PHASE III DEMONSTRATION OF PONDEROSA PINE ROUND POSTS AS ALTERNATIVE TO RECTANGULAR SYP POSTS IN G4(2W) GUARDRAIL SYSTEMS

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16. Abstract

Previously, researchers at the Midwest Roadside Safety Facility (MwRSF) utilized dynamic bogie testing to determine the appropriate diameter, length, and embedment depth for Ponderosa Pine (PP) posts used as a surrogate for 6-in. x 8-in. (152-mm x 203-mm) rectangular Southern Yellow Pine (SYP) posts found in existing, strong-post, G4(2W) W-beam guardrail systems. More specifically, a PP post with an 8½-in. (216-mm) ground line diameter, a 35-in. (889-mm) embedment depth, and a 64-in. (1,626-mm) post length, was recommended as a surrogate in existing Arizona G4(2W) guardrail systems. Further, a PP post with an 8⅝-in. (219-mm) ground line diameter, a 36-in. (914-mm) embedment depth, and a 65-in. (1,651-mm) post length, was recommended as a surrogate in existing U.S. standard G4(2W) guardrail systems.

The research conducted herein further demonstrated that the two noted PP post sizes and configurations provided adequate safety performance according the Test Level 3 (TL-3) impact safety standards published in the National Cooperative Highway Research Program (NCHRP) Report No. 350. One full scale vehicle crash test was successfully performed on a 175-ft (53.34-m) long, G4(2W) guardrail system supported by 8½-in. (216-mm) diameter (ground line) by 64-in. (1,626-mm) long PP posts with a 35-in. (889-mm) embedment depth. The test was conducted with a ¾-ton Chevrolet pickup truck (2000P vehicle) impacting at a speed of 60.7 mph (97.7 km/h) and an angle of 24.8 degrees. The G4(2W) guardrail system with PP posts adequately contained and redirected the pickup truck and met the TL-3 safety performance criteria. Therefore, an 8½-in. (216-mm) diameter PP post with a 35-in. (889-mm) embedment depth and a 64-in. (1,626-mm) ength was further confirmed for use as a surrogate in existing Arizona G4(2W) guardrail systems based on dynamic component testing and full-scale vehicle crash testing. Based on similarities between the two PP posts and prior successful dynamic component testing, an 8⅝-in. (219-mm) diameter PP post with a 36-in. (914-mm) embedment depth and a 65-in. (1,651-mm) length was also recommended for use as a surrogate in existing U.S. standard G4(2W) guardrail systems.

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UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in standard full-scale crash testing and non-standard testing of roadside safety features. Information regarding the uncertainty of measurements for critical parameters is available upon request by the sponsor and the Federal Highway Administration.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Mr. Robert W. Bielenberg, Research Associate Engineer.

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1 INTRODUCTION

Background

Over the last several decades, the southwestern United States experienced numerous forest fires, prompting a need for more preventive techniques. In 2000, President Bill Clinton initiated the creation of the National Fire Plan, which focused on four main goals: (1) improve prevention and suppression; (2) reduce hazardous fuels; (3) restore fire-adapted ecosystems; and (4) promote community assistance [1].

Historically, fuel management has been a commonly-used technique for fire protection. In the 1960s, the U.S. Department of Agriculture (USDA) - Forest Service began managing fuels by using controlled-burn techniques, which are generally effective [2]. In order to remove the small-diameter forest thinnings (SDT) from a certain area, fires were started with containment. The thinnings, which could help fuel a fire in the future, consisted mostly of pine and fir species. However, due to both the lack of economic benefits and the high risk involved with controlled-burn methods, more cost-efficient methods were sought to remove the small-diameter forest thinnings.

Small-diameter trees can be used in a variety of ways, including lumber, structural roundwood, wood composites, wood fiber products, compost, mulch, and fuels [3]. By removing the potential fuel and selling it as various products, the cost of SDT removal would hopefully be recovered. Therefore, more uses for small-diameter trees were recommended for development in order to increase the product potential [4].

In response to this need, researchers at the Midwest Roadside Safety Facility (MwRSF), in cooperation with the Forest Products Laboratory (FPL) and the USDA - Forest Service, developed an adaptation of the Midwest Guardrail System (MGS) that utilized SDT materials as timber posts [5-6]. The study determined appropriate sizes of Southern Yellow Pine (SYP), Douglas Fir (DF), and Ponderosa Pine (PP) round posts for use within the 31-in. (787-mm) tall corrugated W-beam system.

In recent years, several unexpected forest fires also harmed large forests of PP timber in the State of Arizona. With such vast forests of affected timber, local producers within the timber industry deemed it necessary to further explore the use of PP material as posts in guardrail systems. Two additional W-beam guardrail systems were identified as systems that may be compatible with PP posts: the U.S. standard G4(2W) guardrail system and the Arizona DOT G4(2W) guardrail system. Although these W-beam guardrail systems utilize similar components to the wood post version of the MGS, differences in rail height and embedment depth exist between the three systems, as shown in Table 1. As a result, there may be different post performance requirements for each system. Therefore, further research was undertaken with a collaborative effort between the Arizona Timber Industry, MwRSF, and USDA-Forest Service – FPL, to determine the appropriate dimensions (diameter and length) and embedment depth of round PP posts for use within these two strong-post, W-beam guardrail systems.

Phase I of this PP equivalency study incorporated 17 dynamic component tests on various wood posts, 6 of these on rectangular SYP posts and 11 on round PP posts with diameters between 8⅜ in. and 8¾ in. (213 mm and 222 mm). Based on the results of these component tests, an 8½-in. (216-mm) diameter PP post with a 35-in. (889-mm) embedment depth was found to provide strength and soil rotation resistance equivalent to the rectangular SYP post embedded 35 in. (889 mm) [7]. Subsequently, this equivalent round PP post was recommended for use as a surrogate post for use in the Arizona G4(2W) W-beam guardrail system, as noted within Table 1.

However, an equivalent round PP post had yet to be determined for use in the U.S. standard G4(2W) guardrail system.

Table 1. Wood Post Options for W-beam Guardrail Systems

Guardrail System	Top Rail Height in. (mm)	Rectangular SYP Post Option			Round PP Post Option		
		Cross Section in. (mm)	Length in. (mm)	Embedment Depth in. (mm)	Diameter in. (mm)	Length in. (mm)	Embedment Depth in. (mm)
MGS	31 (787)	6 x 8 (152 x 203)	72 (1,829)	40 (1,016)	8 (203)	69 (1,753)	37 (940)
Arizona System	28 (711)	6 x 8 (152 x 203)	64 (1,626)	35 (889)	8½ (216)	64 (1,626)	35 (889)
U.S. System G4(2W)	27¾ (705)	6 x 8 (152 x 203)	72 (1,829)	43¼ (1,099)	8⅝ (219)	65 (1,651)	36 (914)

(light shading) - Determined from Phase I R&D project [7].
(dark shading) - Determined from Phase II R&D project [8].

Phase II of this PP equivalency study incorporated 9 dynamic component tests on various wood posts - 4 test on rectangular SYP posts and 5 tests on round PP posts with diameters approximately between 8½ in. and 8-11/16 in. (216 mm and 221 mm). Based on the results of these component tests, an 8⅝-in. (219-mm) diameter PP post with a 36-in. (914-mm) embedment depth was found to provide strength and soil rotation resistance equivalent to the rectangular SYP post embedded 43¼ in. (1,099 mm) [8]. Subsequently, this equivalent round PP post was recommended for use as a surrogate post for use in the U.S. standard G4(2W) W-beam guardrail system, as noted within Table 1. Within the Phase II study, enhanced grading criteria, materials specifications, and CAD details were provided for PP posts recommended for use in both Arizona and U.S. standard G4(2W) W-beam guardrail systems.

Following the successful completion of the Phase I and II PP equivalency studies noted above [7-8], MwRSF researchers had sufficient component testing results and information to request eligibility from Federal Highway Administration (FHWA) regarding the surrogate use of two PP post sizes within existing Arizona and U.S. standard G4(2W) W-beam guardrail systems. As such, MwRSF researchers began to prepare application materials for seeking FHWA eligibility for both PP post sizes based on dynamic bogie testing results. Around that same time, an opportunity arose to seek and obtain additional R&D funding to conduct one full-scale vehicle crash test to further demonstrate the viability of round PP posts in existing, strong-post, W-beam guardrail systems. Therefore, MwRSF researchers initially held off on seeking FHWA eligibility to first determine whether additional funding would come to fruition to conduct a demonstration crash test. The demonstration test was expected to further confirm results obtained from dynamic bogie testing as well as offer confidence to State DOTs interested in using round PP posts to repair damaged strong-post, W-beam guardrail systems configured with 6-in. x 8-in. (152-mm x 203-mm) rectangular SYP posts.

In early April 2015, MwRSF learned that additional funding would become available from the 2015 Wood Innovations Grant Program through the Arizona State Forestry Division, which was intended to expand and accelerate wood energy and innovative wood building materials. Further, the program stipulated the use of hazardous fuels from National Forest System lands and other forested lands to promote forest health while simultaneously generating rural jobs. As such, the collaborative team moved forward with a Phase III demonstration project.

Research Objectives

The objective for this project was to demonstrate that the previously-identified PP post sizes (diameters and lengths) and embedment depths would adequately and safely serve as surrogates for 6-in. x 8-in. (152-mm x 203-mm) rectangular SYP posts that are used within existing Arizona and U.S. standard G4(2W) W-beam guardrail systems. The specific guardrail systems are those that have either met or been grandfathered under the impact safety standards published in the National Cooperative Highway Research Program (NCHRP) Report No. 350 [9].

As such, one full scale crash test (i.e., compliance test) was performed to further demonstrate the crashworthiness of the Arizona G4(2W) W-beam guardrail system when supported by an 8½-in. (216-mm) diameter (ground line) PP post with a 35-in. (889-mm) embedment depth and a 64-in. (1,626-mm) post length. The demonstration test was conducted according to the Test Level 3 (TL-3) safety criteria published in NCHRP Report No. 350 [9]. The successful completion of the demonstration test also confirmed the use of an 8⅝-in. (219-mm) diameter (ground line) PP post with a 36-in. (914-mm) embedment depth and a 65-in. (1,651-mm) post length within existing U.S. standard G4(2W) W-beam guardrail systems.

Research Scope

The research objective was achieved through the completion of several tasks. First, CAD details were prepared for the overall barrier installation that utilized round PP posts. Second, round PP posts and routed offset blocks were acquired, which included the documentation and archive of mill certifications, material specifications, and/or Certificates of Compliance. Subsequently, the Arizona G4(2W) W-beam guardrail system was constructed with round PP posts and an overall system length of 175 ft (53.3 m) from end post to end post. Next, one TL-3 full-scale vehicle crash test was performed with a ¾-ton pickup truck (2000P vehicle) at the target conditions of 62.1 mph (100 km/h) and 25 degrees using a critical impact point and per test designation no. 3-11 published in the NCHRP Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. The test results were analyzed, evaluated, and documented. Finally, conclusions and recommendations were provided regarding the performance and use of round PP posts in lieu of rectangular SYP posts in Arizona and U.S. standard G4(2W) W-beam guardrail systems.

2 DESIGN DETAILS

The test installation for the guardrail system consisted of 175 ft (53.3 m) of standard 12-gauge (2.66-mm) W-beam supported by round Ponderosa Pine (PP) wood posts. Design details are shown in Figures 1 through 14. Photographs of the test installation are shown in Figures 15 through 17. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The barrier utilized standard 12-ft 6-in. (3.81-m) long 12-gauge (2.66-mm) W-beam rails, as shown in Figures 1, 3, and 10. The W-beam guardrail was mounted with a top-rail height of 28 in. (711 mm) throughout the entire system. The rail splices were located at post locations, as shown in Figures 3 and 15. All lap-splice connections between the rail sections were configured with the upstream segment in front of the downstream segment to minimize the potential for vehicle snag at the splice during the crash test.

The rail was supported by twenty-nine guardrail posts spaced at 75 in. (1,905 mm) on center, as shown in Figures 1, 2, 15, and 16. All twenty-five PP posts were placed in a compacted coarse, crushed limestone material that met Grading B of AASHTO M147-65, as found in NCHRP Report No. 350. The posts were installed using MwRSF's installation procedures which comply with the 2009 *Manual for Assessing Safety Hardware* (MASH) specifications [10] Post nos. 3 through 27 consisted of a nominal 8½ in. (216 mm) diameter at groundline, a 64-in. (1,626-mm) length, and used a soil embedment depth of 35 in. (889 mm). The actual post dimensions and physical data are shown in Table 2. A 6-in. wide x 8-in. deep x 14¼-in. long (152-mm x 203-mm x 362-mm) routed PP wood spacer blockout was used to block the rail away from the front face of each PP post.

The upstream and downstream ends of the guardrail installation were configured with a trailing-end anchorage system, as shown in Figures 5 and 17. This guardrail anchorage system was utilized to simulate the strength of other crashworthy end terminals. The anchorage system consisted of timber posts, foundation tubes, anchor cables, bearing plates, rail brackets, and channel struts, which closely resembled the hardware used in the Modified BCT system and now part of a crashworthy, downstream trailing end terminal [11-14]. Post nos. 1, 2, 28, and 29 were breakaway cable terminal (BCT) timber posts that were inserted into 6-ft (1.8-m) long, steel foundation tubes, as shown in Figure 7.

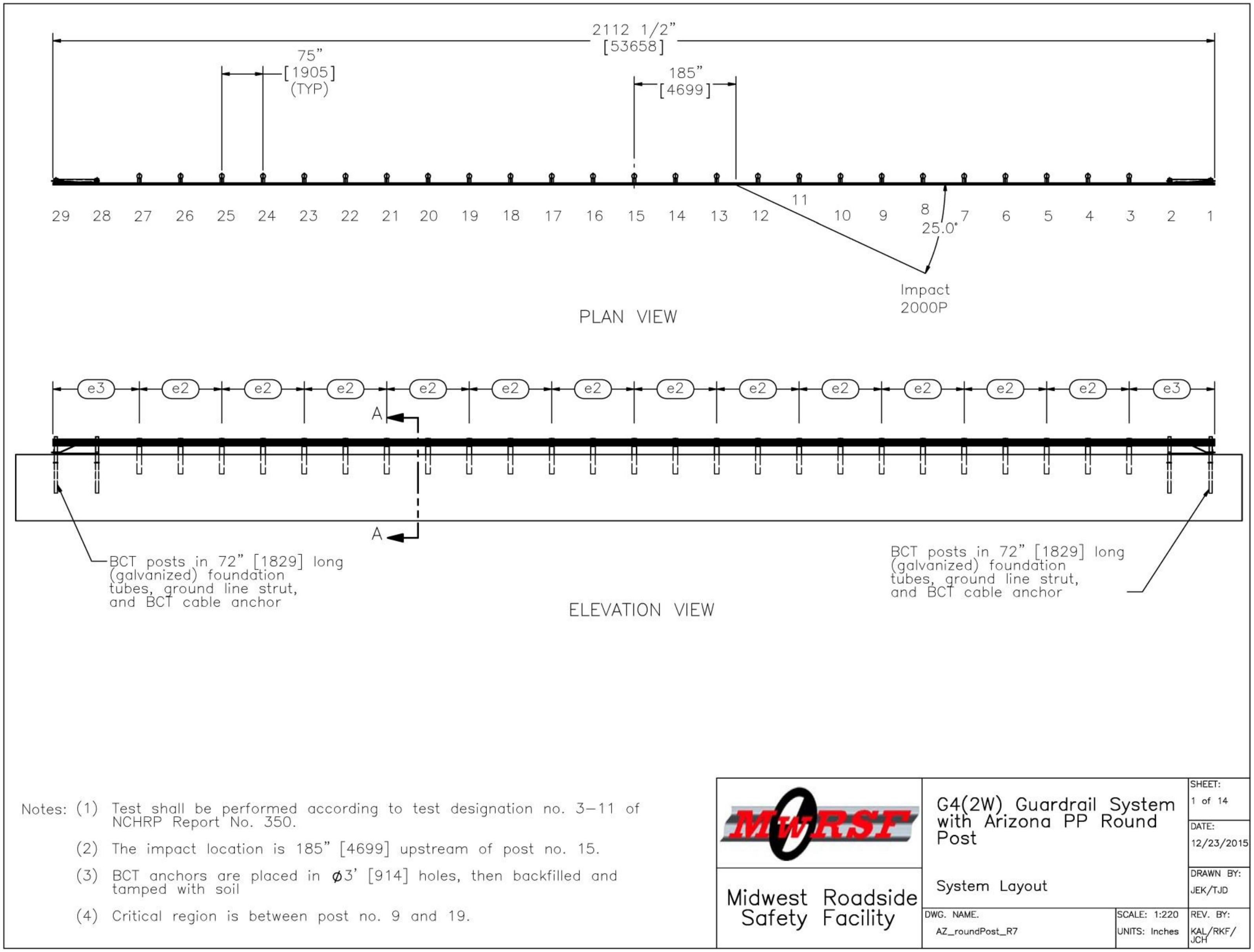

Figure 1. Test Installation Layout, Test No. AZRP-1

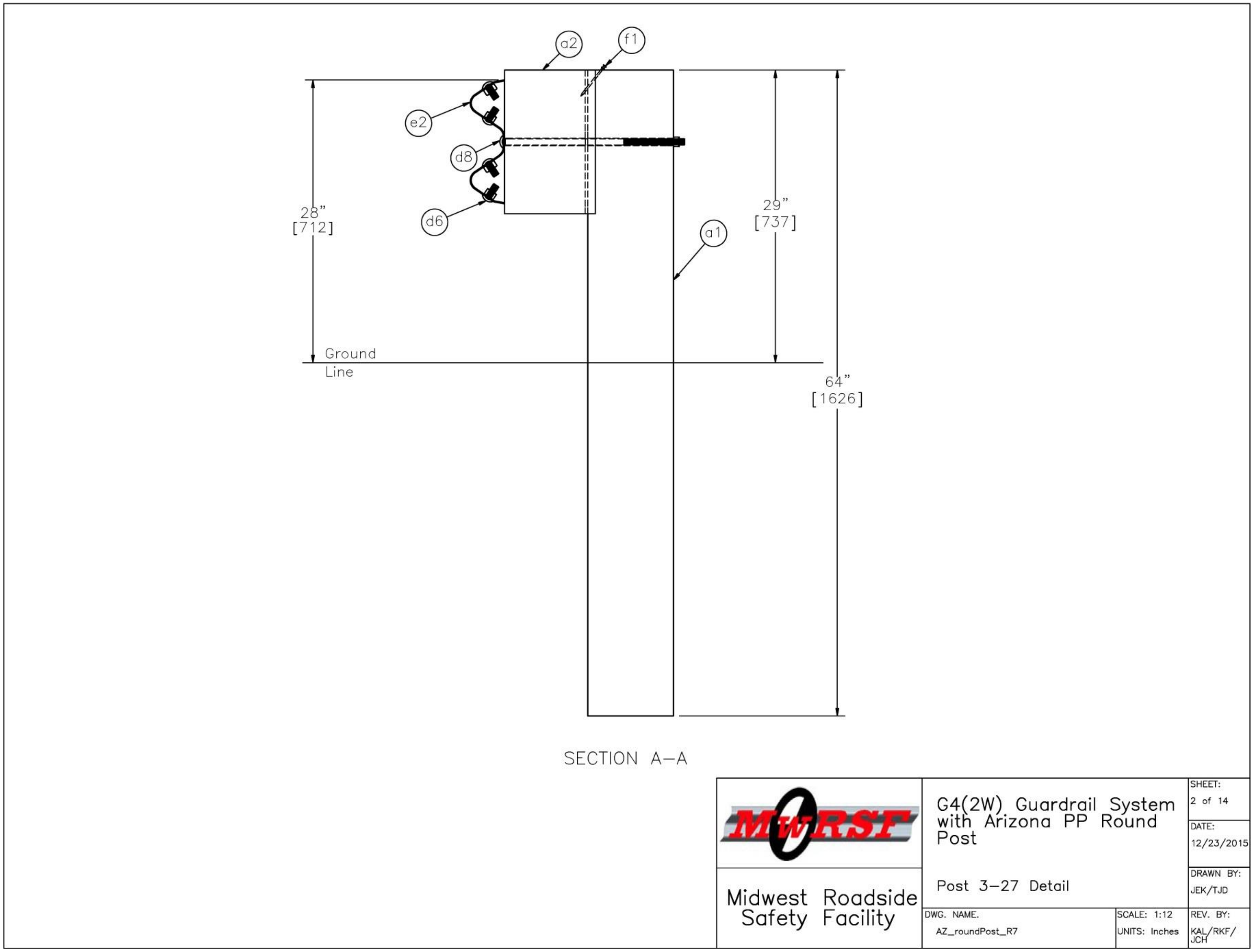

Figure 2. Post Nos. 3 through 27 Details, Test No. AZRP-1

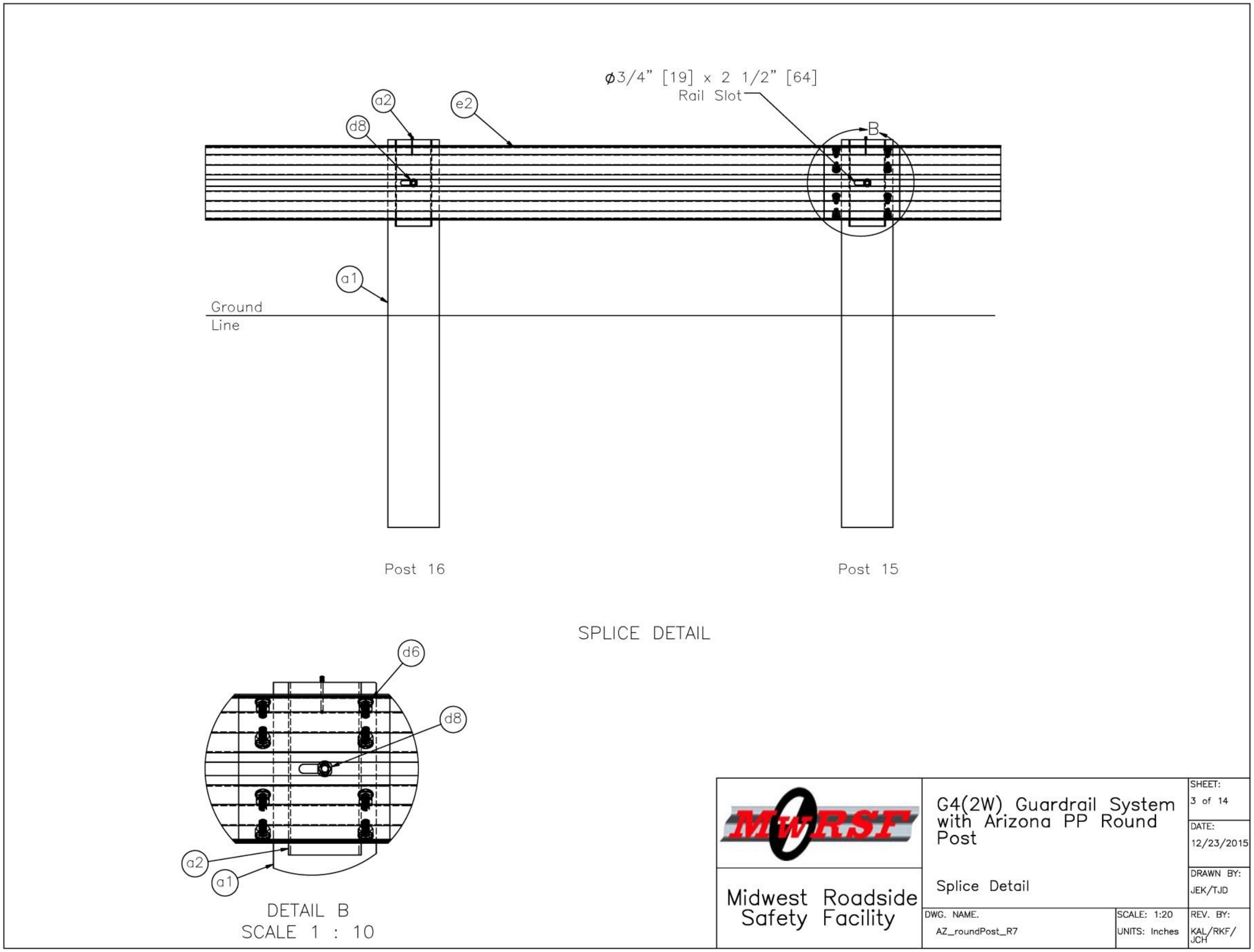

Figure 3. Guardrail Splice Details, Test No. AZRP-1

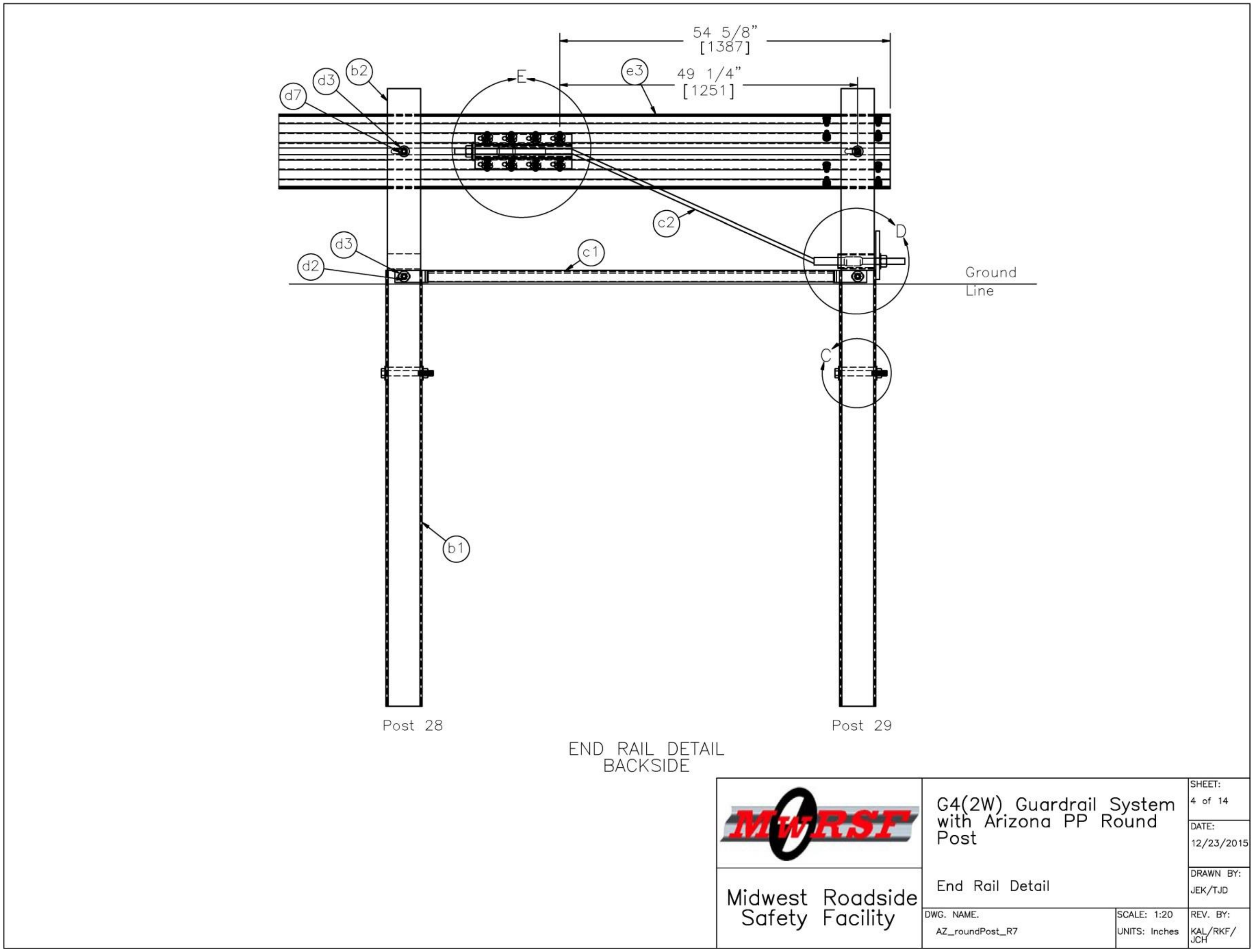

Figure 4. End of Guardrail Details, Test No. AZRP-1

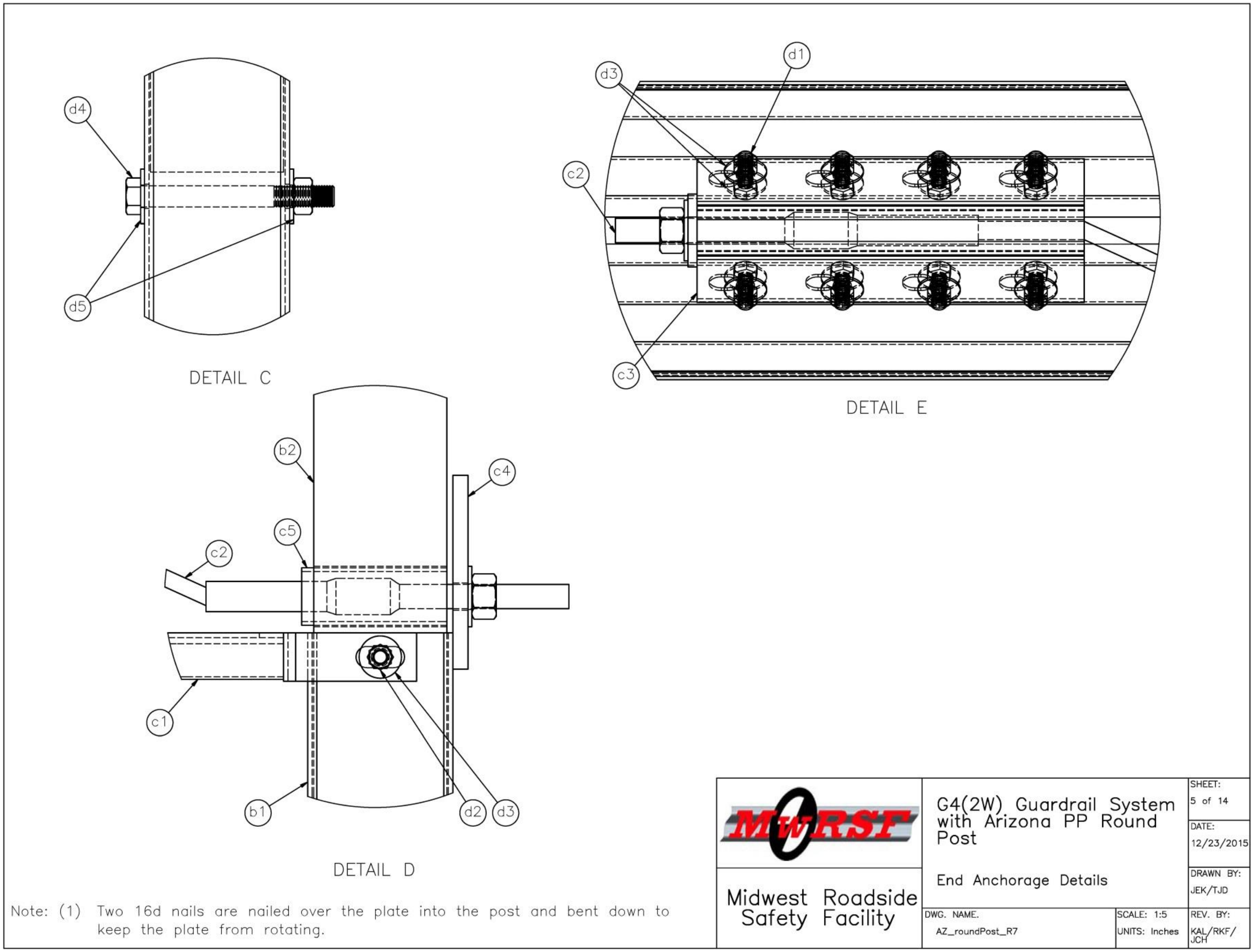

Figure 5. End Anchorage Details, Test No. AZRP-1

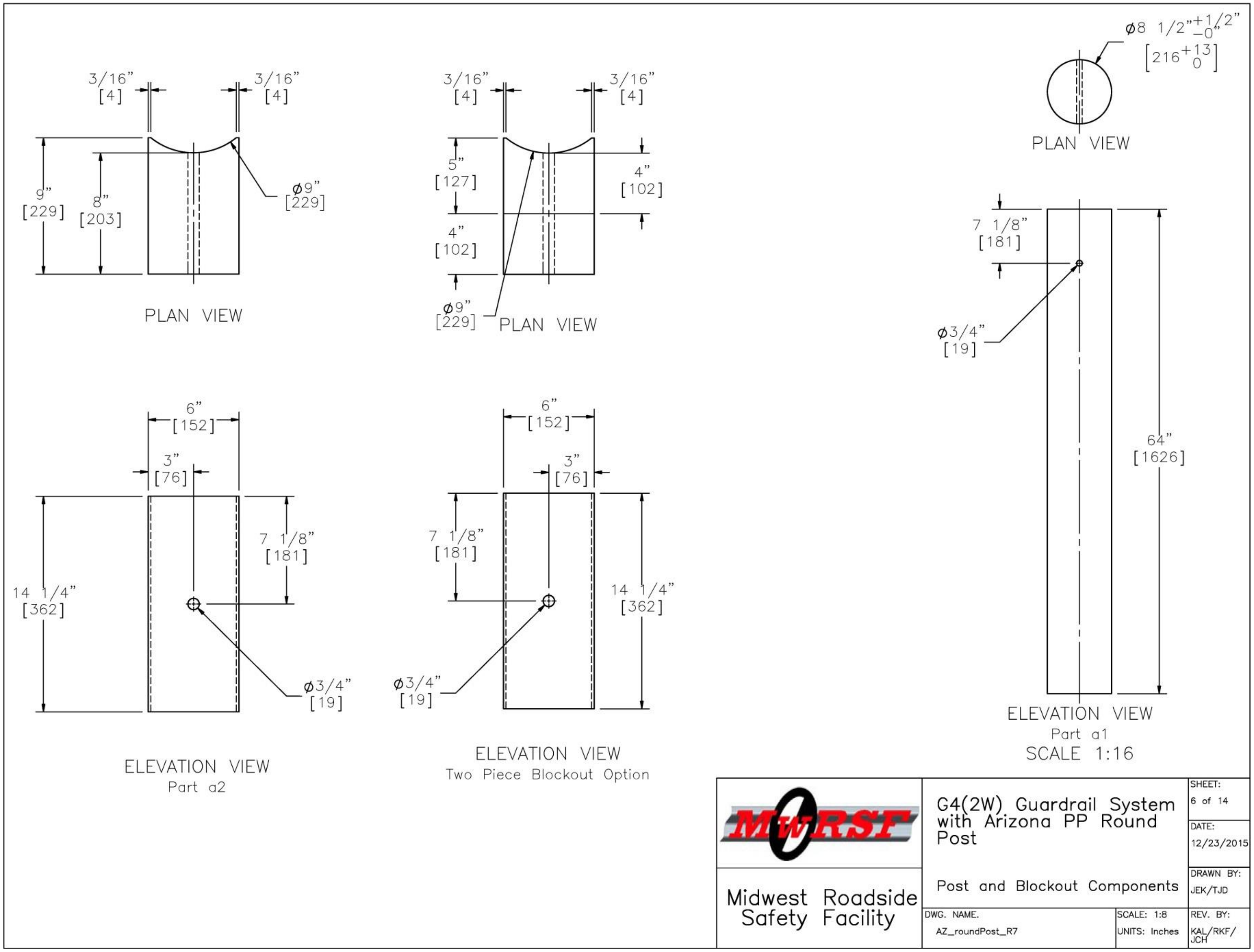

Figure 6. Line Post and Blockout Details, Test No. AZRP-1

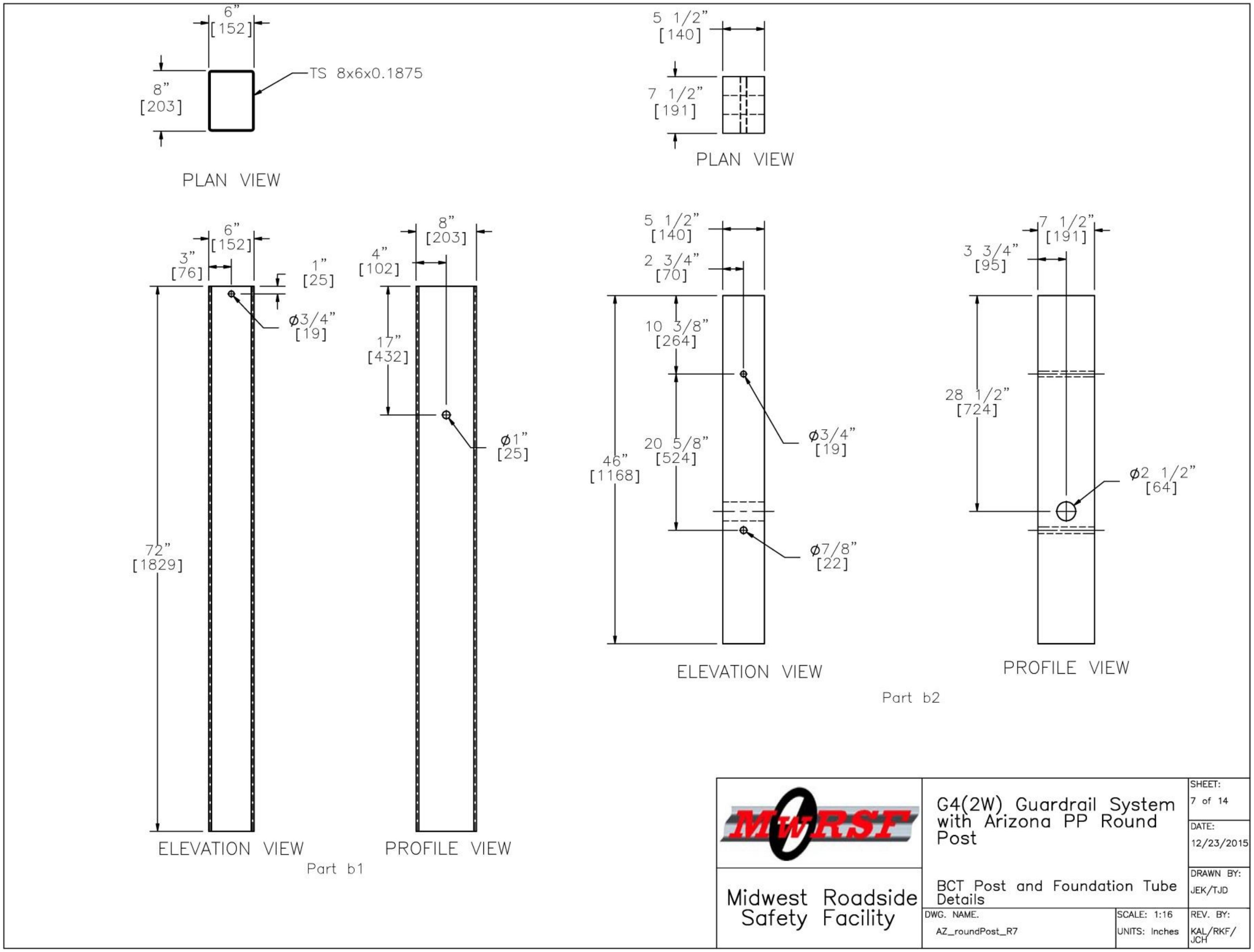

Figure 7. BCT Post and Foundation Tube Details, Test No. AZRP-1

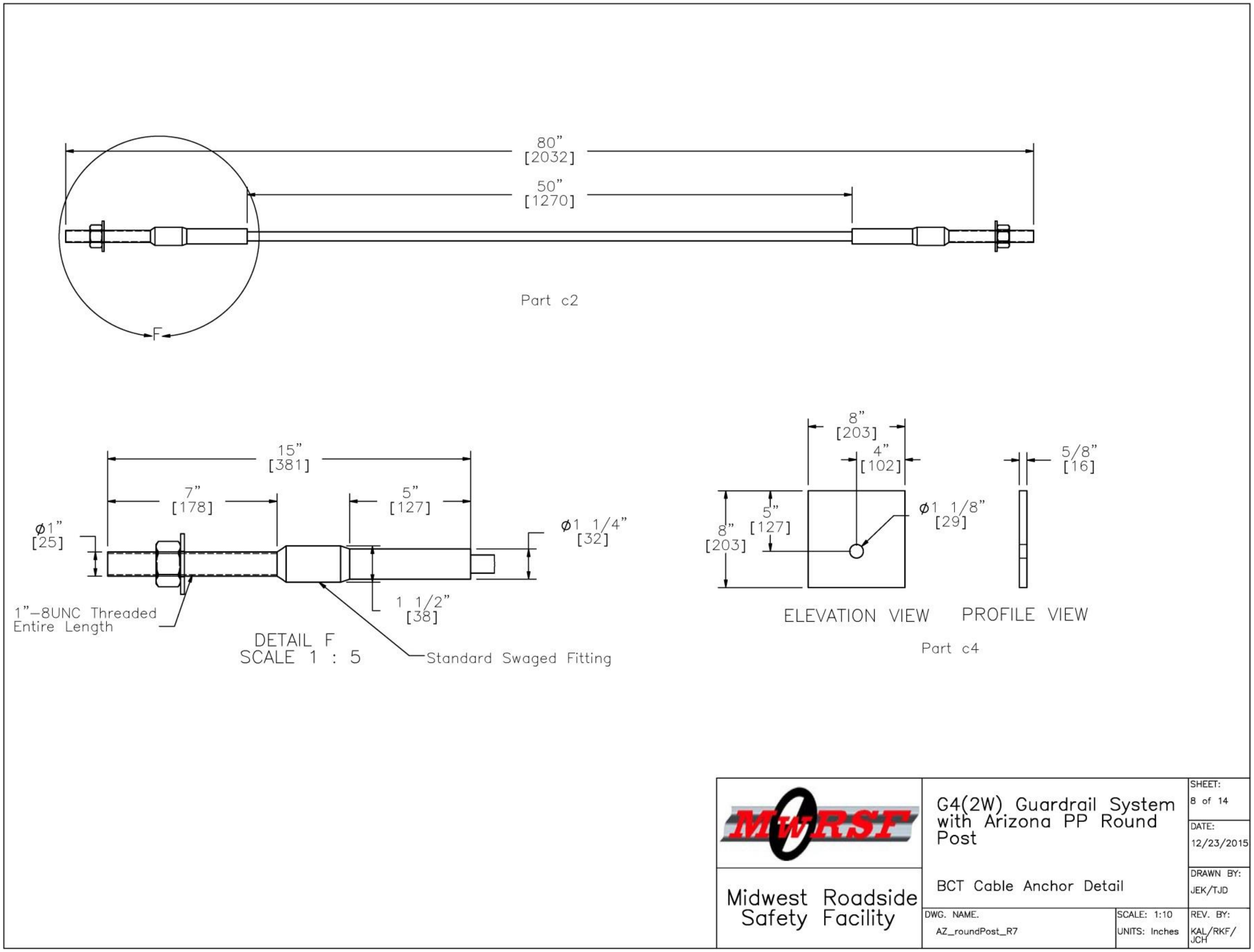

Figure 8. BCT Cable Anchor Details, Test No. AZRP-1

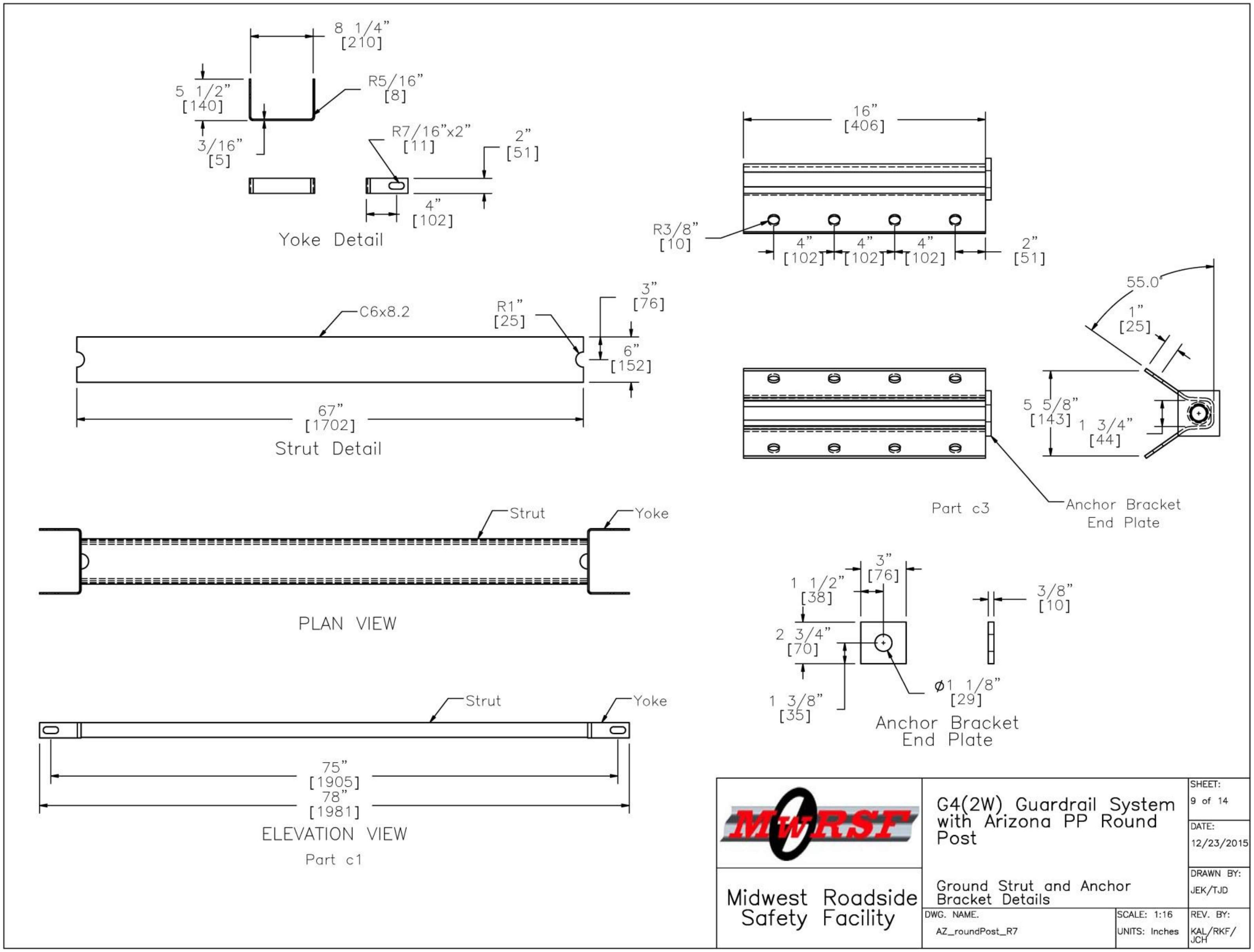

Figure 9. Ground Strut and Anchor Bracket Details, Test No. AZRP-1

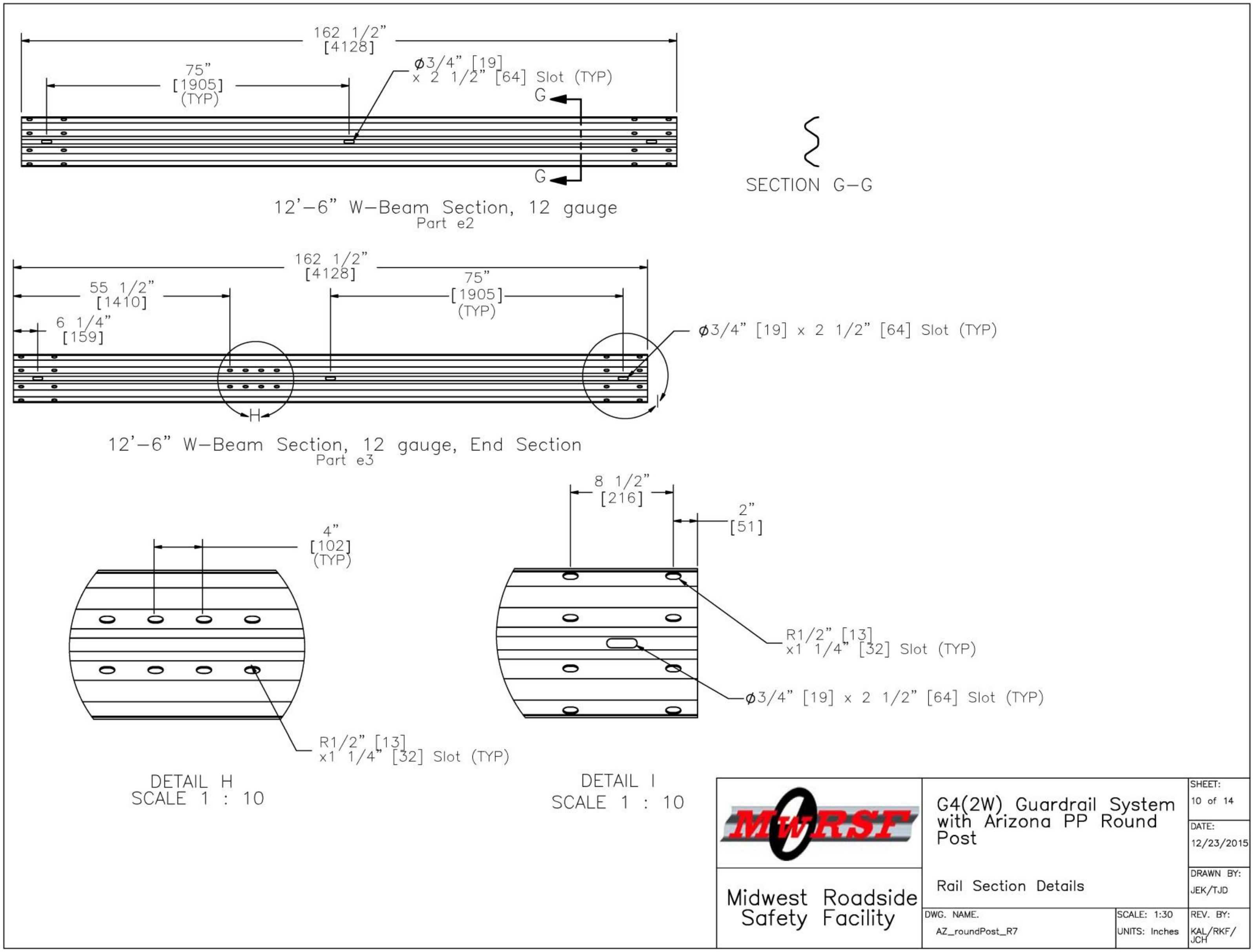

Figure 10. Guardrail Section Details, Test No. AZRP-1

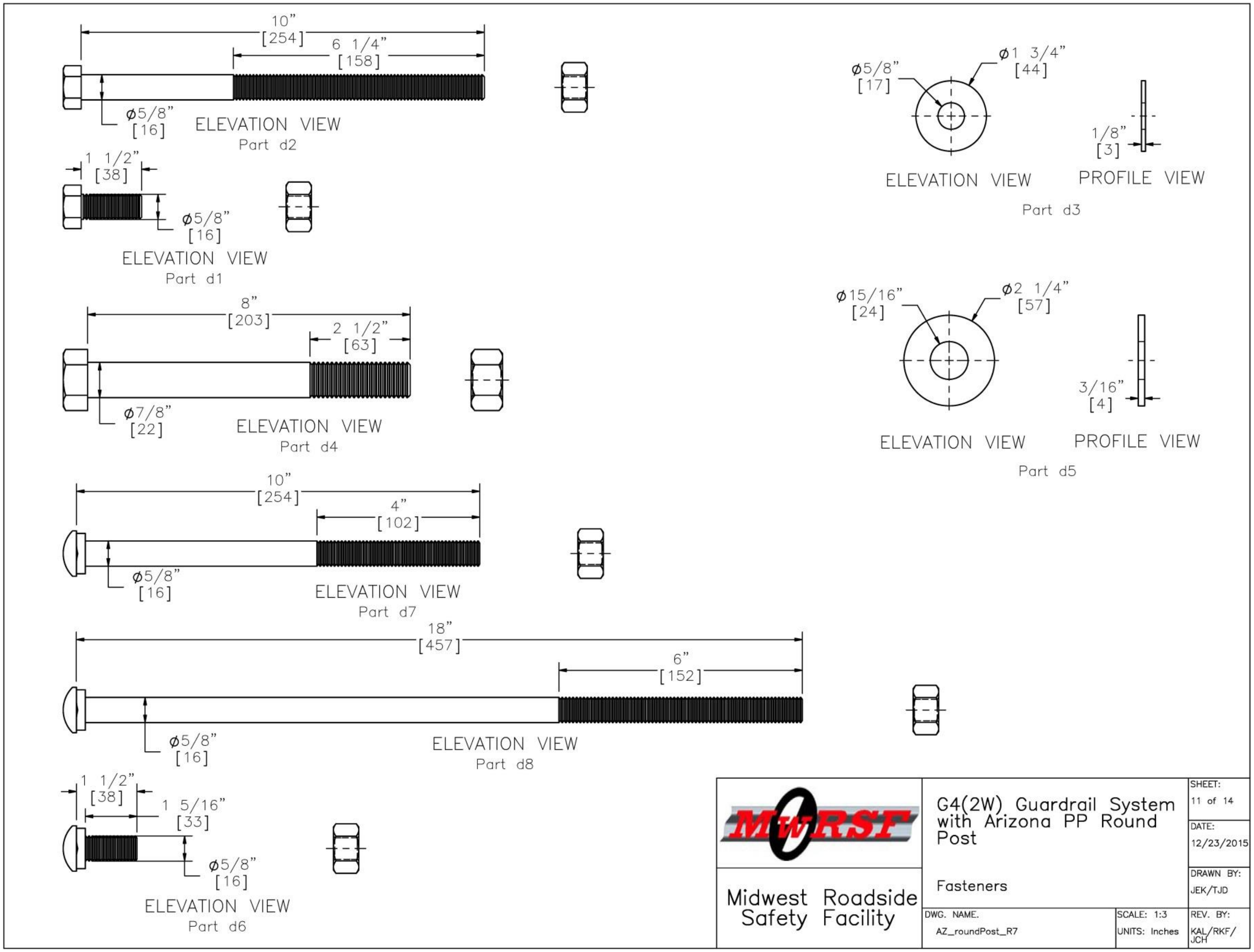

Figure 11. Fastener Details, Test No. AZRP-1

SPECIFICATIONS

The Ponderosa Pine (PP) round post is for use in G4(2W) W-beam guardrail systems and shall be manufactured of material that conforms to the guidelines shown below.

General:
All posts shall meet the current quality requirements of the American National Standards Institute (ANSI) 05.1, Wood Poles, except as supplemented herein:

Manufacture:
All posts shall be smooth-shaved by machine. No ringing of the posts, as caused by improperly adjusted peeling machine, is permitted. All outer and inner bark shall be removed during the shaving process. All knots and knobs shall be trimmed smooth and flush with the surface of the posts. The use of peeler cores is prohibited.

Groundline:
The groundline, for the purpose of applying these restrictions of ANSI 05.1 that reference the groundline, shall be defined as being located 35" [889] from the butt end of each post.

Size:
The size of the posts shall be classified based on their diameter at the groundline and their length. The groundline diameter shall be specified by diameter in 1/8" [3] breaks. The length shall be specified in 1" [25] breaks. Dimension shall apply to fully seasoned posts. When measured between their extreme ends, the post shall be no shorter than the specified lengths but may be up to 3" [76] longer.

Scars:
Scars are permitted in the middle third as defined in ANSI 05.1, provided that the depth of the trimmed scar is not more than 1" [25].

Shape and Straightness:
All PP timber posts shall be nominally round in cross section. A straight line drawn from the centerline of the top to the center of the butt of any post shall not deviate from the centerline of the post more than 1 1/4" [32] at any point. Posts shall be free from reverse bends.

Splits, Checks, and Shakes:
Splits or ring shakes are not permitted in the top two thirds of the post. Checks are not permitted in the top two thirds of the post if wider than one third of the diameter if dry and wider than three eighths of the diameter if not dry. Splits exceeding the diameter in length are not permitted in the bottom one third of the post. A shake or check is permitted in the bottom one third of the post as long as it is not wider than one half of the butt diameter. (Note - check size is determined as the average measured penetration over its length.)

MwRSF	G4(2W) Guardrail System with Arizona PP Round Post		SHEET: 12 of 14
			DATE: 12/23/2015
Midwest Roadside Safety Facility	Post Specifications		DRAWN BY: JEK/TJD
	DWG. NAME. AZ_roundPost_R7	SCALE: 1:512 UNITS: Inches	REV. BY: KAL/RKF/JCH

Figure 12. Ponderosa Pine Round Post Specifications, Test No. AZRP-1

SPECIFICATIONS

Knots:
Knot diameter for Ponderosa Pine posts shall be limited to 3 1/2” [89] or smaller.

Treatment:
Treating - American Wood-Preservers’ Association (AWPA) - Book of Standards (BOS) U1-05. Use category system UCS: user specification for treated wood; commodity specification B; Posts; Wood for Highway Construction must be met using the methods outlined in AWPA BOS T1-05 Section 8.2. Each treated post shall have a minimum sapwood depth of 3/4” [19], as determined by examination of the tops and butts of each post. Material that has been air dried or kiln dried shall be inspected for moisture content in accordance with AWPA standard M2 prior to treatment. Tests of representative pieces shall be conducted. The lot shall be considered acceptable when the average moisture content does not exceed 25 percent. Pieces exceeding 29 percent moisture content shall be rejected and removed from the lot.

Decay:
Allowed in knots only.

Holes:
Pin holes 1/16” [1] or less are not restricted.

Slope of Grain:
1 in 10.

Compression Wood:
Not allowed in the outer 1” [25] or if exceeding one quarter of the radius.

Ring Density:
Ring density shall be at least 6 rings-per-inch, as measured over a 3” [76] distance.

Midwest Roadside Safety Facility	G4(2W) Guardrail System with Arizona PP Round Post		SHEET: 13 of 14
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	Post Specifications		DRAWN BY: JEK/TJD
	DWG. NAME. AZ_roundPost_R7	SCALE: 1:512 UNITS: Inches	REV. BY: KAL/RKF/JCH

Figure 13. Ponderosa Pine Round Post Specifications, Test No. AZRP-1

Item No.	QTY.	Description	Material Spec	Hardware Guide
a1	25	8 1/2" [216] Dia. x 64" [1626] Long Post	Ponderosa Pine	PDE21
a2	25	6"x9 1/4"x14 1/4" [152x235x362] Routed Blockout	Ponderosa Pine	PDB23
b1	4	72" [1829] Foundation Tube	ASTM A500 Grade B Galv.	PTE05
b2	4	BCT 46" [1168] Long Timber Post	SYP Grade No. 1 or better	PDF01
c1	2	Strut and Yoke Assembly	ASTM A36 Steel Galv.	PFP01
c2	2	BCT Cable Anchor Assembly	ϕ3/4" [19] 6x19 IWRC IPS Galvanized Wire Rop	FCA01
c3	2	Anchor Bracket Assembly	ASTM A36 Steel Galv.	FPA01
c4	2	5"x8"x5/8" [127x203x16] Anchor Bearing Plate	ASTM A36 Steel Galv.	FPB01
c5	2	2 3/8" [60] O.D.x 6" [152] Long BCT Hole Insert	P2 Sch. Pipe A36	FMM02
d1	16	5/8" [16] Dia. x 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 Galv.	FBX16a
d2	4	5/8" [16] Dia. x 10" [254] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 Galv.	FBX16a
d3	44	5/8" [16] Dia. Flat Washer	Grade 5	–
d4	4	7/8" [22] Dia. x 7 1/2" [191] Long Hex Head Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 Galv.	FBX22a
d5	8	7/8" [22] Dia. Flat Washer	ASTM F844 Galv.	FWC22a
d6	104	5/8" [16] Dia. x 1 1/2" [38] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 Galv.	FBB01
d7	4	5/8" [16] Dia. x 10" [254] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 Galv.	FBB03
d8	25	5/8" [16] Dia. x 18" [457] Long Guardrail Bolt and Nut	Bolt ASTM A307 Galv., Nut ASTM A563 Galv.	FBB04
e2	13	12'–6" [3810] W–Beam Standard Guardrail Section	12 gauge [2.7] AASHTO M180 Galv.	RWM02a
e3	2	25' [7620] W–Beam Standard Guardrail End Section	12 gauge [2.7] AASHTO M180 Galv.	RMW22a
f1	29*	16D Double Head Nail	–	–

Note: (1) Order 50 posts for extra to sort through, measure, and investigate.

* Additional nail for every blockout using two pieces. Secure the two with nail.

Midwest Roadside Safety Facility

G4(2W) Guardrail System with Arizona PP Round Post

Bill of Materials

SHEET: 14 of 14

DATE: 12/23/2015

DRAWN BY: JEK/TJD

DWG. NAME. AZ_roundPost_R7

SCALE: 1:512

UNITS: Inches

REV. BY: KAL/RKF/JCH

Figure 14. Bill of Materials, Test No. AZRP-1

Figure 15. Test Installation Photographs, Test No. AZRP-1

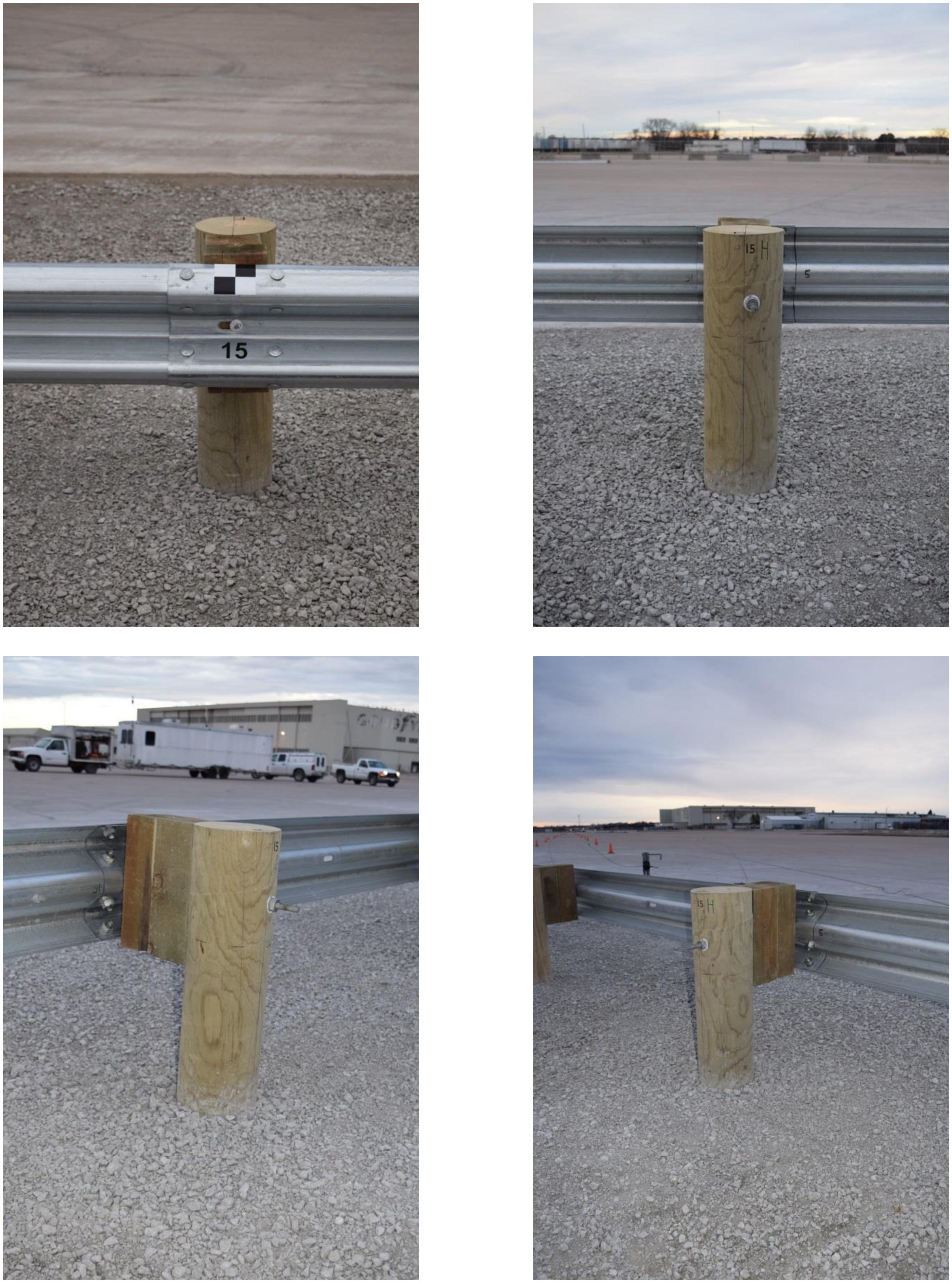


Figure 16. Test Installation Post Photographs, Test No. AZRP-1

Figure 17. Test Installation End Anchorage Photographs, Test No. AZRP-1

Table 2. Ponderosa Pine Round Posts – Selected Data

Post No.	Post Designation	Post Diameter (in.)		Ring Density (rings/in.)	Post Weight (lbs)	Post Length (in.)	Moisture Content (%)	
		Ground Line	8 in. Below Ground Line				Ground Line	8 in. Below Ground Line
3	R	8.75	8.75	12.0	120	64.1	29	30
4	S	8.59	8.59	12.0	75	64.1	22	22
5	T	8.79	8.71	14.0	91	64.1	21	21
6	I	8.75	8.79	12.0	88	64.0	21	24
7	Y	8.79	8.79	11.0	108	64.2	25	21
8	Q	8.59	8.67	13.3	71	64.1	18	18
9	U	8.67	8.63	7.3	90	64.0	22	20
10	X	8.59	8.55	10.3	91	64.1	21	22
11	V	8.55	8.59	15.0	111	64.2	44	44
12	BB	8.79	8.87	13.0	99	64.4	35	37
13	B	8.87	8.83	7.0	111	64.1	36	34
14	W	8.91	8.87	15.0	101	64.4	23	20
15	F	8.59	8.67	9.3	112	64.1	36	35
16	G	8.83	8.87	12.0	80	64.1	19	22
17	A	8.83	8.91	10.7	67	64.2	18	20
18	D	8.59	8.67	11.7	79	64.0	21	19
19	J	8.51	8.55	10.3	90	64.1	27	47
20	H	8.99	9.07	9.3	92	64.1	31	27
21	P	8.59	8.67	9.0	89	64.0	20	19
22	N	8.71	8.63	11.0	98	64.2	26	27
23	O	8.99	9.07	14.7	107	64.2	19	19
24	L	8.71	8.75	9.0	78	64.1	17	20
25	K	8.75	8.75	15.0	84	64.0	25	22
26	E	8.67	8.71	11.7	96	64.1	22	28
27	M	8.71	8.83	13.7	101	64.0	30	31

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

Test Requirements

Longitudinal barriers, such as W-beam guardrails, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the FHWA and for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in NCHRP Report No. 350 [9]. According to TL-3 of NCHRP Report No. 350, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 3.

Table 3. NCHRP Report No. 350 TL-3 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria[1]
				Speed, mph (km/h)	Angle, deg.	
Longitudinal Barrier	3-10	820C	1,808 (820)	62.1 (100)	20	A,D,F,H,I,K,M
	3-11	2000P	4,409 (2,000)	62.1 (100)	25	A,D,F,K,L,M

[1] Evaluation criteria explained in Table 4.

Based on the success of prior small car testing on strong-post, W-beam guardrail systems, the 1,808-lb (820-kg) small car crash test was deemed unnecessary for this demonstration project. Details pertaining to a sampling of prior successful small car tests into strong-post guardrail systems are contained below.

First, test no. GR-1 was performed on a G4(2W) guardrail system that was configured with 6-in. x 8-in. x 14-in. (152-mm x 203-mm x 356-mm) long timber blockouts and supported 6-in. x 8-in. x 6-ft (152-mm x 203-mm x 1.8-m) long timber posts spaced on 6 ft – 3 in. (1,905 mm) centers and according to the NCHRP Report No. 230 safety performance criteria [15]. The barrier successfully contained and redirected a 1,989-lb (902-kg) small car impacting at 60.1 mph (96.7 km/h) and 15.5 degrees [16]. The dynamic deflection was measured as 7.7 in. (196 mm).

A second study was performed on strong-post, W-beam guardrail systems by Texas Transportation Institute (TTI) researchers and included two full-scale crash tests with small cars according to the NCHRP Report No. 230 criteria. First, test no. 1147-1 was performed on a W-beam guardrail system that was configured with 7-in. (178-mm) diameter round wood posts without the use of spacer blocks, embedded 38 in., and spaced on 8 ft – 4 in. (2,540 mm) centers. The barrier successfully contained and redirected a 1,967-lb (892-kg) small car impacting at 61.7 mph (99.3 km/h) and 20.7 degrees, even with significant wheel snag observed on the posts [17]. The dynamic deflection was measured as 16.0 in. (406 mm). Second, test no. 1147-3 was performed on a modified G4(1S) W-beam guardrail system that was configured with steel posts with offset blocks, which were spaced on 8 ft – 4 in. (2,540 mm) centers. The barrier successfully contained and redirected a 1,968-lb (893-kg) small car impacting at 61.5 mph (99.0 km/h) and 20.5 degrees, even with significant wheel snag observed on the posts [17]. The dynamic deflection was measured as 24.0 in. (610 mm).

A third study was performed on strong-post W-beam guardrail systems positioned near curbs, curves, and slopes by researchers at ENSCO, Inc. This effort included test no. 1862-2-89 [18], which was run using NCHRP Report No. 230 criteria to evaluate a G4(1S) guardrail with steel posts and offset blocks spaced on 6 ft – 3 in. (1,905 mm) centers and positioned on a 1,192-ft (363-m) radius curve with flat terrain. The barrier successfully contained and redirected a 1,964-lb (891-kg) small car impacting at 62.2 mph (100.0 km/h) and 20.0 degrees [18].

The fourth study was performed on a modified G4(1S) guardrail system by MiTech Incorporated [19]. The guardrail was configured with steel posts and 6-in. x 8-in. (152-mm x

203-mm) offset blocks, using a 6-ft 3-in. (1,905 mm) post spacing. Test no. 99F003 was performed according to the NCHRP Report No. 350 criteria [9] using a 2,002-lb (908-kg) small car impacting at 62.4 mph (100.4 km/h) and 20.5 degrees. The barrier successfully contained and redirected the small car, even with some wheel snag observed on the posts. The dynamic deflection was measured as 12.8 in. (325 mm).

Finally, test no. GR-6 was performed on a G4(2W) guardrail system that was configured with 6-in. x 8-in. x 14-in. (152-mm x 203-mm x 356-mm) long timber blockouts and supported 6-in. x 8-in. x 6-ft (152-mm x 203-mm x 1.8-m) long timber posts spaced on 6 ft – 3 in. (1,905 mm) centers [20]. The test was also conducted according to the NCHRP Report No. 230 safety performance criteria. The barrier successfully contained and redirected a 1,928-lb (875-kg) small car impacting at 61.9 mph (99.6 km/h) and 21.7 degrees. The dynamic deflection was measured as 10.4 in. (264 mm).

In addition, FHWA was consulted to determine if they would agree to the use of dynamic bogie testing to demonstrate that a particular round PP post (size and length) can be used in lieu of a rectangular or square SYP post and provides similar post-soil behavior. FHWA concurred but was also noted that the system performance when the system is subjected to longitudinal forces would need to be addressed. The intent of the pickup truck test is to evaluate the strength of the system and further justification for not conducting the small car test. The detailed correspondence with FHWA in regards to the demonstration testing is shown in Appendix B.

Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the guardrail to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable.

Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 4 and defined in greater detail in NCHRP Report No. 350. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in NCHRP Report No. 350.

Table 4. NCHRP Report No. 350 Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted. See discussion in Section 5.3 and Appendix E of NCHRP Report No. 350.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant impact velocity (see Appendix A, Section A5.3 of NCHRP Report No. 350 for calculation procedure) should satisfy the following:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>29.5 ft/s
(9 m/s)</td><td>39.4 ft/s
(12 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">Occupant ridedown acceleration (see Appendix A, Section A5.3 of NCHRP Report No. 350 for calculation procedure) should satisfy the following :</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15 g’s</td><td>20 g’s</td></tr>
<tr><td rowspan="3">Vehicle Trajectory</td><td>K.</td><td colspan="3">After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td></tr>
<tr><td>L.</td><td colspan="3">The occupant impact velocity in the longitudinal direction should not exceed 39.4 ft/s (12 m/s) and the occupant ride down acceleration in the longitudinal direction (see Appendix A, Section A5.3 for calculation procedure) should not exceed 20 g’s.</td></tr>
<tr><td>M.</td><td colspan="3">The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device.</td></tr>
</table>

4 TEST CONDITIONS

Test Facility

The testing facility is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles (8.0 km) northwest of the University of Nebraska-Lincoln.

Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the barrier system. A digital speedometer on the tow vehicle increased the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch [21] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

Test Vehicles

For test no. AZRP-1, a 1993 Chevrolet C2500 pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 4,629 lb (2,100 kg), 4,412 lb (2,001 kg), and 4,412 lb (2,001 kg), respectively. The test vehicle is shown in Figures 18 and 19, and vehicle dimensions are shown in Figure 20.

Figure 18. Test Vehicle, Test No. AZRP-1

Figure 19. Test Vehicle Interior, Test No. AZRP-1

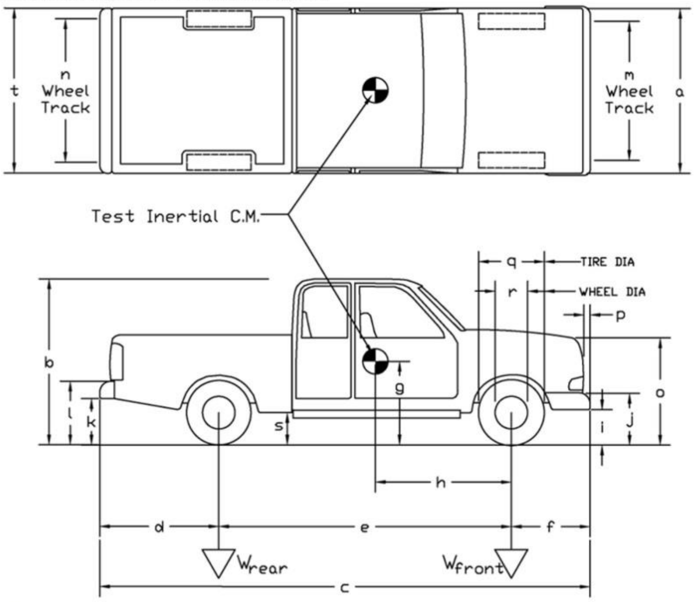
Date: 12/8/2015 **Test Number:** AZRP-1 **Model:** C2500

Make: Chevrolet **Vehicle I.D.#:** 1GCGC24K6PE210581

Tire Size: 225/75R16 **Year:** 1993 **Odometer:** 371162

Tire Inflation Pressure: 50

***(All Measurements Refer to Impacting Side)**



Vehicle Geometry -- in. (mm)

a	74 1/4	(1886)	**b**	72 1/8	(1832)
c	217 1/2	(5525)	**d**	51 3/4	(1314)
e	132	(3353)	**f**	33 3/4	(857)
g	26 1/2	(672)	**h**	57	(1448)
i	18 1/8	(460)	**j**	26 3/4	(679)
k	30 5/8	(778)	**l**	23 1/8	(587)
m	62 3/4	(1594)	**n**	64 1/2	(1638)
o	41 1/4	(1048)	**p**	3 3/4	(95)
q	28 3/8	(721)	**r**	17 1/2	(445)
s	17 7/8	(454)	**t**	72 1/4	(1835)

Wheel Center Height Front	13 3/4	(349)
Wheel Center Height Rear	14	(356)
Wheel Well Clearance (F)	36 1/8	(918)
Wheel Well Clearance (R)	37 1/2	(953)
Frame Height (F)	14 1/8	(359)
Frame Height (R)	26 3/8	(670)
Engine Type	Gasoline	
Engine Size	5.7L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	

Mass Distribution lb. (kg)

Gross Static	**LF** 1298 (589)	**RF** 1209 (548)
	LR 979 (444)	**RR** 926 (420)

Weights lb. (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	2607 (1183)	2507 (1137)	2507 (1137)
W-rear	2022 (917)	1905 (864)	1905 (864)
W-total	4629 (2100)	4412 (2001)	4412 (2001)

GVWR Ratings

Front	3800 lbs
Rear	6000 lbs
Total	8600 lbs

Dummy Data

Type:	NA
Mass:	NA
Seat Position:	NA

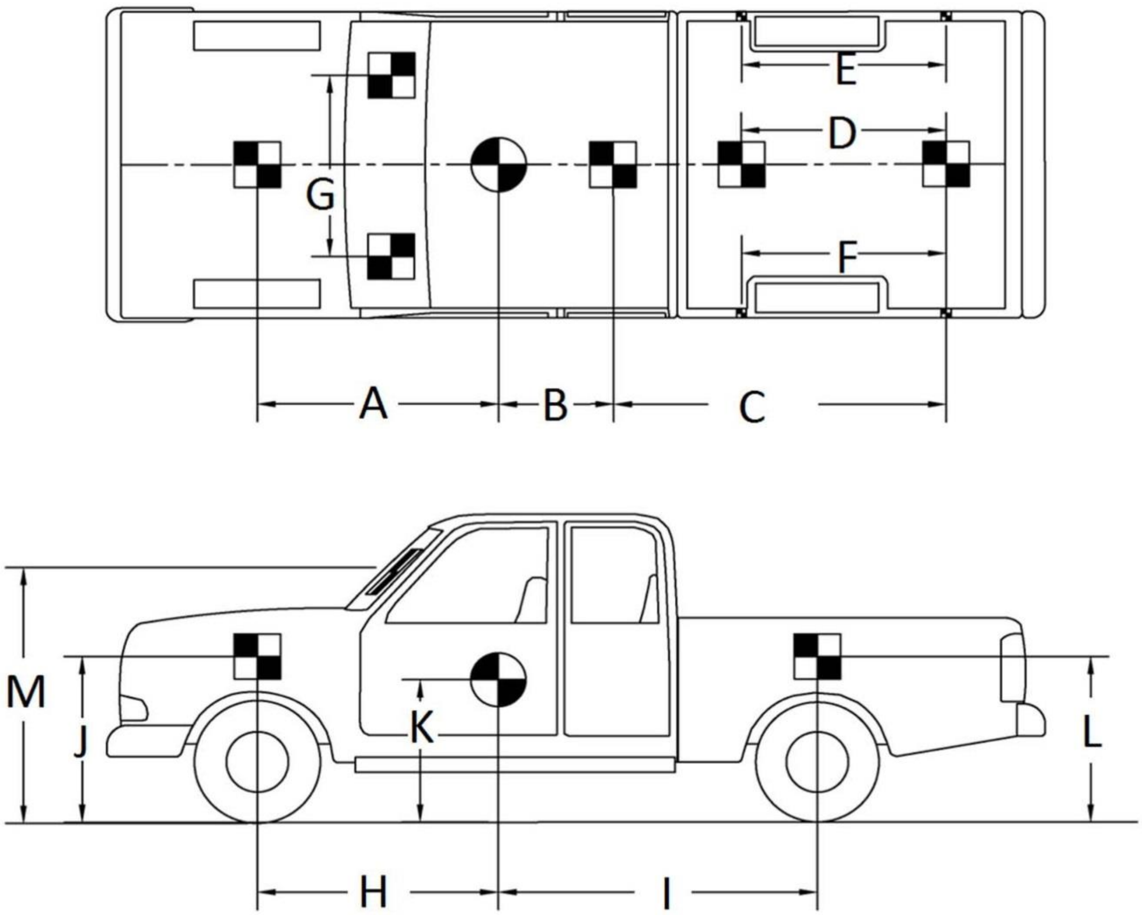
Note any damage prior to test: Rusty cab corners and rocker panels.

Figure 20. Vehicle Dimensions, Test No. AZRP-1

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [22] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The location of the final c.g. is shown in Figures 20 and 21. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure 21. Round, checkered targets were placed on the center of gravity on the left-side door, the right-side door, and the roof of the vehicle.

The front wheels of the test vehicle were aligned to vehicle standards, except the toe-in value was adjusted to zero so that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted on the right side of the vehicle's dash and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed videos. A remote-controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.



TEST #: AZRP-1

TARGET GEOMETRY-- in. (mm)

A	67 1/4	(1708)	F	84 3/4	(2153)	K	26 1/2	(673)
B	7 7/8	(200)	G	34	(864)	L	41 1/2	(1054)
C	97 1/2	(2477)	H	57	(1448)	M	64 1/2	(1638)
D	48	(1219)	I	74 7/8	(1902)			
E	84 3/4	(2153)	J	40	(1016)			

Figure 21. Target Geometry, Test No. AZRP-1

Data Acquisition Systems

4.1.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. All of the accelerometers were mounted near the center of gravity of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [23].

The two systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by DTS of Seal Beach, California. The acceleration sensors were mounted inside the bodies of custom built SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software programs and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.1.2 Rate Transducers

Two identical angle rate sensor systems mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders were used to measure the rates of rotation of the test vehicle. Each SLICE MICRO Triax ARS had a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) and recorded data at 10,000 Hz to the onboard microprocessors. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

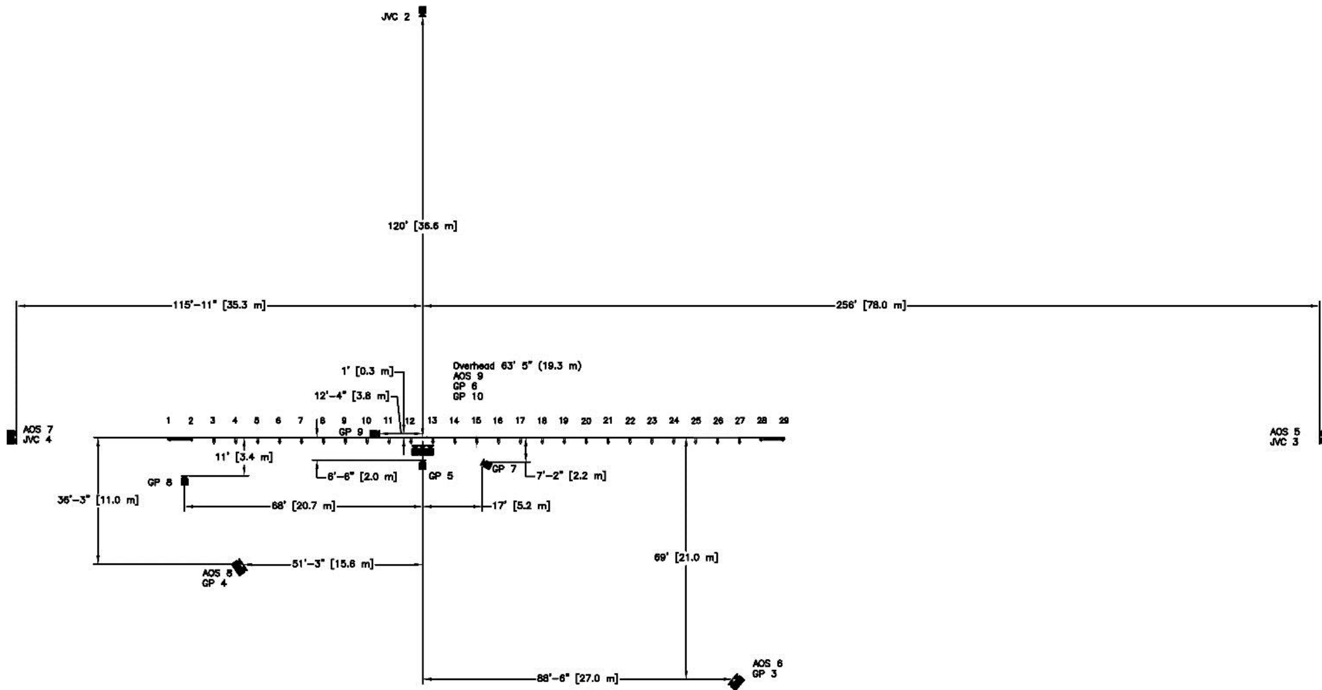
4.1.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the bogie vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the side of the vehicle. When the emitted beam of light was reflected by the targets and returned to the Emitter/Receiver, a signal was sent to the data acquisition computer, recording at 10,000 Hz, as well as the external LED box activating the LED flashes. The speed was then calculated using the spacing between the retroreflective targets and the time between the signals. LED lights and high-speed digital video analysis are only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

4.1.4 Digital Photography

Five AOS high-speed digital video cameras, eight GoPro digital video cameras, and three JVC digital video cameras were utilized to film test no. AZRP-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 22.

The high-speed videos were analyzed using ImageExpress MotionPlus and RedLake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A Nikon D50 digital still camera was also used to document pre- and post-test conditions for all tests.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI Gigabit	500	Vivitar 135mm fixed	--
AOS-6	AOS X-PRI Gigabit	500	Cosmicar 50mm fixed	--
AOS-7	AOS X-PRI Gigabit	500	Fujinon 50mm fixed	--
AOS-8	AOS S-VIT 1531	500	Sigma 28-70mm DG	50
AOS-9	AOS TRI-VIT	500	Kowa 12mm fixed	--
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	240		
GP-10	GoPro Hero 4	240		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 22. Camera Locations, Speeds, and Lens Settings, Test No. AZRP-1

5 FULL-SCALE CRASH TEST NO. AZRP-1

Test No. AZRP-1

The 4,412-lb (2,001-kg) pickup truck impacted a modified Arizona G4(2W) W-beam guardrail system that was supported by 8½-in. (216-mm) nominal diameter PP posts at a speed of 60.7 mph (97.7 km/h) and at an angle of 24.8 degrees. A summary of the test results and sequential photographs are shown in Figure 23. Additional sequential photographs are shown in Figures 24 through 27.

Weather Conditions

Test no. AZRP-1 was conducted on December 8, 2015 at approximately 12:45 pm. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 5.

Table 5. Weather Conditions, Test No. AZRP-1

Temperature	56°F
Humidity	44%
Wind Speed	10 mph
Wind Direction	330° from True North
Sky Conditions	Clear
Visibility	10.00 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in.
Previous 7-Day Precipitation	0 in.

Test Description

Initial vehicle impact was to occur 185 in. (4,699 mm) upstream from post no. 15, as shown in Figure 28, which was selected using the CIP plots found in Section 3.4 of NCHRP Report No. 350 to maximize pocketing and the probability of wheel snag. The actual point of impact was 182¼ in. (4,629 mm) upstream from post no. 15 or 2¾ in. downstream from the targeted impact point. A sequential description of the impact events is contained in Table 6. The vehicle came to rest 121 ft – 3 in. (37.0 m) downstream from the point of impact and 27 ft – 2 in. (8.3 m) laterally behind the guardrail system. The vehicle trajectory and final position are shown in Figures 23 and 29.

Table 6. Sequential Description of Impact Events, Test No. AZRP-1

TIME (sec)	EVENT
0.000	Vehicle right-front bumper contacted rail between post nos. 12 and 13, and vehicle front bumper began to deform.
0.004	Post no. 13 began to deflect backward.
0.006	Post no. 12 began to deflect backward, and vehicle right fender began to deform.
0.008	Vehicle grill began to deform, and post no. 15 began to deflect downstream.
0.018	Vehicle right headlight deformed, and post no. 12 began to twist downstream.
0.024	Vehicle hood began to deform, and post no. 14 began to deflect downstream.
0.028	Post no. 14 began to deflect backward, post no. 15 began to deflect forward, and post nos. 9 through 11 began to twist downstream.
0.032	Post no. 13 began to rotate backward.
0.036	Vehicle rolled toward barrier, and right-front tire contacted post no. 13.
0.038	Vehicle right-front tire contacted rail downstream of post no. 13, and vehicle right-side door began to deform.
0.058	Post no. 15 began to deflect backward, and post no. 14 began to twist upstream.
0.060	Post no. 16 began to deflect backward, and post no. 13 began to deflect upstream.
0.062	Blockout no. 13 split, and post nos. 17 through 20 began to twist upstream.
0.068	Post no. 16 began to deflect downstream.
0.070	Top of right-side door began to separate at the roof.
0.074	Post no. 18 began to deflect backward, post no. 13 began to deflect forward, blockout no. 13 disengaged from post no. 13, and vehicle began to yaw away from barrier.
0.086	Vehicle left fender began to deform, post no. 14 began to rotate backward, and blockout no. 13 detached from rail.
0.092	Vehicle right fender contacted blockout no. 14, and post no. 13 contacted rail.
0.102	Vehicle began to roll away from barrier.
0.106	Vehicle right headlight disengaged.
0.116	Post no. 17 began to deflect backward, and vehicle began to pitch downward.
0.126	Blockout no. 14 split.
0.136	Vehicle left-side door began to deform.
0.146	Blockout no. 14 disengaged from post no. 14.
0.150	Vehicle left-rear tire was airborne, and post no. 16 began to twist upstream.
0.170	Post no. 15 began to rotate backward, and post no. 12 began to twist upstream.
0.182	Post no. 14 disengaged from rail.

0.190	Vehicle hood and right fender began to override barrier.
0.202	Post no. 14 split.
0.228	Vehicle began to roll toward barrier.
0.236	Post no. 15 disengaged from rail.
0.258	Blockout no. 15 disengaged from rail.
0.266	Post no. 17 began to twist downstream, and post nos. 9 and 10 began to twist upstream.
0.272	Vehicle roof began to deform.
0.286	Post no. 18 began to twist downstream.
0.300	Vehicle began to roll away from barrier.
0.314	Vehicle right quarter panel began to override rail.
0.316	Vehicle right fender contacted blockout no. 16.
0.326	Post no. 19 began to twist downstream.
0.342	Vehicle was parallel to system at a speed of 33.3 mph (53.6 km/h).
0.356	Post no. 12 began to deflect forward.
0.364	Post no. 11 began to twist upstream.
0.384	Post no. 16 began to deflect forward.
0.410	Vehicle right fender contacted blockout no. 17.
0.518	Vehicle began to roll toward barrier.
0.624	Vehicle left headlight disengaged.
0.65	Vehicle began to pitch upward.
0.652	Vehicle began to roll away from barrier.
0.718	Vehicle lost contact with system at a speed of 25.5 mph (41.1 km/h) and at angle of 21.3 degrees.
0.81	Vehicle began to yaw toward barrier.
0.926	Vehicle began to pitch downward and roll toward barrier.
1.678	Vehicle began to pitch upward and roll away from barrier.
2.492	Vehicle right-front fender and grill contacted rail between post nos. 28 and 29.
2.502	Post no. 29 began to deflect backward.
2.56	Vehicle front bumper contacted post no. 29.
2.584	Vehicle began to pitch upward, and post no. 29 fractured.
2.886	Vehicle began to pitch downward and roll toward barrier.
5.542	Vehicle came to rest 121 ft – 3 in. (37.0 m) downstream from impact and 27 ft – 2 in. (8.3 m) laterally behind guardrail system.

Barrier Damage

Damage to the barrier was moderate, as shown in Figures 30 through 39. Barrier damage consisted of rail deformation, disengagement of the W-beam rail from the posts, fractured wood posts, split wood blockouts, and displaced posts in soil. The length of vehicle contact along the barrier was approximately 27 ft – 8⅛ in. (8.4 m), which spanned from 32¼ in. (819 mm) upstream from the centerline of post no. 13 through ⅛ in. (3 mm) upstream from the centerline of post no. 17.

Deformation of the W-beam rail occurred between post nos. 12 and 17. Flattening occurred on the bottom corrugation of the rail from post no. 13 through post no. 15. Kinking of the rail was found around the blockouts of post nos. 13 through 16. A maximum splice movement of ¼ in. (6 mm) was recorded at the splices at post nos. 15. The rail released from post no. 14 when the post fractured and from post nos. 15 and 16 where the bolt head pulled through the slots in the rail. Minor rail separation from the blockout occurred at post nos. 4 through 9, 11, and 17 through 21.

Post nos. 13 through 16 rotated backward. In addition, post nos. 14 and 15 fractured, and contact marks were found on post nos. 13 and 14 near the groundline. Blockouts at post nos. 12 and 16 encountered gouging from the rail. Blockouts fractured and were disengaged from post nos. 13 through 14. A portion of the blockout at post no. 15 fractured.

The upstream anchorage was undamaged, except for a ¾-in. (19-mm) soil gap found on the upstream side of the foundation tube at post no. 1 and a $^{1}/_{16}$-in. (2-mm) soil gap found on the downstream side of the foundation tube at post no. 2. Due to the secondary impact of the downstream anchorage, contact marks and kinks were found on the rail between post nos. 28 and 29. Contact marks and gouging were also found on post nos. 28 and 29, and post no. 29 fractured.

The maximum lateral permanent rail and post deflections were 15⅞ in. (403 mm) at the midspan between post nos. 15 and 16 and 18 in. (457 mm) at post no. 14, respectively, as measured in the field. The maximum lateral dynamic rail and post deflections were 28.8 in. (732 mm) at the midspan between at post nos. 14 and 15 and 21.3 in. (541 mm) at post no. 14, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 41.1 in. (1,044 mm), also determined from high-speed digital video analysis.

Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 40 through 44. The maximum occupant compartment deformations are listed in Table 7. During vehicle preparation, the seat frame for the 2000P vehicle was removed and erroneously not placed back in the truck. Previous testing with the 2000P vehicles early in the implementation of NCHRP Report No. 350 found that the seat frame was critical to developing the proper rigidity of the truck floorpan. MwRSF normally has two control points to account for any occupant compartment deformations. However, due to floorboard deformation and movement, both control points encountered movement. Therefore, two sets of data are reported below. Even though both control points encountered minor movement, all deformations were below the previously-recognized NCHRP Report No. 350 deformation limits. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Table 7. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	
	Set 1	Set 2
Wheel Well & Toe Pan	1⅝ (41)	5½ (140)
Floor Pan & Transmission Tunnel	1 (25)	0 (0)
Side Front Panel (in Front of A-Pillar)	2¼ (57)	2⅛ (54)
Side Door (Above Seat)	2⅝ (67)	⅝ (16)
Side Door (Below Seat)	2 (51)	1½ (38)
Roof	4⅝ (117)	3⅜ (86)
Windshield	0 (0)	0 (0)

The majority of the damage was concentrated on the right-front corner, right side, and front of the vehicle where impact had occurred. The right side of the bumper was crushed inward and backward. The right-front fender was dented, buckled, kinked, and was peeled backward. The right-front steel rim was severely deformed with significant crushing and dents. The right-front tire was torn and deflated. The grill was fractured around the right-side headlight assembly. The right-side and left-side headlights and signal lights were disengaged. The radiator deformed inward approximately 2½ in. (64 mm). The right side of the radiator support bent backward approximately 7 in. (178 mm). Denting and scraping were observed on the entire right side. The right-side door had a 1½-in. (38-mm) deep dent starting at the bottom and extending upward 23 in. (584 mm). The right-side B-pillar and the right-side of the pickup box had ¼-in. (6-mm) and 1-in. (25-mm) deep gouging, respectively. The right-side door was ajar approximately 1½ in. (38 mm), while the left-side door was ajar approximately 1¾ in. (44 mm). The left side of the front bumper was bent forward 4 in. (102 mm). The right side of the windshield had an 8 in. (203-mm) wide spider web cracking in the lower right corner. Hairline cracking began at the lower middle of the windshield and extended 29 in. (737 mm) upward, progressing into the right side of the windshield.

The lower-right control arm was scraped and crushed. The right control arm, front frame joints pulled through the frame. The lower-right shock mount bent inward, and the right spring pushed out of the lower spring pocket. The right sway bar bent rearward. The lower-right control arm mounts, the right sway bar frame mount, and the right idler arm deformed inward. The right steering knuckle, wheel bearing fractured, and the tie rod fractured at the knuckle. The drive shaft carrier bearing disengaged away from the mount. The rear transmission mount separated, and the transmission deformed upward 3½ in. (89 mm) and 1½ in. (38 mm) toward the left side. The right frame rail bent inward and forward of the transmission cross member. The frame rail crushed inward 4½ in. (114 mm) at the right-front cab mount. The right frame rail at the lower control arm mount deformed inward 4 in. (102 mm) and upward 2¾ in. (70 mm). A 4-in. (102-mm) long tear was found in the frame rail near the lower-rear control arm mount. The right frame horn bent rearward 4½ in. (114 mm) and buckled 12 in. (305 mm) behind the leading edge. The right-front cab frame mount deformed inward, and the bushings separated. The left-rear cab mount bolt fractured, and the cab shifted laterally toward the left side. The right-front brake line was torn.

Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 8. As stated previously, during vehicle preparation, the seat frame for the 2000P vehicle was removed and erroneously not placed back in the truck. Consequently, lateral and vertical displacement of the floorpan and specifically the transmission tunnel underneath the vehicle transducers was observed in test no. AZRP-1 that adversely affected the acceleration and rate transducer data. These floorpan motions did not exceed the limits for occupant compartment deformation, but they did alter the transducer results. At approximately 0.150 sec after impact, the shift of the floorpan caused localized loading of the acceleration transducer in the longitudinal, lateral, and vertical directions as well as shifting of the rate transducer angular rate data. The data from the transducers recorded after the floorboard shift is not valid and cannot be used to determine occupant risk. The OIVs, which occurred prior to 0.150 sec after impact, were valid, but the ORA values were not.

Due to the floorpan deformation near the mounting plate of the accelerometer units, as shown in Figures 42 and 43, a video analysis procedure, similar to that used in the past to evaluate full-scale crash tests, was used to in order to address the invalid ORAs. The longitudinal

OIV and longitudinal ORA were within the suggested limits provided in NCHRP Report No. 350. Although not required, the lateral OIV and lateral ORA were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk analysis, as determined from the accelerometer data and video analysis, are summarized in Figure 23. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E. The video analysis procedure and correspondence with FHWA is shown in Appendix F.

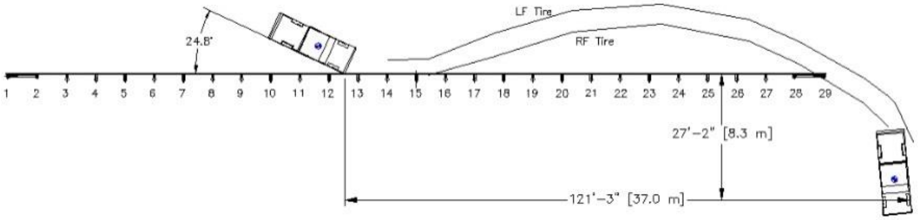
Table 8. Summary of OIV and ORA Values, Test No. AZRP-1

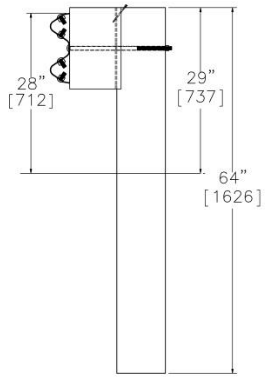
Evaluation Criteria		**Transducer**			**NCHRP 350 Limits**
		SLICE-1	**SLICE-2 (Primary)**	**Video Analysis**	
OIV ft/s (m/s)	Longitudinal	-19.89 (-6.06)	-20.51 (-6.25)	-20.01 (-6.10)	≤ 39.4 (12)
	Lateral	-18.58 (-5.66)	-18.35 (-5.59)	-19.03 (-5.80)	not required
ORA g's	Longitudinal	NA [1]	NA [1]	-7.01	≤ 20
	Lateral	NA [1]	NA [1]	-10.47	not required
MAX. ANGULAR DISPL. deg.	Roll	NA [1]	NA [1]	5.37	not required
	Pitch	NA [1]	NA [1]	Not available	not required
	Yaw	NA [1]	NA [1]	-45.42	not required

[1] The longitudinal and lateral ORAs and maximum angular displacements are deemed invalid due to the floorpan deformation near the center mounting plate of the accelerometer units. See Appendix F for more information.

Discussion

The analysis of the test results for test no. AZRP-1 showed that a modified Arizona G4(2W) W-beam guardrail system that was supported by 8½-in. (216-mm) nominal diameter PP posts adequately contained and redirected the 2000P vehicle with controlled lateral displacements of the barrier. There were no detached elements or fragments which showed potential for penetrating the occupant compartment nor presented undue hazard to other traffic. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate or ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements were deemed acceptable, because they did not adversely influence occupant risk safety criteria or cause rollover. After impact, the vehicle exited the barrier at an angle of 21.3 degrees, as determined by high-speed video analysis, which was slightly higher than the preferable exit angle of 14.8 degrees. The longitudinal occupant impact velocity and ridedown acceleration were within the required limits. Therefore, test no. AZRP-1 conducted on a modified Arizona G4(2W) W-beam guardrail system that was supported by 8½-in. (216-mm) nominal diameter PP posts was determined to be acceptable according to the TL-3 NCHRP Report No. 350 safety performance criteria for test designation no. 3-11.





- Test Agency .... MwRSF
- Test Number AZRP-1
- Date 12/8/2015
- NCHRP Report No. 350 Test Designation No. 3-11
- Test Article .... Arizona G4(2W) supported by 8½-in. (216-mm) PP posts
- Total Length .... 175 ft (53.3 m)
- Key Component – Steel W-Beam Rail
  - Thickness .... 12-gauge (2.66 mm)
  - Top Mounting Height .... 28 in. (711 mm)
- Key Component – Wood Post
  - Shape .... 8½ in. (216-mm) nominal diameter
  - Length .... 64 in. (1,626 mm)
  - Spacing .... 75 in. (1,905 mm)
  - Embedment Depth .... 35 in. (889 mm)
  - Material .... Graded Ponderosa Pine
- Key Component – Routed Wood Blockout
  - Size .... 6 x 9¼ x 14¼ in. (152 x 235 x 362 mm)
  - Material .... Ponderosa Pine
- Soil Type .... AASHTO M147-65(1990) Grade B Coarse Crushed Limestone
  - Compaction Method .... MwRSF Compaction Methods per MASH
- Vehicle Make /Model .... 1993 Chevrolet C2500 Pickup Truck
  - Curb .... 4,629 lb (2,100 kg)
  - Test Inertial .... 4,412 lb (2,001 kg)
  - Gross Static .... 4,412 lb (2,001 kg)
- Impact Conditions
  - Speed .... 60.7 mph (97.7 km/h)
  - Angle .... 24.8 deg
  - Impact Location .... 182¼ in. (4,629 mm) upstream of post no. 15
- Impact Severity (IS) .... 95.4 kip-ft (129.3 kJ)
- Exit Conditions
  - Speed .... 25.5 mph (41.1 km/h)
  - Angle .... 21.3 deg
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 121 ft – 3 in. (37.0 m) downstream
  .... 27 ft – 2 in. (8.3 m) laterally behind
- Vehicle Damage .... Moderate
  - VDS [24] 1-RFQ-5
  - CDC [25] 1-RYEW4
  - OCDI RF010100000
  - Maximum Interior Deformation .... 5½ in. (140 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 18 in. (457 mm)
  - Dynamic .... 28.8 in. (732 mm)
  - Working Width .... 41.1 in. (1,044 mm)
- Transducer Data

Evaluation Criteria		Transducer			NCHRP 350 Limit
		SLICE-1	SLICE-2 (Primary)	Video Analysis	
OIV ft/s (m/s)	Longitudinal	-19.89 (-6.06)	-20.51 (-6.25)	-20.01 (-6.10)	≤ 39.4 (12)
	Lateral	-18.58 (-5.66)	-18.35 (-5.59)	-19.03 (-5.80)	not required
ORA g's	Longitudinal	NA	NA	-7.01	≤ 20
	Lateral	NA	NA	-10.47	not required
MAX ANGULAR DISP. deg.	Roll	NA	NA	5.37	not required
	Pitch	NA	NA	Not available	not required
	Yaw	NA	NA	-45.42	not required

Figure 23. Summary of Test Results and Sequential Photographs, Test No. AZRP-1


0.000 sec


0.000 sec


0.086 sec


0.118 sec


0.228 sec


0.314 sec


0.518 sec


0.718 sec


0.906 sec


1.504 sec


2.546 sec


3.360 sec

Figure 24. Additional Sequential Photographs, Test No. AZRP-1


0.000 sec


0.116 sec


0.258 sec


0.316 sec


0.410 sec


0.650 sec


0.000 sec


0.060 sec


0.146 sec


0.300 sec


0.518 sec


1.032 sec

Figure 25. Additional Sequential Photographs, Test No. AZRP-1

Figure 26. Additional Sequential Photographs, Test No. AZRP-1

0.000 sec

0.033 sec

0.058 sec

0.083 sec

0.108 sec

0.133 sec

0.000 sec

0.025 sec

0.054 sec

0.079 sec

0.100 sec

0.275 sec

Figure 27. Additional Sequential Photographs, Test No. AZRP-1

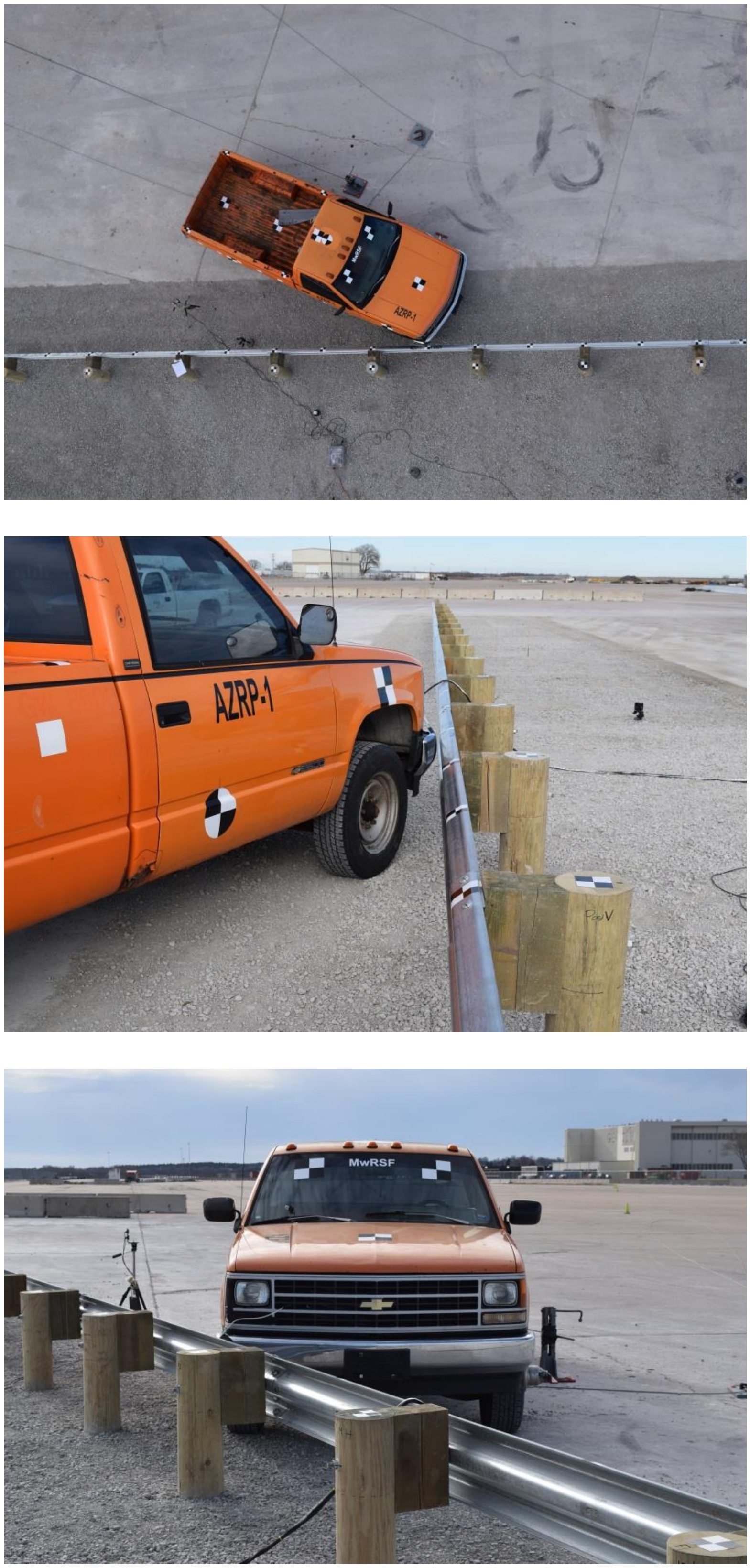


Figure 28. Impact Location, Test No. AZRP-1

Figure 29. Vehicle Final Position and Trajectory Marks, Test No. AZRP-1

Figure 30. System Damage, Test No. AZRP-1

Figure 31. System Damage, Test No. AZRP-1

Figure 32. Rail Damage Between Post Nos. 12 and 17, Test No. AZRP-1

Figure 33. Post No. 13 Damage, Test No. AZRP-1

Figure 34. Post No. 14 Damage, Test No. AZRP-1

Figure 35. Post No. 15 Damage, Test No. AZRP-1

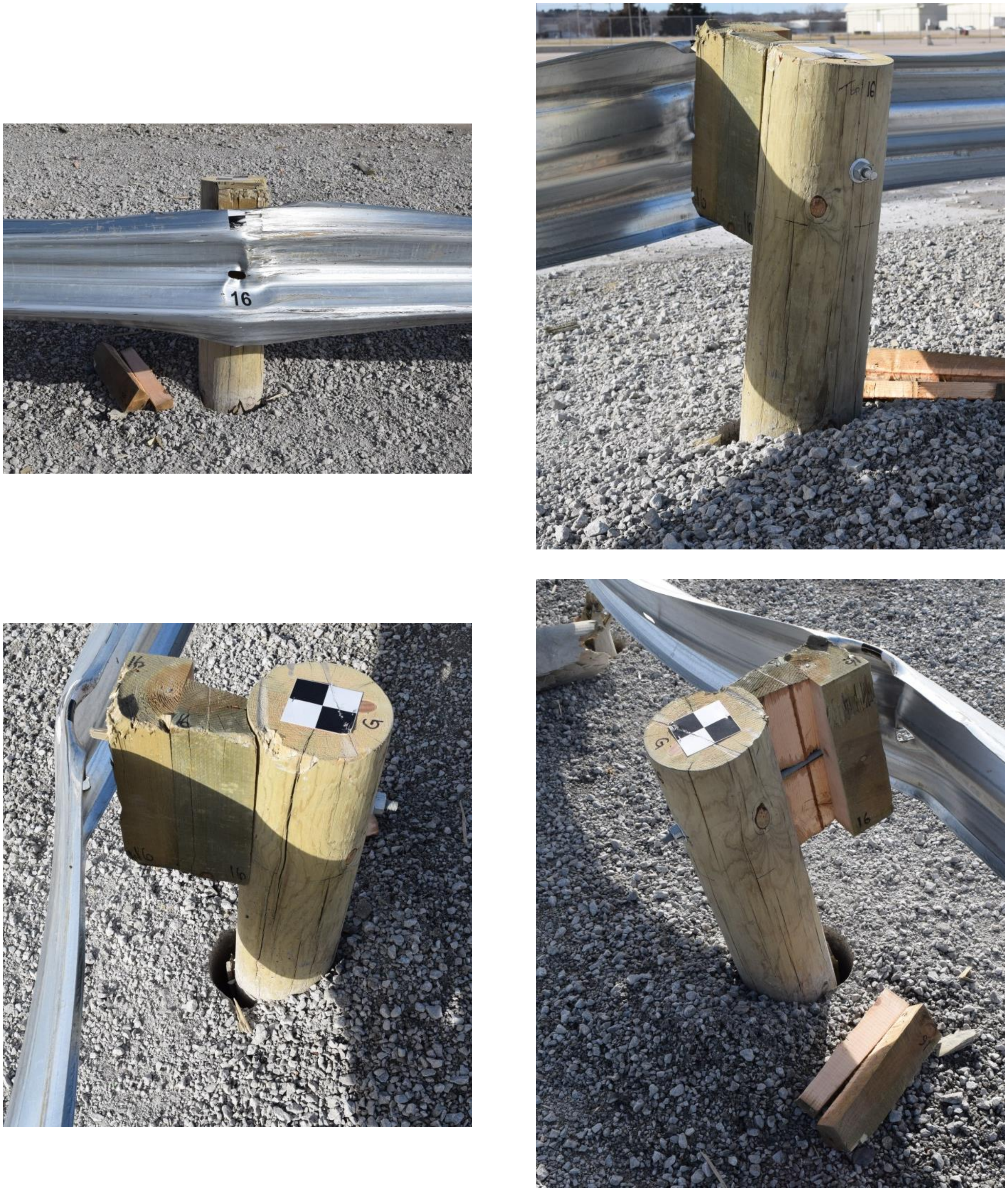


Figure 36. Post No. 16 Damage, Test No. AZRP-1

Upstream Anchorage

Downstream Anchorage (due to secondary impact)

Figure 37. End Anchorage Damage, Test No. AZRP-1

Figure 38. Post Nos. 13 and 14 Damage After Removed from Ground, Test No. AZRP-1

Figure 39. Post Nos. 15 and 16 Damage After Removed from Ground, Test No. AZRP-1

Figure 40. Vehicle Damage, Test No. AZRP-1

Figure 41. Vehicle Damage, Test No. AZRP-1

Figure 42. Vehicle Right-Side Floorboard Deformation, Test No. AZRP-1

Figure 43. Vehicle Left-Side Floorboard Deformation, Test No. AZRP-1

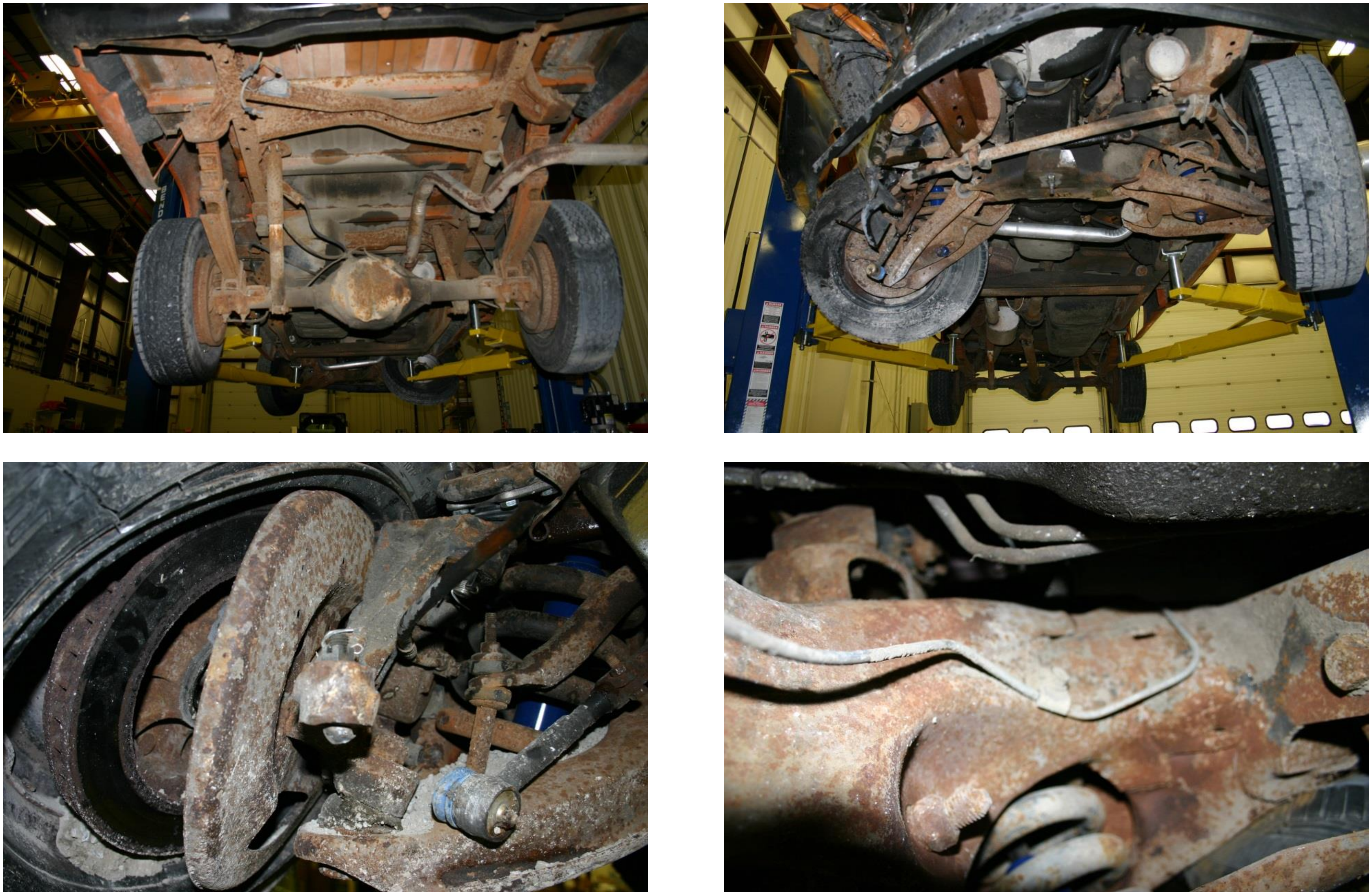


Figure 44. Vehicle Undercarriage Damage, Test No. AZRP-1

6 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective for this Phase III project was to demonstrate that the previously-identified PP post sizes (diameters and lengths) and embedment depths would adequately and safely serve as surrogates for 6-in. x 8-in. (152-mm x 203-mm) rectangular SYP posts that are used within existing Arizona and U.S. standard G4(2W) W-beam guardrail systems. The specific guardrail systems are those that have either met or been grandfathered under the impact safety standards published in the NCHRP Report No. 350 [9].

One full-scale crash test (i.e., compliance test) was performed to further demonstrate the crashworthiness of the 28-in. (711-mm) tall Arizona G4(2W) W-beam guardrail system when supported by 8½-in. (216-mm) nominal diameter PP posts with a 35-in. (889-mm) embedment depth and a 64-in. (1,626-mm) post length. The demonstration test was conducted according to the TL-3 safety criteria published in NCHRP Report No. 350 [9], which consisted of a ¾-ton Chevrolet pickup truck (2000P vehicle) impacting at a speed of 60.7 mph (97.7 km/h) and an angle of 24.8 degrees. The modified Arizona G4(2W) guardrail system with PP posts adequately contained and redirected the pickup truck and met the TL-3 safety performance criteria. During the crash test, the maximum dynamic deflection and working width were observed to be 28.8 in. (732 mm) and 41.1 in. (1,044 mm), respectively. A summary of the safety performance evaluation for test no. AZRP-1 is provided in Table 9.

Therefore, an 8½-in. (216-mm) diameter PP post with a 35-in. (889-mm) embedment depth and a 64-in. (1,626-mm) length was confirmed as a surrogate for use in existing Arizona G4(2W) guardrail systems based on dynamic component testing and full-scale vehicle crash testing. The modified Arizona G4(2W) guardrail system with the specified Ponderosa Pine post is believed to be suitable for use on Federal-aid highways.

The successful demonstration test also confirmed the use of an 8⅝-in. (219-mm) nominal diameter PP post with a 36-in. (914-mm) embedment depth and a 65-in. (1,651-mm) length as a surrogate in existing U.S. standard G4(2W) W-beam guardrail systems. The modified U.S. standard G4(2W) guardrail system with the specified PP post is also believed to be suitable for use on Federal-aid highways.

Design details and material specifications were prepared to support the implementation of the surrogate PP round posts into modified Arizona and U.S. standard G4(2W) guardrail systems, as summarized in Appendix C of Reference [8]. Special attention should be directed toward the proper inspection of timber materials and emphasis for timber suppliers to follow the published PP round-post dimensions and grading criteria. These measures should ensure that the PP posts are fabricated from suitable wood, have adequate strength, provide similar post-soil behavior to the rectangular SYP posts studied in References [7-8], and allow for G4(2W) guardrail systems to perform in an acceptable manner when using either round PP posts or rectangular SYP posts.

Federal, State, and local highway agencies are strongly encouraged to consider the use of surrogate, round PP posts within existing G4(2W) guardrail systems after an FHWA eligibility letter has been issued. Installation of the modified G4(2W) guardrail systems using round timber posts will: (1) continue to provide motorist safety along our nation's highways and roadways; (2) increase markets for wood products across the U.S. as well as in the State of Arizona; and (3) help to reduce the risk of devastating forest fires across the country.

Table 9. Summary of Safety Performance Evaluation Results

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. AZRP-1</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D.</td><td>Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted. See discussion in Section 5.3 and Appendix E of NCHRP Report No. 350.</td><td>S</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant impact velocity (see Appendix A, Section A5.3 of NCHRP Report No. 350 for calculation procedure) should satisfy the following:<table><tr><th colspan="3">Occupant Impact Velocity Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>29.5 ft/s (9 m/s)</td><td>39.4 ft/s (12 m/s)</td></tr></table></td><td>NA</td></tr>
<tr><td>I.</td><td>Occupant ridedown acceleration (see Appendix A, Section A5.3 of NCHRP Report No. 350 for calculation procedure) should satisfy the following :<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and Lateral</td><td>15 g’s</td><td>20 g’s</td></tr></table></td><td>NA</td></tr>
<tr><td rowspan="3">Vehicle Trajectory</td><td>K.</td><td>After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td><td>S</td></tr>
<tr><td>L.</td><td>The occupant impact velocity in the longitudinal direction should not exceed 39.4 ft/s (12 m/s) and the occupant ride down acceleration in the longitudinal direction (see Appendix A, Section A5.3 for calculation procedure) should not exceed 20 g’s.</td><td>S</td></tr>
<tr><td>M.</td><td>The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at the time of vehicle loss of contact with test device.</td><td>S</td></tr>
<tr><td colspan="3">NCHRP Report No. 350 Test Designation No.</td><td>3-11</td></tr>
<tr><td colspan="3">PASS/FAIL</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

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19. Brown, C.M., *Crash Test Between a Modified G4(1S) Guardrail System and a 1997 Geo Metro - Foil Test No. 99F003*, Contract No. DTFH61-99-F-001004, MiTech Incorporated, Silver Spring, Maryland, March 2000.

20. Bronstad, M.E., Michie, J.D., and Mayer, J.B., *Performance of Longitudinal Traffic Barriers*, National Cooperative Highway Research Program (NCHRP) Report No. 289, Transportation Research Board, National Research Council, Washington, D.C., June 1987.

21. Hinch, J., Yang, T.L., and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, Virginia, 1986.

22. *Center of Gravity Test Code - SAE J874 March 1981*, SAE Handbook Vol. 4, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1986.

23. Society of Automotive Engineers (SAE), *Instrumentation for Impact Test – Part 1 – Electronic Instrumentation*, SAE J211/1 MAR95, New York City, NY, July, 2007.

24. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

25. *Collision Deformation Classification – Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

8 APPENDICES

Appendix A. Material Specifications

Arizona Log & TimberWorks
1990 W. Central Ave.
Eagar, AZ 85925
USA

Voice: 928-333-3821
Fax: 928-333-2758
Vendor ID:

BILL OF LADING

Invoice Number: 6605
Invoice Date: Nov 12, 2015
Page: 1

Sales Order Number: 1967

Bill To:	Ship to:
Cash	Jim C. Holloway Midwest Roadside Safety Facilt 4630 NW 36th St. Lincoln, NE 68524

Customer ID	Customer PO	Payment Terms	
Cash	AZ State Forestry	C.O.D.	
Sales Rep ID	**Shipping Method**	**Ship Date**	**Due Date**
	Our Truck		11/13/15

Order Qty	Item	Description	Shipped Prior	This Shipment
100.00		9" x 6' CCA .60 Treated Pole		20.00
30.00		9" X 64" Peeled Guard Rail Post .60 CCA		30.00
50.00		8" X 6" X 14" Guard Rail Blocks .60 CCA		50.00
25.00		6" X 5" X 14" Guard Rail Blocks .60 CCA		25.00
30.00		6" X 1.25" X 14" Guard Rail Block Shims .60 CCA		30.00

Figure A-1. Round Ponderosa Pine Posts and Routed Blockouts

ARIZONA ROUND POST FULL SCALE
ROUND POSTS AND BLOCKS

SAMPLE ID: 128.271.15

DAILY TREATING REPORT

FORM A

Plant: AZ LOG & TIMBERWORKS Charge Number 128-271-15

DENSITY = 24.0 pcf

	%WT OXIDES	%BALANCE
CRO3 =	1.628 %	43.3
CUO =	0.743 %	19.8
AS2O5 =	1.387 %	36.9
TOTAL =	3.758 %WT	100.0

RETENTION

CRO3 =	0.391 pcf
CUO =	0.178 pcf
AS2O5 =	0.333 pcf
TOTAL=	0.902 pcf

CALCULATED RETENTION

Cu. Ft. of Wood 724

Required retention .6 lbs. oxides per cu. ft.

Metal oxides to be absorbed 435 lbs.

Gals. Soln. per lb. of oxides @ .8 % 6.578 gals.

Total gals. of Solution to be absorbed 2289

C.C.A. – Chromated Copper Arsenate

TREATMENT

	VALUE	ON TIME
Initial Vacuum, Inches	18	
Fill Retort		
Solution Pressure	175	
Empty Retort		
Final Vacuum, Inches	18	
Total Treating Time		

RETENTION

BEFORE TREATMENT

Hydrometer reading ______ Temp. ______ °F

Percent Solution ______

Cylinder capacity empty 12600 gals.

Less lumber displacement (cu. ft. x 7.48) 5528 =

Gals. required to fill retort 7072

Gals. in work tank 13698

Less Gals. required to fill retort 7072 =

Gals. in work tank after filling retort 6626

Less gals. to be absorbed 2289 =

Gals. in work tank after pressure 4295

RETENTION

AFTER TREATM...

Total Gals. in storage 13698 (Before Treatment)

Total Gals. in storage 11381 (After Treatment)

Gallons absorbed 2319

Lbs. oxides per gal. @ ______ °F ______ % ______ lbs.

÷ ______ Lbs. oxides absorbed / cubic foot of wood = ______ Retention lbs. per cubit foot

÷ ______ Gallons absorbed / cubic foot of wood = ______ Gals. Soln. absorbed per Cubic foot of wood

RCRA DRIP PAD RESIDENCE TIME

Time on pad ______ Date on pad ______

Time off pad ______ Date off pad ______

MATERIAL TREATED

No. Pieces	Size	Board Feet	Cubic Feet	Species	Remarks
30	9 1/2-20'	.442	265	P.Pine	
30	9 1/2-25'	.442	331	P.Pine	
50	8 1/2-6 1/2	.394	128	P.Pine	
			724		

BORINGS PENETRATION

Boring No.	Sap Wood Depth	Penetration	Boring No.	Sap Wood Depth	Penetration	Boring No.	Sap Wood Depth	Penetration	Boring No.	Sap Wood Depth	Penetration
1	2 1/2	100	6	2 3/4	100%	11	2 3/4	100%	16	2 1/4	100%
2	2 1/4	100%	7	2 5/8	100%	12	2 3/4	100%	17	2 5/8	100%
3	2 1/2	100%	8	2 1/4	100%	13	2 3/8	100%	18	2 3/4	100%
4	2 5/8	100%	9	2 3/4	100%	14	2 3/4	100%	19	2 1/2	100%
5	2 3/4	100%	10	2 1/2	100%	15	2 3/8	100%	20	2 3/4	100%

TREATING ENGINEER ______

Figure A-2. Round Ponderosa Pine Posts and Routed Blockouts

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405

Project: STOCK

Order Number: 1215324 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2884
BOL Number: 80821 Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/14/14

Foundation Tubes Green Paint
R#15-0157 September 2014 SMT

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	701A	.25X11.75X16 CAB ANC	A-36			A3V3361	48,600	69,000	29.1	0.180	0.410	0.010	0.005	0.040	0.270	0.000	0.070	0.001	4
	701A		A-36			JJ4744	50,500	71,900	30.0	0.150	1.060	0.010	0.035	0.240	0.270	0.002	0.090	0.021	4
12	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
15	736G	5'/TUBE SL/.188"X6"X8"FLA	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
12	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
5	783A	5/8X8X8 BEAR PL 3/16 STP	A-36			10903960	56,000	79,500	28.0	0.180	0.810	0.009	0.005	0.020	0.100	0.012	0.030	0.000	4
	783A		A-36			DL13106973	57,000	72,000	22.0	0.160	0.720	0.012	0.022	0.190	0.360	0.002	0.120	0.050	4
20	3000G	CBL 3/4X6'6/DBL	HW			99692													
25	4063B	WD 6'0 POST 6X8 CRT	HW			43360													
15	4147B	WD 3'9 POST 5.5"X7.5"	HW			2401													
20	15000G	6'0 SYT PST/8.5/31" GR HT	A-36			34940	46,000	66,000	25.3	0.130	0.640	0.012	0.043	0.220	0.310	0.001	0.100	0.002	4
10	19948G	.135(10Ga)X1.75X1.75	HW			P34744													
2	33795G	SYT-3"AN STRT 3-HL 6'6	A-36			JJ6421	53,600	73,400	31.3	0.140	1.050	0.009	0.028	0.210	0.280	0.000	0.100	0.022	4
4	34053A	SRT-31 TRM UP PST 2'6.625	A-36			JJ5463	56,300	77,700	31.3	0.170	1.070	0.009	0.016	0.240	0.220	0.002	0.080	0.020	4

1 of 3

Figure A-3. Steel Foundation Tube (Sheet 1 of 3)

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: STOCK

Order Number: 1215324 Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2884
BOL Number: 80821 Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/14/14

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
	34053A		A-36			B3W8704	49,900	68,000	30.1	0.190	0.400	0.009	0.005	0.050	0.240	0.000	0.070	0.001	4
	34053A		A-36			34940	46,000	66,000	25.3	0.130	0.640	0.012	0.043	0.220	0.310	0.001	0.100	0.002	4
3	49398A	ET-31 HBA P1 TOP X 3' 0"	A-36			34940	46,000	66,000	25.3	0.130	0.640	0.012	0.043	0.220	0.310	0.001	0.100	0.002	4
	49398A		A-36			JJ5595	55,100	77,400	26.3	0.160	1.170	0.011	0.031	0.270	0.210	0.002	0.080	0.021	4

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

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

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

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

2 of 3

Figure A-4. Steel Foundation Tube (Sheet 2 of 3)

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: STOCK

Order Number: 1215324
Customer PO: 2884
BOL Number: 80821
Document #: 1
Shipped To: NE
Use State: KS

Prod Ln Grp: 9-End Terminals (Dom)
Ship Date:

As of: 4/14/14

State of Ohio, County of Allen. Sworn and subscribed before me this 14th day of April 2014

Notary Public: Sherri Donoss / Braun
Commission Expires: 4 20 / 2014

STATE OF OHIO
NOTARY PUBLIC
ID# 2009NT0139
Commission Expires
April 20, 2014
ALLEN COUNTY

Trinity Highway Products , LLC
Certified By:
Quality Assurance

3 of 3

Figure A-5. Steel Foundation Tube (Sheet 3 of 3)

R#16-0010
BCT Wood Posts
12posts

AMERICAN TIMBER AND STEEL

This is to certify that the materials shipped, as indicated, conform to the State of Nebraska specifications.
Order Number: 158755
Project Number: N/A

QUANTITY	DESCRIPTION	CHARGE NO.	TREATMENT	TREATER
60	6X8-19" (2H) BLOCK	TX-3547	CCA	ATS-NAC
120	6X8-19" (2H) OS THRIE BLOCK	TX-3547	CCA	ATS-NAC
100	6X12-19" (2H) OS THRIE BLOCK	TX-3547	CCA	ATS-NAC
400	6X12-19" (2H) OS THRIE BLOCK	TX-3546	CCA	ATS-NAC
48	6X8-6' 2H THRIE POST	TX-2360	CCA	ATS-NAC
96	6X8-6' MGS CRT POST	TX-3547	CCA	ATS-NAC
40	5.5X7.5-45" BCT POST	TX-3227	CCA	ATS-NAC
40	5.5X7.5-46" BA POST	TX-3547	CCA	ATS-NAC

ATS – AMERICAN TIMBER AND STEEL, NORWALK, OH
MWT-OK - MIDWEST WOOD TREATING, INC., CHICKASHA, OK
ATS-NAC – AMERICAN TIMBER AND STEEL, NACADOCHES, TX
GAT- GREAT AMERICAN TREATING, TYLER,TX

Made & Treated in the USA. Meets AASHTO Specs M133 & M168.

AMERICAN TIMBER AND STEEL
By Derek Hoebing
Title Guardrail Salesman
Date May 8, 2015

NOTARIZED
Sworn to and subscribed before me
this 8 day of May 2015.
by Andrea L Bender

NOTARY PUBLIC STATE OF OHIO
ANDREA L. BENDER
Seneca County
NOTARY PUBLIC, STATE OF OHIO
My Commission Expires
March 26, 2020

American Timber And Steel Corp ★ 4832 Plank Rd / PO Box 767 ★ Norwalk, OH 44857 ★ Ph: 419.668.1610 ★ Fax: 419.663.1077

" T H E T I M B E R S P E C I A L I S T S "

Figure A-6. BCT Timber Post

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: STOCK

Order Number: 1214903   Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2878
BOL Number: 80278   Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

As of: 3/7/14

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
36	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			0173175	55,871	74,495	31.0	0.160	0.610	0.012	0.009	0.010	0.030	0.000	0.030	0.000	4
20	3000G	CBL 3/4X6'6/DBL	HW			98790													
22	9852A	STRUT & YOKE ASSY	A-1011-SS			163375	48,380	64,020	32.9	0.190	0.520	0.011	0.003	0.030	0.110	0.000	0.050	0.000	4
	9852A		A-36			11237730	45,500	70,000	30.0	0.170	0.500	0.010	0.008	0.020	0.080	0.000	0.070	0.001	4

Ground Strut Green Paint
R#15-0157 September 2014 SMT

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

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

ALL COATINGS PROCESSES OF THE STEEL OR IRON ARE PERFORMED IN USA AND COMPLIES WITH THE "BUY AMERICA ACT"
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM-123 (US DOMESTIC SHIPMENTS)
ALL GALVANIZED MATERIAL CONFORMS WITH ASTM A123 & ISO 1461 (INTERNATIONAL SHIPMENTS)

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

1 of 2

Figure A-7. Upstream End Strut and Yoke Assembly (Sheet 1 of 2)

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405

Order Number: 1214903   Prod Ln Grp: 9-End Terminals (Dom)
Customer PO: 2878   As of: 3/7/14
BOL Number: 80278   Ship Date:
Document #: 1
Shipped To: NE
Use State: KS

Project: STOCK

State of Ohio, County of Allen. Sworn and subscribed before me this 7th day of March, 2014

Notary Public:
Commission Expires:

Trinity Highway Products , LLC
Certified By:
Quality Assurance

2 of 2

Figure A-8. Upstream End Strut and Yoke Assembly (Sheet 2 of 2)

425 E. O'Connor
Lima, OH

Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Sales Order: 1093497
Customer PO: 2030
BOL # 43073
Document # 1

Print Date: 6/30/08
Project: RESALE
Shipped To: NE
Use State: KS

Trinity Highway Products, LLC

Certificate Of Compliance For Trinity Industries, Inc. ** SLOTTED RAIL TERMINAL **

NCHRP Report 350 Compliant

Pieces	Description
64	5/8"X10" GR BOLT A307
192	5/8"X18" GR BOLT A307
32	1" ROUND WASHER F844
64	1" HEX NUT A563
192	WD 6'0 POST 6X8 CRT
192	WD BLK 6X8X14 DR
64	NAIL 16d SRT
64	WD 3'9 POST 5.5X7.5 BAND
32	STRUT & YOKE ASSY
128	SLOT GUARD '98
32	3/8 X 3 X 4 PL WASHER

MGSBR

Ground Strut

09C453-8

Upon delivery, all materials subject to Trinity Highway Products , LLC Storage Stain Policy No. LG-002.

402-761-3288

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
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.
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 – 49100 LB

06/04/2009 16:36

State of Ohio, County of Allen. Sworn and Subscribed before me this 30th day of June, 2008

Notary Public:
Commission Expires

Trinity Highway Products, LLC
Certified By:

2 of 4

Figure A-9. Downstream End Strut and Yoke Assembly

Assembly Specialty Products, Inc.
14700 Brookpark Road
Cleveland, OH 44135

CERTIFICATE OF COMPLIANCE

MGS Long Span/ MGS-PCB Transition
BCT Cables Fabricated into 2part Cables 10qty
R#15-0601 Various Heat Numbers
Sent to Omaha Slings for fabrication
June 2015 SMT

Date: March 5, 2015

To: Gregory Industries
4100 13th Street SW
Canton, OH 44710

We certify that our system and procedures for the control of quality assures that all items furnished on the order will meet applicable tests, requirements and inspection requirements as required by the purchase order and applicable specifications and drawings.

PURCHASE ORDER #: 31050

DATE SHIPPED: March 4, 2015

ASPI SALES ORDER #: 105011

MANUFACTURER: ASSEMBLY SPECIALTY PRODUCTS, INC.

QTY & DESCRIPTION: 3500 pcs. P/N 3012G, (C-2028) Wire Rope Assembly

ATTACHMENTS:

Eaton Steel Corp/Hercules Steel.: Heat #: 498219, 498221 (ArcelorMittal USA) [Swage Fitting]
Keystone Threaded Products: Heat #: 10348290 (Taubensee Steel & Charter Steel) [Threaded Rod]
Heat #: 10350220 (Taubensee Steel & Charter Steel) [Threaded Rod]
Wirerope Works: Reel # 4193610: [Wire Rope]
Heat #: 53131485/03, 53127002/04 (Gerdau)
Heat #: 10342780, 10207730 (Charter Steel)
Heat #: 25807 (ArcellorMittal)
Art Galvanizing Works: Galvanizing [Swage Fitting & Threaded Rod Assembly]

MINIMUM BREAKING STRENGTH: 46,000 lbs.

WIRE ROPE MANUFACTURED IN ACCORDANCE WITH AASHTO DESIGNATION: M30-02 and ASTM A741 TYPE 2, CLASS A
FITTINGS GALVANIZED IN ACCORDANCE WITH ASTM A-153 CLASS C.

REMARKS:

Steel used to manufacture these items was melted and manufactured in the United States of America. All manufacturing processes supplied by or performed by Assembly Specialty Products, Inc. took place in the United States of America

SIGNATURE : ______________
President

Figure A-10. BCT Cable Anchor Assembly (Sheet 1 of 2)

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Test Report
Ship Date: 3/27/2015
Customer P.O.: 031915
Shipped to: GUARDRAIL SYSTEMS
Project : STOCK
GHP Order No.: 7765AA

:ustomer: GUARDRAIL SYSTEMS
8000 SERUM AVE

RALSTON, NE. 68127-4213

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
7800285	0.18	0.74	0.006	0.004	0.07				1160			5/8IN DBL. REC. GR NUT
20351410	0.14	0.33	0.008	0.001	0.09				957			5/8IN X 1 1/4IN SPL. BOLT
144235	0.44	0.76	0.005	0.23	0.23				458			1IN HVY. HX NUT H2
NF14202434	0.44	0.83	0.1	0.022	0.28							1IN HVY. HX NUT H2
NF14101901	0.44	0.87	0.01	0.021	0.26							1IN HVY. HX NUT H2
497844	0.45	0.68	0.009	0.025	0.24							1IN HVY. HX NUT H2
147000	0.04	0.26	0.11	0.001	0.016				458			1IN F844 FLAT WASH.
A37921	0.28	1.15	0.12	0.002	0.25				87			5/8IN F844 FLAT WASH.
20337340	0.11	0.4	0.006	0.001	0.07				58			5/16IN HX NUT
20295630	0.13	0.35	0.009	0.002	0.08				29			3/4IN HX NUT
10317920	0.14	0.37	0.007	0.006	0.08							3/4IN HX NUT
220345	0.006	0.59	0.012	0.002	1.16				116			5/16IN F844 FLAT WASH.
NF14203687	0.36	0.78	0.009	0.016	0.23				58			5/16IN X1IN HEX HEAD BOLT
NF13101149	0.47	0.78	0.008	0.016	0.24				29			5/8" X 9" H-BOLT GRD. 5
NF12203175	0.48	0.84	0.014	0.022	0.24							5/8" X 9" H-BOLT GRD. 5
14203504	0.48	0.8	0.01	0.022	0.24							5/8" X 9" H-BOLT GRD. 5
62134954	0.11	0.66	0.006	0.02	0.19				29			3/4IN X 8 - 1/2IN H-H BOLT A449
62135939	0.44	0.68	0.007	0.025	0.21							3/4IN X 8 - 1/2IN H-H BOLT A449
NF14103089	0.12	0.55	0.016	0.025	0.19				203			5/8IN X 14IN GR P BOLT
NF14203668	0.13	0.51	0.008	0.032	0.17							5/8IN X 14IN GR P BOLT

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.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title CFr 635-410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska & Iowa Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4

By:
Andrew Artar, VP of Sales and Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 30 day of March, 2015

Notary Public, State of Ohio

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

Figure A-11. BCT Cable Anchor Assembly (Sheet 2 of 2)

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1145215
Customer PO: 2441
BOL Number: 61905
Document #: 1
Shipped To: NE
Use State: KS

As of: 4/15/11

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	206G	T12/6'3/S	M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	0.060	0.000	[illegible]
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	0.002	
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	0.002	[illegible]
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	[illegible]
55	260G	T12/25/6'3/S	M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.00	0.050	0.002	[illegible]
			M-180	A	2	139206	61,730	78,580	26.0	0.180	0.710	0.012	0.004	0.020	0.140	0.000	0.050	0.001	[illegible]
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	[illegible]
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	
			M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.000	0.060	0.000	[illegible]
	260G		M-180	A	2	140734	64,240	82,640	26.4	0.190	0.740	0.015	0.006	0.010	0.110	0.00	0.060	0.000	[illegible]
			M-180	A	2	139587	64,220	81,750	28.5	0.190	0.720	0.014	0.003	0.020	0.130	0.000	0.060	0.002	[illegible]
			M-180	A	2	139588	63,850	82,080	24.9	0.200	0.730	0.012	0.004	0.020	0.140	0.000	0.050	0.002	[illegible]
			M-180	A	2	139589	55,670	74,810	27.7	0.190	0.720	0.012	0.003	0.020	0.130	0.000	0.060	0.002	[illegible]
			M-180	A	2	140733	59,000	78,200	28.1	0.190	0.740	0.015	0.006	0.010	0.120	0.000	0.070	0.001	[illegible]
26	701A	.25X11.75X16 CAB ANC	A-36			V911470	51,460	71,280	27.5	0.120	0.800	0.015	0.030	0.190	0.300	0.00	0.090	0.025	4
	701A		A-36			N3540A	46,200	65,000	31.0	0.120	0.380	0.010	0.019	0.010	0.180	0.00	0.070	0.001	4
24	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	0.160	0.004	6
24	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			N4747	63,548	85,106	27.0	0.150	0.610	0.013	0.001	0.040	0.160	0.00	0.160	0.004	6
32	782G	5/8"X8"X8" BEAR PL/OF	A-36			18486	49,000	78,000	25.1	0.210	0.860	0.021	0.036	0.250	0.260	0.00	0.170	0.014	[illegible]
25	974G	T12/TRANS RAIL/6'3"/3'1.5	M-180	A	2	140735	61,390	80,240	27.1	0.200	0.740	0.014	0.005	0.010	0.120	0.00	0.070	0.001	[illegible]

Figure A-12. Anchor Bracket Assembly

Certified Analysis

Trinity Highway Products, LLC
2548 N.E. 28th St.
Ft Worth, TX
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097
Project: RESALE

Order Number: 1095199
Customer PO: 2041
BOL Number: 24481
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/20/08

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/6'3/S	M-180	A		84964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.040	0.080	0.000	0.060	0.000	4
— 20	701A	.25X11.75X16 CAB ANC	A-36			4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	6'0 TUBE SL/.188X8X6	A-500			A8P1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
← 20	782G	5/8"X8"X8" BEAR PL/OF	A-36			6106195	46,700	69,900	23.5	0.180	0.830	0.010	0.005	0.020	0.230	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180	A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	4

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
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.

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 – 49100 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 20th day of June, 2008

Notary Public:
Commission Expires

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires

Trinity Highway Products, LLC
Certified By: Stefanie Oneal

Figure A-13. Anchor Bearing Plate

09Mar'15 13:22 TEST CERTIFICATE No: MAR 268339

INDEPENDENCE TUBE CORPORATION
6226 W. 74TH STREET
CHICAGO, IL 60638
Tel: 708-496-0380 Fax: 708-563-1950

P/O No 4500240795
Rel
S/O No MAR 280576-001
B/L No MAR 163860-003 Shp 09Mar'15
Inv No Inv

Sold To: (5016)
STEEL & PIPE SUPPLY
1003 FORT GIBSON ROAD
CATOOSA, OK 74015

Ship To: (1)
STEEL & PIPE SUPPLY
1003 FORT GIBSON ROAD
CATOOSA, OK 74015

Tel: 918-266-6325 Fax: 918 266-4652

CERTIFICATE of ANALYSIS and TESTS Cert. No: MAR 268339
05Mar'15

Part No 0010
ROUND A500 GRADE B(C)

	Pcs	Wgt
2.375"OD (2"NPS) X SCH40 X 21'	111	8,508

Heat Number	Tag No	Pcs	Wgt
E86298	927111	37	2,836
	YLD=69600/TEN=79070/ELG=24.2		
E86298	927113	37	2,836
E86298	927114	37	2,836

Heat Number *** Chemical Analysis ***
E86298 C=0.1700 Mn=0.5100 P=0.0100 S=0.0110 Si=0.0190 Al=0.0450
Cu=0.0300 Cr=0.0300 Mo=0.0030 V=0.0010 Ni=0.0100 Cb=0.0010
MELTED AND MANUFACTURED IN THE USA

R#15-0626 H#E86298
BCT Pipe Sleeves
June 2015 SMT

WE PROUDLY MANUFACTURE ALL OF OUR HSS IN THE USA.
INDEPENDENCE TUBE PRODUCT IS MANUFACTURED, TESTED,
AND INSPECTED IN ACCORDANCE WITH ASTM STANDARDS.

CURRENT STANDARDS:
..................................A500/A500M-13
..................................A513-12
..................................A252-10
..................................A847/A847M-12

MATERIAL IDENTIFIED AS A500 GRADE B(C) MEETS BOTH
ASTM A500 GRADE B AND A500 GRADE C SPECIFICATIONS.

Page: 1 .... Last

Figure A-14. BCT Hole Insert

33806

Mid West Fabricating

3115 W. Fair Ave.
Lancaster, Oh 43130

CERTIFICATE OF COMPLIANCE

WE CERTIFY THAT ALL BOLTS ARE MADE AND MANUFACTURED IN THE USA.

TO: Trinity Industries, Inc.
Plant #55
550 East Robb Ave.
Lima, Ohio 45801

5/8"x1-1/2" Hex Bolt
Lot#25203 H#10207560 R#16-0009
July 2015 SMT

SHIP DATE: 12/12/12
MANUFACTURER: MID WEST FABRICATING CO.
ASTM: A307A
PROCESSOR
GALVANIZERS: AZZ-Pilot

TO A-153 CLASS C

QTY	PART NO.	HEAT NO.	LOT NO.	P.O. NO.
38,000	5/8 X 1 1/2"	10207560	25203	150897

PASSED & CERTIFIED
DEC 19 2012
Trinity Highway Products, LLC
Dallas, Texas Plant 99

SIGNATURE: Amy Bailes

TITLE: QUALITY CONTROL

Date: 12/12/12

Figure A-15. ⅝-in. Diameter x 1½-in. Long Hex Head Bolt (Sheet 1 of 2)

3380

LOAD Po # 71267

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
FAX (262) 268-2570

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

Beta Steel
44225 Utica Rd.
Laurie Dailey
Utica,MI-48318

Cust P.O.	284371-01
Customer Part	06525010150000SF(SW1015-C)
Charter Sales Order	30048422
Heat #	10207560
Ship Lot #	1074155
Grade	1015 A SK FG IQ 5/8
Process	HR
Finish Size	5/8

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and on the reverse side,and that it satisfies these requirements.

Test Results of Heat Lot# 10207560

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.14	.41	.007	.011	.13	.05	.07	.02	.10	.009	.001

AL	N	B	TI	CA	NB
.022	.0050	.0002	.000	.0001	.004

JOMINY(HRC) JOM01
41

JOMINY SAMPLE TYPE ENGLISH = C
CHEM. DEVIATION EXT.-GREEN =

Test Results of Rolling Lot# 1074155

43,445

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE	3	59.7	60.1	59.9	TENSILE LAB = 0358-02
REDUCTION OF AREA	3	49	56	53	RA LAB = 0358-02

NUM DECARB = 1 AVE DECARB = .003
REDUCTION RATIO = 99:1

Specifications: Manufactured per Charter Steel Quality Manual Rev 9,08-01-09
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = PS-1 Revision = Dated = 11-MAR-08

Additional Comments:

8-8-12

Charter Steel
Saukville, WI, USA

ACCREDITED

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance

Figure A-16. ⅝-in. Diameter x 1½-in. Long Hex Head Bolt (Sheet 2 of 2)

Birmingham Fastener Manufacturing

P.O. Box 10323
Birmingham, Alabama 35202
(205) 595-3512

Pg 1 of 1

Certificate of Compliance

Customer : MIDWEST MACHINE
P.O. # : 2430
BFM # : 100325-00
Date Shipped : 3/21/2011

Item	Quantity	Description	Lot#	Heat #	Specification	Finish
2	100	5/8"-11 x 10" HEX BOLT	154572	780337	ASTM A307 GR A	HDG
3	156	5/8"-11 x 12" HEX BOLT	156402	DL1010223101	ASTM F1554-36	HDG
4	504	5/8"-11 x 19" HEX BOLT	156403	DL1010223101	ASTM F1554-36	HDG
5	102	3/4"-10 x 8" HEX BOLT	156404	JK1110044101	ASTM A36	HDG
6	513	7/8"-9 x 14" HEX BOLT	156405	11907740	ASTM F1554-55	HDG
7	208	7/8"-9 x 16" HEX BOLT	156406	11907740	ASTM F1554-55	HDG
8	48	1"-8 x 24" HEX BOLT	156407	109218	ASTM F1554-55	HDG
9	102	3/4"-10 x 16" HEX BOLT	143841	DL0910629104	ASTM A36	HDG

Birmingham Fastener Manufacturing. hereby certifies that the material furnished in reference to the above purchase order number will meet or exceed the above assigned specifications.

Signed: Brian Hughes **Date:** 03/21/2011

4

Figure A-17. ⅝-in. Dia. x 10-in. Long Hex Head Bolt, Downstream Anchorage (Sheet 1 of 2)

Certificate of Compliance

Birmingham Fastener Manufacturing
PO Box 10323
Birmingham, AL 35202
(205) 595-3512

Customer: MIDWEST MACHINERY — Date Shipped: 03/21/2011

Customer Order Number: 2430 — BFM Order Number: 100325-00

Item Description

Description: 5/8"-11 x 10" HEX BOLT — Qty: 100

Lot #: 154572 — Specification: ASTM A307-07b Gr A — Finish: F2329

Raw Material Analysis

Heat#: 780337

Chemical Composition (wt% Heat Analysis) By Material Supplier

C	Mn	P	S	Si	Cu	Ni	Cr	Mo
0.16	0.54	0.009	0.04	0.18	0.36	0.09	0.13	0.020

Mechanical Properties

Sample #	Hardness	Tensile Strength (lbs)	Tensile Strength (psi)
1	80 HRB	16,700	73,900
2	80 HRB	16,600	73,400
3			
4			
5			

This information represents the most recent analysis of the product supplied on the stated customer order. The samples tested conform to the ASTM standard listed above.
All steel melted and manufactured in the U.S.A.

Authorized Signature: [signature] — Date: 3/21/2011

Brian Hughes
Quality Assurance

Figure A-18. ⅝-in. Dia. x 10-in. Long Hex Head Bolt, Downstream Anchorage (Sheet 2 of 2)

From: 281-391-2044 To: The Boulder Company   Date: 5/24/2012 Time: 3:34:00 PM   Page 2 of 2

May 24, 2012

K-T Bolt Manufacturing Company, Inc.®
1150 Katy Fort-Bend Road
Katy, Texas 77494
Ph: 281-391-2196 Fax: 281-391-2673
shirley@k-tbolt.com

Date: May 24,2012

Original Mill Test Report

Company:	The Boulder Company
Part Description:	125 pcs ⅝ - 11X 9 ½"Finish Hex Bolts
Material Specification:	A307 A
Coating Specification	ASTM F2329-05
Purchase Order Number:	161005
Lot Number:	08334-1
Comments:	None
Material Heat Number:	JK1110419701
Testing Laboratory:	Nucor

Chemical Analysis – Weight Percent

C	Mn	P	S	Si	Cu	Cr	Ni	Mo	V	Cb	Sn	Al	B	Ti	Ca	Co	N
.13	.69	.018	.030	.20	.26	.12	.09	.020	.003	.002	-	-	-	-	-	-	-

100% Melted & Manufactured in the USA. Values reflect originating Steel Mill

Tensile and Hardness Test Results

Property	#1 psi
Tensile:	70.550
Proof/Yield:	52.360
Elongation:	27.5
ROA:	-
Hardness:	149 HBN

Comments

Test results meet mechanical requirements of specification.

Figure A-19. ⅝-in. Dia. x 10-in. Long Hex Head Bolt, Upstream Anchorage

SUPER CHENG INDUSTRIAL CO., LTD.

CERTIFICATE OF INSPECTION

ISO 9001:2008
ISO/TS 16949:2009

NO. 18 BEN-GONG 2nd ROAD., BEN CHOU INDUSTRIAL PARK, KAOHSIUNG COUNTY 820,
TAIWAN R.O.C. TEL:(886-7)6225326-30(5 LINES) FAX:(886-7)6215377/6212335/6225829

CERTIFICATE NO:
TWN6002607

ISSUE DATE : 2014/5/16

CUSTOMER : FASTENAL COMPANY PURCHASING
PART NO. : 1136713
SAMPLING PLAN : MIL-105D S2
Mfg.LOT NO : S13-1402-04
P.O. NUMBER : 210074109
QUANTITY SHIPPED : 45000 PCS
COMMODITY : FIN HEX NUT
SIZE: 5/8-11 O/S 0.020 HDG
MECHANICAL SPEC : ASTM A563 GRADE A
DIMENSIONS SPEC : ANSI/ASME B18.2.2

HEAT NO. : 1BK64

DIMENSION IN INCH

ITEM	SPECIFICATION	ACTUAL RESULT	ACC.	REJ.
APPEARANCE	ASTM F812	GOOD	V	
THREAD	GO/NO GO GAGE	OK	V	
W.A.F.	0.938 ~ 0.922	0.932 ~ 0.926	V	
W.A.C.	1.083 ~ 1.051	1.064 ~ 1.061	V	
THICKNESS	0.559 ~ 0.535	0.547 ~ 0.542	V	
HARDNESS	MAX 107 HRB	95.0 ~ 92.0 HRB	V	
PROOF LOAD	MIN 68000 PSI	PASS	V	

ALL TESTS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN APPLICABLE ASTM & SAE SPECIFICATION. WE CERTIFY THAT THIS DATA IS THE TRUE REPRESENTATION OF INFORMATION PROVIDED BY MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

R#16-0214 5/8-11 Galvanized Hex Nuts
Arizona Round Post Full Scale
November 2015 SMT

AUTHORIZED SIGNATURE

Figure A-20. ⅝-in. Hex Nut (Sheet 1 of 2)

CHINASTEEL 中國鋼鐵

品質證明書
TEST CERTIFICATE

中國鋼鐵股份有限公司
CHINA STEEL CORPORATION
中華民國高雄市小港區中鋼路1號
1 CHUNG KANG ROAD HSIAO KANG, KAOHSIUNG (812)
TAIWAN, REPUBLIC OF CHINA
TEL: (07)802-1111 FAX: (07)802-2511, (07)801-9427

B0369-01 COMPANY REGISTRATION NUMBER: 30414175 1304

客戶名稱 SOLD TO	世暘工廠產業股份有限公司 SUPER CHENG INDUSTRIAL CO., LTD.	產品名稱 PRODUCT	BAR-CARBON STEEL		
		發票號碼 INVOICE NO.	PG11210351	證明書編號 CERTIFICATE NO.	020918B0369
規格名稱 SPEC.	SAE 1010 AL-KILLED (MQ)	客戶編號 CUSTOMER NO.	88700083	中鋼訂單編號 CSC ORDER NO.	LW0578G
		交運日期 SHIPPING DATE	SEP. 17, 2013	證明書日期 T/C ISSUE DATE	SEP. 18, 2013
檢驗 INSP.	CSC MILL INSPECTION. T/C 01	客戶訂單編號 CUST ORDER NO.			

項目 ITEM NO.	產品序號 SEQ. NO.	尺寸 MATERIAL DESCRIPTION 直徑/厚 DIA/THICK mm	寬度 WIDTH	長度 LENGTH mm	數量 QTY	質量 MASS kg	爐號 HEAT NO.	C ×10²	Mn ×10²	P ×10³	S ×10³	Si ×10²	Cu	Ni	Cr	Mo	Al ×10³	備註 REMARKS
020	BA607 01	22.00		COIL	17	38,109	1BK64	10	51	17	7	4					38	
	BA607 02	"		"	37	83,368	2MW81	9	48	10	5	5					44	
	BA607 03	"		"	8	18,111	9L422	9	48	10	5	5					44	
	BA640A01	"		"	12	25,697	3S300	10	52	12	6	5					53	
			TOTAL:		74	165,285												

化學成分 CHEMICAL ANALYSIS %

註釋 NOTES

SURVEYOR TO

茲證明本表所列產品，均依材料規格製造及試驗，並符合規格之要求。
WE HEREBY CERTIFY THAT MATERIAL DESCRIBED HEREIN HAS BEEN MANUFACTURED AND TESTED WITH SATISFACTORY RESULTS IN ACCORDANCE WITH THE REQUIREMENT OF THE ABOVE MATERIAL SPECIFICATION.

Chih-Chung Wu
冶金技術處處長
GENERAL MANAGER, METALLURGICAL DEPARTMENT

Figure A-21. ⅝-in. Hex Nut (Sheet 2 of 2)

CERTIFIED MATERIAL TEST REPORT
FOR ASTM A307, GRADE A - MACHINE BOLTS

FACTORY:LIANYUNGANGSHI PINGXIN FASTENER CO.,LTD DATE: 9/Nov/07
ADDRESS:No.3 jingsan Road,Biotechnology Park,Haizhou Bay,Haitou Town,Ganyu County,Lianyungang CHINA
MFG LOT NUMBER: M-NBPX0339-31
CUSTOMER:
PO NUMBER:17071802

SAMPE SIZE: ACC. TO ASME B18 . 18 . 2M - 93 PART NO:00026-3464-451
SIZE: 7/8-9X8 ZP QNTY: 1440 PCS
HEADMARKS: 307A PLUS PX MANU.DATE:

STEEL PROPERTIES: Q235 25mm
STEEL GRADE: HEAT NUMBER: 04-3280n

CHEMISTRY SPEC:	C %*100 0.29max	Mn%*100 1.20 max	P %*1000 0.04max	S %*1000 0.05max
TEST:	0.15	0.45	0.024	0.033

DIMENSIONAL INSPECTIONS SPECIFICATION: ASME B18.2.1 - 2010

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
**********************	************************************	******************	********	********
VISUAL	ASTM F788/F788M-08	PASSED	100	0
THREAD	ASME B1.3	PASSED	32	0
WIDTH FLATS	1.269-1.312	1.279-1.302	8	0
WIDTH A/C	1.447-1.516	1.457-1.506	8	0
HEAD HEIGHT	0.531-0.604	0.541-0.584	8	0
BODY DIA.	0.8660-0.8750	0.8677-0.8741	8	0
THREAD LENGTH	2.25	2.28-2.38	8	0
LENGTH	7.80-8.16	7.82-8.14	8	0

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A307-2010 GR-A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
********************	*****************	*****************	*****************	********	********
CORE HARDNESS :	ASTM F606-2010a	69-100 HRB	92-95 HRB	8	0
WEDGE TENSILE:	ASTM F606-2010a	Min 60 KSI	82-85 KSI	4	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
********************	*****************	*****************	*****************	********	********
COATINGS OF ZINC	ASTM F1941	Min 4 μm	5 μm	4	0

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

(SIGNATURE OF Q.A. LAB MGR.)
(NAME OF MANUFACTURER)

Figure A-22. ⅞-in. Dia. x 7½-in. Long Hex Head Bolt

ISO/TS 16949 BUREAU VERITAS Certification

GEM-YEAR TESTING LABORATORY
CERTIFICATE OF INSPECTION

ACCREDITED
TESTING CERT 1292-01
MECHANICAL TESTING

MANUFACTURER GEM-YEAR INDUSTRIAL CO., LTD.
ADDRESS : NO.8 GEM-YEAR ROAD,E.D.Z.,JIASHAN,ZHEJIANG,P.R.CHINA

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2010/09/02

PURCHASER : PORTEOUS FASTENER COMPANY.
PO. NUMBER : 10011913
COMMODITY : FINISHED HEX NUT ASTM A563 GR-A
SIZE : 7/8-9 NC
LOT NO : 1N1030101
SHIP QUANTITY : 2,700 PCS
HEADMARKS :

PACKING NO : GEM100811019
INVOICE NO : GEM/PFC-100831 SFS
PART NO : 00200-3400-020
SAMPLING PLAN : ASME B18.18.2
HEAT NO : 10100058-3
MATERIAL : X1008A
FINISH : PLAIN

PERCENTAGE COMPOSITION OF CHEMISTRY :

Chemistry	Al%	C%	Mn%	P%	S%	Si%
Spec. : MIN.	0.0200					
MAX.		0.1000	0.6000	0.0300	0.0350	0.1000
Test Value	0.0500	0.0800	0.3200	0.0110	0.0060	0.0400

DIMENSIONAL INSPECTIONS : ACCORDING TO ASME/ANSI B18.2.2
TEST DATE : 2010/03/31 SAMPLED BY : YAN WANG SAMPLING DATE : 2010/03/31

INSPECTIONS ITEM	SAMPLE	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
WIDTH ACROSS CORNERS	32 PCS	MIL-STD-120	36.770-38.490 MM	37.210-37.250 MM	32	0
THICKNESS	32 PCS	MIL-STD-120	18.410-19.050 MM	18.660-18.700 MM	32	0
WIDTH ACROSS FLATS	32 PCS	MIL-STD-120	32.250-33.300 MM	32.410-32.450 MM	32	0
SURFACE DISCONTINUITIES	100 PCS	ASTM F812		PASSED	100	0
THREAD	32 PCS	MIL-STD-120	2B	PASSED	32	0

MECHANICAL PROPERTIES : ACCORDING TO ASTM A563-2007
TEST DATE : 2010/08/13 SAMPLED BY : GAO MINGHUA SAMPLING DATE : 2010/08/10

INSPECTIONS ITEM	SAMPLE	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	18PCS	ASTM F606/F606M	68-107 HRB	81 HRB	18	0
PROOF LOAD	13PCS	ASTM F606/F606M	Min. 41,600 LBF	OK	13	0

ALL TESTS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM/SAE/ASME/MIL-STD-120 SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.

WE CERTIFY THE PARTS ARE ROHS COMPLIANT.
THIS CERTIFIED MATERIAL TEST REPORT APPLIES TO THE SAMPLES TESTED AND IT CANNOT BE REPRODUCED EXCEPT IN FULL.

SIGNATURE : Jerry

page 1 of 1

Figure A-23. ⅞-in. Dia. Hex Nut

HILLMAN

LETTER OF CONFORMANCE

To Whom It May Concern:

This letter is to certify that all flat washers supplied by Hillman Fastener are manufactured in accordance with ANSI/ASME B18.22.1 specification.

They are all either electro-plated zinc or hot dipped galvanized depending on the part number and all are traceable to the manufacturer by the lot number on the box.

Regards,

Mike Carroll
Quality Assurance Manager

Figure A-24. ⅞-in. Dia. Flat Washer

CS-4171 (12-13)

pennsylvania
DEPARTMENT OF TRANSPORTATION
www.dot.state.pa.us

CERTIFICATE OF COMPLIANCE

1. ◆COUNTY: ______ ◆LR/SR: ______ ◆SEC/SEG: ______ ◆ECMS#: ______
(◆ - To be completed by the party that will ship the material to the project, otherwise leave blank.)

2. I / WE hereby certify that the material listed on line 5 was:

☒ Manufactured ☐ Fabricated ☐ Coated ☐ Precasted ☐ Produced

By Silo Fasteners (Name of Manufacturer, Fabricator, Coater, Precaster or Producer) SILOF (Supplier Code)

3. and the party listed above certifies that the material(s) on line 5 meets the requirements of

Publication 408, Section(s) ASTM A-307-A-10

AASHTO, ASTM, Federal or other designation ______

4. The material listed below is being shipped to: Bennett Bolt Works Inc. (Company Name)

5. LOT NO. QUANTITY APPROVED MATERIAL AS LISTED IN BULLETIN # 14 or 15 BULLETIN # 41 or 42 PRODUCERS, LIST HMA / PCC JMF.

LOT# 0090480-KD 224,113 PCS
HEAT# 20337380

SILO FASTENERS
1415 S BENHAM ROAD
VERSAILLES IND 47042

6. ☒ **CHECK HERE IF YOUR PRODUCT CONTAINS IRON OR STEEL (AND check one of the following boxes, as appropriate.)** I / WE certify the material identified above conforms with Section 106.01 of Publication 408 as indicated below.

☐ 'Identifiable Steel' or Fabricated Structural Steel (Section 1105). Either Steel products that contain permanent markings that identify that the material was melted and manufactured in the United States or which have received in-plant inspection by the Department or a Department representative where verification of Mill Test reports was performed to verify conformance with the PA Steel Procurement Act. **Only Form CS-4171 is required.**

☒ 'Unidentified Steel' – Attach supporting documentation including invoices, bills of lading and mill test reports that positively identify that the steel was melted and manufactured in the United States.

All **manufacturing processes** including coatings application (e.g. epoxy, galvanizing, or painting) have occurred in the United States and we are maintaining copy(s), in our files in accordance with Section106.03(b)3. Note: While coating materials themselves are not covered by Buy America, the application of these materials on steel or iron must occur in the United States.

7. **VENDOR CLASSIFICATION (CHECK ONE BLOCK ONLY) -**

☒ **#1 Manufacturer, Fabricator, Coater, Precaster Listed in Bulletin # 15, or Producer Listed in Bulletin # 14, 41 or 42**
I certify that the above statements are true and to the best of my knowledge, fairly and accurately describe the product(s) listed.

☐ #2 **Distributor, Supplier or *Private Label Company Not Listed in Bulletin # 15. Also, complete line 9**
I certify that the material being supplied is one and the same as provided to us by the manufacturer listed on this document and quantities listed above are accurate.

8. **NAME (print) :** TERRY ELKINS **TITLE:** QUALITY MANAGER

COMPANY NAME: SILO FASTENERS/OHIO ROD PRODUCTS

SIGNATURE: [signature] **DATE:** 11/7/2014

By Responsible Company Offical (QC Staff only if you checked block #1 on line 7)

9. List company that sold you the material (s) documented above: JOHNSTOWN WIRE
(Complete if you checked block #2 on line #7, otherwise leave blank.) (Company Name)

Figure A-25. ⅝-in. Dia. x 1½-in. Long Guardrail Bolt (Splice)

LOAD

CHARTER STEEL
A Division of
Charter Manufacturing Company, Inc.

1658 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
Fax (262) 268-2570

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Cust P.O.	85523
Customer Part #	10005
Charter Sales Order	70058737
Heat #	10351040
Ship Lot #	4310508
Grade	1018 R AK FG RHQ 1-5/32
Process	HRCC
Finish Size	1-5/32
Ship date	21-NOV-14

Telefast Industries Inc.
777 West Bagley Road
Berea,OH-44017
Kind Attn :Jeff Leisinger

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed below and that it satisfies these requirements. The recording of false, fictitious and fraudulent statements or entries on this document may be punishable as a felony under federal statute.

Test results of Heat Lot # 10351040

Lab Code: 7388

CHEM	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
%Wt	.16	.64	.007	.007	.090	.05	.08	.01	.08	.007	.001
	AL	N	B	TI	NB						
	.023	.0060	.0001	.001	.001						

MACRO ETCH SAMPLE TYPE=R
MACRO ETCH SURFACE=1 MACRO ETCH RANDOM=1 MACRO ETCH CENTER=1

Test results of Rolling Lot # 1142551

	# of Tests	Min Value	Max Value	Mean Value	
TENSILE (KSI)	2	62.3	64.0	63.2	TENSILE LAB = 0358-02
REDUCTION OF AREA (%)	2	36	48	42	RA LAB = 0358-02
ROCKWELL B (HRBW)	2	67	69	68	RB LAB = 0358-02

NUM DECARB=1 AVE DECARB (Inch)=.003
REDUCTION RATIO=29:1

Specifications: Manufactured per Charter Steel Quality Manual Rev Date 9/12/12
Meets customer specifications with any applicable Charter Steel exceptions for the following customer documents:
Customer Document = ASTM A29/A29M-12 Revision = Dated = 01-MAY-12

Additional Comments: MELTED AND MANUFACTURED IN THE U.S.A

Charter Steel
Saukville, WI, USA

Rem: Load1,Fax0,Mail0

ACCREDITED
Testing Laboratory

This MTR supersedes all previously dated MTRs for this order
Janice Barnard
Manager of Quality Assurance
Printed Date : 11/21/2014

Figure A-26. ⅝-in. Dia. Nut (Splice)

R#15-0627 H#20297970 L#140530L
5/8x10" Guardrail Bolt
June 2015 SMT White Paint
3500G

TRINITY HIGHWAY PRODUCTS, LLC
425 East O'Connor Ave.
Lima, Ohio 45801
419-227-1296

7/31/14

MATERIAL CERTIFICATION

Customer: Stock
Date: June 25,2014
Invoice Number:
Lot Number: 140530L
Part Number: 3500G
Quantity: 17,173 Pcs.
Description: 5/8" x 10" G.R. Bolt
Heat Numbers: 20297970 17,173

Specification: ASTM A307-A / A153 / F2329

MATERIAL CHEMISTRY

Heat	C	MN	P	S	SI	NI	CR	MO	CU	SN	V	AL	N	B	TI	NB
20297970	.09	.33	.006	.001	.06	.03	.04	.01	.08	.002	.001	.026	.008	.0001	.001	.002

PLATING OR PROTECTIVE COATING

HOT DIP GALVANIZED (Lot Ave.Thickness / Mils) 2.54 (2.0 Mils Minimum)

****THIS PRODUCT WAS MANUFACTURED IN THE UNITED STATES OF AMERICA****

THE MATERIAL USED IN THIS PRODUCT WAS MELTED AND MANUFACTURED IN THE U.S.A

WE HEREBY CERTIFY THAT TO THE BEST OF OUR KNOWLEDGE ALL INFORMATION CONTAINED HEREIN IS CORRECT.

TRINITY HIGHWAY PRODUCTS LLC

STATE OF OHIO, COUNTY OF ALLEN
SWORN AND SUBSCRIBED BEFORE ME THIS 11th day of July 2014

Sherri Braun NOTARY PUBLIC

425 E. O'CONNOR AVENUE LIMA, OHIO 45801 419-227-1296.

NOTARIAL SEAL STATE OF OHIO
SHERRI BRAUN
Notary Public, State of Ohio
My Commission Expires
April 20, 2019

RECEIVED
JUL 11 2014
Trinity Highway Products, LLC
Dallas, Texas. Plant 99

Figure A-27. ⅝-in. Dia. x 10-in. Long Guardrail Bolt and Nut (Sheet 1 of 2)

35006

Trinity Metals Laboratory
A DIVISION OF TRINITY INDUSTRIES
4001 IRVING BLVD. 75247 - P.O. BOX 568887
DALLAS, TX 75356-8887
Phone: 214.589.7591 FAX: 214.589.7594

NVLAP LAB CODE 200554-0

TEST REPORT

Lab No: 14050355F
KEITH HAMBURG
TRINITY HWY PRODUCTS, LLC #55
ROLLFORM
LIMA, OH 45801

Received Date: 05/23/2014
Heat Code: 140530L
Heat Number:
PO or Work Order: 55-81638
Test Spec: F606 ASTM METHODS
Other Information:

Completion Date: 05/27/2014
Weld Spec:
Material Type: A 307 A
Material Size: 5/8" x 10" GR BOLT

OTHER TEST:

Type: HARDNESS ROCKWELL BW
Test Spec: E-18

Quantity amount: 12

Bolt "A": 88.9 - 89.8 - 88.9 - 90.6

Bolt "B": 86.4 - 89.5 - 88.6 - 88.0

Bolt "C": 85.0 - 86.5 - 87.7 - 88.1

Type: BOLT TENSILE STRENGTH
Test Spec: F606

Quantity amount: 3

Bolt tensile "A" fractured @ 18,580 lbs. in the threads (min. 13,550 lbs.).

Bolt tensile "B" fractured @ 18,750 lbs. in the threads (min. 13,550 lbs.).

Bolt tensile "C" fractured @ 18,750 lbs. in the threads (min. 13,550 lbs.).

Type: HEAD MARKINGS
TRN 307A USA R

Quantity amount: 1

We certify the above results to be a true and accurate representation of the sample(s) submitted. Alteration or partial reproduction of this report will void certification. NVLAP Certificate of Accreditation effective through 12-31-14.This report may not be used to claim product certification, approval, or endorsement by NVLAP, NIST, or any agency of the federal government.

Lab Director, Michael S. Beaton, PE

Page 1 of 1

Figure A-28. ⅝-in. Dia. x 10-in. Long Guardrail Bolt and Nut (Sheet 2 of 2)

CERTIFICATE OF COMPLIANCE

ROCKFORD BOLT & STEEL CO.
126 MILL STREET
ROCKFORD, IL 61101
815-968-0514 FAX# 815-968-3111

CUSTOMER NAME: MIDWEST FENCE-GUARDRAIL SYSTEM

CUSTOMER PO: KDG

INVOICE #: 937100 **DATE SHIPPED:** 7/31/07

LOT#: 17743

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

COATING: ASTM A153, CLASS C HOT DIP GALVANIZATION

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si	Cu	Ni	Cr	Mo
GERDAU AMERISTEEL	1010	P070420	.10	.50	.009	.014	.10				

QUANTITY AND DESCRIPTION:

200 PCS 5/8" X 20" GUARD RAIL BOLT

WE HEREBY CERTIFY THE ABOVE BOLTS HAVE BEEN MANUFACTURED BY ROCKFORD BOLT AND STEEL. THE MATERIAL USED WAS MELTED AND MANUFACTURED IN THE U.S.A. WE FURTHER CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIALS SUPPLIER, AND THAT OUR PROCEDURES FOR THE CONTROL OF PRODUCT QUALITY ASSURE THAT ALL ITEMS FURNISHED ON THIS ORDER MEET OR EXCEED ALL APPLICABLE TESTS, PROCESS, AND INSPECTION REQUIREMENTS PER ABOVE SPECIFICATION.

Guardrail bolts for Arizona Full Scale
R#16-0210 H#P070420 White Paint

Figure A-29. ⅝-in. Dia. x 18-in. Long Guardrail Bolt and Nut (Sheet 1 of 2)

GERDAU AMERISTEEL

PERTH AMBOY STEEL MILL
225 ELM STREET
PERTH AMBOY NJ 08862 USA

Page 1

Chemical and Physical Test Report

MADE IN UNITED STATES

This report shall not be reproduced except in full. This report relates only to items tested. The chemistry analysis was determined in accordance with test methods.

SHAPE + SIZE	GRADE	SPECIFICATION	SALES ORDER	CUST P.O. NUMBER
K19/32	1010 AISI	1010 AISI 1010 AISI 1010 AISI		

HEAT I.D.	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Nb	B	N	Sn	Al	Ti	Ca	C Eqv
P070420	.10	.50	.009	.014	.10	.17	.06	.03	.013	.001	.001	.0003	.0078	.007	.001	.00100	.00050	.207

Mechanical Test: Tensile: 60831 PSI, 419.41 MPA Std Dev:0 Idl Diam: .184 %R.A.: 50.6

Customer Requirements SOURCE: CARTERSVILLE CASTING: STRAND CAST

Comment:

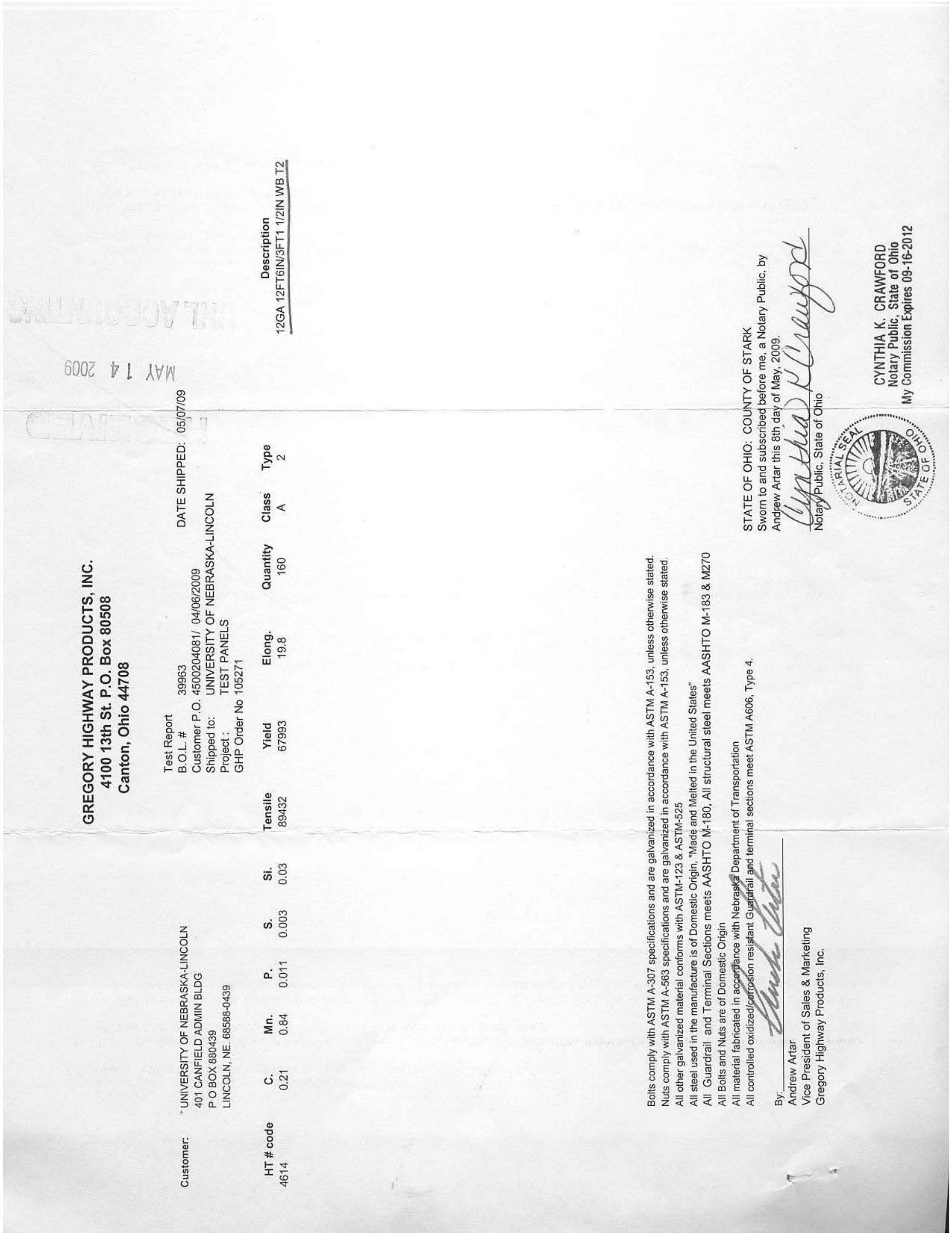
This material, including the billets, was produced and manufactured in the United States of America

Bhaskar Yalamanchili
Quality Director
Gerdau Ameristeel

THE ABOVE FIGURES ARE CERTIFIED EXTRACTS FROM THE ORIGINAL CHEMICAL AND PHYSICAL TEST RECORDS AS CONTAINED IN THE PERMANENT RECORDS OF COMPANY.

Mgr. Metallurg. Svcs.
PERTH AMBOY STEEL MILL

Figure A-30. ⅝-in. Dia. x 18-in. Long Guardrail Bolt and Nut (Sheet 2 of 2)



GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. P.O. Box 80508
Canton, Ohio 44708

Customer: UNIVERSITY OF NEBRASKA-LINCOLN
401 CANFIELD ADMIN BLDG
P O BOX 880439
LINCOLN, NE. 68588-0439

Test Report
B.O.L. # 39963
Customer P.O. 4500204081/ 04/06/2009
Shipped to: UNIVERSITY OF NEBRASKA-LINCOLN
Project : TEST PANELS
GHP Order No 105271

DATE SHIPPED: 05/07/09

MAY 14 2009

HT # code	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
4614	0.21	0.84	0.011	0.003	0.03	89432	67993	19.8	160	A	2	12GA 12FT6IN/3FT1 1/2IN WB T2

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.
All other galvanized material conforms with ASTM-123 & ASTM-525
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: Andrew Artar
Andrew Artar
Vice President of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 8th day of May, 2009.
Cynthia K Crawford
Notary Public, State of Ohio

NOTARIAL SEAL STATE OF OHIO

CYNTHIA K. CRAWFORD
Notary Public, State of Ohio
My Commission Expires 09-16-2012

Figure A-31. 25-ft Long W-beam Guardrail (Post Nos. 5-7)

Gregory Industries 13:54:11 Jun 24 2015 Page 1

HEAT MASTER LISTING

Heat No.	Mill#	Name	YR	Primary Grade	Secondary Grade	CODE	Original Heat Number
9411949	ARC03	ARCELOR MITTAL USA, LLC	15	1021		8534	

******* Chemistry *******

Cr	Si	P	C	Mn	S	Cu	Ni	Mo	Sn	Al	V	Cb	N	Ti
0.0400	0.0100	0.0100	0.2100	0.7500	0.0060	0.0200	0.0100	0.0100	0.0020	0.0580	0.0020	0.0020	0.0042	0.0020

Ca
0.0003

******* Mechanical Test *******

YIELD	TENSILE	ELONGATION	ROCKWELL
56527	75774	27.15	78

Guardrail W-Beam
20ct/25'
100ct/12'
10ct/25ft w/MGS Anchor Panel
July 2015 SMT

Figure A-32. 25-ft Long W-beam Guardrail (Post Nos. 7-11 and 17-19)

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Customer: MIDWEST MACHINERY & SUPPLY CO.
P. O. BOX 703

MILFORD,NE,68405

Test Report
Ship Date: 6/2/2015
Customer P.O.: 3078
Shipped to: MIDWEST MACHINERY & SUPPLY CO.
Project: STOCK
GHP Order No.: 181769

HT # code	Heat #	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
8424	4135788	0.2	0.72	0.01	0.006	0.01	77194	55406	25.48	10	A	1	12GA 15FT 7.5IN WB TI HS 2@6FT3IN 1@3FT1.5IN
8331	4134527	0.24	0.77	0.011	0.005	0.01	82673	63255	27.87	40	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8479	9511340	0.21	0.74	0.009	0.005	0.01	77105	59917	21	40	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8244	31504980	0.2	0.85	0.01	0.002	0.03	84559	62542	13.3	40	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8418	31512700	0.22	0.84	0.008	0.03	0.03	77442	54762	24.66	16	A	1	12GA 12FT6IN/3FT1 1/2IN WB T1
8420	C74349	0.2	0.49	0.008	0.002	0.03	79319	56709	23.4	10	A	1	12 GA 12FT6IN WB T1 FLEAT-SKT COMBO PAN
8367	4166272	0.21	0.78	0.01	0.007	0.01	78865	55889	21.61	6	A	1	12 GA 12FT6IN WB T1 FLEAT-SKT COMBO PAN
8479	9511340	0.21	0.74	0.009	0.005	0.01	77105	59917	21	100	A	1	12GA 25FT0IN 3FT1 1/2IN WB T1
8466	4135789	0.21	0.76	0.009	0.008		79006	61740	23.78	6	A	1	12GA 9FT4 1/2IN 3FT1 1/2IN WB T1

R#15-0602 H#8479
MGS 12'6" Guardrail W-Beam QTY 40
June 2015 SMT

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.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: ______________________
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 3 day of June, 2015

Notary Public, State of Ohio

Figure A-33. 25-ft Long W-beam Guardrail (Post Nos. 1-5, 11-17, and 19-29)

Appendix B. FHWA Correspondence Regarding Demonstrated System Performance

From: Nick.Artimovich@dot.gov [mailto:Nick.Artimovich@dot.gov]
Sent: Tuesday, October 04, 2011 8:51 AM
To: Ronald Faller <rfaller1@unl.edu>
Cc: john.dewar2@dot.gov; will.longstreet@dot.gov; srosenba@unlserve.unl.edu
Subject: RE: Ponderosa Pine Posts for Old W-Beam Guardrail Standards!

Ron,
Thank you. That explanation is just what I would have expected. However, in this era of MASH we need to cover all these bases if we are trying to establish equivalency of one system to another using Report-350 criteria and bogie tests that only evaluate the post strength in one direction.
Nick

Nicholas Artimovich, II
Highway Engineer, Office of Safety Technologies
Federal Highway Administration HSST
1200 New Jersey Avenue SE, Room E71-322
Washington, DC 20590
email: nick.artimovich@dot.gov
phone: 202-366-1331
fax: 202-366-3222
web: http://safety.fhwa.dot.gov

From: Ronald K. Faller [mailto:rfaller1@unl.edu]
Sent: Monday, October 03, 2011 4:53 PM
To: Artimovich, Nick (FHWA)
Cc: Dewar, John (FHWA); Longstreet, Will (FHWA); 'Ronald K. Faller'; 'Scott Rosenbaugh'
Subject: RE: Ponderosa Pine Posts for Old W-Beam Guardrail Standards!

Nick:

Thanks for your prompt response!

The bogie testing will be performed on posts embedded in soil using an orientation which provides a loading perpendicular to the rail axis. As such, the 6x8s will be loaded about their strong-axis of bending. A comparable size and length of PP post will targeted to provide similar behavior to 6x8 SYP post.

As you noted, it may be worthwhile to consider discussing how 6x8 rectangular SYP posts may influence guardrail performance based upon their weak-axis strength. When longitudinal rail is pulled from end to end, the load is transmitted through the post to the soil via a bolted connection. Typically, we do not see significant effect from weak-axis post capacity on system performance when considering common sizes. Occasionally, we observe some side splitting near top of posts at bolt location although inconsequential.

Second, the initial soil stiffness and resistance of a 6x8 post in the direction perpendicular to the wide face (8" surface) would be greater than the narrower face. However, the actual bending capacity of the 6x8 wood post is less about this direction (parallel to rail) due to the reduced section modulus. As such and for a comparable load height, one would expect the 6x8 post to fracture more quickly when loaded parallel to rail.

Even though 6x8 posts may provide different behaviors between parallel and perpendicular load directions, these differences have not been known to be a big source of problem in existing W-beam guardrail designs. Further, posts with similar behavior in both directions have also demonstrated acceptable performance and been approved for use. For example, both round and square SYP posts have performed in acceptable manner in W-beam guardrail and approach guardrail transitions. In addition, the RDG shows 8x8 square posts as an acceptable alternative to 6x8 posts in both 6' and 5' 4" lengths for standard guardrail designs. As such, I would expect round PP posts to behave similarly to round SYP and square SYP posts G4(2W) W-beam guardrail systems when considering the effect of loads imparted parallel to rail axis.

Ron

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From: Nick.Artimovich@dot.gov [mailto:Nick.Artimovich@dot.gov]
Sent: Monday, October 03, 2011 12:25 PM
To: rfaller1@unl.edu
Cc: john.dewar2@dot.gov; will.longstreet@dot.gov
Subject: RE: Ponderosa Pine Posts for Old W-Beam Guardrail Standards!

Ron,

Thanks for your email. I concur in your proposed testing.

If we look at this as modifying the existing Southern Yellow Pine strong-post w-beam guardrail by substituting Ponderosa Pine, we can accept bogie testing as a means for evaluating the current square and rectangular SYP posts side-by-side with the round Ponderosa Pine. Of course, the closer the comparison, the easier it will be to expect "equivalency" in the performance of the guardrail.

As I understand, the highest forces that the posts are subjected to are lateral – the force of the rail pushing them back, perpendicular to traffic. This would be relatively easy to test using a bogie, and compare with square vs. round posts of various species. However, there will also be some longitudinal forces involved that may not be evaluated in the bogie test. If the rectangular posts offer more resistance to that longitudinal load than the proposed round posts, you may see a difference in performance. Or, the longitudinal loads may be insignificant, but I would like to see that issue addressed in your test and evaluation report.

I presume this testing will be conducted under Report 350 guidelines, as that was the criteria that the original guardrail was tested.

Nick

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From: Ronald K. Faller [mailto:rfaller1@unl.edu]
Sent: Monday, October 03, 2011 11:16 AM
To: Artimovich, Nick (FHWA)
Cc: 'Ronald K. Faller'
Subject: Ponderosa Pine Posts for Old W-Beam Guardrail Standards!

Nick:

Recently, the Arizona DOT and timber industry within the State of Arizona contacted us regarding the use of round Ponderosa Pine (PP) posts as a replacement for rectangular and square SYP posts in existing guardrail system in Arizona and across the U.S.

As you already know and several years ago, MwRSF developed a standard for using a round PP post in the MGS under NCHRP 350. In the future, the AzDOT will likely be moving toward using the MGS. However, there is a desire to also use a round PP post in existing guardrail systems in Arizona and across the U.S.

This year, significant forest fires devastated many PP forests in Arizona. As such, the timber industry is looking to manufacture round PP posts for both MGS and existing W-beam systems. Although some post test data exists, MwRSF personnel believed that the data was insufficient to determine the appropriate diameter and embedment depth to replace existing rectangular and square SYP posts in current designs in the field. Thus, we have proposed the use of additional dynamic bogie testing to demonstrate comparable post-soil behavior to what is currently being used in existing guardrails (i.e., different load heights and embedment depths as compared to MGS).

Thus, my question to you is whether FHWA would agree to the use of dynamic bogie testing to demonstrate that a particular round PP post (size and length) can be used in lieu of a rectangular or square SYP post and provides similar post-soil behavior. Please provide your thoughts and comments on this matter! Thanks!

P.S. – I have provided a copy of recent correspondence (attachment) to aid in your evaluation of the situation.

Ron

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Appendix C. Vehicle Center of Gravity Determination

Test: AZRP-1 Vehicle: Chevrolet C2500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unbalasted Truck (Curb)	4629	26.51931	122757.88
+	Hub	29	13.875	402.375
+	Brake Frame	7	27.125	189.875
+	Brake Cylinder (Nitrogen)	29	27.625	801.125
+	Strobe/Brake Battery	5	29.375	146.875
+	Brake Reciever/Wires	5	51.375	256.875
+	CG Plate (EDRs)	22	28.625	629.75
-	Battery	-32	39.375	-1260
-	Oil	-9	20.375	-183.375
-	Interior	-146	26.375	-3850.75
-	Fuel	-197	21.375	-4210.875
-	Coolant	-8	33.375	-267
-	Washer fluid	0	0	0
+	Water Ballast	76	17	1292
				0
				0
				116704.75

Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle

Estimated Total Weight (lb.)	4410
Vertical CG Location (in.)	26.46366

Wheel Base (in.) 132

Center of Gravity	2000P NCHRP 350 Targets	Test Inertial	Difference
Test Inertial Weight (lb.)	4410 ± 100	4412	2.0
Longitudinal CG (in.)	55 ± 6	56.99	1.99456
Lateral CG (in.)	NA	-1.02388	NA
Vertical CG (in.)	27.5 ± 2	26.46	-1.03634

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb.)

	Left	Right
Front	1307	1300
Rear	1036	986

FRONT	2607 lb.
REAR	2022 lb.
TOTAL	4629 lb.

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1298	1209
Rear	979	926

FRONT	2507 lb.
REAR	1905 lb.
TOTAL	4412 lb.

Figure C-1. Vehicle Mass Distribution, Test No. AZRP-1

Test No.: AZRP-1 **Vehicle:** Chevrolet C2500

Date Measu 11/30/2015

C.G. Calculations (As Hung) Measured Day of Hang

Edit Blue Cells Only

Vertical C.G. as Measured from Hanging C.G. Method

Left (in)	=	26.5
Right (in)	=	25.75
Average (in)	=	26.125

Weight of hubs (lbs.) =	149
Total Vehicle Weight with hubs (lbs.) =	4778
Average Wheel Center Height (in) =	13.875

Vertical C.G. with out hubs from ground (in) = 26.51931

Curb Weight Distribution	Left	Right
Front	1307	1300
Rear	1036	986
Total	4629	

Wheel Base (in.) =	132

Longitudinal C.G. as Measured from Hanging C.G. method

From center of rear wheel

Left	74	in.
Right	73.875	in.
Average	73.9375	in.

Longitudinal C.G.
Calculated from Weight Distribution

Left
Distance from center of rear wheel (in) = 73.6338

Right
Distance from center of rear wheel (in) = 75.06562

Average
Distance from center of rear wheel (in) = 74.34971

Figure C-2. Vehicle Vertical Mass Distribution – Suspension Method, Test No. AZRP-1

Appendix D. Vehicle Deformation Records

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

TEST: AZRP-1
VEHICLE: Chevrolet C2500

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	30.492	5.052	0.511	30.877	4.011	-0.503	0.384	-1.041	-1.014
2	32.926	9.623	0.467	33.902	8.556	-0.851	0.977	-1.067	-1.318
3	33.591	16.209	2.038	33.630	14.656	1.365	0.039	-1.553	-0.673
4	32.585	21.258	3.888	32.676	19.607	3.756	0.091	-1.652	-0.132
5	28.331	5.835	-2.861	28.396	4.664	-3.707	0.065	-1.171	-0.846
6	28.967	11.054	-1.880	29.344	9.958	-3.168	0.377	-1.096	-1.288
7	29.392	17.381	-1.213	29.579	16.049	-1.844	0.187	-1.332	-0.631
8	29.663	21.482	-0.376	29.805	20.052	-0.755	0.143	-1.430	-0.379
9	24.784	5.772	-4.884	24.716	4.685	-5.367	-0.068	-1.087	-0.483
10	25.450	10.563	-4.461	25.569	9.415	-4.898	0.120	-1.148	-0.436
11	26.208	16.499	-3.216	26.574	15.285	-3.979	0.367	-1.214	-0.763
12	26.289	21.218	-1.849	26.584	19.962	-2.371	0.295	-1.255	-0.522
13	19.584	5.832	-4.624	19.435	4.905	-4.916	-0.150	-0.927	-0.292
14	20.505	10.163	-4.169	20.529	9.133	-4.128	0.024	-1.030	0.042
15	21.341	15.904	-3.342	21.735	14.929	-3.336	0.394	-0.974	0.006
16	20.612	20.522	-2.571	21.151	19.600	-3.631	0.539	-0.922	-1.060
17	13.696	5.733	-3.872	13.604	5.213	-4.018	-0.092	-0.520	-0.146
18	13.628	9.719	-3.494	13.731	9.053	-3.715	0.103	-0.666	-0.221
19	13.784	13.884	-2.889	14.077	13.186	-2.867	0.293	-0.697	0.022
20	13.509	20.065	-2.063	14.029	19.407	-2.157	0.520	-0.658	-0.093
21	8.063	5.478	-3.361	7.905	5.276	-3.320	-0.158	-0.203	0.041
22	8.293	8.850	-2.957	8.293	8.510	-3.179	0.000	-0.340	-0.222
23	8.377	13.092	-2.252	8.534	12.769	-2.350	0.157	-0.322	-0.098
24	8.245	20.156	-1.587	8.870	19.700	-1.484	0.625	-0.455	0.104
25	1.364	5.400	-2.569	1.574	5.390	-1.654	0.210	-0.011	0.915
26	1.343	9.345	-1.980	1.626	9.409	-1.460	0.283	0.064	0.520
27	1.356	13.144	-1.348	1.844	13.200	-1.268	0.488	0.056	0.080
28	1.346	15.940	-0.927	1.921	16.028	-1.118	0.576	0.088	-0.192

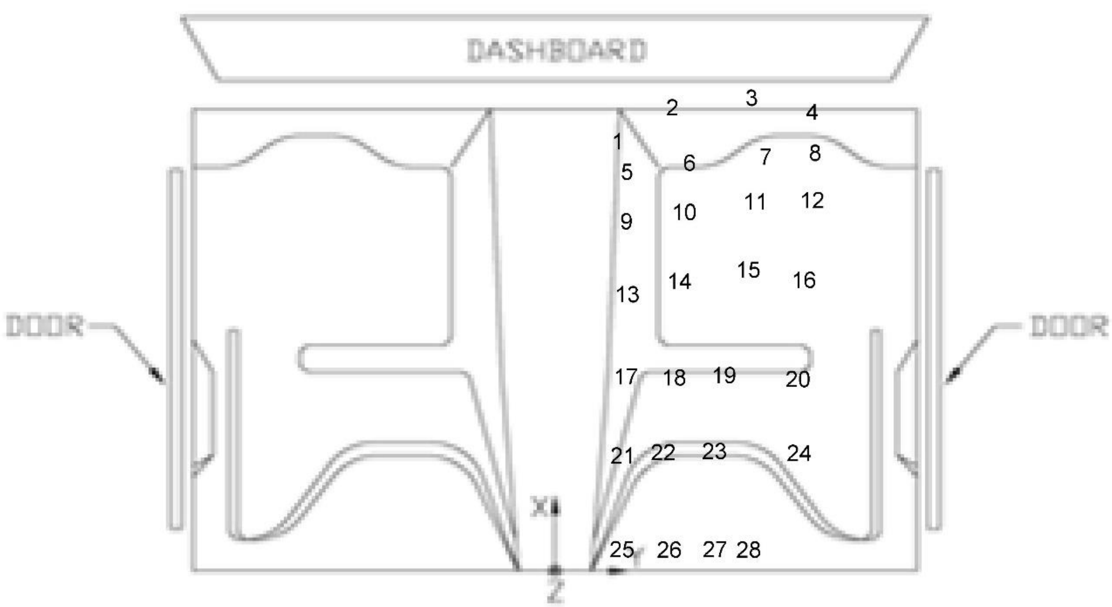


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. AZRP-1

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

TEST: AZRP-1
VEHICLE: Chevrolet C2500

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
1	47.170	13.895	1.296	47.452	12.861	-2.760	0.282	-1.034	-4.056
2	49.416	18.448	0.669	49.966	17.388	-4.562	0.550	-1.060	-5.231
3	49.704	25.296	1.251	49.327	23.931	-4.130	-0.377	-1.365	-5.381
4	48.362	30.470	2.231	48.056	29.097	-3.283	-0.305	-1.373	-5.514
5	45.238	14.104	-2.271	44.848	12.472	-5.900	-0.390	-1.632	-3.629
6	45.474	19.421	-2.156	45.364	17.686	-6.912	-0.110	-1.735	-4.756
7	45.660	25.871	-2.372	45.179	24.054	-7.369	-0.481	-1.817	-4.997
8	45.652	30.023	-2.160	45.075	28.118	-7.490	-0.577	-1.906	-5.330
9	41.854	13.632	-4.518	40.972	11.815	-7.331	-0.882	-1.817	-2.813
10	42.220	18.316	-4.762	41.677	16.489	-8.223	-0.543	-1.827	-3.461
11	42.706	24.435	-4.358	42.122	22.472	-9.075	-0.584	-1.963	-4.717
12	42.427	29.287	-3.759	41.821	27.346	-8.836	-0.605	-1.941	-5.077
13	36.649	13.307	-4.521	35.924	11.771	-6.699	-0.724	-1.536	-2.178
14	37.249	17.790	-4.691	36.649	16.091	-7.154	-0.600	-1.699	-2.463
15	37.818	23.597	-4.702	36.750	21.421	-7.837	-1.068	-2.176	-3.134
16	36.848	28.249	-4.684	36.384	26.223	-9.639	-0.464	-2.027	-4.955
17	30.798	13.147	-4.146	30.074	11.812	-5.568	-0.725	-1.336	-1.423
18	30.421	17.113	-4.361	29.861	15.723	-6.394	-0.560	-1.390	-2.034
19	30.337	21.197	-4.388	29.865	19.908	-6.751	-0.472	-1.290	-2.364
20	29.750	27.458	-4.526	29.401	26.034	-7.851	-0.349	-1.424	-3.325
21	25.085	12.640	-3.905	24.440	11.689	-4.630	-0.646	-0.952	-0.724
22	25.179	16.084	-4.017	24.532	14.990	-5.472	-0.647	-1.094	-1.455
23	24.925	20.331	-3.953	24.468	19.144	-5.865	-0.456	-1.187	-1.912
24	24.585	27.391	-4.390	24.207	26.161	-7.020	-0.378	-1.229	-2.630
25	18.333	12.378	-3.521	18.072	11.928	-2.774	-0.261	-0.450	0.747
26	18.029	16.357	-3.521	17.840	15.760	-3.709	-0.189	-0.597	-0.188
27	17.956	20.114	-3.490	17.755	19.449	-4.594	-0.201	-0.664	-1.104
28	17.765	22.987	-3.510	17.656	22.204	-5.278	-0.109	-0.782	-1.768

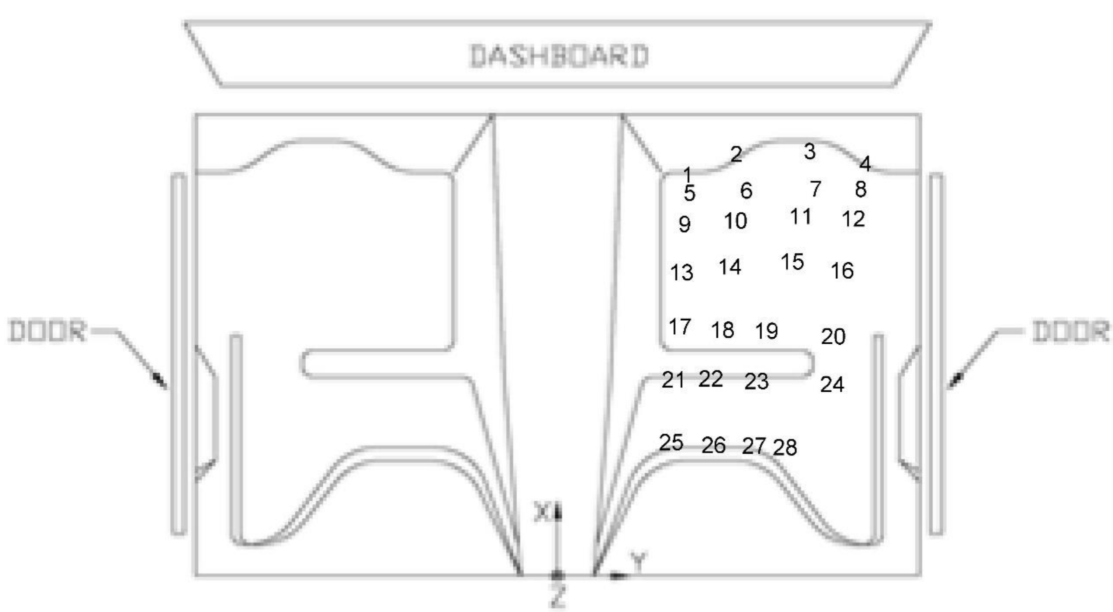


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. AZRP-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

TEST: AZRP-1
VEHICLE: Chevrolet C2500

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	23.052	-6.658	21.770	23.210	-9.156	18.860	0.159	-2.498	-2.909
	2	23.049	6.687	23.752	23.245	3.933	22.233	0.197	-2.754	-1.519
	3	22.619	19.969	25.880	23.053	16.969	25.559	0.434	-3.000	-0.320
	4	17.384	-4.667	13.625	17.205	-6.439	11.252	-0.179	-1.772	-2.373
	5	17.774	9.282	15.967	17.878	7.179	14.819	0.105	-2.102	-1.149
	6	17.834	21.382	18.146	18.152	19.138	17.969	0.317	-2.244	-0.177
SIDE PANEL	7	25.489	23.755	7.507	25.649	21.555	7.374	0.160	-2.200	-0.132
	8	24.537	24.776	1.599	24.619	22.931	1.512	0.082	-1.846	-0.087
	9	30.617	24.052	4.443	30.908	22.191	4.160	0.290	-1.862	-0.283
IMPACT SIDE DOOR	10	15.504	23.798	22.297	15.633	21.101	22.244	0.129	-2.697	-0.053
	11	3.268	23.981	23.910	3.555	21.719	24.074	0.288	-2.262	0.164
	12	-12.351	24.502	25.062	-12.113	22.718	25.605	0.238	-1.784	0.542
	13	13.537	25.746	8.505	13.529	23.728	8.611	-0.008	-2.018	0.106
	14	0.054	26.106	8.453	0.133	24.908	8.856	0.078	-1.199	0.403
	15	-12.287	26.377	9.751	-12.191	26.050	10.436	0.096	-0.327	0.685
ROOF	1	12.743	-11.953	39.160	12.636	-16.117	34.801	-0.107	-4.164	-4.359
	2	12.878	-4.897	40.255	12.978	-9.230	36.792	0.100	-4.333	-3.463
	3	12.563	0.459	41.123	12.734	-4.023	38.292	0.171	-4.482	-2.830
	4	11.381	9.823	42.219	11.710	5.100	40.495	0.329	-4.723	-1.725
	5	5.717	-12.486	42.221	5.523	-16.894	37.687	-0.194	-4.407	-4.534
	6	4.737	-6.471	43.439	4.749	-11.048	39.617	0.012	-4.577	-3.821
	7	3.662	1.338	44.708	3.776	-3.394	41.865	0.114	-4.732	-2.842
	8	2.677	8.066	45.506	2.808	3.025	43.484	0.132	-5.040	-2.022
	9	-0.310	-13.141	43.214	-0.565	-17.492	38.519	-0.255	-4.352	-4.695
	10	-1.328	-6.829	44.360	-1.385	-11.411	40.415	-0.057	-4.582	-3.945
	11	-1.327	0.620	45.379	-1.251	-4.204	42.362	0.076	-4.824	-3.017
	12	-2.959	8.238	46.341	-2.677	3.263	44.262	0.282	-4.976	-2.079

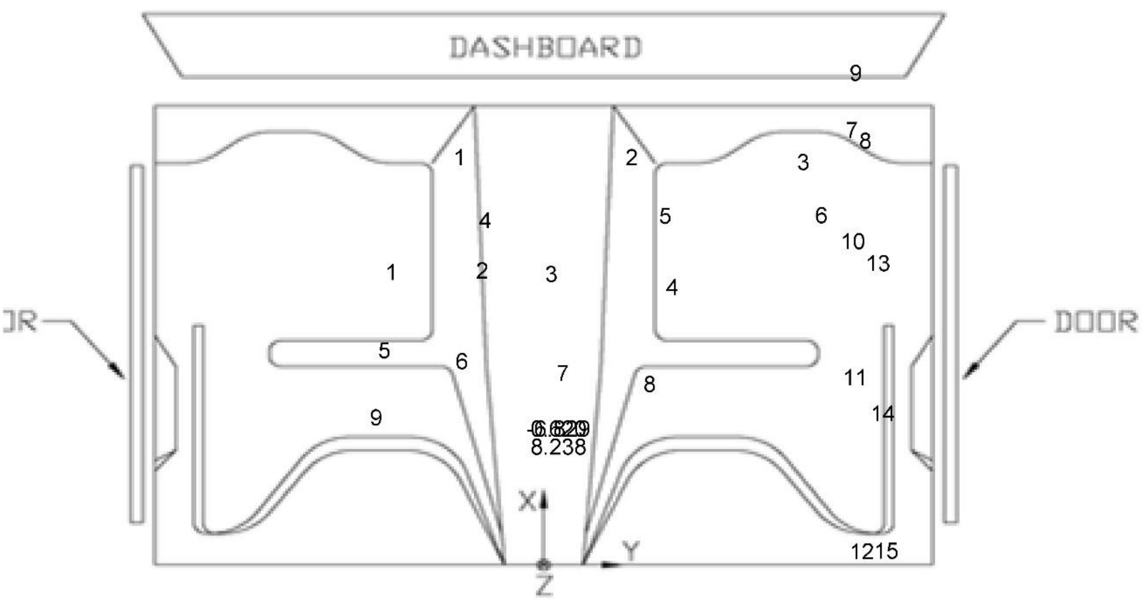


Figure D-3. Occupant Compartment Deformation Data – Set 1, Test No. AZRP-1

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

TEST: AZRP-1
VEHICLE: Chevrolet C2500

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)
DASH	1	38.878	5.175	23.625	41.538	5.436	19.953	2.661	0.261	-3.672
	2	38.137	18.643	23.493	40.509	18.840	19.414	2.372	0.197	-4.079
	3	37.086	31.980	23.586	39.280	32.159	18.898	2.194	0.178	-4.688
	4	33.636	5.586	14.950	34.992	5.304	12.374	1.356	-0.283	-2.576
	5	33.291	19.698	15.148	34.683	19.415	11.696	1.392	-0.282	-3.451
	6	32.681	31.976	15.514	34.056	31.774	11.335	1.376	-0.202	-4.180
SIDE PANEL	7	40.890	33.178	4.957	41.046	31.561	-0.003	0.155	-1.617	-4.960
	8	40.270	33.246	-0.987	39.784	31.135	-5.932	-0.486	-2.111	-4.945
	9	46.342	33.276	2.180	46.014	31.616	-3.370	-0.329	-1.660	-5.551
IMPACT SIDE DOOR	10	29.951	34.914	18.963	31.587	34.680	14.947	1.637	-0.233	-4.015
	11	17.846	34.726	19.847	19.457	34.949	17.145	1.611	0.222	-2.702
	12	2.021	34.618	20.051	3.839	35.255	19.140	1.818	0.637	-0.911
	13	28.825	34.681	4.982	28.780	33.159	1.369	-0.045	-1.522	-3.613
	14	15.426	34.334	4.172	15.377	33.415	1.848	-0.050	-0.919	-2.323
	15	2.992	34.156	4.677	3.127	34.091	3.649	0.136	-0.065	-1.027
ROOF	1	27.686	2.125	40.926	31.975	2.497	37.696	4.289	0.372	-3.230
	2	27.382	9.204	41.007	31.662	9.615	37.686	4.280	0.411	-3.321
	3	26.819	14.576	41.026	31.194	14.997	37.610	4.375	0.420	-3.417
	4	25.166	23.933	40.591	29.474	24.328	37.201	4.308	0.395	-3.390
	5	20.412	1.673	43.656	24.995	2.153	41.046	4.583	0.479	-2.610
	6	19.161	7.704	43.868	23.762	8.294	41.285	4.601	0.590	-2.583
	7	17.671	15.486	43.866	22.286	16.093	41.311	4.615	0.607	-2.554
	8	16.322	22.280	43.573	20.922	22.661	41.064	4.600	0.381	-2.509
	9	14.422	0.830	44.375	19.150	1.180	42.294	4.728	0.350	-2.081
	10	13.123	7.143	44.465	17.789	7.634	42.453	4.665	0.491	-2.012
	11	12.594	14.674	44.338	17.375	15.119	42.279	4.781	0.445	-2.060
	12	10.697	22.305	44.010	15.339	22.768	42.056	4.642	0.464	-1.954

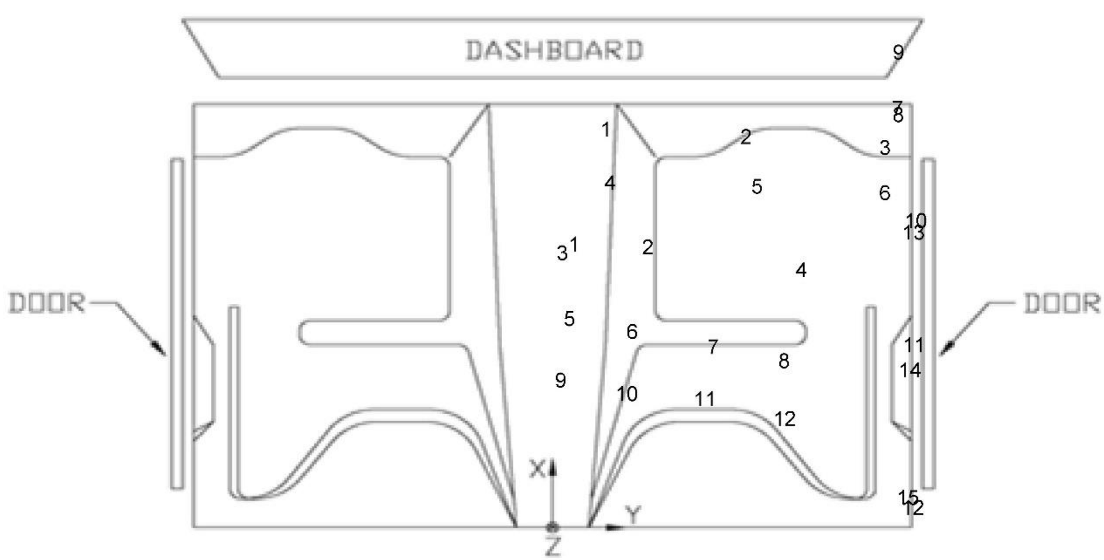
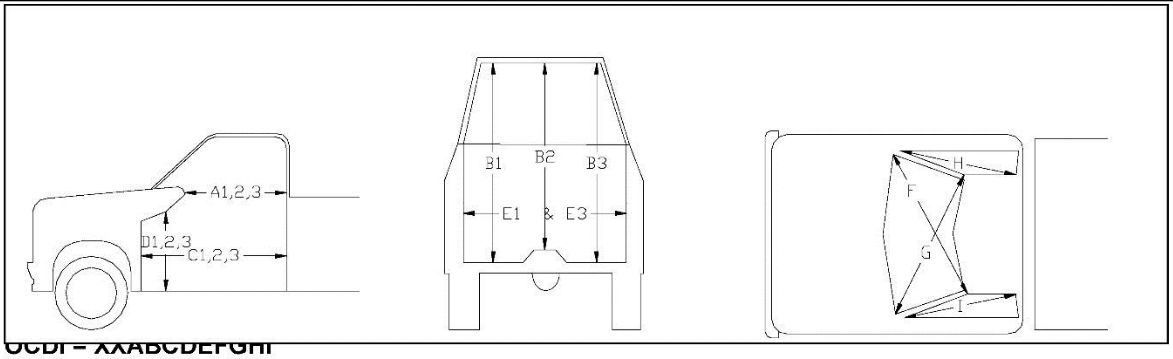


Figure D-4. Occupant Compartment Deformation Data – Set 2, Test No. AZRP-1

Occupant Compartment Deformation Index (OCDI)

Test No.: AZRP-1 **Vehicle:** Chevrolet C2500 **Date:** 12/9/2015



OCDI = XXABCDEFGHI

XX = location of occupant compartment deformation

A = distance between the dashboard and a reference point at the rear of the occupant compartment, such as the top of the rear seat or the rear of the cab on a pickup

B = distance between the roof and the floor panel

C = distance between a reference point at the rear of the occupant compartment and the motor panel

D = distance between the lower dashboard and the floor panel

E = interior width

F = distance between the lower edge of right window and the upper edge of left window

G = distance between the lower edge of left window and the upper edge of right window

H= distance between bottom front corner and top rear corner of the passenger side window

I= distance between bottom front corner and top rear corner of the driver side window

1 = Passenger Side

2 = Middle

3 = Driver Side

Location:	Pre-Test (in.)	Post-Test (in.)	Change (in.)	% Difference	Severity Index
A1	38.50	39.25	0.75	1.95	0
A2	46.50	46.25	-0.25	-0.54	0
A3	45.50	45.25	-0.25	-0.55	0
B1	45.00	44.88	-0.13	-0.28	0
B2	40.75	38.38	-2.38	-5.83	1
B3	45.25	44.75	-0.50	-1.10	0
C1	58.00	57.75	-0.25	-0.43	0
C2	53.00	52.75	-0.25	-0.47	0
C3	58.25	57.50	-0.75	-1.29	0
D1	16.00	16.38	0.38	2.34	0
D2	14.50	13.25	-1.25	-8.62	1
D3	15.25	16.00	0.75	4.92	0
E1	65.50	64.75	-0.75	-1.15	0
E3	67.00	67.25	0.25	0.37	0
F	59.50	60.25	0.75	1.26	0
G	60.00	60.25	0.25	0.42	0
H	41.00	41.00	0.00	0.00	0
I	40.50	40.75	0.25	0.62	0

Note: Maximum severity index for each variable (A-I) is used for determination of final OCDI value

	XX	A	B	C	D	E	F	G	H	I
Final OCDI:	RF	0	1	0	1	0	0	0	0	0

Severity Indices

0 - if the reduction is less than 3%

1 - if the reduction is greater than 3% and less than or equal to 10 %

2 - if the reduction is greater than 10% and less than or equal to 20 %

3 - if the reduction is greater than 20% and less than or equal to 30 %

4 - if the reduction is greater than 30% and less than or equal to 40 %

Figure D-5. Occupant Compartment Deformation Index, Test No. AZRP-1

Appendix E. Accelerometer and Rate Transducer Data Plots, Test No. AZRP-1

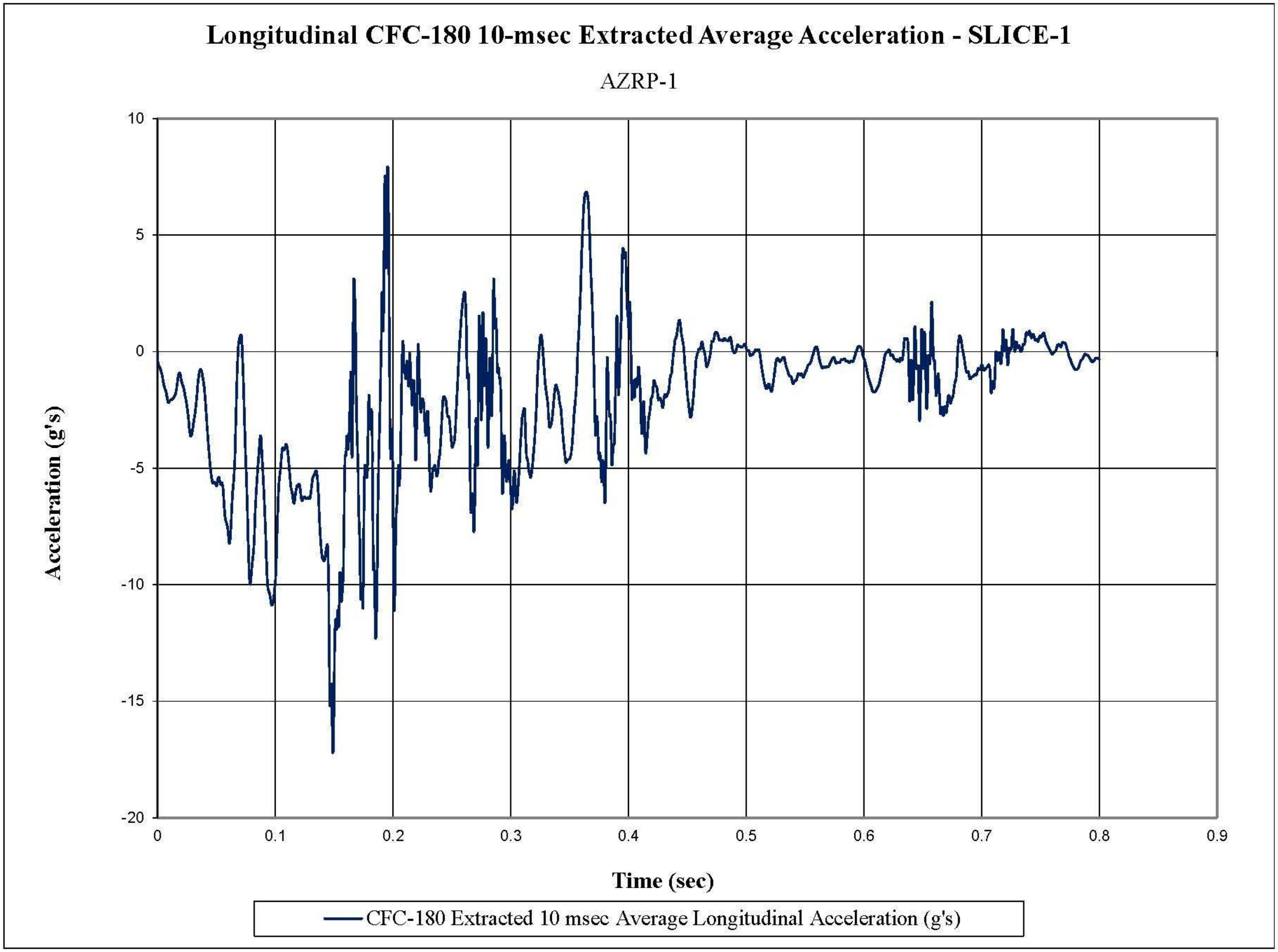


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. AZRP-1

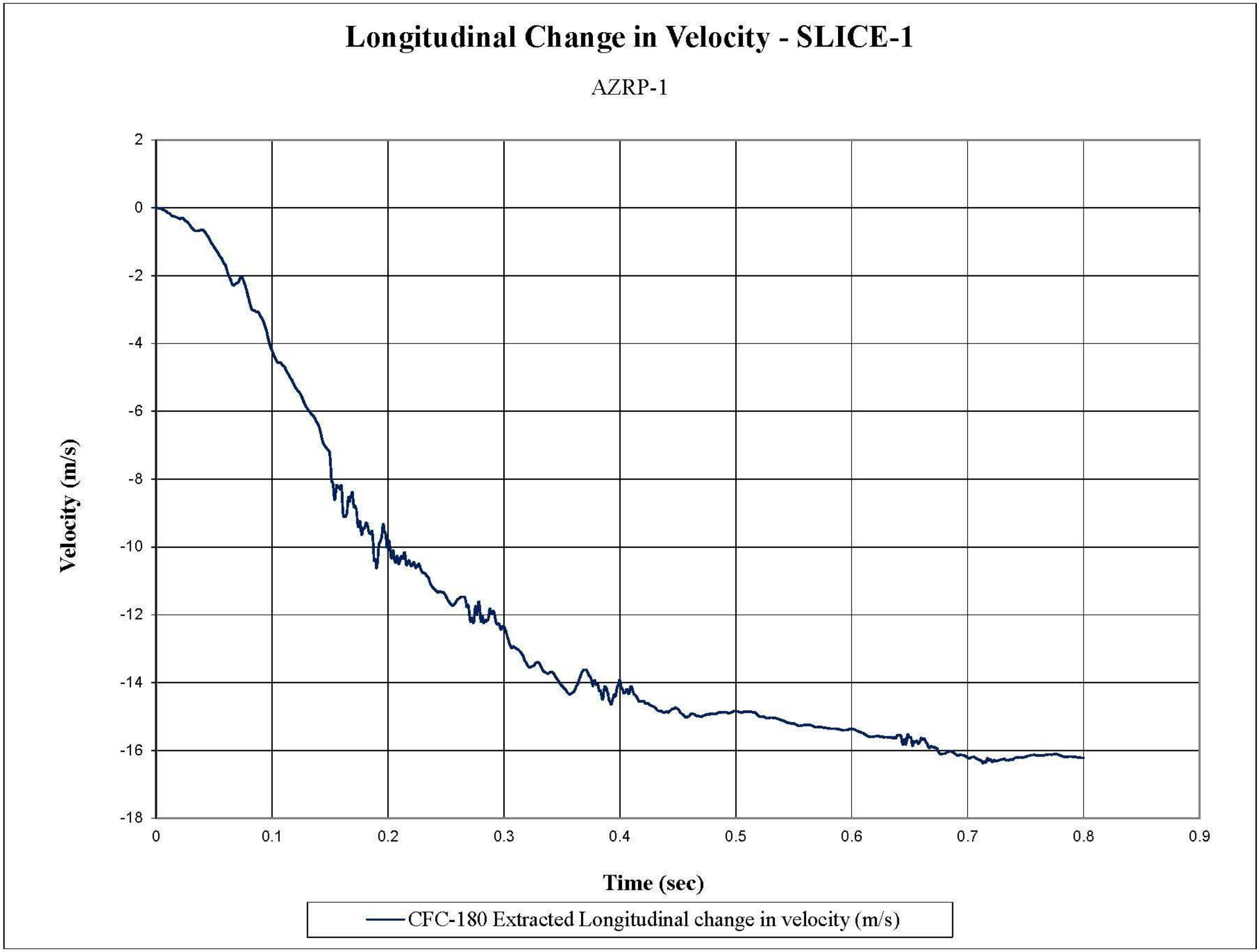


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. AZRP-1

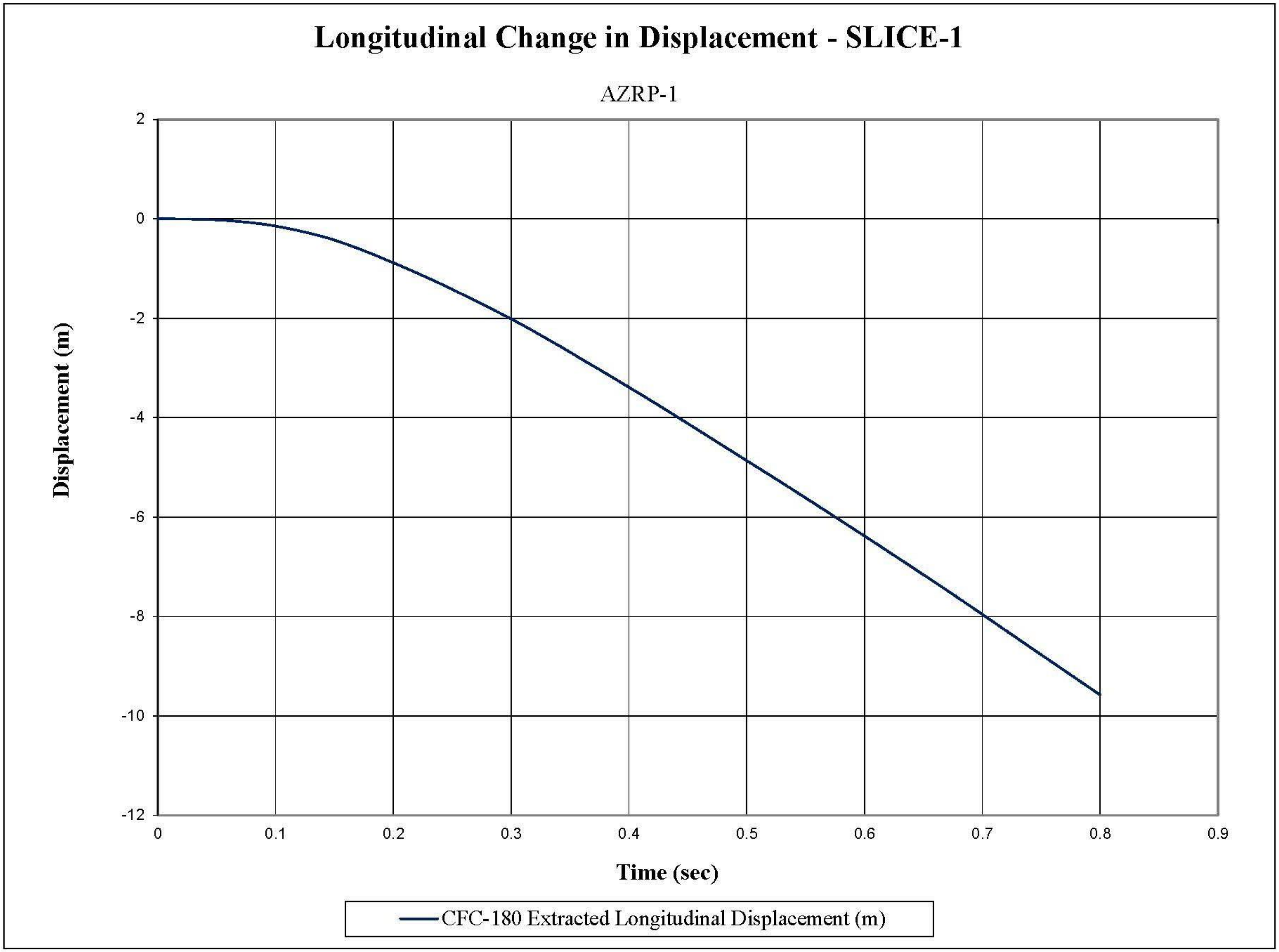


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. AZRP-1

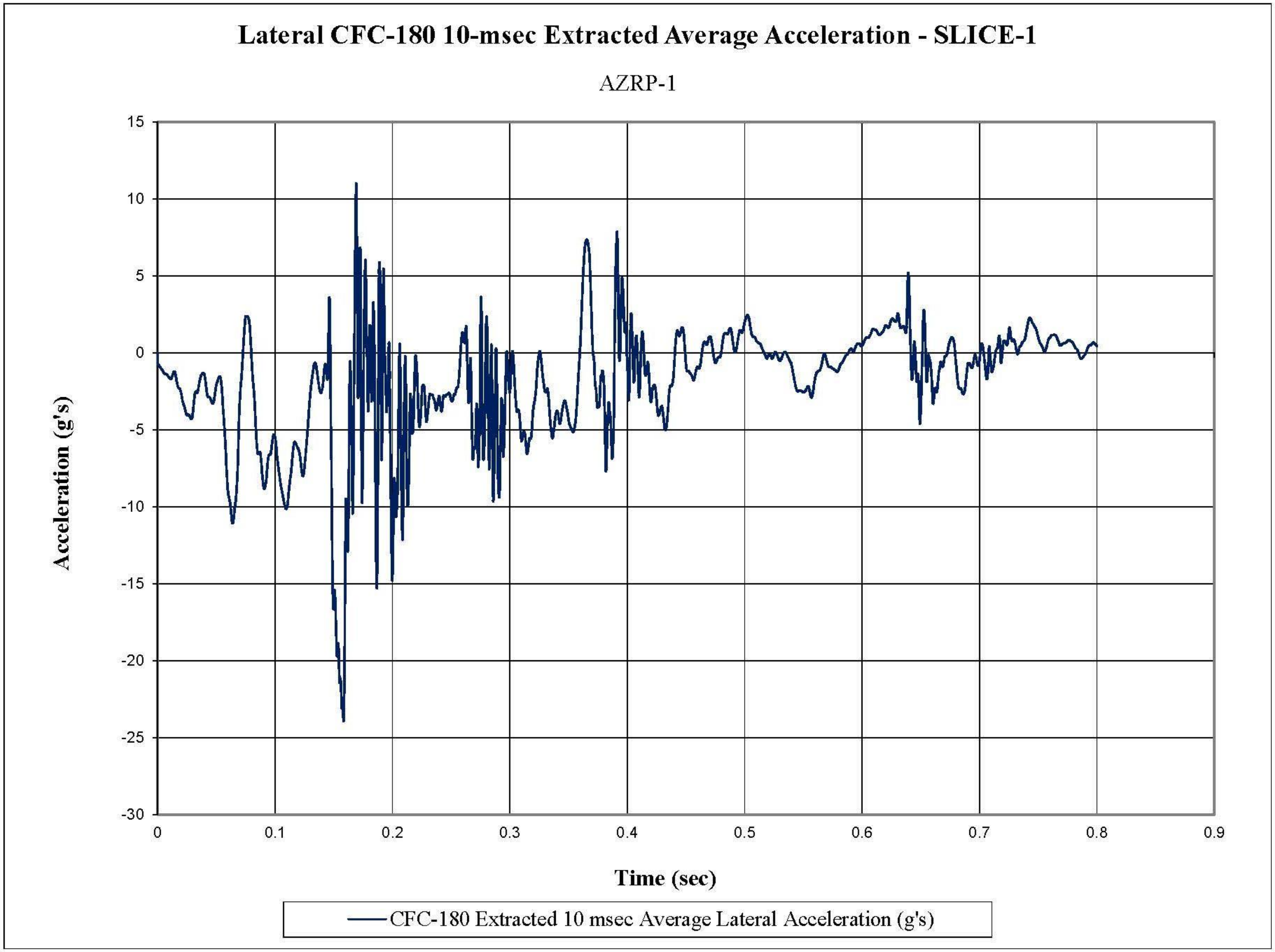


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. AZRP-1

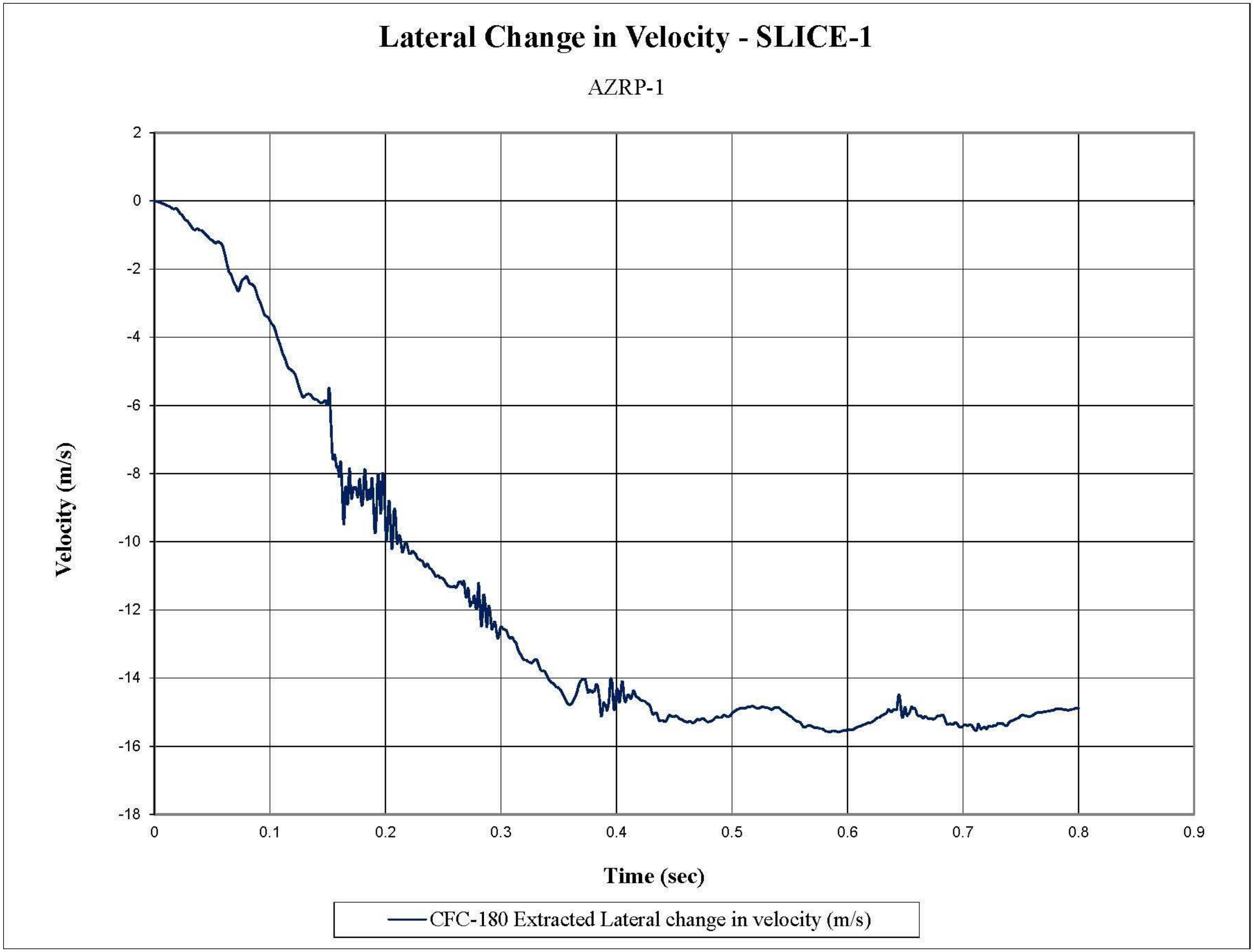


Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. AZRP-1

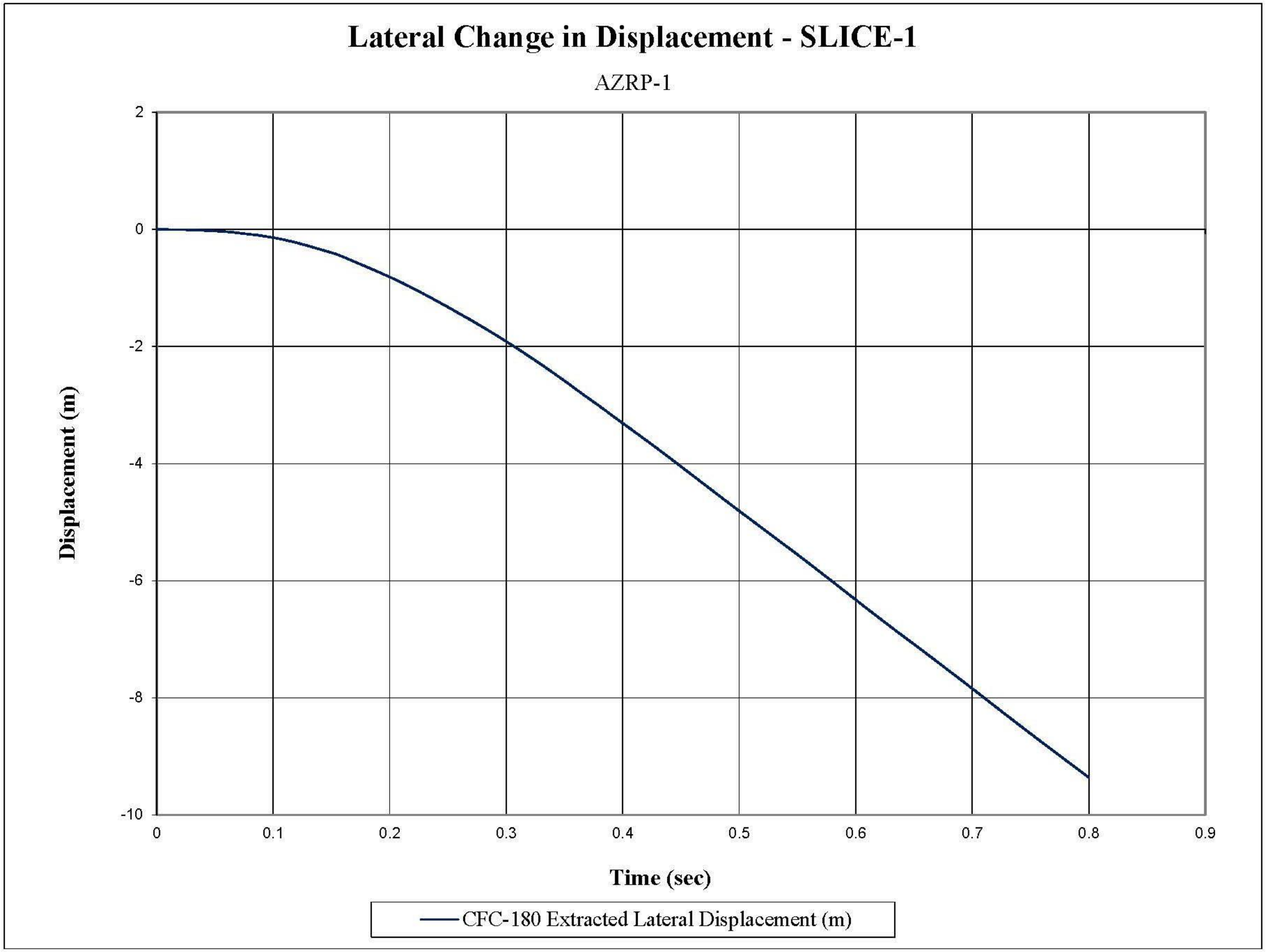


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. AZRP-1

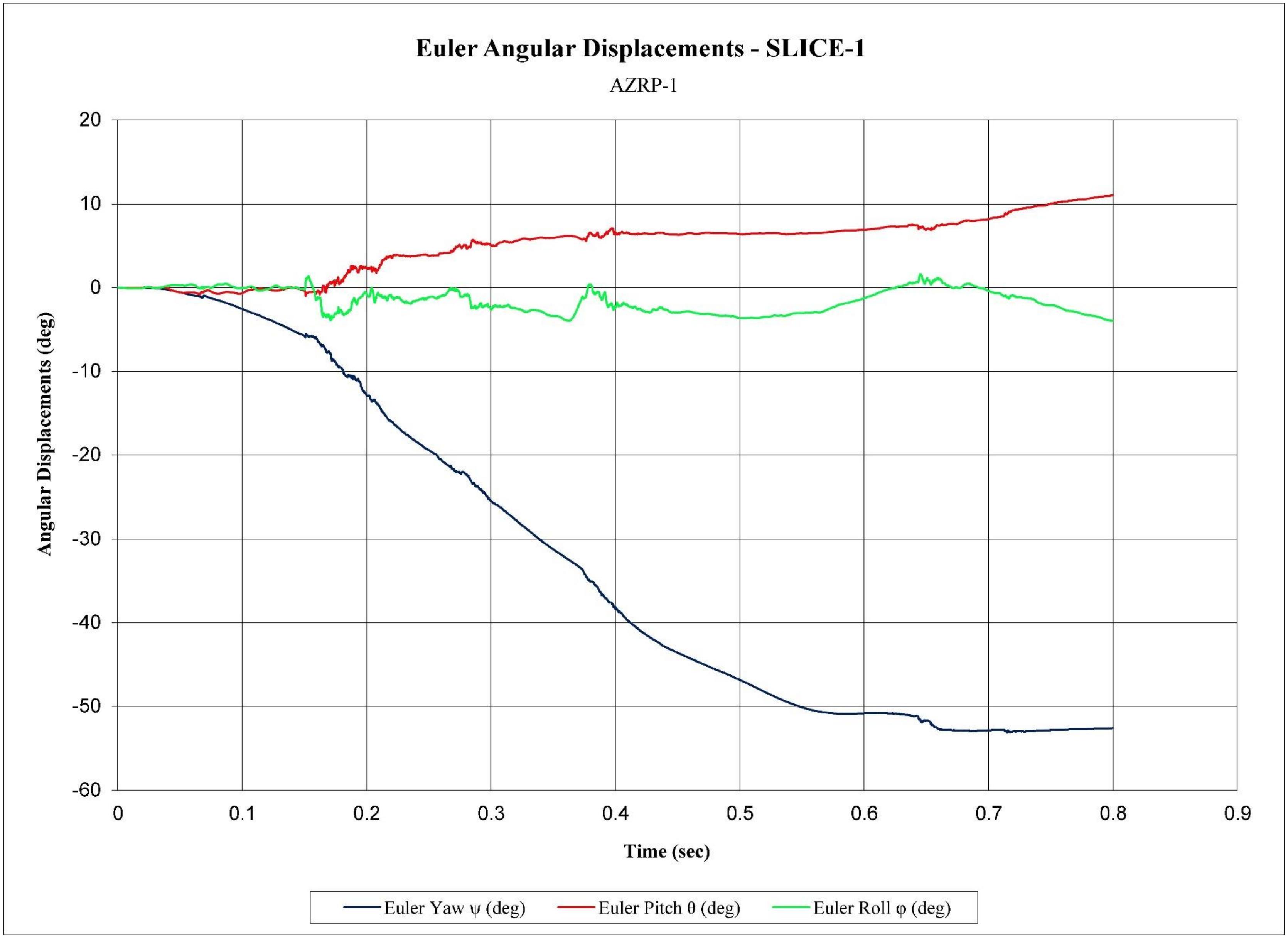


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. AZRP-1

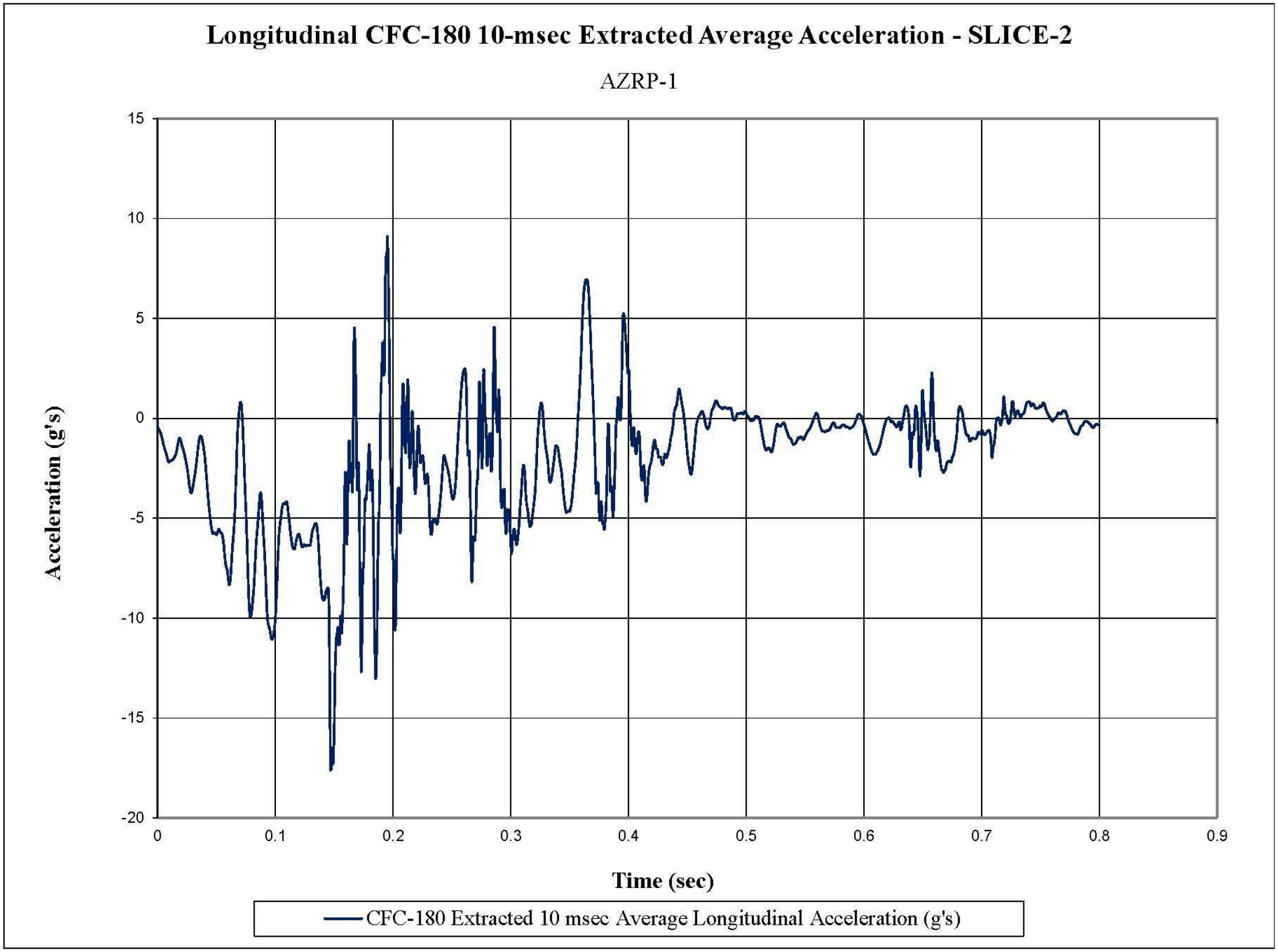


Figure E-8. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. AZRP-1

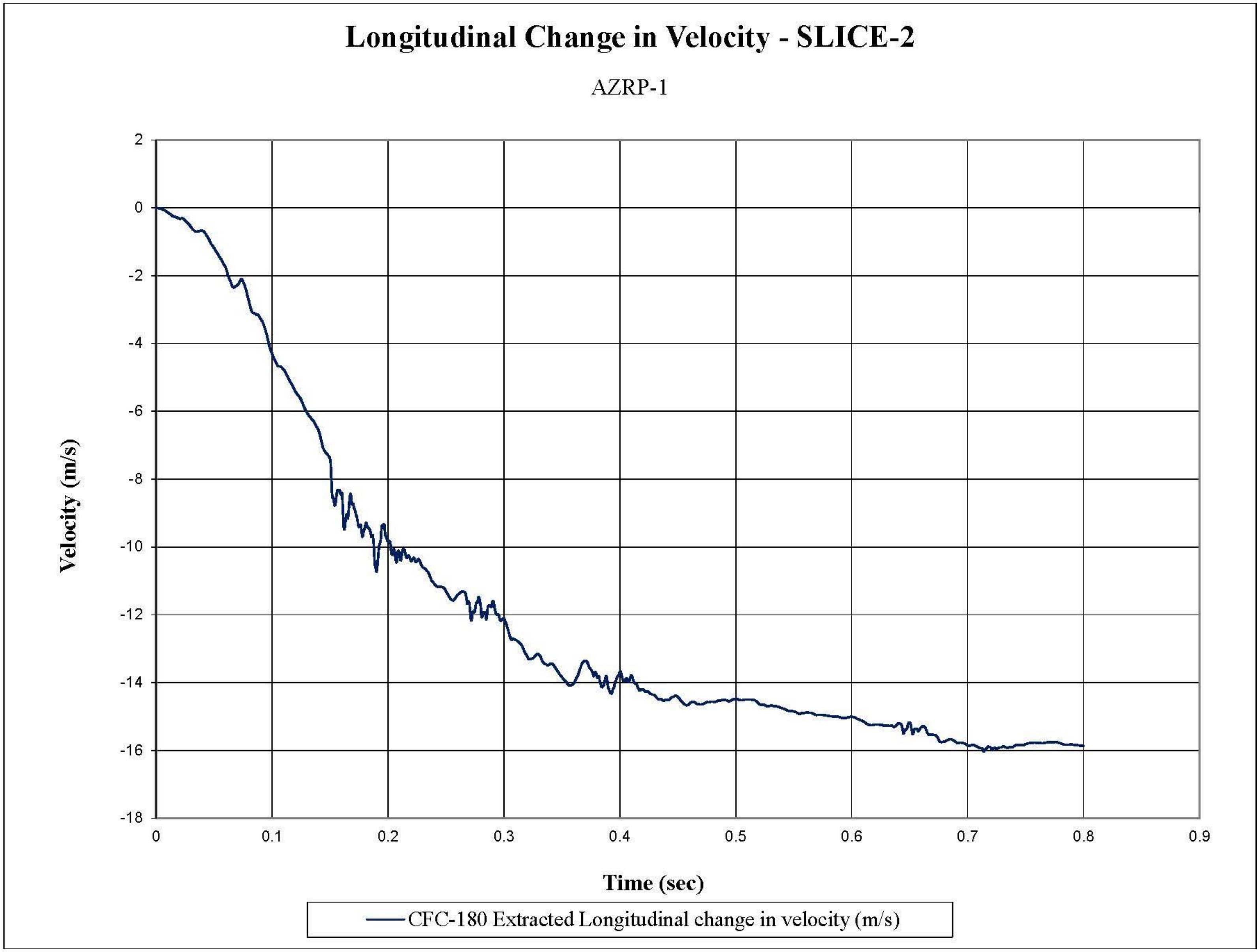


Figure E-9. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. AZRP-1

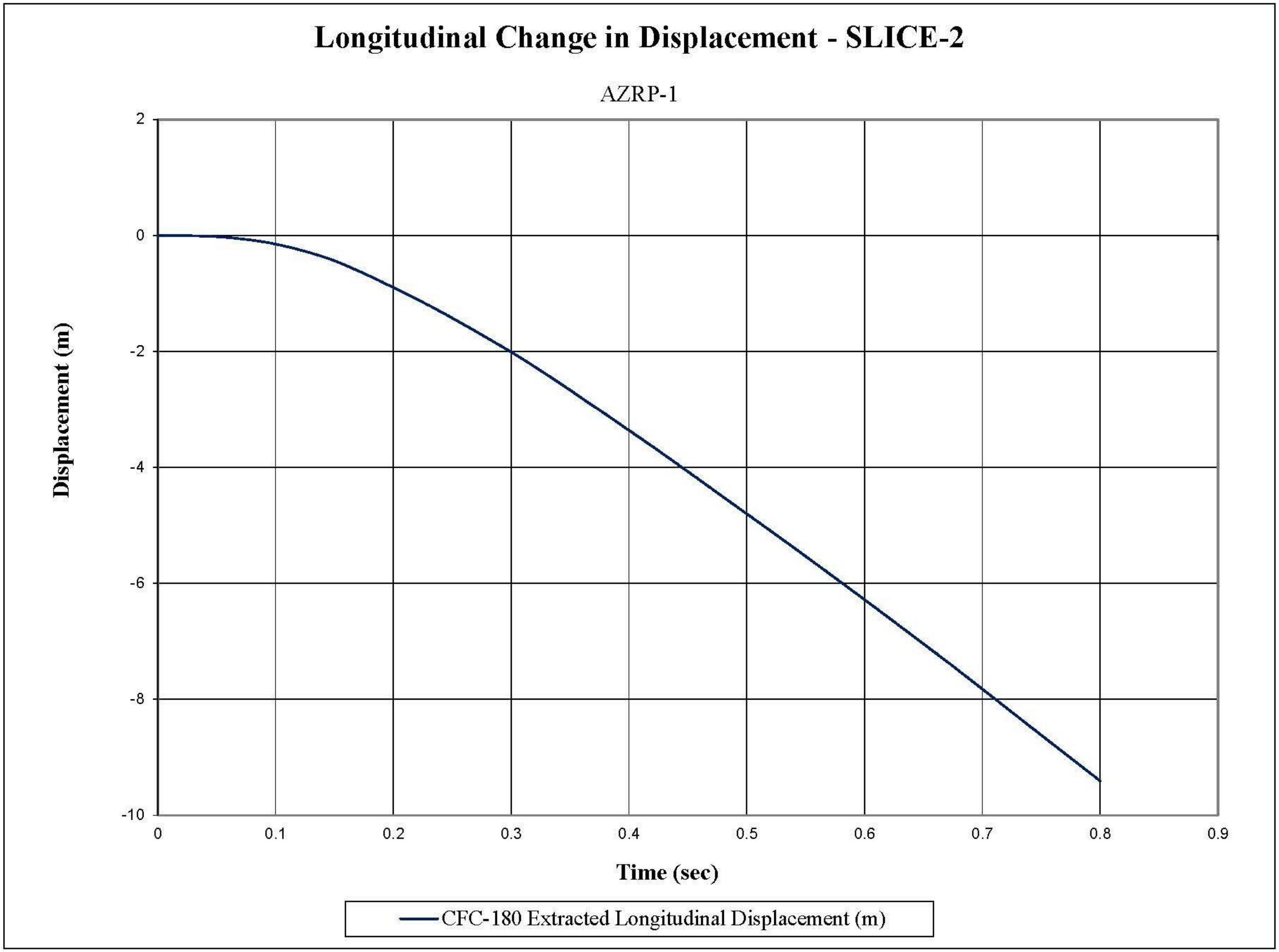


Figure E-10. Longitudinal Occupant Displacement (SLICE-2), Test No. AZRP-1

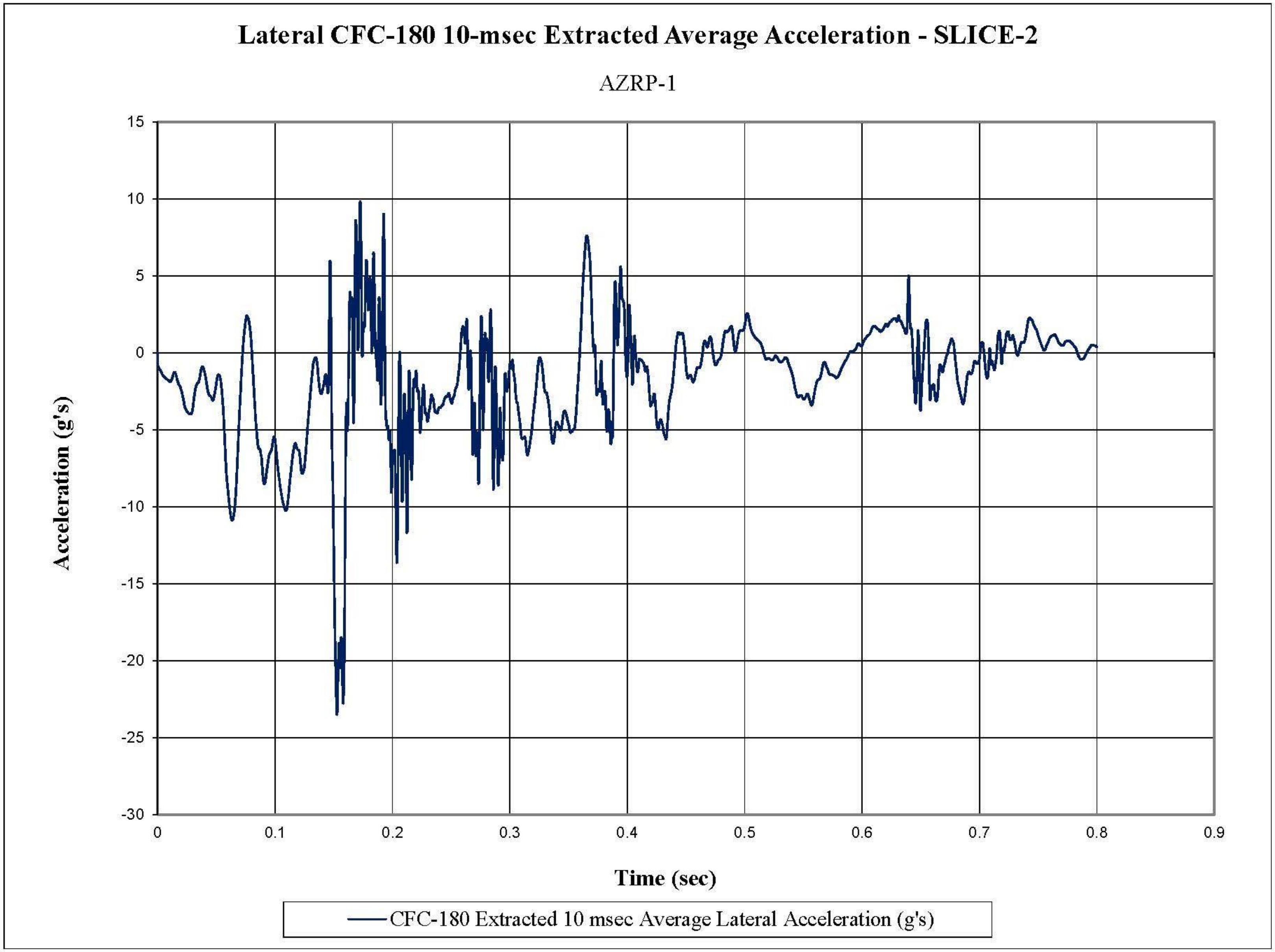


Figure E-11. 10-ms Average Lateral Deceleration (SLICE-2), Test No. AZRP-1

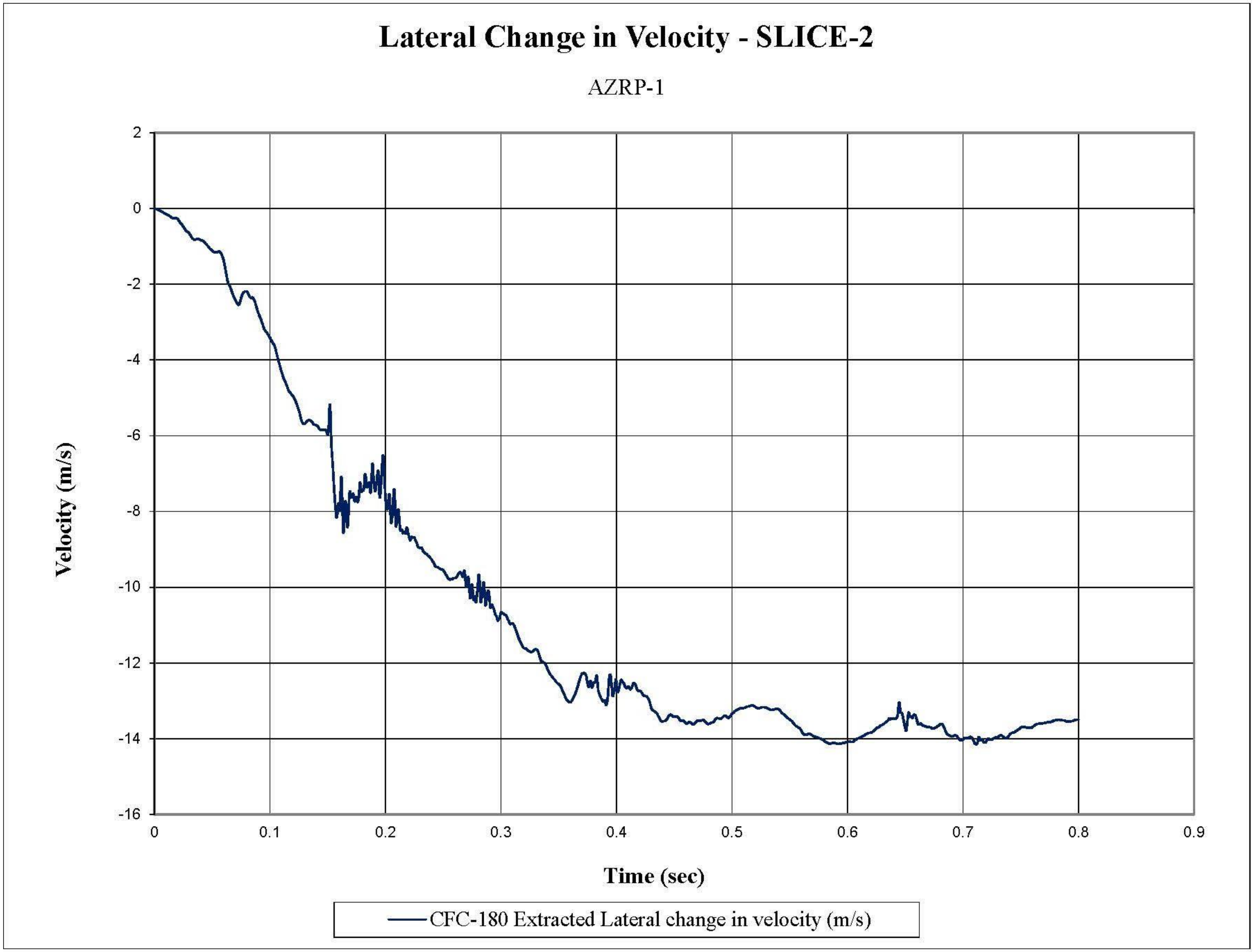


Figure E-12. Lateral Occupant Impact Velocity (SLICE-2), Test No. AZRP-1

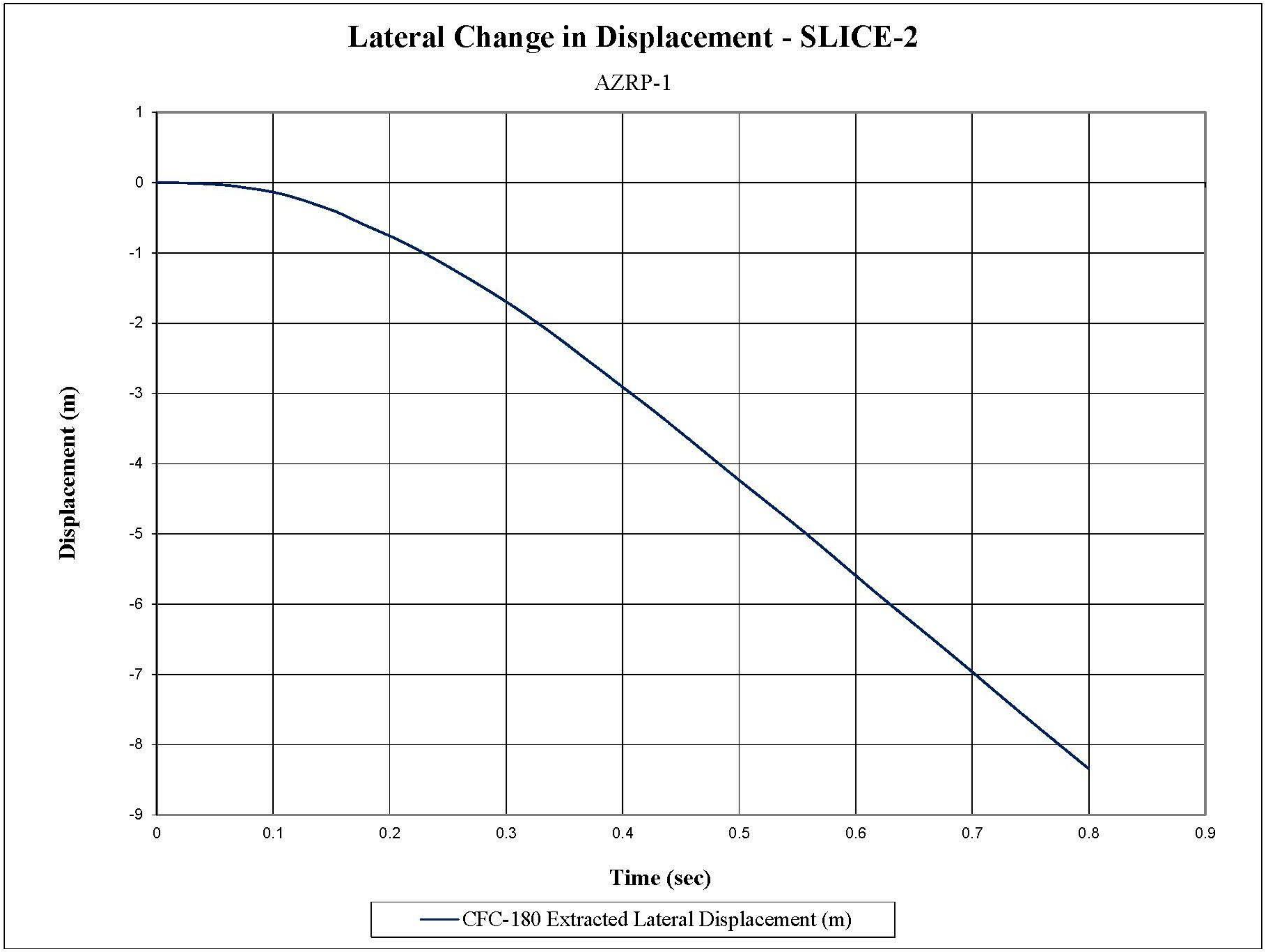


Figure E-13. Lateral Occupant Displacement (SLICE-2), Test No. AZRP-1

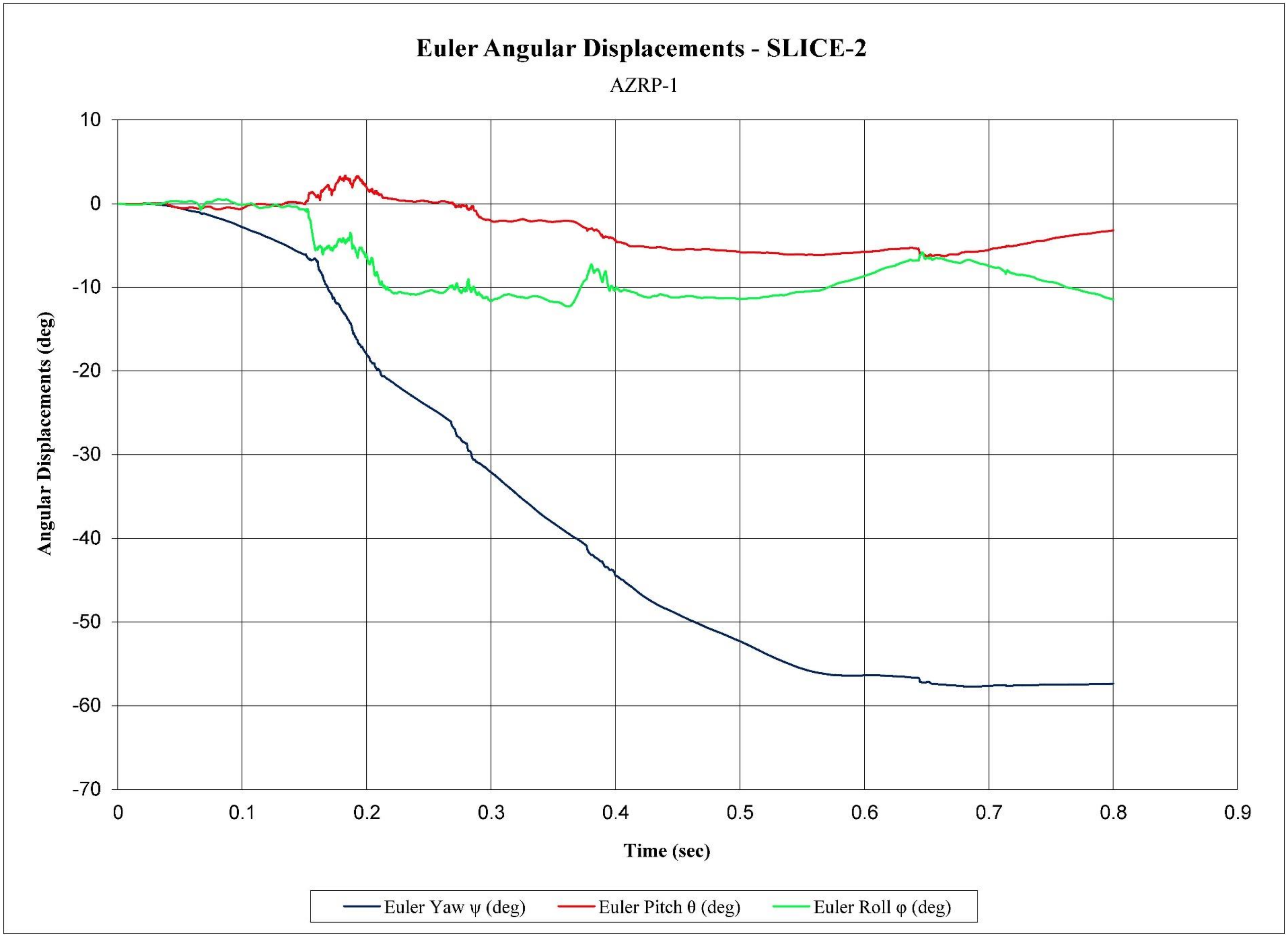


Figure E-14. Vehicle Angular Displacements (SLICE-2), Test No. AZRP-1

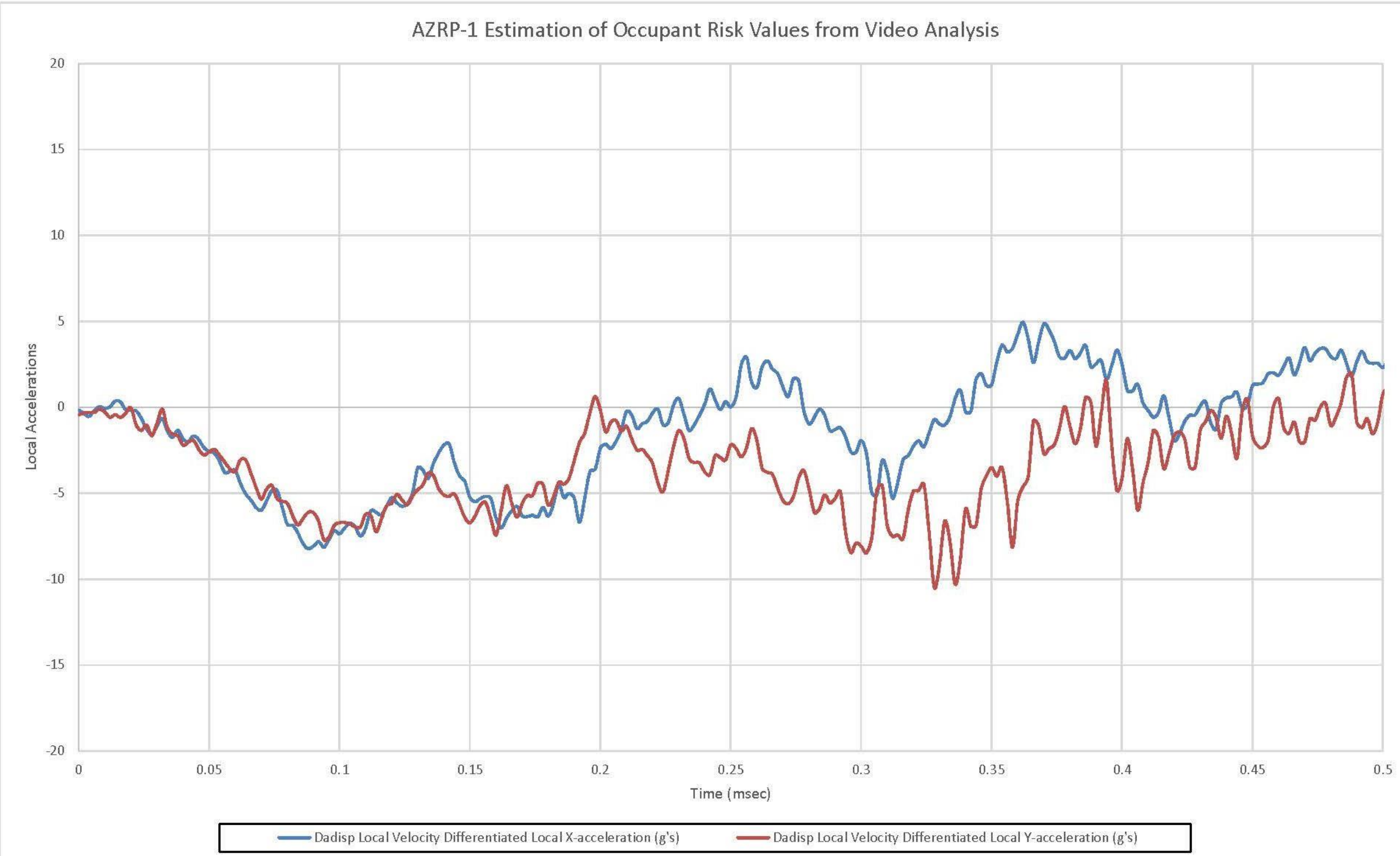


Figure E-15. Longitudinal and Lateral Deceleration (Video Analysis), Test No. AZRP-1

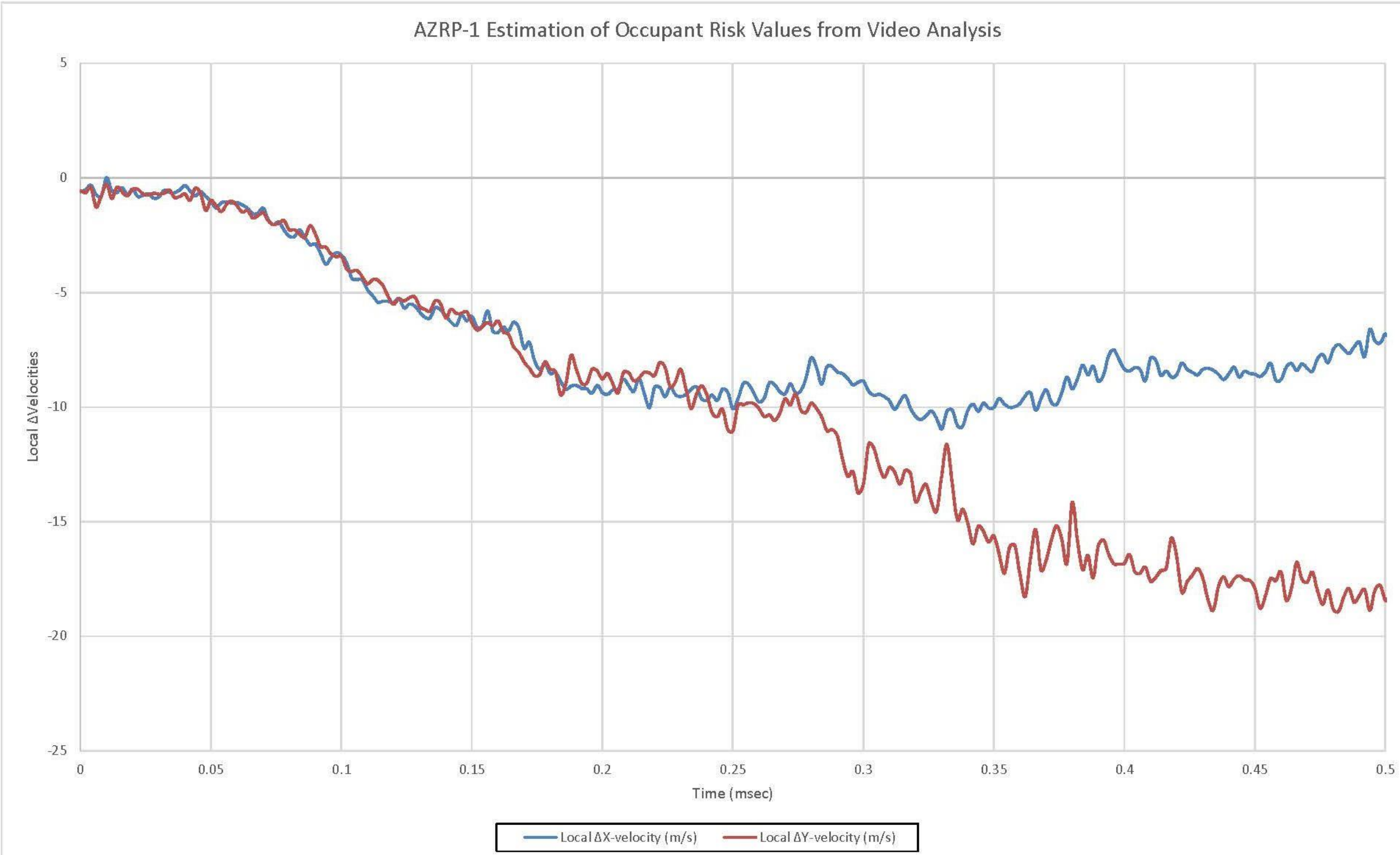


Figure E-16. Longitudinal and Lateral Occupant Impact Velocity (Video Analysis), Test No. AZRP-1

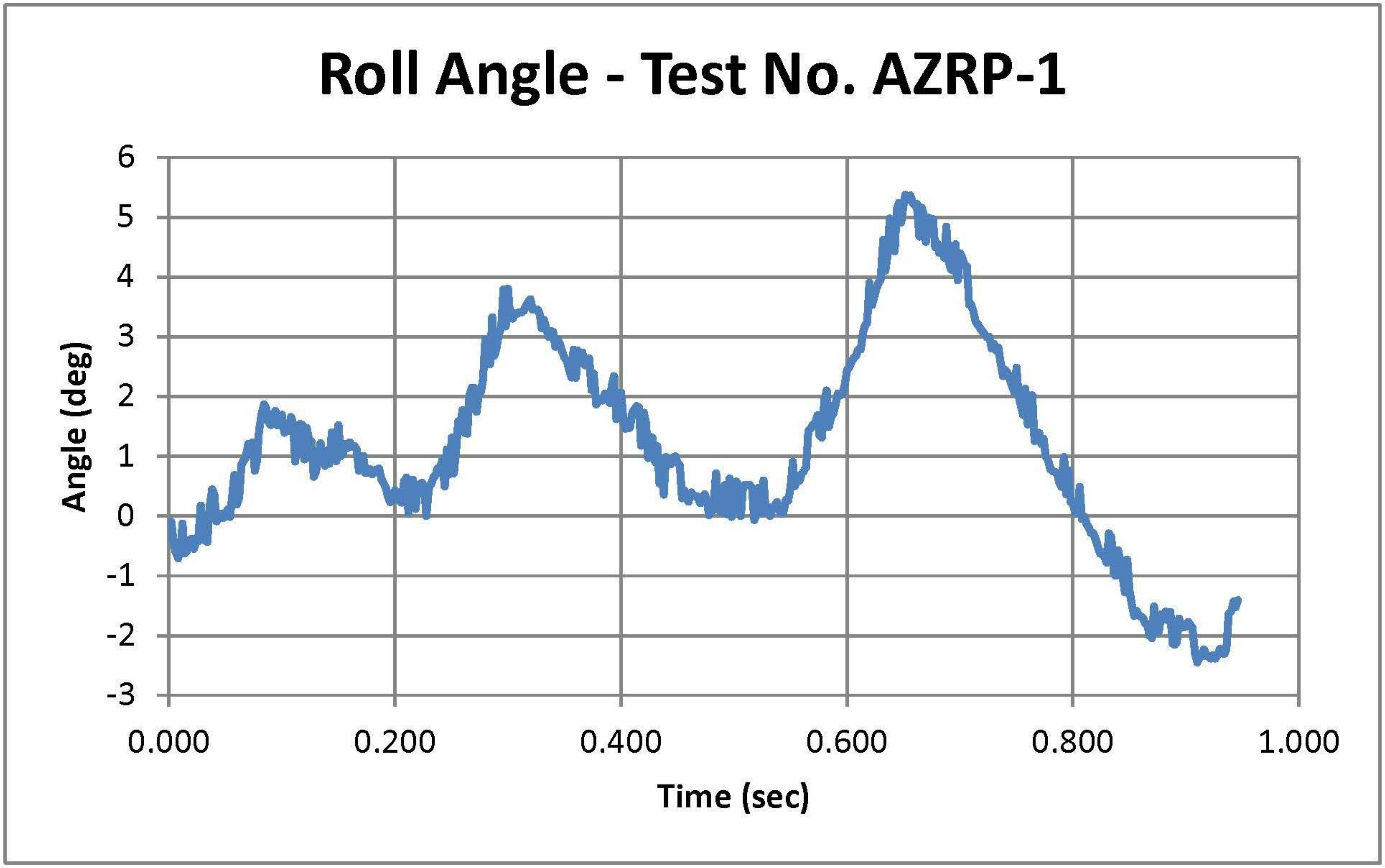


Figure E-17. Vehicle Roll Angular Displacements (Video Analysis), Test No. AZRP-1

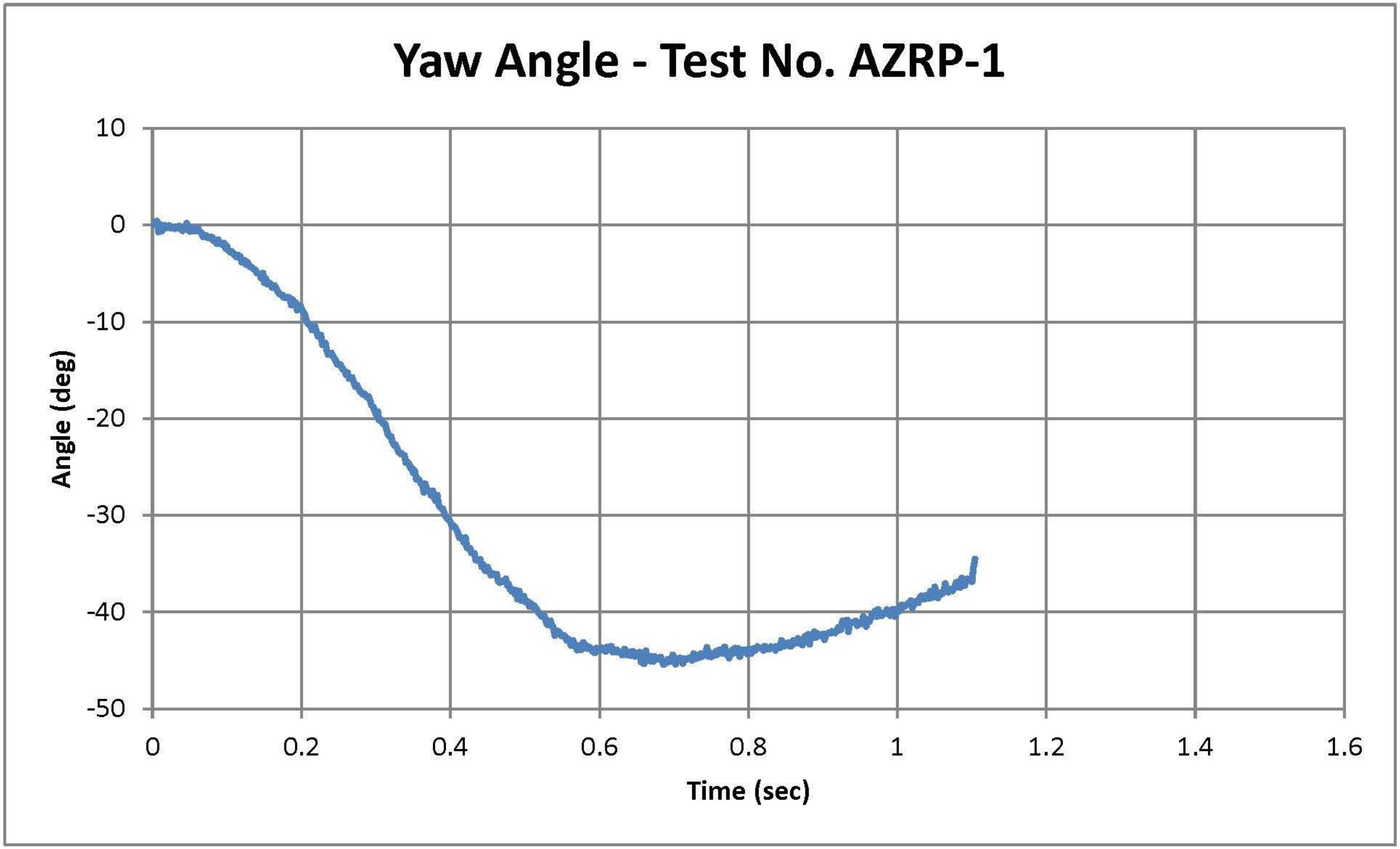


Figure E-18. Vehicle Yaw Angular Displacements (Video Analysis), Test No. AZRP-1

Appendix F. Video Analysis Occupant Risk Procedure, Test No. AZRP-1

Bielenberg 12-19-15

In test no. AZRP-1, MwRSF recorded Occupant Ridedown Acceleration (ORA) values in the lateral direction that exceeded the 20 g limit imposed in NCHRP Report No. 350. Review of the test vehicle found two critical issues.

1. During vehicle preparation for the test, the seat frame for the 2000P vehicle was removed. Previous testing of 2000P vehicles early in the implementation of NCHRP Report No. 350 found that the seat frame was critical to developing the proper rigidity of the truck floorpan. Subsequently, all of the test laboratories agreed to leave the seat frame in place for all 2000P tests. The omission of the seat frame in this test by MwRSF was in error.
2. Lateral and vertical displacement of the floorpan and specifically the transmission tunnel underneath the vehicle transducers was observed in test no. AZRP-1 that adversely affected the acceleration and rate transducer readings. These floorpan motions were did not exceed the limits for occupant compartment deformation, but they did alter the transducer results. At approximately 150 msec after impact, the shift of the floorpan caused localized loading of the acceleration transducer in the longitudinal, lateral, and vertical directions as well as shifting of the rate transducer angular rate data. The data from the transducers recorded after the floorboard shift is not valid and cannot be used to determine occupant risk. This means that the Occupant Impact Velocity (OIV) values from the test, which occurred prior to 150 msec after impact were valid, but the ORA values were not.

In order to address the invalid ORA data, MwRSF has prepared an analysis that uses the data taken from the high-speed film to evaluate the potential for excessive ORA values. Similar procedures have been used in the past to evaluate full-scale crash tests [1-3]. MwRSF based the analysis shown herein on these previously accepted procedures, and did additional analysis and comparison to build confidence in the occupant risk estimates.

In the analysis of test no. AZRP-1, MwRSF analyzed the motion of the 2000P vehicle in a series of steps.

1. Video analysis of the overhead film was used to track the global displacements of 2000P vehicle during the impact. This displacement data was differentiated by the film analysis software to determine global velocities and accelerations of the 2000P vehicle.
2. The global velocity was converted to a global change in velocity using the initial velocity and impact angle of the 2000P vehicle during the test.
3. The angle of the pickup truck with respect to the rail was used to transform the change in velocity data taken from video analysis from global coordinates to the local coordinate system of the transducers in the test vehicle for comparison prior to the floorpan shift. Comparison of the velocity data from the video analysis and the vehicle transducers correlated very well. Additionally, the local change in velocity derived from the video analysis yielded nearly identical time of occupant impact (t*) and OIV values as the vehicle acceleration transducer unit. This indicated that the film analysis was providing reasonable values for the vehicle motions.
4. In order to approximate the ORA values, the researchers derived local acceleration values based on the local change in velocity values determined from the video analysis. In order to do this, the local velocity data was first smoothed to allow it to be numerically differentiated. Numerical differentiation produces mathematical noise that would result unrealistic, non-physical acceleration values if the local change in velocity curve determined from the video analysis was used directly. The local change in velocity curves determined from the video analysis were already

noisy because they were differentiated from the vehicle displacements. Smoothing of the local change in velocity curves determined from the video analysis was done using a 25 msec average. Application of the moving average smoothed to data sufficiently but did not alter the velocity curves significantly from the original data curves when cross-plotted.

5. Once the local velocity data from the video analysis was smoothed, it was numerically differentiated to determine an estimate of the vehicle accelerations during the test and to estimate occupant risk values. Cross-plotting of the video analysis acceleration data with the acceleration transducer from the test showed good correlation prior to the shifting of the floorpan at 150 msec. Additionally, the video analysis acceleration data did not indicate any rapid deceleration of the vehicle near 150 msec indicated by the acceleration transducers in the vehicle due to the floorpan movement.

The analysis of the high speed video from the overhead cameras found good correlation with the velocity, acceleration, and yaw data from the onboard transducers prior to the floorboard movement. As such, it was believed to provide a reasonable estimate of the occupant risk values from test no. AZRP-1. The occupant risk values from test no. AZRP-1 are shown below. Additional documentation of the analysis and comparison of the transducer and video analysis data is shown on the accompanying pages.

Test No. AZRP-1 Occupant Risk Determination					
Calculation Method	Time of Occupant Impact (t*) (sec)	Lateral OIV (m/s)	Longitudinal OIV (m/s)	Lateral ORA (g's)	Longitudinal ORA (g's)
SLICE 2 Transducer	0.1333	-5.59	-6.25	-23.50	-17.62
Video Analysis Estimate	0.134	-5.80	-6.10	-10.47	-7.01

(highlighted) = After Floorpan Displacement I Invalid

References

1. Post, E.R., Full-Scale Vehicle Crash Tests on Guardrail-Bridgerail Transition Designs with Special Post Spacing, Final Report to the Nebraska Department of Roads, NE-DOR-R87-2, Transportation Research Report No. TRP-03-08-87, Civil Engineering Department, University of Nebraska-Lincoln, May 1987.
2. Faller, R.K., Magdaleno, J.A., and Post, E.R., Full-Scale Vehicle Crash Tests on the Iowa Box-Aluminum Bridge Rail, Final Report to Iowa Department of Transportation, Transportation Research Report No. TRP-03-13-88, Civil Engineering Department, University of Nebraska-Lincoln, November 1988.
3. Pfeifer, B.G., Holloway, J.C., Faller, R.K., and Post, E.R., Full-Scale 18,000 lb. Vehicle Crash Test on the Iowa Retrofit Concrete Barrier Rail, Final Report to the Iowa Department of Transportation, Report No. TRP-03-19-90, Civil Engineering Department, University of Nebraska-Lincoln, January 1990.

Table 1. Occupant Risk Data From Primary Accelerometer, Test No. AZRP-1

a) English Units

DTS SLICE 2 - PRIMARY												
Longitudinal		230						MASH				
	ORD	-13.0295753	g's	@	0.1852	sec	ORD	-17.616104	g's	@	0.147	sec
	OIV	-28.616873	ft/s				OIV	-20.510097	ft/s			
	Time	0.1689	sec				Time	0.1347	sec			
Lateral		230						MASH				
	ORD	-23.4988429	g's	@	0.1527	sec	ORD	-23.498843	g's	@	0.1527	sec
	OIV	-18.3466831	ft/s				OIV	-18.346683	ft/s			
	Time	0.1347	sec				Time	0.1347	sec			

b) Metric Units

DTS SLICE 2 - PRIMARY												
Longitudinal		230						MASH				
	ORD	-13.0295753	g's	@	0.1852	sec	ORD	-17.616104	g's	@	0.147	sec
	OIV	-8.72242288	m/s				OIV	-6.2514775	m/s			
	Time	0.1689	sec				Time	0.1347	sec			
Lateral		230						MASH				
	ORD	-23.4988429	g's	@	0.1527	sec	ORD	-23.498843	g's	@	0.1527	sec
	OIV	-5.592069	m/s				OIV	-5.592069	m/s			
	Time	0.1347	sec				Time	0.1347	sec			

*Note that the ORA data is invalid due to shifting of the vehicle floorpan

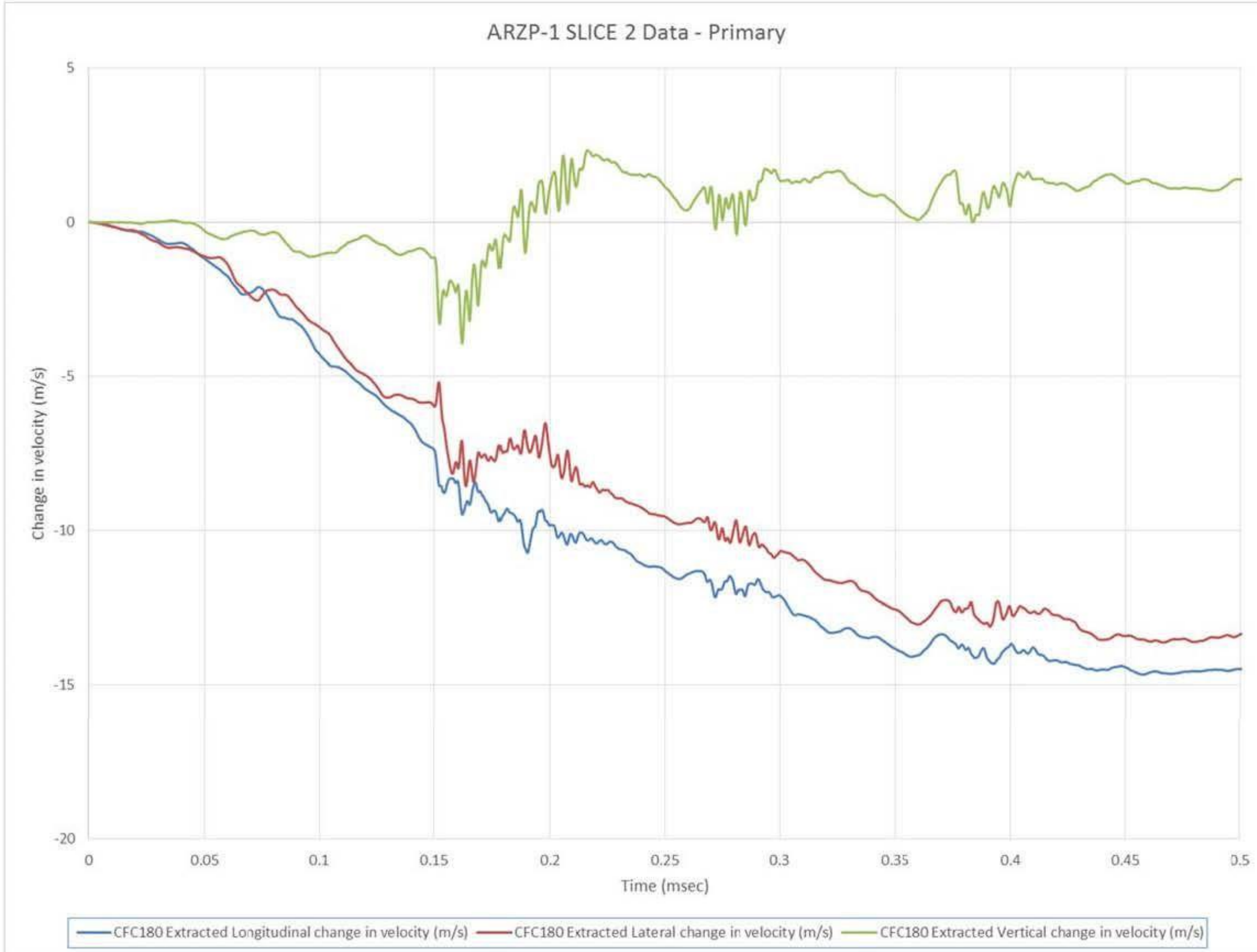
Figure 1. Floorboard Deformation Due to Omission of Seat Frame, Test No. AZRP-1

Figure 2. Standard 2000P Accelerometer Mounting with Seat Frame in Place versus Setup for Test No. AZRP-1

a) Test No. AZRP-1

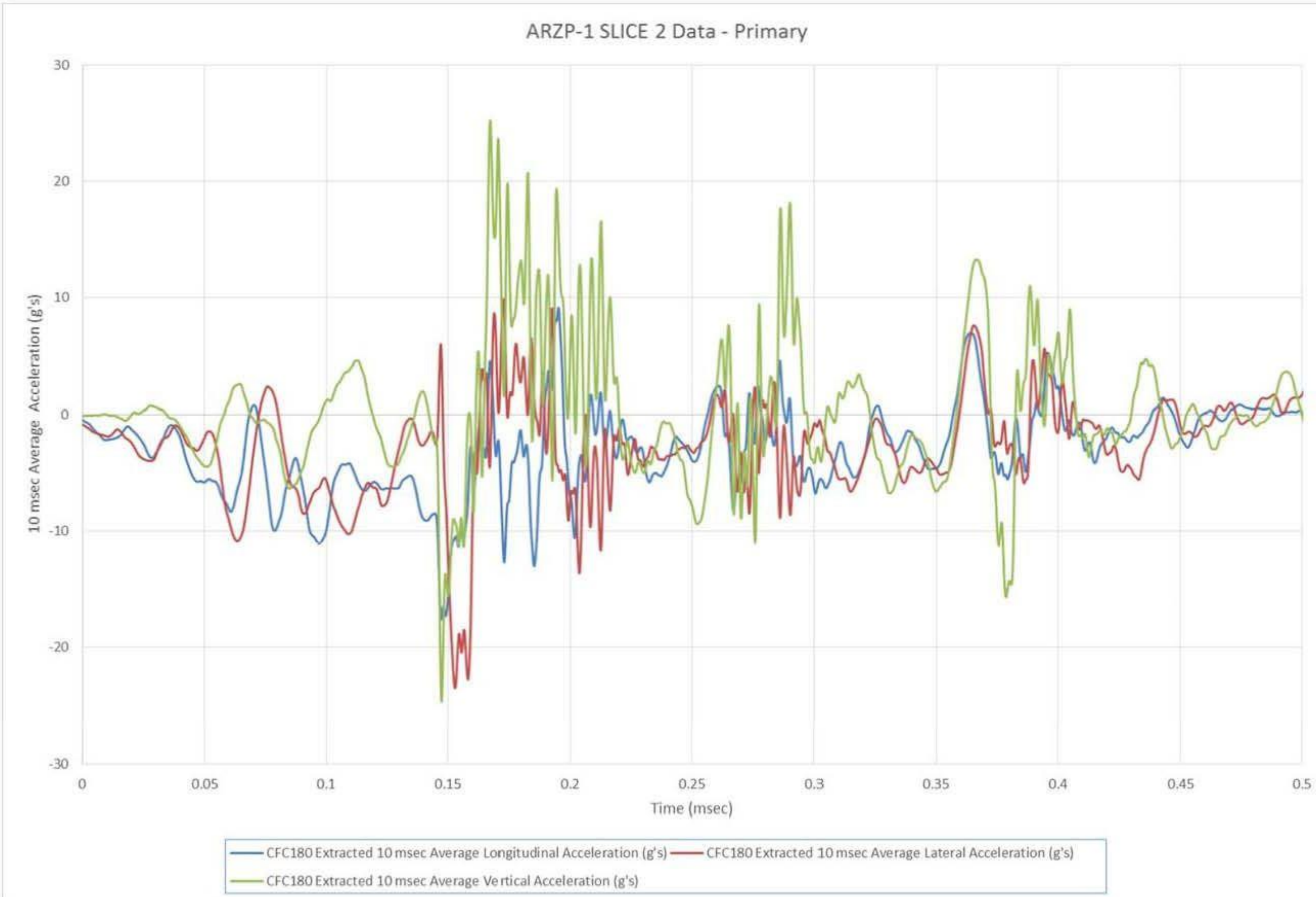
b) Typical NCHRP Report No. 350 Transducer Installation for 2000P Vehicle

Figure 3.SLICE 2 Occupant Impact Velocity (OIV) Plot, Test No. AZRP-1 Acceleration Transducer



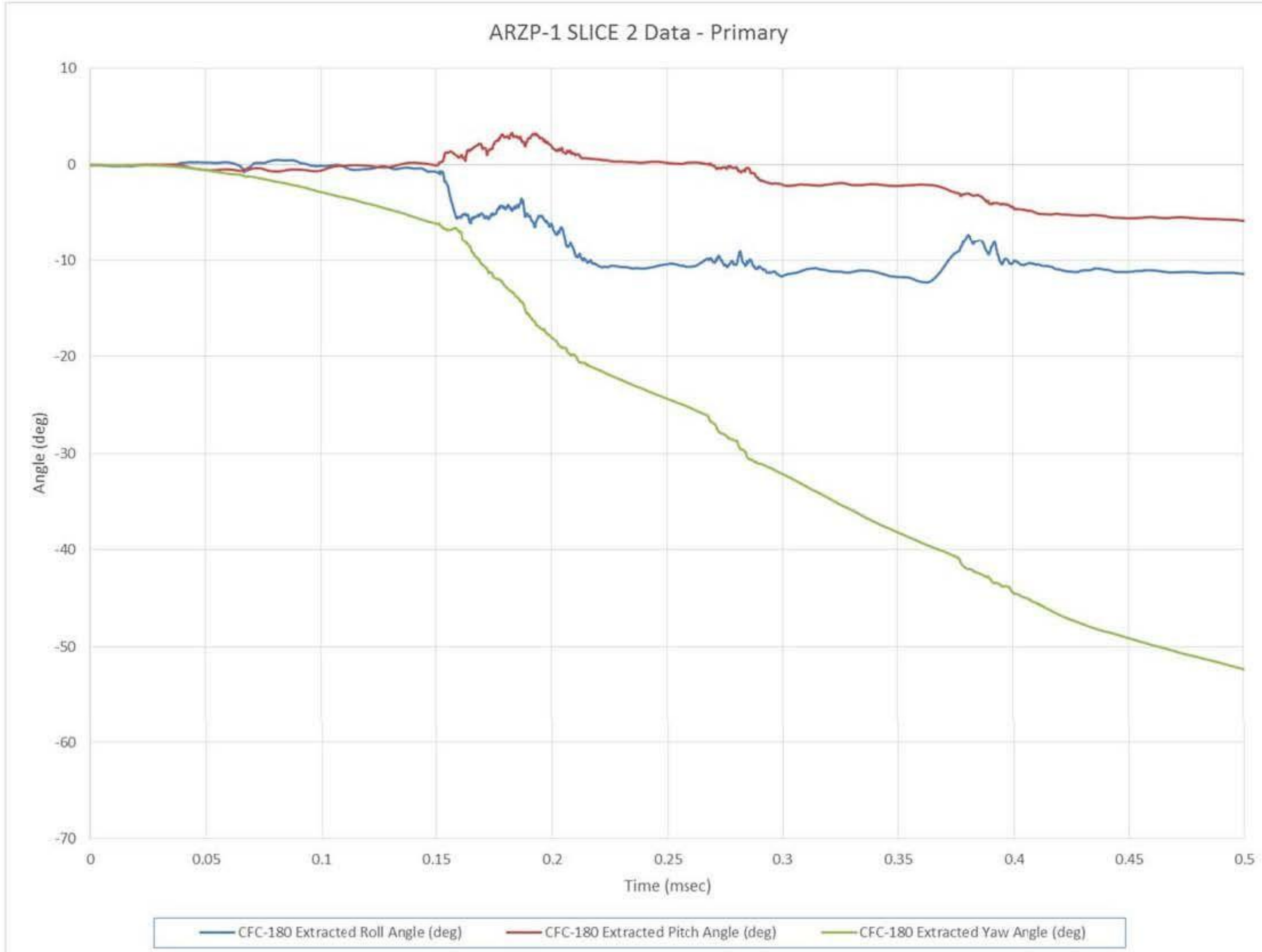
Note abrupt velocity change in all three axes near 0.150 sec

Figure 4. SLICE 2 10 msec Average Occupant Ridedown Acceleration (ORA) Plot, Test No. AZRP-1



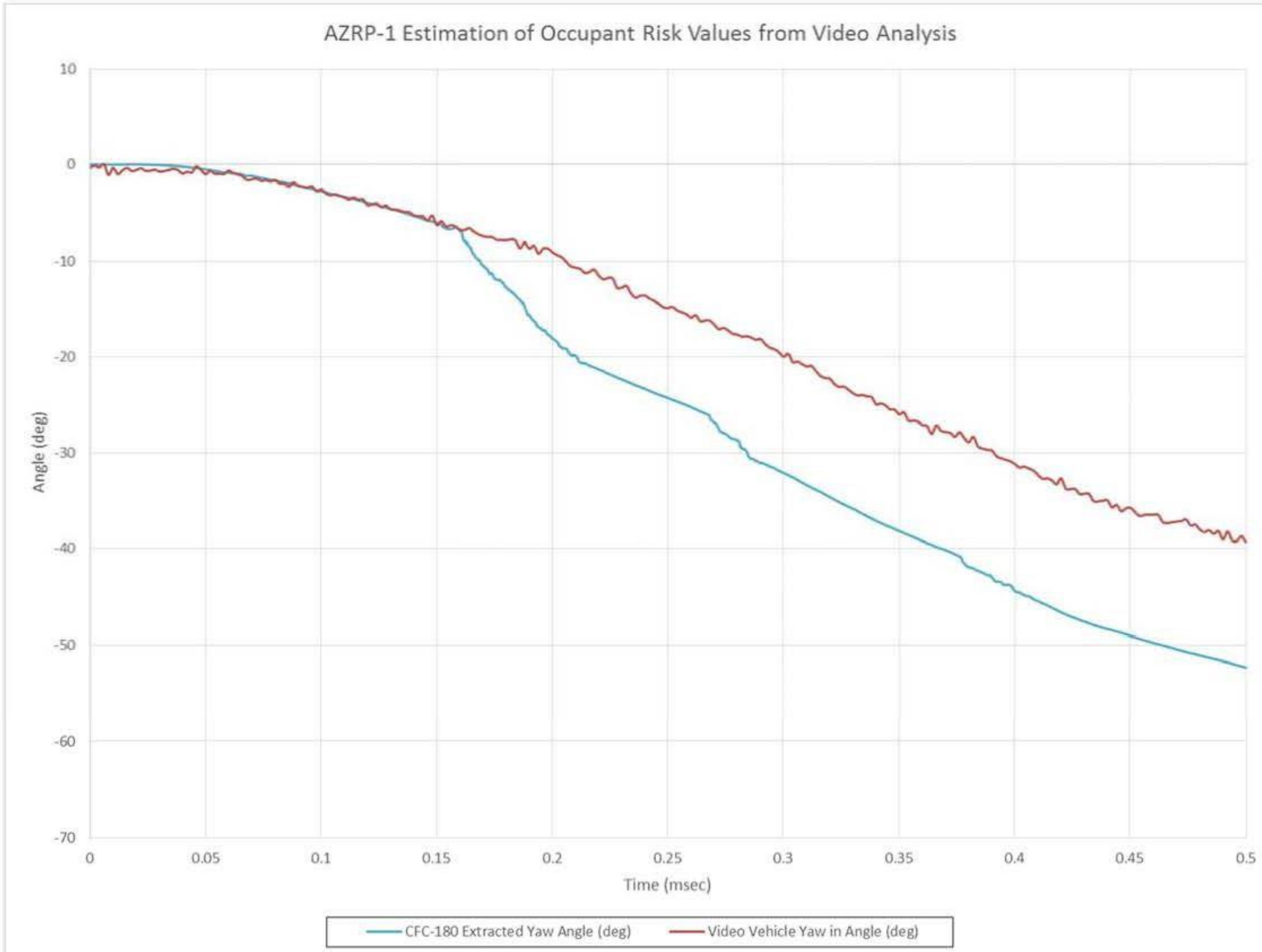
Note that large, non-physical accelerations occur after floorpan movement at 0.150 sec

Figure 5. SLICE 2Angular Displacement Plot, Test No. AZRP-1



Note the five Degrees of roll in 5 msec after 0.150 sec. This is an extremely high roll in a short time period that was not physically seen by the truck, but rather was due to the floor pan shift.

Figure 6. Comparison of SLICE and Overhead Video Analysis Yaw Displacement, Test No. AZRP-1



Note the good correlation of the video analysis and SLICE 2 yaw data prior to floorpan movement. Indicates that floorpan shift affected the transducer data and that the video analysis data was consistent with transducer data prior to floorpan movement.

Figure 7. Overhead Video Analysis Local Velocities, Test No. AZRP-1

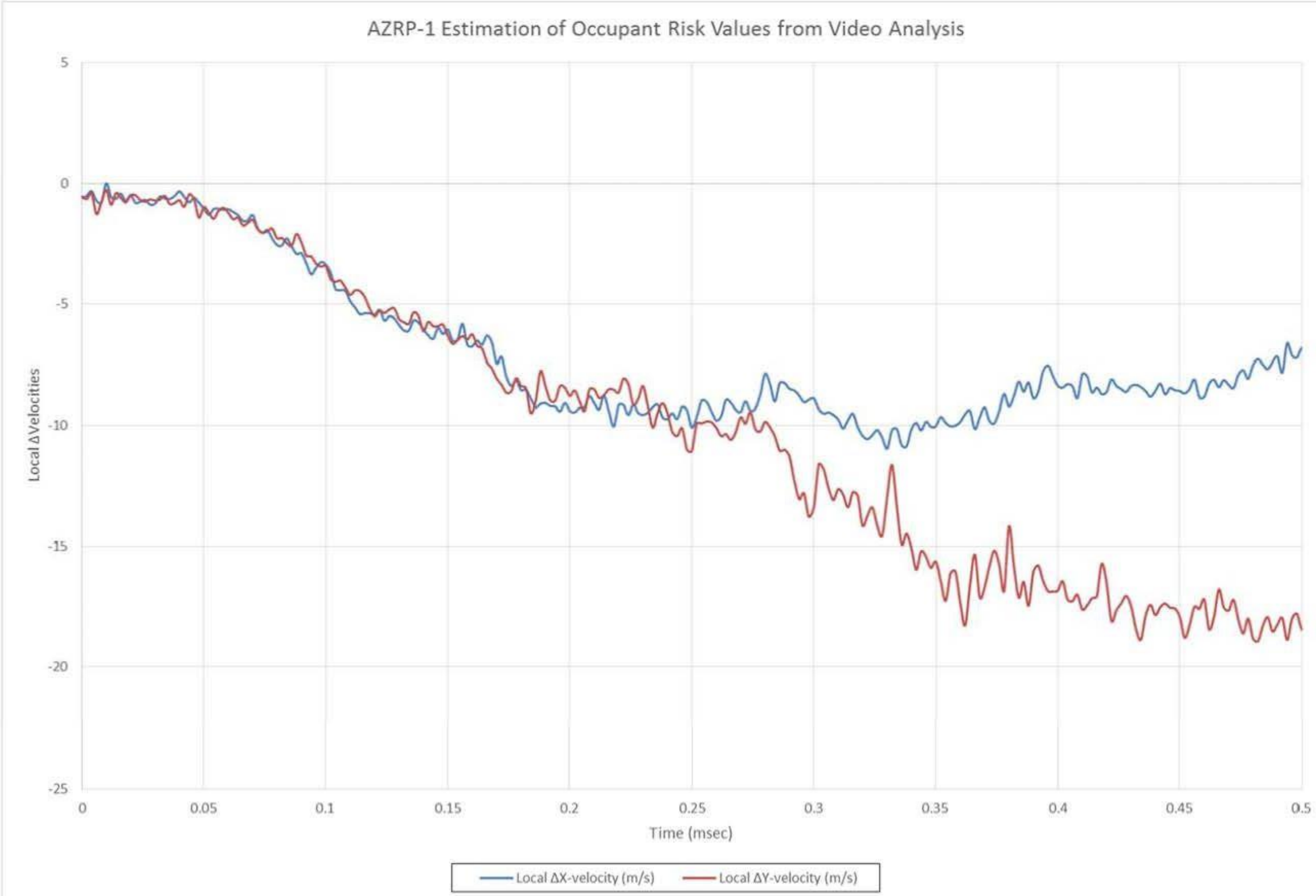


Figure 8. Comparison of Overhead Video Analysis Local Velocities with SLICE 2 Data , Test No. AZRP-1

Note good correlation of velocity data prior to floorpan movement, and less severe velocity change after 0.150 sec for video analysis data.

Figure 9. Overhead Video Analysis Local Velocities, Original and Smoothed Curves for Differentiation, Test No. AZRP-1

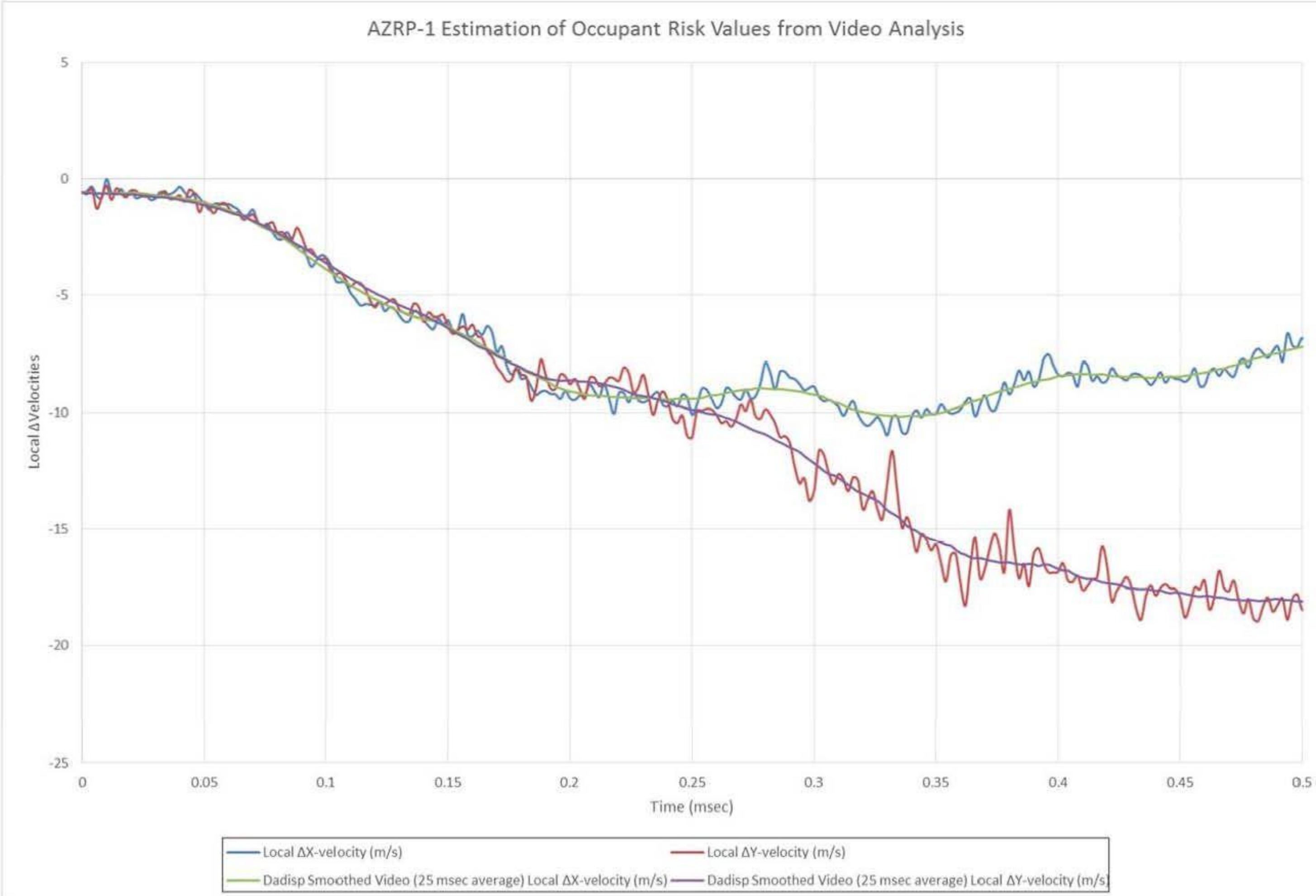


Figure 10. Overhead Video Analysis Local Accelerations, Test No. AZRP-1

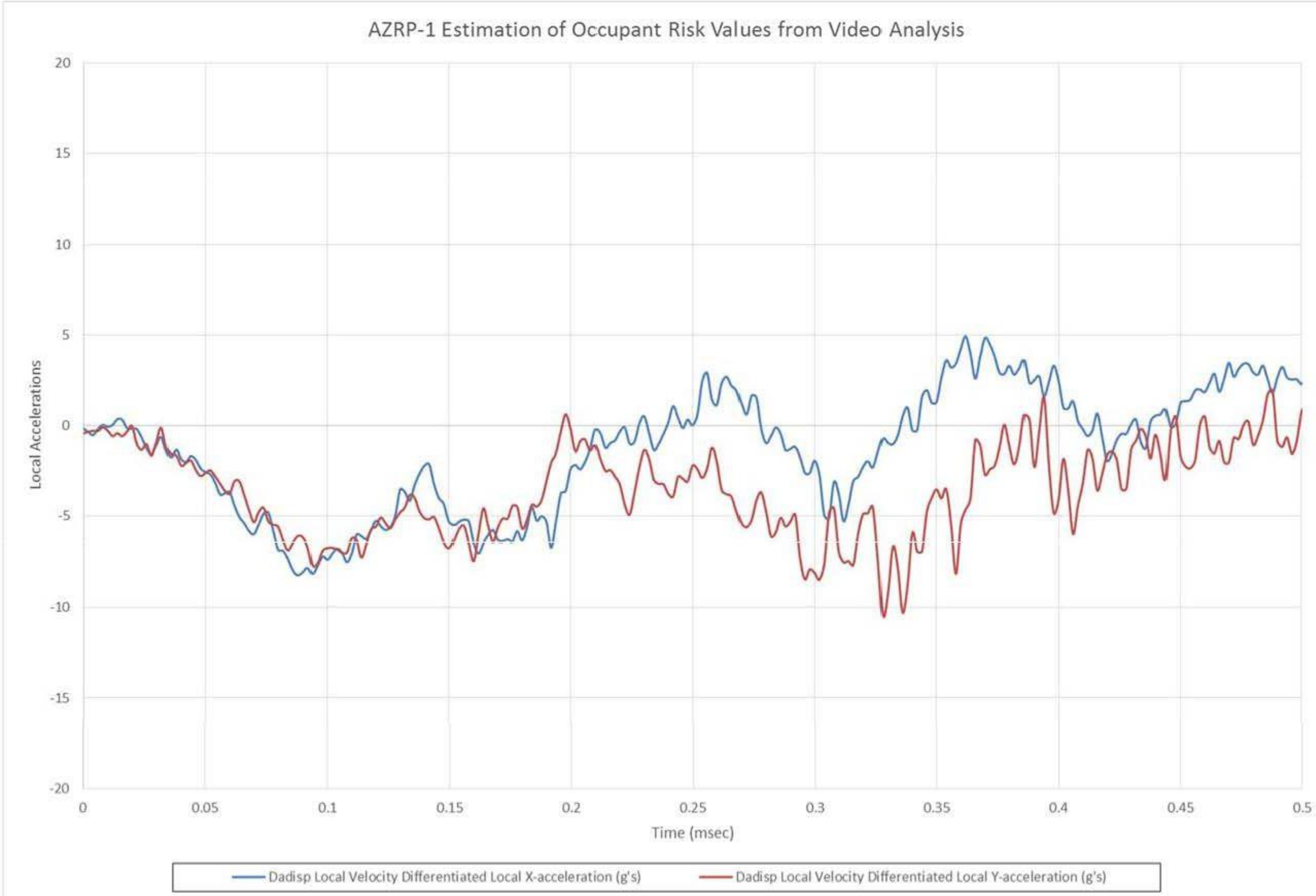
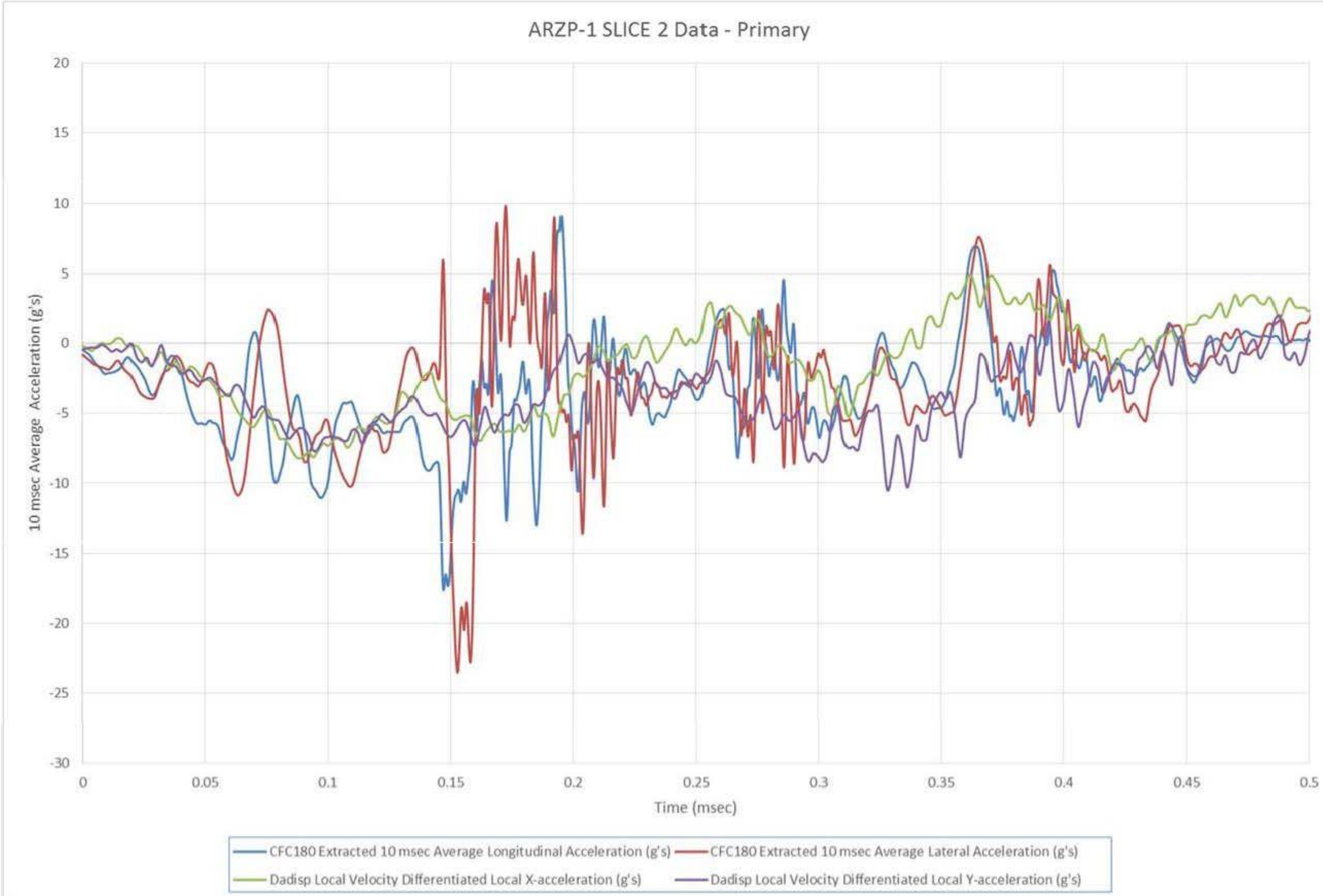


Figure 11. Comparison of Overhead Video Analysis Local Accelerations with SLICE 2 Data, Test No. AZRP-1



Note good correlation of acceleration data prior to floorpan movement, and less severe accelerations after 0.150 sec for video analysis data.

Email Correspondence with FHWA

From: will.longstreet@dot.gov [mailto:will.longstreet@dot.gov]
Sent: Monday, December 21, 2015 10:47 AM
To: Robert Bielenberg <rbielenberg2@unl.edu>
Cc: Karla Lechtenberg <kpolivka@unl.edu>; Ronald Faller <rfaller1@unl.edu>; Nick.Artimovich@dot.gov
Subject: RE: NCHRP 350 Ponderosa Pine W-Beam Guardrail Test!

Hi Bob:

Thanks for your email in reply to subject test. I offer the following in response.

The submitted film analysis can be used for the ORA. However if Safety Admin would happen to decide otherwise, then the fact that your initial submission was made prior to 12-31-15 is considered timely and any additional information (including physical testing) we might request to support subject submission for 350 eligibility may still be submitted in 2016 for eligibility. Please proceed accordingly & thanks.

I'm available via cell phone today if you want to talk, I have it with me in garage. I'm working on my daughters car today. It needs an inspection sticker by end of month & before she returns back to school in Blacksburg, VA. in January…. This is also my Christmas present to her…☺!

Best,

Will

From: Nick.Artimovich@dot.gov [mailto:Nick.Artimovich@dot.gov]
Sent: Monday, December 21, 2015 10:17 AM
To: Robert Bielenberg <rbielenberg2@unl.edu>
Subject: RE: NCHRP 350 Ponderosa Pine W-Beam Guardrail Test!

Bob,

Will is officially handling this one, and he is out today. However, the film analysis showed pretty much what I expected. I recommend you prepare our FORM using the accelerometer data for the OIV and the film analysis for the ORA. Include your film analysis as another attachment to the package. Longstreet will give you the final directions.

I expect that as long as you have your submission into us by 12-31-15 you are good. If we ultimately decide that we want the test re-run, then (as we did when we capped off new testing under NCHRP Report 350 on 1-1-2011) we will accept additional information to support your request that was received prior to our deadline.

Link to
FORM: http://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/acceptprocess/form1R.pdf

Nick

From: Robert Bielenberg [mailto:rbielenberg2@unl.edu]
Sent: Monday, December 21, 2015 9:51 AM
To: Ronald Faller; Artimovich, Nick (FHWA); Longstreet, Will (FHWA)
Cc: Karla Lechtenberg
Subject: RE: NCHRP 350 Ponderosa Pine W-Beam Guardrail Test!
Importance: High

Hello Will and Nick,

Based on the response that Ron received from your office, we have conducted an analysis of the overhead, high-speed video from test no. AZRP-1 in order to estimate the occupant risk values. I have summarized that analysis in the attached document for your review and comment. I have also provided videos at the link below.

https://unl.box.com/s/odqc8ldae66nxz8xpfwlwm9tfm9ay8hb

As Ron noted previously, any quick feedback you can provide regarding this analysis and whether or not it is sufficient for your needs would be very helpful. If the analysis does not meet your needs, we will need to run a crash test in short order with a holiday shutdown looming.

Thanks for looking at this for us on short notice.

Bob Bielenberg, MSME, EIT
Research Associate Engineer
Midwest Roadside Safety Facility
130 Whittier Building
2200 Vine St.
Lincoln NE, 68583-0853
402-472-9064
rbielenberg2@unl.edu

From: Ronald Faller
Sent: Thursday, December 17, 2015 3:44 PM
To: 'Nick Artimovich' <nick.artimovich@dot.gov>; 'Will Longstreet' <will.longstreet@dot.gov>
Cc: Karla Lechtenberg <kpolivka@unl.edu>; Robert Bielenberg <rbielenberg2@unl.edu>; Ronald Faller <rfaller1@unl.edu>
Subject: NCHRP 350 Ponderosa Pine W-Beam Guardrail Test!

Hello Will and Nick!

As you may recall, we planned to run a TL-3 NCHRP Report No. 350 pickup truck (2000P) crash test into a 28-in. high, strong-post, W-beam guardrail system with 8-in. routed blockouts for use on round Ponderosa Pine posts. The barrier system successfully contained and redirected the pickup truck. The right-front wheel contacted one of the posts and pushed on the floorpan but well within even conservative limits.

After the test, we noticed lateral and vertical shifting of center hump where our onboard data recorders were placed. Unfortunately, our 2000P vehicle was prepared with the bench seat (structural element) **removed**, which allowed this shifting of the hump and data recorders. As you can image, there was some concern with data accuracy. Well, the lateral ORA from data analysis was blown out of the water as a result of vertical and lateral hump shift with some rotation too. The accelerometer mounting plate even rolled 6 degrees in 5 ms at the time of the high ORA. We have erroneous results from our data recorders. Note that I will sending to you a link to view videos, selected photos, and electronic data. We do not believe that excessive lateral ORA realistically have been observed in this test based on barrier/post behavior, truck size, vehicle path, observed results, moved mounting plate, etc. However, we understand that the processed data is all that others would see.

Based on this outcome, I have two basic questions. Have you previously observed similar scenarios in submissions where data recorders shifted and provided non-real results for vehicle behavior? Second, how did FHWA/other lab(s) deal with this scenario in the past?

As you recall, we planned to submit this packet before December 31, 2015. If you are unable to evaluate this outcome based on measured lateral ORA, which we believe is erroneous, then we need to move into plan B. Eat the crash test, reconstruct the system, find another old 350 similar 2000P vehicle, and rerun the test over break. Do you have any suggestions for us as this is a rather urgent matter? Thanks!

Ron

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