Texas A&M Transportation Institute Proving Ground

Test Report No. 616391-01

DESIGN AND *MASH* EVALUATION OF TRANSITION BETWEEN GUARDRAIL TO ANCHORED PORTABLE CONCRETE BARRIER

Sponsored by

Washington State Department of Transportation (WsDOT)

TEXAS A&M TRANSPORTATION INSTITUTE PROVING GROUND
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16. Abstract

This report presents the development and full-scale crash testing of the Transition between Guardrail to Anchored Portable Concrete Barrier ("Transition"). The design of the Transition was developed using finite element simulation and analysis. A standard W-beam guardrail was connected to portable concrete barriers that were anchored to underlying asphalt using steel pins. The transition section was comprised of previously crash tested W-beam to nested Thrie-beam transition. This report presents the details and results of simulation analyses. It also presents the assessment of the performance of the Transition according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*), Second Edition (*1*). The crash tests were performed in accordance with *MASH* Test Level 3 (TL-3), which requires two crash tests:

1. ***MASH* Test 3-20:** An 1100C vehicle weighing 2420 lb impacting the longitudinal barrier at 25 degrees, while travelling at 62 mi/h.
2. ***MASH* Test 3-21:** A 2270P vehicle weighing 5000 lb impacting the longitudinal barrier at 25 degrees, while traveling at 62 mi/h.

This report provides details of the Transition, the crash tests and results, and the performance assessment of the Transition for *MASH* TL-3 evaluation criteria for longitudinal barriers.

The Transition between Guardrail to Anchored Portable Concrete Barrier met the performance criteria for *MASH* TL-3 for longitudinal barriers.

17. Key Words Guardrail, Portable Concrete Barrier, PCB, Transition, Crash Test, MASH, Longitudinal Barrier, Anchored, Finite Element Analysis, Simulation, FEA	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia 22312 http://www.ntis.gov

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The results reported herein apply only to the article tested. The full-scale crash tests were performed according to TTI Proving Ground quality procedures and American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware, Second Edition (*MASH*) guidelines and standards.

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square 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

Chapter 1. INTRODUCTION

In many situations, especially in mountainous areas, anchored portable concrete barriers (PCB) may be placed adjacent to steep slopes. Slopes such 2H:1V are not uncommon. Due to the limited space available behind the barrier, PCB segments are usually anchored to restrict their lateral movement on vehicle impact. There is often a need to connect a W-beam guardrail system to the anchored PCB system. Currently there are no available guardrail to anchored PCB transition designs that are *MASH* compliant.

1.1. OBJECTIVE

The goal of this project was to develop a transition between the 31-inch tall, steel-post W-beam guardrail and the 32-inch tall F-shape PCB system that is anchored using inclined steel pins on asphalt pavement. The transition design was required to meet *MASH* TL-3 requirements.

This report presents the design development using finite element (FE) simulations and the assessment of Transition between Guardrail to Portable Concrete Barrier ("Transition") according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*), Second Edition (*1*). The crash tests were performed in accordance with *MASH* Test Level 3 (TL-3), which requires two crash tests (as discussed in Chapter 4).

Chapter 2. DESIGN DEVELOPMENT AND IMPACT SIMULATION

The PCB system selected for this project had 12.5-ft long segments that were connected to each other using the pin-and-loop connection. This anchored PCB system was previously designed and successfully crash tested under MASH. *(2)* It is anchored to an underlying asphalt pavement that is 4 inches thick. Three inclined steel pins are used to anchor each PCB segment. This chapter provides the details of the various concepts that were developed in the initial stages of the project, the FE model of the selected design concept, results of the impact simulations performed with the transition model, and recommendations for crash testing that were made based on the results of the simulations. Subsequent chapters present further details of the prototype test installation constructed for *MASH* testing and the results of the tests performed.

2.1. CONCEPTUAL DESIGN

The research team prepared three initial design concepts for the review and selection of the Technical Representative. These concepts are presented in Figure 2.1 through Figure 2.3. In all concepts, the W-beam guardrail was attached to the anchored PCB system using the W-beam to nested Thrie-beam guardrail transition system. The W-beam to nested Thrie-beam system has previously been crash tested and passed under MASH evaluation criteria for TL-3. The post spacing in the nested Thrie beam section is reduced to quarter-post-spacing (18.75 inches) to stiffen the guardrail in advance of the start of the concrete barrier. The Thrie beam was connected to the PCB system using a Thrie beam end connector.

In the first design concept (Figure 2.1), the F-shape barrier segment adjacent to the nested Thrie beam was rotated 6 inches toward the non-impact side. Three wood blocks of varying depths were placed between the Thrie beam guardrail and the surface of the concrete barrier. These blocks prevented the guardrail from having excessive deformation as the vehicle transitioned from the stiff nested Thrie beam to the PCB segment.

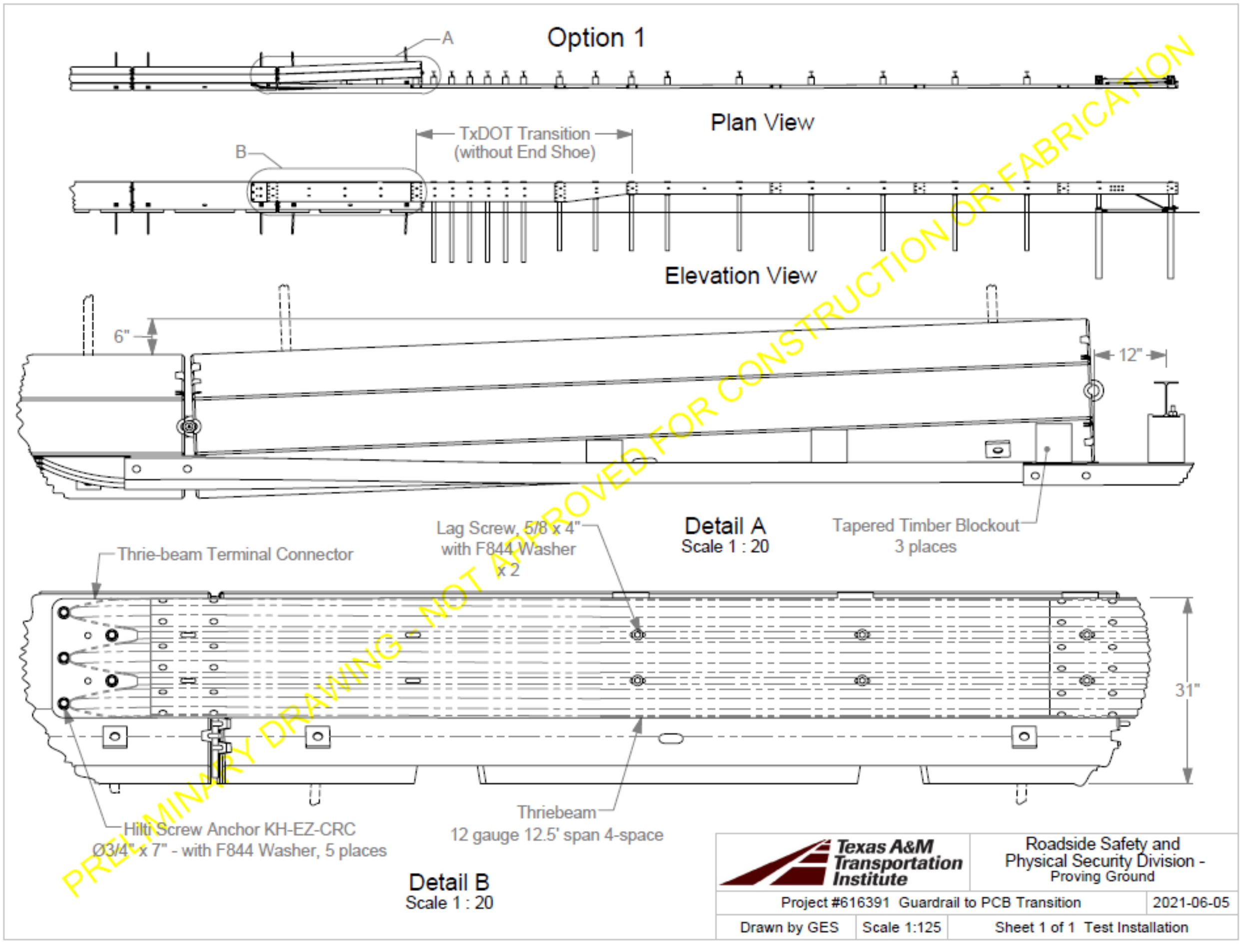


Figure 2.1. Transition Design Concept 1.

The second concept (Figure 2.2) was similar to the first concept, however, the first PCB was not rotated back. Instead, the nested Thrie beam covering the PCB was rotated back to be connected to the second PCB segment using a Thrie beam end connector. This concept also used three wood blocks between the Thrie beam and the first PCB segment.

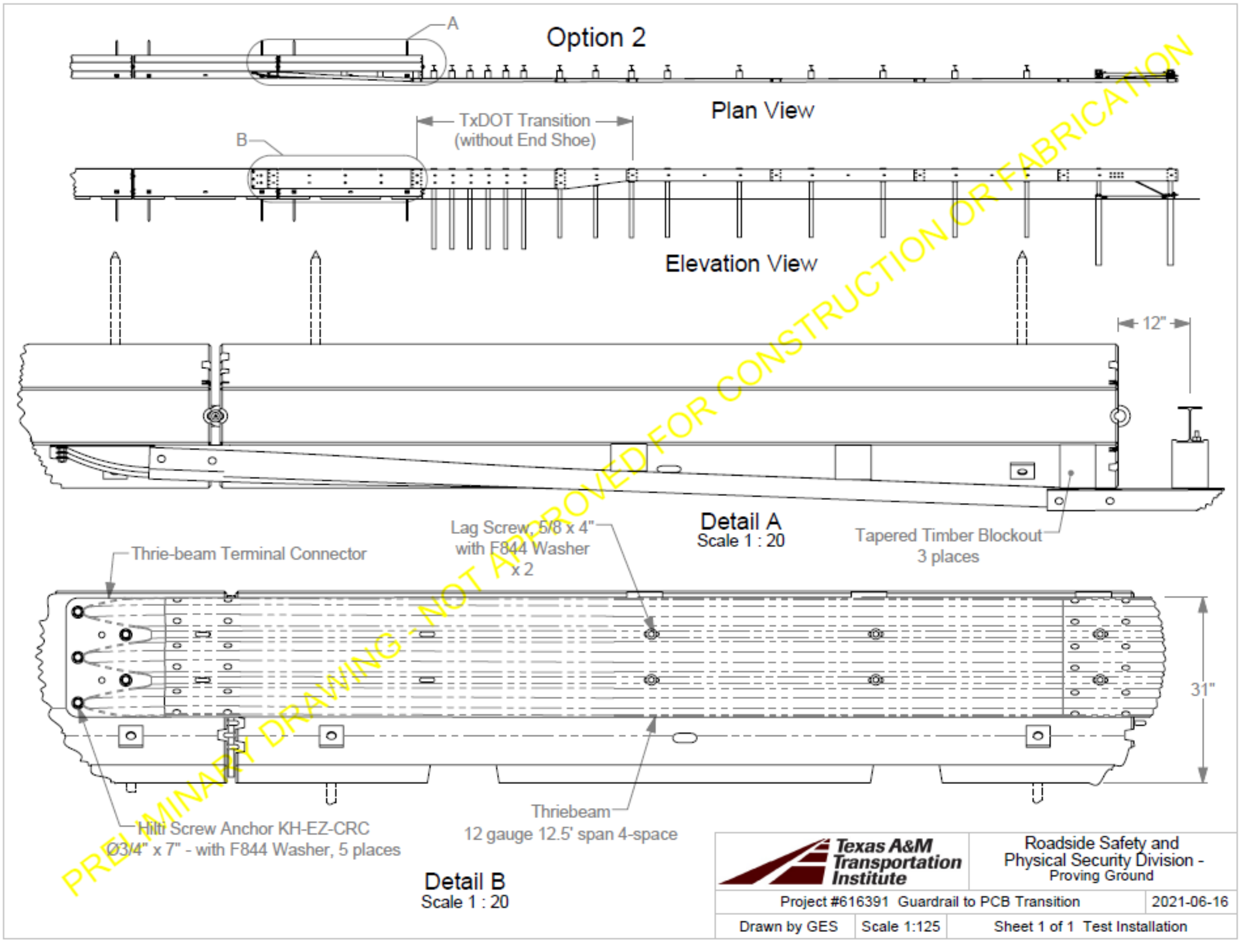


Figure 2.2. Transition Design Concept 2.

In the third concept (Figure 2.3), the Thrie beam system was connected to the end of the first PCB segment, without covering the entire length of the segment. To reduce vehicle snagging potential with the toe of the barrier, a 4-ft long short curb section was proposed that would be installed in advance of the F-shape PCB segment. This curb section transitioned to the shape of the F-shape segment's toe and was to be anchored into the asphalt pavement to prevent it from sliding during the vehicle impact.

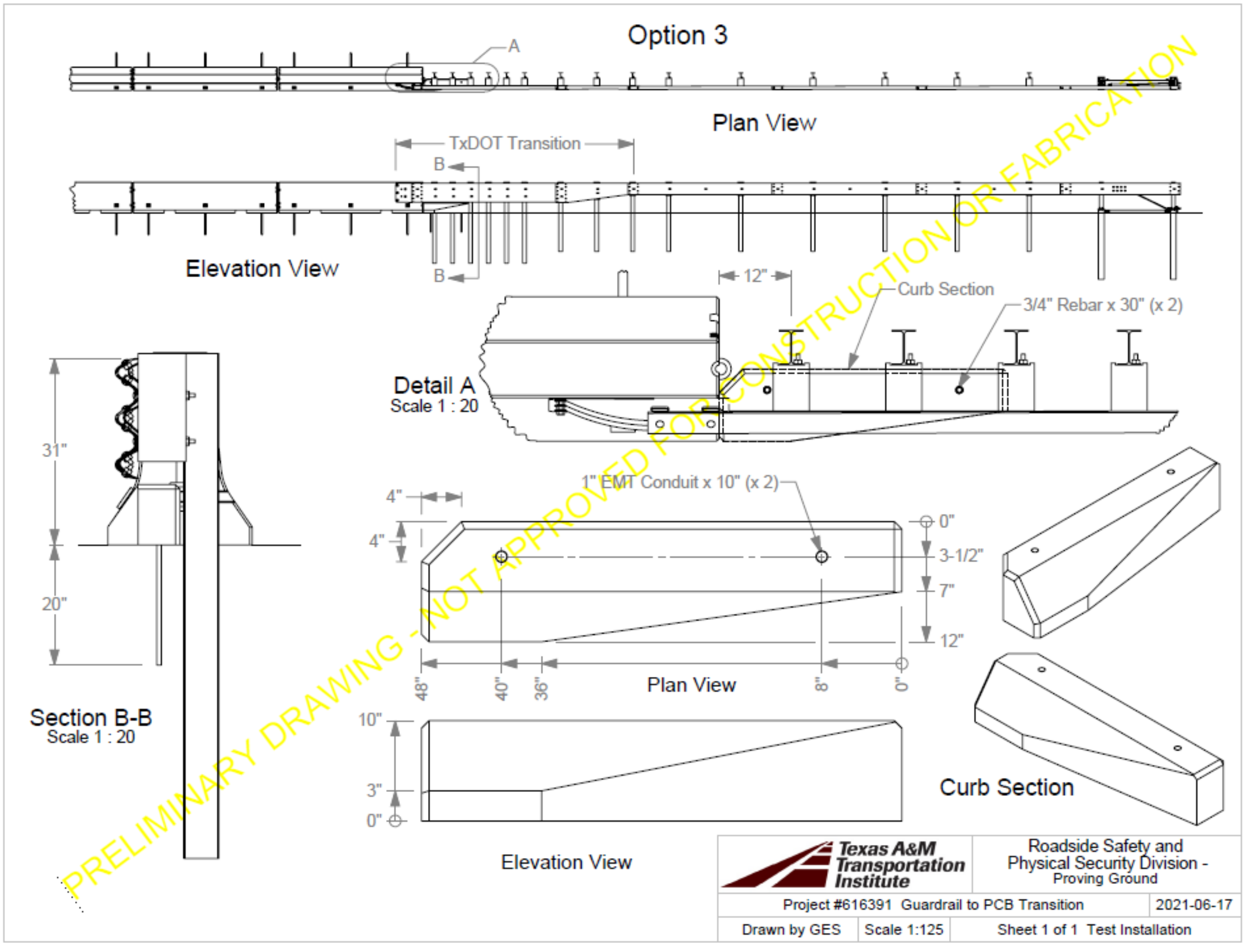


Figure 2.3. Transition Design Concept 3.

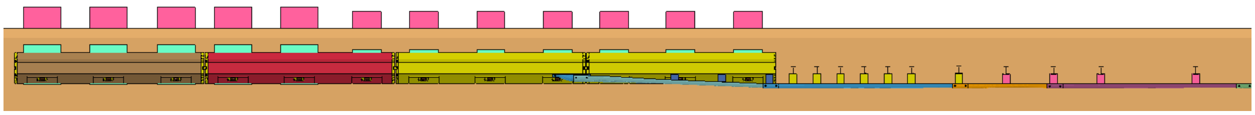
The research team presented the three concepts to the Technical Representative, and the second concept (Figure 2.2) was selected for further development through simulation analysis and full-scale crash testing.

2.2. FINITE ELEMENT MODEL

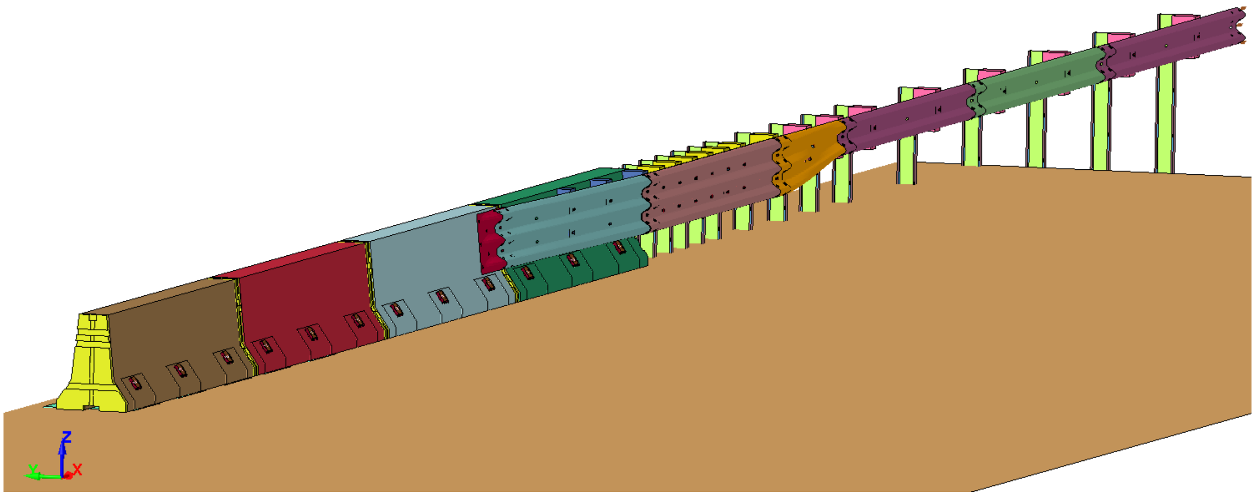
The research team developed a full-scale model of the anchored PCB to W-beam guardrail system proposed in Figure 2.2. The research team then performed impact simulations using *MASH* TL-3 impact conditions. All simulations were performed using the FE method. LS-DYNA, which is a commercially available general-purpose FE analysis software, was used for the analysis.

Figure 2.4 presents different views of the overall anchored PCB to W-beam guardrail system model. The metal guardrail system parts, the barrier connections, and the anchoring pins were modeled with elastic-plastic material representation. The barrier segments were modeled with mostly rigid material representation, except in the regions around the anchoring pins where deformable concrete material was used. The anchoring pins passed through the barrier segments and into the 4-inch thick asphalt pad and the underlying soil. The asphalt and the soil were also modeled with deformable materials that represented their respective properties.

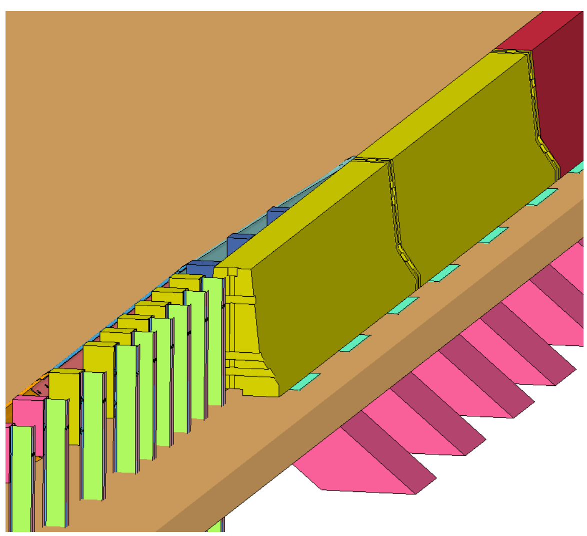
Vehicle models used in the simulation analysis were publicly available models developed by the Center for Collision Safety and Analysis under Federal Highway Administration (FHWA) and National Highway Traffic Safety Administration (NHTSA) sponsorships. These models have been further improved by the TTI research team over the course of various research projects to achieve greater validation and robustness.



Plan View



Isometric View



Back-side Isometric View

Figure 2.4. Finite Element Model of the Transition System.

2.3. IMPACT SIMULATIONS OF MASH TESTS

The researchers performed impact simulations for *MASH* Test 3-21. This involved impacting the transition system with a 5,000-lb pickup truck at an impact speed and angle of 62 mi/h and 25 degrees. A RAM model was used in the simulations. Three simulations were performed with the vehicle impacting 56 inches, 92 inches, 128 inches, and 164 inches upstream of the end of the PCB attached to the Thrie beam. While the vehicle was successfully contained and redirected in all of the simulations, the impact at 92 inches upstream of the end of the anchored PCB was determined to be the critical impact point (CIP) for Test 3-21 due to the greatest vehicle snag potential with the anchored PCB segment. The results of this simulation are shown in Figure 2.5. The maximum occupant impact velocity (OIV) and ride-down acceleration (RA) were 28.2 ft/s and 9.7 g, respectively. The transition system had a maximum dynamic and permanent deflection of 2.04 inches. Results of the simulation showed that the surface-mounted median guardrail design was expected to pass *MASH* Test 3-21 evaluation criteria in a full-scale crash test.

The researchers also performed impact simulations for *MASH* Test 3-21. This involved impacting the transition system with a 3,300-lb small passenger sedan at an impact speed and angle of 62 mi/h and 25 degrees. A Toyota Yaris model was used in the simulations. Three simulations were performed with the vehicle impacting 22.5 inches, 58.5 inches, and 94.5 inches upstream of the end of the anchored PCB attached to the Thrie beam. While the vehicle was successfully contained and redirected in all of the simulations, the impact at 58.5 inches upstream of the end of the anchored PCB was determined to be the CIP for Test 3-21 due to greatest snag potential with the PCB segment. The results of this simulation are shown in Figure 2.6. The maximum OIV and RA were 29.2 ft/s and 16.8 g, respectively. The transition system had a maximum dynamic and permanent deflection of 5.71 inches. Results of the simulation showed that the surface-mounted median guardrail design was expected to pass *MASH* Test 3-20 evaluation criteria in a full-scale crash test.

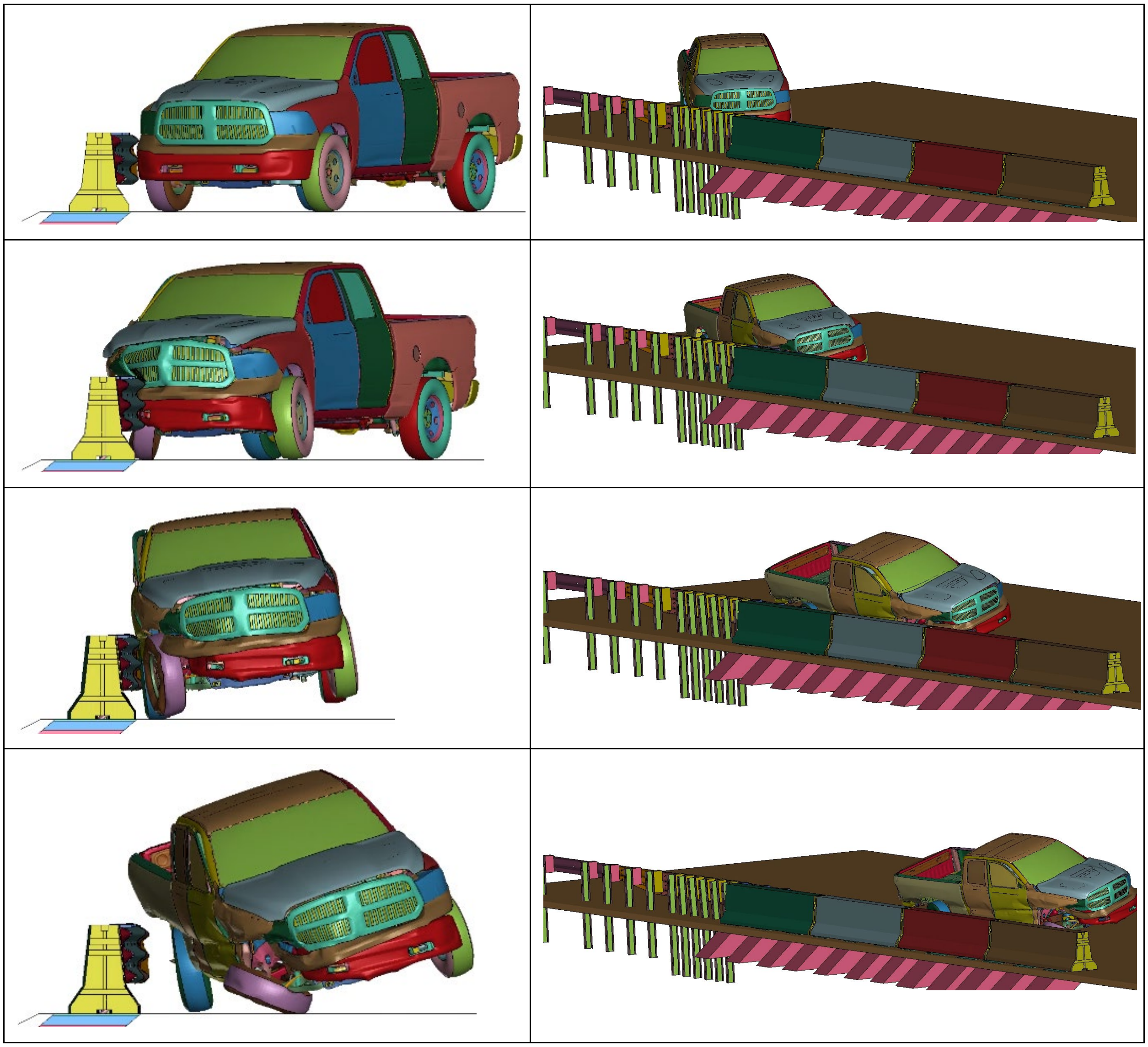


Figure 2.5. Simulation Results of MASH Test 3-21 with Pickup Truck.

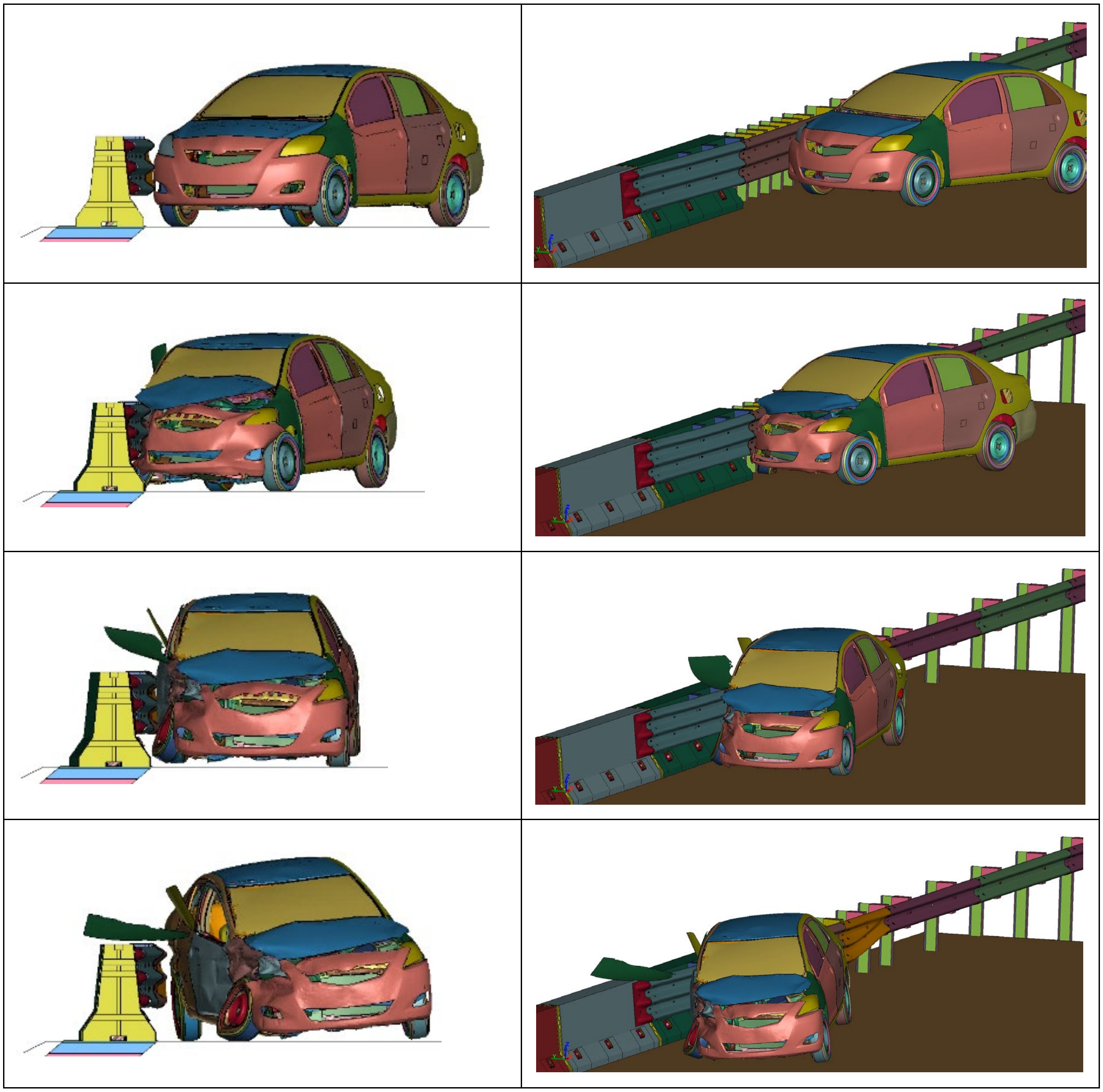


Figure 2.6. Simulation Results of MASH Test 3-20 with Small Passenger Car.

Based on the successful performance of the guardrail in the impact simulations of *MASH* Tests 3-20 and 3-21, the researchers proceeded with the full-scale crash testing. The details of these are presented in the following chapters.

Chapter 3. SYSTEM DETAILS

3.1. TEST ARTICLE AND INSTALLATION DETAILS

The installation was 115 ft-5¼ inches long, and consisted of four 12½ foot long, steel reinforced, F-shape concrete barriers that transitioned to a standard 31-inch-high W-beam guardrail. The concrete barriers were connected to each other via end loops with 1-inch diameter connection pins. They were placed on a 4-inch thick, 8 foot wide, 52 foot long, asphalt pad, which was constructed on top of a 12-inch thick layer of crushed limestone base. Each barrier segment had three 1½-inch diameter anchor pins securing it to the underlying asphalt and base. A 1.5H:1V slope was constructed on the non-impact side of the barriers, with a 12-inch offset from the edge of the barrier segments.

The guardrail transition began approximately 30 inches downstream of the joint between Barriers 1 and 2, and measured 45 ft-1½-inches long to the W-beam lap splice between posts 6 and 7. From the downstream end, it consisted of a Thrie-beam Terminal Connector that was attached to Barrier 2, a 12½ foot long section of 4-space Thrie-beam, a 12½ foot long section of two nested Thrie-beams, a 75-inch long Asymmetric Thrie-beam to W-beam Transition section, and a 12½ foot long section of 4-space W-beam guardrail. The nested Thrie-beams, Asymmetric Transition, and W-beams were supported by W6×8.5 posts and timber blockouts. Timber blocks of varying depth were attached to the Thrie-beam section covering Barrier 1.

Upstream of the transition, a 25-ft long standard 31-inch tall W-beam guardrail was attached. It was terminated by attaching to a Steel Post Terminal on the upstream end.

Figure 3.1 presents the overall information on the Transition, and Figure 3.2 thru Figure 3.7 provide photographs of the installation. Appendix A provides further details on the Transition. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, asphalt was installed by BPI, and construction was performed by TTI Proving Ground personnel.

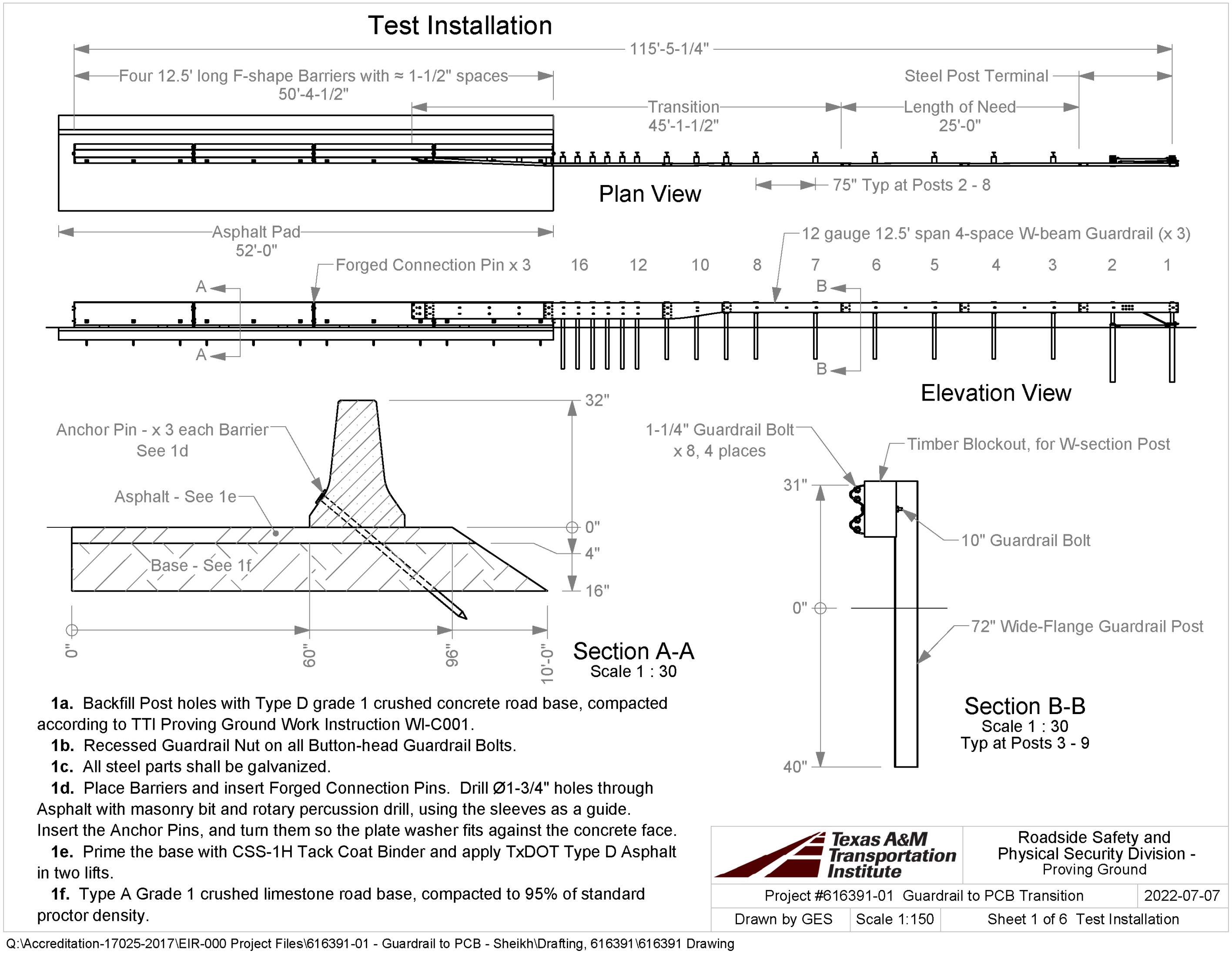


Figure 3.1. Details of Transition System.

Figure 3.2. Transition prior to Testing.

Figure 3.3. Transition prior to Testing.

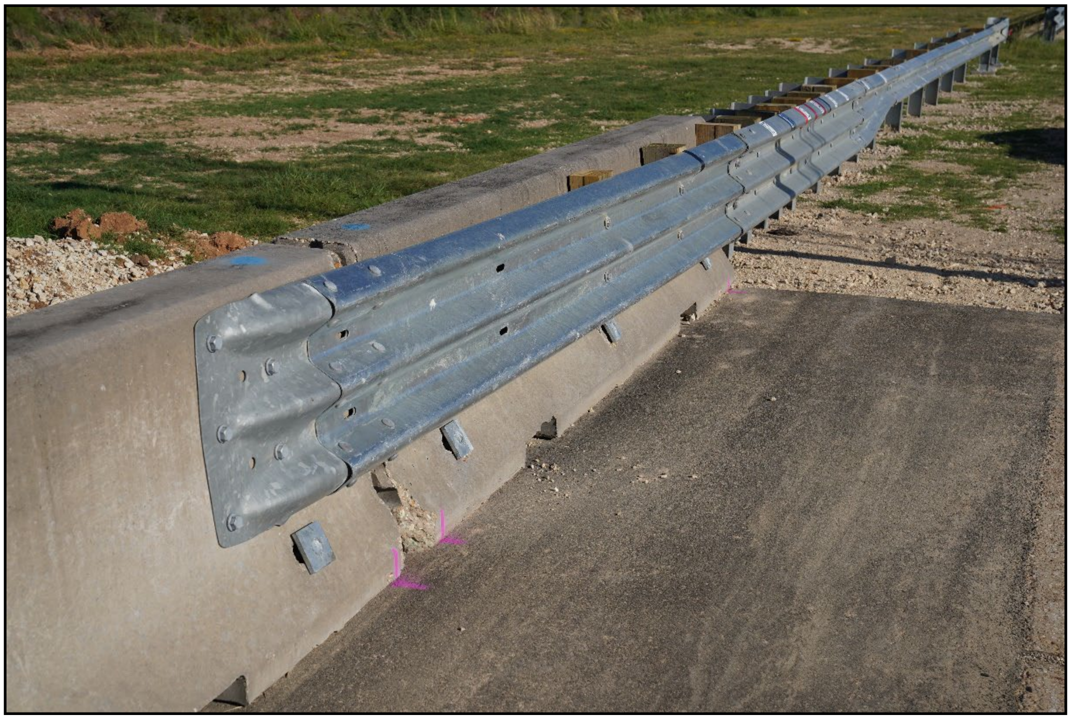


Figure 3.4. Transition prior to Testing.

Figure 3.5. Transition prior to Testing.

Figure 3.6. Transition prior to Testing.

Figure 3.7. Transition prior to Testing.

3.2. DESIGN MODIFICATIONS DURING TESTS

No modifications were made to the installation during the testing phase.

3.3. SOIL CONDITIONS

The posts for the test installation were installed in standard soil meeting Grading D of AASHTO standard specification M 147-17 "Materials for Aggregate and Soil-Aggregate Subbase, Base, and Surface Courses."

In accordance with Appendix B of *MASH*, soil strength was measured on the day of the crash test. During installation of the 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 B.1 in Appendix B presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B.

The tests are summarized in Appendix B, Table B.1 and Table B.2.

On the day of Test 3-20, 2022-09-19, loads on the post at deflections are shown in Table 3.1: the backfill material in which the Transition was installed met minimum *MASH* requirements for soil strength.

Table 3.1. Soil Strength for 616391-01-1.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	9100
10	4981	10,000
15	5282	11,000

On the day of Test 3-21, 2022-10-04, loads on the post at deflections are shown in Table 3.2: the backfill material in which the Transition was installed met minimum *MASH* requirements for soil strength.

Table 3.2. Soil Strength for 616391-01-2.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	11,000
10	4981	N/A*
15	5282	N/A*

*Loads at 10 and 15 inches were not measured due to the high load recorded at 5 inches

Chapter 4. TEST REQUIREMENTS AND EVALUATION CRITERIA

4.1. CRASH TEST PERFORMED/MATRIX

Table 4.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for longitudinal barriers. The target critical impact points (CIPs) for each test were determined using the simulation analysis presented in Chapter 2. Figure 4.1 shows the target CIP for *MASH* Tests 3-20 and 3-21on the Transition.

Table 4.1. Test Conditions and Evaluation Criteria Specified for *MASH* TL-3 Longitudinal Barriers.

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

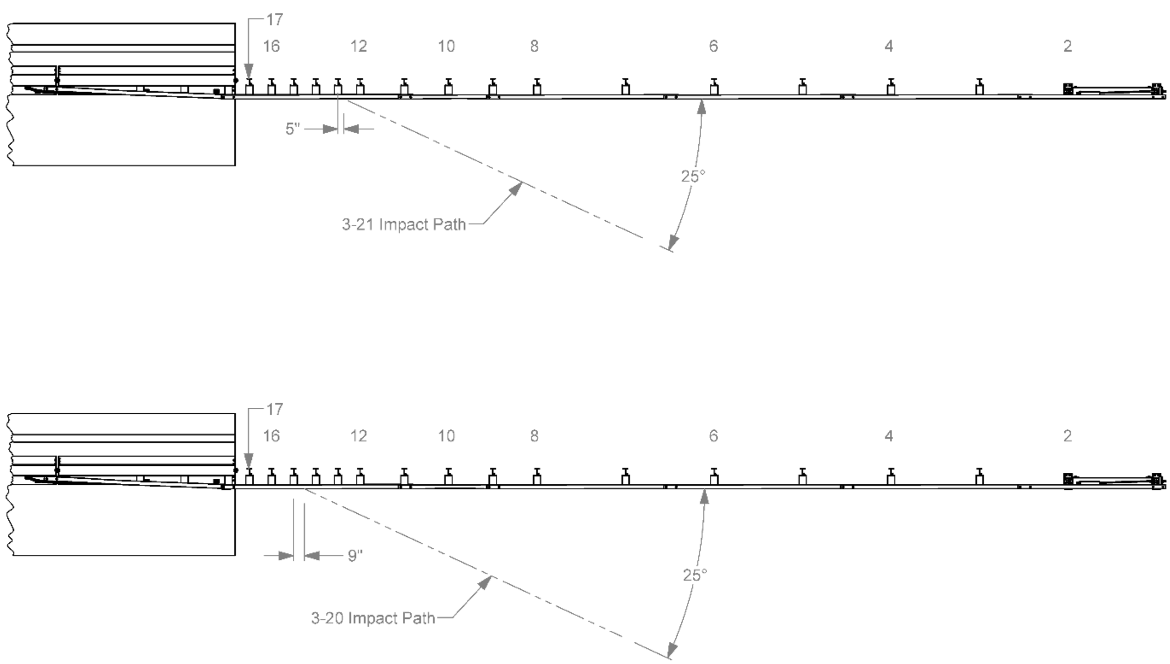


Figure 4.1. Target CIP for *MASH* TL-3 Tests on Transition.

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

4.2. 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. Table 4.1 lists the test conditions and evaluation criteria required for *MASH* TL-3, and Table 4.2 provides detailed information on the evaluation criteria.

Table 4.2. Evaluation Criteria Required for *MASH* Testing.

Evaluation Factors	Evaluation Criteria	*MASH* Test
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.	20, 21
D.	Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of *MASH*.	20, 21
F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	20, 21
H.	Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.	20, 21
I.	The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	20, 21

Chapter 5. TEST CONDITIONS

5.1. TEST FACILITY

The full-scale crash tests reported herein were performed at the 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, as well as *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 mi 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, highway pavement durability and efficacy, and roadside safety hardware and perimeter protective device evaluation. The sites selected for construction and testing are along the edge of an out-of-service apron/runway. The apron/runway 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.

5.2. VEHICLE TOW AND GUIDANCE SYSTEM

For the tests utilizing the 1100C and 2270P vehicles, each 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 and 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.

5.3. DATA ACQUISITION SYSTEMS

5.3.1. Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained onboard data acquisition system. The signal conditioning and acquisition system is a multi-channel data acquisition system (DAS) 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 data acquisition hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 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 in case the primary battery cable is 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 DAS 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 DAS is returned to the factory annually for complete recalibration and to ensure that all instrumentation used in the vehicle conforms to the 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 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 anytime 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 DAS-captured data to compute the occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and 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, and 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 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).

5.3.2. 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, and no dummy was used in the test.

5.3.3. Photographic Instrumentation Data Processing

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

- One located overhead with a field of view perpendicular to the ground and directly over the impact point.
- One placed upstream from the installation at an angle to have a field of view of the interaction of the rear of the vehicle with the installation.
- A third placed with 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 Guardrail to Portable Concrete Barrier. 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.

Chapter 6. *MASH* TEST 3-20 (CRASH TEST NO. 616391-01-1)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 6.1 for details on *MASH* impact conditions for this test and Table 6.2 for the exit parameters. Figure 6.1 and Figure 6.2 depict the target impact setup.

Table 6.1. Impact Conditions for *MASH* Test 3-20 (616391-01-1).

Test Parameter	**Specification**	**Tolerance**	**Measured**
Impact Speed (mi/h)	62	±2.5 mi/h	62.2
Impact Angle (deg)	25	±1.5°	25.2
Impact Severity (kip-ft)	51	≥51 kip-ft	57.6
Impact Location	9 inches upstream from centerline of post 15.	± 12 inches	9.5 inches upstream from centerline of post 15.

Table 6.2. Exit Parameters for *MASH* Test 3-20 (616391-01-1).

Exit Parameter	**Measured**
Speed (mi/h)	47.3
Trajectory (deg)	4
Heading (deg)	4
Brakes applied post impact (s)	3.6
Vehicle at rest position	238 ft downstream of impact point 112 ft to the traffic side 80° left
Comments:	Vehicle remained upright and stable. Vehicle crossed exit box [a] 59 ft downstream from loss of contact.

[a] Not less than 32.8 ft downstream from loss of contact for cars and pickups is optimal.

Figure 6.1. Transition/Test Vehicle Geometrics for Test 616391-01-1.

Figure 6.2. Transition/Test Vehicle Impact Location 616391-01-1.

6.2. WEATHER CONDITIONS

Table 6.3 provides the weather conditions for 616391-01-1.

Table 6.3. Weather Conditions 616391-01-1.

Date of Test	2022-09-19 AM
Wind Speed (mi/h)	4
Wind Direction (deg)	191
Temperature (°F)	86
Relative Humidity (%)	75
Vehicle Traveling (deg)	195

6.3. TEST VEHICLE

Figure 6.3 and Figure 6.4 show the 2016 Nissan Versa used for the crash test. Table 6.4 shows the vehicle measurements. Table C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.

Figure 6.3. Impact Side of Test Vehicle before Test 616391-01-1.

Figure 6.4. Opposite Impact Side of Test Vehicle before Test 616391-01-1.

Table 6.4. Vehicle Measurements 616391-01-1.

Test Parameter	*MASH*	Allowed Tolerance	Measured
Dummy (if applicable)[a] (lb)	165	N/A	165
Inertial Weight (lb)	2420	±55	2458
Gross Static[a] (lb)	2585	±55	2623
Wheelbase (inches)	98	±5	102.4
Front Overhang (inches)	35	±4	32.5
Overall Length (inches)	169	±8	175.4
Overall Width (inches)	65	±3	66.7
Hood Height (inches)	28	±4	30.5
Track Width[b] (inches)	59	±2	58.4
CG aft of Front Axle[c] (inches)	39	±4	42.0
CG above Ground[c,d] (inches)	N/A	N/A	N/A

[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

6.4. TEST DESCRIPTION

Table 6.5 lists events that occurred during Test No. 616391-01-1. Figures C.1 and C.2 in Appendix C.2 present sequential photographs during the test.

Table 6.5. Events during Test 616391-01-1.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0140	Posts 13, 14, 15, 16 and 17 began to lean toward field side
0.0350	Vehicle began to redirect
0.0500	Upstream edge of first PCB began to move toward field side
0.0540	Windshield began to crack due to vehicle body flexing from impact
0.1190	Upstream edge of first PCB stopped moving toward field side
0.1760	Vehicle was parallel with the installation
0.3030	Vehicle exited the installation at 47.4 mi/h with a heading of 4 degrees and a trajectory of 4 degrees

6.5. DAMAGE TO TEST INSTALLATION

The rail was scuffed at the impact location and along the length of the contact. The upstream end of the barrier was pushed back 4 inches. Table 6.7 and Table 6.6 describe the damage to the Transition. Figure 6.5 through Figure 6.13 show the damage to the Transition.

Table 6.6. Post Movement in Test 616391-01-1.

Post Number	Soil Gap (inches)	Post Lean from Vertical (degrees)
12	⅛ t/s	0
13	¼ t/s	0
14	⅜ t/s	1
15	⅜ t/s	1
16	¼ f/s	1
17	¼ f/s	1.5

t/s: traffic side; f/s: field side

Table 6.7. Damage to Transition in Test 616391-01-1.

Test Parameter	Measured
Permanent Deflection/Location	4 inches toward field side, at the upstream end of the first concrete barrier
Maximum Dynamic Deflection	6 inches toward field side, at the top of the upstream end of the first concrete barrier.
Working Width [a] and Height	30.2 inches, at a height of 0 inches at the base of the first concrete barrier

[a] 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 6.5. Transition after Test at Impact Location 616391-01-1.

Figure 6.6. Transition after Test at Grade Near the Impact Point 616391-01-1.

Figure 6.7. Transition after Test In-line with Portable Concrete Barrier 616391-01-1.

Figure 6.8. Asphalt Damage at the Upstream Anchor Pin Location 616391-01-1.

Figure 6.9. Damage to the Upstream Anchor Pin 616391-01-1.

Figure 6.10. Asphalt Damage at the Middle Anchor Pin Location 616391-01-1.

Figure 6.11. Damage to the Middle Anchor Pin 616391-01-1.

Figure 6.12. Asphalt Damage at the Downstream Anchor Pin Location 616391-01-1.

Figure 6.13. Damage to the Downstream Anchor Pin 616391-01-1.

6.6. DAMAGE TO TEST VEHICLE

Figure 6.14 and Figure 6.15 show the damage sustained by the vehicle. Figure 6.16 and Figure 6.17 show the interior of the test vehicle. Table 6.8 and Table 6.9 provide details on the occupant compartment deformation and exterior vehicle damage. The windshield sustained two tears in the laminate: one measuring 13 inches long × 1.25 inches wide and the other 8 inches long × 1.25 inches wide. The windshield's permanent deformation measured 2.75 inches deep. The tears and deformation damage to the windshield was caused by the flexing of the frame members during the impact, and not by any element(s) of the test article. Tables C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

Figure 6.14. Impact Side of Test Vehicle after Test 616391-01-1.

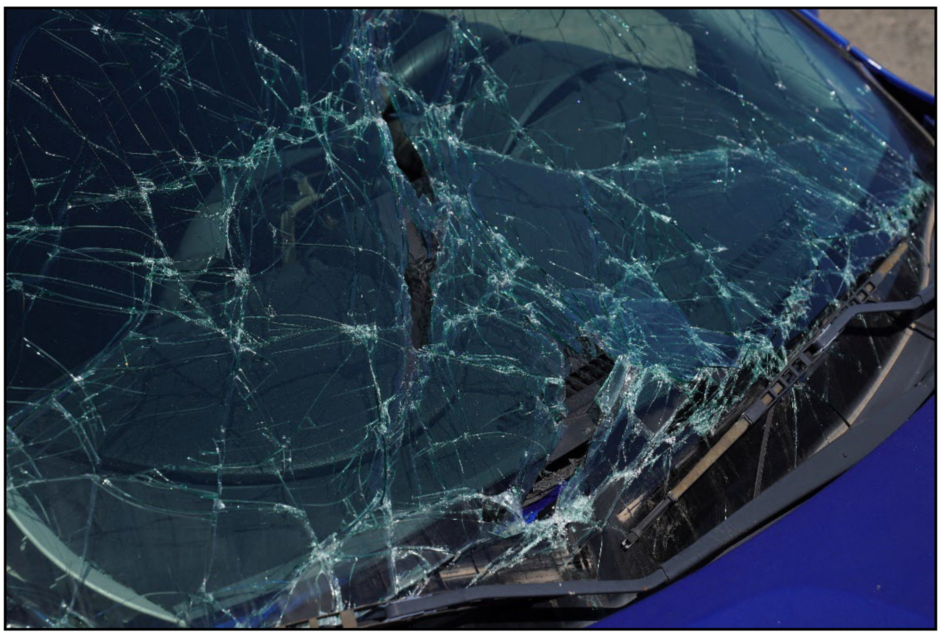


Figure 6.15. Windshield Deformation of the Test Vehicle after Test 616391-01-1.

Figure 6.16. Overall Interior of Test Vehicle after Test 616391-01-1.

Figure 6.17. Interior of Test Vehicle on Impact Side after Test 616391-01-1.

Table 6.8. Occupant Compartment Deformation in Test 616391-01-1.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	2.75 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	3 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	5.5 inches
Front Door (above Seat)	≤9.0 inches	5 inches
Front Door (below Seat)	≤12.0 inches	0 inches

Table 6.9. Exterior Vehicle Damage in Test 616391-01-1.

Side Windows	The side windows remained intact.
Maximum Exterior Deformation	10 inches in the front plane at the right front corner at bumper height
VDS	01RFQ5
CDC	01FREW4
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, right front head light, right front tire and rim, right front a-pillar, windshield, right front door, right front floor pan, roof, right rear door and rear bumper were damaged. The windshield was cracked and deformed in an area 45 inches by 29 inches and 2.75 inches deep. The windshield sustained two tears in the laminate: one measuring 13 inches long × 1.25 inches wide and the other 8 inches long × 1.25 inches wide. The windshield's permanent deformation measured 2.75 inches deep. The tears and deformation damage was caused by the flexing of the frame members during the impact and not caused by any element(s) of the test article. The right front door had a 6-inch gap at the top. The roof had 3 small dents, with maximum deformation of 5 inches wide and 0.5 inches deep.

6.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.10. Figure C.3 in Appendix C.3 shows the vehicle angular displacements, and Figures C.4 through C.6 in Appendix C.4 show acceleration versus time traces.

Table 6.10. Occupant Risk Factors for Test 616391-01-1.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0	21.0	0.0845 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0	25.2	0.0845 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49	5.4	0.1091 - 0.1191 seconds
Ridedown, Lateral (g)	≤20.49	10.4	0.0949 - 0.1049 seconds
THIV (m/s)	N/A	10.1	0.0823 seconds on right side of interior
ASI	N/A	2.1	0.0496 - 0.0996 seconds
50-ms MA Longitudinal (g)	N/A	-11.6	0.0373 - 0.0873 seconds
50-ms MA Lateral (g)	N/A	-16.0	0.0188 - 0.0688 seconds
50-ms MA Vertical (g)	N/A	3.3	0.0158 - 0.0658 seconds
Roll (deg)	≤75	9	0.4277 seconds
Pitch (deg)	≤75	6	1.9995 seconds
Yaw (deg)	N/A	44	2.0000 seconds

0.000 s

0.200 s

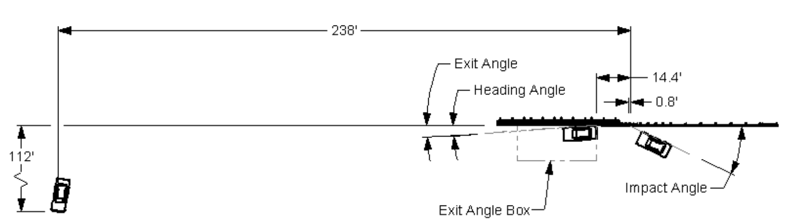
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-20
TTI Project No.	616391-01-1
Test Date	2022-09-19
TEST ARTICLE	
Type	Longitudinal Barrier Transition
Name	Transition between Guardrail to Anchored Portable Concrete Barrier
Length	115 feet 5¼ inches
Key Materials	32-inch tall F-shape concrete barriers pinned on asphalt, Thrie-beam and W-beam Guardrail, 31-inch tall guardrail, 72-inch long wide-flange guardrail posts
Soil Type and Condition	AASHTO M147-65(2004), Grading D Crushed Concrete
TEST VEHICLE	
Type/Designation	1100 C
Year, Make and Model	2016 Nissan Versa
Inertial Weight (lb)	2458
Dummy (lb)	165
Gross Static (lb)	2623
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.2
Impact Angle (deg)	25.2
Impact Location	9.5 inches upstream from centerline of post 15.
Impact Severity (kip-ft)	57.6
EXIT CONDITIONS	
Exit Speed (mi/h)	47.3
Trajectory/Heading Angle (deg)	4 / 4
Exit Box Criteria	Vehicle crossed the exit box
Stopping Distance	238 ft downstream 112 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	6
Permanent (inches)	4
Working Width / Height (inches)	30.2 / 0
VEHICLE DAMAGE	
VDS	01RFQ5
CDC	01FREW4
Max. Ext. Deformation	10
Max Occupant Compartment Deformation	5.5 inches in the side kick panel

OCCUPANT RISK VALUES

Long. OIV (ft/s)	21.0	Long. Ridedown (g)	5.4	Max 50-ms Long. (g)	-11.6	Max Roll (deg)	9
Lat. OIV (ft/s)	25.2	Lat. Ridedown (g)	10.4	Max 50-ms Lat. (g)	-16.0	Max Pitch (deg)	6
THIV (m/s)	10.1	ASI	2.1	Max 50-ms Vert. (g)	3.3	Max Yaw (deg)	44



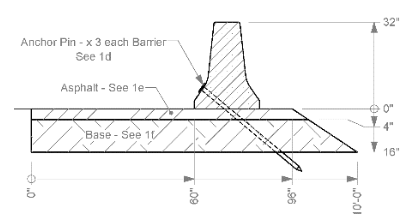


Figure 6.18. Summary of Results for *MASH* Test 3-20 on Transition.

Chapter 7. *MASH* TEST 3-21 (CRASH TEST NO. 616391-01-2)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 7.1 for details on *MASH* impact conditions for this test and Table 7.2 for the exit parameters. Figure 7.1 and Figure 7.2 depict the target impact setup.

Table 7.1. Impact Conditions for *MASH* Test 3-21 616391-01-2.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62 mi/h	± 2.5 mi/h	62.9
Impact Angle (deg)	25°	± 1.5°	25.9
Impact Severity (kip-ft)	106 kip-ft	≥106 kip-ft	127.1
Impact Location	5 inches upstream from the centerline of post 13.	± 12 inches	13 inches upstream from centerline of post 13.

Table 7.2. Exit Parameters for *MASH* Test 3-21 616391-01-2.

Exit Parameter	Measured
Speed (mi/h)	50.8
Trajectory (deg)	5
Heading (deg)	10
Brakes applied post impact (s)	Not Applied
Vehicle at rest position	208 ft downstream of impact point 56 ft to the traffic side 45° left
Comments:	Vehicle remained upright and stable. Vehicle crossed exit box [a] 60 ft downstream from loss of contact.

[a] Not less than 32.8 ft downstream from loss of contact for cars and pickups is optimal.

Figure 7.1. Transition/Test Vehicle Geometrics for Test 616391-01-2.

Figure 7.2. Transition/Test Vehicle Impact Location 616391-01-2.

7.2. WEATHER CONDITIONS

Table 7.3 provides the weather conditions for 616391-01-2.

Table 7.3. Weather Conditions 616391-01-2.

Date of Test	2022-10-04 AM
Wind Speed (mi/h)	2
Wind Direction (deg)	89
Temperature (°F)	80
Relative Humidity (%)	51
Vehicle Traveling (deg)	195

7.3. TEST VEHICLE

Figure 7.3 and Figure 7.4 show the 2016 RAM 1500 used for the crash test. Table 7.4 shows the vehicle measurements. Figure D.1 in Appendix D.1 gives additional dimensions and information on the vehicle.

Figure 7.3. Impact Side of Test Vehicle before Test 616391-01-2.

Figure 7.4. Opposite Impact Side of Test Vehicle before Test 616391-01-2.

Table 7.4. Vehicle Measurements 616391-01-2.

Test Parameter	***MASH***	**Allowed Tolerance**	**Measured**
Dummy (if applicable)[a] (lb)	165	N/A	N/A
Inertial Weight (lb)	5000	± 110	5035
Gross Static[a] (lb)	5000	± 110	5035
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46
Track Width[b] (inches)	67	±1.5	68.25
CG aft of Front Axle[c] (inches)	63	±4	60.9
CG above Ground[c,d] (inches)	28	≥28	28.5

[a] If a dummy is used, the gross static vehicle mass should be increased by the mass of the dummy.
[b] Average of front and rear axles.
[c] For test inertial mass.
[d] 2270P vehicle must meet minimum CG height requirement.

7.4. TEST DESCRIPTION

Table 7.5 lists events that occurred during Test No. 616391-01-2. Figures D.4 through D.6 in Appendix D.2 present sequential photographs during the test.

Table 7.5. Events during Test 616391-01-2.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0160	Posts 12, 13, 14, and15 began to lean toward field side
0.0200	Posts 16 and 17 began to lean toward field side
0.0350	Vehicle began to redirect
0.0700	Upstream edge of first PCB began to move toward field side
0.0830	Windshield began to crack due to vehicle body flexing from impact
0.1530	Upstream edge of first PCB stopped moving toward the field side
0.2030	Vehicle was parallel with the installation
0.4140	Vehicle exited the installation at 50.9 mi/h with a heading of 10 degrees and a trajectory of 5 degrees

7.5. DAMAGE TO TEST INSTALLATION

The upstream pin on the first barrier pulled out 2¼ inches, the middle pin 1¼ inches, and the downstream pin 1¼ inches. The upstream pin on the second barrier pulled out ¾-inch. The rail was scuffed and deformed at impact, with the maximum deformation of the rail being 2½ inches at the centerline of post 14. The upstream and middle blockout on the concrete barrier had a ¾-inch gap between them and the barrier, and the downstream blockout had a ½-inch gap.

Table 7.6 and Table 7.7 describe the damage to the Transition. Figure 7.5 through Figure 7.13 show the damage to the Transition.

Table 7.6. Post Movement on the Transition 616391-01-2.

Post Number	Soil Gap (inches)	Post Lean from Vertical (degrees)
11	⅜ t/s	1.0
12	1 t/s	1.6
13	1 t/s; ¼ f/s	3.2
14	½ f/s	3.4
15	½ f/s	3.4
16	½ f/s	3.4
17	⅜ f/s	3.0

t/s: traffic side; f/s: field side

Table 7.7. Damage to Transition 616391-01-2.

Test Parameter	Measured
Permanent Deflection/Location	2¾ inches toward field side, at the upstream toe of the first concrete barrier.
Maximum Dynamic Deflection	7.3 inches toward field side, at the top of the upstream end of the first concrete barrier.
Working Width [a] and Height	30 inches, at a height of 0 inches at the base of the first concrete barrier

[a] 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 7.5. Transition after Test at Impact Location 616391-01-2.

Figure 7.6. Transition after Test Upstream of Impact In-Line with the Installation 616391-01-2.

Figure 7.7. Transition after Test From the Field Side 616391-01-2.

Figure 7.8. Asphalt Damage at the Upstream Anchor Pin Location 616391-01-2.


Figure 7.9. Damage to the Upstream Anchor Pin 616391-01-2.


Figure 7.10. Asphalt Damage at the Middle Anchor Pin Location 616391-01-2.

Figure 7.11. Damage to the Middle Anchor Pin 616391-01-2.

Figure 7.12. Asphalt Damage at the Downstream Anchor Pin Location 616391-01-2.

Figure 7.13. Damage to the Downstream Anchor Pins 616391-01-2.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.14 and Figure 7.15 show the damage sustained by the vehicle. Figure 7.16 and Figure 7.17 show the interior of the test vehicle. Table 7.9 and Table 7.10 provide details on the occupant compartment deformation and exterior vehicle damage. Figures D.2 and D.3 in Appendix D.1 provide exterior crush and occupant compartment measurements.

Figure 7.14. Impact Side of Test Vehicle after Test 616391-01-2.

Figure 7.15. Rear Impact Side of Test Vehicle after Test 616391-01-2.

Figure 7.16. Overall Interior of Test Vehicle after Test 616391-01-2.

Figure 7.17. Interior of Test Vehicle on Impact Side after Test 616391-01-2.

Table 7.8. Occupant Compartment Deformation 616391-01-2.

Test Parameter	Specification	Measured
Roof	≤4.0 inches	0 inches
Windshield	≤3.0 inches	0 inches
A and B Pillars	≤5.0 overall/≤3.0 inches lateral	0 inches
Foot Well/Toe Pan	≤9.0 inches	3 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	3 inches
Front Door (above Seat)	≤9.0 inches	3 inches
Front Door (below Seat)	≤12.0 inches	0 inches

Table 7.9. Exterior Vehicle Damage 616391-01-2.

Side Windows	The side windows remained intact.
Maximum Exterior Deformation	14 inches in the front plane at the right front corner at bumper height
VDS	01RFQ3
CDC	01FREW3
Fuel Tank Damage	None
Description of Damage to Vehicle:	The right front bumper, hood, grill, radiator and support, right headlight, right front tire and rim, right frame rail, right front upper and lower control arms, windshield, right front floor pan, right front door, right rear door, right front wheel assembly, right tie rod, sway bar, right cab corner, right rear quarter fender, and rear bumper were damaged. The right front door had a 7-inch gap at the top. The windshield had some cracking, but no tears or holes in the laminate.

7.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in **Error! Reference source not found.**. Figure D.7 in Appendix D.3 shows the vehicle angular displacements, and Figures D.8 through C.10 in Appendix D.4 show acceleration versus time traces.

Table 7.10. Occupant Risk Factors for Test 616391-01-2.

Test Parameter	*MASH*	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0	20.0	0.1063 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0	25.6	0.1063 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49	5.0	0.1063 - 0.1163 s
Ridedown, Lateral (g)	≤20.49	11.5	0.1063 - 0.1163 s
THIV (m/s)	N/A	9.5	0.1037 seconds on right side of interior
ASI	N/A	1.5	0.0592 - 0.1092 s
50-ms MA Longitudinal (g)	N/A	-8.5	0.0384 - 0.0884 s
50-ms MA Lateral (g)	N/A	-10.9	0.0431 - 0.0931 s
50-ms MA Vertical (g)	N/A	-4.6	0.0273 - 0.0773 s
Roll (deg)	≤75	40	0.8260 s
Pitch (deg)	≤75	13	0.5328 s
Yaw (deg)	N/A	74	2.0000 s

0.000 s

0.200 s

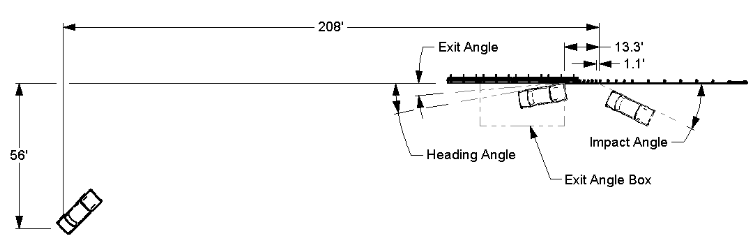
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-21
TTI Project No.	616391-01-2
Test Date	2022-10-04
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Transition between Guardrail to Anchored Portable Concrete Barrier
Length	115 feet 5¼ inches
Key Materials	32-inch tall F-shape concrete barriers anchored on asphalt, Thrie-beam and W-beam Guardrail, 31-inch tall guardrail, 72-inch long wide-flange guardrail posts
Soil Type and Condition	AASHTO M 147-17 Grading D (crushed concrete)
TEST VEHICLE	
Type/Designation	2270 P
Year, Make and Model	2016 RAM 1500
Inertial Weight (lb)	5035
Dummy (lb)	N/A
Gross Static (lb)	5035
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.9
Impact Angle (deg)	25.9
Impact Location	13 inches upstream from centerline of post 13.
Impact Severity (kip-ft)	127.1
EXIT CONDITIONS	
Exit Speed (mi/h)	50.8
Trajectory/Heading Angle (deg)	5 / 10
Exit Box Criteria	Crossed
Stopping Distance	208 ft downstream 56 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	7.3
Permanent (inches)	2¾
Working Width / Height (inches)	30 / 0
VEHICLE DAMAGE	
VDS	01RFQ3
CDC	01FREW3
Max. Ext. Deformation	14
Max Occupant Compartment Deformation	3 inches in the toe pan, door, and sidewall

OCCUPANT RISK VALUES

Long. OIV (ft/s)	20.0	Long. Ridedown (g)	5.0	Max 50-ms Long. (g)	-8.5	Max Roll (deg)	40
Lat. OIV (ft/s)	25.6	Lat. Ridedown (g)	11.5	Max 50-ms Lat. (g)	-10.9	Max Pitch (deg)	13
THIV (m/s)	9.5	ASI	1.5	Max 50-ms Vert. (g)	-4.6	Max Yaw (deg)	74



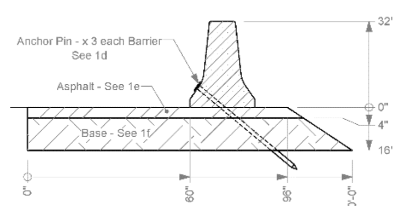


Figure 7.18. Summary of Results for *MASH* Test 3-21 on Transition.

Chapter 8. SUMMARY AND CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS

The crash tests reported herein were performed in accordance with *MASH* TL-3, which involves two tests, on the Transition. Tables at the end of this section provide an assessment of each test based on the applicable safety evaluation criteria for *MASH* TL-3 for longitudinal barriers.

8.2. CONCLUSIONS

Table 8.1 and Table 8.2 shows that the Transition between Guardrail to Anchored Portable Concrete Barrier met the performance criteria for *MASH* TL-3 longitudinal barriers.

8.3. IMPLEMENTATION*

Having passed *MASH* TL-3 testing, the Transition design is ready for implementation. Implementation can be achieved by incorporating the Transition design into the hardware standards of the user state DOT. In the design crash tested under this project, four 12.5-ft long anchored PCB barrier segments were used. Results of the testing showed very minimal deflection of the two anchored PCB segments attached to the Thrie-beam section of the Transition. The remaining segments did not have any noticeable movement. Some states would like to transition from anchored to free-standing PCB. The Transition design developed under this project may be used for this purpose, if at least two PCB segments adjacent to the W-beam to Thrie-beam transition are fully anchored with three anchoring pins per segment.

Some states use PCB barrier segments longer than 12.5 ft. The Transition design developed under this project may be used with longer PCB segments if the Thrie-beam segment covering the anchored PCB segments is extended accordingly to attach to the second anchored PCB segment. In this case, the spacing between the Transition Blockouts should also be adjusted to provide a uniform transition along the length of the barrier segment. For segment lengths greater than 15-ft, it is recommended that at least four anchoring pins be used per PCB segment. For this case, it is also recommended that an additional Transition Blockout be used to support the increased length of the segment.

---

* *The opinions/interpretations identified/expressed in this section of the report are outside the scope of TTI Proving Ground's A2LA Accreditation.*

Table 8.1. Performance Evaluation Summary for *MASH* Test 3-20 on Transition between Guardrail to Anchored Portable Concrete Barrier, 616391-01-1, 2022-09-19.

Evaluation Criteria	*MASH* Description	Assessment
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.	Pass
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. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Pass
F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	Pass
H.	Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s (10 ft/s for supports), or maximum allowable value of 40 ft/s (16 ft/s for supports).	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.	Pass

Table 8.2. Performance Evaluation Summary for *MASH* Test 3-21 on Transition between Guardrail to Anchored Portable Concrete Barrier, 616391-01-2, 2022-10-04.

Evaluation Criteria	*MASH* Description	Assessment
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.	Pass
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. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Pass
F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	Pass
H.	Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s (10 ft/s for supports), or maximum allowable value of 40 ft/s (16 ft/s for supports).	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.	Pass

Table 8.3. Assessment Summary for *MASH* TL-3 Tests on Transition between Guardrail to Anchored Portable Concrete Barrier.

Evaluation Criteria	Test No. 616391-01-1	Test No. 616391-01-2
A	S	S
D	S	S
F	S	S
H	S	S
I	S	S
Overall	Pass	Pass

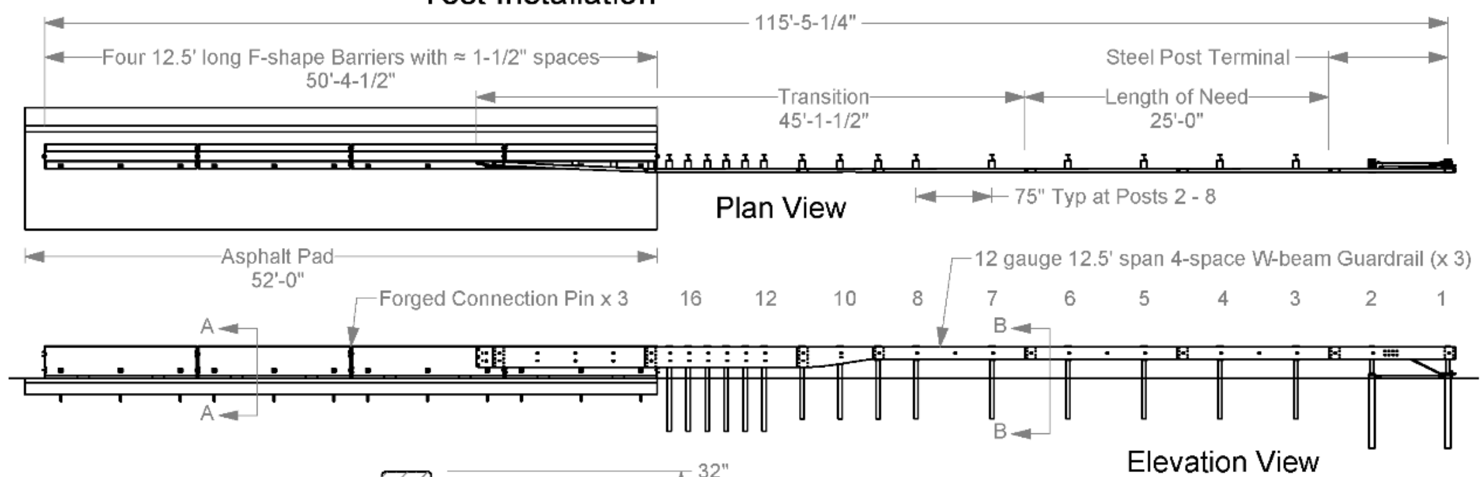
Note: S = Satisfactory; N/A = Not Applicable.

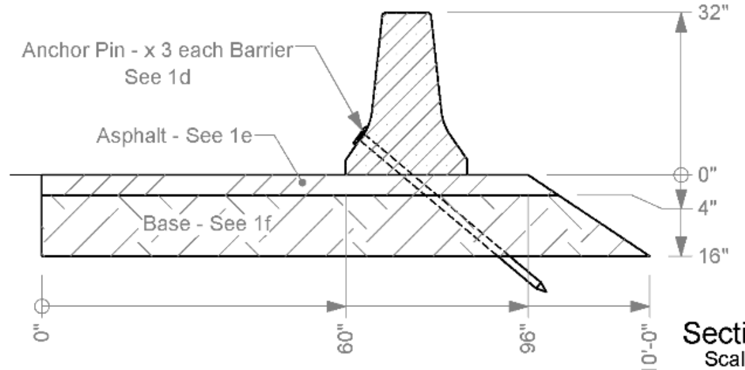
REFERENCES

1. AASHTO. *Manual for Assessing Roadside Safety Hardware*, Second Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2016.
2. N.M. Sheikh, and W.L. Menges. *Development and Testing of Anchored Temporary Concrete Barrier for use on Asphalt.* Texas A&M Transportation Institute, Report 405160-25-1, College Station, Texas, 2012.

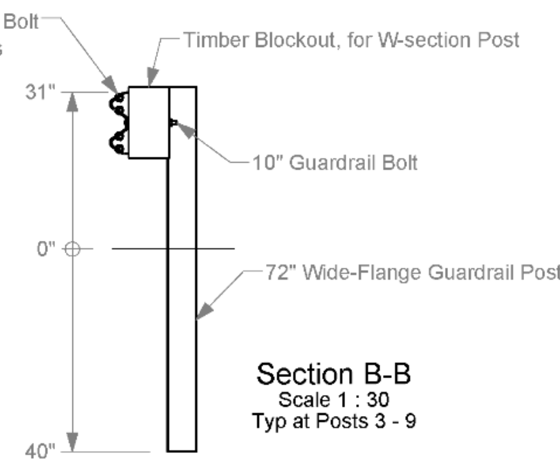
APPENDIX A. DETAILS OF TRANSITION BETWEEN GUARDRAIL TO ANCHORED PORTABLE CONCRETE BARRIER

Test Installation





Section A-A
Scale 1 : 30



Section B-B
Scale 1 : 30
Typ at Posts 3 - 9

1a. Backfill Post holes with Type D grade 1 crushed concrete road base, compacted according to TTI Proving Ground Work Instruction WI-C001.

1b. Recessed Guardrail Nut on all Button-head Guardrail Bolts.

1c. All steel parts shall be galvanized.

1d. Place Barriers and insert Forged Connection Pins. Drill Ø1-3/4" holes through Asphalt with masonry bit and rotary percussion drill, using the sleeves as a guide. Insert the Anchor Pins, and turn them so the plate washer fits against the concrete face.

1e. Prime the base with CSS-1H Tack Coat Binder and apply TxDOT Type D Asphalt in two lifts.

1f. Type A Grade 1 crushed limestone road base, compacted to 95% of standard proctor density.

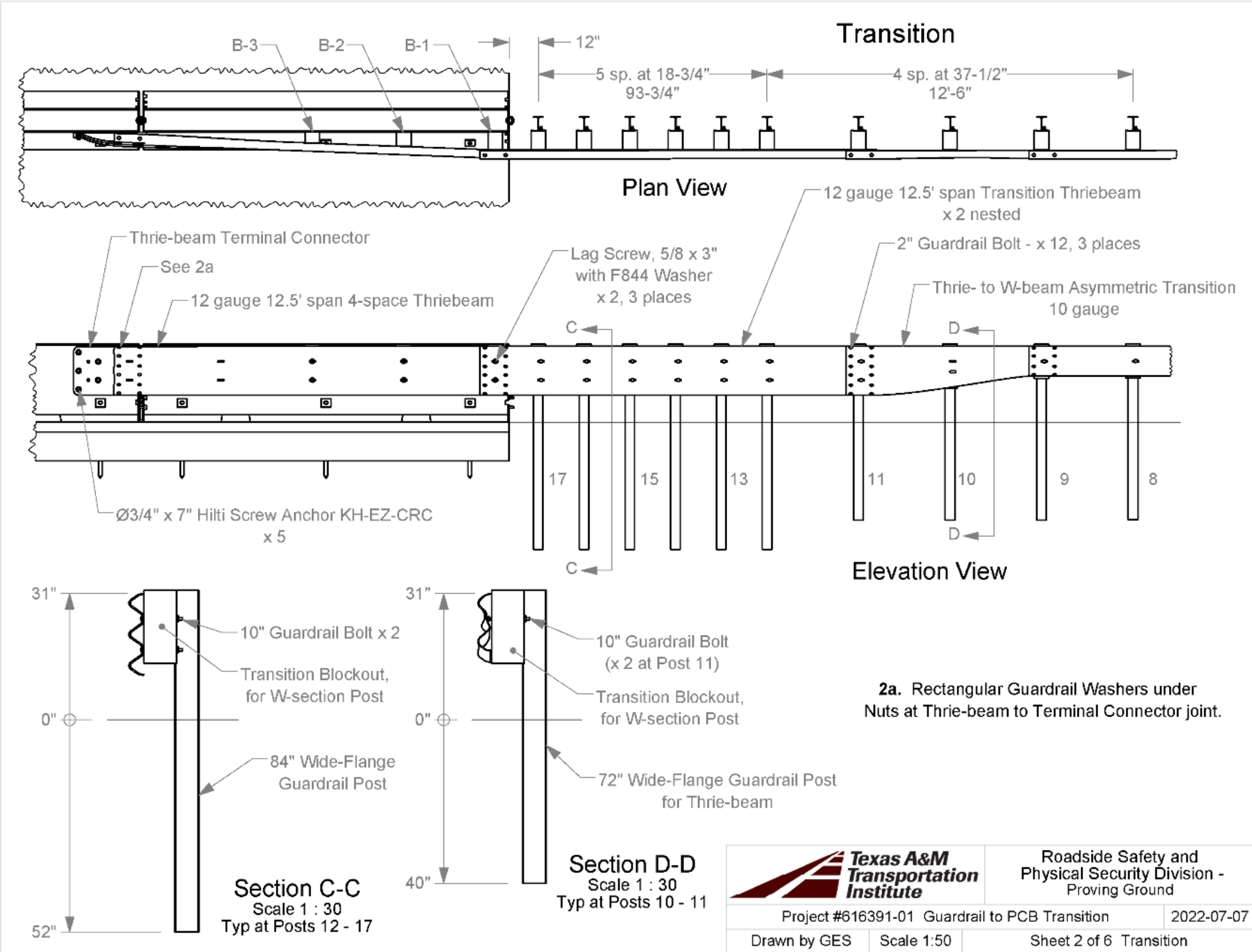
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project #616391-01 Guardrail to PCB Transition | 2022-07-07

Drawn by GES | Scale 1:150 | Sheet 1 of 6 Test Installation

Q:\Accreditation-17025-2017\EIR-000 Project Files\616391-01 - Guardrail to PCB - Sheikh\Drafting, 616391\616391 Drawing



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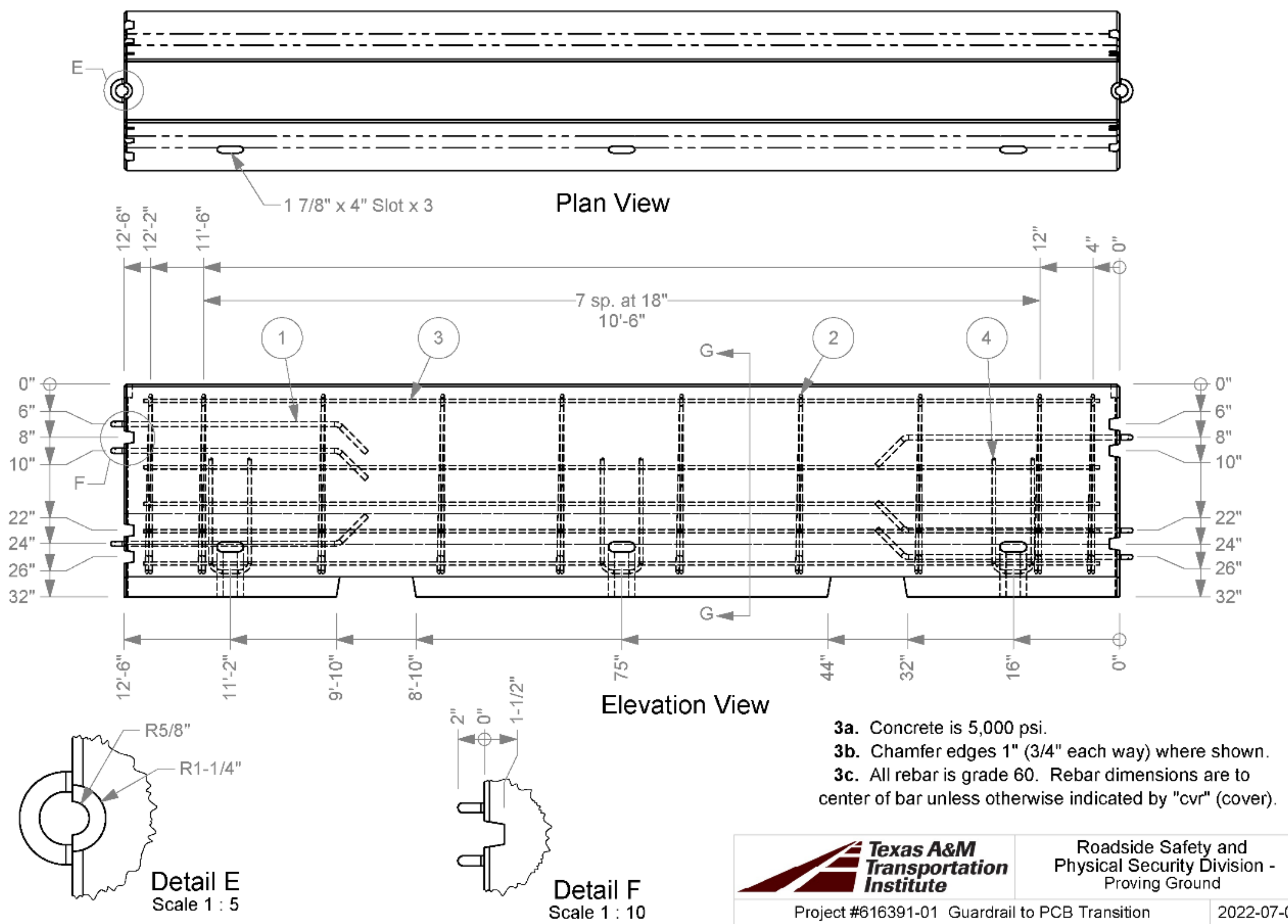
Barrier Details

Section View on next sheet



3a. Concrete is 5,000 psi.

3b. Chamfer edges 1" (3/4" each way) where shown.

3c. All rebar is grade 60. Rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #616391-01 Guardrail to PCB Transition		2022-07-07
Drawn by GES	Scale 1:20	Sheet 3 of 6 Barrier Details

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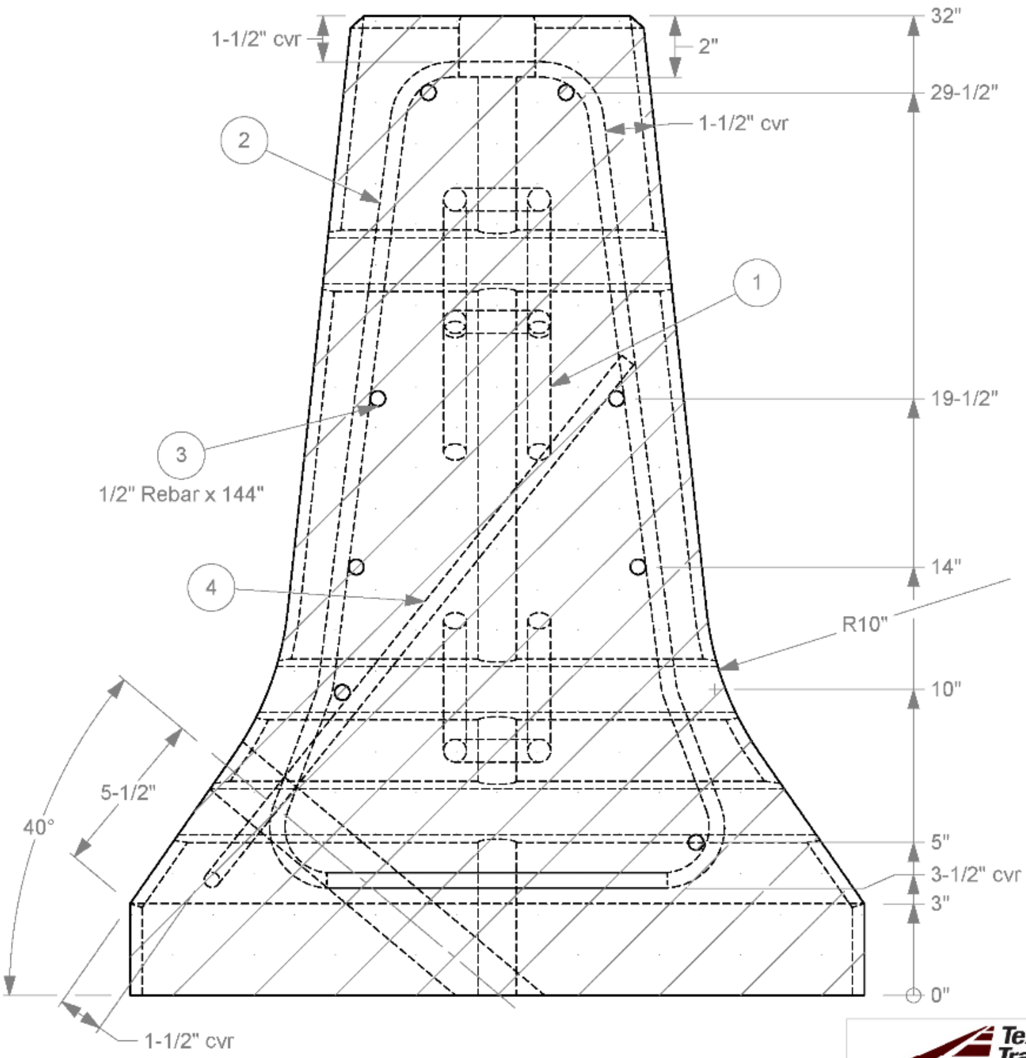
Section G-G



#	Part Name	QTY.
1	End Loop	6
2	Stirrup	10
3	Longitudinal Bar	8
4	403 bar	3

Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project #616391-01 Guardrail to PCB Transition | 2022-07-07

Drawn by GES | Scale 1:5 | Sheet 4 of 6 Section G-G

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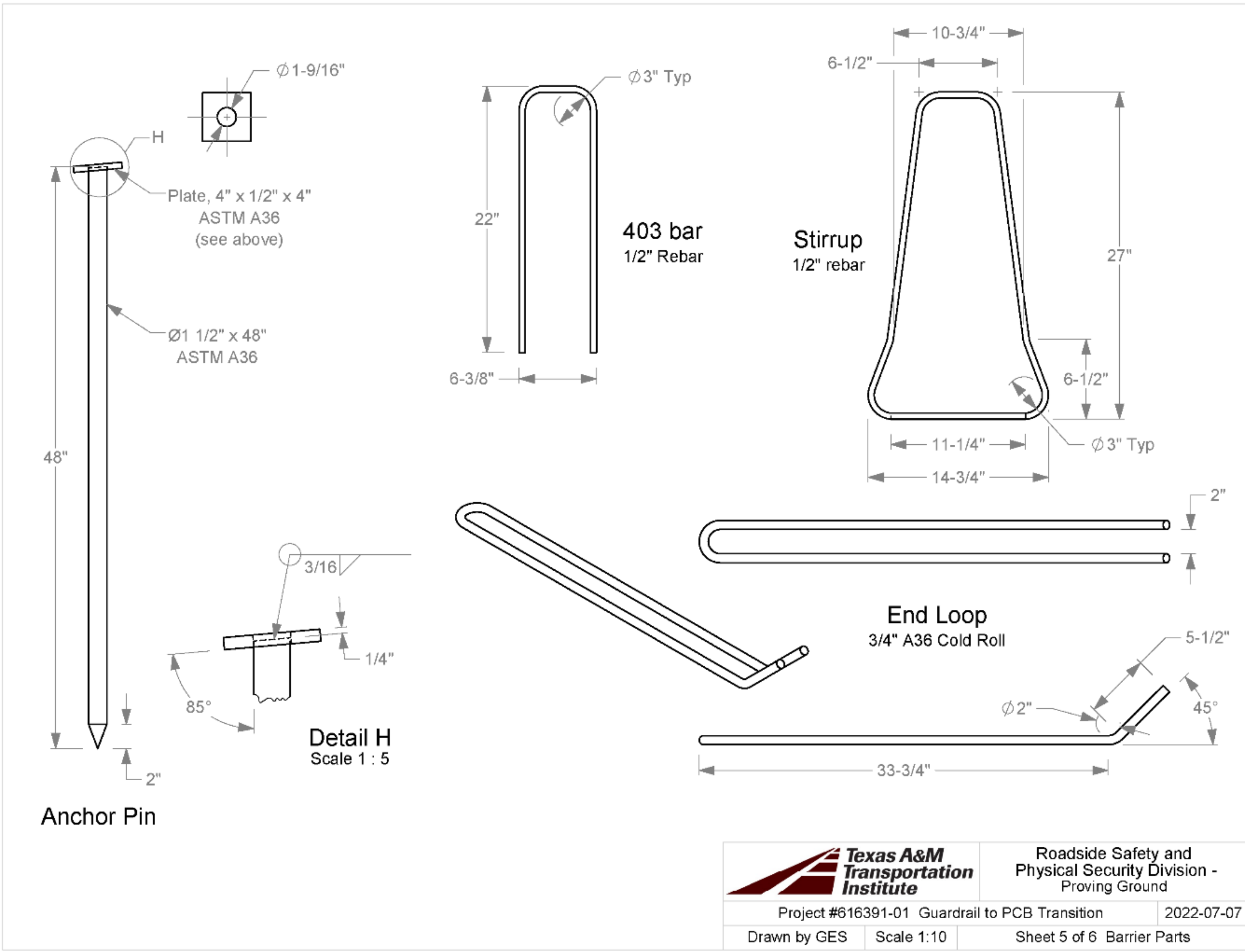

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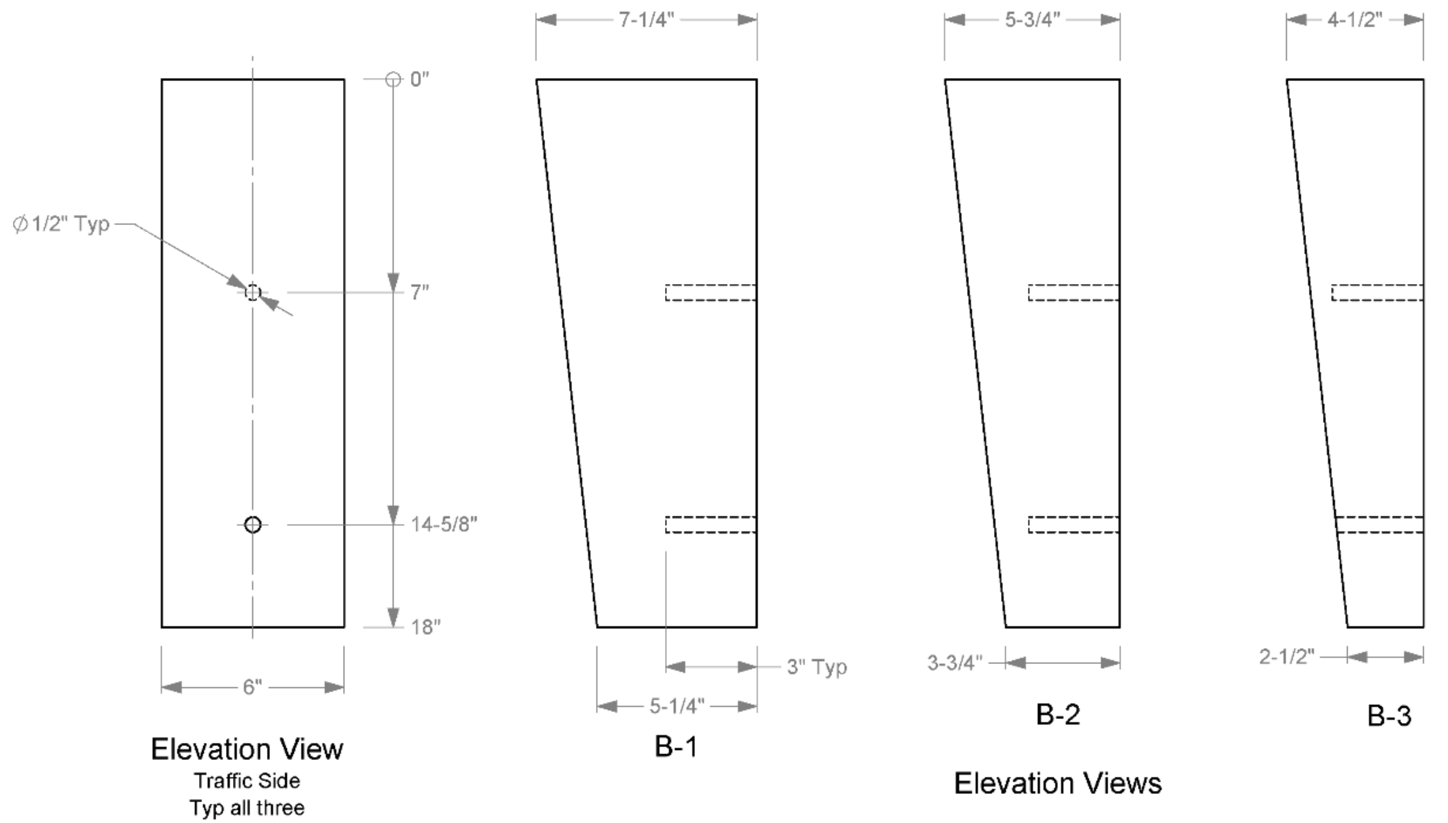
Transition Blockouts

modified Timber Blockout for W-section Posts



6a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project #616391-01 Guardrail to PCB Transition		2022-07-07
Drawn by GES	Scale 1:5	Sheet 6 of 6 Transition Blockouts

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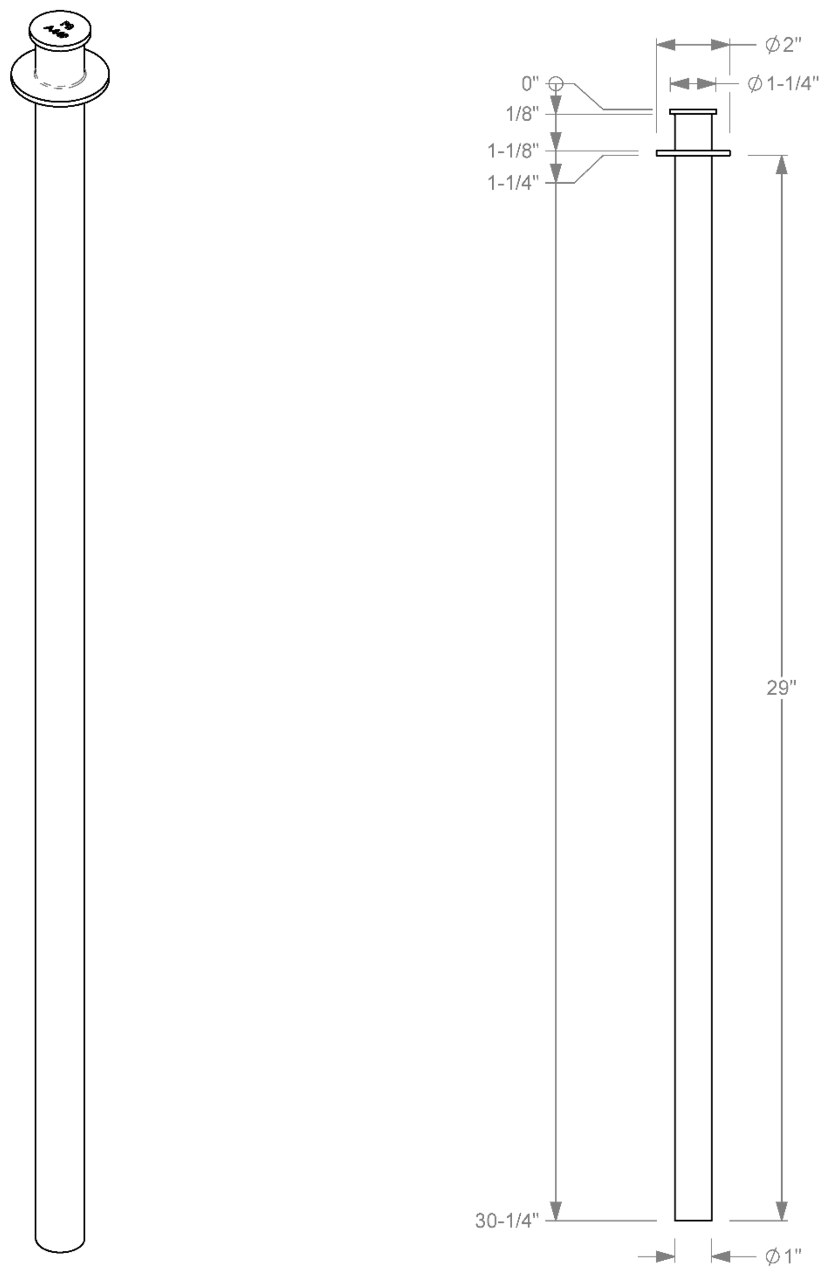
Forged Connection Pin



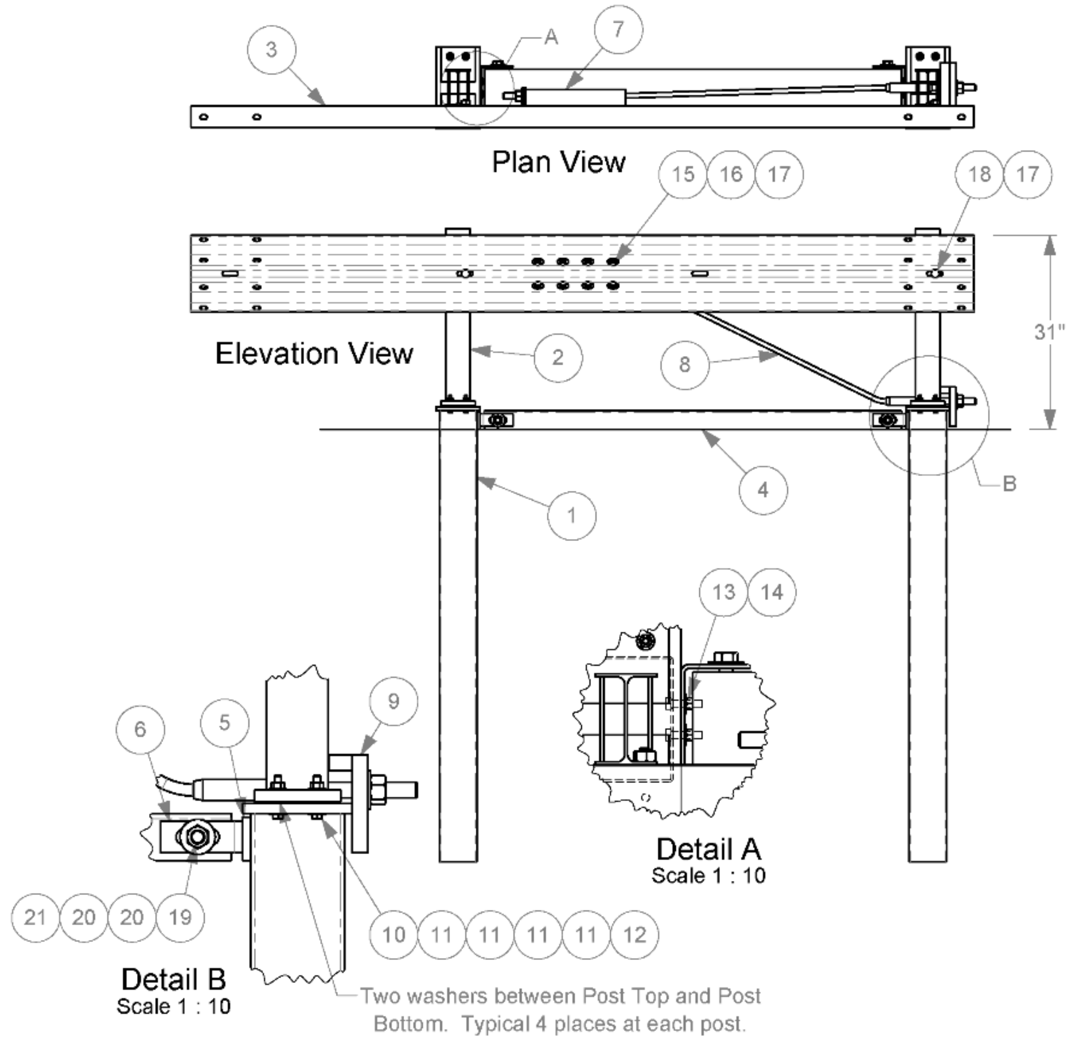
1a. Pin is forged, with no welding, and galvanized per ASTM F2329 and A153.
1b. Material is ASTM A449.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Forged Connection Pin		2021-06-10
Drawn by GES	Scale 1:4	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Concrete Barriers\Forged Connection Pin

Terminal Details

#	Part Name	QTY.
1	Post Bottom	2
2	Post Top	2
3	9'-4" span Terminal Rail	1
4	Strut	1
5	Strut Spacer	2
6	Strut Bracket	2
7	Guardrail Anchor Bracket	1
8	Anchor Cable Assembly	1
9	Bearing Plate	1
10	Bolt, 7/16 x 2 1/2" hex	8
11	Washer, 7/16 F844	32
12	Nut, 7/16 heavy hex	8
13	Nut, 1/2 hex	4
14	Washer, 1/2 F844	4
15	Bolt, 5/8 x 1 1/2" hex	8
16	Washer, 5/8 F844	8
17	Recessed Guardrail Nut	10
18	1-1/4" Guardrail Bolt	2
19	Bolt, 7/8 x 8 1/2" hex	2
20	Washer, 7/8 F844	4
21	Nut, 7/8 hex	2

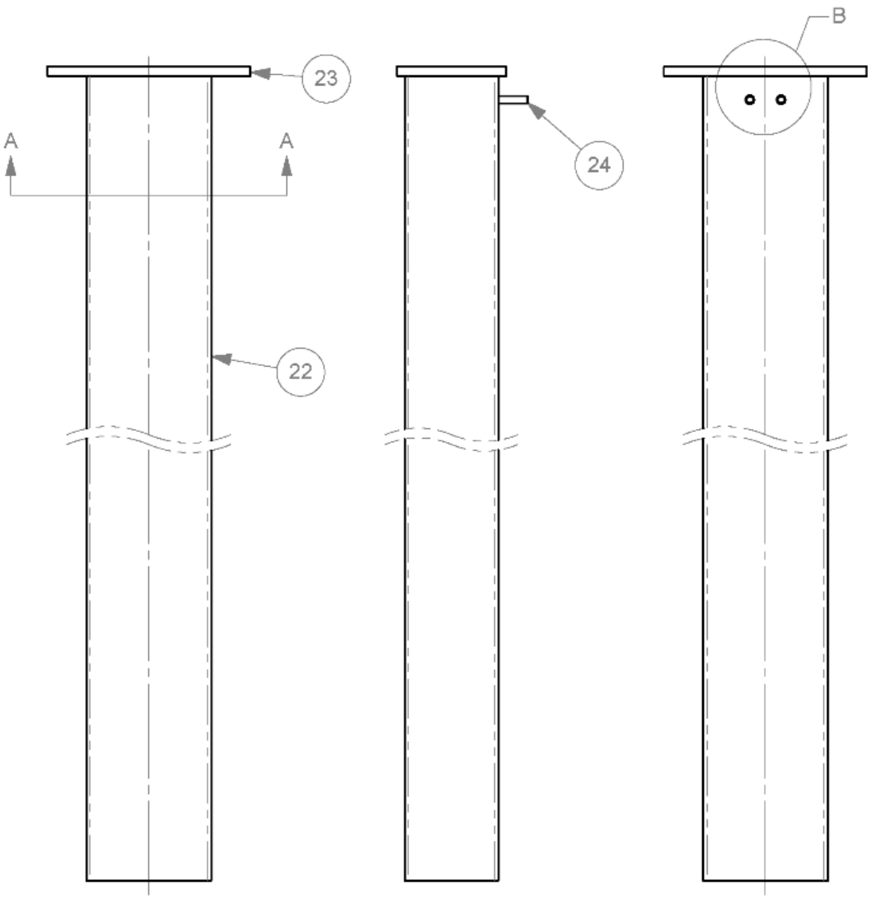


1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.
1c. All steel parts shall be galvanized.

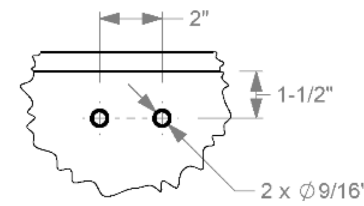
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
	Project # Terminal	2021-06-01
Drawn by GES	Scale 1:25	Sheet 1 of 6 Terminal Details

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Midwest Terminal

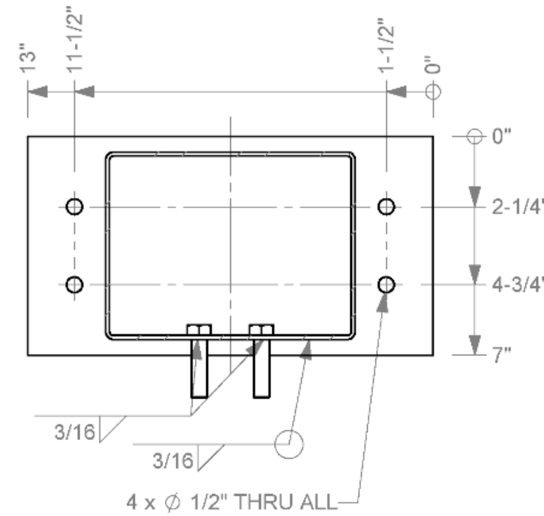
Post Bottom



Elevation Views



Detail B
Scale 1 : 5



Section A-A
Scale 1 : 5

#	Description	Length	Material	Qty
22	HSS 8" x 6" x 1/8"	72"	ASTM A500 Grade B	1
23	Plate, 7" x 5/8"	13"	ASTM A36	1
24	Bolt, 1/2 x 2 hex		ASTM A307	2

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2021-06-01
Drawn by GES	Scale 1:10	Sheet 2 of 6 Post Bottom

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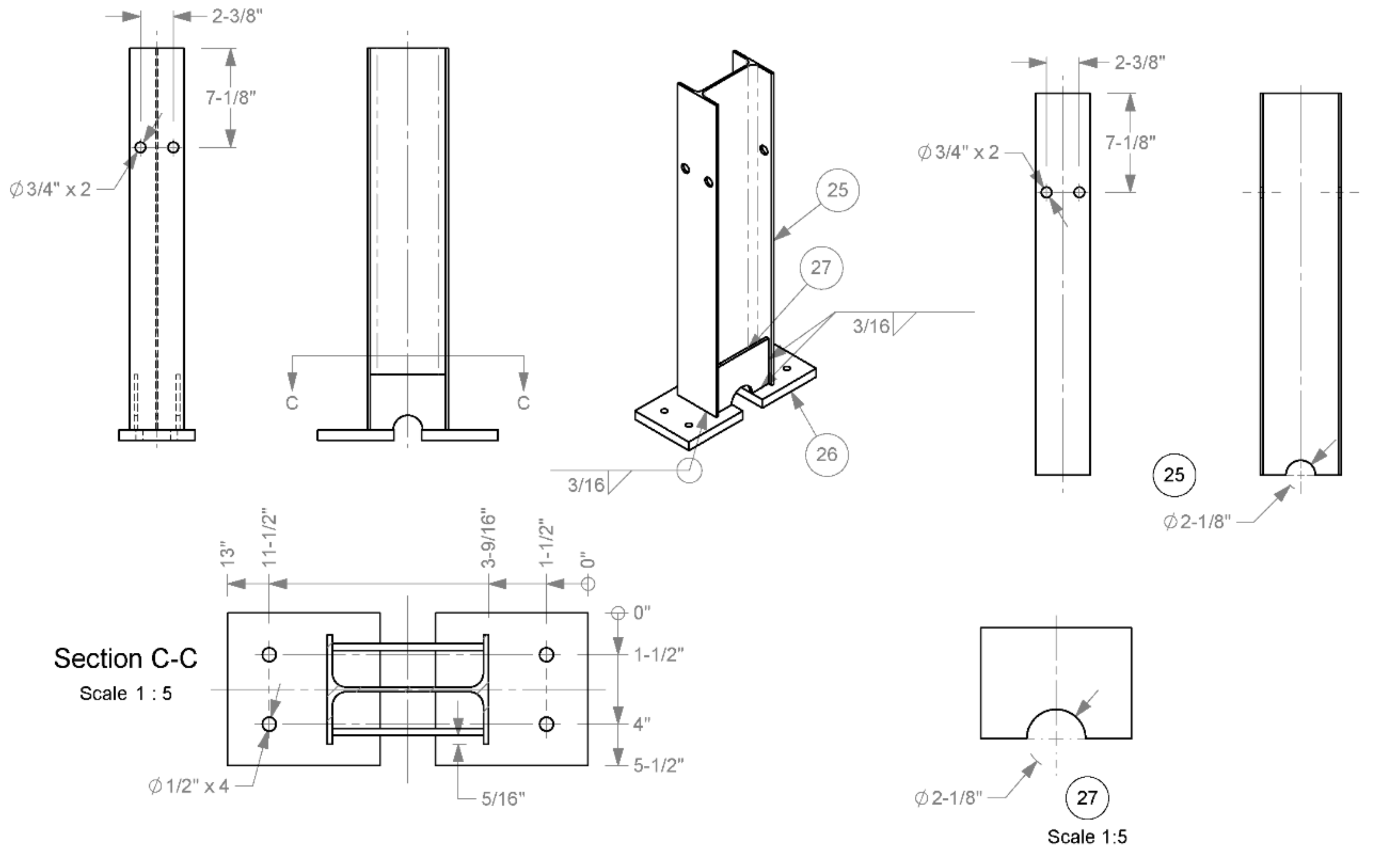

#	Description	Length	Material	Qty
25	W6x8.5	27 1/2"	ASTM A992	1
26	Plate, 5 1/2" x 3/4"	5 1/2"	ASTM A36	2
27	Plate, 5 7/16" x 1/4"	4"	ASTM A36	2

Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project # Terminal | 2021-06-01

Drawn by GES | Scale 1:10 | Sheet 3 of 6 Post Top

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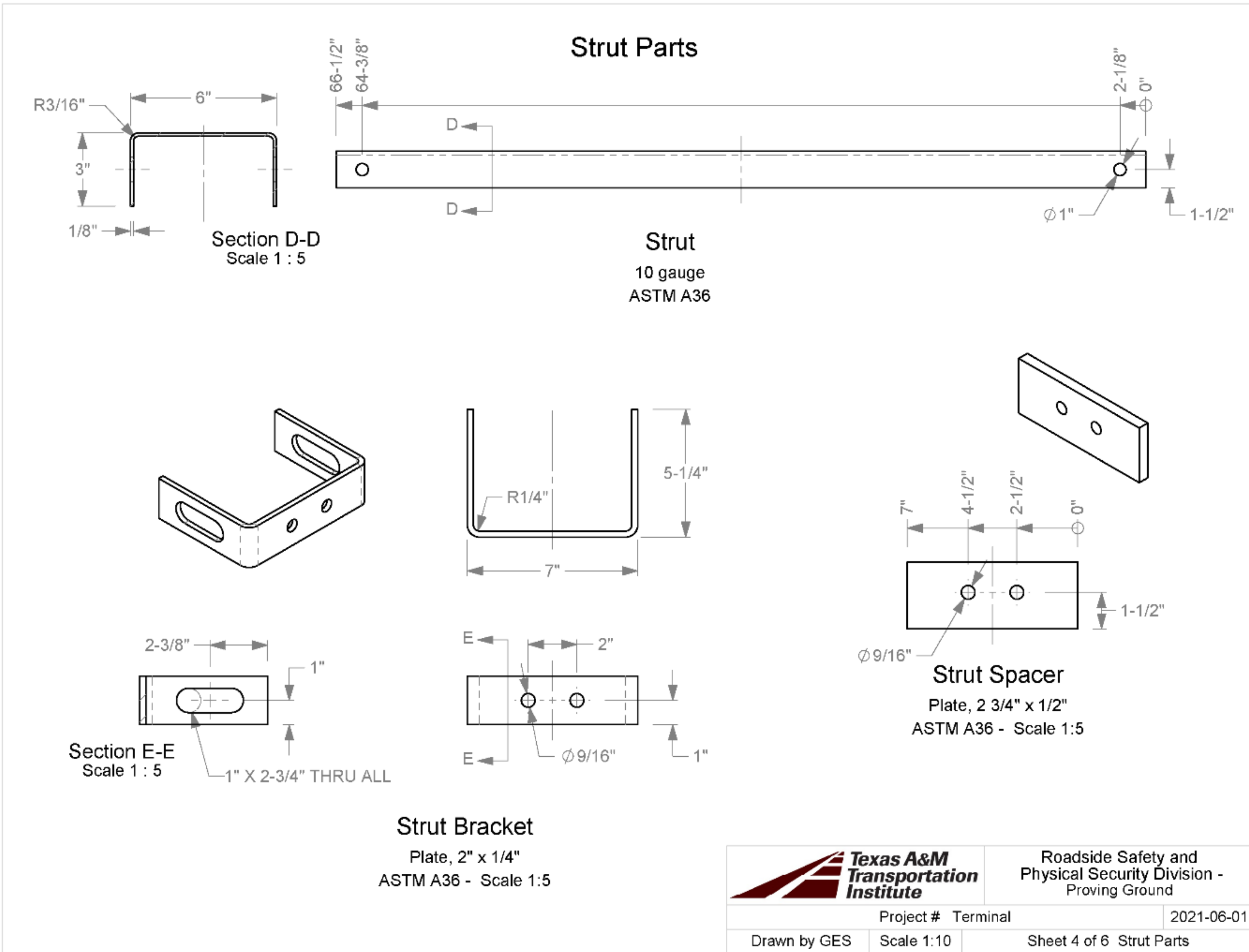

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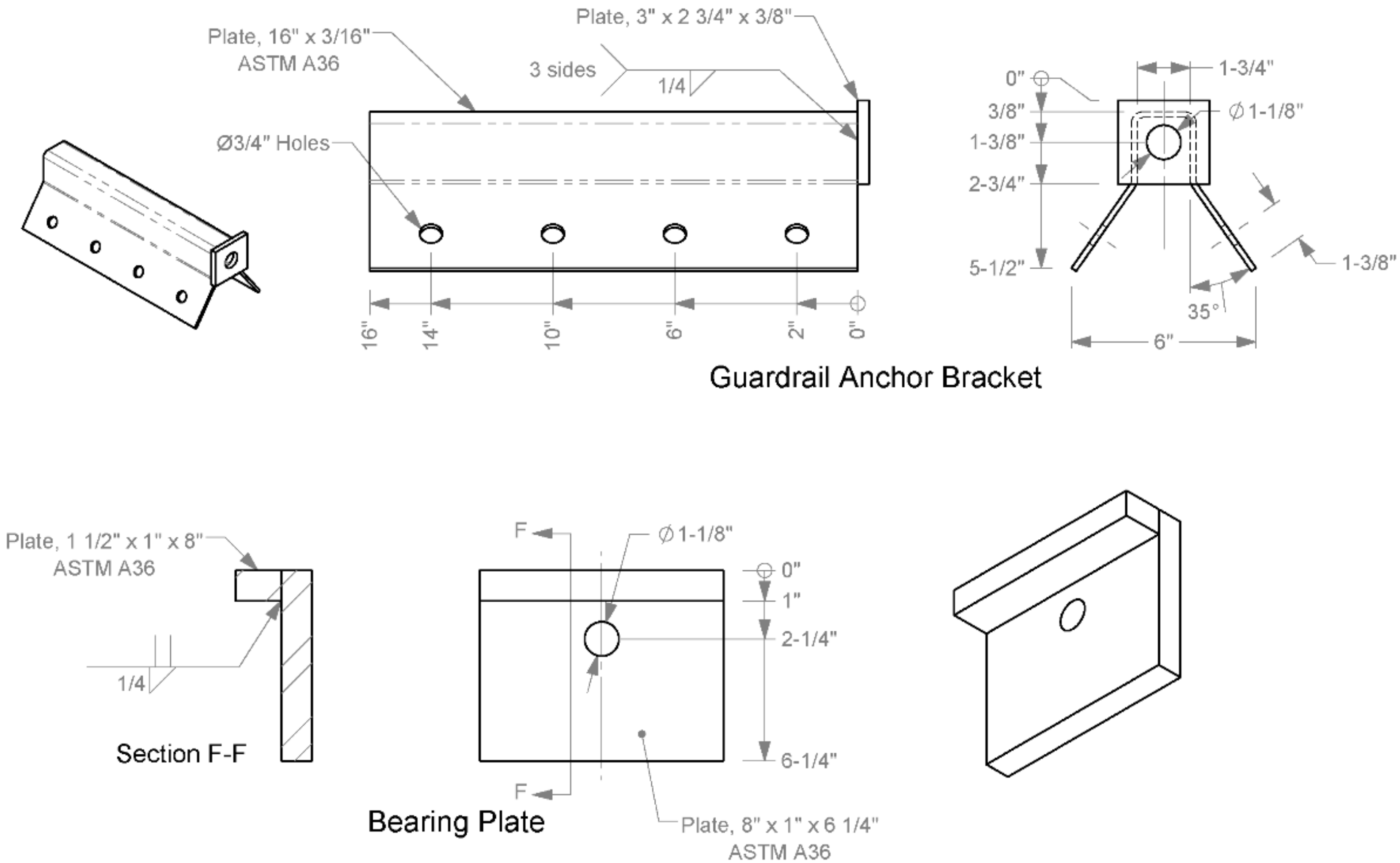

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
Project # Terminal		2021-06-01
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A

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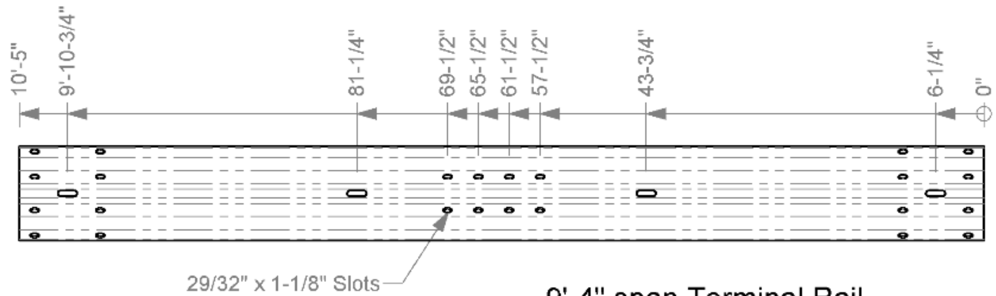
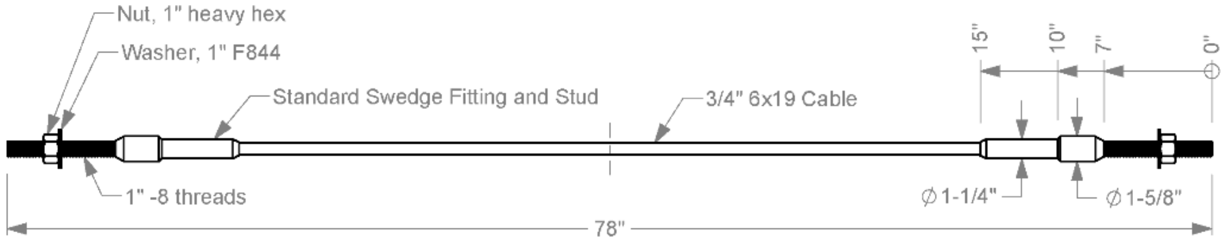


9'-4" span Terminal Rail

Scale 1:20 - See 4-space W-beam Guardrail drawing for cross-section and other dimensions.



Anchor Cable Assembly

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project # Terminal		2021-06-01
Drawn by GES	Scale 1:5	Sheet 6 of 6 Assorted Parts B

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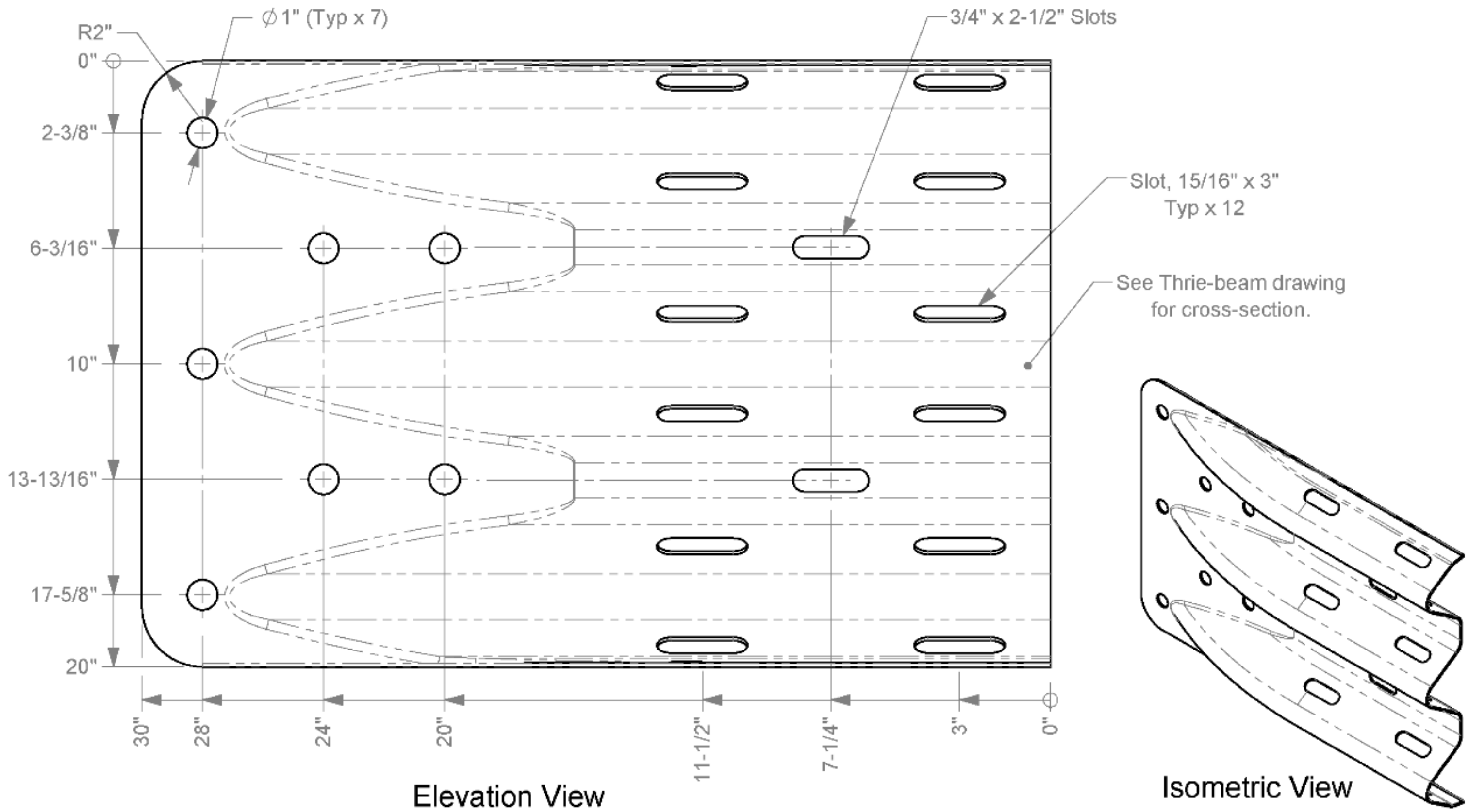
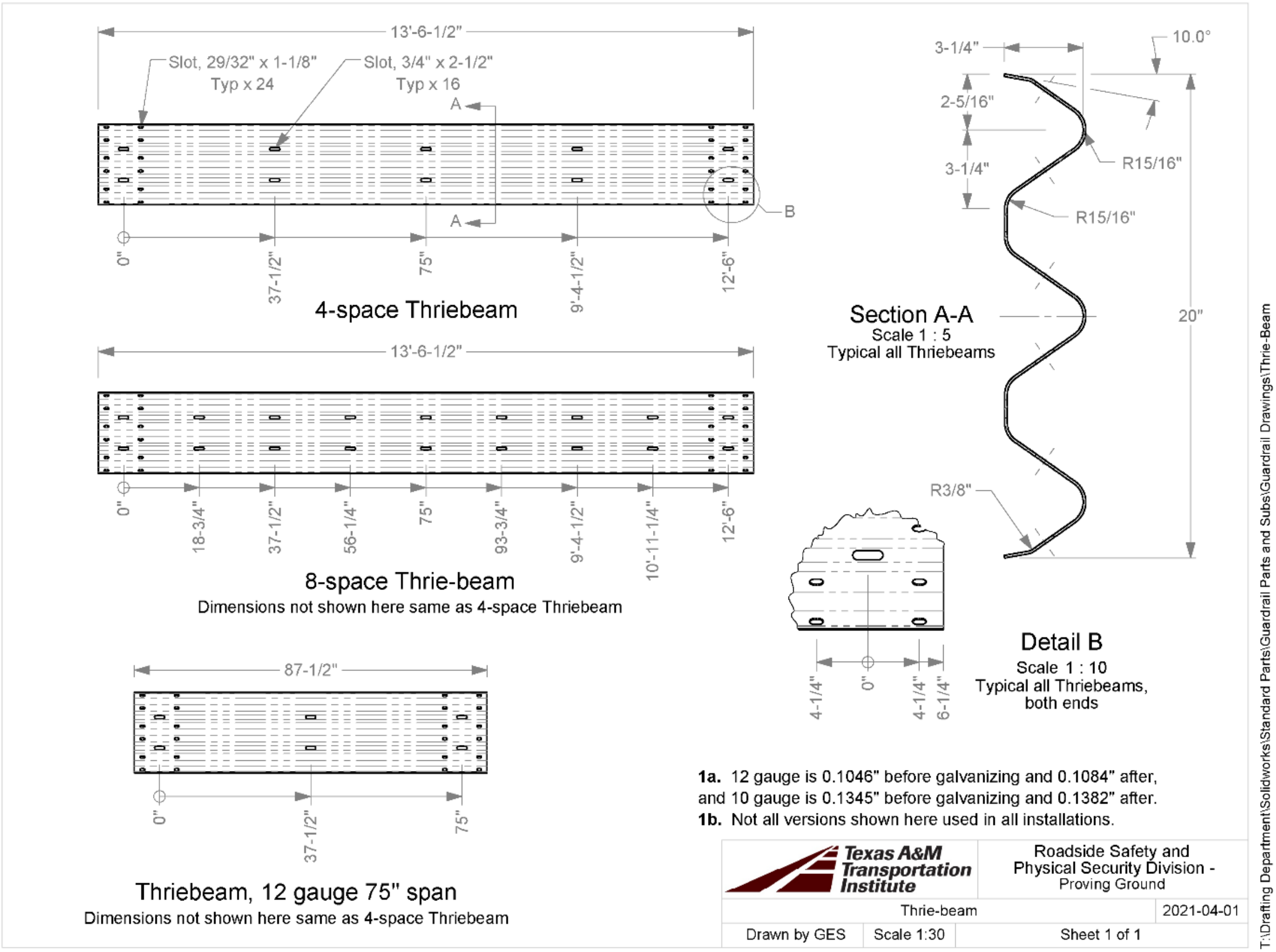
Thrie-beam End Shoe

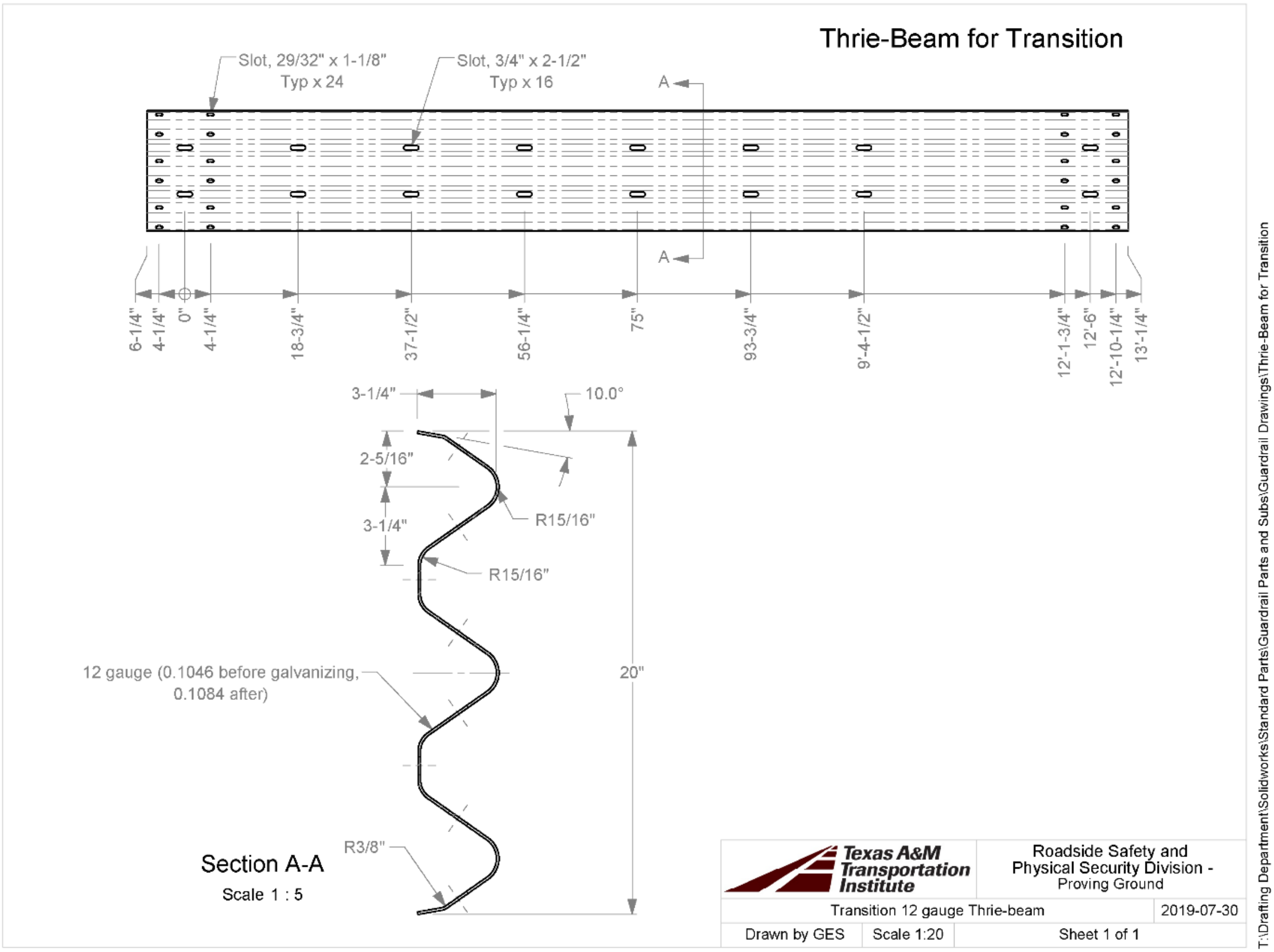
10 gauge (0.1345" before galvanizing)

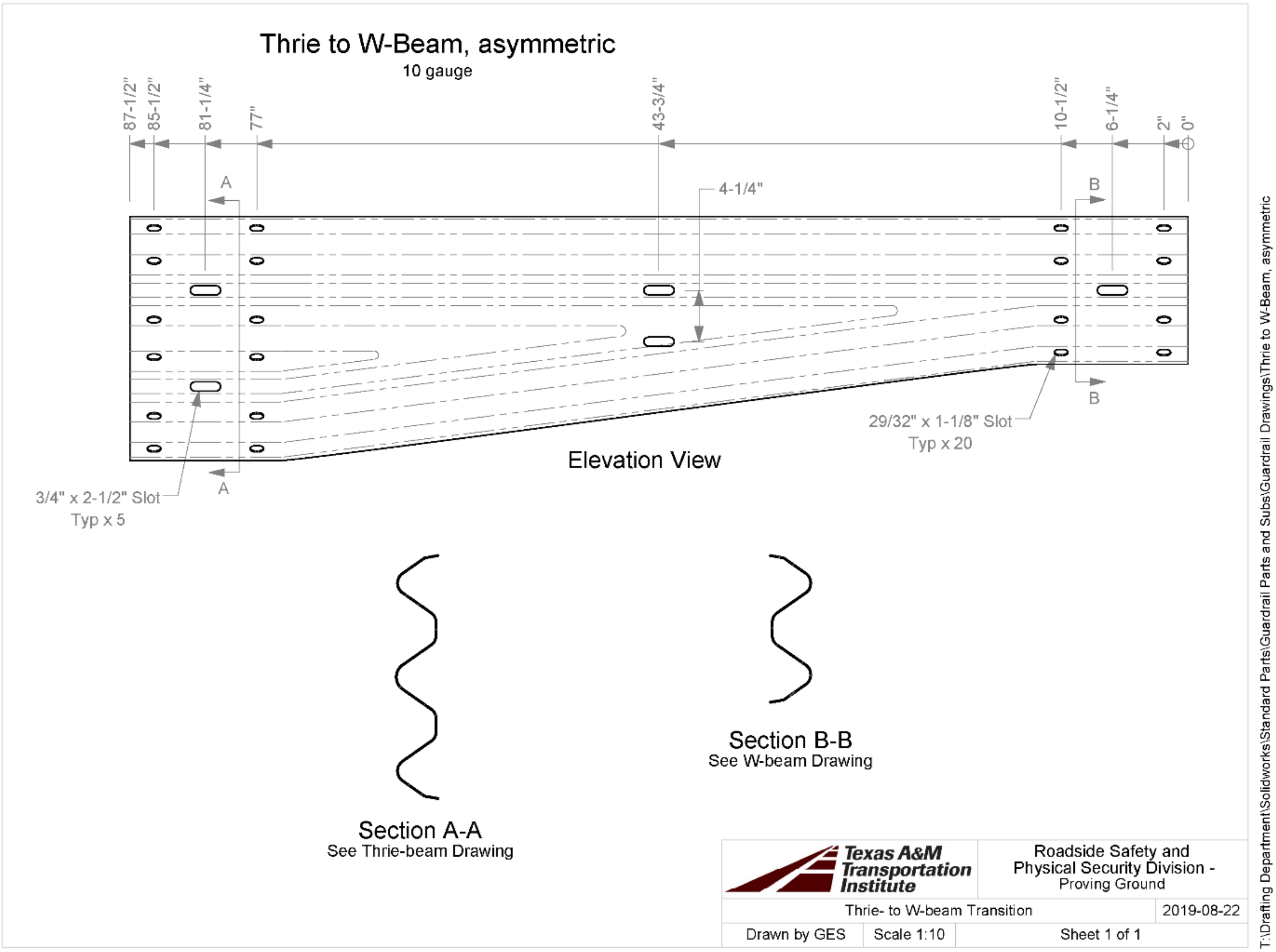


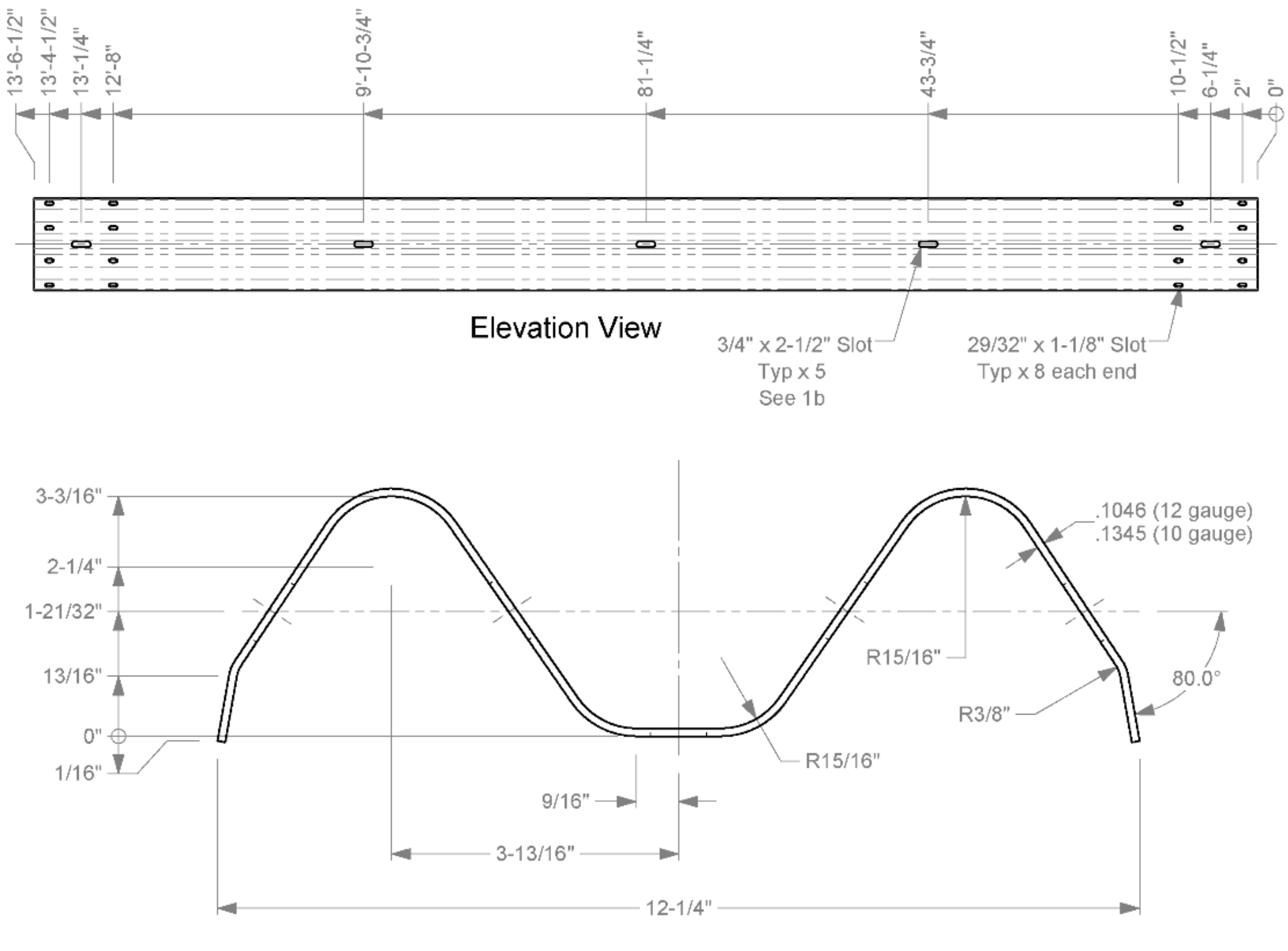
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Thrie-beam Terminal Connector		2019-07-29
Drawn by GES	Scale 1:5	Sheet 1 of 1

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


13'-6-1/2"
Slot, 29/32" x 1-1/8"
Typ x 24
Slot, 3/4" x 2-1/2"
Typ x 16
A
A
B
0"
37-1/2"
75"
9'-4-1/2"
12'-6"
4-space Thriebeam
13'-6-1/2"
0"
18-3/4"
37-1/2"
56-1/4"
75"
93-3/4"
9'-4-1/2"
10'-11-1/4"
12'-6"
8-space Thrie-beam
Dimensions not shown here same as 4-space Thriebeam
87-1/2"
0"
37-1/2"
75"
Thriebeam, 12 gauge 75" span
Dimensions not shown here same as 4-space Thriebeam
3-1/4"
10.0°
2-5/16"
3-1/4"
R15/16"
R15/16"
20"
R3/8"
Section A-A
Scale 1 : 5
Typical all Thriebeams
4-1/4"
0"
4-1/4"
6-1/4"
Detail B
Scale 1 : 10
Typical all Thriebeams, both ends
1a. 12 gauge is 0.1046" before galvanizing and 0.1084" after, and 10 gauge is 0.1345" before galvanizing and 0.1382" after.
1b. Not all versions shown here used in all installations.
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Thrie-beam
2021-04-01
Drawn by GES
Scale 1:30
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts and Subs\Guardrail Parts\Guardrail Drawings\Thrie-Beam


Thrie-Beam for Transition
Slot, 29/32" x 1-1/8"
Typ x 24
Slot, 3/4" x 2-1/2"
Typ x 16
A
A
6-1/4"
4-1/4"
0"
4-1/4"
18-3/4"
37-1/2"
56-1/4"
75"
93-3/4"
9'-4-1/2"
12'-1-3/4"
12'-6"
12'-10-1/4"
13'-1/4"
3-1/4"
10.0°
2-5/16"
3-1/4"
R15/16"
R15/16"
12 gauge (0.1046 before galvanizing,
0.1084 after)
20"
R3/8"
Section A-A
Scale 1 : 5
Texas A&M Transportation Institute
Roadside Safety and
Physical Security Division -
Proving Ground
Transition 12 gauge Thrie-beam
2019-07-30
Drawn by GES
Scale 1:20
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Thrie-Beam for Transition


Thrie to W-Beam, asymmetric
10 gauge
87-1/2"
85-1/2"
81-1/4"
77"
43-3/4"
10-1/2"
6-1/4"
2"
0"
4-1/4"
A
B
Elevation View
3/4" x 2-1/2" Slot
Typ x 5
29/32" x 1-1/8" Slot
Typ x 20
Section A-A
See Thrie-beam Drawing
Section B-B
See W-beam Drawing
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Thrie- to W-beam Transition
2019-08-22
Drawn by GES
Scale 1:10
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Thrie to W-Beam, asymmetric



Section View

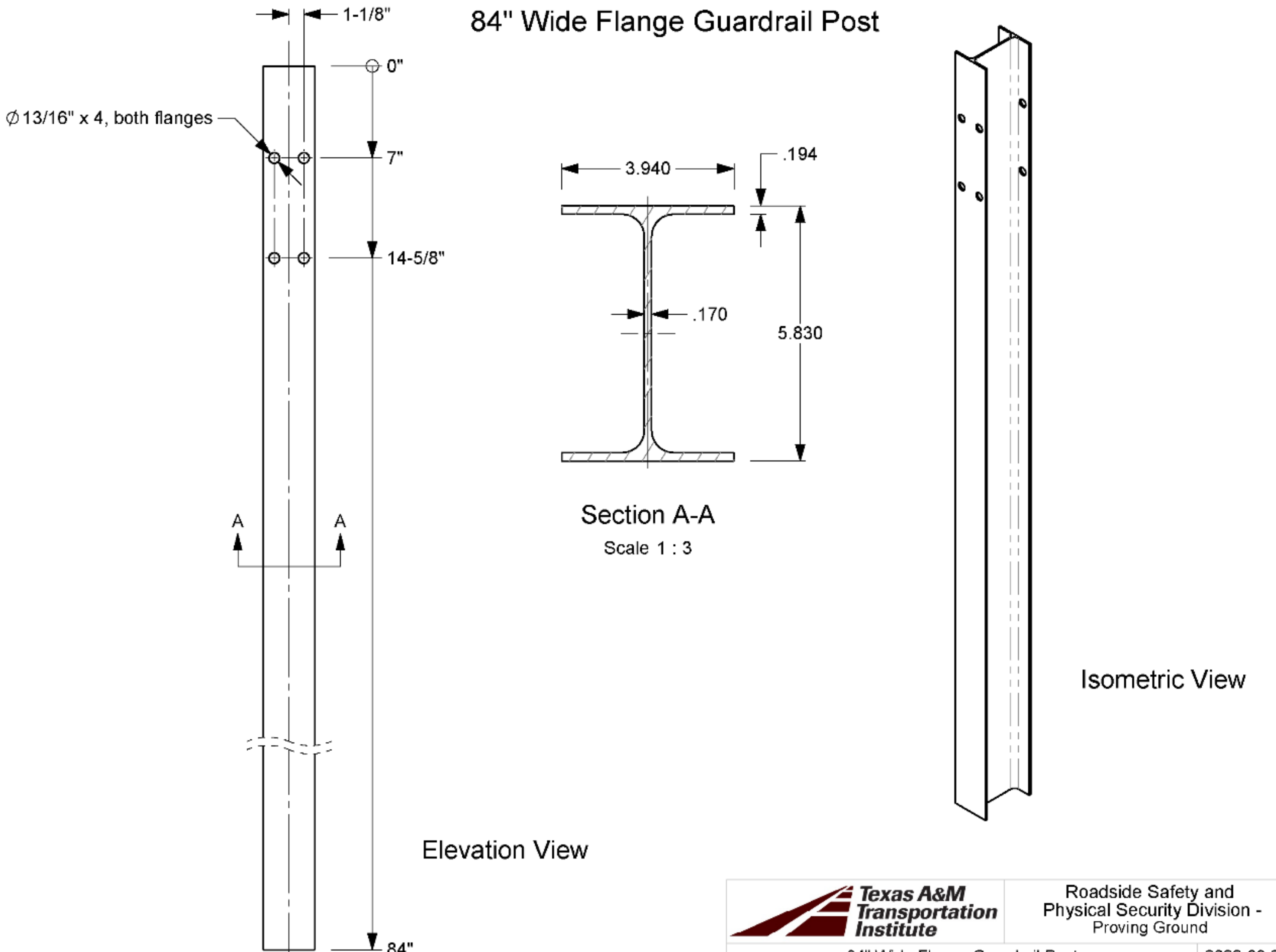
1a. Manufacture per AASHTO M180 specifications.

1b. 4-space Guardrail is shown. Slots typical x 3 for 2-space W-beam spaced at 75", and typical x 9 for 8-space W-beam spaced at 18-3/4". Slots are typical x 4 at 37-1/2" for 9'-4-1/2" span W-beam.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
4-space W-beam Guardrail		2020-06-05
Drawn by GES	Scale 1:20	Sheet 1 of 1

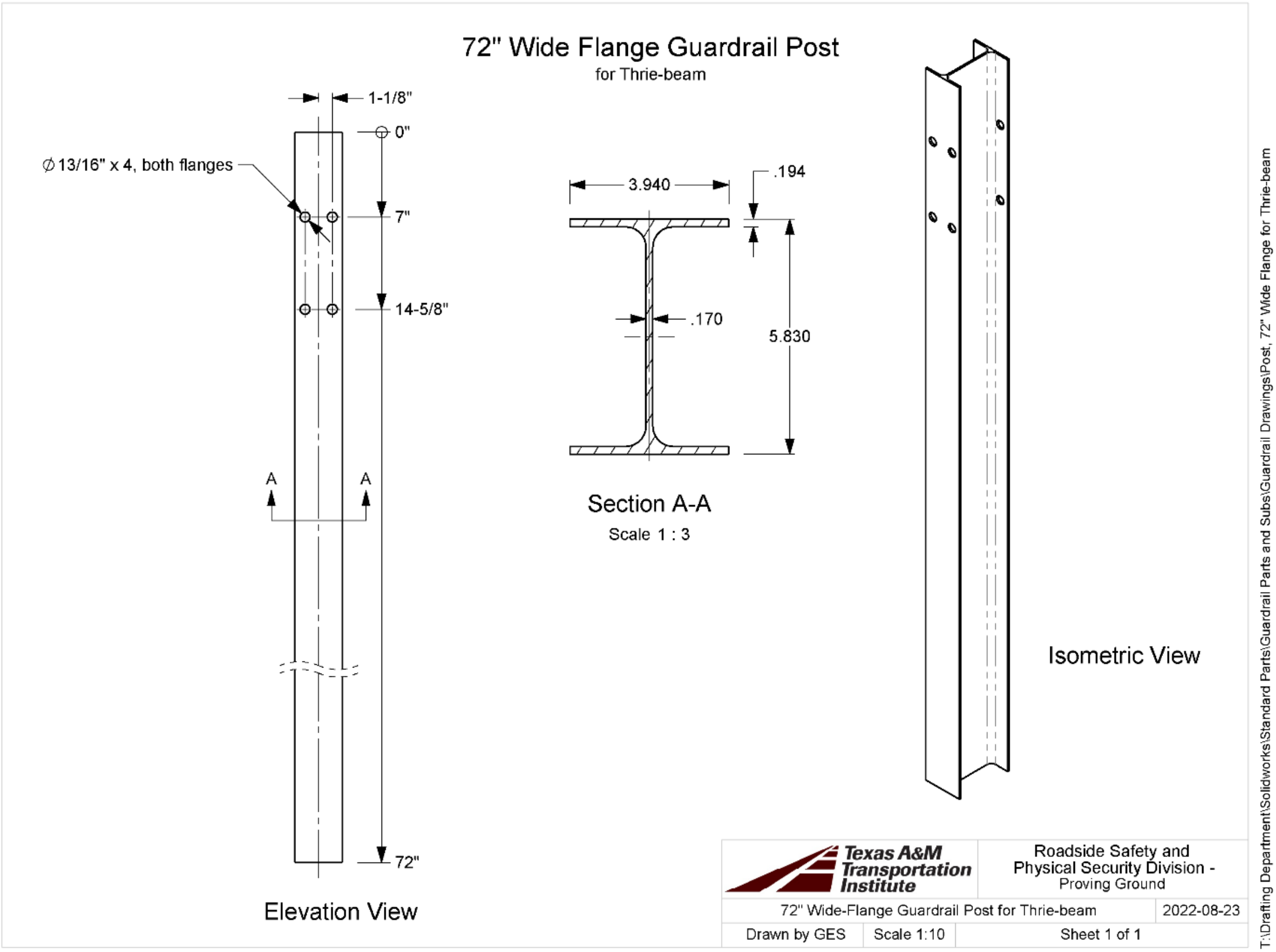
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\W-Beam Guardrail

84" Wide Flange Guardrail Post

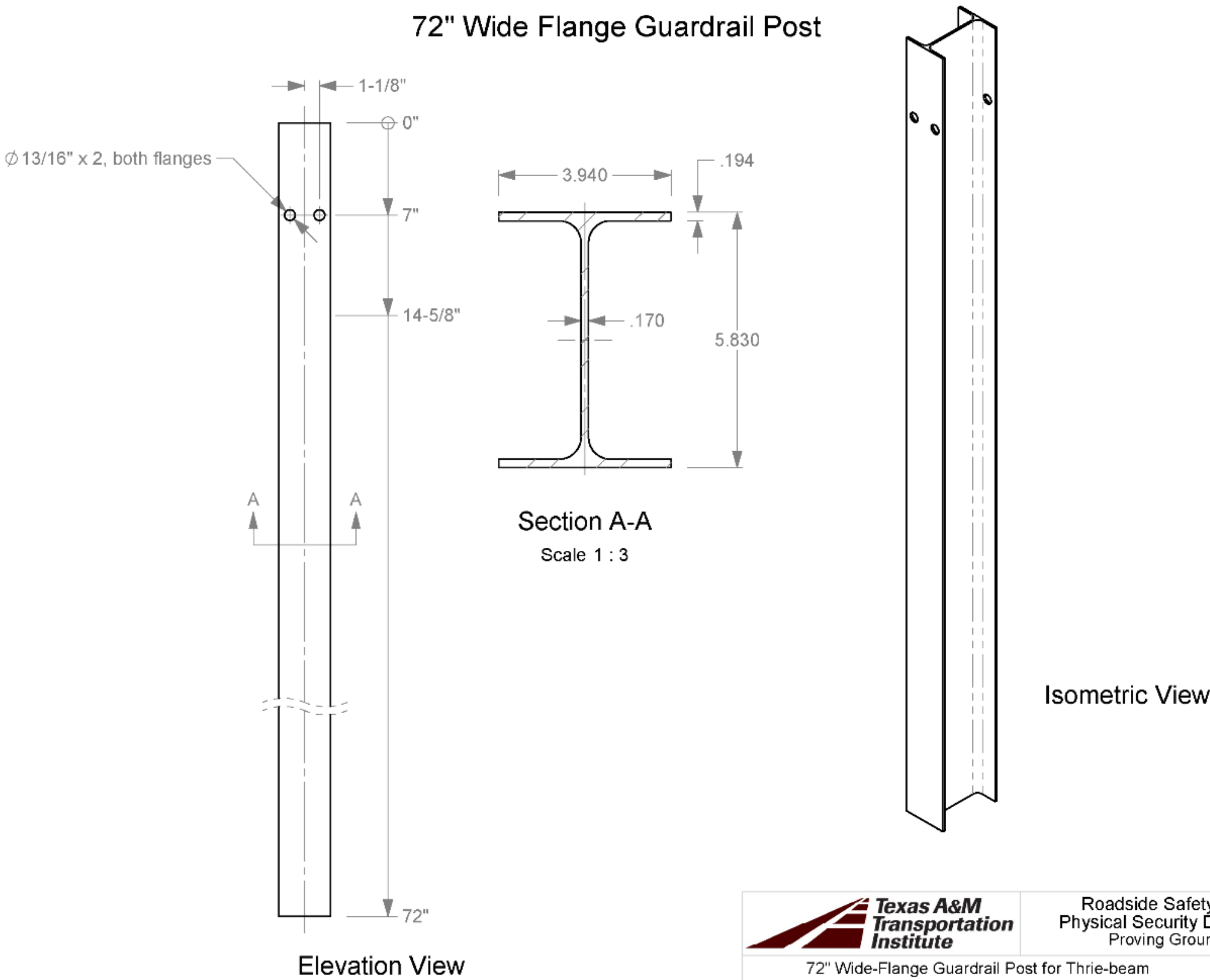


Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
84" Wide-Flange Guardrail Post		2022-08-23
Drawn by GES	Scale 1:10	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 84" Wide Flange Guardrail Post


72" Wide Flange Guardrail Post
for Thrie-beam
1-1/8"
0"
∅13/16" x 4, both flanges
7"
14-5/8"
A
A
72"
Elevation View
3.940
.194
.170
5.830
Section A-A
Scale 1 : 3
Isometric View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
72" Wide-Flange Guardrail Post for Thrie-beam
2022-08-23
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 for Thrie-beam

72" Wide Flange Guardrail Post



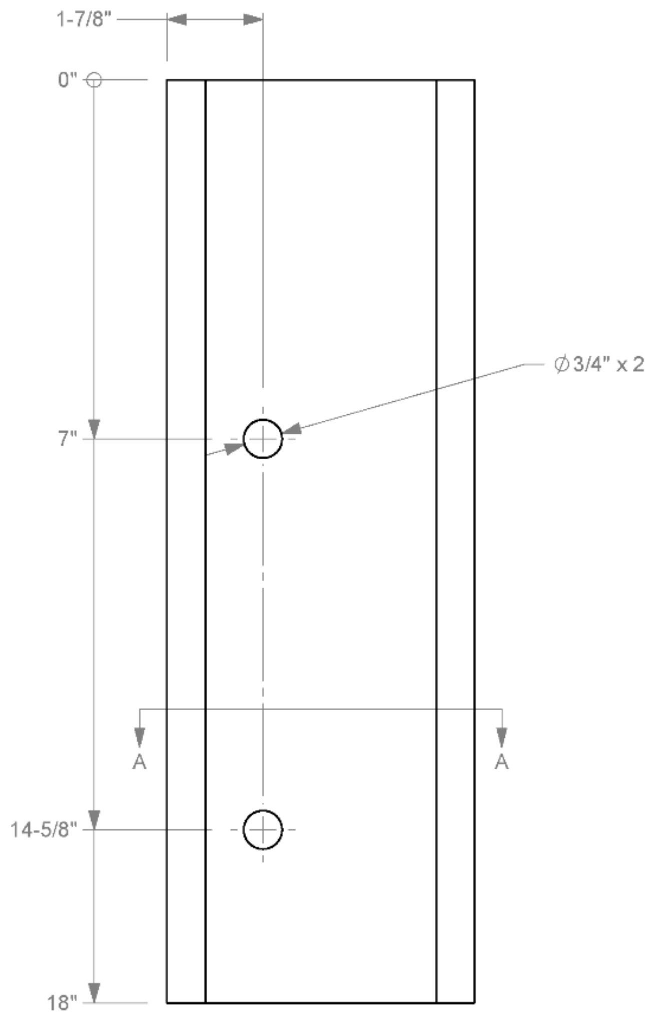
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

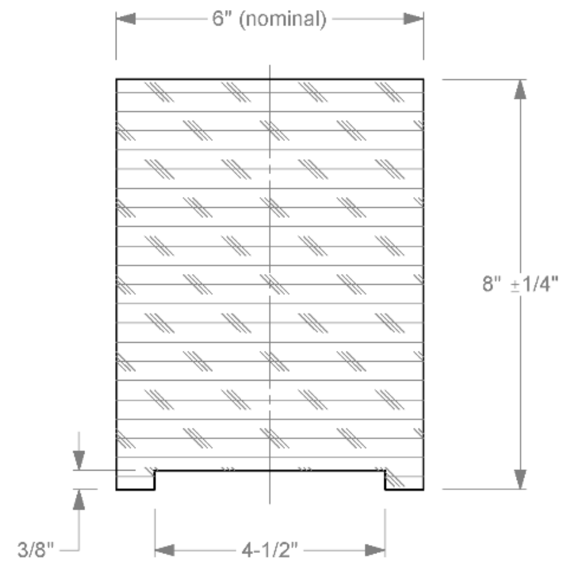
72" Wide-Flange Guardrail Post for Thrie-beam	2020-11-10
Drawn by GES	Scale 1:10
Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam

Transition Blockout for W-section Post



Elevation View



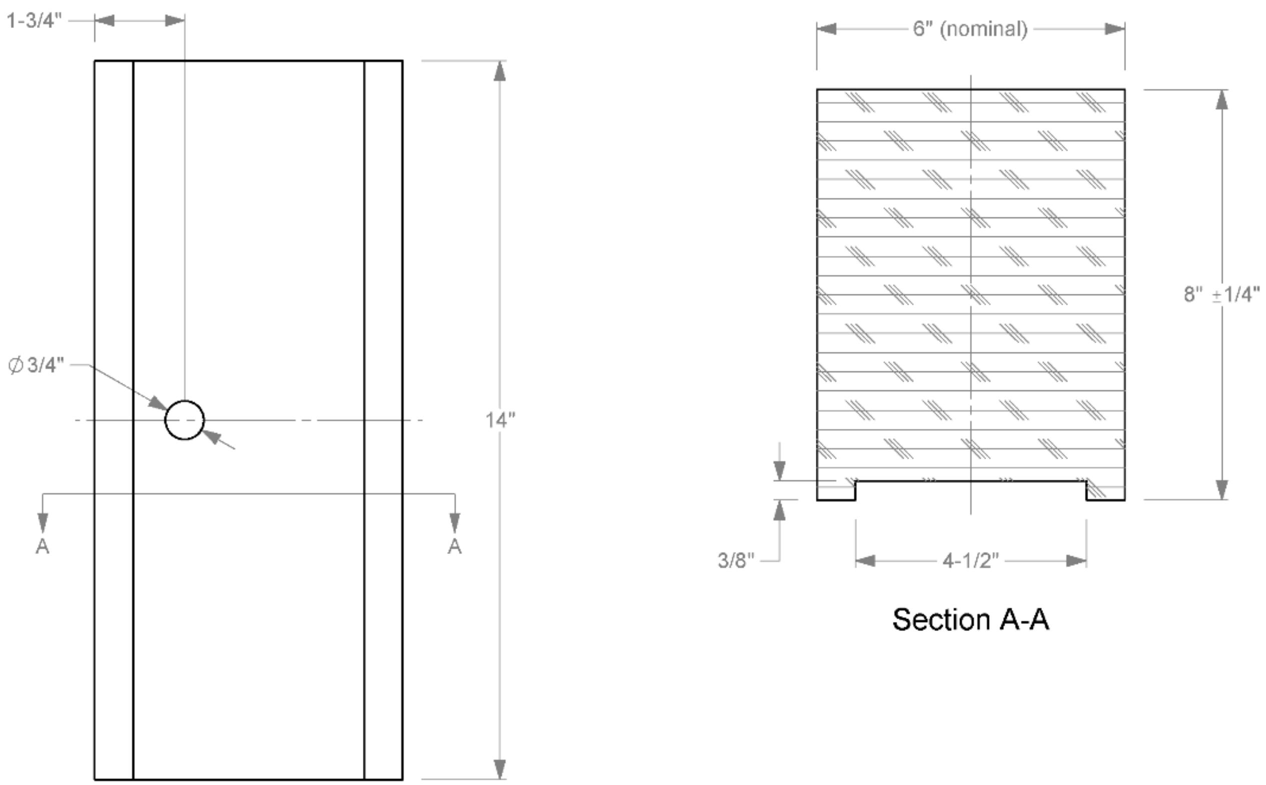
Section A-A

1a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Transition Blockout, for W-section Post			2020-09-14
Drawn by GES	Scale 1:3	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Transition Blockout for W-section Post

Timber Blockout for W-section Post



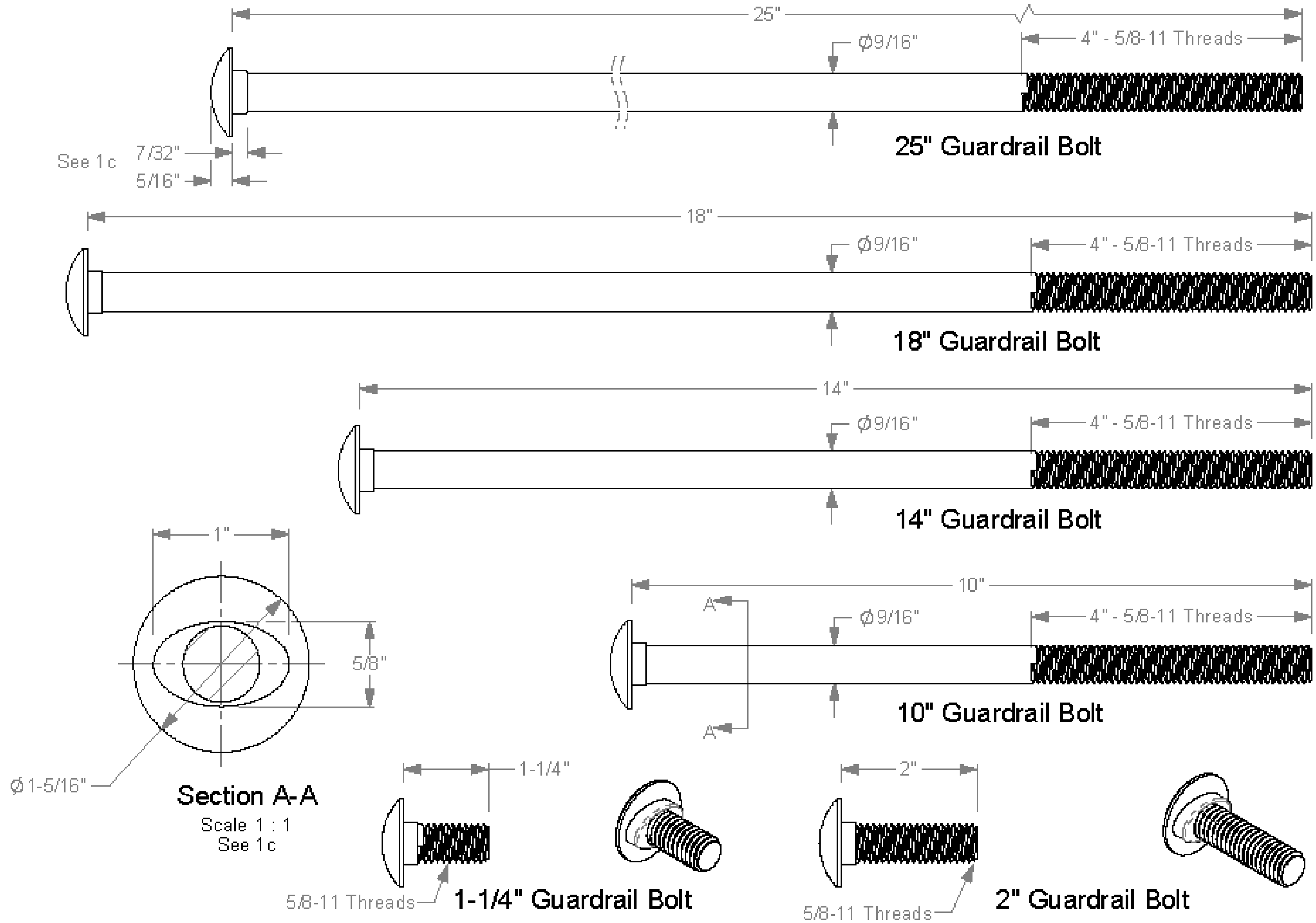
Elevation View

Section A-A

1a. Timber blockouts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Timber Blockout, for W-section Post		2019-07-03
Drawn by GES	Scale 1:3	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Timber Blockout for W-section Post

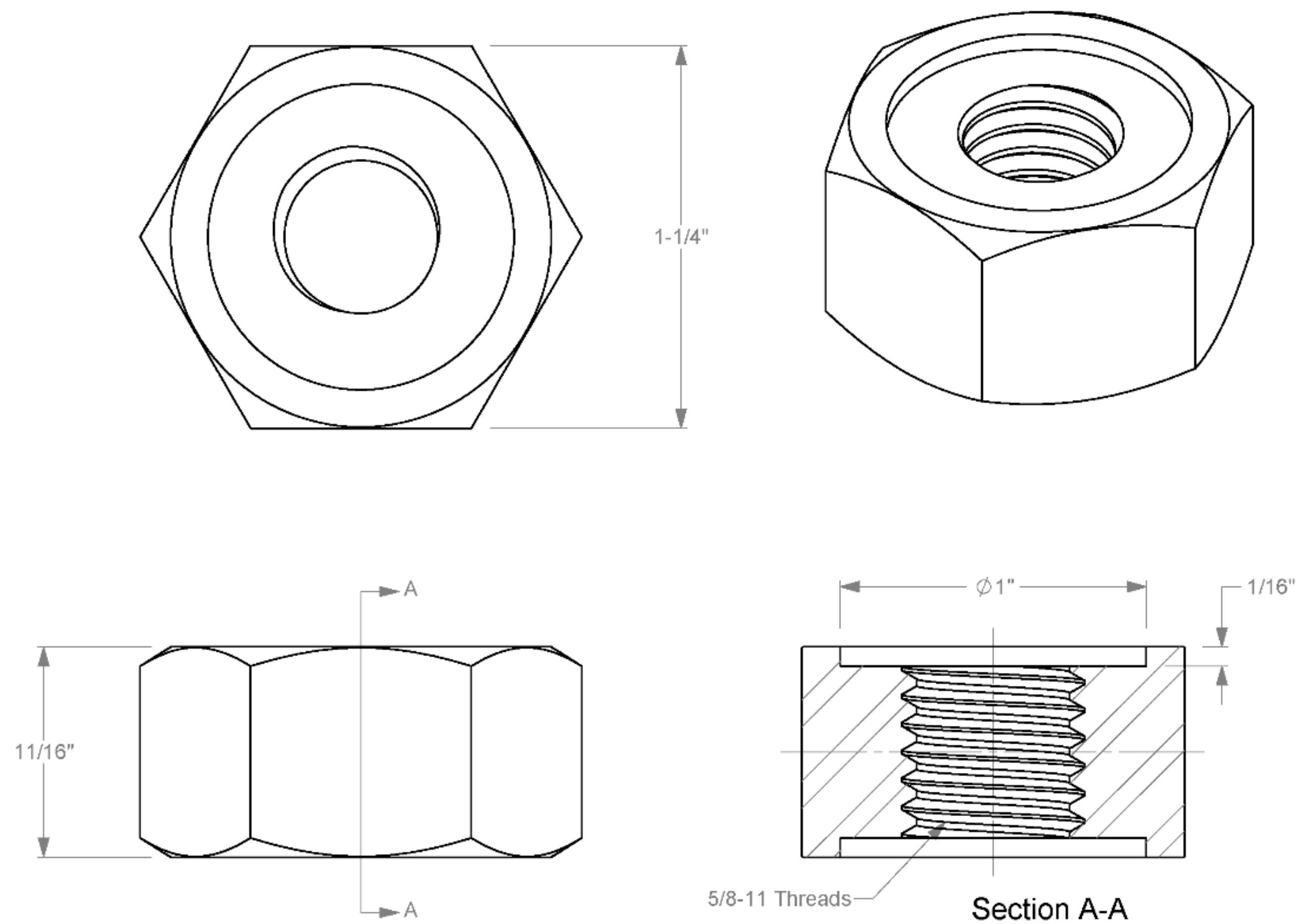


1a. Material is ASTM A307.
1b. All bolt sizes not used in all projects. See system drawing.
1c. Head and shoulder dimensions typical all sizes.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Guardrail Bolt		2020-04-22
Drawn by GES/WS	Scale 1:2	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Guardrail Bolt

Recessed Guardrail Nut



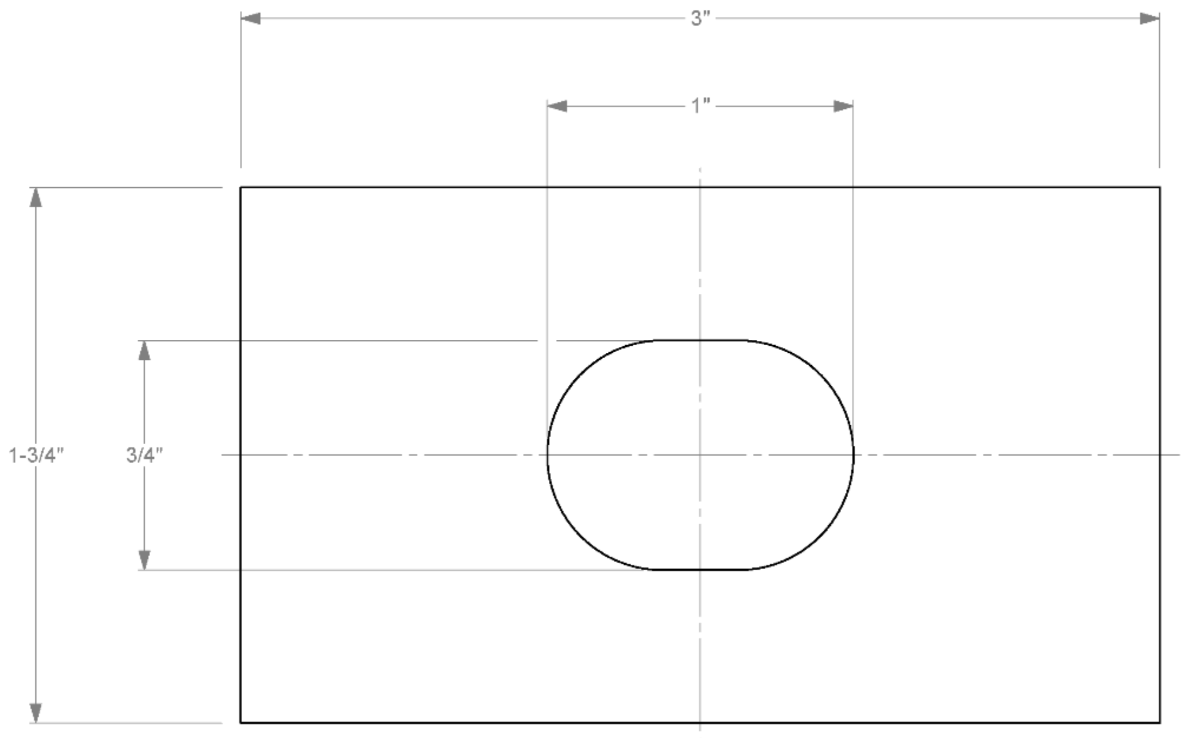
1a. Material is ASTM A 563 Grade A.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Recessed Guardrail Nut		2019-06-27
Drawn by GES	Scale 2:1	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Nut, Recessed Guardrail

Rectangular Guardrail Washer

0.20" thick



Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Rectangular Guardrail Washer			2019-08-08
Drawn by GES	Scale 2:1	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Washer, rect.

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

CERTIFICATE OF TEST

EMJ

Page 01 of 03

Certification Date
5 -AUG-2022

T 449252

CUSTOMER ORDER NUMBER
2747

CUSTOMER PART NUMBER
506038

EARLE M. JORGENSEN COMPANY
6201 LUMBERDALE
HOUSTON TX 77092

Invoice Number
T449252

SOLD TO: CUSTOM FABRICATORS & REPAIRS
1379 N HARVEY MITCHELL PKWY
BRYAN TX 77803

SHIP TO: CUSTOM FABRICATORS & REPAIRS
1379 N HARVEY MITCHELL PKWY
BRYAN TX 77803

Description: 4142 CF HEAT TREATED S/R OR STRESS FREE BAR
1 RD X 12' R/L
Line Total: 37.5 FT
HEAT: 75084411
ITEM: 506038

Specifications:

ASTM A434 CL BC 18	ASTM A193 GR B7 20	MIC 12016 ADD 1 SUP1 16
ASTM E112 13	ASTM E10 18	ASTM A255 10
ASTM A304 16	ASTM E45 METH A 18A	ASTM E381 17
JDM AO QL2 18	ASTM E8 16	ASTM A370 19
CAT 1E0024	EN 10204 3.1	ASME SA193 B7
ASTM A29 16	ASTM A962 SEC 5 19	ASTM A322 13
ASTM A108 18		

CHEMICAL ANALYSIS

C	MN	P	S	SI	NI	CR	MO
0.41	0.95	0.012	0.032	0.26	0.15	0.88	0.16
CU	SN	AL	V	B	CA	NB	H
0.21	0.01	0.026	0.003	0.0003	0.001	0.002	0.0001

RCPT: R293943
VENDOR: MAGELLAN CORPORATION
COUNTRY OF ORIGIN : USA

MECHANICAL PROPERTIES

DESCRIPTION	YLD STR KSI	ULT TEN KSI	%ELONG IN 02 IN	%RED IN AREA	HARDNESS BHN
	136.0	144.0	23.0	58.0	276

EMJ - 1" HT FOR 414271 08/05/2022

The above data were transcribed from the manufacturer's Certificate of Test after verification for completeness and specification requirements of the information on the certificate. All test results remain on file subject to examination.

We hereby certify that the material covered by this report will meet the applicable requirements described herein, including any specification forming a part of the description.

The willful recording of false, fictitious, or fraudulent statements in connection with test results may be punishable as a felony under federal statutes.

Material did not come in contact with mercury while in our possession.

SHANE LU

Shane Lu

Manager, Quality Assurance

CERTIFICATE OF TEST

EMJ

Certification Date
5-AUG-2022

CUSTOMER ORDER NUMBER
2747

CUSTOMER PART NUMBER
506038

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1379 N HARVEY MITCHELL PKWY
BRYAN TX 77803

Description: 4142 CF HEAT TREATED S/R OR STRESS FREE BAR
1 RD X 12' R/L
Line Total: 37.5 FT
HEAT: 75084411 ITEM: 506038
END-QUENCH HARDENABILITY (JOMINY - RC)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
57	57	57	57	57	57	56	55	54	52	51	50	49	48	46

16	18	20	22	24	26	28	30	32
45	45	44	44	42	42	40	38	37

IDEAL DIAMETER : 5.23 IN GRAIN SIZE :5 - 8

CLEANLINESS

	A		B		C		D	
	THIN MAX	THICK MAX	THIN MAX	THICK MAX	THIN MAX	THICK MAX	THIN MAX	THICK MAX
e45	1.6	0.5	1.0	0.2	0.5	0.0	1.0	0.5

STRAND CAST REDUCTION RATIO 103.7 TO 1 VACUUM DEGASSED
MATERIAL IS FREE FROM MERCURY CONTAMINATION
NO WELD REPAIR PERFORMED ON MATERIAL
EDDY CURRENT:YES
THERMAL TREATMENT: OK
AUTENIZE TEMP: 1640 DEG F / TIME: 0.30 MINS
QUENCH TEMP: 88 DEG F / TIME: 0.80 MINS / MEDIA: WATER
TEMPER TEMP: 1350 DEG F / TIME: 0.30 MINS
MACRO: OK
MICRO1: OK

The above data were transcribed from the manufacturer's Certificate of Test after verification for completeness and specification requirements of the information on the certificate. All test results remain on file subject to examination.

We hereby certify that the material covered by this report will meet the applicable requirements described herein, including any specification forming a part of the description.

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Material did not come in contact with mercury while in our possession.

SHANE LU

Manager, Quality Assurance

CERTIFICATE OF TEST

Certification Date
5 -AUG-2022

CUSTOMER ORDER NUMBER
2747

CUSTOMER PART NUMBER
506038

EARLE M. JORGENSEN COMPANY
6201 LUMBERDALE
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1379 N HARVEY MITCHELL PKWY
BRYAN TX 77803

SHIP TO: CUSTOM FABRICATORS & REPAIRS
1379 N HARVEY MITCHELL PKWY
BRYAN TX 77803

Description: 4142 CF HEAT TREATED S/R OR STRESS FREE BAR
1 RD X 12' R/L
Line Total: 37.5 FT
HEAT: 75084411
ITEM: 506038

COMMENTS
material 100% melted & mfg in the usa by the electric arc furnace & cc
red ratio: 103.7:1
macro: s-1 r-1 c-1
gerdau monitors all incoming scrap & all heats of steel to ensure that
products shipped are free of radioactive material
material is 100% recyclable
cal/al treated for castability; fully killed; fg; q&t; water quench;
stress free; t&p; +/-10 gauss; #1590
cold finished, turned and polished

The above data were transcribed from the manufacturer's Certificate of Test after verification for completeness and specification requirements of the information on the certificate. All test results remain on file subject to examination.

We hereby certify that the material covered by this report will meet the applicable requirements described herein, including any specification forming a part of the description.

The willful recording of false, fictitious, or fraudulent statements in connection with test results may be punishable as a felony under federal statutes.

Material did not come in contact with mercury while in our possession.

SHANE LU

Shane Lu

Manager, Quality Assurance

07-09-2022 03:50 **Load - 4113094** **BL - 3919803** blr466

Custom Fabricators **Heat - 2220804**

Cust. PO - 02671 **Order - 21559520**

3919803

AM/NS Calvert LLC
1 AM/NS Way
Calvert, Al. , AL 36513 USA

AM/NS CALVERT

Mill Certificate

CUSTOMER ORIGINAL

Order - Item	Certificate Number	Delivery No	Ship Date	Page
240142-50	1195485140	83260986-10	06/07/2022	1 of 1

Customer No: 10213 Cust PO: HTX-7733165

Customer Part No:

Customer Sold to:	Customer Ship to:	Contact - Stan Bevans
Kloeckner Metals Corp. - Tulsa Kloeckner Metals Corp 3123 E. Apache TULSA OK 74110 USA	Kloeckner Metals Corp. 7400 Mesa Dr. HOUSTON TX 77028 USA	AM/NS Calvert LLC 1 AM/NS Way CALVERT AL 36513 USA Email: Stanley.Bevans@ArcelorMittal.com Ph : 1-251-289-3000

Steel Grade / Customer Specification
Hot Roll Black Coil Conv to A36 / 0.2400 " X 60.0000 " ACCORDING TO A1018 {Hvy 0.230"(6)-1"(25.4)}-Hot Roll Base

Type of Product/Surface
Hot Roll Black Dry Unexposed GENERAL STOCK, CTL SHEET

07/11/2022

TEST METHOD Melted in Mexico Manufactured in USA
ASTM

MATERIAL DESCRIPTION

	ORDERED	Heat No.	Coil No.	Weight Net LB	Weight Gross LB
(mm)	6.096	2220804	1195485140	46,186.000	46,186.000
(in)	0.2400				

CHEMICAL COMPOSITION OF THE LADLE *

Heat No.	C	Si	Mn	P	S	Al	Cr	Cu	Mo	N
2220804	0.1970	0.02	0.83	0.008	0.003	0.040	0.01	0.010	0.001	0.0021

	Ni	Nb	Ti	B	V	Ca
	0.002	0.001	0.002	0.0001	0.001	0.0006

TENSILE TEST

Test Direction	Yield Strength	Tensile Strength	% Total Elong.
T	47 ksi	68 ksi	35

AM/NS Calvert LLC certify that the material herein described has been manufactured, sampled, tested and inspected in accordance with the contract requirements and is fully in compliance.

* - This test is not covered by our current A2LA accreditation

Yasunori Iwasa
Quality Management Director
AM/NS Calvert

Rev.

Kloeckner

FIELD DENSITY TEST REPORT

Report Number: A1171057.0237
Service Date: 07/21/22
Report Date: 07/26/22
Task: PO# 616391-01

Terracon
6198 Imperial Loop
College Station, TX 77845-5765
979-846-3767 Reg No: F-3272

Client

Texas Transportation Institute
Attn: Bill Griffith
TTI Business Office
3135 TAMU
College Station, TX 77843-3135

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Mat. No.	Proctor Ref. No.	Classification and Description	Laboratory Test Method	Lab Test Data: Optimum Water Content (%)	Lab Test Data: Max. Lab Density (pcf)	Project Requirements: Water Content (%)	Project Requirements: Compaction (%)
1	A1171057.0099A	Tan crushed limestone	ASTM D698	6.3	138.0		

Field Test Data

Test No.	Test Location	Lift / Elev.	Mat. No.	Probe Depth (in)	Wet Density (pcf)	Water Content (pcf)	Water Content (%)	Dry Density (pcf)	Percent Compaction (%)
	Paving Base								
1	See Attachment	2	1	8	152.3	6.1	4.2	146.2	100+

Datum: Top of existing grade **Std. Cnt. M:** 560 **Std. Cnt. D:** 1556
S/N: 20016 **Make:** Troxler **Model:** 3430 **Last Cal. Date:** 02/10/2022
Comments:

Services: Perform in-place density and moisture content tests with a Troxler type gauge to determine degree of compaction and material moisture condition.
Terracon Rep.: Mohammed Mobeen
Reported To: Bill at TTI
Contractor: TTI
Report Distribution:
(1) Texas Transportation Institute, Bill Griffith

Start/Stop: 0900-1030

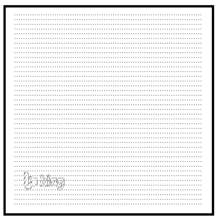
Reviewed By:
Alexander Dunigan
Project Manager

Test Methods: ASTM D6938-07 Method A

The tests were performed in general accordance with applicable ASTM, AASHTO, or DOT test methods. This report is exclusively for the use of the client indicated above and shall not be reproduced except in full without the written consent of our company. Test results transmitted herein are only applicable to the actual samples tested at the location(s) referenced and are not necessarily indicative of the properties of other apparently similar or identical materials.

CR0007, 11-16-12, Rev.7

Page 1 of 1



Test
Retested / Accepted
Deviation

Terracon
6198 Imperial Loop, College Station, TX 77845-5765
979-846-3767
terracon.com

Riverside Campus

Field Density Testing

Exhibit **A-1**

Report Number:	Service Date:	Employee:	Scale:
A1171057.0237	07/21/2022	Mobeen, Mohammed	Refer to Drawing

Table B.1. Test Day Static Soil Strength Documentation for Test No. 616391-01-1.

Date	2022-09-19
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 M 147 17 Grading D (Crushed Concrete)
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 s

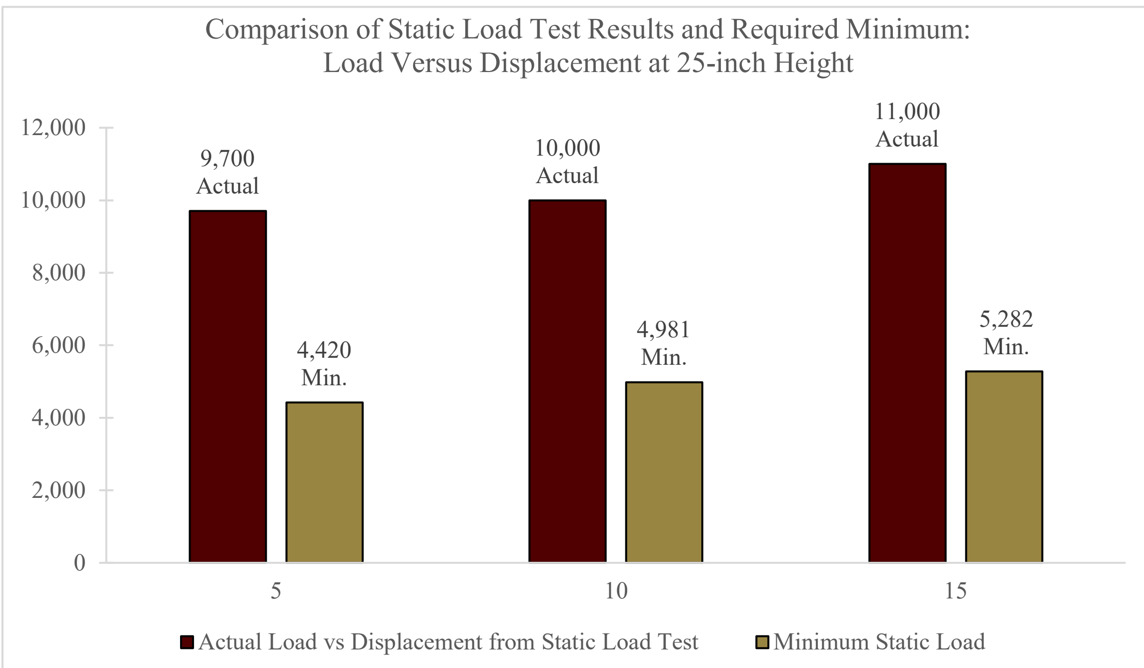


Figure B.1. Test Day Static Soil Strength Documentation for Test No. 616391-01-1.

Table B.2. Test Day Static Soil Strength Documentation for Test No. 616391-01-2.

Date	2022-10-04
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 M 147 17 Grading D (Crushed Concrete)
Description of Fill Placement Procedure	12-inch lifts tamped with a pneumatic compactor for 20 s

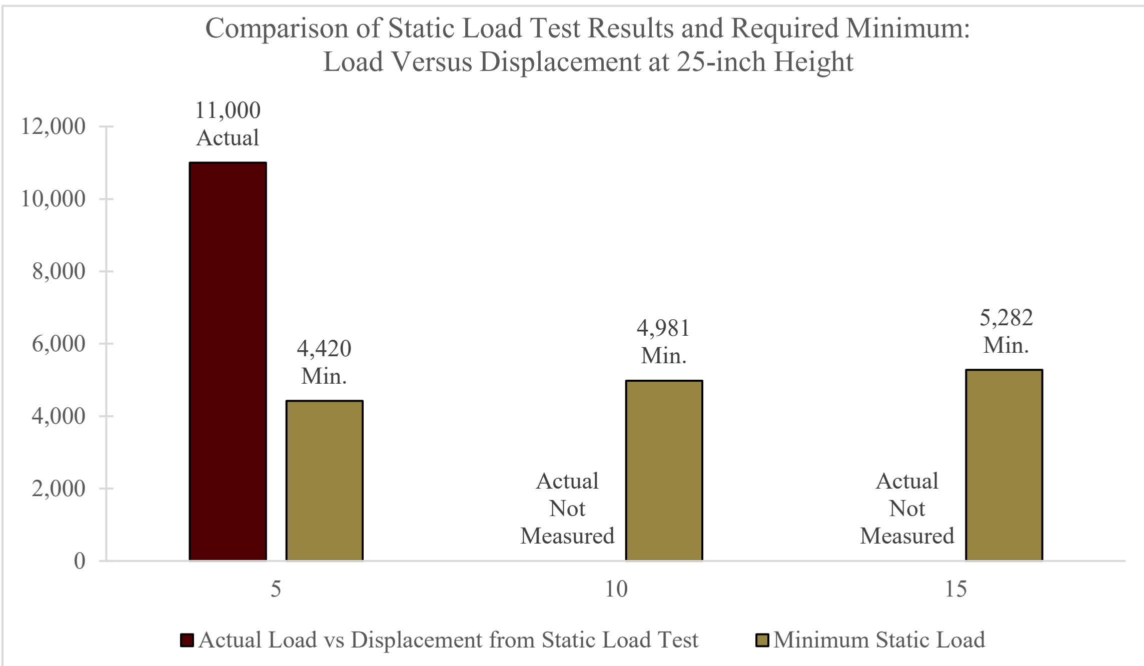


Figure B.2. Test Day Static Soil Strength Documentation for Test No. 616391-01-2.

APPENDIX C. *MASH* TEST 3-20 (CRASH TEST NO. 616391-01-1)

C.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2022-09-19 Test No.: 616391-01-1 VIN No.: 3N1CN7AP9GL867027

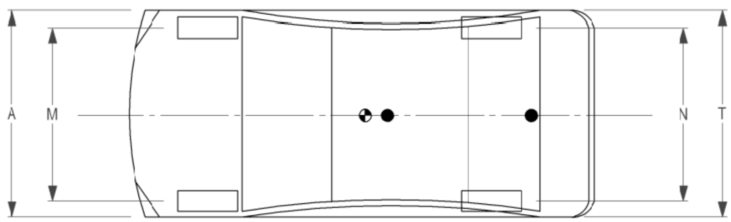
Year: 2016 Make: Nissan Model: Versa

Tire Inflation Pressure: 36 PSI Odometer: 91886 Tire Size: P185/65R15

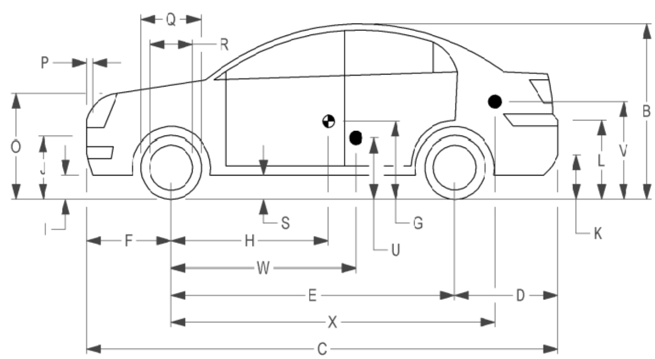
Describe any damage to the vehicle prior to test: None

● 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	66.70	F	32.50	K	12.50	P	4.50	U	15.50
B	59.60	G		L	26.00	Q	24.00	V	21.25
C	175.40	H	41.95	M	58.30	R	16.25	W	42.00
D	40.50	I	7.00	N	58.50	S	7.50	X	79.75
E	102.40	J	22.50	O	30.50	T	64.50		

Wheel Center Ht Front 11.50 Wheel Center Ht Rear 11.50 W-H 0.05

RANGE LIMIT: A = 65 ±3 inches; C = 169 ±8 inches; E = 98 ±5 inches; F = 35 ±4 inches; H = 39 ±4 inches; O (Top of Radiator Support) = 28 ±4 inches
(M+N)/2 = 59 ±2 inches; W-H < 2 inches or use MASH Paragraph A4.3.2

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1750	M_{front}	1430	1451	1536
Back	1687	M_{rear}	955	1007	1087
Total	3389	M_{Total}	2385	2458	2623

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

Mass Distribution:
lb LF: 772 RF: 679 LR: 495 RR: 512

Figure C.1. Vehicle Properties for Test No. 616391-01-1.

Date:	2022-09-19	Test No.:	616391-01-1	VIN No.:	3N1CN7AP9GL867027
Year:	2016	Make:	Nissan	Model:	Versa

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	AT FT BUMPER	15	8	28							-14
2	ABOVE FT BUMPER	15	10	40							60
	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.

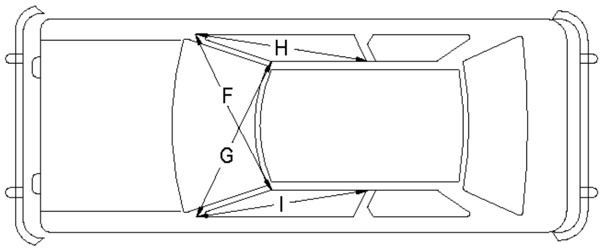
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

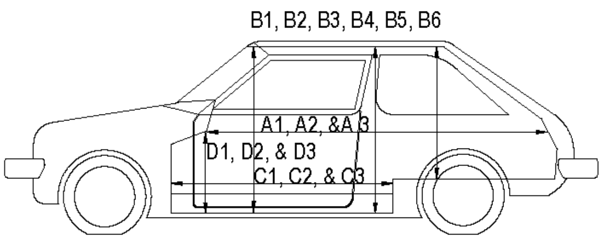
***Measure and document on the vehicle diagram the location of the maximum crush.

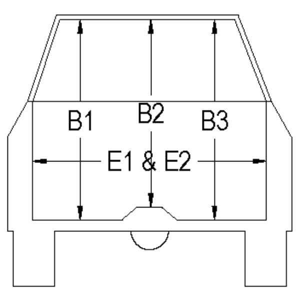
Note: Use as many lines/columns as necessary to describe each damage profile.

Figure C.2. Exterior Crush Measurements for Test No. 616391-01-1.

Date:	2022-09-19	Test No.:	616391-01-1	VIN No.:	3N1CN7AP9GL867027
Year:	2016	Make:	Nissan	Model:	Versa







*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	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	23.00	-3.00
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00
D3	9.50	9.50	0.00
E1	50.00	45.00	-5.00
E2	50.00	53.00	3.00
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*	50.00	44.50	-5.50

Figure C.3. Occupant Compartment Measurements for Test No. 616391-01-1.

C.2. SEQUENTIAL PHOTOGRAPHS

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

Figure C.4. Sequential Photographs for Test No. 616391-01-1 (Overhead Views).

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

Figure C.5. Sequential Photographs for Test No. 616391-01-1 (Frontal Views).

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

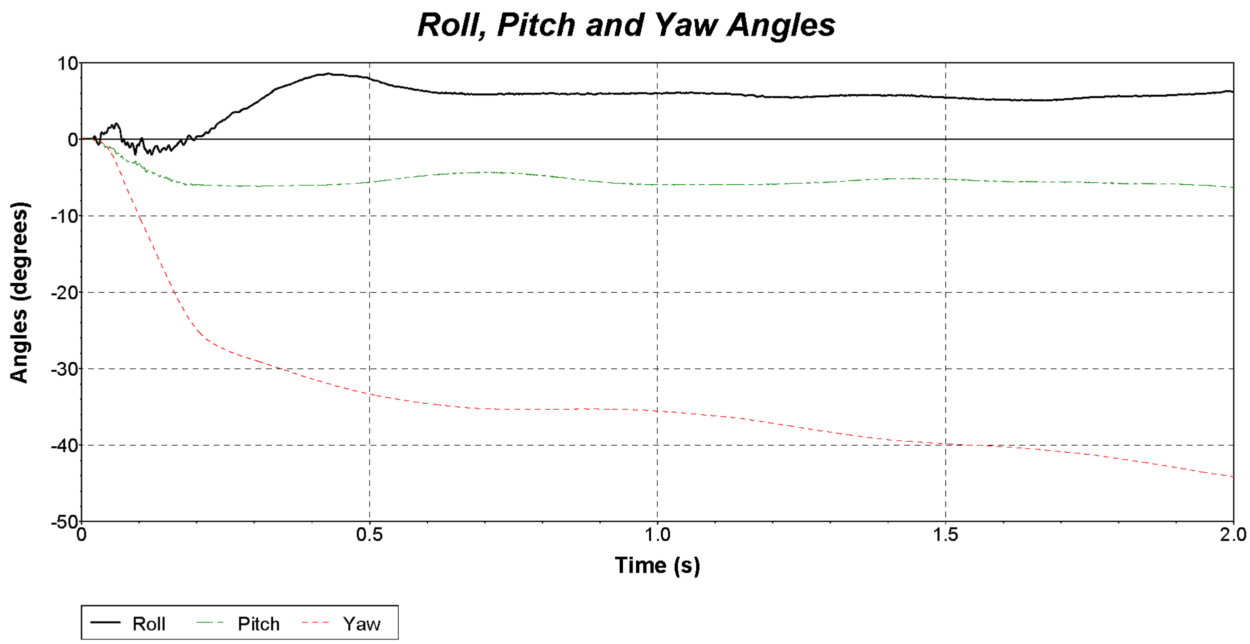
(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

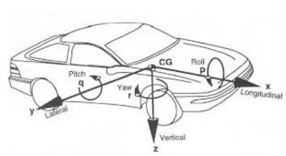
Figure C.6. Sequential Photographs for Test No. 616391-01-1 (Rear Views).

C.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 616391-01-1
Test Standard Test Number: *MASH* Test 3-20
Test Article: Guardrail to Portable Concrete Barrier
Test Vehicle: 2016 Nissan Versa
Inertial Mass: 2458 lb
Gross Mass: 2623 lb
Impact Speed: 62.2 mi/h
Impact Angle: 25.2 degrees

Figure C.7. Vehicle Angular Displacements for Test No. 616391-01-1.

C.4. VEHICLE ACCELERATIONS

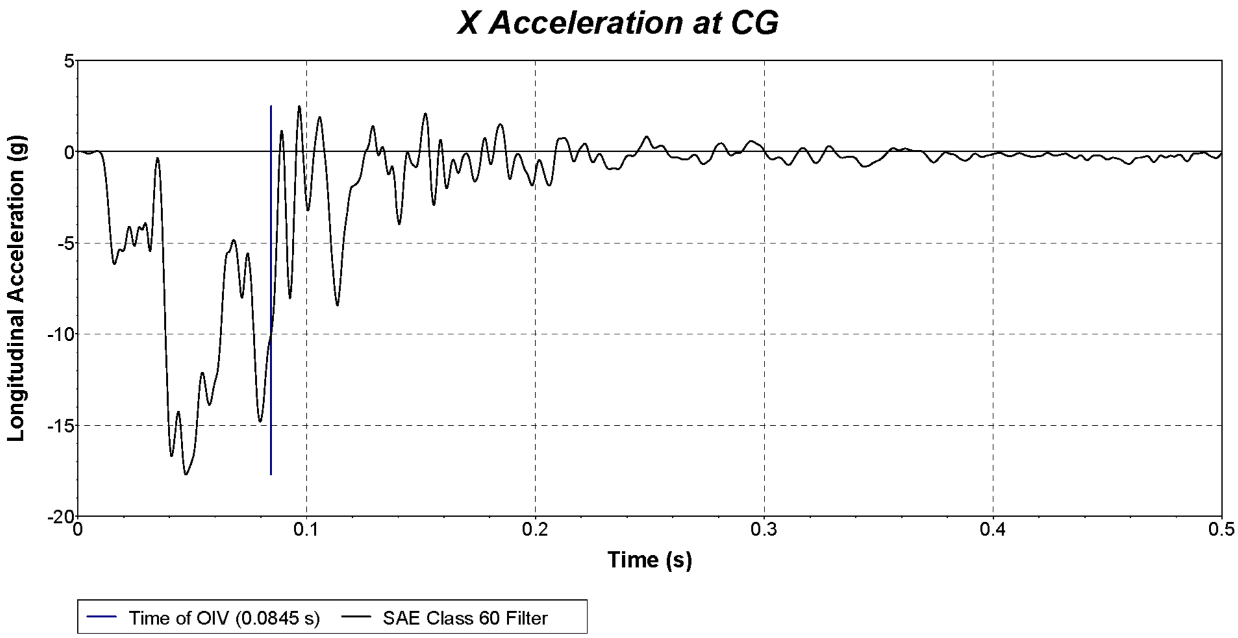


Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test No. 616391-01-1 (Accelerometer Located at Center of Gravity).

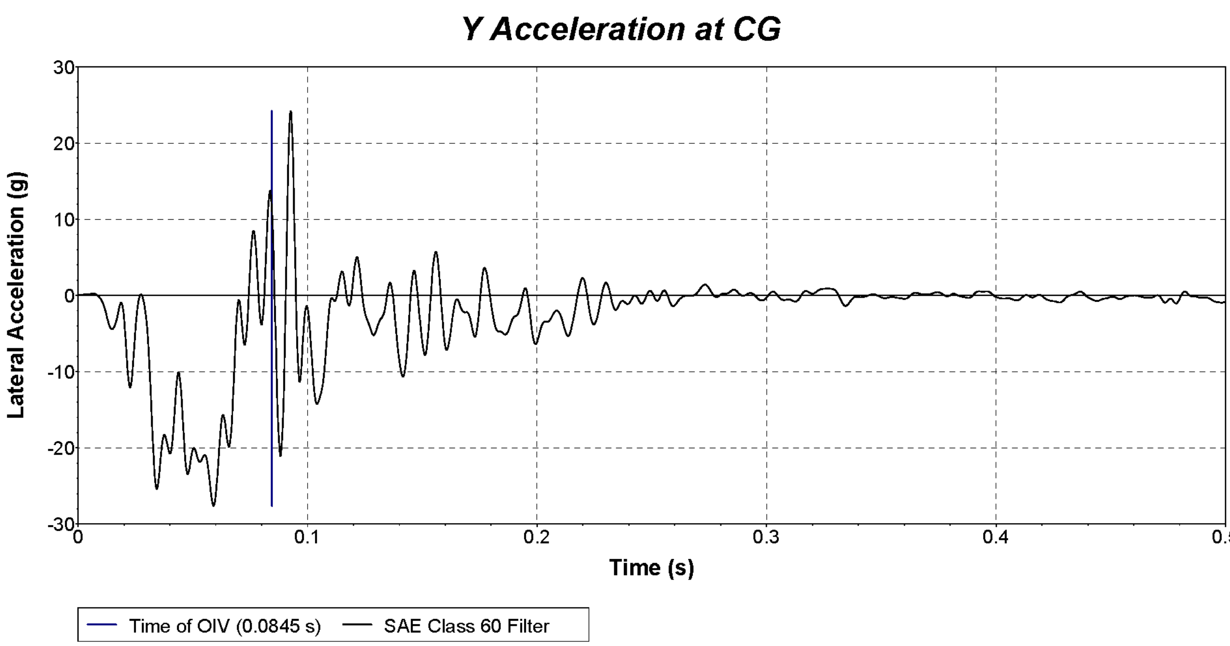


Figure C.9. Vehicle Lateral Accelerometer Trace for Test No. 616391-01-1 (Accelerometer Located at Center of Gravity).

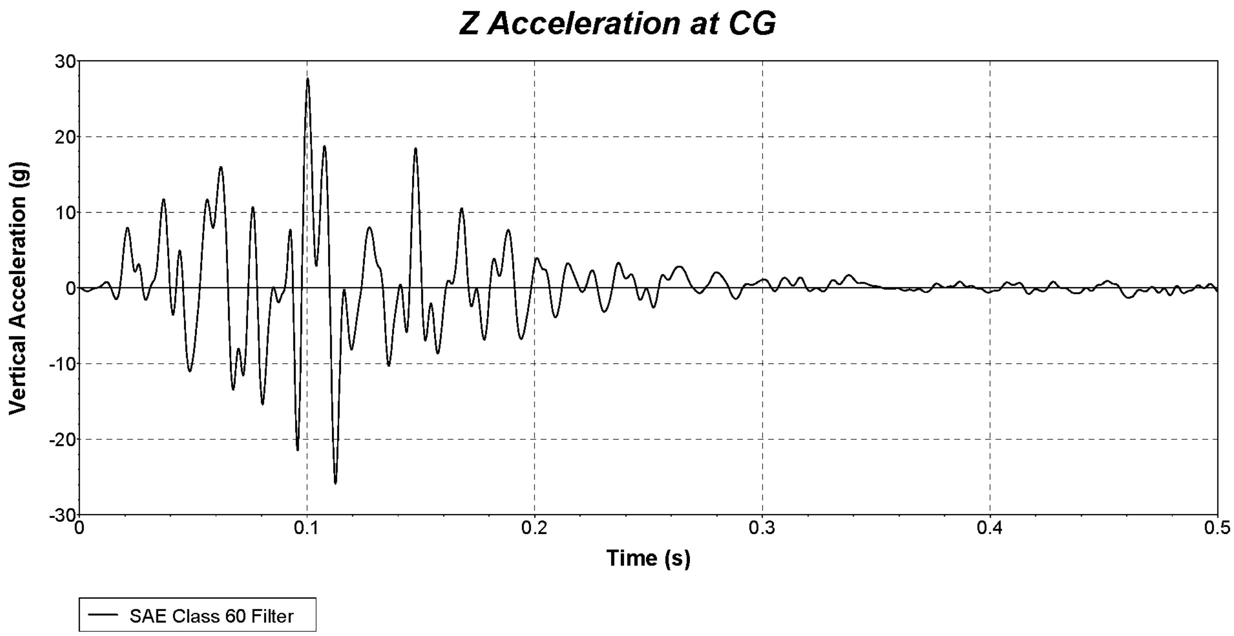


Figure C.10. Vehicle Vertical Accelerometer Trace for Test No. 616391-01-1 (Accelerometer Located at Center of Gravity).

APPENDIX D. *MASH* TEST 3-21 (CRASH TEST NO. 616391-01-2)

D.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2022-10-04 Test No.: 616391-01-2 VIN No.: 1C6RR6GT5GS393984

Year: 2016 Make: RAM Model: 1500

Tire Size: 265/70 R 17 Tire Inflation Pressure: 35 psi

Tread Type: Highway Odometer: 138424

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

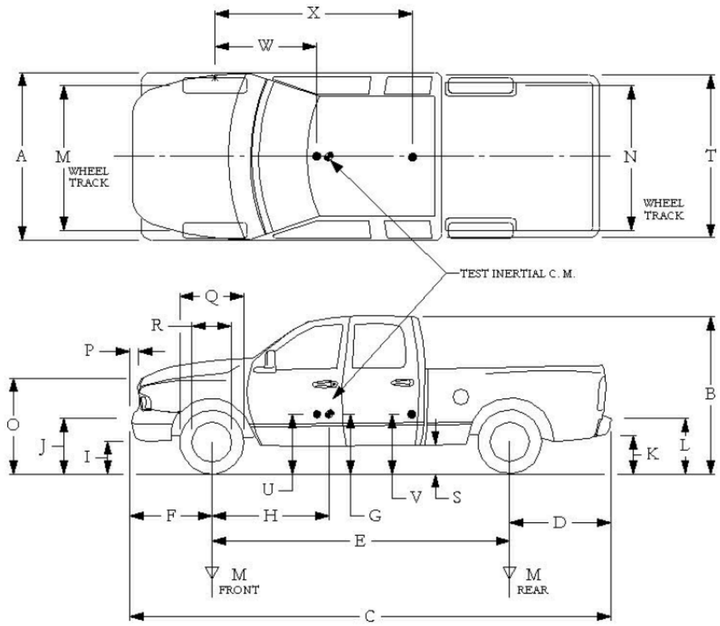
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

Dummy Data:
Type: NONE
Mass:
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.50	L	30.00	Q	30.50	V	30.25
C	227.50	H	60.86	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}	2958	2854	2854
Back	3900	M_{rear}	2090	2181	2181
Total	6700	M_{Total}	5048	5035	5035

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

Mass Distribution:
lb LF: 1467 RF: 1387 LR: 1085 RR: 1096

Figure D.1. Vehicle Properties for Test No. 616391-01-2.

Date:	2022-10-04	Test No.:	616391-01-2	VIN No.:	1C6RR6GT5GS393984
Year:	2016	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		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	AT FT BUMPER	14	14	36							18
2	SAME	14	14	60							76
	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.

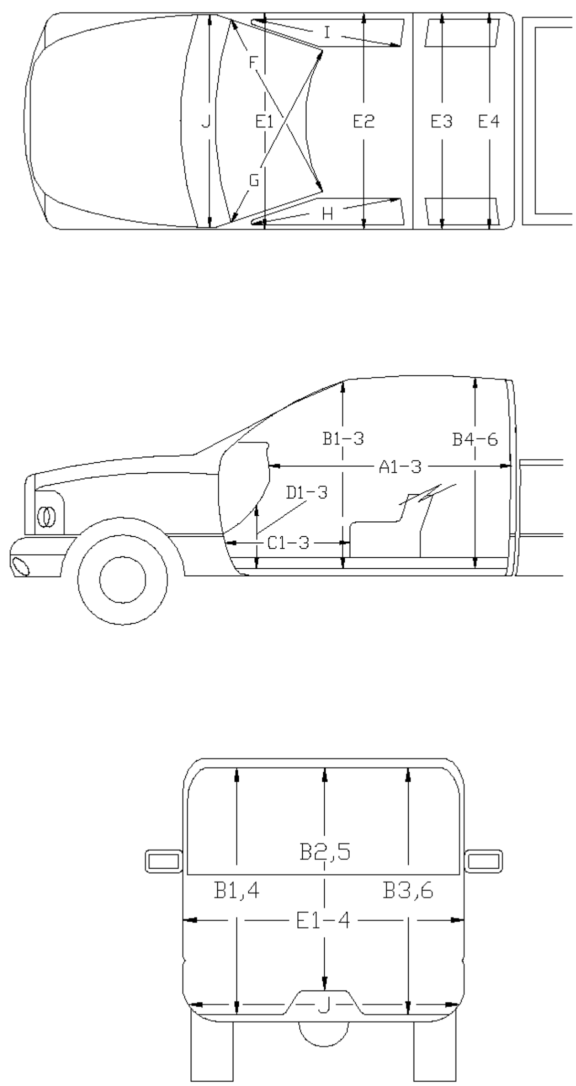
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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.

Figure D.2. Exterior Crush Measurements for Test No. 616391-01-2.

Date:	2022-10-04	Test No.:	616391-01-2	VIN No.:	1C6RR6GT5GS393984
Year:	2016	Make:	RAM	Model:	1500



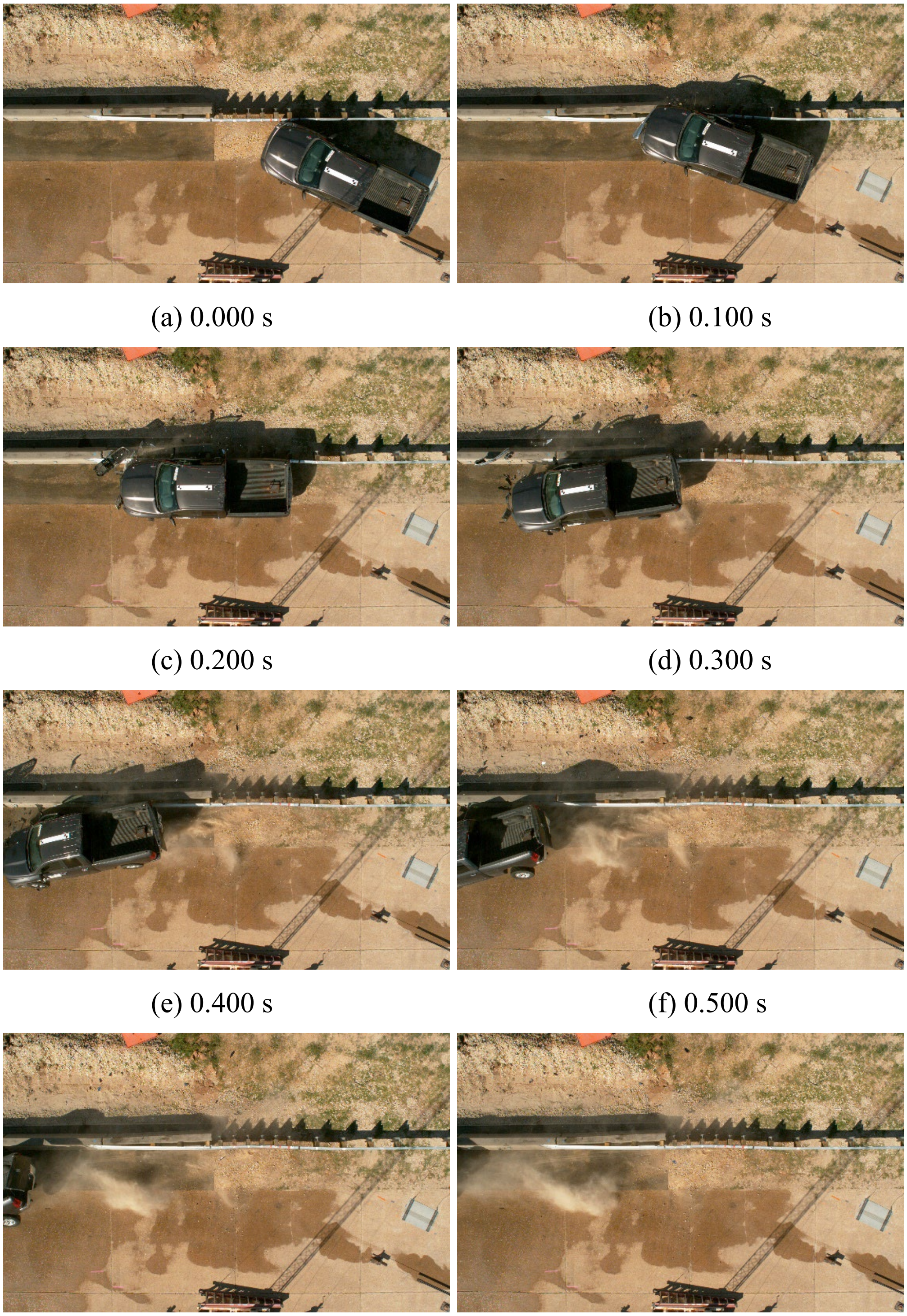
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

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	23.00	-3.00
D1	11.00	11.00	0.00
D2	0.00	0.00	0.00
D3	11.50	11.50	0.00
E1	58.50	55.50	-3.00
E2	63.50	65.50	2.00
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*	24.00	21.00	-3.00

Figure D.3. Occupant Compartment Measurements for Test No. 616391-01-2.

D.2. SEQUENTIAL PHOTOGRAPHS



(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

Figure D.4. Sequential Photographs for Test No. 616391-01-2 (Overhead Views).

(a) 0.000 s (b) 0.100 s

(c) 0.200 s (d) 0.300 s

(e) 0.400 s (f) 0.500 s

(g) 0.600 s (h) 0.700 s

Figure D.5. Sequential Photographs for Test No. 616391-01-2 (Frontal Views).


(a) 0.000 s (b) 0.100 s

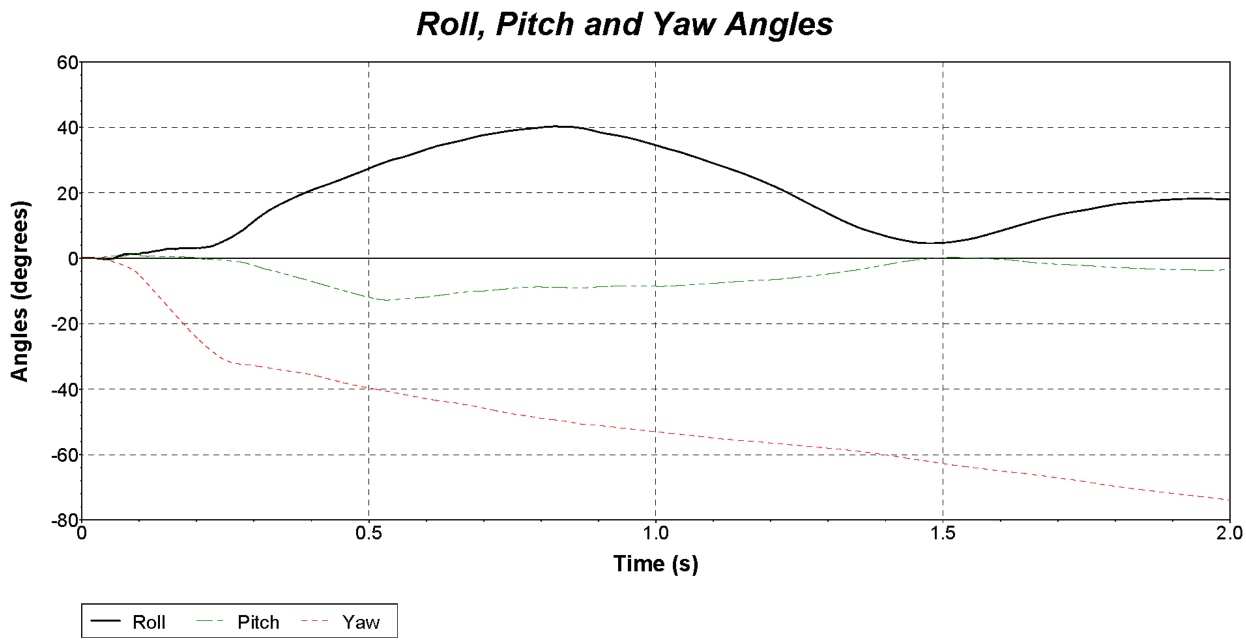

(c) 0.200 s (d) 0.300 s


(e) 0.400 s (f) 0.500 s


(g) 0.600 s (h) 0.700 s

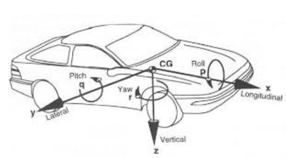
Figure D.6. Sequential Photographs for Test No. 616391-01-2 (Rear Views).

D.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

4. Yaw.
5. Pitch.
6. Roll.



Test Number: 616391-01-2
Test Standard Test Number: *MASH* Test 3-21
Test Article: Guardrail to Portable Concrete Barrier
Test Vehicle: 2016 RAM 1500
Inertial Mass: 5035 lb
Gross Mass: 5035 lb
Impact Speed: 62.9 mi/h
Impact Angle: 25.9 degrees

Figure D.7. Vehicle Angular Displacements for Test No. 616391-01-2.

D.4. VEHICLE ACCELERATIONS

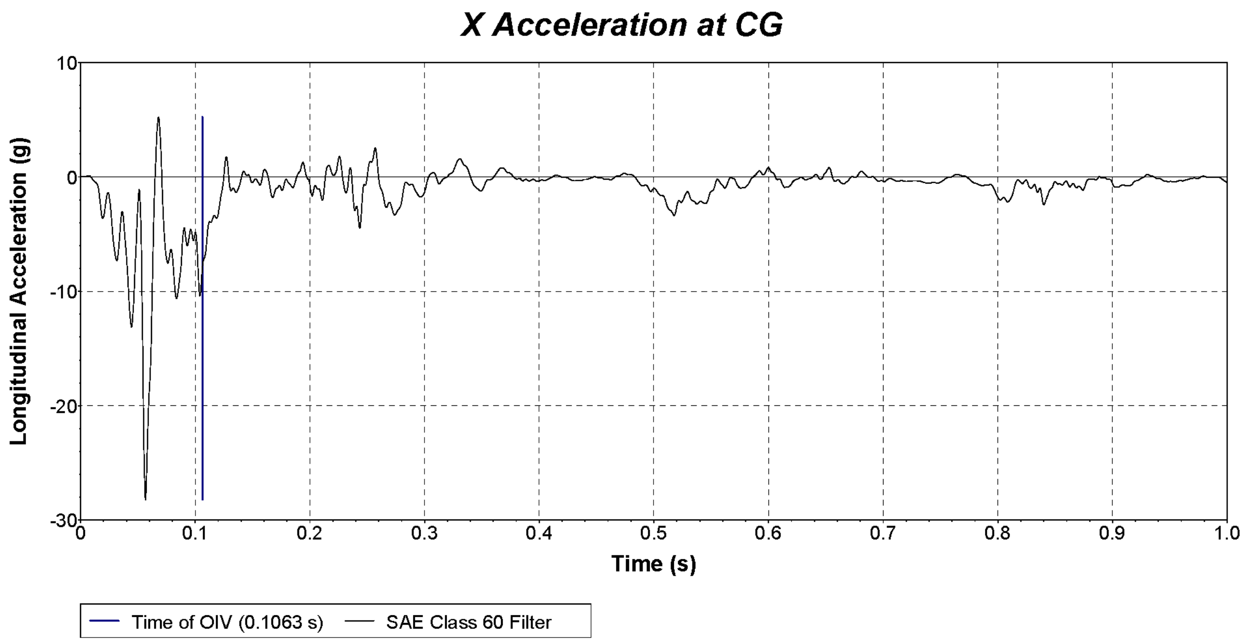


Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test No. 616391-01-2 (Accelerometer Located at Center of Gravity).

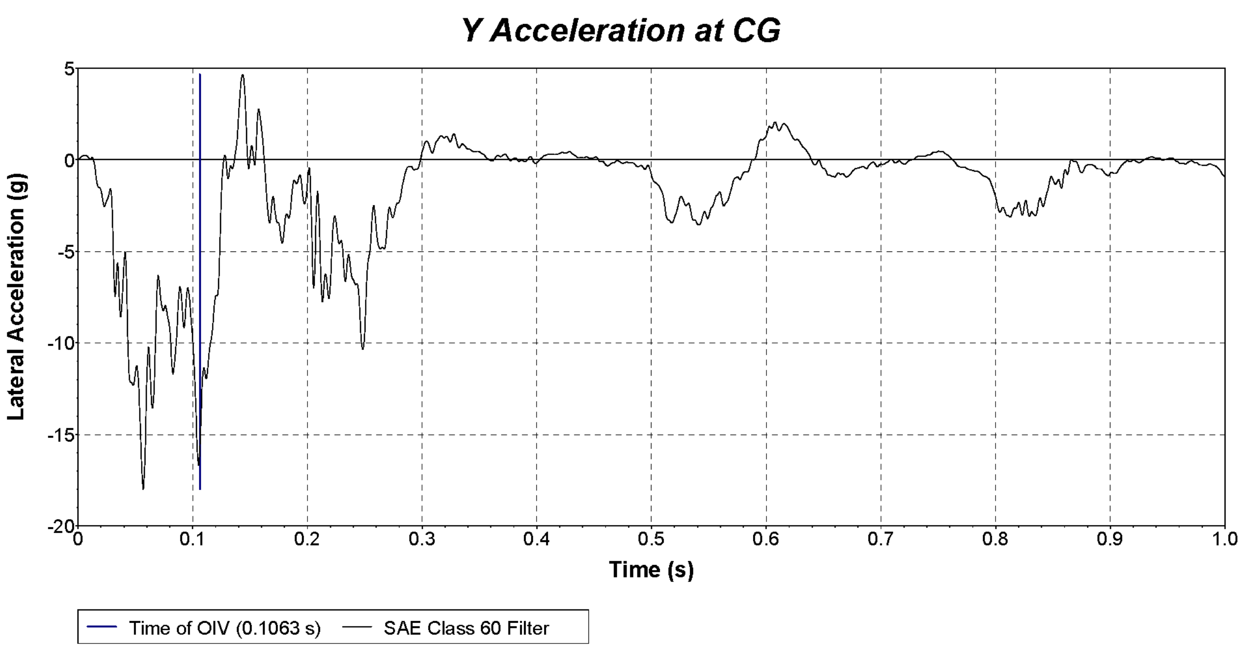


Figure D.9. Vehicle Lateral Accelerometer Trace for Test No. 616391-01-2 (Accelerometer Located at Center of Gravity).

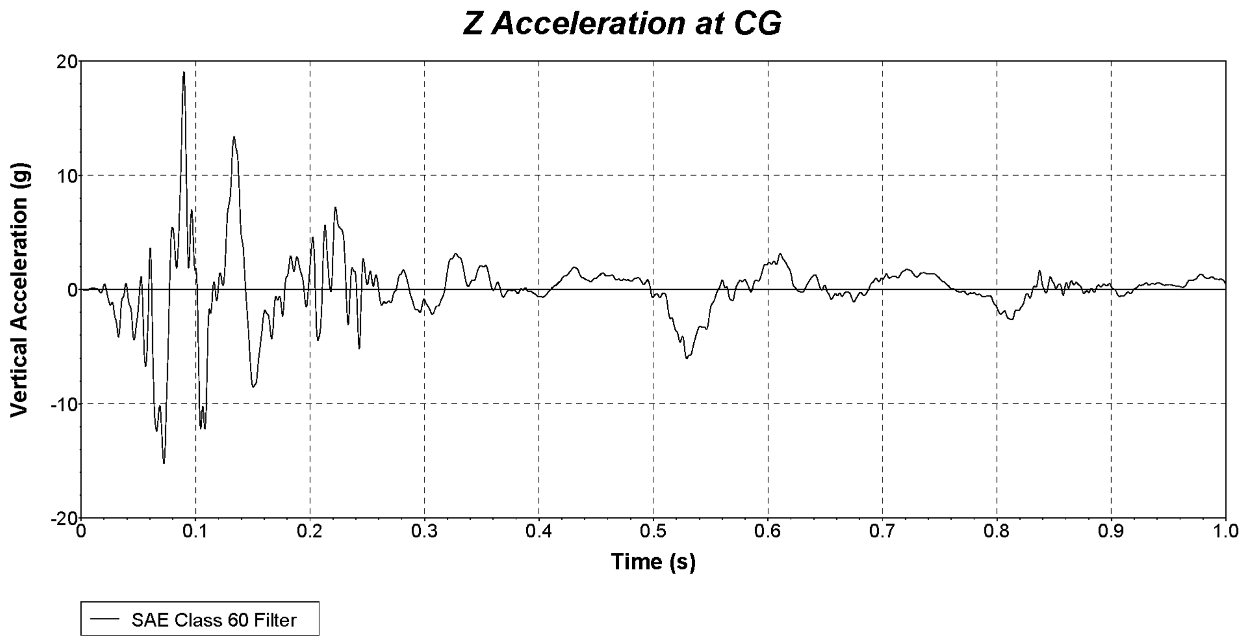


Figure D.10. Vehicle Vertical Accelerometer Trace for Test No. 616391-01-2 (Accelerometer Located at Center of Gravity).