TTI: 0-6968

Texas A&M Transportation Institute

MASH TEST 3-11 EVALUATION OF TxDOT W-BEAM GUARDRAIL WITH 7½-INCH DIAMETER ROUND WOOD POSTS IN CONCRETE MOW STRIP

ACCREDITED
ISO 17025 Laboratory
Testing Certificate # 2821.01

Crash testing performed at:
TTI Proving Ground
3100 SH 47, Building 7091
Bryan, TX 77807

Test Report 0-6968-R2

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE

COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
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16. Abstract

The purpose of the testing reported herein was to assess the performance of the Texas Department of Transportation (TxDOT) W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip according to the safety-performance evaluation guidelines included in the American Association of Safety Highway and Transportation Officials *Manual for Assessing Safety Hardware* (*MASH*) for Test Level Three (TL-3) longitudinal barriers. The crash test performed was in accordance with *MASH* Test 3-11, which involves a 2270P vehicle impacting the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip at a target impact speed and impact angle of 62 mi/h and 25°, respectively.

The TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip performed acceptably for *MASH* Test 3-11.

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer in charge of the project was Roger P. Bligh, Ph.D., P.E., TX #78550.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

TTI PROVING GROUND DISCLAIMER

The results of the crash testing reported herein apply only to the article tested.

REPORT AUTHORIZATION

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SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	Square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lb/in^2

*SI is the symbol for the International System of Units

CHAPTER 1: INTRODUCTION

1.1 PROBLEM

In July 2018, the Texas Department of Transportation (TxDOT) Round Wood Post Guardrail System in soil with 36-inch embedment performed acceptably in the *Manual for Assessing Safety Hardware* (*MASH*) Test 3-11 (*1*, *2*). This system was then evaluated in a concrete mow strip application and did not perform acceptably in *MASH* Test 3-11 (*3*). Following the failed test, dynamic bogie impact tests were performed to evaluate different post alternatives (*4*). Based on the dynamic bogie impact tests, a 7½-inch diameter post was selected for testing.

1.2 OBJECTIVE/SCOPE OF RESEARCH

The purpose of the testing reported herein was to assess the performance of the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO) *MASH* for Test Level Three (TL-3) longitudinal barriers. The crash test was performed in accordance with *MASH* Test 3-11, which involves a 2270P vehicle impacting the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip at a target impact speed and impact angle of 62 mi/h and 25°, respectively.

CHAPTER 2:
SYSTEM DETAILS

2.1 TEST ARTICLE AND INSTALLATION DETAILS

The TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip had a total length of 181 ft-3 inches. This consisted of 162 ft-6 inches of 12-gauge W-beam guardrail attached to 7½ inch diameter wood posts with a TxDOT downstream anchor terminal (DAT) [GF (31) DAT-14] on each end. The top of the rail was located 31 inches above grade, the posts were spaced 75 inches center-to-center, and the guardrail splices were located mid-span between every other post. Standard 12-gauge W-beam guardrail (type RWM04a) was used in the system. Each TxDOT GF (31) DAT-14 terminal was 9 ft-4½ inches long as measured from their anchor posts to the W-beam splice between posts 2 and 3 and posts 28 and 29, respectively.

Guardrail posts 3 through 28 were 6 ft long (including a rounded top) round wood guardrail line posts. The posts were installed 36 inches deep in drilled holes, using 18-inch long guardrail bolts, USS flat washers, and recessed guardrail nuts. The holes were backfilled and compacted with soil meeting Grading B of AASHTO standard specification M147-65(2004) “Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses.” The modified round wood posts nominally measured 14 inches tall × 6 inches wide × 8 inches deep, including a routered 3¾-inch radius on the post side.

Guardrail posts 8 through 23 were placed in 19-inch square voids (leaveouts) cast into the 4-inch thick × 42-inch wide × 100-ft long concrete mow strip. The soil backfill at these post locations stopped at the bottom of the mow strip. The top 4 inches (inside the voids) was filled with low strength grout after the posts were installed.

Figure 2.1 presents overall information on the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip, and Figure 2.2 provides photographs of the installation. Appendix A provides further details of the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip.

2.2 DESIGN MODIFICATIONS DURING TESTS

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

2.3 MATERIAL SPECIFICATIONS

The specified concrete strength for the mow strip for this test was 2000 psi. Concrete strength measured 3040 psi on 2017-10-09 at 17 days of age.

The low-strength grout mix used in the leave-outs was comprised of 188 lb of Type I or II cement, 2719 lb of sand, and 550 lb of water per cubic yard of grout. Grout compressive strength measured 230 psi on 2019-08-16 (on the day of the test) at 21 days of age.

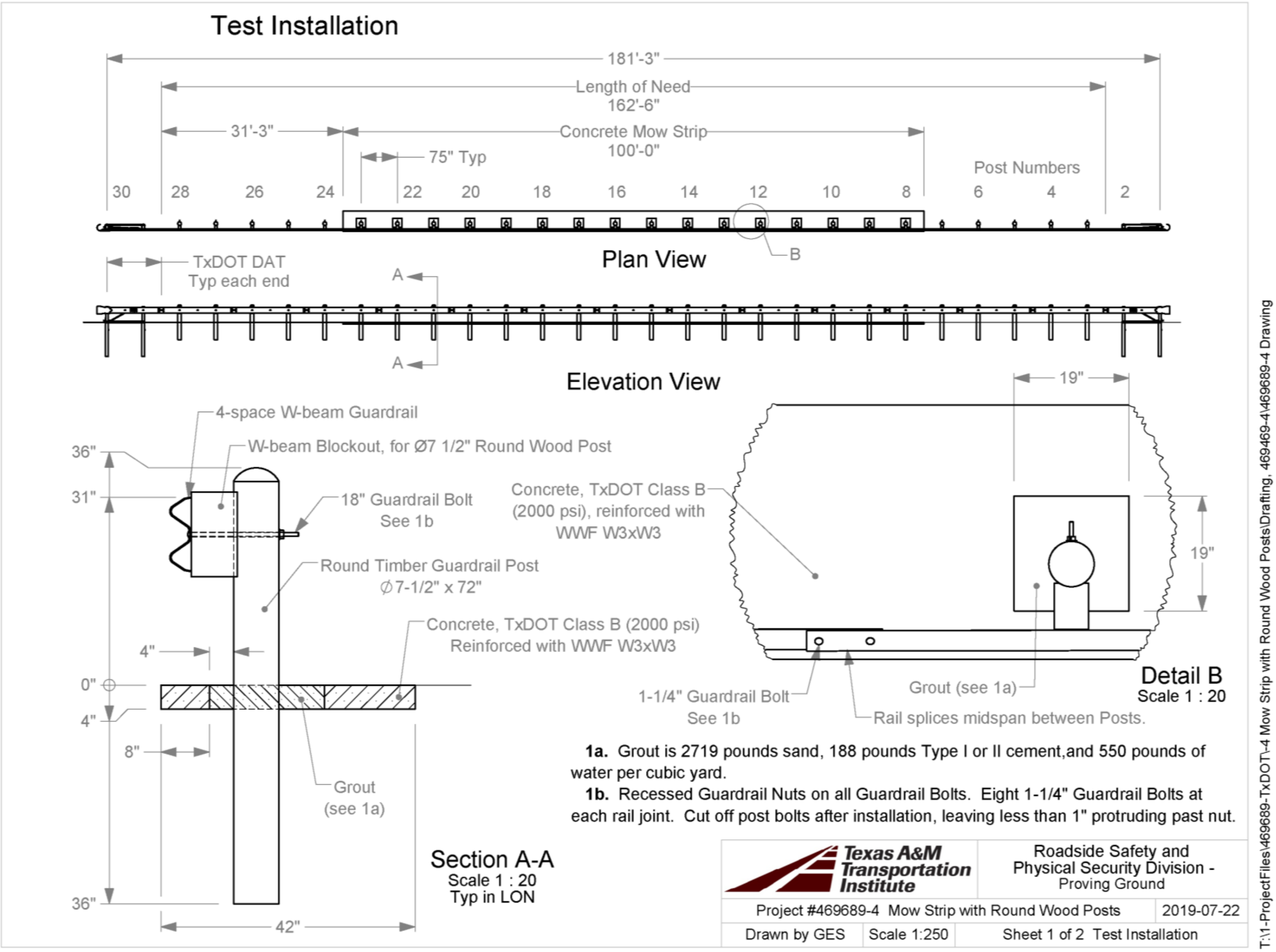


Figure 2.1. Overall Details of TxDOT W-Beam Guardrail with 7½-Inch Diameter Round Wood Posts in Concrete Mow Strip.

Figure 2.2. TxDOT W-Beam Guardrail with 7½-inch Diameter Round Wood Posts in Concrete Mow Strip prior to Testing.

Appendix A.2 provides material certification documents for the materials used to install/construct the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip.

2.4 SOIL CONDITIONS

The test installation was installed in standard soil meeting AASHTO standard specifications for “Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses,” designated M147-65(2004), grading B.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip for full-scale crash testing, two standard W6×16 posts were installed in the immediate vicinity of the installation, using the same fill materials and installation procedures used in the standard dynamic test performed (see Table C.1 in Appendix C for establishment minimum soil strength properties in the dynamic test performed in accordance with *MASH* Appendix B).

As determined in the tests shown in Appendix C, Table C.1, the minimum post load required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, is 3940 lb, 5500 lb, and 6540 lb, respectively (90 percent of static load for the initial standard installation). On the day of the test, August 16, 2019, load on the post at deflections of 5 inches, 10 inches, and 15 inches was 11,290 lbf, 11,428 lbf, and 11,049 lbf, respectively. In Appendix C, Table C.2 shows the strength of the backfill material in which the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip was installed met minimum requirements.

CHAPTER 3: TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 CRASH TEST MATRIX

Table 3.1 shows the test conditions and evaluation criteria for *MASH* TL-3 for longitudinal barriers. *MASH* Test 3-11 involves a 2270P vehicle weighing 5000 lb ±110 lb and impacting the critical impact point (CIP) of the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The target CIP, shown in Figure 3.1, was determined using the information provided in *MASH* Section 2.2.1, Section 2.3.2, and Figure 2-1. The target CIP was 11.75 ft upstream of the center of post 15 (equivalent to 9 inches downstream of the center of post 13).

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

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

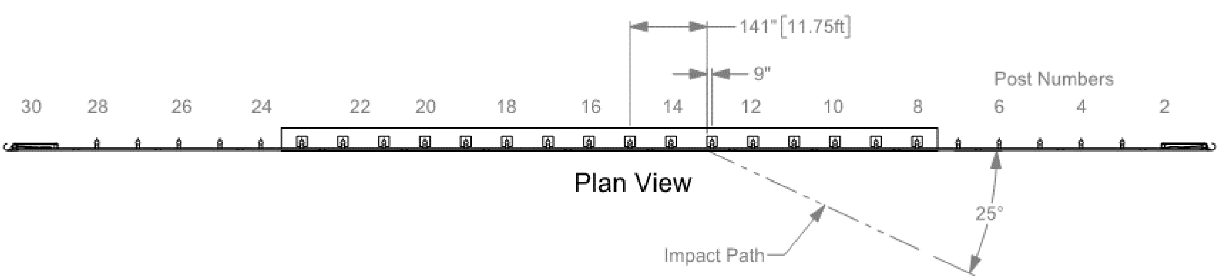


Figure 3.1. Target CIP for *MASH* Test 3-11 on the TxDOT W-Beam Guardrail with 7½-inch Diameter Round Wood Posts in Concrete Mow Strip.

MASH Test 3-10 was not performed on the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip. However, *MASH* Test 3-10 was successfully performed on the guardrail in concrete mow strip with both W6×8.5 steel posts and 6-inch × 8-inch rectangular wood posts (*5*). The geometries of the steel and rectangular wood posts are considered more critical in terms of vehicle snagging and deceleration compared to the round wood post. Therefore, since both the steel and rectangular wood posts in concrete mow strip meet *MASH* Test 3-10 criteria, this test was not performed on the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip.

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

3.2 EVALUATION CRITERIA

The appropriate safety evaluation criteria from Tables 2-2 and 5-1 of *MASH* were used to evaluate the crash test(s) reported herein. The test conditions and evaluation criteria required for *MASH* Test 3-11 are listed in Table 3.1, and the substance of the evaluation criteria in Table 3.2. An evaluation of the crash test results is presented in detail under the section Assessment of Test Results.

Table 3.2. Evaluation Criteria Required for *MASH* Test 3-11.

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

CHAPTER 4:
TEST CONDITIONS

4.1 TEST FACILITY

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

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

4.2 VEHICLE TOW AND GUIDANCE SYSTEM

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

4.3 DATA ACQUISITION SYSTEMS

4.3.1 Vehicle Instrumentation and Data Processing

The test vehicle was instrumented with a self-contained, on-board data acquisition system. The signal conditioning and acquisition system is a 16-channel, Tiny Data Acquisition System (TDAS) Pro produced by Diversified Technical Systems, Inc. The accelerometers, which measure the x, y, and z axis of vehicle acceleration, are strain gauge type with linear millivolt output proportional to acceleration. Angular rate sensors, measuring vehicle roll, pitch, and yaw rates, are ultra-small, solid state units designed for crash test service. The TDAS Pro hardware and software conform to the latest SAE J211, Instrumentation for Impact Test. Each of the 16 channels is capable of providing precision amplification, scaling, and filtering based on transducer specifications and calibrations. During the test, data are recorded from each channel at a rate of 10,000 values per second with a resolution of one part in 65,536. Once data are recorded, internal batteries back these up inside the unit should the primary battery cable be severed. Initial contact of the pressure switch on the vehicle bumper provides a time zero mark and initiates the recording process. After each test, the data are downloaded from the TDAS Pro unit into a laptop computer at the test site. The Test Risk Assessment Program (TRAP) software then processes the raw data to produce detailed reports of the test results.

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

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

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

4.3.2 Anthropomorphic Dummy Instrumentation

According to *MASH*, use of a dummy in the 2270P vehicle is optional, and no dummy was used in the test.

4.3.3 Photographic Instrumentation and Data Processing

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

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

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the installation. 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 5:
MASH TEST 3-11 (CRASH TEST NO. 469689-4-1)

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-11 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the CIP of the test article at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The CIP for *MASH* Test 3-11 on the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip was 11.75 ft ±1 ft upstream of the center of post 15 (equivalent to 9 inches ±1 ft downstream of the center of post 13).

The 2013 RAM 1500 pickup truck used in the test weighed 5017 lb, and the actual impact speed and angle were 63.7 mi/h and 25.1°. The actual impact point was 9 inches downstream of the center of post 13. Minimum target impact severity (IS) was 106 kip-ft, and actual IS was 123 kip-ft.

5.2 WEATHER CONDITIONS

The test was performed on the morning of August 16, 2019. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 254° (vehicle was traveling at magnetic heading of 205°); temperature: 90°F; relative humidity: 70 percent.

5.3 TEST VEHICLE

Figures 5.1 and 5.2 show the 2013 RAM 1500 pickup truck used for the crash test. The vehicle's test inertia weight was 5017 lb, and its gross static weight was 5017 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 28.0 inches. Tables D.1 and D.2 in Appendix D1 give additional dimensions and information on the vehicle. It was directed into the installation using the cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

Figure 5.1. Test Installation/Test Vehicle Geometrics for Test No. 469689-4-1.

Figure 5.2. Test Vehicle before Test No. 469689-4-1.

5.4 TEST DESCRIPTION

The test vehicle was traveling at an impact speed of 63.7 mi/h when it contacted TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip 9 inches downstream of the center of post 13 at an impact angle of 25.1°. Table 5.1 lists events that occurred during Test No. 469689-4-1. Figures D.1 and D.2 in Appendix D2 present sequential photographs during the test.

Table 5.1. Events during Test No. 469689-4-1.

TIME (s)	EVENTS
0.0000	Vehicle contacts guardrail
0.0030	Post 13 begins to rotate clockwise and deflect toward field side
0.0120	Post 14 begins to rotate counterclockwise and deflect toward field side
0.0340	Vehicle begins to redirect
0.0460	Post 15 begins to rotate counterclockwise and deflect toward field side
0.0820	Front right tire begins to run over broken post 14
0.1900	Right rear corner of vehicle contacts rail
0.2690	Vehicle traveling parallel with original rail position
0.5660	Right rear corner of vehicle contacts post 15; the vehicle began to yaw clockwise
0.5950	Vehicle loses contact with guardrail while traveling at 26.7 mi/h, with a trajectory of 19.5° and a heading of 15.6°

It is desirable that the vehicle redirects and exits longitudinal barriers within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The test vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the barrier, the vehicle came to rest 56 ft downstream of the impact and 11.7 ft toward traffic lanes.

5.5 DAMAGE TO TEST INSTALLATION

Figures 5.3 and 5.4 show the damage to the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip. The rail released from posts 1 through 16, and 18. There was a ¾-inch gap in the soil on the upstream side of post 1, and ½-inch gaps on the downstream side of posts 1 and 2. The blockouts rotated clockwise at posts 3 through 11. The blockout rotated clockwise and cracked at post 12. Post 13 had 1½-inch gaps in the grout on the traffic side and ½-inch on the field side, and it was leaning toward the field side at 86°. Post 14 broke off at grade, and the grout cracked near the post. Post 15 also broke off at grade, and had a 2½-inch gap in the grout on the traffic and field sides. Post 16 fractured and broke off at 6 inches above grade, and had a 2-inch gap in the grout on the traffic side and a 4-inch gap on the field side. There was a 1-inch gap in the grout on the traffic side and a 2-inch gap on the field side of post 17, it was leaning back at 83°, and the blockout was broken and detached. There was no apparent damage or post movement from posts 19 through 30. Working width* was 50.9 inches, and height of working width was 54.4 inches. Maximum dynamic deflection during the test was 43.4 inches.

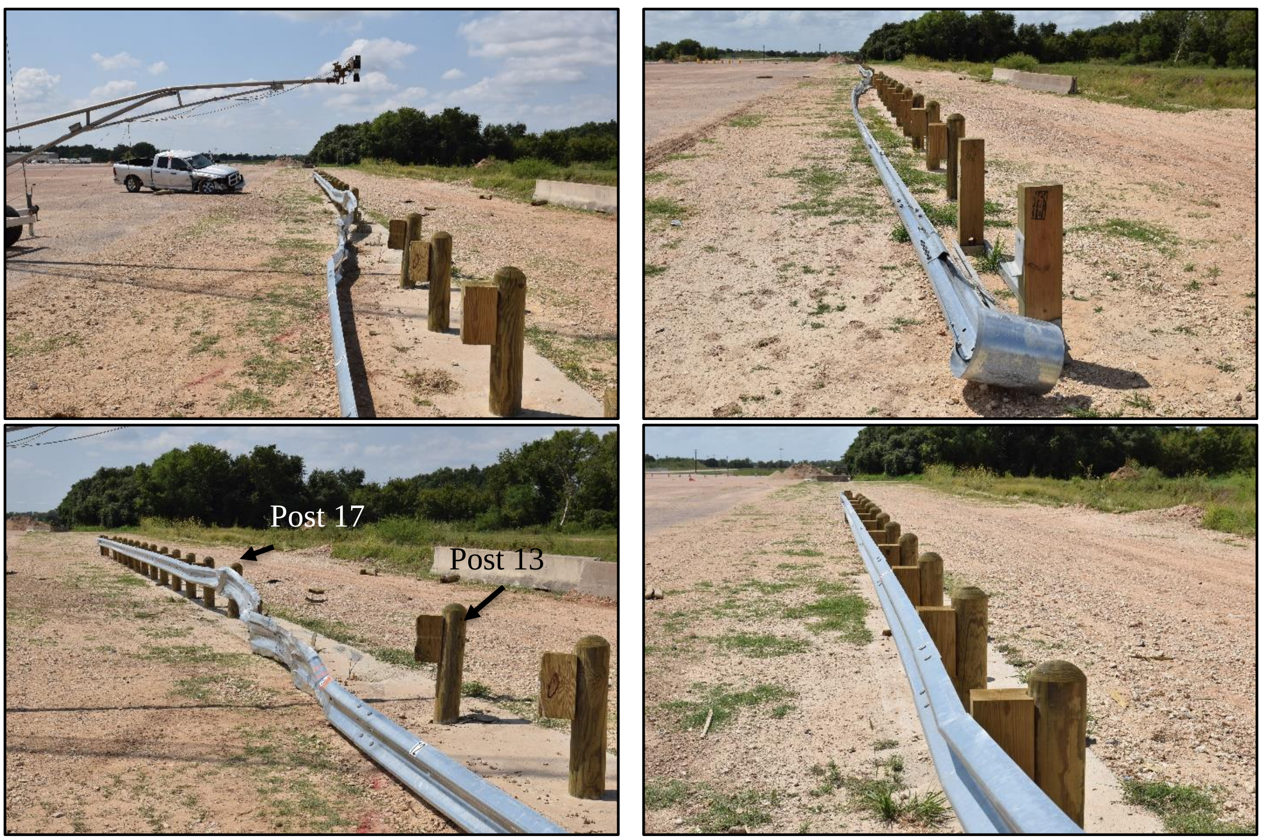


Figure 5.3. TxDOT W-Beam Guardrail with 7½-inch Diameter Round Wood Posts in Concrete Mow Strip after Test No. 469689-4-1.

* Working width is defined as the distance between the traffic face of the barrier before impact and the maximum lateral position of any major part of the barrier or the vehicle after impact.

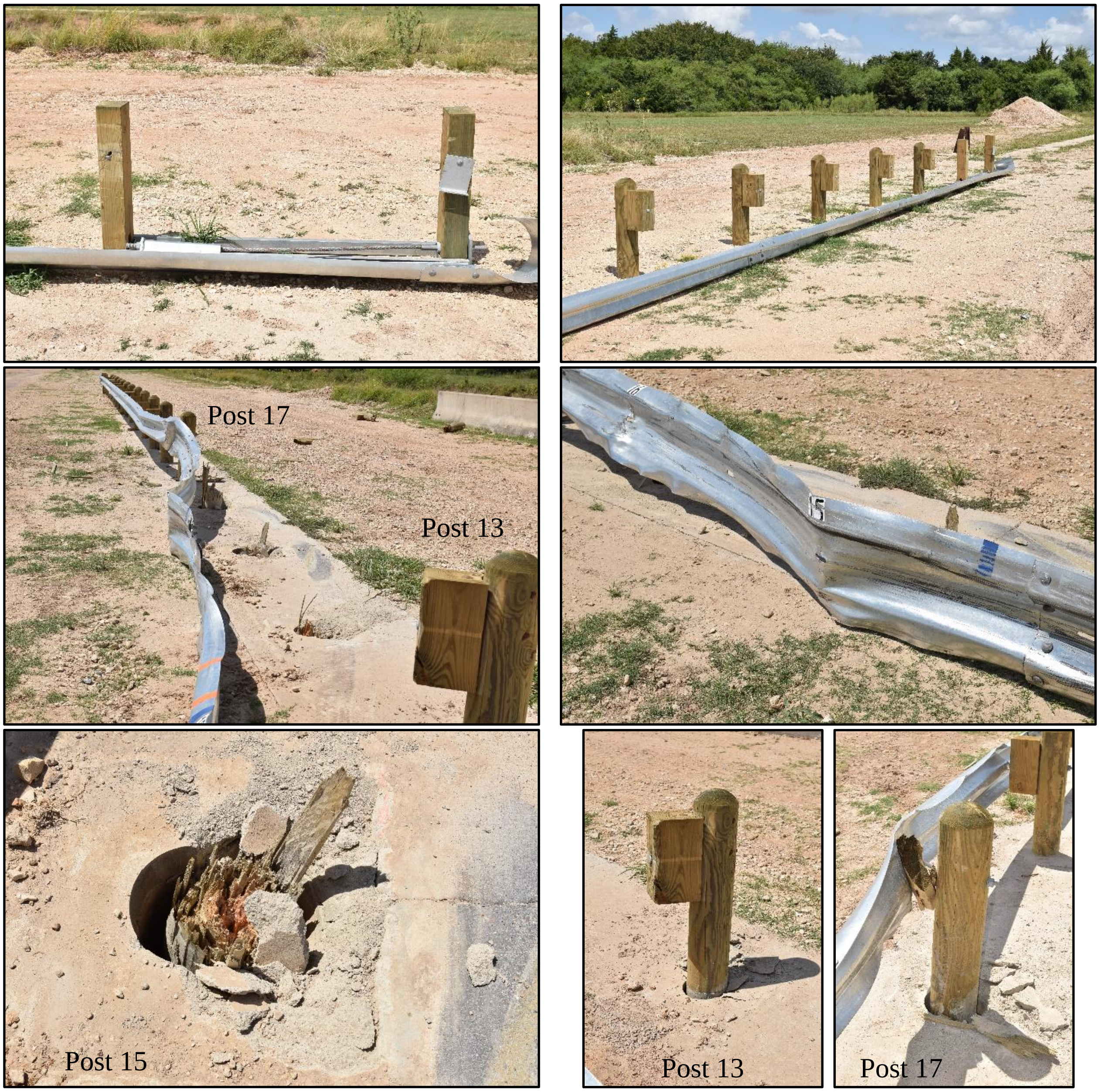


Figure 5.4. Damage to Installation after Test No. 469689-4-1.

5.6 DAMAGE TO TEST VEHICLE

Figure 5.5 shows the damage sustained by the vehicle. The front bumper, grill, radiator support, right front fender, right frame rail, right upper and lower A-arms, right front tire and rim, right front and rear doors, right cab corner, right rear exterior bed, right rear spring and trailing arm, and rear bumper were damaged. Maximum exterior crush to the vehicle was 10.0 inches in the front plane at the right front corner at bumper height. Maximum occupant compartment deformation was 1.5 inches in the right front floor pan. Figure 5.6 shows the interior of the vehicle. Tables D.3 and D.4 in Appendix D1 provide exterior crush and occupant compartment measurements.

Figure 5.5. Test Vehicle after Test No. 469689-4-1.

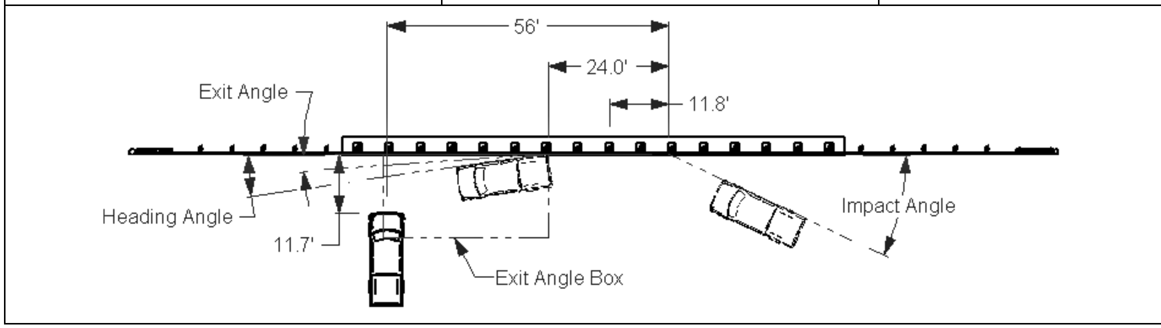
Figure 5.6. Interior of Test Vehicle after Test No. 469689-4-1.

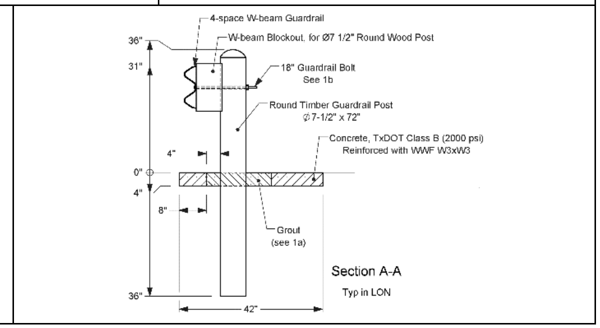
5.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and results are shown in Table 5.2. Figure 5.7 summarizes these data and other pertinent information from the test. Figure D.3 in Appendix D3 shows the vehicle angular displacements, and Figures D.4 through D.9 in Appendix D4 show acceleration versus time traces.

Table 5.2. Occupant Risk Factors for Test No. 469689-4-1.

Occupant Risk Factor	Value	Time
Occupant Impact Velocity (OIV)		
Longitudinal	**20.0 ft/s**	at 0.1485 s on right side of interior
Lateral	**15.7 ft/s**	
Ridedown Accelerations		
Longitudinal	**8.7 g**	0.5583–0.5683 s
Lateral	**8.4 g**	0.2642–0.2742 s
Theoretical Head Impact Velocity (THIV)	**27.8 km/h** **7.7 m/s**	at 0.1426 s on right side of interior
Post Head Deceleration (PHD)	**10.1 g**	0.5552–0.5652 s
Acceleration Severity Index (ASI)	**0.86**	0.1050–0.1550 s
Maximum 50-ms Moving Average		
Longitudinal	**−7.0 g**	0.0704–0.1204 s
Lateral	**−6.1 g**	0.2344–0.2844 s
Vertical	**−3.8 g**	1.8254–1.8754 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**19°**	0.8646 s
Pitch	**12°**	2.0000 s
Yaw	**58°**	2.0000 s





General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-11
TTI Test No.	469689-4-1
Test Date	2019-08-16

Test Article

Type	Longitudinal Barrier - Guardrail
Name	TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip
Installation Length	181 ft-3 inches w/100 ft mow strip incl.
Material or Key Elements	31-inch tall W-beam guardrail with 7½-inch diameter round wood posts at 6 ft-3 inch spacing embedded 36 in

Soil Type and Condition	4 inch thick concrete mow strip with grout-filled leaveouts. AASHTO M147-65(2004), grading B Soil (crushed limestone), Damp

Test Vehicle

Type/Designation	2270P
Make and Model	2013 RAM 1500 Pickup
Curb	4947 lb
Test Inertial	5017 lb
Dummy	No Dummy
Gross Static	5017 lb

Impact Conditions

Speed	63.7 mi/h
Angle	25.1°
Location/Orientation	11.75 ft upstrm of center of post 15

Impact Severity	123 kip-ft

Exit Conditions

Speed	26.7 mi/h
Trajectory/Heading Angle	19.5° / 15.6°

Occupant Risk Values

Longitudinal OIV	20.0 ft/s
Lateral OIV	15.7 ft/s
Longitudinal Ridedown	8.7 g
Lateral Ridedown	8.4 g
THIV	27.8 km/h
PHD	10.1 g
ASI	0.86
Max. 0.050-s Average	
Longitudinal	−7.0 g
Lateral	−6.1 g
Vertical	−3.8 g

Post-Impact Trajectory

Stopping Distance	56 ft downstream 11.7 ft twd traffic

Vehicle Stability

Maximum Yaw Angle	58°
Maximum Pitch Angle	12°
Maximum Roll Angle	19°
Vehicle Snagging	No
Vehicle Pocketing	No

Test Article Deflections

Dynamic	43.4 inches
Permanent	Rail released from downstream posts
Working Width	50.9 inches
Height of Working Width	54.4 inches

Vehicle Damage

VDS	01RFQ5
CDC	01FREW4
Max. Exterior Deformation	10.0 inches
OCDI	RF0010000
Max. Occupant Compartment Deformation	1.5 inches

Figure 5.7. Summary of Results for *MASH* Test 3-11 on TxDOT W-Beam Guardrail with 7½-inch Diameter Round Wood Posts in Concrete Mow Strip.

CHAPTER 6:
SUMMARY AND CONCLUSIONS

6.1 SUMMARY OF RESULTS

Table 6.1 provides an assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-11 on the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip. The installation contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the guardrail. Maximum dynamic deflection during the test was 43.4 inches, and working width was 50.9 inches. Three posts fractured at ground line but did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to others in the area. Maximum occupant compartment deformation was 1.5 inches in the right front floor pan. The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 19° and 12°, respectively. Occupant risk factors were within the preferred limits of *MASH*.

6.2 CONCLUSIONS

The TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip performed acceptably for *MASH* Test 3-11.

Table 6.1. Performance Evaluation Summary for *MASH* Test 3-11 on TxDOT W-Beam Guardrail with 7½-inch Diameter Round Wood Posts in Concrete Mow Strip.

Test Agency: Texas A&M Transportation Institute | Test No.: 469689-4-1 | Test Date: 2019-08-16

***MASH* Test Evaluation Criteria**	**Test Results**	**Assessment**
<u>Structural Adequacy</u> *A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the guardrail. Maximum dynamic deflection during the test was 43.4 inches.	Pass
<u>Occupant Risk</u> *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	Three posts fractured at ground line but did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	Maximum occupant compartment deformation was 1.5 inches in the right front floor pan.	
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 2270P vehicle remained upright during and after the collision event. Maximum roll and pitch angles were 19° and 12°, respectively.	Pass
H. Longitudinal and lateral occupant impact velocities should fall below the preferred value of 30 ft/s, or at least below the maximum allowable value of 40 ft/s.	Longitudinal OIV was 20.0 ft/s, and lateral OIV was 15.7 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 Gs, or at least below the maximum allowable value of 20.49 Gs.	Maximum longitudinal occupant ridedown acceleration was 8.7 g, and maximum lateral occupant ridedown was 8.4 g.	Pass

CHAPTER 7: IMPLEMENTATION*

The testing and evaluation reported herein shows the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip successfully met all requirements for *MASH* Test 3-11, which primarily evaluates the strength of the guardrail system and stability of the 2270P vehicle. The other test considered under *MASH* TL-3, *MASH* Test 3-10, primarily evaluates occupant risk.

MASH Test 3-10 was not performed on the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip. However, *MASH* Test 3-10 was successfully performed on guardrail in concrete mow strip with both W6×8.5 steel posts and 6-inch × 8-inch rectangular wood posts (*5*). The geometries of the steel and rectangular wood posts are considered more critical in terms of vehicle snagging and deceleration compared to the round wood post. Therefore, since both the steel and rectangular wood posts in concrete mow strip meet *MASH* Test 3-10, this test was not considered necessary for the evaluation of the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip.

Based on the results of the testing and evaluation reported herein, the TxDOT W-beam guardrail with 7½-inch diameter round wood posts in concrete mow strip is considered suitable for implementation as a *MASH* TL-3 longitudinal barrier. The guardrail system had a dynamic deflection of 43.4 inches for the pickup truck impact.

Statewide implementation of this barrier can be achieved by TxDOT's Design Division through the development and issuance of a revised standard detail sheet. The guardrail details provided in Appendix A can be used for this purpose.

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

REFERENCES

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

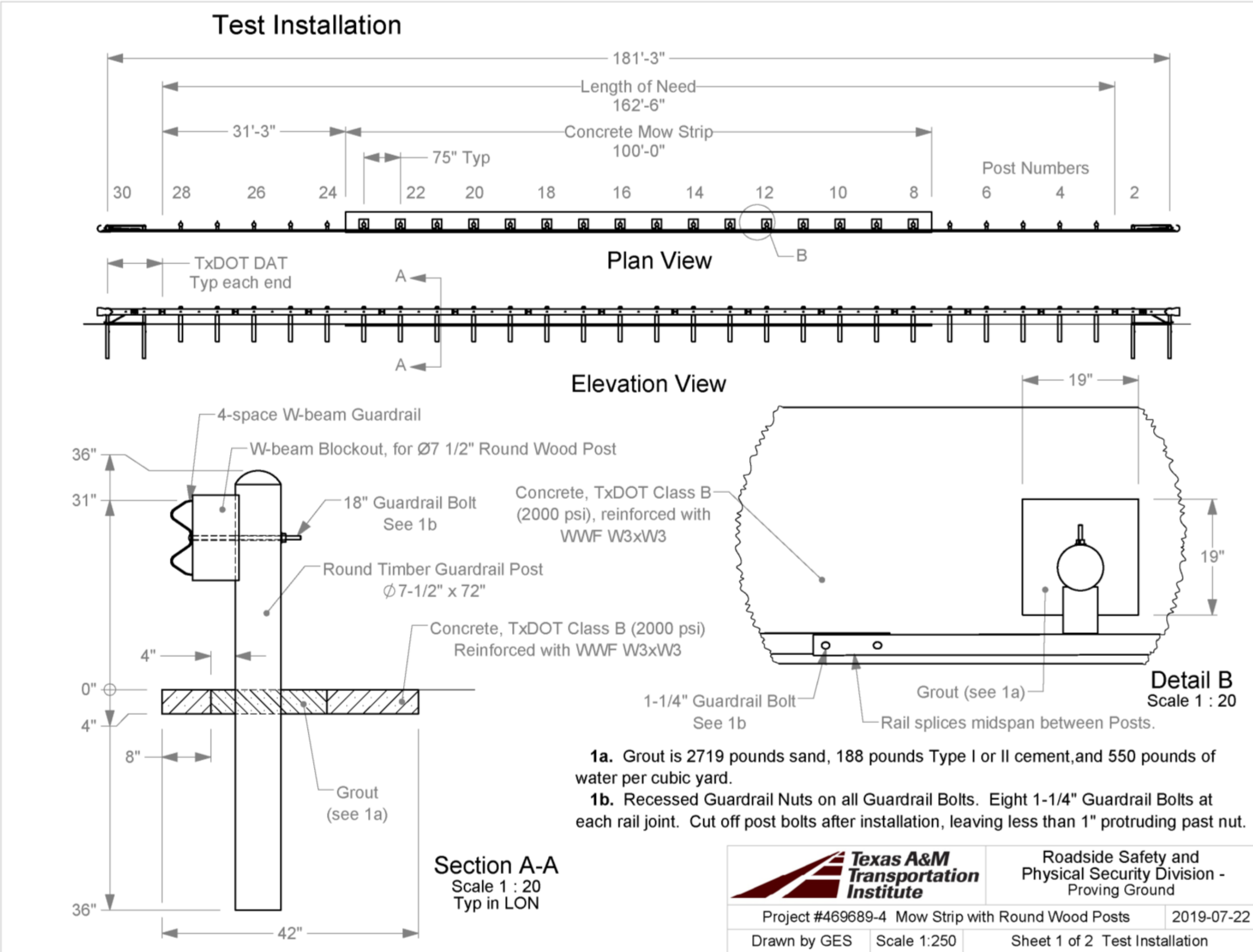
2. James C. Kovar, Roger P. Bligh, Bill L. Griffith, Darrell L. Kuhn, and Glenn E. Schroeder, *MASH Test 3-11 Evaluation of Modified TxDOT Round Wood Post Guardrail System*. Test Report No. 0-6968-R4, Texas A&M Transportation Institute, College Station, Tx, June 2019.

3. Roger P. Bligh, Bill L. Griffith, Glenn E. Schroeder, and Darrell L. Kuhn, MASH *Evaluation of TxDOT Roadside Safety Features – Phase III*. Test Report No. 0-6946-R3 (Test No. 469469-11), Texas A&M Transportation Institute, College Station, Tx, not yet published.

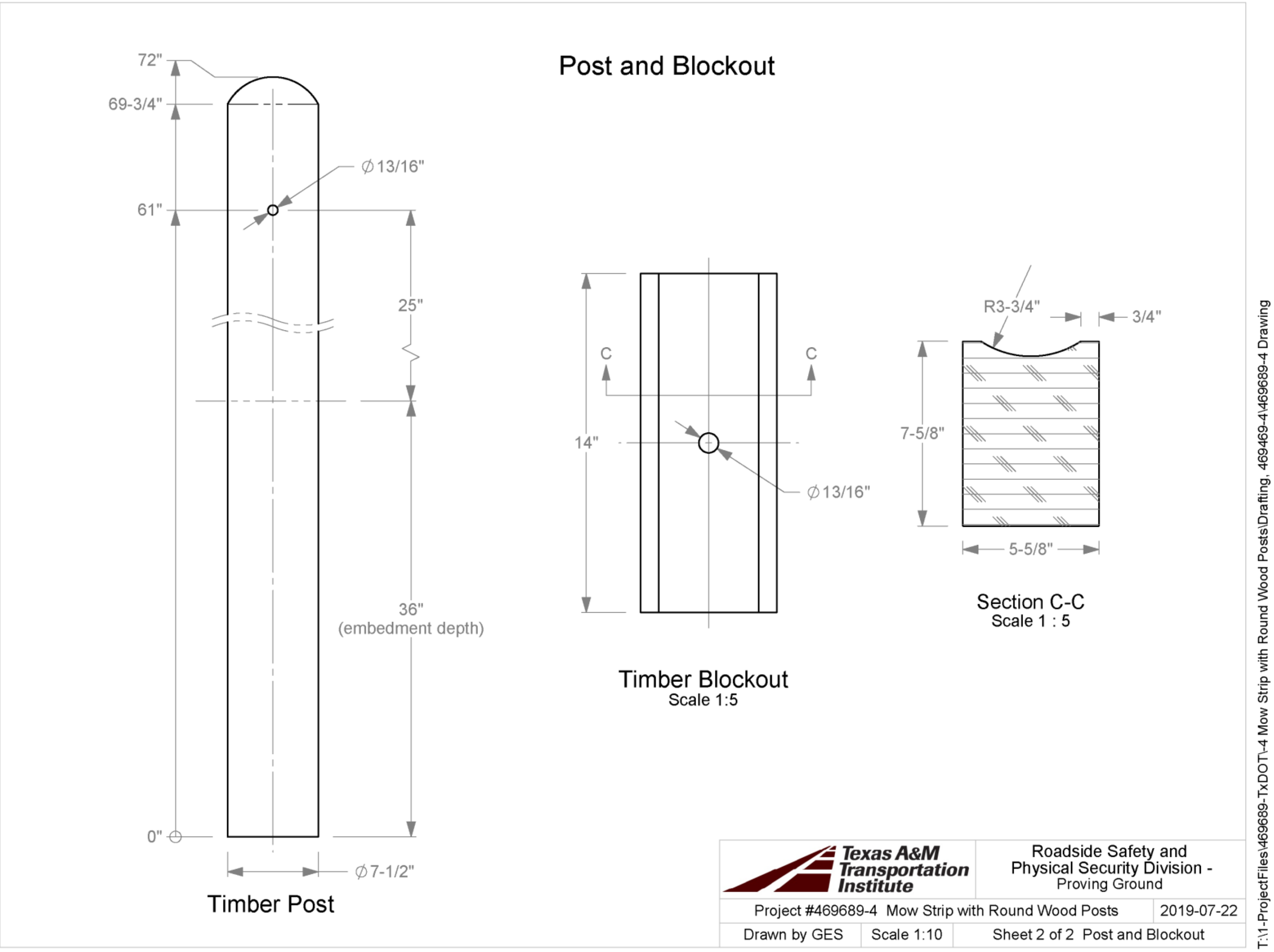
4. Sana M. Moran and Wanda L. Menges, *Various Round Wood Posts in Mow Strip*. Technical Memo No. 690900-AFP B1-B4-B5-B6, Texas A&M Transportation Institute, College Station, TX, August 2019.

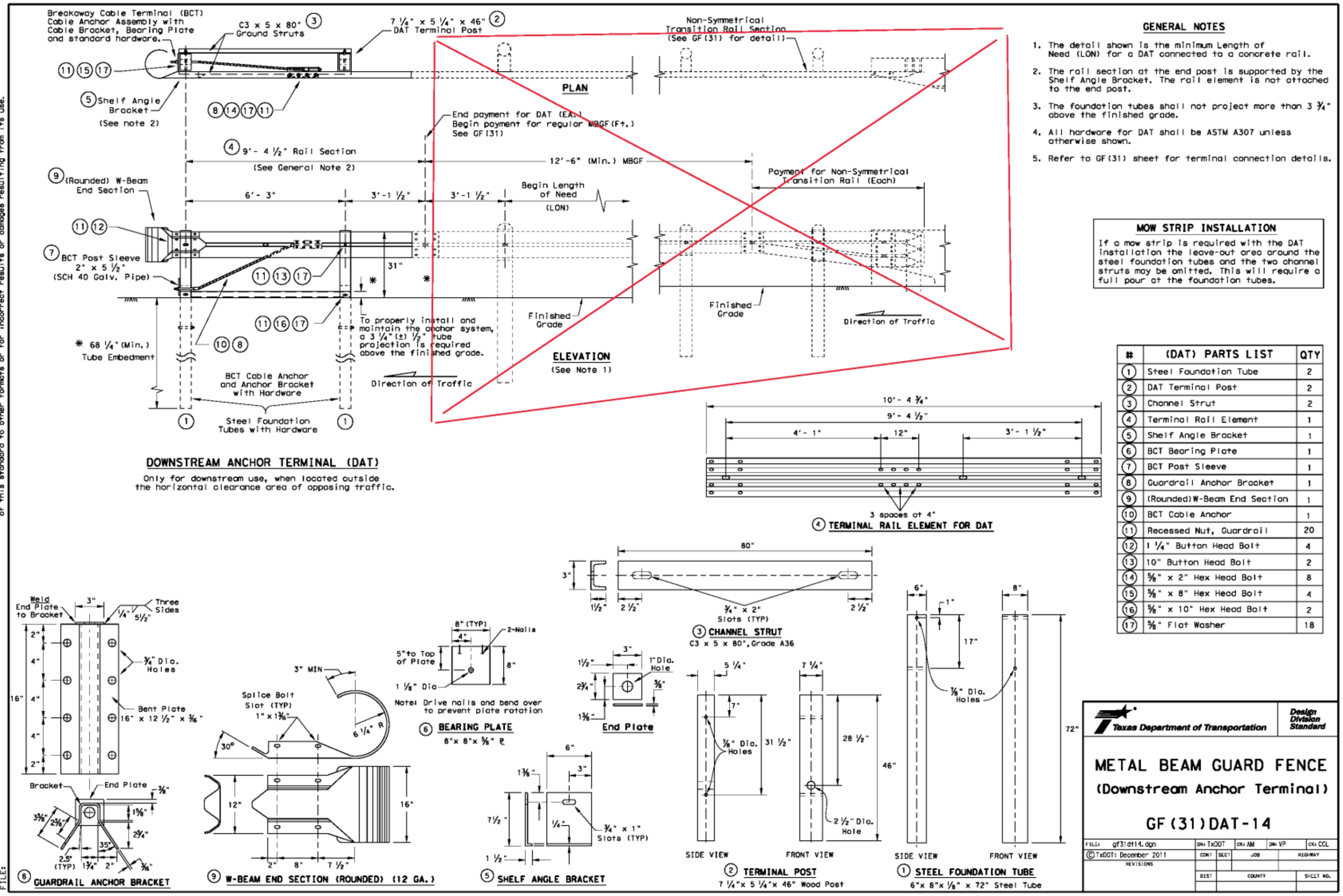
5. Nauman M. Sheikh, Wanda L. Menges, and Darrell L. Kuhn. *MASH TL-3 Evaluation of 31-inch W-Beam Guardrail with Wood and Steel Posts in Concrete Mow Strip*. Test Report No. 608551-1-4, Texas A&M Transportation Institute, College Station, Tx, April 2019.

APPENDIX A. DETAILS OF TEST INSTALLATION

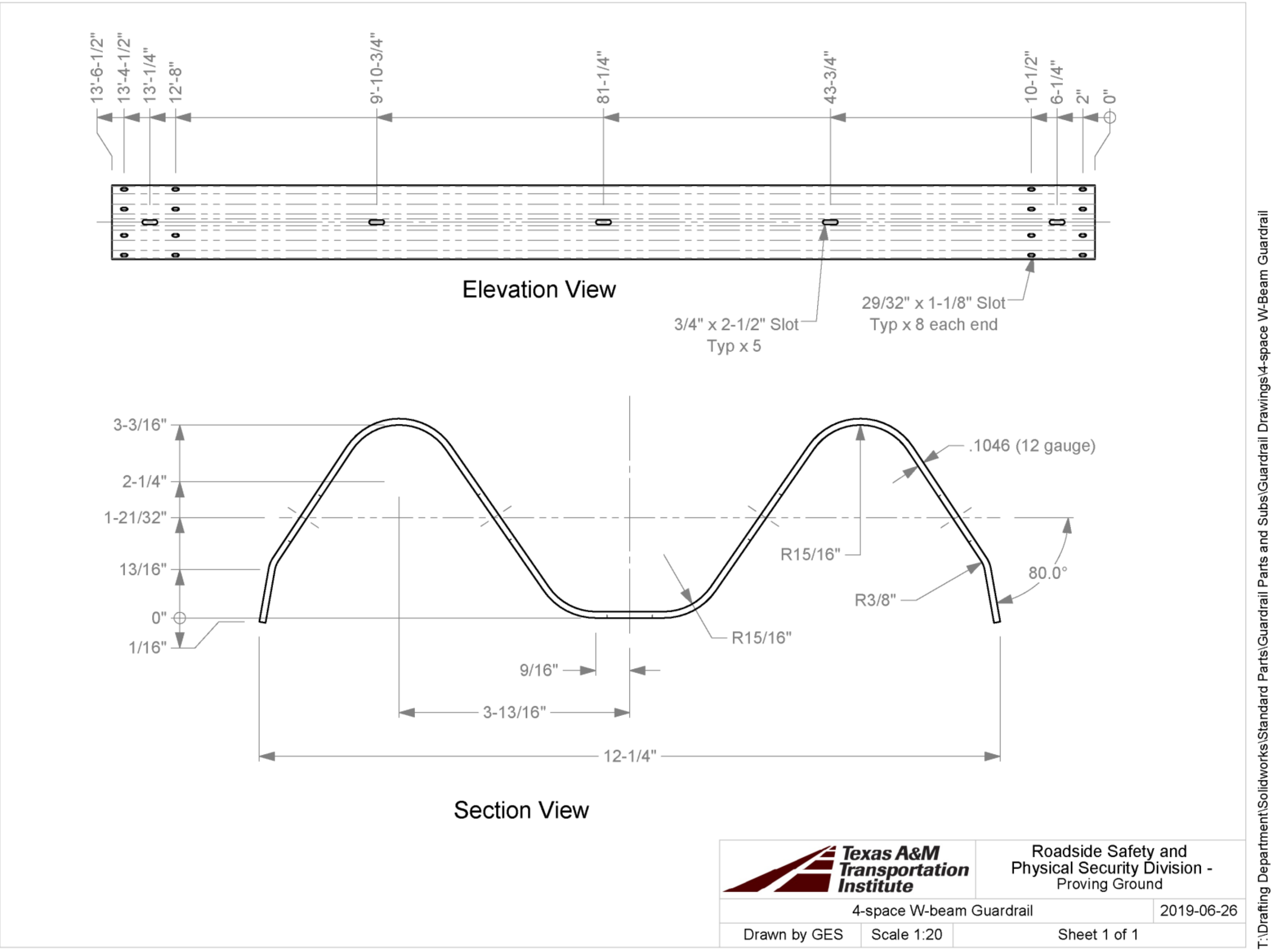


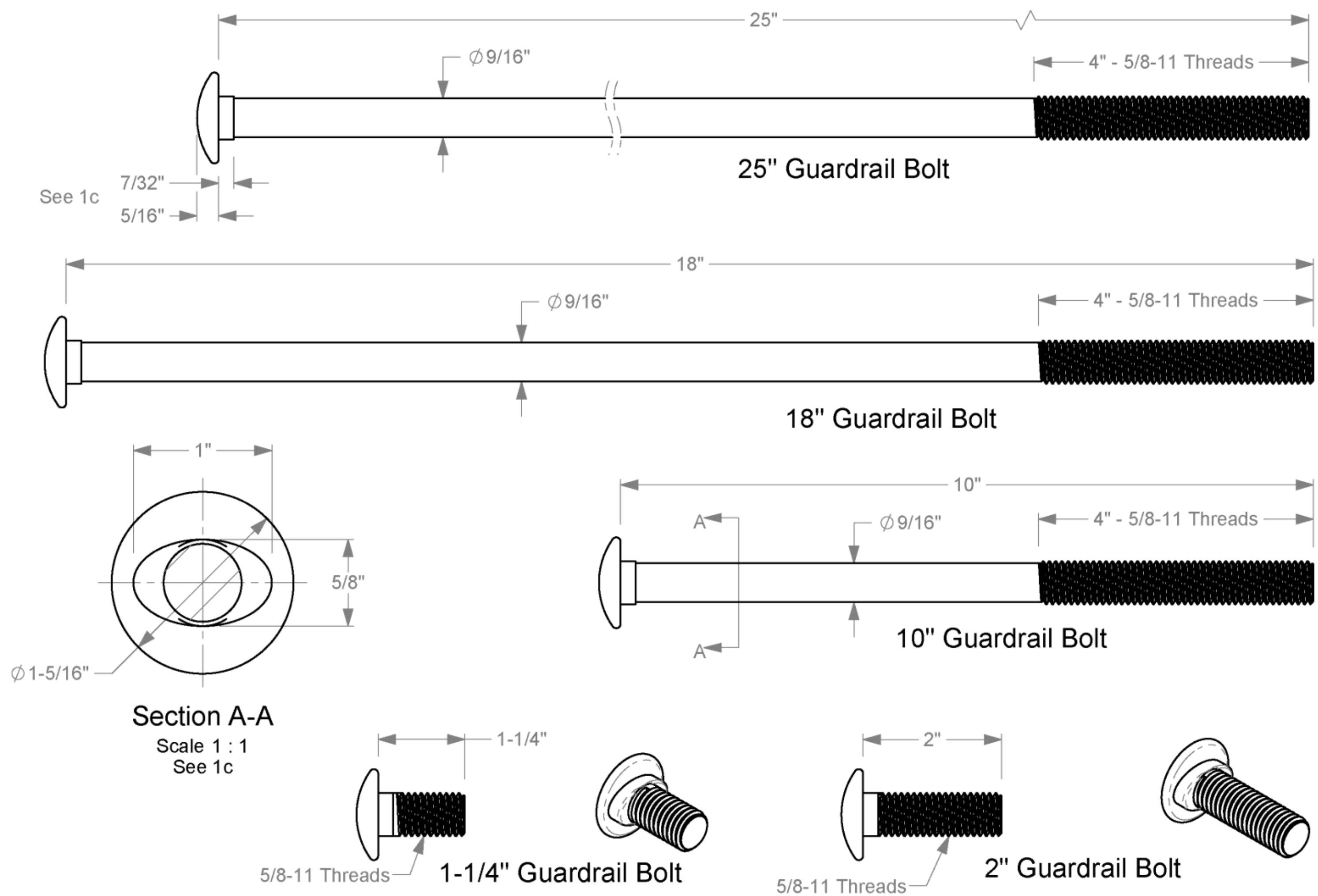
T:\1-ProjectFiles\469689-TxDOT\-4 Mow Strip with Round Wood Posts\Drafting, 469469-4\469689-4 Drawing


Post and Blockout
72"
69-3/4"
61"
0"
⌀13/16"
25"
36"
(embedment depth)
⌀7-1/2"
Timber Post
14"
C
C
⌀13/16"
Timber Blockout
Scale 1:5
R3-3/4"
3/4"
7-5/8"
5-5/8"
Section C-C
Scale 1 : 5
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #469689-4 Mow Strip with Round Wood Posts
2019-07-22
Drawn by GES
Scale 1:10
Sheet 2 of 2 Post and Blockout
T:\1-ProjectFiles\469689-TxDOT\-4 Mow Strip with Round Wood Posts\Drafting, 469469-4\469689-4 Drawing



#	(DAT) PARTS LIST	QTY
1	Steel Foundation Tube	2
2	DAT Terminal Post	2
3	Channel Strut	2
4	Terminal Rail Element	1
5	Shelf Angle Bracket	1
6	BCT Bearing Plate	1
7	BCT Post Sleeve	1
8	Guardrail Anchor Bracket	1
9	(Rounded) W-Beam End Section	1
10	BCT Cable Anchor	1
11	Recessed Nut, Guardrail	20
12	1 ¼" Button Head Bolt	4
13	10" Button Head Bolt	2
14	⅝" x 2" Hex Head Bolt	8
15	⅝" x 8" Hex Head Bolt	4
16	⅝" x 10" Hex Head Bolt	2
17	⅝" Flat Washer	18


13'-6-1/2"
13'-4-1/2"
13'-1/4"
12'-8"
9'-10-3/4"
81-1/4"
43-3/4"
10-1/2"
6-1/4"
2"
0"
Elevation View
3/4" x 2-1/2" Slot
Typ x 5
29/32" x 1-1/8" Slot
Typ x 8 each end
3-3/16"
2-1/4"
1-21/32"
13/16"
0"
1/16"
.1046 (12 gauge)
R15/16"
80.0°
R3/8"
R15/16"
9/16"
3-13/16"
12-1/4"
Section View
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
4-space W-beam Guardrail
2019-06-26
Drawn by GES
Scale 1:20
Sheet 1 of 1
T:\Drafting Department\Solidworks\Standard Parts\Guardrail Parts and Subs\Guardrail Drawings\4-space 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 sizes.

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

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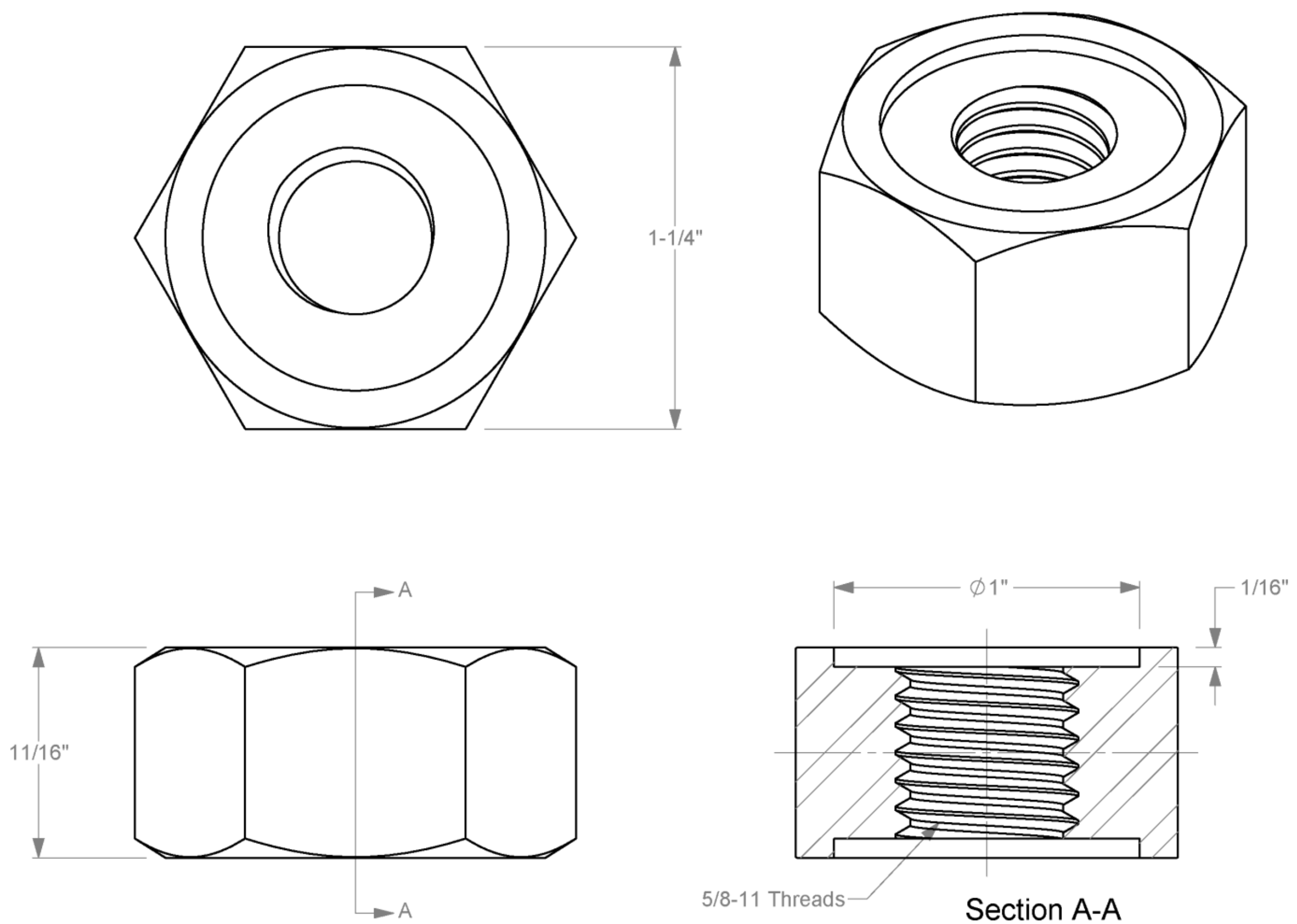
Recessed Guardrail Nut



1a. Material is ASTM A 563 Grade A.

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

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

APPENDIX B. SUPPORTING CERTIFICATION DOCUMENTS

ARNOLD FOREST PRODUCTS CORP.
10818 PROVIDENCE ROAD
SHREVEPORT, LA.71129
(318) 925-6903 FAX (318) 925-6249

SHIPPING TICKET

NO. 21527

SHIP FROM:
Arnold Forest Products Corporation
1081 8 Providence Road
Shreveport, La. 71129

Ship To:
Texas A&M Transportation Institute
3100 SH 47 , Bldg 7091
Bryan, TX. 77807
Sana Moran (979)218-0680

DATE SHIPPED	SHIPPED VIA	CUSTOMER P.O.	FREIGHT P.O.
07/17/2019	RCRR	Sana Moran	A21527

		Quantity Shipped		Description
		29		7 1/2" X 72" D.T.
		29		6 X 8 X 14" C/C

		DATE	RECEIVED BY

469689-4

TICKET NO.

CUSTOMER'S COPY

Martin Marietta

1503 LBJ Freeway
Suite 400
Dallas, Tx 75234

5554007

LOAD TIME	TO JOB	ARRIVE JOB SITE	BEGIN POUR	FINISH POUR	LEAVE JOB SITE	ARRIVE PLANT
10:23	10:	10:50	10:53	:	:	:

WATER ADDED ON JOB AT CUSTOMER'S REQUEST ______ GAL.
ALLOWABLE WATER (withheld from batch) ______ GAL.
TEST CYLINDER TAKEN ☒ YES ☐ NO BY ______
CYLINDER TAKEN ☒ BEFORE ☐ AFTER WATER

ADDITIONAL WATER ADDED TO THIS CONCRETE WILL REDUCE ITS STRENGTH. ANY WATER ADDED IN EXCESS OF SPECIFIED SLUMP IS AT CUSTOMER'S RISK.

CUSTOMER SIGNATURE
X

DELIVERY OF THESE MATERIALS IS SUBJECT TO THE TERMS AN CONDITIONS ON THE REVERSE SIDE HEREOF AS ACCEPTED I SIGNATURE ABOVE.

CUSTOMER NAME AND DELIVERY ADDRESS
TEXAS A & M UNIVERSI
TTI-Riverside Campus

PLANT	TRUCK	ORDER NO.	SLUMP	P.O. #/JOB/LOT	GRID
617	7130	2034	10.	469689-4	

DRIVER NAME	DATE
Billy Lomuscio	7/26/19

CUSTOMER NUMBER	PROJECT	CUM. QTY	ORDERED QTY
783659	79546	5.00	5.00

LOAD QUANTITY	PRODUCT CODE	DESCRIPTION		UNIT PRICE	AMOUNT
5.00	CYDS	EFLOW15	1.5SK FLOW FILL		
1.00	ea	12987	FREIGHT CHARGE		

Grout
469865-4

SPECIAL DELIVERY INSTRUCTIONS
2818-RT ON LEONARD RT ON HWY-47-LFT INTO RELLIS
CAMPUS WILL MEETAT GATE

SALES TAX

TOTAL

DANGER! MAY CAUSE ALKALI BURNS.
SEE WARNINGS ON REVERSE SIDE.

FOR OFFICE USE ONLY **FORM:** 2679626

Truck	Driver	User	Disp Ticket Num	Ticket ID	Time	Date
7130	943616	user	5554007	77920	10:23	7/26/19

Load Size	Mix Code	Returned	Qty	Mix Age	Seq	Load ID
5.00 CYDS	EFLOW15				D	78957

Material	Design Qty	Required	Batched	% Var	% Moisture	Actual Wat
SAND-1	2719 lb	14044 lb	14040 lb	-0.03%	3.20% M	54 gl
CMT-I/II	188 lb	940 lb	940 lb	0.00%		
H20	550 lb	2217 lb	2214 lb	-0.14%		265 gl

Actual Num Batches: 1
Load Total: 17194 lb Design 2.926 Water/Cement 2.926 T Design 329.5 gl Actual 319.1 gl To Add: 10.4
Slump: 10.00 in Water in Truck: 0.0 gl Adjust Water: 0.0 gl / Load Trim Water: -2.0 gl/ CYD

GROUT COMPRESSIVE STRENGTH TEST REPORT

Report Number: A1171057.0057
Service Date: 07/26/19
Report Date: 08/16/19 Revision 2 - 21 day breaks
Task: PO #469689

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

Client

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

Project

Riverside Campus
Riverside Campus
Bryan, TX

Project Number: A1171057

Material Information

Specified Strength: 1,500 psi @

Mix ID: EFLOW15
Supplier: Martin Marietta
Batch Time: 1023 **Plant:**
Truck No.: 7130 **Ticket No.:** 5554007

Field Test Data

Test	Result	Specification
Slump (in):		Not Specified
Grout Temp. (F):	88	40 - 95
Ambient Temp. (F):	87	40 - 95

Sample Information

Sample Date: 07/26/19 **Sample Time:** 1110
Sampled By: David Carpio
Weather Conditions: Clear, light wind
Accumulative Yards: 5/5 **Batch Size:** 5
Sample Size:
Sample Location: Leave outs
Placement Location: Guard rail posts
Form Material: Cardboard Form **No. Units:** 12
Samples Plumb: Yes
Temperature Range: 70 - 102

Laboratory Test Data

Set No.	Specimen ID	Date Received	Date Tested	Age (days)	Area (sq in)	Maximum Load (lbs)	Compressive Strength (psi)	Tested By
1	A	07/30/19	08/14/19	19	11.22	2,660	240	DRH
1	B	07/30/19	08/14/19	19	10.40	2,440	230	DRH
1	C	07/30/19	08/14/19	19	10.24	1,990	190	DRH
						Average (19 days)	**220**	
1	D	07/30/19	08/16/19	21	10.56	2,767	260	
1	E	07/30/19	08/16/19	21	10.56	2,214	210	
1	F	07/30/19	08/16/19	21	10.56	2,324	220	
						Average (21 days)	**230**	
1	G	07/30/19	08/23/19	28				
1	H	07/30/19	08/23/19	28				
1	I	07/30/19	08/23/19	28				

Initial Cure: Onsite Cooler **Final Cure:** Cure Box

Comments:
Samples Made By: Terracon
Services: Obtain sample of grout at the placement location and cast specimens for compressive strength determination.

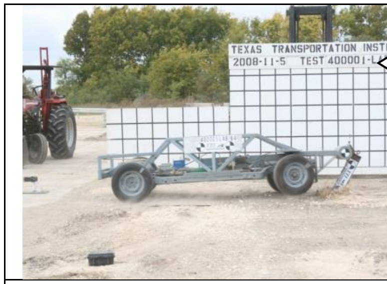
Terracon Rep.: David Carpio **Start/Stop:** 0900-1200
Reported To:
Contractor:
Report Distribution:
(1) Texas Transportation Institute, Gary Gerke (1) Terracon Consultants, Inc., Andrea Allen

Reviewed By: Andrea G. Allen
Andrea Allen
Project Manager

Test Methods: ASTM C109, ASTM C1019

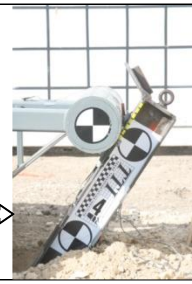
CR0009, 11-16-12, Rev.6 Page 1 of 1

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



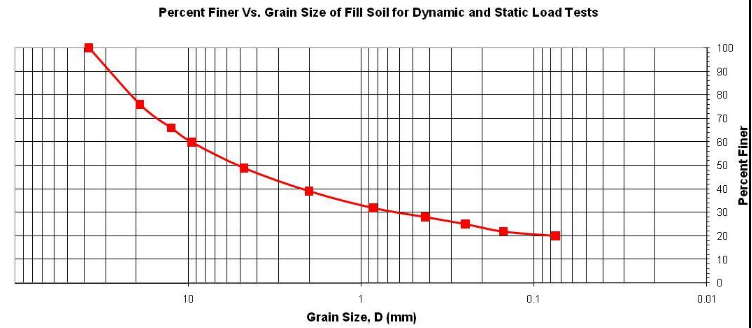
Dynamic Setup

Post-Test Photo of Post

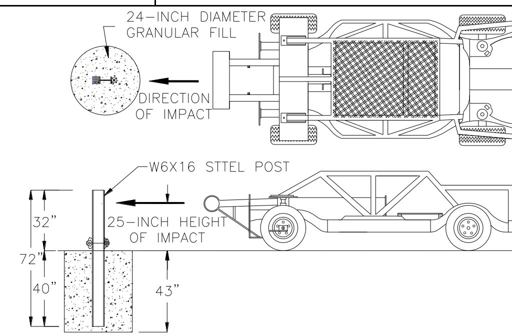


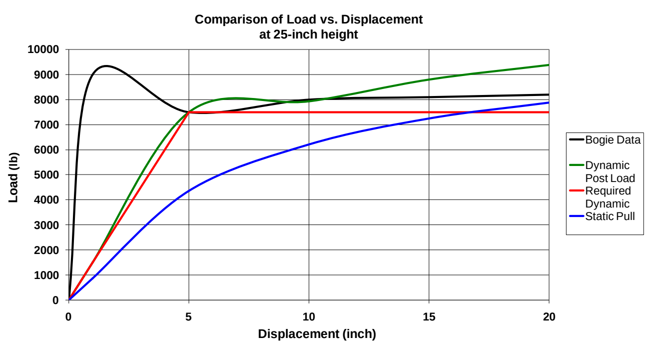
Post-Test Photo

Static Load Test

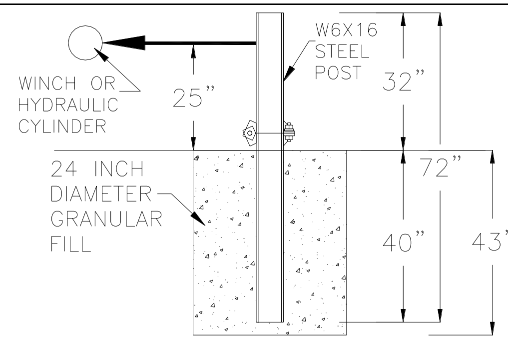


Dynamic Test Installation Details



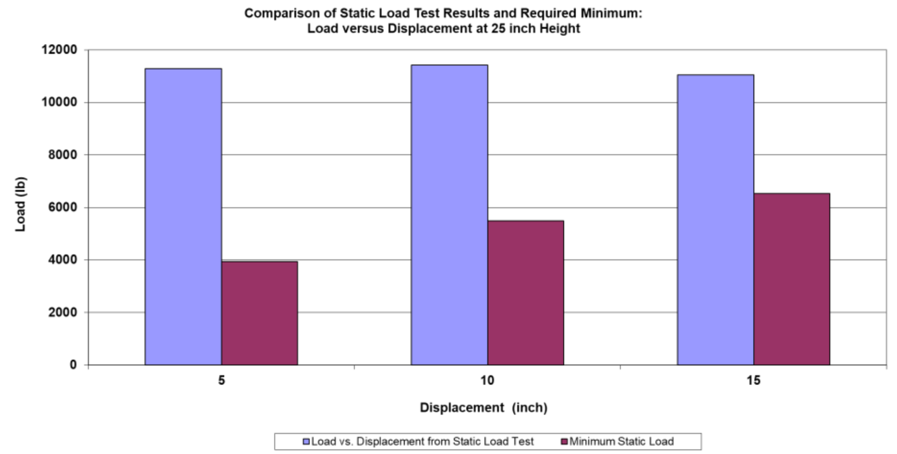


Static Load Test Installation Details

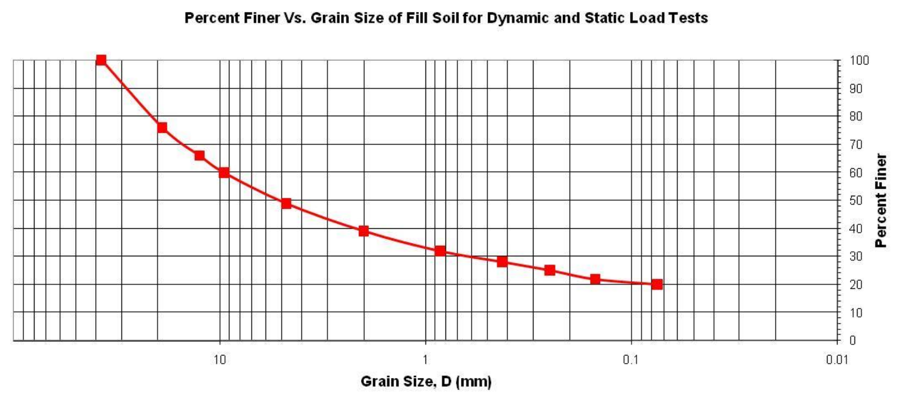


Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill Placement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

Table C.2. Test Day Static Soil Strength Documentation for Test No. 469689-4-1.



Typical Static Load Setup



Post-Test Photo of Post

Date	2019-08-16
Test Facility and Site Location	TTI Proving Ground – 3100 SH 47, Bryan, Tx
In Situ Soil Description (ASTM D2487)	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis)
Description of Fill Placement Procedure	6-inch lifts tamped with a pneumatic compactor

APPENDIX D. *MASH* TEST 3-11 (CRASH TEST NO. 469689-4-1)

D.1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 469689-4-1.

Date: 2019-08-16 Test No.: 469689-4 VIN No.: 1C6RR6FT8DS686274

Year: 2013 Make: RAM Model: 1500

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

Tread Type: Highway Odometer: 128862

Note any damage to the vehicle prior to test: None

● Denotes accelerometer location.

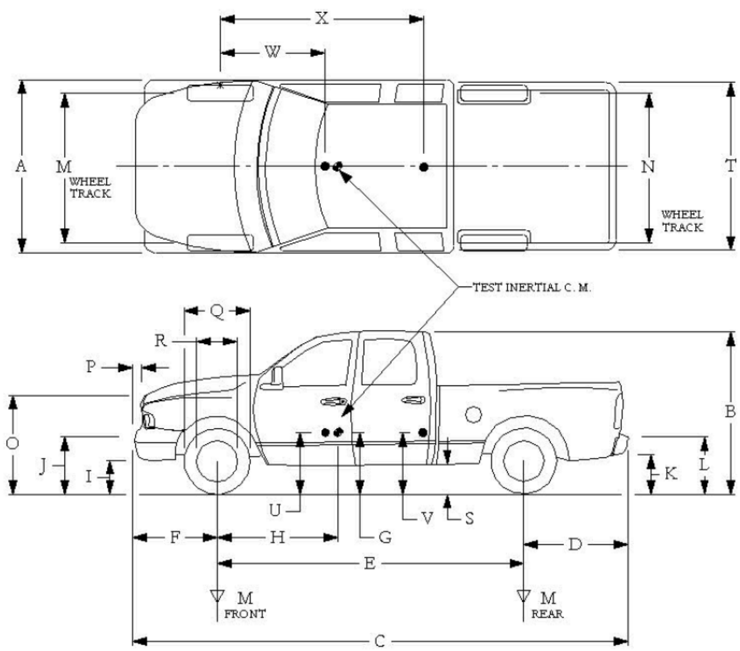
NOTES: None

Engine Type: V-8
Engine CID: 5.7 liter

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

Optional Equipment:
None

Dummy Data:
Type: NONE
Mass: 0 lb
Seat Position: NA



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	26.75
B	74.00	G	28.00	L	30.00	Q	30.50	V	30.25
C	227.50	H	61.21	M	68.50	R	18.00	W	61.20
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}	2874	2831	2831
Back	3900	M_{rear}	2073	2186	2186
Total	6700	M_{Total}	4947	5017	5017

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

Mass Distribution:
lb LF: 1393 RF: 1438 LR: 1140 RR: 1046

Table D.2. Measurements of Vehicle Vertical CG for Test No. 469689-4-1.

Date: 2019-08-16 Test No.: 469689-4 VIN: 1C6RR6FT8DS686274

Year: 2013 Make: RAM Model: 1500

Body Style: Quad Cab Mileage: 128862

Engine: 5.7 liter V-8 Transmission: Automatic

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

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

Measured Vehicle Weights: (lb)							
LF:	1393		RF:	1438		Front Axle:	2831
LR:	1140		RR:	1046		Rear Axle:	2186
Left:	2533		Right:	2484		Total:	5017
							5000 ±110 lb allowed
Wheel Base:	140.50	inches	Track: F:	68.50	inches	R:	68.00 inches
	148 ±12 inches allowed			Track = (F+R)/2 = 67 ±1.5 inches allowed			

Center of Gravity, SAE J874 Suspension Method					
X:	61.22	inches	Rear of Front Axle		(63 ±4 inches allowed)
Y:	-0.33	inches	Left -	Right +	of Vehicle Centerline
Z:	28.00	inches	Above Ground		(minumum 28.0 inches allowed)

Hood Height: 46.00 inches
43 ±4 inches allowed

Front Bumper Height: 27.00 inches

Front Overhang: 40.00 inches
39 ±3 inches allowed

Rear Bumper Height: 30.00 inches

Overall Length: 227.50 inches
237 ±13 inches allowed

Table D.3. Exterior Crush Measurements of Vehicle for Test No. 469689-4-1.

Date:	2019-08-16	Test No.:	469689-4	VIN No.:	1C6RR6FT8DS686274
Year:	2013	Make:	RAM	Model:	1500

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

Note: Measure C_1 to C_6 from Driver to Passenger Side in Front or Rear Impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width*** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bmpr ht	18	10	50	1	2	4	7	8	10	-15
2	Side plane at bmpr ht	18	10	60	1	2	-	-	8	10	+18
	Measurements recorded										
	☑ inches or ☐ mm										

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

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

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

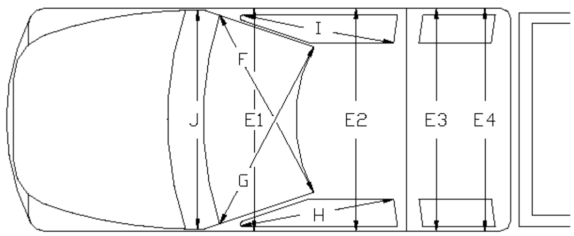
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

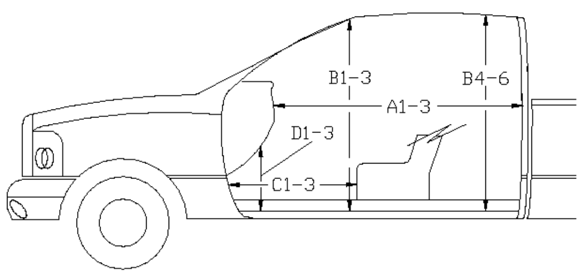
***Measure and document on the vehicle diagram the location of the maximum crush.

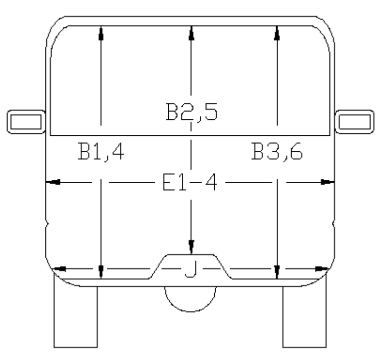
Note: Use as many lines/columns as necessary to describe each damage profile.

Table D.4. Occupant Compartment Measurements of Vehicle for Test No. 469689-4-1.

Date:	2019-08-16	Test No.:	469689-4	VIN No.:	1C6RR6FT8DS686274
Year:	2013	Make:	RAM	Model:	1500







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

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	65.00	65.00	0.00
A2	63.00	63.00	0.00
A3	65.50	65.50	0.00
B1	45.00	45.00	0.00
B2	38.00	38.00	0.00
B3	45.00	45.00	0.00
B4	39.50	39.50	0.00
B5	43.00	43.00	0.00
B6	39.50	39.50	0.00
C1	26.00	26.00	0.00
C2	0.00	0.00	0.00
C3	26.00	24.50	-1.50
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

D.2 SEQUENTIAL PHOTOGRAPHS

0.000 s

0.100 s

0.200 s

0.300 s

Figure D.1. Sequential Photographs for Test No. 469689-4-1 (Overhead and Frontal Views).

0.400 s

0.500 s

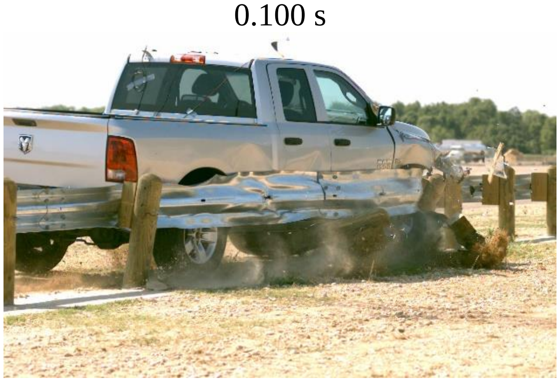
0.600 s

0.700 s

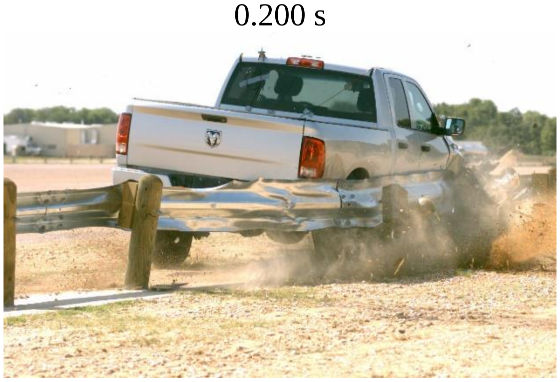
Figure D.1. Sequential Photographs for Test No. 469689-4-1 (Overhead and Frontal Views) (Continued).

0.000 s

0.100 s



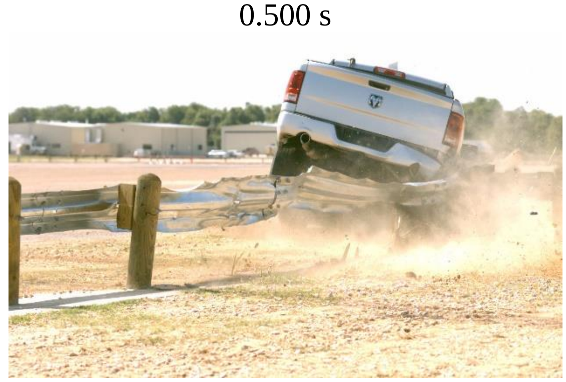
0.200 s



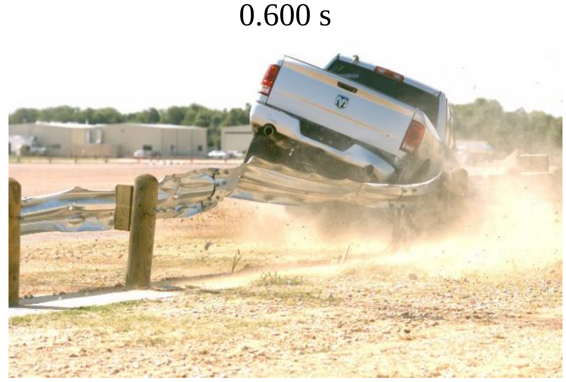
0.300 s

0.400 s

0.500 s

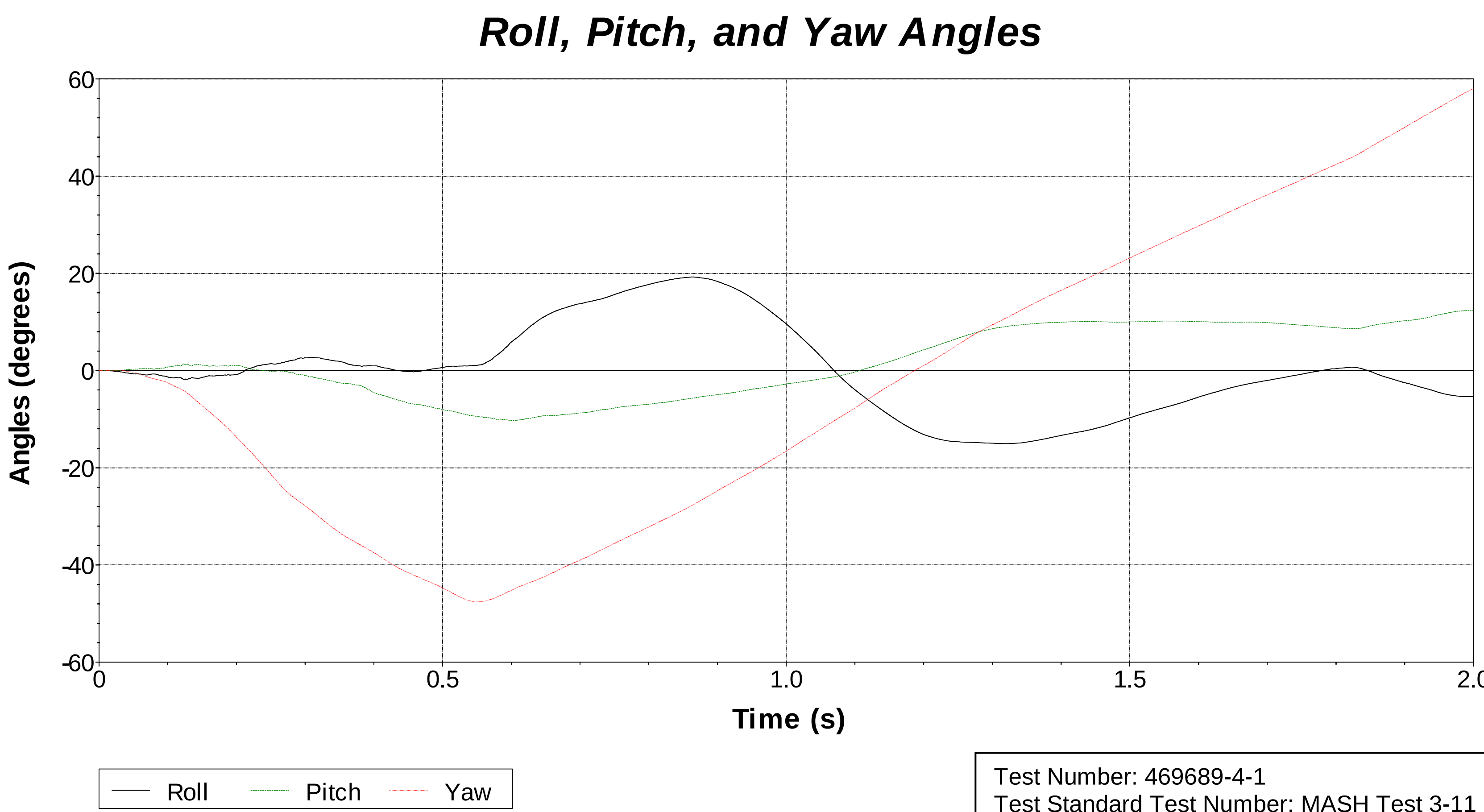


0.600 s

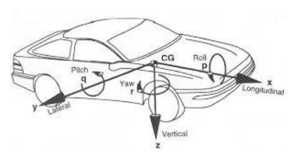


0.700 s

Figure D.2. Sequential Photographs for Test No. 469689-4-1 (Rear View).



Sequence for determining orientation:
1. Yaw.
2. Pitch.
3. Roll.



Test Number: 469689-4-1
Test Standard Test Number: MASH Test 3-11
Test Article: Mowstrip with Round Wood Posts
Test Vehicle: 2013 RAM 1500 Pickup
Inertial Mass: 5017 lb
Gross Mass: 5017 lb
Impact Speed: 63.7 mi/h
Impact Angle: 25.1°

Figure D.3. Vehicle Angular Displacements for Test No. 469689-4-1.

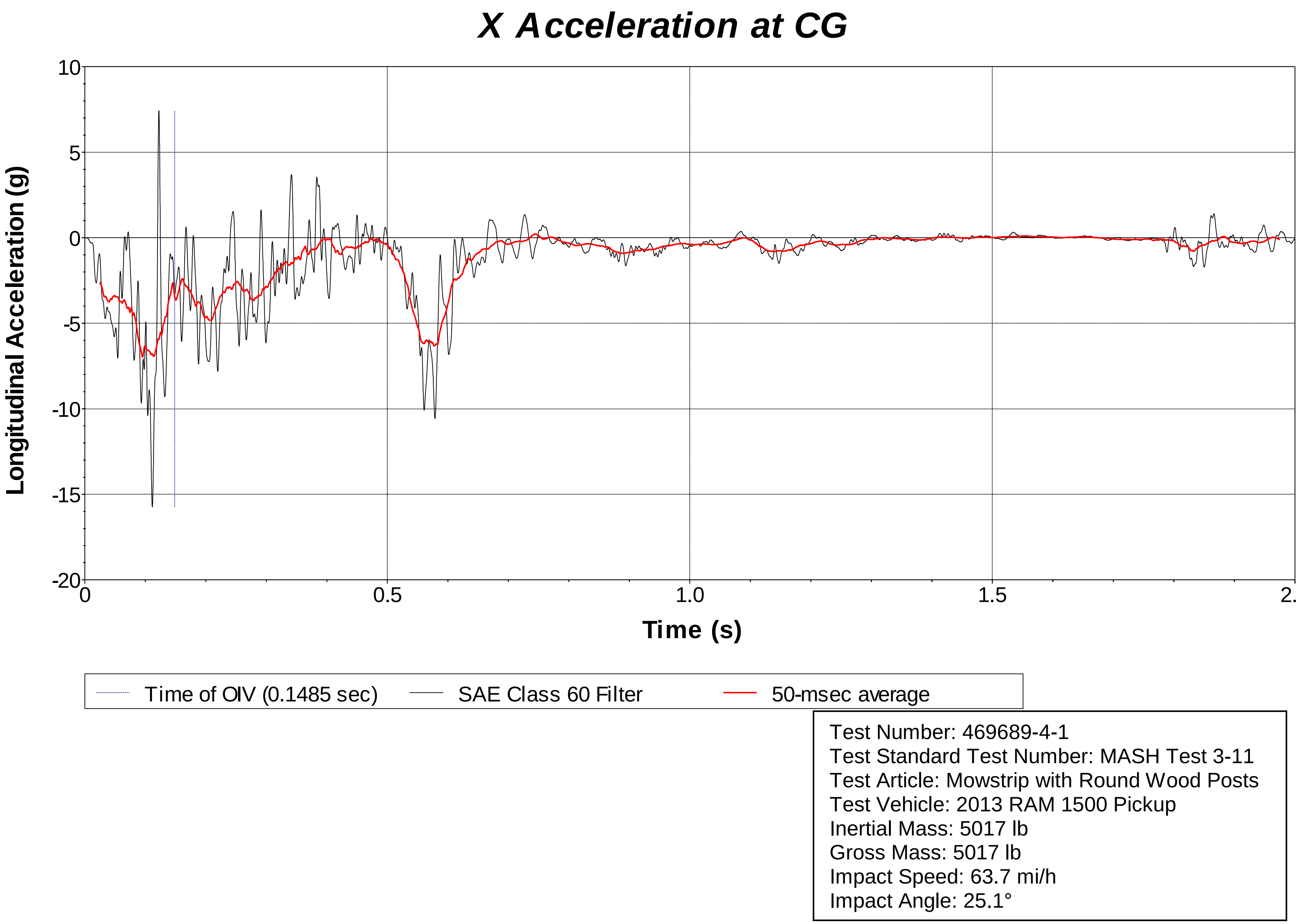
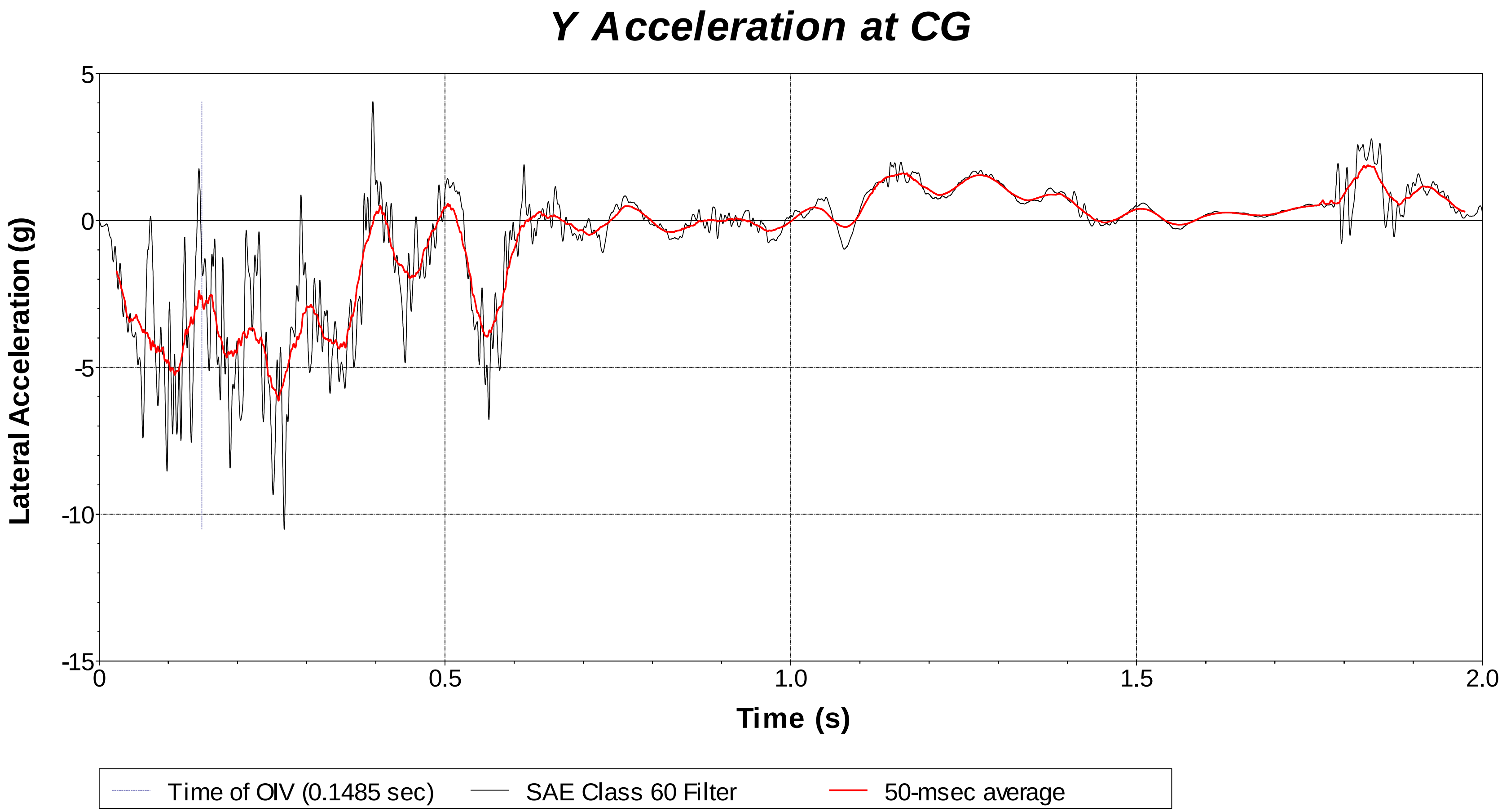


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469689-4-1 (Accelerometer Located at Center of Gravity).



Test Number: 469689-4-1
Test Standard Test Number: MASH Test 3-11
Test Article: Mowstrip with Round Wood Posts
Test Vehicle: 2013 RAM 1500 Pickup
Inertial Mass: 5017 lb
Gross Mass: 5017 lb
Impact Speed: 63.7 mi/h
Impact Angle: 25.1°

Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 469689-4-1 (Accelerometer Located at Center of Gravity).

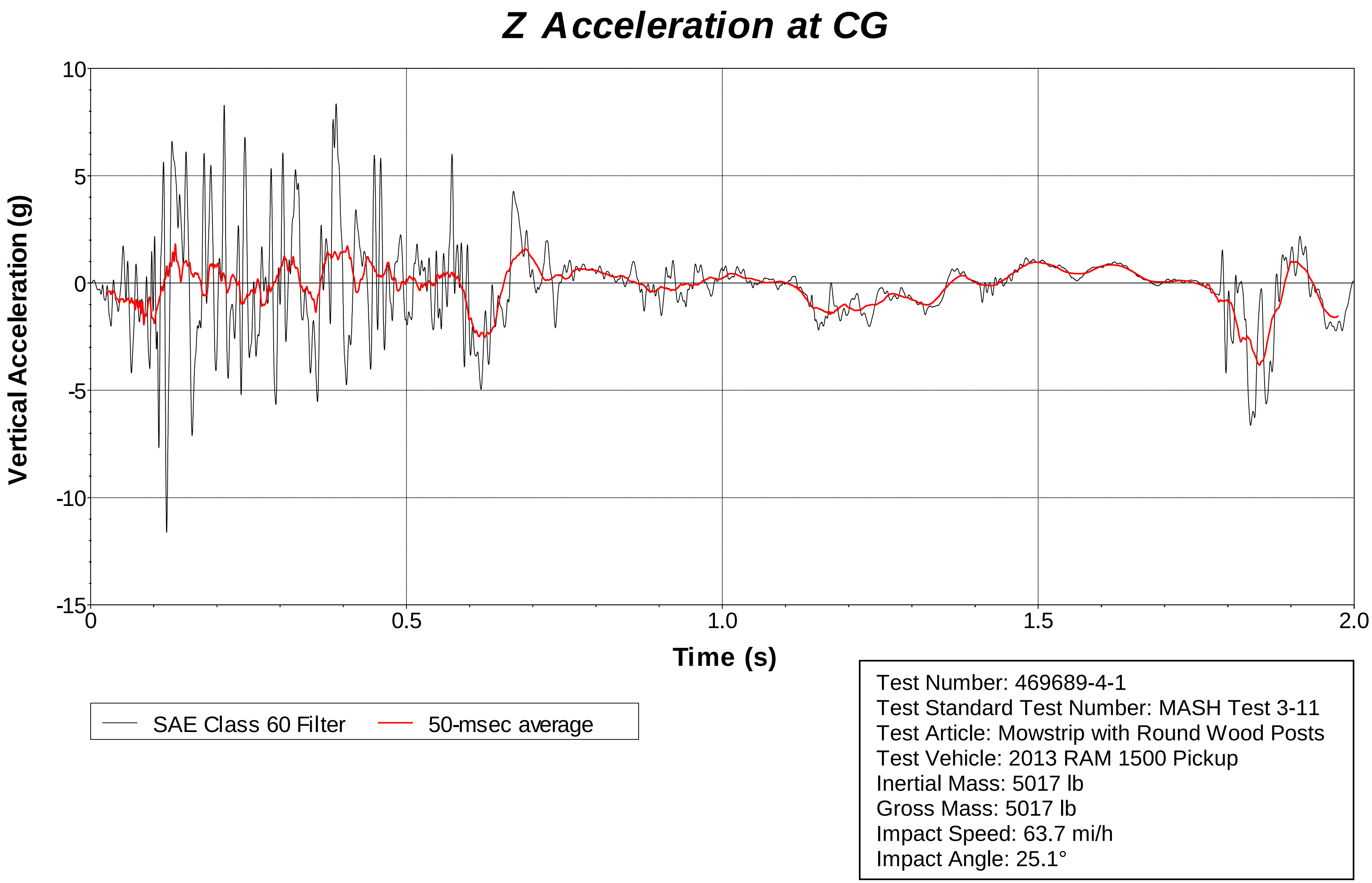


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 469689-4-1 (Accelerometer Located at Center of Gravity).