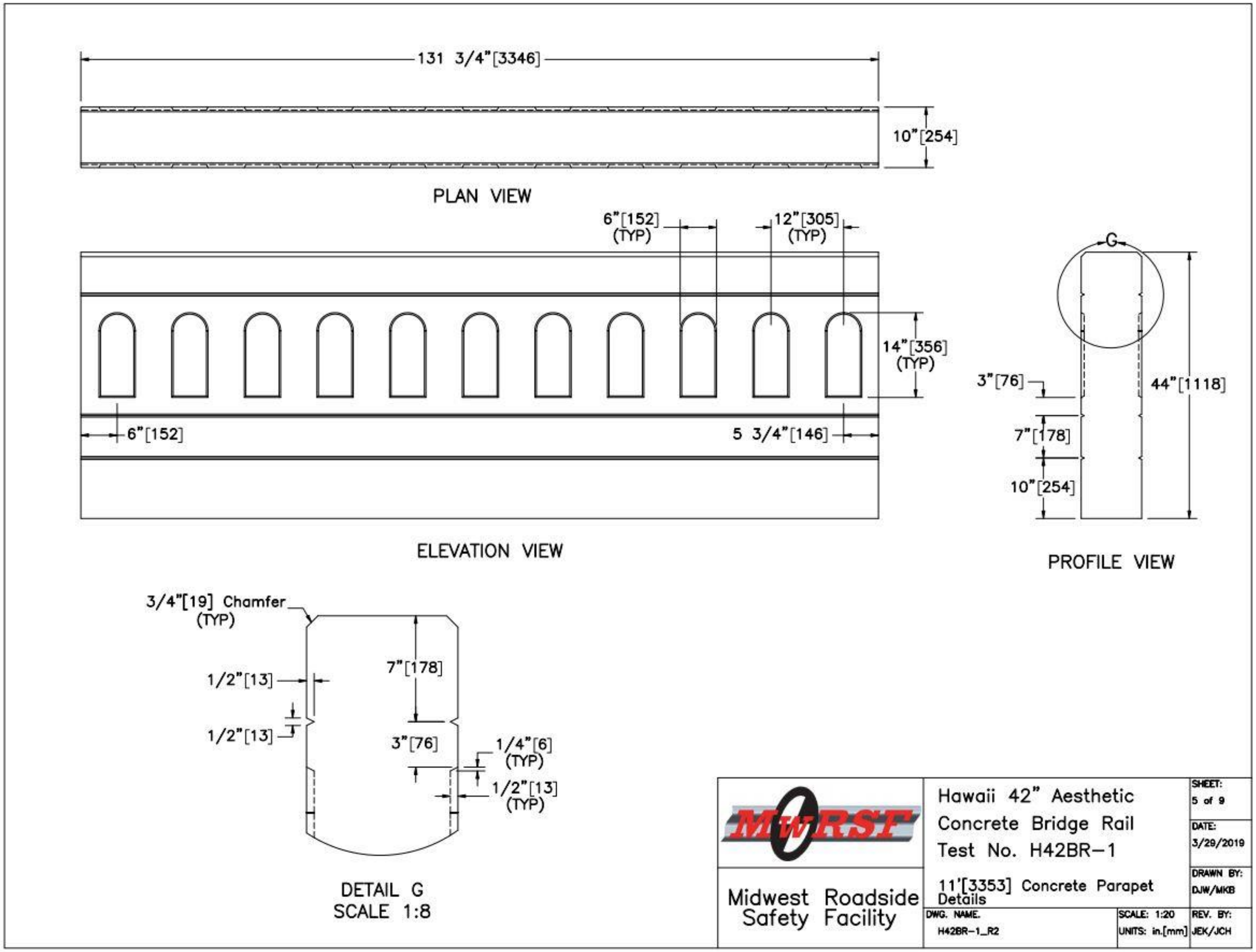


Figure 10. 11-ft Concrete Parapet Details, Test Nos. H42BR-1 and H42BR-2

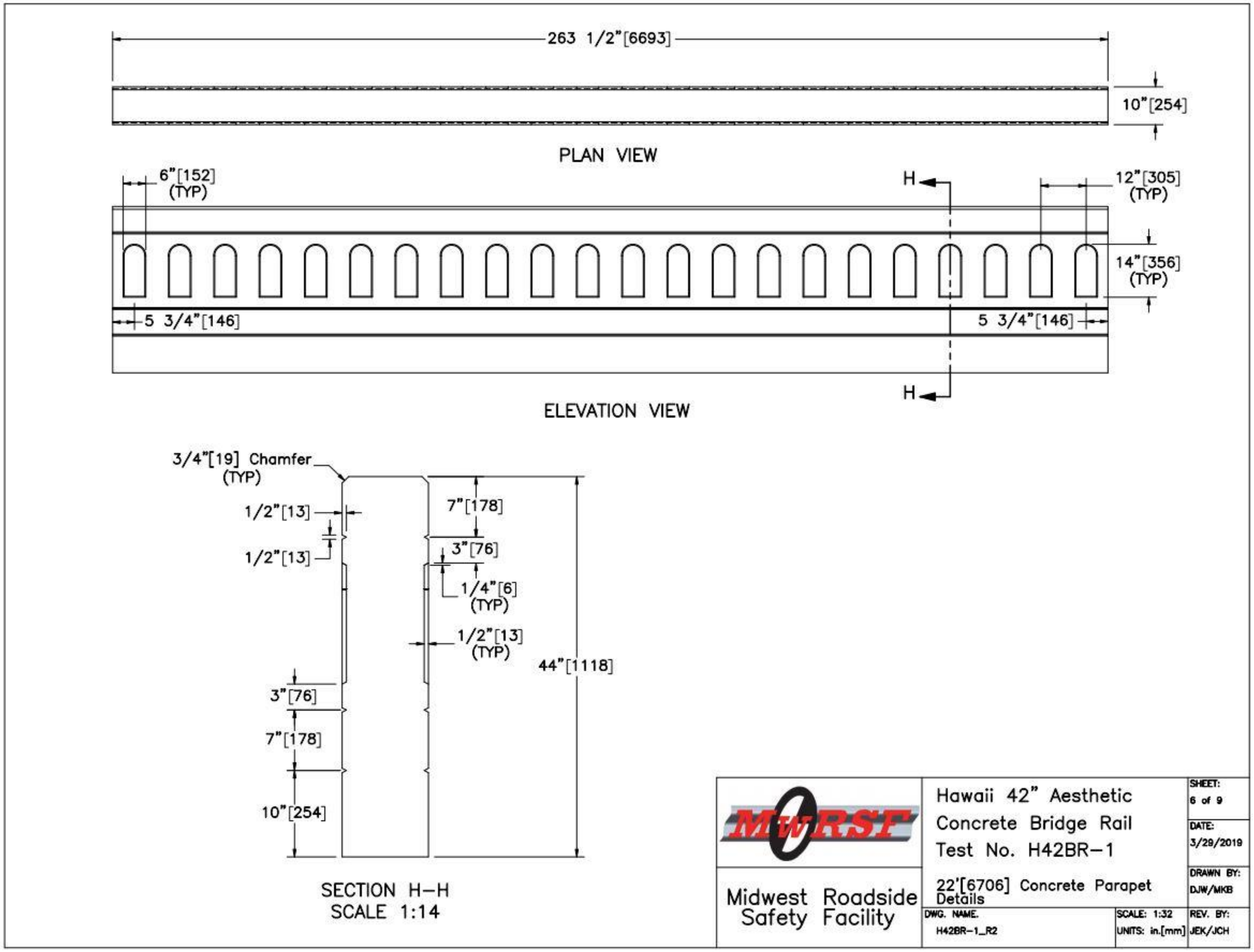
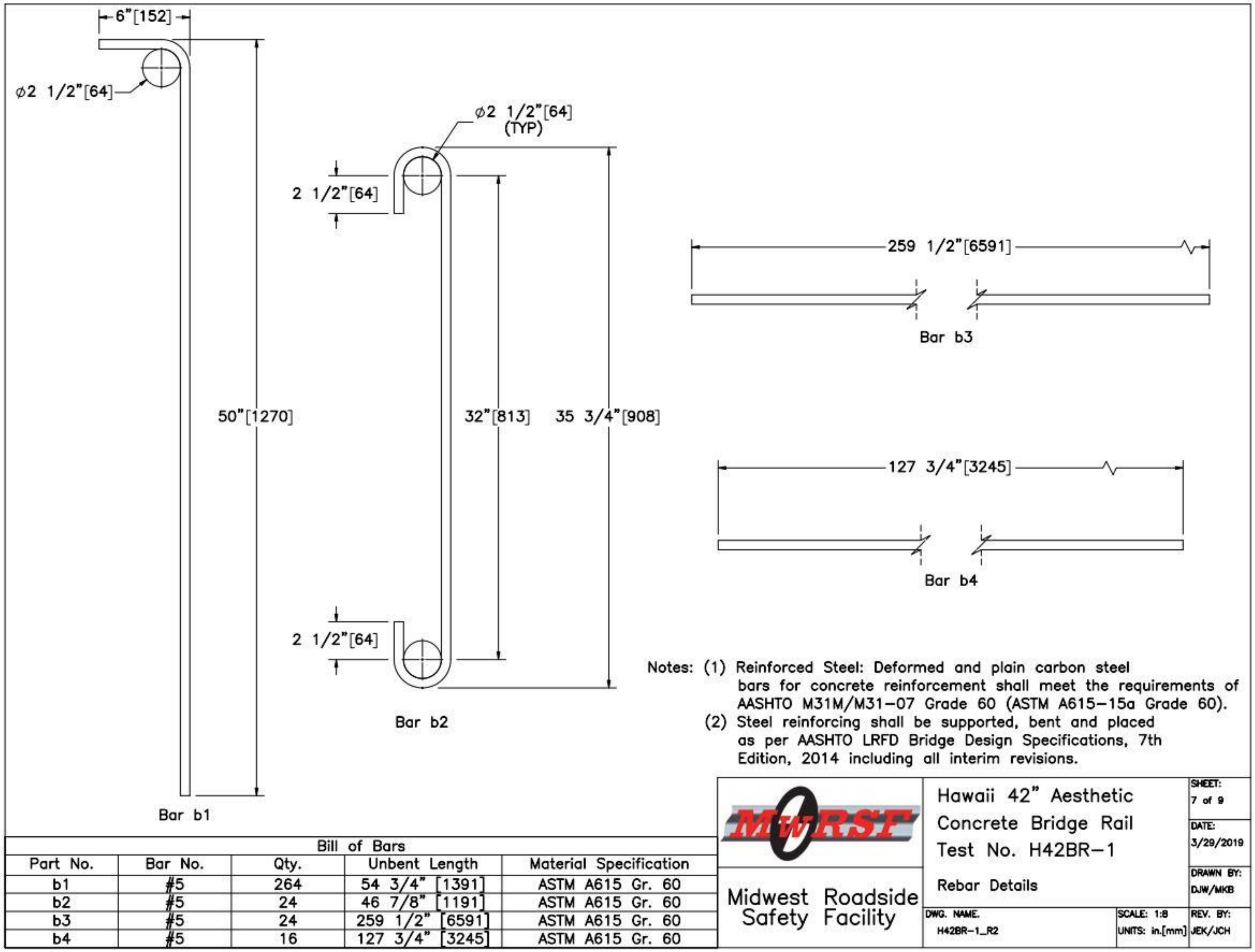


Figure 11. 22-ft Concrete Parapet Details, Test Nos. H42BR-1 and H42BR-2



Bill of Bars

Part No.	Bar No.	Qty.	Unbent Length	Material Specification
b1	#5	264	54 3/4" [1391]	ASTM A615 Gr. 60
b2	#5	24	46 7/8" [1191]	ASTM A615 Gr. 60
b3	#5	24	259 1/2" [6591]	ASTM A615 Gr. 60
b4	#5	16	127 3/4" [3245]	ASTM A615 Gr. 60

Figure 12. Rebar Details, Test Nos. H42BR-1 and H42BR-2

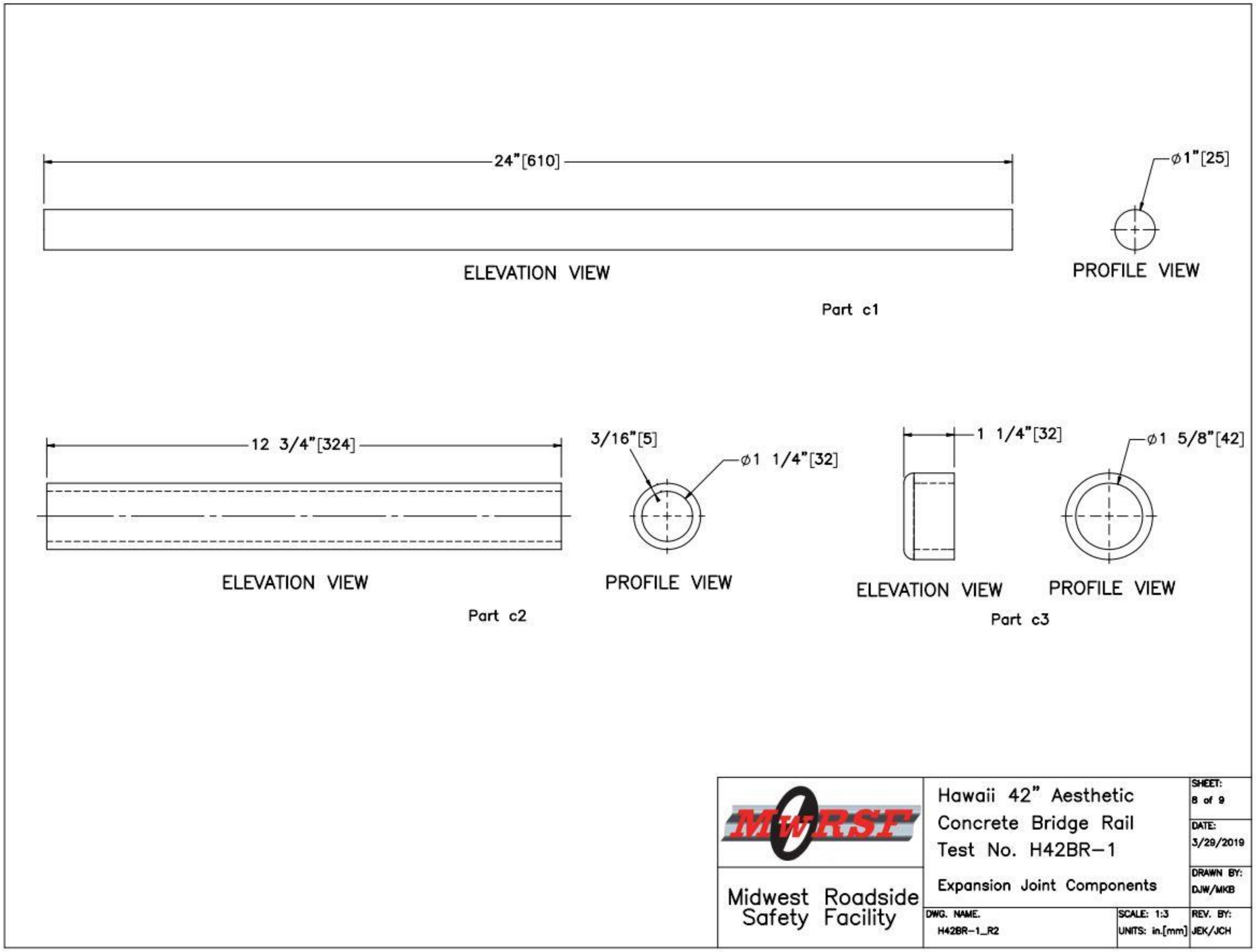


Figure 13. Expansion Joint Components, Test Nos. H42BR-1 and H42BR-2

Item No.	QTY.	Description	Material Specification	Treatment Specification
a1	–	Reinforced Concrete	Min. f'c = 4,000 psi [27.6 MPa] NE Mix 47BD	–
a2	–	Low-Strength Concrete Overlay	Concrete NE Mix 9019 CITY	–
b1	264	#5 [16] Rebar, 54 3/4" [1391] Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)*
b2	24	#5 [16] Rebar, 46 7/8" [1191] Total Unbent Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)*
b3	24	#5 [16] Rebar, 259 1/2" [6591] Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)*
b4	16	#5 [16] Rebar, 127 3/4" [3245] Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)*
c1	16	#8 [25] Smooth Rebar, 24" [288] Total Length	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)*
c2	16	1 1/4" [32] Dia. PVC Pipe	Schedule 80 PVC Gr. 12454	–
c3	16	1 1/4" [32] PVC Cap	Schedule 80 PVC Gr. 12454	–
c4	–	Epoxy Adhesive	Hilti HIT RE-500 V3	–
c5	–	Expansion Joint Filler	AASHTO M33, M153, or M213	–
c6	–	Expansion Joint Sealant	AASHTO M173, M282, M301, ASTM D3581, or ASTM D5893	–

*Rebar does not need to be epoxy-coated for testing purposes.

Midwest Roadside Safety Facility

Hawaii 42" Aesthetic Concrete Bridge Rail
Test No. H42BR-1

Bill of Materials

SHEET: 9 of 9
DATE: 3/29/2019
DRAWN BY: DJW/MKB
DWG. NAME. H42BR-1_R2
SCALE: None
UNITS: in.[mm]
REV. BY: JEK/JCH

Figure 14. Bill of Materials, Test Nos. H42BR-1 and H42BR-2

Figure 15. Construction, Test Nos. H42BR-1 and H42BR-2

Figure 16. System Installation, Test Nos. H42BR-1 and H42BR-2

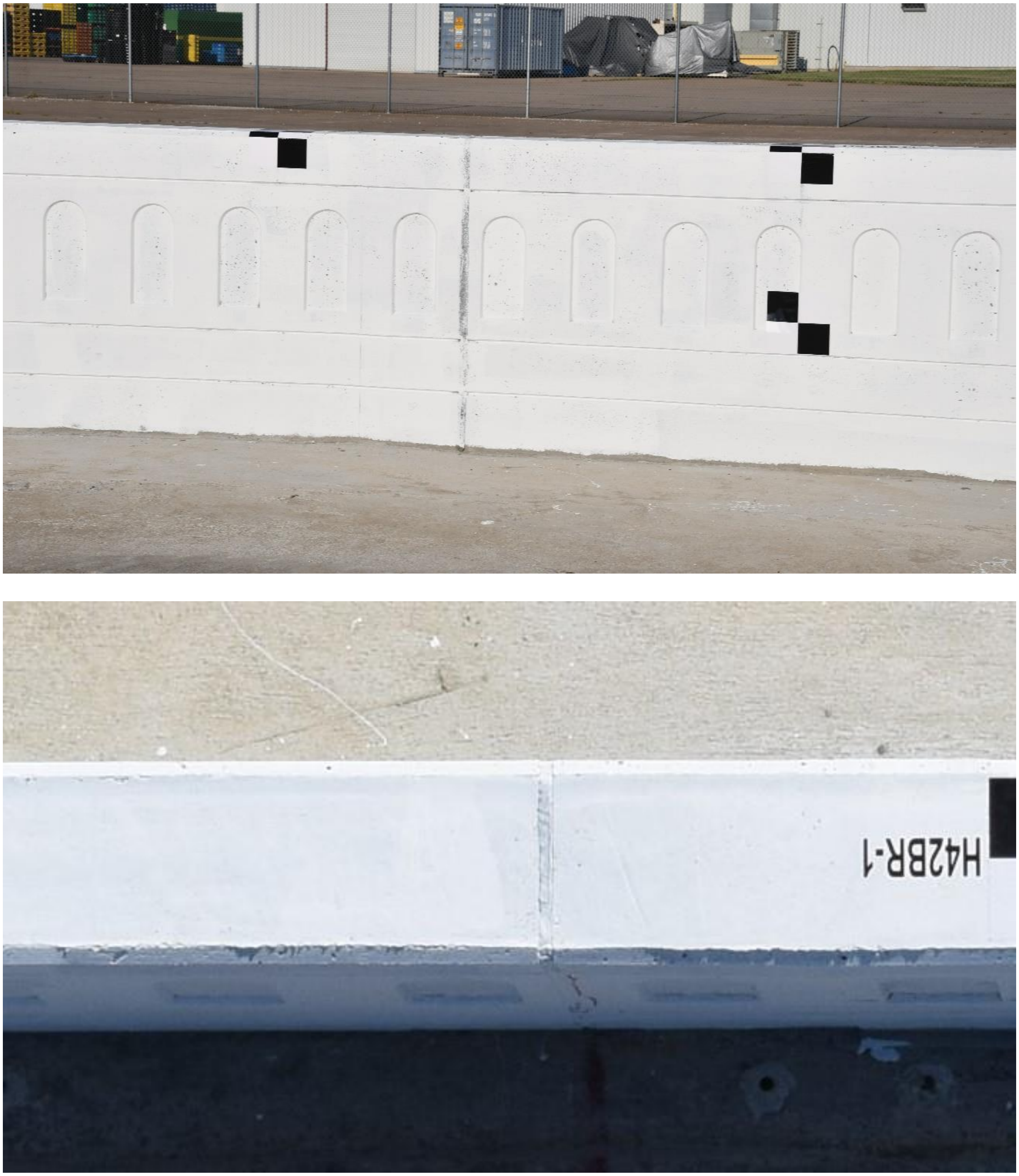


Figure 17. System Installation at Expansion Joint, Test Nos. H42BR-1 and H42BR-2

4 TEST CONDITIONS

4.1 Test Facility

MwRSF's Outdoor Test Site is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately five miles northwest of the University of Nebraska–Lincoln.

4.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [9] was used to steer the test vehicles. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. diameter guide cable was tensioned to approximately 3,500 lb and supported both laterally and vertically every 100 ft by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

4.3 Test Vehicles

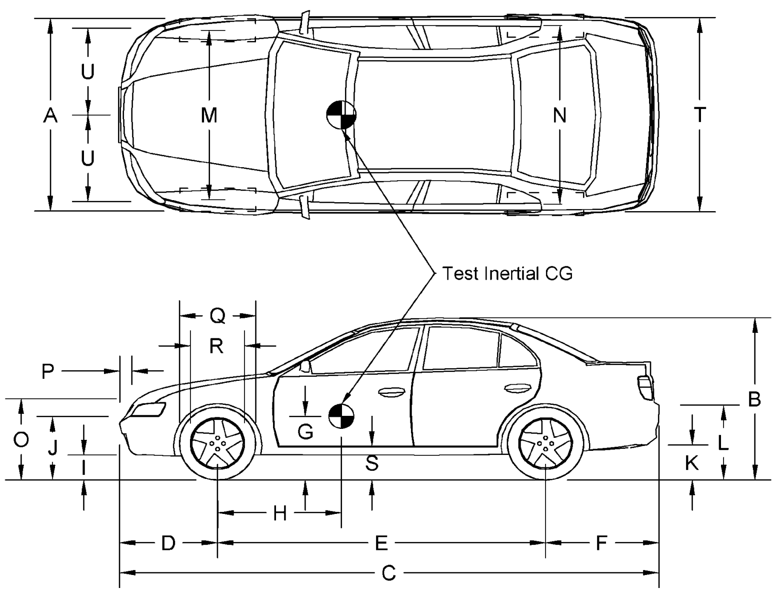
For test no. H42BR-1, a 2009 Kia Rio was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,498 lb, 2,421 lb, and 2,584 lb, respectively. The test vehicle is shown in Figures 18 and 19, and vehicle dimensions are shown in Figure 20. MASH 2016 describes that test vehicles used in crash testing should be no more than six model years old. A 2009 model was used for this test because the vehicle geometry of newer models did not comply with recommended vehicle dimension ranges specified in Table 4.1 of MASH 2016 [8].

The front wheels of the test vehicles were aligned to vehicle standards except the toe-in value was adjusted to zero such that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted on the vehicle's right-side dash for test nos. H42BR-1 and H42BR-2 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 vehicles so the vehicles could be brought safely to a stop after the test.

Figure 18. Test Vehicle, Test No. H42BR-1

Figure 19. Test Vehicle Interior Floorboards and Undercarriage, Test No. H42BR-1

Date:	7/17/2019	**Test Name:**	H42BR-1	**VIN No:**	KNADE223396495453
Year:	2009	**Make:**	Kia	**Model:**	Rio
Tire Size:	185/65R14	**Tire Inflation Pressure:**	32 psi	**Odometer:**	152886



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

A:	65 3/8	(1661)	B:	57 5/8	(1464)
	65±3 (1650±75)				
C:	164 1/2	(4178)	D:	33 1/2	(851)
	169±8 (4300±200)			35±4 (900±100)	
E:	98 1/2	(2502)	F:	33 1/2	(851)
	98±5 (2500±125)				
G:	22 3/16	(564)	H:	36 3/8	(924)
				39±4 (990±100)	
I:	16	(406)	J:	21	(533)
K:	15 3/4	(400)	L:	22	(559)
M:	58	(1473)	N:	57 3/8	(1457)
	56±2 (1425±50)			56±2 (1425±50)	
O:	26 1/2	(673)	P:	1 1/4	(32)
	24±4 (600±100)				
Q:	23	(584)	R:	15 1/2	(394)
S:	11 1/4	(286)	T:	65 1/4	(1657)

U (impact width):	29 1/4	(743)
Top of radiator core support:	26 5/8	(676)
Wheel Center Height (Front):	10 5/8	(270)
Wheel Center Height (Rear):	11 3/8	(289)
Wheel Well Clearance (Front):	24 3/4	(629)
Wheel Well Clearance (Rear):	25	(635)
Bottom Frame Height (Front):	6 1/2	(165)
Bottom Frame Height (Rear):	10 1/2	(267)
Engine Type:	Gasoline	
Engine Size:	1.4L 4 cyl	
Transmission Type:	Automatic	
Drive Type:	FWD	

Mass Distribution - lb (kg)

Gross Static	LF	812	(368)	RF	799	(362)
	LR	477	(216)	RR	496	(225)

Weights lb (kg)	Curb		Test Inertial		Gross Static	
W-front	1576	(715)	1527	(693)	1611	(731)
W-rear	922	(418)	894	(406)	973	(441)
W-total	2498	(1133)	2421	(1098)	2584	(1172)
			2420±55 (1100±25)		2585±55 (1175±50)	

GVWR Ratings lb	
Front	1918
Rear	1874
Total	3638

Surrogate Occupant Data

Type:	Hybrid II
Mass:	163 lb
Seat Position:	Right/Passenger

Note any damage prior to test: None

Figure 20. Vehicle Dimensions, Test No. H42BR-1

For test no. H42BR-2, a 2014 Dodge Ram 1500 quad cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,230 lb, 5,007 lb, and 5,170 lb, respectively. The test vehicle is shown in Figures 21 and 22, and vehicle dimensions are shown in Figure 23. Note that the rear panel on the non-impact side of the pickup truck was dented inward around the fuel filler cap, as shown in Figure 21. This damage was documented prior to testing and did not affect the outcome of test no. H42BR-2.

The longitudinal components of the center of gravity (c.g.) were determined using the measured axle weights. The vertical component of the c.g. for the 1100C vehicle was determined using a procedure published by SAE [10]. The location of the final c.g. for test no. H42BR-1 is shown in Figure 24. The Suspension Method [11] was used to determine the vertical component of the c.g. for the 2270P vehicle. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The pickup truck was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The location of the final c.g. for test no. H42BR-2 is shown in Figure 25. Data used to calculate the locations of the c.g. and ballast information are shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in video analysis, as shown in Figures 24 and 25. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

Figure 21. Test Vehicle, Test No. H42BR-2

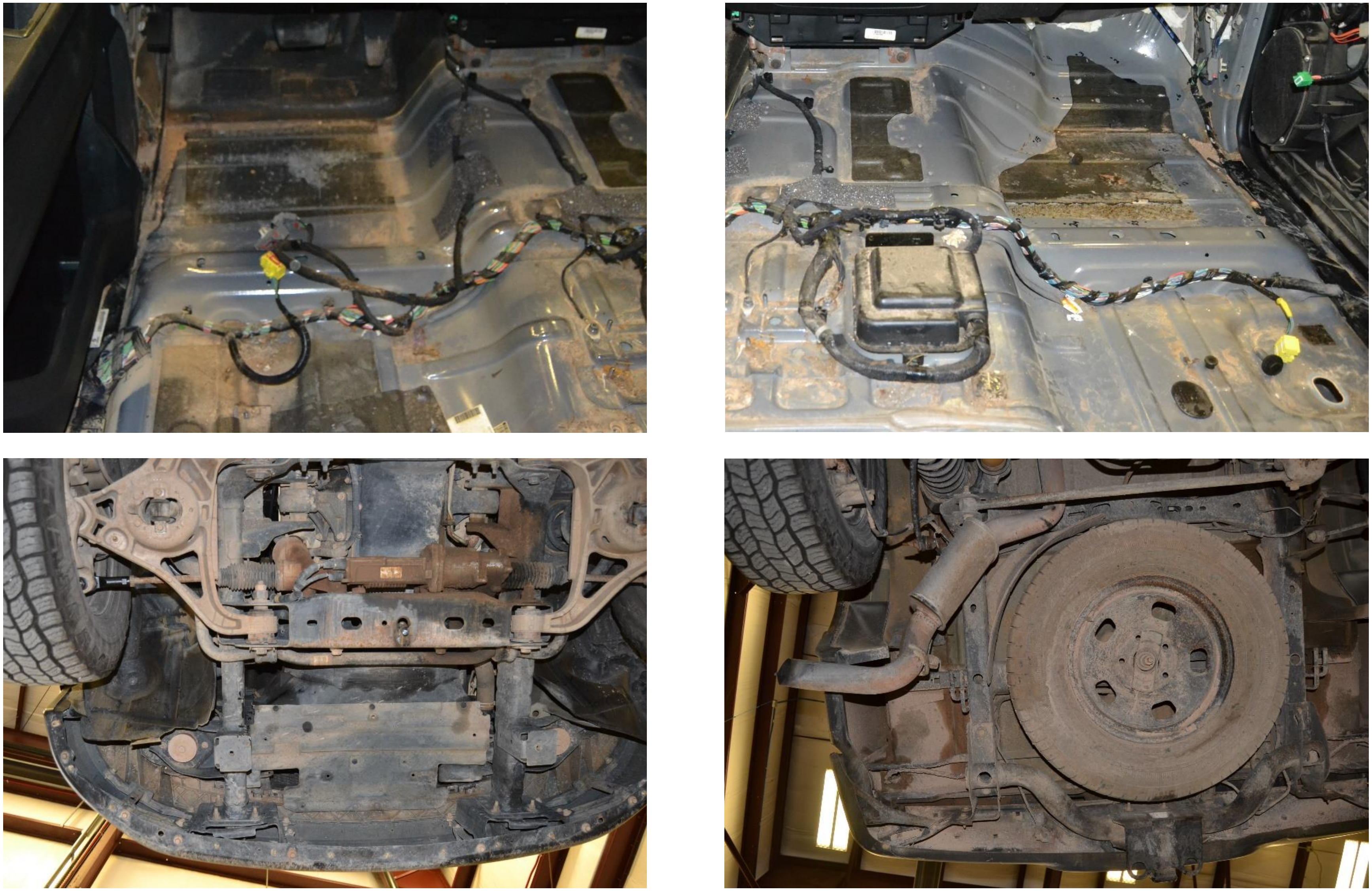
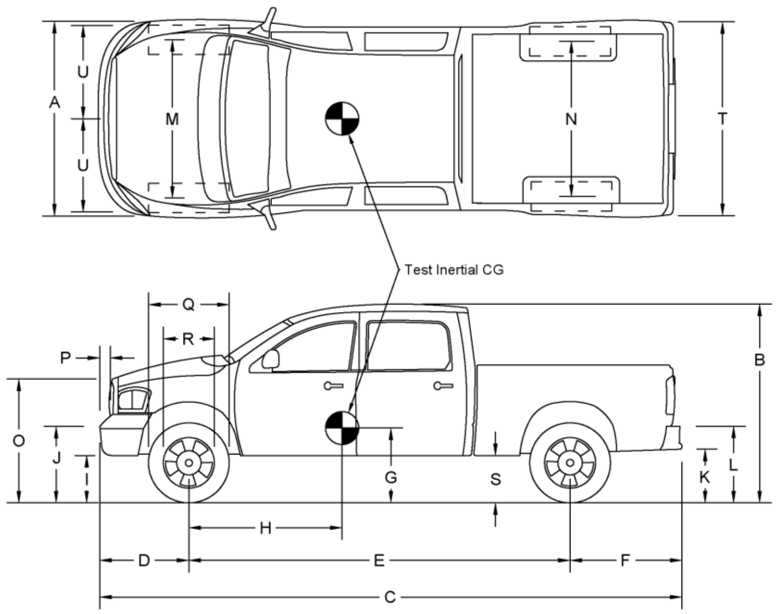


Figure 22. Test Vehicle Interior Floorboards and Undercarriage, Test No. H42BR-2

Date:	8/19/2019	**Test Name:**	H42BR-2	**VIN No:**	1C6RR6FT7ES319996
Year:	2014	**Make:**	Dodge	**Model:**	RAM 1500
Tire Size:	P265/70R17	**Tire Inflation Pressure:**	40 psi	**Odometer:**	215495



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

A:	77 1/2 (1969) 78±2 (1950±50)	B:	74 1/2 (1892)
C:	229 5/8 (5832) 237±13 (6020±325)	D:	41 1/2 (1054) 39±3 (1000±75)
E:	140 1/8 (3559) 148±12 (3760±300)	F:	48 (1219)
G:	28 5/8 (727) min: 28 (710)	H:	60 3/16 (1529) 63±4 (1575±100)
I:	13 3/4 (349)	J:	25 1/2 (648)
K:	20 1/2 (521)	L:	29 1/2 (749)
M:	68 3/8 (1737) 67±1.5 (1700±38)	N:	67 7/8 (1724) 67±1.5 (1700±38)
O:	44 (1118) 43±4 (1100±75)	P:	4 1/2 (114)
Q:	30 3/4 (781)	R:	18 1/2 (470)
S:	15 (381)	T:	77 1/8 (1959)

U (impact width):	36 1/2 (927)
Wheel Center Height (Front):	34 3/4 (883)
Wheel Center Height (Rear):	15 1/4 (387)
Wheel Well Clearance (Front):	14 3/4 (375)
Wheel Well Clearance (Rear):	37 3/4 (959)
Bottom Frame Height (Front):	12 (305)
Bottom Frame Height (Rear):	13 (330)
Engine Type:	Gasoline
Engine Size:	5.7L V8 HEMI
Transmission Type:	Automatic
Drive Type:	RWD
Cab Style:	Quad Cab
Bed Length:	76"

Mass Distribution - lb (kg)

Gross Static	LF	1431 (649)	RF	1519 (689)
	LR	1111 (504)	RR	1109 (503)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2953 (1339)	2857 (1296)	2950 (1338)
W-rear	2277 (1033)	2150 (975)	2220 (1007)
W-total	5230 (2372)	5007 (2271) 5000±110 (2270±50)	5170 (2345) 5165±110 (2343±50)

GVWR Ratings - lb

Front	3700
Rear	3900
Total	6900

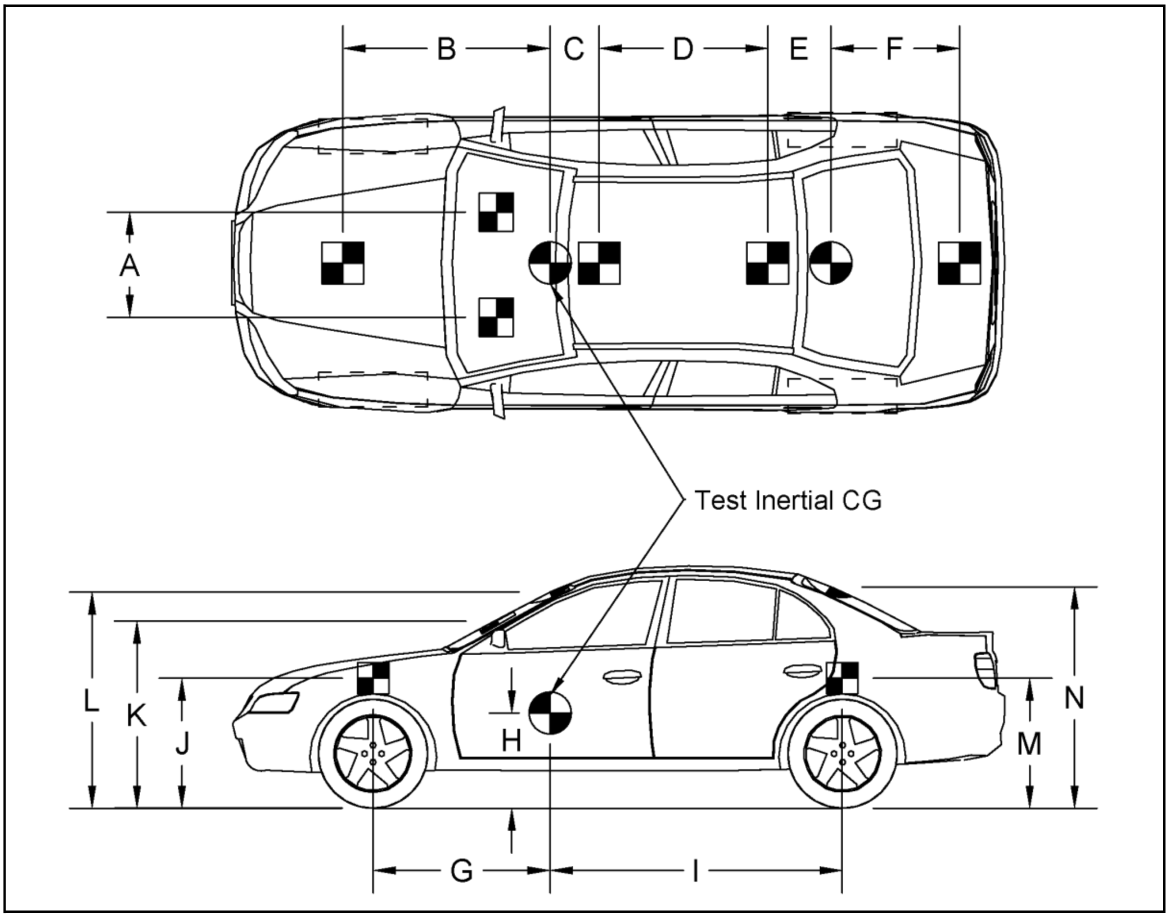
Surrogate Occupant Data

Type:	Hybrid II
Mass:	163 lb
Seat Position:	Right/Passenger

Note any damage prior to test: None

Figure 23. Vehicle Dimensions, Test No. H42BR-2

Date:	7/17/2019	**Test Name:**	H42BR-1	**VIN:**	KNADE223396495453
Year:	2009	**Make:**	Kia	**Model:**	Rio

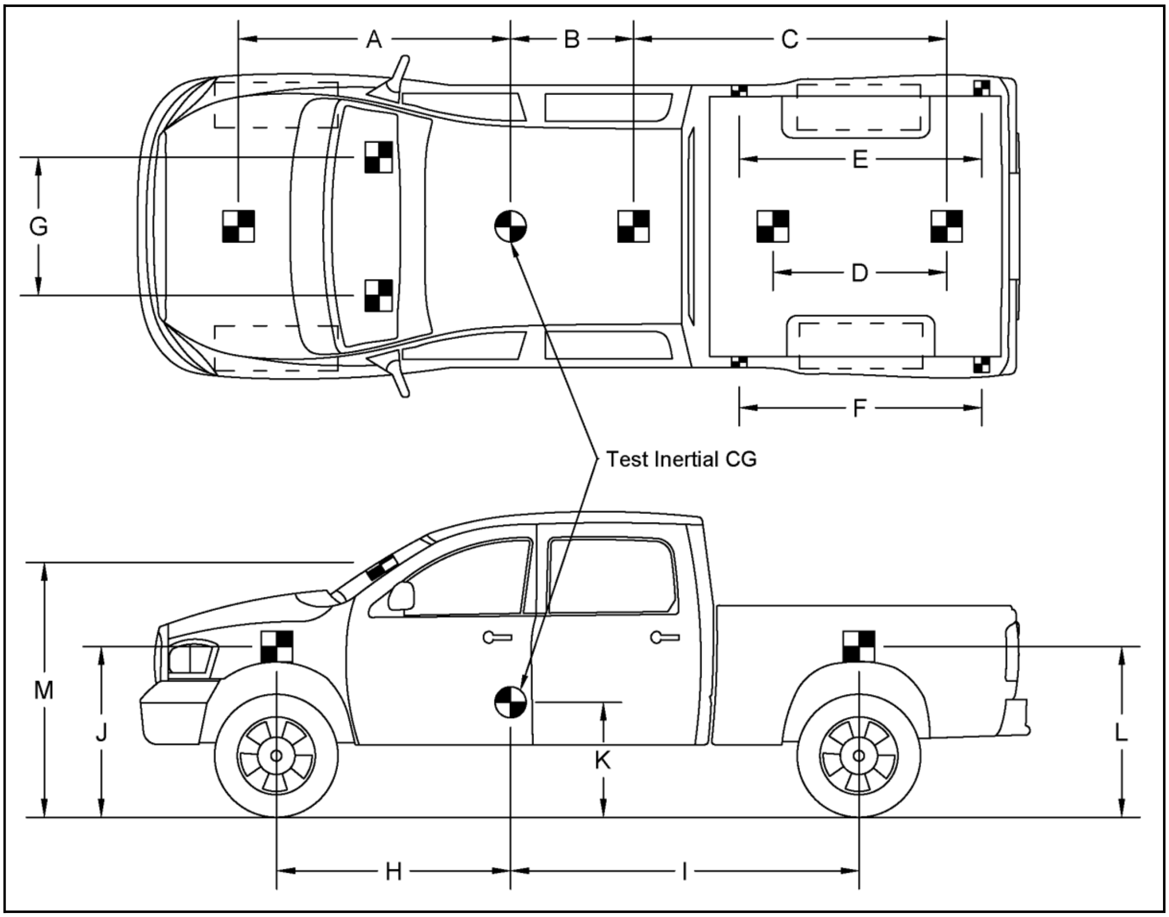


TARGET GEOMETRY-- in. (mm)

A:	26 1/8	(664)	**F:**	22 3/8	(568)	**K:**	47 3/4	(1213)
							Windshield Target	
B:	41 5/8	(1057)	**G:**	36 3/8	(924)	**L:**	52 7/8	(1343)
							Front round CG target	
C:	10 5/8	(270)	**H:**	22 1/8	(562)	**M:**	29 1/4	(743)
D:	37	(940)	**I:**	62 3/8	(1584)	**N:**	52 7/8	(1343)
							Rear Round target	
E:	14 3/4	(375)	**J:**	29	(737)			

Figure 24. Test Vehicle Target Geometry, Test No. H42BR-1

Date:	**8/19/2019**	**Test Name:**	**H42BR-2**	**VIN:**	**1C6RR6FT7ES319996**
Year:	**2014**	**Make:**	**Dodge**	**Model:**	**RAM 1500**



TARGET GEOMETRY-- in. (mm)

A:	**68 1/2**	**(1740)**	**E:**	**66 7/8**	**(1699)**	**J:**	**38 15/16**	**(989)**
B:	**27 1/8**	**(689)**	**F:**	**66 7/8**	**(1699)**	**K:**	**28 9/16**	**(725)**
C:	**76 3/16**	**(1935)**	**G:**	**33 5/16**	**(846)**	**L:**	**41 15/16**	**(1065)**
D:	**44 13/16**	**(1138)**	**H:**	**60 3/16**	**(1529)**	**M:**	**64 9/16**	**(1640)**
			I:	**80 1/8**	**(2035)**			

Figure 25. Test Vehicle Target Geometry, Test No. H42BR-2

4.4 Simulated Occupant

For test nos. H42BR-1 and H42BR-2, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the right-front seat of the test vehicle with the seat belt fastened. The dummy had a final weight of 163 lb in both tests. 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 accelerometer systems were mounted near the c.g. of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [12].

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

4.5.2 Rate Transducers

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

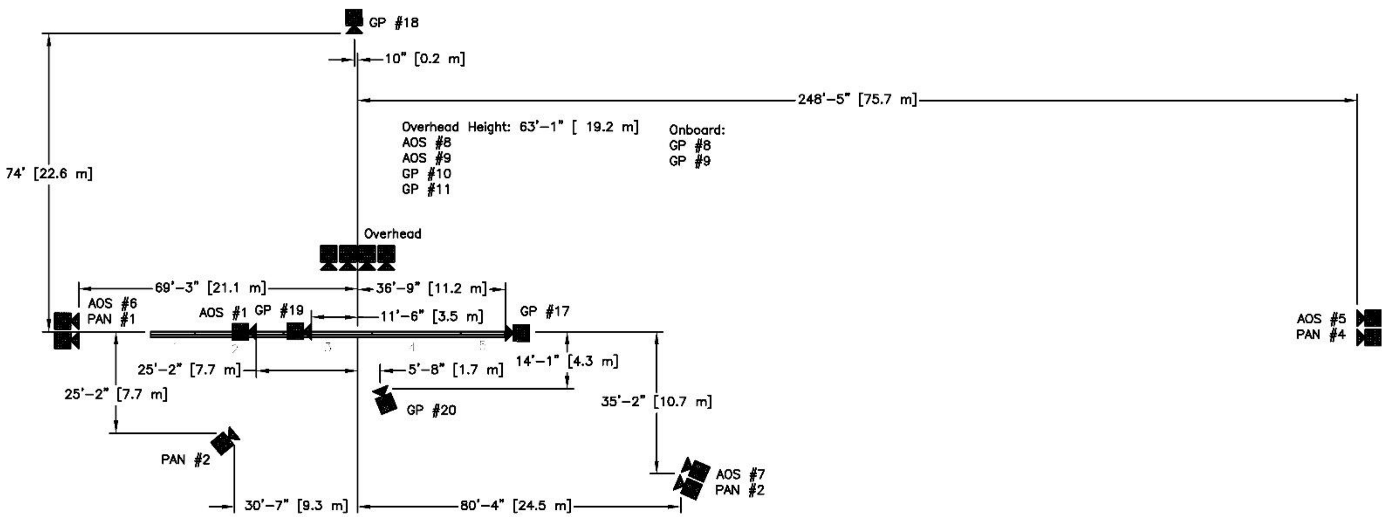
4.5.3 Retroreflective Optic Speed Trap

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

4.5.4 Digital Photography

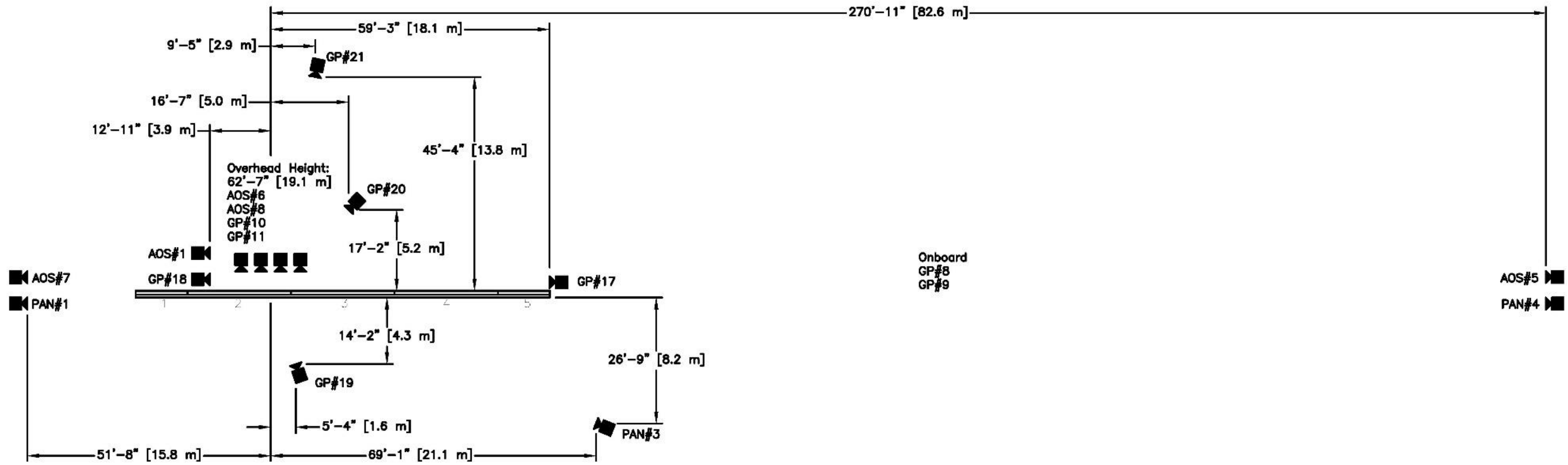
Six AOS high-speed digital video cameras, eight GoPro digital video cameras, and four Panisonic digital video cameras were used to film test no. H42BR-1. Five AOS high-speed digital video cameras, nine GoPro digital video cameras, and three Panisonic digital video cameras were used to document test no H42BR-2. Camera details and operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figures 26 and 27.

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



No.	Type	Operating Speed (frames/sec)	Lens	Lens Zoom Setting
AOS-1	AOS Vitcam	500	Minolta 70-210	100
AOS-5	AOS X-Pri	500	100 mm fixed	
AOS-6	AOS X-Pri	500	Sigma 28-70 #1	50
AOS-7	AOS X-Pri	500	Sigma 28-70 #2	70
AOS-8	AOS S-VIT 1531	500	KOWA 16 mm fixed	
AOS-9	AOS TRI-VIT 2236	500	KOWA 12 mm fixed	
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	120		
GP-11	GoPro Hero 4	240		
GP-17	GoPro Hero 4	240		
GP-18	GoPro Hero 6	240		
GP-19	GoPro Hero 6	240		
GP-20	GoPro Hero 6	240		
PAN-1	Panisonic HC-V770	120		
PAN-2	Panisonic HC-V770	120		
PAN-3	Panisonic HC-V770	120		
PAN-4	Panisonic HC-V770	120		

Figure 26. Camera Locations, Speeds, and Lens Settings, Test No. H42BR-1



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

Figure 27. Camera Locations, Speeds, and Lens Settings, Test No. H42BR-2

5 FULL-SCALE CRASH TEST NO. H42BR-1

5.1 Weather Conditions

Test no. H42BR-1 was conducted on July 17, 2019 at approximately 11:15 a.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. H42BR-1

Temperature	92° F
Humidity	52 percent
Wind Speed	14 mph
Wind Direction	200° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.33 in.
Previous 7-Day Precipitation	0.36 in.

5.2 Test Description

Test no. H42BR -1 was conducted on HDOT's 42-in. Tall, Aesthetic Concrete Bridge Rail under MASH 2016 guidelines for test designation no. 3-10. Test designation no. 3-10 is an impact of an 1100C test vehicle at 62 mph and 25 degrees on the system. The critical impact point for this test was selected to be 3 ft – $7^{3}/_{16}$ in. upstream from the expansion joint between barrier segment nos. 3 and 4 to maximize the potential for vehicle interaction and snag on the expansion joint and the edge of the aesthetic asperities in the rail, as shown in Figure 28, which was selected using Table 2.7 of MASH 2016.

The 2,421-lb small car impacted the HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail at a speed of 63.2 mph and an angle of 24.9 deg. The actual point of impact was 3.9 in. upstream from the target location. During the test, the vehicle was captured and redirected by the system. During the redirection of the vehicle, the right-front fender and right-front wheel experienced minor snag on the expansion joint and the edge of the aesthetic asperities downstream from impact. The snag was sufficient to push the right-front tire backward and crush the front portion of the right-front fender. The snag of the vehicle components did not pose a risk to the vehicle occupant compartment nor pose a hazard due to the velocity change or deceleration of the vehicle. Note that after exiting the barrier, the vehicle continued downstream and impacted a secondary set of portable barriers used to shield adjacent areas of the test site. This secondary impact did not factor into the analysis of the crash test. The vehicle came to rest 159 ft – 2 in. downstream from the impact point and 39 ft – 6 in. laterally behind the traffic side of the barrier.

A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 29 and 30. Documentary photographs of the crash test are shown in Figure 31. The vehicle trajectory and final position are shown in Figure 32.

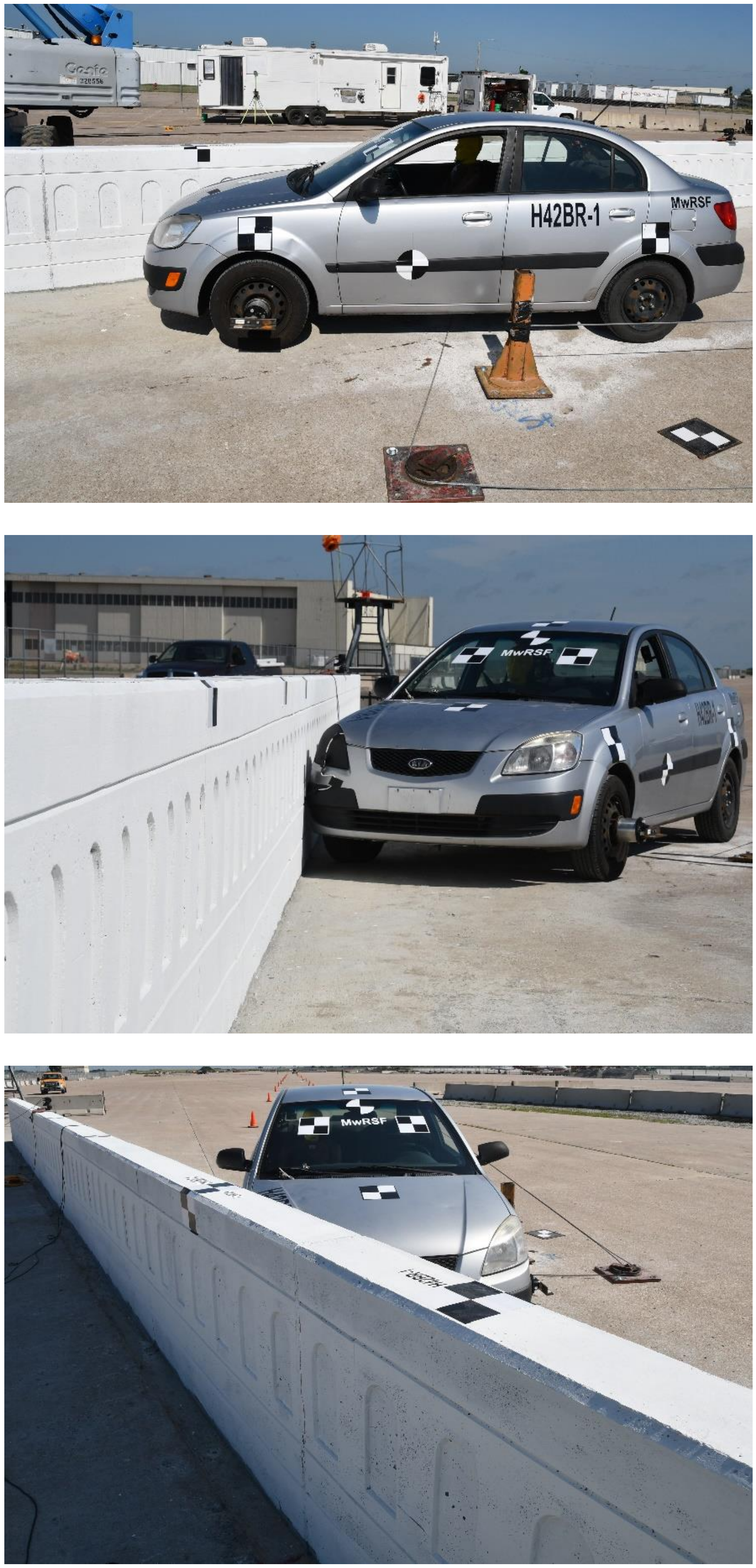


Figure 28. Impact Location, Test No. H42BR-1

Table 4. Sequential Description of Impact Events, Test No. H42BR-1

TIME (sec)	EVENT
0.000	Vehicle's front bumper contacted concrete barrier 47.1 in. upstream from expansion joint between barrier nos. 3 and 4.
0.004	Vehicle's front bumper deformed, and vehicle's right headlight and right fender contacted concrete barrier.
0.006	Vehicle's right headlight deformed, and vehicle's right-front wheel contacted concrete barrier.
0.012	Vehicle's hood contacted concrete barrier.
0.018	Vehicle rolled toward system.
0.024	Vehicle's hood deformed, vehicle's right headlight shattered, and vehicle's right-rear door deformed.
0.026	Vehicle's right fender deformed.
0.028	Vehicle's right-side mirror contacted concrete barrier.
0.030	Vehicle's right side mirror deformed, vehicle's roof deformed, and vehicle's right-side mirror glass cracked.
0.032	Vehicle's right-front door deformed, and vehicle's right-side mirror glass shattered.
0.034	Vehicle's front bumper became disengaged.
0.036	Vehicle's right-front door contacted concrete barrier.
0.038	Vehicle's windshield cracked.
0.040	Vehicle's right-front window cracked, and vehicle yawed away from system.
0.044	Vehicle's right side mirror became disengaged.
0.054	Vehicle's windshield shattered.
0.110	Vehicle rolled away from system.
0.134	Vehicle's right-front window became disengaged.
0.160	Vehicle's right-rear door contacted concrete barrier.
0.170	Vehicle was parallel to system traveling at 44.3 mph.
0.176	Vehicle's right quarter panel contacted concrete barrier.
0.178	Vehicle's right quarter panel deformed.
0.190	Vehicle's rear bumper contacted concrete barrier.
0.192	Vehicle's right taillight contacted concrete barrier and deformed.
0.194	Vehicle's rear bumper deformed.
0.274	Vehicle exited system at 42.8 mph and a 5.6 degree angle.
3.642	Vehicle came to rest.

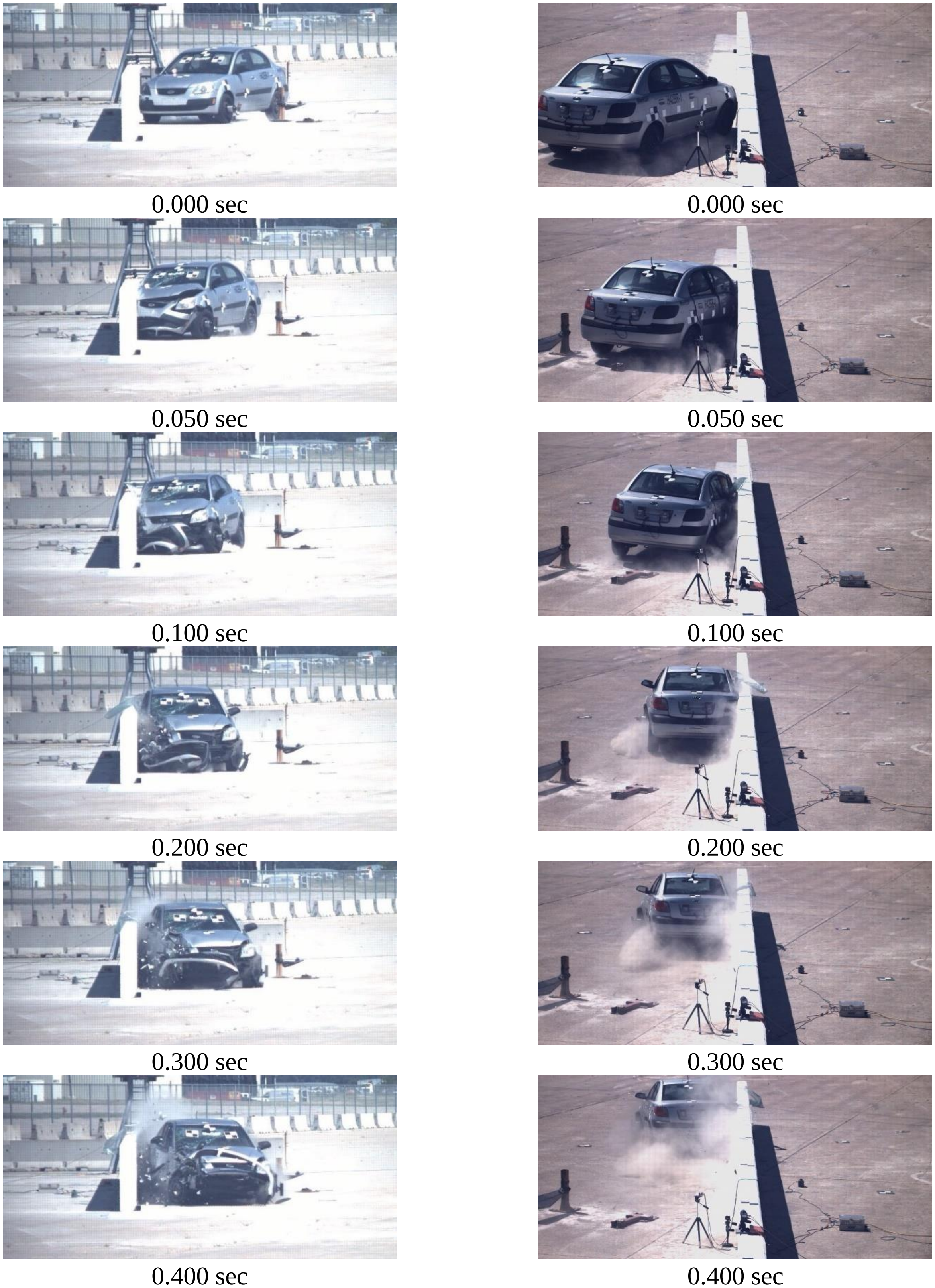


Figure 29. Sequential Photographs, Test No. H42BR-1

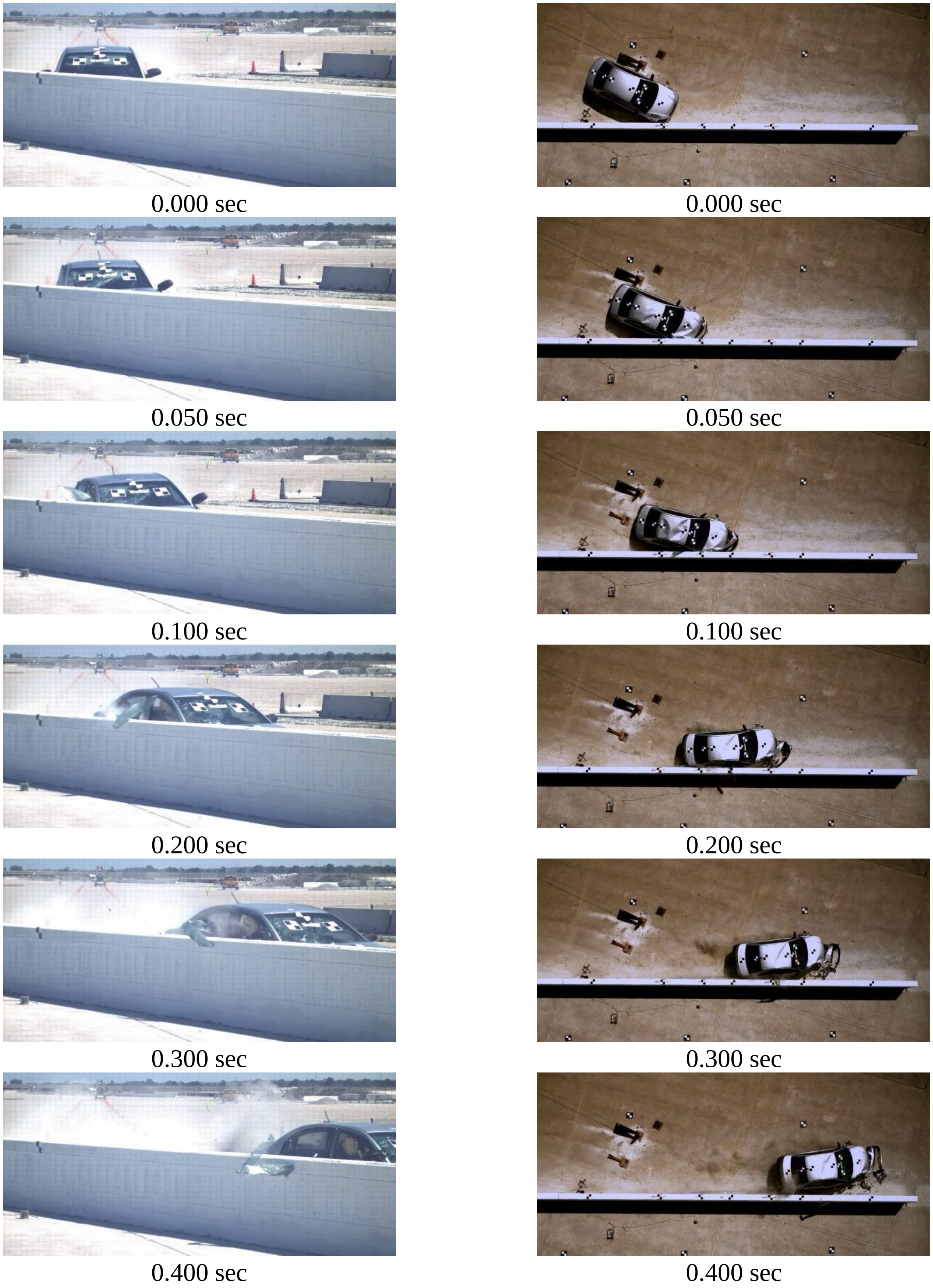


Figure 30. Sequential Photographs, Test No. H42BR-1

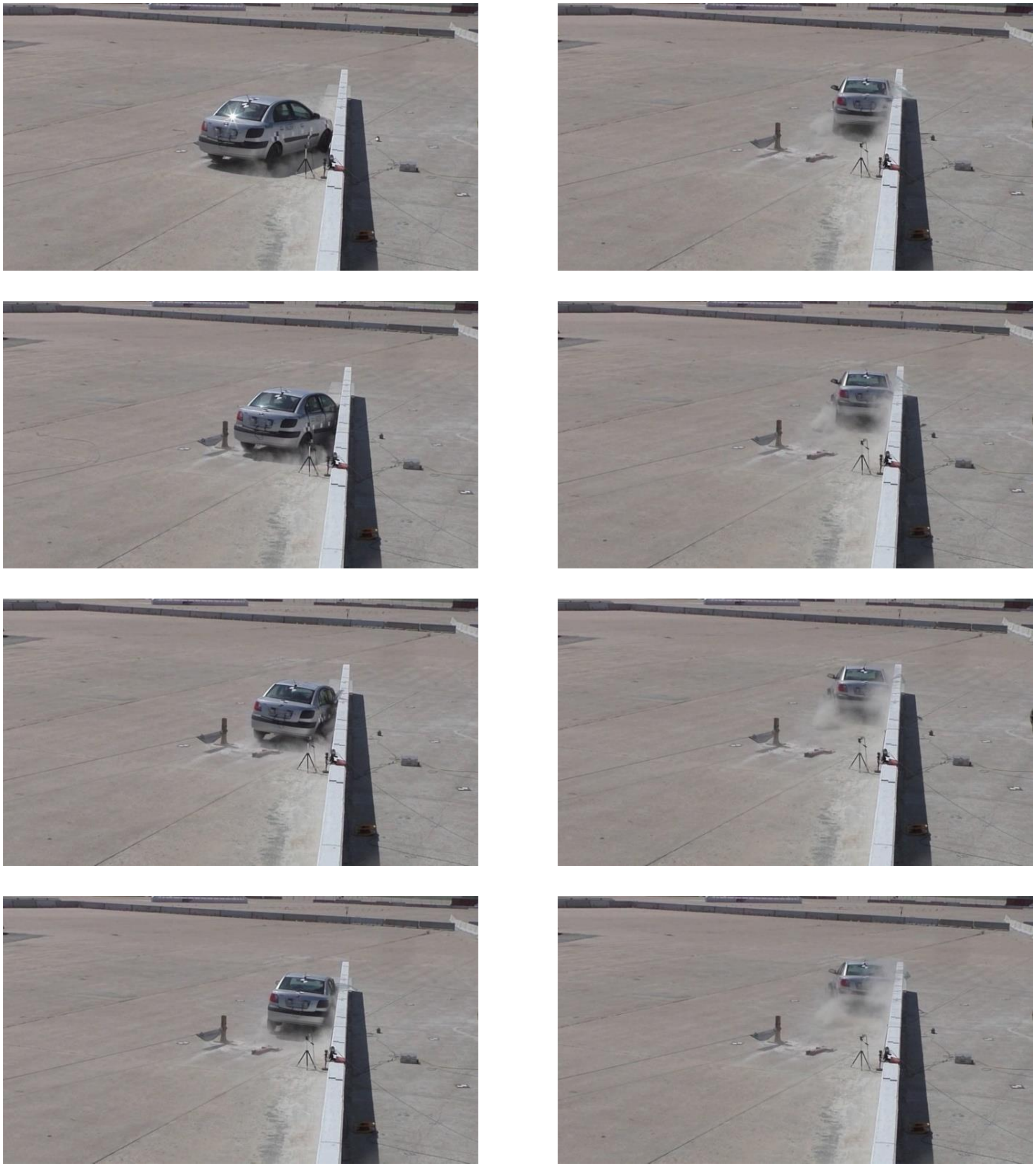


Figure 31. Documentary Photographs, Test No. H42BR-1

Figure 32. Vehicle Final Position and Trajectory Marks, Test No. H42BR-1

5.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 33 through 38. Barrier damage consisted of contact marks and concrete gouging on the front face of the barrier. The total length of vehicle contact along the barrier was 12 ft, which spanned from 22 in. upstream from the impact point to 9 ft – 11 in. downstream from the impact point.

Tire marks were visible on the front face of barrier nos. 3 and 4. Scuff marks were found on the front and top faces of barrier nos. 3 and 4. A 133-in. long by 37¼-in. tall contact mark began 14½ in. upstream from the impact point at the bottom of the barrier. A 3-in. long by 1-in. tall contact mark was found 22 in. upstream from the impact point and 3¾ in. below the top edge of the barrier.

Minor concrete spalling was observed along the second-lowest horizontal seam covering a 4-ft long area, beginning 5½ in. upstream from the impact point. Concrete damage occurred over a 2¾-in. x 10-in. area beginning on the downstream edge of the fourth aesthetic recess upstream from the expansion gap. The rest of the damage to the system consisted of minor concrete damage to the aesthetic recesses and is summarized in Table 5. Note there was no observable damage or cracking to the top or backside of the barrier or to the expansion joint.

Table 5. Damage to Aesthetic Recesses, Test No. H42BR-1

Recess No.	Relative to Expansion Joint[1]	Length in.	Height in.	Recess Edge
5	Upstream	¾	5¼	Downstream
3	Upstream	¾	¾	Upstream
		½	1	Upstream
		¾	12	Downstream
2	Upstream	½	12	Downstream
1	Upstream	½	12	Downstream
1	Downstream	½	1	Downstream

[1] Expansion joint between barrier nos. 3 and 4

Figure 33. System Damage, Test No. H42BR-1

Figure 34. System Damage, Test No. H42BR-1

Figure 35. System Damage, Test No. H42BR-1

Figure 36. System Damage, Test No. H42BR-1

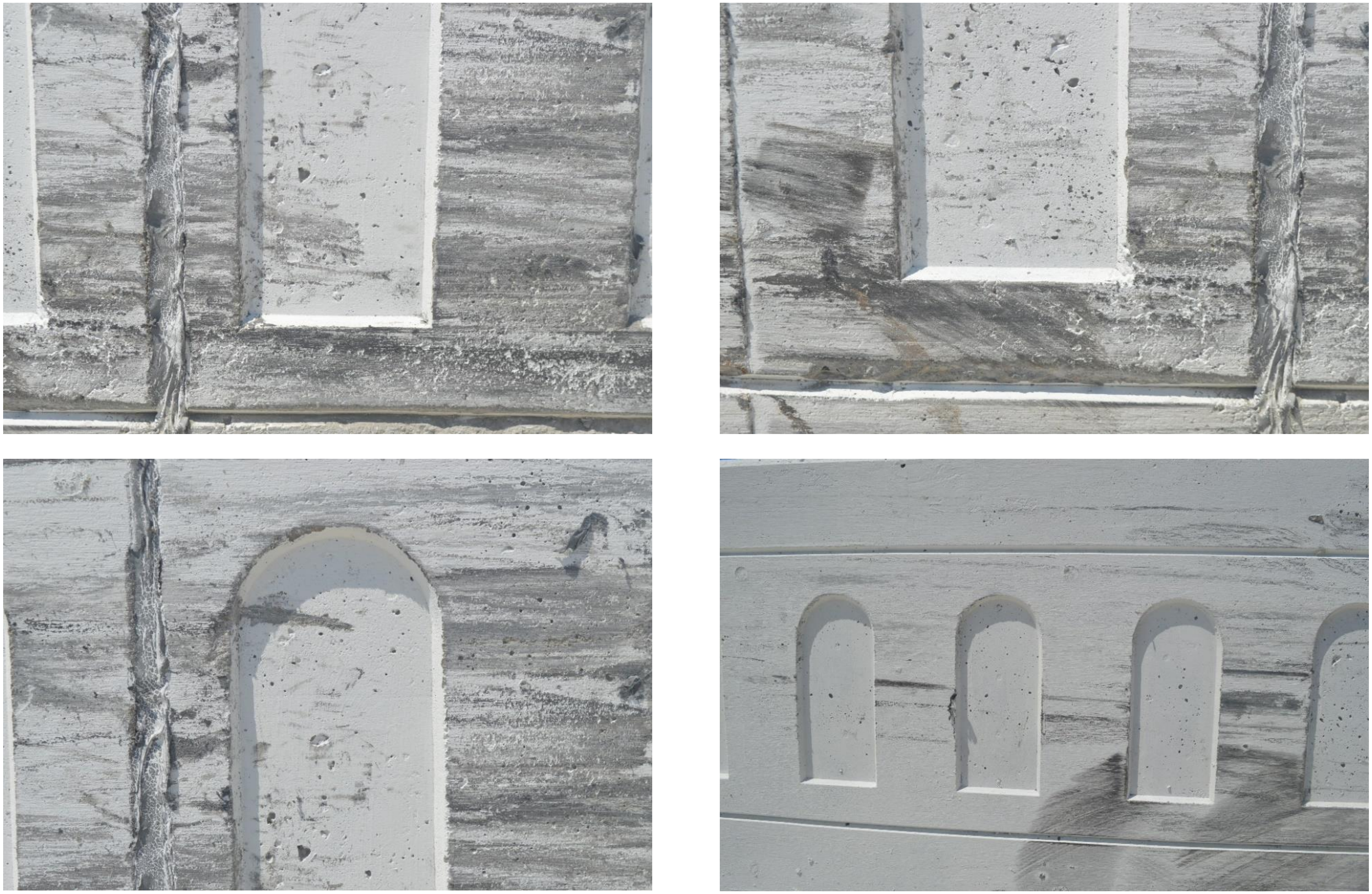


Figure 37. System Damage, Test No. H42BR-1

Figure 38. System Damage at Expansion Joint, Test No. H42BR-1

The maximum lateral permanent set of the barrier system was 0.1 in., as measured in the field. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 0.2 in. at barrier no. 3, as determined from high-speed digital video analysis. The working width of the system was found to be 10.2 in., also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 39

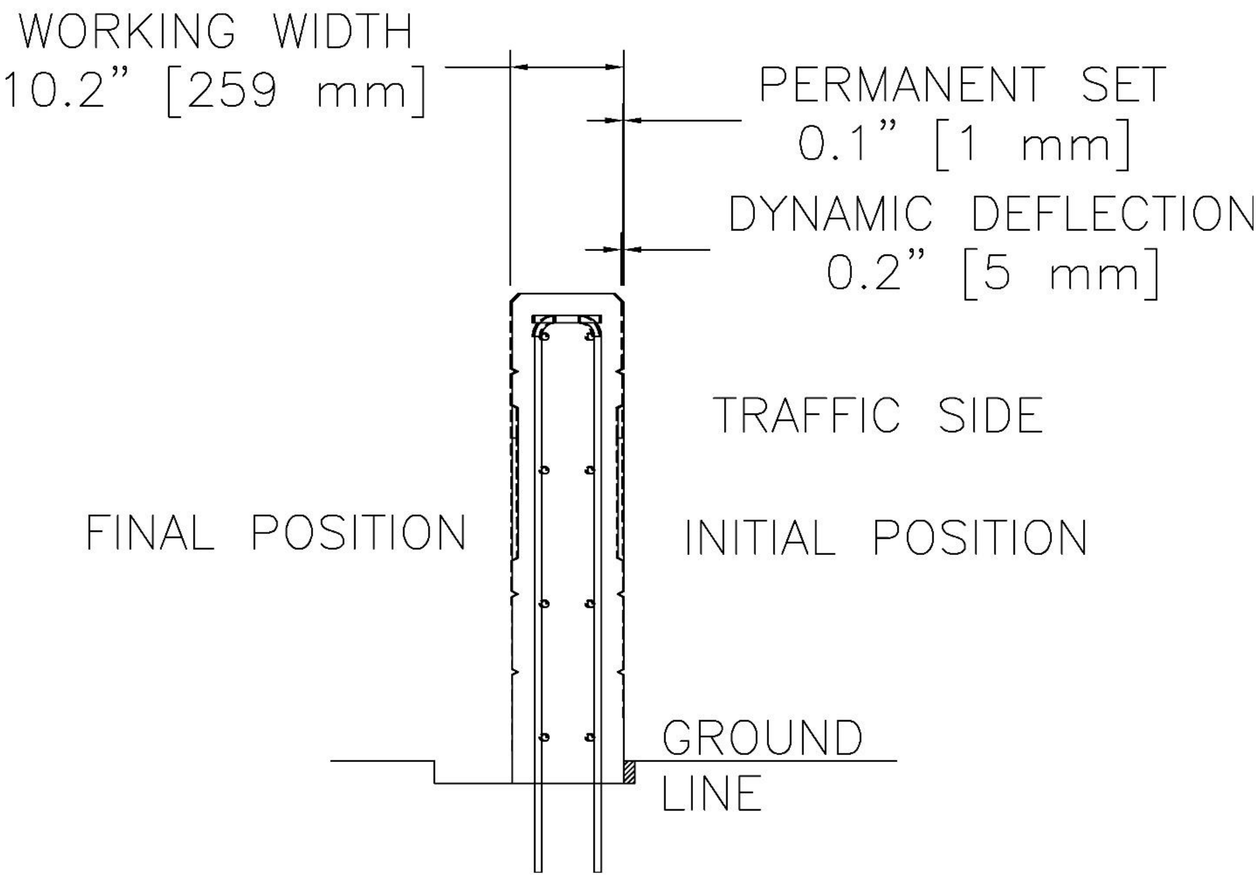


Figure 39. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. H42BR-1

5.4 Vehicle Damage

Damage to the vehicle was moderate, as shown in Figures 40 through 43. The maximum occupant compartment intrusions are listed in Table 6, 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 B-pillar (lateral) and side door deformed slightly outward, which is not considered crush toward the occupant, is denoted as negative numbers in Table 6, and is not evaluated by MASH 2016 criteria. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix C.

Majority of the damage was concentrated on the right-front corner and right side of the vehicle where impact with the system occurred. The right side of the front bumper was crushed inward and back. The front bumper cover was crushed inward, and the right side was torn away from the vehicle. The hood was crushed in toward the engine compartment. The right-front fender was crushed inward and back across its entire length and height. The right-front steel rim was deformed. The right-side headlight shattered and the right-side side mirror was disengaged from the vehicle. Denting and scraping were observed across the entire right side. The right-front door was crushed on the rear of the door seam while the right-rear door was crushed inward just ahead of the door seam. The right-rear bumper cover was scuffed and dented around the wheel. The right-rear bumper was scuffed. The right-side taillight was shattered. The roof was slightly deformed.

A vertical crack on the windshield propagated through the adhesive liner and deformed inward 6.8 in., but did not impact the system or simulated occupant. The deformation of the windshield was such that the deformation limit in MASH 2016 was exceeded. However, the deformation was due to shearing and fracture of the windshield caused by crushing of the right-front corner of the windshield, which propagated a shear crack through the glass. The windshield damage did not occur due to direct contact with the test article, nor did it pose a penetration hazard to the vehicle occupant. Thus, this damage was not a violation of MASH 2016 criteria as neither item occurred due to contact with the test article or debris, nor did they pose an intrusion risk into the occupant compartment. Additionally, the right-front side window was shattered. Review of the high-speed video revealed that the side window damage occurred due to crush of the vehicle’s side door and not from direct contact with the test article. The remaining window glass remained undamaged.

The front anti-roll bar was pushed inward on the right side. The right-side control arm was bent inward and the right-side outer steering control arm joint was compressed. The right-side frame rail was bent downward. The front and rear cross members were pushed inward and the frame horn was pushed backward. The floor pan was opened at the seam of the right-side toe pan connection from vehicle crush. The split seam was not due to intrusion of the barrier or a component of the vehicle.

Figure 40. Vehicle Damage, Test No. H42BR-1

Figure 41. Vehicle Damage, Test No. H42BR-1

Figure 42. Occupant Compartment Damage, Test No. H42BR-1

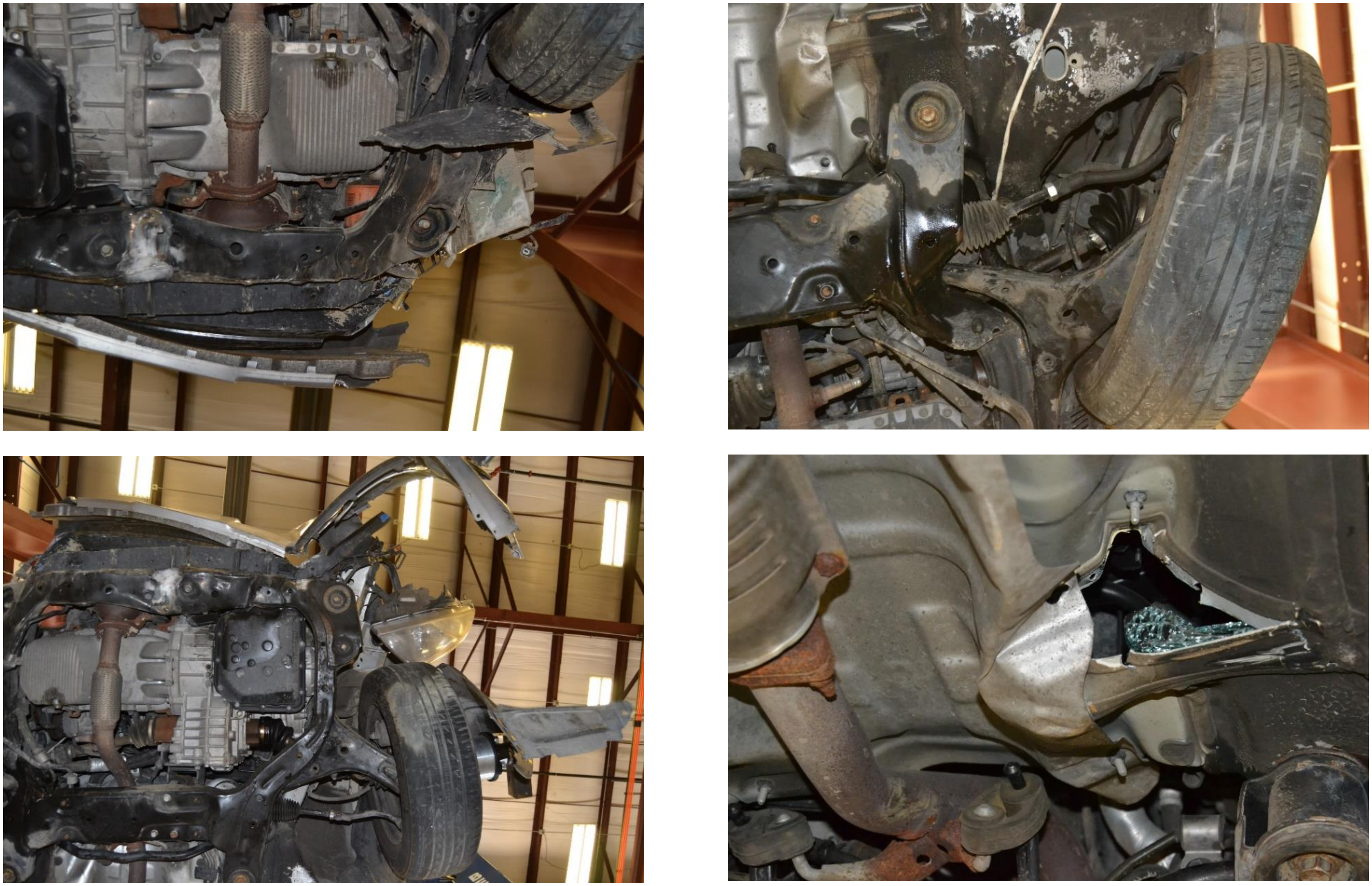


Figure 43. Undercarriage Damage, Test No. H42BR-1

Table 6. Maximum Occupant Compartment Intrusion by Location, Test No. H42BR-1

LOCATION	MAXIMUM INTRUSION in.	MASH 2016 ALLOWABLE INTRUSION in.
Wheel Well & Toe Pan	2.6	≤ 9
Floor Pan & Transmission Tunnel	4.7	≤ 12
A-Pillar	1.5	≤ 5
B-Pillar	1.2	≤ 5
A-Pillar (lateral)	0.6	≤ 3
B-Pillar (lateral)	−1.2	N/A[2]
Side Front Panel	2.3	≤ 12
Side Door (above seat)	0.2	≤ 9
Side Door (below seat)	−1.1	N/A[2]
Roof	2.2	≤ 4
Windshield	6.8*	≤ 3
Side Window	Shattered due to contact with dummy's head	No shattering resulting from contact with structural member of test article
Dash	1.9	N/A[1]

Note: Negative values denote outward deformation
N/A[1] – No MASH 2016 criteria exist for this location
N/A[2] – MASH 2016 criteria are not applicable when deformation is outward
* The windshield damage occurred after a vertical crack propagated through the adhesive liner. The windshield was partially caved in, but this deformation was unrelated to impact and thus does not violate MASH 2016 evaluation criteria.

5.5 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec moving average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 7. 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 7. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix D.

Table 7. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. H42BR-1

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 (primary)	SLICE-2	
OIV ft/s	Longitudinal	−24.54	−24.03	±40
	Lateral	−31.41	−30.61	±40
ORA g's	Longitudinal	−4.01	−3.55	±20.49
	Lateral	−12.15	−13.20	±20.49
MAX. ANGULAR DISPL. deg.	Roll	4.8	3.2	±75
	Pitch	−4.3	−3.4	±75
	Yaw	−33.3	−33.1	not required
THIV ft/s		36.43	33.92	not required
PHD g's		12.79	13.57	not required
ASI		2.45	2.37	not required

5.6 Barrier Loads

The longitudinal and lateral vehicle accelerations, as measured at the vehicle's c.g., were processed using an SAE CFC-60 filter and a 50-msec moving average. The 50-msec moving average vehicle accelerations were then combined with the uncoupled yaw angle versus time data in order to estimate the vehicular loading applied to the barrier system. From the data analysis, the perpendicular impact forces were determined for the bridge rail, as shown in Figure 44. A maximum perpendicular (i.e., lateral) impact load equal to 56.3 kips was imparted on the barrier at 0.031 s after impact, as determined by the SLICE-1 (primary) unit. A peak frictional load of 16.5 kips was observed 0.064 s after impact.

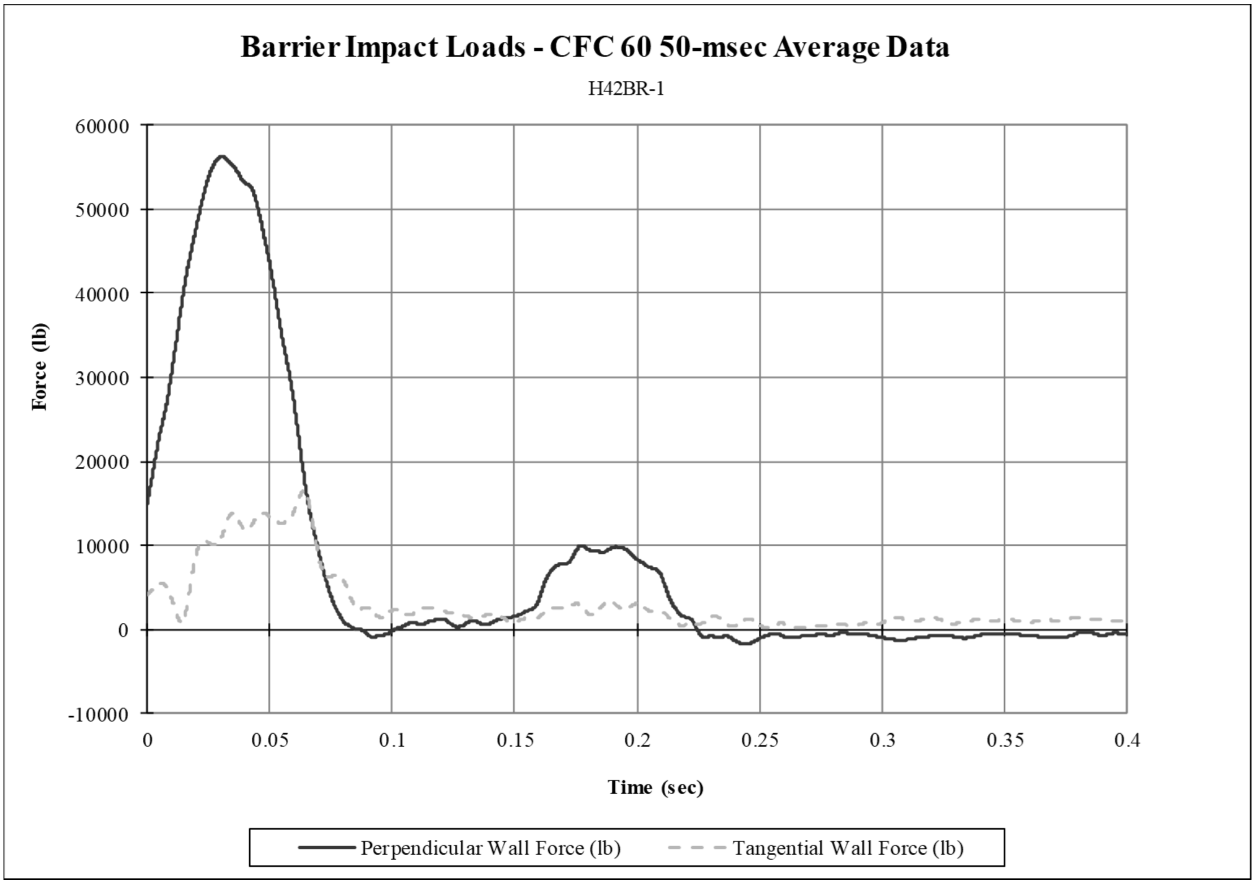
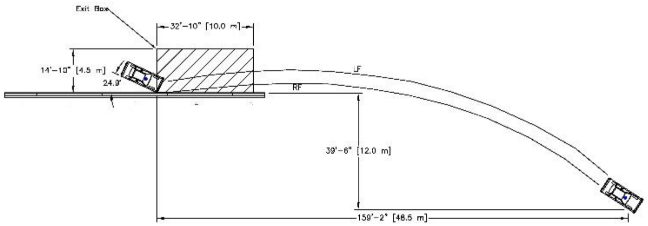


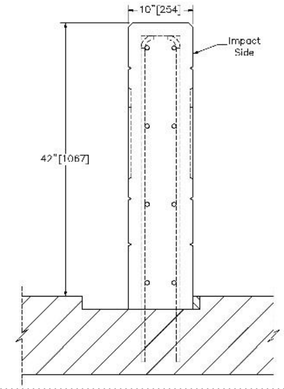
Figure 44. Perpendicular and Tangential Forces Imparted to the Barrier System (SLICE-1), Test No. H42BR-1

5.7 Discussion

The analysis of the test results for test no. H42BR-1 showed that the system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 45. 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 or pedestrians. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. A vertical crack on the windshield propagated through the adhesive liner and deformed inward. Since the deformation was due to shearing and fracture of the windshield caused by crushing of the right-front corner of the windshield and the damage did not occur due to direct contact with the test article or pose a penetration hazard to the vehicle occupant, this damage was not a violation of MASH 2016 criteria. 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 5.6 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. H42BR-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-10.

0.000 sec | 0.050 sec | 0.100 sec | 0.150 sec | 0.250 sec





- Test Agency .... MwRSF
- Test Number H42BR-1
- Date .... July 17, 2019
- MASH 2016 Test Designation No. 3-10
- Test Article .... HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail
- Total Length .... 88 ft
- Key Component – 22-ft Concrete Parapet
  - Length .... 22 ft
  - Height .... 42 in.
  - Width .... 10 in.
- Key Component – 11-ft Concrete Parapet
  - Length .... 11 ft
  - Height .... 42 in.
  - Width .... 10 in.
- Vehicle Make /Model .... 2009 Kia Rio
  - Curb .... 2,498 lb
  - Test Inertial .... 2,421 lb
  - Gross Static .... 2,584 lb
- Impact Conditions
  - Speed .... 63.2 mph
  - Angle .... 24.9 deg.
  - Impact Location .... 47.1 in. U.S. from expansion gap between barrier nos. 3 and 4
- Impact Severity .... 57.4 kip-ft > 51.1 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed .... 42.8 mph
  - Angle .... 5.6 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 159 ft – 2 in. downstream, 39 ft – 6 in. behind barrier
- Vehicle Damage .... Moderate
  - VDS [13] 1-RFQ-4
  - CDC [14] 01RFEW3
  - Maximum Interior Deformation .... 4.7 in.
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... 0.1 in.
  - Dynamic .... 0.2 in.
  - Working Width .... 10.2 in.
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1 (primary)	SLICE-2	
OIV ft/s	Longitudinal	−24.54	−24.03	±40
	Lateral	−31.41	−30.61	±40
ORA g's	Longitudinal	−4.01	−3.55	±20.49
	Lateral	−12.15	−13.20	±20.49
MAX ANGULAR DISP. deg.	Roll	4.8	3.2	±75
	Pitch	−4.3	−3.4	±75
	Yaw	−33.3	−33.1	not required
THIV – ft/s		36.43	33.92	not required
PHD – g's		12.79	13.57	not required
ASI		2.45	2.37	not required

Figure 45. Summary of Test Results and Sequential Photographs, Test No. H42BR-1

6 FULL-SCALE CRASH TEST NO. H42BR-2

6.1 Weather Conditions

Test no. H42BR-2 was conducted on August 19, 2019 at approximately 12:00 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 8.

Table 8. Weather Conditions, Test No. H42BR-2

Temperature	85° F
Humidity	63 percent
Wind Speed	10 mph
Wind Direction	120° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	1.08 in.

6.2 Test Description

Test no. H42BR-2 was conducted on HDOT's 42-in. Tall, Aesthetic Concrete Bridge Rail under MASH 2016 guidelines for test designation no. 3-11. Test designation no. 3-11 is an impact of a 2270P test vehicle at 62 mph and 25 degrees on the system. The critical impact point for this test was selected to be 4 ft – $3^5/_8$ in. upstream from the expansion joint between barrier segment nos. 2 and 3 to maximize the potential for vehicle interaction and snag on the expansion joint and the edge of the aesthetic asperities in the rail, as shown in Figure 46, which was selected from Table 2.7 of MASH 2016. The 5,007-lb quad cab pickup truck impacted the HDOT 42-in Tall, Aesthetic Concrete Bridge Rail at a speed of 62.7 mph and an angle of 25.1 degrees. The actual point of impact was 2.7 in. downstream from the target location. During the test, the vehicle was captured and redirected by the system. During the redirection of the vehicle, the right-front fender and right-front wheel experienced minor snag on the expansion joint and the edge of the aesthetic recesses downstream from impact. The snag was sufficient to push the right-front tire backward and crush the front portion of the right-front fender. 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. The vehicle came to rest 226 ft – 10 in. downstream from the impact point and 29 ft – 10 in. laterally behind the traffic side of the barrier after the vehicle's brakes were applied.

A detailed description of the sequential impact events is contained in Table 9. Sequential photographs are shown in Figure 47. Documentary photographs of the crash test are shown in Figure 48. The vehicle trajectory and final position are shown in Figure 49.

Figure 46. Impact Location, Test No. H42BR-2

Table 9. Sequential Description of Impact Events, Test No. H42BR-2

TIME (sec)	EVENT
0.000	Vehicle’s front bumper contacted concrete barrier 48.9 in. upstream from expansion gap between barrier nos. 2 and 3.
0.002	Vehicle’s right headlight contacted concrete barrier.
0.004	Vehicle’s right headlight deformed.
0.006	Vehicle’s right fender contacted concrete barrier.
0.008	Vehicle’s front bumper deformed, and vehicle’s right-front wheel contacted concrete barrier.
0.010	Vehicle’s right fender deformed, and vehicle’s right headlight shattered.
0.014	Vehicle’s hood contacted concrete barrier.
0.022	Vehicle’s hood deformed, vehicle’s grille contacted concrete barrier, and vehicle’s right-front wheel contacted concrete barrier.
0.024	Vehicle’s right-front wheel deflated.
0.026	Vehicle’s grille deformed.
0.036	Vehicle’s right-front door contacted concrete barrier.
0.038	Vehicle’s right-front door deformed.
0.056	Vehicle yawed away from system and rolled toward system.
0.058	Vehicle’s right-front door flexed away from frame at top.
0.066	Vehicle’s grille became disengaged.
0.068	Vehicle’s windshield cracked, and vehicle’s left headlight deformed.
0.070	Vehicle’s roof experienced flexure.
0.076	Vehicle’s right-front window shattered.
0.096	Vehicle’s left-front tire became airborne.
0.110	Simulated occupant’s head passed through right-front window opening.
0.122	Simulated occupant’s head reentered through right-front window opening.
0.132	Vehicle’s right-rear door contacted concrete barrier.
0.134	Vehicle’s right-rear door deformed.
0.146	Vehicle’s left-rear tire became airborne.
0.168	Vehicle’s right quarter panel contacted concrete barrier.
0.188	Vehicle’s right quarter panel deformed.
0.194	Vehicle was parallel to system traveling at 47.5 mph.
0.196	Vehicle’s right taillight contacted concrete barrier.
0.198	Vehicle’s right taillight deformed.
0.200	Vehicle’s right taillight shattered.
0.204	Vehicle’s rear bumper contacted concrete barrier.

0.206	Vehicle’s rear bumper deformed.
0.214	Vehicle’s left headlight became disengaged.
0.228	Vehicle’s right-front tire became airborne.
0.232	Vehicle pitched downward.
0.356	Vehicle’s right-front tire regained contact with ground.
0.366	Vehicle exited system at 46.3 mph and a 7.8 degree angle.
0.428	Vehicle rolled away from system.
0.446	Vehicle’s left-front tire regained contact with ground.
0.534	Vehicle’s left-rear tire regained contact with ground.
0.738	Vehicle yawed toward system.
0.770	Vehicle pitched downward.
0.772	Vehicle rolled toward system.
1.032	Vehicle rolled away from system.
6.192	Vehicle came to a rest.

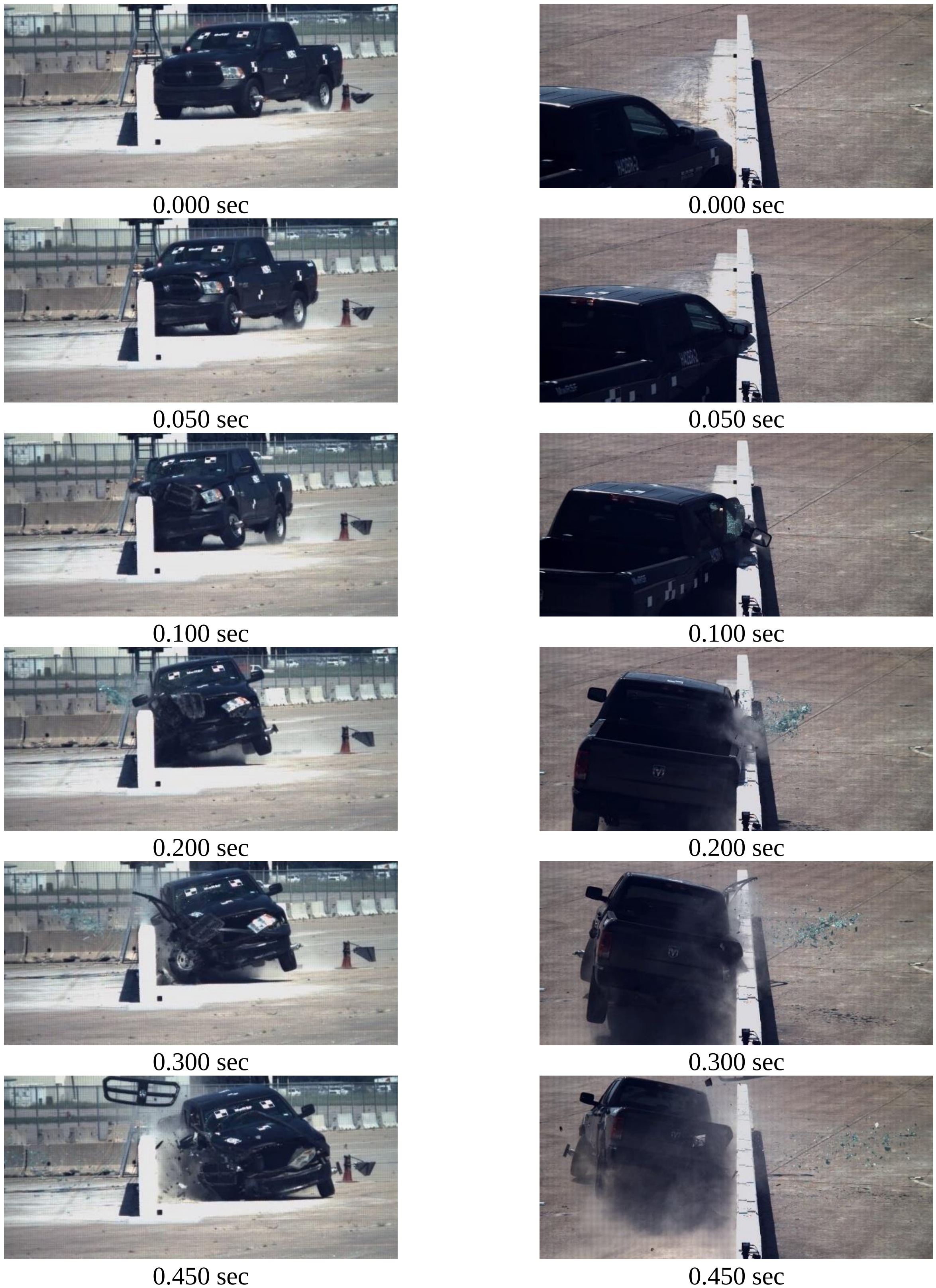


Figure 47. Sequential Photographs, Test No. H42BR-2

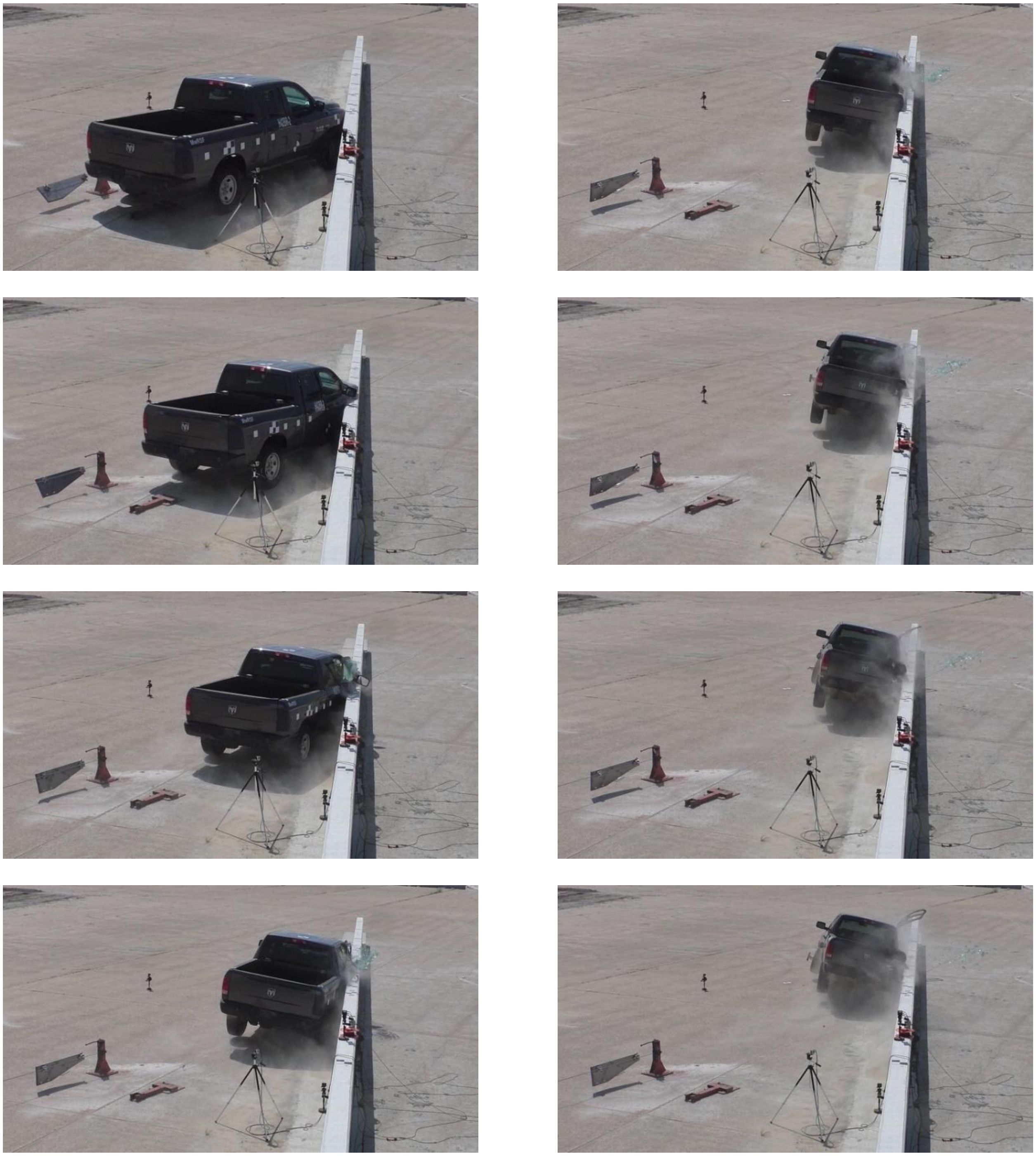


Figure 48. Documentary Photographs, Test No. H42BR-2

Figure 49. Vehicle Final Position and Trajectory Marks, Test No. H42BR-2

6.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 50 through 57. Barrier damage consisted of contact marks and concrete spalling on the front face of the barrier. The total length of vehicle contact along the barrier was 12 ft – 10 in., which spanned from 12½ in. upstream from the impact point to 11 ft – 9½ in. downstream from the impact point. Note that any cracking visible in the system photographs was documented beforehand and not a result of test no. H42BR-2.

Tire marks were visible on the front face of barrier nos. 2 and 3. Scuff marks were also found on the front and top faces of barrier nos. 2 and 3. A 137-in. long by 30-in. tall contact mark began 12½ in. upstream from the impact point at the bottom of the barrier. A 147-in. long by 12-in. tall contact mark began 6 in. upstream from the impact point at the top edge of the barrier. A 117½-in. long by 3¼-in. wide contact mark was found on the top face of the barrier, beginning on the front face 4 in. downstream from the impact point.

Minor surface gouging was observed along the second-lowest horizontal asperity on the barrier, beginning 5 in. downstream from the impact point and extending 39 in. downstream. The front chamfer on the top of the barrier had minor concrete damage, beginning 1½ in. downstream from the impact point and continuing 100 in. downstream. The rest of the damage to the system consisted of minor concrete damage to the aesthetic recesses and is summarized in Table 10. Note there was no observable damage or cracking to the top or backside of the barrier or to the expansion joint.

Table 10. Damage to Aesthetic Recesses, Test No. H42BR-2

Recess No.	Relative to Expansion Joint[1]	Length in.	Height in.	Recess Edge
5	Upstream	¾	4¼	Upstream
		5	6¾	Bottom
		1¾	5	Downstream
4	Upstream	1	10	Upstream
		5½	2	Bottom
		1¼	13	Downstream
3	Upstream	½	1¾	Upstream
		5½	4½	Bottom
		½	8	Downstream
2	Upstream	8	7¾	Upstream Bottom Downstream
1	Upstream	1	6	Upstream
		6	½	Bottom
		4¼	6¾	Downstream
1	Downstream	1	3	Downstream
2	Downstream	¾	3	Downstream

[1] Expansion joint between barrier nos. 2 and 3

Figure 50. System Damage, Test No. H42BR-2

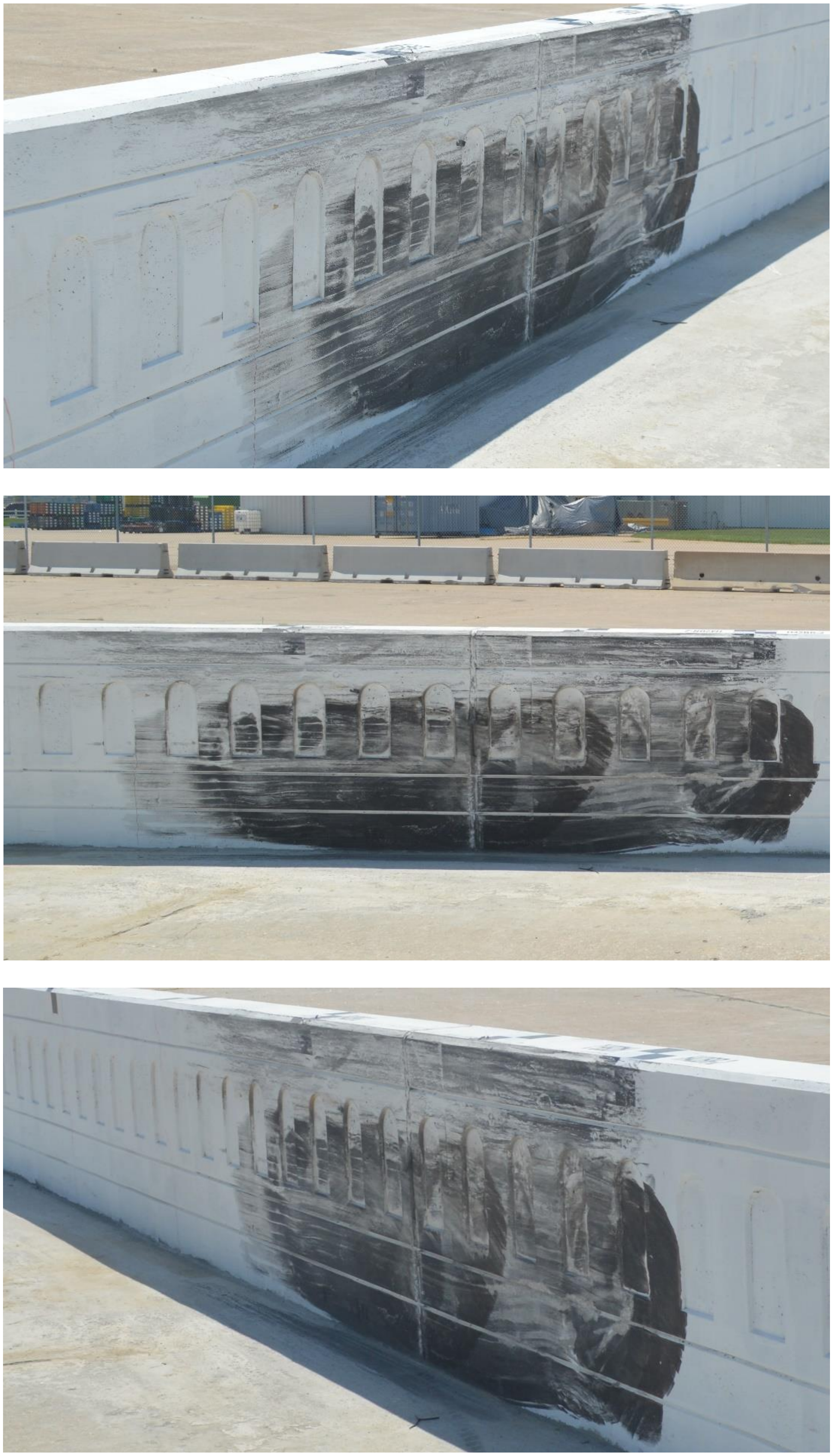


Figure 51. System Damage, Test No. H42BR-2

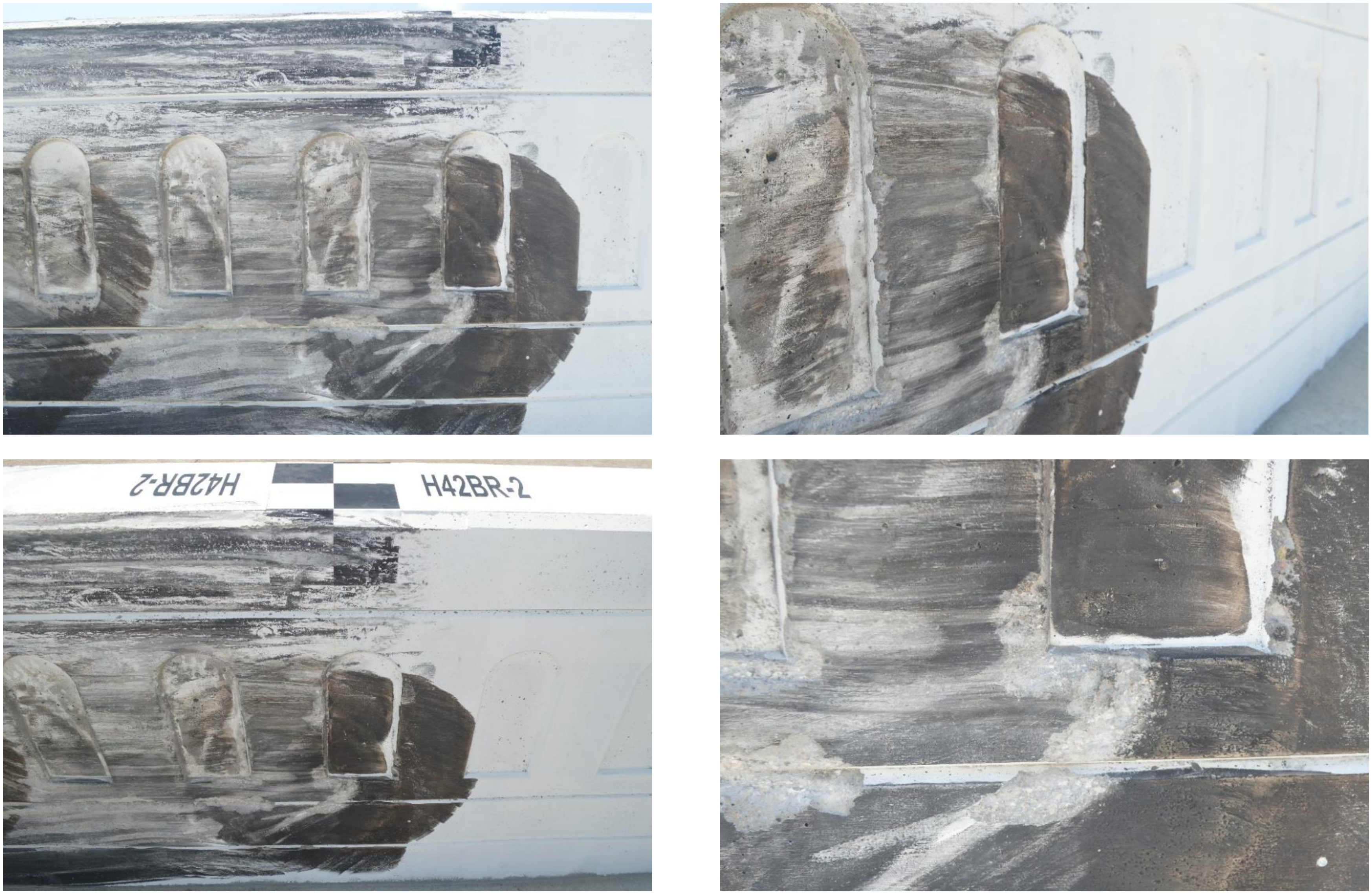


Figure 52. System Damage, Test No. H42BR-2

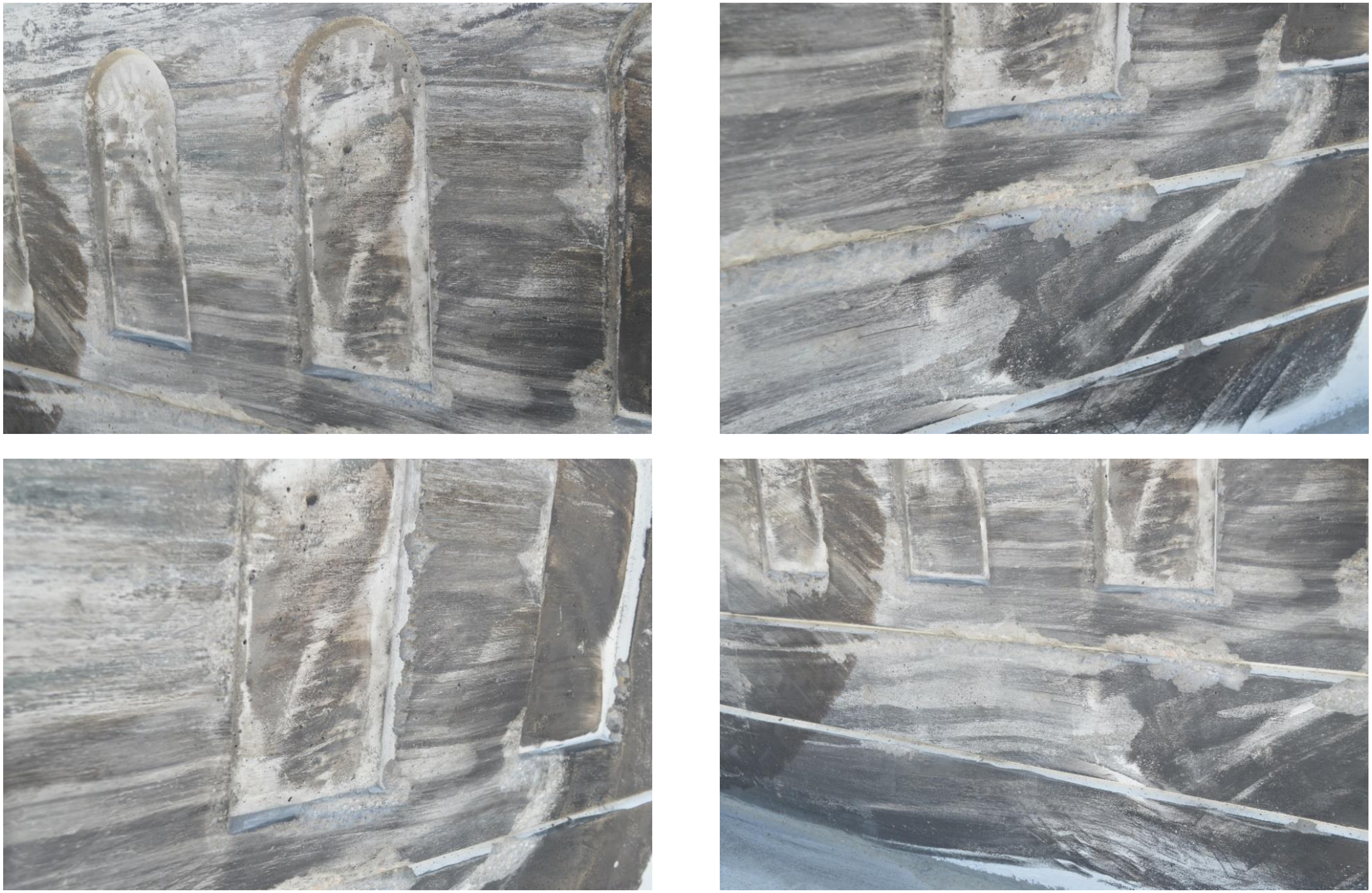


Figure 53. System Damage, Test No. H42BR-2

Figure 54. System Damage, Test No. H42BR-2

Figure 55. System Damage, Test No. H42BR-2

Figure 56. System Damage Behind Impact Point, Test No. H42BR-2

Figure 57. System Damage at Expansion Joint, Test No. H42BR-2

The maximum lateral permanent set of the barrier system was 0.2 in., as measured in the field. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 0.5 in. at barrier no. 3, as determined from high-speed digital video analysis. The working width of the system was found to be 10.5 in., also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 58.

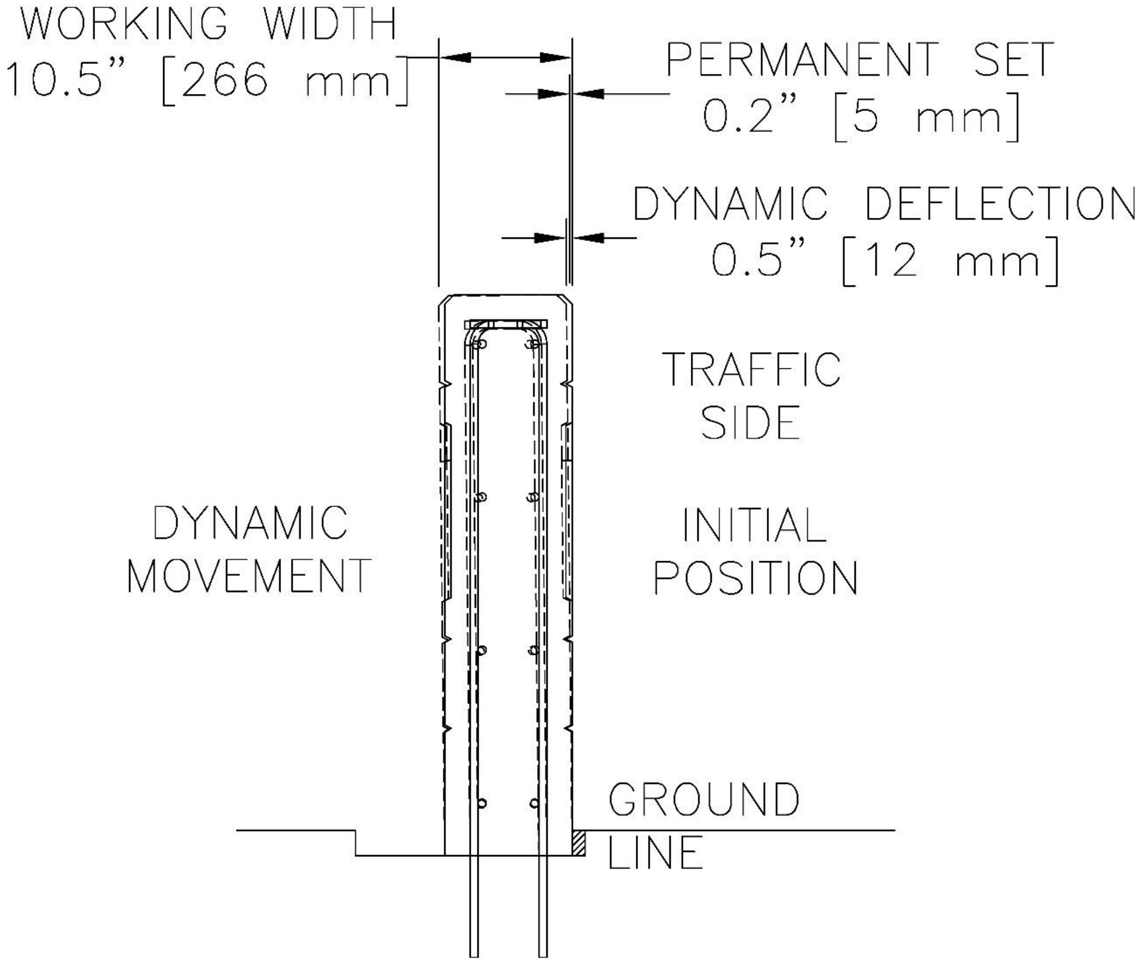


Figure 58. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. H42BR-2

6.4 Vehicle Damage

Damage to the vehicle was moderate, as shown in Figures 59 through 62. The maximum occupant compartment intrusions are listed in Table 11, along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment, and none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix C.

The majority of the damage was concentrated on the right-front corner and right side of the vehicle where impact occurred. The right side of the front bumper was crushed inward and bent across its entire width. The right-front fender was crushed inward across its entire length. The right-front tire was partially disengaged from the steel rim and the right-front steel rim was deformed. The front headlights and front grille were disengaged from the vehicle. The hood was crushed inward on its right edge. The right-front door was crushed in the middle, pinching the latch. The entire right side of the vehicle was scraped. The right side of the bed was crushed inward along its entire length. The right-rear taillight was disengaged from the vehicle. The right side of the rear bumper was crushed inward. The windshield had severe cracking across its entire length. The right-front side window was removed from the vehicle due to crush of the side of the vehicle door and contact with the dummy's head. The window damage was not due to contact with the test article. The roof and remaining window glass remained undamaged. The right-front shock was bent outward. The right-side bump stop mount was crushed inward and compressed. The front anti-roll bar and the right-front steering knuckle were disengaged from the vehicle and the right-side lower control arm was disengaged from its mounts. The right-side upper control arm was bent inward. The right-side tie rod was disengaged from the vehicle. The left-side transmission mount was torn at the bolt holes. The right-side frame rail was bent inward. The middle cross member was buckled near its center and the right-side frame horn was pushed inward.

Figure 59. Vehicle Damage, Test No. H42BR-2

Figure 60. Vehicle Damage, Test No. H42BR-2

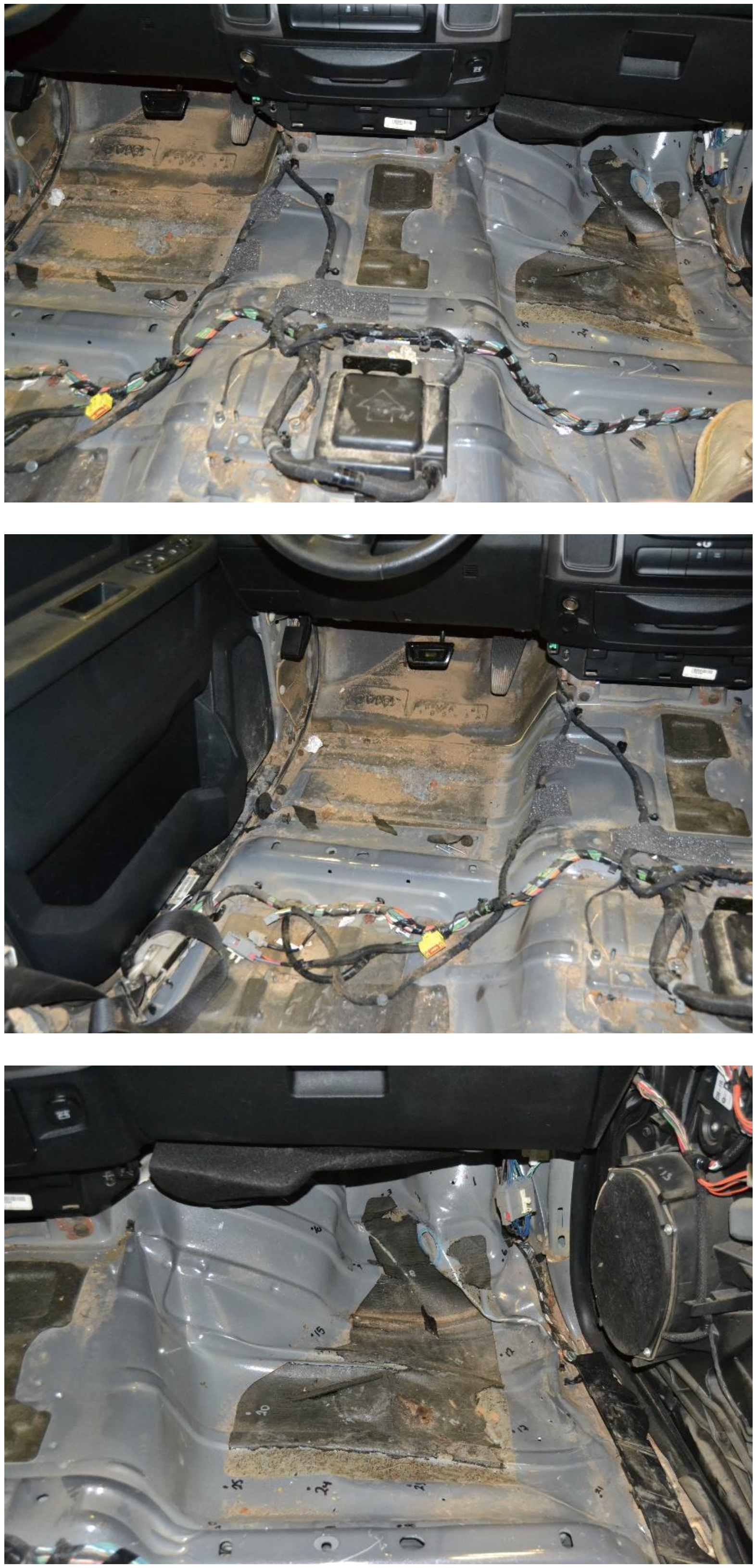


Figure 61. Occupant Compartment Damage, Test No. H42BR-2

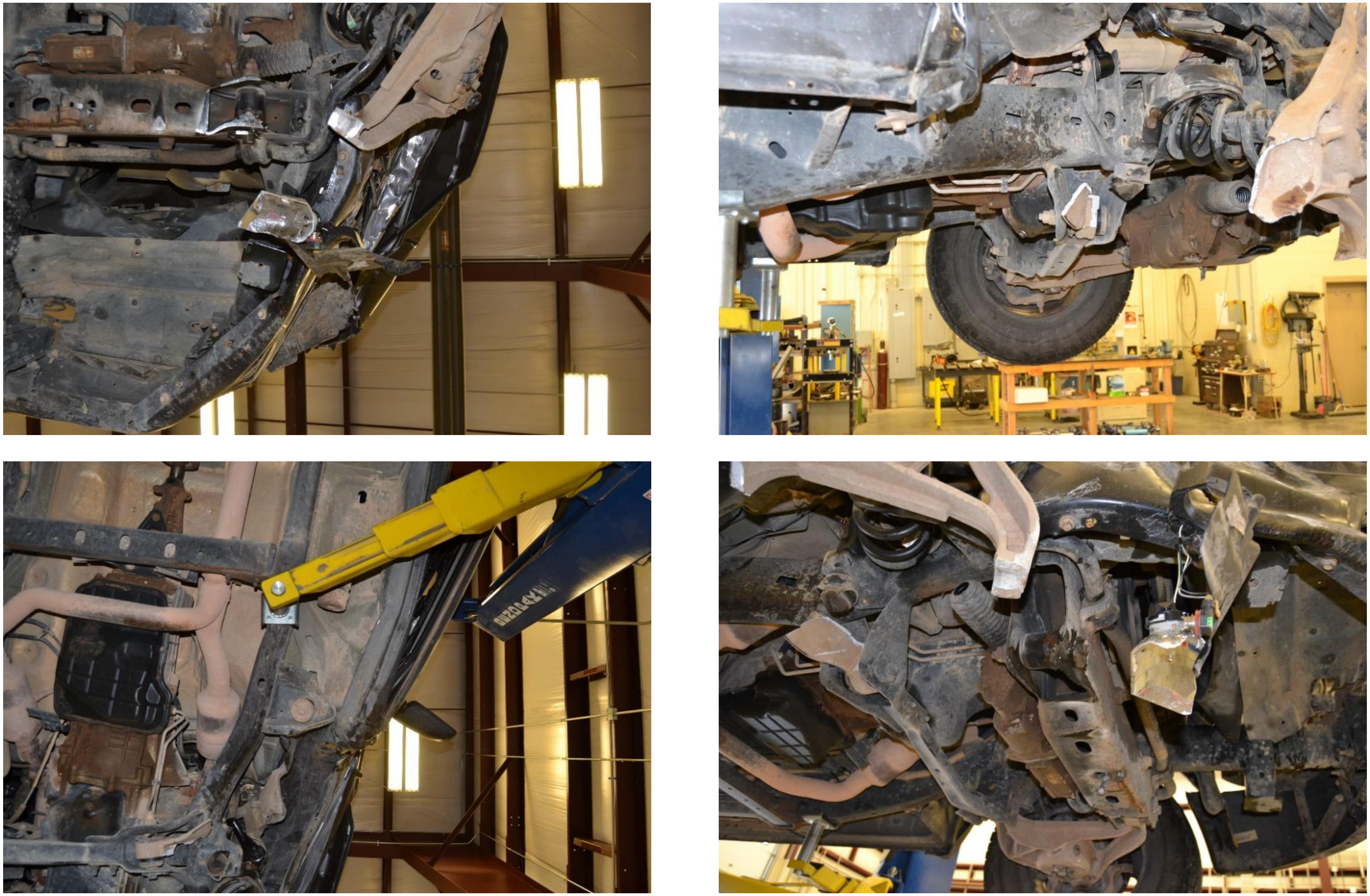


Figure 62. Undercarriage Damage, Test No. H42BR-2

Table 11. Maximum Occupant Compartment Intrusion by Location, Test No. H42BR-2

LOCATION	MAXIMUM INTRUSION in.	MASH 2016 ALLOWABLE INTRUSION in.
Wheel Well & Toe Pan	5.5	≤ 9
Floor Pan & Transmission Tunnel	0.5	≤ 12
A-Pillar	0.1	≤ 5
B-Pillar	0.2	≤ 5
A-Pillar (lateral)	0.1	≤ 3
B-Pillar (lateral)	0.0	≤ 3
Side Front Panel	4.8	≤ 12
Side Door (above seat)	0.9	≤ 9
Side Door (below seat)	2.1	≤ 12
Roof	0.1	≤ 4
Windshield	0.0	≤ 3
Side Window	Shattered due to contact with dummy's head	No shattering resulting from contact with structural member of test article
Dash	1.7	N/A[1]

N/A[1] – No MASH 2016 criteria exist for this location

6.5 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec moving average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 12. 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 7. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 12. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. H42BR-2

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 (primary)	SLICE-2	
OIV ft/s	Longitudinal	−20.88	−21.45	±40
	Lateral	−23.95	−26.92	±40
ORA g's	Longitudinal	−6.02	−6.03	±20.49
	Lateral	−8.04	−6.41	±20.49
MAX. ANGULAR DISPL. deg.	Roll	14.1	10.7	±75
	Pitch	−3.1	−4.9	±75
	Yaw	−40.9	−41.1	not required
THIV ft/s		31.58	33.92	not required
PHD g's		8.47	7.19	not required
ASI		1.70	1.87	not required

6.6 Barrier Loads

The longitudinal and lateral vehicle accelerations, as measured at the vehicle's c.g., were processed using an SAE CFC-60 filter and a 50-msec moving average. The 50-msec moving average vehicle accelerations were then combined with the uncoupled yaw angle versus time data in order to estimate the vehicular loading applied to the barrier system. From the data analysis, the perpendicular impact forces were determined for the bridge rail, as shown in Figure 63. A maximum perpendicular (i.e., lateral) impact load equal to 80.1 kips was imparted on the barrier at 0.051 s after impact, as determined by the SLICE-1 (primary) unit. A peak frictional load of 22.4 kips was observed 0.0255 s after impact.

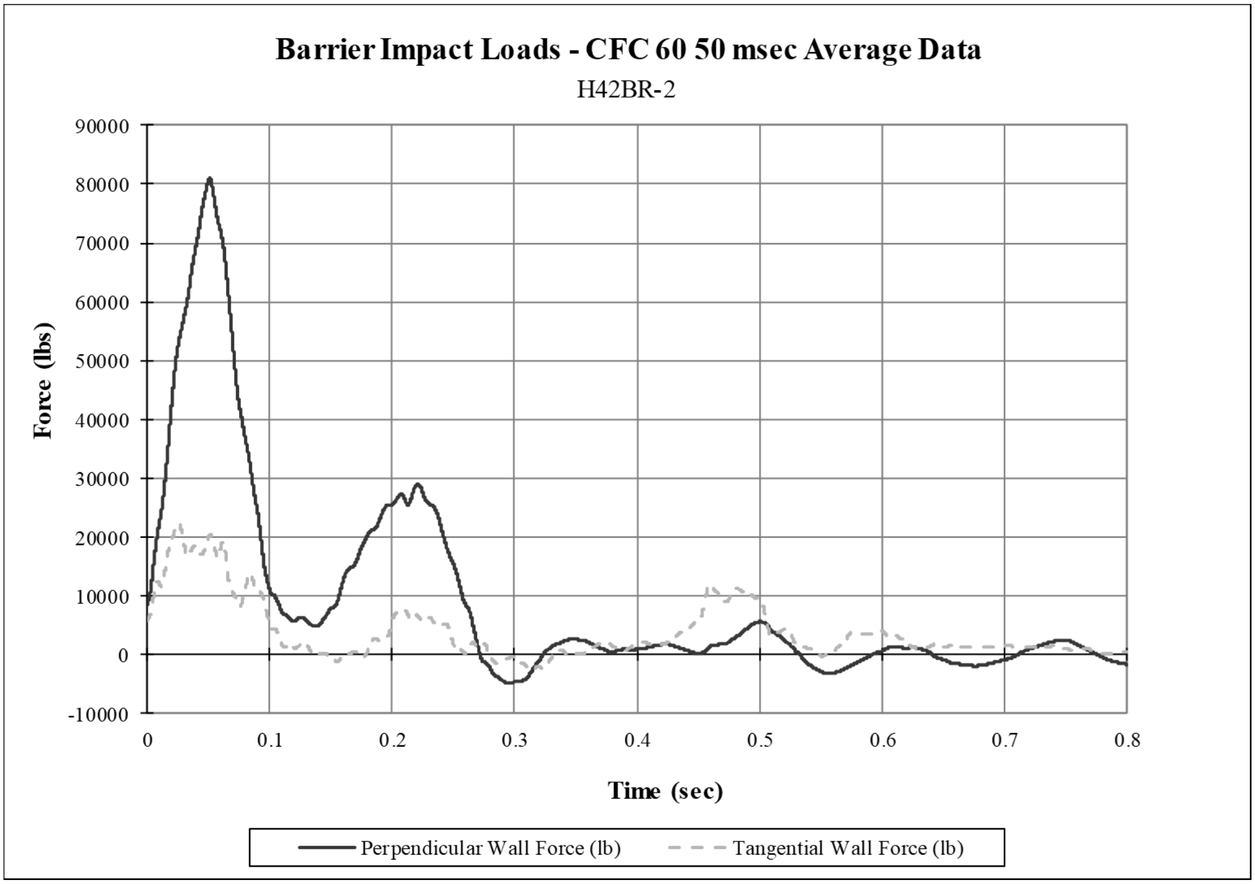
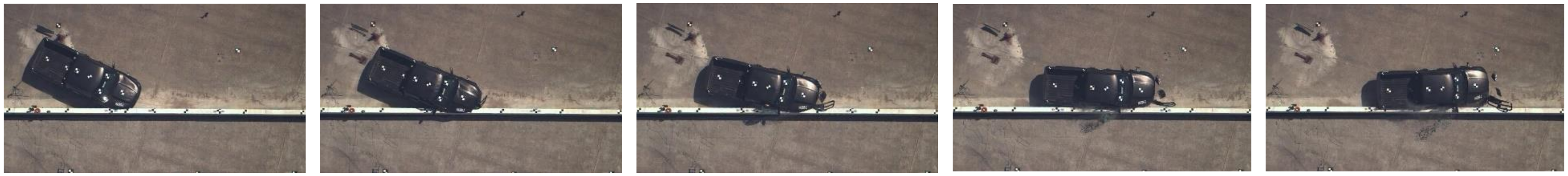


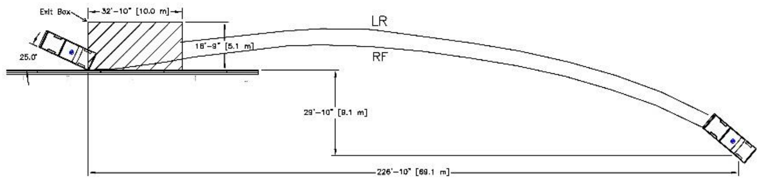
Figure 63. Perpendicular and Tangential Forces Imparted to the Barrier System (SLICE-1), Test No. H42BR-2

6.7 Discussion

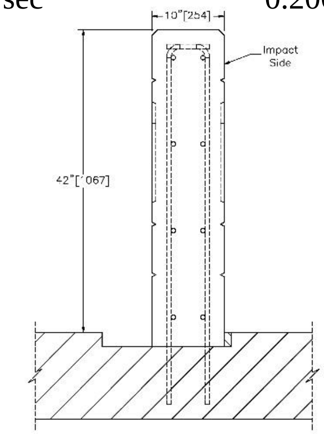
The analysis of the test results for test no. H42BR-2 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 64. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 7.8 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. H42BR-2 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.



0.000 sec | 0.050 sec | 0.100 sec | 0.150 sec | 0.200 sec



- Test Agency .... MwRSF
- Test Number H42BR-2
- Date .... August 19, 2019
- MASH 2016 Test Designation No. 3-11
- Test Article .... HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail
- Total Length .... 88 ft
- Key Component – 22-ft Concrete Parapet
  - Length .... 22 ft
  - Height .... 42 in.
  - Width .... 10 in.
- Key Component – 11-ft Concrete Parapet
  - Length .... 11 ft
  - Height .... 42 in.
  - Width .... 10 in.
- Vehicle Make /Model .... 2014 Dodge Ram 1500
  - Curb .... 5,230 lb
  - Test Inertial .... 5,007 lb
  - Gross Static .... 5,170 lb
- Impact Conditions
  - Speed .... 62.7 mph
  - Angle .... 25.1 deg.
  - Impact Location .... 48.9 in. U.S. from expansion gap between barrier nos. 2 and 3
- Impact Severity .... 118.5 kip-ft > 105.6 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed .... 46.3 mph
  - Angle .... 7.8 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 226 ft – 10 in. downstream, 29 ft – 10 in. behind barrier
- Vehicle Damage .... Moderate
  - VDS [13] 1-RFQ-4
  - CDC [14] 01RFEW3
  - Maximum Interior Deformation .... 5.5 in.



- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... 0.2 in.
  - Dynamic .... 0.5 in.
  - Working Width .... 10.5 in.
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1 (primary)	SLICE-2	
OIV ft/s	Longitudinal	−20.88	−21.45	±40
	Lateral	−23.95	−26.92	±40
ORA g's	Longitudinal	−6.02	−6.03	±20.49
	Lateral	−8.04	−6.41	±20.49
MAX ANGULAR DISP. deg.	Roll	14.1	10.7	±75
	Pitch	−3.1	−4.9	±75
	Yaw	−40.9	−41.1	not required
THIV – ft/s		31.58	33.92	not required
PHD – g's		8.47	7.19	not required
ASI		1.70	1.87	not required

Figure 64. Summary of Test Results and Sequential Photographs, Test No. H42BR-2

7 SUMMARY AND CONCLUSIONS

The objective of this project was to evaluate the HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail in accordance with the MASH 2016 TL-3 safety performance criteria. A summary of the testing and evaluation is shown in Table 13. The system consisted of two 11-ft long end segments and three 22-ft long interior barrier segments with aesthetic recesses on the front and back faces spaced 12 in. apart, measuring 6 in. wide and 14 in. tall with a 3-in. top-edge radius. The design compressive strength of the concrete was 4,000 psi. The existing concrete tarmac surface was milled to a depth of 2 in. and filled with low-strength concrete after removal of the formwork to replicate the wearing surface of a bridge deck. ASTM Grade 60 rebar was used for all longitudinal and vertical reinforcement. Vertical reinforcement bars were anchored to an existing concrete tarmac on both the traffic- and back-side faces to a depth of 8 in. and epoxied with Hilti HIT RE-500 V3 in order to develop the full tensile strength of the bar. Each barrier segment was separated by an expansion joint consisting of a ½-in. open gap filled with expansion joint sealant. The expansion joint assembly consisted of four 24-in. long No. 8 horizontal smooth rebar placed within PVC tubes and caps that were cast into the parapet. The test setup for test nos. H42BR-1 and H42BR-2 were identical with the exception that the impact locations were varied per MASH 2016 guidelines.

In test no. H42BR-1, the 2,421-lb small car impacted the HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail at a speed of 63.2 mph and an angle of 24.9 degrees, resulting in an impact severity of 57.4 kip-ft. Impact occurred 47.1 in. upstream from the expansion gap between barrier nos. 3 and 4, and the vehicle exited the system at a speed of 42.8 mph and an angle of 5.6 degrees. The vehicle was successfully contained and smoothly redirected with minor damage to the system and moderate damage to the vehicle. All vehicle decelerations, occupant compartment deformations, ORAs, and OIVs fell within the recommended safety limits established in MASH 2016. Therefore, test no. H42BR-1 was successful according to the safety criteria of MASH 2016 test designation no. 3-10.

In test no. H42BR-2, the 5,007-lb quad cab pickup truck impacted the HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail at a speed of 62.7 mph and an angle of 25.1 degrees, resulting in an impact severity of 118.5 kip-ft. Impact occurred 48.9 in. upstream from the expansion gap between barrier nos. 2 and 3, and the vehicle exited the system at a speed of 46.3 mph and an angle of 7.8 degrees. The vehicle was successfully contained and smoothly redirected with minor damage to the system and moderate damage to the vehicle. All vehicle decelerations, occupant compartment deformations, ORAs, and OIVs fell within the recommended safety limits established in MASH 2016. Therefore, test no. H42BR-2 was successful according to the safety criteria of MASH 2016 test designation no. 3-11.

Based on the successful completion of the two full-scale crash tests required for evaluation of longitudinal barriers, the HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail meets the safety criteria for MASH 2016 TL-3. It should be noted that test nos. H42BR-1 and H42BR-2 were conducted on the LON interior barrier segments, so the crashworthiness of the end segments and transition buttresses were not evaluated in this report. It is recommended that end sections and buttresses be designed with similar or greater capacity to the bridge rail.

Table 13. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. H42BR-1</th><th>Test No. H42BR-2</th></tr>
<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><td>S</td><td>S</td></tr>
<tr><td rowspan="6">Occupant Risk</td><td rowspan="2">D.</td><td colspan="3">1. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</td><td>S</td><td>S</td></tr>
<tr><td colspan="3">2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>S</td><td>S</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 deg.</td><td>S</td><td>S</td></tr>
<tr><td>H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:
<table><tr><th colspan="3">Occupant Impact Velocity Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>30 ft/s</td><td>40 ft/s</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td>I.</td><td 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:
<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td colspan="5">MASH 2016 Test Designation No.</td><td>3-10</td><td>3-11</td></tr>
<tr><td colspan="5">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory   U – Unsatisfactory   NA - Not Applicable

8 REFERENCES

1. Bullard, L.D., Sheikh N.M., Bligh R.P., Haug, R.R., Schutt, J.R., and Storey, B.J., *Aesthetic Concrete Barrier Design*, NCHRP Report No. 554, Texas Transportation Institute, Texas A&M University, College Station, Texas, 2006.

2. White, M., Jewell, J., and Peter, R., *Crash Testing of Various Textured Barriers*, Contact No. F2001TL17, California Department of Transportation, Sacramento, California, 2002.

3. Taylor, H.W., *HSA-10/B110*, December, 2002.

4. Ross, H.E., Jr., Sicking, D.L., Zimmer, R.A., and Michie, J.D., *Recommended Procedures for the Safety Performane Evaluation of Highway Features,* NCHRP Report No. 350, Transportation Research Board, National Research Council, Washington D. C., 1993.

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

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

9 APPENDICES

Appendix A. Material Specifications

Table A-1. Bill of Materials, Test Nos. H42BR-1 and H42BR-2

Item No.	Description	Material/Treatment Specification	Reference
a1	Reinforced Concrete	Min. f'c = 4,000 psi NE Mix 47BD	Ticket#4216469 #4216463 Test Report #2147371348
a2	Low-Strength Concrete Overlay	Concrete NE Mix 9019 CITY	Ticket#1237834
b1	#5 Rebar 54¾ in. Total Unbent Length	ASTM A615 Gr. 60 Epoxy Coated (ASTM A775 or A934)	H#3600002833
b2	#5 Rebar 46⅞ in. Total Unbent Length	ASTM A615 Gr. 60 Epoxy Coated (ASTM A775 or A934)	H#3600002833
b3	#5 Rebar 259½ in. Total Length	ASTM A615 Gr. 60 Epoxy Coated (ASTM A775 or A934)	H#3600002833
b4	#5 Rebar 127¾ in. Total Length	ASTM A615 Gr. 60 Epoxy Coated (ASTM A775 or A934)	H#3600002833
c1	#8 Smooth Rebar 24 in. Total Length	ASTM A615 Gr. 60 Epoxy Coated (ASTM A775 or A934)	H#KN1503046
c2	1¼-in. Dia. PVC Pipe	Schedule 80 PVC Gr. 12454	Georg Fischer Harvel LLC COC
c3	1¼-in. PVC Cap	Schedule 80 PVC Gr. 12454	COC Fastenal T#120346463 P#0470592
c4	Epoxy Adhesive	Hilti HIT RE-500 V3	Hilti COC
c5	Expansion Joint Filler	AASHTO M33, M153, or M213	W.R. Meadows Seal Tight Fiber Expansion Joint that meets M213 Data Product Sheet
c6	Expansion Joint Sealant	AASHTO M173, M282, M301, ASTM D3581, or ASTM D5893	Pecora 301NS Data Sheet

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	126	9629	62461			H42BR	6/20/19	12:58 PM	4216469

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

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
3.50	12.50	12.50	470031PF	47BD (1PF)	yd	$123.00	$430.50

Water Added On Job At Customer's Request:	SLUMP	Notes:		
____________	4.00 in		TICKET SUBTOTAL	$430.50
			SALES TAX	$0.00
			TICKET TOTAL	**$430.50**
			PREVIOUS TOTAL	$1,107.00
			GRAND TOTAL	**$1,537.50**

CAUTION FRESH CONCRETE

KEEP CHILDREN AWAY

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

Terms & Conditions

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

Figure A-1. Reinforced Concrete, Test Nos. H42BR-1 and H42BR-2

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** 11-Jul-19
Project Name: Miscellaneous Concrete Testing
Placement Location: H42BR

Mix Designation: **Required Strength:**

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-127	C	6/20/2019	7/11/2019	7/11/2019	21	0	21	12	6.01	28.37	138,223	4,870		5	C 1231
URR-128	D	6/20/2019	7/11/2019	7/11/2019	21	0	21	12	6.02	28.46	127,978	4,500		5	C 1231

1 cc: Ms. Karla Lechtenberg
Midwest Roadside Safety Facility

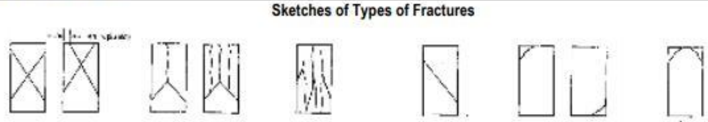
Remarks: Email results to Shaun Tighe (stighe2@unl.edu)

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

Report Number 2147371348
Page 1

Sketches of Types of Fractures



Type 1 Reasonably well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps

Type 2 Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end

Type 3 Columnar vertical cracking through both ends, no well-formed cones

Type 4 Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type 1

Type 5 Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6 Similar to Type 5 but end of cylinder is pointed

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By [signature]

Figure A-2. Compression Test Cylindrical Concrete Specimen, Test Nos. H42BR-1 and H42BR-2

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	242	9264	62461			H42BR	6/20/19	12:02 PM	4216463

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

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
9.00	9.00	12.50	470031PF	47BD (1PF)	yd	$123.00	$1,107.00

Water Added On Job At Customer's Request:	SLUMP	Notes:		
______________	4.00 in		TICKET SUBTOTAL	$1,107.00
			SALES TAX	$0.00
			TICKET TOTAL	**$1,107.00**
			PREVIOUS TOTAL	
			GRAND TOTAL	**$1,107.00**

CAUTION FRESH CONCRETE

KEEP CHILDREN AWAY

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

Terms & Conditions

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

Figure A-3. Reinforced Concrete, Test Nos. H42BR-1 and H42BR-2

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
01	250	9342	62461			H42BR	6/25/19	7:20 AM	1237834

Customer: UNL-MIDWEST ROADSIDE SAFETY

Delivery Address: 4630 NW 36TH ST

Special Instructions: AIRPARK / NORTH OF OLD GOOD YEARHANGERS

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
8.00	8.00	8.00	**14013000**	**SG4000**	yd	$118.50	$948.00

Water Added On Job At Customer's Request: ______

SLUMP: 3.00 in

Notes:

TICKET SUBTOTAL	$948.00
SALES TAX	$0.00
TICKET TOTAL	**$948.00**
PREVIOUS TOTAL	
GRAND TOTAL	**$948.00**

CAUTION FRESH CONCRETE

KEEP CHILDREN AWAY

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

Terms & Conditions

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

Figure A-4. Low-Strength Concrete Overlay, Test Nos. H42BR-1 and H42BR-2

NUCOR

Mill Certification
04/04/2019

MTR#:160551-2
Lot #:360000283320
ONE NUCOR WAY
BOURBONNAIS, IL 60914 US
815-937-3131
Fax: 815-939-5599

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

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

Customer PO	MN-3717	Sales Order #	36003216 - 2.1
Product Group	Rebar	Product #	2110230
Grade	A615 Gr 60/AASHTO M31	Lot #	360000283320
Size	#5	Heat #	3600002833
BOL #	BOL-252680	Load #	160551
Description	Rebar #5/16mm A615 Gr 60/AASHTO M31 40' 0" [480"] 4001-8000 lbs	Customer Part #	
Production Date	03/05/2019	Qty Shipped LBS	37550
Product Country Of Origin	United States	Qty Shipped EA	900
Original Item Description		Original Item Number	

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

Melt Country of Origin : United States — Melting Date: 02/27/2019

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	Cu (%)	V (%)	Nb (%)
0.38	0.88	0.013	0.050	0.190	0.22	0.23	0.07	0.39	0.002	0.001

Other Test Results

Yield (PSI) : 70400

Tensile (PSI) : 107400

Average Deformation Height (IN) : 0.044

Elongation in 8" (%) : 14.0

Bend Test : Pass

Weight Percent Variance (%) : -2.20

Comments:

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

Zach Sprintz

Zachary Sprintz, Process Metallurgist

Page 1 of 1

Figure A-5. #5 Rebar, Test Nos. H42BR-1 and H42BR-2

Page: 1

SOLD TO: DAYTON SUPERIOR
2150B S RT 45-52
KANKAKEE, IL 60901-

NUCOR
NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT

Ship from:
MTR #: 0000076179
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

SHIP TO: DAYTON SUPERIOR
2150B S RT 45-52
KANKAKEE, IL 60901-

Date: 23-Jun-2015
B.L. Number: 503463
Load Number: 261786

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS: YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	CHEMICAL TESTS: C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	176736												
KN1510304501	Nucor Steel - Kankakee Inc	78,806	105,880	15.4%	OK	-.1%	.20	1.21	.019	.036	.26	.30	.43
KN15103045	1" (1.0000) Round	543MPa	730MPa				.15	.20	.048	.070 0	.00		
	45' 2" Gr60/A706												
	ASTM A615M-12 GR 60/A706 CE .50 MAX/ AASHTO M31-07												
	Melted 05/23/15 Rolled 05/28/15												
PO# =>	176736												
KN1510304601	Nucor Steel - Kankakee Inc	79,162	109,168	17.9%	OK	-.1%	.19	1.24	.019	.012	.24	.31	.42
KN15103046	1" (1.0000) Round	546MPa	753MPa				.14	.19	.043	.070 0	.00		
	45' 2" Gr60/A706												
	ASTM A615M-12 GR 60/A706 CE .50 MAX/ AASHTO M31-07												
	Melted 05/23/15 Rolled 05/28/15												
PO# =>	176736												
KN1510304901	Nucor Steel - Kankakee Inc	76,780	103,771	19.1%	OK	.3%	.18	1.21	.015	.035	.24	.29	.41
KN15103049	1" (1.0000) Round	529MPa	715MPa				.16	.17	.051	.070 0	.00		
	45' 2" Gr60/A706												
	ASTM A615M-12 GR 60/A706 CE .50 MAX/ AASHTO M31-07												
	Melted 05/24/15 Rolled 05/28/15												

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material

QUALITY ASSURANCE: Matt Luymes

Matt Luymes

Figure A-6. #8 Smooth Rebar, Test Nos. H42BR-1 and H42BR-2

+GF+

Georg Fischer Harvel LLC
7777 Sloane Drive
Little Rock AR, 72206
USA
T +1 501 490 7777
F +1 501 490 7171
us.ps@georgfischer.com
www.gfps.com

Benjamin Levie
T +1 501 490 7367
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M +1 501 322 0712
Benjamin.levie@georgfischer.com

Little Rock, February 26, 2018

Dear Valued Customer,

This letter is to certify that PVC Schedule 40 & 80 Industrial Pipe manufactured by Georg Fischer Harvel LLC complies with the following.

Item	Standard	Notes
Material used for pipe	ASTM D1784 "Standard Specification for Rigid Polyvinyl Chloride Compounds and Chlorinated Polyvinyl Chloride Compounds	PVC Type I, Grade I material. Meet cell class 12454
Pipe	ASTM D1785 "Standard Specification for Polyvinyl Chloride Plastic Pipe Schedules 40, 80, and 120	Sch 40 sizes 1-1/2" - 12" meet ASTM D2665
Any Pipe Bell	ASTM D2672 "Standard Specification for Joints for IPS PVC Pipe Using Solvent Cement"	Complies
Product marked NSF-pw or NSF 61	NSF 14, California AB 1953-NSF 61 Annex G (NSF/ANSI 372)	Listed by NSF (listing includes required ASTM product standards), exceeds California lead-free requirement
All product marked "Made in USA or "USA"	FTC requirements for unqualified marking "Made in USA" and Buy America Act	All Pipe Complies

Yours sincerely

Georg Fischer Piping Systems Ltd.

Benjamin Levie
Junior Product Manager

Figure A-7. PVC Pipe, Test Nos. H42BR-1 and H42BR-2

FASTENAL®

Certificate of Compliance

Sold To:		**Purchase Order:**	H42BR-1
UNL TRANSPORTATION/Midwest Roadside Safe		**Job:**	Item# c3
		Invoice Date:	05/10/2019

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

10 PCS 1-1/4" Slip 300 lb PVC Flat Pipe Cap SUPPLIED UNDER OUR TRACE NUMBER 120346463 AND UNDER PART NUMBER 0470592

6 PCS 1-1/4" Slip 300 lb PVC Flat Pipe Cap SUPPLIED UNDER OUR TRACE NUMBER 120346463 AND UNDER PART NUMBER 0470592

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

Fastenal Account Representative Signature

Nate Gemmell

Printed Name

5-16-19

Date

Please check current revision to avoid using obsolete copies.

This document was printed on 05/10/2019 and was current at that time.

Fastenal Store Location/Address

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

Figure A-8. 1¼-in. PVC Cap, Test Nos. H42BR-1 and H42BR-2

P.O. Box 21148
Tulsa, OK 74121
P: 800-879-8000
F: 800-879-7000

Date: 5/15/2019

Customer: UNIVERSITY OF NEBRASKA-LINCOLN

Customer PO: H42BR

Subject: Certificate of Conformance - HIT RE-500 V3 Adhesive

Quantity: 20 PCS / 2123404 / Injectable mortar HIT-RE 500 V3/500/1

To Whom it May Concern:

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

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

Sincerely,

B. Mitchell

B. Mitchell, Certification Specialist

HILTI, Inc.
cocRE500 V3

Figure A-9. Epoxy Adhesive, Test Nos. H42BR-1 and H42BR-2

PRODUCT DATA

W. R. MEADOWS
SEALTIGHT

MasterFormat: 03 15 00

NO. 320-F

APRIL 2018
(Supersedes March 2016)

FIBRE EXPANSION JOINT

Multi-Purpose, Expansion-Contraction Joint Filler

DESCRIPTION

FIBRE EXPANSION JOINT is composed of cellular fibers securely bonded together and uniformly saturated with asphalt to assure longevity. Wherever a cost-effective joint filler is required, FIBRE EXPANSION JOINT meets the need. Manufactured and marketed by W. R. MEADOWS since the early 1930s, FIBRE EXPANSION JOINT is backed by over 80 years of proven application experience. FIBRE EXPANSION JOINT is versatile, resilient, flexible, and non-extruding. When compressed to half of its original thickness, it will recover to a minimum of 70% of its original thickness. FIBRE EXPANSION JOINT will not deform, twist, or break with normal on-the-job handling. Breakage, waste and functional failure resulting from the use of inferior, foreign fiber materials can cost you time and dollars and can result in a substandard finished job, generating costly callbacks and rework expenses. However, the purchase and installation of FIBRE EXPANSION JOINT (a small segment of the total project's cost) contributes to both the final cost efficiency and functional success, far greater in proportion than its original cost.

Representative United States patents: USPNs 7,815,722; 8,057,638; 8,038,845; and D558,305. (See also www.wrmeadows.com/patents for further patent/intellectual property information.)

USES

FIBRE EXPANSION JOINT is ideal for use on highways, streets, airport runways, sidewalks, driveways, flatwork, and scores of commercial and industrial applications subject to pedestrian and vehicular traffic.

FEATURES/BENEFITS

- Provides the ideal product for the majority of all expansion/contraction joint requirements.
- Non-extruding ... versatile ... offers a minimum 70% recovery after compression.
- This tough, lightweight, easy-to-use, semi-rigid joint filler is available in strips and shapes fabricated to your requirements.
- Easy to cut ... dimensionally stable ... not sticky in summer or brittle in winter.
- Provides neat, finished joints requiring no trimming.
- Often copied ... but never equaled.
- Remains the standard of the industry today ... with over 80 years of proven and satisfactory performance.
- Can be punched for dowel bars and laminated to thicknesses greater than 1" (25.4 mm).

MADE IN THE U.S.A.
W. R. MEADOWS SEALTIGHT
FIBRE EXPANSION JOINT

Conforms to or meets:	Thickness	Slab Widths	Standard Lengths	Weight per ft.^{3}
• AASHTO M 213 • ASTM D1751 • Corps of Engineers CRD-C 508 • FAA Specification Item P-610-2.7 •HH-F-341 F, Type 1	3/8", 1/2" 3/4", 1" (9.5, 12.7, 19.1, 25.4 mm)	36", 48" (.91, 1.22 m)	10' (3.05 m) Also available: 5', 6', 12' (1.5, 1.83, 3.66 m)	>19 lb.

CONTINUED ON REVERSE SIDE…

W. R. MEADOWS, INC.
P.O. Box 338 • HAMPSHIRE, IL 60140-0338
Phone: 847/214-2100 • Fax: 847/683-4544
1-800-342-5976
www.wrmeadows.com

HAMPSHIRE, IL /CARTERSVILLE, GA /YORK, PA
FORT WORTH, TX /BENICIA, CA /POMONA, CA
GOODYEAR, AZ / MILTON, ON /ST. ALBERT, AB

Figure A-10. Expansion Joint Filler, Test Nos. H42BR-1 and H42BR-2

Pecora 301 NS

Specification Data Sheet

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

Non-Sag Silicone Highway & Pavement Joint Sealant

1. BASIC USES

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

2. MANUFACTURER

Pecora Corporation
165 Wambold Road
Harleysville, PA 19438
Phone: 215-723-6051
800-523-6688
Fax: 215-721-0286
Website: www.pecora.com

3. PRODUCT DESCRIPTION

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

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

Advantages:

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

Limitations:

Pecora 301 NS Silicone Pavement Sealant should not be used:

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

PACKAGING

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

Color: pavement gray

SEALANT COVERAGE CHART RECESS GUIDELINES

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

TABLE 1: TYPICAL UNCURED PROPERTIES

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

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

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

*modified section 14

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

Figure A-11. Expansion Joint Sealant, Test Nos. H42BR-1 and H42BR-2

Appendix B. Vehicle Center of Gravity Determination

Date: 7/17/2019 **Test Name:** H42BR-1 **VIN:** KNADE223396495453
Year: 2009 **Make:** Kia **Model:** Rio

Vehicle CG Determination

	Vehicle Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Car (Curb)	2498	22.762	56859.2
+	Hub	19	10.625	201.875
+	Brake activation cylinder & frame	7	16.0	112.0
+	Pneumatic tank (Nitrogen)	22	14.75	324.5
+	Strobe/Brake Battery	5	19.0	95.0
+	Brake Receiver/Wires	6	33.25	199.5
+	CG Plate including DAQ	13	17.125	222.625
-	Battery	-32	26.5	-848.0
-	Oil	-12	9.5	-114.0
-	Interior	-90	32.0	-2880.0
-	Fuel	-16	15.5	-248.0
-	Coolant	-6	20.0	-120.0
-	Washer fluid	-4	17.0	-68.0
+	Water Ballast (In Fuel Tank)	40	15.5	620.0
+	Onboard Supplemental Battery	0		0
	Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle			54356.7

Estimated Total Weight (lb) 2450

Vehicle Dimensions for C.G. Calculations

Wheel Base: 98.5 in. Front Track Width: 58.0 in.
Roof Height: 57.625 in. Rear Track Width: 57.375 in.

Center of Gravity	1100C MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	2420 ± 55	2421	1.0
Longitudinal CG (in.)	39 ± 4	36.373	-2.627
Lateral CG (in.)	NA	-0.87	NA
Vertical CG (in.)	NA	22.186	NA

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb)

	Left	Right
Front	803	773
Rear	458	464

FRONT	1576	lb
REAR	922	lb
TOTAL	2498	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	796	731
Rear	451	443

FRONT	1527	lb
REAR	894	lb
TOTAL	2421	lb

Figure B-1. Vehicle Mass Distribution, Test No. H42BR-1

Date:	**8/19/2019**	**Test Name:**	**H42BR-2**	**VIN:**	**1C6RR6FT7ES319996**
Year:	**2014**	**Make:**	**Dodge**	**Model:**	**RAM 1500**

Vehicle CG Determination

	Vehicle Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	5230	28.5	148858.2
+	Hub	19	34.8	660.3
+	Brake activation cylinder & frame	7	27.5	192.5
+	Pneumatic tank (Nitrogen)	30	26.5	795
+	Strobe/Brake Battery	5	26	130
+	Brake Receiver/Wires	6	52.5	315
+	CG Plate including DAQ	30	31.4	941.3
-	Battery	-47	43	-2021
-	Oil	-12	17	-204
-	Interior	-88	36	-3168
-	Fuel	-160	17	-2720
-	Coolant	-13	31	-403
-	Washer fluid	-4	35	-140
+	Water Ballast (In Fuel Tank)			0
+	Onboard Supplemental Battery	13	26	338
-	Tailpipe	-13	22	-286
				0
				143288.2

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

Estimated Total Weight (lb): 5003
Vertical CG Location (in.): 28.6405

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140.125 in.
Front Track Width: 68.375 in.
Rear Track Width: 67.875 in.

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	5007	7.0
Longitudinal CG (in.)	63 ± 4	60.169513	-2.83049
Lateral CG (in.)	NA	-0.115651	NA
Vertical CG (in.)	28 or greater	28.64	0.64045

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	1491	1462
Rear	1159	1118

FRONT	2953	lb
REAR	2277	lb
TOTAL	5230	lb

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1427	1430
Rear	1085	1065

FRONT	2857	lb
REAR	2150	lb
TOTAL	5007	lb

Figure B-2. Vehicle Mass Distribution, Test No. H42BR-2

Appendix C. Vehicle Deformation Records

Date: 7/17/2019 Test Name: H42BR-1 VIN: KNADE223396495453
Year: 2009 Make: Kia Model: Rio

VEHICLE DEFORMATION
PASSENGER SIDE FLOOR PAN - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	61.7958	13.5897	5.7945	60.6165	11.5917	7.2368	1.1793	1.9980	-1.4423	2.7318	1.1793	X
	2	62.6287	9.9919	7.1379	61.9279	8.1928	8.4189	0.7008	1.7991	-1.2810	2.3171	0.7008	X
	3	62.2556	5.7924	7.2347	61.3829	4.0483	8.2203	0.8727	1.7441	-0.9856	2.1852	0.8727	X
	4	61.4670	2.4058	7.5755	60.4243	0.7148	8.1137	1.0427	1.6910	-0.5382	2.0582	1.0427	X
	5	60.9859	-2.4247	7.7941	60.6236	-3.8940	8.8508	0.3623	-1.4693	-1.0567	1.8457	0.3623	X
	6	59.8517	14.2192	8.8641	59.4095	12.4698	10.5952	0.4422	1.7494	-1.7311	2.5005	0.4422	X
	7	59.6319	10.0769	8.8692	58.9108	8.3079	10.2596	0.7211	1.7690	-1.3904	2.3627	0.7211	X
	8	59.4369	5.5934	8.8249	58.6258	3.9358	9.8493	0.8111	1.6576	-1.0244	2.1107	0.8111	X
	9	59.4965	2.4143	8.7013	58.4720	0.6901	9.2859	1.0245	1.7242	-0.5846	2.0891	1.0245	X
	10	59.1234	-1.9772	8.8692	58.6883	-3.4618	9.9798	0.4351	-1.4846	-1.1106	1.9044	0.4351	X
FLOOR PAN (Z)	11	55.0882	15.9474	9.6383	54.6595	14.3914	11.2482	0.4287	1.5560	-1.6099	2.2796	-1.6099	Z
	12	54.5128	11.0816	9.6260	53.8570	9.4140	11.1203	0.6558	1.6676	-1.4943	2.3332	-1.4943	Z
	13	54.1974	7.2332	9.5363	53.3911	5.6029	10.7759	0.8063	1.6303	-1.2396	2.2010	-1.2396	Z
	14	53.5624	3.2654	9.5523	52.5603	1.8491	10.1663	1.0021	1.4163	-0.6140	1.8404	-0.6140	Z
	15	53.0199	-0.8184	9.6924	52.1590	-0.9003	7.5444	0.8609	-0.0819	2.1480	2.3155	2.1480	Z
	16	50.5777	16.0480	9.7724	50.1478	14.6039	11.2821	0.4299	1.4441	-1.5097	2.1329	-1.5097	Z
	17	48.9579	9.7142	9.5022	48.3217	8.3770	11.0120	0.6362	1.3372	-1.5098	2.1148	-1.5098	Z
	18	48.6666	5.6927	9.4636	47.7837	4.3555	10.7555	0.8829	1.3372	-1.2919	2.0583	-1.2919	Z
	19	48.2162	2.2431	9.9366	47.3274	1.9099	8.9549	0.8888	0.3332	0.9817	1.3655	0.9817	Z
	20	48.3041	-0.5139	10.1062	48.1029	-0.3680	9.9212	0.2012	0.1459	0.1850	0.3098	0.1850	Z
	21	44.5329	16.0915	9.7191	44.0847	14.9014	11.2647	0.4482	1.1901	-1.5456	2.0015	-1.5456	Z
	22	44.2225	10.1533	9.4321	43.6116	9.0931	10.9914	0.6109	1.0602	-1.5593	1.9821	-1.5593	Z
	23	44.0445	5.8472	9.3984	43.3135	4.7802	10.7594	0.7310	1.0670	-1.3610	1.8775	-1.3610	Z
	24	43.6022	1.5281	9.9157	43.2205	1.3083	10.6479	0.3817	0.2198	-0.7322	0.8545	-0.7322	Z
	25	43.0968	-1.8415	9.6242	43.1003	-1.9984	10.1501	-0.0035	-0.1569	-0.5259	0.5488	-0.5259	Z
	26	39.5506	16.4069	9.3247	39.0433	15.4303	11.1081	0.5073	0.9766	-1.7834	2.0956	-1.7834	Z
	27	39.3375	9.9036	9.3272	38.9081	9.1686	10.8464	0.4294	0.7350	-1.5192	1.7414	-1.5192	Z
	28	39.3867	5.4744	9.2907	38.6346	4.7875	10.5193	0.7521	0.6869	-1.2286	1.5959	-1.2286	Z
	29	39.3525	1.8697	9.3549	38.9870	1.3729	10.1590	0.3655	0.4968	-0.8041	1.0134	-0.8041	Z
	30	39.1263	-1.4344	9.1121	39.0059	-1.9225	10.1365	0.1204	-0.4881	-1.0244	1.1411	-1.0244	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. H42BR-1

Date: 7/17/2019 Test Name: H42BR-1 VIN: KNADE223396495453
Year: 2009 Make: Kia Model: Rio

VEHICLE DEFORMATION
PASSENGER SIDE FLOOR PAN - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	61.9977	30.9960	4.9728	61.1279	28.6725	3.2888	0.8698	2.3235	1.6840	2.9985	1.8954	X, Z
	2	62.8458	27.4224	6.3700	62.5168	25.3058	4.4744	0.3290	2.1166	1.8956	2.8603	1.9239	X, Z
	3	62.4781	23.2249	6.5412	61.9599	21.1583	4.4301	0.5182	2.0666	2.1111	2.9994	2.1738	X, Z
	4	61.6961	19.8438	6.9462	60.9967	17.8249	4.4826	0.6994	2.0189	2.4636	3.2610	2.5610	X, Z
	5	61.2221	15.0172	7.2510	61.2460	13.2382	5.3340	-0.0239	1.7790	1.9170	2.6154	1.9170	Z
	6	60.0789	31.6758	8.0475	60.1516	29.6468	6.6954	-0.0727	2.0290	1.3521	2.4393	1.3521	Z
	7	59.8637	27.5341	8.1249	59.6316	25.4780	6.5117	0.2321	2.0561	1.6132	2.6237	1.6298	X, Z
	8	59.6732	23.0502	8.1584	59.3198	21.0966	6.2450	0.3534	1.9536	1.9134	2.7573	1.9458	X, Z
	9	59.7352	19.8695	8.0884	59.1285	17.8367	5.7849	0.6067	2.0328	2.3035	3.1315	2.3821	X, Z
	10	59.3683	15.4812	8.3340	59.3917	13.7055	6.5792	-0.0234	1.7757	1.7548	2.4966	1.7548	Z
FLOOR PAN (Z)	11	55.3202	33.4124	8.8325	55.4567	31.5947	7.6149	-0.1365	1.8177	1.2176	2.1921	1.2176	Z
	12	54.7500	28.5466	8.9078	54.6478	26.6170	7.6819	0.1022	1.9296	1.2259	2.2884	1.2259	Z
	13	54.4381	24.6970	8.8863	54.1600	22.7987	7.4775	0.2781	1.8983	1.4088	2.3803	1.4088	Z
	14	53.8075	20.7294	8.9750	53.2901	19.0307	7.0316	0.5174	1.6987	1.9434	2.6325	1.9434	Z
	15	53.2707	16.6481	9.1891	52.7120	16.2094	4.5214	0.5587	0.4387	4.6677	4.7214	4.6677	Z
	16	50.8109	33.5111	9.0031	50.9578	31.8162	7.9490	-0.1469	1.6949	1.0541	2.0013	1.0541	Z
	17	49.1957	27.1720	8.8543	49.1181	25.5875	7.9789	0.0776	1.5845	0.8754	1.8119	0.8754	Z
	18	48.9086	23.1502	8.8866	48.5643	21.5614	7.8728	0.3443	1.5888	1.0138	1.9159	1.0138	Z
	19	48.4659	19.7087	9.4219	47.9870	19.0669	6.1769	0.4789	0.6418	3.2450	3.3423	3.2450	Z
	20	48.5582	16.9551	9.6375	48.8265	16.8157	7.1521	-0.2683	0.1394	2.4854	2.5037	2.4854	Z
	21	44.7659	33.5480	9.0003	44.9074	32.1241	8.3348	-0.1415	1.4239	0.6655	1.5781	0.6655	Z
	22	44.4595	27.6055	8.8168	44.4174	26.3113	8.2579	0.0421	1.2942	0.5589	1.4104	0.5589	Z
	23	44.2859	23.2992	8.8579	44.1046	21.9941	8.1682	0.1813	1.3051	0.6897	1.4872	0.6897	Z
	24	43.8527	18.9892	9.4522	44.0046	18.5206	8.1611	-0.1519	0.4686	1.2911	1.3819	1.2911	Z
	25	43.3485	15.6146	9.2223	43.8512	15.2015	7.7659	-0.5027	0.4131	1.4564	1.5951	1.4564	Z
	26	39.7800	33.8519	8.6428	39.8669	32.6575	8.5059	-0.0869	1.1944	0.1369	1.2054	0.1369	Z
	27	39.5740	27.3494	8.7576	39.7149	26.3912	8.4304	-0.1409	0.9582	0.3272	1.0223	0.3272	Z
	28	39.6278	22.9202	8.7959	39.4202	22.0032	8.2462	0.2076	0.9170	0.5497	1.0891	0.5497	Z
	29	39.5981	19.3171	8.9217	39.7477	18.5791	7.9590	-0.1496	0.7380	0.9627	1.2222	0.9627	Z
	30	39.3734	16.0092	8.7370	39.7653	15.2844	8.0281	-0.3919	0.7248	0.7089	1.0869	0.7089	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. H42BR-1

Date: 7/17/2019 Test Name: H42BR-1 VIN: KNADE223396495453
Year: 2009 Make: Kia Model: Rio

VEHICLE DEFORMATION
PASSENGER SIDE INTERIOR CRUSH - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	50.9562	16.3840	-18.3523	51.0410	16.1561	-16.9856	-0.0848	0.2279	1.3667	1.3882	1.3882	X, Y, Z
	2	50.7907	3.3098	-19.3205	51.1202	3.1871	-18.3204	-0.3295	0.1227	1.0001	1.0601	1.0601	X, Y, Z
	3	49.8046	-6.9965	-19.5700	50.3034	-7.1984	-18.8265	-0.4988	-0.2019	0.7435	0.9178	0.9178	X, Y, Z
	4	49.5760	16.6916	-6.7837	49.0328	15.8651	-5.5408	0.5432	0.8265	1.2429	1.5884	1.5884	X, Y, Z
	5	47.2846	-0.0642	-7.8813	47.5086	-0.6589	-7.0368	-0.2240	-0.5947	0.8445	1.0569	1.0569	X, Y, Z
	6	44.3363	-8.2675	-11.9481	44.7782	-8.7018	-11.3397	-0.4419	-0.4343	0.6084	0.8684	0.8684	X, Y, Z
SIDE PANEL (Y)	7	54.8582	18.2287	1.3973	54.3411	16.4112	3.0359	0.5171	1.8175	1.6386	2.5011	1.8175	Y
	8	54.8819	18.9819	5.3194	54.5125	17.1729	7.0507	0.3694	1.8090	1.7313	2.5311	1.8090	Y
	9	59.1690	18.5611	5.0440	58.7414	16.3327	6.6949	0.4276	2.2284	1.6509	2.8061	2.2284	Y
IMPACT SIDE DOOR (Y)	10	47.5707	19.9430	-14.9619	47.0739	20.1232	-13.3174	0.4968	-0.1802	1.6445	1.7273	-0.1802	Y
	11	34.3767	20.6770	-15.4018	34.1715	22.9126	-13.9647	0.2052	-2.2356	1.4371	2.6656	-2.2356	Y
	12	23.6252	20.9175	-16.3909	23.5806	23.9024	-15.1491	0.0446	-2.9849	1.2418	3.2332	-2.9849	Y
	13	43.8790	20.1425	1.5995	43.1402	20.2825	3.1711	0.7388	-0.1400	1.5716	1.7422	-0.1400	Y
	14	34.9090	20.7618	0.5537	34.2932	21.7560	1.9630	0.6158	-0.9942	1.4093	1.8313	-0.9942	Y
	15	28.7953	20.6420	1.2255	28.3542	21.7622	2.5436	0.4411	-1.1202	1.3181	1.7852	-1.1202	Y
ROOF - (Z)	16	30.3517	8.9799	-36.7732	31.1938	10.3123	-36.3043	-0.8421	-1.3324	0.4689	1.6445	0.4689	Z
	17	31.7368	4.0791	-36.8548	32.6371	5.4903	-36.3819	-0.9003	-1.4112	0.4729	1.7394	0.4729	Z
	18	31.7679	0.2317	-37.0611	32.6990	1.6204	-36.6276	-0.9311	-1.3887	0.4335	1.7272	0.4335	Z
	19	30.1467	-2.8344	-37.5478	30.9721	-1.4479	-36.8150	-0.8254	1.3865	0.7328	1.7722	0.7328	Z
	20	30.0267	-7.3079	-37.6309	30.8490	-5.9468	-36.7065	-0.8223	1.3611	0.9244	1.8394	0.9244	Z
	21	19.4021	8.8466	-38.3459	20.1842	10.2852	-37.6657	-0.7821	-1.4386	0.6802	1.7731	0.6802	Z
	22	18.9072	3.6434	-38.7819	19.7276	4.9918	-37.1994	-0.8204	-1.3484	1.5825	2.2351	1.5825	Z
	23	18.7702	-0.4042	-39.0000	19.5026	0.9523	-36.8186	-0.7324	1.3565	2.1814	2.6711	2.1814	Z
	24	18.5617	-3.4604	-39.1141	19.3327	-2.1200	-36.8862	-0.7710	1.3404	2.2279	2.7119	2.2279	Z
	25	18.7483	-5.3630	-39.1347	19.5395	-3.9441	-36.9036	-0.7912	1.4189	2.2311	2.7599	2.2311	Z
	26	9.3849	10.1594	-38.7244	10.2815	11.6186	-38.0466	-0.8966	-1.4592	0.6778	1.8419	0.6778	Z
	27	9.5977	6.4009	-39.0525	10.5072	7.8692	-38.0974	-0.9095	-1.4683	0.9551	1.9737	0.9551	Z
	28	9.4495	2.8199	-39.2964	10.3887	4.3074	-38.3213	-0.9392	-1.4875	0.9751	2.0114	0.9751	Z
	29	9.5529	-1.2259	-39.4777	10.4879	0.1872	-38.7096	-0.9350	1.4131	0.7681	1.8604	0.7681	Z
	30	9.6725	-3.5731	-39.5440	10.6473	-2.1188	-38.9127	-0.9748	1.4543	0.6313	1.8611	0.6313	Z
A-PILLAR Maximum (X, Y, Z)	31	54.9458	17.3020	-20.8454	55.0938	17.1709	-19.3405	-0.1480	0.1311	1.5049	1.5178	1.5106	Y, Z
	32	50.4944	16.5942	-24.0423	50.9185	16.8289	-22.9585	-0.4241	-0.2347	1.0838	1.1873	1.0838	Z
	33	47.5964	16.0292	-26.1141	48.2099	16.5865	-25.3565	-0.6135	-0.5573	0.7576	1.1229	0.7576	Z
	34	44.1340	15.4241	-28.0985	45.0307	16.1857	-27.5297	-0.8967	-0.7616	0.5688	1.3068	0.5688	Z
	35	40.5295	14.8091	-29.9895	41.4946	15.6252	-29.6490	-0.9651	-0.8161	0.3405	1.3090	0.3405	Z
	36	37.3428	14.2046	-31.6864	38.2800	15.3384	-31.3381	-0.9372	-1.1338	0.3483	1.5117	0.3483	Z
A-PILLAR Lateral (Y)	31	54.9458	17.3020	-20.8454	55.0938	17.1709	-19.3405	-0.1480	0.1311	1.5049	1.5178	0.1311	Y
	32	50.4944	16.5942	-24.0423	50.9185	16.8289	-22.9585	-0.4241	-0.2347	1.0838	1.1873	-0.2347	Y
	33	47.5964	16.0292	-26.1141	48.2099	16.5865	-25.3565	-0.6135	-0.5573	0.7576	1.1229	-0.5573	Y
	34	44.1340	15.4241	-28.0985	45.0307	16.1857	-27.5297	-0.8967	-0.7616	0.5688	1.3068	-0.7616	Y
	35	40.5295	14.8091	-29.9895	41.4946	15.6252	-29.6490	-0.9651	-0.8161	0.3405	1.3090	-0.8161	Y
	36	37.3428	14.2046	-31.6864	38.2800	15.3384	-31.3381	-0.9372	-1.1338	0.3483	1.5117	-1.1338	Y
B-PILLAR Maximum (X, Y, Z)	37	16.3689	15.3044	-32.4358	17.1346	16.5299	-31.9053	-0.7657	-1.2255	0.5305	1.5393	0.5305	Z
	38	14.4566	18.2690	-24.6973	15.0585	19.1259	-24.0554	-0.6019	-0.8569	0.6419	1.2282	0.6419	Z
	39	19.1184	19.4436	-17.4944	19.5431	19.9372	-16.6947	-0.4247	-0.4936	0.7997	1.0313	0.7997	Z
	40	15.6345	19.6272	-13.3379	15.9720	19.9834	-12.7069	-0.3375	-0.3562	0.6310	0.7993	0.6310	Z
B-PILLAR Lateral (Y)	37	16.3689	15.3044	-32.4358	17.1346	16.5299	-31.9053	-0.7657	-1.2255	0.5305	1.5393	-1.2255	Y
	38	14.4566	18.2690	-24.6973	15.0585	19.1259	-24.0554	-0.6019	-0.8569	0.6419	1.2282	-0.8569	Y
	39	19.1184	19.4436	-17.4944	19.5431	19.9372	-16.6947	-0.4247	-0.4936	0.7997	1.0313	-0.4936	Y
	40	15.6345	19.6272	-13.3379	15.9720	19.9834	-12.7069	-0.3375	-0.3562	0.6310	0.7993	-0.3562	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. Interior Crush Deformation Data – Set 1, Test No. H42BR-1

Date: 7/17/2019 Test Name: H42BR-1 VIN: KNADE223396495453

Year: 2009 Make: Kia Model: Rio

VEHICLE DEFORMATION
PASSENGER SIDE INTERIOR CRUSH - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	51.0107	33.4114	-19.0058	49.9902	32.7732	-20.2958	1.0205	0.6382	-1.2900	1.7643	1.7643	X, Y, Z
	2	50.8495	20.3248	-19.7900	49.9826	19.7696	-21.2390	0.8669	0.5552	-1.4490	1.7775	1.7775	X, Y, Z
	3	49.8704	10.0153	-19.8885	49.1352	9.3751	-21.3750	0.7352	0.6402	-1.4865	1.7777	1.7777	X, Y, Z
	4	49.7121	33.8795	-7.4331	48.7409	32.8325	-8.7400	0.9712	1.0470	-1.3069	1.9358	1.9358	X, Y, Z
	5	47.4273	17.1084	-8.2803	47.1231	16.2738	-9.6305	0.3042	0.8346	-1.3502	1.6162	1.6162	X, Y, Z
	6	44.4573	8.8468	-12.2110	44.1157	8.1095	-13.4983	0.3416	0.7373	-1.2873	1.5223	1.5223	X, Y, Z
SIDE PANEL (Y)	7	55.0508	35.5348	0.6879	54.6031	33.6278	-0.5522	0.4477	1.9070	-1.2401	2.3184	1.9070	Y
	8	55.1017	36.3428	4.5988	55.0387	34.5104	3.4177	0.0630	1.8324	-1.1811	2.1810	1.8324	Y
	9	59.3870	35.9214	4.2990	59.2350	33.6518	2.8095	0.1520	2.2696	-1.4895	2.7190	2.2696	Y
IMPACT SIDE DOOR (Y)	10	47.6462	37.0148	-15.6416	46.2732	36.8570	-16.4961	1.3730	0.1578	-0.8545	1.6249	0.1578	Y
	11	34.4489	37.7327	-15.9982	33.3560	39.6500	-16.3761	1.0929	-1.9173	-0.3779	2.2390	-1.9173	Y
	12	23.6904	37.9512	-16.9142	22.7099	40.6237	-16.8895	0.9805	-2.6725	0.0247	2.8468	-2.6725	Y
	13	44.0717	37.4430	0.9412	43.4351	37.5227	0.2033	0.6366	-0.0797	-0.7379	0.9778	-0.0797	Y
	14	35.0940	38.0409	-0.0495	34.5275	38.9759	-0.4633	0.5665	-0.9350	-0.4138	1.1689	-0.9350	Y
	15	28.9853	37.9259	0.6672	28.6397	39.0108	0.5070	0.3456	-1.0849	-0.1602	1.1498	-1.0849	Y
ROOF - (Z)	16	30.2826	25.7350	-37.1750	28.9133	26.3851	-38.0785	1.3693	-0.6501	-0.9035	1.7646	-0.9035	Z
	17	31.6713	20.8346	-37.1979	30.3487	21.5603	-38.1048	1.3226	-0.7257	-0.9069	1.7602	-0.9069	Z
	18	31.7042	16.9847	-37.3506	30.3947	17.6846	-38.2366	1.3095	-0.6999	-0.8860	1.7291	-0.8860	Z
	19	30.0823	13.9109	-37.7829	28.6595	14.6154	-38.2166	1.4228	-0.7045	-0.4337	1.6458	-0.4337	Z
	20	29.9655	9.4365	-37.8027	28.5443	10.1220	-37.9639	1.4212	-0.6855	-0.1612	1.5861	-0.1612	Z
	21	19.3224	25.5715	-38.6679	17.8379	26.3378	-38.7100	1.4845	-0.7663	-0.0421	1.6711	-0.0421	Z
	22	18.8288	20.3624	-39.0277	17.4136	21.0618	-38.0543	1.4152	-0.6994	0.9734	1.8546	0.9734	Z
	23	18.6936	16.3120	-39.1882	17.2145	17.0361	-37.5372	1.4791	-0.7241	1.6510	2.3319	1.6510	Z
	24	18.4870	13.2543	-39.2582	17.0408	13.9635	-37.5003	1.4462	-0.7092	1.7579	2.3843	1.7579	Z
	25	18.6750	11.3518	-39.2535	17.2462	12.1394	-37.4760	1.4288	-0.7876	1.7775	2.4127	1.7775	Z
	26	9.3016	26.8714	-38.9937	7.9314	27.6779	-38.4778	1.3702	-0.8065	0.5159	1.6715	0.5159	Z
	27	9.5152	23.1088	-39.2708	8.1537	23.9282	-38.4296	1.3615	-0.8194	0.8412	1.7980	0.8412	Z
	28	9.3683	19.5246	-39.4636	8.0211	20.3615	-38.5371	1.3472	-0.8369	0.9265	1.8368	0.9265	Z
	29	9.4740	15.4768	-39.5891	8.0949	16.2312	-38.8060	1.3791	-0.7544	0.7831	1.7562	0.7831	Z
	30	9.5950	13.1290	-39.6234	8.2407	13.9198	-38.9491	1.3543	-0.7908	0.6743	1.7071	0.6743	Z
A-PILLAR Maximum (X, Y, Z)	31	54.9818	34.2974	-21.5397	53.8789	33.7086	-22.9423	1.1029	0.5888	-1.4026	1.8789	1.2502	X, Y
	32	50.5084	33.5417	-24.6948	49.4742	33.2652	-26.2652	1.0342	0.2765	-1.5704	1.9006	1.0705	X, Y
	33	47.5963	32.9455	-26.7379	46.6135	32.9554	-28.4711	0.9828	-0.0099	-1.7332	1.9925	0.9828	X
	34	44.1205	32.3102	-28.6891	43.2980	32.4951	-30.4170	0.8225	-0.1849	-1.7279	1.9226	0.8225	X
	35	40.5032	31.6661	-30.5457	39.6299	31.8774	-32.2807	0.8733	-0.2113	-1.7350	1.9538	0.8733	X
	36	37.3051	31.0355	-32.2113	36.3109	31.5458	-33.7448	0.9942	-0.5103	-1.5335	1.8975	0.9942	X
A-PILLAR Lateral (Y)	31	54.9818	34.2974	-21.5397	53.8789	33.7086	-22.9423	1.1029	0.5888	-1.4026	1.8789	0.5888	Y
	32	50.5084	33.5417	-24.6948	49.4742	33.2652	-26.2652	1.0342	0.2765	-1.5704	1.9006	0.2765	Y
	33	47.5963	32.9455	-26.7379	46.6135	32.9554	-28.4711	0.9828	-0.0099	-1.7332	1.9925	-0.0099	Y
	34	44.1205	32.3102	-28.6891	43.2980	32.4951	-30.4170	0.8225	-0.1849	-1.7279	1.9226	-0.1849	Y
	35	40.5032	31.6661	-30.5457	39.6299	31.8774	-32.2807	0.8733	-0.2113	-1.7350	1.9538	-0.2113	Y
	36	37.3051	31.0355	-32.2113	36.3109	31.5458	-33.7448	0.9942	-0.5103	-1.5335	1.8975	-0.5103	Y
B-PILLAR Maximum (X, Y, Z)	37	16.3255	32.1090	-32.8273	15.1740	32.7597	-32.9531	1.1515	-0.6507	-0.1258	1.3286	1.1515	X
	38	14.4656	35.1800	-25.1177	13.6197	35.5961	-25.0659	0.8459	-0.4161	0.0518	0.9441	0.8475	X, Z
	39	19.1772	36.4587	-17.9651	18.5796	36.6212	-18.0446	0.5976	-0.1625	-0.0795	0.6244	0.5976	X
	40	15.7226	36.6977	-13.7869	15.2792	36.7949	-13.8335	0.4434	-0.0972	-0.0466	0.4563	0.4434	X
B-PILLAR Lateral (Y)	37	16.3255	32.1090	-32.8273	15.1740	32.7597	-32.9531	1.1515	-0.6507	-0.1258	1.3286	-0.6507	Y
	38	14.4656	35.1800	-25.1177	13.6197	35.5961	-25.0659	0.8459	-0.4161	0.0518	0.9441	-0.4161	Y
	39	19.1772	36.4587	-17.9651	18.5796	36.6212	-18.0446	0.5976	-0.1625	-0.0795	0.6244	-0.1625	Y
	40	15.7226	36.6977	-13.7869	15.2792	36.7949	-13.8335	0.4434	-0.0972	-0.0466	0.4563	-0.0972	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. Interior Crush Deformation Data – Set 2, Test No. H42BR-1

Date: 7/17/2019 Test Name: H42BR-1 VIN: KNADE223396495453
Year: 2009 Make: Kia Model: Rio

VEHICLE DEFORMATION
WINDSHIELD

	POINT	Vertical Reference Length^A	Vertical Reference Side^B (Top or Bottom)	Lateral Referece Length^C	Lateral Reference Side^B (Driver or Pass.)	Examplar Vehicle Measurement	Test Vehicle Measurment	Crush^D (in.)
WINDSHIELD	1	8 3/4	Top	6	Pass.	6 1/4	8	1.75
	2	5 1/8	Top	16 1/4	Driver	5 1/4	7 1/4	2
	3	13 1/4	Top	3 7/8	Pass.	6 1/2	9 1/4	2.75
	4	13 5/8	Top	22 1/8	Pass.	5 3/8	9 3/8	4
	5	15 1/2	Top	26 3/4	Pass.	5 1/2	9 3/8	3.875
	6	17 1/2	Top	5 7/8	Pass.	6 1/4	10 1/4	4
	7	19 7/8	Top	11 3/4	Pass.	5 1/2	11 1/2	6
	8	21 5/8	Top	14 3/4	Pass.	5 1/4	11 3/4	6.5
	9	21 1/4	Top	18 1/8	Pass.	5	11 3/4	6.75
	10	21 1/2	Top	22	Pass.	5	11	6
	11	25	Top	7 3/4	Pass.	6	9 5/8	3.625
	12	25 5/8	Top	16	Pass.	5 1/8	9	3.875
	13	29	Top	6	Pass.	6 1/8	8 1/4	2.125

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

Examplar Vehicle Description

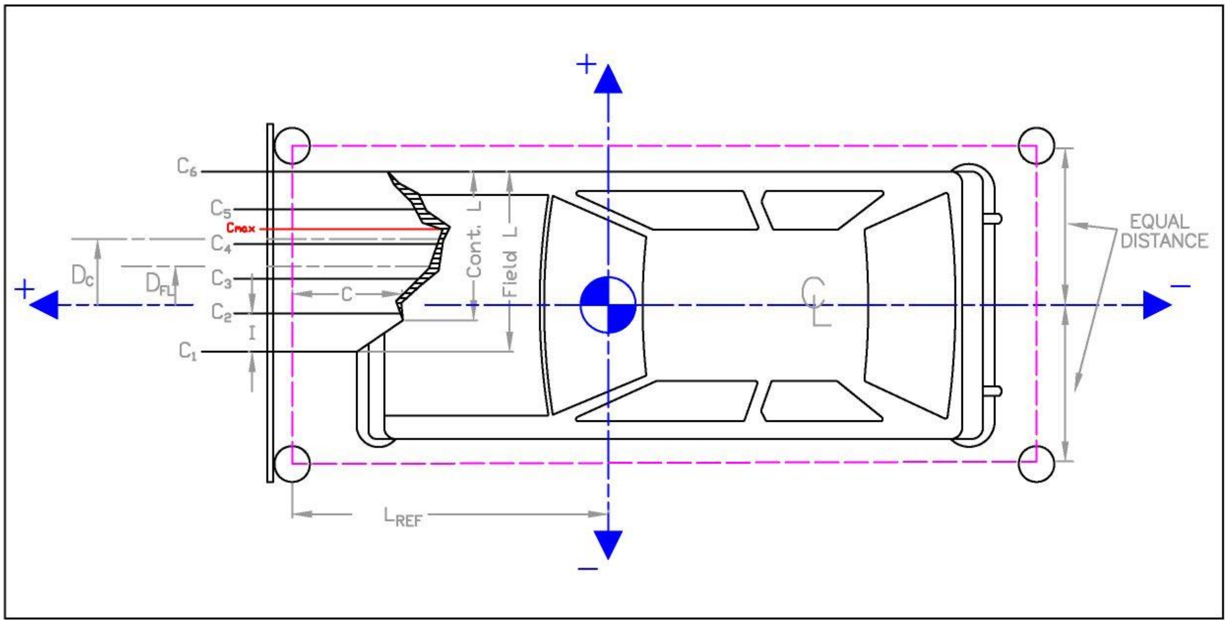
Year: 2009 Make: Kia Model: Rio VIN: KNADE223896580563

Windshield Deformation Notes:

The windshield was not impacted but shattered and torn due to windshield frame movement. The glass sagged after impact and the meaurements reflect this sagging.

Figure C-5. Windshield Deformation Data, Test No. H42BR-1

Date:	7/17/2019	**Test Name:**	H42BR-1	**VIN:**	KNADE223396495453
Year:	2009	**Make:**	Kia	**Model:**	Rio



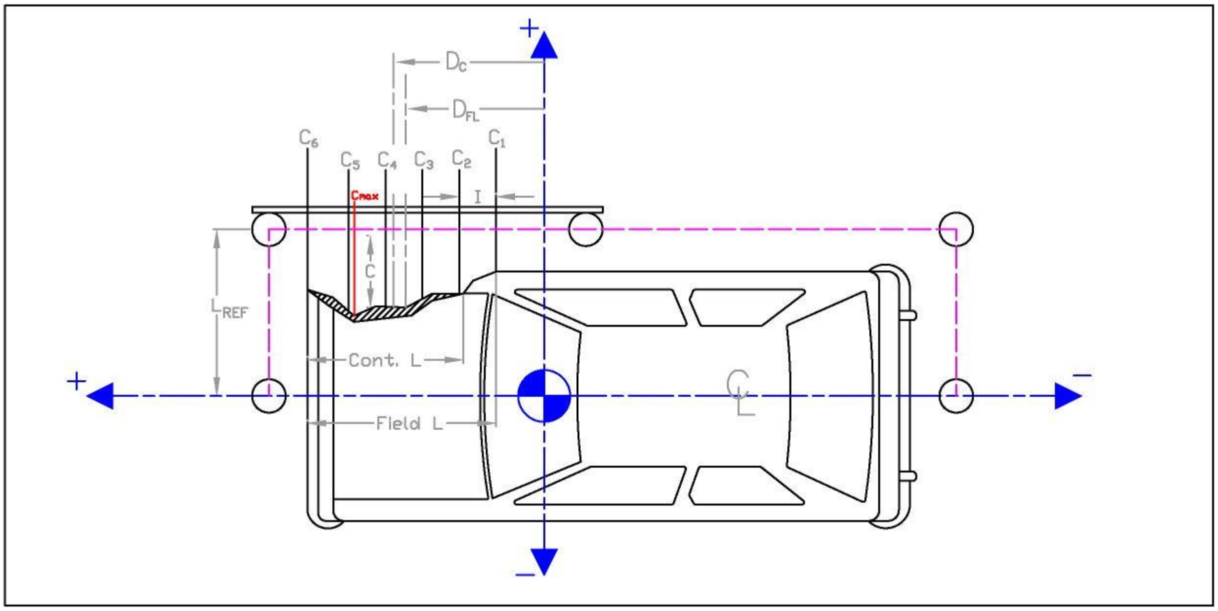
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	73	(1854)
Total Width of Vehicle:	65 3/8	(1661)
Width of contact and induced crush - Field L:	65 3/8	(1661)
Crush measurement spacing interval (L/5) - I:	13 1/8	(333)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	65 3/8	(1661)
Distance from center of vehicle to center of contact damage - D_C:	0	()

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

Crush Measurement			Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	20	(508)	-32 3/4	-(832)	24	(610)	-2 3/8	-(60)	-1 5/8	-(41)
C_2	8 1/2	(216)	-19 5/8	-(498)	8 1/2	(216)			2 3/8	(60)
C_3	8	(203)	-6 1/2	-(165)	6 1/8	(156)			4 1/4	(108)
C_4	8 1/2	(216)	6 5/8	(168)	6 1/8	(156)			4 3/4	(121)
C_5	20	(508)	19 3/4	(502)	8 1/2	(216)			13 7/8	(352)
C_6	N/A	NA	32 7/8	(835)	24	(610)			NA	NA
C_{MAX}	20	(508)	19 3/4	(502)	8 1/2	(216)			13 7/8	(352)

Figure C-6. Exterior Vehicle Crush (NASS) - Front, Test No. H42BR-1

Date:	7/17/2019	Test Name:	H42BR-1	VIN:	KNADE223396495453
Year:	2009	Make:	Kia	Model:	Rio



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	37	(940)
Total Vehicle Length:	164 1/2	(4178)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-12 3/8	-(314)
Width of contact and induced crush - Field L:	164 1/2	(4178)
Crush measurement spacing interval (L/5) - I:	32 7/8	(835)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-12 3/8	-(314)
Width of Contact Damage:	164 1/2	(4178)
Distance from vehicle c.g. to center of contact damage - D_C:	-12 3/8	-(314)

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

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	n/a	NA	-94 5/8	-(2403)	19 1/4	(489)	1	(25)	NA	NA
C_2	n/a	NA	-61 3/4	-(1568)	4	(102)			NA	NA
C_3	4 3/4	(121)	-28 7/8	-(733)	3 5/8	(92)			1/8	(3)
C_4	4 3/4	(121)	4	(102)	3 3/4	(95)			0	()
C_5	n/a	NA	36 7/8	(937)	3 1/4	(83)			NA	NA
C_6	n/a	NA	69 3/4	(1772)	20 1/4	(514)			NA	NA
C_{MAX}	23 3/4	(603)	54 3/4	(1391)	4 7/8	(124)			17 7/8	(454)

Figure C-7. Exterior Vehicle Crush (NASS) - Side, Test No. H42BR-1

Date: 8/19/2019 Test Name: H42BR-2 VIN: 1C6RR6FT7ES319996
Year: 2014 Make: Dodge Model: RAM 1500

VEHICLE DEFORMATION
PASSENGER SIDE FLOOR PAN - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	53.2646	33.5702	0.1981	48.4243	29.4858	-2.2427	4.8403	4.0844	2.4408	6.7874	5.4209	X, Z
	2	53.9060	30.0140	0.9920	50.0366	26.6956	-0.5323	3.8694	3.3184	1.5243	5.3205	4.1588	X, Z
	3	54.1624	26.6828	0.8593	52.1812	24.9177	0.6423	1.9812	1.7651	0.2170	2.6623	1.9930	X, Z
	4	53.5599	23.5085	0.7647	52.5989	22.6448	0.8547	0.9610	0.8637	-0.0900	1.2952	0.9610	X
	5	52.4439	21.7979	-1.2664	51.3135	22.1121	-1.4564	1.1304	-0.3142	0.1900	1.1885	1.1463	X, Z
	6	49.4918	35.0760	3.1961	47.0325	31.5243	2.4362	2.4593	3.5517	0.7599	4.3864	2.5740	X, Z
	7	49.2303	31.2057	3.2297	N/A	N/A	N/A	#VALUE!	#VALUE!	#VALUE!	NA	NA	#VALUE!
	8	49.3927	27.0621	3.1624	49.1515	26.1533	4.4225	0.2412	0.9088	-1.2601	1.5722	0.2412	X
	9	49.4327	23.5737	3.0191	48.5507	23.1676	3.0137	0.8820	0.4061	0.0054	0.9710	0.8820	X, Z
	10	48.5780	20.9686	0.1963	47.3950	20.8977	-0.2159	1.1830	0.0709	0.4122	1.2548	1.2528	X, Z
FLOOR PAN (Z)	11	44.3149	34.9269	5.3745	43.3053	33.4053	5.0639	1.0096	1.5216	0.3106	1.8523	0.3106	Z
	12	44.0297	31.6433	5.3129	43.9427	31.0354	6.7393	0.0870	0.6079	-1.4264	1.5530	-1.4264	Z
	13	44.0043	28.6306	5.2107	43.8621	28.2104	6.6699	0.1422	0.4202	-1.4592	1.5251	-1.4592	Z
	14	44.2042	24.5507	5.1921	43.5622	24.3701	5.3040	0.6420	0.1806	-0.1119	0.6762	-0.1119	Z
	15	44.6352	20.8364	4.6946	43.6033	20.5883	4.1610	1.0319	0.2481	0.5336	1.1879	0.5336	Z
	16	38.2768	34.9517	5.3514	37.9225	33.8123	6.8229	0.3543	1.1394	-1.4715	1.8945	-1.4715	Z
	17	38.4509	31.1309	5.3285	38.4125	30.8774	7.3832	0.0384	0.2535	-2.0547	2.0706	-2.0547	Z
	18	38.9640	27.4274	5.2216	38.8995	27.2556	6.6689	0.0645	0.1718	-1.4473	1.4589	-1.4473	Z
	19	38.7648	21.9961	5.2105	38.7283	21.9452	5.8029	0.0365	0.0509	-0.5924	0.5957	-0.5924	Z
	20	38.7406	17.2507	5.1922	38.7404	17.2654	5.3108	0.0002	-0.0147	-0.1186	0.1195	-0.1186	Z
	21	33.4213	34.6969	5.3532	33.2816	34.1593	7.1790	0.1397	0.5376	-1.8258	1.9084	-1.8258	Z
	22	33.2285	30.3621	5.3472	33.4504	30.2814	6.4374	-0.2219	0.0807	-1.0902	1.1155	-1.0902	Z
	23	33.4035	25.0933	5.3224	33.5421	25.0681	5.8147	-0.1386	0.0252	-0.4923	0.5121	-0.4923	Z
	24	33.4904	20.3548	5.3209	33.5030	20.3278	5.6226	-0.0126	0.0270	-0.3017	0.3032	-0.3017	Z
	25	33.6919	16.5064	5.2067	33.7531	16.4894	5.4141	-0.0612	0.0170	-0.2074	0.2169	-0.2074	Z
	26	29.7814	33.9794	4.3389	29.9724	34.0444	5.7894	-0.1910	-0.0650	-1.4505	1.4645	-1.4505	Z
	27	30.2072	29.5746	4.5424	30.3547	29.5822	5.5067	-0.1475	-0.0076	-0.9643	0.9755	-0.9643	Z
	28	30.2112	24.3381	4.3300	30.3797	24.3659	4.9958	-0.1685	-0.0278	-0.6658	0.6874	-0.6658	Z
	29	30.1673	20.7796	4.5280	30.2853	20.8159	4.9685	-0.1180	-0.0363	-0.4405	0.4575	-0.4405	Z
	30	30.2733	16.3162	4.5359	30.2759	16.3175	4.7346	-0.0026	-0.0013	-0.1987	0.1987	-0.1987	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-8. Floor Pan Deformation Data – Set 1, Test No. H42BR-2

Date: 8/19/2019 Test Name: H42BR-2 VIN: 1C6RR6FT7ES319996
Year: 2014 Make: Dodge Model: RAM 1500

VEHICLE DEFORMATION
PASSENGER SIDE FLOOR PAN - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	57.1091	52.4411	-4.7726	52.0177	48.6071	-6.8249	5.0914	3.8340	2.0523	6.6958	5.4895	X, Z
	2	57.7190	48.7730	-3.9665	53.5965	45.8190	-5.0802	4.1225	2.9540	1.1137	5.1924	4.2703	X, Z
	3	57.9426	45.5969	-4.0988	55.7200	44.0293	-3.8852	2.2226	1.5676	-0.2136	2.7282	2.2226	X
	4	57.2210	42.3459	-4.1464	56.1088	41.7542	-3.6435	1.1122	0.5917	-0.5029	1.3565	1.1122	X
	5	56.1517	40.7872	-6.0057	54.8132	41.2078	-5.9457	1.3385	-0.4206	-0.0600	1.4043	1.3385	X
	6	53.4368	53.9962	-1.7467	50.6591	50.7244	-2.1714	2.7777	3.2718	0.4247	4.3128	2.8100	X, Z
	7	53.0822	50.2113	-1.6792	N/A	N/A	N/A	#VALUE!	#VALUE!	#VALUE!	NA	NA	#VALUE!
	8	53.0980	46.0399	-1.6879	52.7120	45.3532	-0.1175	0.3860	0.6867	-1.5704	1.7569	0.3860	X
	9	53.1689	42.5173	-1.8617	52.0708	42.3573	-1.4862	1.0981	0.1600	-0.3755	1.1715	1.0981	X
	10	52.1209	39.8260	-4.6513	50.8813	40.0602	-4.6841	1.2396	-0.2342	0.0328	1.2620	1.2400	X, Z
FLOOR PAN (Z)	11	48.2268	53.9535	0.5122	46.9603	52.6875	0.4363	1.2665	1.2660	0.0759	1.7924	0.0759	Z
	12	47.8851	50.6746	0.4704	47.5697	50.3318	2.1418	0.3154	0.3428	-1.6714	1.7351	-1.6714	Z
	13	47.8594	47.7230	0.3810	47.4527	47.5074	2.1097	0.4067	0.2156	-1.7287	1.7889	-1.7287	Z
	14	47.8807	43.5209	0.3787	47.1015	43.6537	0.7947	0.7792	-0.1328	-0.4160	0.8932	-0.4160	Z
	15	48.2618	39.7779	-0.1179	47.0925	39.8570	-0.2986	1.1693	-0.0791	0.1807	1.1858	0.1807	Z
	16	42.2523	54.0467	0.5536	41.5857	53.1867	2.1969	0.6666	0.8600	-1.6433	1.9709	-1.6433	Z
	17	42.3346	50.2311	0.5459	42.0389	50.2533	2.7950	0.2957	-0.0222	-2.2491	2.2686	-2.2491	Z
	18	42.7949	46.5034	0.4524	42.4783	46.6165	2.1277	0.3166	-0.1131	-1.6753	1.7087	-1.6753	Z
	19	42.4335	41.0941	0.4667	42.2377	41.2978	1.3318	0.1958	-0.2037	-0.8651	0.9101	-0.8651	Z
	20	42.3667	36.4768	0.4787	42.1890	36.6122	0.9012	0.1777	-0.1354	-0.4225	0.4779	-0.4225	Z
	21	37.3918	53.9306	0.6095	36.9502	53.5979	2.5546	0.4416	0.3327	-1.9451	2.0222	-1.9451	Z
	22	37.0719	49.5785	0.6248	37.0681	49.7087	1.8636	0.0038	-0.1302	-1.2388	1.2456	-1.2388	Z
	23	37.1782	44.2534	0.6212	37.0920	44.4869	1.3094	0.0862	-0.2335	-0.6882	0.7318	-0.6882	Z
	24	37.1534	39.5411	0.6413	36.9918	39.7455	1.1796	0.1616	-0.2044	-0.5383	0.5980	-0.5383	Z
	25	37.3985	35.7097	0.5397	37.1924	35.9018	1.0213	0.2061	-0.1921	-0.4816	0.5580	-0.4816	Z
	26	33.6868	53.1618	-0.3607	33.6377	53.5073	1.1709	0.0491	-0.3455	-1.5316	1.5709	-1.5316	Z
	27	33.9972	48.8443	-0.1400	33.9623	49.0372	0.9463	0.0349	-0.1929	-1.0863	1.1038	-1.0863	Z
	28	33.9475	43.6063	-0.3326	33.9196	43.8148	0.5039	0.0279	-0.2085	-0.8365	0.8625	-0.8365	Z
	29	33.8052	40.0461	-0.1165	33.7797	40.2662	0.5234	0.0255	-0.2201	-0.6399	0.6772	-0.6399	Z
	30	33.8831	35.5337	-0.0910	33.7122	35.7656	0.3486	0.1709	-0.2319	-0.4396	0.5256	-0.4396	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-9. Floor Pan Deformation Data – Set 2, Test No. H42BR-2

Date: 8/19/2019 | Test Name: H42BR-2 | VIN: 1C6RR6FT7ES319996
Year: 2014 | Make: Dodge | Model: RAM 1500

VEHICLE DEFORMATION
PASSENGER SIDE INTERIOR CRUSH - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	43.5815	33.7618	-26.9207	43.6109	33.3886	-27.5666	-0.0294	0.3732	-0.6459	0.7465	0.7465	X, Y, Z
	2	42.7385	22.0075	-27.5116	42.9391	21.7493	-28.0824	-0.2006	0.2582	-0.5708	0.6578	0.6578	X, Y, Z
	3	42.3023	4.8972	-27.9700	42.6571	4.6052	-28.3693	-0.3548	0.2920	-0.3993	0.6088	0.6088	X, Y, Z
	4	38.2917	35.8034	-14.6041	37.1985	35.2911	-15.7388	1.0932	0.5123	-1.1347	1.6568	1.6568	X, Y, Z
	5	37.1820	20.7128	-15.8951	36.9928	20.1102	-16.7658	0.1892	0.6026	-0.8707	1.0757	1.0757	X, Y, Z
	6	35.3933	4.7377	-16.0414	35.4032	4.5627	-16.6277	-0.0099	0.1750	-0.5863	0.6119	0.6119	X, Y, Z
SIDE PANEL (Y)	7	46.9600	37.6774	-4.2630	45.2700	33.2684	-5.0923	1.6900	4.4090	-0.8293	4.7941	4.4090	Y
	8	47.1510	37.6508	0.2608	45.5226	33.5521	-0.4580	1.6284	4.0987	-0.7188	4.4685	4.0987	Y
	9	49.8576	37.6212	-1.0795	47.9636	32.8059	-2.0423	1.8940	4.8153	-0.9628	5.2632	4.8153	Y
IMPACT SIDE DOOR (Y)	10	37.5560	39.5287	-19.7171	36.1040	38.6102	-20.1775	1.4520	0.9185	-0.4604	1.7787	0.9185	Y
	11	25.9624	39.2282	-19.1752	24.6977	40.5886	-19.3642	1.2647	-1.3604	-0.1890	1.8670	-1.3604	Y
	12	13.4830	39.3343	-19.2105	12.4080	41.2757	-19.1392	1.0750	-1.9414	0.0713	2.2203	-1.9414	Y
	13	38.9548	38.3199	-7.8574	37.0474	36.1712	-8.2502	1.9074	2.1487	-0.3928	2.8999	2.1487	Y
	14	27.2688	40.1097	0.2042	26.2512	39.7449	-0.0244	1.0176	0.3648	-0.2286	1.1049	0.3648	Y
	15	15.5930	39.3454	-0.5766	14.5942	40.2855	-0.5528	0.9988	-0.9401	0.0238	1.3718	-0.9401	Y
ROOF - (Z)	16	25.4633	26.1385	-44.4312	25.4910	26.7294	-44.7343	-0.0277	-0.5909	-0.3031	0.6647	-0.3031	Z
	17	26.8313	21.9038	-44.5893	26.8186	22.5148	-44.8729	0.0127	-0.6110	-0.2836	0.6737	-0.2836	Z
	18	27.8869	17.0497	-44.7367	27.9735	17.5330	-44.9518	-0.0866	-0.4833	-0.2151	0.5360	-0.2151	Z
	19	28.6597	11.6098	-44.8270	28.7812	12.2306	-44.9726	-0.1215	-0.6208	-0.1456	0.6491	-0.1456	Z
	20	29.2017	5.0776	-44.8432	29.2381	5.6395	-44.9644	-0.0364	-0.5619	-0.1212	0.5760	-0.1212	Z
	21	15.0635	27.7080	-45.7632	14.9463	28.1642	-45.8382	0.1172	-0.4562	-0.0750	0.4769	-0.0750	Z
	22	15.9017	23.2227	-46.1646	15.9678	23.6454	-46.2618	-0.0661	-0.4227	-0.0972	0.4387	-0.0972	Z
	23	16.0979	17.3453	-46.5082	16.1124	17.8668	-46.8002	-0.0145	-0.5215	-0.2920	0.5979	-0.2920	Z
	24	16.2351	11.4820	-46.7173	16.2628	11.9240	-46.9878	-0.0277	-0.4420	-0.2705	0.5189	-0.2705	Z
	25	16.5565	5.8124	-46.7938	16.5869	6.3833	-47.0303	-0.0304	-0.5709	-0.2365	0.6187	-0.2365	Z
	26	6.8862	26.1784	-46.3087	6.8025	26.6006	-46.2721	0.0837	-0.4222	0.0366	0.4320	0.0366	Z
	27	7.6807	20.2203	-46.7193	7.6711	20.5437	-46.8819	0.0096	-0.3234	-0.1626	0.3621	-0.1626	Z
	28	7.6906	13.4075	-47.0212	7.7011	13.8460	-47.2279	-0.0105	-0.4385	-0.2067	0.4849	-0.2067	Z
	29	7.9791	8.8801	-47.1192	7.9901	9.3110	-47.2830	-0.0110	-0.4309	-0.1638	0.4611	-0.1638	Z
	30	7.9823	4.9641	-47.1462	8.0523	5.3909	-47.3074	-0.0700	-0.4268	-0.1612	0.4616	-0.1612	Z
A-PILLAR Maximum (X, Y, Z)	31	46.2126	36.3481	-28.9766	46.2596	36.3908	-29.5499	-0.0470	-0.0427	-0.5733	0.5768	0.0000	NA
	32	43.9495	35.7790	-30.5703	44.2569	35.7942	-31.3912	-0.3074	-0.0152	-0.8209	0.8767	0.0000	NA
	33	41.7894	35.1580	-32.1893	42.2081	35.2181	-33.2234	-0.4187	-0.0601	-1.0341	1.1173	0.0000	NA
	34	37.8876	34.1330	-34.6902	38.2152	34.4211	-35.5720	-0.3276	-0.2881	-0.8818	0.9838	0.0000	NA
	35	34.4301	33.4018	-37.2588	34.6675	33.8540	-38.0408	-0.2374	-0.4522	-0.7820	0.9340	0.0000	NA
	36	30.1549	32.5467	-39.9970	30.2178	33.1437	-40.6964	-0.0629	-0.5970	-0.6994	0.9217	0.0000	NA
A-PILLAR Lateral (Y)	31	46.2126	36.3481	-28.9766	46.2596	36.3908	-29.5499	-0.0470	-0.0427	-0.5733	0.5768	-0.0427	Y
	32	43.9495	35.7790	-30.5703	44.2569	35.7942	-31.3912	-0.3074	-0.0152	-0.8209	0.8767	-0.0152	Y
	33	41.7894	35.1580	-32.1893	42.2081	35.2181	-33.2234	-0.4187	-0.0601	-1.0341	1.1173	-0.0601	Y
	34	37.8876	34.1330	-34.6902	38.2152	34.4211	-35.5720	-0.3276	-0.2881	-0.8818	0.9838	-0.2881	Y
	35	34.4301	33.4018	-37.2588	34.6675	33.8540	-38.0408	-0.2374	-0.4522	-0.7820	0.9340	-0.4522	Y
	36	30.1549	32.5467	-39.9970	30.2178	33.1437	-40.6964	-0.0629	-0.5970	-0.6994	0.9217	-0.5970	Y
B-PILLAR Maximum (X, Y, Z)	37	5.5186	33.6365	-36.0152	5.3992	33.8946	-35.8766	0.1194	-0.2581	0.1386	0.3164	0.1829	X, Z
	38	2.0239	34.5720	-31.9196	1.9479	34.7424	-31.7277	0.0760	-0.1704	0.1919	0.2677	0.2064	X, Z
	39	6.8231	36.4094	-24.5893	6.7233	36.4996	-24.3969	0.0998	-0.0902	0.1924	0.2348	0.2167	X, Z
	40	3.5959	36.7649	-15.8919	3.5301	36.7234	-15.7283	0.0658	0.0415	0.1636	0.1812	0.1812	X, Y, Z
B-PILLAR Lateral (Y)	37	5.5186	33.6365	-36.0152	5.3992	33.8946	-35.8766	0.1194	-0.2581	0.1386	0.3164	-0.2581	Y
	38	2.0239	34.5720	-31.9196	1.9479	34.7424	-31.7277	0.0760	-0.1704	0.1919	0.2677	-0.1704	Y
	39	6.8231	36.4094	-24.5893	6.7233	36.4996	-24.3969	0.0998	-0.0902	0.1924	0.2348	-0.0902	Y
	40	3.5959	36.7649	-15.8919	3.5301	36.7234	-15.7283	0.0658	0.0415	0.1636	0.1812	0.0415	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-10. Interior Crush Deformation Data – Set 1, Test No. H42BR-2

Date: 8/19/2019 Test Name: H42BR-2 VIN: 1C6RR6FT7ES319996
Year: 2014 Make: Dodge Model: RAM 1500

VEHICLE DEFORMATION
PASSENGER SIDE INTERIOR CRUSH - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	46.8772	52.4252	-31.7876	47.3814	51.9822	-32.3641	-0.5042	0.4430	-0.5765	0.8848	0.8848	X, Y, Z
	2	45.8294	40.6844	-32.3163	46.5032	40.3503	-32.7109	-0.6738	0.3341	-0.3946	0.8493	0.8493	X, Y, Z
	3	45.0999	23.5821	-32.6938	45.9190	23.2115	-32.7515	-0.8191	0.3706	-0.0577	0.9009	0.9009	X, Y, Z
	4	41.7711	54.6078	-19.4178	41.0523	54.1654	-20.5399	0.7188	0.4424	-1.1221	1.4041	1.4041	X, Y, Z
	5	40.3921	39.5328	-20.6287	40.5758	38.9774	-21.3490	-0.1837	0.5554	-0.7203	0.9279	0.9279	X, Y, Z
	6	38.3331	23.5897	-20.6828	38.7141	23.4639	-20.9826	-0.3810	0.1258	-0.2998	0.5009	0.5009	X, Y, Z
SIDE PANEL (Y)	7	50.5935	56.3789	-9.1894	49.1309	52.1525	-9.8969	1.4626	4.2264	-0.7075	4.5279	4.2264	Y
	8	50.8384	56.3682	-4.6682	49.4076	52.4976	-5.2682	1.4308	3.8706	-0.6000	4.1700	3.8706	Y
	9	53.5278	56.2872	-6.0406	51.8285	51.6860	-6.8511	1.6993	4.6012	-0.8105	4.9715	4.6012	Y
IMPACT SIDE DOOR (Y)	10	41.0367	58.3234	-24.5381	39.9979	57.4397	-25.0214	1.0388	0.8837	-0.4833	1.4469	0.8837	Y
	11	29.4471	58.2210	-23.8563	28.6316	59.6302	-24.1922	0.8155	-1.4092	-0.3359	1.6624	-1.4092	Y
	12	16.9717	58.5376	-23.7428	16.3569	60.5368	-23.9294	0.6148	-1.9992	-0.1866	2.0999	-1.9992	Y
	13	42.5575	57.1412	-12.6907	40.9476	55.1544	-13.0642	1.6099	1.9868	-0.3735	2.5843	1.9868	Y
	14	31.0011	59.1621	-4.4980	30.2498	59.0344	-4.8485	0.7513	0.1277	-0.3505	0.8388	0.1277	Y
	15	19.3056	58.5918	-5.1357	18.6020	59.7727	-5.3393	0.7036	-1.1809	-0.2036	1.3896	-1.1809	Y
ROOF - (Z)	16	28.4239	45.0350	-49.0463	29.0767	45.3997	-49.3645	-0.6528	-0.3647	-0.3182	0.8127	-0.3182	Z
	17	29.7184	40.7772	-49.2020	30.3295	41.1608	-49.4479	-0.6111	-0.3836	-0.2459	0.7623	-0.2459	Z
	18	30.6903	35.9054	-49.3405	31.3964	36.1588	-49.4602	-0.7061	-0.2534	-0.1197	0.7597	-0.1197	Z
	19	31.3704	30.4529	-49.4160	32.1108	30.8433	-49.4082	-0.7404	-0.3904	0.0078	0.8371	0.0078	Z
	20	31.8021	23.9124	-49.4097	32.4520	24.2459	-49.3076	-0.6499	-0.3335	0.1021	0.7376	0.1021	Z
	21	18.0367	46.7742	-50.2608	18.5543	47.0042	-50.4480	-0.5176	-0.2300	-0.1872	0.5965	-0.1872	Z
	22	18.7945	42.2738	-50.6523	19.4946	42.4625	-50.8109	-0.7001	-0.1887	-0.1586	0.7422	-0.1586	Z
	23	18.8876	36.3924	-50.9723	19.5355	36.6751	-51.2671	-0.6479	-0.2827	-0.2948	0.7659	-0.2948	Z
	24	18.9235	30.5269	-51.1570	19.5807	30.7286	-51.3704	-0.6572	-0.2017	-0.2134	0.7198	-0.2134	Z
	25	19.1485	24.8524	-51.2122	19.8073	25.1830	-51.3349	-0.6588	-0.3306	-0.1227	0.7472	-0.1227	Z
	26	9.8288	45.3806	-50.7017	10.3827	45.5783	-50.8279	-0.5539	-0.1977	-0.1262	0.6015	-0.1262	Z
	27	10.5180	39.4083	-51.0954	11.1423	39.4990	-51.3544	-0.6243	-0.0907	-0.2590	0.6820	-0.2590	Z
	28	10.4096	32.5950	-51.3672	11.0532	32.7975	-51.6048	-0.6436	-0.2025	-0.2376	0.7153	-0.2376	Z
	29	10.6206	28.0631	-51.4487	11.2623	28.2578	-51.5961	-0.6417	-0.1947	-0.1474	0.6866	-0.1474	Z
	30	10.5576	24.1475	-51.4584	11.2555	24.3373	-51.5647	-0.6979	-0.1898	-0.1063	0.7310	-0.1063	Z
A-PILLAR Maximum (X, Y, Z)	31	49.5266	54.9580	-33.8863	50.0742	54.9087	-34.4004	-0.5476	0.0493	-0.5141	0.7527	0.0493	Y
	32	47.2352	54.4205	-35.4503	48.0538	54.3214	-36.2252	-0.8186	0.0991	-0.7749	1.1315	0.0991	Y
	33	45.0456	53.8292	-37.0406	45.9876	53.7555	-38.0410	-0.9420	0.0737	-1.0004	1.3761	0.0737	Y
	34	41.0972	52.8596	-39.4901	41.9717	52.9956	-40.3624	-0.8745	-0.1360	-0.8723	1.2426	0.0000	NA
	35	37.5973	52.1761	-42.0139	38.4044	52.4560	-42.8091	-0.8071	-0.2799	-0.7952	1.1671	0.0000	NA
	36	33.2757	51.3817	-44.6970	33.9320	51.7866	-45.4370	-0.6563	-0.4049	-0.7400	1.0688	0.0000	NA
A-PILLAR Lateral (Y)	31	49.5266	54.9580	-33.8863	50.0742	54.9087	-34.4004	-0.5476	0.0493	-0.5141	0.7527	0.0493	Y
	32	47.2352	54.4205	-35.4503	48.0538	54.3214	-36.2252	-0.8186	0.0991	-0.7749	1.1315	0.0991	Y
	33	45.0456	53.8292	-37.0406	45.9876	53.7555	-38.0410	-0.9420	0.0737	-1.0004	1.3761	0.0737	Y
	34	41.0972	52.8596	-39.4901	41.9717	52.9956	-40.3624	-0.8745	-0.1360	-0.8723	1.2426	-0.1360	Y
	35	37.5973	52.1761	-42.0139	38.4044	52.4560	-42.8091	-0.8071	-0.2799	-0.7952	1.1671	-0.2799	Y
	36	33.2757	51.3817	-44.6970	33.9320	51.7866	-45.4370	-0.6563	-0.4049	-0.7400	1.0688	-0.4049	Y
B-PILLAR Maximum (X, Y, Z)	37	8.7110	52.9041	-40.4257	9.1505	53.0430	-40.5323	-0.4395	-0.1389	-0.1066	0.4731	0.0000	NA
	38	5.2820	53.9158	-36.2927	5.7318	54.0104	-36.3826	-0.4498	-0.0946	-0.0899	0.4683	0.0000	NA
	39	10.1993	55.7029	-29.0285	10.5675	55.7873	-29.0963	-0.3682	-0.0844	-0.0678	0.3838	0.0000	NA
	40	7.0834	56.1495	-20.2949	7.4146	56.1905	-20.4195	-0.3312	-0.0410	-0.1246	0.3562	0.0000	NA
B-PILLAR Lateral (Y)	37	8.7110	52.9041	-40.4257	9.1505	53.0430	-40.5323	-0.4395	-0.1389	-0.1066	0.4731	-0.1389	Y
	38	5.2820	53.9158	-36.2927	5.7318	54.0104	-36.3826	-0.4498	-0.0946	-0.0899	0.4683	-0.0946	Y
	39	10.1993	55.7029	-29.0285	10.5675	55.7873	-29.0963	-0.3682	-0.0844	-0.0678	0.3838	-0.0844	Y
	40	7.0834	56.1495	-20.2949	7.4146	56.1905	-20.4195	-0.3312	-0.0410	-0.1246	0.3562	-0.0410	Y

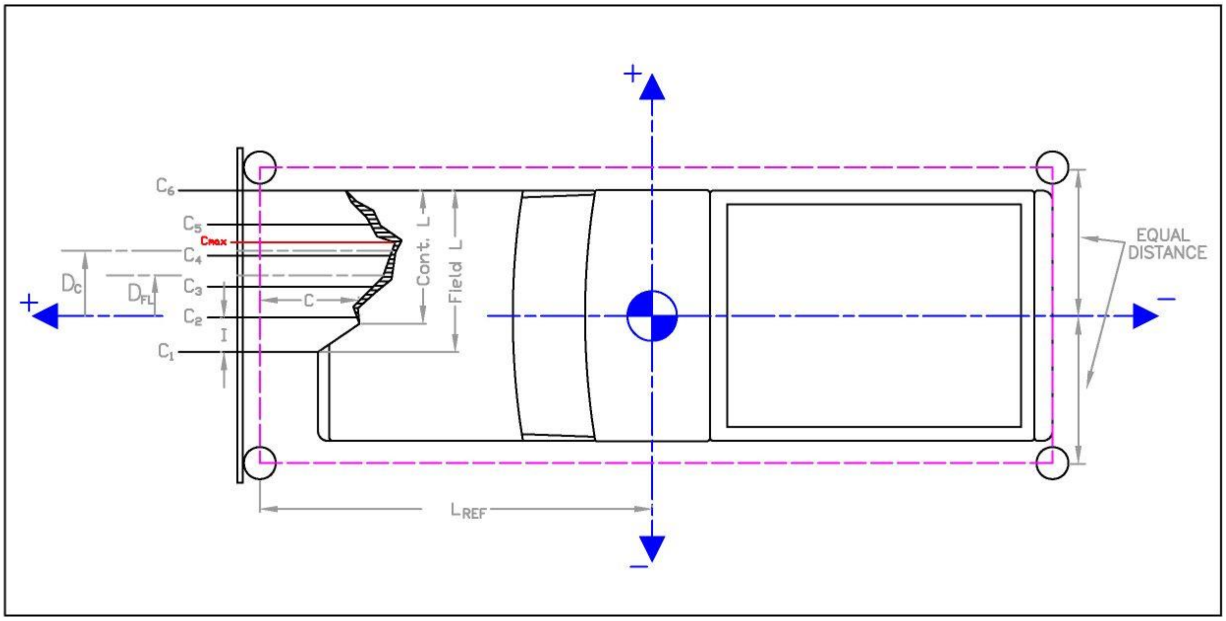
[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[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-11. Interior Crush Deformation Data – Set 2, Test No. H42BR-2

Date:	8/21/2019	Test Name:	H42BR-2	VIN:	1C6RR6FT7ES319996
Year:	2014	Make:	Dodge	Model:	RAM 1500



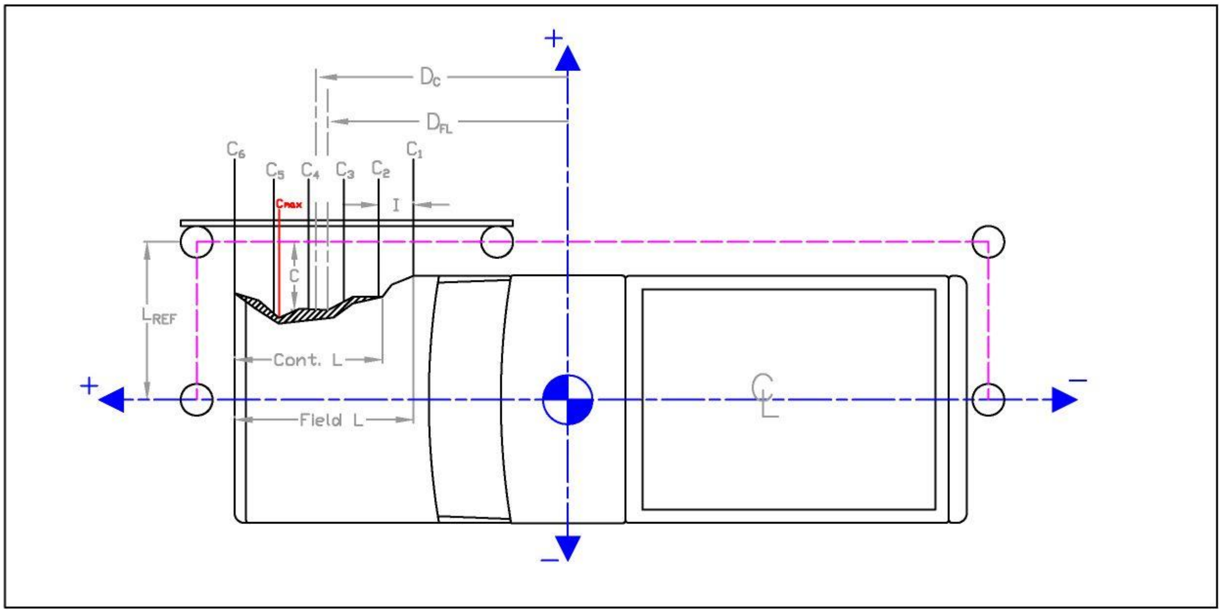
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	102	(2591)
Total Vehicle Width:	77 1/2	(1969)
Width of contact and induced crush - Field L:	47	(1194)
Crush measurement spacing interval (L/5) - I:	9 3/8	(238)
Distance from center of vehicle to center of Field L - D_{FL}:	9	(229)
Width of Contact Damage:	11	(279)
Distance from center of vehicle to center of contact damage - D_C:	10 1/4	(260)

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	1 3/4	(44)	-14 1/2	-(368)	4 7/8	(124)	-2 4/7	-(65)	- 4/7	-(14)
C_2	1	(25)	-5 1/8	-(130)	4 1/8	(105)			- 4/7	-(14)
C_3	1	(25)	4 1/4	(108)	4	(102)			- 4/9	-(11)
C_4	3 3/4	(95)	13 5/8	(346)	4 3/4	(121)			1 4/7	(40)
C_5	21 3/4	(552)	23	(584)	6 1/8	(156)			18 1/5	(462)
C_6	N/A	N/A	32 3/8	(822)	11 1/8	(283)			N/A	N/A
C_{MAX}	21 3/4	(552)	23	(584)	6 1/8	(156)			18 1/5	(462)

Figure C-12. Exterior Vehicle Crush (NASS) - Front, Test No. H42BR-2

Date:	8/21/2019	Test Name:	H42BR-2	VIN:	1C6RR6FT7ES319996
Year:	2014	Make:	Dodge	Model:	RAM 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	44	(1118)
Total Vehicle Length:	229 5/8	(5832)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-6 5/8	-(168)
Width of contact and induced crush - Field L:	229 5/8	(5832)
Crush measurement spacing interval (L/5) - I:	45 7/8	(1165)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-6 5/8	-(168)
Width of Contact Damage:	229 5/8	(5832)
Distance from vehicle c.g. to center of contact damage - D_C:	-6 5/8	-(168)

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

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	N/A	N/A	-121 1/2	-(3086)	33 1/2	(851)	0	()	N/A	N/A
C_2	N/A	N/A	-75 5/8	-(1921)	5 1/4	(133)			N/A	N/A
C_3	3 7/8	(98)	-29 3/4	-(756)	5 5/8	(143)			-1 3/4	-(44)
C_4	3 5/8	(92)	16 1/8	(410)	5 1/8	(130)			-1 1/2	-(38)
C_5	N/A	N/A	62	(1575)	5 1/8	(130)			N/A	N/A
C_6	N/A	N/A	107 7/8	(2740)	30	(762)			N/A	N/A
C_{MAX}	18 1/2	(470)	81	(2057)	5 1/2	(140)			13	(330)

Figure C-13. Exterior Vehicle Crush (NASS) - Side, Test No. H42BR-2

Appendix D. Accelerometer and Rate Transducer Data Plots, Test No. H42BR-1

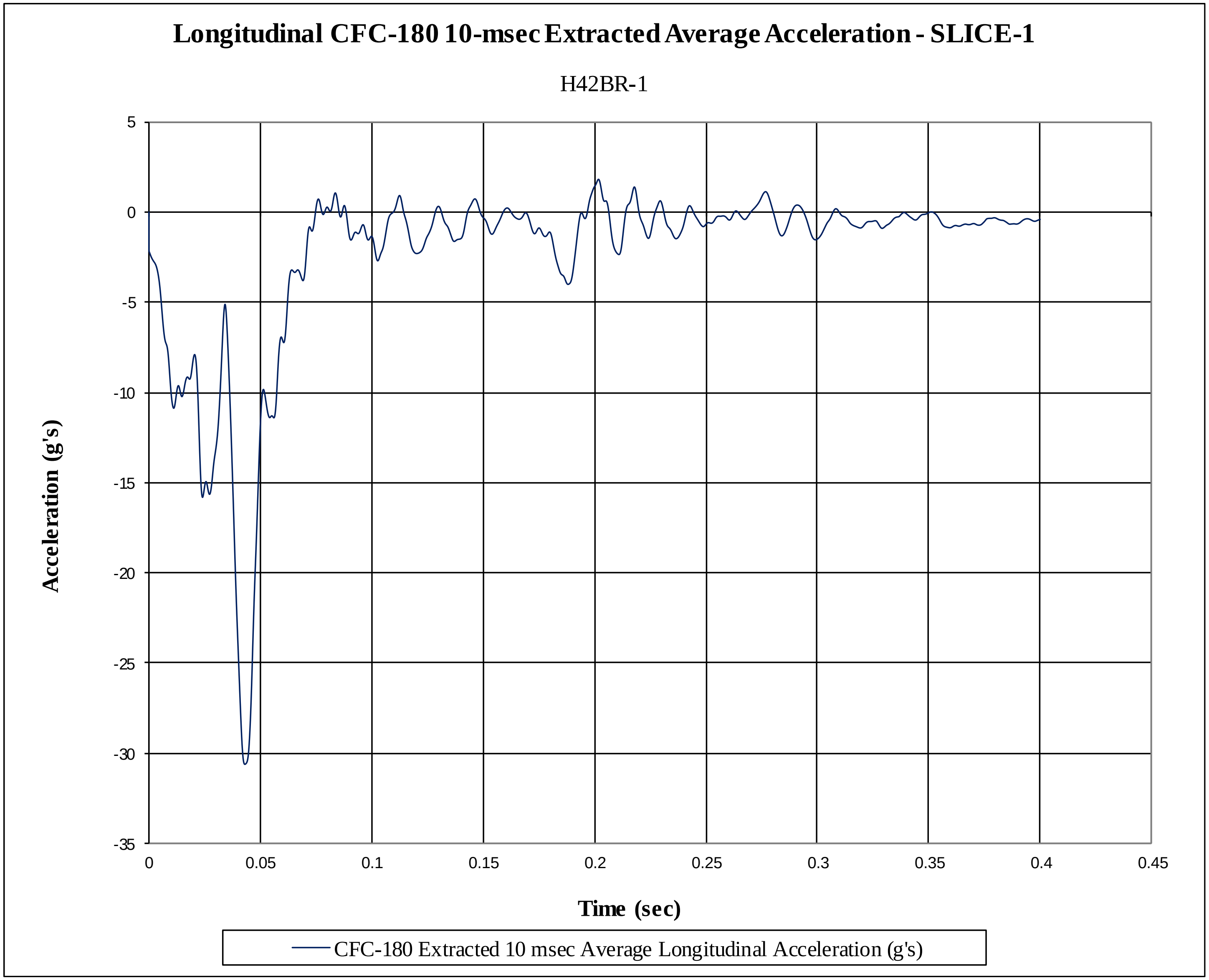


Figure D-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. H42BR-1

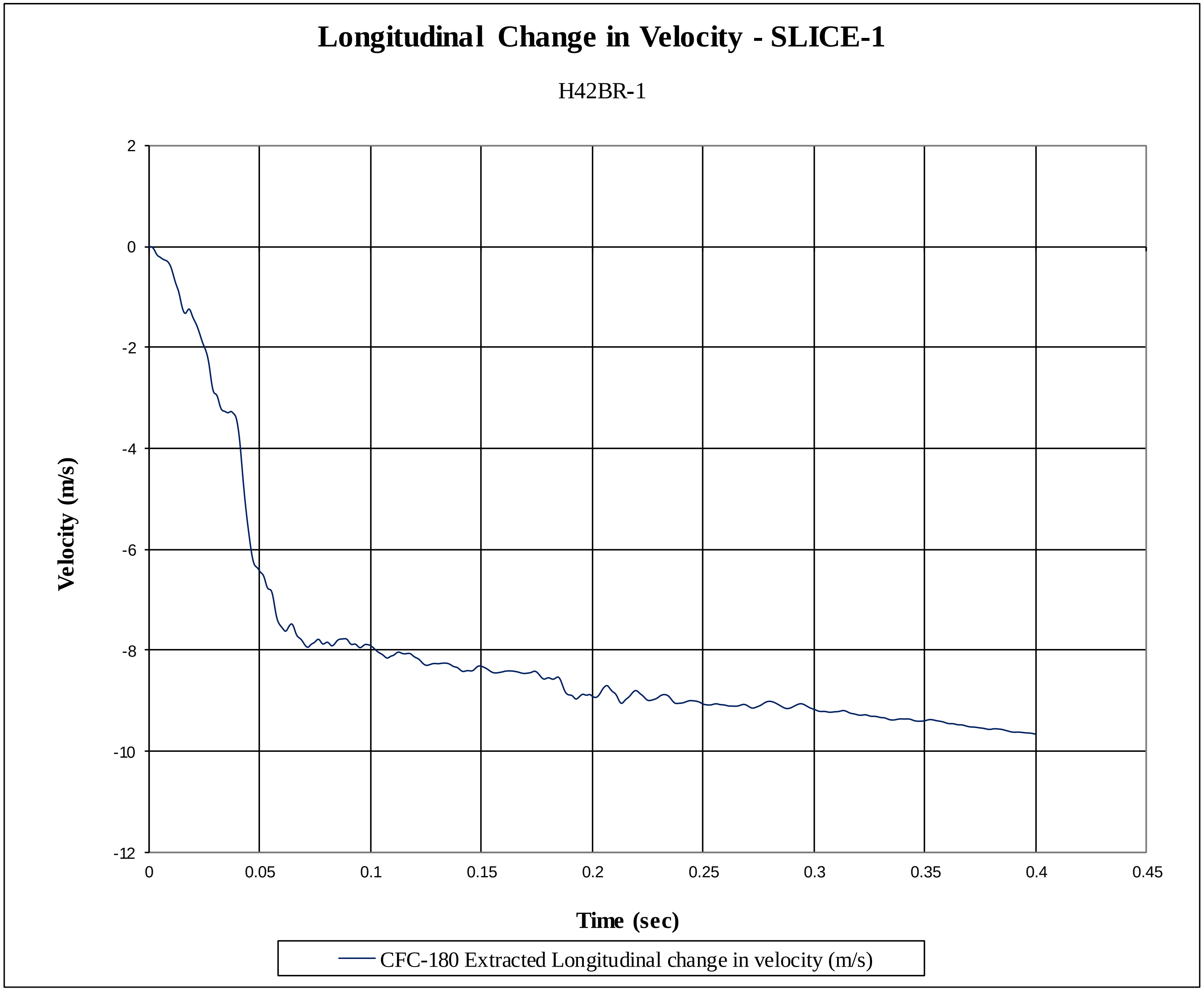


Figure D-2. Longitudinal Change in Velocity (SLICE-1), Test No. H42BR-1

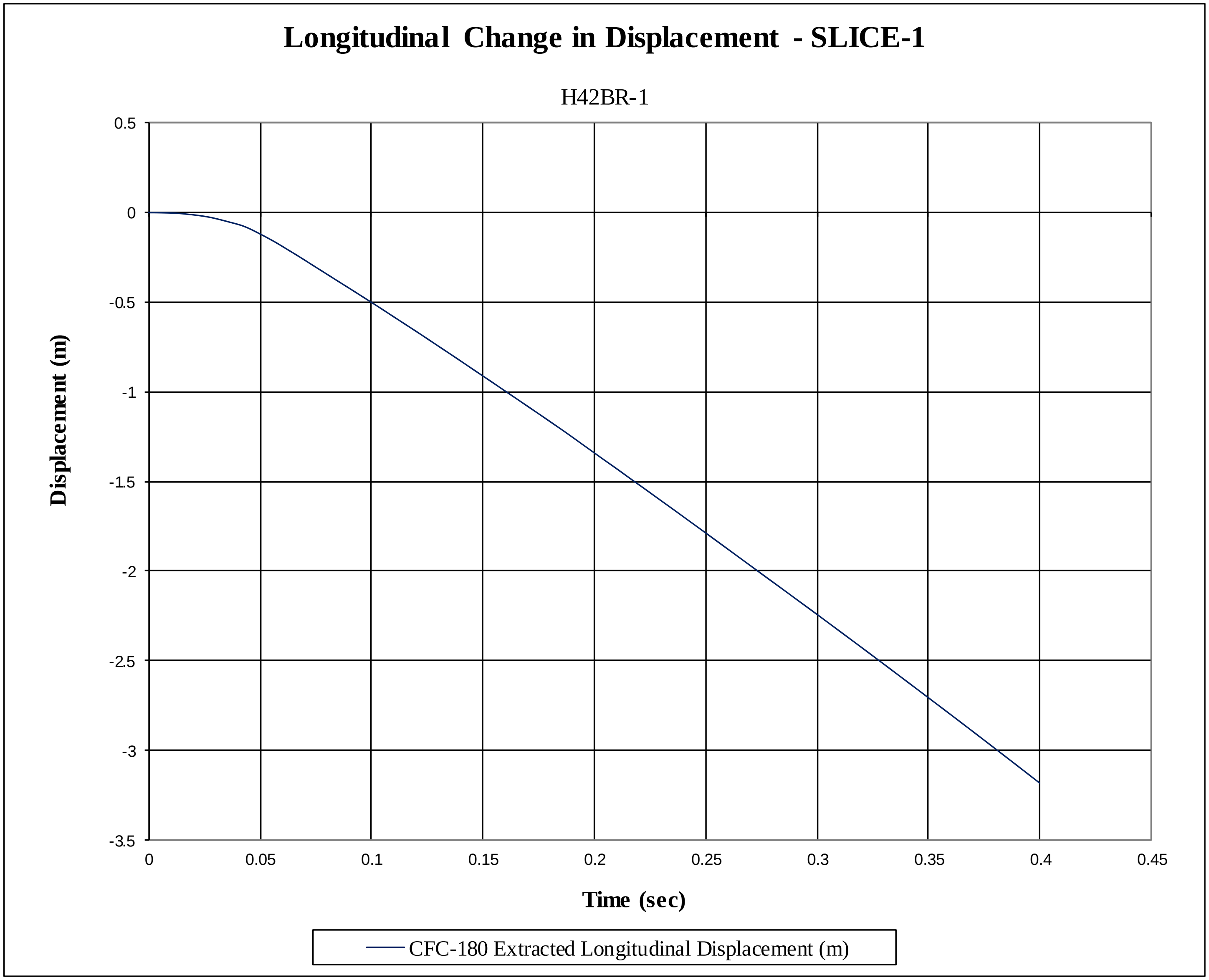


Figure D-3. Longitudinal Change in Displacement (SLICE-1), Test No. H42BR-1

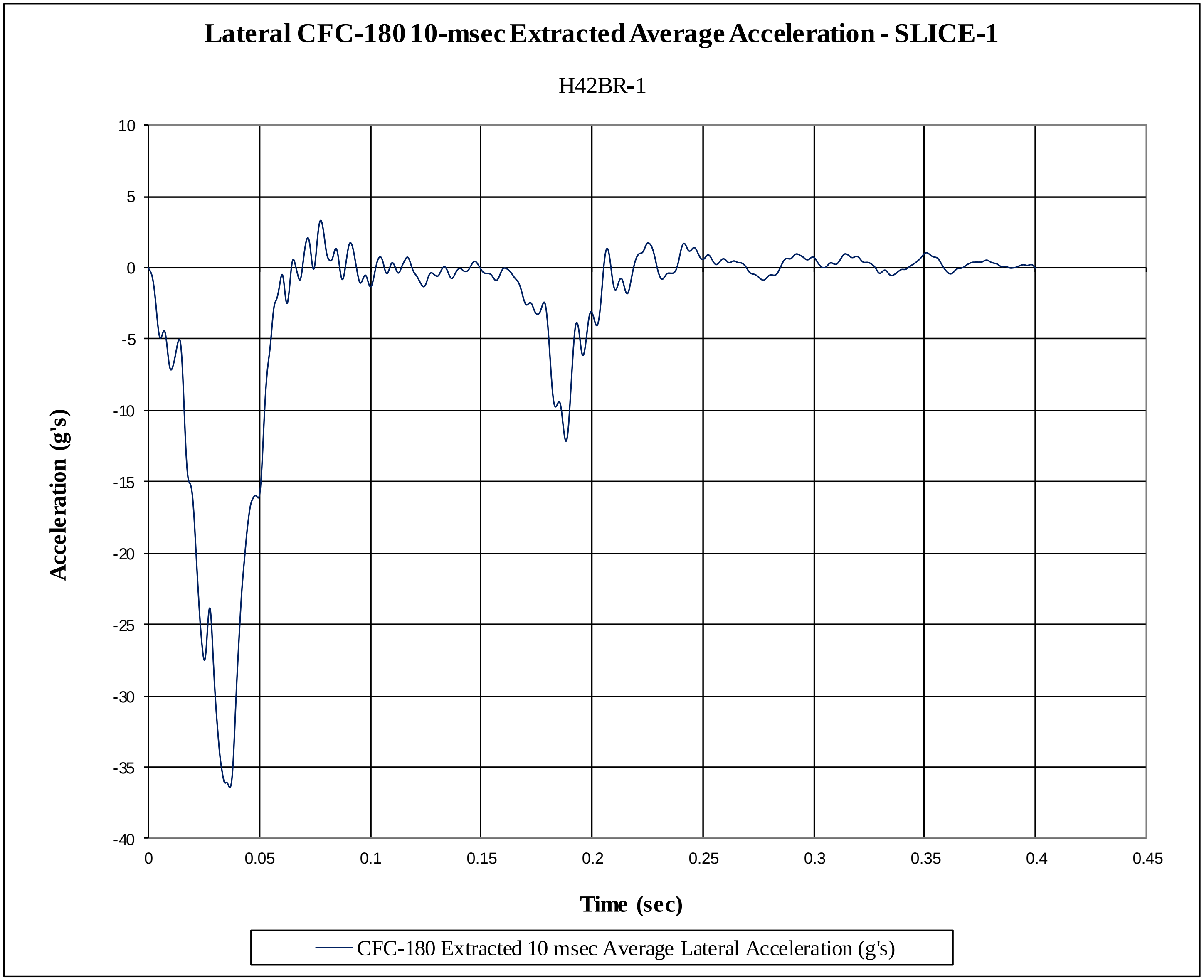


Figure D-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. H42BR-1

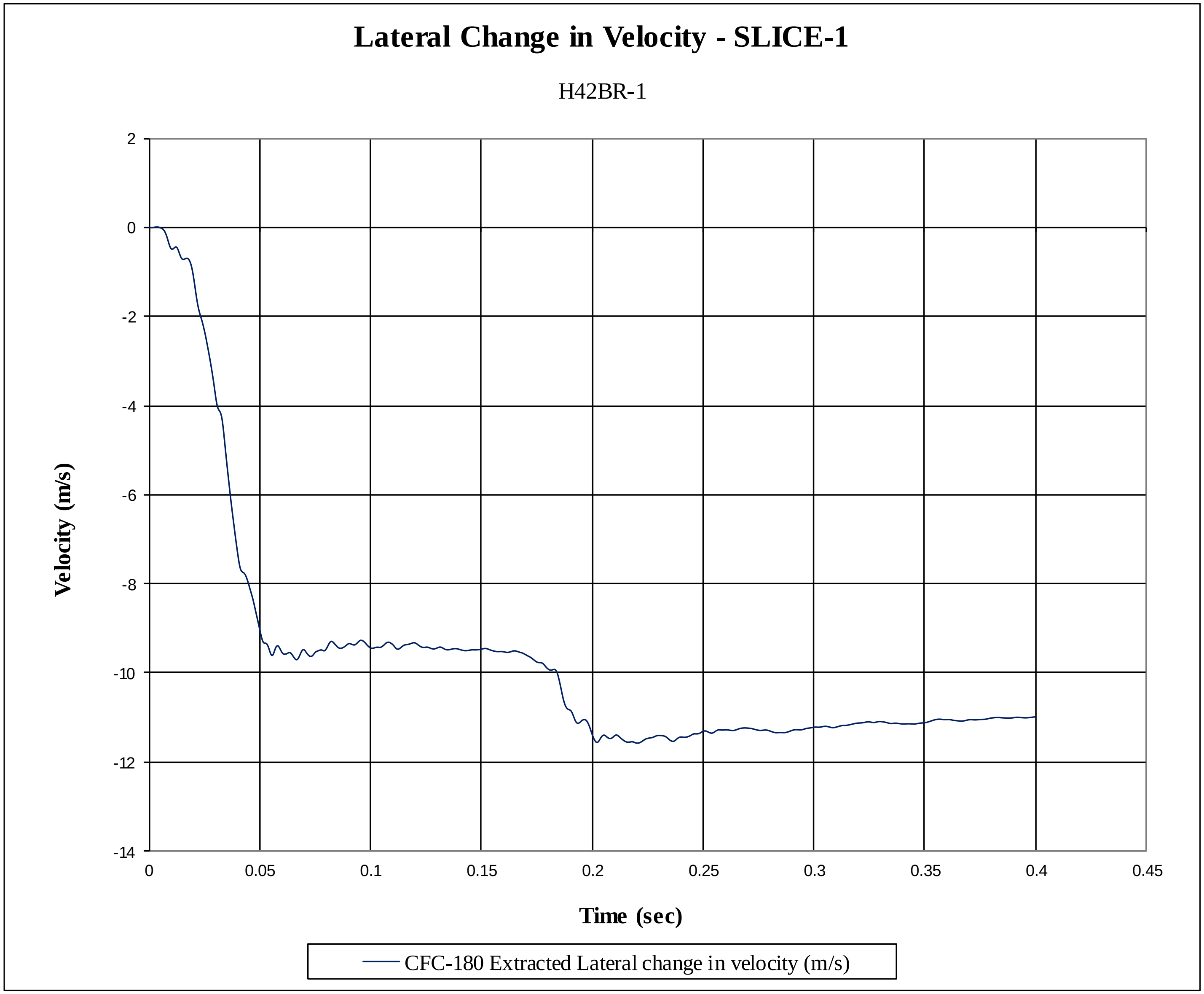


Figure D-5. Lateral Change in Velocity (SLICE-1), Test No. H42BR-1

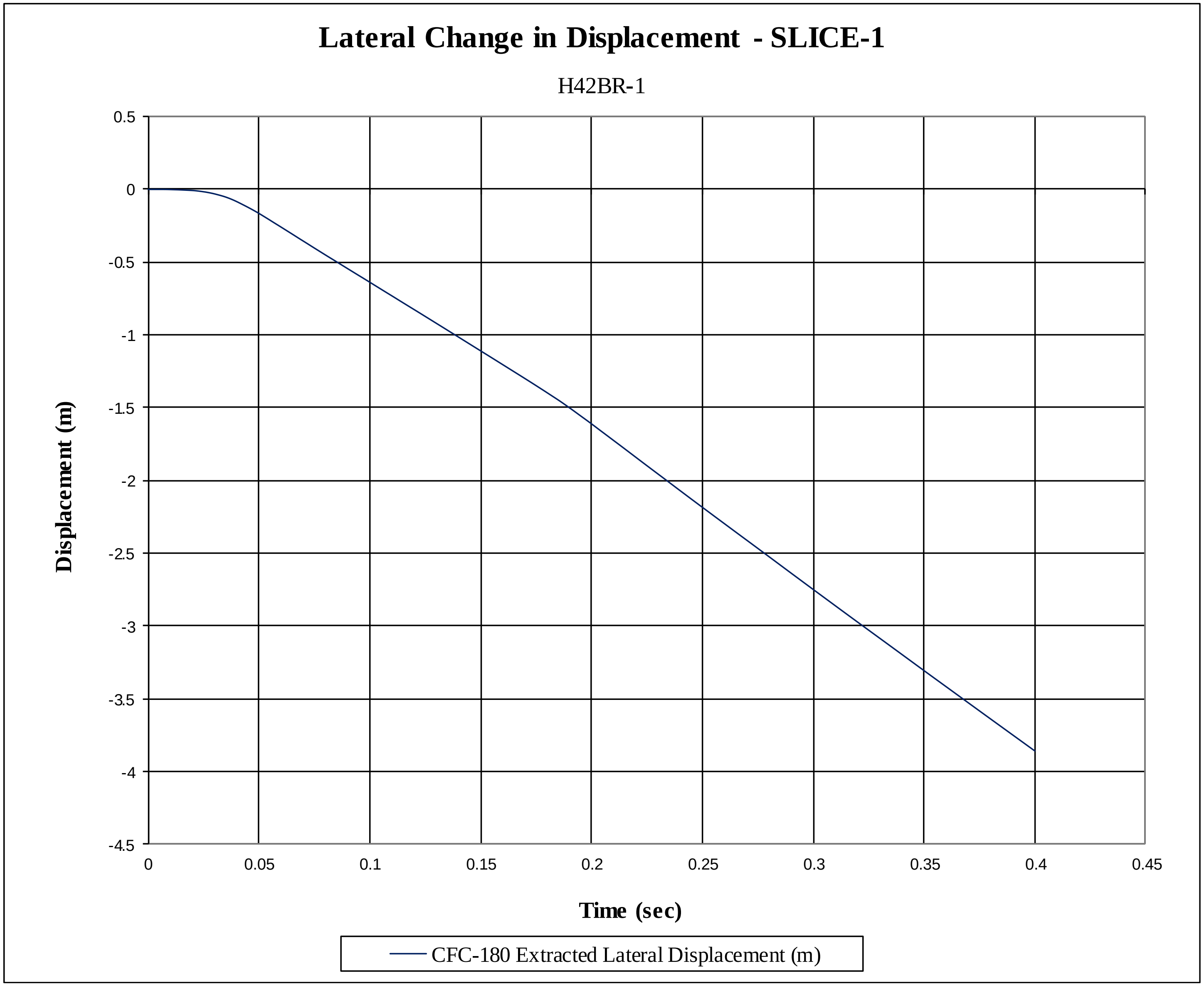


Figure D-6. Lateral Change in Displacement (SLICE-1), Test No. H42BR-1

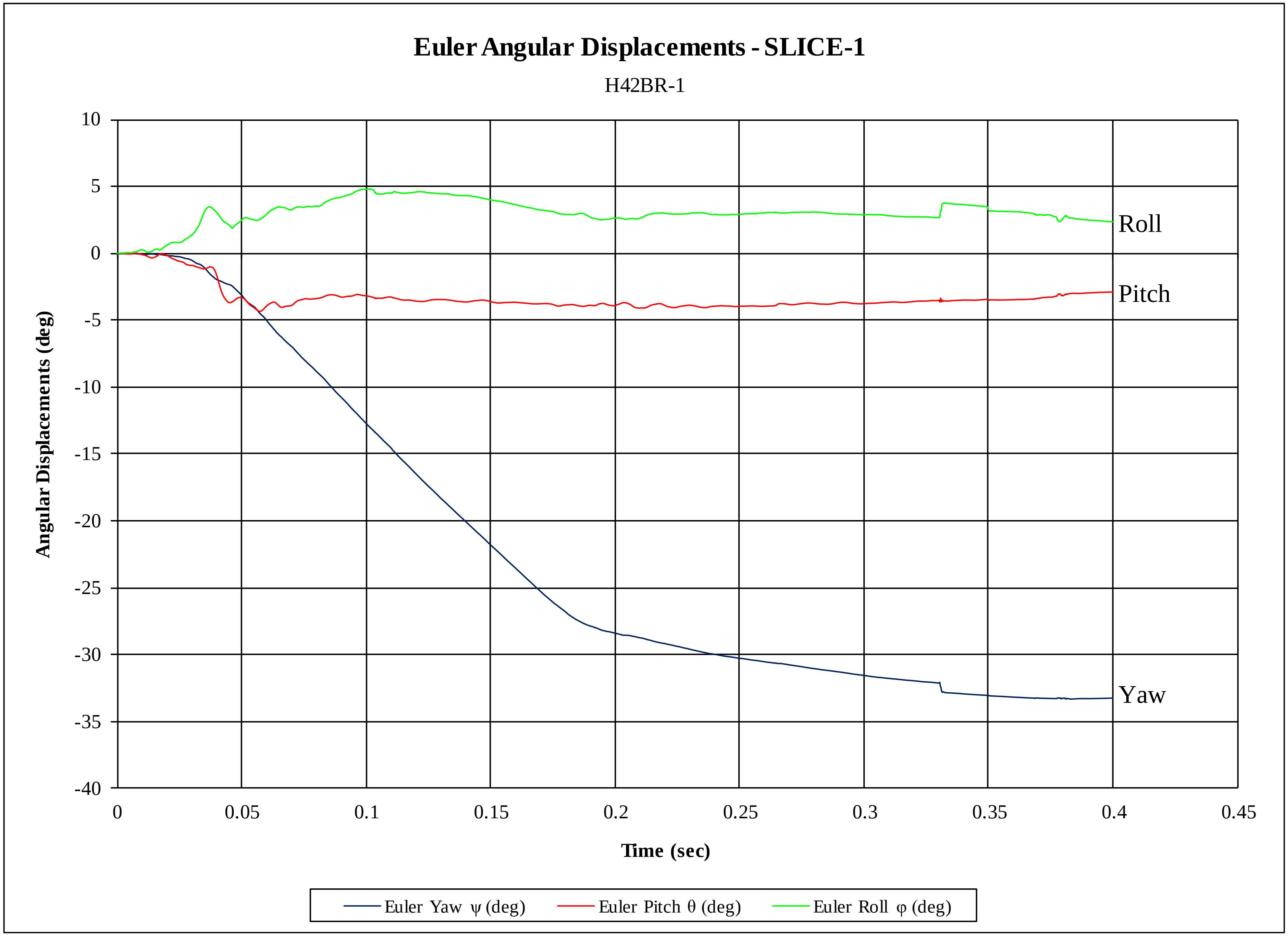


Figure D-7. Vehicle Angular Displacements (SLICE-1), Test No. H42BR-1

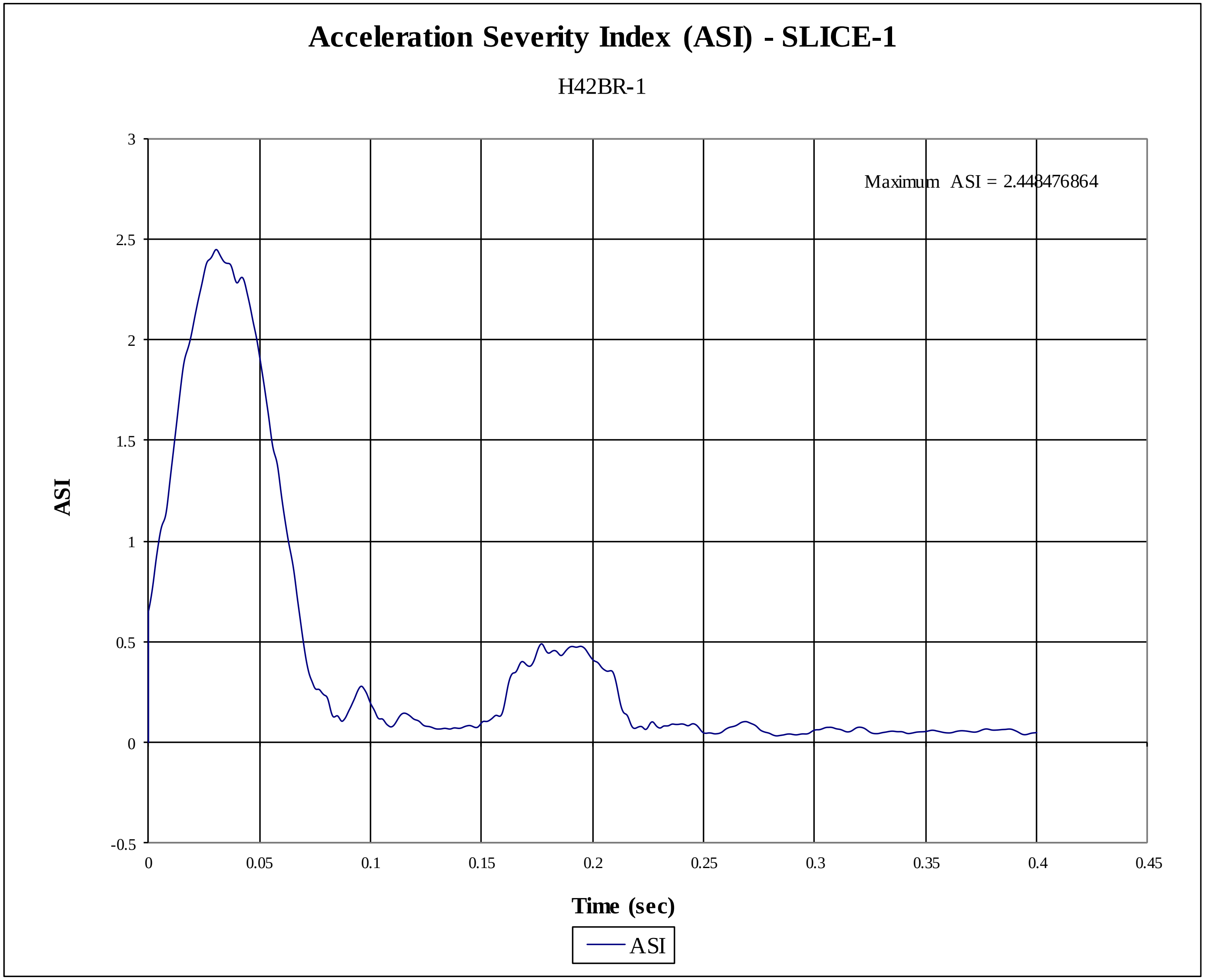


Figure D-8. Acceleration Severity Index (SLICE-1), Test No. H42BR-1

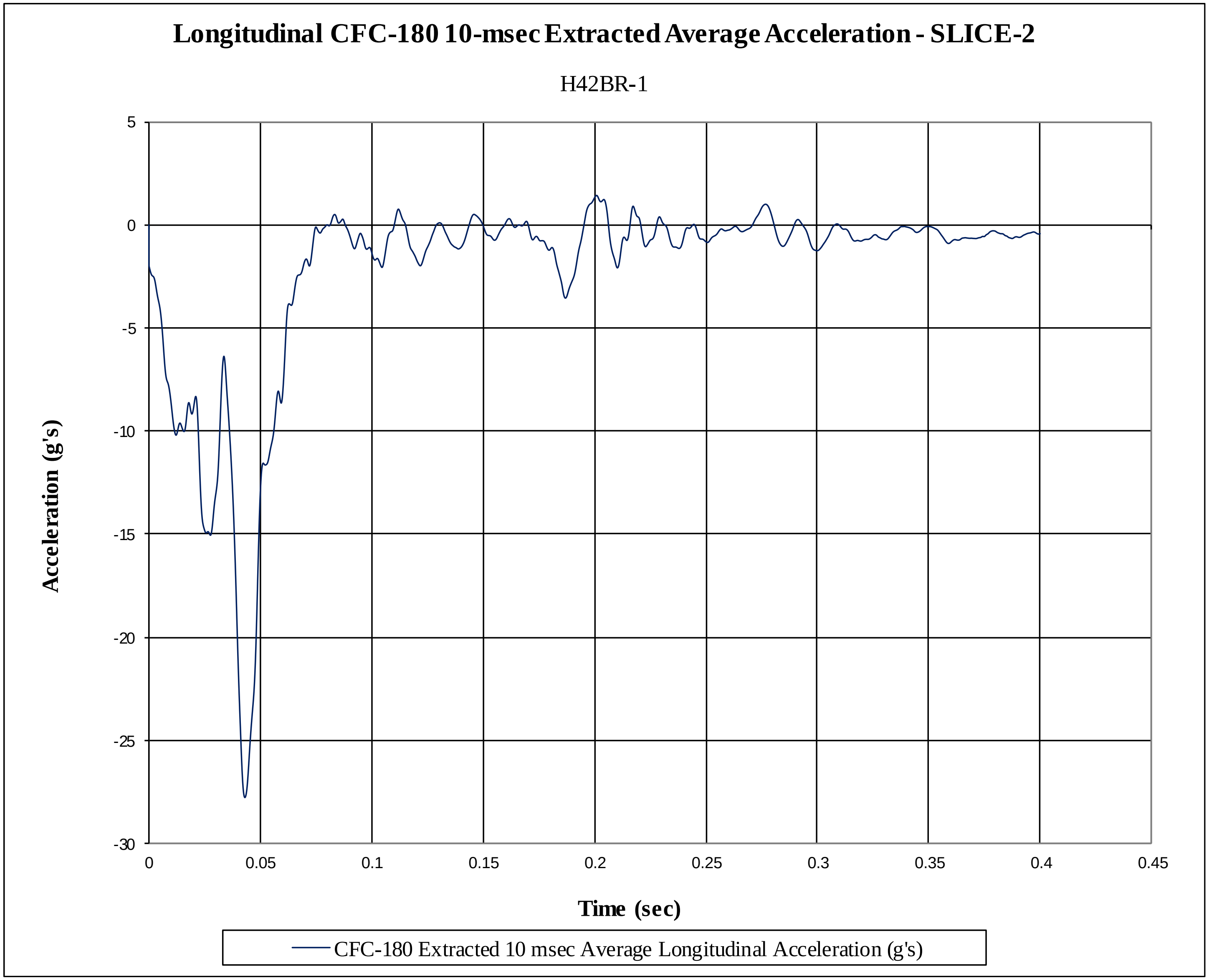


Figure D-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. H42BR-1

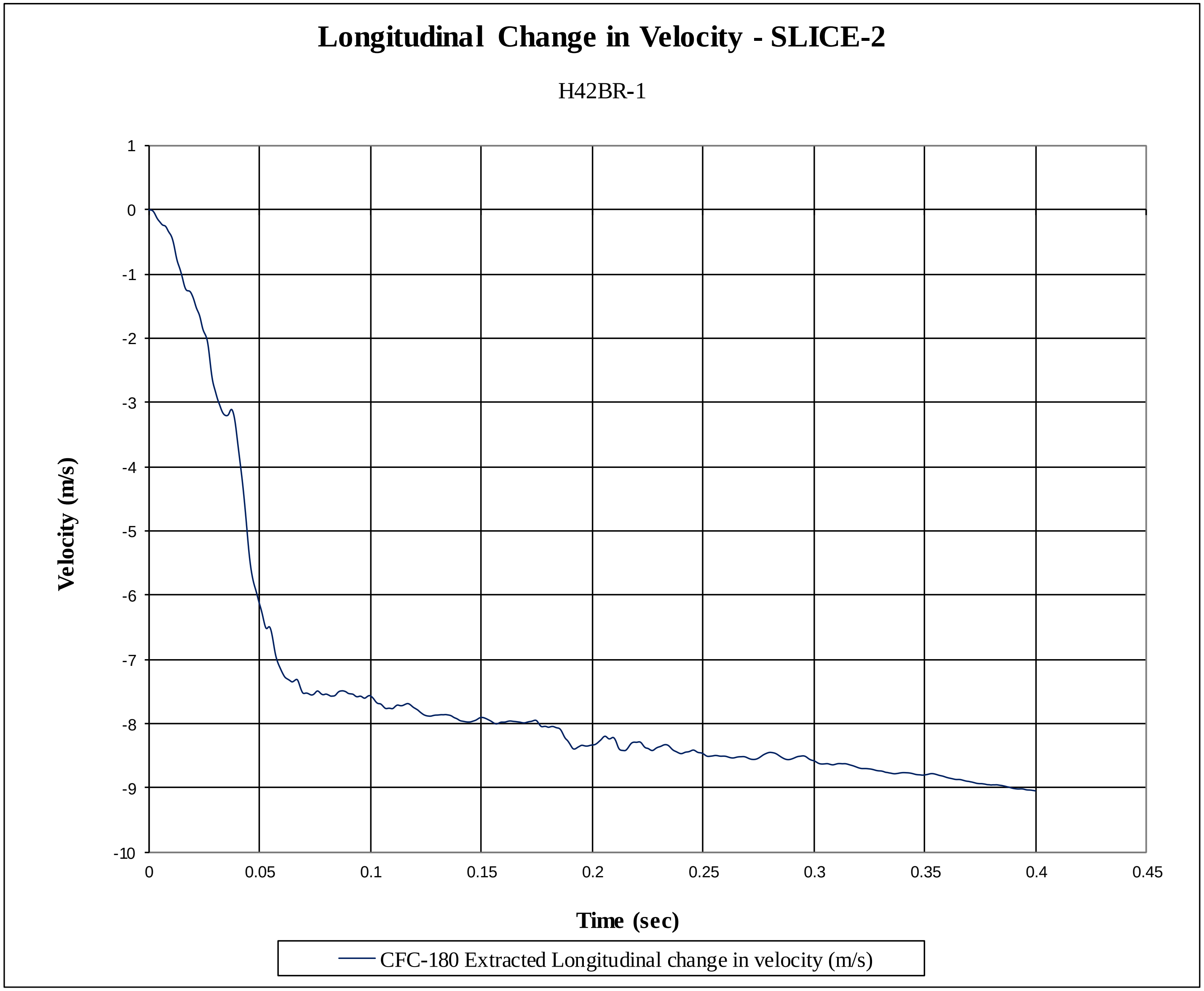


Figure D-10. Longitudinal Change in Impact Velocity (SLICE-2), Test No. H42BR-1

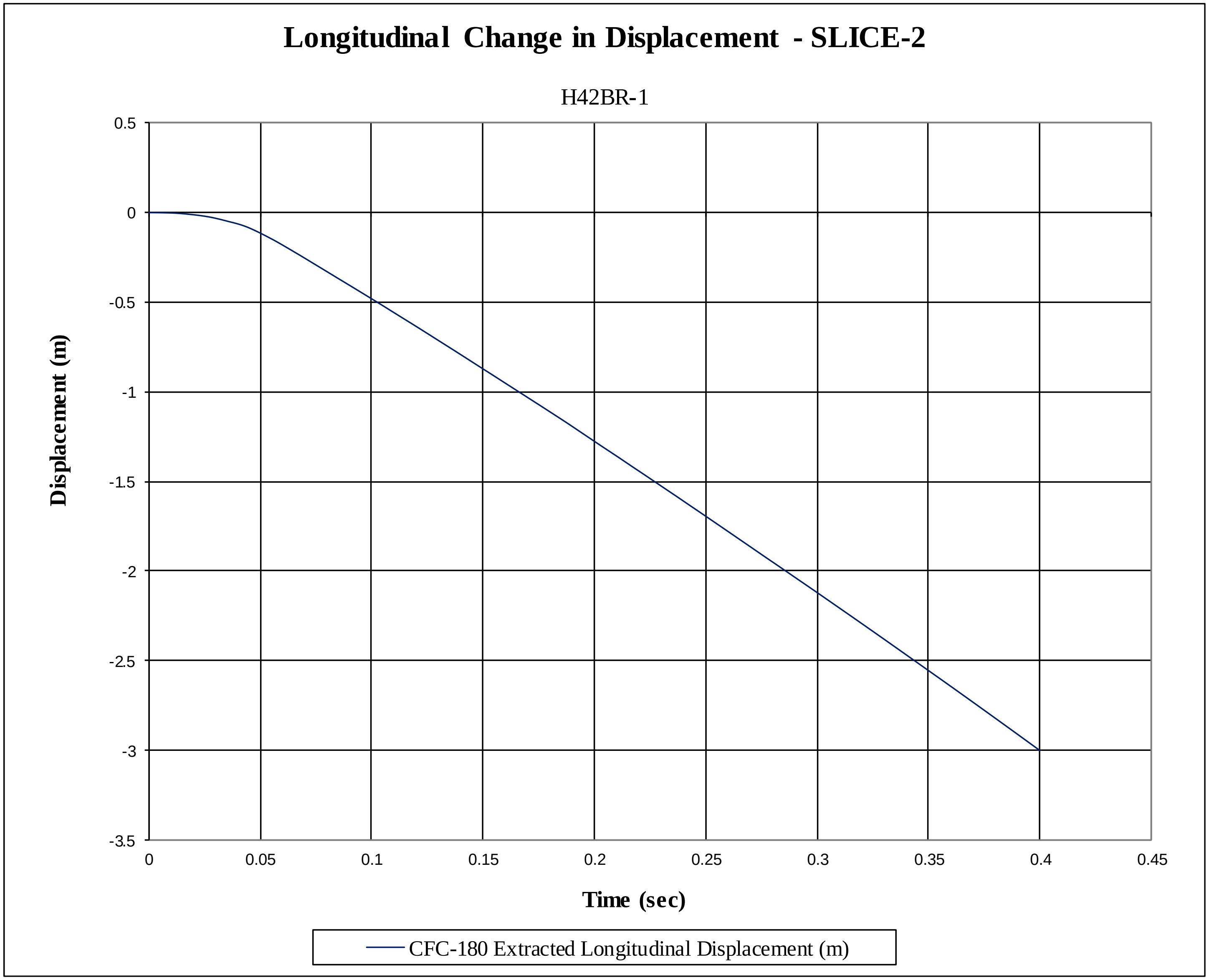


Figure D-11. Longitudinal Change in Displacement (SLICE-2), Test No. H42BR-1

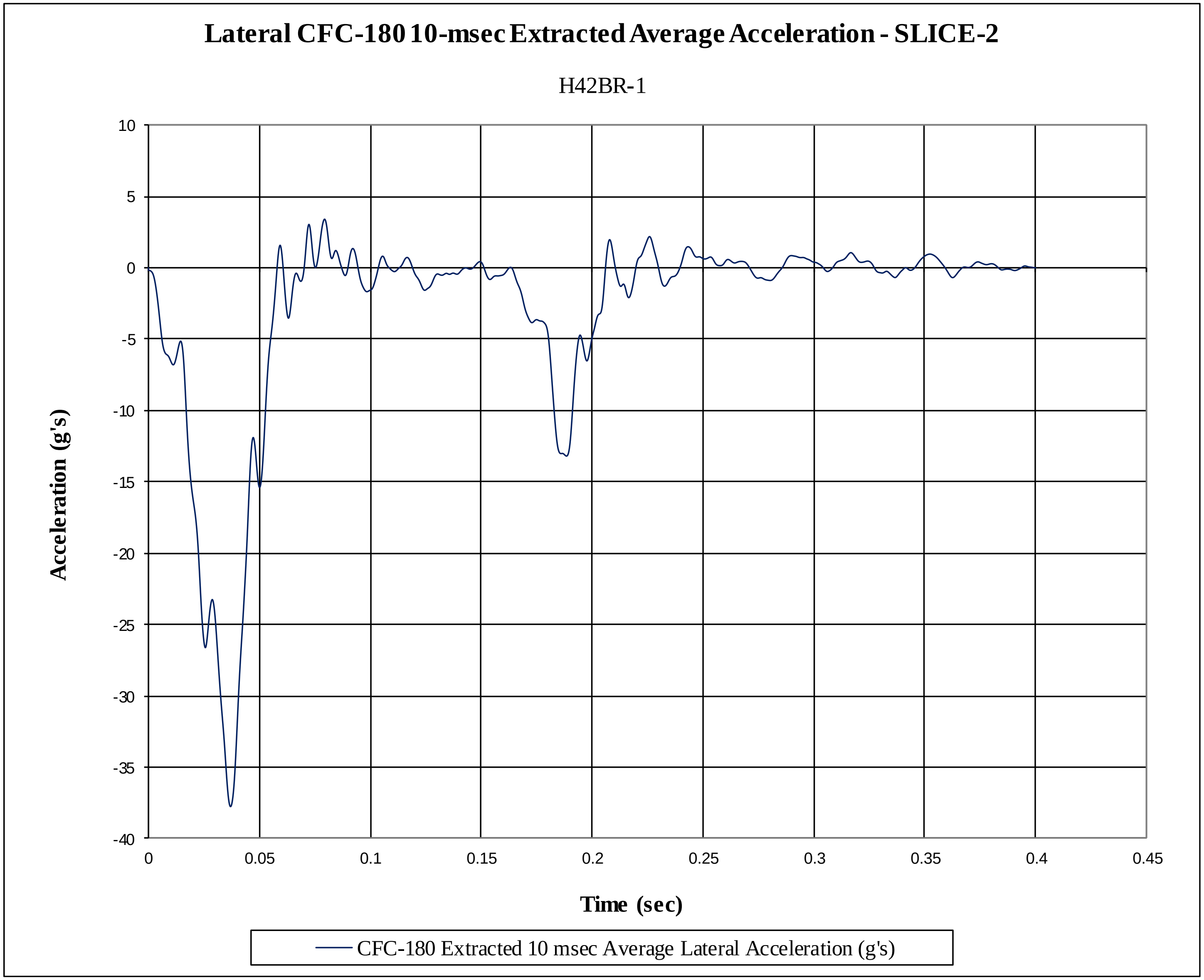


Figure D-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. H42BR-1

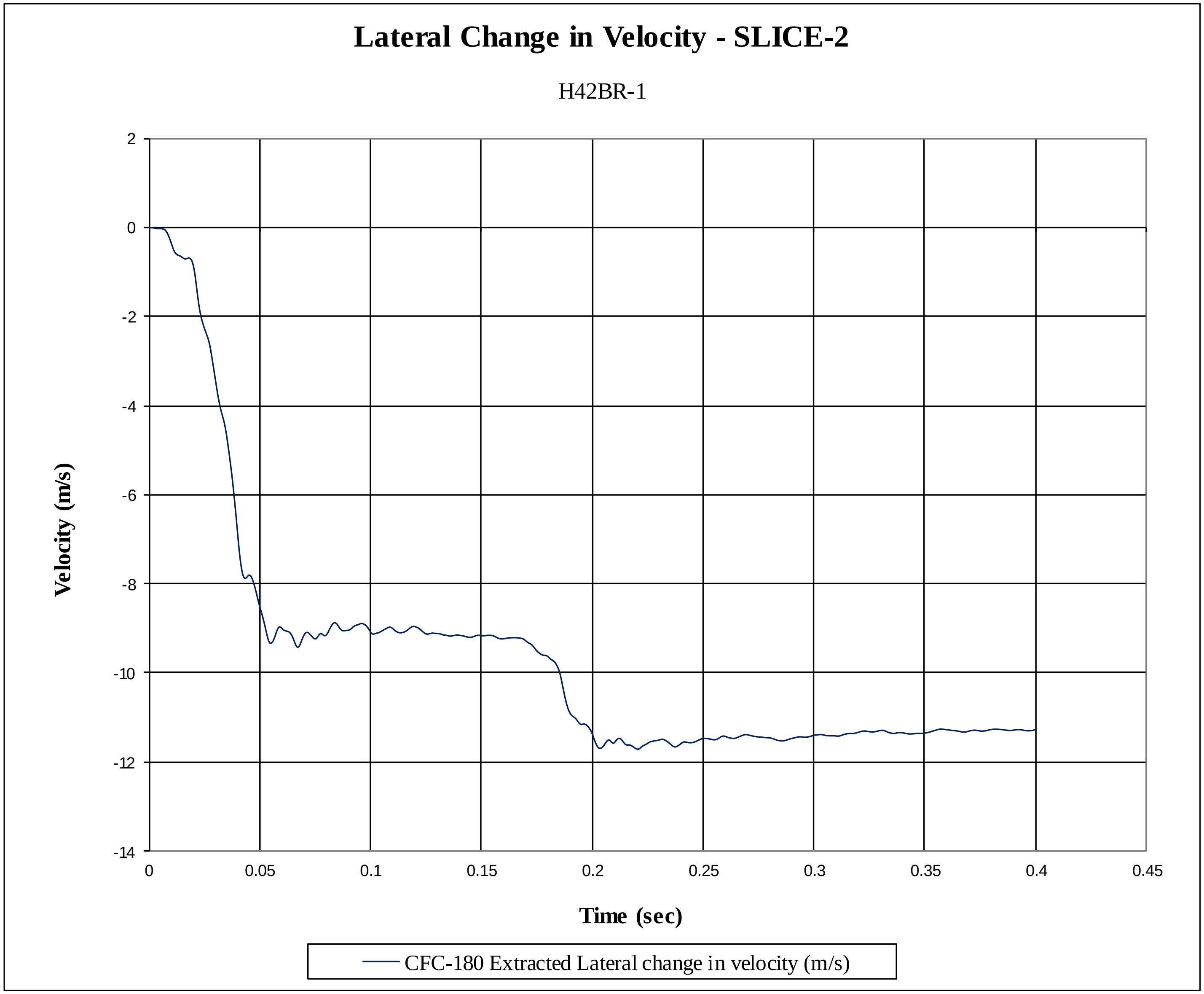


Figure D-13. Lateral Change in Velocity (SLICE-2), Test No. H42BR-1

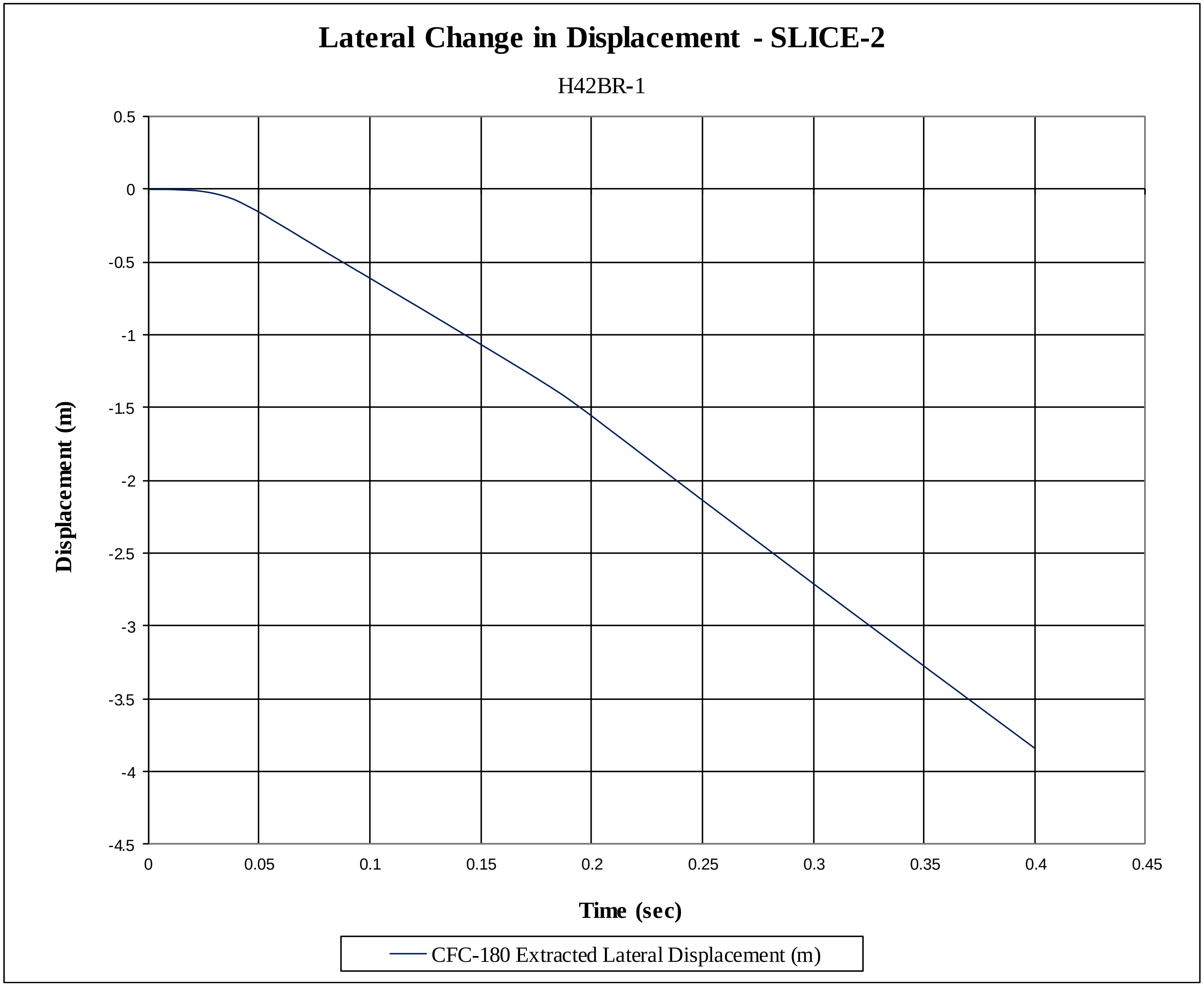


Figure D-14. Lateral Change in Displacement (SLICE-2), Test No. H42BR-1

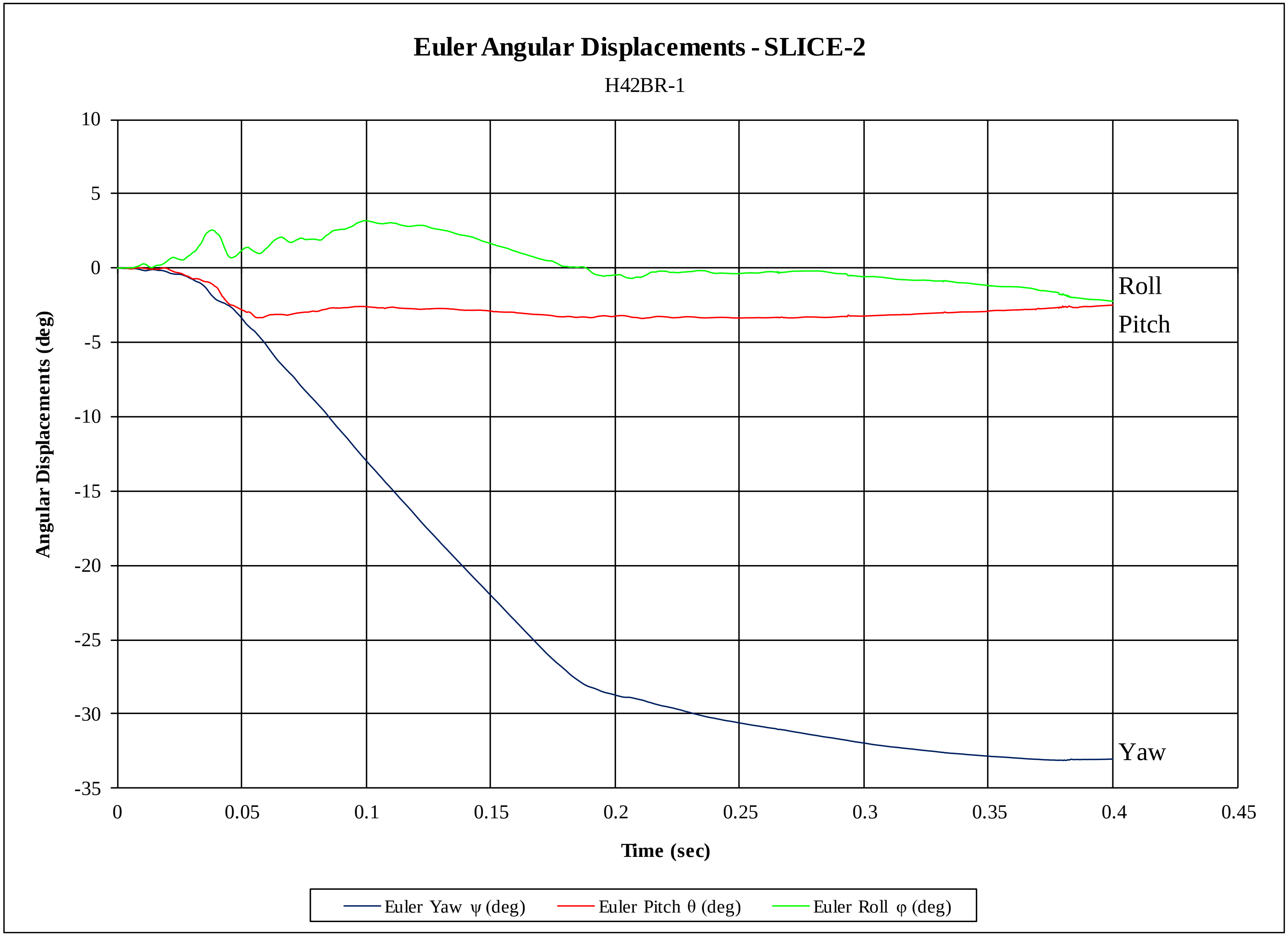


Figure D-15. Vehicle Angular Displacements (SLICE-2), Test No. H42BR-1

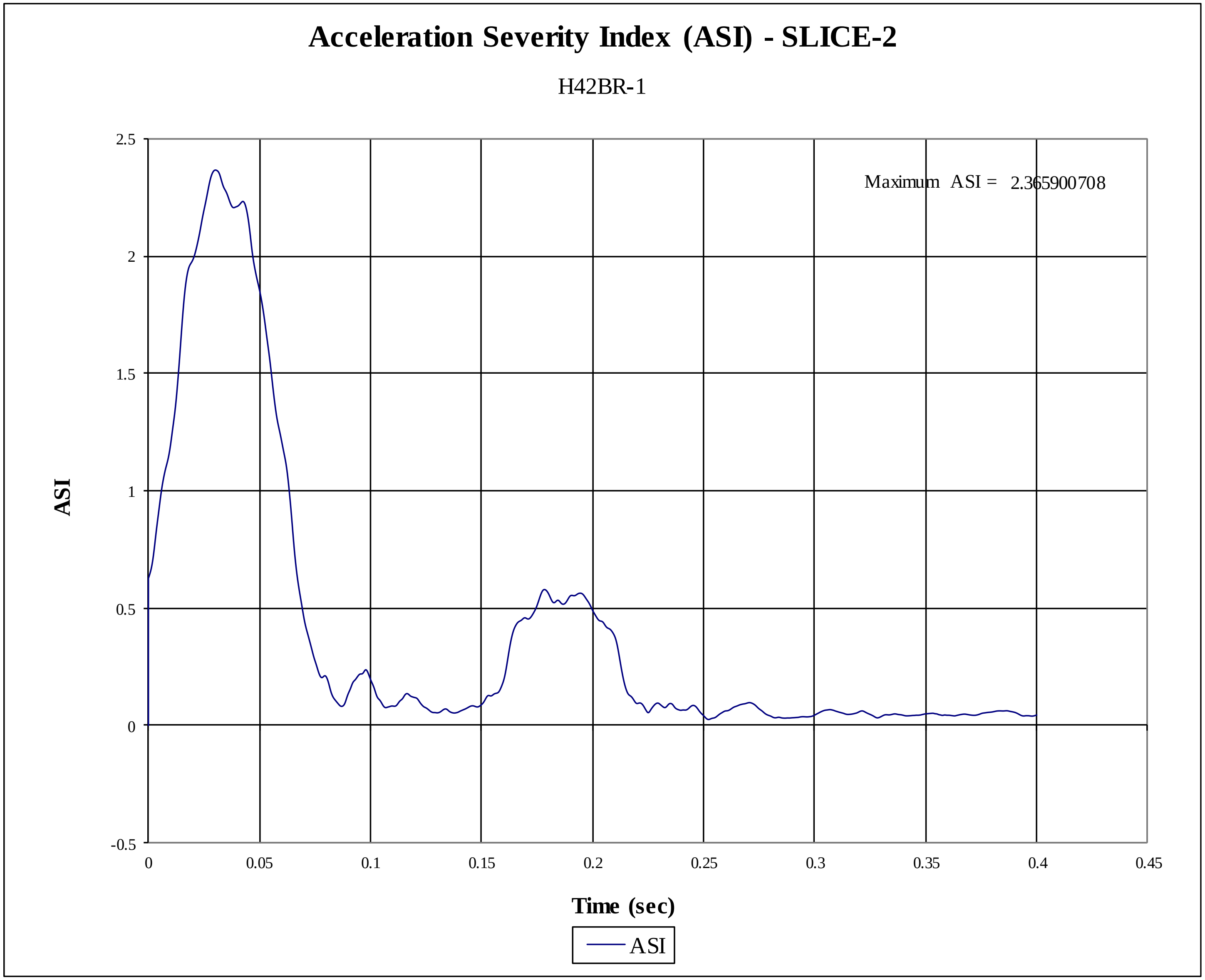


Figure D-16. Acceleration Severity Index (SLICE-2), Test No. H42BR-1

Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. H42BR-2

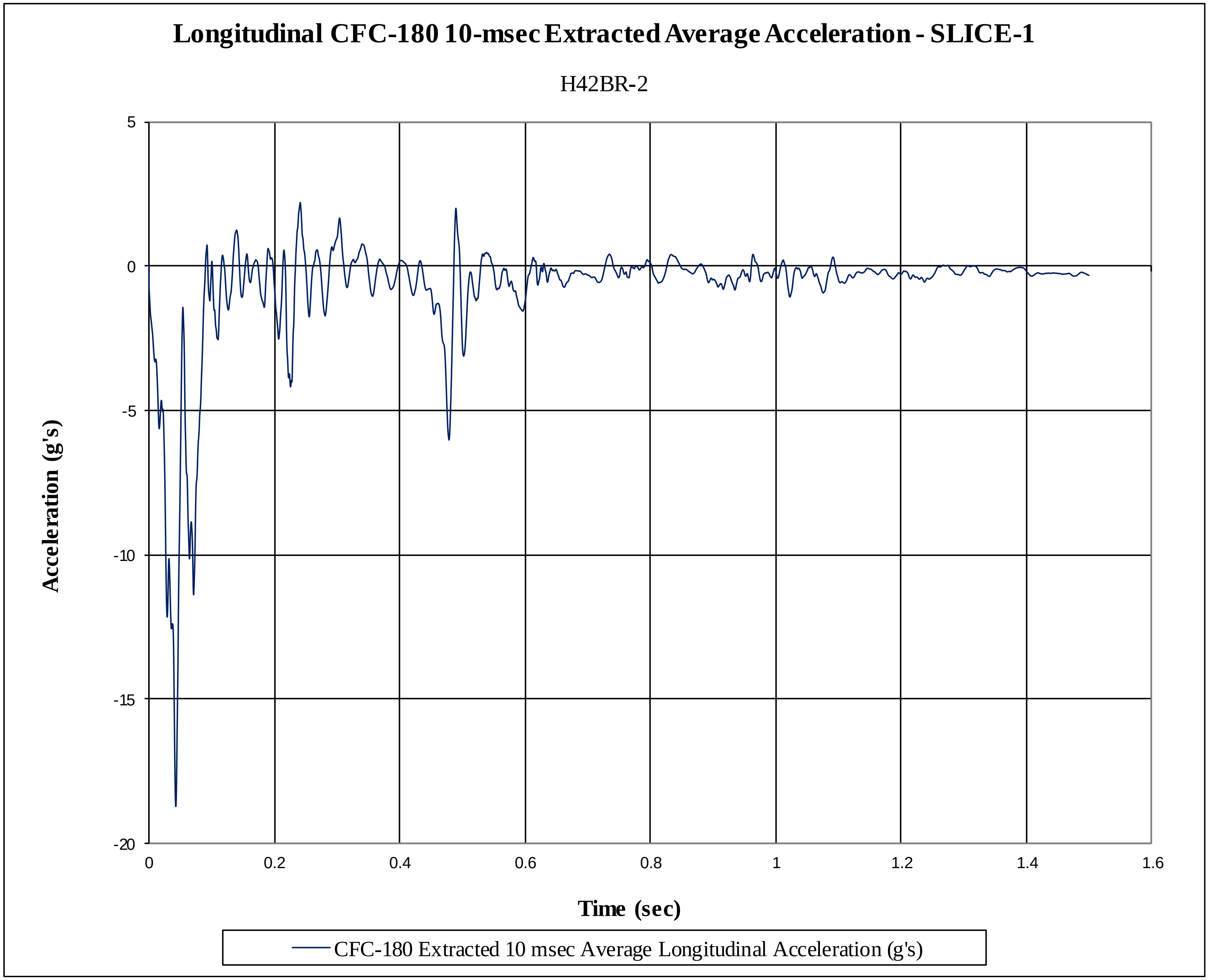


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. H42BR-2

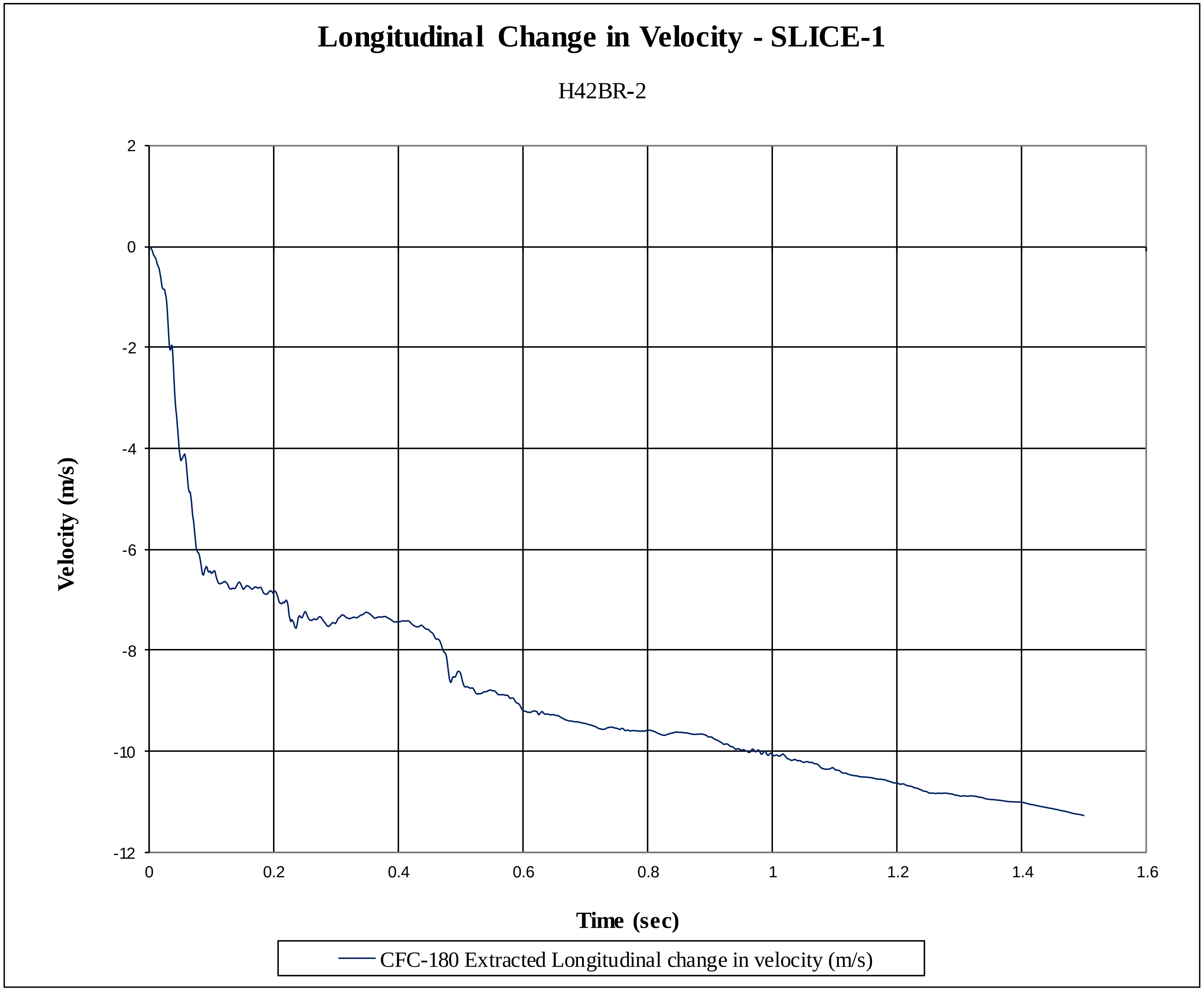


Figure E-2. Longitudinal Change in Velocity (SLICE-1), Test No. H42BR-2

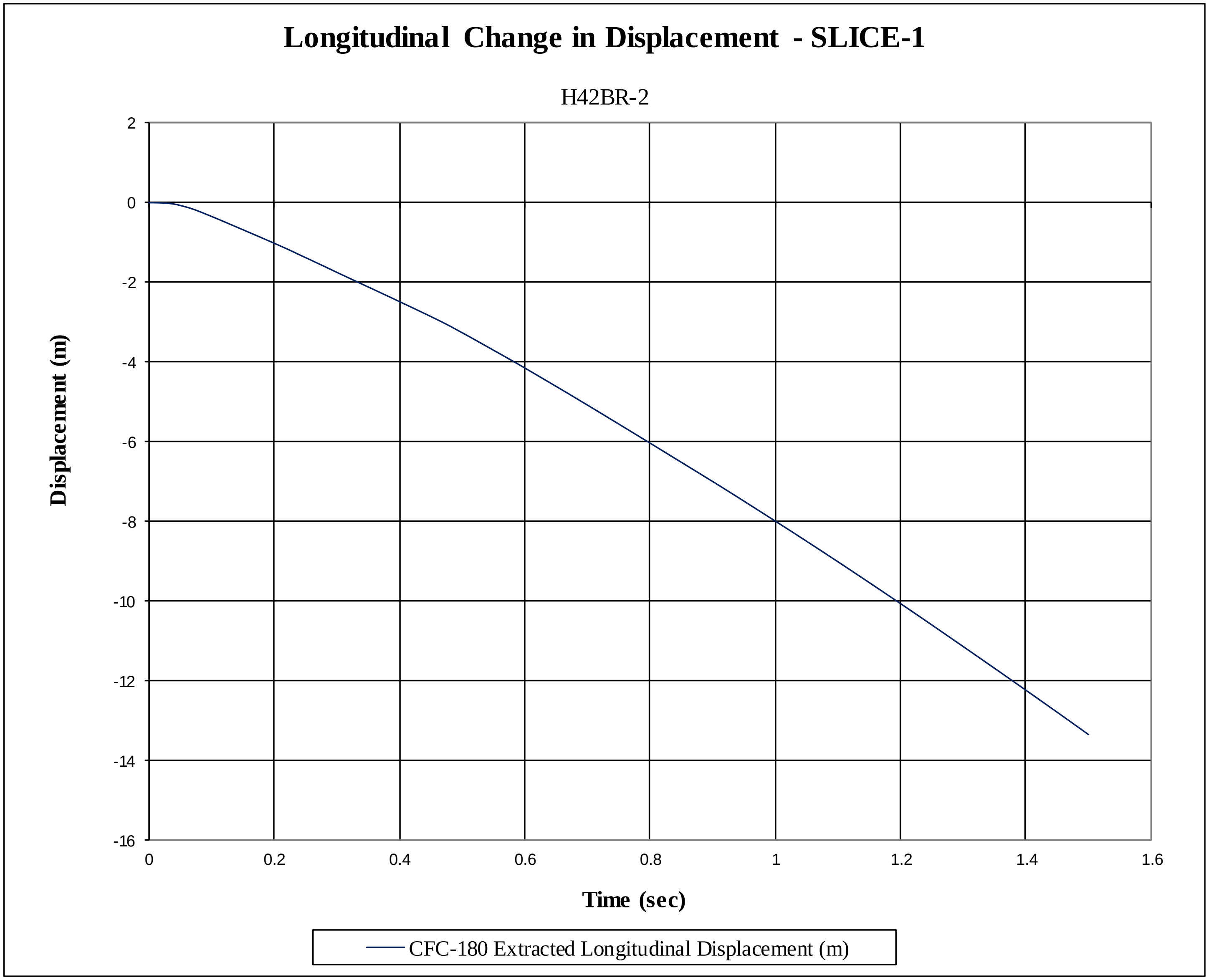


Figure E-3. Longitudinal Change in Displacement (SLICE-1), Test No. H42BR-2

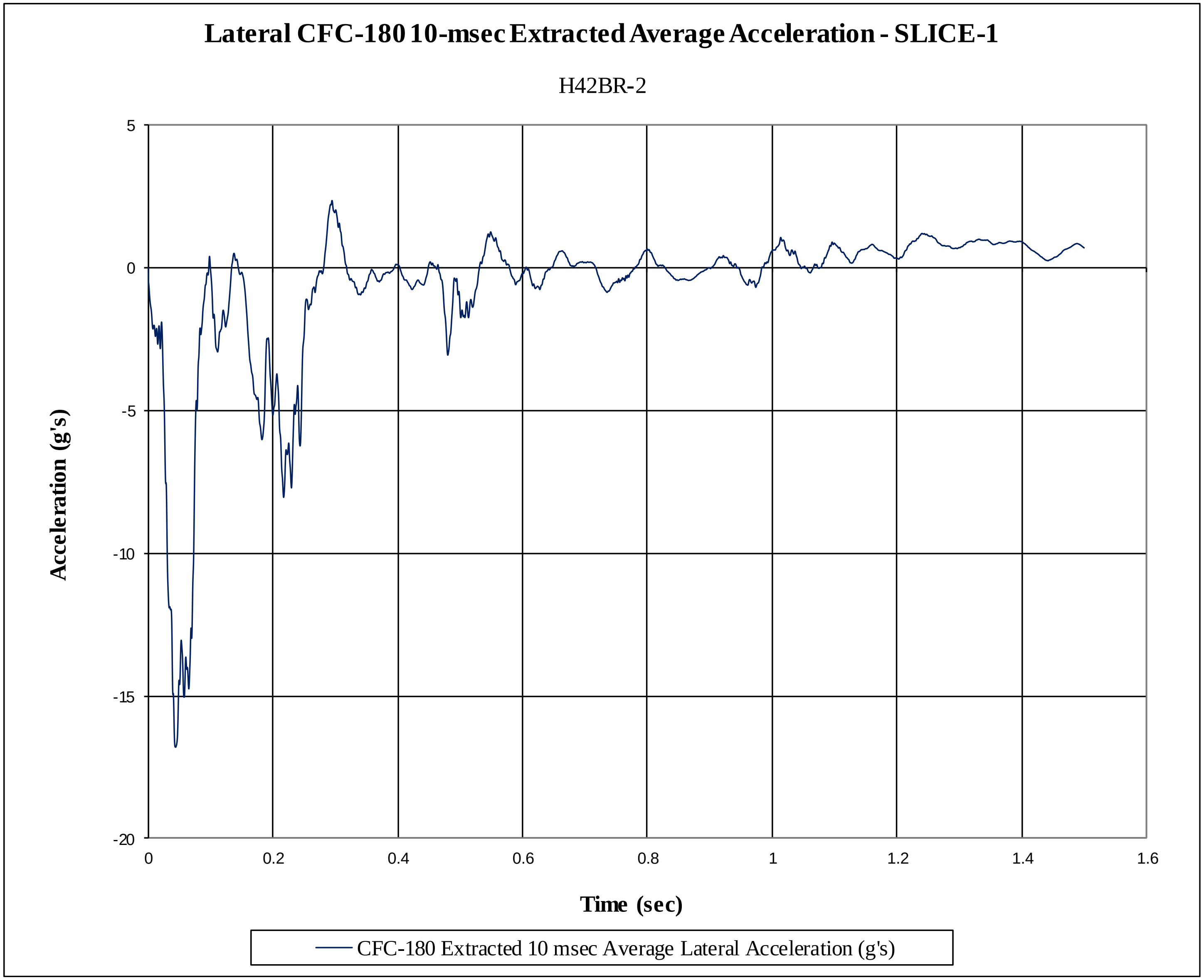


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. H42BR-2

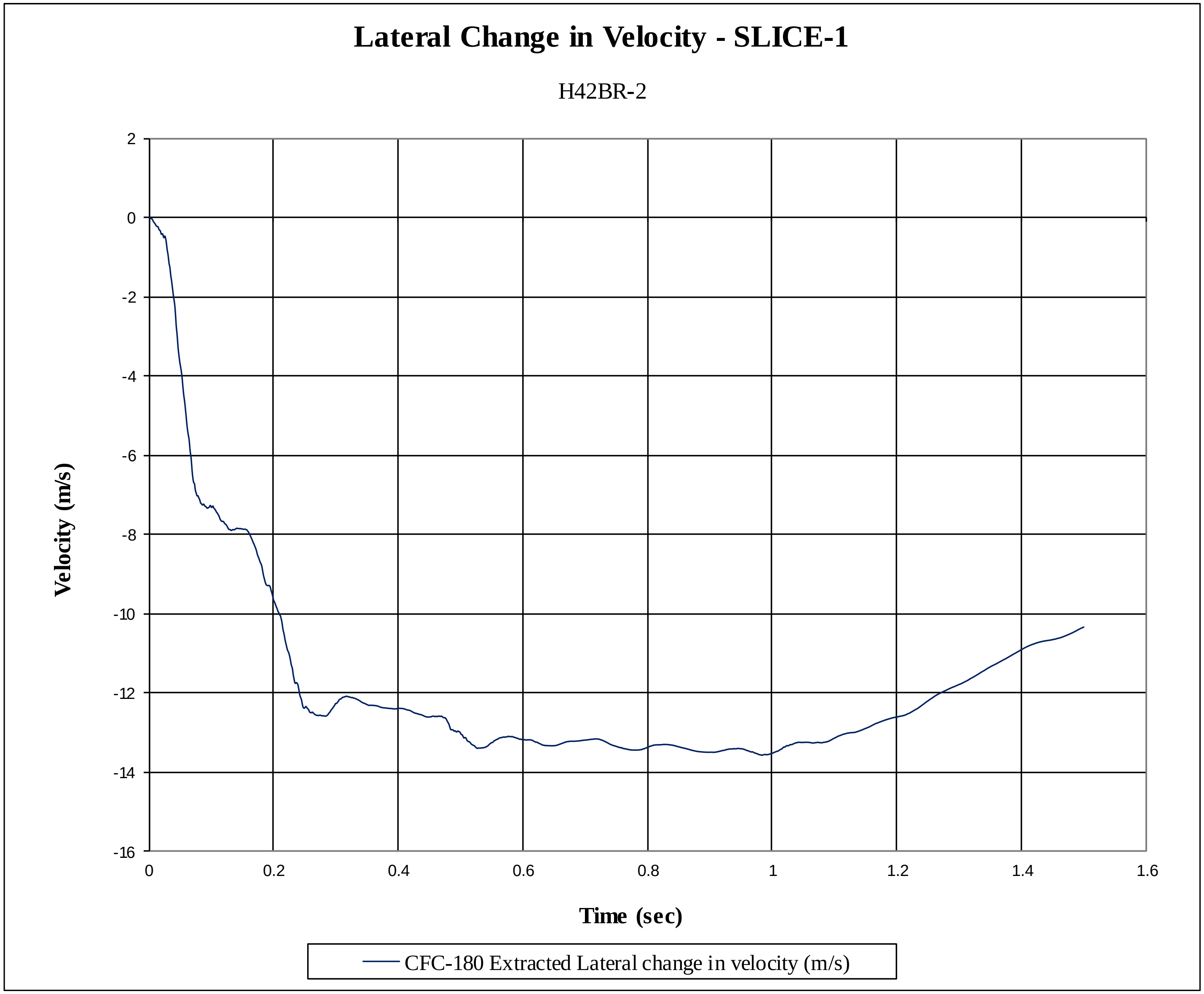


Figure E-5. Lateral Change in Velocity (SLICE-1), Test No. H42BR-2

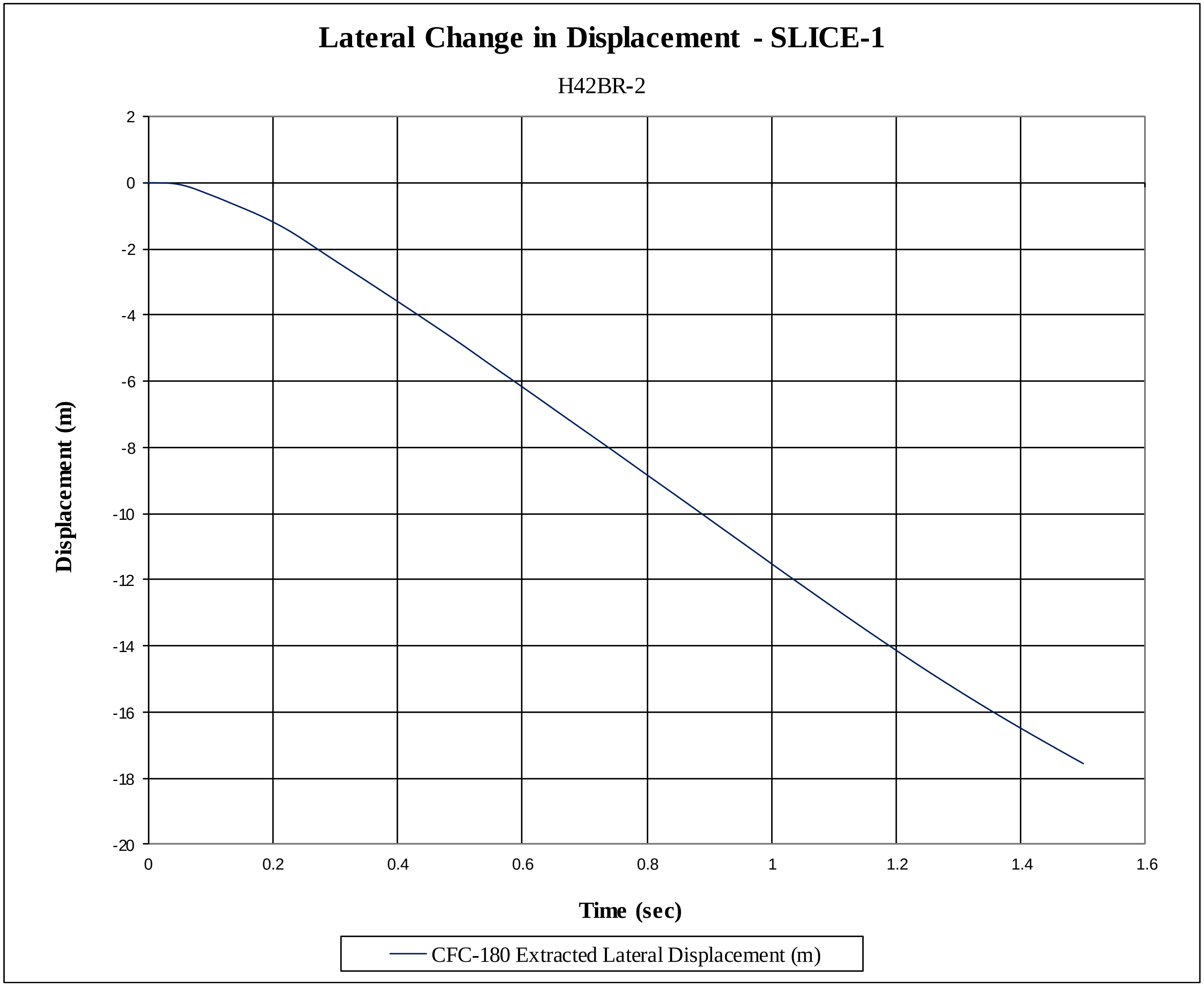


Figure E-6. Lateral Change in Displacement (SLICE-1), Test No. H42BR-2

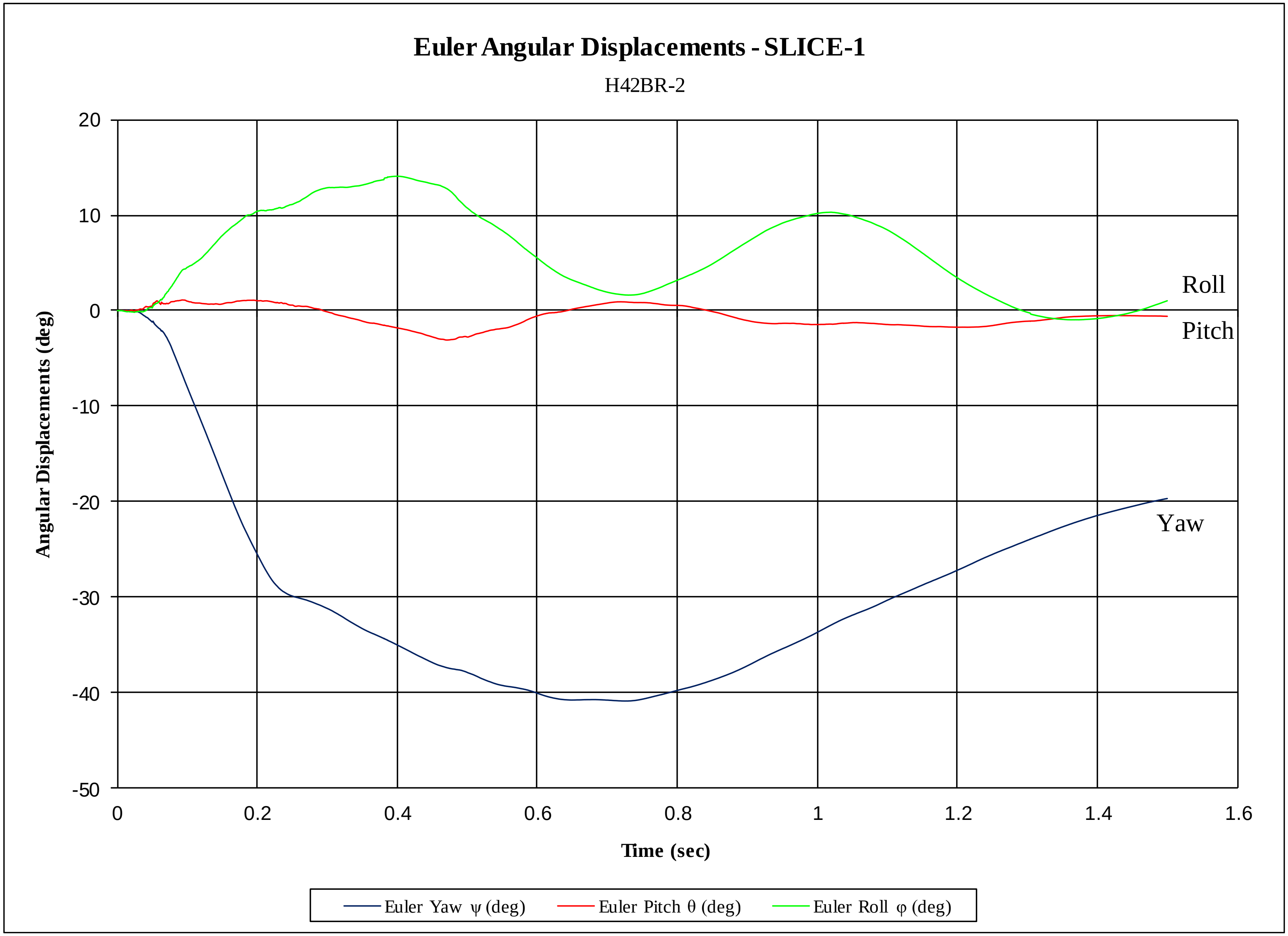


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. H42BR-2

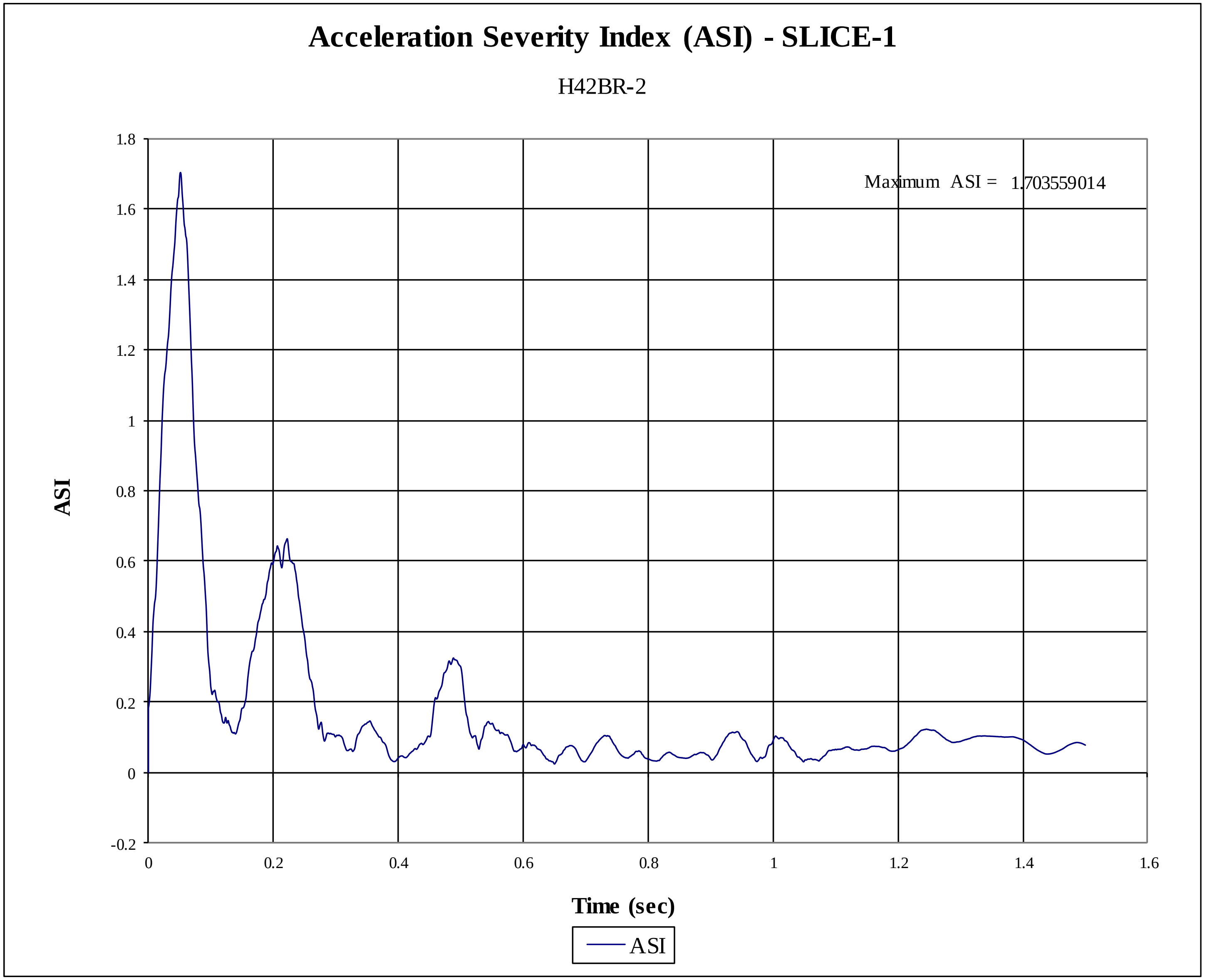


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. H42BR-2

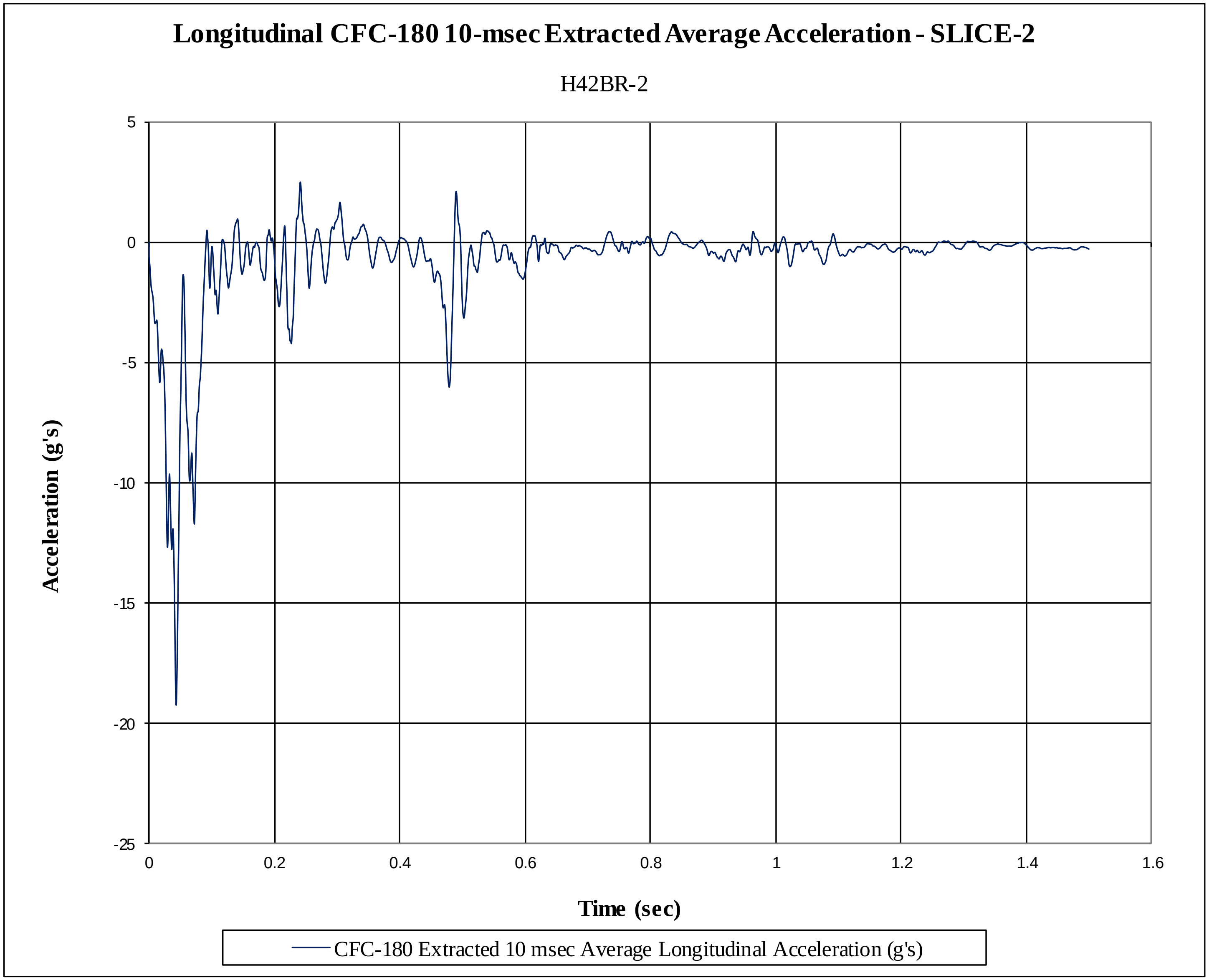


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. H42BR-2

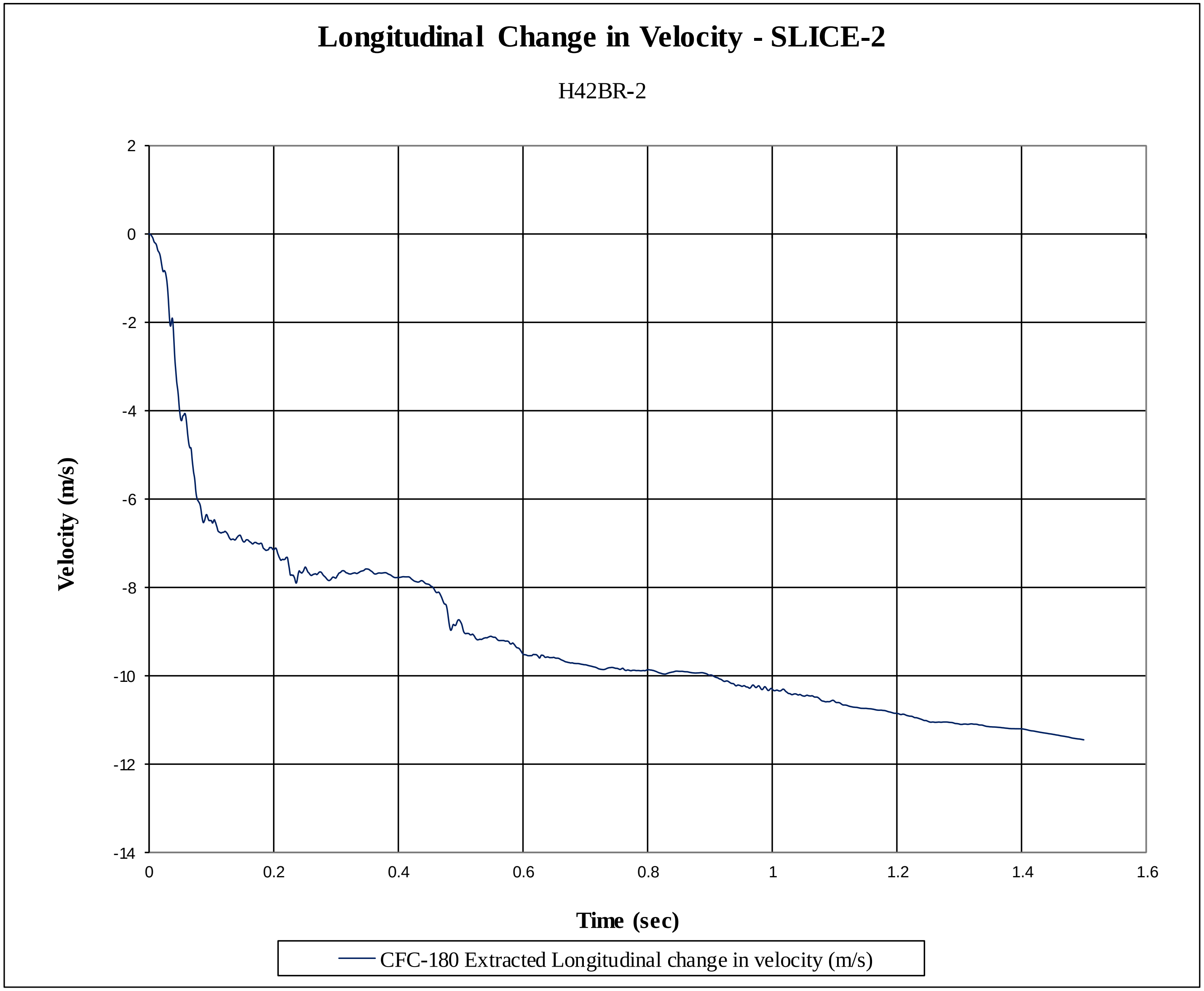


Figure E-10. Longitudinal Change in Velocity (SLICE-2), Test No. H42BR-2

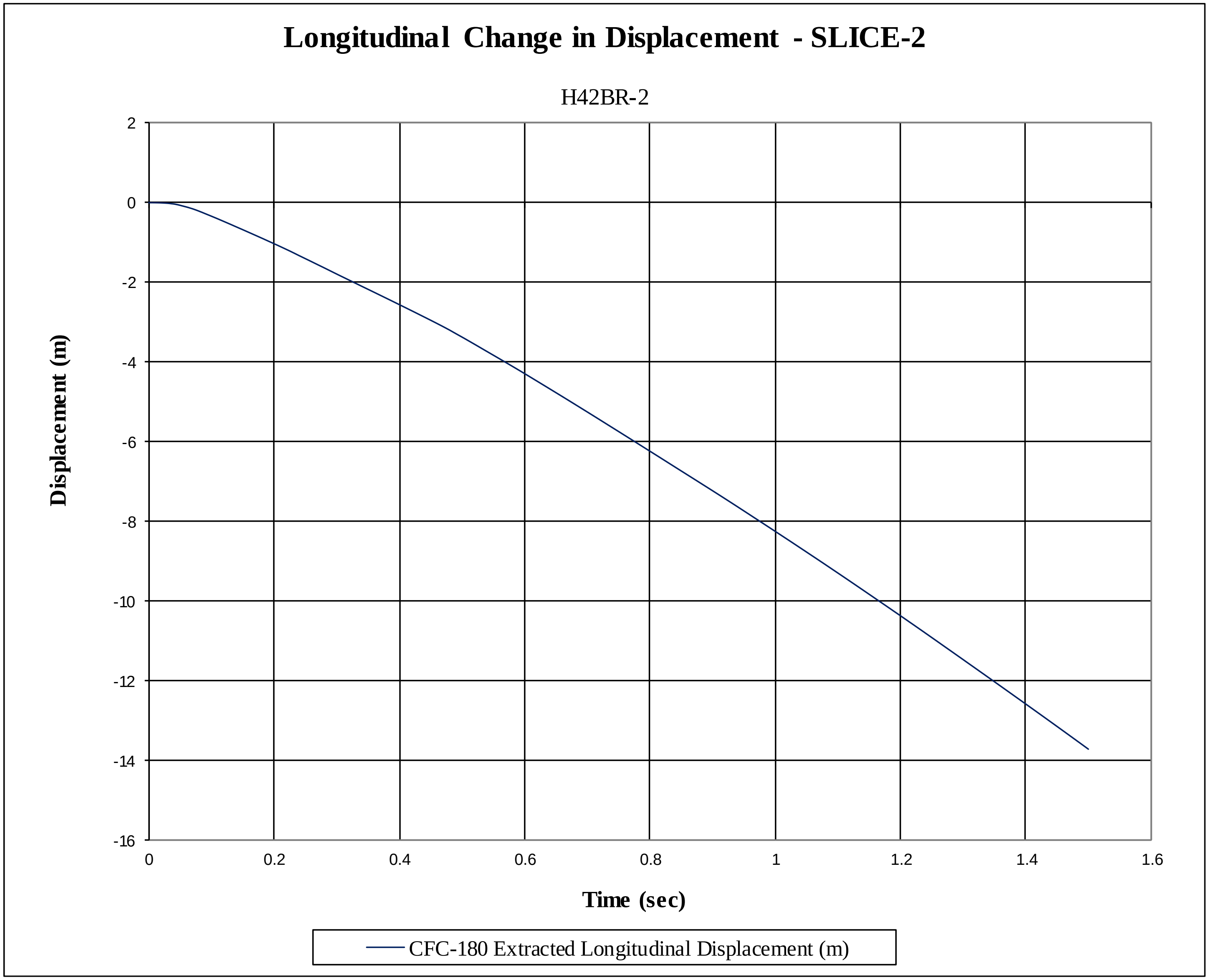


Figure E-11. Longitudinal Change in Displacement (SLICE-2), Test No. H42BR-2

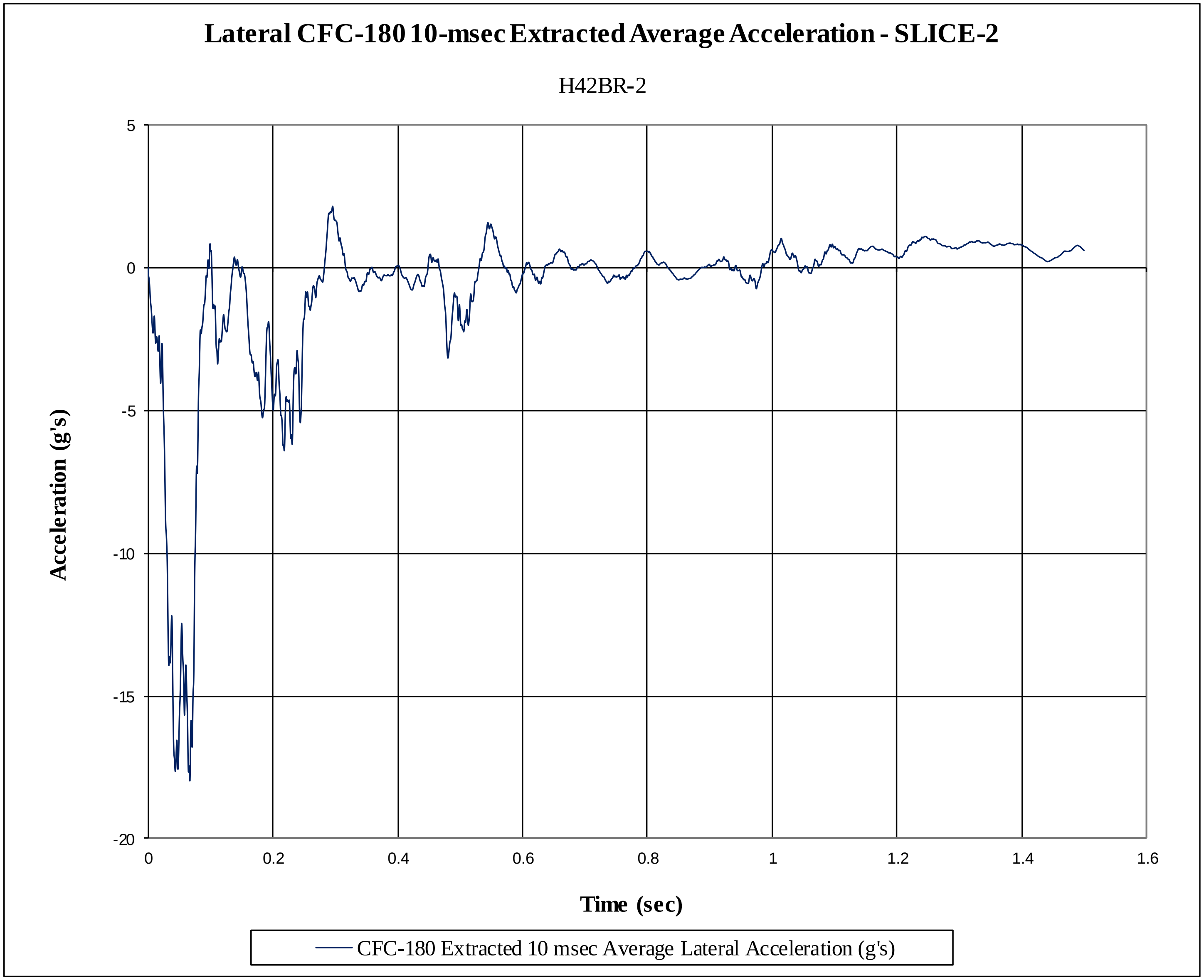


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. H42BR-2

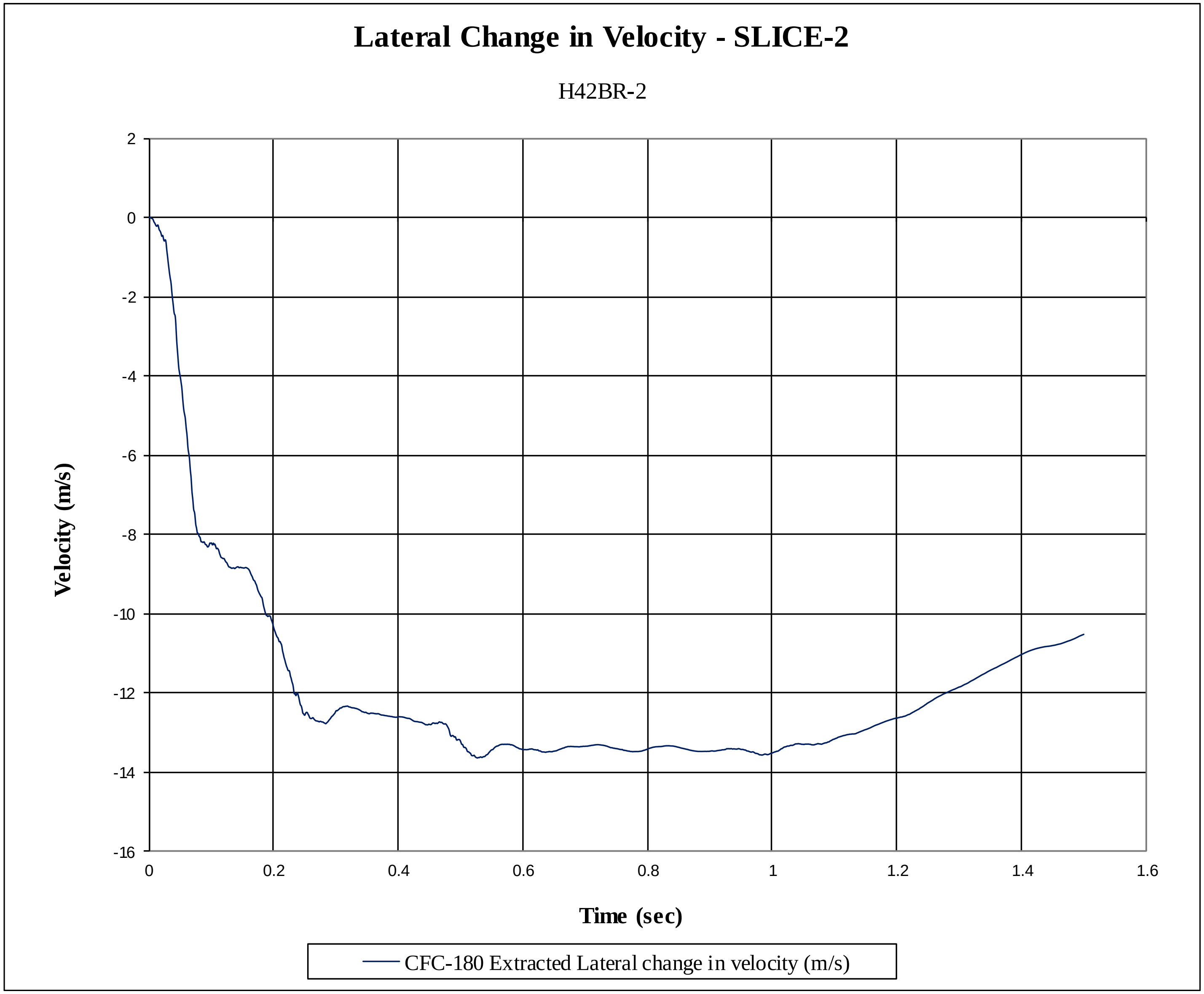


Figure E-13. Lateral Change in Velocity (SLICE-2), Test No. H42BR-2

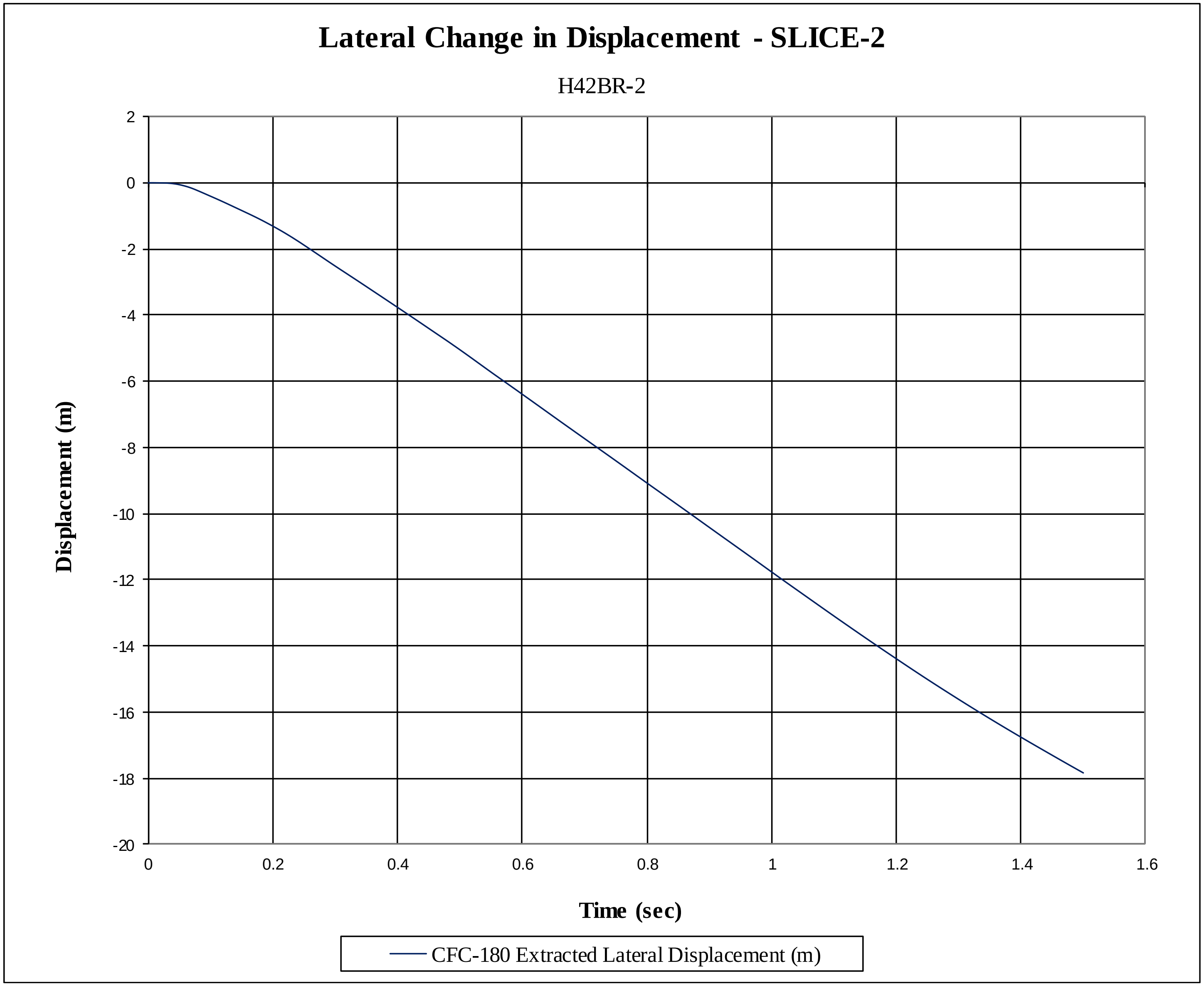


Figure E-14. Lateral Change in Displacement (SLICE-2), Test No. H42BR-2

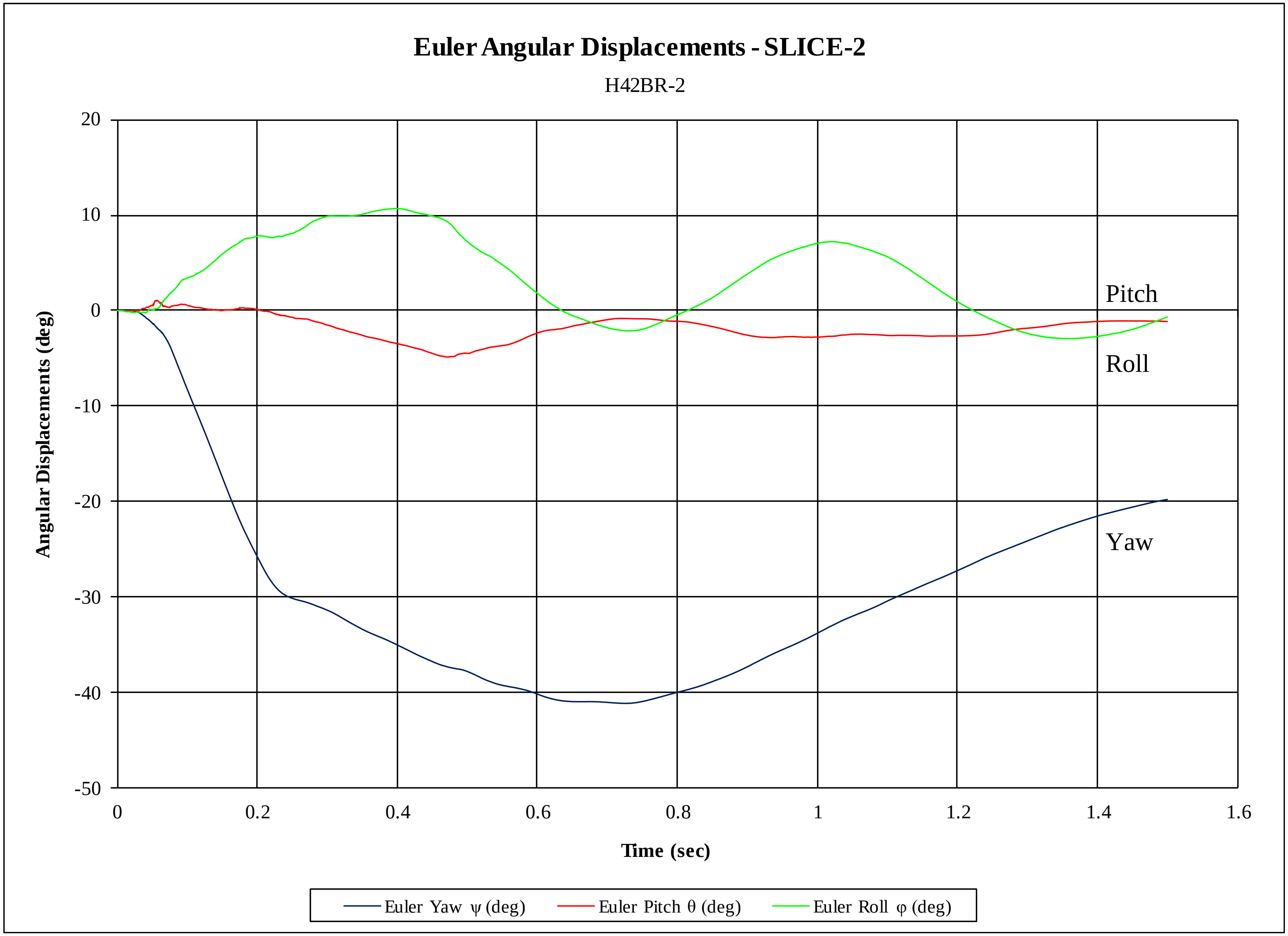


Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. H42BR-2

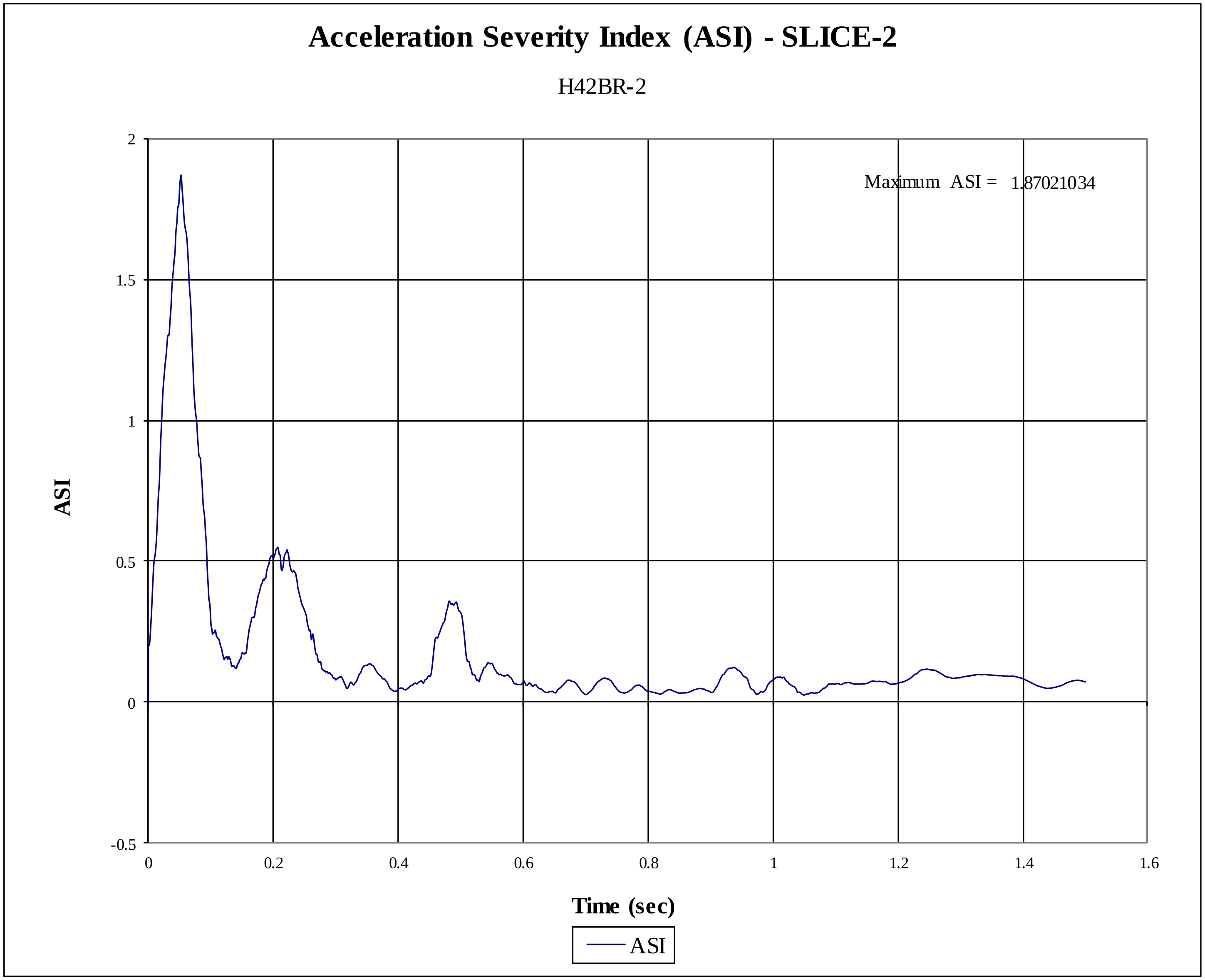


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. H42BR-2

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