Texas A&M Transportation Institute
Proving Ground

Test Report No. 608221-1
Test Report Date: September 2017

MASH TEST 3-10 OF PENNDOT G2 WEAK POST W-BEAM GUARDRAIL

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16. Abstract

The purpose of the test reported herein was to assess the performance of the PennDOT G2 weak post W-beam guardrail system (herein, referred to as G2 weak post W-beam guardrail system) according to the safety-performance evaluation guidelines included in the American Association of State Highway and Transportation Officials (AASHTO), *Manual for Assessing Safety Hardware* (*MASH*). The crash test was performed in accordance with *MASH* Test 3-10, which involves an 1100C vehicle impacting the G2 weak post W-beam guardrail system at a target impact speed and impact angle of 62 mi/h and 25 degrees, respectively.

This report provides details of the G2 weak post W-beam guardrail system, documentation of the crash test performed, and the results and assessment of the performance of the G2 weak post W-beam guardrail system according to *MASH* Test 3-10 evaluation criteria.

The G2 weak post W-beam guardrail system contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the guardrail was 71.8 inches. A few of the W-beam backup plates separated from the installation, however, these 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 0.5 inch in the floor pan/toe pan area. No intrusion of the occupant compartment occurred. The 1100C vehicle remained upright during and after the collision period. Maximum roll and pitch angles were 12 degrees and 6 degrees, respectively. Occupant risk factors were within the preferred limits of *MASH*.

The PennDOT G2 weak post W-beam guardrail system performed acceptably for *MASH* Test 3-10.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSTIONS 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
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSTIONS 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
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		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. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Chapter 1. INTRODUCTION

Pennsylvania Department of Transportation (PennDOT) developed a variation of the weak post guardrail system (G2) that is referred to as the PennDOT Type 2 system. In 2000, under Texas A&M Transportation Institute (TTI) Research Project 473750, National Cooperative Highway Research Program (NCHRP) *Report 350* Tests 3-10 and 3-11 were performed on the modified PennDOT Type 2 guardrail (*1*,*2*). The Type 2 PennDOT (modified G2) guardrail successfully met *NCHRP Report 350* test conditions 3-10 and 3-11, thus fully qualifying it as an *NCHRP Report 350* TL-3 rail system.

The primary differences between the PennDOT Type 2 guardrail system and the G2 include an increase in the W-beam rail mounting height to 32 inches, the use of W-beam backup plates at the posts, and the relocation of the rail splices from the posts to mid-span between posts. Additionally, the rail mounting bolts and washers, and the post shelf bolt details differ from the original G2 system.

TTI researchers believed the modified weak-post W-beam guardrail system (G2) (PennDOT Type 2) warranted consideration for evaluation with the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) 2270P vehicle due to the height of the system and the opportunity for the weak-post systems to drop the rail off the posts in advance of the impacting vehicle, thus allowing the vehicle to travel over the rail element and behind the installation (*3*). The *MASH* 2270P test vehicle has demonstrated sensitivity to rail height. In addition, previous testing has shown that the impact performance of this system and other weak-post guardrail systems are sensitive to the post-to-rail attachment detail. Therefore, *MASH* test 3-11 was performed in NCHRP project 22-14(03) for the modified weak-post W-beam guardrail system (G2) (PennDOT Type 2) and reported in *NCHRP Web-Only Document 157* (*2*).

The modified G2 weak post W-beam guardrail (PennDOT Type 2) contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the weak post guardrail. Maximum dynamic deflection of the rail during the test was 8.6 ft. The rail element detached from several posts; however, it did not penetrate or show potential for penetrating the occupant compartment, or present hazard to others in the area. Maximum occupant compartment deformation was 0.25 inches in the lateral area across the cab at the driver's side hip area. The 2270P vehicle remained upright during and after the collision event. Maximum roll angle was 12 degrees. Occupant risk factors were within the limits specified in *MASH*. The 2270P vehicle remained within the exit box. The modified G2 weak post W-beam guardrail performed acceptably when impacted by the 2270P vehicle for *MASH* Test 3-11.

The purpose of the test reported herein was to assess the performance of the G2 weak post W-beam guardrail system according to the safety-performance evaluation guidelines included in the AASHTO *MASH* for Test 3-10. *MASH* Test 3-10 involves an 1100C vehicle impacting the G2 weak post W-beam guardrail system at a target impact speed and impact angle of 62 mi/h and 25 degrees, respectively.

This report provides details of the G2 weak post W-beam guardrail system, detailed documentation of the crash test results, and an assessment of the performance of the G2 weak post W-beam guardrail system according to *MASH* Test 3-10 evaluation criteria.

The test reported herein, along with the prior 3-11 test performed and reported in *NCHRP Web-Only Document 157*, complete the evaluation of the PennDOT G2 weak post W-beam guardrail system in accordance with *MASH*.

Chapter 2. SYSTEM DETAILS

2.1. TEST ARTICLE AND INSTALLATION DETAILS

The test installation was comprised of a 32-inch tall W-beam guardrail system utilizing PennDOT Type 2-W S3×5.7 guardrail posts with soil plates (posts 3-23), with a TxDOT Downstream Anchor Terminal (DAT-14) on each end for a total installation length of 281 ft-3 inches. Posts 3 to 23 were equally spaced at 12 ft-6 inches. Standard 12-gauge W-beam guardrail (type RWM02a) was used in the system, and guardrail splices were located mid-span between every post. Each DAT-14 end terminal was 31 inches tall and 9 ft-4½ inches long. The 32-inch tall guardrail transitioned to the 31-inch tall DAT terminals over a 25-ft long section adjacent to each terminal.

The W-beam guardrail was supported on each post by a ASTM A307 ½-inch diameter × 1½-inch long shelf hex bolt and two heavy hex nuts. The guardrail and a RWB01a back-up plate were secured to each post with a ASTM A307 $^{5}/_{16}$-inch diameter × 2⅜-inch long hex bolt, two 1¾-inch ×⅛-inch thick square plate washers, a $^{5}/_{16}$-inch flat washer, and two heavy hex nuts. The first nut was hand tightened plus one turn, and then secured with the second nut.

The posts were installed in 2-ft diameter holes drilled to the embedment depth of 33 inches and backfilled with Type B Grade 1 crushed limestone road base, compacted to *MASH* standards.

Figure 2.1 presents overall information on the G2 weak post W-beam guardrail system, and Figure 2.2 provides photographs of the installation. Appendix A provides further details of the G2 weak post W-beam guardrail system.

2.2. MATERIAL SPECIFICATIONS

Materials for the test article were supplied by Gannett-Fleming, Inc. (through Trinity Highway Products, LLC) and installed by TTI Proving Ground personnel. Dimensions of all supplied test installation components were verified via comparison with sponsor supplied drawings. Appendix B provides material certification documents for the materials used for the G2 weak post W-beam guardrail system.

2.3. SOIL CONDITIONS

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

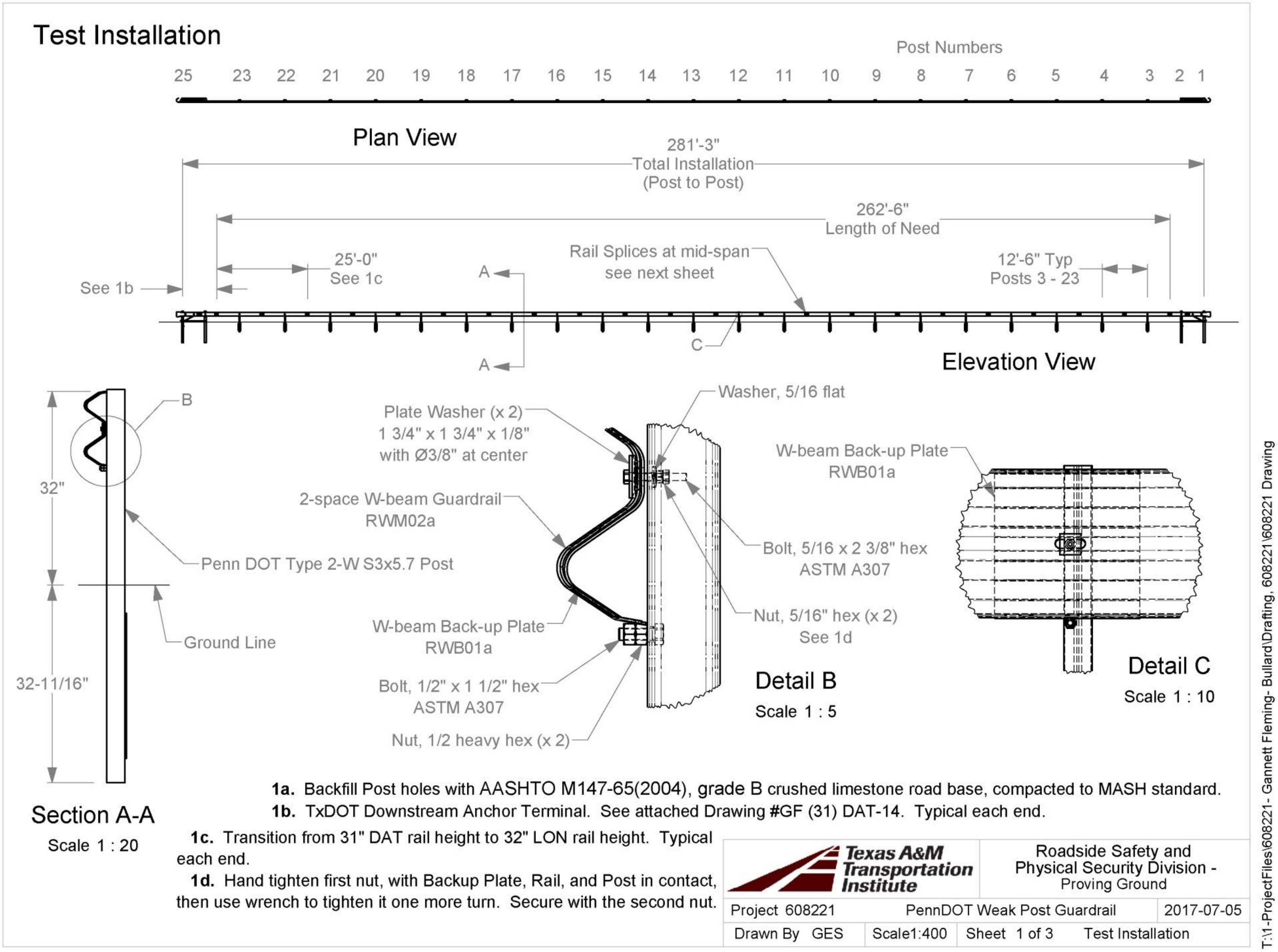


Figure 2.1. Details of the G2 Weak Post W-Beam Guardrail System.

Figure 2.2. G2 Weak Post W-Beam Guardrail System prior to Testing.

In accordance with Appendix B of *MASH*, soil strength was measured the day of the crash test. During installation of the G2 weak post W-beam guardrail system for full-scale crash testing, two W6×16 posts were installed in the immediate vicinity of the test installation utilizing the same fill materials and installation procedures used in the test installation and standard dynamic test (see Table C.1 in Appendix C for establishment of minimum soil strength properties in the dynamic test performed in accordance with *MASH* Appendix B).

As determined from the tests shown in Appendix C, Table C.1, the minimum post loads required for deflections at 5 inches, 10 inches, and 15 inches, measured at a height of 25 inches, are 3940 lb, 5500 lb, and 6540 lb, respectively (90% of static load for the initial standard installation). On the day of the test, July 14, 2017, loads on the post at deflections of 5 inches, 10 inches, and 15 inches were 7810 lbf, 8725 lbf, and 9350 lbf, respectively. Appendix C, Table C.2 shows that the strength of the backfill material in which the G2 weak post W-beam guardrail system was installed met minimum requirements.

Chapter 3. TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1. CRASH TEST PERFORMED

Table 3.1 shows the test conditions and evaluation criteria for *MASH* Test 3-10. *MASH* Test 3-10 involves an 1100C vehicle weighing 2420 lb ±55 lb and impacting the critical impact point (CIP) of the G2 weak post W-beam guardrail system at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The target CIP selected for the test was determined according to the information provided in *MASH* Section 2.3.2 and Figure 2-8, and was 15 ft ±1 ft upstream of a post nearest the centerline of the test installation, which equated to 30 inches upstream of post 12.

Table 3.1. Test Conditions and Evaluation Criteria Specified for *MASH* Test 3-10.

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

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 3-10 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 3-10.

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 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 G2 weak post W-beam guardrail system 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 as well as 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 is 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

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the front seat on the impact side of the 1100C vehicle. The dummy was not instrumented.

4.3.3 Photographic Instrumentation Data Processing

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

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

A flashbulb on the impacting vehicle was activated by a pressure-sensitive tape switch to indicate the instant of contact with the G2 weak post W-beam guardrail system. 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 3-10 (CRASH TEST NO. 608221-1)

5.1 TEST DESIGNATION AND ACTUAL IMPACT CONDITIONS

MASH Test 3-10 involves an 1100C vehicle weighing 2420 lb ±55 lb impacting the CIP of the G2 weak post W-beam guardrail system at an impact speed of 62 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The CIP for *MASH* Test 3-10 on the guardrail system was 15 ft ±1 ft upstream of a post nearest the centerline of the test installation, which equated to 30 inches upstream of post 12.

The 2011 Kia Rio used in the test weighed 2443 lb, and the actual impact speed and angle were 62.0 mi/h and 25.2 degrees, respectively. The actual impact point was 32.5 inches upstream of post 12. Minimum target impact severity (IS) was 51 kip-ft, and actual IS was 57 kip-ft.

5.2 WEATHER CONDITIONS

The test was performed on the morning of July 14, 2017. Weather conditions at the time of testing were as follows: wind speed: 3 mi/h; wind direction: 53 degrees (vehicle was traveling in a southwesterly direction); temperature: 93°F; relative humidity: 55 percent.

5.3 TEST VEHICLE

The 2011 Kia Rio, shown in Figures 5.1 and 5.2, was used for the crash test. The vehicle's test inertia weight was 2443 lb, and its gross static weight was 2608 lb. The height to the lower edge of the vehicle bumper was 7.5 inches, and height to the upper edge of the bumper was 21.5 inches. Table D.1 in Appendix D1 gives additional dimensions and information on the vehicle. The vehicle 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. G2 Weak Post W-Beam Guardrail System/Test Vehicle Geometrics for Test No. 608221-1.

Figure 5.2. Test Vehicle before Test No. 608221-1.

5.4 TEST DESCRIPTION

The test vehicle, traveling at an impact speed of 62.0 mi/h, contacted the G2 weak post W-beam guardrail system 32.5 inches upstream of post 12 at an impact angle of 25.2 degrees. Table 5.1 lists times and significant events that occurred during Test No. 608221-1. Figures D.1 and D.2 in Appendix D2 present sequential photographs during the test.

Table 5.1. Events during Test No. 608221-1.

TIME (s)	EVENTS
0.008	Post #12 begins to rotate counterclockwise and deflect to field side
0.020	Bumper impacts Post #12
0.025	Post #12 detaches from guardrail
0.030	Right front tire impacts Post #12
0.031	Post #11 begins to deflect to field side
0.032	Vehicle begins to redirect
0.047	Post #13 begins to deflect to field side
0.048	W-beam backup plate separates from guardrail at Post #12
0.096	Post #13 detaches from guardrail
0.111	Top of passenger door opens slightly
0.137	Dummy head close but does not appear to impact window glass
0.139	W-beam backup plate separates from guardrail at Post #13
0.141	Guardrail at Post #11 lifts off of shoulder bolt
0.142	Post #14 detaches from guardrail
0.199	W-beam backup plate separates from guardrail at Post #14
0.239	W-beam backup plate separates from guardrail at Post #15
0.250	Guardrail overrides top of Post #15
0.285	W-beam backup plate separates from guardrail at Post #16
0.296	Guardrail over rides top of Post #16
0.316	Vehicle traveling parallel with the guardrail

Table 5.1 Events during Test No. 608221-1 (Continued).

TIME (s)	EVENTS
0.360	Max deflection of guardrail between Posts #13 and #14
0.390	Working width measured to bumper cover
0.979	Guardrail splice between Posts #12 and #13 touches ground
1.575	Vehicle loses contact with guardrail traveling at 45.6 mi/h and 3.7 degrees

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 impact for cars and pickups). The 2270P vehicle exited within the exit box criteria defined in *MASH*. Brakes on the vehicle were applied at 3.4 s, and the vehicle subsequently came to rest 248 ft downstream of the impact and 20 ft toward traffic.

5.5 DAMAGE TO TEST INSTALLATION

Figures 5.3 through 5.7 show the damage to the G2 weak post W-beam guardrail system. Post 1 was pulled downstream 1 inch, and the rail element released from posts 10 through 19. Post 11 displaced 2.5 inches toward the field side and was leaning toward the field side 79 degrees. Posts 12 through 18 were leaning downstream at approximately 15 degrees from horizontal. Post 19 was leaning downstream at 39 degrees. Eight backup plates separated from the rail element and posts, and all came to rest 7 ft to 50 ft toward the field side. Working width was 92.0 inches at a height of 35.6 inches above ground. Maximum dynamic deflection during the test was 71.8 inches, and maximum permanent deformation was 28.0 inches.

Figure 5.3. G2 Weak Post W-Beam Guardrail System and Test Vehicle after Test No. 608221-1.

Figure 5.4. G2 Weak Post W-Beam Guardrail System after Test No. 608221-1.

Figure 5.5. Posts 11 through 14 after Test No. 608221-1.

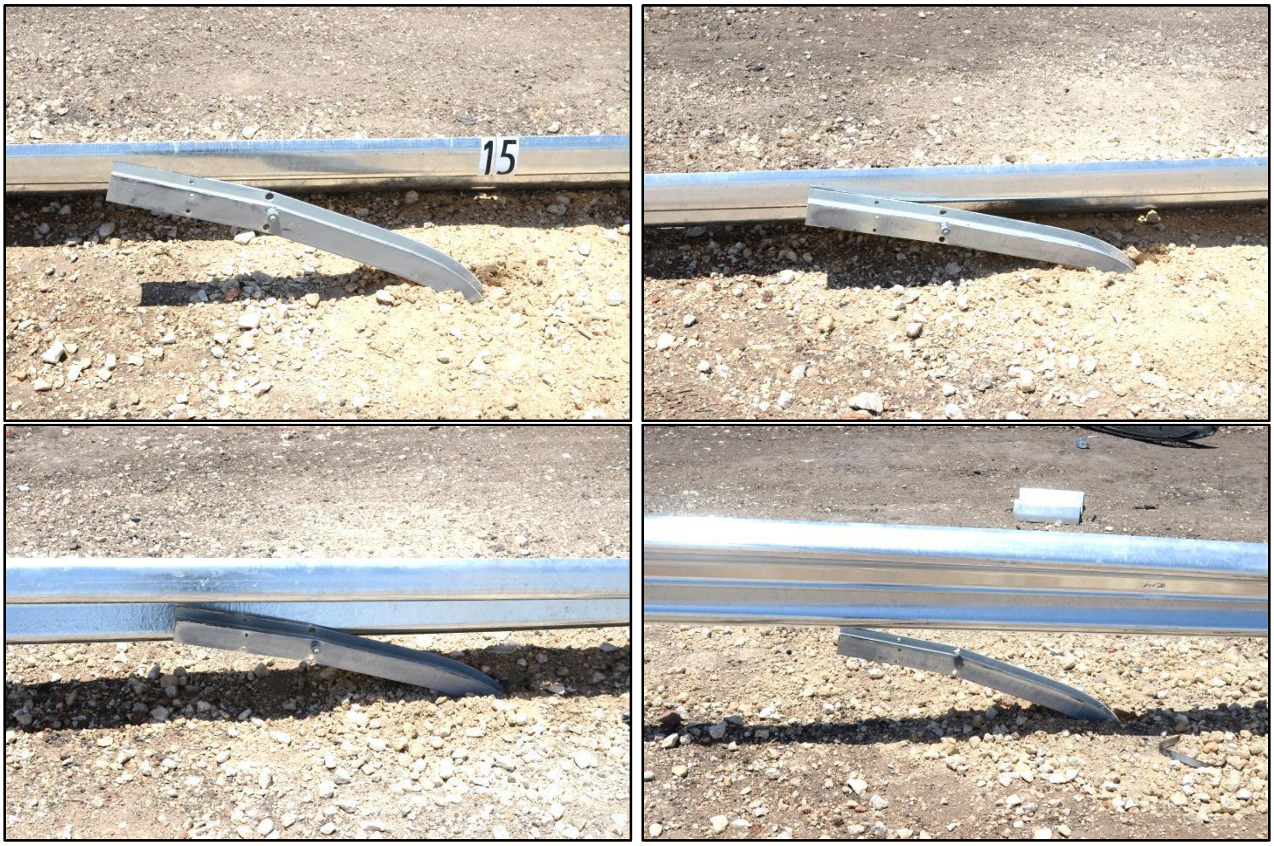


Figure 5.6. Posts 15 through 18 after Test No. 608221-1.

Figure 5.7. Field Side of G2 Weak Post W-Beam Guardrail System after Test No. 608221-1.

5.6 VEHICLE DAMAGE

Figures 5.8 and 5.9 show the damage sustained by the vehicle. The front bumper, hood, radiator support, right front fender, right front strut and tower, right front tire, right front and rear doors, right rear quarter panel, and left rear tire were damaged. Several small scrapes were noted on the underside of the vehicle (see Figure 5.9), including the floor pan, oil pan, fuel tank, and trunk floor. No punctures were observed anywhere on the vehicle. Maximum exterior crush to the vehicle was 9.25 inches in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation was 0.5 inches in the floor pan/toe pan area. Figure 5.10 shows the interior of the vehicle. Tables D.2 and D.3 in Appendix D1 provide exterior crush and occupant compartment measurements.

Figure 5.8. Test Vehicle after Test No. 608221-1.

Figure 5.9. Under Side of Test Vehicle after Test No. 608221-1.

Before Test After Test

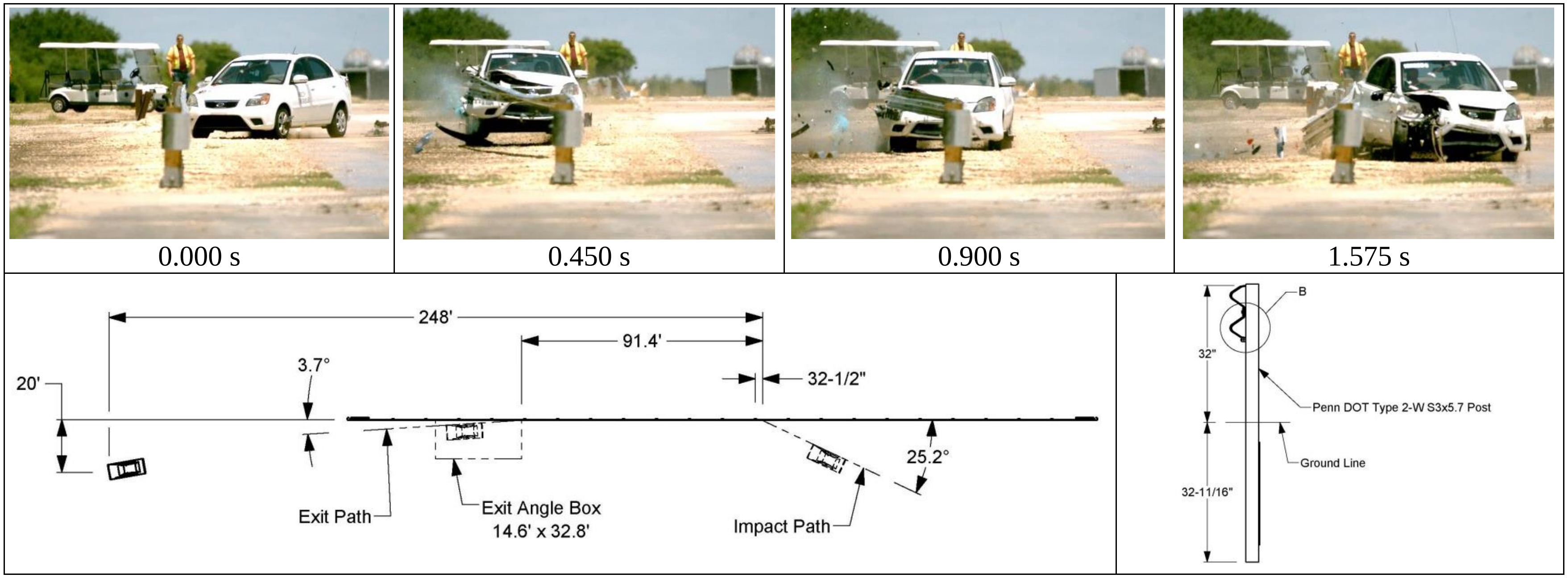
Figure 5.10. Interior of Test Vehicle for Test No. 608221-1.

5.7 OCCUPANT RISK FACTORS

Data from the accelerometer, located at the vehicle center of gravity, were digitized for evaluation of occupant risk. Results are shown in Table 5.2. Figure 5.11 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 accelerations versus time traces.

Table 5.2. Occupant Risk Factors for Test No. 608221-1.

Occupant Risk Factor	Value	Time
Impact Velocity		
Longitudinal	**13.4 ft/s**	at 0.1695 s on right side of interior
Lateral	**13.8 ft/s**	
Ridedown Accelerations		
Longitudinal	**4.8 g**	0.5028 - 0.5128 s
Lateral	**5.9 g**	0.3814 - 0.3914 s
THIV	**20.4 km/h** **5.7 m/s**	at 0.1627 s on right side of interior
PHD	**6.0 g**	0.3813 - 0.3913 s
ASI	**0.45**	0.1423 - 0.1923 s
Maximum 50-ms Moving Average		
Longitudinal	**-3.6 g**	0.1020 - 0.1520 s
Lateral	**-3.6 g**	0.0938 - 0.1438 s
Vertical	**-2.4 g**	0.1848 - 0.2348 s
Maximum Roll, Pitch, and Yaw Angles		
Roll	**11.6°**	0.2672 s
Pitch	**6.3°**	1.0843 s
Yaw	**35.7°**	1.6296 s



General Information

Test Agency	Texas A&M Transportation Institute (TTI)
Test Standard Test No.	MASH Test 3-10
TTI Test No.	608221-1
Test Date	2017-07-14
Test Article	
Type	Longitudinal Barrier - Guardrail
Name	G2 Weak Post W-Beam Guardrail
Installation Length	281 ft 3 inches
Material or Key Elements	32-inch tall W-beam guardrail system with PennDOT Type 2-W S3×5.7 posts with soil plates, and TxDOT DAT-14 terminals
Soil Type and Condition	AASHTO M147-65(2004), grading B Soil (crushed limestone), Damp
Test Vehicle	
Type/Designation	1100C
Make and Model	2011 Kia Rio
Curb	2495 lb
Test Inertial	2443 lb
Dummy	165 lb
Gross Static	2608 lb

Impact Conditions

Speed	62.0 mi/h
Angle	25.2 degrees
Location/Orientation	32.5 inches upstrm of Post 12
Impact Severity	57 kip-ft
Exit Conditions	
Speed	45.6 mi/h
Angle	3.7 degrees
Occupant Risk Values	
Longitudinal OIV	13.4 ft/s
Lateral OIV	13.8 ft/s
Longitudinal Ridedown	4.8 g
Lateral Ridedown	5.9 g
THIV	20.4 km/h
PHD	6.0 g
ASI	0.45
Max. 0.050-s Average	
Longitudinal	-3.6 g
Lateral	-3.6 g
Vertical	-2.4 g

Post-Impact Trajectory

Stopping Distance	248 ft downstream 20 ft twd traffic
Vehicle Stability	
Maximum Yaw Angle	36 degrees
Maximum Pitch Angle	6 degrees
Maximum Roll Angle	12 degrees
Vehicle Snagging	No
Vehicle Pocketing	No
Test Article Deflections	
Dynamic	71.8 inches
Permanent	28.0 inches
Working Width	92.0 inches
Height of Working Width	35.6 inches
Vehicle Damage	
VDS	01RFQ4
CDC	01FREW4
Max. Exterior Deformation	9.25 inches
OCDI	RF0001000
Max. Occupant Compartment Deformation	0.5 inches

Figure 5.11. Summary of Results for *MASH* Test 3-10 on G2 Weak Post W-Beam Guardrail System.

Chapter 6. SUMMARY AND CONCLUSIONS

6.1. ASSESSMENT OF TEST RESULTS

An assessment of the test based on the applicable safety evaluation criteria for *MASH* Test 3-10 is provided in Table 6.1.

6.2 CONCLUSIONS

The G2 weak post W-beam guardrail system contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the guardrail was 71.8 inches. A few of the W-beam backup plates separated from the installation, however, these did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard for others in the area. Maximum occupant compartment deformation was 0.5 inch in the floor pan/toe pan area. No intrusion of the occupant compartment occurred. The 1100C vehicle remained upright during and after the collision period. Maximum roll and pitch angles were 12 degrees and 6 degrees, respectively. Occupant risk factors were within the preferred limits of *MASH*.

The G2 weak post W-beam guardrail system performed acceptably for *MASH* Test 3-10.

The test reported herein along with the prior 3-11 test performed and reported in *NCHRP Web Document 157* complete the evaluation of the PennDOT G2 weak post W-beam guardrail system in accordance with *MASH*.

Table 6.1. Performance Evaluation Summary for *MASH* Test 3-10 on G2 Weak Post W-Beam Guardrail System.

Test Agency: Texas A&M Transportation Institute | Test No.: 608221-1 | Test Date: 2017-07-14

MASH Test 3-10 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 G2 weak post W-beam guardrail system contained and redirected the 1100C vehicle. The vehicle did not penetrate, underride, or override the installation. Maximum dynamic deflection of the guardrail was 71.8 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.	Several of the W-beam backup plates separated from the installation, however, these did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard for others in the area.	Pass
Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH.	Maximum occupant compartment deformation was 0.5 inch in the floor pan/toe pan area. No intrusion of the occupant compartment occurred.	
F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	The 1100C vehicle remained upright during and after the collision period. Maximum roll and pitch angles were 12 degrees and 6 degrees, respectively.	Pass
H. Occupant impact velocities (OIV) should satisfy the following limits: Preferred value of 30 ft/s, or maximum allowable value of 40 ft/s.	Longitudinal OIV was 13.4 ft/s, and lateral OIV was 13.8 ft/s.	Pass
I. The occupant ridedown accelerations should satisfy the following limits: Preferred value of 15.0 g, or maximum allowable value of 20.49 g.	Longitudinal occupant ridedown acceleration was 4.8 g, and lateral occupant ridedown acceleration was 5.9 g.	Pass

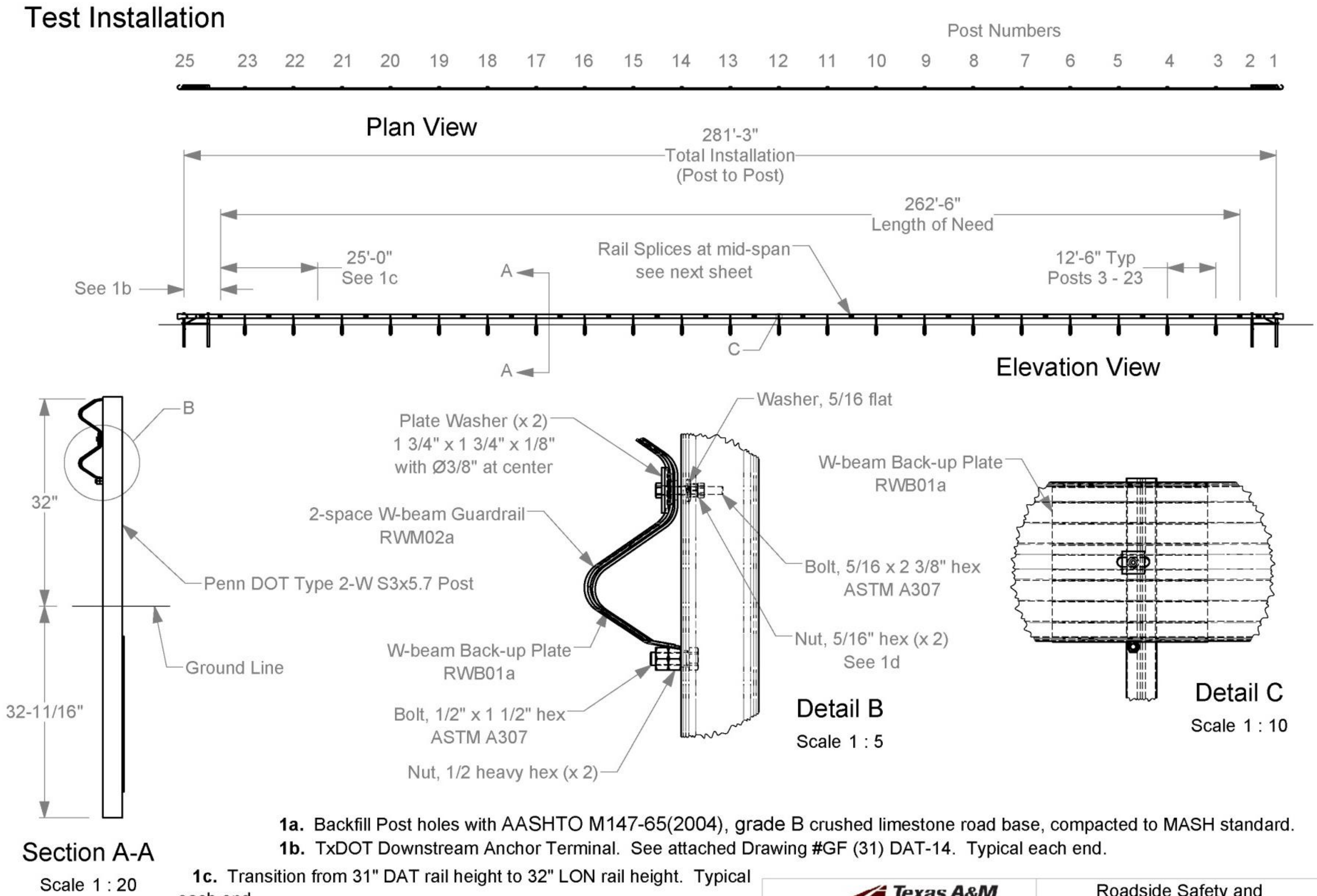
REFERENCES

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

2. D. Lance Bullard, Jr., Roger P. Bligh, Wanda L. Menges, and Rebecca R. Haug. *Volume I: Evaluation of Existing Roadside Safety Hardware Using Updated Criteria—Technical Report*. *NCHRP Web-Only Document 157*, Texas A&M Transportation Institute, College Station, TX, March 2010.

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

APPENDIX A. DETAILS OF THE G2 WEAK POST W-BEAM GUARDRAIL SYSTEM



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

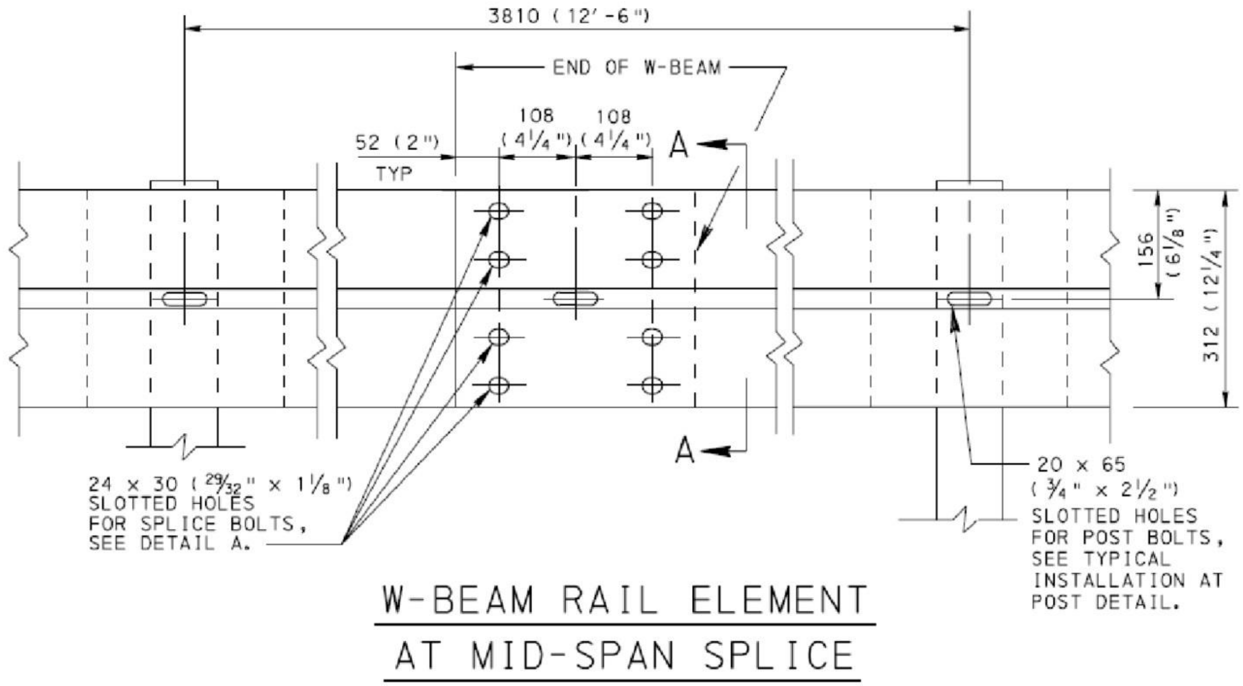
1b. TxDOT Downstream Anchor Terminal. See attached Drawing #GF (31) DAT-14. Typical each end.

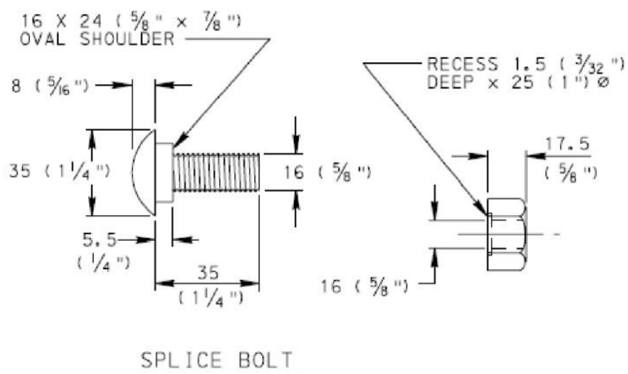
1c. Transition from 31" DAT rail height to 32" LON rail height. Typical each end.

1d. Hand tighten first nut, with Backup Plate, Rail, and Post in contact, then use wrench to tighten it one more turn. Secure with the second nut.

Texas A&M Transportation Institute		Roadside Safety and Physical Security Division - Proving Ground	
Project 608221	PennDOT Weak Post Guardrail		2017-07-05
Drawn By GES	Scale1:400	Sheet 1 of 3	Test Installation

T:\1-ProjectFiles\608221- Gannett Fleming- Bullard\Drafting, 608221\608221 Drawing





Rail Splice Details

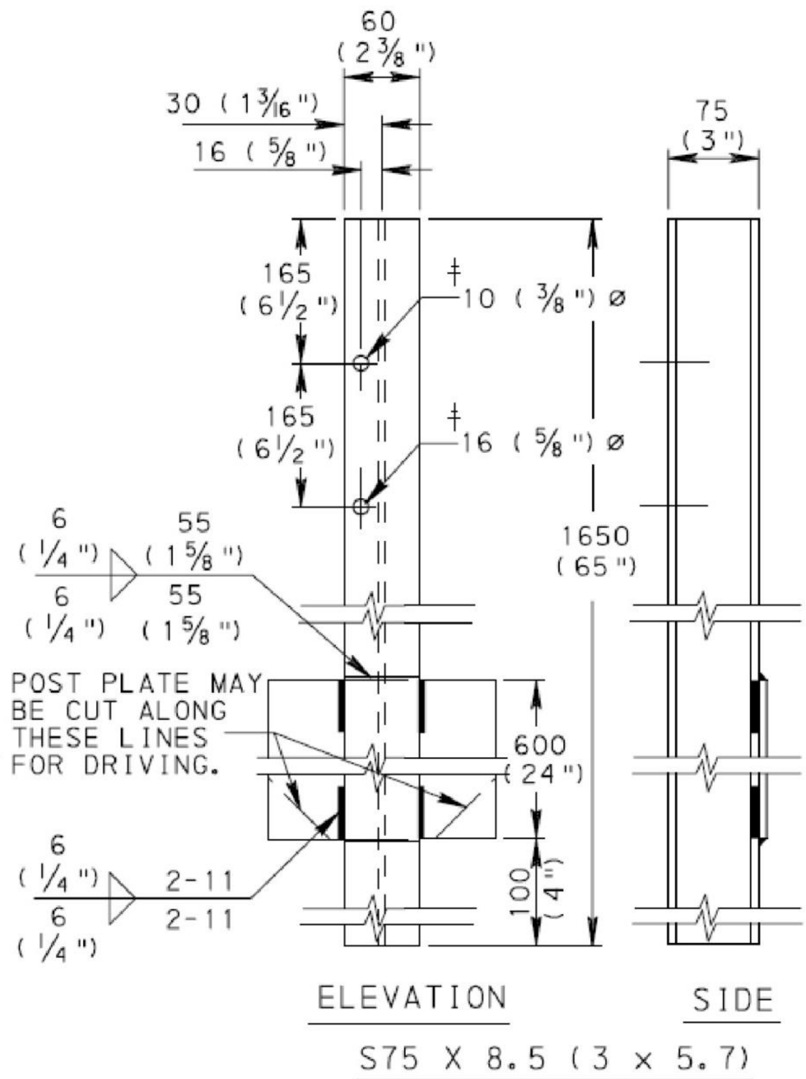
(excerpts from PennDOT *Type 2 Weak Post Guide Rail* Drawing #RC-53M, dated 2010)

Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project 608221	PennDOT Weak Post Guardrail	2017-07-05
Drawn By GES	Scale1:400	Sheet 2 of 3 Splice Details

T:\1-ProjectFiles\608221- Gannett Fleming- Bullard\Drafting, 608221\608221 Drawing

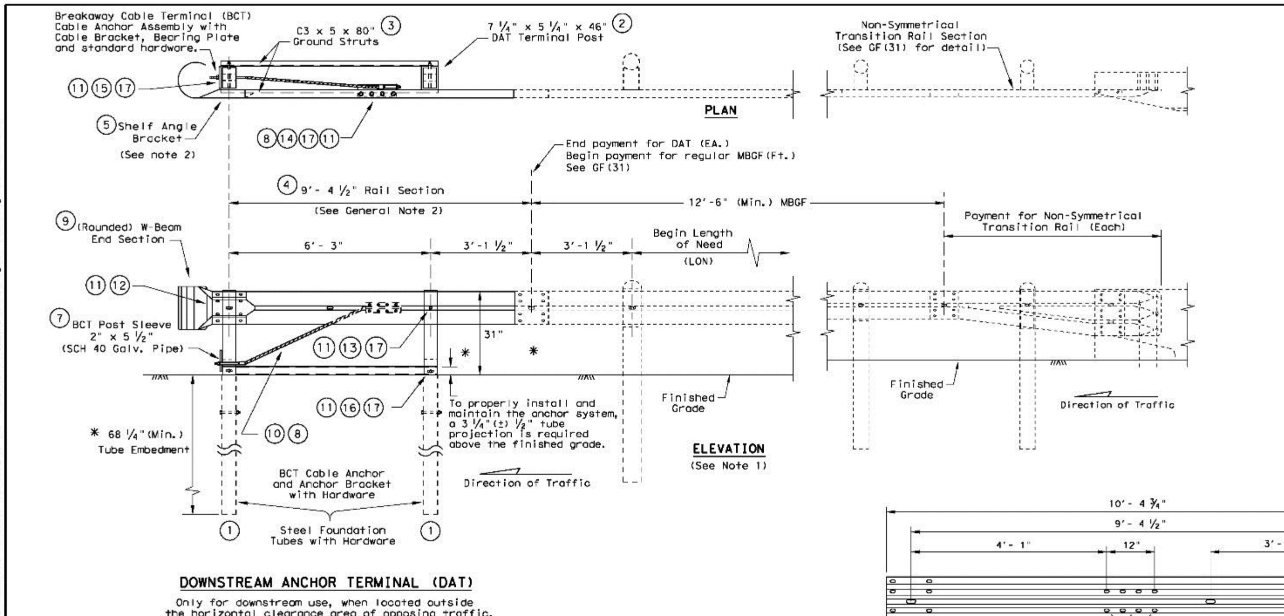
PennDOT Type 2-W S3x5.7 Post Details

(detail below is excerpt from PennDOT *Type 2 Weak Post Guide Rail* Drawing #RC-53M, dated 2010)



Texas A&M Transportation Institute	Roadside Safety and Physical Security Division - Proving Ground	
Project #608221 PennDOT Weak Post Guardrail		2017-07-05
Drawn by GES	Scale 1:400	Sheet 3 of 3 / Post Details

T:\1-ProjectFiles\608221- Gannett Fleming- Bullard\Drafting, 608221\608221 Drawing



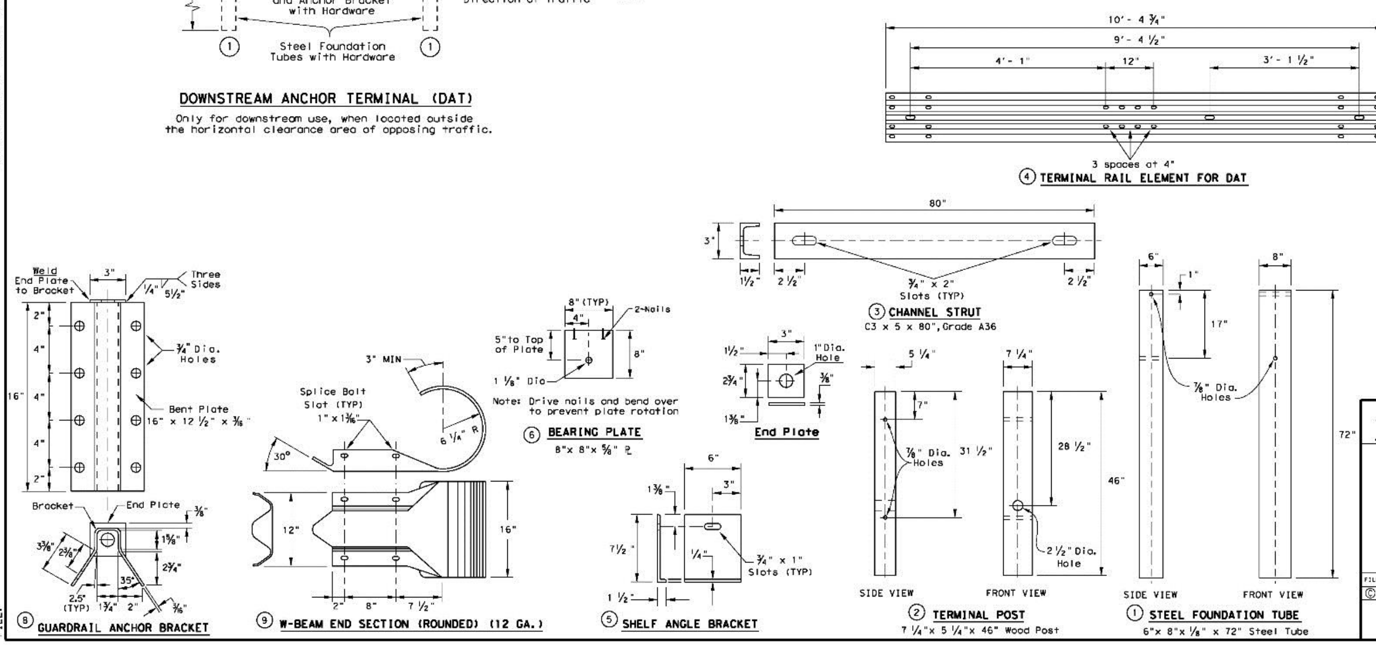
GENERAL NOTES

1. The detail shown is the minimum Length of Need (LON) for a DAT connected to a concrete rail.
2. The rail section at the end post is supported by the Shelf Angle Bracket. The rail element is not attached to the end post.
3. The foundation tubes shall not project more than 3 3/4" above the finished grade.
4. All hardware for DAT shall be ASTM A307 unless otherwise shown.
5. Refer to GF(31) sheet for terminal connection details.

MOW STRIP INSTALLATION

If a mow strip is required with the DAT installation the leave-out area around the steel foundation tubes and the two channel struts may be omitted. This will require a full pour at the foundation tubes.

#	(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 1/4" Button Head Bolt	4
13	10" Button Head Bolt	2
14	5/8" x 2" Hex Head Bolt	8
15	5/8" x 8" Hex Head Bolt	4
16	5/8" x 10" Hex Head Bolt	2
17	5/8" Flat Washer	18



Texas Department of Transportation

Design Division Standard

METAL BEAM GUARD FENCE
(Downstream Anchor Terminal)

GF(31)DAT-14

FILE: gf31dt14.dgn | DN: TxDOT | CK: AM | DW: YP | CK: CCL

© TxDOT: December 2011 | CONT | SECT | JOB | HIGHWAY

REVISIONS | DIST | COUNTY | SHEET NO.

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: TEXAS A&M TRANS INSTITUTE
ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135

Order Number: 1281406 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: #608221 PennDOT
BOL Number: 67440 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 6/28/17

Project: #608221 PennDot Weak Post Gr

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
4	724G	6'0 TUBE SL/.125X8X6	A-500			A83576	70,400	90,800	28.8	0.200	0.480	0.009	0.001	0.030	0.090	0.001	0.060	0.001	4
2	850G	12/BUFFER/ROLLED	M-180	A	2	11704360	49,800	62,200	33.0	0.060	0.520	0.009	0.003	0.030	0.080	0.002	0.030	0.003	4
2	3000G	CBL 3/4X6'6/DBL	HW			268241													
4	4140B	WD 4'0.25 POST 5.5X7.5	HW			TX-5372													
86	4303G	1/2" HEX NUT A563 GR A	HW			P37003													
4	19481G	C3X5#X6'-8" RUBRAIL	A-36			JW16106292	56,000	73,300	26.0	0.110	0.780	0.010	0.024	0.200	0.230	0.000	0.240	0.036	4
2	20207G	12/9'4.5/8-HOLE ANCH/S	RHC		2	L24916													4
			M-180	A	2	207477	62,700	81,130	23.3	0.200	0.720	0.014	0.004	0.030	0.130	0.000	0.080	0.000	4
			M-180	A	2	207481	63,200	81,210	26.9	0.200	0.730	0.012	0.003	0.030	0.120	0.000	0.070	0.000	4
			M-180	A	2	207684	61,620	81,370	24.2	0.200	0.730	0.012	0.002	0.020	0.090	0.000	0.050	0.002	4
			M-180	A	2	207685	63,600	80,670	25.3	0.190	0.710	0.015	0.002	0.020	0.100	0.000	0.070	0.000	4
			M-180	A	2	207686	61,690	80,740	25.0	0.190	0.710	0.011	0.003	0.020	0.090	0.000	0.050	0.001	4
			M-180	A	2	207687	61,690	80,100	23.6	0.180	0.730	0.014	0.004	0.020	0.100	0.000	0.070	0.000	4
			M-180	A	2	208320	62,280	81,680	23.4	0.190	0.730	0.011	0.003	0.020	0.120	0.000	0.060	0.002	4
			M-180	A	2	208321	60,680	79,990	26.9	0.190	0.740	0.014	0.004	0.020	0.100	0.000	0.050	0.001	4
			M-180	A	2	208322	62,340	80,640	24.5	0.190	0.730	0.011	0.003	0.020	0.110	0.000	0.060	0.002	4
2	36120A	DAT-31-TX-HDW-CAN	A-36			2051048	54,500	75,900	28.0	0.150	0.640	0.009	0.027	0.200	0.300	0.015	0.038	0.000	4
	36120A		HW			p37486													
	36120A		HW			17-35-010													

1 of 3

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: TEXAS A&M TRANS INSTITUTE
ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135

Project: #608221 PennDot Weak Post Gr

Order Number: 1281406 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: #608221 PennDOT
BOL Number: 67440 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 6/28/17

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
	36120A		HW			P37490													
	36120A		HW			P36286													
	36120A		HW			29783-B													
	36120A		HW			P37510													
	36120A		HW			p37423													
	36120A		HW			29495													
	36120A		HW			29849-B													
	36120A		A-36			4153553	46,400	70,000	33.0	0.200	0.400	0.010	0.007	0.010	0.030	0.001	0.030	0.001	4
	36120A		A-36			W6L617	52,000	75,000	26.0	0.190	0.910	0.010	0.003	0.240	0.250	0.000	0.100	0.003	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy QMS-LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT , 23 CFR 635.410.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36 UNLESS OTHERWISE STATED.

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT", 23 CFR 635.410.
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A-123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

FINISHED GOOD PART NUMBERS ENDING IN SUFFIX B,P, OR S, ARE UNCOATED

Certified Analysis

Trinity Highway Products , LLC
2548 N.E. 28th St.
Ft Worth (THP), TX 76111 Phn:(817) 665-1499

Customer: TEXAS A&M TRANS INSTITUTE
ROADSIDE SAFETY & PHYSICA
BUSINESS OFFICE
3135 TAMU
COLLEGE STATION, TX 77843-3135

Project: #608221 PennDot Weak Post Gr

Order Number: 1281406 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: #608221 PennDOT
BOL Number: 67440 Ship Date:
Document #: 1
Shipped To: TX
Use State: TX

As of: 6/28/17

BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
WASHERS COMPLY WITH ASTM F-436 SPECIFICATION AND/OR F-844 AND ARE GALVANIZED IN ACCORDANCE WITH ASTM F-2329.
3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 46000 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 28th day of June, 2017 .

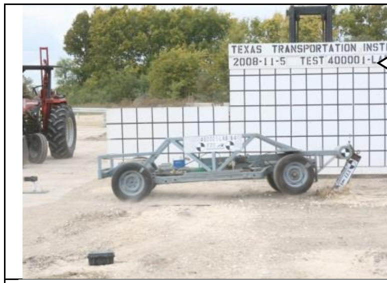
Notary Public:
Commission Expires:

JOMARY LUGINSLAND
Notary Public, State of Texas
My Commission Expires
May 28, 2019

Jomary Luginsland

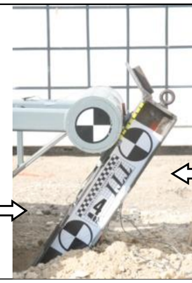
Trinity Highway Products , LLC
Certified By: Luis Ortiz
Quality Assurance

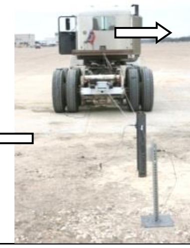
Table C.1. Summary of Strong Soil Test Results for Establishing Installation Procedure.



Dynamic Setup

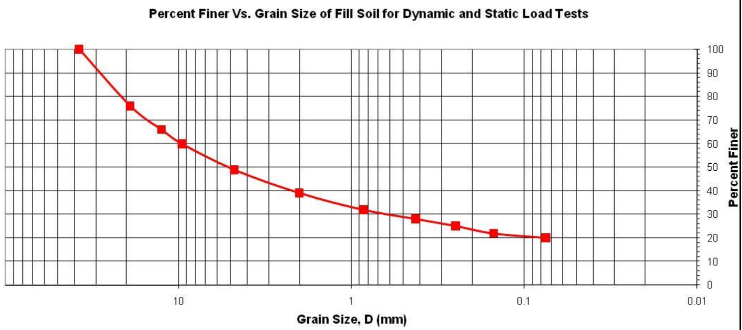
Post-Test Photo of post



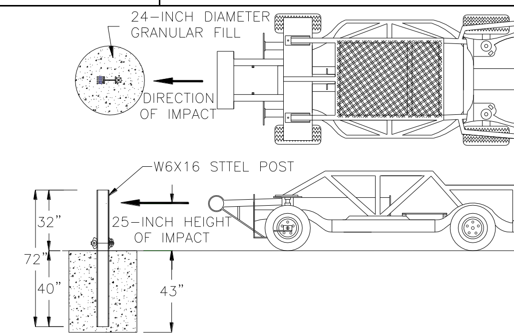


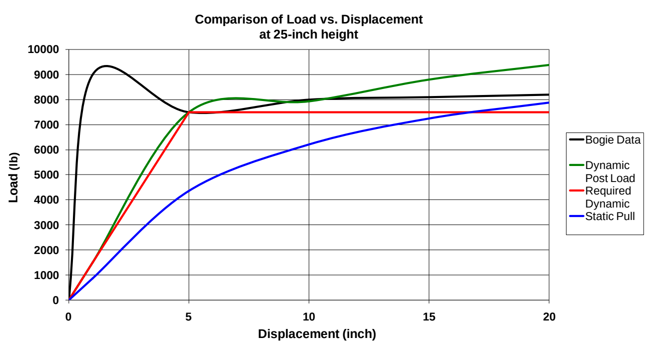
Post-Test Photo

Static Load Test

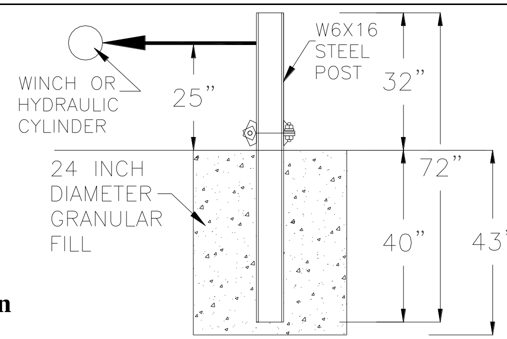


Dynamic Test Installation Details



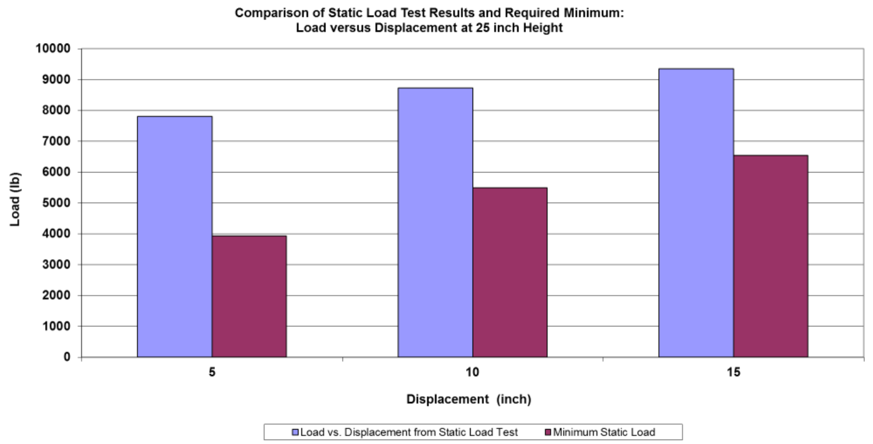


Static Load Test Installation Details

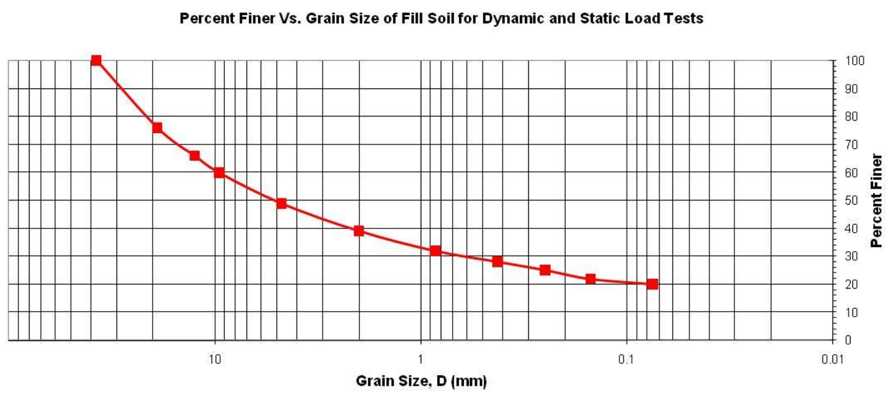


Date	2008-11-05
Test Facility and Site Location	TTI Proving Ground, 3100 SH 47, Bryan, TX 77807
In Situ Soil Description (ASTM D2487	Sandy gravel with silty fines
Fill Material Description (ASTM D2487) and sieve analysis	AASHTO Grade B Soil-Aggregate (see sieve analysis above)
Description of Fill Placement 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. 608221-1.



Static Load Setup



Post-Test Photo of Post

Date..	2017-07-14
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

APPENIDX D. *MASH* TEST 3-10 (CRASH TEST NO. 608221-1)

D1 VEHICLE PROPERTIES AND INFORMATION

Table D.1. Vehicle Properties for Test No. 608221-1.

Date:	2017-07-14	Test No.:	608221-1	VIN No.:	KNADH4A39B6714491
Year:	2011	Make:	Kia	Model:	Rio
Tire Inflation Pressure:	32 psi	Odometer:	139546	Tire Size:	185/65R14

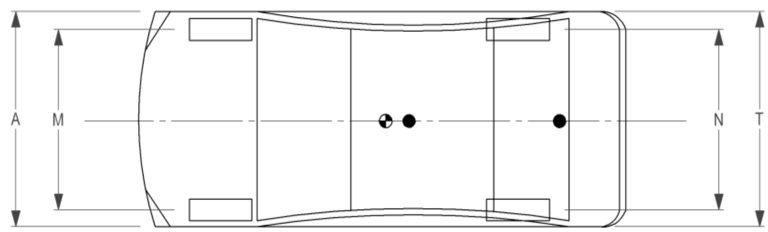
Describe any damage to the vehicle prior to test: None

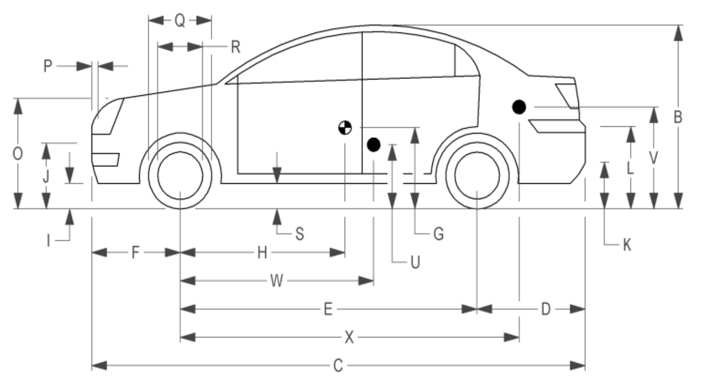
● Denotes accelerometer location.

NOTES: None

Engine Type: 4 cylinder
Engine CID: 1.6 liter
Transmission Type:
x Auto or ____ Manual
x FWD ____ RWD ____ 4WD
Optional Equipment:
None

Dummy Data:
Type: 50th percentile male
Mass: 165 lb
Seat Position: Front passenger





Geometry: inches

A	66.38	F	33.00	K	11.75	P	4.125	U	14.00
B	58.25	G	-----	L	25.00	Q	22.50	V	19.50
C	165.75	H	35.40	M	57.75	R	15.50	W	35.40
D	34.00	I	7.50	N	57.70	S	9.00	X	105.00
E	98.75	J	21.50	O	28.00	T	66.20		

Wheel Center Ht Front 11.00 Wheel Center Ht Rear 11.00 W-H 0

GVWR Ratings:		**Mass:** lb	Curb	Test Inertial	Gross Static
Front	1718	M_{front}	1609	1567	1652
Back	1874	M_{rear}	886	876	956
Total	3638	M_{Total}	2495	2443	2608

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

Mass Distribution:
lb LF: 780 RF: 787 LR: 463 RR: 413

Table D.2. Exterior Crush Measurements for Test No. 608221-1.

Date:	2017-07-14	Test No.:	608221-1	VIN No.:	KNADH4A39B6714491
Year:	2011	Make:	Kia	Model:	Rio

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front plane at bumper ht	24	9	24	---	---	---	---	---	9	+14
2	Side plane at bumper ht	24	9.25	40	1.5	3.25	5	5.25	7	9.25	+60
	Measurements recorded										
	in 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.

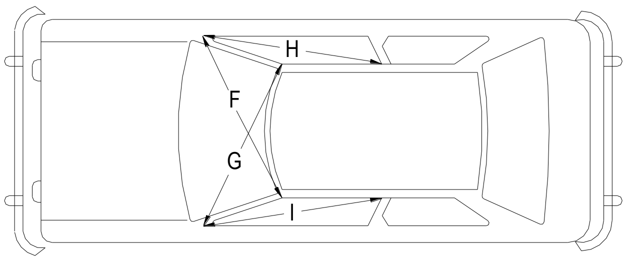
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

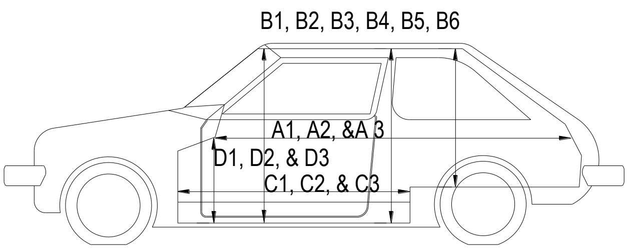
***Measure and document on the vehicle diagram the location of the maximum crush.

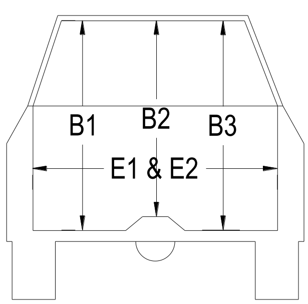
Note: Use as many lines/columns as necessary to describe each damage profile.

Table D.3. Occupant Compartment Measurements for Test No. 608221-1.

Date:	2017-07-14	Test No.:	608221-1	VIN No.:	KNADH4A39B6714491
Year:	2011	Make:	Kia	Model:	Rio







OCCUPANT COMPARTMENT DEFORMATION MEASUREMENT

	Before	After (inches)	Differ.
A1	67.50	67.50	0
A2	67.25	67.25	0
A3	67.50	67.50	0
B1	40.50	40.50	0
B2	36.50	36.50	0
B3	40.50	40.50	0
B4	36.25	36.25	0
B5	35.75	35.75	0
B6	36.25	36.25	0
C1	26.00	26.00	0
C2	----	----	----
C3	26.00	26.00	0
D1	9.50	9.00	-0.50
D2	----	----	----
D3	9.50	9.00	-0.50
E1	46.00	46.00	0
E2	51.00	51.00	0
F	51.00	51.00	0
G	51.00	51.00	0
H	37.50	37.50	0
I	37.50	37.50	0
J*	51.00	50.75	-0.25

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

D2 SEQUENTIAL PHOTOGRAPHS

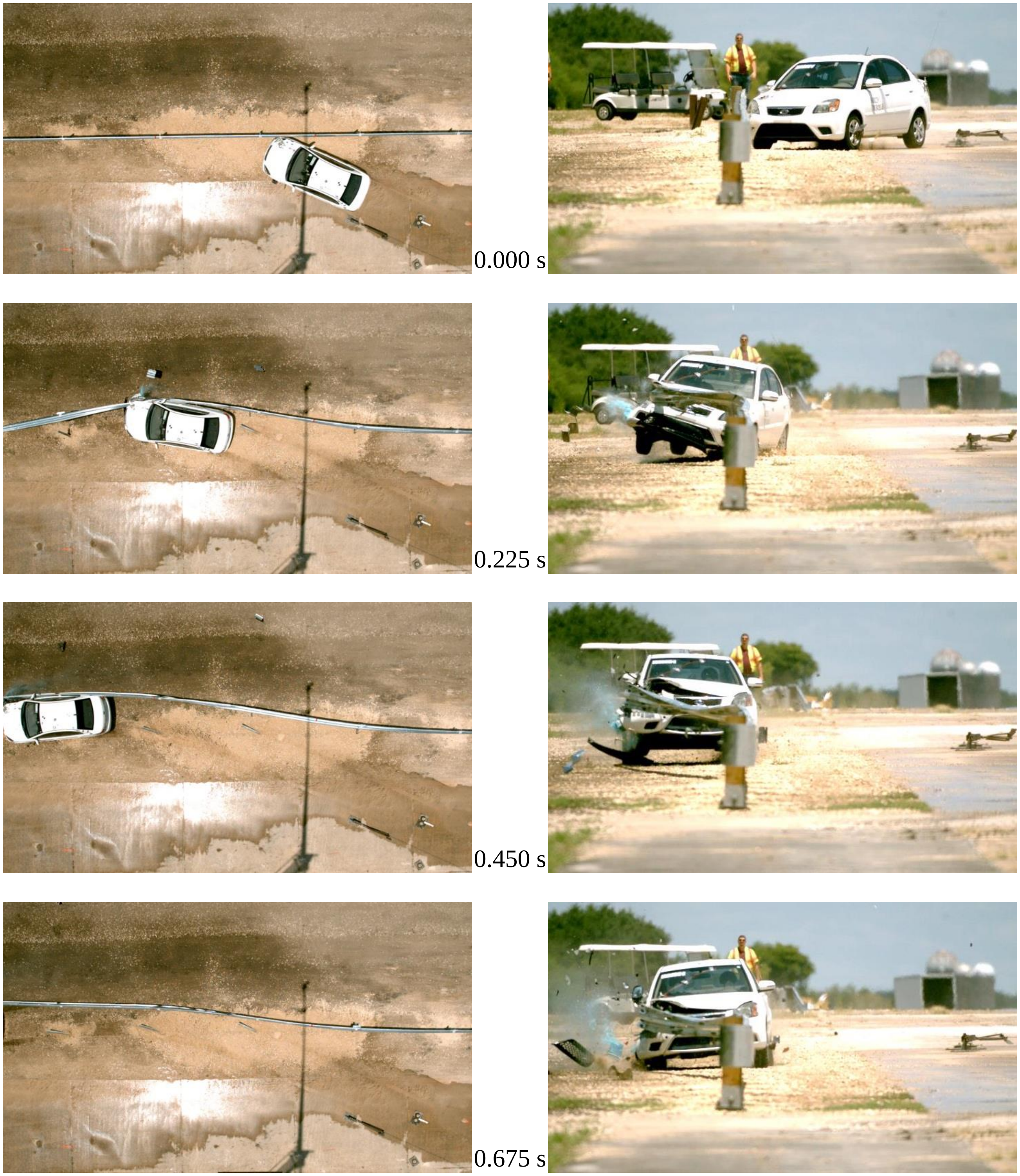


Figure D.1. Sequential Photographs for Test No. 608221-1 (Overhead and Frontal Views).

Out of View

0.900 s

Out of View

1.125 s

Out of View

1.350 s

Out of View

1.575 s

Figure D.1. Sequential Photographs for Test No. 608221-1 (Overhead and Frontal Views) (Continued).

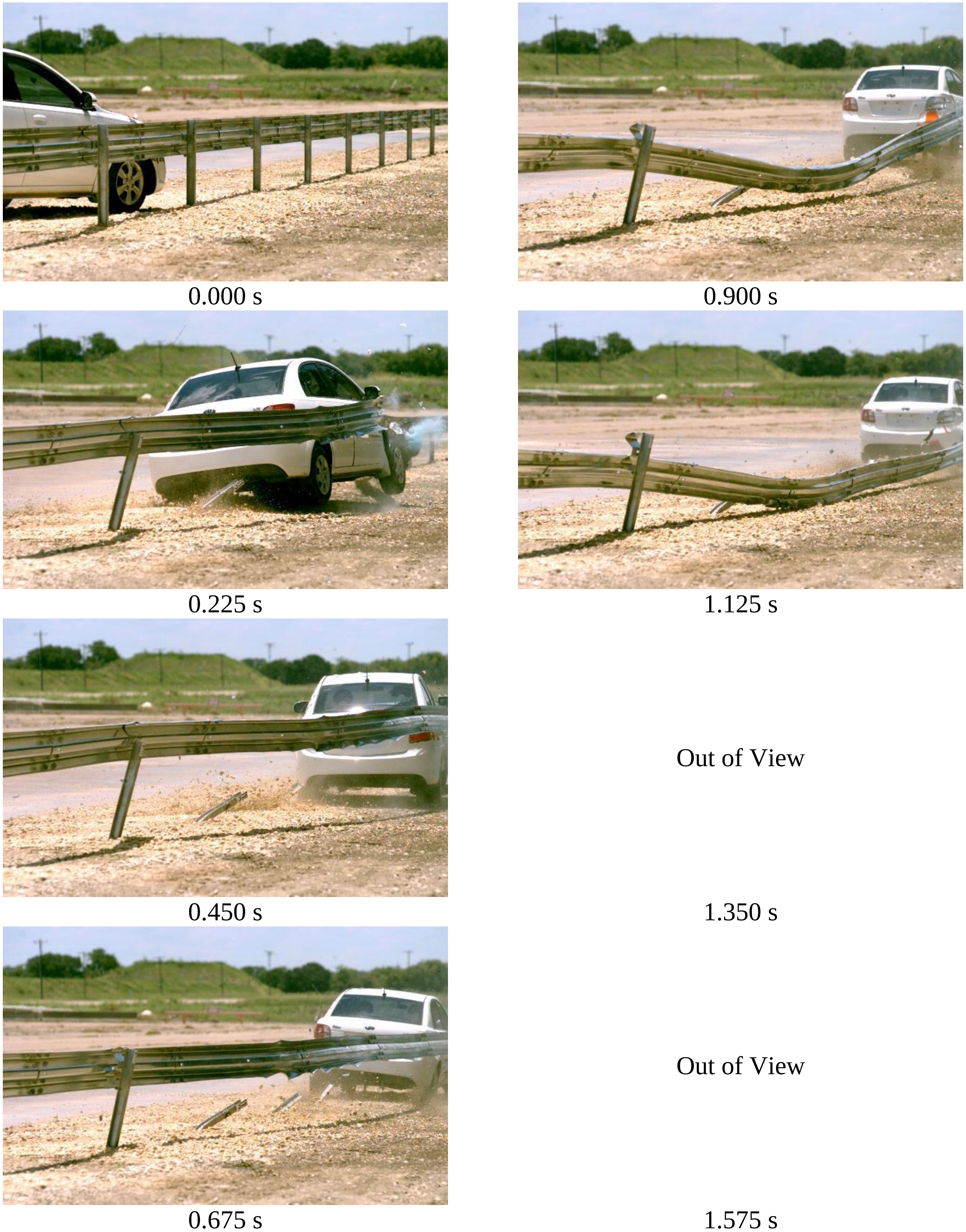
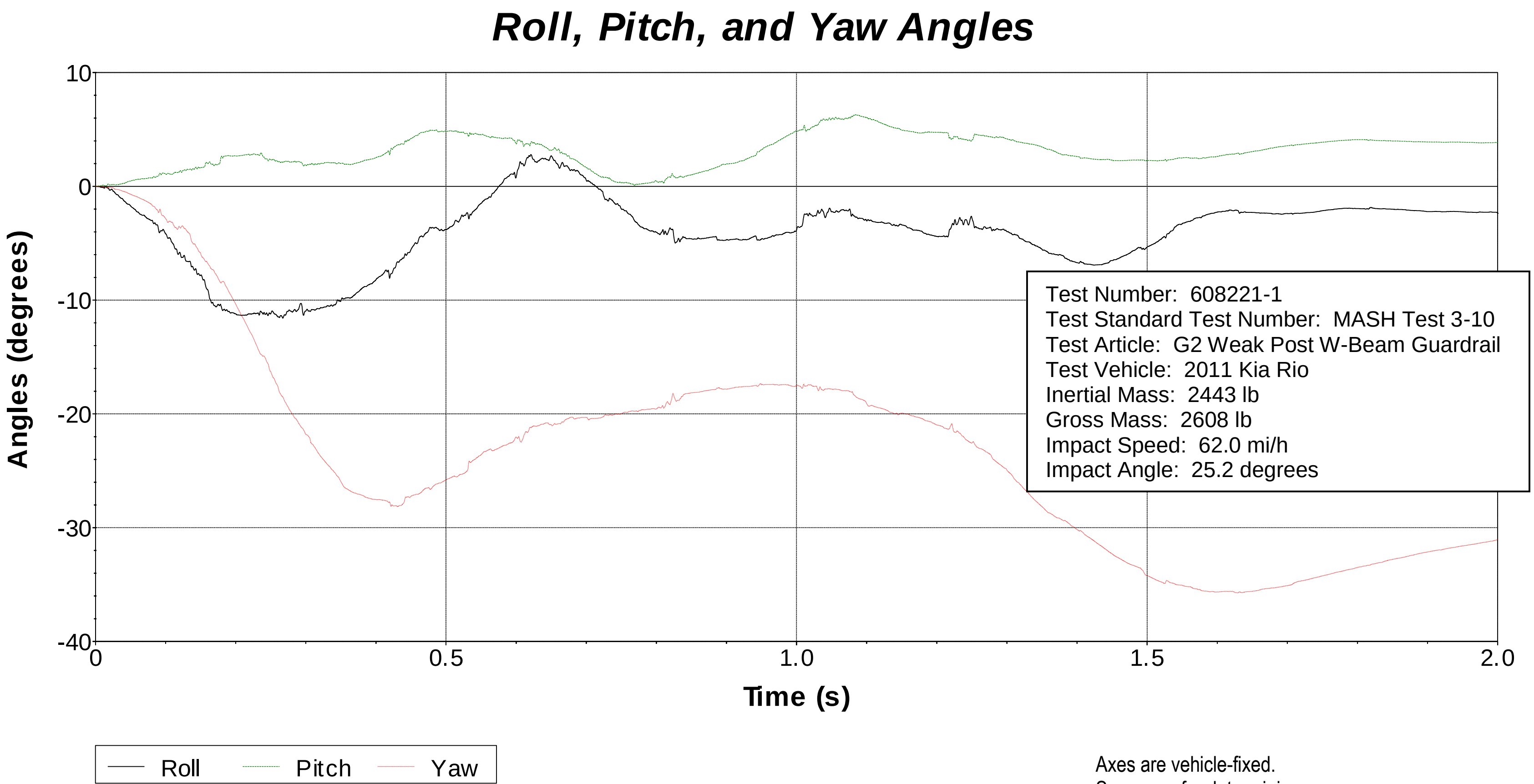


Figure D.2. Sequential Photographs for Test No. 608221-1 (Rear View).



Axes are vehicle-fixed.
Sequence for determining orientation:

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

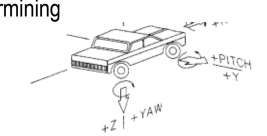


Figure D.3. Vehicle Angular Displacements for Test No. 608221-1.

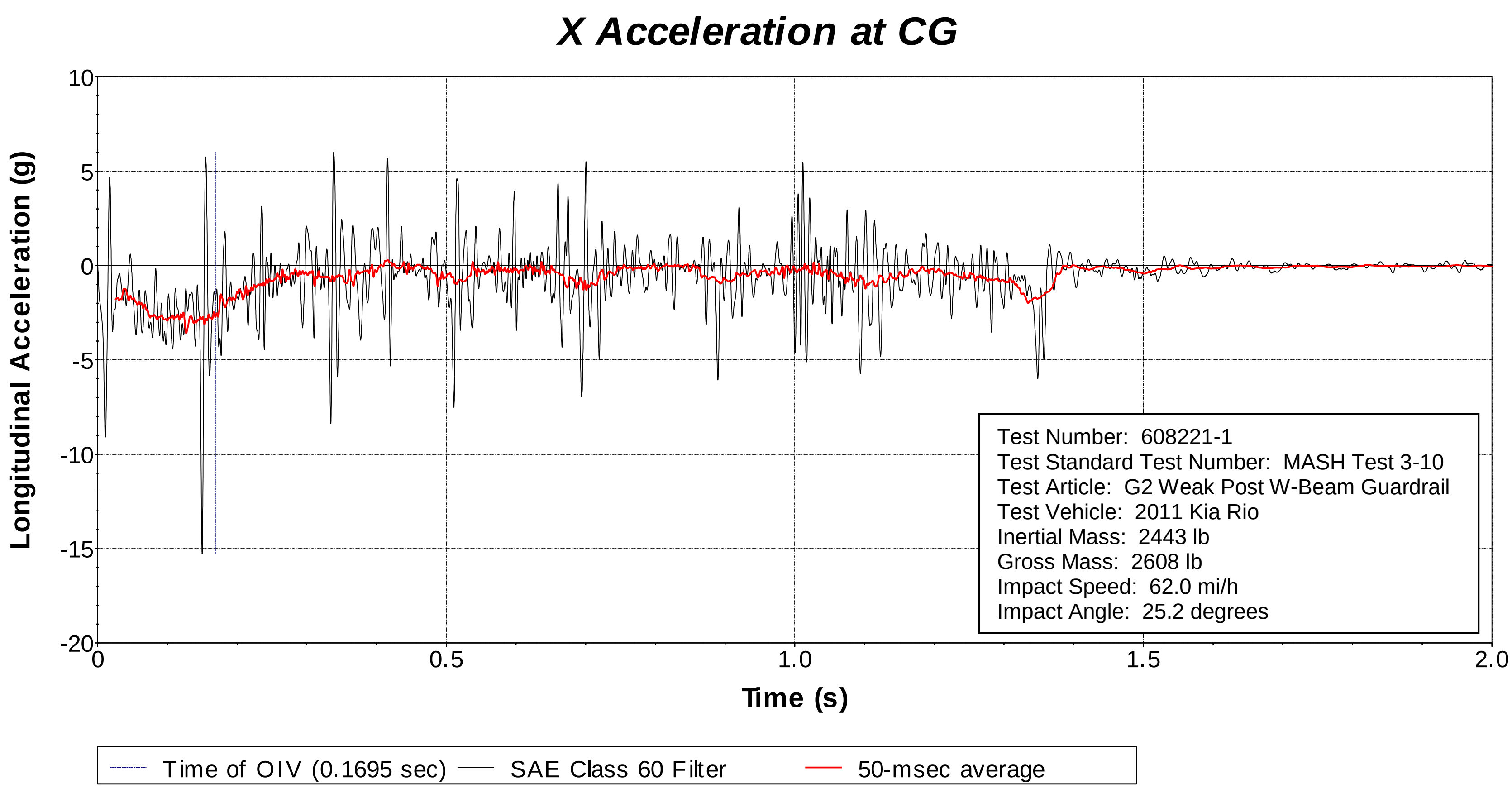


Figure D.4. Vehicle Longitudinal Accelerometer Trace for Test No. 608221-1 (Accelerometer Located at Center of Gravity).

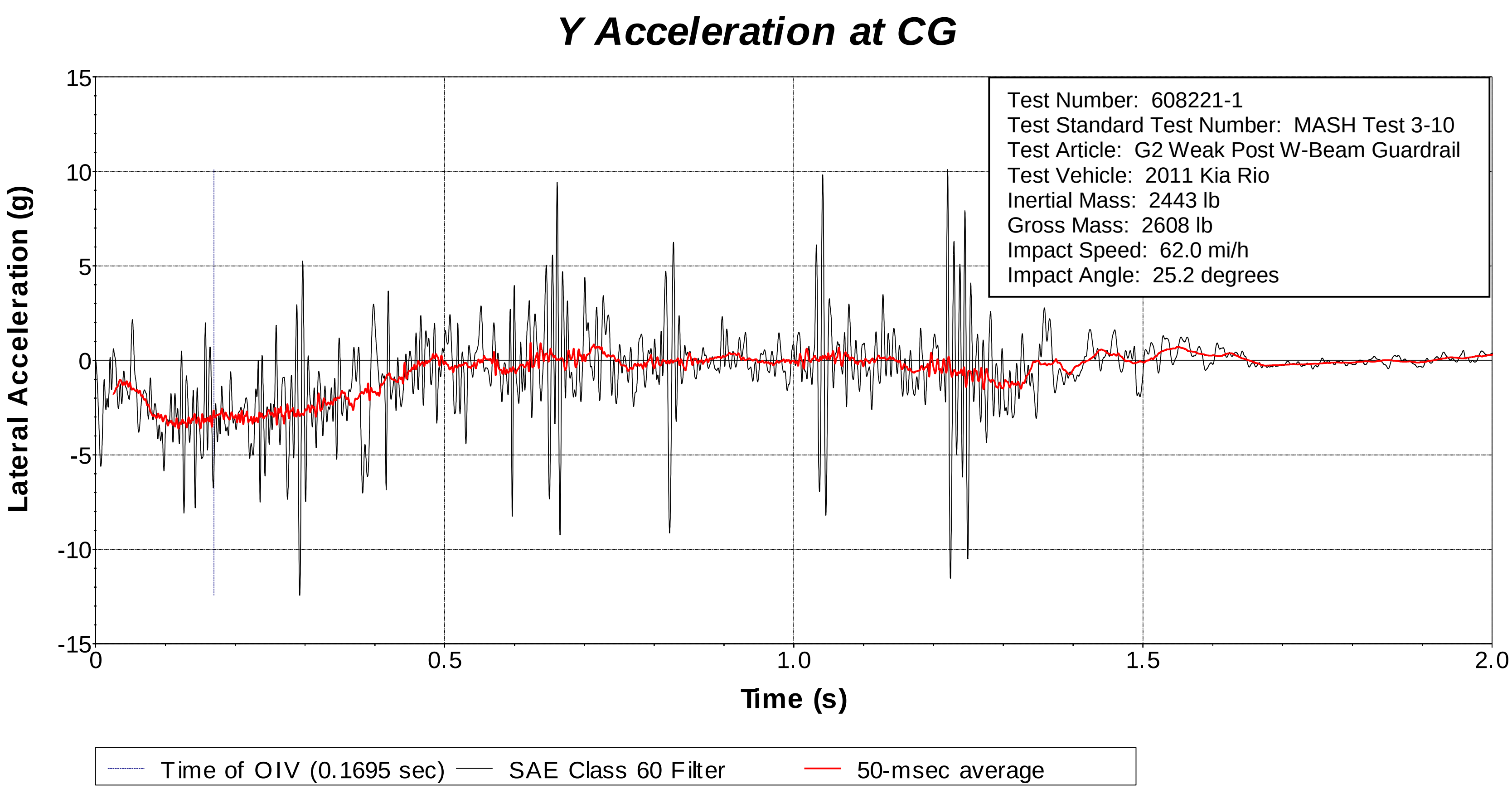


Figure D.5. Vehicle Lateral Accelerometer Trace for Test No. 608221-1 (Accelerometer Located at Center of Gravity).

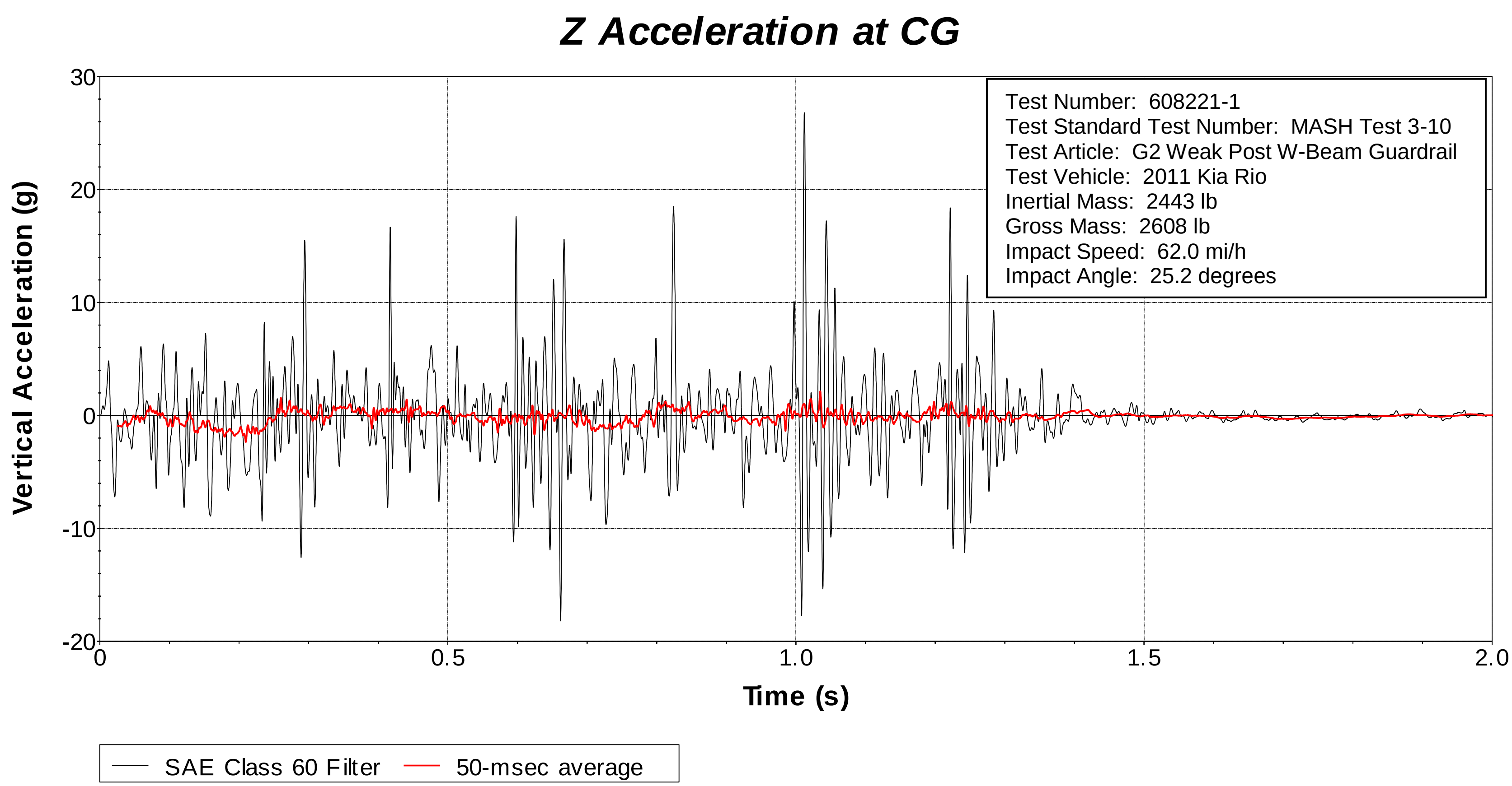


Figure D.6. Vehicle Vertical Accelerometer Trace for Test No. 608221-1 (Accelerometer Located at Center of Gravity).

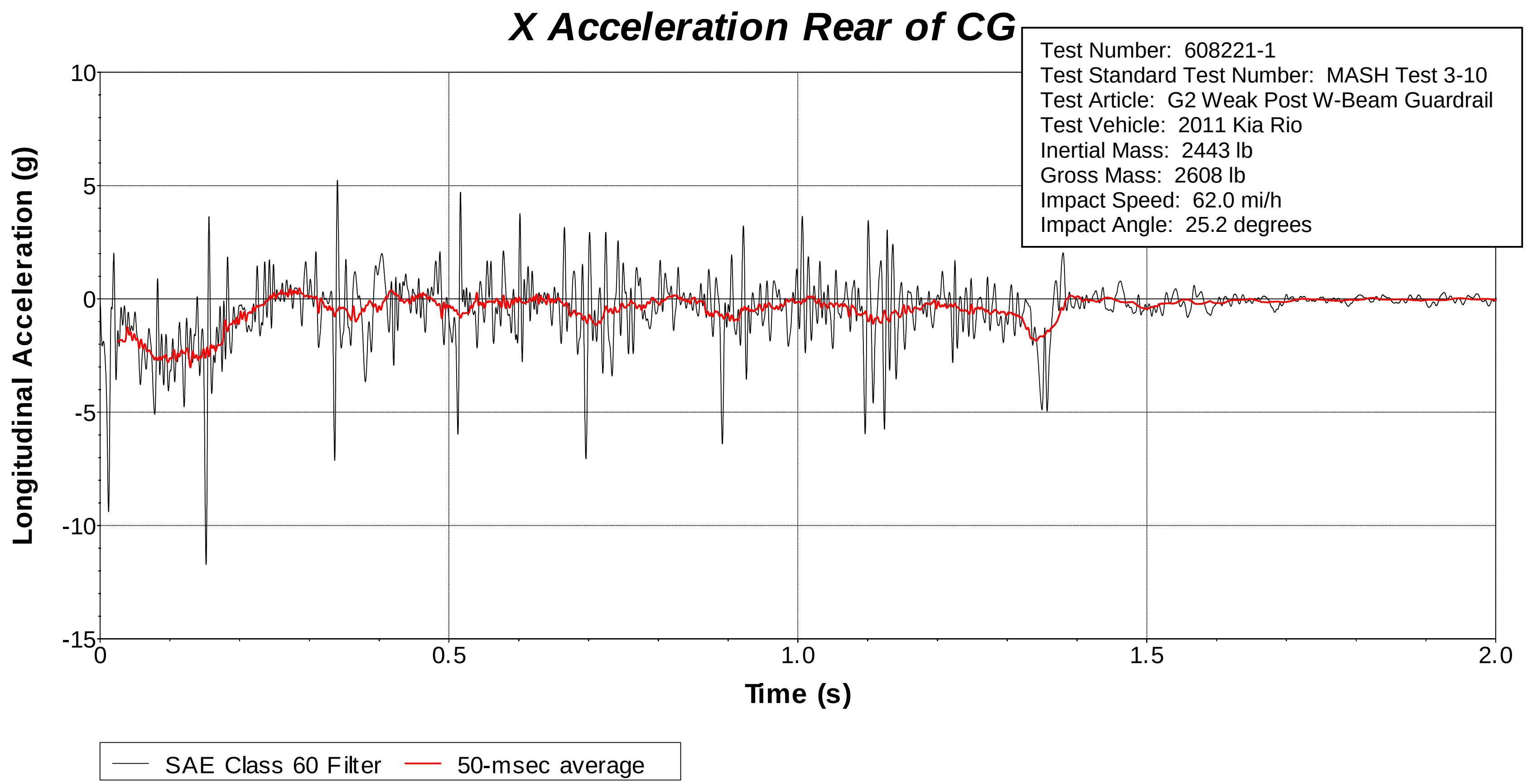


Figure D.7. Vehicle Longitudinal Accelerometer Trace for Test No. 608221-1 (Accelerometer Located Rear of Center of Gravity).

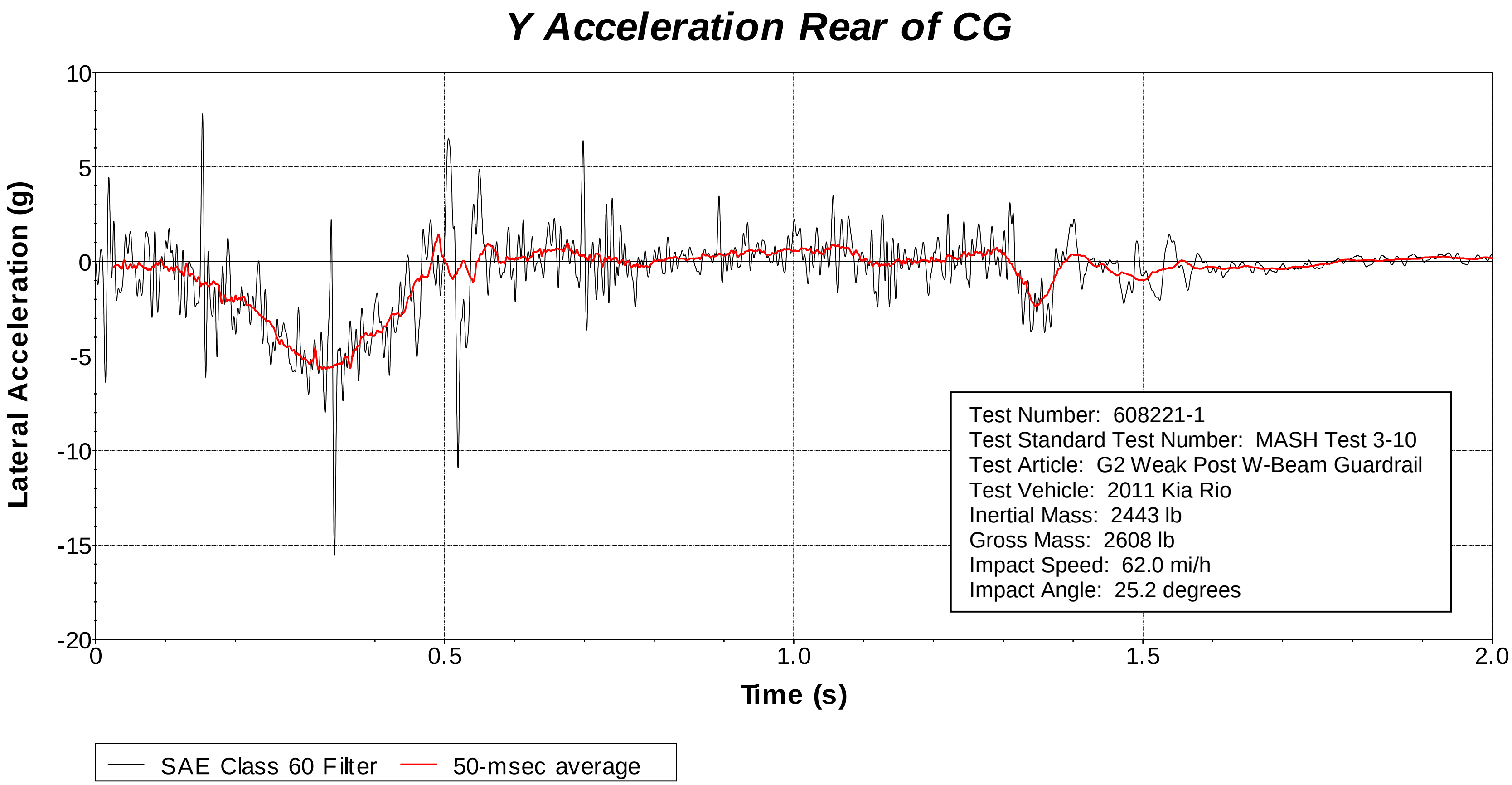


Figure D.8. Vehicle Lateral Accelerometer Trace for Test No. 608221-1 (Accelerometer Located Rear of Center of Gravity).

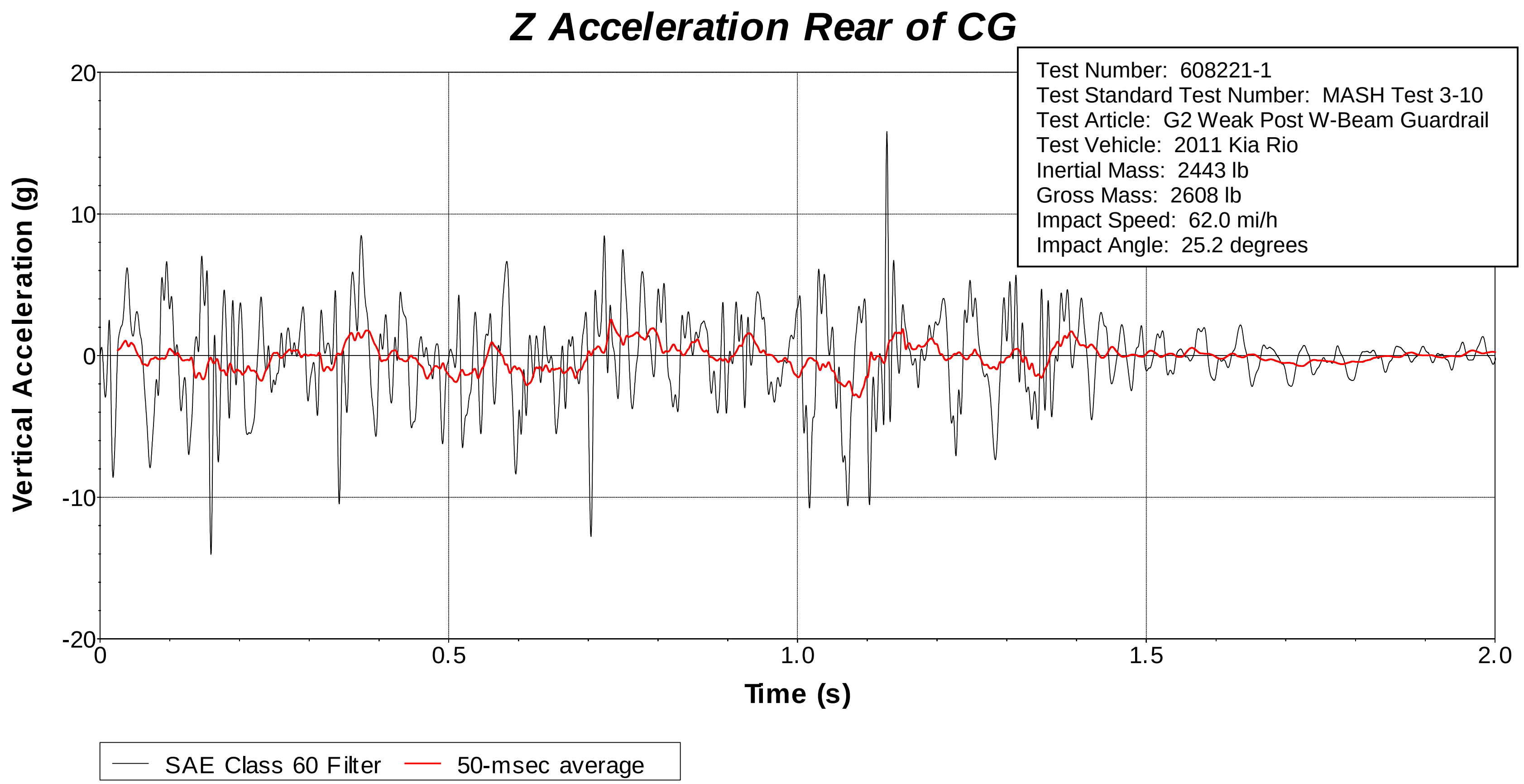


Figure D.9. Vehicle Vertical Accelerometer Trace for Test No. 608221-1 (Accelerometer Located Rear of Center of Gravity).