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DEVELOPMENT AND CRASH TESTING OF THE HAWAII CONCRETE POST AND BEAM BRIDGE RAIL

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16. Abstract

The Hawaii Department of Transportation (HDOT) has utilized bridge railings similar to the Hawaii Modified Natchez Trace Bridge Rail to safely redirect vehicles on bridges. However, the crashworthiness of this bridge rail had not been investigated under current impact safety standards, the *Manual for Assessing Safety Hardware* (MASH). Previously within this project, crash test no. HNTBR-1 was conducted on this railing according to MASH test designation no. 3-11. In this test, the occupant compartment intrusion at the wheel well and toe pan measured 12.7 in., which exceeded the MASH limit of 9 in. Thus, test no. HNTBR-1 failed to meet MASH safety criteria.

An investigation into the cause of this test failure was conducted. The failure was attributed to two key causes: (1) a reduced curb-to-rail offset, which caused the vehicle rim to gouge into the concrete rail while the wheel was traversing over the curb, and (2) the angled bottom edge of the rail which increased the severity of the rim-rail snag. Design modifications were proposed and discussed with HDOT. The selected modifications included changing the shape the bridge rail to a vertical front face for the both the railing and the lower curb. This shape change would minimize wheel climb and reduce snagging at the rail's bottom edge. Reinforcement of the rail and curb was adjusted accordingly.

Two full-scale crash tests were conducted to evaluate the safety performance of the new Hawaii Concrete Post and Beam Bridge Rail. Test nos. HNTBR-2 and HNTBR-3 were conducted according to MASH test designation nos. 3-11 and 3-10, respectively. In both tests, the vehicles were safely contained and redirected with minimal damage to the bridge rail. All occupant risk measurements were found to be within the established MASH limits, including the occupant compartment deformations that had been an issue with the previous design configuration. Therefore, test nos. HNTBR-2 and HNTBR-3 satisfied all safety performance criteria, and the Hawaii Concrete Post and Beam Bridge Rail was determined to be crashworthy according to MASH TL-3.

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UNCERTAINTY OF MEASUREMENT STATEMENT

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

A2LA ACCREDITATION

The tests reported herein are within the scope of MwRSF's A2LA Accreditation. MwRSF's accreditation documentation can be found in Appendix A.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority for the data contained herein was Mr. Brandon Perry, Research Engineer.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in.	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short ton (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE & PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in.
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliter	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or “metric ton”)	1.103	short ton (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE & PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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1 INTRODUCTION

1.1 Background

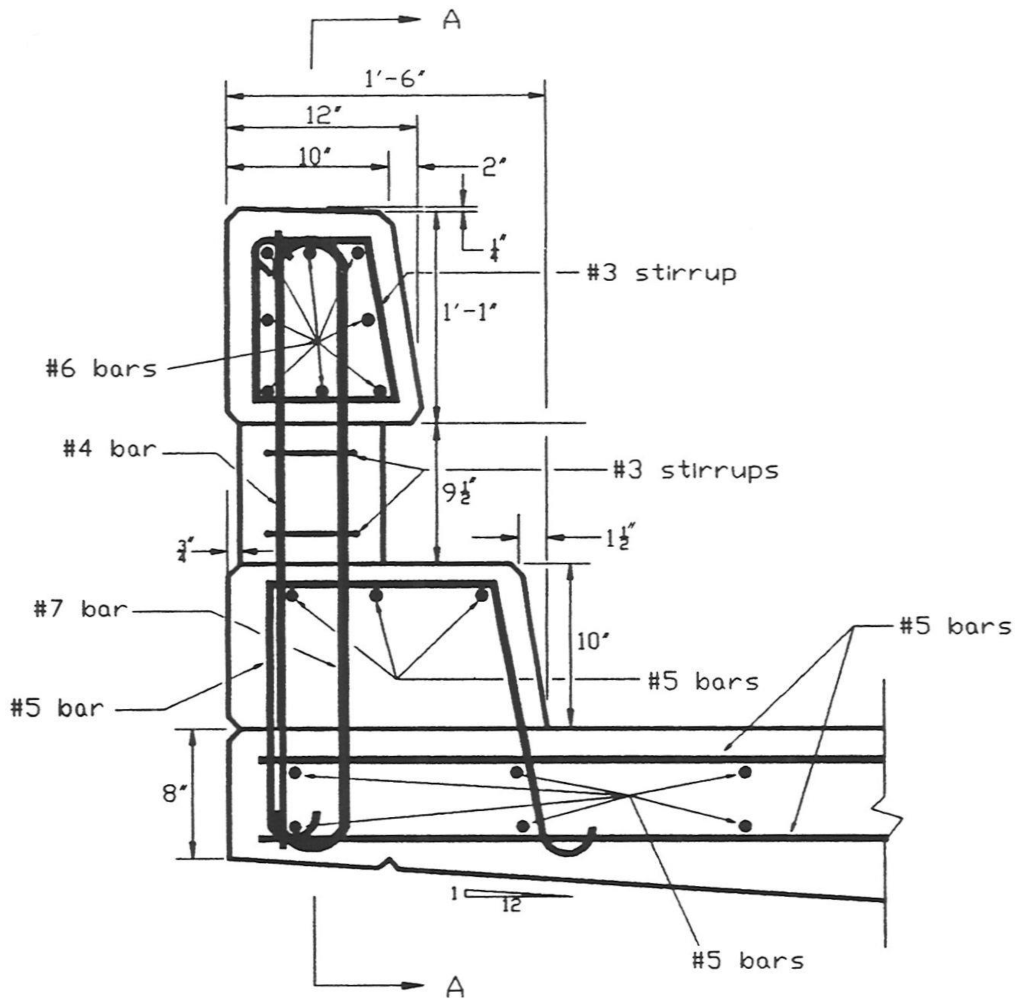
In recent years, the Hawaii Department of Transportation (HDOT) utilized bridge railings similar to the Hawaii Modified Natchez Trace Bridge Rail to safely redirect vehicles on bridges. However, the crashworthiness of this bridge rail had not been investigated under current impact safety standards of the American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware* (MASH) [1]. Therefore, HDOT desired to evaluate the Hawaii Modified Natchez Trace Bridge Rail via crash testing according to MASH Test Level 3 (TL-3).

In 1992, the original Natchez Trace Parkway Bridge Rail [2] was evaluated to Performance Level 1 (PL-1) criteria according to the *AASHTO Guide Specifications for Bridge Railings* [3] at the Midwest Roadside Safety Facility (MwRSF). The Natchez Trace Bridge Rail was an open concrete bridge rail positioned atop a 10-in. tall curb, as shown in Figure 1. The railing incorporated a 13-in. tall by 12-in. wide concrete rail supported by 9-in. x 18-in. concrete posts spaced 7 ft – 6¾ in. apart. The face of the curb extended approximately 4½ in. out from the face of the concrete railing.

In test no. NTBR-1, a 1984 Chevrolet Custom Deluxe 20 pickup truck impacted the bridge rail at 45.2 mph and an angle of 22.4 degrees. Upon impact, the test vehicle was smoothly redirected. There was no intrusion or deformation of the occupant compartment, and the bridge rail received only superficial damage. In test no. NTBR-2, a 1984 Renault Encore small car impacted the bridge rail at 51.5 mph and an angle of 19.5 degrees. Similarly, the vehicle was smoothly redirected with minimal bridge rail damage. Thus, the Natchez Trace Bridge Rail successfully passed all requirements for AASHTO PL-1.

In 2001, researchers at the Texas A&M Transportation Institute (TTI) conducted crash tests to evaluate the Natchez Trace Bridge Rail [4] in accordance with NCHRP Report 350 [5]. The test installation, shown in Figure 2, was identical to the system crash tested at MwRSF except for minor variations in reinforcement.

In test no. 405181-11, a 1997 Geo Metro small car impacted the Natchez Trace Bridge Rail at 62.1 mph and an impact angle of 19.8 degrees. The bridge rail safely contained and redirected the passenger car, resulting in the test successfully passing NCHRP 350 test 3-10 safety requirements. In test no. 405181-12, a 1997 Chevrolet 2500 pickup truck impacted the Natchez Trace Bridge Rail at 61.1 mph and an impact angle of 26.1 degrees. The bridge rail safely contained and redirected the pickup truck, and the test successfully met NCHRP 350 test 3-11 evaluation criteria.



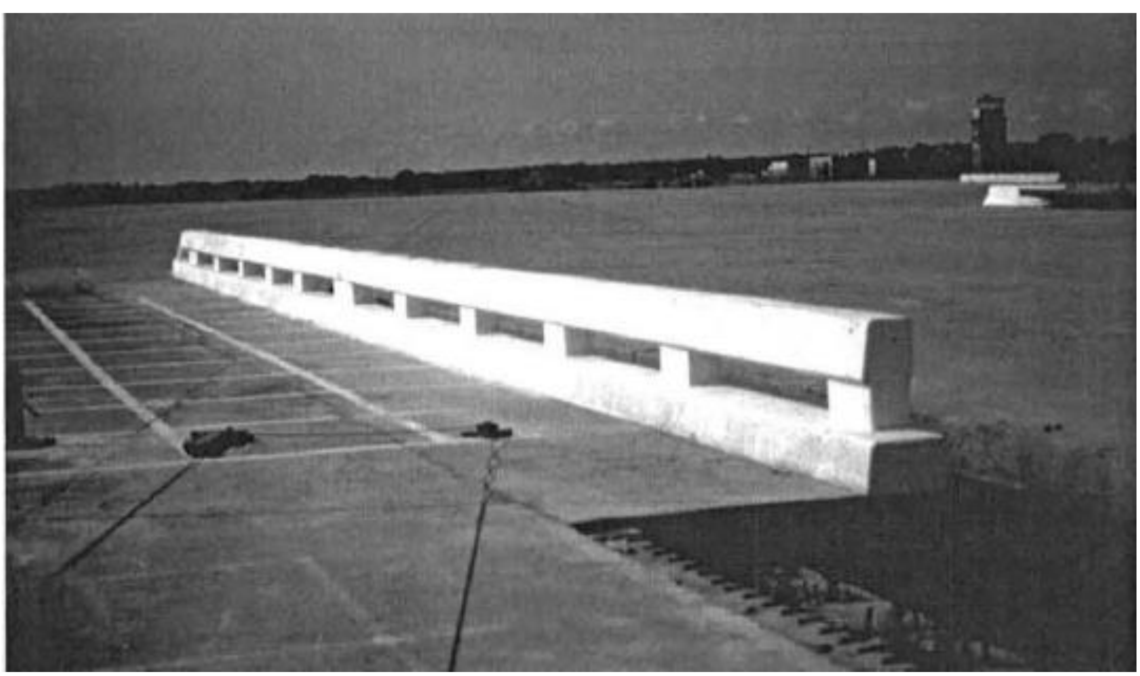


Figure 1. Natchez Trace Bridge Rail Design Details, Test No. NTBR-1 [2]

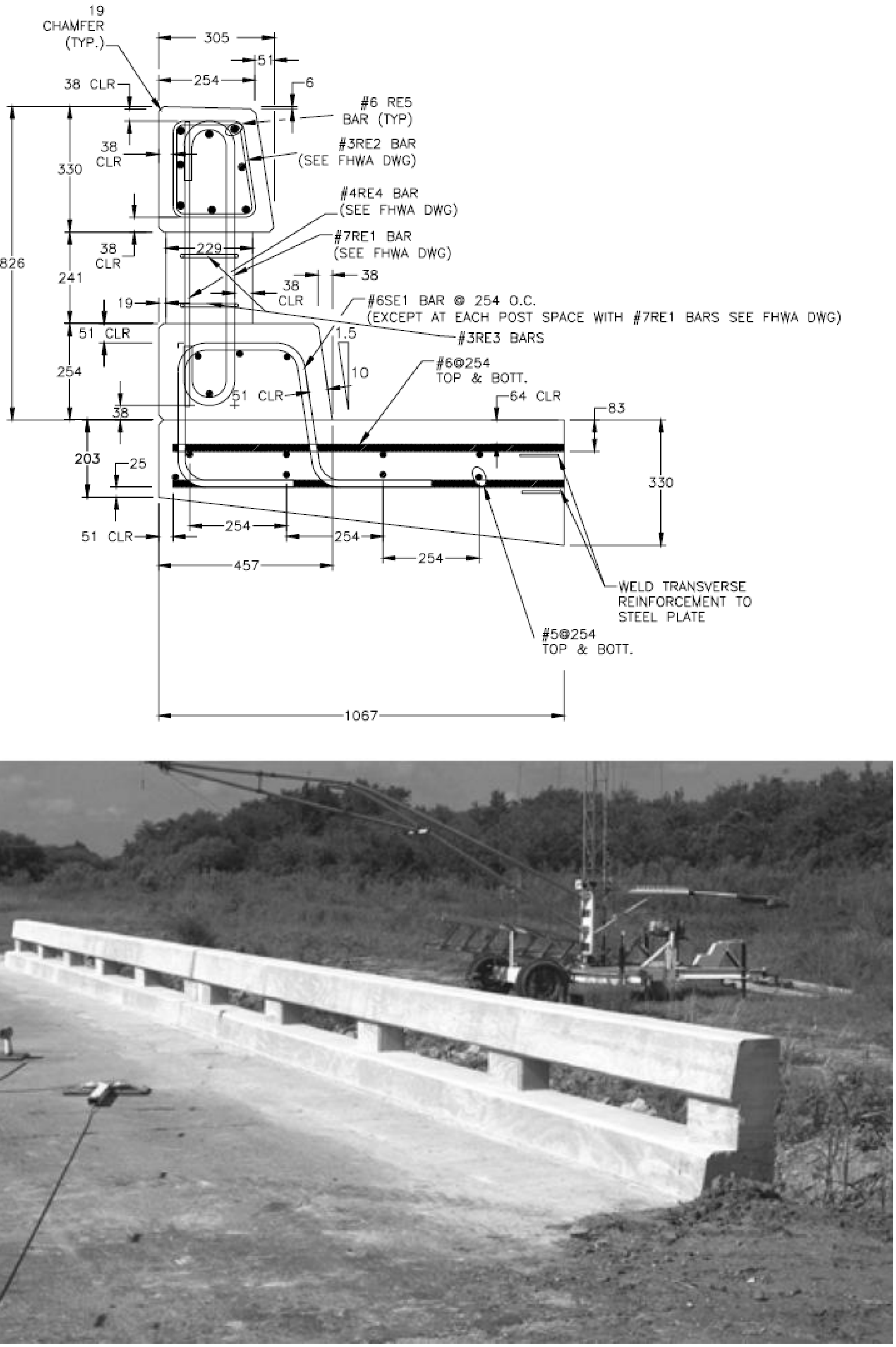


Figure 2. Natchez Trace Bridge Rail Design Details, Test Nos. 405181-11 and 405181-12 (dimensions in mm) [4]

Recently, HDOT desired to have its modified version of the Natchez Trace Bridge Rail evaluated according to MASH TL-3 criteria [1]. The Hawaii Modified Natchez Trace Bridge Rail had several differences compared to the original design previously crash tested at MwRSF [2] and TTI [4]. The height of the Hawaii modified design increased from 32½ in. to 36 in., and the width of the railing also increased significantly. The original Natchez Trace Bridge Rail had a top width of 10 in., a base width of 18 in., and a 4½-in offset between the bottom corner of the rail and the top corner of the curb. The Hawaii modified design had a top width of 18¼ in., a base width of 24 in., and a 1½-in. offset between the bottom corner of the rail and the top corner of the curb. Note, this offset effectively gave the Hawaii-modified design a single slope profile when combining the rail and the curb. The Hawaii-modified design used smaller, 12-in. long by 12-in. wide posts to support the rail. Finally, the Hawaii design incorporated a steel tube, pedestrian handrail mounted to the back side of the concrete rail. Details for the Hawaii Modified Natchez Trace Bridge Railing are shown in Figure 3.

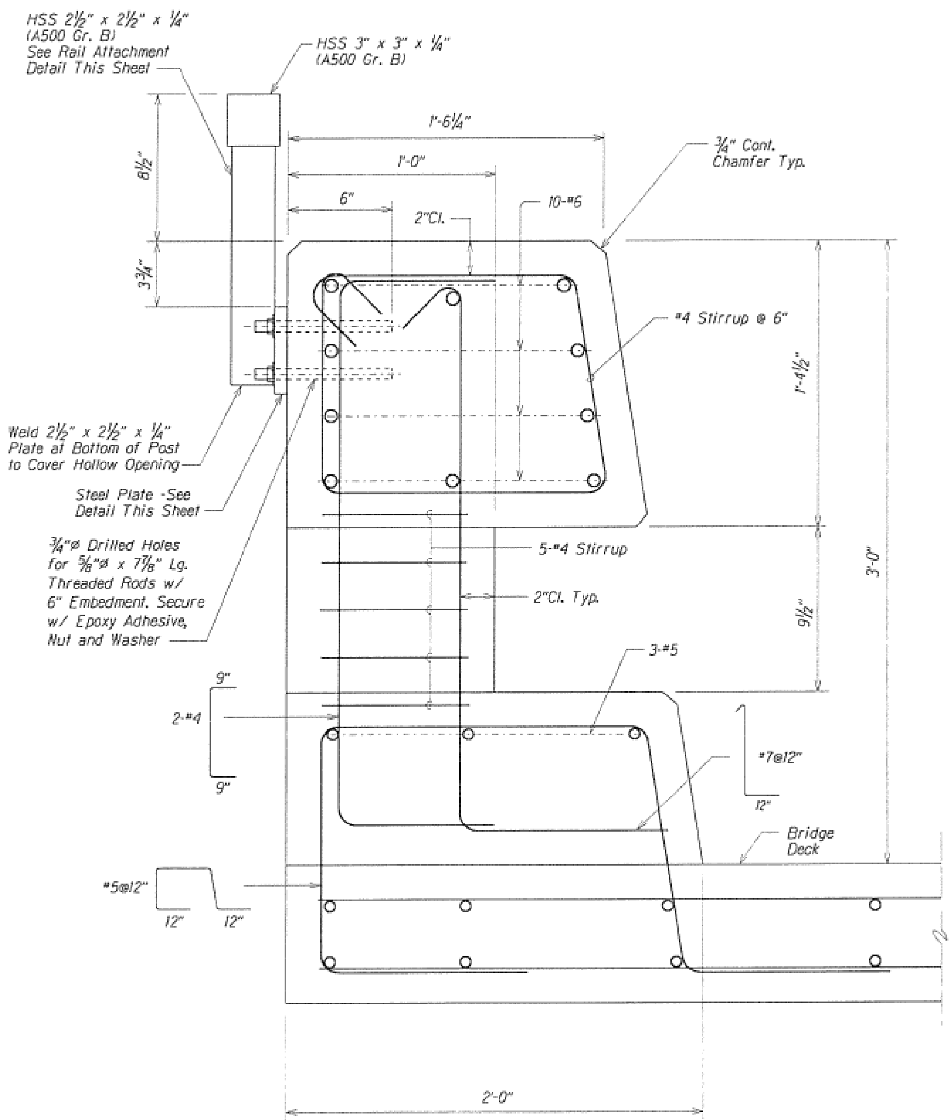


Figure 3. Hawaii Modified Natchez Trace Bridge Rail Design Details

MASH evaluation of the Hawaii Modified Natchez Trace Bridge Rail began with a pickup truck impact in accordance with MASH test designation no. 3-11. In test no. HNTBR-1, a 5,032-lb crew cab pickup truck impacted the Hawaii Modified Natchez Trace Bridge Rail, as shown in Figure 4, at a speed of 62.3 mph and an angle of 25.0 degrees. The vehicle was contained and redirected with minimal damage to the bridge railing. However, there was extensive damage to the vehicle, as shown in Figure 5. The vehicle's wheel well and toe pan had intrusion deformations of 12.7 in., which exceeded the MASH limit of 9 in. Therefore, test no. HNTBR-1 failed the safety criteria of MASH test designation no. 3-11. Test no. HNTBR-1 was previously documented in a separate test report [6].

Figure 4. Hawaii Modified Natchez Trace Bridge Rail – Test No. HNTBR-1

Figure 5. Vehicle Damage and Excessive Wheel and Toe Pan Intrusion – Test No. HNTBR-1

1.2 Objective

The objective of this project was to redesign the Hawaii Modified Natchez Trace Bridge Rail to pass the safety performance criteria of MASH TL-3. The bridge railing needed to be modified to mitigate occupant compartment deformations and to satisfy MASH TL-3 safety performance criteria.

1.3 Scope

The research objective was achieved through the completion of several tasks. First, an investigation was conducted into the potential causes of the excessive toe pan deformations that led to the failure of test no. HNTBR-1. Next, design modifications were recommended to improve the crashworthiness of the bridge rail, and a new railing configuration was selected. The revised bridge railing was subjected to two full-scale crash tests in accordance with MASH Tests 3-11 and 3-10. The full-scale vehicle crash test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made regarding the safety performance of the new Hawaii Concrete Post and Beam Bridge Rail.

2 DESIGN MODIFICATIONS

Upon the failure of test no. HNTBR-1, an investigation into the potential causes of the excessive toe pan deformations was conducted. Vehicle deformations were caused by the impact-side wheel snagging on the bridge railing and being shoved back toward the occupant compartment as the vehicle traveled downstream. Through a review and comparison of the previous crash tests on the original Natchez Trace Bridge Railing and the Hawaii Modified Natchez Trace Bridge Rail [2, 4, and 6], three factors were identified as contributors to the MASH test failure: (1) increased impact severity of the MASH test compared to the previous crash testing standards, (2) the limited curb-to-rail offset of the Hawaii Modified Natchez Trace Bridge Rail, and (3) the angled bottom edge of the upper railing.

The mass of the MASH pickup truck is significantly greater than the mass of the pickup truck specified in NCHRP Report 350. Even though the speed and impact angle for the TL-3 pickup tests were the same, the increased mass resulted in a 14 percent increase in targeted impact severity. This increase in impact severity likely contributed to increased loading during redirection and increased damage to the vehicle. Unfortunately, the MASH impact conditions were not something that could be changed, so the increased impact severity would have to be accounted for in the redesign process.

The original Natchez Trace Bridge Rail had a 4.5 in. lateral offset between the top of the curb and the lower edge of the upper rail. This allowed the impacting wheel to traverse up and over the curb prior to impacting the upper rail. The Hawaii Modified Natchez Trace Bridge Rail reduced this lateral offset to only 1.5 in., which gave the railing more of a "single slope" front face, as shown previously in Figure 3. The limited offset resulted in the wheel impacting and being loaded against the upper rail while trying to traverse over the curb at the same time. The combined lateral loading and vertical motion of the wheel caused the rim to gouge into and snag on the lower edge of the railing. As the vehicle continued to move downstream and against the bridge rail, the wheel was pushed back toward the occupant compartment and deformed the vehicle toe pan.

The shape of the upper rail also contributed to this snag. Most open concrete bridge rails have a rectangular shaped upper rail, whereas the Hawaii Modified Natchez Trace Bridge Rail had an angled lower edge that was more susceptible to gouging and snag, as highlighted in Figure 6. Thus, the severity of the rim snag described above was increased by the angled lower edge of the railing.

Following the failure analysis of test no. HNTBR-1, the research team identified various options to alter the bridge railing to alleviate the rim gouging and snag issues. These options are explored in the following sections.

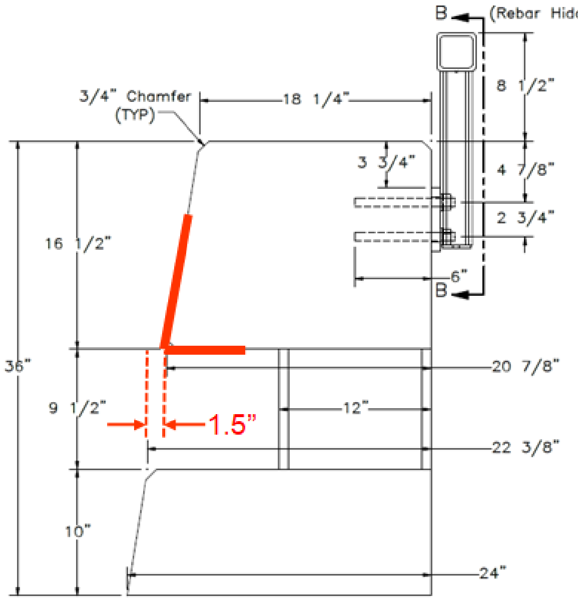


Figure 6. Limited Curb-to-Railing Offset and Angled Lower Edge of Railing

2.1 Curb-to-Rail Offset

One suggested modification was to increase the curb-to-rail offset, as shown in Figure 7, by changing the top rail's slope face to either a vertical face (left) or a recessed sloped face (right). This adjustment provided the vehicle's wheel with sufficient time to climb before contacting the rail, thus reducing the severity of the impact. The vertical loads into the bottom edge of the rail would be reduced, which would reduce wheel snag and the associated occupant compartment deformations. This design change would bring the new railing configuration closer to the original Natchez Trace Bridge Rail.

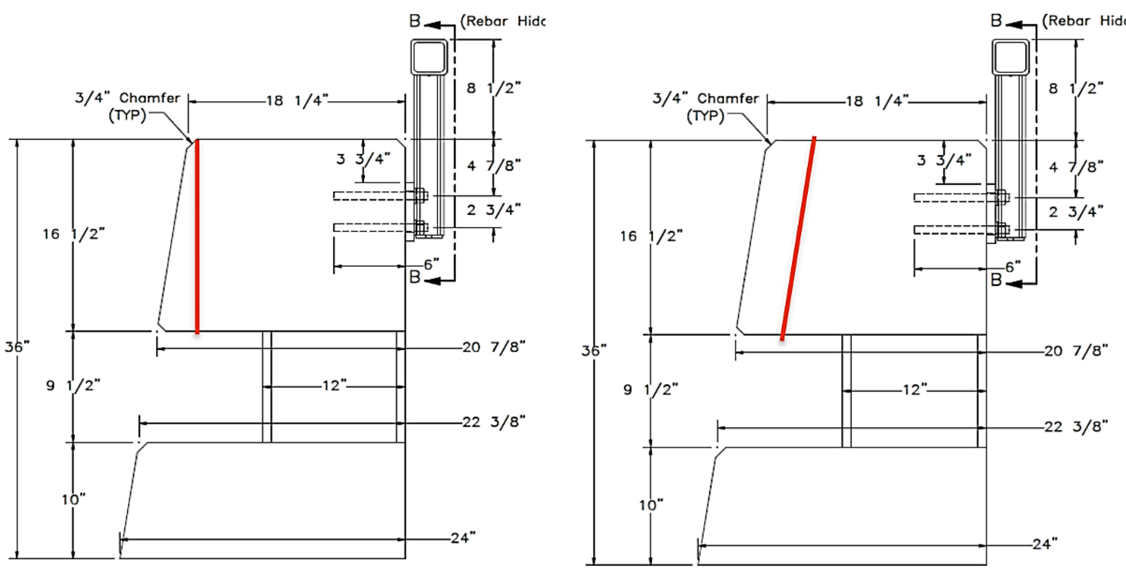


Figure 7. Potential Modifications for Curb-Rail Offset Increase: Vertical Rail Face (left) and Recessed Sloped Rail Face (right)

2.2 Railing Face Geometry

To reduce the risk of snagging on the bottom edge of the rail, researchers proposed changing the curb's face from sloped to vertical, as shown in Figure 8. This alteration would minimize wheel climbing and vertical loading to the upper rail, thereby reducing wheel snag on the bottom edge of the rail.

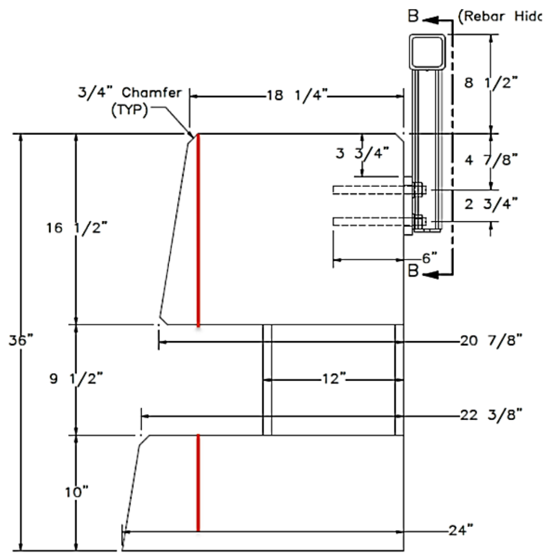


Figure 8. Potential Modification for Aligning Front Face of Rail and Curb

Another explored design modification was to eliminate the angled bottom edge of the rail by either rounding or cutting back the bottom edge, as shown in Figure 9. Elimination of the sharp angled edge would reduce the severity of rim-rail snag and create a smoother vehicle redirection.

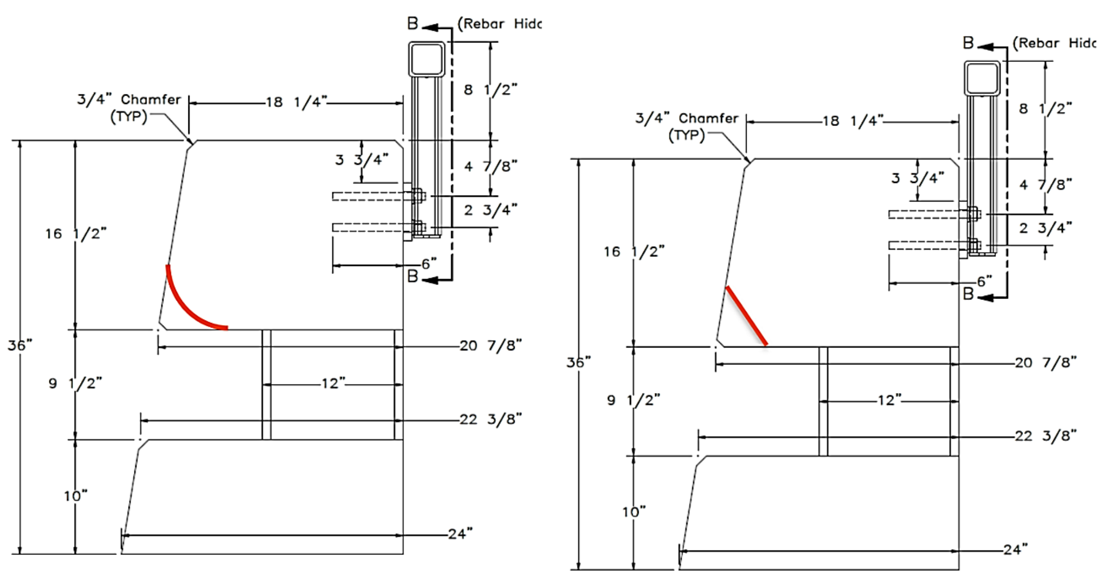


Figure 9. Potential Modification for Elimination of Angled Bottom Rail Edge

The final proposed design modification was to reduce the opening height between the curb and the rail by either raising the curb height or lowering the bottom of the rail, as shown in Figure 10. Reducing the opening and increasing the contact area on the face of the railing would likely reduce the severity of rim snag on the lower edge of the railing.

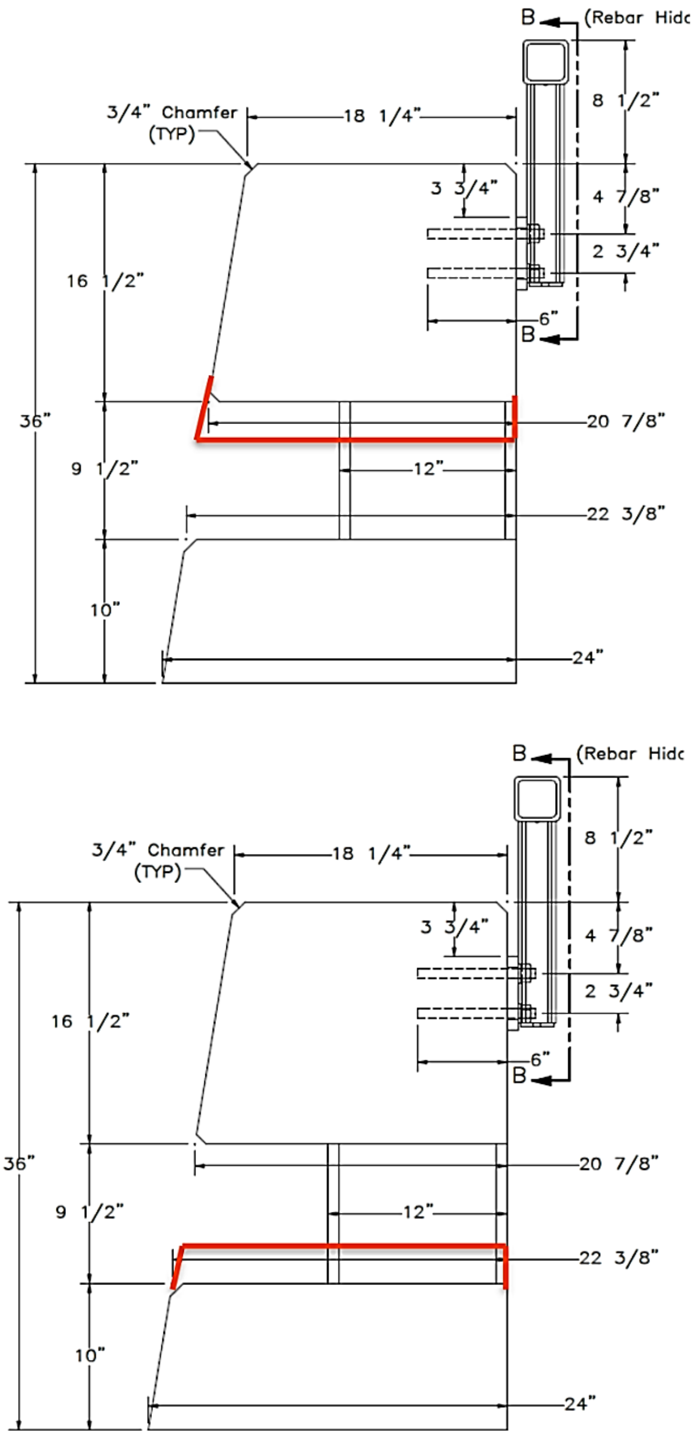


Figure 10. Potential Modification for Reducing the Opening Height between Curb and Rail

2.3 Selected Design Modifications

After discussions with HDOT, a vertical face for both the top rail and bottom curb was selected for the new bridge railing configuration. The vertical front face was aligned with the original top edge of the railing and the base width of the railing was reduced. Reinforcement in both the top rail and bottom curb was adjusted to accommodate the new cross section, as detailed in the following chapter, but the overall reinforcement configuration remained very similar to the previous Hawaii modified version of the bridge rail. The new bridge rail cross section is detailed in Figure 11.

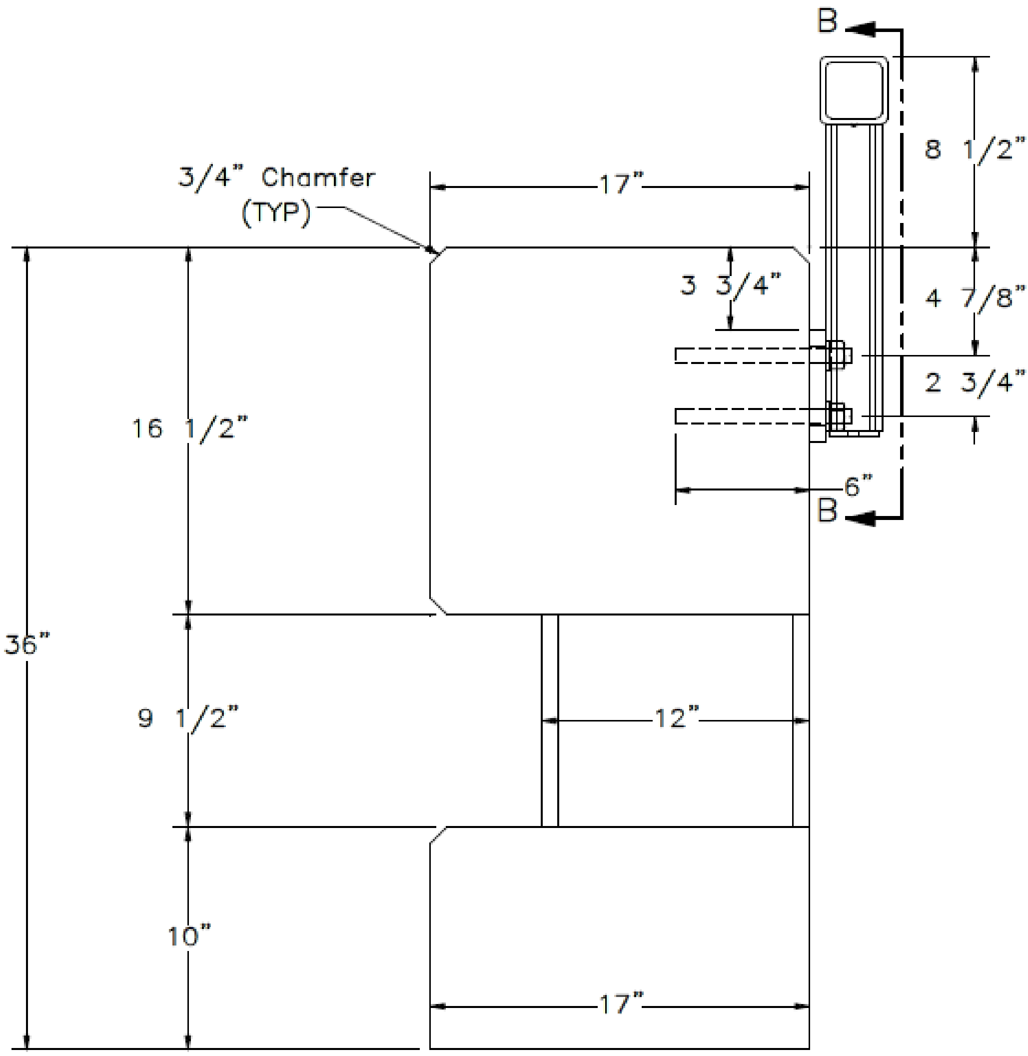


Figure 11. Selected Configuration for Hawaii Concrete Post and Beam Bridge Rail

3 DESIGN DETAILS

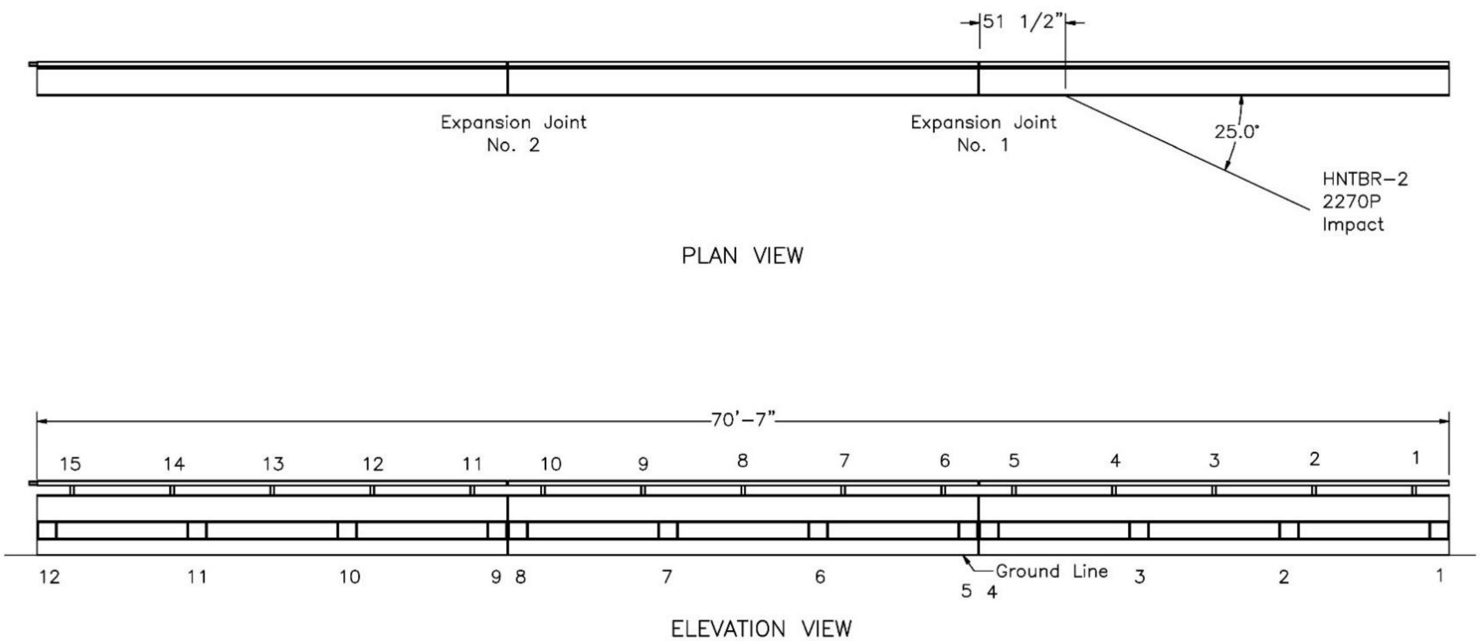
The new Hawaii Concrete Post and Beam Bridge Rail was a 36-in. tall open concrete barrier with a pedestrian handrail mounted to the backside of the railing, as shown in Figures 12 through 23. Photographs of the test installation are shown in Figures 24 and 25. The same test installation was used for both test nos. HNTBR-2 and HNTBR-3, only the impact location was changed.

The Hawaii Concrete Post and Beam Bridge Rail featured a 16½-in. tall by 17-in. wide concrete rail supported by 12-in. x 12-in. x 9½-in. tall concrete posts spaced 90 in. apart. The post-and-beam railing was mounted on top of a 10-in. tall by 17-in. wide concrete curb such that the face of the railing was flush with the face of the curb. The test installation had a length of 70 ft – 7 in. and was comprised of three 23.5-ft long rail segments with ½-in. expansion joins placed at the end of each rail segment.

The rail, posts, and curb were reinforced with a combination of transverse and longitudinal rebar, as shown in Figure 20. The rail had nine longitudinal #6 bars and #4 hoop stirrups. Reinforcement in the posts consisted of four #7 vertical bars spaced equally along the traffic face of each post with four #4 vertical bars spaced along the non-traffic side. All vertical bars in the posts were enclosed by five #4 stirrups that were spaced at 2¾ in. Reinforcement of the curb consisted of three longitudinal #5 bars and U-shaped #5 transverse bars, as shown in Figure 18. The U-shaped transverse reinforcing bars were epoxied into the concrete tarmac to a depth of 6 in. using Hilti HIT RE-500 epoxy. All of the rebar was epoxy coated.

The pedestrian handrail, which was mounted to a height of 44½ in. above the tarmac, consisted of an HSS3x3x¼ steel tube supported by HSS2½x2½x¼ posts spaced at 60 in. on-center. The tube posts were welded to 8-in. x 5-in. x ¾-in. thick steel base plates. Each welded handrail assembly was 23.5-ft long, matching the length of the concrete barrier segments. HSS2x2x¼ splice tubes were welded to one side of each handrail segment and extended into the adjacent handrail tube. The handrail was mounted to the backside of the concrete railing using four ⅝-in. diameter threaded rods, which were epoxied into the railing to a depth of 6 in.

The concrete mix for the railing, posts, and curb required a minimum 28-day compressive strength of 4,000 psi. The actual strength of the concrete curb was measured to be 4,340 psi. All reinforcing steel were ASTM A615 Grade 60 rebar. The HSS tubes and the baseplate comprising the pedestrian handrail were ASTM 500 Grade B and ASTM A36 steel, respectively. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix B.



Notes: (1) Test no. HNTBR-2 will be performed according to test designation no. 3-11 of MASH 2016 criteria.
(2) The impact location for test no. HNTBR-2 is 51 1/2" upstream from the centerline of expansion joint no. 1.

Midwest Roadside Safety Facility	Hawaii Concrete Post and Beam Bridge Rail Test No. HNTBR-2 Bridge Rail Layout	SHEET: 1 of 11 DATE: 2/10/2025 DRAWN BY: ZMM/MSW/JJO
	DWG. NAME. HNTBR-2_R8	SCALE: 1:90 UNITS: in.	REV. BY: KAL

Figure 12. Test Installation Layout, Test No. HNTBR-2

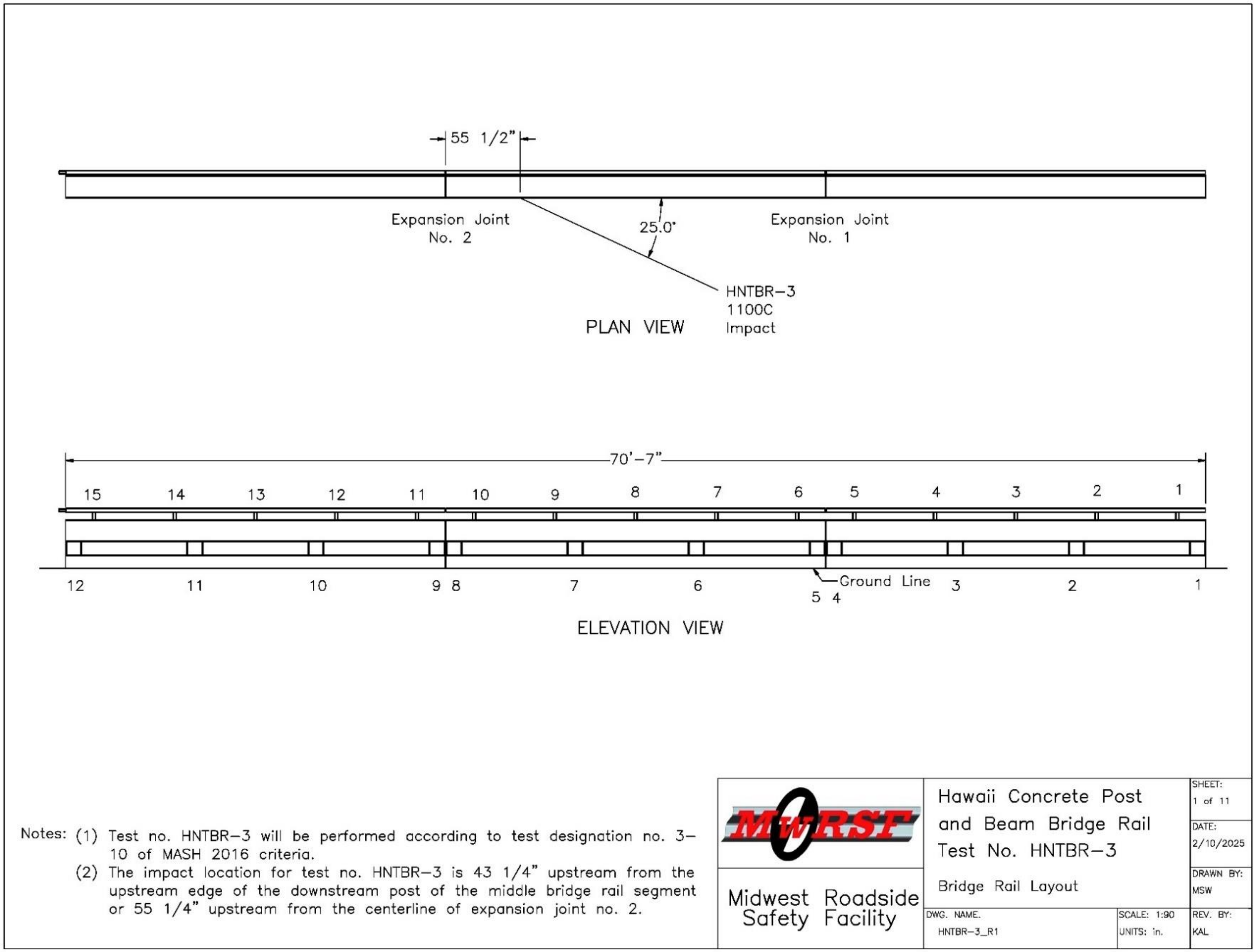


Figure 13. Test Installation Layout, Test No. HNTBR-3

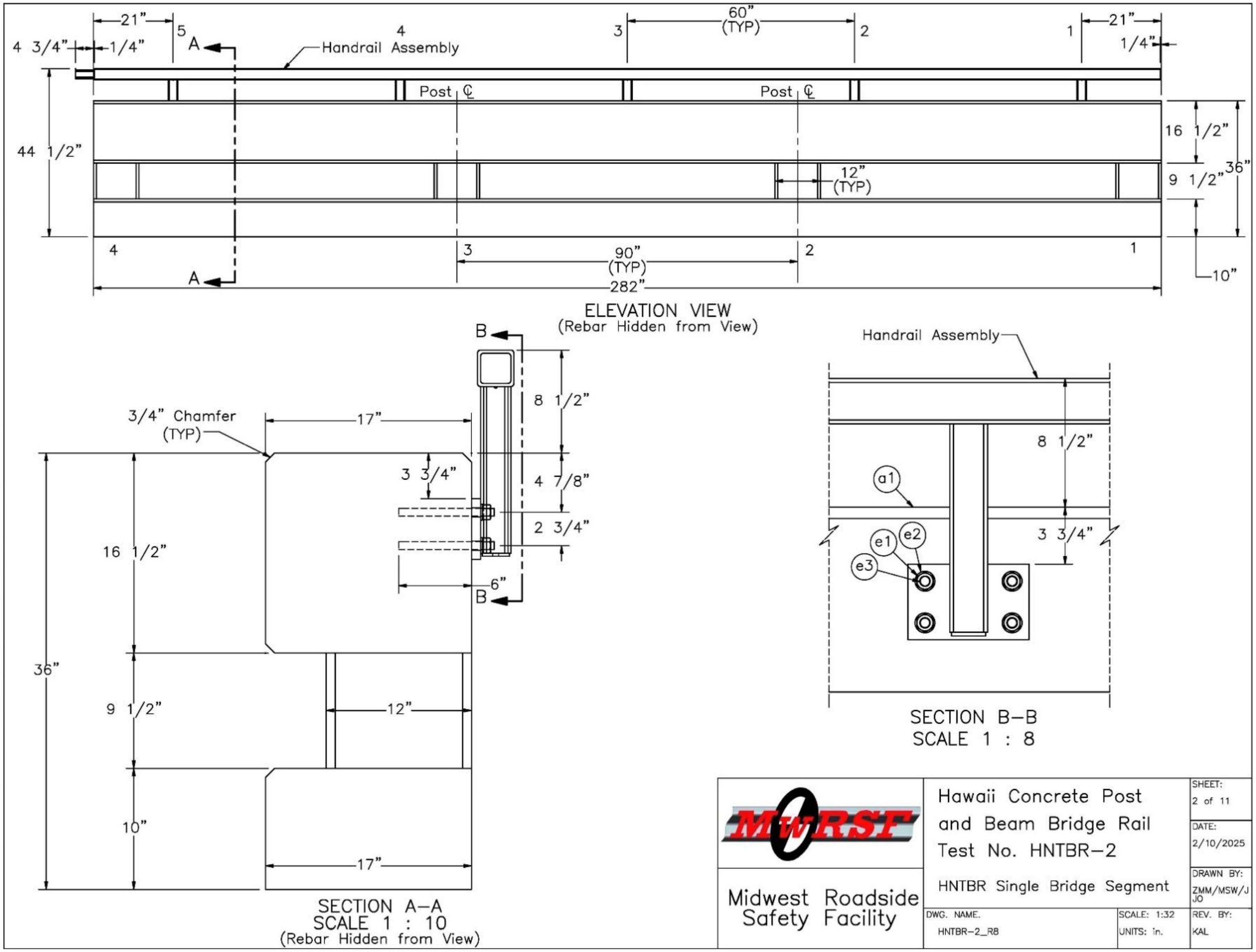


Figure 14. Bridge Rail Layout, Test Nos. HNTBR-2 and HNTBR-3

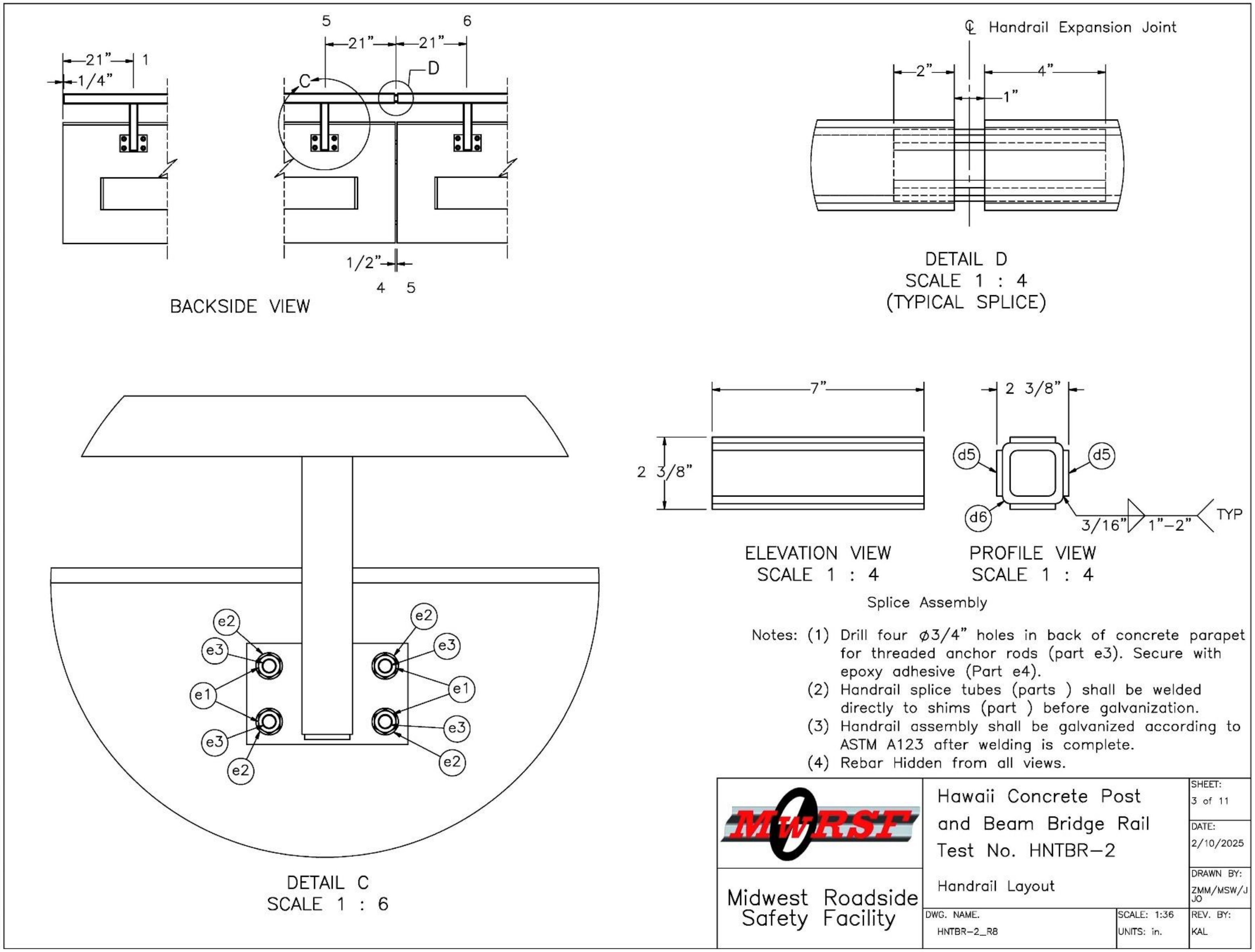
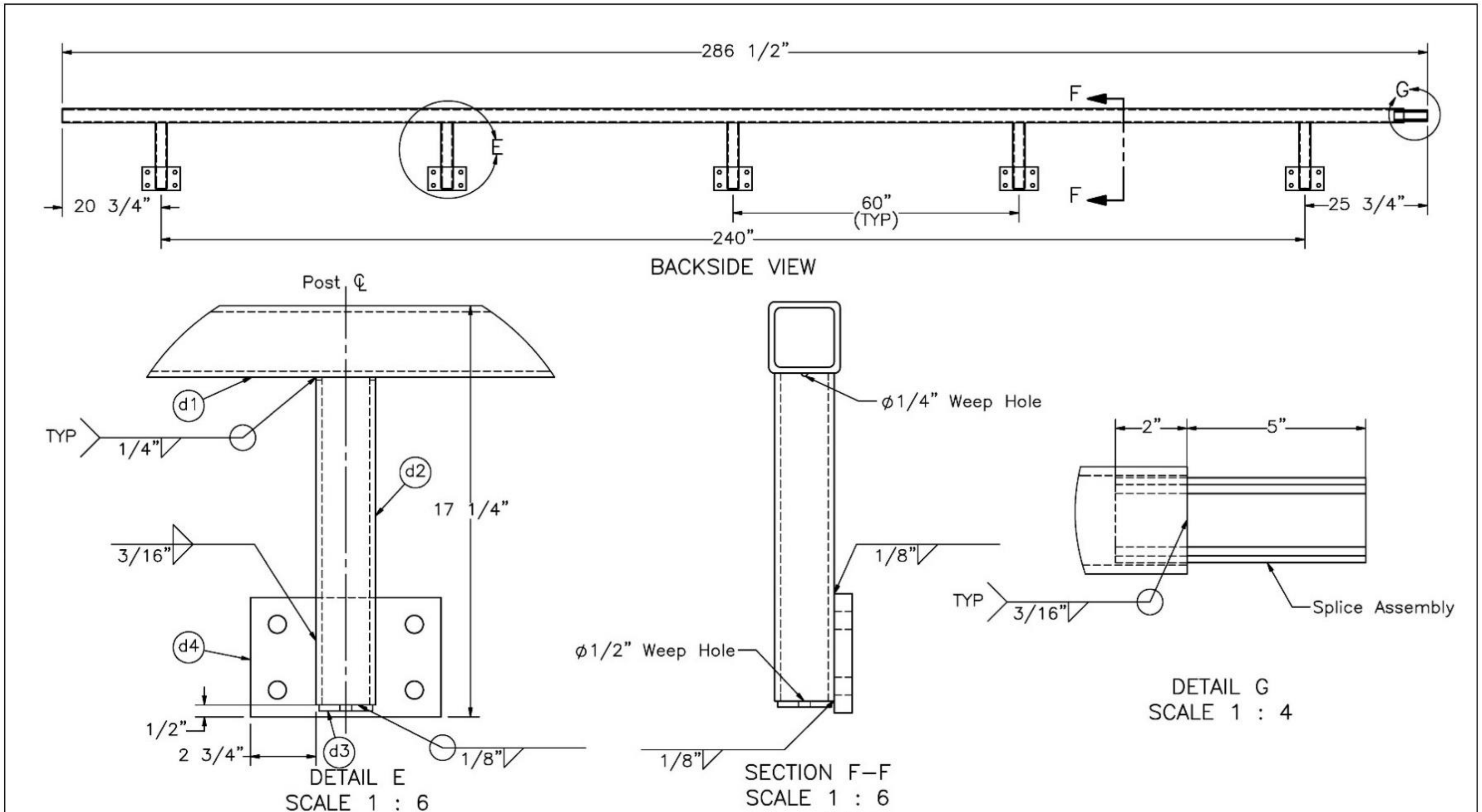


Figure 15. Handrail Detail, Test Nos. HNTBR-2 and HNTBR-3



Notes:
(1) Handrail assemblies shall be galvanized according to ASTM A123 after all welding is complete.
(2) Details are typical for all handrail assemblies.

Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Handrail Assembly	–	ASTM A123
d1	1	HSS 3"x3"x1/4", 281 1/2" Long	ASTM A500 Gr. B	See Assembly
d2	5	HSS 2 1/2"x2 1/2"x1/4", 13 3/4" Long	ASTM A500 Gr. B	See Assembly
d3	5	2 1/4"x2 1/4"x1/4" Steel Plate	ASTM A36	See Assembly
d4	5	8"x5"x3/4" Steel Plate	ASTM A36	See Assembly
d5	4	7"x1 1/2"x3/16" Shim	ASTM A36	See Assembly
d6	1	HSS 2"x2"x1/4", 7" Long	ASTM A500 Gr. B	See Assembly

Midwest Roadside Safety Facility

Hawaii Concrete Post and Beam Bridge Rail Test No. HNTBR-2

Handrail Assembly Details

SHEET: 4 of 11

DATE: 2/10/2025

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DWG. NAME. HNTBR-2_R8

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Figure 16. Handrail Detail, Test Nos. HNTBR-2 and HNTBR-3

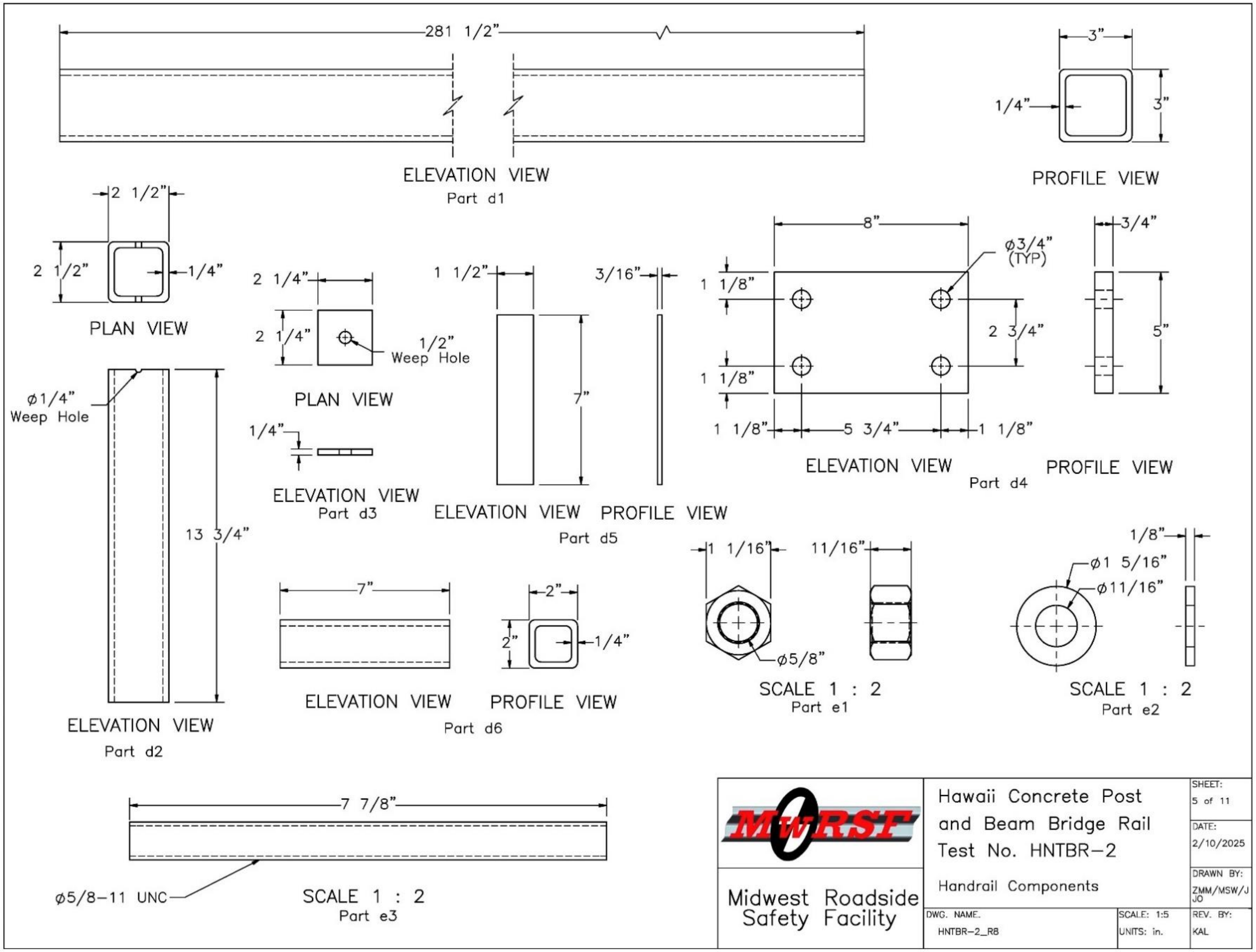


Figure 17. Handrail Assembly Components, Test Nos. HNTBR-2 and HNTBR-3

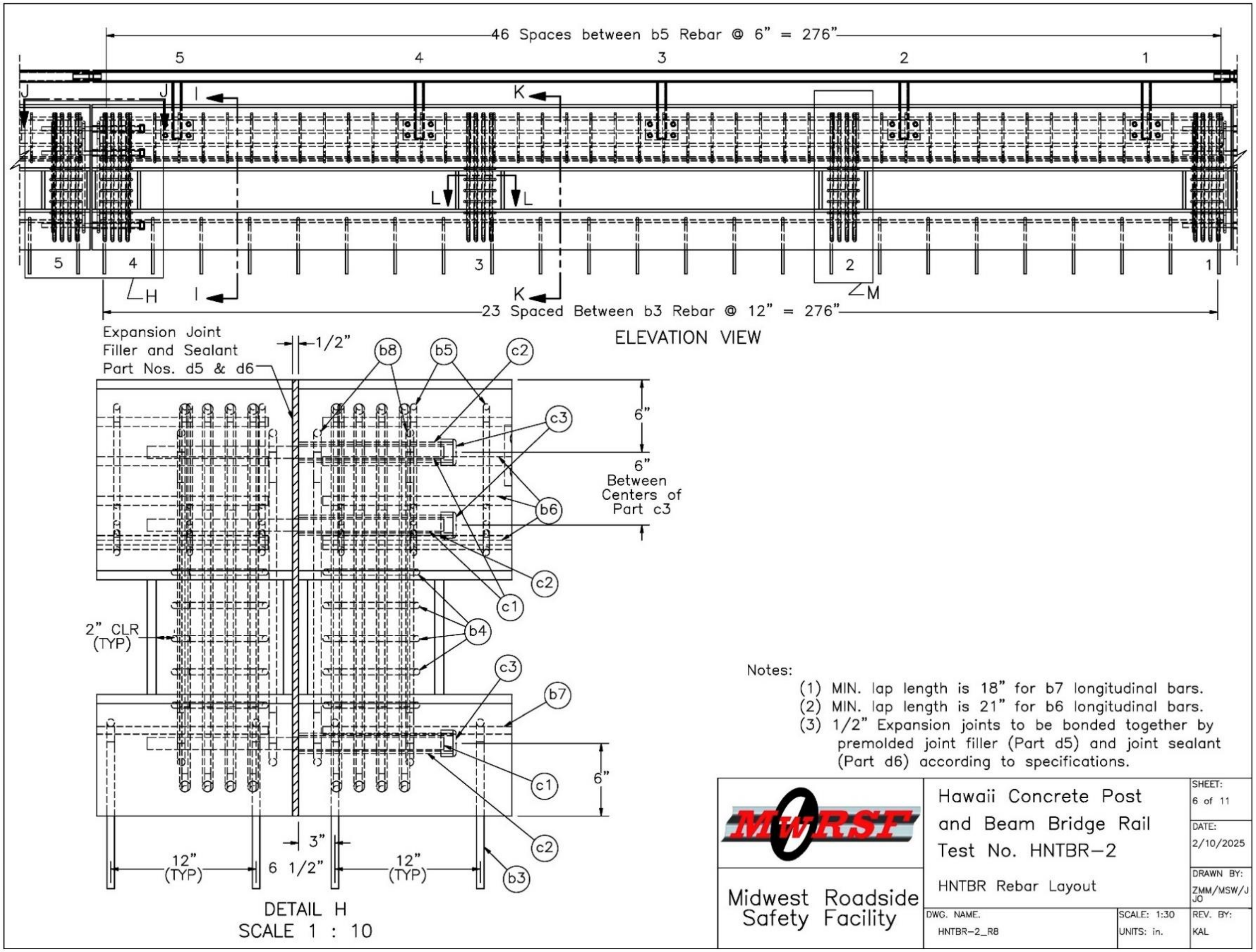


Figure 18. Rails Rebar Detail, Test Nos. HNTBR-2 and HNTBR-3

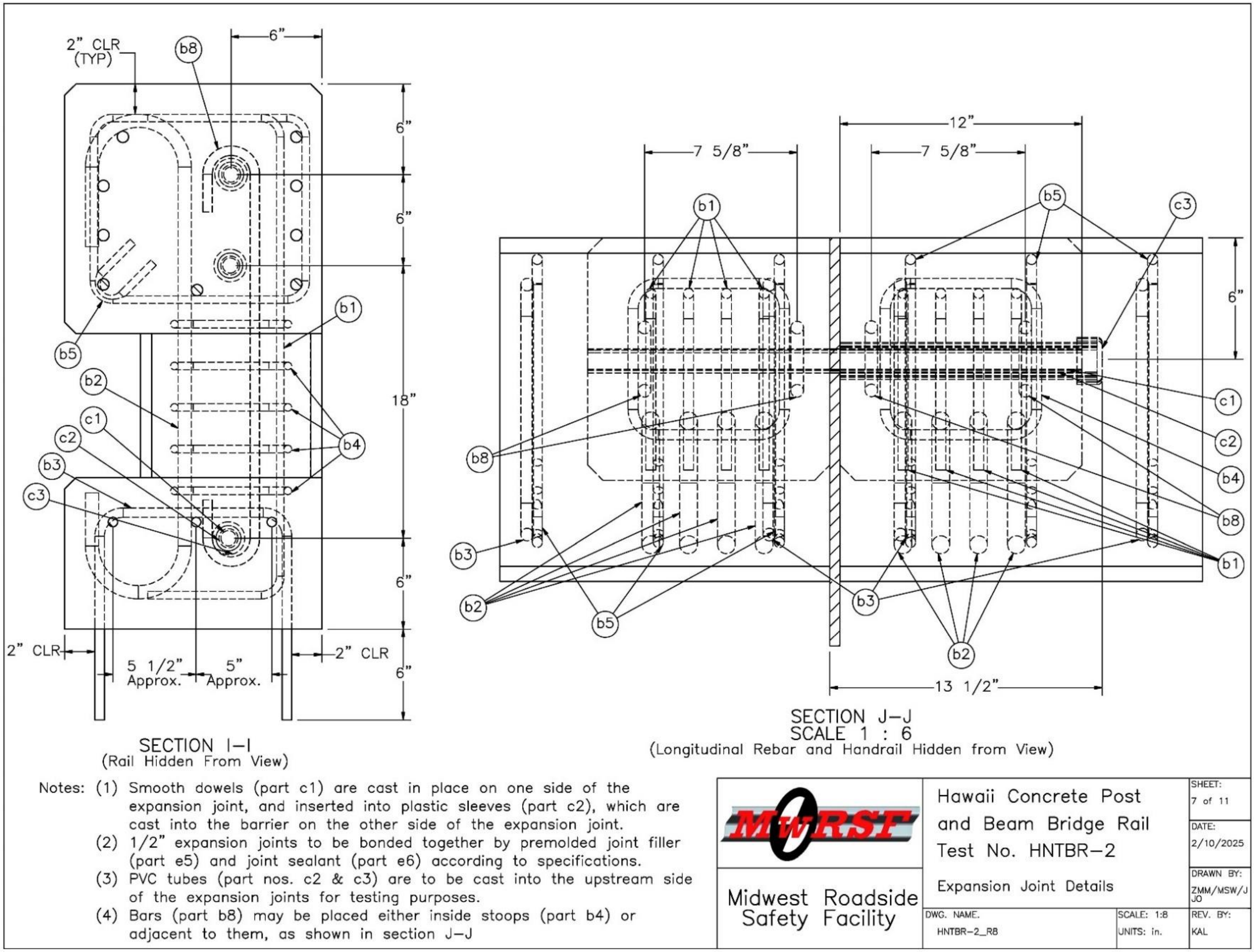


Figure 19. Post-Rail Rebar Arrangement, Test Nos. HNTBR-2 and HNTBR-3

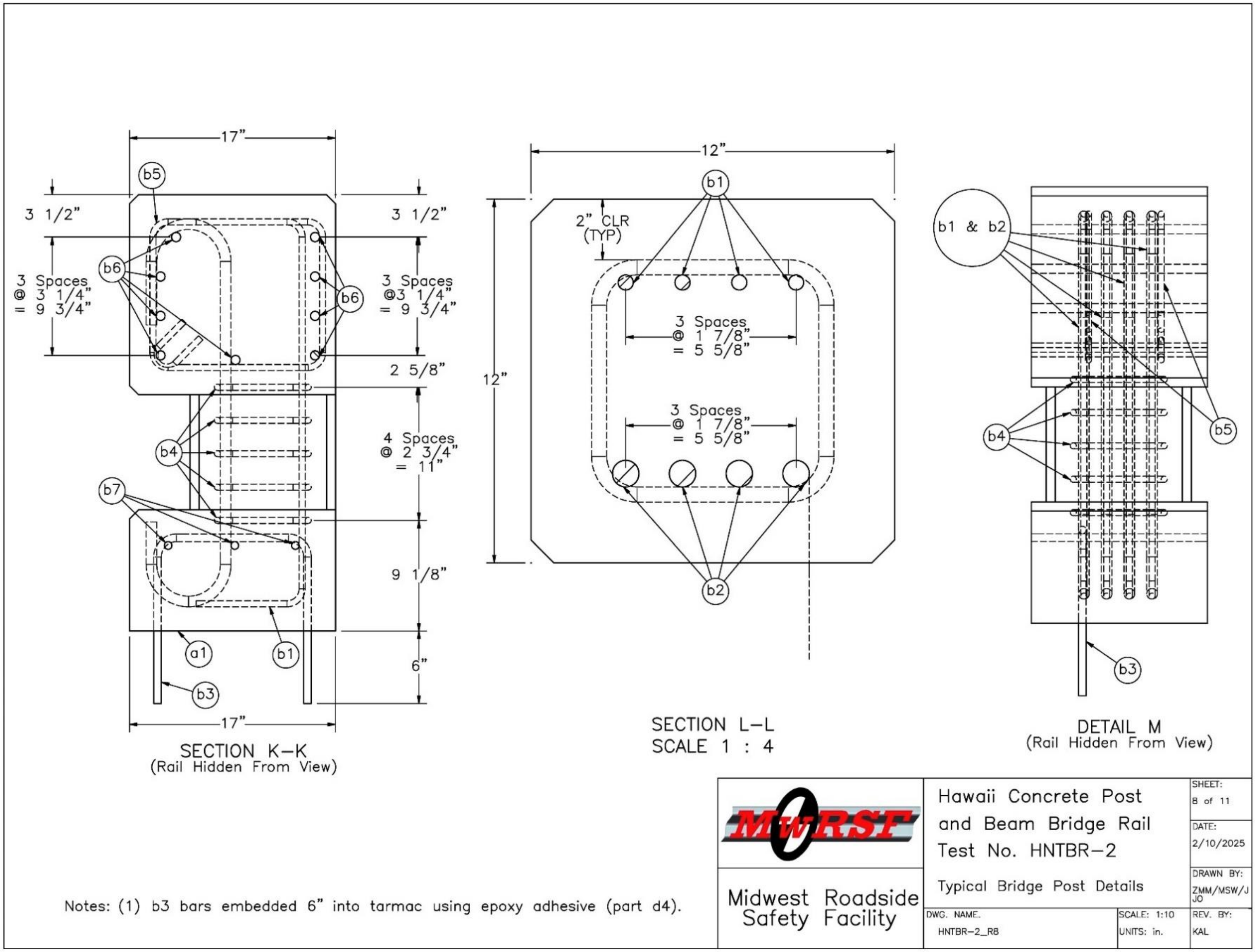
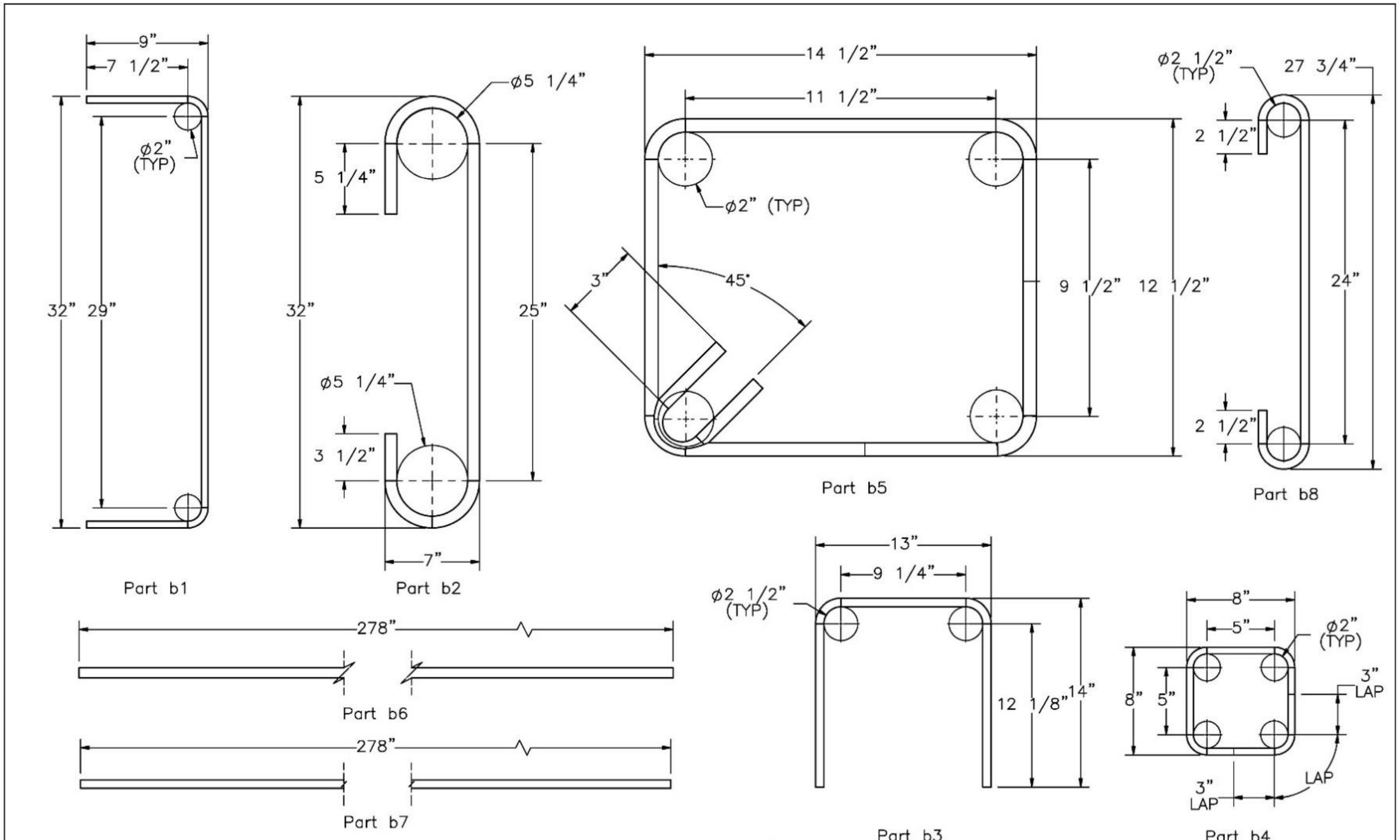


Figure 20. Post-Rail Rebar Arrangement, Test Nos. HNTBR-2 and HNTBR-3



Bill of Bars					
Part No.	Size	QTY	Unbent Length	Min. Lap	Material Specification
b1	#4	48	47 1/2"	–	ASTM A615 Gr. 60
b2	#7	48	43 1/2"	–	ASTM A615 Gr. 60
b3	#5	72	38 1/2"	–	ASTM A615 Gr. 60
b4	#4	60	35"	8"	ASTM A615 Gr. 60
b5	#4	141	57"	–	ASTM A615 Gr. 60
b6	#6	27	278"	21"	ASTM A615 Gr. 60
b7	#5	9	278"	18"	ASTM A615 Gr. 60
b8	#5	8	39"	–	ASTM A615 Gr. 60

Midwest Roadside Safety Facility

Hawaii Concrete Post and Beam Bridge Rail Test No. HNTBR-2

Bridge Rail Rebar

SHEET: 9 of 11

DATE: 2/10/2025

DRAWN BY: ZMM/MSW/JJO

DWG. NAME. HNTBR-2_R8

SCALE: 1:10

UNITS: in.

REV. BY: KAL

Figure 21. Rebar Details, Test Nos. HNTBR-2 and HNTBR-3

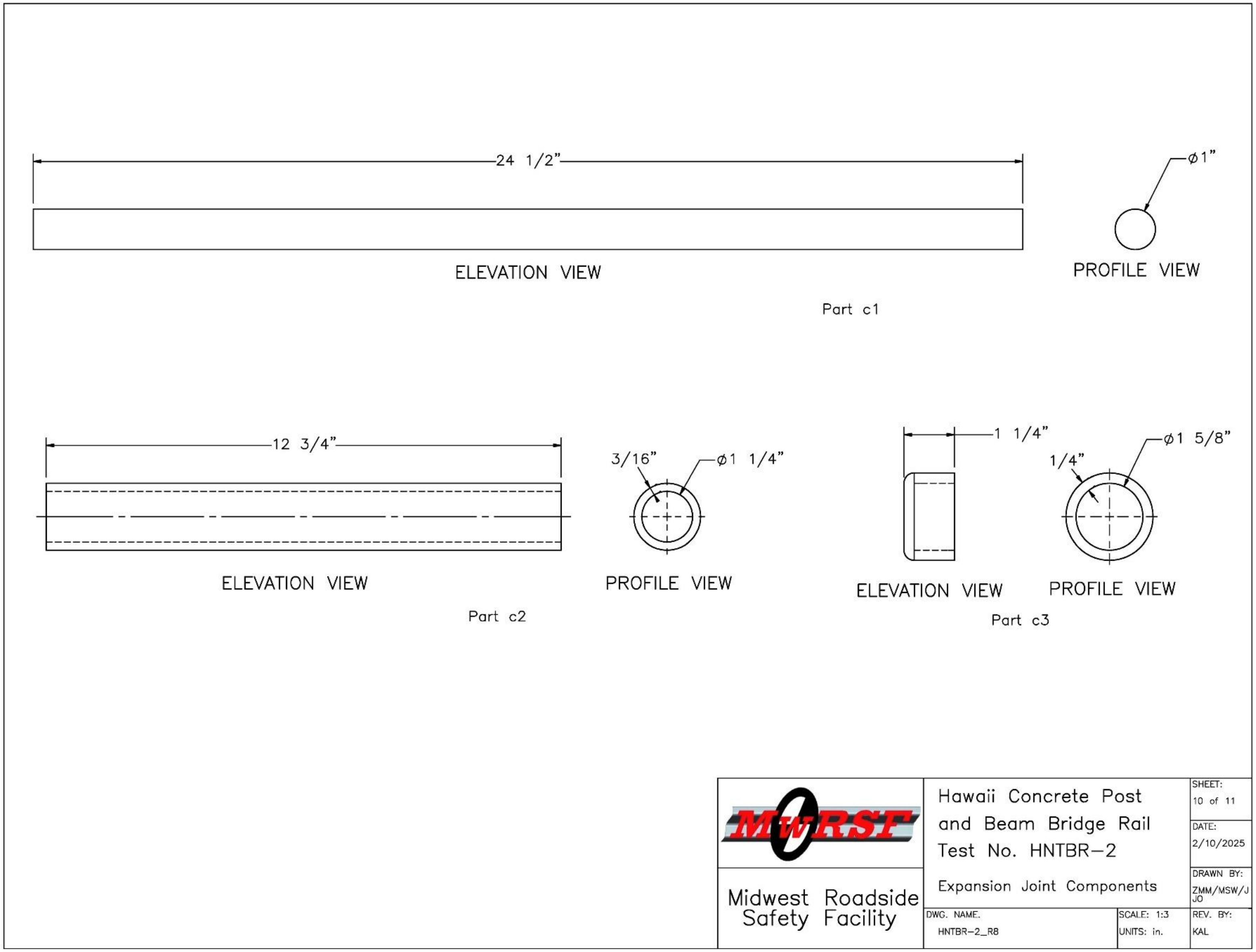


Figure 22. Pipe Details, Test Nos. HNTBR-2 and HNTBR-3

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	3	Concrete*	Min. f'c = 4,000 psi	–	–
b1	48	#4 Rebar, 47 1/2" Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b2	48	#7 Rebar, 43 1/2"" Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b3	72	#5 Rebar, 38 1/2" Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b4	60	#4 Rebar, 35" Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b5	141	#4 Rebar, 57" Total Unbent Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b6	27	#6 Rebar, 278" Total Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b7	9	#5 Rebar, 278" Total Length	ASTM A615 Gr. 60	**Epoxy–Coated (ASTM A775 or A934)	–
b8	8	#5 Rebar, 39" Total Unbent Length	ASTM A615 Gr. 60	**Epoxy Coated (ASTM A775 or A934)	–
c1	6	#8 Smooth Rebar, 24 1/2" Long	ASTM A615 Gr. 60	**Epoxy Coated (ASTM A775 or A934)	–
c2	6	1 1/4" Dia. PVC Pipe	Schedule 80 PVC Gr. 12454	–	–
c3	6	1 1/4" Dia. PVC End Cap	Schedule 80 PVC Gr. 12454	–	–
d1	3	HSS 3"x3"x1/4", 281 1/2" Long	ASTM A500 Gr. B	See Assembly	–
d2	15	HSS 2 1/2"x2 1/2"x1/4", 13 3/4" Long	ASTM A500 Gr. B	See Assembly	–
d3	15	2 1/4"x2 1/4"x1/4" Steel Plate	ASTM A36	See Assembly	–
d4	15	8"x5"x3/4" Steel Plate	ASTM A36	See Assembly	–
d5	12	7"x1 1/2"x3/16" Shim	ASTM A36	See Assembly	–
d6	3	HSS 2"x2"x1/4", 7" Long	ASTM A500 Gr. B	See Assembly	–
e1	60	5/8"–11 UNC Heavy Hex Nut	ASTM A563–15 Grade DH	ASTM F2329	FNX18b
e2	60	5/8" Dia. Hardened Washer	ASTM F436	ASTM F2329	FWC18b
e3	60	5/8"–11 UNC, 7 7/8" Long Threaded Rod	ASTM F1554–15 Gr. 105	ASTM F2329	–
e4	–	Epoxy Adhesive	Hilti HIT RE–500 V3	–	–
e5	–	Joint Filler	AASHTO M33, M153, or M213	–	–
e6	–	Expansion Joint Sealant	AASHTO M173, M282, M301, ASTM D3581, or ASTM D5893	–	–

* NE Mix 47B15/1PF4000HW was used for testing purposes.
** Rebar does not need to be epoxy–coated for testing purposes.

Midwest Roadside Safety Facility

Hawaii Concrete Post and Beam Bridge Rail Test No. HNTBR–2

HNTBR BOM

SHEET:	DATE:	DRAWN BY:	DWG. NAME.	SCALE:	UNITS:	REV. BY:
11 of 11	2/10/2025	ZMM/MSW/JJO	HNTBR–2_R8	1:192	in.	KAL

Figure 23. Bill of Materials, Test Nos. HNTBR-2 and HNTBR-3

Figure 24. Test Installation Photographs, Test Nos. HNTBR-2 and HNTBR-3

Figure 25. Test Installation Photographs, Handrail Assembly, Test Nos. HNTBR-2 and HNTBR-3

4 TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1 Test Requirements

Longitudinal barriers, such as concrete bridge rails, must satisfy impact safety standards to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System. For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016. According to TL-3 of MASH, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 1. Two crash tests were conducted under test designation nos. 3-10 and 3-11 and are reported herein.

Table 1. MASH 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.

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

4.2 Evaluation Criteria

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

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

Table 2. MASH Evaluation Criteria for Longitudinal Barrier

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

5 TEST CONDITIONS

5.1 Test Facility

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

5.2 Vehicle Tow and Guidance System

A reverse-cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle was 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 [7] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. diameter guide cable was tensioned to approximately 3,500 lb and supported both laterally and vertically every 100 ft by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

5.3 Test Vehicle

In test no. HNTBR-2, a 2018 Dodge Ram 1500 crew cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,216 lb, 4,995 lb, and 5,159 lb, respectively. The test vehicle is shown in Figures 26 and 27, and vehicle dimensions are shown in Figure 28. Note, the impact side of the vehicle, or the passenger's side, is referred to as the vehicle's right side throughout this report. The non-impact side, or driver's side, is referred to as the vehicle's left side.

In test no. HNTBR-3, a 2019 Kia Rio was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,483 lb, 2,400 lb, and 2,563 lb, respectively. The test vehicle is shown in Figures 29 and 30, and vehicle dimensions are shown in Figure 31.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [8] was used to determine the vertical component of the c.g. for the 2270P vehicle. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by the Society of Automotive Engineer (SAE) [9]. The final c.g. locations are shown in Figures 28 and 31. Ballast information and data used to calculate the location of the c.g. are shown in Appendix C.

Square, black-and-white checkered targets were placed on the vehicles for reference, as shown in Figures 32 and 33, to serve as a reference in the high-speed digital video and aid in the video analysis. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

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

Figure 26. Test Vehicle, Test No. HNTBR-2

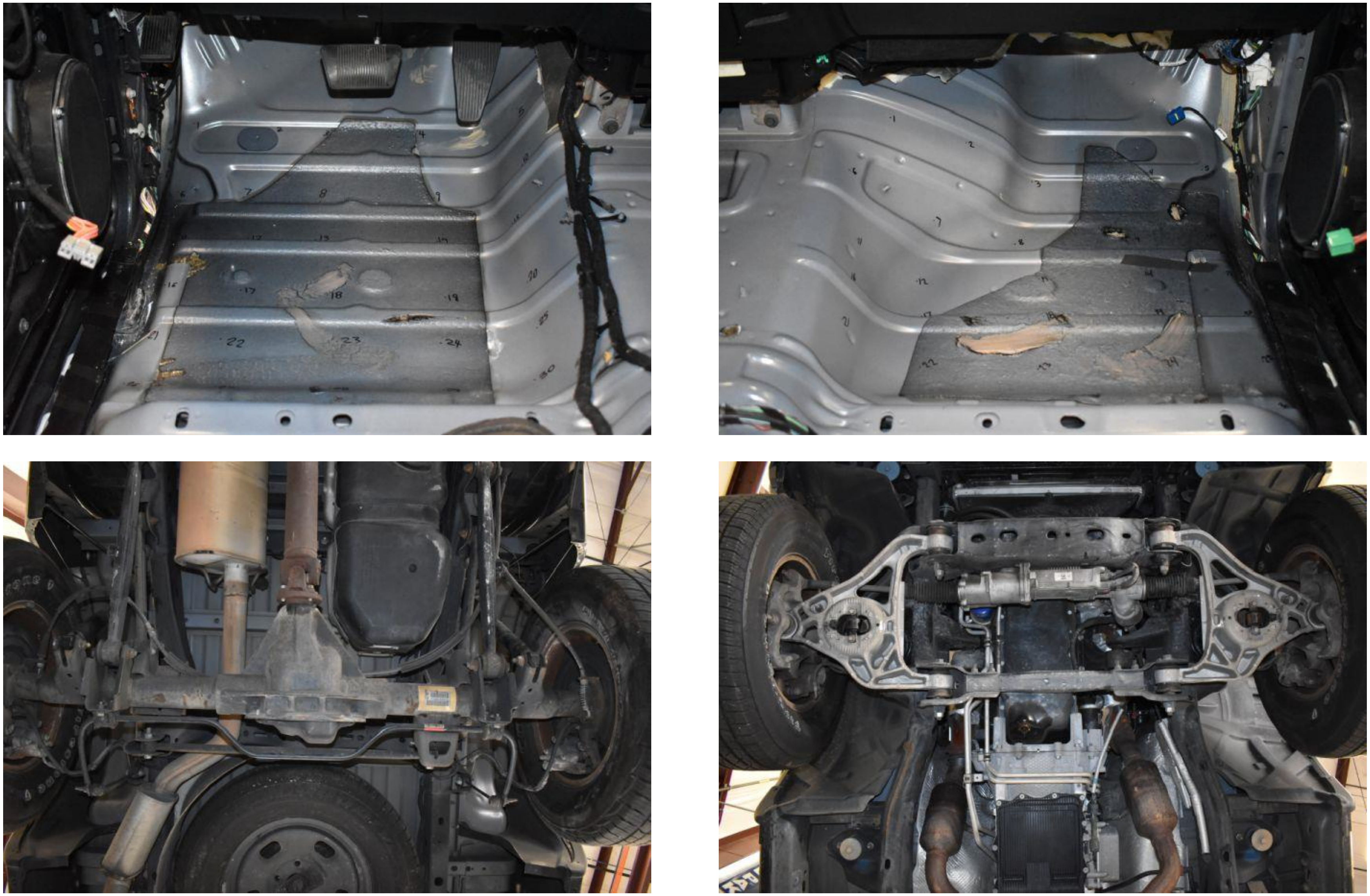


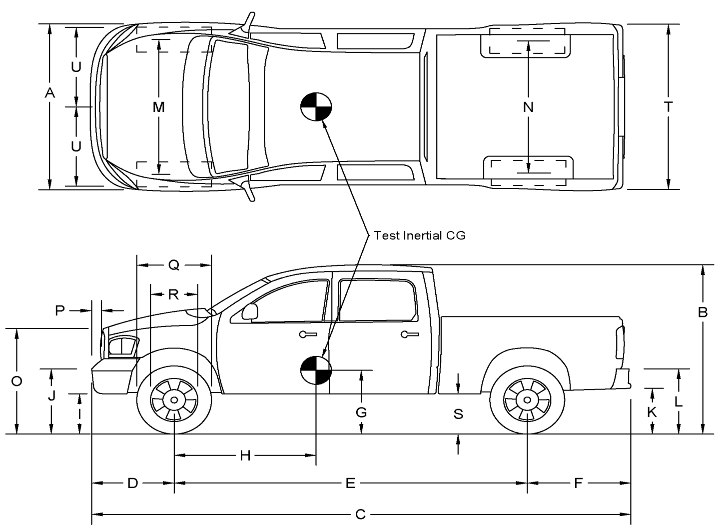
Figure 27. Vehicle’s Interior Floorboards and Undercarriage, Test No. HNTBR-2

Test Name: HNTBR-2 **VIN No:** 3C6RR6KT6JG137519

Model Year: 2018 **Make:** RAM **Model:** 1500

Tire Size: 265/17/R17 **Tire Inflation Pressure:** 40 psi **Odometer:** 202866

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



	in.	(mm)		in.	(mm)
A:	76 3/4	1949 9/20	B:	74 1/2	1892 3/10
	78±2 (1950±50)				
C:	229 1/4	5822 19/20	D:	41 5/8	1057 11/40
	237±13 (6020±325)			39±3 (1000±75)	
E:	140 3/4	3575 1/20	F:	46 7/8	1190 5/8
	148±12 (3760±300)				
G:	28 7/16	722 5/16	H:	60 3/4	1543 1/20
	min: 28 (710)			63±4 (1575±100)	
I:	13	330 1/5	J:	24 3/8	619 1/8
K:	21 3/16	538 13/80	L:	29 13/16	757 19/80
M:	67 3/8	1711 13/40	N:	67 13/16	1722 7/16
	67±1.5 (1700±38)			67±1.5 (1700±38)	
O:	44 1/4	1123 19/20	P:	4 1/2	114 3/10
	43±4 (1100±75)				
Q:	30 3/4	781 1/20	R:	18 1/4	463 11/20
S:	15 3/8	390 21/40	T:	77	1955 4/5
			U (impact width):	36 1/4	920 3/4

Mass Distribution - lb (kg)

Gross Static	LF	1454 (660)	RF	1483 (673)
	LR	1088 (494)	RR	1134 (514)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2942 (1334)	2840 (1288)	2937 (1332)
W-rear	2274 (1031)	2155 (977)	2222 (1008)
W-total	5216 (2366)	4995 (2266)	5159 (2340)
		5000±110 (2270±50)	5165±110 (2343±50)

	in.	(mm)
Wheel Center Height (Front):	15	381
Wheel Center Height (Rear):	15	381
Wheel Well Clearance (Front):	34 7/8	885 33/40
Wheel Well Clearance (Rear):	37 15/16	963 49/80
Bottom Frame Height (Front):	18 1/2	469 9/10
Bottom Frame Height (Rear):	25 5/8	650 7/8

Engine Type: Gasoline
Engine Size: 5.7L V8
Transmission Type: Automatic
Drive Type: RWD
Cab Style: Crew Cab
Bed Length: 67"

GVWR Ratings - lb

Front	3700
Rear	3900
Total	6900

Surrogate Occupant Data

Type: Hybrid II
Mass: 164 lb
Seat Position: Passenger Side

Note any damage prior to test: The front right passenger side corner of the front bumper cover where the chrome part meets the plastic is bent inward slightly (abt a 1/4 inch)

Figure 28. Vehicle Dimensions, Test No. HNTBR-2

Figure 29. Test Vehicle, Test No. HNTBR-3

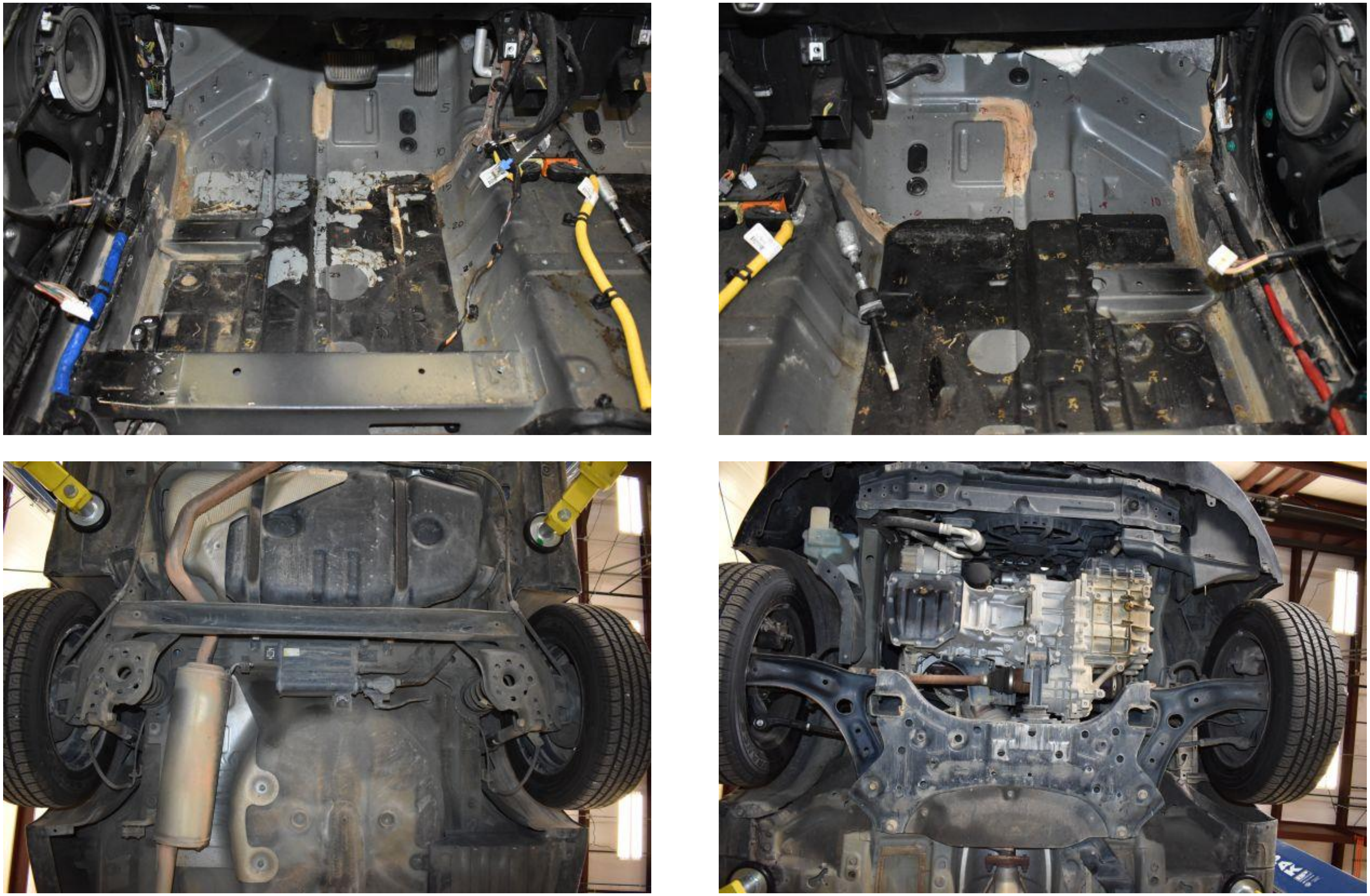
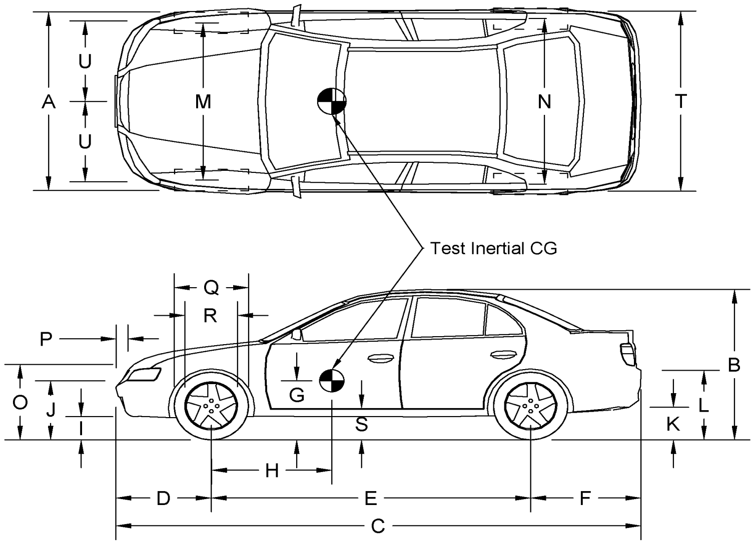


Figure 30. Vehicle’s Interior Floorboards and Undercarriage, Test No. HNTBR-3

Test Name: HNTBR-3 **VIN No:** 3KPA24AB8KE215156

Model Year: 2019 **Make:** Kia **Model:** Rio

Tire Size: 185/65r15 **Tire Inflation Pressure:** 33 psi **Odometer:** 145639



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

A: 67 1/4 (1708) 65±3 (1650±75)		B: 57 (1448)	
C: 172 5/8 (4385) 169±8 (4300±200)		D: 33 1/8 (841) 35±4 (900±100)	
E: 101 1/4 (2572) 98±5 (2500±125)		F: 38 1/4 (972)	
G: 22 3/8 (568)		H: 38 1/16 (967) 39±4 (990±100)	
I: 8 3/8 (213)		J: 28 1/8 (714)	
K: 1 1/2 (38)		L: 25 7/8 (657)	
M: 60 (1524) 59±2 (1498±50)		N: 59 15/16 (1522) 59±2 (1425±50)	
O: 31 3/4 (806) 28±4 (711±100)		P: 5 9/16 (141)	
Q: 23 1/2 (597)		R: 16 3/8 (416)	
S: 8 1/4 (210)		T: 67 1/2 (1715)	

U (impact width):	33 3/4 (857)
Top of radiator core support:	29 1/8 (740)
Wheel Center Height (Front):	11 5/8 (295)
Wheel Center Height (Rear):	11 3/4 (298)
Wheel Well Clearance (Front):	25 15/16 (659)
Wheel Well Clearance (Rear):	25 3/4 (654)
Bottom Frame Height (Front):	15 7/16 (392)
Bottom Frame Height (Rear):	15 7/8 (403)
Engine Type:	Gasoline
Engine Size:	1.6L 4 cyl
Transmission Type:	Automatic
Drive Type:	FWD

Mass Distribution - lb (kg)

Gross Static	LF	811 (368)	RF	764 (347)
	LR	502 (228)	RR	486 (220)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	1540 (699)	1498 (679)	1575 (714)
W-rear	943 (428)	902 (409)	988 (448)
W-total	2483 (1126)	2400 (1089) 2420±55 (1100±25)	2563 (1163) 2585±55 (1175±50)

GVWR Ratings lb

Front	1940
Rear	1852
Total	3616

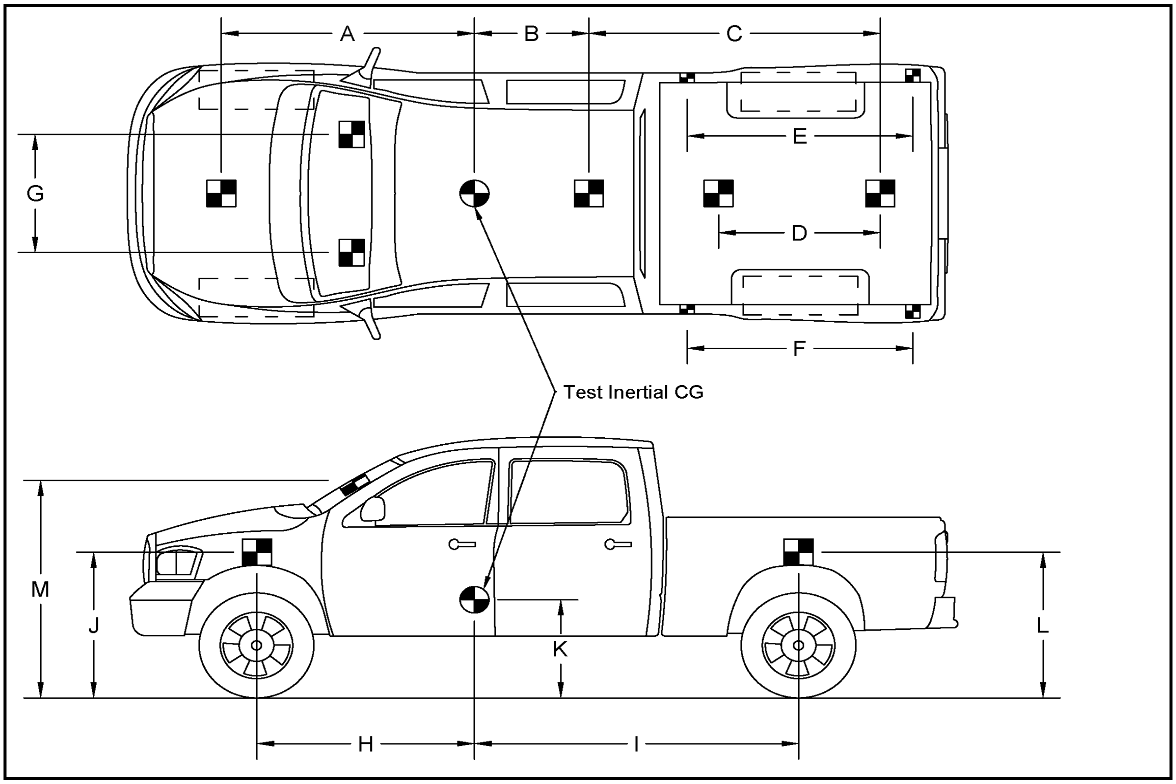
Surrogate Occupant Data

Type:	Hybrid II
Mass:	163 lb
Seat Position:	Front Left

Note any damage prior to test: cracked windshield, dents on right side rocker panel, small dent on left rear quarter panel, cracks on bumper flares, small dent on roof

Figure 31. Vehicle Dimensions, Test No. HNTBR-3

Test Name: HNTBR-2 **VIN:** 3C6RR6KT6JG137519
Model Year: 2018 **Make:** RAM **Model:** 1500

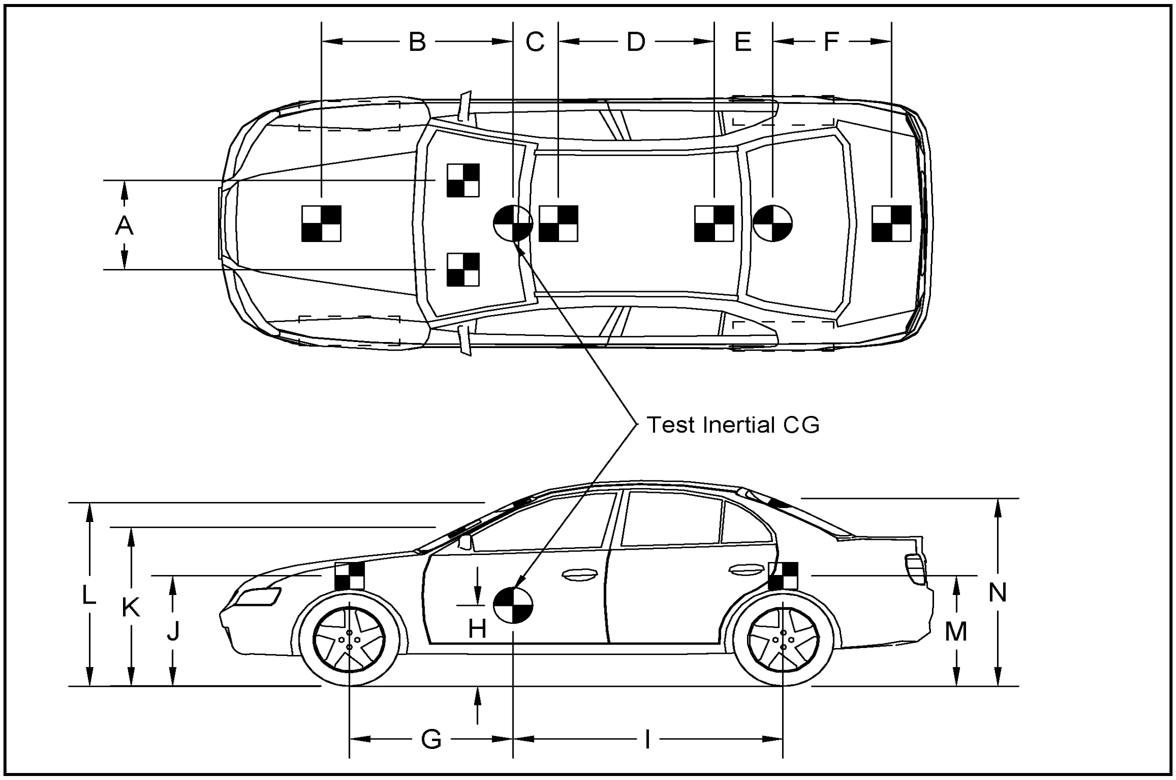


TARGET GEOMETRY-- in. (mm)

A: 81 1/8 (2061)	E: 54 5/8 (1387)	J: 38 7/8 (987)
B: 30 1/16 (764)	F: 54 5/8 (1387)	K: 28 7/16 (722)
C: 71 3/4 (1822)	G: 28 7/16 (722)	L: 42 (1067)
D: 31 3/4 (806)	H: 60 3/4 (1543)	M: 62 1/16 (1576)
	I: 79 15/16 (2030)	

Figure 32. Target Geometry, Test No. HNTBR-2

		Test Name:	**HNTBR-3**	**VIN:**	**3KPA24AB8KE215156**
Model Year:	**2019**	**Make:**	**Kia**	**Model:**	**Rio**



TARGET GEOMETRY-- in. (mm)

A:	**19 15/16 (506)**	**F:**	**32 3/8 (822)**	**K:**	**47 5/8 (1210)** Windshield Target
B:	**47 5/8 (1210)**	**G:**	**38 1/8 (968)**	**L:**	**53 9/16 (1360)** Front round CG target
C:	**9 1/4 (235)**	**H:**	**22 3/8 (568)**	**M:**	**29 5/8 (752)**
D:	**40 5/8 (1032)**	**I:**	**63 3/4 (1619)**	**N:**	**53 9/16 (1360)** Rear Round target
E:	**10 1/4 (260)**	**J:**	**29 7/8 (759)**		

Figure 33. Target Geometry, Test No. HNTBR-3

5.4 Simulated Occupant

For test nos. HNTBR-2 and HNTBR-3, a Hybrid II 50th-Percentile, Adult Male Dummy equipped with footwear with the seat belt fastened. The simulated occupant was positioned in right-front passenger seat for test no. HNTBR-2 and the left-front seat for test no. HNTBR-3. The simulated occupants had final weights of 164 lb and 163 lb for test nos. HNTBR-2 and HNTBR-3, respectively. As recommended by MASH, the simulated occupant weight was not included in calculating the c.g. location.

5.5 Data Acquisition Systems

5.5.1 Accelerometers and Rate Transducers

The accelerometer and rate transducer systems used in the full-scale crash testing were the SLICE-1 and SLICE-2 units described below. Units were positioned near the c.g. of the test vehicles. The SLICE-2 unit was designated as the primary transducer for test no. HNTBR-2 and the SLICE-1 unit was designated as the primary transducer for test no. HNTBR-3 based on proximity to the c.g. of the test vehicles. Data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAEJ211/1 specifications [10].

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

5.5.2 Retroreflective Optic Speed Trap

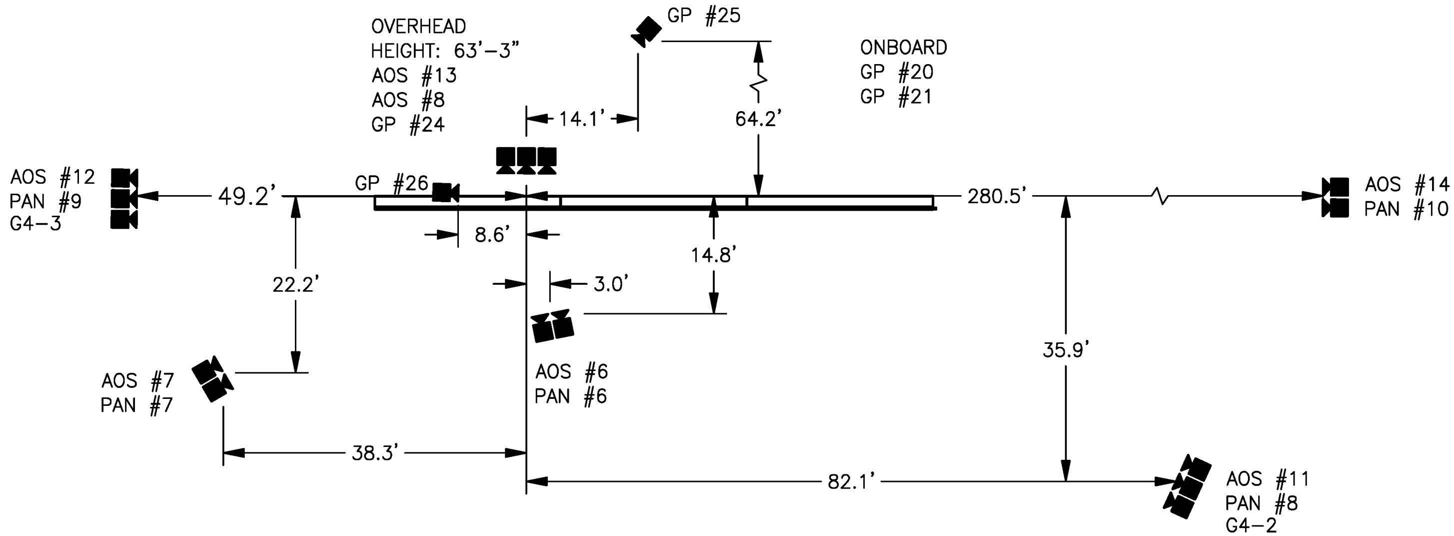
A retroreflective optic speed trap was used to determine the speed of the test vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. intervals, were applied to the side of the vehicles. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver,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

5.5.3 Digital Photography

Seven AOS high-speed digital video cameras, five GoPro digital video cameras, five Panasonic digital video cameras, and one Ubiquiti G4 Plus camera were utilized to film test no.

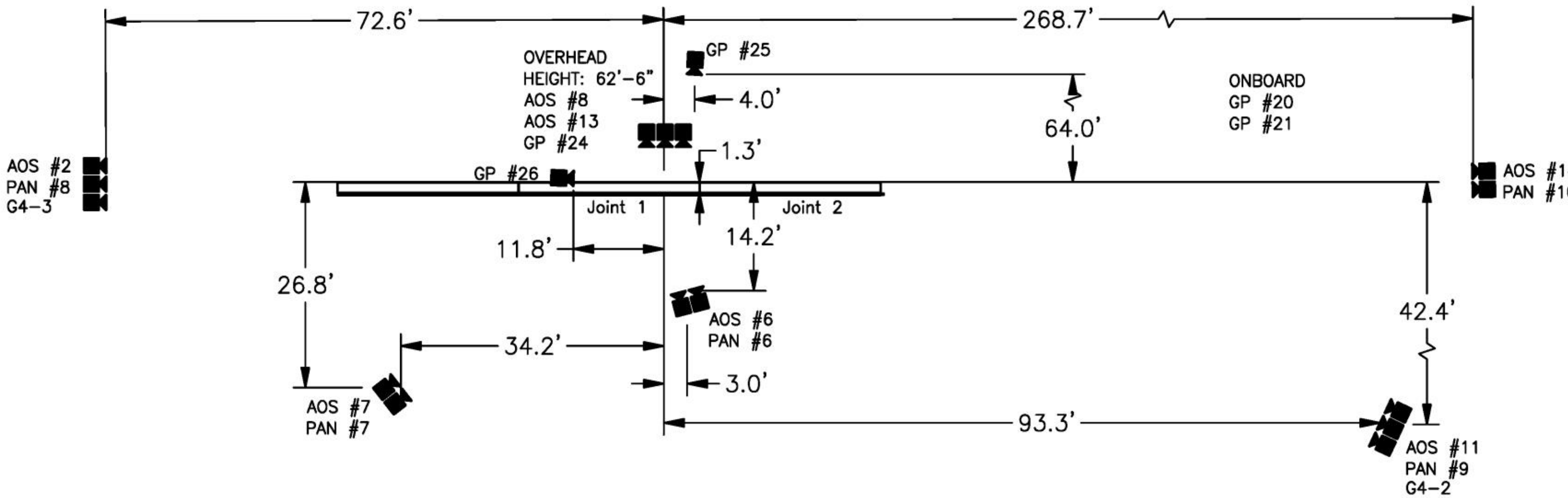
HNTBR-2. Seven AOS high-speed digital video cameras, five GoPro digital video cameras, five Panasonic digital video cameras, and two Ubiquiti G4 Plus cameras were utilized to film test no. HNTBR-3. Camera details, camera operating speeds, lens information, and schematics of the camera locations relative to the system are shown in Figures 34 and 35.

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



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-6	AOS X-PRI	500	KOWA 16mm Fixed	-
AOS-7	AOS X-PRI	500	Sigma 28-70	28
AOS-8	AOS S-VIT 1531	500	Fujinon 50mm Fixed	-
AOS-11	AOS J-PRI	500	Sigma 24-135	35
AOS-12	AOS J-PRI	500	Sigma 17-50	35
AOS-13	AOS J-PRI	500	Canon EF 14mm Fixed	-
AOS-14	AOS J-PRI	500	Canon EF 24-70	70
GP-20	GoPro Hero 6	240		
GP-21	GoPro Hero 6	240		
GP-24	GoPro Hero 7	240		
GP-25	GoPro Hero 10	240		
GP-26	GoPro Hero 10	240		
PAN-6	Panasonic HC-VX981	120		
PAN-7	Panasonic HC-VX981	120		
PAN-8	Panasonic HC-VX981	120		
PAN-9	Panasonic HC-VX981	120		
PAN-10	Panasonic HC-VX981	120		
G4-2	Ubiquiti G4 Plus	20		
G4-3	Ubiquiti G4 Plus	20		

Figure 34. Camera Locations, Speeds, and Lens Settings, Test No. HNTBR-2



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-6	AOS X-PRI	500	KOWA 16mm Fixed	-
AOS-7	AOS X-PRI	500	Sigma 28-70	28
AOS-8	AOS S-VIT 1531	500	KOWA 12mm Fixed	-
AOS-11	AOS J-PRI	500	Sigma 24-135	70
AOS-12	AOS J-PRI	500	Sigma 17-50	50
AOS-13	AOS J-PRI	500	Canon EF 14mm Fixed	-
AOS-14	AOS J-PRI	500	Canon EF 24-70	70
GP-20	GoPro Hero 6	240		
GP-21	GoPro Hero 6	240		
GP-24	GoPro Hero 7	240		
GP-25	GoPro Hero 10	240		
GP-26	GoPro Hero 10	240		
PAN-5	Panasonic HC-VX981	120		
PAN-6	Panasonic HC-VX981	120		
PAN-7	Panasonic HC-VX981	120		
PAN-8	Panasonic HC-VX981	120		
PAN-10	Panasonic HC-VX981	120		
G4-2	Ubiquiti G4 Plus	20		
G4-3	Ubiquiti G4 Plus	20		

Figure 35. Camera Locations, Speeds, and Lens Settings, Test No. HNTBR-3

6 FULL-SCALE CRASH TEST NO. HNTBR-2

6.1 Weather Conditions

Test no. HNTBR-2 was conducted on August 14, 2024, at approximately 2:15 p.m. The weather conditions as reported by the National Oceanic and Atmospheric Administration (station 14939/KLNK) are shown in Table 3.

Table 3. Weather Conditions, Test No. HNTBR-2

Temperature	87°F
Humidity	61%
Wind Speed	18 mph
Wind Direction	160° from True North
Sky Conditions	Partly Cloudy
Visibility	8.00
Pavement Surface	Dry
Previous 3-Day Precipitation	0.55 in.
Previous 7-Day Precipitation	0.76 in.

6.2 Test Description

Initial vehicle impact was to occur 51½ in. upstream from the centerline of expansion joint no. 1, as shown in Figure 36, which was selected using the CIP plots found in Section 2.3 of MASH to maximize loading to the bridge rail adjacent to the expansion joint. The 4,995-lb crew cab pickup truck impacted the concrete bridge rail at a speed of 62.7 mph and an angle of 25.2 degrees. The actual point of impact was 8 in. upstream from the targeted CIP. The vehicle was contained and redirected and remained stable throughout the impact event. After exiting the bridge rail, the brakes were applied remotely, and the vehicle came to rest 273.1 ft downstream from impact after impacting a row of concrete containment barriers.

A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 37 and 38. Documentary photographs of the crash test are shown in Figure 39. The vehicle trajectory and final position are shown in Figure 40.

Figure 36. Target Impact Location, Test No. HNTBR-2

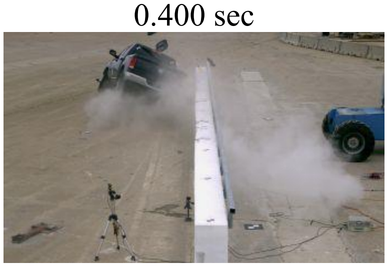
Table 4. Sequential Description of Impact Events, Test No. HNTBR-2

Time (sec)	Event
0.000	Vehicle's front bumper and right headlight contacted concrete bridge rail between post nos. 3 and 4. Concreted spalled.
0.006	Vehicle's right fender and right-front tire contacted concrete bridge segment, fender was scraped and crushed.
0.020	Vehicle's grille contacted concrete bridge rail and disengaged. Vehicle's right-front tire deflated.
0.032	Vehicle rolled toward system. Vehicle's right-front tire snagged on concrete bridge rail and disengaged. Vehicle yawed away from system.
0.040	Vehicle's right-front door contacted concrete bridge rail and deformed.
0.068	Vehicle pitched upward.
0.088	Vehicle's right-front window glass deformed and disengaged from the vehicle.
0.100	Vehicle's left-front tire was airborne.
0.188	Vehicle's right quarter panel contacted concrete bridge rail.
0.198	Vehicle was parallel to system with a speed of 50.3 mph. Vehicle's rear bumper contacted concrete bridge rail.
0.392	Vehicle's left-rear tire was airborne.
0.456	Vehicle exited the system at a speed of 47.4 mph and an angle of -5.1 degrees.
0.470	Vehicle's front bumper contacted ground.
0.540	Vehicle rolled away from system.
0.550	Vehicle pitched downward.
0.848	Vehicle's left-front tire contacted ground.
1.058	Vehicle's left-rear tire contacted ground.
5.508	Vehicle contacted secondary containment barriers and came to rest.

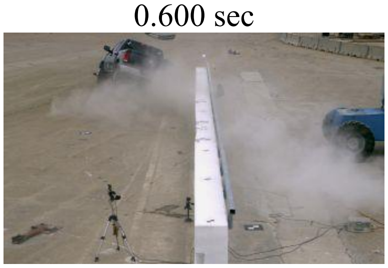
0.000 sec

0.200 sec

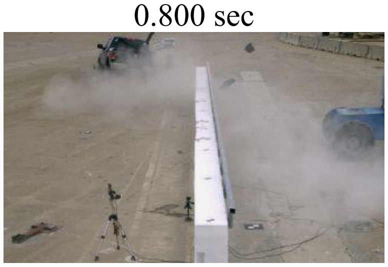
0.400 sec



0.600 sec



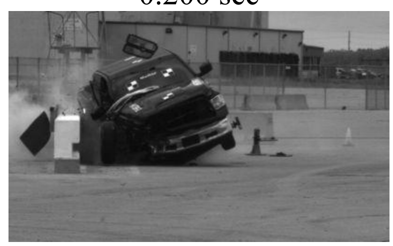
0.800 sec



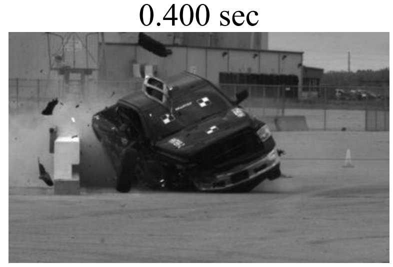
1.000 sec

0.000 sec

0.200 sec



0.400 sec



0.600 sec

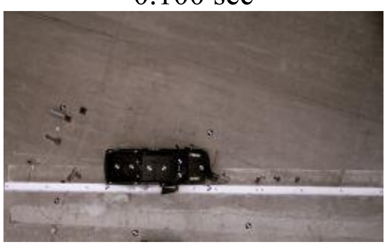
0.800 sec

1.000 sec

Figure 37. Sequential Photographs, Test No. HNTBR-2


0.000 sec


0.100 sec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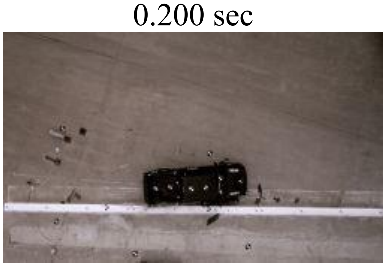
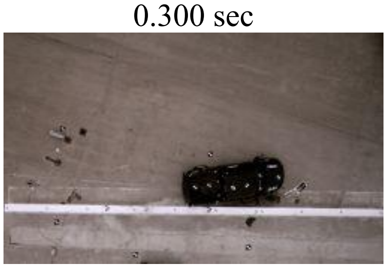

0.300 sec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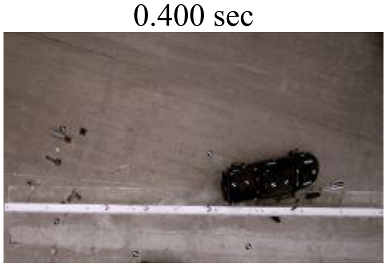
0.500 sec


0.000 sec


0.100 sec


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0.300 sec


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Figure 38. Sequential Photographs, Test No. HNTBR-2

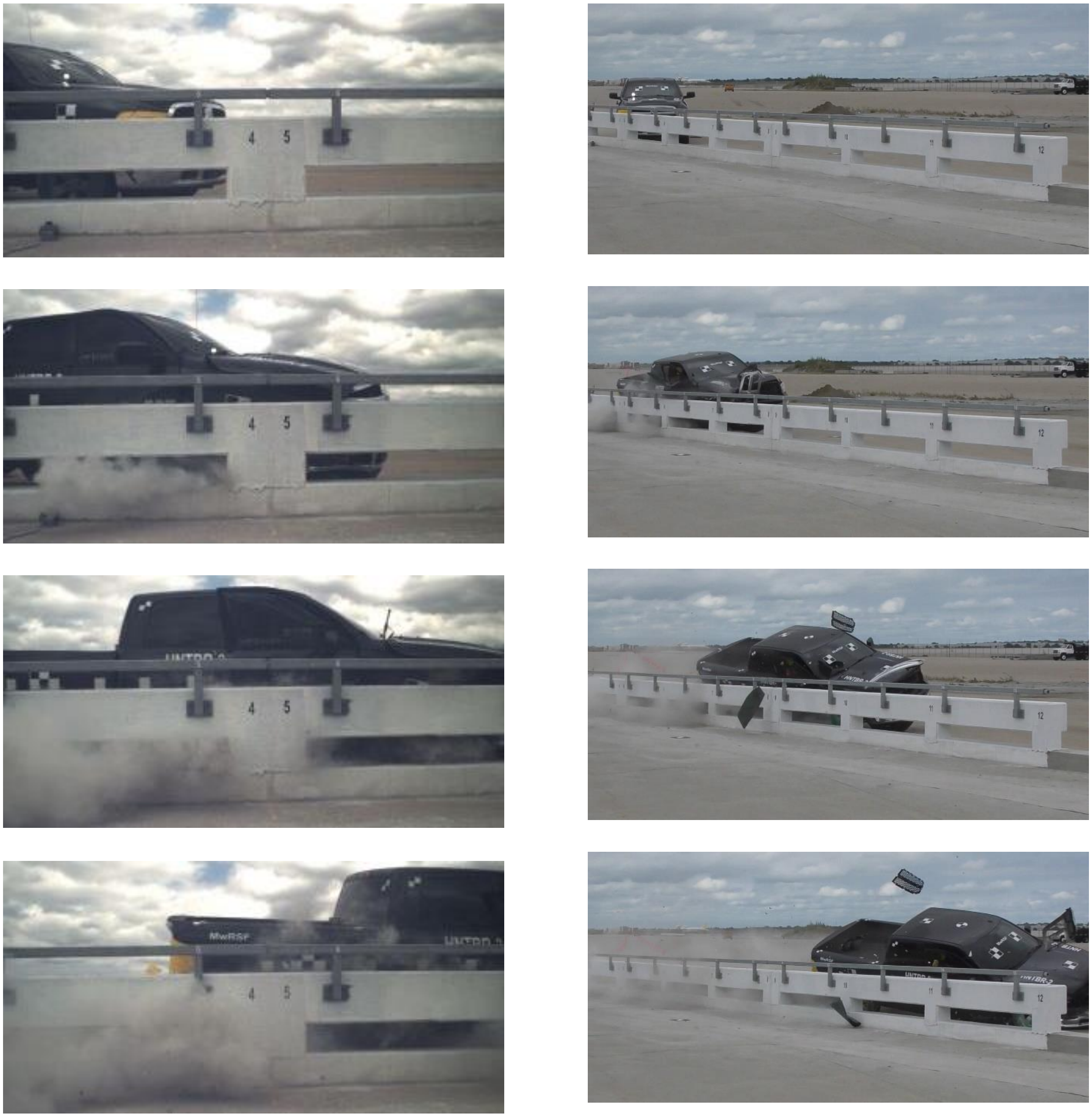


Figure 39. Documentary Photographs, Test No. HNTBR-2

Figure 40. Vehicle Final Position and Trajectory Marks, Test No. HNTBR-2

6.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 41 through 43. Barrier damage consisted of concrete spalling, gouging, and contact marks on the front face of the concrete segments. The length of vehicle contact along the concrete rail was 12 ft – 7¼ in., beginning approximately 44 in. downstream from post no. 3. Contact marks were observed on the face of the barrier throughout the contact region. A 41-in. long and 1½-in. wide gouge was observed on the lower edge of the upper rail beginning 23 in. upstream from the centerline of post no. 4. Several other smaller gouges were located on the front faces of the top rail within the contact region. Concrete spalling was also observed on the edge of the curb adjacent to the expansion joint. The pedestrian handrail was undamaged as it was only contacted by disengaged vehicle components.

The maximum lateral permanent set of the barrier system was 0.4 in. located on the downstream side of expansion joint no. 1, as measured in the field. The maximum lateral dynamic barrier deflection was 1.7 in. located on the downstream side of expansion joint no. 1, as determined from high-speed digital video analysis. The working width of the system was found to be 22.2 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 44.

Figure 41. System Damage, Test No. HNTBR-2

Figure 42. Curb and Concrete Rail Damage, Test No. HNTBR-2

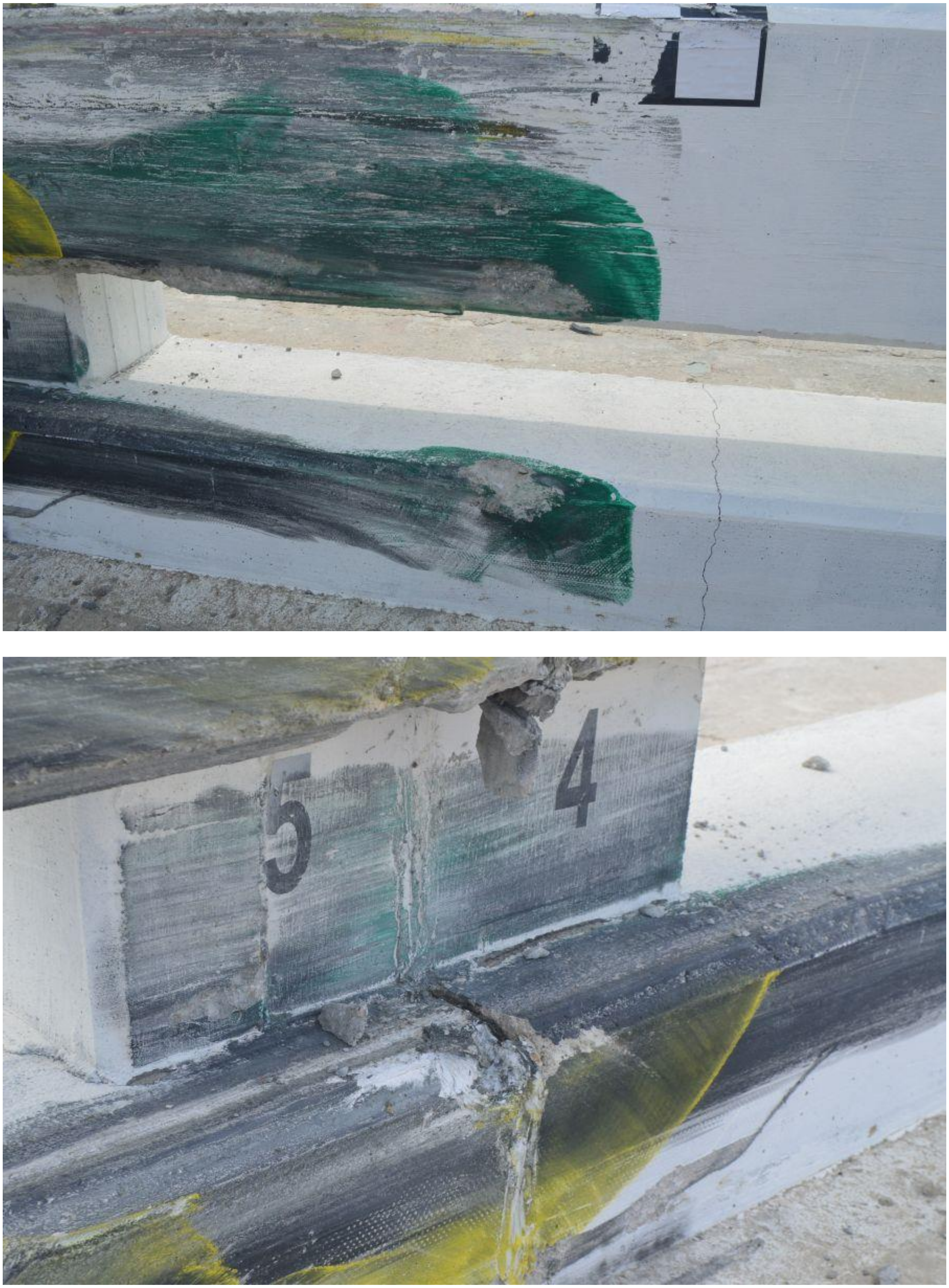


Figure 43. Curb and Concrete Rail Damage, Test No. HNTBR-2

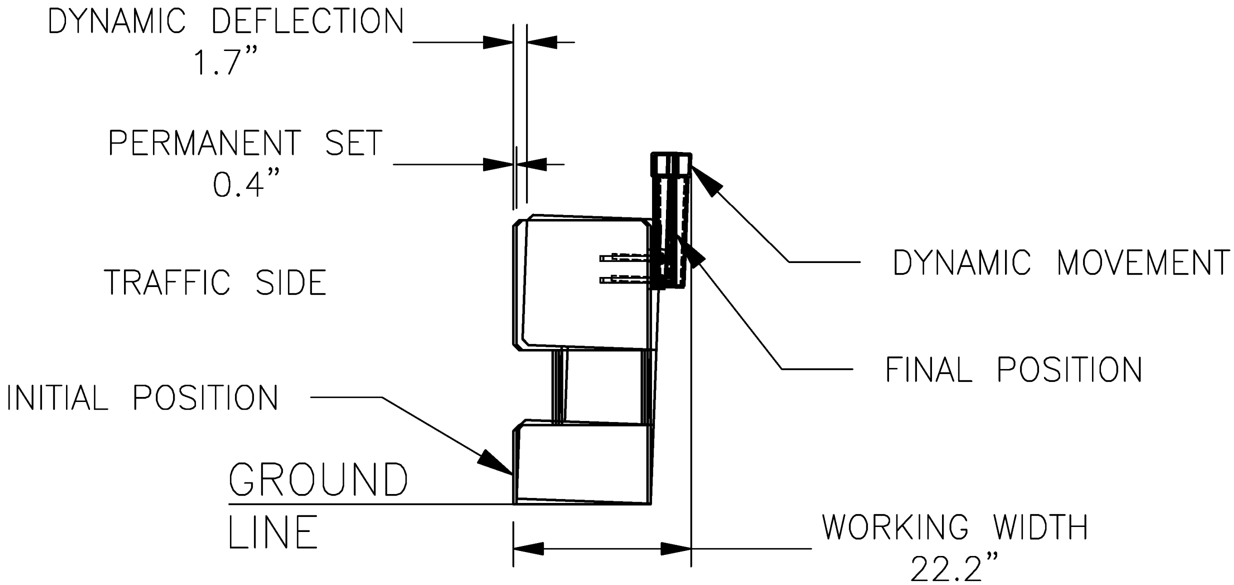


Figure 44. Permanent Set, Dynamic Deflection, and Working Width, Test No. HNTBR-2

6.4 Vehicle Damage

The damage to the vehicle was severe, as shown in Figures 45 through 49. Note that there was a secondary impact with a row of containment barriers downstream from the test article which contributed to the damage on the front of the vehicle. Vehicle damage prior to the secondary impact is shown in Figure 45. The impact side of the vehicle, or the passenger's side, is referred to as the vehicle's right side throughout this report. The non-impact side, or driver's side, is referred to as the vehicle's left side. The majority of the damage was concentrated on the right-front corner and right side of the vehicle where the impact occurred. The right side of the front bumper was bent rearward and scraped. The right-front headlight and grille were disengaged from the vehicle. Scrapes and dents were observed throughout the right-side of the vehicle including the fender, doors, rear quarter panel, and rear bumper. Cracks were observed on the right side of the windshield, and the right-front side window was disengaged from the vehicle due to a combination of door flexure and contact with the dummy. Note, neither the side window nor the dummy contacted the bridge railing.

On the undercarriage, the right-front side spring was disengaged and the right-front shocks were bent rearward. The left-side end link was bent rearward, and the left steering knuckle was disengaged. The right lower control arm disengaged from the vehicle, and the right upper control arm was bent backward. The right tie rod disengaged and the steering rack case was fractured. The right end of the front engine cross member was scraped and twisted slightly, and the rear cross member was bent and slightly scraped. The right frame horn was bent and twisted inward, and the left frame horn was bent outward. The right-front wheel detached from the vehicle and the right rear wheel was scraped.

The maximum occupant compartment intrusions are listed in Table 5, along with the intrusion limits established in MASH for various areas of the occupant compartment. The maximum intrusion was 4.4 in. to the side front panel, which was within the 12 in. MASH limit.

Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D. MASH defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There was no penetration into the occupant compartment, and no established MASH deformation limits were violated. Outward deformations, which are denoted as negative numbers in Appendix D, are not considered crush toward the occupant, and are not evaluated by MASH criteria.

Figure 45. Vehicle Damage before Secondary Impact, Test No. HNTBR-2

Figure 46. Vehicle Damage, Test No. HNTBR-2

Figure 47. Vehicle Damage, Test No. HNTBR-2

Figure 48. Vehicle’s Floor Pan and Interior Compartment Damage, Test No. HNTBR-2

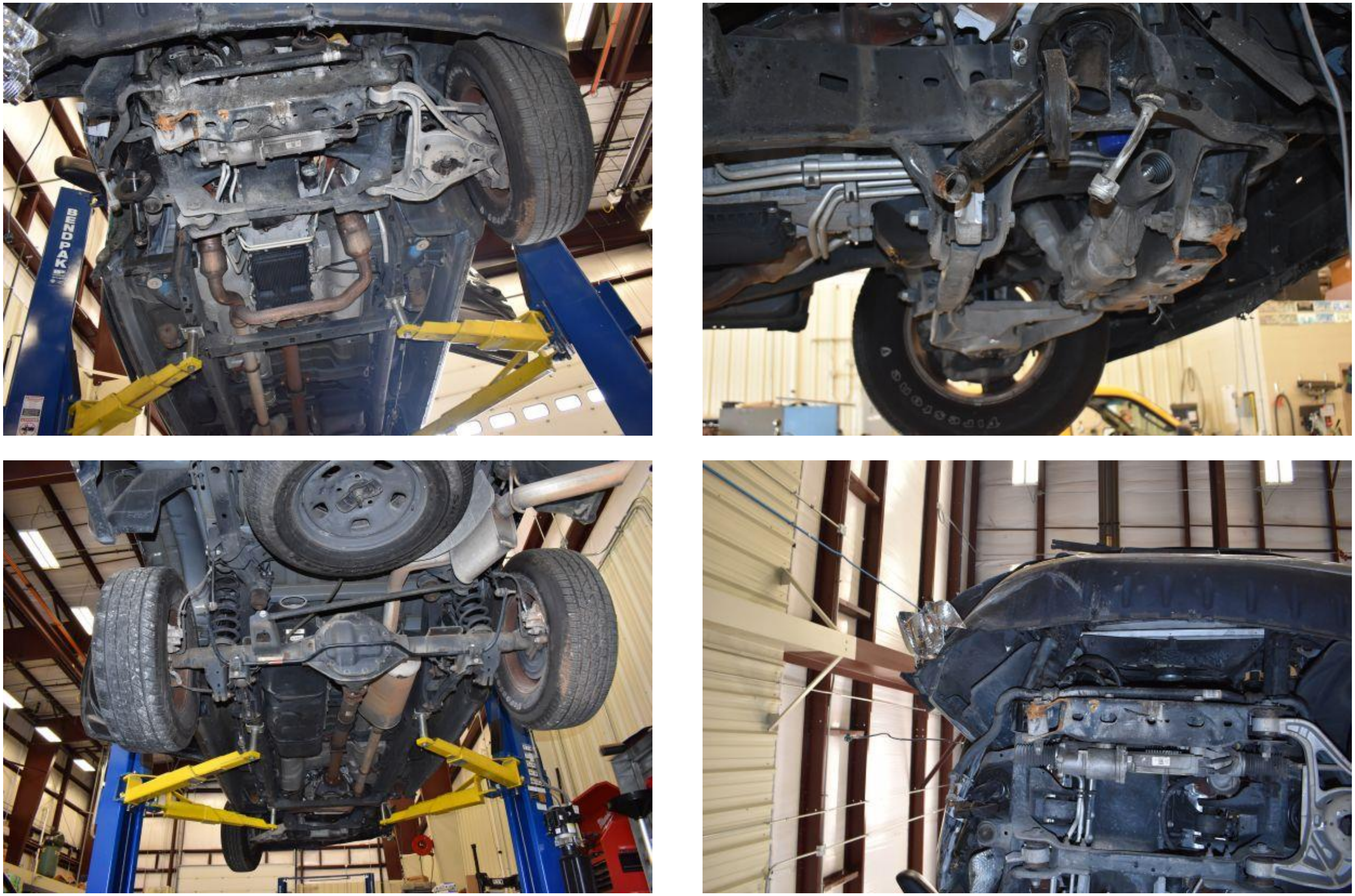


Figure 49. Vehicle’s Undercarriage Damage, Test No. HNTBR-2

Table 5. Maximum Occupant Compartment Intrusion by Location, Test No. HNTBR-2

Location	Maximum Intrusion in.	MASH Allowable Intrusion in.
Wheel Well & Toe Pan	3.1	≤ 9
Floor Pan & Transmission Tunnel	0.2	≤ 12
A-Pillar	0.0	≤ 5
A-Pillar (Lateral)	0.0*	≤ 3
B-Pillar	0.1	≤ 5
B-Pillar (Lateral)	0.0*	≤ 3
Side Front Panel (in Front of A-Pillar)	4.4	≤ 12
Side Door (Above Seat)	0.0*	≤ 9
Side Door (Below Seat)	0.5	≤ 12
Roof	0.0*	≤ 4
Windshield	0.0	≤ 3
Side Window	Disengaged	No shattering resulting from contact with structural member of test article
Dash	1.7	N/A

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

6.5 Occupant Risk

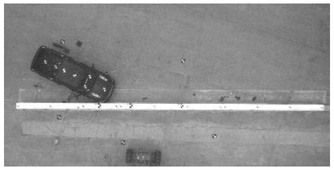
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 6. Note that the OIVs and ORAs were within suggested limits, as provided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

Table 6. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. HNTBR-2

Evaluation Criteria		Transducer		MASH Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s	Longitudinal	-21.48	-22.31	±40
	Lateral	-24.70	-27.58	±40
ORA g's	Longitudinal	6.01	5.89	±20.49
	Lateral	-13.61	-10.29	±20.49
Maximum Angular Displacement deg.	Roll	26.6	22.1	±75
	Pitch	-5.8	-8.3	±75
	Yaw	-40.8	-41.0	not required
THIV – ft/s		32.36	35.03	not required
PHD – g's		14.33	11.43	not required
ASI		1.69	1.83	not required

6.6 Discussion

The analysis of the test results for test no. HNTBR-2 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. 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 as they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 5.1 degrees, and its trajectory did not violate the bounds of the exit box. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. Therefore, test no. HNTBR-2 was determined to be acceptable according to the safety performance criteria for MASH test designation no. 3-11. A summary of the test results and sequential photographs are shown in Figure 50.



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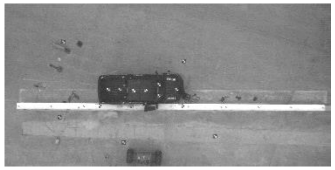

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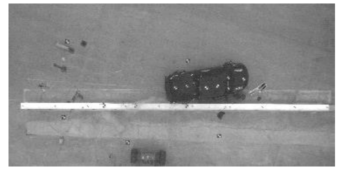

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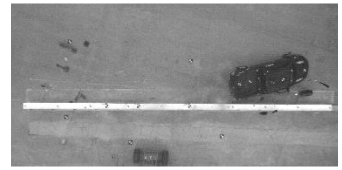

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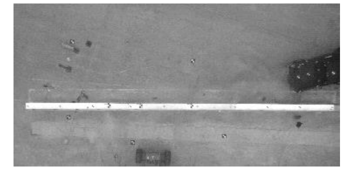

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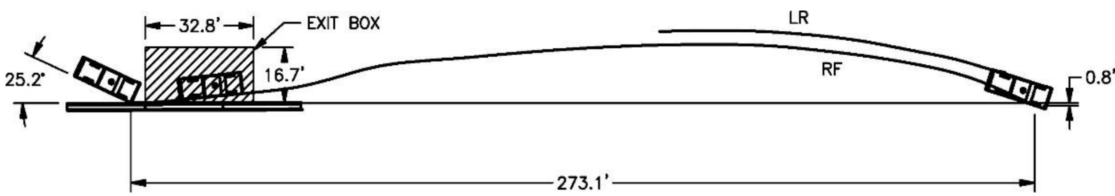

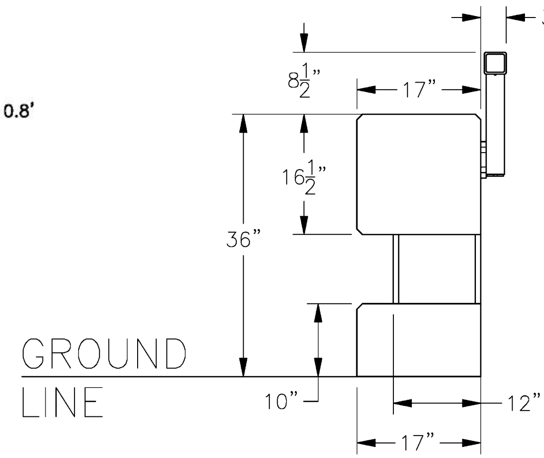

- Test Agency .... MwRSF
- Test Number HNTBR-2
- Date 8/14/2024
- MASH Test No. 3-11
- Test Article .... Hawaii Concrete Post and Beam Bridge Rail
- Total Length .... 70 ft – 7 in.
- Key Component - Rail
  - Length .... 23½ ft
  - Width .... 16½ in.
  - Depth .... 17 in.
- Key Component - Post
  - Length .... 9½ in.
  - Width .... 12 in.
  - Spacing .... 90 in.
- Vehicle Make /Model .... 2018 Dodge Ram 1500 Crew Cab
  - Curb .... 5,216 lb
  - Test Inertial .... 4,995 lb (MASH Limit 5,000 ± 110 lb)
  - Gross Static .... 5,159 lb (MASH Limit 5,165 ± 110 lb
- Impact Conditions
  - Speed .... 62.7 mph (MASH Limit 62 ± 2.5 mph)
  - Angle .... 25.2 deg. (MASH Limit 25 ± 1.5 deg.)
  - Impact Location .... 59½ in. upstream from the centerline of expansion joint no. 1
- Impact Severity .... 119.0 kip-ft > 106 kip-ft MASH limit
- Exit Conditions
  - Speed .... 47.4 mph
  - Angle .... -5.1 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Pass
- Vehicle Stopping Distance .... 273 ft downstream
- Vehicle Damage .... Severe
  - VDS [11] 01-RFQ-6
  - CDC [12] 01-RFEW-3
  - Maximum Interior Deformation ..... 4.4 in. at Side Front Panel ≤ 12-in. MASH limit
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... 0.4 in.
  - Dynamic .... 1.7 in.
  - Working Width .... 22.2 in.
- Transducer Data

Evaluation Criteria		Transducer		MASH Limits
		TADAS	SLICE-2 (primary)	
OIV ft/s	Longitudinal	-21.48	-22.31	±40
	Lateral	-24.70	-27.58	±40
ORA g's	Longitudinal	6.01	5.89	±20.49
	Lateral	-13.61	-10.29	±20.49
Maximum Angular Displacement deg.	Roll	26.6	22.1	±75
	Pitch	-5.8	-8.3	±75
	Yaw	-40.8	-41.0	not required
THIV – ft/s		32.36	35.03	not required
PHD – g's		14.33	11.43	not required
ASI		1.69	1.83	not required

Figure 50. Summary of Test Results and Sequential Photographs, Test No. HNTBR-2

7 FULL-SCALE CRASH TEST NO. HNTBR-3

7.1 Weather Conditions

Test no. HNTBR-3 was conducted on August 21, 2024, at approximately 2:00 p.m. The weather conditions as reported by the National Oceanic and Atmospheric Administration (station 14939/KLNK) are shown in Table 7.

Table 7. Weather Conditions, Test No. HNTBR-3

Temperature	83°F
Humidity	53%
Wind Speed	15 mph
Wind Direction	120 ° from True North
Sky Conditions	Partly Cloudy
Visibility	6.00
Pavement Surface	Dry
Previous 3-Day Precipitation	0.27 in.
Previous 7-Day Precipitation	0.68 in.

7.2 Test Description

Initial vehicle impact was to occur 43¼ in. upstream from a post, which was selected using MASH Table 2-7 to maximize the potential for vehicle snag. Post no. 8, which was just upstream from expansion joint no. 2, was selected as the targeted snag post to simultaneously apply impact loads near a joint. Thus, the targeted impact point was also 55½ in. upstream from the centerline of expansion joint no. 2, as shown in Figure 51. The 2,400-lb Kia Rio impacted the concrete bridge rail at a speed of 63.6 mph and at an angle of 24.9 degrees. The actual point of impact was 4.8 in. downstream of the targeted impact location. The vehicle was contained and redirected and remained stable throughout the impact event. After exiting the bridge rail, the brakes were applied remotely, and the vehicle came to rest 254 ft downstream from impact after impacting a row of concrete containment barriers.

A detailed description of the sequential impact events is contained in Table 8. Sequential photographs are shown in Figures 52 and 53. Documentary photographs of the crash test are shown in Figure 54. The vehicle trajectory and final position are shown in Figure 55.

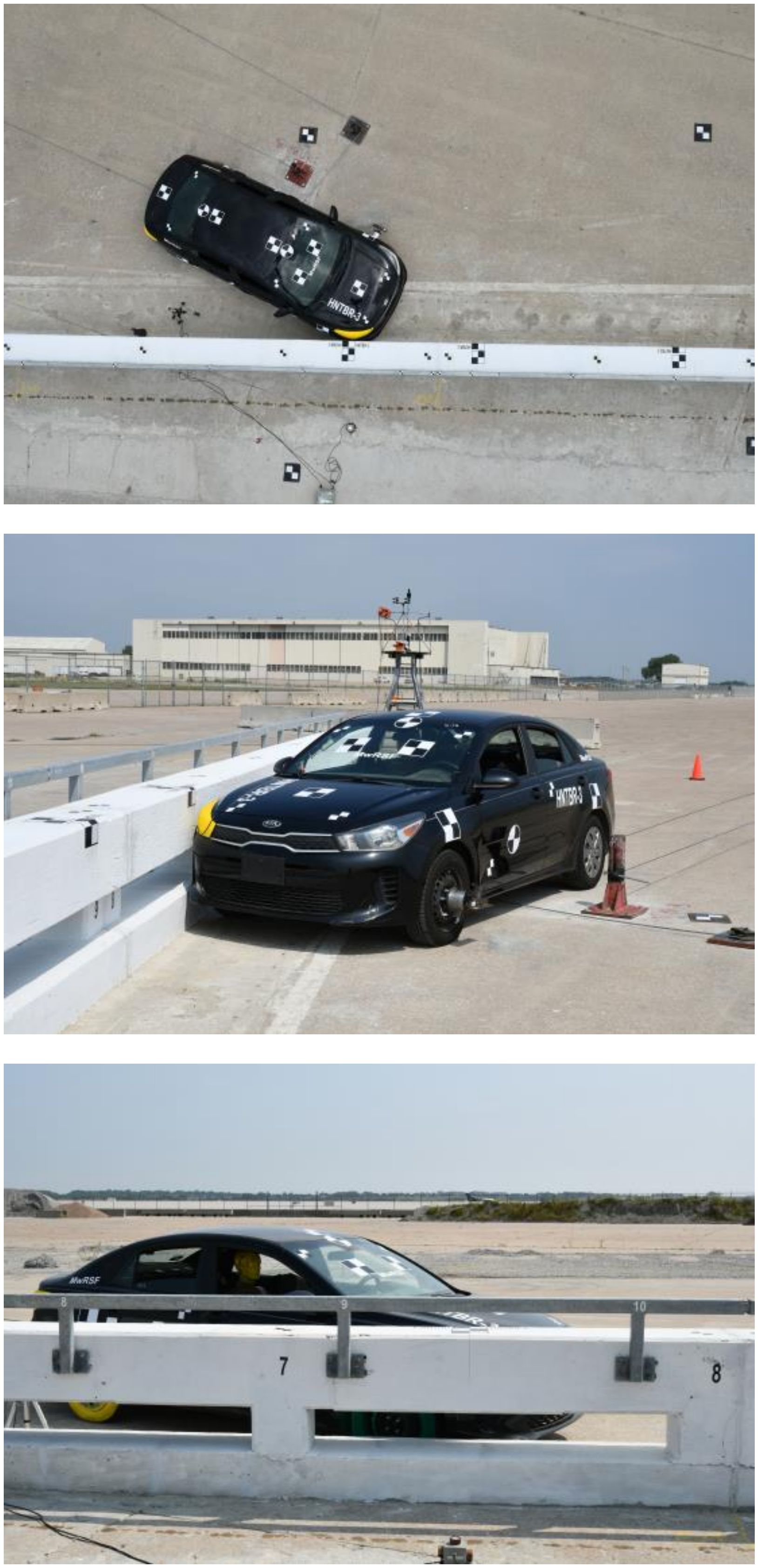

Figure 51. Target Impact Location, Test No. HNTBR-3

Table 8. Sequential Description of Impact Events, Test No. HNTBR-3

Time (sec)	Event
0.000	Vehicle's front bumper contacted concrete bridge rail between post nos. 7 and 8. Bumper cover detached and bumper crushed rearward.
0.006	Vehicle's right headlight, right-front tire, and right fender contacted concrete bridge rail Headlight shattered, fender was scraped, dented, and buckled.
0.016	Vehicle yawed away from system. Vehicle's hood contacted concrete bridge rail and crushed rearward.
0.030	Vehicle pitched downward. Vehicle's windshield cracked.
0.038	Vehicle's right-front door contacted concrete bridge rail and dented. Vehicle's right-front tire deflated.
0.050	Vehicle rolled toward system.
0.082	Simulated occupant's head contacted right-front window, which shattered.
0.120	Vehicle's left-rear tire became airborne.
0.166	Vehicle's right-rear door contacted concrete bridge rail. Vehicle became parallel to system with a speed of 49.1 mph.
0.194	Vehicle's rear bumper contacted concrete bridge rail.
0.256	Vehicle pitched upward.
0.294	Vehicle exited system at a speed of 47.5 mph and an angle of -4.7 degrees.
0.340	Vehicle rolled away from system.
0.479	Vehicle's left-rear tire contacted ground.
4.692	Vehicle impacted secondary containment barriers and came to rest.


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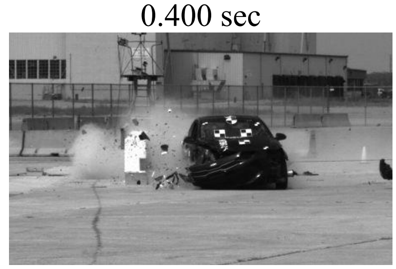
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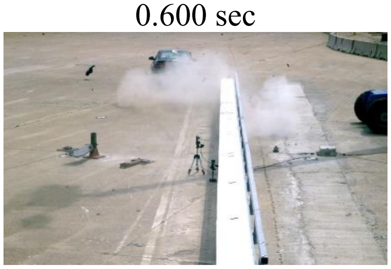
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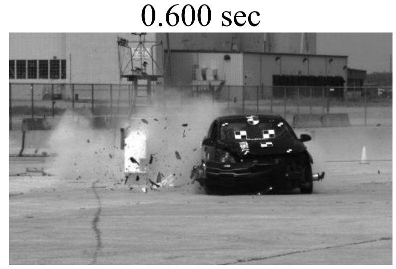
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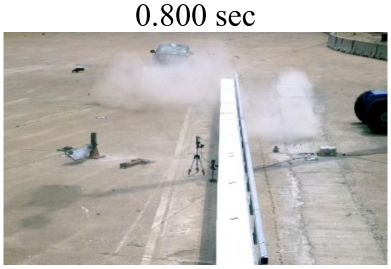
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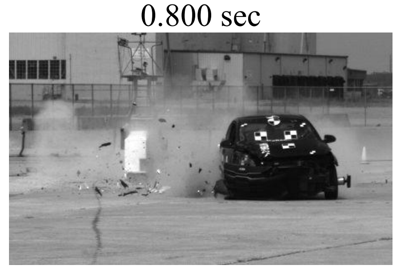
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Figure 52. Sequential Photographs, Test No. HNTBR-3


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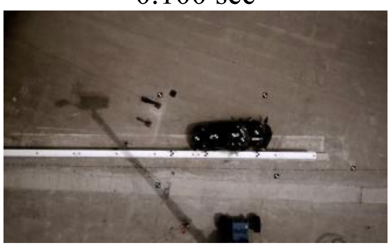
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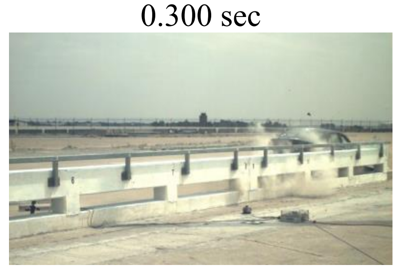
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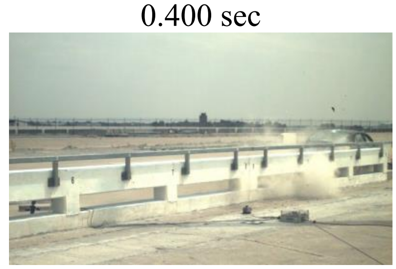
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Figure 53. Sequential Photographs, Test No. HNTBR-3

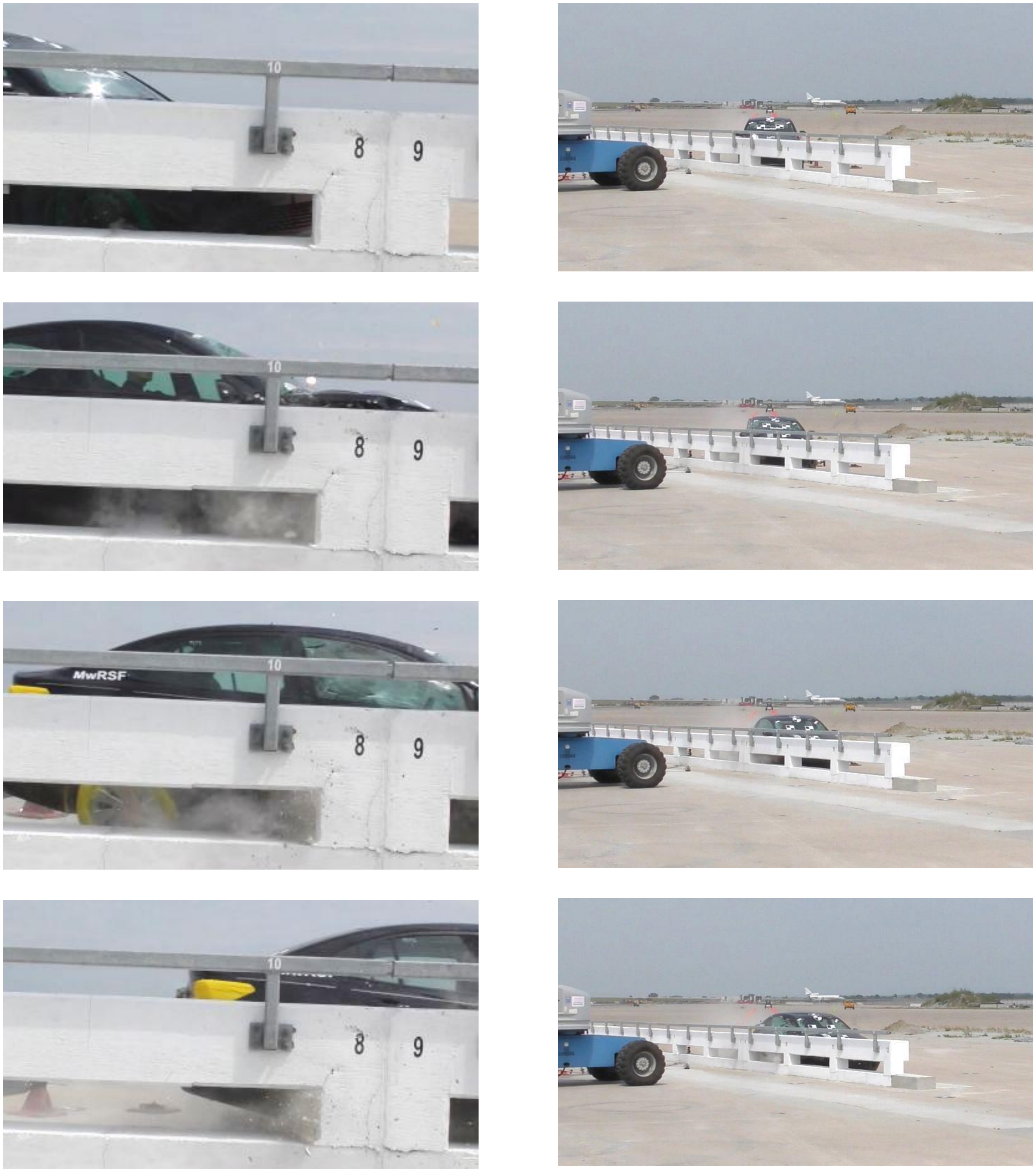


Figure 54. Documentary Photographs, Test No. HNTBR-3

Figure 55. Vehicle Final Position and Trajectory Marks, Test No. HNTBR-3

7.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 56 through 58. The length of vehicle contact along the concrete rail was 10 ft, beginning 51 in. upstream from expansion joint no. 2. Barrier damage consisted of concrete spalling and contact marks on the upper rail and lower curb of the concrete bridge rail. Concrete spalling on the top edge of the curb began near impact and continued downstream for 50 in. (to the expansion joint.). Various contact marks, minor gouges, and hairline cracks were found on the front face of both the upper rail and the lower curb throughout the contact region. Contact marks were also observed on the face of post nos. 8 and 9, which were adjacent to the expansion joint.

The maximum lateral permanent set of the barrier system was 1.1 in. at the upstream end of the third bridge rail segment, as measured in the field. The maximum lateral dynamic barrier deflection was 1.1 in. at the upstream end of the third bridge rail segment, as determined from high-speed digital video analysis. The working width of the system was found to be 21.6 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 59.

Figure 56. System Damage, Test No. HNTBR-3

Figure 57. Curb and Concrete Rail Damage, Test No. HNTBR-3

Figure 58. Curb and Concrete Rail Damage, Test No. HNTBR-3

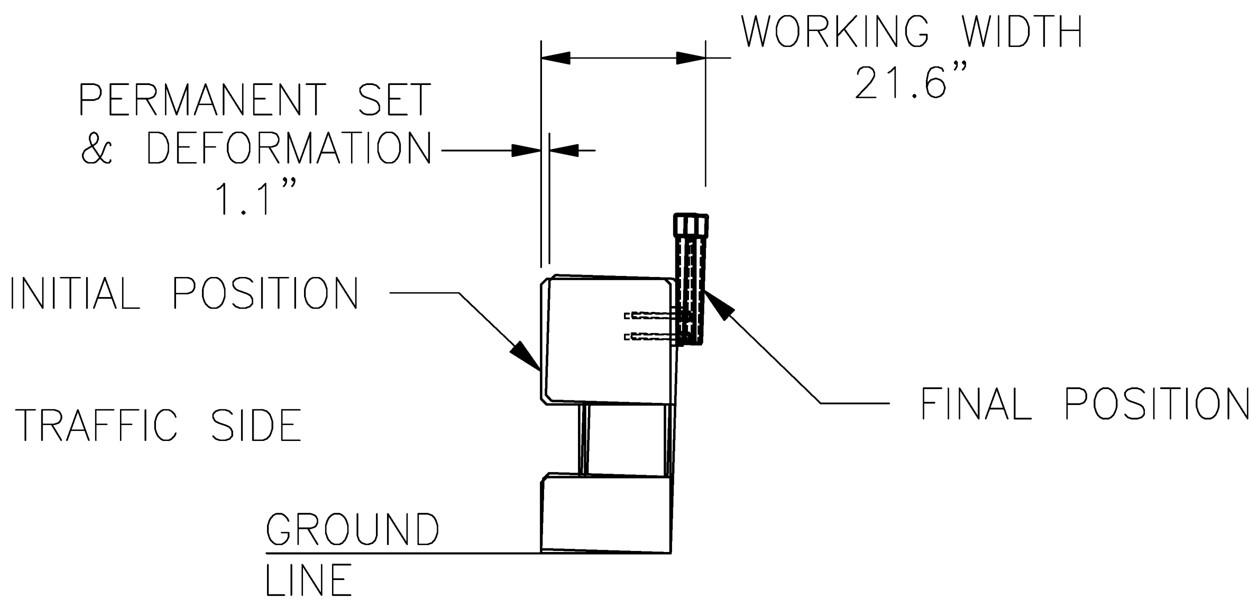


Figure 59. Permanent Set, Dynamic Deflection, and Working Width, Test No. HNTBR-3

7.4 Vehicle Damage

The damage to the vehicle was severe, as shown in Figures 60 through 63. Note that there was a secondary impact with a row of containment barriers downstream from the test article. Vehicle damage prior to the secondary impact is shown Figure 60. The impact side of the vehicle, or the passenger's side, is referred to as the vehicle's right side throughout this report. The non-impact side, or driver's side, is referred to as the vehicle's left side. The majority of the damage was concentrated on the right-front corner and right side of the vehicle where the impact had occurred. The front bumper cover detached, and the front bumper was pushed back into the radiator. Both front headlights were disengaged from the vehicle, and the hood was deformed. The front fender was dented and crushed. The base of the A-pillar was deformed and crushed inward. The right-front door's leading edge was dented and scraped, and the right-front window was detached from the vehicle. The right-rear door was dented along its length, and the right quarter panel was dented inward. The entire right side of the vehicle was scraped from the front fender to the rear bumper. The front half of the roof was kinked and buckled.

The windshield shattered and tore, with a maximum deformation of 4.2 in. However, this damage was caused by loading and deformations at the base of the A-pillar rather than direct contact between the bridge rail and windshield. Furthermore, a secondary impact with a row of containment barriers downstream of the test article contributed to additional damage and deformations to the windshield. Thus, the windshield damage was not in violation of MASH safety criteria. Note, similar 1100C windshield and front window damage has been observed in previous evaluations of MASH-crashworthy concrete barriers [13, 14].

On the undercarriage, the sway bar right end link bar was bent, the right-side lower control arm was twisted, and the right inner tie rod was bent rearward. The front plastic transmission cover was cracked. The bumper bracket at the frame horn was crushed rearward, with the frame horn crushed rearward on both sides. There was also minor buckling of the right-side floor pan.

The maximum occupant compartment intrusions are listed in Table 9, along with the intrusion limits established in MASH for various areas of the occupant compartment. Aside from the windshield deformations discussed above, the maximum intrusion was 1.3 in. in the toe pan, which was within the MASH recommended 9-in. limit. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D. MASH defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There was no penetration into the occupant compartment, and none of the established MASH deformation limits were violated. Outward deformations, which are denoted as negative numbers in Appendix D, are not considered crush toward the occupant, and are not evaluated by MASH criteria.

Figure 60. Vehicle Damage before Secondary Impact, Test No. HNTBR-3

Figure 61. Vehicle Damage, Test No. HNTBR-3

Figure 62. Vehicle’s Interior Compartment Damage, Test No. HNTBR-3

Figure 63. Vehicle’s Undercarriage Damage, Test No. HNTBR-3

Table 9. Maximum Occupant Compartment Intrusion by Location, Test No. HNTBR-3

Location	Maximum Intrusion in.	MASH Allowable Intrusion in.
Wheel Well & Toe Pan	1.3	≤ 9
Floor Pan & Transmission Tunnel	0.8	≤ 12
A-Pillar	0.4	≤ 5
A-Pillar (Lateral)	0.4	≤ 3
B-Pillar	0.2	≤ 5
B-Pillar (Lateral)	0.0*	≤ 3
Side Front Panel (in Front of A-Pillar)	1.0	≤ 12
Side Door (Above Seat)	0.5	≤ 9
Side Door (Below Seat)	0.9	≤ 12
Roof	0.0*	≤ 4
Windshield	4.2**	≤ 3
Side Window	Shattered due to contact with simulated occupant's head	No shattering resulting from contact with structural member of test article
Dash	1.6	N/A

N/A – No MASH criteria exist for this location.
*Negative value reported as 0.0. See Appendix D for further information.
** Windshield damaged by A-pillar deformations and secondary impact with containment barriers.

7.5 Occupant Risk

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

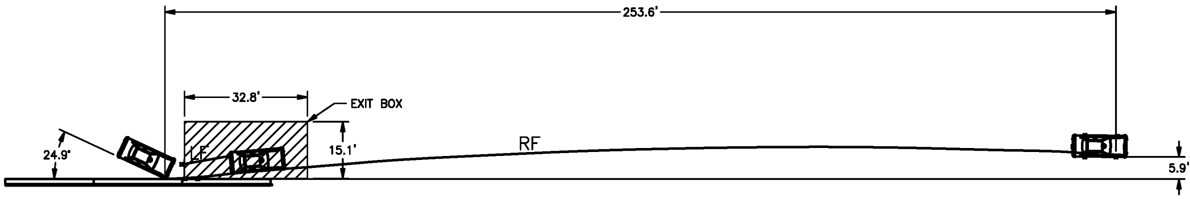
Table 10. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. HNTBR-3

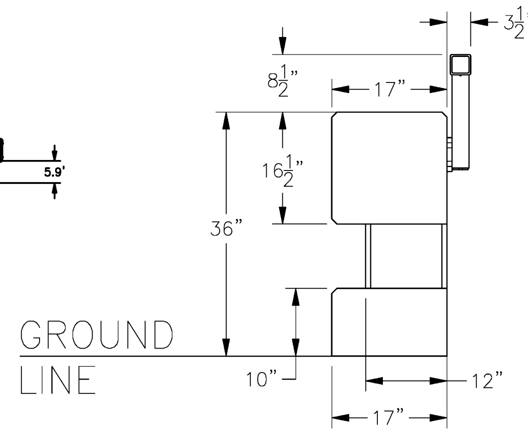
Evaluation Criteria		Transducer		MASH Limits
		SLICE-1 (primary)	SLICE-2	
OIV ft/s	Longitudinal	-24.51	-24.18	±40
	Lateral	-30.55	-28.60	±40
ORA g's	Longitudinal	-4.81	-4.20	±20.49
	Lateral	-14.14	-16.73	±20.49
Maximum Angular Displacement deg.	Roll	-9.7	-10.3	±75
	Pitch	-4.7	-4.7	±75
	Yaw	-30.0	-31.1	not required
THIV – ft/s		33.46	31.89	not required
PHD – g's		14.71	17.08	not required
ASI		2.50	2.40	not required

7.6 Discussion

The analysis of the test results for test no. HNTBR-3 showed that the system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix F, were deemed acceptable because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of -4.7 degrees, and its trajectory did not violate the bounds of the exit box. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The windshield had a maximum deformation of 4.2 in.; however, this damage was caused by loading and deformations at the base of the A-pillar rather than direct contact between the bridge rail and windshield. Furthermore, the secondary impact with a row of containment barriers downstream of the test article contributed to additional damage and deformation to the windshield. Thus, the windshield damage did not constitute grounds for violating MASH safety criteria. Therefore, test no. HNTBR-3 satisfied the safety performance criteria for MASH test designation no. 3-10. A summary of the test results and sequential photographs are shown in Figure 64.

0.000 sec | 0.150 sec | 0.300 sec | 0.450 sec | 0.600 sec





- Test Agency .... MwRSF
- Test Number HNTBR-3
- Date 8/21/2024
- MASH Test Designation No. 3-10
- Test Article .... Modified Hawaii DOT Natchez Trace Bridge Rail
- Total Length .... 70 ft – 7 in.
- Key Component - Rail
  - Length .... 23½ ft
  - Width .... 16½ in.
  - Depth .... 17 in.
- Key Component - Post
  - Length .... 9½ in.
  - Width .... 12 in.
  - Spacing .... 90 in.
- Vehicle Make /Model .... 2019 Kia Rio
  - Curb .... 2,483 lb
  - Test Inertial .... 2,400 lb (MASH Limit 2,420 ± 55 lb)
  - Gross Static .... 2,563 lb (MASH Limit 2,585 ± 55 lb
- Impact Conditions
  - Speed .... 63.6 mph (MASH Limit 62 ± 2.5 mph)
  - Angle .... 24.9 deg. (MASH Limit 25 ± 1.5 deg.)
  - Impact Location .... 38.5 in. upstream from post no. 8
- Impact Severity .... 57.5 kip-ft > 78.0 kip-ft MASH limit
- Exit Conditions
  - Speed .... 47.5 mph
  - Angle .... -4.7 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Pass
- Vehicle Stopping Distance .... 253.6 ft downstream, 5.9 ft laterally in front of barrier
- Vehicle Damage .... Severe
  - VDS [11] 01-RFQ-6
  - CDC [12] 01-RFEW-3
  - Maximum Interior Deformation .... 1.6 in. at dash (no MASH limit)
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... 1.1 in.
  - Dynamic .... 1.1 in.
  - Working Width .... 21.6 in.
- Transducer Data

Evaluation Criteria		Transducer SLICE-1 (primary)	Transducer SLICE-2	MASH Limits
OIV ft/s	Longitudinal	-24.51	-24.18	±40
	Lateral	-30.55	-28.60	±40
ORA g's	Longitudinal	-4.81	-4.20	±20.49
	Lateral	-14.14	-16.73	±20.49
Maximum Angular Displacement deg.	Roll	-9.7	-10.3	±75
	Pitch	-4.7	-4.7	±75
	Yaw	-30.0	-31.1	not required
THIV – ft/s		33.46	31.89	not required
PHD – g's		14.71	17.08	not required
ASI		2.50	2.40	not required

Figure 64. Summary of Test Results and Sequential Photographs, Test No. HNTBR-3

8 SUMMARY AND CONCLUSIONS

The Hawaii Department of Transportation (HDOT) used bridge railings similar to the Hawaii Modified Natchez Trace Bridge Rail to contain and redirect vehicles on bridges. However, the crashworthiness of this bridge rail had not been investigated under current impact safety standards. To address this, full-scale crash testing was conducted to evaluate the safety performance of the Hawaii Modified Natchez Trace Bridge Rail. As detailed in a previous report, the initial crash test, test no. HNTBR-1, was conducted according to MASH test designation no. 3-11 [6]. In this test, the occupant compartment intrusion at the wheel well and toe pan measured 12.7 in., which exceeded the MASH limit of 9 in. Thus, test no. HNTBR-1 failed to meet MASH safety criteria.

An investigation into the potential causes was conducted, and the failure was attributed to two key causes: (1) the limited curb-to-rail offset, which resulted in combined lateral and vertical loading to the wheel as it traversed over the curb and caused the vehicle rim to gouge into the concrete rail; and (2) the angled bottom edge of the rail which increased the severity of the rim-rail snag. To mitigate such snag, the face of the bridge rail was changed from a single-slope type profile to a vertical profile. Thus, the impacting wheel would not be subject to vertical motion as it would no longer traverse the curb, and the impact loads would be distributed to both the lower curb and the upper rail. To accommodate this shape change, the reinforcement of the rail and curb was adjusted accordingly.

The final design of the Hawaii Concrete Post and Beam Bridge Rail had a vertical face, a height of 36 in., and a rail width of 17 in. The lower curb was 10 in. tall, and the upper rail had a height of 16½ in. Posts measuring 12 in. x 12 in. x 9½ in. tall and spaced at 90-in. intervals were used to support the upper rail above the lower curb. Finally, a pedestrian handrail fabricated from HSS3x3x¼ steel tube was mounted to the back-side of the bridge rail with a top height of 44½ in.

The Hawaii Concrete Post and Beam Bridge Rail was subjected to two full-scale crash tests in accordance with the TL-3 evaluation criteria of MASH. Test nos. HNTBR-2 and HNTBR-3 were conducted according to MASH Tests 3-11 and 3-10, respectively. The test evaluation is summarized in Table 11.

In test no. HNTBR-2, a 4,995-lb crew cab pickup truck impacted the Hawaii Concrete Post and Beam Bridge Rail at a speed of 62.7 mph and an angle of 25.2 degrees. The impact occurred 59½ in. upstream from the centerline of expansion joint no. 1 with an impact severity of 119.0 kip-ft. The vehicle was contained and smoothly redirected with minimal roll and pitch angular displacements. Damage to the bridge rail was minimal. All occupant risk values fell within the recommended safety limits established in MASH. Therefore, test no. HNTBR-2 satisfied the safety performance criteria of MASH test designation no. 3-11.

In test no. HNTBR-3, a 2,400-lb small car impacted the Hawaii Concrete Post and Beam Bridge Rail at a speed of 63.6 mph and an angle of 24.9 degrees. The impact occurred 38.5 in. upstream from post no. 8 with an impact severity of 57.5 kip-ft. The vehicle was contained and smoothly redirected with minimal roll and pitch angular displacements. Damage to the bridge rail was minimal. All occupant risk values fell within the recommended safety limits established in MASH. The windshield was cracked and torn with a maximum deformation of 4.2 in. However, this windshield damage was the result of deformations to the base of the A-pillar during redirection and made worse by a secondary, head-on impact into a row of containment barriers downstream from the test article. The barrier system was never in direct contact with the windshield, so the windshield damage did not violate MASH safety criteria. Therefore, test no. HNTBR-3 satisfied the safety performance criteria of MASH test designation no. 3-10.

Based on the successful evaluations of test nos. HNTBR-2 and HNTBR-3, the new Hawaii Concrete Post and Beam Bridge Rail was determined to be crashworthy to MASH TL-3 impact safety standards. Note, the pedestrian handrail on the backside of the railing was not a critical structural member and did not play a part in the vehicle crash tests. Thus, the new Hawaii Concrete Post and Beam Bridge Rail is MASH TL-3 crashworthy with or without the attachment of the pedestrian handrail.

Table 11. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. HNTBR-2</th><th>Test No. HNTBR-3</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="11">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.</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 degrees.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s</td><td>40 ft/s</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</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>
<tr><td colspan="5">MASH Test Designation No.</td><td>3-11</td><td>3-10</td></tr>
<tr><td colspan="5">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Pass</td></tr>
</table>

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

9 MASH EVALUATION

The Hawaii Concrete Post and Beam Bridge Rail was developed following its predecessor, the Hawaii Modified Natchez Trace Bridge Rail, failed to satisfy MASH TL-3 safety performance standards. The Hawaii Concrete Post and Beam Bridge Rail was an open concrete bridge railing standing 36 in. tall and 17 in. wide, as shown in Figure 65. The upper railing was 16½-in. tall by 17-in. wide concrete rail supported by 12-in. x 12-in. x 9½-in. tall concrete posts spaced 90 in. on-center. The post-and-beam railing was mounted on top of a 10-in. tall by 17-in. wide concrete curb such that the face of the railing was flush with the face of the curb. The vertical posts were offset 5 in. laterally from the face of the railing. The railing, posts, and curb were reinforced with a combination of longitudinal and transverse rebar. Finally, a pedestrian handrail fabricated from an HSS3x3x¼ steel tube was mounted to the backside of the railing with a top height of 44½ in.

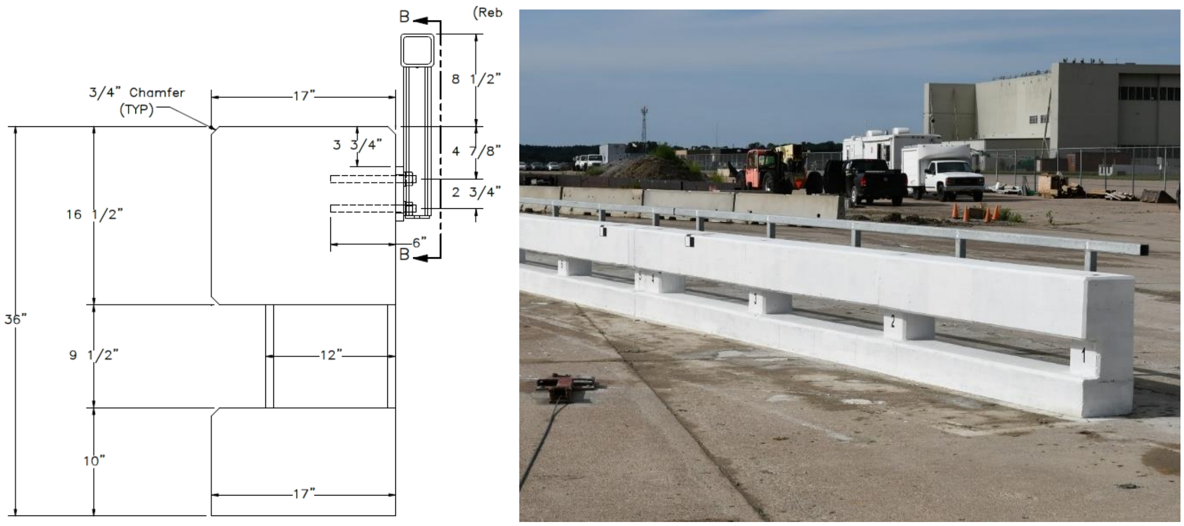


Figure 65. Hawaii Concrete Post and Beam Bridge Railing

According to TL-3 of MASH, longitudinal barrier systems, such as concrete bridge railings, must be subjected to two full-scale vehicle crash tests, as summarized in Table 12. Both crash tests were conducted as part of the evaluation of the Hawaii Concrete Post and Beam Bridge Rail.

Table 12. MASH 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 from MASH 2016

Test no. HNTBR-2 was conducted according to MASH test designation no. 3-11 with the 2270P pickup truck impacting 59½ in. upstream from an expansion joint to maximize loading to the bridge rail adjacent to a discontinuity. The 4,995-lb crew cab pickup truck impacted the concrete bridge rail at a speed of 62.7 mph and an angle of 25.2 degrees. The vehicle was contained and redirected with minimal roll and pitch angular displacements, while the bridge rail sustained minor damage in the form of hairline cracks, scraping, and gouging. All ORA and OIV occupant risk values and occupant compartment deformations were within the MASH recommended safety limits. Thus, test no. HNTBR-2 satisfied the safety performance criteria of MASH test designation no. 3-11

Test no. HNTBR-3 was conducted according to MASH test designation no. 3-10 with the 1100C small car impacting 38.5 in. upstream from a post to maximize the risk of vehicle snag on the post. The 2,400-lb Kia Rio impacted the concrete bridge rail at a speed of 63.6 mph and at an angle of 24.9 degrees. The vehicle was contained and redirected with minimal roll and pitch angular displacements, while the bridge rail sustained minor cosmetic damage in the form of scraping and gouging. All ORA and OIV occupant risk values and occupant compartment deformations were within the MASH recommended safety limits. Thus, test no. HNTBR-3 satisfied the safety performance criteria of MASH test designation no. 3-10

Based on the results of the two successful crash tests conducted on the bridge railing, the Hawaii Concrete Post and Beam Bridge Railing has satisfied the safety performance requirements for MASH TL-3.

10 REFERENCES

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

2. Faller, R.K., Holloway, J.C., Pfeifer, B.G., and Luedke, J. K., *AASHTO PL-1 Performance Crash Tests on the Natchez Trace Parkway Bridge Rail*, Report No. TRP-03-34-92, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 1992.

3. *Guide Specifications for Bridge Railings*, American Association of State Highway and Transportation Officials, Washington, DC, 1989.

4. Bullard, D.L., Menges, W.L., Eugene C.B., and Haug, R.R., *Guardrail Testing Program IV Volume I: Technical Report*, Report No. FHWA-HRT-04-086, Texas Transportation Institute, TX, October 2003.

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

6. Asadollahi Pajouh, M., Rosenbaugh, S.K., Rajaee, M., Galusha, E., and Faller, R.K., *Evaluation of the Hawaii Modified Natchez Trace Bridge Rail: MASH Test Designation No. 3-11*, Report No. TRP-03-478a-25, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, May 16, 2025.

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

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

9. MacInnis, D., Cliff, W., and Ising, K., *A Comparison of the Moment of Inertia Estimation Techniques for Vehicle Dynamics Simulation*, SAE Technical Paper Series – 970951, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1997.

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

12. *Collision Deformation Classification*, SAE International Surface Vehicle Recommended Practice, SAE Standard J224_201702, Society of Automotive Engineers, Warrendale, PA, February 2017.

13. Bielenberg, R.W., Yoo, S.H., Faller, R.K., and Urbank, E.L., *Crash Testing and Evaluation of the HDOT 34-in. Tall Aesthetic Concrete Bridge Rail: MASH Test Designation Nos. 3-10 and 3-11*, Report No. TRP-03-420-19, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 21, 2019.

14. Bielenberg, R.W., Dowler, N.T., Faller, R.K., and Urbank, E.L., *Crash Testing and Evaluation of the HDOT 42-in. Tall, Aesthetic Concrete Bridge Rail: MASH Test Designation Nos. 3-10 and 3-11*, Report No. TRP-03-424-20, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, January 9, 2020.

11 APPENDICES

Appendix A. A2LA Accreditation Documents

Accredited Laboratory

A2LA has accredited

MIDWEST ROADSIDE SAFETY FACILITY (MwRSF)

Lincoln, NE

for technical competence in the field of

Mechanical Testing

This laboratory is accredited in accordance with the recognized International Standard ISO/IEC 17025:2017 *General requirements for the competence of testing and calibration laboratories*. This accreditation demonstrates technical competence for a defined scope and the operation of a laboratory quality management system (*refer to joint ISO-ILAC-IAF Communiqué dated April 2017*).

American Association for Laboratory Accreditation
CORPORATE SEAL 1978
DISTRICT OF COLUMBIA
A2LA

Presented this 27th day of June 2024.

Mr. Trace McInturff, Vice President, Accreditation Services
For the Accreditation Council
Certificate Number 2937.01
Valid to November 30, 2025

For the tests to which this accreditation applies, please refer to the laboratory's Mechanical Scope of Accreditation.

Figure A-1. Midwest Roadside Safety Facility A2LA Accreditation Certificate No. 2937.01

SCOPE OF ACCREDITATION TO ISO/IEC 17025:2017

MIDWEST ROADSIDE SAFETY FACILITY (MwRSF)[1]
University of Nebraska-Lincoln
4630 NW 36th Street
Lincoln, NE 68524
Ms. Karla Lechtenberg Phone: 402 472 9070

MECHANICAL

Valid To: November 30, 2025 Certificate Number: 2937.01

In recognition of the successful completion of the A2LA evaluation process, accreditation is granted to this laboratory to perform the following tests:

Tests	Test Methods
Full-Scale Vehicle Crash Tests of Highway Safety Features	NCHRP Report 350; MASH; EN 1317
Full-Scale Vehicle Crash Tests of Perimeter Protection Systems and Access Control Devices	ASTM F2656; SD-STD-02.01 Revision A
Bogie Dynamic Tests of Highway Safety Features	Non-Standard Test Method: Dynamic Testing of Steel Post and Rigid Foundation; Non-Standard Test Method: Dynamic Testing of Post in Soil; Non-Standard Test Method: Dynamic Testing of Spacer Blocks
Crushable Nose Bogie Testing for Breakaway Supports	Non-Standard Test Method: Dynamic Testing of Breakaway Supports; AASHTO Breakaway Poles and Supports; NCHRP Report 350

On the following types of products, materials, and/or structures:
Metal, Wood, Concrete and Plastic Structures, Components of Structures, Fasteners, and Roadway Pavements.

[1] Administrative office located at: 2200 Vine Street, 130 Whittier Building, Lincoln, NE 68583-0853.

(A2LA Cert. No. 2937.01) 06/27/2024 Page 1 of 1

5202 Presidents Court, Suite 220 | Frederick, MD 21703-8515 | Phone: 301 644 3248 | Fax: 240 454 9449 | www.A2LA.org

Figure A-2. Midwest Roadside Safety Facility Scope of Accreditation to ISO/IEC 17025

Appendix B. Material Specifications, Test Nos. HNTBR-2 and HNTBR-3

Table B-1. Bill of Materials, Test Nos. HNTBR-2 and HNTBR-3

Item No.	Description	Material Specification	Reference
a1	Concrete	Min. f'c = 4,000 psi	Curb: 8/5/2024 Break Rail: 8/12/2024 Break
b1	#4 Rebar, 47½" Total Unbent Length	ASTM A615 Gr. 60	H#4400020131
b2	#7 Rebar, 43½" Total Unbent Length	ASTM A615 Gr. 60	H#7021691
b3	#5 Rebar, 38½" Total Unbent Length	ASTM A615 Gr. 60	H#9700019113
b4	#4 Rebar, 35" Total Unbent Length	ASTM A615 Gr. 60	H#4400020131
b5	#4 Rebar, 57" Total Unbent Length	ASTM A615 Gr. 60	H#4400020131
b6	#6 Rebar, 278" Total Length	ASTM A615 Gr. 60	H#9700017142
b7	#5 Rebar, 278" Total Length	ASTM A615 Gr. 60	H#9700019113
b8	#5 Rebar, 39" Total Unbent Length	ASTM A615 Gr. 60	H#9700019113
c1	#8 Smooth Rebar, 24½" Long	ASTM A615 Gr. 60	H#188924
c2	1¼" Dia. PVC Pipe	Schedule 80 PVC Gr. 12454	#G1939804
c3	1¼" Dia. PVC End Cap	Schedule 80 PVC Gr. 12454	#G0475745
d1	HSS 3"x3"x¼", 281½" Long	ASTM A500 Gr. B	H#NM5532
d2	HSS 2½"x2½"x¼", 13¾" Long	ASTM A500 Gr. B	H#05606D
d3	2¼"x2¼"x¼" Steel Plate	ASTM A36	H#B2209440
d4	8"x5"x¾" Steel Plate	ASTM A36	H#A2K317
d5	7"x1½"x3/16" Shim	ASTM A36	H#22112982
d6	HSS 2"x2"x¼", 7" Long	ASTM A500 Gr. B	H#2125151
e1	⅝"-11 UNC Heavy Hex Nut	ASTM A563-15 Grade DH	CoC 8/7/2024
e2	⅝" Dia. Hardened Washer	ASTM F436	CoC 8/7/2024
e3	⅝"-11 UNC, 7⅞" Long Threaded Rod	ASTM F1554-15 Gr. 105	CoC 8/7/2024
e4	Epoxy Adhesive	Hilti HIT RE-500 V3	CoC 12/13/2016
e5	Joint Filler	AASHTO M33, M153, or M213	Tech Sheet
e6	Expansion Joint Sealant	AASHTO M173, M282, M301, ASTM D3581, or ASTM D5893	Tech Sheet

benesch

Concrete Sample Test Report
Cylinder Compressive Strength

Project Name:	Midwest Roadside Safety - Misc Testing
Project Number:	00110546.00
Client:	Midwest Roadside Safety Facility
Location:	Midwest Roadside Safety
Sample:	06112024.1
Description:	HNTBR-2 - Curb 1

Field Data (ASTM C172)

		Property	Test Result
Supplier:			
Mix Name:		C143 Slump (in):	
Ticket Number:		C231 Air Content (%):	
Truck Number:		C138 Unit Weight (lb/ft³):	
Load Volume (yd³):		Air Temp (°F):	
Mold Date:	06/11/2024	C1064 Mix Temp (°F):	
Molded By:		Min Temp (°F):	
Initial Cure Method:		Max Temp (°F):	

Laboratory Test Data (ASTM C39)

Sample Number:	06112024.1					
Set Number:	55					
Specimen Number:	1					
Age:	55					
Length (in):	12					
Diameter (in):	5.98					
Area (in²):	28.09					
Density (lb/ft³):	139					
Cylinder Condition:	Good					
Capping:	C1231 - Neoprene					
Test Date:	08/05/2024					
Break Type:	3					
Max Load (lbf):	121,899					
Strength (psi):	4,340					
Spec Strength (psi):						
Excl in Avg Strength:	☐	☐	☐	☐	☐	☐

Remarks:
Set 55, Specimen 1, 55-day Compressive Strength (psi): **4,340**

Sample Receive Date: 08/05/2024

Approved by:

Matt Roessler Manager

Date: 08/05/2024

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

335 S 9th St
Lincoln, NE 68507
Benesch
Phone: 402-479-2424

Version 1 Created by Matt Roessler Manager (mroessler@benesch.com) on 08/05/2024 3:08 PM CDT

Figure B-1. Concrete Curb, Test Nos. HNTBR-2 and HNTBR-3 (Item a1) benesch

Concrete Sample Test Report
Cylinder Compressive Strength

Project Name:	Midwest Roadside Safety - Misc Testing
Project Number:	00110546.00
Client:	Midwest Roadside Safety Facility
Location:	Midwest Roadside Safety
Sample:	07302024.1
Description:	HNTBR-2 - Rail 1

Field Data (ASTM C172)

		Property	Test Result
Supplier:			
Mix Name:		C143 Slump (in):	
Ticket Number:		C231 Air Content (%):	
Truck Number:		C138 Unit Weight (lb/ft³):	
Load Volume (yd³):		Air Temp (°F):	
Mold Date:	07/30/2024	C1064 Mix Temp (°F):	
Molded By:		Min Temp (°F):	
Initial Cure Method:		Max Temp (°F):	

Laboratory Test Data (ASTM C39)

Sample Number:	07302024.1	07302024.1				
Set Number:	6	13				
Specimen Number:	1000	1000				
Age:	13	7				
Length (in):	8	12				
Diameter (in):	4.01	5.97				
Area (in²):	12.63	27.99				
Density (lb/ft³):	137	135				
Cylinder Condition:	Good	Good				
Capping:	C1231 - Neoprene	C1231 - Neoprene				
Test Date:	08/12/2024	08/05/2024				
Break Type:	3	3				
Max Load (lbf):	50,122	98,841				
Strength (psi):	3,970	3,530				
Spec Strength (psi):						
Excl in Avg Strength:	☐	☐	☐	☐	☐	☐

Remarks:
Set 13, Specimen 1000, 7-day Compressive Strength (psi): **3,530**

Sample Receive Date: 08/05/2024

Approved by:

Matt Roessler Manager

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

Date: 08/13/2024

335 S 9th St
Lincoln, NE 68507
Benesch
Phone: 402-479-2424

Figure B-2. Concrete Rail, Test Nos. HNTBR-2 and HNTBR-3 (Item a1)

4400020131 06-28-22

NUCOR®

Mill Certification
06/28/2022

MTR#: 1068214-3
Lot #:440002013120
912 Cheney Avenue
Marion, OH 43302 US
800 333-4011
Fax: 740 383-6429

Sold To: SIMCOTE INC
250 N GREENWOOD ST
MARION, OH 43302 US

Ship To: SIMCOTE INC - MARION
250 N GREENWOOD ST
MARION, OH 43302 US

Customer PO	OH-2222	Sales Order #	44010643 - 1.1
Product Group	Rebar	Product #	1059653
Grade	A615 Gr 60/M31 C	Lot #	440002013120
Size	#4	Heat #	4400020131
BOL #	BOL-1167949	Load #	1068214
Description	Rebar #4/13mm A615 Gr 60/M31 C 40' 0" [480"] Epoxy 4001-8000 lbs	Customer Part #	
Production Date	06/21/2022	Qty Shipped LBS	25650
Product Country Of Origin	United States	Qty Shipped EA	960
Original Item Description		Original Item Number	

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

Melt Country of Origin : United States — Melting Date: 06/20/2022

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	Cu (%)	V (%)	Sn (%)
0.20	0.63	0.013	0.026	0.184	0.16	0.18	0.05	0.27	0.004	0.017

Tensile testing

	Yield (PSI)	Tensile (PSI)	Elongation in 8" (%)
(1)	79100	96400	10.9

Mechanical

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

Other Test Results
Tensile / Yield Ratio : 1.22 — Weight Percent Variance (%) : -4.19

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

4400020131 06-28-22

Figure B-3. #4 Rebar, Test Nos. HNTBR-2 and HNTBR-3 (Items b1, b4, and b5)

CMC STEEL TENNESSEE
1919 Tennessee Avenue
Knoxville TN 37921-2686

CERTIFIED MILL TEST REPORT
For additional copies call
865-202-5972/888-870-0766

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

Jim Hall
Quality Assurance Manager

HEAT NO.:7021691 SECTION: REBAR 22MM (#7) 60'0" 420/60 SIM GRADE: ASTM A615-20 Gr 420/60 SIM ROLL DATE: 10/25/2021 MELT DATE: 10/25/2021 Cert. No.: 83638480 / 021691L792	SOLD TO	Simcote Inc 1645 Red Rock Rd Saint Paul MN US 55119-6014 6517359660	SHIP TO	Simcote Inc 1645 Red Rock Rd Saint Paul MN US 55119-6014 6517359660

Delivery#: 83638480
BOL#: 2159834
CUST PO#: MN-3782
CUST P/N:
DLVRY LBS / HEAT: 117732.000 LB
DLVRY PCS / HEAT: 960 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.33%	Bend Test 1	Passed		
Mn	0.69%	Rebar Deformation Avg. Spaci	0.535IN		
P	0.015%	Rebar Deformation Avg. Heigh	0.053IN		
S	0.048%	Rebar Deformation Max. Gap	0.135IN		
Si	0.22%				
Cu	0.27%				
Cr	0.19%				
Ni	0.10%				
Mo	0.019%				
V	0.003%				
Sn	0.005%				
Yield Strength test 1	87.1ksi				
Yield Strength test 1 (metri	601MPa				
Tensile Strength test 1	106.0ksi				
Tensile Strength 1 (metric)	731MPa				
Elongation test 1	12%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.22				
Elongation Gage Lgth 1(metri	200mm				

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

REMARKS :

Figure B-4. #7 Rebar, Test Nos. HNTBR-2 and HNTBR-3 (Item b2)

NUCOR

Mill Certification
02/16/2023

MTR#:1258616-3
Lot #:970001911321
500 REBAR ROAD
SEDALIA, MO 65301 US
660 951-1679
Fax: 660 951-1698

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

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

Customer PO	MN-3843	Sales Order #	97008781 - 2.13
Product Group	Rebar	Product #	2110230
Grade	A615 Gr 60/AASHTO M31	Lot #	970001911321
Size	#5	Heat #	9700019113
BOL #	BOL-1353385	Load #	1258616
Description	Rebar #5/16mm A615 Gr 60/AASHTO M31 40' 0" [480"] 4001-8000 lbs	Customer Part #	
Production Date	10/01/2022	Qty Shipped LBS	31708
Product Country Of Origin	United States	Qty Shipped EA	760
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: 10/01/2022

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	V (%)	Nb (%)
0.25	0.83	0.006	0.024	0.243	0.11	0.10	0.03	0.005	0.003

Tensile testing

	Yield (PSI)	Tensile (PSI)	Elongation in 8" (%)
(1)	82600	95500	15.2

Mechanical

	Average Deformation Height (IN)	Bend Test
(1)	0.038	Pass

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

Anil Rochester, Quality Supervisor

Page 1 of 1

Figure B-5. #5 Rebar, Test Nos. HNTBR-2 and HNTBR-3 (Items b3, b7, and b8)

NUCOR

Mill Certification
07/19/2022

MTR#:1087642-4
Lot #:970001714220
500 REBAR RD
SEDALIA, MO 65301 US
660 951-1679
Fax: 660 951-1698

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

Ship To: SIMCOTE DNS 232752 000
NEWPORT MN N11
NEWPORT, MN 55055 US

Customer PO	MN-3814	Sales Order #	97006876 - 3.1
Product Group	Rebar	Product #	2110264
Grade	A615 Gr 60/AASHTO M31	Lot #	970001714220
Size	#6	Heat #	9700017142
BOL #	BOL-1185401	Load #	1087642
Description	Rebar #6/19mm A615 Gr 60/AASHTO M31 40' 0" [480"] 6001-10000 lbs	Customer Part #	
Production Date	07/10/2022	Qty Shipped LBS	54670
Product Country Of Origin	United States	Qty Shipped EA	910
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: 07/10/2022

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	V (%)	Nb (%)
0.29	0.98	0.009	0.020	0.177	0.14	0.16	0.04	0.005	0.002

Tensile testing

	Yield (PSI)	Tensile (PSI)	Elongation in 8" (%)
(1)	76300	95000	13.3

Mechanical

	Average Deformation Height (IN)	Bend Test
(1)	0.045	Pass

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

Figure B-6. #6 Rebar, Test Nos. HNTBR-2 and HNTBR-3 (Item b6)

CERTIFIED MILL TEST REPORT

ASI
ALTON STEEL INC

Alton Steel Test Lab
#5 Cut Street
Alton, IL. 62002-9011
(618) 463-4490 EXT 2486
(618) 463-4491 (Fax)

BILL TO
WADY Industries, Inc
510 East Grove Street
Maquoketa, IA 52060

SHIP TO
WADY Industries, Inc
510 East Grove Street
Maquoketa, IA 52060

Date	11/12/2018	Customer PO	11352	**Specifications**
ASI Ord No.	96071	Customer PT.	1.000-GRADE80-362	
ASI Ord Line Item	1			AASHTO M227 GR 80, ASTM A615-16 GR40

tem Description
teel Bar, Hot Rolled, 1.0000, 30' 2 "

Strand Cast, RR =62.39:1

Heat Number	Yield PSI	Tensile PSI	% Elongation	% ROA	Bend Test
188397	65100	97100	15 in 8"	32	Pass
188829	74400	99700	15 in 8"	37	Pass
188830	60200	90400	20 in 8"	36	Pass
188924	66400	98900	19 in 8"	37	Pass
188925	63500	94800	17 in 8"	36	Pass

CHEMICAL ANALYSIS TEST METHODS ASTM E-415 & E-1019

Heat #	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	Nb/Cb	V	B	Ti	N	Pb	Ca
88397	0.38	0.82	0.011	0.021	0.20	0.24	0.101	0.170	0.029	0.011	0.025	0.002	0.005	0.0002	0.0018	0.0107	0.0044	0.0024
88829	0.34	0.75	0.010	0.023	0.23	0.27	0.079	0.139	0.024	0.010	0.001	0.001	0.046	0.0004	0.0007	0.0095	0.0023	0.0017
88830	0.31	0.79	0.013	0.026	0.26	0.26	0.104	0.194	0.034	0.010	0.002	0.001	0.006	0.0003	0.0008	0.0104	0.0027	0.0023
88924	0.32	0.78	0.012	0.023	0.25	0.28	0.110	0.207	0.033	0.011	0.002	0.002	0.006	0.0003	0.0006	0.0115	0.0034	0.0019
88925	0.32	0.83	0.017	0.022	0.25	0.29	0.093	0.202	0.028	0.011	0.002	0.002	0.006	0.0004	0.0007	0.0115	0.0039	0.0015

JOMINY HARDENABILITY USING ASTM A-255 CALCULATED FROM CHEMICAL DI

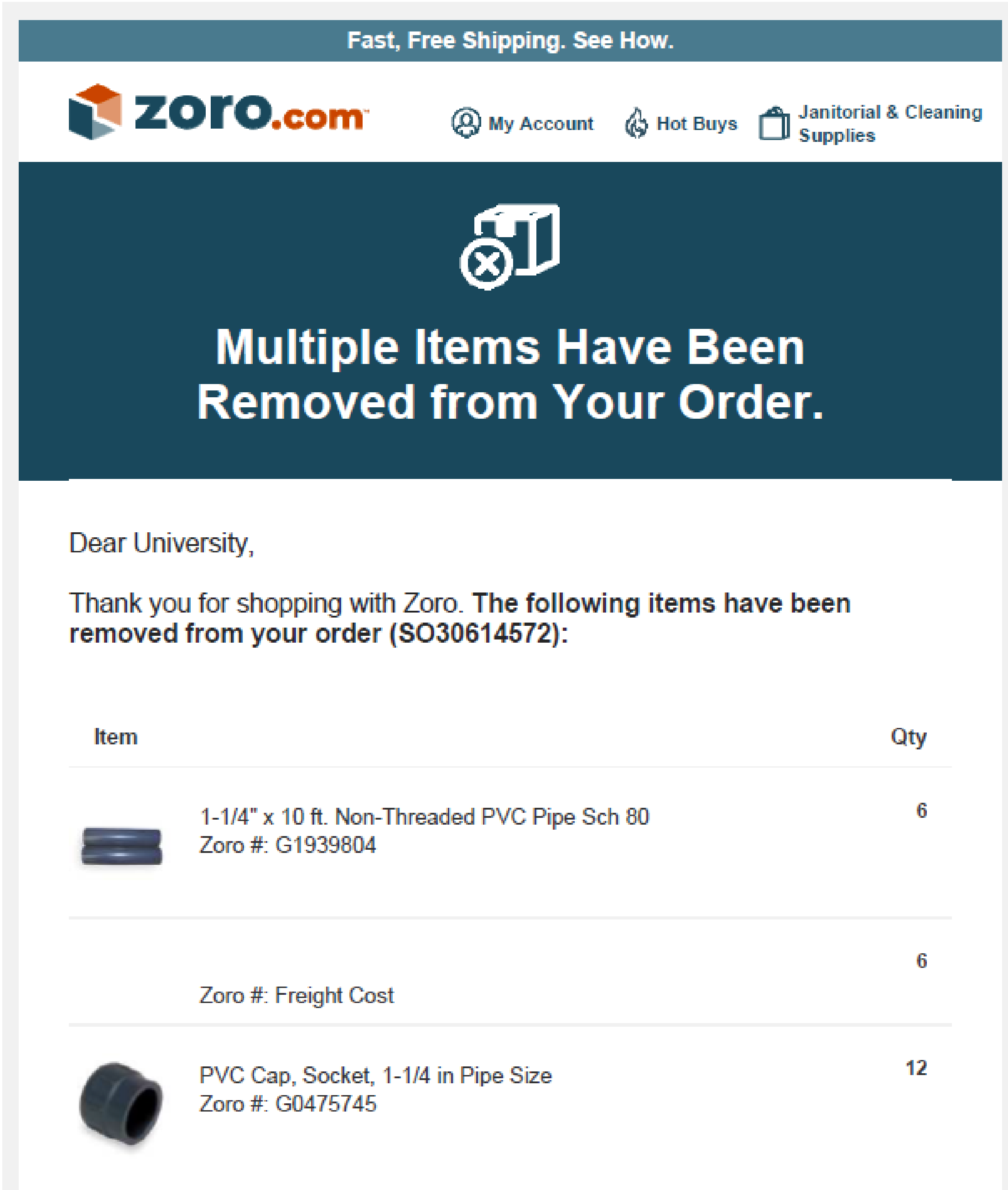
eat Number	GS	DI
38397	8	1.50
38829	8	1.27
38830		1.28
38924		1.35
38925		1.40

SPECIAL TEST RESULTS

	ASTM E-45 Method A:								ASTM E-45 Method C:		SAE J422		ASTM E-381			Charpy	Hardness		
eat Number	TA	TB	TC	TD	HA	HB	HC	HD	S	O	S	O	S	R	C		RC	RB	BHN
88397																			172
88829																			195
88830																			176
88924																			172
88925																			185

ADDITIONAL COMMENTS

Figure B-7. #8 Rebar, Test Nos. HNTBR-2 and HNTBR-3 (Item c1)



Fast, Free Shipping. See How.

zoro.com

My Account | Hot Buys | Janitorial & Cleaning Supplies

Multiple Items Have Been Removed from Your Order.

Dear University,

Thank you for shopping with Zoro. **The following items have been removed from your order (SO30614572):**

Item	Qty
1-1/4" x 10 ft. Non-Threaded PVC Pipe Sch 80 Zoro #: G1939804	6
Zoro #: Freight Cost	6
PVC Cap, Socket, 1-1/4 in Pipe Size Zoro #: G0475745	12

Figure B-8. 1¼-in. Dia. PVC Pipe and Cap, Test Nos. HNTBR-2 and HNTBR-3 (Items c2 and c3)

NUCOR TUBULAR PRODUCTS

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

https://www.nucortubular.com
https://www.ntpportal.com
Certificate Number: BHM 872827

Sold By:
NUCOR TUBULAR PRODUCTS INC.
BIRMINGHAM DIVISION
3525 RICHARD ARRINGTON JR. BLVD N
BIRMINGHAM, AL 35201
Tel: 205 251-1884
Fax: 205 251-1553

Purchase Order No: 4500539383
Sales Order No: BHM 593391 - 2
Bill of Lading No: BHM 51194 - 4
Invoice No:

Shipped: 10/28/2022
Invoiced:

Sold To:
5018 - STEEL & PIPE SUPPLY
4750 W. MARSHALL AVENUE
LONGVIEW, TX 75604

Ship To:
1 - STEEL & PIPE SUPPLY
4750 W. MARSHALL AVENUE
LONGVIEW, TX 75604

CERTIFICATE of ANALYSIS and TESTS

Customer Part No:

Certificate No: BHM 872827
Test Date: 10/26/2022

TUBING A500 GRADE B(C)
3" SQ X 1/4" X 24'

Total Pieces	Total Weight Lbs
100	21,145

Bundle Tag	Mill	Heat	Specs	Y/T Ratio	Pieces	Weight Lbs
197201	40N	SM5708	YLD=65000/TEN=73500/ELG=25.5	0.8844	20	4,229
197206	40N	NM5532	YLD=61800/TEN=74300/ELG=26	0.8318	20	4,229
197207	40N	NM5532	YLD=61800/TEN=74300/ELG=26	0.8318	20	4,229
197210	40N	NM5148	YLD=63500/TEN=72900/ELG=23	0.8711	20	4,229
197211	40N	NM5148	YLD=63500/TEN=72900/ELG=23	0.8711	20	4,229

Mill #: 40N Heat #: NM5148 Carbon Eq: 0.2841 Heat Src Origin: MELTED AND MANUFACTURED IN THE USA

C	Mn	P	S	Si	Al	Cu	Cr	Mo	V	Ni	Nb	Sn
0.2000	0.3900	0.0040	0.0020	0.0270	0.0340	0.1000	0.0400	0.0100	0.0020	0.0300	0.0060	0.0020

N	B	Ti	Ca
0.0050	0.0001	0.0020	0.0020

Mill #: 40N Heat #: NM5532 Carbon Eq: 0.2894 Heat Src Origin: MELTED AND MANUFACTURED IN THE USA

C	Mn	P	S	Si	Al	Cu	Cr	Mo	V	Ni	Nb	Sn
0.2000	0.4100	0.0070	0.0010	0.0200	0.0290	0.1200	0.0400	0.0100	0.0020	0.0400	0.0060	0.0030

N	B	Ti	Ca
0.0060	0.0002	0.0010	0.0011

Mill #: 40N Heat #: SM5708 Carbon Eq: 0.2667 Heat Src Origin: MELTED AND MANUFACTURED IN THE USA

C	Mn	P	S	Si	Al	Cu	Cr	Mo	V	Ni	Nb	Sn
0.1900	0.3500	0.0050	0.0040	0.0230	0.0380	0.1200	0.0300	0.0100	0.0020	0.0300	0.0070	0.0020

N	B	Ti	Ca
0.0053	0.0004	0.0010	0.0017

Figure B-9. HSS3x3x¼, Test Nos. HNTBR-2 and HNTBR-3 (Item d1)

EXLTUBE

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

STEEL VENTURES, LLC dba EXLTUBE

Certified Test Report

Customer:	Size: 02.50X02.50 / Gauge: 1/4	Customer Order No:	Customer Part No:
SPS - Tulsa 1020 Fort Gibson Road Catoosa OK 74015-3033		4500524183	6521625040
	Date: 02/09/2022	Delivery No: 85142099 Load No: 7138474	Length: 40 FT
	Specification: ASTM A500-21 Gr.B/C		

Heat No	Yield KSI	Tensile KSI	Elongation % 2 Inch
05606D	61.7	70.4	30.00

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
05606D	0.1600	0.7900	0.0120	0.0070	0.0110	0.0400	0.0200	0.0600	0.0000	0.0000

This material was melted & manufactured in the U.S.A. This material meets the Buy America requirement of 23 CFR 635.410.
Coil Producing Mill: UNITED STATES STEEL, Granite City, IL

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

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

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

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

STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe
Quality Assurance Manager

Figure B-10. HSS2½x2½x¼, Test Nos. HNTBR-2 and HNTBR-3 (Item d2)

STEEL AND PIPE SUPPLY

SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 01/26/2023
TIME 07:05:13

SOLD TO

SHIP TO
13716
Kansas City Warehouse
401 New Century Parkway
New Century KS 66031-1127

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40397361-0020	70872120	1/4 72 X 120 A36 STP MIL PLT	16	9,801.600			01/25/2023

Chemical Analysis

Heat No. B2209440 Vendor STEEL DYNAMICS SOUTHWEST, LLC DOMESTIC Mill STEEL DYNAMICS SOUTHWEST, LLC **Melted and Manufactured in the USA**
Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.0500	0.8600	0.0060	0.0040	0.0200	0.0400	0.0400	0.0100	0.0000	0.1000	0.0290	0.0000	0.0040	0.0020	0.0080	0.0050

Mechanical / Physical Properties

Mill Coil No. 22B114642

Tensile (PSI)	Yield (PSI)	% Elong (2 in)	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
64000.000	50700.000	36.50			0	NA			
62600.000	47600.000	36.50			0	NA			
64200.000	46300.000	37.50			0	NA			
63200.000	45800.000	36.00			0	NA			

Batch 1001159632 16 EA 9,801.600 LB

Figure B-11. ¼-in. Steel Plate, Test Nos. HNTBR-2 and HNTBR-3 (Item d3)

SSAB — **Test Certificate**

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

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

Form TC1: Revision 5: Date 22 Aug 2022

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

MANHATTAN
KS 66502

Customer P.O.No.:4500540178 | **Mill Order No.** 41-692042-02 | **Shipping Manifest:** MT476914

Product Description: ASTM A36(19)/A709(21)36/ASME SA36(21) AASHTO M270(20)36

Ship Date: 02 Dec 22
Cert Date: 02 Dec 22
Cert No: 061199049
(Page 1 of 1)

Size: 0.750 X 96.00 X 120.0 (IN)

Tested Pieces:				Tensiles:							Charpy Impact Tests					
Heat Id	Piece Id	Tested Thickness	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in	Elong % 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1 2 3 Avg	% Shear 1 2 3 Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp %Shr
A2J254	B33	0.747 (DISCRT)	L	42	65		38		T							
A2K317	B13	0.745 (DISCRT)	L	43	67		39		T							
A2K317	B14	0.746 (DISCRT)	L	43	67		37		T							

Chemical Analysis

Heat Id	C	Mn	P	S	Si	Tot Al	Cu	Ni	Cr	Mo	Cb	V	Ti	B	N	ORGN
A2J254	.20	.53	.009	.001	.06	.032	.34	.11	.11	.03	.000	.003	.008	.0000	.0068	USA
A2K317	.19	.53	.015	.001	.06	.031	.36	.10	.16	.03	.001	.003	.007	.0000	.0080	USA

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED, POURED, AND ROLLED IN THE USA
PRODUCTS SHIPPED:
A2K317 B12 PCES: 8, LBS: 19600 A2J254 B33 PCES: 2, LBS: 4900

(P) Cust Part #:722496120

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

Brian Wales
PRINCIPAL METALLURGIST

Figure B-12. ¾-in. Steel Plate, Test Nos. HNTBR-2 and HNTBR-3 (Item d4)

STEEL AND PIPE SUPPLY

SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 12/13/2022
TIME 07:22:11

SOLD TO

SHIP TO
13716
Kansas City Warehouse
401 New Century Parkway
New Century KS 66031-1127

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40395681-0020	70672120	3/16 72 X 120 A36 STP MIL PLT	6	2,757.600			12/12/2022

Chemical Analysis

Heat No. 22112982 Vendor BIG RIVER STEEL LLC DOMESTIC Mill BIG RIVER STEEL LLC **Melted and Manufactured in the USA**
Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.0600	0.8100	0.0060	0.0030	0.0200	0.0300	0.0300	0.0100	0.0001	0.0600	0.0250	0.0000	0.0020	0.0010	0.0095	0.0028

Mechanical / Physical Properties

Mill Coil No. 22112982-03

Tensile (PSI)	Yield (PSI)	% Elong (2 in)	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
64100.000	46800.000	31.00			0	NA			
64100.000	47200.000	30.00			0	NA			
66700.000	48000.000	27.50			0	NA			
66200.000	48300.000	31.00			0	NA			

Batch 1001086664 6 EA 2,757.600 LB Batch 1001086661 21 EA 9,651.600 LB

Figure B-13. $^{3}/_{16}$-in. Shim, Test Nos. HNTBR-2 and HNTBR-3 (Item d5)

Atlas Tube Arkansas
6651 E Hwy 137
Blytheville Arkansas USA
72315
Tel:
Fax:

Atlas Tube
A DIVISION OF ZEKELMAN INDUSTRIES

REF.B/L: 81115225
Date: 10/13/2022
Customer: 179

MATERIAL TEST REPORT

Sold To
Steel & Pipe Supply Company
PO Box 1688
MANHATTAN KS 66505
USA

Shipped To
Steel & Pipe c/o Longview Whse
4750 West Marshall Avenue
LONGVIEW TX 75604
USA

Material: 2.0x2.0x250x40'0"0(10x3). **Material No:** 200202504000 **Made in:** USA

Melted and Poured in: USA

Sales Order: 1832937 **Purchase Order:** 4500537759 **Cust Material#:** 6520025040

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N	Ca
2125151	0.200	0.780	0.011	0.002	0.030	0.020	0.080	0.002	0.010	0.040	0.040	0.003	0.002	0.0000	0.0060	0.0020

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.35
M400217625	30	066583 Psi	081008 Psi	29 %	ASTM A500-21 GRADE B&C	

Heat	MILL	Mill Location	Method	Recycled_Content	Post_Consumer	Pre-Consumer (Post Industrial)	% Harvested	Within Miles of Location
2125151	NUCOR	HICKMAN,AR	EAF	52.50%	31.80%	20.70%	74%	500

Material Note:
Sales Or. Note:

Authorized by Quality Assurance: Jason Richard

The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
CE calculated using the AWS D1.1 method. This document is in compliance with the requirements of EN 10204 type 3.1

Steel Tube Institute OF NORTH AMERICA

Metals Service Center Institute

Page: 1 of 1

Figure B-14. HSS2x2x¼, Test Nos. HNTBR-2 and HNTBR-3 (Item d6)

FASTENAL

Certificate of Compliance

Sold To:
UNL MIDWEST ROADSIDE SAFETY FACILITY

Purchase Order: need mill certs
Job:
Invoice Date: 08/7/2024

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

6 PCS 5/8"-11 x 10 ft ASTM A307 Gr A Hot Dip Galvanized Low Carbon Steel Threaded Rod SUPPLIED UNDER OUR TRACE NUMBER 210311919 AND UNDER PART NUMBER 47638

60 PCS 5/8" ASTM F436 Type 1 Hot Dipped Galvanized Steel Structural Flat Washer Made in USA SUPPLIED UNDER OUR TRACE NUMBER 210328509 AND UNDER PART NUMBER 0156025

60 PCS 5/8"-11 A-563 Grade DH Hot Dip Galvanized Heavy Hex Nut SUPPLIED UNDER OUR TRACE NUMBER 120512968 AND UNDER PART NUMBER 36755

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

Please check current revision to avoid using obsolete copies.

Fastenal Account Representative Signature

This document was printed on 08/7/2024 and was current at that time.

Sam Rice
Printed Name

Fastenal Store Location/Address:
3201 N 23rd St
Unit 1
LINCOLN, NE 68521 USA
Phone: (402)476-7900
Fax: 402/476-7958
Email: NELIN@stores.fastenal.com

8-7-24
Date

Page 1 of 1

Figure B-15. ⅝-in. Nut, Washer, and Threaded Rod, Test Nos. HNTBR-2 and HNTBR-3 (Items e1, e2, e3)

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

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

Date: 12/13/2016

Subject: Certificate of Conformance

Product: HIT RE-500 V3 Adhesive

To Whom it May Concern:

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

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

Sincerely,

Hilti, Inc.

5400 South 122 East Avenue

Tulsa, Oklahoma 74146

800-879-8000

800-879-7000 fax

US-Sales@hilti.com

Figure B-16. Epoxy Adhesive, Test Nos. HNTBR-2 and HNTBR-3 (Item e4)

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 B-17. Joint Filler, Test Nos. HNTBR-2 and HNTBR-3 (Item e5)

Pecora 301 NS

Specification Data Sheet

PECORA CORPORATION
Architectural Waterproofing Products
U.S.A. • since 1862

Non-Sag Silicone Highway & Pavement Joint Sealant

1. BASIC USES

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

2. MANUFACTURER

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

3. PRODUCT DESCRIPTION

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

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

Advantages:

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

Limitations:

Pecora 301 NS Silicone Pavement Sealant should not be used:

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

PACKAGING

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

Color: pavement gray

SEALANT COVERAGE CHART
RECESS GUIDELINES

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

TABLE 1: TYPICAL UNCURED PROPERTIES

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

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

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

*modified section 14

Figure B-18. Expansion Joint Sealant, Test Nos. HNTBR-2 and HNTBR-3 (Item e6)

Appendix C. Vehicle Center of Gravity Determination

	Test Name: HNTBR-2	VIN:	3C6RR6KT6JG137519
Model Year: 2018	Make: RAM	Model:	1500

Vehicle CG Determination

	Vehicle Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	5216	28.306173	147645
+	Hub	19	15	285
+	Brake activation cylinder & frame	7	27.75	194.25
+	Pneumatic tank (Nitrogen)	20	27.25	545
+	Strobe/Brake Battery	5	30.5	152.5
+	Brake Receiver/Wires	5	53.25	266.25
+	CG Plate including DAQ	50	30	1500
-	Battery	-41	40.5	-1660.5
-	Oil	-12	20	-240
-	Interior	-89	29	-2581
-	Fuel	-170	20.5	-3485
-	Coolant	-13	37	-481
-	Washer fluid	-4	36.5	-146
+	Water Ballast (In Fuel Tank)			0
+	Onboard Supplemental Battery			0
				0
				0
				141994.5

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

Estimated Total Weight (lb)	4993
Vertical CG Location (in.)	28.43871

Vehicle Dimensions for C.G. Calculations

Wheel Base:	140.75 in.	Front Track Width:	67.375 in.
		Rear Track Width:	67.8125 in.

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	4995	-5.0
Longitudinal CG (in.)	63 ± 4	60.723974	-2.27603
Lateral CG (in.)	NA	-0.128557	NA
Vertical CG (in.)	28 or greater	28.44	0.43871

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	1512	1430
Rear	1134	1140
FRONT	2942	lb
REAR	2274	lb
TOTAL	5216	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	1444	1396
Rear	1063	1092
FRONT	2840	lb
REAR	2155	lb
TOTAL	4995	lb

Figure C-1. Vehicle Mass Distribution, Test No. HNTBR-2

		Test Name:	HNTBR-3	VIN:	3KPA24AB8KE215156
Model Year:	2019	Make:	Kia	Model:	Rio

Vehicle CG Determination

	Vehicle Equipment	Weight (lb)
+	Unballasted Car (Curb)	2483
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	23
+	Strobe/Brake Battery	5
+	Brake Receiver/Wires	5
+	CG Plate including DAQ	22
-	Battery	-28
-	Oil	-8
-	Interior	-86
-	Fuel	-20
-	Coolant	-8
-	Washer fluid	0
+	Water Ballast (In Fuel Tank)	
+	Onboard Supplemental Battery	

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

Estimated Total Weight (lb) 2414

Vehicle Dimensions for C.G. Calculations

Wheel Base:	101.25	in.	Front Track Width:	60.0	in.
Roof Height:	57.0	in.	Rear Track Width:	59.938	in.

Center of Gravity	1100C MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	2420 ± 55	2400	-20.0
Longitudinal CG (in.)	39 ± 4	38.053	-0.947
Lateral CG (in.)	NA	0.1	NA
Vertical CG (in.)	NA	22.375	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	790	750
Rear	473	470

FRONT	1540	lb
REAR	943	lb
TOTAL	2483	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	750	748
Rear	446	456

FRONT	1498	lb
REAR	902	lb
TOTAL	2400	lb

Figure C-2. Vehicle Mass Distribution, Test No. HNTBR-3

Appendix D. Vehicle Deformation Records

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

Model Year: 2018 | Test Name: HNTBR-2 | VIN: 3C6RR6KT6JG137519
Make: RAM | Model: 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)	71	54.4554	13.9963	-1.8504	53.8724	14.2286	-2.3144	0.5830	-0.2323	0.4640	0.7805	0.7451	X, Z
	72	55.5383	18.2426	0.3502	54.8991	18.3573	0.2335	0.6392	-0.1147	0.1167	0.6598	0.6498	X, Z
	73	56.8217	22.2886	3.9006	56.0947	22.0973	4.1003	0.7270	0.1913	-0.1997	0.7778	0.7270	X
	74	57.2690	29.7907	3.4514	54.3090	27.7882	2.5962	2.9600	2.0025	0.8552	3.6746	3.0811	X, Z
	75	57.4425	33.4061	3.3221	54.6304	30.7244	2.0699	2.8121	2.6817	1.2522	4.0826	3.0783	X, Z
	76	49.9647	12.3507	-0.9642	49.7273	12.1466	-1.1390	0.2374	0.2041	0.1748	0.3586	0.2948	X, Z
	77	51.2336	16.5028	3.3122	50.7714	16.2068	3.1940	0.4622	0.2960	0.1182	0.5614	0.4771	X, Z
	78	52.0176	21.0953	5.4057	51.3769	20.9711	5.3933	0.6407	0.1242	0.0124	0.6527	0.6408	X, Z
	79	52.2383	28.2594	5.2716	51.8683	27.8926	6.9023	0.3700	0.3668	-1.6307	1.7119	0.3700	X
	80	52.6461	32.9598	5.2402	51.2527	31.7868	5.6106	1.3934	1.1730	-0.3704	1.8587	1.3934	X
FLOOR PAN (Z)	81	46.9007	13.0411	1.4870	46.6429	12.8776	1.3703	0.2578	0.1635	0.1167	0.3268	0.1167	Z
	82	48.1747	15.6396	5.1399	47.8892	15.5331	4.9759	0.2855	0.1065	0.1640	0.3460	0.1640	Z
	83	48.3387	22.4706	5.1433	48.0357	22.3851	5.8159	0.3030	0.0855	-0.6726	0.7426	-0.6726	Z
	84	48.8197	28.4096	5.2696	48.3960	28.2513	6.6298	0.4237	0.1583	-1.3602	1.4334	-1.3602	Z
	85	49.0812	33.1859	5.3485	48.6141	32.4243	6.7045	0.4671	0.7616	-1.3560	1.6239	-1.3560	Z
	86	44.2413	13.0813	1.8426	44.0293	13.1896	1.6508	0.2120	-0.1083	0.1918	0.3057	0.1918	Z
	87	45.5408	16.0586	5.4095	45.2849	15.9490	5.3844	0.2559	0.1096	0.0251	0.2795	0.0251	Z
	88	45.0241	22.6076	5.0298	44.7715	22.5351	5.6691	0.2526	0.0725	-0.6393	0.6912	-0.6393	Z
	89	45.3354	28.5117	5.2262	45.0473	28.3072	6.8706	0.2881	0.2045	-1.6444	1.6819	-1.6444	Z
	90	45.2775	33.4328	5.3300	44.9399	33.0032	7.0208	0.3376	0.4296	-1.6908	1.7769	-1.6908	Z
	91	41.4545	13.1746	2.1746	41.2280	13.4701	1.9442	0.2265	-0.2955	0.2304	0.4378	0.2304	Z
	92	41.5999	16.3879	5.2910	41.3230	16.3082	5.2832	0.2769	0.0797	0.0078	0.2882	0.0078	Z
	93	41.3732	22.2396	5.2505	41.1085	22.1155	5.4844	0.2647	0.1241	-0.2339	0.3744	-0.2339	Z
	94	41.7718	28.4594	5.2280	41.5643	28.2822	5.9525	0.2075	0.1772	-0.7245	0.7742	-0.7245	Z
	95	41.7583	33.5830	5.3216	41.2926	33.1378	6.7803	0.4657	0.4452	-1.4587	1.5946	-1.4587	Z
	96	38.0725	13.9044	4.0315	37.7916	13.9044	3.9072	0.2809	0.0000	0.1243	0.3072	0.1243	Z
	97	38.0277	17.2627	4.5668	37.8050	17.1710	4.5965	0.2227	0.0917	-0.0297	0.2427	-0.0297	Z
	98	37.3561	22.3047	4.4712	37.1768	22.2689	4.5349	0.1793	0.0358	-0.0637	0.1936	-0.0637	Z
	99	37.1798	28.8884	4.4440	37.0229	28.8531	4.6165	0.1569	0.0353	-0.1725	0.2358	-0.1725	Z
	100	37.6122	32.9980	4.2684	37.4918	32.9590	4.9326	0.1204	0.0390	-0.6642	0.6761	-0.6642	Z

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

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

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

Pretest Floor Pan

Posttest Floor Pan

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

Test Name: HNTBR-2 VIN: 3C6RR6KT6JG137519
Model Year: 2018 Make: RAM Model: 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)	71	57.1781	28.6635	-6.4439	56.6452	28.5933	-7.1627	0.5329	0.0702	0.7188	0.8975	0.8948	X, Z
	72	58.3364	32.9098	-4.2819	57.7670	32.7430	-4.6900	0.5694	0.1668	0.4081	0.7201	0.7005	X, Z
	73	59.7036	36.9624	-0.7706	59.0619	36.5220	-0.8939	0.6417	0.4404	0.1233	0.7880	0.6534	X, Z
	74	60.2488	44.4545	-1.2760	57.3651	42.2194	-2.4745	2.8837	2.2351	1.1985	3.8403	3.1228	X, Z
	75	60.4702	48.0662	-1.4321	57.7342	45.1406	-3.0506	2.7360	2.9256	1.6185	4.3202	3.1789	X, Z
	76	52.6730	27.0853	-5.5097	52.4739	26.6050	-5.9198	0.1991	0.4803	0.4101	0.6622	0.4559	X, Z
	77	54.0330	31.2493	-1.2730	53.6271	30.7143	-1.6614	0.4059	0.5350	0.3884	0.7758	0.5618	X, Z
	78	54.8962	35.8450	0.7818	54.3361	35.5014	0.4559	0.5601	0.3436	0.3259	0.7335	0.6480	X, Z
	79	55.2129	43.0044	0.5956	54.9635	42.4361	1.8494	0.2494	0.5683	-1.2538	1.3990	0.2494	X
	80	55.6841	47.6985	0.5279	54.4063	46.3196	0.5003	1.2778	1.3789	0.0276	1.8801	1.2781	X, Z
FLOOR PAN (Z)	81	49.6387	27.8342	-3.0387	49.4245	27.4310	-3.3972	0.2142	0.4032	0.3585	0.5805	0.3585	Z
	82	50.9778	30.4404	0.5854	50.7487	30.1208	0.1548	0.2291	0.3196	0.4306	0.5831	0.4306	Z
	83	51.2343	37.2684	0.5395	51.0243	36.9816	0.8834	0.2100	0.2868	-0.3439	0.4946	-0.3439	Z
	84	51.7967	43.2010	0.6203	51.4959	42.8526	1.5998	0.3008	0.3484	-0.9795	1.0823	-0.9795	Z
	85	52.1236	47.9738	0.6635	51.7889	47.0217	1.6057	0.3347	0.9521	-0.9422	1.3807	-0.9422	Z
	86	46.9832	27.9131	-2.6619	46.8194	27.7943	-3.1003	0.1638	0.1188	0.4384	0.4828	0.4384	Z
	87	48.3521	30.8970	0.8734	48.1557	30.5898	0.5780	0.1964	0.3072	0.2954	0.4693	0.2954	Z
	88	47.9211	37.4497	0.4520	47.7622	37.1878	0.7611	0.1589	0.2619	-0.3091	0.4352	-0.3091	Z
	89	48.3139	43.3503	0.6043	48.1509	42.9724	1.8673	0.1630	0.3779	-1.2630	1.3284	-1.2630	Z
	90	48.3235	48.2723	0.6741	48.1284	47.6714	1.9429	0.1951	0.6009	-1.2688	1.4174	-1.2688	Z
	91	44.2007	28.0466	-2.3079	44.0261	28.1296	-2.7883	0.1746	-0.0830	0.4804	0.5178	0.4804	Z
	92	44.4152	31.2791	0.7845	44.2001	31.0184	0.5037	0.2151	0.2607	0.2808	0.4394	0.2808	Z
	93	44.2674	37.1330	0.7048	44.0908	36.8311	0.6134	0.1766	0.3019	0.0914	0.3615	0.0914	Z
	94	44.7501	43.3464	0.6355	44.6603	42.9953	0.9784	0.0898	0.3511	-0.3429	0.4989	-0.3429	Z
	95	44.8068	48.4702	0.6932	44.4822	47.8676	1.7304	0.3246	0.6026	-1.0372	1.2427	-1.0372	Z
	96	40.8442	28.8352	-0.4289	40.6149	28.6567	-0.8042	0.2293	0.1785	0.3753	0.4746	0.3753	Z
	97	40.8494	32.1974	0.0832	40.6924	31.9332	-0.1677	0.1570	0.2642	0.2509	0.3967	0.2509	Z
	98	40.2453	37.2473	-0.0423	40.1545	37.0399	-0.3060	0.0908	0.2074	0.2637	0.3476	0.2637	Z
	99	40.1580	43.8324	-0.1144	40.1186	43.6262	-0.3291	0.0394	0.2062	0.2147	0.3003	0.2147	Z
	100	40.6446	47.9344	-0.3223									Z

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

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

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

Pretest Floor Pan	Posttest Floor Pan
	

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

Test Name: HNTBR-2 VIN: 3C6RR6KT6JG137519
Model Year: 2018 Make: RAM Model: 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)	101	51.3026	33.7062	-26.6256	50.9257	33.9331	-27.8616	0.3769	-0.2269	-1.2360	1.3120	1.3120	X, Y, Z
	102	49.3718	21.4476	-26.2782	49.1542	21.7181	-27.2622	0.2176	-0.2705	-0.9840	1.0434	1.0434	X, Y, Z
	103	50.0298	4.6535	-27.7969	50.0281	4.8324	-28.3897	0.0017	-0.1789	-0.5928	0.6192	0.6192	X, Y, Z
	104	46.1256	34.2084	-15.8536	45.2507	34.3169	-17.3286	0.8749	-0.1085	-1.4750	1.7184	1.7184	X, Y, Z
	105	45.3443	22.2013	-16.0535	45.0047	22.2718	-17.2218	0.3396	-0.0705	-1.1683	1.2187	1.2187	X, Y, Z
	106	43.4231	4.8697	-19.9985	43.2998	5.1532	-20.5640	0.1233	-0.2835	-0.5655	0.6445	0.6445	X, Y, Z
SIDE PANEL (Y)	107	55.4304	36.1761	-1.9049	53.3901	32.3536	-3.1389	2.0403	3.8225	-1.2340	4.5052	3.8225	Y
	108	59.1132	36.0999	-0.1124	57.0221	31.7281	-1.6387	2.0911	4.3718	-1.5263	5.0808	4.3718	Y
	109	54.7652	36.0674	2.7978	53.4734	33.1656	1.7549	1.2918	2.9018	-1.0429	3.3432	2.9018	Y
IMPACT SIDE DOOR (Y)	110	23.3582	38.6361	-17.5730	22.1692	42.2933	-17.8666	1.1890	-3.6572	-0.2936	3.8568	-3.6572	Y
	111	30.6222	38.5619	-17.6762	29.3478	41.2885	-18.1835	1.2744	-2.7266	-0.5073	3.0522	-2.7266	Y
	112	42.2261	38.4663	-15.8238	40.8643	39.2768	-16.7124	1.3618	-0.8105	-0.8886	1.8169	-0.8105	Y
	113	23.5235	38.7838	-2.0300	22.5468	41.4339	-2.2003	0.9767	-2.6501	-0.1703	2.8295	-2.6501	Y
	114	31.0611	39.5803	-3.1634	30.0636	40.6615	-3.6587	0.9975	-1.0812	-0.4953	1.5522	-1.0812	Y
	115	40.5211	39.5318	-1.7503	39.4301	39.0266	-2.6309	1.0910	0.5052	-0.8806	1.4903	0.5052	Y
ROOF - (Z)	116	42.0369	5.4673	-42.8976	42.1228	5.7987	-43.0441	-0.0859	-0.3314	-0.1465	0.3724	-0.1465	Z
	117	40.8497	16.9680	-42.7089	40.9382	17.2706	-42.9480	-0.0885	-0.3026	-0.2391	0.3957	-0.2391	Z
	118	38.2915	26.6105	-42.2989	38.3022	26.8741	-42.6833	-0.0107	-0.2636	-0.3844	0.4662	-0.3844	Z
	119	35.0909	5.1853	-45.7673	35.1859	5.4804	-45.9295	-0.0950	-0.2951	-0.1622	0.3499	-0.1622	Z
	120	34.2112	15.4087	-45.5896	34.2747	15.7280	-45.8214	-0.0635	-0.3193	-0.2318	0.3996	-0.2318	Z
	121	31.9828	24.9424	-45.2137	31.9721	25.2069	-45.5283	0.0107	-0.2645	-0.3146	0.4112	-0.3146	Z
	122	17.5090	3.3920	-47.3411	17.6562	3.5397	-47.4687	-0.1472	-0.1477	-0.1276	0.2445	-0.1276	Z
	123	16.8762	12.1181	-47.2163	16.9456	12.2230	-47.3758	-0.0694	-0.1049	-0.1595	0.2031	-0.1595	Z
	124	16.6430	21.5292	-46.7707	16.6479	21.6563	-47.0172	-0.0049	-0.1271	-0.2465	0.2774	-0.2465	Z
	125	-4.5841	3.8010	-47.6041	-4.5286	3.8502	-47.7101	-0.0555	-0.0492	-0.1060	0.1294	-0.1060	Z
	126	-4.6801	12.2840	-47.4907	-4.7149	12.3066	-47.6360	0.0348	-0.0226	-0.1453	0.1511	-0.1453	Z
	127	-4.8435	21.4710	-47.1327	-4.8232	21.4643	-47.2950	-0.0203	0.0067	-0.1623	0.1637	-0.1623	Z
	128	-20.6254	3.2285	-47.1013	-20.5469	3.1616	-47.1622	-0.0785	0.0669	-0.0609	0.1198	-0.0609	Z
	129	-21.0112	10.6698	-47.0307	-20.9545	10.6510	-47.1465	-0.0567	0.0188	-0.1158	0.1303	-0.1158	Z
	130	-21.3439	21.2042	-46.6927	-21.4127	21.1625	-46.8300	0.0688	0.0417	-0.1373	0.1591	-0.1373	Z
A-PILLAR Maximum (X, Y, Z)	131	37.8760	31.0201	-39.8448	37.8972	31.4956	-40.3112	-0.0212	-0.4755	-0.4664	0.6664	0.0000	NA
	132	42.1237	32.2830	-38.3232	42.1388	32.7885	-38.8822	-0.0151	-0.5055	-0.5590	0.7538	0.0000	NA
	133	44.4318	32.0952	-35.7801	44.4896	32.6481	-36.4213	-0.0578	-0.5529	-0.6412	0.8486	0.0000	NA
	134	48.4515	33.7575	-34.0698	48.4873	34.3665	-34.7526	-0.0358	-0.6090	-0.6828	0.9156	0.0000	NA
	135	51.8538	34.3911	-29.7605	51.8540	34.9182	-30.4171	-0.0002	-0.5271	-0.6566	0.8420	0.0000	NA
	136	55.0272	35.0316	-27.4436	55.1211	35.6124	-27.9947	-0.0939	-0.5808	-0.5511	0.8061	0.0000	NA
A-PILLAR Lateral (Y)	131	37.8760	31.0201	-39.8448	37.8972	31.4956	-40.3112	-0.0212	-0.4755	-0.4664	0.6664	-0.4755	Y
	132	42.1237	32.2830	-38.3232	42.1388	32.7885	-38.8822	-0.0151	-0.5055	-0.5590	0.7538	-0.5055	Y
	133	44.4318	32.0952	-35.7801	44.4896	32.6481	-36.4213	-0.0578	-0.5529	-0.6412	0.8486	-0.5529	Y
	134	48.4515	33.7575	-34.0698	48.4873	34.3665	-34.7526	-0.0358	-0.6090	-0.6828	0.9156	-0.6090	Y
	135	51.8538	34.3911	-29.7605	51.8540	34.9182	-30.4171	-0.0002	-0.5271	-0.6566	0.8420	-0.5271	Y
	136	55.0272	35.0316	-27.4436	55.1211	35.6124	-27.9947	-0.0939	-0.5808	-0.5511	0.8061	-0.5808	Y
B-PILLAR Maximum (X, Y, Z)	137	13.8927	32.6878	-36.2314	13.8105	32.9000	-36.3806	0.0822	-0.2122	-0.1492	0.2721	0.0822	X
	138	12.0709	35.0937	-28.6400	11.9975	35.2849	-28.8330	0.0734	-0.1912	-0.1930	0.2814	0.0734	X
	139	15.2343	35.5229	-23.0427	15.1419	35.7239	-23.1702	0.0924	-0.2010	-0.1275	0.2553	0.0924	X
	140	12.0364	35.7810	-15.5899	11.9324	35.8867	-15.7162	0.1040	-0.1057	-0.1263	0.1948	0.1040	X
B-PILLAR Lateral (Y)	137	13.8927	32.6878	-36.2314	13.8105	32.9000	-36.3806	0.0822	-0.2122	-0.1492	0.2721	-0.2122	Y
	138	12.0709	35.0937	-28.6400	11.9975	35.2849	-28.8330	0.0734	-0.1912	-0.1930	0.2814	-0.1912	Y
	139	15.2343	35.5229	-23.0427	15.1419	35.7239	-23.1702	0.0924	-0.2010	-0.1275	0.2553	-0.2010	Y
	140	12.0364	35.7810	-15.5899	11.9324	35.8867	-15.7162	0.1040	-0.1057	-0.1263	0.1948	-0.1057	Y

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

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

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

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

Test Name: HNTBR-2 | VIN: 3C6RR6KT6JG137519

Model Year: 2018 | Make: RAM | Model: 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)	101	54.0897	48.2428	-31.3304	53.8319	47.9381	-32.9982	0.2578	0.3047	-1.6678	1.7149	1.7149	X, Y, Z
	102	51.9959	36.0144	-30.8814	51.8484	35.7680	-32.1879	0.1475	0.2464	-1.3065	1.3377	1.3377	X, Y, Z
	103	52.4138	19.2027	-32.2874	52.4119	18.8535	-33.0510	0.0019	0.3492	-0.7636	0.8397	0.8397	X, Y, Z
	104	49.0084	48.8898	-20.5206	48.2547	48.5914	-22.4262	0.7537	0.2984	-1.9056	2.0708	2.0708	X, Y, Z
	105	48.0629	36.8934	-20.6298	47.7953	36.5558	-22.1238	0.2676	0.3376	-1.4940	1.5549	1.5549	X, Y, Z
	106	45.8748	19.5627	-24.4375	45.7574	19.4195	-25.1762	0.1174	0.1432	-0.7387	0.7616	0.7616	X, Y, Z
SIDE PANEL (Y)	107	58.4531	50.8271	-6.6620	56.4787	46.7086	-8.2744	1.9744	4.1185	-1.6124	4.8436	4.1185	Y
	108	62.1490	50.7132	-4.8988	60.1116	46.0421	-6.7944	2.0374	4.6711	-1.8956	5.4372	4.6711	Y
	109	57.8250	50.7599	-1.9534	56.6182	47.5968	-3.3952	1.2068	3.1631	-1.4418	3.6797	3.1631	Y
IMPACT SIDE DOOR (Y)	110	26.2897	53.6149	-22.0865	25.3152	56.9710	-22.9020	0.9745	-3.3561	-0.8155	3.5886	-3.3561	Y
	111	33.5510	53.4412	-22.2480	32.4718	55.8326	-23.2619	1.0792	-2.3914	-1.0139	2.8127	-2.3914	Y
	112	45.1673	53.2005	-20.4891	43.9628	53.6384	-21.8537	1.2045	-0.4379	-1.3646	1.8721	-0.4379	Y
	113	26.5844	53.8677	-6.5468	25.8111	56.3545	-7.2276	0.7733	-2.4868	-0.6808	2.6918	-2.4868	Y
	114	34.1226	54.5538	-7.7468	33.3003	55.4243	-8.7353	0.8223	-0.8705	-0.9885	1.5528	-0.8705	Y
	115	43.5923	54.3864	-6.4101	42.6446	53.6382	-7.7587	0.9477	0.7482	-1.3486	1.8102	0.7482	Y
ROOF - (Z)	116	44.3092	20.0208	-47.3282	44.4002	19.7279	-47.6533	-0.0910	0.2929	-0.3251	0.4469	-0.3251	Z
	117	43.2795	31.5377	-47.2106	43.4209	31.2193	-47.7319	-0.1414	0.3184	-0.5213	0.6270	-0.5213	Z
	118	40.8555	41.2167	-46.8476	40.9587	40.8716	-47.5999	-0.1032	0.3451	-0.7523	0.8341	-0.7523	Z
	119	37.3367	19.8136	-50.1394	37.4344	19.4882	-50.4759	-0.0977	0.3254	-0.3365	0.4782	-0.3365	Z
	120	36.5970	30.0490	-50.0264	36.7068	29.7509	-50.5251	-0.1098	0.2981	-0.4987	0.5913	-0.4987	Z
	121	34.5012	39.6144	-49.6994	34.5758	39.2731	-50.3653	-0.0746	0.3413	-0.6659	0.7520	-0.6659	Z
	122	19.7198	18.2488	-51.5581	19.8604	17.8380	-51.8391	-0.1406	0.4108	-0.2810	0.5172	-0.2810	Z
	123	19.2063	26.9834	-51.4894	19.3054	26.5330	-51.8799	-0.0991	0.4504	-0.3905	0.6043	-0.3905	Z
	124	19.1043	36.3996	-51.1080	19.1787	35.9747	-51.6705	-0.0744	0.4249	-0.5625	0.7089	-0.5625	Z
	125	-2.3671	18.9565	-51.6450	-2.3166	18.5425	-51.9024	-0.0505	0.4140	-0.2574	0.4901	-0.2574	Z
	126	-2.3473	27.4406	-51.5903	-2.3517	27.0010	-51.9627	0.0044	0.4396	-0.3724	0.5762	-0.3724	Z
	127	-2.3833	36.6312	-51.2955	-2.2940	36.1635	-51.7681	-0.0893	0.4677	-0.4726	0.6709	-0.4726	Z
	128	-18.4101	18.6057	-51.0082	-18.3394	18.1503	-51.2114	-0.0707	0.4554	-0.2032	0.5037	-0.2032	Z
	129	-18.6944	26.0520	-50.9866	-18.6134	25.6450	-51.3127	-0.0810	0.4070	-0.3261	0.5278	-0.3261	Z
	130	-18.8816	36.5920	-50.7199	-18.8816	36.1668	-51.1615	0.0000	0.4252	-0.4416	0.6130	-0.4416	Z
A-PILLAR Maximum (X, Y, Z)	131	40.5200	45.6484	-44.4212	40.6562	45.5368	-45.2991	-0.1362	0.1116	-0.8779	0.8954	0.1116	Y
	132	44.7967	46.8638	-42.9430	44.9323	46.7760	-43.9260	-0.1356	0.0878	-0.9830	0.9962	0.0878	Y
	133	47.1229	46.6622	-40.4174	47.3012	46.6327	-41.4827	-0.1783	0.0295	-1.0653	1.0805	0.0295	Y
	134	51.1785	48.2815	-38.7514	51.3429	48.3054	-39.8749	-0.1644	-0.0239	-1.1235	1.1357	0.0000	NA
	135	54.6244	48.8985	-34.4744	54.7558	48.8656	-35.5767	-0.1314	0.0329	-1.1023	1.1106	0.0329	Y
	136	57.8250	49.5118	-32.1878	58.0553	49.5396	-33.1929	-0.2303	-0.0278	-1.0051	1.0315	0.0000	NA
A-PILLAR Lateral (Y)	131	40.5200	45.6484	-44.4212	40.6562	45.5368	-45.2991	-0.1362	0.1116	-0.8779	0.8954	0.1116	Y
	132	44.7967	46.8638	-42.9430	44.9323	46.7760	-43.9260	-0.1356	0.0878	-0.9830	0.9962	0.0878	Y
	133	47.1229	46.6622	-40.4174	47.3012	46.6327	-41.4827	-0.1783	0.0295	-1.0653	1.0805	0.0295	Y
	134	51.1785	48.2815	-38.7514	51.3429	48.3054	-39.8749	-0.1644	-0.0239	-1.1235	1.1357	-0.0239	Y
	135	54.6244	48.8985	-34.4744	54.7558	48.8656	-35.5767	-0.1314	0.0329	-1.1023	1.1106	0.0329	Y
	136	57.8250	49.5118	-32.1878	58.0553	49.5396	-33.1929	-0.2303	-0.0278	-1.0051	1.0315	-0.0278	Y
B-PILLAR Maximum (X, Y, Z)	137	16.5919	47.6671	-40.6254	16.6328	47.4355	-41.1930	-0.0409	0.2316	-0.5676	0.6144	0.2316	Y
	138	14.8652	50.1500	-33.0365	14.9270	49.9724	-33.6700	-0.0618	0.1776	-0.6335	0.6608	0.1776	Y
	139	18.0799	50.5748	-27.4682	18.1270	50.4450	-28.0411	-0.0471	0.1298	-0.5729	0.5893	0.1298	Y
	140	14.9469	50.9278	-19.9917	14.9846	50.7840	-20.5645	-0.0377	0.1438	-0.5728	0.5918	0.1438	Y
B-PILLAR Lateral (Y)	137	16.5919	47.6671	-40.6254	16.6328	47.4355	-41.1930	-0.0409	0.2316	-0.5676	0.6144	0.2316	Y
	138	14.8652	50.1500	-33.0365	14.9270	49.9724	-33.6700	-0.0618	0.1776	-0.6335	0.6608	0.1776	Y
	139	18.0799	50.5748	-27.4682	18.1270	50.4450	-28.0411	-0.0471	0.1298	-0.5729	0.5893	0.1298	Y
	140	14.9469	50.9278	-19.9917	14.9846	50.7840	-20.5645	-0.0377	0.1438	-0.5728	0.5918	0.1438	Y

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

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

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

Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. HNTBR-2

Test Name: HNTBR-2 VIN: 3C6RR6KT6JG137519

Model Year: 2018 Make: RAM Model: 1500

Passenger Side Maximum Deformation							
Reference Set 1				**Reference Set 2**			
Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]	Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Roof	-0.4	≤ 4	Z	Roof	-0.8	≤ 4	Z
Windshield[D]	0.0	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	0.0	≤ 5	NA	A-Pillar Maximum	0.1	≤ 5	Y
A-Pillar Lateral	-0.6	≤ 3	Y	A-Pillar Lateral	0.1	≤ 3	Y
B-Pillar Maximum	0.1	≤ 5	X	B-Pillar Maximum	0.2	≤ 5	Y
B-Pillar Lateral	-0.2	≤ 3	Y	B-Pillar Lateral	0.2	≤ 3	Y
Toe Pan - Wheel Well	3.1	≤ 9	X, Z	Toe Pan - Wheel Well	3.2	≤ 9	X, Z
Side Front Panel	4.4	≤ 12	Y	Side Front Panel	4.7	≤ 12	Y
Side Door (above seat)	-3.7	≤ 9	Y	Side Door (above seat)	-3.4	≤ 9	Y
Side Door (below seat)	0.5	≤ 12	Y	Side Door (below seat)	0.7	≤ 12	Y
Floor Pan	0.2	≤ 12	Z	Floor Pan	0.5	≤ 12	Z
Dash - no MASH requirement	1.7	NA	X, Y, Z	Dash - no MASH requirement	2.1	NA	X, Y, Z

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

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

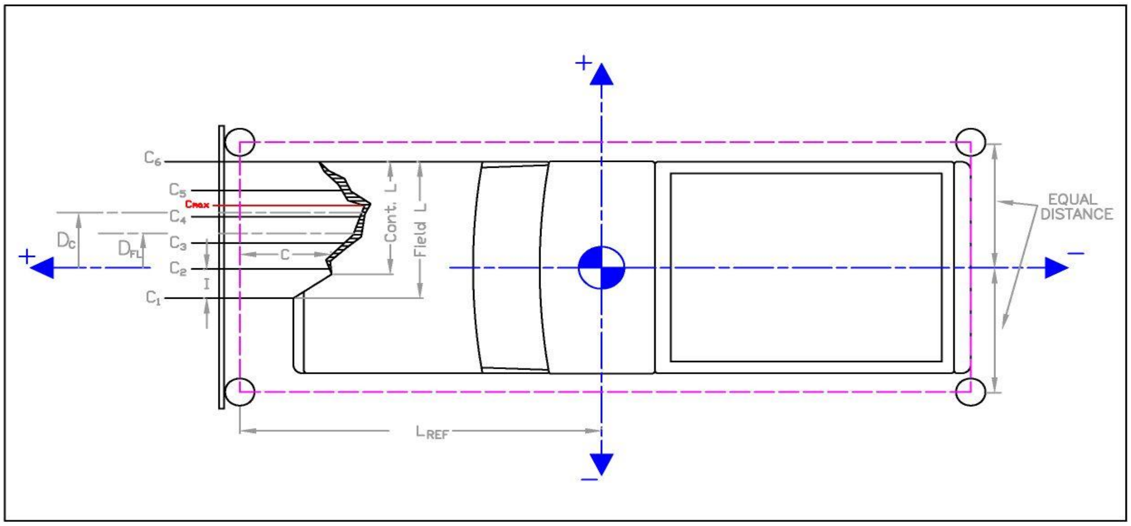
[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include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

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

Notes on vehicle interior crush:

Figure D-5. Maximum Occupant Compartment Deformations by Location, Test No. HNTBR-2

		Test Name: HNTBR-2	VIN: 3C6RR6KT6JG137519
Model Year: 2018		Make: RAM	Model: 1500



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	116	(2946)
Total Vehicle Width:	76 3/4	(1949)
Width of contact and induced crush - Field L:	76 3/4	(1949)
Crush measurement spacing interval (L/5) - I:	15 3/8	(391)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	23 3/8	(594)
Distance from center of vehicle to center of contact damage - D_C:	26 2/3	(678)

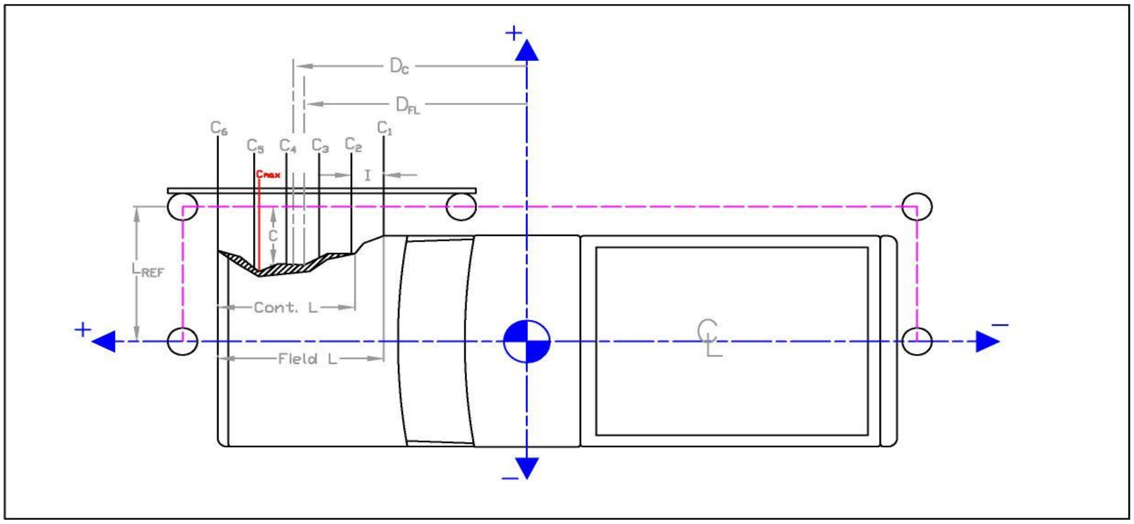
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	N/a	N/A	-38 3/8	-(975)	22 1/2	(572)	11 1/2	(292)	N/A	N/A
C_2	23	(584)	-23	-(584)	6 1/2	(165)			5	(127)
C_3	20 5/8	(524)	-7 5/8	-(194)	4 1/4	(108)			4 7/8	(124)
C_4	20 1/2	(521)	7 3/4	(197)	4 1/4	(108)			4 3/4	(121)
C_5	25	(635)	23 1/8	(587)	6 1/8	(156)			7 3/8	(187)
C_6	N/a	N/A	38 1/2	(978)	20 1/2	(521)			N/A	N/A
C_{MAX}	29	(737)	28	(711)	8	(203)			9 1/2	(241)

Figure D-6. Exterior Vehicle Crush (NASS) – Front, Test No. HNTBR-2

Test Name: HNTBR-2 | VIN: 3C6RR6KT6JG137519

Model Year: 2018 | Make: RAM | Model: 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	48	(1219)
Total Vehicle Length:	229 1/4	(5823)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-12 1/4	-(311)
Width of contact and induced crush - Field L:	229 1/4	(5823)
Crush measurement spacing interval (L/5) - I:	45 7/8	(1165)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-12 1/4	-(311)
Width of Contact Damage:	229 1/4	(5823)
Distance from vehicle c.g. to center of contact damage - D_C:	-12 1/4	-(311)

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	12 1/4	(311)	-126 7/8	-(3223)	33 1/2	(851)	4	(102)	-25 1/4	-(641)
C_2	N/a	N/A	-81	-(2057)	5 1/2	(140)			N/A	N/A
C_3	8 1/2	(216)	-35 1/8	-(892)	5 7/8	(149)			-1 3/8	-(35)
C_4	8 5/8	(219)	10 3/4	(273)	5	(127)			- 3/8	-(10)
C_5	N/a	N/A	56 5/8	(1438)	5 5/8	(143)			N/A	N/A
C_6	N/a	N/A	102 1/2	(2604)	13 1/4	(337)			N/A	N/A
C_{MAX}	19 1/2	(495)	80	(2032)	5 1/2	(140)			10	(254)

Figure D-7. Exterior Vehicle Crush (NASS) – Side, Test No. HNTBR-2

Test Name: HNTBR-3 VIN: 3KPA24AB8KE215156
Model Year: 2019 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)	71	87.7776	24.7223	5.1815	87.6365	24.0150	4.7165	0.1411	0.7073	0.4650	0.8581	0.4859	X, Z
	72	88.2306	29.6761	4.8153	87.9394	28.7761	4.0795	0.2912	0.9000	0.7358	1.1984	0.7913	X, Z
	73	87.7811	33.4985	4.1425	87.2688	32.5147	3.1549	0.5123	0.9838	0.9876	1.4851	1.1126	X, Z
	74	88.0855	36.1177	3.9198	87.8032	35.1375	3.1059	0.2823	0.9802	0.8139	1.3050	0.8615	X, Z
	75	87.7844	39.2958	3.7604	87.2108	38.2351	2.6282	0.5736	1.0607	1.1322	1.6541	1.2692	X, Z
	76	81.4630	25.3447	8.9684	81.3754	24.9848	8.1254	0.0876	0.3599	0.8430	0.9208	0.8475	X, Z
	77	81.7132	30.5406	8.8200	81.5618	29.7614	8.2462	0.1514	0.7792	0.5738	0.9794	0.5934	X, Z
	78	81.8464	34.0747	7.7889	81.6463	33.3540	7.1856	0.2001	0.7207	0.6033	0.9609	0.6356	X, Z
	79	82.0082	37.7960	8.6611	81.9635	37.0189	7.9200	0.0447	0.7771	0.7411	1.0748	0.7424	X, Z
	80	82.3320	40.8320	8.5022	82.4309	40.2768	7.5630	-0.0989	0.5552	0.9392	1.0955	0.9392	Z
FLOOR PAN (Z)	81	75.5045	25.0147	9.6140	75.5822	24.6024	9.0428	-0.0777	0.4123	0.5712	0.7087	0.5712	Z
	82	76.0892	30.8234	9.8619	76.0037	30.1604	9.5453	0.0855	0.6630	0.3166	0.7397	0.3166	Z
	83	76.6939	34.4489	8.7003	76.5960	33.7308	8.2622	0.0979	0.7181	0.4381	0.8469	0.4381	Z
	84	76.4180	38.2301	9.7809	76.4643	37.5127	9.2226	-0.0463	0.7174	0.5583	0.9102	0.5583	Z
	85	76.4293	41.2992	9.7598	76.4727	40.6283	9.0353	-0.0434	0.6709	0.7245	0.9884	0.7245	Z
	86	72.2011	24.9319	9.7609	72.2923	24.5171	9.0964	-0.0912	0.4148	0.6645	0.7886	0.6645	Z
	87	72.4350	30.7679	9.8645	72.4061	30.0552	9.4075	0.0289	0.7127	0.4570	0.8471	0.4570	Z
	88	72.1156	34.5822	8.8587	72.1686	33.8928	8.6385	-0.0530	0.6894	0.2202	0.7257	0.2202	Z
	89	71.8806	38.5094	9.7939	71.8754	37.9095	9.3416	0.0052	0.5999	0.4523	0.7513	0.4523	Z
	90	71.1394	42.7650	9.8258	71.2161	42.1558	9.0590	-0.0767	0.6092	0.7668	0.9823	0.7668	Z
	91	68.9706	24.7433	9.9181	68.9846	24.2971	9.1660	-0.0140	0.4462	0.7521	0.8746	0.7521	Z
	92	68.1373	31.1836	9.9900	68.1851	30.6478	10.0089	-0.0478	0.5358	-0.0189	0.5383	-0.0189	Z
	93	67.9125	34.8673	9.0407	68.0372	34.3417	8.6797	-0.1247	0.5256	0.3610	0.6497	0.3610	Z
	94	67.9074	38.8325	10.0018	68.0239	38.3142	9.6144	-0.1165	0.5183	0.3874	0.6575	0.3874	Z
	95	68.0140	42.8954	9.9435	68.0652	42.3805	9.1485	-0.0512	0.5149	0.7950	0.9486	0.7950	Z
	96	65.6453	24.7315	10.0301	65.7969	24.4272	9.2213	-0.1516	0.3043	0.8088	0.8773	0.8088	Z
	97	65.7806	31.3407	10.0885	65.8533	31.0298	9.6005	-0.0727	0.3109	0.4880	0.5832	0.4880	Z
	98	65.5490	34.8078	9.1469	65.6015	34.3703	8.8273	-0.0525	0.4375	0.3196	0.5443	0.3196	Z
	99	65.4062	39.1571	10.0439	65.6876	39.3225	9.5810	-0.2814	-0.1654	0.4629	0.5664	0.4629	Z
	100	65.4980	42.9071	10.0155	65.5516	42.4382	9.3404	-0.0536	0.4689	0.6751	0.8237	0.6751	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.
[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.
[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan	Posttest Floor Pan
	

Figure D-8. Floor Pan Deformation Data – Set 1, Test No. HNTBR-3

Model Year: 2019 | Test Name: HNTBR-3 | VIN: 3KPA24AB8KE215156
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)	71	88.5057	-1.8978	5.2693	88.4887	-1.9779	4.0230	0.0170	-0.0801	1.2463	1.2490	1.2464	X, Z
	72	88.9592	3.0622	5.0020	88.7636	2.7826	3.3692	0.1956	0.2796	1.6328	1.6681	1.6445	X, Z
	73	88.5094	6.8975	4.4068	88.0660	6.5157	2.4425	0.4434	0.3818	1.9643	2.0496	2.0137	X, Z
	74	88.8140	9.5206	4.2363	88.5886	9.1406	2.3798	0.2254	0.3800	1.8565	1.9083	1.8701	X, Z
	75	88.5134	12.7012	4.1413	87.9772	12.2344	1.9008	0.5362	0.4668	2.2405	2.3506	2.3038	X, Z
	76	82.1976	-1.3505	9.0785	82.2655	-1.0249	7.5053	-0.0679	0.3256	1.5732	1.6080	1.5732	Z
	77	82.4488	3.8473	9.0342	82.4331	3.7528	7.6106	0.0157	0.0945	1.4236	1.4268	1.4237	X, Z
	78	82.5809	7.4014	8.0741	82.4894	7.3427	6.5391	0.0915	0.0587	1.5350	1.5388	1.5377	X, Z
	79	82.7451	11.1044	9.0205	82.8000	11.0110	7.2594	-0.0549	0.0934	1.7611	1.7644	1.7611	Z
	80	83.0692	14.1429	8.9221	83.2492	14.2698	6.8878	-0.1800	-0.1269	2.0343	2.0462	2.0343	Z
FLOOR PAN (Z)	81	76.2401	-1.6922	9.7273	76.4856	-1.4290	8.4942	-0.2455	0.2632	1.2331	1.2846	1.2331	Z
	82	76.8265	4.1102	10.0909	76.8896	4.1321	8.9762	-0.0631	-0.0219	1.1147	1.1167	1.1147	Z
	83	77.4301	7.7582	9.0013	77.4511	7.7013	7.6761	-0.0210	0.0569	1.3252	1.3266	1.3252	Z
	84	77.1568	11.5170	10.1581	77.3150	11.4853	8.6276	-0.1582	0.0317	1.5305	1.5390	1.5305	Z
	85	77.1688	14.5859	10.1987	77.3079	14.6004	8.4316	-0.1391	-0.0145	1.7671	1.7726	1.7671	Z
	86	72.9369	-1.7773	9.8782	73.1970	-1.5281	8.5882	-0.2601	0.2492	1.2900	1.3393	1.2900	Z
	87	73.1723	4.0553	10.0985	73.2910	4.0113	8.8825	-0.1187	0.0440	1.2160	1.2226	1.2160	Z
	88	72.8521	7.8891	9.1701	73.0279	7.8457	8.1058	-0.1758	0.0434	1.0643	1.0796	1.0643	Z
	89	72.6195	11.7968	10.1844	72.7263	11.8631	8.8014	-0.1068	-0.0663	1.3830	1.3887	1.3830	Z
	90	71.8793	16.0510	10.3030	72.0455	16.1058	8.5151	-0.1662	-0.0548	1.7879	1.7964	1.7879	Z
	91	69.7067	-1.9685	10.0369	69.8913	-1.7618	8.6986	-0.1846	0.2067	1.3383	1.3667	1.3383	Z
	92	68.8750	4.4692	10.2396	69.0752	4.5878	9.5337	-0.2002	-0.1186	0.7059	0.7433	0.7059	Z
	93	68.6493	8.1713	9.3648	68.8955	8.2773	8.1962	-0.2462	-0.1060	1.1686	1.1989	1.1686	Z
	94	68.6467	12.1164	10.4054	68.8766	12.2523	9.1199	-0.2299	-0.1359	1.2855	1.3129	1.2855	Z
	95	68.7541	16.1796	10.4285	68.8950	16.3175	8.6423	-0.1409	-0.1379	1.7862	1.7970	1.7862	Z
	96	66.3816	-1.9820	10.1542	66.7040	-1.6450	8.7924	-0.3224	0.3370	1.3618	1.4394	1.3618	Z
	97	66.5184	4.6247	10.3451	66.7370	4.9589	9.1527	-0.2186	-0.3342	1.1924	1.2575	1.1924	Z
	98	66.2860	8.1101	9.4737	66.4616	8.2961	8.3734	-0.1756	-0.1860	1.1003	1.1296	1.1003	Z
	99	66.1457	12.4405	10.4581	66.5359	13.2506	9.1122	-0.3902	-0.8101	1.3459	1.6186	1.3459	Z
	100	66.2382	16.1903	10.5050	66.3837	16.3651	8.8646	-0.1455	-0.1748	1.6404	1.6561	1.6404	Z

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

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

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

Pretest Floor Pan	Posttest Floor Pan
	

Figure D-9. Floor Pan Deformation Data – Set 2, Test No. HNTBR-3

Test Name: HNTBR-3 | VIN: 3KPA24AB8KE215156

Model Year: 2019 | 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)	101	75.1993	41.3611	-19.0681	75.6024	41.0831	-20.5491	-0.4031	0.2780	-1.4810	1.5599	1.5599	X, Y, Z
	102	74.8982	31.3499	-19.8176	75.2056	31.0458	-21.1019	-0.3074	0.3041	-1.2843	1.3551	1.3551	X, Y, Z
	103	74.9044	21.8166	-20.0652	75.2116	21.5191	-21.1591	-0.3072	0.2975	-1.0939	1.1745	1.1745	X, Y, Z
	104	72.5353	42.2926	-12.7319	72.5874	42.1012	-14.2601	-0.0521	0.1914	-1.5282	1.5410	1.5410	X, Y, Z
	105	71.4065	31.7710	-12.1521	71.7510	31.5421	-13.3706	-0.3445	0.2289	-1.2185	1.2868	1.2868	X, Y, Z
	106	71.0131	22.7992	-12.0456	71.6911	22.5879	-12.9062	-0.6780	0.2113	-0.8606	1.1158	1.1158	X, Y, Z
SIDE PANEL (Y)	107	79.9981	45.2302	1.6217	79.9355	44.5105	0.5696	0.0626	0.7197	-1.0521	1.2762	0.7197	Y
	108	78.7612	45.4219	3.5218	78.7570	44.6383	2.4385	0.0042	0.7836	-1.0833	1.3370	0.7836	Y
	109	81.4489	45.3713	3.7113	81.8802	44.3351	2.2708	-0.4313	1.0362	-1.4405	1.8261	1.0362	Y
IMPACT SIDE DOOR (Y)	110	72.1583	46.1578	-17.2745	72.0258	45.7845	-18.3023	0.1325	0.3733	-1.0278	1.1015	0.3733	Y
	111	61.6195	47.4504	-18.2429	61.5119	47.0632	-19.0751	0.1076	0.3872	-0.8322	0.9242	0.3872	Y
	112	50.6225	47.8152	-18.6072	50.4650	47.2982	-19.2847	0.1575	0.5170	-0.6775	0.8667	0.5170	Y
	113	74.7261	46.9158	1.0156	74.8902	47.2119	-0.0076	-0.1641	-0.2961	-1.0232	1.0777	-0.2961	Y
	114	61.6193	47.9332	3.8678	61.9070	47.5894	2.7756	-0.2877	0.3438	-1.0922	1.1806	0.3438	Y
	115	54.4479	48.3016	3.9072	54.6410	47.3834	3.1191	-0.1931	0.9182	-0.7881	1.2253	0.9182	Y
ROOF - (Z)	116	63.4379	19.6328	-34.3671	63.2665	20.2447	-34.9814	0.1714	-0.6119	-0.6143	0.8838	-0.6143	Z
	117	63.4649	25.9050	-34.2538	63.1841	26.5140	-35.0528	0.2808	-0.6090	-0.7990	1.0431	-0.7990	Z
	118	62.7529	36.5286	-33.5425	62.3363	37.1174	-34.8082	0.4166	-0.5888	-1.2657	1.4568	-1.2657	Z
	119	50.6233	20.5808	-37.4442	50.3843	21.0643	-38.1773	0.2390	-0.4835	-0.7331	0.9101	-0.7331	Z
	120	50.7385	26.8814	-37.2795	50.5066	27.3291	-37.5785	0.2319	-0.4477	-0.2990	0.5862	-0.2990	Z
	121	50.9445	34.6804	-36.6729	50.5433	35.1771	-37.4660	0.4012	-0.4967	-0.7931	1.0182	-0.7931	Z
	122	40.7057	19.4277	-37.9796	40.4959	19.8364	-38.5145	0.2098	-0.4087	-0.5349	0.7051	-0.5349	Z
	123	40.9576	26.0415	-37.8569	40.7318	26.4507	-38.2948	0.2258	-0.4092	-0.4379	0.6405	-0.4379	Z
	124	41.2634	35.1930	-37.1445	40.9484	35.6284	-37.5778	0.3150	-0.4354	-0.4333	0.6903	-0.4333	Z
	125	24.4091	17.7116	-37.5160	24.2130	17.9797	-37.8320	0.1961	-0.2681	-0.3160	0.4585	-0.3160	Z
	126	24.6809	24.9268	-37.4842	24.4053	25.2098	-37.8562	0.2756	-0.2830	-0.3720	0.5426	-0.3720	Z
	127	24.8475	33.4167	-36.9723	24.5122	33.6715	-37.4167	0.3353	-0.2548	-0.4444	0.6122	-0.4444	Z
	128	9.1924	17.1592	-35.3365	9.1001	17.3315	-35.5929	0.0923	-0.1723	-0.2564	0.3224	-0.2564	Z
	129	9.5355	24.0268	-35.3790	9.3766	24.2011	-35.6633	0.1589	-0.1743	-0.2843	0.3694	-0.2843	Z
	130	10.7559	35.6388	-34.7397	10.5872	35.8879	-35.0979	0.1687	-0.2491	-0.3582	0.4678	-0.3582	Z
A-PILLAR Maximum (X, Y, Z)	131	66.8639	41.2381	-30.4239	66.5796	41.5565	-31.5475	0.2843	-0.3184	-1.1236	1.2019	0.2843	X
	132	69.9743	41.7479	-28.2625	69.6554	41.9019	-29.4066	0.3189	-0.1540	-1.1441	1.1977	0.3189	X
	133	73.8114	42.3681	-27.1247	73.4886	42.3694	-28.2531	0.3228	-0.0013	-1.1284	1.1737	0.3228	X
	134	74.6338	42.5721	-25.4283	74.3941	42.4983	-26.5474	0.2397	0.0738	-1.1191	1.1469	0.2508	X, Y
	135	77.5681	43.1212	-24.8915	77.2280	42.8865	-26.0246	0.3401	0.2347	-1.1331	1.2061	0.4132	X, Y
	136	79.4394	43.5522	-21.6530	79.1779	43.1941	-22.7284	0.2615	0.3581	-1.0754	1.1632	0.4434	X, Y
A-PILLAR Lateral (Y)	131	66.8639	41.2381	-30.4239	66.5796	41.5565	-31.5475	0.2843	-0.3184	-1.1236	1.2019	-0.3184	Y
	132	69.9743	41.7479	-28.2625	69.6554	41.9019	-29.4066	0.3189	-0.1540	-1.1441	1.1977	-0.1540	Y
	133	73.8114	42.3681	-27.1247	73.4886	42.3694	-28.2531	0.3228	-0.0013	-1.1284	1.1737	-0.0013	Y
	134	74.6338	42.5721	-25.4283	74.3941	42.4983	-26.5474	0.2397	0.0738	-1.1191	1.1469	0.0738	Y
	135	77.5681	43.1212	-24.8915	77.2280	42.8865	-26.0246	0.3401	0.2347	-1.1331	1.2061	0.2347	Y
	136	79.4394	43.5522	-21.6530	79.1779	43.1941	-22.7284	0.2615	0.3581	-1.0754	1.1632	0.3581	Y
B-PILLAR Maximum (X, Y, Z)	137	42.7590	44.7021	-18.1175	42.5722	44.8893	-18.7067	0.1868	-0.1872	-0.5892	0.6458	0.1868	X
	138	39.0003	44.9809	-12.1923	38.9266	45.0487	-12.7668	0.0737	-0.0678	-0.5745	0.5832	0.0737	X
	139	44.6429	44.9630	-10.0254	44.5806	44.9894	-10.6843	0.0623	-0.0264	-0.6589	0.6624	0.0623	X
	140	39.6838	45.0483	-8.4930	39.6434	45.0552	-9.0564	0.0404	-0.0069	-0.5634	0.5649	0.0404	X
B-PILLAR Lateral (Y)	137	42.7590	44.7021	-18.1175	42.5722	44.8893	-18.7067	0.1868	-0.1872	-0.5892	0.6458	-0.1872	Y
	138	39.0003	44.9809	-12.1923	38.9266	45.0487	-12.7668	0.0737	-0.0678	-0.5745	0.5832	-0.0678	Y
	139	44.6429	44.9630	-10.0254	44.5806	44.9894	-10.6843	0.0623	-0.0264	-0.6589	0.6624	-0.0264	Y
	140	39.6838	45.0483	-8.4930	39.6434	45.0552	-9.0564	0.0404	-0.0069	-0.5634	0.5649	-0.0069	Y

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

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

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

Figure D-10. Occupant Compartment Deformation Data – Set 1, Test No. HNTBR-3

Test Name: HNTBR-3 VIN: 3KPA24AB8KE215156

Model Year: 2019 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)	101	75.8906	15.2271	-18.6201	76.0756	14.9681	-21.1411	-0.1850	0.2590	-2.5210	2.5410	2.5410	X, Y, Z
	102	75.5861	5.2330	-19.5700	75.7148	4.9278	-21.6614	-0.1287	0.3052	-2.0914	2.1175	2.1175	X, Y, Z
	103	75.5897	-4.2934	-20.0090	75.7605	-4.5989	-21.6923	-0.1708	-0.3055	-1.6833	1.7193	1.7193	X, Y, Z
	104	73.2374	16.0316	-12.2620	73.1331	15.9913	-14.8187	0.1043	0.0403	-2.5567	2.5591	2.5591	X, Y, Z
	105	72.1073	5.5007	-11.8917	72.3525	5.4313	-13.8900	-0.2452	0.0694	-1.9983	2.0145	2.0145	X, Y, Z
	106	71.7121	-3.4714	-11.9648	72.3362	-3.5217	-13.4001	-0.6241	-0.0503	-1.4353	1.5659	1.5659	X, Y, Z
SIDE PANEL (Y)	107	80.7248	18.6788	2.1353	80.6509	18.4732	-0.0864	0.0739	0.2056	-2.2217	2.2324	0.2056	Y
	108	79.4911	18.8327	4.0409	79.4947	18.6013	1.7964	-0.0036	0.2314	-2.2445	2.2564	0.2314	Y
	109	82.1791	18.7777	4.2249	82.6169	18.3108	1.5914	-0.4378	0.4669	-2.6335	2.7102	0.4669	Y
IMPACT SIDE DOOR (Y)	110	72.8537	19.9874	-16.7253	72.5068	19.6608	-18.8639	0.3469	0.3266	-2.1386	2.1910	0.3266	Y
	111	62.3135	21.3011	-17.6499	61.9789	20.8930	-19.5122	0.3346	0.4081	-1.8623	1.9356	0.4081	Y
	112	51.3160	21.6752	-17.9884	50.9294	21.0809	-19.5878	0.3866	0.5943	-1.5994	1.7495	0.5943	Y
	113	75.4522	20.3773	1.5719	75.5875	21.1518	-0.6095	-0.1353	-0.7745	-2.1814	2.3188	-0.7745	Y
	114	62.3504	21.3397	4.4660	62.6377	21.4824	2.3306	-0.2873	-0.1427	-2.1354	2.1594	-0.1427	Y
	115	55.1791	21.7085	4.5248	55.3773	21.2468	2.7631	-0.1982	0.4617	-1.7617	1.8319	0.4617	Y
ROOF - (Z)	116	64.0989	-6.1873	-34.3327	63.6536	-5.9625	-35.3644	0.4453	0.2248	-1.0317	1.1460	-1.0317	Z
	117	64.1275	0.0813	-34.0935	63.5437	0.3061	-35.4521	0.5838	-0.2248	-1.3586	1.4957	-1.3586	Z
	118	63.4189	10.6886	-33.1678	62.6540	10.9065	-35.2266	0.7649	-0.2179	-2.0588	2.2071	-2.0588	Z
	119	51.2794	-5.1753	-37.3687	50.7300	-5.2062	-38.4054	0.5494	-0.0309	-1.0367	1.1737	-1.0367	Z
	120	51.3962	1.1207	-37.0776	50.8330	1.0608	-37.8255	0.5632	0.0599	-0.7479	0.9382	-0.7479	Z
	121	51.6050	8.9058	-36.3148	50.8378	8.9091	-37.7351	0.7672	-0.0033	-1.4203	1.6143	-1.4203	Z
	122	41.3607	-6.3157	-37.9105	40.8436	-6.4767	-38.6188	0.5171	-0.1610	-0.7083	0.8916	-0.7083	Z
	123	41.6142	0.2943	-37.6554	41.0541	0.1392	-38.4202	0.5601	0.1551	-0.7648	0.9606	-0.7648	Z
	124	41.9232	9.4297	-36.7598	41.2404	9.3197	-37.7313	0.6828	0.1100	-0.9715	1.1925	-0.9715	Z
	125	25.0645	-8.0377	-37.4542	24.5782	-8.4000	-37.7328	0.4863	-0.3623	-0.2786	0.6674	-0.2786	Z
	126	25.3379	-0.8246	-37.2779	24.7396	-1.1692	-37.7794	0.5983	-0.3446	-0.5015	0.8534	-0.5015	Z
	127	25.5072	7.6533	-36.5959	24.8159	7.2940	-37.3646	0.6913	0.3593	-0.7687	1.0945	-0.7687	Z
	128	9.8513	-8.6309	-35.2607	9.4966	-9.1055	-35.3080	0.3547	-0.4746	-0.0473	0.5944	-0.0473	Z
	129	10.1958	-1.7639	-35.1659	9.7430	-2.2350	-35.4007	0.4528	-0.4711	-0.2348	0.6943	-0.2348	Z
	130	11.4198	9.8327	-34.2955	10.9109	9.4584	-34.8825	0.5089	0.3743	-0.5870	0.8624	-0.5870	Z
A-PILLAR Maximum (X, Y, Z)	131	67.5362	15.3338	-29.9620	66.9177	15.3726	-32.0301	0.6185	-0.0388	-2.0681	2.1590	0.6185	X
	132	70.6503	15.7994	-27.7961	70.0179	15.7370	-29.9278	0.6324	0.0624	-2.1317	2.2244	0.6355	X, Y
	133	74.4895	16.3959	-26.6524	73.8628	16.2238	-28.8224	0.6267	0.1721	-2.1700	2.2652	0.6499	X, Y
	134	75.3147	16.5657	-24.9536	74.7885	16.3613	-27.1282	0.5262	0.2044	-2.1746	2.2467	0.5645	X, Y
	135	78.2501	17.1034	-24.4109	77.6268	16.7629	-26.6410	0.6233	0.3405	-2.2301	2.3405	0.7102	X, Y
	136	80.1268	17.4688	-21.1675	79.6154	17.0880	-23.3697	0.5114	0.3808	-2.2022	2.2926	0.6376	X, Y
A-PILLAR Lateral (Y)	131	67.5362	15.3338	-29.9620	66.9177	15.3726	-32.0301	0.6185	-0.0388	-2.0681	2.1590	-0.0388	Y
	132	70.6503	15.7994	-27.7961	70.0179	15.7370	-29.9278	0.6324	0.0624	-2.1317	2.2244	0.0624	Y
	133	74.4895	16.3959	-26.6524	73.8628	16.2238	-28.8224	0.6267	0.1721	-2.1700	2.2652	0.1721	Y
	134	75.3147	16.5657	-24.9536	74.7885	16.3613	-27.1282	0.5262	0.2044	-2.1746	2.2467	0.2044	Y
	135	78.2501	17.1034	-24.4109	77.6268	16.7629	-26.6410	0.6233	0.3405	-2.2301	2.3405	0.3405	Y
	136	80.1268	17.4688	-21.1675	79.6154	17.0880	-23.3697	0.5114	0.3808	-2.2022	2.2926	0.3808	Y
B-PILLAR Maximum (X, Y, Z)	137	43.4526	18.5543	-17.5482	43.0545	18.6405	-18.9070	0.3981	-0.0862	-1.3588	1.4185	0.3981	X
	138	39.7040	18.7147	-11.6123	39.4808	18.8012	-12.9236	0.2232	-0.0865	-1.3113	1.3330	0.2232	X
	139	45.3501	18.6522	-9.4556	45.1599	18.7716	-10.9101	0.1902	-0.1194	-1.4545	1.4717	0.1902	X
	140	40.3936	18.7076	-7.9135	40.2427	18.8212	-9.2223	0.1509	-0.1136	-1.3088	1.3224	0.1509	X
B-PILLAR Lateral (Y)	137	43.4526	18.5543	-17.5482	43.0545	18.6405	-18.9070	0.3981	-0.0862	-1.3588	1.4185	-0.0862	Y
	138	39.7040	18.7147	-11.6123	39.4808	18.8012	-12.9236	0.2232	-0.0865	-1.3113	1.3330	-0.0865	Y
	139	45.3501	18.6522	-9.4556	45.1599	18.7716	-10.9101	0.1902	-0.1194	-1.4545	1.4717	-0.1194	Y
	140	40.3936	18.7076	-7.9135	40.2427	18.8212	-9.2223	0.1509	-0.1136	-1.3088	1.3224	-0.1136	Y

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

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

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

Figure D-11. Occupant Compartment Deformation Data – Set 2, Test No. HNTBR-3

Test Name:	HNTBR-3	VIN:	3KPA24AB8KE215156
Model Year: 2019	Make: Kia	Model:	Rio

Passenger Side Maximum Deformations							
Reference Set 1				Reference Set 2			
Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]	Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Roof	-1.3	≤ 4	Z	Roof	-2.1	≤ 4	Z
Windshield[D]	0.0	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	0.4	≤ 5	X, Y	A-Pillar Maximum	0.7	≤ 5	X, Y
A-Pillar Lateral	0.4	≤ 3	Y	A-Pillar Lateral	0.4	≤ 3	Y
B-Pillar Maximum	0.2	≤ 5	X	B-Pillar Maximum	0.4	≤ 5	X
B-Pillar Lateral	-0.2	≤ 3	Y	B-Pillar Lateral	-0.1	≤ 3	Y
Toe Pan - Wheel Well	1.3	≤ 9	X, Z	Toe Pan - Wheel Well	2.3	≤ 9	X, Z
Side Front Panel	1.0	≤ 12	Y	Side Front Panel	0.5	≤ 12	Y
Side Door (above seat)	0.5	≤ 9	Y	Side Door (above seat)	0.6	≤ 9	Y
Side Door (below seat)	0.9	≤ 12	Y	Side Door (below seat)	0.5	≤ 12	Y
Floor Pan	0.8	≤ 12	Z	Floor Pan	1.8	≤ 12	Z
Dash - no MASH requirement	1.6	NA	X, Y, Z	Dash - no MASH requirement	2.6	NA	X, Y, Z

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

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

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

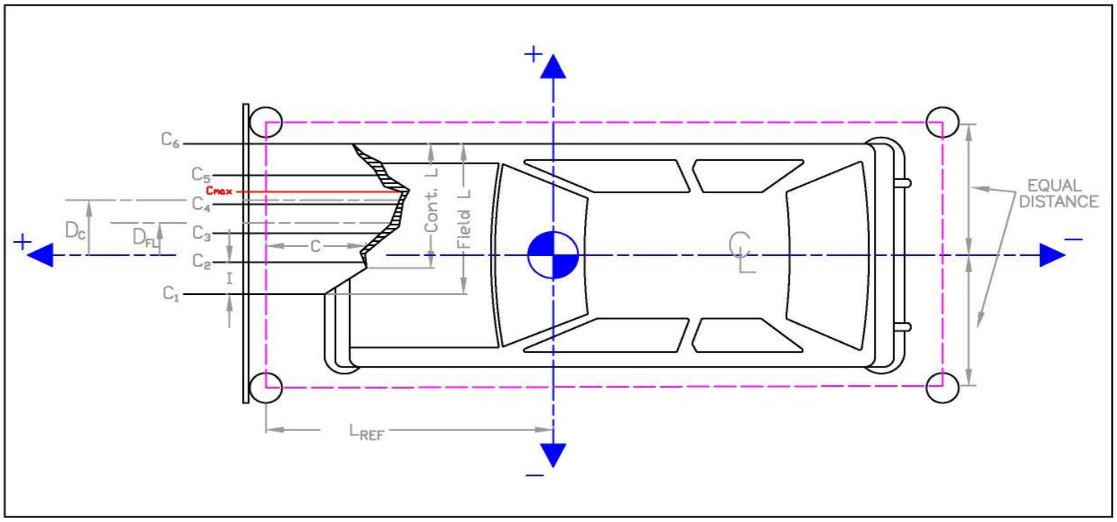
[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle crush:

Figure D-12. Maximum Occupant Compartment Deformations by Location, Test No. HNTBR-3

Test Name: HNTBR-3 VIN: 3KPA24AB8KE215156

Model Year: 2019 Make: Kia Model: Rio



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	78	(1981)
Total Width of Vehicle:	67 1/4	(1708)
Width of contact and induced crush - Field L:	61 1/4	(1556)
Crush measurement spacing interval (L/5) - I:	12 1/4	(311)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	67 1/4	(1708)
Distance from center of vehicle to center of contact damage - D_C:	0	()

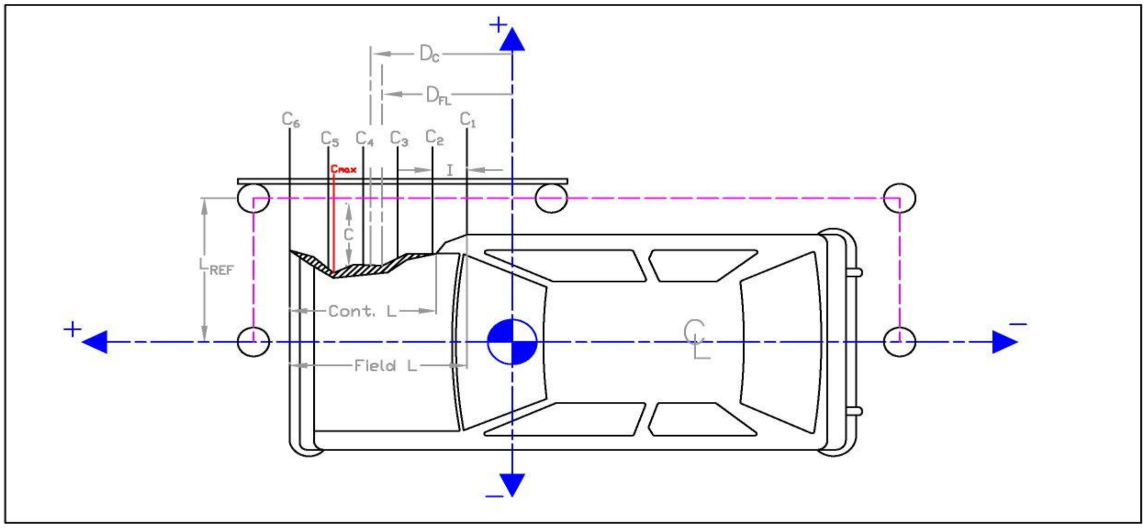
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	N/a	NA	-30 5/8	-(778)	23 3/8	(594)	-3 1/3	-(84)	NA	NA
C_2	18 3/4	(476)	-18 3/8	-(467)	12 1/8	(308)			10	(252)
C_3	19 3/4	(502)	-6 1/8	-(156)	10 1/4	(260)			12 4/5	(325)
C_4	20 5/8	(524)	6 1/8	(156)	10 1/8	(257)			13 4/5	(351)
C_5	20 1/4	(514)	18 3/8	(467)	12 1/8	(308)			11 4/9	(291)
C_6	N/a	NA	30 5/8	(778)	23	(584)			NA	NA
C_{MAX}	21	(533)	0	()	10 1/8	(257)			14 1/5	(360)

Figure D-13. Exterior Vehicle Crush (NASS) – Front, Test No. HNTBR-3

Test Name: HNTBR-3 VIN: 3KPA24AB8KE215156

Model Year: 2019 Make: Kia Model: Rio



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	38 1/2	(978)
Total Vehicle Length:	172 5/8	(4385)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-15 1/8	-(384)
Width of contact and induced crush - Field L:	172 5/8	(4385)
Crush measurement spacing interval (L/5) - I:	34 1/2	(876)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-15 1/8	-(384)
Width of Contact Damage:	172 5/8	(4385)
Distance from vehicle c.g. to center of contact damage - D_C:	-15 1/8	-(384)

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	-101 1/2	-(2578)	43 1/4	(1099)	-4 3/4	-(121)	NA	NA
C_2	N/A	NA	-67	-(1702)	10 1/2	(267)			NA	NA
C_3	6 3/8	(162)	-32 1/2	-(826)	10 1/4	(260)			7/8	(22)
C_4	6 3/8	(162)	2	(51)	10 1/4	(260)			7/8	(22)
C_5	N/a	NA	36 1/2	(927)	10 1/2	(267)			NA	NA
C_6	N/a	NA	71	(1803)	37 1/2	(953)			NA	NA
C_{MAX}	22 3/4	(578)	54 1/2	(1384)	11 1/4	(286)			16 1/4	(413)

Figure D-14. Exterior Vehicle Crush (NASS) – Side, Test No. HNTBR-3

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

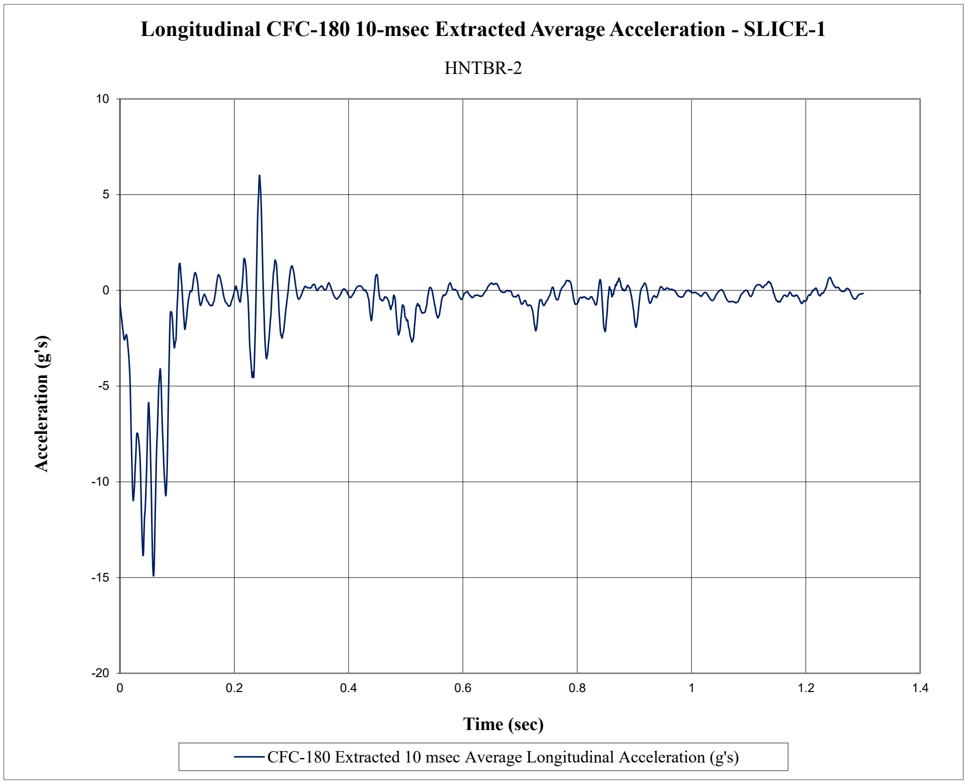


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. HNTBR-2

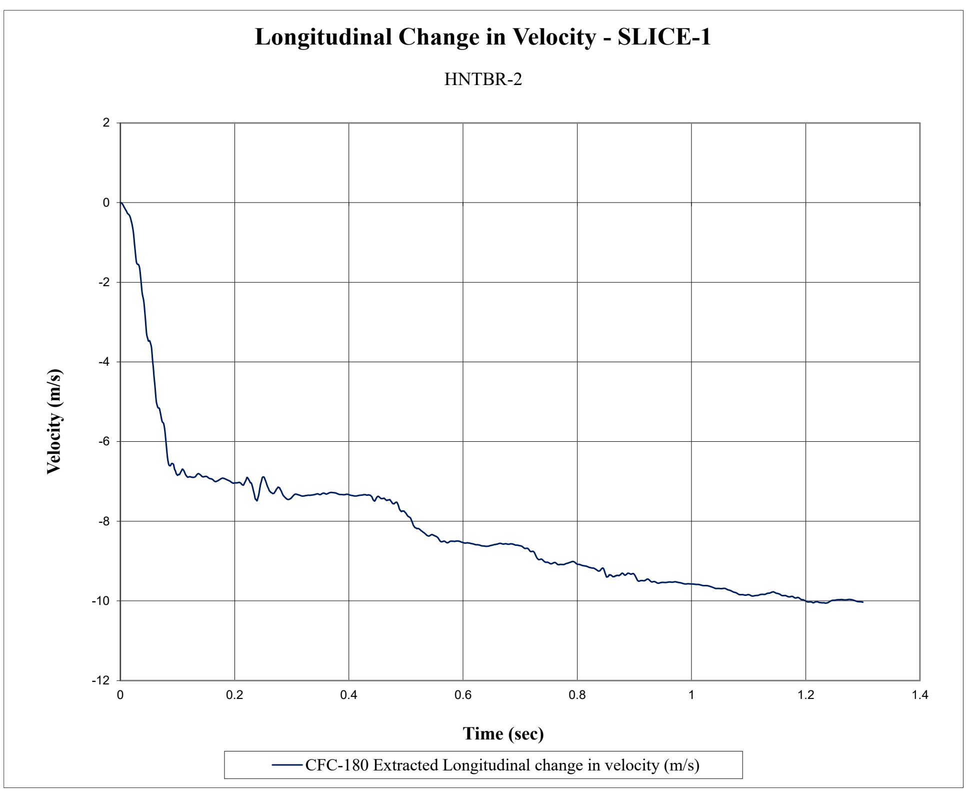


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. HNTBR-2

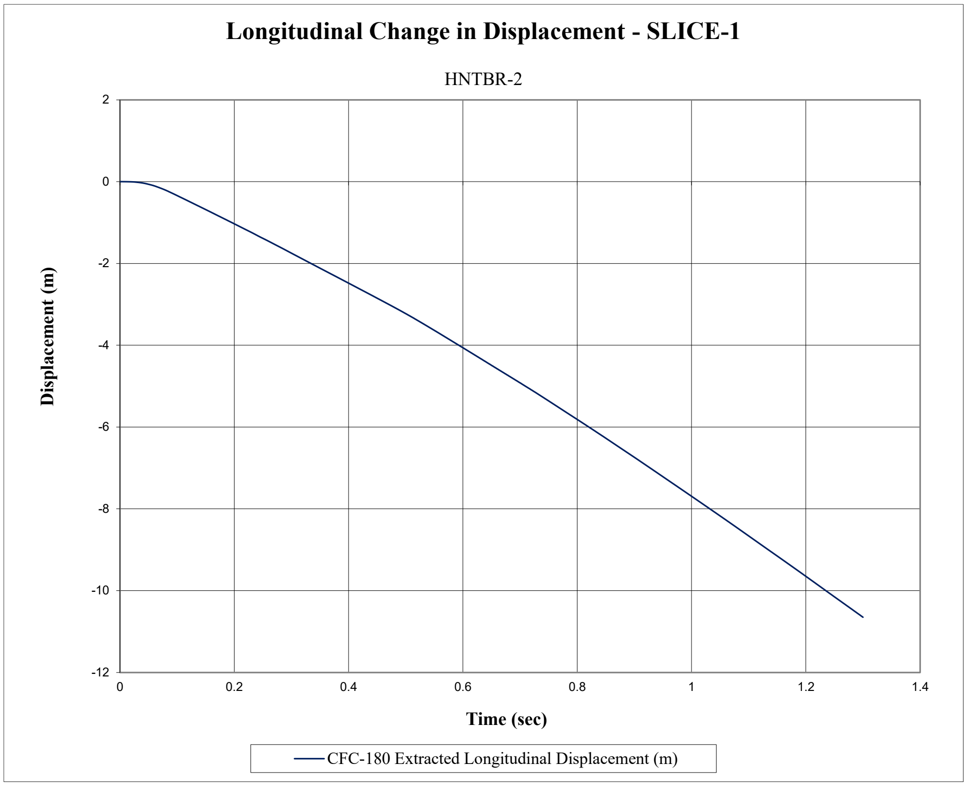


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. HNTBR-2

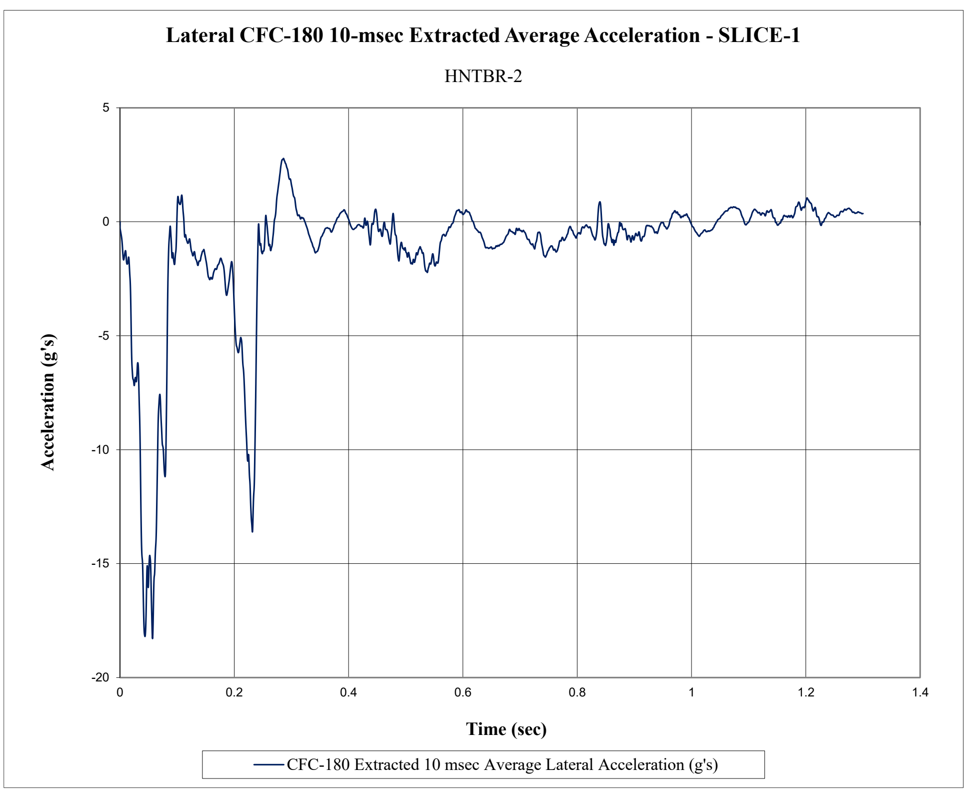


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. HNTBR-2

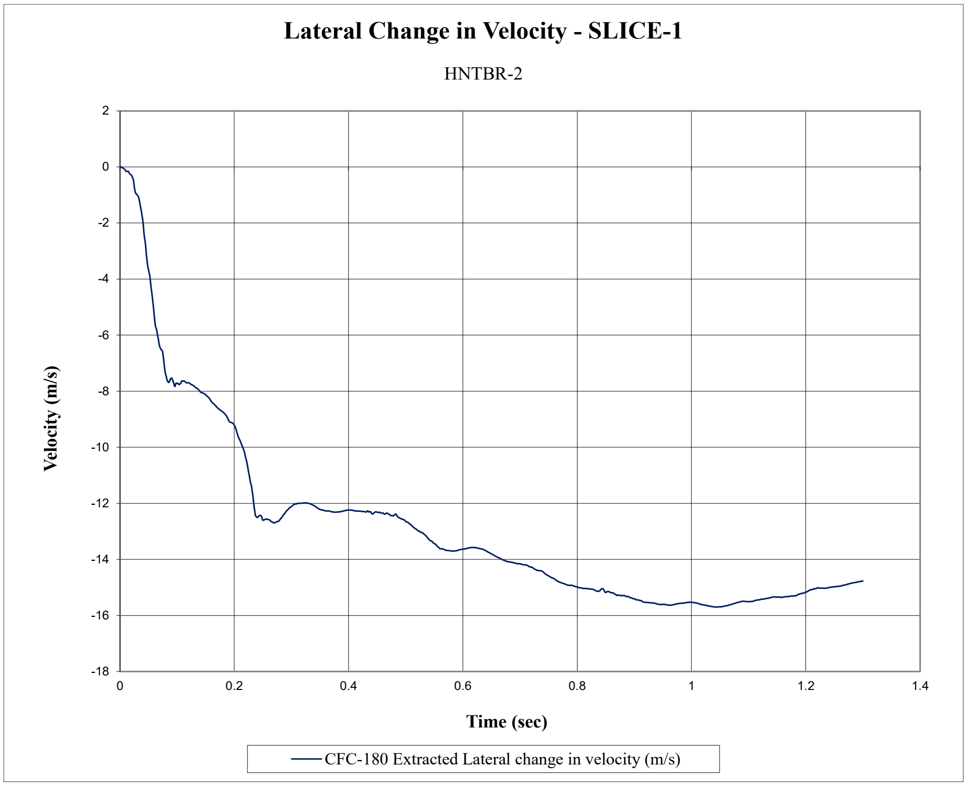


Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. HNTBR-2

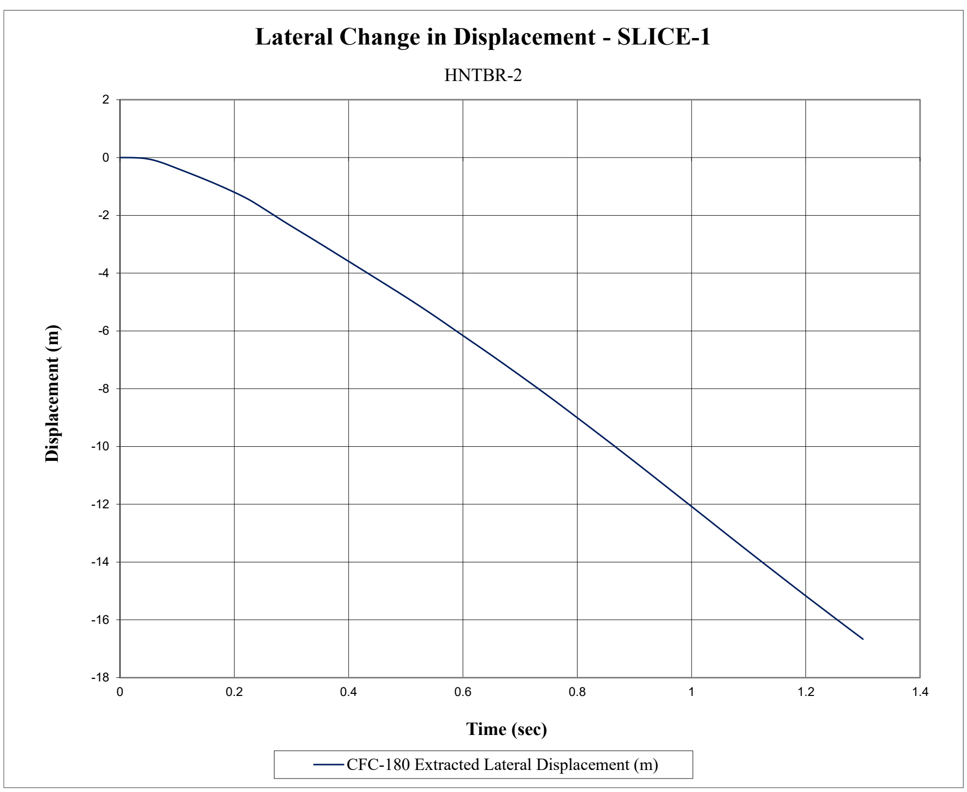


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. HNTBR-2

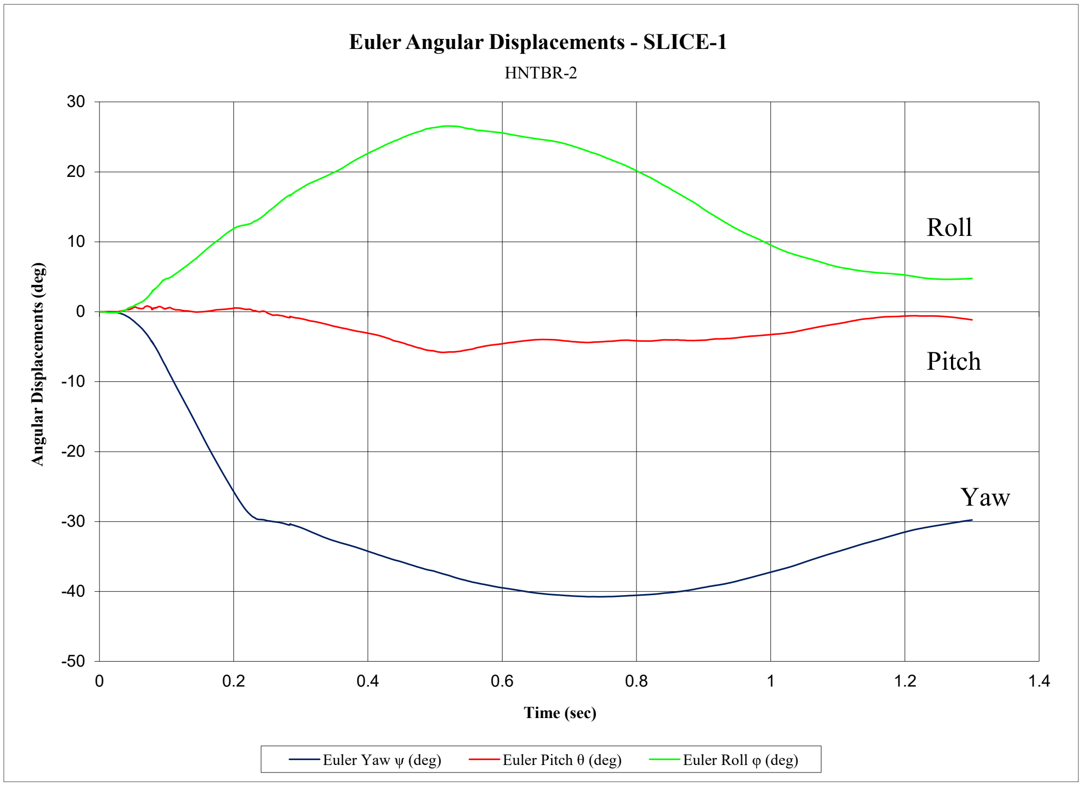


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. HNTBR-2

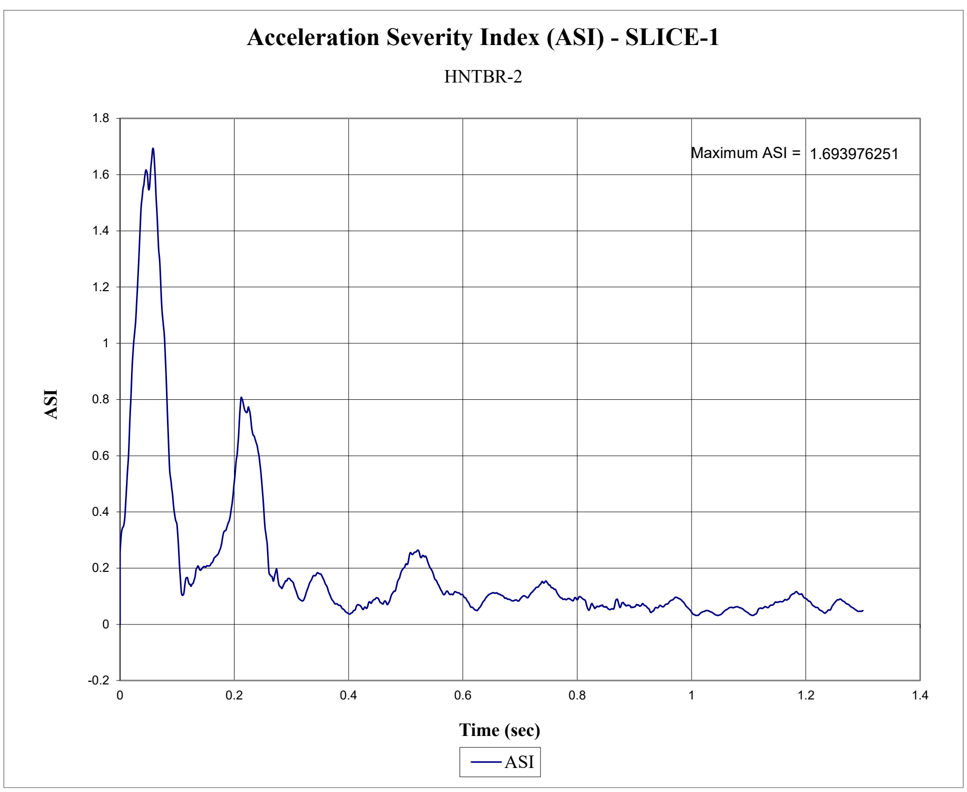


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. HNTBR-2

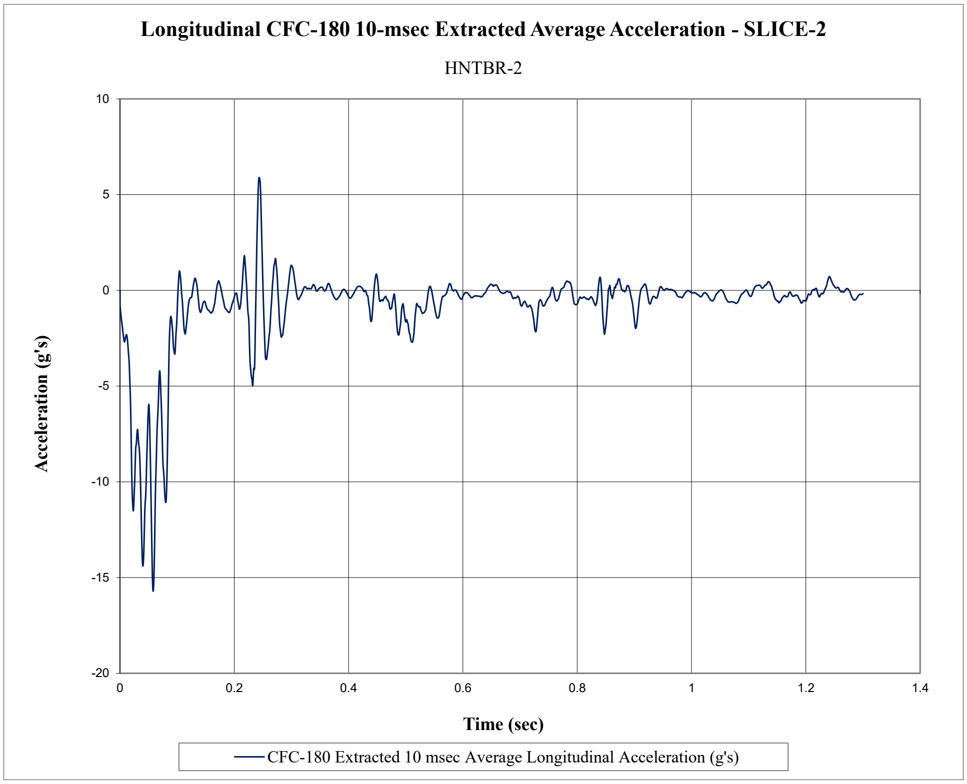


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. HNTBR-2

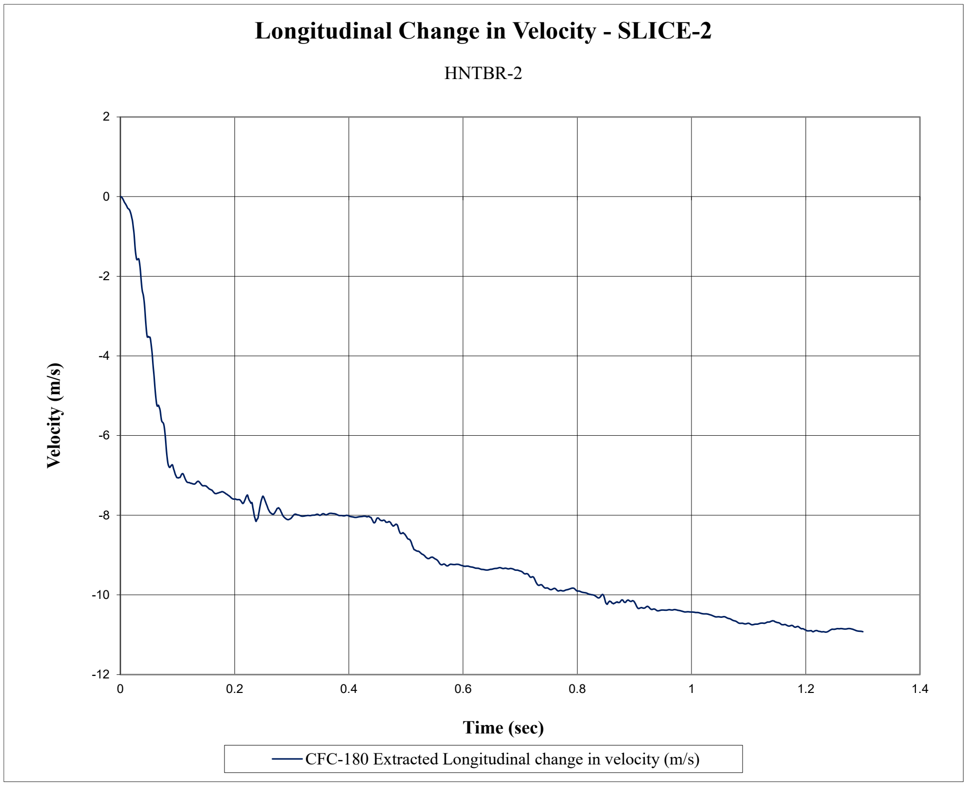


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. HNTBR-2

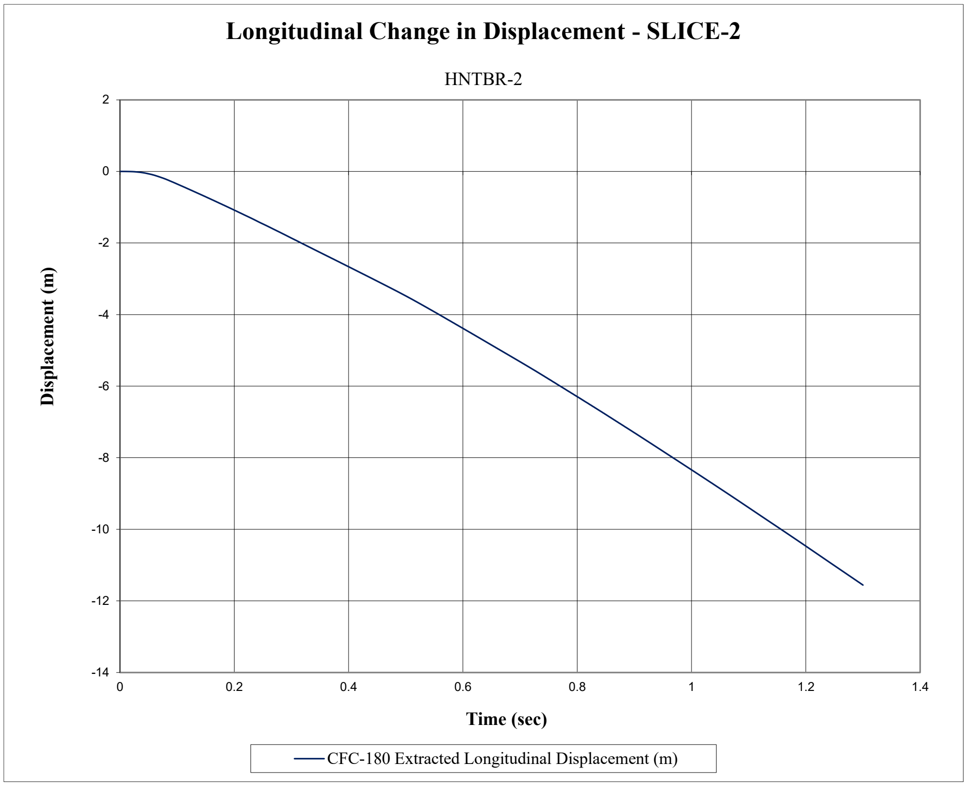


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. HNTBR-2

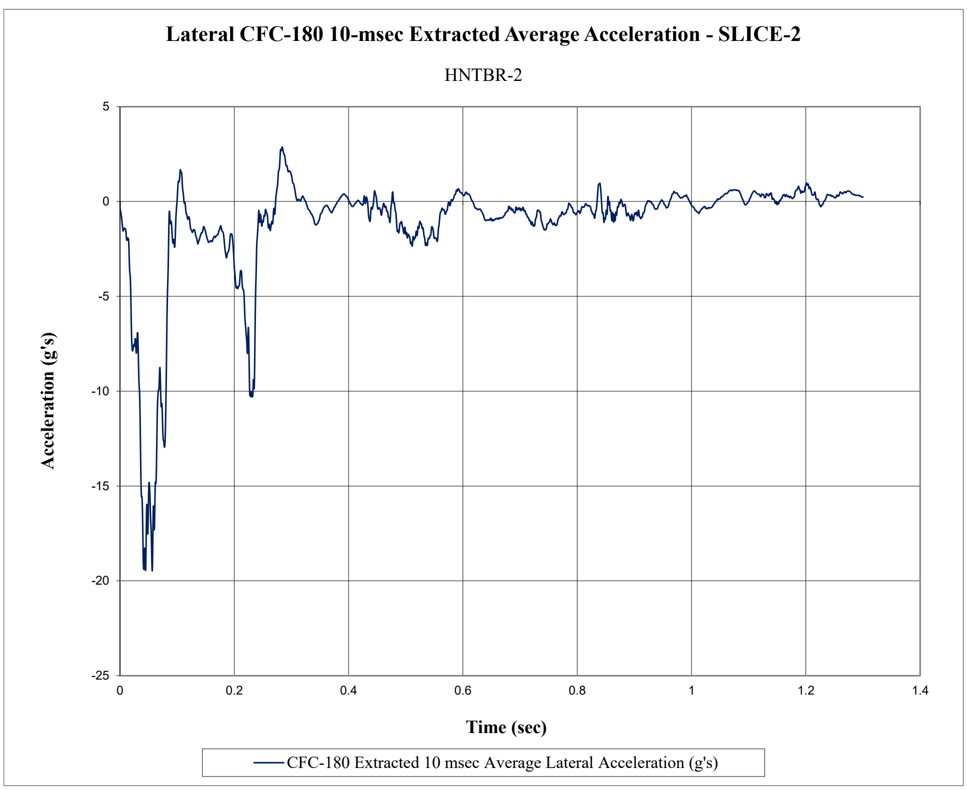


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. HNTBR-2

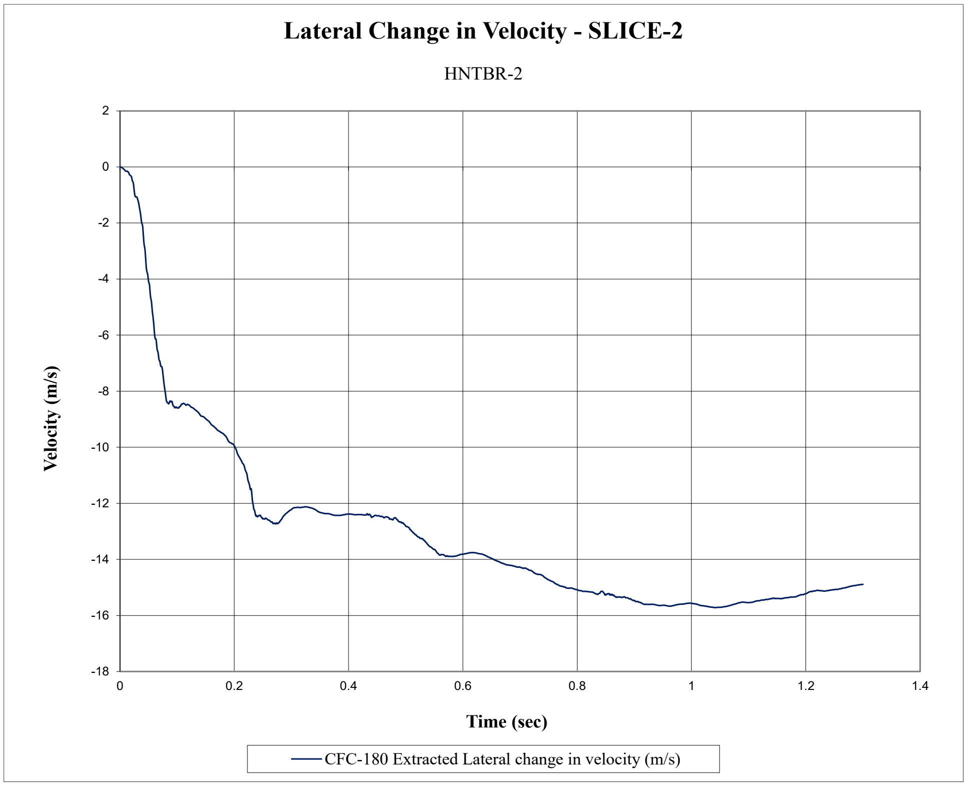


Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. HNTBR-2

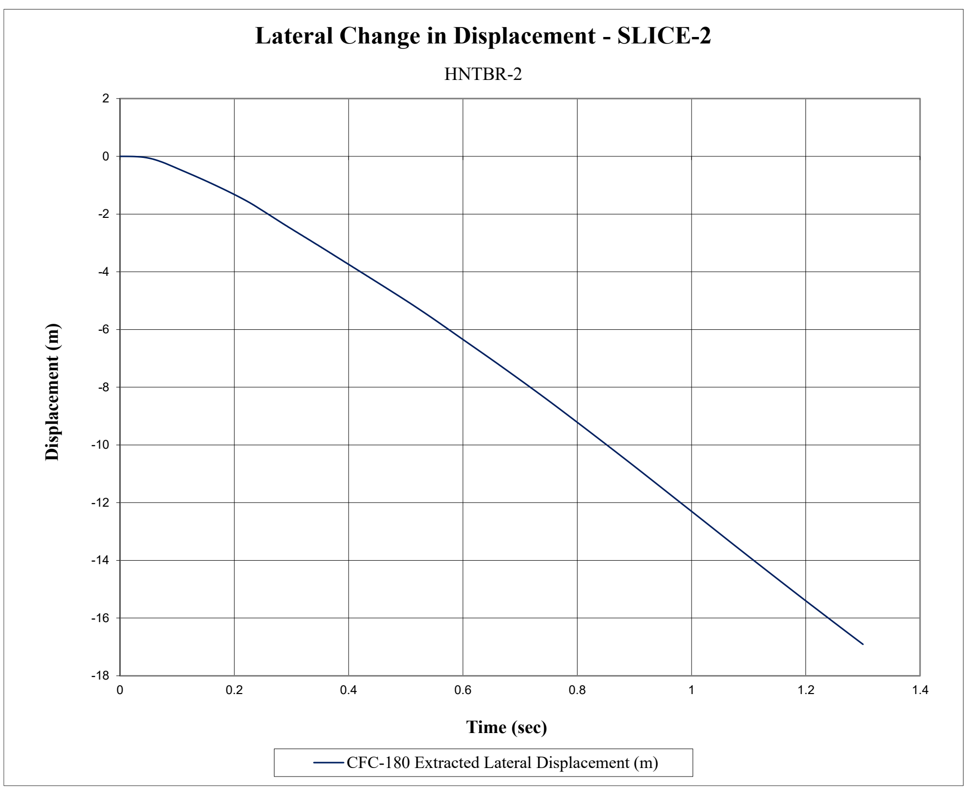


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. HNTBR-2

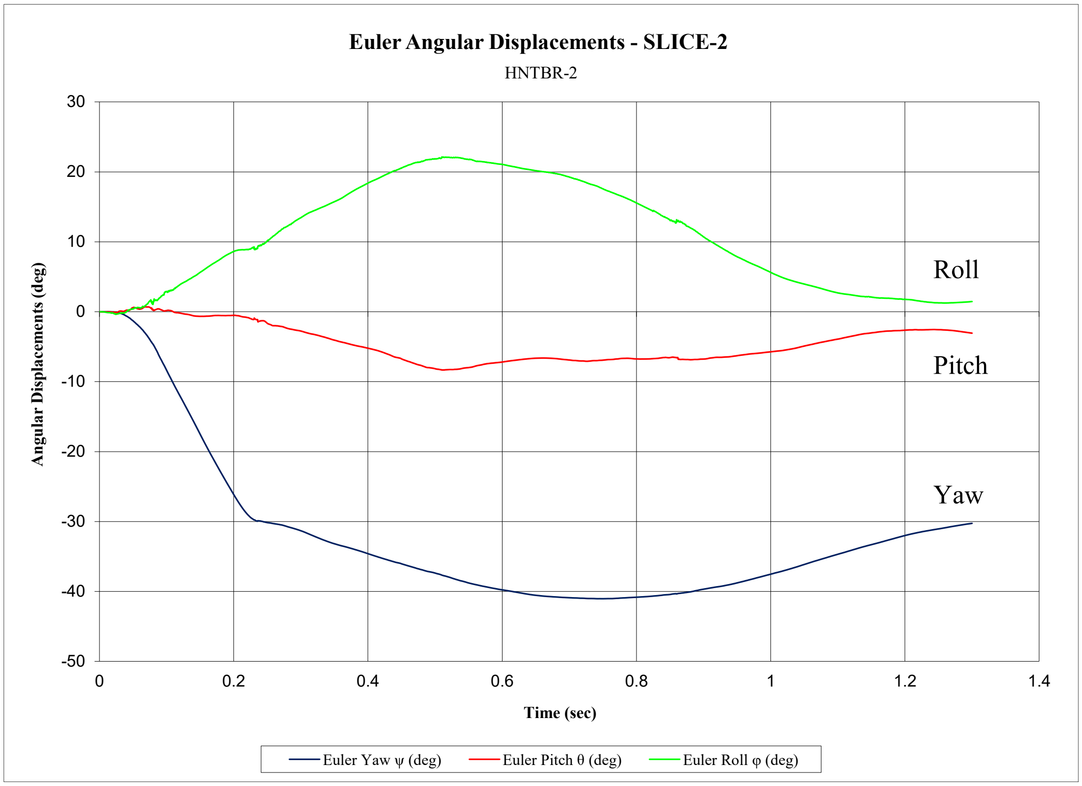


Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. HNTBR-2

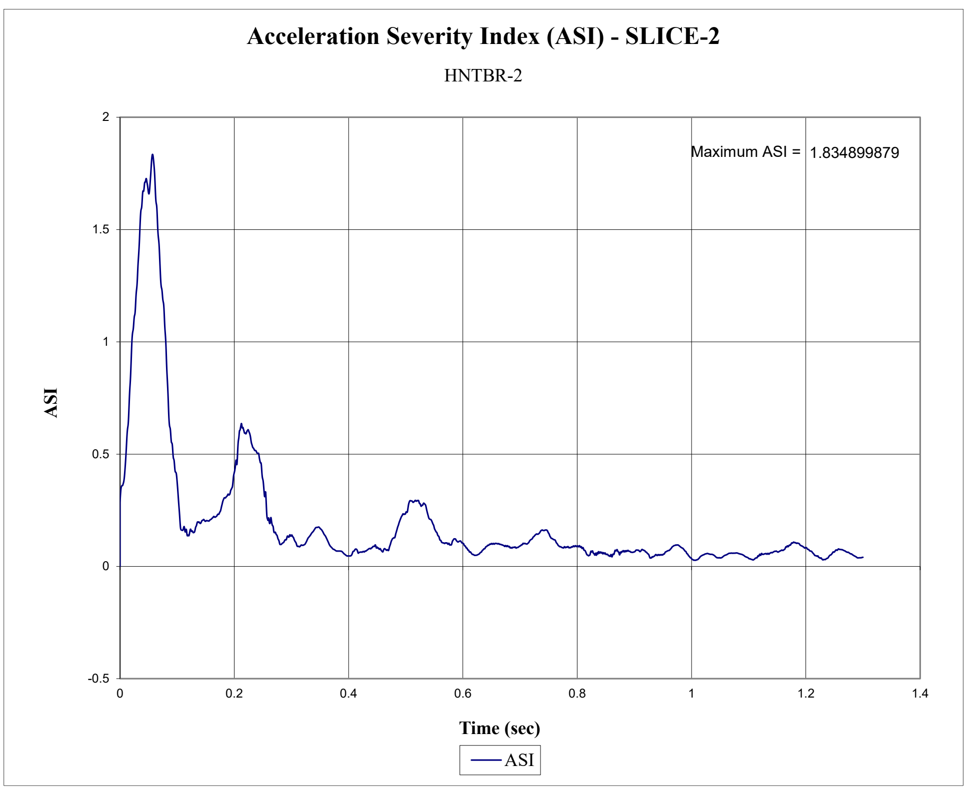


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. HNTBR-2

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

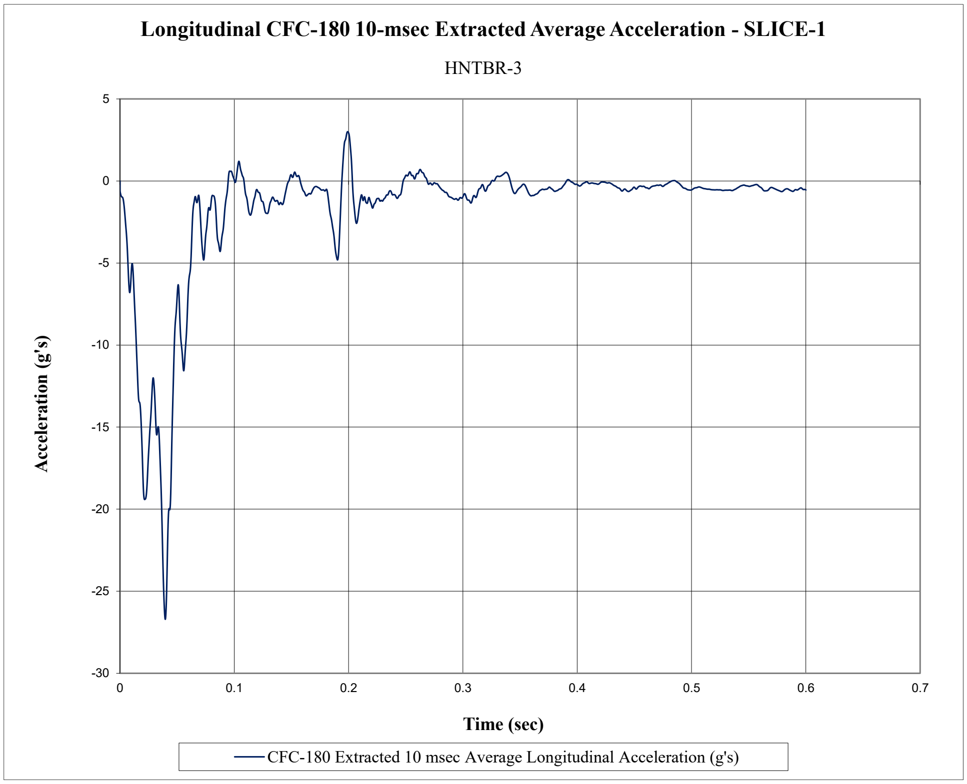


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. HNTBR-3

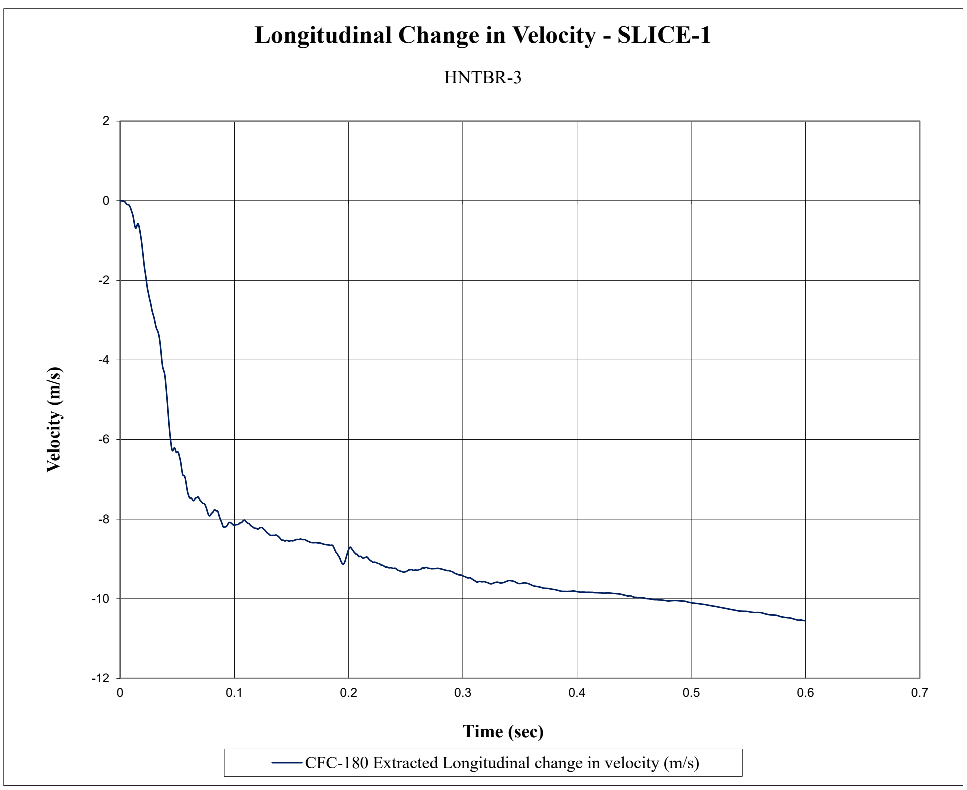


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. HNTBR-3

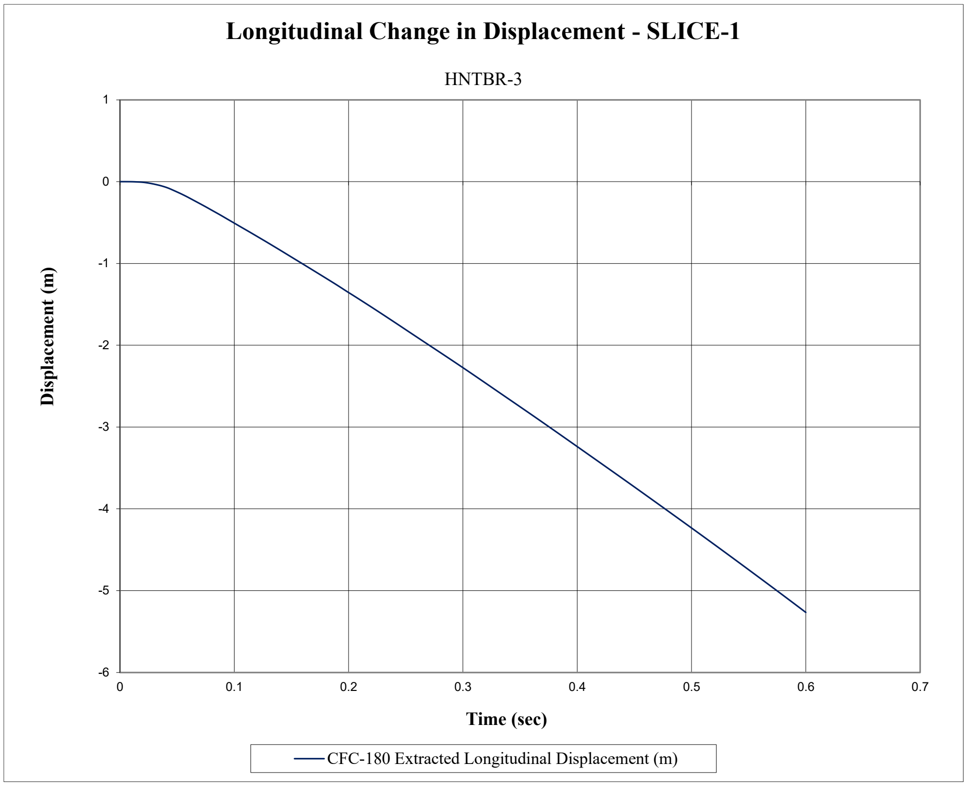


Figure F-3. Longitudinal Occupant Displacement (SLICE-1), Test No. HNTBR-3

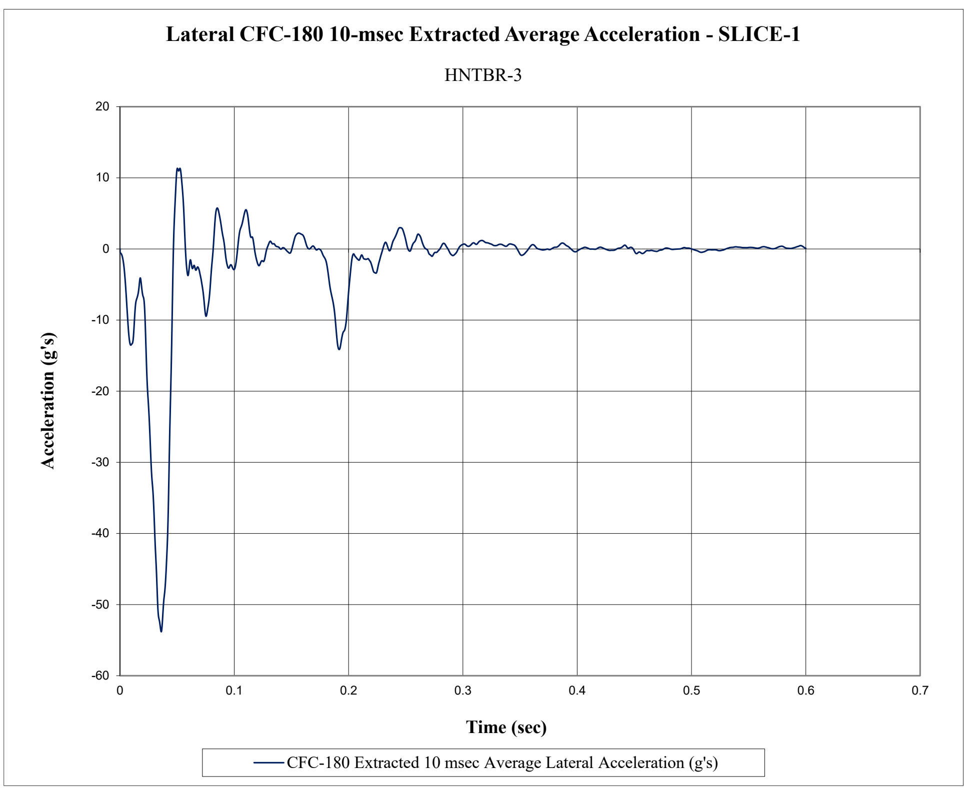


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. HNTBR-3

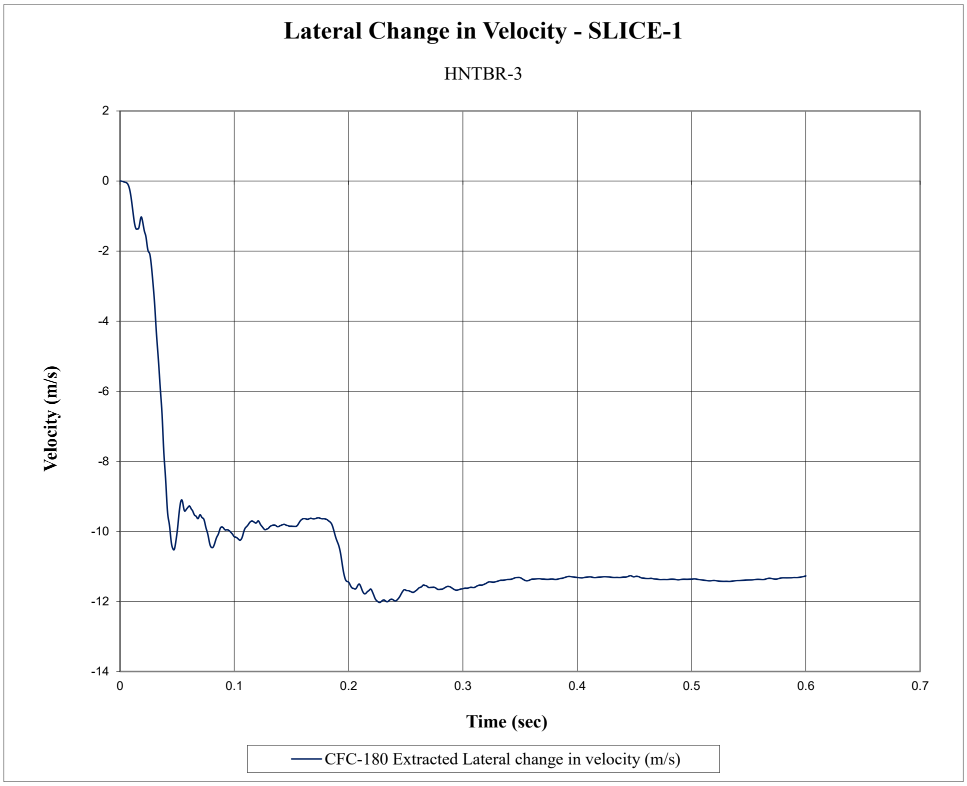


Figure F-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. HNTBR-3

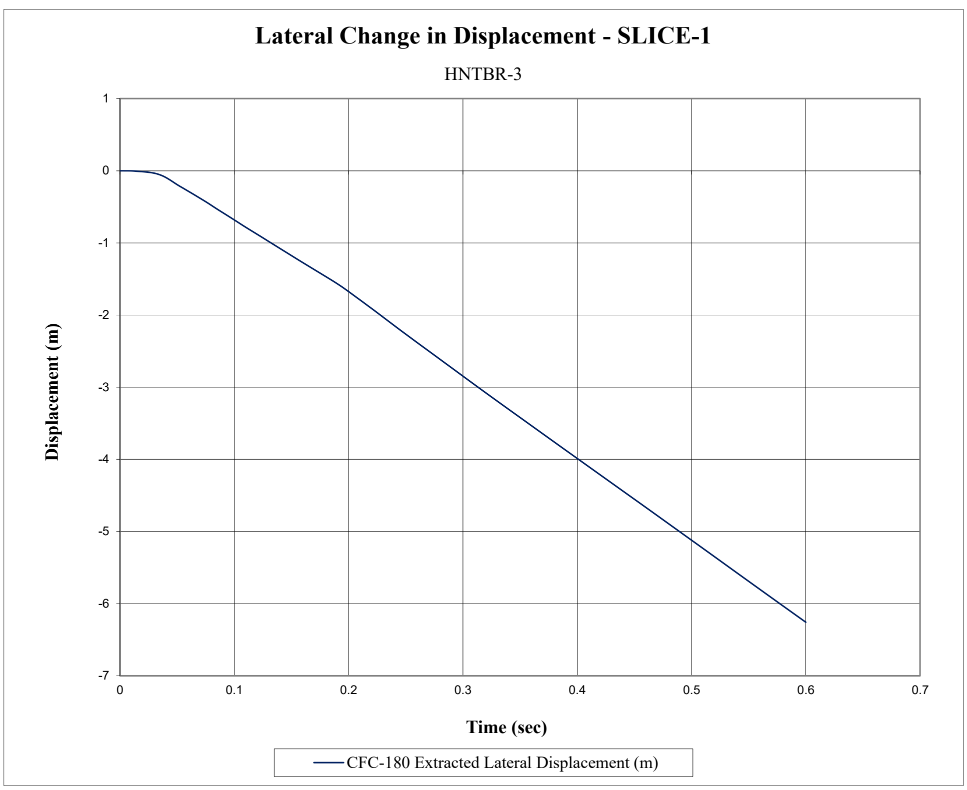


Figure F-6. Lateral Occupant Displacement (SLICE-1), Test No. HNTBR-3

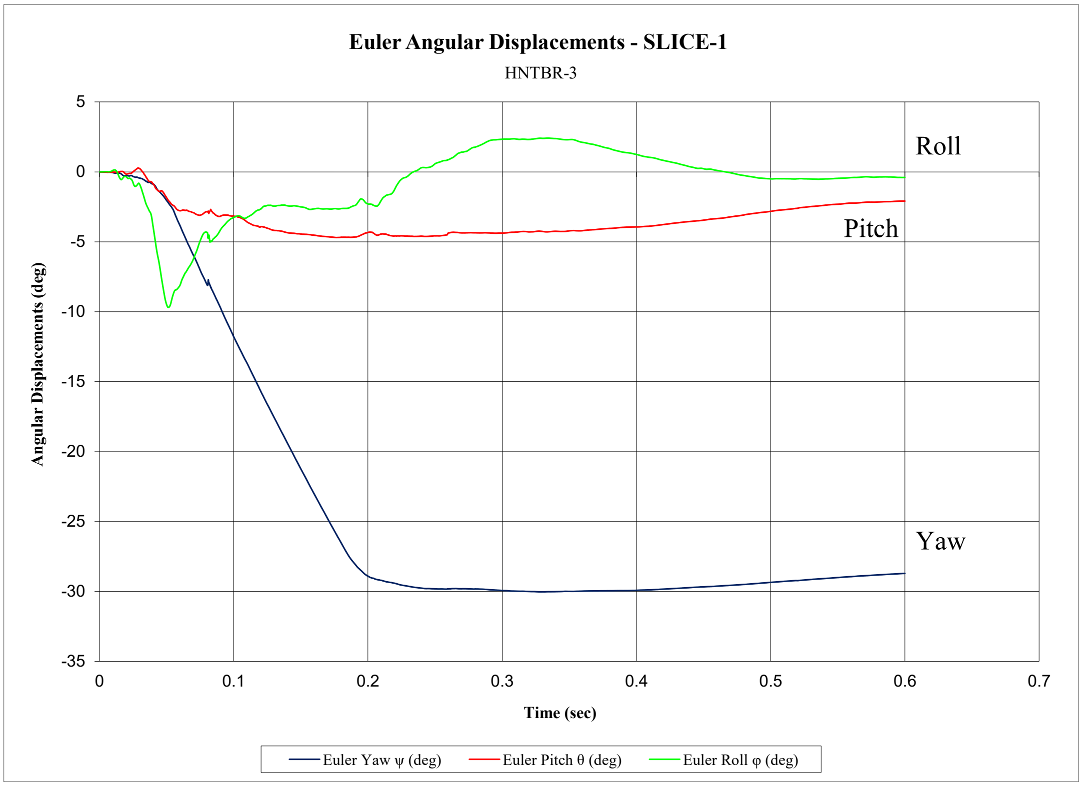


Figure F-7. Vehicle Angular Displacements (SLICE-1), Test No. HNTBR-3

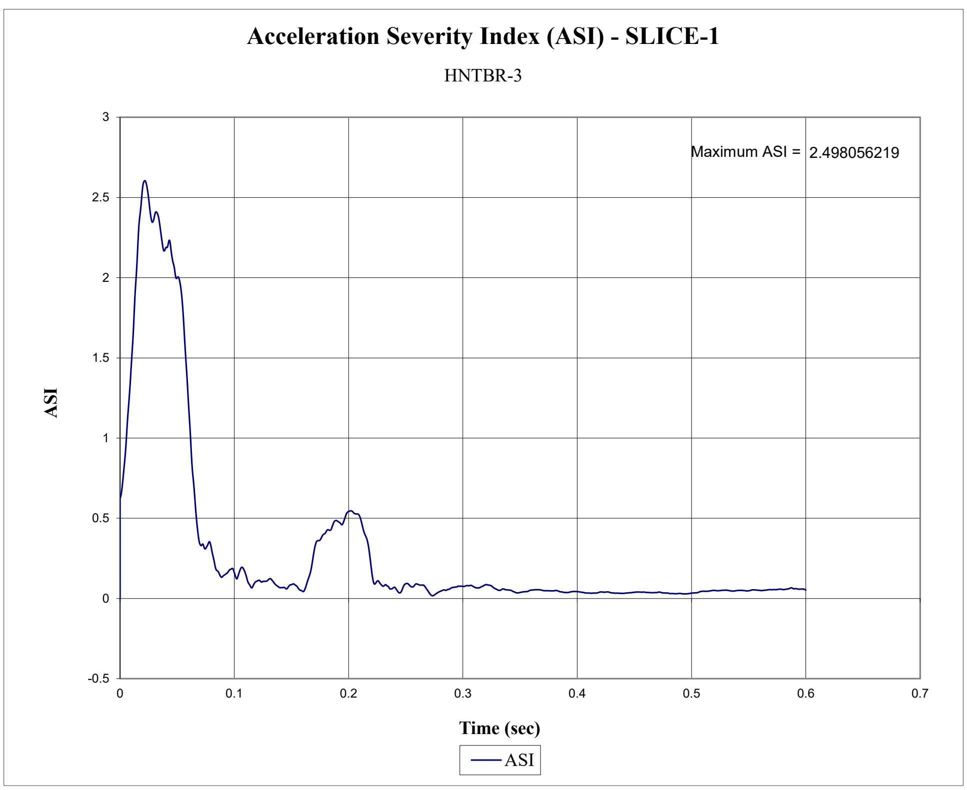


Figure F-8. Acceleration Severity Index (SLICE-1), Test No. HNTBR-3

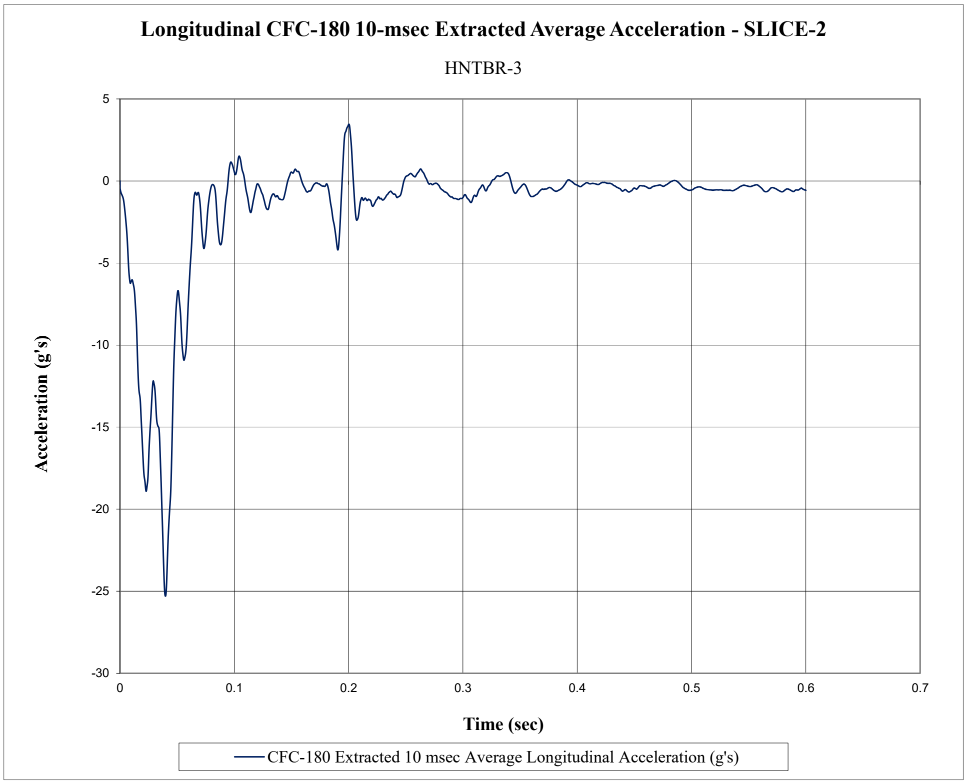


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. HNTBR-3

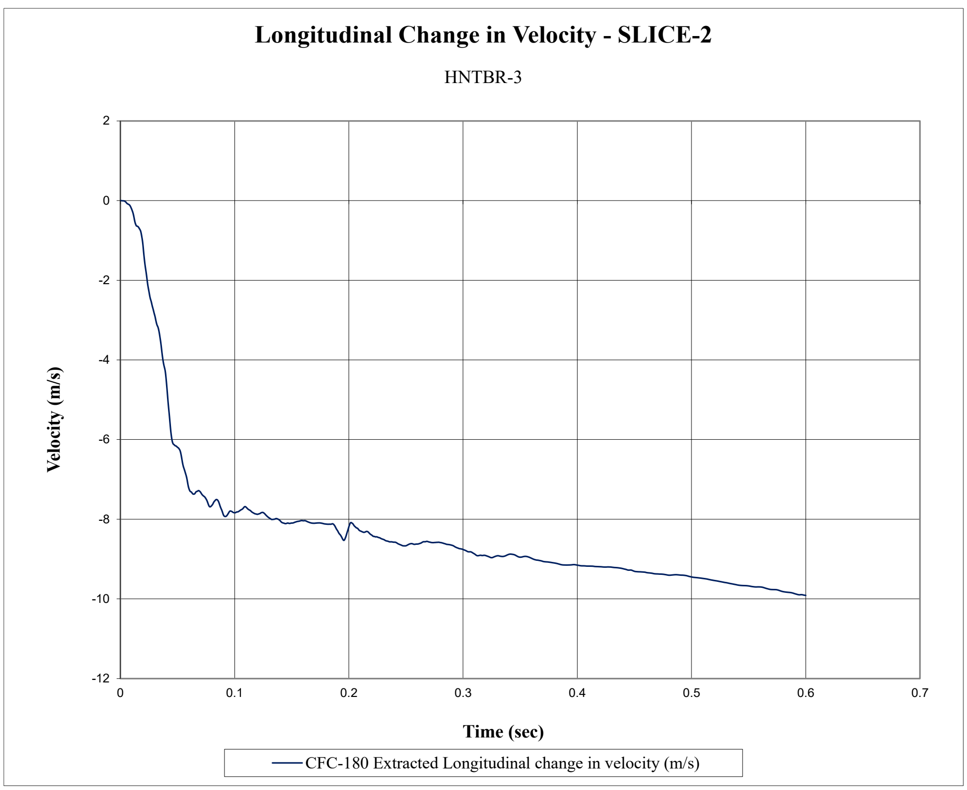


Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. HNTBR-3

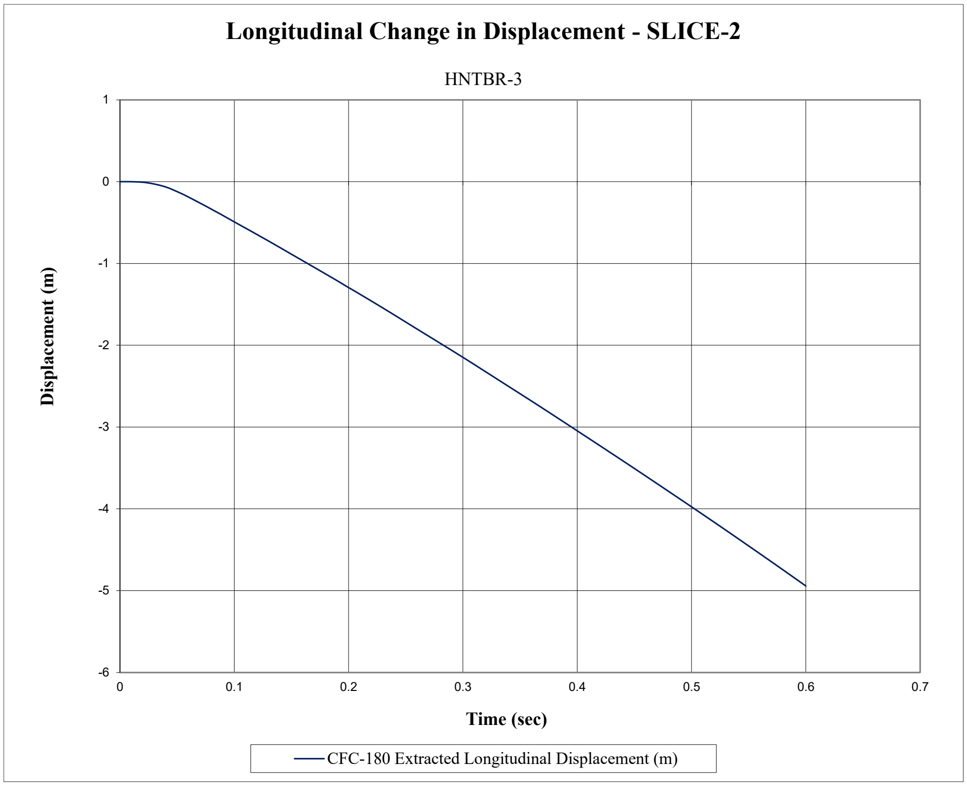


Figure F-11. Longitudinal Occupant Displacement (SLICE-2), Test No. HNTBR-3

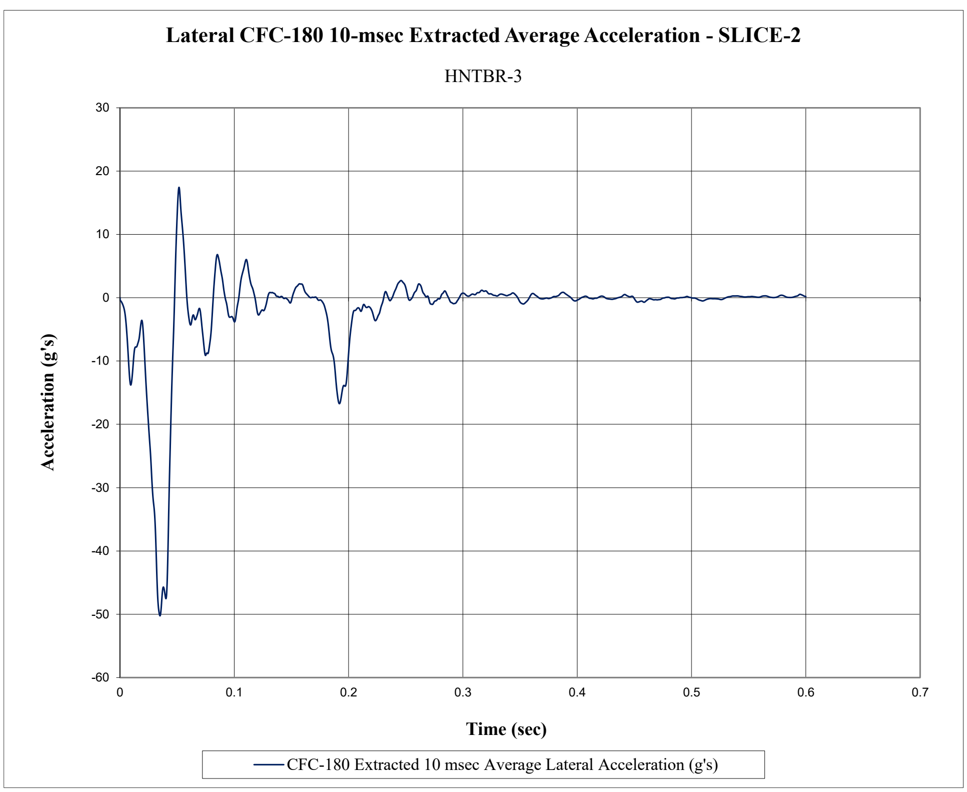


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. HNTBR-3

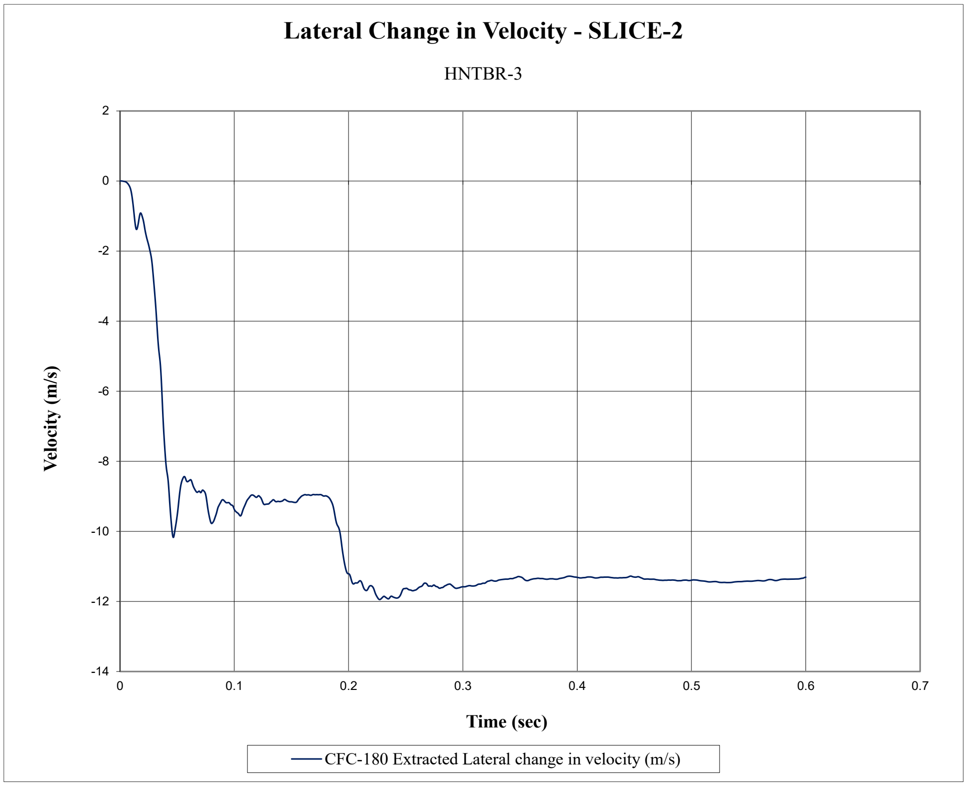


Figure F-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. HNTBR-3

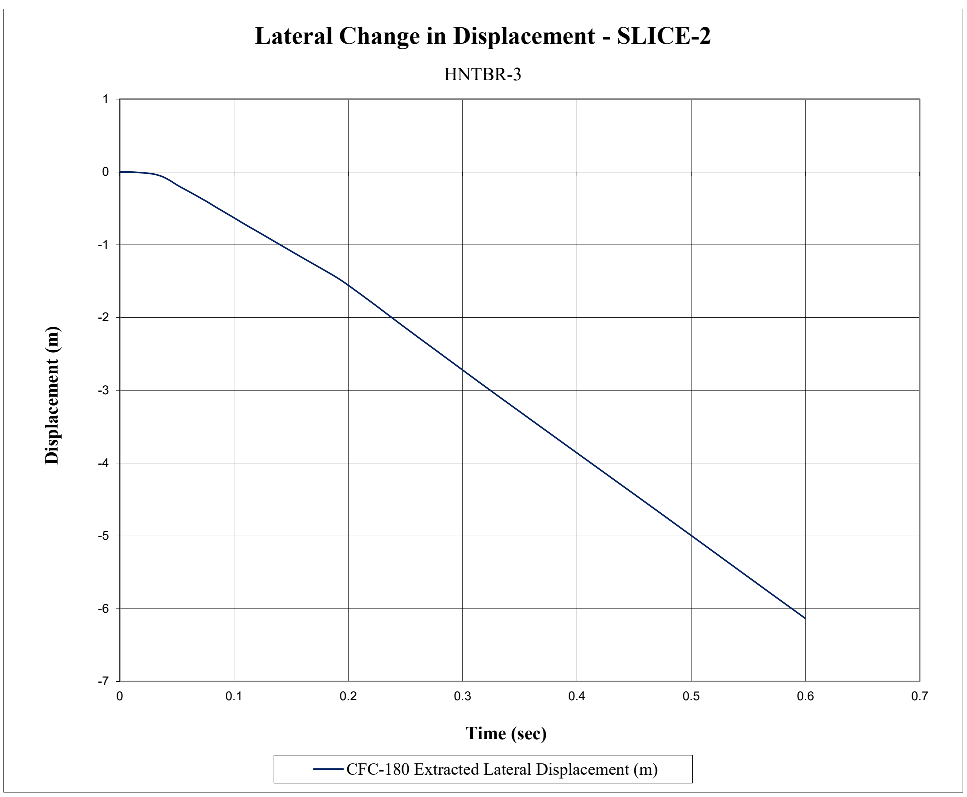


Figure F-14. Lateral Occupant Displacement (SLICE-2), Test No. HNTBR-3

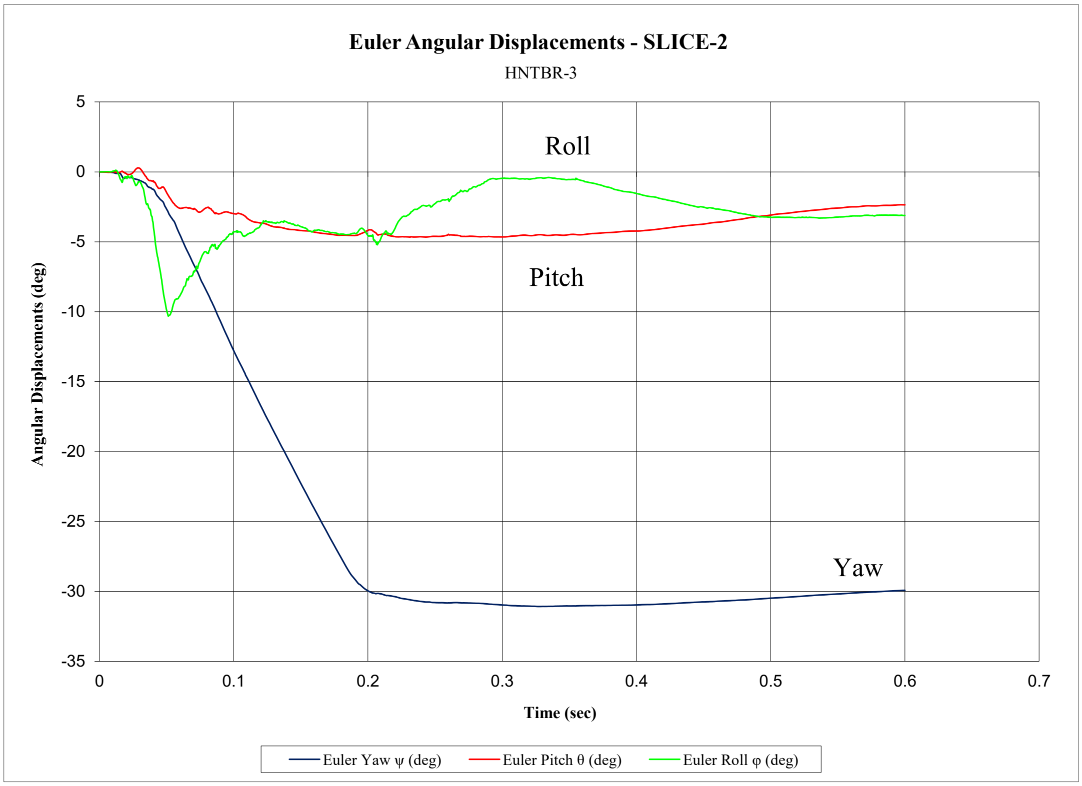


Figure F-15. Vehicle Angular Displacements (SLICE-2), Test No. HNTBR-3

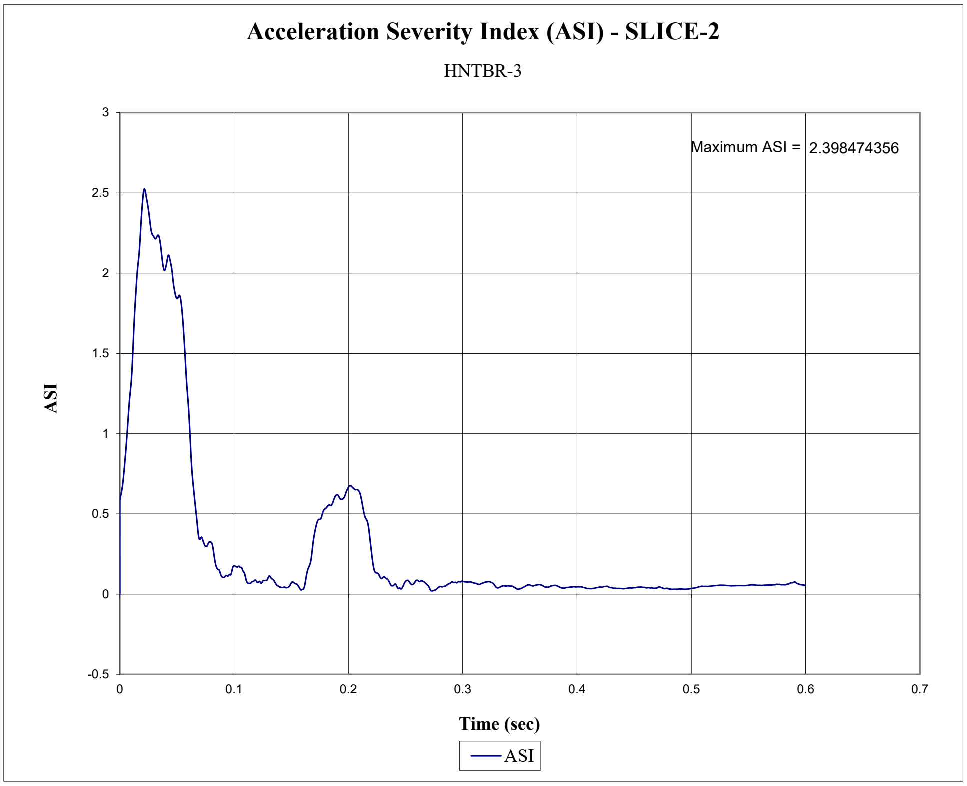


Figure F-16. Acceleration Severity Index (SLICE-2), Test No. HNTBR-3

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