



Test Report No. 608331-4-6
Test Report Date: March 2020

MASH TL-3 EVALUATION OF 2019 MASH 2-TUBE BRIDGE RAIL THRIE BEAM TRANSITION

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Contract No.: 1602767

Test No.: 608331-01-4/608331-01-5 / 608331-01-6

Test Date: 2019-09-02 / 2019-09-05 / 2019-12-19

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1. Report No. I	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle MASH TL-3 EVALUATION OF 2019 MASH 2-TUBE BRIDGE RAIL THRIE BEAM TRANSITION		5. Report Date March 2020	
		6. Performing Organization Code	
7. Author(s) William F. Williams, Wanda L. Menges, Glenn E. Schroeder, and Darrell L. Kuhn		8. Performing Organization Report No. Test Report No. 608331-01-4-6	
9. Performing Organization Name and Address Texas A&M Transportation Institute Proving Ground 3135 TAMU College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. 1602767	
12. Sponsoring Agency Name and Address State of Alaska Department of Transportation and Public Facilities Bridge Section 3132 Channel Drive - Room 100 Juneau, AK 99811-2500		13. Type of Report and Period Covered Technical Report: February 2016 - March 2020	
		14. Sponsoring Agency Code HFHWY00063 FHWA-AK-RD-4000-169	
15. Supplementary Notes Project Title: MASH Testing - Bridge Rail and Thrie Beam Transition Name of Contacting Representative: Elmer E. Marx - Alaska DOT&PF			
16. Abstract The purpose of the tests reported herein was to assess the performance of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition according to the safety-performance evaluation guidelines included in AASHTO <i>MASH</i>. The crash tests were performed in accordance with <i>MASH</i> TL-3, which involves two full-scale crash tests (<i>MASH</i> Tests 3-20 and 3-21). However, <i>MASH</i> states that when there are transitions between two barrier types with different stiffness, one from a more flexible barrier and the other to a more rigid barrier, a full-scale crash test is recommended for both types. Therefore, <i>MASH</i> Test 3-21 was performed at the transition from the thrie beam rail to bridge rail, and at the transition from the W-beam rail to thrie beam rail. This report provides details of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition, detailed documentation of the crash tests and results, and an assessment of the performance of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition for <i>MASH</i> TL-3 transition evaluation criteria. The 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition performed acceptably for <i>MASH</i> TL-3 transitions.			
17. Key Words Transition, bridge rail, thrie beam, longitudinal barrier, crash testing, MASH, roadside safety.		18. Distribution Statement Copyrighted. Not to be copied or reprinted without consent from the State of Alaska Department of Transportation and Public Facilities and North Dakota Department of Transportation.	
19. Security Classification (of this report) Unclassified	20. Security Classification (of this page) Unclassified	21. No. of Pages 122	22. Price

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APPROXIMATE CONVERSIONS TO SI UNITS				
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LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
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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 yards	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 1000L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 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
FORCE and 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 yards	yd ²
ha	hectares	2.47	acres	ac
km ²	Square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	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 tons (2000lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
FORCE and 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

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Chapter 1. INTRODUCTION

1.1 BACKGROUND

In May 1998, Texas A&M Transportation Institute contracted with the Alaska Department of Transportation to perform engineering analyses, design, and full-scale testing on the following:

- 1.) Alaska Multi-State (2-Tube) Bridge Rail (1, 2, 3).
- 2.) Alaska Multi-State Bridge Rail Thrie Beam Transition (4, 5).
- 3.) Alaska Multi-State W-Beam Transition (6, 7).

Under that project (TTI Project No. 404311), TTI researchers performed engineering analyses, developed engineering details, and performed full-scale crash testing on the Alaska Multi-State (2-Tube) Bridge Rail (1-3). The bridge rail successfully met the performance requirements of National Cooperative Highway Research Program (NCHRP) *Report 350* Test Level 4 (TL-4) (8). TTI researchers evaluated the strength and performance of a new, taller Alaska Multi-State 2-Tube Bridge Rail, herein after it was re-designated as the 2019 MASH 2-Tube Bridge Rail, with respect to American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (*MASH*), Second Edition 2016, specifications (9, 10). TTI researchers performed engineering analyses and developed engineering details for this design to meet the performance requirements of *MASH* TL-4. TTI Proving Ground performed full-scale crash testing on the 2019 MASH 2-Tube Bridge Rail with respect to *MASH* TL-4, and the bridge rail performed acceptably.

1.2 OBJECTIVE

As part of this current project, TTI researchers performed analyses, designed, and full-scale tested a new Alaska Multi-State Bridge Rail Thrie Beam Transition. This new thrie beam transition design was tested with respect to *MASH* TL-3.

The purpose of the tests reported herein was to assess the performance of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition according to the safety-performance evaluation guidelines included in AASHTO *MASH*. The crash tests were performed in accordance with *MASH* TL-3, which involves two full-scale crash tests (*MASH* Tests 3-20 and 3-21). However, *MASH* states that when there are transitions between two barrier types with different stiffness, one from a more flexible barrier and the other to a more rigid barrier, a full-scale crash test is recommended for both types. Therefore, *MASH* Test 3-21 was performed at the transition from the thrie beam rail to bridge rail, and at the transition from the W-beam rail to thrie beam rail.

This report provides details of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition, detailed documentation of the three crash tests and results, and an assessment of the performance of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition for *MASH* TL-3 evaluation criteria.

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Chapter 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The 2019 MASH 2-Tube Bridge Rail test installation was comprised of a 154-ft long section of reinforced concrete bridge deck that incorporated two steel rails, a 12½-ft long (nominal) section of two nested thrie beams (RTM08a) attached to the bridge rails with a thrie beam terminal connector (RTE01b) and unique guardrail connector, a standard symmetrical 75-inch long (nominal) thrie-beam-to-W-beam transition rail section (RWT01b), 25 ft of W-beam guardrail (in length of need), and a standard 9 ft-4½ inch long TxDOT DAT terminal (posts 1 and 2) at the end.

The total length of the installation was approximately 207 ft-3½ inches (53 ft-3½ inches transition + 154 ft bridge deck). The top edges of the DAT rail and W-beam were located 31 inches above grade. The top edge of the nested thrie beam was 34¾ inches above grade, and the top of the upper bridge rail was 38 inches above the bridge deck.

Posts 3 through 6 were 72 inches long (embedded 40 inches), posts 7 and 8 were 72 inches long, and posts 9 through 15 were 78 inches long. Posts 1 through 6 were spaced at 75 inches; posts 7 through 10 were at 37½ inches; and posts 10 through 15 were at 18¾ inches. Timber blockouts, 8-inches deep, were installed on posts 2 through 6. Posts 7 and 8 were fitted with 12-inch deep, short (14 inches) steel hollow structural section (HSS) tubing blockouts, and posts 9 through 15 were fitted with 12-inch deep, long (21⅞ inches) steel HSS blockouts,

The concrete portion of the 2019 MASH 2-Tube Bridge Rail test installation consisted of a reinforced cantilevered deck and curb, with two 2-inch wide joints extending through both the curb and the deck. The curb was 10 inches tall, with a 4-inch thick lift of grout, yielding a 6-inch tall traffic side face. The curb was 18 inches wide at the base, and 17 inches wide at the top, with the traffic side face sloping 1-inch toward the field side. Anchor bolts were cast in the deck and extended through the curb.

Sixteen fabricated steel posts were longitudinally spaced on 10 ft centers, beginning at 24 inches from each end of the concrete curb. Two steel rectangular HSS rail elements spanned the posts and extended past them at each end of the installation. The tops of the rails were located 24 inches and 38 inches above grade.

Figure 2.1 presents overall information on the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition, and Figure 2.2 provides photographs of the installation. Appendix A provides further details of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition.

2.2. DESIGN MODIFICATIONS DURING TESTS

No modification was made to the installation during the testing phase.

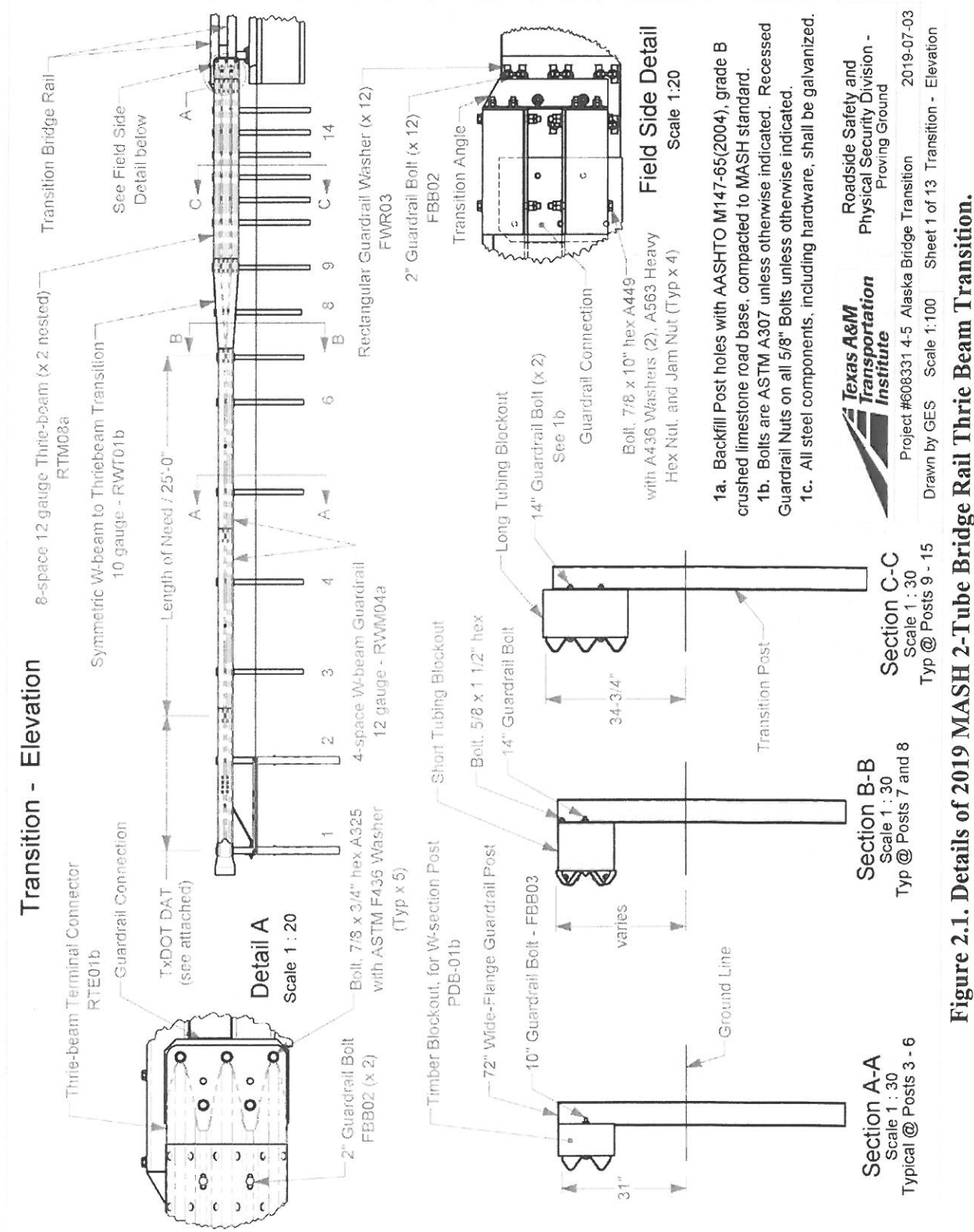


Figure 2.1. Details of 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition.



Figure 2.2. 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition prior to Testing.

2.3. MATERIAL SPECIFICATIONS

The specified minimum unconfined compressive strength of the concrete was 4000 psi for the curb, and 5000 psi for the deck. On December 10, 2018 (date of the first test on the 2-Tube Bridge Rail and deck), the average compressive strength of the concrete was 5060 psi (at 42 days) for the curb, and 5670 psi (at 44 days) for the deck.

Appendix B provides material certification documents for the materials used to install/construct the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition.

2.4. SOIL CONDITIONS

The transition and terminal of the test installation were installed in soil meeting grading B of AASHTO standard specification M147 “Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses.”

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition for full-scale crash testing, two 6-ft long W6×16 posts were installed in the immediate vicinity of the transition using the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table C.1 in Appendix C presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B.

As determined by the tests summarized in Appendix C, Table C.1, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 3940 lb, 5500 lb, and 6540 lb, respectively (90 percent of static load for the initial standard installation).

On the day of Test No. 608331-01-4, September 2, 2019, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 9087 lbf, 9948 lbf, and 10,395 lbf. Table C.2 in Appendix C shows the strength of the backfill material in which the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition was installed met minimum *MASH* requirements.

On the day of Test No. 608331-01-5, September 5, 2019, load on the post at 5 inches of deflection was 11,359 lbf, which was almost triple the required load. It was determined during the test pull that any additional loading may impart stresses on the W6×16 post that could cause it to yield and bend, or could cause damage to the test pull equipment (e.g. winch, load cell, etc.) Therefore, the test was terminated and the loads at deflections of 10 inches and 15 inches were not measured. Table C.3 in Appendix C shows the strength of the backfill material in which the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition was installed met minimum *MASH* requirements.

On the day of Test No. 608331-01-6, December 19, 2019, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 9225 lbf, 8537 lbf, and 7504 lbf. Table C.2 in Appendix C shows the strength of the backfill material in which the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition was installed met minimum *MASH* requirements.

Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST PERFORMED / MATRIX

Table 3.1 shows the test conditions and evaluation criteria recommended for *MASH* TL-3 transitions. However, *MASH* states that when there are transitions between two barrier types with different stiffness, one from a more flexible barrier and the other to a more rigid barrier, a full-scale crash test is recommended for both types. Therefore, *MASH* Test 3-21 was performed at the transition from the thrie beam rail to bridge rail, and at the transition from the W-beam rail to thrie beam rail.

Table 3.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Transitions.

Test Article	Test Designation	Test Vehicle	Impact Conditions		Evaluation Criteria
			Speed	Angle	
Transitions	3-20	1100C	62 mi/h	25°	A, D, F, H, I
	3-21	2270P	62 mi/h	25°	A, D, F, H, I

The target critical impact point (CIP) for each test was determined in accordance with the guidance provided in *MASH Section 2.3.2* and *MASH Figure 2-1*. For *MASH* Test 3-20, the target CIP was 5.1 ft upstream of the end of the concrete curb/deck. The target CIP for *MASH* Test 3-21 on the thrie beam to bridge rail transition was 7.0 ft upstream of the concrete curb/deck. The target CIP for *MASH* Test 3-21 on the W-beam to thrie beam transition was 7.3 ft upstream of the centerline of post 7. TTI researchers determined that *MASH* Test 3-20 on the W-beam to thrie beam transition was not necessary and was therefore not performed.

The crash tests and data analysis procedures were in accordance with guidelines presented in *MASH*. Chapter 4 presents brief descriptions of these procedures.

3.2. EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash tests reported herein. The test conditions and evaluation criteria required for *MASH* TL-3 transitions are listed in Table 3.1, and the substance of the evaluation criteria in Table 3.2. An evaluation of the crash test results is presented in detail under the section Assessment of Test Results.

Table 3.2. Evaluation Criteria Required for MASH TL-3 Transitions.

Evaluation Factors	Evaluation Criteria
Structural Adequacy	<i>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the test article is acceptable.</i>
Occupant Risk	<i>D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present 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.</i>
	<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>
	<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.</i>
	<i>I. The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>

Chapter 4. TEST CONDITIONS

4.1. TEST FACILITY

The full-scale crash tests reported herein were performed at Texas A&M Transportation Institute (TTI) Proving Ground, an International Standards Organization (ISO)/International Electrotechnical Commission (IEC) 17025-accredited laboratory with American Association for Laboratory Accreditation (A2LA) Mechanical Testing Certificate 2821.01. The full-scale crash tests were performed according to TTI Proving Ground quality procedures, and according to the *MASH* guidelines and standards.

The test facilities of the TTI Proving Ground are located on the Texas A&M University System RELLIS Campus, which consists of a 2000-acre complex of research and training facilities situated 10 miles northwest of the flagship campus of Texas A&M University. The site, formerly a United States Army Air Corps base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and evaluation of roadside safety hardware and perimeter protective devices. The site selected for construction and testing of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition was along the edge of an out-of-service apron. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks nominally 6 inches deep. The aprons were built in 1942, and the joints have some displacement, but are otherwise flat and level.

4.2 VEHICLE TOW AND GUIDANCE SYSTEM

Each test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2:1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released and ran unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site (no sooner than 2 s after impact), after which the brakes were activated, if needed, to bring the test vehicle to a safe and controlled stop.

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

Each test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems, Inc. The accelerometers, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid state units designed for crash test service. The TDAS Pro hardware

and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 samples per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

Each of the TDAS Pro units is returned to the factory annually for complete recalibration and all instrumentation used in the vehicle conforms to all specifications outlined by SAE J211. All accelerometers are calibrated annually by means of an ENDEVCO® 2901, precision primary vibration standard. This standard and its support instruments are checked annually and receive a National Institute of Standards Technology (NIST) traceable calibration. The rate transducers used in the data acquisition system receive a calibration via a Genisco Rate-of-Turn table. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are also made any time data are suspect. Acceleration data are measured with an expanded uncertainty of ± 1.7 percent at a confidence factor of 95 percent ($k=2$).

TRAP uses the data from the TDAS Pro to compute occupant/compartiment impact velocities, time of occupant/compartiment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. TRAP calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with an SAE Class 180-Hz low-pass digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals, then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact. Rate of rotation data is measured with an expanded uncertainty of ± 0.7 percent at a confidence factor of 95 percent ($k=2$).

4.3.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the front seat on the impact side of the 1100C vehicle. The dummy was not instrumented.

According to *MASH*, use of a dummy in the 2270P vehicle is optional. However, it is recommended a dummy be used when testing “any longitudinal barrier with a height greater than or equal to 33 inches.” Use of the dummy in the 2270P vehicle is recommended for tall rails to

evaluate the “potential for an occupant to extend out of the vehicle and come into direct contact with the test article.” Although this information is reported, it is not part of the impact performance evaluation. Since the rail height of the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition was 34¾ inches, a dummy was placed in the front seat of the 2270P vehicle on the impact side and restrained with lap and shoulder belts.

A dummy was not used in *MASH* Test 3-21 test of the W-beam to thrie beam transition as the rail height at impact was 31 inches.

4.3.3 Photographic Instrumentation Data Processing

Photographic coverage of each test included three digital high-speed cameras:

- One overhead with a field of view perpendicular to the ground and directly over the impact point;
- One placed behind the installation at an angle; and
- A third placed to have a field of view parallel to and aligned with the installation at the downstream end.

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the transition. The flashbulb was visible from each camera. The video files from these digital high-speed cameras were analyzed to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A digital camera recorded and documented conditions of each test vehicle and the installation before and after the test.

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Chapter 5. *MASH* TEST 3-20 (CRASH TEST NO. 608331-01-4)

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-20 involves an 1100C vehicle weighing 2420 lb $\pm$ 55 lb impacting the CIP of the transition at an impact speed of 62 mi/h $\pm$ 2.5 mi/h and an angle of 25° $\pm$ 1.5°. The target CIP for *MASH* Test 3-20 on the 2019 *MASH* 2-Tube Bridge Rail Thrie Beam Transition was 5.10 ft $\pm$ 1 ft upstream of the end of the concrete curb/deck. Figure 5.1 depicts the target CIP.

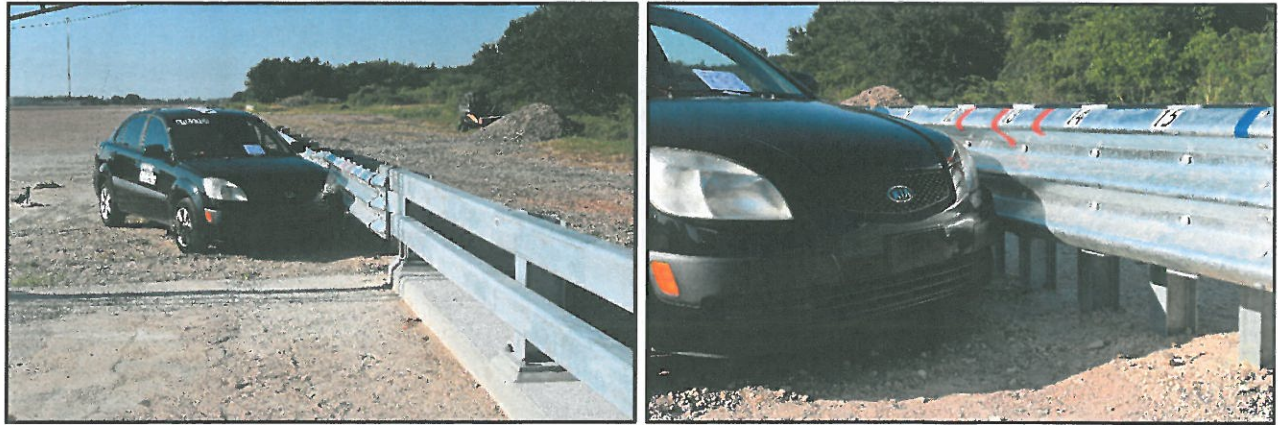


Figure 5.1. Transition/Test Vehicle Geometrics for Test No. 608331-01-4.

The 2007 Kia Rio* used in the test weighed 2446 lb, and the actual impact speed and angle were 60.9 mi/h and 26.5°, respectively. The actual impact point was 6.06 ft upstream of the end of the concrete curb/deck. Minimum target impact severity (IS) was 51 kip-ft, and actual IS was 61 kip-ft.

5.2 WEATHER CONDITIONS

The test was performed on the morning of September 2, 2019. Weather conditions at the time of testing were as follows: wind speed: 4 mi/h; wind direction: 105° (vehicle was traveling at magnetic heading of 335°); temperature: 93°F; relative humidity: 53 percent.

5.3 TEST VEHICLE

Figures 5.1 and 5.2 show the 2007 Kia Rio used for the crash test. The vehicle's test inertia weight was 2446 lb, and its gross static weight was 2611 lb. The height to the lower edge of the vehicle bumper was 7.75 inches, and height to the upper edge of the bumper was 21.5 inches. Table D.1 in Appendix D1 gives additional dimensions and information on the

* The 2007 model vehicle used is older than the 6-year age noted in *MASH*, and was selected based upon availability. An older model vehicle is permitted by AASHTO as long as it is otherwise *MASH* compliant. Other than the vehicle's year model, this 2007 model vehicle met the *MASH* requirements.

vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

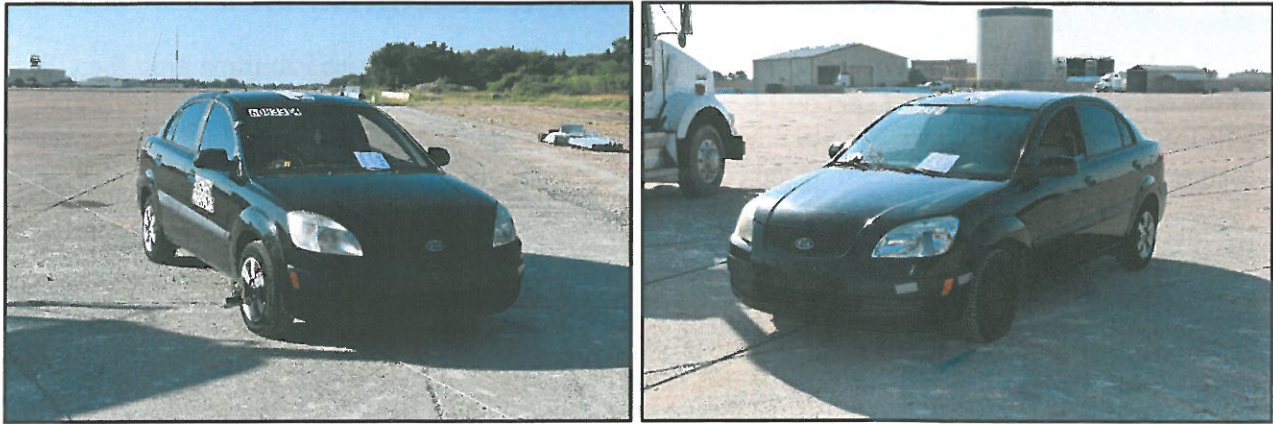


Figure 5.2. Test Vehicle before Test No. 608331-01-4.

5.4 TEST DESCRIPTION

The test vehicle was traveling at an impact speed of 60.9 mi/h when it contacted the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition 6.06 ft upstream of the end of the concrete curb/deck at an impact angle of 26.5°. Table 5.1 lists events that occurred during Test No. 608331-01-4. Figures D.1 and D.2 in Appendix D2 present sequential photographs during the test.

Table 5.1. Events during Test No. 608331-01-4.

TIME (s)	EVENTS
0.000	Vehicle contacts transition
0.023	Vehicle begins to redirect
0.091	Vehicle makes a slight increase in clockwise yaw rate
0.234	Vehicle traveling parallel with transition
0.355	Left rear corner and bumper of vehicle contacts transition
0.447	Vehicle loses contact with transition while traveling at 39.5 mi/h, trajectory of 7.1°, and heading of 14.0°

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the transition, the vehicle came to rest 145 ft downstream of the impact point and 137 ft toward the traffic lanes.

5.5 DAMAGE TO TEST INSTALLATION

Figure 5.3 shows the damage to the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition. Posts 12 through 15 were leaning back at 89°, and the soil was disturbed around each

of those posts. There was no visible soil disturbance at posts 1 and 2. The bottom edge of the thrie beam rail was deformed in the impact area, and the concrete deck cracked at post 16 (the first post on the bridge deck). Working width* was 26.1 inches, and height of working width was 34.75 inches. Maximum dynamic deflection during the test was 3.5 inches, and maximum permanent deformation was 1.25 inches.

5.6 DAMAGE TO TEST VEHICLE

Figure 5.4 shows the damage sustained by the vehicle. The front bumper, hood, grill, radiator and support, left front strut and tower, left lower control arm, left front tire and rim, left front fender, left front door and glass, left front floor pan, and left rear quarter panel were damaged. No fuel tank damage was observed. The windshield sustained stress cracks from displacement of the left A-pillar, and the roof was slightly deformed. A small hole in the windshield was caused by the impact of the hood. Maximum exterior crush to the vehicle was 14.0 inches in the side plane at the left front corner at bumper height. Maximum occupant compartment deformation was 3.5 inches in the left kick panel area. Figure 5.5 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D1 provide exterior crush and occupant compartment measurements.

5.7 OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 5.2. Figure D.3 in Appendix D3 shows the vehicle angular displacements, and Figures D.4 through D.6 in Appendix D4 show acceleration versus time traces. Figure 5.6 summarizes pertinent information from the test.

* Per *MASH*, "The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article." In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.

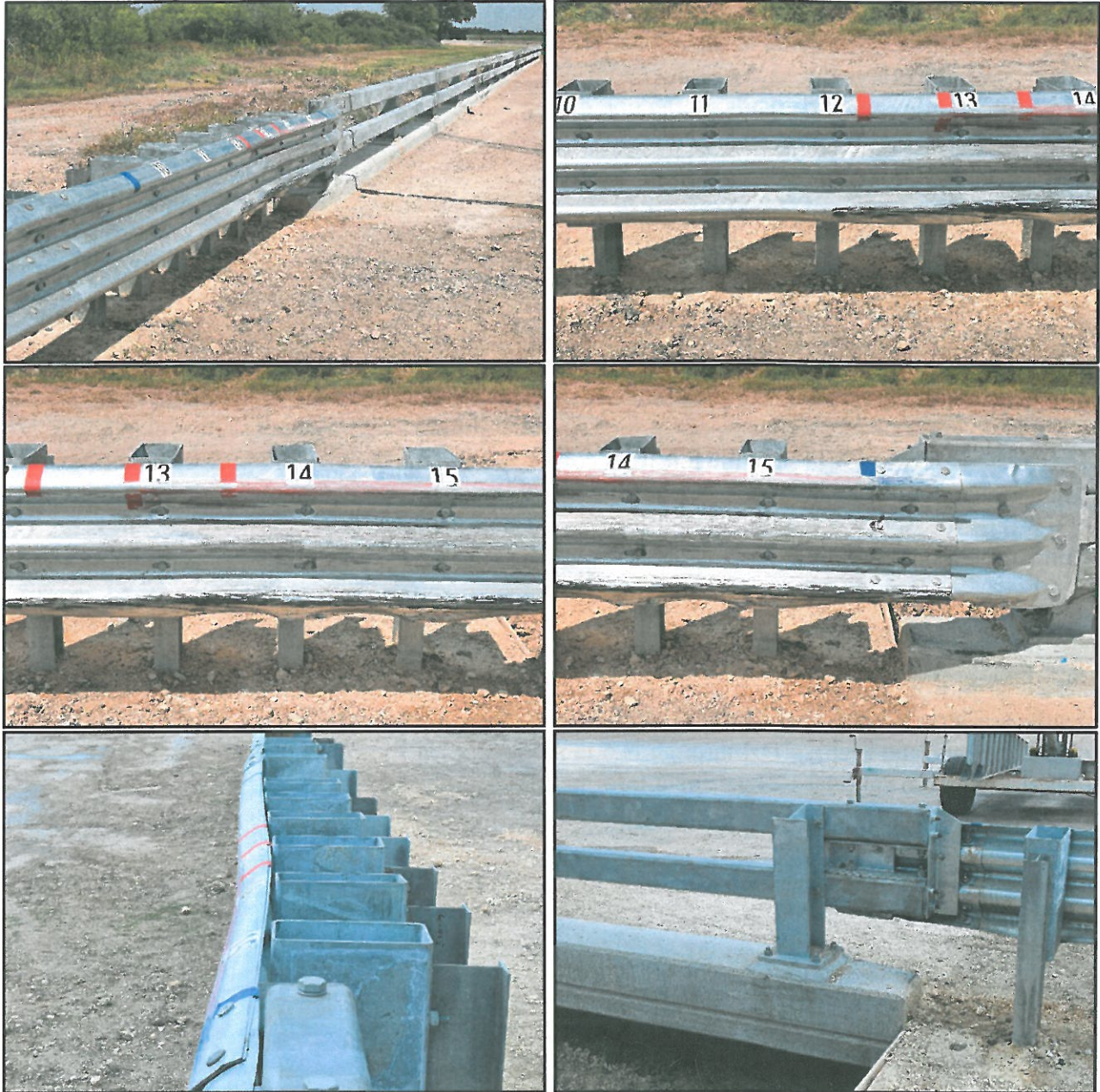


Figure 5.3. Transition after Test No. 608331-01-4.

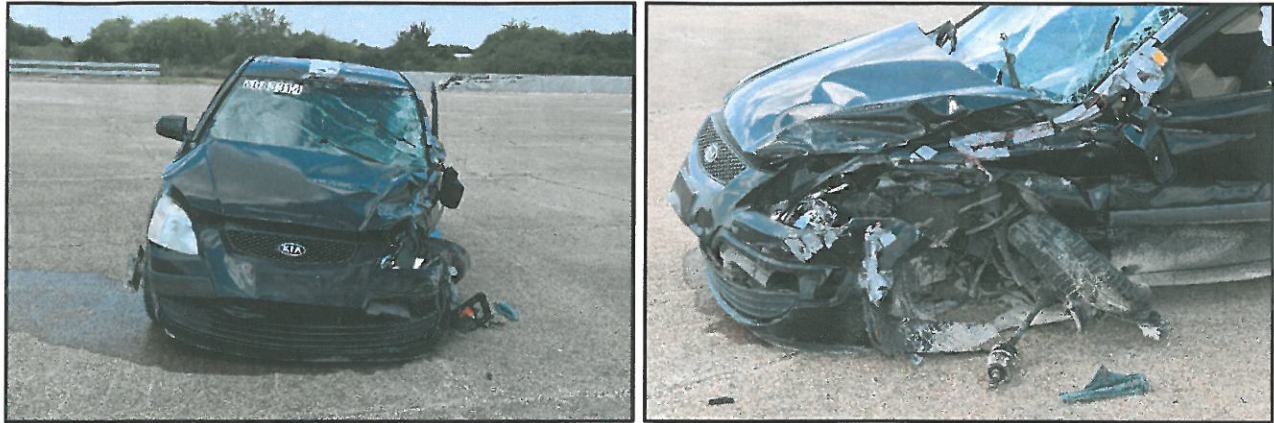


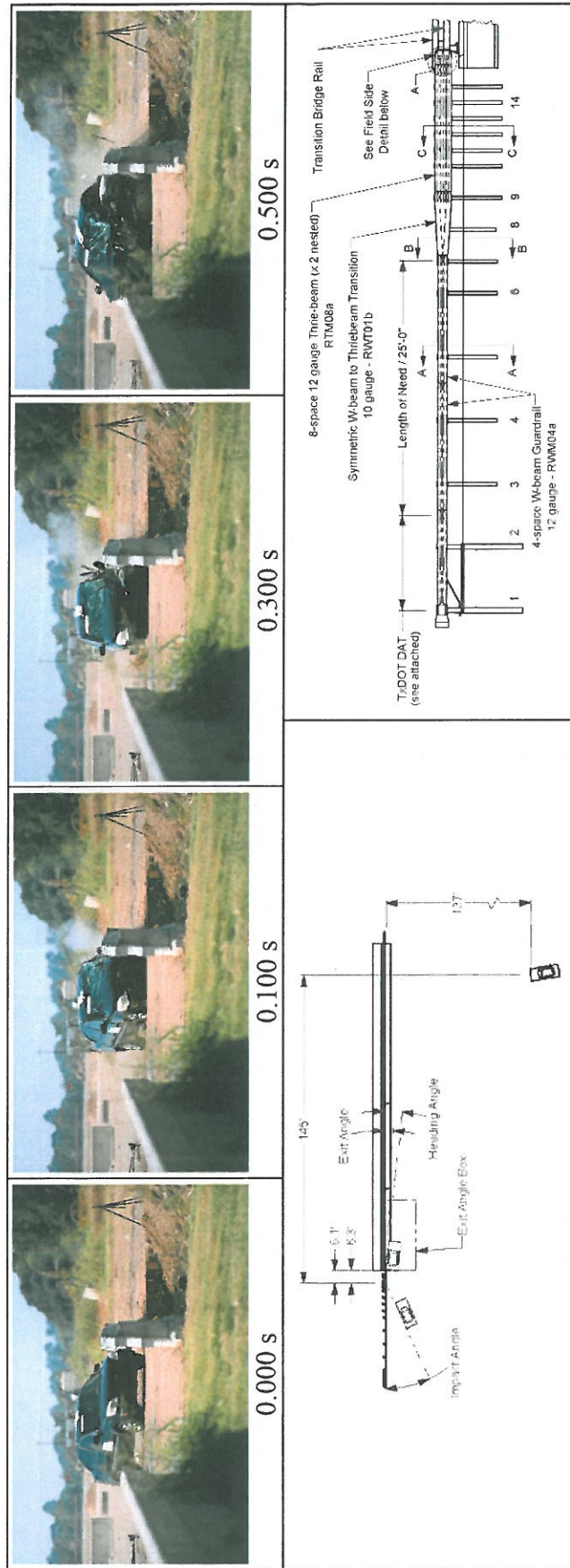
Figure 5.4. Test Vehicle after Test No. 608331-01-4.



Figure 5.5. Interior of Test Vehicle after Test No. 608331-01-4.

Table 5.2. Occupant Risk Factors for Test No. 608331-01-4.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	22.6 ft/s	at 0.0824 s on left side of interior
Lateral	30.5 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	14.5 g	0.0975 - 0.1075 s
Lateral	9.2 g	0.0940 - 0.1040 s
Theoretical Head Impact Velocity (THIV)	41.0 km/h 11.4 m/s	at 0.0805 s on left side of interior
Acceleration Severity Index (ASI)	2.17	0.0496 - 0.0996 s
Maximum 50-ms Moving Average		
Longitudinal	-12.0 g	0.0292 - 0.0792 s
Lateral	16.8 g	0.0303 - 0.0803 s
Vertical	-3.6 g	0.0850 - 0.1350 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	12°	1.9987 s
Pitch	3°	2.0000 s
Yaw	63°	1.5386 s



General Information		Impact Conditions		Post-Impact Trajectory	
Test Agency.....	Texas A&M Transportation Institute (TTI)	Speed	60.9 mi/h	Stopping Distance.....	145 ft downstream
Test Standard Test No.	MASH Test 3-20	Angle	26.5°		137 ft twd traffic
TTI Test No.	608331-01-4	Location/Orientation.....	6.06 ft upstream of end of curb/deck	Vehicle Stability	
Test Date	2019-09-02	Impact Severity.....	61 kip-ft	Maximum Yaw Angle.....	63°
Test Article		Exit Conditions		Maximum Pitch Angle.....	3°
Type	Transition	Speed	39.5 mi/h	Maximum Roll Angle.....	12°
Name.....	2019 MASH 2-Tube Bridge Rail Thrie Beam Transition	Trajectory/Heading Angle.....	7.1° / 14.0°	Vehicle Snagging.....	No
Installation Length.....	207 ft 3½ inches (incl 154 ft of deck)	Occupant Risk Values		Vehicle Pocketing.....	No
Material or Key Elements	Thrie beam guardrail terminal to 38-inch tall 2-tube bridge rail, 34¾ inch tall thrie beam guardrail section, symmetrical W-beam to thrie beam terminal, 25 ft of W-beam guardrail	Longitudinal OIV	22.6 ft/s	Test Article Deflections	
Soil Type and Condition	AASHTO M147 Grading B Soil (crushed limestone), Damp	Lateral OIV	30.5 ft/s	Dynamic.....	3.5 inches
		Longitudinal Ridedown	14.5 g	Permanent.....	1.25 inches
		Lateral Ridedown	9.2 g	Working Width.....	26.1 inches
Test Vehicle		THIV	41.0 km/h	Height of Working Width	34.75 inches
Type/Designation.....	1100C	ASI.....	2.17	Vehicle Damage	
Make and Model	2007 Kia Rio	Max. 0.050-s Average		VDS.....	11LFQ6
Curb.....	2470 lb	Longitudinal	-12.0 g	CDC.....	11FLEW5
Test Inertial.....	2446 lb	Lateral	16.8 g	Max. Exterior Deformation.....	14.0 inches
Dummy.....	165 lb	Vertical.....	-3.6 g	OCDI	FL0010000
Gross Static.....	2611 lb			Max. Occupant Compartment Deformation	3.5 inches

Figure 5.6. Summary of Results for MASH Test 3-20 on 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition.

Chapter 6. *MASH* TEST 3-21 AT TRANSITION FROM THRIE BEAM TO BRIDGE RAIL (CRASH TEST NO. 608331-01-5)

6.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-21 involves a 2270P vehicle weighing 5000 lb $\pm$ 110 lb impacting the CIP of the transition at an impact speed of 62 mi/h $\pm$ 2.5 mi/h and an angle of 25° $\pm$ 1.5°. The target CIP for *MASH* Test 3-21 on the 2019 *MASH* 2-Tube Bridge Rail Thrie Beam Transition was 7.00 ft $\pm$ 1 ft upstream of the end of the concrete curb/deck. Figure 6.1 depicts the target CIP.

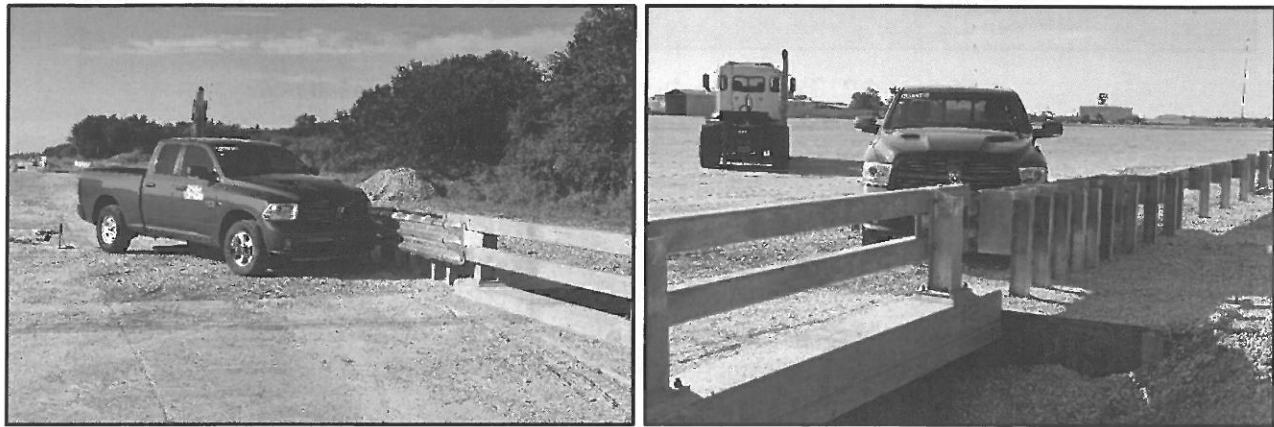


Figure 6.1. 2019 Transition/Test Vehicle Geometrics for Test No. 608331-01-5.

The 2013 RAM 1500 pickup truck used in the test weighed 5050 lb, and the actual impact speed and angle were 61.9 mi/h and 25.3°, respectively. The actual impact point was 6.52 ft upstream of the end of the concrete curb/deck. Minimum target IS was 106 kip-ft, and actual IS was 118 kip-ft.

6.2 WEATHER CONDITIONS

The test was performed on the morning of September 5, 2019. Weather conditions at the time of testing were as follows: wind speed: 2 mi/h; wind direction: 244° (vehicle was traveling at magnetic heading of 335°); temperature: 91°F; relative humidity: 57 percent.

6.3 TEST VEHICLE

Figures 6.1 and 6.2 show the 2013 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5050 lb, and its gross static weight was 5215 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.25 inches. Tables E.1 and E.2 in Appendix E1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 6.2. Test Vehicle before Test No. 608331-01-5.

6.4 TEST DESCRIPTION

The test vehicle was traveling at an impact speed of 61.9 mi/h when it contacted the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition 6.52 ft upstream of the end of the concrete curb/deck at an impact angle of 25.3°. Table 6.1 lists events that occurred during Test No. 608331-01-5. Figures E.1 and E.2 in Appendix E2 present sequential photographs during the test.

Table 6.1. Events during Test No. 608331-01-5.

TIME (s)	EVENTS
0.000	Vehicle contacts transition
0.035	Vehicle begins to redirect
0.149	Right front tire leaves the pavement
0.210	Vehicle traveling parallel with transition
0.207	Left rear bumper and corner of vehicle contacts transition
0.377	Vehicle loses contact with transition while traveling at 47.9 mi/h, trajectory of 6.9°, and heading of 6.5°

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 3.0 s after impact, and the vehicle subsequently came to rest 174 ft downstream of the impact point.

6.5 DAMAGE TO TEST INSTALLATION

Figure 6.3 shows the damage to the 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition. There was no visible indication of movement at posts 1 through 10. The soil was disturbed around post 10, and posts 10, 11, and 12 were leaning 89° toward the field side. There was a 0.5-inch gap in the soil on the traffic side of post 12. Posts 13-15 were leaning slightly toward field side, posts 13 and 15 had an 0.5-inch gap between the posts and soil on the traffic

and field sides, and post 14 on the field side only. Working width* was 26.9 inches, and height of working width was 34.75 inches. Maximum dynamic deflection during the test was 6.1 inches, and maximum permanent deformation was 3.75 inches.

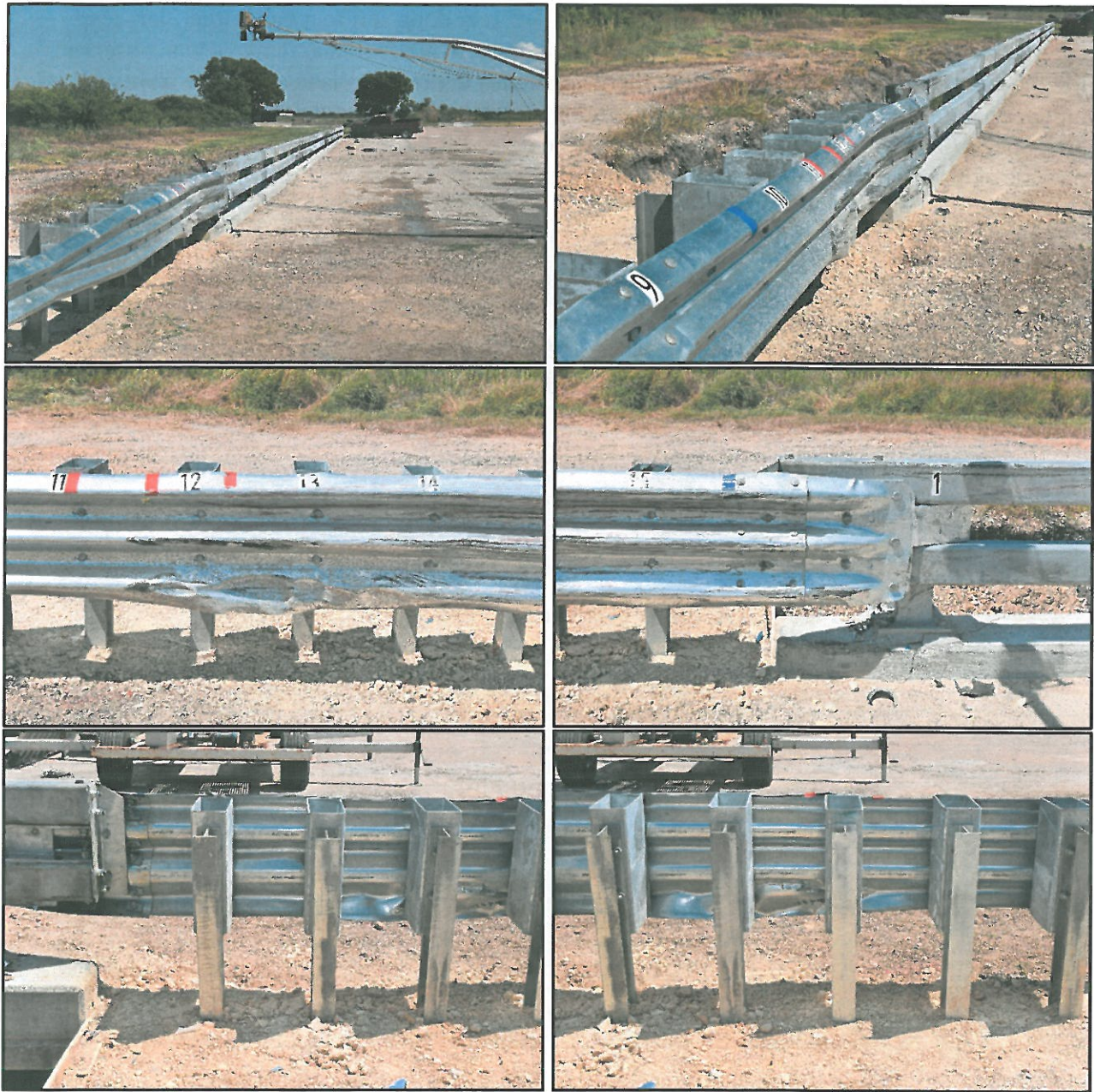


Figure 6.3. Transition after Test No. 608331-01-5.

* Per *MASH*, "The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article." In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.

6.6 DAMAGE TO TEST VEHICLE

Figure 6.4 shows the damage sustained by the vehicle. The front bumper, hood, grill, radiator and support, left front fender, left front tire and rim, left upper and lower A-arms, left front door and window glass, left front floor pan, left rear door, left rear cab corner, left rear exterior bed, left rear rim, and rear bumper were damaged. No fuel tank damage was observed. Maximum exterior crush to the vehicle was 15.0 inches in the side plane at the left front at bumper height. Maximum occupant compartment deformation was 4.0 inches in the left side kick panel. Figure 5.5 shows the interior of the vehicle. Tables E.3 and E.4 in Appendix E1 provide exterior crush and occupant compartment measurements.



Figure 6.4. Test Vehicle after Test No. 608331-01-5.



Figure 6.5. Interior of Test Vehicle after Test No. 608331-01-5.

6.7 OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.2. Figure E.3 in Appendix E3 shows the vehicle angular displacements, and Figures E.4 through E.6 in Appendix E4 show acceleration versus time traces. Figure 6.6 summarizes pertinent information from the test.

Table 6.2. Occupant Risk Factors for Test No. 608331-01-5.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	20.3 ft/s	at 0.1075 s on left side of interior
Lateral	23.6 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	7.4 g	0.1313 - 0.1413 s
Lateral	13.0 g	0.2459 - 0.2559 s
THIV	9.3 m/s	at 0.1042 s on left side of interior
ASI	1.51	0.0598 - 0.1098 s
Maximum 50-ms Moving Average		
Longitudinal	-8.7 g	0.0477 - 0.0977 s
Lateral	10.9 g	0.0386 - 0.0886 s
Vertical	-4.7 g	0.0572 - 0.1072 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	8°	1.1616 s
Pitch	11°	1.9957 s
Yaw	43°	0.8706 s



General Information

Test Agency Texas A&M Transportation Institute (TTI)
 Test Standard Test No. MASH Test 3-21
 TTI Test No. 608331-01-5
 Test Date 2019-09-05

Test Article

Type Transition
 Name 2019 MASH 2-Tube Bridge Rail Thrie
 Installation Length Beam Transition
 Material or Key Elements ... 207 ft 3 1/2 inches (incl 154 ft of deck)
 Thrie beam guardrail terminal to 38-inch
 tall 2-tube bridge rail, 34 1/4 inch tall thrie
 beam guardrail section, symmetrical
 W-beam to thrie beam terminal, 25 ft of
 W-beam guardrail
 AASHTO M147 Grading B Soil (crushed
 limestone), Damp

Soil Type and Condition

Type/Designation 2270P
 Make and Model 2013 RAM 1500 Pickup
 Curb 5168 lb
 Test Inertial 5050 lb
 Dummy 165 lb
 Gross Static 5215 lb

Test Vehicle

Max. 0.050-s Average
 Longitudinal -8.7 g
 Lateral 10.9 g
 Vertical -4.7 g

Impact Conditions

Speed 61.9 mi/h
 Angle 25.3°
 Location/Orientation 6.52 ft upstream of
 end of curb/deck
 Impact Severity 118 kip-ft

Exit Conditions

Speed 47.9 mi/h
 Trajectory/Heading Angle 6.9° / 6.5°

Occupant Risk Values

Longitudinal OIV 20.3 ft/s
 Lateral OIV 23.6 ft/s
 Longitudinal Ridedown 7.4 g
 Lateral Ridedown 13.0 g
 THIV 33.5 km/h
 ASI 1.51

Post-Impact Trajectory

Stopping Distance 174 ft downstream
 Aligned w/traffic face

Vehicle Stability

Maximum Yaw Angle 43°
 Maximum Pitch Angle 11°
 Maximum Roll Angle 8°
 Vehicle Snagging No
 Vehicle Pocketing No

Test Article Deflections

Dynamic 6.1 inches
 Permanent 3.75 inches
 Working Width 26.9 inches
 Height of Working Width 34.75 inches
 Vehicle Damage
 VDS 11LFQ5
 CDC 11FLEW4
 Max. Exterior Deformation 15.0 inches
 OCDI FL0011000
 Max. Occupant Compartment
 Deformation 4.0 inches

Figure 6.6. Summary of Results for MASH Test 3-21 on 2019 MASH 2-Tube Transition from Thrie Beam to Bridge Rail.

Chapter 7. *MASH* TEST 3-21 AT TRANSITION FROM W-BEAM TO THRIE BEAM (CRASH TEST NO. 608331-01-6)

7.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-21 involves a 2270P vehicle weighing 5000 lb $\pm$ 110 lb impacting the CIP of the transition at an impact speed of 62 mi/h $\pm$ 2.5 mi/h and an angle of 25° $\pm$ 1.5°. The target CIP for *MASH* Test 3-21 on the 2019 *MASH* 2-Tube Bridge Rail Thrie Beam Transition was 7.3 ft $\pm$ 1 ft upstream of the centerline of post 7. Figure 7.1 depicts the target CIP.



Figure 7.1. Transition/Test Vehicle Geometries for Test No. 608331-01-6.

The 2013 RAM 1500 used in the test weighed 5038 lb, and the actual impact speed and angle were 62.6 mi/h and 24.9°. The actual impact point was 7.5 ft upstream of the centerline of post 7. Minimum target IS was 106 kip-ft, and actual IS was 117 kip-ft.

7.2 WEATHER CONDITIONS

The test was performed on the morning of December 19, 2019. Weather conditions at the time of testing were as follows: wind speed: 1 mi/h; wind direction: 140° (vehicle was traveling at magnetic heading of 335°); temperature: 45°F; relative humidity: 66 percent.

7.3 TEST VEHICLE

Figure 7.2 shows the 2013 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5038 lb, and its gross static weight was 5038 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 29.0 inches. Tables F.1 and F.2 in Appendix F1 give additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.



Figure 7.2. Test Vehicle before Test No. 608331-01-6.

7.4 TEST DESCRIPTION

Table 7.1 lists events that occurred during Test No. 608331-01-6. Figures F.1 and F.2 in Appendix F2 present sequential photographs during the test.

Table 7.1. Events during Test No. 608331-01-6.

TIME (s)	EVENTS
0.000	Vehicle contacts transition
0.017	Post 5 and 6 begin to deflect toward protected side
0.028	Vehicle begins to redirect
0.028	Post 7 begins to deflect toward protected side
0.053	Post 4 begins to rotate counter-clockwise
0.125	Right front tire lifts off pavement
0.203	Right rear tire lifts off pavement
0.284	Vehicle is traveling parallel with transition
0.609	Vehicle loses contact with transition while traveling at 31.8 mi/h, trajectory of 23.3°, and heading of 24.7°
0.776	Right front tire makes contact with pavement
0.885	Left rear tire makes contact with pavement

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 3.5 s after impact. After loss of contact with the barrier, the vehicle came to rest 133 ft downstream of the impact and 2 ft toward traffic lanes.

7.5 DAMAGE TO TEST INSTALLATION

Figures 7.3 through 7.5 show the damage to the transition. The metal rail element released from posts 1-5 and 7-10. Post 1 was pulled downstream 0.75 inch and post 2 was split.

Post 5 was leaning toward field side 88°, and there was a gap between the soil and post of 0.5 inch on the field side and 1.0 inch on the traffic side. Post 6 was leaning toward field side 76°, and there was a gap between the soil and post of 1.5 inches on the field side and 6.0 inches on the traffic side. Posts 7 through 9 were pushed toward field side and downstream. Post 10 was leaning toward field side 80°, and the gap between the soil and post was 3.0 inches on the field side and 0.75 inch on the traffic side. Post 11 was leaning toward field side 84°, and the gap between the soil and post was 3.0 inches on the field side. Post 12 was leaning toward field side 87°, and the gap between the post and soil was 0.13 inches on the traffic side and 1.5 inches on the field side. Post 13 was leaning toward field side 88°, and the post was pushed toward field side 0.75 inch. Post 14 was pushed toward field side 0.5 inch, and the soil around post 15 was disturbed only. Working width* was 44.7 inches, and height of working width was 61.8 inches. Maximum dynamic deflection during the test was 33.6 inches, and maximum permanent deformation was 28.0 inches.



Figure 7.3. Transition after Test No. 608331-01-6.

* Per *MASH*, "The working width is the maximum dynamic lateral position of any major part of the system or vehicle. These measurements are all relative to the pre-impact traffic face of the test article." In other words, working width is the total barrier width plus the maximum dynamic intrusion of any portion of the barrier or test vehicle past the field side edge of the barrier.



Figure 7.4. Posts 1 through 5 after Test No. 608331-01-6.

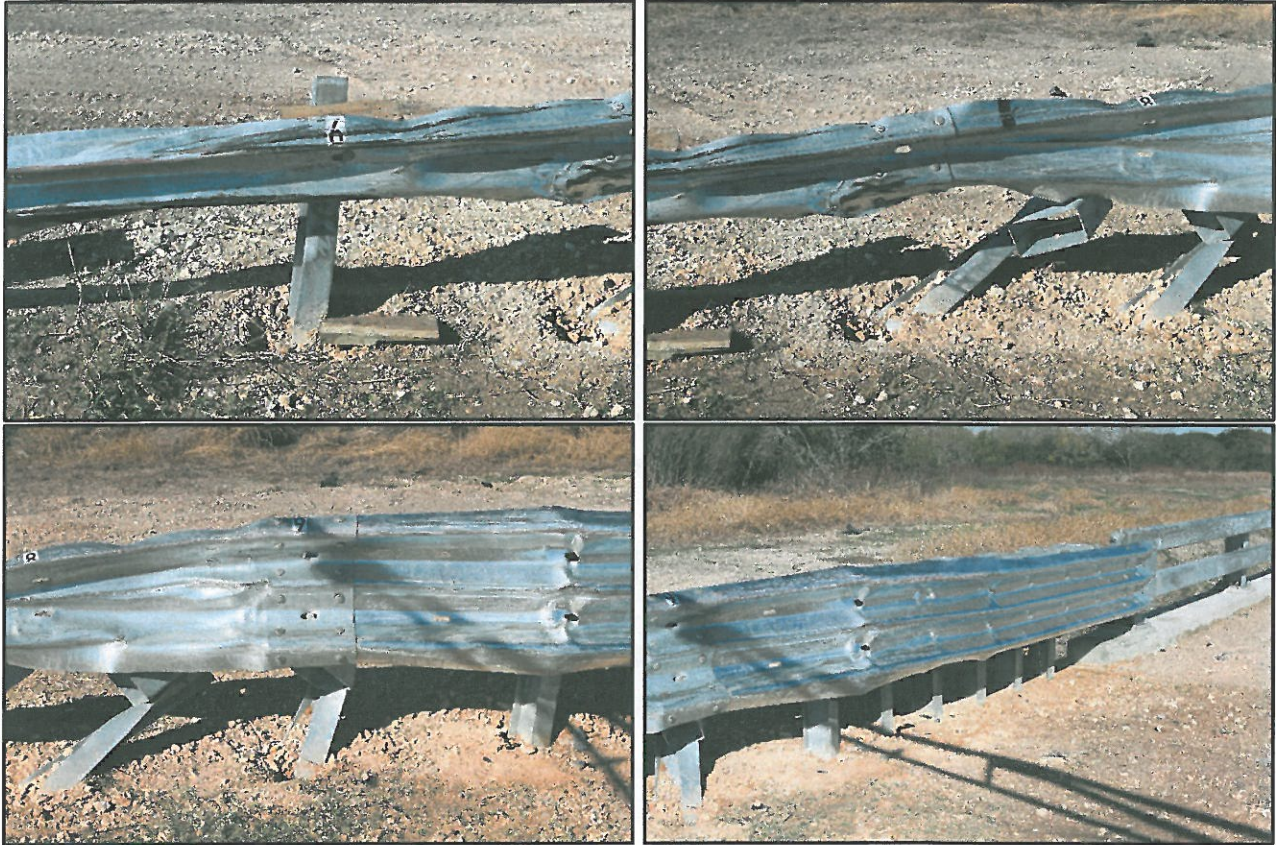


Figure 7.5. Posts 6 through 15 after Test No. 608331-01-6.

7.6 DAMAGE TO TEST VEHICLE

Figure 7.6 shows the damage sustained by the vehicle. The front bumper, radiator and support, hood, grill, left front fender, left frame rail, left upper and lower control arms, left front tire and rim, left front door, left rear exterior bed, left rear rim, and rear bumper were damaged. No fuel tank damage was observed. The windshield showed stress cracks radiating upward and inward from the lower left A-post. Maximum exterior crush to the vehicle was 20.0 inches in the side plane at the left front corner at bumper height. No occupant compartment deformation or intrusion was observed. Figure 7.7 shows the interior of the vehicle. Tables F.3 and F.4 in Appendix F1 provide exterior crush and occupant compartment measurements.

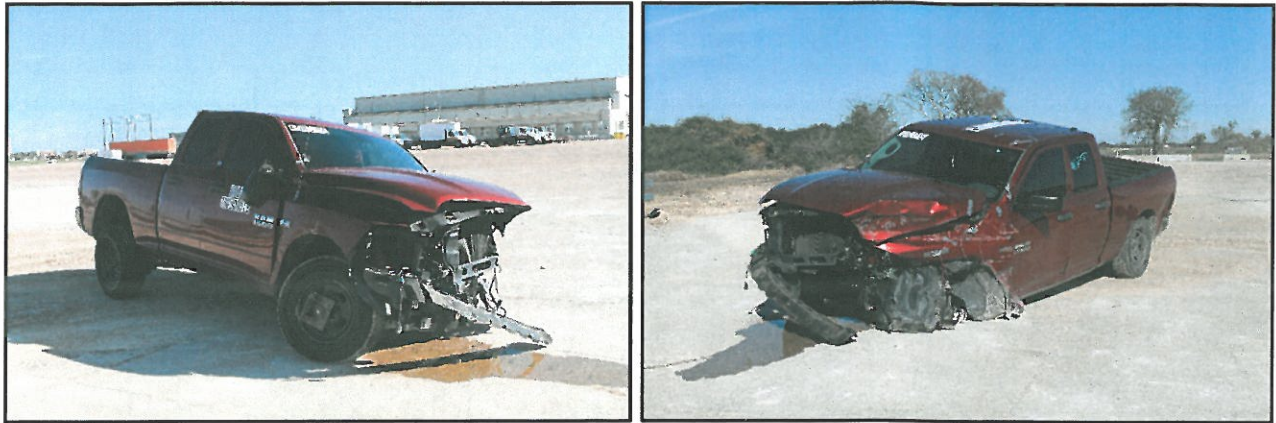


Figure 7.6. Test Vehicle after Test No. 608331-01-6.

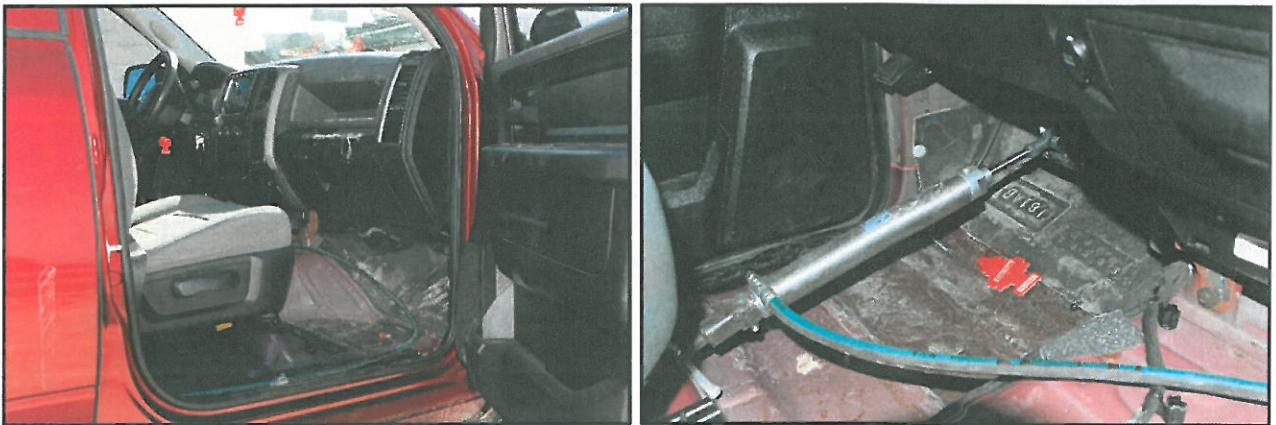


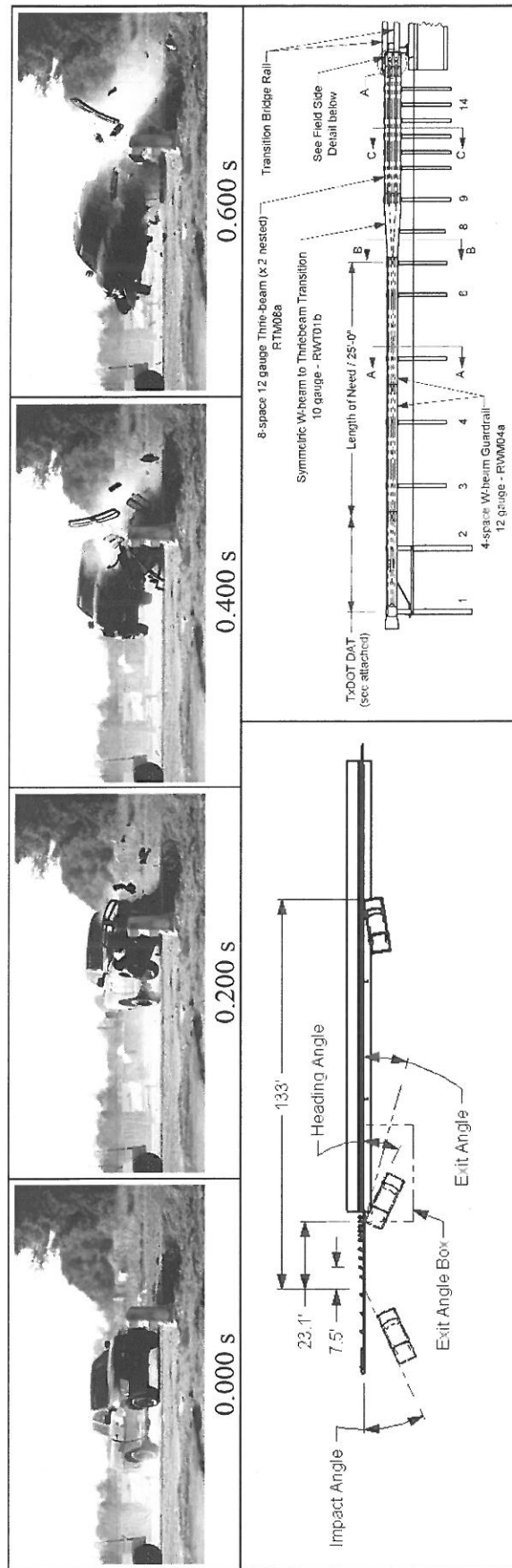
Figure 7.7. Interior of Test Vehicle after Test No. 608331-01-6.

7.7 OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.2. Figure F.3 in Appendix F3 shows the vehicle angular displacements, and Figures F.4 through F.6 in Appendix F4 show acceleration versus time traces. Figure 7.8 summarizes pertinent information from the test.

Table 7.2. Occupant Risk Factors for Test No. 608331-01-6.

Occupant Risk Factor	Value	Time
OIV		
Longitudinal	24.9 ft/s	at 0.1439 s on left side of interior
Lateral	16.4 ft/s	
Occupant Ridedown Accelerations		
Longitudinal	10.7 g	0.1467 - 0.1567 s
Lateral	9.8 g	0.2125 - 0.2225 s
THIV	8.6 m/s	at 0.1373 s on left side of interior
ASI	1.02	0.2115 - 0.2615 s
Maximum 50-ms Moving Average		
Longitudinal	-9.1 g	0.1163 - 0.1663 s
Lateral	7.7 g	0.1863 - 0.2363 s
Vertical	-4.6 g	0.7919 - 0.8419 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	15°	0.7865 s
Pitch	14°	0.8046 s
Yaw	53°	0.8341 s



General Information		Impact Conditions		Post-Impact Trajectory	
Test Agency	Texas A&M Transportation Institute (TTI)	Speed	62.6 mi/h	Stopping Distance	133 ft downstream
Test Standard	MASH Test 3-21	Angle	24.9°		2 ft twd traffic
TTI Test No.	608331-01-6	Location/Orientation	7.5 ft upstream of post 7	Vehicle Stability	
Test Date	2019-12-19	Impact Severity	117 kip-ft	Maximum Yaw Angle	53°
Test Article		Exit Conditions		Maximum Pitch Angle	14°
Type	Transition	Speed	31.8 mi/h	Maximum Roll Angle	15°
Name	2019 MASH 2-Tube Bridge Rail Thrie	Trajectory/Heading Angle	23.3° / 24.7°	Vehicle Snagging	No
Installation Length	Beam Transition	Occupant Risk Values		Vehicle Pocketing	No
Material or Key Elements	Thrie beam guardrail terminal to 38-inch tall 2-tube bridge rail, 34 3/4 inch tall thrie beam guardrail section, symmetrical W-beam to thrie beam terminal, 25 ft of W-beam guardrail	Longitudinal OIV	24.9 ft/s	Test Article Deflections	
	AASHTO M147 Grading B Soil (crushed limestone), Damp	Longitudinal Ridedown	10.7 g	Dynamic	33.6 inches
Soil Type and Condition		Lateral Ridedown	9.8 g	Permanent	28.0 inches
Test Vehicle		THIV	8.6 m/s	Working Width	44.7 inches
Type/Designation	2270P	ASI	1.02	Height of Working Width	61.8 inches
Make and Model	2013 RAM 1500 Pickup	Max. 0.050-s Average		Vehicle Damage	
Curb	4890 lb	Longitudinal	-9.1 g	VDS	11LFQ5
Test Inertial	5038 lb	Lateral	7.7 g	CDC	11FLEW4
Dummy	No dummy	Vertical	-4.6 g	Max. Exterior Deformation	20.0 inches
Gross Static	5038 lb			OCDI	LF0000000
				Max. Occupant Compartment Deformation	None

Figure 7.8. Summary of Results for MASH Test 3-21 2019 MASH 2-Tube Transition from W-Beam to Thrie Beam.

Chapter 8. SUMMARY AND CONCLUSIONS

8.1 ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-3 transitions. An assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-3 transitions is provided in Tables 8.1 through 8.3.

8.2 CONCLUSIONS

Table 8.4 shows the 2019 *MASH* 2-Tube Bridge Rail Thrie Beam Transition performed acceptably as reported herein for a *MASH* TL-3 transition.

Table 8.1. Performance Evaluation Summary for MASH Test 3-20 on 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition.

Test Agency: Texas A&M Transportation Institute		Test No.: 608331-01-4	Test Date: 2019-09-02
MASH Test 3-20 Evaluation Criteria		Test Results	Assessment
Structural Adequacy			
<i>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</i>		The 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection was 3.5 inches.	Pass
Occupant Risk			
<i>D. 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.</i>		No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>		Maximum occupant compartment deformation was 3.5 inches in the left kick panel area.	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.</i>		The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 12° and 3°, respectively.	Pass
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>		Longitudinal OIV was 22.6 ft/s, and lateral OIV was 30.5 ft/s.	Pass
		Longitudinal occupant ridedown acceleration was 14.5 g, and lateral occupant ridedown acceleration was 9.2 g.	Pass

Table 8.2. Performance Evaluation Summary for MASH Test 3-21 on 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition from Thrie Beam to Bridge Rail.

Test Agency: Texas A&M Transportation Institute		Test No.: 608331-01-5	Test Date: 2019-09-05
MASH Test 3-21 Evaluation Criteria		Test Results	Assessment
Structural Adequacy			
<i>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</i>		The 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection was 6.1 inches.	Pass
Occupant Risk			
<i>D. 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.</i>		No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>		Maximum occupant compartment deformation was 4.0 inches in the left front kick panel.	
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>		The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 8° and 11°, respectively.	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.</i>		Longitudinal OIV was 20.3 ft/s, and lateral OIV was 23.6 ft/s.	Pass
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>		Longitudinal occupant ridedown acceleration was 7.4 g, and lateral occupant ridedown acceleration was 13.0 g.	Pass

Table 8.3. Performance Evaluation Summary for MASH Test 3-21 on 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition from W-Beam to Thrie Beam.

Test Agency: Texas A&M Transportation Institute		Test No.: 608331-01-6	Test Date: 2019-12-19
MASH Test 3-21 Evaluation Criteria		Test Results	Assessment
Structural Adequacy			
<i>A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop, the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the test article is acceptable.</i>		The 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition contained and redirected the 2270P vehicle. The vehicle did not penetrate, underide, or override the installation. Maximum dynamic deflection was 33.6 inches.	Pass
Occupant Risk			Pass
<i>D. 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.</i>		No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area.	Pass
<i>Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.</i>		No occupant compartment deformation or intrusion was observed.	
<i>F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</i>		The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 15° and 14°, respectively.	Pass
<i>H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.</i>		Longitudinal OIV was 24.9 ft/s, and lateral OIV was 16.4 ft/s.	Pass
<i>I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.</i>		Longitudinal occupant ridedown acceleration was 10.7 g, and lateral occupant ridedown acceleration was 9.8 g.	Pass

Table 8.4. Assessment Summary for *MASH* TL-3 Testing on 2019 *MASH* 2-Tube Bridge Rail Thrie Beam Transition.

Evaluation Factors	Evaluation Criteria	Test No. 608331-01-4	Test No. 608331-01-5	Test No. 608331-01-6
Structural Adequacy	A	S	S	S
Occupant Risk	D	S	S	S
	F	S	S	S
	H	S	S	S
	I	S	S	S
<i>MASH</i> Test No.		<i>MASH</i> Test 3-20	<i>MASH</i> Test 3-21 at Transition to Bridge Rail	<i>MASH</i> Test 3-21 at Transition to Thrie Beam
Pass/Fail		Pass	Pass	Pass

Key: S = Satisfactory
U = Unsatisfactory
NA = Not applicable

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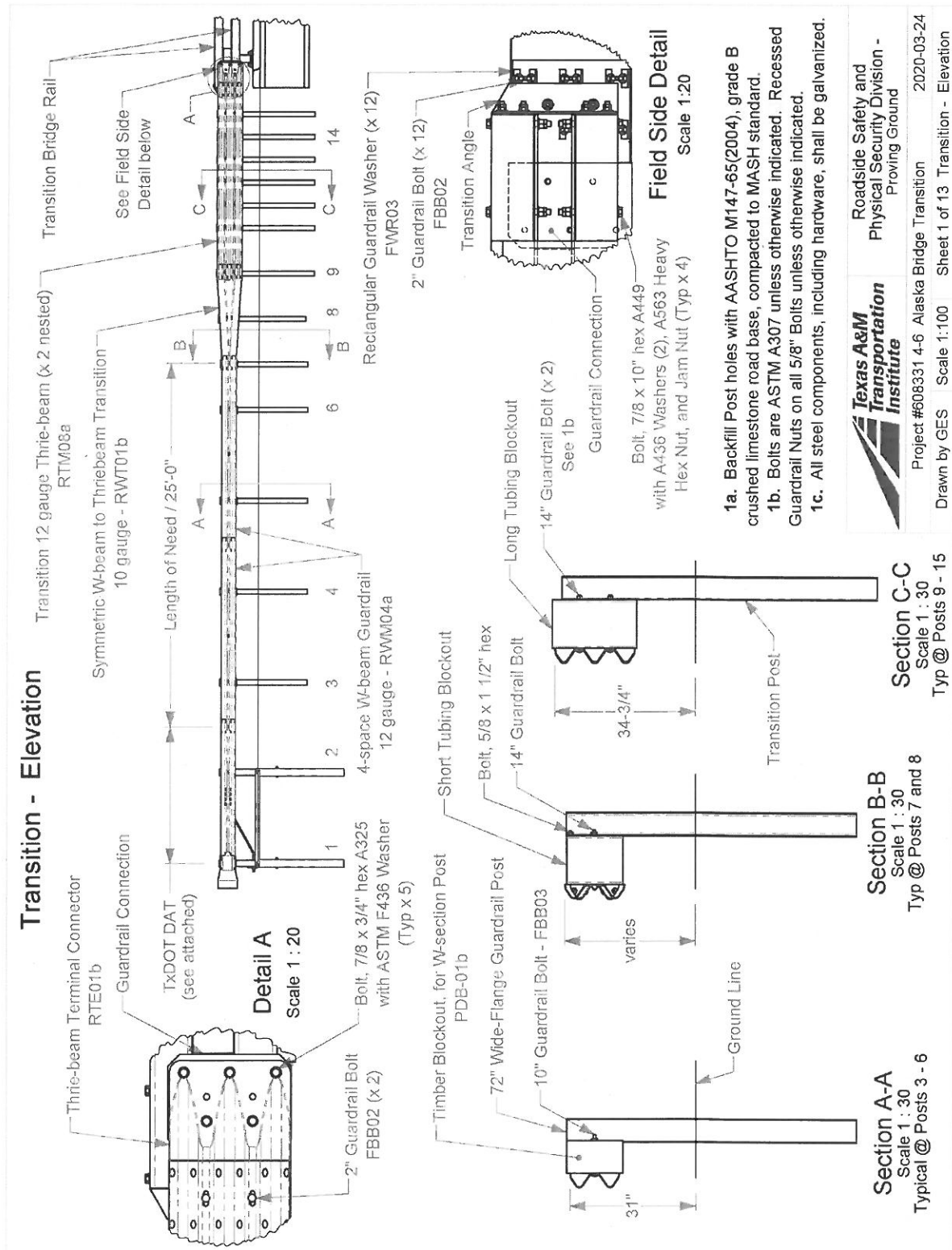
REFERENCES

1. C. E. Buth, W. F. Williams, W. L. Menges, and S. K. Schoeneman. *NCHRP Report 350 Test 4-10 of the Alaska Multi-State Bridge Rail*, Test Report No.; 404311-1, Texas A&M Transportation Institute, College Station, TX, December 1998.
2. C. E. Buth, W. F. Williams, W. L. Menges, and S. K. Schoeneman. *NCHRP Report 350 Test 4-11 of the Alaska Multi-State Bridge Rail*, Test Report No.; 404311-2, Texas A&M Transportation Institute, College Station, TX, December 1998.
3. C. E. Buth, W. F. Williams, W. L. Menges, and S. K. Schoeneman. *NCHRP Report 350 Test 4-12 of the Alaska Multi-State Bridge Rail*, Test Report No.; 404311-3, Texas A&M Transportation Institute, College Station, TX, February 1998.
4. C. E. Buth, W. F. Williams, W. L. Menges, and S. K. Schoeneman. *NCHRP Report 350 Test 4-21 of the Alaska Multi-State Bridge Rail Thrie Beam Transition*, Test Report No.; 404311-5, Texas A&M Transportation Institute, College Station, TX, July 1999.
5. C. E. Buth, W. F. Williams, W. L. Menges, and S. K. Schoeneman. *NCHRP Report 350 Test 4-22 of the Alaska Multi-State Bridge Rail Thrie Beam Transition*, Test Report No.; 404311-6, Texas A&M Transportation Institute, College Station, TX, July 1999.
6. C. E. Buth, W. F. Williams, W. L. Menges, and S. K. Schoeneman. *NCHRP Report 350 Test 3-21 of the Alaska Multi-State Bridge Rail W-Beam Transition*, Test Report No.; 404311-7, Texas A&M Transportation Institute, College Station, TX, July 2000.
7. C. E. Buth, W. F. Williams, W. L. Menges, and S. K. Schoeneman. *NCHRP Report 350 Test 3-20 of the Alaska Multi-State Bridge Rail W-Beam Transition*, Test Report No.; 404311-8, Texas A&M Transportation Institute, College Station, TX, August 2000.
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10. AASHTO. *Manual for Assessing Roadside Safety Hardware, Second Edition*. 2016, American Association of State Highway and Transportation Officials: Washington, D.C.
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https://safety.fhwa.dot.gov/roadway_dept/countermeasures/reduce_crash_severity/docs/memo_joint_implementation_agmt.pdf, January 7, 2016, last access January 2019.

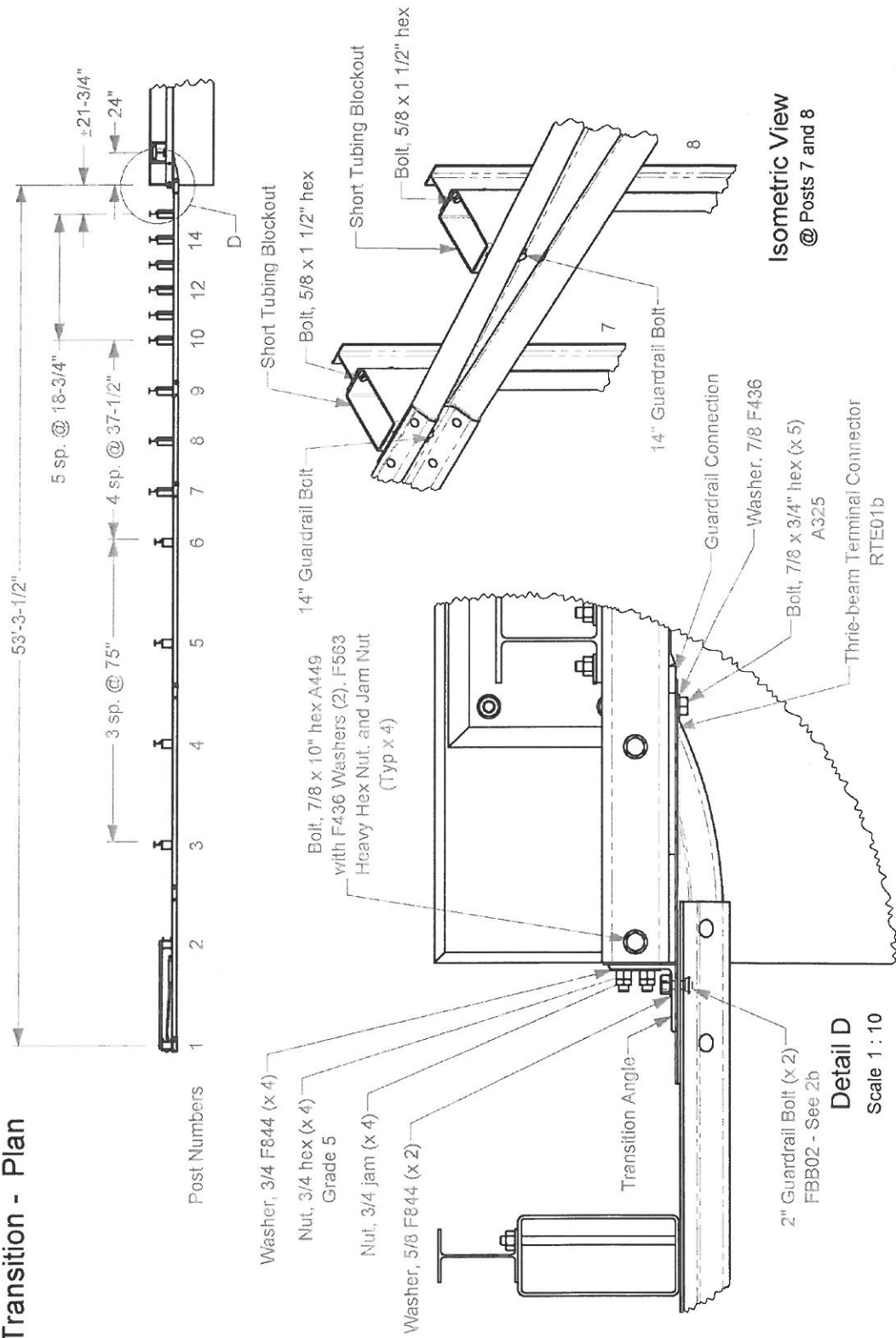
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APPENDIX A. DETAILS OF THE 2019 MASH 2-TUBE BRIDGE RAIL

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Transition - Plan



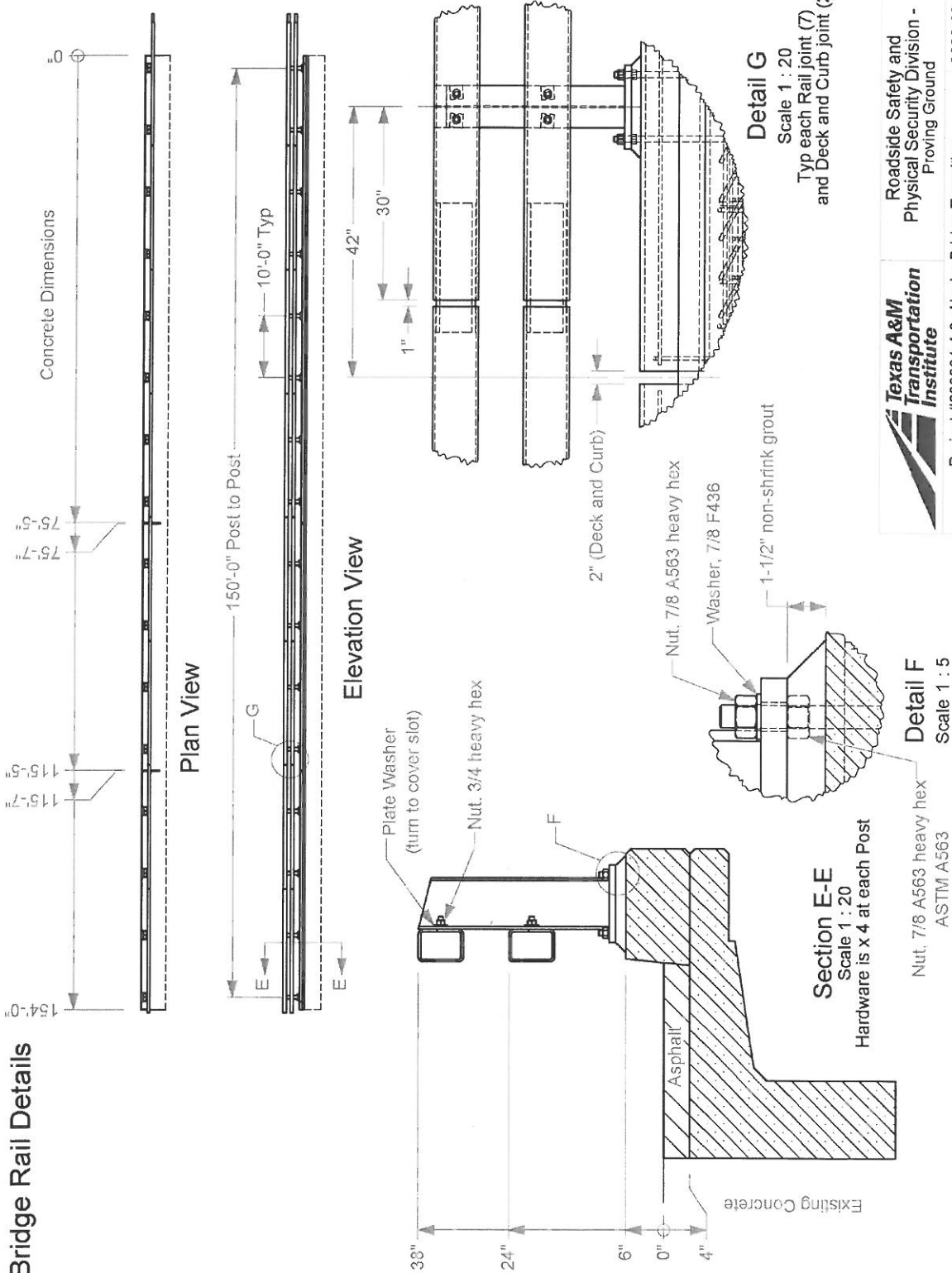
- 2a. Backfill Post holes with AASHTO M147-65(2004), grade B crushed limestone road base, compacted to MASH standard.
- 2b. Recessed Guardrail Nuts on all 5/8" Bolts unless otherwise indicated.
- 2c. All steel components, including hardware, shall be galvanized.



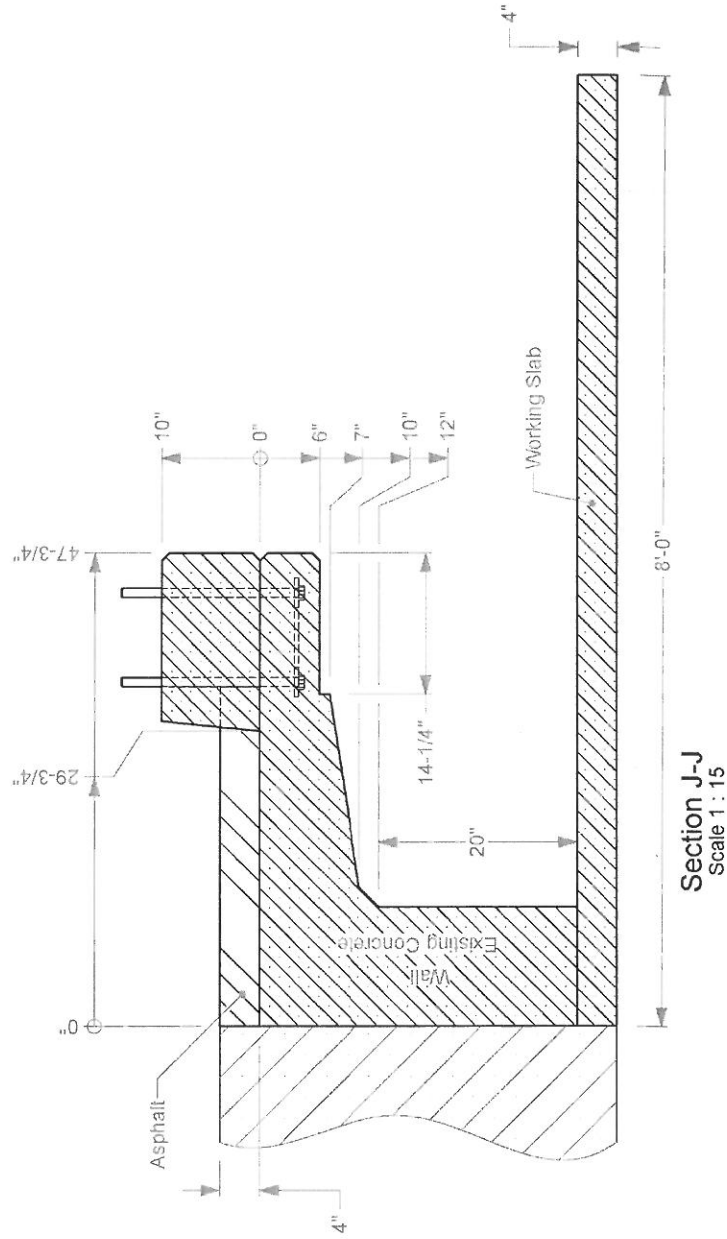
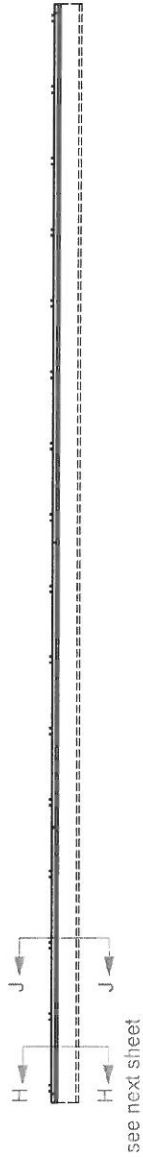
Roadside Safety and
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Proving Ground

Project #608331 4-6 Alaska Bridge Transition 2020-03-24
Drawn by GES Scale 1:100 Sheet 2 of 13 Transition - Plan

Bridge Rail Details



Concrete Details, Elevation



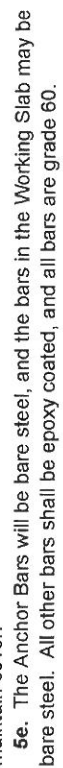
4a. Concrete Strength is 5000psi for the Wall and Deck, 3000 psi for the Working Slab, and 4000 psi for the Curb.

4b. Chamfer Field Side edges of Deck, and field side and top edges at end of Curb 3/4" each way as shown.

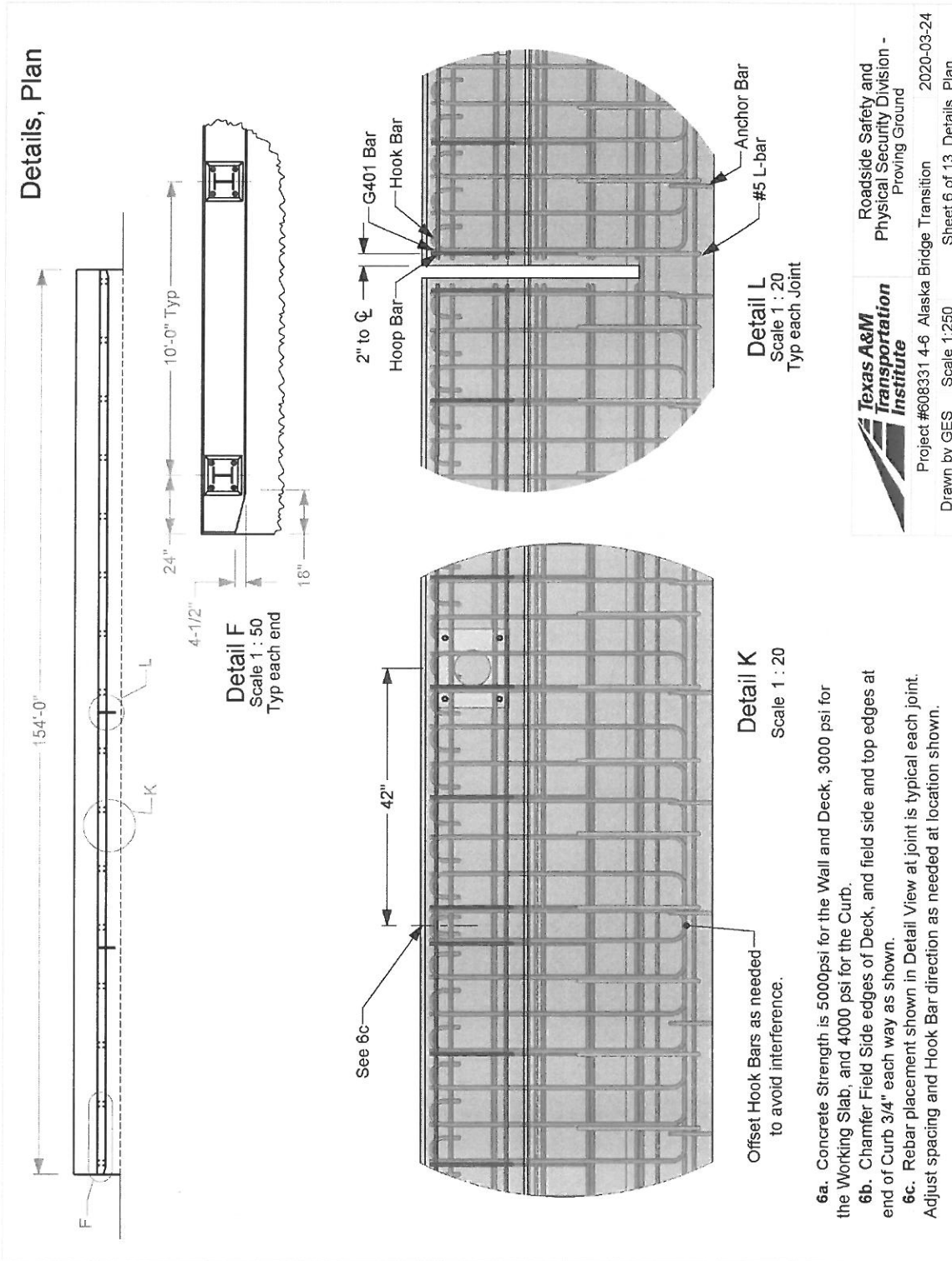


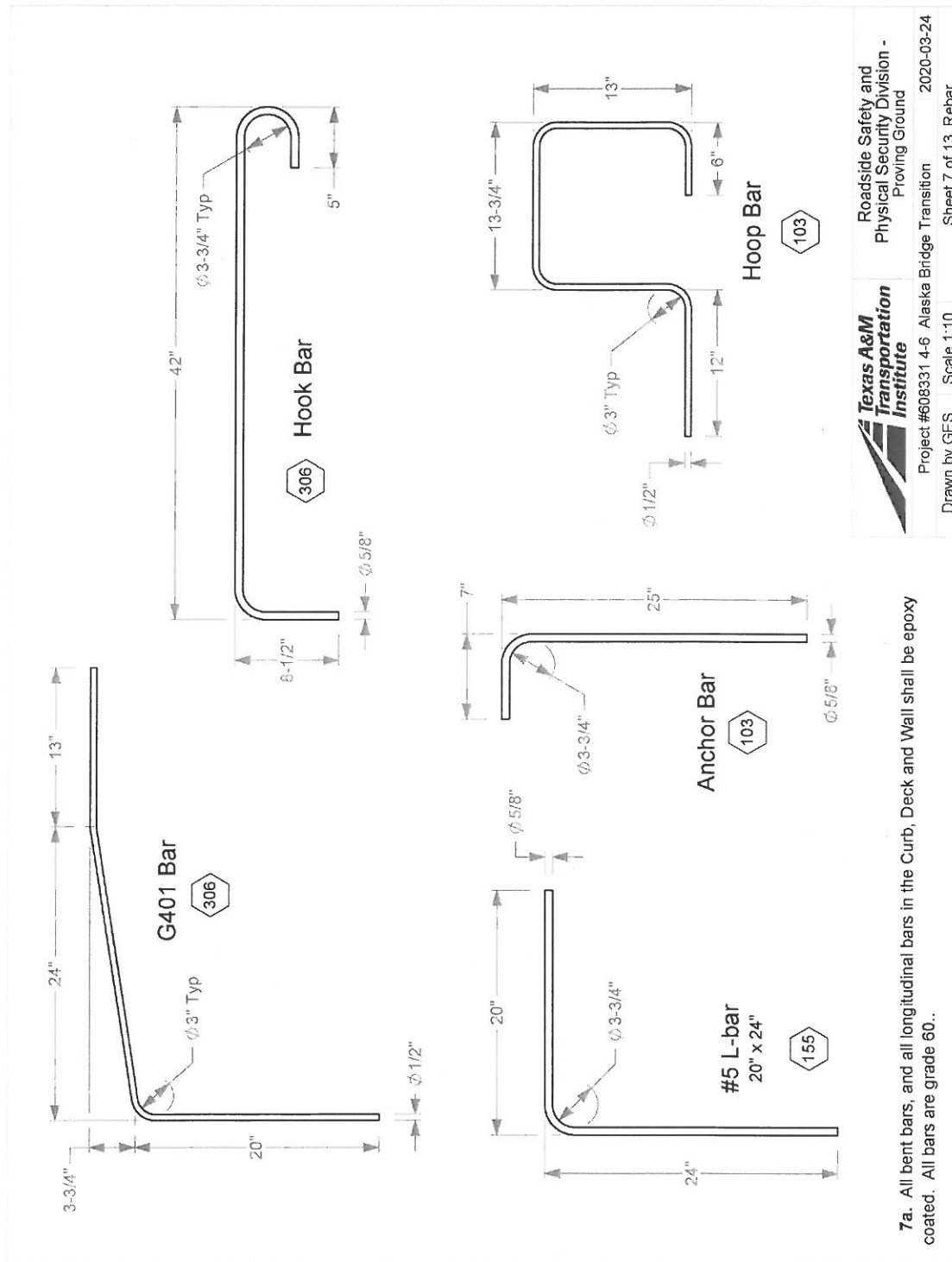
Roadside Safety and
Physical Security Division -
Proving Ground

Project #608331 4-6 Alaska Bridge Transition 2020-03-24
Drawn by GES Scale 1:250 Sheet 4 of 13 Concrete Details, Elevation

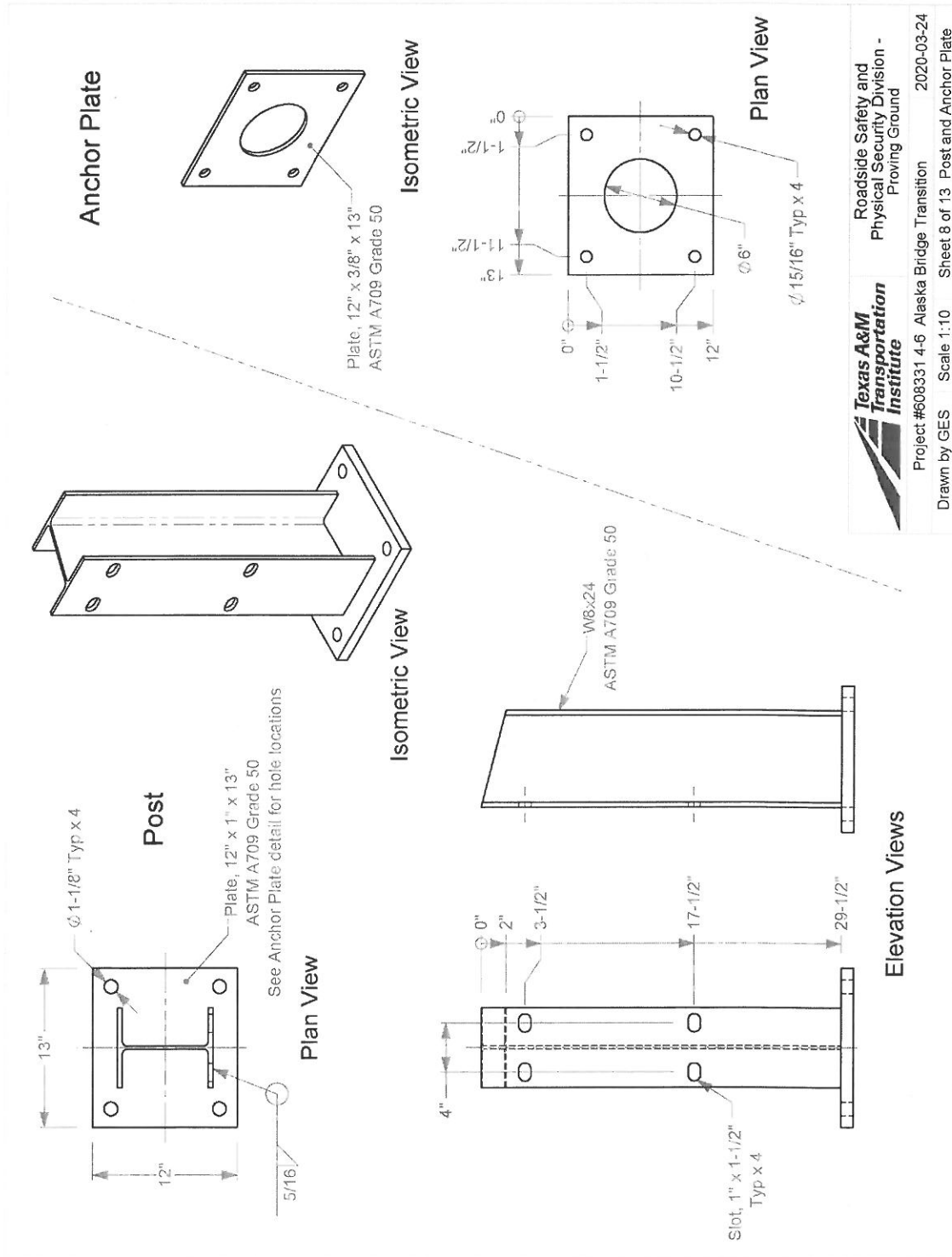


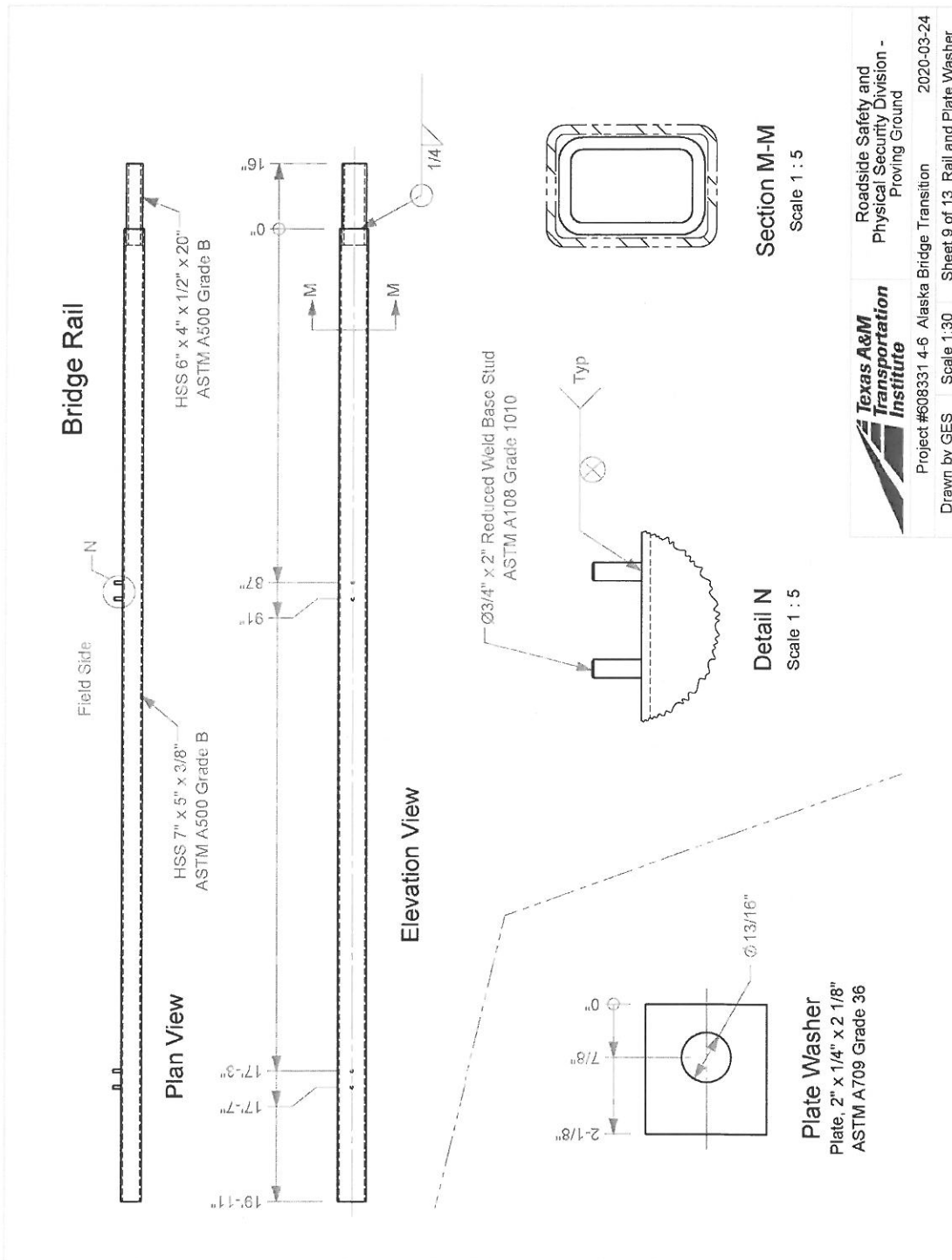
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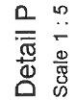


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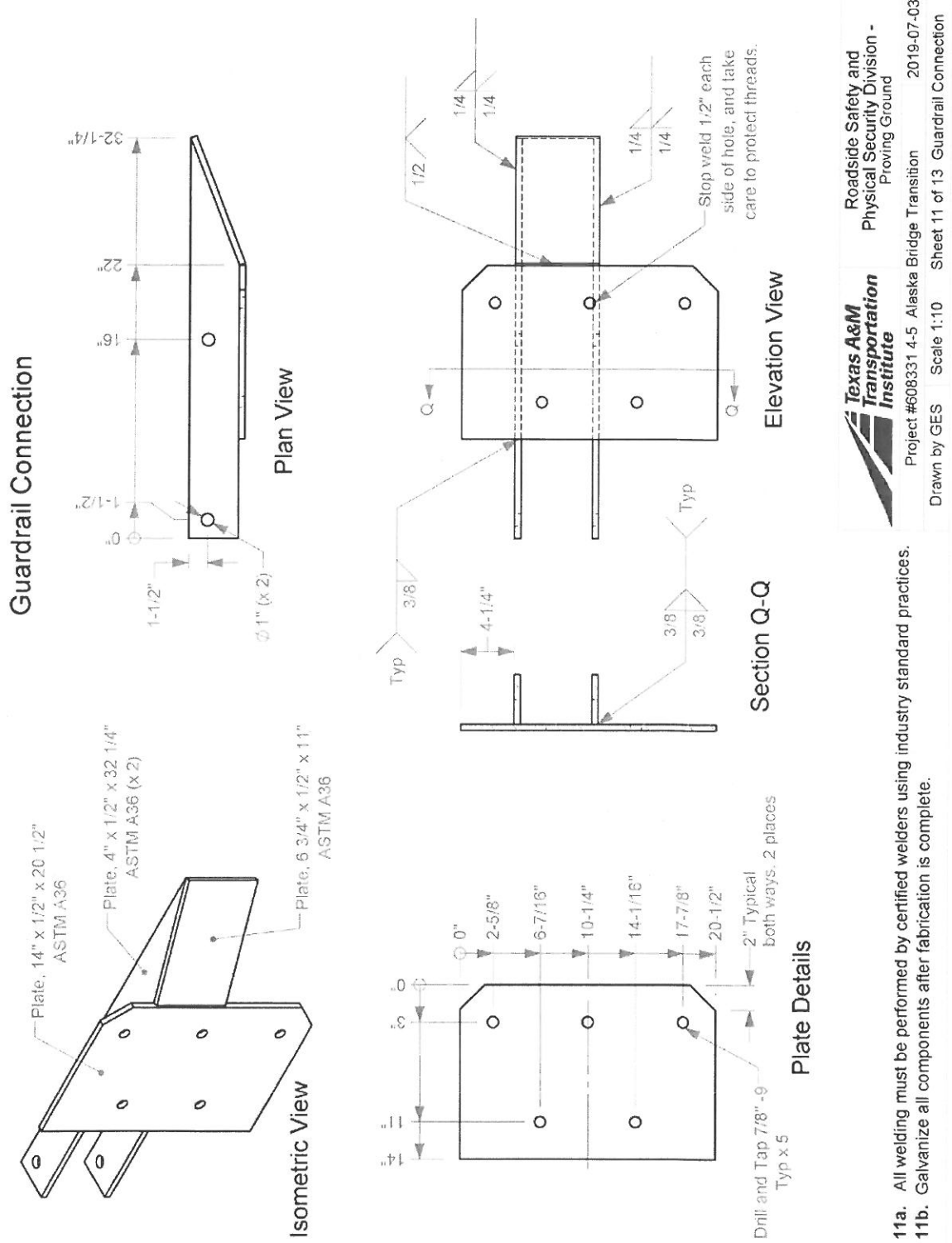
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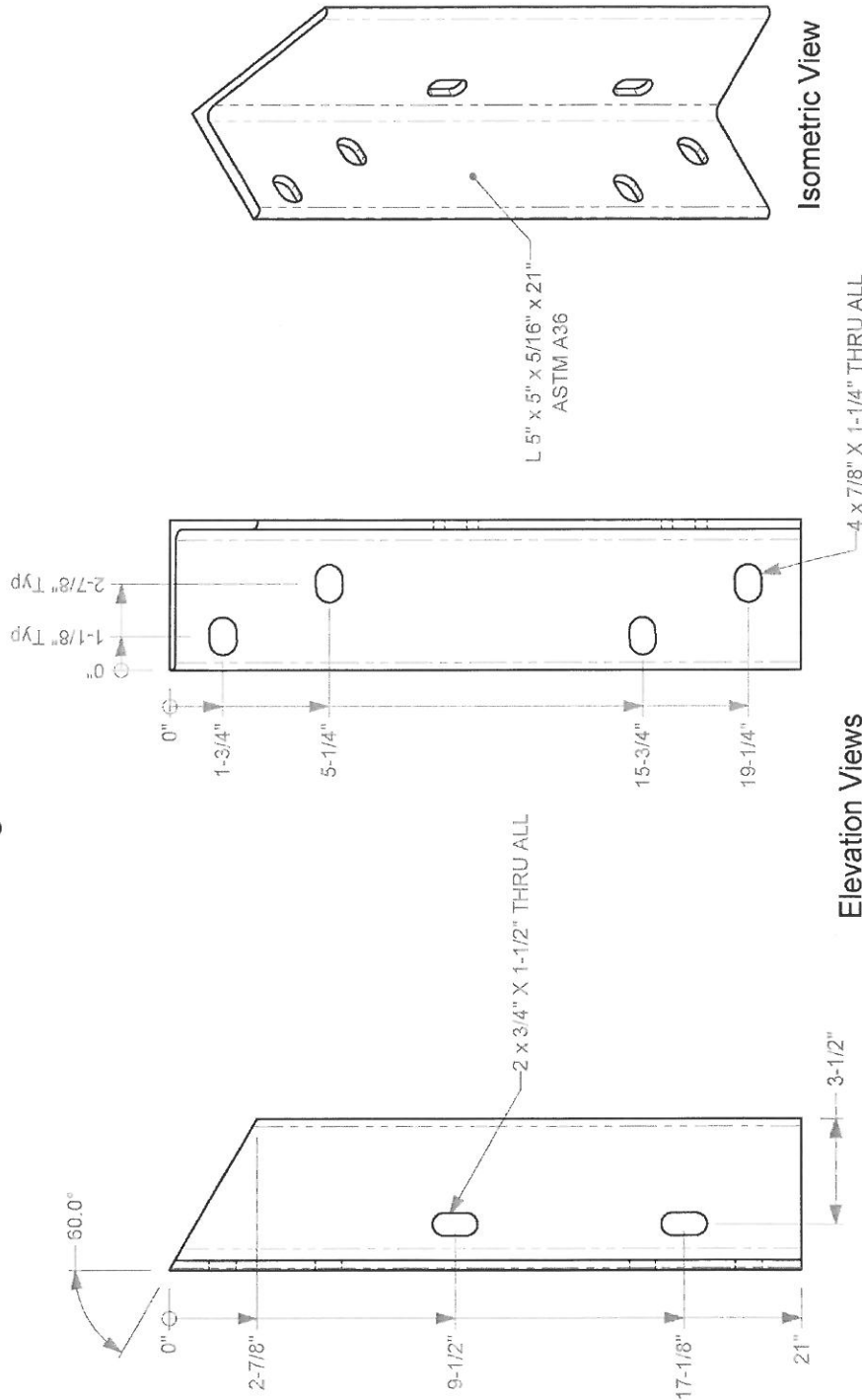
Section O-0
Scale 1 : 5

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Transportation
Institute**

Project #608331 4-6 Alaska Bridge Transition	2020-03-24
Drawn by GES Scale 1:30	Sheet 10 of 13 Transition Rail



Transition Angle

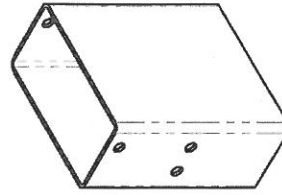
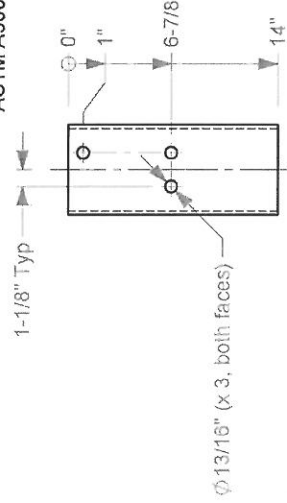
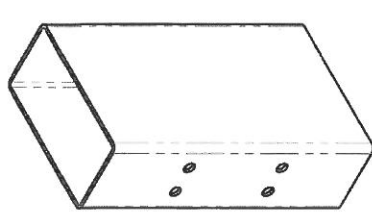
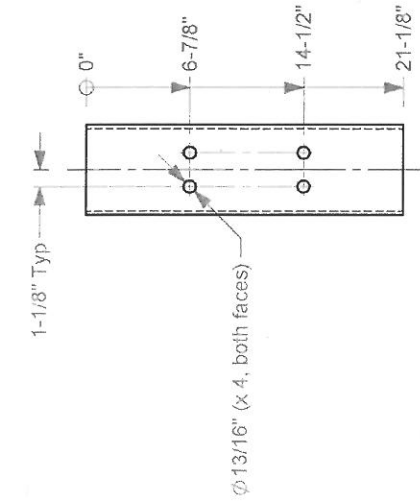
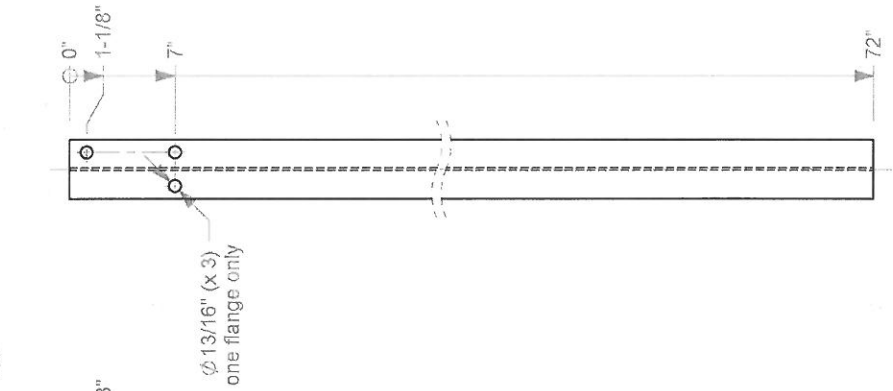
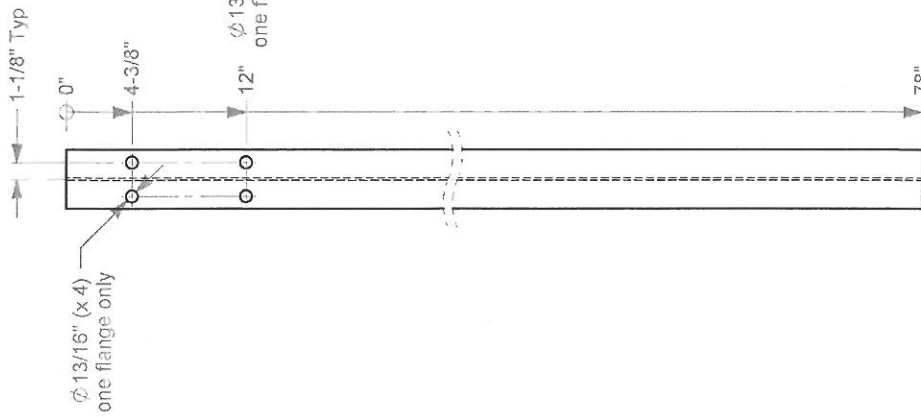


Elevation Views

	Roadside Safety and Physical Security Division - Proving Ground	
	Project #608331 4-6 Alaska Bridge Transition	2020-03-24
	Drawn by GES	Scale 1:5
	Sheet 12 of 13 Transition Angle	

12a. Galvanize after fabrication is complete.

Posts and Blockouts



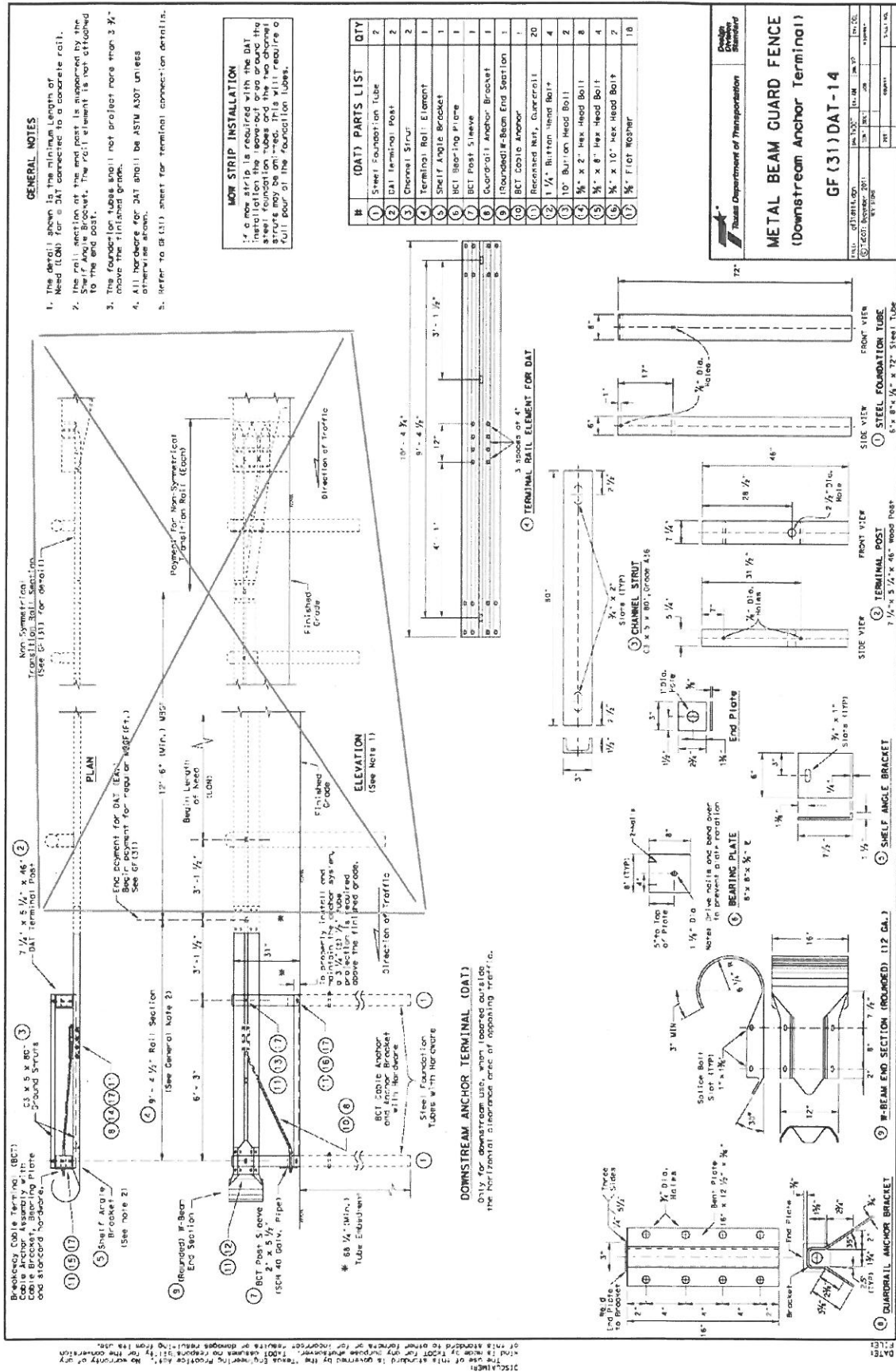
Transition Post
W6x8.5 x 78"
ASTM A992 Steel
(at 9 - 15)

Posts 7 and 8
W6x8.5 x 72"
ASTM A992

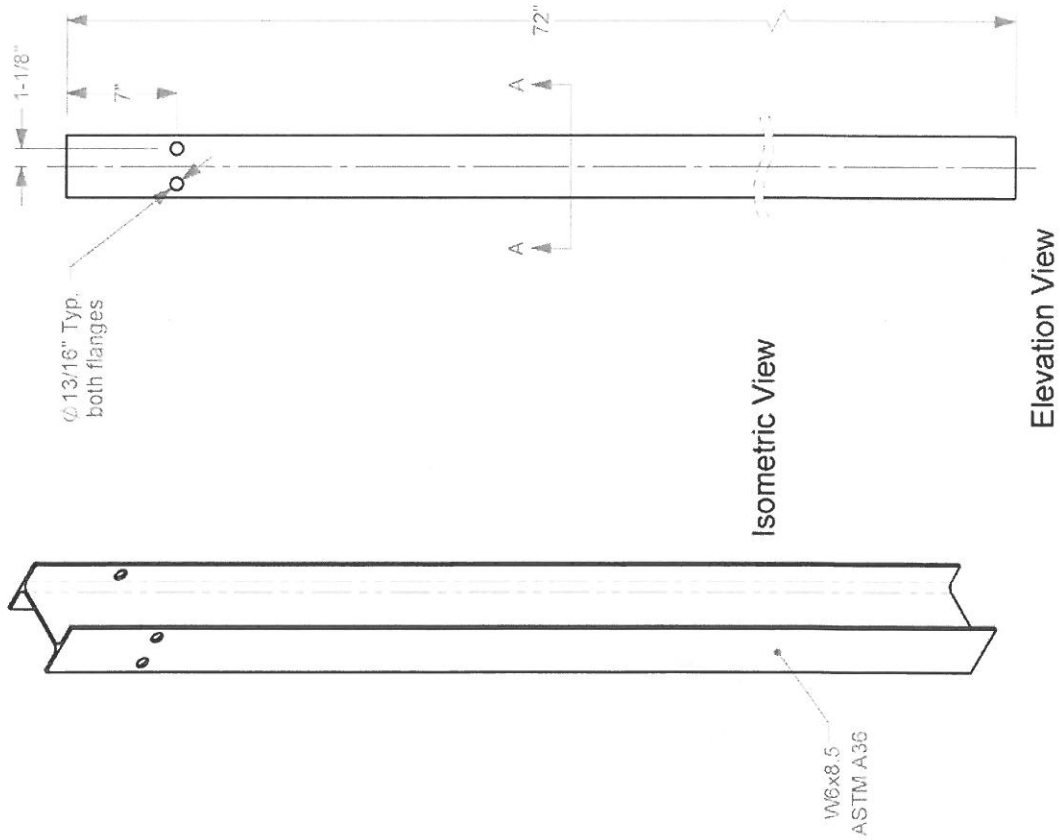


Roadside Safety and
Physical Security Division -
Proving Ground

Project #608331 4-6 Alaska Bridge Transition 2020-03-24
Drawn by GES Scale 1:10 Sheet 13 of 13 Posts and Blockouts



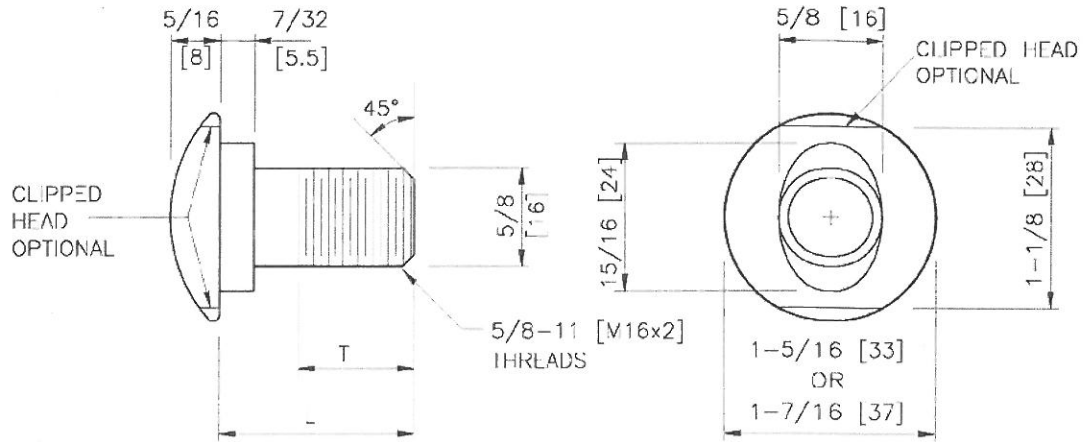
72" Wide Flange Guardrail Post



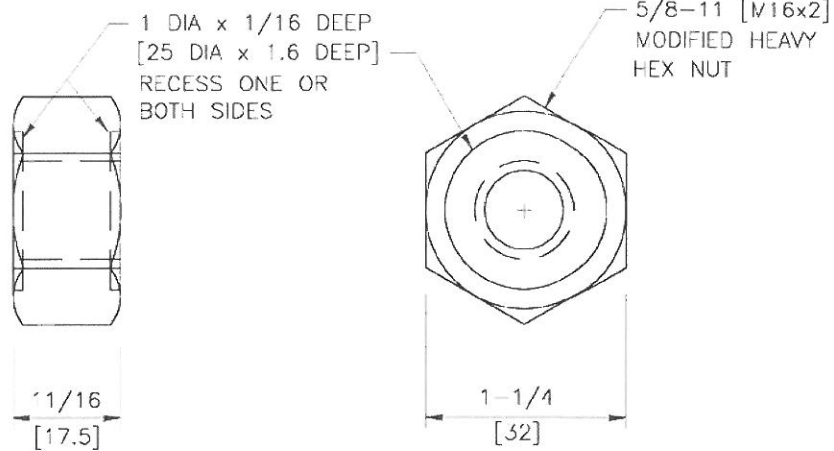
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	Roadside Safety and Physical Security Division - Proving Ground	2019-07-01
	72" Wide-Flange Guardrail Post	Drawn by GES Scale 1:10 Sheet 1 of 1

- NOTES:** 1. ALL FILLETS SHALL HAVE A MINIMUM RADIUS OF 1/16 [2].
2. IF THE BOLT EXTENDS MORE THAN 1/4 [6] FROM THE NUT THE BOLT SHOULD BE TRIMMED BACK.



DESIGNATOR	L	T (MIN)
FBB01	1-1/4 [32]	1-1/8 [28]
FBB02	2 [51]	1-3/4 [44]
FBB03	10 [254]	4 [102]
FBB04	18 [457]	4 [102]
FBB05	25 [635]	4 [102]



GUARDRAIL BOLT AND RECESSED NUT

TF
13

FBB01-05

SHEET NO.	DATE:
1 of 2	5/2/2018

SPECIFICATIONS

The geometry and material specifications for this oval shoulder button-headed bolt and hex nut are found in AASHTO M 180. The bolt shall have 5/8-11 [M16x2] threads as defined in ANSI B1.1 [ANSI B1.13M] for Class 2A [6g] tolerances. Bolt material shall conform to ASTM A307 Grade A [ASTM F 568M Class 4.6], with a tensile strength of 60 ksi [400 MPa] and yield strength of 36 ksi [240 MPa]. Material for corrosion-resistant bolts shall conform to ASTM A325 Type 3 [ASTM F 568M Class 8.8.3], with tensile strength of 120 ksi [830 MPa] and yield strength of 92 ksi [660 MPa]. This bolt material has corrosion resistance comparable to ASTM A588 steels. Metric zinc-coated bolt heads shall be marked as specified in ASTM F 568 Section 9 with the symbol "4.6."

Nuts shall have ANSI B1.1 Class 2B [ANSI B1.13M Class 6h] 5/8-11 [M16x2] threads. The geometry of the nuts, with the exception of the recess shown in the drawing, shall conform to ANSI B18.2.2 [ANSI B18.2.4.1M Style 1] for zinc-coated hex nuts (shown in drawing) and ANSI B18.2.2 [ANSI B18.2.4.6M] for heavy hex corrosion-resistant nuts (not shown in drawing). Material for zinc-coated nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade A [AASHTO M 291M (ASTM A 563M) Class 5], and material for corrosion-resistant nuts shall conform to the requirements of AASHTO M 291 (ASTM A 563) Grade C3 [AASHTO M 291M (ASTM A 563M) Class 8S3].

When zinc-coated bolts and nuts are required, the coating shall conform to either AASHTO M 232 (ASTM A 153/A 153M) for Class C or AASHTO M 298 (ASTM B 695) for Class 50. Zinc-coated nuts shall be tapped over-size as specified in AASHTO M 291 (ASTM A 563) [AASHTO M 291M (ASTM A 563M)], except that a diametrical allowance of 0.020 inch [0.510 mm] shall be used instead of 0.016 inches [0.420 mm].

Designator	Stress Area of Threaded Bolt Shank (in ² [mm ²])	Min. Bolt Tensile Strength (kips [kN])
FBB01-05	0.226 [157.0]	13.6 [62.8]

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

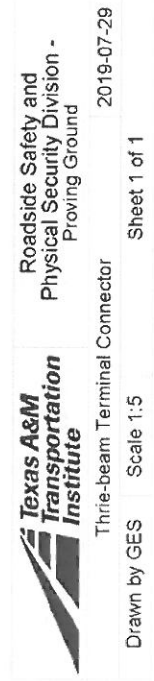
INTENDED USE

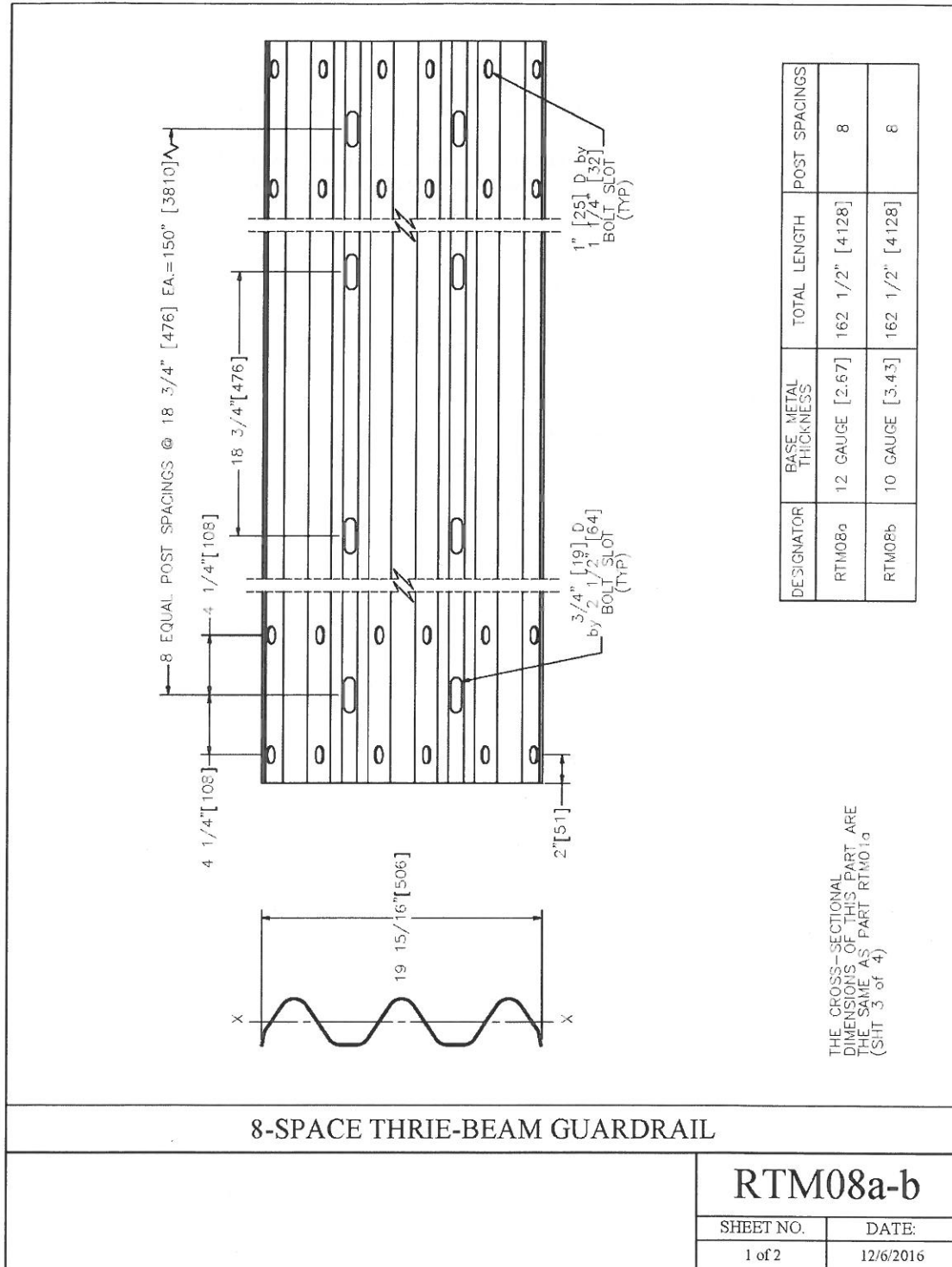
These bolts and nuts are used in numerous guardrail and median barrier designs.

GUARDRAIL BOLT AND RECESSED NUT

FBB01-05		
SHEET NO.	DATE	
2 of 2	5/2/2018	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Sub\Guardrail Drawings\Thrie-beam End Shoe





SPECIFICATIONS

Corrugated sheet thrie beam guardrail shall conform to the current requirements of AASHTO M180. The section shall be manufactured from sheets with a nominal width of 29½" [750]. RTM08a shall conform to AASHTO M180 Class A and RTM08b shall conform to Class B. Thrie beams may be either Type I or II (zinc-coated) or Type IV (corrosion resistant steel). Corrosion resistant steel should conform to ASTM A606 for Type IV material and shall not be zinc-coated, painted or otherwise treated. Inertial properties are calculated for the whole cross-section without a reduction for the splice bolt holes or slots.

Designator	Area in. ² [10 ³ mm ²]	I _x in. ⁴ [10 ⁶ mm ⁴]	I _y in. ⁴ [10 ⁶ mm ⁴]	S _x in. ³ [10 ³ mm ³]	S _y in. ⁴ [10 ³ mm ³]
RTM08a	3.16 [2.0]	3.8 [1.6]	--	2.22 [36.4]	--
RTM08b	4.03 [2.6]	4.8 [2.0]	--	2.87 [47.0]	--

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

The 8-space thrie beam guardrail is used in the W-beam to thrie beam transition with standard posts (STG03a-b).

8-SPACE THRIE-BEAM GUARDRAIL

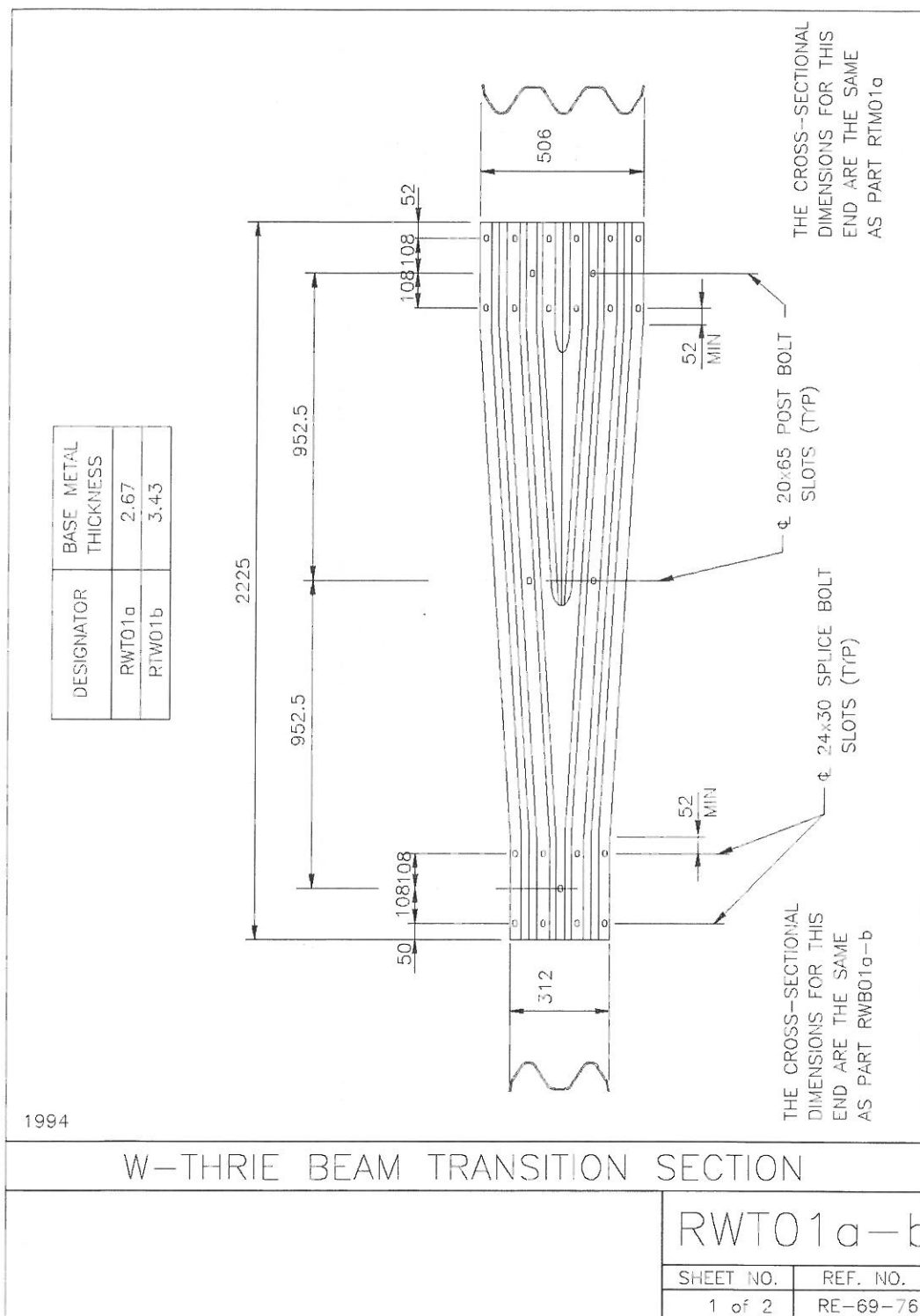
RTM08a-b

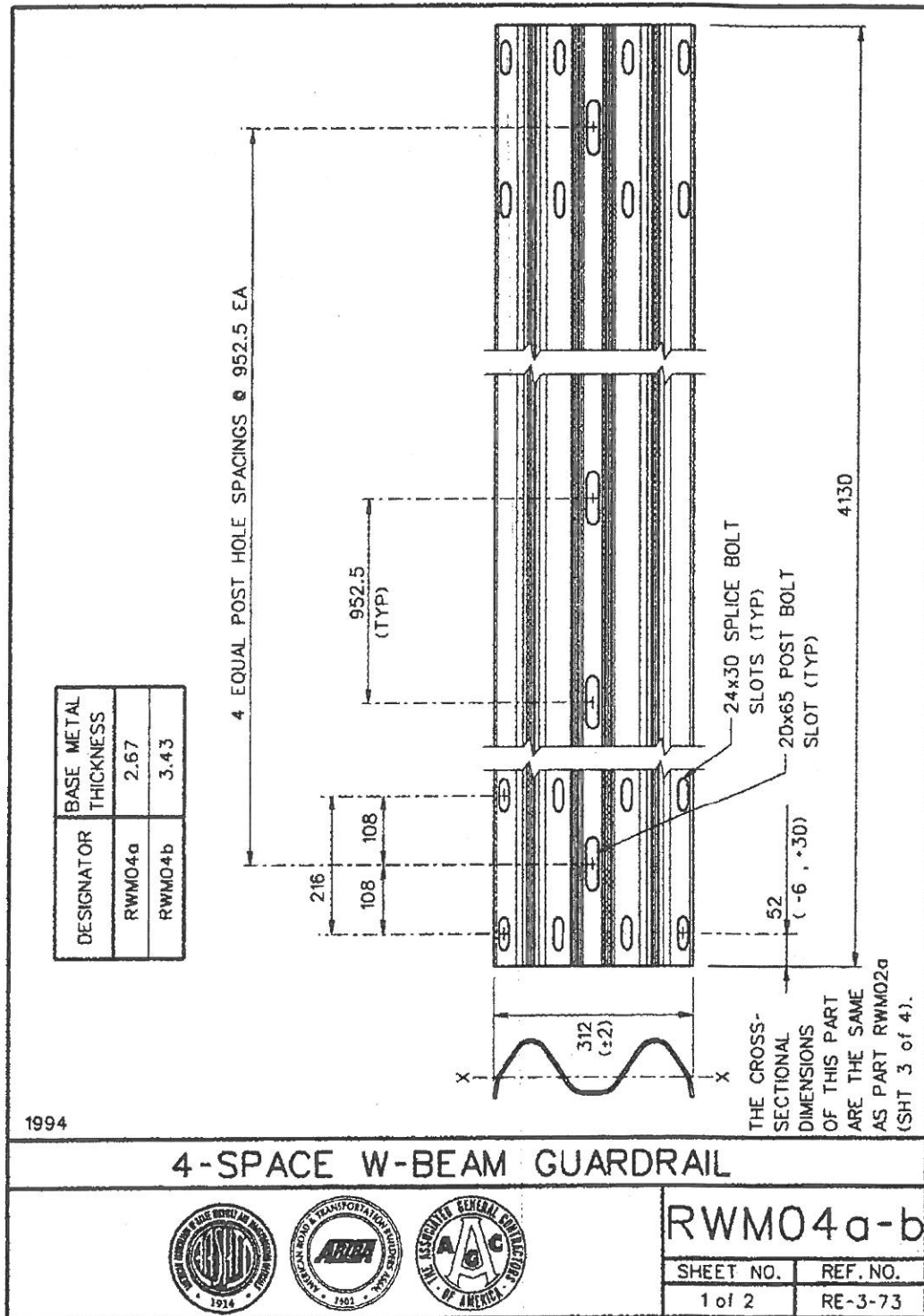
SHEET NO.

DATE:

2 of 2

12/6/2016





SPECIFICATIONS

Corrugated sheet steel beams shall conform to the current requirements of AASHTO M180. The section shall be manufactured from sheets with a nominal width of 483 mm. Guardrail RWM04a shall conform to AASHTO M180 Class A and RWM04b shall conform to Class B. Corrosion protection may be either Type II (zinc-coated) or Type IV (corrosion resistant steel). Corrosion resistant steel should conform to ASTM A606 for Type IV material and shall not be zinc-coated, painted or otherwise treated. Inertial properties are calculated for the whole cross-section without a reduction for the splice bolt holes.

Designator	Area (10 ³ mm ²)	I _x (10 ⁶ mm ⁴)	I _y (10 ⁶ mm ⁴)	S _x (10 ³ mm ³)	S _y (10 ³ mm ³)
RWM04a-b	1.3	1.0	--	23	--

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

This corrugated sheet steel beam is used as a rail element in transition systems STB02 and STB03 or when a reduced post spacing is desired in the SGR02, SGR04a-b, SGM02, and SGM04a-b.

4-SPACE W-BEAM GUARDRAIL

RWM04a-b

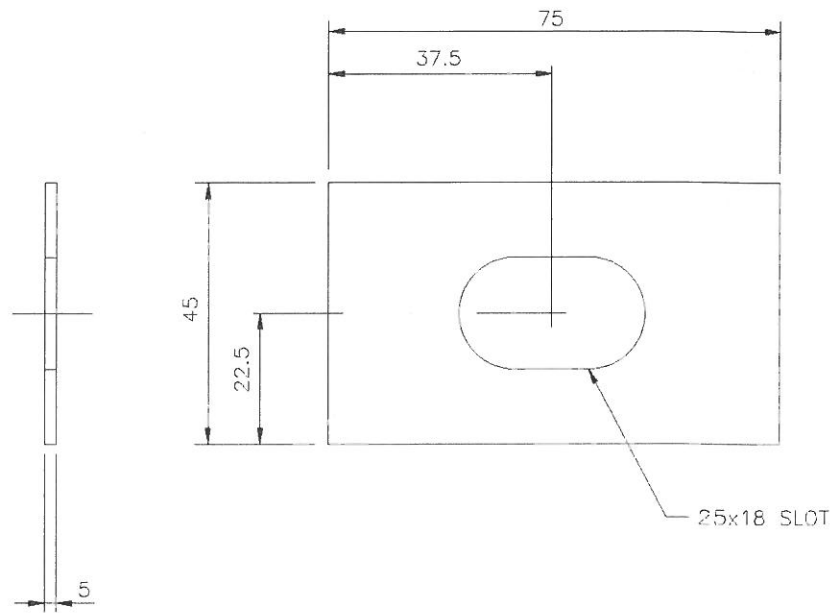
SHEET NO.

2 of 2

DATE

04-01-95





1994

RECTANGULAR GUARDRAIL PLATE WASHER

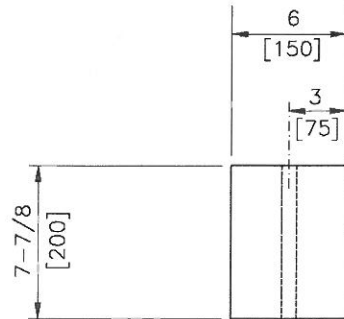
FWR03

SHEET NO.

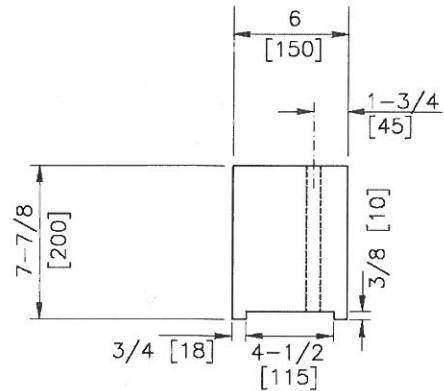
REF. NO.

1 of 2

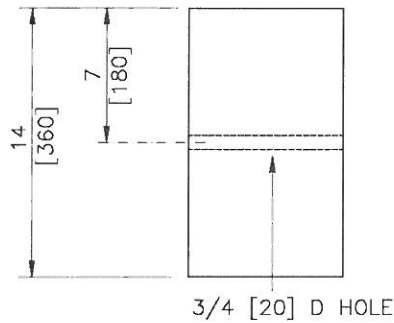
F-12-73



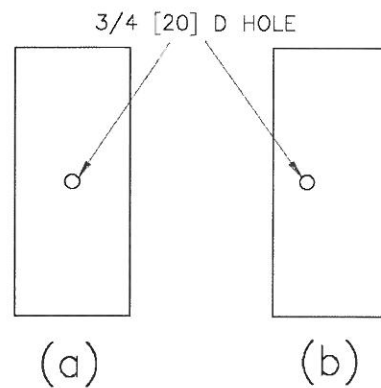
PLAN (a)



PLAN (b)



SIDE



FRONT

1994

W-BEAM TIMBER BLOCKOUT

PDB01a-b

SHEET NO.

DATE:

1 of 2

6/30/2005

SPECIFICATIONS

Blockouts shall be made of timber with a stress grade of at least 1160 psi [8 MPa]. Grading shall be in accordance with the rules of the West Coast Lumber Inspection Bureau, Southern Pine Inspection Bureau, or other appropriate timber association. Timber for blockouts shall be either rough-sawn (unplaned) or S4S (surfaced four sides) with nominal dimensions indicated. The variation in size of blockouts in the direction parallel to the axis of the bolt holes shall not be more than $\pm \frac{1}{4}$ inch [6 mm]. Only one type of surface finish shall be used for posts and blockouts in any one continuous length of guardrail.

All timber shall receive a preservation treatment in accordance with AASHTO M 133 after all end cuts are made and holes are drilled.

Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

INTENDED USE

Blockout PDB01a is used with wood post PDE01 or PDE02 in the SGR04b strong-post W-beam guardrail and the SGM04b median barrier. Blockout PDB01b is routed to be used with steel post PWE01 or PWE02 in the SGR04c guardrail and the SGM04a median barrier.

W-BEAM TIMBER BLOCKOUT

PDB01a-b		
SHEET NO.	DATE	
2 of 2	7/06/2005	

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

PLATE A36 TEMPER LEVELED
1/2 X 48.0000" X 96.0000"

PO/REL HOU-35377/
HEAT: J75904

BL HOU-775673-8 6/21/2019
Order HOU-251290-9 Page:1



TRIPLE-S STEEL SUPPLY CO.
6000 JENSEN DRIVE
HOUSTON, TX 77026

CERTIFICATE OF ANALYSIS

Cert Number 38789-5 6/18/2019
Test Reference 52133

Issued from
BESHERT STEEL PROCESSING
JOINT VENTURE OF
STEEL WAREHOUSE CO &
TRIPLE-S STEEL HOLDINGS INC.
15255 JACINTO PORT BOULEVARD
HOUSTON, TX 77055

Sold To: TRIPLE-S STEEL SUPPLY CO., 6000 JENSEN DRIVE, HOUSTON, TX 77026
Ship To: TRIPLE-S STEEL, 6000 JENSEN DRIVE, HOUSTON, TX 77026

Customer 100200/0 Your Order HOU-185586 (6/12/2019)
Our Order 19485-1-1 Packing List 38789-1 (6/18/2019)
Product Information

TEMPERED LEVELED PLATE A36/SA36
0.5000" x 48" x 96"

Heat
J75904

Tag	Pcs	LBS
23666C	15	9,805
23666D	15	9,805
23666E	15	9,805
23666F	10	6,536
	55	35,951

Part PL35TML1248
Conform To ASTM-A36-.312-.750 4/27/2013

Chemical Composition						C.E.: 0.1935	D.I.: 0
C	Mn	Si	P	S	Cr	Ni	Mo
0.0466	0.80	0.022	0.013	0.0031	0.02	0.04	0.01
Cu	Al	V	Ti	Cb	CbV		
0.07	0.016	0.001	0.001	0.013	0.014		

Physical Tests			
YIELD - H (T)	TENSILE - H (T)	ELONGATION - H (T)	YIELD - M (T)
55.7 KSI	63.2 KSI	34.5 %	56.7 KSI
TENSILE - M (T)	ELONGATION - M (T)		
62.6 KSI	34.5 %		

Product of Coil
Country of Origin: Korea

608331

6/18/2019 09:33 AM ☐ ☒ 1

007 07067 19485-1-1 1007 07067 19485-1-1

PO:REL HOU-35377/
HEAT: J75904

BL HOU-775573-8 6/21/2019
Order HOU-251290-9 Page 2



양진제철소: 양진당전시 준-을 북부신업로 1400
1400 Buthanrup-Ro, Songsh-Eup, Daejeon-Si, Chungnam, Korea

증명서 번호
Certificate No.
: 20190324-HS-013-010

발행 일자
Date of Issue
: 2019-03-24

검사증명서
MILL TEST CERTIFICATE

주문번호 Order No.	E190200039
품명 Commodity	Hot Rolled Coil
제품규격 Specification	ASTM A 36

Hot Rolling Co.	고객사	Bushen Steel
ASTM A 36	CUSTOMER	
	주요지	SRC
	Contractor	

주모자 : SKC
Contractor:

[illegible]

Position: 1: Top, M: Middle, B: Bottom
 Female test: 2 (0.2% off-iso), 5 (0.5% underland), U (Upper yield point), L (Lower yield point)
 Division: P: Product direction, A: Angle

WE HEREBY CERTIFY THAT THE MATERIAL HAS BEEN MADE AND TESTED IN ACCORDANCE WITH THE ABOVE SPECIFICATION AND THE REQUIREMENTS

Signature S. B. Park
Date Of Quilty Assurance Term

[illegible]

RECTANGULAR TUBING A500 GR B
12 X 6 X .250 X 20'

PO/PEL HOU-35377/
HEAT: ABU3188

BL HOU-775673-9 6/21/2019
Order HOU-251290-10 Page 1

Southland Tube
a Nucor Company

3525 Richard Arrington Jr Blvd N
Birmingham, AL 35234
800-543-9024
Fax: 205-251-1553

<https://www.nucortubular.com>
<https://www.ntportal.com>
Certificate Number: BHM 950476

Sold By:
SOUTHLAND TUBE INCORPORATED
3525 Richard Arrington Jr Blvd N
Birmingham, AL 35234
Tel: 800-543-9024
Fax: 205-251-1553

Purchase Order No: HOU-183284
Sales Order No: BHM 494279 - 4
Bill of Lading No: BHM 3197 - 3
Invoice No:

Shipped: 1/4/2019
Invoiced:

Sold To:
2039 - TRIPLE "S" STEEL SUPPLY
P.O. BOX 21119
HOUSTON, TX 77226

Ship To:
8 - IRVINGTON WAREHOUSE
8411 IRVINGTON
HOUSTON, TX 77022

CERTIFICATE of ANALYSIS and TESTS

Customer Part No:

Certificate No: BHM 950476

TUBING A500 GRADE B(C)
12" X 6" X 1/4" X 40'

Test Date: 1/3/2019

Total Pieces 18 Total Weight 21,045

Bundle Tag	Mill	Heat	Specs	Y/T Ratio	Pieces	Weight
415341	6N	A8U3188	YLD=65284/TEN=80606/ELG=29.5/RWB=84.4	0.8099	6	7,015
719919	78	1815098	YLD=56200/TEN=75300/ELG=31/RWB=83.37	0.7463	6	7,015
731578	78N	1815097	YLD=61000/TEN=76800/ELG=32.5/RWB=84.89	0.7943	6	7,015

Mill #: 78N Heat #: 1815097 Carbon Eq: 0.3766 Heat Src Origin: MELTED AND MANUFACTURED IN THE USA

C	Mn	P	S	Si	Al	Cu	Cr	Mo	V	Ni	Sn	N
0.2200	0.8400	0.0050	0.0010	0.0300	0.0280	0.0900	0.0300	0.0100	0.0030	0.0300	0.0050	0.0050
Ti	Ca											
0.0010	0.0020											

LEED Information (based on the most recent LEED information from the producing mill)

Method	Location	Recycled Content	Post Consumer	Post Industrial
EAF	Berkeley, SC	40.0%	29.8%	10.2%

Mill #: 78 Heat #: 1815098 Carbon Eq: 0.3621 Heat Src Origin: MELTED AND MANUFACTURED IN THE USA

C	Mn	P	S	Si	Al	Cu	Cr	Mo	V	Ni	Sn	N
0.2100	0.8200	0.0050	0.0030	0.0300	0.0260	0.0700	0.0300	0.0100	0.0040	0.0300	0.0050	0.0060
Ti	Ca											
0.0010	0.0030											

LEED Information (based on the most recent LEED information from the producing mill)

Method	Location	Recycled Content	Post Consumer	Post Industrial
EAF	Berkeley, SC	40.0%	29.8%	10.2%

Mill #: 6N Heat #: A8U3188 Carbon Eq: 0.3995 Heat Src Origin: MELTED AND MANUFACTURED IN THE USA

C	MN	P	S	Si	Cu	Sn	Ni	Cr	Mo	Al	N	V
0.2200	0.9000	0.0090	0.0060	0.0400	0.1500	0.0000	0.0500	0.0600	0.0160	0.0240	0.0060	0.0050
Cb	Ti	B	Ca	Ce								
0.0030	0.0020	0.0002	0.0014	0.3995								

LEED Information (based on the most recent LEED information from the producing mill)

Method	Location	Recycled Content	Post Consumer	Post Industrial
EAF	Tuscaloosa, AL	56.6%	31.6%	25.0%

RECTANGULAR TUBING A500 GR B
12 X 6 X .250 X 20'

PO/REL HOU-35377/
HEAT: A8U3188

BL HOU-775673-9 6/21/2019
Order HOU-251290-10 Page.2

Southland Tube
a Nucor Company

3525 Richard Arrington Jr Blvd N
Birmingham, AL 35234
800-543-8024
Fax: 205-251-1553

<https://www.nucortubular.com>
<https://www.nipportal.com>
Certificate Number: BHM 950476

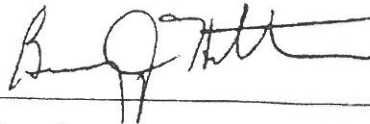
Certification:

I certify that the above results are a true and correct copy of records prepared and maintained by Southland Tube Incorporated.
Sworn this day, 1/3/2019.

WE PROUDLY MANUFACTURE ALL OUR PRODUCTS IN THE USA
NUCOR TUBULAR PRODUCTS ARE MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.
MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

CURRENT STANDARDS:

A252-10
A500/A500M-18
A513/A513M-15
ASTM A53/A53M-12 | ASME SA-53/SA-53M-13
A847/A847M-14
A1085/A1085M-15



Barney Hatten
Supervisor of Technical Services & Quality Standards

FLAT BAR A-36/A 529 GR50
1/2 X 4 X 20'

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APPENDIX C. SOIL PROPERTIES

Table C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.

Dynamic Setup

Post-Test Photo of post

Static Load Test

Post-Test Photo

Percent Finer Vs. Grain Size of Fill Soil for Dynamic and Static Load Tests

Grain Size, D (mm)	Percent Finer (%)
0.075	100
0.15	100
0.3	100
0.6	100
1.2	100
2.5	100
4.75	10
9.5	5
19	2
37.5	1
75	0

Comparison of Load vs. Displacement at 25-inch height

Displacement (inch)	Dynamic Load (lb)	Post Load (lb)	Static Pull (lb)
0	0	0	0
2.5	8000	7000	6000
5	9000	7500	6500
7.5	8500	7000	6000
10	7500	6500	5500
12.5	6500	5500	4500
15	5500	4500	3500
17.5	4500	3500	2500
20	3500	2500	1500

Dynamic Test Installation Details

Static Load Test Installation Details

Date 2008-11-05

Test Facility and Site Location TTI Proving Ground, 3100 SH 47, Bryan, TX 77807

In Situ Soil Description (ASTM D2487) Sandy gravel with silty fines

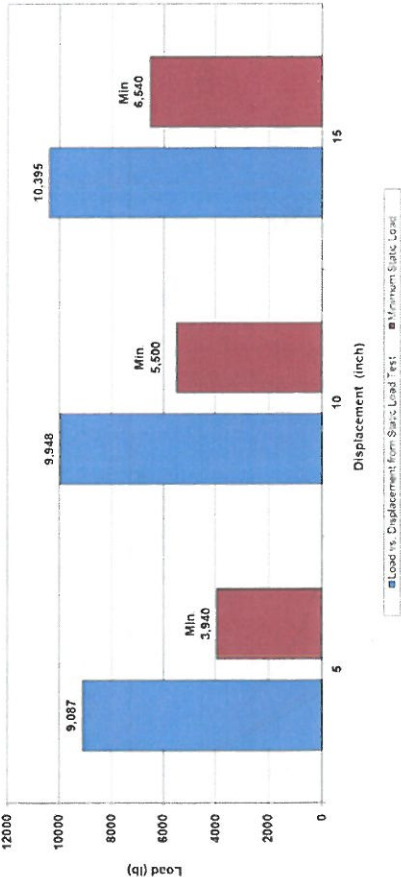
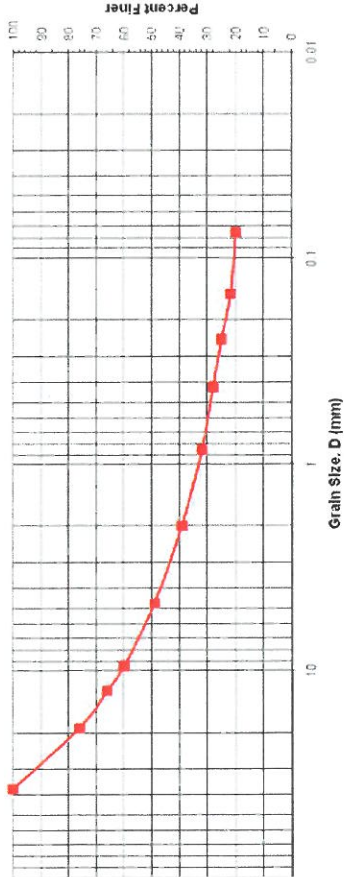
Description of Fill Placement Procedure AASHTO Grade B Soil-Aggregate (see sieve analysis above)

Bogie Weight 6-inch lifts tamped with a pneumatic compactor

Impact Velocity 5009 lb

20.5 mph

Table C.2. Test Day Static Soil Strength Documentation for Test No. 608331-01-4.

Comparison of Static Load Test Results and Required Minimum: Load versus Displacement at 25 Inch Height  <table><tr><th>Displacement (inch)</th><th>Load (lb)</th><th>Minimum (lb)</th></tr><tr><td>5</td><td>9,087</td><td>3,940</td></tr><tr><td>10</td><td>9,948</td><td>5,500</td></tr><tr><td>15</td><td>10,395</td><td>6,540</td></tr></table>	Displacement (inch)	Load (lb)	Minimum (lb)	5	9,087	3,940	10	9,948	5,500	15	10,395	6,540	Typical Static Load Setup 														
Displacement (inch)	Load (lb)	Minimum (lb)																									
5	9,087	3,940																									
10	9,948	5,500																									
15	10,395	6,540																									
Percent Finer Vs. Grain Size of Fill Soil for Dynamic and Static Load Tests  <table><tr><th>Grain Size D (mm)</th><th>Percent Finer (%)</th></tr><tr><td>10</td><td>100</td></tr><tr><td>20</td><td>95</td></tr><tr><td>30</td><td>90</td></tr><tr><td>40</td><td>85</td></tr><tr><td>60</td><td>75</td></tr><tr><td>75</td><td>65</td></tr><tr><td>100</td><td>55</td></tr><tr><td>150</td><td>45</td></tr><tr><td>200</td><td>35</td></tr><tr><td>250</td><td>30</td></tr><tr><td>300</td><td>25</td></tr><tr><td>425</td><td>20</td></tr></table>	Grain Size D (mm)	Percent Finer (%)	10	100	20	95	30	90	40	85	60	75	75	65	100	55	150	45	200	35	250	30	300	25	425	20	Post-Test Photo of Post 
Grain Size D (mm)	Percent Finer (%)																										
10	100																										
20	95																										
30	90																										
40	85																										
60	75																										
75	65																										
100	55																										
150	45																										
200	35																										
250	30																										
300	25																										
425	20																										

Date

Test Facility and Site Location

In Situ Soil Description (ASTM D2487)

Fill Material Description (ASTM D2487) and sieve analysis ..

Description of Fill Placement Procedure

2019-09-02

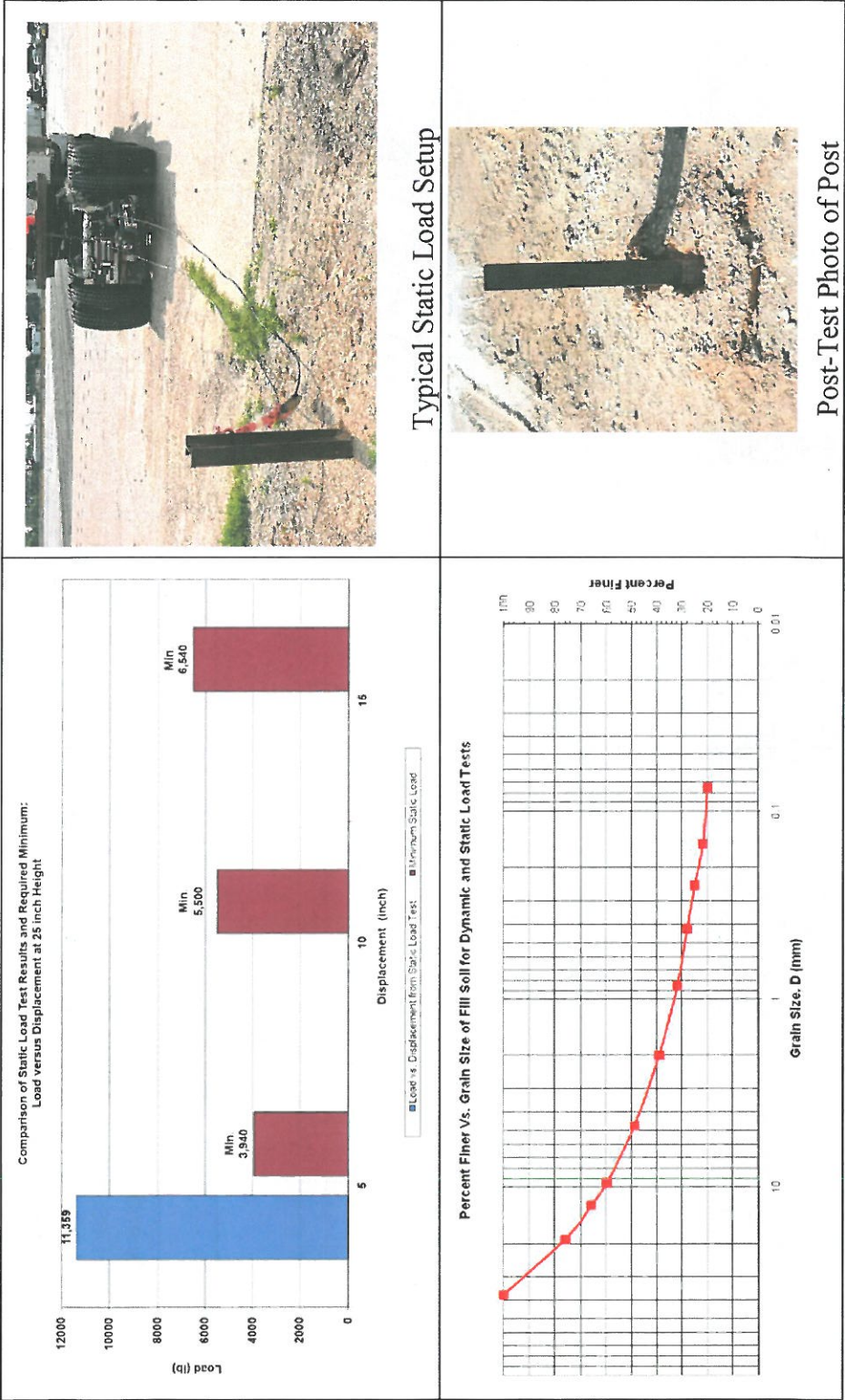
TTI Proving Ground – 3100 SH 47, Bryan, Tx

Sandy gravel with silty fines

AASHTO Grade B Soil-Aggregate (see sieve analysis)

6-inch lifts tamped with a pneumatic compactor

Table C.3. Test Day Static Soil Strength Documentation for Test No. 608331-01-5.



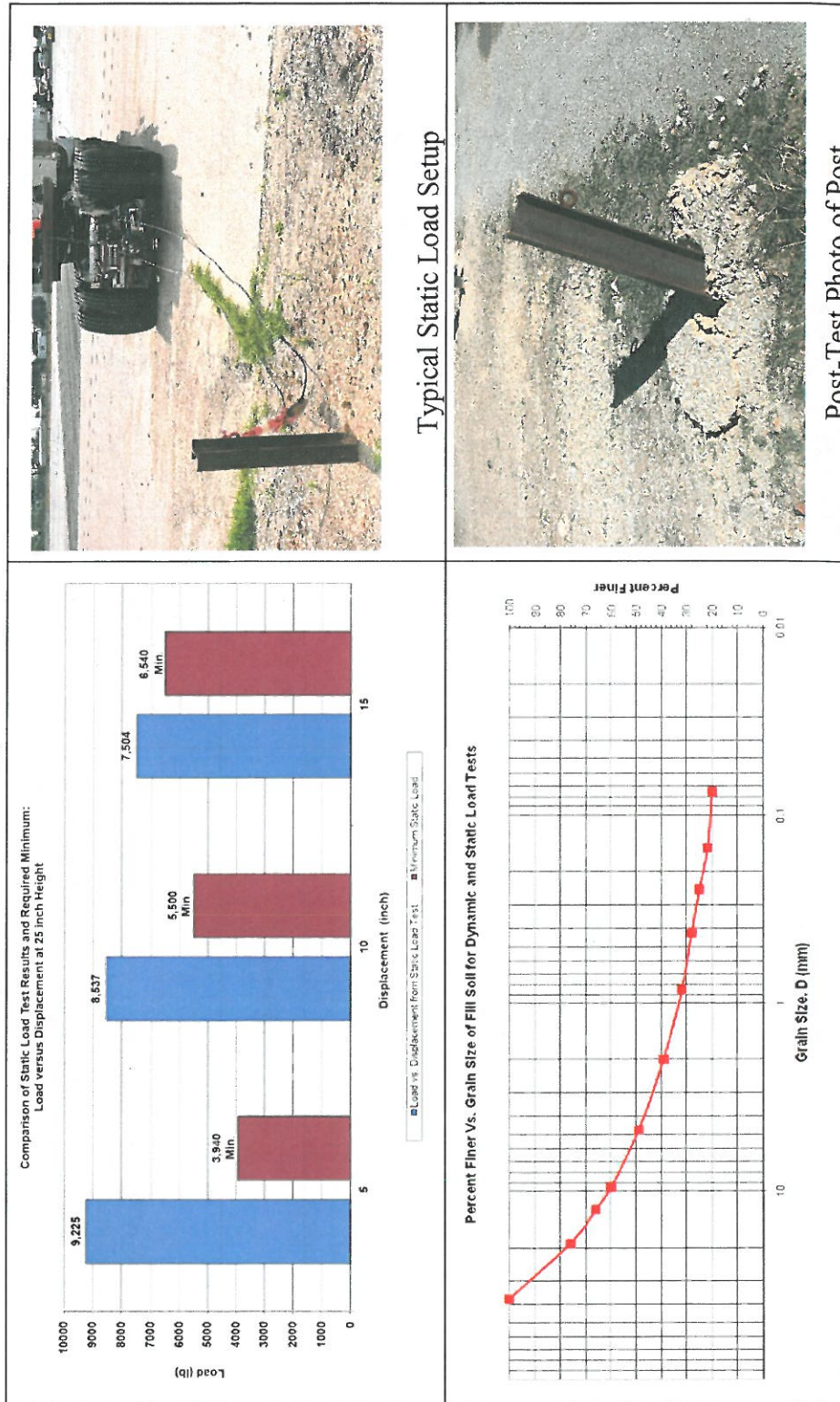
Post-Test Photo of Post

Percent Finer Vs. Grain Size of Fill Soil for Dynamic and Static Load Tests

Grain Size D (mm)	Percent Finer (%)
0.075	100
0.15	95
0.3	85
0.6	75
1.18	65
2.5	55
5.0	45
10.0	35
20.0	25
40.0	15
75.0	10
150.0	5
300.0	2
600.0	1
1000.0	0

Date.....	2019-09-05
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis ..	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

Table C.4. Test Day Static Soil Strength Documentation for Test No. 608331-01-6.



APPENDIX D. MASH TEST 3-20 (CRASH TEST NO. 608331-01-4)

D1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 608331-01-4.

Date: 2019-09-02 Test No.: 608331-4 VIN No.: KNADE123376251020

Year: 2007 Make: Kia Model: Rio

Tire Inflation Pressure: 32 PSI Odometer: 137463 Tire Size: 185/65R14

Describe any damage to the vehicle prior to test: None

• Denotes accelerometer location.

NOTES: None

Engine Type: 4 CYL

Engine CID: 1.6 L

Transmission Type:

☒ Auto or ☐ Manual
☒ FWD ☐ RWD ☐ 4WD

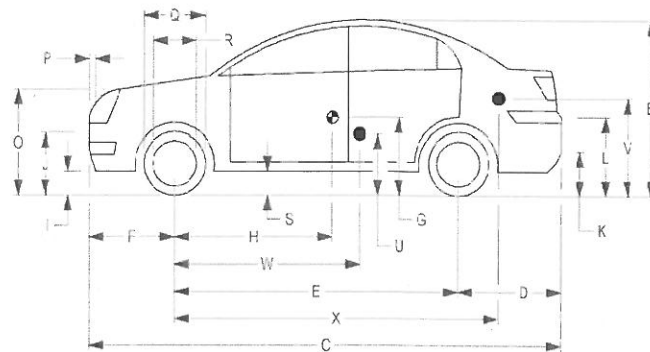
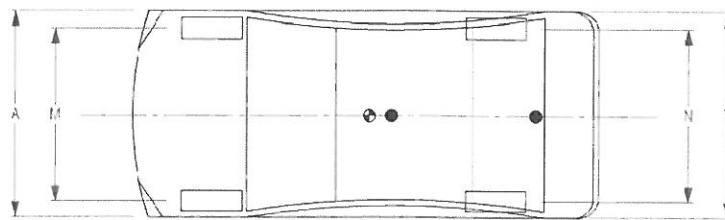
Optional Equipment:
None

Dummy Data:

Type: 50th Percentile Male

Mass: 165 lb

Seat Position: IMPACT SIDE



Geometry: inches

A <u>66.38</u>	F <u>33.00</u>	K <u>12.25</u>	P <u>4.12</u>	U <u>14.75</u>
B <u>51.50</u>	G <u> </u>	L <u>25.25</u>	Q <u>22.50</u>	V <u>20.50</u>
C <u>165.75</u>	H <u>35.04</u>	M <u>57.75</u>	R <u>15.50</u>	W <u>35.00</u>
D <u>34.00</u>	I <u>7.75</u>	N <u>57.70</u>	S <u>8.25</u>	X <u>72.50</u>
E <u>98.75</u>	J <u>21.50</u>	O <u>27.00</u>	T <u>66.20</u>	
Wheel Center Ht Front <u>11.00</u>		Wheel Center Ht Rear <u>11.00</u>		W-H <u>0.00</u>

RANGE LIMIT: A = 65 ±3 inches; C = 169 ±8 inches; E = 98 ±5 inches; F = 35 ±4 inches; H = 39 ±4 inches; O (Bottom of Hood Lip) = 24 ±4 inches
TOP OF RADIATOR SUPPORT = 28.25 inches; (M+N)/2 = 56 ±2 inches; W-H < 2 inches or use MASH Paragraph A4.3.2

GWR Ratings:	Mass: lb	<u>Curb</u>	<u>Test Inertial</u>	<u>Gross Static</u>
Front	<u>1718</u>	M _{front} <u>1602</u>	<u>1578</u>	<u>1663</u>
Back	<u>1874</u>	M _{rear} <u>868</u>	<u>868</u>	<u>948</u>
Total	<u>3638</u>	M _{Total} <u>2470</u>	<u>2446</u>	<u>2611</u>

Allowable TIM = 2420 lb ±55 lb | Allowable GSM = 2585 lb ± 55 lb

Mass Distribution:

lb LF: 766 RF: 812 LR: 452 RR: 416

Table D.2. Exterior Crush Measurements for Test No. 608331-01-4.

Date: 2019-09-02 Test No.: 608331-4 VIN No.: KNADE123376251020
 Year: 2007 Make: Kia Model: Rio

VEHICLE CRUSH MEASUREMENT SHEET¹

Complete When Applicable	
End Damage	Side Damage
Undeformed end width _____ Corner shift: A1 _____ A2 _____ End shift at frame (CDC) (check one) < 4 inches _____ ≥ 4 inches _____	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant $\frac{X1 + X2}{2} = \underline{\hspace{2cm}}$

Note: Measure C₁ to C₆ from Driver to Passenger Side in Front or Rear Impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L***	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	±D
		Width*** (CDC)	Max**** Crush								
1	Front plane at bumper ht	15	8	20	8	6	2	-	-	-	-22
2	Side plane at bumper ht	15	14	48	1	3	5	8	10	15	64
	Measurements recorded										
	☒ inches or ☐ mm										

¹Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc.

Record the value for each C-measurement and maximum crush.

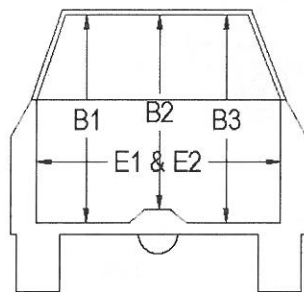
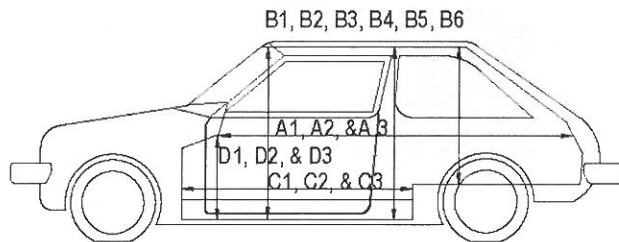
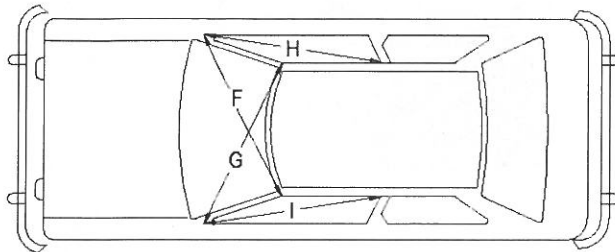
***Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

****Measure and document on the vehicle diagram the location of the maximum crush.

Note: Use as many lines/columns as necessary to describe each damage profile.

Table D.3. Occupant Compartment Measurements for Test No. 608331-01-4.

Date: 2019-09-02 Test No.: 608331-4 VIN No.: KNADE123376251020
 Year: 2007 Make: Kia Model: Rio



*Lateral area across the cab from driver's side kick panel to passenger's side kick panel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	67.50	67.50	0.00
A2	67.25	67.25	0.00
A3	67.75	67.75	0.00
B1	40.50	40.50	0.00
B2	39.00	39.00	0.00
B3	40.50	40.50	0.00
B4	36.25	36.25	0.00
B5	36.00	36.00	0.00
B6	36.25	36.25	0.00
C1	26.00	23.00	-3.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	9.50	11.50	2.00
D2	0.00	0.00	0.00
D3	9.50	9.50	0.00
E1	51.50	53.00	1.50
E2	51.00	55.50	4.50
F	51.00	51.00	0.00
G	51.00	51.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	51.00	47.50	-3.50

D2 SEQUENTIAL PHOTOGRAPHS

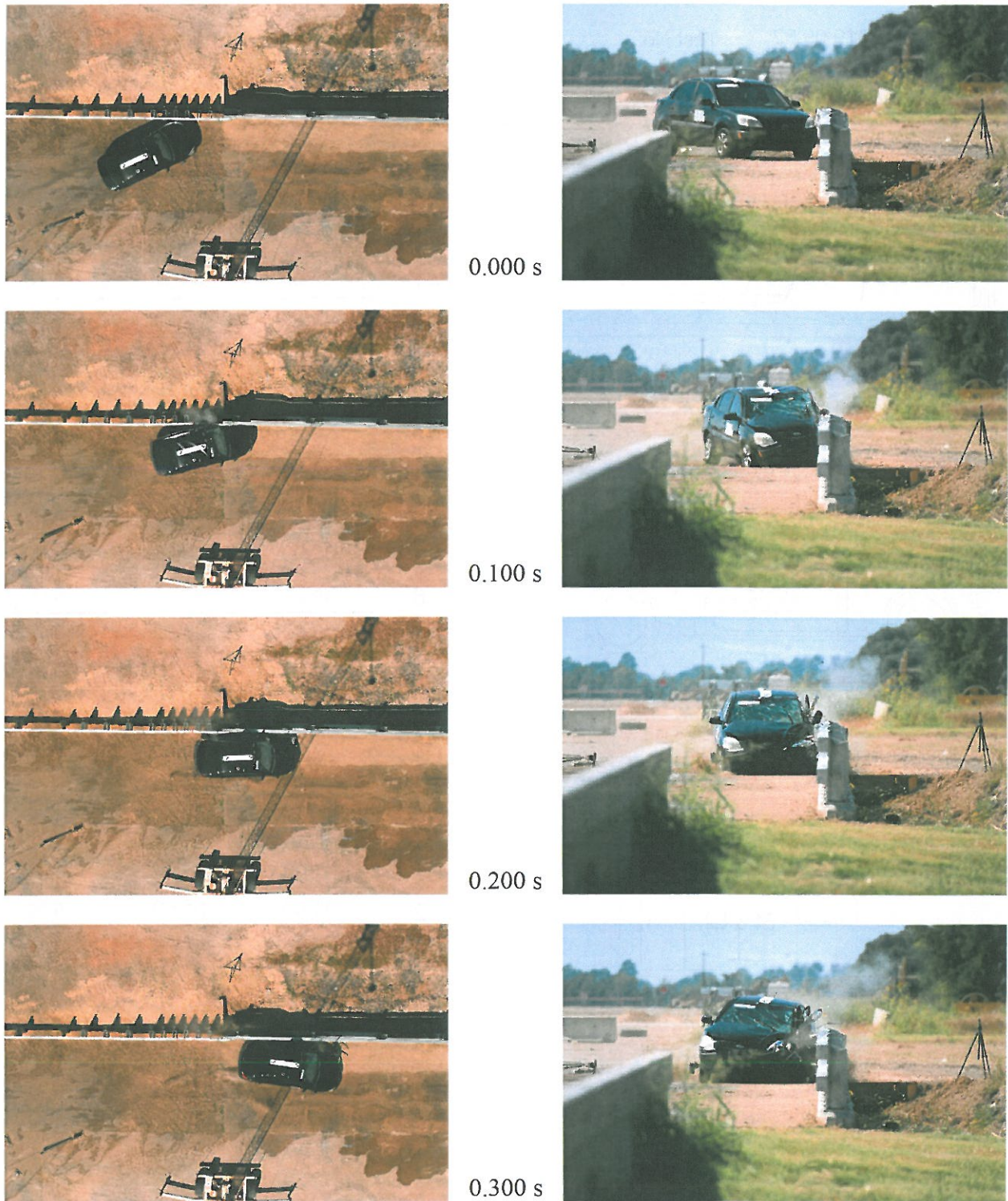
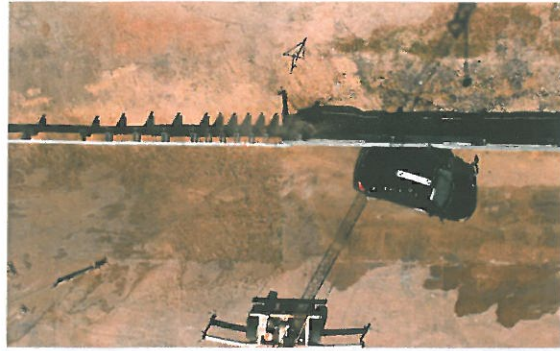
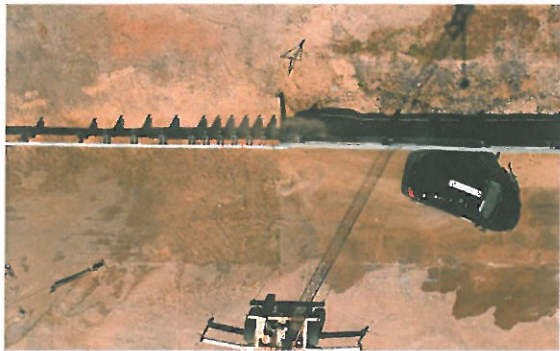


Figure D.1. Sequential Photographs for Test No. 608331-01-4 (Overhead and Frontal Views).



0.400 s



0.500 s



0.600 s



0.700 s



**Figure D.1. Sequential Photographs for Test No. 608331-01-4 (Overhead and Frontal Views)
(Continued).**



0.000 s



0.400 s



0.100 s



0.500 s



0.200 s



0.600 s



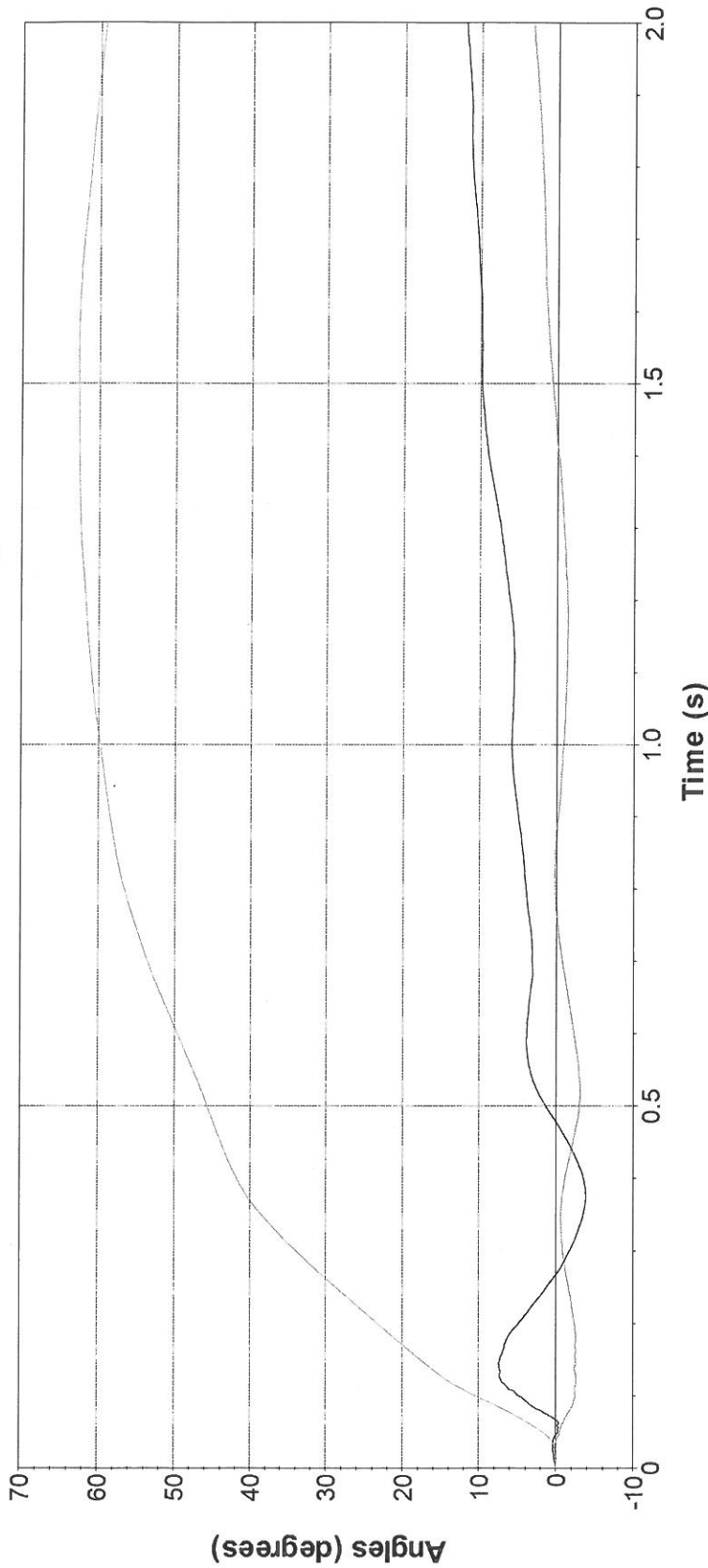
0.300 s



0.700 s

Figure D.2. Sequential Photographs for Test No. 608331-01-4 (Rear View).

Roll, Pitch, and Yaw Angles

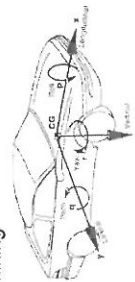


— Roll — Pitch — Yaw

Axes are vehicle-fixed.

Sequence for determining orientation:

1. Yaw.
2. Pitch.
3. Roll.



Test Number: 608331-01-4
 Test Standard Test Number: MASH Test 3-20
 Test Article: 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition
 Test Vehicle: 2007 Kia Rio
 Inertial Mass: 2446 lb
 Gross Mass: 2611 lb
 Impact Speed: 60.9
 Impact Angle: 26.5°

Figure D.3. Vehicle Angular Displacements for Test No. 608331-01-4.

X Acceleration at CG

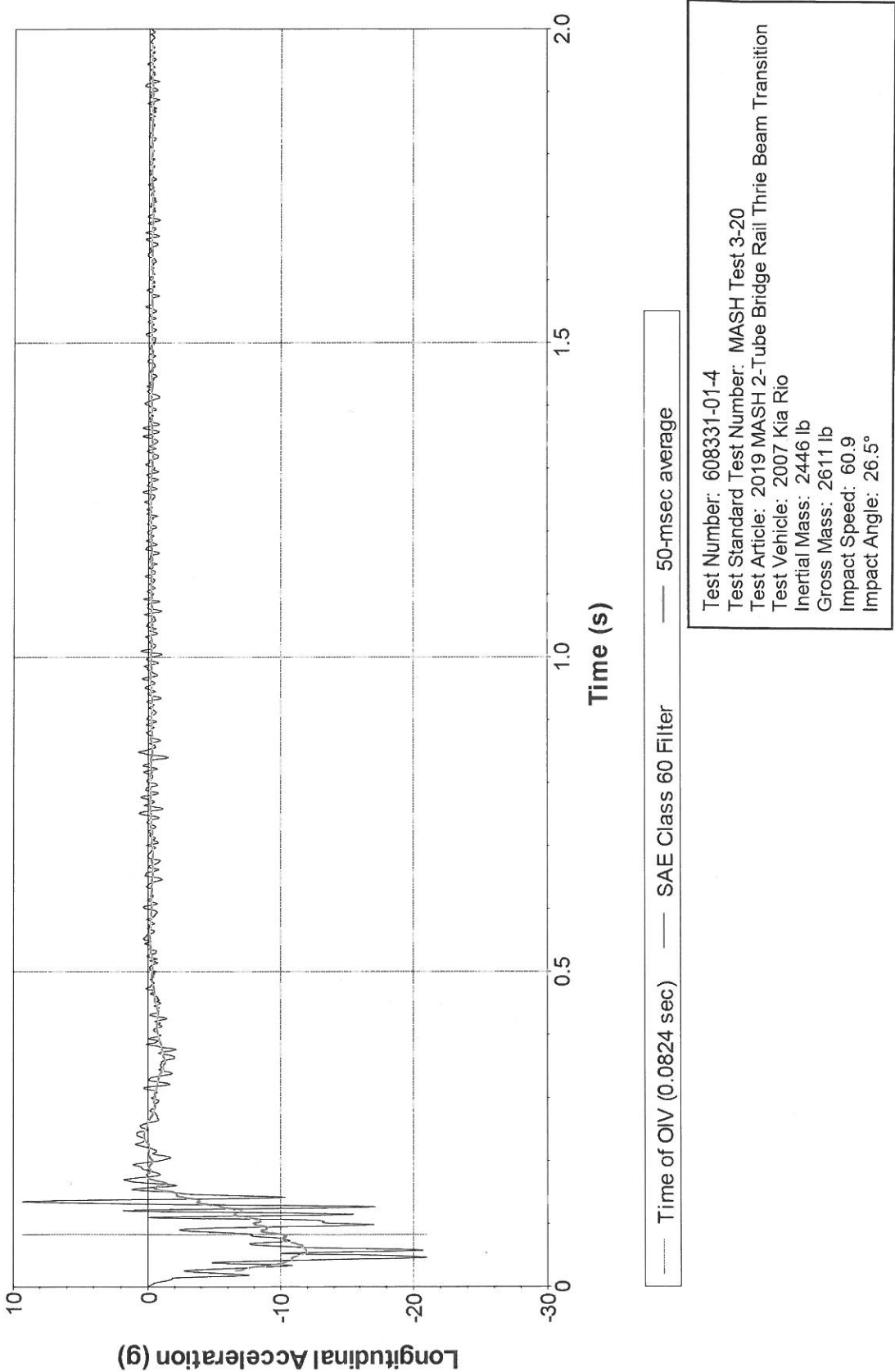
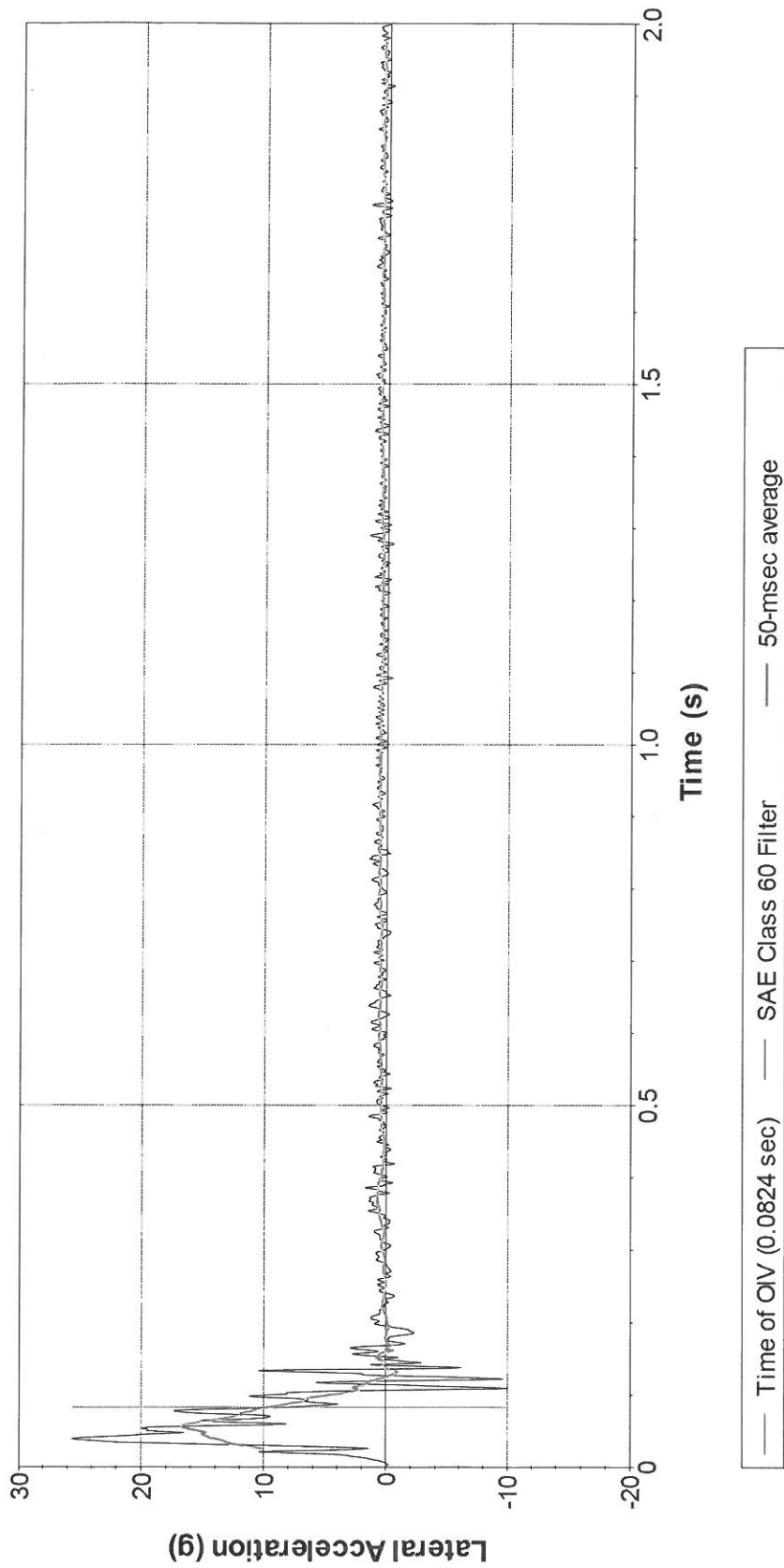


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608331-01-4
(Accelerometer Located at Center of Gravity).

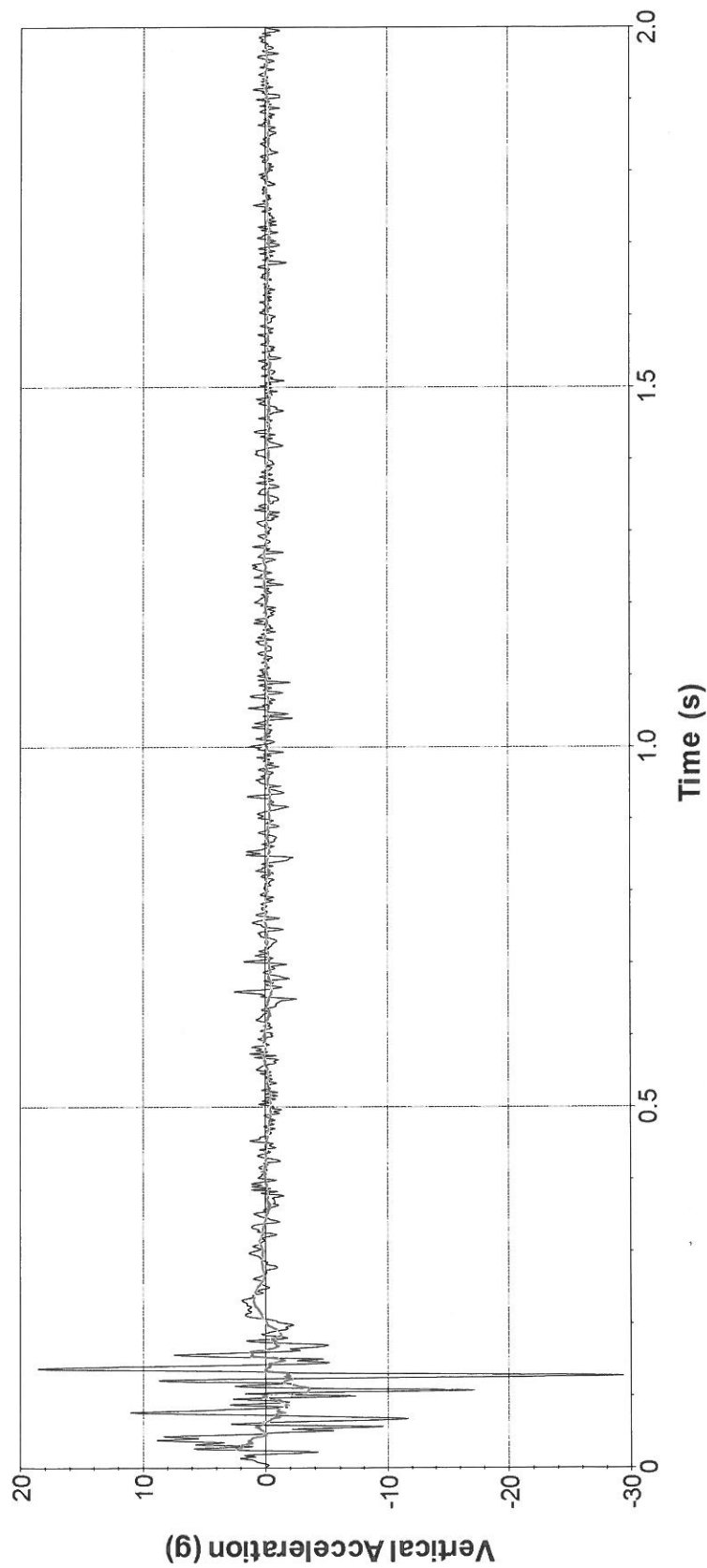
Y Acceleration at CG



Test Number: 608331-01-4
 Test Standard Test Number: MASH Test 3-20
 Test Article: 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition
 Test Vehicle: 2007 Kia Rio
 Inertial Mass: 2446 lb
 Gross Mass: 2611 lb
 Impact Speed: 60.9
 Impact Angle: 26.5°

Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 608331-01-4
 (Accelerometer Located at Center of Gravity).

Z Acceleration at CG



— SAE Class 60 Filter — 50-msec average

Test Number: 608331-01-4
 Test Standard Test Number: MASH Test 3-20
 Test Article: 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition
 Test Vehicle: 2007 Kia Rio
 Inertial Mass: 2446 lb
 Gross Mass: 2611 lb
 Impact Speed: 60.9
 Impact Angle: 26.5°

**Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 608331-01-4
 (Accelerometer Located at Center of Gravity).**

APPENDIX E. MASH TEST 3-21 (CRASH TEST NO. 608331-01-5)

E1 VEHICLE PROPERTIES AND INFORMATION

Table E.1. Vehicle Properties for Test No. 608331-01-5.

Date: 2019-09-05 Test No.: 608331-5 VIN No.: 1C6RR6HTODS501020
 Year: 2013 Make: RAM Model: 1500
 Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi
 Tread Type: Highway Odometer: 152402
 Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

NOTES: None

Engine Type: V-8
 Engine CID: 4.7 liter

Transmission Type:
☒ Auto or ☐ Manual
☐ FWD ☒ RWD ☐ 4WD

Optional Equipment:
None

Dummy Data:
 Type: 50th percentile male
 Mass: 165 lb
 Seat Position: IMPACT SIDE

Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.25	L	30.00	Q	30.50	V	30.25
C	227.50	H	60.84	M	68.50	R	18.00	W	60.80
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		
Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.50				
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	22.50				

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; (M+N)/2=67 ±1.5 inches

GVWR Ratings:	Mass: lb	Curb	Test Inertial	Gross Static
Front	3700	M _{front} 2962	2863	2948
Back	3900	M _{rear} 2206	2187	2267
Total	6700	M _{Total} 5168	5050	5215

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:

lb LF: 1475 RF: 1388 LR: 1070 RR: 1117

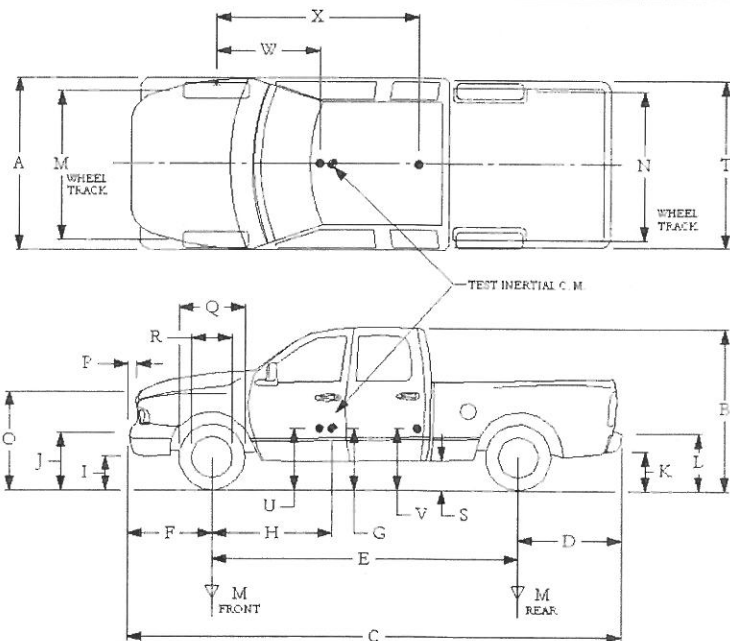


Table E.2. Measurements of Vehicle Vertical CG for Test No. 608331-01-5.

Date:	<u>2019-09-05</u>	Test No.:	<u>608331-5</u>	VIN:	<u>1C6RR6HTODS501020</u>
Year:	<u>2013</u>	Make:	<u>RAM</u>	Model:	<u>1500</u>
Body Style:	<u>Quad Cab</u>	Mileage:	<u>152402</u>		
Engine:	<u>4.7 liter</u>	<u>V-8</u>	Transmission:	<u>Automatic</u>	
Fuel Level:	<u>Empty</u>	Ballast:	<u>100</u>		(440 lb max)
Tire Pressure: Front:	<u>35</u>	psi	Rear:	<u>35</u>	psi
Size:	<u>265/70 R 17</u>				

Measured Vehicle Weights: (lb)

LF:	<u>1475</u>	RF:	<u>1388</u>	Front Axle:	<u>2863</u>
LR:	<u>1070</u>	RR:	<u>1117</u>	Rear Axle:	<u>2187</u>
Left:	<u>2545</u>	Right:	<u>2505</u>	Total:	<u>5050</u>
					5000 ±110 lb allowed

Wheel Base:	<u>140.50</u>	inches	Track: F:	<u>68.50</u>	inches	R:	<u>68.00</u>	inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed				

Center of Gravity, SAE J874 Suspension Method

X:	<u>60.85</u>	inches	Rear of Front Axle	(63 ±4 inches allowed)
Y:	<u>-0.27</u>	inches	Left - Right +	of Vehicle Centerline
Z:	<u>28.25</u>	inches	Above Ground	(minumum 28.0 inches allowed)

Hood Height:	<u>46.00</u>	inches	Front Bumper Height:	<u>27.00</u>	inches
	43 ±4 inches allowed				
Front Overhang:	<u>40.00</u>	inches	Rear Bumper Height:	<u>30.00</u>	inches
	39 ±3 inches allowed				
Overall Length:	<u>227.50</u>	inches			
	237 ±13 inches allowed				

Table E.3. Exterior Crush Measurements for Test No. 608331-01-5.

Date: 2019-09-05 Test No.: 608331-5 VIN No.: 1C6RR6HTODS501020
 Year: 2013 Make: RAM Model: 1500

VEHICLE CRUSH MEASUREMENT SHEET¹

Complete When Applicable	
End Damage	Side Damage
Undeformed end width _____ Corner shift: A1 _____ A2 _____ End shift at frame (CDC) (check one) < 4 inches _____ ≥ 4 inches _____	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant $\frac{X1 + X2}{2} = \underline{\hspace{2cm}}$

Note: Measure C₁ to C₆ from Driver to Passenger Side in Front or Rear Impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L***	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	±D
		Width** (CDC)	Max**** Crush								
1	Front plane at bumper ht	22	14	28	14	9.5	5	3	1	0	-12
2	Side plane at bumper ht	22	15	62	15	11	-	-	8	8	+75
	Measurements recorded										
	☒ inches or ☐ mm										

¹Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc.

Record the value for each C-measurement and maximum crush.

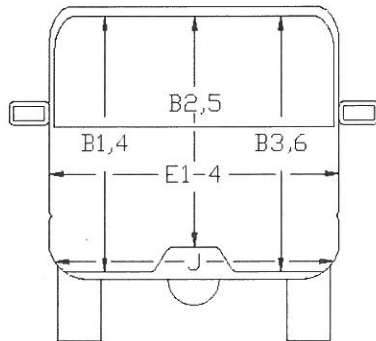
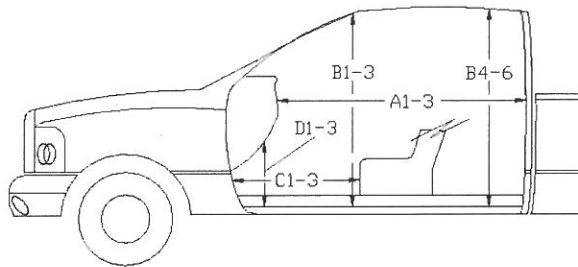
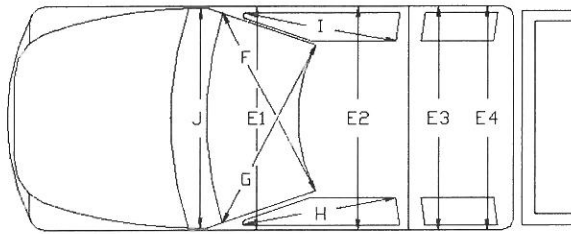
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***Measure and document on the vehicle diagram the location of the maximum crush.

Note: Use as many lines/columns as necessary to describe each damage profile.

Table E.4. Occupant Compartment Measurements for Test No. 608331-01-5.

Date: 2019-09-05 Test No.: 608331-5 VIN No.: 1C6RR6HTODS501020
Year: 2013 Make: RAM Model: 1500

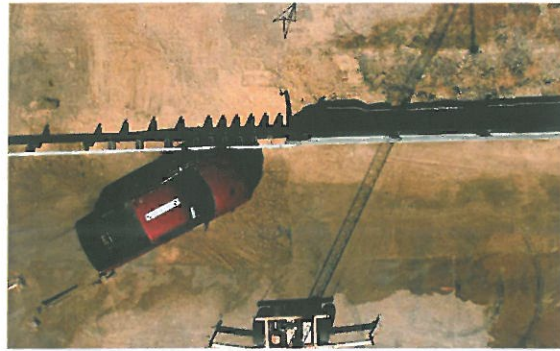


*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

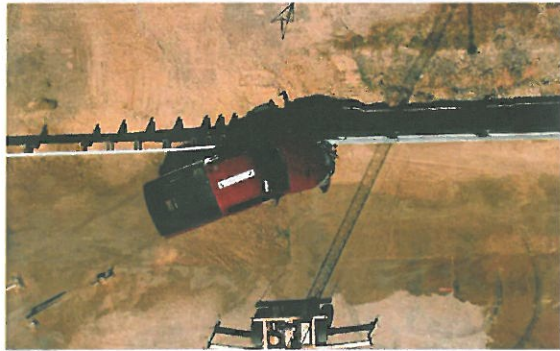
**OCCUPANT COMPARTMENT
DEFORMATION MEASUREMENT**

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	25.00	-1.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	10.00	-1.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	60.50	2.00
E2	63.50	67.50	4.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	21.00	-4.00

E2 SEQUENTIAL PHOTOGRAPHS



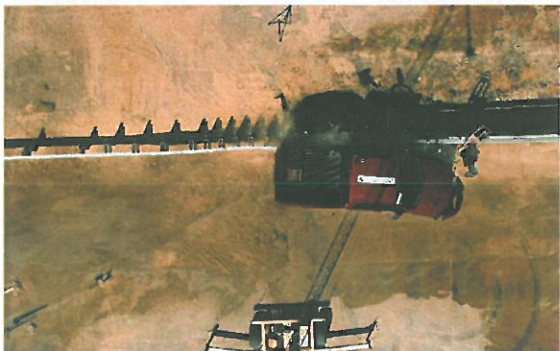
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0.100 s



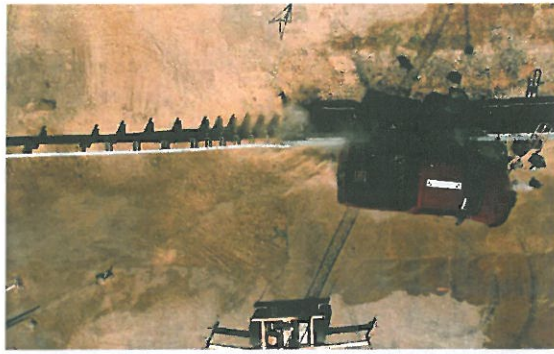
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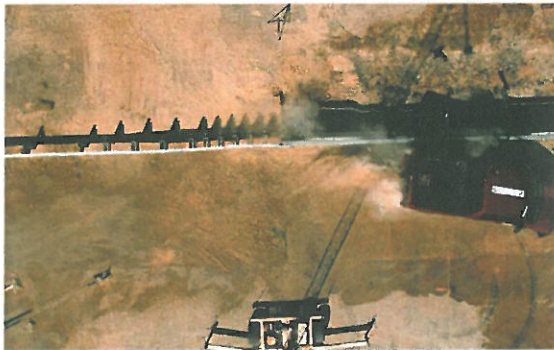
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Figure E.1. Sequential Photographs for Test No. 608331-01-5 (Overhead and Frontal Views).



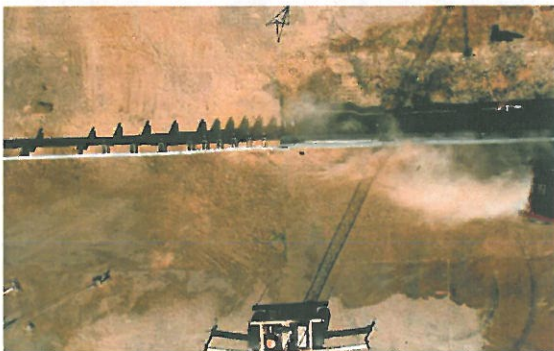
0.400 s



0.500 s



0.600 s



0.700 s



**Figure E.1. Sequential Photographs for Test No. 608331-01-5 (Overhead and Frontal Views)
(Continued).**



0.000 s



0.400 s



0.100 s



0.500 s



0.200 s



0.600 s



0.300 s



0.700 s

Figure E.2. Sequential Photographs for Test No. 608331-01-5 (Rear View).

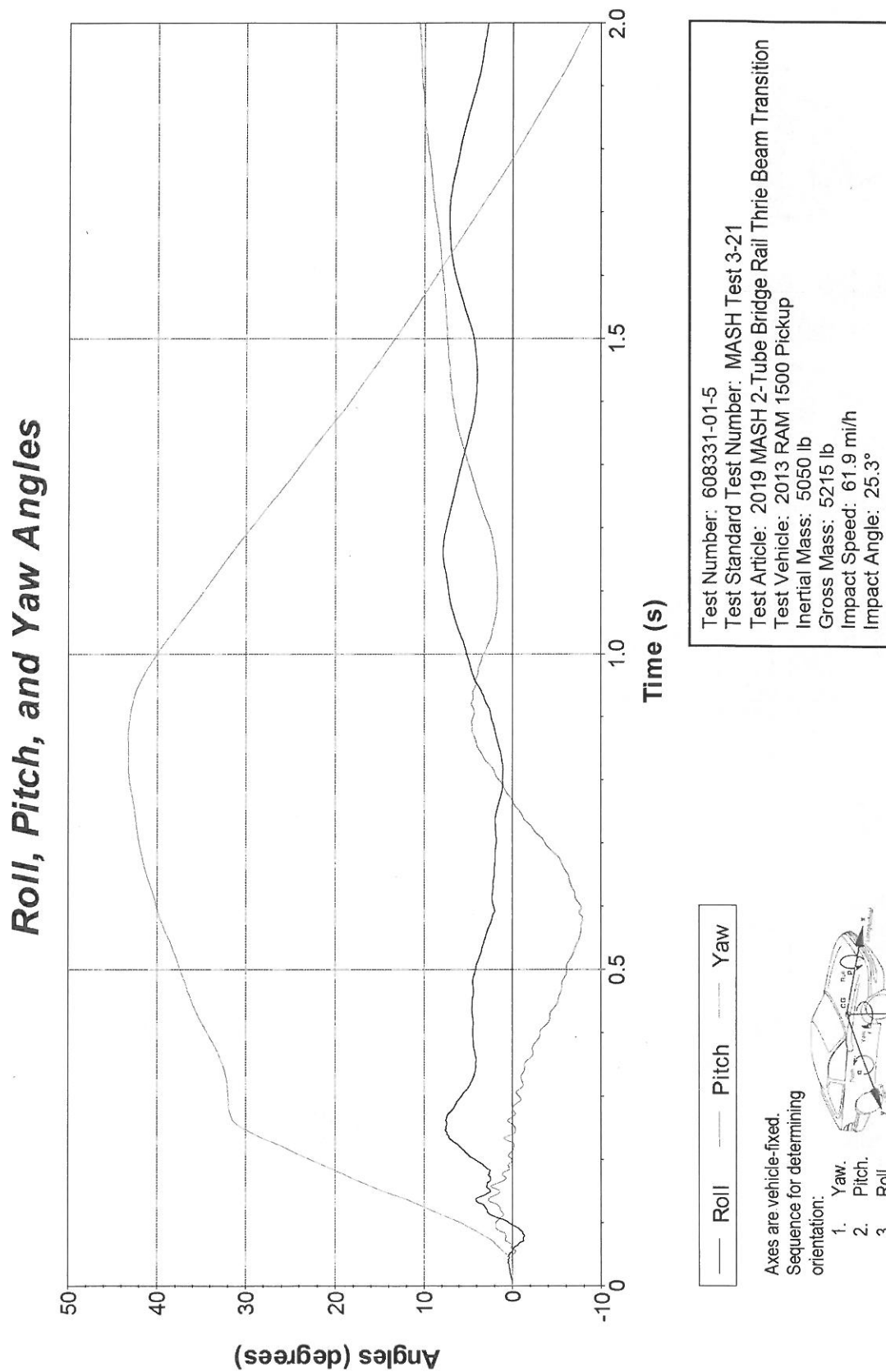
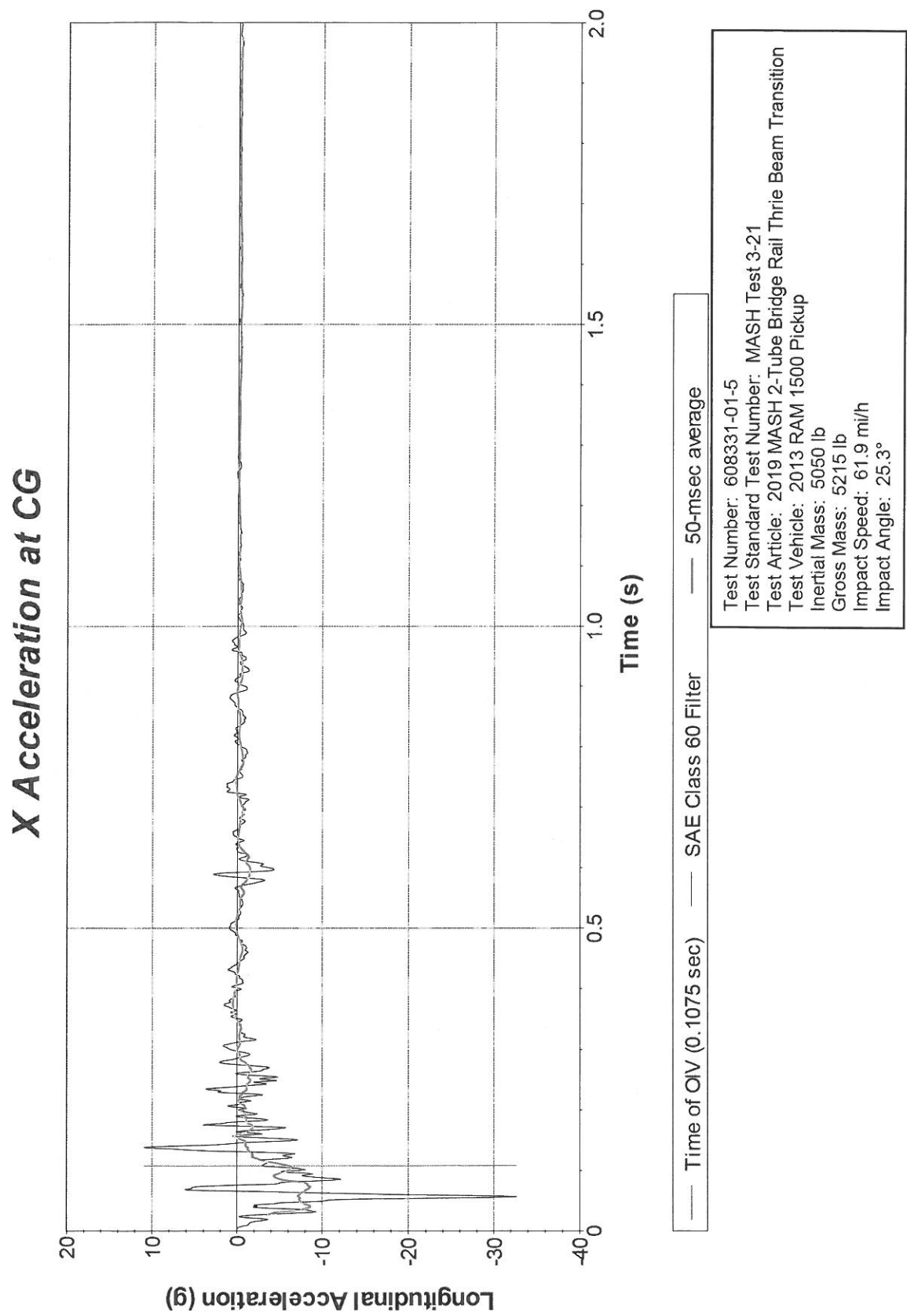
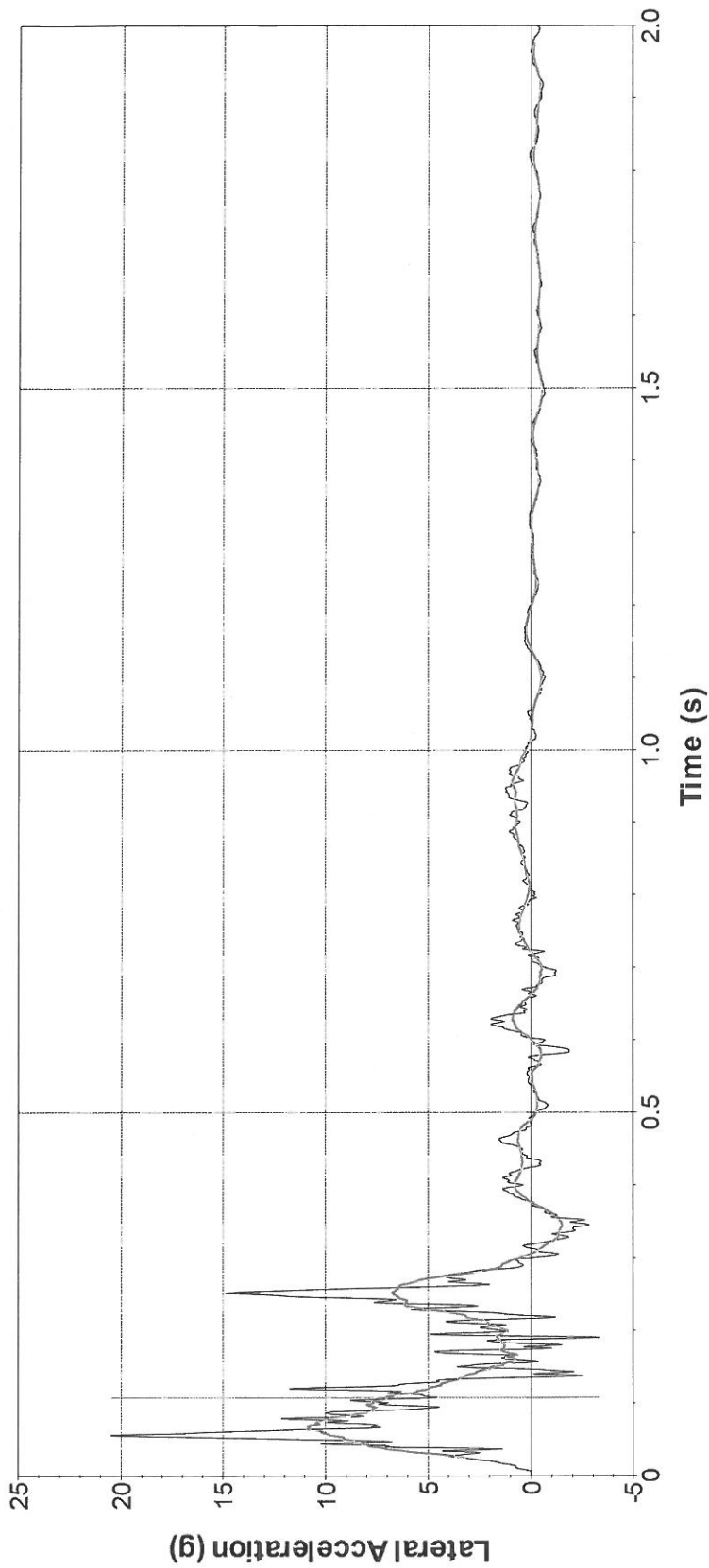


Figure E.3. Vehicle Angular Displacements for Test No. 608331-01-5.



**Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608331-01-5
(Accelerometer Located at Center of Gravity).**

Y Acceleration at CG

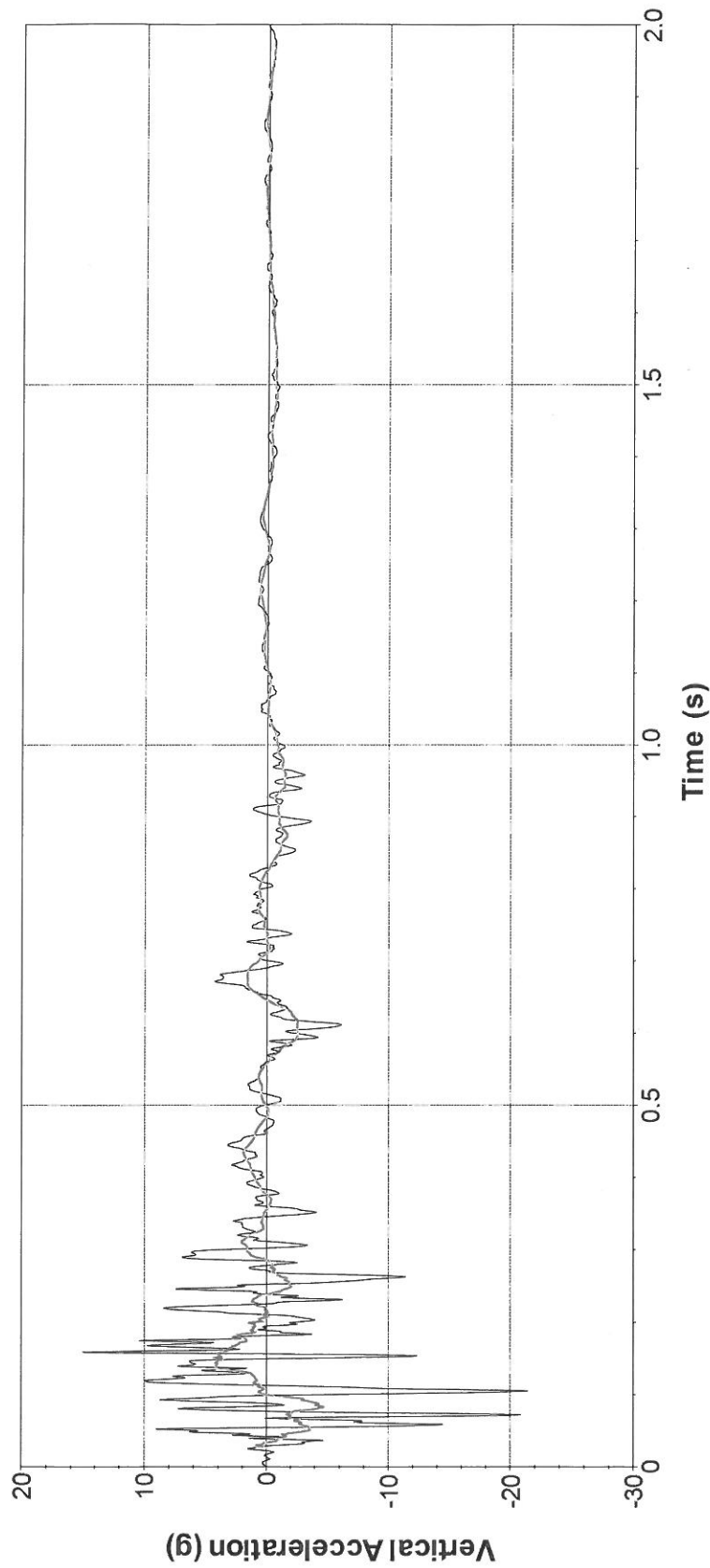


Time of OIV (0.1075 sec) — SAE Class 60 Filter — 50-msec average

Test Number: 608331-01-5
 Test Standard: MASH Test 3-21
 Test Article: 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition
 Test Vehicle: 2013 RAM 1500 Pickup
 Inertial Mass: 5050 lb
 Gross Mass: 5215 lb
 Impact Speed: 61.9 mi/h
 Impact Angle: 25.3°

**Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 608331-01-5
 (Accelerometer Located at Center of Gravity).**

Z Acceleration at CG



— SAE Class 60 Filter — 50-msec average

Test Number: 608331-01-5
 Test Standard: Test Number: MASH Test 3-21
 Test Article: 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition
 Test Vehicle: 2013 RAM 1500 Pickup
 Inertial Mass: 5050 lb
 Gross Mass: 5215 lb
 Impact Speed: 61.9 mi/h
 Impact Angle: 25.3°

**Figure E.6. Vehicle Vertical Accelerometer Trace for Test No. 608331-01-5
 (Accelerometer Located at Center of Gravity).**

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APPENDIX F. MASH TEST 3-21 (CRASH TEST NO. 608331-01-6)

F1 VEHICLE PROPERTIES AND INFORMATION

Table F.1. Vehicle Properties for Test No. 608331-01-6.

Date: 2019-12-19 Test No.: 608331-6 VIN No.: 1C6RR6FT8DS724487
 Year: 2013 Make: RAM Model: 1500
 Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi
 Tread Type: Highway Odometer: 144145
 Note any damage to the vehicle prior to test: None

• Denotes accelerometer location.

NOTES: None

Engine Type: V-8

Engine CID: 4.7 liter

Transmission Type:

☒ Auto or ☐ Manual
☐ FWD ☒ RWD ☐ 4WD

Optional Equipment:

None

Dummy Data:

Type: No dummy used

Mass: 0 lb

Seat Position:

Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	29.00	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.52	M	68.50	R	18.00	W	61.50
D	44.00	I	11.75	N	68.00	S	13.00	X	79.00
E	140.50	J	27.00	O	46.00	T	77.00		
Wheel Center Height Front	14.75	Wheel Well Clearance (Front)	6.00	Bottom Frame Height - Front	12.50				
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	22.50				

RANGE LIMIT: A=78 ±2 inches; C=237 ±13 inches; E=148 ±12 inches; F=39 ±3 inches; G = > 28 inches; H = 63 ±4 inches; O=43 ±4 inches; (M+N)/2=67 ±1.5 inches

GVWR Ratings:

Front	3700
Back	3900
Total	6700

Mass: lb

M _{front}	2877
M _{rear}	2013
M _{Total}	4890

Curb

2877
2013
4890

Test Inertial

2832
2206
5038

Gross Static

2832
2206
5038

(Allowable Range for TIM and GSM = 5000 lb ±110 lb)

Mass Distribution:

lb

LF: 1393

RF: 1439

LR: 1157

RR: 1049

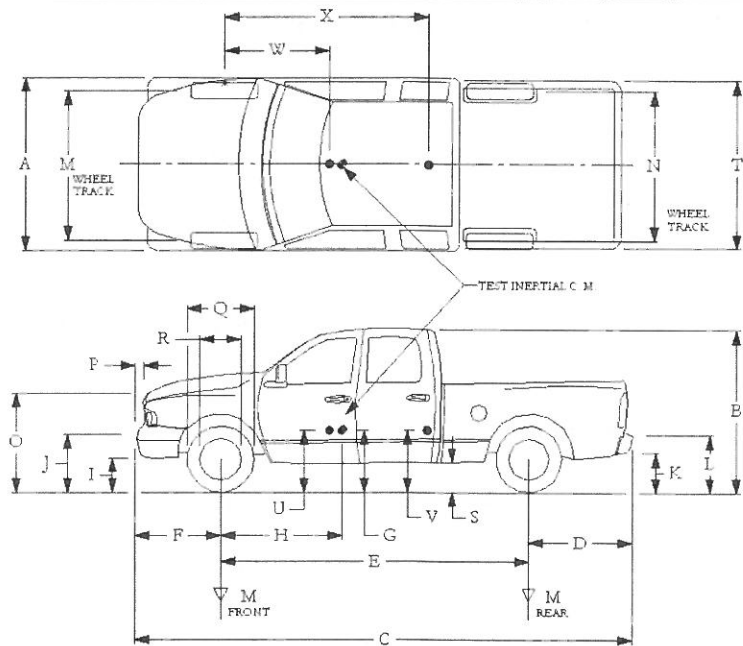


Table F.2. Measurements of Vehicle Vertical CG for Test No. 608331-01-6.

Date: 2019-12-19 Test No.: 608331-6 VIN: 1C6RR6FT8DS724487
 Year: 2013 Make: RAM Model: 1500
 Body Style: Quad Cab Mileage: 144145
 Engine: 4.7 liter V-8 Transmission: Automatic
 Fuel Level: Empty Ballast: 180 (440 lb max)

Tire Pressure: Front: 35 psi Rear: 35 psi Size: 265/70 R 17

Measured Vehicle Weights: (lb)

LF: <u>1393</u>	RF: <u>1439</u>	Front Axle: <u>2832</u>
LR: <u>1157</u>	RR: <u>1049</u>	Rear Axle: <u>2206</u>
Left: <u>2550</u>	Right: <u>2488</u>	Total: <u>5038</u>
		5000 ±110 lb allowed
Wheel Base: <u>140.50</u> inches	Track: F: <u>68.50</u> inches	R: <u>68.00</u> inches
148 ±12 inches allowed	Track = (F+R)/2 = <u>67 ±1.5</u> inches allowed	

Center of Gravity, SAE J874 Suspension Method

X: <u>61.52</u> inches	Rear of Front Axle	(63 ±4 inches allowed)
Y: <u>-0.42</u> inches	Left - Right +	of Vehicle Centerline
Z: <u>29.00</u> inches	Above Ground	(minumum 28.0 inches allowed)

Hood Height: 46.00 inches Front Bumper Height: 27.00 inches
 43 ±4 inches allowed

Front Overhang: 40.00 inches Rear Bumper Height: 30.00 inches
 39 ±3 inches allowed

Overall Length: 227.50 inches
 237 ±13 inches allowed

Table F.3. Exterior Crush Measurements for Test No. 608331-01-6.

Date:	2019-12-19	Test No.:	608331-6	VIN No.:	1C6RR6FT8DS724487
Year:	2013	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET¹

Complete When Applicable	
End Damage	Side Damage
Undeformed end width _____	Bowing: B1 _____ X1 _____
Corner shift: A1 _____	B2 _____ X2 _____
A2 _____	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1 + X2}{2} = \underline{\hspace{2cm}}$
< 4 inches _____	
≥ 4 inches _____	

Note: Measure C₁ to C₆ from Driver to Passenger Side in Front or Rear Impacts – Rear to Front in Side Impacts.

[illegible]

¹Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc.

Record the value for each C-measurement and maximum crush.

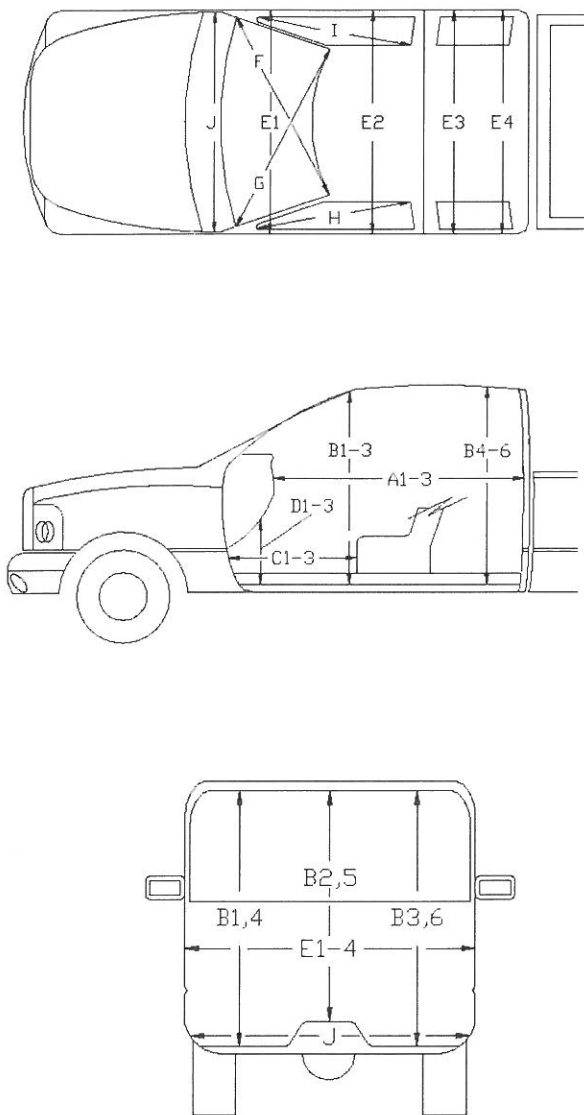
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***Measure and document on the vehicle diagram the location of the maximum crush.

Note: Use as many lines/columns as necessary to describe each damage profile.

Table F.4. Occupant Compartment Measurements for Test No. 608331-01-6.

Date: 2019-12-19 Test No.: 608331-6 VIN No.: 1C6RR6FT8DS724487
 Year: 2013 Make: RAM Model: 1500

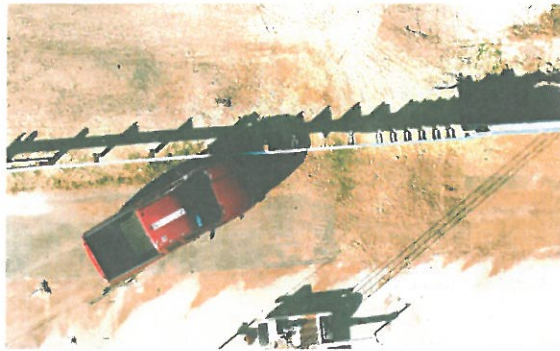


**OCCUPANT COMPARTMENT
DEFORMATION MEASUREMENT**

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	58.50	0.00
E2	63.50	63.50	0.00
E3	63.50	63.50	0.00
E4	63.50	63.50	0.00
F	59.00	59.00	0.00
G	59.00	59.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	25.00	25.00	0.00

*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

F2 SEQUENTIAL PHOTOGRAPHS



0.000 s



0.100 s



0.200 s



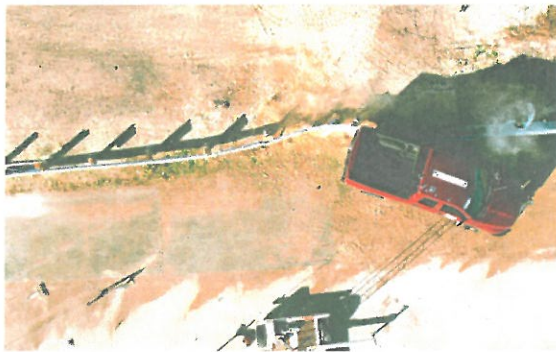
0.300 s



Figure F.1. Sequential Photographs for Test No. 608331-01-6 (Overhead and Frontal Views).



0.400 s



0.500 s



0.600 s



0.700 s



**Figure F.1. Sequential Photographs for Test No. 608331-01-6 (Overhead and Frontal Views)
(Continued).**



0.000 s



0.400 s



0.100 s



0.500 s



0.200 s



0.600 s



0.300 s



0.700 s

Figure F.2. Sequential Photographs for Test No. 608331-01-6 (Rear View).

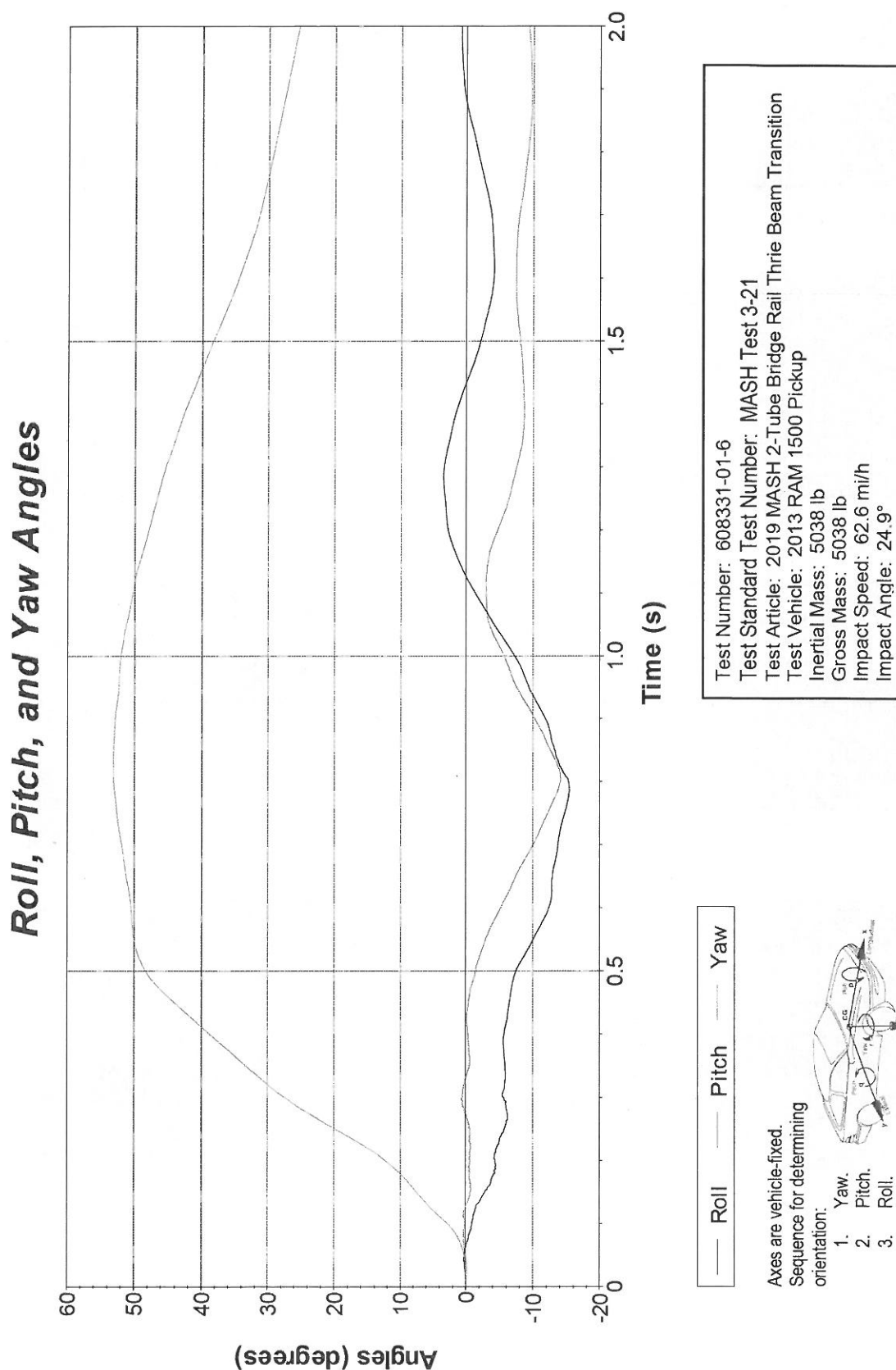


Figure F.3. Vehicle Angular Displacements for Test No. 608331-01-6.

X Acceleration at CG

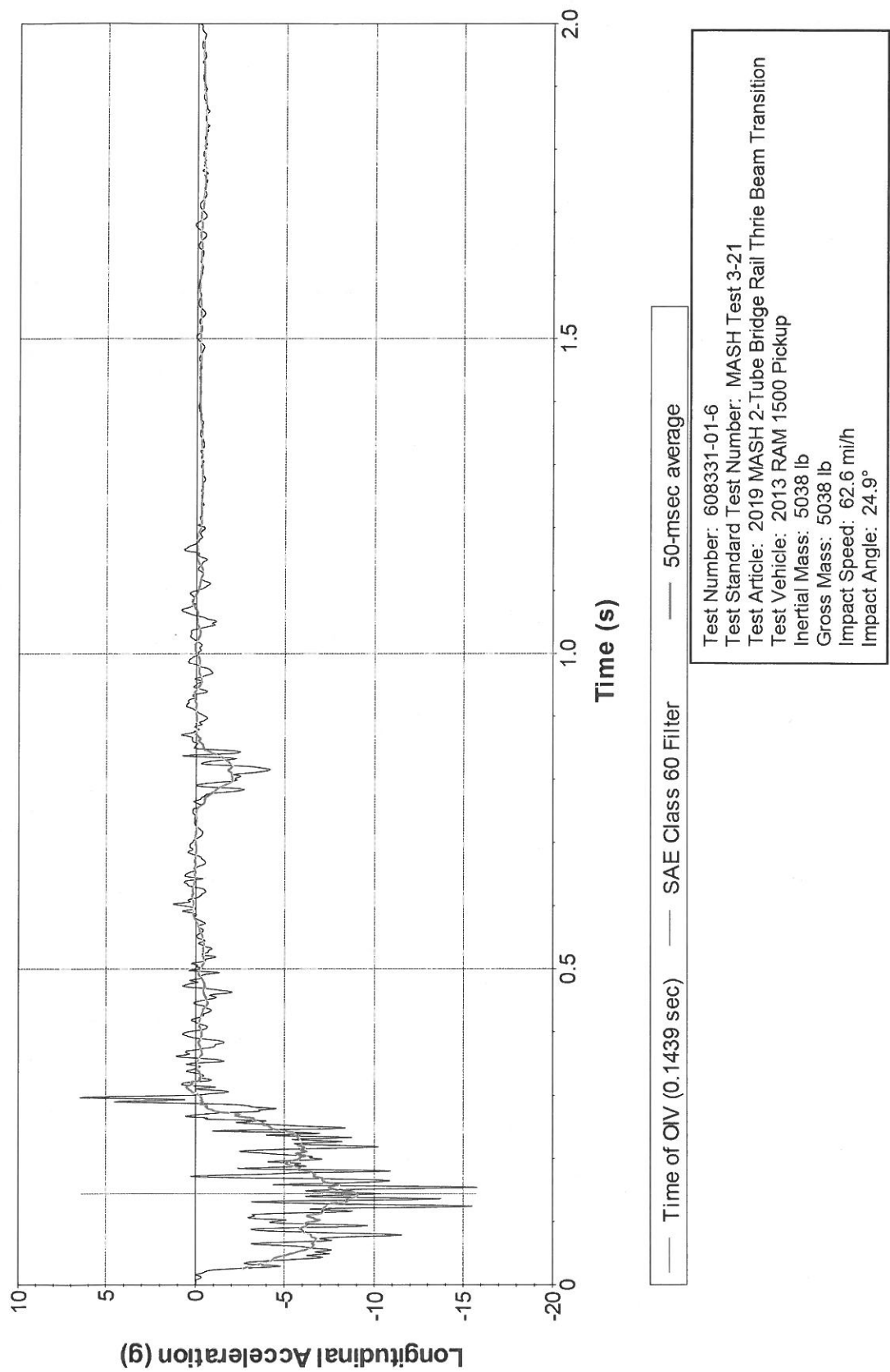
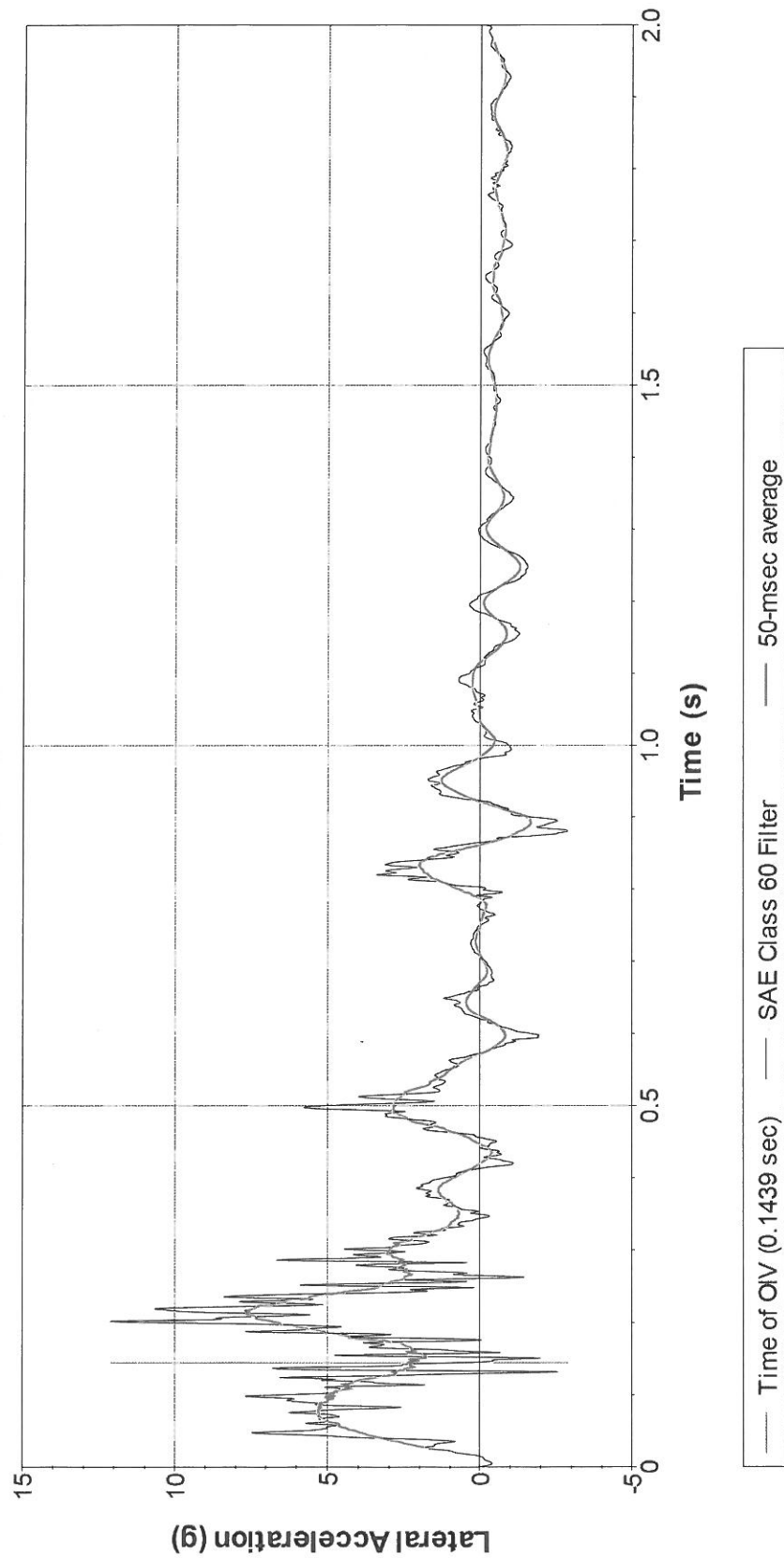


Figure F.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608331-01-6
(Accelerometer Located at Center of Gravity).

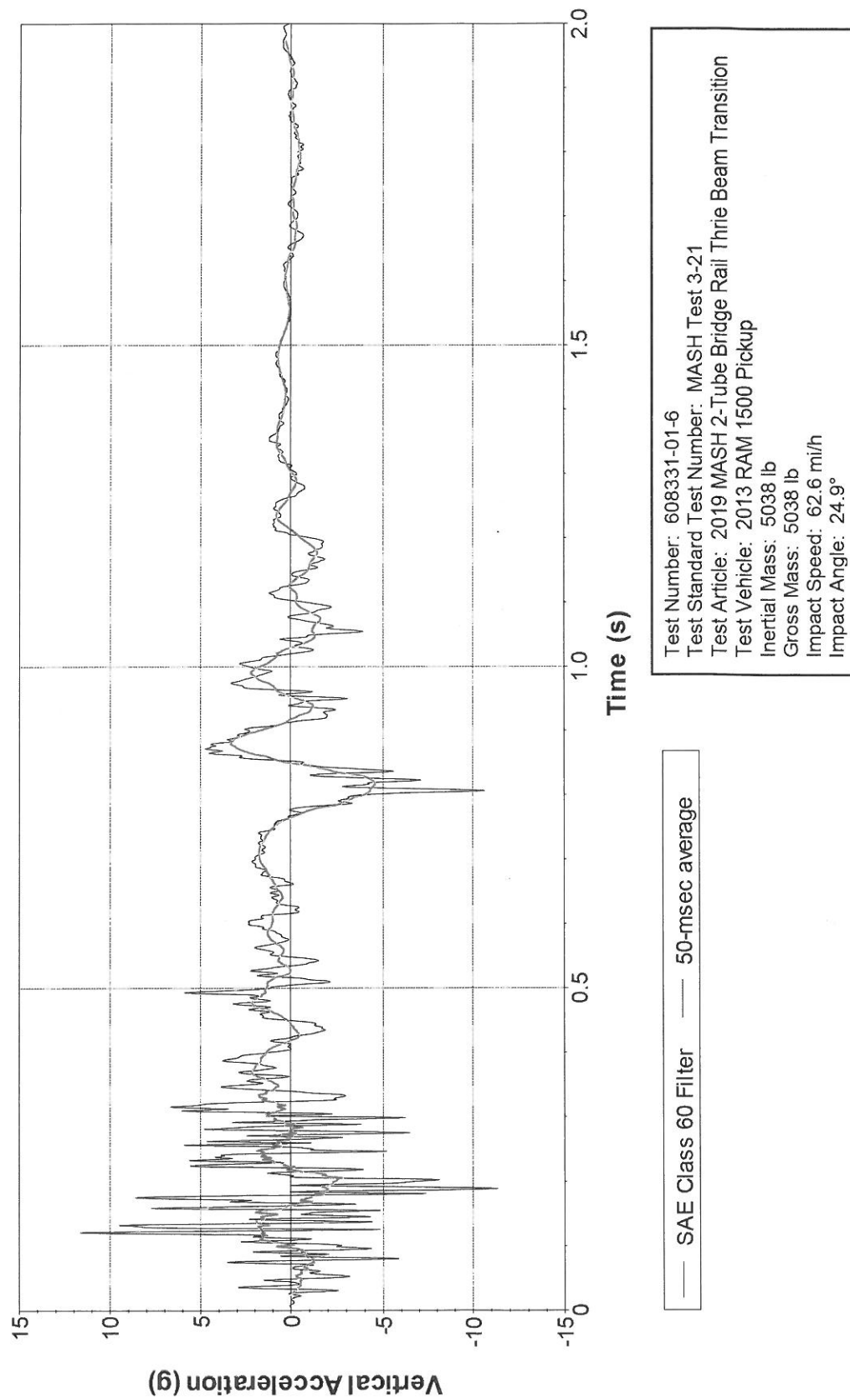
Y Acceleration at CG



Test Number: 608331-01-6
Test Standard Test Number: MASH Test 3-21
Test Article: 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition
Test Vehicle: 2013 RAM 1500 Pickup
Inertial Mass: 5038 lb
Gross Mass: 5038 lb
Impact Speed: 62.6 mi/h
Impact Angle: 24.9°

**Figure F.5. Vehicle Lateral Accelerometer Trace for Test No. 608331-01-6
(Accelerometer Located at Center of Gravity).**

Z Acceleration at CG



**Figure F.6. Vehicle Vertical Accelerometer Trace for Test No. 608331-01-6
(Accelerometer Located at Center of Gravity).**

