Texas A&M Transportation Institute
Proving Ground

**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


by

William F. Williams, P.E.
Associate Research Engineer

Wanda L. Menges
Research Specialist

Glenn E. Schroeder
Research Specialist

and

Darrell L. Kuhn, P.E.
Research Specialist



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**TEXAS A&M TRANSPORTATION INSTITUTE PROVING GROUND**

Mailing Address:
Roadside Safety & Physical Security
Texas A&M University System
3135 TAMU
College Station, TX 77843-3135

Located at:
Texas A&M University System RELLIS Campus
Building 7091
3100 State Highway 47
Bryan, TX 77807

ACCREDITED
ISO 17025 Laboratory
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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 *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 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 transition evaluation criteria.

The 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition performed acceptably for *MASH* TL-3 transitions.

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## SI* (MODERN METRIC) CONVERSION FACTORS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| **APPROXIMATE CONVERSIONS TO SI UNITS** | | | | |
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square 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 | $lb/in^2$ |

*SI is the symbol for the International System of Units

# REPORT AUTHORIZATION

## REPORT REVIEWED BY:

| | |
|---|---|
| DocuSigned by: Glenn Schroeder E692F9CB5047487... | DocuSigned by: Ken Reeves 60D556935596468... |
| Glenn Schroeder, Research Specialist<br>Drafting & Reporting | Ken Reeves, Research Specialist<br>Electronics Instrumentation |
| DocuSigned by: Gary Gerke FBA2101E9F6B4B7... | DocuSigned by: Richard Badillo 0F51DA60AB144F9... |
| Gary Gerke, Research Specialist<br>Construction | Richard Badillo, Research Specialist<br>Photographic Instrumentation |
| DocuSigned by: Scott Dobrovolny 1C613885787C44C... | DocuSigned by: Wanda L. Menges B92179622AF24FE... |
| Scott Dobrovolny, Research Specialist<br>Mechanical Instrumentation | Wanda L. Menges, Research Specialist<br>Research Evaluation and Reporting |
| DocuSigned by: Bill Griffith 44A122CB271845B... | DocuSigned by: Darrell L. Kuhn D4CC23E85D5B4E7... |
| Bill L. Griffith, Research Specialist<br>Deputy Quality Manager | Darrell L. Kuhn, P.E., Research Specialist<br>Quality Manager |
| DocuSigned by: Matt Robinson EAA22BFA5BFD417... | DocuSigned by: William F. Williams, P.E. 2B8AC4D2B3784AE... |
| Matthew N. Robinson, Research Specialist<br>Test Facility Manager & Technical Manager | William F. Williams, P.E.<br>Associate Research Engineer |

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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 (21⅛ 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.

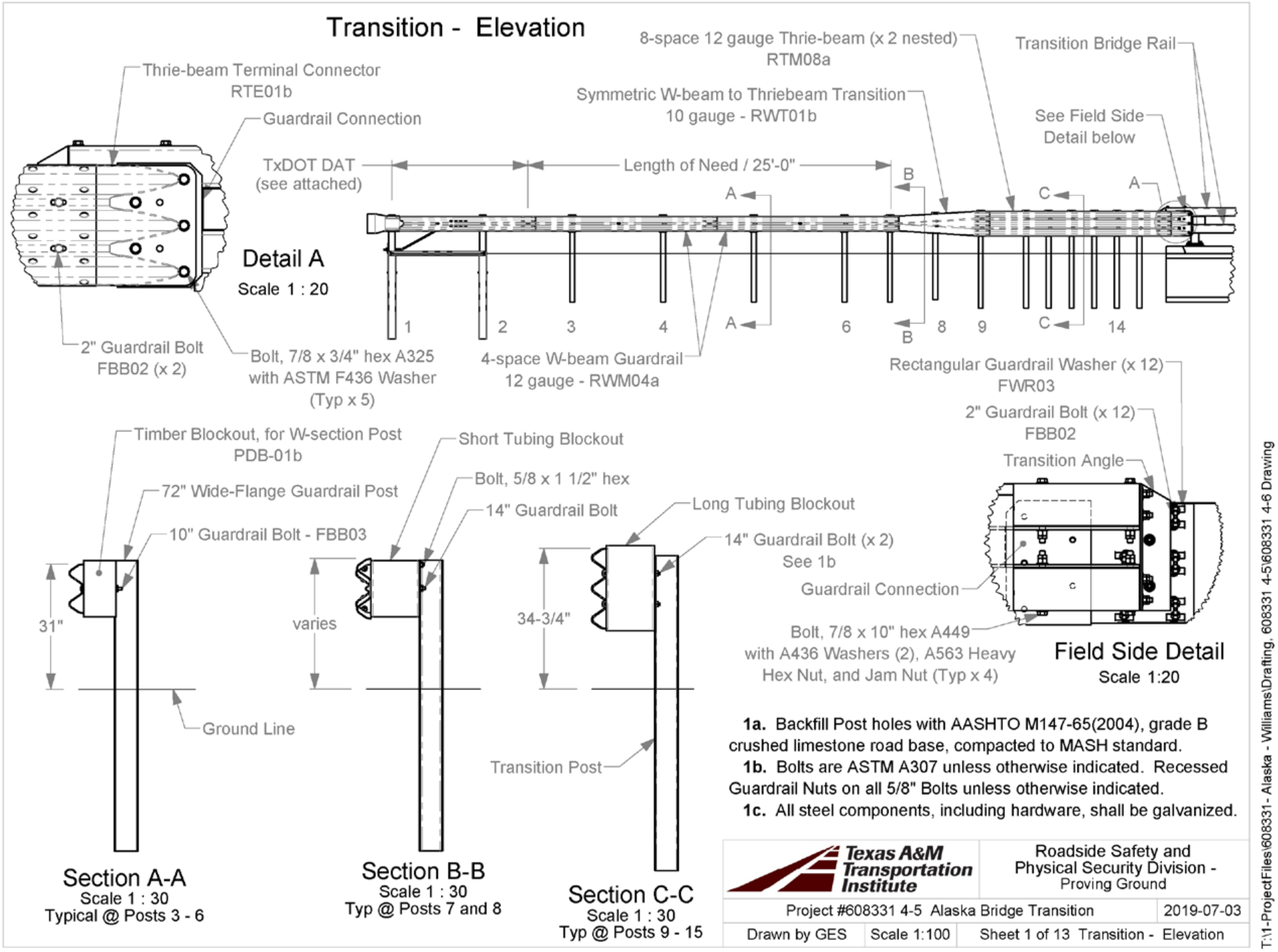


**Figure 2.1. Details of 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition.**


**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** | *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.* |
| **Occupant Risk** | *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.*<br>*Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.* |
| | *F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.* |
| | *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 occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.* |

# 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/compartment impact velocities, time of occupant/compartment 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 ±55 lb impacting the CIP of the transition at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±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 ±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.

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* 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.**

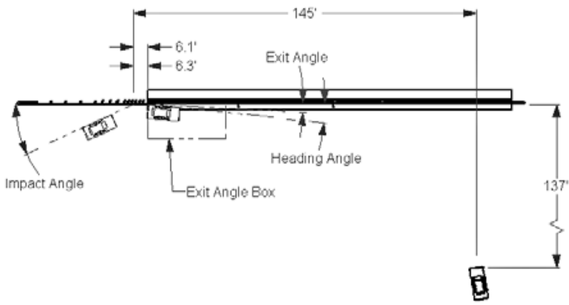
| Occupant Risk Factor | Value | Time |
|---|---|---|
| **Occupant Impact Velocity (OIV)** | | |
| Longitudinal | 22.6 ft/s | at 0.0824 s on left side of interior |
| Lateral | 30.5 ft/s | |
| **Occupant Ridedown Accelerations** | | |
| Longitudinal | 14.5 g | 0.0975 - 0.1075 s |
| Lateral | 9.2 g | 0.0940 - 0.1040 s |
| **Theoretical Head Impact Velocity (THIV)** | 41.0 km/h<br>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 |

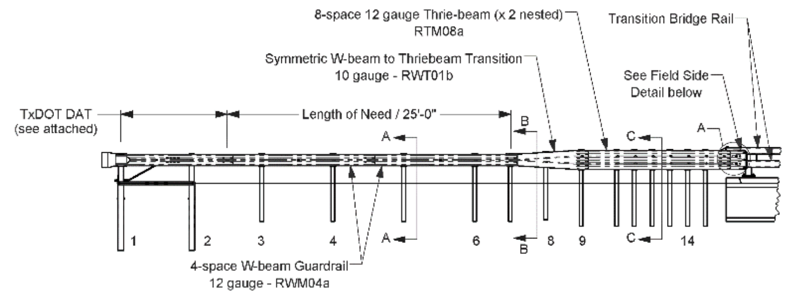
0.000 s

0.100 s

0.300 s

0.500 s




**General Information**

| | |
|---|---|
| Test Agency | Texas A&M Transportation Institute (TTI) |
| Test Standard Test No. | MASH Test 3-20 |
| TTI Test No. | 608331-01-4 |
| Test Date | 2019-09-02 |

**Test Article**

| | |
|---|---|
| Type | Transition |
| Name | 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition |
| Installation Length | 207 ft 3½ inches (incl 154 ft of deck) |
| 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 |

| | |
|---|---|
| **Soil Type and Condition** | AASHTO M147 Grading B Soil (crushed limestone), Damp |

**Test Vehicle**

| | |
|---|---|
| Type/Designation | 1100C |
| Make and Model | 2007 Kia Rio |
| Curb | 2470 lb |
| Test Inertial | 2446 lb |
| Dummy | 165 lb |
| Gross Static | 2611 lb |

**Impact Conditions**

| | |
|---|---|
| Speed | 60.9 mi/h |
| Angle | 26.5° |
| Location/Orientation | 6.06 ft upstream of end of curb/deck |

| | |
|---|---|
| **Impact Severity** | 61 kip-ft |

**Exit Conditions**

| | |
|---|---|
| Speed | 39.5 mi/h |
| Trajectory/Heading Angle | 7.1° / 14.0° |

**Occupant Risk Values**

| | |
|---|---|
| Longitudinal OIV | 22.6 ft/s |
| Lateral OIV | 30.5 ft/s |
| Longitudinal Ridedown | 14.5 g |
| Lateral Ridedown | 9.2 g |
| THIV | 41.0 km/h |
| ASI | 2.17 |
| Max. 0.050-s Average | |
| Longitudinal | -12.0 g |
| Lateral | 16.8 g |
| Vertical | -3.6 g |

**Post-Impact Trajectory**

| | |
|---|---|
| Stopping Distance | 145 ft downstream 137 ft twd traffic |

**Vehicle Stability**

| | |
|---|---|
| Maximum Yaw Angle | 63° |
| Maximum Pitch Angle | 3° |
| Maximum Roll Angle | 12° |
| Vehicle Snagging | No |
| Vehicle Pocketing | No |

**Test Article Deflections**

| | |
|---|---|
| Dynamic | 3.5 inches |
| Permanent | 1.25 inches |
| Working Width | 26.1 inches |
| Height of Working Width | 34.75 inches |

**Vehicle Damage**

| | |
|---|---|
| VDS | 11LFQ6 |
| CDC | 11FLEW5 |
| Max. Exterior Deformation | 14.0 inches |
| OCDI | FL0010000 |
| 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 ±110 lb impacting the CIP of the transition at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±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 ±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

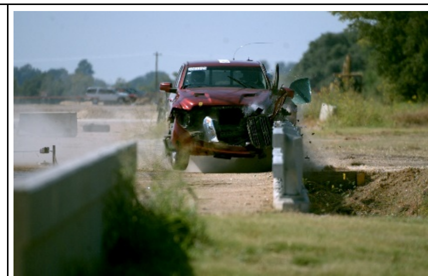
Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.2. Figure E.3 in Appendix E3 shows the vehicle angular displacements, and Figures E.4 through E.6 in Appendix E4 show acceleration versus time traces. Figure 6.6 summarizes pertinent information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

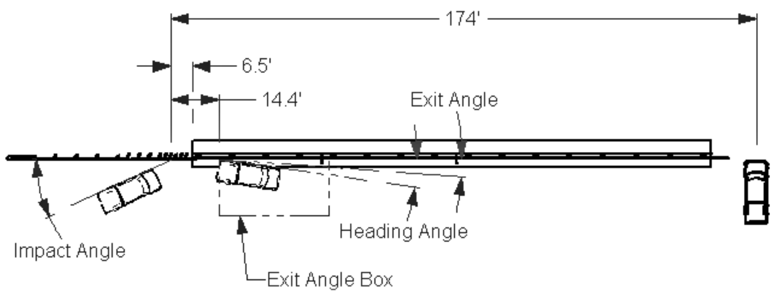
0.000 s

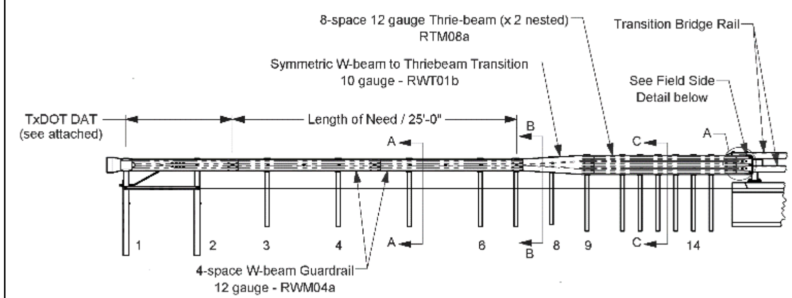
0.100 s



0.200 s

0.400 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 Beam Transition |
| Installation Length | 207 ft 3½ inches (incl 154 ft of deck) |
| 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 |
| **Soil Type and Condition** | AASHTO M147 Grading B Soil (crushed limestone), Damp |

**Test Vehicle**

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

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

**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 ±110 lb impacting the CIP of the transition at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±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 ±1 ft upstream of the centerline of post 7. Figure 7.1 depicts the target CIP.


**Figure 7.1. Transition/Test Vehicle Geometrics 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.

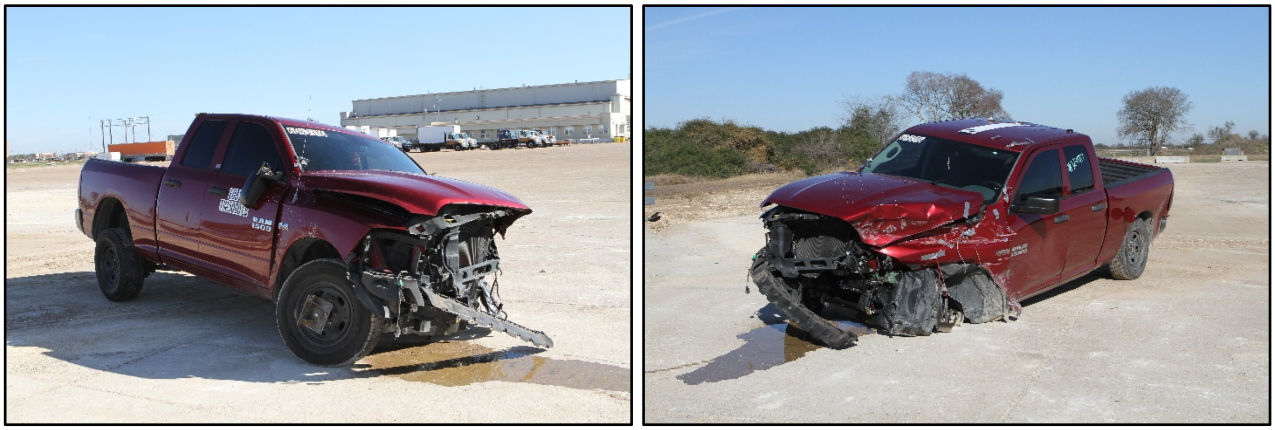


**Figure 7.6. Test Vehicle after Test No. 608331-01-6.**

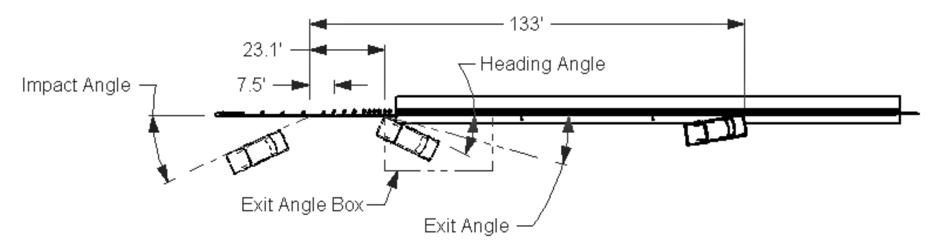
**Figure 7.7. Interior of Test Vehicle after Test No. 608331-01-6.**

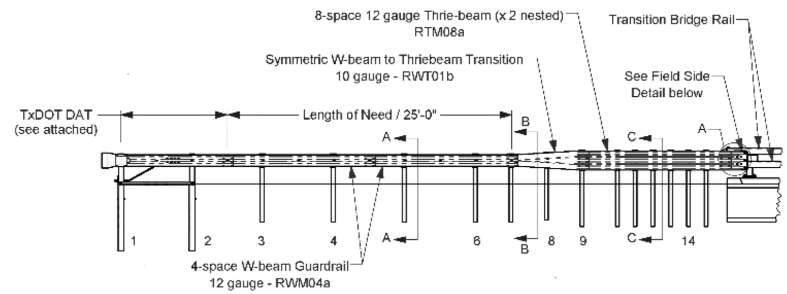
## 7.7 OCCUPANT RISK FACTORS

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**
Test Agency: Texas A&M Transportation Institute (TTI)
Test Standard Test No.: MASH Test 3-21
TTI Test No.: 608331-01-6
Test Date: 2019-12-19

**Test Article**
Type: Transition
Name: 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition
Installation Length: 207 ft 3½ inches (incl 154 ft of deck)
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

**Soil Type and Condition**: AASHTO M147 Grading B Soil (crushed limestone), Damp

**Test Vehicle**
Type/Designation: 2270P
Make and Model: 2013 RAM 1500 Pickup
Curb: 4890 lb
Test Inertial: 5038 lb
Dummy: No dummy
Gross Static: 5038 lb

**Impact Conditions**
Speed: 62.6 mi/h
Angle: 24.9°
Location/Orientation: 7.5 ft upstream of post 7

**Impact Severity**: 117 kip-ft

**Exit Conditions**
Speed: 31.8 mi/h
Trajectory/Heading Angle: 23.3° / 24.7°

**Occupant Risk Values**
Longitudinal OIV: 24.9 ft/s
Lateral OIV: 16.4 ft/s
Longitudinal Ridedown: 10.7 g
Lateral Ridedown: 9.8 g
THIV: 8.6 m/s
ASI: 1.02
Max. 0.050-s Average
Longitudinal: -9.1 g
Lateral: 7.7 g
Vertical: -4.6 g

**Post-Impact Trajectory**
Stopping Distance: 133 ft downstream 2 ft twd traffic

**Vehicle Stability**
Maximum Yaw Angle: 53°
Maximum Pitch Angle: 14°
Maximum Roll Angle: 15°
Vehicle Snagging: No
Vehicle Pocketing: No

**Test Article Deflections**
Dynamic: 33.6 inches
Permanent: 28.0 inches
Working Width: 44.7 inches
Height of Working Width: 61.8 inches

**Vehicle Damage**
VDS: 11LFQ5
CDC: 11FLEW4
Max. Exterior Deformation: 20.0 inches
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** | | |
| *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.* | 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** | | |
| *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.* | 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 |
| *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.* | Maximum occupant compartment deformation was 3.5 inches in the left kick panel area. | |
| *F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.* | The 1100C vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 12° and 3°, respectively. | Pass |
| *H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.* | Longitudinal OIV was 22.6 ft/s, and lateral OIV was 30.5 ft/s. | Pass |
| *I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.* | 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** | | |
| *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.* | 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** | | |
| *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.* | 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 |
| *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.* | Maximum occupant compartment deformation was 4.0 inches in the left front kick panel. | |
| *F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.* | The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 8° and 11°, respectively. | Pass |
| *H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.* | Longitudinal OIV was 20.3 ft/s, and lateral OIV was 23.6 ft/s. | Pass |
| *I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.* | 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** |
|---|---|---|
| **<u>Structural Adequacy</u>** | | |
| *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.* | 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 33.6 inches. | Pass |
| **<u>Occupant Risk</u>** | | |
| *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.* | 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 |
| *Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.* | No occupant compartment deformation or intrusion was observed. | |
| *F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.* | The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 15° and 14°, respectively. | Pass |
| *H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.* | Longitudinal OIV was 24.9 ft/s, and lateral OIV was 16.4 ft/s. | Pass |
| *I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.* | 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 |
| ***MASH* Test No.** | | ***MASH* Test 3-20** | ***MASH* Test 3-21 at Transition to Bridge Rail** | ***MASH* 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.

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

9. W. F. Williams, W. L. Menges, and Bill L. Griffith. *MASH TL-4 Evaluation of 2019 MASH 2-Tube Bridge Rail*. Test Report No. 608331-01-1A-2-3. Texas A&M Transportation Institute, College Station, TX, April 2019.

10. AASHTO. *Manual for Assessing Roadside Safety Hardware, Second Edition.* 2016, American Association of State Highway and Transportation Officials: Washington, D.C.

11. AASHTO/FHWA Joint Implementation Agreement for Manual for Assessing Safety Hardware (MASH). 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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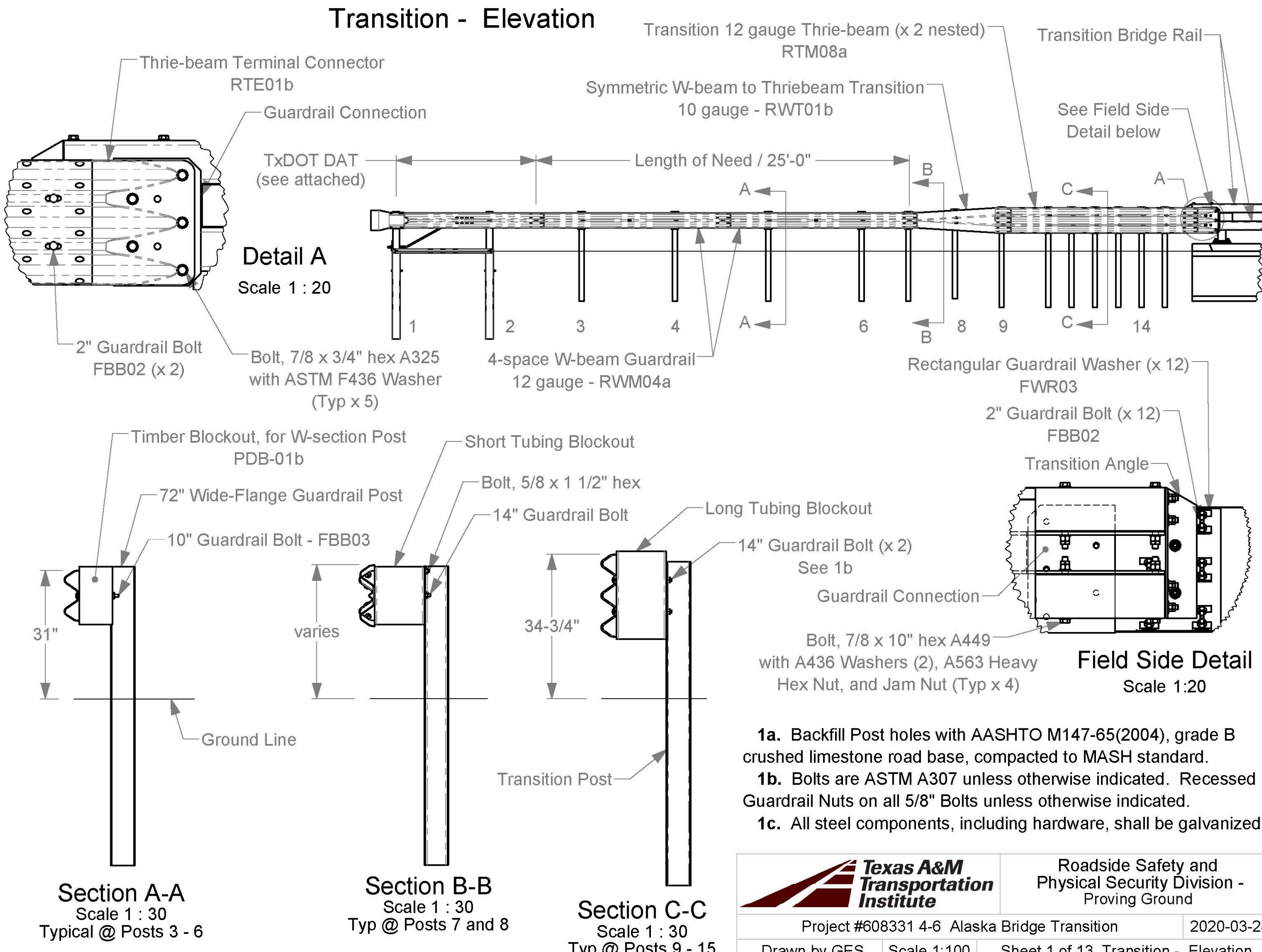
# APPENDIX A. DETAILS OF THE 2019 MASH 2-TUBE BRIDGE RAIL




**1a.** Backfill Post holes with AASHTO M147-65(2004), grade B crushed limestone road base, compacted to MASH standard.

**1b.** Bolts are ASTM A307 unless otherwise indicated. Recessed Guardrail Nuts on all 5/8" Bolts unless otherwise indicated.

**1c.** All steel components, including hardware, shall be galvanized.

| | | | |
|---|---|---|---|
| Texas A&M Transportation Institute | | Roadside Safety and Physical Security Division - Proving Ground | |
| Project #608331 4-6 Alaska Bridge Transition | | | 2020-03-24 |
| Drawn by GES | Scale 1:100 | Sheet 1 of 13 Transition - Elevation | |

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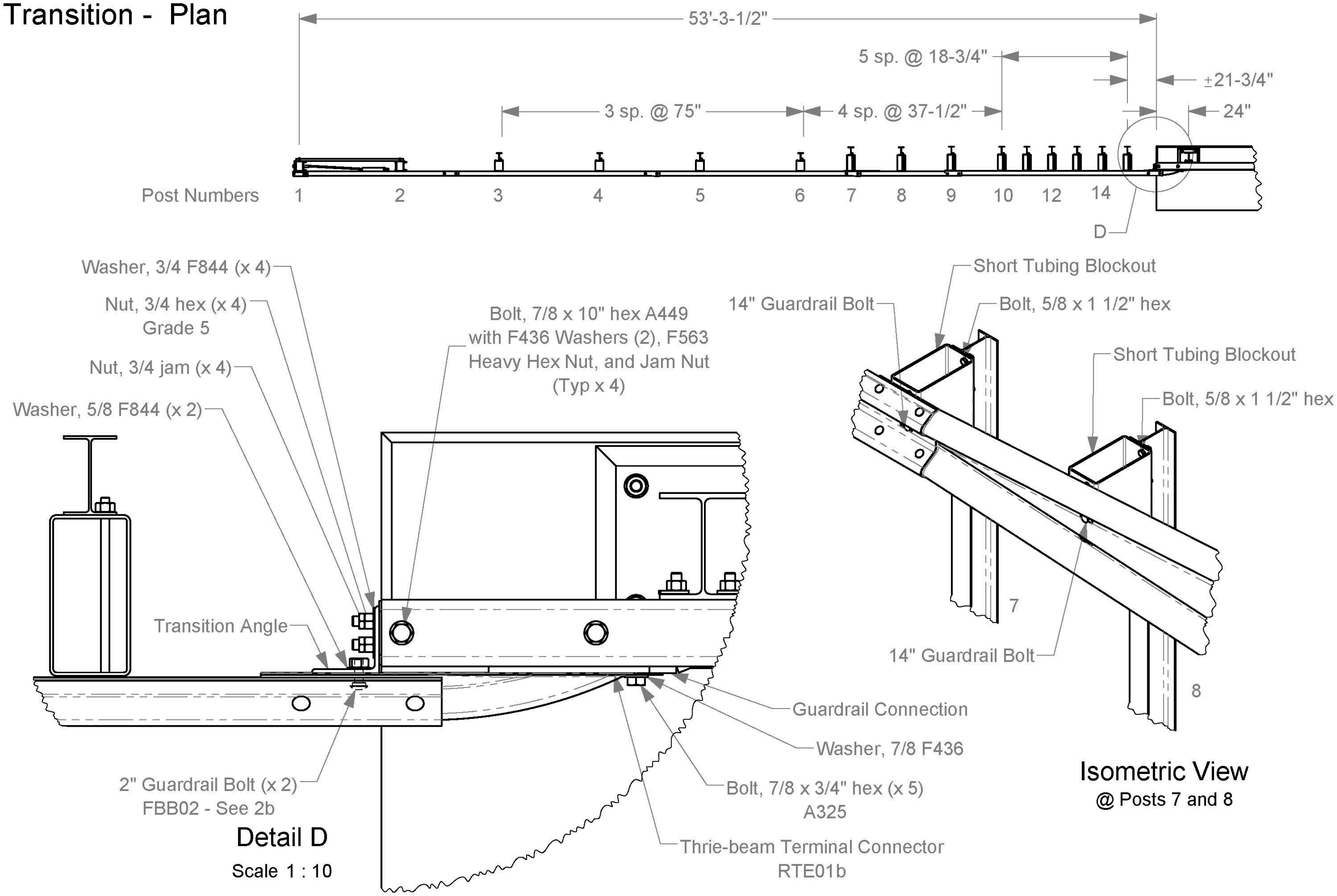
# Transition - Plan




**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.

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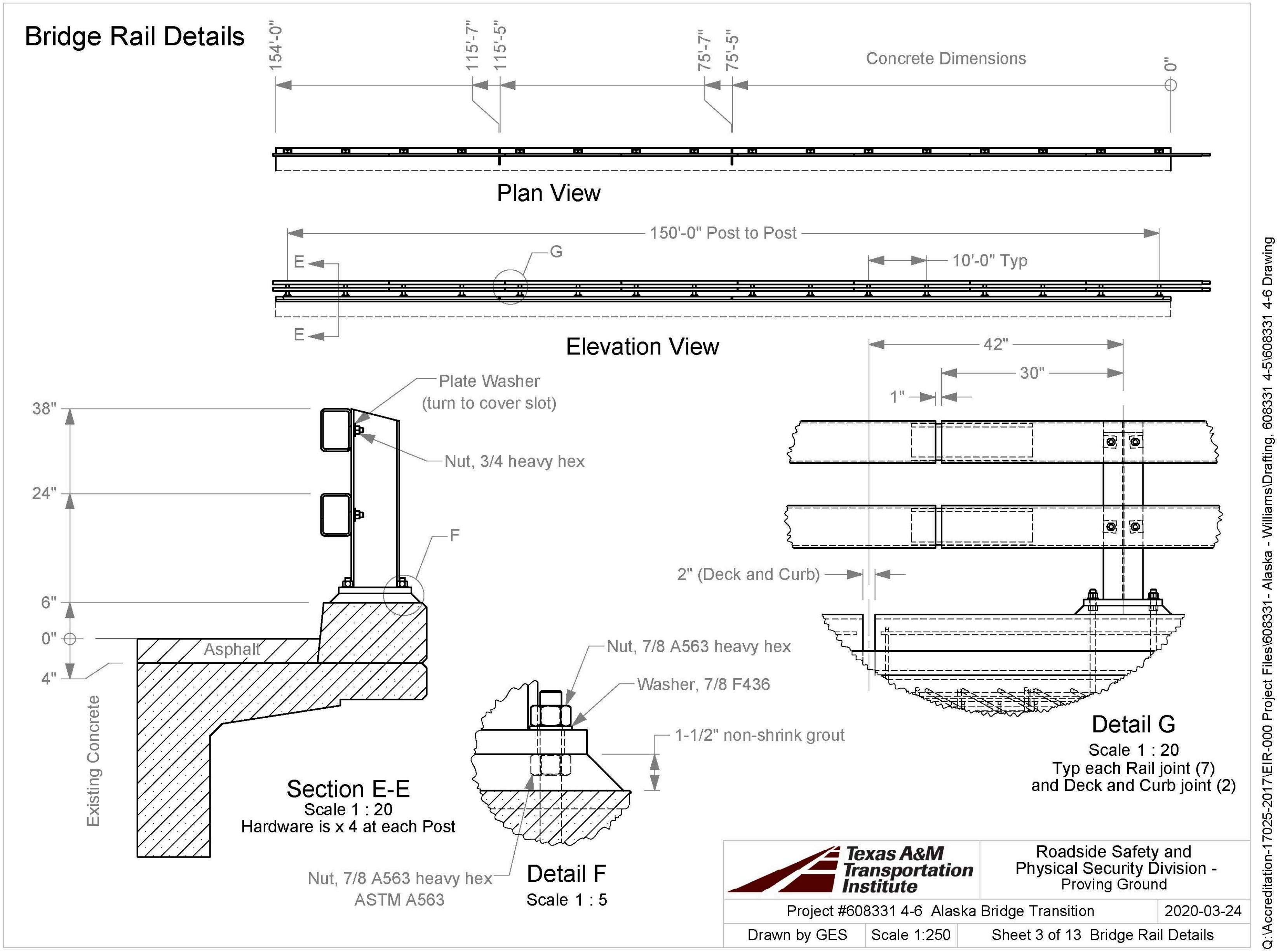
Bridge Rail Details
154'-0"
115'-7"
115'-5"
75'-7"
75'-5"
Concrete Dimensions
0"
Plan View
150'-0" Post to Post
G
E
10'-0" Typ
E
Elevation View
42"
30"
1"
Plate Washer
(turn to cover slot)
Nut, 3/4 heavy hex
38"
24"
F
6"
0"
4"
Asphalt
Existing Concrete
Section E-E
Scale 1 : 20
Hardware is x 4 at each Post
Nut, 7/8 A563 heavy hex
Washer, 7/8 F436
1-1/2" non-shrink grout
Nut, 7/8 A563 heavy hex
ASTM A563
Detail F
Scale 1 : 5
2" (Deck and Curb)
Detail G
Scale 1 : 20
Typ each Rail joint (7)
and Deck and Curb joint (2)
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Project #608331 4-6 Alaska Bridge Transition
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Scale 1:250
Sheet 3 of 13 Bridge Rail Details
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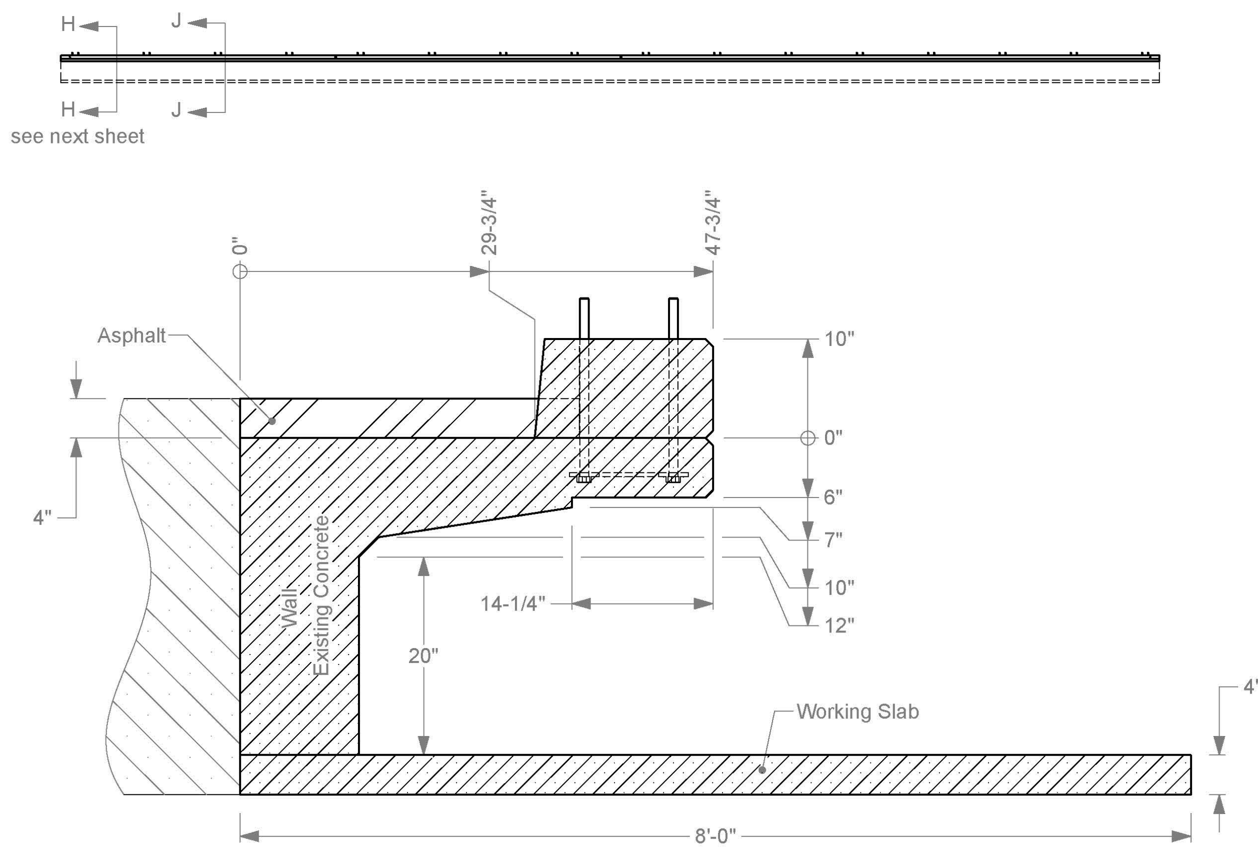
# Concrete Details, Elevation




Section J-J
Scale 1 : 15

**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.

| | | | |
|---|---|---|---|
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| Drawn by GES | Scale 1:250 | Sheet 4 of 13 Concrete Details, Elevation | |

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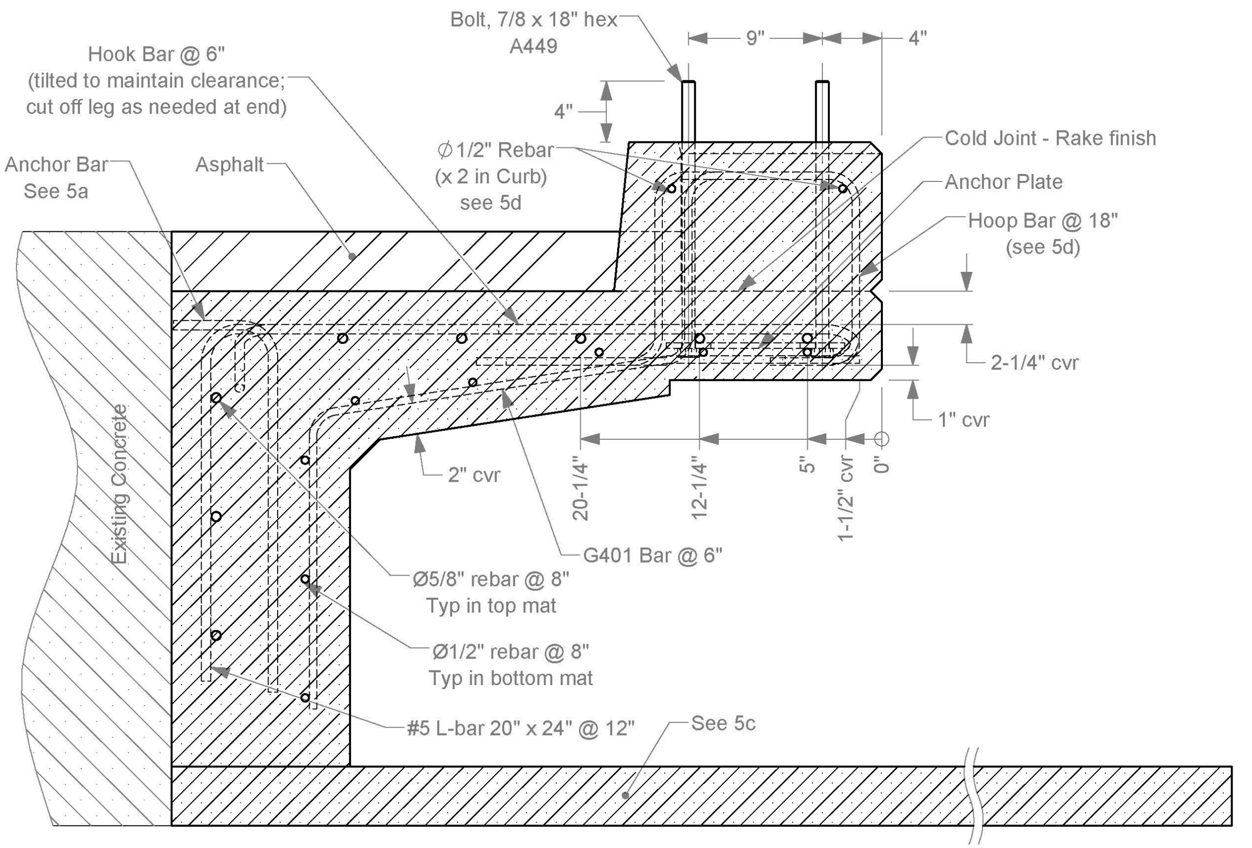


Section H-H

Scale 1 : 10

**5a.** Place the Anchor Bars @ maximum 18" spacing and secure to existing rebar protruding from the runway with minimum 3" weld. (Existing rebar not shown here.)

**5b.** Minimum rebar lap is 24" for #4 bars and 30" for #5 bars.

**5c.** Place one mat of Ø1/2 (#4) bars in Working Slab @ 12" each way with ≈1-1/2" cover at top. These bars are not shown here.

**5d.** Field bend traffic side longitudinal bar and turn Hoop Bars at ends of Curb to maintain cover.

**5e.** The Anchor Bars will be bare steel, and the bars in the Working Slab may be bare steel. All other bars shall be epoxy coated, and all bars are grade 60.

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|---|---|---|
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| Drawn by GES | Scale 1:10 | Sheet 5 of 13 Rebar Details |

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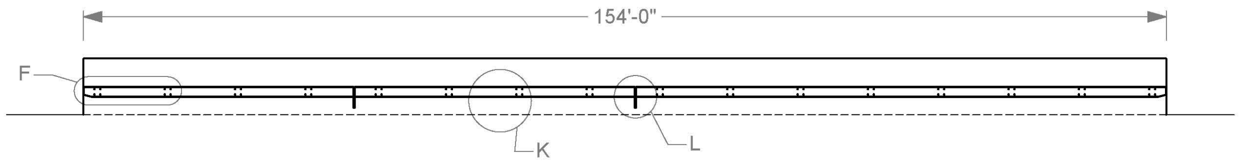
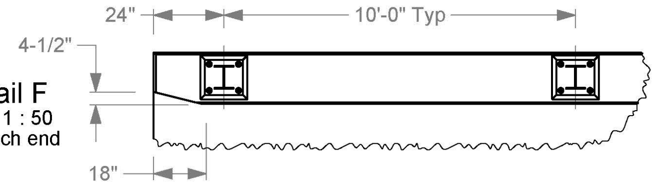
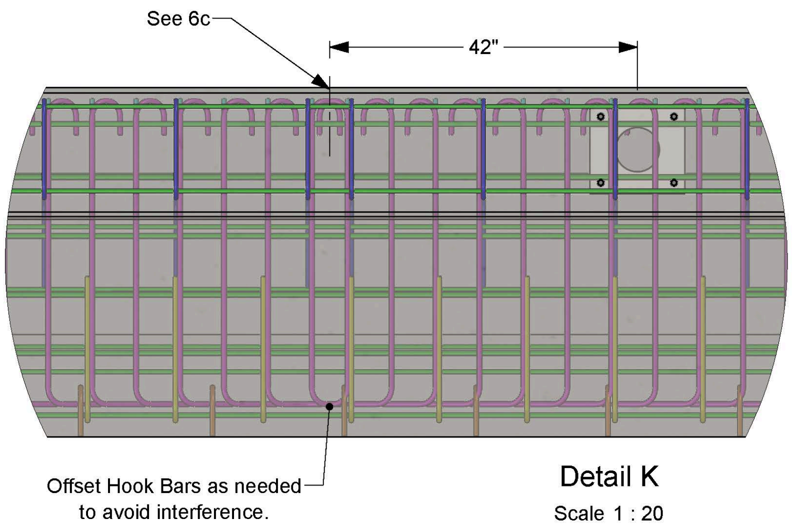
# Details, Plan

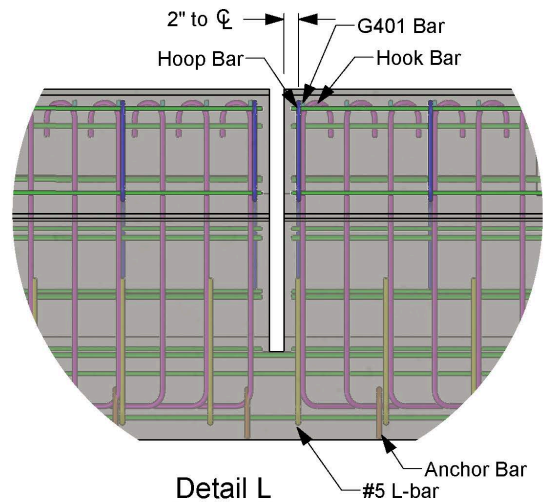



Detail F
Scale 1 : 50
Typ each end




Detail K
Scale 1 : 20




Detail L
Scale 1 : 20
Typ each Joint

**6a.** Concrete Strength is 5000psi for the Wall and Deck, 3000 psi for the Working Slab, and 4000 psi for the Curb.
**6b.** Chamfer Field Side edges of Deck, and field side and top edges at end of Curb 3/4" each way as shown.
**6c.** Rebar placement shown in Detail View at joint is typical each joint. Adjust spacing and Hook Bar direction as needed at location shown.

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

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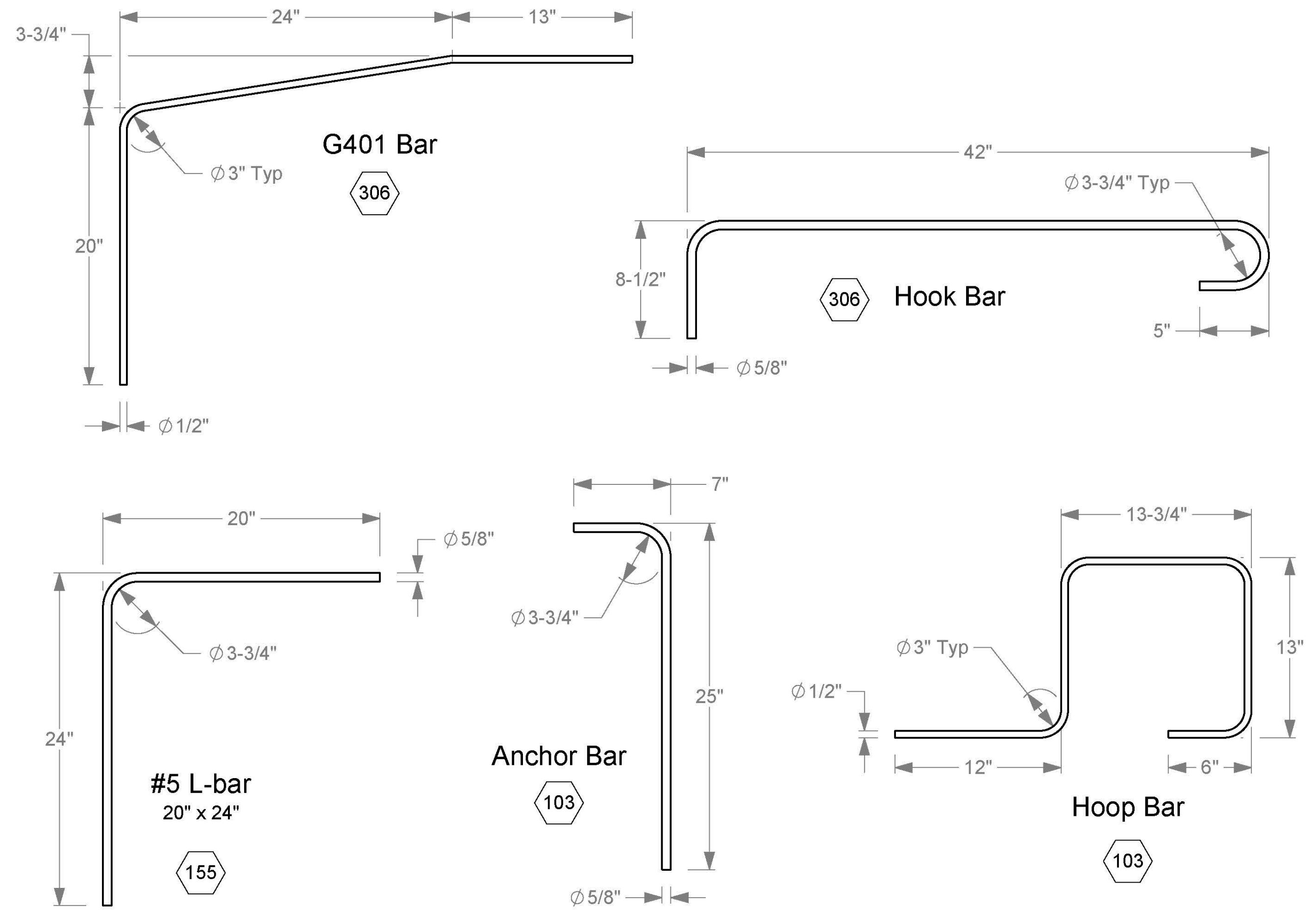
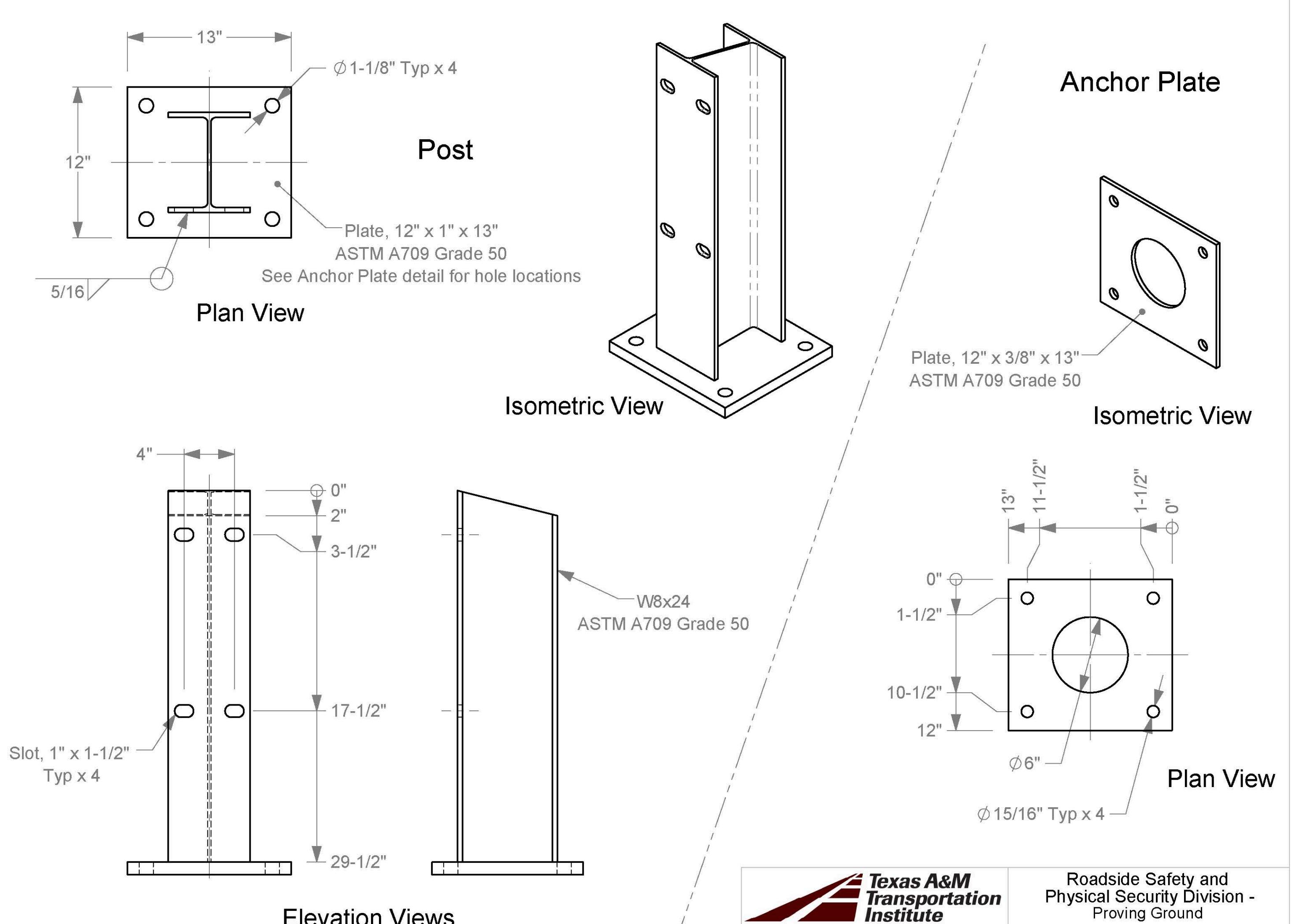



**7a.** All bent bars, and all longitudinal bars in the Curb, Deck and Wall shall be epoxy coated. All bars are grade 60..

| Texas A&M Transportation Institute | 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 7 of 13 Rebar |




| | |
|---|---|
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| Project #608331 4-6 Alaska Bridge Transition | 2020-03-24 |
| Drawn by GES | Scale 1:10 | Sheet 8 of 13 Post and Anchor Plate |

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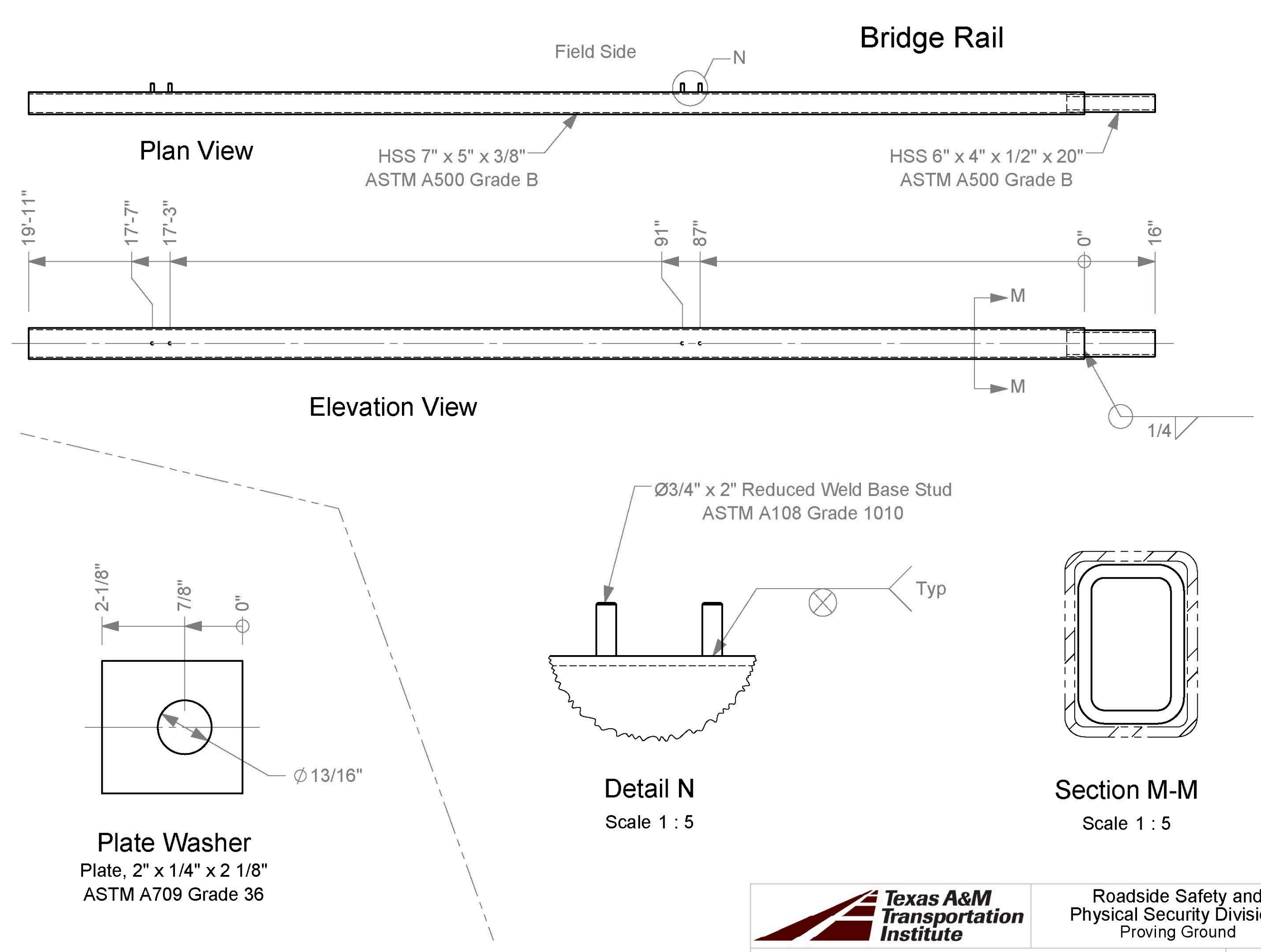
# Bridge Rail




Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project #608331 4-6 Alaska Bridge Transition | 2020-03-24

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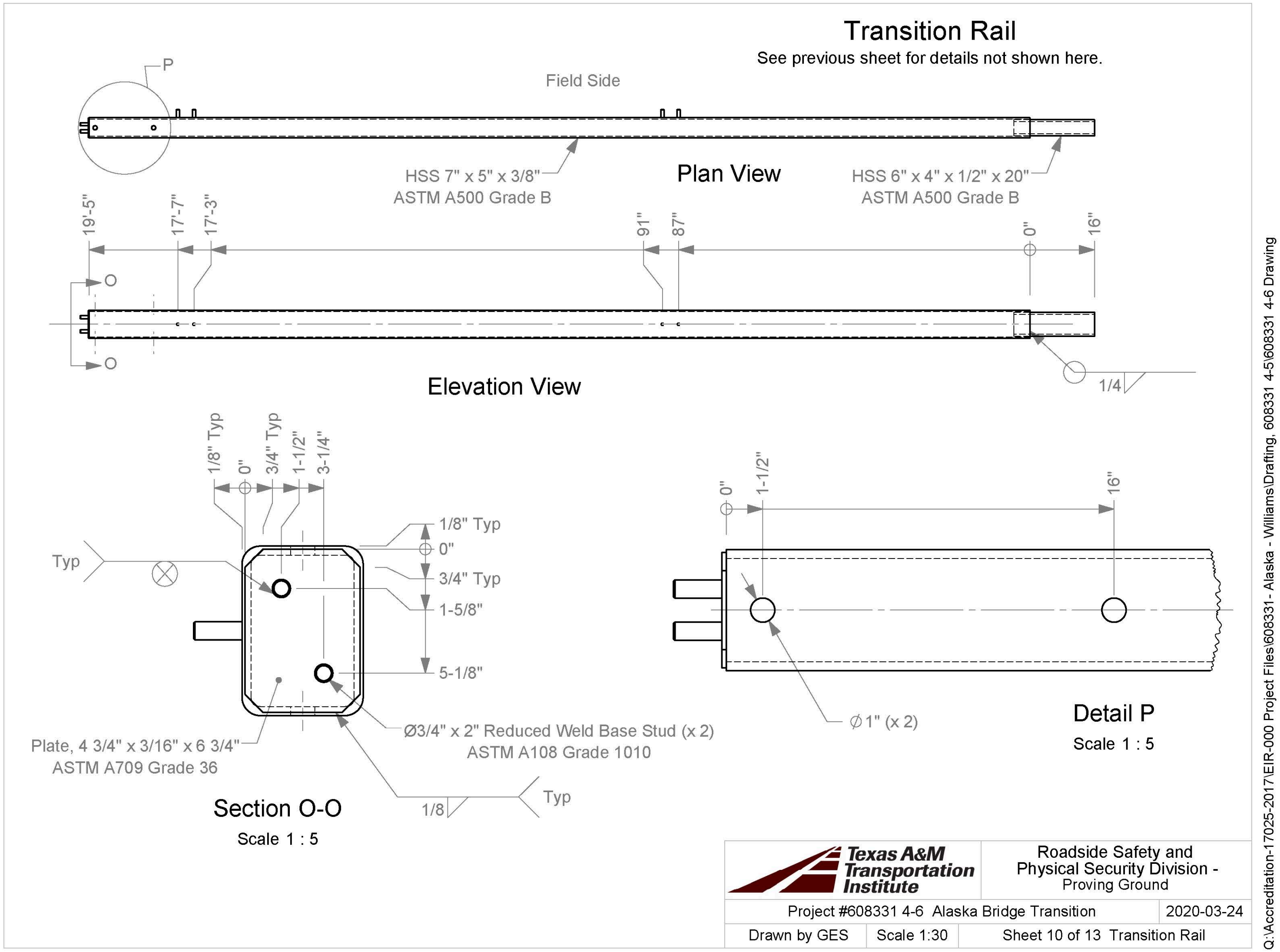
Transition Rail
See previous sheet for details not shown here.
Field Side
P
HSS 7" x 5" x 3/8"
ASTM A500 Grade B
Plan View
HSS 6" x 4" x 1/2" x 20"
ASTM A500 Grade B
19'-5"
17'-7"
17'-3"
91"
87"
0"
16"
O
O
1/4
Elevation View
1/8" Typ
0"
3/4" Typ
1-1/2"
3-1/4"
1/8" Typ
0"
3/4" Typ
1-5/8"
5-1/8"
Typ
Plate, 4 3/4" x 3/16" x 6 3/4"
ASTM A709 Grade 36
Ø3/4" x 2" Reduced Weld Base Stud (x 2)
ASTM A108 Grade 1010
1/8
Typ
Section O-O
Scale 1 : 5
0"
1-1/2"
16"
Ø1" (x 2)
Detail P
Scale 1 : 5
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #608331 4-6 Alaska Bridge Transition
2020-03-24
Drawn by GES
Scale 1:30
Sheet 10 of 13 Transition Rail
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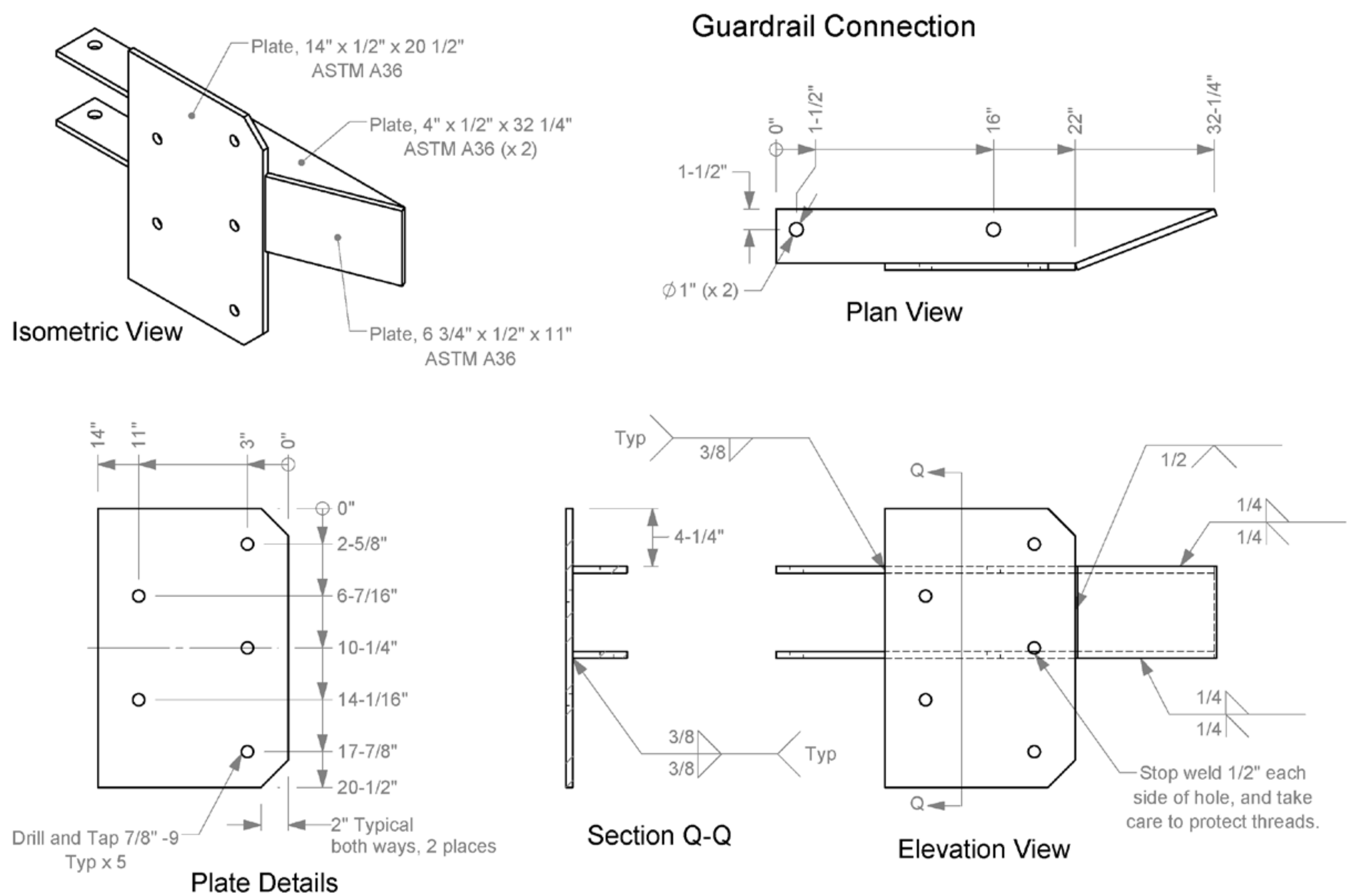


**11a.** All welding must be performed by certified welders using industry standard practices.
**11b.** Galvanize all components after fabrication is complete.

| Texas A&M Transportation Institute | | Roadside Safety and Physical Security Division - Proving Ground |
|---|---|---|
| Project #608331 4-5 Alaska Bridge Transition | | 2019-07-03 |
| Drawn by GES | Scale 1:10 | Sheet 11 of 13 Guardrail Connection |

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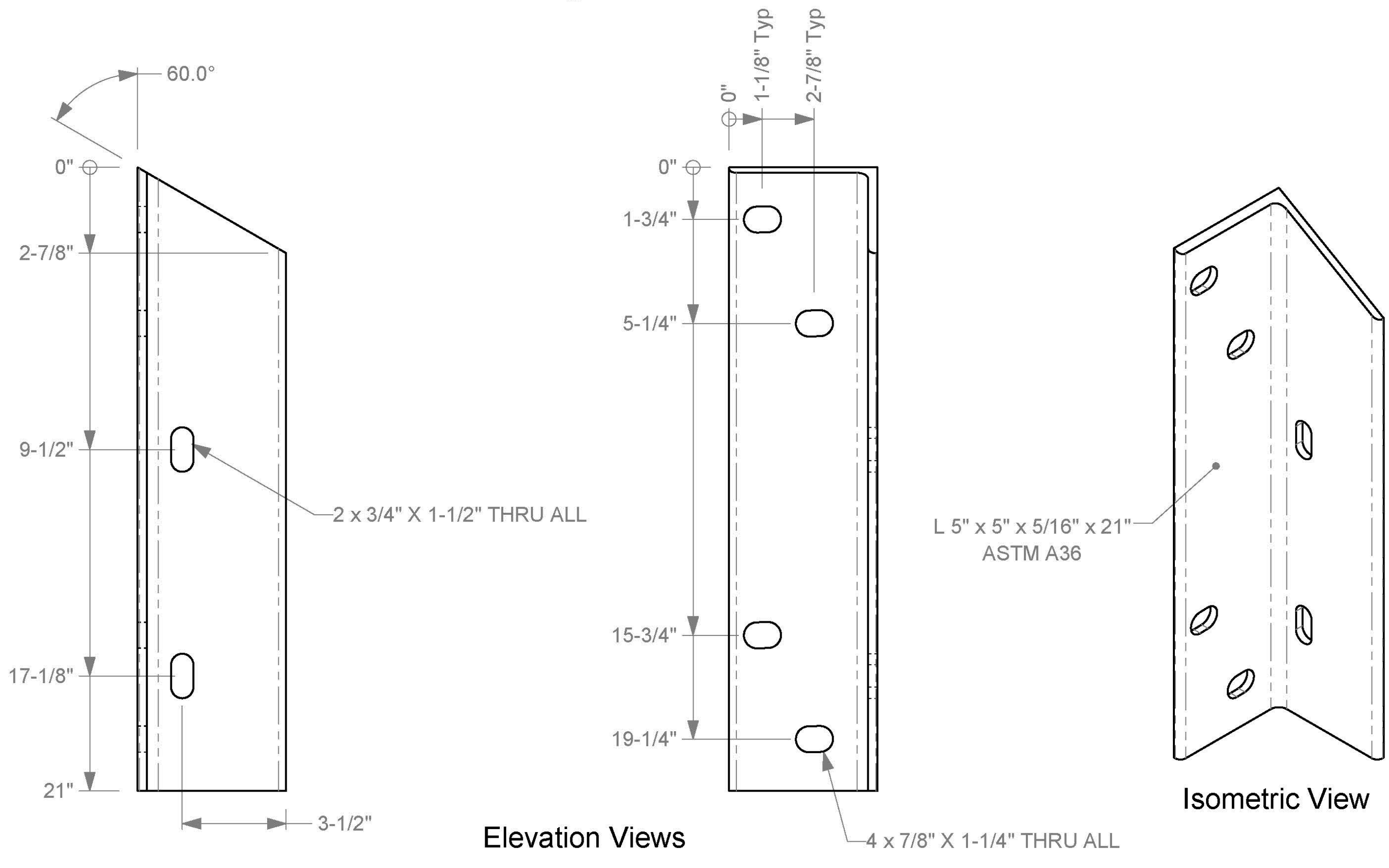
# Transition Angle




**12a.** Galvanize after fabrication is complete.

| Texas A&M Transportation Institute | 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 |

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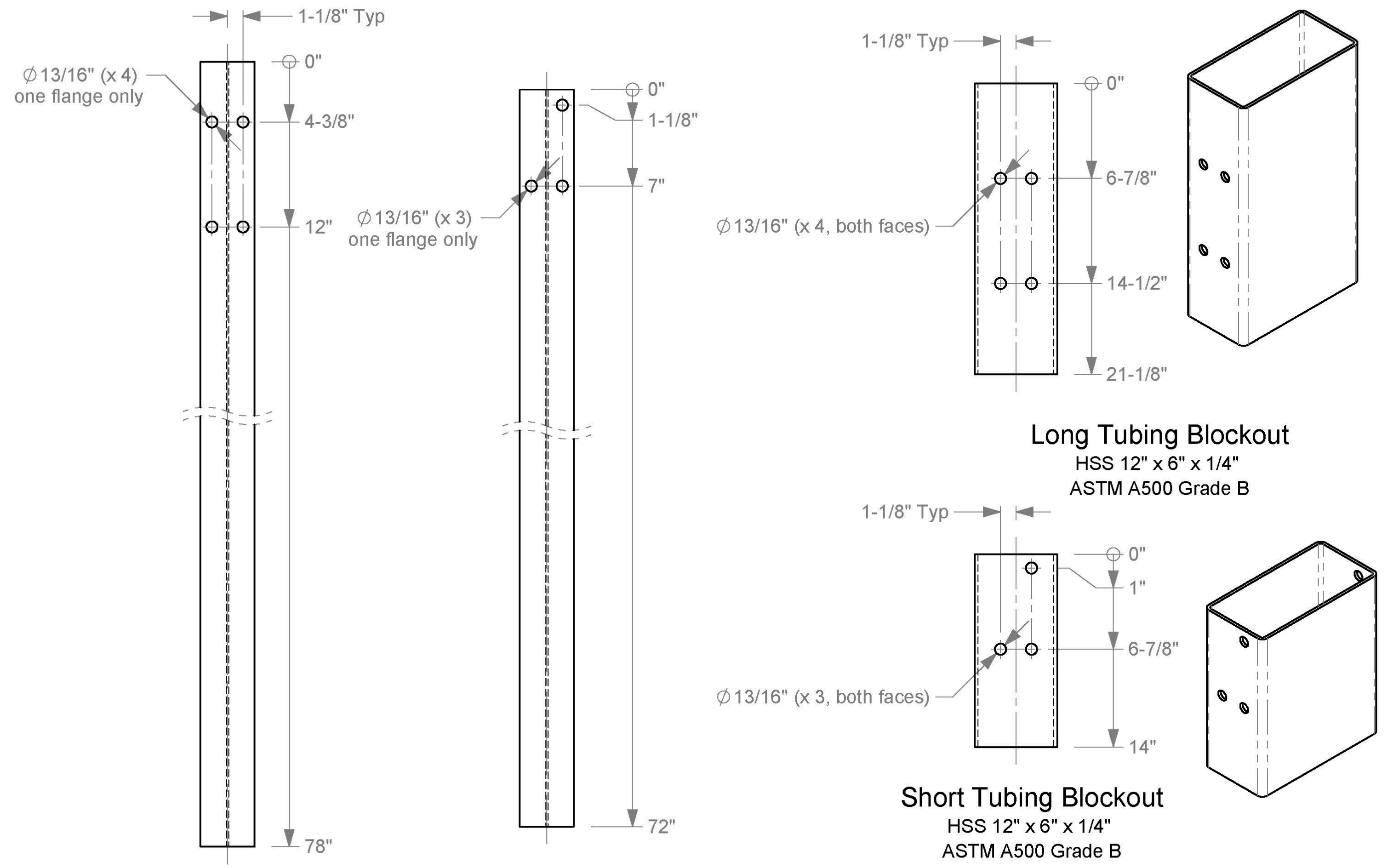
# Posts and Blockouts




Long Tubing Blockout
HSS 12" x 6" x 1/4"
ASTM A500 Grade B

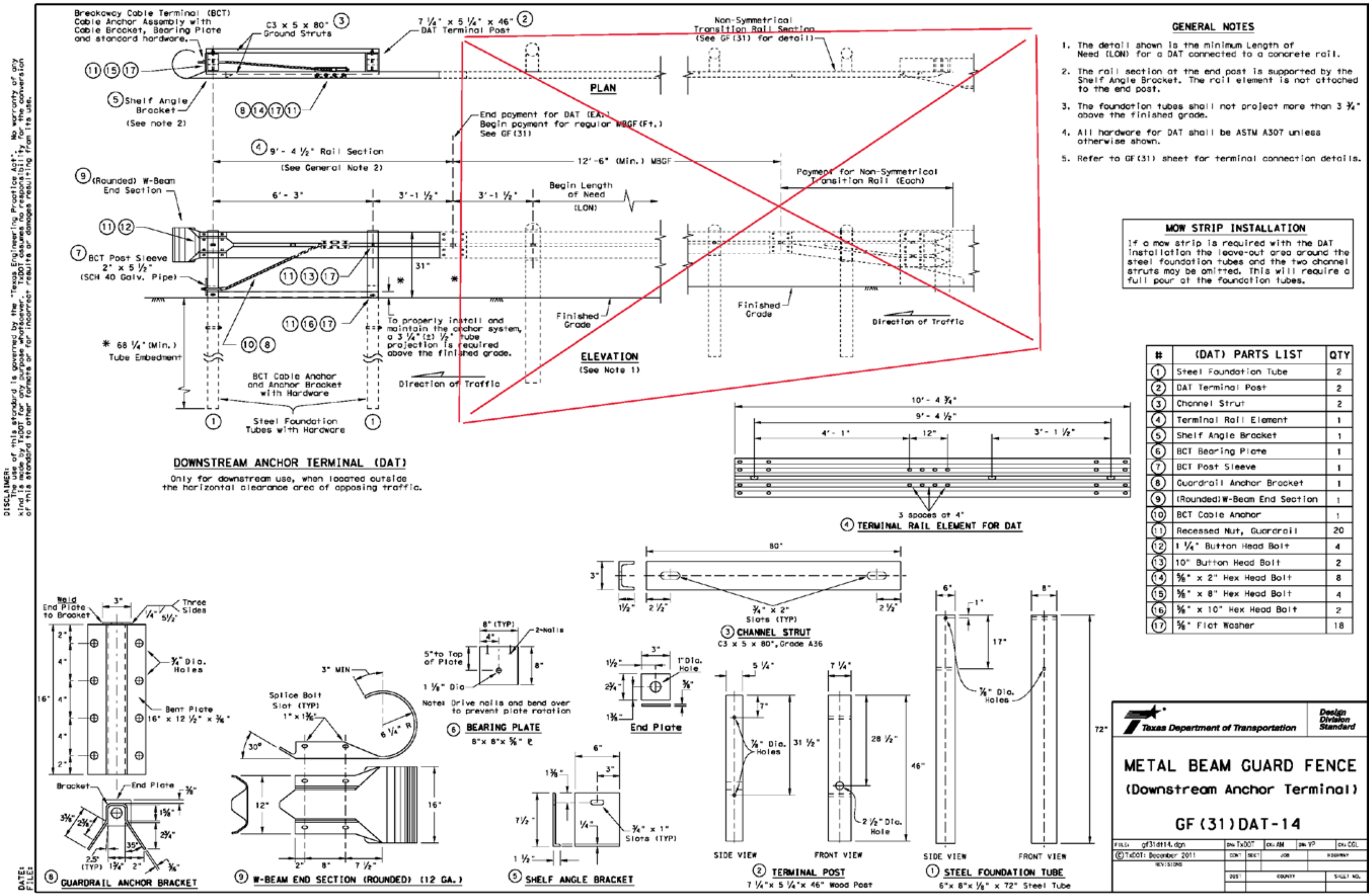
Short Tubing Blockout
HSS 12" x 6" x 1/4"
ASTM A500 Grade B

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

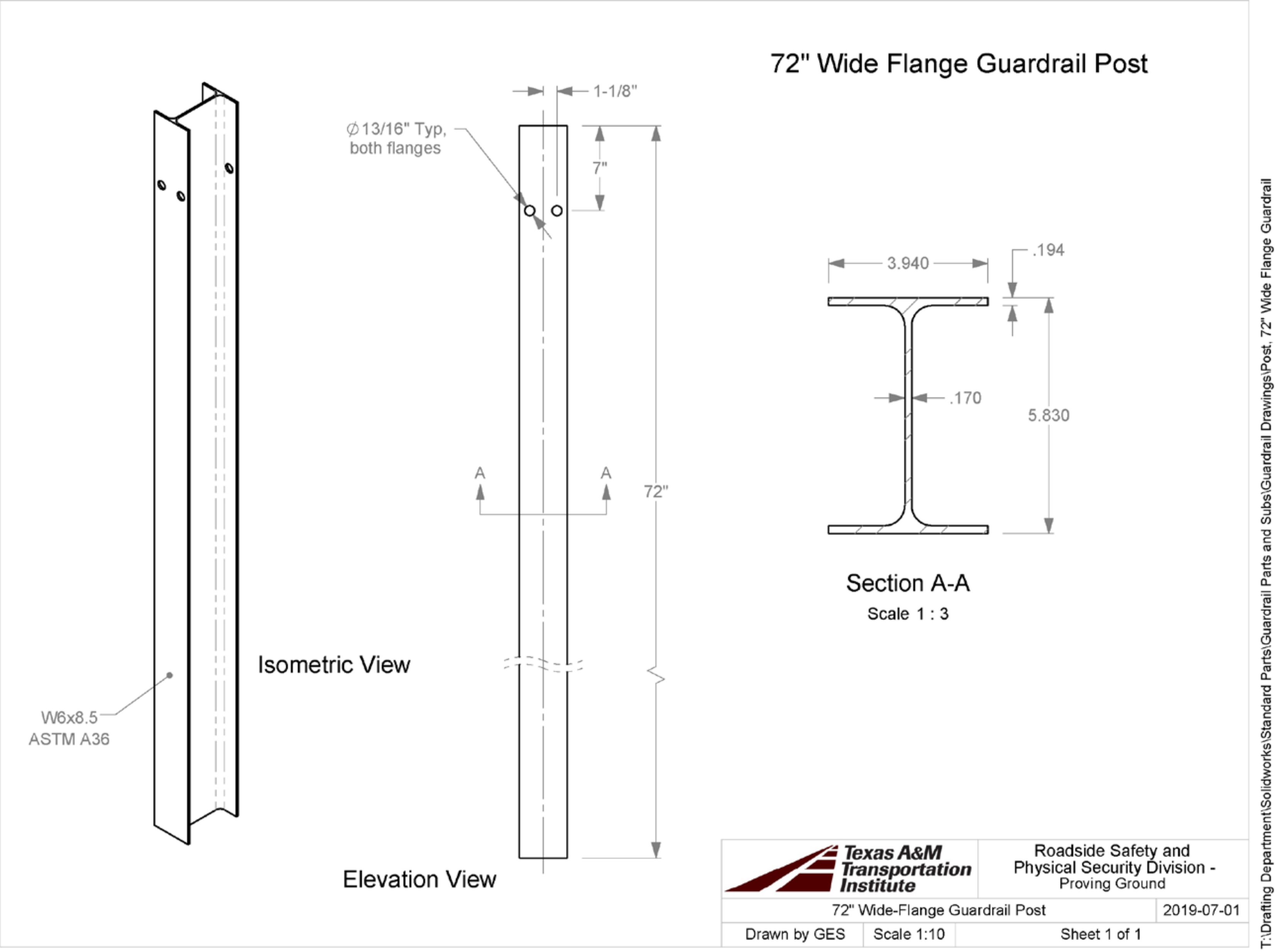
Posts 7 and 8
W6x8.5 x 72"
ASTM A992

| | | |
|---|---|---|
| Texas A&M Transportation Institute | 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 |

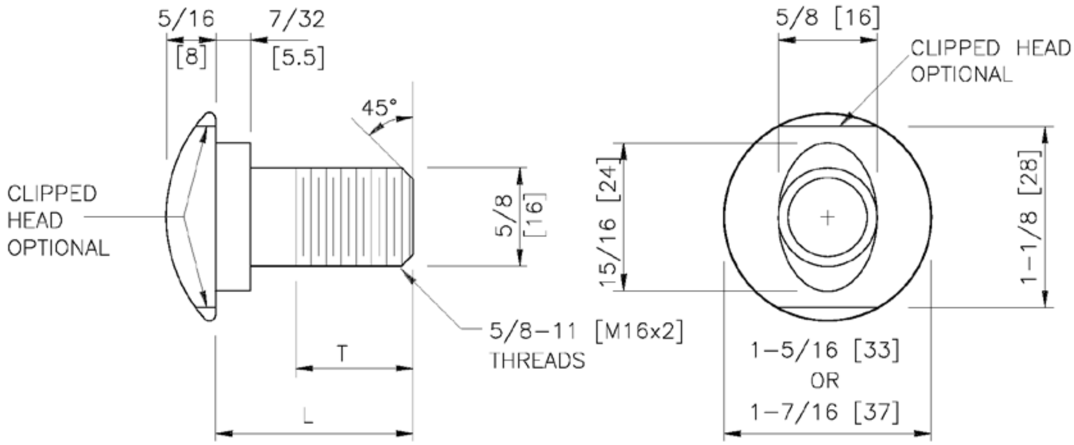
Q:\Accreditation-17025-2017\EIR-000 Project Files\608331- Alaska - Williams\Drafting, 608331 4-5\608331 4-6 Drawing



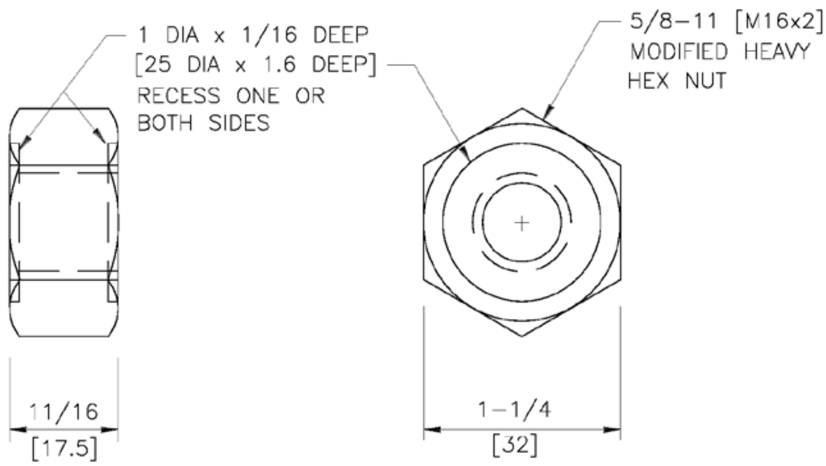
GENERAL NOTES
1. The detail shown is the minimum Length of Need (LON) for a DAT connected to a concrete rail.
2. The rail section at the end post is supported by the Shelf Angle Bracket. The rail element is not attached to the end post.
3. The foundation tubes shall not project more than 3 ¾" above the finished grade.
4. All hardware for DAT shall be ASTM A307 unless otherwise shown.
5. Refer to GF(31) sheet for terminal connection details.
MOW STRIP INSTALLATION
If a mow strip is required with the DAT installation the leave-out area around the steel foundation tubes and the two channel struts may be omitted. This will require a full pour of the foundation tubes.
(DAT) PARTS LIST
# | (DAT) PARTS LIST | QTY
1 Steel Foundation Tube 2
2 DAT Terminal Post 2
3 Channel Strut 2
4 Terminal Rail Element 1
5 Shelf Angle Bracket 1
6 BCT Bearing Plate 1
7 BCT Post Sleeve 1
8 Guardrail Anchor Bracket 1
9 (Rounded) W-Beam End Section 1
10 BCT Cable Anchor 1
11 Recessed Nut, Guardrail 20
12 1 ¼" Button Head Bolt 4
13 10" Button Head Bolt 2
14 ⅝" x 2" Hex Head Bolt 8
15 ⅝" x 8" Hex Head Bolt 4
16 ⅝" x 10" Hex Head Bolt 2
17 ⅝" Flat Washer 18
Breakaway Cable Terminal (BCT) Cable Anchor Assembly with Cable Bracket, Bearing Plate and standard hardware.
C3 x 5 x 80" Ground Struts
7 ¼" x 5 ¼" x 46" DAT Terminal Post
Non-Symmetrical Transition Rail Section (See GF(31) for detail)
PLAN
Shelf Angle Bracket (See note 2)
End payment for DAT (EA.) Begin payment for regular MBGF (Ft.) See GF(31)
9'- 4 ½" Rail Section (See General Note 2)
12'-6" (Min.) MBGF
Payment for Non-Symmetrical Transition Rail (Each)
(Rounded) W-Beam End Section
6'- 3"
3'-1 ½"
3'-1 ½"
Begin Length of Need (LON)
BCT Post Sleeve 2" x 5 ½" (SCH 40 Galv. Pipe)
31"
Finished Grade
Direction of Traffic
* 68 ¼" (Min.) Tube Embedment
To properly install and maintain the anchor system, a 3 ¼" (±) ½" tube projection is required above the finished grade.
BCT Cable Anchor and Anchor Bracket with Hardware
Steel Foundation Tubes with Hardware
ELEVATION (See Note 1)
DOWNSTREAM ANCHOR TERMINAL (DAT)
Only for downstream use, when located outside the horizontal clearance area of opposing traffic.
10'- 4 ¾"
9'- 4 ½"
4'- 1"
12"
3'- 1 ½"
3 spaces at 4"
4 TERMINAL RAIL ELEMENT FOR DAT
80"
¾" x 2" Slots (TYP)
3 CHANNEL STRUT
C3 x 5 x 80", Grade A36
Weld End Plate to Bracket
Three Sides
¾" Dia. Holes
Bent Plate 16" x 12 ½" x ⅜"
Bracket
End Plate
8 GUARDRAIL ANCHOR BRACKET
Splice Bolt Slot (TYP) 1" x 1⅜"
3" MIN.
6 ¼" R
9 W-BEAM END SECTION (ROUNDED) (12 GA.)
5" to Top of Plate
1 ⅜" Dia
Note: Drive nails and bend over to prevent plate rotation
6 BEARING PLATE
8" x 8" x ⅝" ℄
End Plate
¾" x 1" Slots (TYP)
5 SHELF ANGLE BRACKET
⅞" Dia. Holes
2 ½" Dia. Hole
SIDE VIEW
FRONT VIEW
2 TERMINAL POST
7 ¼" x 5 ¼" x 46" Wood Post
⅞" Dia. Holes
1 STEEL FOUNDATION TUBE
6" x 8" x ⅛" x 72" Steel Tube
Texas Department of Transportation
Design Division Standard
METAL BEAM GUARD FENCE
(Downstream Anchor Terminal)
GF(31)DAT-14
© TxDOT: December 2011
DISCLAIMER: The use of this standard is governed by the "Texas Engineering Practice Act". No warranty of any kind is made by TxDOT for any purpose whatsoever. TxDOT assumes no responsibility for the conversion of this standard to other formats or for incorrect results or damages resulting from its use.


72" Wide Flange Guardrail Post
1-1/8"
∅13/16" Typ, both flanges
7"
A
A
72"
3.940
.194
.170
5.830
Section A-A
Scale 1 : 3
Isometric View
W6x8.5
ASTM A36
Elevation View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
72" Wide-Flange Guardrail Post
2019-07-01
Drawn by GES
Scale 1:10
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange Guardrail

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

| | | |
|---|---|---|
| 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.

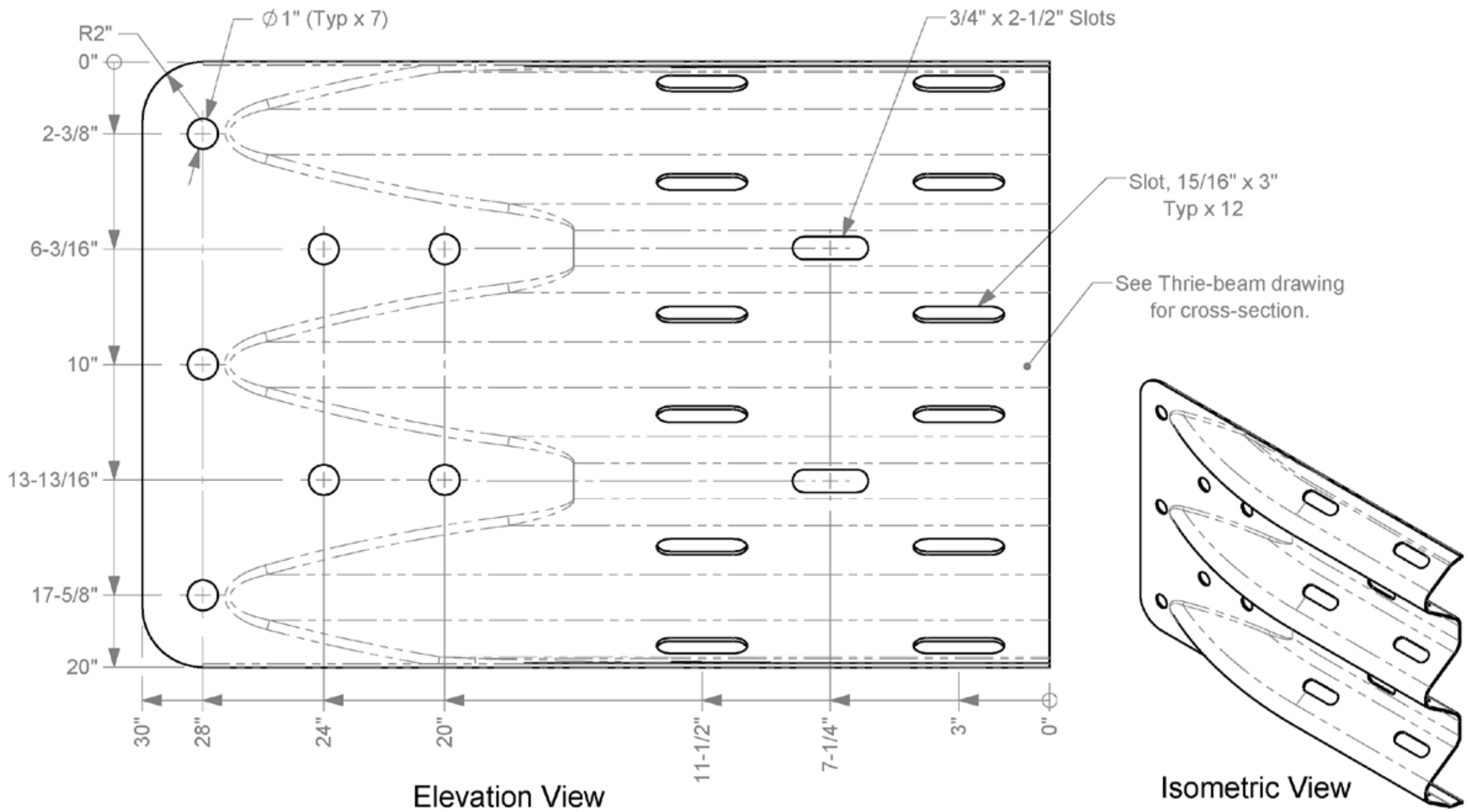
**GUARDRAIL BOLT AND RECESSED NUT**

**FBB01-05**

| SHEET NO. | DATE |
|---|---|
| 2 of 2 | 5/2/2018 |

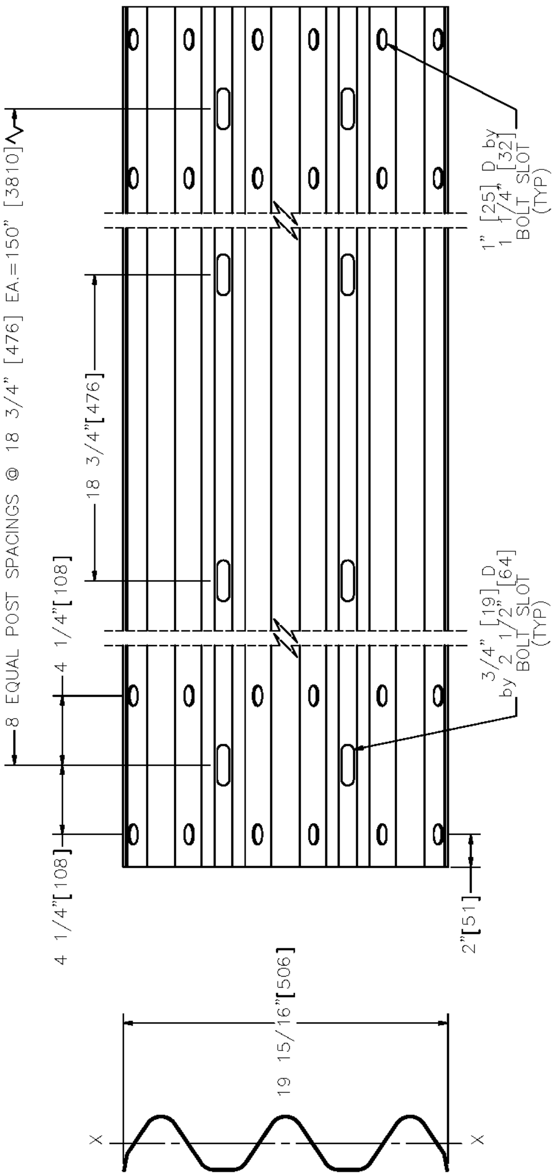
# Thrie-beam End Shoe

10 gauge (0.1345" before galvanizing)




| Texas A&M Transportation Institute | Roadside Safety and Physical Security Division - Proving Ground | |
|---|---|---|
| Thrie-beam Terminal Connector | | 2019-07-29 |
| Drawn by GES | Scale 1:5 | Sheet 1 of 1 |

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




| DESIGNATOR | BASE METAL THICKNESS | TOTAL LENGTH | POST SPACINGS |
|---|---|---|---|
| RTM08a | 12 GAUGE [2.67] | 162 1/2" [4128] | 8 |
| RTM08b | 10 GAUGE [3.43] | 162 1/2" [4128] | 8 |

THE CROSS-SECTIONAL DIMENSIONS OF THIS PART ARE THE SAME AS PART RTM01a (SHT 3 of 4)

8-SPACE THRIE-BEAM GUARDRAIL

RTM08a-b

| SHEET NO. | DATE: |
|---|---|
| 1 of 2 | 12/6/2016 |

## 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] | -- |

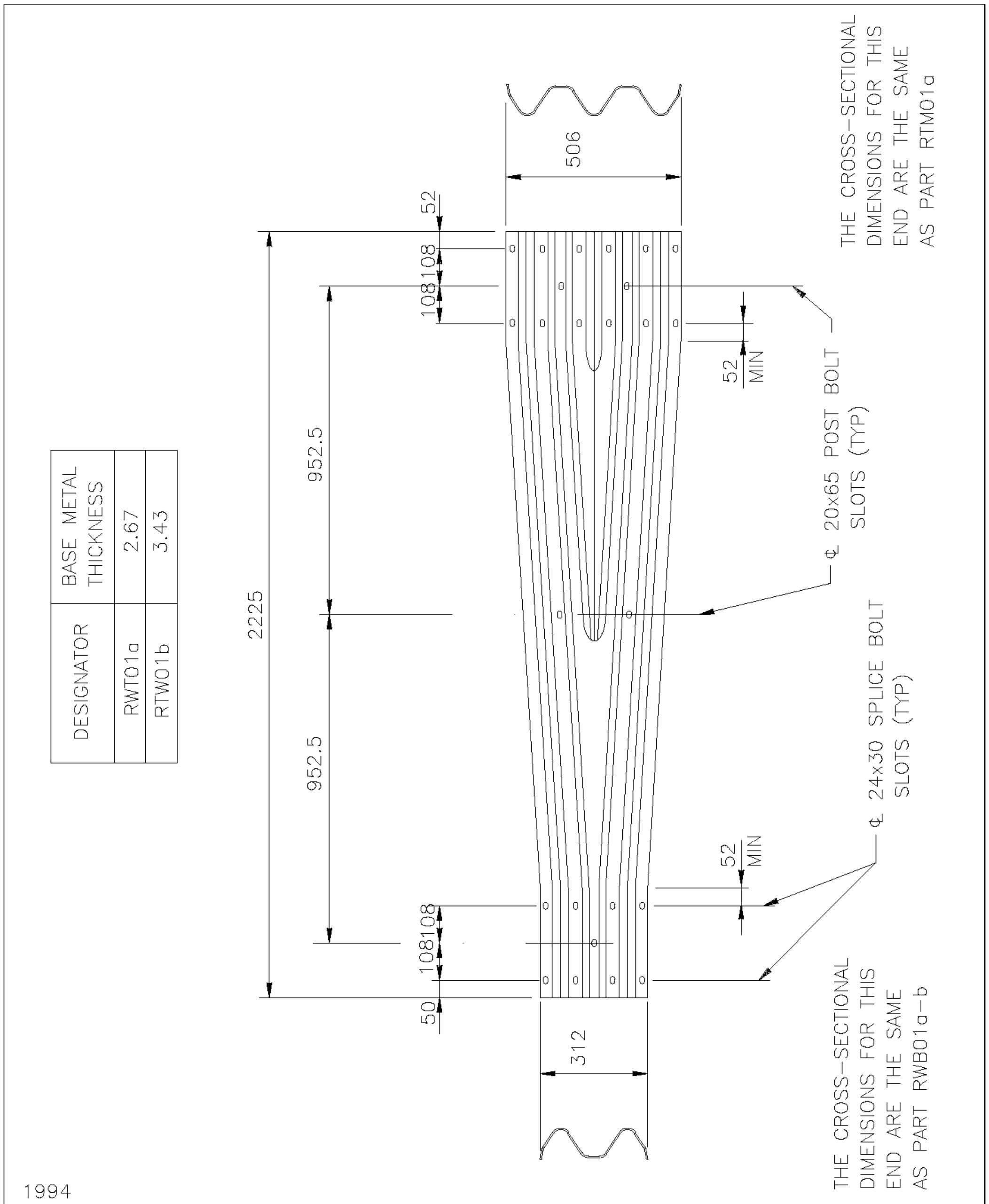
Dimensional tolerances not shown or implied are intended to be those consistent with the proper functioning of the part, including its appearance and accepted manufacturing practices.

## INTENDED USE

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

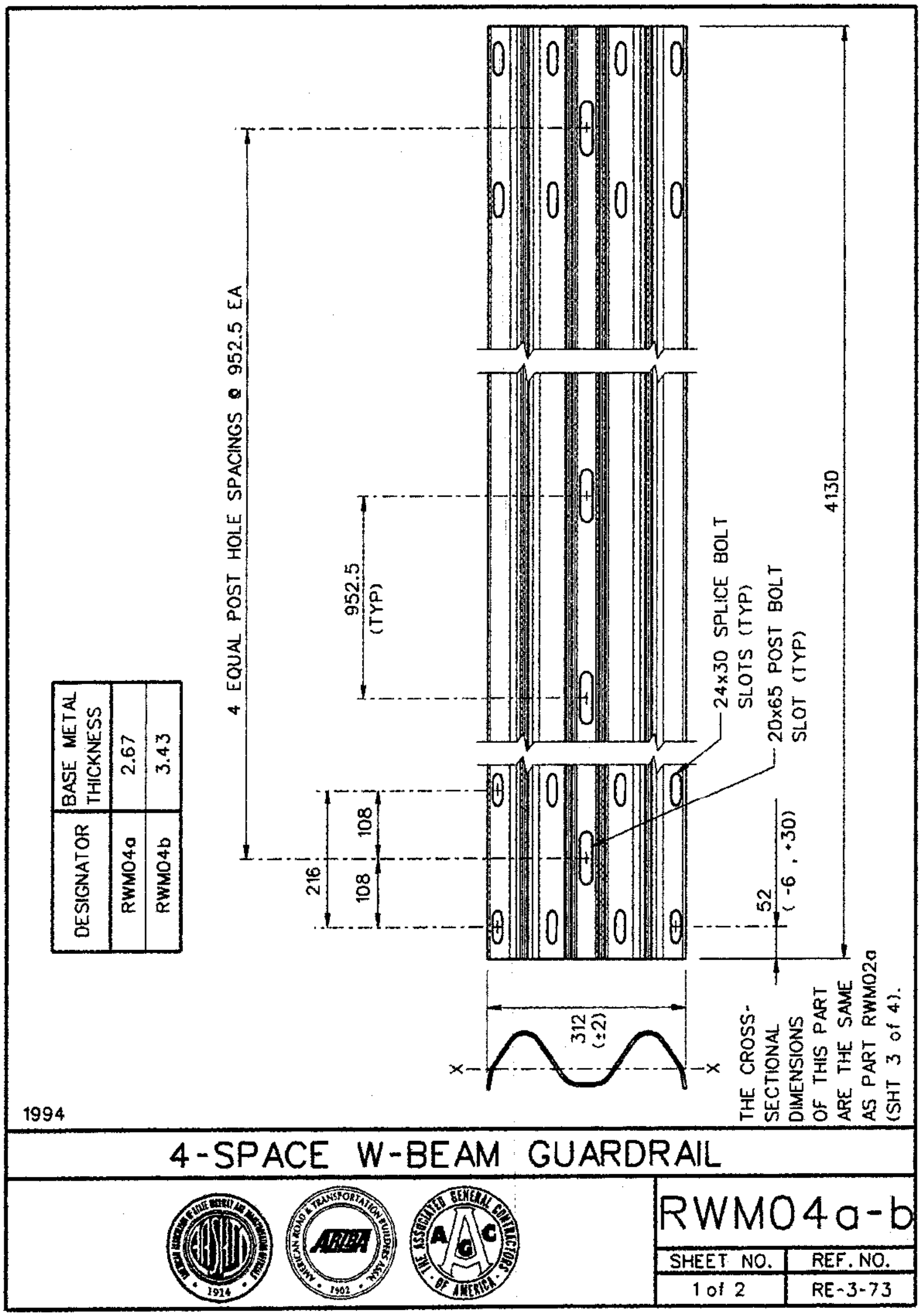
8-SPACE THRIE-BEAM GUARDRAIL

| RTM08a-b | |
|---|---|
| SHEET NO. | DATE: |
| 2 of 2 | 12/6/2016 |




# W–THRIE BEAM TRANSITION SECTION

| | |
|---|---|
| RWT01a–b | |
| SHEET NO. | REF. NO. |
| 1 of 2 | RE-69-76 |


4 EQUAL POST HOLE SPACINGS @ 952.5 EA
952.5 (TYP)
4130
24x30 SPLICE BOLT SLOTS (TYP)
20x65 POST BOLT SLOT (TYP)
216
108
108
52 ( -6 , +30)
312 (±2)
X
X
THE CROSS-SECTIONAL DIMENSIONS OF THIS PART ARE THE SAME AS PART RWM02a (SHT 3 of 4).
DESIGNATOR | BASE METAL THICKNESS
RWM04a | 2.67
RWM04b | 3.43
1994
4-SPACE W-BEAM GUARDRAIL
RWM04a-b
SHEET NO. 1 of 2
REF. NO. RE-3-73

**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.

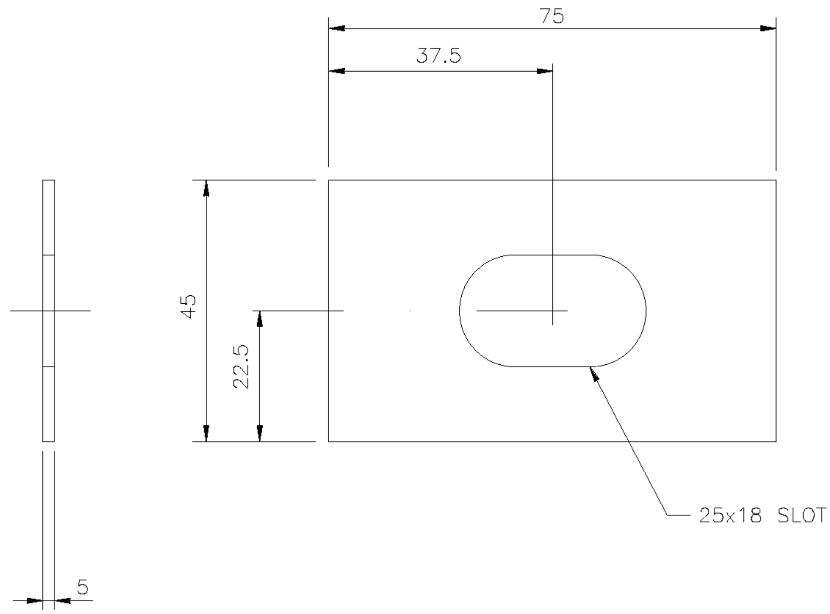
**INTENDED USE**

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

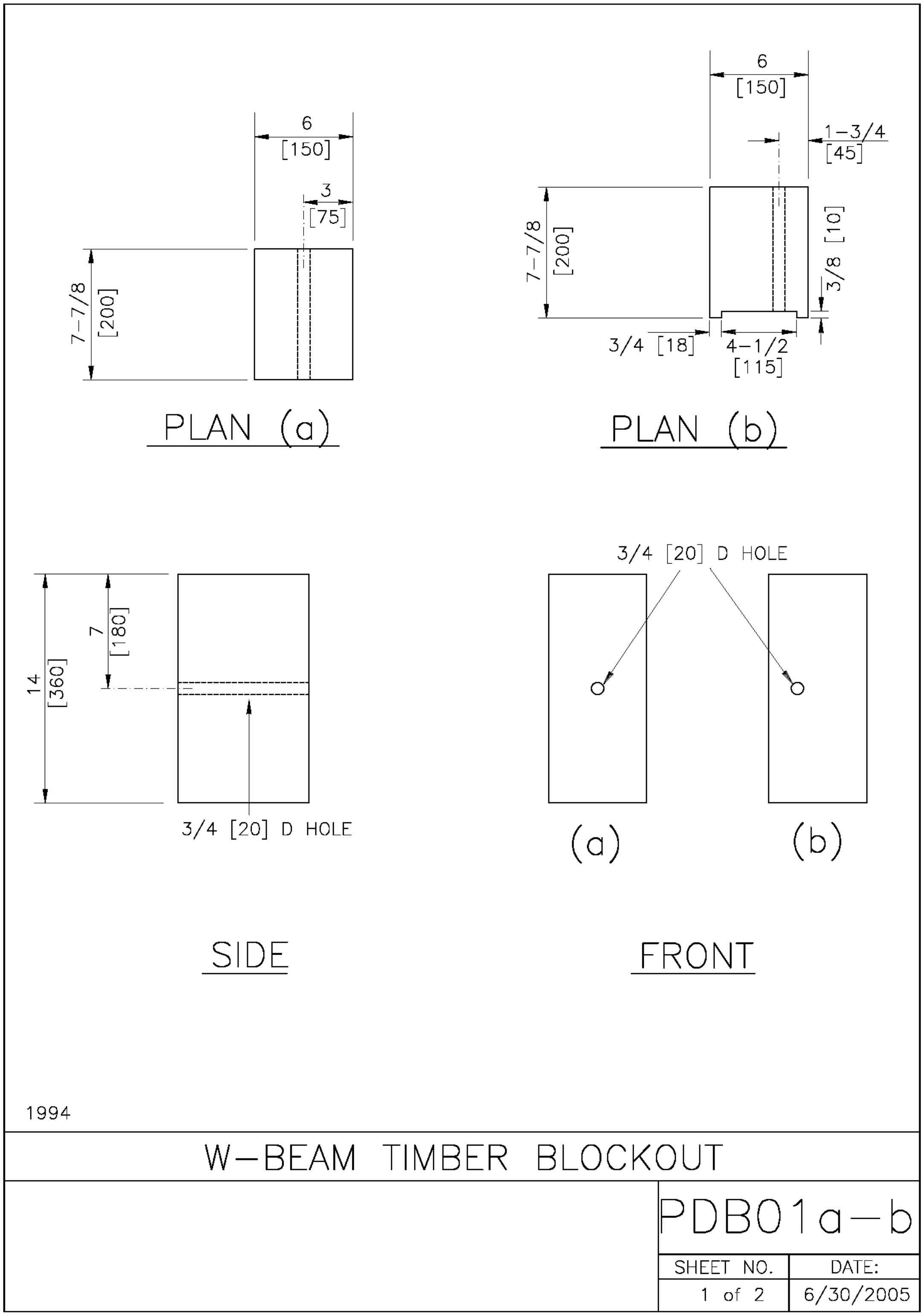
| SHEET NO. | DATE |
|---|---|
| 2 of 2 | 04-01-95 |




1994

RECTANGULAR GUARDRAIL PLATE WASHER

| | | |
|---|---|---|
| | FWR03 | |
| | SHEET NO. | REF. NO. |
| | 1 of 2 | F-12-73 |


6
[150]
3
[75]
7-7/8
[200]
PLAN (a)
6
[150]
1-3/4
[45]
7-7/8
[200]
[10]
3/8
3/4 [18]
4-1/2
[115]
PLAN (b)
14
[360]
7
[180]
3/4 [20] D HOLE
SIDE
3/4 [20] D HOLE
(a)
(b)
FRONT
1994
W-BEAM TIMBER BLOCKOUT
PDB01a-b
SHEET NO.
1 of 2
DATE:
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 ± ¼ 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

## CERTIFICATE OF ANALYSIS

Beshert STEEL PROCESSING

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

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

Issued from
BESHERT STEEL PROCESSING
JOINT VENTURE OF
STEEL WAREHOUSE CO &
TRIPLE-S STEEL HOLDINGS INC.
15355 JACINTO PORT BOULEVARD
HOUSTON, TX 77015

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

**Reference**

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

**Product Information**

| | Heat | Tag | Pcs | LBS |
|---|---|---|---|---|
| TEMPERED LEVELED PLATE A36/SA36<br>0.5000" x 48" x 96" | J75904 | 23666C | 15 | 9,805 |
| | | 23666D | 15 | 9,805 |
| | | 23666E | 15 | 9,805 |
| | | 23666F | 10 | 6,536 |
| | | | 55 | 35,951 |

Part PL36TML1248
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

TR No. 608331-4-6

68

2020-03-26

PLATE A36 TEMPER LEVELED
1/2 X 48.0000" X 96.0000"
Our Order 19485-1-1 Your Order HOU-

# 검 사 증 명 서
## MILL TEST CERTIFICATE

HYUNDAI STEEL
당진제철소 : 충남 당진시 송악읍 북부산업로 1480
1480 Bukbusanup-Ro, Songak-Eup, Dangjin-Si, Chungnam, Korea

주문번호 Order No. : E190200039

품 명 Commodity : Hot Rolled Coil

제품규격 Specification : ASTM A 36

고객사 Customer : Beshert Steel

주문자 Contractor : SKC

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

발행일자 Date of Issue : 2019-03-24

| 제품치수 Dimension (inch) | 수량 Quantity | 중량 Weight (Kg) | 제강번호 Heat No. | 제품번호 Product No. | Position | 인장시험 Tensile Test YP (N/mm²) | TS (N/mm²) | EL (%) | YP-EL (%) | RA (%) | YR (%) | YP Mtd | 화학성분 Chemical Composition(%) 단위 Unit 2:x100 3:x1,000 4:x10,000 5:x100,000 Division | C | Si | Mn | P | S | Cr | Ni | Cu | Mo | Nb | Ti | V | Sol-Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5063"NOM x 48" x C | 1 | 21,460 | J75902 | HCS0563 | B | 360.9 | 448.9 | 41 | | | | | | 4 | 3 | 3 | 4 | 4 | 2 | 2 | 3 | 2 | 3 | 3 | 3 | 3 |
| 0.5063"NOM x 48" x C | 1 | 21,640 | J75902 | HCS0564 | B | 360.9 | 449.9 | 41 | | | | 2 | L | 446 | 28 | 920 | 120 | 24 | 2 | 3 | 70 | 1 | 12 | 1 | 2 | 25 |
| 0.5063"NOM x 48" x C | 1 | 21,450 | J75902 | HCS0565 | B | 344.8 | 446.0 | 42 | | | | 2 | L | 446 | 26 | 920 | 120 | 24 | 2 | 3 | 70 | 1 | 12 | 1 | 2 | 25 |
| 0.5063"NOM x 48" x C | 1 | 21,480 | J75904 | HCS0573 | B | 344.1 | 444.2 | 42 | | | | 2 | L | 446 | 26 | 920 | 120 | 24 | 2 | 3 | 70 | 1 | 12 | 1 | 2 | 25 |
| 0.5063"NOM x 48" x C | 1 | 21,680 | J75904 | HCS0574 | B | 344.1 | 444.2 | 42 | | | | 2 | L | 466 | 22 | 800 | 130 | 31 | 2 | 4 | 70 | 1 | 13 | 1 | 1 | 16 |
| *** Sub Total(016) *** | 5 | 107,710(Kg) | | | | | | | | | | 2 | L | 466 | 22 | 800 | 130 | 31 | 2 | 4 | 70 | 1 | 13 | 1 | 1 | 16 |

PO/REL HOU-35377/
HEAT: J75904

NOTE
- Position – T:Top, M:Middle, B:Bottom
- Tensile test - Direction:Tranverse, Gauge length:50mm (Rectangular), YP Mtd : 2 (0.2% off-set),5 (0.5% underload), U (Upper yield point), L (Lower yield point)
- Division – P:Product analysis, L:Ladle analysis

상기의 제품은 검사의 결과 지정된 규격에 합격한 것을 증명합니다.
WE HEREBY CERTIFY THAT THE MATERIAL HAS BEEN MADE AND TESTED IN ACCORDANCE WITH THE ABOVE SPECIFICATION AND THE REQUIREMENTS

Signature S. B. Park
Chief Of Quality Assurance Team

BL HOU-775673-8 6/21/2019
Order HOU-251290-9 Page:2

- 본 검사증명서는 원본인 전자문서(전자서명 정보 포함)로부터 출력된 사본입니다 전자문서의 내용은 현대제철 고객포털에서 확인하실 수 있습니다.(http://sm.hyundai-steel.com/cs/cm/login.jsp)
- This Mill Test Certificate is a copy that has been printed from original electronic document(with digital signing). You are able to check an original electronic document at hyundaisteel's customer portal( http://sm.hyundai-steel.com/cs/cm/login.jsp) ＊ QRcode scanner App : 'QReal'
- [사용상 주의사항] 본 검사증명서에 명기된 규격 외 사용시 제품손상 및 안전상 문제가 발생할 수 있습니다.
- [Caution for Use] Damage on products and safety problems may arise if used other than to the spec stated in this Mill Test Certification.

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: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.ntpportal.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
**Test Date:** 1/3/2019

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

| Total Pieces | Total Weight |
|---|---|
| 18 | 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

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Birmingham, AL 35234
800-543-9024
Fax: 205-251-1553

https://www.nucortubular.com
https://www.ntpportal.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

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BL HOU-775673-10 6/21/2019
Order HOU-251290-11 Page:1

GERDAU

# CERTIFIED MATERIAL TEST REPORT

Page 1/1

-ML-JACKSON TN
I GERDAU AMERISTEEL ROAD
CKSON, TN 38305
A

| CUSTOMER SHIP TO | CUSTOMER BILL TO | GRADE | SHAPE / SIZE | DOCUMENT ID: |
|---|---|---|---|---|
| TRIPLE S STEEL SUPPLY<br>6000 JENSEN DR<br>HOUSTON,TX 77026-1113<br>USA | TRIPLE S STEEL<br>6000 JENSEN DR<br>HOUSTON,TX 77226-1119<br>USA | GGMULTI | Flat Bar / 1/2 X 4 | 0000222766 |

| LENGTH | WEIGHT | HEAT / BATCH |
|---|---|---|
| 20'00" | 39,168 LB | 63191654/02 |

| SALES ORDER | CUSTOMER MATERIAL N° |
|---|---|
| 7834148/000050 | |

| USTOMER PURCHASE ORDER NUMBER | BILL OF LADING | DATE |
|---|---|---|
| )U-185454 | 1333-0000129880 | 06/08/2019 |

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

HEMICAL COMPOSITION

| C % | Mn % | P % | S % | Si % | Cu % | Ni % | Cr % | Mo % | V % | Nb % | Al % | CEqyA529 % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.16 | 0.75 | 0.019 | 0.025 | 0.21 | 0.34 | 0.11 | 0.16 | 0.034 | 0.004 | 0.008 | 0.002 | 0.39 |

HEMICAL COMPOSITION

| Sn % |
|---|
| 0.012 |

ECHANICAL PROPERTIES

| Elong. % | G/L Inch | G/L mm | UTS PSI | UTS MPa | YS PSI |
|---|---|---|---|---|---|
| 25.00 | 8.000 | 200.0 | 78067 | 538 | 56337 |
| 23.00 | 8.000 | 200.0 | 77750 | 536 | 56579 |

ECHANICAL PROPERTIES

| YS MPa |
|---|
| 388 |
| 390 |

PO/REL HOU-35377/
HEAT: 63191654

:OMETRIC CHARACTERISTICS

| R:R |
|---|
| 17.38 |

MMENTS / NOTES

is grade meets the requirements for the following grades:
TM Grades: A36; A529-50; A572-50; A709-36; A709-50
A Grades: 44W; 50W
SHTO Grades: M270-36; M270-50
ME Grades: SA36

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

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

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

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

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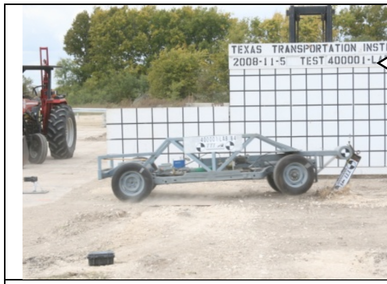
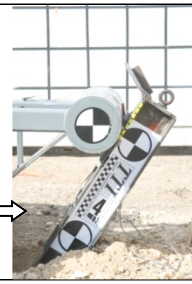
**Table C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.**



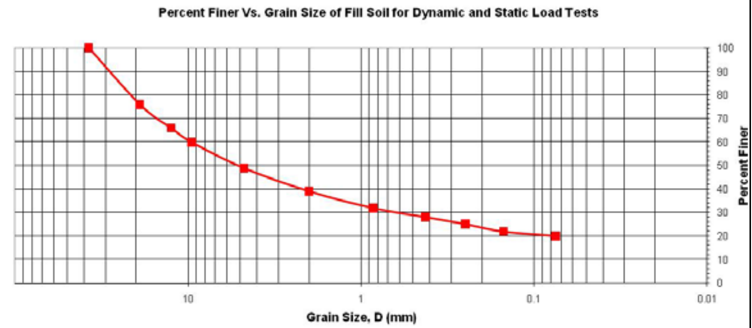

**Dynamic Setup**

**Post-Test Photo of post**

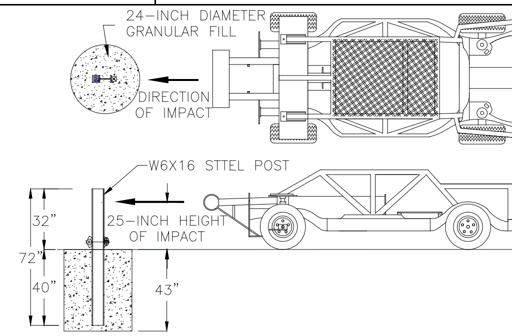


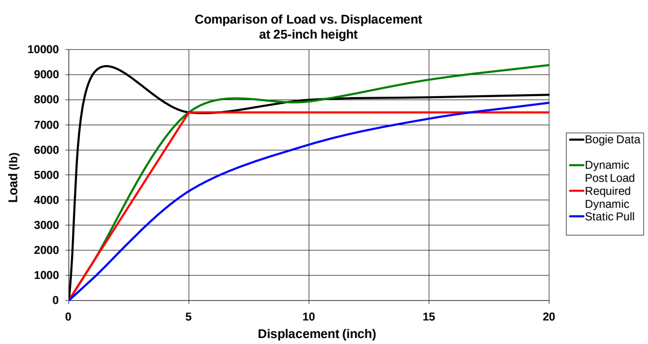
**Post-Test Photo**

**Static Load Test**

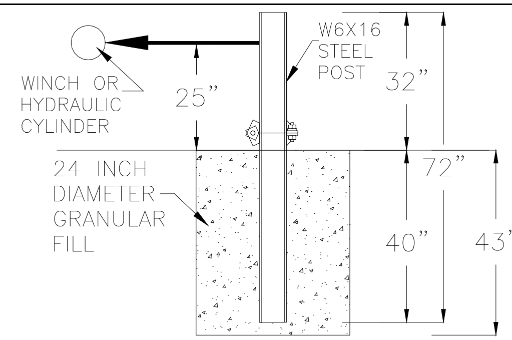



**Dynamic Test Installation Details**



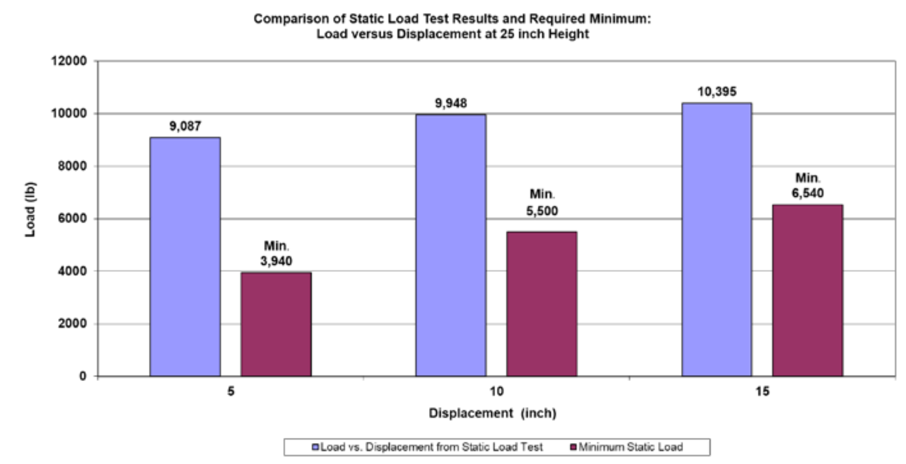




**Static Load Test Installation Details**

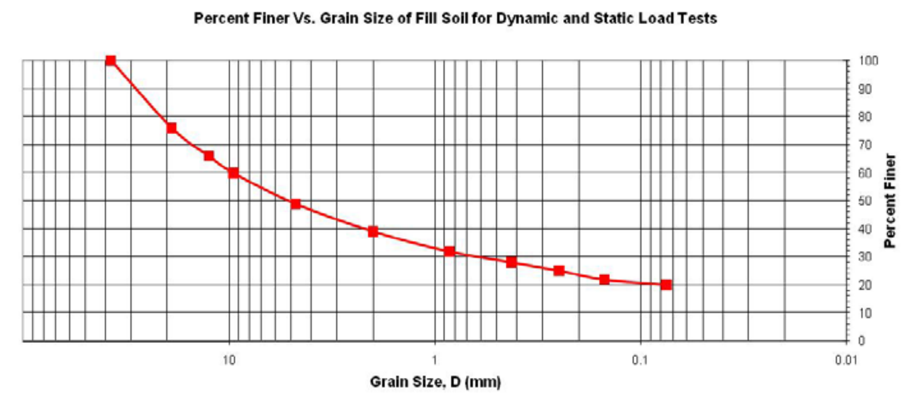



| | |
|---|---|
| Date | 2008-11-05 |
| Test Facility and Site Location | TTI Proving Ground, 3100 SH 47, Bryan, TX 77807 |
| In Situ Soil Description (ASTM D2487) | Sandy gravel with silty fines |
| Fill Material Description (ASTM D2487) and sieve analysis | AASHTO Grade B Soil-Aggregate (see sieve analysis above) |
| Description of Fill Placement Procedure | 6-inch lifts tamped with a pneumatic compactor |
| Bogie Weight | 5009 lb |
| Impact Velocity | 20.5 mph |

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



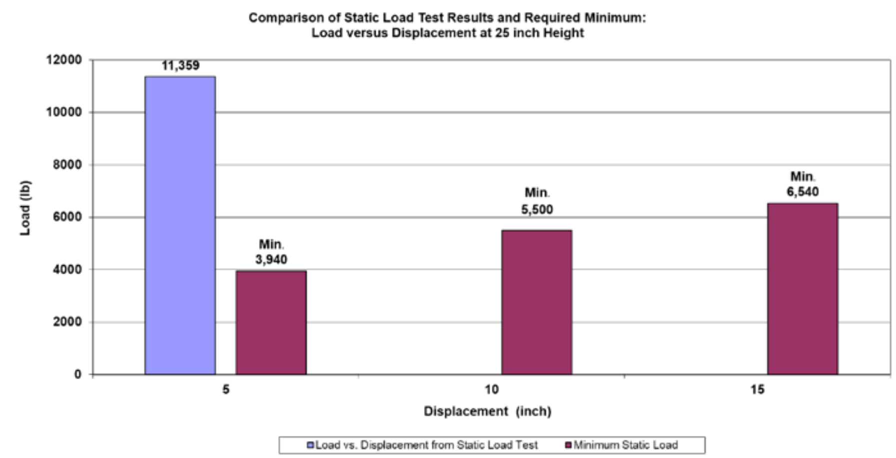

Typical Static Load Setup



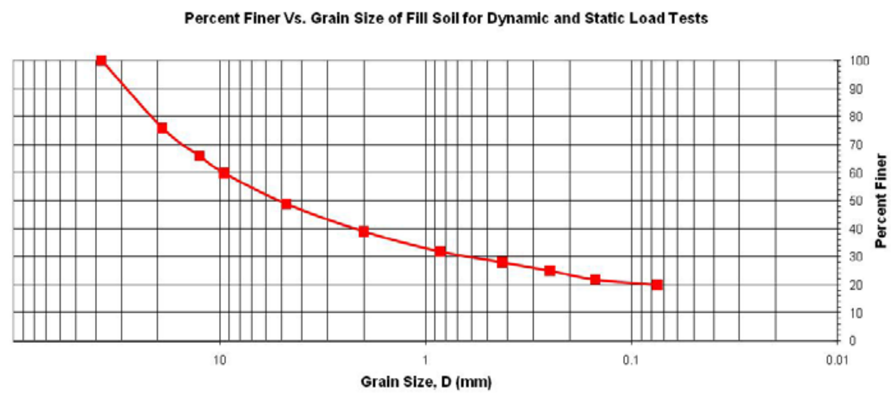

Post-Test Photo of Post

| | |
|---|---|
| Date........................................................................... | 2019-09-02 |
| 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.3. Test Day Static Soil Strength Documentation for Test No. 608331-01-5.



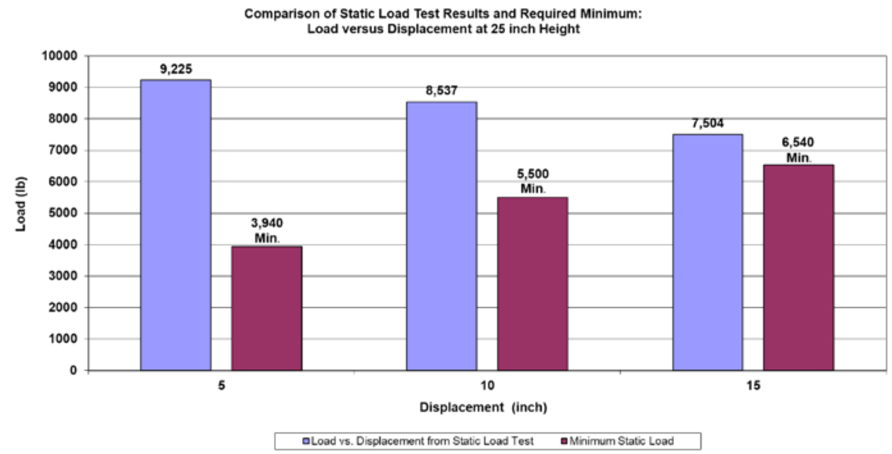

Typical Static Load Setup



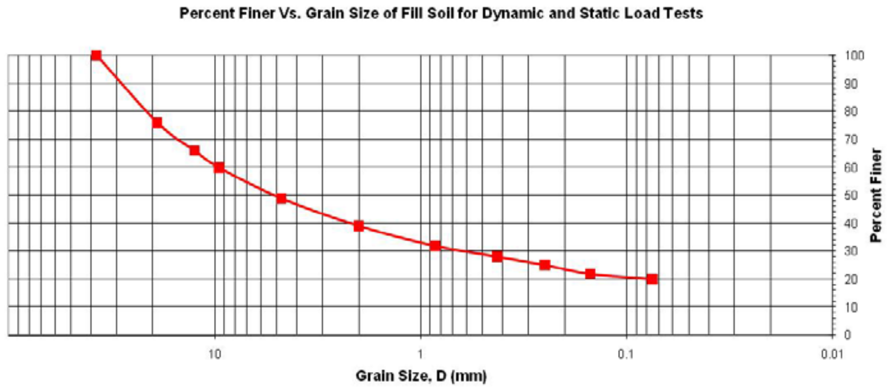

Post-Test Photo of Post

| | |
|---|---|
| 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.**




Typical Static Load Setup




Post-Test Photo of Post

| | |
|---|---|
| Date | 2019-12-19 |
| 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 |

# 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.

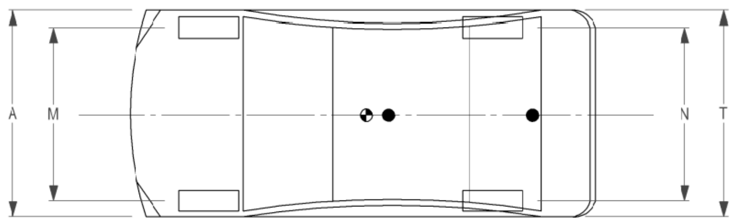
Date: 2019-09-02 Test No.: 608331-4 VIN No.: KNADE123376251020

Year: 2007 Make: Kia Model: Rio

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

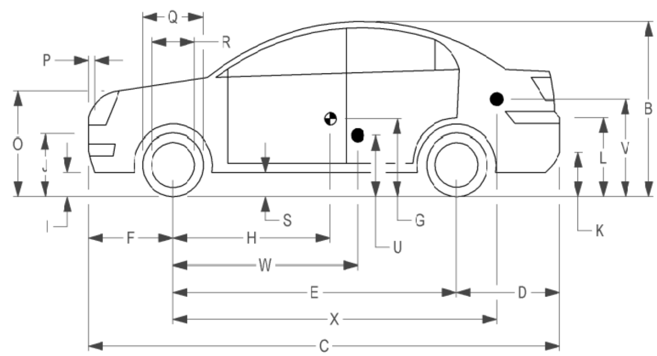
Describe any damage to the vehicle prior to test: None

● 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 | 66.38 | F | 33.00 | K | 12.25 | P | 4.12 | U | 14.75 |
| B | 51.50 | G | | L | 25.25 | Q | 22.50 | V | 20.50 |
| C | 165.75 | H | 35.04 | M | 57.75 | R | 15.50 | W | 35.00 |
| D | 34.00 | I | 7.75 | N | 57.70 | S | 8.25 | X | 72.50 |
| E | 98.75 | J | 21.50 | O | 27.00 | T | 66.20 | | |

Wheel Center Ht Front 11.00 Wheel Center Ht Rear 11.00 W-H 0.00

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

| **GVWR Ratings:** | | **Mass:** lb | Curb | Test Inertial | Gross Static |
|---|---|---|---|---|---|
| Front | 1718 | $M_{front}$ | 1602 | 1578 | 1663 |
| Back | 1874 | $M_{rear}$ | 868 | 868 | 948 |
| Total | 3638 | $M_{Total}$ | 2470 | 2446 | 2611 |

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 SHEET[1]

| 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) | $\frac{X1+X2}{2}$ = ______ |
| < 4 inches ________ | |
| ≥ 4 inches ________ | |

Note: Measure $C_1$ to $C_6$ 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 Width** (CDC) | Direct Damage Max*** Crush | Field L** | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | ±D |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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** | | | | | | | | | | |
| | | | | | | | | | | | |

[1]Table 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.

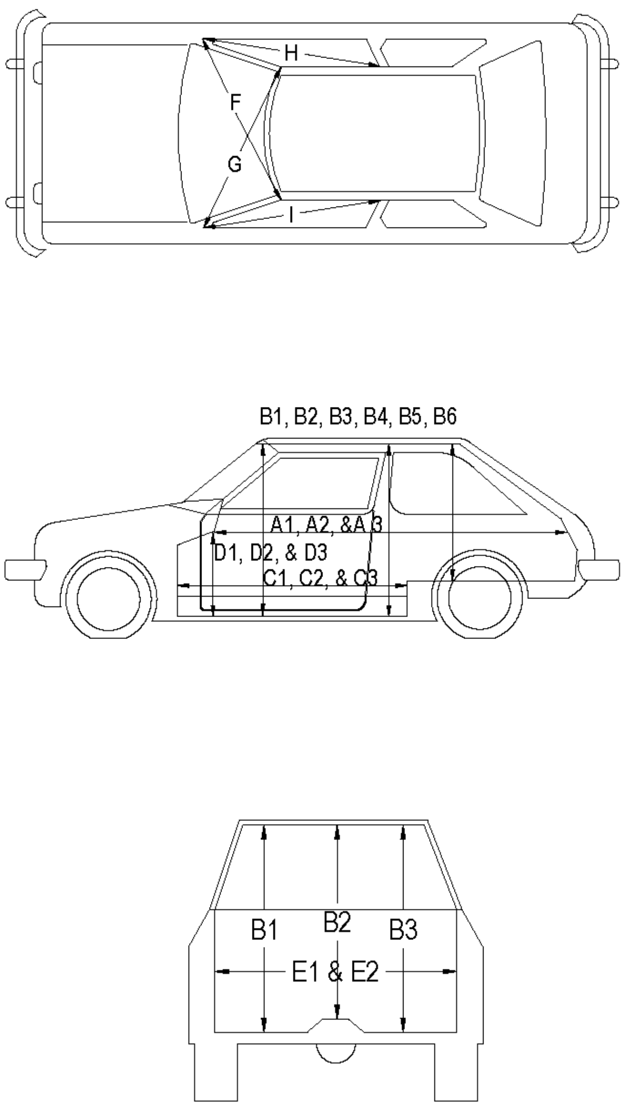
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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

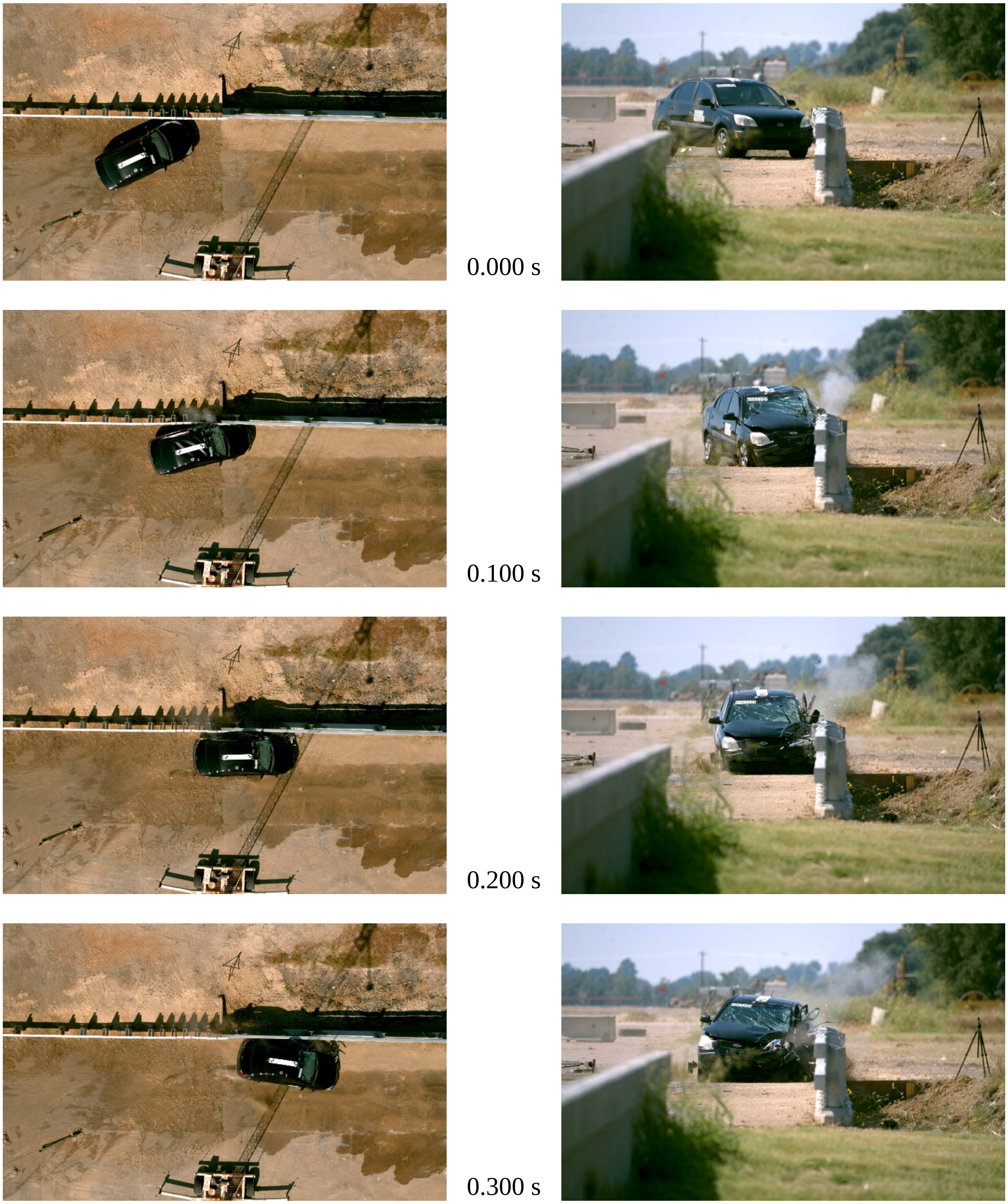



**Figure D.1. Sequential Photographs for Test No. 608331-01-4 (Overhead and Frontal Views).**

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).**

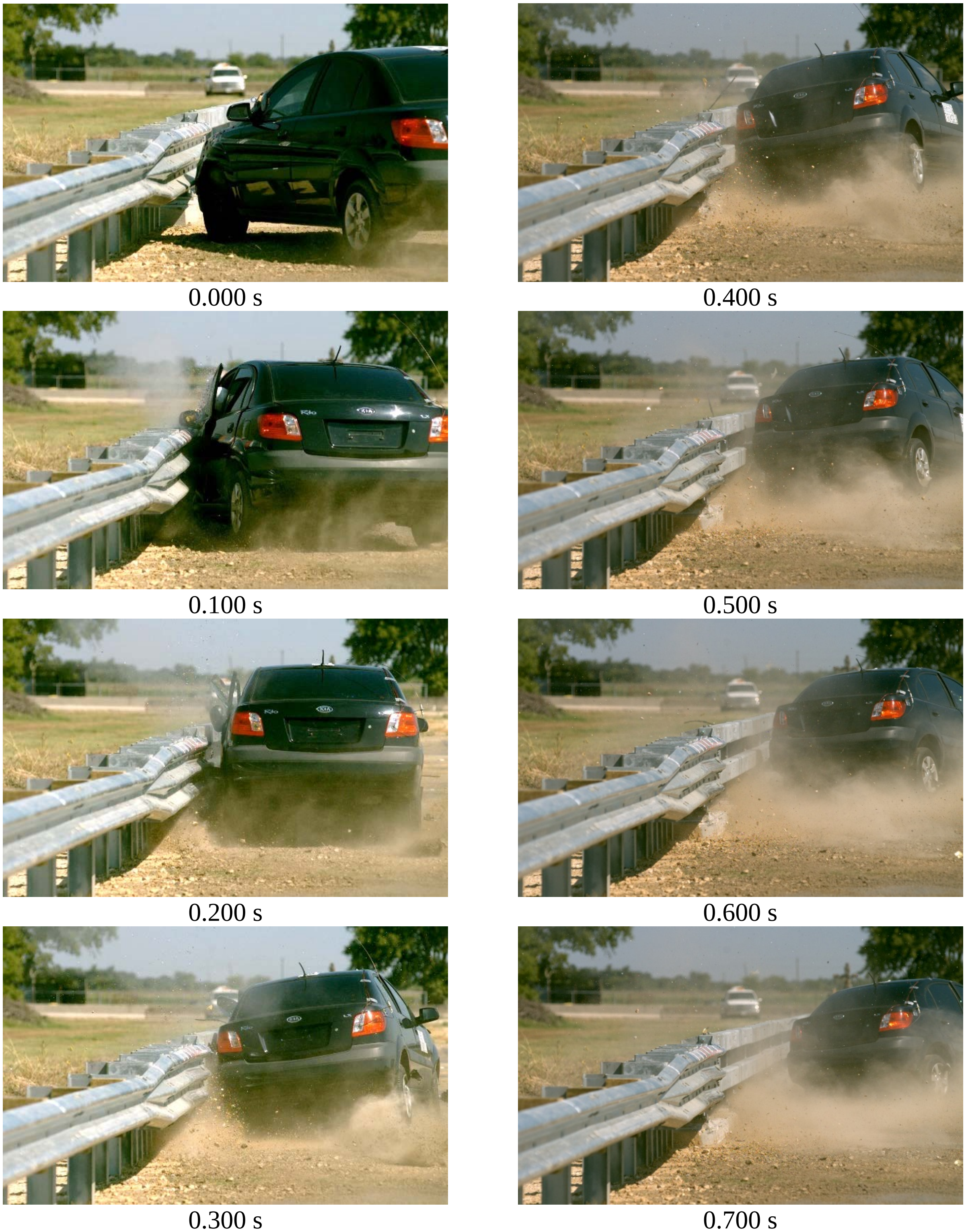



**Figure D.2. Sequential Photographs for Test No. 608331-01-4 (Rear View).**

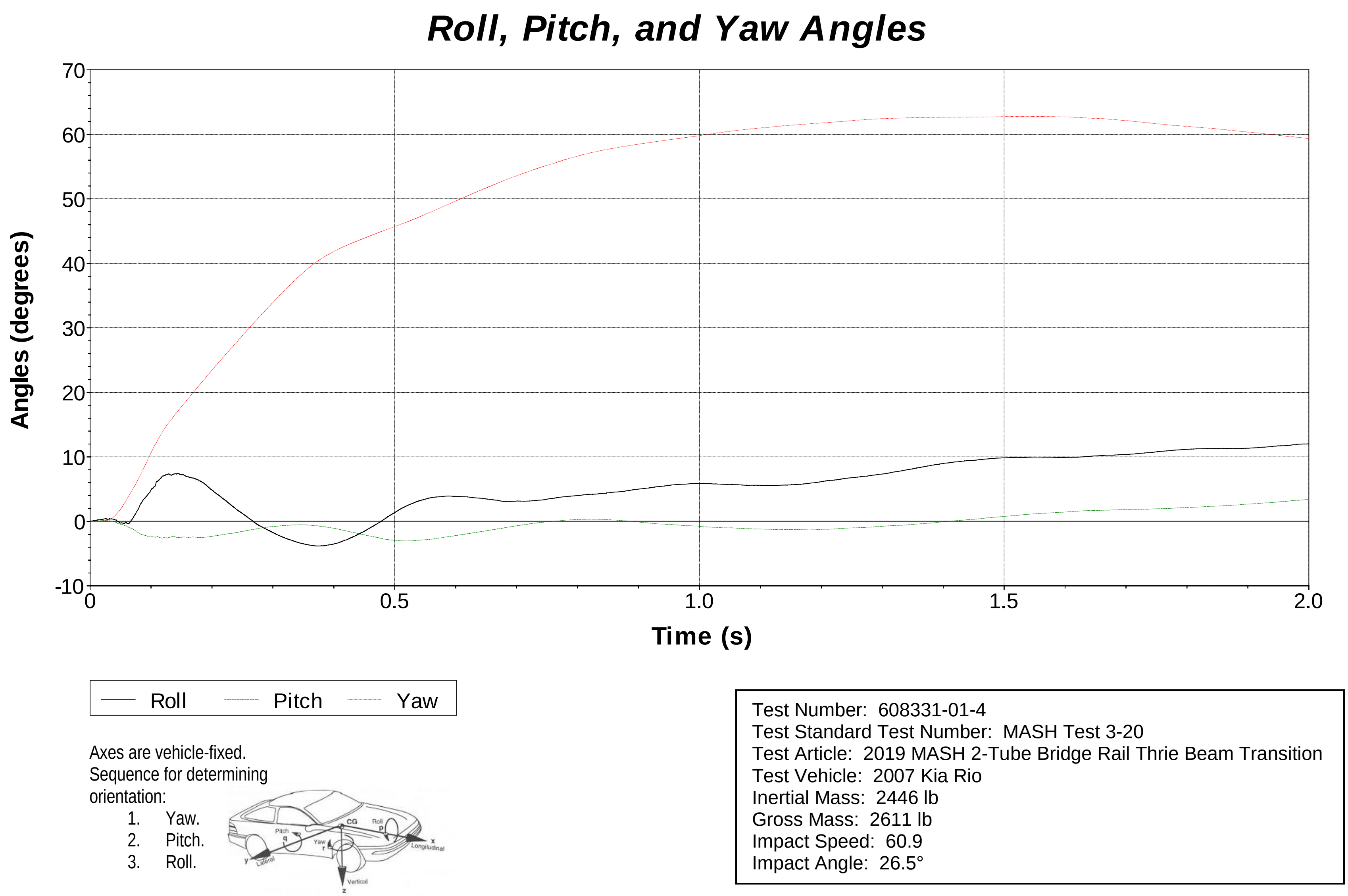
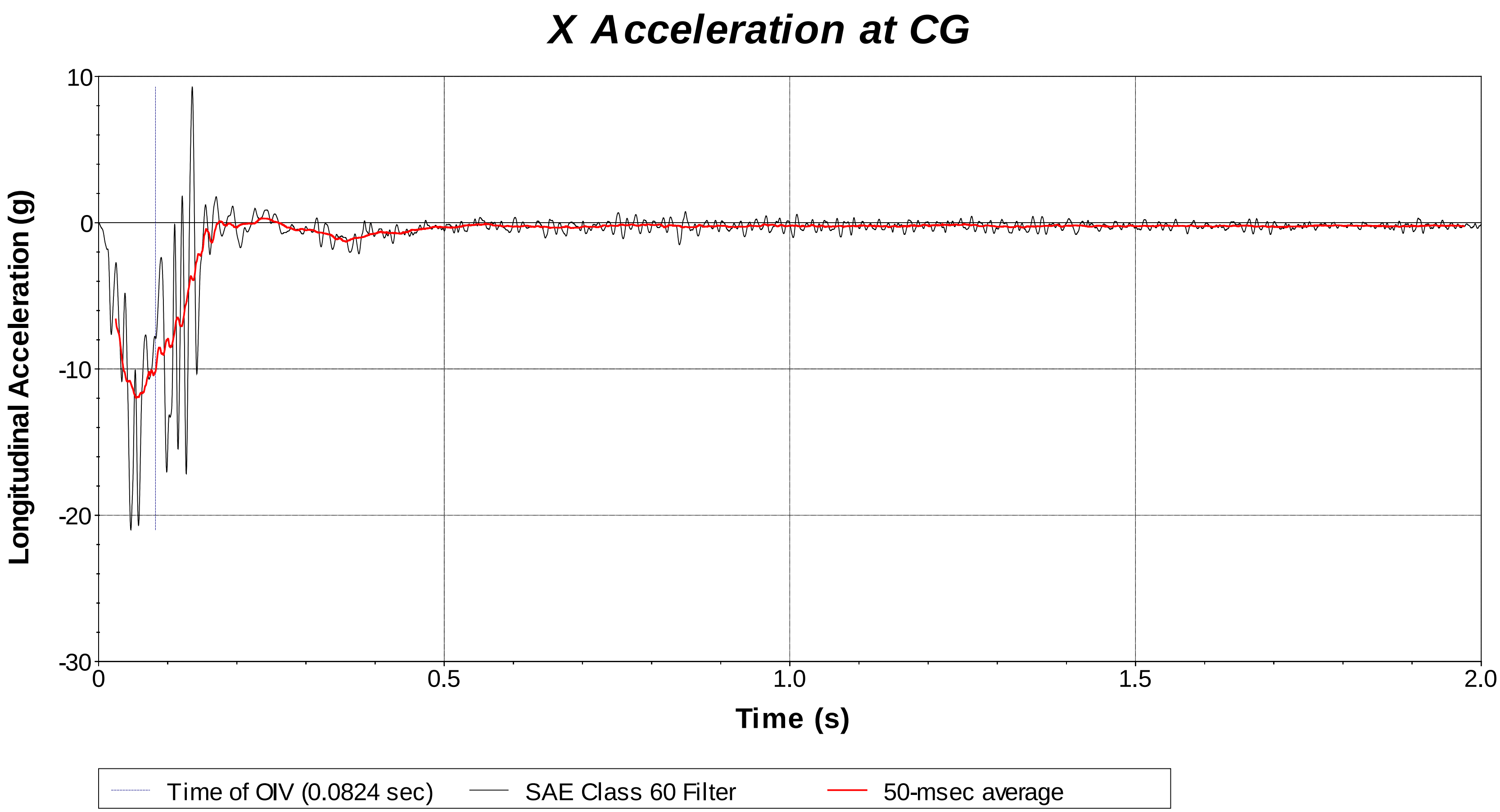
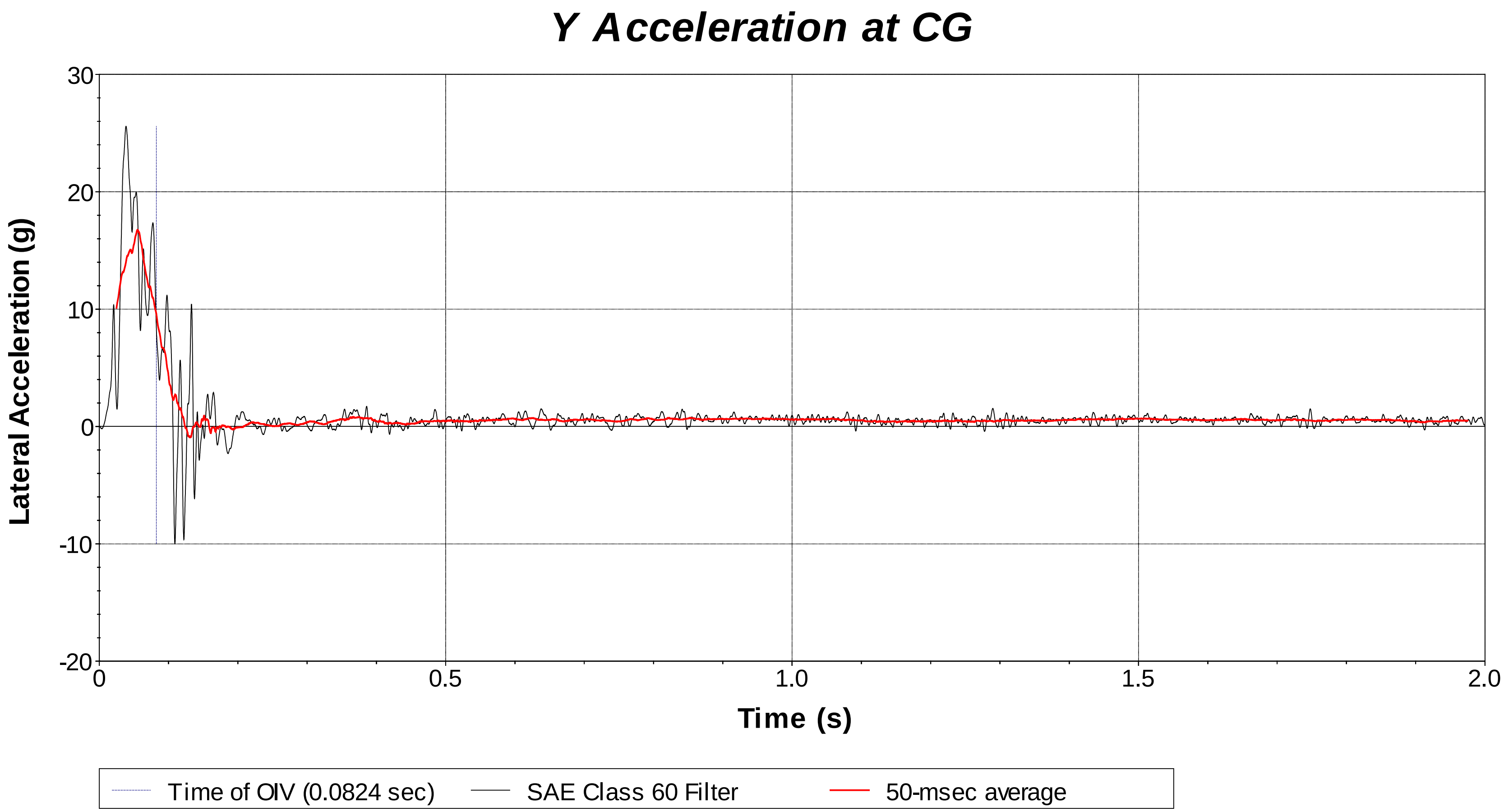



**Figure D.3. Vehicle Angular Displacements for Test No. 608331-01-4.**



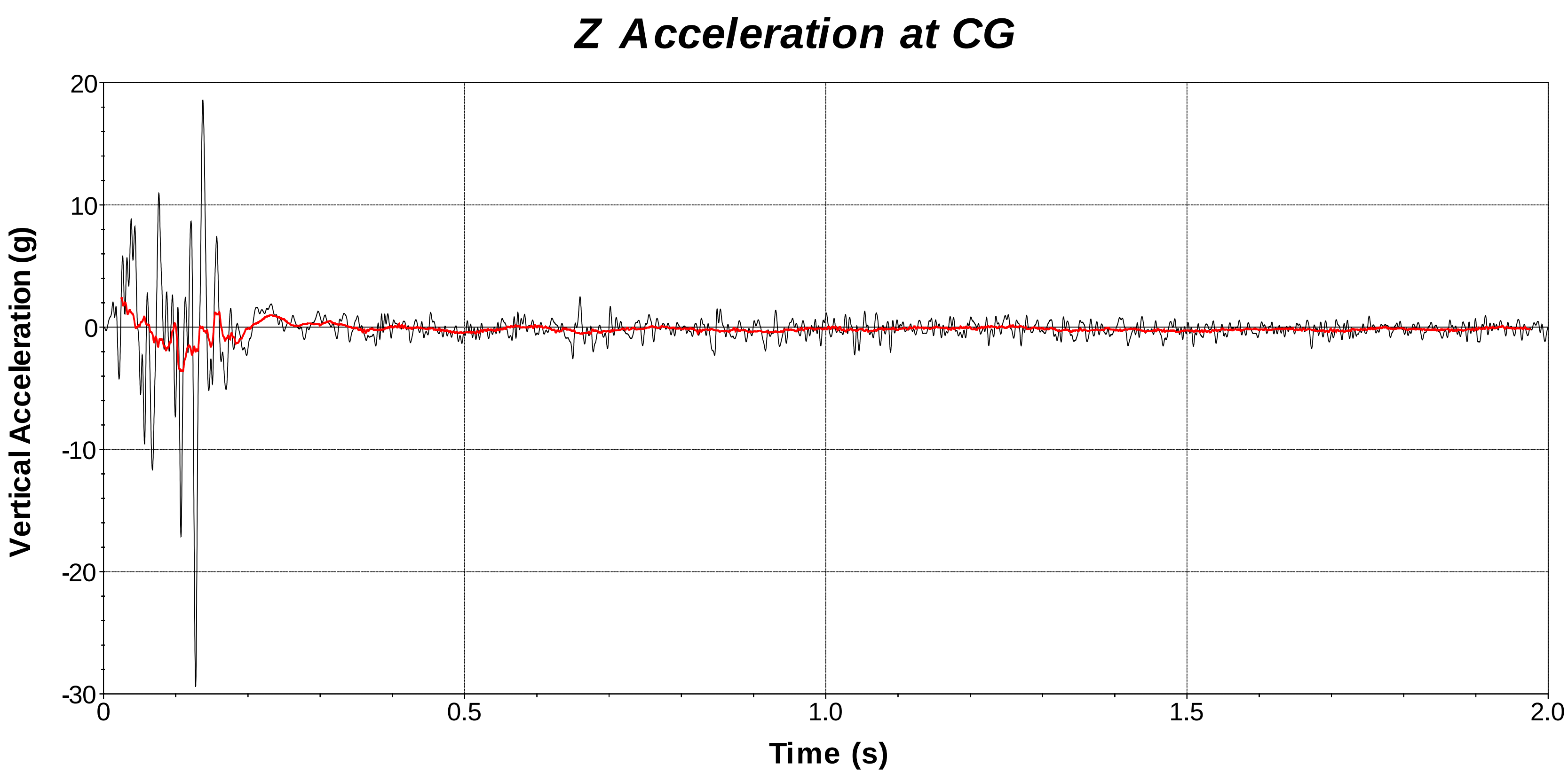

Test Number: 608331-01-4
Test Standard Test Number: MASH Test 3-20
Test Article: 2019 MASH 2-Tube Bridge Rail Thrie Beam Transition
Test Vehicle: 2007 Kia Rio
Inertial Mass: 2446 lb
Gross Mass: 2611 lb
Impact Speed: 60.9
Impact Angle: 26.5°

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




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).**




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.

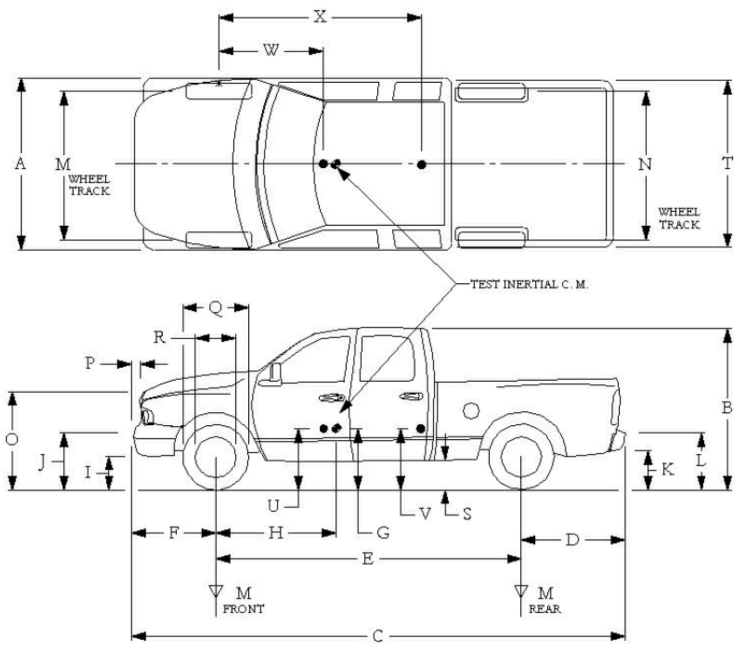
NOTES: None

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: 2019-09-05 Test No.: 608331-5 VIN: 1C6RR6HTODS501020

Year: 2013 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 152402

Engine: 4.7 liter V-8 Transmission: Automatic

Fuel Level: Empty Ballast: 100 (440 lb max)

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Measured Vehicle Weights:** (lb) | | | | | | | |
| LF: | 1475 | RF: | 1388 | | Front Axle: | 2863 | |
| LR: | 1070 | RR: | 1117 | | Rear Axle: | 2187 | |
| Left: | 2545 | Right: | 2505 | | Total: | 5050 | |
| | | | | | 5000 ±110 lb allowed | | |
| Wheel Base: | 140.50 | inches | Track: F: | 68.50 | inches R: | 68.00 | inches |
| | 148 ±12 inches allowed | | | Track = (F+R)/2 = 67 ±1.5 inches allowed | | | |
| **Center of Gravity,** SAE J874 Suspension Method | | | | | | | |
| X: | 60.85 | inches | Rear of Front Axle | (63 ±4 inches allowed) | | | |
| Y: | -0.27 | inches | Left - Right + | of Vehicle Centerline | | | |
| Z: | 28.25 | inches | Above Ground | (minumum 28.0 inches allowed) | | | |

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

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

Overall Length: 227.50 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 SHEET[1]

| 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) | $\frac{X1+X2}{2}$ = ______ |
| < 4 inches ________ | |
| ≥ 4 inches ________ | |

Note: Measure $C_1$ to $C_6$ 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 Width** (CDC) | Max*** Crush | Field L** | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | ±D |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 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** | | | | | | | | | | |
| | | | | | | | | | | | |

[1]Table 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.

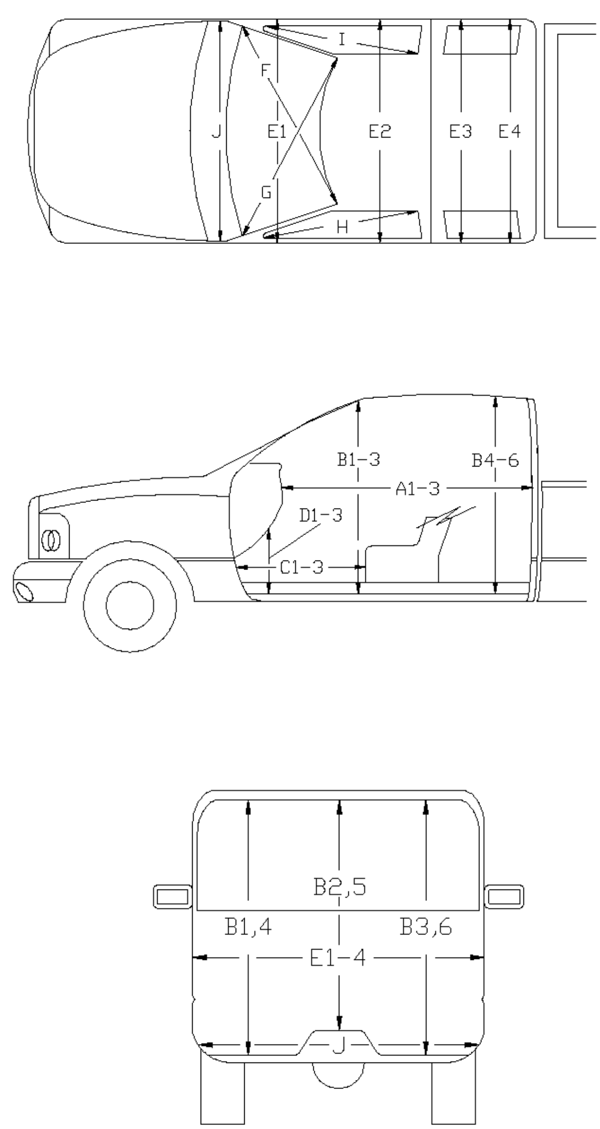
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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

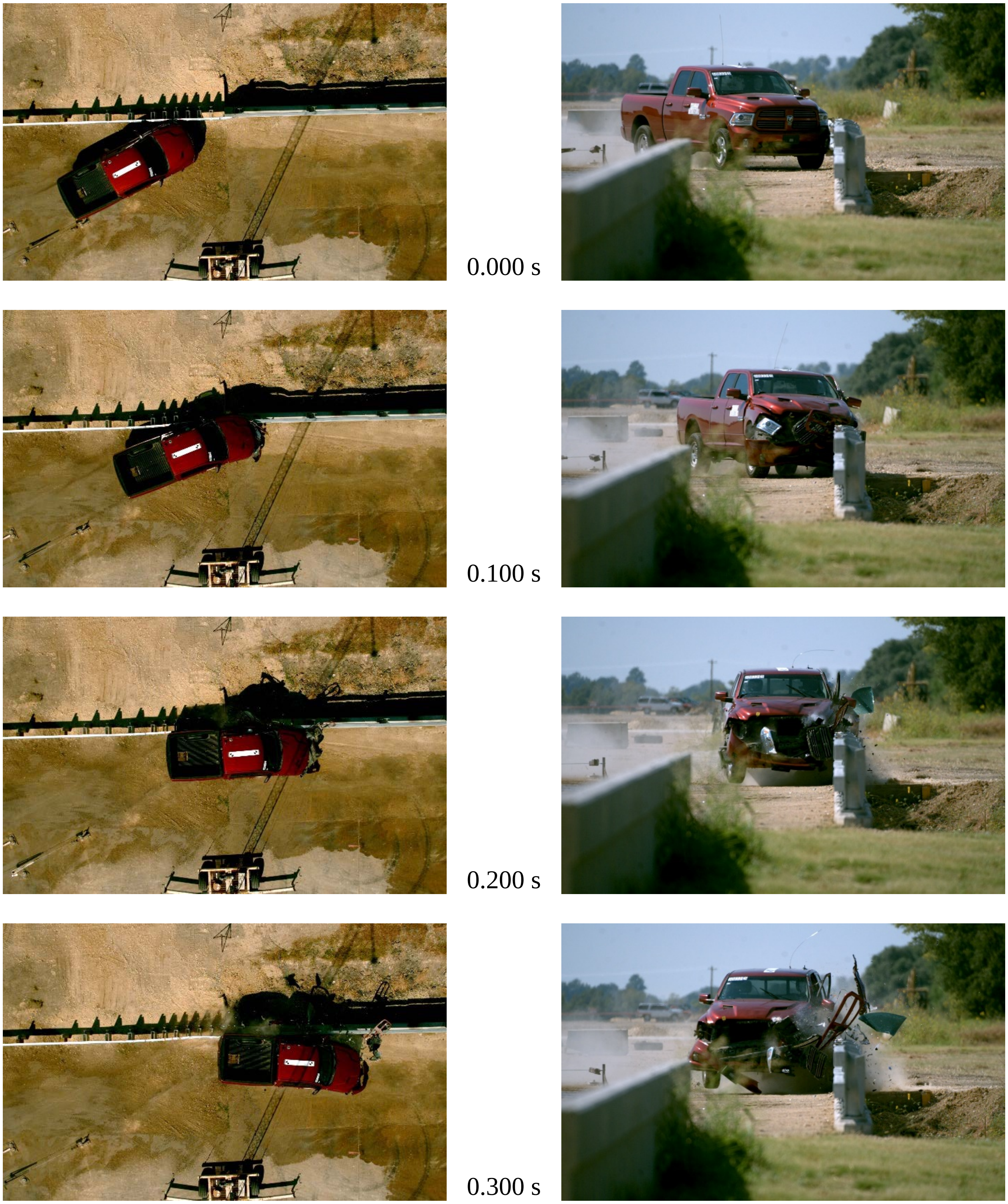



**Figure E.1. Sequential Photographs for Test No. 608331-01-5 (Overhead and Frontal Views).**

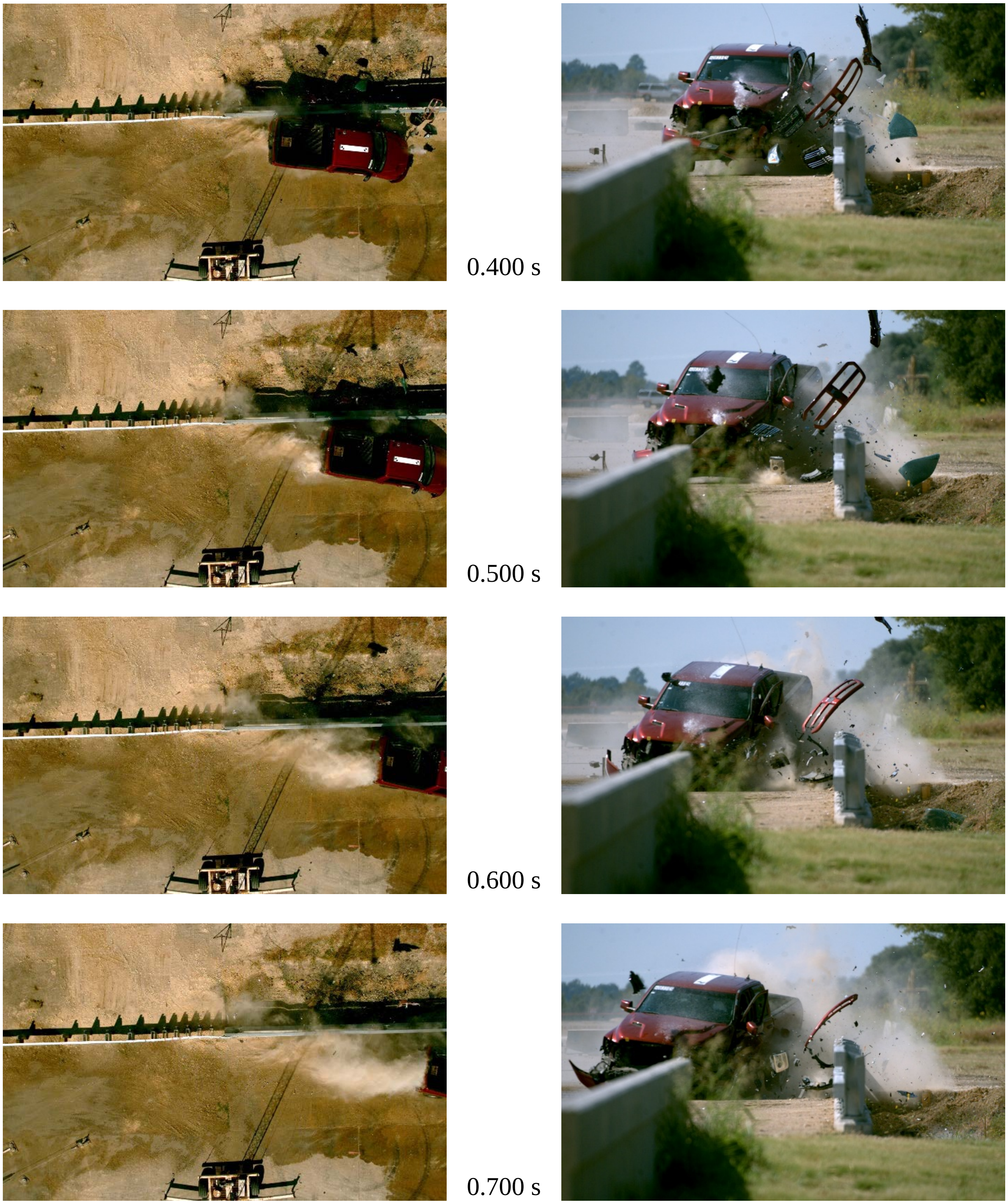



**Figure E.1. Sequential Photographs for Test No. 608331-01-5 (Overhead and Frontal Views) (Continued).**

0.000 s

0.100 s

0.200 s

0.300 s

0.400 s

0.500 s

0.600 s

0.700 s

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

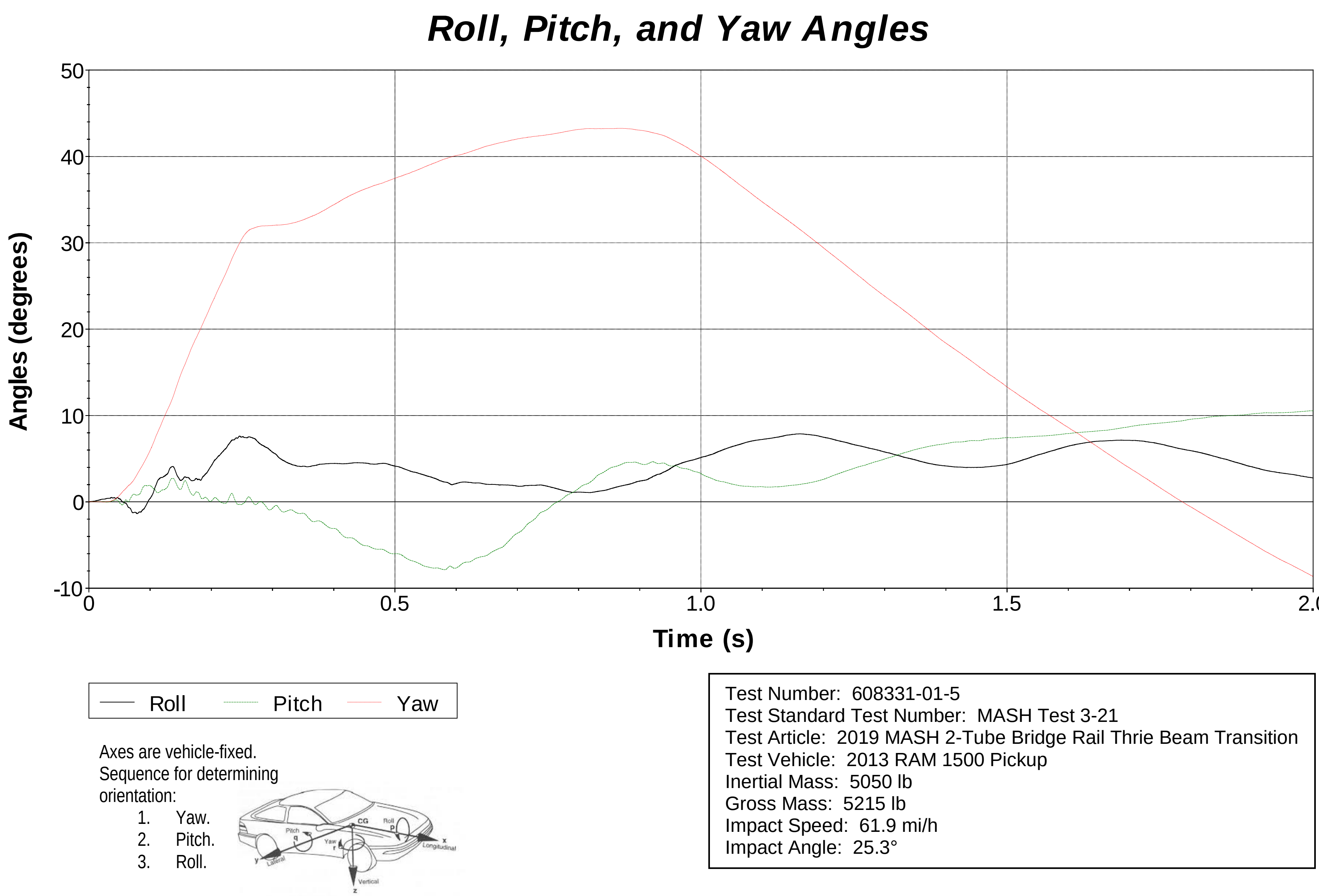



**Figure E.3. Vehicle Angular Displacements for Test No. 608331-01-5.**

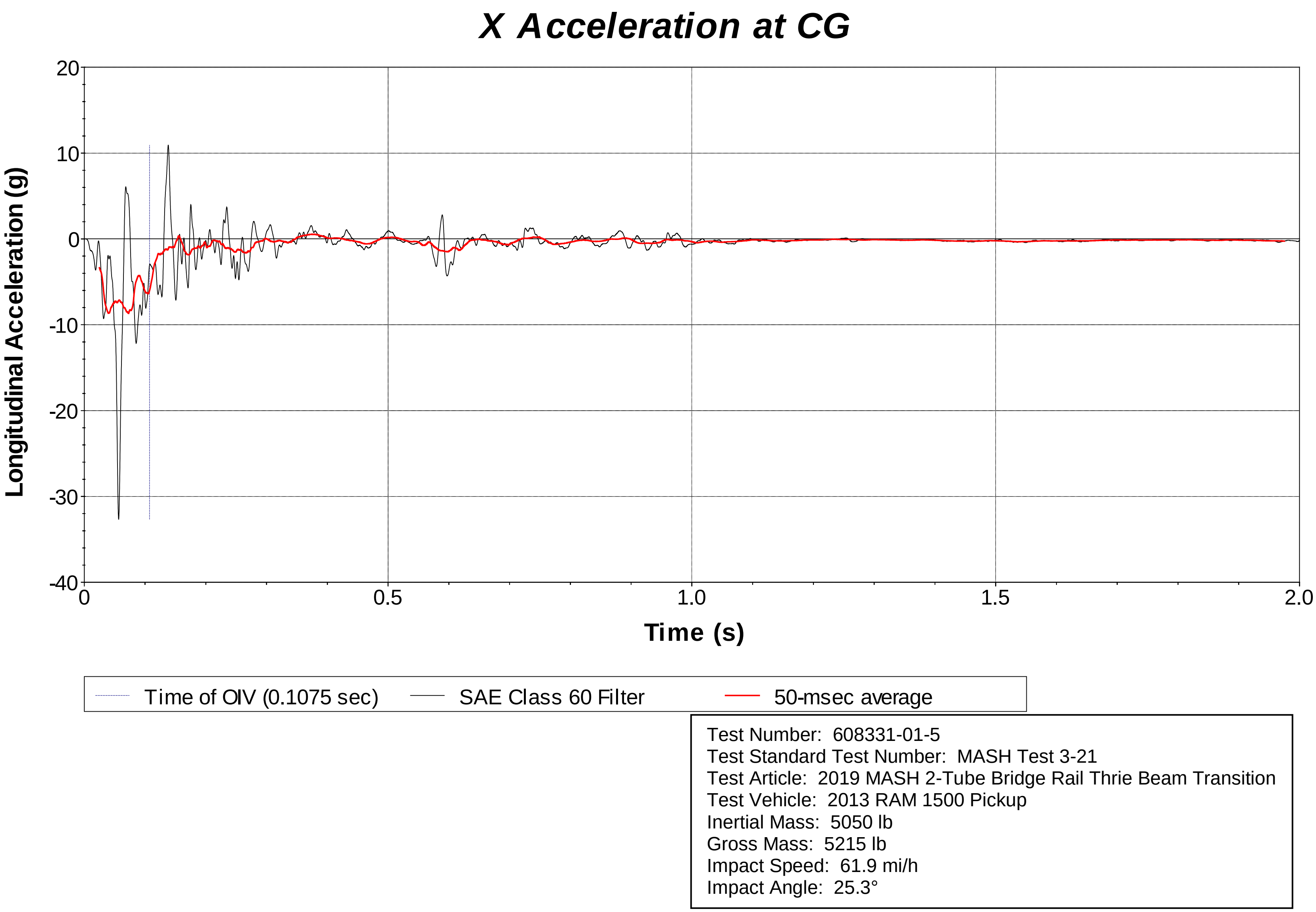



**Figure E.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608331-01-5 (Accelerometer Located at Center of Gravity).**

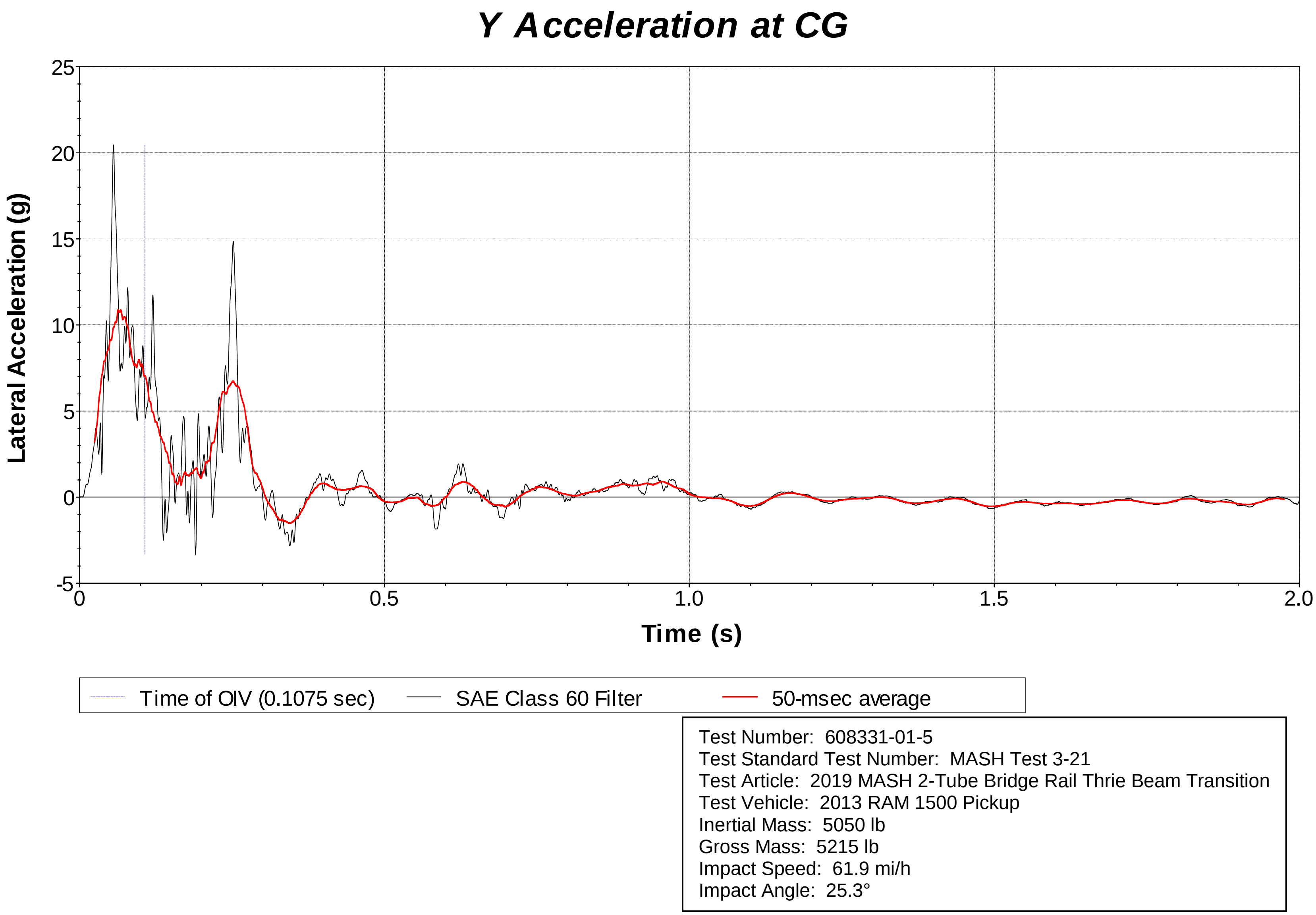
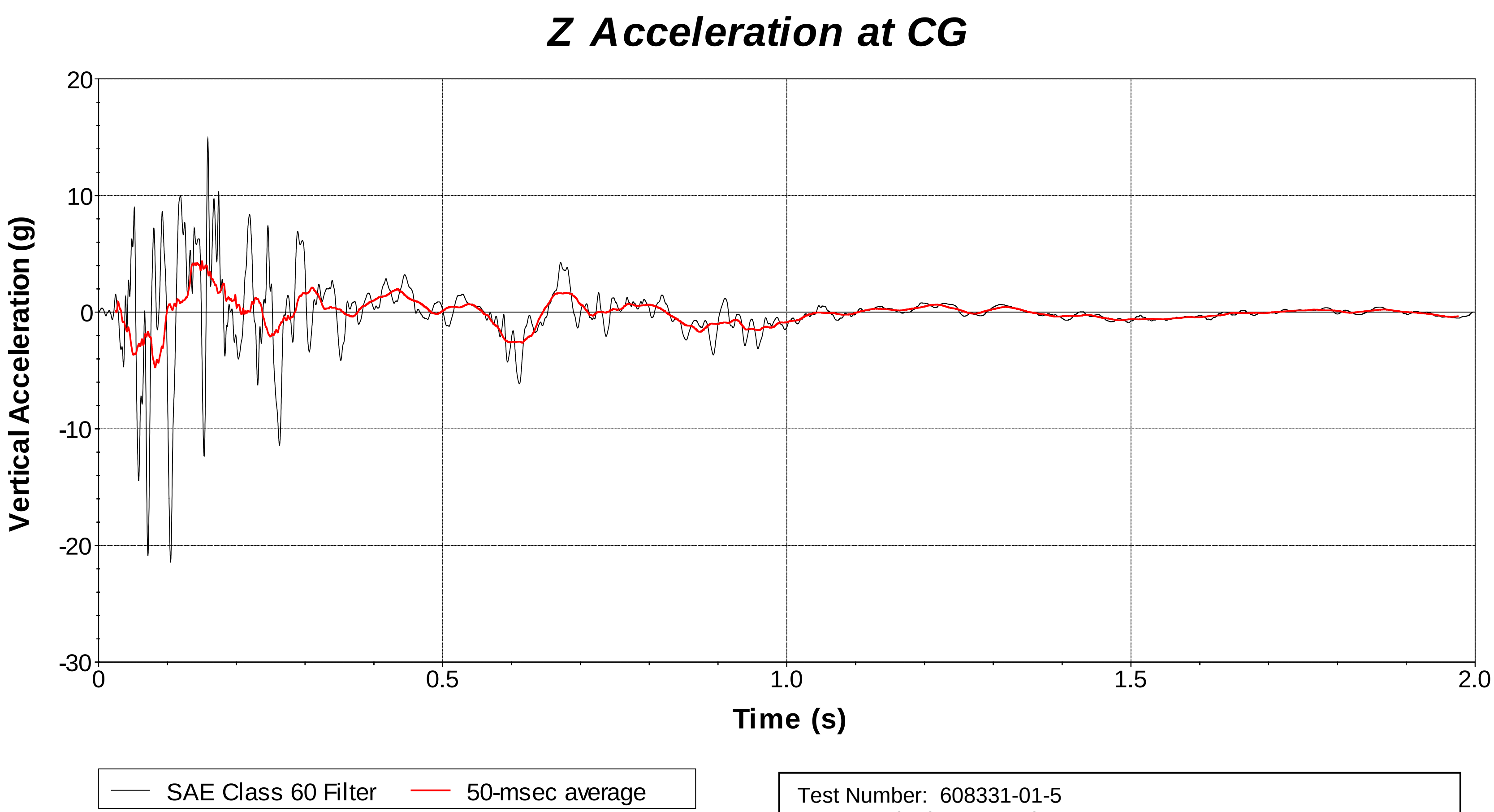



**Figure E.5. Vehicle Lateral Accelerometer Trace for Test No. 608331-01-5 (Accelerometer Located at Center of Gravity).**




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.

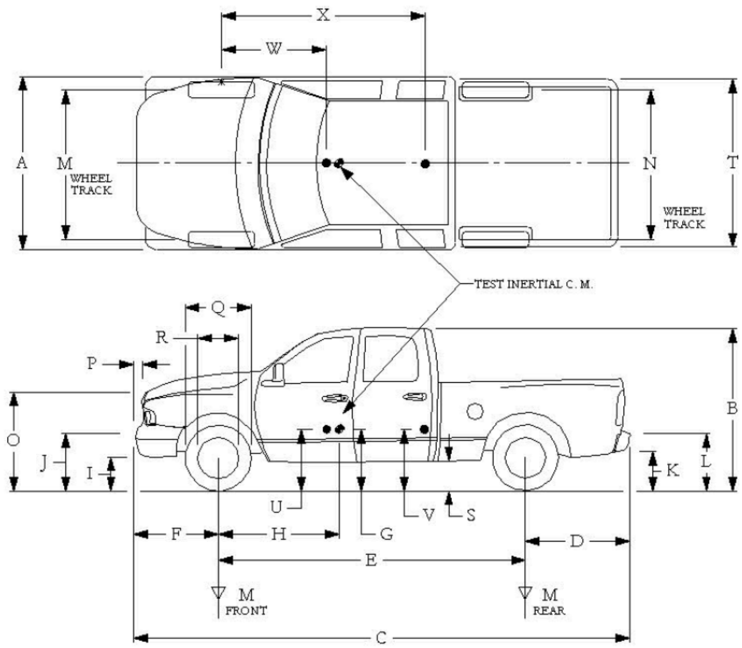
NOTES: None

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:** | | **Mass:** lb | Curb | Test Inertial | Gross Static |
|---|---|---|---|---|---|
| Front | 3700 | $M_{front}$ | 2877 | 2832 | 2832 |
| Back | 3900 | $M_{rear}$ | 2013 | 2206 | 2206 |
| Total | 6700 | $M_{Total}$ | 4890 | 5038 | 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: | 1393 | | RF: | 1439 | | Front Axle: | 2832 | |
| LR: | 1157 | | RR: | 1049 | | Rear Axle: | 2206 | |
| Left: | 2550 | | Right: | 2488 | | Total: | 5038 | |
| | | | | | | 5000 ±110 lb allowed | | |
| Wheel Base: | 140.50 | inches | Track: F: | 68.50 | inches | R: | 68.00 | inches |
| | 148 ±12 inches allowed | | | Track = (F+R)/2 = 67 ±1.5 inches allowed | | | | |
| **Center of Gravity,** SAE J874 Suspension Method | | | | | | | | |
| X: | 61.52 | inches | Rear of Front Axle | (63 ±4 inches allowed) | | | | |
| Y: | -0.42 | inches | Left - | Right + | of Vehicle Centerline | | | |
| Z: | 29.00 | 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 SHEET[1]

| 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) | $\frac{X1+X2}{2}$ = _______ |
| < 4 inches ________ | |
| ≥ 4 inches ________ | |

Note: Measure $C_1$ to $C_6$ 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 Width** (CDC) | Direct Damage Max*** Crush | Field L** | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | ±D |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Front plane at bmpr ht | 18 | 16 | - | 16 | - | - | - | - | - | - |
| 2 | Side plane at bmpr ht | 18 | 20 | 54 | 2 | 4 | 9 | 12 | 18 | 20 | +70 |
| | | | | | | | | | | | |
| | | | | | | | | | | | |
| | Measurements recorded | | | | | | | | | | |
| | ☑ **inches** **or** ☐ **mm** | | | | | | | | | | |
| | | | | | | | | | | | |

[1]Table 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.

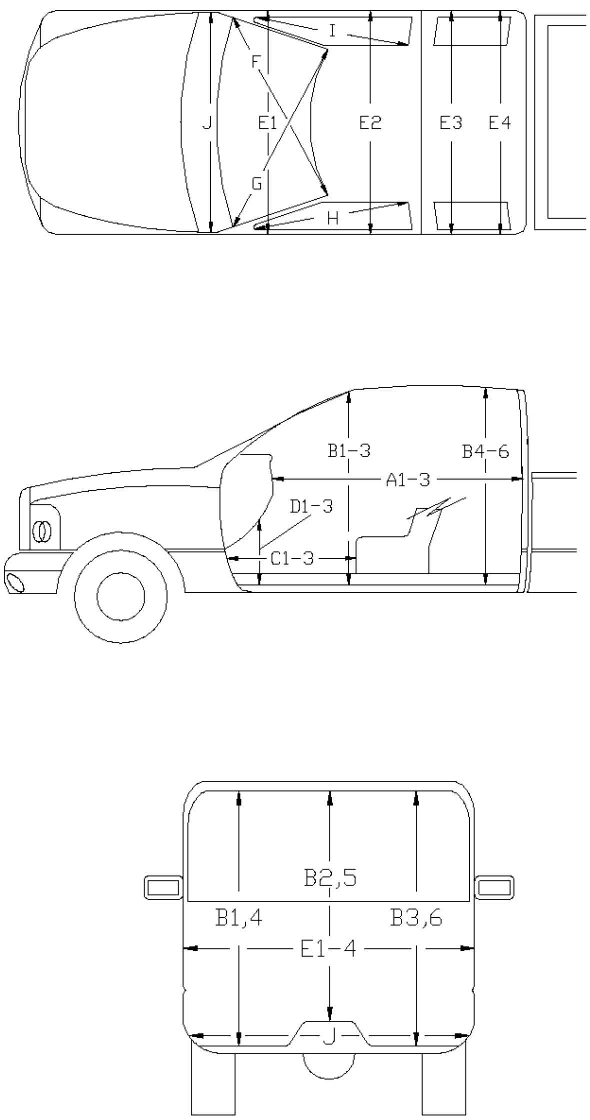
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 |




*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 | 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 |

## 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).**

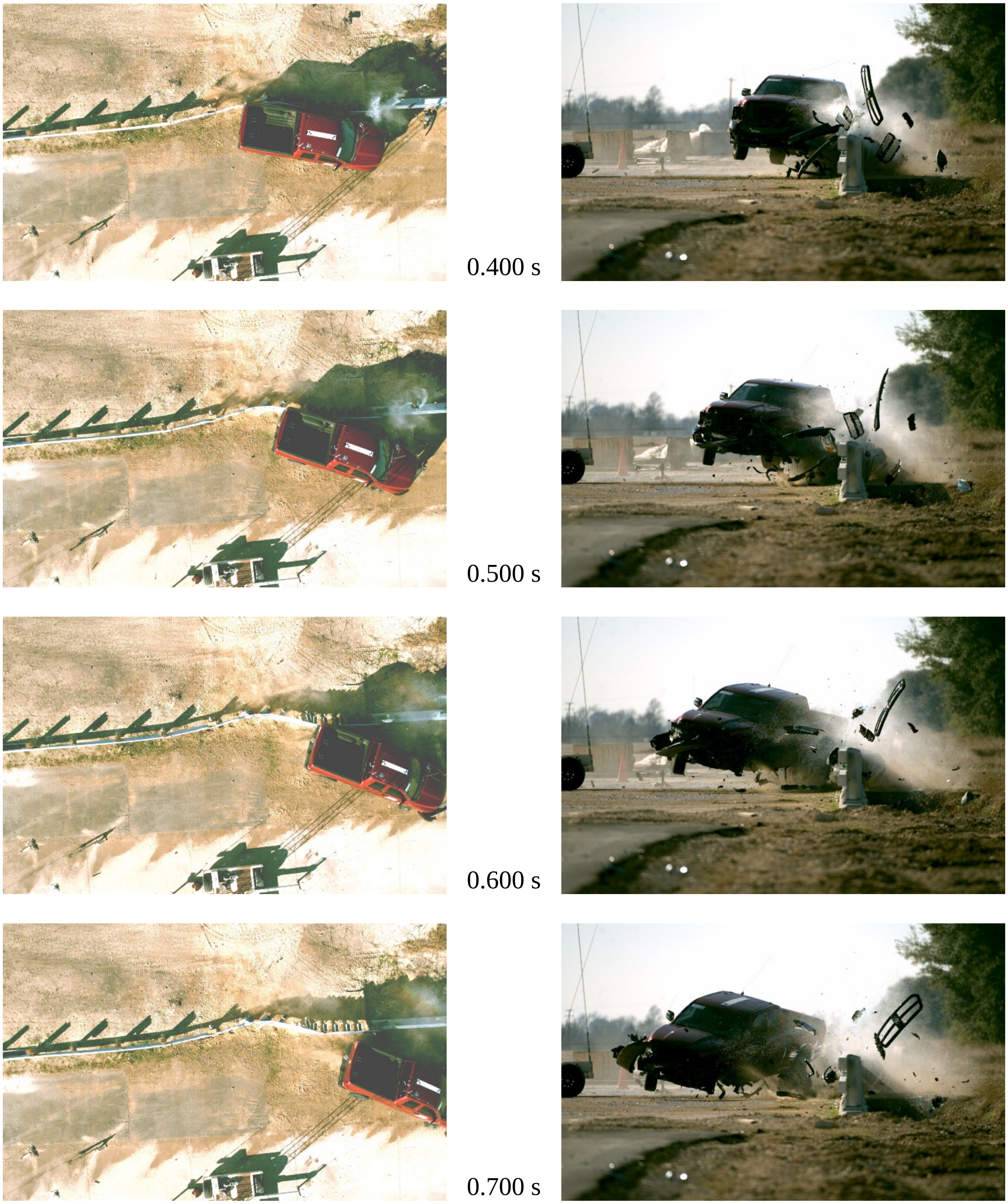
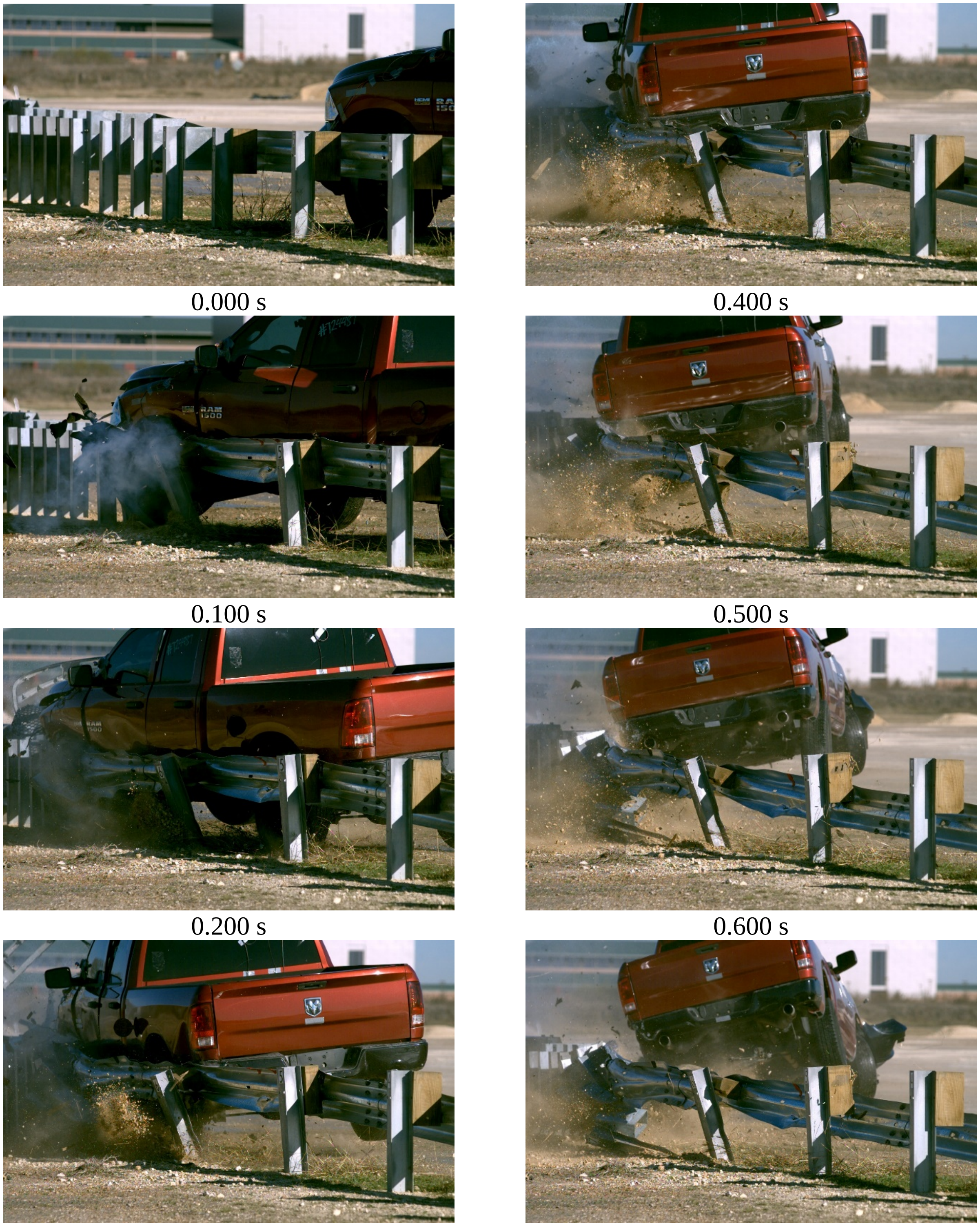
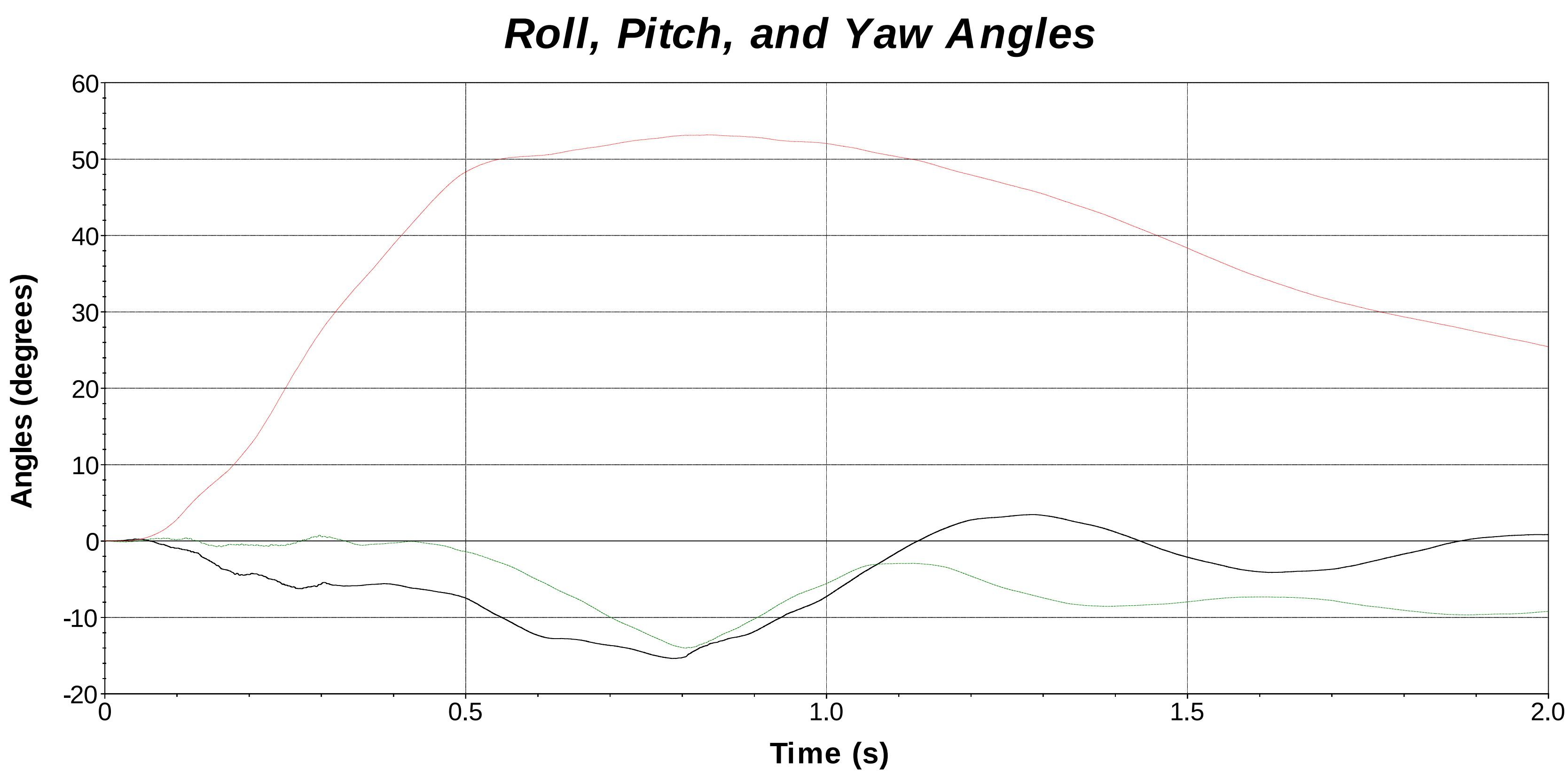



**Figure F.1. Sequential Photographs for Test No. 608331-01-6 (Overhead and Frontal Views) (Continued).**



0.000 s | 0.400 s
0.100 s | 0.500 s
0.200 s | 0.600 s
0.300 s | 0.700 s

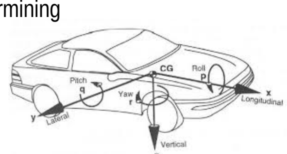
**Figure F.2. Sequential Photographs for Test No. 608331-01-6 (Rear View).**




Roll — Pitch — Yaw

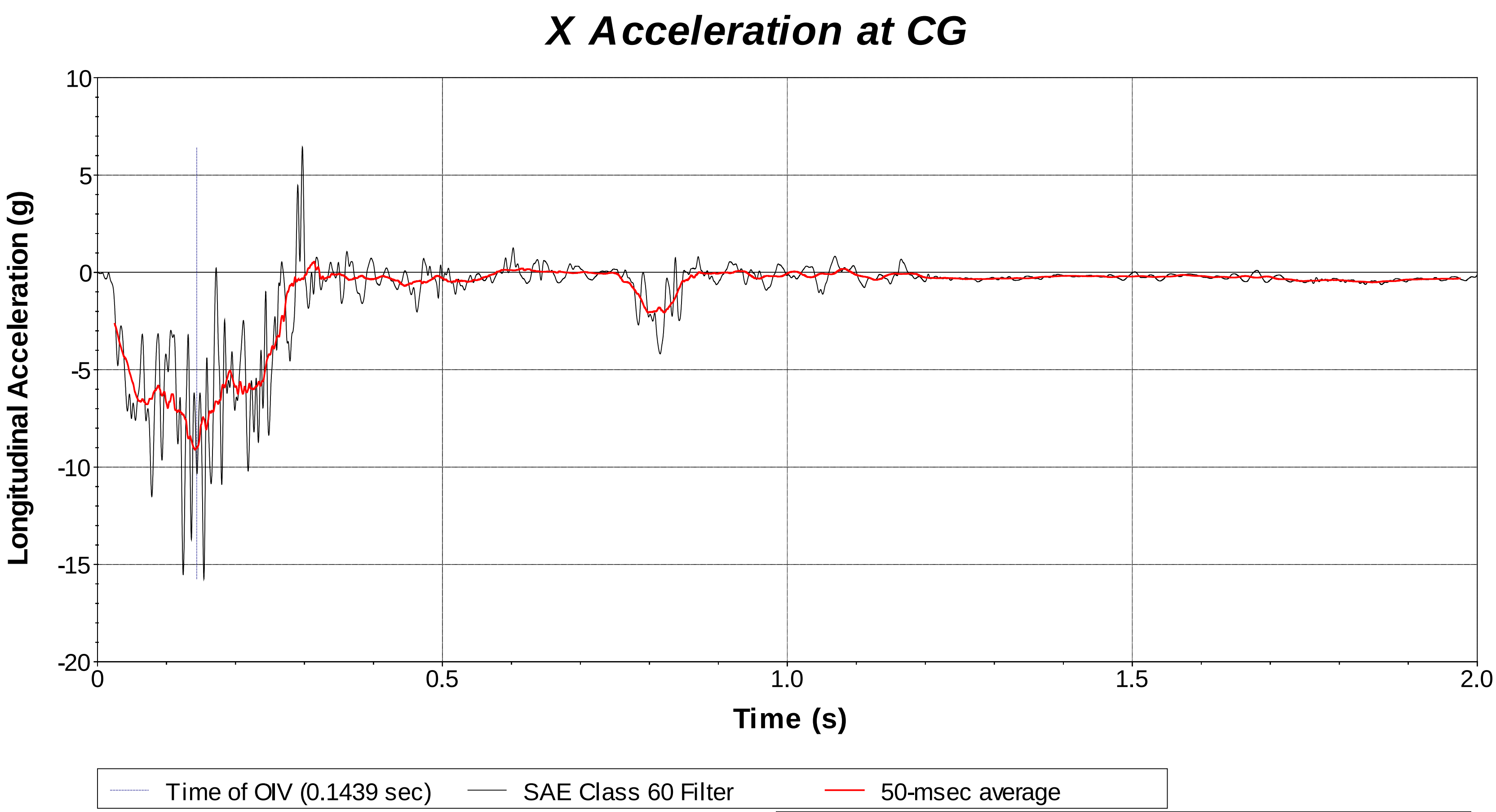
Axes are vehicle-fixed.
Sequence for determining orientation:

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




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




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

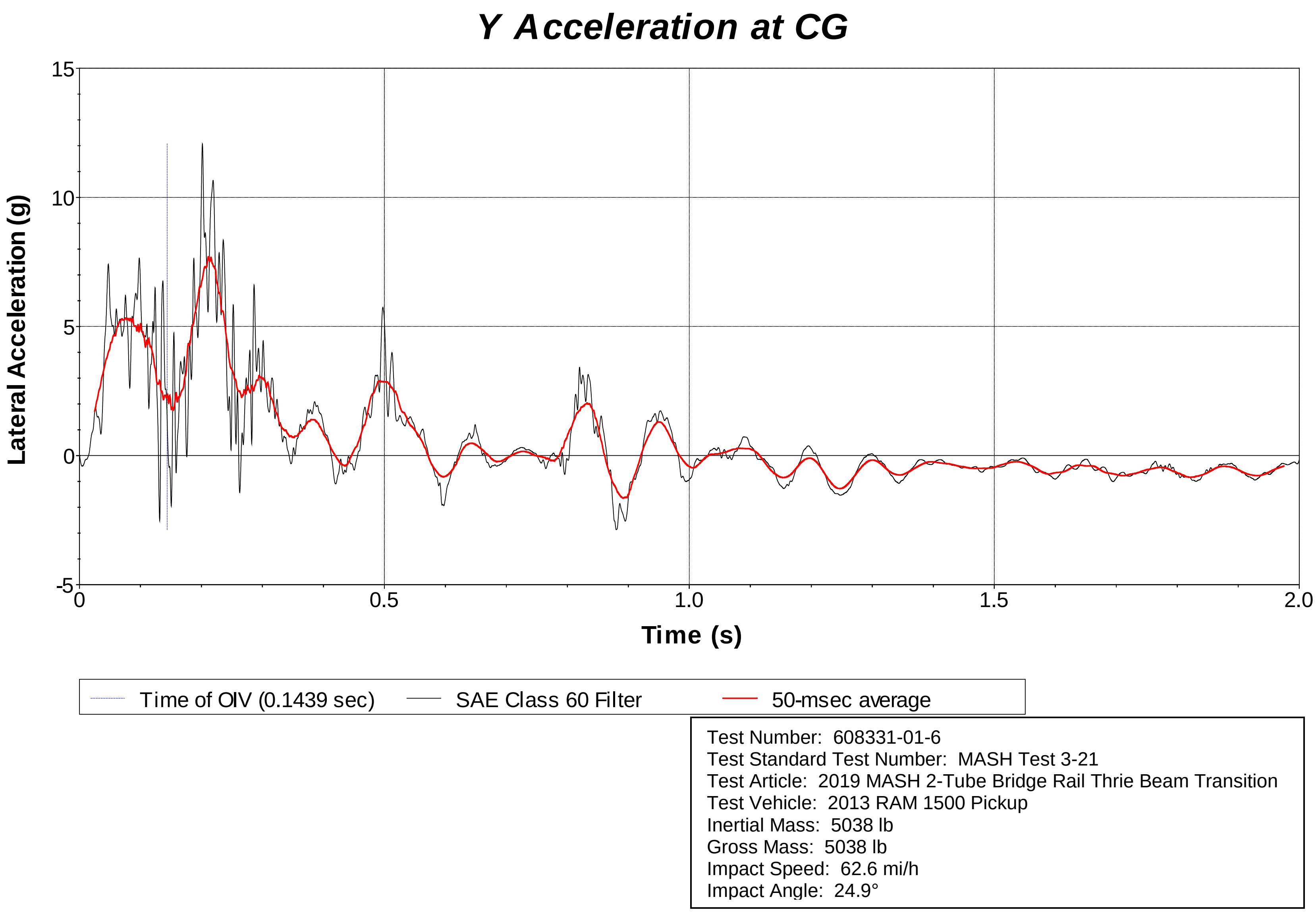



**Figure F.5. Vehicle Lateral Accelerometer Trace for Test No. 608331-01-6 (Accelerometer Located at Center of Gravity).**

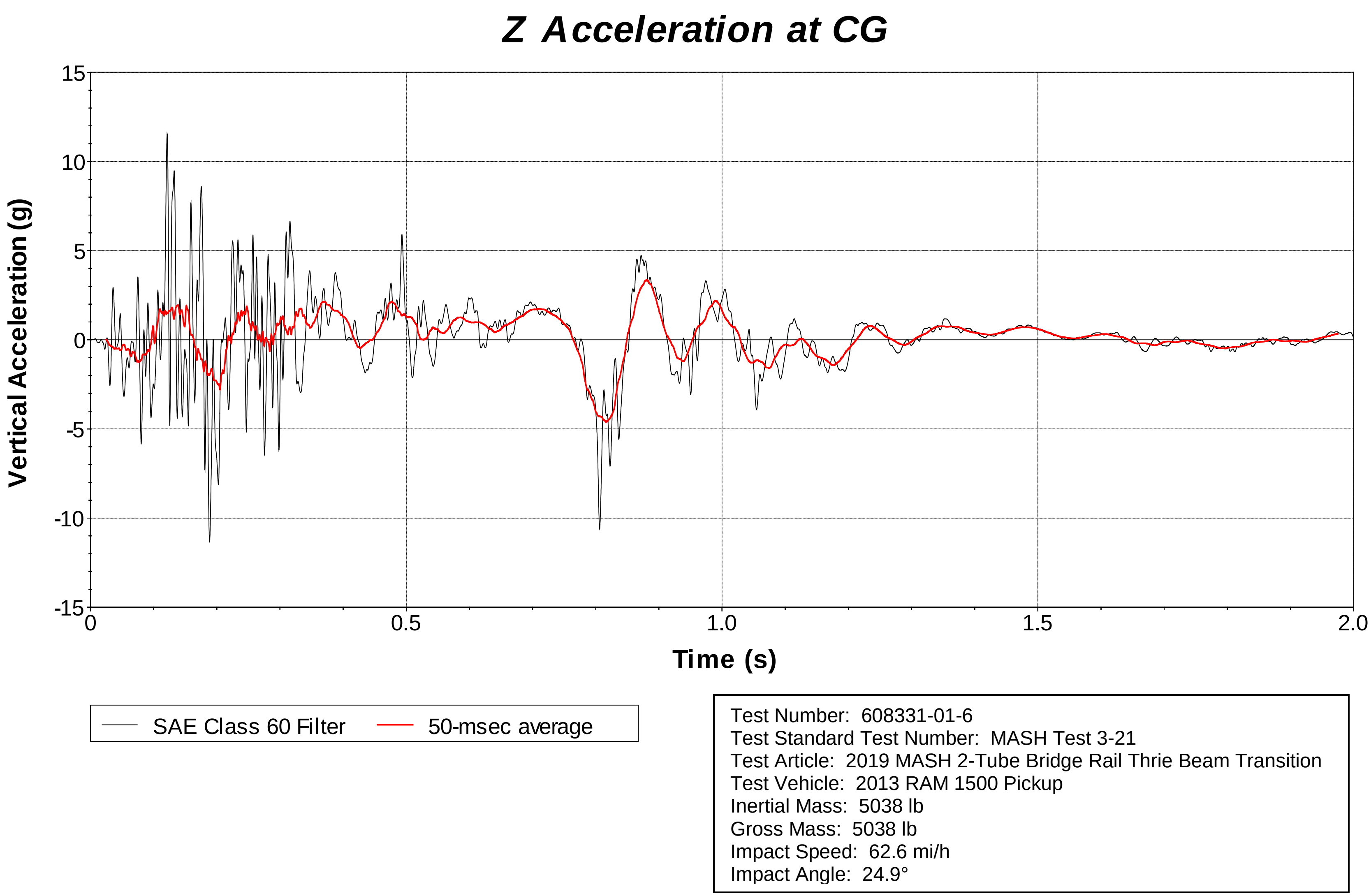



**Figure F.6. Vehicle Vertical Accelerometer Trace for Test No. 608331-01-6 (Accelerometer Located at Center of Gravity).**