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MASH TL-3 EVALUATION OF CONCRETE AND ASPHALT TIED-DOWN ANCHORAGE FOR PORTABLE CONCRETE BARRIER

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16. Abstract

The objective of this research was to evaluate Wisconsin DOT's F-shaped portable concrete barriers (PCBs) with a bolt-through, tie-down anchorage system for concrete road surfaces with a reduced embedment epoxy anchorage and a steel pin tie-down anchorage system for asphalt surfaces according to *Manual for Assessing Safety Hardware 2016* (MASH 2016) Test Level 3 (TL-3) test designation no. 3-11 criteria.

Test no. WITD-1 consisted of PCBs with a bolt-through, tie-down configuration on concrete tarmac. The system was installed with the rear toe of the PCBs placed 1 in. (25 mm) away from the edge of the simulated bridge deck. Barrier nos. 5 through 13 were attached on the traffic side with three 1⅛-in. (29-mm) diameter A307 Grade A threaded rods per barrier epoxied into the concrete with an embedment depth of 5¼ in. (133 mm). The test results for test no. WITD-1 showed that the system sufficiently contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier, and the barrier system was deemed acceptable according to MASH 2016 TL-3 criteria. Test no. WITD-2 consisted of PCBs with a pinned, tie-down configuration placed on a 2-in. (51-mm) thick asphalt pad. The rear toe of the PCBs were installed 6 in. (152 mm) from the edge of a 36-in. wide x 36-in. deep (914-mm x 914-mm) trench. Barrier nos. 6 through 14 were anchored on the traffic side of the system with three 1½-in. (38-mm) diameter steel pins driven through the bolt anchor pockets on each barrier. During test no. WITD-2 the wheel well and toe pan were deformed a maximum of 13½ in. (343 mm), which surpassed the MASH 2016 deformation limits. Due to the deformation, test no. WITD-2 was deemed unacceptable under the MASH 2016 TL-3 test designation no. 3-11 safety criteria. Potential barrier modifications for improving the performance were noted for future research.

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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. Scott Rosenbaugh, Research Engineer.

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1 INTRODUCTION

1.1 Background

Portable concrete barriers (PCBs) are often used in applications where it is desired that their deflection during vehicular impacts be limited. Free-standing PCB systems develop their redirective capacity through a combination of various forces and mechanisms, including inertial resistance developed by the acceleration of several barrier segments, lateral friction loads, and the tensile loads developed from the mass and friction of the barrier segments upstream and downstream from the impacted region. Crash testing was performed in accordance with Test Level 3 (TL-3) impact safety standards published in the *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) [1] upon free-standing F-shape PCBs that are used in many of the Midwest Pooled Fund states and have demonstrated dynamic deflections in excess of 6.6 ft (2.0 m) [2]. For many installations, this deflection is undesirable. Therefore, tie-down systems for anchoring PCB segments have been designed to limit dynamic barrier deflections and restrain barrier segments.

The Midwest Roadside Safety Facility (MwRSF) previously developed and full-scale crash tested a tie-down system for use on concrete bridge decks and with the redesigned F-shape temporary concrete barriers, as shown in Figure 1 [3]. The tie-down system consisted of three 1⅛-in. (29-mm) diameter Grade 2 (ASTM A307) threaded rods embedded approximately 12 in. (305 mm) into the concrete on the traffic side of each of the redesigned F-shape temporary concrete barriers. The barriers were placed 1 in. (25 mm) away from a concrete bridge deck edge drop-off. During full-scale crash testing, the barrier safely redirected the ¾-ton pickup truck with minimal barrier deflections. The barrier system was determined to be acceptable according to the TL-3 safety performance criteria presented in National Cooperative Highway Research Program (NCHRP) Report No. 350 [4].

A related study conducted by MwRSF investigated the dynamic performance of epoxy anchors in concrete [5]. As part of that effort, MwRSF conducted dynamic component testing of the 1⅛-in. (29-mm) diameter Grade 2 (ASTM A307) threaded rod, with an embedment depth of 5¼ in. (133 mm), was placed in the bolt through tie-down meant for concrete road surfaces. The ultimate shear value obtained during the component tests was determined to be far greater than the nominal shear capacity of the anchor, and the ultimate tension capacity was within one percent of the nominal tension capacity of the concrete strength in the component tests. Therefore, the anchorage design with a 5¼-in. (133-mm) embedment depth utilizing Hilti HIT-RE 500-SD epoxy adhesive was considered an adequate alternative anchorage design for the 1⅛-in. (29-mm) diameter rods used in the tie-down temporary concrete barrier tested under NCHRP Report No. 350 TL-3 because the tested capacities met the nominal capacities of the anchorages used in the full-scale crash test.

However, the failure in the tension test created significant concrete damage. This concrete damage would be expected to occur to the bridge decks of real-world installations during severe, high-energy impacts. In addition, the compressive strength of the concrete used in these component tests may have been higher than the typical strength of concrete bridge decks. Thus, a decrease in the anchor capacity would be expected for lower strength concrete. This decrease in strength would likely be offset to some extent by the presence of reinforcing steel in the bridge deck. Thus, it was believed that using the ASTM A307 rod with Hilti HIT-RE 500 or Hilti HIT-RE 500 SD epoxy adhesive with a 5¼-in. (133 mm) embedment depth should provide similar anchorage to the tested system, but increased deflection and increased deck damage may result. It was also noted that epoxy adhesive manufacturer recommendations for anchor installation should be closely followed to prevent concerns for anchor creep and reductions in anchor capacity. The performance of the reduced embedment depth anchor under a MASH 2016 TL-3 impact conditions was unknown.

A tie-down system for asphalt road surfaces was also developed at MwRSF that utilized three 1½-in. (38-mm) diameter x 38½-in. (978-mm) long ASTM A36 steel pins with 3-in. (76-mm) x 3-in. (76-mm) x ½-in. (13-mm) ASTM A36 steel caps installed in holes on the front face of each barrier segment, as shown in Figure 2 [6]. The tie-down system was then installed in combination with sixteen F-shape barriers on a 2-in. (51-mm) thick asphalt pad and crash tested according to NCHRP Report No. 350 test designation no. 3-11. The results showed that the vehicle was safely contained and redirected, and the test was judged acceptable according to the NCHRP Report No. 350 criteria. Barrier deflections for the system were reduced, and all barriers in the system were safely restrained on the asphalt road surface.

Wisconsin Department of Transportation (WisDOT) currently uses two tie-down anchorages with F-shape PCBs that were successfully developed and crash tested according to NCHRP Report No. 350 TL-3: (1) the bolt through tie-down for use on concrete road surfaces (Figure 1) and (2) the steel pin tie-down for use on asphalt road surfaces (Figure 2). WisDOT desires to continue to have access to these two tie-down anchorages following the MASH 2016 implementation date of December 31, 2019 for longitudinal barriers. However, the increased mass and kinetic energy of the MASH 2009 and 2016 test vehicles has been shown to increase impact loading and dynamic deflection of PCB systems [7]. Thus, a need existed to evaluate these two tie-down anchorages for use with F-shape PCBs under the MASH 2016 criteria and determine if the barrier segment and the tie-down systems have sufficient capacity to constrain barrier motions, define its dynamic deflections, and ensure its safety performance adjacent to vertical drop-offs.

As noted previously, WisDOT in cooperation with MwRSF evaluated the dynamic loading of epoxy anchors [5]. That research suggested there was potential to apply the bolt through tie-down for use on concrete road surfaces with a reduced anchor depth. As such, WisDOT desired to evaluate the bolt through tie-down for use on concrete road surfaces using the minimal anchor embedment depth of 5¼ in. (133 mm).

1.2 Objective

The objective of this research was to evaluate the safety performance of the WisDOT F-shape PCB with both the bolt-through, tie-down anchorage system for concrete road surfaces with a reduced embedment epoxy anchorage and the steel pin tie-down anchorage system for asphalt surfaces. Both systems were evaluated according to the TL-3 criteria of MASH 2016.

1.3 Scope

The research objective was achieved through the completion of several tasks. One full-scale crash test was conducted on each F-shape PCB anchorage system according to MASH 2016 test designation no. 3-11. Next, the full-scale vehicle crash test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made pertaining to the safety performance of the tie-down anchorages for the F-shape PCB.

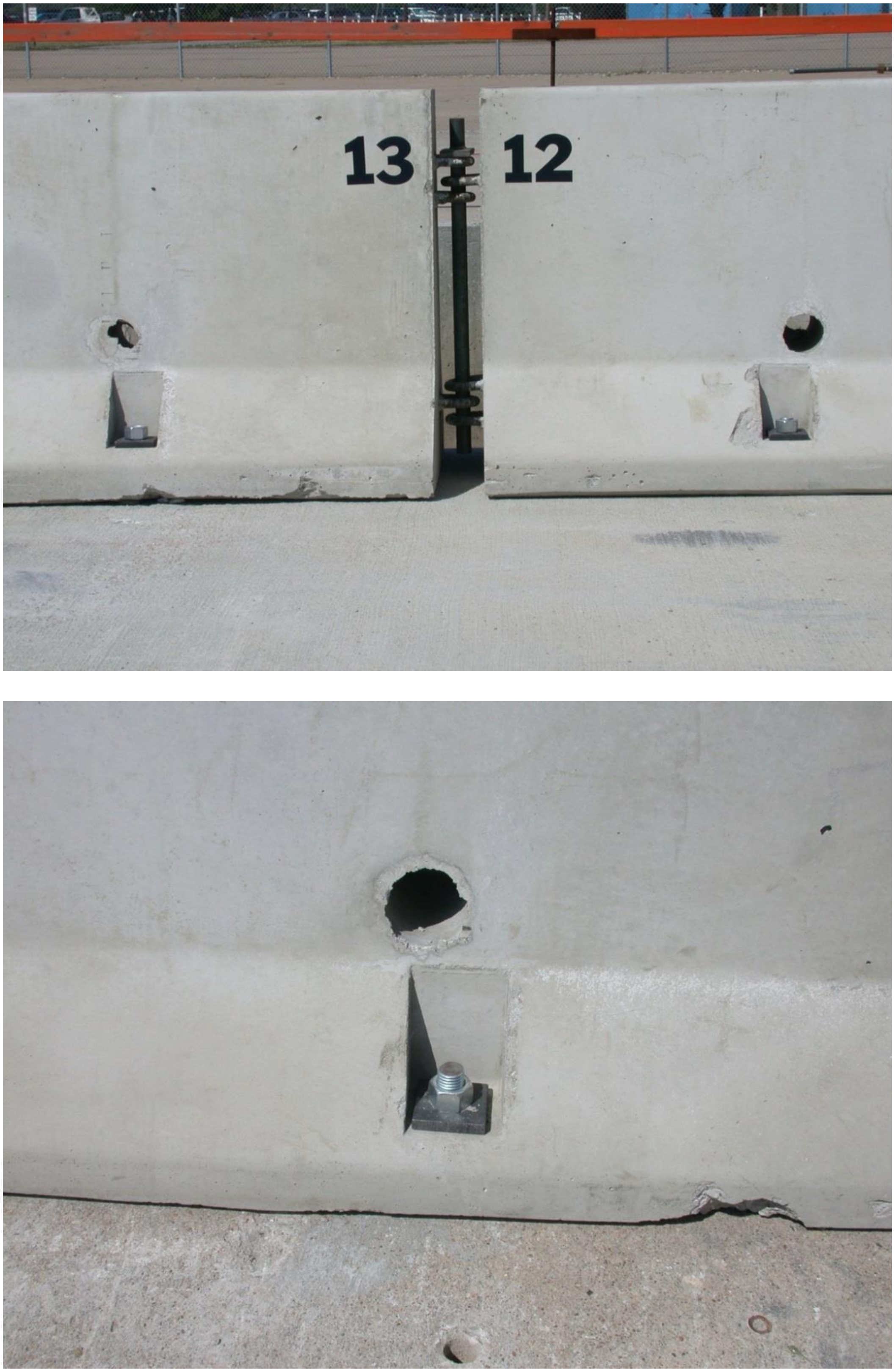


Figure 1. Bolt-Through Tie-Down for F-Shape PCB

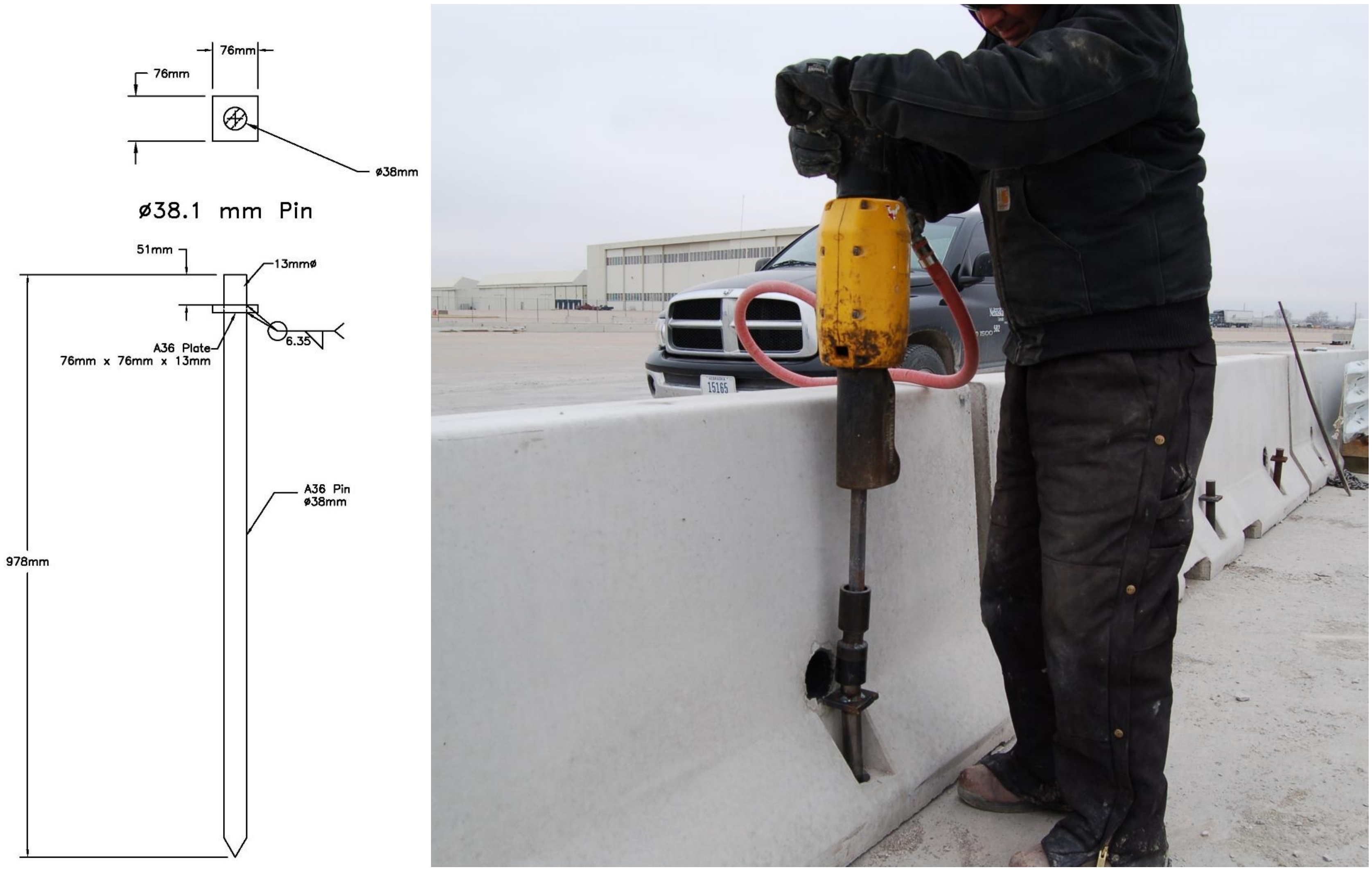


Figure 2. Steel Pin Tie-Down for F-Shape PCB – Asphalt Road Surface

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as PCBs, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [1]. Note that there is no difference between MASH 2009 and MASH 2016 for most longitudinal barriers, such as the anchored PCB systems tested in this project, except that additional occupant compartment deformation measurements are required by MASH 2016. According to TL-3 of MASH 2016, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 1.

Table 1. MASH 2016 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	1100C	2,420 (1,100)	62 (100)	25	A,D,F,H,I
	3-11	2270P	5,000 (2,270)	62 (100)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

Only test no. 3-11 was deemed critical for evaluation of the two tie-down anchorage systems for F-shape PCB herein. Test no. 7069-3, found in the Federal Highway Administration (FHWA) report nos. FHWA-RD-93-058 and FHWA-RD-93-064 and performed under MASH TL-3 standards, have indicated that safety-shape barriers can safely redirect 1100C vehicles. In test no. 2214NJ-1, found in MwRSF report no. TRP-03-177-06, MASH test designation no. 3-10 was successfully conducted on a permanent New Jersey shape concrete parapet under NCHRP Project 22-14(2) [8]. In test report no. 607911-1&2, MASH test designation no. 3-10 was also successfully conducted on a free-standing F-shape PCB similar to the barrier used in this study by the Texas A&M Transportation Institute (TTI) [9]. These two tests indicate that safety shape barriers are capable of successfully capturing and redirecting the 1100C vehicle in both a free-standing PCB and permanent concrete parapet applications. Additionally, the increased toe height of New Jersey shape barriers tends to produce increased vehicle climb and instability as compared to the F-shape geometry. Thus, one would expect that the anchored F-shape PCBs evaluated in this study would perform similarly to these previous MASH 1100C vehicle tests in terms of capture and redirection, and it was believed that test designation no. 3-10 with the 1100C vehicle may be deemed non-critical for evaluation of the tie-down anchorages for use with F-shape PCBs. MASH 2016 test designation no. 3-11 was the more critical evaluation test due to concerns for increased barrier loading during 2270P impacts, the need to evaluate the barrier restraint system, and in order to determine dynamic deflection and working width. Thus, only test designation no. 3-11 was conducted on the anchored PCB systems evaluated herein.

Table 2. MASH 2016 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 or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="9">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 should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</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>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</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>15.0 g's</td><td>20.49 g's</td></tr>
</table>

It should be noted that the test matrix detailed herein represents the researchers' best engineering judgement with respect to the MASH 2016 safety requirements and their internal evaluation of critical tests necessary to evaluate the crashworthiness of the barrier system. However, the recent switch to new vehicle types as part of the implementation of the MASH 2016 criteria and the lack of experience and knowledge regarding the performance of the new vehicle types with certain types of hardware could result in unanticipated barrier performance. Thus, any tests within the evaluation matrix deemed non-critical may eventually need to be evaluated based on additional knowledge gained over time or revisions to the MASH 2016 criteria.

2.2 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 PCB system 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 2 and defined in greater detail in MASH 2016. The full-scale vehicle crash tests documented herein were conducted and reported in accordance with the procedures provided in MASH 2016.

In addition to the standard occupant risk measures, the Post-Impact Head Deceleration (PHD), the Theoretical Head Impact Velocity (THIV), and the Acceleration Severity Index (ASI) were determined and reported. Additional discussion on PHD, THIV and ASI is provided in MASH 2016.

2.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH 2016, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, W6x16 (W152x23.8) posts are installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips (33.4 kN) at post deflections between 5 and 20 in. (127 and 508 mm) measured at a height of 25 in. (635 mm). If dynamic testing near the system is not desired, MASH 2016 permits a static test to be conducted instead and compared against the results of a previously established baseline test. In this situation, the soil must provide a resistance of at least 90% of the static baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Further details can be found in Appendix B of MASH 2016. No static soil test was conducted prior to test no. WITD-1 as the system was evaluated on the concrete tarmac.

For test no. WITD-2, the F-shape PCBs were placed on an asphalt pad placed on an in-situ soil and anchored with steel pins that passed through the barrier and into the asphalt and soil. While no baseline soil test with identical properties was available for direct comparison, a static soil test was still conducted to ensure that the soil beneath the asphalt pad was consistent with previous soils used at MwRSF for MASH testing, as shown in Appendix C. The static test results found that the in-situ soil used for test no. WITD-2 developed higher loads when compared with previous static soil baseline tests used for MwRSF testing. Thus, the in-situ soil was deemed acceptable for evaluation of the anchored PCB system in test no. WITD-2.

3 TEST CONDITIONS

3.1 Test Facility

The Outdoor Test Site 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.

3.2 Vehicle Tow and Guidance System

A reverse-cable, tow system with a 1:2 mechanical advantage was used to propel the test vehicles. The distance traveled and the speed of the tow vehicle were one-half that of the test vehicles. The test vehicles were 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 [10] was used to steer the test vehicles. A guide flag, attached to the left-front wheels 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 vehicles were towed down the line, the guide flag struck and knocked each stanchion to the ground.

3.3 Test Vehicles

For test no. WITD-1, a 2011 Dodge Ram 1500 quad cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 4,950 lb (2,245 kg), 5,000 lb (2,268 kg), and 5,154 lb (2,338 kg), respectively. The test vehicle is shown in Figures 3 and 4, and vehicle dimensions are shown in Figure 5. Note that pre-test photographs of the vehicle’s undercarriage for test no. WITD-1 are not available.

For test no. WITD-2, a 2010 Dodge Ram 1500 quad cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,075 lb (2,302 kg), 5,003 lb (2,269 kg), and 5,157 lb (2,339 kg), respectively. The test vehicle is shown in Figures 6 and 7, and vehicle dimensions are shown in Figure 8.

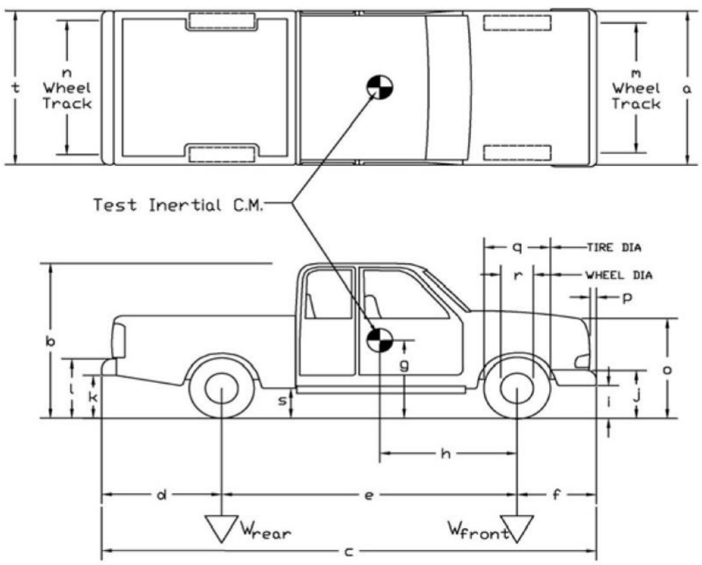
The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [11] was used to determine the vertical component of the c.g. for the pickup trucks. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicles were 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. for test no. WITD-1 is shown in Figures 5 and 9. The location of the final c.g. for test no. WITD-2 is shown in Figures 8 and 10. 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 vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 9 and 10. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

Figure 3. Test Vehicle, Test No. WITD-1

Figure 4. Test Vehicle Pre-Test Interior Floorboard and Occupant Compartment Test No. WITD-1

Date:	5/30/2017	Test Name:	WITD-1	VIN No:	1D7RB1GKXAS249304
Year:	2011	Make:	Dodge	Model:	Ram 1500
Tire Size:	LT265/70R17	Tire Inflation Pressure:	40 Psi	Odometer:	150033



Vehicle Geometry - in. (mm)
Target Ranges listed below

a:	77 7/8 (1978) 78±2 (1950±50)	b:	73 3/4 (1873)
c:	229 (5817) 237±13 (6020±325)	d:	46 7/8 (1191)
e:	140 5/8 (3572) 148±12 (3760±300)	f:	40 3/8 (1026) 39±3 (1000±75)
g:	28 1/16 (713) min: 28 (710)	h:	65 1/16 (1653) 63±4 (1575±100)
i:	8 1/8 (206)	j:	27 1/4 (692)
k:	19 (483)	l:	28 7/8 (733)
m:	68 5/8 (1743) 67±1.5 (1700±38)	n:	68 (1727) 67±1.5 (1700±38)
o:	46 1/8 (1172) 43±4 (1100±75)	p:	4 7/8 (124)
q:	31 3/8 (797)	r:	18 3/8 (467)
s:	13 (330)	t:	77 1/8 (1959)

Wheel Center Height (Front):	15 (381)
Wheel Center Height (Rear):	15 1/8 (384)
Wheel Well Clearance (Front):	34 3/4 (883)
Wheel Well Clearance (Rear):	37 (940)
Bottom Frame Height (Front):	13 3/4 (349)
Bottom Frame Height (Rear):	24 1/2 (622)
Engine Type:	Gasoline
Engine Size:	3.7L V6
Transmission Type:	Automatic
Drive Type:	RWD
Cab Style:	Quad Cab
Bed Length:	76"

Mass Distribution lb (kg)

Gross Static	LF	1399 (635)	RF	1380 (626)
	LR	1204 (546)	RR	1171 (531)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2689 (1220)	2687 (1219)	2779 (1261)
W-rear	2261 (1026)	2313 (1049)	2375 (1077)
W-total	4950 (2245)	5000 (2268) 5000±110 (2270±50)	5154 (2338) 5165±110 (2343±50)

GVWR Ratings lb

Front	3700
Rear	3900
Total	6700

Dummy Data

Type:	Hybrid II
Mass:	154 lb
Seat Position:	Passenger

Note any damage prior to test: Dent on passenger side of rear bumper. Paint taken off driver side above gas tank cover.

Figure 5. Vehicle Dimensions, Test No. WITD-1

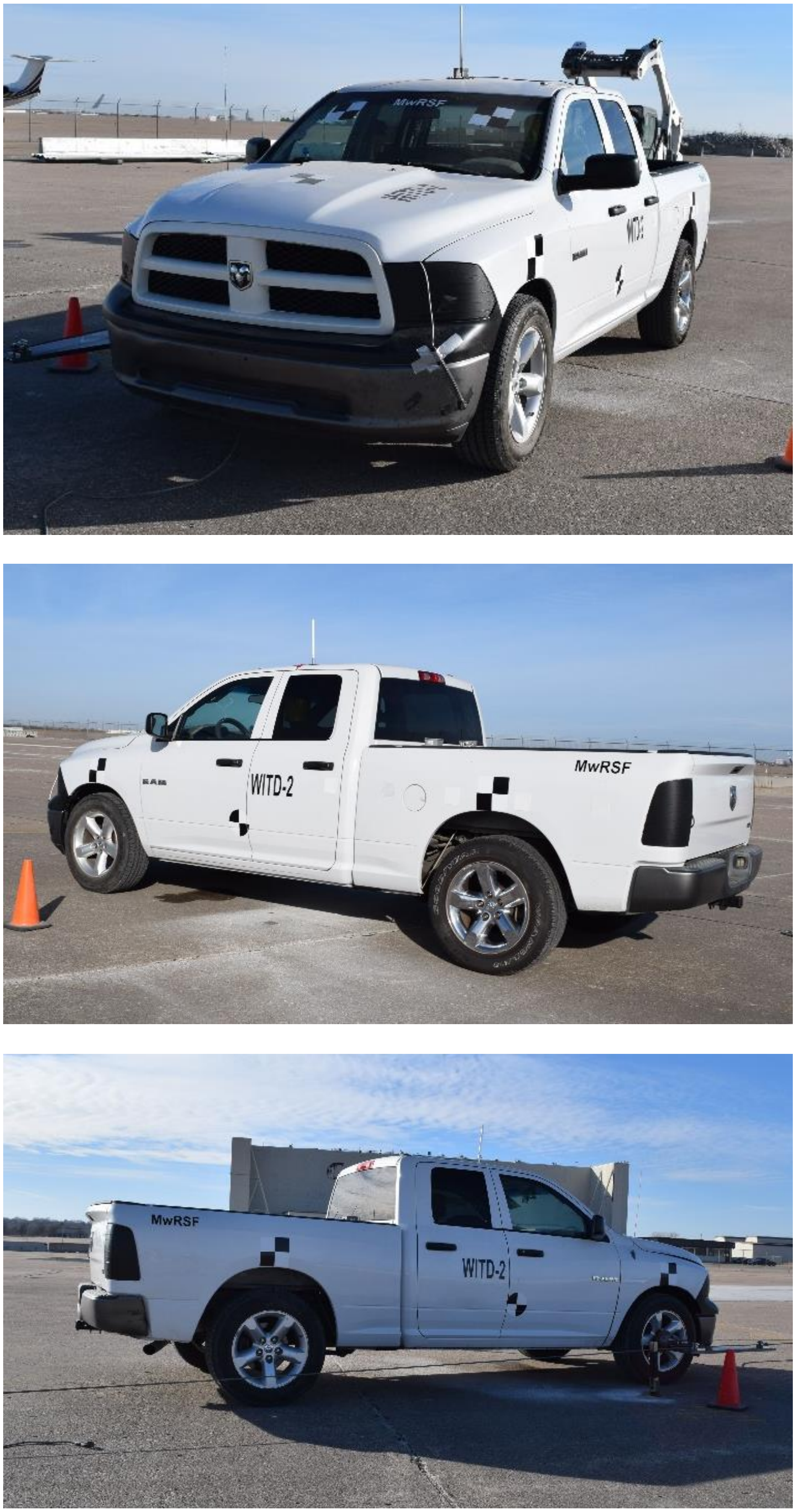
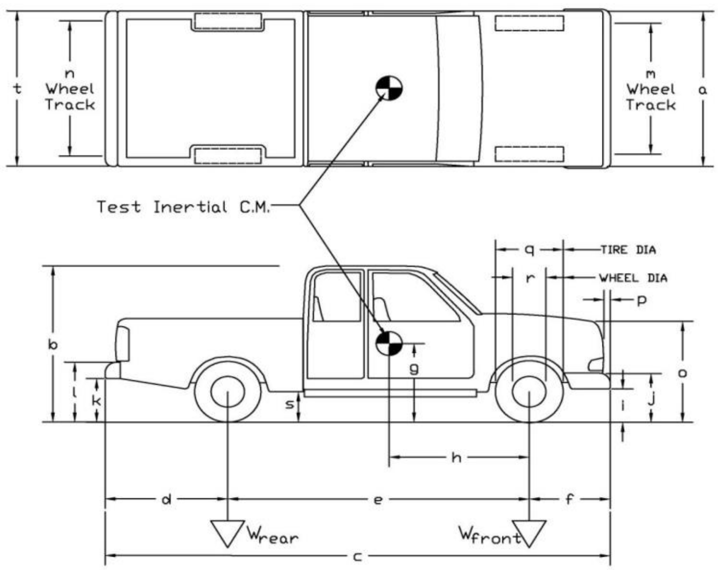


Figure 6. Test Vehicle, Test No. WITD-2

Figure 7. Test Vehicle Pre-Test Interior Floorboard and Undercarriage, Test No. WITD-2

Date:	12/14/2017	Test Name:	WITD-2	VIN No:	1D7RB1GP4AS121538
Year:	2010	Make:	Dodge	Model:	Ram 1500
Tire Size:	P275/60R20 114T	Tire Inflation Pressure:	40 Psi	Odometer:	216936



Vehicle Geometry - in. (mm)
Target Ranges listed below

a:	78	(1981)	b:	74 3/4	(1899)
	78±2 (1950±50)				
c:	229 1/8	(5820)	d:	48 5/8	(1235)
	237±13 (6020±325)				
e:	141 1/4	(3588)	f:	40 1/8	(1019)
	148±12 (3760±300)			39±3 (1000±75)	
g:	28 3/8	(721)	h:	62 3/8	(1584)
	min: 28 (710)			63±4 (1575±100)	
i:	13	(330)	j:	24 1/4	(616)
k:	21 1/4	(540)	l:	29 7/8	(759)
m:	68 5/8	(1743)	n:	68 1/8	(1730)
	67±1.5 (1700±38)			67±1.5 (1700±38)	
o:	46 5/8	(1184)	p:	4 3/8	(111)
	43±4 (1100±75)				
q:	33 1/8	(841)	r:	21 5/8	(549)
s:	14 3/8	(365)	t:	78 3/8	(1991)

Wheel Center Height (Front):	15 3/4	(400)
Wheel Center Height (Rear):	15 3/4	(400)
Wheel Well Clearance (Front):	35 5/8	(905)
Wheel Well Clearance (Rear):	38 3/8	(975)
Bottom Frame Height (Front):	18 3/4	(476)
Bottom Frame Height (Rear):	25 3/4	(654)
Engine Type:	Gasoline	
Engine Size:	4.7L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	
Cab Style:	Quad Cab	
Bed Length:	76"	

Mass Distribution lb (kg)

Gross Static	LF	1461	(663)	RF	1426	(647)
	LR	1149	(521)	RR	1121	(508)

Weights lb (kg)	Curb		Test Inertial		Gross Static	
W-front	2848	(1292)	2794	(1267)	2887	(1310)
W-rear	2227	(1010)	2209	(1002)	2270	(1030)
W-total	5075	(2302)	5003	(2269)	5157	(2339)
			5000±110 (2270±50)		5165±110 (2343±50)	

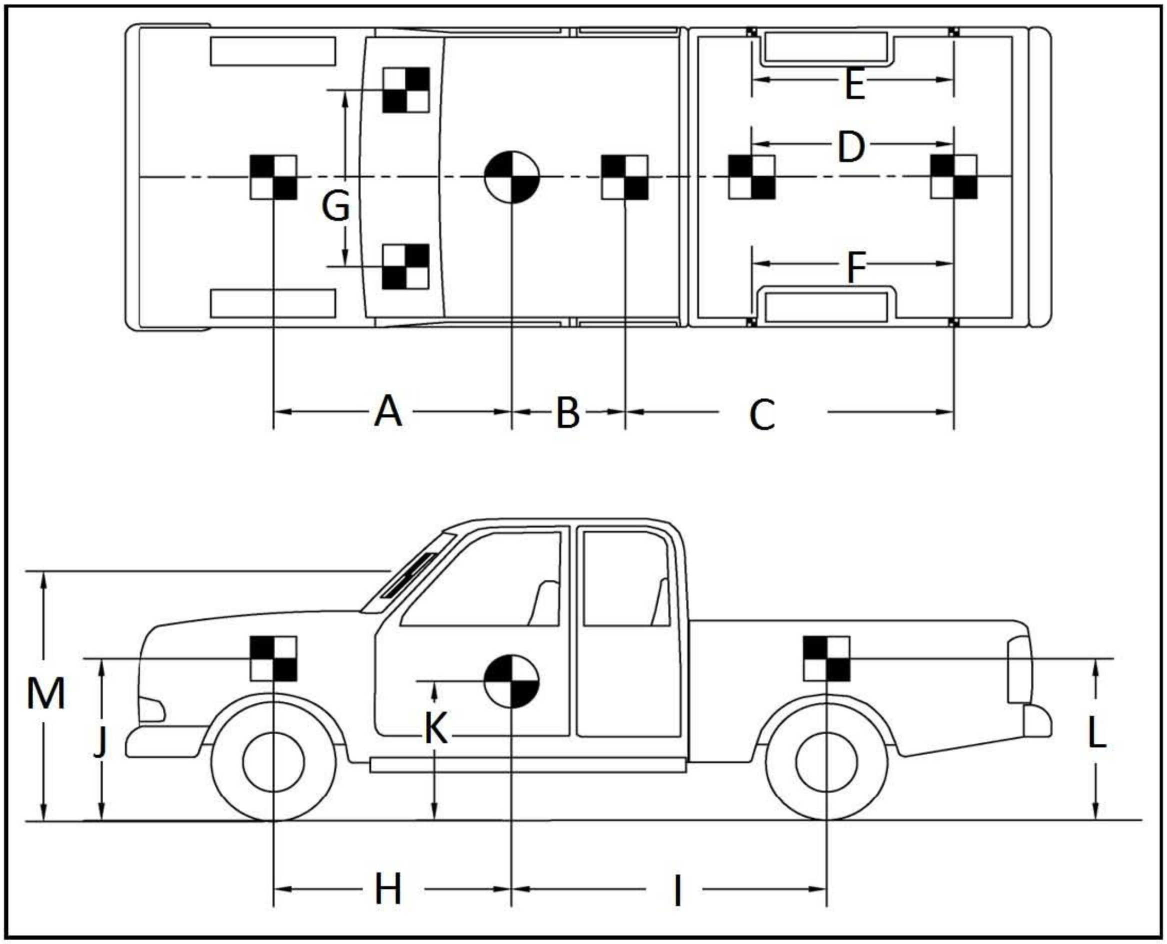
GVWR Ratings lb	
Front	3700
Rear	3900
Total	6700

Dummy Data	
Type:	Hybrid II
Mass:	154 lb
Seat Position:	Driver

Note any damage prior to test: NONE

Figure 8. Vehicle Dimensions, Test No. WITD-2

Date:	5/30/2017	Test Name:	WITD-1	VIN:	1D7RB1GKXAS249304
Year:	2011	Make:	Dodge	Model:	Ram 1500

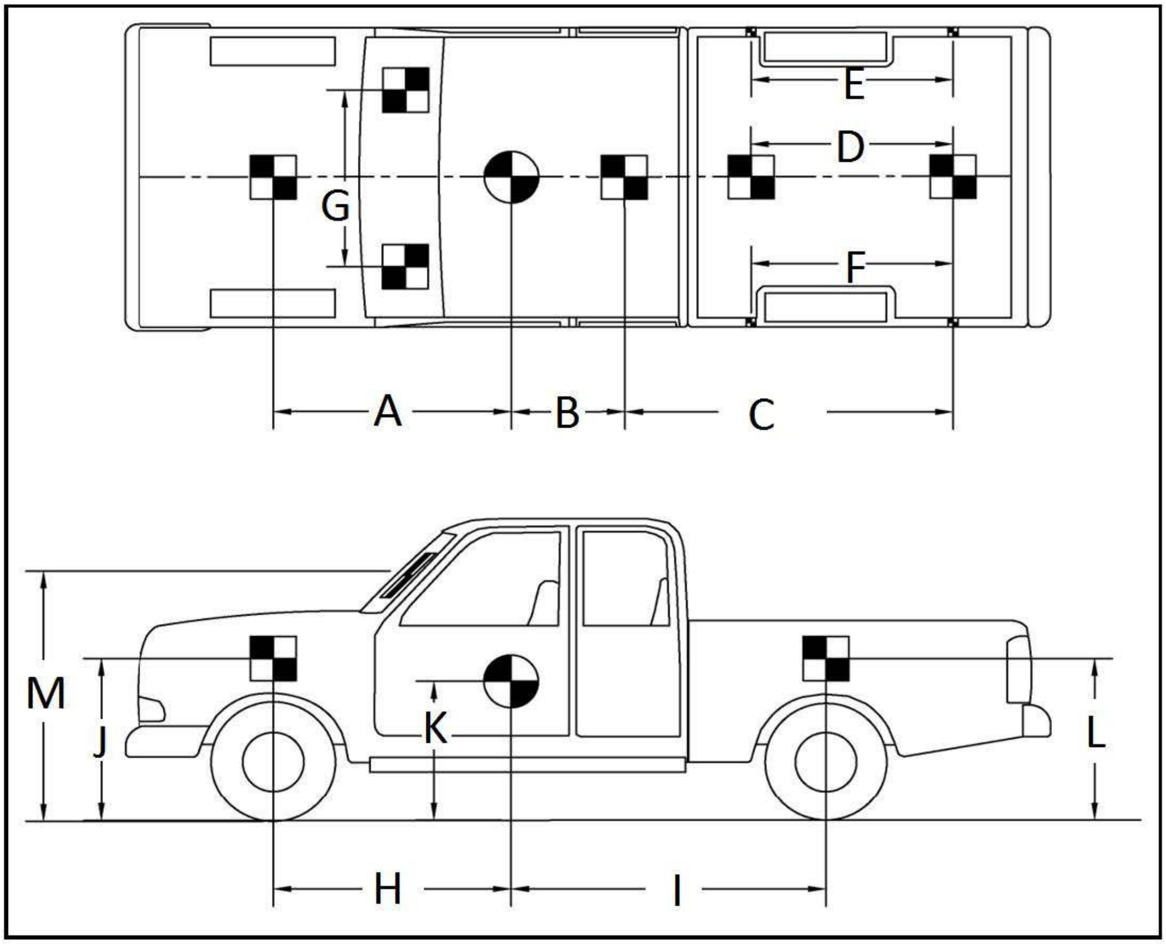


TARGET GEOMETRY-- in. (mm)

A:	78 1/8 (1984)	E:	63 1/4 (1607)	J:	40 3/8 (1026)
B:	24 1/2 (622)	F:	63 3/16 (1605)	K:	28 1/8 (714)
C:	78 1/8 (1984)	G:	36 1/4 (921)	L:	42 5/8 (1083)
D:	48 (1219)	H:	65 1/8 (1654)	M:	65 1/2 (1664)
		I:	75 1/2 (1918)		

Figure 9. Target Geometry, Test No. WITD-1

Date:	11/22/2017	Test Name:	WITD-2	VIN:	1D7RB1GP4AS121538
Year:	2010	Make:	Dodge	Model:	Ram 1500



TARGET GEOMETRY-- in. (mm)

A:	78	(1981)	E:	63 1/8	(1603)	J:	39 1/2	(1003)
B:	27 11/16	(703)	F:	63 1/8	(1603)	K:	28 5/16	(719)
C:	68 3/16	(1732)	G:	35 5/8	(905)	L:	42 1/8	(1070)
D:	33 7/16	(849)	H:	62 3/8	(1584)	M:	65 1/8	(1654)
			I:	78	(1981)			

Figure 10. Target Geometry, Test No. WITD-2

The front wheels of the test vehicles were aligned to vehicle standards except the toe-in value was adjusted to zero such that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted under the vehicles' right-side windshield wipers for both tests 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 digital videos. A remote-controlled brake system was installed in the test vehicles so the vehicles could be brought safely to a stop after the test.

3.4 Simulated Occupant

For test nos. WITD-1 and WITD-2, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the right-front and left-front seat of the test vehicles, respectively, with the seat belt fastened. The dummy, which had a final weight of 154 lb (70 kg) in both tests, was represented by model no. 572, and was manufactured by Android Systems of Carson, California. As recommended by MASH 2016, the dummy was not included in calculating the c.g. location.

3.5 Data Acquisition Systems

3.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometer systems were mounted near the c.g. 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 [12].

The two systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SLICE-2 unit was designated as the primary system for both tests. 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.

3.5.2 Rate Transducers

Two identical angular 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 vehicles. 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.

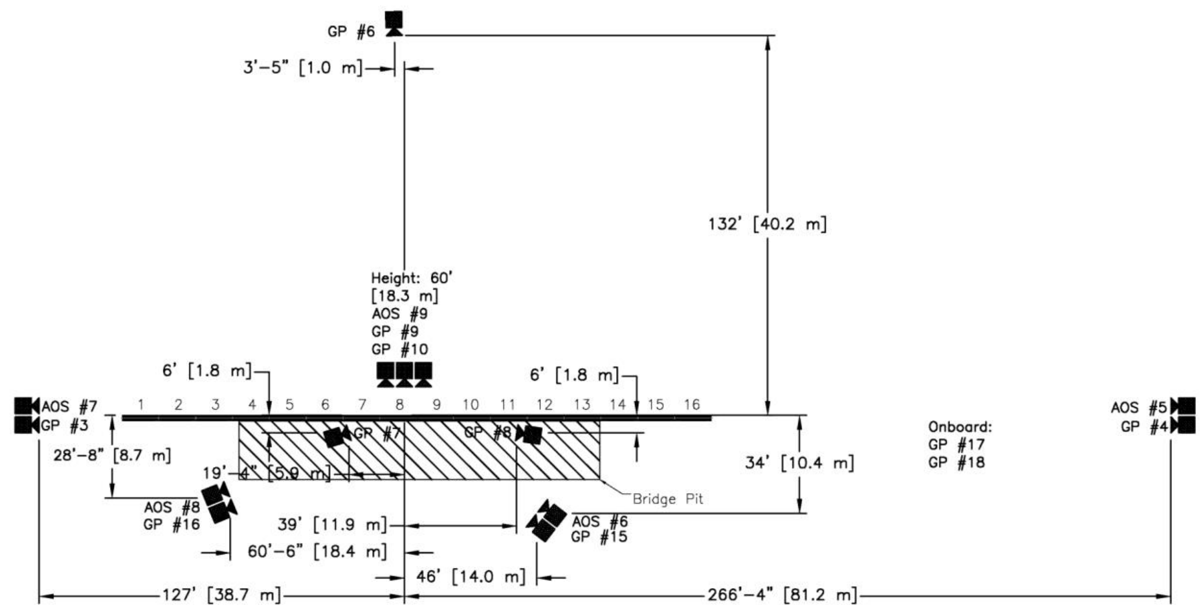
3.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the test vehicles before impact. Five retroreflective targets, spaced at approximately 18-in. (457-mm) intervals, were applied to the sides of the vehicles. 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.

3.5.4 Digital Photography

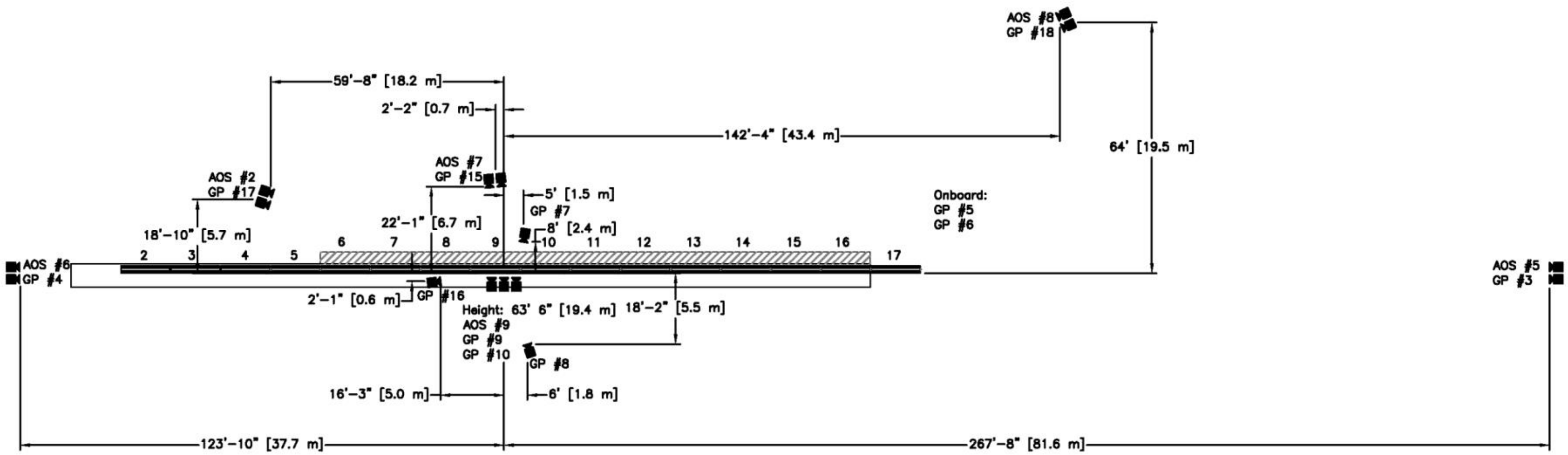
Five AOS high-speed digital video cameras and eleven GoPro digital video cameras were utilized to film test no. WITD-1. Six AOS high-speed digital video cameras and twelve GoPro digital video cameras were utilized to film test no. WITD-2. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figures 11 and 12.

The high-speed videos were analyzed using TEMA Motion and Redlake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A Nikon digital still camera was also used to document pre- and post-test conditions for each test.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI	500	VIVITAR 135mm Fixed	-
AOS-6	AOS X-PRI	500	KOWA 25mm Fixed	-
AOS-7	AOS X-PRI	500	Fujinon 35mm Fixed	-
AOS-8	AOS S-VIT 1531	500	Fujinon 50mm Fixed	-
AOS-9	AOS TRI-VIT 2236	500	KOWA 12mm Fixed	-
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	240		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
GP-15	GoPro Hero 4	240		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	120		
GP-18	GoPro Hero 4	120		

Figure 11. Camera Locations, Speeds, and Lens Settings, Test No. WITD-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam	500	KOWA 25mm Fixed	-
AOS-5	AOS X-PRI	500	135mm Fixed	-
AOS-6	AOS X-PRI	500	Fujinon 50mm Fixed	-
AOS-7	AOS X-PRI	500	KOWA 16mm Fixed	-
AOS-8	AOS S-VIT 1531	500	Sigma 28-70	50
AOS-9	AOS TRI-VIT 2236	500	KOWA 12mm Fixed	-
GP-3	GoPro Hero 3+ w/ Cosmicar 12.5mm	120		
GP-4	GoPro Hero 3+ w/ Computar 12.5mm	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
GP-15	GoPro Hero 4	240		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	240		
GP-18	GoPro Hero 4	240		

Figure 12. Camera Locations, Speeds, and Lens Settings, Test No. WITD-2

4 DESIGN DETAILS – TEST NO. WITD-1

The test installation consisted of sixteen 12-ft 6-in. (3.8-m) long WisDOT PCBs in a bolt-through, tie-down configuration for use on concrete. The system was installed with the rear toe of the PCBs placed 1 in. (25 mm) away from the edge of the simulated bridge deck, as shown in Figures 13 through 21. Photographs of the test installation are shown in Figures 22 and 23. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The concrete mix for the barrier sections required a minimum compressive strength of 5,000 psi (34.5 MPa). A minimum concrete cover of 2 in. (51 mm) was specified. Each PCB was reinforced with ASTM A615 Grade 60 rebar. The barrier sections used a connection pin, as shown in Figure 15. Each connection pin measured 28 in. (711 mm) in length, 1¼ in. (32 mm) in diameter, and was used to interlock the ¾-in. (19-mm) diameter ASTM A705 Grade 60 connection loop bars, as shown in Figures 15 and 16.

Barrier nos. 5 through 13 were each anchored to the concrete tarmac through the bolt anchor pockets on the front (traffic) side with three 1⅛-in. (29-mm) diameter by 12-in. (305-mm) long, ASTM A307 Grade A threaded rods inserted and epoxied with Hilti HIT-RE 500 V3 epoxy into 1¼-in. (32-mm) diameter holes in the concrete tarmac, as shown in Figures 13 and 15. Equivalent strength epoxies and and/or epoxy anchorage configurations could also be used in real-world installations. During installation, the barrier segments were pulled in a direction parallel to their longitudinal axes, and slack was removed from all joints. After slack was removed from all the joints, 1¼-in. (32-mm) diameter holes were drilled for bolt anchors at the bolt anchor pocket locations on the front (traffic) side. The threaded rod anchors were embedded to a depth of 5¼ in. (133 mm), as shown in Figure 15.

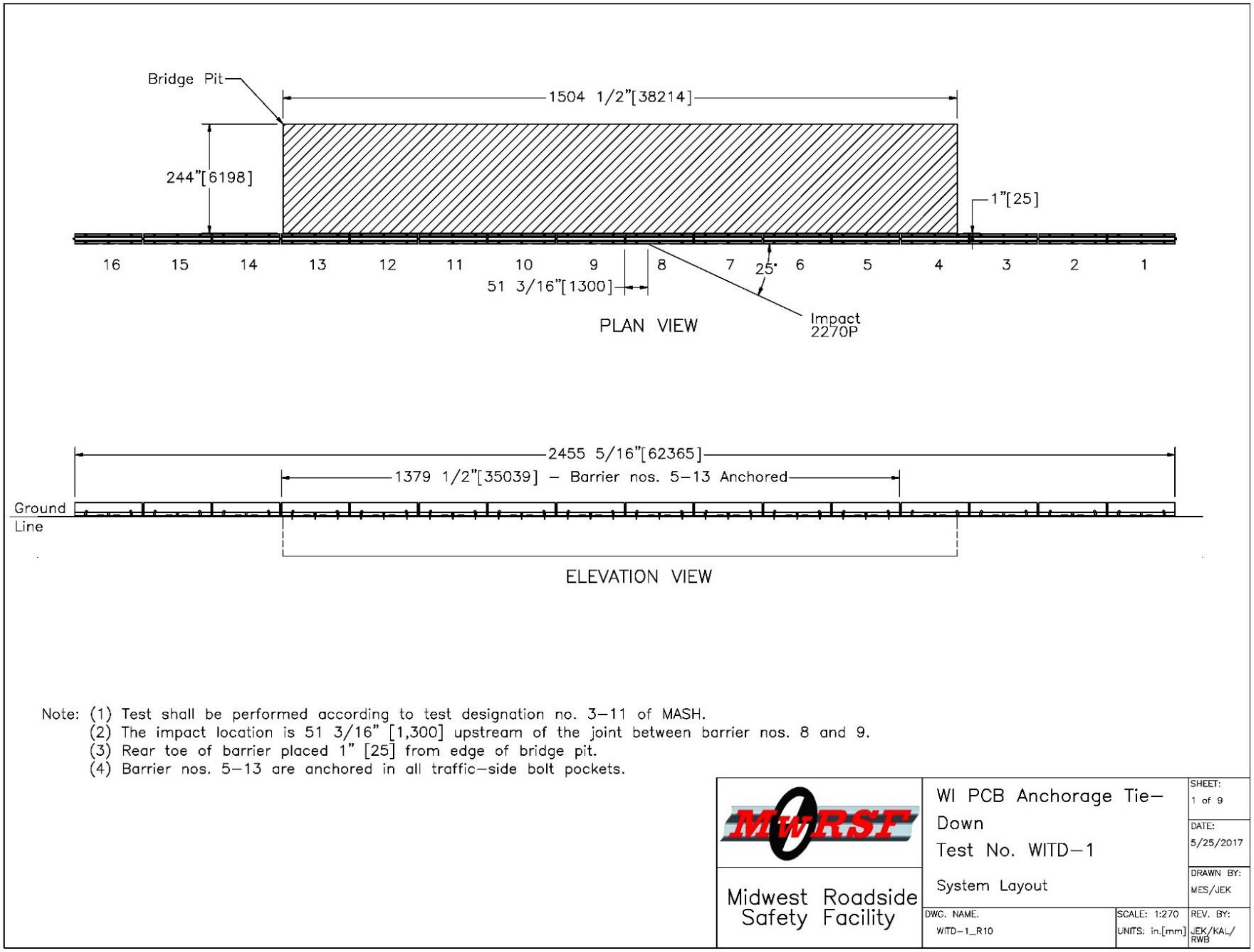
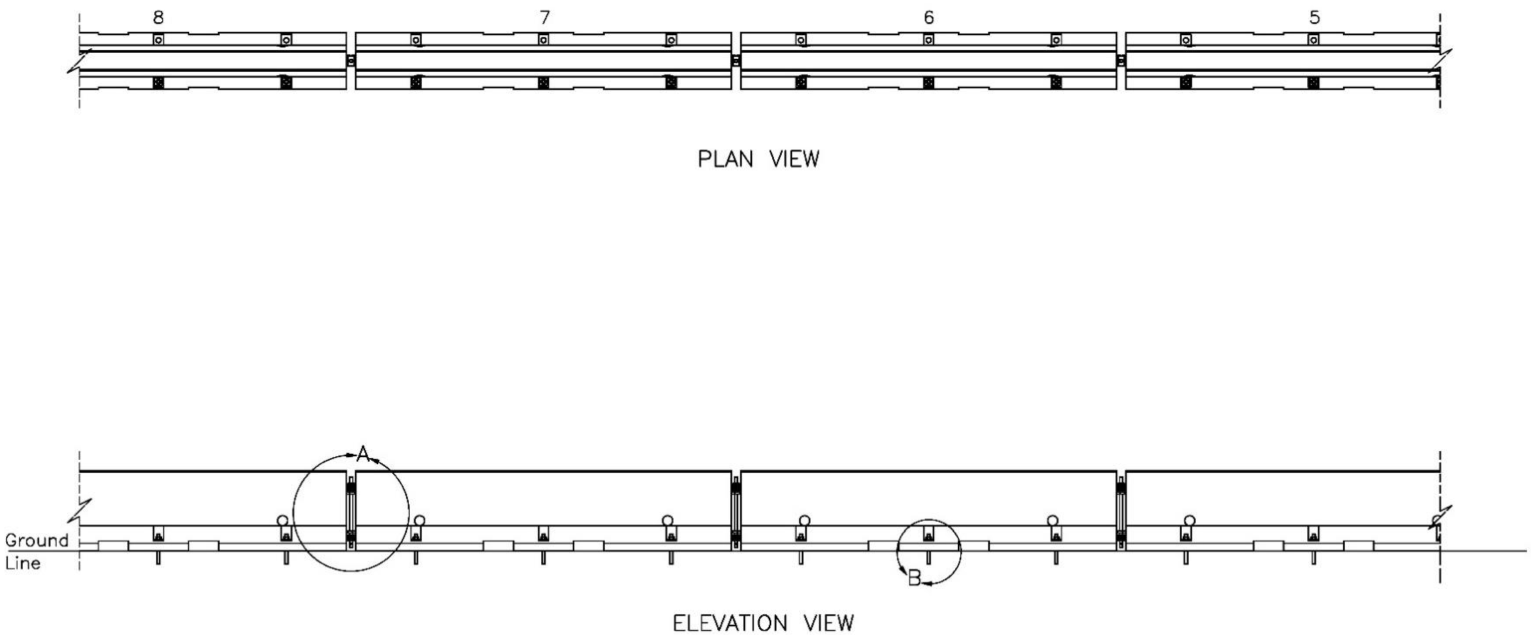


Figure 13. System Layout, Test No. WITD-1



Note: (1) Barrier nos. 5–13 are anchored in all traffic–side bolt pockets.
(2) Threaded rod epoxy anchored using Hilti HIT–RE 500 V3 epoxy or equivalent.

Midwest Roadside Safety Facility	WI PCB Anchorage Tie–Down Test No. WITD–1 Concrete Barrier Assembly	SHEET: 2 of 9 DATE: 5/25/2017 DRAWN BY: MES/JEK
	DWG. NAME. WITD–1_R10	SCALE: 1:60 UNITS: in.[mm]
		REV. BY: JEK/KAL/RWB

Figure 14. Concrete Barrier Assembly, Test No. WITD-1

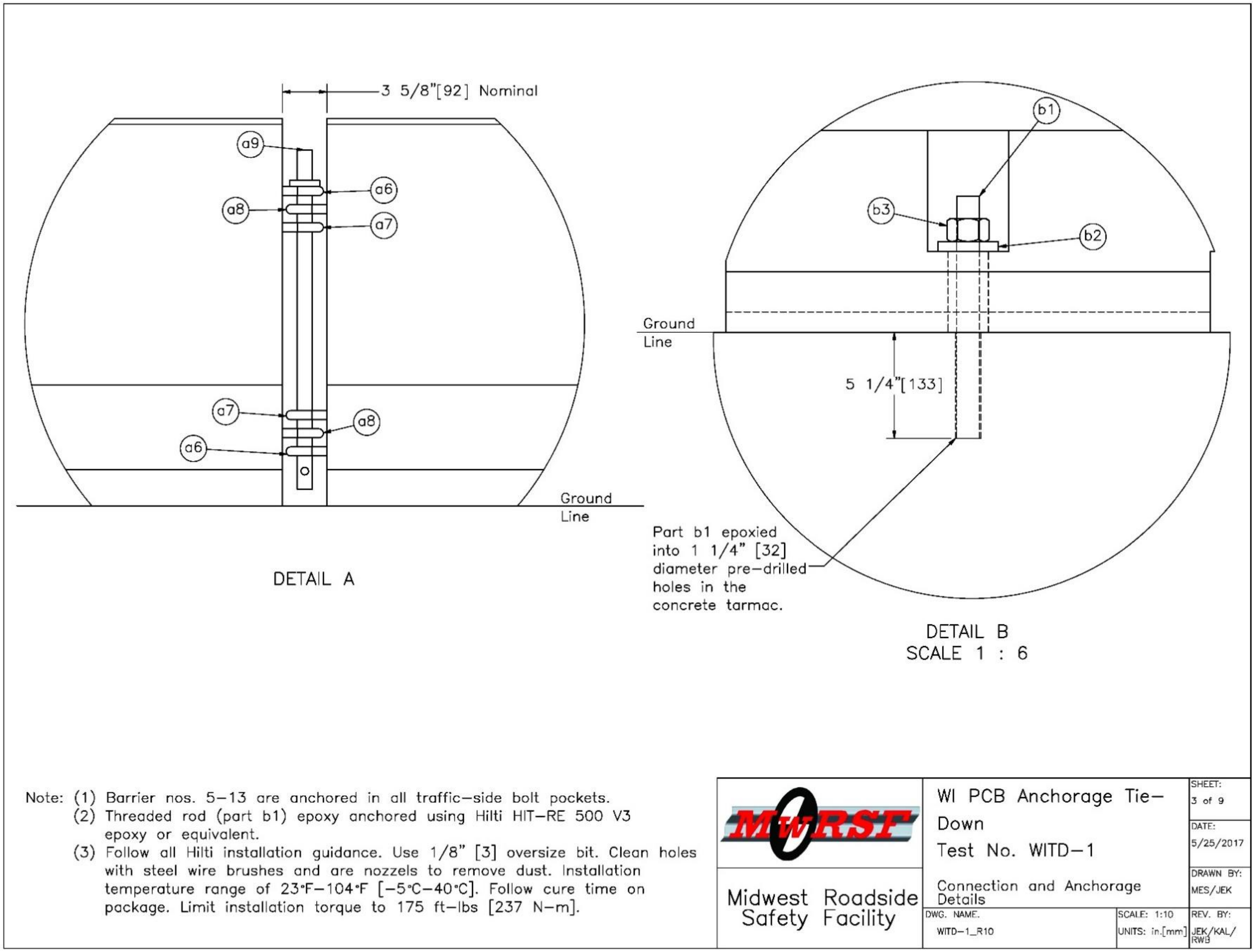


Figure 15. Connection and Anchorage Details, Test No. WITD-1

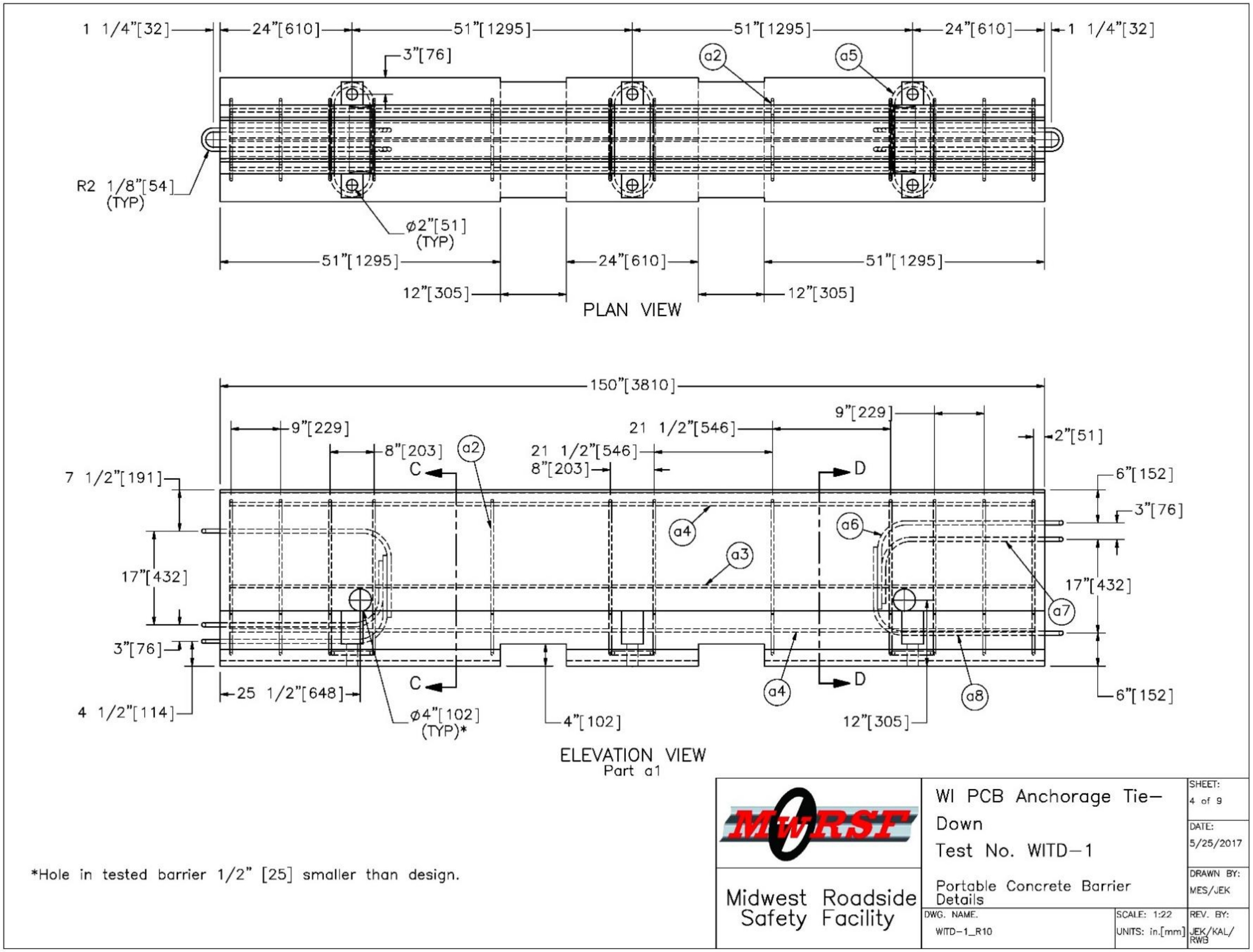


Figure 16. Portable Concrete Barrier Details, Test No. WITD-1

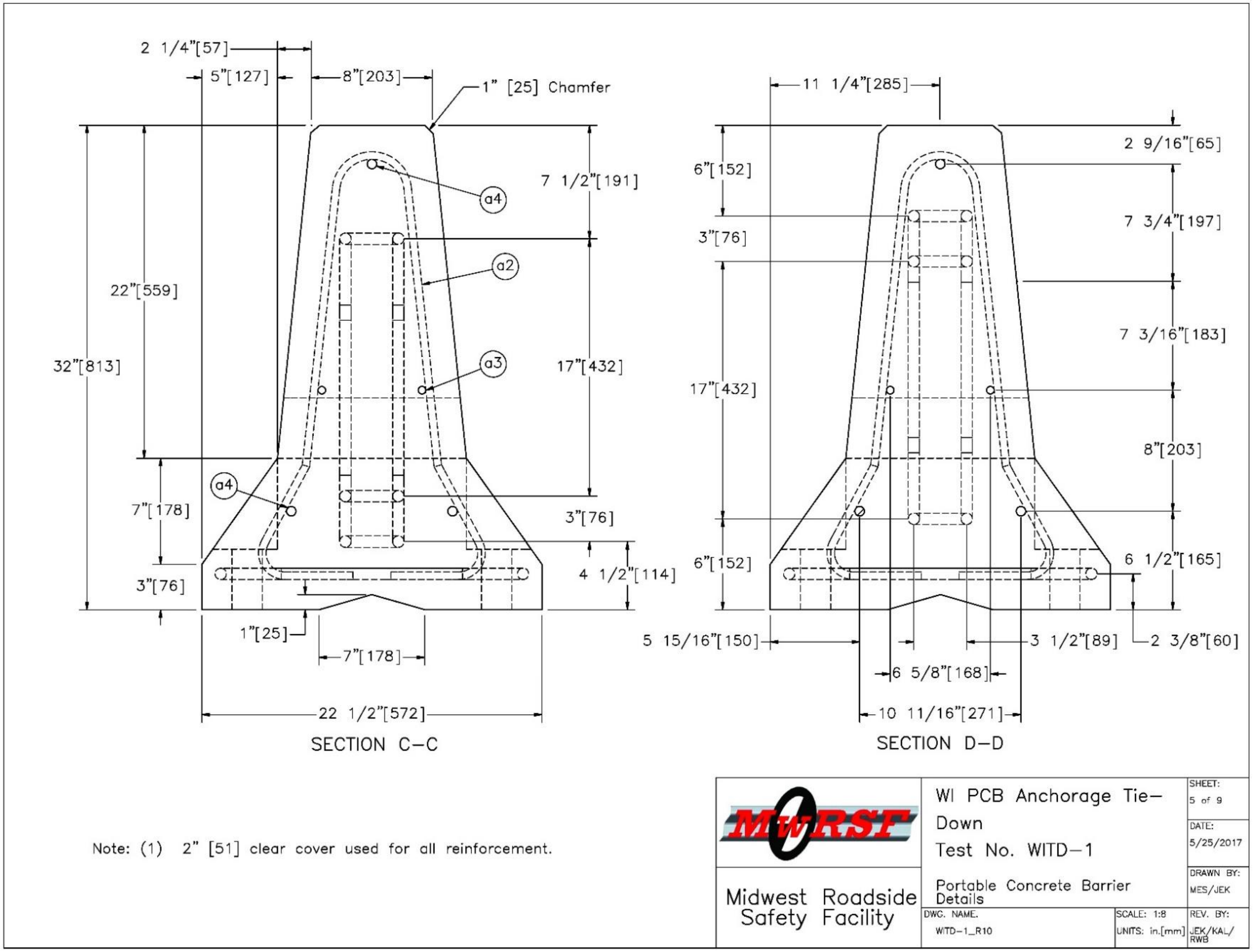
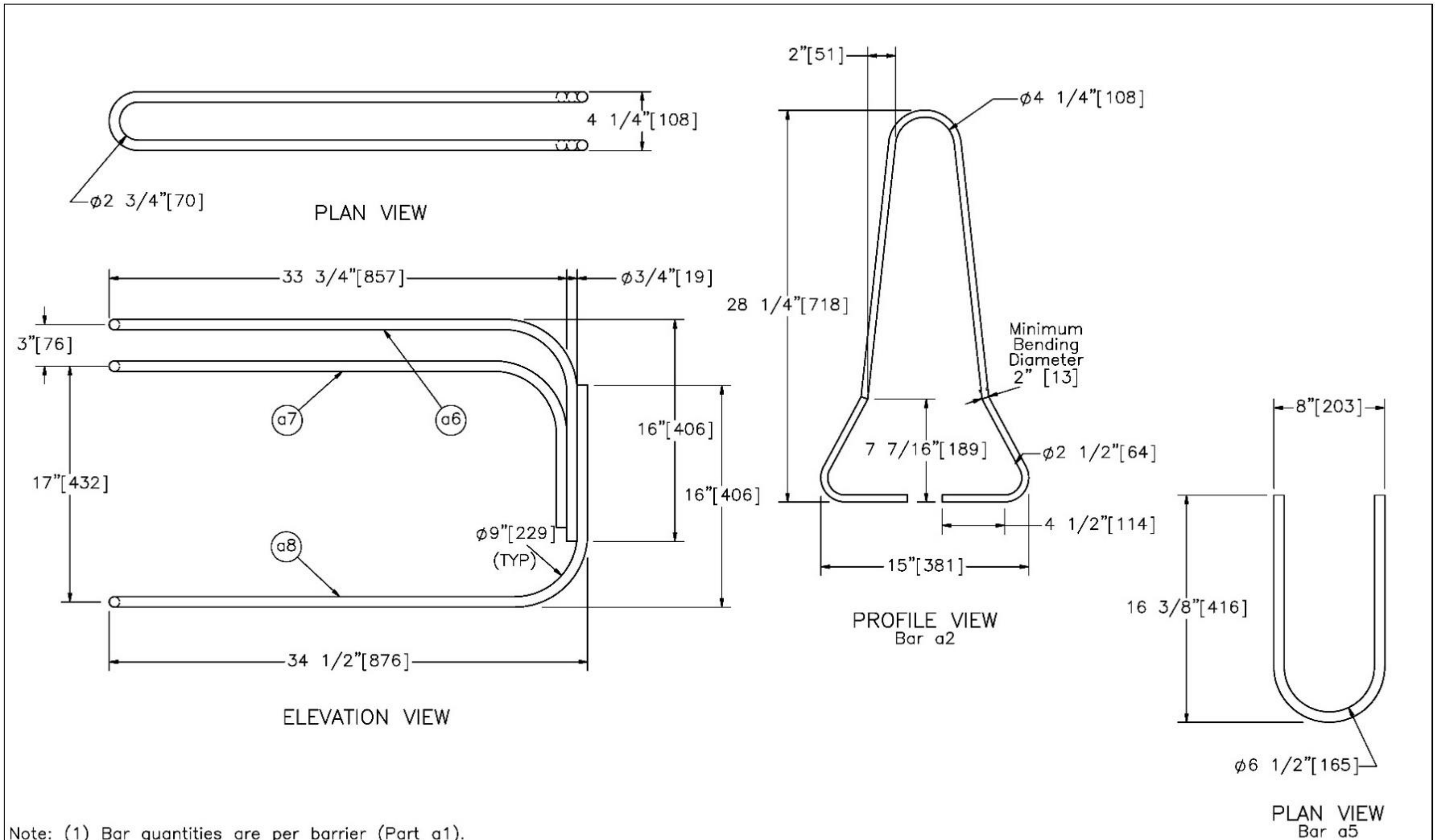


Figure 17. Portable Concrete Barrier Details, Test No. WITD-1



Note: (1) Bar quantities are per barrier (Part a1).

Bill of Bars

Bar	QTY	Size	Total Length	Material
a2	12	#4	72"[1829]	A615 Gr.60
a3	2	#4	146"[3708]	A615 Gr.60
a4	3	#5	146"[3708]	A615 Gr.60
a5	6	#6	35"[889]	A615 Gr.60
a6	2	#6	101"[2565]	A709 Gr.70 or A706 Gr.60
a7	2	#6	91"[2311]	A709 Gr.70 or A706 Gr.60
a8	2	#6	102"[2591]	A709 Gr.70 or A706 Gr.60

MwRSF
Midwest Roadside Safety Facility

WI PCB Anchorage Tie-Down
Test No. WITD-1
Portable Concrete Barrier Rebar Details

SHEET: 6 of 9
DATE: 5/25/2017
DRAWN BY: MES/JEK
DWG. NAME. WITD-1_R10
SCALE: 1:10
UNITS: in.[mm]
REV. BY: JEK/KAL/RWB

Figure 18. Portable Concrete Barrier Details, Test No. WITD-1

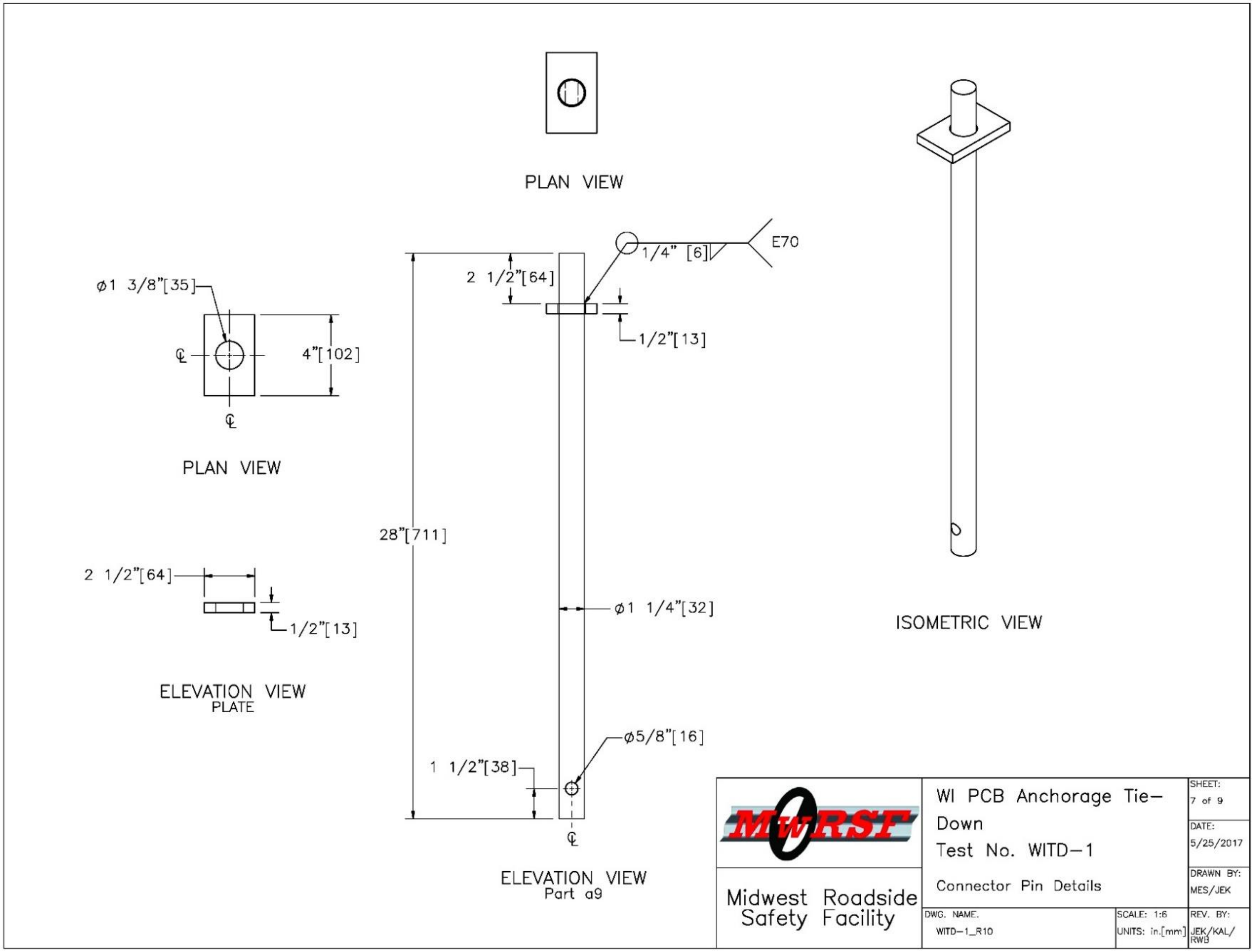


Figure 19. Connector Pin Details, Test No.WITD-1

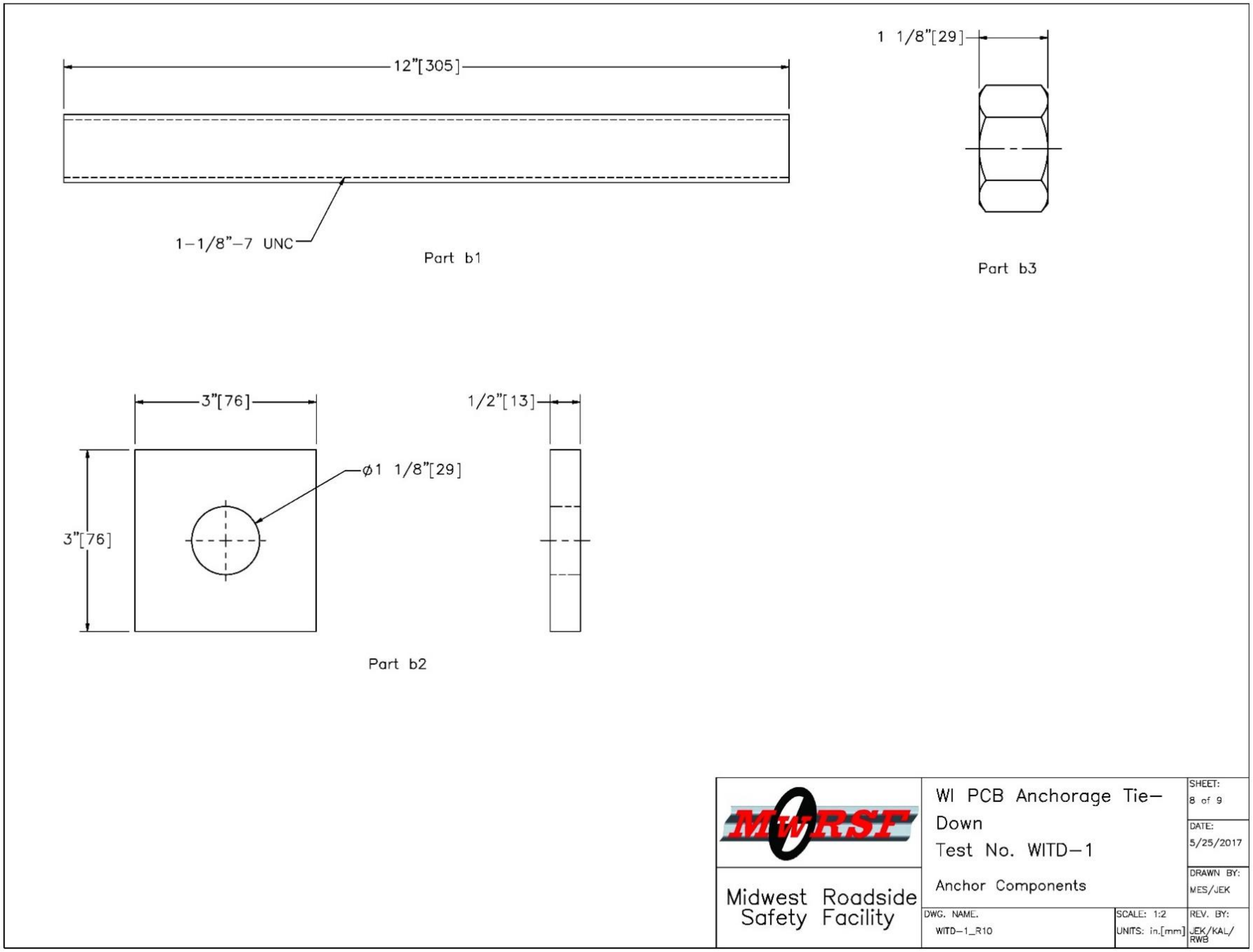


Figure 20. Anchor Components, Test No.WITD-1

Item No.	QTY.	Description	Material Spec	Galvanization Spec	Hardware Guide
a1	16	Portable Concrete Barrier	Min f'c = 5,000 psi [34.5 MPa]	–	SWC09
a2	192	1/2" [13] Dia., 72" [1,829] Long Form Bar	ASTM A615 Gr. 60	–	SWC09*
a3	32	1/2" [13] Dia., 146" [3,708] Long Longitudinal Bar	ASTM A615 Gr. 60	–	SWC09*
a4	48	5/8" [16] Dia., 146" [3,708] Long Longitudinal Bar	ASTM A615 Gr. 60	–	SWC09*
a5	96	3/4" [19] Dia., 36" [914] Long Anchor Loop Bar	ASTM A615 Gr. 60	–	SWC09*
a6	32	3/4" [19] Dia., 101" [2,565] Long Connection Loop Bar	ASTM A709 Gr. 70 or A706 Gr. 60	–	SWC09*
a7	32	3/4" [19] Dia., 91" [2,311] Long Connection Loop Bar	ASTM A709 Gr. 70 or A706 Gr. 60	–	SWC09*
a8	32	3/4" [19] Dia., 102" [2,591] Long Connection Loop Bar	ASTM A709 Gr. 70 or A706 Gr. 60	–	SWC09*
a9	15	1 1/4" [32] Dia., 28" [711] Long Connector Pin	ASTM A36	–	FMW02
b1	27	1 1/8" [29] Dia. UNC, 12" [305] Long Threaded Rod	ASTM A307 Gr. A	**ASTM A153 or B695 Class 55 or F2329	–
b2	27	3"x3"x1/2" [76x76x13] Washer Plate	ASTM A36	**ASTM A123	–
b3	27	1 1/8" [29] Dia. Heavy Hex Nut	ASTM A563A	**ASTM A153 or B695 Class 55 or F2329	–
c1	–	Hilti HIT-RE 500 V3 Epoxy or equivalent	Minimum bond strength for 1 1/8" [29] anchor > 1,650 psi [11 MPa] in uncracked concrete	–	–

* Included in SWC09 hardware guide designation.
** Component does not need to be galvanized for testing purposes.

Midwest Roadside Safety Facility

WI PCB Anchorage Tie-Down
Test No. WITD-1
Bill of Materials

SHEET: 9 of 9
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DRAWN BY: MES/JEK
DWG. NAME. WITD-1_R10
SCALE: 1:768
UNITS: in.[mm]
REV. BY: JEK/KAL/RWB

Figure 21. Bill of Materials, Test No.WITD-1

Figure 22. Test Installation Photographs, Test No. WITD-1

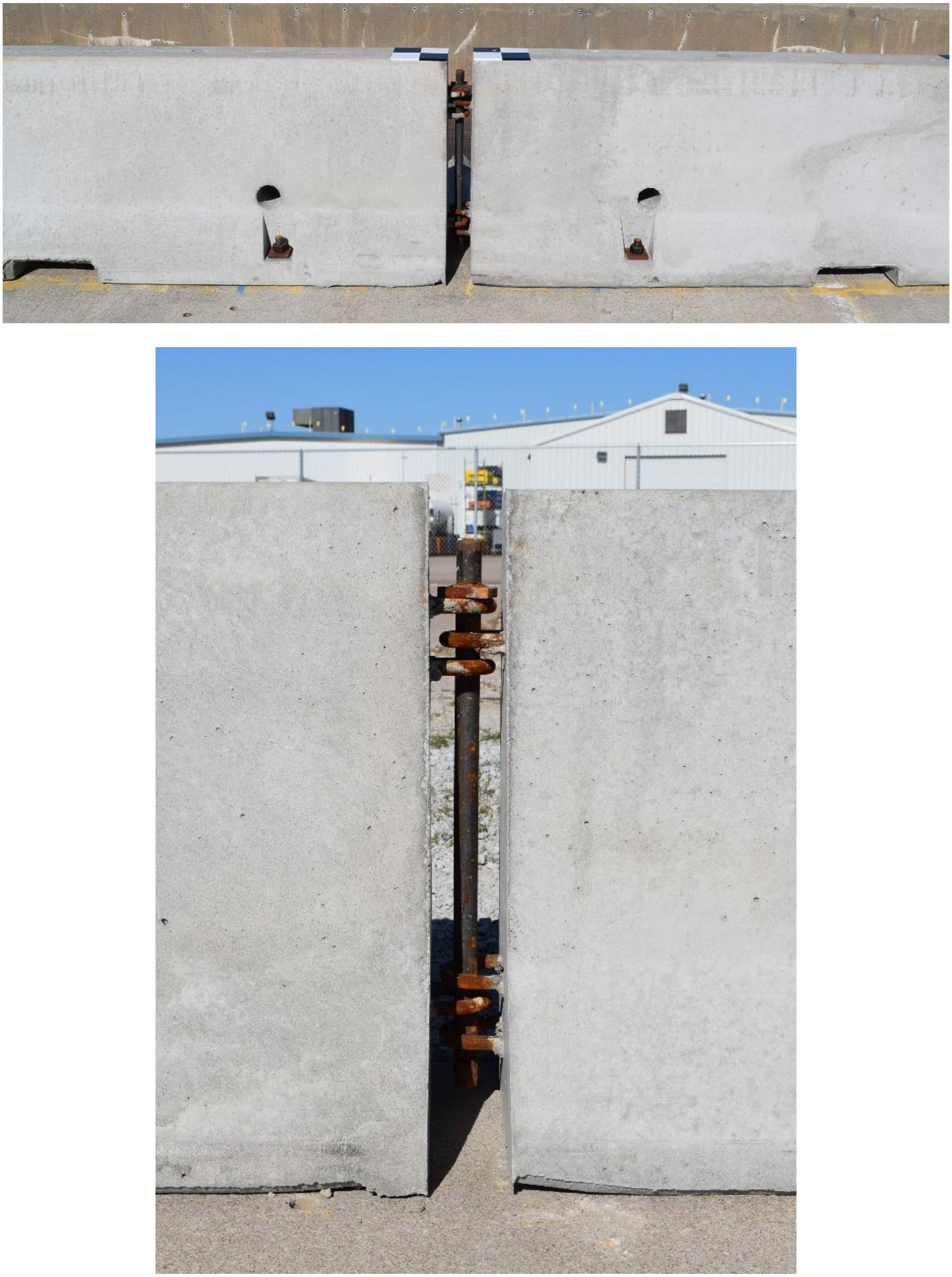


Figure 23. Connection and Anchor Pin Details, Test No. WITD-1

5 FULL-SCALE CRASH TEST NO. WITD-1

5.1 Weather Conditions

Test no. WITD-1 was conducted on May 30, 2017 at approximately 1:45 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

Table 3. Weather Conditions, Test No. WITD-1

Temperature	81° F
Humidity	21%
Wind Speed	17 mph
Wind Direction	330° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.42 in.
Previous 7-Day Precipitation	0.42 in.

5.2 Test Description

Initial vehicle impact was to occur 4 ft – 3$^3/_{16}$ in. (1.3 m) upstream from the centerline of the joint between barrier nos. 8 and 9, as shown in Figure 24, which was selected using Table 2.7 of MASH 2016. The 5,000-lb (2,268-kg) quad cab pickup truck impacted the bolt-through tie-down PCB system on concrete at a speed of 62.0 mph (99.8 km/h) and at an angle of 25.6 degrees. The actual point of impact was 6.9 in. (175 mm) downstream from the target location. The vehicle came to rest 243 ft – 2 in. (74.1 m) downstream from the impact point and 23 ft – 10 in. (7.3 m) laterally in front of the traffic facing side of the barrier after brakes were applied.

A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 25 and 26. Documentary photographs of the crash test are shown in Figures 27and 28. The vehicle trajectory and final position are shown in Figure 29.

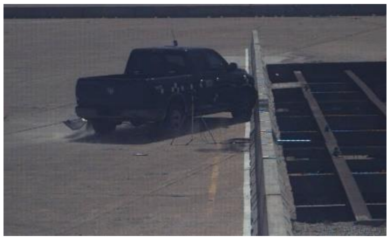
5.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 30 through 36. Barrier damage consisted of contact marks on the front face of the concrete segments, spalling of the concrete, and concrete cracking and fracture. The length of vehicle contact along the barrier was approximately 18 ft – 1¾ in. (5.5 m) which spanned from 5 ft – 4¾ in. upstream from the downstream edge of barrier no. 8 to 3¼ in. (83 mm) upstream from the downstream end of barrier no. 9.

Figure 24. Impact Location, Test No. WITD-1

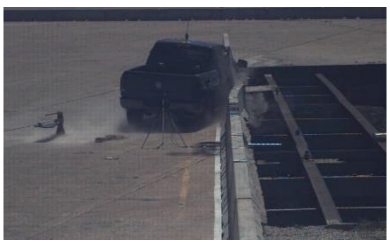
Table 4. Sequential Description of Impact Events, Test No. WITD-1

TIME (sec)	EVENT
0.000	Vehicle’s front bumper contacted barrier no. 8 at 3 ft – 8$^{5}/_{16}$ in. (1.1 m) upstream from the centerline of the joint between barrier nos. 8 and 9.
0.004	Vehicle’s front bumper deformed and right-front tire contacted barrier no. 8.
0.016	Vehicle’s right-front tire rode up barrier no. 8.
0.018	Vehicle rolled toward barrier.
0.028	Vehicle’s front bumper contacted barrier no. 9.
0.032	Vehicle’s right-front door contacted barrier no. 8, and concrete barrier no. 8 rotated clockwise about vertical axis.
0.036	Barrier no. 9 twisted counterclockwise about the downstream end.
0.040	Vehicle yawed away from barrier and pitched upward.
0.044	Vehicle’s right airbag deployed.
0.046	Vehicle’s left airbag deployed.
0.064	Rear toe of barrier no. 9 spalled between midspan and upstream end of barrier.
0.074	Rear toe of barrier no. 8 spalled at the midspan of the barrier.
0.082	Barrier no. 9 cracked at midspan of barrier.
0.088	Barrier no. 8 spalled at downstream end.
0.098	Vehicle’s left-front tire became airborne.
0.120	Occupant’s head contacted right-front door’s window.
0.132	Barrier no. 8 cracked between midspan and upstream end of barrier.
0.172	Vehicle was parallel to system at a speed of 52.6 mph (84.7 km/h).
0.176	Vehicle’s rear bumper contacted barrier no. 8.
0.180	Vehicle pitched downward.
0.212	Vehicle’s right taillight disengaged and vehicle’s right-front tire became airborne.
0.214	Barrier no. 9 spalled at downstream end.
0.226	Vehicle’s left-rear tire became airborne.
0.336	Vehicle’s right-rear tire became airborne.
0.346	Vehicle exited system while airborne at a speed of 49.7 mph (80.0 km/h) and angle of 4.4 degrees.
0.410	Vehicle’s right-front tire regained contact with ground.
0.534	Vehicle’s front bumper contacted ground.
0.580	Vehicle rolled away from barrier.
0.606	Vehicle’s rear regained contact with ground.
0.790	Vehicle’s left-front tire regained contact with ground.
0.950	Vehicle’s right-rear tire regained contact with ground.
0.994	Vehicle’s left-rear tire regained contact with ground.
1.038	Vehicle’s right-rear wheel disengaged and vehicle pitched downward.



0.000 sec

0.046 sec



0.120 sec

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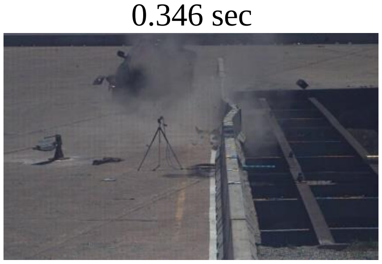
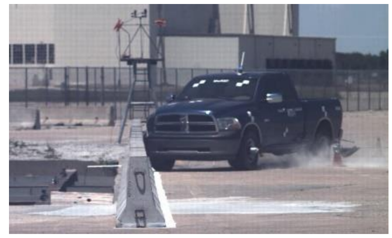
0.346 sec



0.790 sec



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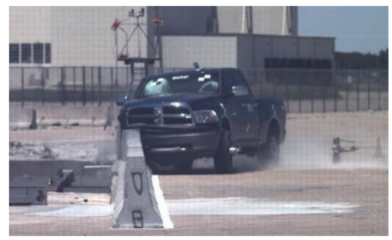

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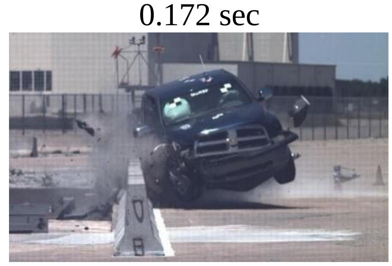

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Figure 25. Sequential Photographs, Test No. WITD-1

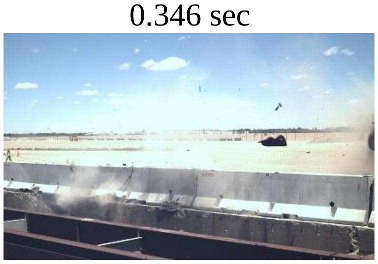
0.000 sec

0.046 sec

0.120 sec

0.212 sec

0.346 sec

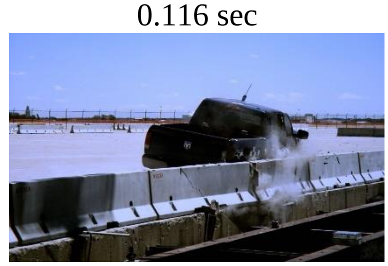


0.580 sec

0.000 sec

0.044 sec

0.116 sec



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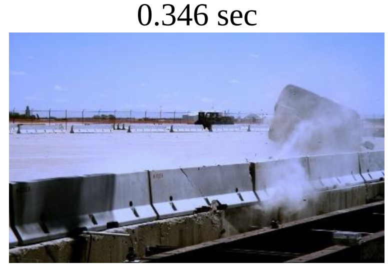


0.606 sec

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

Figure 27. Documentary Photographs, Test No. WITD-1

Figure 28. Additional Documentary Photographs, Test No. WITD-1

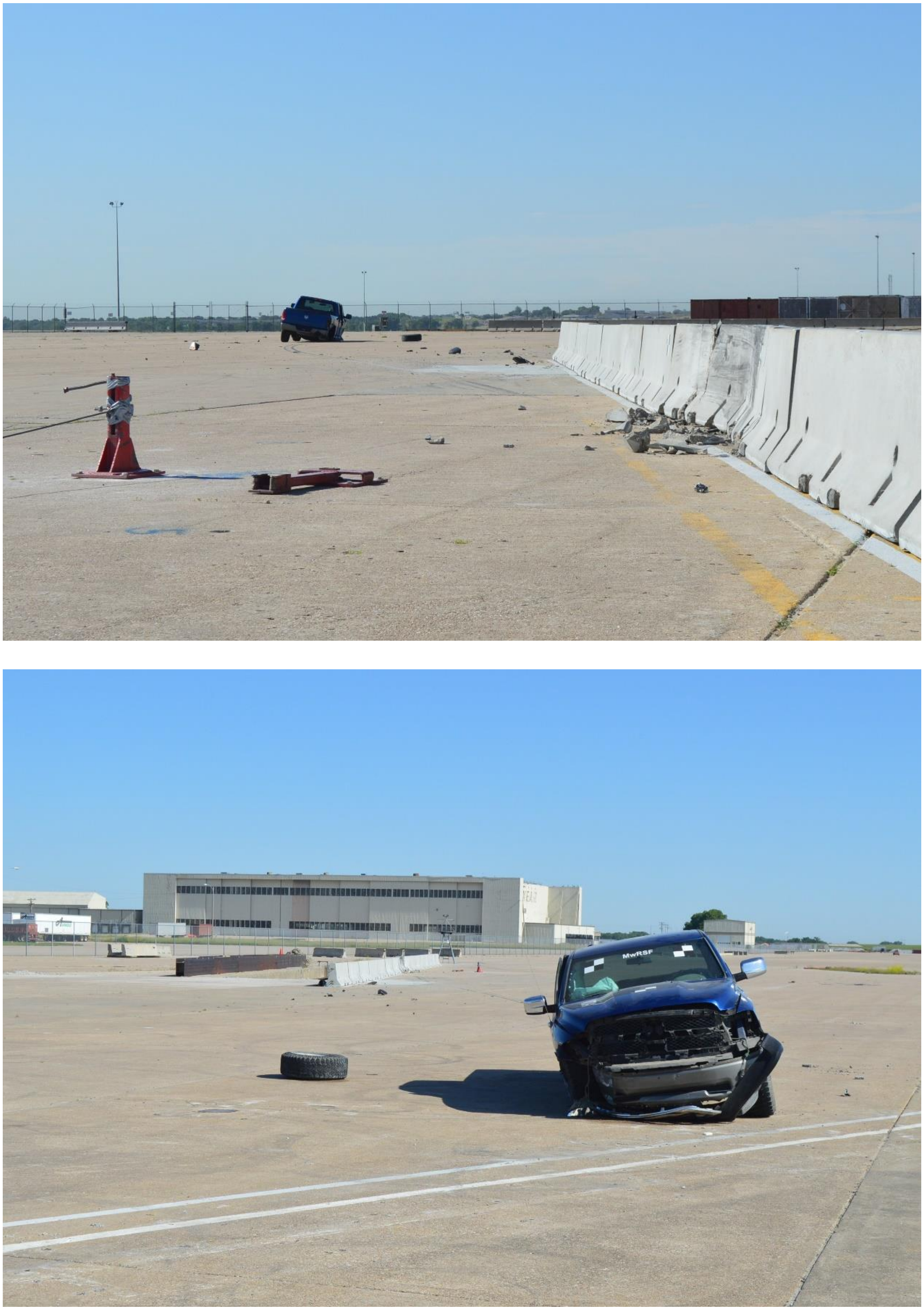


Figure 29. Vehicle Final Position and Trajectory Marks, Test No. WITD-1

Figure 30. System Damage – Front, Back, Downstream, and Upstream Views, Test No. WITD-1

Figure 31. System Damage at Impact Location, Test No. WITD-1

Figure 32. System Damage – Barrier No. 8 Traffic Side, Test No. WITD-1

Figure 33. System Damage – Additional Views of Damage on Barrier No. 8 Traffic Side, Test No. WITD-1

Figure 34. System Damage – Barrier No. 9 Traffic Side, Test No. WITD-1

Figure 35. System Damage – Additional Views of Damage on Barrier No. 9 Traffic Side, Test No. WITD-1

Figure 36. System Damage – Barrier Nos. 8 and 9 Non-Traffic Side, Test No. WITD-1

Tire marks were visible on the front face of barrier nos. 8 and 9. The front face of barrier no. 8 also contained extensive spalling, gouging, cracking and fracturing. Two major cracks were found 7 ft – 1⅜ in. (2.2 m) downstream from the upstream edge of barrier no. 8 and 7 ft – 4⅜ in. (2.2 m) downstream from the upstream edge of barrier no. 8, which extended across the front, top, and partially down the rear faces of the barrier. An additional major crack was found 4 ft – 2¾ in. (1.3 m) upstream from the downstream edge of barrier no. 8, which extended vertically across the front face of the barrier and terminated on the top face 3 ft – 10⅝ in. upstream from the downstream end of the barrier. These cracks measured 3 ft – ½ in. (0.9 m), 2 ft – 9⅞ in. (0.9 m), and 2 ft – 9¼ in. (0.8 m) in length, respectively. Minor cracks were also found across the front face of barrier no. 8 located 4 ft – 4¾ in. (1.3 m) downstream from the upstream edge and 2 ft – 1¾ in. (0.7 m) upstream from the downstream edge. Concrete spalling with disengaged pieces occurred on the front face of barrier no. 8. One disengaged piece of concrete measured 27¾ in. x 10½ in. x 7⅞ in. (705 mm x 267 mm x 200 mm) and was located 5 ft – 1 in. (1.5 m) downstream from the upstream edge of barrier no. 8. Another disengaged piece of concrete measured 39 in. x 6½ in. x 10⅜ in. (991 mm x 165 mm x 264 mm) and was located 3 ft – 7⅛ in. (1.1 m) upstream from the downstream edge of barrier no. 8. A 30½-in. (775-mm) long fracture was also found on the front face of barrier no. 8, starting 5 ft – 3 in. (1.6 m) downstream from the upstream edge of barrier no. 8 at its base and extending vertically through the entire barrier. A piece of concrete, measuring 29½ in. x 7⅝ in. x 3 in. (749 mm x 194 mm x 76 mm), disengaged from the back side of barrier no. 8 approximately 6 ft – 3½ in. (1.9 m) upstream from the downstream edge of the barrier.

The front face of barrier no. 9 had similar damage to the front face of barrier no. 8. A major crack originated at the base of the barrier 6 ft – 6½ in. (2.0 m) downstream from the upstream edge of barrier no. 9 and extended vertically 27½ in. (699-mm) across the front and top faces before terminating on the top rear edge. Significant spalling on the front face of barrier no. 9 occurred 1 ft – 1 in. (0.3 m) downstream from the upstream edge, 5 ft – 6⅛ in. (1.7 m) downstream from the upstream edge, and 2 ft – 8 ⅞ (0.8 m) upstream from the downstream edge; the disengaged pieces measured 23 in. x 5⅛ in. x 20¾ in. (584 mm x 130 mm x 527 mm), 19½ in. x 13 in. x 6½ in. (495 mm x 330 mm x 165 mm), and 19¼ in. x 5¼ in. x 12⅜ in. (489-mm x 133-mm x 314-mm), respectively. A fracture was found 4 ft – 9⅛ in. (1.5 m) downstream from the upstream edge of barrier no. 9 which began at the base and continued all the way through the top face. The back side of barrier no. 9 also encountered two major disengaged pieces of concrete, measuring 23½ in. (597 mm) and 65½ in. (1,664 mm) in length, and were found 9½ in. (241-mm) upstream from the downstream edge of barrier no. 9 and 1 ft – 10 in. (0.6 m) downstream from the upstream edge of barrier no. 9, respectively. The remaining barriers, as well as the joint connection pins between all barriers, showed no damage.

The anchor rods and anchor pockets in barrier nos. 8 and 9 were damaged. Anchor pocket nos. 2 and 3 (middle anchor and downstream pockets) in barrier no. 8 and all three anchor pockets in barrier no. 9 spalled and exposed the anchor pocket rebar loop bars. Anchor rod no. 3 (downstream anchor rod) in barrier no. 8 and anchor rod no.1 (upstream anchor) in barrier no. 9 bent and fractured at the ground line. The anchor pocket no. 2 (middle anchor pocket) exposed rebar loop bar in barrier no. 9 was also deformed downward. Anchor rods and anchor pockets on all remaining barriers remained undamaged.

The maximum lateral permanent set deflection of the barrier system was 8½ in. (216 mm), which occurred at the downstream end of barrier no. 8, as measured in the field. The maximum lateral dynamic barrier deflection, including barrier rotation of the top of the barrier, was 14.3 in. (363 mm) at the upstream end of barrier no. 9, as determined from high-speed digital video analysis. The working width of the system was found to be 36.8 in. (935 mm), also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 37.

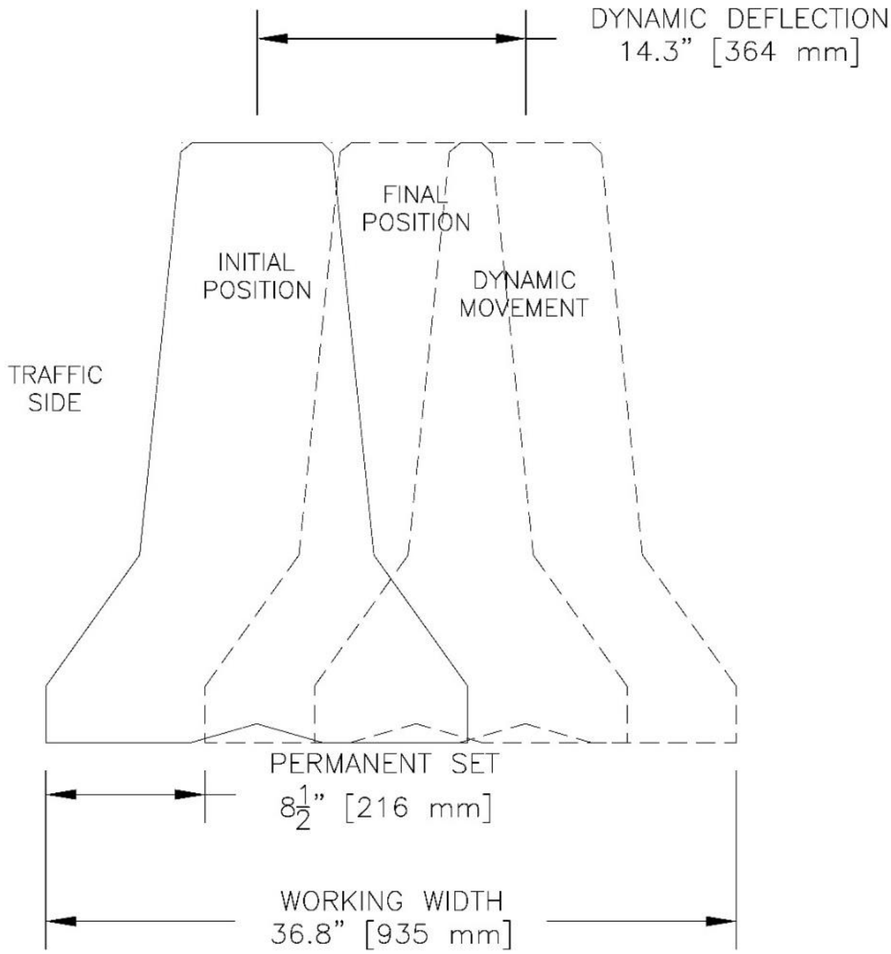


Figure 37. Permanent Set Deflection, Dynamic Deflection and Working Width, Test No. WITD-1

5.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 38 through 43. The maximum occupant compartment intrusions are listed in Table 5 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment and none of the established MASH 2016 deformation limits were violated. The A-pillar (lateral) and side door (above seat) deformed slightly outward, which is not considered crush toward the occupant, is denoted as negative numbers in Table 5, and is not evaluated by MASH 2016 criteria. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

Figure 38. Vehicle Damage, Test No. WITD-1

Figure 39 Vehicle Damage – Impact Side, Test No. WITD-1

Figure 40. Vehicle Damage – Impact Side, Test No. WITD-1

Figure 41.Vehicle Damage, Windshield Damage Test No. WITD-1

Figure 42. Occupant Compartment Damage, Test No. WITD-1

Figure 43. Undercarriage Vehicle Damage, Test No. WITD-1

Table 5. Maximum Occupant Compartment Intrusion by Location, Test No. WITD-1

LOCATION	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	¾ (19)	≤ 9 (229)
Floor Pan & Transmission Tunnel	⅛ (3)	≤ 12 (305)
A-Pillar	½ (13)	≤ 5 (127)
A-Pillar (Lateral)	-⅜ (-10)	N/A
B-Pillar	⅝ (16)	≤ 5 (127)
B-Pillar (Lateral)	½ (13)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	⅜ (10)	≤ 12 (305)
Side Door (Above Seat)	-2 (-51)	N/A
Side Door (Below Seat)	¼ (6)	≤ 12 (305)
Roof	⅛ (3)	≤ 4 (102)
Windshield	0 (0)	≤ 3 (76)
Side Window	Intact	No shattering resulting from contact with structural member of test article
Dash	⅝ (16)	N/A

Note: Negative values denote outward deformation
N/A – Not applicable

The majority of the damage was concentrated on the right-front corner and right side of the vehicle where the impact occurred. Scraping and contact marks extended the entire length of the vehicle on the right side. The right-rear taillight, the right-rear wheel, the right and left headlights, the front bumper fascia, and the grille disengaged from the vehicle. Numerous dents were found along the right side of the vehicle. The largest dent measured 43½ in. x 14 in. x 1¾ in. (1,105 mm x 356 mm x 44 mm) and was located near the rear edge of the right-front door. No other dent measured more than 20 in. (508 mm) long. Small bends or buckles were found on the right quarter panel, the brake backing plate, the right-rear door, and the right fender. Several larger kinks were visible on the front bumper where impact occurred. A few notable gouges were found on the right quarter panel just behind the right-rear door, one measuring 15 in. (381 mm) in length. Smaller gouges were scattered along the front bumper. The right-front, right-rear, and left-front doors all had gaps along their rear front and top edges. The right-rear door had the largest gap of 3¼ in. (83 mm) and the left-front door had the smallest gaps, never surpassing 2 in. (51 mm). Tearing was found near the right-front door, the side wall of the right-front tire, and the right side of the front bumper fascia. The right-front, left-front, and right-rear doors could not open because of their deformations. The windshield had a 25-in. x 6-in. (635-mm x 152-mm) spider-web crack. All other window glass as well as the roof remained undamaged. The left-front and left-rear wheels and doors were undamaged.

5.5 Occupant Risk

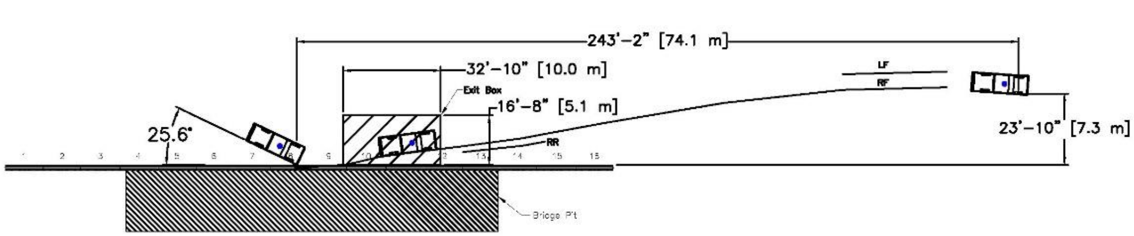
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 6. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 6. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

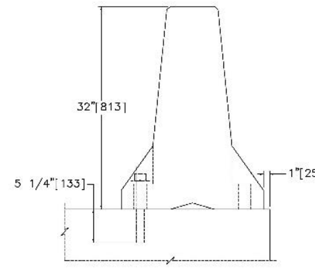
Table 6. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. WITD-1

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-13.14 (4.01)	-12.75 (3.89)	±40 (12.2)
	Lateral	-20.39 (6.21)	-22.29 (6.79)	±40 (12.2)
ORA g's	Longitudinal	-6.66	-6.69	±20.49
	Lateral	-20.41	-17.46	±20.49
MAX. ANGULAR DISPL. deg.	Roll	26.3	23.2	±75
	Pitch	-13.2	-14.8	±75
	Yaw	-38.9	-38.2	not required
THIV ft/s (m/s)		24.83 (7.57)	25.64 (7.81)	not required
PHD g's		21.42	18.61	not required
ASI		1.32	1.41	not required

5.6 Discussion

The analysis of the test results for test no. WITD-1 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 44. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 4.4 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. WITD-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.





- Test Agency .... MwRSF
- Test Number WITD-1
- Date 5/30/2017
- MASH 2016 Test Designation No. 3-11
- Test Article .... Bolted-Through Tie-Down F-Shape PCB
- Total Length .... 200 ft (61.0 m)
- Key Component – F-Shape PCB
  - Length .... 12 ft – 6 in. (3.8 m)
  - Width .... 22½ in. (572 mm)
  - Height .... 32 in. (813 mm)
- Key Component – Anchor Bolts
  - Pin Size .... 1⅛-in. (29-mm) diameter threaded rod
  - Pin Material .... ASTM A307 Grade A
  - Pin Length .... 12 in. (305 mm)
  - Embedment Depth .... 5¼ in. (133 mm)
  - Number of Pins per Barrier 3
  - Pinned Barrier Nos. 5-13
- Type of Support Surface .... Concrete Tarmac
- Vehicle Make /Model .... 2011 Dodge Ram 1500
  - Curb .... 4,950 lb (2,245 kg)
  - Test Inertial .... 5,000 lb (2,268 kg)
  - Gross Static .... 5,154 lb (2,338 kg)
- Impact Conditions
  - Speed .... 62.0 mph (99.8 km/h)
  - Angle .... 25.6 deg.
  - Impact Location .... 3 ft – $8^{5}/_{16}$ in. (1125.5 mm) upstream from joint 8-9
- Impact Severity ......119.7 kip-ft (162.3 kJ) > 106 kip-ft (144 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 49.7 mph (80.0 km/h)
  - Angle .... 4.4 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 243 ft – 2 in. (74.1 m) downstream
  23 ft – 10 in. (7.3 m) laterally in front
- Vehicle Damage .... Moderate
  - VDS [13] 01-RFQ-3
  - CDC [14] 01-RYEW-3
  - Maximum Interior Deformation .... ¾ in. (19.1 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 8½ in. (216 mm)
  - Dynamic .... 14.3 in. (363 mm)
  - Working Width .... 36.8 in. (935 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-13.14 (4.01)	-12.75 (3.89)	±40 (12.2)
	Lateral	-20.39 (6.21)	-22.29 (6.79)	±40 (12.2)
ORA g's	Longitudinal	-6.66	-6.69	±20.49
	Lateral	-20.41	-17.46	±20.49
MAX ANGULAR DISP. deg.	Roll	26.3	23.2	±75
	Pitch	-13.2	-14.8	±75
	Yaw	-38.9	-38.2	not required
THIV – ft/s (m/s)		24.83 (7.57)	25.64 (7.81)	not required
PHD – g's		21.42	18.61	not required
ASI		1.32	1.41	not required

Figure 44. Summary of Test Results and Sequential Photographs, Test No. WITD-1

6 DESIGN DETAILS – TEST NO. WITD-2

The test installation consisted of sixteen 12-ft 6-in. (3.8-m) long WisDOT PCBs in a pinned, tie-down configuration for use with asphalt, as shown in Figures 45 through 55. Photographs of the test installation are shown in Figures 56 and 57. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

The concrete mix for the barrier sections required a minimum compressive strength of 5,000 psi (34.5 MPa) and a minimum concrete cover of 2 in. (51 mm) was specified for the barriers. Each PCB was reinforced with ASTM A615 Grade 60 rebar. The barrier sections used a connection pin, as shown in Figure 53. Each connection pin measured 28 in. (711 mm) in length, 1¼ in. (32 mm) in diameter, and was used to interlock the ¾-in. diameter ASTM A705 Grade 60 connection loop bars, as shown in Figures 49 and 50.

The barrier installation was placed on top of a 2-in. (51-mm) thick asphalt pad composed of NE SPS mix with 52-34 grade binder. The thickness of the asphalt pad was identical to the thickness used in the original NCHRP Report No. 350 evaluation of the steel pin tie-down for asphalt road surfaces. In the original research study, dynamic component testing of steel pins in asphalt was conducted. For these tests, steel pins with diameters of 1.125-in. (28.575-mm) and 1.5-in. (38.1-mm) were tested with 2-in. (51-mm), 4-in. (102-mm), and 6-in. (152-mm) asphalt cover depths. Review of the test data from the component tests with the various asphalt depths found that the amount of asphalt cover had little or no effect on the steel pin performance. Thus, full-scale testing was conducted with a minimal asphalt depth to evaluate the most critical case. A similar approach was applied in this testing. The rear toe of the PCBs were installed 6 in. (152 mm) from the edge of a 36-in. wide x 36-in. deep (914-mm x 914-mm) trench, as shown in Figures 45 through 48. During installation, the barrier segments were pulled in a direction parallel to the longitudinal axis of the system, and slack was removed in all joints. After slack was removed from all the joints, barrier nos. 6 through 14 were each anchored on the traffic side of the barrier with three 38½-in. long x 1½-in. diameter (978-mm x 38-mm) ASTM A36 pins driven through the bolt anchor pockets as shown in Figures 48 and 49. The steel anchor pins were embedded to a depth of 32 in. (813 mm), as shown in Figure 46.

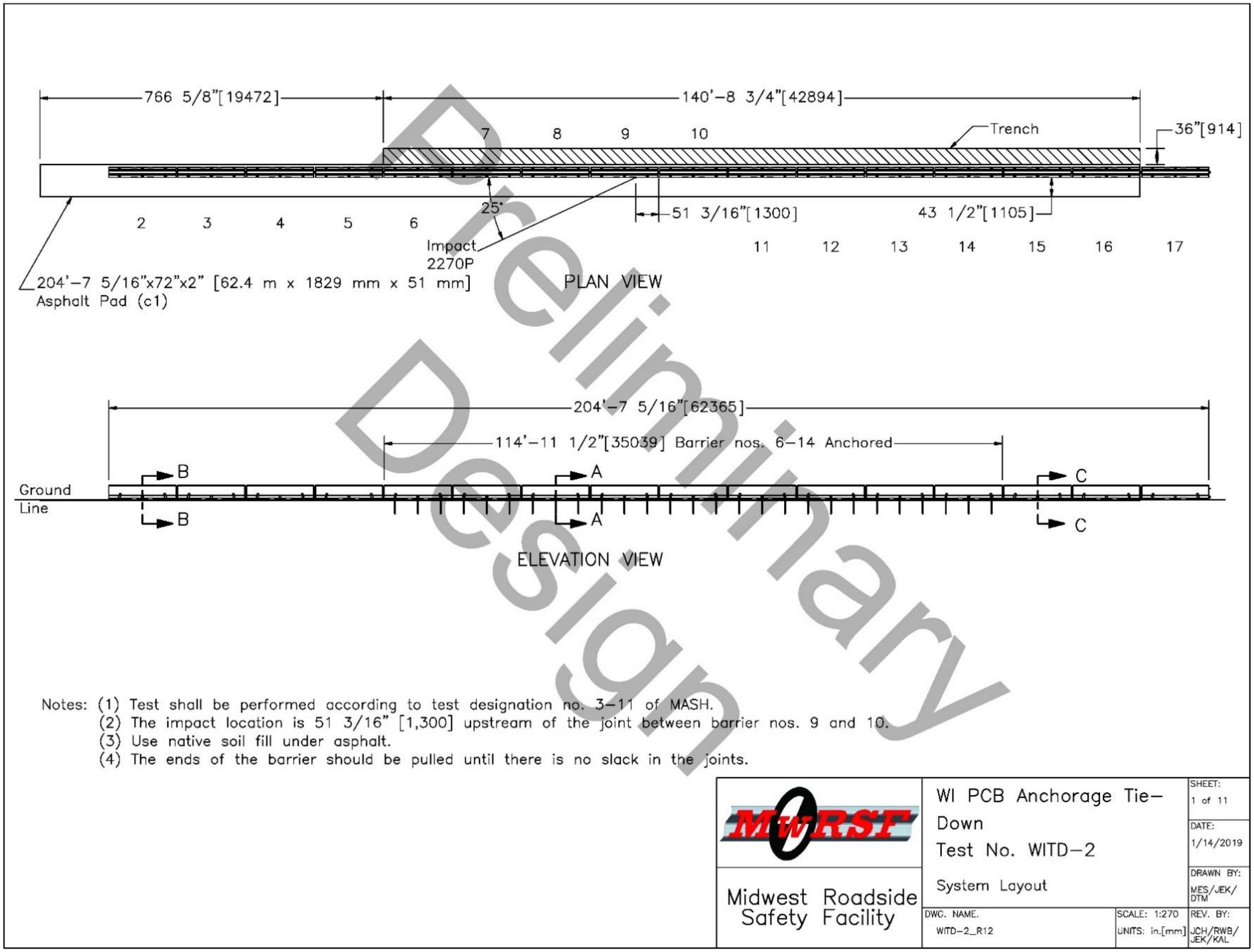


Figure 45. System Layout, Test No. WITD-2

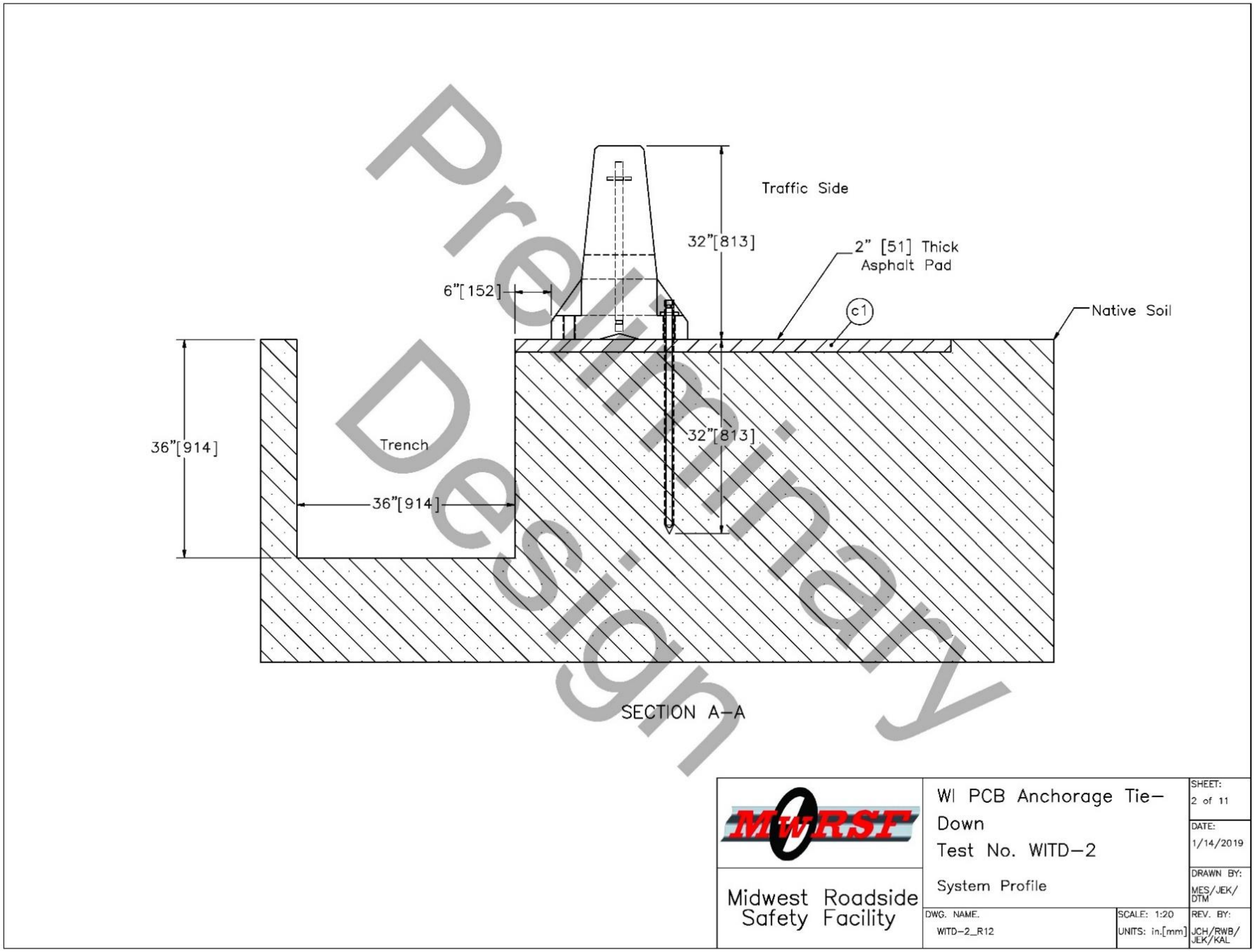


Figure 46. System Profile, Test No. WITD-2

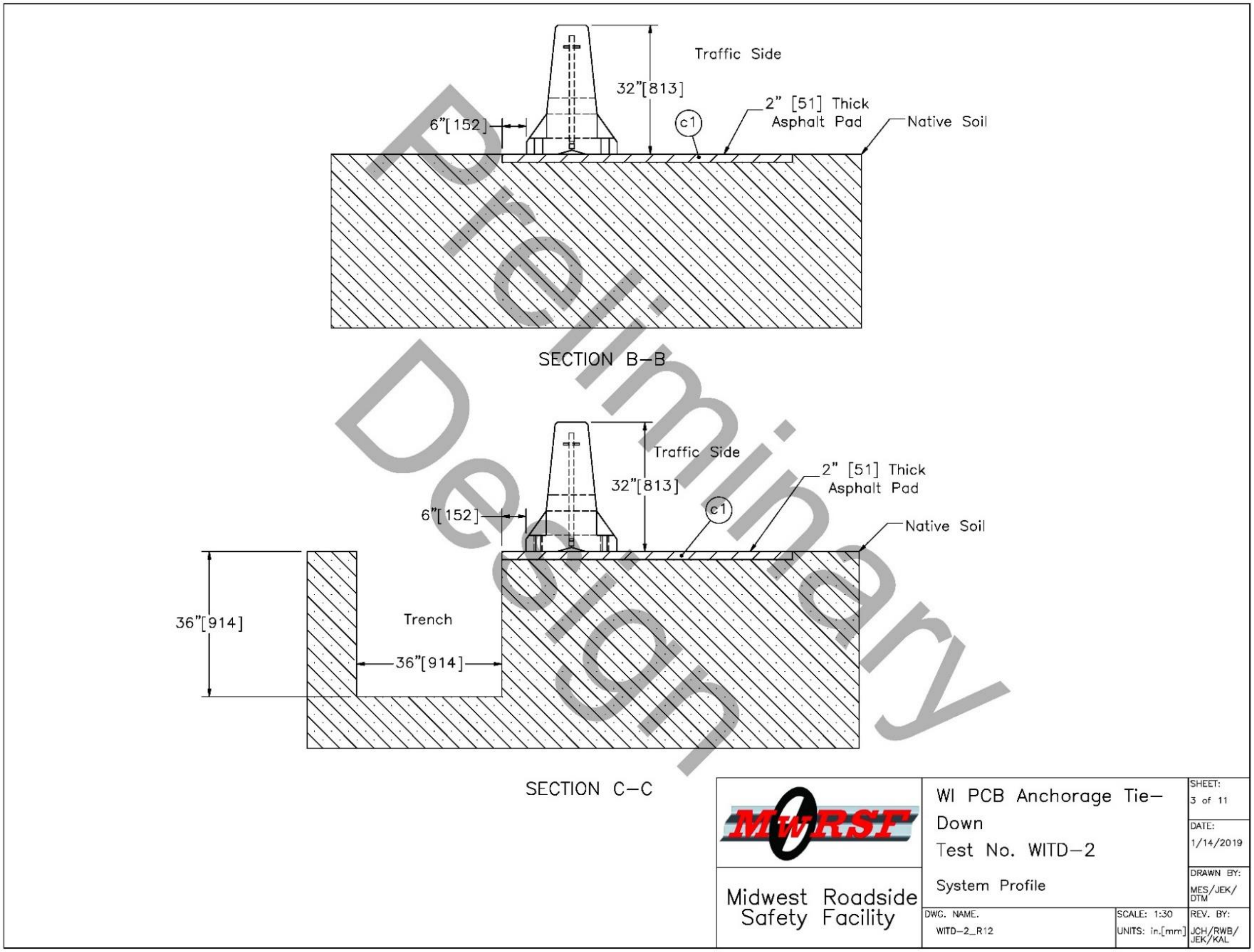


Figure 47. System Profile, Test No. WITD-2

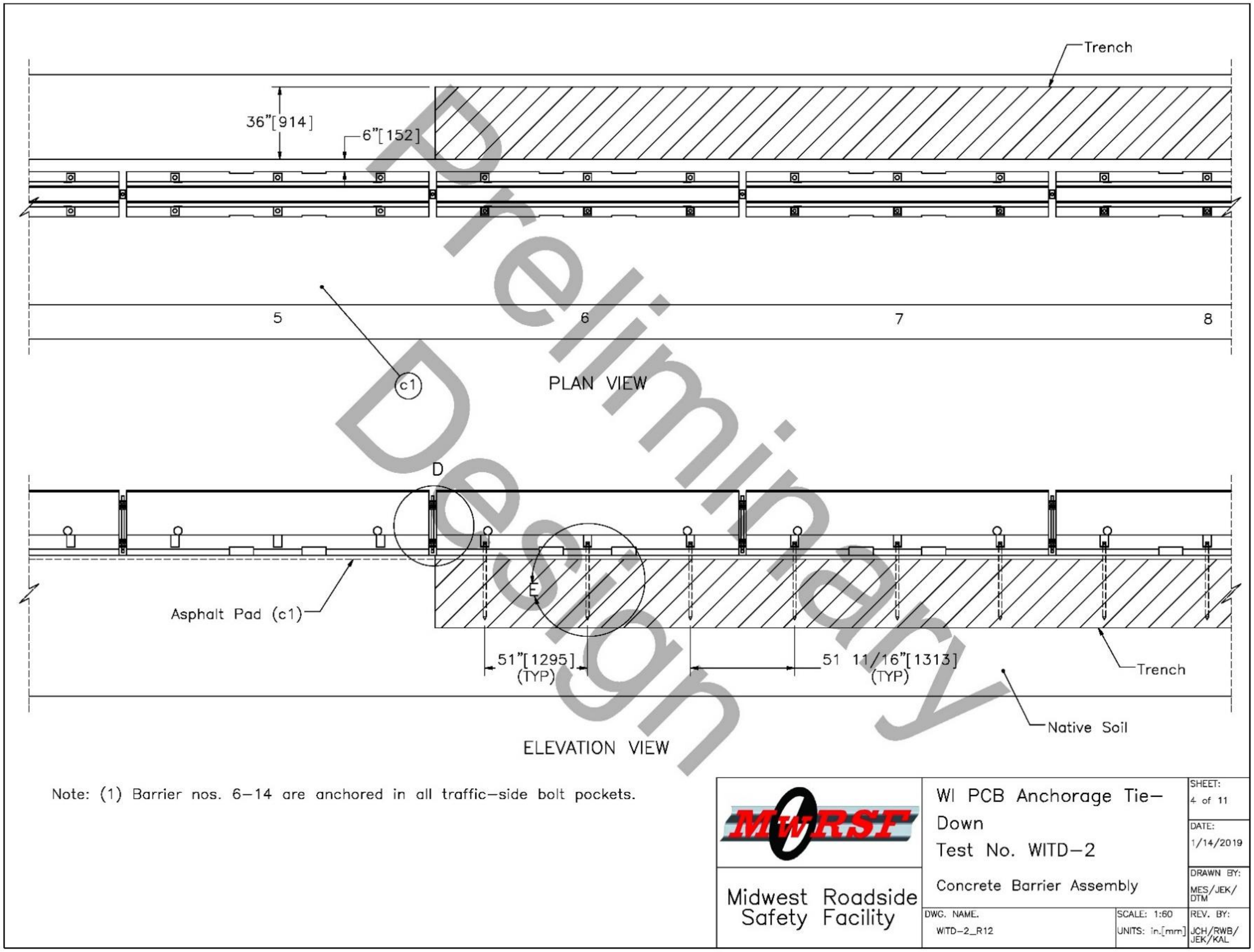


Figure 48. Concrete Barrier Assembly, Test No. WITD-2

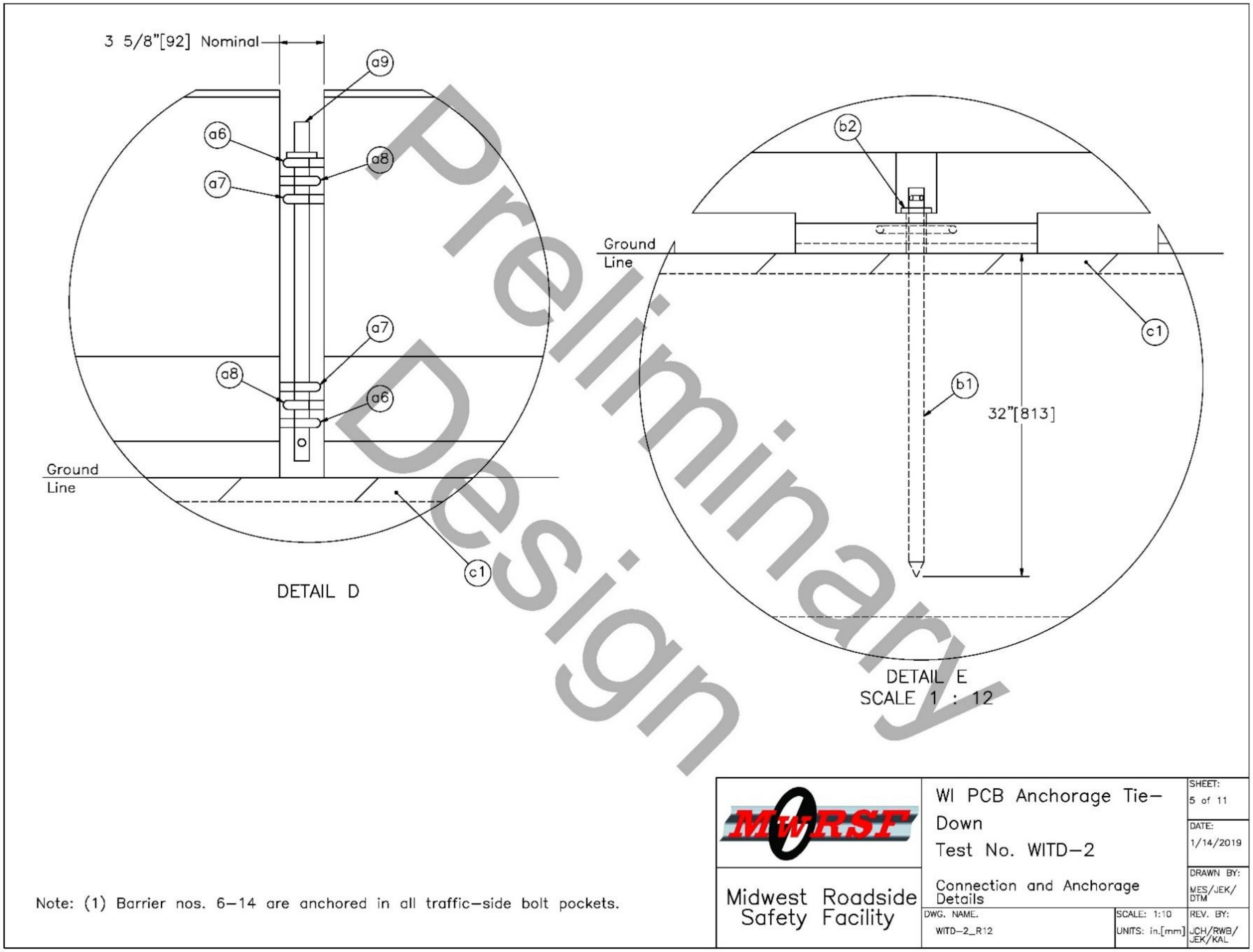


Figure 49. Connection and Anchorage Details, Test No. WITD-2

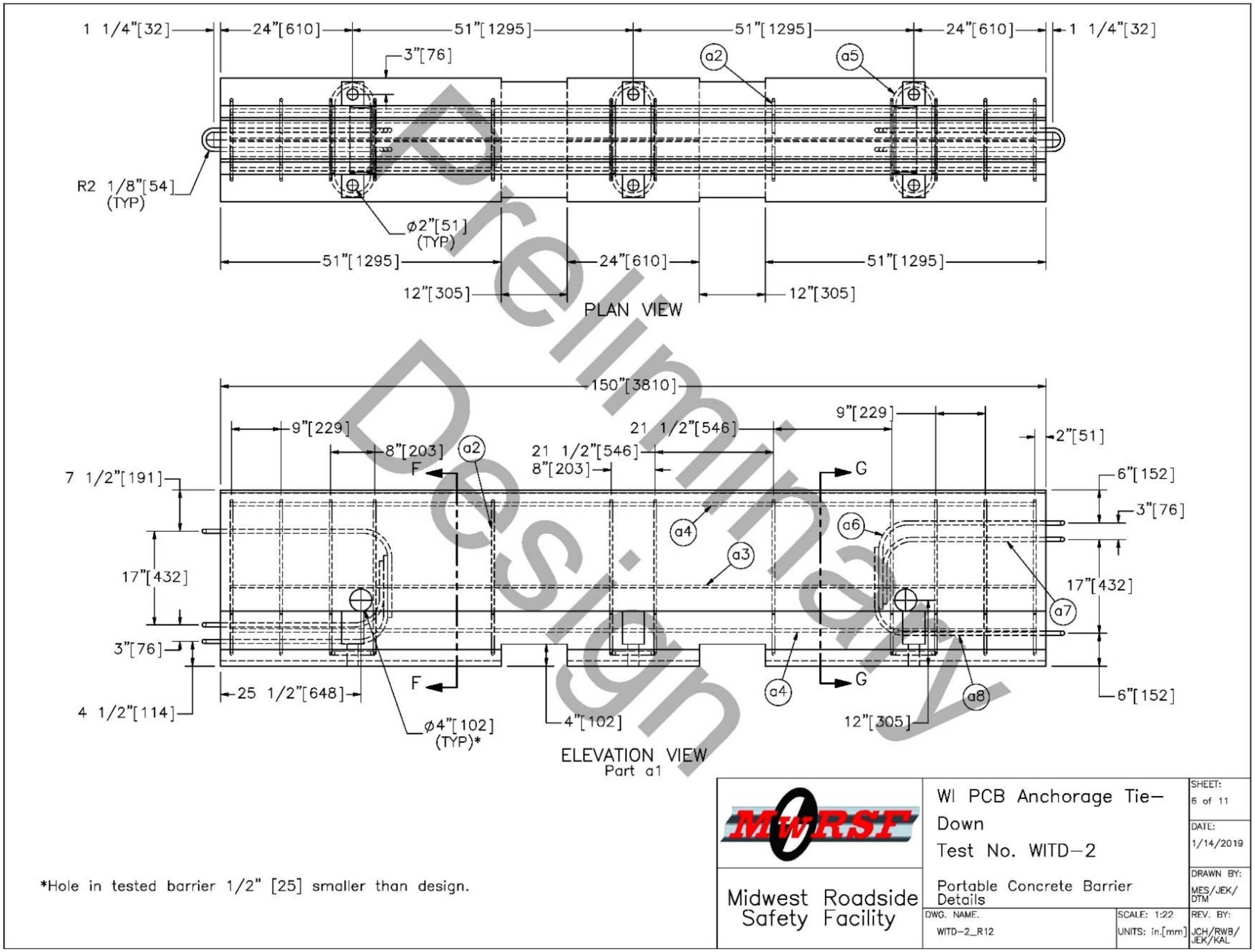


Figure 50. Portable Concrete Barrier Details, Test No. WITD-2

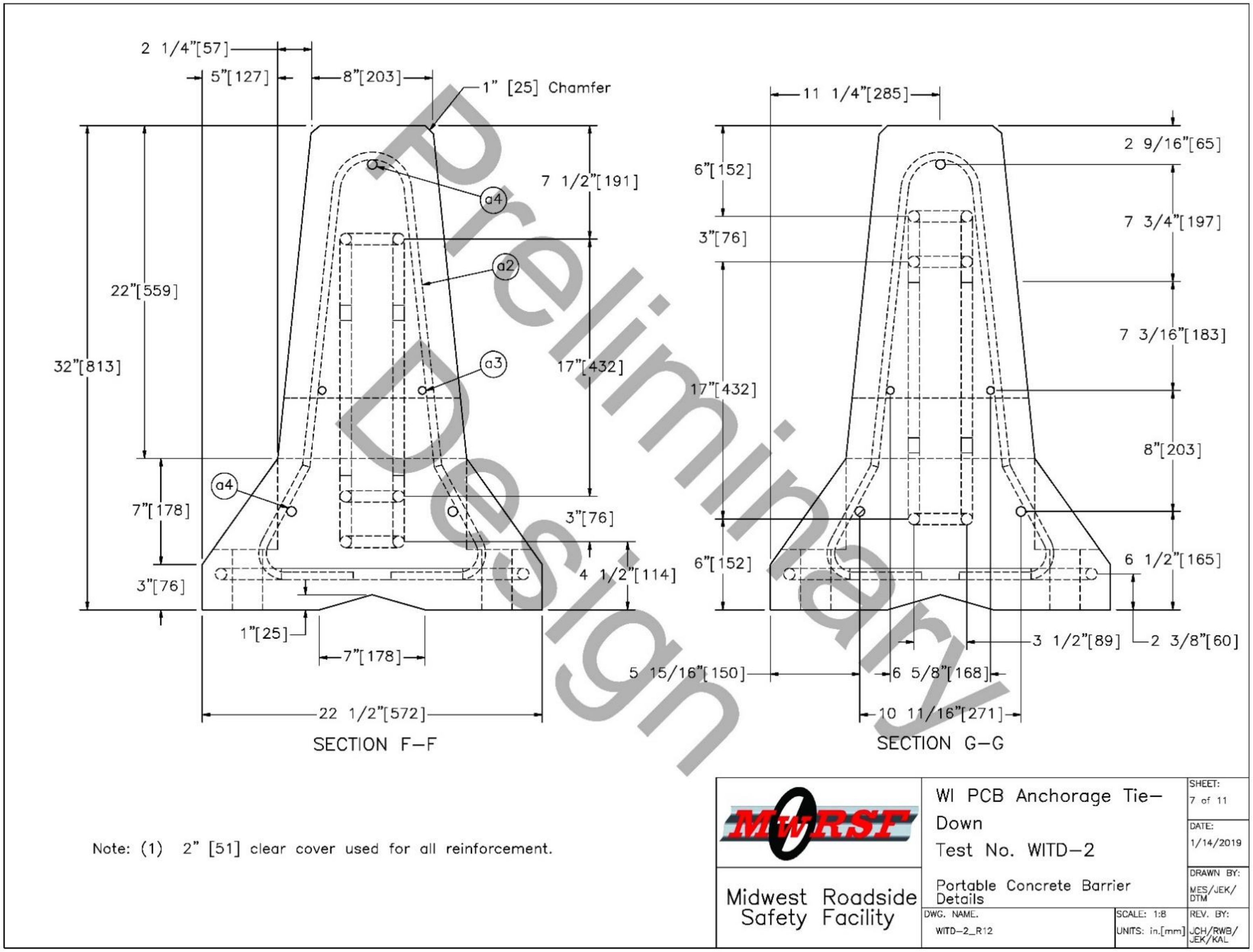
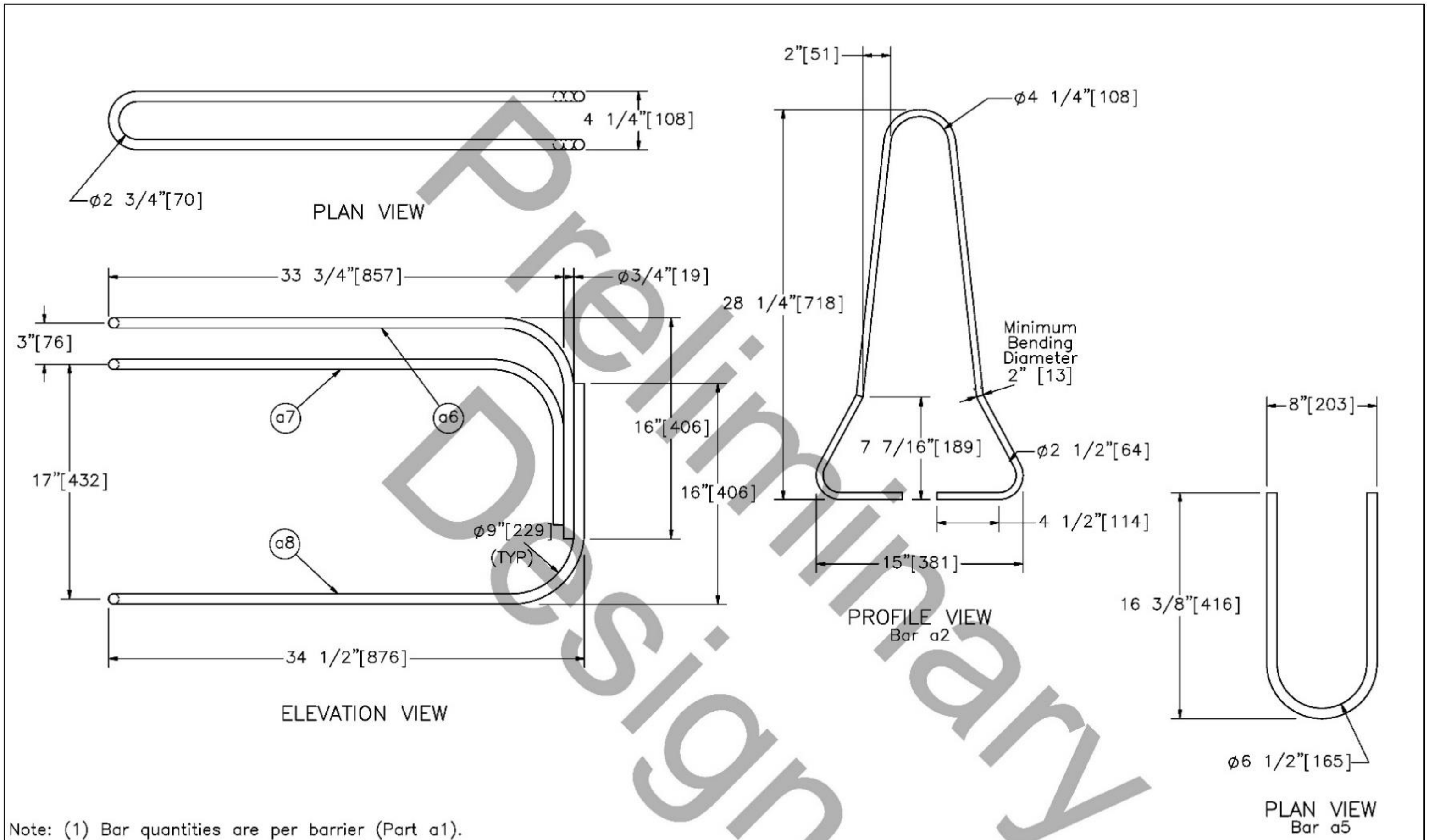


Figure 51. Portable Concrete Barrier Details, Test No. WITD-2



Note: (1) Bar quantities are per barrier (Part a1).

Bill of Bars

Bar	QTY	Size	Total Length	Material
a2	12	#4	72"[1829]	A615 Gr.60
a3	2	#4	146"[3708]	A615 Gr.60
a4	3	#5	146"[3708]	A615 Gr.60
a5	6	#6	35"[889]	A615 Gr.60
a6	2	#6	101"[2565]	A709 Gr.70 or A706 Gr.60
a7	2	#6	91"[2311]	A709 Gr.70 or A706 Gr.60
a8	2	#6	102"[2591]	A709 Gr.70 or A706 Gr.60

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WI PCB Anchorage Tie-Down
Test No. WITD-2

Portable Concrete Barrier Rebar Details

SHEET: 8 of 11
DATE: 1/14/2019
DRAWN BY: MES/JEK/DTM
DWG. NAME. WITD-2_R12
SCALE: 1:10
UNITS: in.[mm]
REV. BY: JCH/RWB/JEK/KAL

Figure 52. Portable Concrete Barrier Rebar Details, Test No. WITD-2

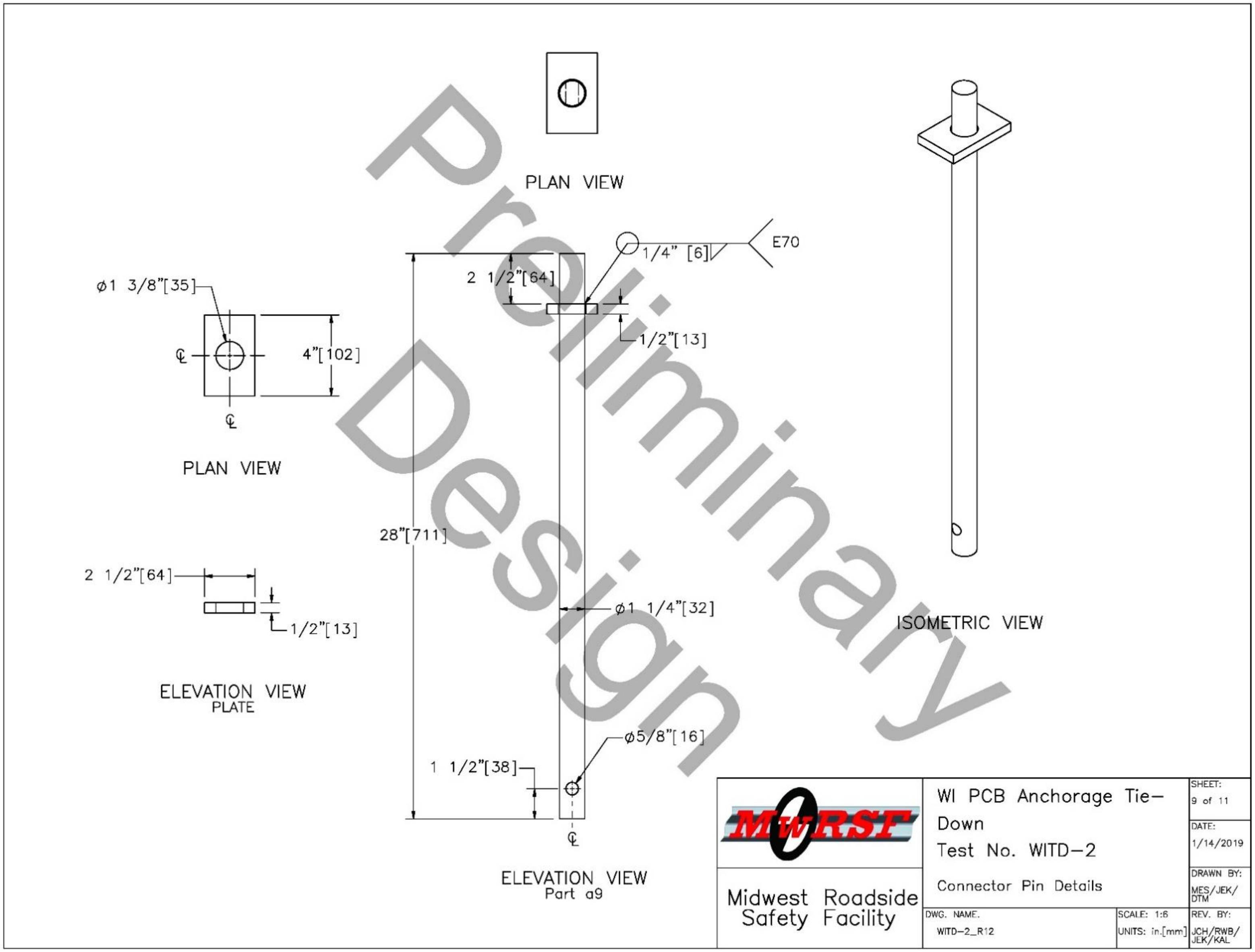

Figure 53. Connector Pin Details, Test No. WITD-2

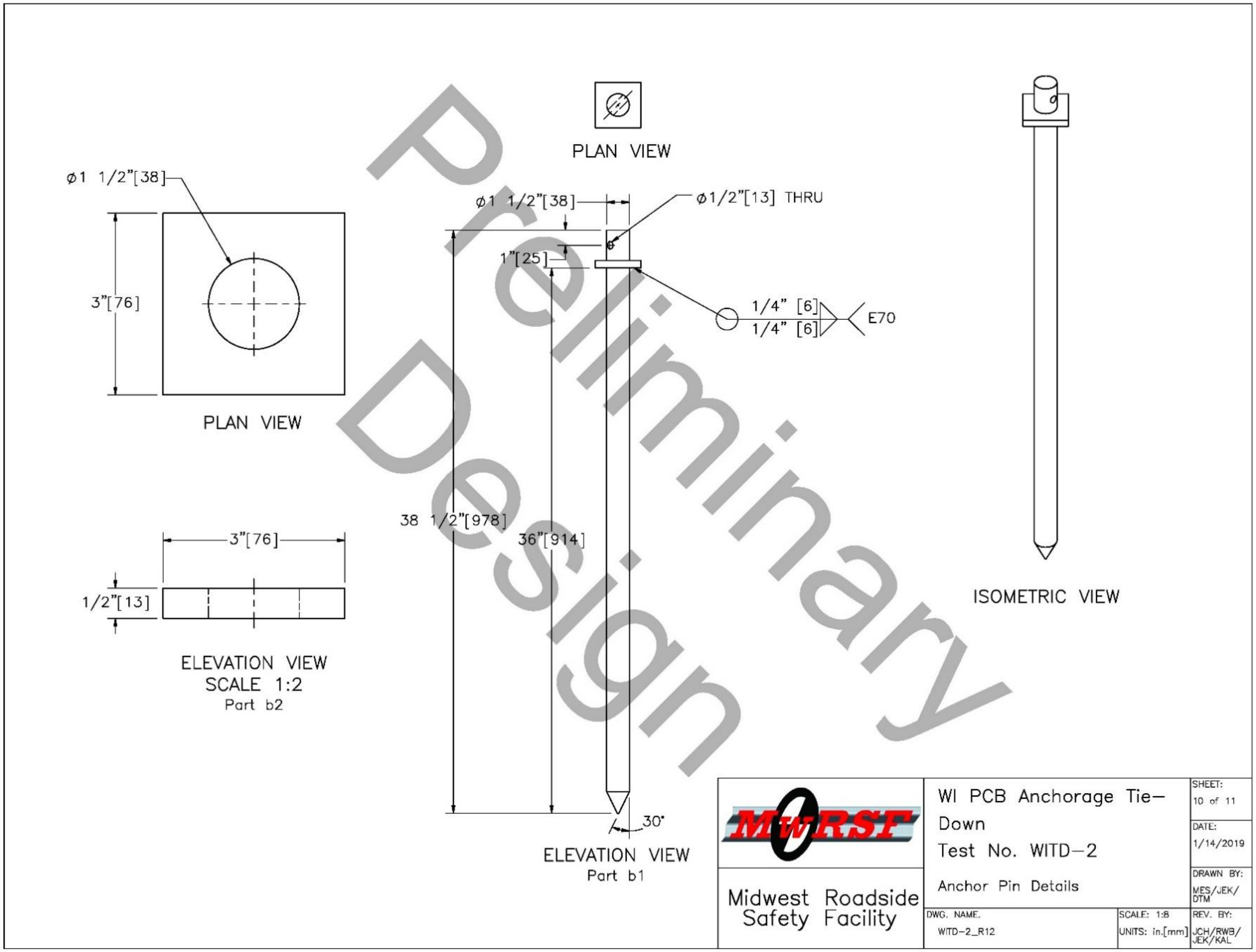

Figure 54. Anchor Pin Details, Test No. WITD-2

Item No.	QTY.	Description	Material Specification	Galvanization Specification	Hardware Guide
a1	16	Portable Concrete Barrier	Min f'c = 5,000 psi [34.5 MPa]	–	SWC09
a2	192	1/2" [13] Dia., 72" [1829] Long Form Bar	ASTM A615 Gr. 60	–	SWC09*
a3	32	1/2" [13] Dia., 146" [3708] Long Longitudinal Bar	ASTM A615 Gr. 60	–	SWC09*
a4	48	5/8" [16] Dia., 146" [3708] Long Longitudinal Bar	ASTM A615 Gr. 60	–	SWC09*
a5	96	3/4" [19] Dia., 36" [914] Long Anchor Loop Bar	ASTM A615 Gr. 60	–	SWC09*
a6	32	3/4" [19] Dia., 101" [2565] Long Connection Loop Bar	ASTM A709 Gr. 70 or A706 Gr. 60	–	SWC09*
a7	32	3/4" [19] Dia., 91" [2311] Long Connection Loop Bar	ASTM A709 Gr. 70 or A706 Gr. 60	–	SWC09*
a8	32	3/4" [19] Dia., 102" [2591] Long Connection Loop Bar	ASTM A709 Gr. 70 or A706 Gr. 60	–	SWC09*
a9	15	1 1/4" [32] Dia., 28" [711] Long Connector Pin	ASTM A36	–	FMW02
b1	27	1 1/2" [38] Dia., 38 1/2" [978] Long Anchor Pin	ASTM A36	ASTM A123 ***	FRS01
b2	27	3"x3"x1/2" [76x76x13] Washer Plate	ASTM A36	ASTM A123 ***	FRS01**
c1	1	2400"x72"x2" [60,960x183x51] Asphalt Pad	NE SPS Mix with 52–34 Grade Binder	–	–

* Included in SWC09 hardware guide designation.
** Included in FRS01 hardware guide designation.
*** Component does not need to be galvanized for testing purposes.

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WI PCB Anchorage Tie–Down
Test No. WITD–2
Bill of Materials

SHEET: 11 of 11
DATE: 1/14/2019
DRAWN BY: MES/JEK/DTM
DWG. NAME. WITD–2_R12
SCALE: 1:768
UNITS: in.[mm]
REV. BY: JCH/RWB/JEK/KAL

Figure 55. Bill of Materials, Test No. WITD-2

Figure 56. Test Installation Photographs, Test No. WITD-2

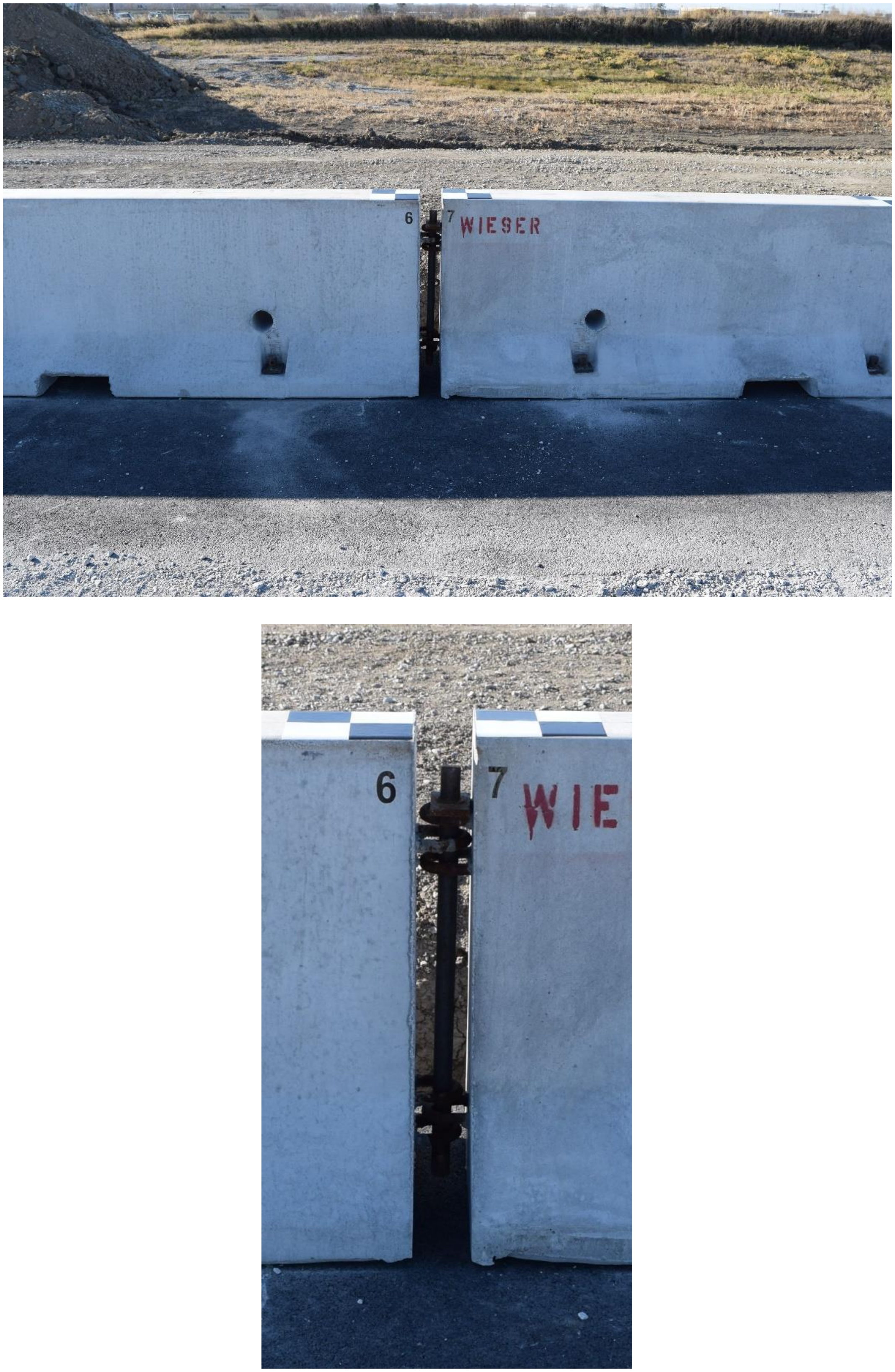


Figure 57. Connection and Anchor Pin Details, Test No. WITD-2

7 FULL-SCALE CRASH TEST NO. WITD-2

7.1 Static Soil Test

Before full-scale crash test no. WITD-2 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. While no baseline soil test with identical properties was available for direct comparison, a static soil test was still conducted to ensure that the soil beneath the asphalt pad was consistent with previous soils used at MwRSF for MASH testing, as shown in Appendix C. The static test results found that the in-situ soil used for test no. WITD-2 developed higher loads when compared with previous static soil baseline tests used for MwRSF testing. Thus, the in-situ soil was deemed acceptable for evaluation of the anchored PCB system in test no. WITD-2.

7.2 Weather Conditions

Test no. WITD-2 was conducted on November 22, 2017 at approximately 2:40 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 7.

Table 7. Weather Conditions, Test No. WITD-2

Temperature	43° F
Humidity	34%
Wind Speed	14 mph
Wind Direction	190° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.06 in.

7.3 Test Description

Initial vehicle impact was to occur 4 ft – $3^3/_{16}$ in. (1.3 m) upstream from the centerline of the joint between barrier nos. 9 and 10, as shown in Figure 58, which was selected using Table 2.7 of MASH 2016. The 5,003-lb (2,269-kg) quad cab pickup truck impacted the pinned, tie-down PCB system on asphalt at a speed of 62.0 mph (99.8 km/h) and at an angle of 25.1 degrees. The actual point of impact was 4.3 in. (109 mm) downstream from the target location. The vehicle came to rest 160 ft – 4 in. (48.9 m) downstream from the impact point and 8 ft – 11 in. (2.7 m) laterally behind the traffic side of the barrier after brakes were applied.

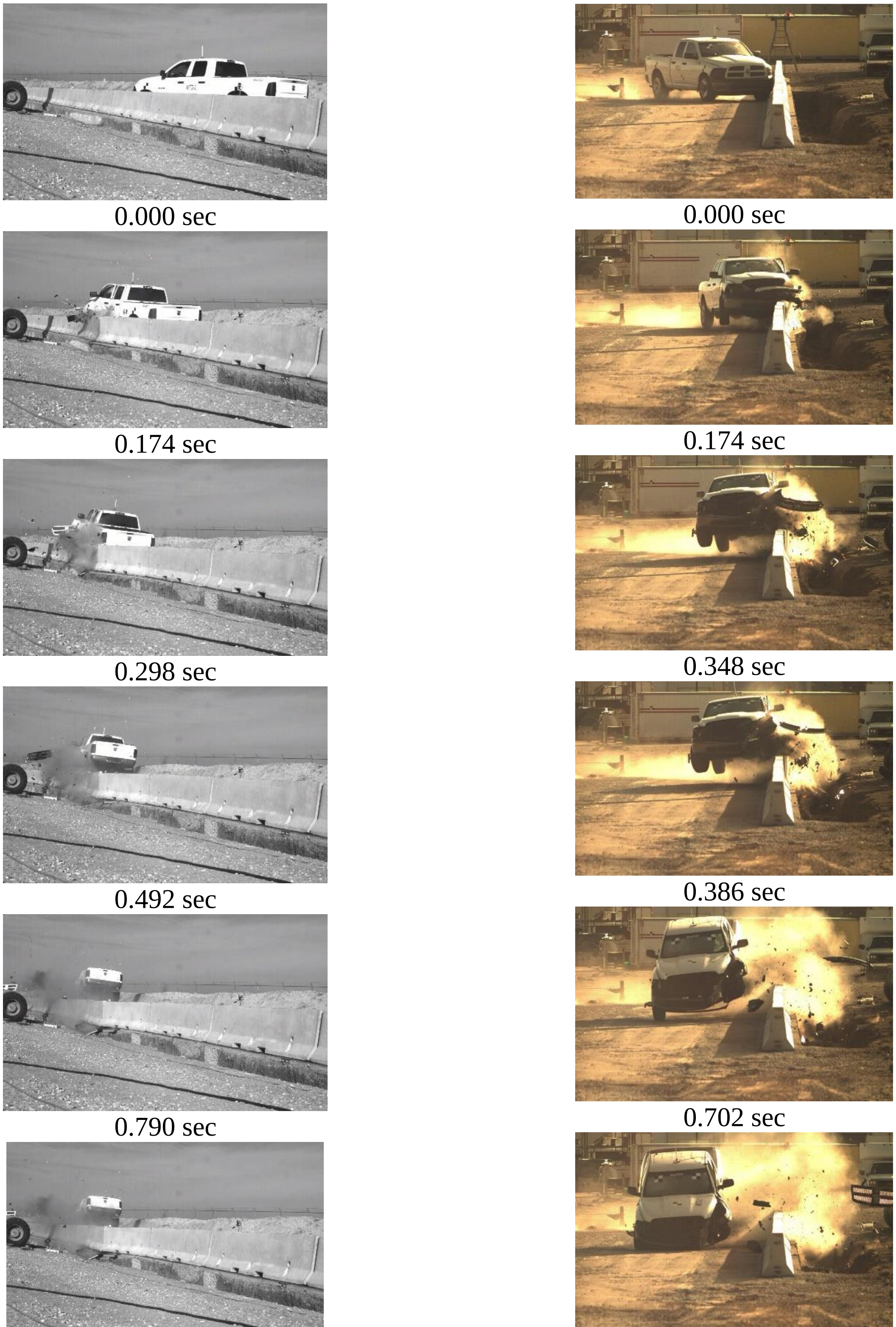
A detailed description of the sequential impact events is contained in Table 8. Sequential photographs are shown in Figures 59 and 60. Documentary photographs of the crash test are shown in Figure 61. The vehicle trajectory and final position are shown in Figure 62.

Note that the barriers in the system are numbered as 2 through 17. The referenced events, impact, and system damage contained within the report reference the numbers that appear on the physical barriers.

Figure 58. Impact Location, Test No. WITD-2

Table 8. Sequential Description of Impact Events, Test No. WITD-2

TIME (sec)	EVENT
0.000	Vehicle’s left-front tire contacted barrier no. 9 at 3 ft – 10.9 in. (1.2 m) upstream from the centerline of the joint between barrier nos. 9 and 10.
0.002	Vehicle’s front bumper contacted barrier no. 9.
0.018	Barrier no. 9 rotated counterclockwise about its upstream end.
0.022	Vehicle’s grille contacted barrier no. 9 and vehicle yawed away from barrier.
0.026	Asphalt and soil beneath barriers no. 9 and no. 10 displaced laterally.
0.042	Barrier no. 10 rotated clockwise about its downstream end.
0.066	Vehicle’s left-front wheel snagged on joint between barrier nos. 9 and 10.
0.076	Barrier no. 10 cracked on back side between midspan and upstream end of barrier.
0.086	Barrier no. 10 rolled away from traffic side of system.
0.110	Concrete barrier no. 11 rotated clockwise about its downstream end.
0.116	Vehicle’s right-front tire became airborne.
0.122	Barrier no. 11 rolled away from traffic side of system.
0.174	Barrier no. 12 rotated clockwise about its downstream end.
0.254	Vehicle was parallel to system at a speed of 46.5 mph (74.8 km/h).
0.282	Vehicle’s right-rear tire became airborne.
0.348	Vehicle’s left-front tire became airborne.
0.386	Vehicle exited system at a speed of 49.0 mph (78.8 km/h) and angle of 8.2 degrees.
0.440	Vehicle’s left-rear tire became airborne.
0.492	Asphalt and soil underneath the backside downstream end of concrete barrier no. 9 disengaged from the surrounding soil.
0.702	Vehicle’s right-front tire regained contact with ground.
0.766	Vehicle’s front bumper contacted ground.
0.872	Vehicle’s left-front tire regained contact with ground.
0.996	Vehicle’s left-rear tire regained contact with ground.
1.020	Vehicle’s right-front tire became airborne.
1.072	Vehicle’s right-rear tire regained contact with ground.
1.174	Vehicle’s right-front tire regained contact with ground.
1.504	Vehicle’s right-front tire became airborne.
1.634	Vehicle’s right-front tire regained contact with ground.



0.000 sec

0.174 sec

0.298 sec

0.492 sec

0.790 sec

0.830 sec

0.000 sec

0.174 sec

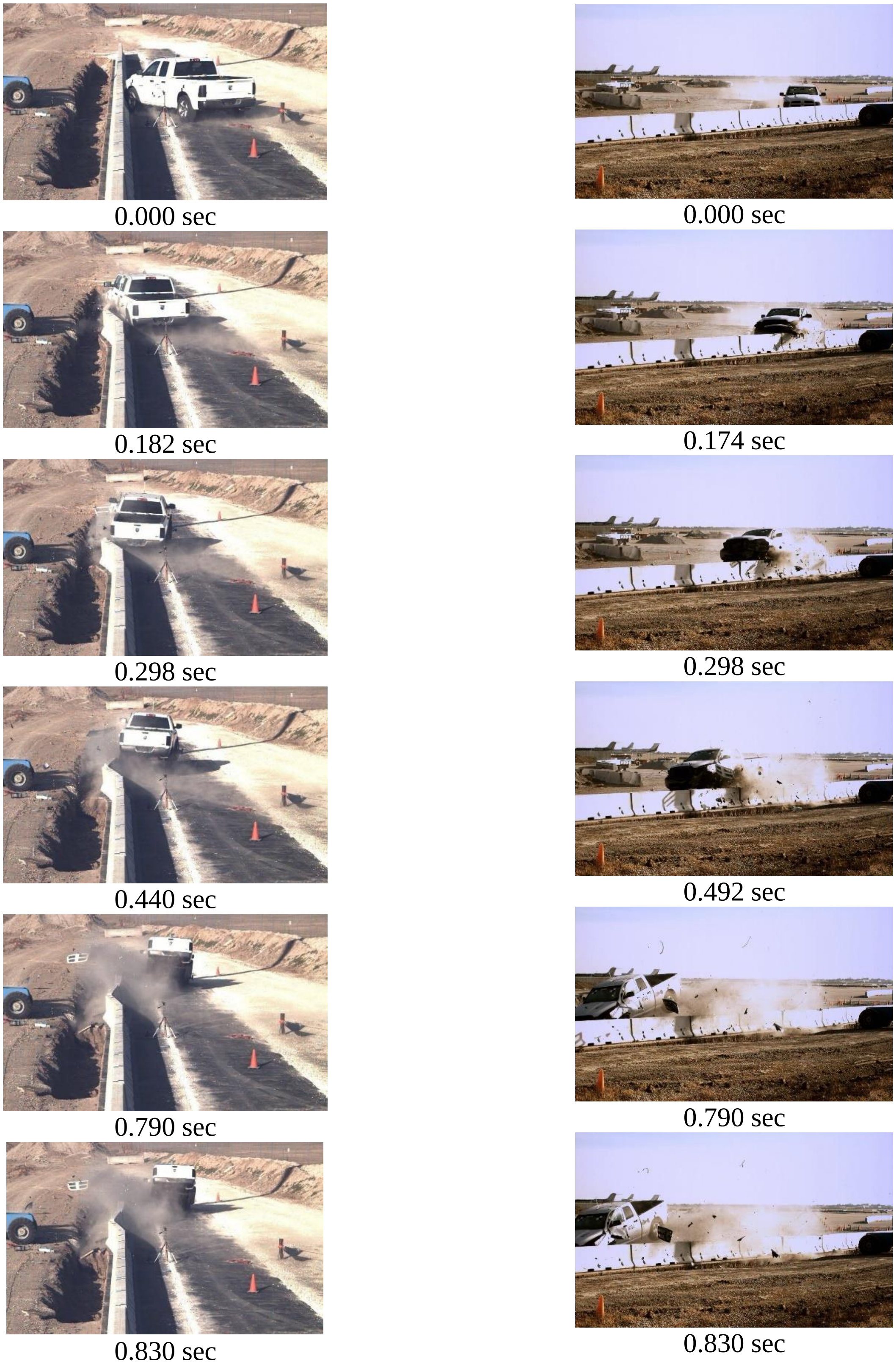
0.348 sec

0.386 sec

0.702 sec

0.830 sec

Figure 59. Additional Sequential Photographs, Test No. WITD-2



0.000 sec | 0.000 sec
0.182 sec | 0.174 sec
0.298 sec | 0.298 sec
0.440 sec | 0.492 sec
0.790 sec | 0.790 sec
0.830 sec | 0.830 sec

Figure 60. Additional Sequential Photographs, Test No. WITD-2

Figure 61. Documentary Photographs, Test No. WITD-2

Figure 62. Vehicle Final Position and Trajectory Marks, Test No. WITD-2

7.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 63 through 70. Barrier damage consisted of contact marks on the front face of the concrete segments, spalling of the concrete, and concrete and asphalt cracking. The length of vehicle contact along the barrier spanned from 7 in. (178 mm) downstream from the centerline of barrier no. 9 to 7 in. (178 mm) downstream from the upstream edge of barrier no. 11.

Tire marks were visible on the front face of barrier nos. 9, 10, and 11. Barrier no. 8 had a 14-in. (356-mm) long crack starting 31½ in. (800 mm) upstream from the downstream end of barrier no. 8. A large vertical crack located 45 in. (1143 mm) downstream from the upstream edge of barrier no. 9 extended along the entire height of the barrier, including 6 in. (152 mm) onto its top surface. Two more vertical cracks on barrier no. 9 extended completely through its top surface, located 22 in. (559 mm) and 28 in. (711 mm) downstream from the centerline, respectively. Barrier no. 10 had a large crack, starting 50 in. (1270 mm) downstream from the upstream edge and 3 in. (76 mm) from the bottom of barrier no. 10, which extended diagonally 16 in. (406 mm) downstream, 13 in. (330 mm) upward, and penetrated through the back side of the barrier. Barrier no. 11 had two major cracks: (1) a vertical crack began 12 in. (305 mm) upstream from the centerline of the barrier and spanned the entire barrier height and (2) a 22-in. (559-mm) long horizontal crack began 9½ in. (241 mm) upstream from the centerline of the barrier.

Barrier nos. 9, 10, and 11 encountered concrete spalling. An 11-in. (219-mm) long piece of concrete, located 11 in. (279 mm) from the base of the barrier, disengaged from barrier no. 9. Another piece of concrete, measuring 23 in. x 5 in. x 2 in. (584 mm x 127 mm x 51 mm) and located at the toe of barrier no. 9 around the farthest downstream anchor pin, disengaged from barrier no. 9 and exposed the steel reinforcement. Two pieces of concrete, measuring 20 in. x 9½ in. x 4 in. (508 mm x 241 mm x 102 mm) and 28 in. x 4½ in. x 2 in. (711 mm x 114 mm x 51 mm), disengaged from the toe of barrier no. 10. The steel reinforcement for the anchor pockets approximately 16 in. (406 mm) downstream from the upstream edge of barrier no. 10 and 32 in. (813 mm) upstream from the downstream edge of barrier no. 10 were exposed.

A piece of concrete at the front-upstream corner of barrier no. 10 disengaged beginning 12 in. (305 mm) from the base of barrier no. 10 and extending to the top. Spalling was found on barrier no. 11 along its upstream edge. Anchor pocket reinforcement was exposed 18 in. (457 mm) downstream from the upstream edge of barrier no. 11. However, the spalling found on barrier no. 11 was much less significant than the spalling found on barrier nos. 9 and 10. The joint connection pin located between barriers nos. 9 and 10 was bent at the top and bottom, as shown in Figure 67. The joint connection pins located between all other barriers were undamaged.

All three anchor pockets on barrier no. 8 were undamaged. The three anchor pins on barrier nos. 8 and 9 were displaced vertically. Anchor pin nos. 2 and 3 (middle and downstream anchor pins) on barrier no. 9 were also displaced laterally in the asphalt. All three anchor pins on barrier no. 10 were displaced vertically and laterally in the asphalt. The three anchor pins on barrier no. 11 were displaced vertically while anchor pin nos. 1 and 2 (upstream and middle anchor pins) were also displaced laterally in the asphalt. The remaining anchor pins and anchor pockets were undamaged.

Figure 63. System Damage – Front, Back, Downstream, and Upstream Views, Test No. WITD-2

Figure 64. System Damage at Impact Location, Test No. WITD-2

Figure 65. Barrier No. 10 Barrier Damage, Test No. WITD-2

Figure 66. Barrier No. 9 Barrier Damage, Test No. WITD-2

Figure 67. Barrier Nos. 9 and 10 Connection Pin Damage, Test No. WITD-2

Figure 68. Barrier No. 10 Asphalt Pin Damage and Displacement, Test No. WITD-2

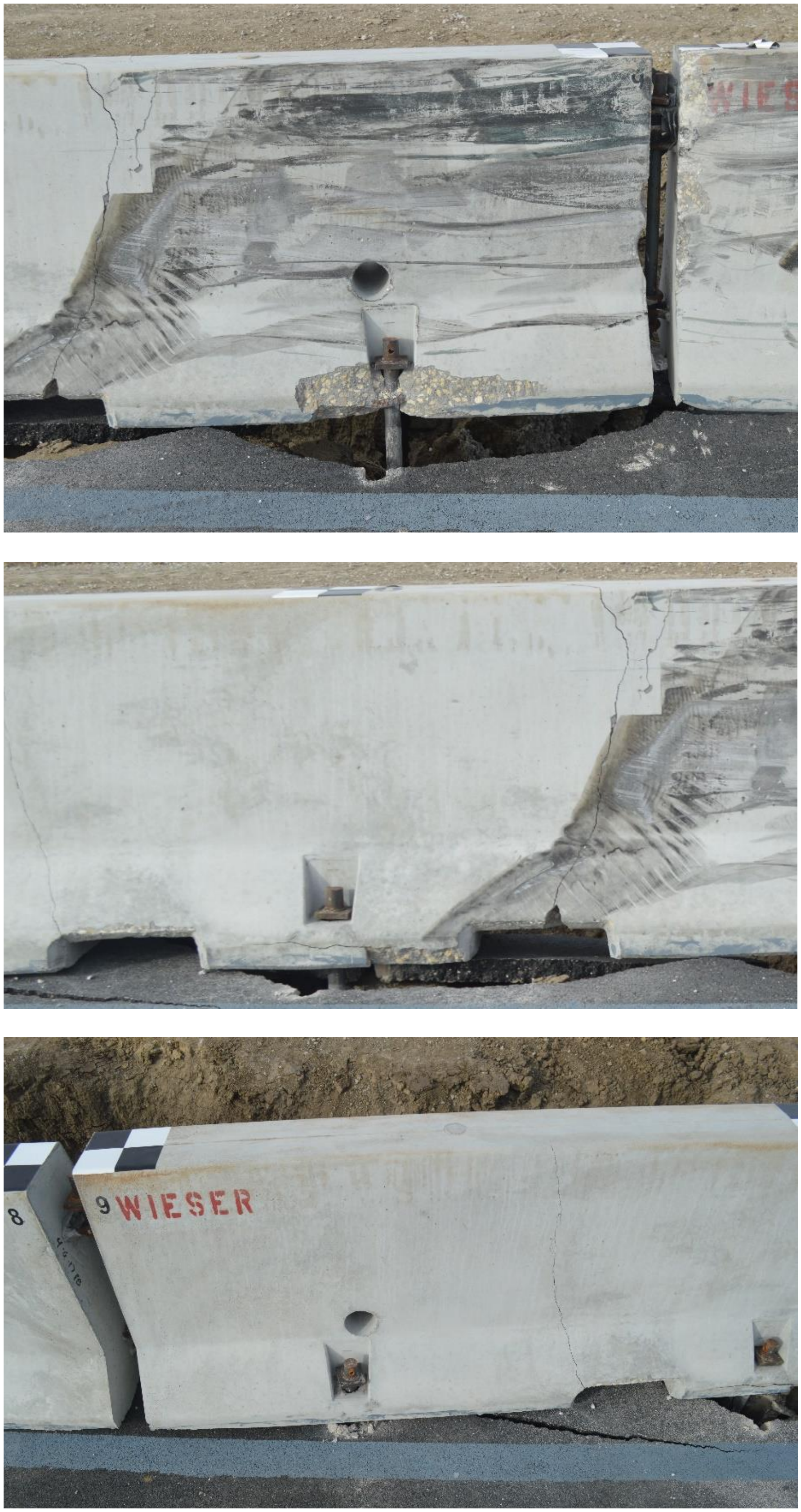


Figure 69. Barrier No. 9 Asphalt Pin Damage and Displacement, Test No. WITD-2

Figure 70. Barrier Joint Snag, Test No. WITD-2

Cracking in the asphalt and lateral soil displacement adjacent to the vertical drop off was extensive. The largest asphalt crack was 19 ft – 10 in. (6.0 m) long, which began 9 in. (229 mm) upstream from the centerline of barrier no. 9 and ended 2 in. (51 mm) downstream from barrier no. 10. In this area, all anchor pins were pulled out of the asphalt. Other significant asphalt cracks were found at the rear of barrier no. 8, measuring 8 ft – 2 in. (2.5 m) long, and at the toe of barrier no. 10 near the centerline, measuring 8 ft – 7 in. (2.6 m) long. The asphalt and soil disengaged at many different locations behind barrier nos. 9 and 10, totaling almost 15 ft (4.6 m) in length. Smaller asphalt cracks were also found behind and underneath barrier no. 11.

The maximum lateral permanent set deflection of the barrier system was 14⅜ in. (365 mm), which occurred at the downstream end of barrier no. 9, as measured in the field. The maximum lateral dynamic barrier deflection, including barrier rotation of the top of the barrier, was 24.5 in. (623 mm) at the upstream end of barrier no. 10, as determined from high-speed digital video analysis. The working width of the system was found to be 47.0 in. (1195 mm), also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 71.

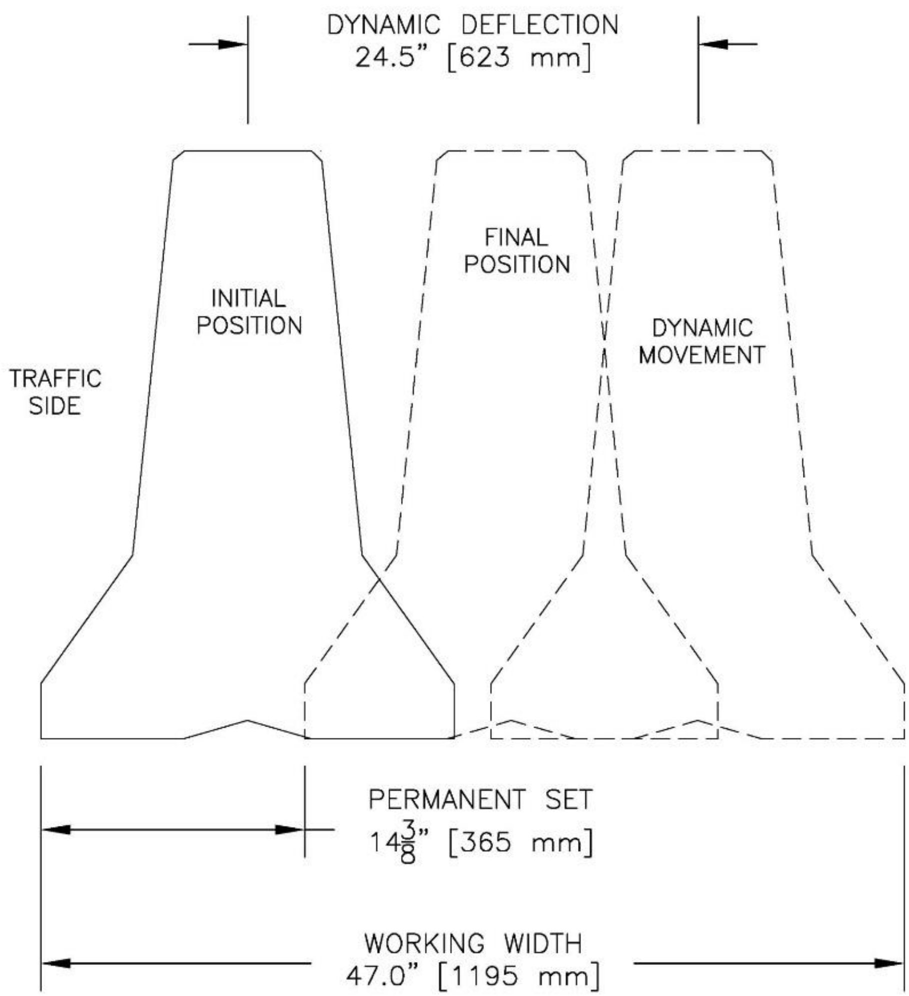


Figure 71. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No.WITD-2

7.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 72 through 76. The maximum occupant compartment intrusions are listed in Table 9 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. The side door (above seat and below seat) deformed outward, which is not considered crush toward the occupant, is denoted as negative numbers in Table 9, and is not evaluated by MASH 2016 criteria. Note that the maximum wheel well and toe pan deformation of 13½ in. (343 mm) exceeded the MASH 2016 intrusion limit of 9 in. (229 mm). In addition to exceeding the maximum toe pan and wheel well intrusion criteria, the intrusion of the wheel rim led to several tears in the floor pan. Thus, the occupant compartment intrusion limits were violated, which resulted in the failure of test no. WITD-2 to meet the MASH 2016 criteria. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

The majority of damage was concentrated on the left-front corner and left side of the vehicle where the impact occurred. The left side of the front bumper was crushed inward and backward to a depth of 17 in. (432 mm) and the right side of the front bumper bent upward 4 in. (102 mm). The left side of the front bumper cover was ripped off starting 21 in. (533 mm) from the center. The vehicle grille completely detached, leaving a 2½-in. x 6-in. (64-mm x 152-mm) piece at the attachment point to the right of the center point. Both headlights were crushed. The left-front fender was crushed and almost disengaged from the vehicle, but remained attached at two points. The left-front wheel assembly was detached and crushed into the wheel well and toe pan. The toe pan on the left side of the vehicle deformed upward into the brake pedal and contained multiple tears, as shown in Figure 76. The left-rear wheel assembly had scrapes along the outer circumference of the rim and a 3-in. x 4-in. (76-mm x 102-mm) I-shaped puncture in the tire. The left rocker panel had a 48-in. (1,219-mm) long x 6-in. (152-mm) wide x 2-in. (51-mm) deep indentation. The left-front door was also deformed and rotated slightly counter-clockwise. The right-front fender was bent away from the front bumper. Cracking in the windshield began in the lower-right corner and expanded outward in a spider web formation. The side windows, roof, and rest of the right side remained undamaged.

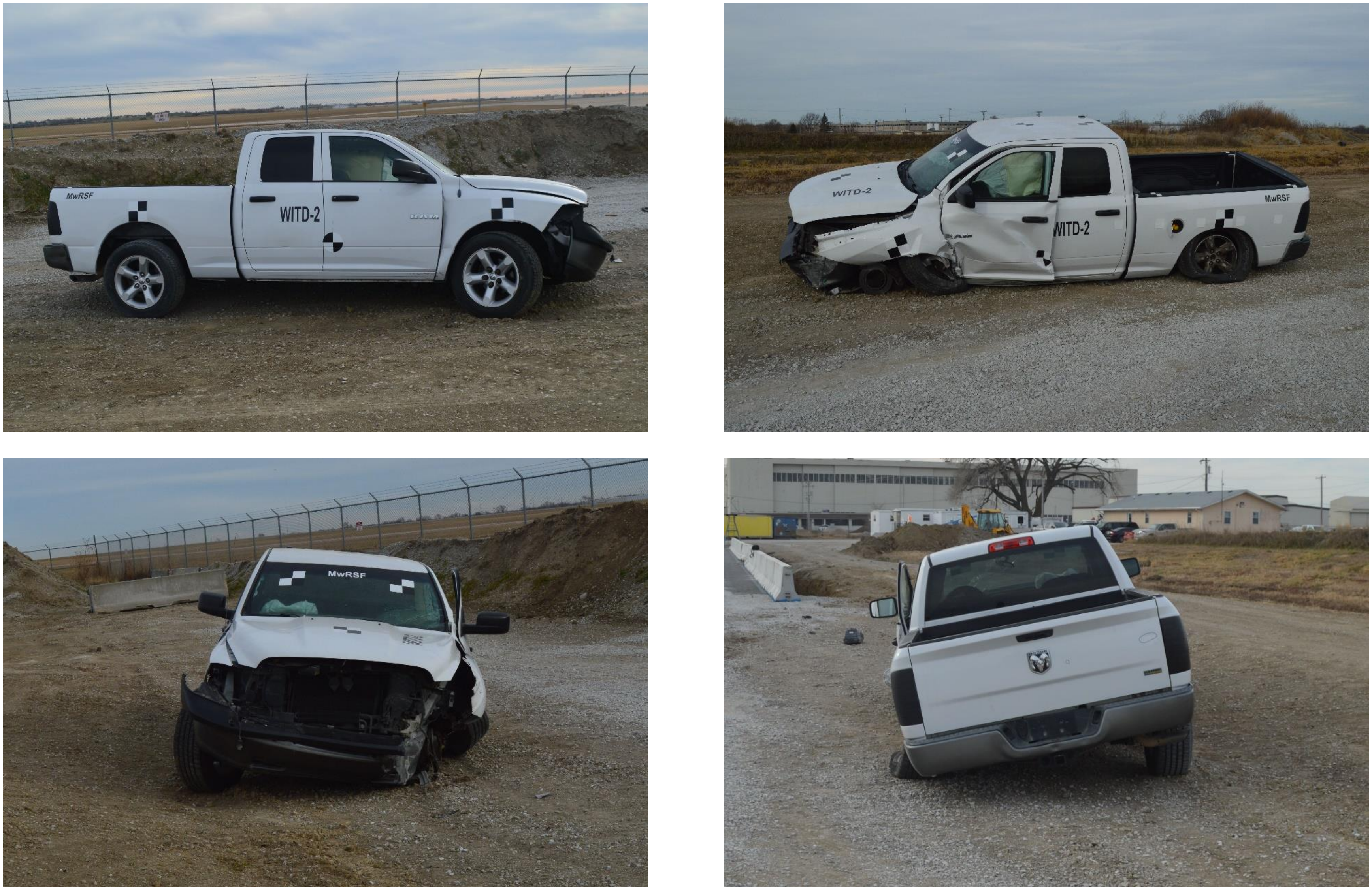


Figure 72. Vehicle Damage, Test No. WITD-2

Figure 73.Vehicle Damage, Windshield Damage Test No. WITD-2

Figure 74. Vehicle Damage, Test No. WITD-2

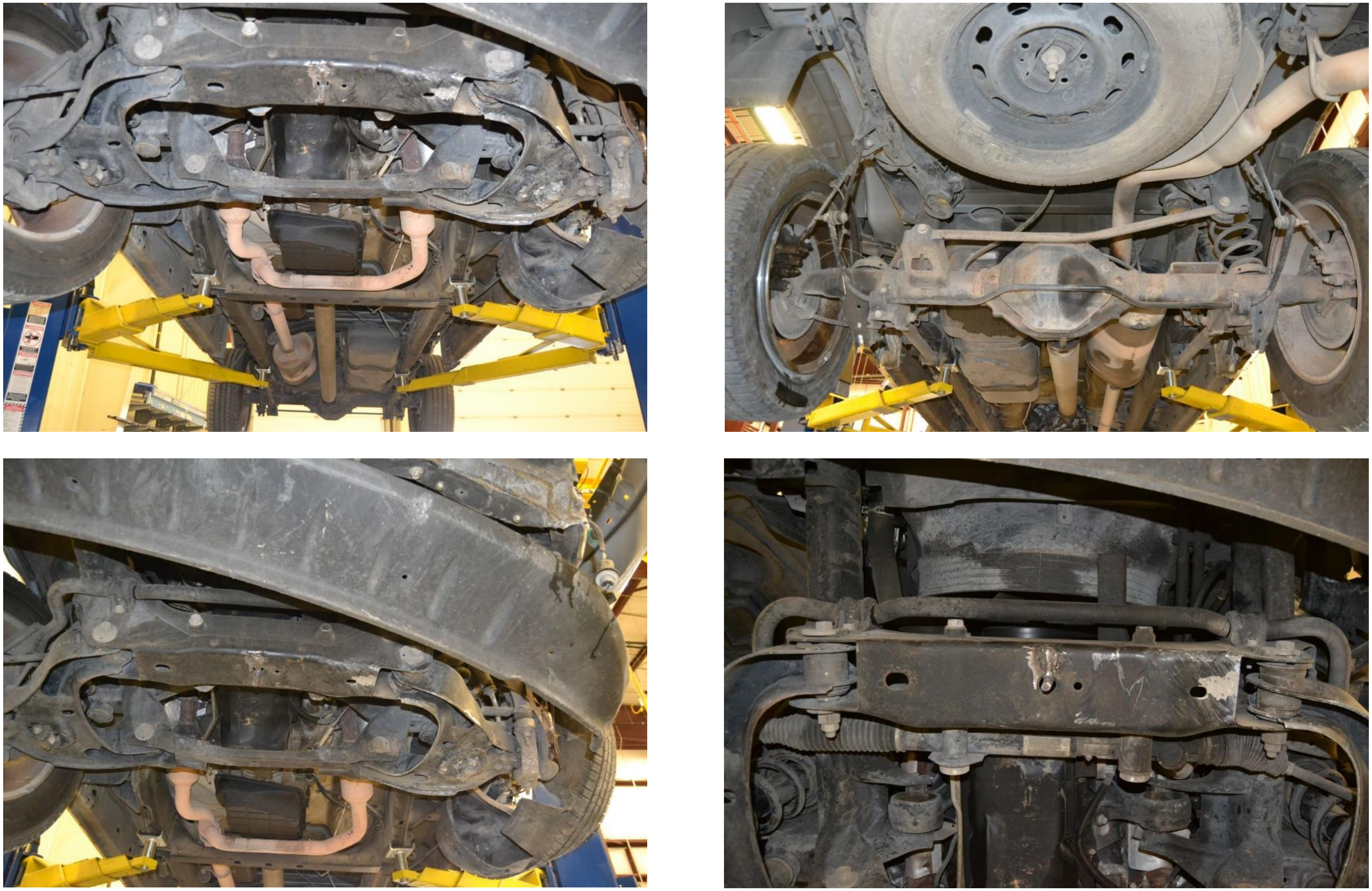


Figure 75. Vehicle Undercarriage Damage, Test No. WITD-2

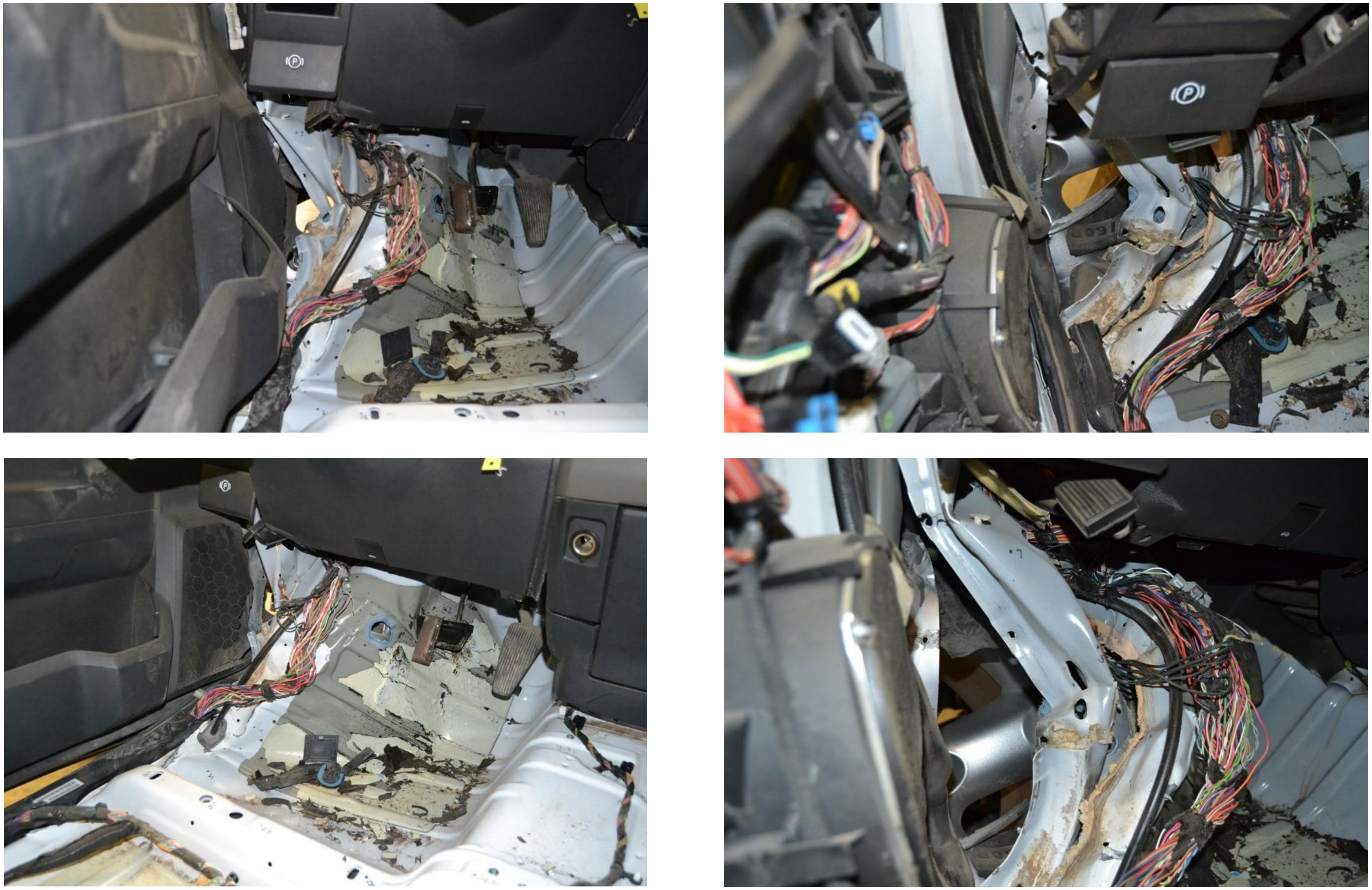


Figure 76. Occupant Compartment Damage, Test No. WITD-2

Table 9. Maximum Occupant Compartment Intrusion by Location, Test No. WITD-2

LOCATION	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	13½ (343)	≤ 9 (229)
Floor Pan & Transmission Tunnel	7¾ (197)	≤ 12 (305)
A-Pillar	3⅛ (79)	≤ 5 (127)
A-Pillar (Lateral)	½ (13)	≤ 3 (76)
B-Pillar	1⅛ (29)	≤ 5 (127)
B-Pillar (Lateral)	½ (13)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	4⅝ (117)	≤ 12 (305)
Side Door (Above Seat)	-3½ (-89)	N/A
Side Door (Below Seat)	-3½ (-89)	N/A
Roof	1⅜ (35)	≤ 4 (102)
Windshield	0 (0)	≤ 3 (76)
Side Window	Intact	No shattering resulting from contact with structural member of test article
Dash	4⅞ (124)	N/A

Note: Negative values denote outward deformation
N/A – Not applicable

7.6 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 10. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 10. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 10. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. WITD-2

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-23.25 (-7.09)	-23.88 (-7.28)	±40 (12.2)
	Lateral	15.16 (4.62)	19.10 (5.82)	±40 (12.2)
ORA g's	Longitudinal	-9.52	-9.68	±20.49
	Lateral	10.05	8.71	±20.49
MAX. ANGULAR DISPL. deg.	Roll	-2.4	6.4	±75
	Pitch	-11.8	-10.5	±75
	Yaw	31.6	31.7	not required
THIV ft/s (m/s)		30.09 (9.17)	29.64 (9.04)	not required
PHD g's		10.30	10.37	not required
ASI		1.51	1.54	not required

7.7 Discussion

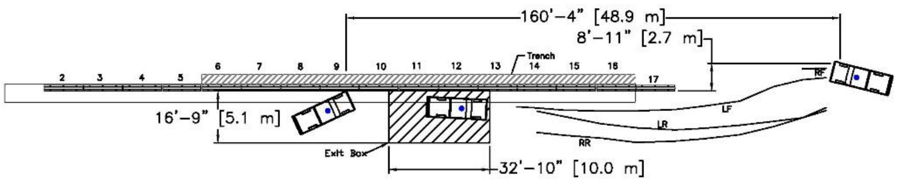
The analysis of the test results for test no. WITD-2 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 77. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment in the wheel well, toe pan, and floor pan exceeded deformation limits in MASH 2016. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix F, were deemed acceptable because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 8.2 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. WITD-2 was determined to be unacceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.

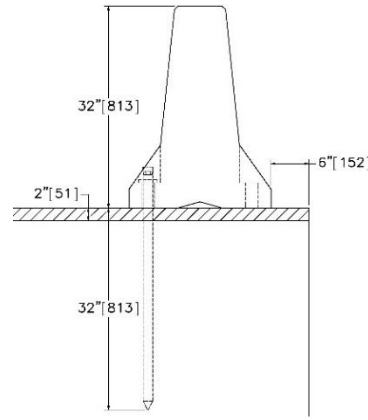
While the vehicle was captured and redirected successfully in test no. WITD-2, excessive occupant compartment deformations observed in the test caused it to be deemed a failure. Further review of the test results found that wheel snag on the joint between the anchored PCB segments contributed to the excessive occupant compartment deformations. In test no. WITD-2, the impact point was selected to maximize vehicle snag and loading of the barrier joint. During the impact, the asphalt and a portion of the soil next to the excavated trench behind the system was disengaged, which allowed increased motion of the PCB segments. It is believed that the increased barrier deflection caused by displacement of the asphalt and soil allowed upstream barriers impacted by the vehicle to deflect/rotate back laterally, while the downstream barriers remained anchored with limited displacement. This exposed the upstream face of the downstream barrier segments and promoted snagging of the wheel and tire as it traversed the joints between barrier segments, as shown in Figure 70. The front tire climbed the toe of the PCBs as well, which increased the exposure of the upstream faces of the downstream barriers to the wheel. This wheel snag may have occurred at the joint between barrier nos. 9 and 10, the joint between barrier nos. 10 and 11, or a combination of snag at both joints. Review of the accelerometer data from the 2270P vehicle found that there were increases in the longitudinal acceleration pulses between 65 msec and 90 msec that would correlate with the timing of the wheel traversing the joint between barrier nos. 9 and 10.

The wheel snag rotated the left-front wheel 90 degrees and pushed it back toward the floor pan of the pickup. This in turn caused excessive toe pan deformations, opened a hole in the floor pan, and allowed a portion of the wheel rim to penetrate the occupant compartment, as shown in Figure 76. The combination of the excessive occupant compartment deformations, opening of the floor pan, and penetration of the wheel rim into the occupant compartment led to the test being deemed unacceptable under the MASH TL-3 safety requirements.

After the test, it was noted that test no. WITD-1, conducted on a bolted-through tie-down anchorage for the F-shape PCB used on concrete, had less severe wheel snag and was capable of meeting MASH 2016 TL-3 criteria. It was believed that the epoxied anchor rods used in that system more effectively reduced motion of the barrier, thus lessening the joint separation and wheel snag severity. As such, MwRSF researchers believe that there may be ways to improve the barrier performance from test no. WITD-2 to mitigate the wheel snag. Potential options to improve the asphalt pin tie-down anchorage performance include increasing the offset of the barriers from the excavation or introducing a shear transfer element at the joint that prevents the joint separation.

0.000 sec | 0.110 sec | 0.250 sec | 0.364 sec | 0.492 sec





- Test Agency .... MwRSF
- Test Number WITD-2
- Date 11/22/2017
- MASH 2016 Test Designation No. 3-11
- Test Article .... Pinned Tie-Down F-Shape PCB
- Total Length .... 200 ft (61.0 m)
- Key Component – F-Shape PCB
  - Length .... 12 ft – 6 in. (3.8 m)
  - Width .... 22½ in. (572 mm)
  - Height .... 32 in. (813 mm)
- Key Component – Anchor Pins
  - Pin Size .... 1½-in. (38-mm) diameter steel pins
  - Pin Material .... ASTM A36
  - Pin Length .... 38½ in. (978 mm)
  - Embedment Depth .... 32 in. (813 mm)
  - Number of Pins per Barrier 3
  - Pinned Barrier Nos. 6-14
- Type of Support Surface .... 2-in. (51-mm) thick asphalt pad
- Soil Type .... In-Situ Low Plasticity Silt
- Vehicle Make /Model .... 2010 Dodge Ram 1500
  - Curb .... 5,075 lb (2,302 kg)
  - Test Inertial .... 5,003 lb (2,269 kg)
  - Gross Static .... 5,157 lb (2,339 kg)
- Impact Conditions
  - Speed .... 62.0 mph (99.8 km/h)
  - Angle .... 25.1 deg.
  - Impact Location .... 3 ft – 10.9 in. (1191.3 mm) upstream from joint 9-10
- Impact Severity ..... 115.3 kip-ft (156.3 kJ) > 106 kip-ft (144 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 49.0 mph (78.8 km/h)
  - Angle .... 8.2 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 160 ft – 4 in. (48.9 m) downstream
  8 ft – 11 in. (2.7 m) laterally behind
- Vehicle Damage .... Moderate
  - VDS [13] 11-LFQ-4
  - CDC [14] 11-LYEW-4
  - Maximum Interior Deformation .... 13½ in. (343 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 14⅜ in. (365 mm)
  - Dynamic .... 24.5 in. (622 mm)
  - Working Width .... 47.0 in. (1,194 mm)
- Transducer Data

Evaluation Criteria		Transducer SLICE-1	Transducer SLICE-2 (primary)	MASH 2016 Limit
OIV ft/s (m/s)	Longitudinal	-23.25 (-7.09)	-23.88 (-7.28)	±40 (12.2)
	Lateral	15.16 (4.62)	19.10 (5.82)	±40 (12.2)
ORA g's	Longitudinal	-9.52	-9.68	±20.49
	Lateral	10.05	8.71	±20.49
MAX ANGULAR DISP. deg.	Roll	-2.4	6.4	±75
	Pitch	-11.8	-10.5	±75
	Yaw	31.6	31.7	not required
THIV – ft/s (m/s)		30.09 (9.17)	29.64 (9.04)	not required
PHD – g's		10.30	10.37	not required
ASI		1.51	1.54	not required

Figure 77. Summary of Test Results and Sequential Photographs, Test No. WITD-2

8 SUMMARY AND CONCLUSIONS

This research effort assessed the crashworthiness of two different tie-down anchorages for F-shape PCBs in accordance with MASH 2016 TL-3 evaluation criteria: (1) a bolt-through tie-down for use on concrete road surfaces and (2) a steel pin tie-down for use on asphalt road surfaces. Both systems used a 32-in. (813-mm) tall by 22½-in. (572-mm) wide by 12-ft 6-in. (3.8-m) long F-shape PCB with a pin and loop connection and anchor pockets in the toe of the barrier. The bolt through tie-down for concrete road surfaces used 1⅛-in. (29-mm) diameter by 12-in. (305-mm) long, ASTM A307 Grade A threaded rods embedded and epoxied into the concrete to a depth of 5¼ in. (133 mm). Three rods were installed through the anchor pockets on the traffic-side face of each PCB segment. For the testing, the PCBs were installed with the back of the barrier 1 in. (25 mm) from the edge of a simulated bridge deck. The steel pin tie-down for use on asphalt road surfaces used 1½-in. (38-mm) diameter steel pins installed through the anchor pockets on the traffic-side face of each PCB segment. The pins were driven through a 2-in. (51-mm) thick layer of asphalt and into the soil to a depth of 32 in. (813 mm). The PCB segments for the asphalt tie-down anchorage were installed with the back of the barrier 6 in. (152 mm) from the edge of a 3-ft (914-mm) deep vertical trench. MASH 2016 test designation no. 3-11 was conducted on each anchored PCB system in order to evaluate its performance. Test no. WITD-1 was conducted on the bolt-through tie-down for use on concrete road surfaces, and test no. WITD-2 was conducted on the steel pin tie-down for use on asphalt road surfaces. A summary of the test results is shown in Table 11.

In test no. WITD-1, the 2270P pickup truck impacted the barrier at a speed of 62.0 mph (99.8 km/h), an angle of 25.6 degrees, and a location 3 ft – 8$^{3}/_{16}$ (1.1 m) upstream from the centerline of the joint between barrier nos. 8 and 9, thus resulting in an impact severity of 119.7 kip-ft (162.3 kJ). After impacting the barrier system, the vehicle exited the system at a speed of 49.7 mph (80.0 km/h) and an angle of 4.4 degrees. The vehicle was safely contained and redirected by the anchored PCB system. Barrier damage was moderate and consisted of cracking and spalling of the concrete barrier as well as fracturing of two of the threaded rod anchors. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 14.3 in. (363 mm) at the upstream end of barrier no. 9, while the working width of the system was found to be 36.8 in. (935 mm). The maximum lateral permanent set deflection of the barrier system was 8½ in. (216 mm) at the downstream end of barrier no. 8. All occupant risk values were found to be within limits, and the occupant compartment deformations were also deemed acceptable. Subsequently, test no. WITD-1 was determined to satisfy the safety performance criteria for MASH 2016 test designation no. 3-11.

Table 11. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th><th>Test No. WITD-1</th><th>Test No. WITD-2</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td><td>S</td></tr>
<tr><td rowspan="4">Occupant Risk</td><td>D.</td><td>1. 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.
2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>S
S</td><td>S
U</td></tr>
<tr><td>F.</td><td>The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td><td>S</td></tr>
<tr><td>H.</td><td>Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:<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>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td>I.</td><td>The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:<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>15.0 g's</td><td>20.49 g's</td></tr></table></td><td>S</td><td>S</td></tr>
<tr><td colspan="3">MASH 2016 Test Designation No.</td><td>3-11</td><td>3-11</td></tr>
<tr><td colspan="3">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Fail</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

In test no. WITD-2, the 2270P pickup truck impacted the barrier at a speed of 62.0 mph (99.8 km/h), an angle of 25.1 degrees, and a location 3 ft – 10⅞ in. (1.2 m) upstream from the centerline of the joint between barrier nos. 9 and 10, thus resulting in an impact severity of 115.3 kip-ft (156.3 kJ). After impacting the barrier system, the vehicle exited the system at a speed of 49.0 mph (78.9 km/h) and an angle of 8.2 degrees. The vehicle was contained and redirected by the anchored PCB system. However, snagging of the left-front wheel was observed at the barrier joints. This snag pushed the wheel back toward the rear of the wheel well and the toe pan causing high toe pan deformation, opening of the toe pan, and intrusion of a portion of the wheel rim into the occupant compartment. The maximum lateral dynamic barrier deflection, including barrier rotation, was 24.5 in. (622 mm) at the upstream end of barrier no. 10, while the working width of the system was found to be 47.0 in. (1,195 mm). The maximum lateral permanent set deflection of the barrier system was 14⅜ in. (365 mm), which occurred at the downstream end of barrier no. 9. All occupant risk values were found to be within limits. However, the wheel well and toe pan were deformed a maximum of 13½ in. (343 mm), which exceeded the MASH 2016 deformation limit of 9 in. (229 mm). The combination of the excessive occupant compartment deformations, opening of the floor pan, and the penetration of the wheel rim into the occupant compartment led to the test being deemed unacceptable under the MASH 2016 TL-3 safety requirements. Subsequently, test no. WITD-2 was determined to be unacceptable according to the safety performance criteria for MASH 2016 test designation no. 3-11.

As with any system that is successfully evaluated for use on the roadway, the bolt-through tie-down system for use on concrete road surfaces has several important points that should be noted with respect to its application.

1. The threaded rods used to anchor this system were epoxied into the concrete to a depth of 5¼ in. (133 mm) using Hilti HIT-RE 500 V3 epoxy. Other epoxies may be used if they have equal or greater bond strength. Similarly, deeper embedment could be applied to achieve equivalent shear and tensile capacities. Thus, it is recommended that alternative epoxy anchorage configurations for use with this system be capable of developing the same shear and tensile strengths of the 1⅛-in. (29-mm) diameter ASTM A307 Grade A threaded rod anchored with the Hilti HIT-RE 500 V3 epoxy to a depth of 5¼ in. (133 mm) used in this evaluation.

2. For bridge deck applications, the threaded rods could be passed completely through the bridge deck and fixed with a plate washer and nut. This would provide equal or greater anchorage to the epoxy anchored system evaluated herein. A 3-in. by 3-in. by ¼-in. (76-mm by 76-mm by 6-mm) plate washer is recommended.

3. The termination and anchorage system described herein was designed for use with the pinned tie-down F-shape PCB system. Therefore, it should not be used with other PCB systems or joint designs without further study. Although this termination and anchorage system may potentially be adapted to other approved temporary concrete barrier systems, it is first necessary to consider several factors, such as barrier connections, segment lengths, reinforcement, and geometry, as noted below.

    a. Joints between barrier segments must have comparable or greater torsional rigidity about the longitudinal barrier axis when compared to that of the as-tested configuration.

    b. Alternative barrier segment lengths would be acceptable as long as they are at least 12½ ft (3.8 m) long and utilize an equivalent or greater number of anchors per foot of barrier length. With shorter barrier lengths, it is believed that additional barrier rotation may occur due to the greater number of joints, thus resulting in the propensity for increased climb and rollover.

c. Alternative barrier segments should have comparable mass per unit length.

d. The reinforcement in the alternative barrier segments should be equal or greater than the F-shape barrier described herein. This reinforcement recommendation is to include the longitudinal steel, shear stirrups, and containment steel bars surrounding the anchor boxes used with the vertical anchor rods.

e. The shape of alternative barrier segments may require further study. Past research has shown that the different barrier shapes produce variation in vehicle climb, pitch, and roll. Therefore, further study may be needed to assure safe performance when applying the designs to other barrier shapes.

4. End users may wish to apply the anchorage shown on both sides of the system to create an anchored PCB system in a median or two-way traffic application. However, the researchers cannot recommend using anchorage on both sides of the PCB without further research and evaluation. Placing anchorage on the back side of the barrier may induce increased tipping of the barrier segments which could increase the potential for vehicles to climb the sloped barrier face and become unstable.

5. The threaded rod anchorage evaluated in test no. WITD-1 is not intended for use on concrete surfaces with asphalt overlays. Extension of the epoxied anchors through several inches of asphalt will change the anchor loading from primarily shear and tensile loads to bending loads. This will cause increased anchor failure and may adversely affect the behavior of the system.

Additional research is needed to revise the asphalt pin anchorage evaluated in test no. WITD-2 to reduce the wheel snag and corresponding occupant compartment damage that resulted in the crash test failure. As noted previously, various modifications may improve the performance of the barrier, which include increasing the barrier offset from the excavation or introducing a shear transfer element at the joint that prevents joint separation.

9 MASH EVALUATION

A bolt-through tie-down anchorage for use with an F-shape PCB installed on a concrete road surface was evaluated to determine its compliance with MASH 2016 TL-3 evaluation criteria. This barrier system consisted of a 32-in. (813-mm) tall by 22½-in. (572-mm) wide by 12-ft 6-in. (3.8-m) long F-shape PCB with a pin and loop connection and anchor pockets in the toe of the barrier. The bolt-through tie-down for concrete road surfaces used 1⅛-in. (29-mm) diameter by 12-in. (305-mm) long, ASTM A307 Grade A threaded rods embedded and epoxied into the concrete to a depth of 5¼ in. (133 mm). Three threaded rods were installed through anchor pockets on the traffic-side face of each PCB segment. For the testing, the PCBs were installed with the back of the barrier 1 in. (25 mm) from the edge of a simulated bridge deck.

MASH 2016 TL-3 currently requires two full-scale crash tests for evaluation of longitudinal barrier systems. Only test designation no. 3-11 was deemed critical for evaluation of the anchored PCB system. Test designation no. 3-10 with the 1100C vehicle is typically required to evaluate vehicle capture, vehicle stability, and occupant risk concerns for the 1100C vehicle. Previous full-scale crash tests of safety-shape concrete barriers under MASH TL-3 have indicated that safety-shape barriers can safely redirect 1100C vehicles. In test no. 3-10 (2214NJ-1), MASH test designation no. 3-10 was successfully conducted on a permanent New Jersey shape concrete parapet under NCHRP Project 22-14(2) [8]. In test no. 607911-1&2, MASH test designation no. 3-10 was also successfully conducted by TTI on a free-standing F-shape PCB similar to the barrier used in this study [9]. These two tests indicate that safety shape barriers are capable of successfully capturing and redirecting the 1100C vehicle in both free-standing PCB and permanent concrete parapet applications. Additionally, the increased toe height of New Jersey shape barriers tends to produce increased vehicle climb and instability as compared to the F-shape geometry. Thus, one would expect that the anchored F-shape PCBs evaluated in this study would perform similarly to these previous MASH 1100C vehicle tests in terms of containment and redirection, and it was believed that test designation no. 3-10 with the 1100C vehicle was deemed non-critical for evaluation of the tie-down anchorages for use with F-shape PCBs.

Test no. WITD-1 was conducted to evaluate the crashworthiness of the barrier system to MASH 2016 TL-3 evaluation criteria. In test no. WITD-1, the 2270P pickup truck impacted the barrier at a 25.6-degree angle with a speed of 62.0 mph (99.8 km/h), thus resulting in an impact severity of 119.7 kip-ft (162.3 kJ). After impacting the barrier system, the vehicle was parallel to the system at a speed of 52.6 mph (84.7 km/h) and exited the system at a speed of 49.7 mph (80.0 km/h) and an angle of 4.4 degrees. The vehicle was safely contained and redirected by the anchored PCB systems. Barrier damage was moderate and consisted of cracking and spalling of the concrete barrier as well as fracturing of two of the threaded rod anchors. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 14.3 in. (363 mm) at the upstream end of barrier no. 9, while the working width of the system was found to be 36.8 in. (935 mm). The maximum lateral permanent set deflection of the barrier system was 8½ in. (216 mm) at the downstream end of barrier no. 8. All occupant risk values were found to be within limits, and the occupant compartment deformations were also deemed acceptable. Subsequently, test no. WITD-1 was determined to satisfy the safety performance criteria for MASH 2016 test designation no. 3-11.

Based on the evaluation of the successful full-scale crash testing in test no. WITD-1 and the review of previous MASH crash testing of similar permanent and portable concrete barriers with a 1100C vehicle, it is believed that the tie-down anchorage for use with an F-shape PCB installed on a concrete road surface meets all of the requirements for compliance with MASH 2016 TL-3.

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

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11 APPENDICES

Appendix A. Material Specifications

Table A-1. Bill of Materials, Test No. WITD-1

Item No.	Description	Material Specification	Reference
a1	Portable Concrete Barrier	ACI GRADE 1 ASTM C39 Min f'c = 5,000 psi [34.5 MPa]	Project Nebraska Barrier
a2	1/2" [13] Dia., 72" [1,829] Long Form Bar	ASTM A615/A615M-14 GR 60[420] AASHTO M31-07	R#17-328 L#KN1610574101 H#KN16105741 L#KN1610574201 H#KN16105742
a3	1/2" [13] Dia., 146" [3,708] Long Longitudinal Bar	ASTM A615/A615M-14 GR 60[420] AASHTO M31-07	R#17-328 L#KN1610574101 H#KN16105741 L#KN1610574201 H#KN16105742
a4	5/8" [16] Dia., 146" [3,708] Long Longitudinal Bar	A615M GR420 (Gr60) ASTM A615/A615M-15 GR 60(420) AASHTO M31 -07	R#17-328 L#KN1610418601 H#KN16104186 L#KN1610418701 H#KN16104187
a5	3/4" [19] Dia., 36" [914] Long Anchor Loop Bar	A615M GR420 (Gr60) ASTM A615/A615M-15 GR 60(420) AASHTO M31 -07	H#KN16104234 L#KN1610423401
a6	3/4" [19] Dia., 101" [2,565] Long Connection Loop Bar	ASTM A706/A706M-09b GR60 [420]	R#17-328 L#KN1610065601 H#KN16100656
a7	3/4" [19] Dia., 91" [2,311] Long Connection Loop Bar	ASTM A706/A706M-09b GR60 [420]	R#17-328 L#KN1610065601 H#KN16100656
a8	3/4" [19] Dia., 102" [2,591] Long Connection Loop Bar	ASTM A706/A706M-09b GR60 [420]	R#17-328 L#KN1610065601 H#KN16100656
a9	1 1/4" [32] Dia., 28" [711] Long Connector Pin	ASME SA36 ASTM A6-14, A36-14, ASTM A709A, AASHTO M270-12	H#62138817/06
b1	1 1/8" [29] Dia. UNC, 12" [305] Long Threaded Rod	ASTM A307 Gr. A	R#17-513 H#606782
b2	3"x3"x1/2" [76x76x13] Washer Plate	ASTM A36	R#17-568 H#B702406
b3	1 1/8" [29] Dia. Heavy Hex Nut	ASTM A563 Gr. A Heavy Hex	R#17-674 H#C4070634
c1	Hilti HIT-RE 500 V3 Epoxy or equivalent	Minimum bond strength for 1 1/8" [29] anchor > 1,650 psi [11 MPa] in uncracked concrete	TECHNICAL DATA ONLINE

Table A-2. Bill of Materials, Test No. WITD-2

Item No.	Description	Material Specification	Reference
a1	Portable Concrete Barrier	ACI GRADE 1 ASTM C39 Min f'c = 5,000 psi [34.5 MPa]	Project Nebraska Barrier
a2	1/2" [13] Dia., 72" [1829] Long Form Bar	ASTM A615/A615M-14 GR 60[420] AASHTO M31-07	L#KN1610574101 H#KN16105741 L#KN1610574201 H#KN16105742
a3	1/2" [13] Dia., 146" [3708] Long Longitudinal Bar	ASTM A615/A615M-14 GR 60[420] AASHTO M31-07	L#KN1610574101 H#KN16105741 L#KN1610574201 H#KN16105742
a4	5/8" [16] Dia., 146" [3708] Long Longitudinal Bar	A615M GR420 (Gr60) ASTM A615/A615M-15 GR 60(420) AASHTO M31 -07	R#17-328 L#KN1610418601 H#KN16104186 L#KN1610418701 H#KN16104187
a5	3/4" [19] Dia., 36" [914] Long Anchor Loop Bar	A615M GR420 (Gr60) ASTM A615/A615M-15 GR 60(420) AASHTO M31 -07	H#KN16104234 L#KN1610423401
a6	3/4" [19] Dia., 101" [2565] Long Connection Loop Bar	ASTM A706/A706M-09b GR60 [420]	R#17-328 L#KN1610065601 H#KN16100656
a7	3/4" [19] Dia., 91" [2311] Long Connection Loop Bar	ASTM A706/A706M-09b GR60 [420]	L#KN1610065601 H#KN16100656
a8	3/4" [19] Dia., 102" [2591] Long Connection Loop Bar	ASTM A706/A706M-09b GR60 [420]	L#KN1610065601 H#KN16100656
a9	1 1/4" [32] Dia., 28" [711] Long Connector Pin	ASME SA36 ASTM A6-14, A36-14, ASTM A709A, AASHTO M270-12	H#62138817/06
b1	1 1/2" [38] Dia., 38 1/2" [978] Long Anchor Pin	ASTM A36-14/A529-14 Gr. 50	H#2056210
b2	3"x3"x1/2" [76x76x13] Washer Plate	ASTM A36	H#B617195
c1	2400"x72"x2" [60,960x183x51] Asphalt Pad	NE SPS Mix with 52-34 Grade Binder SUPERPAVE TESTING RESULTS SAYS: 64-34	Project Number: 540624

WIESER CONCRETE PRODUCTS, INC.
W3716 U.S. HWY 10 • MAIDEN ROCK, WI 54750
(715) 647-2311 800-325-8456 Fax (715) 647-5181
Website: www.wieserconcrete.com

CONCRETE TEST RESULTS

PROJECT: Nebraska Barrier

Testing By: Jason Hendricks

CONCRETE SUPPLIER Wieser Concrete

ACI GRADE 1
ASTM C39
5000 PSI Mix

SET	TEST	POUR DATE	RESULTS	AVERAGE	TEST TYPE
	1		8251		
1	2	4/4/2017	8293	**8272**	14 Day
	1		8240		
2	2	4/5/2017	7742	**7991**	14 Day
	1		7209		
3	2	4/6/2017	7418	**7314**	14 Day
	1		9040		
4	2	4/7/2017	8737	**8889**	14 Day
	1		6814		
5	2	4/10/2017	6791	**6803**	14 Day
	1		8475		
6	2	4/11/2017	8340	**8408**	14 Day
	1		8157		
7	2	4/12/2017	8292	**8225**	14 Day
	1		7879		
8	2	4/13/2017	7751	**7815**	14 Day

Jason Hendricks
Signature

Figure A-1. Concrete Barriers, Test Nos. WITD-1 and WITD-2

SOLD TO: ADELPHIA METALS I LLC
411 MAIN ST E
NEW PRAGUE, MN 56071-

NUCOR
NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT

Page: 1

Ship from:
MTR #: 0000149483
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

SHIP TO: ADELPHIA METALS LLC
411 MAIN STREET EAST
NEW PRAGUE, MN 56071-

Date: 15-Nov-2016
B.L. Number: 530660
Load Number: 279950

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS: YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	CHEMICAL TESTS: C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	819831												
KN1610574101	Nucor Steel - Kankakee Inc	67,201	102,596	14.9%	OK	-5.8%	.37	.99	.015	.042	.20	.29	
KN16105741	13/#4 Rebar	463MPa	707MPa			.028	.21	.16	.055	.009	.001		
	40' A615M GR420 (Gr60)												
	ASTM A615/A615M-14 GR 60[420]								.54				
	AASHTO M31-07												
	Melted 10/06/16 Rolled 10/18/16												
PO# =>	819831												
KN1610574201	Nucor Steel - Kankakee Inc	72,534	107,791	13.3%	OK	-5.0%	.39	.99	.016	.049	.20	.34	
KN16105742	13/#4 Rebar	500MPa	743MPa			.028	.21	.15	.054	.010	.001		
	40' A615M GR420 (Gr60)												
	ASTM A615/A615M-14 GR 60[420]								.50				
	AASHTO M31-07												
	Melted 10/06/16 Rolled 10/18/16												

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material.

QUALITY ASSURANCE: Matt Luymes *Matt Luymes*

Figure A-2. Concrete Barrier Rebar, Test Nos. WITD-1 and WITD-2

R#17-328
WI DOT Tie Down Barriers and Rebar

SOLD TO: ADELPHIA METALS I LLC
411 MAIN ST E
NEW PRAGUE, MN 56071-

NUCOR
NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT Page: 1

SHIP TO: ADELPHIA METALS LLC
C/O MIDWEST TERMINAL SERVICES
1745 165TH ST
HAMMOND, IN 46320-

Ship from:
MTR #: 0000133903
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

Date: 29-Jul-2016
B.L. Number: 525039
Load Number: 276710

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	818928												
KN1610418601	Nucor Steel - Kankakee Inc	69,407	105,847	10.8%	OK	-3.4%	.41	1.08	.019	.049	.20	.29	
KN16104186	16/#5 Rebar	479MPa	730MPa			.039	.18	.14	.059	.009	.001		
	60' A615M GR420 (Gr60)							.59					
	ASTM A615/A615M-15 GR 60[420]												
	AASHTO M31-07												
	Melted 07/08/16 Rolled 07/10/16												
PO# =>	818928												
KN1610418701	Nucor Steel - Kankakee Inc	65,863	102,581	15.3%	OK	-4.3%	.39	1.06	.019	.043	.20	.33	
KN16104187	16/#5 Rebar	454MPa	707MPa			.039	.17	.13	.053	.009	.001		
	60' A615M GR420 (Gr60)												
	ASTM A615/A615M-15 GR 60[420]												
	AASHTO M31-07												
	Melted 07/08/16 Rolled 07/10/16												

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material.

QUALITY ASSURANCE: Matt Luymes

Figure A-3. Concrete Barrier Rebar, Test Nos. WITD-1 and WITD-2

NUCOR
NSKNK-KANKAKEE, IL

MILL CERTIFICATION DETAILS

Purchase Order #: 818379
Customer: ADELPHIA METALS I LLC - NEW PRAGUE
Bill of Lading : 524861
Certified By : Matt Luymes
Lot #: KN1610423401
Grade: ASTM A615/A615M-15 GR 60[420] AASHTO M31-07
Melt Date : 07/10/2016
Qty Shipped LBS: 12978
Comments:

Heat #: KN16104234
Customer Part #:
Length: 30'0"
Date: 07/12/2016
Tag #: KN1613081042
Size : # 6(19) RS
Divison : NSKNK-Kankakee, IL
Qty Shipped PCS : 288
Roll Date : 07/12/2016

Chemical Properties -Wt.%

C	Mn	Si	S	P	Cu	Cr	Ni	Mo
0.39	1.06	0.18	0.048	0.020	0.37	0.14	0.19	0.056

V	Nb	Sn
0.0088	0.001	0.019

.57

Physical Properties

	Imperial-psi
Tensile:	102731
Yield:	66178
Elongation (in 8 inches):	14
Elongation (in 2 inches):	
Bend Test:	OK

Carbon Equiv:

I hereby certify that the material described herein has been manufactured in accordance with the specification and standards listed above and that it satisfies those requirements. All melting and manufacturing process were performed in the United States of America unless otherwise noted on the mill test report.

Matt Luymes

Matt Luymes, Chief Metallurgist

Figure A-4. Concrete Barrier Rebar, Test Nos. WITD-1 and WITD-2

Page: 1

SOLD TO: ADELPHIA METALS I LLC
411 MAIN ST E
NEW PRAGUE, MN 56071-

NUCOR
NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT

Ship from:
MTR #: 0000112570
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

SHIP TO: ADELPHIA METALS
411 MAIN STREET EAST
NEW PRAGUE, MN 56071-

Date: 24-Mar-2016
B.L. Number: 517112
Load Number: 271351

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative.

NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS				CHEMICAL TESTS							
		YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	817132												
KN1610065601	Nucor Steel - Kankakee Inc	76,513	99,415	15.8%	OK		.16	1.12	.010	.021	.22	.37	.37
KN16100656	3/4" (.7500) Round	528MPa	685MPa				.17	.10	.071	.061 0	.00		
	24' A706												
	ASTM A706/A706M-09b GR60 [420]												
	TEN/YD = 1.3												
	Melted 02/11/16 Rolled 02/14/16												

3/4" smooth

I hereby certify that the material described herein has been manufactured in accordance with the specifications and standards listed above and that it satisfies those requirements.
1.) Weld repair was not performed on this material.
2.) Melted and Manufactured in the United States.
3.) Mercury, Radium, or Alpha source materials in any form have not been used in the production of this material.

QUALITY ASSURANCE: Matt Luymes

Matt Luymes

Figure A-5. Concrete Barrier Bar, Test Nos. WITD-1 and WITD-2

CERTIFIED MATERIAL TEST REPORT

Page 1/1

GERDAU

US-ML-ST PAUL
1678 RED ROCK ROAD
SAINT PAUL, MN 55119
USA

CUSTOMER SHIP TO / CUSTOMER BILL TO	Challman and Company P.O. #: 9730
GRADE	A36
SHAPE / SIZE	Round Bar / 1 1/4"
LENGTH	20'00"
WEIGHT	9,300 LB
HEAT / BATCH	62138817/06
SALES ORDER	2571711/000010
CUSTOMER MATERIAL N°	
SPECIFICATION / DATE or REVISION	ASME SA36 ASTM A6-14, A36-14 ASTM A709-13A, AASHTO M270-12
CUSTOMER PURCHASE ORDER NUMBER	03046178M3
BILL OF LADING	1332-0000031395
DATE	07/29/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Sn %
0.19	0.75	0.012	0.027	0.22	0.28	0.18	0.18	0.033	0.003	0.001	0.013

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS KSI	UTS MPa	YS KSI	YS MPa
31.20	8.000	71.4	492	48.9	0
28.80	8.000	71.7	495	49.3	0

GEOMETRIC CHARACTERISTICS

R:R
21.45

HARDENABILITY

DI A255
Inch
0.74

COMMENTS / NOTES

Material 100% melted and rolled in the USA. Manufacturing processes for this steel, which may include scrap melted in an electric arc furnace and hot rolling, has been performed at Gerdau St. Paul Mill, 1678 Red Rock Rd., St. Paul, Minnesota, USA. All products produced from strand cast billets. Silicon killed (deoxidized) steel. No weld repairment performed. Steel not exposed to mercury or any liquid alloy which is liquid at ambient temperatures during processing or while in Gerdau St. Paul Mill's possession. Any modification to this certification as provided by Gerdau - St. Paul Mill without the expressed written consent of Gerdau St. Paul Mill negates the validity of this test report. This report shall not be reproduced except in full, without the expressed written consent of Gerdau St. Paul Mill. Gerdau St. Paul Mill is not responsible for the inability of this material to meet specific applications.
Roll batch 62138817/06 roll dtd 7/14/2015
ASME SA36/SA36M-13

RECEIVED JAN 25 2016

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

Bhaskar
BHASKAR YALAMANCHILI
QUALITY DIRECTOR

ALEA BRANDENBURG
QUALITY ASSURANCE MGR.

Barrier Pins

Figure A-6. Concrete Barrier Connecting Pin, Test Nos. WITD-1 and WITD-2

WI DOT Tie Down
Threaded Rod
R#17-513

MANGAL STEEL ENTERPRISES LTD.
FINAL INSPECTION CERTIFICATE

DATE : 24.03.2017

CUSTOMER : FASTENAL COMPANY PURCHASING IMPORT TRAFFIC

PART NAME : CARBON STEEL ALL THREADED RODS

SIZE : 1-1/8" - 7 X 10 FT | DATE : 02.11.2016

PART NO. (Customer) : 47150 | REPORT NO. : M 32

MATERIAL/DIA : 28 MM | SHIPPING NO. 120258344 (LOT#3)

HEAT NO. : 606782 | ORDER NO. : 120258344

LOT QTY. : 40 PCS | LOT NO. : 28 V- 3/16

SPECIFICATION : ASTM A 307 GRADE A; 1A THREAD FIT

QUANTITY TESTED : 2 PCS

	INSPECTION ITEM	SPECIFICATION		INSPECTION RESULT		REMARKS
		Min	Max	1st Sample	2nd Sample	
1	TENSILE (ksi)	60	-	76.4	76.5	OK
2	YIELD STRENGTH					
3	ELONGATION					
4	HARDNESS	69 - 100 HRB		86 HRB	86 HRB	OK
5	COATING	μ		μ	μ	OK
6	APPEARANCE	VISUAL		OK	OK	OK

	PHYSICAL DIMENSIONS	SPECIFICATION		INSPECTION RESULT		REMARKS
		Min	Max	1st Sample	2nd Sample	
1	MAJOR DIA (inches)	1.098"	1.122"	1.103"	1.104"	OK
2	PITCH DIA (inches)	1.019"	1.030"	1.020"	1.023"	OK
3	LENGTH (FT)	10' (± 1/8")		10'	10'	OK
4	GO GAUGE	PASS		PASS	PASS	OK
5	NO-GO GAUGE	DOES NOT PASS		DOES NOT PASS	DOES NOT PASS	OK

INSPECTED BY : [signature] CERTIFIED BY : [signature]

Figure A-7. 1⅛-in. (26-mm) Diameter Threaded Rod, Test No. WITD-1

RASHTRIYA ISPAT NIGAM LIMITED

VISAKHAPATNAM STEEL PLANT
QUALITY ASSURANCE & TECHNOLOGY DEVELOPMENT DEPARTMENT
VISAKHAPATNAM

TEST CERTIFICATE

PAGE 1 OF 1

DETAILS	CUSTOMER/DESTINATION	WAGON/TRUCK/TRAILOR NUMBERS	R.R. WEIGHT (TONS)
T.C.NO: QMS/R/QAD/RM/22/L/2016-17/9710/000838 DATE: 14.09.2016 INV NO: 7710601878 DATE: 14.09.2016	MANGAL STEEL ENTERPRISES LTD, 15/1, 'F' RD, BELGACHIA ,, HOWRAH, Howrah-Dist, West Bengal, India	WBIIC 6764.	30.670

HEAT / LOT NUMBER	NOMINAL SIZE (mm)	NO. OF COILS/ BUNDLES/ BILLETS/ BLOOMS	CHEMICAL COMPOSITION									MECHANICAL PROPERTIES						COLOR CODE	GRADE/ DESIGNATION
			C	MN	P	S	SI	AL	CR	CU	CE	YS	UTS	%EL	RA	BEND TEST	RE-BEND TEST		
			%	%	%	%	%	%	%	%	%	N/mm²	N/mm²	%	%				
606782	28	8	0.190	0.730	0.019	0.019	0.140	0.013	0.008	---	0.313	324.000	495.000	28.000	45.000	NA	NA	PINK+ORANGE	SAE1018

STANDARD SPECIFICATION:

CHEMICAL	C	Mn	P	S	Si	Al	Cr	Cu	Ce	V	Ti	B
	0.150 - 0.200	0.600 - 0.900	<= 0.040	<= 0.050	<= 0.300	0.010 - 0.150	<= 0.050	NA	0.250 - 0.360	---.	---	---

MECHANICAL	YS	UTS	%EL	RA
	200 - 450	300 - 550	>= 15	>= 35

THE MATERIAL SUPPLIED CONFORMS TO THE STANDARD ROLLING AND MASS TOLERANCES

AVERAGE WEIGHT OF EACH BUNDLE/COIL/BILLET/BLOOM IS 3.834 TONS APPROXIMATELY
MANUFACUTRING ROUTE: BOF-LF/IRUT-CCM-BILLETS-ROUND
REDUCTION RATIO: 125.28 : 1

FOR (QA & TD)
VISAKHAPATNAM STEEL PLANT

Figure A-8. 1⅛-in. (26-mm) Diameter Threaded Rod, Test No. WITD-1

STEEL AND PIPE SUPPLY
SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 03/13/2017
TIME 20:13:36
USER J.DUBOIS

SOLD TO:
WI DOT BARRIER TIE DOWN
1/2" THICK SQUARE WASHERS
R#17-568 APRIL 2017
66031-1127

SHIP TO:
13716
Kansas City Warehouse
401 New Century Parkway
NEW CENTURY KS

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40281814-0060	701672240TM	1/2 72 X 240 A36 TEMPERPASS STPMLPL	3	7,351.200			03/13/2017

Chemical Analysis

Heat No. B702406 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS **Melted and Manufactured in the USA**
Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.0600	0.8500	0.0160	0.0020	0.0300	0.0300	0.0700	0.0200	0.0001	0.1000	0.0300	0.0030	0.0050	0.0030	0.0072	0.0070

Mechanical / Physical Properties

Mill Coil No. 17B727160

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
62700.000	46500.000	36.30			0	NA			
63000.000	45900.000	33.30			0	NA			
62600.000	44100.000	36.50			0	NA			
62400.000	44600.000	38.20			0	NA			

Batch 0004680154 3 EA 7,351.200 LB Batch 0004681055 3 EA 7,351.200 LB Batch 0004681059 3 EA 7,351.200 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

Figure A-9. ½-in. (13-mm) Thick Washer Plate, Test No. WITD-1

R#17-674 1-1/8" A563 Grade A Heavy Hex Nuts
WI DOT Tie Down May2017 SMT

Certified Material Test Report to BS EN 10204-2004 3.1
FOR ASTM A563-07,GRADE A HEAVY HEX NUTS

FACTORY: NINGBO HAIXIN HARDWARE CO.,LTD. DATE: OCT.05.2014
ADDRESS: XIJINGTANG,LUOTUO NINGBO ZHEJIANG 315205 CHINA
LOT NO: 5079750001
CUSTOMER: FASTENAL COMPANY PURCHASING--IMPORT TRAFFIC PO NO: 180091083
QNTY SHIPPED: 2700PCS PART NO: 36521
SAMPLE SIZE : ACC. TO ASME B18 . 18 . 1 - 11 MFG DATE: SEP.15.2014
SIZE & DESCRIPTION: 1.1/8-7(PLN)

STEEL PROPERTIES
STEEL GRADE: 45# SIZE: 32mm HEAT NO: C4070634
CHEMISTRY COMPOSITION:

CHEMIST	C %	Mn %	P %	S %	Si %	Cr %	Ni %	Cu %	Mo %	OTHERS
SPE:	MIN 0.40	MAX 1.00	MAX 0.04	MAX 0.05	MAX 0.40					
TEST:	0.45	0.58	0.028	0.005	0.25					

DIMENSIONAL INSPECTIONS SPECIFICATION: ASME/ANSI B18 . 2 . 2 - 2010

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
********************	****************	**************	****************	******	********
APPEARANCE	ASTM F812-12		PASSED	100	0
WIDTH A/F	1.756"-1.812"		1.776"-1.789"	32	0
WIDTH A/C	2.002"-2.093"		2.031"-2.067"	32	0
THREAD	ASME B1.1-03		PASSED	8	0
HEIGHT	1.079"-1.139"		1.093"-1.121"	32	0
MARK	/		PASSED	100	0

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A563-07 GR-A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	******************		***************	********	*******
HARDNESS :	ASTM E18-12	Min B68-C32 Max	HRB86-93	5	0
PROOF LOAD:	ASTM F606-11	MIN100000 PSI	100000 PSI	5	0
DECARBURIZATION	SAE J121-97		PASSED	1	0
MACROETCH	ASTM E381-12	S1/R1/C1~S4/R4/C4	S2/R2/C2	5	0

ASTM OR SAE SPECIFICATION. WE CERTIFY THATTHIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
Maker's ISO#00109Q211593ROM/3302

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

Figure A-10. 1⅛-in. (26-mm) Diameter Hex Nuts, Test No. WITD-1

CMC STEEL SOUTH CAROLINA
310 New State Road
Cayce SC 29033-3704

CERTIFIED MILL TEST REPORT
For additional copies call
800-637-3227

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

Richard S. Ray

Richard S. Ray - CMC Steel SC
Quality Assurance Manager

1SERIES-BPS®

HEAT NO.:2056210 SECTION: ROUND 1-1/2 x 20'0" A36/52950 GRADE: ASTM A36-14/A529-14 Gr 50 ROLL DATE: 11/25/2016 MELT DATE: 11/23/2016	SOLD TO Steel & Pipe Supply Co Inc 555 Poyntz Ave Manhattan KS US 66502-6085 7855875182 7855872282	SHIP TO Steel & Pipe Supply Co 1003 Fort Gibson Rd Catoosa OK US 74015-0000 9182666325	Delivery#: 81947876 BOL#: 71852389 CUST PO#: 4500275184 CUST P/N: DLVRY LBS / HEAT: 5047.000 LB DLVRY PCS / HEAT: 42 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.17%	Elongation Gage Lgth test 1	8IN		
Mn	0.67%	Reduction of Area test 1	54%		
P	0.010%	Yield to tensile ratio test1	0.72		
S	0.027%	Yield Strength test 2	53.3ksi		
Si	0.24%	Tensile Strength test 2	73.1ksi		
Cu	0.28%	Elongation test 2	29%		
Cr	0.14%	Elongation Gage Lgth test 2	8IN		
Ni	0.12%	Reduction of Area test 2	51%		
Mo	0.040%	Yield to tensile ratio test2	0.73		
V	0.030%	C+(Mn/6)	0.28%		
Cb	0.000%				
Sn	0.009%				
Al	0.001%				
Ti	0.001%				
N	0.0065%				
Carbon Eq A529	0.39%				
Yield Strength test 1	52.4ksi				
Tensile Strength test 1	72.8ksi				
Elongation test 1	29%				

THIS MATERIAL IS FULLY KILLED, 100% MELTED AND MANUFACTURED IN THE USA, WITH NO WELD REPAIR OR MERCURY CONTAMINATION IN THE PROCESS.

REMARKS :

ALSO MEETS ASTM GRADE A36 REV-03A, A529 GR.50, A572-2015 GR.50, A709 GR.36, A709 GR.50, A992, AASHTO GRADE M270 GR.36, M270 GR.50, CSA G40.21-04 GRAD 44W, 50WASME SA-36 2008A ADDEND A.

11/28/2016 18:40:45
Page 1 OF 1

Figure A-11. 1½-in. (38-mm) Diameter Anchor Pin, Test No. WITD-2

STEEL AND PIPE SUPPLY
SPS Coil Processing Tulsa
5275 Bird Creek Ave.
Port of Catoosa, OK 74015

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 01/03/2017
TIME 10:08:16
USER WILLIAMR

SOLD TO

SHIP TO
13713
Warehouse 0020
1050 Fort Gibson Rd
CATOOSA OK 74015-3033

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40277056-0050	70164896TM	1/2 48 X 96 A36 TEMPERPASSED STPMP	15	9,801.600			01/03/2017

Chemical Analysis

Heat No. B617195 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA

Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.2200	0.4600	0.0100	0.0040	0.0200	0.0300	0.0500	0.0200	0.0001	0.0900	0.0260	0.0020	0.0030	0.0020	0.0078	0.0050

Mechanical / Physical Properties

Mill Coil No. 16B701058

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
70100.000	43600.000	32.00			0	NA			
67500.000	42000.000	39.20			0	NA			
71400.000	44700.000	34.20			0	NA			
68200.000	42300.000	32.70			0	NA			

Batch 0004594474 15 EA 9,801.600 LB
Batch 0004594476 15 EA 9,801.600 LB
Batch 0004594489 15 EA 9,801.600 LB
Batch 0004594490 15 EA 9,801.600 LB

THE CHEMICAL, PHYSICAL, OR MECHANICAL TESTS REPORTED ABOVE ACCURATELY REFLECT INFORMATION AS CONTAINED IN THE RECORDS OF THE CORPORATION.
The material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

Figure A-12. ½-in. (13-mm) Thick Washer Plate, Test No. WITD-2

03/13/17

SUPERPAVE TESTING RESULTS

SAMPLE NUM.:	2017-005	DATE:	03/03/17	LOT :		TON :	
PLANT:	CATHER CONST.	PROJECT NUM.:	540624	LANE :		LIFT :	
MIX TYPE:	2 NON-ARTERIAL	LOCATION:	2017-01 MIX DESIGN VERIFY				
PLACED BY:	CATHER CONST.	JOBMIX:	2017-01	AC SOURCE	MONARCH		

TARGET Pb	5.20	35%-RAP	AC GRADE	64-34
Pb (Ignition)	5.39	25%-3A CSG	Gb @ 60 F	1.0370
Pbe	3.95	15%-LS MAN SAND	Gb @ 77 F	1.0309
Gmm (Rice)	2.464	15%-3/8" LS CHIPS		DESIGN
Gsb (Agg.)	2.574	05%-3/4" LS ROCK	FAA	44.4
Gse	2.676	05%-RAS	CAA	96/84

GYRATORY VOLUMETRICS

Superpave: SPR			
Level	Nini	Ndes	Nmax
Gyrations	7	65	100
Gmb	2.201	2.393	2.416
%Gmm	89.3	97.1	98.1
Spec.	N/A	96.0-98.0	N/A
Va		2.9	3 +/- 1
VMA		12.0	12 Min.
VFA		76.1	70-80
Mix Adjusted to		3.0 % Air Voids	
Pb (Est.)		5.35	

IGNITION COMBINES

	BAND	SPR
1"	100.0	
3/4"	100.0	
5/8"		
1/2"	97.2	
3/8"	95.1	81/96
#4	80.3	
#8	56.0	46/56
#10		
#16	35.5	
#30	23.5	
#50	14.9	12/21
#200	7.9	4/9
DP	1.5	0.7-1.7

DENSITY CORE RESULTS

CORE NUM.	THICKNESS (in.)	SG CORE	COMPACTION (%)	DATE (MM/DD/YY) RECD.	TESTED	DAYS
1					N/A	
2					N/A	
3				AVG. COMPACT. (%)		

Figure A-13. Asphalt, Test No. WITD-2

CITY OF LINCOLN MATERIALS TESTING LAB
ASPHALT AGGREGATE WORKSHEET

CONTRACTOR		Cather Const.		Specific Gravity of Coarse Aggregate (AASHTO T 85)	
SUPERPAVE LEVEL		SPR			GsbC (Coarse)
MIX TYPE		NON-ARTERIAL		Oven Dry Weight (A)	2086.4
JOBMIX		2017-01		SSD Weight (B)	2107.7
DATE REC'D.		02/06/17		Weight in Water (C)	1315.3
PROJECT NUMBER		540624		Bulk S.G. (A/(B-C))	2.633
Wt. of Sample (Wtt)	9995.0	Wt.	%	Absorption ((B-A)/A)*100	1.0
Wt. of +#4 (Wtc)	%C (100(Wtc/Wtt))	2126.6	21.3	Date Ran	02/15/17
Wt. of -#4 (Wtf)	%F (100(Wtf/Wtt))	7868.4	78.7	Ran By	JEB

Fine Aggregate Angularity (AASHTO T 304)			Specific Gravity of Fine Aggregate (AASHTO T 84)	FAA	GsbF(Fine)
Volume of Measure (V)	100.0		SSD Weight (S)	500.0	500.0
Mass of Empty Measure (E)	190.0		Oven Dry Weight (A)	493.8	490.3
RUN	1	2	Flask Number	1	1
Gross Mass (D)	334.5	334.4	Flask Weight+Water to Line (B)	672.8	672.8
Net Mass, (F=D-E)	144.5	144.4	Flask+SSD Weight+Water to Line (C)	982.8	981.2
U=[(V-(F/G))/V]*100			Volume of Sample (S-(C-B))	190.0	191.6
FINE AGG. ANGULARITY (U)	44.4	44.4	Bulk S.G. (A/(B+S-C))	2.599	2.559
FAA, Average of two runs	44.4		Absorption ((S-A)/A)*100	1.3	2.0
Date Ran	02/21/17		Date Ran	02/17/17	02/14/17
Ran By	JEB		Ran By	AJR	AJR
			GsB (100/((%C/GsbC)+(%F/GsbF)))	2.574	

Coarse Aggregate Angularity (ASTM D 5821-95)

Total weight of sample (A)	500.0
Mass or count of particles with one fractured face (B)	57.0
Mass or count of particles with at least two fractured faces (C)	422.0
Mass or count of particles in the uncrushed category not meeting the fractured particle criteria (A-(B+C))	21.0
Percentage with one or more fractured faces. ((B+C)/A*100)	96
Percentage of particles with at least two fractured faces ((C/A)*100)	84
Date Ran	02/21/17
Ran By	JEB

Flat and Elongated Particles (ASTM D 4791)

Sieve Size	Total Wt.	Fail Wt.	% Flat and Elongated Particles	
1.0 in. (25.0 mm)			0.0%	
3/4 in. (19.0 mm)			0.0%	
1/2 in. (12.5 mm)	222.4	0.0	0.0%	
3/8 in. (9.5 mm)	187.2	0.0	0.0%	
			Total % Flat and Elongated Particles	0%
			Date Ran	02/21/17
			Ran By	JEB

Sand Equivalent (AASHTO T 176)

Soaking Start	Sedimentation Start	Clay	Sand	Sand Equivalent	
				0.0	
				0.0	
				0.0	
				Sand Equivalent Average	0
				Date Ran	
				Ran By	

Figure A-14. Asphalt, Test No. WITD-2

CATHER CONST. TYPE 2 (SPR) 2017

CATHER CONST. TYPE 2 (SPR) 2017-01		CONTRACTOR TESTS											
		AGGREGATE GRADATIONS											
%	MATERIAL	S.G.	1"	3/4	1/2	3/8	#4	#8	#16	#30	#50	#200	SOURCE
0	2A GRAVEL-LR												
0	QTZ. MAN SAND-EVERIST												
0	QTZ. 3/4" ROCK												
0	QTZ. 3/16" DOWN												
0	5/8" SPECIAL-KER.												
15	3/8" LS CHIPS-MM		100.0	100.0	100.0	99.0	33.0	3.0	2.0	1.0	1.0	1.0	02/06/17
0	SCREENINGS-KER.												
5	3/4" LS-MM		100.0	100.0	40.0	12.0	6.0	5.0	4.0	3.0	2.0	1.0	02/06/17
0	1/4" LS CHIPS												
0	47B GRAVEL-LR												
0	WASH SAND-WSG												
15	LS MAN SAND-MM		100.0	100.0	100.0	100.0	94.0	64.0	32.0	12.0	3.0	1.5	02/06/17
25	3A CSG-VONTZ CONST.		100.0	100.0	100.0	100.0	93.0	56.0	34.0	20.0	12.0	5.5	02/06/17
5	RAS		100.0	100.0	100.0	100.0	99.0	95.0	79.0	61.0	53.0	32.0	02/06/17
35	RAP		100.0	100.0	97.0	94.0	83.0	64.0	47.0	34.0	22.0	9.0	02/06/17
100	BLEND		100.0	100.0	96.0	93.4	76.6	51.5	34.2	22.1	14.1	6.6	
								*				*	* INDEPENDENT ADJ.

GRADATION BAND % PASSING

SIEVE	"SPR" BAND	
200	4.0	9.0
50	12.0	21.0
30		
16		
8	46.0	56.0
4		
3/8"	81.0	96.0
1/2"		
3/4"		
1"		

TEST COMPARISON

	CAL. BLEND		IGNITION	
		CITY LAB	CITY LAB	
#200	6.6	5.9	7.9	7.0
#50	14.1	13.1	14.9	14.7
#30	22.1	20.8	23.6	23.2
#16	34.2	32.4	35.5	35.6
#8	51.5	51.0	56.0	53.6
#4	76.6	77.4	80.3	76.2
3/8"	93.4	94.5	95.1	92.7
1/2"	96.0	96.8	97.2	94.4
3/4"	100.0	99.9	100.0	100.0
1"	100.0	100.0	100.0	100.0

	POWER
	.45
0	0.000
	0.312
	0.582
	0.795
	1.077
	1.472
	2.016
	2.754
100	3.116
	3.762
	4.257

CATHER CONST. TYPE 2 (SPR) 2017-01		CITY LAB TESTS											
		AGGREGATE GRADATIONS											
%	MATERIAL	S.G.	1"	3/4	1/2	3/8	#4	#8	#16	#30	#50	#200	SOURCE
0	2A GRAVEL-LR												
0	QTZ. MAN SAND-EVERIST												
0	QTZ. 3/4" ROCK												
0	QTZ. 3/16" DOWN												
0	5/8" SPECIAL-KER.												
15	3/8" LS CHIPS-MM		100.0	100.0	100.0	99.3	35.9	3.2	1.6	1.2	1.1	1.0	02/13/17
0	SCREENINGS-KER.												
5	3/4" LS-MM		100.0	98.9	43.0	12.6	6.3	4.6	3.1	2.2	1.7	1.4	02/13/17
0	1/4" LS CHIPS												
0	47B GRAVEL-LR												
0	WASH SAND-WSG												
15	LS MAN SAND-MM		100.0	100.0	100.0	100.0	92.1	59.3	27.0	9.8	2.8	1.2	02/13/17
25	3A CSG-VONTZ CONST.		100.0	100.0	100.0	100.0	92.0	53.1	29.6	16.7	9.6	3.8	02/13/17
5	RAS		100.0	100.0	100.0	100.0	98.2	94.3	76.3	59.0	50.2	29.4	02/13/17
35	RAP		100.0	100.0	98.9	97.1	85.5	66.9	47.8	34.0	21.4	8.8	02/13/17
100	BLEND		100.0	99.9	96.8	94.5	77.4	51.0	32.4	20.8	13.1	5.9	
								*				*	* INDEPENDENT ADJ.

Figure A-15. Asphalt, Test No. WITD-2

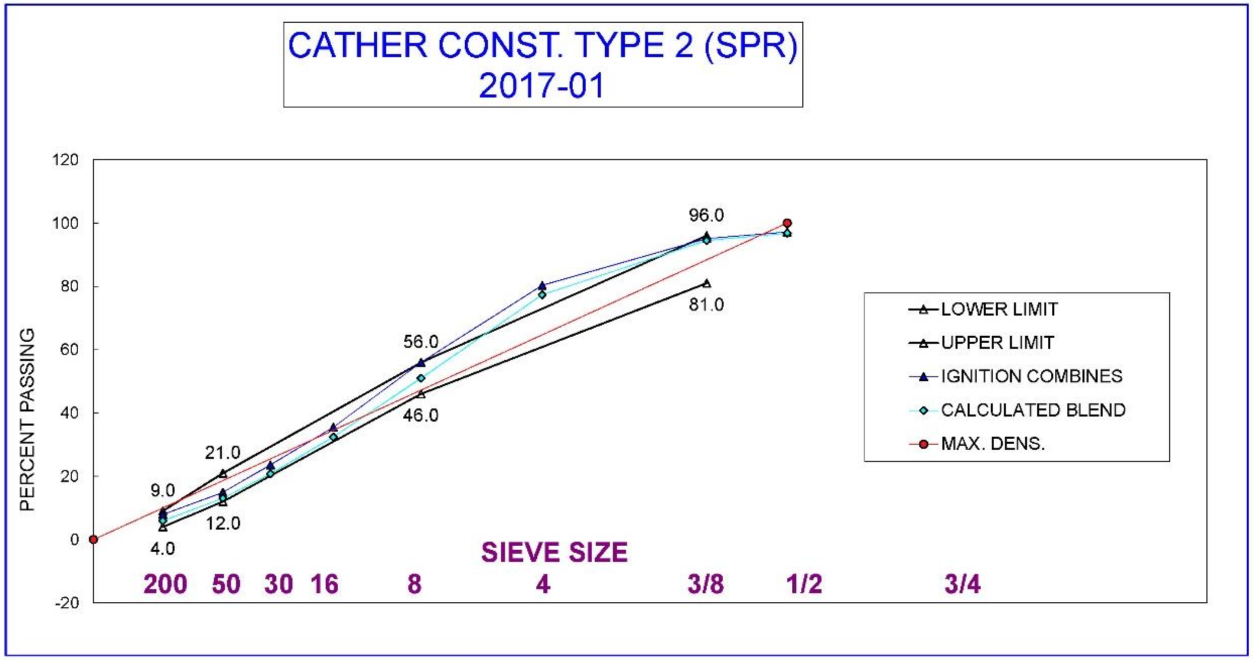


Figure A-16. Asphalt, Test No. WITD-2

Appendix B. Vehicle Center of Gravity Determination

Date:	5/30/2017	Test Name:	WITD-1	VIN:	1D7RB1GKXAS249304
Year:	2011	Make:	Dodge	Model:	Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vertical CG (in)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	4950	28	138909.38
+	Hub	19	15	285
+	Brake activation cylinder & frame	7	26 1/2	185.5
+	Pneumatic tank (Nitrogen)	28	26	728
+	Strobe/Brake Battery	5	24 3/4	123.75
+	Brake Receiver/Wires	5	51 1/2	257.5
+	CG Plate including DAS	42	29 1/2	1239
-	Battery	-33	39	-1287
-	Oil	-2	27	-54
-	Interior	-80	26 1/4	-2100
-	Fuel	-172	18	-3096
-	Coolant	-8	34	-272
-	Washer fluid	-2	34	-68
+	Water Ballast (In Fuel Tank)	158	18	2844
+	Onboard Supplemental Battery	12	25 1/2	306
	Steel Ballast	67	34 3/4	2328.25
				140329.38

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

Estimated Total Weight (lb)	4996
Vertical CG Location (in.)	28.0883

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140 5/8 in.
Front Track Width: 68 5/8 in.
Rear Track Width: 68 in.

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	5000	0.0
Longitudinal CG (in.)	63 ± 4	65.053125	2.05312
Lateral CG (in.)	NA	-0.901725	NA
Vertical CG (in.)	28 or greater	28.09	0.08835

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	1375	1314
Rear	1153	1108

FRONT	2689	lb
REAR	2261	lb
TOTAL	4950	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	1387	1300
Rear	1179	1134

FRONT	2687	lb
REAR	2313	lb
TOTAL	5000	lb

Figure B-1. Vehicle Mass Distribution, Test No. WITD-1

Date:	12/14/2017	Test Name:	WITD-2	VIN:	1D7RB1GP4AS121538
Year:	2010	Make:	Dodge	Model:	Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	5075	28 5/8	145271.88
+	Hub	19	15 3/4	299.25
+	Brake activation cylinder & frame	7	25	175
+	Pneumatic tank (Nitrogen)	28	27	756
+	Strobe/Brake Battery	5	26 1/2	132.5
+	Brake Receiver/Wires	5	52 1/4	261.25
+	CG Plate including DAS	42	29 1/2	1239
-	Battery	-52	42	-2184
-	Oil	-10	26 1/2	-265
-	Interior	-98	37 1/2	-3675
-	Fuel	-171	19	-3249
-	Coolant	-7	34 1/2	-241.5
-	Washer fluid	-7	33	-231
+	Water Ballast (In Fuel Tank)	96	16 1/4	1560
+	Onboard Supplemental Battery	12	26 3/4	321
				0
Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle				140170.38

Estimated Total Weight (lb)	4944
Vertical CG Location (in.)	28.3516

Vehicle Dimensions for C.G. Calculations

Wheel Base:	141 1/4	in.	Front Track Width:	68 5/8	in.
			Rear Track Width:	68 1/8	in.

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	5003	3.0
Longitudinal CG (in.)	63 ± 4	62.36683	-0.63317
Lateral CG (in.)	NA	0.3211698	NA
Vertical CG (in.)	28 or greater	28.35	0.35161

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	1455	1393
Rear	1122	1105

FRONT	2848	lb
REAR	2227	lb
TOTAL	5075	lb

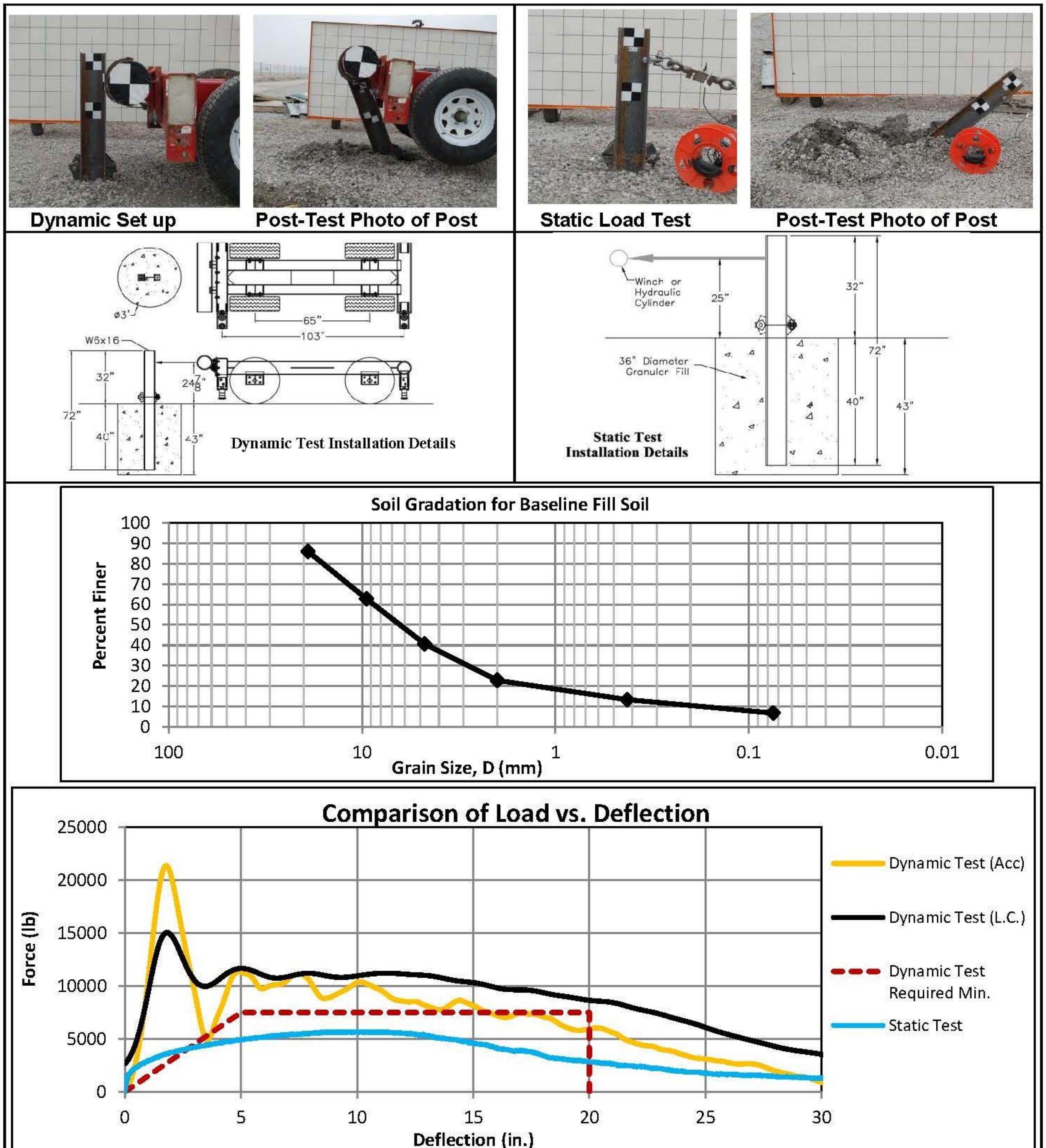
TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	1375	1419
Rear	1103	1106

FRONT	2794	lb
REAR	2209	lb
TOTAL	5003	lb

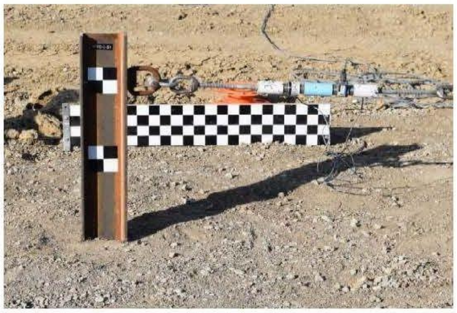
Figure B-2. Vehicle Mass Distribution, Test No. WITD-2

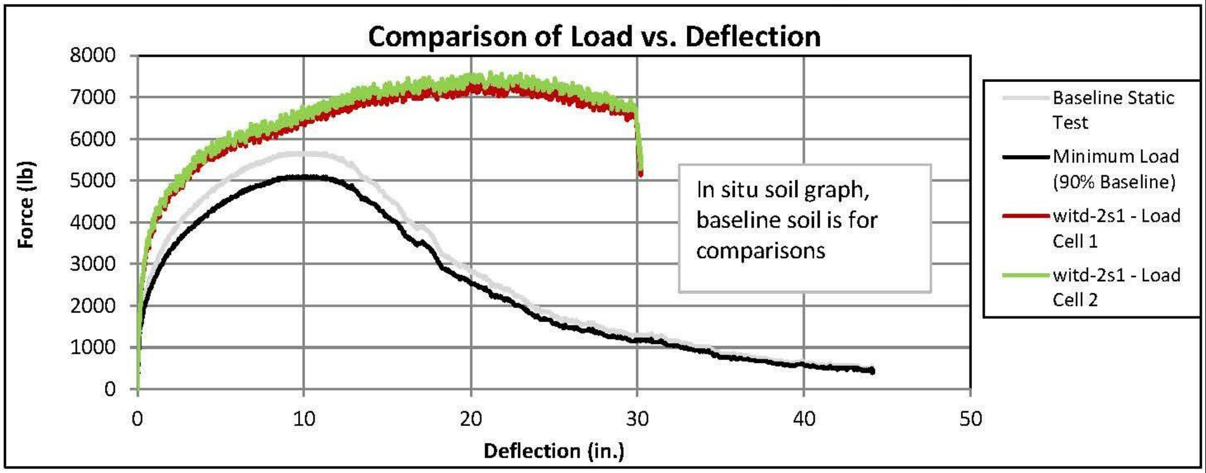
Appendix C. Static Soil Tests

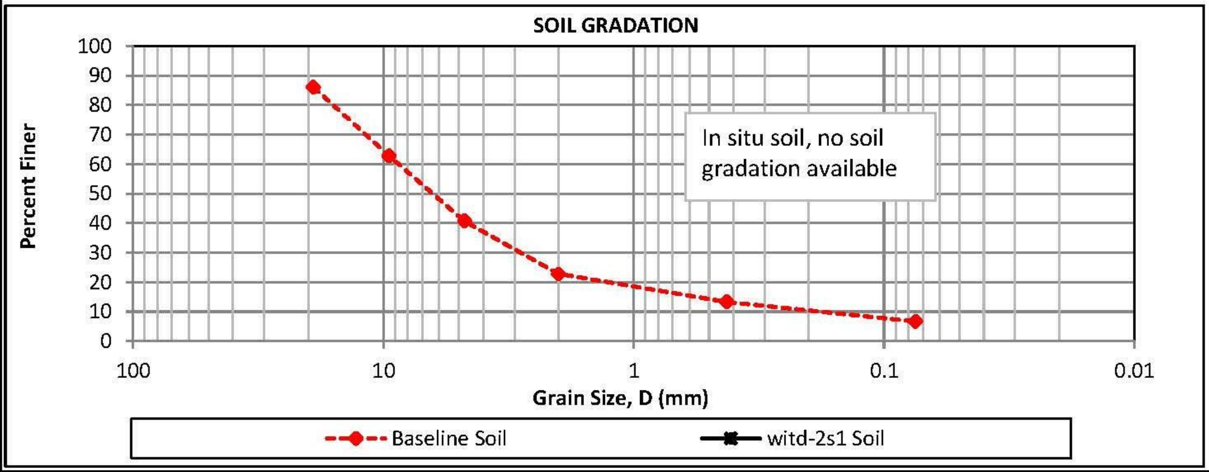


Date	5/17/2013	
Test Facility & Site Location	Midwest Roadside Safety Facility	
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)	
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)	
Description of fill placement procedure	H.E.-8	
Bogie Weight	1857 lb	842 kg
Impact Velocity	20.6 mph	33.2 km/h

Figure C-1. Soil Strength, Initial Calibration Tests

Static Load Test Setup	Post-Test Photo of Post
	





Date	11/22/2017
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Low Plasticity Silt (ML)
Fill material description (ASTM D2487)	N/A
Description of fill placement procedure	Static post driven into in situ soil

Figure C-2. Static Soil Test, Test No. WITD-2

Appendix D. Vehicle Deformation Records

Date: 5/30/2017 | Test Name: WITD-1 | VIN: 1D7RB1GKXAS249304
Year: 2011 | Make: Dodge | Model: Ram 1500

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	24.824	12.303	4.016	24.712	12.633	4.182	-0.113	0.330	0.165	0.386
2	25.655	15.728	2.514	25.527	16.149	2.708	-0.128	0.421	0.194	0.481
3	26.913	20.725	-0.065	26.678	20.881	0.292	-0.234	0.156	0.357	0.455
4	26.825	27.451	1.585	26.178	27.578	2.008	-0.648	0.127	0.424	0.784
5	21.499	11.309	2.396	21.416	11.573	2.592	-0.083	0.264	0.196	0.339
6	22.431	15.825	0.336	22.295	16.088	0.472	-0.136	0.263	0.137	0.326
7	23.477	20.972	-1.976	23.319	21.190	-1.722	-0.158	0.218	0.254	0.370
8	23.298	28.262	-1.237	23.266	28.443	-1.099	-0.032	0.181	0.138	0.230
9	18.226	10.301	0.759	18.201	10.625	0.879	-0.025	0.324	0.121	0.346
10	19.313	15.304	-1.750	19.273	15.552	-1.670	-0.040	0.248	0.079	0.264
11	20.275	21.121	-3.781	20.227	21.343	-3.642	-0.049	0.222	0.140	0.266
12	19.988	27.758	-2.933	19.892	27.980	-2.781	-0.096	0.221	0.152	0.285
13	15.232	10.170	-1.227	15.209	10.327	-1.097	-0.023	0.157	0.130	0.205
14	16.506	14.665	-4.490	16.559	14.957	-4.399	0.053	0.292	0.091	0.311
15	16.751	21.326	-4.237	16.701	21.534	-4.177	-0.049	0.209	0.060	0.223
16	16.495	27.630	-3.695	16.454	27.821	-3.668	-0.041	0.191	0.027	0.198
17	12.037	9.692	-2.396	12.019	9.926	-2.321	-0.018	0.233	0.074	0.245
18	12.209	13.379	-5.113	12.191	13.587	-5.049	-0.019	0.207	0.064	0.218
19	12.583	21.034	-4.290	12.522	21.178	-4.277	-0.061	0.144	0.013	0.157
20	12.649	27.969	-3.679	12.582	28.122	-3.771	-0.067	0.153	-0.092	0.191
21	5.672	11.774	-5.203	5.656	12.038	-5.172	-0.016	0.264	0.031	0.266
22	5.548	15.450	-4.985	5.541	15.693	-4.962	-0.007	0.244	0.023	0.245
23	5.491	21.761	-4.314	5.411	21.963	-4.320	-0.080	0.202	-0.006	0.217
24	5.711	27.461	-3.753	5.821	27.648	-3.783	0.110	0.187	-0.030	0.219
25	-0.407	11.394	-1.413	-0.489	11.558	-1.418	-0.082	0.164	-0.006	0.184
26	-0.464	14.761	-1.066	-0.555	14.898	-1.068	-0.091	0.137	-0.003	0.165
27	-0.375	18.860	-0.714	-0.483	19.109	-0.702	-0.108	0.249	0.012	0.272
28	-0.421	26.250	0.126	-0.490	26.415	0.127	-0.069	0.164	0.001	0.178

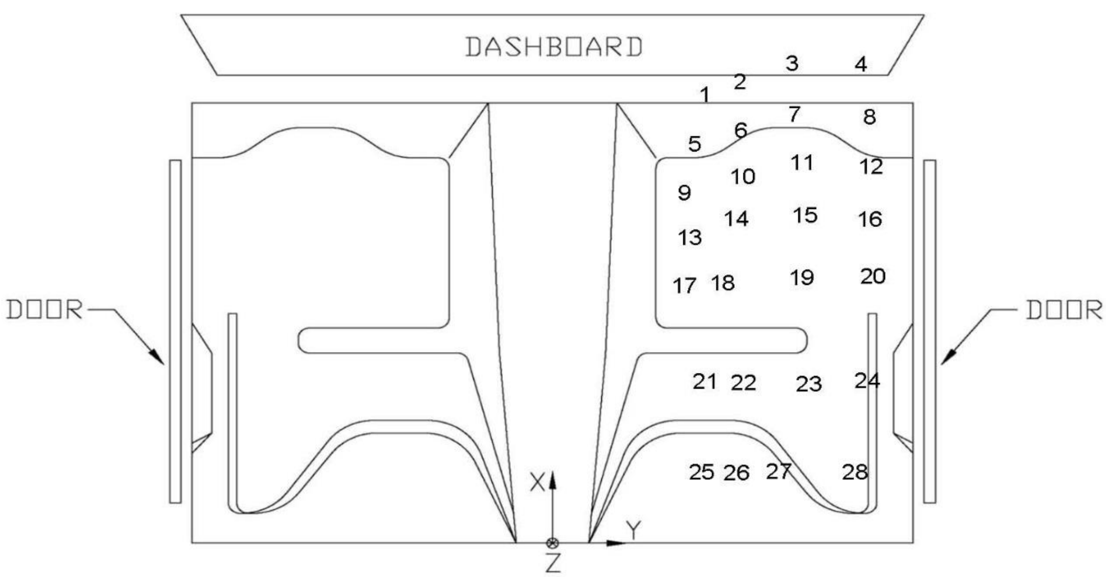


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. WITD-1

Date: 5/30/2017 Test Name: WITD-1 VIN: 1D7RB1GKXAS249304
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	49.889	12.268	4.604	49.821	12.398	4.454	-0.069	0.129	-0.149	0.209
2	50.785	15.612	2.820	50.656	15.761	2.668	-0.129	0.150	-0.153	0.250
3	52.079	20.257	-0.046	51.841	20.275	-0.118	-0.238	0.018	-0.072	0.249
4	52.144	27.173	1.219	51.531	27.023	1.072	-0.613	-0.150	-0.147	0.648
5	46.530	11.157	3.093	46.454	11.287	2.946	-0.076	0.131	-0.148	0.211
6	47.456	15.484	0.693	47.423	15.579	0.488	-0.032	0.094	-0.204	0.227
7	48.647	20.459	-1.972	48.501	20.459	-2.125	-0.146	0.000	-0.153	0.211
8	48.674	27.826	-1.684	48.593	27.724	-2.075	-0.081	-0.102	-0.391	0.412
9	43.238	10.179	1.477	43.181	10.219	1.354	-0.057	0.040	-0.123	0.141
10	44.370	14.999	-1.440	44.336	14.898	-1.591	-0.034	-0.101	-0.152	0.185
11	45.508	20.604	-3.760	45.383	20.515	-4.048	-0.125	-0.089	-0.288	0.326
12	45.343	27.317	-3.369	45.261	27.211	-3.679	-0.082	-0.107	-0.310	0.338
13	40.213	9.922	-0.477	40.215	9.896	-0.633	0.002	-0.027	-0.155	0.158
14	41.559	14.142	-4.040	41.562	14.103	-4.253	0.003	-0.038	-0.213	0.217
15	41.908	20.813	-4.248	41.802	20.748	-4.569	-0.107	-0.064	-0.321	0.344
16	41.790	27.177	-4.137	41.758	27.097	-4.564	-0.033	-0.080	-0.427	0.436
17	37.051	9.446	-1.643	36.984	9.409	-1.770	-0.067	-0.037	-0.128	0.149
18	37.283	12.899	-4.578	37.216	12.852	-4.777	-0.067	-0.047	-0.199	0.216
19	37.763	20.624	-4.283	37.665	20.487	-4.623	-0.099	-0.138	-0.340	0.380
20	37.987	27.577	-4.143	37.934	27.407	-4.672	-0.053	-0.170	-0.529	0.558
21	30.689	11.470	-4.575	30.591	11.411	-4.741	-0.098	-0.059	-0.166	0.201
22	30.714	15.129	-4.602	30.642	15.068	-4.833	-0.072	-0.061	-0.232	0.250
23	30.678	21.485	-4.355	30.613	21.400	-4.695	-0.065	-0.086	-0.340	0.356
24	31.131	27.157	-4.191	31.088	27.040	-4.621	-0.042	-0.118	-0.430	0.448
25	24.611	11.438	-0.748	24.556	11.396	-0.925	-0.055	-0.042	-0.177	0.190
26	24.564	14.787	-0.642	24.510	14.731	-0.853	-0.054	-0.056	-0.212	0.225
27	24.709	18.893	-0.569	24.678	18.862	-0.826	-0.031	-0.031	-0.257	0.261
28	24.858	26.360	-0.237	24.828	26.278	-0.587	-0.030	-0.082	-0.350	0.360

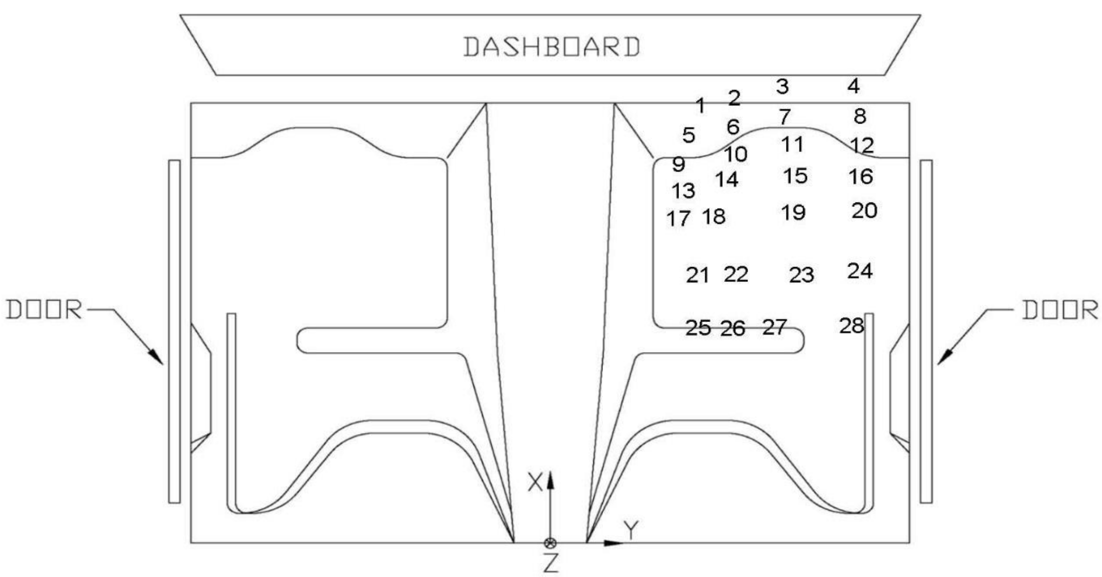


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. WITD-1

Date: 5/30/2017 Test Name: WITD-1 VIN: 1D7RB1GKXAS249304
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	10.989	-3.237	25.037	10.932	-2.931	25.058	-0.056	0.305	0.021	0.311
	2	13.262	14.861	25.185	13.170	15.114	25.347	-0.092	0.253	0.162	0.314
	3	13.624	25.591	26.984	13.531	25.907	27.131	-0.093	0.316	0.147	0.360
	4	8.391	-2.100	13.574	8.343	-1.809	13.655	-0.049	0.291	0.081	0.306
	5	10.319	16.698	15.920	10.249	16.964	16.101	-0.070	0.266	0.181	0.329
	6	11.021	28.462	17.712	10.866	28.772	17.902	-0.154	0.310	0.190	0.395
SIDE PANEL	7	19.994	31.654	6.444	19.826	31.397	6.539	-0.168	-0.257	0.095	0.321
	8	24.101	31.745	8.356	23.903	31.751	8.483	-0.198	0.006	0.126	0.235
	9	19.741	32.245	-0.349	19.675	32.288	-0.305	-0.066	0.043	0.045	0.090
IMPACT SIDE DOOR	10	11.563	31.050	24.538	10.790	31.596	24.726	-0.773	0.546	0.188	0.965
	11	-1.001	30.910	24.769	-1.730	32.162	24.945	-0.729	1.252	0.176	1.459
	12	-14.455	30.925	24.930	-15.205	32.738	25.115	-0.750	1.813	0.185	1.970
	13	14.100	33.183	12.598	13.320	32.997	12.641	-0.780	-0.186	0.043	0.803
	14	0.950	33.885	12.784	0.335	34.721	12.890	-0.614	0.836	0.106	1.043
	15	-12.423	32.936	12.506	-13.053	33.721	12.545	-0.630	0.784	0.039	1.007
ROOF	16	7.050	-4.744	41.065	6.827	-4.622	41.094	-0.223	0.122	0.029	0.256
	17	6.762	1.935	41.762	6.558	2.142	41.794	-0.204	0.207	0.032	0.292
	18	5.828	8.289	42.365	5.627	8.322	42.399	-0.201	0.033	0.035	0.206
	19	4.545	14.234	42.772	4.193	14.346	42.876	-0.351	0.113	0.104	0.383
	20	2.625	19.507	43.022	2.239	19.661	43.131	-0.386	0.154	0.109	0.430
	21	1.062	-5.137	43.764	0.871	-5.019	43.724	-0.192	0.118	-0.040	0.228
	22	0.648	0.658	44.371	0.419	0.814	44.365	-0.229	0.156	-0.005	0.277
	23	-0.106	6.382	44.884	-0.342	6.414	44.891	-0.236	0.032	0.007	0.238
	24	-1.390	11.600	45.330	-1.666	11.685	45.354	-0.276	0.085	0.025	0.290
	25	-3.048	17.150	45.666	-3.407	17.216	45.719	-0.359	0.066	0.054	0.369
	26	-4.031	-5.352	44.644	-4.184	-5.257	44.562	-0.153	0.096	-0.081	0.198
	27	-4.976	-0.038	45.241	-5.204	0.112	45.191	-0.227	0.150	-0.050	0.277
	28	-5.733	6.030	45.698	-6.065	6.127	45.679	-0.333	0.097	-0.019	0.347
	29	-6.244	10.027	45.958	-6.550	10.116	45.947	-0.306	0.089	-0.011	0.319
	30	-7.153	16.429	46.275	-7.494	16.591	46.292	-0.341	0.162	0.017	0.378
A PILLAR	31	4.249	23.251	40.676	4.043	23.410	40.838	-0.205	0.159	0.162	0.306
	32	9.121	24.676	38.055	8.792	24.813	38.188	-0.329	0.137	0.133	0.380
	33	14.204	26.220	34.740	13.902	26.378	34.786	-0.302	0.158	0.046	0.344
	34	19.397	27.797	30.633	19.084	27.969	30.737	-0.313	0.172	0.104	0.372
B PILLAR	35	-18.148	30.887	8.362	-18.321	30.806	8.360	-0.174	-0.081	-0.002	0.192
	36	-23.305	30.798	8.591	-23.477	30.333	8.564	-0.171	-0.465	-0.027	0.496
	37	-18.895	29.972	16.908	-19.167	29.814	16.956	-0.272	-0.158	0.047	0.318
	38	-23.155	29.956	16.641	-23.404	29.599	16.536	-0.249	-0.357	-0.105	0.448
	39	-19.780	28.707	25.588	-20.083	28.564	25.591	-0.303	-0.143	0.003	0.335
	40	-23.622	28.685	25.570	-23.865	28.434	25.560	-0.243	-0.251	-0.009	0.350

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

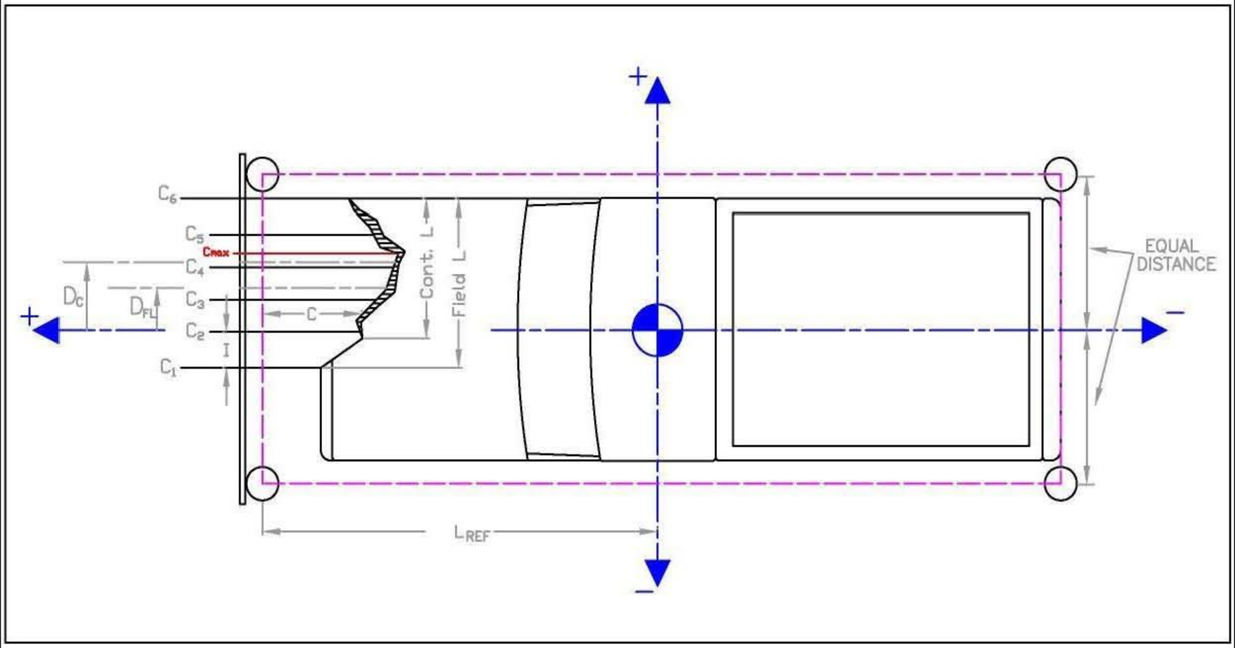
Date: 5/30/2017 Test Name: WITD-1 VIN: 1D7RB1GKXAS249304
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	35.711	-1.566	26.601	35.828	-1.173	26.596	0.117	0.393	-0.006	0.410
	2	38.364	16.395	25.555	38.398	16.730	25.318	0.034	0.335	-0.237	0.412
	3	38.938	27.232	26.619	39.021	27.705	26.283	0.083	0.473	-0.336	0.586
	4	33.159	-1.153	15.115	33.191	-0.936	15.105	0.032	0.217	-0.010	0.219
	5	35.438	17.632	16.150	35.476	17.934	16.008	0.038	0.303	-0.143	0.337
	6	36.371	29.627	17.110	36.351	29.936	16.871	-0.020	0.309	-0.238	0.390
SIDE PANEL	7	45.330	31.789	5.695	45.296	31.359	5.325	-0.034	-0.430	-0.370	0.568
	8	49.499	31.933	7.622	49.389	31.788	7.155	-0.110	-0.145	-0.467	0.502
	9	45.141	31.916	-1.143	45.067	31.698	-1.589	-0.074	-0.218	-0.446	0.502
IMPACT SIDE DOOR	10	37.038	32.610	23.742	36.355	33.209	23.412	-0.683	0.599	-0.329	0.966
	11	24.410	32.700	24.026	23.821	34.048	23.654	-0.588	1.348	-0.372	1.517
	12	10.982	32.966	24.231	10.408	34.909	23.813	-0.573	1.943	-0.418	2.068
	13	39.530	33.851	11.712	38.906	33.565	11.275	-0.624	-0.286	-0.437	0.813
	14	26.449	34.811	11.888	25.917	35.574	11.464	-0.532	0.763	-0.424	1.022
	15	13.041	34.094	11.571	12.512	34.813	11.184	-0.529	0.719	-0.387	0.973
ROOF	16	31.751	-1.949	42.763	31.768	-1.556	42.721	0.017	0.393	-0.042	0.395
	17	31.551	4.895	43.009	31.556	5.314	42.914	0.005	0.420	-0.096	0.430
	18	30.815	11.140	43.142	30.848	11.586	42.975	0.032	0.446	-0.166	0.477
	19	29.580	17.146	43.166	29.591	17.625	42.946	0.010	0.479	-0.220	0.527
	20	27.780	22.514	43.032	27.693	22.881	42.827	-0.087	0.368	-0.205	0.430
	21	25.733	-1.998	45.475	25.797	-1.564	45.407	0.064	0.434	-0.068	0.444
	22	25.371	3.870	45.697	25.529	4.300	45.562	0.158	0.430	-0.135	0.477
	23	24.806	9.607	45.795	24.898	10.016	45.632	0.092	0.409	-0.163	0.450
	24	23.626	14.829	45.873	23.684	15.235	45.678	0.057	0.406	-0.195	0.454
	25	22.018	20.512	45.830	21.983	20.858	45.614	-0.035	0.346	-0.216	0.409
	26	20.598	-2.001	46.370	20.762	-1.593	46.274	0.164	0.408	-0.096	0.450
	27	19.667	3.360	46.610	19.821	3.791	46.478	0.154	0.431	-0.133	0.476
	28	19.131	9.361	46.638	19.233	9.782	46.467	0.103	0.422	-0.170	0.466
	29	18.641	13.482	46.625	18.780	13.841	46.426	0.140	0.359	-0.199	0.434
	30	17.842	19.902	46.498	17.941	20.354	46.251	0.099	0.451	-0.247	0.524
A PILLAR	31	29.553	26.093	40.533	29.480	26.440	40.203	-0.073	0.347	-0.329	0.484
	32	34.415	27.226	37.770	34.306	27.565	37.453	-0.109	0.339	-0.316	0.476
	33	39.483	28.411	34.252	39.458	28.754	33.856	-0.025	0.342	-0.396	0.524
	34	44.749	29.614	30.082	44.559	29.882	29.692	-0.190	0.268	-0.390	0.511
B PILLAR	35	7.279	31.872	7.656	7.109	31.691	7.389	-0.170	-0.182	-0.266	0.365
	36	2.084	31.899	7.920	1.978	31.342	7.616	-0.106	-0.557	-0.304	0.643
	37	6.472	31.565	16.248	6.341	31.414	15.907	-0.131	-0.151	-0.340	0.395
	38	2.277	31.614	15.915	2.089	31.250	15.590	-0.188	-0.365	-0.325	0.523
	39	5.623	30.925	24.936	5.388	30.877	24.709	-0.235	-0.048	-0.228	0.331
	40	1.797	30.966	24.994	1.588	30.825	24.672	-0.209	-0.142	-0.323	0.409

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

Date:	5/7/2017	Test Name:	WITD-1	VIN:	1D7RB1GKXAS249304
Year:	2011	Make:	Dodge	Model:	Ram 1500



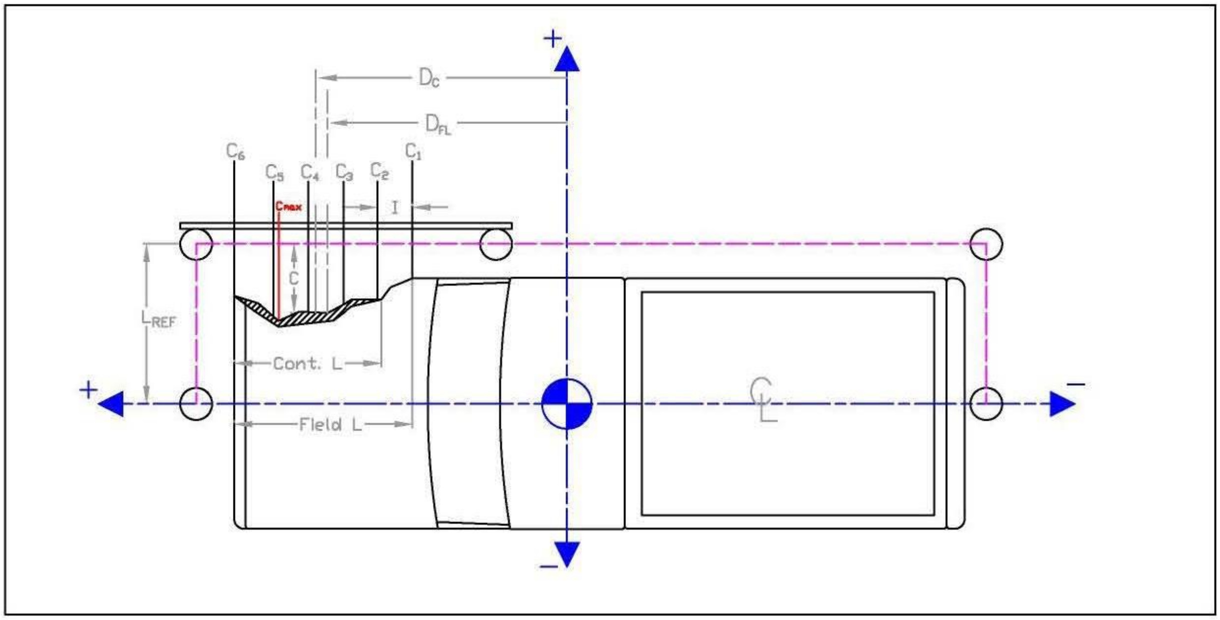
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	122 1/2	(3112)
Total Vehicle Width:	77 7/8	(1978)
Width of contact and induced crush - Field L:	51	(1294)
Crush measurement spacing interval (L/5) - I:	10 1/4	(260)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	19 1/2	(495)
Distance from center of vehicle to center of contact damage - D_C:	24 1/2	(622)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	20 1/2	(521)	-25 1/2	-(648)	7	(178)	13 4/7	(344)	-0	-(2)
C_2	16 7/8	(429)	-15 1/4	-(387)	4 7/8	(124)			-1 4/7	-(40)
C_3	16 3/4	(425)	-5	-(127)	4 1/8	(105)			-1	-(24)
C_4	18	(457)	5 1/4	(133)	4 1/8	(105)			1/3	(8)
C_5	20 1/8	(511)	15 1/2	(394)	5	(127)			1 4/7	(40)
C_6	38 5/8	(981)	25 3/4	(654)	6 7/8	(175)			18 1/5	(462)
C_{MAX}	39 1/2	(1003)	26	(660)	7	(178)			19	(481)

Figure D-5. Exterior Vehicle Crush (NASS) - Front, Test No. WITD-1

Date:	5/7/2017	Test Name:	WITD-1	VIN:	1D7RB1GKXAS249304
Year:	2011	Make:	Dodge	Model:	Ram 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	42 1/8	(1070)
Total Vehicle Length:	229	(5817)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-9	-(230)
Width of contact and induced crush - Field L:	229	(5817)
Crush measurement spacing interval (L/5) - I:	45 3/4	(1162)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-9	-(229)
Width of Contact Damage:	229	(5817)
Distance from vehicle c.g. to center of contact damage - D_C:	-9	-(229)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	N/A	#VALUE!	-123 1/2	-(3137)	33 1/2	(851)	-1 7/8	-(48)	#VALUE!	#VALUE!
C_2	N/A	#VALUE!	-77 3/4	-(1975)	5 1/4	(133)			#VALUE!	#VALUE!
C_3	4 3/8	(111)	-32	-(813)	5 1/2	(140)			3/4	(19)
C_4	3 3/8	(86)	13 3/4	(349)	5 1/8	(130)			1/8	(3)
C_5	9 3/4	(248)	59 1/2	(1511)	5	(127)			6 5/8	(168)
C_6	N/A	#VALUE!	105 1/4	(2673)	30	(762)			#VALUE!	#VALUE!
C_{MAX}	29 7/8	(759)	101 3/4	(2584)	15 3/8	(391)			16 3/8	(416)

Figure D-6. Exterior Vehicle Crush (NASS) - Side, Test No. WITD-1

Date: 12/14/2017 Test Name: WITD-2 VIN: 1D7RB1GP4AS121538
Year: 2010 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
1	29.231	-22.278	1.548	19.527	-16.715	8.500	9.704	5.563	6.952	13.170	11.937
2	31.164	-17.832	0.001	22.797	-12.571	7.992	8.368	5.261	7.991	12.710	11.570
3	32.108	-12.484	-1.060	26.624	-12.044	4.211	5.483	0.440	5.271	7.618	7.606
4	28.896	-6.779	-0.375	27.770	-6.605	1.255	1.126	0.173	1.630	1.989	1.981
5	26.540	-23.169	-2.234	16.994	-17.005	6.705	9.547	6.164	8.939	14.458	13.078
6	27.566	-17.705	-3.315	18.911	-13.065	4.274	8.655	4.640	7.589	12.411	11.511
7	27.364	-12.595	-3.445	22.240	-10.877	1.424	5.124	1.717	4.869	7.274	7.069
8	26.030	-6.247	-3.756	25.071	-6.615	-2.436	0.959	-0.368	1.319	1.672	1.631
9	22.811	-23.215	-5.406	14.693	-15.073	2.312	8.118	8.142	7.718	13.848	7.718
10	22.826	-17.838	-5.411	15.997	-13.557	0.754	6.829	4.281	6.165	10.147	6.165
11	22.942	-10.986	-5.421	20.433	-10.455	-2.927	2.509	0.531	2.494	3.577	2.494
12	22.968	-6.438	-5.450	22.252	-6.718	-4.759	0.717	-0.280	0.691	1.034	0.691
13	18.448	-22.622	-7.316	11.831	-18.897	-0.814	6.618	3.725	6.502	9.997	6.502
14	18.195	-17.699	-7.268	14.594	-16.107	-3.613	3.601	1.592	3.655	5.372	3.655
15	18.032	-11.750	-7.250	17.516	-12.163	-6.935	0.515	-0.413	0.315	0.732	0.315
16	18.021	-6.704	-7.287	17.837	-7.252	-7.030	0.184	-0.548	0.257	0.633	0.257
17	13.466	-22.695	-7.206	10.636	-21.471	-4.823	2.830	1.224	2.383	3.897	2.383
18	13.282	-17.999	-7.152	12.521	-18.173	-7.246	0.761	-0.174	-0.094	0.786	-0.094
19	13.253	-11.377	-6.988	12.623	-12.474	-7.394	0.631	-1.097	-0.406	1.329	-0.406
20	13.100	-6.428	-7.153	13.000	-6.879	-7.042	0.100	-0.452	0.111	0.476	0.111
21	7.085	-22.379	-7.031	6.497	-22.451	-6.744	0.588	-0.072	0.287	0.658	0.287
22	6.802	-17.813	-7.021	6.330	-17.996	-7.627	0.472	-0.183	-0.606	0.789	-0.606
23	6.982	-11.716	-7.022	6.805	-11.921	-7.288	0.176	-0.205	-0.266	0.379	-0.266
24	6.995	-6.420	-7.056	6.925	-6.640	-7.071	0.070	-0.220	-0.015	0.231	-0.015
25	-0.290	-20.159	-2.873	-0.400	-20.105	-2.445	0.110	0.055	0.428	0.445	0.428
26	-0.208	-15.052	-2.856	-0.290	-15.026	-2.567	0.082	0.026	0.289	0.302	0.289
27	-0.137	-11.761	-2.857	-0.251	-11.776	-2.660	0.114	-0.015	0.196	0.227	0.196
28	-0.112	-5.593	-2.874	-0.226	-5.620	-2.869	0.114	-0.027	0.004	0.117	0.004

Note: Crush column is deformation perpendicular to the plane area of interest

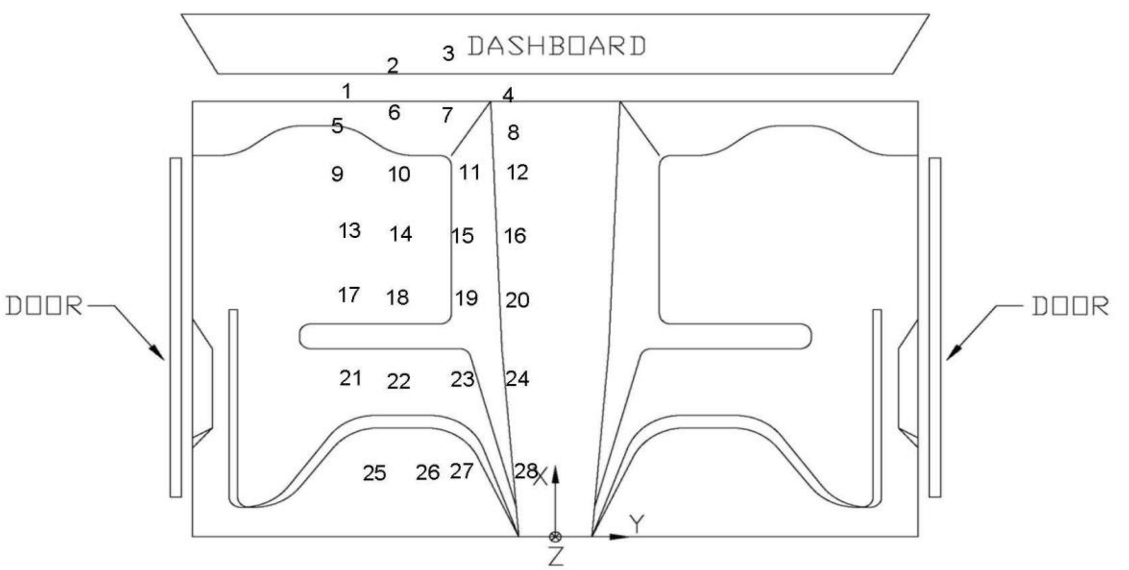


Figure D-7. Floor Pan Deformation Data – Set 1, Test No. WITD-2

Date: 12/14/2017 Test Name: WITD-2 VIN: 1D7RB1GP4AS121538
Year: 2010 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
1	56.511	-20.848	4.824	46.075	-16.194	11.544	10.436	4.654	6.720	13.256	12.413
2	58.464	-16.318	3.346	49.437	-11.615	11.354	9.028	4.703	8.007	12.951	12.067
3	59.363	-11.076	2.353	53.384	-10.988	7.774	5.979	0.088	5.421	8.071	8.071
4	55.980	-5.365	2.872	54.589	-5.451	4.945	1.391	-0.086	2.073	2.498	2.496
5	53.972	-21.807	0.967	43.700	-16.171	9.674	10.271	5.636	8.707	14.597	13.465
6	54.989	-16.268	-0.076	45.725	-12.089	7.365	9.264	4.179	7.441	12.596	11.882
7	54.657	-11.134	-0.239	49.241	-9.747	4.761	5.415	1.387	5.000	7.500	7.370
8	53.280	-4.790	-0.543	52.207	-5.404	1.132	1.073	-0.614	1.675	2.082	1.989
9	50.430	-21.901	-2.319	41.629	-14.134	5.130	8.801	7.767	7.449	13.902	7.449
10	50.258	-16.500	-2.385	43.044	-12.536	3.731	7.214	3.964	6.116	10.255	6.116
11	50.312	-9.688	-2.362	47.643	-9.319	0.342	2.669	0.369	2.704	3.818	2.704
12	50.223	-5.011	-2.415	49.491	-5.526	-1.362	0.732	-0.514	1.053	1.382	1.053
13	46.110	-21.367	-4.434	39.010	-17.909	1.817	7.100	3.458	6.251	10.072	6.251
14	45.740	-16.367	-4.397	41.894	-15.054	-0.775	3.846	1.313	3.622	5.444	3.622
15	45.530	-10.480	-4.413	45.006	-10.984	-3.822	0.524	-0.504	0.591	0.937	0.591
16	45.393	-5.405	-4.418	45.277	-6.169	-3.856	0.116	-0.765	0.562	0.956	0.562
17	41.068	-21.550	-4.508	38.096	-20.412	-2.344	2.973	1.138	2.164	3.849	2.164
18	40.793	-16.766	-4.458	40.048	-17.045	-4.612	0.745	-0.279	-0.155	0.810	-0.155
19	40.714	-10.180	-4.294	40.102	-11.287	-4.617	0.611	-1.106	-0.323	1.304	-0.323
20	40.434	-5.237	-4.465	40.446	-5.745	-4.145	-0.012	-0.508	0.320	0.600	0.320
21	34.711	-21.320	-4.564	34.042	-21.350	-4.537	0.669	-0.030	0.027	0.670	0.027
22	34.252	-16.773	-4.566	33.879	-16.913	-5.303	0.373	-0.140	-0.738	0.838	-0.738
23	34.421	-10.639	-4.557	34.209	-10.858	-4.825	0.212	-0.219	-0.267	0.405	-0.267
24	34.369	-5.372	-4.588	34.335	-5.564	-4.506	0.034	-0.192	0.082	0.211	0.082
25	27.122	-19.141	-0.678	26.974	-19.200	-0.571	0.147	-0.058	0.107	0.191	0.107
26	27.123	-14.051	-0.657	27.038	-14.164	-0.585	0.085	-0.113	0.072	0.159	0.072
27	27.131	-10.784	-0.657	27.084	-10.861	-0.612	0.047	-0.077	0.045	0.101	0.045
28	27.052	-4.610	-0.671	27.008	-4.696	-0.706	0.043	-0.086	-0.035	0.103	-0.035

Note: Crush column is deformation perpendicular to the plane area of interest

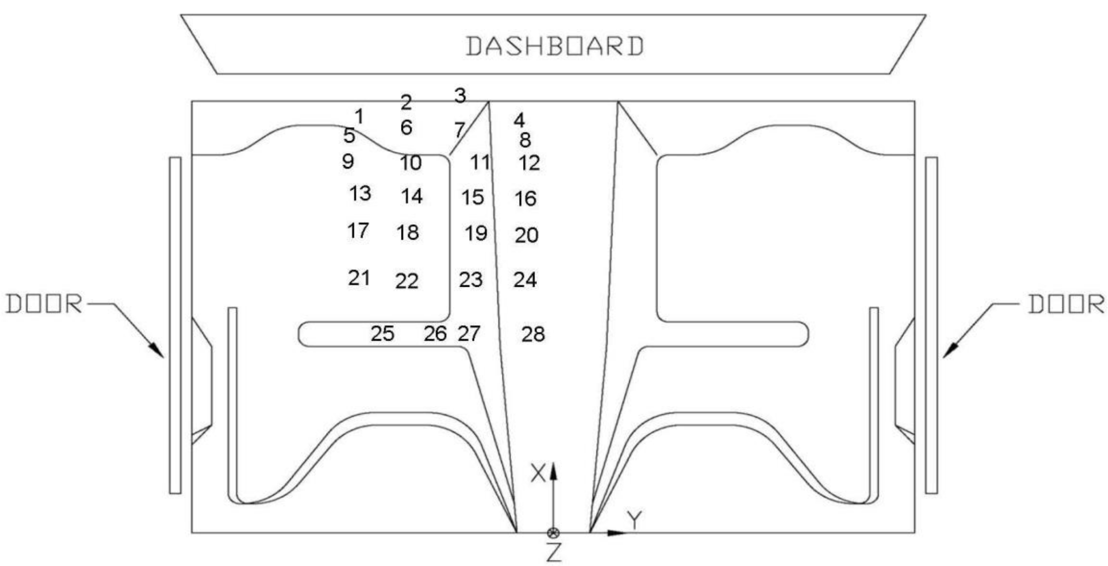


Figure D-8. Floor Pan Deformation Data – Set 2, Test No. WITD-2

Date: 12/14/2017 Test Name: WITD-2 VIN: 1D7RB1GP4AS121538
Year: 2010 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
DASH	1	16.730	-23.418	24.761	16.036	-22.525	27.957	0.693	0.893	3.196	3.390	3.390
	2	14.945	-3.501	24.854	14.418	-2.916	25.807	0.527	0.585	0.953	1.237	1.237
	3	12.016	6.286	24.682	11.844	6.925	25.299	0.172	-0.638	0.617	0.904	0.904
	4	11.869	-23.285	13.940	9.446	-22.608	18.037	2.423	0.677	4.097	4.808	4.808
	5	11.033	-5.681	13.088	9.608	-5.275	14.527	1.426	0.406	1.439	2.066	2.066
	6	9.026	6.185	13.630	8.134	6.489	14.518	0.892	-0.305	0.888	1.295	1.295
SIDE PANEL	7	20.529	-25.986	3.531	14.888	-23.694	8.165	5.642	2.292	4.634	7.652	2.292
	8	20.507	-25.977	-0.659	13.093	-21.306	5.054	7.414	4.671	5.714	10.461	4.671
	9	23.248	-26.096	1.765	16.277	-21.707	6.718	6.971	4.389	4.953	9.612	4.389
IMPACT SIDE DOOR	10	-13.208	-27.373	21.869	-15.281	-29.551	22.966	2.073	-2.178	1.097	3.201	-2.178
	11	-0.482	-27.288	21.376	-2.649	-29.843	23.446	2.167	-2.555	2.071	3.938	-2.555
	12	12.649	-27.338	20.691	10.460	-30.329	23.645	2.189	-2.991	2.954	4.740	-2.991
	13	-8.529	-28.859	3.026	-10.134	-31.550	4.705	1.605	-2.692	1.678	3.555	-2.692
	14	-1.719	-29.089	5.098	-3.350	-30.777	6.885	1.631	-1.688	1.787	2.950	-1.688
	15	5.739	-29.056	1.470	4.088	-29.235	3.534	1.651	-0.179	2.064	2.649	-0.179
ROOF	16	4.795	-16.439	40.572	4.965	-16.119	41.953	-0.170	0.321	1.381	1.428	1.381
	17	6.539	-10.633	40.674	6.679	-10.283	41.873	-0.140	0.350	1.199	1.257	1.199
	18	7.629	-5.101	40.748	7.776	-4.758	41.752	-0.148	0.344	1.003	1.071	1.003
	19	8.212	0.825	40.883	8.383	1.184	41.682	-0.172	-0.359	0.799	0.893	0.799
	20	8.555	5.747	40.854	8.619	6.178	41.549	-0.064	-0.430	0.695	0.820	0.695
	21	-1.784	-15.697	43.579	-1.695	-15.305	44.775	-0.089	0.391	1.196	1.261	1.196
	22	-0.325	-9.940	43.812	-0.290	-9.532	44.896	-0.035	0.408	1.083	1.158	1.083
	23	0.333	-4.191	44.028	0.394	-3.719	44.975	-0.061	0.472	0.947	1.059	0.947
	24	0.455	1.512	44.197	0.582	2.001	44.985	-0.127	-0.489	0.789	0.937	0.789
	25	-0.260	6.400	44.403	-0.080	6.886	45.057	-0.180	-0.486	0.653	0.834	0.653
	26	-6.171	-15.881	44.284	-6.110	-15.437	45.397	-0.061	0.444	1.113	1.200	1.113
	27	-5.866	-10.281	44.636	-5.766	-9.759	45.675	-0.101	0.521	1.040	1.167	1.040
	28	-5.672	-4.597	44.909	-5.629	-4.130	45.829	-0.043	0.467	0.920	1.033	0.920
	29	-5.635	1.639	45.140	-5.551	2.137	45.909	-0.084	-0.497	0.769	0.919	0.769
	30	-5.905	6.349	45.202	-5.733	6.897	45.847	-0.172	-0.548	0.645	0.864	0.645
A PILLAR	31	4.702	-20.996	38.413	4.960	-20.763	40.099	-0.258	0.233	1.686	1.721	0.233
	32	9.787	-22.184	35.508	10.228	-22.038	37.477	-0.442	0.146	1.970	2.024	0.146
	33	14.294	-23.236	32.391	14.587	-22.967	34.716	-0.293	0.269	2.325	2.358	0.269
	34	19.627	-24.458	28.106	19.650	-23.985	31.175	-0.022	0.473	3.070	3.106	0.473
B PILLAR	35	-22.184	-25.343	22.677	-22.338	-25.054	23.574	0.153	0.288	0.896	0.954	0.288
	36	-18.927	-25.317	22.763	-19.103	-25.080	23.690	0.175	0.237	0.927	0.973	0.237
	37	-22.546	-24.432	29.418	-22.703	-24.048	30.331	0.157	0.384	0.914	1.003	0.384
	38	-19.382	-24.399	29.409	-19.514	-24.064	30.339	0.132	0.335	0.929	0.997	0.335
	39	-22.934	-21.420	37.826	-22.920	-20.938	38.632	-0.014	0.481	0.806	0.939	0.481
	40	-20.122	-21.353	37.937	-20.069	-20.944	38.720	-0.053	0.410	0.783	0.886	0.410

Note: Crush column is deformation perpendicular to the plane area of interest

Figure D-9. Occupant Compartment Deformation Data – Set 1, Test No. WITD-2

Date: 12/14/2017 Test Name: WITD-2 VIN: 1D7RB1GP4AS121538
Year: 2010 Make: Dodge Model: Ram 1500

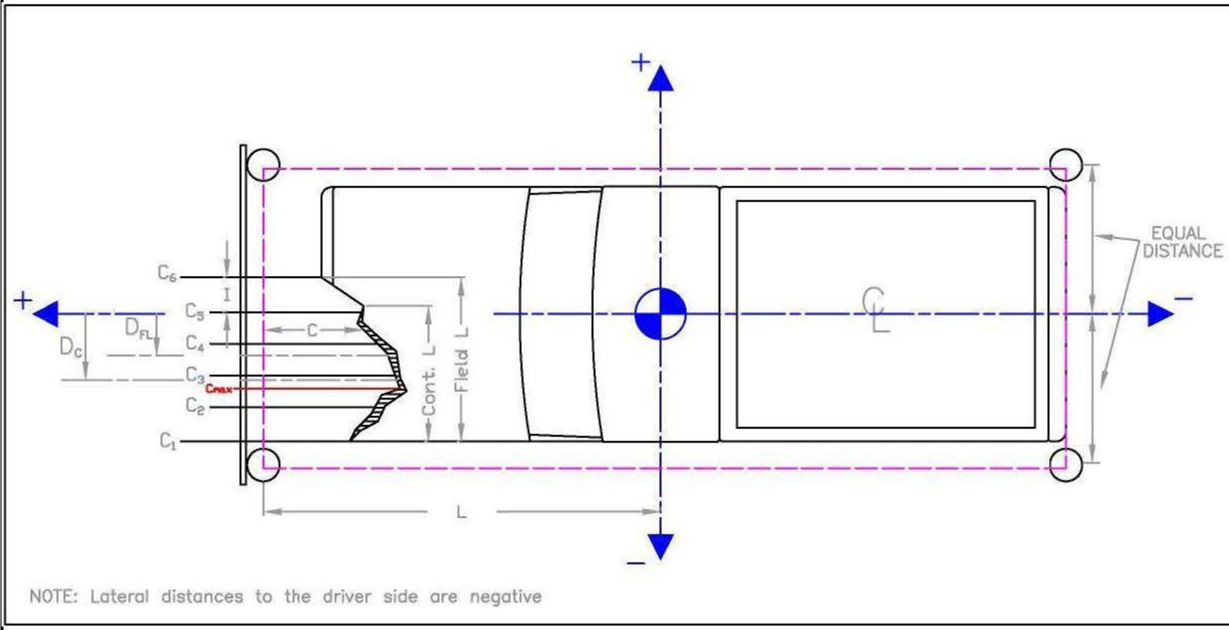
VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
DASH	1	43.023	-22.315	27.495	41.511	-22.104	30.670	1.512	0.211	3.175	3.523	3.523
	2	40.975	-2.444	27.528	39.923	-2.466	28.859	1.052	-0.022	1.331	1.697	1.697
	3	37.925	7.319	27.285	37.199	7.466	28.336	0.726	-0.147	1.050	1.285	1.285
	4	38.509	-22.287	16.544	35.626	-21.943	20.478	2.883	0.344	3.933	4.889	4.889
	5	37.479	-4.687	15.707	35.737	-4.621	17.299	1.742	0.066	1.592	2.360	2.360
	6	35.338	7.108	16.119	34.159	7.179	17.302	1.179	-0.070	1.183	1.672	1.672
SIDE PANEL	7	47.543	-24.909	6.495	41.650	-22.865	10.865	5.893	2.044	4.370	7.616	2.044
	8	47.701	-24.896	2.199	39.999	-20.354	7.671	7.702	4.542	5.472	10.483	4.542
	9	50.355	-24.987	4.820	43.227	-20.890	9.737	7.128	4.098	4.917	9.580	4.098
IMPACT SIDE DOOR	10	13.446	-26.664	23.525	10.788	-29.121	23.864	2.658	-2.457	0.339	3.636	-2.457
	11	26.137	-26.366	23.540	23.423	-29.352	25.066	2.714	-2.987	1.526	4.315	-2.987
	12	39.315	-26.229	23.252	36.397	-29.752	25.892	2.918	-3.524	2.639	5.282	-3.524
	13	18.810	-28.051	4.905	17.086	-30.825	5.665	1.724	-2.775	0.760	3.354	-2.775
	14	25.600	-28.177	7.205	23.573	-30.084	8.443	2.027	-1.907	1.238	3.046	-1.907
	15	33.223	-28.020	3.821	31.207	-28.412	5.540	2.016	-0.393	1.719	2.678	-0.393
ROOF	16	30.602	-15.480	42.889	29.699	-16.031	44.128	0.903	-0.552	1.240	1.630	1.240
	17	32.225	-9.594	43.078	31.300	-10.174	44.274	0.925	-0.581	1.196	1.619	1.196
	18	33.186	-4.135	43.202	32.343	-4.715	44.313	0.843	-0.580	1.111	1.511	1.111
	19	33.710	1.869	43.346	32.940	1.328	44.369	0.770	0.542	1.022	1.390	1.022
	20	33.943	6.860	43.353	33.114	6.309	44.345	0.829	0.552	0.992	1.406	0.992
	21	23.927	-14.849	45.664	22.767	-15.222	46.607	1.159	-0.373	0.944	1.541	0.944
	22	25.229	-9.064	45.962	24.132	-9.534	46.904	1.098	-0.470	0.942	1.521	0.942
	23	25.782	-3.248	46.212	24.766	-3.804	47.121	1.016	-0.556	0.909	1.472	0.909
	24	25.794	2.396	46.388	24.904	1.904	47.249	0.890	0.491	0.861	1.332	0.861
	25	25.048	7.355	46.556	24.156	6.879	47.375	0.892	0.475	0.819	1.301	0.819
	26	19.512	-15.192	46.200	18.501	-15.552	46.937	1.011	-0.360	0.736	1.302	0.736
	27	19.699	-9.483	46.579	18.658	-9.871	47.346	1.041	-0.389	0.767	1.350	0.767
	28	19.731	-3.827	46.866	18.746	-4.234	47.615	0.986	-0.407	0.749	1.303	0.749
	29	19.698	2.461	47.103	18.733	1.950	47.819	0.965	0.511	0.716	1.306	0.716
	30	19.327	7.192	47.161	18.447	6.741	47.838	0.880	0.451	0.677	1.198	0.677
A PILLAR	31	30.614	-20.024	40.793	29.769	-20.616	42.201	0.845	-0.592	1.408	1.746	-0.592
	32	35.902	-21.150	38.055	35.291	-21.789	39.839	0.611	-0.639	1.784	1.991	-0.639
	33	40.386	-22.078	35.106	39.970	-22.799	37.228	0.416	-0.721	2.122	2.279	-0.721
	34	45.992	-23.243	30.986	45.195	-23.718	33.604	0.797	-0.476	2.618	2.778	-0.476
B PILLAR	35	4.475	-24.767	24.072	3.661	-24.925	24.007	0.814	-0.159	-0.065	0.832	-0.159
	36	7.675	-24.691	24.248	6.871	-24.910	24.352	0.803	-0.219	0.103	0.839	-0.219
	37	3.802	-23.864	30.799	2.846	-24.052	30.768	0.956	-0.188	-0.031	0.975	-0.188
	38	6.967	-23.775	30.920	6.063	-24.025	30.988	0.903	-0.250	0.068	0.940	-0.250
	39	3.156	-20.884	39.132	2.115	-21.108	39.107	1.041	-0.223	-0.025	1.065	-0.223
	40	5.916	-20.764	39.366	4.870	-21.072	39.401	1.046	-0.308	0.035	1.091	-0.308

Note: Crush column is deformation perpendicular to the plane area of interest

Figure D-10. Occupant Compartment Deformation Data – Set 2, Test No. WITD-2

Date:	12/20/2017	Test Name:	WITD-2	VIN:	1D7RB1GP4AS121538
Year:	2010	Make:	Dodge	Model:	Ram 1500



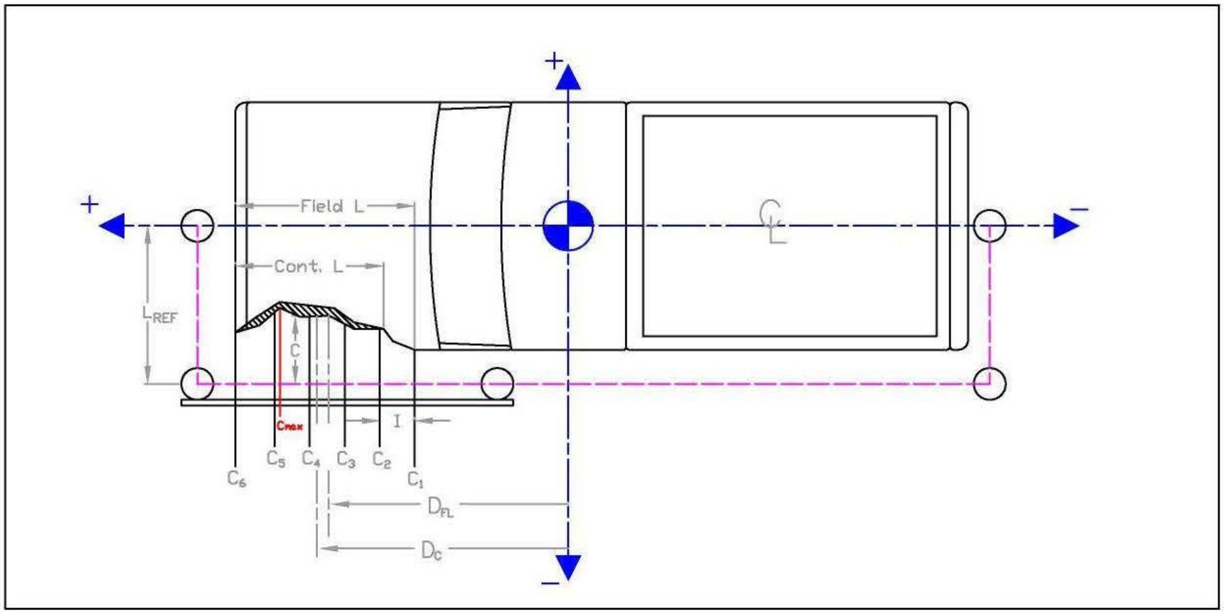
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	129 1/2	(3289)
Total Vehicle Width:	78	(1981)
Width of contact and induced crush - Field L:	30	(762)
Crush measurement spacing interval (L/5) - I:	6	(152)
Distance from center of vehicle to center of Field L - D_{FL}:	27	(686)
Width of Contact Damage:	26	(660)
Distance from center of vehicle to center of contact damage - D_C:	29	(737)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	55 1/2	(1410)	12	(305)	4 5/8	(117)	23 7/8	(606)	27	(686)
C_2	49 1/2	(1257)	18	(457)	5 1/4	(133)			20 3/8	(518)
C_3	38 1/2	(978)	24	(610)	6 3/8	(162)			8 1/4	(210)
C_4	31	(787)	30	(762)	9 1/4	(235)			-2 1/8	-(54)
C_5	29 5/8	(752)	36	(914)	15 1/4	(387)			-9 1/2	-(241)
C_6	29 1/4	(743)	42	(1067)	20 1/2	(521)			-15 1/8	-(384)
C_{MAX}	55 1/2	(1410)	12	(305)	4 5/8	(117)			27	(686)

Figure D-11. Exterior Vehicle Crush (NASS) - Front, Test No. WITD-2

Date:	12/20/2017	**Test Name:**	WITD-2	**VIN:**	1D7RB1GP4AS121538
Year:	2010	**Make:**	Dodge	**Model:**	Ram 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	76 1/2	(1943)
Total Vehicle Length:	229 1/8	(5820)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-12	-(306)
Width of contact and induced crush - Field L:	62	(1575)
Crush measurement spacing interval (L/5) - I:	12 3/8	(314)
Distance from vehicle c.g. to center of Field L - D_{FL}:	81	(2057)
Width of Contact Damage:	64	(1626)
Distance from vehicle c.g. to center of contact damage - D_C:	85	(2159)

NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., front of vehicle has been pushed inward or tire has been removed)

NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	29	(737)	50	(1270)	5 7/8	(149)	32 1/2	(826)	-9 3/8	-(238)
C_2	31 1/4	(794)	62 3/8	(1584)	5 7/8	(149)			-7 1/8	-(181)
C_3	33 1/4	(845)	74 3/4	(1899)	5 1/2	(140)			-4 3/4	-(121)
C_4	34 1/2	(876)	87 1/8	(2213)	6 1/2	(165)			-4 1/2	-(114)
C_5	55 3/4	(1416)	99 1/2	(2527)	17 3/8	(441)			5 7/8	(149)
C_6	54	(1372)	111 7/8	(2842)	33 1/2	(851)			-12	-(305)
C_{MAX}	60	(1524)	16 1/2	(419)	5 1/8	(130)			22 3/8	(568)

Figure D-12. Exterior Vehicle Crush (NASS) - Side, Test No. WITD-2

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

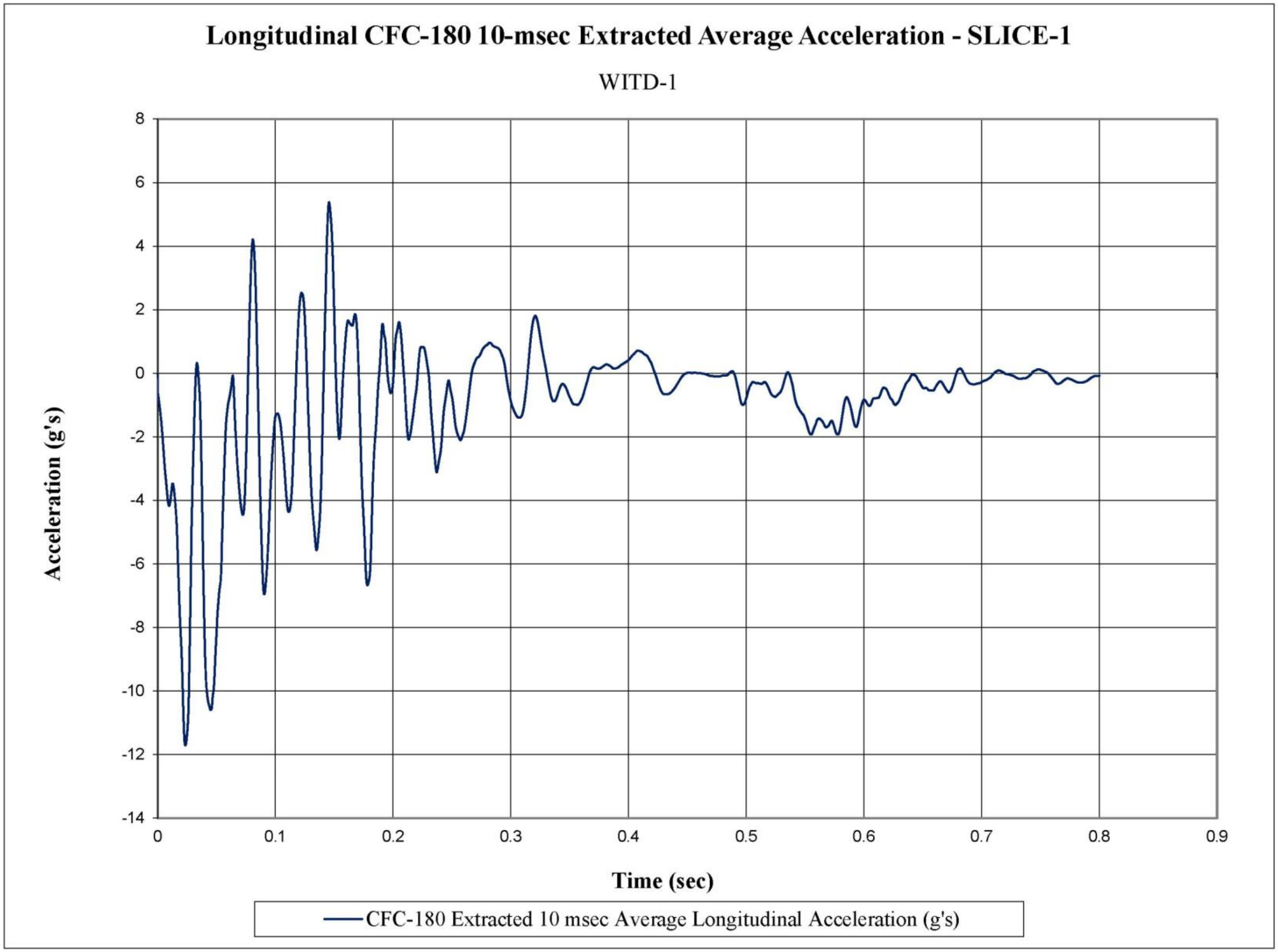


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. WITD-1

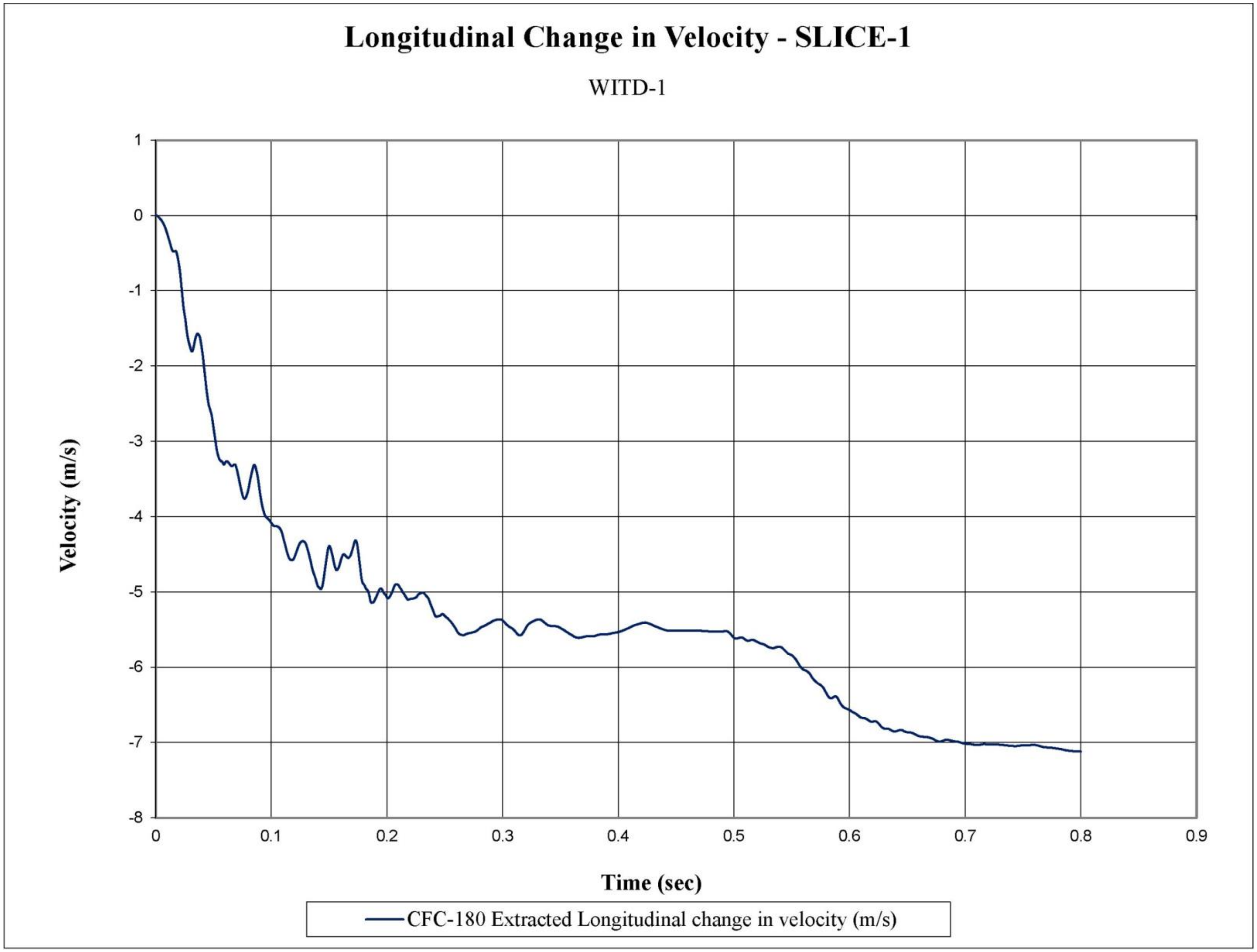


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. WITD-1

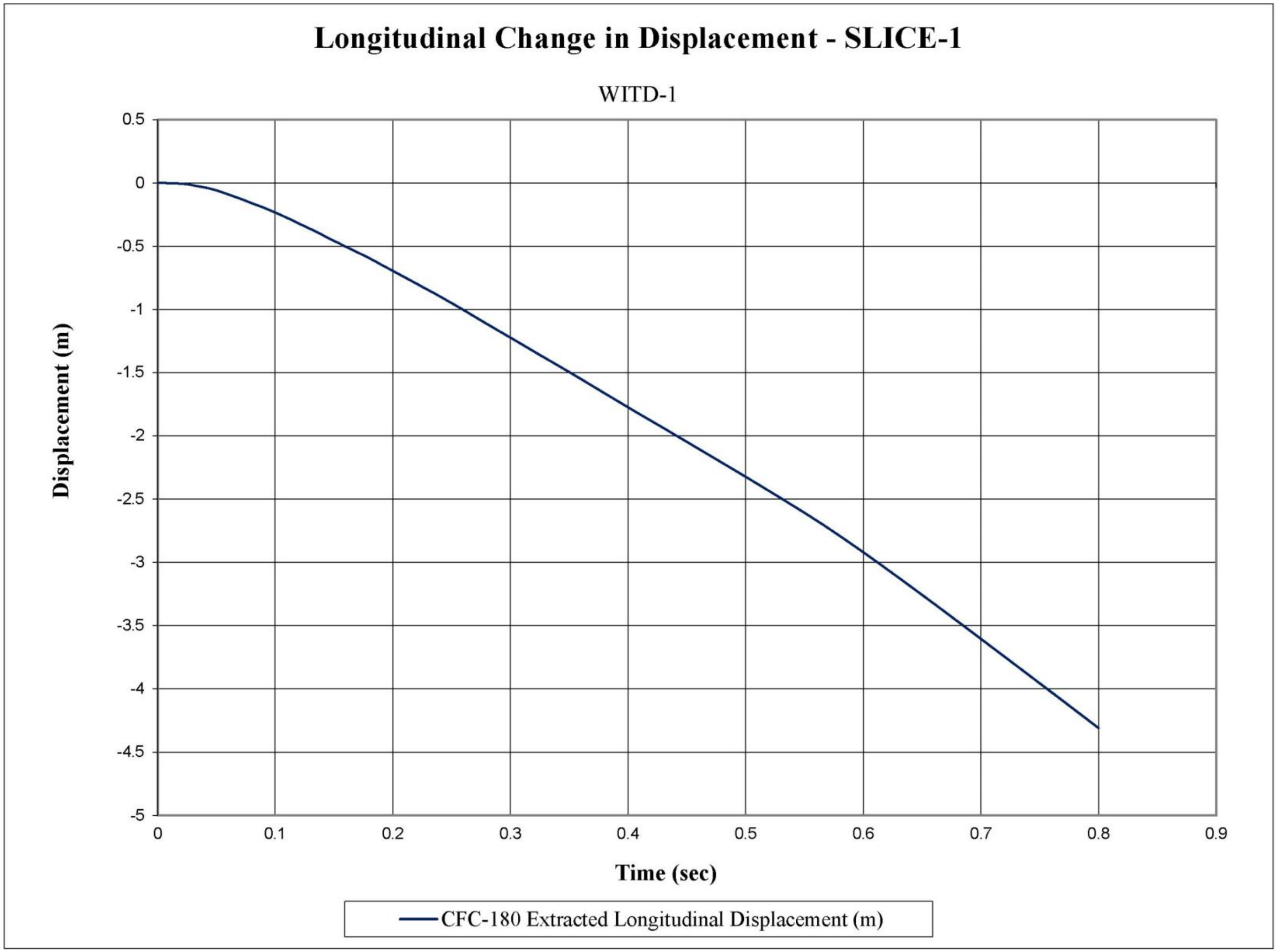


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. WITD-1

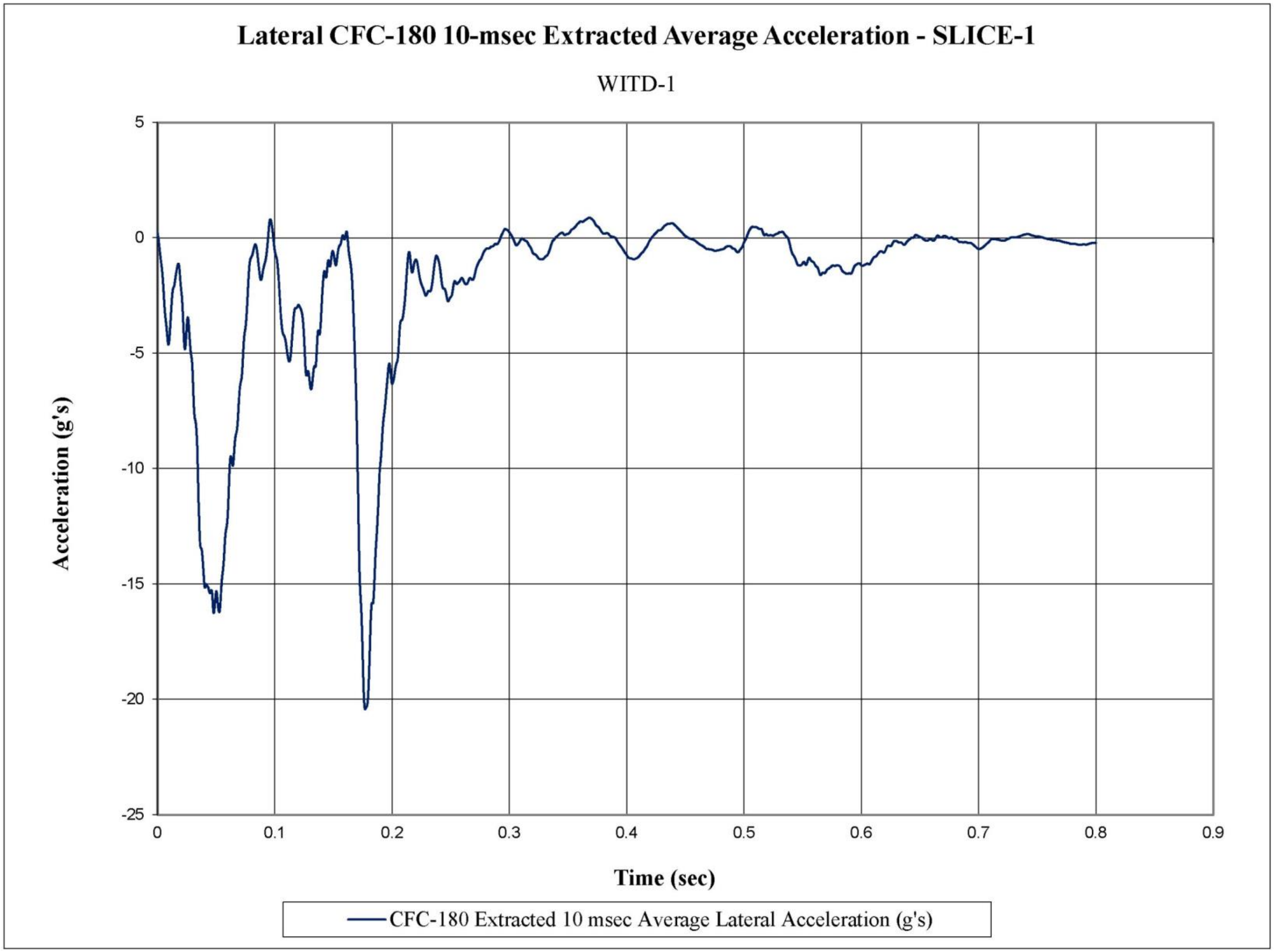


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. WITD-1

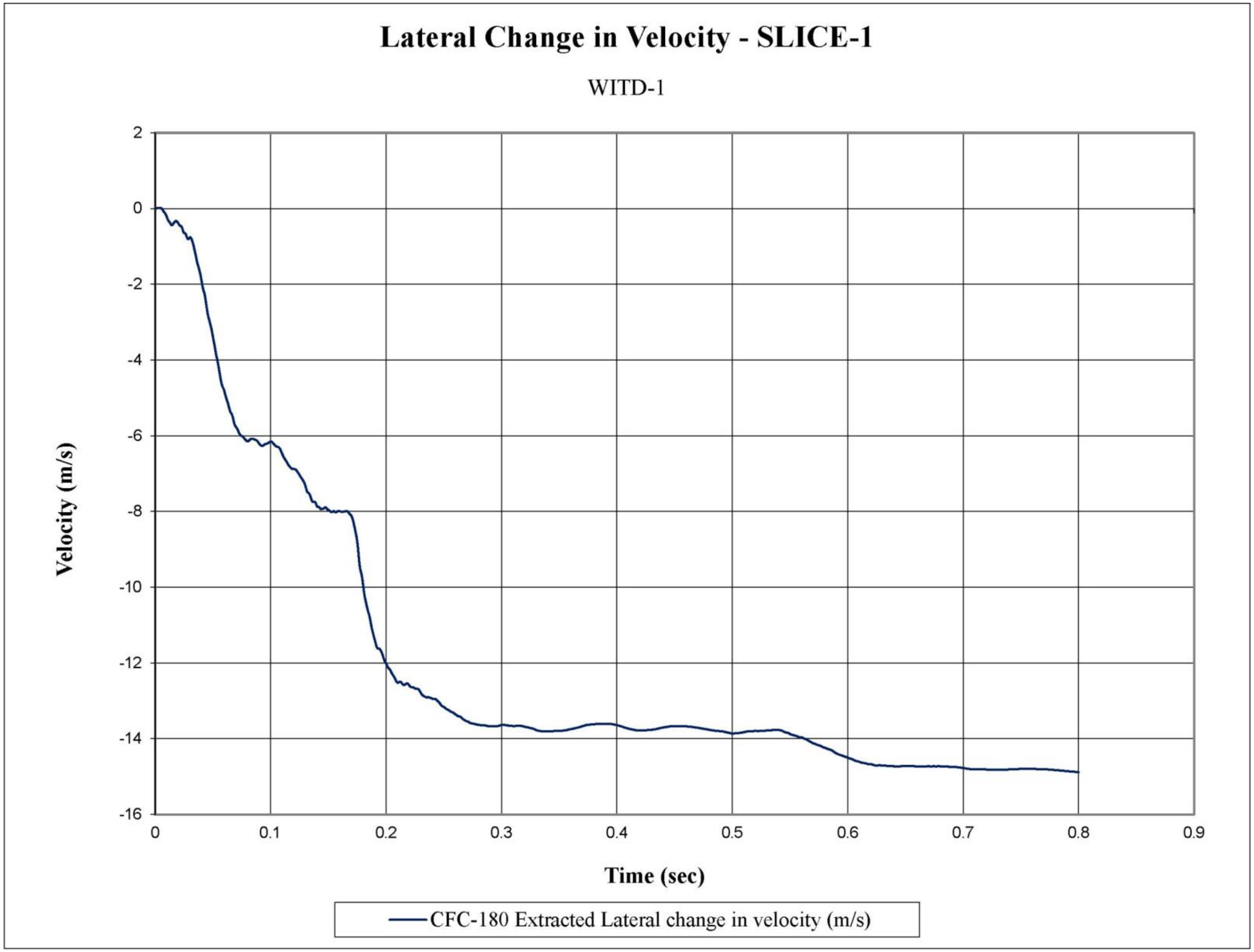


Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. WITD-1

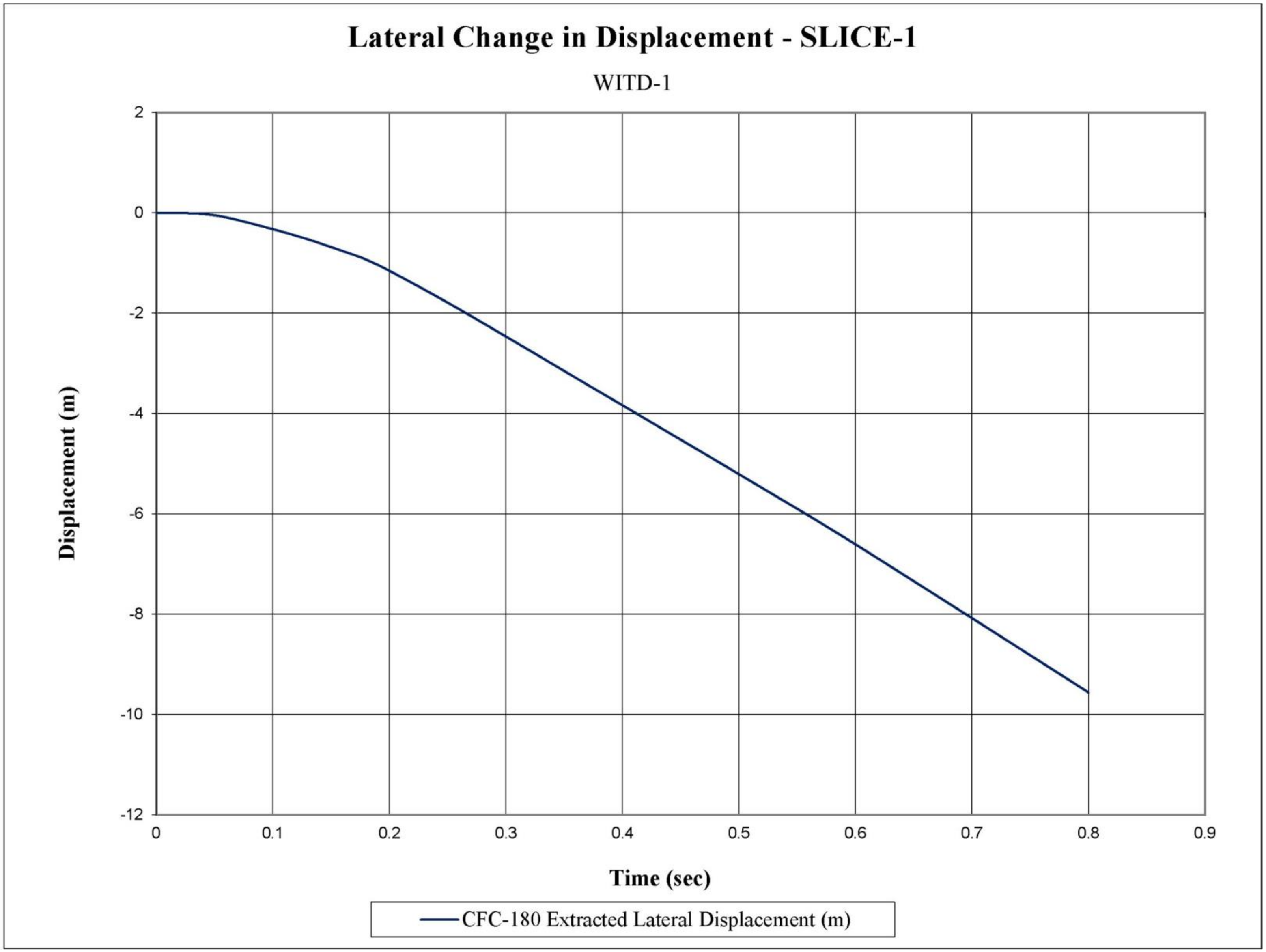


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. WITD-1

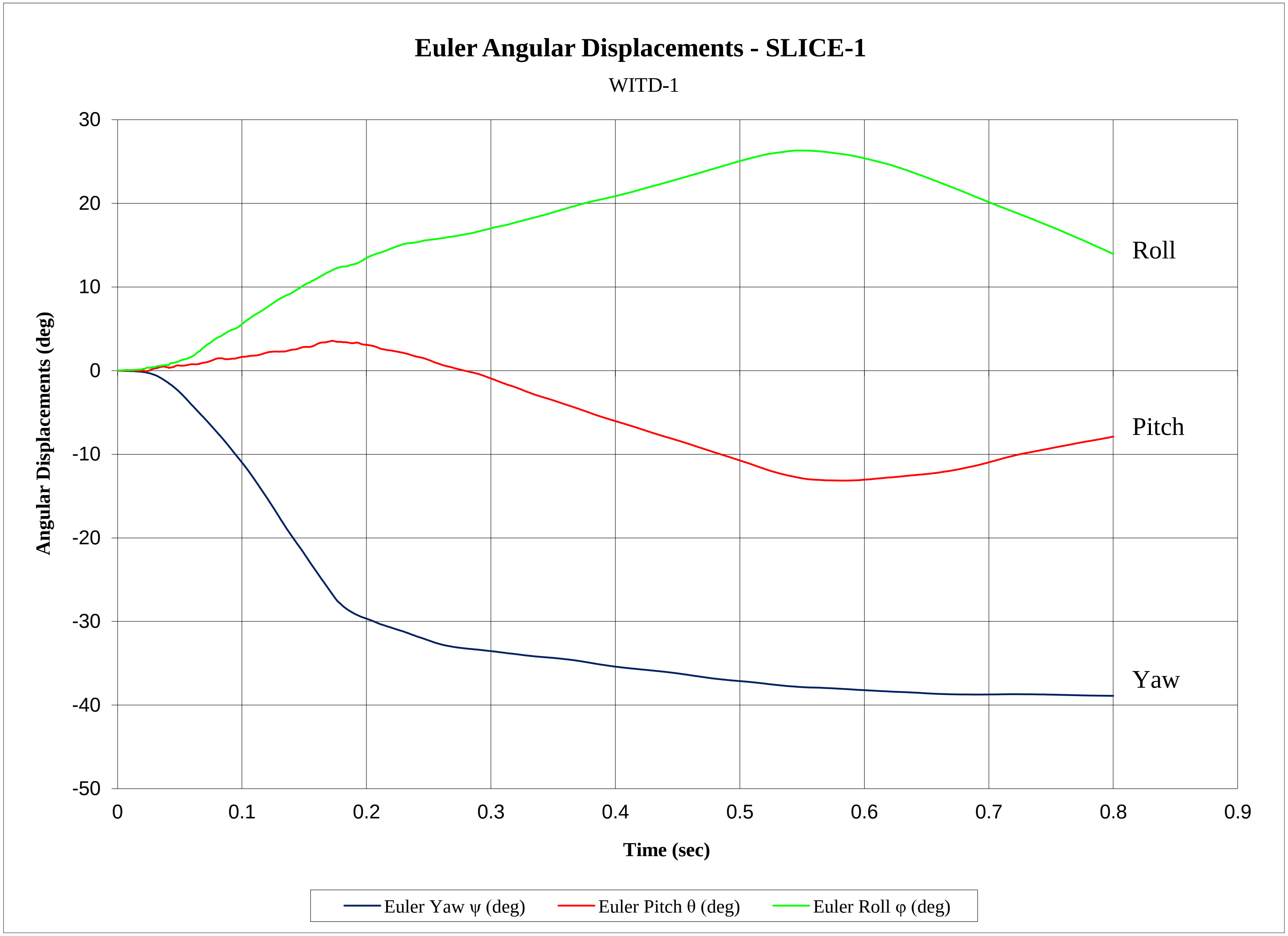


Figure E-7. Vehicle Angular Displacements (SLICE-1), Test No. WITD-1

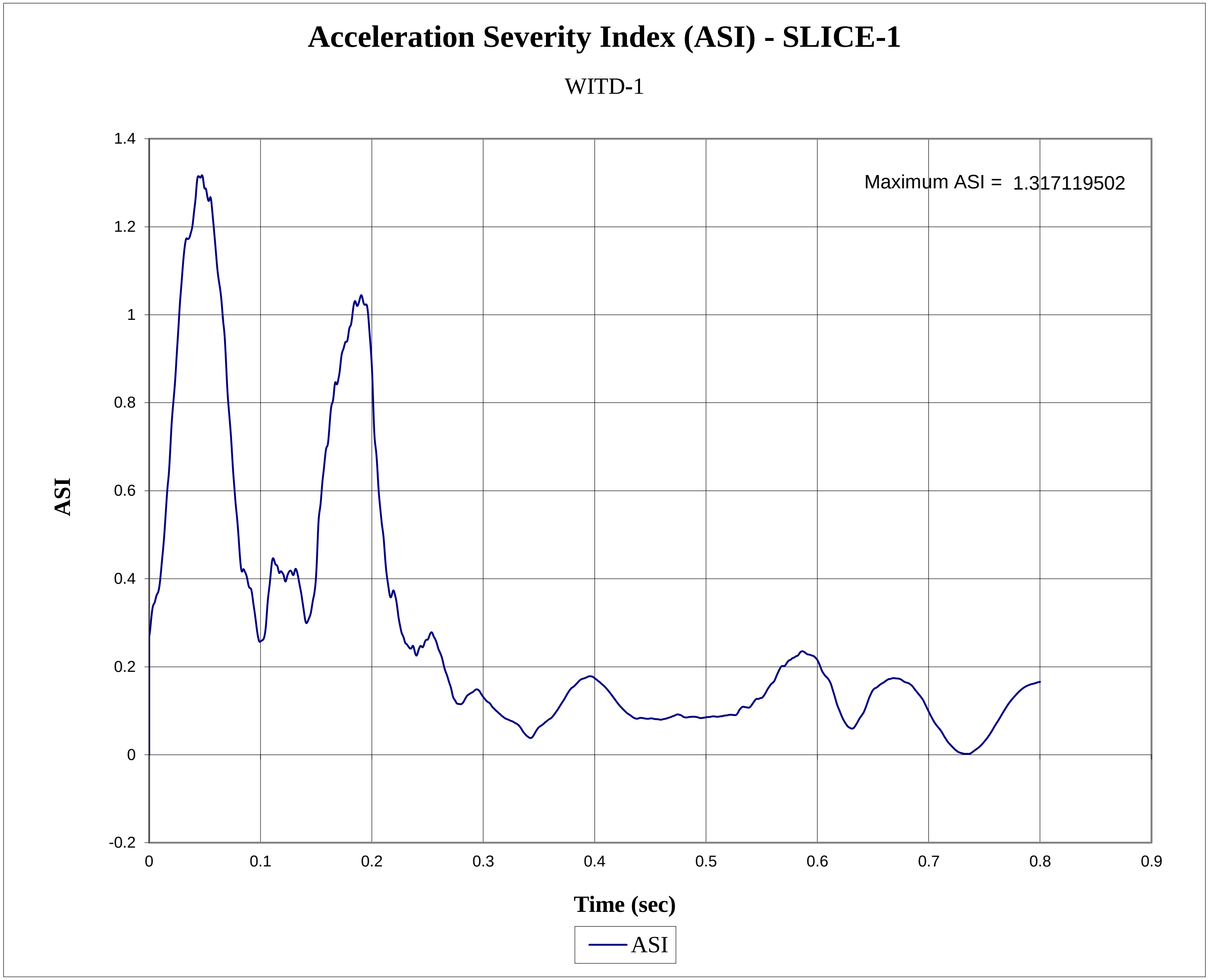


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. WITD-1

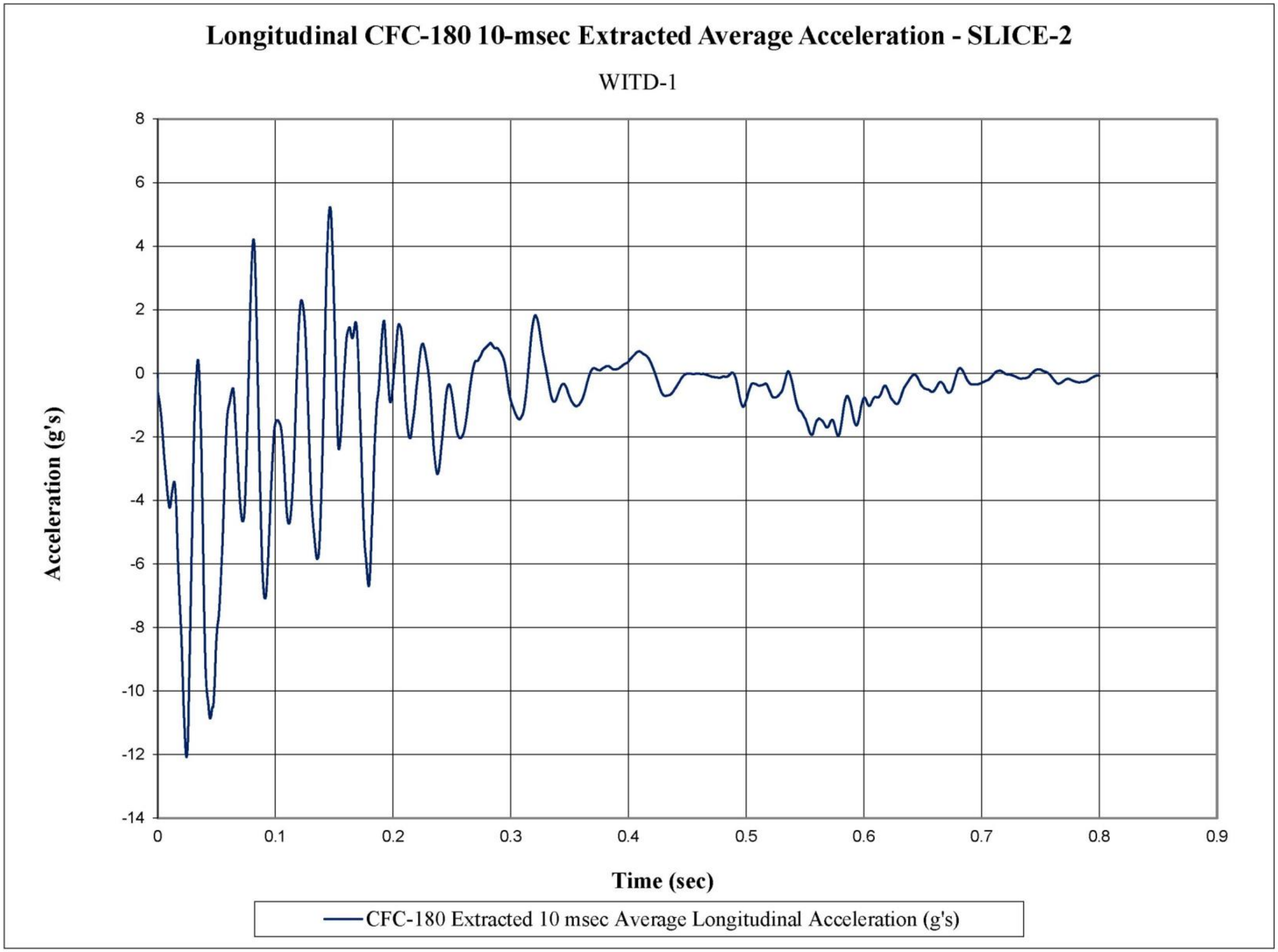


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. WITD-1

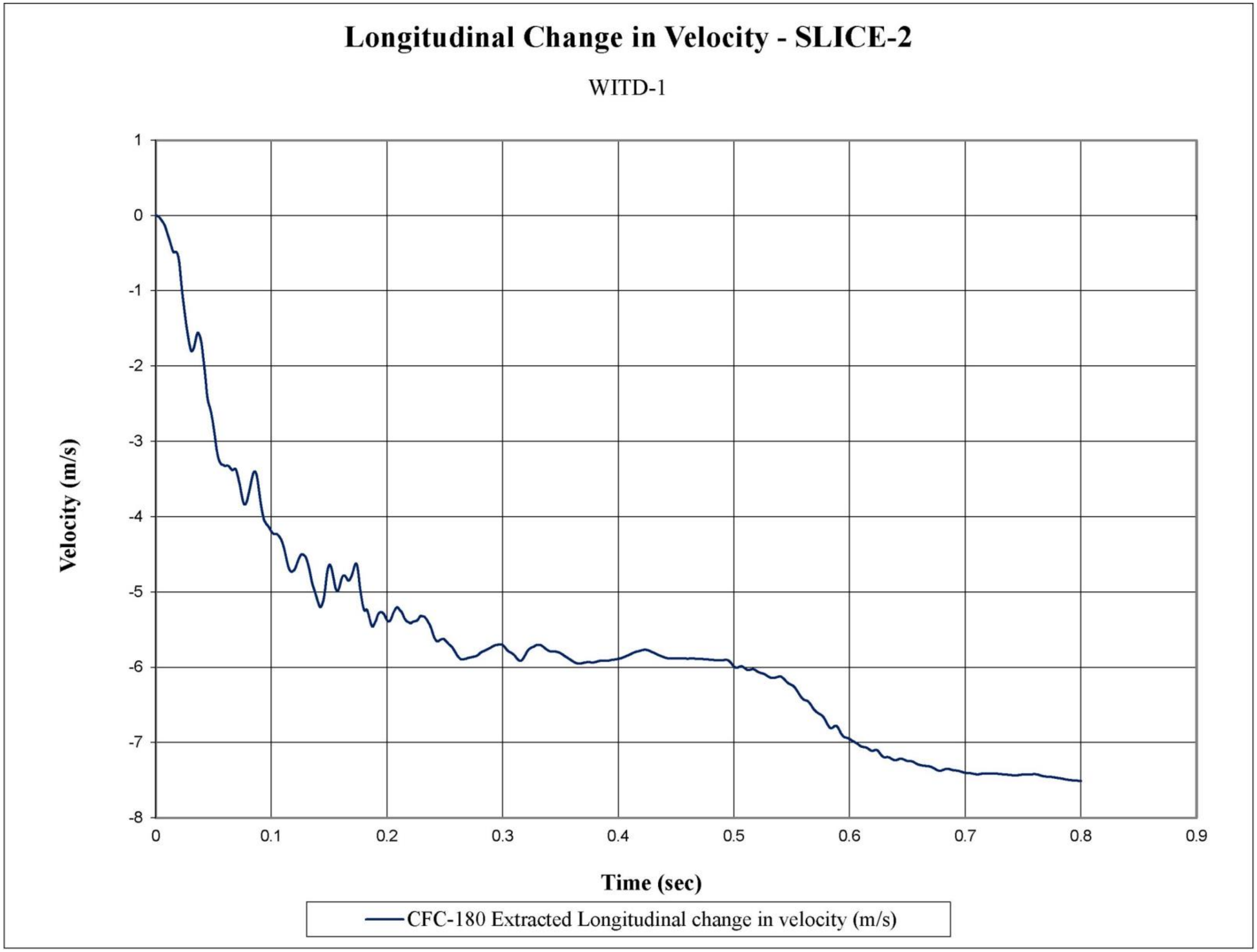


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. WITD-1

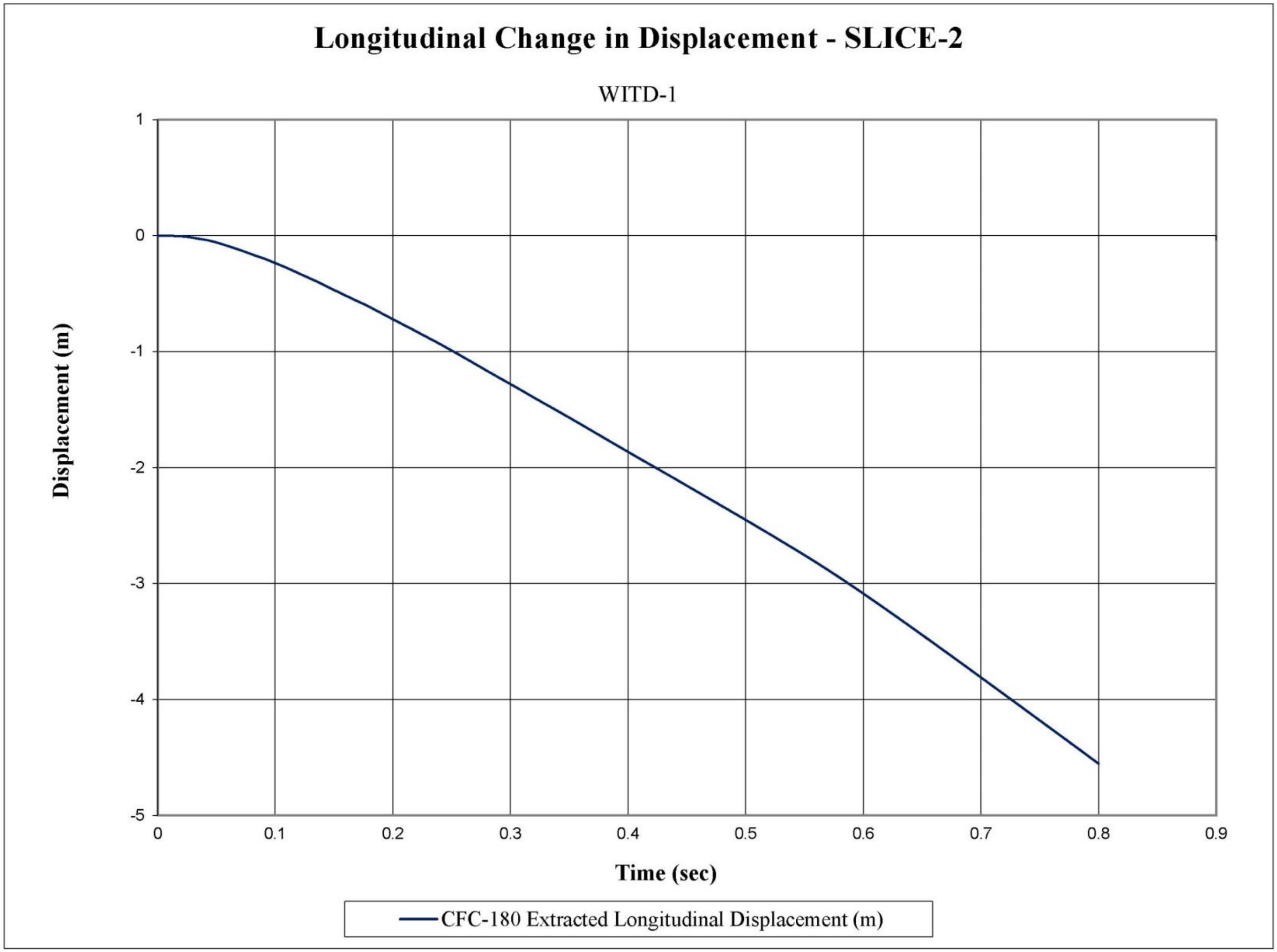


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. WITD-1

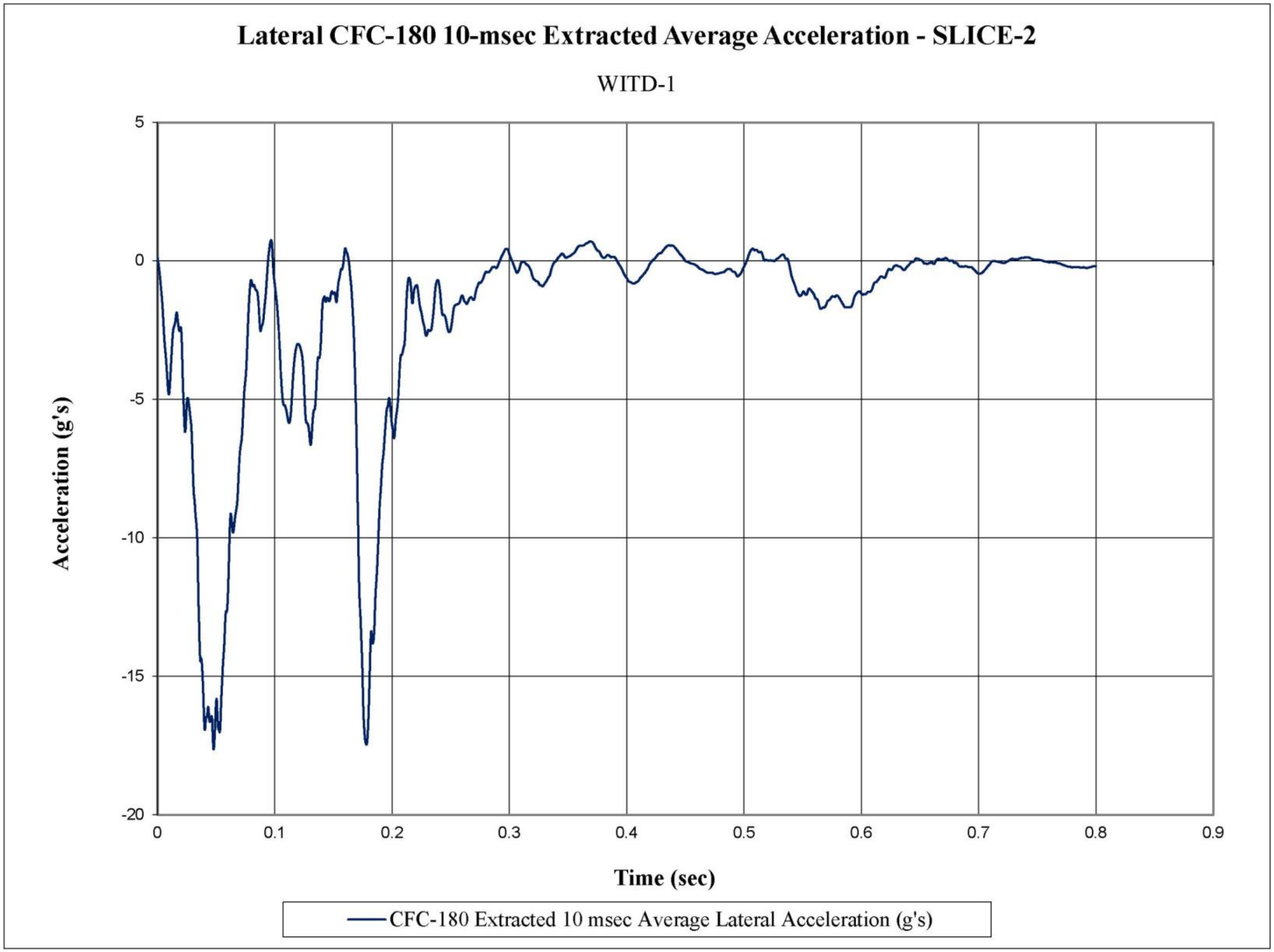


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. WITD-1

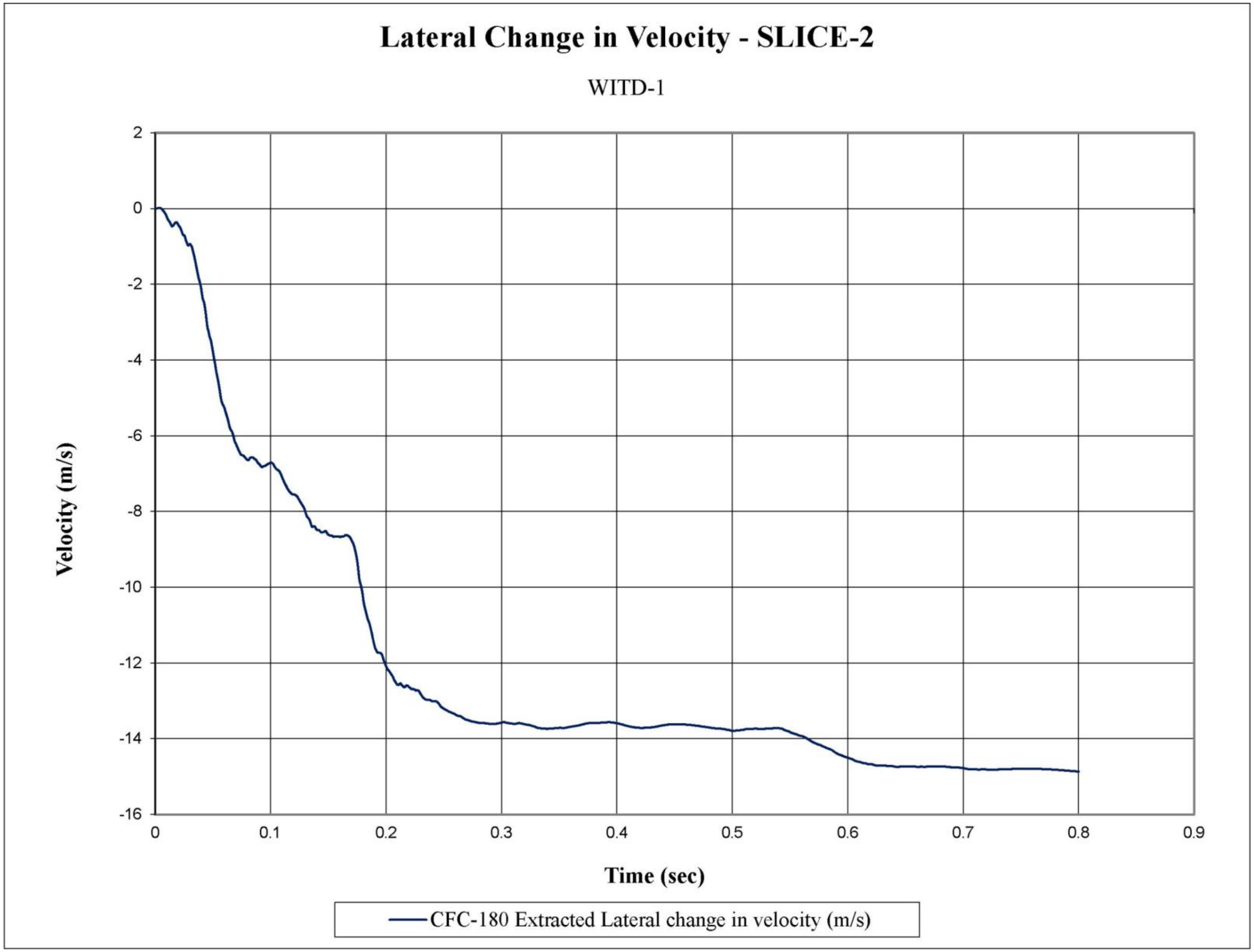


Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. WITD-1

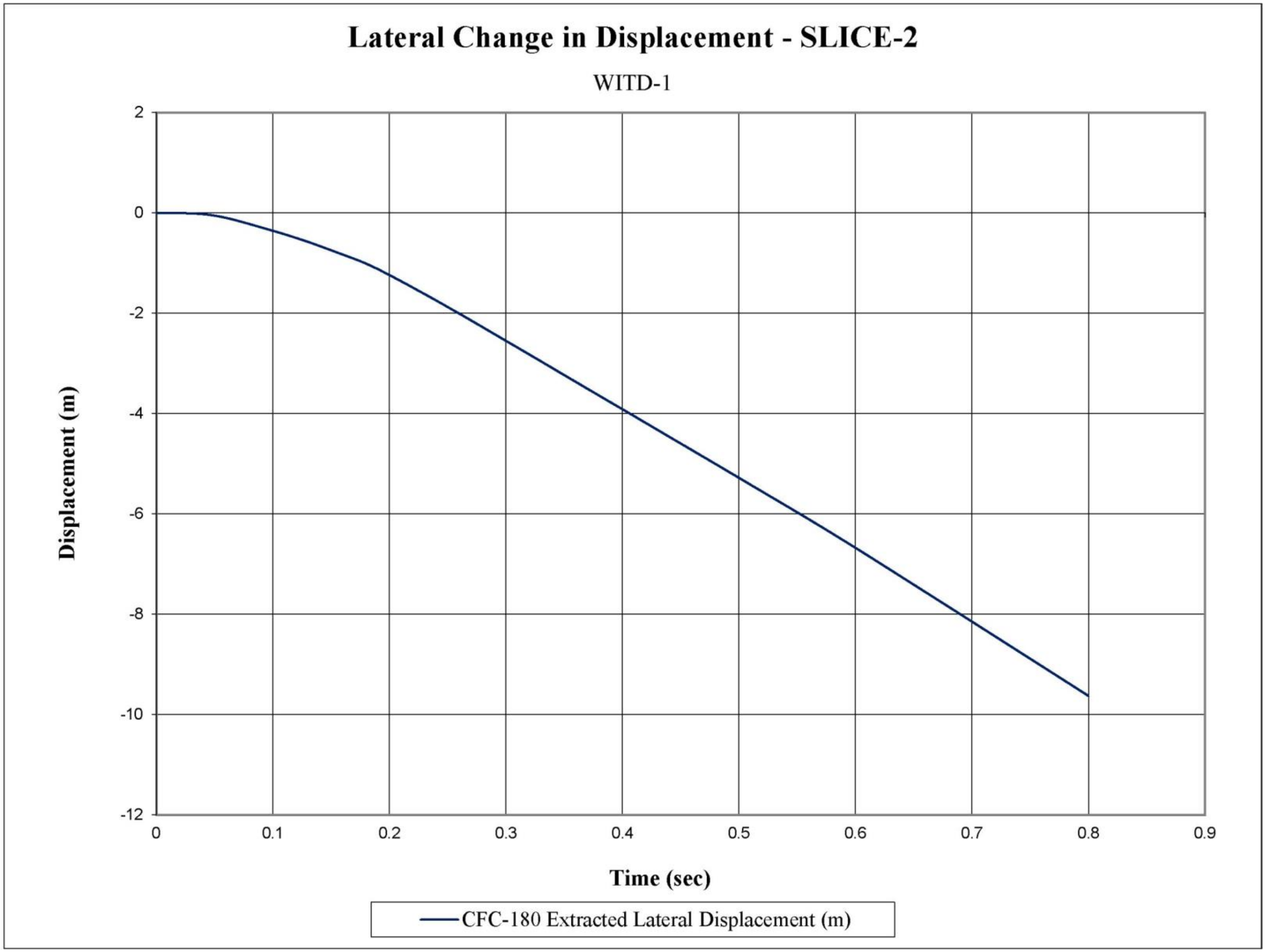


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. WITD-1

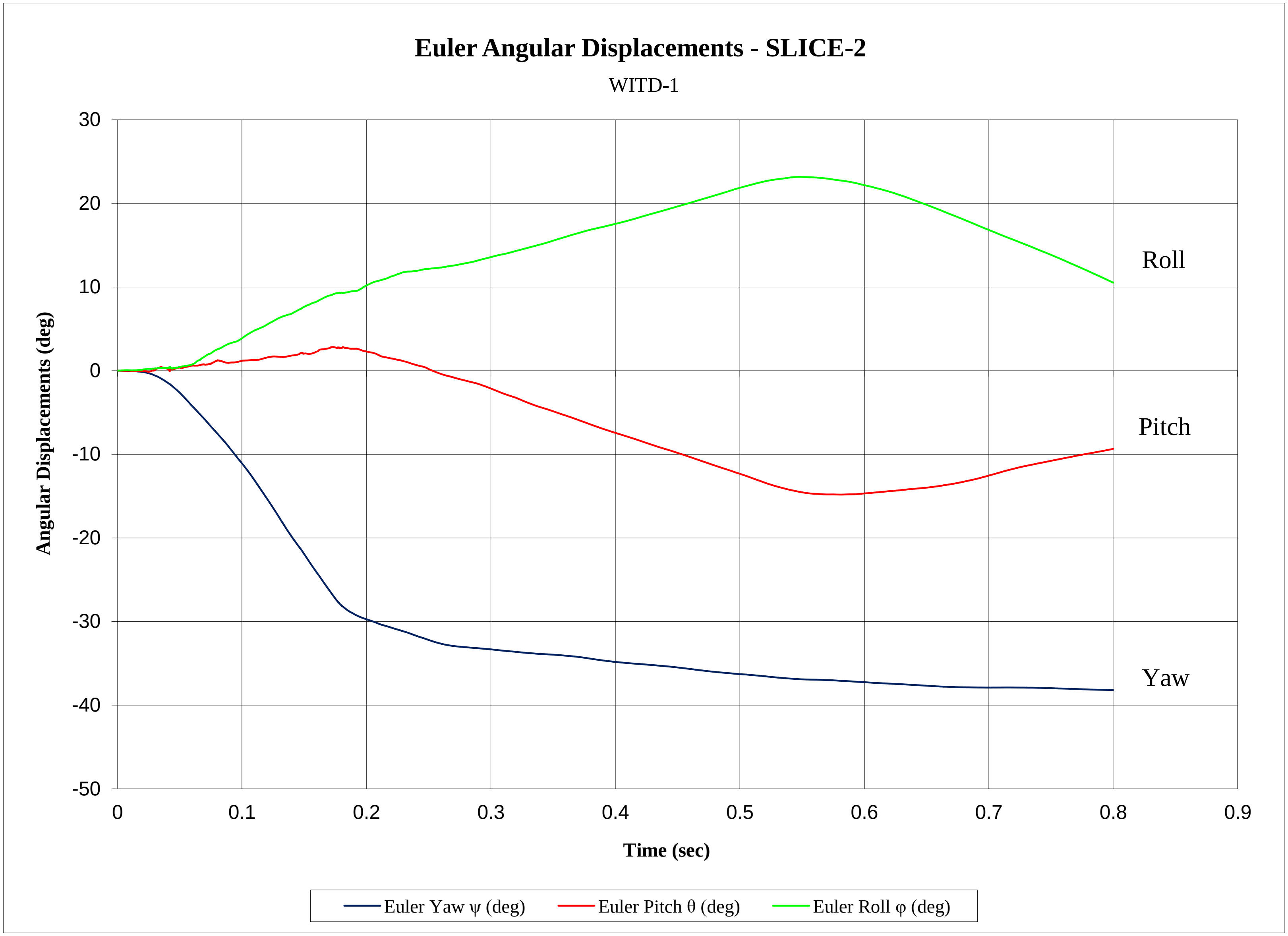


Figure E-15. Vehicle Angular Displacements (SLICE-2), Test No. WITD-1

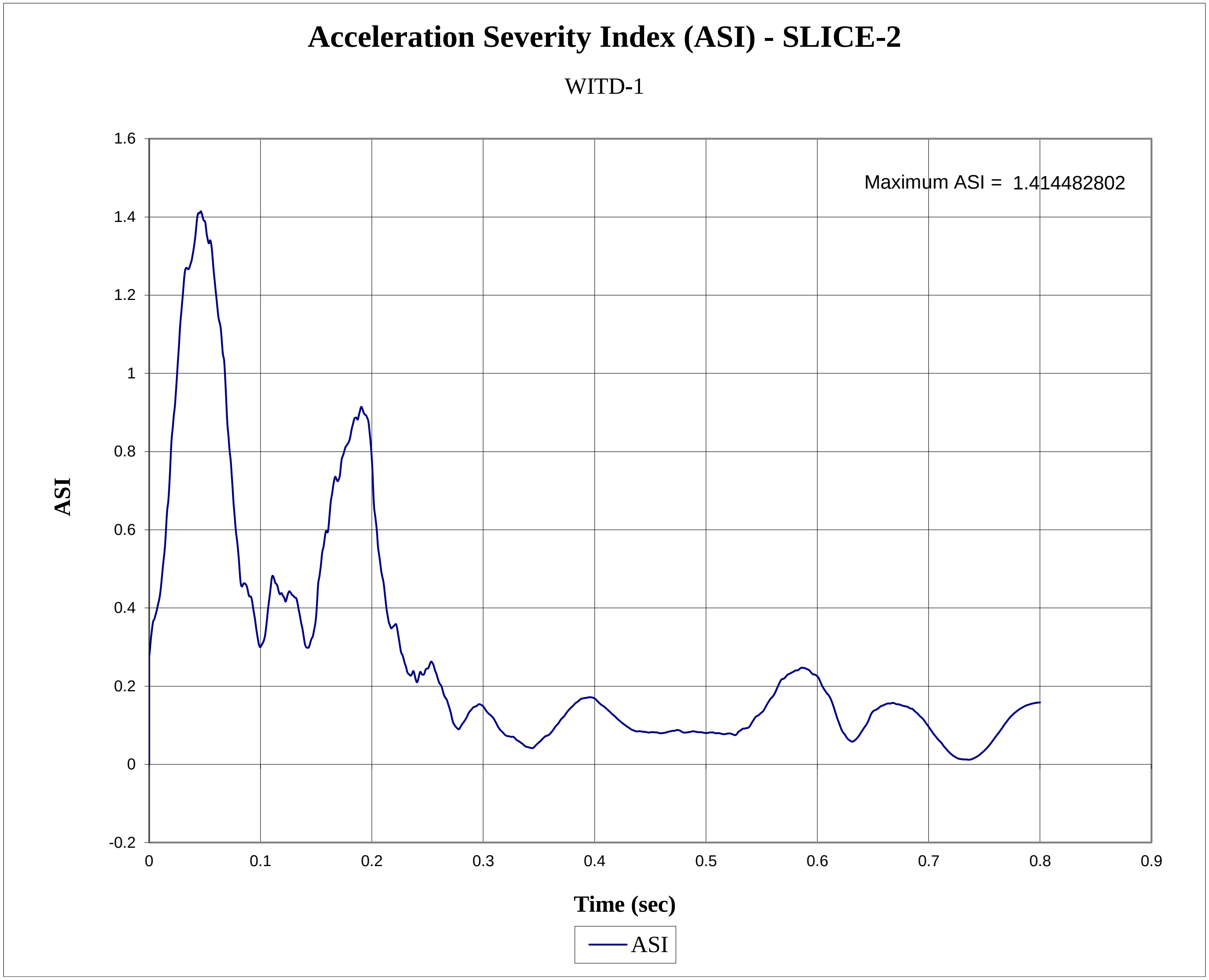


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. WITD-1

Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. WITD-2

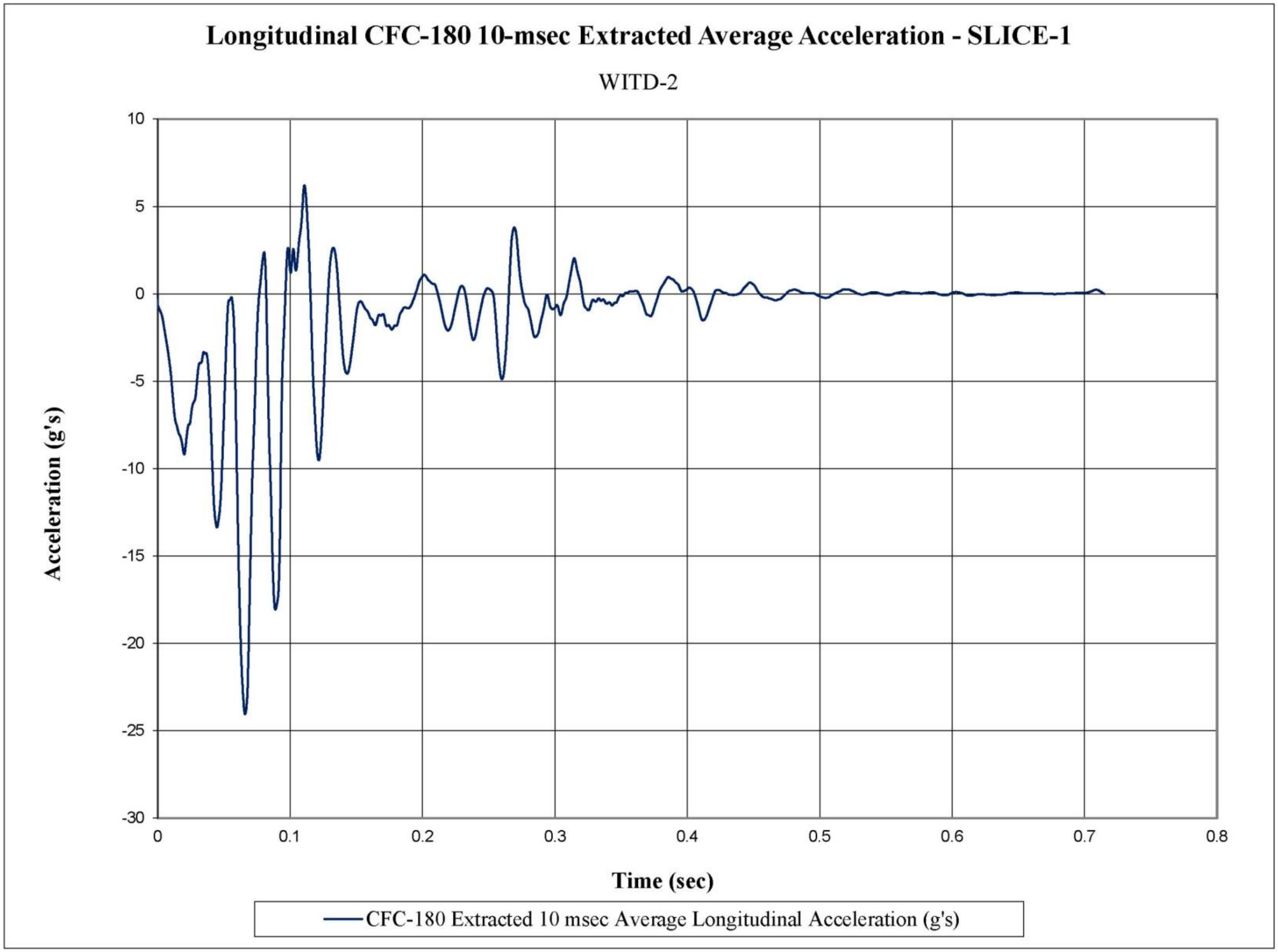


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. WITD-2

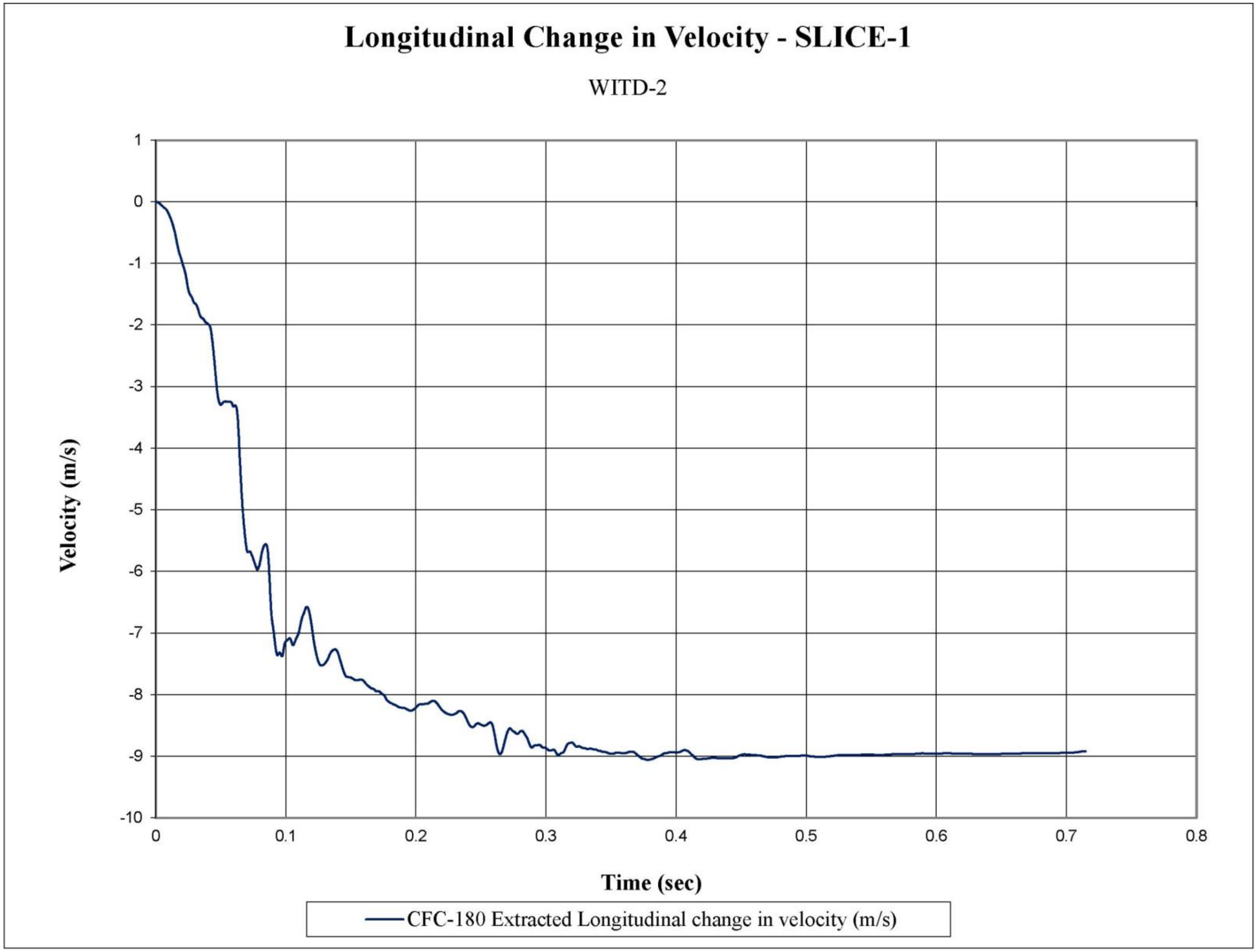


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. WITD-2

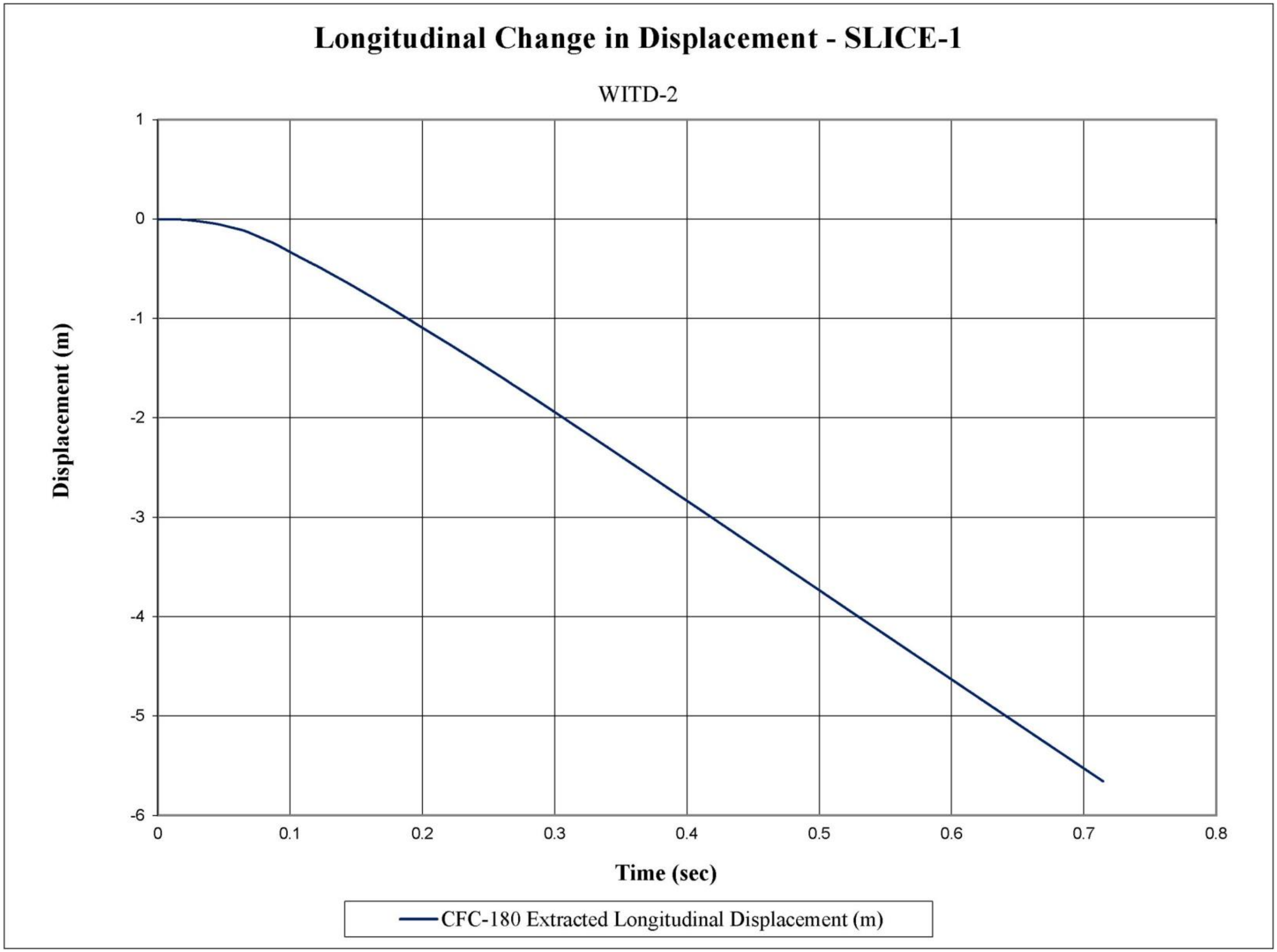


Figure F-3. Longitudinal Occupant Displacement (SLICE-1), Test No. WITD-2

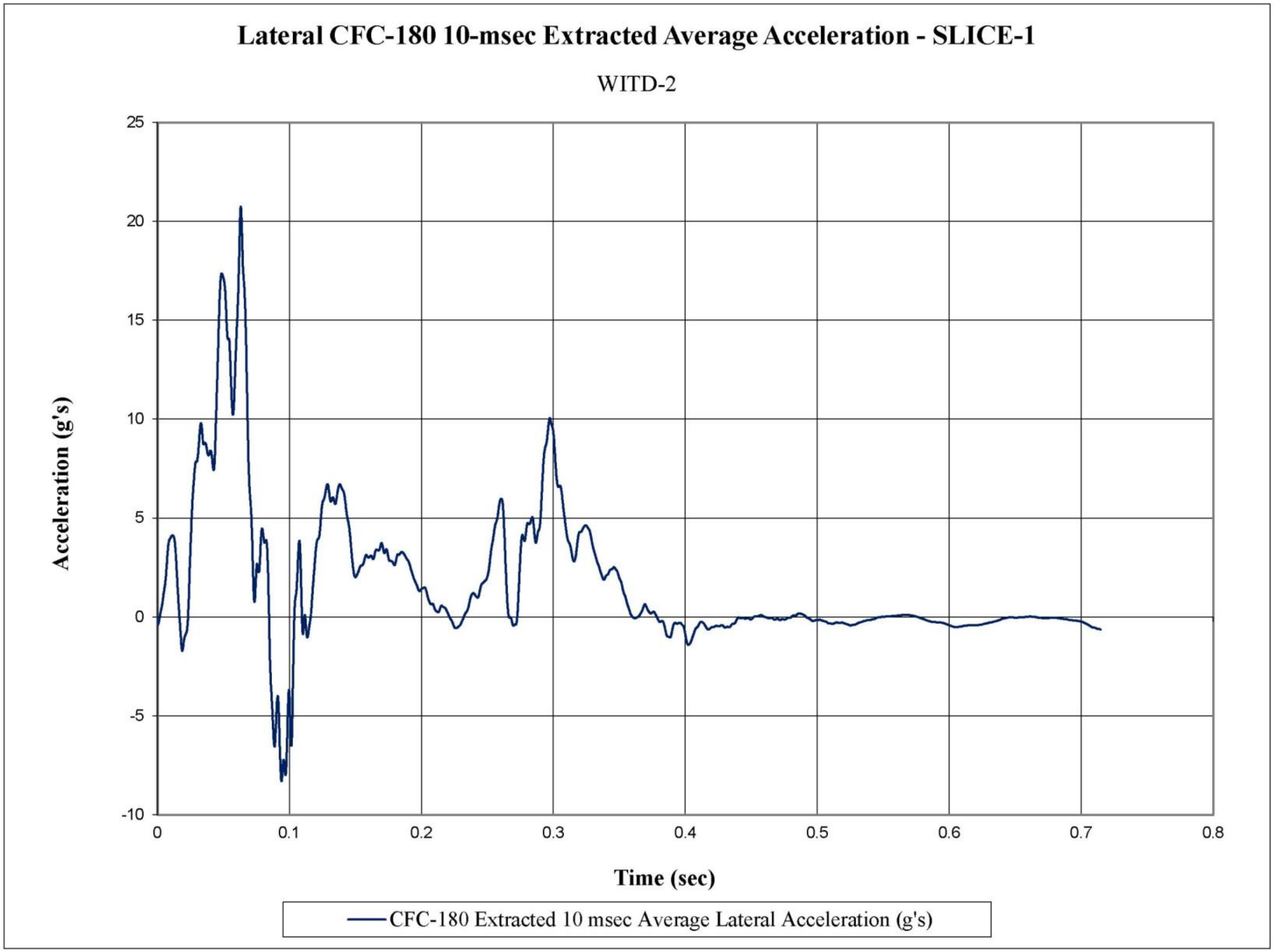


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. WITD-2

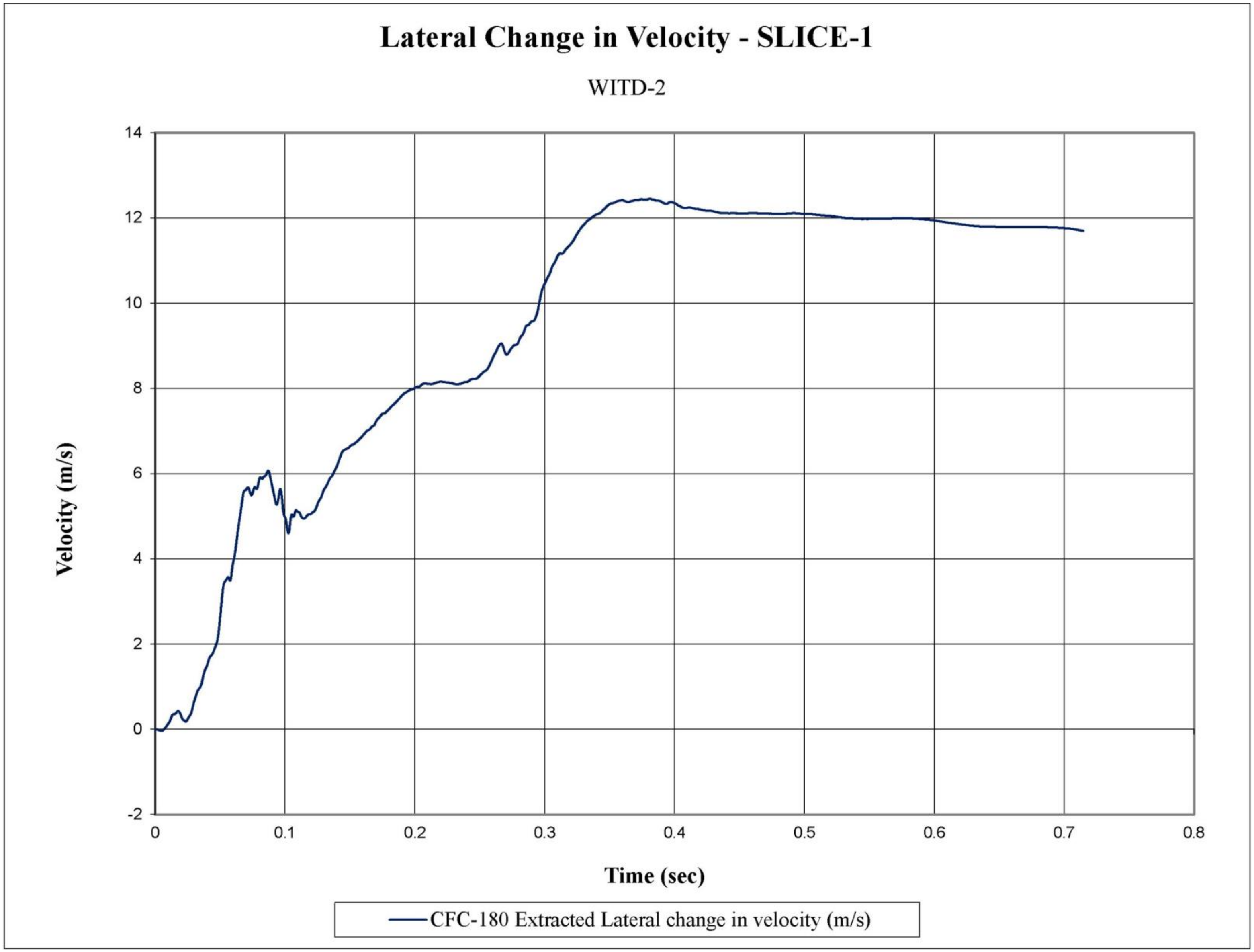


Figure F-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. WITD-2

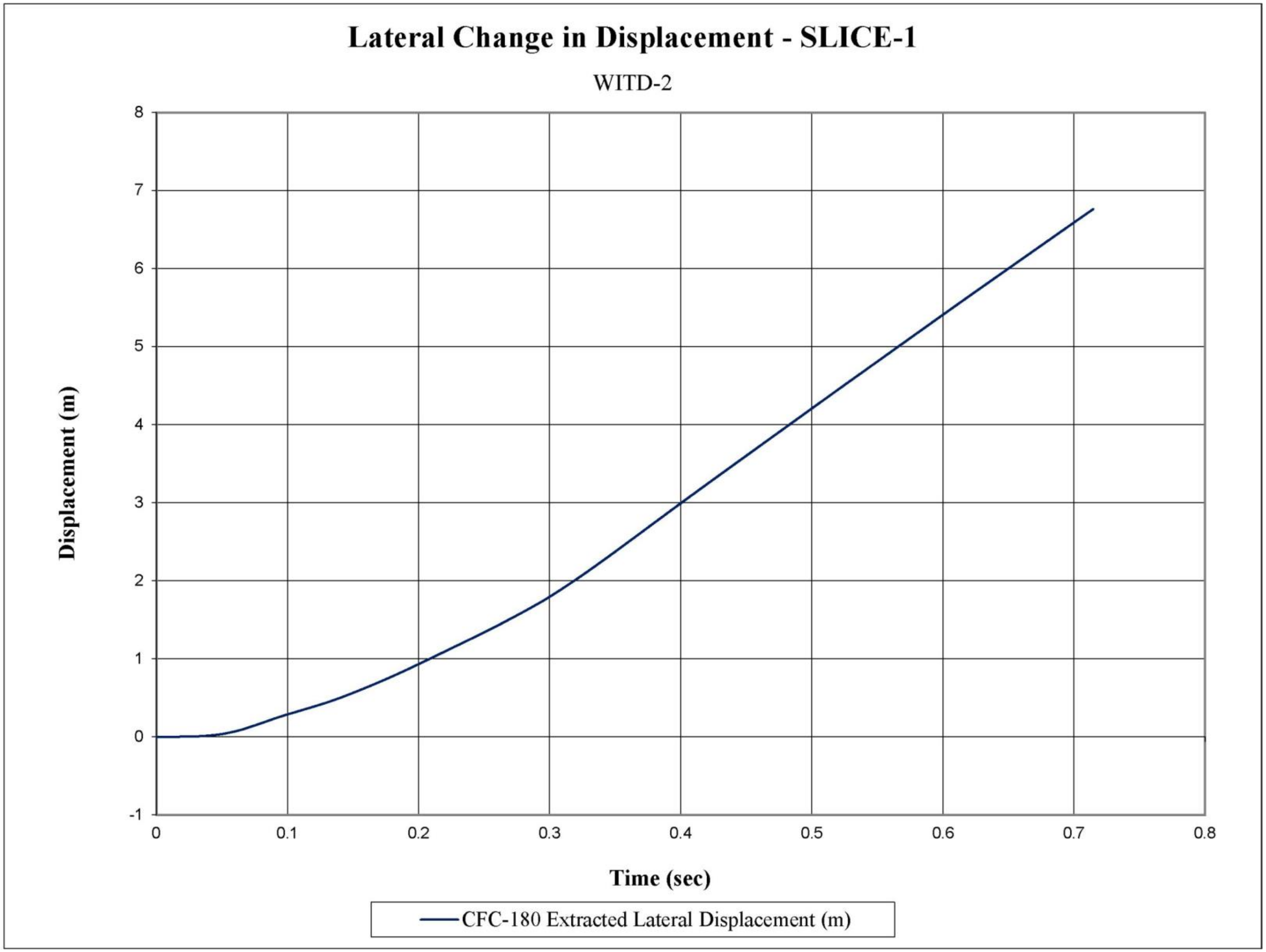


Figure F-6. Lateral Occupant Displacement (SLICE-1), Test No. WITD-2

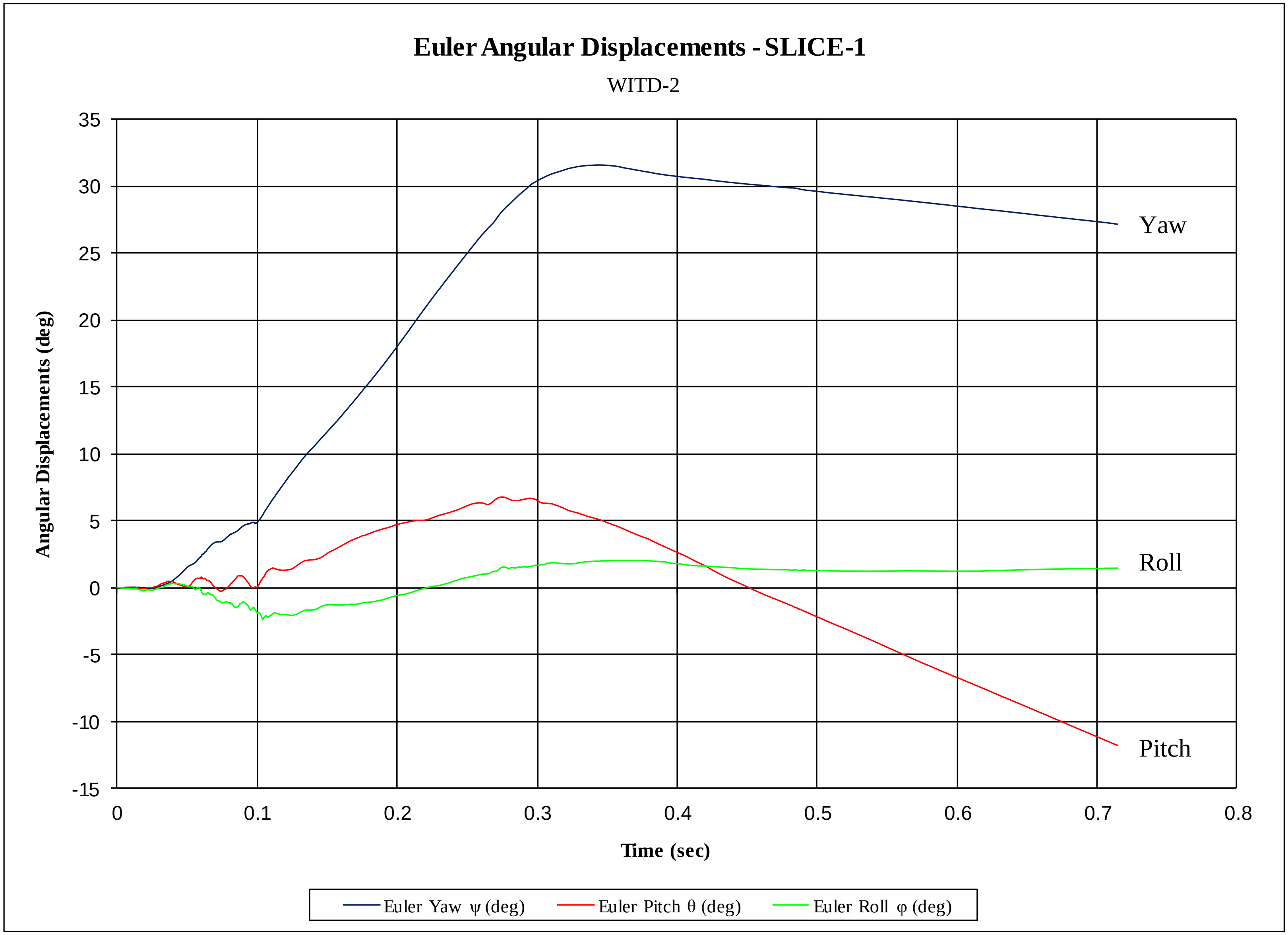


Figure F-7. Vehicle Angular Displacements (SLICE-1), Test No. WITD-2

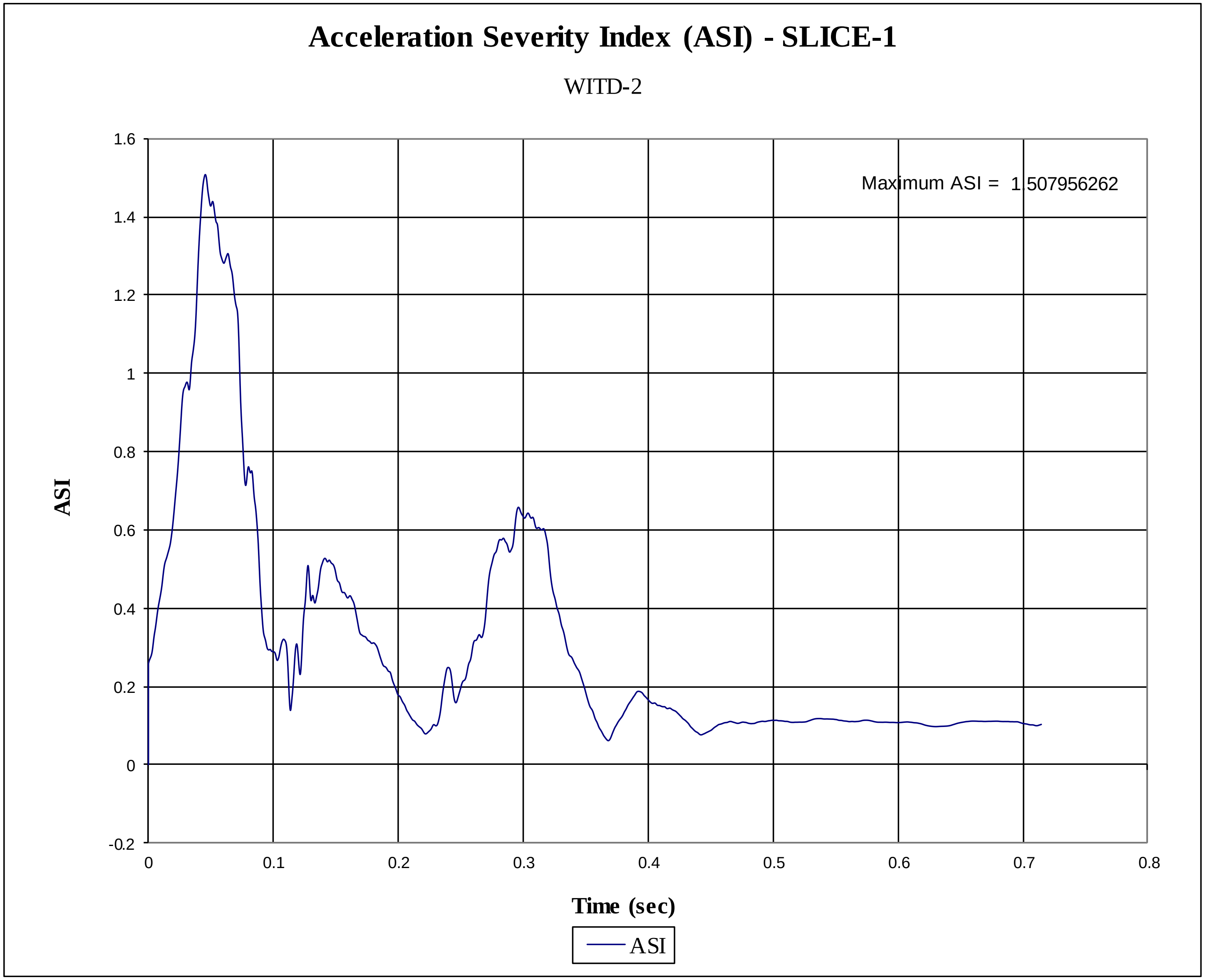


Figure F-8. Acceleration Severity Index (SLICE-1), Test No. WITD-2

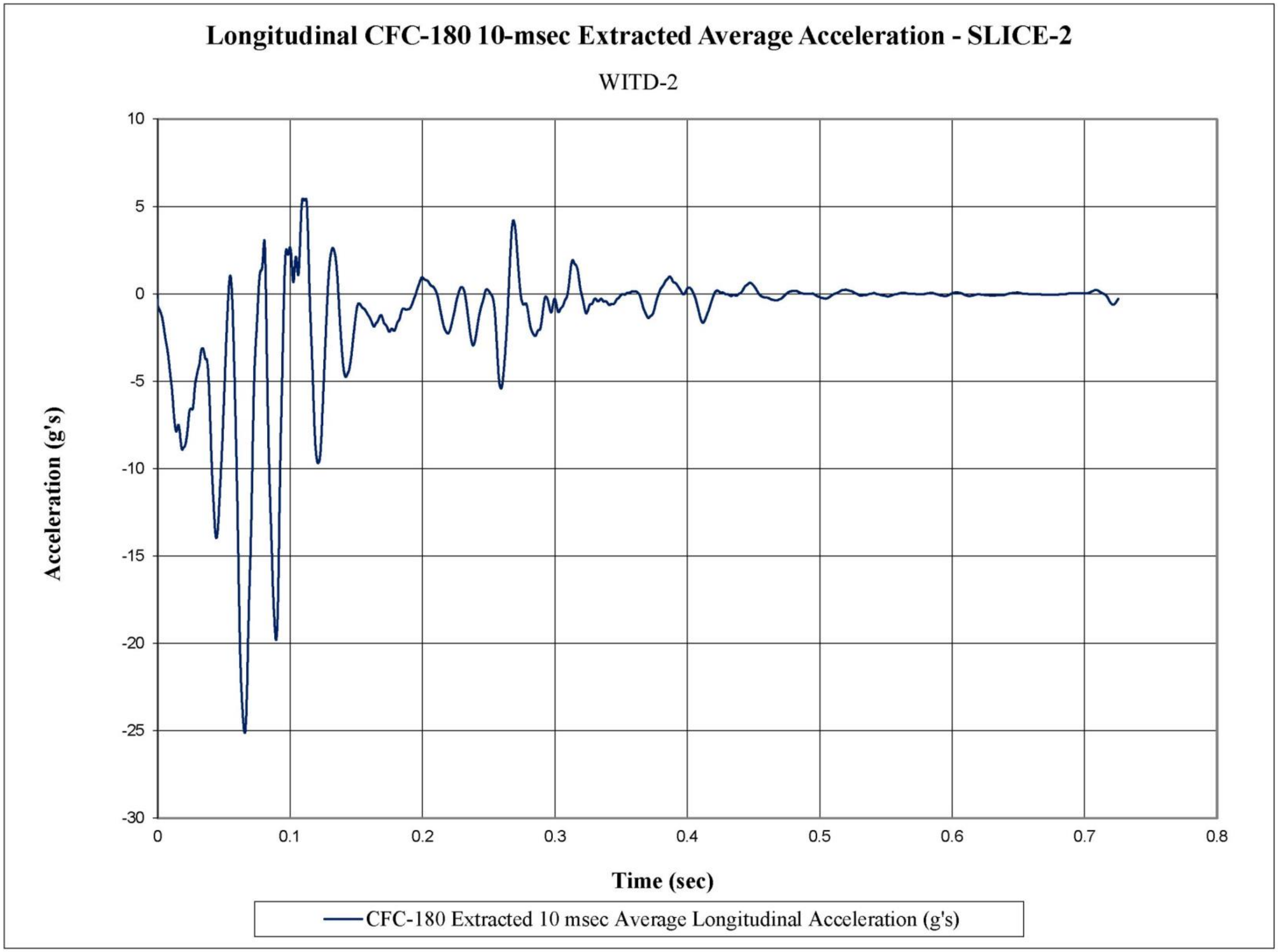


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. WITD-2

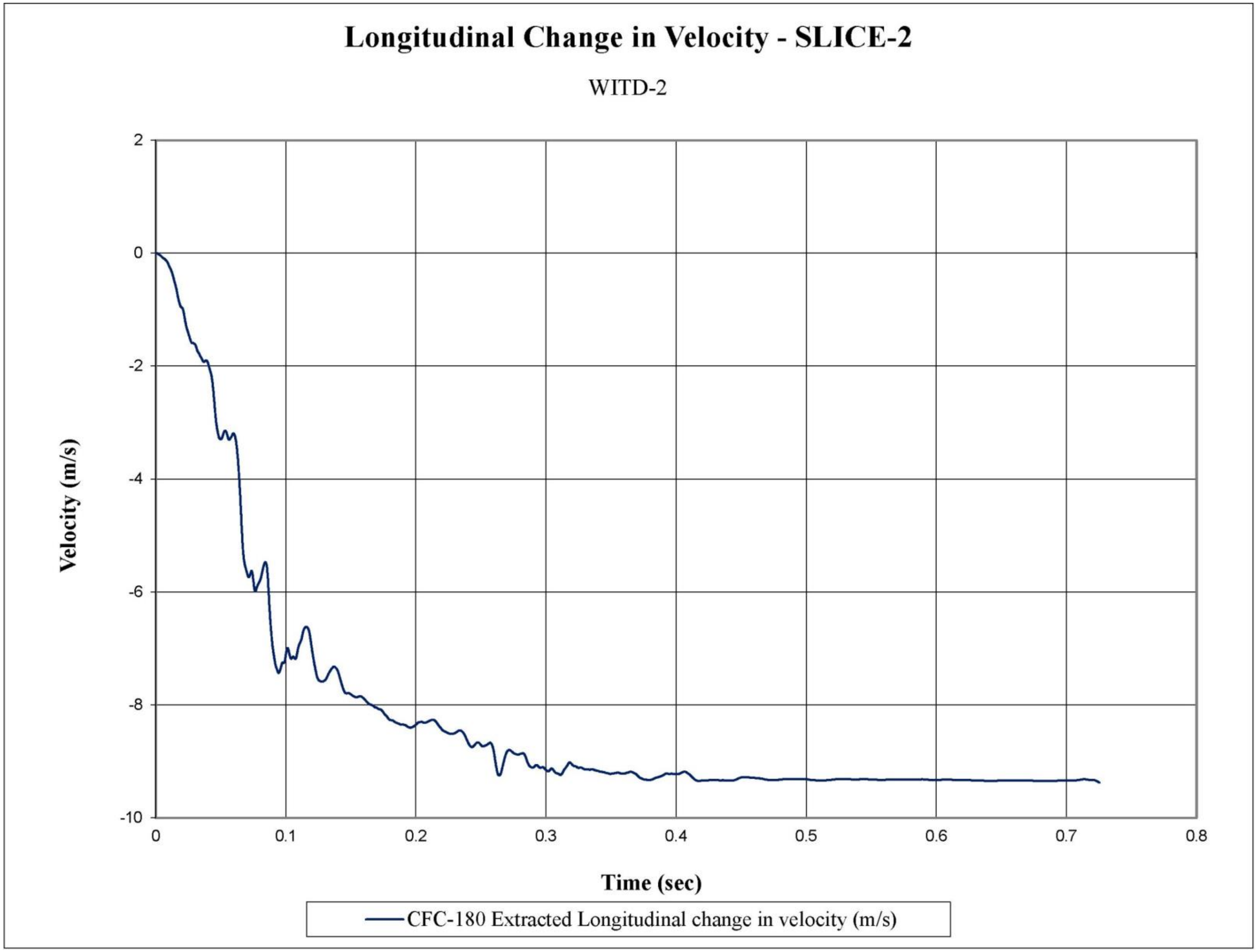


Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. WITD-2

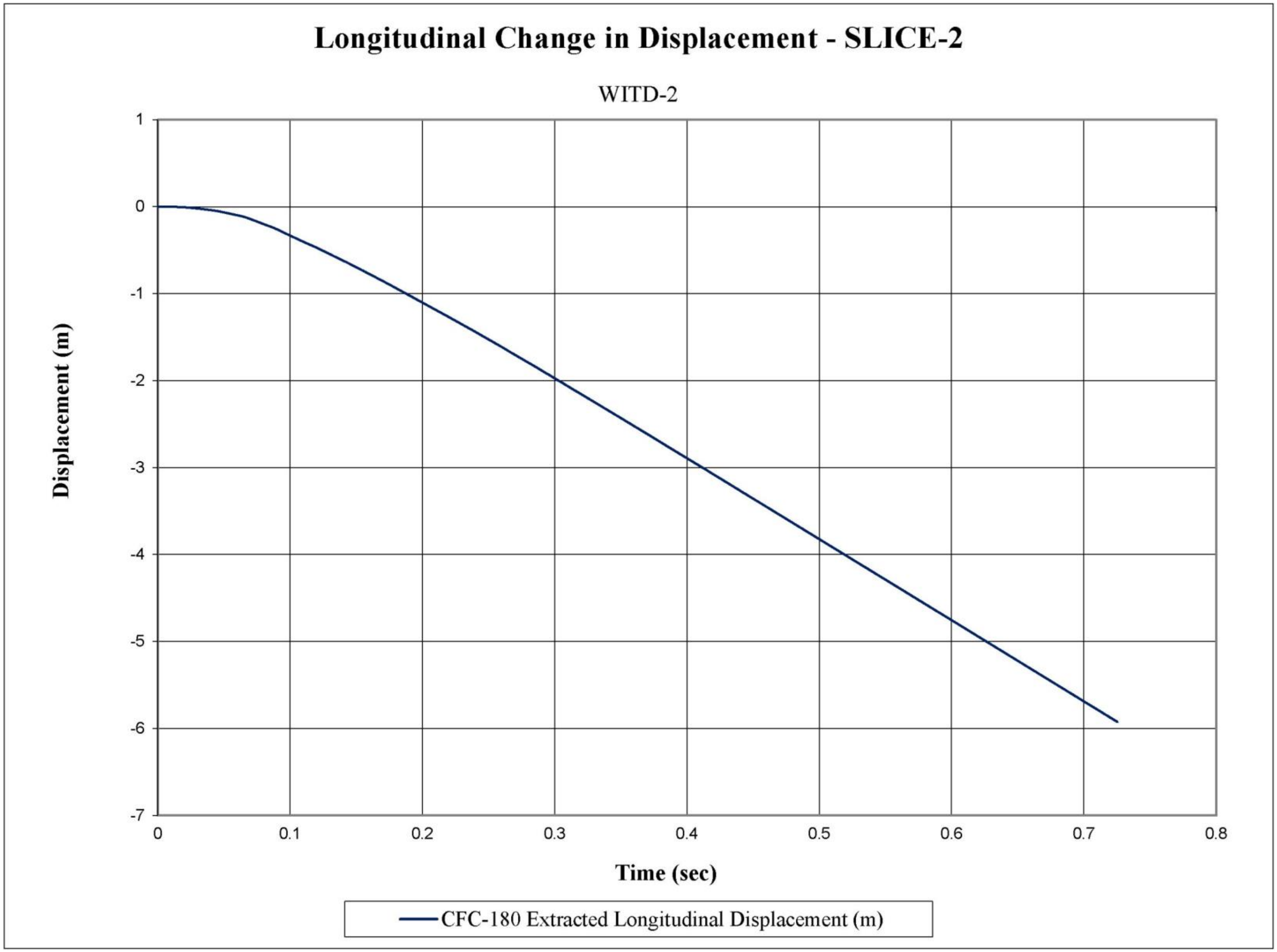


Figure F-11. Longitudinal Occupant Displacement (SLICE-2), Test No. WITD-2

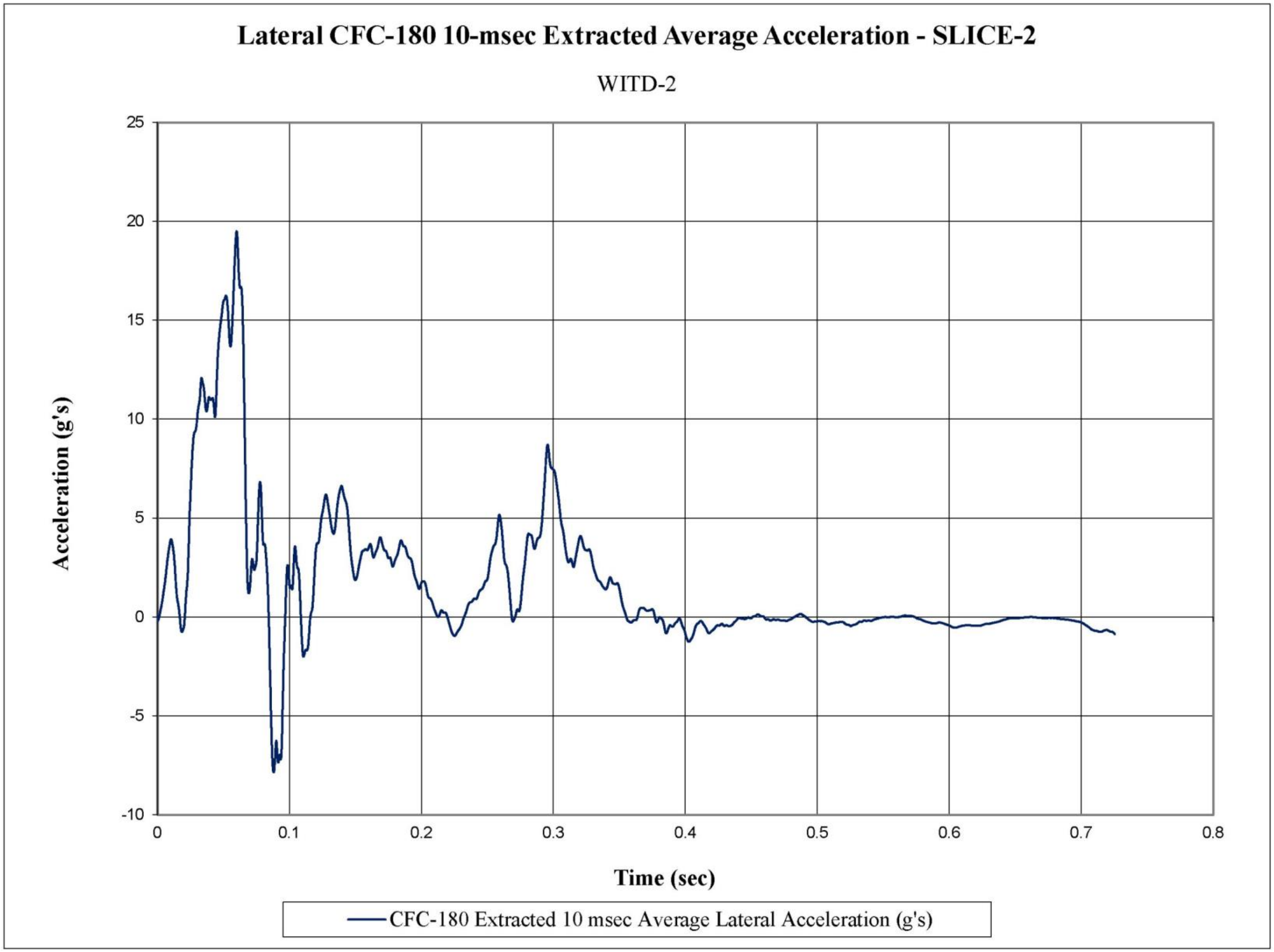


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. WITD-2

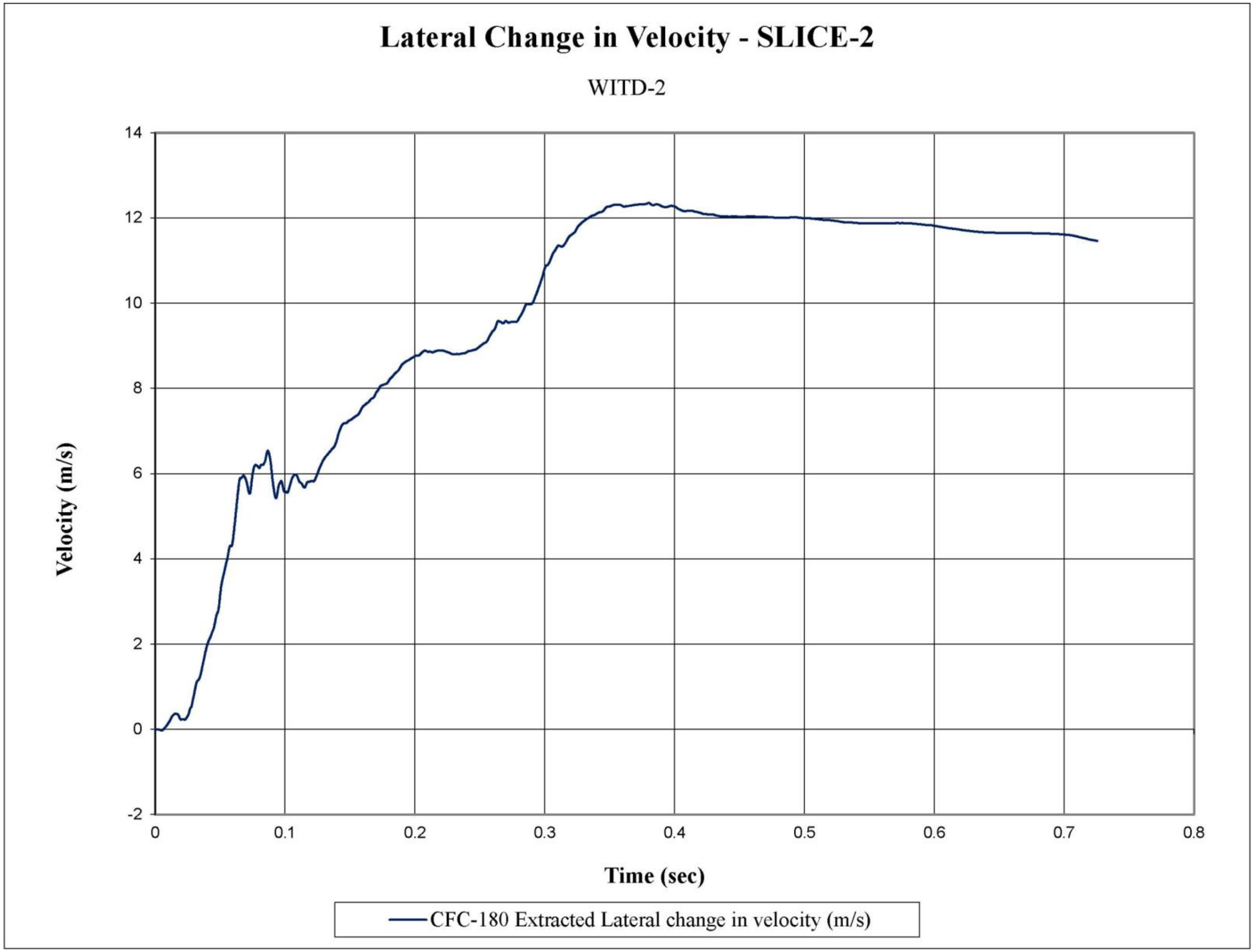


Figure F-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. WITD-2

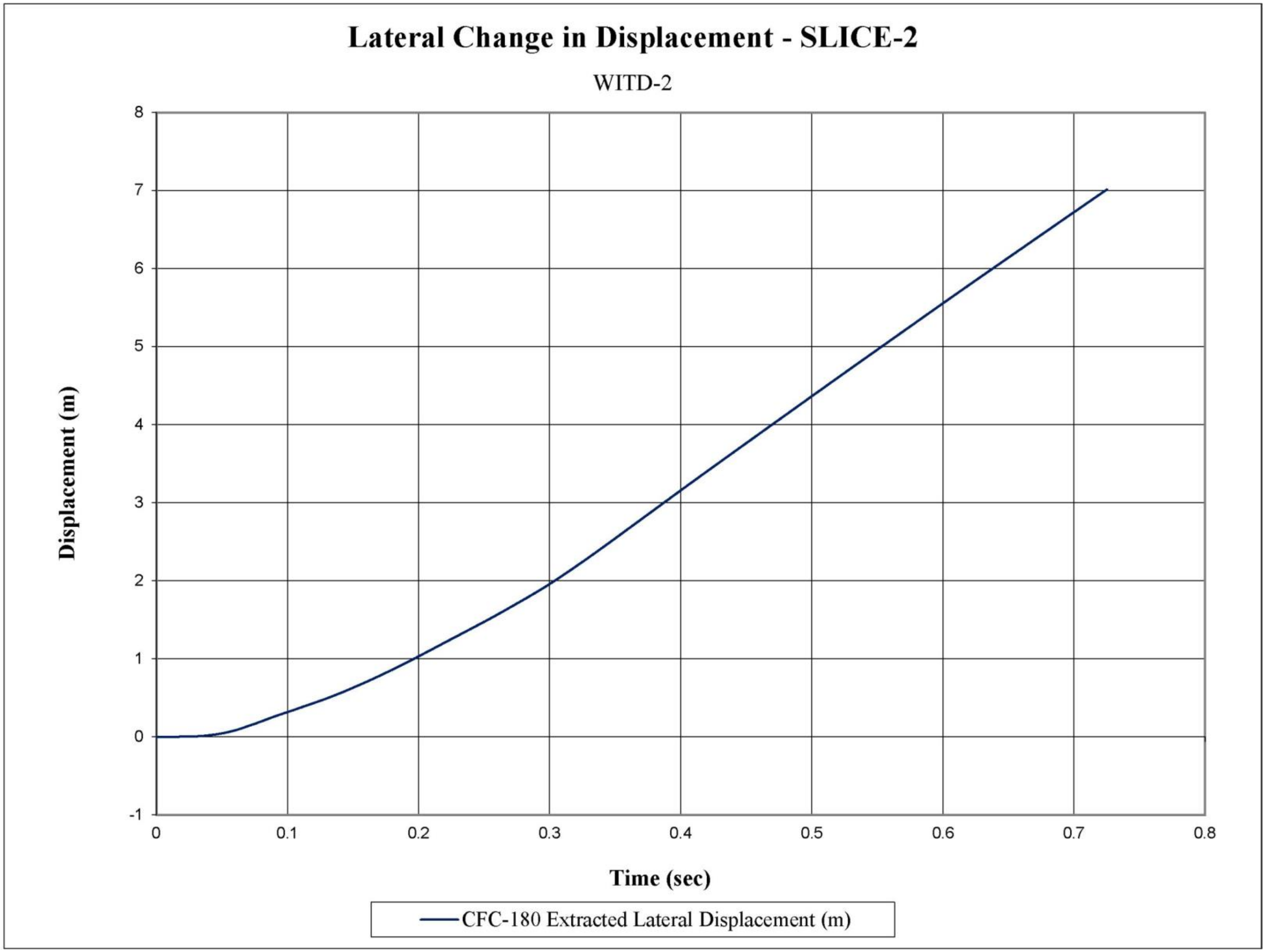


Figure F-14. Lateral Occupant Displacement (SLICE-2), Test No. WITD-2

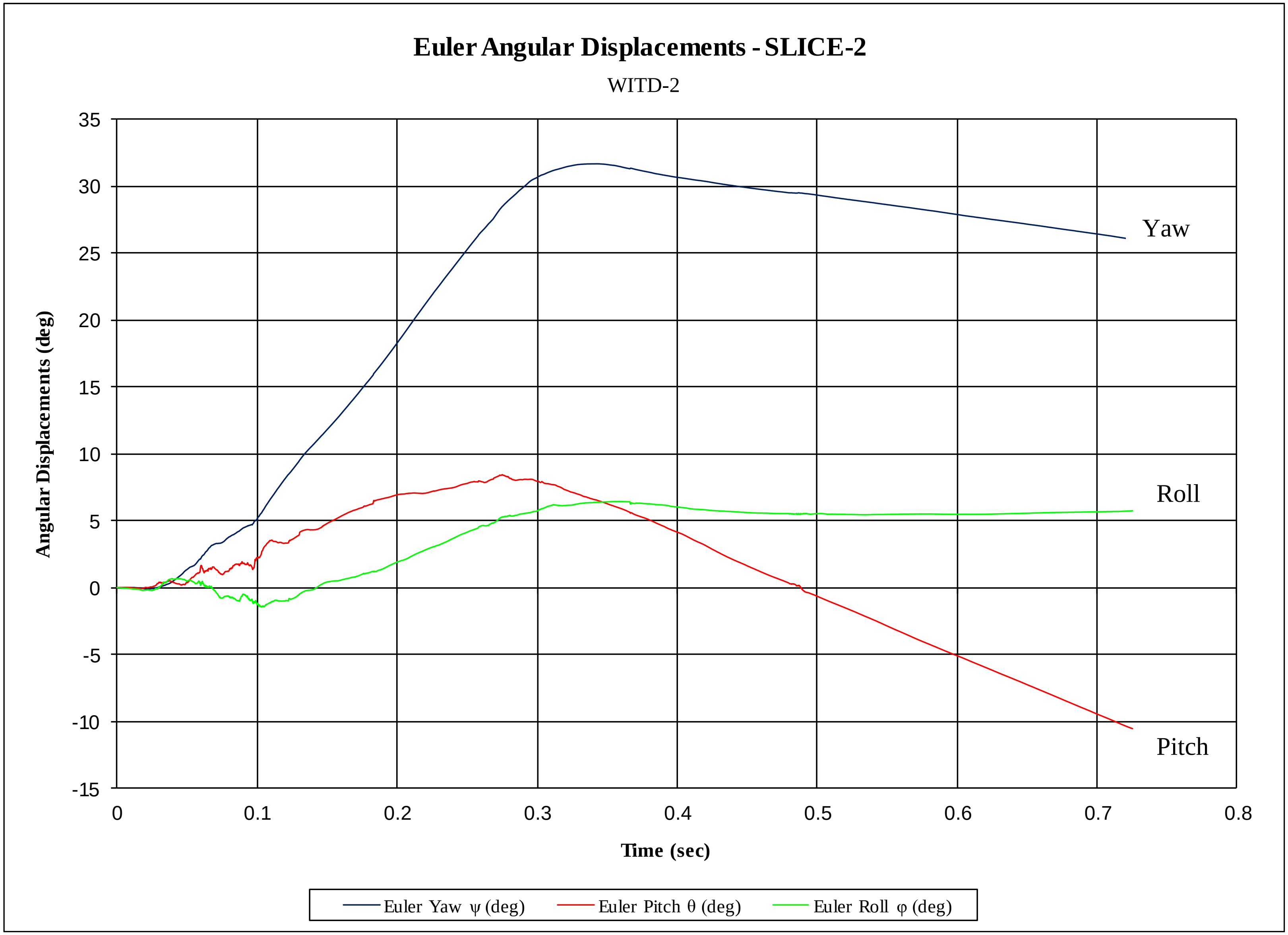


Figure F-15. Vehicle Angular Displacements (SLICE-2), Test No. WITD-2

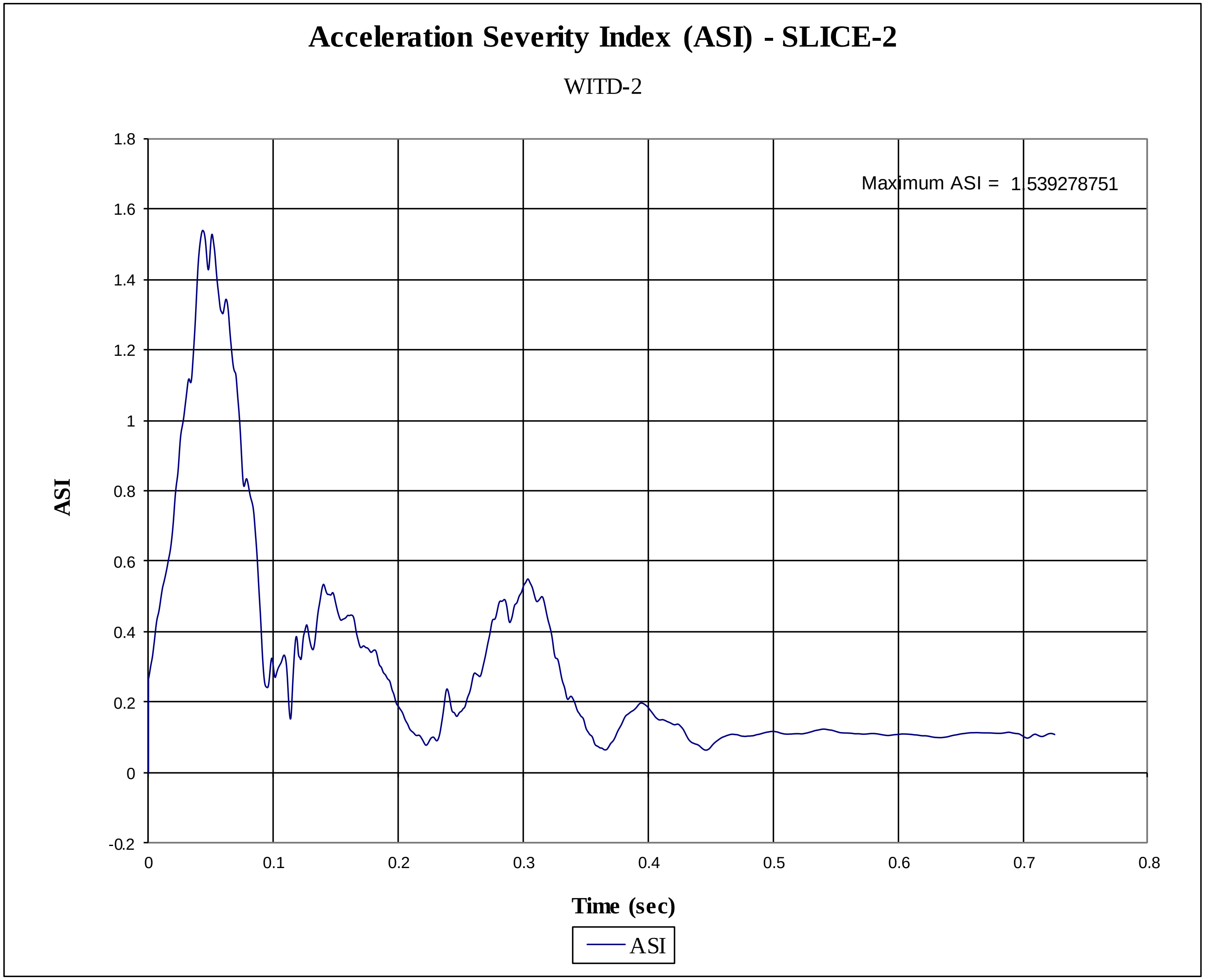


Figure F-16. Acceleration Severity Index (SLICE-2), Test No. WITD-2

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