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MASH TL-3 EVALUATION OF LONG-SPAN W-BEAM GUARDRAIL IN FRONT OF FALL-PROTECTION FENCE

Sponsored by

Washington State Department of Transportation

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16. Abstract

This research report presents the evaluation of the Long-Span Guardrail system installed in front of a fall-protection fence. The design was evaluated through finite element modeling and simulation, followed by full-scale crash testing. Details of the simulation and crash testing evaluation are presented in this report.

The crash tests were performed to assess the performance of the Long-Span Guardrail installed in front of the fall-protection fence according to the safety-performance evaluation guidelines included in the second edition of the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) (*1*). The crash tests were performed in accordance with *MASH* Test Level 3 (TL-3), which involves performing the following tests:

1. ***MASH* Test 3-10:** An 1100C vehicle weighing 2420 lb impacting the longitudinal barrier while travelling at 62 mi/h and 25 degrees.
2. ***MASH* Test 3-11:** A 2270P vehicle weighing 5000 lb impacting the longitudinal barrier while traveling at 62 mi/h and 25 degrees.

The Long-Span Guardrail installed in front of the fall-protection fence met the performance criteria for *MASH* TL-3 for longitudinal barrier.

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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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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

Washington State Department of Transportation (WSDOT) has fish passages crossing state highways that use concrete culverts underneath the roadways. WSDOT commonly uses the Long-span W-beam guardrail system as the roadside barrier over the span of these culverts (WSDOT Standard Plan C-20.40-07). This system allows the guardrail to be installed across the width of the culvert without having to install the posts in soil while spanning the concrete culvert.

Maintenance workers and pedestrians may need to work or walk behind the guardrail system. Since this can be a fall hazard, WSDOT wants to install a fall-protection fence behind the Long-Span Guardrail system. The posts of the fence would be installed in the concrete culvert's headwall. The fence may be installed with some offset from the Long-Span Guardrail, or it may be installed with no offset from the back of the guardrail posts to the inner face of the culvert headwall.

WSDOT was concerned that the installation of a fall-protection fence behind the guardrail may interfere with the performance of the Long-Span Guardrail system, or there may be other hazards to an impacting vehicle that might lead to unsuccessful performance of the guardrail with the fence 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*).

In this project, the TTI research team evaluated the installation of a fall-protection fence behind the Long-Span Guardrail system using the *MASH* TL-3 evaluation criteria. The research team developed a finite element (FE) simulation model of the Long-Span Guardrail system with the fence installed with no offset from the back of the guardrail posts to the inner face of the culvert headwall. The research team then performed vehicle impact simulations with the guardrail and fence system using *MASH* TL-3 impact conditions and made recommendations for full-scale crash testing (as discussed in Chapter 2).

Full-scale crash testing was performed to assess the performance of the Long-Span Guardrail system installed in front of the fall-protection fence in accordance with *MASH* Test Level 3 (TL-3) (as discussed in Chapter 4).

Chapter 2. DESIGN AND SIMULATION

This chapter presents the details of the simulation analysis performed to assess the performance of the Long-Span Guardrail system with the fall-protection fence. The simulations were performed using the finite element (FE) method. LS-DYNA, which is a commercially available FE software was used for all simulations.

2.1. LONG-SPAN GUARDRAIL SYSTEM MODELING

The Long-Span Guardrail system was crash tested by Midwest Roadside Safety Facility (MwRSF) under MASH Test 3-11 criteria with a 5,000-lb pickup truck (2). This successful test led to acceptance of the Long-Span Guardrail system as a MASH TL-3 compliant system. The design was adopted by WSDOT in its standard plan C-20.40-07.

Key design details of the Long-Span Guardrail system test by MwRSF are shown in Figure 2.1. The test installation was comprised of 181.25 ft of standard W-beam guardrail supported by W6x9 steel posts. The guardrail spanned a 25-ft wide concrete culvert without any posts. Three adjacent posts on each side of the unsupported W-beam guardrail span were timber CRT posts. The height to the top of the W-beam rail was 31.0 inches. A surrogate concrete culvert was used in the crash testing. It was comprised of 9.0-inch thick x 48.0-inch tall reinforced concrete wall that was installed flush with the back of the CRT posts. Some photos of MwRSF test installation are shown in Figure 2.2.

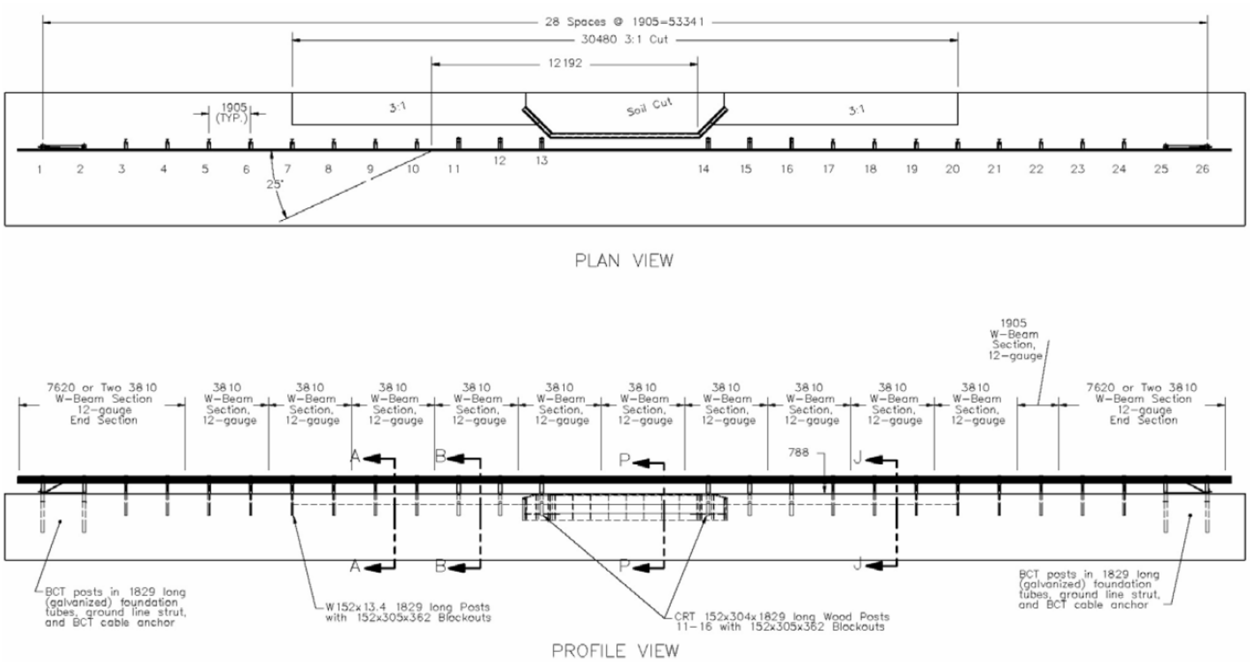


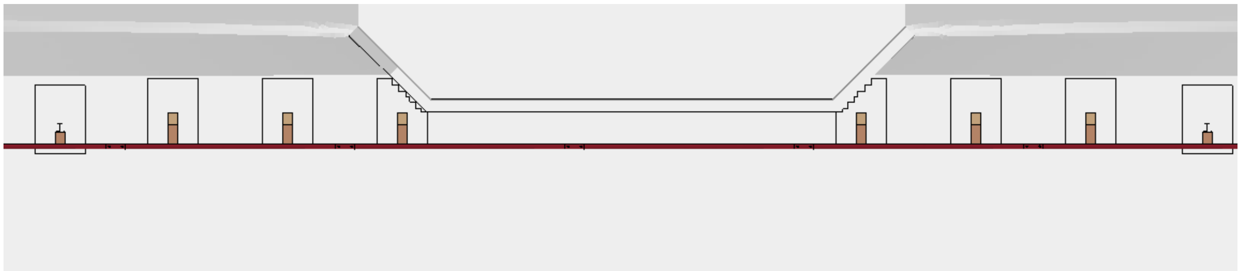
Figure 2.1. Details of Long-Span Guardrail Test 3-11 (MwRSF Test LSC-2).

Figure 2.2. Long-Span Guardrail Test Installation Photos (MwRSF Test LSC-2).

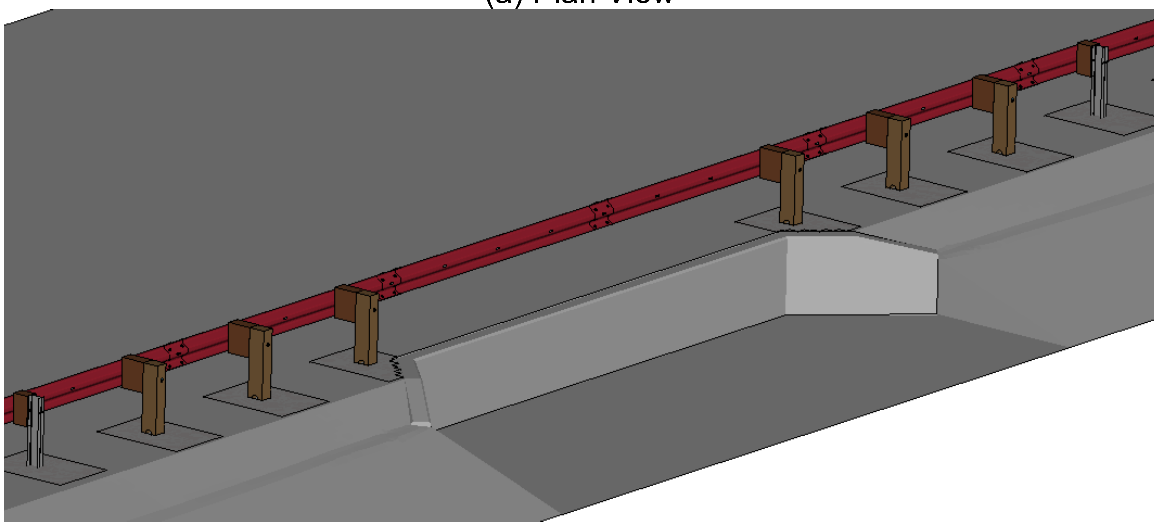
2.1.1. FE Model Development and Validation

Since the fall-protection fence was to be installed behind the Long-Span Guardrail system described above, the researchers first developed a full-scale FE model of the guardrail system. To validate the guardrail system model, the researchers performed impact simulation with the model using the impact conditions of MASH Test 3-11 that was performed by MwRSF. The researchers then compared the simulation results with Test 3-11 results to establish that the guardrail model was reasonably valid for further use in assessing the guardrail with the fall-protection fence installed behind it.

The full-scale model of the Long-Span Guardrail system is shown in Figure 2.3. The model captured the test installation design used in Test 3-11. The model incorporated elastic-plastic material representation for the guardrail parts, which included the W-beam rail, steel posts, guardrail bolts, etc. The soil was incorporated into the model as a continuum surrounding each post. The culvert wall and the ground surface were modeled with rigid material representation since no movement or deflection of these parts was expected. The timber CRT posts were also included in the model. Their material properties incorporated failure of the wood, which is a key performance factor in the functioning of the CRT posts and the Long-Span Guardrail.



(a) Plan View



(b) Isometric View of Full Model

Figure 2.3. Finite Element Model of the Long-Span Guardrail System.

The researchers performed an impact simulation of the Long-span Guardrail System with a MASH pickup truck model using the impact conditions of the Test 3-11 performed by MwRSF. Figure 2.4 and Figure 2.5 show the sequential images comparing the results of the crash test and the simulation model. It can be observed that the simulation results closely matched the test results. Furthermore, the maximum dynamic rail deflection in the crash test was 73.1 inches at 74.7 inches downstream of post 13. In the simulation, the maximum dynamic deflection was 77.5 inches at 75.0 inches downstream of post 13. This implies that the simulation model closely matches the maximum dynamic deflection of the guardrail and the location of the dynamic deflection observed in the crash test.

Based on the above-mentioned comparisons of simulation and test results, the researchers concluded that the FE model of the Long-Span Guardrail System reasonably matched the test results and was therefore considered validated for further use in the assessment of a fall-protection fence behind the guardrail.

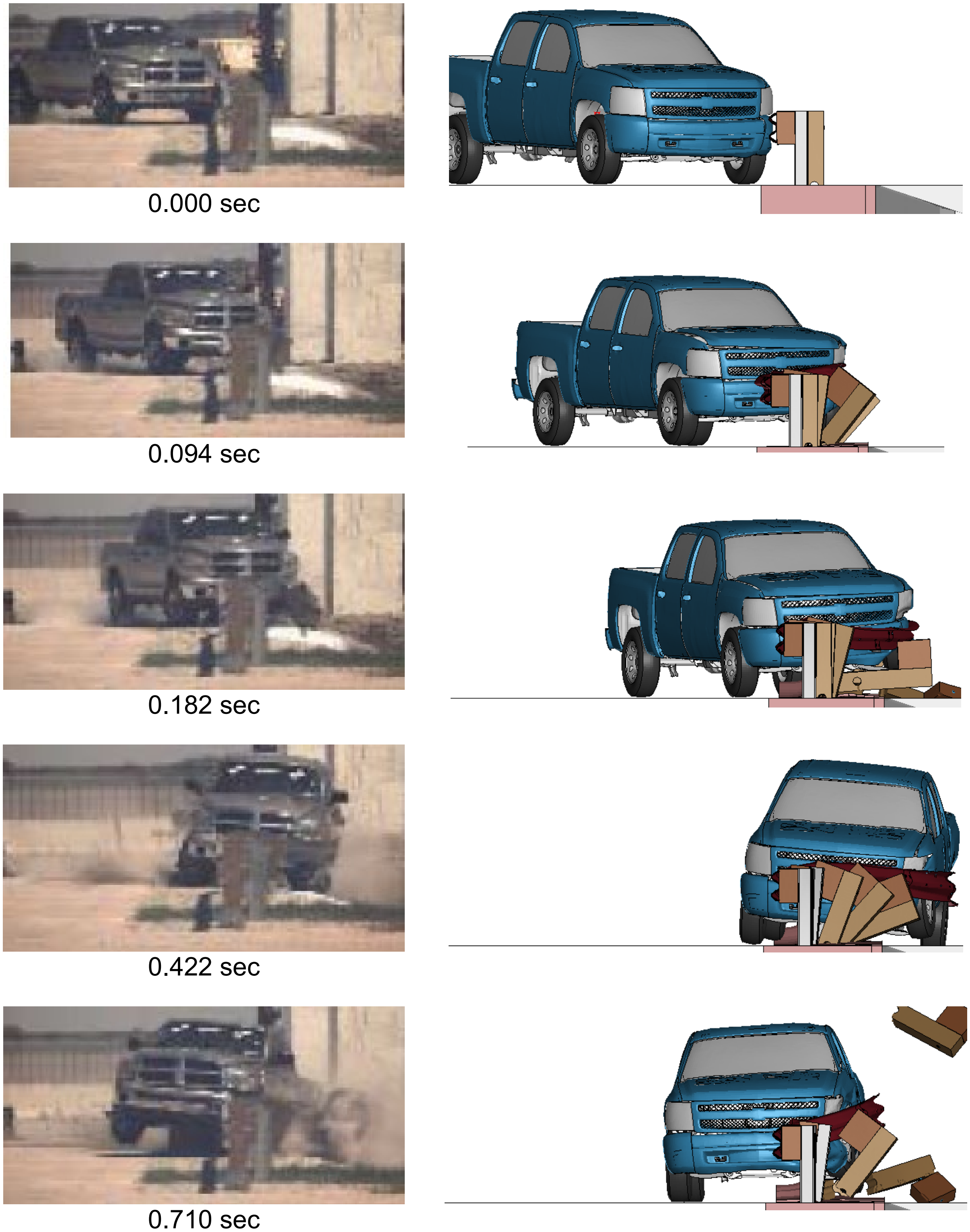


Figure 2.4. Sequential Images Comparing Test and Simulation Results (Gut View).

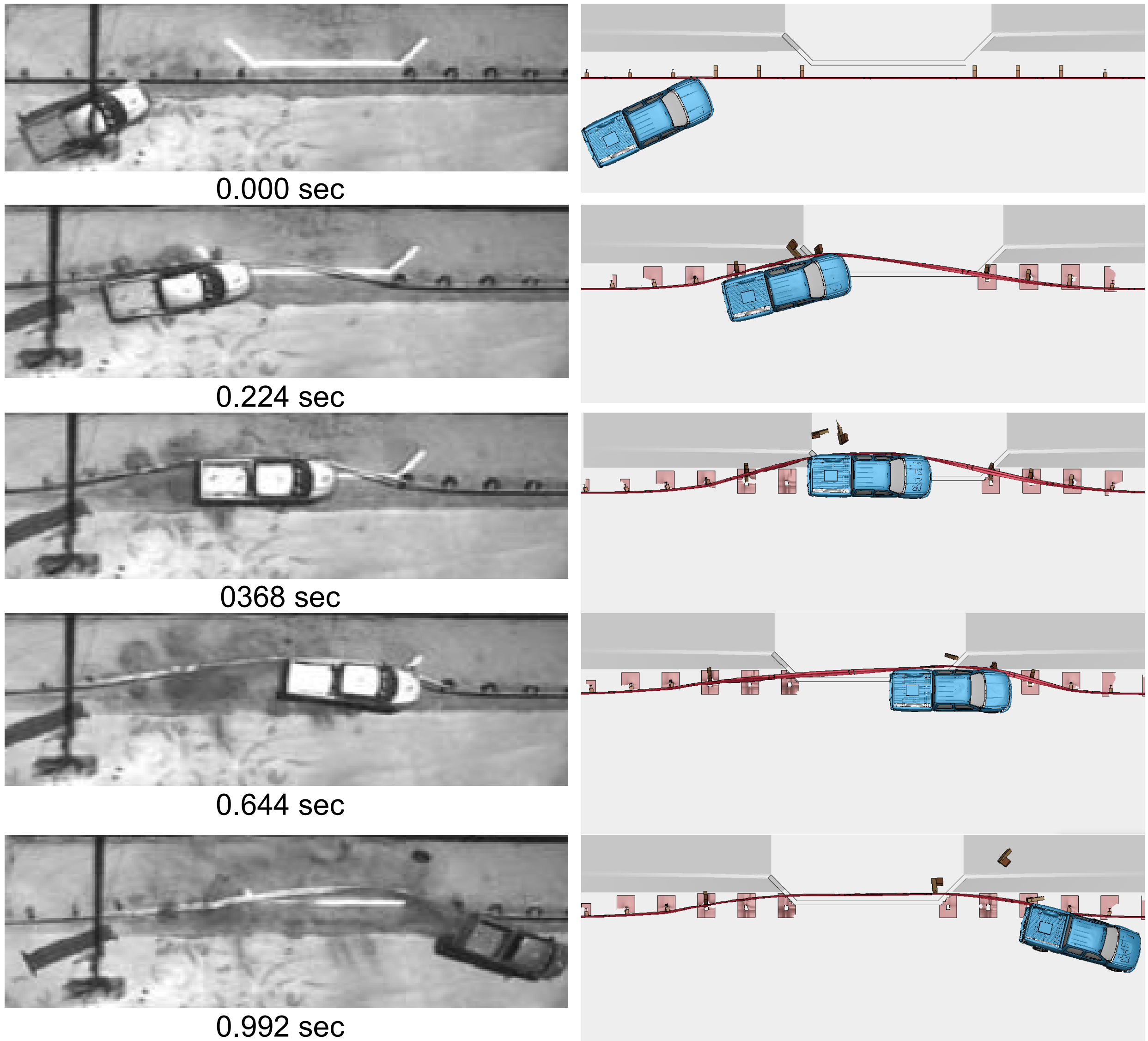


Figure 2.5. Sequential Images Comparing Test and Simulation Results (Top View).

2.2. GUARDRAIL WITH FALL-PROTECTION FENCE

WSDOT did not have a state standard for the fall-protection fence. However, for the purposes of this project, WSDOT provided drawings of an existing installation that uses such a fall-protection fence (Figure 2.6). The researchers used the details of this system to develop the preliminary fall-protection fence model for evaluation through simulation and crash testing. The fall-protection fence was comprised of posts and cross members of a typical industrial-grade chain-link fence hardware. The vertical posts were typical 2-inch NPS pipes, and the horizontal cross-members were 1-3/8-inch NPS pipes. Both were Schedule 40 pipes of ASTM A53 Grade A material. The posts were inserted into the concrete wall that had holes cast into them for embedding the posts. Cross members were attached to the posts at two locations along the height of the posts. The embedment of the posts in the concrete wall was 12 inches, and the height of the fence to the center of the top cross members was 42 inches. Standard fencing hardware was used to attach the post to the cross members. In the simulation analysis and subsequent full-scale crash testing, the researchers used a surrogate concrete culvert wall that was only comprised of a section of the vertical wall. The model of the fall-protection fence incorporated into the long span guardrail system model is shown in Figure 2.7.

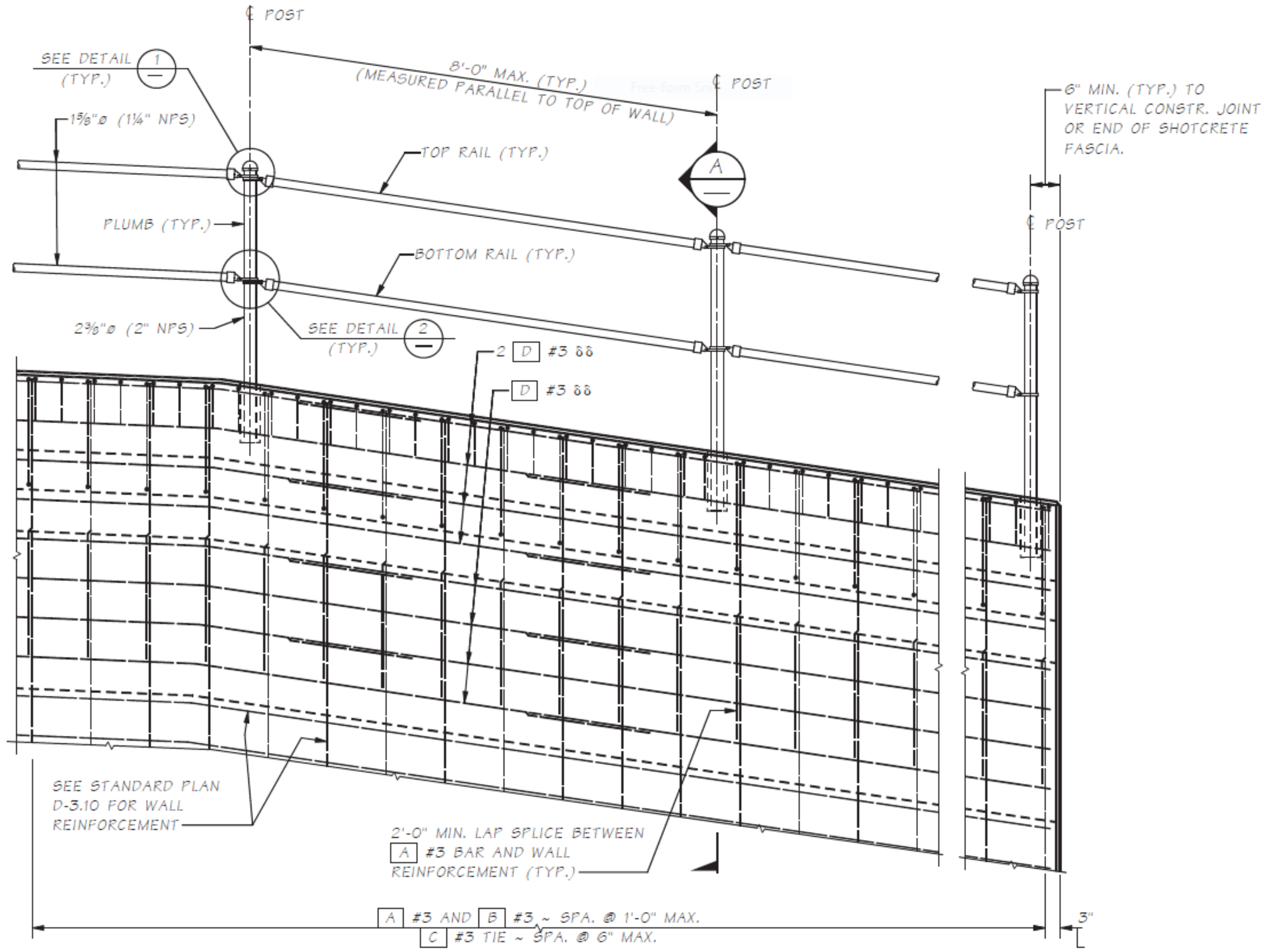
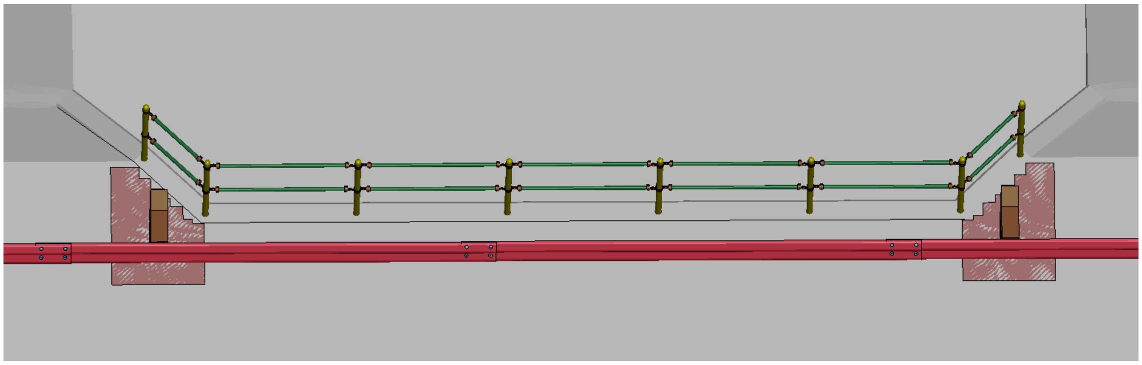
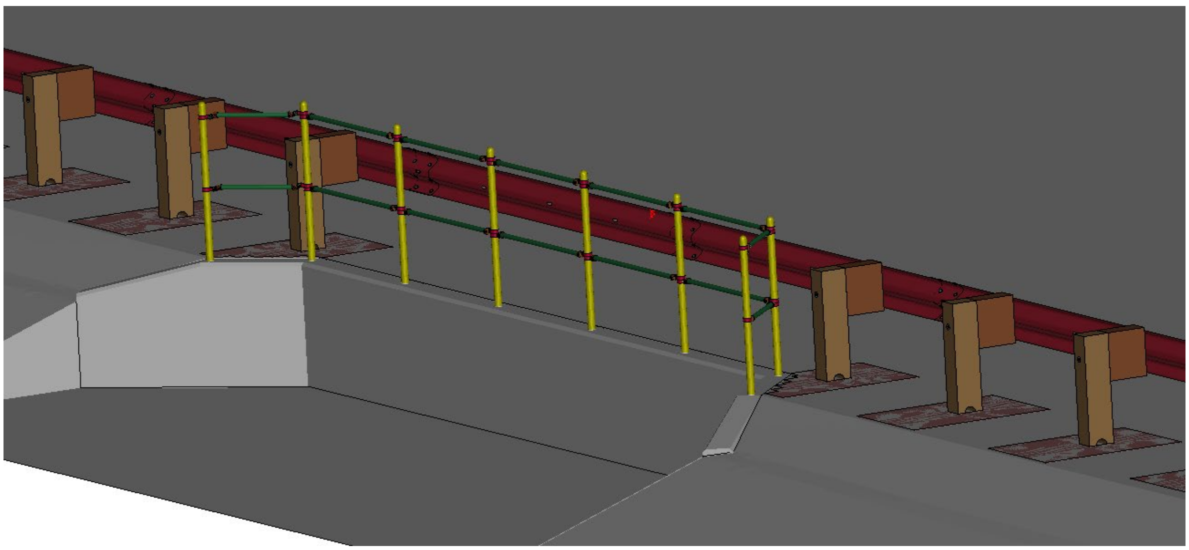


Figure 2.6. Fence System Drawings of a Current WSDOT Installation.



(a) Plan View



(b) Isometric View of Full Model

Figure 2.7. FE Model of Fall-Protection Fence with Long-Span Guardrail System.

After developing the model of the fall-protection fence and the Long-Span Guardrail system, the researchers performed MASH Test 3-11 and Test 3-10 impact simulations. These involved impacting the guardrail system with a 5,000-lb pickup truck (Test 3-11) and a 2,420-lb small car (Test 3-10) at an impact speed and angle of 62 mi/h and 25 degrees, respectively. The pickup truck and the small car models used in the simulations were developed by Center for Collision Safety and Analysis and were improved over the course of various projects by TTI researchers to achieve better validations and robustness. Details of the simulations are presented next.

2.2.1. MASH Test 3-11 Simulation Analysis

In this simulation, the pickup truck model impacted the Long-span Guardrail system 41 ft-3 inches upstream of the first downstream post after the long unsupported span of the guardrail. This impact point was similar to the one selected in the full-scale crash testing of the Long-Span Guardrail system performed by MwRSF. Results of the simulation are presented in Figure 2.8 and Table 2.1. The vehicle was successfully contained and redirected in a stable manner. The occupant risk numbers were within MASH thresholds. The maximum dynamic and permanent deflections of the guardrail were about 55 inches and 49 inches, respectively. Based on the results of the simulation, the system was expected to pass MASH Test 3-11.

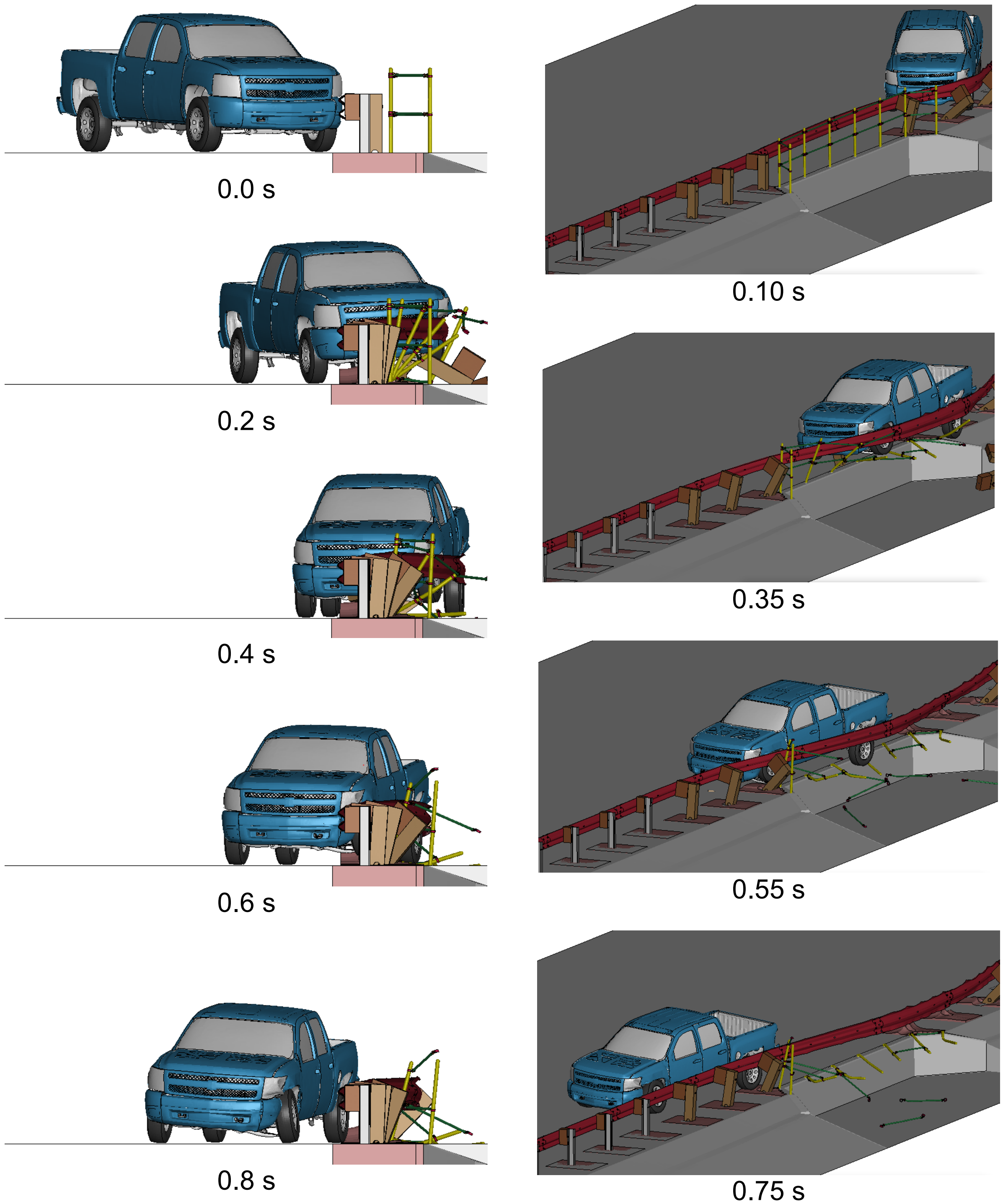


Figure 2.8. MASH Test 3-11 Impact Simulation Sequential Images.

Table 2.1 Occupant Risk Factors for MASH Test Level 3-11 Simulations.

Occupant Impact Velocity (ft/s)	Longitudinal	11.48
	Lateral	-11.81
Ridedown Acceleration (g)	Longitudinal	-7.3
	Lateral	6.4
Max. Angles (degrees)	Roll	-7.4
	Pitch	2.5
	Yaw	36.3

2.2.2. MASH Test 3-10 Simulation Analysis

For MASH Test 3-10 impact condition, the researchers evaluated the design at two impact locations with the goal of selecting the more critical of the two for full-scale crash testing. One of the impact locations was upstream on the CRT posts and the other was at the midpoint of the unsupported long-span of the W-beam rail.

Figure 2.9 and Figure 2.10 show the results of the simulation at the impact point upstream of the CRT posts and at the midpoint of the long-span guardrail section, respectively. The MASH occupant risk factors are presented in Table 2.2

In both simulations, the vehicle was successfully contained and redirected. The occupant risk numbers were within MASH thresholds. The maximum dynamic and permanent deflections of the guardrail were about 57 inches and 27 inches, respectively for the impact upstream of the CRT posts. The maximum dynamic and permanent deflections of the guardrail were about 55 inches and 32 inches, respectively for the impact at the midpoint of the long-span of the W-beam guardrail.

While the two impact points performed very similar to each other, the research team recommended crash testing with the impact point upstream of the CRT posts as the vehicle encountered greater number of fence posts and had more opportunity to drop into the culvert compared to the impact at midpoint between the long-span rail section.

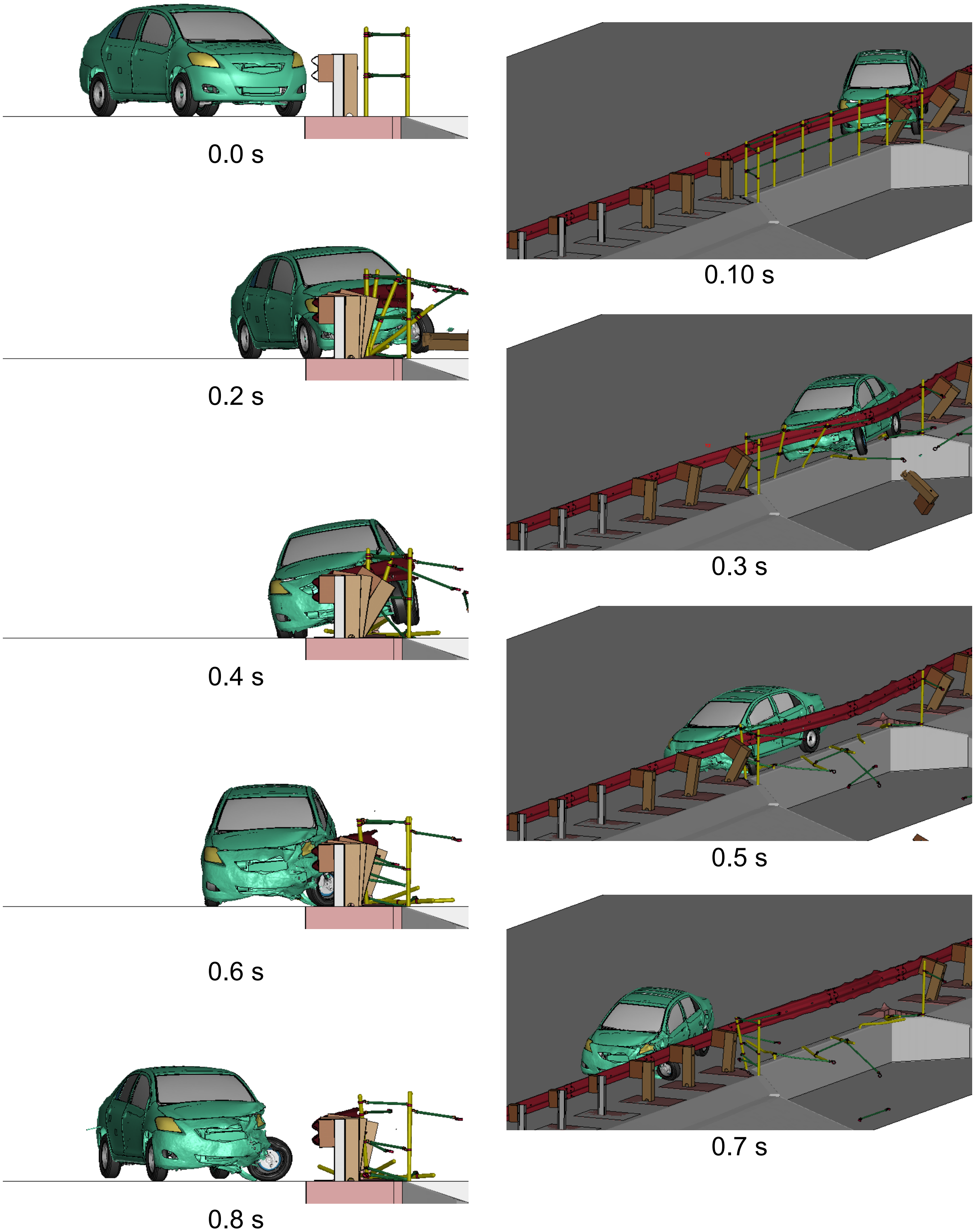


Figure 2.9. MASH Test 3-10 Impact Simulation Sequential Images for Impact between CRT Posts.

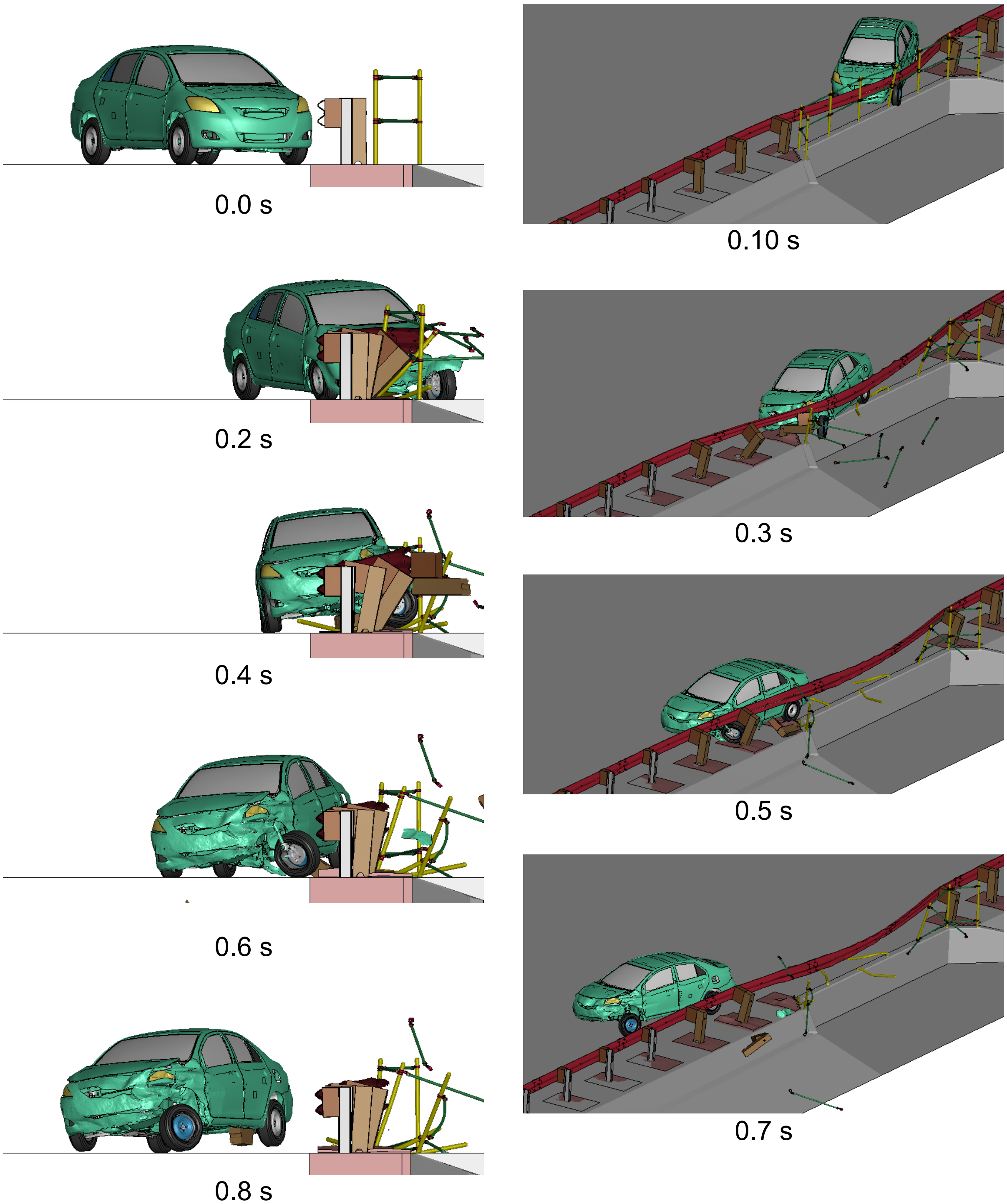


Figure 2.10. MASH Test 3-10 Impact Simulation Sequential Images for Impact at Midpoint of the Long-Span.

Table 2.2 Occupant Risk Factors for MASH Test Level 3-10 Simulations.

Impact Point		Midpoint of Long-Span	Between CRT Posts
Occupant Impact Velocity (ft/s)	Longitudinal.	27.56	20.01
	Lateral	16.40	14.11
Ridedown Acceleration (g)	Longitudinal.	-12.7	-14.0
	Lateral	-7.8	12.4
Max. Angles (degrees)	Roll	8.7	10.2
	Pitch	4.3	3.7
	Yaw	53.2	34.7

Based on the successful results of the simulations for Test 3-11 and Test 3-10 impact conditions, the researchers recommended performing full-scale crash testing of the Long-Span Guardrail System with the fall-protection fence installed behind it, while having no offset from back of post to inner face of headwall. The details of the crash tested system are presented in the following chapter.

Chapter 3. SYSTEM DETAILS

3.1. TEST ARTICLE AND INSTALLATION DETAILS

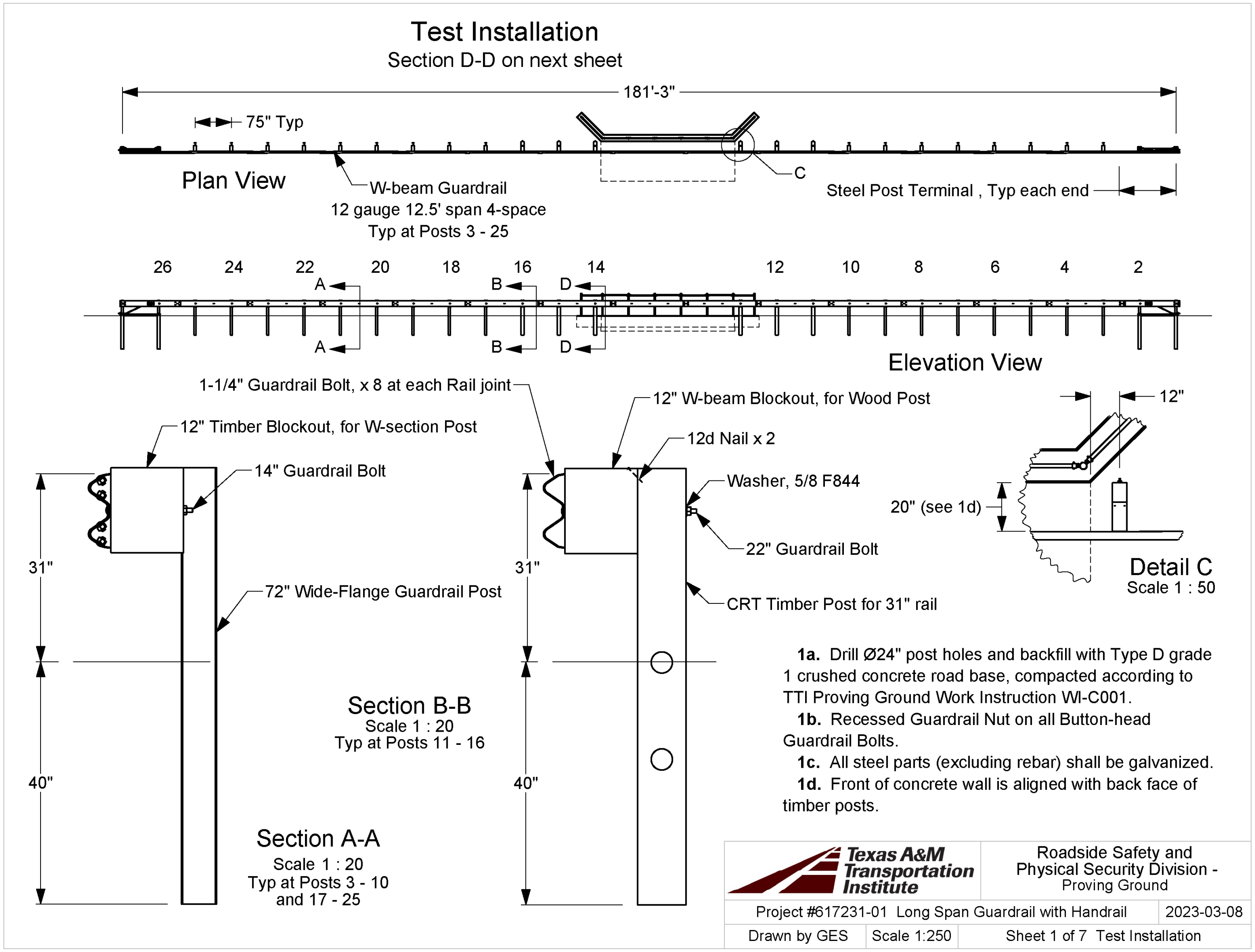
The installation consisted of a Long-Span Guardrail system with a fall-protection fence installed behind it. The Long-Span Guardrail system was comprised of a W-beam guardrail that was 181 feet 3 inches long, with 13 posts on the upstream end spaced at 75 inches, then a span of 25 feet where no posts were present, and then 14 posts spaced at 75 inches. Posts 3 through 10 and 17 through 25 were 72-inch-long standard wide flange guardrail posts, with 12-inch timber blockouts that held the W-beam guardrail 31 inches above grade to the top of the rail. Posts 11 through 16 were CRT timber posts with 12-inch wood blockouts. The ends of the installation were terminated with a steel rail terminal.

Centered between posts 13 and 14, and beginning at 20 inches from the field side of the W-beam rail element, was an embedded 24-inch tall and 14 inches wide concrete wall mounted on an 8 inch thick slab. The slab spanned 23 feet in length and 96 inches wide, with the vertical wall set parallel with the length of the slab. A 71-inch section of 24-inch tall wall on either end of the slab extended out past the slab towards the field side at a 45 degree angle. Mounted on top of the parapet was a fall-protection handrail with posts spaced at 54 inches parallel to the guardrail and at 62 inches on the wings at each end, with two cross members between each handrail post.

Figure 3.1 presents the overall information on the Long-Span Guardrail with the fall-protection fence, and Figure 3.2 thru Figure 3.7 provide photographs of the installation. Appendix A provides further details on the test installation. Drawings were provided by the Texas A&M Transportation Institute (TTI) Proving Ground, and construction was performed by TTI Proving Ground Personnel.

3.2. DESIGN MODIFICATIONS DURING TESTS

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



S:\Accreditation-17025-2017\EIR-000 Project Files\617231-01 Long Span Guardrail with fall Prot. Fnc\Drafting, 617231-01\617231-01 Drawing

Figure 3.1. Details of Long-Span Guardrail System with Fall-Protection Fence.

Figure 3.2. An Overall View of the Test Installation.

Figure 3.3. Upstream In-Line View of the Test Installation.

Figure 3.4. Test Installation at Impact Point Prior to Testing.

Figure 3.5. Downstream In-line View of the Test Installation Prior to Testing.

Figure 3.6. Field Side View of the Test Installation Prior to Testing.

Figure 3.7. Test Installation’s Upstream End Terminal Prior to Testing.

3.3. MATERIAL SPECIFICATIONS

Appendix B provides material certification documents for the materials used to install/construct the Long-Span Guardrail with the fall-protection fence. Table 3.1 shows the average compressive strengths of the concrete on the day of the test 2023-02-13.

Table 3.1. Concrete Strength.

Location	Design Strength (psi)	Average Strength (psi)	Age (days)	Detailed Location
Moment Slab	4500	4540	23	100% of slab
Deck	4500	4683	14	100% of deck

3.4. SOIL CONDITIONS

The test installation was installed in standard soil meeting Type 1 Grade D of AASHTO standard specification M147-17 “Materials for Aggregate and Soil Aggregate Subbase, Base, and Surface Courses.”

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the guardrail for full-scale crash testing, two 6-ft long W6×16 posts were installed in the immediate vicinity of the test installation using the same fill materials and installation procedures used in the test installation and the standard dynamic test.

On the day of Test 3-10, 2023-02-13, loads on the post at deflections were as follows: the backfill material in which the test installation was installed met the minimum *MASH* requirements for soil strength.

Table 3.2. Soil Strength for Test 617231-01-1.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	8757
10	4981	8969
15	5282	8242

On the day of Test 3-11, 2023-02-23, loads on the post at deflections were as follows: the backfill material in which the Long-Span Guardrail was installed met the minimum *MASH* requirements for soil strength.

Table 3.3. Soil Strength for Test 617231-01-2.

Displacement (in)	Minimum Load (lb)	Actual Load (lb)
5	4420	8454
10	4981	9818
15	5282	10787

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 information provided in Chapter 2. Figure 4.1 shows the target CIP for *MASH* TL-3 tests on the Long-Span Guardrail with fall-protection fence.

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

Test Designation	Test Vehicle	Impact Speed	Impact Angle	Evaluation Criteria
3-10	1100C	62 mi/h	25º	A, D, F, H, I
3-11	2270P	62 mi/h	25º	A, D, F, H, I

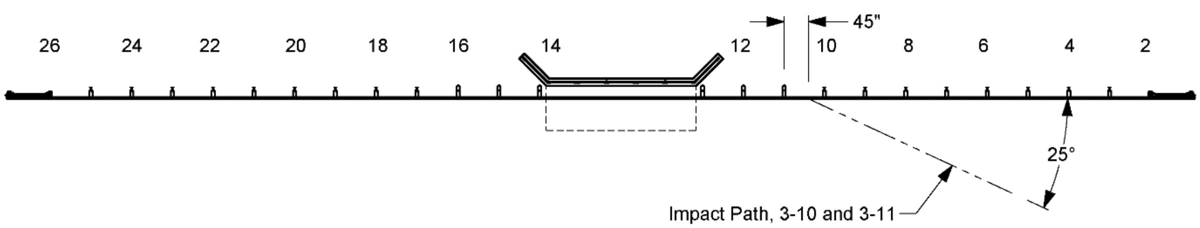


Figure 4.1. Target CIP for *MASH* TL-3 Tests on the Test Installation.

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
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.
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*.
F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.
H.	Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 10 ft/s, or maximum allowable value of 16 ft/s.
I.	The occupant ridedown accelerations should satisfy the following: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.

Chapter 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 testing 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

Each 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 impact 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 Long-Span Guardrail. 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 3-10 (CRASH TEST 617231-01-1)

6.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 6.1 for details of *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 3-10,* Crash Test 617231-01-1.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	62.7
Impact Angle (deg)	25	±1.5°	24.8
Impact Severity (kip-ft)	51	≥51 kip-ft	56.2
Impact Location	45 inches upstream from the centerline of post 11	± 12 inches	44 inches upstream from the centerline of post 11

Table 6.2. Exit Parameters for *MASH TEST 3-10,* Crash Test 617231-01-1.

Exit Parameter	Measured
Speed (mi/h)	Not Measurable
Trajectory (deg)	Not Measurable
Heading (deg)	Not Measurable
Brakes applied post impact (s)	>5
Vehicle at rest position	72 ft downstream of impact point 58 ft to the traffic side 80° left
Comments:	Vehicle remained upright and stable. Vehicle crossed the exit box [a] 14 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. Test Installation/Test Vehicle Geometrics for Test 617231-01-1.

Figure 6.2. Test Installation/Test Vehicle Impact Location for Test 617231-01-1.

6.2. WEATHER CONDITIONS

Table 6.3 provides the weather conditions for Test 617231-01-1.

Table 6.3. Weather Conditions for Test 617231-01-1.

Date of Test	2023-02-13 AM
Wind Speed (mi/h)	6
Wind Direction (deg)	184
Temperature (°F)	59
Relative Humidity (%)	83
Vehicle Traveling (deg)	195

6.3. TEST VEHICLE

Figure 6.3 and Figure 6.4 show the 2019 Nissan Versa used for the crash test. Table 6.4 shows the vehicle measurements. Figure C.1 in Appendix C.1 gives additional dimensions and information on the vehicle.

Figure 6.3. Impact Side of Test Vehicle before Test 617231-01-1.

Figure 6.4. Opposite Impact Side of Test Vehicle before Test 617231-01-1.

Table 6.4. Vehicle Measurements for Test 617231-01-1.

Test Parameter	Specification	Tolerance	Measured
Dummy (if applicable)[a] (lb)	165	N/A	165
Inertial Weight (lb)	2420	±55	2430
Gross Static[a] (lb)	2585	±25	2595
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	41.7
CG above Ground[c,d] (inches)	N/A	N/A	N/A

Note: N/A = not applicable; CG = center of gravity.
[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 617231-01-1. Figures C.4, C.5, and C.6 in Appendix C.2 present sequential photographs during the test.

Table 6.5. Events during Test 617231-01-1.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0130	Post 11 began to lean toward field side
0.0320	Vehicle began to redirect
0.0330	Post 12 began to lean toward field side
0.0620	Post 10 began to twist clockwise
0.1740	W-beam rail contacted handrail post #2
0.2360	Handrail post #2 contacted by right front tire and sheared off at grade
0.2420	Vehicle was parallel with installation
0.3180	Handrail post #3 contacted by right front tire, and bent over
0.6750	Vehicle lost contact with guardrail

6.5. DAMAGE TO TEST INSTALLATION

There was some soil disturbance at post 9. Post 10 had a 0.5-inch soil gap on the traffic and field sides of the post and was leaning back 1 degree from vertical. Posts 11 through 13 were broken off at grade. Post 14 had a 0.5-inch gap in the soil on the traffic side of the post and was leaning 1 degree back from vertical. The fall-protection fence was also damaged, with post 2 broken off at grade, post 3 leaning downstream, and post 4 leaning towards the field side and downstream. The rail cross members released from posts 1 through the upstream side of post 4. One cross member travelled 111 feet towards the traffic side and 322 feet downstream.

Table 6.6 presents the deflection and working width of the Long-Span Guardrail. Figure 6.5 and Figure 6.6 show the damage to the test installation.

Table 6.6. Deflection and Working Width of the Long-Span Guardrail for Test 617231-01-1.

Test Parameter	Measured
Permanent Deflection/Location	18.9 inches toward field side, at the centerline of post 12
Dynamic Deflection	38.2 inches toward field side between posts 12 and 13
Working Width[a] and Height	46.2 inches, at a height of 16 inches at the front impact side tire

[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. Test Installation from the Field Side at Impact Location after Test 617231-01-1.

Figure 6.6. Test Installation from the Field Side at Impact Location after Test 617231-01-1.

6.6. DAMAGE TO TEST VEHICLE

Figure 6.7 and Figure 6.8 show the damage sustained by the vehicle. Figure 6.9 and Figure 6.10 show the interior of the test vehicle. Table 6.7 and Table 6.8 provide details on the occupant compartment deformation and exterior vehicle damage. Figures C.2 and C.3 in Appendix C.1 provide exterior crush and occupant compartment measurements.

Figure 6.7. Front Impact Side of Test Vehicle after Test 617231-01-1.

Figure 6.8. Rear Impact Side of Test Vehicle after Test 617231-01-1.

Figure 6.9. Overall Interior of Test Vehicle after Test 617231-01-1.

Figure 6.10. Interior of Test Vehicle on Impact Side after Test 617231-01-1.

Table 6.7. Occupant Compartment Deformation in Test 617231-01-1.

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	0 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	1.5 inches
Side Front Panel	≤12.0 inches	1 inch
Front Door (above Seat)	≤9.0 inches	1.5 inches
Front Door (below Seat)	≤12.0 inches	0 inches

Table 6.8. Exterior Vehicle Damage in Test 617231-01-1.

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	01RFQ3
CDC	01FREW2
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, right headlight, right front quarter fender, right front tire and rim, right front strut and tower, right lower control arm, right CV shaft and joints, right front and rear door, right rear quarter fender, rear bumper, front rack and pinion, steering shaft, and right rocker panel were damaged. The right front door had a 1.5-inch gap at the top.

6.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 6.9. Figure C.7 in Appendix C.3 shows the vehicle angular displacements, and Figures C.8 through C.10 in Appendix C.4 show acceleration versus time traces.

Table 6.9. Occupant Risk Factors for Test 617231-01-1.

Test Parameter	*Specification* [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	14.0	0.1182 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	19.1	0.1182 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	8.5	0.3034 - 0.3134 seconds
Ridedown, Lateral (g)	≤20.49 *15.0*	10.2	0.2599 - 0.2699 seconds
Theoretical Head Impact Velocity (THIV) (m/s)	N/A	7.1	0.1149 seconds on right side of interior
Acceleration Severity Index (ASI)	N/A	0.8	0.0950 - 0.1450 seconds
50-ms Moving Avg. Accelerations (MA) Longitudinal (g)	N/A	-4.8	0.0664 - 0.1164 seconds
50-ms MA Lateral (g)	N/A	-6.6	0.0387 - 0.0887 seconds
50-ms MA Vertical (g)	N/A	2.6	0.3159 - 0.3659 seconds
Roll (deg)	≤75	9.2	2.0000 seconds
Pitch (deg)	≤75	8.2	2.0000 seconds
Yaw (deg)	N/A	105.6	2.0000 seconds

[a]. *Values in italics are the preferred MASH values*

6.8. TEST SUMMARY

Figure 6.11 summarizes the results of *MASH* Test 617231-01-1.

0.000 s

0.200 s

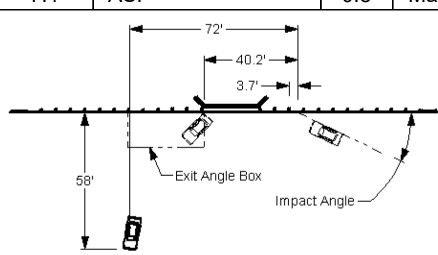
0.400 s

0.600 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-10
TTI Project No.	617231-01-1
Test Date	2023-02-13
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Long-Span Guardrail with Fall-Protection Fence
Length	181 feet 3 inches
Key Materials	W-beam guardrail, 72-inch wide-flange steel posts, CRT timber posts, sch. 40 ASTM A53 Grade A pipe
Soil Type and Condition	AASHTO M147 grading D type 1 crushed concrete
TEST VEHICLE	
Type/Designation	1100C
Year, Make and Model	2019 Nissan Versa
Inertial Weight (lb)	2430
Dummy (lb)	165
Gross Static (lb)	2595
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.7
Impact Angle (deg)	24.8
Impact Location	44 inches upstream from centerline of post 11
Impact Severity (kip-ft)	56.1867426757816
EXIT CONDITIONS	
Exit Speed (mi/h)	Not Measurable
Trajectory/Heading Angle (deg)	Not Measurable / Not Measurable
Exit Box Criteria	Vehicle crossed the exit box a 14 ft downstream from loss of contact.
Stopping Distance	72 ft downstream 58 ft to the traffic side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	38.2
Permanent (inches)	18.875
Working Width / Height (inches)	46.2 / 16
VEHICLE DAMAGE	
VDS	01RFQ3
CDC	01FREW2
Max. Ext. Deformation (inches)	10
Max Occupant Compartment Deformation	1.5 inches in the right floor pan and right driver's side door

OCCUPANT RISK VALUES

Long. OIV (ft/s)	14.0	Long. Ridedown (g)	8.5	Max 50-ms Long. (g)	-4.8	Max Roll (deg)	9.2
Lat. OIV (ft/s)	19.1	Lat. Ridedown (g)	10.2	Max 50-ms Lat. (g)	-6.6	Max Pitch (deg)	8.2
THIV (m/s)	7.1	ASI	0.8	Max 50-ms Vert. (g)	2.6	Max Yaw (deg)	105.6



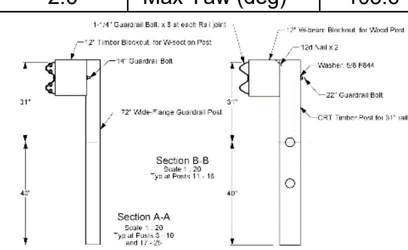


Figure 6.11. Summary of Results for *MASH* Test 3-10 on Long-Span Guardrail with Fall-Protection Fence.

Chapter 7. *MASH* TEST 3-11 (CRASH TEST 617231-01-2)

7.1. TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

See Table 7.1 for details of *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 3-11, Crash Test 617231-01-2.

Test Parameter	Specification	Tolerance	Measured
Impact Speed (mi/h)	62	±2.5 mi/h	62.2
Impact Angle (deg)	25	±1.5°	24.9
Impact Severity (kip-ft)	106	≥≥106 kip-ft	115.6
Impact Location	45 inches upstream from the centerline of post 11.	±12 inches	46.3 inches upstream from the centerline of post 11.

Table 7.2. Exit Parameters for *MASH* TEST 3-11, Crash Test 617231-01-2.

Exit Parameter	Measured
Speed (mi/h)	Not Measurable
Trajectory (deg)	Not Measurable
Heading (deg)	Not Measurable
Brakes applied post impact (s)	3.25
Vehicle at rest position	182 ft downstream of impact point 8 ft to the field side 75° right
Comments:	Vehicle remained upright and stable. Vehicle crossed the exit box a 47 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 7.1Test Installation/Test Vehicle Geometrics for Test 617231-01-2.

Figure 7.2. Test Installation/Test Vehicle Impact Location for Test 617231-01-2.

7.2. WEATHER CONDITIONS

Table 7.3 provides the weather conditions for Test 617231-01-2.

Table 7.3. Weather Conditions for Test 617231-01-2.

Date of Test	2023-02-23 AM
Wind Speed (mi/h)	8
Wind Direction (deg)	66
Temperature (°F)	76
Relative Humidity (%)	75
Vehicle Traveling (deg)	195

7.3. TEST VEHICLE

Figure 7.3 and Figure 7.4 show the 2017 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 617231-01-2.

Figure 7.4. Opposite Impact Side of Test Vehicle before Test 617231-01-2.

Table 7.4. Vehicle Measurements for Test 617231-01-2.

Test Parameter	Specification	Tolerance	Measured
Dummy (if applicable)[a] (lb)	165	N/A	165
Inertial Weight (lb)	5000	±110	5043
Gross Static[a] (lb)	5165	±5000	5208
Wheelbase (inches)	148	±12	140.5
Front Overhang (inches)	39	±3	40.0
Overall Length (inches)	237	±13	227.5
Overall Width (inches)	78	±2	78.5
Hood Height (inches)	43	±4	46.0
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

Note: N/A = not applicable; CG = center of gravity.
[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 617231-01-2. Figures D.4, D.5, and D.6 in Appendix D.2 present sequential photographs during the test.

Table 7.5. Events during Test 617231-01-2.

Time (s)	Events
0.0000	Vehicle impacted the installation
0.0080	Post 11 and 10 began to lean toward field side
0.0470	Vehicle began to redirect
0.0480	Post 12 began to lean toward field side
0.0910	Post 13 began to lean toward field side
0.1330	Handrail post #2 was contacted by the W-beam guardrail just past guardrail post 13 and began leaning downstream and toward field side.
0.1500	Guardrail contacted handrail post 3, and the handrail and post began leaning toward field side
0.1660	Guardrail contacted handrail post 4, and the handrail and post began leaning toward field side
0.2200	Front passenger side tire left ground over embankment
0.3370	Vehicle was parallel with installation
0.5070	Vehicle right side left embankment area, leaving the front passenger side tire behind.

7.5. DAMAGE TO TEST INSTALLATION

The rail released from post 2 through 17. Posts 8 and 9 were twisted clockwise, posts 11 through 14 broke off at grade, and post 15 was split at the guardrail bolt. Handrail posts 2 through 7 were bent over and their crossmembers released from the posts. Table 7.6 presents the soil gap around the posts and the post lean after the crash test. Table 7.7 presents the deflection and working width of the Long-Span Guardrail. Figure 7.5 and Figure 7.6 show the damage to the test installation.

Table 7.6 Soil Gap Around Post and Post Lean after Test 617231-01-2.

Post	Soil Gap	Post Lean (from vertical)
1	3 inches u/s	8.1° d/s
2	2.5 inches u/s	4.8° d/s
8	soil disturbed	-
9	0.125 inches	1.6° f/s
10	0.5 inches f/s; 2 inches t/s	11.4° f/s
15	0.25 inches t/s	0.9° f/s
16	soil disturbed	-

u/s: upstream; d/s: downstream; f/s: field side; t/s: traffic side; -:zero measurement

Table 7.7. Deflection and Working Width of the Long-Span Guardrail for Test 617231-01-2.

Test Parameter	Measured
Permanent Deflection/Location	48 inches toward field side, 22 inches upstream from the centerline of handrail post 5
Dynamic Deflection	64.9 inches toward field side, between posts 13 and 14
Working Width[a] and Height	72.3 inches, at a height of 59.4 inches at the right-side mirror

[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. Overall View of Test Installation after Test 617231-01-2.

Figure 7.6. Long-Span Guardrail at the Maximum Permanent Deformation after Test 617231-01-2.

7.6. DAMAGE TO TEST VEHICLE

Figure 7.7 and Figure 7.8 show the damage sustained by the vehicle. Figure 7.9 and Figure 7.10 show the interior of the test vehicle. Table 7.8 and Table 7.9 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 7.7. Front Impact Side of Test Vehicle after Test 617231-01-2.

Figure 7.8. Rear Impact Side of Test Vehicle after Test 617231-01-2.

Figure 7.9. Overall Interior of Test Vehicle after Test 617231-01-2.

Figure 7.10. Interior of Test Vehicle on Impact Side after Test 617231-01-2.

Table 7.8. Occupant Compartment Deformation for Test 617231-01-2.

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	0 inches
Floor Pan/Transmission Tunnel	≤12.0 inches	0 inches
Side Front Panel	≤12.0 inches	0 inches
Front Door (above Seat)	≤9.0 inches	0 inches
Front Door (below Seat)	≤12.0 inches	0 inches

Table 7.9. Exterior Vehicle Damage for Test 617231-01-2.

Side Windows	The side windows remained intact
Maximum Exterior Deformation	12 inches in the front plane at the right front corner at bumper height
VDS	01RFQ3
CDC	01FREW2
Fuel Tank Damage	None
Description of Damage to Vehicle:	The front bumper, hood, grill, right headlight, right front quarter fender, right frame rail, right front tire and rim, right upper and lower control arms, right front tire and rim, sway bar and tie rod end, right front door, right rear door, right cab corner, right rear quarter fender, right rear tire and rim, and rear bumper were damaged. The right front door had a 0.5-inch gap at the top of the door.

7.7. OCCUPANT RISK FACTORS

Data from the accelerometers were digitized for evaluation of occupant risk, and the results are shown in Table 7.10. Figure D.7 in Appendix D.3 shows the vehicle angular displacements, and Figures D.8 through D.10 in Appendix D.4 show acceleration versus time traces.

Table 7.10. Occupant Risk Factors for Test 617231-01-2.

Test Parameter	Specification [a]	Measured	Time
OIV, Longitudinal (ft/s)	≤40.0 *30.0*	9.6	0.1714 seconds on right side of interior
OIV, Lateral (ft/s)	≤40.0 *30.0*	12.3	0.1714 seconds on right side of interior
Ridedown, Longitudinal (g)	≤20.49 *15.0*	6.4	0.4973 - 0.5073 seconds
Ridedown, Lateral (g)	≤20.49 *15.0*	6.6	0.2640 - 0.2740 seconds
THIV (m/s)	N/A	4.6	0.1655 seconds on right side of interior
ASI	N/A	0.6	0.2719 - 0.3219 seconds
50-ms MA Longitudinal (g)	N/A	-4.0	0.4575 - 0.5075 seconds
50-ms MA Lateral (g)	N/A	-4.9	0.2529 - 0.3029 seconds
50-ms MA Vertical (g)	N/A	-2.2	1.2033 - 1.2533 seconds
Roll (deg)	≤75	10.2	1.1884 seconds
Pitch (deg)	≤75	7.0	0.8950 seconds
Yaw (deg)	N/A	43.2	0.9086 seconds

[a.] Values in italics are the preferred MASH values.

7.8. TEST SUMMARY

Figure 7.11 summarizes the results of *MASH* Test 617231-01-2.

0.000 s

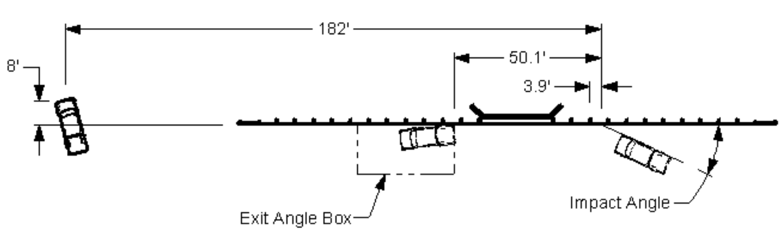
0.100 s

0.200 s

0.300 s

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard/Test No.	*MASH* 2016, Test 3-11
TTI Project No.	617231-01-2
Test Date	2023-02-23
TEST ARTICLE	
Type	Longitudinal Barrier
Name	Long-Span Guardrail
Length	181 feet 3 inches
Key Materials	W-beam guardrail, 72-inch wide-flange steel posts, CRT timber posts, sch. 40 ASTM A53 Grade A pipe
Soil Type and Condition	AASHTO M147 grading D type 1 crushed concrete
TEST VEHICLE	
Type/Designation	2270P
Year, Make and Model	2017 RAM 1500
Inertial Weight (lb)	5043
Dummy (lb)	165
Gross Static (lb)	5208
IMPACT CONDITIONS	
Impact Speed (mi/h)	62.2
Impact Angle (deg)	24.9
Impact Location	46.3 inches upstream from centerline of post 11.
Impact Severity (kip-ft)	115.620702837795
EXIT CONDITIONS	
Exit Speed (mi/h)	Not Measurable
Trajectory/Heading Angle (deg)	Not Measurable / Not Measurable
Exit Box Criteria	Vehicle crossed the exit box a 47 ft downstream from loss of contact.
Stopping Distance	182 ft downstream 8 ft to the field side
TEST ARTICLE DEFLECTIONS	
Dynamic (inches)	64.9
Permanent (inches)	48
Working Width / Height (inches)	72.3 / 59.4
VEHICLE DAMAGE	
VDS	01RFQ3
CDC	01FREW2
Max. Ext. Deformation (inches)	12
Max Occupant Compartment Deformation	No occupant compartment deformation

OCCUPANT RISK VALUES							
Long. OIV (ft/s)	9.6	Long. Ridedown (g)	6.4	Max 50-ms Long. (g)	-4.0	Max Roll (deg)	10.2
Lat. OIV (ft/s)	12.3	Lat. Ridedown (g)	6.6	Max 50-ms Lat. (g)	-4.9	Max Pitch (deg)	7.0
THIV (m/s)	4.6	ASI	0.6	Max 50-ms Vert. (g)	-2.2	Max Yaw (deg)	43.2



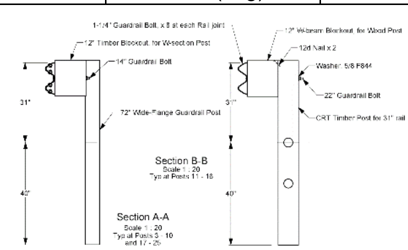


Figure 7.11. Summary of Results for *MASH* Test 3-11 on Long-Span Guardrail with Fall-Protection Fence.

Chapter 8. SUMMARY AND CONCLUSIONS

8.1. ASSESSMENT OF TEST RESULTS AND CONCLUSIONS

The crash tests reported herein were performed in accordance with *MASH* TL-3, which involves two tests on the Long-Span Guardrail with fall-protection fence.

Table 8.1 shows that the Long-Span Guardrail with fall-protection fence met the performance criteria for *MASH* TL-3 for longitudinal barriers.

Table 8.1. Assessment Summary for *MASH* TL-3 Tests on Long-Span Guardrail with Fall-Protection Fence.

Evaluation Criteria	Description	Test 617231-01-1	Test 617231-01-2
A	Contain, Redirect, or Controlled Stop	S	S
D	No Penetration into Occupant Compartment	S	S
F	Roll and Pitch Limit	S	S
H	OIV Threshold	S	S
I	Ridedown Threshold	S	S
Overall	Summary of Results	Pass	Pass

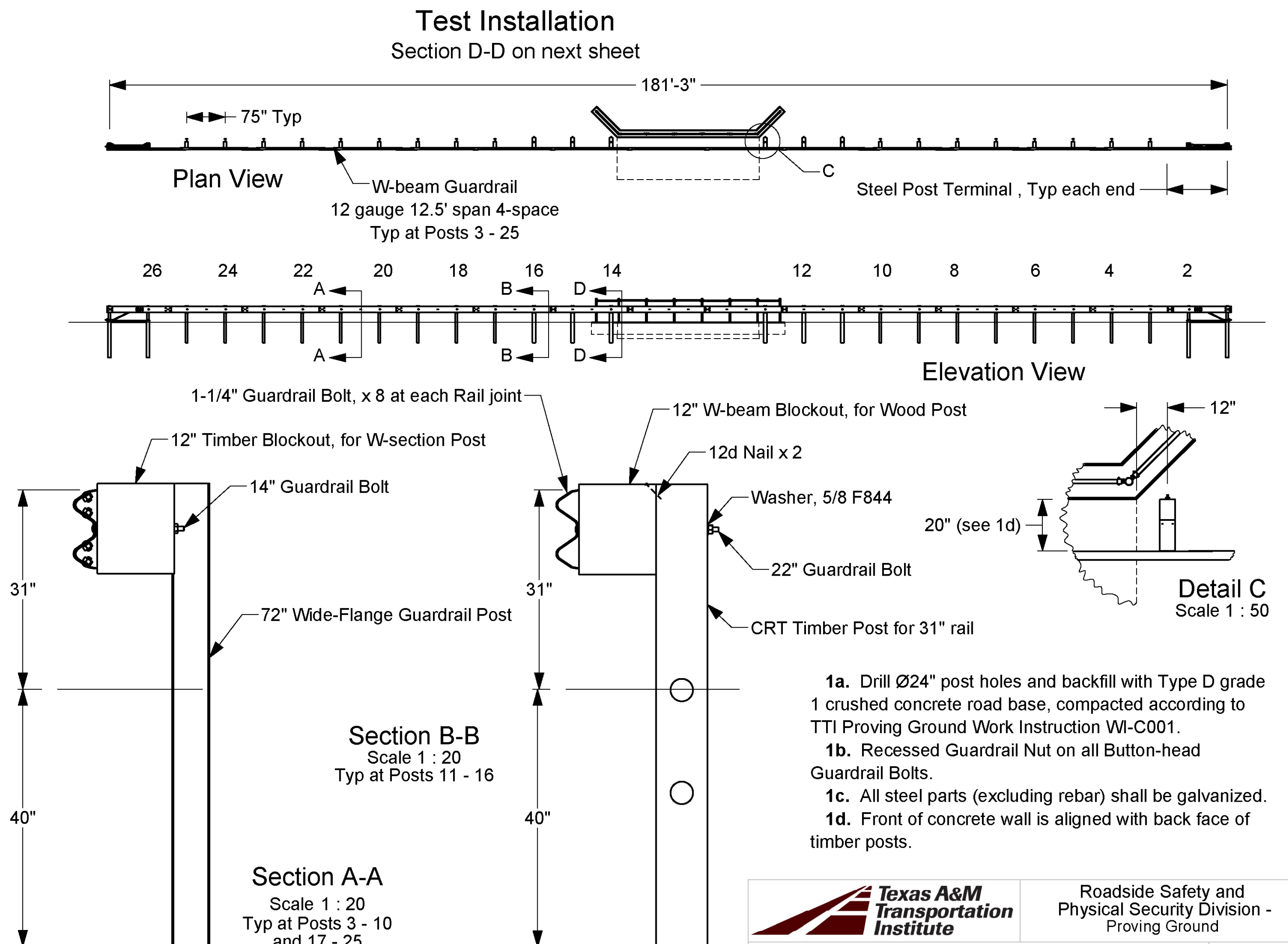
Note: S = Satisfactory; N/A = Not Applicable.
[1] See Table 4.2 for details

REFERENCES

1. AASHTO. *Manual for Assessing Safety Hardware*, Second Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2016.

2. Bielenberg, R.W., Faller, R.K., Rohde, J.R., Reid, J.D., Sicking, D.L., Holloway, J.C., Allison, E.M., and Polivka, K.A*., "Midwest Guardrail System for Long-Span Culvert Applications."* Research Report TRP-030187-07, Midwest Roadside Safety Facility, Lincoln, Nebraska, 2007.

APPENDIX A. DETAILS OF LONG-SPAN GUARDRAIL WITH FALL PROTECTION FENCE



1a. Drill Ø24" post holes and backfill 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 (excluding rebar) shall be galvanized.

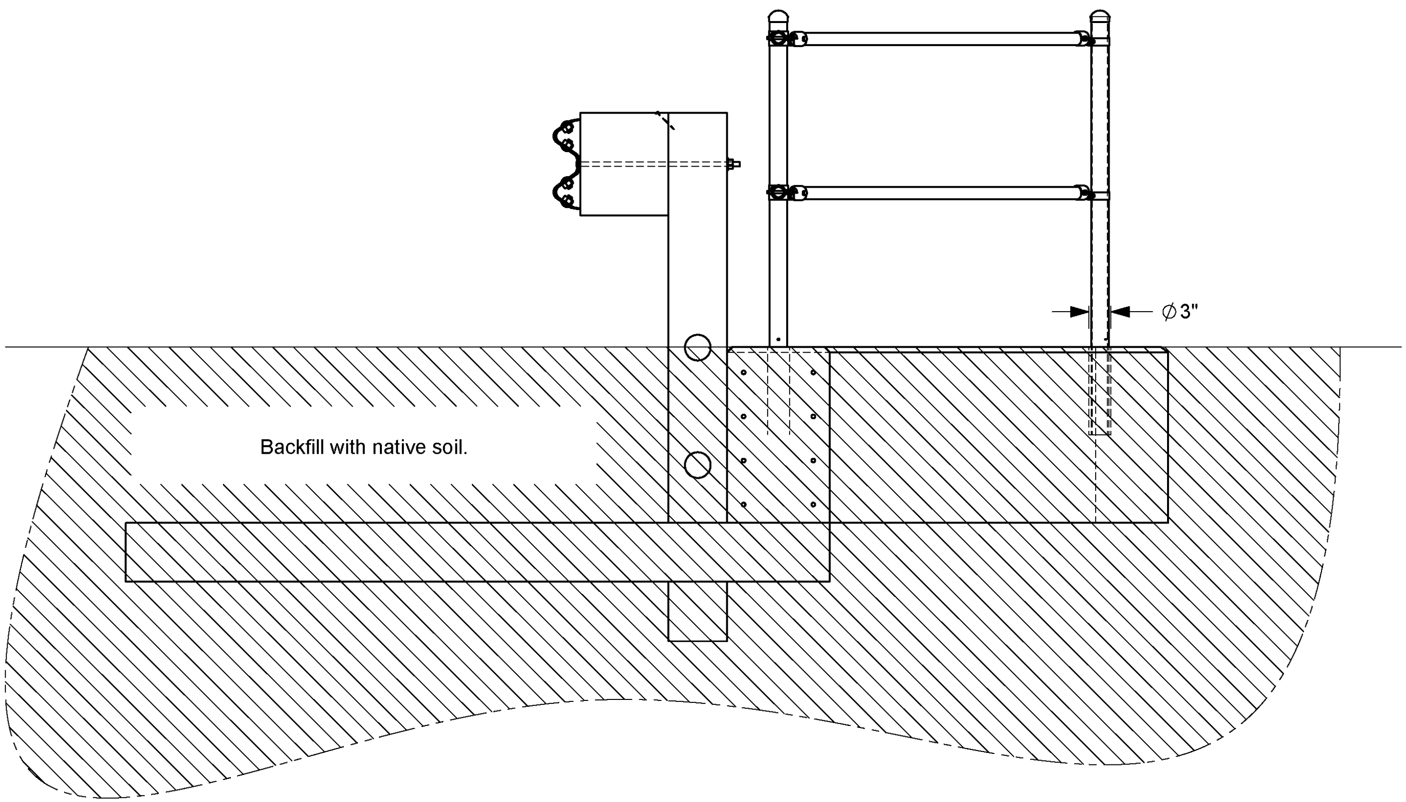
1d. Front of concrete wall is aligned with back face of timber posts.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #617231-01 Long Span Guardrail with Handrail		2023-03-08
Drawn by GES	Scale 1:250	Sheet 1 of 7 Test Installation

S:\Accreditation-17025-2017\EIR-000 Project Files\617231-01 Long Span Guardrail with fall Prot. Fnc\Drafting, 617231-01\617231-01 Drawing

Section D-D

Rebar not shown for clarity

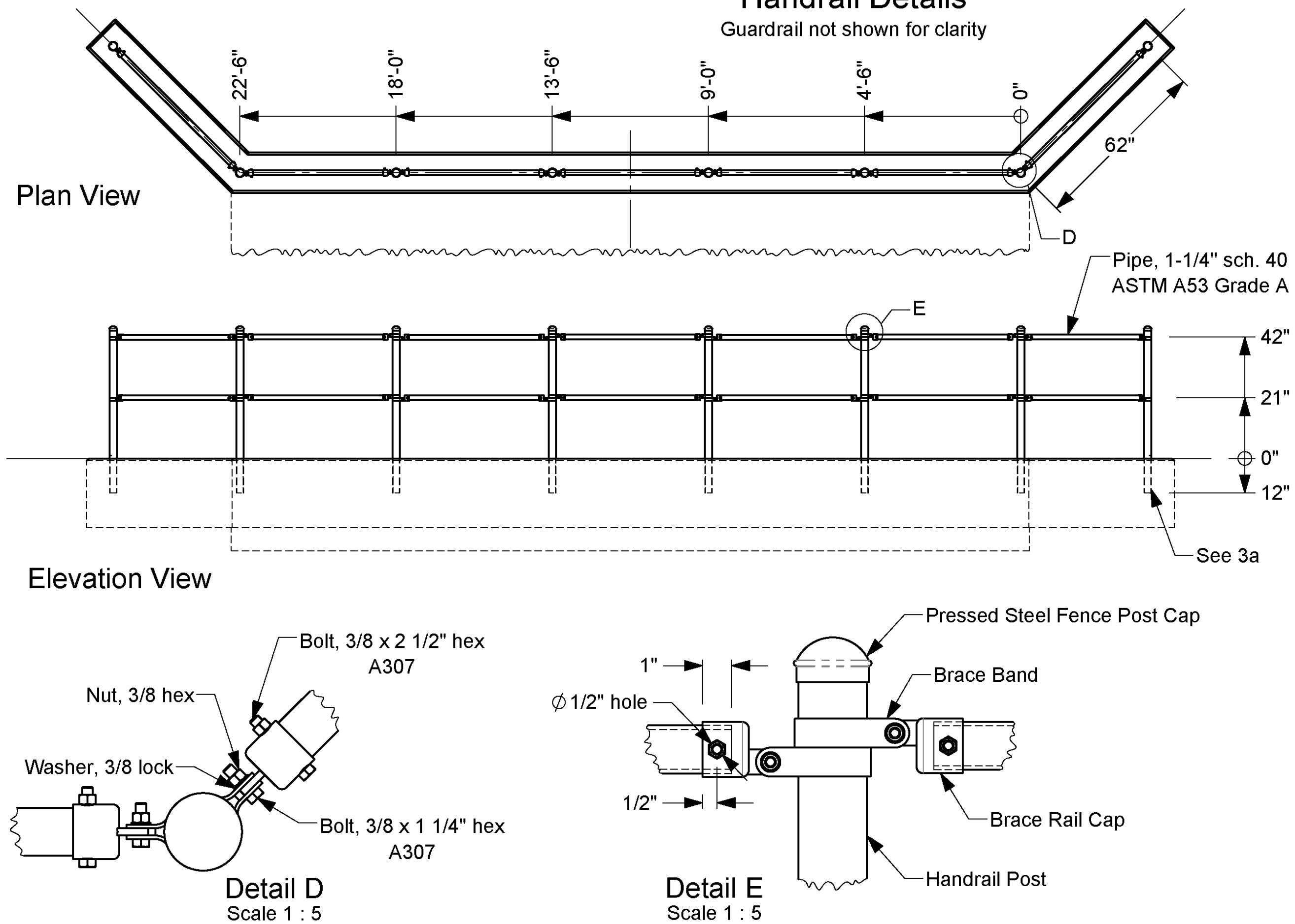


Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #617231-01 Long Span Guardrail with Handrail		2023-03-08
Drawn by GES	Scale 1:20	Sheet 2 of 7 Section D-D

S:\Accreditation-17025-2017\EIR-000 Project Files\617231-01 Long Span Guardrail with fall Prot. Fnc\Drafting, 617231-01\617231-01 Drawing

Handrail Details

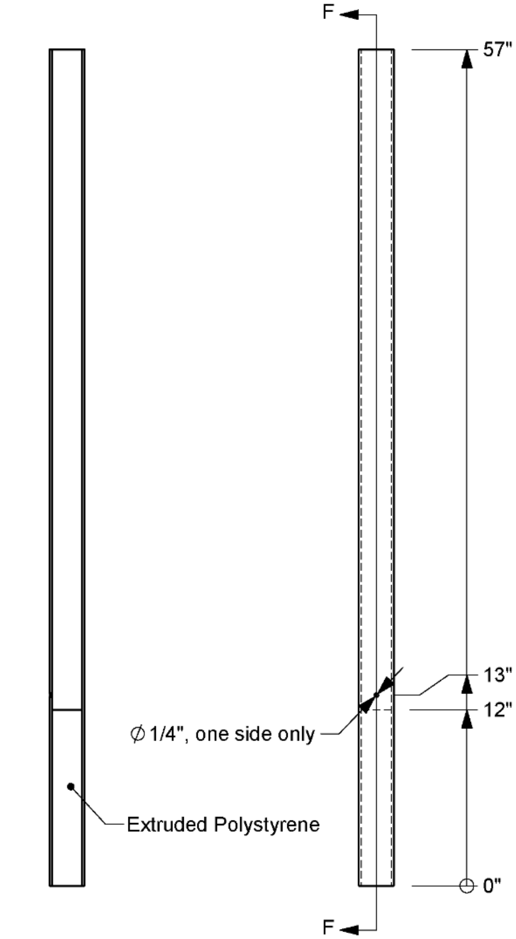
Guardrail not shown for clarity



3a. Core Ø3" holes 12" deep for posts and roughen the sides. Secure the posts with Hilti HIT-RE 500 V3 epoxy according to manufacturer's instructions. Posts are centered on Wall.

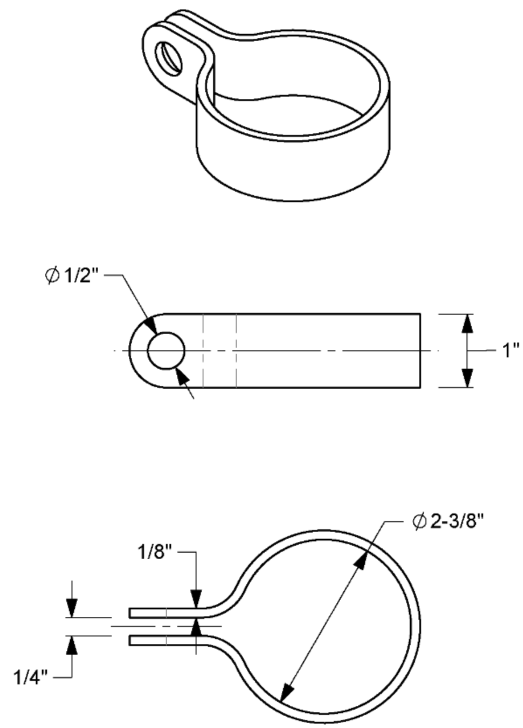
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #617231-01 Long Span Guardrail with Handrail		2023-03-08
Drawn by GES	Scale 1:50	Sheet 3 of 7 Handrail Details

S:\Accreditation-17025-2017\EIR-000 Project Files\617231-01 Long Span Guardrail with fall Prot. Fnc\Drafting, 617231-01\617231-01 Drawing



Section F-F

Handrail Post
Pipe, 2" sch. 40 x 57"
ASTM A53 Grade A

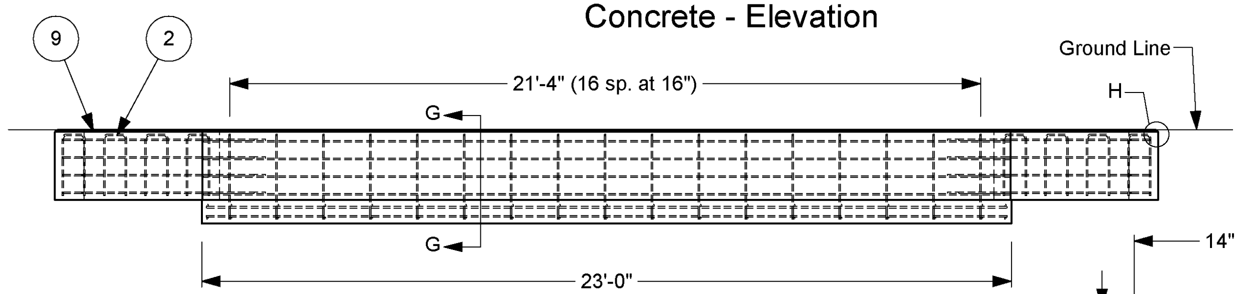


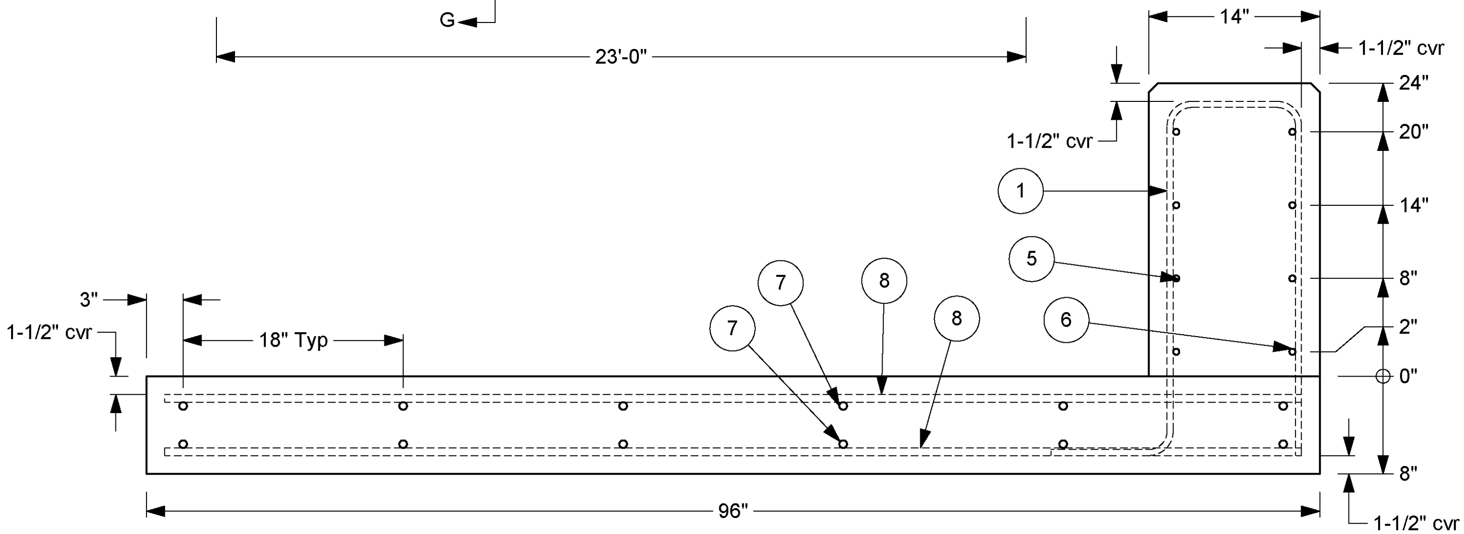
Brace Band
ASTM F626
Scale 1:10

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #617231-01 Long Span Guardrail with Handrail		2023-03-08
Drawn by GES	Scale 1:10	Sheet 4 of 7 Handrail Post / Brace Band

S:\Accreditation-17025-2017\EIR-000 Project Files\617231-01 Long Span Guardrail with fall Prot. Fnc\Drafting, 617231-01\617231-01 Drawing

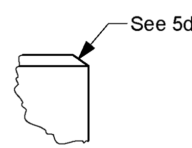
Concrete - Elevation





Section G-G
Scale 1 : 12

#	Part Name	QTY.
1	A-bar	17
2	B-bar	8
3	R-bar	8
4	S-bar	8
5	Ø1/2" Longitudinal in Wall	4
6	Ø1/2" Longitudinal in Wall	4
7	Ø5/8" Longitudinal in Deck	12
8	Transverse Bar, Ø5/8" x 93"	38
9	4,000 psi Concrete	1



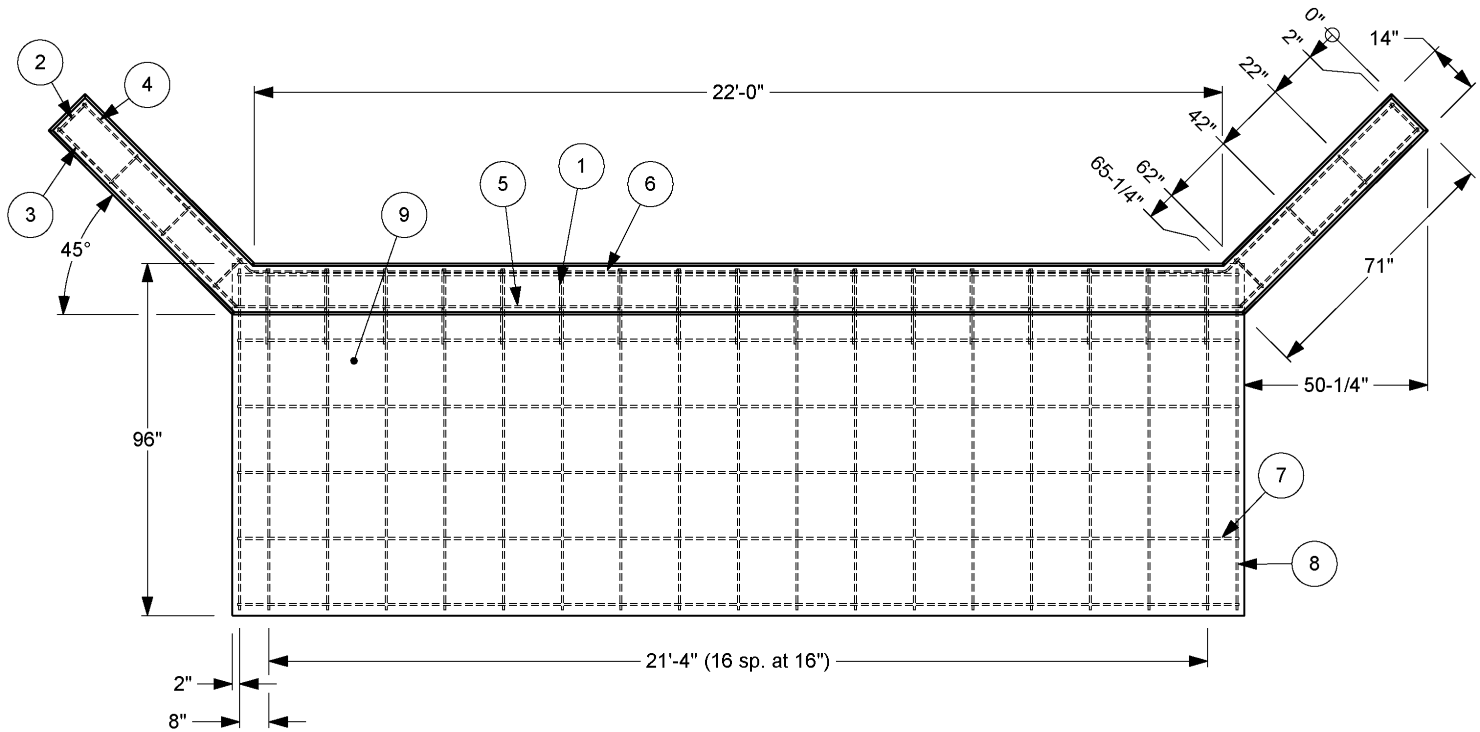
Detail H
Scale 1 : 10

5a. All rebar dimensions are to center of bar unless otherwise indicated by "cvr" (cover).
5b. Minimum rebar lap is 15" for #4 bars.
5c. All rebar is grade 60.
5d. Chamfer top edges of wall 1" (3/4" each way).

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #617231-01 Long Span Guardrail with Handrail		2023-03-08
Drawn by GES	Scale 1:50	Sheet 5 of 7 Concrete - Elevation

S:\Accreditation-17025-2017\EIR-000 Project Files\617231-01 Long Span Guardrail with fall Prot. Fnc\Drafting, 617231-01\617231-01 Drawing

Concrete - Plan

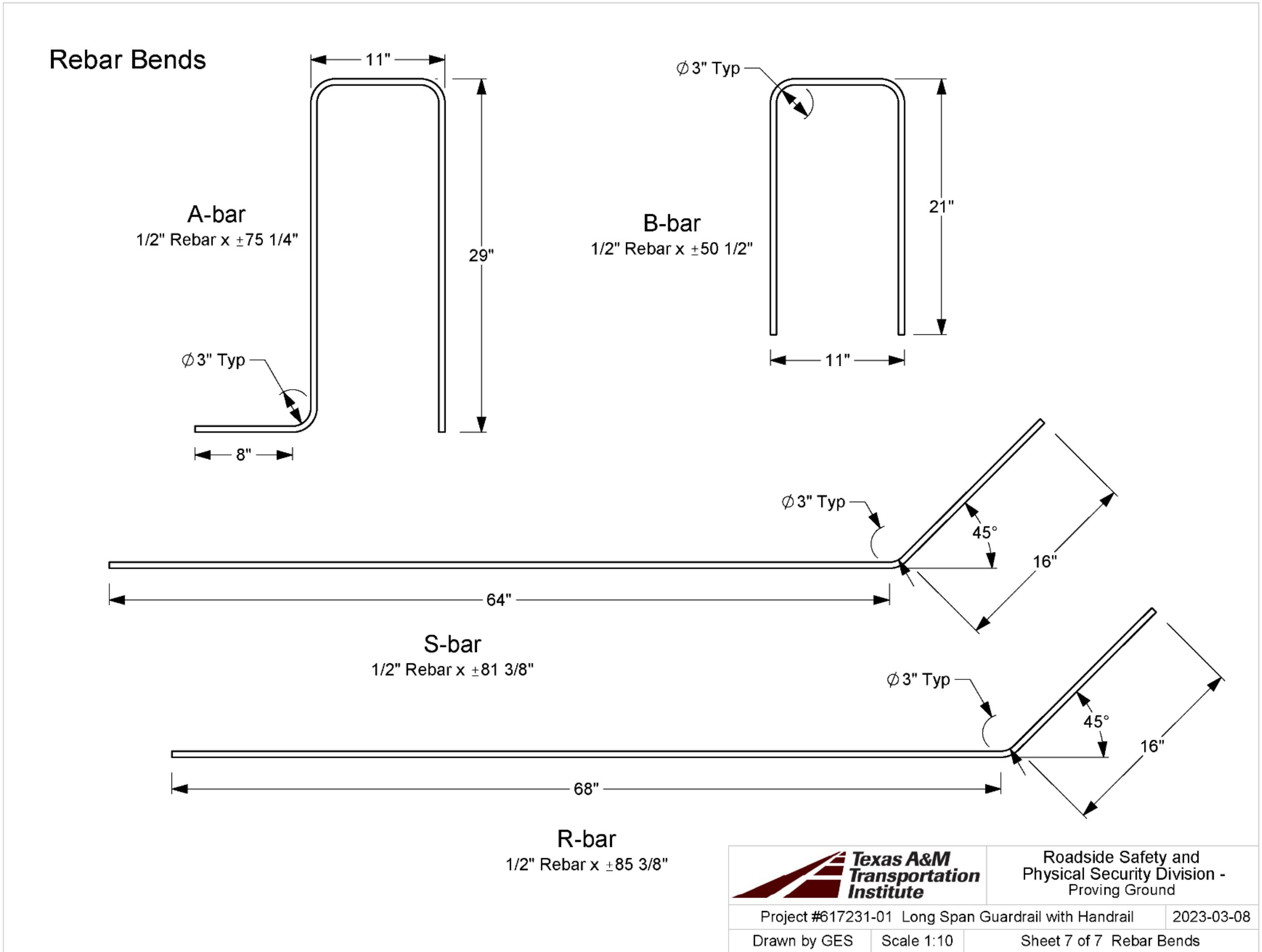


Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project #617231-01 Long Span Guardrail with Handrail	2023-03-08
Drawn by GES / Scale 1:40	Sheet 6 of 7 Concrete - Plan

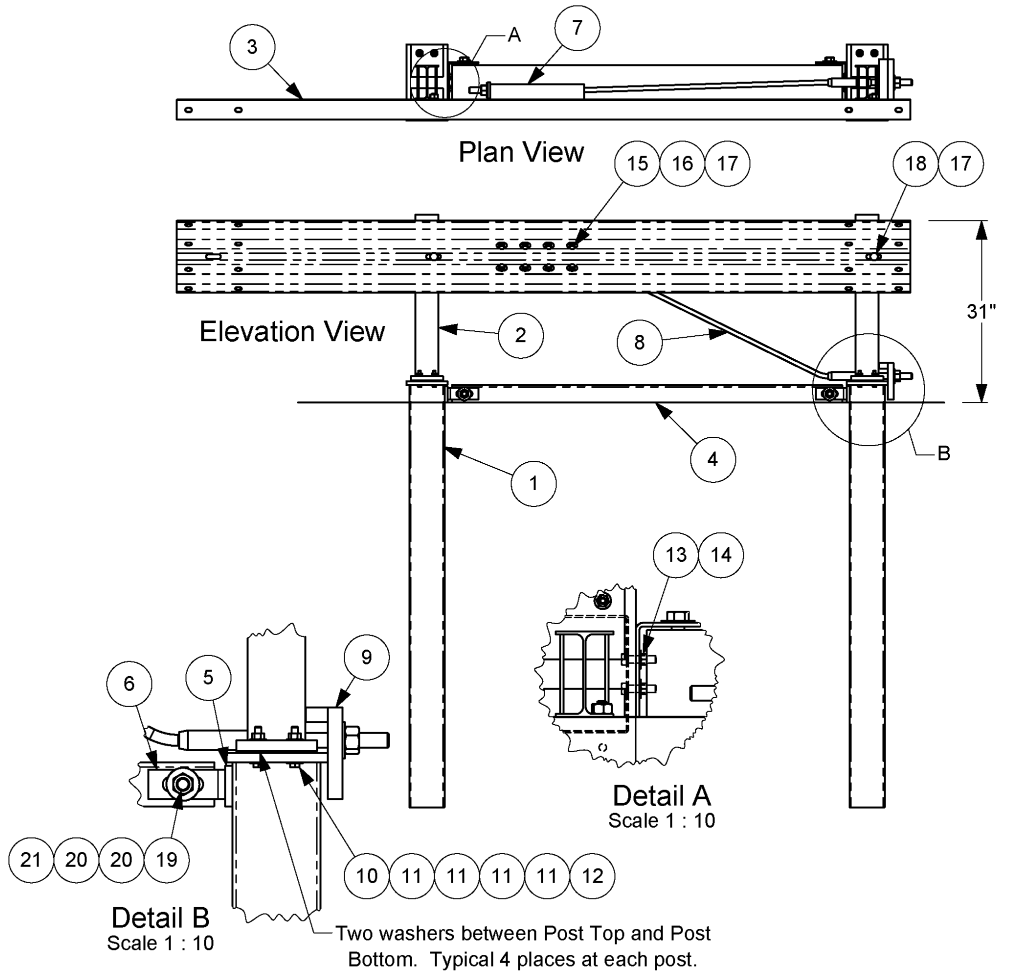
S:\Accreditation-17025-2017\EIR-000 Project Files\617231-01 Long Span Guardrail with fall Prot. Fnc\Drafting, 617231-01\617231-01 Drawing



S:\Accreditation-17025-2017\EIR-000 Project Files\617231-01 Long Span Guardrail with fall Prot. Fnc\Drafting, 617231-01\617231-01 Drawing

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



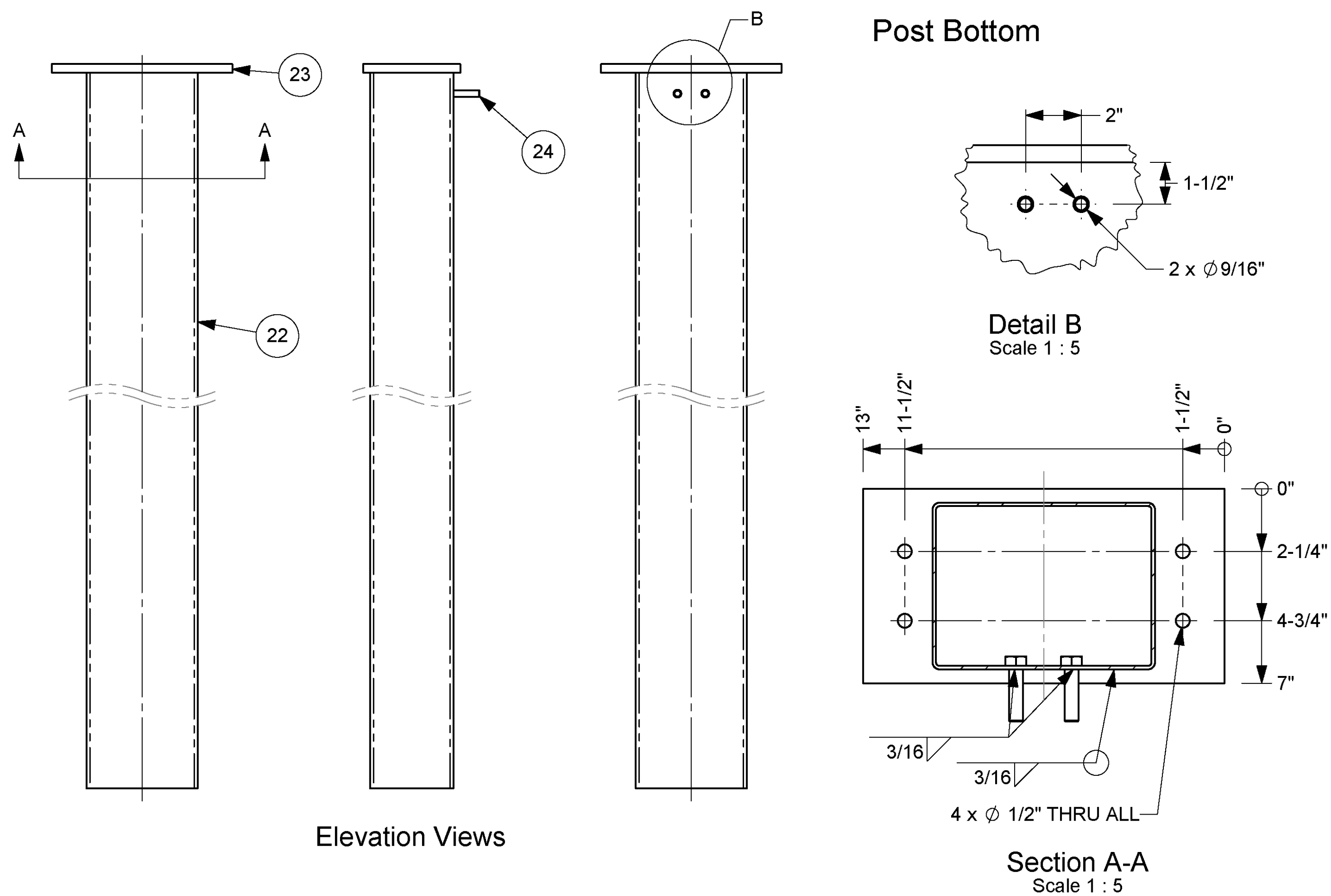
1a. 7/16" x 2-1/2" Bolts are ASTM A449. All other Bolts are ASTM A307. All Nuts (except Recessed Guardrail Nuts) are ASTM A563A unless otherwise indicated.

1c. All steel parts shall be galvanized.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
Project # Terminal			2022-07-08
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



#	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

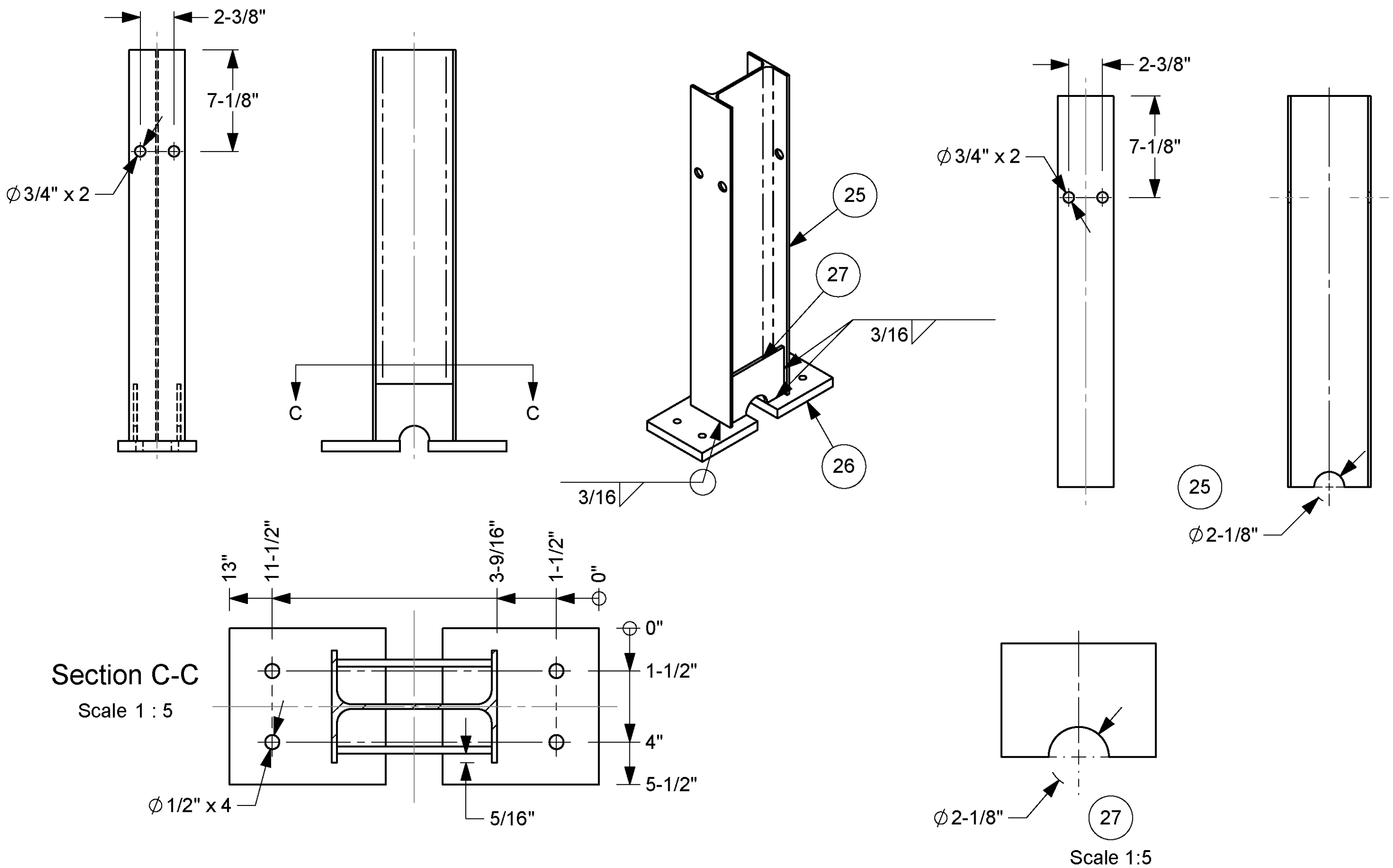
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

Project # Terminal 2022-07-08

Drawn by GES Scale 1:10 Sheet 2 of 6 Post Bottom

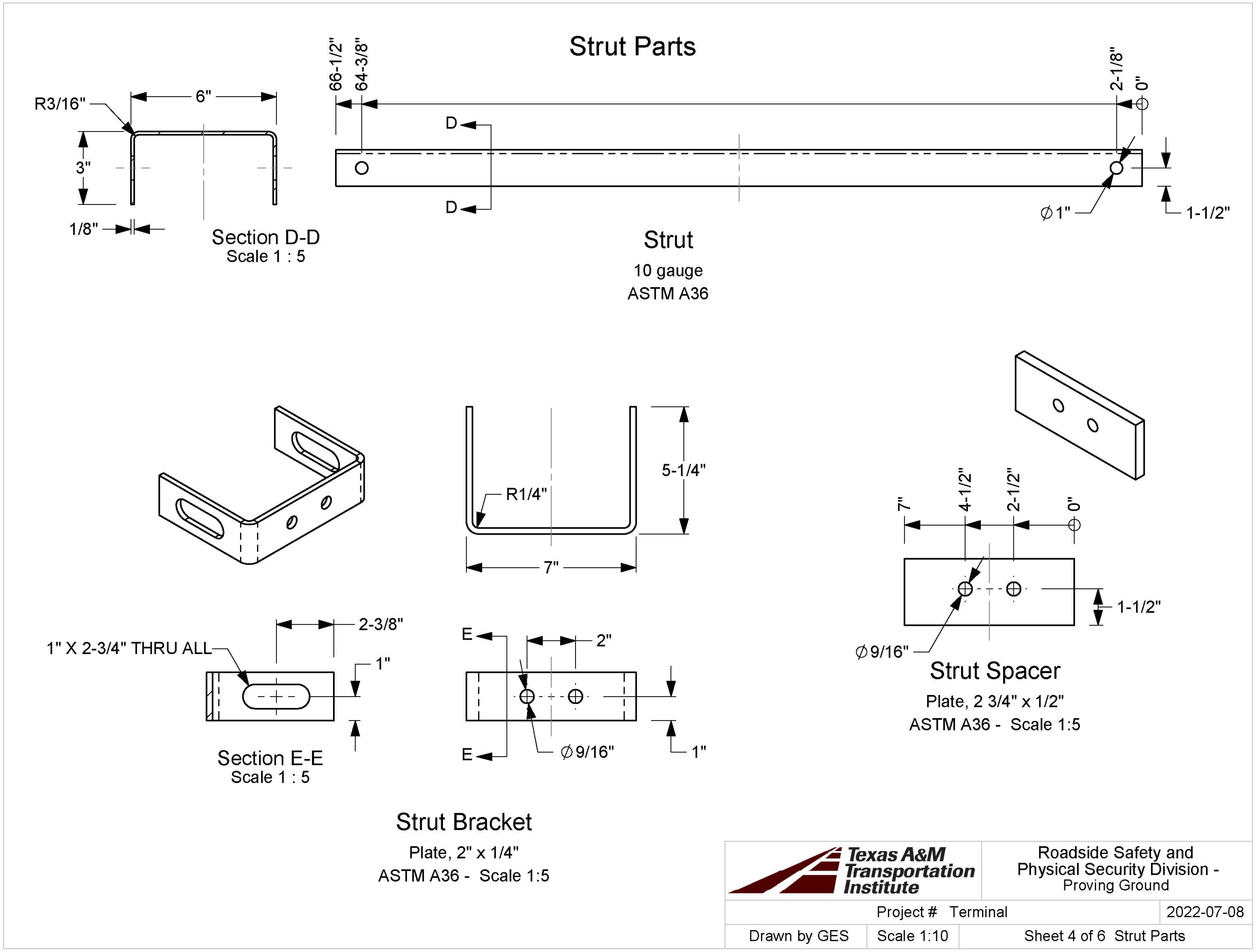
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Midwest Terminal



#	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		2022-07-08
Drawn by GES	Scale 1:10	Sheet 3 of 6 Post Top	

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



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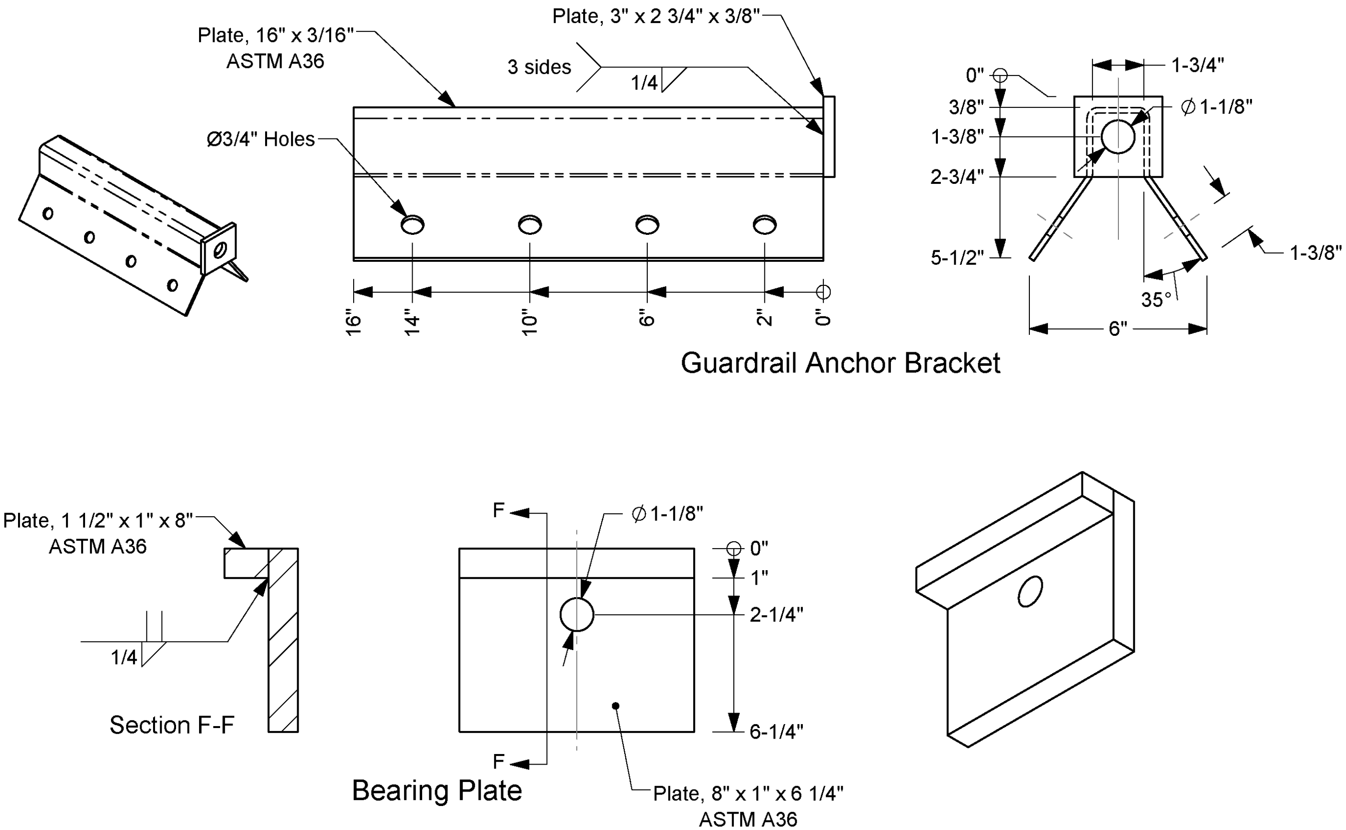
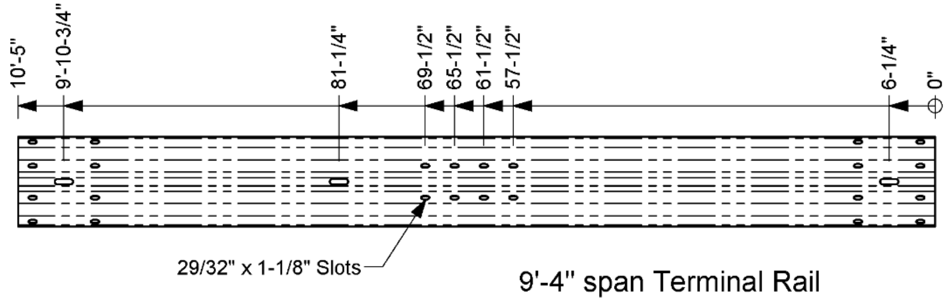


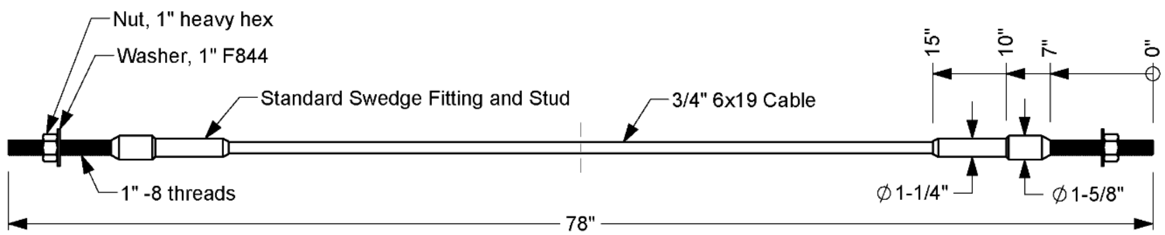
Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground		
	Project # Terminal		2022-07-08
Drawn by GES	Scale 1:5	Sheet 5 of 6 Assorted Parts A	

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



9'-4" span Terminal Rail

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

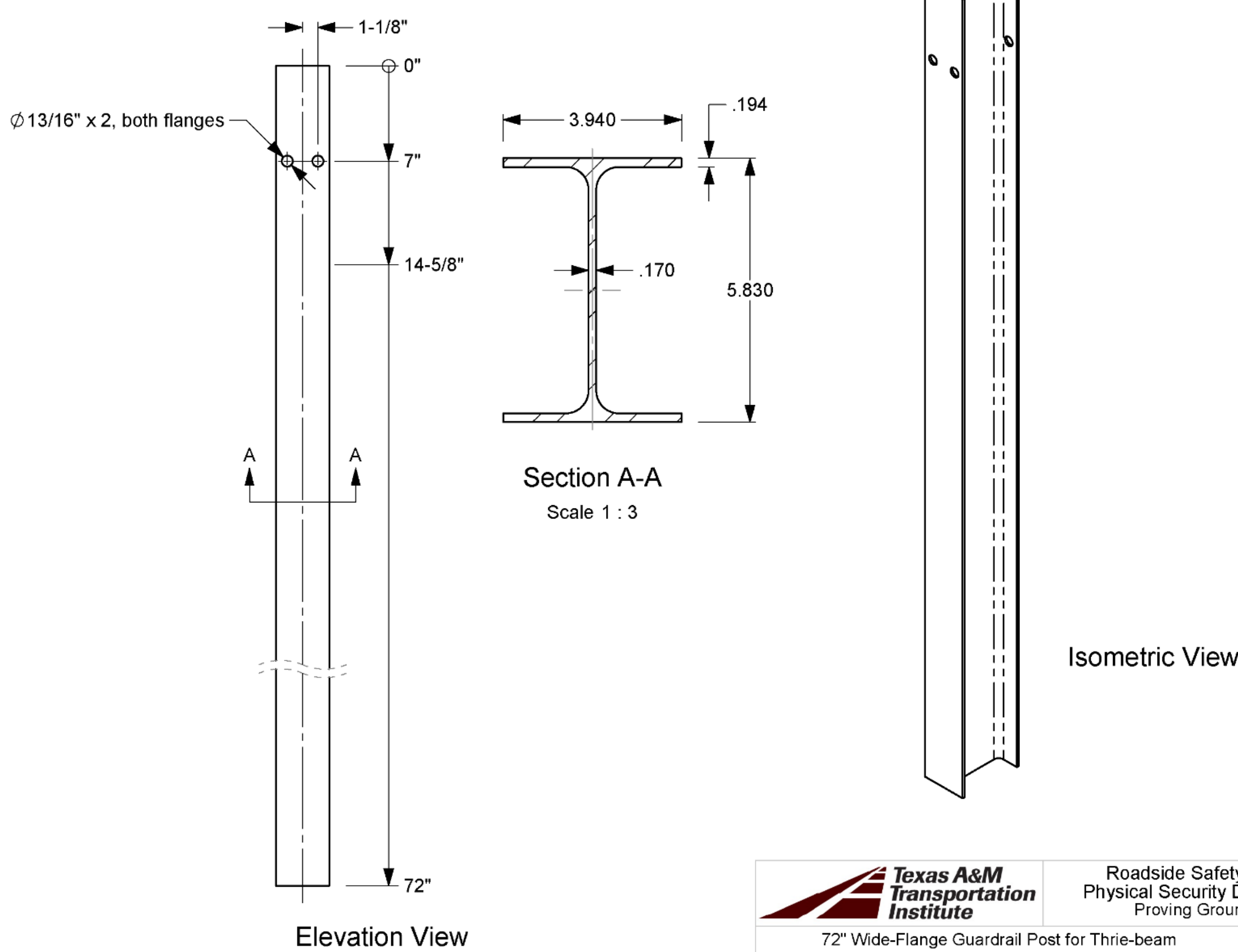


Anchor Cable Assembly

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
	Project # Terminal		2022-07-08
Drawn by GES	Scale 1:5	Sheet 6 of 6 Assorted Parts B	

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

72" Wide Flange Guardrail Post

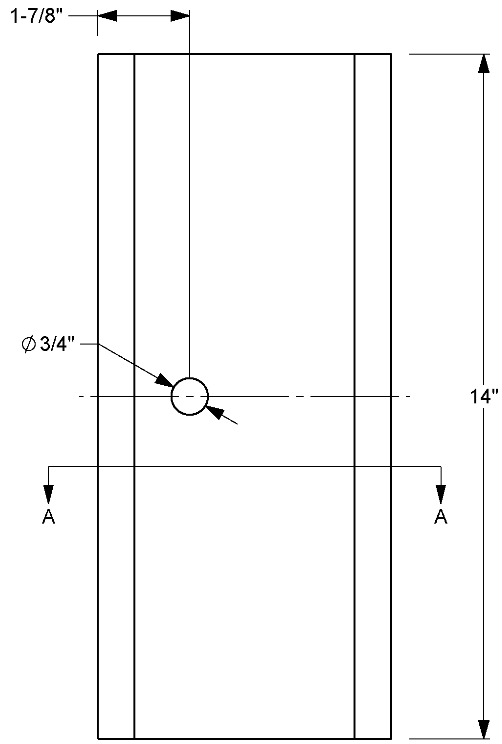


Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground
72" Wide-Flange Guardrail Post for Thrie-beam		2022-07-08
Drawn by GES	Scale 1:10	Sheet 1 of 1

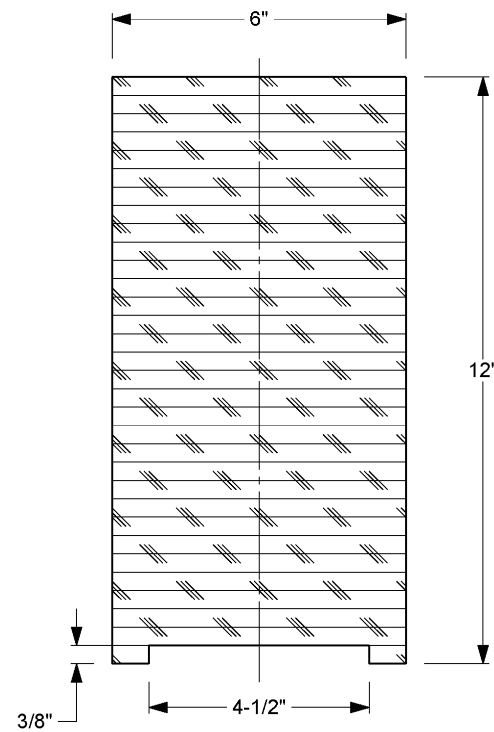
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, 72" Wide Flange for W-beam

Timber Blockout 12in for W-section Post

All dimensions except hole diameter are nominal



Elevation View



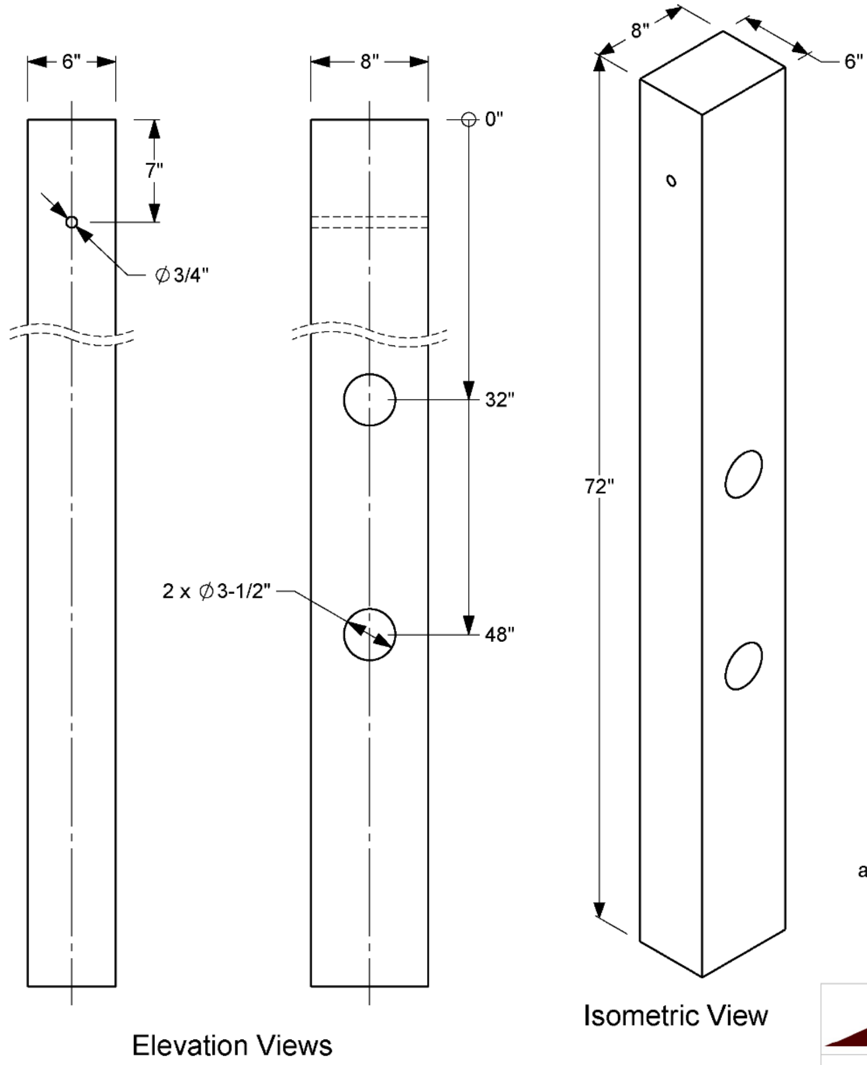
Section A-A

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		
12" Timber Blockout, for W-section Post			2022-11-18
Drawn by GES	Scale 1:3	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Timber Blockout 12in for W-section Post

CRT Timber Post

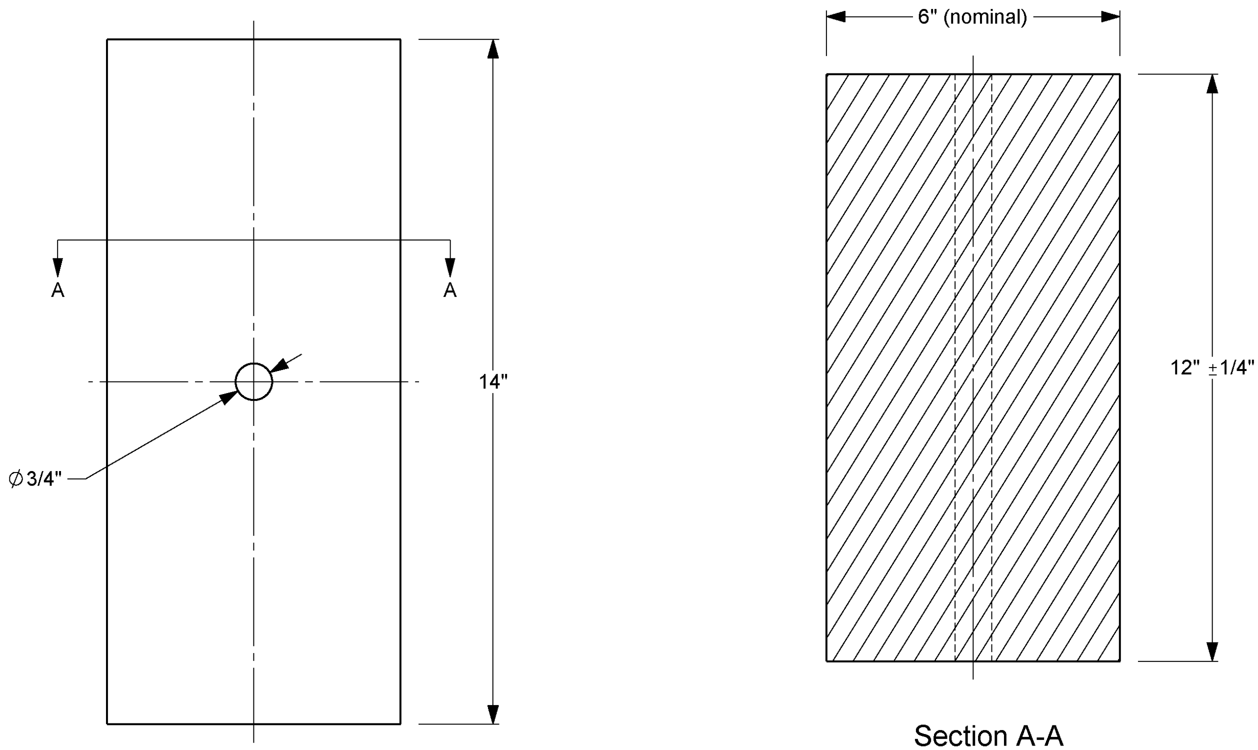


1a. Timber posts are treated with a preservative in accordance with AASHTO M 133 after all cutting and drilling.
1b. Post thickness and width are nominal dimensions.

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
CRT Timber Post for 31" rail		2022-10-19
Drawn by GES	Scale 1:10	Sheet 1 of 1

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Post, CRT Timber

Timber Blockout, 12" for 6x8 Wood Post



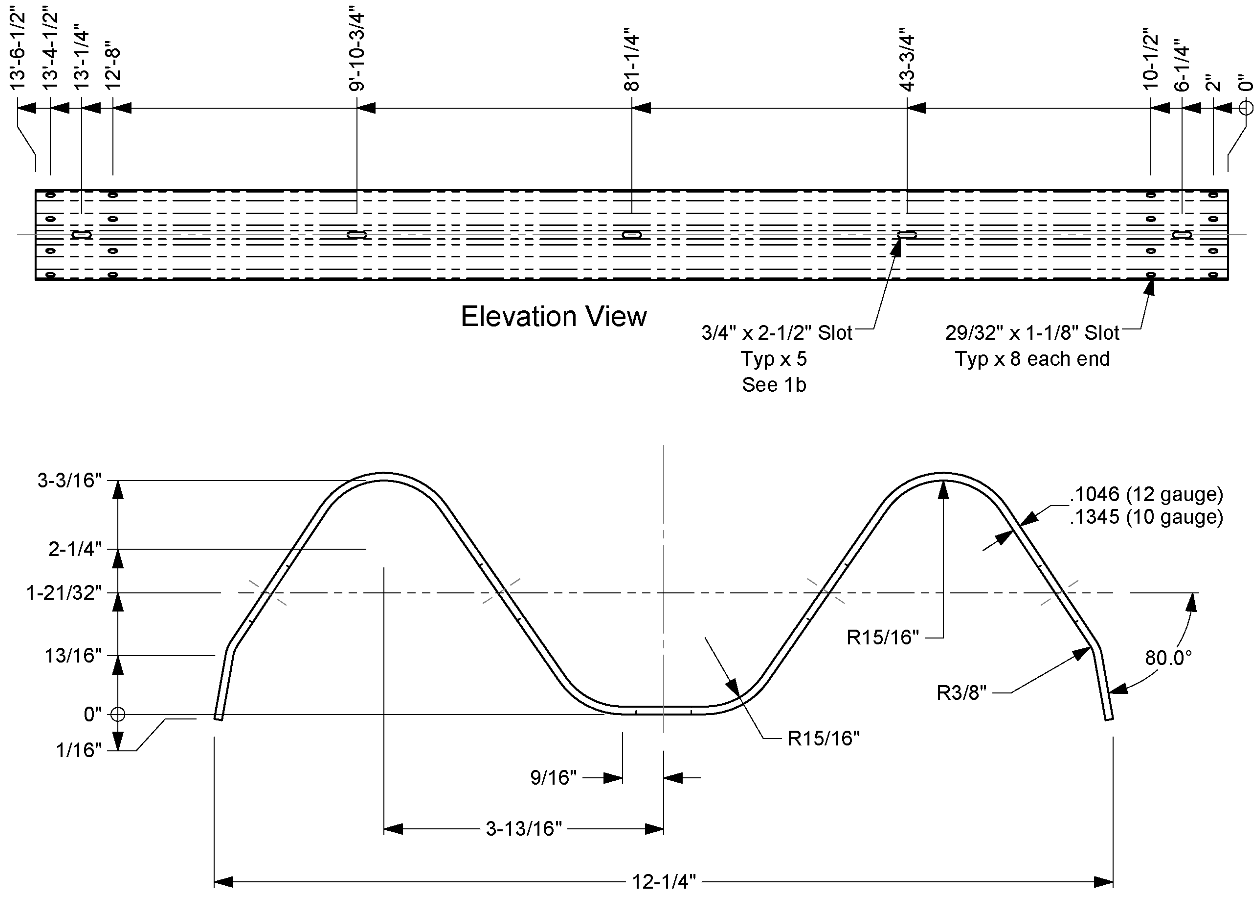
Elevation View

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	
12" W-beam Blockout, for Wood Post			2020-10-18
Drawn by GES	Scale 1:3	Sheet 1 of 1	

T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\Timber Blockout, 12" for 6x8 Wood Post



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.

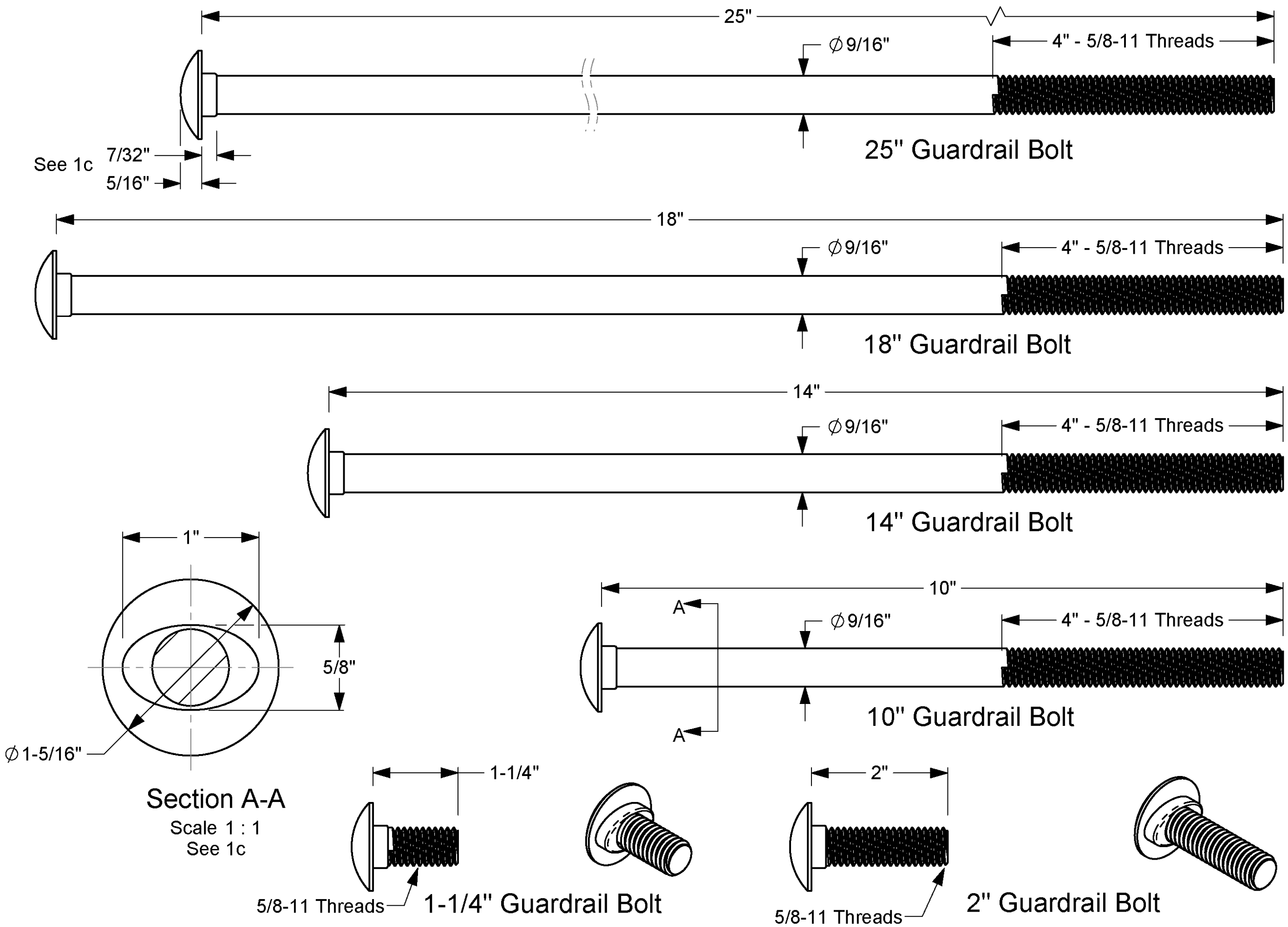
Texas A&M Transportation Institute

Roadside Safety and Physical Security Division - Proving Ground

W-beam Guardrail 2022-07-13

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



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

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Guardrail Bolt		2020-07-08
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

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

CMC

CMC STEEL TEXAS
1 STEEL MILL DRIVE
SEGUIN TX 78155-7510

CERTIFIED MILL TEST REPORT

For additional copies call
800-227-6489

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

Rolando A Davila
Quality Assurance Manager

HEAT NO.:3118483 SECTION: REBAR 13MM (#4) 20'0" 420/60 GRADE: ASTM A615-20 Gr 420/60 ROLL DATE: 10/13/2022 MELT DATE: 09/19/2022 Cert. No.: 85220201 / 118483A130	S O L D T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	S H I P T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 85220201 BOL#: 75060812 CUST PO#: 933303 CUST P/N: DLVRY LBS / HEAT: 21910.000 LB DLVRY PCS / HEAT: 1640 EA

Characteristic	Value
C	0.43%
Mn	0.79%
P	0.011%
S	0.035%
Si	0.22%
Cu	0.35%
Cr	0.12%
Ni	0.22%
Mo	0.093%
V	0.000%
Cb	0.000%
Sn	0.009%
Al	0.002%
Yield Strength test 1	68.0ksi
Tensile Strength test 1	105.9ksi
Elongation test 1	11%
Elongation Gage Lgth test 1	8IN
Tensile to Yield ratio test1	1.56
Bend Test 1	Passed

Characteristic	Value
Bend Test Diameter	1.750IN

617231

Characteristic	Value

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

REMARKS :

Page 1 OF 1 11/09/2022 14:46:27

CMC

CMC STEEL FLORIDA
16770 Rebar Road
Jacksonville FL 32234-4100

CERTIFIED MILL TEST REPORT

For additional copies call
904-266-1468

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

Alex Renosto
Quality Assurance Manager

HEAT NO.:5021242 SECTION: REBAR 16MM (#5) 20'0" 420/60 GRADE: ASTM A615-20 Gr 420/60 ROLL DATE: 07/04/2022 MELT DATE: 06/29/2022 Cert. No.: 85221258 / 021242X371	S O L D T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845 7950 979 774 5900	S H I P T O	CMC Construction Svcs College Stati 10650 State Hwy 30 College Station TX US 77845-7950 979 774 5900	Delivery#: 85221258 BOL#: 75062224 CUST PO#: 933308 CUST P/N: DLVRY LBS / HEAT: 2003.000 LB DLVRY PCS / HEAT: 96 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.46%	Elongation Gage Lgth 1(metri	200mm		
Mn	0.87%	Bend Test 1	Passed		
P	0.010%	Rebar Deformation Avg. Spaci	0.419IN		
S	0.032%	Rebar Deformation Avg. Heigh	0.039IN		
Si	0.18%	Rebar Deformation Max. Gap	0.134IN		
Cu	0.33%				
Cr	0.18%				
Ni	0.08%				
Mo	0.019%				
V	0.003%				
Cb	0.001%				
Sn	0.013%				
Yield Strength test 1	66.9ksi				
Yield Strength test 1 (metri	461MPa				
Tensile Strength test 1	108.0ksi				
Tensile Strength 1 (metric)	745MPa				
Elongation test 1	16%				
Elongation Gage Lgth test 1	8IN				
Tensile to Yield ratio test1	1.61				

617231

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

REMARKS : ALSO MEETS AASHTO M31

Page 1 OF 1 11/08/2022 10:50:01

Texas A&M Transportation Institute	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Revision Date: 2020-07-29
Quality Form	Revised by: B.L. Griffith Approved by: D. L. Kuhn	Revision: 7	Page: 1 of 1

Project No: 617231 **Casting Date:** 12/12/2022 **Mix Design (psi):** 4500

Name of Technician Taking Sample: Terracon

Name of Technician Breaking Sample: Terracon

Signature of Technician Taking Sample: Terracon

Signature of Technician Breaking Sample: Terracon

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	119	130396	100% of moment slab

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average

TEXCRETE
Redi-mix Concrete Company

REMIT PAYMENT TO:
P.O. BOX138
KURTEN, TX 77862

TEXCRETE

130396

5222 Sandy Point RD.
Bryan, Tx 77807

17534 SH 6 South
College Station, TX 77845

18935 Circle Lake Dr.
Pinehurst, TX 77362

BCS DISPATCH - 979-316-2906
PINEHURST DISPATCH - 936-232-5815
OFFICE - 979-985-3636

TEXAS A&M TRANSPORTATIO
RELLIS CAMPUS, BRYAN TX

RT 2818, RT HWY 21, LT SILVER HILL, RT AT THE "T", RT HWY 47, LT INTORELLIS ENTRANCE, STAY STRAIGHTALL THE WAY DOWN TO THE GATE

TIME	FORMULA	LOAD SIZE	YARD ORDERED		DRIVER/TRUCK		PLANT TRANSACTION#
10:23	FN94520050	6.00	6.00	PO#	JJ	119	72353
DATE		LOAD#	YARDS DEL.	BATCH#	WATER TRIM	SLUMP	TICKET NUMBER
12/12/22	PROJECT TTIRELL	6.00	6.00			5.00 in	70541

QUANTITY	CODE	DESCRIPTION	UNIT PRICE	EXTENDED PRICE
6.00 yd	FN945200500	COM, 4500, BLND, 5"		
1.00 ea	FUEL	Fuel Charge		

Thank you for your business

LEFT PLANT	ARRIVED JOB	START UNLOADING	SLUMP	CONCRETE TEMP.	AIR TEMP
10:31	10:46				
FINISH UNLOADING	LEFT JOB	ARRIVED AT PLANT	ON SITE TESTING		

TESTING LAB: TERRACON GESSNER CME OTHER

TESTED ☐ YES ☐ NO

AIR CYLINDERS

Tax
Prev. AMT
Ticket Total

ADDITIONAL CHARGE 1
ADDITIONAL CHARGE 2
GRAND TOTAL

WARNING
IRRITATING TO THE SKIN AND EYES

Contains Portland Cement, Wear Rubber Boots and Gloves. PROLONGED CONTACT MAY CAUSE BURNS. Avoid Contact With Eyes and Prolonged Contact with Skin. In Case of Contact with Skin or Eyes, Rinse Thoroughly With Water. If Irritation Persists. Get Medical Attention. **KEEP CHILDREN AWAY.**

CONCRETE is a PERISHABLE COMMODITY and BECOMES THE PROPERTY of the PURCHASER UPON LEAVING the PLANT. ANY CHANGES or CANCELLATION of ORIGINAL INSTRUCTIONS MUST be TELEPHONED to the OFFICE BEFORE LOADING starts. The undersigned promises to pay all costs, including reasonable attorney's fees incurred in collecting any sums owed.

All accounts not paid within 30 days of delivery will bear interest at the rate of 18% per annum. Not Responsible For Reactive Aggregate or Color Quality. No Claim Allowed Unless Made at Time Material is Delivered.
A $25.00 Service Charge and Loss of the Cash Discounted will be Collected on all Returned Checks. Demerge charge after 90 min. will be $100.00/hr.

PROPERTY DAMAGE RELEASE
(TO BE SIGNED IF DELIVERY TO BE MADE INSIDE CURB LINE)

Dear Customer - The driver of this truck in presenting this RELEASE to you for your signature is of the opinion that the size and weight of this truck may possibly cause damage to the premises and/or adjacent property if he places the material in this load where you desire it. It is our wish to help you in everyway that we can, but in order to do this the driver is requesting that you sign this RELEASE relieving him and this supplier from any responsibility from damage that may occur to the premises and or adjacent property, buildings, sidewalks, driveways, curbs, etc. by the delivery of this material and that you also agree to help him remove mud from the wheels of his vehicle so that he will not liter the public streets. Further as additional consideration; the undersigned agrees to indemnify and hold harmless the driver of this truck and this supplier for any and all damage to the premises and /or adjacent property which may be claimed by anyone to have arisen out of delivery of this order
SIGNED:

X

Excessive Water is Detrimental to Concrete Performance.
H_2O Added by Request/Authorized By:

0 GAL X

WEIGHMASTER

Surcharge for credit cards

NOTICE: MY SIGNATURE BELOW INDICATES THAT I HAVE READ THE HEALTH WARNING NOTICE AND SUPPLIER WILL NOT BE RESPONSIBLE FOR ANY DAMAGE CAUSED WHEN DELIVERING INSIDE CURB LINE.

LOAD RECEIVED BY
X

130396

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0261
Service Date: 12/12/22
Report Date: 01/24/23 Revision 1 -
Task: PO# 617231

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
Specified Strength: 4,500 psi @ 28 days

Mix ID: FN94520050>iiii>>>ii>iiiii(?
Supplier: Texcrete
Batch Time: 1115 **Plant:**
Truck No.: 119 **Ticket No.:** 72353

Sample Information
Sample Date: 12/12/22 **Sample Time:** 2315
Sampled By: Randy Rippstein
Weather Conditions: Cloudy, Heavy Wind
Accumulative Yards: 6 **Batch Size (cy):** 6
Placement Method: Direct Discharge
Water Added Before (gal): 10
Water Added After (gal): 0
Sample Location: Middle
Placement Location: North West Runway

Field Test Data

Test	Result	Specification
Slump (in):	6	
Air Content (%):	1.6	
Concrete Temp. (F):	81	
Ambient Temp. (F):	64	
Plastic Unit Wt. (pcf):	147.0	
Yield (Cu. Yds.):		

Laboratory Test Data

Set No.	Spec ID	Cyl. Cond.	Avg Diam. (in)	Area (sq in)	Date Received	Date Tested	Age at Test (days)	Max Load (lbs)	Comp Strength (psi)	Frac Type	Tested By
1	A	Good	6.00	28.27		01/04/23	23	126,960	4,490	5	CRM
1	B	Good	6.00	28.27		01/04/23	23	131,110	4,640	5	CRM
1	C	Good	6.00	28.27		01/04/23	23	127,370	4,500	5	CRM
							Average (23 days)		**4,540**		
1	D						Hold				

Initial Cure: Outside Plastic Lids **Final Cure:** Field Cured **Sample Description:** 6-inch diameter cylinders

Comments: Note: Reported air content does not include Aggregate Correction Factor (ACF).

Samples Made By: Terracon
Services: Obtain samples of fresh concrete at the placement locations (ASTM C 172), perform required field tests and cast, cure, and test compressive strength samples (ASTM C 31, C 39, C 1231).

Terracon Rep.: Randy Rippstein
Reported To: Bill w/ TTI
Contractor: MBC Management
Report Distribution:
(1) Texas Transportation Institute, Bill Griffith

Start/Stop: 1100-1300

Reviewed By:
Alexander Dunigan
Project Manager

Test Methods: ASTM C 31, ASTM C143, ASTM C231, ASTM C1064

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.

Texas A&M Transportation Institute	QF 7.3-01 Concrete Sampling	Doc. No. QF 7.3-01	Revision Date: 2020-07-29
Quality Form	Revised by: B.L. Griffith Approved by: D. L. Kuhn	Revision: 7	Page: 1 of 1

Project No: 617231 **Casting Date:** 12/21/2022 **Mix Design (psi):** 4500

Name of Technician Taking Sample: Terracon

Name of Technician Breaking Sample: Terracon

Signature of Technician Taking Sample: Terracon

Signature of Technician Breaking Sample: Terracon

Load No.	Truck No.	Ticket No.	Location (from concrete map)
T1	Justin Hosey13	144247	100% of Deck

Load No.	Break Date	Cylinder Age	Total Load (lbs)	Break (psi)	Average

144247

TEXCRETE Redi-mix Concrete Company

TEXCRETE

REMIT PAYMENT TO:
P.O. BOX138
KURTEN, TX 77862

5222 Sandy Point RD. Bryan, Tx 77807 | 17534 SH 6 South College Station, TX 77845 | 18935 Circle Lake Dr. Pinehurst, TX 77362

BCS DISPATCH - 979-316-2906
PINEHURST DISPATCH - 936-232-5815
OFFICE - 979-985-3636

TEXAS A&M TRANSPORTATIO
RELLIS CAMPUS, BRYAN TX

RT 2818, RT HWY 21, LT SILVER HILL, RT AT THE "T", RT HWY 47, LT INTORELLIS ENTRANCE, STAY STRAIGHTALL THE WAY DOWN TO THE GATE

TIME	FORMULA	LOAD SIZE	YARD ORDERED		DRIVER/TRUCK		PLANT TRANSACTION#
10:54	FN94520050	4.00	4.00	PO#	JUSTIN HOSEY13		72707
DATE	**PROJECT**	**LOAD#**	**YARDS DEL.**	**BATCH#**	**WATER TRIM**	**SLUMP**	**TICKET NUMBER**
12/21/22	TTIRELL	4.00	4.00			5.00 in	70901

QUANTITY	CODE	DESCRIPTION	UNIT PRICE	EXTENDED PRICE
4.00 yd	FN945200500	COM, 4500, BLND, 5"		
1.00 ea	FUEL	Fuel Charge		

Thank you for your business

Tax
Prev. AMT
Ticket Total

LEFT PLANT	ARRIVED JOB	START UNLOADING	SLUMP	CONCRETE TEMP.	AIR TEMP
11:00	11:16				
FINISH UNLOADING	**LEFT JOB**	**ARRIVED AT PLANT**	**ON SITE TESTING**		
			TESTING LAB: TERRACON / GESSNER / CME / OTHER		
TESTED			**AIR**	**CYLINDERS**	
☐ YES ☐ NO					

ADDITIONAL CHARGE 1 ____________

ADDITIONAL CHARGE 2 ____________

GRAND TOTAL

WARNING
IRRITATING TO THE SKIN AND EYES

Contains Portland Cement. Wear Rubber Boots and Gloves. PROLONGED CONTACT MAY CAUSE BURNS. Avoid Contact With Eyes and Prolonged Contact with Skin. In Case of Contact with Skin or Eyes, Rinse Thoroughly With Water. If Irritation Persists. Get Medical Attention. **KEEP CHILDREN AWAY.**

CONCRETE is a PERISHABLE COMMODITY and BECOMES THE PROPERTY of the PURCHASER UPON LEAVING the PLANT. ANY CHANGES or CANCELLATION of ORIGINAL INSTRUCTIONS MUST be TELEPHONED to the OFFICE BEFORE LOADING starts. The undersigned promises to pay all costs, including reasonable attorney's fees, incurred in collecting any sums owed.

All accounts not paid within 30 days of delivery will bear interest at the rate of 18% per annum. Not Responsible For Reactive Aggregate or Color Quality. No Claim Allowed Unless Made at Time Material is Delivered.
A $25.00 Service Charge and Loss of the Cash Discounted will be Collected on all Returned Checks. Demerge charge after 90 min. will be $100.00/hr.

PROPERTY DAMAGE RELEASE
(TO BE SIGNED IF DELIVERY TO BE MADE INSIDE CURB LINE)

Dear Customer - The driver of this truck in presenting this RELEASE to you for your signature is of the opinion that the size and weight of this truck may possibly cause damage to the premises and/or adjacent property if he places the material in this load where you desire it. It is our wish to help you in everyway that we can, but in order to do this the driver is requesting that you sign this RELEASE relieving him and this supplier from any responsibility from damage that may occur to the premises and or adjacent property, buildings, sidewalks, driveways, curbs, etc. by the delivery of this material and that you also agree to help him remove mud from the wheels of his vehicle so that he will not liter the public streets. Further as additional consideration; the undersigned agrees to indemnify and hold harmless the driver of this truck and this supplier for any and all damage to the premises and /or adjacent property which may be claimed by anyone to have arisen out of delivery of this order SIGNED:

X ____________

Excessive Water is Detrimental to Concrete Performance.

H_2O Added by Request/Authorized By:

______ GAL X ____________

WEIGHMASTER

Surcharge for credit cards

NOTICE: MY SIGNATURE BELOW INDICATES THAT I HAVE READ THE HEALTH WARNING NOTICE AND SUPPLIER WILL NOT BE RESPONSIBLE FOR ANY DAMAGE CAUSED WHEN DELIVERING INSIDE CURB LINE.

LOAD RECEIVED BY

x ____________

144247

CONCRETE COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0263
Service Date: 12/21/22
Report Date: 01/24/23 Revision 1 -
Task: PO# 617231

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
Specified Strength: 4,500 psi @ 28 days

Mix ID: Fn945200500
Supplier: Texcrete
Batch Time: 1054 **Plant:** 2
Truck No.: 13 **Ticket No.:** 70901

Sample Information
Sample Date: 12/21/22 **Sample Time:** 1150
Sampled By: Brian Maass
Weather Conditions: Cloudy moderate wind
Accumulative Yards: 4/4 **Batch Size (cy):** 10
Placement Method: Direct Discharge
Water Added Before (gal): 10
Water Added After (gal): 0
Sample Location: Center
Placement Location: Northwest barier

Field Test Data

Test	Result	Specification
Slump (in):	5 1/2	
Air Content (%):	3.7	
Concrete Temp. (F):	64	
Ambient Temp. (F):	44	
Plastic Unit Wt. (pcf):	146.3	
Yield (Cu. Yds.):		

Laboratory Test Data

Set No.	Spec ID	Cyl. Cond.	Avg Diam. (in)	Area (sq in)	Date Received	Date Tested	Age at Test (days)	Max Load (lbs)	Comp Strength (psi)	Frac Type	Tested By
1	A	Good	6.00	28.27		01/04/23	14 F	133,680	4,730	2	CRM
1	B	Good	6.00	28.27		01/04/23	14 F	129,480	4,580	5	CRM
1	C	Good	6.00	28.27		01/04/23	14 F	133,900	4,740	2	CRM
1	D						Hold				

Initial Cure: Outside Plastic Lids **Final Cure:** Field Cured **Sample Description:** 6-inch diameter cylinders

Comments: **F = Field Cured**
Note: Reported air content does not include Aggregate Correction Factor (ACF).

Samples Made By: Terracon
Services: Obtain samples of fresh concrete at the placement locations (ASTM C 172), perform required field tests and cast, cure, and test compressive strength samples (ASTM C 31, C 39, C 1231).

Terracon Rep.: Brian Maass
Reported To:
Contractor: MBC Management
Report Distribution:
(1) Texas Transportation Institute, Bill Griffith

Start/Stop: 1030-1300

Reviewed By:
Alexander Dunigan
Project Manager

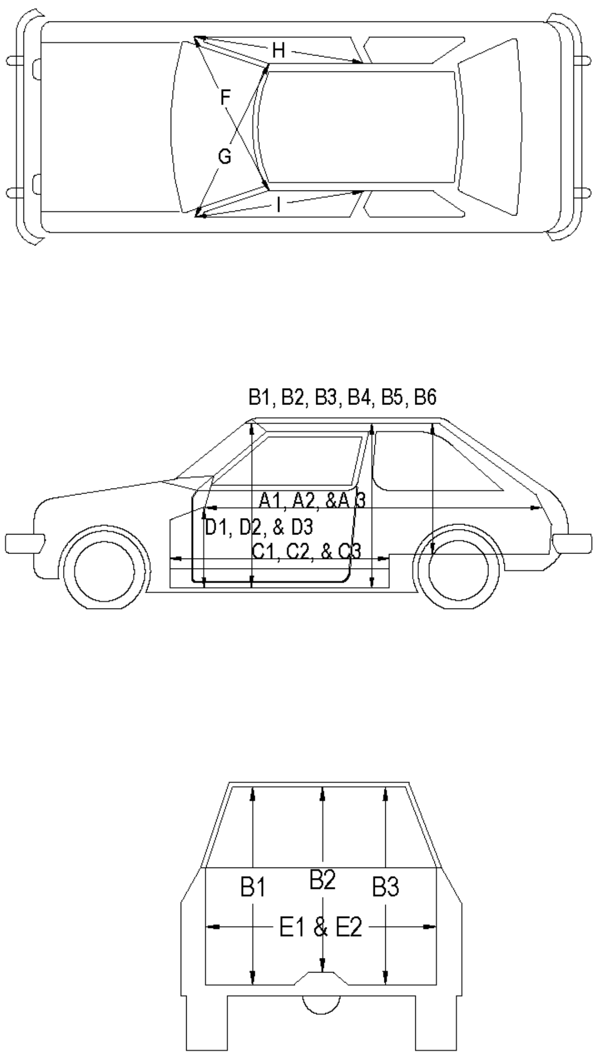
Test Methods: ASTM C 31, ASTM C143, ASTM C231, ASTM C1064

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.

APPENDIX C. *MASH* TEST 3-10 (CRASH TEST 617231-01-1)

C.1. VEHICLE PROPERTIES AND INFORMATION

Date:	2023-02-13	Test No.:	617231-01-1	VIN No.:	3N1CN7AP1KL865491
Year:	2019	Make:	Nissan	Model:	Versa



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	26.00	0.00
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00
D3	9.50	8.00	-1.50
E1	51.50	50.00	-1.50
E2	51.00	51.50	0.50
F	51.00	51.00	0.00
G	51.00	51.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	51.00	50.00	-1.00

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

Figure C.1. Vehicle Properties for Test 617231-01-1.

Date:	2023-02-13	Test No.:	617231-01-1	VIN No.:	3N1CN7AP1KL865491
Year:	2019	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	12	10	28							14
2	ABOVE FT BUMPER	12	8	36							52
	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.

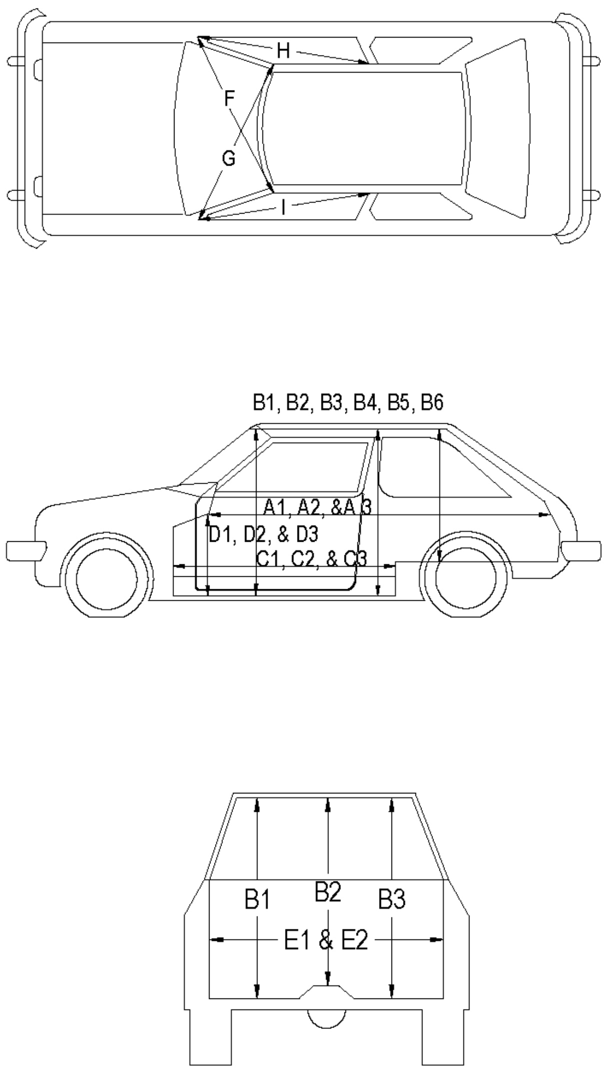
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 617231-01-1.

Date:	2023-02-13	Test No.:	617231-01-1	VIN No.:	3N1CN7AP1KL865491
Year:	2019	Make:	Nissan	Model:	Versa



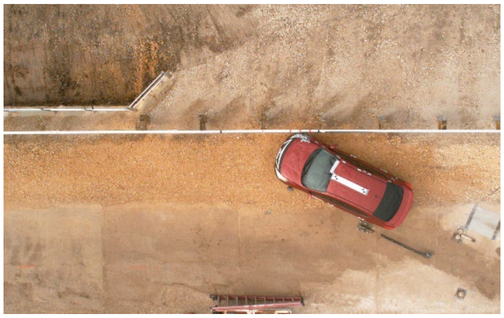
OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	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	26.00	0.00
D1	9.50	9.50	0.00
D2	0.00	0.00	0.00
D3	9.50	8.00	-1.50
E1	51.50	50.00	-1.50
E2	51.00	51.50	0.50
F	51.00	51.00	0.00
G	51.00	51.00	0.00
H	37.50	37.50	0.00
I	37.50	37.50	0.00
J*	51.00	50.00	-1.00

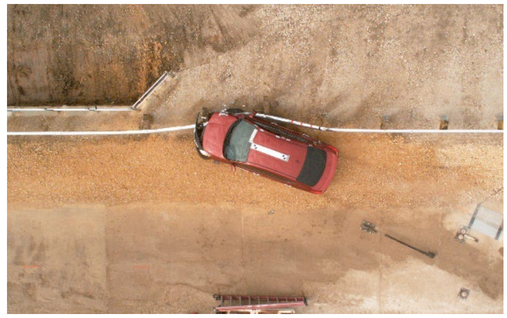
*Lateral area across the cab from
driver's side kick panel to passenger's side kick panel.

Figure C.3. Occupant Compartment Measurements for Test 617231-01-1.

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 617231-01-1 (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 617231-01-1 (Frontal Views).

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

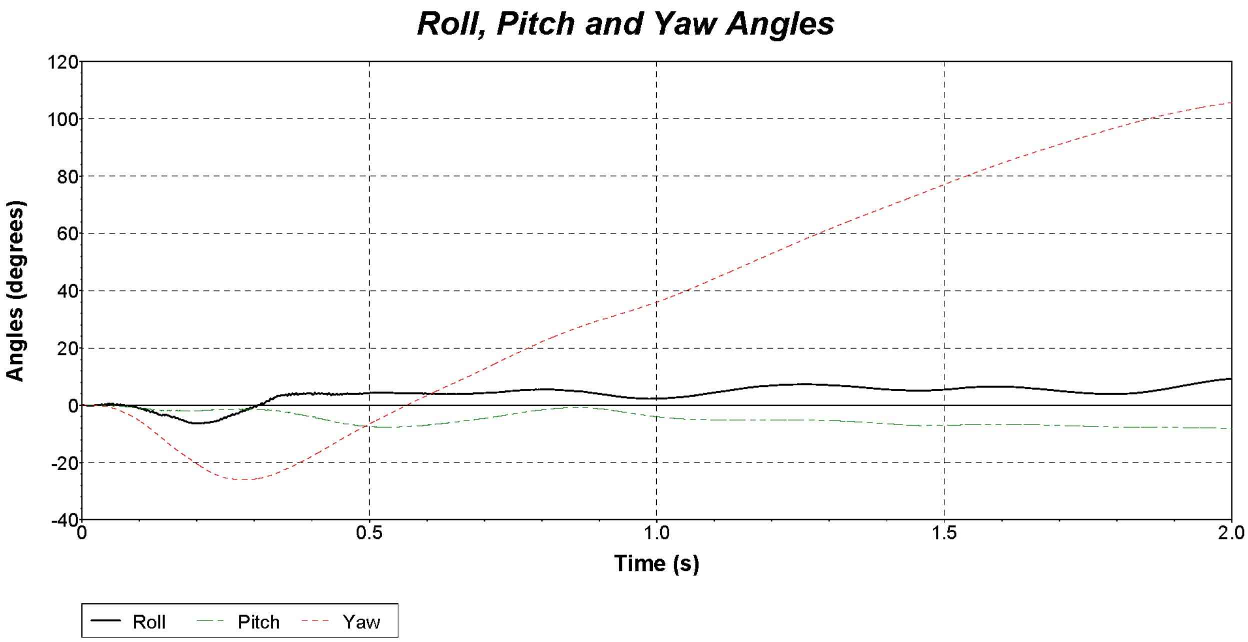
(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

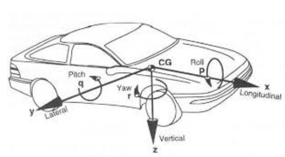
Figure C.6. Sequential Photographs for Test 617231-01-1 (Rear Views).

C.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 617231-01-1
Test Standard Test Number: *MASH* Test 3-10
Test Article: Long-Span Guardrail
Test Vehicle: 2019 Nissan Versa
Inertial Mass: 2430 lbs
Gross Mass: 2595 lbs
Impact Speed: 62.7 mi/h
Impact Angle: 24.8 °

Figure C.7. Vehicle Angular Displacements for Test 617231-01-1.

C.4. VEHICLE ACCELERATIONS

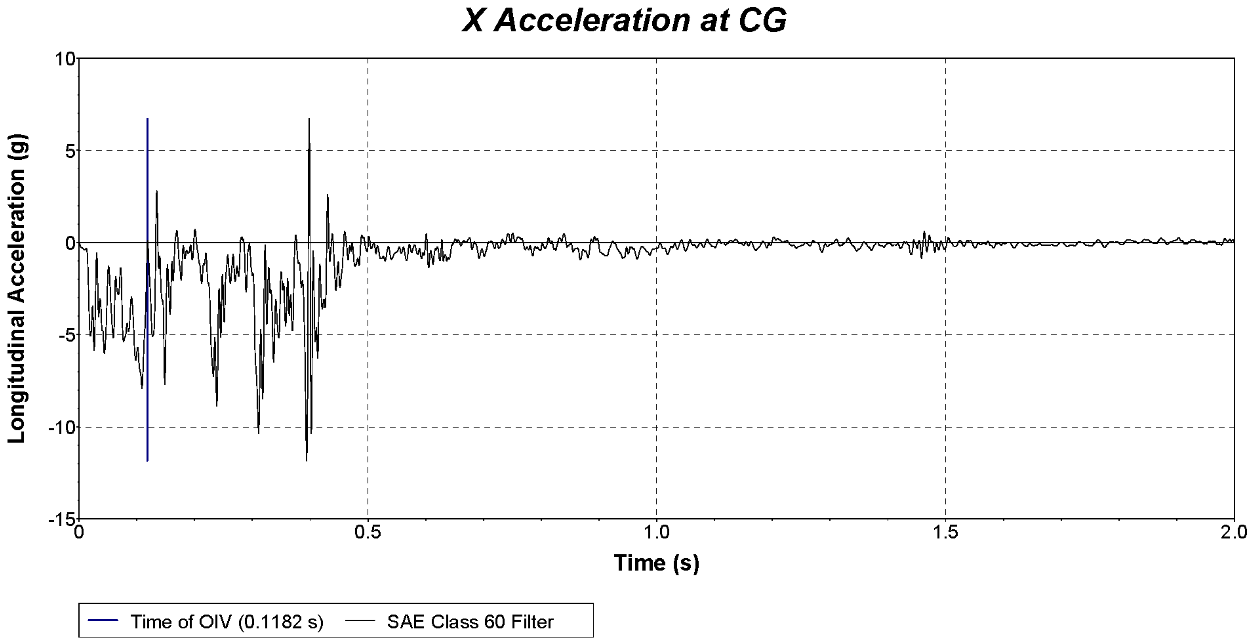


Figure C.8. Vehicle Longitudinal Accelerometer Trace for Test 617231-01-1 (Accelerometer Located at Center of Gravity).

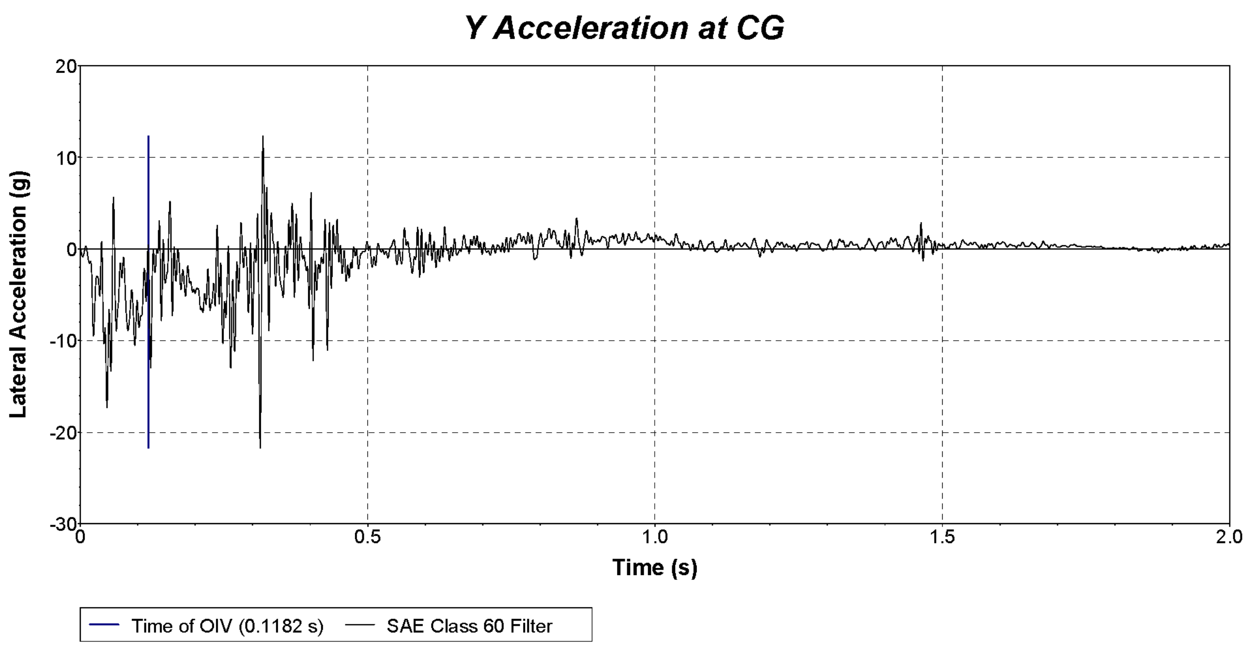


Figure C.9. Vehicle Lateral Accelerometer Trace for Test 617231-01-1 (Accelerometer Located at Center of Gravity).

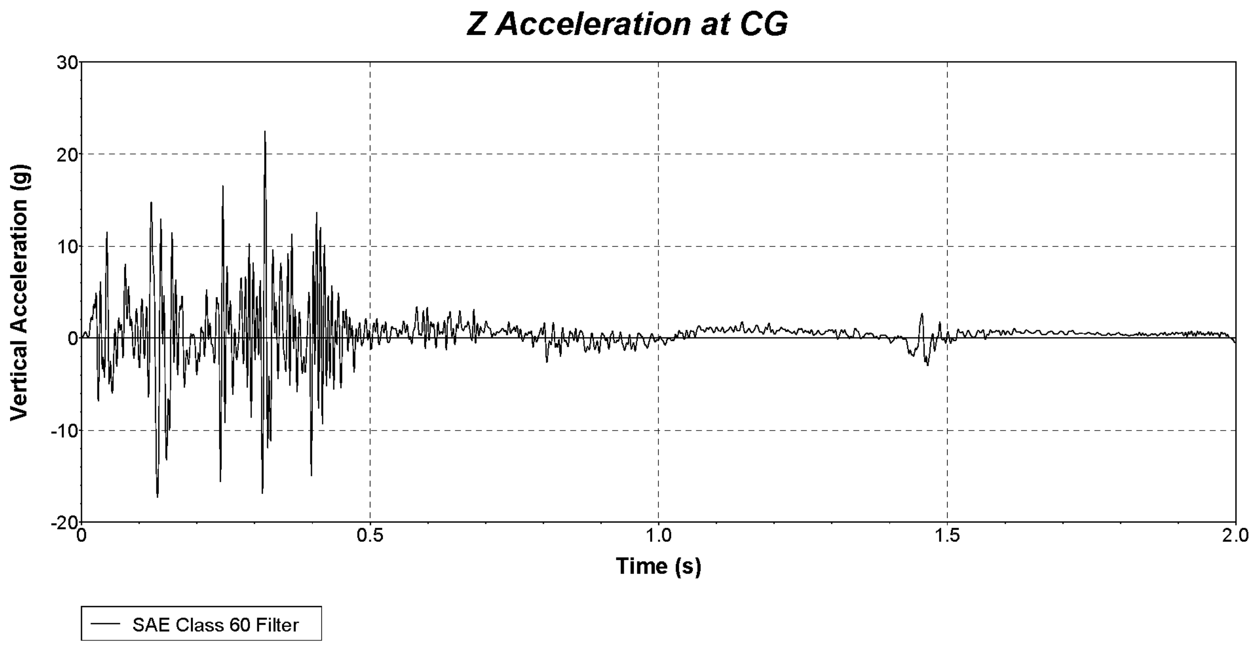


Figure C.10. Vehicle Vertical Accelerometer Trace for Test 617231-01-1 (Accelerometer Located at Center of Gravity).

APPENDIX D. *MASH* TEST 3-11 (CRASH TEST 617231-01-2)

D.1. VEHICLE PROPERTIES AND INFORMATION

Date: 2023-02-23 Test No.: 617231-01-2 VIN No.: 1C6RR6FT5HS542672

Year: 2017 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 155665

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

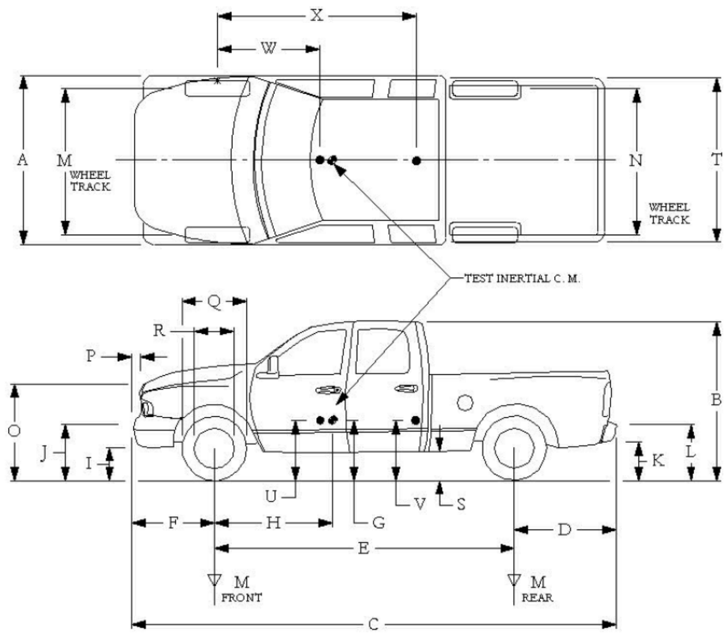
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

Dummy Data:
Type: 50th Percentile Male
Mass: lb
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	60.90	M	68.50	R	18.00	W	60.90
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}	2964	2857	2857
Back	3900	M_{rear}	2085	2186	2186
Total	6700	M_{Total}	5049	5043	5043

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

Mass Distribution:
lb LF: 1426 RF: 1431 LR: 1113 RR: 1073

Figure D.1. Vehicle Properties for Test 617231-01-2.

Date:	2023-02-23	Test No.:	617231-01-2	VIN No.:	1C6RR6FT5HS542672
Year:	2017	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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	14	12	60							9
2	SAME	14	10	56							72
	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.

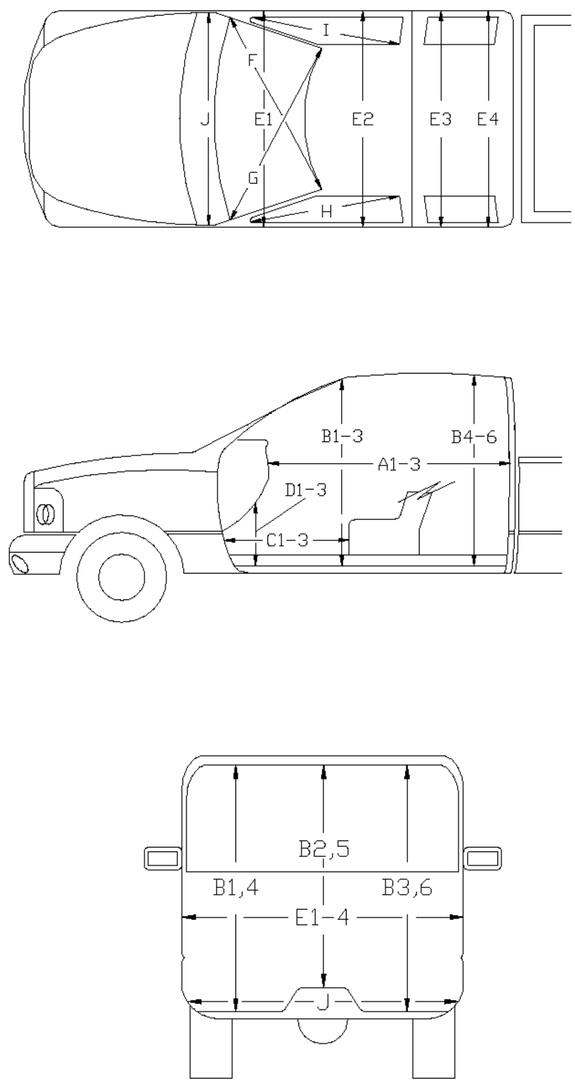
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 617231-01-2.

Date:	2023-02-23	Test No.:	617231-01-2	VIN No.:	1C6RR6FT5HS542672
Year:	2017	Make:	RAM	Model:	1500



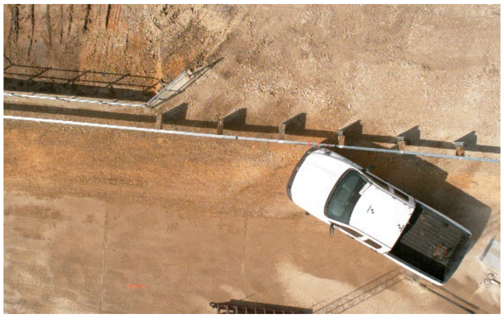
*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

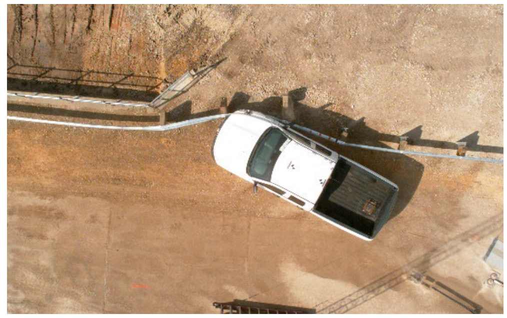
OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

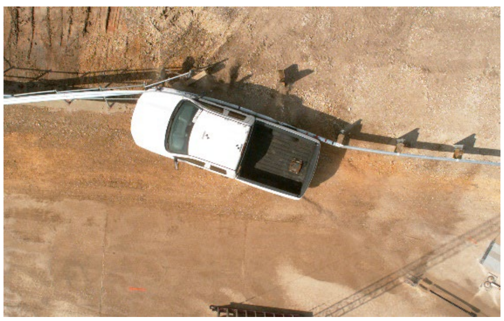
	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	26.00	0.00
D1	11.00	11.00	0.00
D2	0.00	0.00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

Figure D.3. Occupant Compartment Measurements for Test 617231-01-2.

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 617231-01-2 (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 617231-01-2 (Frontal Views).

(a) 0.000 s

(b) 0.100 s

(c) 0.200 s

(d) 0.300 s

(e) 0.400 s

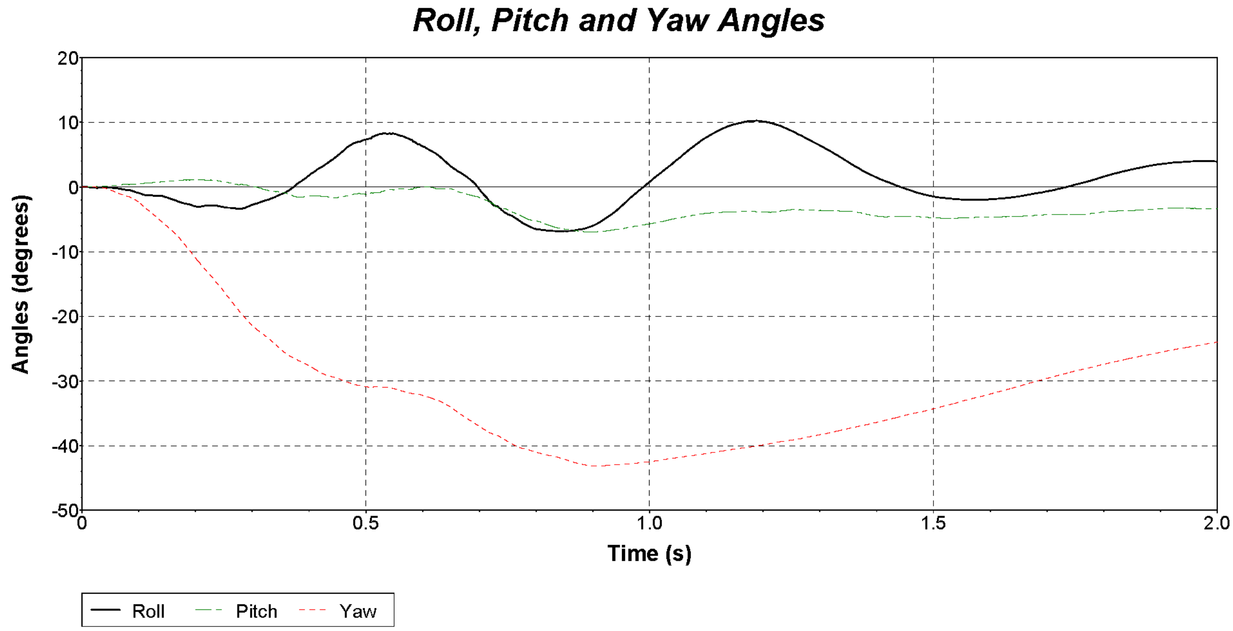
(f) 0.500 s

(g) 0.600 s

(h) 0.700 s

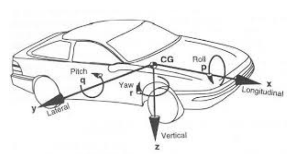
Figure D.6. Sequential Photographs for Test 617231-01-2 (Rear Views).

D.3. VEHICLE ANGULAR DISPLACEMENTS



Axes are vehicle-fixed.
Sequence for
determining orientation:

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



Test Number: 617231-01-2
Test Standard Test Number: *MASH* Test 3-11
Test Article: Long-Span Guardrail
Test Vehicle: 2017 RAM 1500
Inertial Mass: 5043 lbs
Gross Mass: 5043 lbs
Impact Speed: 62.2 mi/h
Impact Angle: 24.9 °

Figure D.7. Vehicle Angular Displacements for Test 617231-01-2.

D.4. VEHICLE ACCELERATIONS

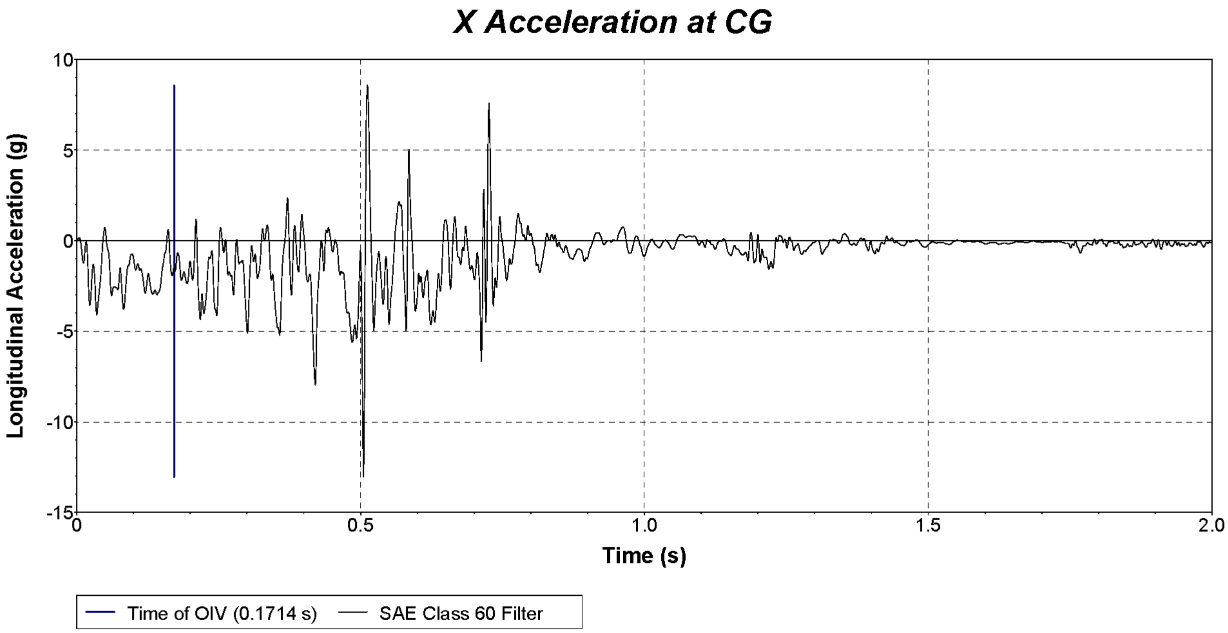


Figure D.8. Vehicle Longitudinal Accelerometer Trace for Test 617231-01-2 (Accelerometer Located at Center of Gravity).

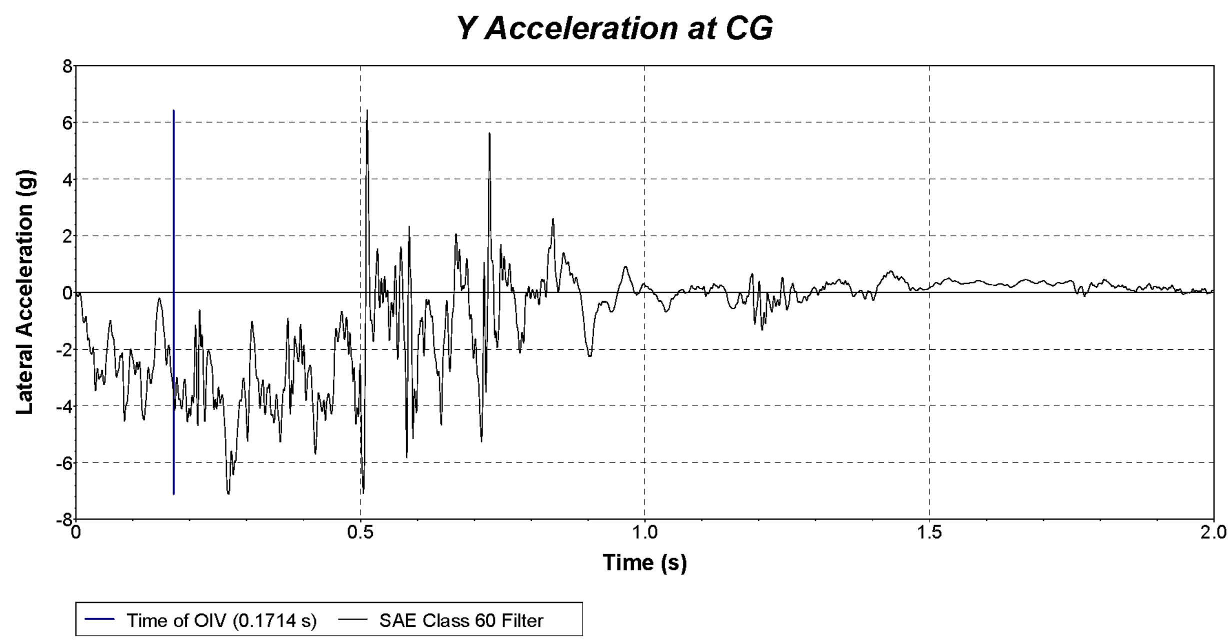


Figure D.9. Vehicle Lateral Accelerometer Trace for Test 617231-01-2 (Accelerometer Located at Center of Gravity).

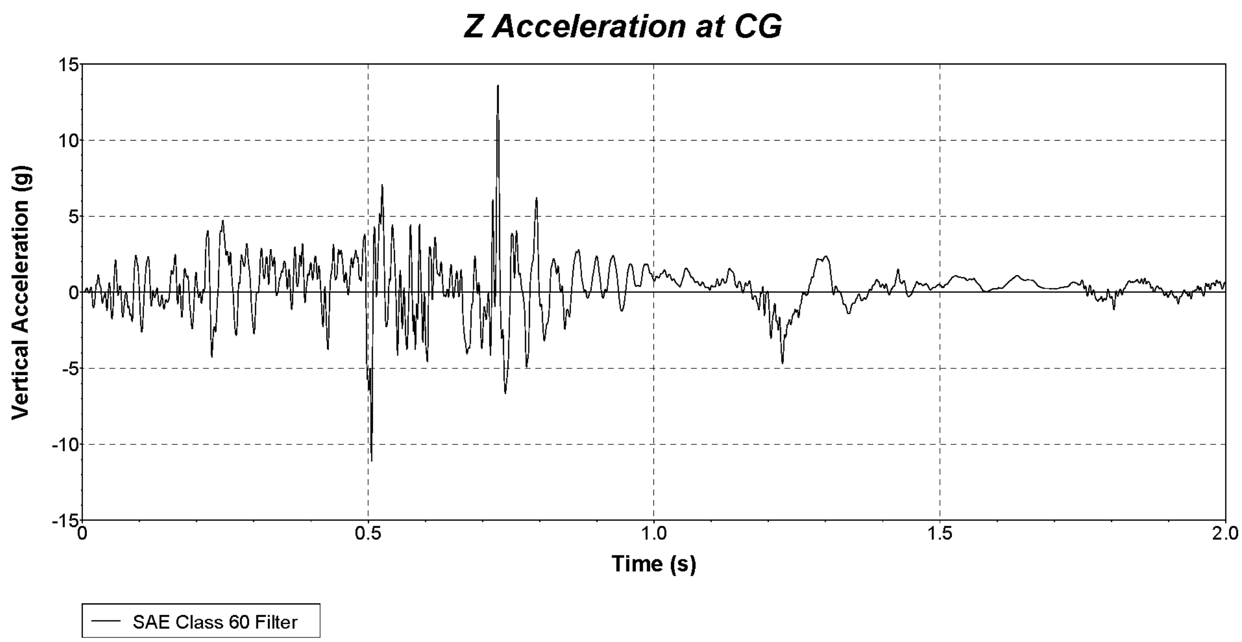


Figure D.10. Vehicle Vertical Accelerometer Trace for Test 617231-01-2 (Accelerometer Located at Center of Gravity).