TTI: 0-6968

MASH TEST 3-11 EVALUATION OF MODIFIED TxDOT ROUND WOOD POST GUARDRAIL SYSTEM

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-R4

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE

COLLEGE STATION, TEXAS

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 Modified TxDOT Round Wood Post Guardrail System in soil according to the safety-performance evaluation guidelines included in American Association of State Highway and Transportation Officials' *Manual for Assessing Safety Hardware (MASH)* for Test Level Three. The modification involved reducing the guardrail post embedment depth from 40 inches to 36 inches to reduce the soil resistance and decrease the force required to deflect the post through the soil. The crash test performed was in accordance with *MASH* Test 3-11 criteria, which involves a 2270P pickup truck impacting the barrier at a target impact speed and angle of 62 mi/h and 25°, respectively.

The Modified TxDOT Round Wood Post Guardrail System in soil successfully contained and redirected the pickup truck. The barrier performed acceptably for *MASH* Test 3-11. The maximum dynamic deflection and permanent deformation were 44.1 inches and 37.0 inches, respectively.

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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 researcher in charge of the project was James Kovar.

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

TTI PROVING GROUND DISCLAIMER

The results reported herein apply only to the article being tested. The full-scale crash test was performed according to TTI Proving Ground quality procedures and according to the *MASH* guidelines and standards.

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CHAPTER 1: INTRODUCTION

1.1 PROBLEM

In response to the Joint Implementation Agreement between the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration, the Texas Department of Transportation (TxDOT) elected to test their National Cooperative Highway Research Program (NCHRP) Report 350 compliant W-beam guardrail system with round wood posts for *Manual for Assessing Safety Hardware* (*MASH*) compliance. TTI researchers conducted *MASH* Test 3-11 on this W-beam guardrail system with round wood posts. During the test, several posts fractured, which allowed the vehicle to pocket in the system. This pocketing, combined with the test vehicle traversing over the fractured posts, caused the test vehicle to override the system and eventually roll onto its roof. TTI researchers were then tasked with modifying the round-post guardrail system to improve its crashworthiness. The test reported herein was conducted to assess the impact performance of the modified round wood post W-beam guardrail system according to *MASH* Test 3-11 evaluation criteria.

1.2 BACKGROUND

In November 2017, *MASH* Test 3-11 was performed on the TxDOT round wood post configuration of their metal beam guard fence system (*1*). This was a NCHRP Report 350 compliant system that was being tested to evaluate compliance with *MASH* (*2*, *3*). During *MASH* test 3-11, several round wood posts fractured before they could rotate through the soil, dissipate energy, and contribute to a successful redirection of the vehicle. This caused the vehicle to pocket in system and traverse over the fractured posts. The vehicle subsequently overrode the system, thus preventing it from meeting *MASH* criteria.

TTI researchers contributed the failure to the change in impact severity between the original NCHRP Report 350 test and the new *MASH* test. The increase in impact severity in the *MASH* test raised the flexural demand on the round wood posts, which caused the posts to fracture before they could significantly displace through the soil and help dissipate impact energy of the vehicle. The NCHRP Report 350 compliant round wood post guardrail system consisted of a W-beam steel rail at a height of 27-inches above grade, with 7 ¼-inch nominal round wooden posts embedded 44-inches below grade. With the development of the Midwest Guardrail System (MGS), the TxDOT guardrail system was updated by raising the rail height to 31-inches, decreasing the embedment depth to 40-inches, and moving the splices to the mid-span between posts. TTI researchers believe that the taller guardrail height was one of two primary contributors to the fracturing of the posts. This increase in height of 4 inches increases the moment arm of the impact load applied to the post during an impact and, consequently, increases the moment on the post. The other contributor to the fracturing of the posts is the increased weight of the *MASH* pickup truck compared to the NCHRP Report 350 pickup truck. The *MASH* pickup truck weighs 5000-lb, while the NCHRP Report 350 pickup truck weighed approximately 4409-lb. This 13 percent increase in weight results in a higher impact severity and greater impact force and moment on the post.

TTI researchers considered modifications to the post designed to either increase the structural capacity of the post to accommodate the increased impact moment or reduce soil resistance to enable the post to deflect through the soil at a lower force threshold. Dynamic impact tests using a gravitational pendulum were performed to assist with the evaluation of the design modifications. Ultimately, in consultation with TxDOT engineers, it was decided to reduce the embedment depth of the posts from 40 inches to 36-inches. This reduction in embedment depth will allow the posts to rotate through the soil at a reduced level of force and, thereby, increase the energy dissipation of the posts.

1.3 OBJECTIVE/SCOPE OF RESEARCH

The primary objective of this research was to test a modified version of the TxDOT round wood post guardrail system, in accordance with AASHTO *MASH* criteria. The modification involved reducing the guardrail post embedment depth from 40 inches to 36 inches to reduce the soil resistance and decrease the force required to deflect the post through the soil. The crash test performed was in accordance with *MASH* Test 3-11 criteria, which involves a 2270P pickup truck impacting the guardrail at a target impact speed and angle of 62 mi/h and 25°, respectively.

CHAPTER 2:
ORGANIZATION AND STYLES

2.1 TEST ARTICLE AND INSTALLATION DETAILS

The test installation consisted of round wood posts, 8-inch deep wooden block-outs, and 12-gauge W-beam guardrail. The posts were embedded 36 inches in soil and spaced at 75 inches on center. A TxDOT Downstream Anchor Terminal was installed on each end for a total installation length of 181.25 ft. The top edge of the W-beam was 31 inches above grade. The W-beam splices were located midway between the posts.

Figure 2.1 presents overall details on the round wood post guardrail system, and Figure 2.2 provides photographs of the completed test installation. Appendix A provides further details of the round post guardrail system.

2.3 SOIL CONDITIONS

The test installation was installed in soil meeting grading B of AASHTO standard specification M147-65(2004) "Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses." Soil strength was measured the day of the crash test in accordance with Appendix B of *MASH*. During installation of the guardrail for full-scale crash testing, two W6×16 posts were installed in the immediate vicinity of the guardrail utilizing the same fill materials and installation procedures used in the test installation and the standard dynamic test. Table B.1 in Appendix B presents minimum soil strength properties established through the dynamic testing performed in accordance with *MASH* Appendix B.

As determined by the tests summarized in Appendix B, Table B.1, the minimum post loads required at deflections of 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 3940 lb, 5500 lb, and 6540 lb, respectively (90 percent of static load for the initial standard installation). On the day of the test, July 6, 2018, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 8030 lbf, 8080 lbf, and 7575 lbf, respectively. Table B.2 in Appendix B shows the strength of the backfill material in which the guardrail was installed met minimum *MASH* requirements.

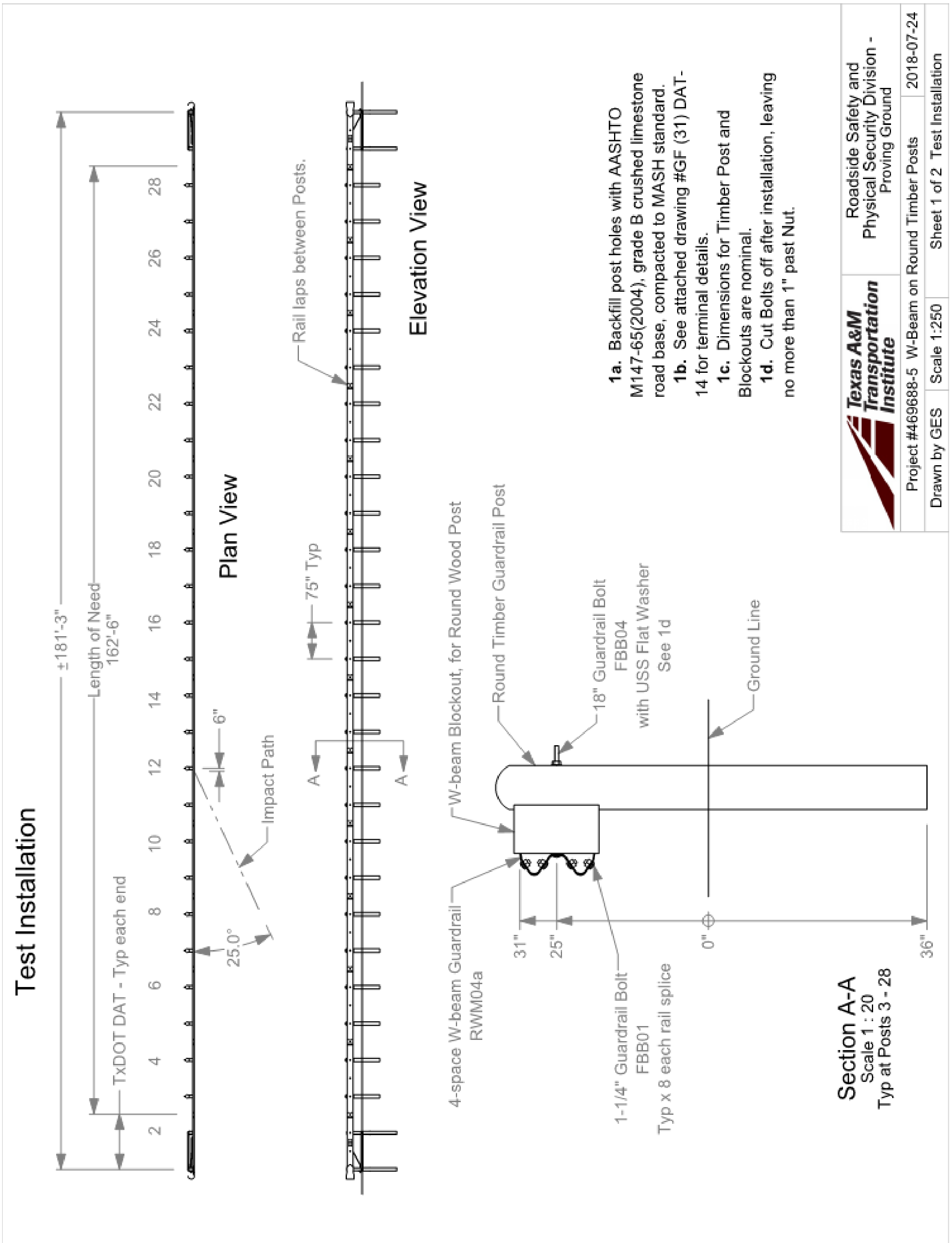


Figure 2.1. Overall Details of the Modified TxDOT Round Wood Post Guardrail System.

Figure 2.2. Modified TxDOT Round Wood Post Guardrail System prior to Testing.

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. *MASH* Test 3-11 involves a 2270P vehicle weighing 5000 lb ±110 lb impacting the critical impact point (CIP) of the barrier at a target impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. *MASH* Test 3-10 involves an 1100C vehicle weighing 2425 lb ±55 lb impacting the CIP of the barrier at a target impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. *MASH* Test 3-11 primarily evaluates the strength of the guardrail system and stability of the 2270P vehicle, while *MASH* Test 3-10 primarily evaluates occupant risk.

MASH Test 3-11 was viewed as the critical test for the system based upon previous successful *MASH* testing of guardrail systems that present higher potential for vehicle snagging than the round wood post system. Both a W6x8.5 steel post MGS system without offset blocks (*5*) and an MGS system with nominal 6-inch × 8-inch rectangular wood posts (*6*) successfully passed *MASH* Test 3-10. Both these systems pose a higher risk for vehicle snag than the round wood posts because of the innate post shapes. Consequently, *MASH* Test 3-10 was considered non-critical and was not performed.

This report presents testing of the modified round post W-beam guardrail system in accordance with *MASH* Test 3-11. The target CIP selected for the test was determined according to the information provided in *MASH* Section 2.2.1 and 2.3.2.2, and was 6 inches upstream of post 12.

Table 3.1. Test Conditions and Evaluation Criteria Specified for *MASH* Test 3-11.

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

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 2-2A and 5-1A through 5-1C of *MASH* were used to evaluate the crash test 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 are summarized 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 limits: 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 the Texas A&M Transportation Institute (TTI) Proving Ground, an International Standards Organization (ISO) 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 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 testing of the barrier was along the edge of one of these out-of-service aprons. The apron consists of an unreinforced jointed-concrete pavement in 12.5-ft × 15-ft blocks that are nominally 6 inches deep. The apron was 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 can provide 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 60-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 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.
- 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 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 5:
MASH TEST 3-11 (CRASH TEST NO. 469688-5-1)

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 barrier at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25° ±1.5°. The target CIP for *MASH* Test 3-11 on the modified round post guardrail system was ½ ft ±1 ft upstream of post 12.

The 2013 RAM 1500 pickup truck used in the test weighed 5018 lb, and the actual impact speed and angle were 62.7 mi/h and 25.5°, respectively. The actual impact point was 0.8 ft upstream of post 12. Minimum target impact severity (IS) was 106 kip-ft, and actual IS was 122 kip-ft.

5.2 WEATHER CONDITIONS

The test was performed the afternoon of July 6, 2018. Weather conditions at the time of testing were as follows: wind speed: 6 mi/h; wind direction: 92° with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 93°F; relative humidity: 51 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 and gross static weight was 5018 lb. The height to the lower edge of the vehicle bumper was 11.75 inches, and height to the upper edge of the bumper was 27.0 inches. The height to the vehicle's center of gravity was 29 inches. Table C.1 in Appendix C1 gives additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be freewheeling and unrestrained just prior to impact.

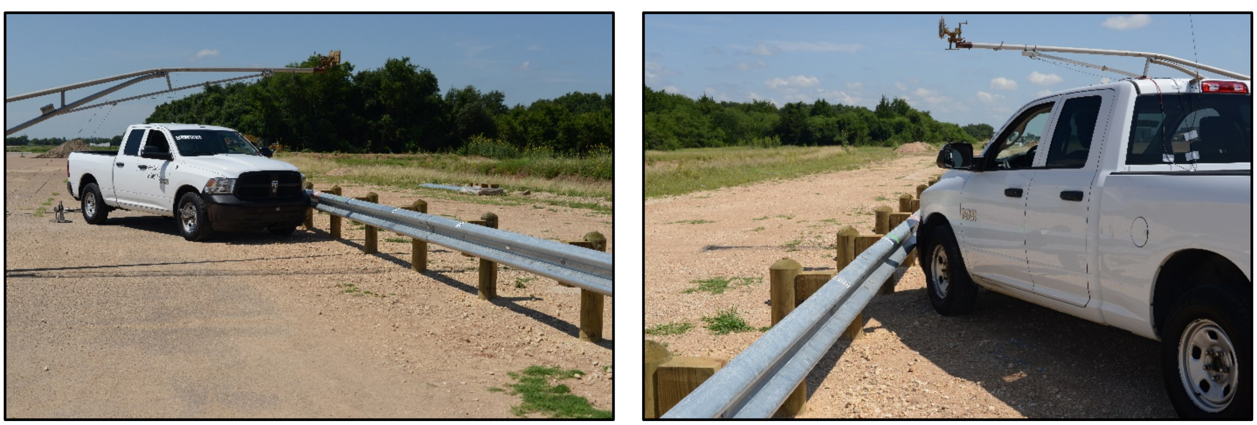


Figure 5.1. Guardrail/Test Vehicle Geometrics for Test No. 469688-5-1.

Figure 5.2. Test Vehicle before Test No. 469688-5-1.

5.4 TEST DESCRIPTION

The test vehicle was traveling at a speed of 62.7 mi/h as it contacted the barrier 0.8 ft upstream of post 12 at an angle of 25.5°. Table 5.1 lists times and events that occurred during Test No. 469688-5-1. Figures C.1 and C.2 in Appendix C2 present sequential photographs during the test.

Table 5.1. Events during Test No. 469688-5-1.

TIME (s)	EVENT
0.000	Vehicle makes contact with guardrail
0.043	Vehicle begins to redirect
0.079	Post 14 broken at ground and detached from rail element
0.132	Post 15 broken at ground and separated from rail element
0.135	Rail detached from posts upstream of impact point
0.169	Post 16 detached from guardrail and broken at ground
0.249	Post 17 broken at ground
0.300	Post 17 detached from rail element
0.396	Vehicle becomes parallel with guardrail
0.418	Post 18 detached from rail with broken blockout
0.655	Vehicle loses contact with guardrail while traveling at 27.1 mi/h

For longitudinal barriers, it is desirable that the vehicle redirects and exits the barrier within the exit box criteria (not less than 32.8 ft downstream from loss of contact for cars and pickups). The 2270P vehicle exited within the exit box criteria defined in *MASH*. After loss of contact with the guardrail, the vehicle yawed counterclockwise and came to rest 110 ft downstream of the impact point and adjacent to the traffic face of the guardrail.

5.5 DAMAGE TO TEST INSTALLATION

Figure 5.3 shows the damage to the barrier. The rail released from posts 1 through 19. Posts 11–16 and 18 were broken at ground level, and post 17 was pulled out of the ground. Working width for the test was 62.2 inches, and the height of the working width was 57.4 inches. Maximum dynamic deflection during the test was 44.1 inches, and maximum permanent deformation was 37 inches at post 16.

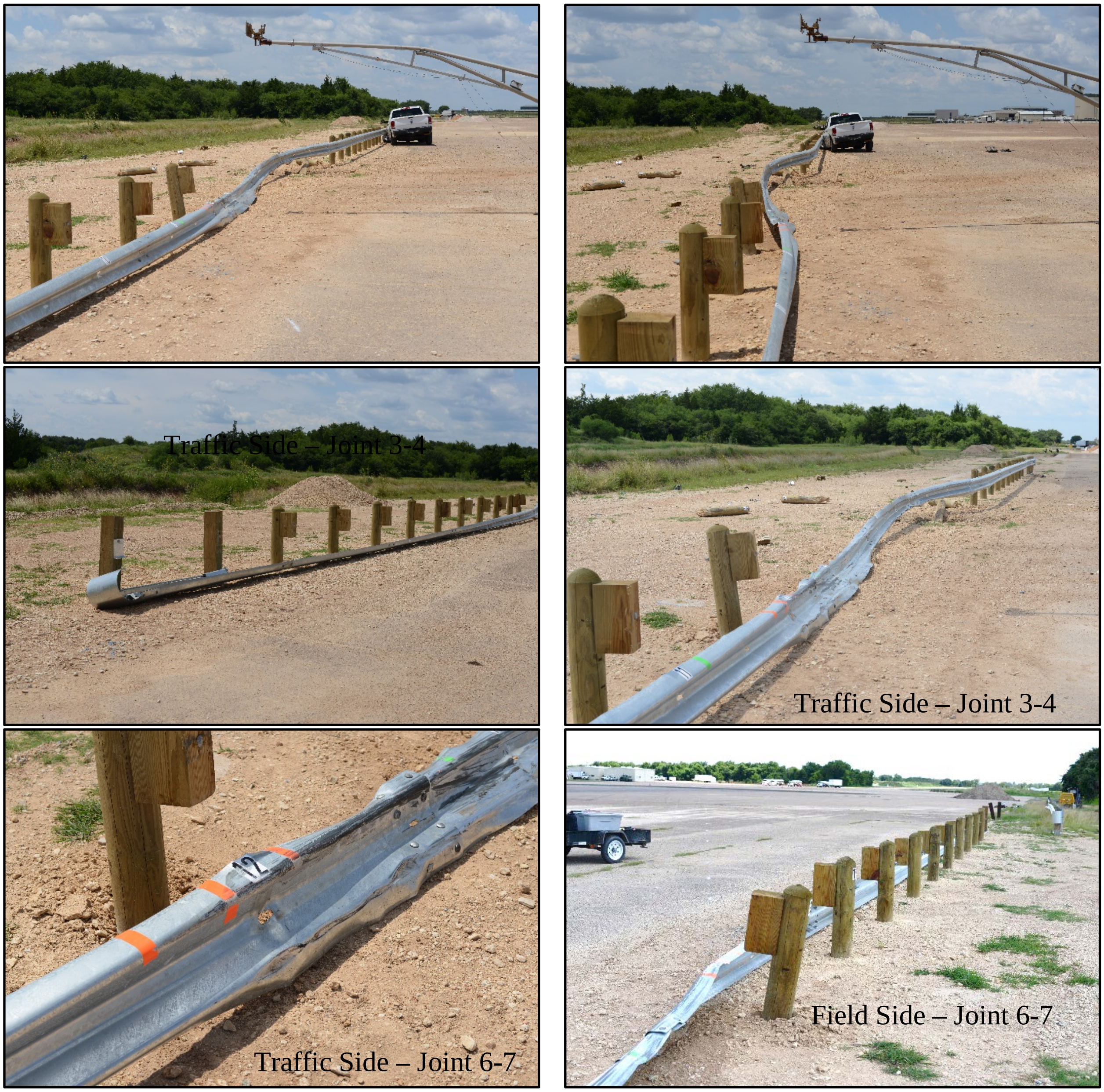


Figure 5.3. Barrier after Test No. 469688-5-1.

5.6 DAMAGE TO TEST VEHICLE

Figure 5.4 shows the damage sustained by the vehicle. The front bumper, hood, grill, left headlight, left front fender, left front tire and rim, left front lower A-arm, and left front door were damaged. Maximum exterior crush to the vehicle was 11.0 inches in the horizontal at bumper height. No measurable occupant compartment deformation occurred. Figure 5.5 shows the interior of the vehicle.

Figure 5.4. Test Vehicle after Test No. 469688-5-1.

Before Test After Test

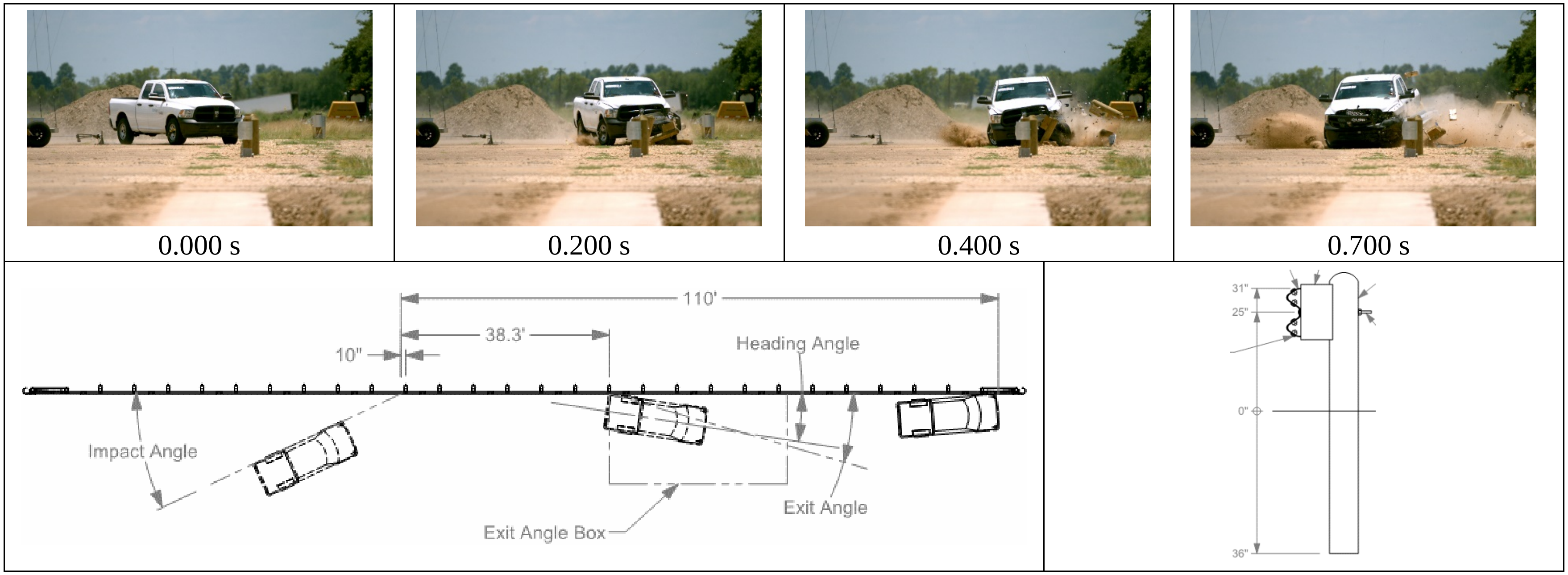
Figure 5.5. Interior of Test Vehicle for Test No. 469688-5-1.

5.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk and are shown in Table 5.2. Figure 5.6 summarizes these data and other pertinent information from the test. Figure C.3 in Appendix C3 shows the vehicle angular displacements, and Figures C.4 through C.9 in Appendix C4 show accelerations versus time traces.

Table 5.2. Occupant Risk Factors for Test No. 469688-5-1.

Occupant Risk Factor	Value		Time
Occupant Impact Velocity (OIV)	m/s	ft/s	at 0.1540 seconds on left side of interior
Longitudinal	**4.7**	**15.4**	
Lateral	**−4.4**	**−14.4**	
Occupant Ridedown Accelerations (G's)			
Longitudinal	**−11**		(0.5048–0.5148 seconds)
Lateral	**6.8**		(0.2480–0.2580 seconds)
Theoretical Head Impact Velocity (THIV)	km/h	mi/h	at 0.1466 seconds on left side of interior
	22.2	**13.8**	
	m/s	ft/s	
	6.2	**20.3**	
Post Head Deceleration (PHD) (G's)	**11.3**		(0.5050–0.5150 seconds)
Acceleration Severity Index (ASI)	**0.6**		(0.2579–0.3079 seconds)
Maximum 50-ms Moving Average (G's)			
Longitudinal	**−5.5**		(0.4653–0.5153 seconds)
Lateral	**5.1**		(0.2340–0.2840 seconds)
Vertical	**2**		(0.2767–0.3267 seconds)
Maximum Roll, Pitch, and Yaw Angles	**Degrees**		
Roll	**7.4**		(0.2920 seconds)
Pitch	**4.3**		(0.8174 seconds)
Yaw	**33.9**		(1.0510 seconds)



General Information	
Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-11
TTI Test No.	469688-5-1
Test Date	2018-07-06
Test Article	
Type	Longitudinal Barrier – Guardrail
Name	TxDOT Round Post Guardrail System
Installation Length	181.2 ft
Material or Key Elements	W-Beam rail, round wood posts embedded 36 inches in soil at 75 inch spacing
Soil Type and Condition	AASHTO M147-65(2004), grading B Soil (crushed limestone), Damp
Test Vehicle	
Type/Designation	2270P
Make and Model	2013 RAM 1500
Curb	5006 lb
Test Inertial	5018 lb
Dummy	No dummy
Gross Static	5018 lb

Impact Conditions	
Speed	62.7 mi/h
Angle	25.5°
Location/Orientation	10.0 inches upstream of post 12
Impact Severity	122 kip-ft
Exit Conditions	
Speed	27.1 mi/h
Exit Traj./Heading Angle	16.2° / 8.9°
Occupant Risk Values	
Longitudinal OIV	15.4 ft/s
Lateral OIV	14.4 ft/s
Longitudinal Ridedown	11.0 g
Lateral Ridedown	6.8 g
THIV	20.3 ft/s
PHD	11.3 g
ASI	0.62
Max. 0.050-s Average	
Longitudinal	-5.5 g
Lateral	5.1 g
Vertical	2.0 g

Post-Impact Trajectory	
Stopping Distance	110 ft downstream adjacent to rail
Vehicle Stability	
Maximum Yaw Angle	34°
Maximum Pitch Angle	4°
Maximum Roll Angle	7°
Vehicle Snagging	No
Vehicle Pocketing	Moderate
Test Article Deflections	
Dynamic	44.1 inches
Permanent	37.0 inches
Working Width	62.2 inches
Height of Working Width	57.4 inches
Vehicle Damage	
VDS	11-LFQ-X
CDC	11FLEWX
Max. Exterior Deformation	11.0 inches
OCDI	LF0010000
Max. Occupant Compartment Deformation	None

Figure 5.6. Summary of Results for *MASH* Test 3-11 on 31-inch Tall TxDOT Round Post Guardrail System.

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.

6.2 CONCLUSIONS

The Modified TxDOT Round Wood Post Guardrail System in soil performed acceptably for *MASH* Test 3-11.

Table 6.1. Performance Evaluation Summary for *MASH* Test 3-11 on Modified TxDOT Round Wood Post Guardrail System.

Test Agency: Texas A&M Transportation Institute | Test No.: 469688-5-1 | Test Date: 2018-07-06

***MASH* Test 3-11 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy *A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The round post guardrail system contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 44.1 inches.	Pass
Occupant Risk *D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.*	No detached elements, fragments, or other debris were present to penetrate or show potential for penetrating the occupant compartment, or to present hazard to others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.3 and Appendix E of MASH.	There was no measurable occupant compartment deformation.	
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 7° and 4°, 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 15.4 ft/s, and lateral OIV was 14.4 ft/s.	Pass
I. Longitudinal and lateral occupant ridedown accelerations should fall below the preferred value of 15.0 g, or at least below the maximum allowable value of 20.49 g.	Longitudinal occupant ridedown acceleration was 11.0 g, and lateral occupant ridedown acceleration was 6.8 g.	Pass

CHAPTER 7: IMPLEMENTATION STATEMENT [1]

The testing and evaluation reported herein shows the Modified TxDOT Round Wood Post Guardrail System in soil successfully passed *MASH* Test 3-11, which primarily evaluates the strength of the guardrail system and stability of the 2270P vehicle. The other test considered under Test Level 3, *MASH* Test 3-10, primarily evaluates occupant risk.

MASH Test 3-11 was viewed as the critical test for the Modified TxDOT Round Wood Post Guardrail System in soil. *MASH* Test 3-10 was not considered necessary based upon previous successful *MASH* testing of guardrail systems that present higher potential for vehicle snagging than the round wood post system. Both a W6×8.5 steel post MGS system without offset blocks (*5*) and an MGS system with nominal 6-inch × 8-inch rectangular wood posts (*6*) successfully passed *MASH* Test 3-10. Both these systems pose a higher risk for vehicle snag than the round wood posts based on post geometry. Consequently, *MASH* Test 3-10 was considered non-critical and was not performed.

Based on the results of the testing and evaluation reported herein, the Modified TxDOT Round Wood Post Guardrail System in soil is considered suitable for implementation as a *MASH* TL-3 system. The guardrail system had a dynamic deflection of 44.1 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.

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

REFERENCES

1. R. P. Bligh, W. L. Menges, B. L. Griffith. *MASH Evaluation of TxDOT Roadside Safety Features – Phase II*. Test Report No. 0-6946-2, Texas A&M Transportation Institute, College Station, TX, August 2018.

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

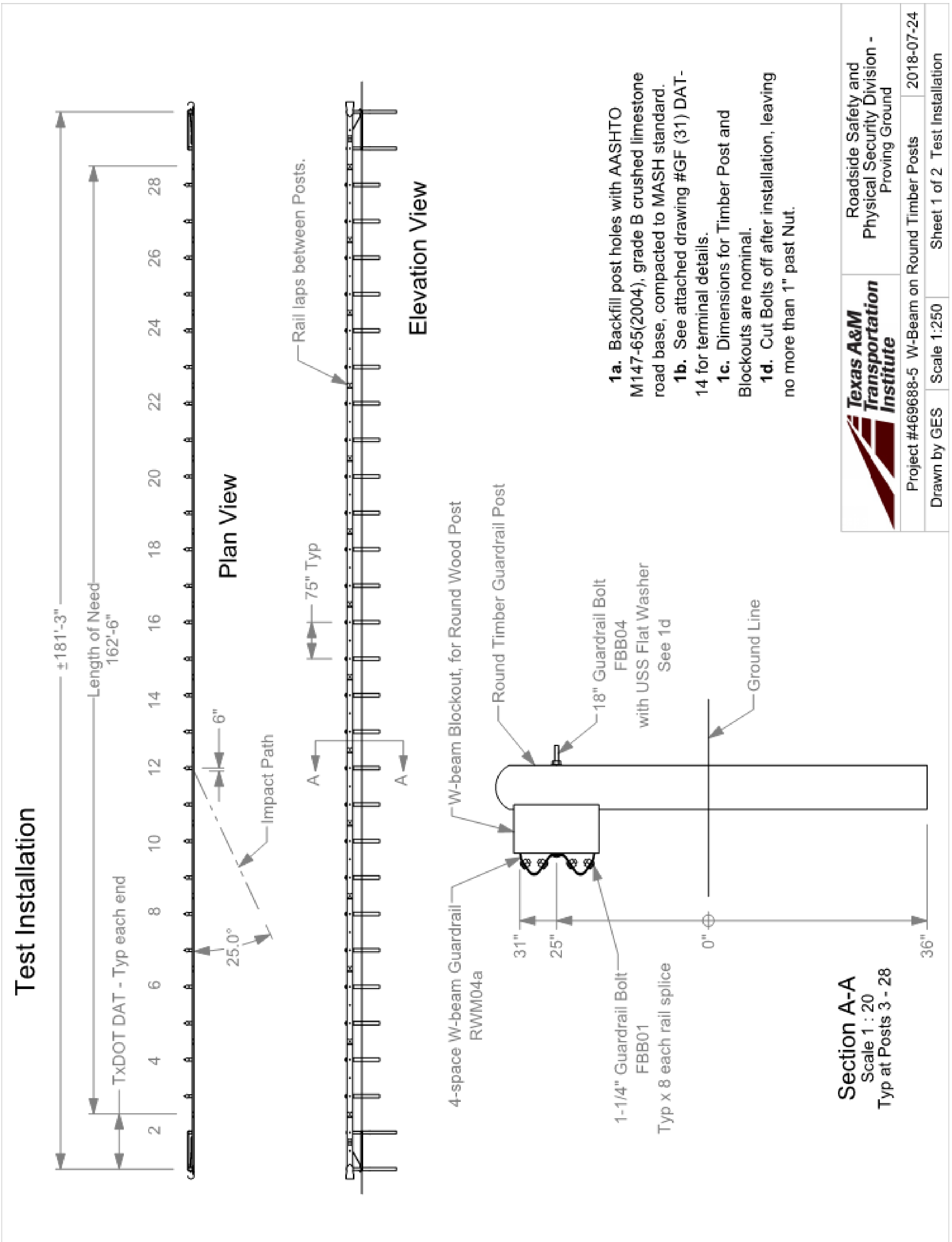
3. H.E. Ross, Jr., D.L. Sicking, R.A. Zimmer, and J.D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

4. R. P. Bligh, J. C. Kovar, and B. L. Griffith. *Round Post W-Beam Guardrail Pendulum Testing*. Tech Memo 0-06968-5(P1-P5), Texas A&M Transportation Institute, College Station, TX, August 2018.

5. Schrum, K.D., Lechtenberg, K.A., Bielenberg, R.W., Rosenbaugh, S.K., Faller, R.K., Reid, J.D., and Sicking, D.L. *Safety Performance Evaluation of the Non-Blocked Midwest Guardrail System (MGS)*. TRP-03-262-12. Midwest Roadside Safety Facility, Lincoln, NE, January 2013.

6. Gutierrez, D.A., Lechtenberg, K.A., Bielenberg, R.W., Faller, R.K., Reid, J.D., and Sicking, D.L. *Midwest Guardrail System (MGS) with Southern Yellow Pine Posts*. TRP-03-272-13. Midwest Roadside Safety Facility, Lincoln, NE, September 2013.

APPENDIX A. DETAILS OF MODIFIED TXDOT ROUND WOOD POST GUARDRAIL SYSTEM



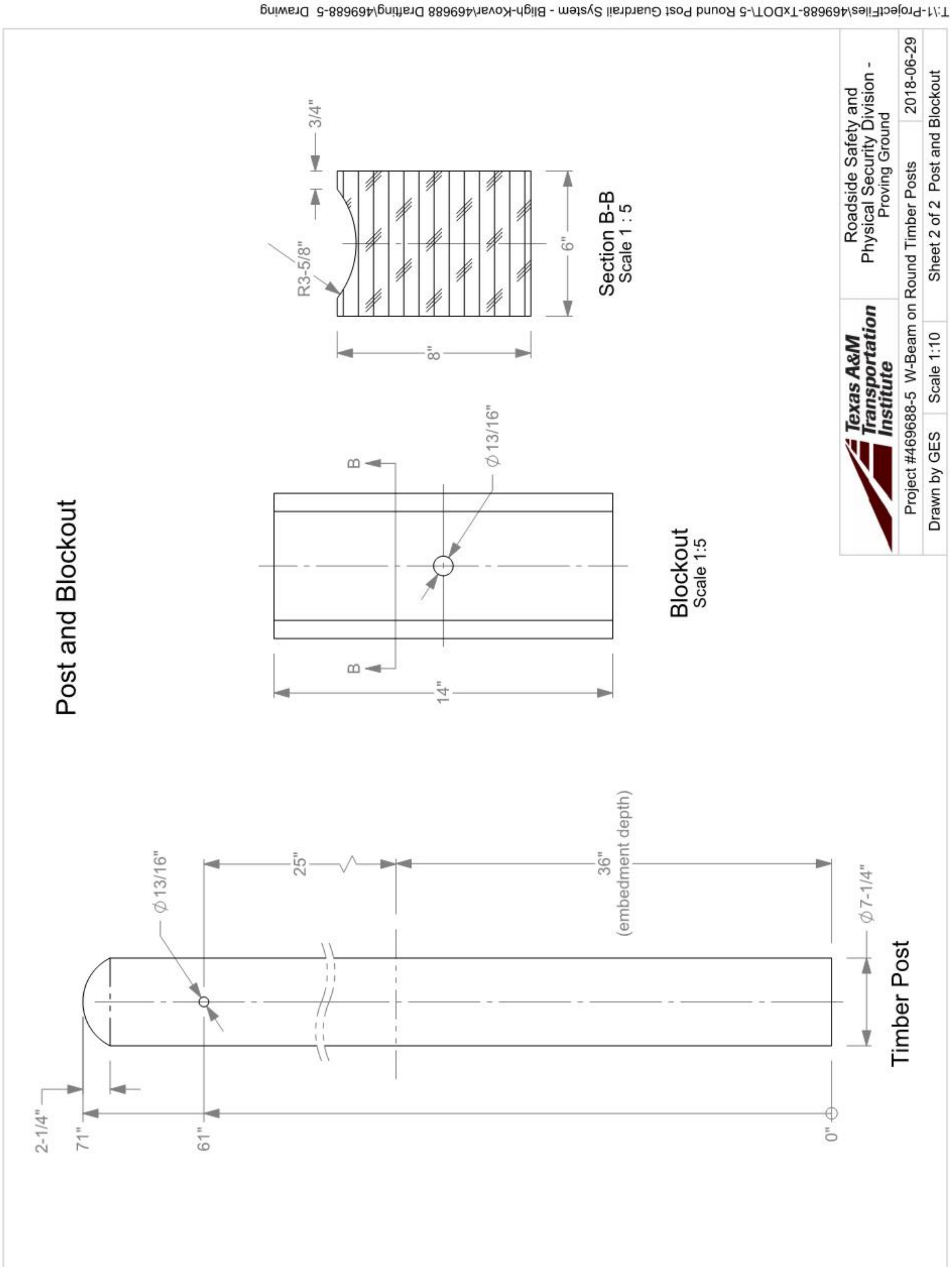
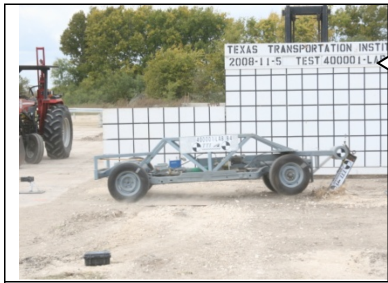
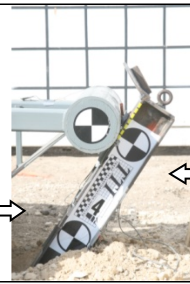

T:\1-ProjectFiles\469688-TxDOT\-5 Round Post Guardrail System - Bligh-Kovar\469688 Drafting\469688-5 Drawing
Post and Blockout
2-1/4"
71"
61"
0"
⌀13/16"
25"
36"
(embedment depth)
⌀7-1/4"
Timber Post
14"
B
B
⌀13/16"
Blockout
Scale 1:5
8"
R3-5/8"
3/4"
6"
Section B-B
Scale 1 : 5
Texas A&M Transportation Institute
Roadside Safety and Physical Security Division - Proving Ground
Project #469688-5 W-Beam on Round Timber Posts
2018-06-29
Drawn by GES
Scale 1:10
Sheet 2 of 2 Post and Blockout

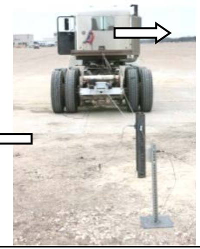
Table B.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.



Dynamic Setup

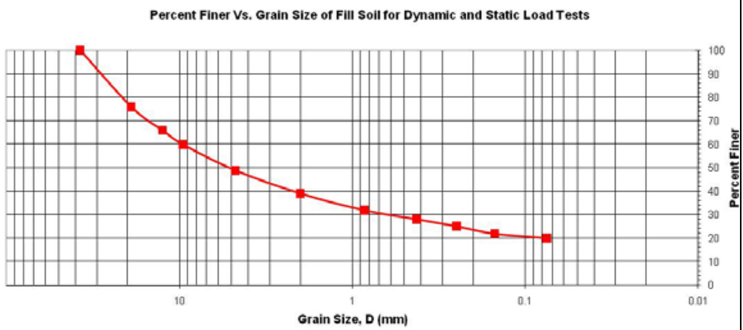
Post-Test Photo of post



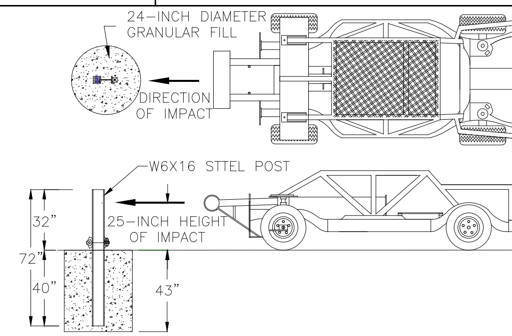


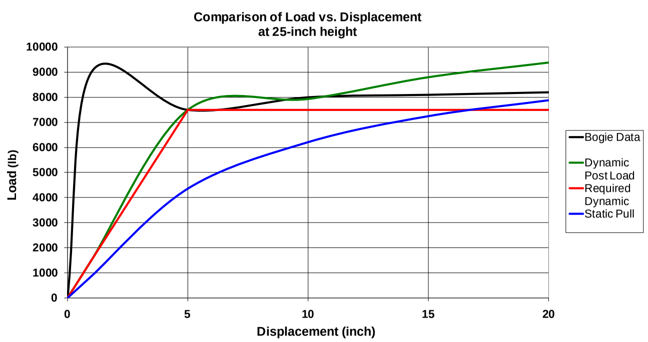
Post-Test Photo

Static Load Test

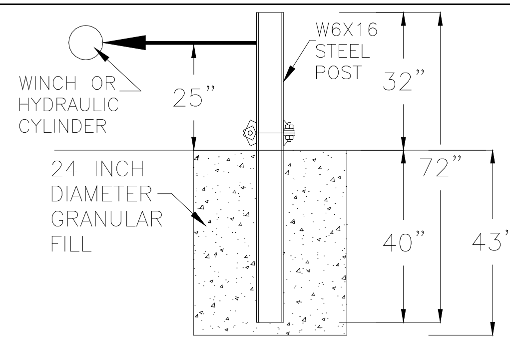


Dynamic Test Installation Details



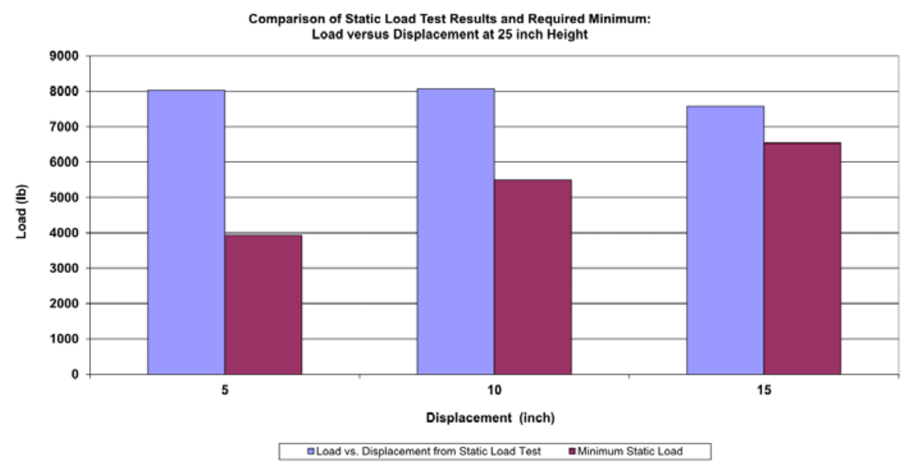


Static Load Test Installation Details

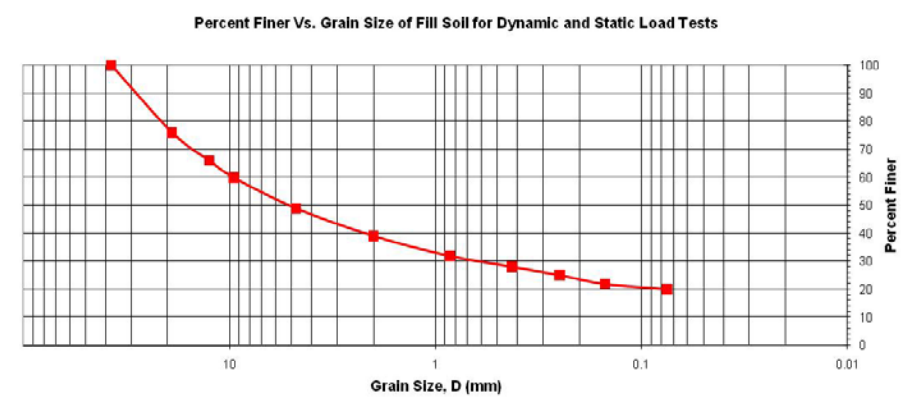


Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill Placement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

Table B.2. Test Day Static Soil Strength Documentation for Test No. 469688-5-1.



Static Load Setup



Post-Test Photo of Post

Date	2018-07-06
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 C. *MASH* TEST 3-11 (CRASH TEST NO. 469688-5-1)

C.1 VEHICLE PROPERTIES AND INFORMATION

Table C.1. Vehicle Properties for Test No. 469688-5-1.

Date:	2018-07-06	Test No.:	469688-5-1	VIN No.:	1C6RR6FP8DS693034
Year:	2013	Make:	RAM	Model:	1500

Tire Size: 265/70 R 17 — Tire Inflation Pressure: 35 PSI

Tread Type: HIGHWAY — Odometer: 173012

Note any damage to the vehicle prior to test: NONE

● Denotes accelerometer location.

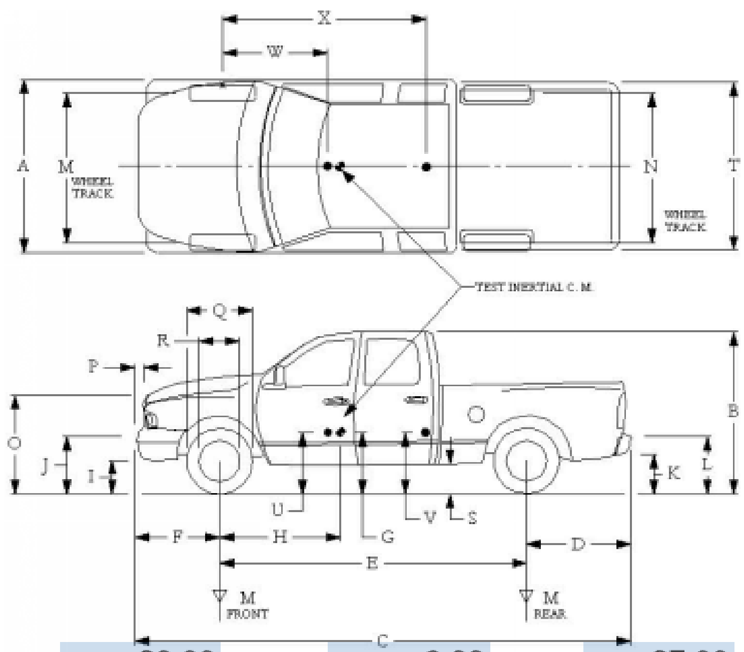
NOTES:

Engine Type: V-8
Engine CID: 4.7 L

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

Optional Equipment:
NONE

Dummy Data:
Type: NONE
Mass:
Seat Position:



Geometry: inches

A	78.50	F	40.00	K	20.00	P	3.00	U	27.00
B	74.00	G	29.00	L	30.00	Q	30.50	V	30.25
C	227.50	H	59.20	M	68.50	R	18.00	W	59.20
D	44.00	I	11.75	N	68.00	S	13.00	X	78.50
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	12.00
Wheel Center Height Rear	14.75	Wheel Well Clearance (Rear)	9.25	Bottom Frame Height - Rear	25.50

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}	2914	2903	
Back	3900	M_{rear}	2092	2115	
Total	6700	M_{Total}	5006	5018	

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

Mass Distribution:
lb — LF: 1455 — RF: 1448 — LR: 1038 — RR: 1077

Table C.2. Measurements of Vehicle Vertical CG for Test No. 469688-5-1.

Date: 2018-07-06 Test No.: 469688-5-1 VIN: 1C6RR6FP8DS693034

Year: 2013 Make: RAM Model: 1500

Body Style: QUAD CAB Mileage: 173012

Engine: 4.7L V-8 Transmission: AUTO

Fuel Level: EMPTY Ballast: 60 LBS (440 lb max)

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

Measured Vehicle Weights: (lb)					
LF:	1455	RF:	1448	Front Axle:	2903
LR:	1038	RR:	1077	Rear Axle:	2115
Left:	2493	Right:	2525	Total:	5018
					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:	59.20 inches	Rear of Front Axle	(63 ±4 inches allowed)		
Y:	0.22 inches	Left - Right +	of Vehicle Centerline		
Z:	29.00 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 C.3. Exterior Crush Measurements of Vehicle for Test No. 469688-5-1.

Date:	2018-07-06	Test No.:	469688-5-1	VIN No.:	1C6RR6FP8DS693034
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	AT FT BUMPER	24	11	16	11	6	3				-26
2	ABOVE FT BUMPER	24	10	47	2	2.5	3.5	5.5	7	11	+74
	inches										

[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.

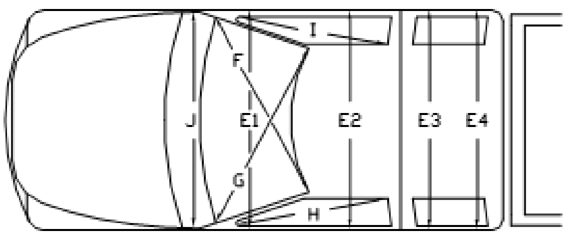
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

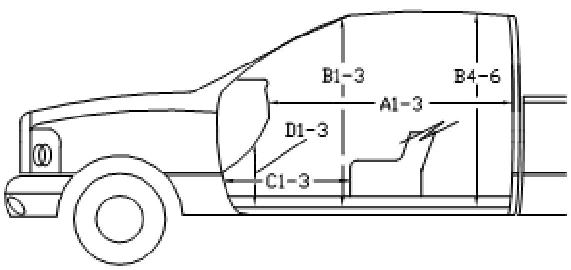
***Measure and document on the vehicle diagram the location of the maximum crush.

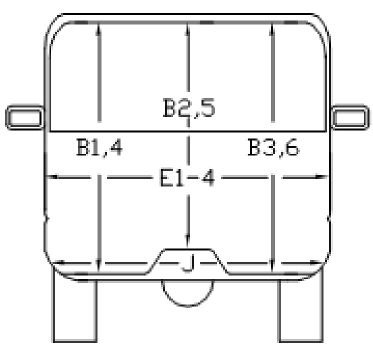
Note: Use as many lines/columns as necessary to describe each damage profile.

Table C.4. Occupant Compartment Measurements of Vehicle for Test No. 469688-1-2.

Date:	2018-07-06	Test No.:	469688-5-1	VIN No.:	1C6RR6FP8DS693034
Year:	2013	Make:	RAM	Model:	1500





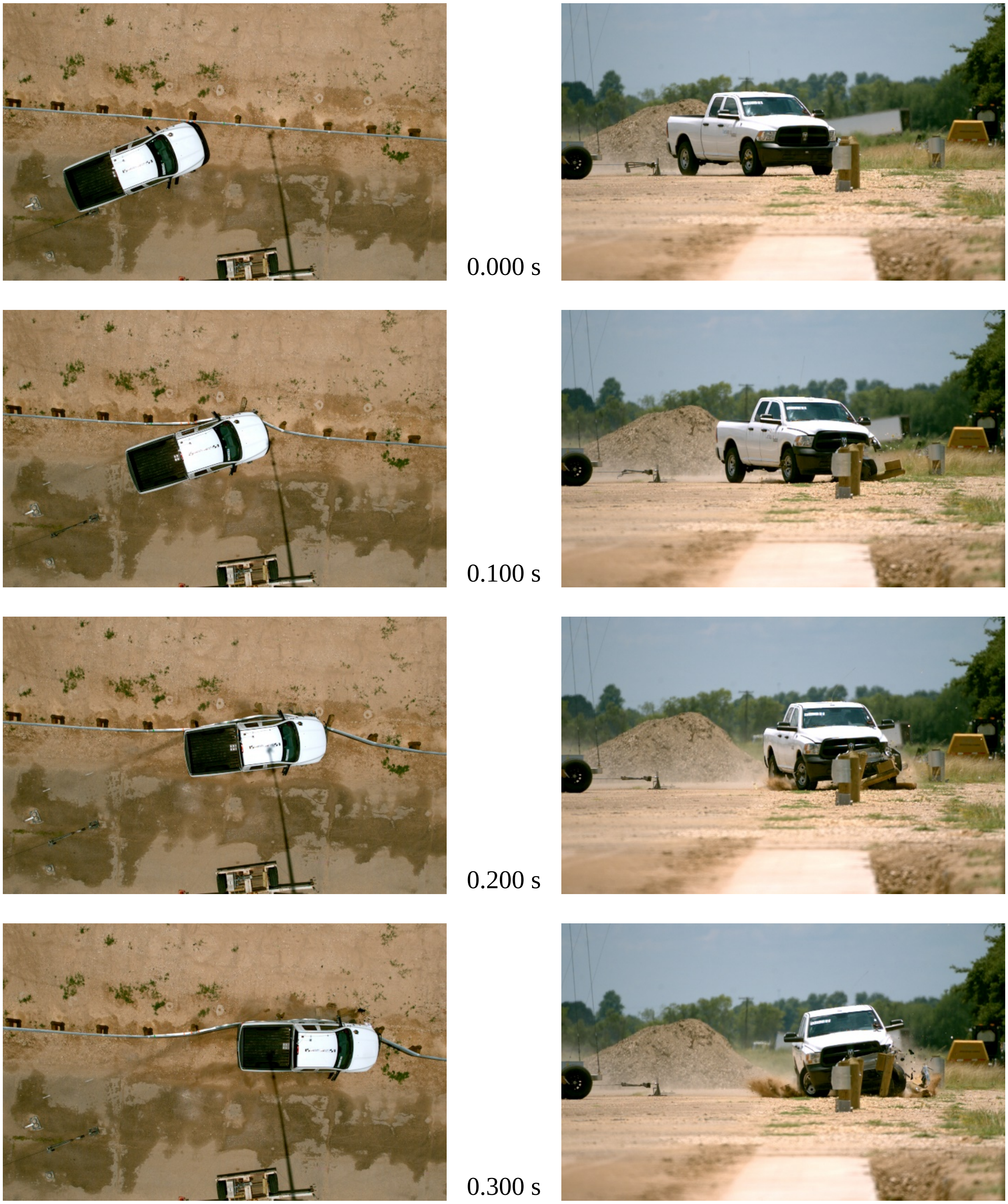


*Lateral area across the cab from driver's side kickpanel to passenger's side kickpanel.

OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

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

C.2 SEQUENTIAL PHOTOGRAPHS



0.000 s

0.100 s

0.200 s

0.300 s

Figure C.1. Sequential Photographs for Test No. 469688-5-1 (Overhead and Frontal Views).

0.400 s

0.500 s

0.600 s

0.700 s

Figure C.1. Sequential Photographs for Test No. 469688-5-1 (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 C.2. Sequential Photographs for Test No. 469688-5-1 (Rear View).

C.3 VEHICLE ANGULAR DISPLACEMENT

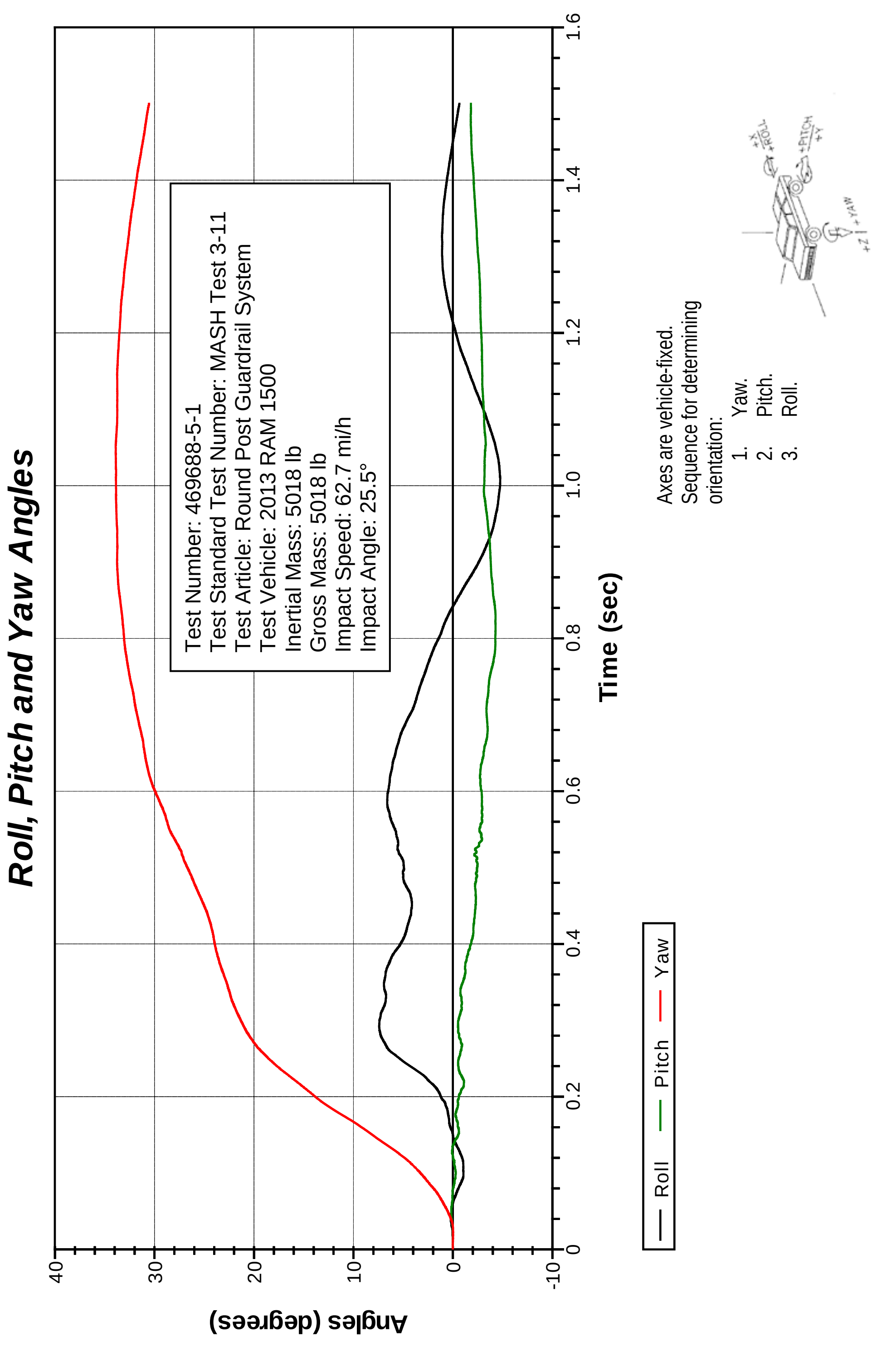


Figure C.3. Vehicle Angular Displacements for Test No. 469688-5-1.

C.4 VEHICLE ACCELERATIONS

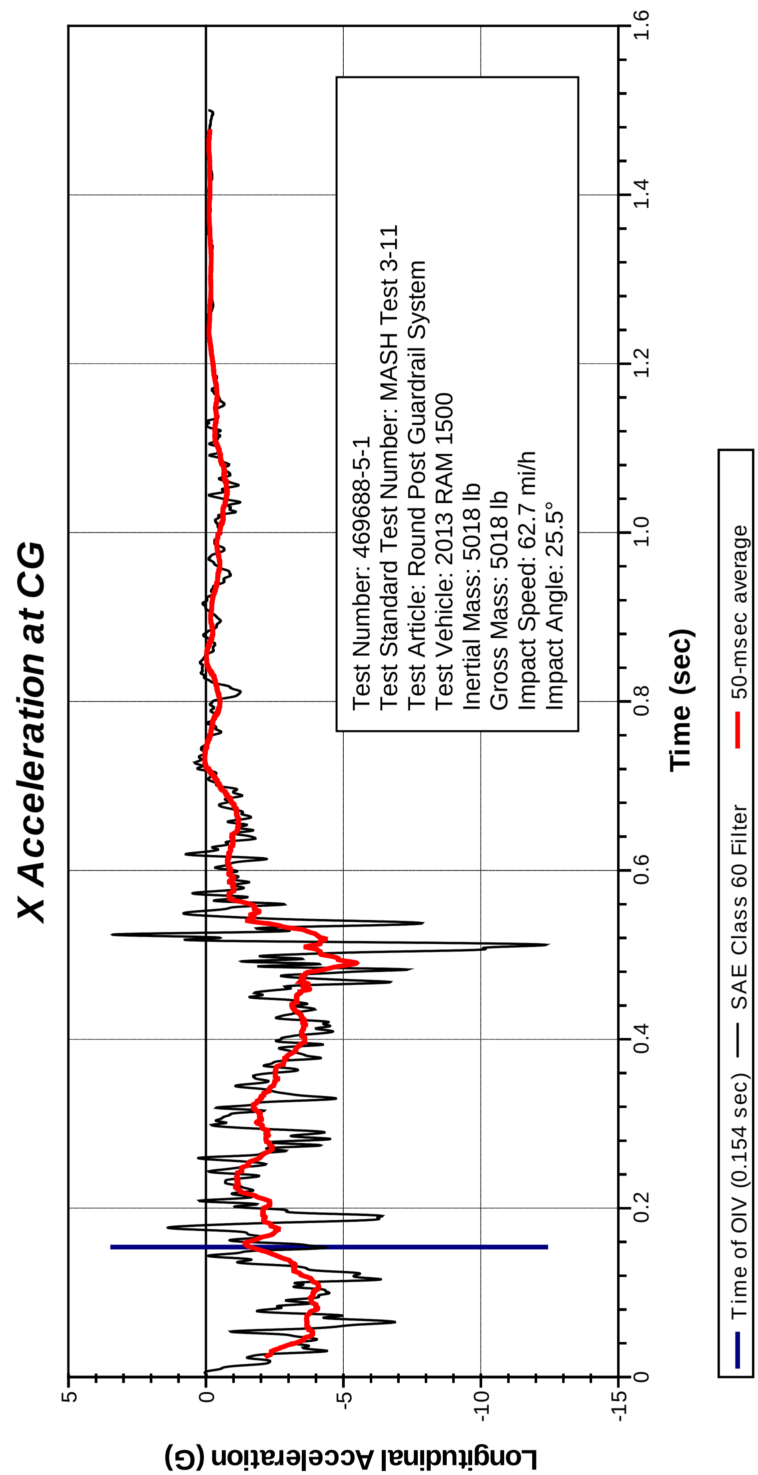


Figure C.4. Vehicle Longitudinal Accelerometer Trace for Test No. 469688-5-1 (Accelerometer Located at Center of Gravity).

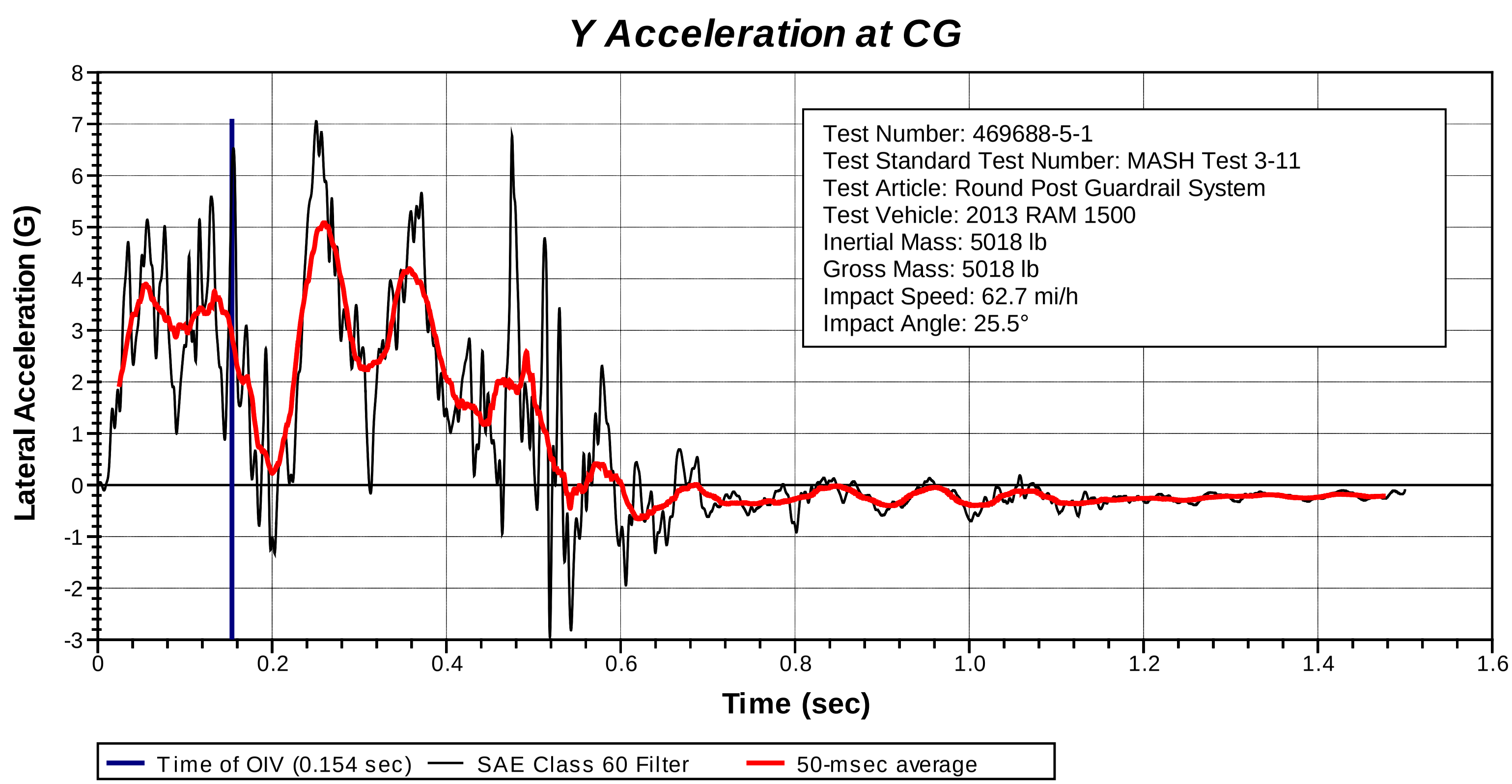


Figure C.5. Vehicle Lateral Accelerometer Trace for Test No. 469688-5-1 (Accelerometer Located at Center of Gravity).

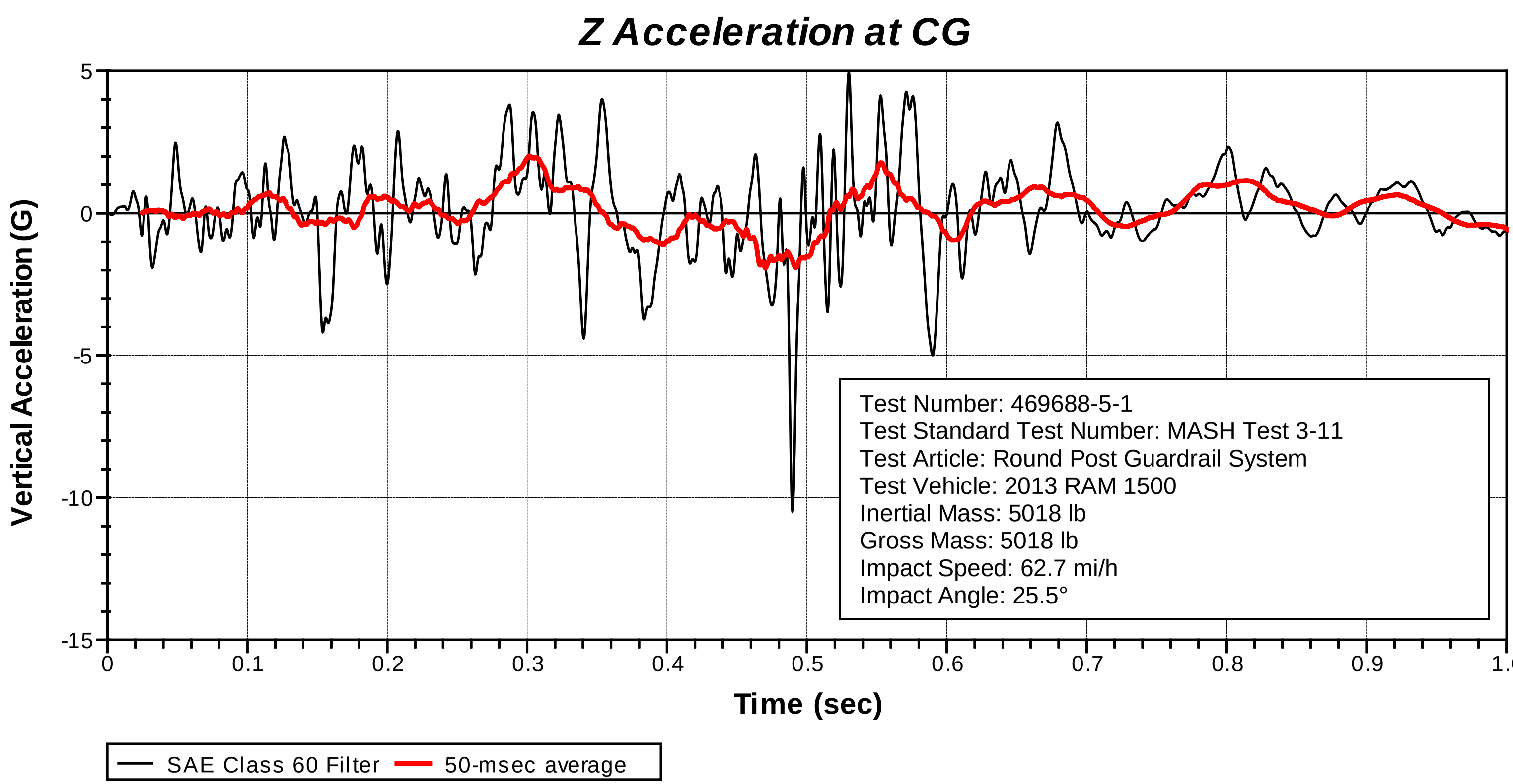


Figure C.6. Vehicle Vertical Accelerometer Trace for Test No. 469688-5-1 (Accelerometer Located at Center of Gravity).

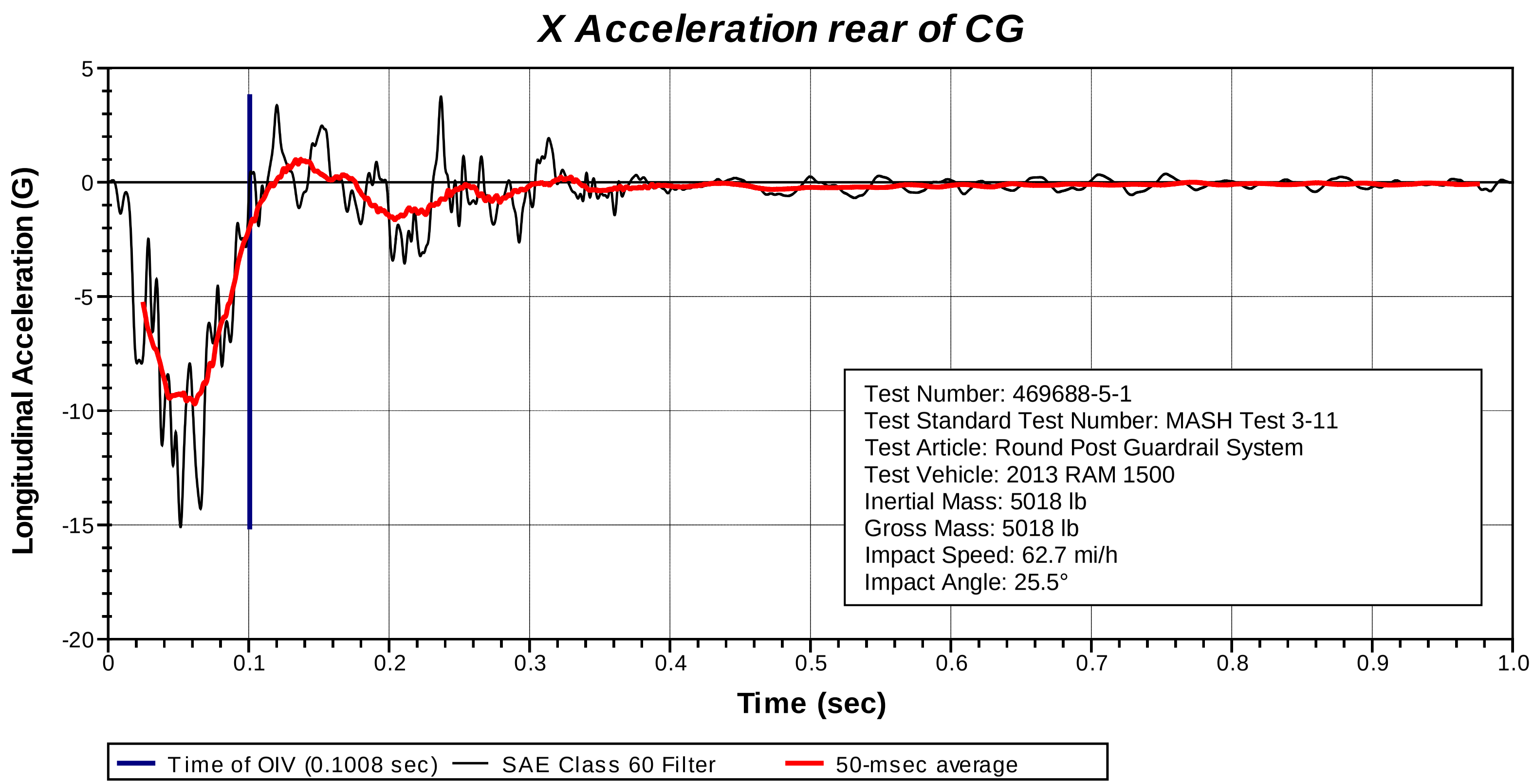


Figure C.7. Vehicle Longitudinal Accelerometer Trace for Test No. 469688-5-1 (Accelerometer Located Rear of Center of Gravity).

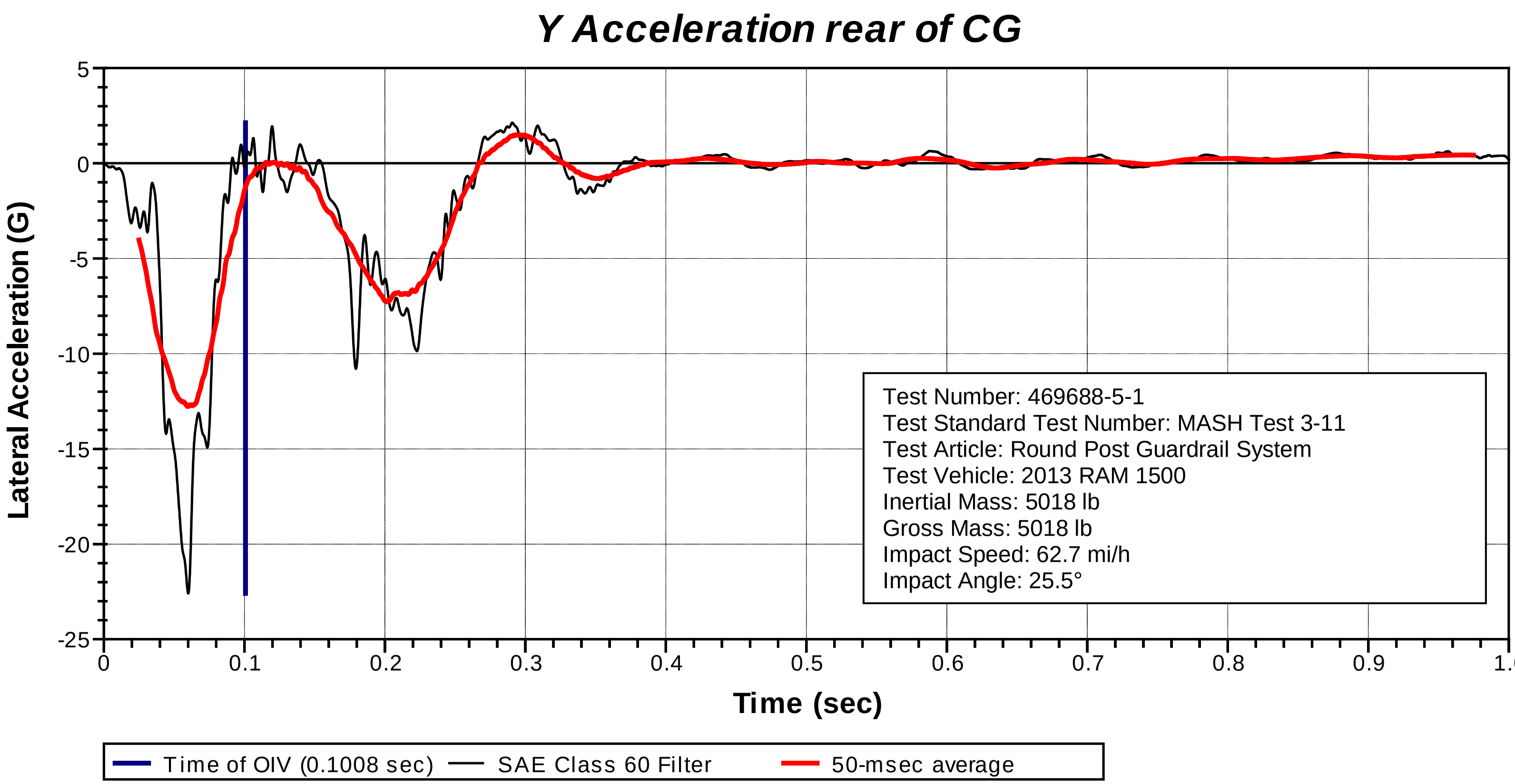


Figure C.8. Vehicle Lateral Accelerometer Trace for Test No. 469688-5-1 (Accelerometer Located Rear of Center of Gravity).

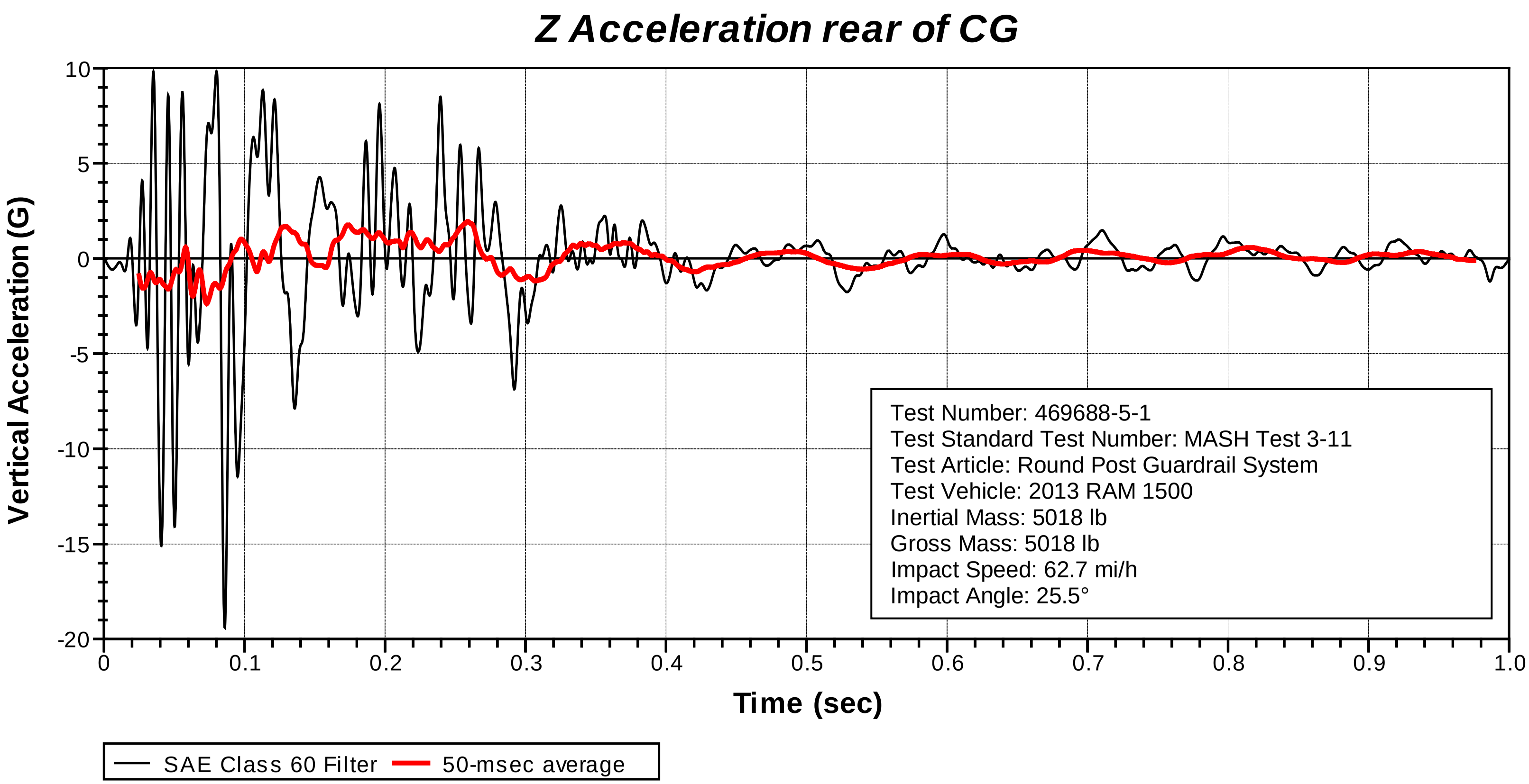


Figure C.9. Vehicle Vertical Accelerometer Trace for Test No. 469688-5-1 (Accelerometer Located Rear of Center of Gravity).