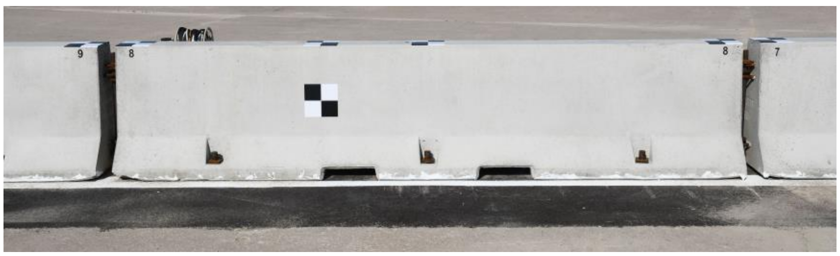
Research Project Number TPF-5(193) Supplement #136
NDOT Sponsoring Agency Code FY19-WISC-1-PCB-TIE-DOWN-MOD

MODIFICATION AND MASH 2016 TL-3 EVALUATION OF THE ASPHALT PIN TIE-DOWN FOR F-SHAPE PCB



Submitted by

Robert W. Bielenberg, M.S.M.E.
Research Engineer

Miguel A. Hinojosa
Former Graduate Research Assistant

Ronald K. Faller, Ph.D., P.E.
Research Professor & MwRSF Director

Fengtao Bai, Ph.D.
Former Post-Doctoral Research Associate

MIDWEST ROADSIDE SAFETY FACILITY
Nebraska Transportation Center
University of Nebraska-Lincoln

Main Office
Prem S. Paul Research Center at Whittier School
Room 130, 2200 Vine Street
Lincoln, Nebraska 68583-0853
(402) 472-0965

Outdoor Test Site
4630 N.W. 36th Street
Lincoln, Nebraska 68524

Submitted to

WISCONSIN DEPARTMENT OF TRANSPORTATION
4802 Sheboygan Avenue
Madison, Wisconsin 53705

MwRSF Research Report No. TRP-03-428-21

August 23, 2021

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. TRP-03-428-21	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Modification and MASH 2016 TL-3 Evaluation of the Asphalt Pin Tie-Down for F-shape PCB		**5. Report Date** August 23, 2021 **6. Performing Organization Code**
7. Author(s) Bielenberg, R.W., Hinojosa, M.A., Faller, R.K., and Bai, F.		**8. Performing Organization Report No.** TRP-03-428-21
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) Nebraska Transportation Center University of Nebraska-Lincoln Main Office: Prem S. Paul Research Center at Whittier School Room 130, 2200 Vine Street Lincoln, Nebraska 68583-0853 Outdoor Test Site: 4630 N.W. 36th Street Lincoln, Nebraska 68524		**10. Work Unit No.** **11. Contract** TPF-5(193) Supplement #136
12. Sponsoring Agency Name and Address Wisconsin Department of Transportation 4802 Sheboygan Avenue Madison, Wisconsin 53705		**13. Type of Report and Period Covered** Final Report: 2018-2021 **14. Sponsoring Agency Code** FY19-WISC-1-PCB-TIE-DOWN-MOD

15. Supplementary Notes

Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration

16. Abstract

The objective of this research was to develop and evaluate potential design modifications for the F-shaped portable concrete barrier (PCB) with a steel pin tie-down anchorage system for asphalt surfaces. Previous full-scale crash testing of the original asphalt pin tie-down anchorage according to *Manual for Assessing Safety Hardware 2016* (MASH 2016) Test Level 3 (TL-3) test designation no. 3-11 criteria resulted in a failure due to wheel snag on the barrier joint that led to excess occupant compartment deformation. Potential design modifications were developed to mitigate wheel snag, and a preferred modifications was selected for full-scale crash testing. The modified barrier system was full-scale crash tested and evaluated the MASH 2016 TL-3 test designation no. 3-11 criteria.

Test no. WITD-3 consisted of sixteen F-shape PCB segments installed with a pinned, tie-down configuration placed on a 2-in. (51-mm) thick asphalt pad. The rear toe of the PCBs was installed 18 in. (457 mm) from the edge of a 36-in. wide x 36-in. deep (914-mm x 914-mm) trench. Barrier nos. 5 through 13 were anchored on the traffic side of the system with three 1½-in. (38-mm) diameter x 38½-in. (978-mm) long steel pins placed through the bolt anchor pockets on each barrier segment and driven through the asphalt and into the underlying soil. A 5,011-lb (2,273-kg) quad cab pickup truck impacted the anchored PCB system at a speed of 61.9 mph (99.6 km/h) and at an angle of 25.1 degrees. During test no. WITD-3 the wheel well and toe pan were deformed a maximum of 10.4 in. (264 mm), which surpassed the MASH 2016 deformation limits. Due to the deformation, test no. WITD-3 was deemed unacceptable under the MASH 2016 TL-3 test designation no. 3-11 safety criteria.

17. Key Words Highway Safety, Crash Test, Roadside Appurtenances, Compliance Test, MASH 2016, Test Level 3, Portable Concrete Barrier, Temporary Concrete Barrier, Pinned Barrier, Concrete Foundation, Asphalt Foundation		**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service. 5285 Port Royal Road Springfield, VA 22161	
19. Security Classification (of this report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No. of Pages** 123	**22. Price**

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

DISCLAIMER STATEMENT

This material is based upon work supported by the Federal Highway Administration, U.S. Department of Transportation and the Wisconsin Department of Transportation under TPF-5(193) Supplement #136. The contents of this report reflect the views and opinions of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Wisconsin Department of Transportation nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation. Trade or manufacturer's names, which may appear in this report, are cited only because they are considered essential to the objective of the report. The United States (U.S.) government and the State of Wisconsin do not endorse products or manufacturers.

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 Dr. Cody Stolle, Research Assistant Professor.

ACKNOWLEDGEMENTS

The authors wish to acknowledge several sources that contributed to this project: (1) the Wisconsin Department of Transportation for sponsoring this project and (2) MwRSF personnel for constructing the barrier and conducting the crash test. Acknowledgement is also given to the following individuals who contributed to the completion of this research project.

Midwest Roadside Safety Facility
J.D. Reid, Ph.D., Professor (Retired)
J.C. Holloway, M.S.C.E., Research Engineer & Assistant Director –Physical Testing Division
K.A. Lechtenberg, M.S.M.E., Research Engineer
S.K. Rosenbaugh, M.S.C.E., Research Engineer
J.D. Rasmussen, Ph.D., P.E., Former Research Associate Professor
C.S. Stolle, Ph.D., Research Assistant Professor
M. Asadollahi Pajouh, Research Assistant Professor
A.T. Russell, B.S.B.A., Testing and Maintenance Technician II
E.W. Krier, B.S., Construction and Testing Technician II
S.M. Tighe, Construction and Testing Technician I
D.S. Charroin, Construction and Testing Technician I
R.M. Novak, Construction and Testing Technician I
T.C. Donahoo, Construction and Testing Technician I
J.T. Jones, Construction and Testing Technician I
J.E. Kohtz, B.S.M.E., Former CAD Technician
E.L. Urbank, B.A., Research Communication Specialist
J.R. Revell, Research Communication Specialist Assistant
Z.Z. Jabr, Engineering Technician
Undergraduate and Graduate Research Assistants

Wisconsin Department of Transportation
Jerry Zogg, P.E., former Chief Roadway Standards Engineer
Erik Emerson, P.E., Standards Development Engineer
Rodney Taylor, P.E., Roadway Design Standards Unit Supervisor
David Stertz, P.E., Design Standards and Oversite Section Chief to the WisDOT Staff

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

Portable Concrete Barriers (PCBs) are often used in temporary applications where available space behind the barrier is limited and it is desired that barrier deflection during vehicular impacts be limited. Free-standing PCB systems develop their re-directive capacity through a combination of various forces and mechanisms. These include 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. Previous crash testing of free-standing F-shape PCBs, in accordance with the Test Level 3 (TL-3) impact safety standards published in the *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) [1], 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 vehicle crash tested a tie-down system for PCBs on asphalt road surfaces that utilized three 1½-in. (38-mm) diameter x 38½-in. (978-mm) long ASTM A36 steel pins with 3-in. x 3-in. x ½-in. (76-mm x 76-mm x 13-mm) ASTM A36 steel caps installed in holes on the front face of each barrier segment, as shown in Figure 1 [3]. The tie-down system was installed in combination with sixteen F-shape barriers on a 2-in. (51-mm) thick asphalt pad and crash tested according to the National Cooperative Highway Research Program (NCHRP) Report No. 350 [4] test designation no. 3-11. For the test, the F-shape PCBs were installed with the back of the barrier 6 in. (152 mm) from a 3-ft (0.9-m) deep vertical trench. The full-scale crash test showed that the vehicle was safely contained and redirected, and the test was judged acceptable according to the NCHRP Report 350 criteria. Barrier deflections for the system were reduced, and all of the barriers in the system were safely restrained on the asphalt road surface. It was noted that a significant section of the asphalt and soil were fractured and separated in the impact region.

While this system successfully met the NCHRP Report 350 criteria, previous MASH testing of free-standing PCB systems indicated that the anchor loads and barrier loads were expected to increase. This suggested the potential for increased barrier deflections and increased damage to the barrier and/or anchorages. Thus, the barrier system needed to be evaluated to the MASH TL-3 criteria to determine if it would safely redirect errant vehicles under the updated criteria and to determine the working width of the barrier system.

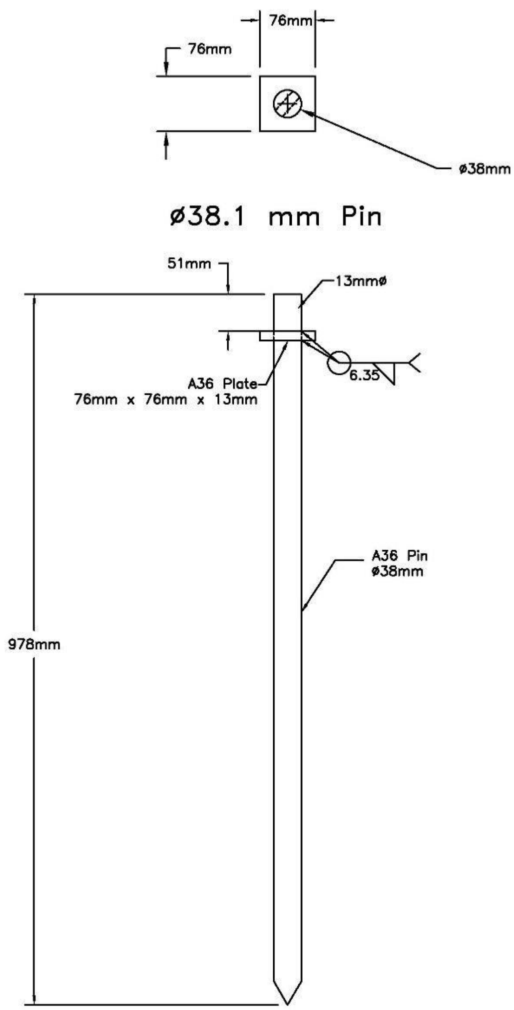


Figure 1. Asphalt Pin Tie-Down for F-Shape PCB

A MASH TL-3 test of the F-shape barrier tie-down system for asphalt road surfaces was also conducted at MwRSF [5]. The barrier system and test setup for this test was identical to the previous NCHRP Report 350 full-scale crash test. In test no. WITD-2, the 2270P vehicle impacted the barrier system at a speed of 62.0 mph (99.8 km/h) and an angle of 25.1 degrees. The impact point for this test was selected to maximize vehicle snag and loading of the barrier joint. The vehicle was captured and successfully redirected. The asphalt and a portion of the soil next to the excavated trench behind the system were disengaged similar to the previous NCHRP Report 350 crash test. Maximum dynamic lateral barrier deflection for test no. WITD-2 was 24½ in. (622 mm), as compared to 18.4 in. (467 mm) in the NCHRP Report 350 crash test. The left-front tire snagged on the first barrier joint it encountered, as shown in Figure 2. The cause of the wheel snag was similar to that observed in previous tests of the asphalt tie-down anchorage, in that the upstream barrier was loaded and deflected/rotated back laterally while the downstream barrier remained anchored. This exposed the face of the downstream barrier and promoted snagging of the wheel and tire as it traversed the joint. The front tire climbed the toe of the PCB barrier as well, which increased the exposure of the face of the downstream barrier to the wheel.

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

The wheel snag rotated the left-front wheel 90 degrees and pushed it back toward the floor pan of the pickup. This caused excessive floor 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 3. Maximum deformation of the floor pan area was 13.2 in. (335 mm), which exceeded the MASH limit for floor pan deformation of 9 in. (229 mm). The combination of the excessive occupant compartment deformations and the penetration of the wheel rim into the occupant compartment led to the test being deemed unacceptable under the MASH TL-3 safety requirements.

Figure 3. Occupant Compartment Damage, Test No. WITD-2

Following the test, it was noted that test no. WITD-1, a MASH TL-3 full-scale crash test of a concrete bolted tie-down anchorage for the F-shape PCB, had less severe wheel snag than test no. WITD-2, and that system satisfied MASH 2016 TL-3 performance requirements [5]. It was believed that the epoxied anchor rods used in that system more effectively reduced motion of the barrier and lessened the joint separation and wheel snag severity. This suggested 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 included increasing the offset of the barriers from the excavation and introducing a shear transfer element at the joint to prevent joint separation. Thus, a need existed to modify and re-evaluate the PCB tie-down system for asphalt surfaces under the MASH 2016 criteria to determine if the system has sufficient capacity to constrain barrier motions, define its dynamic deflection, and ensure its safety performance when installed adjacent to vertical drop-offs.

1.2 Objective

The objective of this research was to review and evaluate modifications to the F-shape PCB with steel pin tie-down anchorages for asphalt road surfaces and full-scale crash test the modified barrier system to evaluate it to MASH 2016 TL-3.

1.3 Scope

The research objective was achieved through the completion of several tasks. The study began with development of potential modifications to improve the safety performance of the steel pin tie-down system for asphalt surfaces for use with F-shape PCBs. The researchers brainstormed design modifications and evaluated their potential to reduce joint separation and wheel snag. The most promising modifications were presented to the sponsor for review and selection of a preferred design modification for full-scale crash testing. One full-scale crash test was conducted on the modified F-shape PCB anchorage system according to MASH 2016 test designation no. 3-11. 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 anchorage for the F-shape PCB.

2 ASPHALT TIE-DOWN ANCHORAGE DESIGN MODIFICATIONS

Design modifications for the steel pin tie-down system for asphalt surfaces for use with F-shape PCBs were developed based on design concepts to mitigate the wheel snag observed in test no. WITD-2. These design concepts were then presented to the project sponsor along with their potential advantages and disadvantages, and the sponsor was asked to select the preferred concept for full-scale crash testing and evaluation.

2.1 Design Concepts

Design of modifications to mitigate the wheel snag and excessive occupant compartment deformations observed in test no. WITD-2 focused on two main criteria. First, it was believed that minimizing the relative lateral displacement between adjacent barrier segments at the joint would reduce the wheel snag by exposing the wheel to less contact area on the end of the downstream barrier segment. The PCB anchorage system evaluated in test no. WITD-1, which utilized epoxied threaded rods anchored in concrete on the traffic face of the PCB segments, provided increased resistance to lateral barrier motion. This exposed less of the end of the downstream barrier segment to the vehicle wheel as it traversed the joint and allowed this system to meet MASH TL-3 requirements when the asphalt pin tie-down anchorage did not. Thus, design modifications were considered that further limited barrier segment rotation and displacement or provide shear transfer across the barrier segment joint such that the relative lateral displacement between the barrier segments was limited. Second, design concepts also focused on physically shielding the barrier segment joint and the end of the downstream barrier segment from wheel snag by placing some form of protection across the joint.

Other design considerations were taken into account for the potential barrier modifications. First, the modification had to work as a retrofit to the existing F-shape PCB segment such that the joint design, segment geometry, and barrier reinforcement were unchanged. It was also desired to use readily available hardware and components to the extent possible. The proposed design modifications for the F-shape PCB with steel pin tie-down anchorage for asphalt road surfaces are outlined in the subsequent sections.

2.1.1 Design Concept A – Steel Saddle Cap

Design Concept A consisted of a steel saddle cap that spanned across the joint between adjacent barrier segments, as shown in Figures 4 and 5. The saddle cap was fabricated from a 37⅝-in. (956-mm) long x ⅛-in. (3-mm) thick, U-shaped, steel plate that sat on the top of the barrier segments and extended 6¾ in. (171 mm) down each side of the barrier. The saddle cap was anchored to the adjacent barrier segments with four ¾-in. diameter wedge bolt mechanical anchors along the sides of the saddle cap. Design Concept A was intended to provided shear transfer across the barrier segment joint and restrain relative lateral displacement of the barrier segments. Additionally, the sides of the saddle cap would provide some degree of physical shielding and wheel snag mitigation for the upper portion of the barrier joint. One benefit of this concept was that it was symmetric with respect to the front and back sides of the barrier which would reduce the potential for the retrofit to be installed in an improper orientation. The primary drawback of this type of installation was the need for additional steel component and anchorage hardware at every joint in the PCB system.

2.1.2 Design Concept B – Thick Rear Shear Plate

Design Concept B consisted of a steel, shear plate that spanned across the joint between adjacent barrier segments, as shown in Figures 6 through 8. The 37⅝-in. (956-mm) long x 6-in. (152-mm) wide x 1-in. (25-mm) thick steel plate was mounted on the non-traffic side face of the barrier segment, centered 4 in. (102 mm) down from the top of the barrier segment, and centered longitudinally across the barrier joint. The shear plate was anchored to the barrier segments with four ¾-in. (19 mm) diameter wedge bolt mechanical anchors. Design Concept B was intended to provided shear transfer across the barrier segment joint and restrain relative lateral displacement of the barrier segments. The concept only required hardware mounted on the non-traffic side of the barrier segments and required only four anchors. The concept was not symmetric with respect to the front and back sides of the barrier, which could increase the potential for the retrofit to be installed in an improper orientation. Another drawback of this type of installation was the need for additional steel component and anchorage hardware at every joint in the PCB system.

2.1.3 Design Concept C – Rear Shear Tube

Design Concept C consisted of a steel, shear tube that spanned across the joint between adjacent barrier segments, as shown in Figures 9 through 11. The 37⅝-in. (956-mm) long HSS3½x3½x¼ tube was mounted on the non-traffic side face of the barrier segment, centered 4 in. (102 mm) down from the top of the barrier segment, and centered longitudinally across the barrier joint. The shear plate was anchored to the barrier segments with four ¾-in. (19 mm) diameter x 4¾-in. (121-mm) long hex bolts threaded into ¾ in. Red Head drop-in anchors. Design Concept C was intended to provided shear transfer across the barrier segment joint and restrain relative lateral displacement of the barrier segments. The concept only required hardware mounted on the non-traffic side of the barrier segments and required only four anchors. The concept was not symmetric with respect to the front and back sides of the barrier, which could increase the potential for the retrofit to be installed in an improper orientation. Another drawback of this type of installation was the need for additional steel component and anchorage hardware at every joint in the PCB system.

2.1.4 Design Concept D – Rear W-Beam

Design Concept D consisted of a two, 10-gauge W-beam terminal connectors that spanned across the joint between adjacent barrier segments, as shown in Figures 12 through 14. The 30-in. (762-mm) long W-beam terminal connectors were mounted on the non-traffic side face of the barrier segment, aligned vertically with the lower edge of the W-beam at the inflection point of the upper two sloped faces of the F-shape barrier, and centered longitudinally across the barrier joint. The W-beam end shoes were spliced together with standard splice bolts and anchored to the barrier segments with three ¾-in. (19 mm) diameter wedge bolt mechanical anchors. Design Concept D was intended to provided shear transfer across the barrier segment joint and restrain relative lateral displacement of the barrier segments. Ideally, the W-beam would have been mounted for more effect restraint of the upper sections of the barrier segments, but the placement of the mechanical anchors interfered with the reinforcing steel. The concept only required hardware mounted on the non-traffic side of the barrier segments and used standard guardrail components. The concept was not symmetric with respect to the front and back sides of the barrier, which could increase the potential for the retrofit to be installed in an improper orientation. Another drawback of this type of installation was the need for additional steel component and anchorage hardware at every joint in the PCB system.

2.1.5 Design Concept E – Thin Front Shear Plate

Design Concept E consisted of a steel, shear plate that spanned across the joint between adjacent barrier segments, as shown in Figures 15 through 17. The 23⅝-in. (600-mm) long x 21⅝-in. (549-mm) wide, 10-gauge, steel plate was mounted on the traffic side face of the barrier segment, spanned the entire height of the upper sloped face of the barrier segments, and was centered longitudinally across the barrier joint. The shear plate was anchored to the barrier segments with four ¾-in. (19-mm) diameter wedge bolt mechanical anchors. Design Concept E was intended to provided shear transfer across the barrier segment joint and restrain relative lateral displacement of the barrier segments. Additionally, the plate would provide some degree of physical shielding and wheel snag mitigation for the upper portion of the barrier joint. The concept only required hardware mounted on the traffic side of the barrier segments and required only four anchors. The concept was not symmetric with respect to the front and back sides of the barrier, which could increase the potential for the retrofit to be installed in an improper orientation. Another drawback of this type of installation was the need for additional steel component and anchorage hardware at every joint in the PCB system.

2.1.6 Design Concept F – Increased Barrier Offset

Design Concept F consisted of a increasing the offset between the backside of the barrier segments and the vertical drop-off being shielded by the anchored PCB, as shown in Figure 18. In test no WITD-1, the steel pin, asphalt tie-down anchorage for F-shape PCBs was evaluated with a 6-in. (152-mm) wide gap between the rear toe of the PCB and the vertical drop-off. During the test, it was noted that a large section of the soil and asphalt disengaged under load. It was believed that increasing the offset from the vertical drop-off would prevent the disengagement of the soil and asphalt under load, increase the resistive forces and decrease the deflection of the steel anchor pins, and limit the relative lateral displacement of the barrier segments. Thus, Design Concept E proposed to increase the offset between the rear toe of the barrier segments and the vertical drop-off to 18 in. (457 mm). The concept required no hardware mounted on the barrier segments, but it was not known if the increased lateral offset would limit relative lateral barrier displacements and wheel snag sufficiently.

2.2 Selection of Preferred Design Concept

The proposed design modification concepts were presented to the research sponsor for review and selection of a preferred modification for evaluation through full-scale crash testing. All of the proposed concepts had the potential to improve the performance of the system. Design concepts B-E were not as desirable as the sponsor desired a dual-sided or symmetric retrofit solution to alleviate incorrect installation orientation concerns. Thus, Design Concept A was preferred out of the concepts that utilized retrofit hardware to transfer shear and/or mitigate vehicle snag. Design Concept F was also preferred as it was likely to reduce relative lateral displacement of the barrier segments and it did not require additional hardware. As Design Concept F provided the simplest modification to implement with the anchored PCB system it was selected for evaluation through full-scale crash testing. It was also noted that if the increased offset was successful, there may be a future desire to revisit the use of external hardware at the barrier joint to reduce the lateral offset.

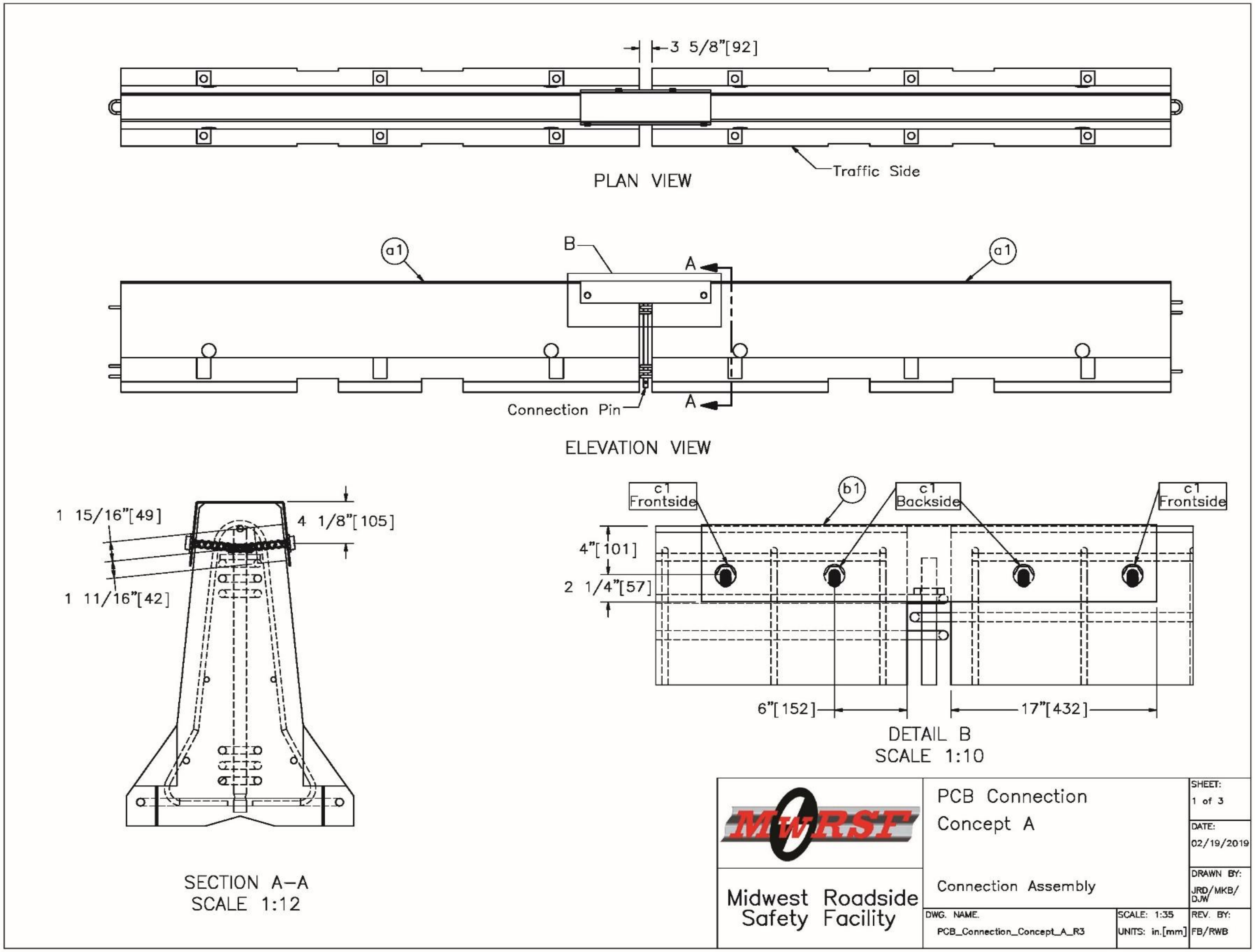


Figure 4. Design Concept A

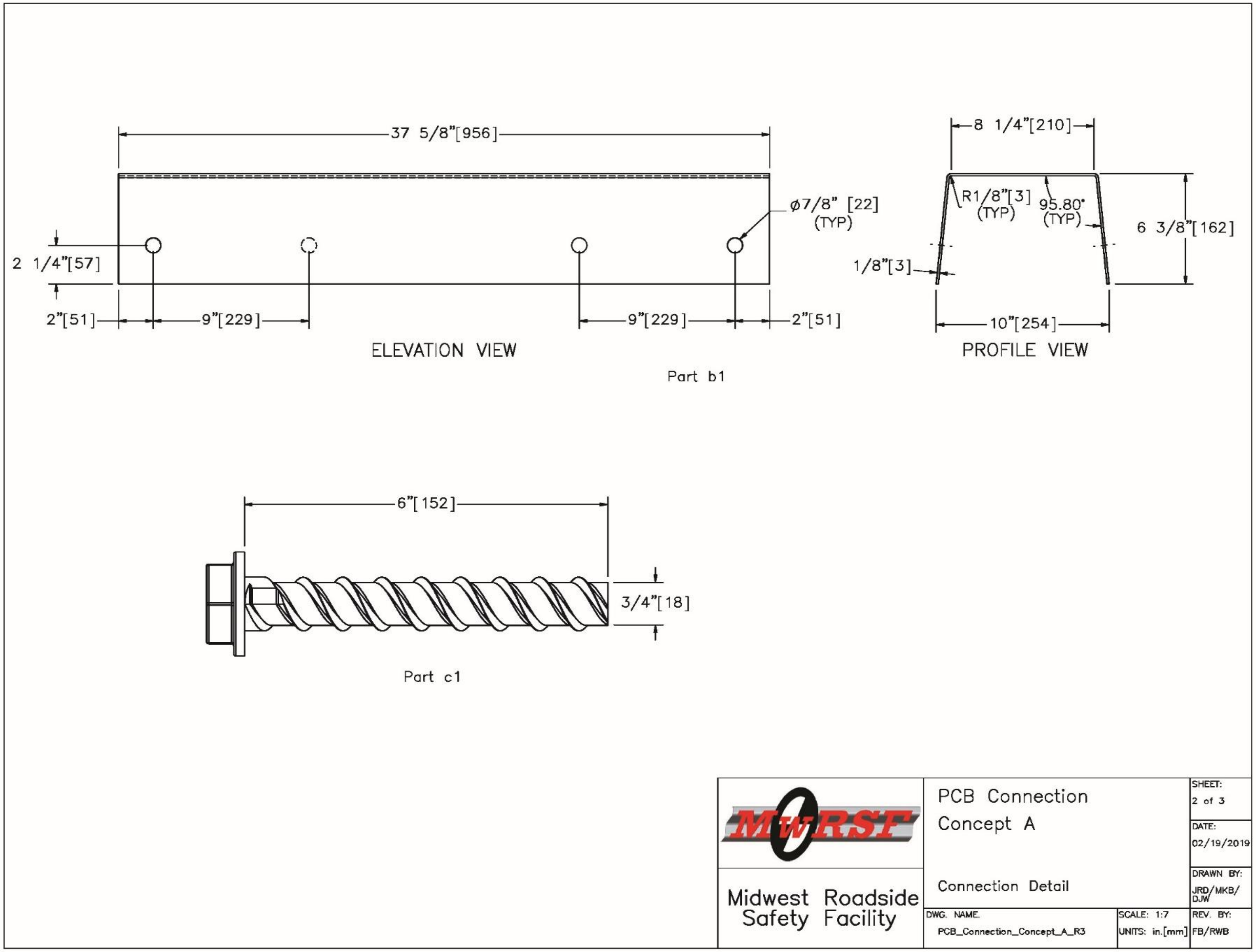


Figure 5. Design Concept A

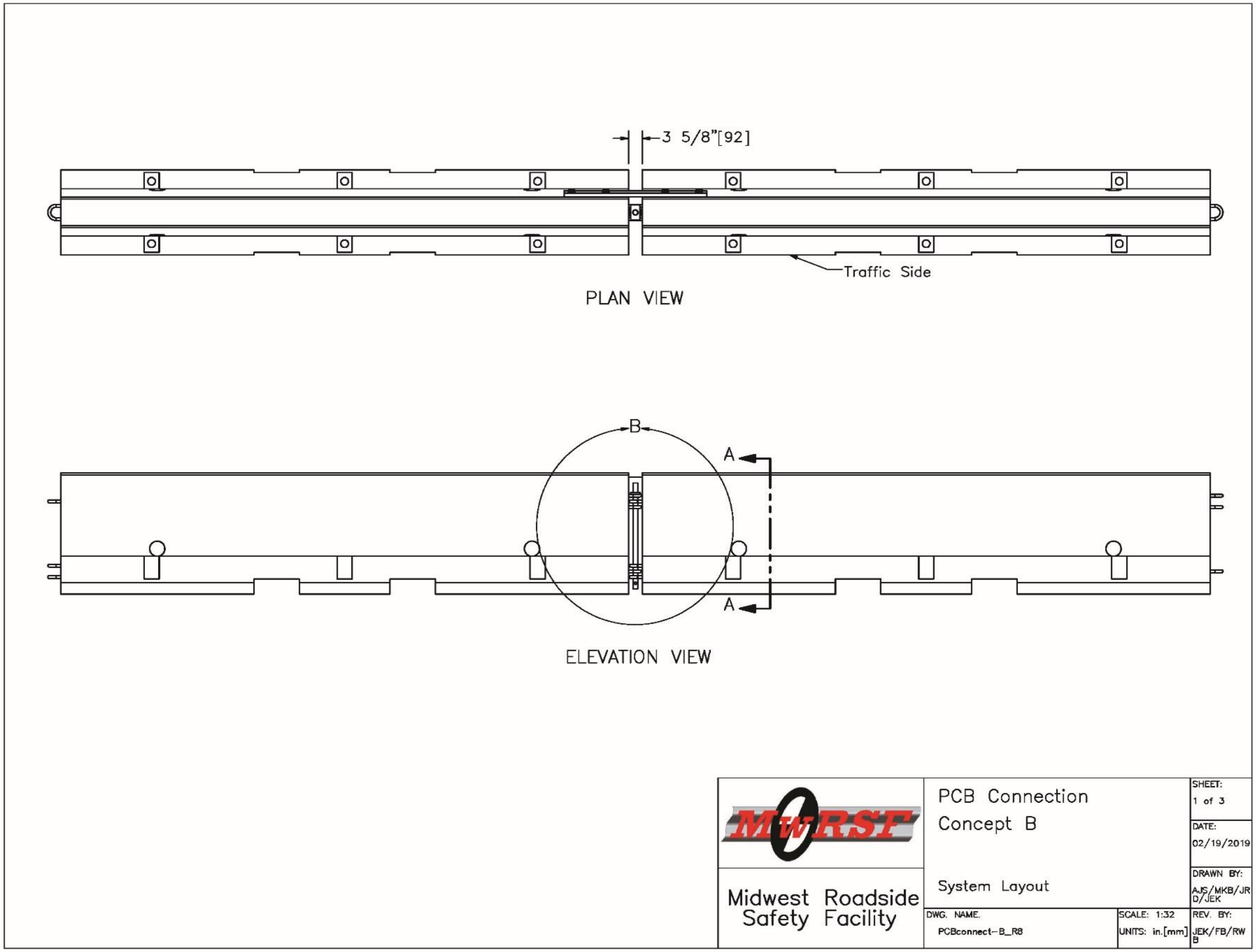


Figure 6. Design Concept B

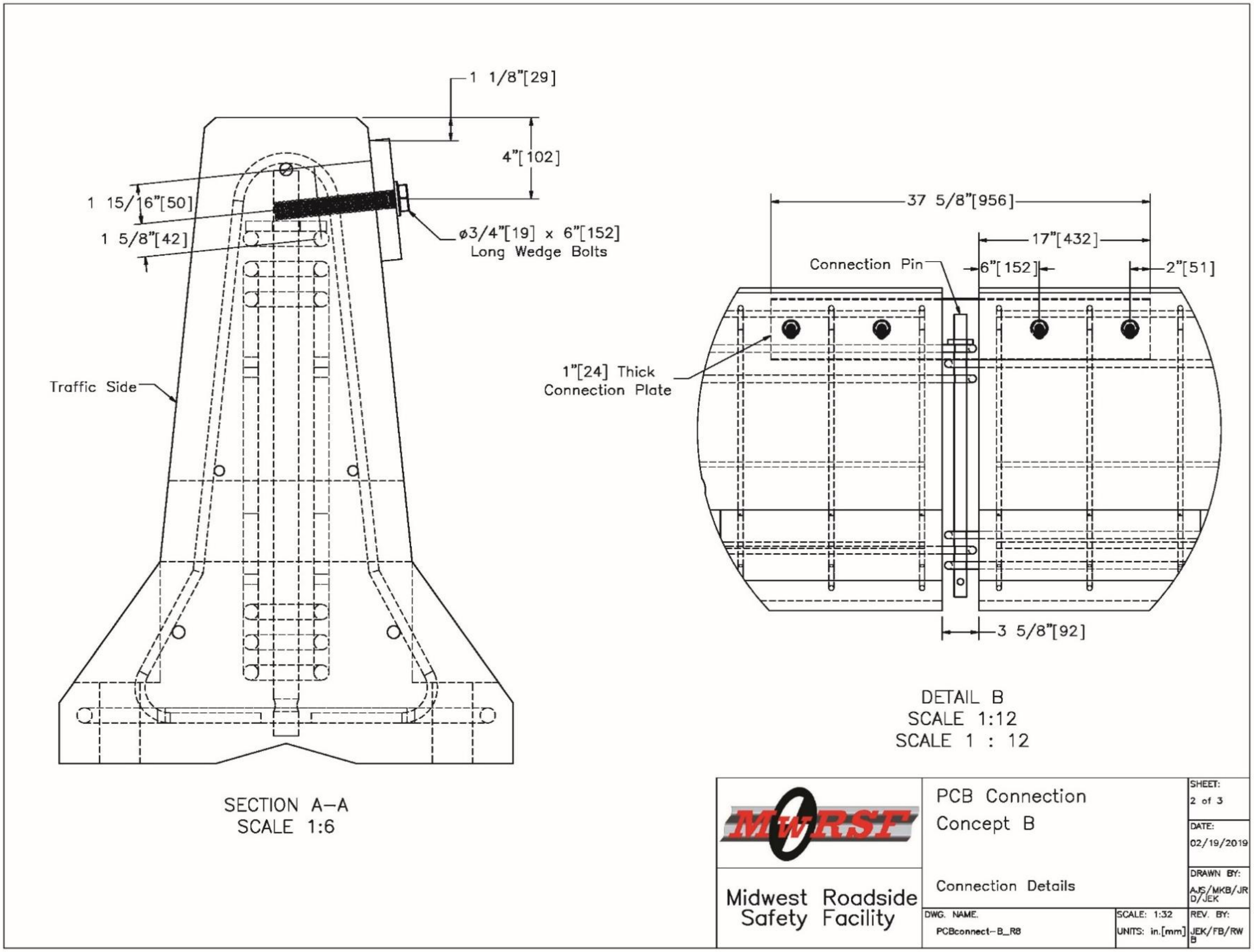


Figure 7. Design Concept B

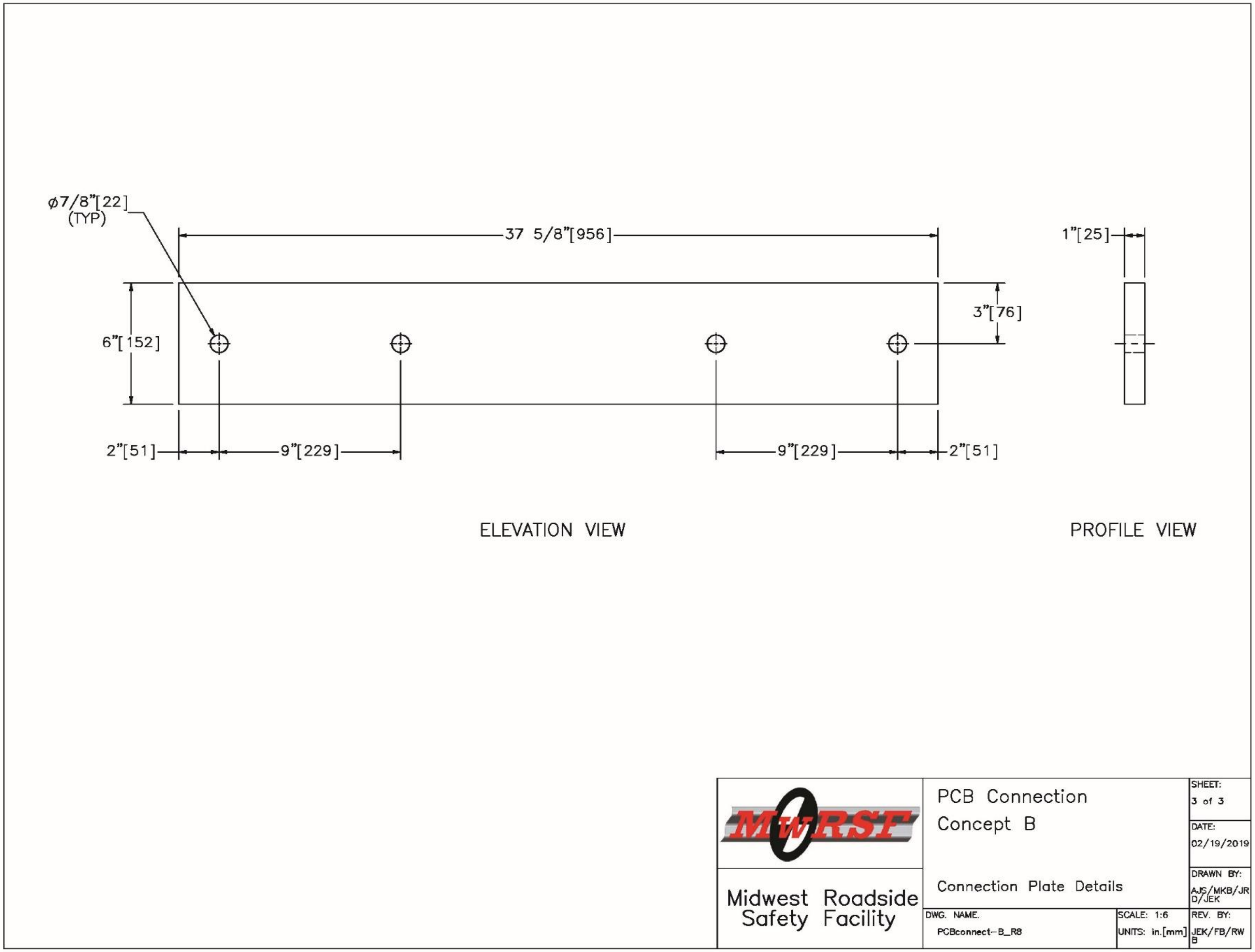


Figure 8. Design Concept B

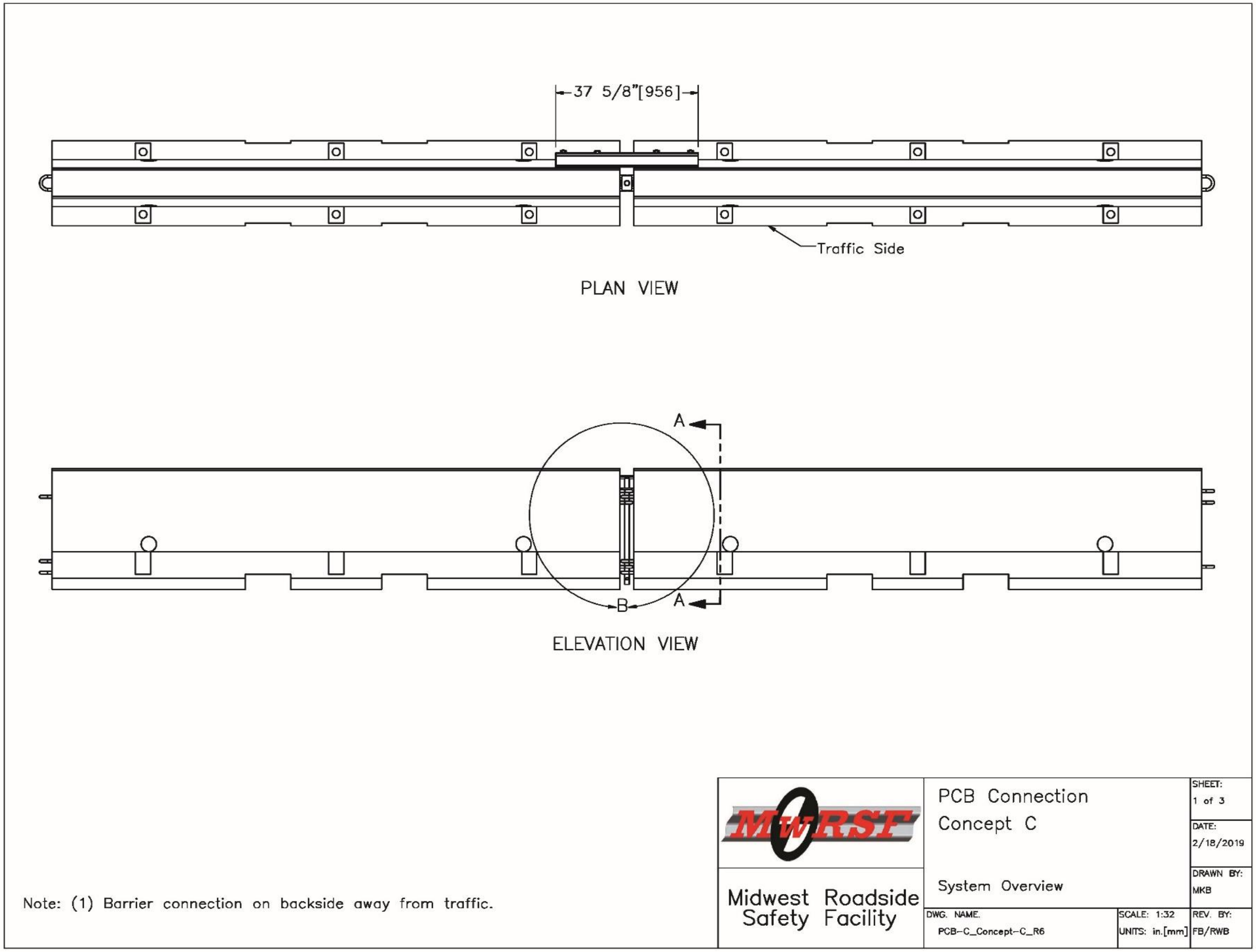


Figure 9. Design Concept C

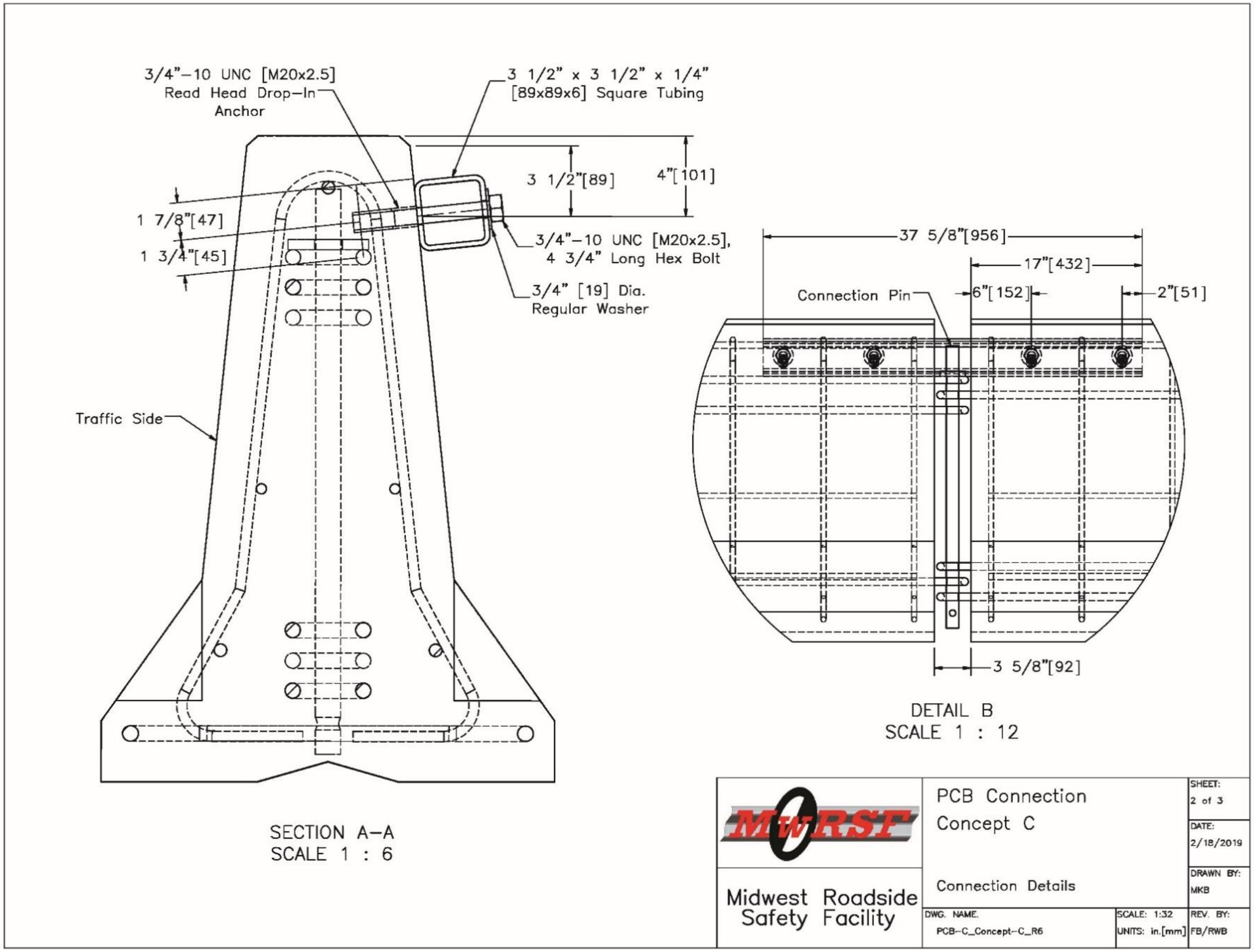


Figure 10. Design Concept C

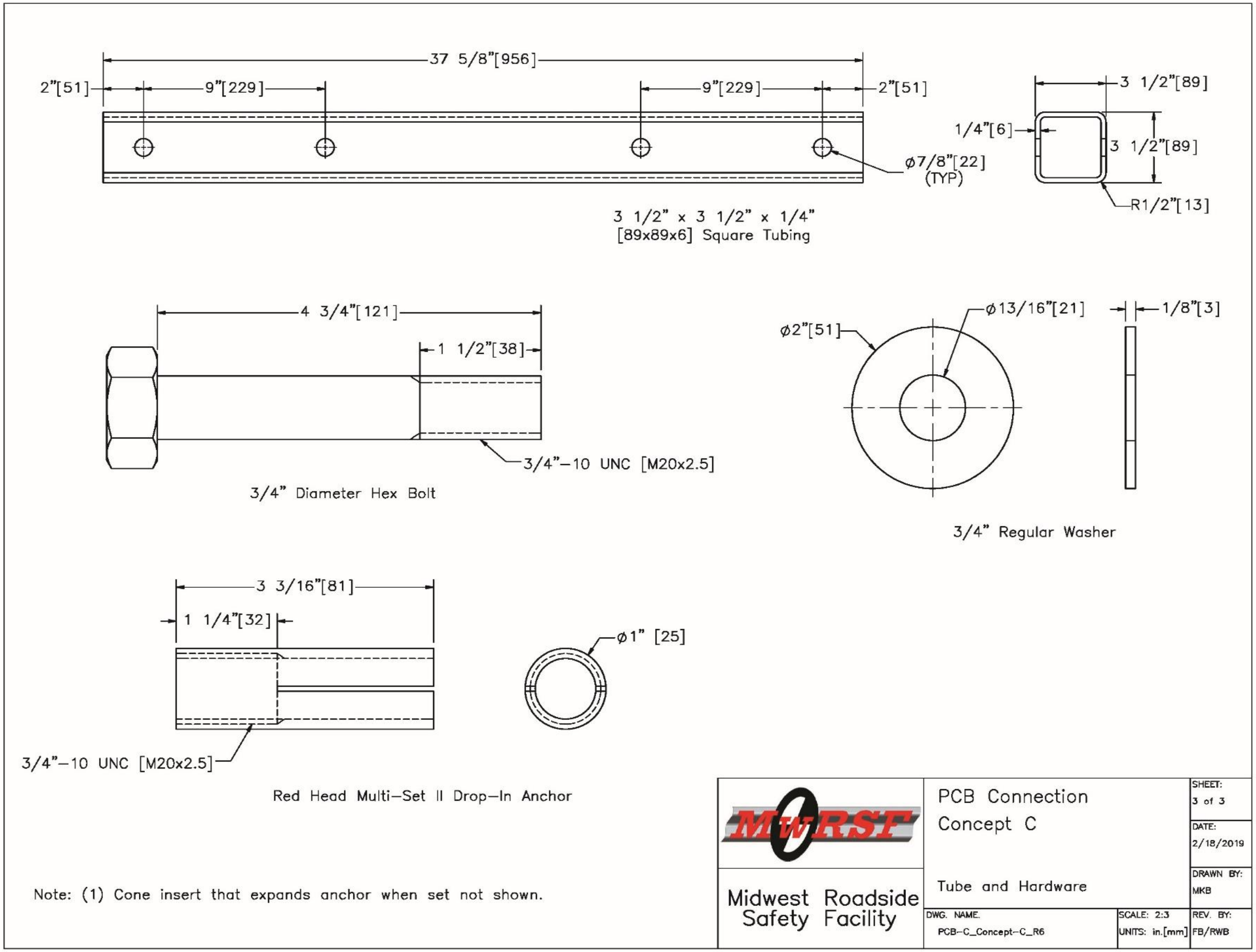


Figure 11. Design Concept C

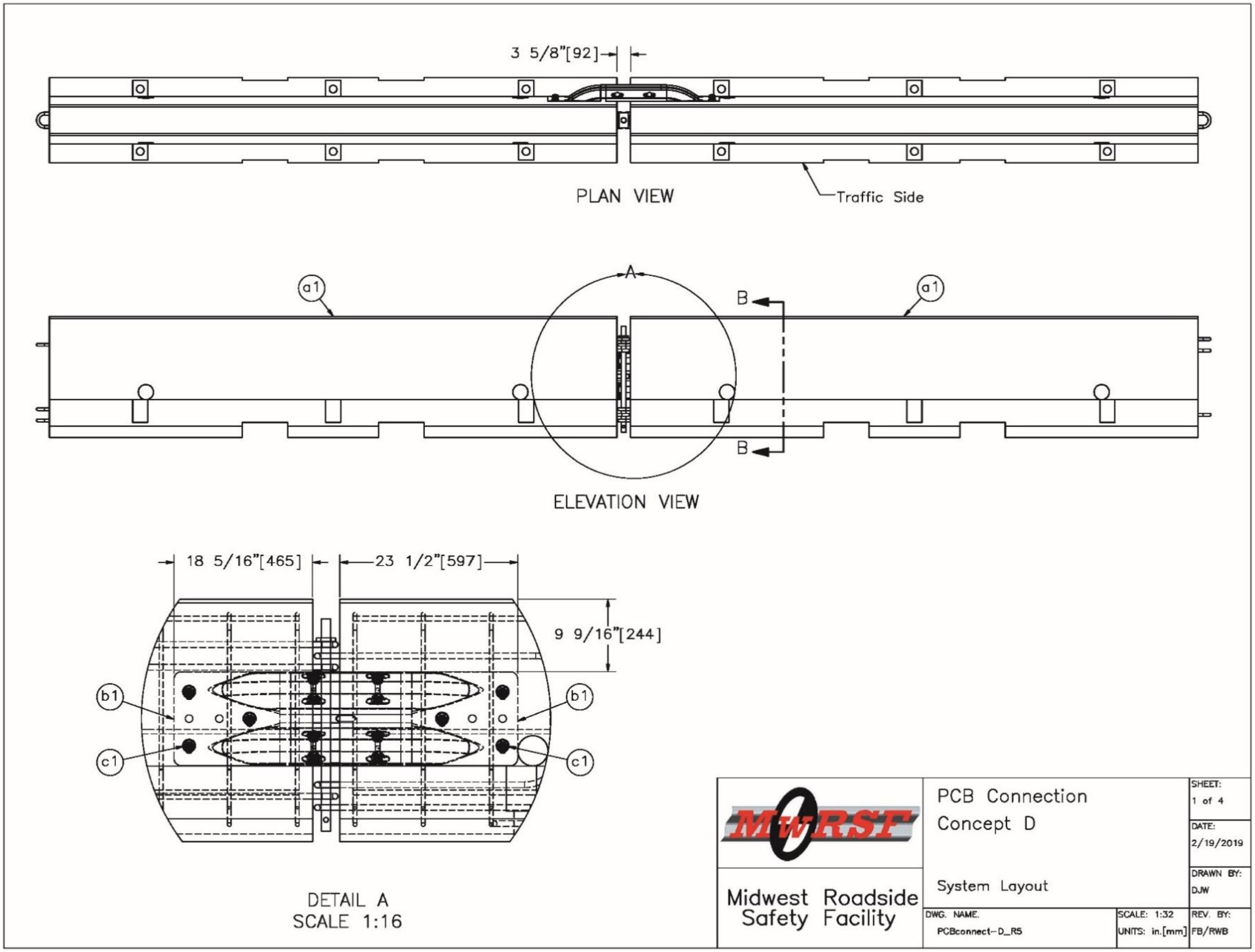


Figure 12. Design Concept D

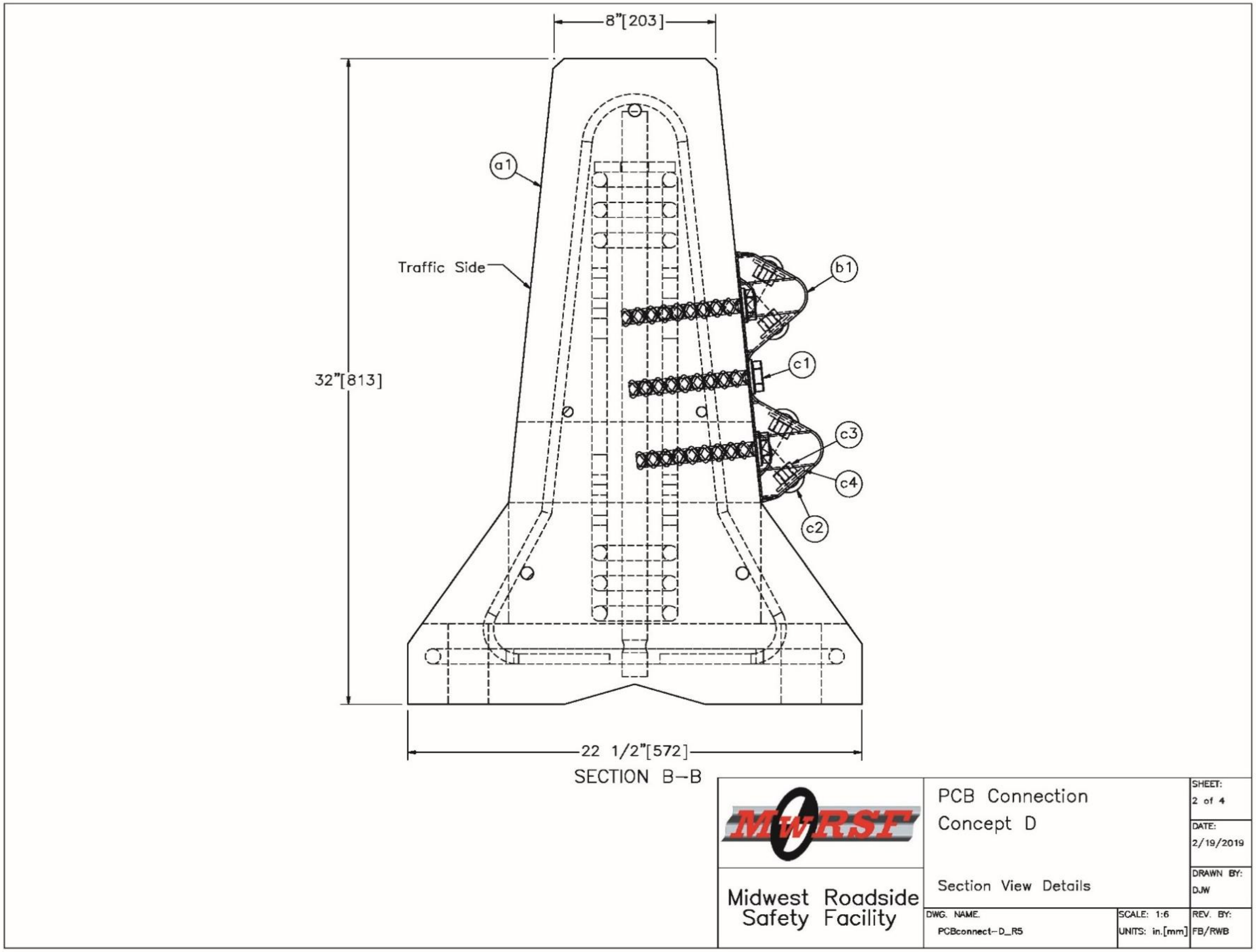


Figure 13. Design Concept D

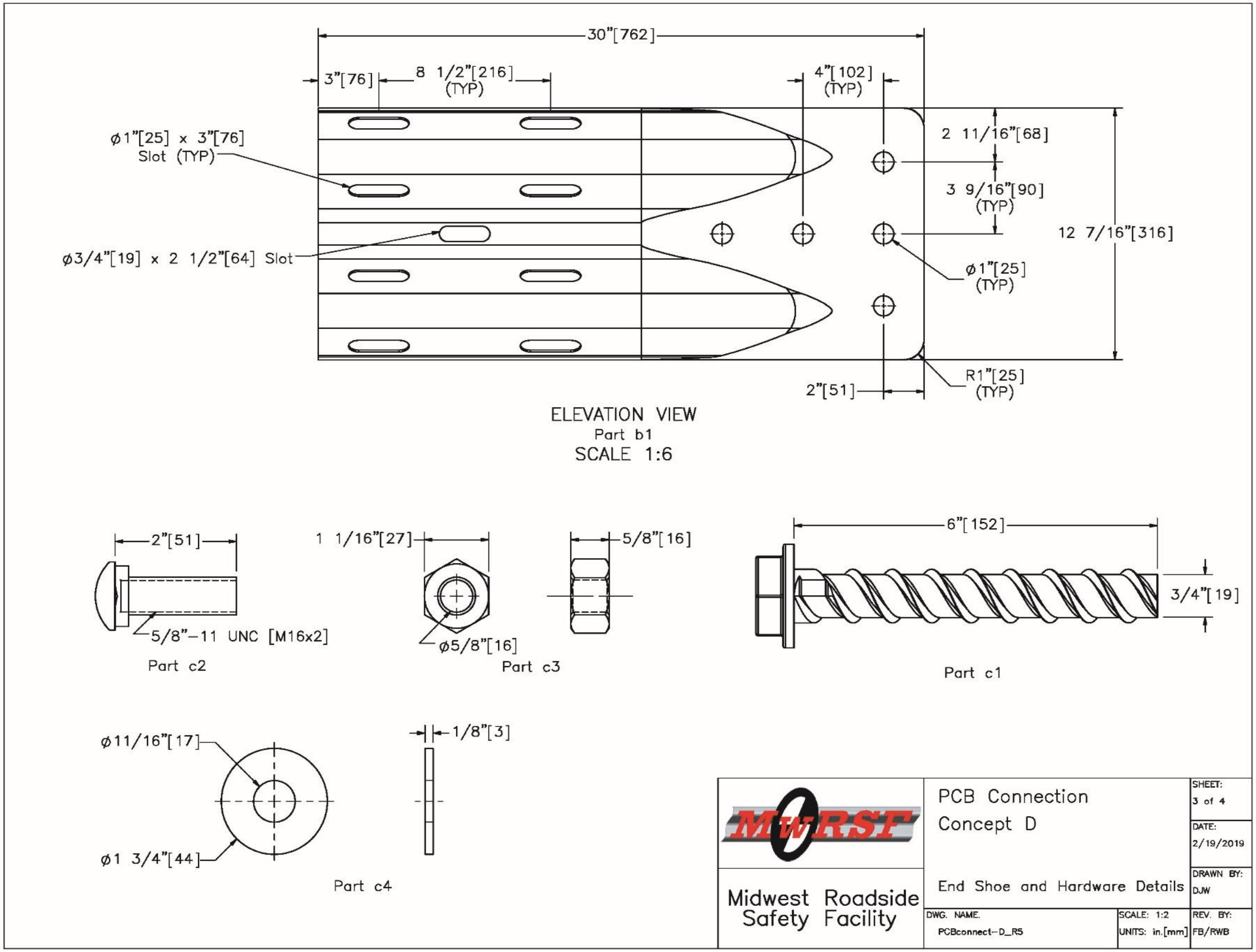


Figure 14. Design Concept D

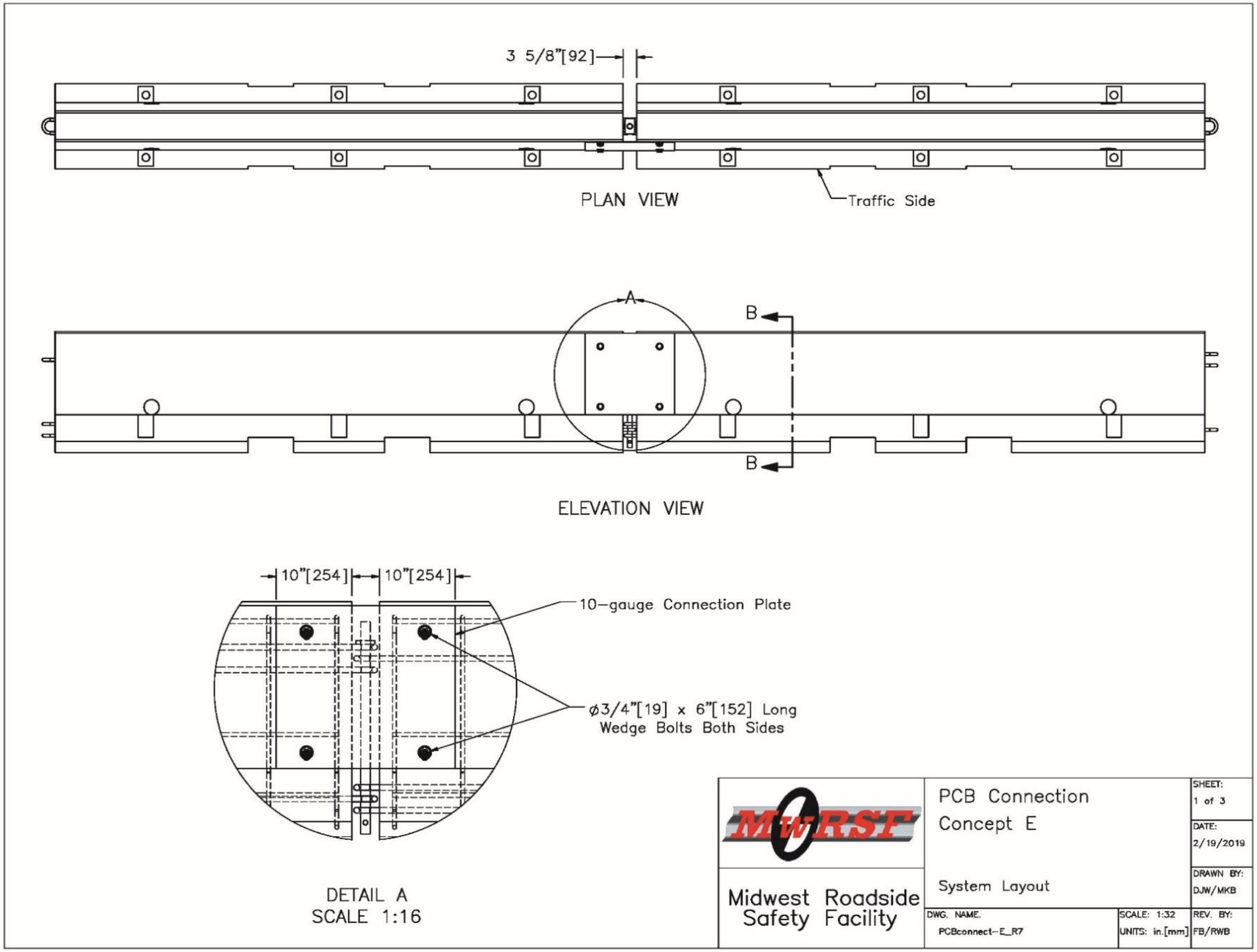


Figure 15. Design Concept E

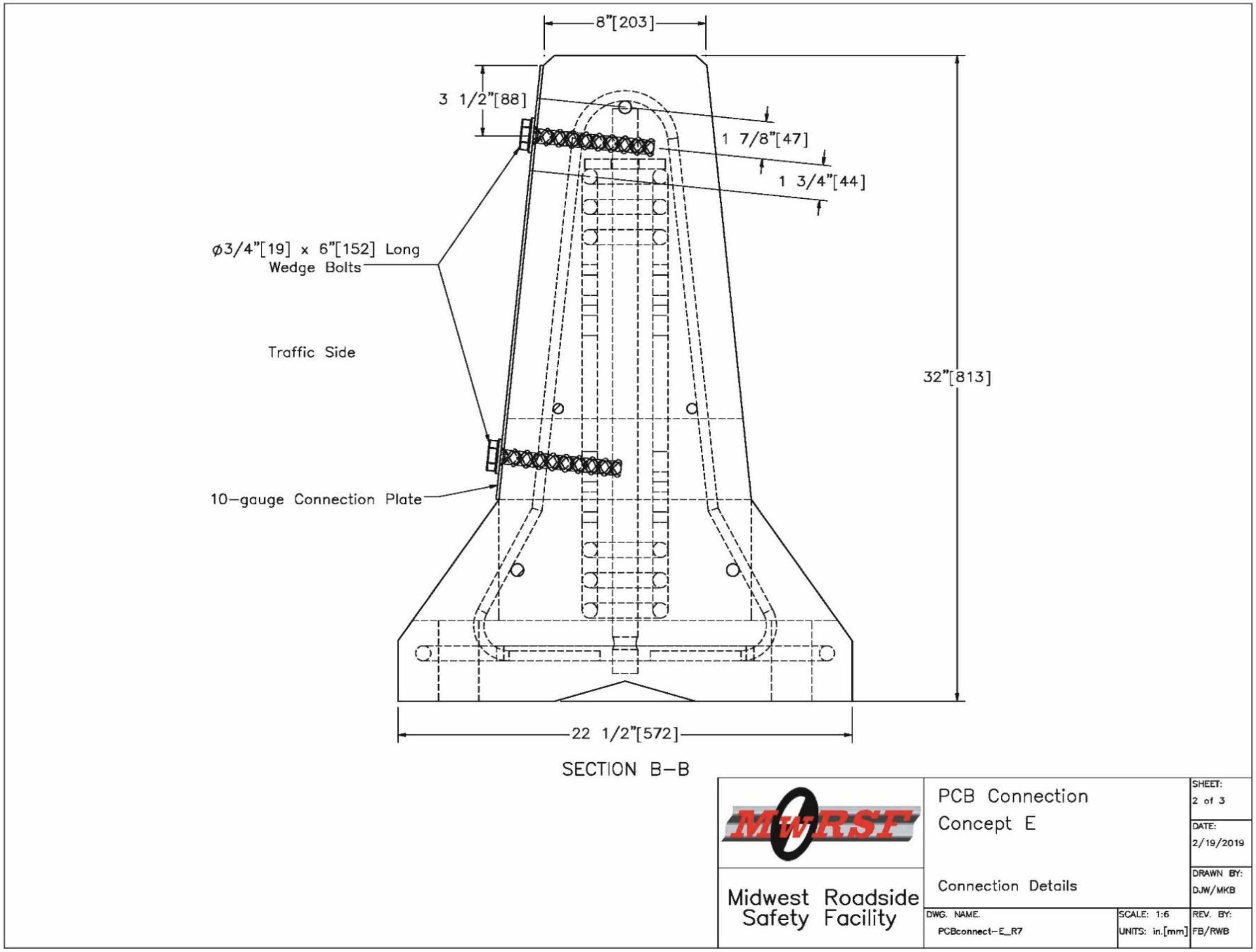


Figure 16. Design Concept E

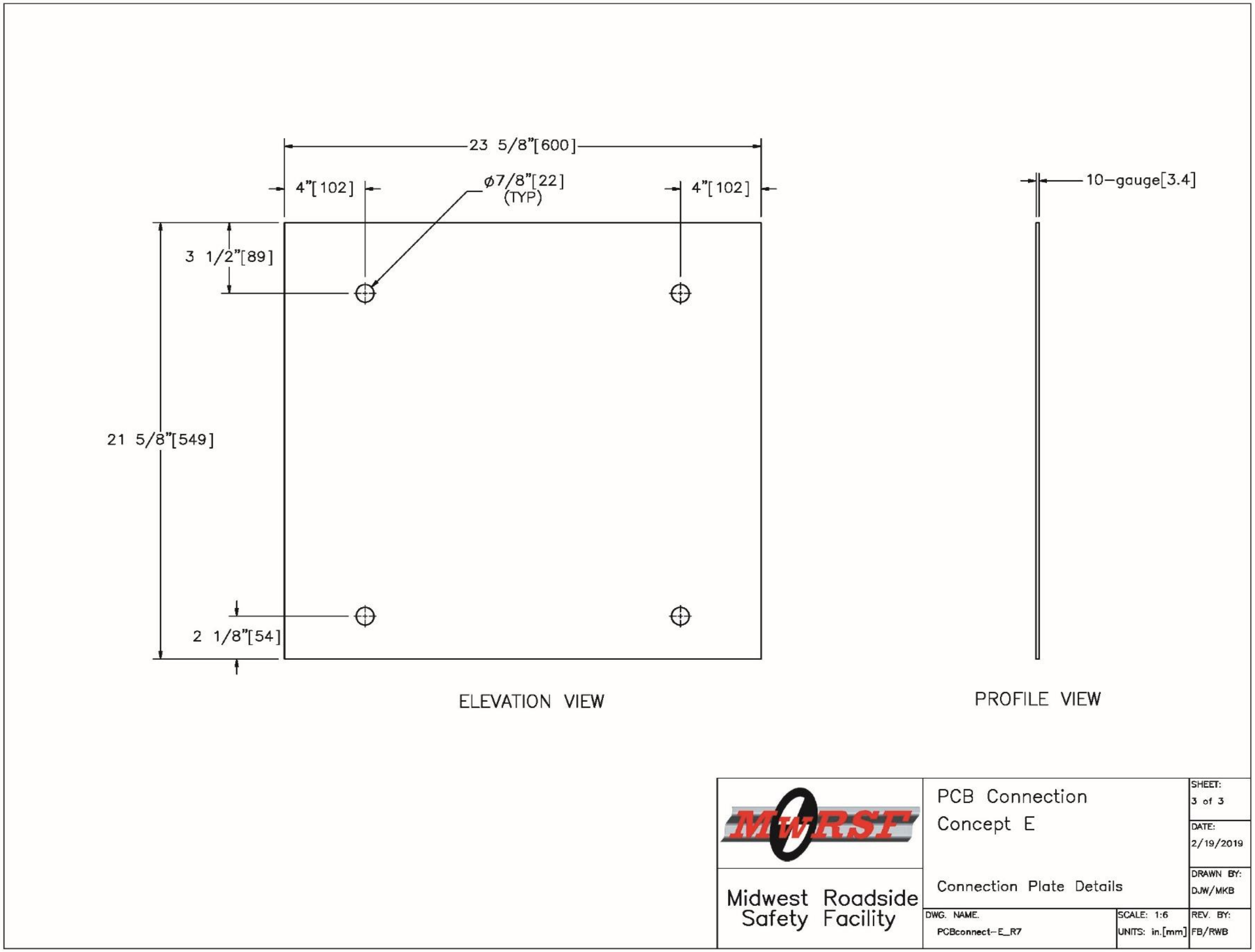


Figure 17. Design Concept E

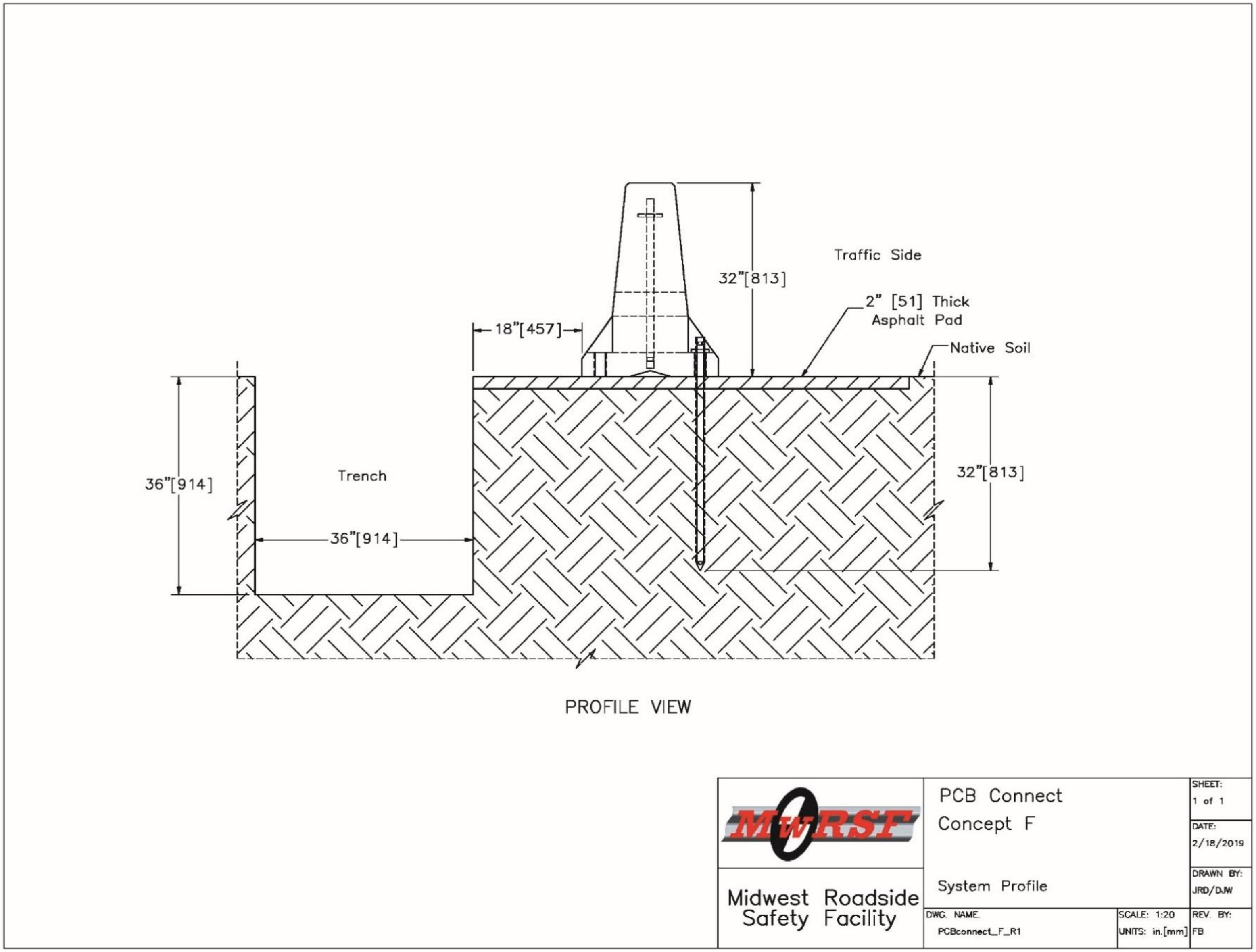


Figure 18. Design Concept F

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 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]. 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. However, only the 2270P crash test was deemed necessary, as other prior small car tests were used to support a decision to deem the 1100C crash test not critical.

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.

Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barriers

<table>
<tr><td>Structural Adequacy</td><td colspan="3">A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="9">Occupant Risk</td><td colspan="3">D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. 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 colspan="3">F. 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 colspan="3">H. 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 colspan="3">I. The Occupant Ride down 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 Ride down Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td></td><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

Only MASH test no. 3-11 was deemed critical for the evaluation of the F-shape PCB tie-down anchorage system for asphalt surfaces. Test no. 7069-3 [9, 10] performed under MASH TL-3 standards, 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 no. 3-10 was successfully conducted on a permanent New Jersey shape concrete parapet under NCHRP Project 22-14(2) [11]. 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. Another successful MASH test no. 3-10 crash test was conducted by the Texas A&M Transportation Institute (TTI) on a free-standing F-shape PCB similar to the barrier used in this study [12]. These 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. The anchored F-shape PCB evaluated in this study would be expected to perform similarly to these previous MASH 1100C vehicle tests in terms of capture and redirection. Therefore, test no. 3-10 with the 1100C vehicle was deemed non-critical for evaluation of the asphalt tie-down anchorage for use with F-shape PCBs. MASH 2016 test no. 3-11 was the critical evaluation test in terms of increased loading to the barrier and tie-down anchorages during 2270P impacts and the need to determine dynamic deflection and working width. Accordingly, only MASH test no. 3-11 was conducted on the anchored PCB systems evaluated in this research.

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 anchored PCB system. However, the recent switch to new vehicle types as part of the implementation of the MASH 2016 criteria and the limited 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.

3.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three factors: (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 test was 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.

3.3 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 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-3. For test no. WITD-3, the F-shape PCBs were placed on top of an asphalt pad that covered in-situ soil, and the PCBs were anchored with steel pins that passed through the barrier and into the asphalt and soil. This type of installation did not allow for a representative static soil test to be conducted in the critical area of the installation.

4 TEST CONDITIONS

4.1 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 five miles (8 km) northwest of the University of Nebraska-Lincoln.

4.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [13] was used to steer the test vehicles. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

4.3 Test Vehicle

For test no. WITD-3, a 2013 Dodge Ram 1500 quad cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,166 lb (2,343 kg), 5,011 lb (2,273 kg), and 5,180 lb (2,350 kg), respectively. The test vehicle is shown in Figures 19 and 20, and vehicle dimensions are shown in Figure 21.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [14] was used to determine the vertical component of the c.g. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The location of the final c.g. for test no. WITD-3 is shown in Figures 21 and 22. Data used to calculate the location of the c.g. and ballast information are shown in Appendix A.

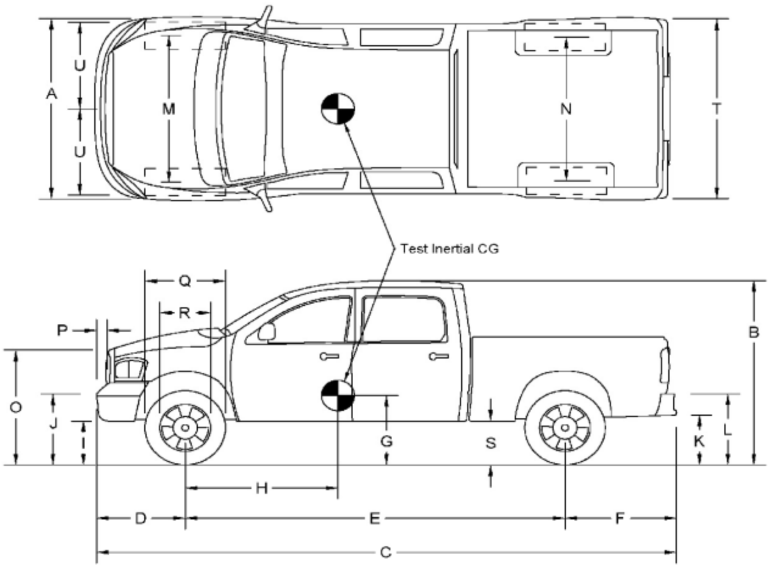
Square, black-and-white checkered targets were placed on the vehicle, as shown in Figure 22, to serve as reference in the high-speed digital video and aid in the video analysis. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicle.

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

Figure 19. Test Vehicle, Test No. WITD-3

Figure 20. Test Vehicle’s Pre-Test Interior Floorboards and Undercarriage, Test No. WITD-3

Date:	7/18/2019	Test Name:	WITD-3	VIN No:	1C6RR6FP2DS673555
Year:	2013	Make:	Dodge	Model:	Ram 1500
Tire Size:	265/70 R17	Tire Inflation Pressure:	40 psi	Odometer:	203314



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

A:	76 3/4 (1949) 78±2 (1950±50)	B:	74 1/4 (1886)
C:	229 3/8 (5826) 237±13 (6020±325)	D:	41 (1041) 39±3 (1000±75)
E:	141 1/8 (3585) 148±12 (3760±300)	F:	47 1/4 (1200)
G:	28 3/8 (721) min: 28 (710)	H:	61 1/2 (1562) 63±4 (1575±100)
I:	13 1/2 (343)	J:	25 1/4 (641)
K:	20 1/2 (521)	L:	28 1/2 (724)
M:	68 3/8 (1737) 67±1.5 (1700±38)	N:	67 3/4 (1721) 67±1.5 (1700±38)
O:	45 (1143) 43±4 (1100±75)	P:	3 (76)
Q:	31 (787)	R:	18 1/2 (470)
S:	15 3/8 (391)	T:	76 1/2 (1943)

U (impact width): 36 1/2 (927)

Mass Distribution - lb (kg)

Gross Static	LF	1443 (655)	RF	1487 (674)
	LR	1126 (511)	RR	1124 (510)

Wheel Center Height (Front):	15 1/4 (387)
Wheel Center Height (Rear):	15 1/2 (394)
Wheel Well Clearance (Front):	35 1/8 (892)
Wheel Well Clearance (Rear):	37 5/8 (956)
Bottom Frame Height (Front):	12 1/2 (318)
Bottom Frame Height (Rear):	13 (330)
Engine Type:	Gasoline
Engine Size:	V6
Transmission Type:	Automatic
Drive Type:	RWD
Cab Style:	Quad Cab
Bed Length:	76"

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2907 (1319)	2827 (1282)	2930 (1329)
W-rear	2259 (1025)	2184 (991)	2250 (1021)
W-total	5166 (2343)	5011 (2273) 5000±110 (2270±50)	5180 (2350) 5165±110 (2343±50)

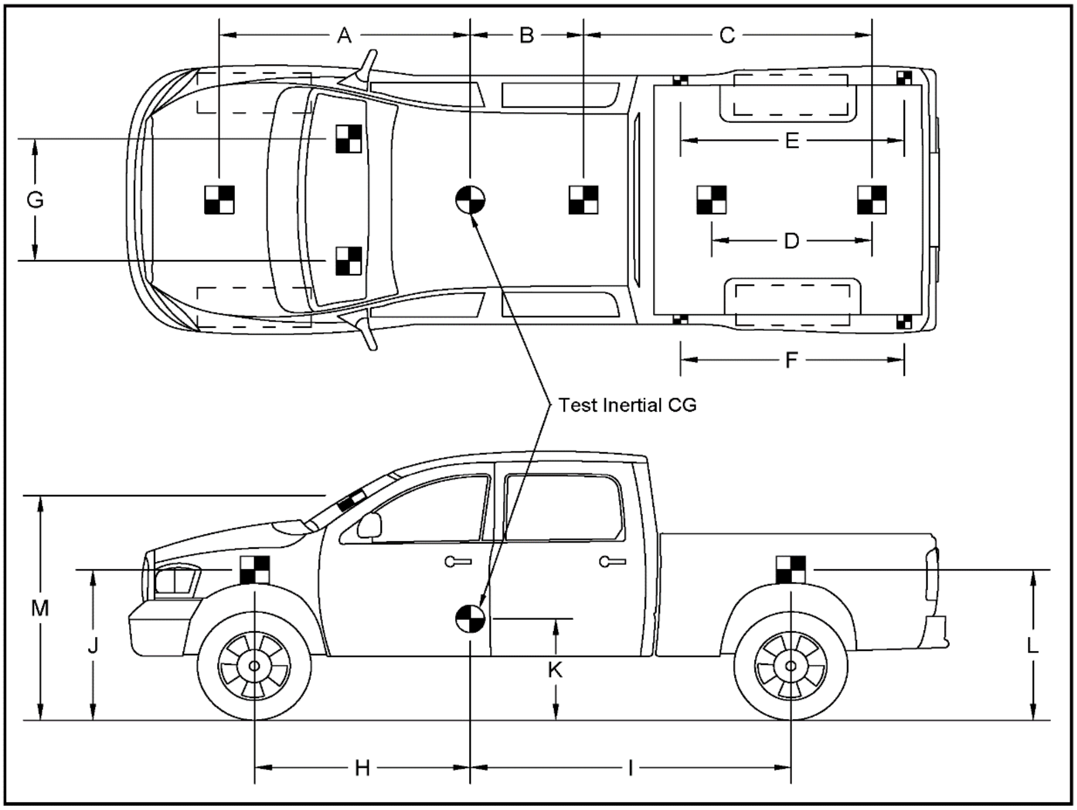
GVWR Ratings - lb	
Front	3700
Rear	3900
Total	6700

Surrogate Occupant Data	
Type:	Hybrid II
Mass:	169 lb
Seat Position:	Right/Passenger

Note any damage prior to test:

Figure 21. Vehicle Dimensions, Test No. WITD-3

Date:	7/18/2019	Test Name:	WITD-3	VIN:	1C6RR6FP2DS673555
Year:	2013	Make:	Dodge	Model:	Ram 1500



TARGET GEOMETRY-- in. (mm)

A:	67 13/16 (1722)	E:	66 3/4 (1695)	J:	39 1/4 (997)
B:	27 (686)	F:	66 3/4 (1695)	K:	28 1/4 (718)
C:	82 3/8 (2092)	G:	27 (686)	L:	41 7/8 (1064)
D:	53 1/2 (1359)	H:	61 3/4 (1568)	M:	64 3/4 (1645)
		I:	79 5/8 (2022)		

Figure 22. Target Geometry, Test No. WITD-3

4.4 Simulated Occupant

For test no. WITD-3, A Hybrid II 50th-Percentile, Adult Male Dummy equipped with footwear was placed in the right-front seat of the test vehicle with the seat belt fastened. The dummy had a final weight of 169 lb (76.7 kg). As recommended by MASH 2016, the simulated occupant weight was not included in calculating the c.g. location.

4.5 Data Acquisition Systems

4.5.1 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 vehicle. 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 [15].

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

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

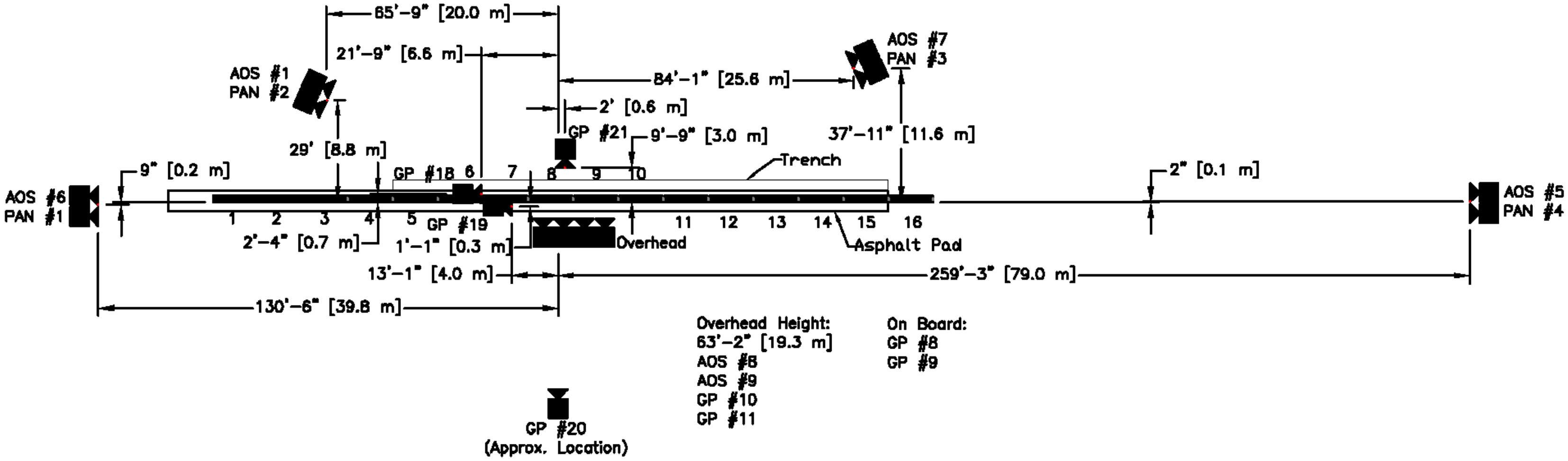
4.5.3 Retroreflective Optic Speed Trap

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

4.5.4 Digital Photography

Six AOS high-speed digital video cameras, eight GoPro digital video cameras, and four Panasonic digital video cameras were utilized to film test no. WITD-3. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 23.

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 the test.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam	500	Minolta 70-210	70
AOS-5	AOS X-PRI	500	100 mm fixed	
AOS-6	AOS X-PRI	500	Sigma 28-70 #1	35
AOS-7	AOS X-PRI	500	Sigma 28-70 #2	35
AOS-8	AOS S-VIT 1531	500	KOWA 16 min Fixed	
AOS-9	AOS TRI-VIT 2236	500	KOWA 12 mm Fixed	
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	120		
GP-11	GoPro Hero 4	240		
GP-18	GoPro Hero 6	240		
GP-19	GoPro Hero 6	240		
GP-20	GoPro Hero 6	240		
GP-21	GoPro Hero 6	240		
PAN-1	Panasonic HC-V770	120		
PAN-2	Panasonic HC-V770	120		
PAN-3	Panasonic HC-V770	120		
PAN-4	Panasonic HC-V770	120		

Figure 23. Camera Locations, Speeds, and Lens Settings, Test No. WITD-3

5 DESIGN DETAILS

The test installation consisted of sixteen 12-ft 6-in. (3.8-m) long Wisconsin Department of Transportation PCBs with a steel pin tie-down anchorage system for use with asphalt surfaces, as shown in Figures 24 through 34. The system was installed with the rear toe of the PCBs placed 18 in. (457 mm) away from the edge of both a 2-in. (51-mm) thick asphalt pad and the 36-in. (914-mm) wide x 36-in. (914-mm) deep trench. Photographs of the test installation are shown in Figures 36 and 37. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix B.

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 for all reinforcement. Each PCB was reinforced with ASTM A615 Grade 60 rebar. The barrier sections used a connection pin, as shown in Figure 28. 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 A709 Grade 70 connection loop bars, as shown in Figures 28 and 29.

The barrier installation was placed on top of a 2-in. (51-mm) thick asphalt pad composed of NE SPR Mix with 64-34 Grade binder. Barrier nos. 5 through 13 were each anchored to the ground surface through the bolt anchor pockets on the traffic-side with three 1½-in. (38-mm) diameter by 38½-in. (978-mm) long, ASTM A36 steel anchor pins driven through the 2-in. (51-mm) thick asphalt pad and into the underlying soil, as shown in Figures 24 and 25, as well as in Figures 27 and 28. 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, steel anchor pins were embedded to a depth of 32 in. (813 mm), as shown in Figures 25 and 28.

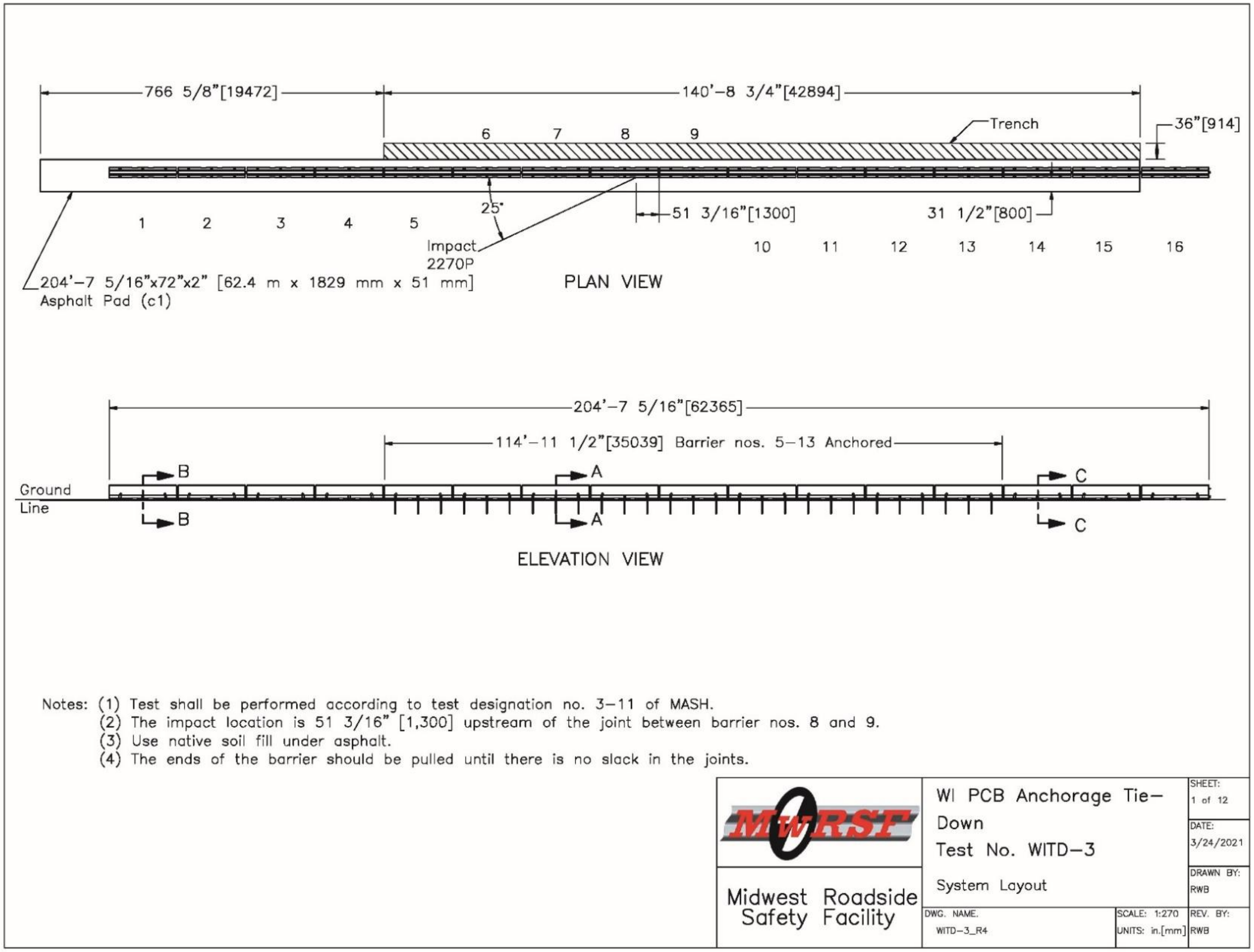


Figure 24. System Layout, Test No. WITD-3

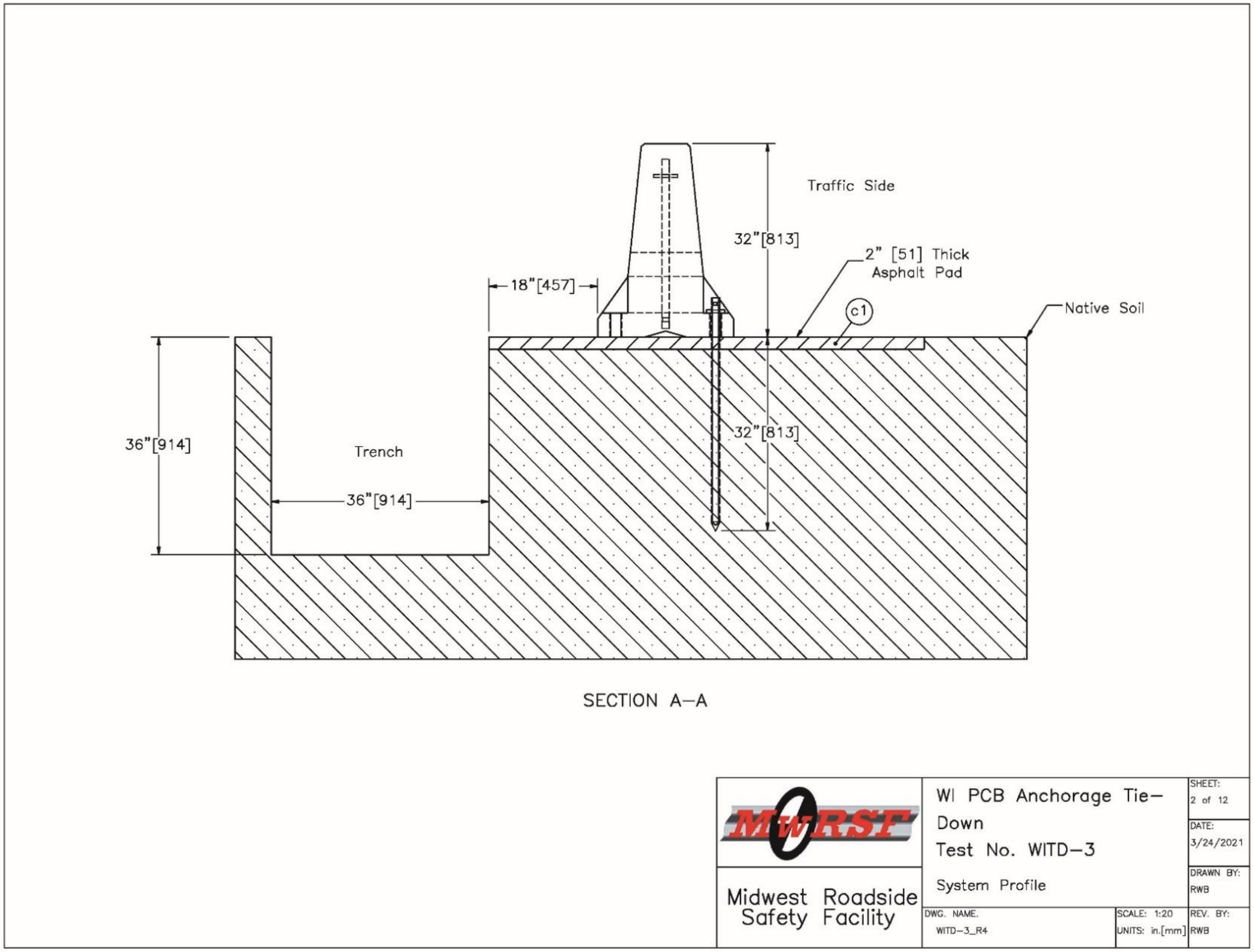


Figure 25. System Profile, Test No. WITD-3

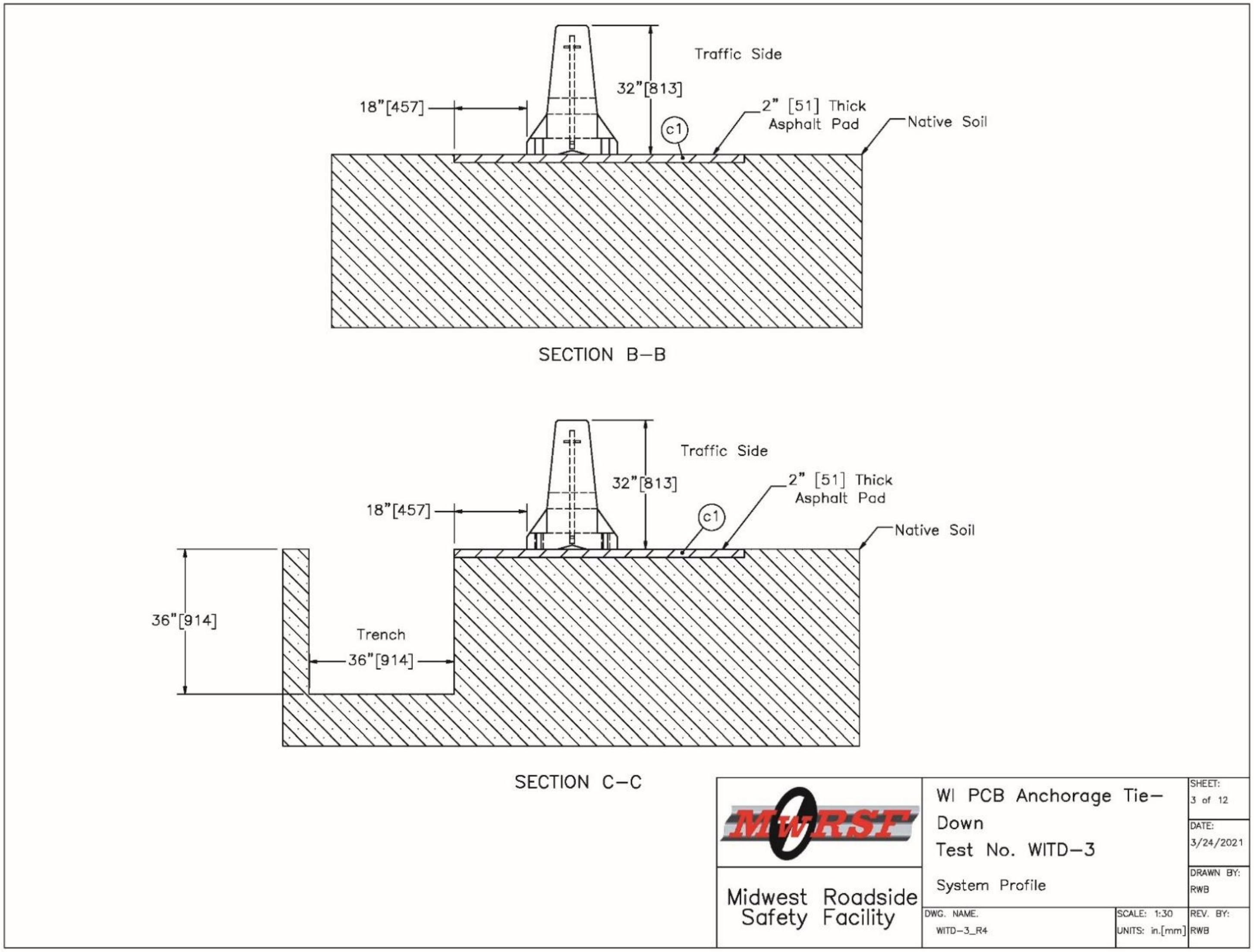


Figure 26. System Profile, Test No. WITD-3

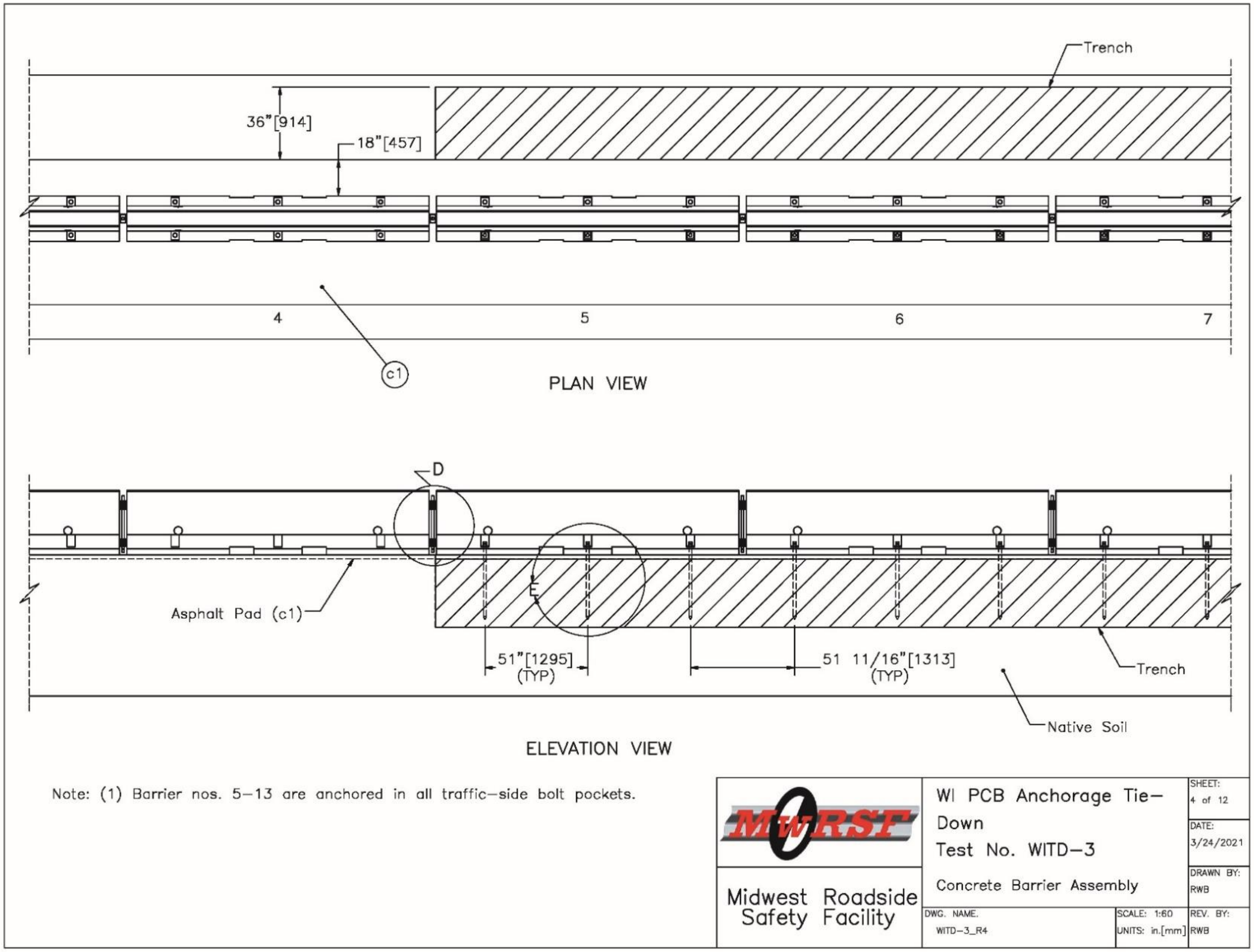


Figure 27. Concrete Barrier Assembly, Test No. WITD-3

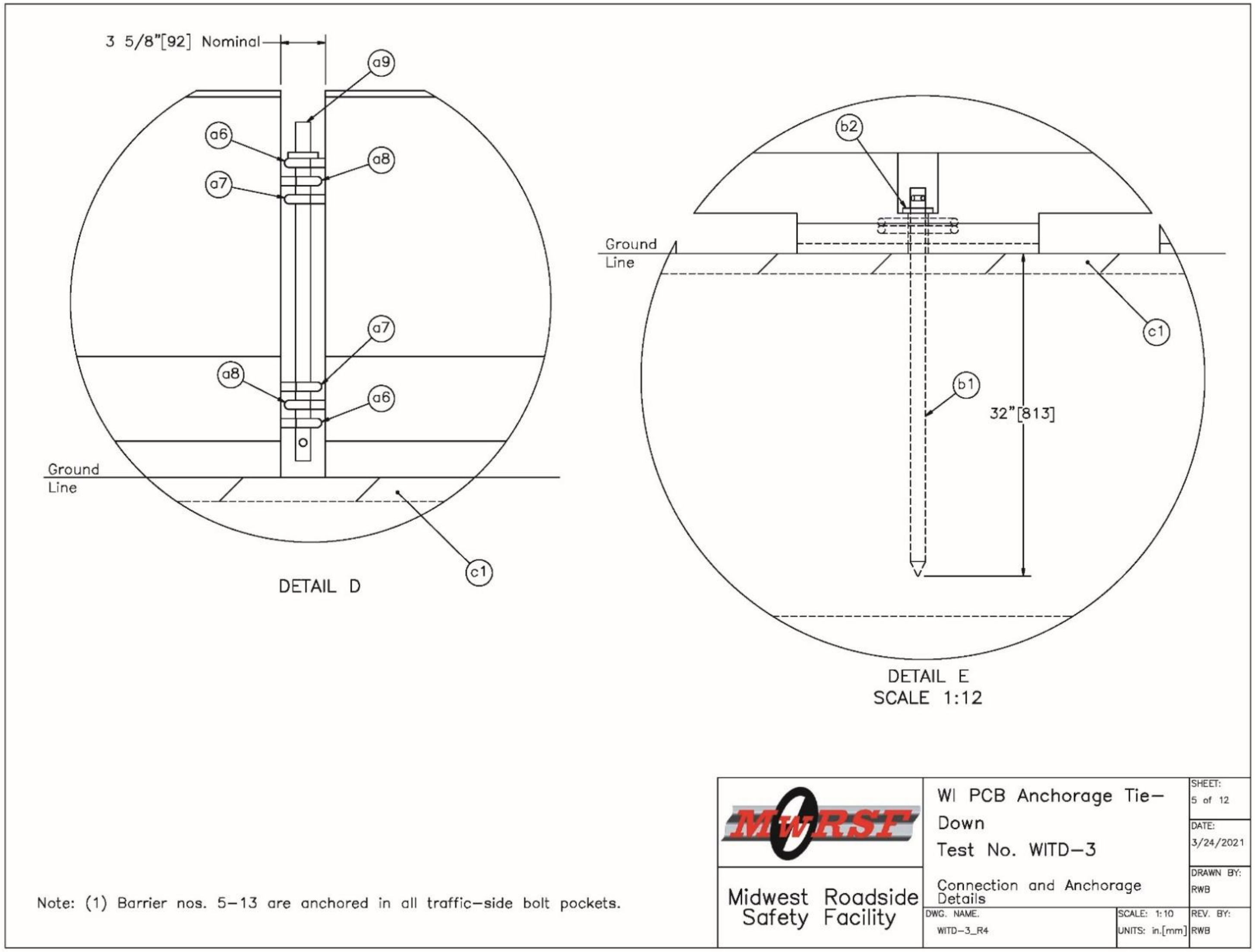


Figure 28. Connection and Anchorage Details, Test No. WITD-3

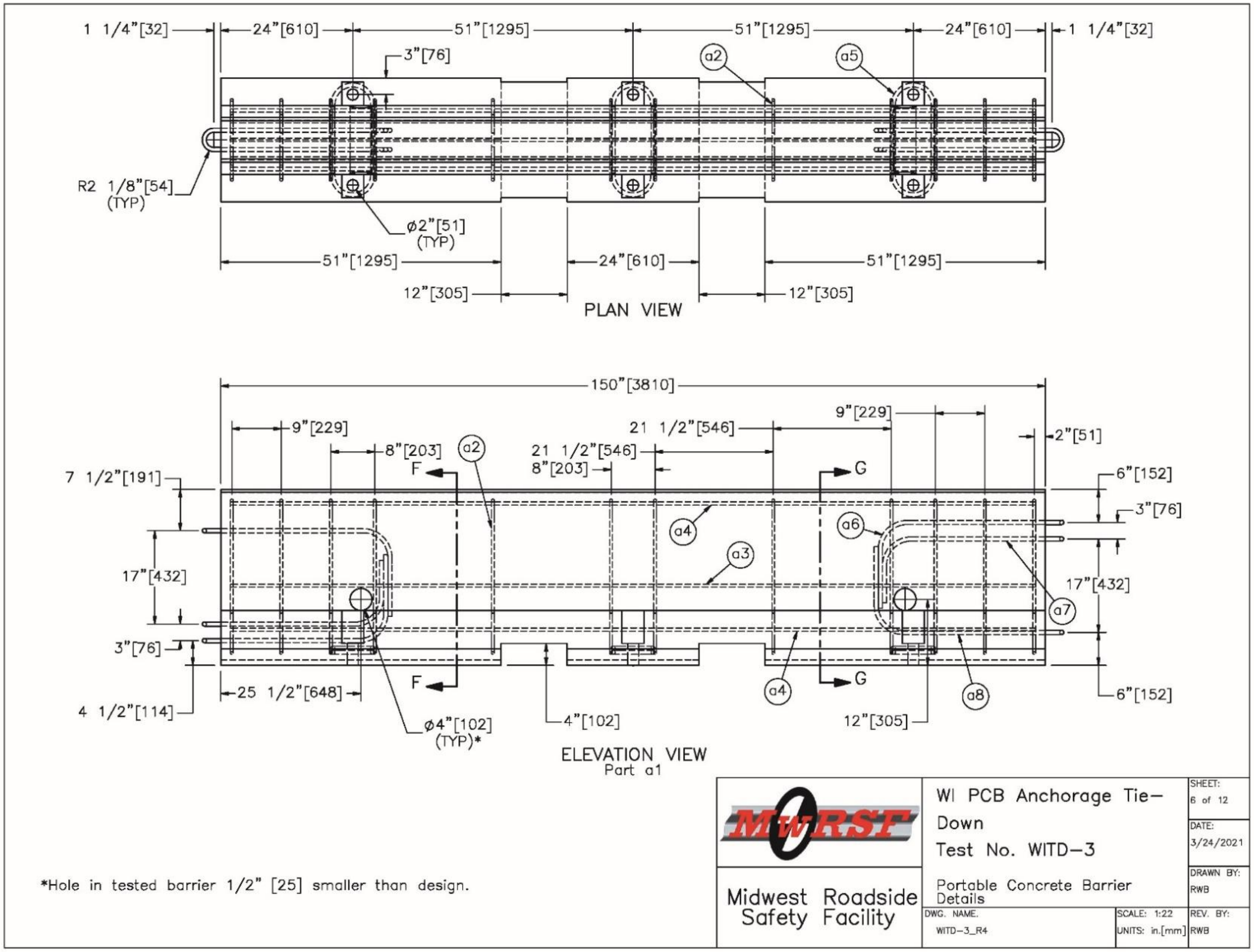


Figure 29. PCB Details, Test No. WITD-3

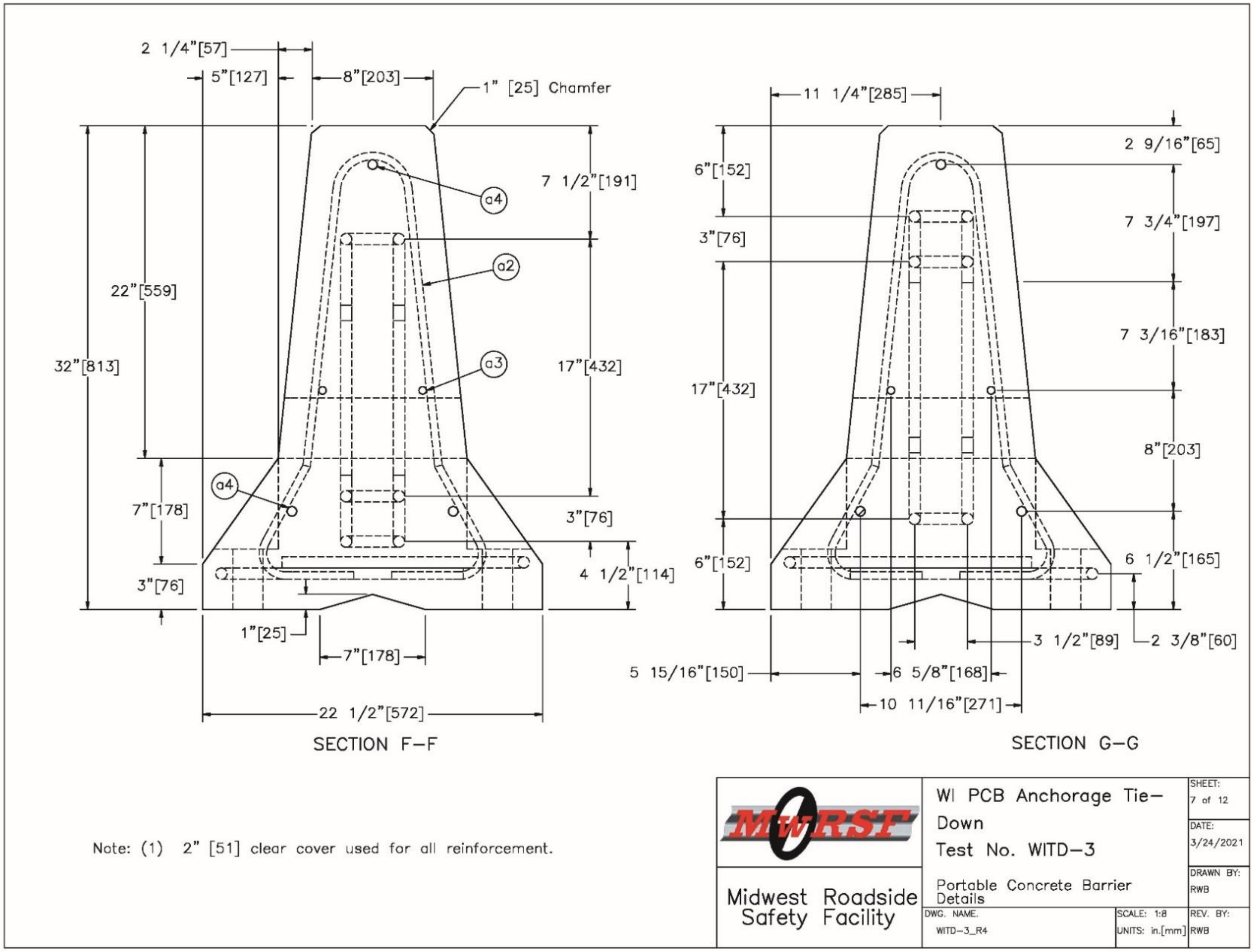
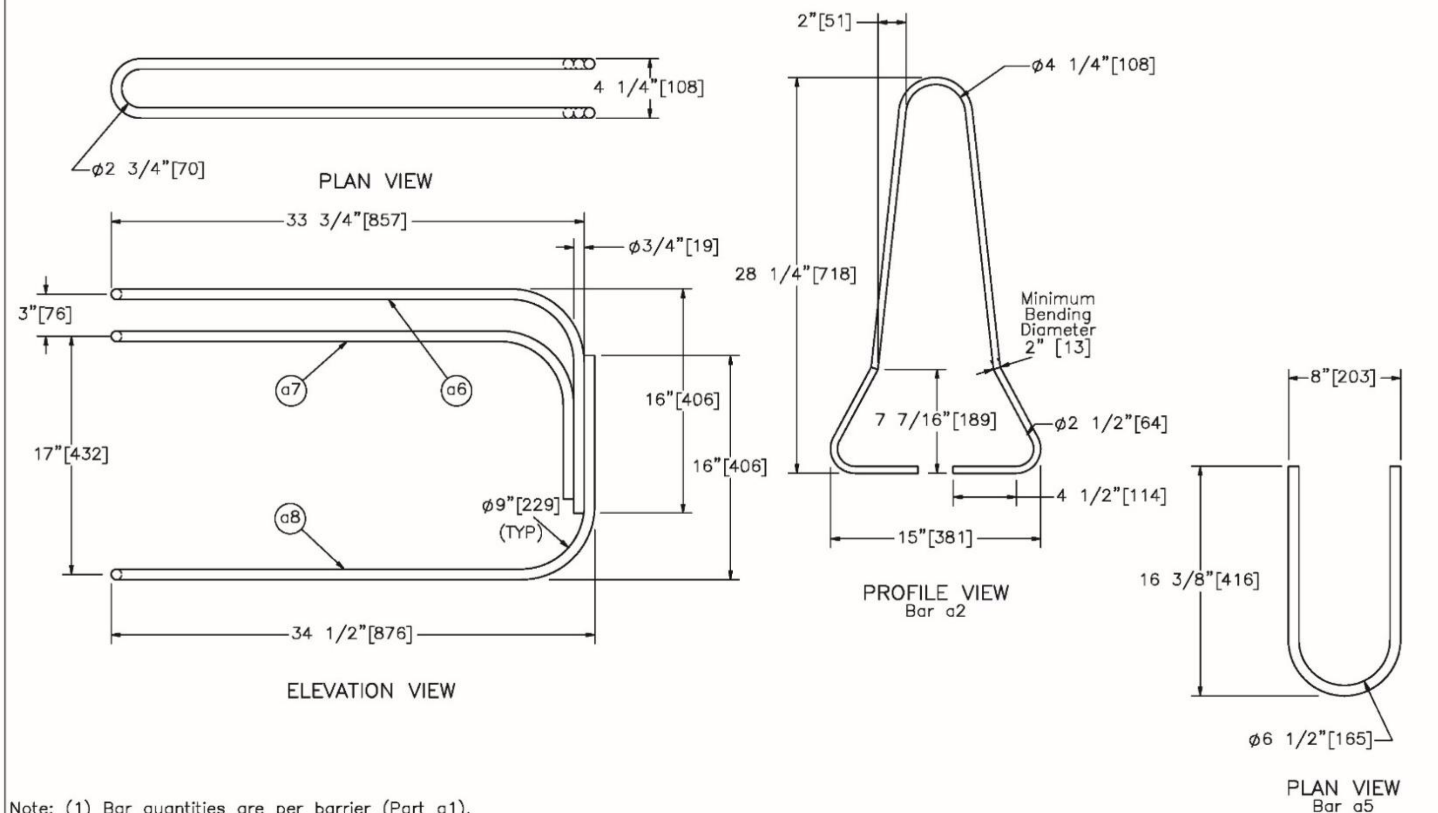


Figure 30. PCB Details, Test No. WITD-3



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-3
Portable Concrete Barrier Rebar Details

SHEET: 8 of 12
DATE: 3/24/2021
DRAWN BY: RWB
DWG. NAME. WITD-3_R4
SCALE: 1:10
UNITS: in.[mm]
REV. BY: RWB

Figure 31. PCB Rebar Details, Test No. WITD-3

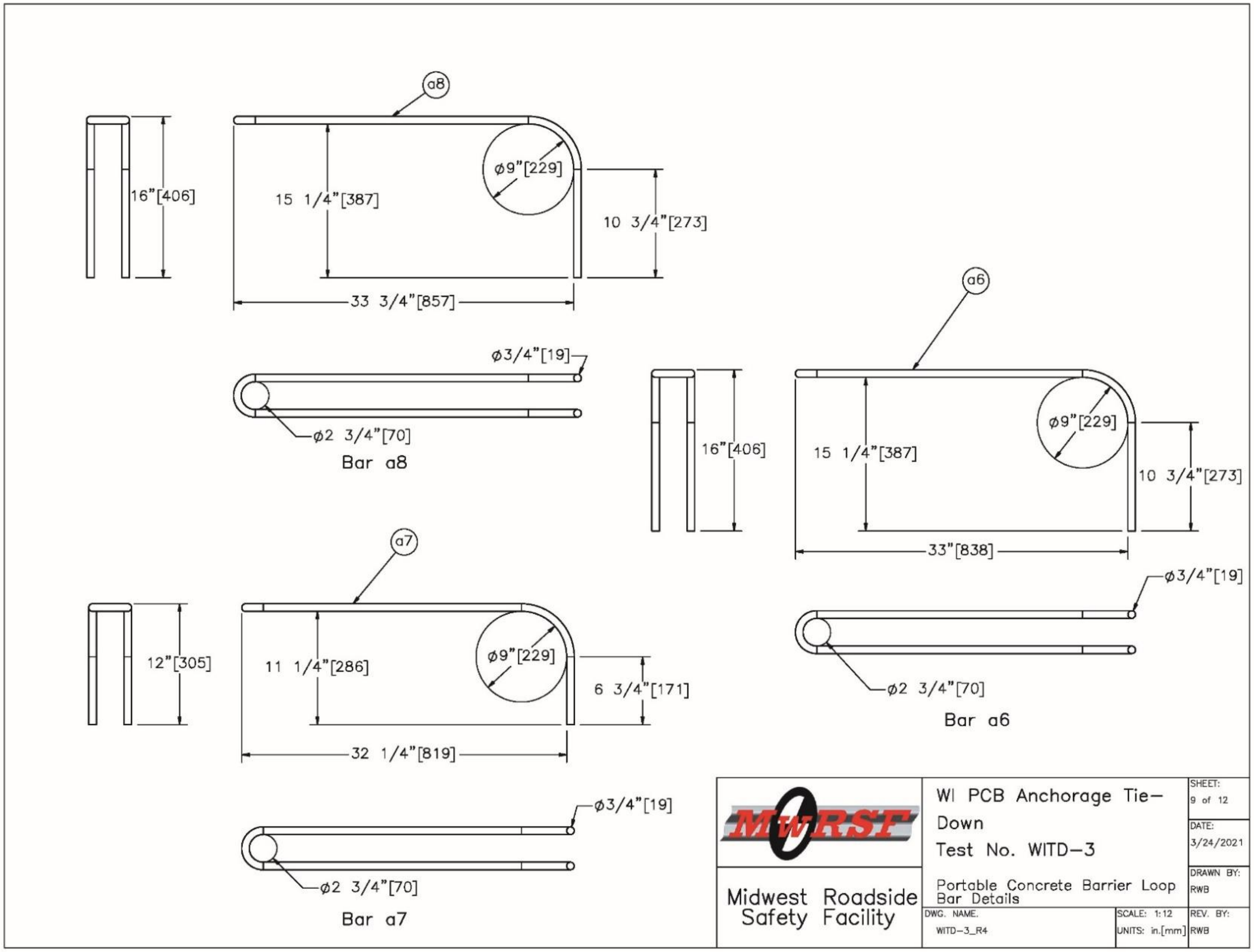


Figure 32. PCB Loop Bar Details, Test No. WITD-3

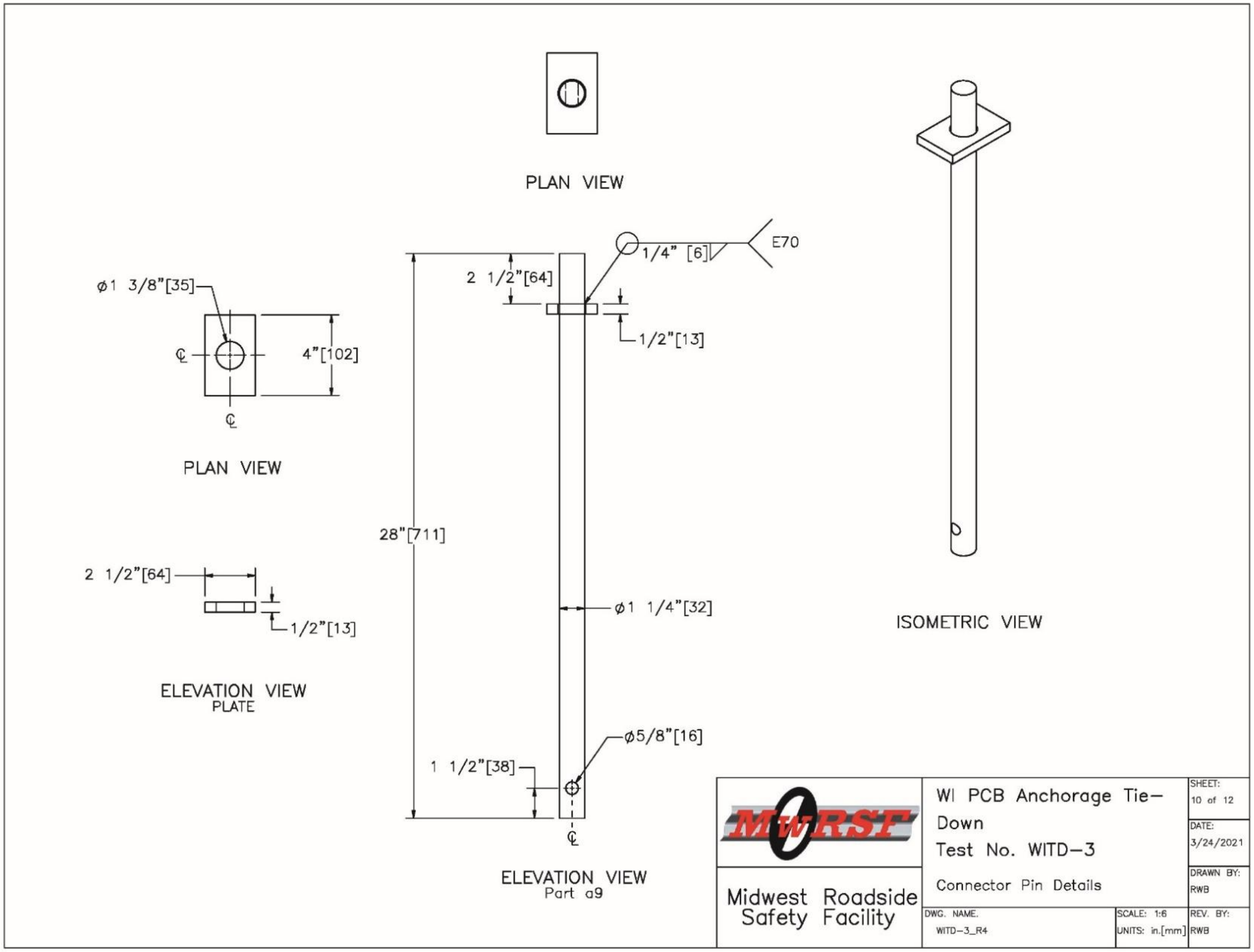


Figure 33. Connector Pin Details Test No. WITD-3

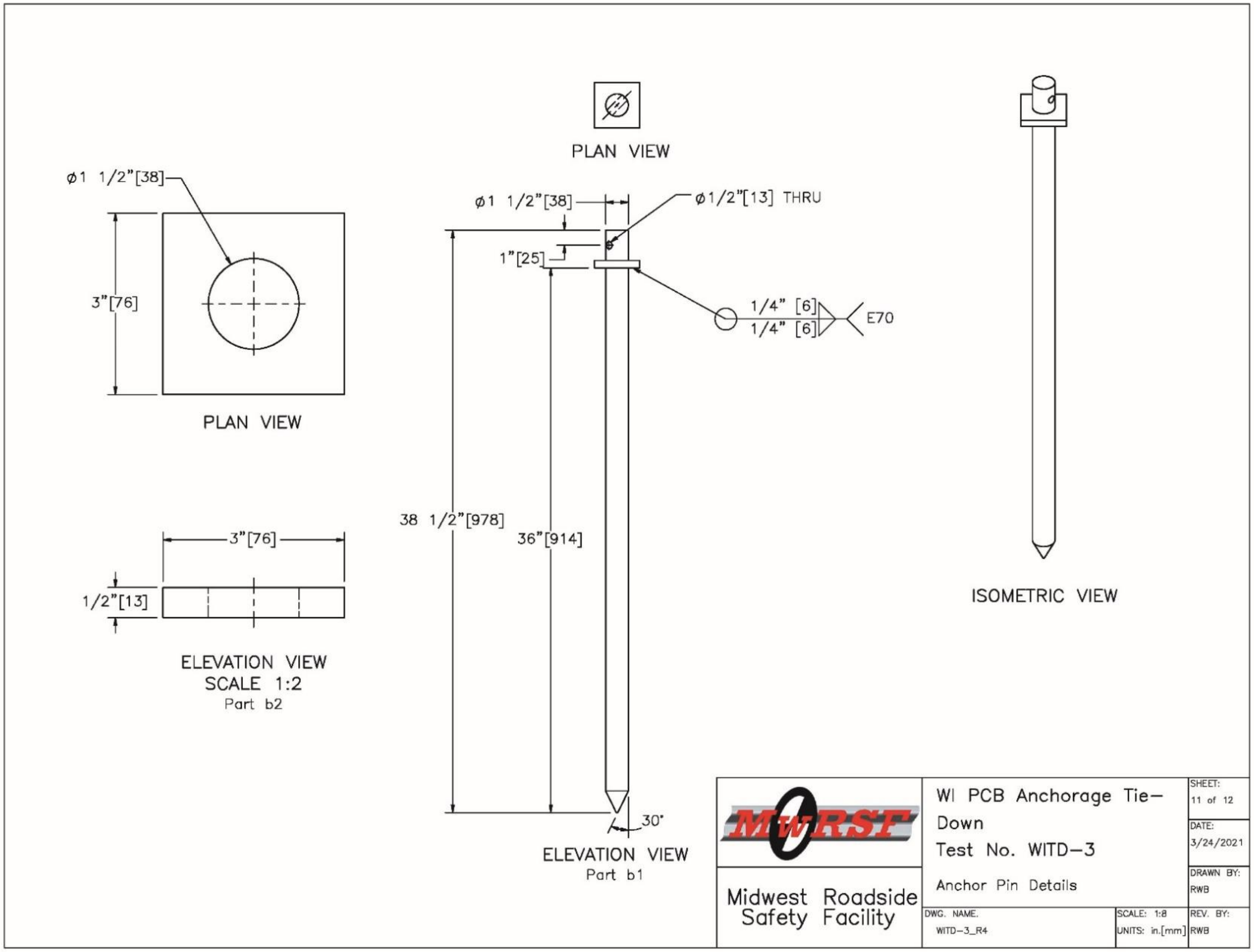


Figure 34. Anchor Pin Details, Test No. WITD-3

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 SPR Mix with 64–34 Grade Binder	–	–

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

Midwest Roadside Safety Facility	WI PCB Anchorage Tie–Down Test No. WITD–3	SHEET: 12 of 12
		DATE: 3/24/2021
	Bill of Materials	DRAWN BY: RWB
	DWG. NAME. WITD–3_R4	SCALE: None UNITS: in.[mm]
		REV. BY: RWB

Figure 35. Bill of Materials, Test No. WITD-3

Figure 36. Test Installation Photographs, Test No. WITD-3

Figure 37. Test Installation Photographs, Connection and Anchor Pin Details, Test No. WITD-3

6 FULL-SCALE CRASH TEST NO. WITD-3

6.1 Weather Conditions

Test no. WITD-3 was conducted on July 18, 2019 at approximately 11:45 a.m. The weather conditions as reported by the National Oceanic and Atmospheric Administration (station 14939/LNK) are shown in Table 3.

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

Temperature	93°F
Humidity	52%
Wind Speed	20 mph
Wind Direction	200° from True North
Sky Conditions	Clear
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.33 in.
Previous 7-Day Precipitation	0.35 in.

6.2 Test Description

Initial vehicle impact was to occur 51³⁄₁₆ in. (1,300 mm) upstream from the centerline of the joint between barrier nos. 8 and 9, as shown in Figure 38, which was selected using Table 2.7 of MASH 2016. The 5,011-lb (2,273-kg) quad cab pickup truck impacted the anchored PCB system at a speed of 61.9 mph (99.6 km/h) and at an angle of 25.1 degrees. The actual point of impact was 48.3 in. (1,227 mm) upstream from the centerline of the joint between barrier nos. 8 and 9. During the test, the vehicle was captured and redirected by the anchored, F-shape PCB system. As the vehicle was redirected, right front wheel of the vehicle climbed the toe of the F-shape PCB and displaced barrier no. 8 laterally prior to the vehicle reaching the upstream end of barrier no. 9. At approximately 70 to 90 msec after impact, the right front wheel snagged on the upstream face of barrier segment no. 9. The snag was sufficient to push the right-front wheel backwards into the floor pan of the vehicle and damage the joint between barrier nos. 8 and 9. The displacement of the right-front wheel caused intrusion of the floor pan and created an opening in the floor pan caused by contact with the wheel and tire. Following the snag event, the pickup truck climbed the barrier significantly, but the vehicle continued downstream and was redirected in a stable manner. After the brakes were applied, the vehicle came to rest 203 ft – 4 in. (62.0 m) downstream from the impact point and 3 ft – 9 in. (1.1 m) laterally in front of the traffic side of the barrier.

A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 39 through 41. Documentary photographs of the crash test are shown in Figures 42 and 43. The vehicle trajectory and final position are shown in Figure 44.

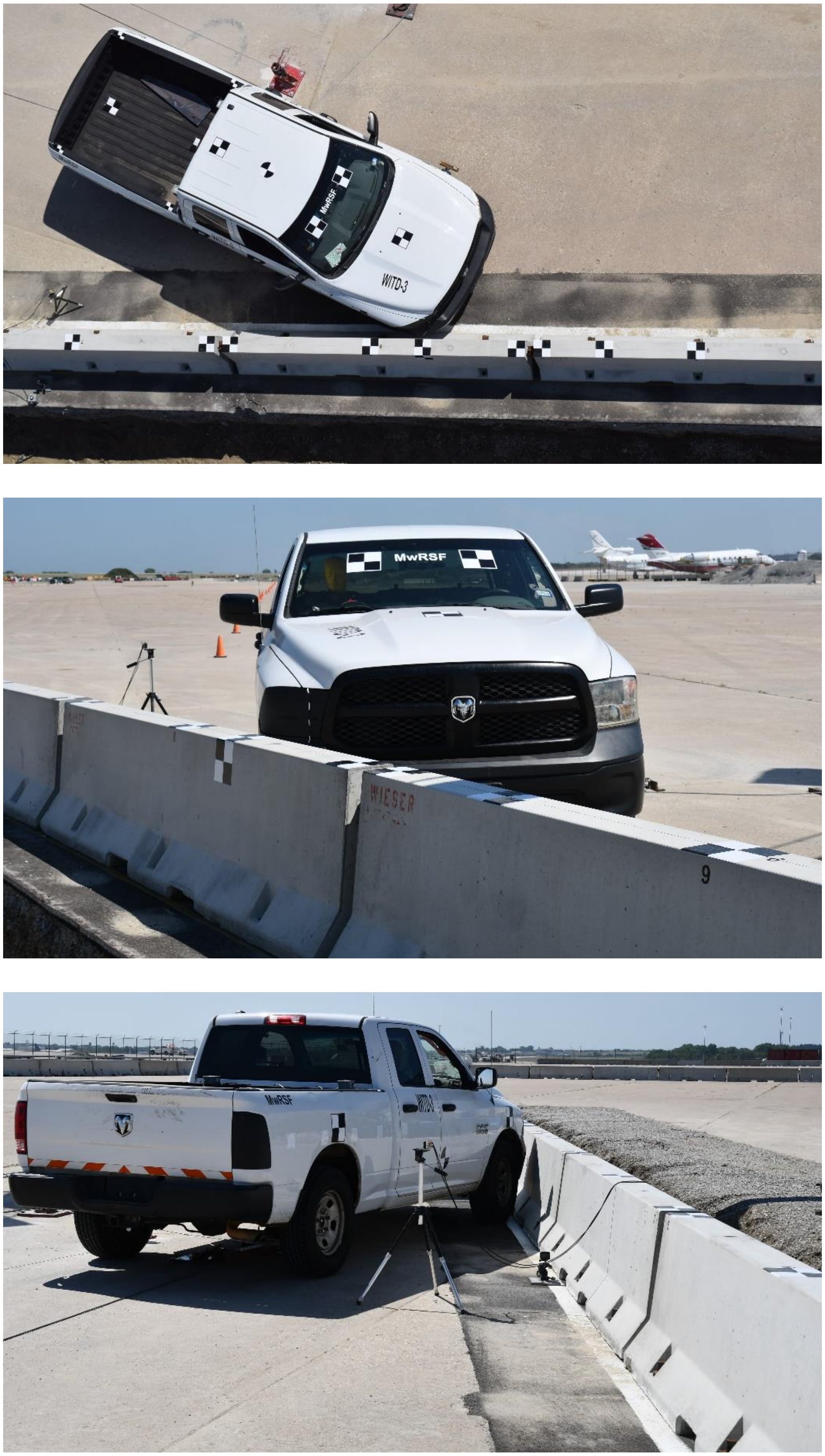


Figure 38. Impact Location, Test No. WITD-3

Table 4. Sequential Description of Impact Events, Test No. WITD-3

Time sec	Event
0.000	Vehicle's front bumper contacted barrier no. 8.
0.002	Vehicle's front bumper deformed and right-front tire contacted barrier no. 8.
0.004	Vehicle's right headlight contacted barrier no. 8 and vehicle's right fender contacted barrier no. 8.
0.016	Vehicle’s right-front tire lifted from the ground and began to climb the toe of barrier no. 8.
0.018	Barrier no. 8 began to rotate clockwise and rolled away from the traffic-side of the system.
0.022	Vehicle's grille contacted barrier no. 9.
0.024	Vehicle began to pitch upward.
0.036	Vehicle’s hood deformed.
0.038	Vehicle's right-front door contacted barrier no. 8.
0.048	Barrier no. 9 rotated counterclockwise and rolled away from the traffic side of the system.
0.060	Barrier no. 7 deflected backward.
0.084	Vehicle's right-front tire snagged on barrier no. 9.
0.088	Vehicle's windshield cracked.
0.092	Vehicle rolled away from system.
0.094	Portion of concrete on barrier no. 9 detached on the back side of the upstream joint.
0.110	Vehicle's left-front tire became airborne.
0.112	Vehicle’s grille disengaged.
0.116	Barrier no. 10 deflected backward.
0.118	Barrier no. 9 cracked on the back side between midspan and the upstream end of the barrier.
0.176	Vehicle’s right-rear tire lifted off the ground.
0.232	Vehicle was parallel to system at a speed of 45.7 mph (73.6 km/h).
0.242	Vehicle's right-rear tire contacted barrier no. 9.
0.254	Vehicle's quarter panel contacted barrier no. 9.
0.260	Vehicle's rear bumper contacted barrier no. 8.
0.272	Vehicle's rear bumper contacted barrier no. 9.
0.290	Vehicle's left-rear tire became airborne.
0.292	Vehicle pitched downward.
0.348	Barrier no. 8 rotated counterclockwise. Barrier no. 9 rotated clockwise.
0.376	Vehicle's right-front tire became airborne.
0.436	Vehicle's right-rear tire became airborne and the vehicle exited system at a speed of 44.4 mph (71.5 km/h) and at an angle of -9.5 degrees.

Table 5. Sequential Description of Impact Events, Test No. WITD-3, Cont.

Time sec	Event
0.554	Barrier no. 10 portion detached on back side upstream end.
0.608	System came to rest.
0.744	Vehicle’s left-front tire regained contact with ground.
0.818	Vehicle’s front bumper contacted ground.
0.844	Vehicle rolled toward system.
0.874	Vehicle pitched upward.
0.968	Vehicle’s right-front tire regained contact with ground.
1.092	Vehicle’s right-rear tire regained contact with the ground and vehicle’s left-front tire became airborne.
1.108	Vehicle’s left-rear tire regained contact with ground.
1.148	Vehicle yawed toward system.
1.184	Vehicle rolled away from system.
1.258	Vehicle’s left-front tire regained contact with ground.
1.278	Vehicle pitched downward.
1.334	Vehicle’s left headlight disengaged.
1.468	Vehicle pitched upward.

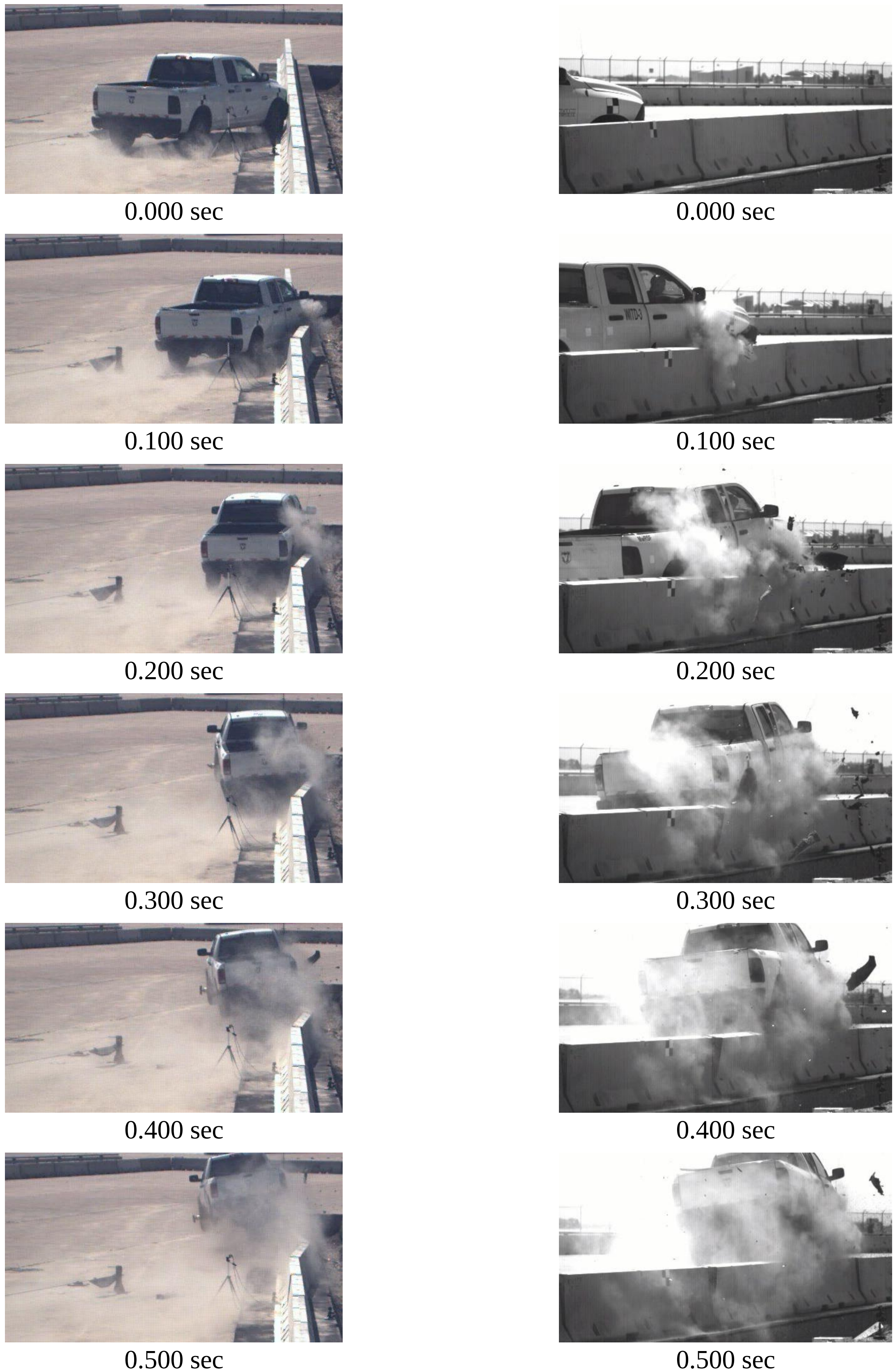
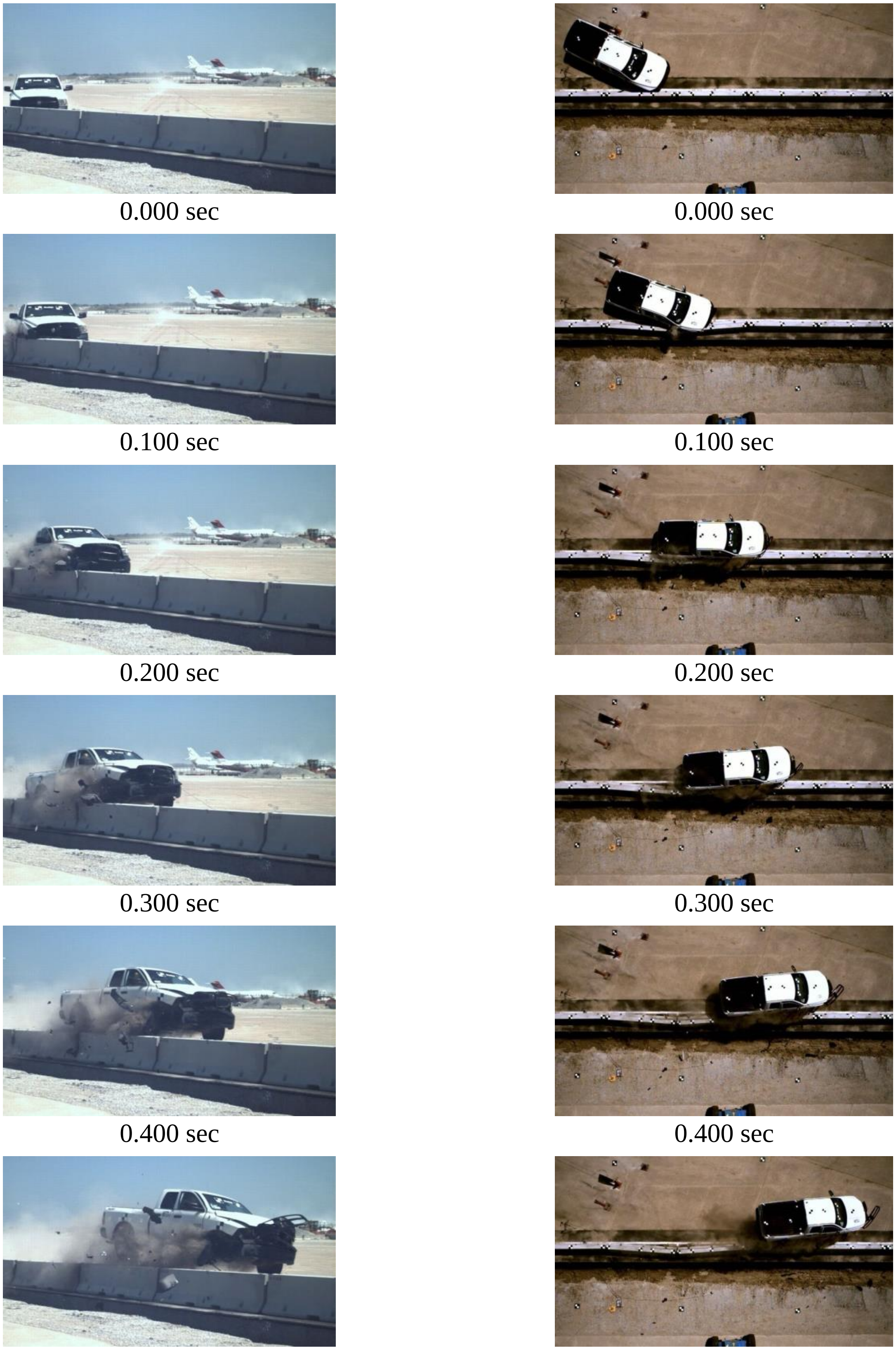


Figure 39. Sequential Photographs, Test No. WITD-3



0.000 sec 0.000 sec

0.100 sec 0.100 sec

0.200 sec 0.200 sec

0.300 sec 0.300 sec

0.400 sec 0.400 sec

0.500 sec 0.500 sec

Figure 40. Sequential Photographs, Test No. WITD-3

0.000 sec | 0.600 sec
0.100 sec | 0.700 sec
0.200 sec | 0.800 sec
0.300 sec | 0.900 sec
0.400 sec | 1.000 sec
0.500 sec | 1.100 sec

Figure 41. Sequential Photographs, Test No. WITD-3

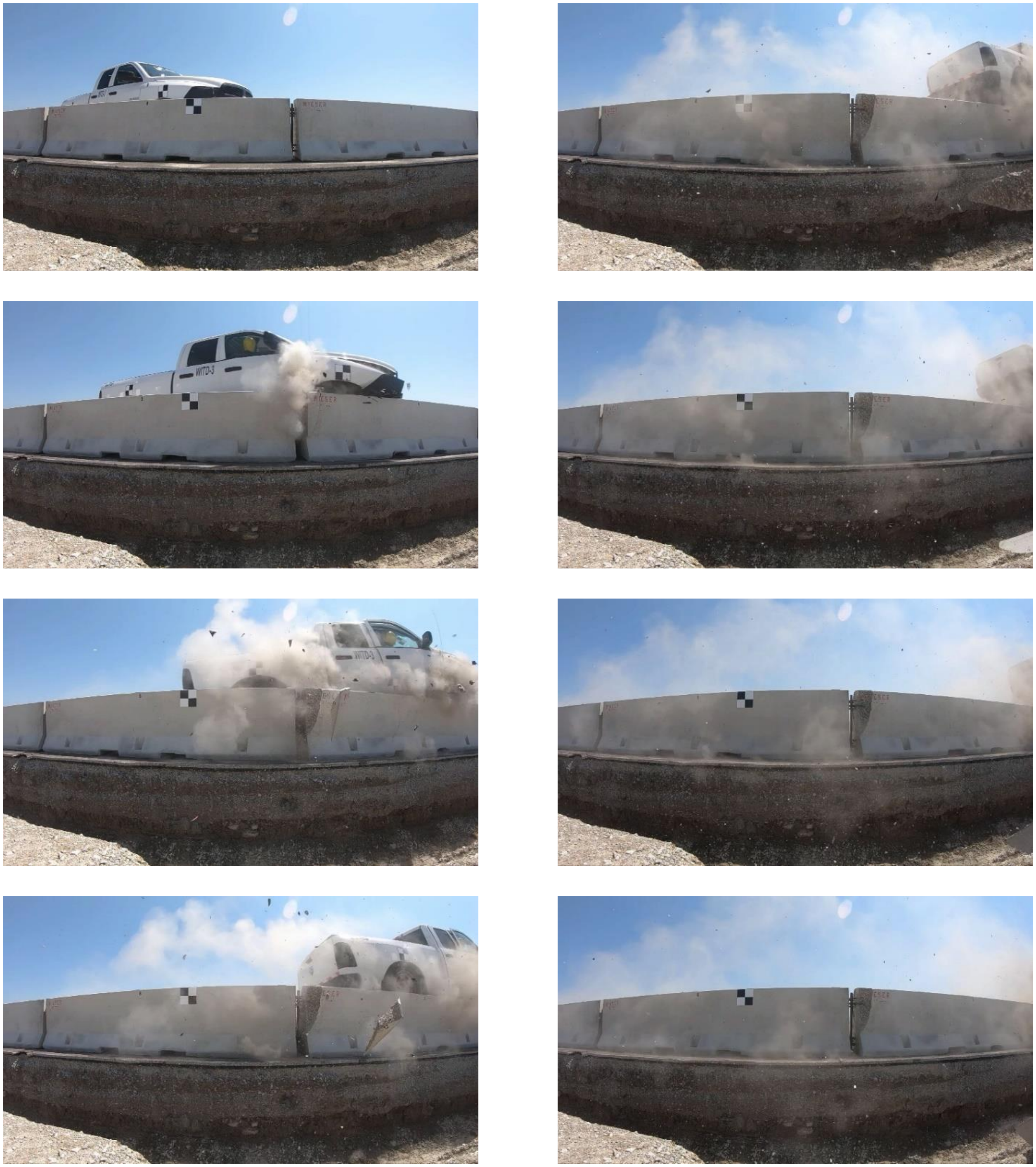


Figure 42. Documentary Photographs, Test No. WITD-3

Figure 43. Additional Documentary Photographs, Test No. WITD-3

Figure 44. Vehicle Final Position and Trajectory Marks, Test No. WITD-3

6.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 45 through 51. 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 26 ft – 7 in. (8.1 m), which spanned from 5 ft – 11 in. (1.8 m) upstream from the center of the joint between barrier nos. 8 and 9 and continued downstream.

Tire marks were visible on the front face of barrier nos. 8 and 9. The front face of barrier no. 8 also contained spalling, gouging, and cracking. Three vertical cracks were found across the front face of barrier no. 8. The cracks measured 31 in. (787mm), 29 in. (737 mm), and 29 in. (737 mm) in length and were located 4 ft – 2½ in. (1.3 m), 5 ft – 2 in. (1.6 m), and 6 ft – 3 in. (1.9 m) downstream from upstream end of barrier no. 8, respectively. Concrete spalling and breakout, with disengaged pieces of concrete, occurred on the front face of barrier no. 8 at each of the anchor pocket locations. One disengaged piece of concrete measured 9½ in. x 4 in. (241 mm x 102 mm) and was located 6 ft – 3 in. (1.9 m) downstream from the upstream end of barrier no. 8, at the middle anchor pocket. Another disengaged piece of concrete measured 7 in. x 3½ in. (178 mm x 89 mm) and was located 2 ft (0.6 m) upstream from the downstream end of barrier no. 8 at the downstream anchor pocket.

Spalling, gouging, and cracking were also present on barrier no. 9. Four major cracks extended vertically across the front face of barrier no. 9 located at 4 ft – 2½ in. (1.3 m), 5 ft – 3 in. (1.6 m), 6 ft (1.8 m), and 8 ft – 4 in. (2.5 m) downstream from the upstream end of barrier no. 9. Additional cracking occurred across the top and non-traffic side faces of barrier no. 9. A significant crack extending diagonally across the non-traffic side face was located 5 ft – 10 in. (1.8 m) downstream from the upstream end of barrier no. 9. Concrete spalling and breakout, with disengaged pieces of concrete, occurred on the front face of barrier no. 9. One disengaged piece of concrete measured 13½ in. x 3½ in. x 2½ in. (343 mm x 89 mm x 64 mm) and was located at 2 ft – 3 in. (0.7 m) downstream from upstream end of barrier no. 9, at the upstream anchor pocket on the traffic side of the PCB. Additional concrete breakout occurred at the middle anchor pocket location on the traffic side of the PCB and measured 8 in. x 5 in. x 2 in. (203 mm x 127 mm x 51 mm). Further concrete breakout occurred on the upstream non-traffic side corner of barrier no. 9, which measured 7½ in. x 21 in. x 2½ in. (191 mm x 533 mm x 64 mm) and exposed the top connection loop bar, as shown in Figures 46 through 49. Concrete spalling occurred on the upstream, traffic-side corner of barrier no. 9.

Barrier no. 10 experienced minor damage, which included concrete spalling and breakout. Concrete spalling occurred on the top, upstream, traffic side corner of barrier no. 10, which measured 2½ in. x 2 in. x ½ in. (64 mm x 51 mm x 13 mm). Three concrete breakout areas were observed at barrier no. 10. The concrete breakout areas measured 27 in. x 6½ in. (686 mm x 165 mm), 8 in. x 1½ in. (203 mm x 38 mm), and 5-in. x 14-in. x 2-in. (127-mm x 356-mm x 51-mm) in size and were located 31 in (787 mm) downstream from the upstream end, 74 in. (1,880 mm) upstream from the downstream end, and upstream non-traffic side corner of barrier no. 10, respectively.

Several of the anchor rods in the impact region were deflected laterally through the asphalt and pulled upward vertically, and the anchor pockets in the barrier toes were damaged. The middle and downstream anchor pocket in barrier no. 8 and the upstream and middle anchor pockets in barrier no. 9 spalled and exposed the anchor pocket rebar loop bars. It should be noted that the anchor rods were still constrained in the toes of the barriers by a reinforcing bar loop. The anchor rods in barrier nos. 7 through 10 displaced upward, and plowing of the anchors rods through the asphalt pad was observed at the anchor rod locations on barrier nos. 8 and 9 due to lateral anchor rod displacements, as shown in Figures 50 and 51. No extending cracking or segmented disengagement of the asphalt and support soil were noted in this test. The anchor rods themselves displayed little to no permanent deformation during the impact.

Figure 45. System Damage, Test No. WITD-3

Figure 46. System Damage at Impact Location, Test No. WITD-3.

Figure 47. System Damage at Barrier No. 9, Test No. WITD-3

Figure 48. System Damage at Barrier No. 8, Test No. WITD-3

Figure 49. Barrier Nos. 8 and 9 Connection Pin Damage, Test No. WITD-3

Figure 50. Barrier No. 8 Anchor Damage, Test No. WITD-3

Figure 51. Barrier No. 9 Anchor Damage, Test No. WITD-3

The maximum lateral permanent set of the barrier system was 10.9 in. (277 mm) at the upstream end of barrier no. 9, as measured in the field. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 16.3 in. (413 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 38.8 in. (984 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 52.

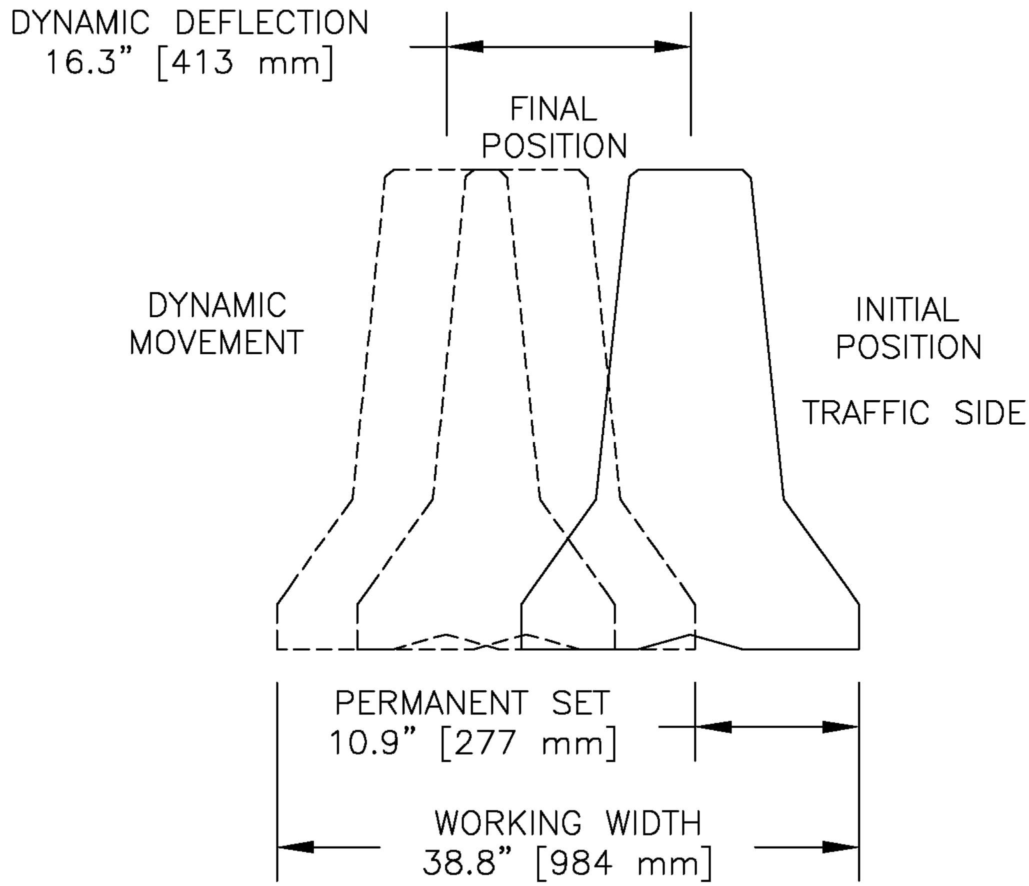


Figure 52. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No.WITD-3

6.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 53 through 57. The maximum occupant compartment intrusions are listed in Table 6 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. Complete occupant compartment and vehicle deformations, as well as the corresponding locations are provided in Appendix C. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. Outward deformations, which are denoted as negative numbers in Appendix C, are not considered crush toward the occupant, and are not evaluated by MASH 2016 criteria.

Note that the maximum wheel well and toe pan deformation of 10.4 in. (264 mm) exceeded the MASH 2016 intrusion limit of 9 in. (229 mm). In addition to exceeding the maximum wheel well and toe pan intrusion criteria, the intrusion of the wheel rim caused the floor pan to tear at the seam where the floor pan, toe pan, and kicker panel meet, as shown in Figure 57. This violation of occupant compartment intrusion limits resulted in the failure of test no. WITD-3 to meet the MASH 2016 criteria.

The majority of the vehicle damage was concentrated on the right-front corner and the right side of the vehicle where the impact occurred. The right side of the bumper was crushed inward toward the centerline of the vehicle and back. The right-front fender was pushed rearward near the door panel and was dented behind the right-front wheel. The right-front steel rim was severely deformed with significant crushing. The right-front tire was torn, deflated, and deformed. The grille disengaged from the vehicle and both headlight assemblies were detached from the vehicle. Denting and scraping were observed on the right side of the vehicle extending across the bottom of both doors, and minor scratches were observed on the right side of the bed. The right-front door was ajar but remained latched, and the right-rear door was slightly dented and scratched. The right-rear wheel assembly was deformed outward. The right-rear steel rim had no significant damage, but scuff marks were found on the tire. The right side of the rear bumper was scraped and dented. The left-front fender was deformed towards the rear of the vehicle. The right side of the windshield had a series of cracks, but the remaining window glass remained undamaged.

The right-front lower control arm fractured through the arms of the casting and was disengaged, and the right-front upper control arm was disengaged from the vehicle. The steering rack casing was fractured, exposing the control circuit board, and the right-side steering control arm was disengaged from the vehicle. The right-side frame rail was bent in towards the centerline of the vehicle, and the floor pan was torn at the floor pan, toe pan, and kicker panel seam.

Figure 53. Vehicle Damage, Test No. WITD-3

Figure 54. Vehicle Damage, Windshield Damage Test No. WITD-3

Figure 55. Vehicle Damage, Test No. WITD-3

Figure 56. Vehicle Undercarriage Damage, Test No. WITD-3

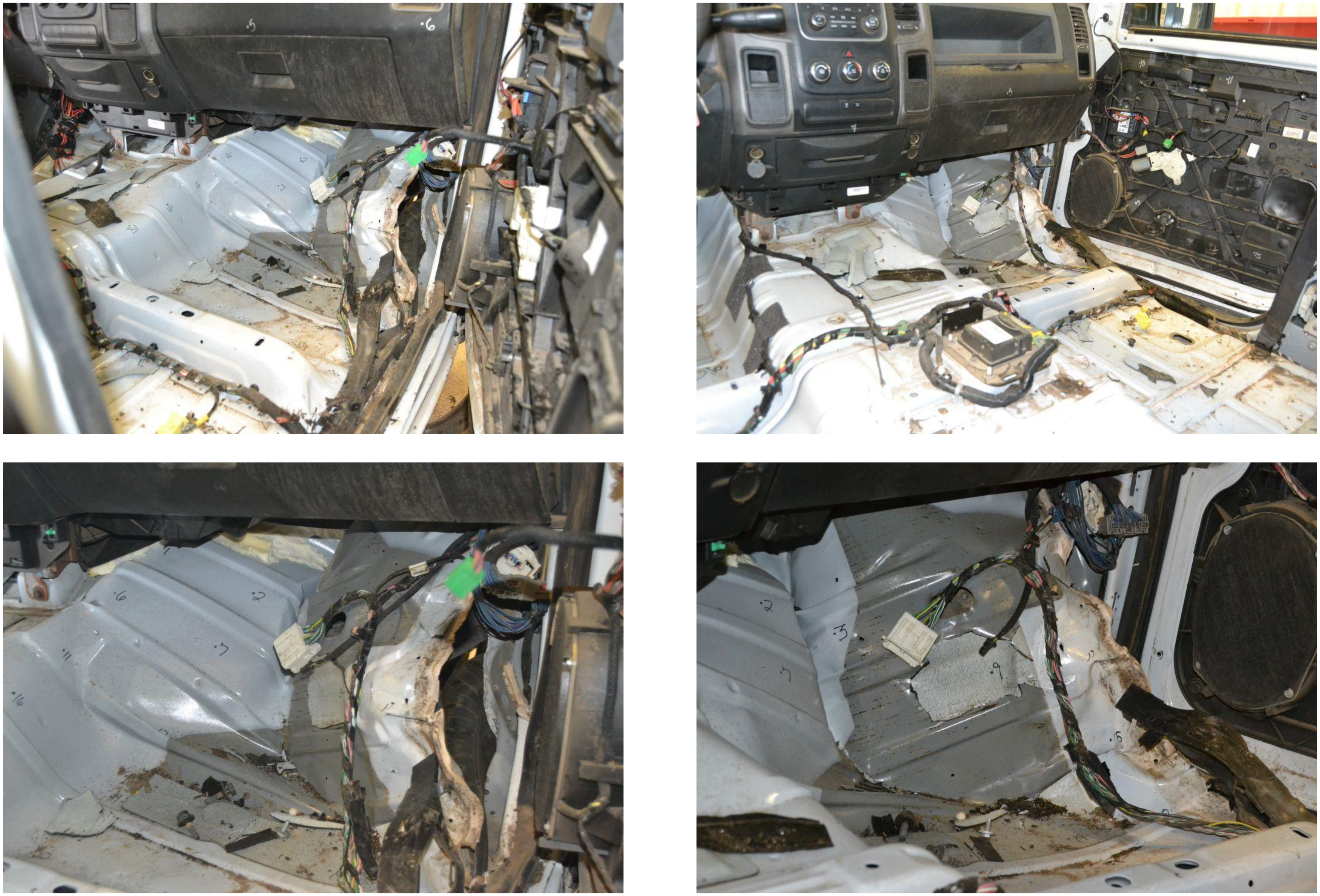


Figure 57. Occupant Compartment Damage, Test No. WITD-3

Table 6. Maximum Occupant Compartment Intrusion by Location, Test No. WITD-3

Location	Maximum Intrusion in. (mm)	MASH 2016 Allowable Intrusion in. (mm)
Wheel Well & Toe Pan	10.4 (264)	≤ 9 (229)
Floor Pan & Transmission Tunnel	3.8 (97)	≤ 12 (305)
A-Pillar	0.7 (18)	≤ 5 (127)
A-Pillar (Lateral)	0.0 (0)	≤ 3 (76)
B-Pillar	0.7 (18)	≤ 5 (127)
B-Pillar (Lateral)	0.0 (0)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	0.0 (0)	≤ 12 (305)
Side Door (Above Seat)	0.0 (0)	≤ 9 (229)
Side Door (Below Seat)	0.0 (0)	≤ 12 (305)
Roof	0.0 (0)	≤ 4 (102)
Windshield	0.0 (0)	≤ 3 (76)
Side Window	Intact	No shattering resulting from contact with structural member of test article
Dash	2.6 (66)	N/A

N/A – No MASH 2016 criteria exist for this location.

6.5 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ride down accelerations (ORAs) in both the longitudinal and lateral direction, as determined from accelerometer data, are shown in Table 7. 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 7. The recorded data from the accelerometers and rate transducers are shown graphically in Appendix D.

Table 7. Summary of Occupant Risk Values, Test No. WITD-3

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-19.42 (-5.92)	-17.60 (-5.36)	±40 (12.2)
	Lateral	-15.73 (-4.79)	-17.09 (-5.21)	±40 (12.2)
ORA g's	Longitudinal	-4.82	-8.80	±20.49
	Lateral	-5.88	-6.40	±20.49
Maximum Angular Displacement deg.	Roll	16.8	-14.7	±75
	Pitch	-16.0	-15.5	±75
	Yaw	-34.9	-34.4	not required
THIV – ft/s (m/s)		23.19 (7.07)	24.84 (7.57)	not required
PHD – g's		8.65	9.72	not required
ASI		1.31	1.37	not required

6.6 Discussion

The analysis of the test results for test no. WITD-3 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. 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 D, 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 -9.4 degrees, and its trajectory did not violate the bounds of the exit box. However, deformations of the wheel well and toe pan exceeded the occupant compartment intrusion limits defined in MASH 2016 by 1.4 in. (36 mm). Additionally, the displacement of the right-front wheel created large intrusion of the floor pan and created an opening in the floor pan caused by contact with the wheel and tire. Therefore, test no. WITD-3 was determined to be unacceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.

Following the evaluation of the system, the researchers reviewed the performance of the modified barrier system in test no. WITD-3. In test no. WITD-3, the impact point was selected to maximize vehicle snag and loading of the barrier joint. While the vehicle was captured and redirected successfully in test no. WITD-3, excessive occupant compartment deformations observed in the test and intrusion of the wheel assembly into the floor pan caused it to be deemed a failure. Further review of the test results found that right-front wheel snag on the joint between the anchored PCB segments at barrier nos. 8 and 9 contributed to the excessive occupant compartment deformations. Evidence of the wheel snag was visible on the face of the upstream end of barrier no. 9 in the form of tire marks and damaged concrete, as shown in Figure 58. This barrier damage and the corresponding wheel snag suggested that impact of the vehicle caused relative lateral displacement and vertical rotation of barrier no. 8 with respect to barrier no. 9 that exposed the upstream face of barrier no. 9 as the vehicle traversed the barrier joint. Specifically, barrier no. 8 was impacted first which caused it to displace laterally and rotate backward vertically about its base, while the steel anchor pins restrained lateral motion and rotation of barrier no. 9 prior to the vehicle reaching the joint. The front tire climbed the toe of the barrier no. 8 as well, which combined with the vertical rotation barrier segment to further increase the exposure of the upstream face of the barrier no. 9 to the wheel assembly. Review of the accelerometer data from the 2270P vehicle found that there were increases in the longitudinal acceleration pulses between approximately 70 msec and 90 msec that would correlate with the timing of the wheel traversing the joint between barrier nos. 8 and 9.

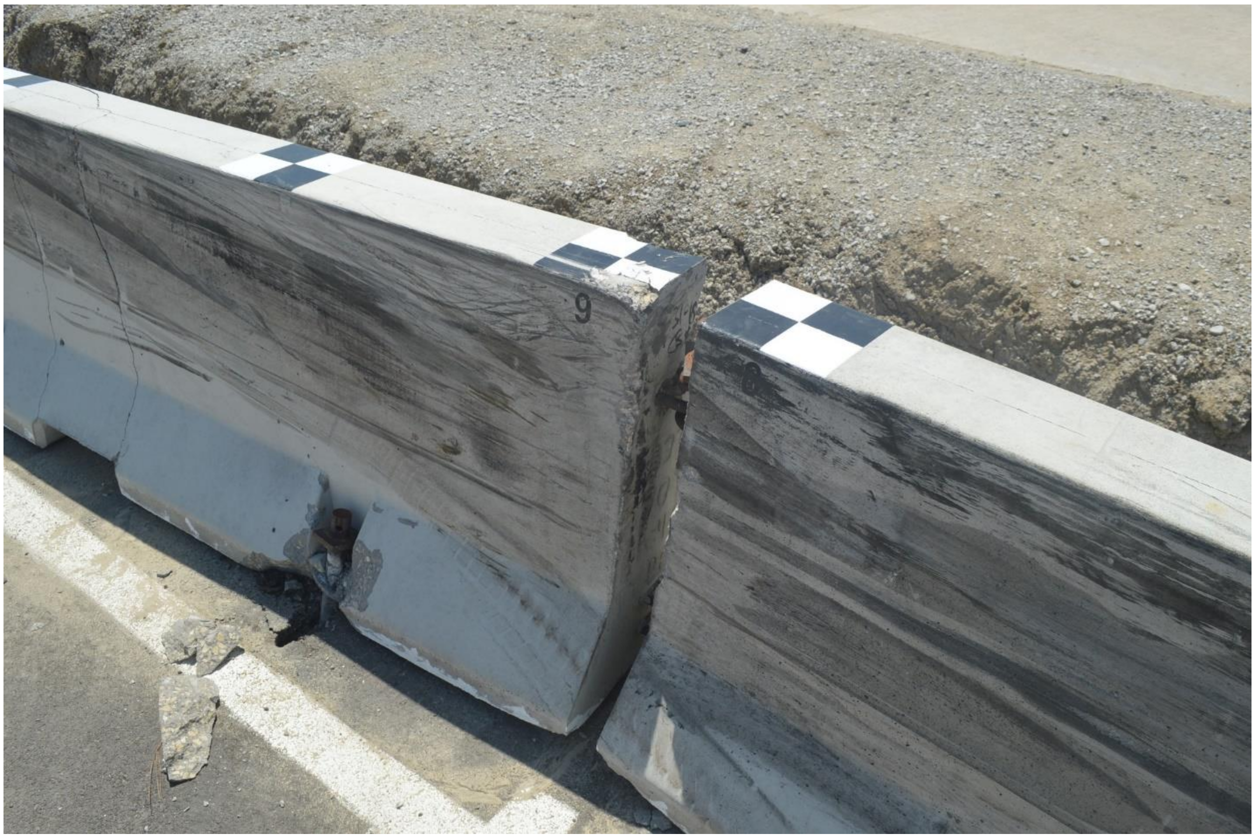


Figure 58. Evidence of Vehicle Wheel Snag, Test No. WITD-3

The wheel snag pushed the right-front wheel back toward the floor pan of the pickup. The displacement of the right-front wheel created intrusion of the floor pan of 10.4 in., which exceed the MASH limit of 9 in., and created an opening in the floor pan caused by contact with the wheel and tire. The floor pan intrusion and opening were cause for this test to fail the MASH occupant compartment criteria. Thus, the wheel snag and corresponding floor pan deformation observed previously in test no. WITD-2 were observed once again in test no. WITD-3.

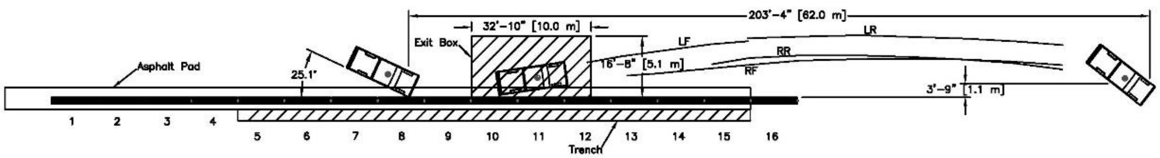
The researchers also compared the performance of the modified barrier system evaluated in test no. WITD-3 with the original system evaluated in test no. WITD-2 to determine if the increased barrier offset provided any performance benefit. Comparisons of relevant metrics are shown in Table 8. Sequential photographs and a summary of the test results for test no. WITD-3 are shown in Figure 59.

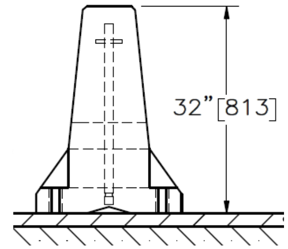
Table 8. Barrier Performance Metrics, Test Nos. WITD-2 and WITD-3

Performance Metric	Test	
	Test No. WITD-2	Test No. WTID-3
Dynamic Deflection (in.)	24.5	16.3
Permanent Set Deflection (in.)	14.6	10.9
Maximum Occupant Compartment Deformation (in.)	13.5	10.4
Longitudinal Occupant Impact Velocity (ft/s)	-23.9	-17.6
Lateral Occupant Impact Velocity (ft/s)	19.1	-17.1
Longitudinal Occupant Ridedown Acceleration (g's)	-9.7	-8.80
Lateral Occupant Ridedown Acceleration (g's)	8.7	-6.40
Soil/Asphalt Disengagement	Multiple areas of soil and asphalt fracture beneath impacted barrier segments	None

Comparison of various metrics from both full-scale crash tests suggested that increasing the offset of the PCB segments from the edge of the vertical drop-off did improve the performance of the anchored PCB system. Dynamic and permanent set deflections were significantly lower in test no. WITD-3. These reduced deflections were consistent with the increased barrier offset in test no. WITD-3 leading to a lack of disengagement of large sections of soil in asphalt beneath the barrier segments as observed previously in test no. WITD-2. Thus, the increased barrier offset seemed to reduce barrier deflections. However, the reduced deflection was not sufficient to mitigate the wheel snag as the vehicle traversed the joint. Review of the occupant risk numbers and the floor pan deformation found that these values were lower across the board for test no. WITD-3 as compared to test no. WITD-2. This would suggest that the increased barrier offset did mitigate wheel snag and the associated occupant compartment deformation to some degree during test no. WTID-3, but it was not sufficient to reduce the snag and associated floor pan deformation to acceptable levels. Thus, additional system modification is necessary to allow the asphalt tie-down anchorage for F-shape PCB to meet MASH TL-3. Further modifications may include shear transfer at the barrier segment joints or shielded of the joints to reduce or eliminate the potential wheel snag. These types of modifications may also allow the barrier segments to be placed at their original offset relative to a vertical drop-off.

0.000 sec | 0.100 sec | 0.200 sec | 0.300 sec | 0.400 sec





- Test Agency .... MwRSF
- Test Number WITD-3
- Date 7/18/19
- MASH 2016 Test Designation 3-11
- Test Article .... Anchored F-Shape PCB
- Total Length .... 204 ft – 7⁵⁄₁₆ in. (62.4 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 .... 1½-in. (38-mm) diameter
  - 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. 5-13
- Type of Support Surface .... 2-in. (51-mm) thick asphalt
- Vehicle Make /Model .... 2013 Dodge Ram 1500
  - Curb .... 5,166 lb (2,343 kg)
  - Test Inertial .... 5,011 lb (2,273 kg)
  - Gross Static .... 5,180 lb (2,350 kg)
- Impact Conditions
  - Speed .... 61.9 mph (99.6 km/h) (MASH 2016 Limit 62.0 ± 2.5 mph)
  - Angle .... 25.1 deg. (MASH 2016 Limit 25 ± 1.5 deg.)
  - Impact Location .... 51³⁄₁₆ in. (1.3 m) upstream from joint 8-9
- Impact Severity ...... 116.4 kip-ft (157.8 kJ) > 106 kip-ft (144 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 44.4 mph (71.5 km/h)
  - Angle .... -9.4 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 203 ft – 4 in. (62.0 m) downstream
  3 ft – 9 in. (1.1 m) laterally in front
- Vehicle Damage .... Moderate
  - VDS [16] 01-RFQ-3
  - CDC [17] 01-RYEW-3
  - Maximum Interior Deformation .... 10.4 in. (264 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 10.9 in. (277 mm)
  - Dynamic .... 16.3 in. (413 mm)
  - Working Width .... 38.8 in. (984 mm)
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-19.42 (-5.92)	-17.60 (-5.36)	±40 (12.2)
	Lateral	-15.73 (-4.79)	-17.09 (-5.21)	±40 (12.2)
ORA g's	Longitudinal	-4.82	-8.80	±20.49
	Lateral	-5.88	-6.40	±20.49
Maximum Angular Displacement deg.	Roll	16.8	-14.7	±75
	Pitch	-16.0	-15.5	±75
	Yaw	-34.9	-34.4	not required
THIV – ft/s (m/s)		23.19 (7.07)	24.84 (7.57)	not required
PHD – g's		8.65	9.72	not required
ASI		1.31	1.37	not required

Figure 59. Summary of Test Results and Sequential Photographs, Test No. WITD-3

7 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This research effort assessed the crashworthiness of a modified, steel pin tie-down anchorage for F-shape PCBs installed on asphalt road surfaces in accordance with MASH 2016 TL-3 evaluation criteria. The test installation utilized 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 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 18-in. (457-mm) from the edge of a 36-in. (914-mm) wide by 36-in. (914-mm) deep trench. This offset was increased 12 in. (305 mm) over the offset used in a previously unsuccessful full-scale crash test of the anchored PCB system in an effort to limit barrier deflections and mitigate wheel snag at the barrier joint. Test no. WITD-3 was conducted according to MASH 2016 test designation no. 3-11 on the steel pin tie down PCB anchorage to evaluate its performance. A summary of the test results is shown in Table 9.

In test no. WITD-3, the 2270P pickup truck impacted the barrier at a speed of 61.9 mph (99.6 km/h), and at an angle of 25.1 degrees, and at a location 51³⁄₁₆ in. (1,300 mm) upstream from the centerline of the joint between barrier nos. 8 and 9, thus resulting in an impact severity of 116.4 kip-ft (157.8 kJ). During the test, the vehicle was captured and redirected by the anchored, F-shape PCB system. As the vehicle was redirected, right front wheel of the vehicle climbed the toe of the F-shape PCB and displaced barrier no. 8 laterally prior to the vehicle reaching the upstream end of barrier no. 9. At approximately 70 to 90 msec after impact, the right front wheel snagged on the upstream face of barrier segment no. 9. The snag was sufficient to push the right-front wheel backwards into the floor pan of the vehicle and damage the barrier joint at the upstream end of barrier no. 9. The displacement of the right-front wheel caused intrusion of the floor pan and created an opening in the floor pan caused by contact with the wheel and tire. Following the snag event, the pickup truck climbed the barrier significantly, but the vehicle continued downstream and was redirected in a stable manner. After impacting the barrier system, the vehicle exited the system at a speed of 44.4 mph (71.5 km/h) and an angle of -9.4 degrees. The vehicle was contained and redirected by the anchored PCB system. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 16.3 in. (413 mm) at the upstream end of barrier no. 9, while the working width of the system was found to be 38.8 in. (984 mm).

Due to the wheel snag observed in the test, the toe pan was deformed a maximum of 10.4 in. (264 mm), which exceeded the MASH 2016 deformation limit of 9 in. (229 mm). Additionally, the intrusion of the wheel during the test caused the floor pan to tear at the seam where the floor pan, toe pan, and kicker panel meet. The combination of the excessive occupant compartment deformation and opening of the floor pan led to the test being deemed unacceptable under the MASH 2016 TL-3 safety requirements. Subsequently, test no. WITD-3 was determined to be unacceptable according to the safety performance criteria for MASH 2016 test no. 3-11.

Review of the results of test no. WITD-3 found that the increased barrier offset reduced barrier deflections and lowered occupant risk levels and floor pan deformation as compared to previous testing with a reduced offset. However, this was not sufficient to improve the barrier performance and reduce wheel snag to a level where the system performance met the MASH TL-3 safety performance criteria. As such, additional research is needed to revise the asphalt pin anchorage evaluated in test no. WITD-3 to reduce the wheel snag and corresponding occupant compartment damage that resulted in the crash test failure. Potential design modifications that may improve the barrier performance could include modifications that improve the shear transfer at the barrier joints and/or shielding of the barrier joint to mitigate wheel snag.

Table 9. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. WITD-3</th></tr>
<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><td>S</td></tr>
<tr><td rowspan="6">Occupant Risk</td><td rowspan="2">D.</td><td colspan="3">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.</td><td>U</td></tr>
<tr><td colspan="3">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>U</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><td>S</td></tr>
<tr><td>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:
Occupant Impact Velocity Limits
Component | Preferred | Maximum
Longitudinal and Lateral | 30 ft/s | 40 ft/s</td><td>S</td></tr>
<tr><td>I.</td><td colspan="3">The Occupant Ride down Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:
Occupant Ride down Acceleration Limits
Component | Preferred | Maximum
Longitudinal and Lateral | 15.0 g’s | 20.49 g’s</td><td>S</td></tr>
<tr><td colspan="5">MASH 2016 Test Designation No.</td><td>3-11</td></tr>
<tr><td colspan="5">Final Evaluation (Pass or Fail)</td><td>Fail</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA – Not Applicable

8 REFERENCES

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

2. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, B.W., Reid, J.D., and Coon, B.A., *Performance Evaluation of the Free-Standing Temporary Barrier – Update to NCHRP 350 Test No. 3-11 with 28" C.G. Height (2214TB-2),* Report No. TRP-03-174-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 2006.

3. Bielenberg, B.W., Faller, R.K., Rohde, J.R., Reid, J.D., Sicking, D.L., and Holloway, J.C., *Development of Tie-Down and Transition Systems for Temporary Concrete Barrier on Asphalt Road Surfaces*, Report No. TRP-03-180-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, February 2007.

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

5. Bielenberg, R.W., Asselin, N.M., and Faller, R.K., *MASH TL-3 Evaluation of Concrete and Asphalt Tied-Down Anchorage for Portable Concrete Barrier*. Report No. TRP-03-386-19, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, February 2019.

6. Williams, W.F., Menges, W.L., and Kuhn D.L., *MASH Test 3-11 of the Anchored Temporary Barrier*, Test Report No. 690900-IND1, Texas A&M Transportation Institute, Texas A&M University, College Station, TX, March 26, 2015.

7. Williams, W.F., Menges, W.L., and Kuhn D.L., *MASH Test 3-11 of the Indiana Anchored Temporary Concrete Barrier with Wedge Anchor Studs*, Test Report No. 690900-IND2, Texas A&M Transportation Institute, Texas A&M University, College Station, TX, June 2015.

8. Williams, W.F., Menges, W.L., and Kuhn D.L., *MASH Test 3-11 of the Indiana Anchored Temporary Concrete Barrier with Wedge Anchor Studs and Modified Top Connection*, Test Report No. 690900-IND3, Texas A&M Transportation Institute, Texas A&M University, College Station, TX, August 2015.

9. Buth, C. E., Hirsch, T. J., and Menges, W. L. Testing of New Bridge Rail and Transition Designs—Volume I: Technical Report. Report FHWA-RD-93-058. FHWA, 1997.

10. Buth, C. E., Hirsch, T. J., and Menges, W. L. Testing of New Bridge Rail and Transition Designs—Volume IIV: Appendix F. Report FHWA-RD-93-064. FHWA, 1997.

11. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, B.W., Reid, J.D., and Coon, B.A., *Performance Evaluation of the Permanent New Jersey Safety Shape Barrier - Update to NCHRP 350 Test No. 3-10 (2214NJ-1)*, Report No. TRP-03-177-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 13, 2006.

12. Sheikh, N.M., Menges, W.L., Kuhn, D.L., *MASH TL-3 Testing and Evaluation of Free-Standing Portable Concrete Barrier*, Test Report No. 607911-1&2, Texas A&M Transportation Institute, Texas A&M University, College Station, Texas, May 2017.

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

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

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

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

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

9 APPENDICES

Appendix A. Vehicle Center of Gravity Determination

Date:	7/18/2019	Test Name:	WITD-3	VIN:	1C6RR6FP2DS673555
Year:	2013	Make:	Dodge	Model:	Ram 1500

Vehicle CG Determination

Vehicle Equipment		Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	5166	28.477521	147114.88
+	Hub	19	15.25	289.75
+	Brake activation cylinder & frame	8	28 1/2	228
+	Pneumatic tank (Nitrogen)	31	26 3/4	829.25
+	Strobe/Brake Battery	5	25 1/2	127.5
+	Brake Receiver/Wires	6	52 1/2	315
+	CG Plate including DAQ	42	30 1/4	1270.5
-	Battery	-46	41	-1886
-	Oil	-11	19	-209
-	Interior	-112	36	-4032
-	Fuel	-169	18 1/2	-3126.5
-	Coolant	-11	33	-363
-	Washer fluid	-5	38 1/2	-192.5
+	Water Ballast (In Fuel Tank)	76	18 1/2	1406
+	Onboard Supplemental Battery	13	25 1/2	331.5
				0
				0
				142103.38

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

Estimated Total Weight (lb)	5012
Vertical CG Location (in.)	28.3526

Vehicle Dimensions for C.G. Calculations

Wheel Base:	141.125 in.	Front Track Width:	68.375 in.
		Rear Track Width:	67.75 in.

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	5011	11.0
Longitudinal CG (in.)	63 ± 4	61.508082	-1.49192
Lateral CG (in.)	NA	-0.522931	NA
Vertical CG (in.)	28 or greater	28.35	0.35263

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	1481	1426
Rear	1136	1123

FRONT	2907	lb
REAR	2259	lb
TOTAL	5166	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	1432	1395
Rear	1112	1072

FRONT	2827	lb
REAR	2184	lb
TOTAL	5011	lb

Figure A-1. Vehicle Mass Distribution, Test No. WITD-3

Appendix B. Material Specifications

Table B-1. Bill of Materials, Test No. WITD-3

Item No.	Description	Material Specification	Reference
a1	Portable Concrete Barrier	Min f'c = 5,000 psi [34.5 MPa]	Concrete Test Reports: 7031/7582
a2	½" [13] Dia., 72" [1829] Long Form Bar	ASTM A615 Gr. 60	H#5716717603
a3	½" [13] Dia., 146" [3708] Long Longitudinal Bar	ASTM A615 Gr. 60	H#5716717603
a4	⅝" [16] Dia., 146" [3708] Long Longitudinal Bar	ASTM A615 Gr. 60	H#5717263002
a5	¾" [19] Dia., 36" [914] Long Anchor Loop Bar	ASTM A615 Gr. 60	H#5717147402
a6	¾" [19] Dia., 101" [2565] Long Connection Loop Bar	ASTM A709 Gr. 70 or A706 Gr. 60	H#KN17102927 H#KN17102928
a7	¾" [19] Dia., 91" [2311] Long Connection Loop Bar	ASTM A709 Gr. 70 or A706 Gr. 60	H#KN17102927 H#KN17102928
a8	¾"[19] Dia., 102" [2591] Long Connection Loop Bar	ASTM A709 Gr. 70 or A706 Gr. 60	H#KN17102927 H#KN17102928
a9	1¼" [32] Dia., 28" [711] Long Connector Pin	ASTM A36	H#5415671902
b1	1½" [38] Dia., 38½" [978] Long Anchor Pin	ASTM A36	H#2068693
b2	3"x3"x½" [76x76x13] Washer Plate	ASTM A36	H#19013461
c1	2400"x72 "x2" [60,960x183x51] Asphalt Pad	NE SPS Mix with 52-34 Grade Binder	Lab#43224

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: Barrier **Testing By:** Jason Hendricks

CONCRETE SUPPLIER Wieser Concrete **ACI GRADE 1**

SET	TEST	POUR DATE	RESULTS	AVERAGE	TEST TYPE
1	1 2 3	5/31/2018	7312 7211	**7262**	28 Day
2	1 2 3	6/22/2018	7455 7582	**7519**	28 Day
3	1 2 3	6/25/2018	7267 7346	**7307**	28 Day
4	1 2 3	6/26/2018	7118 7031	**7075**	28 Day
5					
6					
7					

Jason Hendricks
Signature

Figure B-1. Portable Concrete Barrier, Test No. WITD-3 (Item No. a1)

GERDAU

CERTIFIED MATERIAL TEST REPORT

Page 1/1

US-ML-KNOXVILLE
1919 TENNESSEE AVENUE N. W.
KNOXVILLE, TN 37921
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
SBP ACQUISITION LLC 2309 ADVANCE ROAD MADISON,WI 53718 USA	SBP ACQUISITION LLC 2309 ADVANCE ROAD MADISON,WI 53718 USA	60 (420) TMX	Rebar / #4 (13MM)	0000000000

LENGTH	WEIGHT	HEAT / BATCH
60'00"	6,733 LB	57167176/03

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
5504615/000010		ASTM A615/A615M-15 E1

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4507990023	4751-0000021119	08/22/2017

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.30	0.59	0.014	0.069	0.18	0.32	0.11	0.09	0.013	0.007	0.003	0.42

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
85450	589	101260	698	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
12.50	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
3.89	0.029	0.121	0.315

COMMENTS / NOTES

.40

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
Phone: (409) 769-1014 Email: Bhaskar.Yalamanchili@gerdau.com

Jim Hall
JIM HALL
QUALITY ASSURANCE MGR
Phone: 865-202-5972 Email: Jim.hall@gerdau.com

Figure B-2. ½-in. (13-mm) Diameter Bar, Test No. WITD-3 (Item Nos. a2 and a3)

GERDAU

US-ML-KNOXVILLE
1919 TENNESSEE AVENUE N. W.
KNOXVILLE, TN 37921
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
SBP ACQUISITION LLC 2309 ADVANCE ROAD MADISON,WI 53718 USA	SBP ACQUISITION LLC 2309 ADVANCE ROAD MADISON,WI 53718 USA	60 (420) TMX	Rebar / #5 (16MM)	0000000000

LENGTH	WEIGHT	HEAT / BATCH
60'00"	9,387 LB	57172630/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
6376327/000010		ASTM A615/A615M-16

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
171513-00	4751-0000023742	04/17/2018

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.35	0.63	0.015	0.050	0.22	0.33	0.09	0.19	0.030	0.012	0.004	0.49

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
86260	595	104080	718	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
13.80	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
4.32	0.042	0.126	0.386

COMMENTS / NOTES

.46

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
Phone: (409) 769-1014 Email: Bhaskar.Yalamanchili@gerdau.com

Jim Hall
JIM HALL
QUALITY ASSURANCE MGR.
Phone: 865-202-5972 Email: Jim.hall@gerdau.com

Figure B-3. ⅝-in. (16-mm) Diameter, 146-in. (3,708-mm) Long Longitudinal Bar, Test No. WITD-3 (Item No. a4)

CERTIFIED MATERIAL TEST REPORT Page 1/1

GERDAU

US-ML-KNOXVILLE
1919 TENNESSEE AVENUE N. W.
KNOXVILLE, TN 37921
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
SBP ACQUISITION LLC 2309 ADVANCE ROAD MADISON,WI 53718 USA	SBP ACQUISITION LLC 2309 ADVANCE ROAD MADISON,WI 53718 USA	60 (420) TMX	Rebar / #6 (19MM)	0000000000

LENGTH	WEIGHT	HEAT / BATCH
60'00"	9,372 LB	57171474/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
6113220/000010		ASTM A615/A615M-16

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
168887-00	4751-0000023364	02/27/2018

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.35	0.58	0.009	0.071	0.16	0.26	0.10	0.08	0.020	0.005	0.003	0.47

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
78700	543	99350	685	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
11.80	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
4.39	0.051	0.124	0.477

COMMENTS / NOTES

.45

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.

Bhaskary
BHASKAR YALAMANCHILI
QUALITY DIRECTOR
Phone: (409) 769-1014 Email: Bhaskar.Yalamanchili@gerdau.com

Jim Hall
JIM HALL
QUALITY ASSURANCE MGR.
Phone: 865-202-5972 Email: Jim.hall@gerdau.com

Figure B-4. ¾-in. (19-mm) Diameter, 36-in. (914-mm) Long Anchor Loop Bar, Test No. WITD-3 (Item No. a5)

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
411 MAIN STREET EAST
NEW PRAGUE, MN 56071-

Ship from:

MTR #: 0000177330
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

Date: 26-Jun-2017
B.L. Number: 540365
Load Number: 286372

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# =>	821360												
KN1710292701	Nucor Steel - Kankakee Inc	72,129	98,764	16.6%	OK	1.5%	.16	1.26	.015	.040	.20	.33	.39
KN17102927	3/4" (.7500) Round 24'	497MPa	681MPa				.18	.14	.058	.064	.001		
	A706/A615 Grade 60												
	ASTM A615/A615M-12--A706/A706M-09b grade 60												
	TEN/YD = 1.37												
	Melted 06/08/17 Rolled 06/11/17												
PO# =>	821360												
KN1710292801	Nucor Steel - Kankakee Inc	69,386	95,408	15.5%	OK	1.2%	.17	1.28	.016	.037	.20	.29	.41
KN17102928	3/4" (.7500) Round 24'	478MPa	658MPa				.18	.15	.056	.064	.001		
	A706/A615 Grade 60												
	ASTM A615/A615M-12--A706/A706M-09b grade 60												
	TEN/YD = 1.38												
	Melted 06/08/17 Rolled 06/12/17												

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: Caitlin Widdicombe Caitlin Widdicombe

Figure B-5. ¾-in. (19-mm) Diameter, Connection Loop Bar, Test No. WITD-3 (Item Nos. a6, a7, and a8)

Challman PO #10731

GERDAU

US-ML-CHARLOTTE
6601 LAKEVIEW ROAD
CHARLOTTE, NC 28269
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
SOUTH ST PAUL STEEL SUPPLY 200 HARDMAN AVE N SOUTH SAINT PAUL,MN 55075-2420 USA		A36/44W	Round Bar / 1 1/4"	0000037194

LENGTH	WEIGHT	HEAT / BATCH
20'00"	38,051 LB	54156719/02

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
6074513/000010		ASME SA36 ASTM A6-14, A36-14 ASTM A709-15, AASHTO M270-12 CSA G40.20-13/G40.21-13

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
	1321-0000052993	01/25/2018

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Sn %
0.19	0.70	0.014	0.032	0.22	0.28	0.17	0.14	0.030	0.004	0.002	0.013

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
27.30	8.000	70456	486	48340	333

GEOMETRIC CHARACTERISTICS

R:R
20.00

COMMENTS / NOTES

RECEIVED
JAN 29 2018
PDB

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

Jordan Foster JORDAN FOSTER
QUALITY ASSURANCE MGR.

Phone: (409) 769-1014 Email: Bhaskar.Yalamanchili@gerdau.com

Phone: (704) 596-0361 EX3708 Email: Jordan.Foster@gerdau.com

Figure B-6. 1¼-in. (32-mm) Diameter, 28-in. (711-mm) Long Connector Pin, Test No. WITD-3 (Item No. a9)

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.:2068693 SECTION: ROUND 1-1/2 x 20'0" A36/52950 GRADE: ASTM A36-14/A529-14 Gr 50 ROLL DATE: 06/20/2018 MELT DATE: 06/19/2018 Cert. No.: 82438846 / 068693D441	SOLD TO	Steel & Pipe Supply Co Inc 555 Poyntz Ave Manhattan KS US 66502-6085 7855875182 7855872282	SHIP TO	Steel & Pipe Supply 4750 W Marshall Ave Longview TX US 75604-4817 9037591859	Delivery#: 82438846 BOL#: 72553675 CUST PO#: 4500311757 CUST P/N: 9011620 DLVRY LBS / HEAT: 15141.000 LB DLVRY PCS / HEAT: 126 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.17%	Elongation Gage Lgth test 1	8IN		
Mn	0.66%	Reduction of Area test 1	31%		
P	0.011%	Yield to tensile ratio test1	0.75		
S	0.011%	Yield Strength test 2	57.8ksi		
Si	0.23%	Tensile Strength test 2	76.3ksi		
Cu	0.33%	Elongation test 2	23%		
Cr	0.13%	Elongation Gage Lgth test 2	8IN		
Ni	0.13%	Reduction of Area test 2	31%		
Mo	0.042%	Yield to tensile ratio test2	0.76		
V	0.030%	C+(Mn/6)	0.28%		
Cb	0.000%				
Sn	0.014%				
Al	0.001%				
Ti	0.001%				
N	0.0077%				
Carbon Eq A529	0.39%				
Yield Strength test 1	57.4ksi				
Tensile Strength test 1	76.2ksi				
Elongation test 1	22%				

The Following is true of the material represented by this MTR:
- *Material is fully killed*
- *100% melted and rolled in the USA*
- *EN10204:2004 3.1 compliant*
- *Contains no weld repair*
- *Contains no Mercury contamination*
- *Manufactured in accordance with the latest version of the plant quality manual*
- *Meets the "Buy America" requirements of 23 CFR635.410*

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 GRA 44W, 50WASME SA-36 2008A ADDEND A.

07/09/2018 19:13:06
Page 1 OF 1

Figure B-7. 1½-in. (38-mm) Diameter, 38½-in. (978-mm) Long Anchor Pin, Test No. WITD-3 (Item No. b1)

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 03/18/2019
TIME 05:59:15

SOLD TO
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
40325723-0010	701672120TM	1/2 72 X 120 A36 TEMPERPASS STPMLPL	8	9,801.600			03/15/2019

Chemical Analysis

Heat No. 19013461 Vendor BIG RIVER STEEL LLC DOMESTIC Mill BIG RIVER STEEL LLC **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
0.2100	0.8500	0.0090	0.0010	0.0400	0.0400	0.0300	0.0140	0.0002	0.0800	0.0300	0.0010	0.0030	0.0020	0.0058	0.0036

Mechanical / Physical Properties

Mill Coil No. 19013461-04

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
72100.000	48100.000	34.40			0	NA			
68000.000	43600.000	33.40			0	NA			

Batch 0005724365 8 EA 9,801.600 LB Batch 0005724393 8 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 B-8. 3-in. x 3-in. x ½-in. (76-mm x 76-mm x 13-mm) Washer Plate, Test No. WITD-3 (Item No. b2)

Project:	City of Lincoln 84th & Havelock	Date:	April 5, 2019	Type Mix:	SLX	Sample ID:	Cather SLX Field Verification Testing	
Lab No.	43224	Date Produced:		N initial		N design	50	N Max.

Maximum Specific Gravity (Gmm)

Laboratory Number		
Sample + pycometer in Air	*a*	4019.0
Pycometer in Air	*b*	2018.8
Dry Wt. Sample **(A)** **(a-b)**	*A*	2000.2
Test Temperature	*d*	77 ***Must be 77 F***
Sample + pycometer under Water, gms	*C*	2458.7
Pycometer under water, gm.	*B*	1274.83
Theoretical Maximum Specific Gravity **(Gmm)**	*Gmm*	2.450

Gyratory Specimen Data (Gmb)

Sample ID		#1	#2	#3
Weight in Air	L	4,754.0		
Weight in Water	M	2,749.2		
Weight SSD in Air	N	4,758.5		
Volume (N-M)	O	2,009.3	-	-
Gmb Measured (L/O)	P	2.366	#DIV/0!	#DIV/0!
Height @ N ini	Q	115.40		
Height @ N des	R	115.40		
Height @ N Max	S	115.40		

	Avg			
Gmb @ Nini	2.366	2.366	-	-
Gmb @Ndes	2.366	2.366	-	-
Gmb @ Nmax	2.366	2.366	-	-

Bulk Specific Gravity of Asphalt Cement **(Gb)**	1.028
Bulk Specific Gravity of Combined Aggregate **(Gsb)**	2.577
Bulk Specific Gravity of Coarse Aggregate **(Gsb)**	2.644
Bulk Specific Gravity of Fine Aggregate **(Gsb)**	2.558
Bulk Specific Gravity of FAA **(Gsb)**	2.580

		Spec.
Avg % Voids @ Nini	3.4	
Avg % Voids @ Ndes	3.4	3% +/- 1%
Avg % Voids @ Nmax	3.4	
VMA	13.16	16min
VFA	73.88	n/a
Fine Aggregate Angularity (2.580 Gsb)	43.40	43min
Coarse Aggregate Angularity (1 Face / 2 Face)	99/98	n/a
Sand Equivalent	75	45min

Mix Correction	0	
Total Sample + Trays before Ignition	4880.8	
Weight of Trays	2860.2	
Total Weight of Sample before Ignition	2020.6	
Total Weight of Sample after Ignition	4771	
Corrected Weight of Sample after Ignition	1910.8	
Percent Asphalt Cement by Mixture	**5.43**	5.3min
Weight of Seive anslysis sample prior to washing	1905.5	

Design:

22% 3/8" LS Chips
33% 3A CSG
10% LS Man Sand
30% RAP
5% RAS
5.7% PG 64-34

Sieve Designation	1"	3/4"	1/2'	3/8"	#4	#8	#16	#30	#50	#100	#200
Weight Retained	0	0	11.5	41.3	499.8	1045	1363.4	1530.6	1594.2	1712.9	1758.1
% Retained		0.0	0.6	2.2	26.2	54.8	71.6	80.3	83.7	89.9	92.3
% Passing		100.0	99.4	97.8	73.8	45.2	28.4	19.7	16.3	10.1	7.7
Specifications			**98-100**	**93-100**	**70-87**	**45-65**	**25-41**	**15-31**	**10-21**		**4-10**

Figure B-9. Asphalt Pad, Test No. WITD-3 (Item No. c1)

Appendix C. Vehicle Deformation Records

The following figures and tables describe all occupant compartment measurements taken on the test vehicles used in full-scale crash testing herein. MASH 2016 defines intrusion as the occupant compartment being deformed and reduced in size with no penetration. Outward deformations, which are denoted as negative numbers within this Appendix, are not considered as crush toward the occupant, and are not subject to evaluation by MASH 2016 criteria.

Date: 7/18/2019 Test Name: WITD-3 VIN: 1C6RR6FP2DS673555
Year: 2013 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
PASSENGER SIDE FLOOR PAN - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX^A (in.)	ΔY^A (in.)	ΔZ^A (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	53.1502	33.5012	-7.9851	52.6256	33.3198	-10.0202	0.5246	0.1814	2.0351	2.1094	2.1016	X, Z
	2	53.7950	38.9164	-5.2093	52.5727	39.0377	-7.9759	1.2223	-0.1213	2.7666	3.0270	3.0246	X, Z
	3	55.4328	44.4028	-1.3378	51.5690	42.1536	-6.5154	3.8638	2.2492	5.1776	6.8407	6.4604	X, Z
	4	55.1103	50.2287	-1.5288	NA	NA	NA	NA	NA	NA	NA	NA	X, Z
	5	54.7251	54.6083	-1.4303	NA	NA	NA	NA	NA	NA	NA	NA	X, Z
	6	49.3003	32.9416	-6.0815	48.6565	32.6576	-8.4014	0.6438	0.2840	2.3199	2.4243	2.4076	X, Z
	7	50.6396	38.4931	-3.2271	49.5594	38.3903	-5.7508	1.0802	0.1028	2.5237	2.7471	2.7452	X, Z
	8	51.8992	44.0389	0.5156	NA	NA	NA	NA	NA	NA	NA	NA	X, Z
	9	51.7207	50.3159	0.5499	46.4824	47.1580	-5.4603	5.2383	3.1579	6.0102	8.5752	7.9726	X, Z
	10	51.2005	54.9136	0.8712	44.1362	50.9405	-6.8184	7.0643	3.9731	7.6896	11.1723	10.4419	X, Z
FLOOR PAN (Z)	11	44.9277	32.8152	-4.8391	44.9653	31.9414	-6.2011	-0.0376	0.8738	1.3620	1.6186	1.3620	Z
	12	46.4920	36.8467	0.0078	45.6484	36.7374	-2.4770	0.8436	0.1093	2.4848	2.6264	2.4848	Z
	13	46.7942	43.7286	1.2536	NA	NA	NA	NA	NA	NA	NA	NA	Z
	14	46.5039	49.7191	1.2164	NA	NA	NA	NA	NA	NA	NA	NA	Z
	15	46.3523	54.2991	1.4204	43.8664	52.4801	-2.4125	2.4859	1.8190	3.8329	4.9173	3.8329	Z
	16	40.4974	32.8022	-4.1898	40.5961	32.3725	-5.4876	-0.0987	0.4297	1.2978	1.3706	1.2978	Z
	17	41.8693	36.6285	1.5681	42.1260	36.4011	0.0500	-0.2567	0.2274	1.5181	1.5564	1.5181	Z
	18	42.0355	43.6499	1.4411	42.1968	43.3404	0.7255	-0.1613	0.3095	0.7156	0.7962	0.7156	Z
	19	42.0245	49.0626	1.4178	42.0703	48.7405	0.9987	-0.0458	0.3221	0.4191	0.5306	0.4191	Z
	20	41.5229	53.6350	1.4870	41.5058	53.3212	0.7329	0.0171	0.3138	0.7541	0.8170	0.7541	Z
	21	35.8552	32.6671	-4.0002	35.8846	32.4214	-5.1888	-0.0294	0.2457	1.1886	1.2141	1.1886	Z
	22	36.2673	36.3299	1.4730	36.5709	36.0857	0.3210	-0.3036	0.2442	1.1520	1.2161	1.1520	Z
	23	36.4134	43.4922	1.4738	36.6140	43.2508	0.5439	-0.2006	0.2414	0.9299	0.9814	0.9299	Z
	24	35.9946	49.1735	1.4328	36.1245	48.8188	0.7270	-0.1299	0.3547	0.7058	0.8005	0.7058	Z
	25	35.7399	54.0354	1.3779	35.9468	53.6387	0.7069	-0.2069	0.3967	0.6710	0.8065	0.6710	Z
	26	32.4792	32.8172	-4.0409	32.6711	32.5663	-4.9953	-0.1919	0.2509	0.9544	1.0053	0.9544	Z
	27	32.6553	37.1642	0.4278	32.9313	36.9075	-0.5009	-0.2760	0.2567	0.9287	1.0023	0.9287	Z
	28	32.6793	43.8175	0.4143	32.9457	43.5663	-0.5550	-0.2664	0.2512	0.9693	1.0362	0.9693	Z
	29	32.8243	49.4967	0.5554	33.0897	49.1706	-0.4058	-0.2654	0.3261	0.9612	1.0491	0.9612	Z
	30	34.4806	46.7800	-6.5358	33.1164	53.4088	-0.8510	1.3642	-6.6288	-5.6848	8.8385	-5.6848	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan

Posttest Floor Pan

Figure C-1. Floor Pan Deformation Data – Set 1, Test No. WITD-3

Date: 7/18/2019 Test Name: WITD-3 VIN: 1C6RR6FP2DS673555
Year: 2013 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
PASSENGER SIDE FLOOR PAN - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX^A (in.)	ΔY^A (in.)	ΔZ^A (in.)	Total Δ (in.)	$Crush^B$ (in.)	Directions for $Crush^C$
TOE PAN - WHEEL WELL (X, Z)	1	52.0422	13.2613	-4.1985	51.3248	13.8649	-5.0168	0.7174	-0.6036	0.8183	1.2444	1.0882	X, Z
	2	52.7296	18.6599	-1.4004	51.2418	19.5537	-2.8942	1.4878	-0.8938	1.4938	2.2899	2.1083	X, Z
	3	54.4170	24.1197	2.4873	50.2175	22.6483	-1.4030	4.1995	1.4714	3.8903	5.9106	5.7245	X, Z
	4	54.1202	29.9478	2.3268	NA	NA	NA	NA	NA	NA	NA	NA	X, Z
	5	53.7558	34.3286	2.4491	NA	NA	NA	NA	NA	NA	NA	NA	X, Z
	6	48.2019	12.7101	-2.2733	47.3367	13.1775	-3.4564	0.8652	-0.4674	1.1831	1.5384	1.4657	X, Z
	7	49.5848	18.2412	0.5996	48.2019	18.8734	-0.7156	1.3829	-0.6322	1.3152	2.0104	1.9084	X, Z
	8	50.8935	23.7628	4.3612	NA	NA	NA	NA	NA	NA	NA	NA	X, Z
	9	50.7442	30.0404	4.4273	45.1139	27.6340	-0.3413	5.6303	2.4064	4.7686	7.7608	7.3783	X, Z
	10	50.2472	34.6387	4.7743	42.7814	31.4335	-1.6755	7.4658	3.2052	6.4498	10.3736	9.8660	X, Z
FLOOR PAN (Z)	11	43.8367	12.5976	-1.0039	43.6193	12.4281	-1.3119	0.2174	0.1695	0.3080	0.4133	0.3080	Z
	12	45.4501	16.5981	3.8526	44.2523	17.1724	2.4865	1.1978	-0.5743	1.3661	1.9055	1.3661	Z
	13	45.7919	23.4723	5.1300	NA	NA	NA	NA	NA	NA	NA	NA	Z
	14	45.5290	29.4642	5.1239	NA	NA	NA	NA	NA	NA	NA	NA	Z
	15	45.3998	34.0438	5.3512	42.4560	32.9114	2.7476	2.9438	1.1324	2.6036	4.0899	2.6036	Z
	16	39.4106	12.6017	-0.3267	39.2413	12.8463	-0.6465	0.1693	-0.2446	0.3198	0.4368	0.3198	Z
	17	40.8364	16.3934	5.4411	40.6994	16.7986	4.9649	0.1370	-0.4052	0.4762	0.6401	0.4762	Z
	18	41.0341	23.4144	5.3473	40.7558	23.7279	5.7376	0.2783	-0.3135	-0.3903	0.5728	-0.3903	Z
	19	41.0480	28.8273	5.3504	40.6212	29.1235	6.0842	0.4268	-0.2962	-0.7338	0.8991	-0.7338	Z
	20	40.5679	33.4015	5.4451	40.0561	33.7071	5.8752	0.5118	-0.3056	-0.4301	0.7351	-0.4301	Z
	21	34.7691	12.4869	-0.1083	34.5264	12.8878	-0.4052	0.2427	-0.4009	0.2969	0.5548	0.2969	Z
	22	35.2326	16.1209	5.3799	35.1416	16.4756	5.1631	0.0910	-0.3547	0.2168	0.4256	0.2168	Z
	23	35.4117	23.2824	5.4148	35.1757	23.6369	5.4859	0.2360	-0.3545	-0.0711	0.4318	-0.0711	Z
	24	35.0189	28.9657	5.4041	34.6792	29.2015	5.7403	0.3397	-0.2358	-0.3362	0.5329	-0.3362	Z
	25	34.7863	33.8289	5.3746	34.4976	34.0211	5.7850	0.2887	-0.1922	-0.4104	0.5373	-0.4104	Z
	26	31.3936	12.6527	-0.1269	31.3107	13.0277	-0.2493	0.0829	-0.3750	0.1224	0.4031	0.1224	Z
	27	31.6180	16.9769	4.3618	31.5117	17.3062	4.3079	0.1063	-0.3293	0.0539	0.3502	0.0539	Z
	28	31.6725	23.6300	4.3805	31.5210	23.9651	4.3465	0.1515	-0.3351	0.0340	0.3693	0.0340	Z
	29	31.8446	29.3077	4.5485	31.6583	29.5669	4.5752	0.1863	-0.2592	-0.0267	0.3203	-0.0267	Z
	30	33.4436	26.6183	-2.5663	31.6868	33.8109	4.1893	1.7568	-7.1926	-6.7556	10.0229	-6.7556	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan

Posttest Floor Pan

Figure C-2. Floor Pan Deformation Data – Set 2, Test No. WITD-3

Date: 7/18/2019 Test Name: WITD-3 VIN: 1C6RR6FP2DS673555
Year: 2013 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
PASSENGER SIDE INTERIOR CRUSH - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	42.3245	25.9133	-30.5491	41.5442	25.6295	-31.8645	0.7803	0.2838	-1.3154	1.5555	1.5555	X, Y, Z
	2	45.0211	41.3164	-29.7882	44.1738	40.9962	-31.5645	0.8473	0.3202	-1.7763	1.9939	1.9939	X, Y, Z
	3	45.7212	55.9218	-29.7070	44.6836	55.5106	-32.1082	1.0376	0.4112	-2.4012	2.6479	2.6479	X, Y, Z
	4	39.6758	24.4444	-17.3315	39.1256	24.3264	-18.5504	0.5502	0.1180	-1.2189	1.3425	1.3425	X, Y, Z
	5	41.2285	42.2001	-19.2938	40.3956	42.0562	-21.0909	0.8329	0.1439	-1.7971	1.9860	1.9860	X, Y, Z
	6	42.0643	55.0304	-19.6065	40.9367	54.8622	-21.9748	1.1276	0.1682	-2.3683	2.6284	2.6284	X, Y, Z
SIDE PANEL (Y)	7	54.9635	56.5031	-7.6024	NA	NA	NA	NA	NA	NA	NA	NA	Y
	8	51.0252	56.5263	-7.3573	NA	NA	NA	NA	NA	NA	NA	NA	Y
	9	51.1765	56.5178	-3.7573	NA	NA	NA	NA	NA	NA	NA	NA	Y
IMPACT SIDE DOOR (Y)	10	41.2953	58.4332	-23.6148	40.0452	59.8430	-25.2508	1.2501	-1.4098	-1.6360	2.4954	-1.4098	Y
	11	30.3599	58.2796	-23.2755	29.2212	60.6479	-24.2655	1.1387	-2.3683	-0.9900	2.8081	-2.3683	Y
	12	18.2301	58.5013	-23.4475	17.1436	61.4309	-23.8739	1.0865	-2.9296	-0.4264	3.1535	-2.9296	Y
	13	38.1128	58.9285	-6.3021	37.6176	59.4765	-7.7414	0.4952	-0.5480	-1.4393	1.6177	-0.5480	Y
	14	30.5098	59.1194	-3.5697	30.3250	60.3598	-4.6223	0.1848	-1.2404	-1.0526	1.6373	-1.2404	Y
	15	22.4346	58.5376	-4.4584	22.2437	60.0454	-5.1855	0.1909	-1.5078	-0.7271	1.6848	-1.5078	Y
ROOF - (Z)	16	36.9227	25.9968	-46.4875	36.0584	25.8817	-47.5181	0.8643	0.1151	-1.0306	1.3500	-1.0306	Z
	17	37.0450	32.3079	-46.6190	36.2546	32.2091	-47.7648	0.7904	0.0988	-1.1458	1.3955	-1.1458	Z
	18	36.0474	37.7056	-46.6854	35.2038	37.6282	-47.9086	0.8436	0.0774	-1.2232	1.4879	-1.2232	Z
	19	34.7805	42.3775	-46.1786	33.9519	42.2900	-47.4818	0.8286	0.0875	-1.3032	1.5468	-1.3032	Z
	20	33.8054	48.5130	-45.8947	33.0040	48.4622	-47.3618	0.8014	0.0508	-1.4671	1.6725	-1.4671	Z
	21	27.4971	25.1088	-50.0645	26.5515	24.9946	-50.9485	0.9456	0.1142	-0.8840	1.2995	-0.8840	Z
	22	26.8978	31.3546	-50.0553	26.0307	31.2149	-50.9959	0.8671	0.1397	-0.9406	1.2869	-0.9406	Z
	23	26.3149	36.6045	-49.9361	25.4223	36.4681	-50.9319	0.8926	0.1364	-0.9958	1.3442	-0.9958	Z
	24	25.9478	42.0708	-49.6406	24.9962	41.9540	-50.6991	0.9516	0.1168	-1.0585	1.4281	-1.0585	Z
	25	25.7280	46.6036	-49.2415	24.8940	46.5078	-50.3310	0.8340	0.0958	-1.0895	1.3754	-1.0895	Z
	26	18.9629	24.7810	-50.8117	18.0224	24.6427	-51.5048	0.9405	0.1383	-0.6931	1.1765	-0.6931	Z
	27	18.1640	31.1532	-50.7851	17.3080	31.1205	-51.5197	0.8560	0.0327	-0.7346	1.1285	-0.7346	Z
	28	18.1142	36.9592	-50.5239	17.1490	36.7650	-51.3360	0.9652	0.1942	-0.8121	1.2763	-0.8121	Z
	29	18.3161	42.3729	-50.2291	17.3490	42.2639	-51.1149	0.9671	0.1090	-0.8858	1.3160	-0.8858	Z
	30	18.1665	46.5564	-49.8627	17.3085	46.4833	-50.6977	0.8580	0.0731	-0.8350	1.1995	-0.8350	Z
A-PILLAR Maximum (X, Y, Z)	31	52.1791	55.4964	-31.1776	51.7194	55.7232	-33.3009	0.4597	-0.2268	-2.1233	2.1843	0.4597	X
	32	48.4292	54.7518	-33.1775	48.2031	54.9264	-35.4732	0.2261	-0.1746	-2.2957	2.3134	0.2261	X
	33	45.2476	53.9534	-36.9013	44.8717	54.0303	-39.0355	0.3759	-0.0769	-2.1342	2.1684	0.3759	X
	34	41.6639	53.1470	-39.5432	41.1414	53.1652	-41.5148	0.5225	-0.0182	-1.9716	2.0397	0.5225	X
	35	37.9515	52.3032	-41.9981	37.3649	52.3032	-43.8072	0.5866	0.0000	-1.8091	1.9018	0.5866	X, Y
	36	33.7930	51.3097	-44.3214	33.0658	51.2599	-45.9199	0.7272	0.0498	-1.5985	1.7568	0.7289	X, Y
A-PILLAR Lateral (Y)	31	52.1791	55.4964	-31.1776	51.7194	55.7232	-33.3009	0.4597	-0.2268	-2.1233	2.1843	-0.2268	Y
	32	48.4292	54.7518	-33.1775	48.2031	54.9264	-35.4732	0.2261	-0.1746	-2.2957	2.3134	-0.1746	Y
	33	45.2476	53.9534	-36.9013	44.8717	54.0303	-39.0355	0.3759	-0.0769	-2.1342	2.1684	-0.0769	Y
	34	41.6639	53.1470	-39.5432	41.1414	53.1652	-41.5148	0.5225	-0.0182	-1.9716	2.0397	-0.0182	Y
	35	37.9515	52.3032	-41.9981	37.3649	52.3032	-43.8072	0.5866	0.0000	-1.8091	1.9018	0.0000	Y
	36	33.7930	51.3097	-44.3214	33.0658	51.2599	-45.9199	0.7272	0.0498	-1.5985	1.7568	0.0498	Y
B-PILLAR Maximum (X, Y, Z)	37	9.8243	51.1831	-44.8286	9.1266	51.1114	-45.4092	0.6977	0.0717	-0.5806	0.9105	0.7014	X, Y
	38	6.8996	52.4569	-41.3054	6.2493	52.4024	-41.7196	0.6503	0.0545	-0.4142	0.7729	0.6526	X, Y
	39	10.6397	54.4936	-35.7689	10.0480	54.4126	-36.3277	0.5917	0.0810	-0.5588	0.8179	0.5972	X, Y
	40	6.3843	54.7425	-31.7399	5.9198	54.6404	-32.2360	0.4645	0.1021	-0.4961	0.6872	0.4756	X, Y
B-PILLAR Lateral (Y)	37	9.8243	51.1831	-44.8286	9.1266	51.1114	-45.4092	0.6977	0.0717	-0.5806	0.9105	0.0717	Y
	38	6.8996	52.4569	-41.3054	6.2493	52.4024	-41.7196	0.6503	0.0545	-0.4142	0.7729	0.0545	Y
	39	10.6397	54.4936	-35.7689	10.0480	54.4126	-36.3277	0.5917	0.0810	-0.5588	0.8179	0.0810	Y
	40	6.3843	54.7425	-31.7399	5.9198	54.6404	-32.2360	0.4645	0.1021	-0.4961	0.6872	0.1021	Y

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

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

Date: 7/18/2019 | Test Name: WITD-3 | VIN: 1C6RR6FP2DS673555
Year: 2013 | Make: Dodge | Model: Ram 1500

VEHICLE DEFORMATION
PASSENGER SIDE INTERIOR CRUSH - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	40.7594	6.1328	-26.7222	40.6816	6.3682	-27.0050	0.0778	-0.2354	-0.2828	0.3761	0.3761	X, Y, Z
	2	43.5125	21.5226	-25.8954	43.3520	21.7205	-26.4433	0.1605	-0.1979	-0.5479	0.6043	0.6043	X, Y, Z
	3	44.2618	36.1249	-25.7391	43.9135	36.2395	-26.7698	0.3483	-0.1146	-1.0307	1.0940	1.0940	X, Y, Z
	4	38.1948	4.6002	-13.4953	38.0539	4.8818	-13.7498	0.1409	-0.2816	-0.2545	0.4049	0.4049	X, Y, Z
	5	39.7936	22.3612	-15.3710	39.4158	22.6421	-16.0148	0.3778	-0.2809	-0.6438	0.7976	0.7976	X, Y, Z
	6	40.6701	35.1902	-15.6192	40.0087	35.4577	-16.7057	0.6614	-0.2675	-1.0865	1.2998	1.2998	X, Y, Z
SIDE PANEL (Y)	7	53.6547	36.5543	-3.6945	NA	NA	NA	NA	NA	NA	NA	NA	Y
	8	49.7182	36.5893	-3.4227	NA	NA	NA	NA	NA	NA	NA	NA	Y
	9	49.8937	36.5605	0.1760	NA	NA	NA	NA	NA	NA	NA	NA	Y
IMPACT SIDE DOOR (Y)	10	39.8855	38.6174	-19.6035	39.1827	40.4879	-19.9229	0.7028	-1.8705	-0.3194	2.0235	-1.8705	Y
	11	28.9522	38.4981	-19.1913	28.3472	41.3132	-19.0928	0.6050	-2.8151	0.0985	2.8811	-2.8151	Y
	12	16.8223	38.7608	-19.2802	16.2674	42.1292	-18.8760	0.5549	-3.3684	0.4042	3.4376	-3.3684	Y
	13	36.8213	39.0282	-2.2673	36.4840	39.8777	-2.4601	0.3373	-0.8495	-0.1928	0.9341	-0.8495	Y
	14	29.2376	39.2293	0.5174	29.1468	40.7395	0.5589	0.0908	-1.5102	0.0415	1.5135	-1.5102	Y
	15	21.1546	38.6791	-0.3200	21.0743	40.4591	-0.1331	0.0803	-1.7800	0.1869	1.7916	-1.7800	Y
ROOF - (Z)	16	35.2506	6.3216	-42.6231	35.4388	6.8627	-42.7359	-0.1882	-0.5411	-0.1128	0.5839	-0.1128	Z
	17	35.3932	12.6329	-42.7210	35.6576	13.1924	-42.8884	-0.2644	-0.5595	-0.1674	0.6411	-0.1674	Z
	18	34.4132	18.0342	-42.7511	34.6253	18.6163	-42.9702	-0.2121	-0.5821	-0.2191	0.6571	-0.2191	Z
	19	33.1653	22.7073	-42.2102	33.3809	23.2755	-42.4957	-0.2156	-0.5682	-0.2855	0.6714	-0.2855	Z
	20	32.2127	28.8444	-41.8862	32.4496	29.4483	-42.3014	-0.2369	-0.6039	-0.4152	0.7702	-0.4152	Z
	21	25.7983	5.4844	-46.1412	25.9833	6.0554	-46.3247	-0.1850	-0.5710	-0.1835	0.6276	-0.1835	Z
	22	25.2199	11.7320	-46.0937	25.4819	12.2773	-46.2904	-0.2620	-0.5453	-0.1967	0.6362	-0.1967	Z
	23	24.6554	16.9831	-45.9419	24.8882	17.5310	-46.1601	-0.2328	-0.5479	-0.2182	0.6340	-0.2182	Z
	24	24.3085	22.4488	-45.6141	24.4750	23.0143	-45.8549	-0.1665	-0.5655	-0.2408	0.6368	-0.2408	Z
	25	24.1065	26.9801	-45.1888	24.3807	27.5628	-45.4228	-0.2742	-0.5827	-0.2340	0.6852	-0.2340	Z
	26	17.2582	5.1889	-46.8325	17.4628	5.7388	-47.0171	-0.2046	-0.5499	-0.1846	0.6151	-0.1846	Z
	27	16.4808	11.5635	-46.7657	16.7681	12.2184	-46.9497	-0.2873	-0.6549	-0.1840	0.7384	-0.1840	Z
	28	16.4522	17.3681	-46.4725	16.6231	17.8602	-46.6871	-0.1709	-0.4921	-0.2146	0.5634	-0.2146	Z
	29	16.6741	22.7794	-46.1495	16.8361	23.3547	-46.3838	-0.1620	-0.5753	-0.2343	0.6420	-0.2343	Z
	30	16.5409	26.9613	-45.7591	16.8017	27.5678	-45.9066	-0.2608	-0.6065	-0.1475	0.6765	-0.1475	Z
A-PILLAR Maximum (X, Y, Z)	31	50.7082	35.6862	-27.2556	50.9673	36.4467	-27.8510	-0.2591	-0.7605	-0.5954	1.0000	0.0000	NA
	32	46.9425	34.9650	-29.2341	47.4827	35.6925	-30.0884	-0.5402	-0.7275	-0.8543	1.2454	0.0000	NA
	33	43.7333	34.1975	-32.9407	44.2040	34.8582	-33.7141	-0.4707	-0.6607	-0.7734	1.1208	0.0000	NA
	34	40.1291	33.4175	-35.5628	40.5098	34.0408	-36.2627	-0.3807	-0.6233	-0.6999	1.0116	0.0000	NA
	35	36.3976	32.5994	-37.9971	36.7666	33.2238	-38.6251	-0.3690	-0.6244	-0.6280	0.9594	0.0000	NA
	36	32.2202	31.6325	-40.2976	32.4975	32.2248	-40.8185	-0.2773	-0.5923	-0.5209	0.8361	0.0000	NA
A-PILLAR Lateral (Y)	31	50.7082	35.6862	-27.2556	50.9673	36.4467	-27.8510	-0.2591	-0.7605	-0.5954	1.0000	-0.7605	Y
	32	46.9425	34.9650	-29.2341	47.4827	35.6925	-30.0884	-0.5402	-0.7275	-0.8543	1.2454	-0.7275	Y
	33	43.7333	34.1975	-32.9407	44.2040	34.8582	-33.7141	-0.4707	-0.6607	-0.7734	1.1208	-0.6607	Y
	34	40.1291	33.4175	-35.5628	40.5098	34.0408	-36.2627	-0.3807	-0.6233	-0.6999	1.0116	-0.6233	Y
	35	36.3976	32.5994	-37.9971	36.7666	33.2238	-38.6251	-0.3690	-0.6244	-0.6280	0.9594	-0.6244	Y
	36	32.2202	31.6325	-40.2976	32.4975	32.2248	-40.8185	-0.2773	-0.5923	-0.5209	0.8361	-0.5923	Y
B-PILLAR Maximum (X, Y, Z)	37	8.2483	31.5879	-40.6437	8.5530	32.1456	-40.6785	-0.3047	-0.5577	-0.0348	0.6365	0.0000	NA
	38	5.3517	32.8519	-37.0939	5.6229	33.3928	-37.0154	-0.2712	-0.5409	0.0785	0.6102	0.0785	Z
	39	9.1357	34.8459	-31.5717	9.3439	35.3131	-31.5372	-0.2082	-0.4672	0.0345	0.5127	0.0345	Z
	40	4.9085	35.0867	-27.5128	5.1537	35.4954	-27.5067	-0.2452	-0.4087	0.0061	0.4767	0.0061	Z
B-PILLAR Lateral (Y)	37	8.2483	31.5879	-40.6437	8.5530	32.1456	-40.6785	-0.3047	-0.5577	-0.0348	0.6365	-0.5577	Y
	38	5.3517	32.8519	-37.0939	5.6229	33.3928	-37.0154	-0.2712	-0.5409	0.0785	0.6102	-0.5409	Y
	39	9.1357	34.8459	-31.5717	9.3439	35.3131	-31.5372	-0.2082	-0.4672	0.0345	0.5127	-0.4672	Y
	40	4.9085	35.0867	-27.5128	5.1537	35.4954	-27.5067	-0.2452	-0.4087	0.0061	0.4767	-0.4087	Y

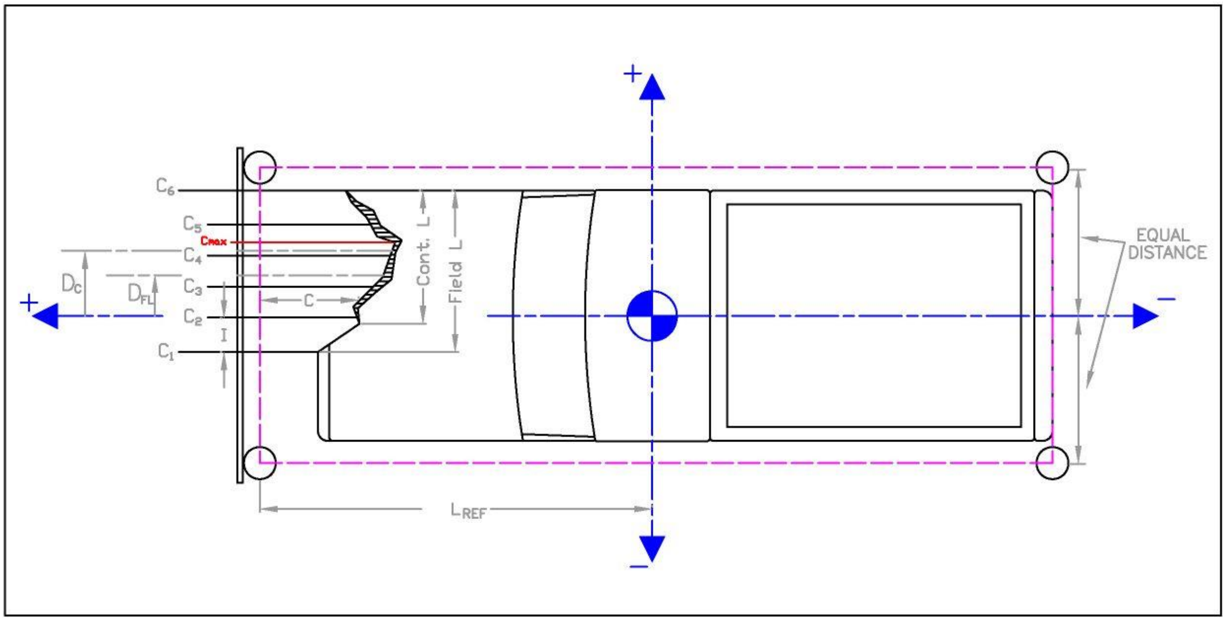
[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Figure C-4. Occupant Compartment Deformation Data – Set 2, Test No. WITD-3

Date:	**7/22/2019**	**Test Name:**	**WITD-3**	**VIN:**	**1C6RR6FP2DS673555**
Year:	**2013**	**Make:**	**Dodge**	**Model:**	**Ram 1500**



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	**104**	**(2642)**
Total Vehicle Width:	**76 3/4**	**(1949)**
Width of contact and induced crush - Field L:	**76 3/4**	**(1949)**
Crush measurement spacing interval (L/5) - I:	**15 3/8**	**(391)**
Distance from center of vehicle to center of Field L - D_{FL}:	**0**	**()**
Width of Contact Damage:	**76 3/4**	**(1949)**
Distance from center of vehicle to center of contact damage - D_C:	**0**	**()**

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

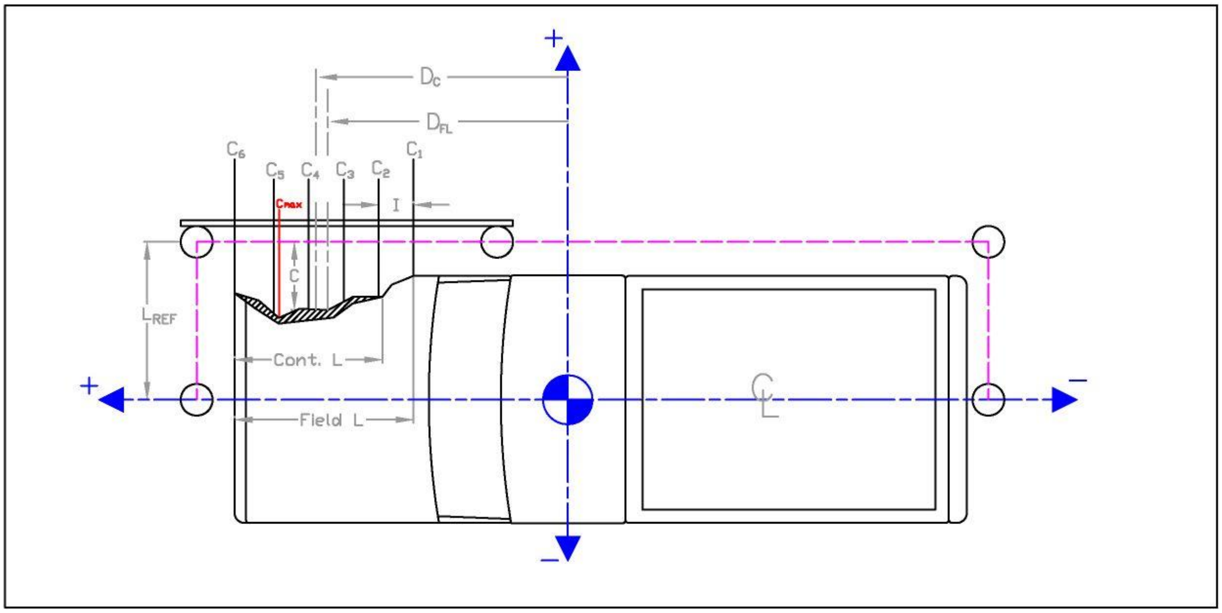
NOTE: All values must be filled out above before crush measurements are filled out.

	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	N/A	N/A	-38 3/8	-(975)	22 1/2	(572)	- 7/8	-(22)	N/A	N/A
C_2	4	(102)	-23	-(584)	6 1/2	(165)			-1 5/8	-(41)
C_3	1 7/8	(48)	-7 5/8	-(194)	4 1/4	(108)			-1 1/2	-(38)
C_4	2 1/4	(57)	7 3/4	(197)	4 1/4	(108)			-1 1/8	-(29)
C_5	21	(533)	23 1/8	(587)	6 1/8	(156)			15 3/4	(400)
C_6	N/A	N/A	38 1/2	(978)	20 1/2	(521)			N/A	N/A
C_{MAX}	21	(533)	23 1/8	(587)	6 1/8	(156)			15 3/4	(400)

Figure C-5. Exterior Vehicle Crush (NASS) – Front, Test No. WITD-3

Date: 7/22/2019 | Test Name: WITD-3 | VIN: 1C6RR6FP2DS673555

Year: 2013 | Make: Dodge | Model: Ram 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	44	(1118)
Total Vehicle Length:	229 3/8	(5826)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-6	-(151)
Width of contact and induced crush - Field L:	229 3/8	(5826)
Crush measurement spacing interval (L/5) - I:	45 7/8	(1165)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-6	-(152)
Width of Contact Damage:	229 3/8	(5826)
Distance from vehicle c.g. to center of contact damage - D_C:	-6	-(152)

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	N/A	-120 3/4	-(3067)	33 1/2	(851)	0	()	N/A	N/A
C_2	N/A	N/A	-74 7/8	-(1902)	5 1/4	(133)			N/A	N/A
C_3	6	(152)	-29	-(737)	5 5/8	(143)			3/8	(10)
C_4	7 1/4	(184)	16 7/8	(429)	5 1/8	(130)			2 1/8	(54)
C_5	N/A	N/A	62 3/4	(1594)	5	(127)			N/A	N/A
C_6	N/A	N/A	108 5/8	(2759)	30	(762)			N/A	N/A
C_{MAX}	22 1/2	(572)	82	(2083)	5 5/8	(143)			16 7/8	(429)

Figure C-6. Exterior Vehicle Crush (NASS) – Side, Test No. WITD-3

Date: 7/18/2019 Test Name: WITD-3 VIN: 1C6RR6FP2DS673555
Year: 2013 Make: Dodge Model: Ram 1500

Passenger Side Maximum Deformation

Reference Set 1				Reference Set 2			
Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]	Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Roof	-1.5	≤ 4	Z	Roof	-0.4	≤ 4	Z
Windshield[D]	0.0	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	0.7	≤ 5	X, Y	A-Pillar Maximum	0.0	≤ 5	NA
A-Pillar Lateral	0.0	≤ 3	Y	A-Pillar Lateral	-0.8	≤ 3	Y
B-Pillar Maximum	0.7	≤ 5	X, Y	B-Pillar Maximum	0.1	≤ 5	Z
B-Pillar Lateral	0.0	≤ 3	Y	B-Pillar Lateral	-0.6	≤ 3	Y
Toe Pan - Wheel Well	10.4	≤ 9	X, Z	Toe Pan - Wheel Well	9.9	≤ 9	X, Z
Side Front Panel	0.0	≤ 12	Y	Side Front Panel	0.0	≤ 12	Y
Side Door (above seat)	-2.9	≤ 9	Y	Side Door (above seat)	-3.4	≤ 9	Y
Side Door (below seat)	-1.5	≤ 12	Y	Side Door (below seat)	-1.8	≤ 12	Y
Floor Pan	3.8	≤ 12	Z	Floor Pan	2.6	≤ 12	Z
Dash - no MASH requirement	2.6	NA	X, Y, Z	Dash - no MASH requirement	2.6	NA	X, Y, Z

[A] Items highlighted in red do not meet MASH allowable deformations.
[B] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.
[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment. If direction of deformation is "NA" then no intrusion is recorded and deformation will be 0.
[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle interior crush:

The Side Front Panel was so damaged and shrouded by the floor pan that meaurements were not possible.

Figure C-7. Driver Side Maximum Deformation, Test No. WITD-3

Appendix D. Accelerometer and Rate Transducer Data Plots, Test No. WITD-3

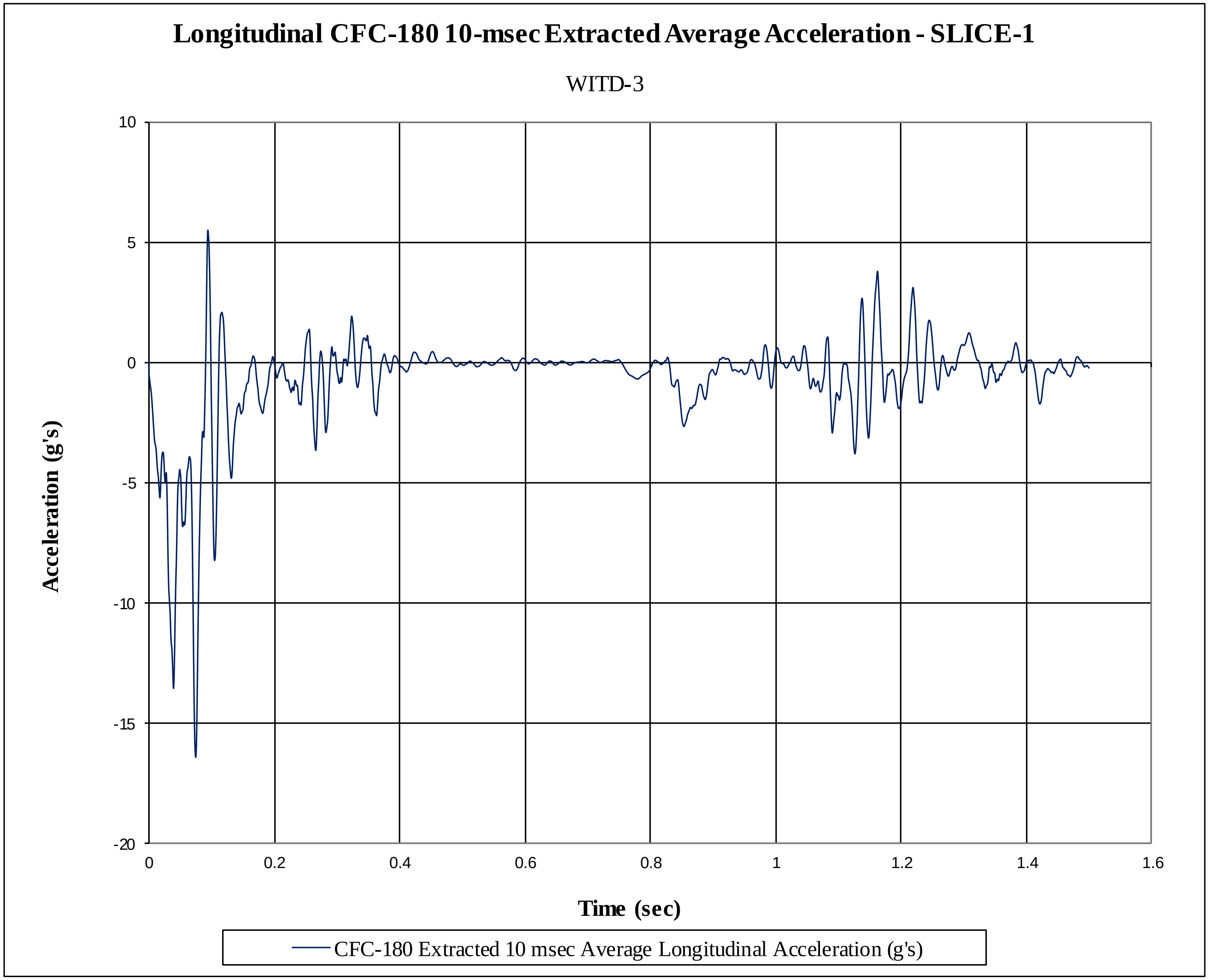


Figure D-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. WITD-3

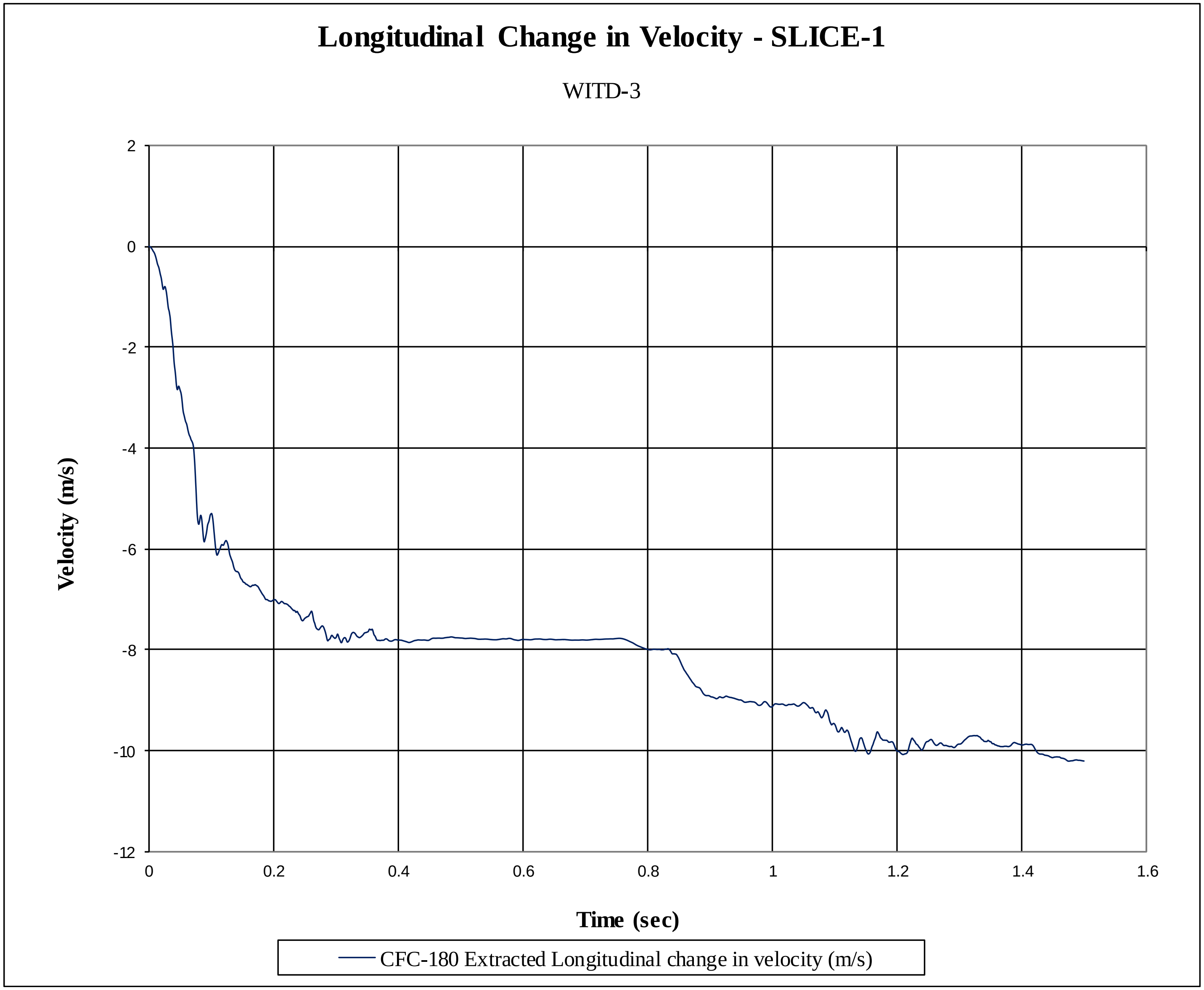


Figure D-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. WITD-3

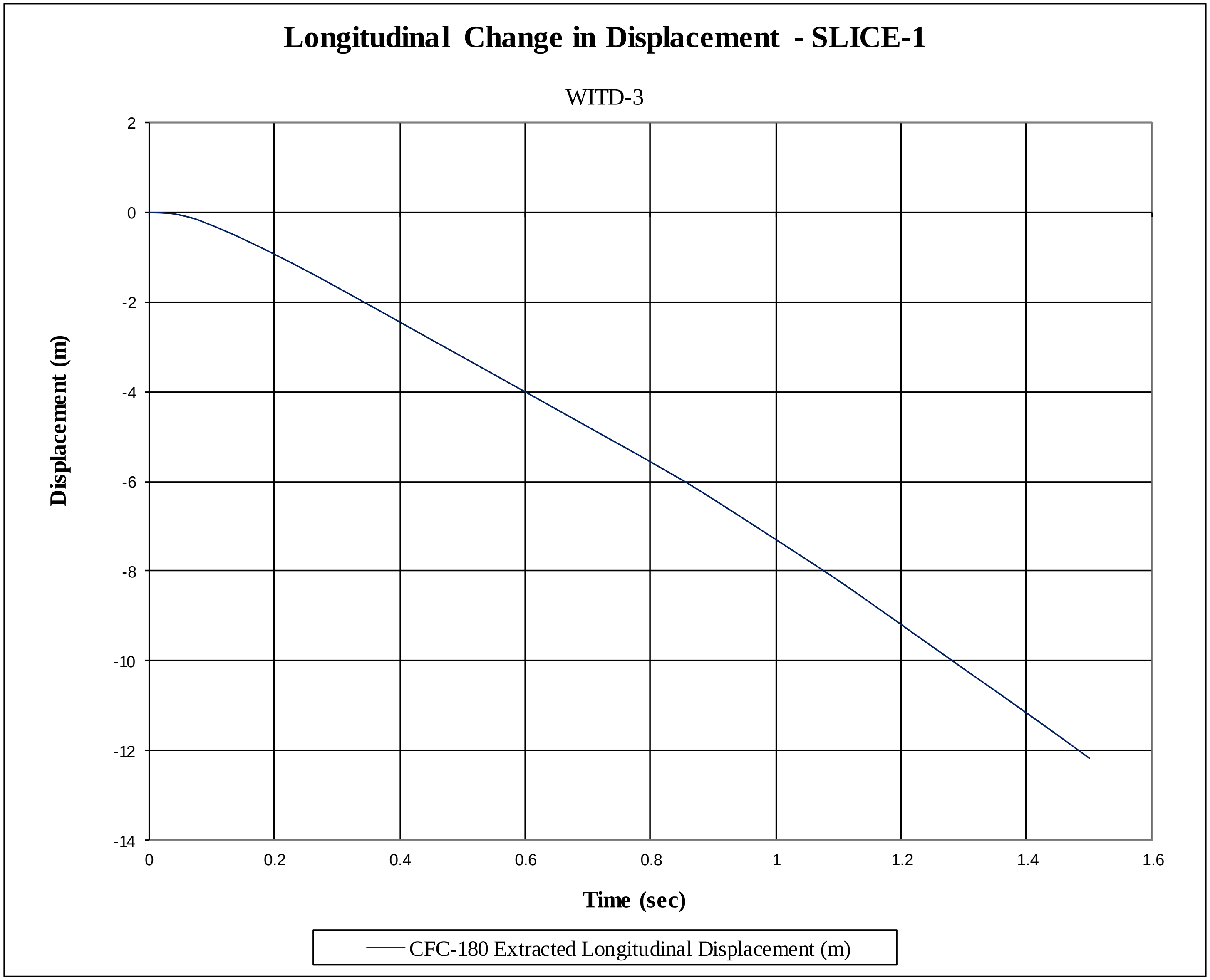


Figure D-3. Longitudinal Occupant Displacement (SLICE-1), Test No. WITD-3

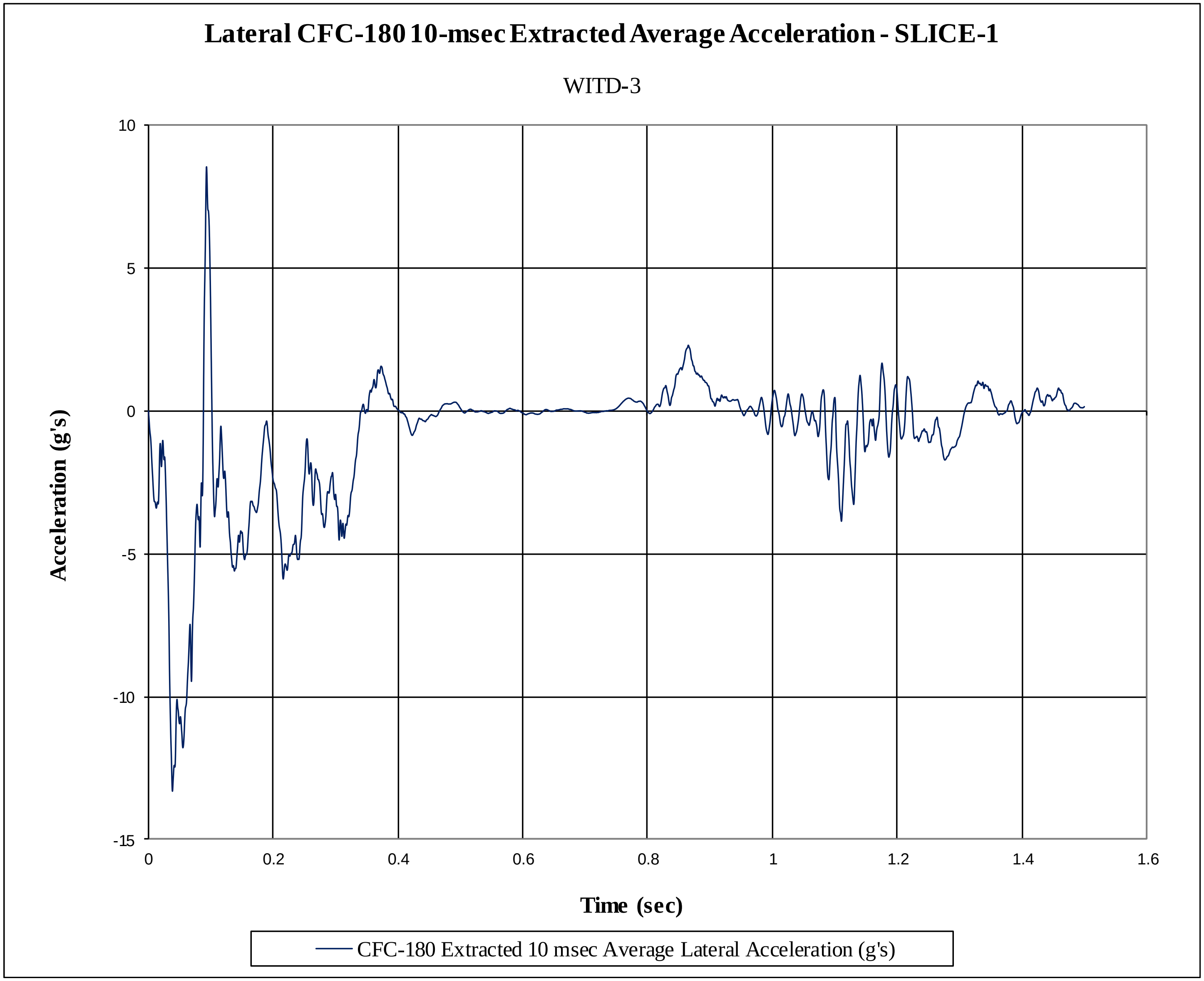


Figure D-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. WITD-3

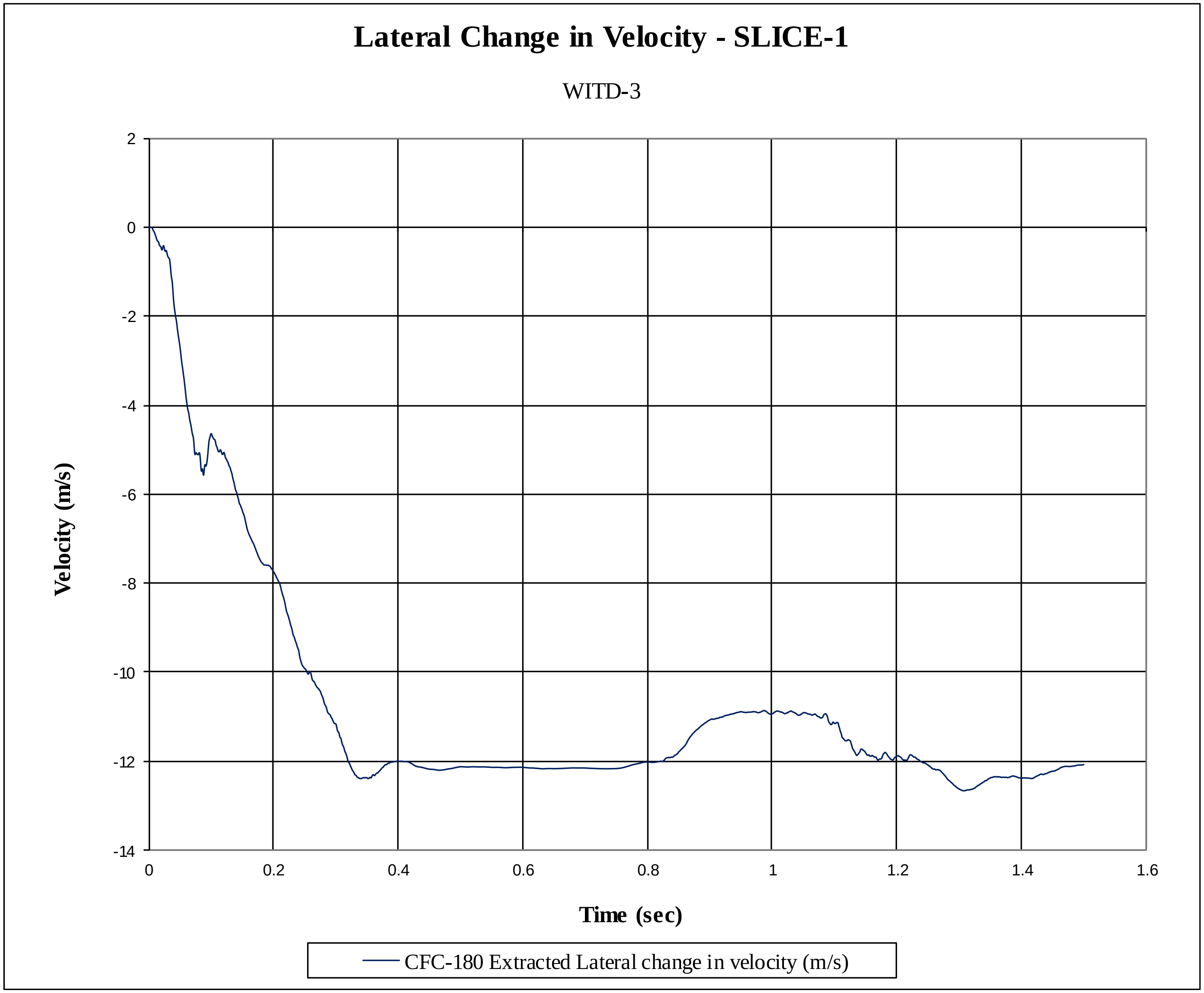


Figure D-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. WITD-3

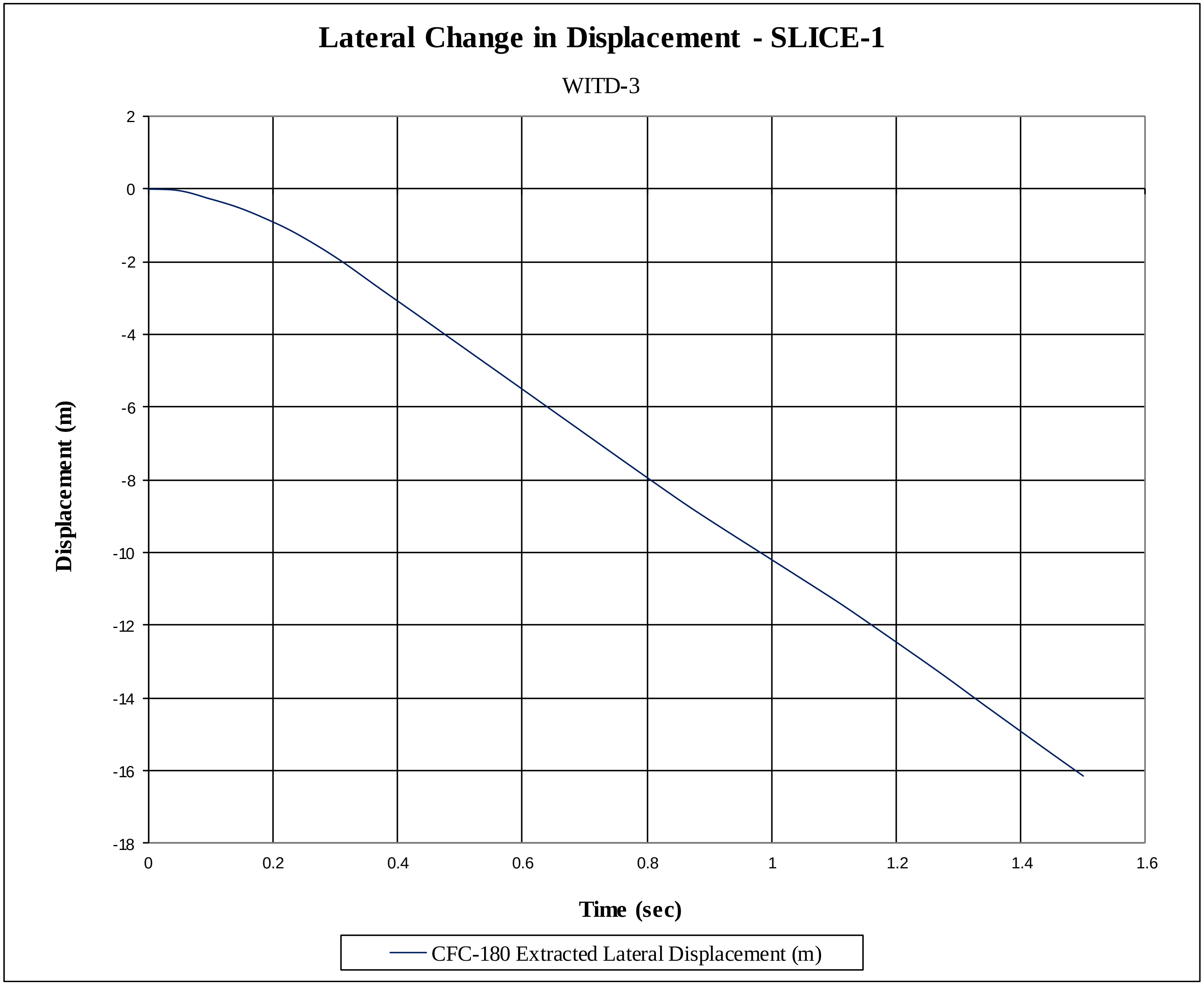


Figure D-6. Lateral Occupant Displacement (SLICE-1), Test No. WITD-3

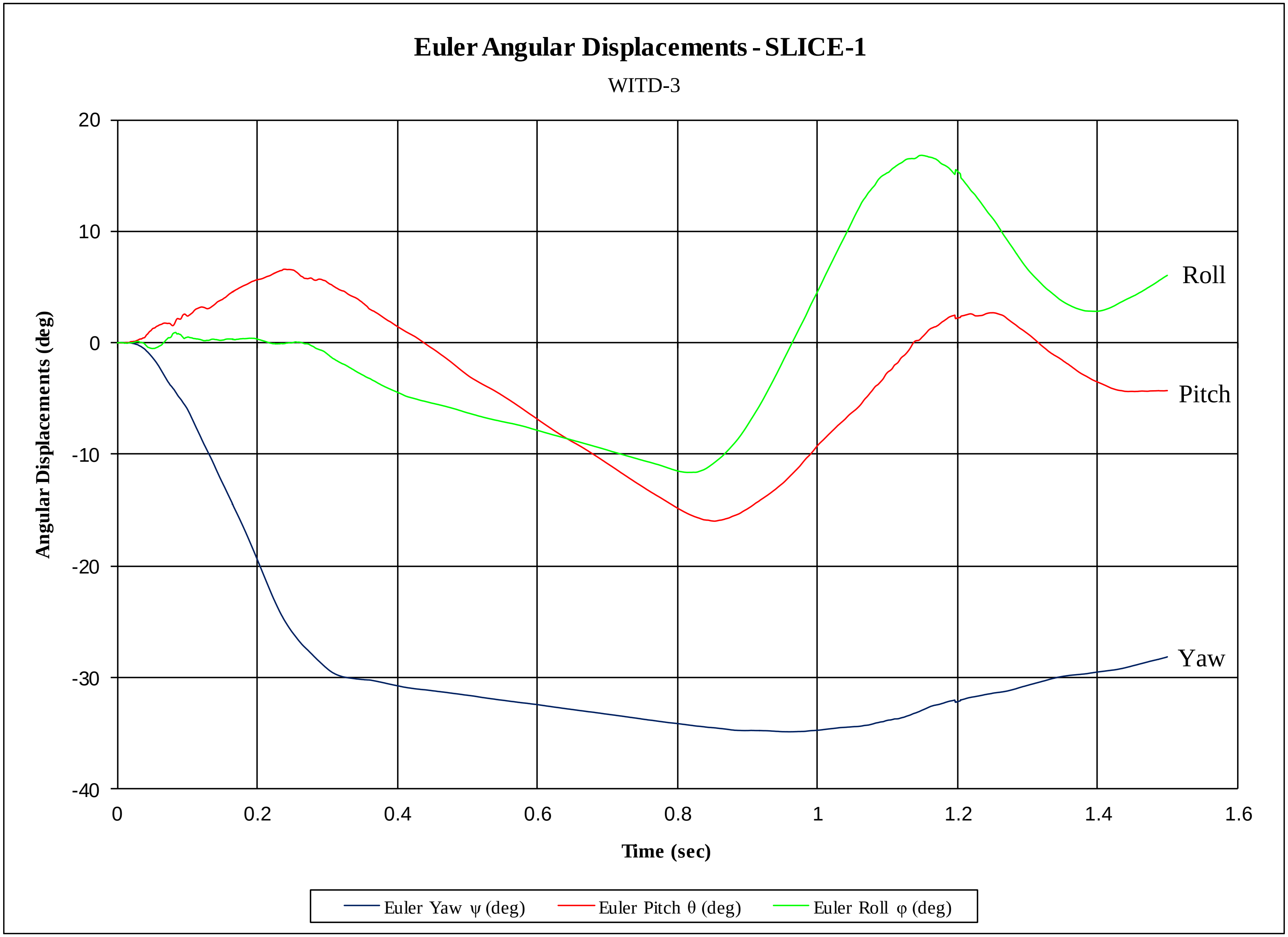


Figure D-7. Vehicle Angular Displacements (SLICE-1), Test No. WITD-3

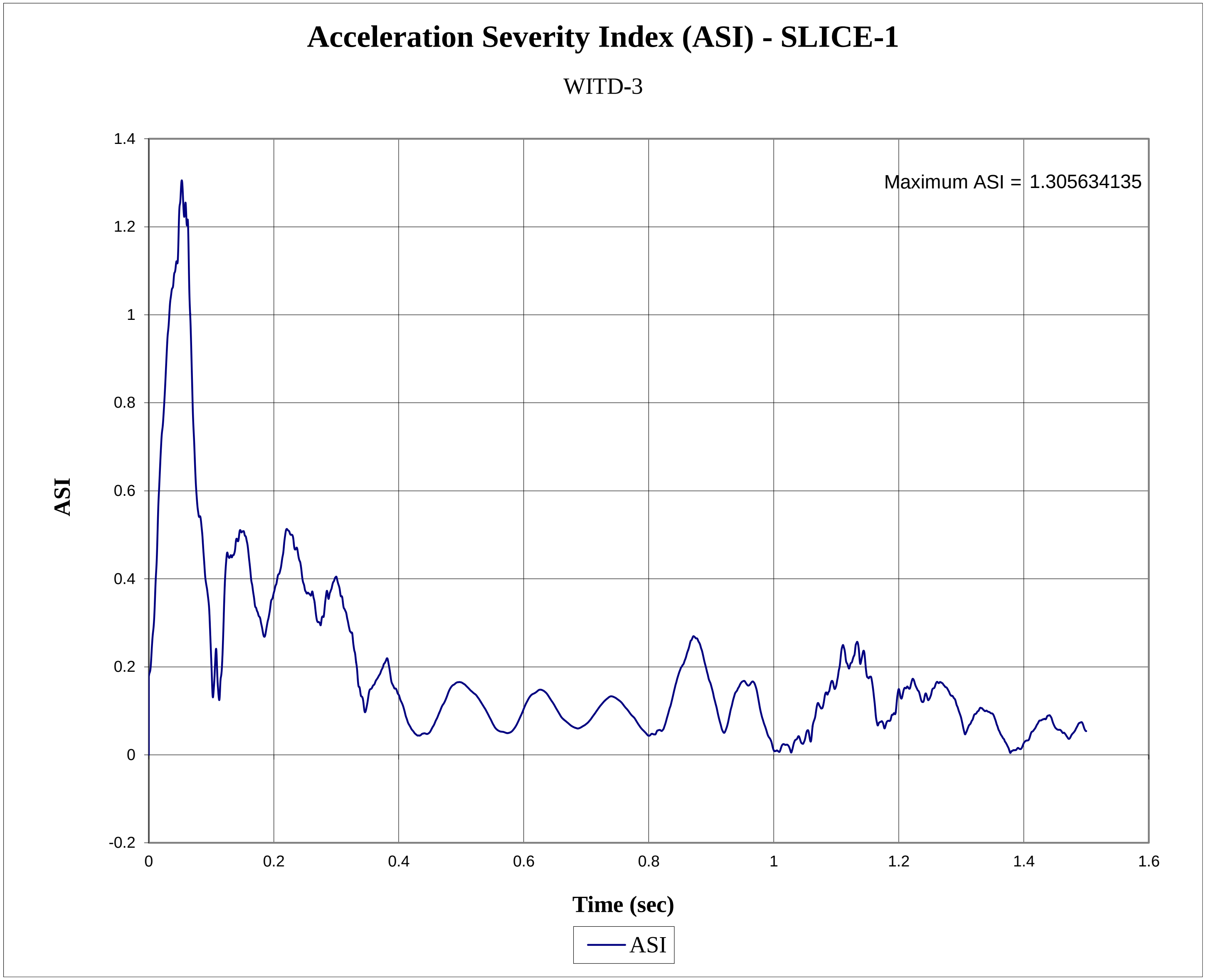


Figure D-8. Acceleration Severity Index (SLICE-1), Test No. WITD-3

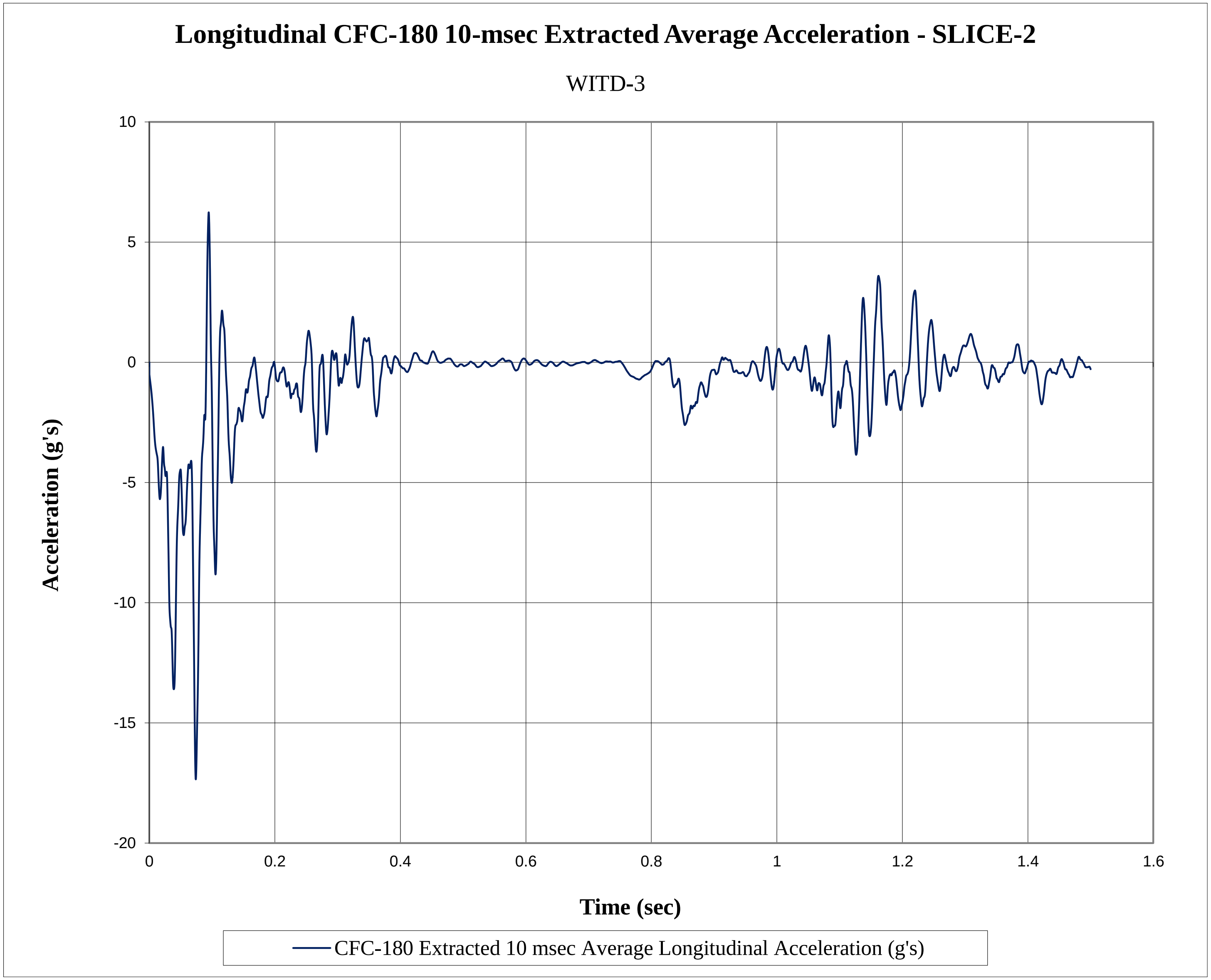


Figure D-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. WITD-3

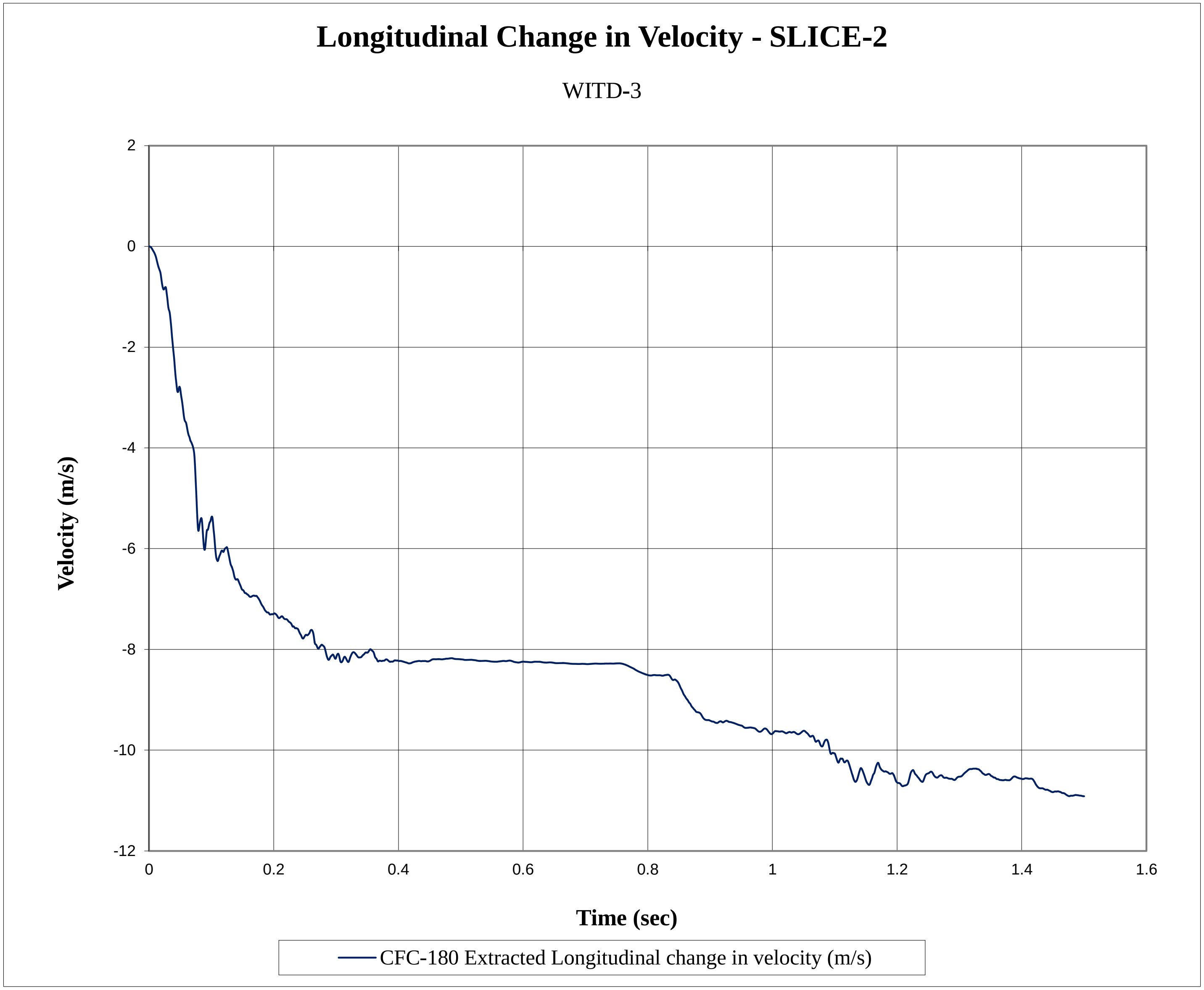


Figure D-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. WITD-3

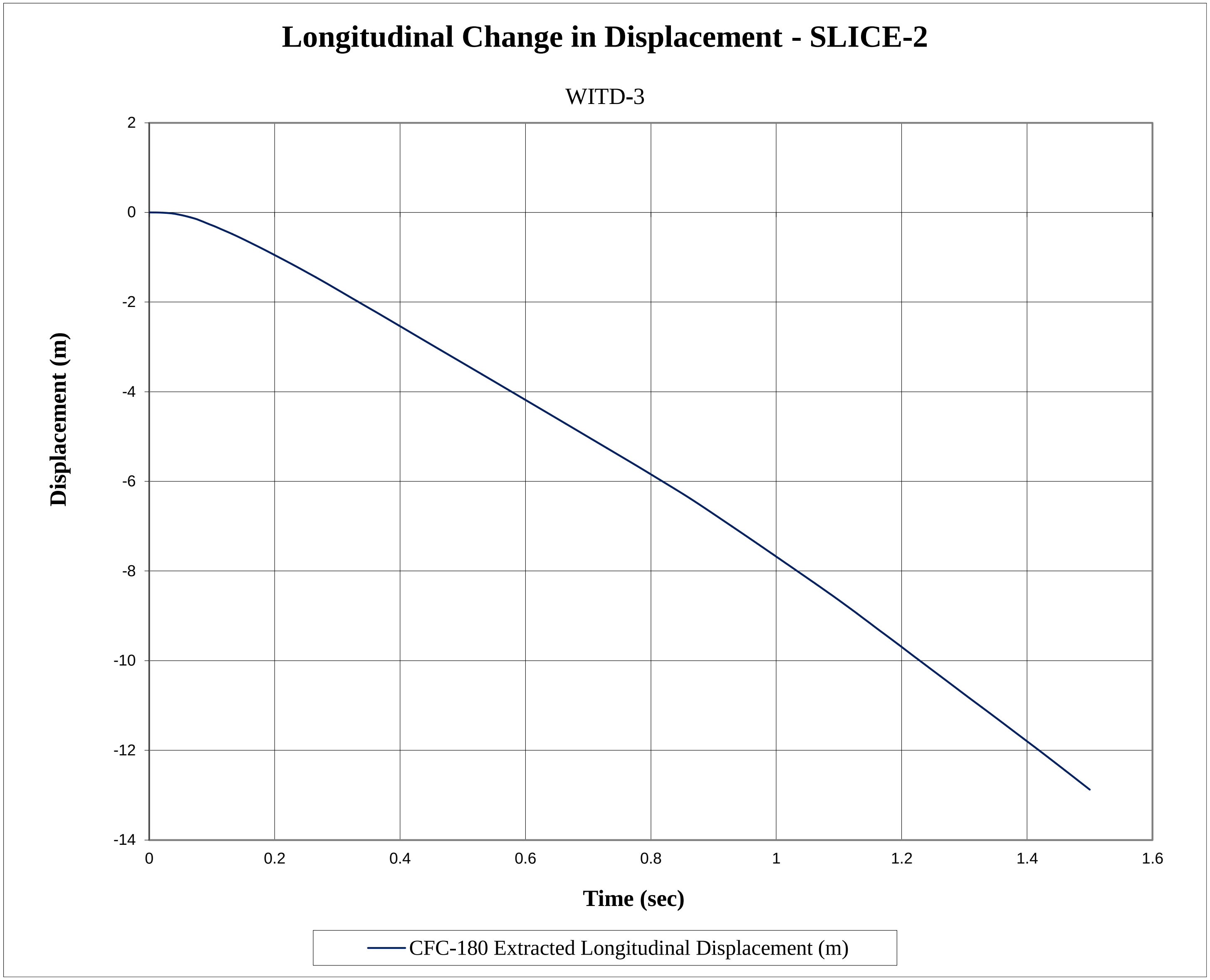


Figure D-11. Longitudinal Occupant Displacement (SLICE-2), Test No. WITD-3

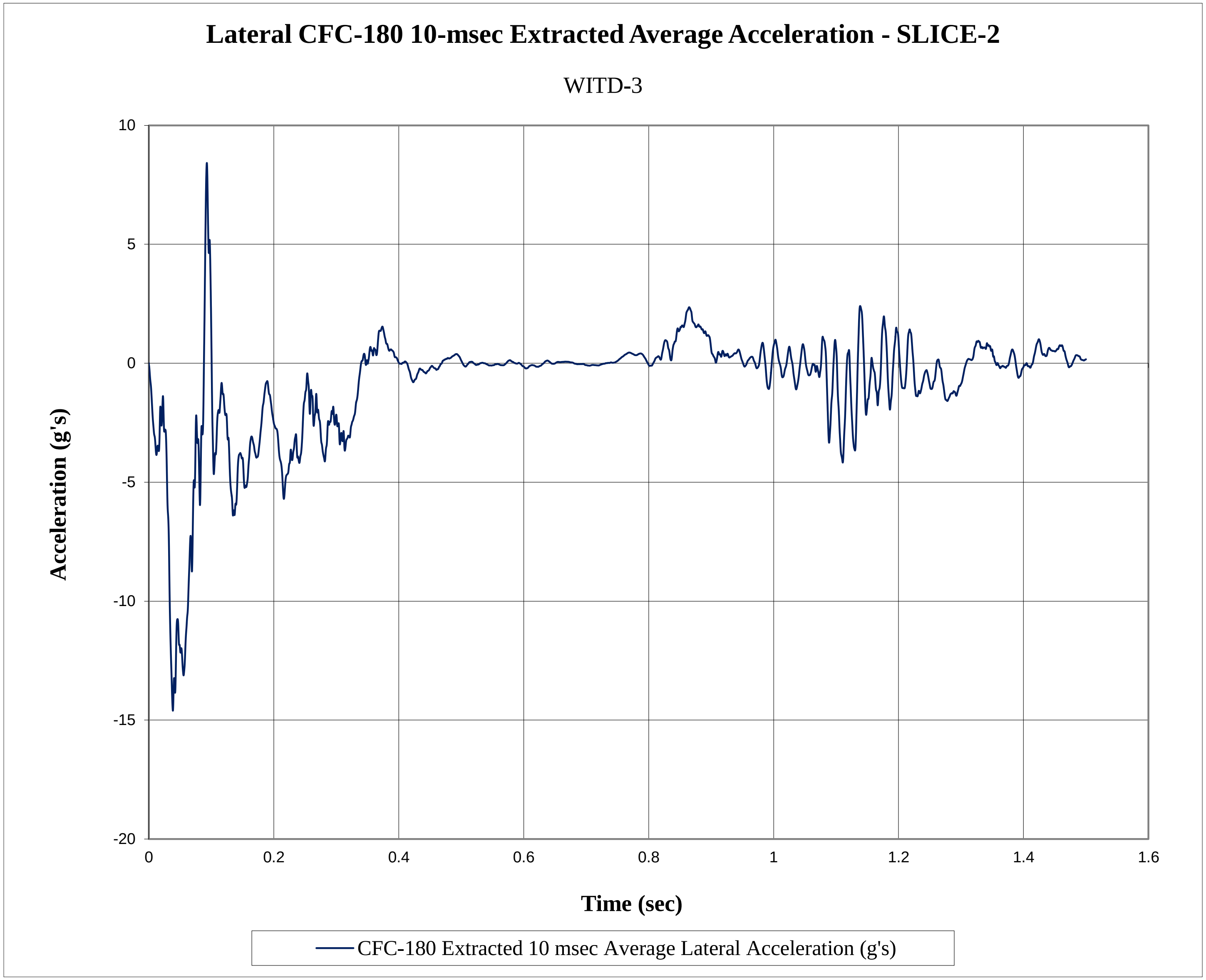


Figure D-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. WITD-3

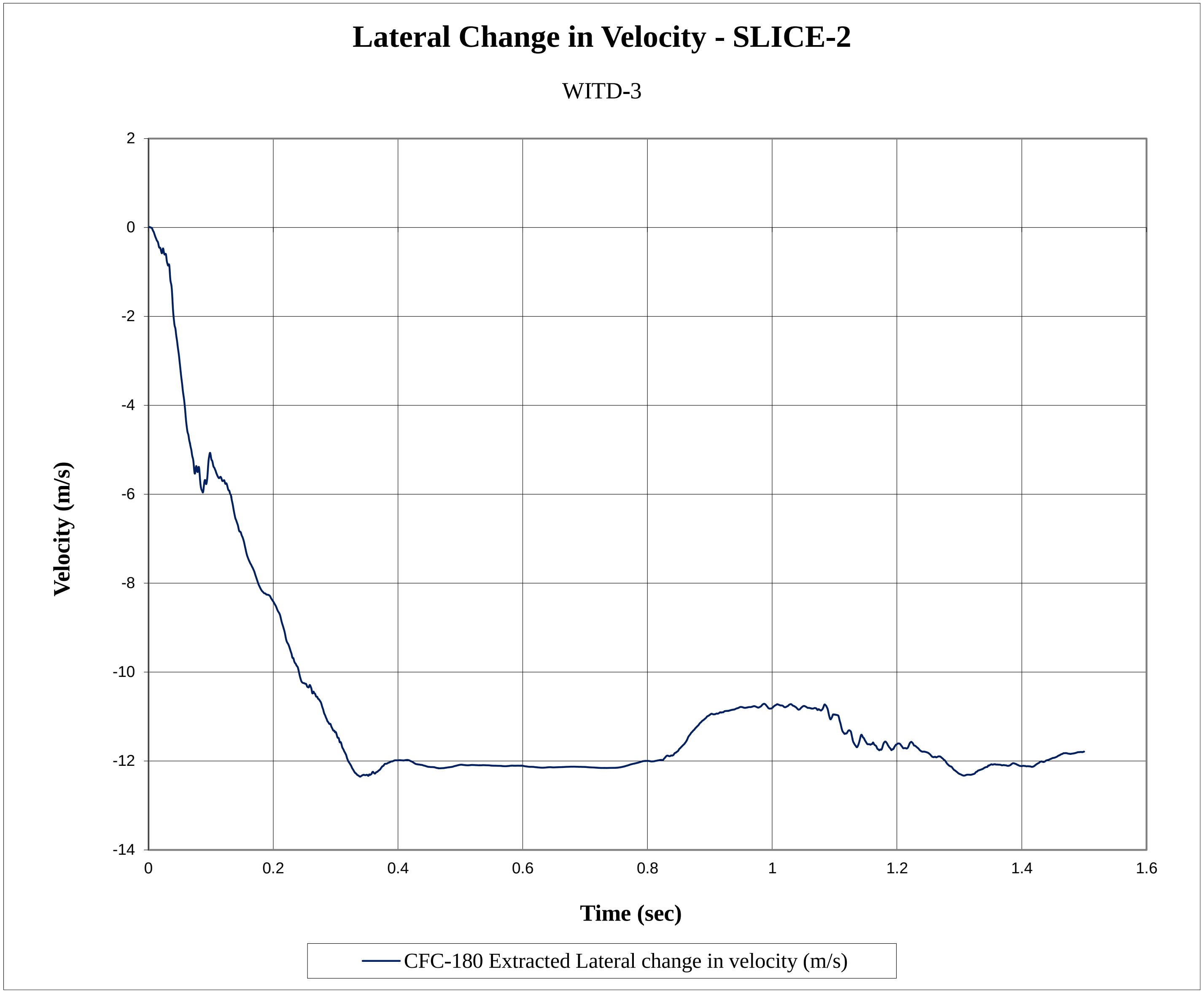


Figure D-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. WITD-3

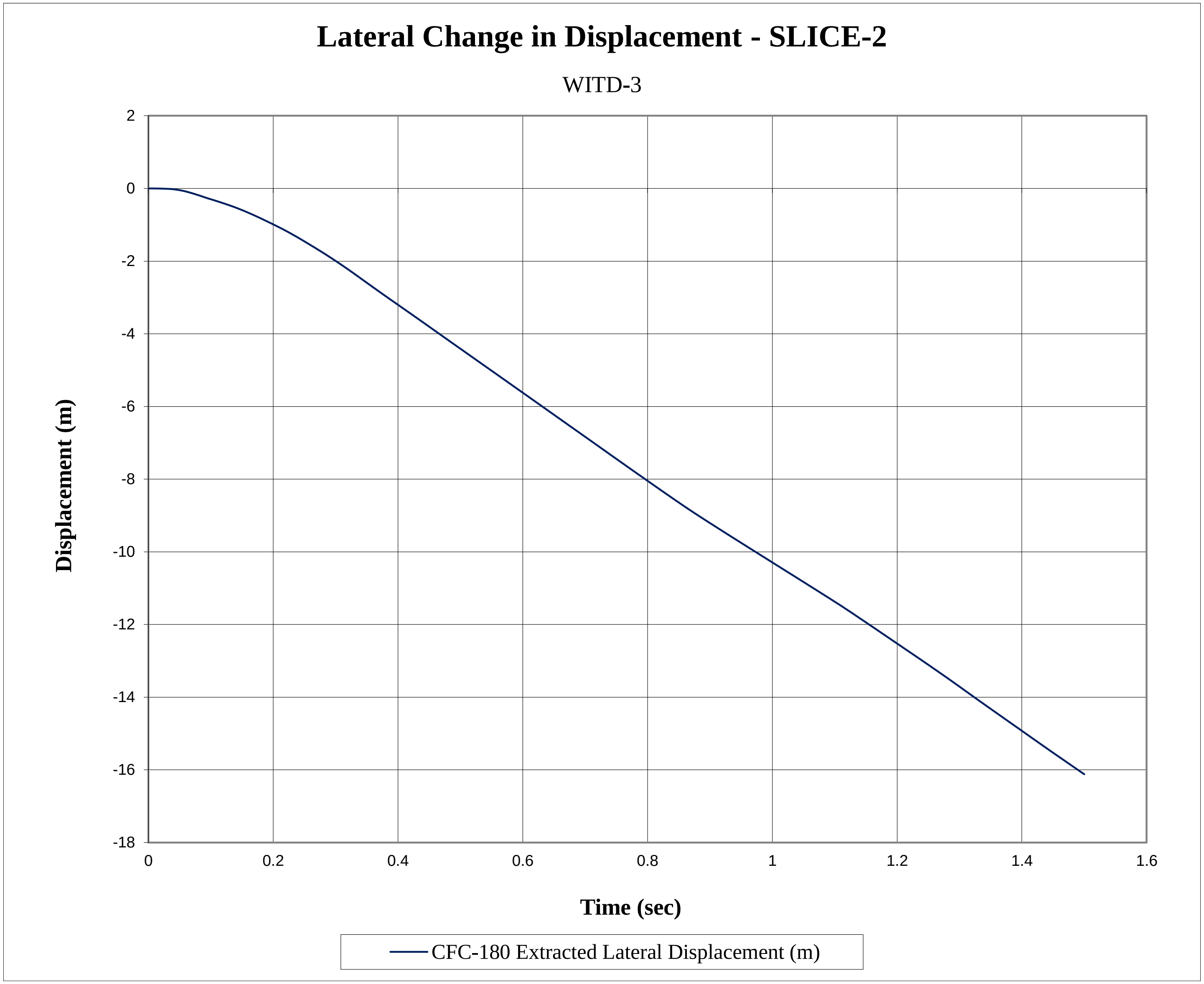


Figure D-14. Lateral Occupant Displacement (SLICE-2), Test No. WITD-3

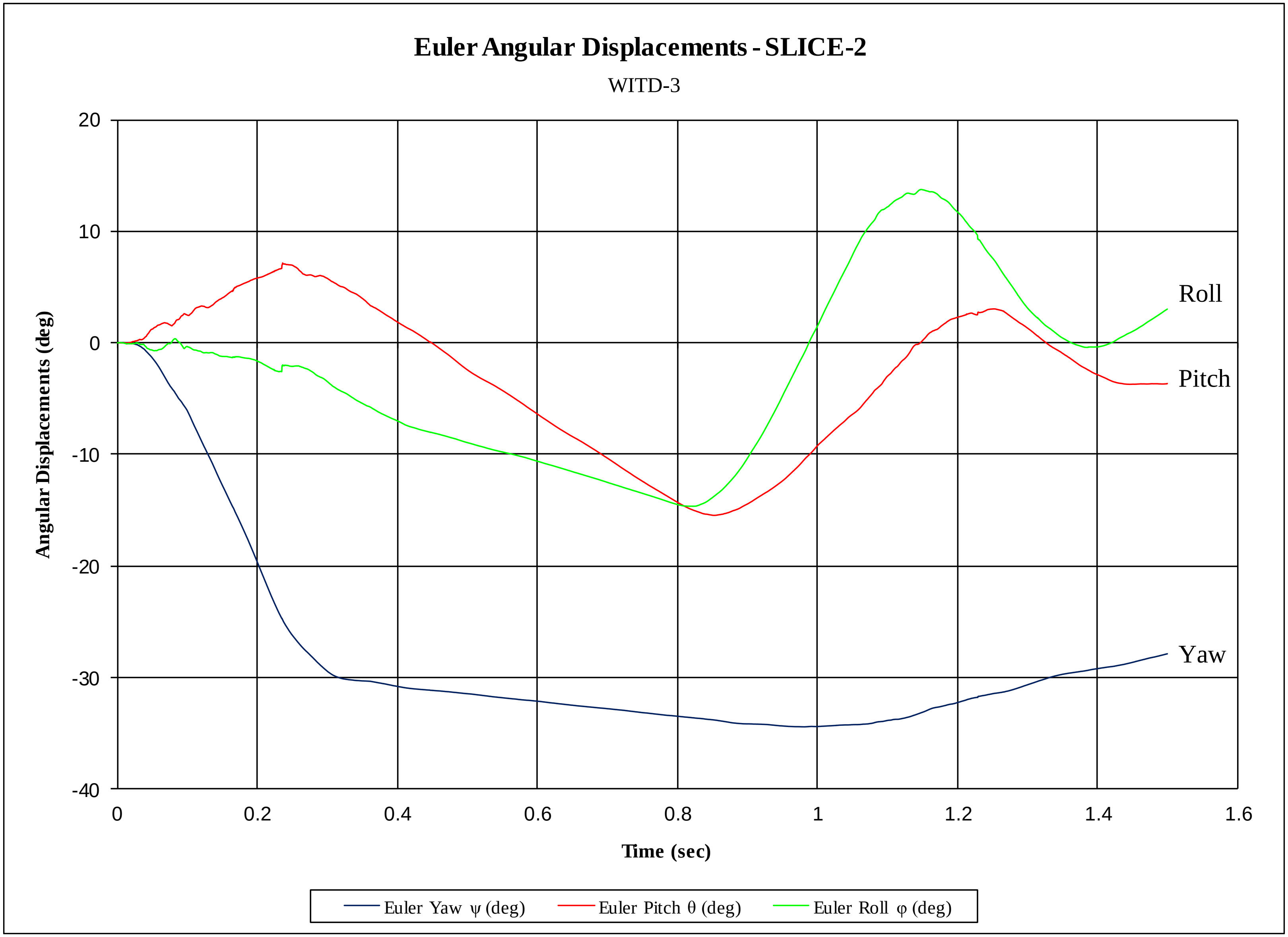


Figure D-15. Vehicle Angular Displacements (SLICE-2), Test No. WITD-3

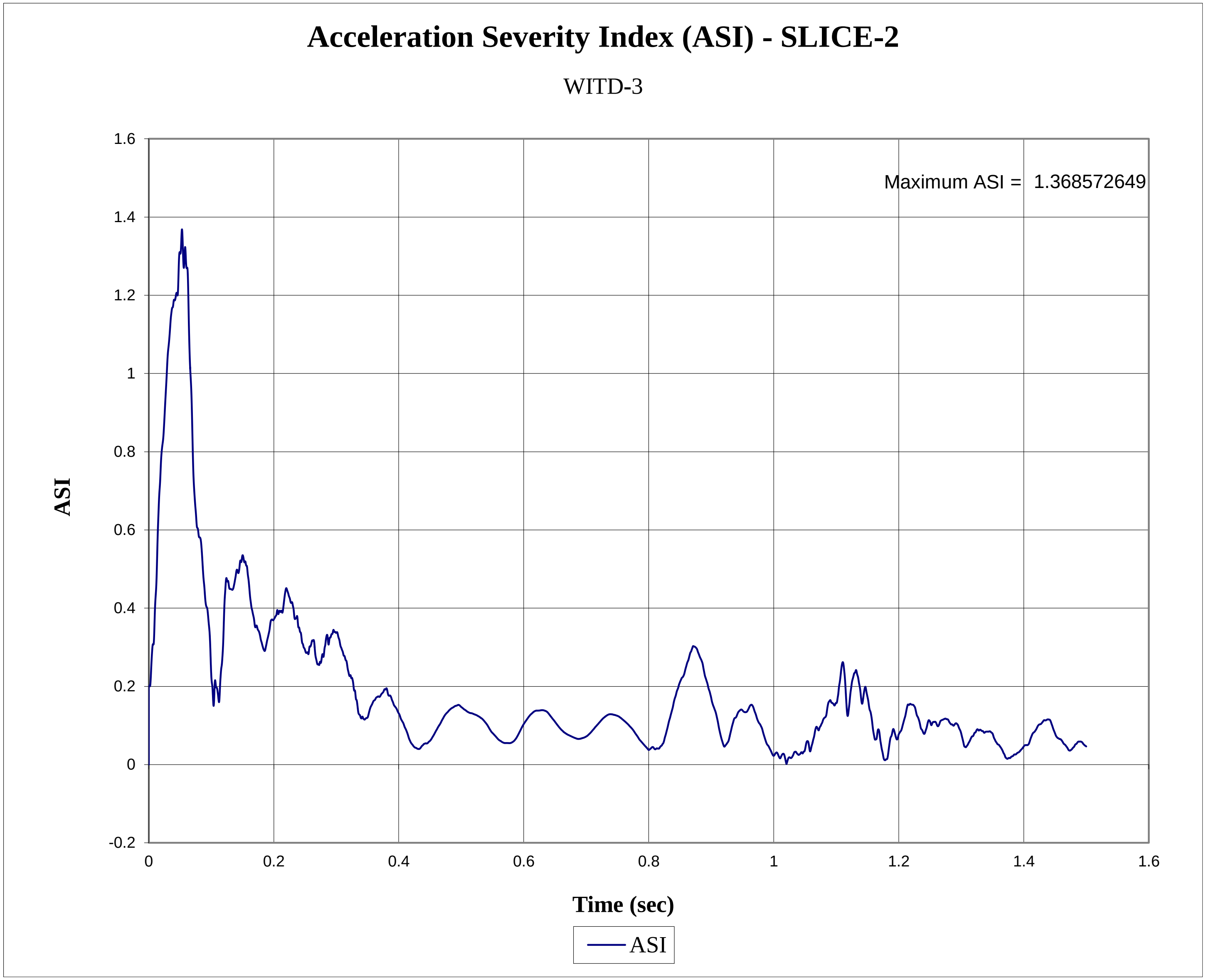


Figure D-16. Acceleration Severity Index (SLICE-2), Test No. WITD-3

END OF DOCUMENT