Midwest Pooled Fund Research Program
Fiscal Years 2017-2019 (Years 28 and 30)
Research Project Number TPF-5(193) Supplement #123
NDOT Sponsoring Agency Code RPFP-18-BULLNOSE

PHASE I MASH TESTING OF A THRIE BEAM BULLNOSE WITH BREAKAWAY STEEL POSTS (TEST NOS. MSPBN-1, -2, AND -3)

Submitted by

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

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

Thomas J. Ammon
Former Graduate Research Assistant

James C. Holloway, M.S.M.E., E.I.T.
Research Engineer & Assistant Director – Physical Testing Division

Karla A. Lechtenberg, M.S.M.E., E.I.T.
Research Engineer

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

MIDWEST POOLED FUND PROGRAM
Nebraska Department of Transportation
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

MwRSF Research Report No. TRP-03-389-20

August 27, 2020

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.
TRP-03-389-20

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Phase I MASH Testing of a Thrie Beam Bullnose with Breakaway Steel Posts (Test Nos. MSPBN-1, -2, and -3)

5. Report Date
August 27, 2020

6. Performing Organization Code

7. Author(s)
Bielenberg, R.W., Faller, R.K., Ammon, T.J., Holloway, J.C., and Lechtenberg, K.A.

8. **Performing Organization Report No.**
TRP-03-389-19

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 #123

12. Sponsoring Agnecy Name and Address
Midwest Pooled Fund Program
Nebraska Department of Transportation
1500 Nebraska Highway 2
Lincoln, Nebraska 68502

13. Type of Report and Period Covered
Final Report: 2017 – 2020

14. Sponsoring Agency Code
RPFP-18-BULLNOSE

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

16. Abstract
The objective of this research study was to evaluate the thrie-beam bullnose system using Universal Breakaway Steel Posts (UBSPs) to *Manual for Assessing Safety Hardware* (MASH 2016) criteria. In Phase I, three full-scale crash tests were conducted to evaluate the bullnose design. The crash tests were conducted according to the TL-3 criteria outlined in MASH 2016. The first test, test no. MSPBN-1, was conducted according to MASH 2016 test designation no. 3-35 with a 2270P vehicle at a speed of 62.9 mph (101.3 km/h) and an angle of 25.1 degrees. Test no. MSPBN-1 was conducted to examine the non-gating, thrie-beam bullnose crash cushion at critical impact point on the system where the behavior transitioned from capture to redirection. The second test, test no. MSPBN-2, was conducted according to MASH 2016 test designation no. 3-34 with an 1100C vehicle at a speed of 62.1 mph (100.0 km/h) and an angle of 14.7 degrees. Test no. MSPBN-2 was conducted to evaluate the impact performance of the bullnose as the device behavior changed from capture to redirection. The third test, test no. MSPBN-3, was conducted according to MASH 2016 test designation no. 3-32 with an 1100C vehicle at a speed of 62.7 mph (101.0 km/h) and an angle of 15.1 degrees. Test no. MPSNB-3 was conducted to evaluate the bullnose behavior during oblique impacts on the end or nose of the system.

The tests were successful and met the MASH 2016 TL-3 safety requirements. Based on the successful completion of the first three critical tests in the MASH 2016 evaluation of the thrie-beam bullnose, it is believed that the remaining MASH 2016 TL-3 test matrix should be completed to certify the MASH 2016 compliance of the thrie beam bullnose system.

17. Key Words
Highway Safety, Crash Test, Roadside Appurtenances, Median, Compliance Test, MASH, Bullnose, Thrie Beam, UBSP, Universal Breakaway Steel Post, BCT, Guardrail Envelope, and Crash Cushion

18. Distribution Statement
No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161

19. Security Classification (of this report)	**20. Security Classification (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	257	

DISCLAIMER STATEMENT

This material is based upon work supported by the Federal Highway Administration, U.S. Department of Transportation and the Midwest Pooled Fund Program under TPF-5(193) Supplement #123. 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 University of Nebraska-Lincoln, state highway departments participating in the Midwest Pooled Fund Program nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names, which may appear in this report, are cited only because they are considered essential to the objectives of the report. The United States (U.S.) government and the State of Nebraska 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. Jennifer Rasmussen.

ACKNOWLEDGEMENTS

The authors wish to acknowledge several sources that made a contribution to this project: the Midwest Pooled Fund Program funded by the California Department of Transportation, Florida Department of Transportation, Georgia Department of Transportation, Hawaii Department of Transportation, Illinois Department of Transportation, Indiana Department of Transportation, Iowa Department of Transportation, Kansas Department of Transportation, Kentucky Department of Transportation, Minnesota Department of Transportation, Missouri Department of Transportation, Nebraska Department of Transportation, New Jersey Department of Transportation, North Carolina Department of Transportation, Ohio Department of Transportation, South Carolina Department of Transportation, South Dakota Department of Transportation, Utah Department of Transportation, Virginia Department of Transportation, Wisconsin Department of Transportation, and Wyoming Department of Transportation for sponsoring this project; and (2) MwRSF personnel for constructing the barriers and conducting the crash tests.

Acknowledgement is also given to the following individuals who made a contribution to the completion of this research project.

Midwest Roadside Safety Facility
J.D. Reid, Ph.D., Professor
S.K. Rosenbaugh, M.S.C.E., E.I.T., Research Engineer
J.D. Rasmussen, Ph.D., P.E., Research Associate Professor
C.S. Stolle, Ph.D., E.I.T., Research Assistant Professor
J.S. Steelman, Ph.D., P.E., Associate Professor
M. Asadollahi Pajouh, Ph.D., P.E., 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., CAD Technician
E.L. Urbank, B.A., Research Communication Specialist
Z.Z. Jabr, Engineering Technician
Undergraduate and Graduate Research Assistants

California Department of Transportation
Bob Meline, Chief, Roadside Safety Research Branch
David Whitesel, P.E., Transportation Engineer
John Jewell, P.E., Senior Transportation Engineer, Specialist

Florida Department of Transportation
Derwood C. Sheppard, Jr., P.E., Design Standards Publication Manager, Roadway Design Engineer

Georgia Department of Transportation
Brent Story, P.E., State Design Policy Engineer
Frank Flanders IV, P.E., Assistant State Design Policy Engineer

Hawaii Department of Transportation
James Fu, P.E., State Bridge Engineer
Dean Takiguchi, P.E., Engineer, Bridge Design Section
Kimberly Okamura, Engineer, Bridge Design Section

Illinois Department of Transportation
Filiberto Sotelo, Safety Evaluation Engineer
Martha Brown, P.E., Safety Evaluation Unit Chief

Indiana Department of Transportation
Katherine Smutzer, P.E., Standards Engineer
Elizabeth Phillips, P.E., Standards and Policy Manager

Iowa Department of Transportation
Chris Poole, P.E., Roadside Safety Engineer
Brian Smith, P.E., Methods Engineer
Daniel Harness, P.E., Transportation Engineer Specialist
Stuart Nielsen, P.E., Transportation Engineer Administrator, Design
Elijah Gansen, P.E., Geometrics Engineer

Kansas Department of Transportation
Ron Seitz, P.E., Director of Design
Scott King, P.E., Road Design Bureau Chief
Thomas Rhoads, P.E., Road Design Leader, Bureau of Road Design
Brian Kierath Jr., Engineering Associate III, Bureau of Road Design

Kentucky Department of Transportation
Jason J. Siwula, P.E., Assistant State Highway Engineer
Kevin Martin, P.E., Transportation Engineer Specialist
Gary Newton, Engineering Tech III, Design Standards

Minnesota Department of Transportation
Michael Elle, P.E., Design Standards Engineer
Michelle Moser, P.E., Assistant Design Standards Engineer

Missouri Department of Transportation
Sarah Kleinschmit, P.E., Policy and Innovations Engineer

Nebraska Department of Transportation
Phil TenHulzen, P.E., Design Standards Engineer
Jim Knott, P.E., Construction Engineer
Mike Owen, P.E., State Roadway Design Engineer
Jodi Gibson, Former Research Coordinator
Mick Syslo, P.E., Materials and Research Engineer & Division Head
Mark Fischer, P.E., PMP, Research Program Manager
Lieska Halsey, Research Project Manager
Angela Andersen, Research Coordinator
David T. Hansen, Internal Research Coordinator

New Jersey Department of Transportation
Hung Tang, Senior Engineer, Transportation
Joseph Warren, Assistant Engineer, Transportation

North Carolina Department of Transportation
Neil Mastin, P.E., Manager, Transportation Program Management – Research and Development
D. D. “Bucky” Galloway, P.E., CPM, Field Operations Engineer
Brian Mayhew, P.E., State Traffic Safety Engineer
Joel Howerton, P.E., Plans and Standards Engineer

Ohio Department of Transportation
Don Fisher, P.E., Roadway Standards Engineer

South Carolina Department of Transportation
J. Adam Hixon, P.E., Design Standards Associate
Mark H. Anthony, P.E., Letting Preparation Engineer
Henry Cross, P.E., Design Standards Engineer
Jason Hall, P.E., Engineer

South Dakota Department of Transportation
David Huft, P.E., Research Engineer
Bernie Clocksin, P.E., Standards Engineer

Utah Department of Transportation
Shawn Debenham, Traffic and Safety Specialist
Glenn Blackwelder, Operations Engineer

Virginia Department of Transportation
Charles Patterson, P.E., Standards/Special Design Section Manager
Andrew Zickler, P.E., Complex Bridge Design and ABC Support Program Manager

Wisconsin Department of Transportation
Erik Emerson, P.E., Standards Development Engineer
Rodney Taylor, P.E., Roadway Design Standards Unit Supervisor

Wyoming Department of Transportation
William Wilson, P.E., Architectural and Highway Standards Engineer

Federal Highway Administration
David Mraz, Division Bridge Engineer, Nebraska Division Office

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

In 2009, the American Association of State Highway and Transportation Officials (AASHTO) implemented an updated standard for the evaluation of roadside hardware. The new standard, entitled the *Manual for Assessing Safety Hardware* (MASH 2009) [1], improved the criteria for evaluating roadside hardware beyond the previous National Cooperative Highway Research Program (NCHRP) Report No. 350 standard [2] through updates to test vehicles, test matrices, and impact conditions. In an effort to encourage state departments of transportation and hardware developers to advance hardware designs, the Federal Highway Administration (FHWA) and AASHTO collaborated to develop a MASH implementation policy that included sunset dates for various roadside hardware categories. Further, the MASH 2009 safety criteria were updated in 2016, thus resulting in the MASH 2016 document [3]. The new policy requires that devices installed on federal aid roadways after the sunset dates to have been evaluated to MASH 2016.

Midwest Pooled Fund Program members currently use several roadside hardware systems that were originally developed and evaluated under NCHRP Report No. 350 criteria. One of those systems is a non-proprietary, thrie-beam, bullnose, median barrier system that was successfully developed and crash tested for use in shielding median hazards within divided highways and roadways. Many state DOTs desire to continue to have the thrie-beam bullnose available for use following the MASH implementation dates. Thus, a need exists to evaluate the thrie-beam bullnose system to the MASH 2016 criteria.

From 1997 through 2000, the Midwest Roadside Safety Facility (MwRSF) developed a thrie-beam bullnose guardrail system for shielding median hazards found between divided highways [2, 4-6]. The new, non-proprietary bullnose guardrail system was successfully full-scale crash tested and evaluated according to the Test Level 3 (TL-3) safety performance evaluation criteria provided in NCHRP Report No. 350.

Controlled Release Terminal (CRT) wood posts were used in the original thrie-beam bullnose guardrail system. Although the CRT posts adequately met the TL-3 safety requirements, these wood posts have several drawbacks. First, the properties and performance of wood posts are highly variable due to knots, checks, and splits, thus requiring grading and inspection of posts. Second, two holes are drilled into the CRT posts that allow them to break away upon impact. These holes expose the interior of the wood to the environment, which can accelerate deterioration. Further, chemical preservatives used to treat the wood posts have been identified as harmful to the environment by some government agencies. Thus, the treated wood posts may require special consideration during disposal. Due to these concerns, a need existed for a breakaway steel post option for use in the thrie-beam bullnose guardrail system.

A Universal Breakaway Steel Post (UBSP) was developed to replace the CRT posts in the existing thrie-beam bullnose median barrier system [7-9]. The UBSP was based on a fracturing-bolt concept and was designed to match the cantilevered bending capacities of existing wood CRT posts about their strong and weak axes, as well as for a biaxial loading condition. The embedded portion of the UBSP had a similar cross section and slightly lower embedment as compared to the CRT post which provided comparable rotational resistance in the soil. The mass, general geometry, and the breakaway characteristics of the upper UBSP section were also similar to the CRT wood post. The lower portion of the UBSP consisted of a foundation tube with the lower base plate. The upper portion of the UBSP consisted of a post with the upper base plate. The bullnose system utilized Breakaway Cable Terminal (BCT) posts for the first two posts as well as for the last two anchorage posts on each side of the barrier. Post nos. 3 through 8 were UBSPs, and the remaining posts were standard thrie-beam guardrail steel posts. The system was subjected to test designation nos. 3-30, 3-31, and 3-38 of NCHRP Report No. 350 to determine if it met the TL-3 safety performance criteria and to ensure the UBSP design was providing similar performance to the original CRT posts. In all three full-scale crash tests, the vehicle was safely contained and decelerated, and the barrier did not cause vehicle instability.

After surveying the member states in the Midwest Pooled Fund Program, it was decided that the MASH 2016 evaluation of the thrie-beam bullnose system would focus on evaluation of the system with the UBSPs. If the evaluation of this post type was successful, there may be potential to evaluate the CRT post design using a smaller subset of critical tests in a subsequent research effort.

1.2 Objective

The research objective of the following report was to conduct full scale crash testing on the thrie-beam bullnose median barrier system according to the TL-3 of the MASH 2016 impact safety standards [3]. Due to the extensive number of full scale crash tests that are required to evaluate a thrie-beam bullnose system, MwRSF and the Midwest Pooled Fund Program members decided to phase the crash testing in order to efficiently determine if the thrie-beam bullnose system could meet the TL-3 criteria. Phase I, which is described herein, evaluated the bullnose design with three critical crash tests.

1.3 Scope

Three full-scale crash tests were conducted on the thrie-beam bullnose system. Test no. MSPBN-1 was conducted according to MASH 2016 test designation no. 3-35. Test designation no. 3-35 required a pickup truck weighing approximately 5,000 lb (2,268 kg) with target impact conditions of a speed of 62 mph (100 km/h) and an angle of 25 degrees. This test was completed to evaluate the non-gating, thrie-beam bullnose crash cushion at the critical impact point on the system where the behavior transitioned from capture to redirection. Test no. MSPBN-2 was conducted according to MASH 2016 test designation no. 3-34. Test designation no. 3-34 requires a small car weighing approximately 2,425 lb (1,100 kg) with target impact conditions of a speed of 62 mph (100 km/h) and an angle of 15 degrees. This test was completed to evaluate the impact performance criteria of the thrie-beam bullnose at the critical impact point on the system where the behavior transitioned from capture to redirection. Test no. MPSBN-3 was conducted according to MASH 2016 test designation no. 3-32. Test designation no. 3-32 required a small car weighing approximately 2,425 lb (1,100 kg) with target impact conditions of a speed of 62 mph (100 km/h) and an angle of 15 degrees. This test was conducted to evaluate the safety performance of the thrie-beam bullnose system when impacted at an angle by a small car vehicle on the nose or end of the system.

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

The thrie-beam bullnose system is classified as a non-gating, redirective crash cushion for the purposes of evaluation and must satisfy impact safety standards. For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [3], and as many as nine full-scale crash tests are potentially required to evaluate this type of hardware, as shown in Table 1. Note that there is no difference between MASH 2009 [1] and MASH 2016 with respect to non-gating redirective crash cushions, except that additional occupant compartment deformation measurements and photographic documentation are required by MASH 2016.

Table 1. MASH 2016 TL-3 Crash Test Conditions for Bullnose Guardrails

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed, mph (km/h)	Angle, deg.	
Terminals and Redirective Crash Cushions	3-30	1100C	2,420 (1,100)	62 (100)	0	A,D,F,H,I (non-gating)
	3-31	2270P	5,000 (2,270)	62 (100)	0	A,D,F,H,I (non-gating)
	3-32	1100C	2,425 (1,100)	62 (100)	5-15	A,D,F,H,I (non-gating)
	3-33	2270P	5,000 (2,270)	62 (100)	5-15	A,D,F,H,I (non-gating)
	3-34	1100C	2,425 (1,100)	62 (100)	15	A,D,F,H,I (non-gating)
	3-35	2270P	5,000 (2,270)	62 (100)	25	A,D,F,H,I
	3-36	2270P	5,000 (2,270)	62 (100)	25	A,D,F,H,I (non-gating)
	3-37a	2270P	5,000 (2270)	62 (100)	25	A,D,F,H,I (non-gating)
	3-37b	1100C	2,425 (1,100)	62 (100)	25	A,D,F,H,I (non-gating)
	3-38	1500A	3,300 (1,500)	62 (100)	0	A,D,F,H,I (non-gating)

[1] Evaluation criteria explained in Table 2 [3]

Table 2. MASH 2016 Evaluation Criteria for Thrie-Beam Bullnose Guardrails

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="10">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

As noted previously, Phase I of the research effort consisted of the evaluation of the thrie-beam bullnose system with three critical tests from the recommended MASH 2016 test matrix. Based on the previous development and testing of the thrie-beam bullnose system, it was believed that test designation nos. 3-32, 3-34, and 3-35 would be the most critical for evaluation of the system. Test designation nos. 3-34 and 3-35 are conducted at the critical impact point (CIP) of the non-gating, redirective crash cushions where it is unknown if the bullnose will capture or redirect the vehicle. Because of difficulties in passing tests regarding the CIP at the point of capture/redirection in past evaluations, it was believed that these tests should be evaluated early in the effort. Another concern with the bullnose system evaluation under MASH was the capture and safe deceleration of the 1100C small car vehicle. As such, it was recommended that test designation no. 3-32 be conducted early in the research effort to determine the validity of this concern.

Test designation nos. 3-34 and 3-35 are required to be conducted at a CIP where the behavior of the crash cushion transitions between capture and redirection of the impacting vehicle. In order to identify CIPs for these impacts, MwRSF reviewed previous testing of the thrie-beam bullnose system and end terminals and compared this data with the MASH 2016 impact conditions for test designation nos. 3-34 and 3-35. When testing the steel and wood post bullnose according to NCHRP Report No. 350 criteria, MwRSF conducted a test similar to MASH 2016 test designation no. 3-35 with the 2000P vehicle impacting the system at post no. 2 at an angle of 20 degrees, and it proved to be a very difficult test to pass. For reference, a schematic of the bullnose system with post numbers is provided in Figure 1. For MASH 2016 test designation no. 3-35, the impact angle increased to 25 degrees, and the mass of the pickup truck increased. Thus, there was reason to expect that when impacted at post no. 2, the bullnose system would capture the vehicle rather than redirect it. It was also expected that the potential is greater for the system to redirect the vehicle when nearing post no. 5, which is when the rail becomes parallel to the road and the impact is 12.5 ft (3.8 m) from the anchor. This behavior would correlate with post no. 3 for a standard guardrail end terminal, which is typically used for the beginning of length of need (LON) in terminal impacts. Thus, it was determined that the CIP for MASH test designation no. 3-35 be located at post no. 3, which is halfway between the cable anchor at post no. 1 and the assumed beginning of LON/redirection point at post no. 5.

A small car test of the CIP of the transition from capture to redirection was not conducted on the thrie-beam bullnose under NCHRP Report No. 350 as it was not required. Due to the lack of previous thrie-beam bullnose data related to this test, the researchers reviewed MASH terminal testing for the MSKT [10] and the SoftStop [11]. Note that these systems have posts a 75-in. post spacing while the bullnose uses 37 ½-in. post spacing, as shown in Figure 1. Test designation no. 3-34 on the SoftStop impacted at post no. 1 in the system (at the impact head). Test designation no. 3-35 on the Softstop was conducted at the beginning of LON, and the impact point was at post no. 3. For the MSKT, test designation no. 3-34 was conducted with the impact point at post no. 2, and test designation no. 3-35 was conducted with the impact point at post no. 3. Thus, it appeared that test designation no. 3-34 has been typically conducted upstream from the system's LON point based on the test having a reduced impact angle of 15 degrees and the lighter vehicle mass than test designation no. 3-35. Because the thrie-beam bullnose uses as similar cable anchorage to existing end terminal designs near the nose, it was believed that test designation no. 3-34 should be conducted upstream of the LON for end terminals, which would correspond to the third post on a typical end terminal and the fifth post on the thrie-beam bullnose. Additionally, it was noted previously that test designation no. 3-35 should be conducted on the thrie-beam bullnose with the CIP located at post no. 3. Thus, the 1100C impact in test designation no. 3-34 should be located upstream from post no. 3 due to the lighter vehicle mass and reduced impact angle. Placement of the CIP at post no. 1 would eliminate the potential for vehicle redirection as the cable anchorage is connected to that post. Thus, post no. 2 on the thrie-beam bullnose was selected as the CIP for evaluation of the transition of the system's behavior from capture to redirection for test designation no. 3-34.

Finally, MASH 2016 test designation no. 3-32 consists of a 1100C vehicle impacting the center of the nose of the system at an angle ranging from 5 to 15 degrees. The lower end of the angle range is typically recommended for evaluation of gating end terminal systems. MASH 2016 recommends that non-gating redirective systems be impacted at a 15-degree angle for this test.

Thus, the thrie-beam bullnose was evaluated with at 15-degree impact angle in test designation no. 3-32.

It should be noted that the remaining tests recommended in the MASH 2016 test matrix for non-gating, redirective crash cushions will be addressed in subsequent research if the initial critical tests are successful.

2.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the bullnose guardrail to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH 2016. The full-scale vehicle crash tests documented herein were conducted and reported in accordance with the procedures provided in MASH 2016.

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

2.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH 2016, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, additional W6x16 (W152x23.8) posts are installed near the impact region utilizing the same installation procedures as the system itself. Prior to full-scale testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips (33.4 kN) at post deflections between 5 and 20 in. (127 and 508 mm) measured at a height of 25 in. (635 mm). If dynamic testing near the system is not desired, MASH 2016 permits a static test to be conducted instead and compared against the results of a previously established baseline test. In this situation, the soil must provide a resistance of at least 90% of the static baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Further details can be found in Appendix B of MASH 2016.

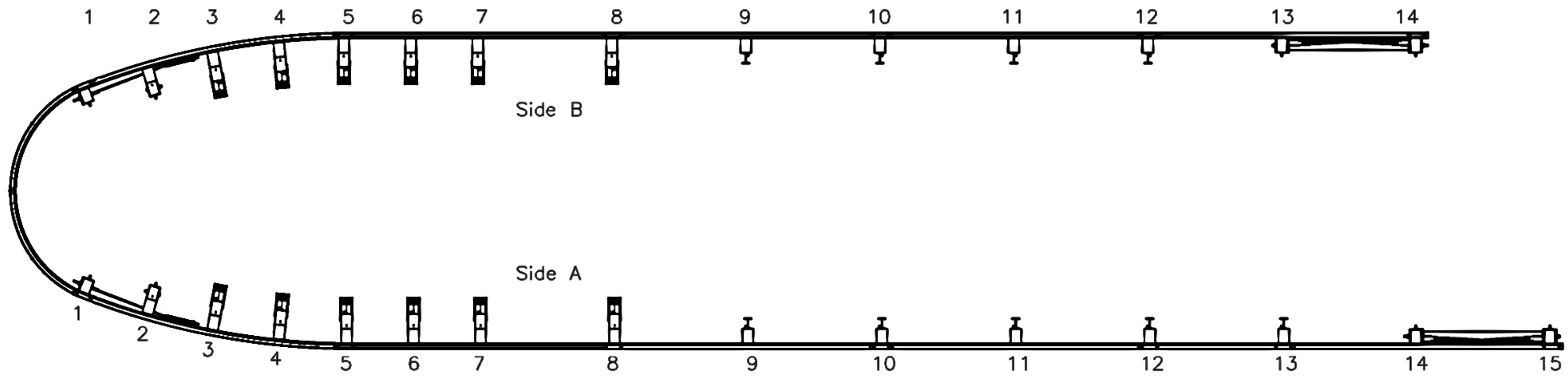


Figure 1. Bullnose Schematic with Post Nos.

3 DESIGN DETAILS

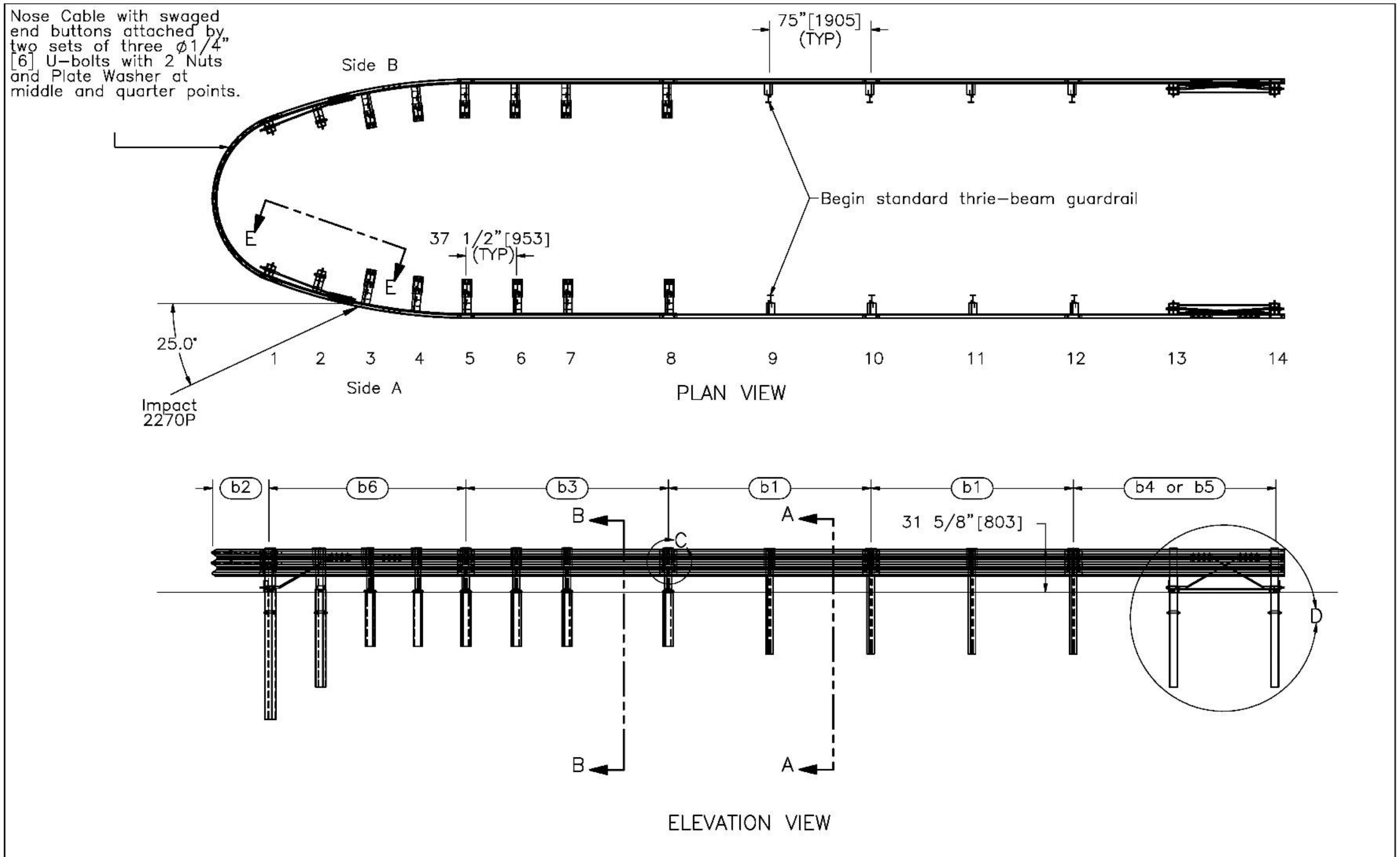
The test installation consisted of a thrie-beam, bullnose median barrier system, which utilized USBPs, as shown in Figures 2 through 27. Photographs of the test installations are shown in Figures 28 through 35. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

A one-half barrier system was utilized for the testing program in order to reduce costs and construction time. Note that a dual cable end anchorage was used on each end of the system to provide tensile and compressive resistance at the end of the one-half barrier system, thus mimicking the proper resistance of a complete installation. The 177¼-in. (4502-mm) bullnose system was constructed with twenty-eight posts, with fourteen posts positioned on each side of the system. The two sides of the system were labeled Side A and Side B, and their posts were numbered A1 to A14 and B1 to B14 respectively. Each side of the system contained two BCT posts, six UBSPs, four W6x8.5 standard guardrail posts, and two BCT anchorage posts, respectively, from the nose of the system. Note that both W6x8.5 and W6x9 post sections have been typically been allowed for both the line posts and the upper section of the UBSP as these posts have very similar section properties and have been used interchangeably in guardrail systems. The lower portion of the UBSP consisted of a foundation tube with the lower base plate. The upper portion of the UBSP consisted of a post with the upper base plate. The upper and lower halves of the UBSP were connected with a series of four bolts that were designed to allow the upper portion of the post to disengage a specific force levels when loaded in the lateral and longitudinal directions.

Two minor modifications were made to the UBSP as compared to iterations of the post design evaluated in previous research efforts [7-9, 12]. First, several weld sizes were altered for the welds connecting the W-section to the upper base plate and the tube to the lower base plate. These welds were reduced in size as the original welds were specified too large for the thickness of the welded parts and the additional weld was unnecessary. Thus, the weld connecting the top of the W6x8.5 post to the upper baseplate was changed to a ¼-in. (6-mm) fillet weld on the front and back of each post flange and to a $^{3}/_{16}$-in. (5-mm) fillet weld on each side of the web. The weld connecting the tube to the lower base plate was changed to a $^{3}/_{16}$-in. (5-mm) fillet weld around the tube.

The second modification to the UBSP was a slight increase of the thickness of the base plate on the lower section of the post. Previous full-scale crash testing of systems with the UBSP demonstrated a tendency for deformation of the lower base plate during impact events. A slight increase in the thickness of the base plate was not expected to degrade the performance of the UBSP. However, it was anticipated that the thickness increase could prevent damage to the lower section of the UBSP and allow the lower section to be reused in an installation. Reuse of the base of the post would provide a significant reduction in the repair costs of the system by eliminating the need to dig up and replace the UBSP following an impact. Thus, the thickness of the base plate on the lower section of the post was increased from ½ in. (13 mm) to ⅝ in. (16 mm).

All posts were embedded in a coarse, crushed limestone aggregate. The soil was compacted in 3-ft (610-mm) diameter augured holes using 8-in. (203-mm) lifts. Also, the fracturing bolts in the breakaway posts were torqued to 60 to 75 ft-lb (81.3 to 101.7 N-m) for the full-scale crash testing program.



Notes: (1) The test shall be performed to test designation no. 3-35 of MASH criteria.
(2) The impact location is centerline of post no. 3.
(3) All posts are to be installed using ⌀3' [914] augered holes with the HE8 compaction method.
(4) BCT Anchors are to be placed in ⌀3' [914] holes and backfilled with soil.

MwRSF Midwest Roadside Safety Facility	Bullnose with UBSP Test No. MSPBN-1	SHEET: 1 of 24
		DATE: 4/17/2020
	System Layout	DRAWN BY: MES/JEK/DT M/MKB/JDJ
	DWG. NAME. Bullnose_R19	SCALE: 1:100 UNITS: In.[mm]
		REV. BY: JEK/KAL/R WB/JCH

Figure 2. Test Installation Layout, Test Nos. MSPBN-1

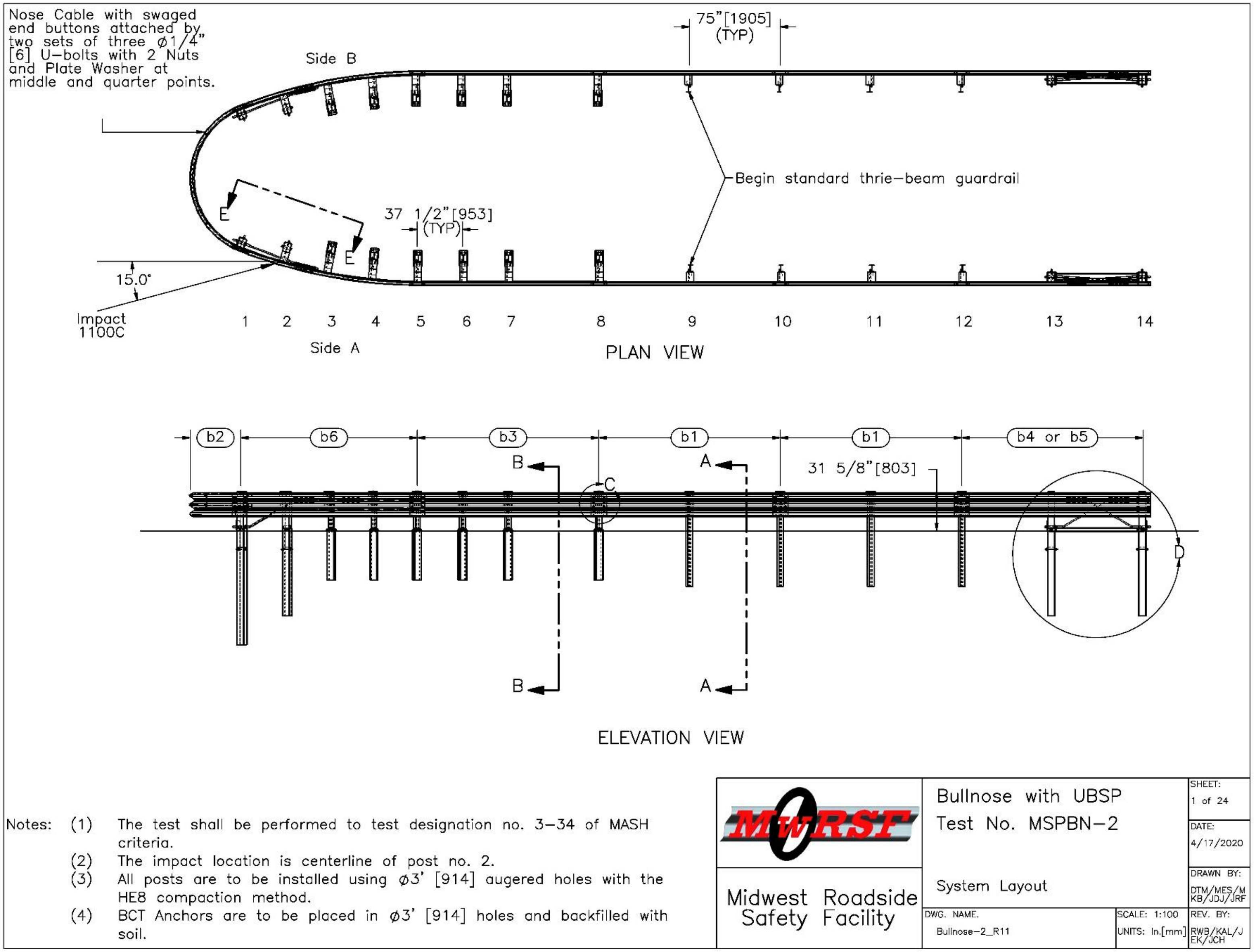
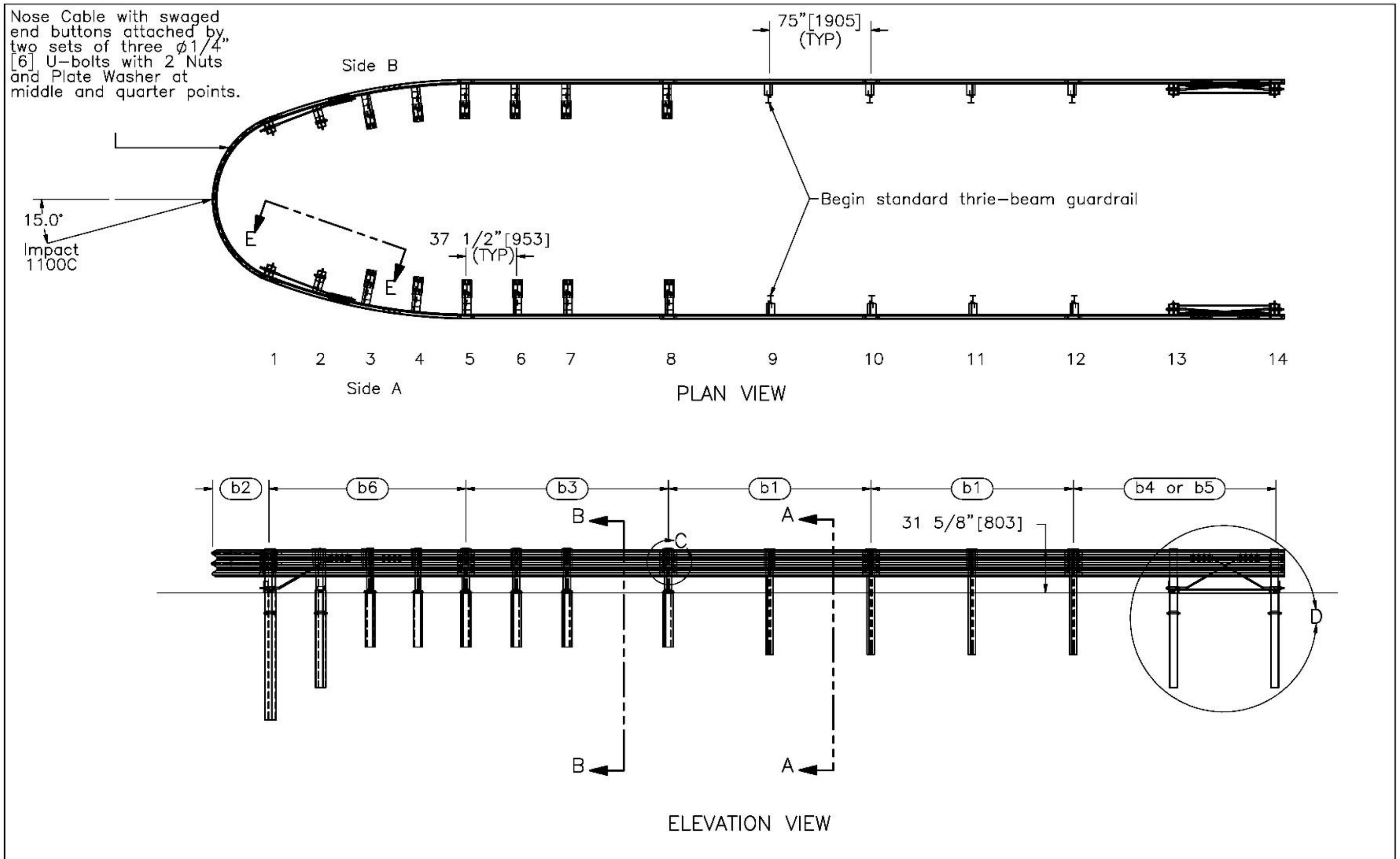


Figure 3. Test Installation Layout, Test No. MSPBN-2

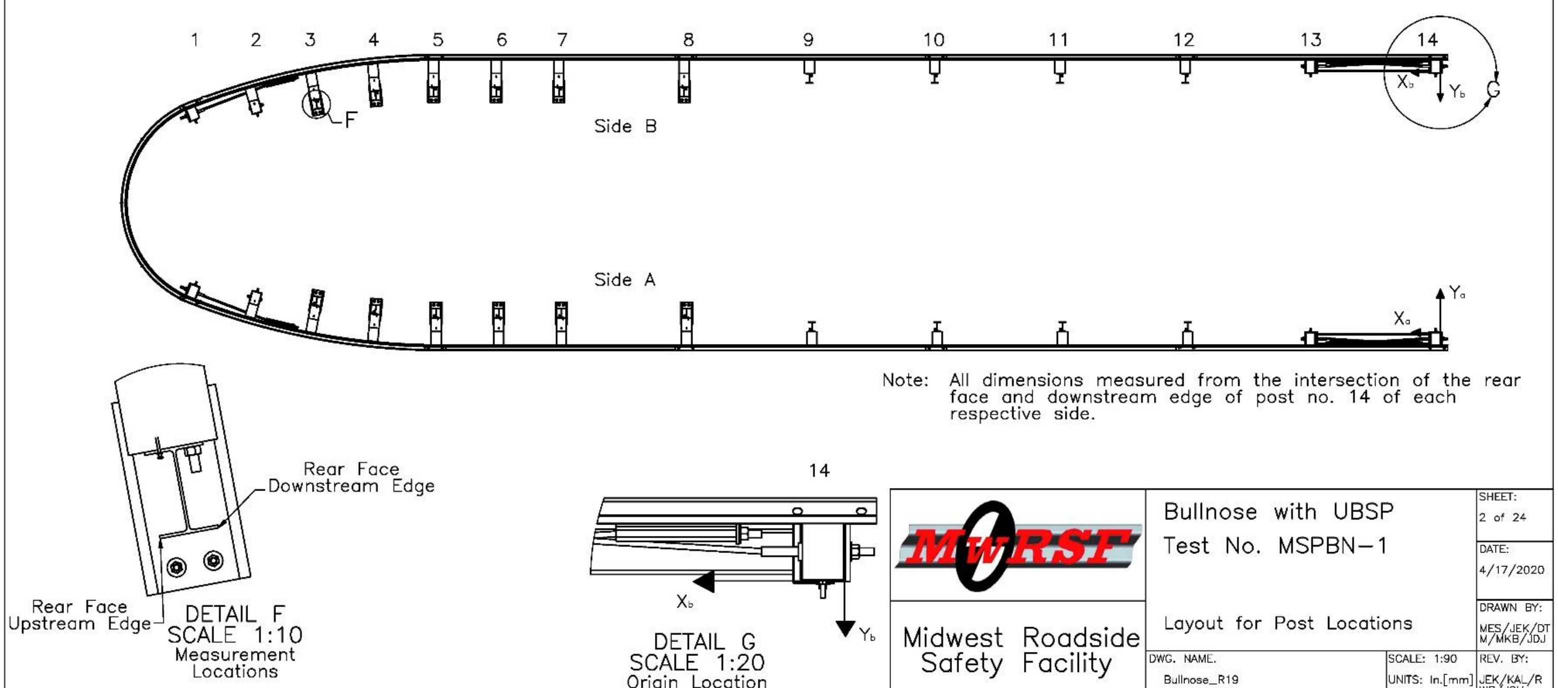


Notes: (1) The test shall be performed to test designation no. 3–32 of MASH criteria.
(2) The impact location is the bullnose tip.
(3) All posts are to be installed using ø3' [914] augered holes with the HE8 compaction method.
(4) BCT Anchors are to be placed in ø3' [914] holes and backfilled with soil.

MwRSF	Bullnose with UBSP Test No. MSPBN–3		SHEET: 1 of 24
			DATE: 4/17/2020
Midwest Roadside Safety Facility	System Layout		DRAWN BY: DTM/MES/M KB/JDJ/JRF
	DWG. NAME. Bullnose–3_R11	SCALE: 1:100 UNITS: In.[mm]	REV. BY: RWB/KAL/ JEK/JCH

Figure 4. Test Installation Layout, Test No. MSPBN-3

Post No.	Side A				Side B			
	Rear Face–DS Edge		Rear Face–US Edge		Rear Face–DS Edge		Rear Face–US Edge	
	X	Y	X	Y	X	Y	X	Y
1	61'–10 7/8"	2'–3 1/8"	62'–4"	2'–5 1/8"	61'–10 7/8"	2'–3 1/8"	62'–4"	2'–5 1/8"
2	58'–9 3/4"	1'–11 1/4"	59'–3 1/8"	2'–0 3/4"	58'–9 3/4"	1'–11 1/4"	59'–3 1/8"	2'–0 3/4"
3	55'–10 1/4"	1'–9 3/8"	56'–2 1/8"	1'–10 1/8"	55'–10 1/4"	1'–9 3/8"	56'–2 1/8"	1'–10 1/8"
4	52'–11 1/4"	1'–4 3/8"	53'–3 1/8"	1'–4 3/4"	52'–11 1/4"	1'–4 3/8"	53'–3 1/8"	1'–4 3/4"
5	50'–0 3/4"	1'–2 3/8"	50'–4 3/4"	1'–2 3/8"	50'–0 3/4"	1'–2 3/8"	50'–4 3/4"	1'–2 3/8"
6	46'–11 1/4"	1'–2 3/8"	47'–3 1/4"	1'–2 3/8"	46'–11 1/4"	1'–2 3/8"	47'–3 1/4"	1'–2 3/8"
7	43'–9 3/4"	1'–2 3/8"	44'–1 3/4"	1'–2 3/8"	43'–9 3/4"	1'–2 3/8"	44'–1 3/4"	1'–2 3/8"
8	37'–6 3/4"	1'–2 3/8"	37'–10 3/4"	1'–2 3/8"	37'–6 3/4"	1'–2 3/8"	37'–10 3/4"	1'–2 3/8"
9	31'–3 3/4"	6 3/8"	31'–7 3/4"	6 3/8"	31'–3 3/4"	6 3/8"	31'–7 3/4"	6 3/8"
10	25'–0 3/4"	6 3/8"	25'–4 3/4"	6 3/8"	25'–0 3/4"	6 3/8"	25'–4 3/4"	6 3/8"
11	18'–9 3/4"	6 3/8"	19'–1 3/4"	6 3/8"	18'–9 3/4"	6 3/8"	19'–1 3/4"	6 3/8"
12	12'–6 3/4"	6 3/8"	12'–10 3/4"	6 3/8"	12'–6 3/4"	6 3/8"	12'–10 3/4"	6 3/8"
13	6'–3"	0"	6'–8 1/2"	0"	6'–3"	0"	6'–8 1/2"	0"
14	0"	0"	5 1/2"	0"	0"	0"	5 1/2"	0"



Midwest Roadside Safety Facility	Bullnose with UBSP Test No. MSPBN–1 Layout for Post Locations	SHEET: 2 of 24
		DATE: 4/17/2020
		DRAWN BY: MES/JEK/DTM/MKB/JDJ
	DWG. NAME. Bullnose_R19 · SCALE: 1:90 · UNITS: in.[mm]	REV. BY: JEK/KAL/RWB/JCH

Figure 5. Layout for Post Locations, Test Nos. MSPBN-1 through MSPBN-3

Post No.	Rear Face–DS Edge		Rear Face–US Edge	
	X_a and X_b	Y_a and Y_b	X_a and X_b	Y_a and Y_b
1	11'–10 1/8"	1'–6 5/8"	12'–3 1/4"	1'–8 5/8"
2	8'–9"	1'–2 3/4"	9'–2 3/8"	1'–4 1/4"
3	5'–9 1/2"	1'–0 7/8"	6'–1 3/8"	1'–1 5/8"
4	2'–10 1/2"	7 7/8"	3'–2 3/8"	8 1/4"
5	0"	5 7/8"	4"	5 7/8"

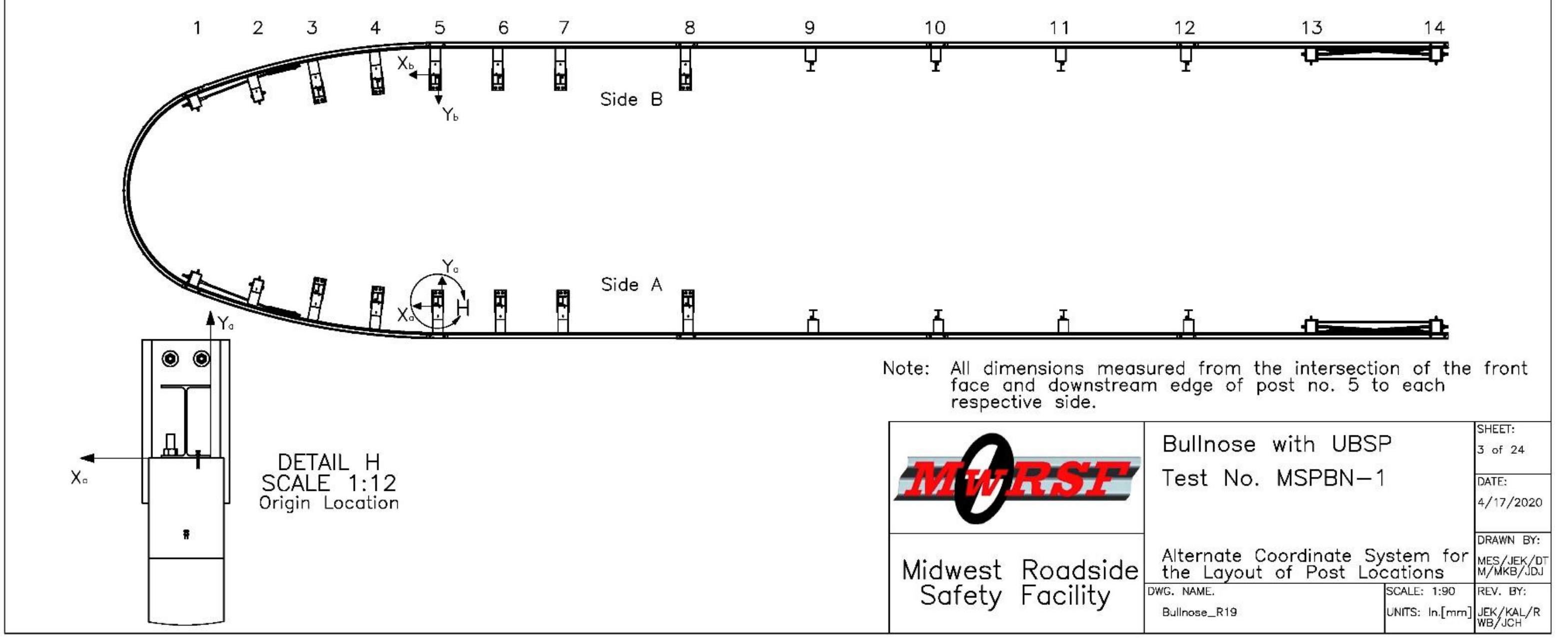


Figure 6. Alternate Coordinate System for the Layout of Post Locations, Test Nos. MSPBN-1 through MSPBN-3

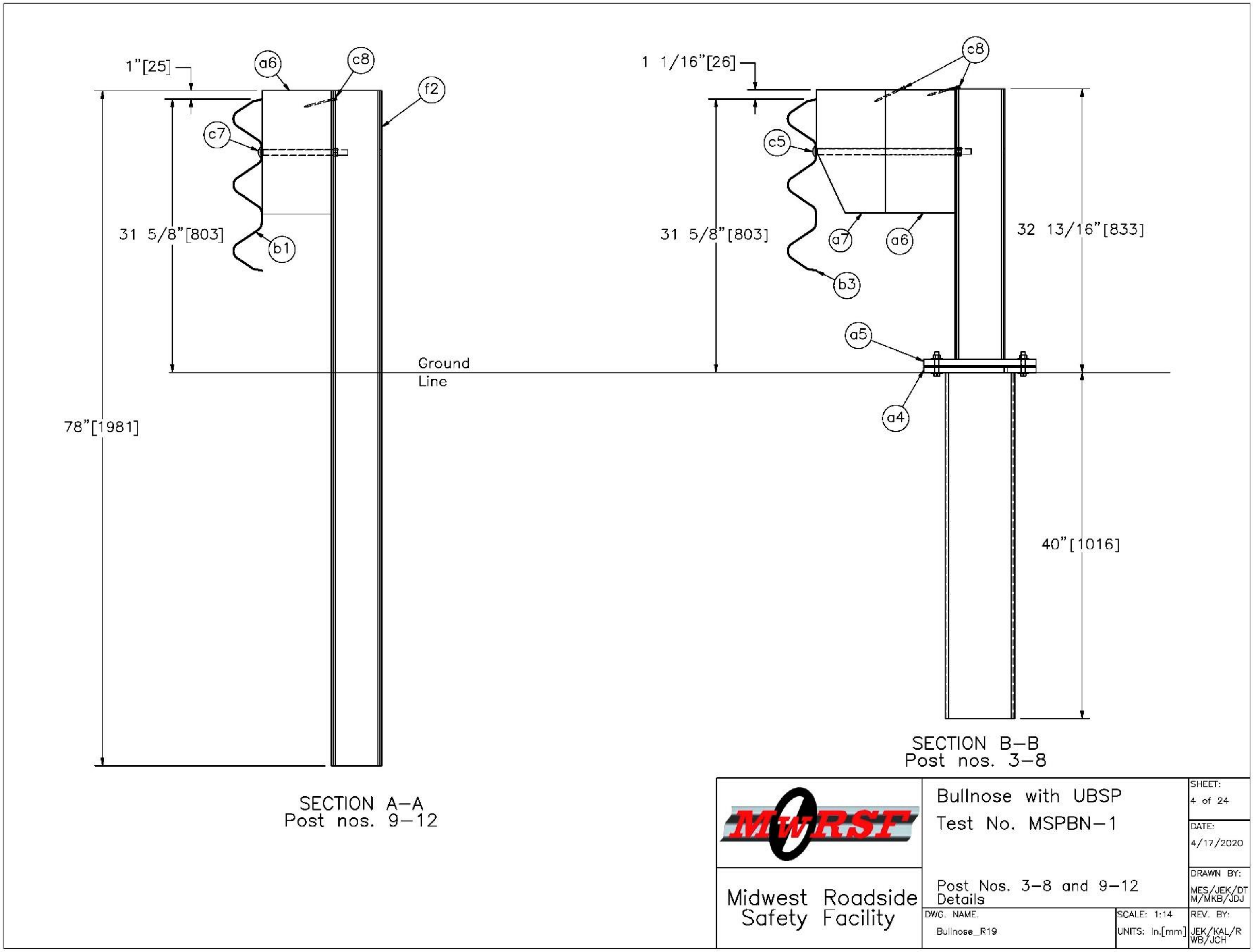


Figure 7. Post Nos. 3 through 8 and 9 through 12 Details, Test Nos. MSPBN-1 through MSPBN-3

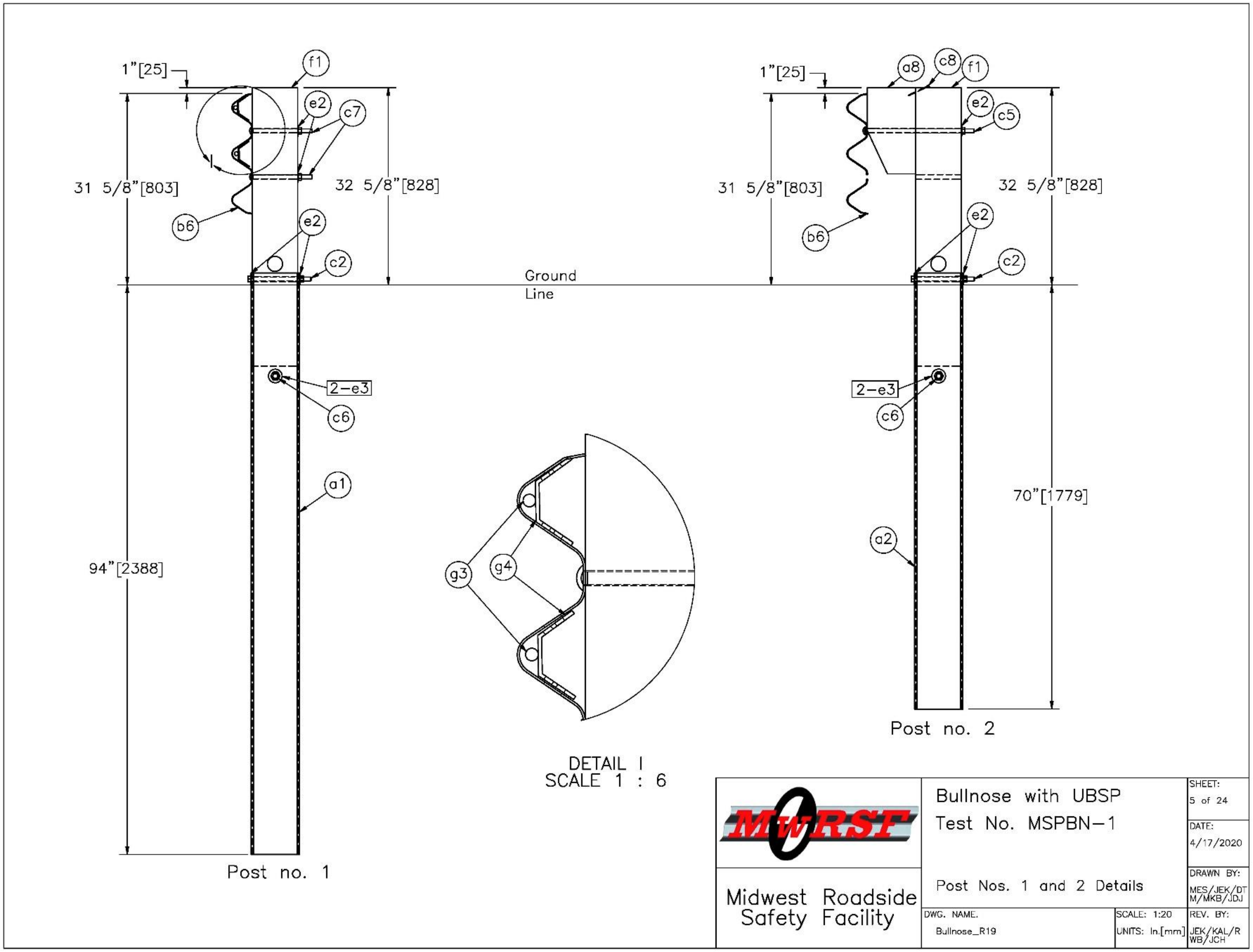


Figure 8. Post Nos. 1 and 2 Details, Test Nos. MSPBN-1 through MSPBN-3

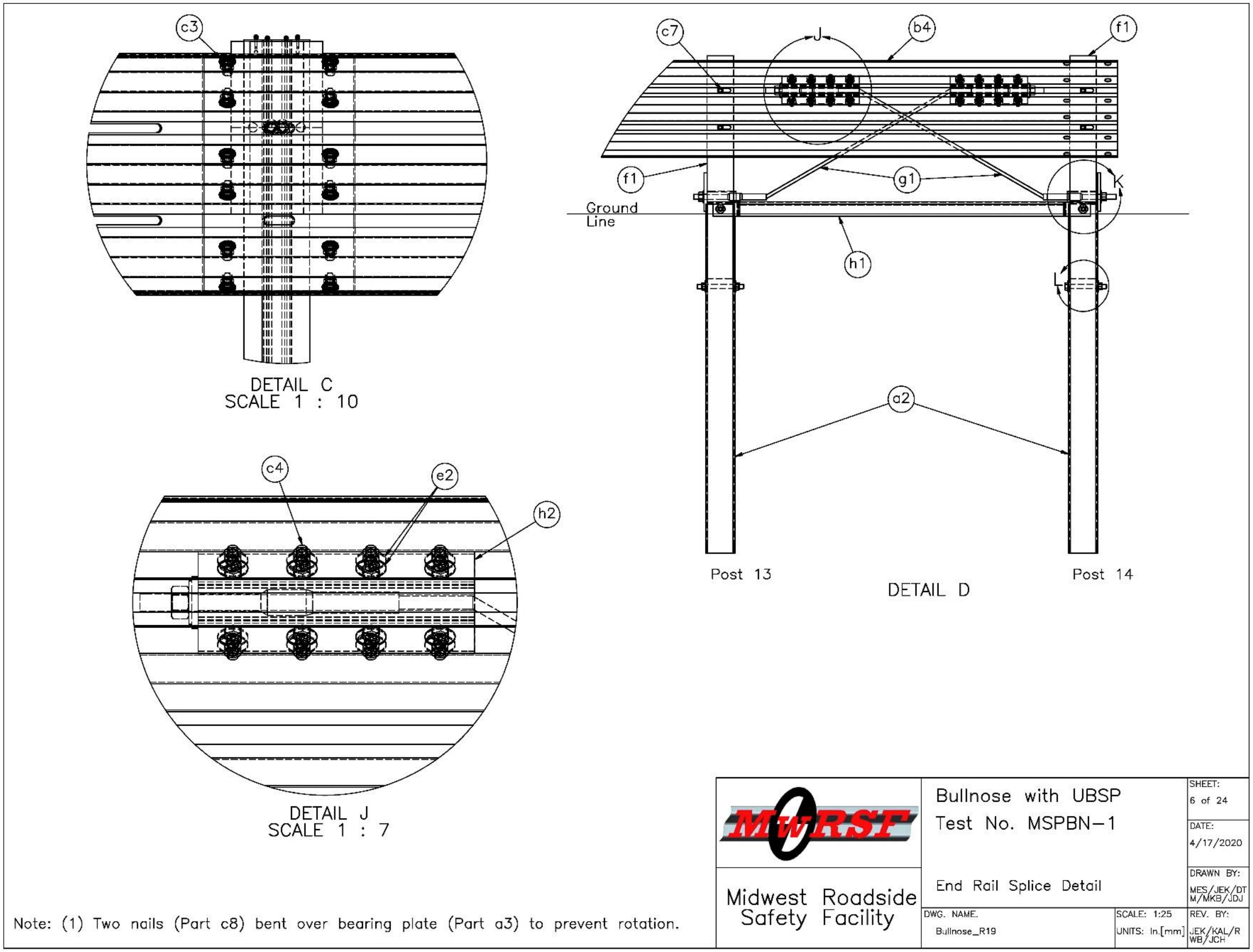


Figure 9. End Rail Splice Detail, Test Nos. MSPBN-1 through MSPBN-3

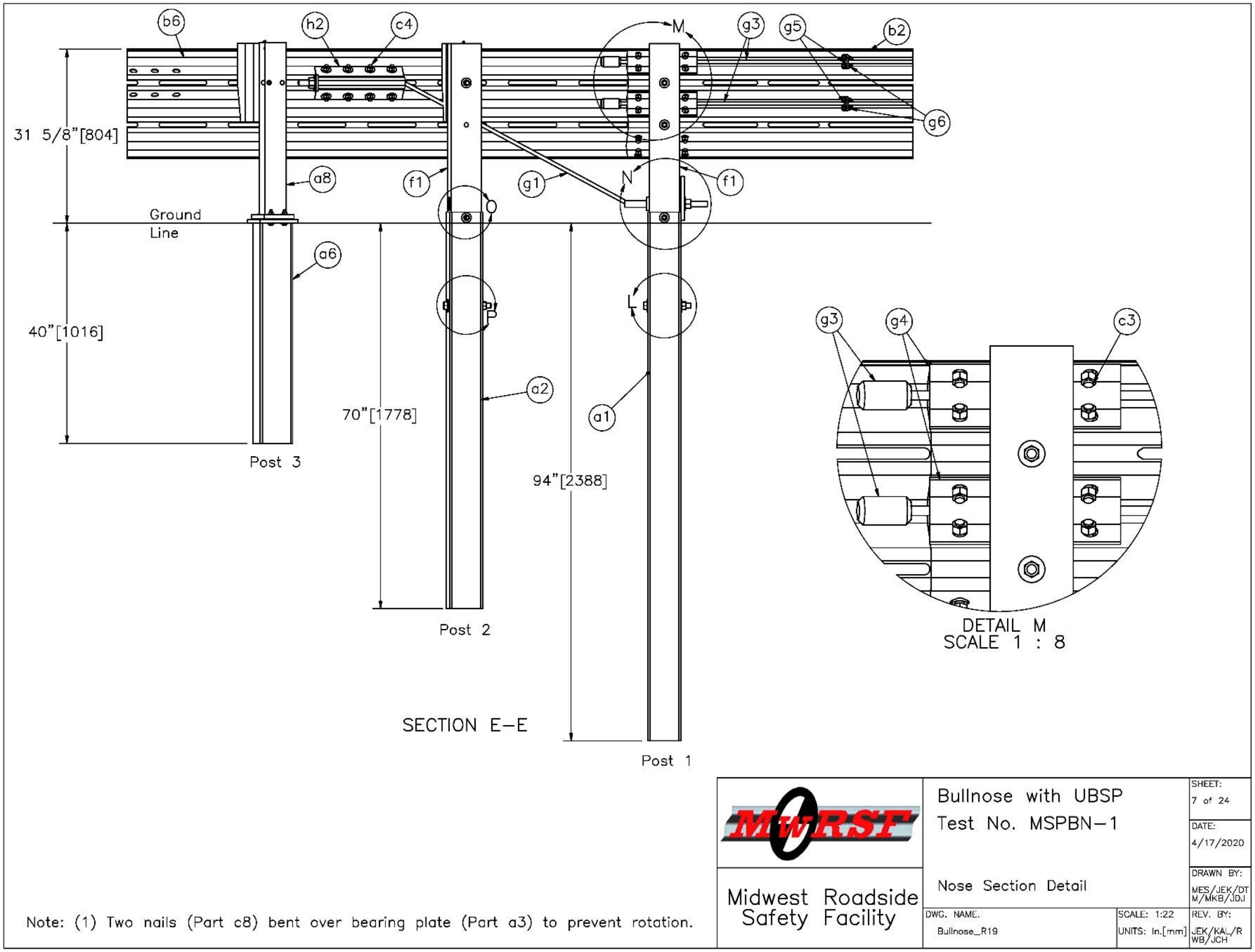


Figure 10. Nose Section Detail, Test Nos. MSPBN-1 through MSPBN-3

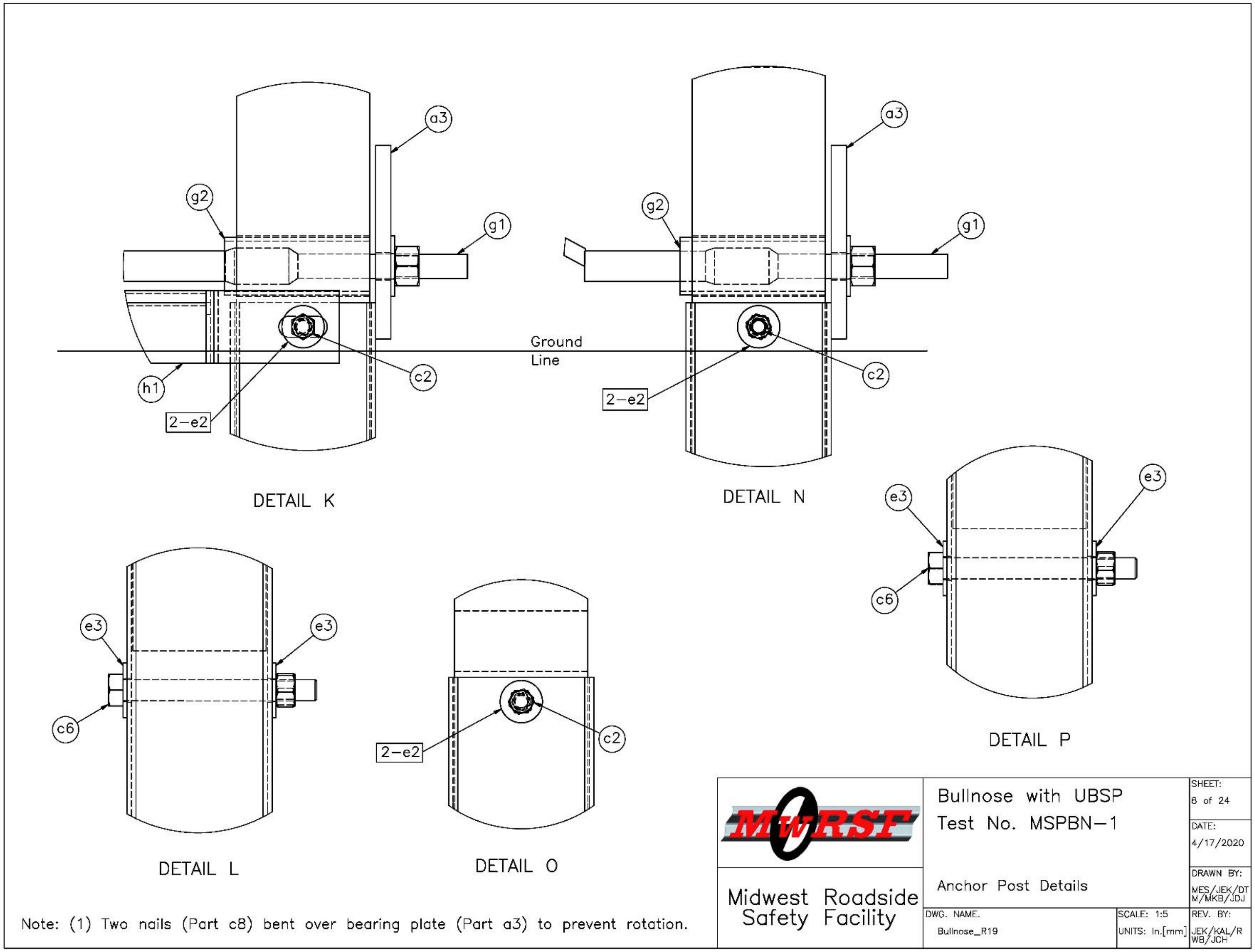


Figure 11. Anchor Post Details, Test Nos. MSPBN-1 through MSPBN-3

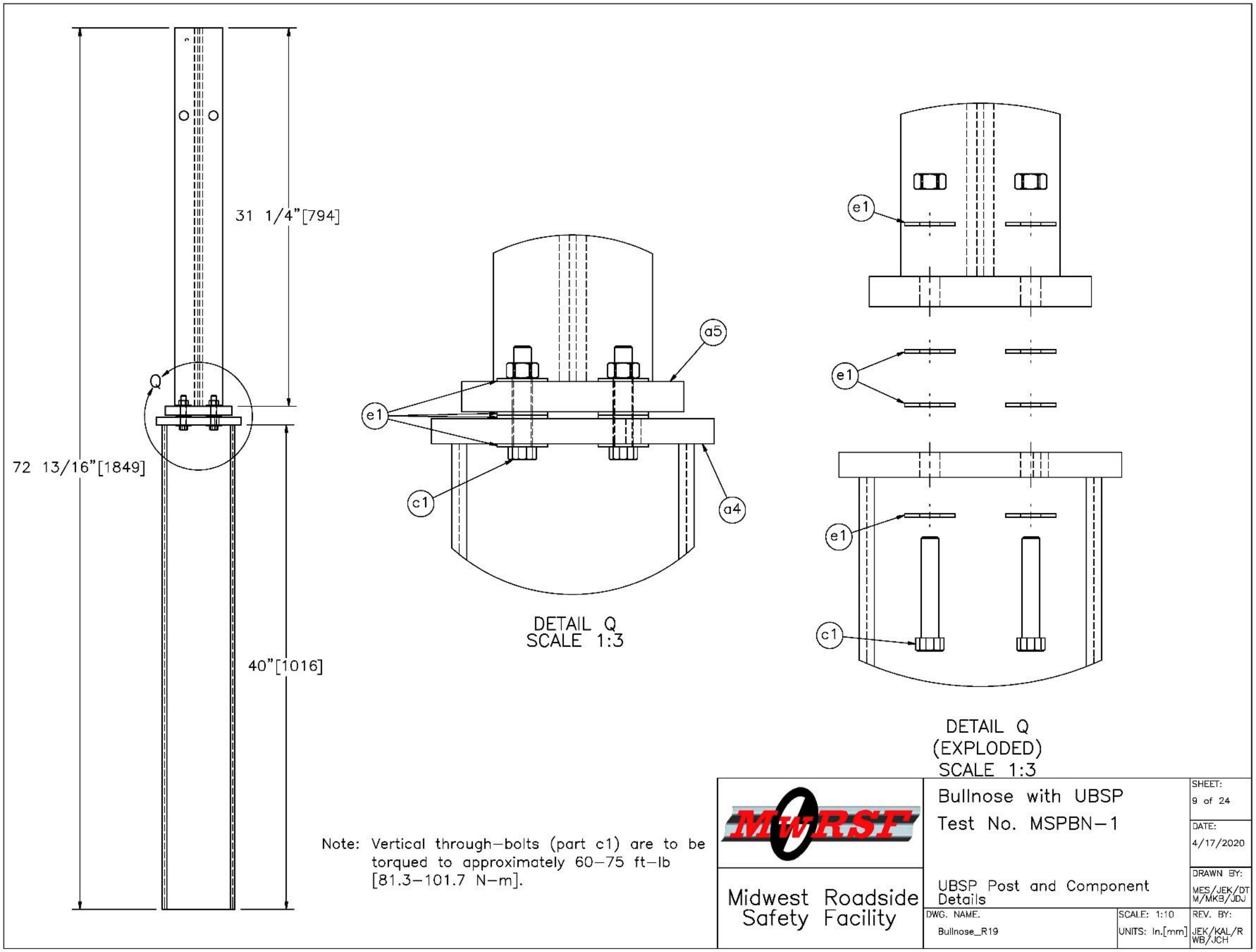


Figure 12. UBSP and Component Details, Test Nos. MSPBN-1 through MSPBN-3

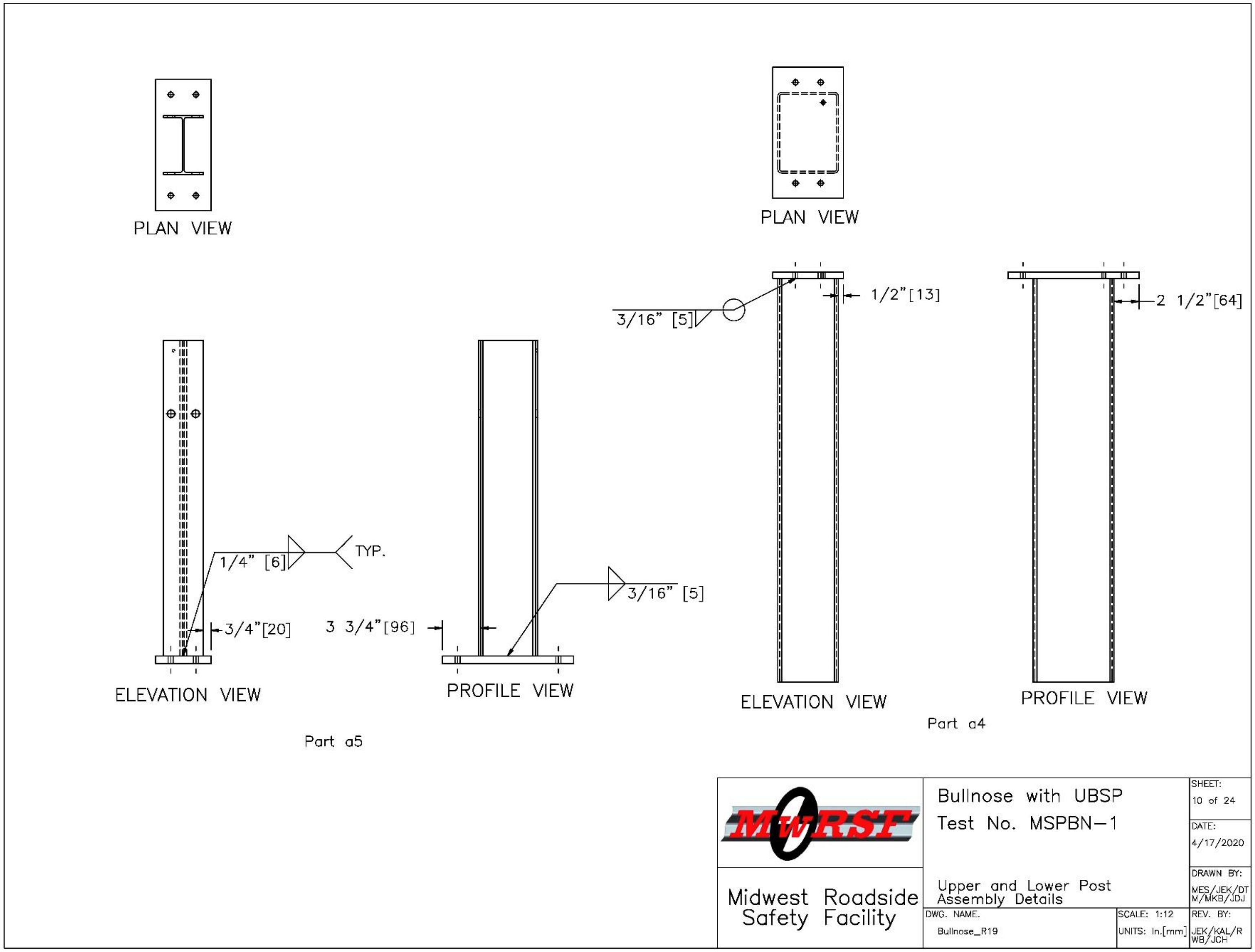


Figure 13. Upper and Lower Post Assembly Details, Test Nos. MSPBN-1 through MSPBN-3

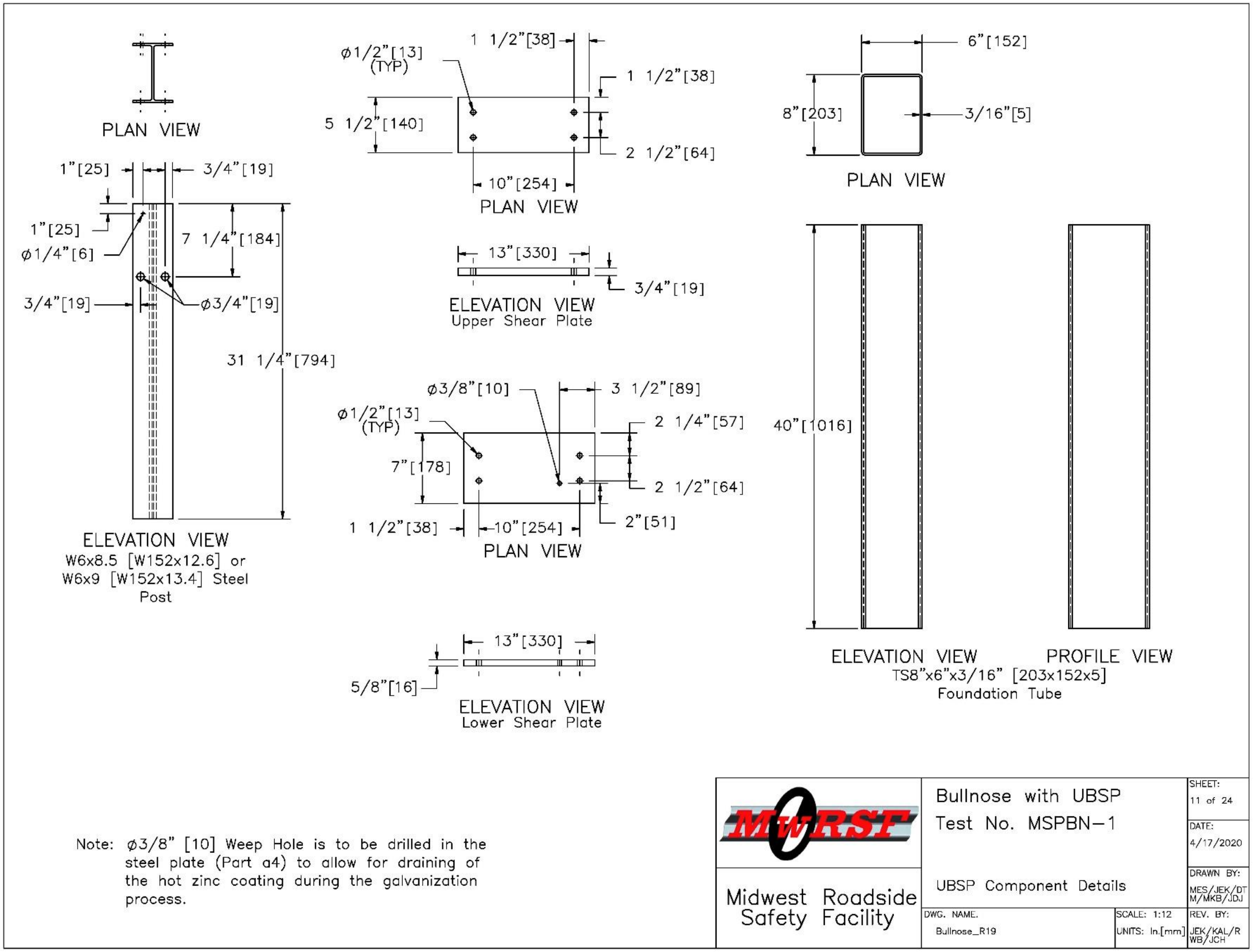


Figure 14. UBSP Component Details, Test Nos. MSPBN-1 through MSPBN-3

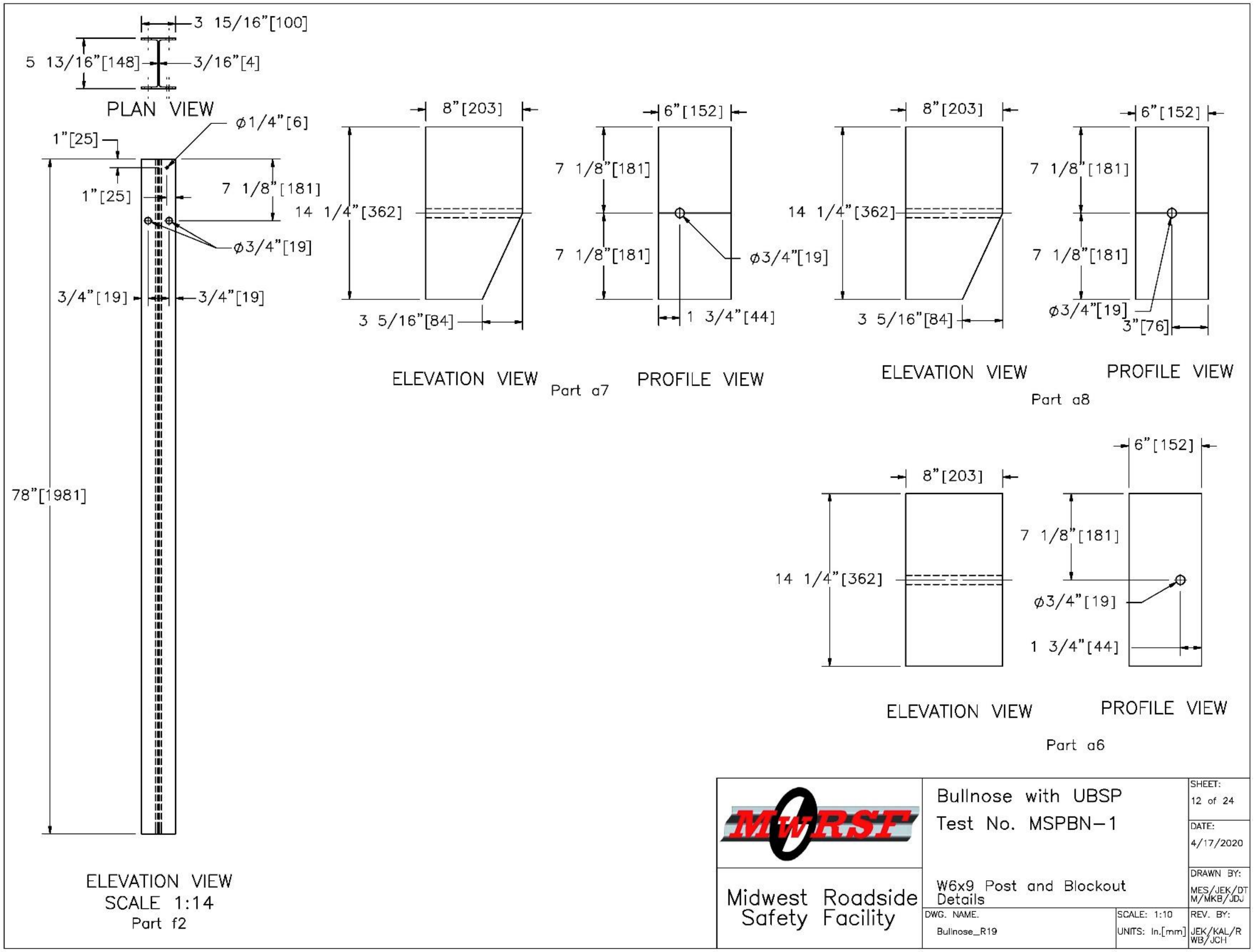


Figure 15. W6x9 Post and Blockout Details, Test Nos. MSPBN-1 through MSPBN-3

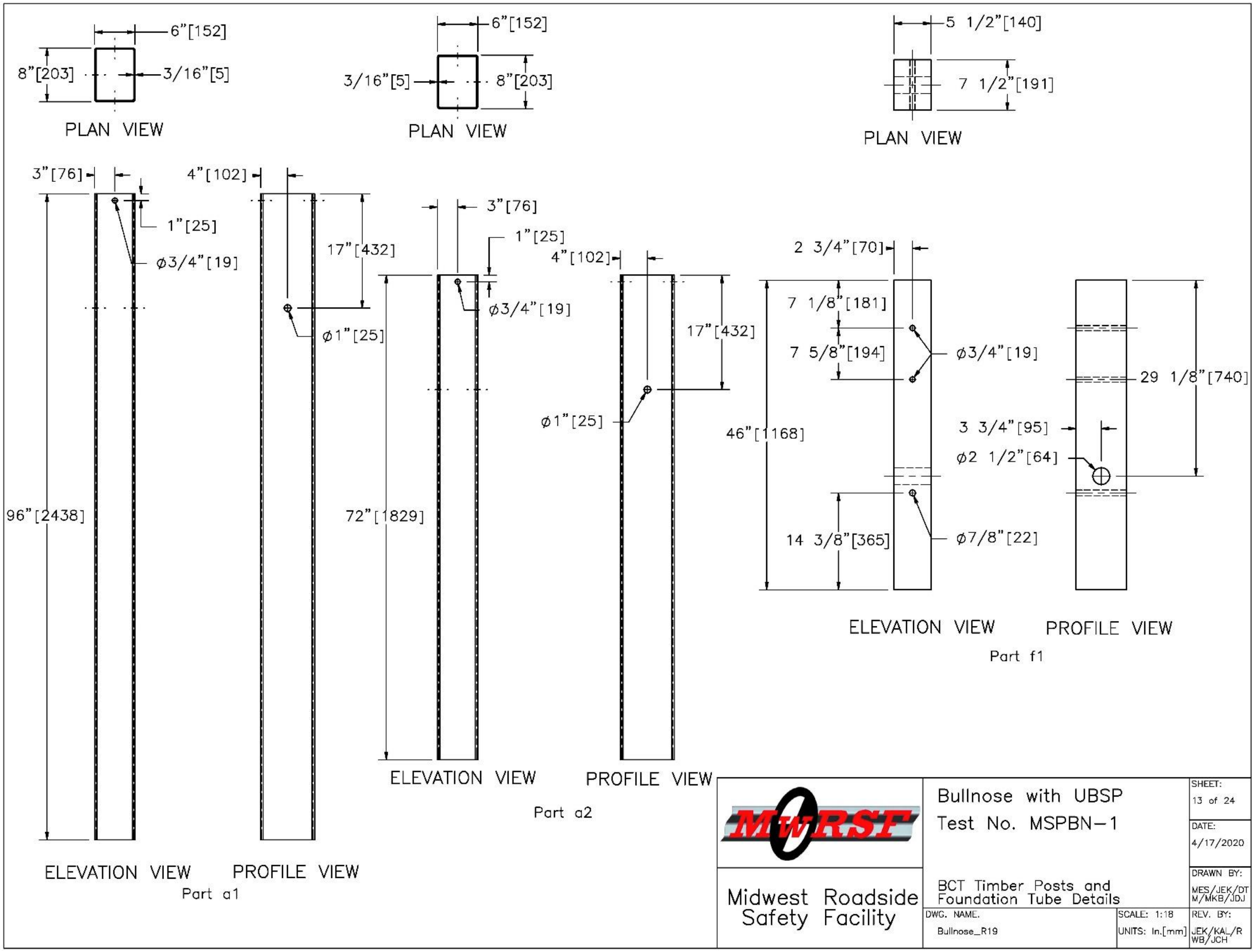


Figure 16. BCT Timber Posts and Foundation Tube Details, Test Nos. MSPBN-1 through MSPBN-3

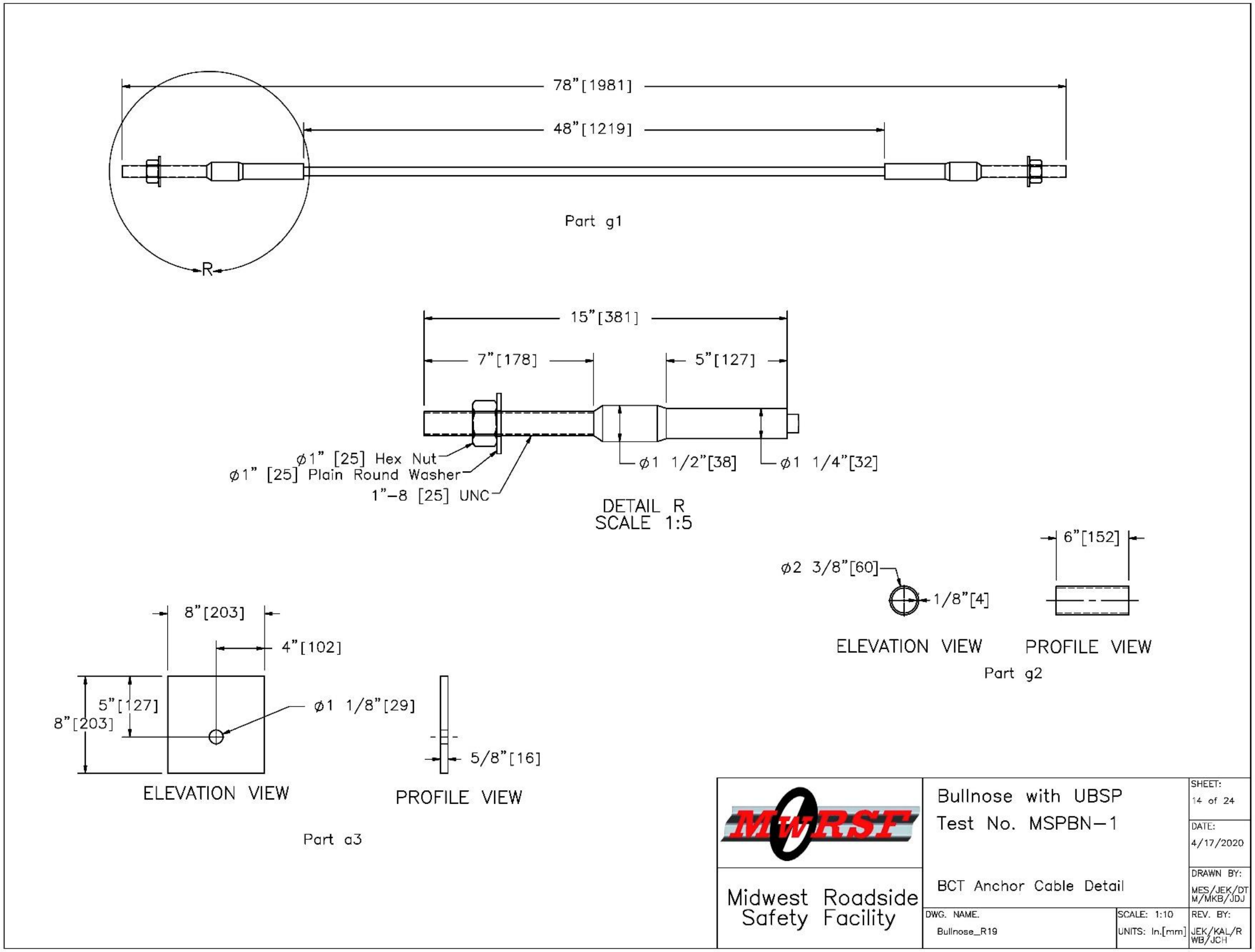


Figure 17. BCT Anchor Cable Detail, Test Nos. MSPBN-1 through MSPBN-3

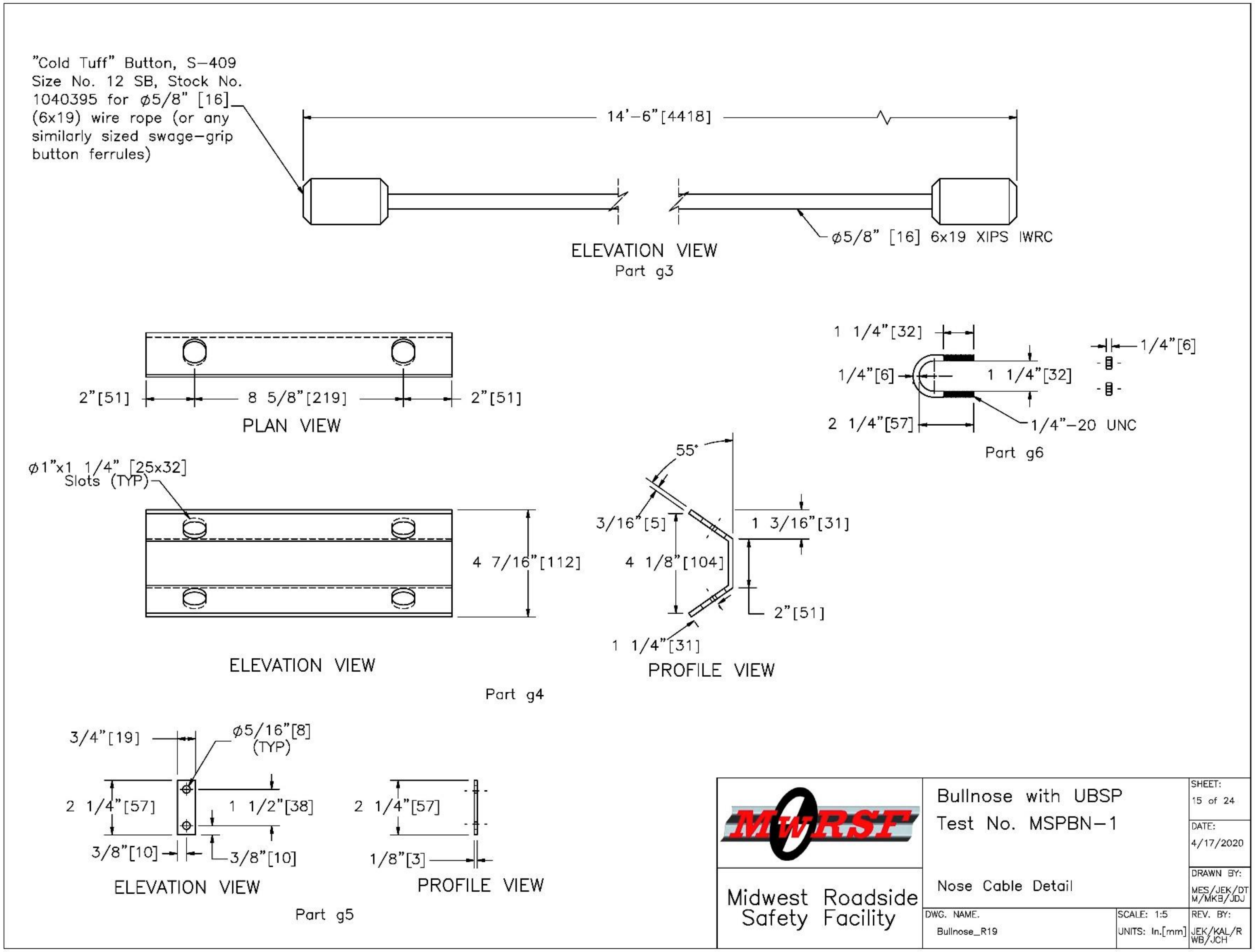


Figure 18. Nose Cable Detail, Test Nos. MSPBN-1 through MSPBN-3

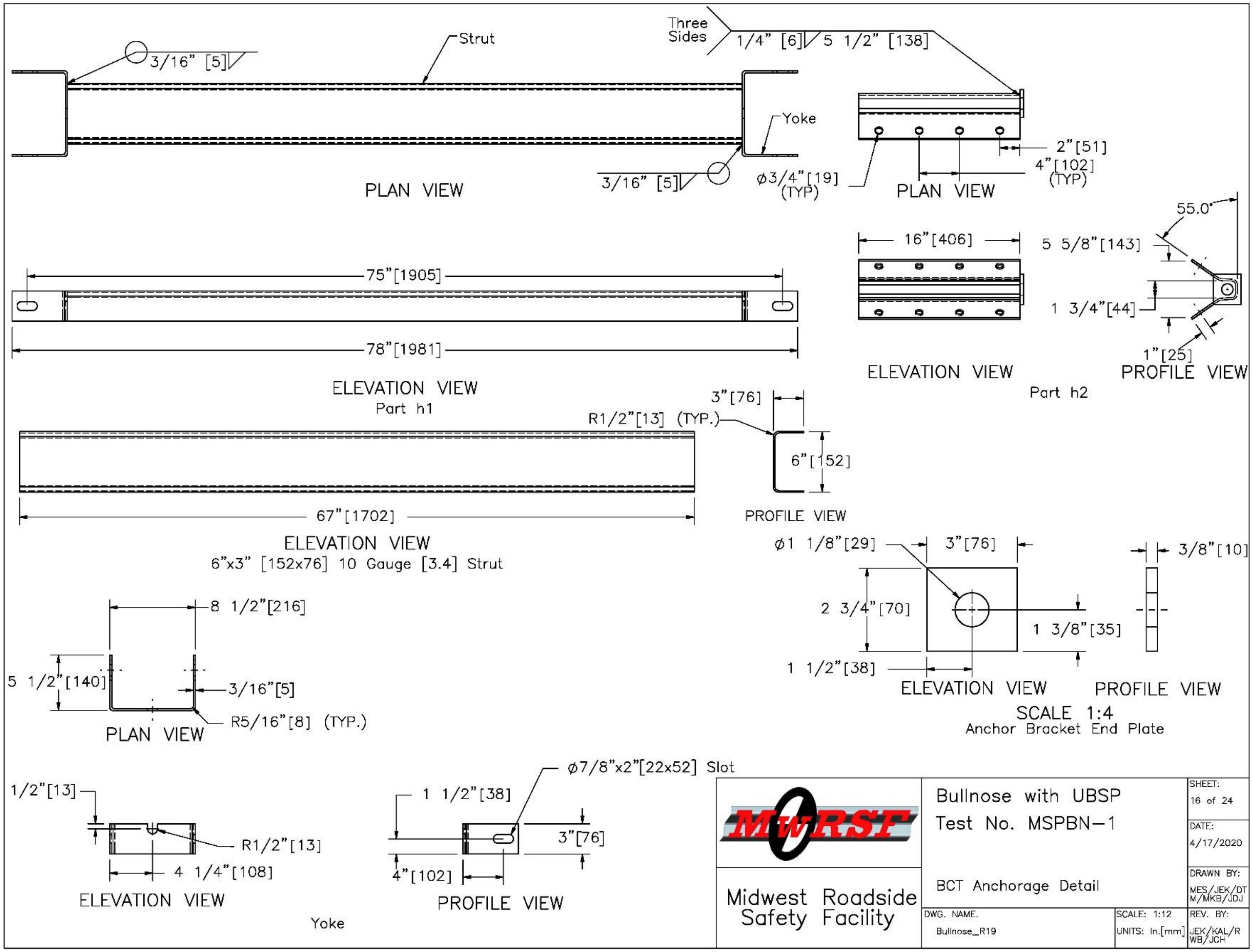


Figure 19. BCT Anchorage Detail, Test Nos. MSPBN-1 through MSPBN-3

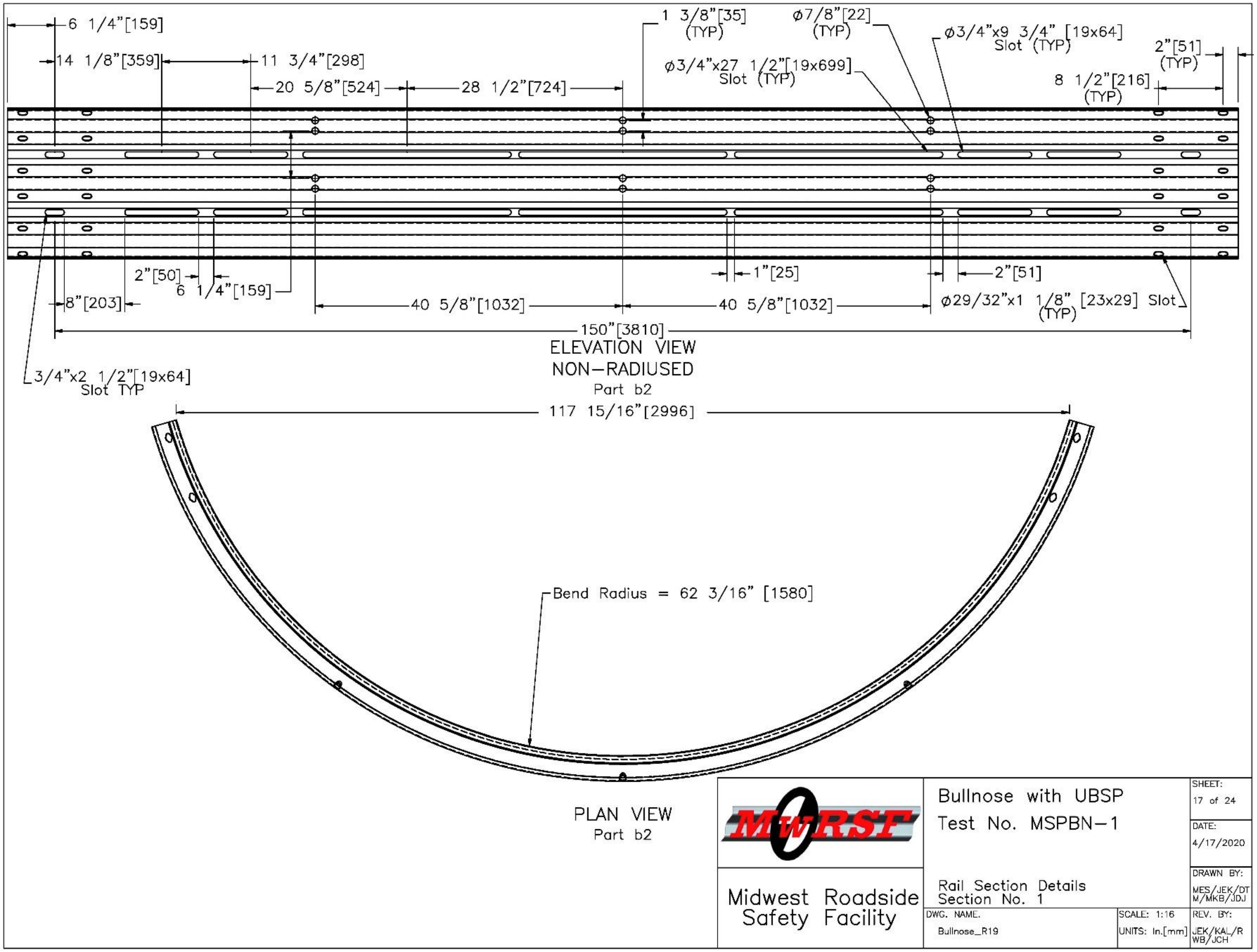


Figure 20. Rail Section Details Section No. 1, Test Nos. MSPBN-1 through MSPBN-3

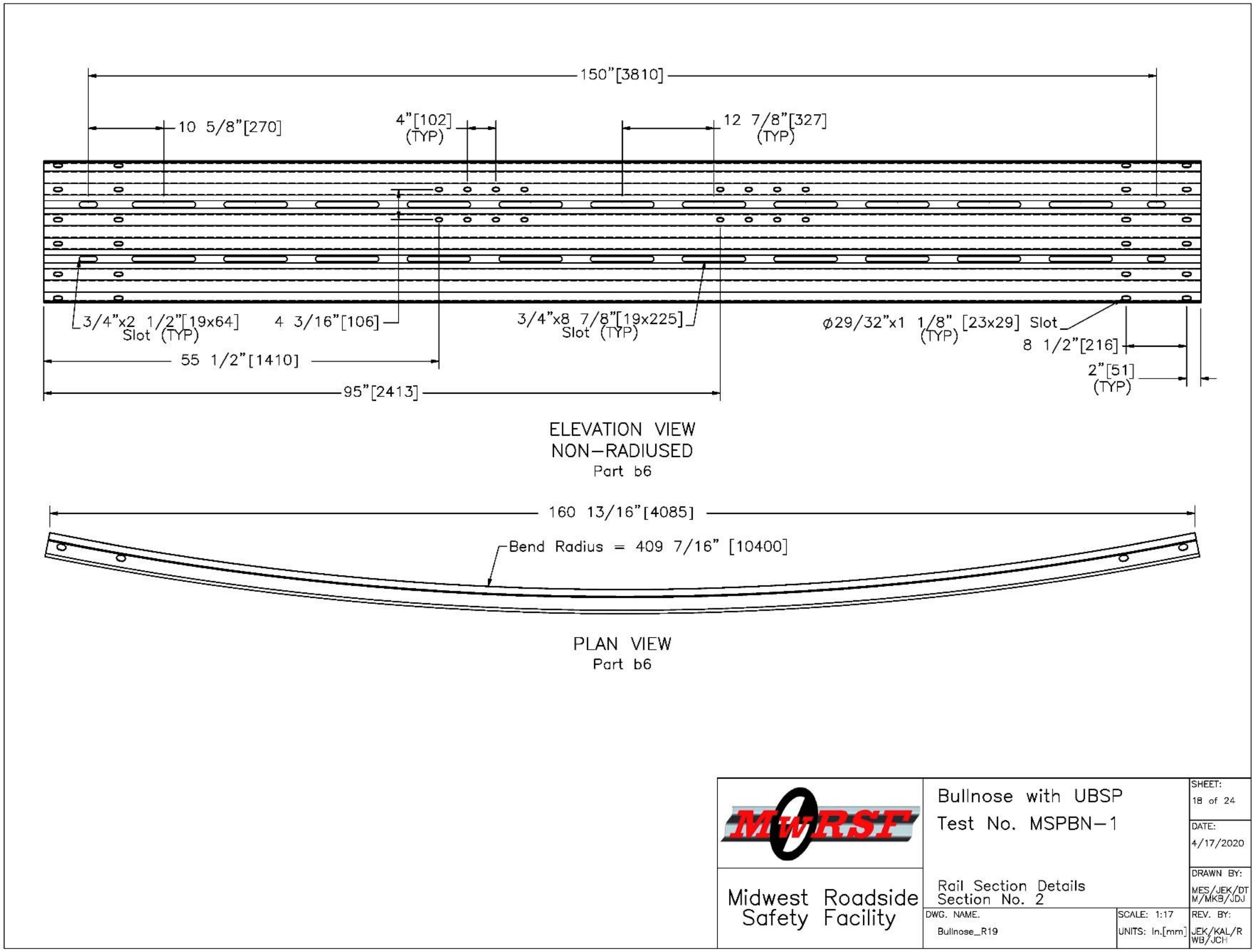


Figure 21. Rail Section Details Section No. 2, Test Nos. MSPBN-1 through MSPBN-3

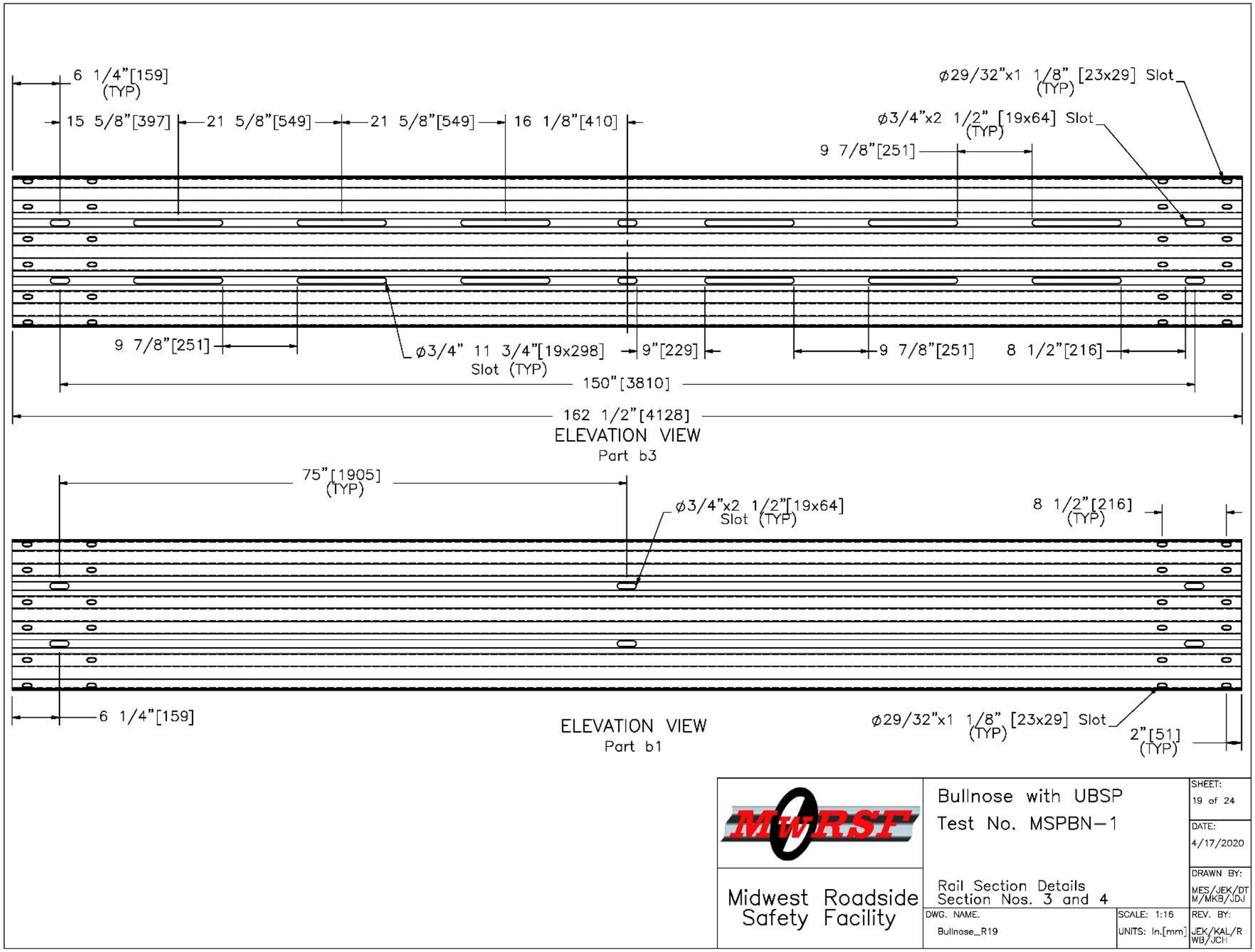


Figure 22. Rail Section Details Section Nos. 3 and 4, Test Nos. MSPBN-1 through MSPBN-3

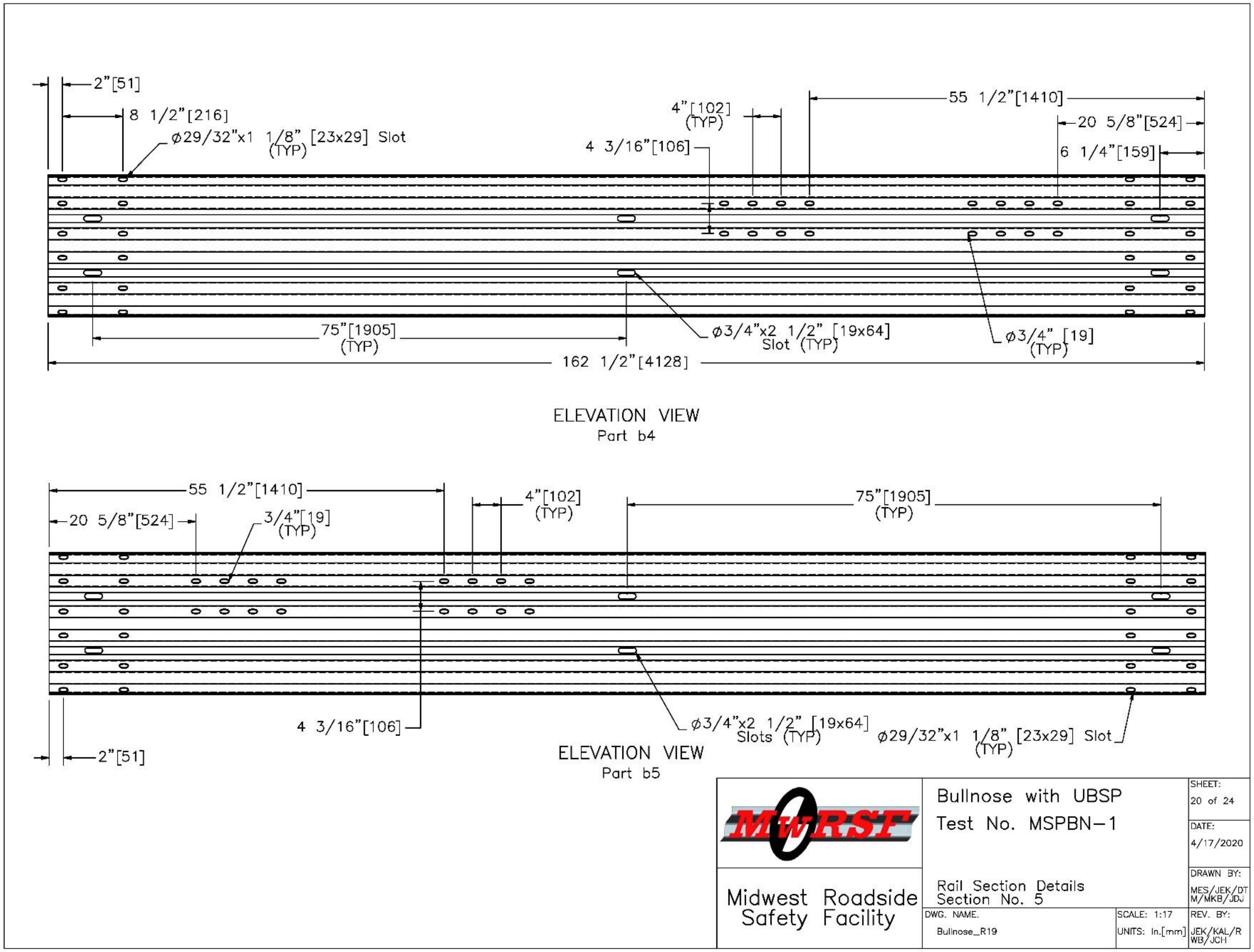


Figure 23. Rail Section Details Section No. 5, Test Nos. MSPBN-1 through MSPBN-3

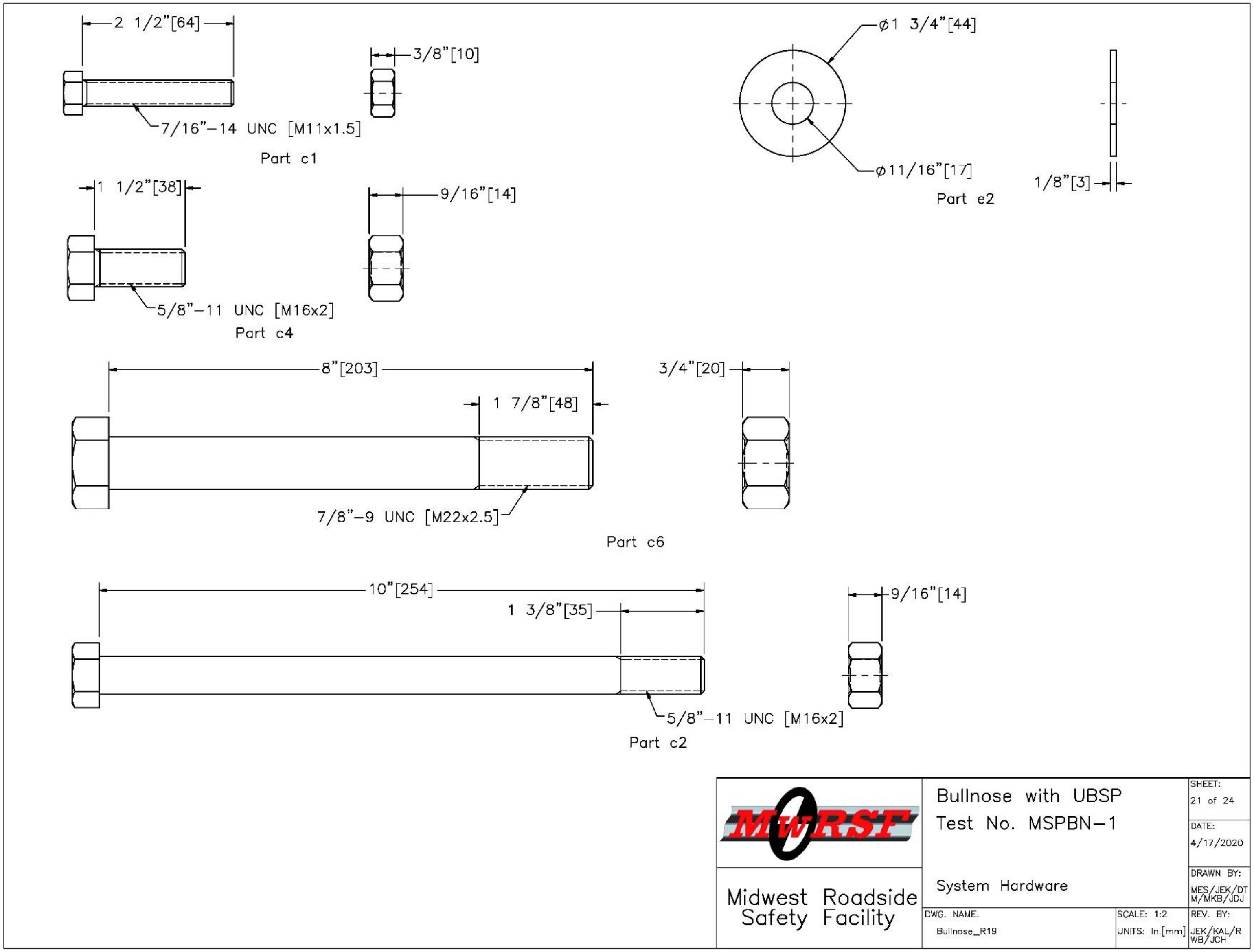


Figure 24. System Hardware, Test Nos. MSPBN-1 through MSPBN-3

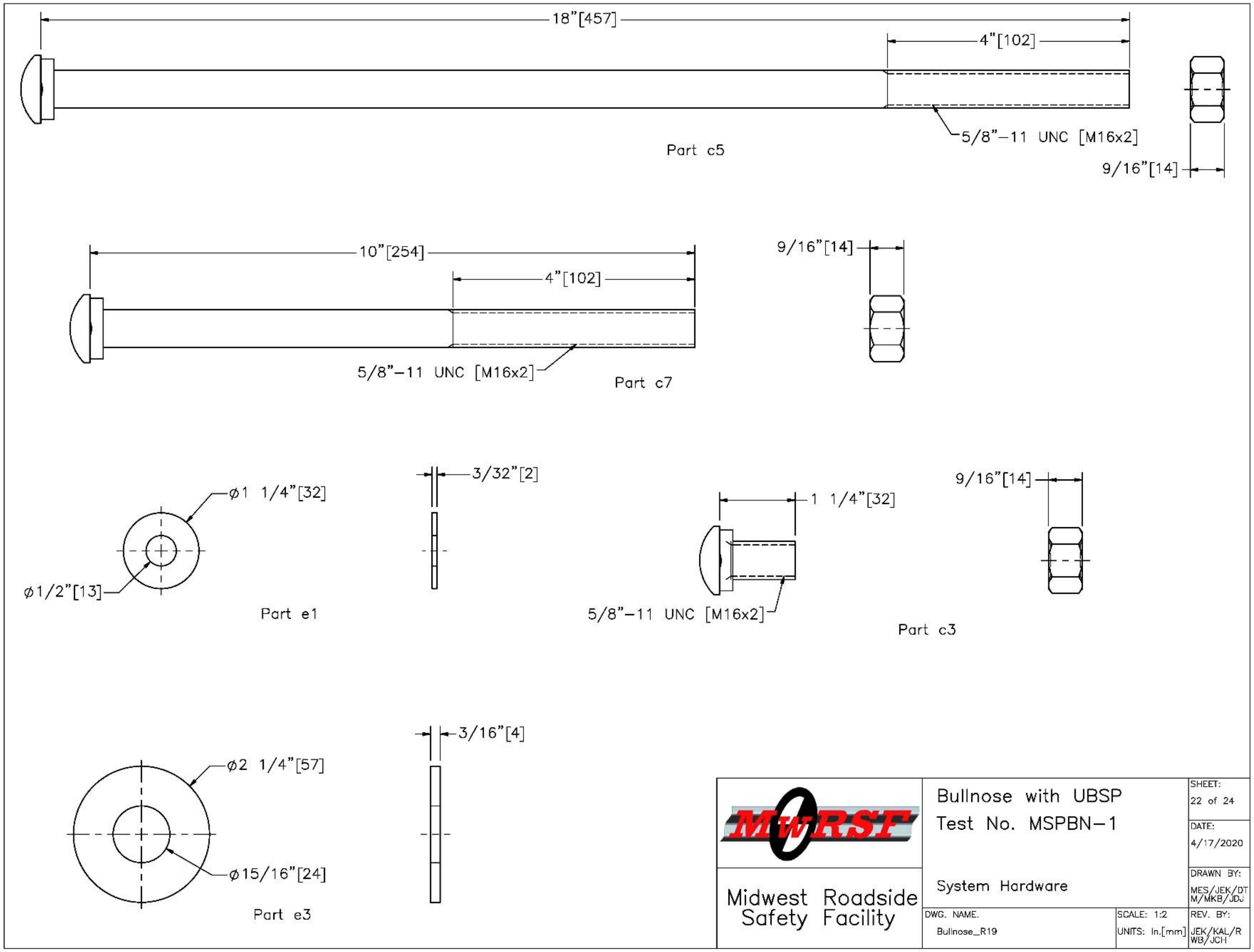


Figure 25. System Hardware, Test Nos. MSPBN-1 through MSPBN-3

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	2	TS8"x6"x3/16" [203x152x5], 96" [2,438] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123	PTE07
a2	6	TS8"x6"x3/16" [203x152x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123	PTE06
a3	6	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
a4	12	Lower Slip Post Assembly	Plate–ASTM A36 Foundation Tube–ASTM A500 Gr. B	ASTM A123	PTE08
a5	12	Upper Slip Post Assembly	Plate–ASTM A36 Post– ASTM A992	ASTM A123	PWE11
a6	20	6"x8"x14 1/4" [152x203x362] Timber Blockout	SYP Grade No. 1 or better	–	PDB09
a7	12	6"x8"x14 1/4" [152x203x362] Tapered Timber Blockout	SYP Grade No. 1 or better	–	PDB20
a8	2	6"x8"x14 1/4" [152x203x362] Tapered Timber Blockout – Post 2	SYP Grade No. 1 or better	–	PDB12
b1	4	12'–6" [3,810] 12 gauge [2.7] Thrie Beam Section	AASHTO M180	ASTM A123 or A653	RTM02a
b2	1	12'–6" [3,810] 12 gauge [2.7] Bent Thrie Beam Section	AASHTO M180	ASTM A123 or A653	RTM07a
b3	2	12'–6" [3,810] 12 gauge [2.7] Thrie Beam Section	AASHTO M180	ASTM A123 or A653	RTM07e
b4	1	12'–6" [3,810] 12 gauge [2.7] Thrie Beam End Section – Side A	AASHTO M180	ASTM A123 or A653	–
b5	1	12'–6" [3,810] 12 gauge [2.7] Thrie Beam End Section – Side B	AASHTO M180	ASTM A123 or A653	–
b6	2	12'–6" [3,810] 12 gauge [2.7] Bent Thrie Beam Section	AASHTO M180	ASTM A123 or A653	RTM07d
c1	48	7/16" [11] Dia. UNC, 2 1/2" [64] Long Hex Tap Bolt (Fully Threaded) and Nut	Bolt – ASTM A449 or SAE J429 Gr. 5 Nut – ASTM A563DH or SAE J995 Gr. 5	ASTM A153 or B695 Class 55 or F2329	–
c2	8	5/8"–11 UNC [M16x2], 10" [254] Long Hex Head Bolt	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 for Class 50 or F2329	FBX16a
c3	120	5/8"–11 UNC [M16x2], 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 for Class 50 or F2329	FBB01
c4	48	5/8"–11 UNC [M16x2], 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 for Class 50 or F2329	FBX16a
c5	14	5/8"–11 UNC [M16x2], 18" [457] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 for Class 50 or F2329	FBB04
c6	8	7/8"–9 UNC [M22x2.5], 8" [203] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 for Class 50 or F2329	–
c7	20	5/8"–11 UNC [M16x2], 10" [254] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 for Class 50 or F2329	FBB03
c8	46	16D Double Head Nail	–	–	–

Midwest Roadside Safety Facility

Bullnose with UBSP
Test No. MSPBN–1

Bill of Materials

SHEET: 23 of 24
DATE: 4/17/2020
DRAWN BY: MES/JEK/DT M/MKB/JDJ
DWG. NAME. Bullnose_R19
SCALE: None
UNITS: In.[mm]
REV. BY: JEK/KAL/R WB/JCH

Figure 26. Bill of Materials, Test Nos. MSPBN-1 through MSPBN-3

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
e1	192	7/16" [11] Dia. Plain Round Washer	ASTM F844 or F436 Type 1	ASTM A153 or B695 Class 55 or F2329	–
e2	118	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A153 or B695 Class 55 or F2329	FWC16a
e3	16	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A153 or B695 Class 55 or F2329	–
f1	8	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots +/– 18" [457] from ground on tension face)	–	PDF04
f2	8	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 78" [1,981] Long Steel Post	ASTM A992	ASTM A123	–
g1	12	BCT Anchor Cable Assembly	–		FCA01
g2	6	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	FMM02
g3	2	5/8" Dia. [15.9] x 14.4' [4,389] Long Cable and Swage Button	"Cold Tuff" Button, S–409 Size No. 12 SB, Stock No. 1040395 for 5/8" [16] Dia. (6x19) wire rope (or any similarly sized swage–grip button ferrules)	Wire Rope – Class A Coating	RCM02
g4	4	12 5/8"x5 13/16"x3/16" [321x148x5] Nose Cable Anchor Plate	ASTM A36	ASTM A123	FPA04
g5	6	2 1/4"x3/4" [57x19] 11 gauge [3] U–Bolt Plate Washer	ASTM A1011 CS Type B	ASTM A123	–
g6	6	1/4" [6] Dia. U–Bolt and Nut	U–Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	–
h1	2	Ground Strut Assembly	ASTM A36	ASTM A123	PFP01
h2	6	Anchor Bracket Assmbely	ASTM A36	ASTM A123	FPA01

MwRSF
Midwest Roadside Safety Facility

Bullnose with UBSP
Test No. MSPBN–1

Bill of Materials

SHEET: 24 of 24
DATE: 4/17/2020
DRAWN BY: MES/JEK/DTM/MKB/JDJ
DWG. NAME. Bullnose_R19
SCALE: None
UNITS: In.[mm]
REV. BY: JEK/KAL/RWB/JCH

Figure 27. Bill of Materials, Test Nos. MSPBN-1 through MSPBN-3

Figure 28. Test Installation Photographs, Test No. MSPBN-1

Figure 29. Test Installation Photographs, Test No. MSPBN-1

Figure 30. Test Installation Photographs, Test No. MSPBN-1

Figure 31. Test Installation Photographs, Test No. MSPBN-2

Figure 32. Test Installation Photographs, Test No. MSPBN-2

Figure 33. Test Installation Photographs, Test No. MSPBN-2

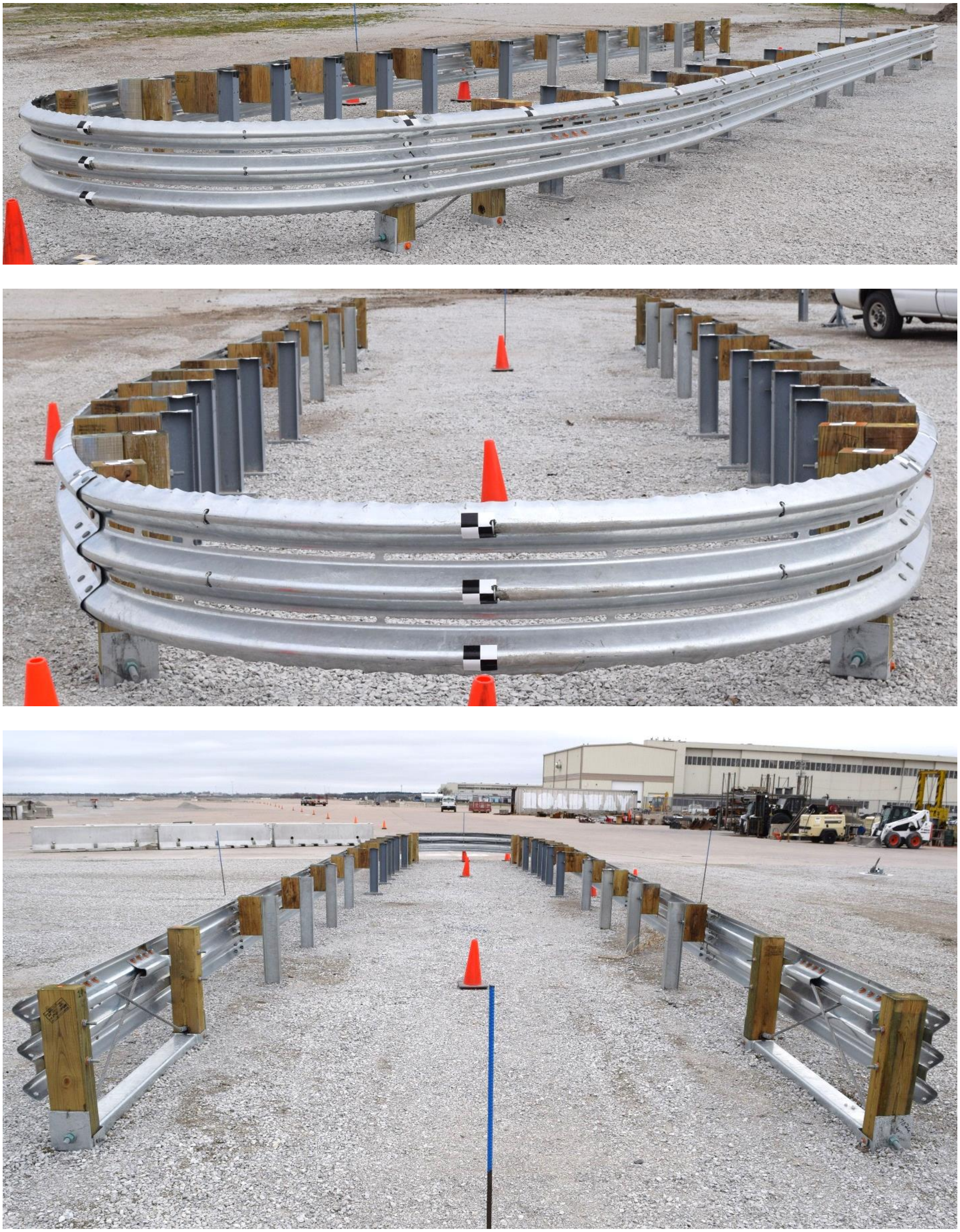


Figure 34. Test Installation Photographs, Test No. MSPBN-3

Figure 35. Test Installation Photographs, Test No. MSPBN-3

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

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 5 miles (8.0 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 vehicle. A guide flag, attached to the right-front wheel for test nos. MSPBN-1 and MSPBN-2 and attached to the left-front wheel for test no. MSPBN-3 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 Vehicles

For test no. MSPBN-1, a 2010 Dodge RAM 1500 quad cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,108 lb (2,317 kg), 5,001 lb (2,268 kg), and 5,162 lb (2,341 kg), respectively. The test vehicle is shown in Figures 37 and 38, and vehicle dimensions are shown in Figure 39.

For test no. MSPBN-2, a 2010 Kia Rio was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,476 lb (1,123 kg), 2,448 lb (1,110 kg), and 2,610 lb (1,184 kg), respectively. The test vehicle is shown in Figures 40 and 41, and vehicle dimensions are shown in Figure 42.

For test no. MSPBN-3, a 2011 Hyundai Accent was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,464 lb (1,118 kg), 2,441 lb (1,107 kg), and 2,599 lb (1,179 kg), respectively. The test vehicle is shown in Figures 43 and 44, and vehicle dimensions are shown in Figure 45. Note that pre-test photographs of the three vehicles' undercarriages were not taken and thus are not available.

It should be noted that the test vehicles used were within 6 years of the research project contract date. Additionally, it should be noted that the vehicle hood height denoted for the small car vehicle in test no. MSPBN-3 did not meet the hood height requirements in MASH. The hood height measurement has been an issue in recent years due to changes in the vehicle hood geometry that have altered the hood line but not the basic vehicle front end structure. As such, the hood height denoted herein was not considered an issue for full-scale testing. Recently, testing laboratories have agreed to measure hood height relative to the top of the radiator mount for consistency and improved compliance with MASH guidelines. However, that guidance was not available at the time of this testing.

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. for the 2270P vehicle. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicles were suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. locations for the test inertial condition. The vertical component of the c.g. for the 1100C vehicles was determined utilizing a procedure published by SAE [15]. The location of the final c.g. is shown in Figures 39, 42, and 45. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figures 46 through 48. Round, checkered targets were placed on the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

The front wheels of the test vehicles were aligned to vehicle standards except the toe-in value was adjusted to zero such that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted under the vehicle's left-side windshield wiper for test nos. MSPBN-1 and MSPBN-2, under the vehicle's right-side windshield wiper for test no. MSPBN-3, and was fired by a pressure tape switch mounted at the impact corner of the bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed digital videos. A remote-controlled brake system was installed in the test vehicles so the vehicles could be brought safely to a stop after the tests.

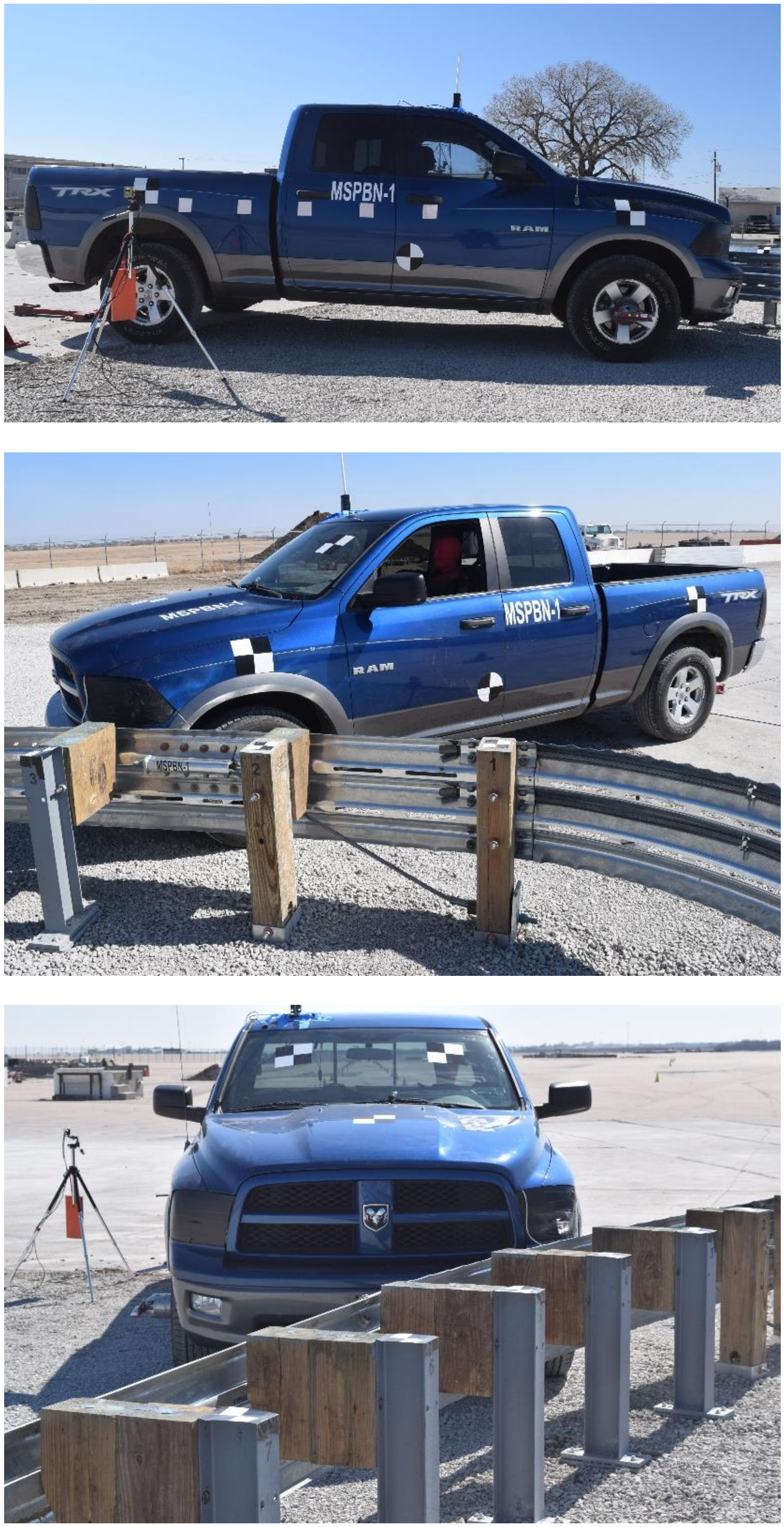
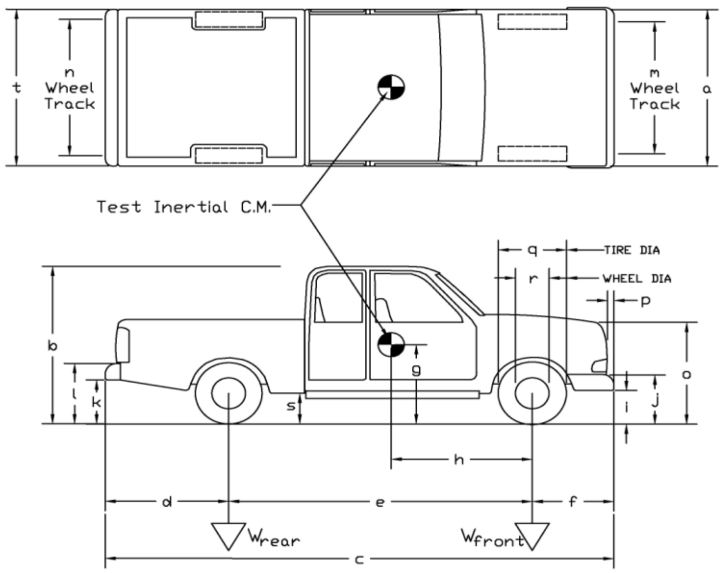


Figure 37. Test Vehicle, Test No. MSPBN-1

Figure 38. Test Vehicle Floor Pan, Test No. MSPBN-1

Date:	3/3/2017	**Test Name:**	MSPBN-1	**VIN No:**	1D7RB1GP9AS171061
Year:	2010	**Make:**	Dodge	**Model:**	RAM 1500
Tire Size:	265/70 R17 115 S	**Tire Inflation Pressure:**	37 Psi	**Odometer:**	152153



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

a: 79 1/8 (2010) 78±2 (1950±50)		**b:** 74 3/8 (1889)	
c: 229 1/4 (5823) 237±13 (6020±325)		**d:** 48 1/8 (1222)	
e: 140 1/4 (3562) 148±12 (3760±300)		**f:** 41 1/4 (1048) 39±3 (1000±75)	
g: 28 3/8 (721) min: 28 (710)		**h:** 60 9/16 (1538) 63±4 (1575±100)	
i: 8 5/8 (219)		**j:** 27 1/8 (689)	
k: 19 1/2 (495)		**l:** 29 (737)	
m: 67 (1702) 67±1.5 (1700±38)		**n:** 67 3/4 (1721) 67±1.5 (1700±38)	
o: 46 1/8 (1172) 43±4 (1100±75)		**p:** 4 3/4 (121)	
q: 31 3/4 (806)		**r:** 18 1/2 (470)	
s: 14 (356)		**t:** 80 1/2 (2045)	

Wheel Center Height (Front):	14 3/4	(375)
Wheel Center Height (Rear):	15	(381)
Wheel Well Clearance (Front):	35	(889)
Wheel Well Clearance (Rear):	37 3/4	(959)
Bottom Frame Height (Front):	13 3/4	(349)
Bottom Frame Height (Rear):	20 3/4	(527)
Engine Type:	Gasoline	
Engine Size:	4.7L V8	
Transmission Type:	Automatic	
Drive Type:	RWD	
Cab Style:	Quad Cab	
Bed Length:	76"	

Mass Distribution lb (kg)

Gross Static	**LF**	1531	(694)	**RF**	1409	(639)
	LR	1123	(509)	**RR**	1099	(498)

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	2911 (1320)	2841 (1289)	2940 (1334)
W-rear	2197 (997)	2160 (980)	2222 (1008)
W-total	5108 (2317)	5001 (2268) 5000±110 (2270±50)	5162 (2341) 5165±110 (2343±50)

GVWR Ratings lb		**Dummy Data**	
Front	3700	**Type:**	Hybrid II
Rear	3900	**Mass:**	161 lb
Total	6700	**Seat Position:**	Driver

Note any damage prior to test: Some paint is scuffed off the corner of the driver side front fender.

Figure 39. Vehicle Dimensions, Test No. MSPBN-1

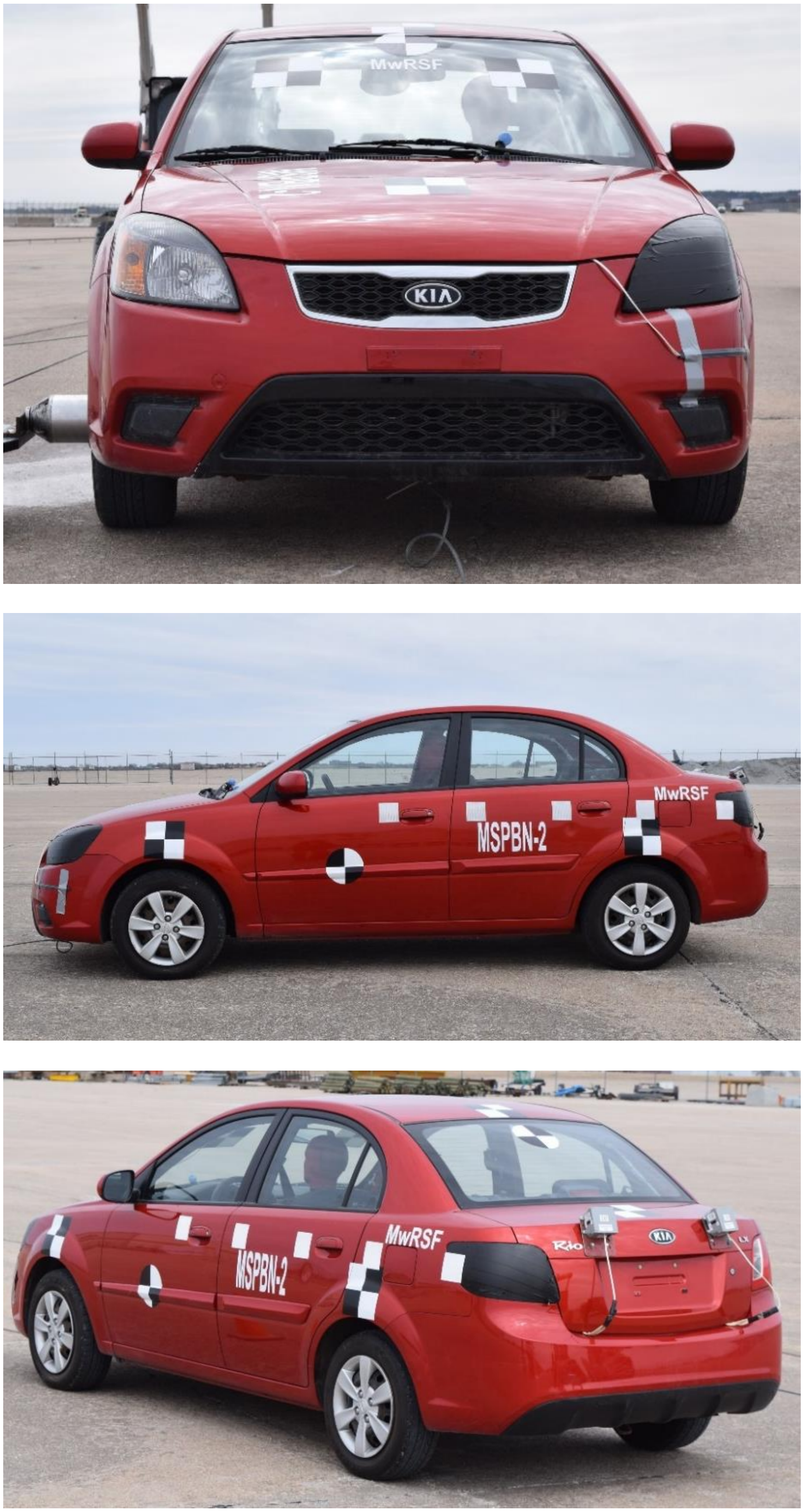
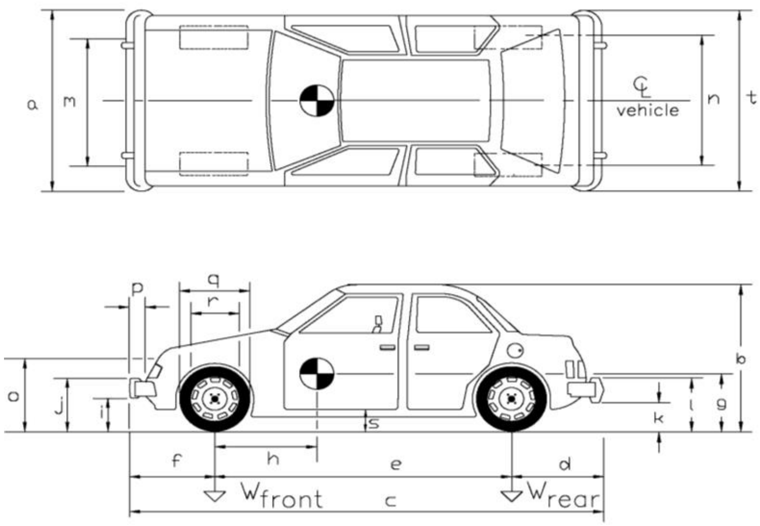


Figure 40. Test Vehicle, Test No. MSPBN-2

Figure 41. Test Vehicle Floor Pan, Test No. MSPBN-2

Date:	3/22/2017	**Test Number:**	MSPBN-2	**VIN:**	KNADH4A34A6680510
Year:	2010	**Make:**	Kia	**Model:**	Rio
Tire Size:	185/65R14 86T	**Tire Inflation Pressure:**	0 Psi	**Odometer:**	92256



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

a:	65 1/4	(1657)	b:	58 1/8	(1476)
	65±3 (1650±75)				
c:	167 1/8	(4245)	d:	35 5/8	(905)
	169±8 (4300±200)				
e:	98 1/2	(2502)	f:	33 1/8	(841)
	98±5 (2500±125)			35±4 (900±100)	
g:	22 15/16	(583)	h:	36 5/16	(922)
				39±4 (990±100)	
i:	8	(203)	j:	23	(584)
k:	10 1/8	(257)	l:	25	(635)
m:	57 3/4	(1467)	n:	57 3/8	(1457)
	56±2 (1425±50)			56±2 (1425±50)	
o:	28	(711)	p:	4 1/2	(114)
	24±4 (600±100)				
q:	23 3/4	(603)	r:	15 3/8	(391)
s:	11 1/2	(292)	t:	65 1/4	(1657)

Mass Distribution lb (kg)

Gross Static	LF	837 (380)	RF	791 (359)
	LR	496 (225)	RR	486 (220)

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	1577 (715)	1545 (701)	1628 (738)
W-rear	899 (408)	903 (410)	982 (445)
W-total	2476 (1123)	2448 (1110)	2610 (1184)
		2420±55 (1100±25)	2585±55 (1175±50)

Top of radiator core support:	29	(737)
Wheel Center Height (Front):	10 3/4	(273)
Wheel Center Height (Rear):	11	(279)
Wheel Well Clearance (Front):	25 1/8	(638)
Wheel Well Clearance (Rear):	24 5/8	(625)
Bottom Frame Height (Front):	17	(432)
Bottom Frame Height (Rear):	15 1/2	(394)
Engine Type:	Gasoline	
Engine Size:	1.6L	
Transmission Type:	Automatic	
Drive Type:	FWD	

GVWR Ratings lb

Front:	1918
Rear:	1874
Total:	3638

Dummy Data

Type:	Hybrid II
Mass:	162 lb
Seat Position:	Driver

Note any damage prior to test: none

Figure 42. Vehicle Dimensions, Test No. MSPBN-2

Figure 43. Test Vehicle, Test No. MSPBN-3

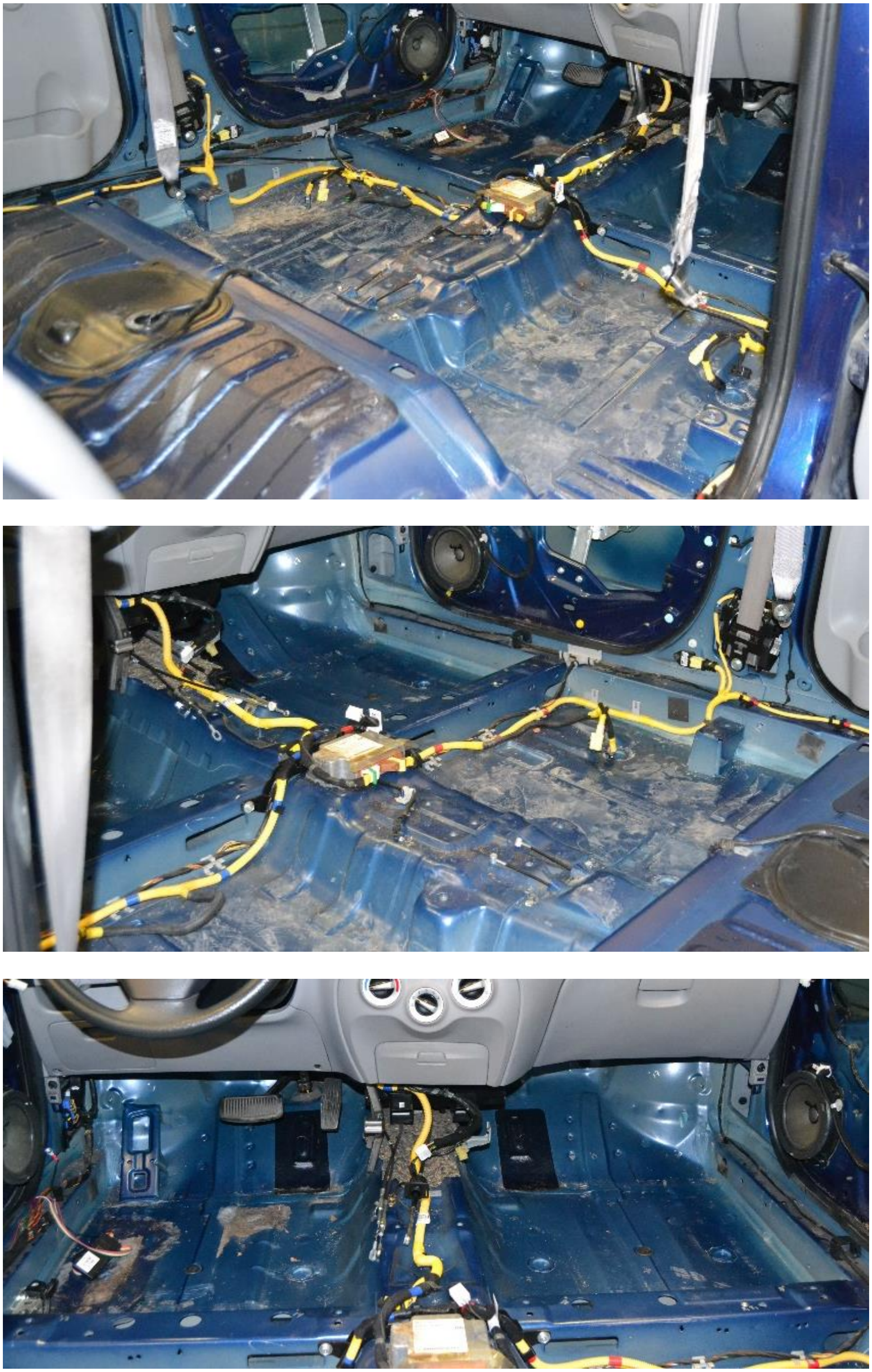
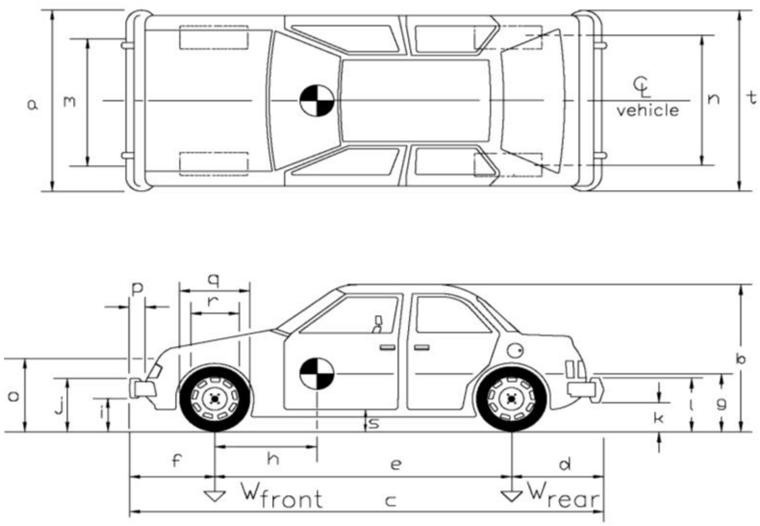


Figure 44. Test Vehicle Floor Pan, Test No. MSPBN-3

Date:	4/11/2017	**Test Number:**	MSPBN-3	**VIN:**	KMHCN4AC5BU612118
Year:	2011	**Make:**	Hyundai	**Model:**	Accent
Tire Size:	P185/65 R14	**Tire Inflation Pressure:**	32 Psi	**Odometer:**	108388



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

a:	65 3/4	(1670)	**b:**	57 1/4	(1454)
	65±3 (1650±75)				
c:	168 1/4	(4274)	**d:**	37	(940)
	169±8 (4300±200)				
e:	98 1/2	(2502)	**f:**	32 3/4	(832)
	98±5 (2500±125)			35±4 (900±100)	
g:	22 11/16	(576)	**h:**	36 13/16	(935)
				39±4 (990±100)	
i:	9	(229)	**j:**	22	(559)
k:	11 1/2	(292)	**l:**	22 1/2	(572)
m:	57 3/4	(1467)	**n:**	57 3/8	(1457)
	56±2 (1425±50)			56±2 (1425±50)	
o:	29	(737)	**p:**	4	(102)
	24±4 (600±100)				
q:	23 1/2	(597)	**r:**	15 1/2	(394)
s:	11 1/2	(292)	**t:**	64 1/2	(1638)

Mass Distribution lb (kg)

Gross Static	**LF**	806	(366)	**RF**	809	(367)
	LR	485	(220)	**RR**	499	(226)

Weights lb (kg)	**Curb**		**Test Inertial**		**Gross Static**	
W-front	1566	(710)	1528	(693)	1615	(733)
W-rear	898	(407)	913	(414)	984	(446)
W-total	2464	(1118)	2441	(1107)	2599	(1179)
			2420±55 (1100±25)		2585±55 (1175±50)	

Top of radiator core support:	29	(737)
Wheel Center Height (Front):	10 3/4	(273)
Wheel Center Height (Rear):	10 7/8	(276)
Wheel Well Clearance (Front):	25 1/4	(641)
Wheel Well Clearance (Rear):	24 5/8	(625)
Bottom Frame Height (Front):	6 1/2	(165)
Bottom Frame Height (Rear):	15 7/8	(403)
Engine Type:	4 cyl. Gas	
Engine Size:	1.6L	
Transmission Type:	Automatic	
Drive Type:	FWD	

GVWR Ratings lb

Front:	1918
Rear:	1874
Total:	3638

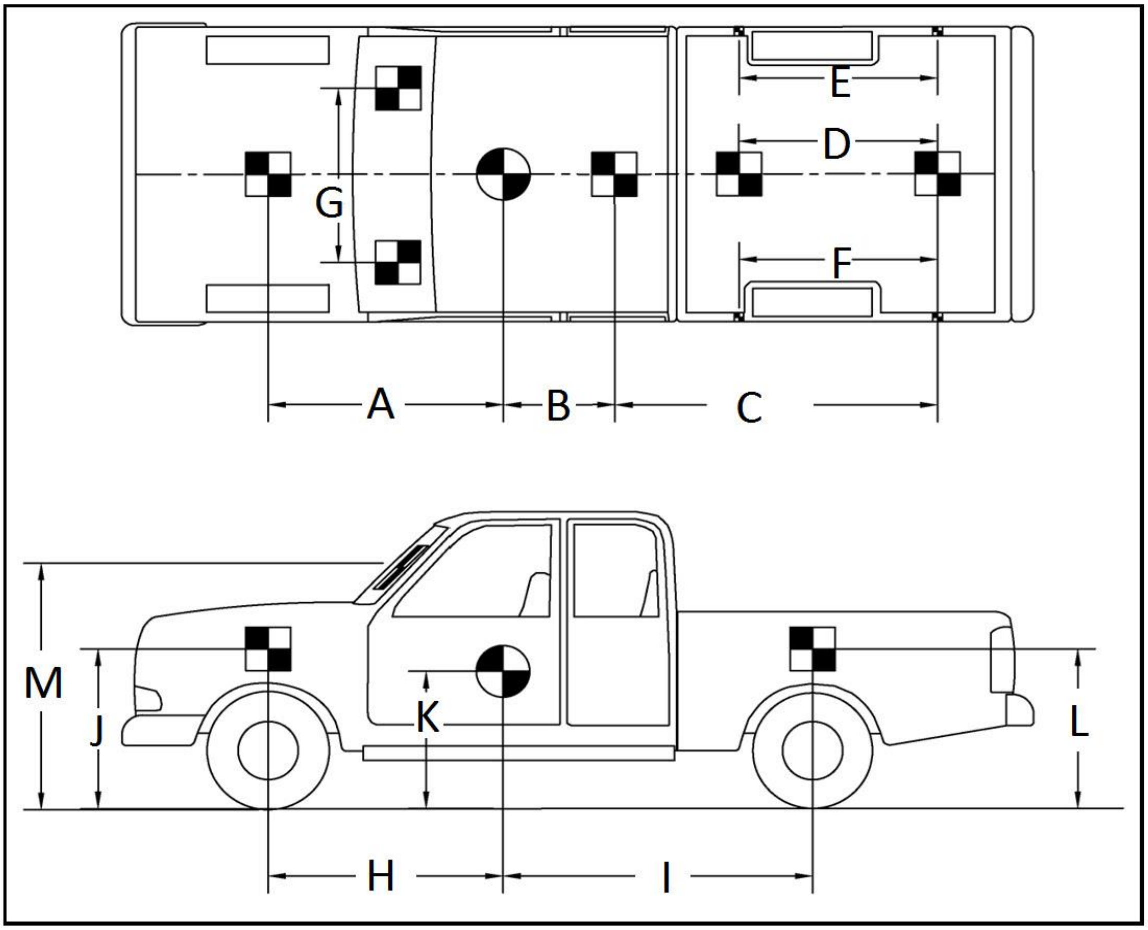
Dummy Data

Type:	Hybrid II
Mass:	158 lb
Seat Position:	Passenger

Note any damage prior to test: small dent/scrape along driver's sidetop rear wheel arch

Figure 45. Vehicle Dimensions, Test No. MSPBN-3

Date:	3/3/2017	Test Name:	MSPBN-1	VIN:	1D7RB1GP9AS171061
Year:	2010	Make:	Dodge	Model:	Ram TRX

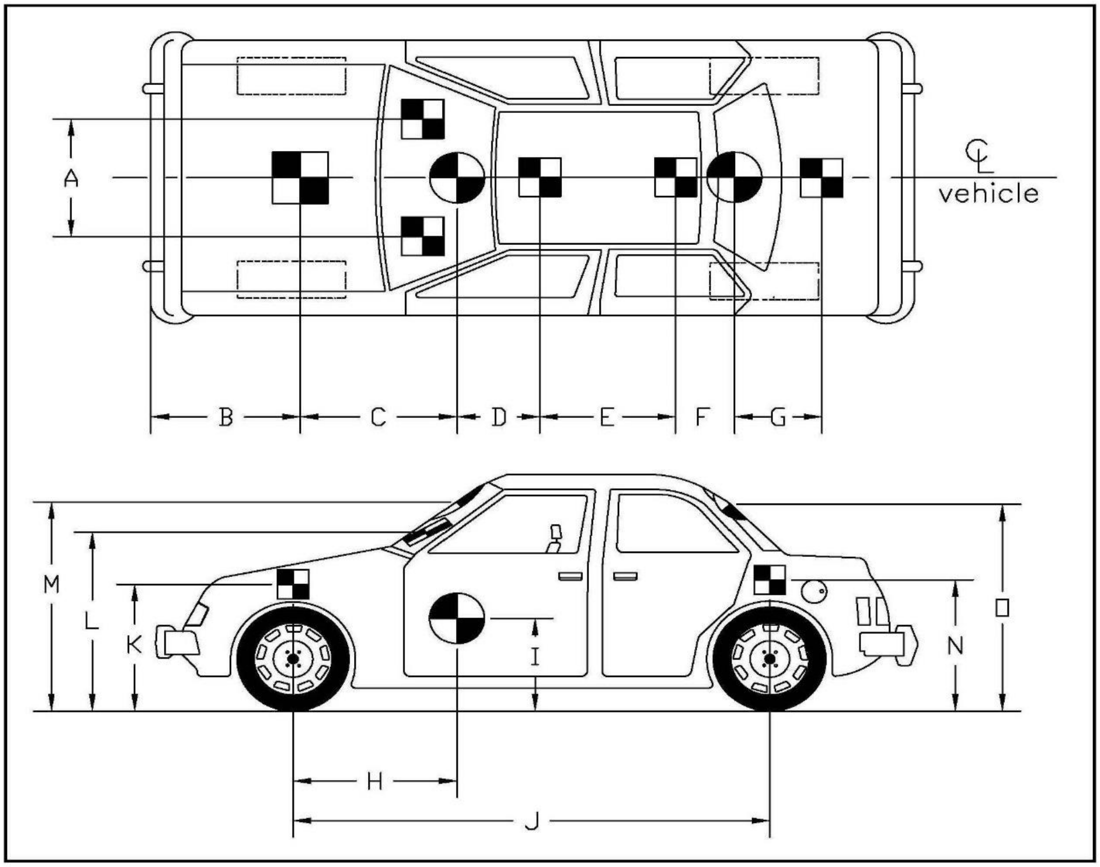


TARGET GEOMETRY-- in. (mm)

A:	75 1/4 (1911)	E:	63 5/16 (1608)	J:	42 7/8 (1089)
B:	28 7/8 (733)	F:	63 1/2 (1613)	K:	28 1/4 (718)
C:	77 1/4 (1962)	G:	32 7/8 (835)	L:	45 7/8 (1165)
D:	48 (1219)	H:	60 11/16 (1541)	M:	64 5/8 (1641)
		I:	79 7/16 (2018)		

Figure 46. Target Geometry, Test No. MSPBN-1

Date:	3/22/2017	Test Name:	MSPBN-2	VIN:	KNADH4A34A6680510
Year:	2010	Make:	Kia	Model:	Rio

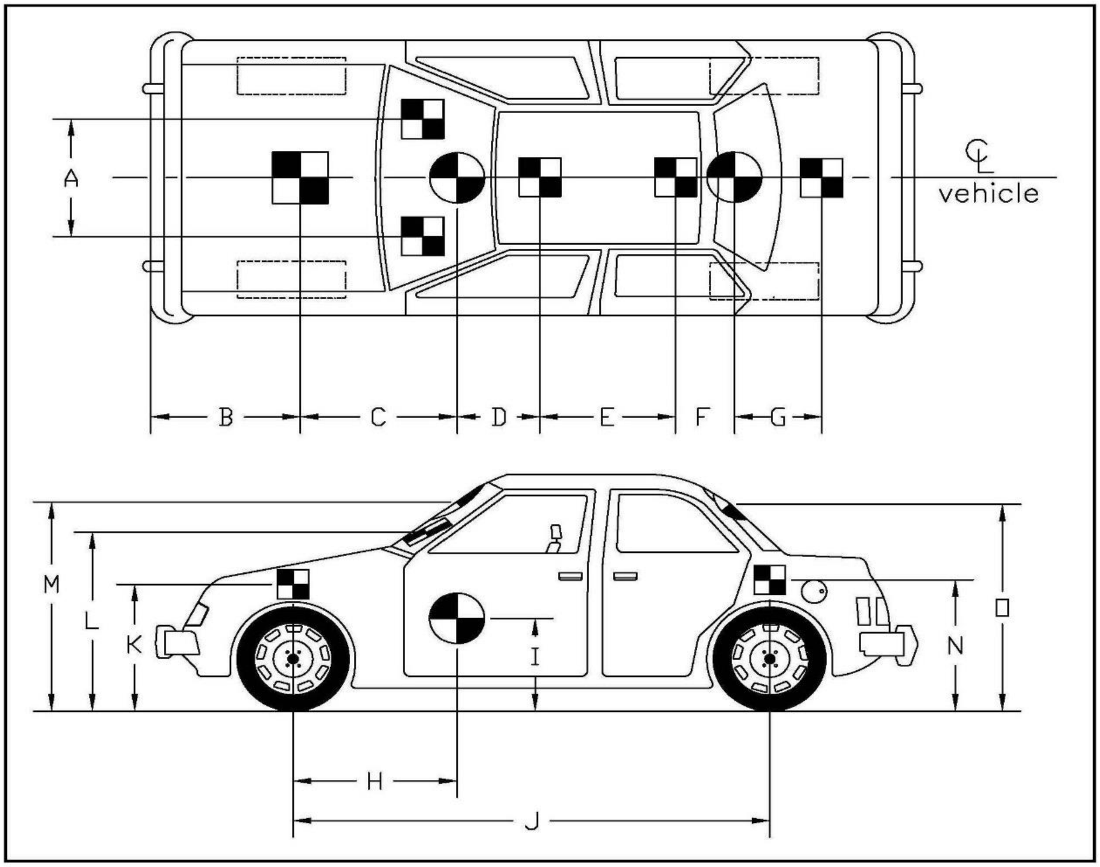


TARGET GEOMETRY - in. (mm)

A	27 7/8	(708)	F	10 3/4	(273)	K	29	(737)
B	20 1/8	(511)	G	22 1/8	(562)	L	48 5/8	(1235)
C	49 1/8	(1248)	H	36 3/8	(924)	M	52 5/8	(1337)
D	7 3/8	(187)	I	23	(584)	N	28 3/4	(730)
E	45 3/8	(1153)	J	98 1/2	(2502)	O	52 1/4	(1327)

Figure 47. Target Geometry, Test No. MSPBN-2

Date: 4/11/2017 Test Name: MSPBN-3 VIN: KMHCN4AC5BU612118
Year: 2011 Make: Hyundai Model: Accent



TARGET GEOMETRY - in. (mm)

A	26 1/4	(667)	F	11 3/8	(289)	K	29	(737)
B	21 7/8	(556)	G	23 3/8	(594)	L	48	(1219)
C	47	(1194)	H	36 7/8	(935)	M	52 3/4	(1340)
D	14 1/4	(362)	I	22 3/4	(578)	N	28 1/2	(724)
E	36 3/8	(924)	J	98 1/2	(2502)	O	52 3/4	(1340)

Figure 48. Target Geometry, Test No. MSPBN-3

4.4 Simulated Occupant

For test nos. MSPBN-1, MSPBN-2, and MSPBN-3, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the left-front seat of the test vehicle with the seat belt fastened. The dummy had a final weight of 161 lb (73 kg), 162 lb (73 kg) and 158 lb (72 kg) for test nos. MSPBN-1, MSPBN-2, and MSPBN-3, respectively. As recommended by MASH 2016, the dummy 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 accelerometers were mounted near the c.g. of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [16].

The two systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. For test no. MSPBN-1, the SLICE-2 unit was designated as the primary system, and for test nos. MSPBN-2 and MSPBN-3, the SLICE-1 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 program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

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

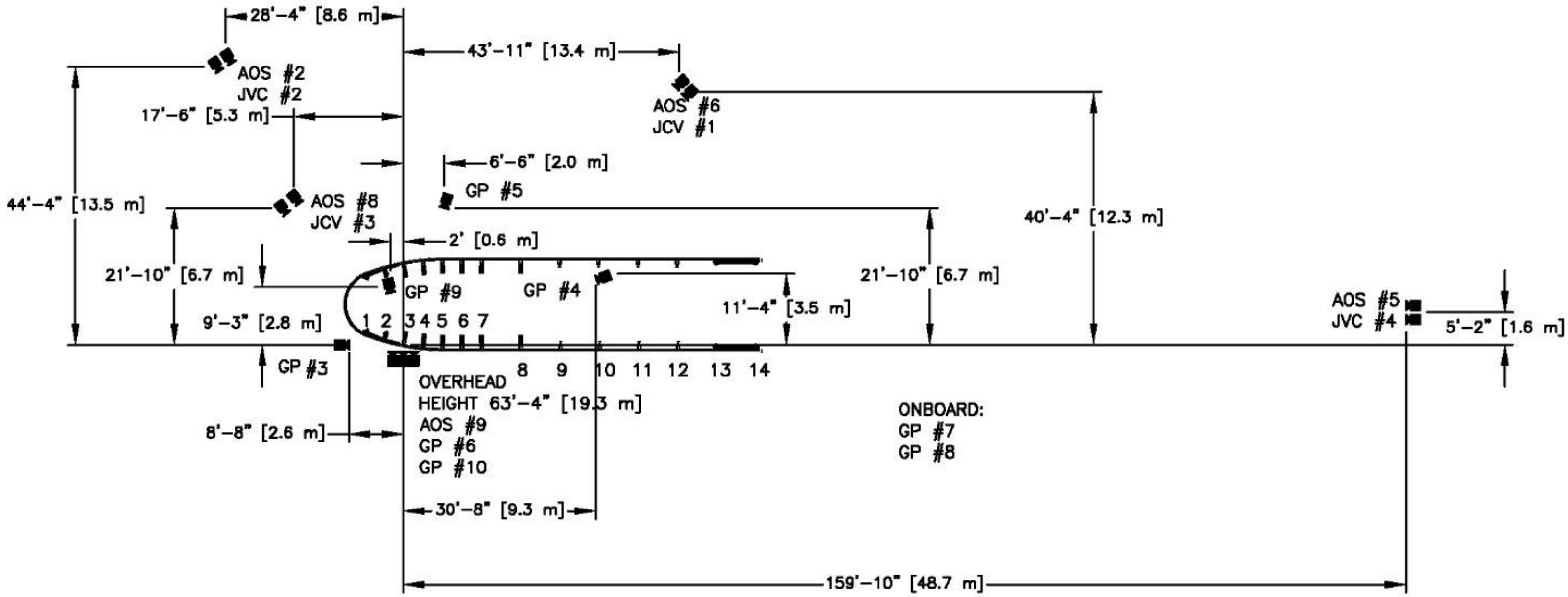
4.5.3 Retroreflective Optic Speed Trap

The 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 only used as a backup in the event that vehicle speeds cannot be determined from the electronic data.

4.5.4 Digital Photography

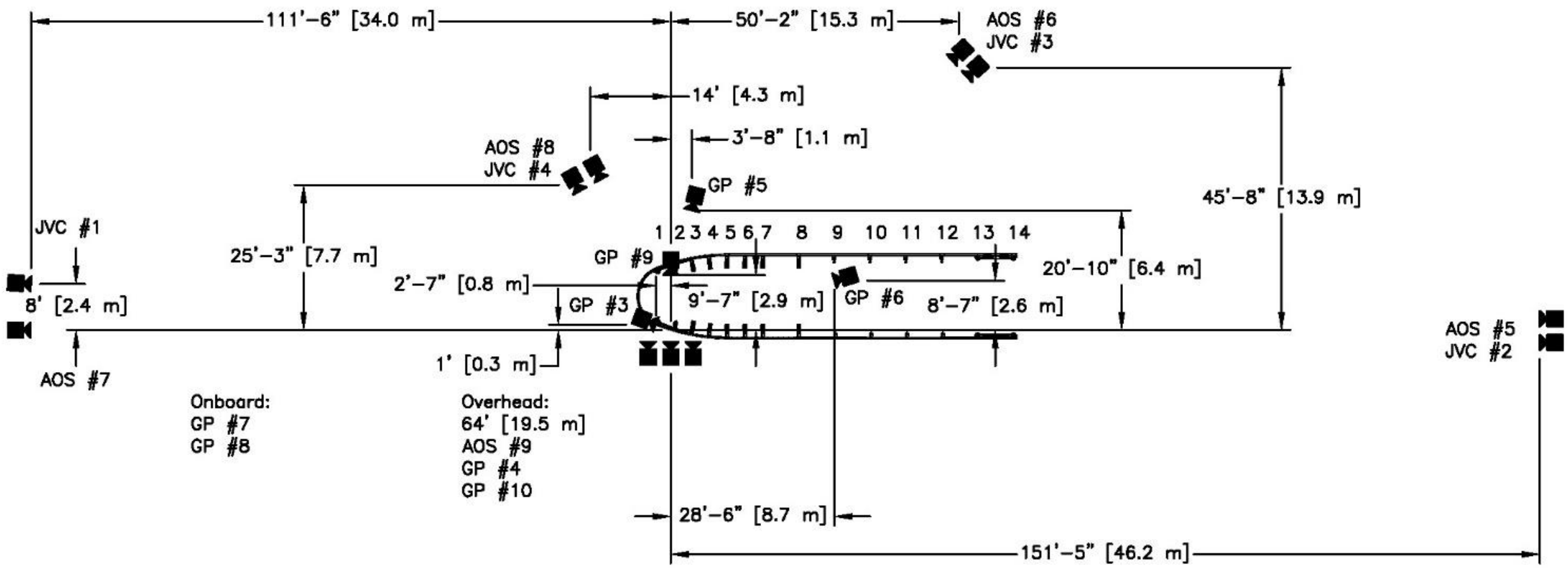
Five AOS high-speed digital video cameras, eight GoPro digital video cameras, and four JVC digital video cameras were utilized to film test no. MSPBN-1. Five AOS high-speed digital video cameras, eight GoPro digital video cameras, and four JVC digital video cameras were utilized to film test no. MSPBN-2. Five AOS high-speed digital video cameras and eleven GoPro digital video cameras were utilized to film test no. MSPBN-3. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figures 49, 50, and 51 respectively. Note that in test no. MSPBN-1, camera views from JVC-1 and JVC-2 are not available due to technical difficulties.

The high-speed videos were analyzed using ImageExpress MotionPlus, 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 digital still camera was also used to document pre- and post-test conditions for all tests.



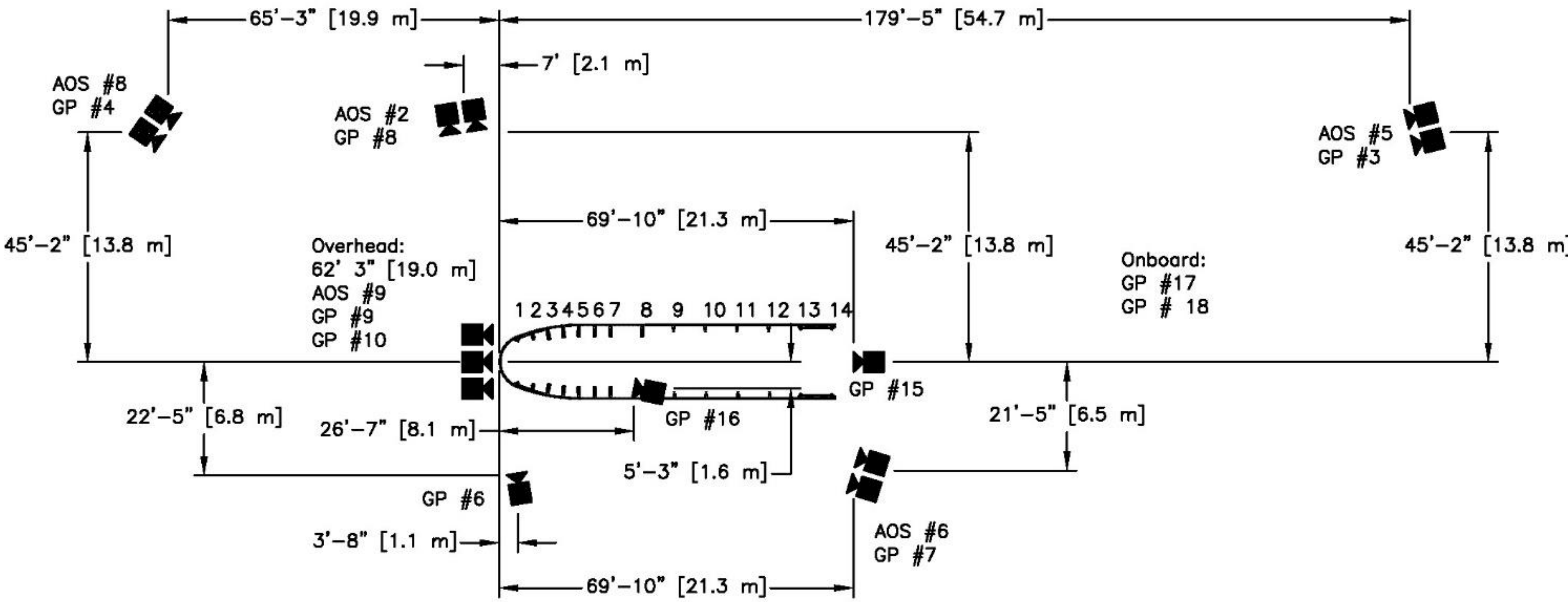
No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam CTM	500	KOWA 25mm Fixed	-
AOS-5	AOS X-PRI Gigabit	500	SIGMA 28-70	70
AOS-6	AOS X-PRI Gigabit	500	FUJINON 35mm Fixed	-
AOS-8	AOS S-VIT 1531	500	SIGMA 28-70 OG	35
AOS-9	AOS TRI-VIT	500	KOWA 12 Fix	-
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	240		
GP-10	GoPro Hero 4	240		
JVC-1	JVC – GZ-MC500 (Everio)	29.97		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 49. Camera Locations, Speeds, and Lens Settings, Test No. MSPBN-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS Vitcam CTM	500	SIGMA 28-70	70
AOS-6	AOS X-PRI Gigabit	500	FUJINON 50 mm Fixed	-
AOS-7	AOS X-PRI Gigabit	500	SIGMA 28-70 DG	70
AOS-8	AOS S-VIT 1531	500	FUJINON 35 mm Fixed	-
AOS-9	AOS TRI-VIT	500	KOWA 12 mm Fix	-
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	240		
GP-10	GoPro Hero 4	240		
JVC-1	JVC – GZ-MC500 (Everio)	29.97		
JVC-2	JVC – GZ-MG27u (Everio)	29.97		
JVC-3	JVC – GZ-MG27u (Everio)	29.97		
JVC-4	JVC – GZ-MG27u (Everio)	29.97		

Figure 50. Camera Locations, Speeds, and Lens Settings, Test No. MSPBN-2



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam CTM	500	FUJINON 35 mm Fixed	-
AOS-5	AOS X-PRI Gigabit	500	VIVITAR 135 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	SIGMA 28-70	35
AOS-8	AOS S-VIT 1531	500	SIGMA 28-70	35
AOS-9	AOS TRI-VIT	500	KOWA 12 mm Fixed	-
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	240		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	240		
GP-10	GoPro Hero 4	120		
GP-15	GoPro Hero 4	240		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	120		
GP-18	GoPro Hero 4	120		

Figure 51. Camera Locations, Speeds, and Lens Settings, Test No. MSPBN-3

5 FULL-SCALE CRASH TEST NO. MSPBN-1

5.1 Static Soil Test

Before full-scale crash test no. MSPBN-1 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

5.2 Weather Conditions

Test no. MSPBN-1 was conducted on March 3, 2017 at approximately 2:30 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

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

Temperature	55° F
Humidity	28 %
Wind Speed	23 mph (37 km/h)
Wind Direction	170° from True North
Sky Conditions	Sunny / Overcast
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in. (0 mm)
Previous 7-Day Precipitation	0.09 in. (2.3 mm)

5.3 Test Description

Initial vehicle impact was to occur at the centerline of post no. 3, which was selected based on prior testing as described in Chapter 2, as shown in Figure 52. The 5,001-lb (2,268-kg) quad cab pickup truck impacted the bullnose with breakaway steel posts at a speed of 62.9 mph (101.3 km/h) and at an angle of 25.1 degrees. The actual point of impact was 2.7 in. (69 mm) downstream from the centerline of post no. 3. After initial impact, the vehicle was contained and safely redirected by the bullnose system. As the vehicle redirected, UBSP nos. A5 through A8 disengaged due to fracture of the base plate bolts. This post disengagement created limited vehicle pocketing and snag at post nos. A9 and A10, which were the first two standard W6x8.5 line posts in the system. However, this behavior did not compromise vehicle capture or stability and did not negatively affect the occupant risk values. The vehicle came to rest 66 ft – 1 in. (20.1 m) downstream from and 1 ft (300 mm) behind the initial impact point after the brakes were applied.

A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 53 through 54. Documentary photographs of the crash test are shown in Figure 55. The vehicle trajectory and final position are shown in Figure 56.

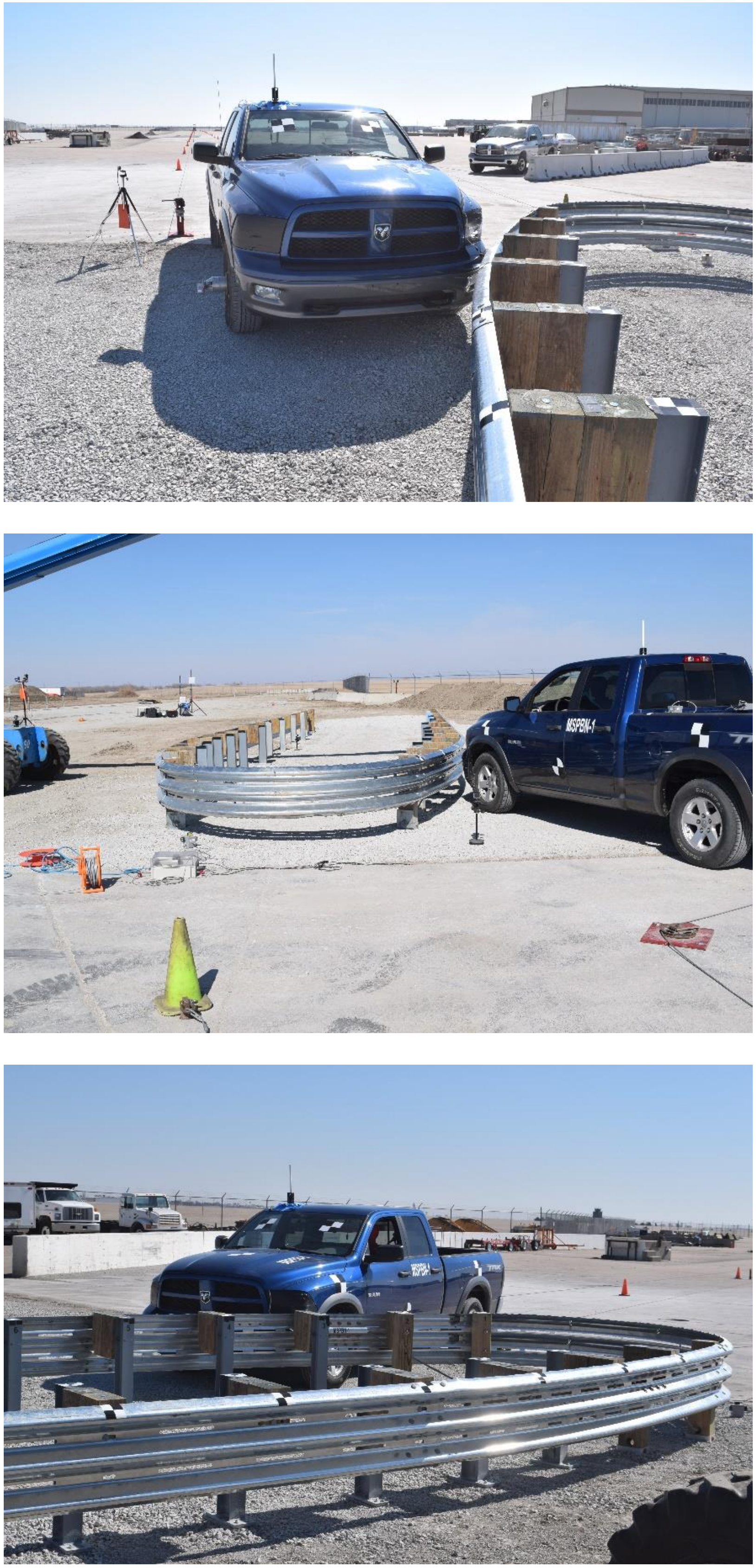


Figure 52. Impact Location, Test No. MSPBN-1

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

TIME (sec)	EVENT
0.000	Vehicle's left-front bumper impacted rail at 2.7 in. (69 mm) downstream from centerline of post no. 3.
0.002	Vehicle's front bumper deformed, post no. A3 deflected backward, and rail deformed.
0.005	Vehicle's left fender contacted rail between post nos. A3 and A4. Post no. A4 deflected backward, vehicle's left headlight and left fender deformed, and vehicle's left headlight contacted rail between post nos. A3 and A4.
0.009	Vehicle's grille contacted rail between post nos. A3 and A4 and deformed.
0.012	Post no. A5 deflected backward.
0.014	Soil heave formed on non-traffic flange of post no. A3.
0.018	Post no. A6 deflected backward.
0.020	Post no. A7 deflected backward.
0.022	Post no. A4 rotated counterclockwise, soil heave formed on non-traffic flange of post no. A4, and vehicle's left headlight shattered.
0.028	Post no. A1 deflected downstream.
0.030	Soil heave formed on non-traffic flange of post no. A5.
0.036	Post no. A2 rotated counterclockwise, and post no. A3 rotated counterclockwise.
0.040	Vehicle yawed away from barrier, and post no. A2 deflected downstream.
0.043	Post no. A5 rotated downstream about blockout no. A5.
0.048	Post no. A9 rotated clockwise.
0.050	Vehicle's hood deformed.
0.054	Vehicle's left-front door experienced flexure.
0.066	Soil heave formed on non-traffic flange of post no. A6.
0.068	Post no. A8 deflected backward, piece of vehicle's left fender disengaged, and post no. A5 disengaged from foundation post.
0.072	Vehicle rolled away from barrier.
0.076	Post no. A9 deflected backward.
0.078	Vehicle's left-front door contacted rail and deformed.
0.086	Vehicle's left-front tire contacted post no. A5.
0.088	Post no. A10 deflected backward.
0.090	Blockout no. A6 disengaged from rail at post no. A6.
0.096	Post no. A6 disengaged from foundation post.
0.108	Soil heave formed on non-traffic flange of post no. A7.
0.114	Vehicle pitched forward.
0.120	Vehicle's left-rear door contacted rail and deformed.
0.126	Vehicle's left-front tire contacted post no. A6.
0.128	Blockout no. A7 disengaged from rail at post no. A7.
0.130	Post no. A7 disengaged from foundation post.

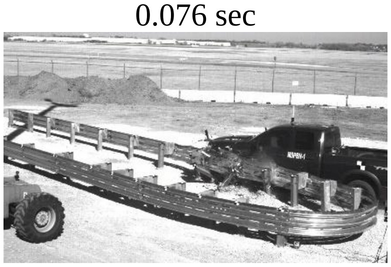
Table 5. Sequential Description of Impact Events, Test No. MSPBN-1, Cont.

TIME (sec)	EVENT
0.148	Soil heave formed on the non-traffic flange of post no. A8.
0.166	Vehicle pitched downward.
0.172	Vehicle's left-front tire contacted post no. A7.
0.186	Post no. A9 bent backward.
0.192	Soil heave formed on the non-traffic flange of post no. A9.
0.194	Vehicle's grille disengaged, and vehicle's left quad panel contacted rail at post no. A4 and deformed.
0.200	Post no. A8 disengaged from foundation post.
0.222	Vehicle's rear bumper deformed.
0.260	Post no. A8 rotated downstream about blockout no. A8.
0.279	Post no. A10 rotated counterclockwise.
0.280	Post no. A10 bent downstream.
0.282	Blockout no. A9 disengaged from the rail at post no. A9.
0.290	Vehicle was parallel to system at a speed of 40.4 mph (65.1 km/h).
0.308	Soil heave formed on non-traffic flange of post no. A10.
0.434	Vehicle rolled toward barrier.
0.451	Vehicle yawed toward barrier.
0.499	Blockout no. A10 disengaged from rail at post no. A10.
0.502	Vehicle's left-front tire disengaged.
0.618	Vehicle pitched forward.
0.738	Vehicle exited system at a speed of 17.8 mph (28.6 km/h) and an angle of 18.9 degrees.
0.846	Vehicle pitched downward.
0.897	Vehicle's left-front tire detached.
1.965	System came to rest.

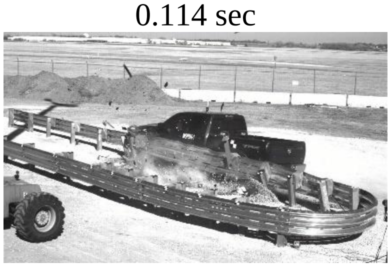
0.000 sec

0.036 sec

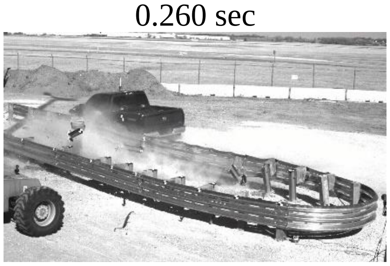
0.076 sec



0.114 sec



0.260 sec



0.738 sec

0.000 sec

0.050 sec

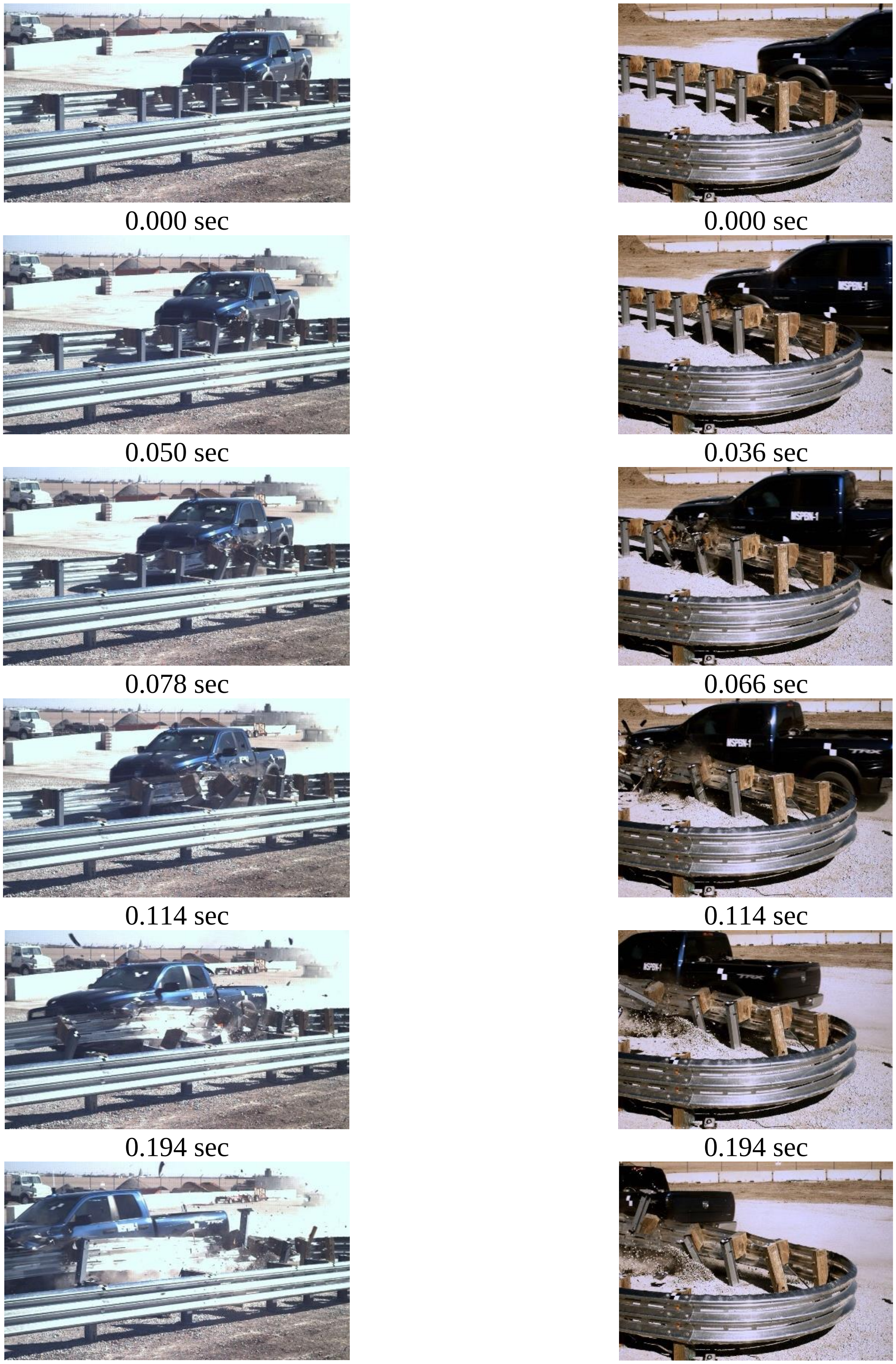
0.128

0.280 sec

0.451 sec

0.738 sec

Figure 53. Sequential Photographs, Test No. MSPBN-1



0.000 sec
0.050 sec
0.078 sec
0.114 sec
0.194 sec
0.290 sec

0.000 sec
0.036 sec
0.066 sec
0.114 sec
0.194 sec
0.290 sec

Figure 54. Additional Sequential Photographs, Test No. MSPBN-1

Figure 55. Documentary Photographs, Test No. MSPBN-1

Figure 56. Vehicle Final Position and Trajectory Marks, Test No. MSPBN-1

5.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 57 through 65. Barrier damage consisted of contact marks on the front face of the guardrail, kinking and flattening of the rail, and post deformation and disengagement. The length of vehicle contact along the barrier was approximately 38 ft – 10 in. (11.8 m), which spanned from 4¼ in. (108 mm) downstream from the center target at post no. 3 to 20 in. (508 mm) downstream from the center of the target at post no. 11.

The foundation tube of post no. A1 was crushed in on the upstream side. Post no. A2 fractured on the upstream side of the post at the foundation tube bolt. The post base bolts of post nos. A5 through A8 fractured at the ground line. Post nos. A6 and A7 were detached from the rail. Post no. A9 was bent backward and downstream, the blockout disengaged from the post and the rail, the guardrail bolt fractured, and there were dents on the front and back upstream flanges 17 in. (432 mm) and 20½ in. (521 mm) from the top of the post, respectively. The back upstream flange of post no. B9 was dented 18½ in. (470 mm) from the bottom by post no. A7, which flew backward.

Kinks in the thrie-beam were located at the center of the target of post no. A1, 10 in. (254 mm) and 24 in. (610 mm) downstream from the target and on the lower face of the lower corrugation 12 in. (305 mm) downstream from post no. A1. The rail was dented on the upper face of the lower corrugation, 10½ in. (267 mm) upstream from the center of post no. A2. Kinks were located on the top of the rail at 2 in. (51 mm), 3 in. (76 mm), 8¾ in. (222 mm) and 34½ in. (876 mm) downstream from the center target of post no. A2. Multiple dents were located between post nos. A2 and A4. The rail began to flatten 35 in. (889 mm) downstream from post no. A3. A 3-in. (76-mm) diameter dent was located 8 in. (203 mm) upstream from the center of post no. A5. A kink was found 1 in. (25 mm) upstream from post no. A5 on the bottom on the rail. A 1⅛-in. (29-mm) tear was found on the top face of the upper corrugation of the top upstream bolt hole of the splice at post no. A5. A kink was found 13 in (330 mm) downstream from post no. A5 on the top face of the top flange and 27 in. (686 mm) downstream from post no. A5 on the lower face of the lower corrugation. Kinks were located on the top flange of the rail at 2 in. (51 mm) and 28 in. (711 mm) downstream from the centerline of post no. A6 and on the lower flange of the rail 14 in. (356 mm) and 34½ in. (876 mm) downstream from post no. A6. The top flange of the rail was kinked 10½ in. (267 mm), 38½ in. (978 mm) and 55½ in. (1,410 mm) downstream from post no. A7, and the rail was kinked on the bottom flange 18 in. (457 mm), 37 in. (940 mm), and 58½ in. (1,486 mm) downstream from post no. A7. Kinking was found on the bottom rail flange 20 in. (508 mm) and 47½ in. (1,207 mm) downstream from post no. A8 and on the top rail flange, 4½ in. (114 mm) and 45 in. (1,143 mm) downstream from post no. A8. The rail along the centerline of post no. A9 was kinked on bottom flange and had a 6-in. (152-mm) diameter, ½-in. (13-mm) deep dent. Kinks were located on the top rail flange, 5 in. (127 mm), 39 in. (991 mm), and 67½ in. (1,715 mm) downstream from post no. A10 and on the bottom rail flange 38 in. (965 mm) and 89 in. (2,261 mm) downstream from post no. A10. The post bolt of post no. A11 began to pull through the rail. Post no. A1 was pushed back and downstream, resulting in a 1-in. (25-mm) soil gap upstream and ¼-in. (6-mm) soil gap on the front side of the post.

Figure 57. System Damage, Test No. MSPBN-1

Figure 58. Post Nos. A1 through A5 Damage, Test No. MSPBN-1

Figure 59. Post Nos. A6 through A13 Damage, Test No. MSPBN-1

Figure 60. Post Nos. A1 through A3 Damage, Test No. MSPBN-1

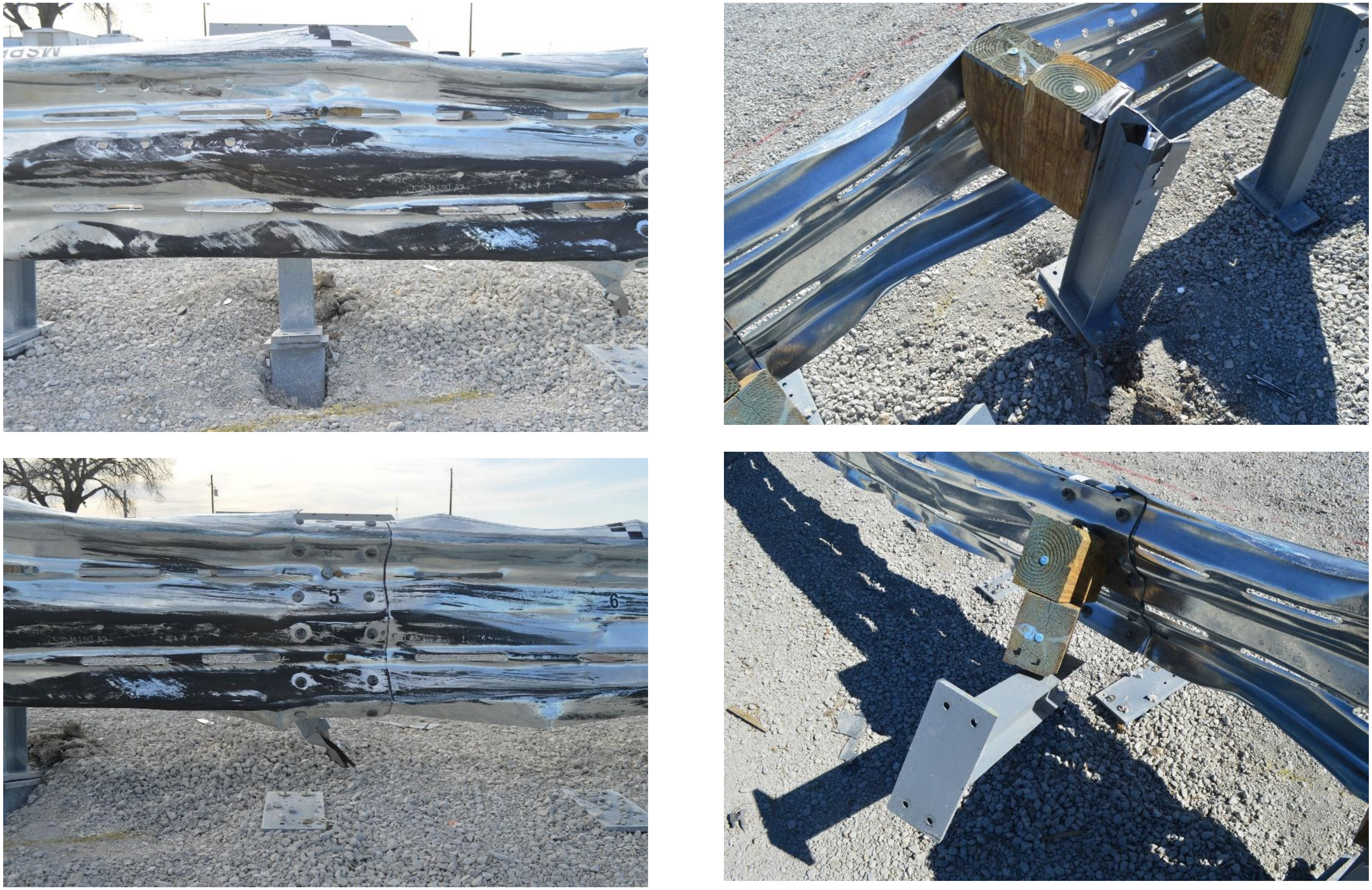


Figure 61. Post Nos. A4 and A5 Damage, Test No. MSPBN-1

Figure 62. Post Nos. A6 and A7 Damage, Test No. MSPBN-1

Figure 63. Post Nos. A8 and A9 Damage, Test No. MSPBN-1

Figure 64. Post Nos. A10 and A11 Damage, Test No. MSPBN-1

Figure 65. Post No. B9 Damage, Test No. MSPBN-1

The maximum lateral dynamic barrier deflection was 46.2 in. (1,173 mm) at the rail at post no. A6, as determined from high-speed digital video analysis. The vehicle was successfully redirected during the impact event. The system working width was 177.25 in. (4,502 mm) based on the width of the bullnose system. Note that working width for redirective impacts is defined based on the maximum of the lateral dynamic deflection of the system, the lateral extension of the vehicle, and the barrier width as measured from the front face of the barrier during a vehicle impact. However, the bullnose system is sufficiently wide to allow for lateral deflection and vehicle extension internal to the barrier width. Thus, the working width is defined based on the overall width of the system. The system deformation is shown in Figure 66.

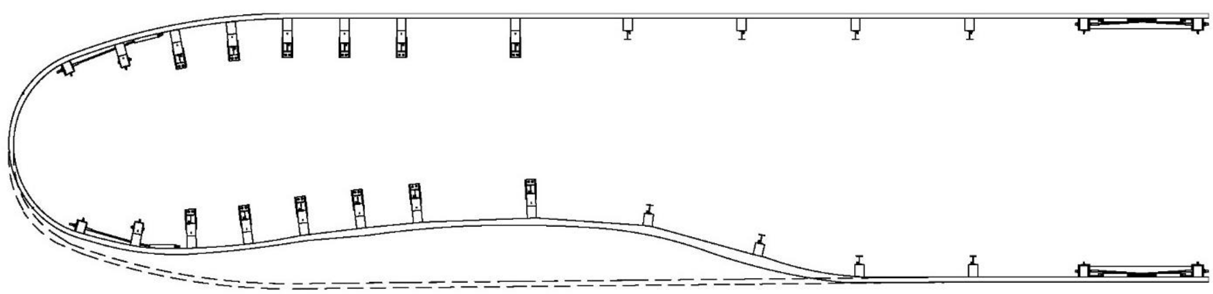


Figure 66. System Deformation After Impact, Test No. MSPBN-1

5.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 67 through 71. 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. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. Note that none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix D.

The majority of the damage was concentrated on the on the left-front corner and left-front side of the vehicle where the impact occurred. The entire grille assembly was disengaged from the front of the vehicle. A 21-in. x 6-in. (533-mm x 152-mm) section on the left side of the front facia above the front bumper was detached. The remainder of the front facia was only attached by a small section on the right side of the vehicle. The left headlight and left-front fog light were disengaged. The left side of the front bumper was dented and crushed inward. The left fender was bent up and inward, and the rear section was separated. The left-front wheel, brake assembly, and tie rod were disengaged. The inner wheel well plastic was dented and kinked, and the top portion was separated from the vehicle. The front of the left-front door had a series of dents and scrapes at the middle of the door. The left-rear corner of the cab and the front edge of the right quarter panel were dented and scraped. Dents and scraping were located on the left quarter panel just below the taillight. A 27-in. (686-mm) diameter spider web crack was found in the windshield due to right-side airbag activation.

Figure 67. Vehicle Damage, Test No. MSPBN-1

Figure 68. Vehicle Damage, Test No. MSPBN-1

Figure 69. Windshield Damage Test No. MSPBN-1

Figure 70. Interior Floorboard Damage, Test No. MSPBN-1

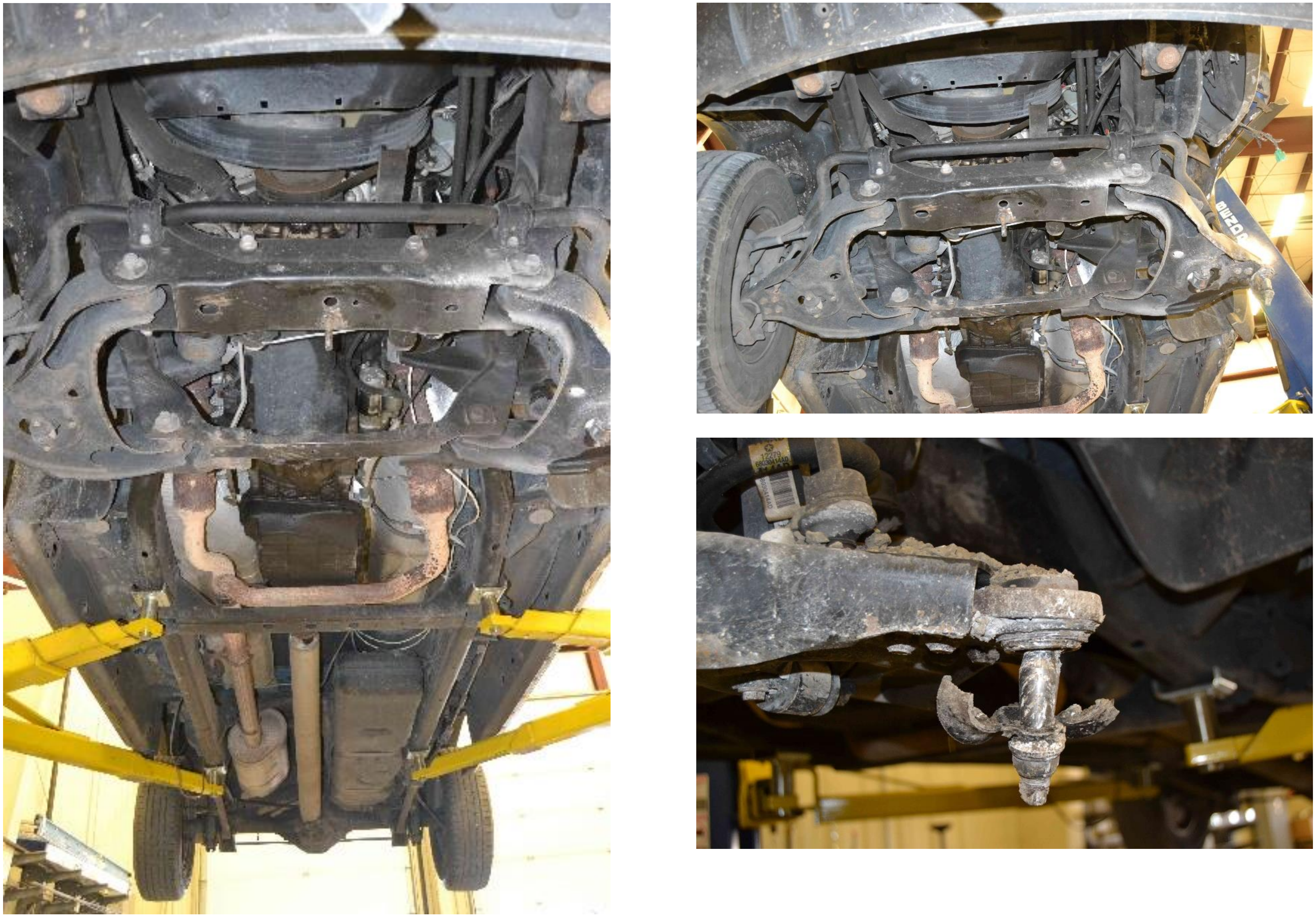


Figure 71. Undercarriage Damage, Test No. MSPBN-1

Table 6. Maximum Occupant Compartment Intrusion by Location, Test No. MSPBN-1

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

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

5.6 Occupant Risk

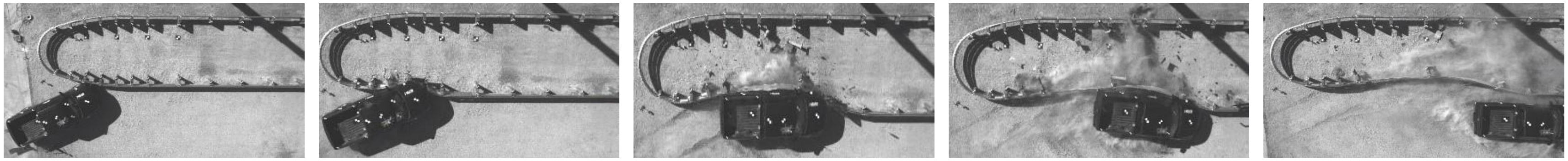
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 7. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 7. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 7. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MSPBN-1

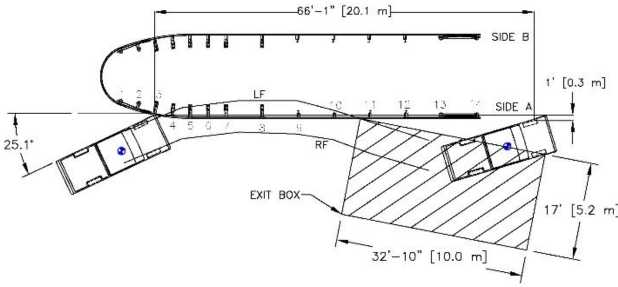
Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	−19.76 (−6.02)	−17.99 (−5.48)	±40 (12.2)
	Lateral	13.26 (4.04)	13.84 (4.22)	±40 (12.2)
ORA g's	Longitudinal	−11.74	−11.92	±20.49
	Lateral	6.76	7.22	±20.49
MAX. ANGULAR DISPL. deg.	Roll	−13.33	−12.28	±75
	Pitch	−4.21	−4.70	±75
	Yaw	32.85	31.60	not required
THIV ft/s (m/s)		21.72 (6.62)	21.88 (6.67)	not required
PHD g's		12.37	12.31	not required
ASI		0.71	0.77	not required

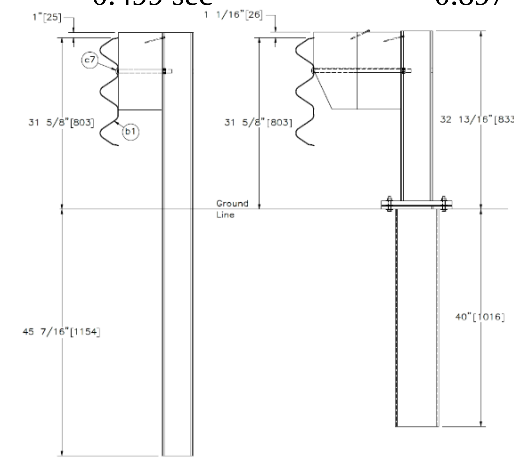
5.7 Discussion

The analysis of the test results for test no. MSPBN-1 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. A summary of the test results is shown in Figure 72. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix E, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 18.9 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. MSPBN-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-35.



0.000 sec | 0.088 sec | 0.292 sec | 0.499 sec | 0.897 sec





- Test Agency .... MwRSF
- Test Number MSPBN-1
- Date 3/3/17
- MASH 2016 Test Designation No. 3-35
- Test Article .... Steel Bullnose with Breakaway Posts
- Total Length .... 66 ft (20 m)
- Key Component – Thrie Beam
  - Thickness .... 12 gauge (2.7 mm)
  - Mounting Height .... 31⅝ in. (803 mm)
- Key Component – Breakaway Steel Post
  - Length .... $72\frac{1}{16}$ in. (1,849 mm)
  - Spacing .... 37½ in. (953 mm)
- Soil Type .... Coarse, Crushed Limestone
- Vehicle Make /Model .... Dodge Ram 1500 Quad Cab Pickup Truck
  - Curb .... 5,108 lb (2,317 kg)
  - Test Inertial .... 5,001 lb (2,268 kg)
  - Gross Static .... 5,162 lb (2,341 kg)
- Impact Conditions
  - Speed .... 62.9 mph (101.3 km/h)
  - Angle .... 25.1 deg.
  - Impact Location .... 2.7 in. (69 mm) DS of the CL of post no. 3
- Impact Severity 119.0 kip-ft (161.3 kJ) ≥ 106.0 kip-ft (144.0 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 17.8 mph (28.6 km/h)
  - Angle .... 18.9 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 66 ft (20 m) downstream, 1 ft (300 mm) behind system
- Vehicle Damage .... Moderate
  - VDS [17] 11-LFQ-4
  - CDC [18] 11-LFEW-5
  - Maximum Interior Deformation .... ⅝ in. (16 mm)

- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... N/A
  - Dynamic .... 46.2 in. (1,173 mm)
  - Working Width .... 177.25 in. (4,502 mm)*
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	−19.76 (−6.02)	−17.99 (−5.48)	±40 (12.2)
	Lateral	13.26 (4.04)	13.84 (4.22)	±40 (12.2)
ORA g's	Longitudinal	−11.74	−11.92	±20.49
	Lateral	6.76	7.22	±20.49
MAX ANGULAR DISP. deg.	Roll	−13.32	−12.28	±75
	Pitch	−4.21	−4.70	±75
	Yaw	32.85	31.60	Not required
THIV – ft/s (m/s)		21.72 (6.62)	21.88 (6.67)	Not required
PHD – g's		12.37	12.31	Not required
ASI		0.71	0.77	Not required

*Note: Working width was defined based on overall system width and not interior dynamic deflections or vehicle extension interior to the barrier

Figure 72. Summary of Test Results and Sequential Photographs, Test No. MSPBN-1

6 FULL-SCALE CRASH TEST NO. MSPBN-2

6.1 Static Soil Test

Before full-scale crash test no. MSPBN-2 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

6.2 Weather Conditions

Test no. MSPBN-2 was conducted on March 22, 2017 at approximately 1:30 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 8.

Table 8. Weather Conditions, Test No. MSPBN-2

Temperature	53° F
Humidity	26 %
Wind Speed	16 mph (25.7 km/h)
Wind Direction	120° from True North
Sky Conditions	Partly Cloudy
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in.
Previous 7-Day Precipitation	0.01 in. (0.3 mm)

6.3 Test Description

Initial vehicle impact was to occur at the centerline of post no. 2, which was selected based on testing of similar systems as described in Chapter 2, as shown in Figure 73. The 2,448-lb (1,110-kg) small car impacted the bullnose with breakaway steel posts at a speed of 62.1 mph (100.0 km/h) and at an angle of 14.7 degrees. The actual point of impact was 0.6 in. (16 mm) upstream from the target impact location. After initial impact, the vehicle was captured and safely redirected by the bullnose system. As the vehicle redirected, BCT post no. 2 and UBSP post nos. 3 through 6 were deflected laterally, but none of the posts disengaged. The cable anchorage at post no. 1 remained engaged as well. The vehicle exited and came to rest 99 ft – 6 in. (30.3 m) downstream from and 25 ft – 1 in (7.7 m) in front of the initial impact point after brakes were applied. Note that some of the vehicle damage observed in the test was due to vehicle impact on an earth berm used to shield a portion of the test site after exiting the system.

A sequential description of the impact events is contained in Table 9. Sequential photographs are shown in Figures 74 and 75. Documentary photographs of the crash test are shown in Figure 76. The vehicle trajectory and final position are shown in Figure 77.

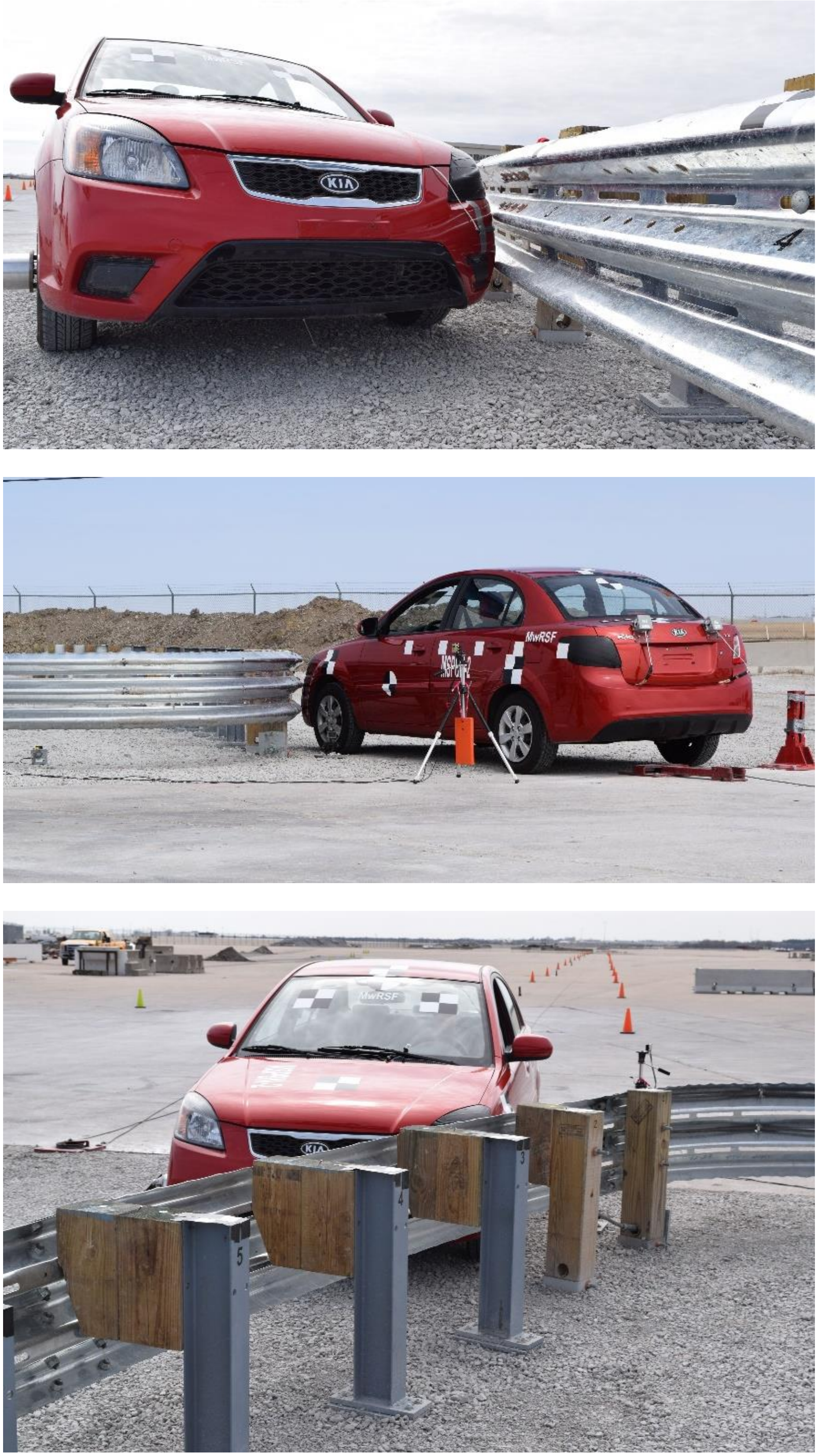
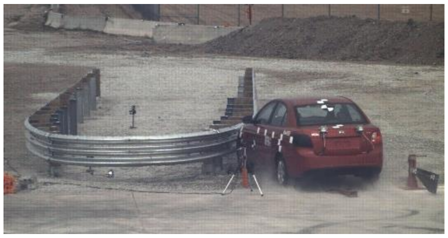


Figure 73. Impact Location, Test No. MSPBN-2

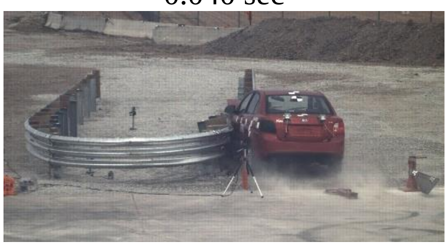
Table 9. Sequential Description of Impact Events, Test No. MSPBN-2

TIME (sec)	EVENT
0.000	Vehicle's left-front bumper impacted rail 0.6 in. (16 mm) upstream from post no. 2.
0.008	Vehicle's left headlight contacted rail between post nos. 2A and 3A.
0.010	Vehicle's hood deformed.
0.012	Post no. 2A deflected backward.
0.014	Vehicle's left fender contacted rail.
0.016	Post no. 1A deflected backward.
0.018	Post no. 3A deflected backward, and vehicle's left fender deformed.
0.020	Vehicle's hood contacted rail.
0.026	Soil heave formed on non-traffic flange of post no. 3A.
0.028	Post no. 4A deflected backward.
0.040	Vehicle yawed away from barrier.
0.044	Soil heave formed on non-traffic flange of post no. 4A.
0.056	Post no. 5A deflected backward.
0.060	Vehicle's left-front bumper contacted post no. 4A.
0.062	Vehicle rolled away from barrier.
0.066	Vehicle pitched downward.
0.068	Vehicle's left-front door contacted rail.
0.078	Soil heave formed on non-traffic flange of post no. 5A, and vehicle's left-front tire wheel contacted post no. 4A.
0.080	Post no. 4A rotated counterclockwise, and vehicle's left-front tire rim deformed.
0.082	Vehicle's left-front door deformed.
0.098	Vehicle's left-front bumper contacted post no. 5A, and dummy head impacted left-front window.
0.104	Post no. 6A deflected backward.
0.106	Vehicle's left-front tire contacted base of post no. 5A.
0.110	Soil heave formed on non-traffic flange of post no. 6A.
0.112	Vehicle's left-front tire contacted post no. 5A.
0.140	Vehicle rolled toward barrier.
0.154	Vehicle was parallel to system at a speed of 44.1 mph (71.0 km/h).
0.160	Vehicle left-front wheel contacted post no. 6A.
0.206	Vehicle's left quarter panel contacted rail.
0.296	Vehicle's right-front tire became airborne.
0.306	Vehicle exited system at a speed of 42.0 mph (67.6 km/h) and an angle of 17.1 degrees.
0.372	Vehicle rolled away from barrier.
0.396	Vehicle's right-front tire regained contact with ground.
0.722	Vehicle's hood contacted windshield.

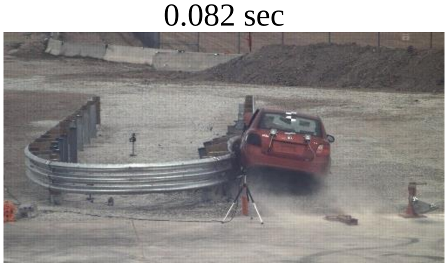


0.000 sec

0.040 sec



0.082 sec



0.140 sec

0.206 sec

0.396 sec

0.000 sec

0.026 sec

0.044

0.062 sec

0.154 sec

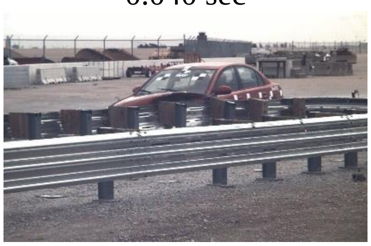
0.306 sec

Figure 74. Sequential Photographs, Test No. MSPBN-2

0.000 sec

0.020 sec

0.040 sec



0.062 sec

0.104 sec

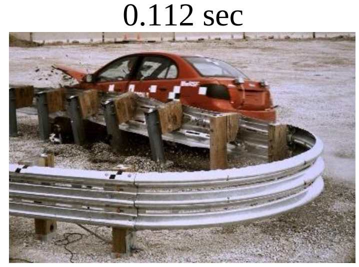
0.306 sec

0.000 sec

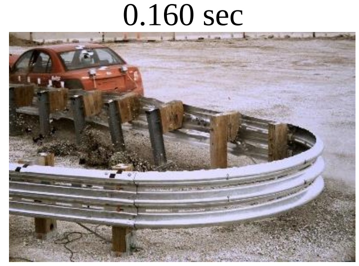
0.040 sec

0.078 sec

0.112 sec



0.160 sec



0.306 sec

Figure 75. Additional Sequential Photographs, Test No. MSPBN-2

Figure 76. Documentary Photographs, Test No. MSPBN-2

Figure 77. Vehicle Final Position and Trajectory Marks, Test No. MSPBN-2

6.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 78 through 82. Barrier damage consisted of contact marks on the front face of the guardrail, kinking and flattening of the rail, and post deformation and disengagement. The length of vehicle contact along the barrier was approximately 12 ft – 9 in. (3.9 m), which spanned from 2 in. (51 mm) downstream from the center target at post no. 2 to 4.9 in. (124 mm) downstream of the center line at post no. 6.

No movement or damage was seen for post no. A1. The top downstream corner of the block out for post no. A2 had a chip measuring ¾ in. (19 mm) deep, 1¾ in. (44 mm) wide and 2 in. (51 mm) tall. Post no. A3 rotated backward, the top downstream corner of the block out was chipped, and the post bolt partially pulled through the slot in the thrie-beam. Tire marks were found on the front flange of post no. A4, 3 in. (76 mm) from the bottom and in front of the base plate. Post no. A4 also rotated backward during the impact. Post no. A5 experienced a backward rotation, and tire marks were found on the front of the base.

Kinking occurred on the top of the top bolt slot 32¾ in. (832 mm) downstream from the first splice, on the bottom of the top bolt slots 28½ in. (724 mm) downstream from the first splice, and on the top of the bottom bolt slots 29¼ in. (743 mm) downstream from the first splice. Kinking was found 32¾ in. (832 mm) downstream from the first splice, 22½ (572 mm) downstream from post no. A5, 17 in. (432 mm) downstream from post no. A6, and 11 in. (279 mm) downstream from post no. A7. Kinking was also found on the bottom rail 15 in. downstream from post no. A5 and 4½ in. (114 mm) downstream from post no. A6. Contact marks extending 141 in. (3,581 mm) and starting 6 in. (152 mm) downstream from the impact target were found in the middle of the rail. Marks were also found on the bottom peak of the rail extending 154 in. (3,912 mm) and starting 3 in. (76 mm) downstream from the impact point. Multiple dents were located between post nos. A3 and A4. The bottom of the rail was flattened starting 6 in. (152 mm) upstream from the target impact point and extending to the center of post no. A6.

The maximum lateral dynamic barrier deflection was 13.7 in. (349 mm) at the rail at post no. A4, as determined from high-speed digital video analysis. As the vehicle was successfully redirected during the impact event and the rail experienced slight outward deformation around the nose, the system working width was 177.25 in. (4,502 mm) based on the width of the bullnose system. Note that working width for redirective impacts is defined based on the maximum of the lateral dynamic deflection of the system, the lateral extension of the vehicle, and the barrier width as measured from the front face of the barrier during a vehicle impact. However, the bullnose system is sufficiently wide to allow for lateral deflection and vehicle extension internal to the barrier width. Thus, the working width is defined based on the overall width of the system. The system deformation is shown in Figure 83.

Figure 78. System Damage, Test No. MSPBN-2

Figure 79. Post nos. A1 through A5 Damage, Test No. MSPBN-2

Figure 80. Blockout Damage, Test No. MSPBN-2

Figure 81. Post Nos. A2 and A3 Damage, Test No. MSPBN-2

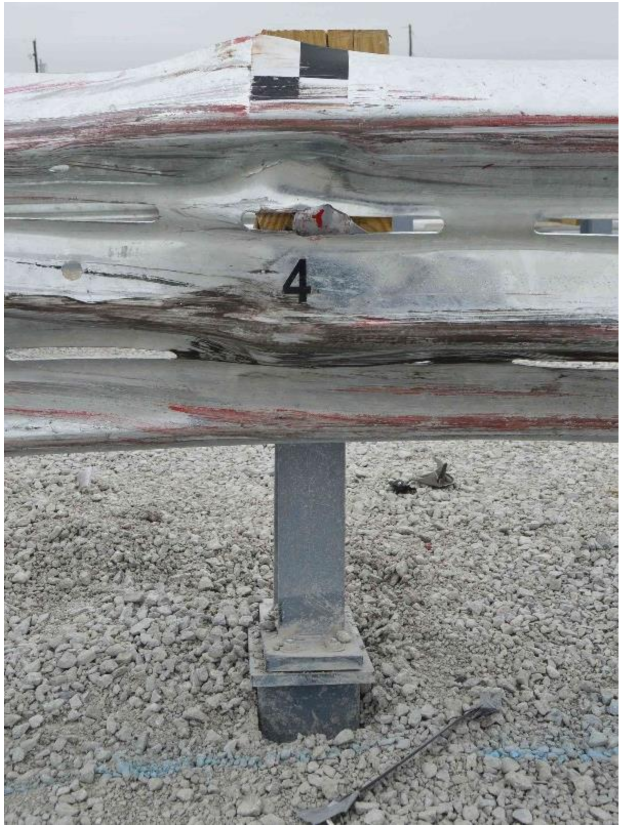


Figure 82. Post Nos. A4 and A5 Damage, Test No. MSPBN-2

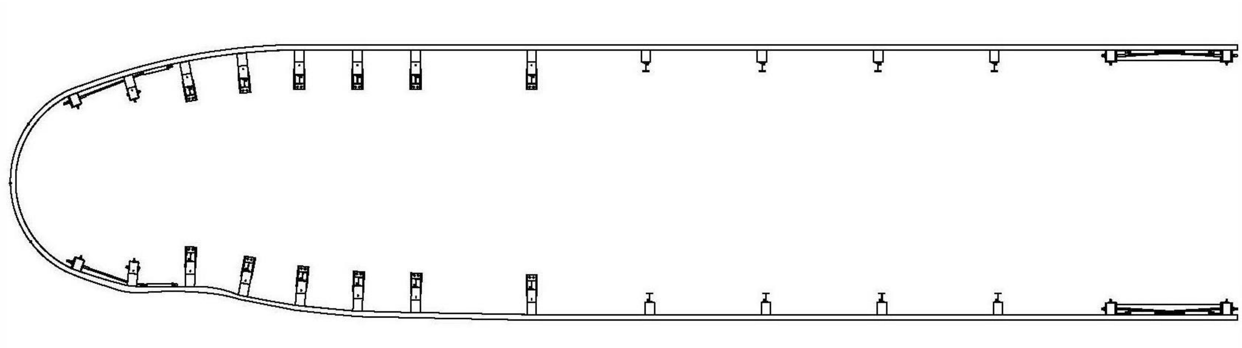


Figure 83. System Deformation After Impact, Test No. MSPBN-2

6.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 84 through 87. The maximum occupant compartment intrusions are listed in Table 10 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. As noted previously, a secondary impact with an earth berm downstream from the impact with the thrie-beam bullnose may have contributed to the observed vehicle damage and intrusions. Note that none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle intrusions and the corresponding locations are provided in Appendix D.

The majority of the damage was concentrated on the left-front corner and left-front side of the vehicle where the impact occurred. A crease developed along the length of the vehicle on the left side along with multiple contact marks and small dents. The vehicle's fuel door on the vehicle disengaged and the fuel door hinge cracked just above the mounting bolt. An 8½-in. (216-mm) diameter dent was found 2 in. (51 mm) from the left-front door and 10 in. (254 mm) from the bottom of the window. An 11-in. x 4-in. (279-mm x 102-mm) dent formed on the rear section of the left-front door. Contact marks and multiple tears were located along the entire front of the fascia. The damage on the right side of the vehicle was mostly due to the impact with earth berm. The lower right corner of the grille assembly and the left headlight detached. A 13-in. (330-mm) tall crack extended the entire length of the windshield. A 3½-in. (89-mm) gap was found between the front right fender and the front of the hood that decreased to 1¾ in. (44 mm) at the rear of the hood. The right-front tire came into contact with the rear of the front wheel well.

Figure 84. Vehicle Damage, Test No. MSPBN-2

Figure 85. Vehicle Damage, Test No. MSPBN-2

Figure 86. Floorboard Damage, Test No. MSPBN-2

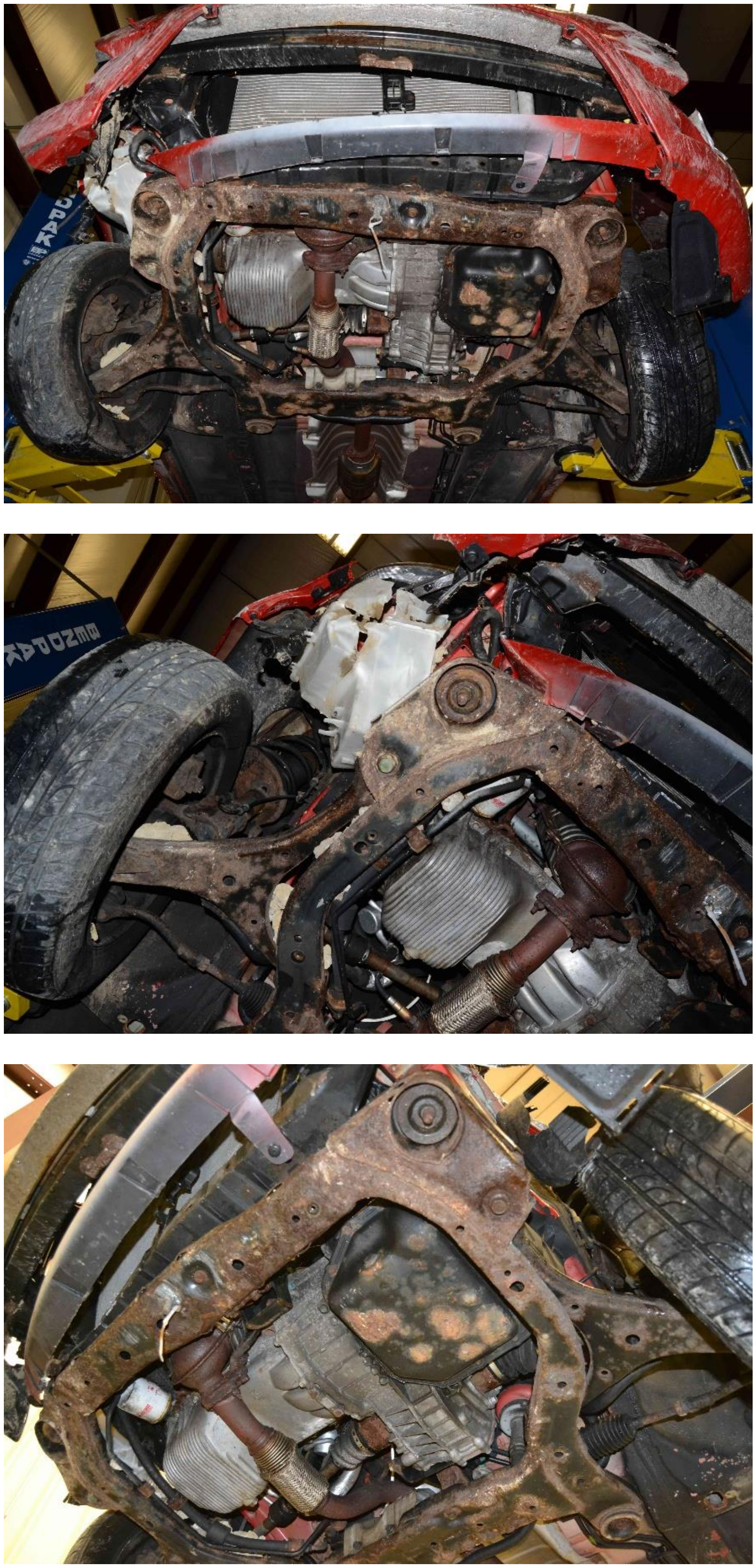


Figure 87. Undercarriage Damage, Test No. MSPBN-2

Table 10. Maximum Occupant Compartment Intrusions by Location, Test No. MSPBN-2

LOCATION	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	½ (13)	≤ 9 (229)
Floor Pan & Transmission Tunnel	2 (51)	≤ 12 (305)
A-Pillar	½ (13)	≤ 5 (127)
A-Pillar (Lateral)	⅜ (10)	≤ 3 (76)
B-Pillar	⅜ (10)	≤ 5 (127)
B-Pillar (Lateral)	⅛ (3)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	⅜ (10)	≤ 12 (305)
Side Door (Above Seat)	1⅜ (35)	≤ 9 (229)
Side Door (Below Seat)	1⅝ (41)	≤ 12 (305)
Roof	½ (13)	≤ 4 (102)
Windshield	N/A	≤ 3 (76)
Side Window	N/A	No shattering resulting from contact with structural member of test article
Dash	⅜ (10)	N/A

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

6.6 Occupant Risk

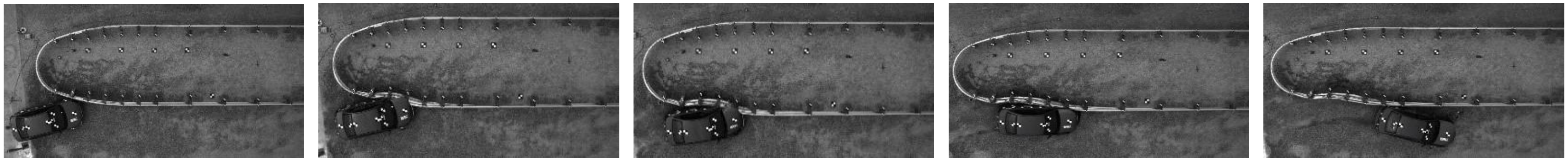
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 11. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 11. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

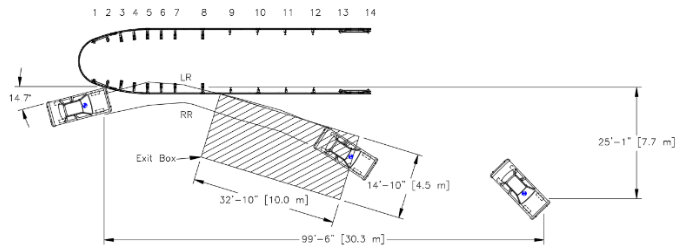
Table 11. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MSPBN-2

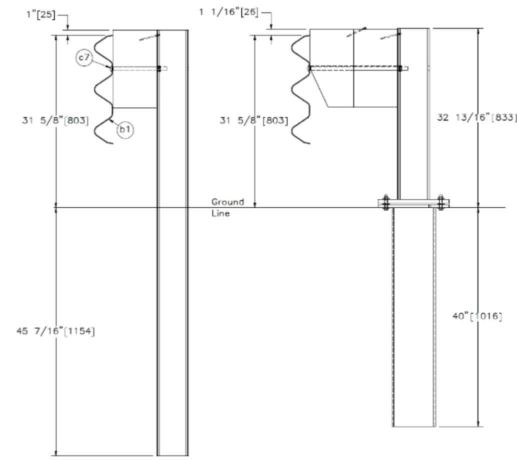
Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 (primary)	SLICE-2	
OIV ft/s (m/s)	Longitudinal	−20.55 (−6.26)	−20.73 (−6.32)	±40 (12.2)
	Lateral	23.32 (7.11)	21.73 (6.62)	±40 (12.2)
ORA g's	Longitudinal	−5.14	−5.02	±20.49
	Lateral	8.90	8.54	±20.49
MAX. ANGULAR DISPL. deg.	Roll	8.60	10.01	±75
	Pitch	−2.92	−3.15	±75
	Yaw	40.80	40.24	not required
THIV ft/s (m/s)		28.08 (8.56)	28.61 (8.72)	not required
PHD g's		9.69	8.01	not required
ASI		1.27	1.23	not required

6.7 Discussion

The analysis of the test results for test no. MSPBN-2 showed that the system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 88. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix F, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 17.1 degrees and 42.0 mph (67.6 km/h), and its trajectory did not violate the bounds of the exit box. Therefore, test no. MSPBN-2 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-34.







- Test Agency .... MwRSF
- Test Number MSPBN-2
- Date 3/22/17
- MASH 2016 Test Designation No. 3-34
- Test Article .... Steel Bullnose with Breakaway Posts
- Total Length .... 66 ft (20 m)
- Key Component – Thrie Beam
  - Thickness .... 12 gauge (2.7 mm)
  - Mounting Height .... 31⅝ in. (803 mm)
- Key Component – Breakaway Steel Post
  - Length .... 72$^{1}/_{16}$ in. (1,849 mm)
  - Spacing .... 37½ in. (953 mm)
- Soil Type .... Coarse, Crushed Limestone
- Vehicle Make /Model .... Kia Rio
  - Curb .... 2,476 lb (1,123 kg)
  - Test Inertial .... 2,448 lb (1,110 kg)
  - Gross Static .... 2,610 lb (1,184 kg)
- Impact Conditions
  - Speed .... 62.1 mph (100.0 km/h)
  - Angle .... 14.7 deg.
  - Impact Location .... 0.62 in. (16 mm) US from post no. 2
- Impact Severity .... 20.3 kip-ft (27.6 kJ) ≥19.0 kip-ft (26.0 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 42.0 mph (67.6 km/h)
  - Angle .... 17.1 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 99 ft – 6 in. (30.3 m) downstream
- Vehicle Damage .... Moderate
  - VDS [17] 11-LFQ-6
  - CDC [18] 11-LFEW-3
  - Maximum Interior Deformation .... 2 in. (51 mm)
- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... N/A
  - Dynamic .... 13.7 in. (349 mm)
  - Working Width .... 177.25 in. (4,502 mm))
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1 (primary)	SLICE-2	
OIV ft/s (m/s)	Longitudinal	−20.55 (−6.26)	−20.73 (−6.32)	±40 (12.2)
	Lateral	23.32 (7.11)	21.73 (6.62)	±40 (12.2)
ORA g's	Longitudinal	−5.14	−5.02	±20.49
	Lateral	8.90	8.54	±20.49
MAX ANGULAR DISP. deg.	Roll	8.60	10.01	±75
	Pitch	−2.92	−3.15	±75
	Yaw	40.80	40.24	not required
THIV – ft/s (m/s)		28.08 (8.56)	28.61 (8.72)	not required
PHD – g's		9.69	8.01	not required
ASI		1.27	1.23	not required

*Note: Working width was defined based on overall system width and not interior dynamic deflections or vehicle extension interior to the barrier

Figure 88. Summary of Test Results and Sequential Photographs, Test No. MSPBN-2

7 FULL-SCALE CRASH TEST NO. MSPBN-3

7.1 Static Soil Test

Before full-scale crash test no. MSPBN-3 was conducted, the strength of the foundation soil was evaluated with a static test, as described in MASH 2016. The static test results, as shown in Appendix C, demonstrated a soil resistance above the baseline test limits. Thus, the soil provided adequate strength, and full-scale crash testing could be conducted on the barrier system.

7.2 Weather Conditions

Test no. MSPBN-3 was conducted on April 11, 2017 at approximately 2:15 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 12.

Table 12. Weather Conditions, Test No. MSPBN-3

Temperature	61° F
Humidity	35 %
Wind Speed	5 mph (8 km/h)
Wind Direction	170° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in. (0 mm)
Previous 7-Day Precipitation	0.04 in. (1 mm)

7.3 Test Description

Initial vehicle impact was to occur with the vehicle centerline aligned with the centerline of the system's nose at a 15-degree angle, which was selected as recommended in MASH and as described in Chapter 2, as shown in Figure 89. The 2,441-lb (1,107-kg) small car impacted the bullnose with breakaway steel posts at a speed of 62.7 mph (101.0 km/h) and at an angle of 15.1 degrees. The actual point of impact occurred with the vehicle's centerline aligned with the centerline of the system's nose at a 15.1-degree angle. Following the initial impact, the nose of the bullnose system wrapped around the front of the small car. The lower peak of the thrie beam was pushed below the bumper and fractured, while the top two peaks of the thrie beam engaged the vehicle above the bumper and captured the vehicle. As the vehicle continued into the system, the thrie-beam rail was deformed and pulled downstream, and the breakaway posts in the system disengaged. These two actions dissipated the kinetic energy of the small car and decelerated it. The small car impacted the back side of post nos. B3 through B5, which further decelerated the small car. The vehicle was brought to a controlled stop approximately 0.800 seconds after impact. The vehicle came to rest 23 ft (7 m) from the initial impact location in the middle of the bullnose.

A sequential description of the impact events is contained in Table 13. Sequential photographs are shown in Figures 90 and 91. Documentary photographs of the crash test are shown in Figure 92. The vehicle trajectory and final position are shown in Figure 93.

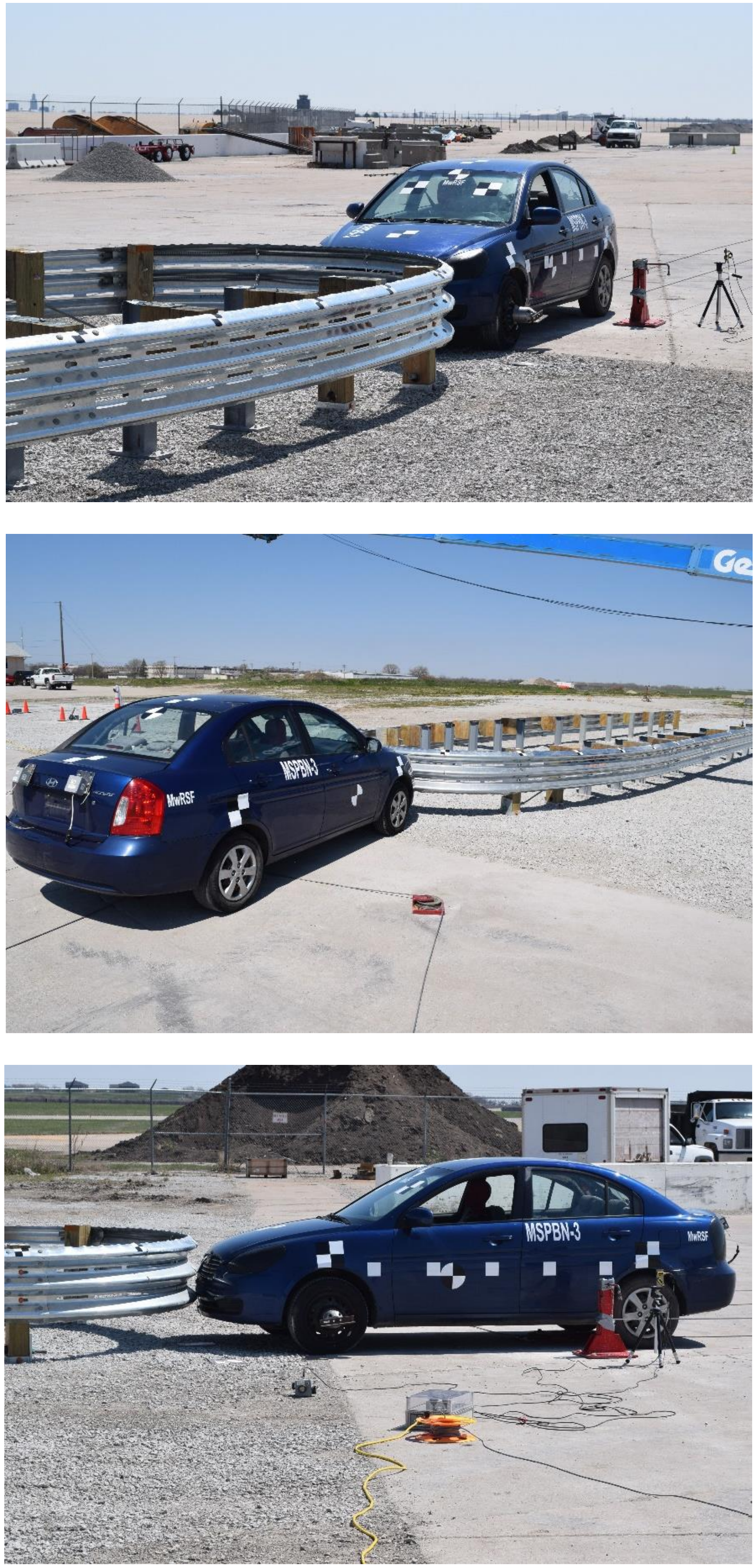


Figure 89. Impact Location, Test No. MSPBN-3

Table 13. Sequential Description of Impact Events, Test No. MSPBN-3

TIME (sec)	EVENT
0.0	Vehicle’s front bumper impacted rail at the centerline of the bullnose system.
0.002	Vehicle’s front bumper deformed.
0.004	Vehicle’s hood and right headlight contacted rail.
0.006	Vehicle’s hood deformed, vehicle’s right headlight shattered, and vehicle’s right fender contacted rail.
0.008	Vehicle’s right fender deformed, and vehicle’s left headlight contacted rail.
0.010	Vehicle’s left headlight deformed.
0.016	Vehicle’s left fender deformed, and rail buckled between post nos. A1 and B1.
0.018	Vehicle’s left headlight shattered and vehicle left fender contacted rail.
0.030	Post nos. B1 and A1 deflected backward.
0.038	Post no. A2 deflected backward.
0.044	Vehicle’s left-front tire contacted rail.
0.060	Vehicle rolled toward barrier.
0.062	Post no. A1 disengaged and fractured from rail at post no. A1.
0.072	Post no. B1 deflected downstream.
0.076	Blockout no. A2 disengaged from rail at post no. A2.
0.078	Rail buckled between post nos. B1 and B2.
0.082	Post no. B1 twisted counterclockwise.
0.094	Blockout no. B2 disengaged from rail at post no. B2.
0.096	Blockout no. A3 disengaged from rail at post no. A3, and post no. B1 fractured.
0.106	Blockout no. B3 disengaged from rail at post no. B3.
0.112	Vehicle’s left-front door deformed and contacted rail.
0.114	Vehicle’s left side mirror contacted rail.
0.118	Post no. B2 twisted counterclockwise.
0.120	Post no. B2 deflected downstream, and vehicle’s left side mirror deformed.
0.126	Blockout no. B4 disengaged from rail at post no. B4, and post no. A2 fractured.
0.128	Vehicle pitched downward.
0.130	Soil heave formed on non-traffic flange of post no. B2.
0.132	Post no. B2 fractured.
0.138	Vehicle rolled away from barrier.
0.158	Post no. B3 twisted counterclockwise, and vehicle’s front bumper contacted post no. B3.
0.172	Post no. B3 upper post detached from lower.
0.180	Soil heave formed on downstream flange of post no. B3.
0.182	Vehicle yawed counterclockwise.
0.184	Vehicle’s right side mirror contacted rail.
0.186	Vehicle’s right side mirror deformed.
0.204	Rail buckled between post nos. B2 and B3.

Table 14. Sequential Description of Impact Events, Test No. MSPBN-3, Cont.

TIME (sec)	EVENT
0.210	Post no. B4 deflected downstream, vehicle's front bumper contacted post no. B4, and post no. B3 contacted blockout no. B4.
0.218	Post no. A3 twisted clockwise.
0.222	The upper portion of post no. B4 detached from the lower portion.
0.224	Post no. B4 twisted counterclockwise.
0.232	The upper portion of post no. A3 detached from the lower portion.
0.236	Vehicle's left-rear tire became airborne.
0.256	Vehicle's left-rear door contacted rail.
0.260	The upper portion of post no. B5 detached from the lower portion.
0.270	Blockout no. B5 disengaged from rail at post no. B5.
0.298	Blockout no. B6 disengaged from rail at post no. B6.
0.310	Blockout no. B7 disengaged from rail at post no. B7.
0.340	Post no. B6 deflected downstream.
0.350	The upper portion of post no. B6 detached from the lower portion.
0.362	Vehicle's right quarter panel contacted rail.
0.380	Post no. A4 deflected downstream.
0.392	The upper portion of post no. A4 detached from the lower portion.
0.406	Blockout no. A4 disengaged from rail at post no. A4.
0.408	Vehicle's right side mirror disengaged.
0.419	The upper portion of post no. B7 detached from the lower portion.
0.420	Post no. B7 deflected downstream.
0.462	Vehicle's rear bumper deformed.
0.534	Vehicle yawed away from barrier.
0.624	Vehicle rolled toward barrier.
0.880	Vehicle left-rear tire regained contact with ground.


0.000 sec


0.072 sec


0.138 sec


0.340 sec

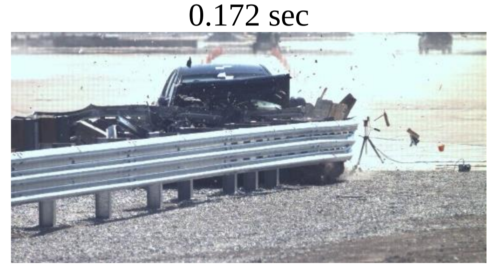

0.624 sec

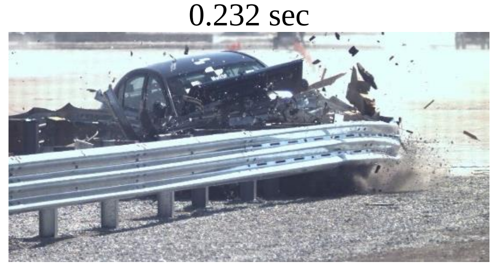

0.880 sec


0.000 sec


0.096 sec


0.172 sec


0.232 sec


0.340 sec

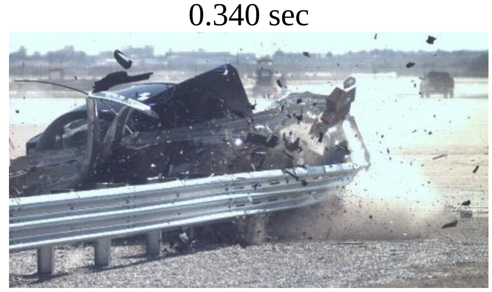
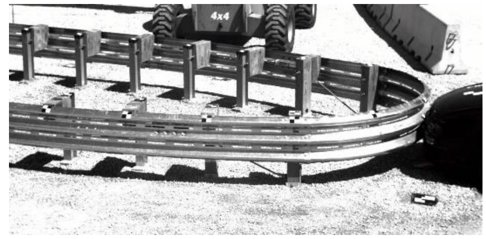

0.624 sec

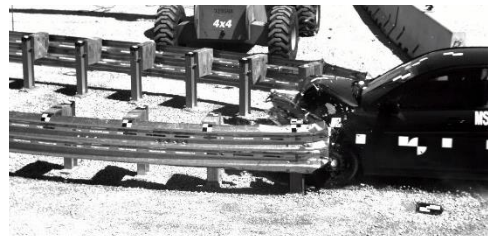
Figure 90. Sequential Photographs, Test No. MSPBN-3

0.000 sec



0.000 sec

0.076 sec

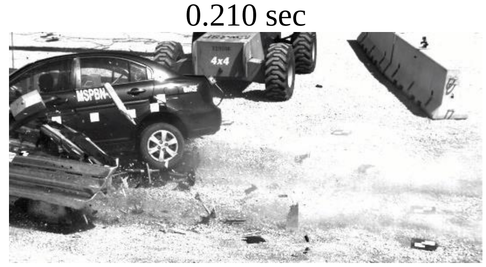


0.072 sec

0.232 sec

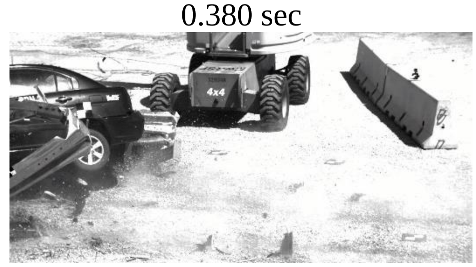
0.210 sec

0.298 sec



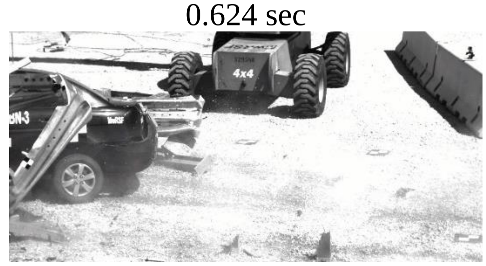
0.380 sec

0.420 sec



0.624 sec

0.624 sec



0.880 sec

Figure 91. Additional Sequential Photographs, Test No. MSPBN-3

Figure 92. Documentary Photographs, Test No. MSPBN-3

Figure 93. Vehicle Final Position and Trajectory Marks, Test No. MSPBN-3

7.4 Barrier Damage

Damage to the barrier was extensive, as shown in Figures 94 through 97. Barrier damage consisted of contact marks on the front face of the guardrail, kinking and flattening of the rail, and post deformation and disengagement.

The railing on the system's nose experienced extensive damage. The middle and lower thrie-beam corrugations fractured due to impact. The nose cables attached to the top thrie-beam corrugation remained intact after impact. The railing experienced extensive damage on side A. Kinking occurred on the top edge of the rail 9¾ in. (248 mm) downstream from post no. A1. Kinking also occurred 7¼ in. (184 mm), 13 in. (330 mm), and 18½ in. (470 mm) upstream from post no. A1. A tear was found in the bottom valley 3¼ in. (83 mm) long at the top edge of the third slot on post no. A1. Buckling occurred in the top corrugation at the first U-bolt upstream from post no. A1. The U-bolt on the center corrugation upstream from post no. A1 experienced a pull out. Multiple tears were found alongside A of the barrier, including one ¼-in. (5-mm) long tear upstream from post no. A1 on the top edge of the upper valley, a ¼-in. (6-mm) long tear at the bottom edge of the top valley upstream from post no. A1, and one 2¼-in. (57-mm) long tear upstream from post no. A1 on the top valley. A 1-in. (25-mm) long horizontal tear was found at the bottom valley between the third and fourth slots of post no. A1, an 8-in. (203-mm) long tear was located at the bottom edge of the valley upstream from post no. A1. A 9-in. (229-mm) long vertical tear was located at the top edge of the bottom valley near the fourth slot upstream from post no. A1, and a 1-in. (25-mm) long horizontal tear was located on the top valley between the third and fourth slots upstream from post no. A1. Buckling occurred in the rail 4½ in. (114 mm) upstream from post no. A2, in the bottom valley of the guard rail 8½ in. (216 mm) upstream from post no. A4, in the bottom corrugation 3½ in. (89 mm) upstream from post no. A4, and in the top corrugation 1¾ in. (44 mm) upstream from post no. A4. Flattening of the rail on side A of the system was only found along the top valley between post nos. A3 and A4. Contact marks were found beginning 6 in. (152 mm) downstream from post no. A1 and ending 9 in (229 mm) upstream from post no. A1.

The railing on side B also experienced extensive damage. Contact marks were found beginning 13½ in. (343 mm) downstream from the first U-bolt upstream from post no. A1 and ending 2¼ in. (57 mm) upstream from the first U-bolt upstream from post no. B1. Kinks were found on the top edge of the rail 15 in. (381 mm) downstream from post no. B1, along the top valley 10 in. (254 mm) downstream from post no. B1, in the lower valley 22 in. (559 mm) downstream from post no. B1, and on the upper peak near the second U-bolt upstream from post no. B1. Local flattening and deformation of the guardrail occurred in the lower valley 22 in. (559 mm) downstream from post no. B1. Local deformation was found on the lower U-bolt upstream from post no. B1. A 2-in. (51-mm) long vertical tear was located 20 in. (508 mm) upstream from the first U-bolt downstream from post no. B1 at the top edge of the middle peak. The middle valley folded 2 in. (51 mm) downstream from the center of the bullnose on side B to 16 in. (406 mm) downstream from the center of the bullnose on side A. Kinks were found through the upper and middle peaks 3 in. (76 mm) upstream from the first U-bolt after post no. B1, 3 in. (76 mm) upstream from the first U-bolt upstream from post no. B1 and along the bottom flange 8 in. (203 mm) upstream from post no. B1. Kinking was also found along the bottom flange 8 in. (203 mm) downstream from post no. B1, and through the full depth of 12 in. (305 mm) upstream from post no. B2. Local bending of the guardrail was extensive. Bends were located in the upper valley slot

15 in. (381 mm) upstream from post no. B1, along the top flange 12 in. (305 mm) upstream from post no. B1 and along the top flange 18 in. (457 mm) upstream from post no. B1. Bending of the guardrail was also found 5 in. (127 mm) upstream from post no. B2 on the top flange, and 2 in. (51 mm) upstream from the center line of post no. B2 along the lower slot in the lower valley. Tearing occurred in the lower valley slot 14 in. (356 mm) upstream from post no. B1 with a length of 3 in. (76-mm), a 5-in. (127-mm) long tear was found in the bottom valley between slots starting 11 in. (279 mm) downstream from post no. B1, and a 3-in. (76-mm) tear was found in the lower valley slot 14 in. (356 mm) upstream from post no. B1. Additional kinks were found on the lower slot 26 in. (660 mm) upstream from post no. B4, on the top flange 5 in. (127 mm) upstream from post no. B4, and at the lower slot on post no. B6. Bolt tear outs on side B of the bullnose system were found at post nos. B2, B4, B6, and B7.

The timber post damage included crushing, splits, dents, and fractures at the foundation tube. Post nos. 1A, 2A, and 2B fractured at the ground line through the BCT hole and disengaged at the base. Post no. 1A was crushed along a horizontal line on the front face and split on the upstream side. Post no. 2A had a 1-in. (25-mm) long x ½-in. (13-mm) wide dent that was ⅛ in. (3 mm) deep on the front-upstream corner 11-in. (280-mm) from top of the post. The rail was detached from post no. 2A. Post no. 1B fractured diagonally from upstream to downstream on the front face of post 9-in. (229-mm) above the foundation tube. Post no. 1B also fractured diagonally on upstream face 10-in. (254-mm) from the foundation tube.

Steel post damage included fracture of bolts, twisting, rotation, and detachment from the post bases. All base bolts on post nos. 3B through 7B fractured at the ground line. Post no. 3B detached from the rail and the post twisted in counter-clockwise direction. Contact marks were found on the lower base plate from the upstream to downstream corner and 5 in. (127 mm) from the back edge. The top of post nos. 5B, 9B, 10B, and 11B twisted counter-clockwise. The blockouts attached to post nos. 6B, 8B, and 9B split on the upstream face. All base bolts on post nos. 3A and 4A fractured at the ground line. The rail detached from post nos. 3A and 4A. Crushing measuring 2½ in. (64 mm) long x 1½ in. (38 mm) wide and ¼ in. (6 mm) deep was found on the front and downstream corner of the blockout on post no. 3A. The blockout of post no. 4A disengaged from the post, but the rail remained attached.

The maximum lateral dynamic barrier deflection was 72.0 in. (1,829 mm) at the impact point as determined from high-speed digital video analysis. The vehicle was contained within the bullnose system after the impact, which resulted in a working width in both the longitudinal and lateral directions. This working width envelope contained a 23 ft – 7 in. (7.2 m) longitudinal working width and a 16 ft – 11 in. (5.2 m) lateral working width. The system deformation is shown in Figure 98.

Figure 94. System Damage, Test No. MSPBN-3

Figure 95. Post Nos. A1, A2, A3, B1, B2, and B3 Damage, Test No. MSPBN-3

Figure 96. Post Nos. A3, A4, and A5 Damage, Test No. MSPBN-3

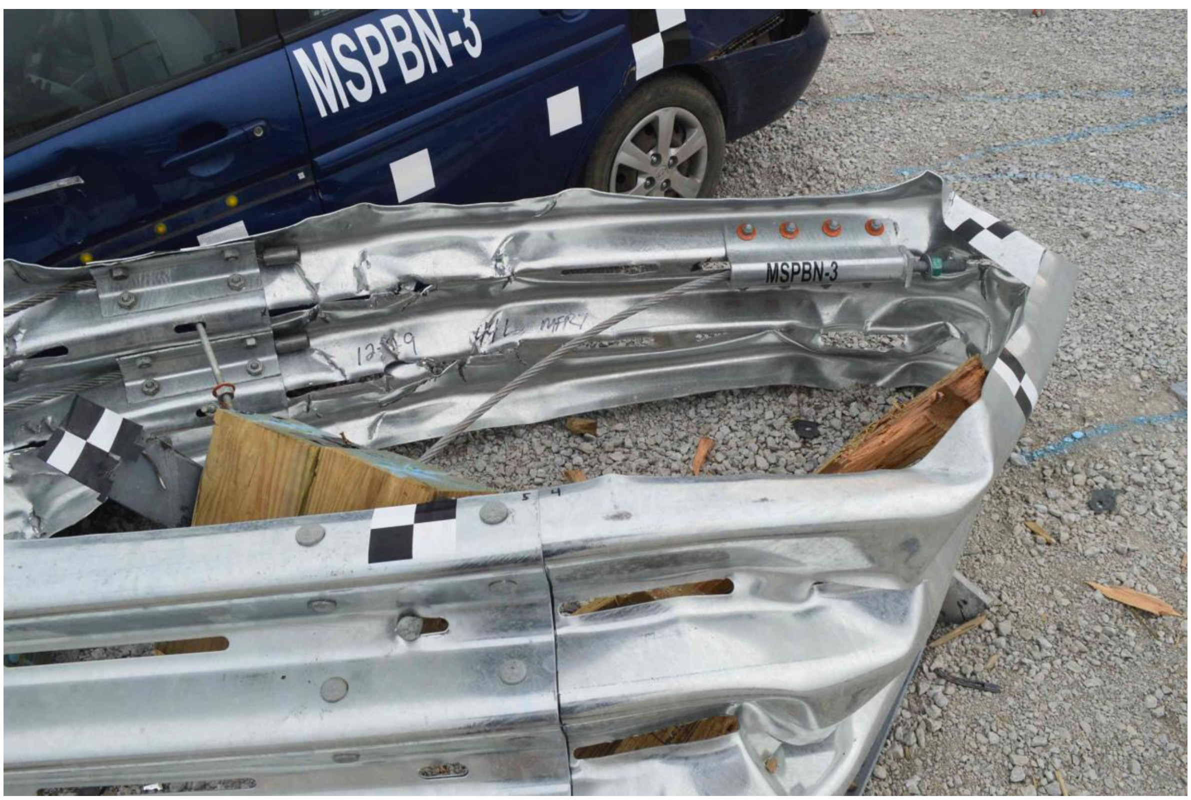


Figure 97. Post nos. B3, B4, and B5 Damage, Test No. MSPBN-3

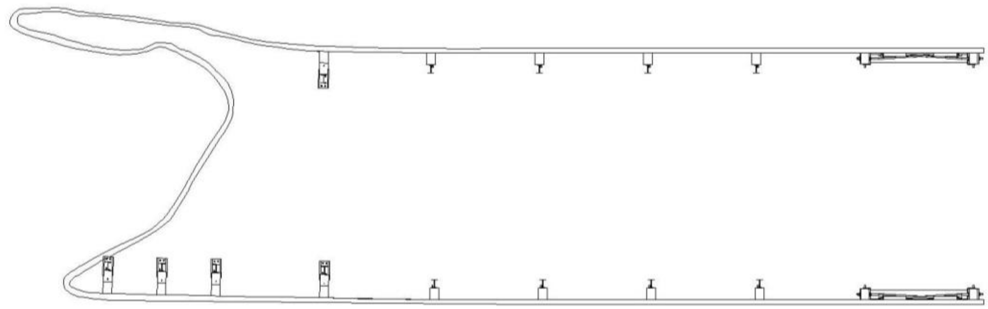


Figure 98. System Deformation After Impact, Test No. MSPBN-3

7.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 99 through 103. The maximum occupant compartment intrusions are listed in Table 15 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. Note that none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle intrusions and the corresponding locations are provided in Appendix D.

Table 15. Maximum Occupant Compartment Intrusions by Location, Test No. MSPBN-3

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

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

The majority of the damage was concentrated on the front side of the vehicle where the impact had occurred. Both headlights, fog lights, and side mirrors, as well as the front grille and front bumper cover disengaged from the vehicle. The radiator on the front side showed bending and detached from its mounts. The grille disengaged from the vehicle. The hood bucked upward approximately 5 in. (127 mm) on the left side and 13 in. (330 mm) on the right side. A 40-in. (1,016-mm) wide by 7-in. (178-mm) long dent that was 5 in. (127 mm) deep was found in the front of the hood. The AC condenser had a 10-in. (254-mm) diameter by 1-in. (25-mm) deep dent. A 2½-in. (64-mm) gap was found between the A-pillar and the right-front fender. A 31-in. (787-mm) long crease developed at the right-front door and the bottom of the window. The right side of rear bumper cover was disengaged from the vehicle, but the left-side rear bumper remained attached. Numerous dents were found on the right-rear door. The right-rear fender was crushed, and the right-rear tire deflated and contained a 1-in. (25-mm) tear. An 11-in. (279-mm) wide x 33-in. (838-mm) long x 1-in. (25-mm) deep dent was found starting 2½ in. (64 mm) from the rear of the left-front door and 6 in. (152 mm) from the bottom of the door. A ½-in. (13-mm) gap was found at the top corner of left-front door. A 14-in. (356-mm) long x 3-in. (76-mm) wide x ½-in. (13-mm) deep dent was observed on the left-rear quarter panel. The fenders on the left-front side and right-front side were crushed. The buckling of the left-front fender started 9½ in. (241 mm) from the rear of the fender and folded back over whole width. Many scrapes, contact marks could be observed. The left-front tire was deflated but still partially attached to the wheel. Dents, measuring 3 in. (76 mm) and 4½ in. (114 mm) long, were found on outer wheel rim. Both the left-front and right-front doors would not open after the test. The hood contacted the bottom-right side of windshield during impact, causing a 29-in. (737-mm) by 12-in. (305-mm) spider web crack that was found on the bottom right side of the windshield, with additional cracks extending on top of the windshield. A 4-in. (102-mm) long longitudinal tear was found 5 in. (127 mm) from the bottom of the windshield and 1 in. (25 mm) from the right side of the windshield. A 5-in. (127 mm) long vertical tear was found 5 in. (127 mm) from the bottom of the windshield and 5 in. (127 mm) from the right side of the windshield. Note that the windshield damage was likely due to contact with the hood not due to contact with the bullnose system. The side windows remained undamaged.

Figure 99. Vehicle Damage, Test No. MSPBN-3

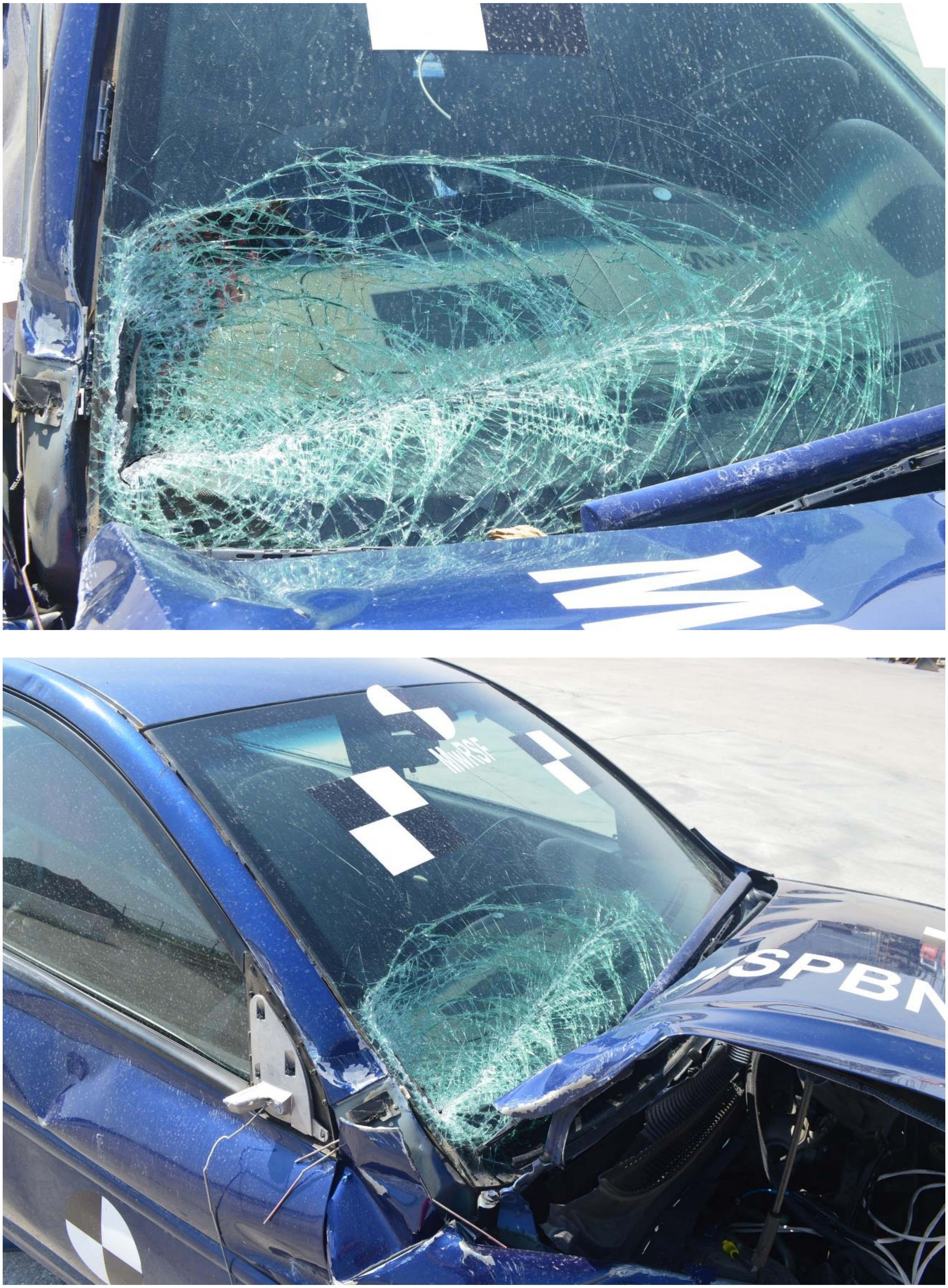


Figure 100. Windshield Damage, Test No. MSPBN-3

Figure 101. Floorboard Damage, Test No. MSPBN-3

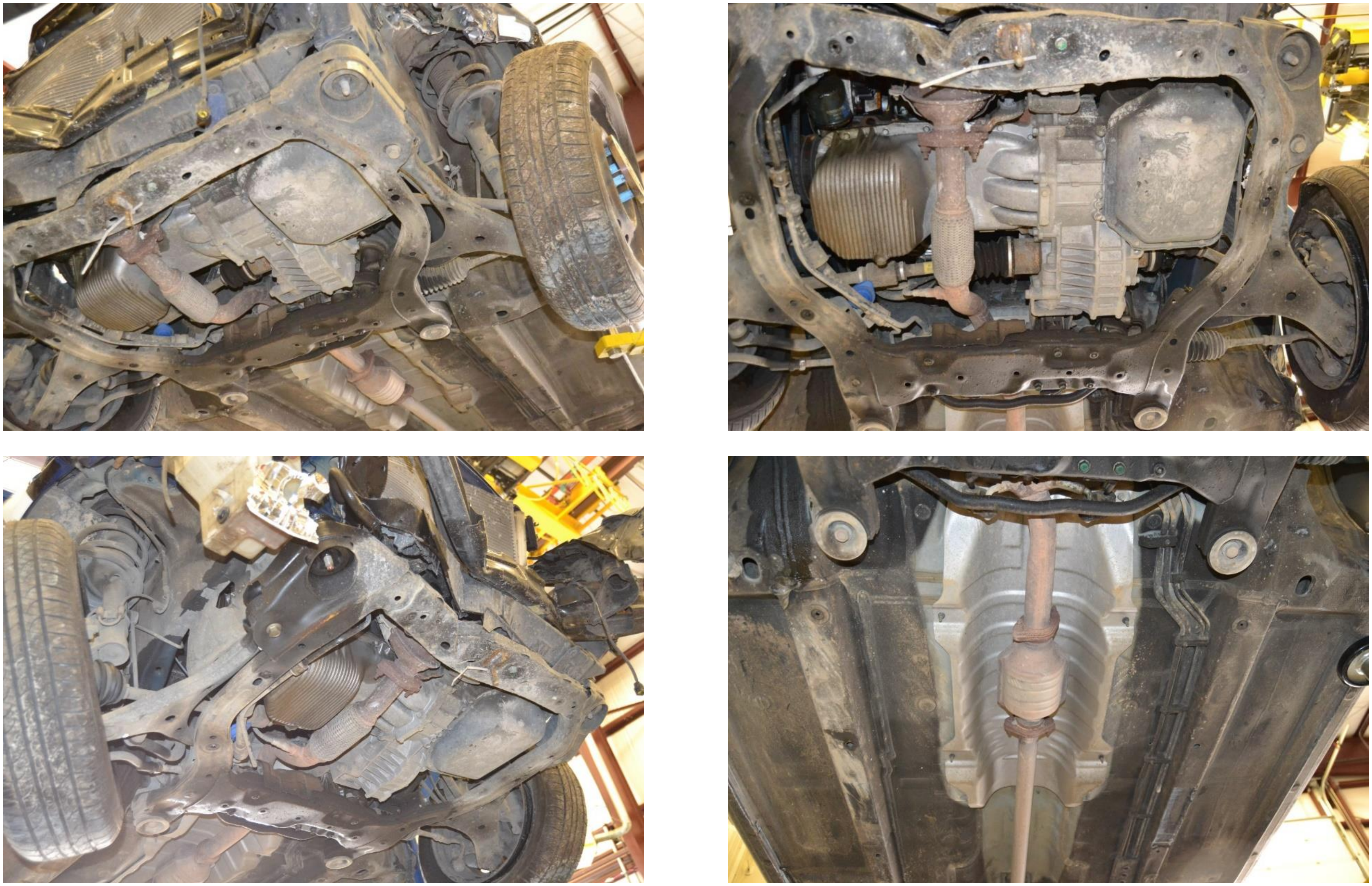


Figure 102. Undercarriage Damage, Test No. MSPBN-3

Figure 103. Undercarriage Damage, Test No. MSPBN-3

7.6 Occupant Risk

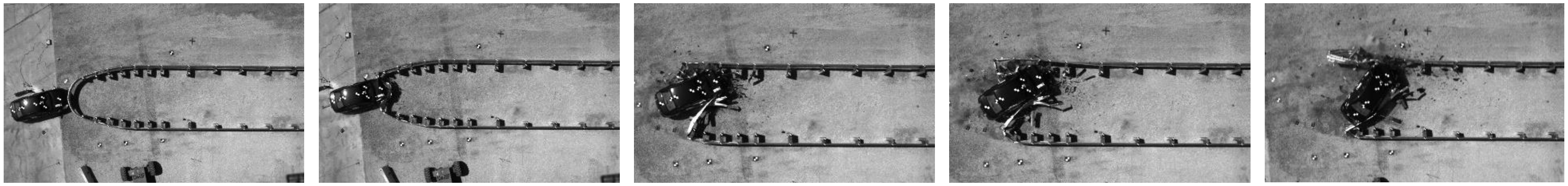
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions, as determined from the accelerometer data, are shown in Table 16. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 16. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix E.

Table 16. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MSPBN-3

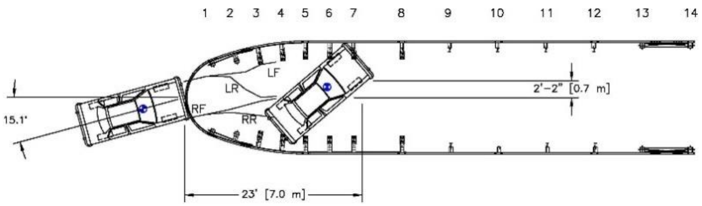
Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 (primary)	**SLICE-2**	
OIV ft/s (m/s)	Longitudinal	−25.79 (−7.86)	−25.52 (−7.78)	±40 (12.2)
	Lateral	3.72 (1.14)	3.29 (1.00)	±40 (12.2)
ORA g's	Longitudinal	−16.34	−14.96	±20.49
	Lateral	−9.41	−8.58	±20.49
MAX. ANGULAR DISPL. deg.	Roll	22.28	18.92	±75
	Pitch	−3.77	4.44	±75
	Yaw	−38.23	−38.94	not required
THIV ft/s (m/s)		26.12 (7.96)	25.79 (7.86)	not required
PHD g's		16.87	15.51	not required
ASI		0.67	0.64	not required

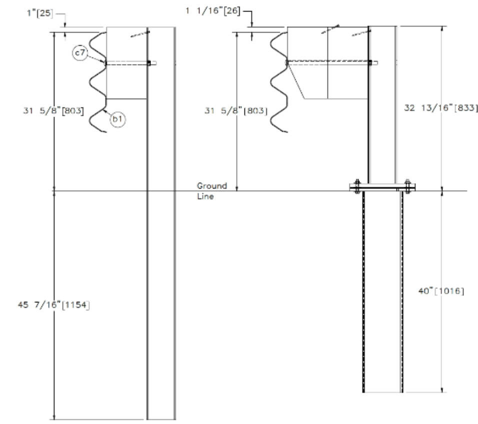
7.7 Discussion

The analysis of the test results for test no. MSPBN-3 showed that the system adequately contained the 1100C vehicle with controlled lateral displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 104. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix G, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle did not exit the barrier. Therefore, test no. MSPBN-3 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-32.



0.000 sec | 0.062 sec | 0.256 sec | 0.310 sec | 0.534 sec





- Test Agency .... MwRSF
- Test Number MSPBN-3
- Date 4/11/17
- MASH 2016 Test Designation No. 3-32
- Test Article .... Steel Bullnose with Breakaway Posts
- Total Length .... 66 ft (20 m)
- Key Component – Thrie Beam
  - Thickness .... 12 gauge (2.7 mm)
  - Mounting Height .... 31⅝ in. (803 mm)
- Key Component – Breakaway Steel Post
  - Length .... 72$^{1}/_{16}$ in. (1,849 mm)
  - Spacing .... 37½ in. (953 mm)
- Soil Type .... Coarse, Crushed Limestone
- Vehicle Make /Model .... Kia Rio
  - Curb .... 2,464 lb (1,118 kg)
  - Test Inertial .... 2,441 lb (1,107 kg)
  - Gross Static .... 2,599 lb (1,179 kg)
- Impact Conditions
  - Speed .... 62.7 mph (101.0 km/h)
  - Angle .... 15.1 deg.
  - Impact Location .... CL of vehicle on the CL of the system's nose
- Kinetic Energy . 321.2 kip-ft (435.5 kJ) ≥ 288.0 kip-ft (390.0 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 0 mph
  - Angle .... N/A
- Exit Box Criterion .... N/A
- Vehicle Stability .... N/A
- Vehicle Stopping Distance .... 23 ft (7 m) downstream
- Vehicle Damage .... Moderate
  - VDS [17] 12-FD-6
  - CDC [18] 12-FDEW-9
  - Maximum Interior Deformation .... ½ in. (13 mm)
- Test Article Damage .... Extensive
- Maximum Test Article Deflections
  - Permanent Set .... N/A
  - Dynamic .... 72.0 in. (1,829 mm)
  - Working Width ... 23 ft – 7 in. (7.2 m) longitudinally, 16 ft – 11 in. (5.2 m) laterally
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1 (primary)	SLICE-2	
OIV ft/s (m/s)	Longitudinal	−25.79 (−7.86)	−25.52 (−7.78)	±40 (12.2)
	Lateral	3.72 (1.14)	3.29 (1.00)	±40 (12.2)
ORA g's	Longitudinal	−16.34	−14.96	±20.49
	Lateral	−9.41	−8.58	±20.49
MAX ANGULAR DISP. deg.	Roll	22.28	18.92	±75
	Pitch	−3.77	4.44	±75
	Yaw	−38.23	−38.94	Not required
THIV – ft/s (m/s)		26.12 (7.96)	25.79 (7.86)	Not required
PHD – g's		16.87	15.51	Not required
ASI		0.67	0.64	Not required

Figure 104. Summary of Test Results and Sequential Photographs, Test No. MSPBN-3

8 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Three critical tests were completed on the thrie-beam, bullnose system according to the MASH 2016 TL-3 criteria. The tests conducted were test designation nos. 3-32, 3-34, and 3-35 in the MASH 2016 test matrix for crash cushions. The first test, test no. MSPBN-1, was conducted according to MASH 2016 test designation no. 3-35 with a 2270P vehicle at an impact speed of 62.9 mph (101.3 km/h) and an angle of 25.1 degrees. Test no. MSPBN-1 was conducted to examine the CIP of the bullnose system where its behavior transitioned from capture to redirection. The second test, test no. MSPBN-2, was conducted according to MASH 2016 test designation no. 3-34 with an 1100C vehicle at an impact speed of 62.1 mph (100 km/h) and an angle of 14.7 degrees. Test no. MSPBN-2 was conducted to evaluate the impact performance of the bullnose at the point where the device transitioned from capture to redirection. The third test, test no. MSPBN-3, was conducted according to MASH 2016 test designation no. 3-32 with an 1100C vehicle at an impact speed of 62.7 mph (101.0 km/h) and an angle of 15.1 degrees. Test no. MPSNB-3 was conducted to evaluate the bullnose behavior during oblique impacts on the end or nose of the system. All three crash tests were successful and met the MASH 2016 TL-3 safety requirements. A summary of test results is shown in Table 17.

Based on the successful completion of the first three critical tests in the MASH 2016 evaluation of the bullnose, it was believed that the remaining required MASH 2016 TL-3 test matrix should be completed to certify the MASH 2016 compliance of the thrie-beam, bullnose system. In MASH 2016, as many as nine full-scale crash tests are potentially required to evaluate this type of hardware, as shown in Table 18.

Out of the nine required crash tests, three tests have been completed (test designation nos. 3-32, 3-34, and 3-35), and two tests may potentially be deemed non-critical. Test designation no. 3-36 on the transition to the rigid structure may not be required as it is assumed that the bullnose will use MASH 2016 TL-3 approved thrie-beam, approach guardrail transitions for attachment to any rigid structures. Test designation no. 3-38 is intended to evaluate the performance of mid-sized sedan vehicles with terminals and crash cushions. However, MASH 2016 uses an analytical estimation of 1500A vehicle decelerations based on the results of test designation no. 3-31 to determine whether or not this test is required. Thus, test designation no. 3-38 is currently deemed non-critical until the results from the analytical estimation of 1500A vehicle decelerations are known. Thus, four remaining required tests are recommended in order to complete the MASH 2016 TL-3 test matrix for evaluation of the thrie-beam, bullnose system. It should be noted that any tests within the evaluation matrix deemed not critical may eventually need to be evaluated based on additional knowledge gained over time or additional FHWA eligibility letter requirements.

Table 17. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. MSPBN-1</th><th>Test No. MSPBN-2</th><th>Test No. MSPBN-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><td>S</td><td>S</td></tr>
<tr><td rowspan="12">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>S</td><td>S</td><td>S</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>S</td><td>S</td><td>S</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><td>S</td><td>S</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s (9.1 m/s)</td><td>40 ft/s (12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td rowspan="4">S</td><td rowspan="4">S</td><td rowspan="4">S</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
<tr><td colspan="5">MASH 2016 Test Designation No.</td><td>3-35</td><td>3-34</td><td>3-32</td></tr>
<tr><td colspan="5">Final Evaluation (Pass or Fail)</td><td>Pass</td><td>Pass</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

Table 18. MASH TL-3 Test Matrix for the Thrie-Beam, Bullnose System

Test No.	Vehicle	Speed mph (km/h)	Angle (deg)	Impact Point	Other Notes
3-30	1100C	62 (100)	0	Center of nose @ ¼ offset	Phase II
3-31	2270P	62 (100)	0	Center of nose	Phase II
3-32	1100C	62 (100)	5-15	Center of nose	Test Completed
3-33	2270P	62 (100)	5-15	Center of nose	Phase II
3-34	1100C	62 (100)	15	CIP for capture/redirection	Test Completed
3-35	2270P	62 (100)	25	CIP for capture/redirection	Test Completed
3-36	2270P	62 (100)	25	CIP @ transition to rigid structure	Deemed non-critical if using MASH TL-3 AGT
3-37a	2270P	62 (100)	25	CIP for reverse direction	Phase II
3-37b	1100C	62 (100)	25	CIP for reverse direction	Phase II
3-38	1500A	62 (100)	0	Center of nose @ ¼ offset	Deemed non-critical based on 1500A estimation procedure

9 REFERENCES

1. *Manual for Assessing Safety Hardware (MASH)*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2009.

2. 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.

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

4. Bielenberg, R.W., Faller, R.K., Reid, J.D., Rohde, J.R., Sicking, D.L., and Keller, E.A., *Concept Development of a Bullnose Guardrail System for Median Applications* Report No. TRP-03-73-98, Project No. SPR-3(017)-Year 7, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, May 22, 1998.

5. Bielenberg, R.W., Reid, J.D., Faller, R.K., Rohde, J.R., Sicking, D.L., Keller, E.A., and Holloway, J.C., *Phase II Development of a Bullnose Guardrail System for Median Applications*, Report No. TRP-03-78-98, Project No. SPR-3(017)-Years 7 and 8, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, December 18, 1998.

6. Bielenberg, R.W., Faller, R.K., Reid, J.D., Rohde, J.R., Sicking, D.L., Keller, E.A., Holloway, J.C., and Supencheck, L.L., *Phase III Development of a Bullnose Guardrail System for Median Applications*, Report No. TRP-03-95-00, Project No. SPR-3(017)-Years 7 and 8, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, June 1, 2000.

7. Arens, S.W., Sicking, D.L., Faller, R.K., Reid, J.D., Bielenberg, R.W., Rohde, J.R., and Lechtenberg, K.A., *Investigating the Use of a New Universal Breakaway Steel Post*, Report No. TRP-03-218-09, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, August 3, 2009.

8. Schmidt, J.D., Sicking, D.L, Faller, R.K., Reid, J.D., Bielenberg, R.W., and Lechtenberg, K.A., *Investigating the Use of a New Universal Breakaway Steel Post – Phase 2*, Report No. TRP-03-230-10, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, August 9, 2010.

9. Schmidt, J.D., Sicking, D.L, Faller, R.K., Reid, J.D., Bielenberg, R.W., and Lechtenberg, K.A., *Investigating the Use of a New Universal Breakaway Steel Post – Phase 3*, Report No. TRP-03-244-10, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, December 16, 2010.

10. Griffith, M.S., Federal Highway Administration. *Eligibility Letter No. HSST-1/CC-126 for MASH Sequentially Kinking Terminal (MSKT)*, to Kaddo Kothmann, Road Systems, Inc., June 10, 2016.

11. Griffith, M.S., Federal Highway Administration. *Eligibility Letter No. HSST/CC-115A for Trinity SOFT-STOP Terminal for line posts with 8" wood offset blocks*, to Brian Smith, Trinity Highway Products, LLC, September 7, 2012.

12. Meyer, D.T., Reid, J.D., Lechtenberg, K.A., Bielenberg, R.W., and Faller, R.K., *Increased Span Length for the MGS Long-Span Guardrail System Part II: Full-Scale Crash Testing*, Research Report No. TRP-03-339-17, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, April 7, 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. MacInnis, D., Cliff, W., and Ising, K., *A Comparison of the Moment of Inerita Estimation Techniques for Vehicle Dynamics Simulation*, SAE Technical Paper Series – 970951, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1997.

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

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

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

10 APPENDICES

Appendix A. Material Specifications

Table A-1. Bill of Materials, Test Nos. MSPBN-1 through MSPBN-3

Item No.	Description	Material Spec	Material Cert Reference
a1	TS8"x6"x3/16" [203x152x5], 96" [2,438] Long Foundation Tube	ASTM A500 Gr. B	H#A49248
a2	TS8"x6"x3/16" [203x152x5], 72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	H#A49248
a3	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	H#DL15103543
a4	Lower Slip Post Assembly	Plate-ASTM A36 Foundation Tube-ASTM A500 Gr. B	Tube: H#167623 Plate: H#B6U5630
a5	Upper Slip Post Assembly	Plate: ASTM A36 Post: ASTM A992	Plate: H#M6E147 Post: H#59072444
a6	6"x8"x14 1/4" [152x203x362] Timber Blockout	SYP Grade No. 1 or better	Charge#22927 P#GS6846PST
a7	6"x8"x14 1/4" [152x203x362] Tapered Timber Blockout -Side A	SYP Grade No. 1 or better	Charge#22927 P#GS6846PST
a8	6"x8"x14 1/4" [152x203x362] Tapered Timber Blockout -Side B	SYP Grade No. 1 or better	Charge#22927 P#GS6846PST
a9	6"x8"x14 1/4" [152x203x362] Tapered Timber Blockout -Post 2	SYP Grade No. 1 or better	Charge#22927 P#GS6846PST
b1	12'-6" [3,810] 12 gauge [2.7] Thrie Beam Section	AASHTO M180	H#L33814
b2	12'-6" [3,810] 12 gauge [2.7] Bent Thrie Beam Section	AASHTO M180	H#L35116
b3	12'-6" [3,810] 12 gauge [2.7] Thrie Beam Section	AASHTO M180	H#L33814
b4	12'-6" [3,810] 12 gauge [2.7] Thrie Beam End Section -Side A	AASHTO M180	H#L33814
b5	12'-6" [3,810] 12 gauge [2.7] Thrie Beam End Section -Side B	AASHTO M180	H#L33814
b6	12'-6" [3,810] 12 gauge [2.7] Bent Thrie Beam Section -Side A	AASHTO M180	H#L34713
b7	12'-6" [3,810] 12 gauge [2.7] Bent Thrie Beam Section Side B	AASHTO M180	H#L34713
c1	7/16" [11] Dia. UNC, 2 1/4" [57] Long Heavy Hex Bolt and Nut	Bolt – ASTM F3125 Gr. A325 or ASTM A449 or SAE J429 Gr. 5 Nut - ASTM A563DH	Bolts: H#5210760BA Nuts: H#169D0620
c2	5/8" [16] Dia. UNC, 10" [254] Long Hex Head Bolt	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	H#DL15107048
c3	5/8" [16] Dia. UNC, 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#10435580 Nut:0055551-116146
c4	5/8" [16] Dia. UNC, 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#10207560 Nut: P#36713 C#210101523 COC
c5	5/8" [16] Dia. UNC, 18" [457] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#NF16102734 Nut: 0055551-116146

Table A-2. Bill of Materials, Test Nos. MSPBN-1 through MSPBN-3, Cont.

Item No.	Description	Material Spec	Material Cert Reference
c6	7/8" [22] Dia. UNC, 8" [203] Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#2038622 Nut: H#NF12101054
c7	5/8" [16] Dia. UNC, 10" [254] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolt: H#20351510 Nut: 0055551-116146
c8	16D Double Head Nail	-	L# 97812A109
e1	7/16" [11] Dia. Plain Round Washer	ASTM F844 or ASTM F436 Type 1	H#1GX24 L#57253FNEA
e2	5/8" [16] Dia. Plain Round Washer	ASTM F844	n/a
e3	7/8" [22] Dia. Plain Round Washer	ASTM F844	n/a
f1	BCT Timber Post - MGS Height	SYP Grade No. 1 or better (No knots +/- 18" [457] from ground on tension face)	Charge#22927 P#GS6846PST
f2	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 78" [1,981] Long Steel Post	ASTM A992	H#55044245
g1	BCT Anchor Cable Assembly	-	Nuts: L#366055B H#DL15103032
g2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	H#A79999
g3	5/8" Dia. [15.9] x 14.4' [4,389] Long Cable and Swage Button	"Cold Tuff" Button, S-409 Size No. 12 SB, Stock No. 1040395 for 5/8" [16] Dia. (6x19) wire rope (or any similarly sized swage-grip button ferrules)	Order#248853
g4	12 5/8"x5 13/16"x3/16" [321x148x5] Nose Cable Anchor Plate	ASTM A36	H#B4M5475
g5	2 1/4"x3/4" [57x19] 11 gauge [3] U-Bolt Plate Washer	ASTM A1011 CS Type B	H#B609769
g6	1/4" [6] Dia. U-Bolt and Nut	U-Bolt-ASTM A307 Gr.A Nut-ASTM A563DH or ASTM A563A	Bolt: H#71067E Nut: H#184259
h1	Ground Strut Assembly	ASTM 1011-12 SS GRADE 36 TYPE 2	H#195070
h2	Anchor Bracket Assembly	ASTM A36	H#JK16101488

/2016

ACCREDITED
TESTING CERT # 2914.01

CERTIFIED REPORT OF CHEMICAL ANALYSIS AND MECHANICAL TESTS

ArcelorMittal

This report will not be reproduced in whole or in part without the prior written approval from ArcelorMittal USA LLC. Page 1 of 1

SOLD TO	VENDOR
MARUICHI LEAVITT PIPE & T 1717 W 115TH ST CHICAGO IL	ArcelorMittal Riverdale LLC. 13500 South Perry Avenue Riverdale, IL 60827

SHIP TO	ORDER INFORMATION
MARUICHI LEAVITT PIPE & TUBE SOUTH PLANT DIVISION 1900 W 119TH ST CHICAGO IL	PO#: 00490/10 LoadID # 02583356 SO#: 859202 Carrier: Steel Transport, Inc. Date Of Issuance/ Shipped 8/4/2016

ORDERED DIMENSIONAL INFORMATION

Heat	Coil	Thickness (in)	Width (in)	Weight (tons)	Reduction Ratio
A49248	119239	0.170	56.257	4.7	92.15% (13:1)

HEAT NUMBER IS BEING USED AS CERTIFICATE NUMBER COUNTRY OF ORIGIN/EXPORT COUNTRY IS USA FOR QUESTIONS CONCERNING IMPORTATION OF THIS MATERIAL PLEASE CONTACT JOSE CISNEROS, 1 SOUTH DEARBORN ST , CHICAGO, IL, 60603. TEL +1 (312) 899 3796 EML Jose.Cisneros@arcelormittal.com

PRODUCT INFORMATION

Grade	Part Number	Product Description	Comments
LEAVITT B15-106	HB1705625-	Hot Band Prime	

This material was melted and manufactured in the USA. All products are strand cast and free of mercury or radioactive elements. Elongation based on 2" gage length

MECHANICAL/PHYSICAL TEST RESULTS

Heat	Coil	Yield (ksi)	Tensile (ksi)	El (%)	Dir	N-Value	N-Range	Hardness	Ft-lbs	°F	Size	Dir
A49248	119239	58.0KSI	75.8 KSI	29.0 %	L							
A49248		58.9KSI	76.0 KSI	29.0 %	L							

* Material tested in accordance with ISO 17025 by an accredited lab.

CHEMICAL TEST RESULTS

Heat	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Cb	V	Al
A49248	.20	.81	.014	.002	.04	.02	.02	.04	.00	.000	.001	.020
	N	Sn	B	Ti	Ca	Sb						
	.0033	.001	.0001	.0020	.0011	.0010						

Chemical analysis was performed by ArcelorMittal Riverdale, Inc. in accordance with the Current Version of ASTM E415 and E1019.

We hereby certify the above is correct as contained in the records of the corporation. All tests peformed to the current standard to date unless otherwise noted. Uncertainties of measurements estimated and are available upon request. These results relate only to the items tested. Test results marked with an asterisk (*) were reported by an external accredited lab and with double asterisk(**) were reported by an internal laboratory.

R N Fritz

Ryan N Fritz
Manager - Quality
13500 South Perry Ave., Riverdale IL 60827
T+708 392 1077 | Ryan.Fritz@ArcelorMittal.com

Figure A-1. Foundation Tube Material Specification, Test Nos. MSPBN-1 through MSPBN-3

NUCOR
NUCOR CORPORATION
NUCOR STEEL SOUTH CAROLINA

Mill Certification
7/30/2015

MTR #: 0000087896
300 Steel Mill Road
DARLINGTON, SC 29540
(843) 393-5841
Fax: (843) 395-8701

Sold To: TRINITY INDUSTRIES INC
ROLLFORM ACCOUNTING-4TH FLOOR
PO BOX 568887
DALLAS, TX 75356-8887
(214) 689-0847
Fax: (214) 589-8535

Ship To: TRINITY INDUSTRIES LIMA
550 E. ROBB AVENUE
PLANT 55
LIMA, OH 45801-0000
(214) 589-8407
Fax: (214) 589-8420

Customer P.O.	171075	Sales Order	229472.1
Product Group	Merchant Bar Quality	Part Number	5362580024010W0
Grade	NUCOR MULTIGRADE	Lot #	DL1510354303
Size	5/8x8" Flat	Heat #	DL15103543
Product	5/8x8" Flat 20' NUCOR MULTIGRADE	B.L. Number	C1-668702
Description	NUCOR MULTIGRADE	Load Number	C1-347435
Customer Spec		Customer Part #	100395B

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.

Roll Date: 6/22/2015 Melt Date: 6/18/2015 Qty Shipped LBS: 45,929 Qty Shipped Pcs: 135

Melt Date: 6/18/2015

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.15%	0.75%	0.013%	0.025%	0.20%	0.36%	0.09%	0.09%	0.021%	0.0500%	0.003%	0.016%
Ti	CE4020										
0.001%	0.34%										

CE4020: C. E. CSA G4020, AASHTO M270

Roll Date: 6/22/2015

Yield 1: 58,000psi Tensile 1: 74,000psi Elongation: 25% in 8"(% in 203.3mm)
Yield 2: 58,000psi Tensile 2: 74,000psi Elongation 25% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/A36M-12, A529/529M-05(2009) GR50(345), A572/572M-13A GR50(345), A709/709M-13A GR36(250) & GR50(345), CSA G40.21-04 GR44W(300W) & GR50W(350W) AASHTO M270/M270M-10 GR36(270) & GR50(345), ASME SA36/SA36M-07, QQ-S-741D, KILLED FG PRACTICE

1. WELDING OR WELD REPAIR WAS NOT PERFORMED ON THIS MATERIAL
2. MELTED AND MANUFACTURED IN THE USA
3. MERCURY, RADIUM, OR ALPHA SOURCE MATERIALS IN ANY FORM HAVE NOT BEEN USED IN THE PRODUCTION OF THIS MATERIAL

James H. Blew
Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 1

Figure A-2. Anchor Bearing Plate Material Specification, Test Nos. MSPBN-1 through MSPBN-3

Atlas Tube Corp (Chicago)
1855 East 122nd Street
Chicago, Illinois, USA
60633
Tel: 773-646-4500
Fax: 773-646-6128

Atlas *Tube*
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80745585
Date: 12.27.2016
Customer: 179

MATERIAL TEST REPORT

Sold to

Steel & Pipe Supply Company
PO Box 1688
MANHATTAN KS 66505
USA

Shipped to

Steel & Pipe Supply Company
310 Smith Road
JONESBURG MO 63351
USA

Material: 5.0x5.0x250x24'0"0(4x4). Material No: 500502502400 Made in: USA
Melted in: Canada
Sales order: 1144226 Purchase Order: 4500278309 Cust Material #: 6550025024

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
3539C4	0.200	0.770	0.010	0.004	0.030	0.035	0.020	0.000	0.000	0.010	0.030	0.000	0.001	0.000	0.000

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.34
M800672698	16	059250 Psi	073827 Psi	29 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 8.0x6.0x188x40'0"0(2x3). Material No: 800601884000 Made in: USA
Melted in: USA
Sales order: 1144578 Purchase Order: 4500278335 Cust Material #: 6680060018840

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
167623	0.190	0.840	0.010	0.001	0.024	0.033	0.078	0.000	0.013	0.040	0.075	0.001	0.003	0.000	0.009

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.36
M800670389	6	060259 Psi	076210 Psi	29 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 8.0x6.0x188x40'0"0(2x3). Material No: 800601884000 Made in: USA
Melted in: USA
Sales order: 1144578 Purchase Order: 4500278335 Cust Material #: 6680060018840

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
167622	0.190	0.840	0.011	0.002	0.020	0.025	0.078	0.000	0.015	0.037	0.071	0.001	0.002	0.000	0.007

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.36
M800670386	6	059855 Psi	075450 Psi	29 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Authorized by Quality Assurance:
The results reported on this report represent the actual attributes of the material furnished and indicate full compliance with all applicable specification and contract requirements.
Calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 2 Of 3

Metals Service Center Institute

Figure A-3. Lower Slip Post Tube Assembly Material Specification, Test Nos. MSPBN-1 through MSPBN-3

NUCOR

NUCOR STEEL TUSCALOOSA, INC.

MILL TEST CERTIFICATE

1700 HOLT RD N.E.
Tuscaloosa, AL 35404-1000
800 800-8204
customerservice@nucortusk.com

Page:1 of 1

Load Number	Tally	Mill Order Number	PO NO | Line NO	Part Number	Certificate Number	Prepared
T132130	00000000685654	N-149191-001	4500271472 1		S68565401-1	08/25/2016 09:58

Grade	Customer:
Order Description: Hot Roll Plate From Coil A36, 0.7500 IN x 72.000 IN x 120.000 IN **Quality Plan Description:** A36/SA36/A70936: ASTM A36-14/A709-36-15/ASME SA36-13/M270-36	**Sold TO:** STEEL AND PIPE SUPPLY CO INC LONGVIEW TX **Ship TO:** Longview Warehouse Longview TX **Sent TO:**

Shipped Item	Heat/Slab Number	Certified By	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Cb	V	Al	Ti	N2	B	Ca	Sn	CEV	ACI
6H1808B	B6U5630-04 ***	B6U5630	0.18	0.86	0.008	0.005	0.03	0.11	0.04	0.05	0.016	0.001	0.003	0.025	0.001	0.007	0.0001	0.0021			
6H1808C	B6U5630-04 ***	B6U5630	0.18	0.86	0.008	0.005	0.03	0.11	0.04	0.05	0.016	0.001	0.003	0.025	0.001	0.007	0.0001	0.0021			
6H1808D	B6U5630-04 ***	B6U5630	0.18	0.86	0.008	0.005	0.03	0.11	0.04	0.05	0.016	0.001	0.003	0.025	0.001	0.007	0.0001	0.0021			

Shipped Item	Certified By	Heat Number	Yield ksi	Tensile ksi	Y/T %	ELONGATION %		Bend OK?	Hard HB	Charpy Impacts (ft-lbs)					Shear %				Test Temp
						2"	8"			Size mm	1	2	3	Avg	1	2	3	Avg	
6H1808B	S6H1808FTT	B6U5630 ***	51.9	68.2	76.1	39.6													
6H1808B	S6H1808MTT	B6U5630 ***	51.8	65.1	79.6	40.3													
6H1808C	S6H1808FTT	B6U5630 ***	51.9	68.2	76.1	39.6													
6H1808C	S6H1808MTT	B6U5630 ***	51.8	65.1	79.6	40.3													
6H1808D	S6H1808FTT	B6U5630 ***	51.9	68.2	76.1	39.6													
6H1808D	S6H1808MTT	B6U5630 ***	51.8	65.1	79.6	40.3													

Items: 3 **PCS:** 25 **Weight:** 45943 **LBS**

Mercury has not come in contact with this product during the manufacturing process nor has any mercury been used by the manufacturing process. Certified in accordance with EN 10204 3.1. No weld repair has been performed on this material. Manufactured to a fully killed fine grain practice. NUTEMPER TEMPER PASSED plate from coil
ISO 9001:2008 Registered, PED Certified

"***" indicates Heats melted and Manufactured in the U.S.A.

We hereby certify that the product described above passed all of the tests required by the specifications.

Dr. Quilin Yu - Metallurgist

Figure A-4. Lower Slip Post Plate Assembly Material Specification, Test Nos. MSPBN-1 through MSPBN-3

SSAB

Test Certificate

12400 Highway 43 North, Axis, Alabama 36505, US

Form TC1: Revision 2: Date 23 Apr 2014

Customer: STEEL & PIPE SUPPLY P.O. BOX 1688 MANHATTAN KS 66502	Customer P.O. No.: 4500264885	Mill Order No.: 41-468885-01	Shipping Manifest : AT226267
	Product Description: ASTM A572-50/M345(15)/A709-50/M345(16A)	Ship Date: 02 Jun 16 Cert Date: 02 Jun 16	Cert No: 081561410 (Page 1 of 1)
	Size: 0.625 X 96.00 X 240.0 (IN)		

Tested Pieces			Tensiles								Charpy Impact Tests					
Heat Id	Piece Id	Tested Thickness	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1 2 3 Avg	% Shear 1 2 3 Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp %Shr
M6E147	A35	0.623 (DISCRT)	L	66	87		19	T							

Chemical Analysis

Heat Id	C	Mn	P	S	Si	Tot Al	Cu	Ni	Cr	Mo	Cb	V	Ti	ORGN
M6E147-A35	.18	1.10	.012	.002	.23	.026	.22	.13	.17	.08	.000	.065	.007	USA

KILLED STEEL
MERCURY IS NOT A METALLURGICAL COMPONENT OF THE STEEL AND NO MERCURY WAS INTENTIONALLY ADDED DURING THE MANUFACTURE OF THIS PRODUCT.
MTR EN 10204:2004 INSPECTION CERTIFICATE 3.1 COMPLIANT
100% MELTED AND MANUFACTURED IN THE USA.
PRODUCTS SHIPPED:
M6E147 A35 PCES: 4, LBS: 16336

R#17-392 Bullnose 2part Posts
Jan2017 SMT

(U) Cust Part # : 722096240A2

WE HEREBY CERTIFY THAT THIS MATERIAL WAS TESTED IN ACCORDANCE WITH, AND MEETS THE REQUIREMENTS OF, THE APPROPRIATE SPECIFICATION

Justin Ward
SENIOR METALLURGIST - PRODUCT

Figure A-5. Upper Slip Plate Assembly Material Specification, Test Nos. MSPBN-1 through MSPBN-3

GERDAU

US-ML-MIDLOTHIAN
300 WARD ROAD
MIDLOTHIAN, TX 76065
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
STEEL & PIPE SUPPLY CO INC JONESBURG INDUSTRIAL PARK JONESBURG,MO 63351 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	A992/A572-50	Wide Flange Beam / 6 X 9# / 150 X 13.5	0000068771

LENGTH	WEIGHT	HEAT / BATCH
40'00"	8,640 LB	59072444/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
4481119/000020	000000000037690040	ASTM A6-14 ASTM A709-15 ASTM A992-11 (2015), A572-15 CSA G40.21-13 345WM

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500277171	1327-0000217277	11/28/2016

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.07	0.92	0.013	0.035	0.21	0.24	0.09	0.13	0.018	0.005	0.002	0.011	0.003

CHEMICAL COMPOSITION

CEqyA6 %
0.28

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	Y/T rati %	G/L Inch
55973	69803	386	481	0.802	8.000
56818	70847	392	489	0.802	8.000

MECHANICAL PROPERTIES

G/L mm	Elong. %
200.0	23.90
200.0	24.00

COMMENTS / NOTES

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

TOM HARRINGTON
QUALITY ASSURANCE MGR.
Phone: 972-779-1872 Email: Tommy.Harrington@gerdau.com

Figure A-6. Upper Slip Post Assembly Material Specification, Test Nos. MSPBN-1 through MSPBN-3

CENTRAL NEBRASKA WOOD PRESERVERS, INC.

P. O. Box 630 • Sutton, NE 68979
Pone 402-773-4319
FAX 402-773-4513

R#17-282 BCT Posts 70 Acct AND Wood Blocks for Bullnose
Nov2016 SMT Wood Blockouts are painted Light Blue

Date: 11/11/16

CERTIFICATE OF COMPLIANCE

Shipped TO: Midwest Machinery + Supply BOL# 10055387

Customer PO# 3339 Preservative: CCA – C 0.60 pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GR6806.5PST	6x8-6.5" PST	35	22973	.679
GR6806.5CRT	6x8-6.5" CRT	35	22973	.679
GS6846PST	5.5-7.5-46" BCT	42	22927	.638
GR61214BCK	6x12-14" OCD	168	22927	.638

I certify the above referenced material has been produced, treated and tested in accordance with AWPA standards and conforms to AASHTO M133 & M168.

VA: Central Nebraska Wood Preservers certifies that the treated wood products listed above have been treated in accordance with AWPA standards, Section 236 of the VDOT Road & Bridge Specifications and meets the applicable minimum penetration and retention requirements.

Nick Sowl, General Counsel

11/11/16
Date

Figure A-7. Timber Blockout and BCT Timber Post Certificate of Compliance, Test Nos. MSPBN-1 through MSPBN-3

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: UNIVERSITY OF NEBRASKA BOARD
OF REGENTS
3835 HOLDREGE STREET
LINCOLN, NE 68583-0745
Project: NDOR SPECS

Order Number: 1271004 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 4500279419
BOL Number: 98199 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 12/28/16

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
10	209G	T12/12'6/6'3/S	RHC		2	L33814													4
			M-180	A	2	182997	58,340	76,890	26.9	0.180	0.730	0.014	0.004	0.010	0.130	0.000	0.060	0.001	4
			M-180	A	2	182998	60,310	78,910	25.4	0.200	0.730	0.012	0.006	0.010	0.140	0.000	0.050	0.001	4
			M-180	A	2	182997	58,340	76,890	26.9	0.180	0.730	0.014	0.004	0.010	0.130	0.000	0.060	0.001	4
			M-180	A	2	182998	60,310	78,910	25.4	0.200	0.730	0.012	0.006	0.010	0.140	0.000	0.050	0.001	4
6	12379G	T12/12'6/SPEC/S 34'RCX	RHC		2	L34713													4
			M-180	A	2	172876	55,930	72,020	31.4	0.190	0.720	0.014	0.002	0.020	0.130	0.000	0.080	0.000	4
			M-180	A	2	172876	55,930	72,020	31.4	0.190	0.720	0.014	0.002	0.020	0.130	0.000	0.080	0.000	4
6	12383G	T12/12'6/6'3/SPEC SLOTS/S	RHC		2	L33814													4
			M-180	A	2	182997	58,340	76,890	26.9	0.180	0.730	0.014	0.004	0.010	0.130	0.000	0.060	0.001	4
			M-180	A	2	182998	60,310	78,910	25.4	0.200	0.730	0.012	0.006	0.010	0.140	0.000	0.050	0.001	4
			M-180	A	2	182997	58,340	76,890	26.9	0.180	0.730	0.014	0.004	0.010	0.130	0.000	0.060	0.001	4
			M-180	A	2	182998	60,310	78,910	25.4	0.200	0.730	0.012	0.006	0.010	0.140	0.000	0.050	0.001	4
3	12385G	T12/12'6/SPEC/S 5'RCX			2	L35116													
			M-180	A	2	209331	62,090	81,500	28.1	0.190	0.720	0.013	0.002	0.020	0.110	0.000	0.070	0.002	4
			M-180	A	2	209332	61,400	81,290	25.3	0.190	0.730	0.014	0.003	0.020	0.120	0.000	0.060	0.001	4
			M-180	A	2	209333	61,200	80,050	25.8	0.200	0.740	0.016	0.005	0.010	0.120	0.000	0.070	0.002	4
			M-180	A	2	209331	62,090	81,500	28.1	0.190	0.720	0.013	0.002	0.020	0.110	0.000	0.070	0.002	4
2	119013B	CUSTOM161"MFTGR.PALL	HW			123456													

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

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

1 of 2

Figure A-8. Thrie Beam Material Specification, Test Nos. MSPBN-1 through MSPBN-3

QUALITY CERTIFICATE

NINGBO JINDING FASTENING PIECE CO.,LTD

XIJINGTANG JIULONGHU NINGBO CHINA TEL:+86-574-86530122 FAX: +86-574-86530858

Customer:	FASTENAL COMPANY PURCHASING—IMPORT	Date :	2016-08-01
Product:	HEX CAP SCREWS	Contract No:	16JDF223T
Class:	5	Invoice No:	16-01336006
Size:	7/16-14X2-1/4	Lot No:	3412980006
Marking:	JDF three radius	Order No.	220021716
Quantity:	7.750 mpcs	Part No.	110120366
		Production Date	2016-05-13
Dimensions Of SPEC:		Certificate No.:	

R#17-398 BULLNOSE
7/16"
BOLTS,NUTS,WASHERS
7/8" BOLTS,NUTS
JAN2017 SMT

Inspection Items		Standard	Result	Sample	Pass
Visual Appearance		-----------	OK	20	20
Body Diameter		0.430-0.437	0.431-0.432	20	20
Thread	Go	3A	OK	20	20
	No Go	2A	OK	20	20
Width Across Flats		0.625-0.612	0.613-0.614	20	20
Width Across Corners		0.722-0.698	0.702-0.705	20	20
Major Diameter		0.426-0.436	0.433-0.435	20	20
Head Height		0.291-0.272	0.281-0.282	20	20
Total Length		2.250-2.191	2.226-2.226	20	20
Thread Length		min 1.128	1.223-1.226	20	20
Mechanical Properties					
CharacTeristics		Standard	Result		
Surface Hardness	[30N]	MAX 54	43-44	10	10
Core Hardness	[HRC]	25-34	27-28	10	10
Wedge Strength	[psi]	min 119880	134538-138021	8	8
Yield Strength	[psi]	min 91869	105511-112188	8	8
Elongation	[%]	min 14	16.6-18.1	8	8
Reduction Of area	[%]	min 35	45.2-52.4	8	8
Proof Load	[Ib]	9050	9050	4	4
Decarburization		N≥1/2H1 HV0.3	317.43 317.43 290.57	6	6
HV2>=HV1-30, HV3<=HV1+30		G 0.0006max		6	6
CHEMICAL COMPOSITION(%)					

Heat No		C	Si	Mn	P	S	Cr	Ni	Cu	Mo	B
Spec.:	min	0.2500									
	max	0.5500			0.0250	0.0250					0.0030
35#	5210760BA	0.36	0.16	0.64	0.016	0.010					
Thickness	[UM]	min 5				10.0-13.5		20		20	

Surface Coating:	ZPCr3+(coating test method: X ray according to ASTM B568M 2007 standard test method for measurement of coating thickness by X-Ray spectrometry)
Parts are manufactured and tested according to above specification and compliance with order	
we certify that this is a true representation of information provided by manufacturer and laboratory.	
Thread Specification: ASME B1.1 2008, UNIFIED INCH SCREW THREADS(UN AND UNR THREAD FORM)	
Sampling Dimension Specification: ASME B18.18-2011 inspection and quality assurance for high-volume machine assembly fasteners	
Dimension Specification: ASME B18.2.1 2012, HEX CAP SCREWS	
Sampling mechanical properties specification: ASTM F1470 2012 Standard Guide for Fastener Sampling for Specified Mechanical Properties and Performance Inspection	
Mechanical Properties: SAE J429 2014, MECHANICAL AND MATERIAL REQUIREMENTS FOR EXTERNALLY THREADED FASTENERS	
Surface Defect: ASTM F788/F788M-2013, SURFACE DISCONTINUITIES OF BOLTS, SCREWS, AND STUDS	
Plating Specification: ASTM 1941 2015, Electrodeposited Coatings On Threaded Fasteners	
Quality Control Supervisor	Quality Control Manager

Figure A-9. $^{7}/_{16}$-in. (11-mm) Dia. 2¼-in. (57-mm) Long Heavy Hex Bolt Material Specification, Test Nos. MSPBN-1 through MSPBN-3

ISO/TS 16949 BUREAU VERITAS Certification

GEM-YEAR TESTING LABORATORY
CERTIFICATE OF INSPECTION

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

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2016/06/15

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 210110353
COMMODITY : FINISHED HEX NUT GR-5
SIZE : 7/16-14 NC
LOT NO : 1N1640850
SHIP QUANTITY : 22,500 PCS
LOT QUANTITY 181,067 PCS
HEADMARKS : GENIUS SYMBOL & 2 ARC LINES(120 DEGREE)
MANUFACTURE DATE : 2016/05/17
COUNTRY OF ORIGIN : CHINA

PACKING NO : GEM160602037
INVOICE NO : GEM/FNL-160618ED
PART NO : 1136308
SAMPLING PLAN : ASME B18.18-2011(Category.2)/ASTM F1470-2012
HEAT NO : 169D0620
MATERIAL : 1022A
FINISH : Fe/Zn 3AN ASTM F1941/F1941M-2015

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO SAE J995-2012

Chemistry	AL%	C%	MN%	P%	S%	SI%
Spec. : MIN.			0.3000			
MAX.		0.5500		0.0500	0.1500	
Test Value	0.0280	0.2000	0.8000	0.0130	0.0060	0.1000

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.2.2-2010

SAMPLED BY : FCHUN

INSPECTIONS ITEM	SAMPLE	SPECIFIED		ACTUAL RESULT	ACC.	REJ.
WIDTH ACROSS CORNERS	6PCS	ASME B18.2.2-2010	0.7680-0.7940 inch	0.7730-0.7920 inch	6	0
FIM	15PCS		Max. 0.0180 inch	0.0060-0.0170 inch	15	0
THICKNESS	6PCS		0.3650-0.3850 inch	0.3670-0.3770 inch	6	0
WIDTH ACROSS FLATS	6PCS		0.6750-0.6880 inch	0.6760-0.6800 inch	6	0
SURFACE DISCONTINUITIES	29PCS		ASTM F812-2012	PASSED	29	0
THREAD	15PCS		GAGING SYSTEM 21	PASSED	15	0

MECHANICAL PROPERTIES : ACCORDING TO SAE J 995-2012

SAMPLED BY : GDAN LIAN

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	15 PCS	ASTM F606-2014		Max. 32 HRC	12-16 HRC	15	0
PROOF LOAD	6 PCS	ASTM F606-2014		Min. 120,000 PSI	OK	6	0
PLATING THICKNESS(μm)	29 PCS	ASTM B568-1998		>=3	3.48-4.98	29	0
SALT SPRAY TEST	15 PCS	ASTM B117-11		6 HOURS NO WHITE RUST, 12 HOURS NO RED RUST	OK	15	0

WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY .WHICH ACCREDITED BY ISO/IEC17025(CERTIFICATE NUMBER:3358.01)
WE CERTIFY THAT THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH THE REQUIREMENTS OF THE ORDER

Quality Supervisor: [signature]

page 1 of 1

Figure A-10. $^{7}/_{16}$-in. (11-mm) Dia. Heavy Hex Nut Material Specification, Test Nos. MSPBN-1 through MSPBN-3

Certificate of Compliance

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

Customer Midwest Machinery **Date Shipped** 06/16/2016

Customer Order Number 3275 **BFM Order Number** 1338859

Item Description

Description 5/8"-11 x 10" Hex Bolt **Qty** 157

Lot # 208977 **Specification** ASTM A307-14 Gr A **Finish** ASTM F2329

Raw Material Analysis

Heat# DL15107048

Chemical Composition (wt% Heat Analysis) By Material Supplier

C	Mn	P	S	Si	Cu	Ni	Cr	Mo
0.22	0.82	0.007	0.010	0.27	0.20	0.06	0.10	0.015

Mechanical Properties

Sample #	Hardness	Tensile Strength (lbs)	Tensile Strength (psi)
1	91 HRBW	21,700	97,660
2			
3			
4			
5			

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

Authorized Signature: **Date:** 6/16/2016

Brian Hughes
Quality Assurance

Figure A-11. ⅝-in. (16-mm) Dia., 10-in. (254-mm) Long Hex Bolt Material Specification, Test Nos. MSPBN-1 through MSPBN-3

33606

Customer:	Trinity Highway Products	Date:	10-28-16
Description:	5/8-11 x 1-1/4 Guard Rail Bolt A307 HDG-A153 Class C	P/N:	003360G
Order No:	40563	Lot #:	0053777-AAJ

Physical Test

Sample	Hardness 69-100HRB	Plating	Stress Area	Proof Load	Ultimate Tensile		
Required				LBS.	PSI	LBS. ≥13,560	PSI ≥60,000
1	84		0.226			21,500	95,200
2	85		0.226			21,400	94,700
3	86		0.226			21,500	95,100
4	84		0.226			22,400	94,600
5	85		0.226			21,300	94,300

Chemistry

Heat #	C	MN	P	S	SI	NI	CR	MO	PB	V	B	AL	CU	Other
10435580	.16	.68	.007	.013	.220	.04	.07	.01	-	.002	.0001	.023	.07	-

Dimensional Check

Head Height:	.230	Thread Length:	1.031
.220/.250	.234	Full Thread	1.033
Body Diameter:	.618	1.00 MIN	1.034
.594/.656	.621		
Length:	1.244	Point:	IN THE DIE
1.188/1.312	1.250	Total Volume:	224,000 pcs
	1.269	Pc Wt:	178.84/1,000 Pcs.

SILO FASTENERS

1415 S BENHAM ROAD

VERSAILLES IND 47042

Name: JOE KILPATRICK

Title: QUALITY TECHNICIAN

Date: 10-28-16

Figure A-12. ⅝-in. (16-mm) Dia., 1¼-in. (32-mm) Long Guardrail Bolt Material Specification, Test Nos. MSPBN-1 through MSPBN-3

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1269489 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3346
BOL Number: 97457 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 11/7/16

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
	701A	ANchor Box	A-36			JK16101488	56,172	75,460	25.0	0.160	0.780	0.017	0.028	0.200	0.280	0.001	0.140	0.028	4
	701A		A-36			535133	43,300	68,500	33.0	0.019	0.460	0.013	0.016	0.013	0.090	0.001	0.090	0.002	4
4	729G	TS 8X6X3/16X8'-0" SLEEVE	A-500			A49248	64,818	78,412	32.0	0.200	0.810	0.014	0.002	0.040	0.020	0.000	0.040	0.001	4
20	738A	5'TUBE SL.188X6X8 1/4 /PL	A-36		2	4182184	45,000	67,900	31.0	0.210	0.760	0.012	0.008	0.010	0.050	0.001	0.030	0.002	4
	738A		A-500			A49248	64,818	78,412	32.0	0.200	0.810	0.014	0.002	0.040	0.020	0.000	0.040	0.001	4
6	749G	TS 8X6X3/16X6'-0" SLEEVE	A-500			A49248	64,818	78,412	32.0	0.200	0.810	0.014	0.002	0.040	0.020	0.000	0.040	0.001	4
6	782G	5/8"X8"X8" BEAR PL/OF	A-36			DL15103543	58,000	74,000	25.0	0.150	0.750	0.013	0.025	0.200	0.360	0.003	0.090	0.000	4
20	783A	5/8X8X8 BEAR PL 3/16 STP	A-36			PL14107973	48,167	69,811	25.0	0.160	0.740	0.012	0.041	0.190	0.370	0.000	0.220	0.002	4
	783A		A-36			DL15103543	58,000	74,000	25.0	0.150	0.750	0.013	0.025	0.200	0.360	0.003	0.090	0.000	4
45	3000G	CBL 3/4X6'6/DBL	HW			119048													
7,000	3340G	5/8" GR HEX NUT	HW			0055551-116146													
4,000	3360G	5/8"X1.25" GR BOLT	HW			0053777-115516													
450	3500G	5/8"X10" GR BOLT A307	HW			28971-B													
1,225	3540G	5/8"X14" GR BOLT A307	HW			29053-B													

Figure A-13. ⅝-in. (16-mm) Dia. Nut, Test Nos. MSPBN-1 through MSPBN-3

3380

LOAD Po # 71267

CHARTER STEEL

A Division of
Charter Manufacturing Company, Inc.

CHARTER STEEL TEST REPORT
Reverse Has Text And Codes

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

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

Cust P.O.	284371-01
Customer Part#	062501015000SF(SW1015-C)
Charter Sales Order	30048422
Heat #	10207560
Ship Lot #	1074155
Grade	1015 A SK FG IQ 5/8
Process	HR
Finish Size	5/8

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

Test Results of Heat Lot# 10207560

Lab Code: 7388

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

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

JOMINY(HRC) JOM01
41

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

Test Results of Rolling Lot# 1074155

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

43,445

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

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

Additional Comments:

8-8-12

Charter Steel
Saukville, WI, USA

ACCREDITED

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance

Figure A-14. ⅝-in. (16-mm) Dia., 1½-in. (38-mm) Long Hex Bolt Material Specification, Test Nos. MSPBN-1 through MSPBN-3

R#16-0217
BCT Hex Nuts
December 2015 SMT
Fastenal part#36713
Control# 210101523

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

- Sales Order #: 129980
- Part No: AFH2G0625C
- Cust Part No: 36713
- Quantity (PCS): 1200
- Description: 5/8-11 Fin Hx Nut Gr2 HDG/TOS 0.020
- Specification: SAE J995(99) - GRADE 2 / ANSI B18.2.2
- Stelfast I.D. NO: 595689-O201087
- Customer PO: 210101523
- Warehouse: DAL

The data in this report is a true representation of the information provided by the material supplier certifying that the product meets the mechanical and material requirements of the listed specification. This certificate applies to the product shown on this document, as supplied by STELFAST INC. Alterations to the product by our customer or a third party shall render this certificate void.

This document may only be reproduced unaltered and only for certifying the same or lesser quantity of the product specified herein. Reproduction or alteration of this document for any other purpose is prohibited.

Stelfast certifies parts to the above description. The customer part number is only for reference purposes.

David Biss
Quality Manager

December 07, 2015

Page 1 of 1

Figure A-15. ⅝-in. (16-mm) Dia. Hex Nut Certificate of Compliance, Test Nos. MSPBN-1 through MSPBN-3

3580G

CERTIFICATE OF COMPLIANCE

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

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 180129

SHIPPER #: 058945
DATE SHIPPED: 10/20/2016

LOT#: 29145-B

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE: SPEC: 60,000 psi*min RESULTS: 78,212
77,960

HARDNESS: 100 max 85.30
84.60

*Pounds Per Square Inch.

COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
ROGERS GALVANIZE: 29145-B

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si
NUCOR	1010	NF16102734	.10	.54	.012	.017	.15

QUANTITY AND DESCRIPTION:

4,500 PCS 5/8" X 18" GUARD RAIL BOLT
P/N 3580G

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

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS

20th DAY OF October 2016 Linda McComas 10/20/16
Merry F. Shane

APPROVED SIGNATORY DATE

OFFICIAL SEAL
MERRY F. SHANE
NOTARY PUBLIC – STATE OF ILLINOIS
MY COMMISSION EXPIRES OCTOBER 3, 2018

Figure A-16. ⅝-in. (16-mm) Dia., 18-in. (457-mm) Long Guardrail Bolt Material Specification, Test Nos. MSPBN-1 through MSPBN-3

From: FAXmaker To: 1-815-877-0734 Page: 1/1 Date: 5/14/2015 4:00:16 PM

Heat Number	Shipper No	Invoice No	Customer PO#	Customer Name
2038622	680907	701917	5-7-2015 MIKE	GAFFNEY BOLT CO.

CMC

1SERIES-BPS®

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

	SOLD TO	SHIP TO	
HEAT NO.:2038622 SECTION: ROUND 7/8 x 40'0" A36/52950 GRADE: ASTM A36-12/A529-05 Gr 50 ROLL DATE: 09/09/2014 MELT DATE: 09/08/2014	Infra-Metals - Mars 1601 Broadway St Marseilles IL US 61341-9326 8009875283	Infra-Metals - Mars 1601 Broadway St Marseilles IL US 61341-9326 8009875283	Delivery#: 81471569 BOL#: 70533247 CUST PO#: CE-485729 CUST P/N: DLVRY LBS / HEAT: 9075.000 LB DLVRY PCS / HEAT: 111 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.16%	Elongation Gage Lgth test 1	8IN		
Mn	0.73%	Reduction of Area test 1	58%		
P	0.013%	Yield to tensile ratio test1	0.75		
S	0.021%	Yield Strength test 2	56.9ksi		
Si	0.22%	Tensile Strength test 2	76.5ksi		
Cu	0.32%	Elongation test 2	25%		
Cr	0.13%	Elongation Gage Lgth test 2	8IN		
Ni	0.10%	Reduction of Area test 2	57%		
Mo	0.027%	Yield to tensile ratio test2	0.74		
V	0.000%	C+(Mn/6)	0.28%		
Cb	0.026%				
Sn	0.010%				
Al	0.000%				
Ti	0.001%				
N	0.0084%				
Carbon Eq A529	0.38%				
Yield Strength test 1	57.1ksi				
Tensile Strength test 1	76.3ksi				
Elongation test 1	23%				

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

REMARKS :

ALSO MEETS ASTM GRADE A36 REV-03A, A529 GR.50, A572-2013A GR.50, A709 GR.36, A709 GR.50, A992, AASHTO GRADE M270 GR.36, M270 GR.50, CSA G40.21-04 GRADE 44W, 50WASME SA-36 2008A ADDEND A.

03/18/2015 14:05:35
Page 1 OF 1

Figure A-17. ⅞-in. (22-mm) Dia., 8-in. (203-mm) Long Hex Bolt Material Specification, Test Nos. MSPBN-1 through MSPBN-3

INSPECTION CERTIFICATE

Customer	Specification	Size	Lot No.	Date
	ASTM A-563 GRADE DH HEAVY HEX NUT	7/8- 9 UNC	WA651	Jun. 29,'12

UNYTITE, INC.
One Unytite Drive
Peru, Illinois 61354
815-224-2221 — FAX# 815-224-3434

Mechanical properties tested in accordance to ASTM F606/F606M, ASTM A370, ASTM E18

Chemical Composition (%)

Mill Maker	Material Size	Heat No.	Spec.	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	
NUCOR	CARBON			0.20 0.55	-	MIN. 0.60	MAX. 0.040	MAX. 0.050	-	-	-	-	-
STEEL	STEEL	12101054		0.43	0.24	0.87	0.015	0.020	0.09	0.04	0.08	-	-

Mechanical Property Inspection

Item	Proof Load	Cone stripping	Hardness	After Heat Treatment Hardness	Absorbed Energy	Heat Treatment
Spec.	80,850 lbf	- kN·kgf·lbf	24-38 HrC	HrB·HB	j·kgfm·ftlbf	T:MIN.800 F
Results	n 5 Results GOOD	n - Results -	29.4 28.9 29.7 29.7 29.5 29.4	5 Piece Average After Heat Treament; Hardness Treatment After 24 Hr.X °F(°C)	at °F(°C)	Q:FORGING Q (W.Q.) T:1058 F/45M. (W.C.)

Q: Quenching
T: Tempering
ST: Solution Treatment

Shape & Dimension	
Inspection	ANSI B18.2.2 GOOD
Thread Precision Inspection	ANSI B1.1 CLASS 2B GOOD
Appearance Inspection	GOOD

Remarks:
"DH U"

Production Quantity 22,391 pcs.

BCT Foundation Tube
Keeper Bolt Nuts
R#15-0600 June 2015 SMT

OFFICIAL SEAL
JEAN MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/18/13
07-10-12

Material used for the nut was melted and manufactured in the USA. The nut was manufactured in the USA to the above specification.

We hereby certify that the material described has been manufactured and inspected satisfactorily with the requirement of the above specification.

Chief of Quality Assurance Section

Figure A-18. ⅞-in. (22-mm) Dia. Hex Nut Material Specification, Test Nos. MSPBN-1 through MSPBN-3

350ab

CHARTER STEEL
A Division of Charter Manufacturing Company, Inc

EMAIL

1650 Cold Springs Road
Saukville, Wisconsin 53080
(262) 268-2400
1-800-437-8789
Fax (262) 268-2570

CHARTER STEEL TEST REPORT

Melted in USA Manufactured in USA

Trinity Industries Inc.
2525 Stemmons Frwy, 4th Floor
Dallas,TX-75207
Kind Attn : Material Certifications Dept.

Cust P.O.	160532M-11
Customer Part #	100941B
Charter Sales Order	70057033
Heat #	20351510
Ship Lot #	2073852
Grade	1010 R AK FG RHQ 41/64
Process	HR
Finish Size	41/64
Ship date	27-OCT-14

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

Test results of Heat Lot # 20351510

Lab Code: 125544

CHEM %Wt	C	MN	P	S	SI	NI	CR	MO	CU	SN	V
	.09	.33	.007	.002	.060	.04	.05	.01	.06	.004	.001
	AL	N	B	TI	NB						
	.028	.0070	.0001	.001	.001						

Test results of Rolling Lot # 2073852

REDUCTION RATIO=152:1

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

Additional Comments:

Charter Steel
Cuyahoga Heights, OH, USA

Rem: Load1,Fax0,Mail0

ACCREDITED
Testing Laboratory

Page 1 of 2

This MTR supersedes all previously dated MTRs for this order

Janice Barnard
Manager of Quality Assurance
Printed Date : 10/27/2014

Figure A-19. ⅝-in. (16-mm) Dia., 10-in. (254-mm) Long Guardrail Bolt Material Specification, Test Nos. MSPBN-1 through MSPBN-3

MCMASTER-CARR

Certificate of Compliance

600 N County Line Rd
Elmhurst IL 60126-2081
630-600-3600
chi.sales@mcmaster.com

University of Nebraska
Midwest Roadside Safety Facility
M W R S F
4630 Nw 36TH St
Lincoln NE 68524-1802
Attention: Shaun M Tighe
Midwest Roadside Safety Facility

Purchase Order
E000357170

Order Placed By
Shaun M Tighe

McMaster-Carr Number
2098331-01

Page 1 of 1

Line		Product	Ordered	Shipped
1	**97812A109**	Steel Double-Headed Nail Size 16D, 3" Length, .16" Shank Diameter, 200 Pieces/Pack, Packs of 5	**5 Packs**	**5**

Certificate of compliance

This is to certify that the above items were supplied in accordance with the description and as illustrated in the catalog. Your order is subject only to our terms and conditions, available at www.mcmaster.com or from our Sales Department.

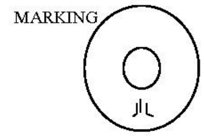
Sarah Weinberg
Compliance Manager

Figure A-20. 16D Double Head Nail Certificate of Compliance, Test Nos. MSPBN-1 through MSPBN-3

HEXICO ENTERPRISE CO., LTD.

NO.355-3,SEC. 3,CHUNG SHAN ROAD,KAU-JEN,TAINAN,TAIWAN,R.O.C.
TEL : 886 - 6 - 2390616 FAX : 886 - 6 - 2308947

INSPECTION CERTIFICATE



CUSTOMER	**FASTENAL COMPANY**		
PART NAME	FLAT WASHER		
SIZE	7/16 "	DATE	July 20, 2016
PART NO.	WYA3C3500S2LQ5	REPORT NO.	1050720-33
CUST. PART NO.	1133860	ORDER NO.	180121681
MATERIAL	1050 / 1.8 mm	DOCUMENT NO.	10502005
HEAT(COIL) NO.	1GX24	LOT NO.	57253FNEA
LOT QTY	67,500 PCS	MAF. QTY	67,500 PCS

THE PRODUCTS SUPPLIED ARE IN COMPLIANCE WITH REQUIREMENT OF THE ORDER.

SAMPLING PLAN STANDARD	ASME B18.18-2011
DIMENSION STANDARD	ASME B18.21.1-2009
COATING STANDARD	ASTM F1941-2011
HARDNESS TEST METHOD	ASTM F606-2014
COATING TEST METHOD	ASTM E376-2011
SALT PRAY TEST METHOD	ASTM B117-2011

DIMENSIONS IN inch

INSPECTION ITEM		SPECIFICATION	TEST QTY	INSPECTION RESULTS		INSPECTION EQUIPMENT
				MIN.	MAX.	
1	OUTSIDE DIAMETER	1.2430 - 1.2800	8	1.2528	1.2555	Caliper
2	INSIDE DIAMETER	0.4950 - 0.5150	8	0.4976	0.5016	Caliper
3	THICKNESS	0.0640 - 0.1040	8	0.0685	0.0705	Caliper
4	HARDNESS	HRC 38 - 45	5	40.3	41.4	Rockwell
5	COATING (BAKED)	ZINC YEL.CR6^{+} 0.0002 in.	5	0.0003	0.0004	Eddy current
6	SALT SPRAY TEST	72 hrs. No White Rust 96 hrs. No Red Rust	4	OK		S.S.T tester
7	APPEARANCE	VISUAL	100	OK		

INSPECTOR *Yu Tain Lin* QC CHIEF *Jing Yeh Tsao*

Figure A-21. $^{7}/_{16}$-in. (11-mm) Dia. Plain Round Washer Material Specification, Test Nos. MSPBN-1 through MSPBN-3

CERTIFIED MATERIAL TEST REPORT Page 1/1

GERDAU

US-ML-CARTERSVILLE
384 OLD GRASSDALE ROAD NE
CARTERSVILLE, GA 30121
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
HIGHWAY SAFETY CORP 473 W FAIRGROUND ST MARION,OH 43302-1701 USA	HIGHWAY SAFETY CORP GLASTONBURY,CT 06033-0358 USA	A992/A709-36	Wide Flange Beam / 6 X 8.5# / 150 X 13.0	0000000000
		LENGTH 39'00"	WEIGHT 41,766 LB	HEAT / BATCH 55044245/05

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
3399484/000020		ASTM A6-14 ASTM A709-13A ASTM A992-11 CSA G40.21-13 345WM

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
0001677110 IB-B0600800	1323-0000067912	04/13/2016

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %
0.14	0.92	0.015	0.027	0.20	0.30	0.09	0.12	0.027	0.015	0.017	0.001

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	G/L Inch	Elong. %
52500	71600	362	494	8.000	21.90
53200	72400	367	499	8.000	22.60

COMMENTS / NOTES

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 YALAMANCHILI
QUALITY DIRECTOR

YAN WANG
QUALITY ASSURANCE MGR.

Figure A-22. W6-in. x 8.5-in. (W152-mm x12.6-mm), 78-in. (1,981-mm) Long Steel Post Material Specification, Test Nos. MSPBN-1 through MSPBN-3

R#17-282: Bullnose hardware BCT Cable Nuts

L#366055B H#DL15103032

NUCOR
FASTENER DIVISION

LOT NO. 366055B

Post Office Box 6100
Saint Joe, Indiana 46785
Telephone 260/337-1600

CUSTOMER NO/NAME
8061 STRUCTURAL BOLT CO LLC
NUCOR ORDER # 957233
TEST REPORT SERIAL# F3482520
CUST PART #
TEST REPORT ISSUE DATE 1/08/16
DATE SHIPPED 1/21/16
CUSTOMER P.O. # 18131
NAME OF LAB SAMPLER: JOSEPH BYERLY, LAB TECHNICIAN

*****************CERTIFIED MATERIAL TEST REPORT*****************

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175647	3600	366055B	1-8 GR DH HV H.D.G. HEX NUT H.D.G./GREEN LUBE

MANUFACTURE DATE 10/01/15

--CHEMISTRY MATERIAL GRADE -1045L

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER NUCOR STEEL - SOUTH CAROL

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM030068	DL15103032	.45	.67	.003	.019	.20

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A563-07a

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH DEG-WEDGE (LBS)	STRESS (PSI)
N/A	30.8	PASS	N/A	N/A
N/A	28.6	PASS	N/A	N/A
N/A	26.6	PASS	N/A	N/A
N/A	26.2	PASS	N/A	N/A
N/A	24.5	PASS	N/A	N/A
AVERAGE VALUES FROM TESTS	27.3			

PRODUCTION LOT SIZE 42800 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A563-07a 80 PCS. SAMPLED LOT PASSED

--COATING - HOT DIP GALVANIZED TO ASTM F2329-13 - GALVANIZING PERFORMED IN THE U.S.A.

1. 0.00278 2. 0.00892 3. 0.00428 4. 0.00257 5. 0.00321 6. 0.00228 7. 0.00603
8. 0.00676 9. 0.00315 10. 0.00321 11. 0.00371 12. 0.00264 13. 0.00252 14. 0.00348
15. 0.00287

AVERAGE THICKNESS FROM 15 TESTS .00388
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2012

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.823	1.833
Thickness	32	0.978	0.996

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO INTENTIONAL ADDITIONS OF BISMUTH, SELENIUM, TELLURIUM, OR LEAD WERE USED IN THE STEEL USED TO PRODUCE THIS PRODUCT.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7014. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

A2LA ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 01/31/16

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Figure A-23. BCT Anchor Cable Assembly, Test Nos. MSPBN-1 through MSPBN-3

EXLTUBE

1000 BURLINGTON STREET, NORTH KANSAS CITY, MO 64116 1-816-474-5210 TOLL FREE 1-800-892-TUBE

STEEL VENTURES, LLC dba EXLTUBE

Certified Test Report

Customer:	Size:	Customer Order No:	Date:
SPS - New Century 401 New Century Parkway NEW CENTURY KS 66031-1127	02.375	4500269918	07/25/2016
	Gauge: .154	Delivery No: 82799116 Load No. 3774661	
	Specification: ASTM A500-13 Gr.B/C, ASTM A53-12 Gr.B BNT*, ASME SA53 Gr.B BNT*		

Heat No	Yield KSI	Tensile KSI	Elongation % 2 inch
A79999	63.2	67.3	31.00

R#17-175 H#A79999
BCT Post Sleeves QTY 8
Oct 2016 SMT

Heat No	C	MN	P	S	SI	CU	NI	CR	MO	V
A79999	0.0700	0.8400	0.0110	0.0040	0.0200	0.1500	0.0500	0.0600	0.0200	0.0010

This material was melted & manufactured in the U.S.A.
We hereby certify that all test results shown in this report are correct as contained in the records of our company. All testing and manufacturing is in accordance to A.S.T.M. parameters encompassed within the scope of the specifications denoted in the specification and grade tiles above. This product was manufactured in accordance with your purchase order requirements.
BNT=Grade B not pressure tested - meets tensile & chemical properties ONLY.

This material has not come into direct contact with mercury, any of its compounds, or any mercury bearing devices during our manufacturing process, testing, or inspections.

This material is in compliance with EN 10204 Section 4.1 Inspection Certificate Type 3.1

This material has passed NDE (eddy current, A309) testing. This material has passed flattening tests.

Tensile test completed using test specimen with 3/4" reduced area.

STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe
Quality Assurance Manager

Figure A-24. 2⅜-in. (60-mm), 6-in. (152-mm) Long BCT Post Sleeve Material Specification, Test Nos. MSPBN-1 through MSPBN-3

COMMERCIAL GROUP
LIFTING PRODUCTS

66966

AUGUST 19th, 2016

SOLD TO:
TRINITY HIGHWAY PRODUCTS, LLC
PO BOX 566028, MAILSTOP 7115
DALLAS, TX 75356-6028

SHIP TO:
TRINITY HIGHWAY PRODUCTS, LLC PLT-
550 EAST ROBB AVE
ATTN: KEITH HAMBURG
LIMA, OH 45801-3037

CERTIFICATON

CGLP ORDER# 248853
TRINITY PO# 178817

THIS LETTER AND THE ENCLOSED ATTACHMENTS ARE TO CERTIFY THAT THE FOLLOWING ITEMS WERE 100% MANUFACTURED IN THE UNITED STATES OF AMERICA.

50 PCS, PART#6696G, 5/8IN X 14FT 4.75IN, DOUBLE SWAGE GUARD RAIL ASSEMBLYS.

THEY SHOW THE DOMESTICITY OF ALL MATERIAL USED, 100% MELTED & MANUFACTURED IN THE USA. THESE ITEMS ARE HOT DIPPED GALVANIZED TO ASTM-153 SPECIFICATIONS AND STANDARDS, GALV PROCESS ALSO TOOK PLACE IN THE U.S.A.

ATTACHMENTS:

NUMBERS USED IN PRODUCTION OF THESE ASSEMBLYS ARE AS FOLLOWS:

(WIRE ROPE) WIRECO WORLD GROUP REEL# 428-660971-1 / HEAT #S 585464, 567595, 581839, 582607, 578851, 578342, 576237, 552215.
(EVRAZ / ROCKY MOUNTAIN STEEL) ***** BUTTONS #12, MUNCY: HEAT# 5171023
(REPUBLIC STEEL)

** KORNS GALVANIZING CO JOHNSTOWN, PA. (GALVANIZING

VERY TRULY YOURS
Matt Glynn
MAT GLYNN
GENERAL MGR FLINT OFFICE

HEADQUARTERS	FLINT BRANCH	CLEVELAND BRANCH
12801 UNIVERSAL DRIVE	G2427 E. JUDD ROAD	5213 GRANT AVE
TAYLOR, MI 48180	BURTON, MI 48529	CLEVELAND, OH 44105
NEW PH# (734) 947-4000	PH# (810) 744-4540	PH# (216) 641-4100
NEW FAX# (734) 947-4004	FAX# (810) 744-1588	FAX# (216) 641-1814

Figure A-25. ⅝-in. (16-mm) Dia., 14.4-ft (4,389-mm) Long Cable and Swage Button Certificate of Compliance, Test Nos. MSPBN-1 through MSPBN-3

Certified Analysis

Trinity Highway Products , LLC
550 East Robb Ave.
Lima, OH 45801 Phn:(419) 227-1296
Customer: MIDWEST MACH.& SUPPLY CO.
P. O. BOX 703

MILFORD, NE 68405
Project: RESALE

Order Number: 1269489 Prod Ln Grp: 3-Guardrail (Dom)
Customer PO: 3346
BOL Number: 97457 Ship Date:
Document #: 1
Shipped To: NE
Use State: NE

As of: 11/7/16

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
175	3580G	5/8"X18" GR BOLT A307	HW			29145-B													
6	6696G	CBL 5/8"X14'4.75/DBL BTN	HW			248853													
400	6740B	PLYMR BLK 6X12X14 MT	HW			27950													
4	9852A	STRUT & YOKE ASSY	A-36			195070	52,940	69,970	31.1	0.190	0.520	0.014	0.004	0.020	0.110	0.000	0.050	0.000	4
7	12379G	T12/12'6/SPEC/S 34'RCX	RHC		2	L34713													4
			M-180	A	2	172876	55,930	72,020	31.4	0.190	0.720	0.014	0.002	0.020	0.130	0.000	0.080	0.000	4
			M-180	A	2	172876	55,930	72,020	31.4	0.190	0.720	0.014	0.002	0.020	0.130	0.000	0.080	0.000	4
6	12383G	T12/12'6/6'3/SPEC SLOTS/S	RHC			L33814													4
			M-180	A		182997	58,340	76,890	26.9	0.180	0.730	0.014	0.004	0.010	0.130	0.000	0.060	0.001	4
			M-180	A		182998	60,310	78,910	25.4	0.200	0.730	0.012	0.006	0.010	0.140	0.000	0.050	0.001	4
			M-180	A		182997	58,340	76,890	26.9	0.180	0.730	0.014	0.004	0.010	0.130	0.000	0.060	0.001	4
			M-180	A		182998	60,310	78,910	25.4	0.200	0.730	0.012	0.006	0.010	0.140	0.000	0.050	0.001	4
3	12385G	T12/12'6/SPEC/S 5'RCX			2	L34416													
			M-180	A	2	208318	64,140	81,540	24.5	0.190	0.720	0.011	0.003	0.020	0.110	0.000	0.060	0.000	4
24	19361G	BNT PL 3/16X12-5/8X5-1/2	A-36			B4M5475	46,800	70,400	29.1	0.180	0.840	0.007	0.008	0.060	0.170	0.000	0.070	0.001	4

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

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

Figure A-26. 12⅝-in. x $5^{13}/_{16}$-in. x $^{3}/_{16}$-in. (321-mm x 148-mm x 5-mm) Nose Cable Anchor Plate Material Specification, Test Nos. MSPBN-1 through MSPBN-3

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 08/02/2016
TIME 10:25:48
USER WILLIAMR

SOLD TO: 66031-1127

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

R#17-393 U-Bolt Galvanized Plate Washers for Bullnose SMT

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40267215-0010	801148120TM	11GA 48 X 120 A1011-CS-TYB TEMP HS	25	5,000			08/02/2016

Chemical Analysis

Heat No. B609769 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA
Batch 0004412124 25 EA 5,000 LB

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.0700	0.3500	0.0110	0.0030	0.0200	0.0300	0.0600	0.0100	0.0001	0.0900	0.0260	0.0000	0.0020	0.0010	0.0036	0.0050

Mechanical/ Physical Properties

Mill Coil No. 16B647053

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen

Chemical Analysis

Heat No. B609769 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA
Batch 0004412121 50 EA 10,000 LB

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.0700	0.3500	0.0110	0.0030	0.0200	0.0300	0.0600	0.0100	0.0001	0.0900	0.0260	0.0000	0.0020	0.0010	0.0036	0.0050

Mechanical/ Physical Properties

Mill Coil No. 16B647053

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen

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

Figure A-27. 2¼-in. x ¾-in. (57-mm x 19-mm), 11-gauge, U-Bolt Plate Washer Material Specification, Test Nos. MSPBN-1 through MSPBN-3

Chicago Hardware & Fixture Company

9100 Parklane Avenue
Franklin Park, Illinois 60131
(847) 455-6609
Fax (847) 455-0012
www.chicagohardware.com

American Owned
American Made
American Quality

DROP FORGED PRODUCTS
Turnbuckles
Shackles
Wire Rope Clips
(also malleable)
Machinery Eye Bolts
Eye Bolts
regular & shoulder
Eye Nuts
Rod Ends
blank & machined
Ring Bolts
Hooks
Swivels
Pad Eyes
Yoke Ends

WIRE PRODUCTS
"S" Hooks
U-Bolts (galv. & zinc)
rd., sq. & long tangent
Turned Eye Bolts (threaded)
lag, mach. or welded
Threaded Rod

OTHER PRODUCTS
Alloy Steel Hoist Rings
Wire Rope Thimbles
Bevel Washers
Clevis Pins
Coupling Nuts
Plated Steel Shapes
Brass
rounds, flats & angles

STAINLESS & METRIC
(check availability)
Eye Bolts & Eye Nuts
U-Bolts
"S" Hooks
Wire Rope Clips
Blank Rod Ends
Threaded Rods

SPECIAL PRODUCTS
Manufactured to Specifications

WAREHOUSE LOCATIONS:
Chino, CA (909) 591-1099
Monroe, GA (770) 266-5600
Houston, TX (713) 664-7722

JANUARY 4, 2017

THE STRUCTURAL BOLT CO.
2140 CORNHUSKER HWY.
LINCOLN, NE 68521

R#17-250 H#71067E Bullnose U-Bolts (Different Nuts Used)

C E R T I F I C A T I O N

THIS IS TO CERTIFY THAT OUR PART NO. 536264, STOCK #6HG, THE ¼ X 1-1/4 X 2-1/4" GALVANIZED U-BOLTS AND PLATES FURNISHED AGAINST YOUR PURCHASE ORDER NO. 19624 HAVE BEEN MADE IN THE U.S.A. FROM DOMESTIC ASTM-307, C-1010 STEEL AND ARE HOT DIP GALVANIZED TO ASTM-153 SPECIFICATIONS.

U-BOLT: HEAT # 71067E C .11 Mn .42 P .004 S .013

PLATE: HEAT#2507326 C .08 Mn .34 P .009 S .003

CHICAGO HARDWARE & FIXTURE CO.

MICHAEL ZERBE

Figure A-28. ¼-in. (6-mm) U-Bolt Certificate of Compliance, Test Nos. MSPBN-1 through MSPBN-3

R#17-297 Bullnose U-Bolt NUts
December 2016 SMT

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

FACTORY: IFI & Morgan Ltd. Haiyan Office
ADDRESS: Haiyan, Zhejiang, China

REPORT DATE:05 JULY,2016

CUSTOMER:

MFG LOT NUMBER: GL16187-1

SAMPLE SIZE: ACC. TO ASME B18.18-11;ASTM F1470-12
SIZE: 1/4-20 HDG QTY: 75000 PCS

PO NUMBER:220022071

PART NO: 1136701

STEEL PROPERTIES
STEEL GRADE: Q195

HEAT NUMBER: 184259

	C %*100	Mn%*100	P %*1000	S %*1000
CHEMISTRY SPEC: ASTM A563 GRADE A	0.55max	min	0.12max	0.15max
TEST:	0.08	0. 34	0.022	0.022

DIMENSIONAL INSPECTIONS — SPECIFICATION: ASME-B18.2.2-2010

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
**********************	*****************	******************	******************	********	********
APPEARANCE	ASTM F812-2013		PASSED	29	0
THREAD	ASME B1.3-2003 2B		PASSED	15	0
WIDTH A/F	0.438-0.428		0.432-0.430	5	0
WIDTH A/C	0.505-0.488		0.499-0.495	3	0
HEIGHT	0.226-0.212		0.219-0.217	4	0

MECHANICAL PROPERTIES: 1/4" to 1 1/2" — SPECIFICATION: ASTM A563-07a GR-A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	******************	*****************	*****************	********	********
HARDNESS :	ASTM F606-2014	B68-C32 Max(107HRB)	C25-27	15	0
PROOF LOAD :	ASTM F606-2014	Min 68 Ksi	72 Ksi	5	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	****************	******************	*****************	********	********
HOT DIP GALVANIZED	ASTM F2329-05	MIN 2.10miu	2.50miu	4	0

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

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

Figure A-29. ¼-in. (6-mm) Hex Nut Material Specification, Test Nos. MSPBN-1 through MSPBN-3

Certified Test Report

NORTH STAR BLUESCOPE STEEL LLC
6767 County Road 9
Delta, Ohio 43515
Telephone: (888) 822-2112

Customer: The Universal Steel Company

6600 Grant Avenue	Order #	337280	Ord Width (mm/in) 1435.100 / 56.500		Weight (kg/lb) 20955 / 46196
Cleveland, OH 44105	Line Item #	1	Ord Gauge (mm/in) 3.175 / 0.125		
Customer P.O.: 1-64906	Heat #	195070	Material Description ASTM A1011-12 SS Grade 36 Type 2		
Cust. Ref/Part #	Coil #	1546077	Production Date/Time Sep 13 2015 10:41AM		

Heat Chemical Analysis (wt%)

Type	C	Mn	P	S	Si	Al	Cu	Cr	Ni	Mo	Sn	N	B	V	Nb	Ti	Ca	Pb
Heat	0.19	0.52	0.014	0.004	0.02	0.03	0.11	0.05	0.07	0.01	0.00	0.007	0.0001	0.000	0.000	0.000	0.001	0.000

Mechanical Test Report

	Yield Strength	Tensile Strength	% Elongation in 2 inches
Tail	52,940 psi	69,870 psi	31.1%

This hot rolled steel has been produced to conform to DIN/EN 10204:2005 3.1 and has been manufactured to a fully killed fine grain practice. This hot rolled steel has been produced and tested in accordance with each of the following applicable standards: ASTM E 1806-96, ASTM E 415-99a, ASTM A 751-01, ASTM A 370-03a, JIS Z 2201:1998, JIS Z 2241:1998. Pressure Equipment Directive (PED) 97/23/EC 7/2, Annex I, Paragraph 4.3 Compliant. This report certifies that the above test results are representative of those contained in the records of North Star BlueScope Steel LLC for the material identified in this test report and is intended to comply with the requirements of the material description. North Star BlueScope Steel LLC is not responsible for the inability of this material to meet specific applications. Any modifications to this certification as provided negates the validity of this test report. All reproductions must have the written approval of North Star BlueScope Steel. This product was manufactured, melted, cast, and hot-rolled (min. 3:1 reduction ratio), entirely within the U.S.A at North Star BlueScope Steel LLC, Delta, Ohio. This material was not exposed to Mercury or any alloy which is liquid at ambient temperature during processing or while in North Star BlueScope Steel LLC possession. Test equipment calibration certificates are available upon request. NIST traceability is established through test equipment calibration certificates which are available upon request. Uncertainty calculations are calculated in accordance with NIST standards and are maintained at ≥ 4:1 ratio in accordance with NIST standards. Uncertainty data is available upon request.

Tim Mitchell — Manager Quality Assurance and Technology

Date Issued: Sep 15, 2015 12:30:47
Revision#: 01

Page: 002

Figure A-30. Ground Strut Assembly Material Specification, Test Nos. MSPBN-1 through MSPBN-3

NUCOR
NUCOR STEEL JACKSON, INC.

Mill Certification
7/27/2016

MTR #: M1-150903
NUCOR STEEL JACKSON, INC.
3630 Fourth Street
Flowood, MS 39232
(601) 939-1623
Fax: (601) 936-6202

Sold To: O'NEAL STEEL INC
ATTN ACCOUNTS PAYABLE
PO BOX 98
BIRMINGHAM, AL 35202-0098
(205) 599-8000
Fax: (205) 599-8052

Ship To: O'NEAL STEEL INC
4530 MESSER-AIRPORT HWY
BIRMINGHAM, AL 35222
(205) 599-8000
Fax: (205) 599-8052

Customer P.O.	00771356	Sales Order	343125.5
Product Group	Merchant Bar Quality	Part Number	5350030024010W0
Grade	NUCOR MULTIGRADE	Lot #	JK1610148801
Size	1/2x3" Flat	Heat #	JK16101488
Product	1/2x3" Flat 20' NUCOR MULTIGRADE	B.L. Number	M1-429898
Description	NUCOR MULTIGRADE	Load Number	M1-150903
Customer Spec		Customer Part #	00777557

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.

Roll Date: 4/5/2016 Melt Date: 3/30/2016 Qty Shipped LBS: 4,900 Qty Shipped Pcs: 48

Melt Date: 3/30/2016

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Cb	Sn
0.16%	0.78%	0.017%	0.028%	0.20%	0.28%	0.09%	0.14%	0.020%	0.0280%	0.001%	0.010%
CE4020	CEA529										
0.35%	0.39%										

CE4020: C. E. CSA G4020, AASHTO M270
CEA529: A529 CARBON EQUIVALENT

Roll Date: 4/5/2016

Yield 1: 56,172psi	Tensile 1: 75,460psi	Elongation: 25% in 8"(% in 203.3mm)
Yield 2: 56,126psi	Tensile 2: 76,500psi	Elongation 25% in 8"(% in 203.3mm)

Specification Comments: NUCOR MULTIGRADE MEETS THE REQUIREMENTS OF: ASTM A36/36M, ASTM A529/529M GR50 ASTM A572/572M GR50 ASTM709/709M GR36/GR50 CSA G40.21 GR44W(300W)/GR50W(350W) AASHTO M270/M270M GR36/GR50 ASME SA36/SA36M MEETS EN10204 SEC 3.1 REPORTING REQUIREMENTS

ALL MANUFACTURING PROCESSES OF THE STEEL MATERIALS IN THIS PRODUCT, INCLUDING MELTING, HAVE OCCURRED WITHIN THE UNITED STATES. ALL PRODUCTS PRODUCED ARE WELD FREE. MERCURY, IN ANY FORM, HAS NOT BEEN USED IN THE PRODUCTION OR TESTING OF THIS MATERIAL.

QA Approved
SI# 777557

Christopher Smith
Christopher Smith
Division Metallurgist

NBMG-10 January 1, 2012

Page 1 of 1

Figure A-31. Anchor Bracket Assembly Material Specification, Test Nos. MSPBN-1 through MSPBN-3

Appendix B. Vehicle Center of Gravity Determination

Date: 3/3/2017 **Test Name:** MSPBN-1 **VIN:** 1D7RB1GP9AS171061
Year: 2010 **Make:** Dodge **Model:** RAM 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)	Vertical CG (in.)	Vertical M (lb.-in.)
+	Unballasted Truck (Curb)	5108	28 3/8	144939.5
+	Hub	19	14 3/4	280.25
+	Brake activation cylinder & frame	7	29 1/2	206.5
+	Pneumatic tank (Nitrogen)	27	28	756
+	Strobe/Brake Battery	5	26 1/2	132.5
+	Brake Receiver/Wires	5	52 1/2	262.5
+	CG Plate including DAS	42	30 1/4	1270.5
-	Battery	-44	42	-1848
-	Oil	-14	27	-378
-	Interior	-101	28	-2828
-	Fuel	-197	17	-3349
-	Coolant	-11	35	-385
-	Washer fluid	-7	36	-252
+	Water Ballast (In Fuel Tank)	131	17	2227
+	Onboard Supplemental Battery	14	26 1/2	371
				0
Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle				141405.75

Estimated Total Weight (lb.) 4984
Vertical CG Location (in.) 28.3719

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140 1/4 in.
Front Track Width: 67 in.
Rear Track Width: 67 3/4 in.

Center of Gravity	**2270P MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb.)	5000 ± 110	5001	1.0
Longitudinal CG (in.)	63 ± 4	60.575885	-2.42412
Lateral CG (in.)	NA	-0.343544	NA
Vertical CG (in.)	28 or greater	28.37	0.37194

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	1501	1410
Rear	1100	1097

FRONT 2911 lb.
REAR 2197 lb.
TOTAL 5108 lb.

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1442	1399
Rear	1084	1076

FRONT 2841 lb.
REAR 2160 lb.
TOTAL 5001 lb.

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

Date:	3/22/2017	Test Name:	MSPBN-2	VIN:	KNADH4A34A6680510
Year:	2010	Make:	Kia	Model:	Rio

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)
+	Unbalasted Car (Curb)	2476
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	27
+	Strobe/Brake Battery	6
+	Brake Reciever/Wires	6
+	CG Plate including DAS	13
-	Battery	-37
-	Oil	-9
-	Interior	-61
-	Fuel	-17
-	Coolant	-8
-	Washer fluid	-1
+	Water Ballast (In Fuel Tank)	
+	Onboard Battery	14

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

Estimated Total Weight (lb.) 2435

Vehicle Dimensions for C.G. Calculations

Roof Height:	58 1/8	in.	Front Track Width:	57 3/4	in.
Wheel Base:	98 1/2	in.	Rear Track Width:	57 3/8	in.

Center of Gravity	1100C MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb.)	2420 ± 55	2448	28
Longitudinal CG (in.)	39 ± 4	36.33395	-2.6660539
Lateral CG (in.)	NA	0.329197	NA
Vertical CG (in.)	NA	22.91742	NA

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	812	765
Rear	445	454

FRONT	1577	lb.
REAR	899	lb.
TOTAL	2476	lb.

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	766	779
Rear	444	459

FRONT	1545	lb.
REAR	903	lb.
TOTAL	2448	lb.

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

Date:	**4/11/2017**	**Test Name:**	**MSPBN-3**	**VIN:**	**KMHCN4AC5BU612118**
Year:	**2011**	**Make:**	**Hyundai**	**Model:**	**Accent**

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)
+	Unbalasted Car (Curb)	2464
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	27
+	Strobe/Brake Battery	5
+	Brake Reciever/Wires	5
+	CG Plate including DAS	13
-	Battery	-28
-	Oil	-7
-	Interior	-60
-	Fuel	-12
-	Coolant	-8
-	Washer fluid	-6
+	Water Ballast (In Fuel Tank)	0
+	Onboard Battery	12

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

Estimated Total Weight (lb.) 2431

Vehicle Dimensions for C.G. Calculations

Roof Height:	57 1/4	in.	Front Track Width:	57 3/4	in.
Wheel Base:	98 1/2	in.	Rear Track Width:	57 3/8	in.

Center of Gravity	**1100C MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb.)	2420 ± 55	2441	21
Longitudinal CG (in.)	39 ± 4	36.84166	-2.1583367
Lateral CG (in.)	NA	-0.74282	NA
Vertical CG (in.)	NA	22.70178	NA

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	814	752
Rear	433	465

FRONT	1566	lb.
REAR	898	lb.
TOTAL	2464	lb.

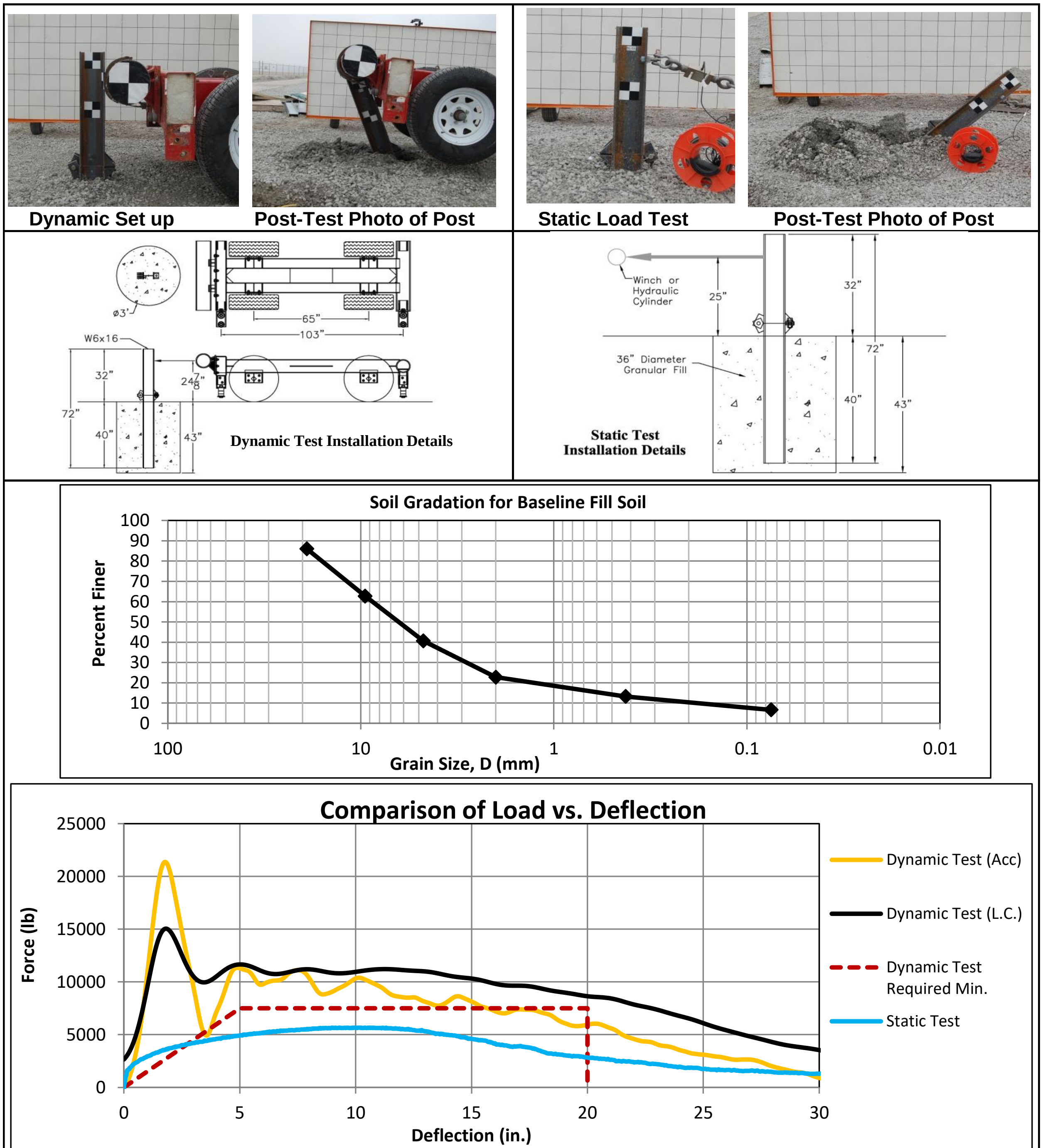
TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	784	744
Rear	468	445

FRONT	1528	lb.
REAR	913	lb.
TOTAL	2441	lb.

Figure B-3. Vehicle Mass Distribution, Test No. MSPBN-3

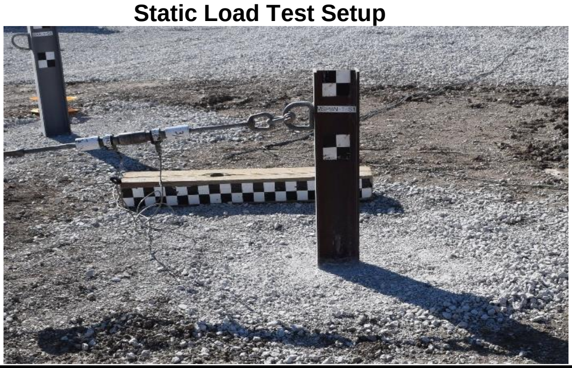
Appendix C. Static Soil Tests



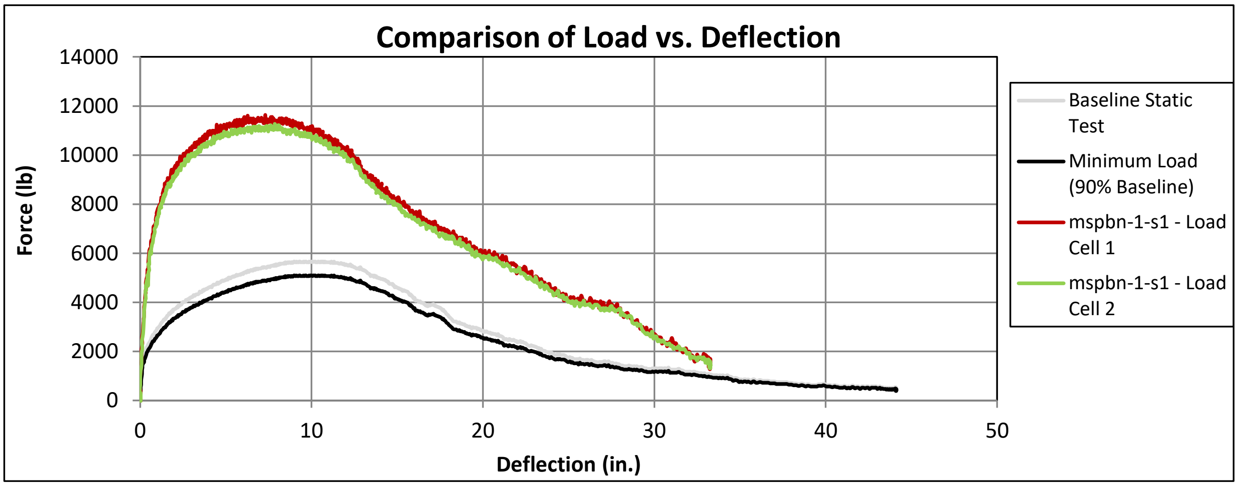
Date	5/17/2013
Test Facility & Site Location	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure	H.E.-8
Bogie Weight	1857 lb 842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

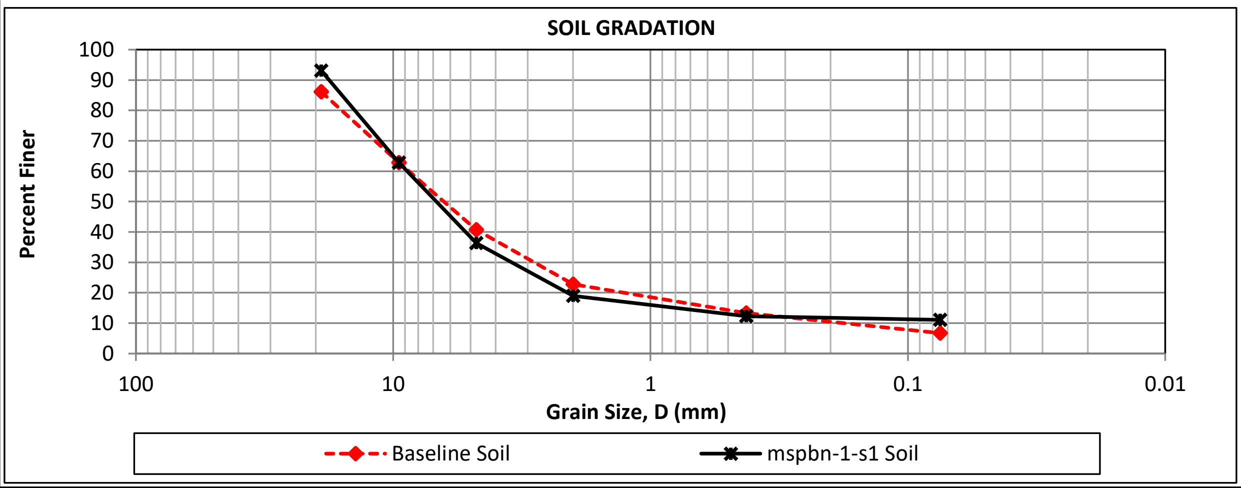
Figure C-1. Soil Strength, Initial Calibration, Test No. MSPBN-1

Static Load Test Setup



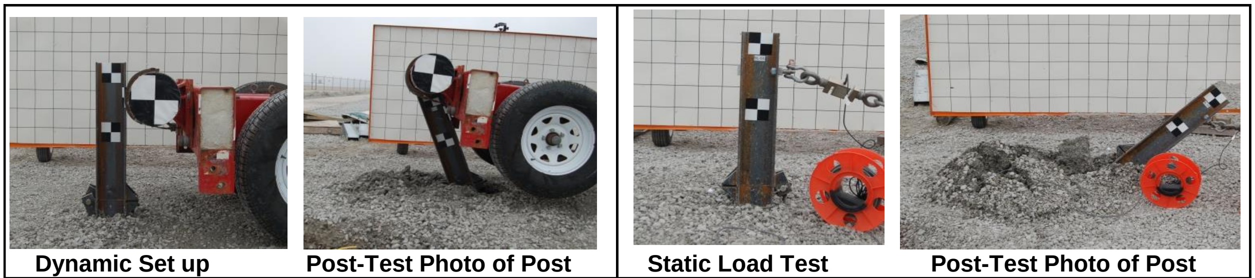
Post-Test Photo of Post

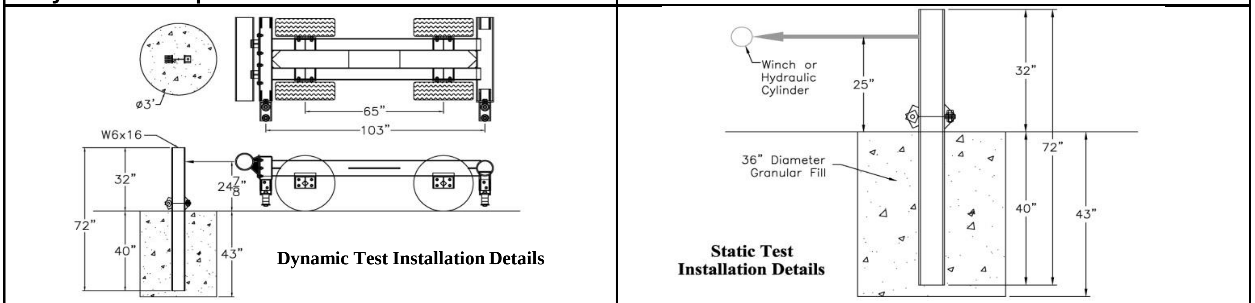


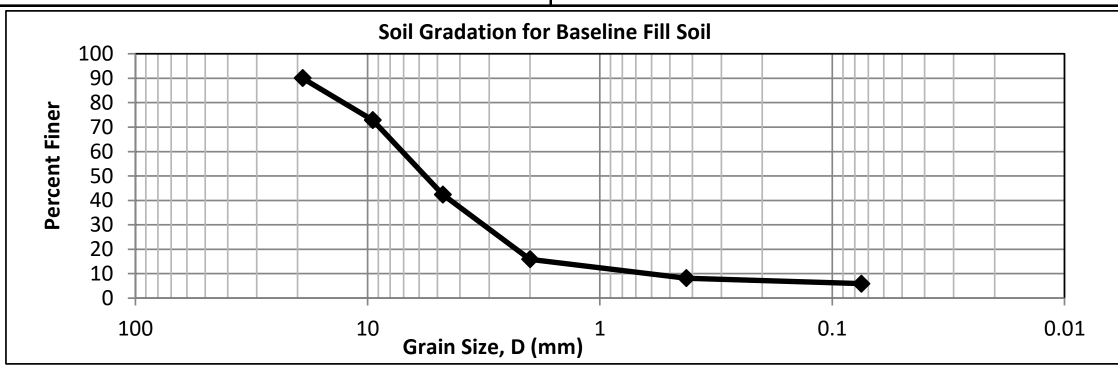


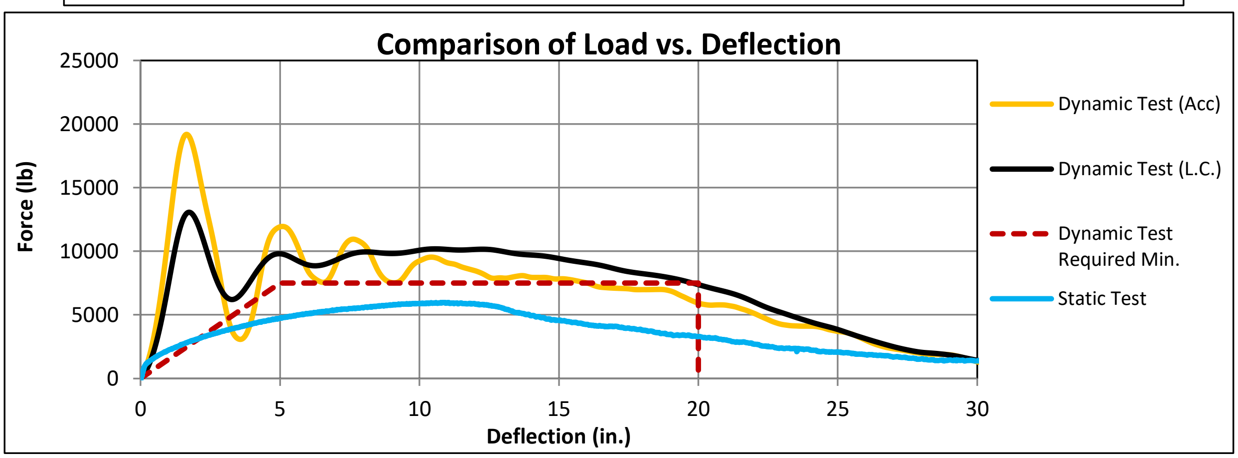
Date……………………………………………	11/17/2017
Test Facility & Site Location……………………	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)…………	Low Plasticity Silt (ML)
Fill material description (ASTM D2487)………	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure………	8-inch lifts tamped with a pneumatic compactor

Figure C-2. Static Soil Test, Test No. MSPBN-1





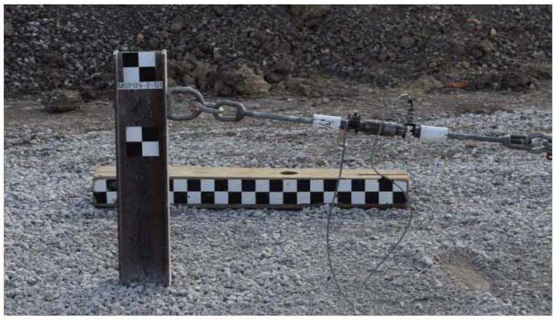




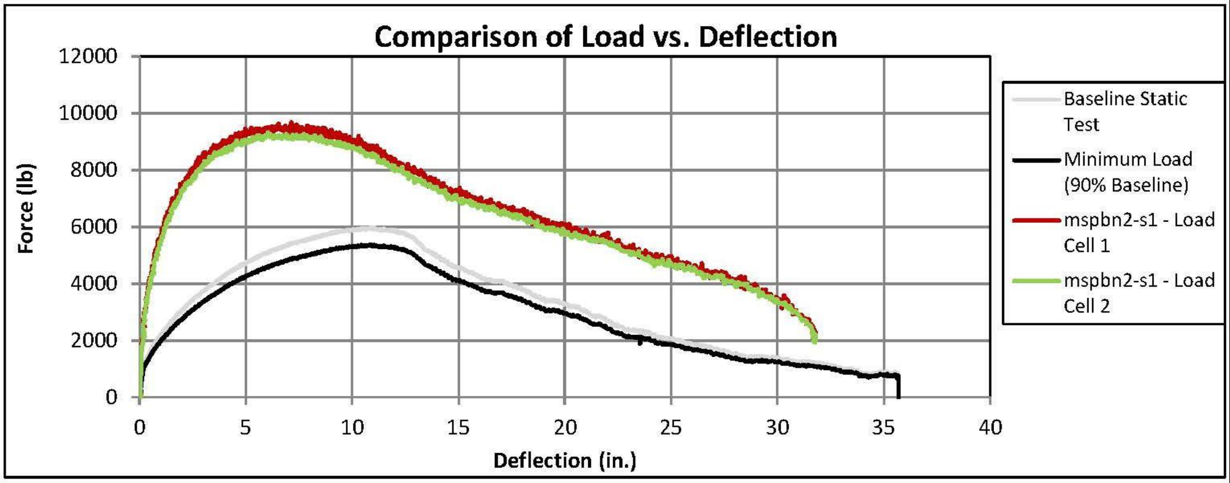
Date...	3/20/2012			
Test Facility & Site Location........................	Midwest Roadside Safety Facility			
In situ soil description (ASTM D2487)............	Well-Graded Gravel (GW)			
Fill material description (ASTM D2487).........	Well-Graded Gravel (GW) (see sieve analyses above)			
Description of fill placement procedure.........	8" lift 3-4 passes			
Bogie Weight...	1843	lb	836	kg
Impact Velocity...	20.0	mph	32.2	km/h

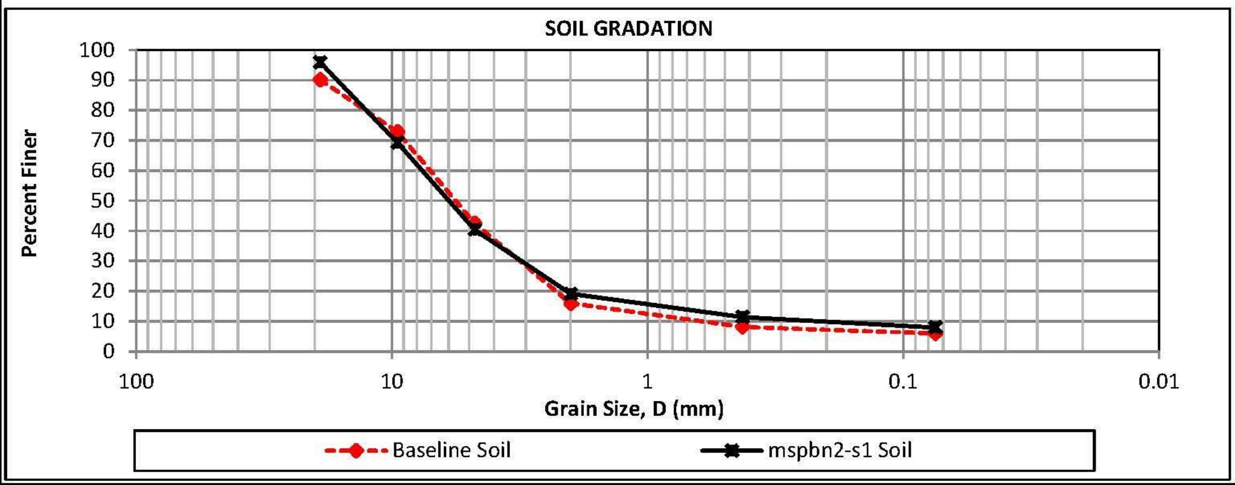
Figure C-3. Soil Strength, Initial Calibration, Test No. MSPBN-2

Static Load Test Setup



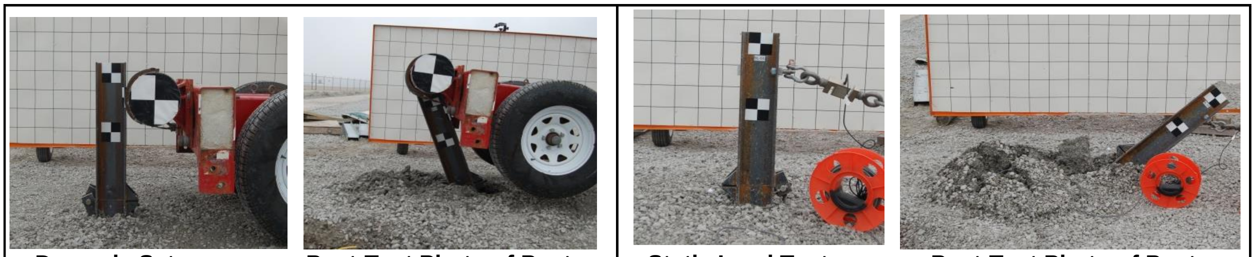
Post-Test Photo of Post

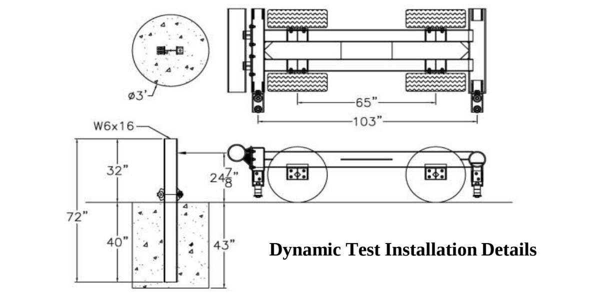


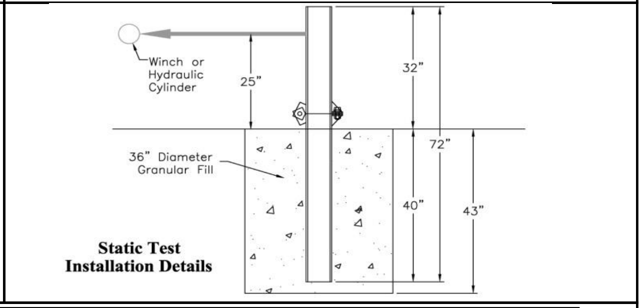


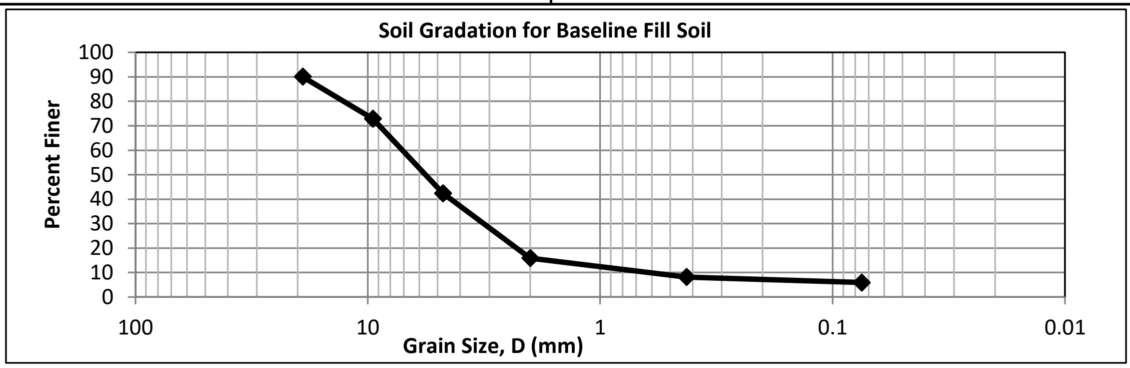
Date..	11/17/2017
Test Facility & Site Location.......................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)..........	Low Plasticity Silt (ML)
Fill material description (ASTM D2487).........	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure........	8-inch lifts tamped with a pneumatic compactor

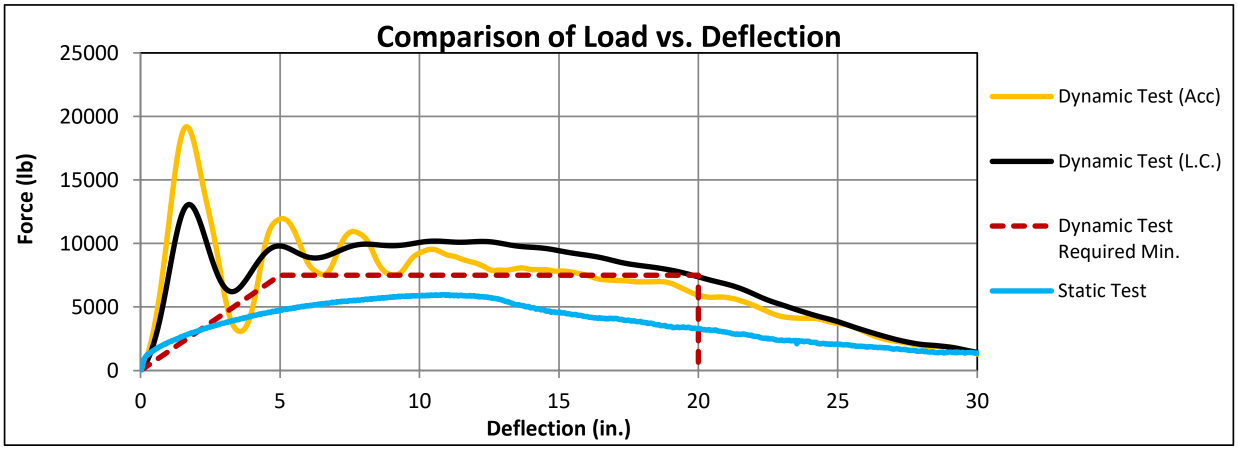
Figure C-4. Static Soil Test, Test No. MSPBN-2









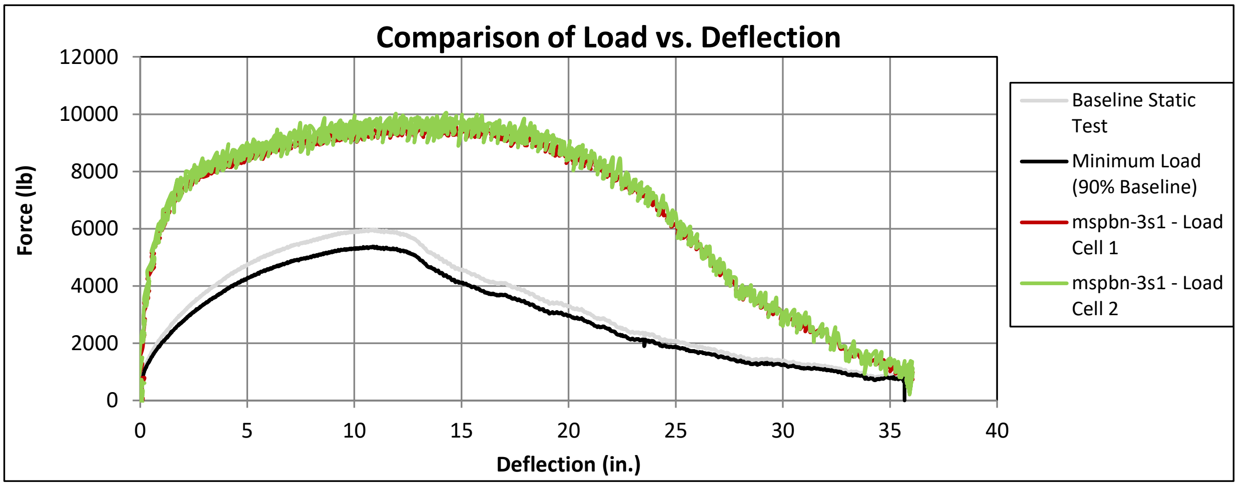


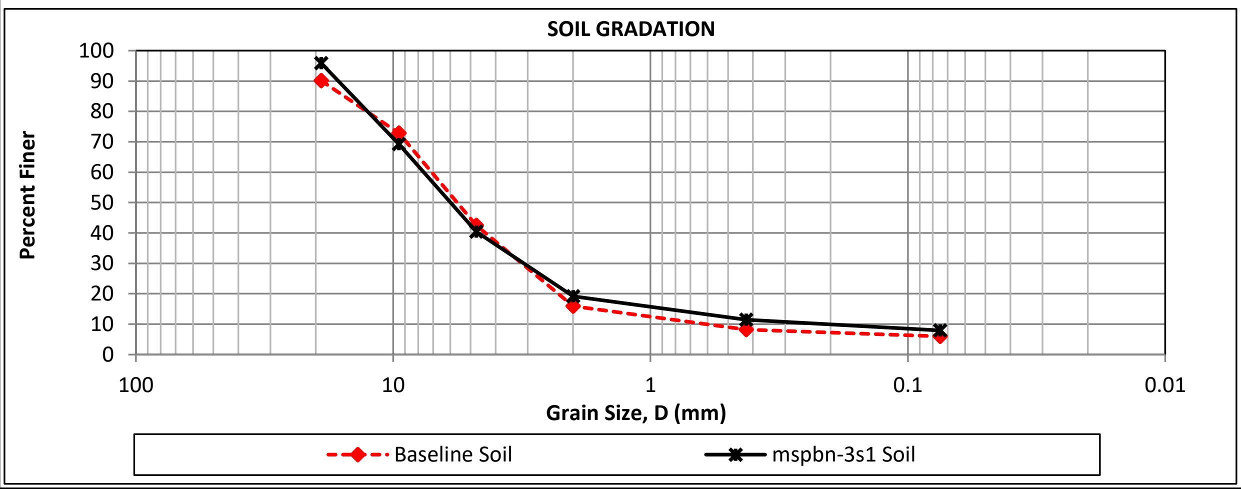
Date..	3/20/2012			
Test Facility & Site Location........................	Midwest Roadside Safety Facility			
In situ soil description (ASTM D2487)...........	Well-Graded Gravel (GW)			
Fill material description (ASTM D2487).........	Well-Graded Gravel (GW) (see sieve analyses above)			
Description of fill placement procedure........	8" lift 3-4 passes			
Bogie Weight..	1843	lb	836	kg
Impact Velocity...	20.0	mph	32.2	km/h

Figure C-5. Soil Strength, Initial Calibration, Test No. MSPBN-3

Static Load Test Setup

Post-Test Photo of Post





Date..	11/17/2017
Test Facility & Site Location........................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)...........	Low Plasticity Silt (ML)
Fill material description (ASTM D2487).........	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure........	8-inch lifts tamped with a pneumatic compactor

Figure C-6. Static Soil Test, Test No. MSPBN-3

Appendix D. Vehicle Deformation Records

Date: 3/3/2017 Test Name: MSPBN-1 VIN: 1D7RB1GP9AS171061
Year: 2010 Make: Dodge Model: Ram TRX

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	29.668	-27.443	5.069	29.434	-27.458	5.085	-0.234	-0.014	0.017	0.235
2	31.131	-23.291	2.835	30.909	-23.264	2.816	-0.223	0.027	-0.019	0.225
3	30.827	-16.467	0.542	30.602	-16.422	0.519	-0.225	0.045	-0.023	0.230
4	28.850	-12.103	0.644	28.598	-12.114	0.605	-0.252	-0.011	-0.040	0.255
5	28.418	-27.988	3.084	28.147	-27.993	3.002	-0.271	-0.005	-0.082	0.283
6	29.145	-23.803	0.548	28.881	-23.808	0.505	-0.264	-0.005	-0.043	0.268
7	27.854	-16.479	-0.970	27.649	-16.444	-0.968	-0.205	0.035	0.002	0.208
8	26.855	-11.947	-1.488	26.590	-11.964	-1.515	-0.265	-0.018	-0.027	0.267
9	26.887	-28.452	0.322	26.669	-28.426	0.318	-0.218	0.026	-0.005	0.219
10	26.383	-24.004	-0.652	26.152	-23.979	-0.679	-0.232	0.025	-0.027	0.235
11	25.998	-17.316	-1.845	25.770	-17.271	-1.869	-0.228	0.045	-0.024	0.234
12	25.680	-12.442	-2.595	25.410	-12.389	-2.646	-0.269	0.053	-0.051	0.279
13	24.219	-28.655	-1.162	23.969	-28.623	-1.189	-0.251	0.032	-0.027	0.254
14	23.816	-24.375	-1.856	23.624	-24.327	-1.853	-0.191	0.048	0.003	0.197
15	23.630	-17.532	-2.770	23.421	-17.483	-2.779	-0.209	0.049	-0.009	0.215
16	23.350	-13.068	-3.447	23.132	-13.077	-3.458	-0.218	-0.009	-0.010	0.218
17	20.673	-28.065	-2.918	20.413	-28.049	-2.943	-0.260	0.016	-0.026	0.262
18	20.601	-24.029	-3.400	20.322	-24.074	-3.420	-0.279	-0.045	-0.020	0.284
19	20.338	-18.424	-4.178	20.159	-18.506	-4.168	-0.179	-0.081	0.010	0.197
20	20.230	-12.966	-4.910	20.002	-12.969	-4.924	-0.227	-0.003	-0.014	0.228
21	14.225	-28.568	-3.066	13.995	-28.593	-3.089	-0.231	-0.024	-0.023	0.233
22	14.107	-24.262	-3.588	13.921	-24.240	-3.615	-0.186	0.022	-0.027	0.189
23	13.823	-18.401	-4.210	13.592	-18.436	-4.222	-0.231	-0.035	-0.012	0.234
24	13.174	-13.473	-5.056	12.972	-13.496	-5.071	-0.203	-0.024	-0.014	0.205
25	0.888	-26.421	0.868	0.667	-26.410	0.847	-0.220	0.011	-0.021	0.222
26	0.717	-21.395	0.201	0.525	-21.414	0.189	-0.192	-0.020	-0.011	0.193
27	0.570	-16.956	-0.409	0.389	-16.943	-0.419	-0.181	0.012	-0.010	0.182
28	0.436	-11.988	-1.096	0.227	-11.938	-1.110	-0.210	0.050	-0.014	0.216

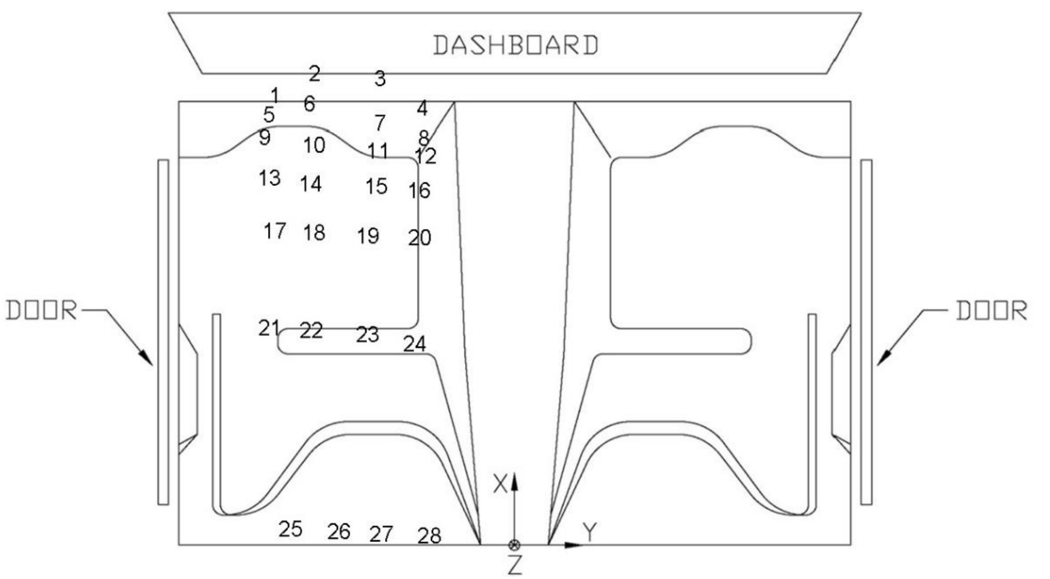


Figure D-1. Floor Pan Deformation Data – Set 1, Test No. MSPBN-1

Date: 3/3/2017 Test Name: MSPBN-1 VIN: 1D7RB1GP9AS171061
Year: 2010 Make: Dodge Model: Ram TRX

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	51.813	-28.810	4.592	52.067	-28.797	4.582	0.254	0.013	-0.011	0.254
2	53.474	-24.504	2.736	53.742	-24.498	2.758	0.268	0.006	0.022	0.269
3	53.531	-17.548	1.145	53.714	-17.435	1.072	0.183	0.113	-0.073	0.227
4	51.675	-13.116	1.581	51.865	-13.085	1.523	0.190	0.031	-0.057	0.201
5	50.584	-29.126	2.522	50.842	-29.112	2.538	0.258	0.015	0.016	0.259
6	51.517	-24.782	0.421	51.796	-24.734	0.405	0.278	0.049	-0.015	0.283
7	50.564	-17.294	-0.439	50.727	-17.169	-0.449	0.163	0.125	-0.010	0.206
8	49.684	-12.761	-0.616	49.877	-12.619	-0.684	0.194	0.143	-0.069	0.250
9	49.133	-29.314	-0.241	49.370	-29.298	-0.274	0.237	0.016	-0.033	0.240
10	48.803	-24.741	-0.835	49.043	-24.703	-0.870	0.239	0.038	-0.034	0.245
11	48.652	-18.016	-1.453	48.937	-17.931	-1.453	0.285	0.085	0.000	0.298
12	48.509	-13.063	-1.778	48.849	-12.968	-1.752	0.340	0.095	0.026	0.354
13	46.447	-29.299	-1.811	46.728	-29.236	-1.826	0.281	0.062	-0.014	0.288
14	46.258	-24.915	-2.108	46.509	-24.899	-2.127	0.252	0.016	-0.020	0.253
15	46.415	-17.996	-2.374	46.608	-17.992	-2.420	0.193	0.005	-0.046	0.199
16	46.236	-13.548	-2.693	46.458	-13.462	-2.727	0.221	0.086	-0.035	0.240
17	43.017	-28.416	-3.552	43.193	-28.331	-3.604	0.176	0.085	-0.052	0.202
18	43.098	-24.337	-3.676	43.332	-24.279	-3.707	0.234	0.058	-0.031	0.243
19	43.103	-18.705	-3.944	43.319	-18.678	-3.967	0.217	0.026	-0.023	0.220
20	43.161	-13.172	-4.203	43.372	-13.083	-4.227	0.211	0.089	-0.024	0.231
21	36.543	-28.649	-3.871	36.799	-28.591	-3.916	0.256	0.058	-0.045	0.266
22	36.657	-24.291	-4.015	36.856	-24.266	-4.046	0.199	0.024	-0.031	0.202
23	36.572	-18.393	-4.118	36.792	-18.379	-4.139	0.219	0.014	-0.021	0.221
24	36.095	-13.377	-4.537	36.308	-13.338	-4.554	0.213	0.039	-0.017	0.217
25	23.259	-26.351	-0.022	23.503	-26.340	-0.066	0.244	0.011	-0.044	0.249
26	23.237	-21.247	-0.250	23.483	-21.210	-0.283	0.246	0.037	-0.033	0.251
27	23.263	-16.778	-0.464	23.497	-16.740	-0.488	0.234	0.038	-0.024	0.238
28	23.314	-11.739	-0.712	23.534	-11.708	-0.727	0.220	0.031	-0.015	0.222

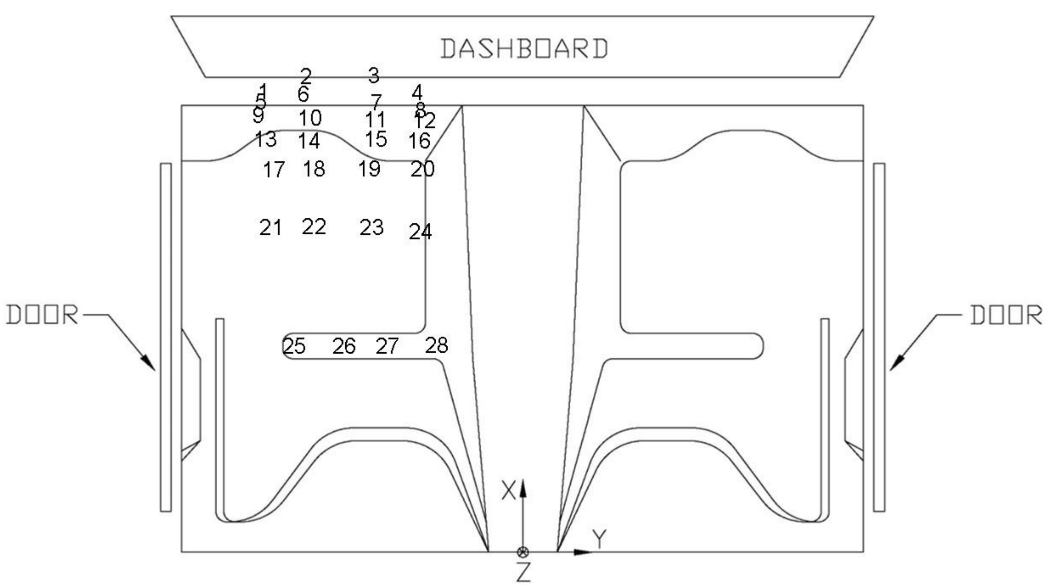


Figure D-2. Floor Pan Deformation Data – Set 2, Test No. MSPBN-1

Date: 3/3/2017 Test Name: MSPBN-1 VIN: 1D7RB1GP9AS171061
Year: 2010 Make: Dodge Model: Ram TRX

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	15.919	-26.428	27.763	15.744	-26.329	27.780	-0.175	0.099	0.016	0.202
	2	13.467	-13.770	29.816	13.312	-13.682	29.865	-0.155	0.088	0.049	0.185
	3	11.722	3.516	24.824	11.567	3.664	24.800	-0.155	0.149	-0.023	0.216
	4	12.846	-27.449	17.818	12.651	-27.296	17.934	-0.195	0.153	0.116	0.274
	5	10.657	-16.515	15.686	10.437	-16.279	15.756	-0.220	0.236	0.071	0.330
	6	8.857	1.566	13.614	8.668	1.710	13.646	-0.189	0.145	0.032	0.240
SIDE PANEL	7	21.835	-30.963	6.776	21.607	-30.760	6.801	-0.228	0.203	0.025	0.306
	8	24.755	-31.042	6.148	24.505	-30.919	6.175	-0.251	0.122	0.027	0.280
	9	23.290	-31.301	3.725	23.112	-31.184	3.735	-0.178	0.117	0.010	0.214
IMPACT SIDE DOOR	10	-13.061	-31.171	26.304	-13.437	-31.203	26.334	-0.376	-0.032	0.029	0.379
	11	-2.052	-30.745	25.850	-2.419	-30.646	25.915	-0.367	0.100	0.065	0.386
	12	12.155	-30.154	25.359	11.713	-29.922	25.347	-0.442	0.232	-0.013	0.499
	13	-13.329	-33.296	13.062	-13.734	-33.313	13.101	-0.405	-0.017	0.039	0.407
	14	-1.821	-33.489	12.941	-2.161	-33.310	12.947	-0.340	0.178	0.006	0.384
	15	12.544	-32.187	11.991	12.134	-31.807	11.970	-0.410	0.380	-0.021	0.559
ROOF	16	4.239	-20.148	43.675	4.107	-20.104	43.633	-0.133	0.044	-0.042	0.146
	17	6.479	-12.837	42.966	6.311	-12.769	42.923	-0.168	0.068	-0.043	0.186
	18	7.299	-7.330	42.442	7.176	-7.279	42.363	-0.124	0.051	-0.078	0.155
	19	7.970	-0.812	41.645	7.741	-0.759	41.606	-0.228	0.053	-0.038	0.238
	20	7.915	5.733	40.866	7.809	5.777	40.747	-0.106	0.044	-0.119	0.165
	21	-1.365	-17.865	46.361	-1.559	-17.815	46.336	-0.194	0.050	-0.025	0.202
	22	-0.457	-12.161	45.977	-0.650	-12.063	45.939	-0.194	0.098	-0.038	0.220
	23	-0.143	-6.300	45.510	-0.267	-6.209	45.438	-0.124	0.091	-0.072	0.170
	24	0.385	-0.892	44.859	0.267	-0.791	44.768	-0.118	0.101	-0.091	0.180
	25	0.221	5.477	44.069	0.143	5.579	43.948	-0.078	0.103	-0.120	0.176
	26	-5.528	-16.995	46.963	-5.649	-16.889	46.923	-0.120	0.106	-0.039	0.165
	27	-5.295	-12.416	46.710	-5.455	-12.261	46.663	-0.160	0.155	-0.047	0.228
	28	-4.914	-5.103	46.132	-5.040	-5.000	46.059	-0.126	0.104	-0.072	0.179
	29	-3.482	-0.353	45.446	-3.705	-0.266	45.373	-0.223	0.088	-0.073	0.250
	30	-3.298	5.828	44.642	-3.421	5.915	44.537	-0.123	0.087	-0.106	0.184
A PILLAR	31	5.858	-22.076	41.945	5.641	-22.017	41.893	-0.217	0.059	-0.052	0.231
	32	11.717	-23.636	38.908	11.569	-23.595	38.880	-0.148	0.041	-0.028	0.156
	33	15.331	-24.634	36.519	15.183	-24.591	36.461	-0.149	0.043	-0.058	0.165
	34	18.863	-25.643	33.704	18.769	-25.594	33.636	-0.094	0.050	-0.068	0.126
B PILLAR	35	-20.584	-31.995	9.918	-20.846	-31.967	10.016	-0.262	0.029	0.098	0.281
	36	-17.046	-31.852	10.055	-17.268	-31.851	9.988	-0.222	0.001	-0.068	0.232
	37	-21.529	-30.402	20.559	-21.773	-30.400	20.470	-0.244	0.003	-0.089	0.260
	38	-17.092	-30.195	20.976	-17.377	-30.186	21.018	-0.285	0.009	0.042	0.288
	39	-21.641	-28.123	31.826	-21.894	-28.125	31.734	-0.253	-0.002	-0.091	0.269
	40	-18.354	-27.906	32.024	-18.556	-27.875	32.046	-0.202	0.031	0.023	0.206

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

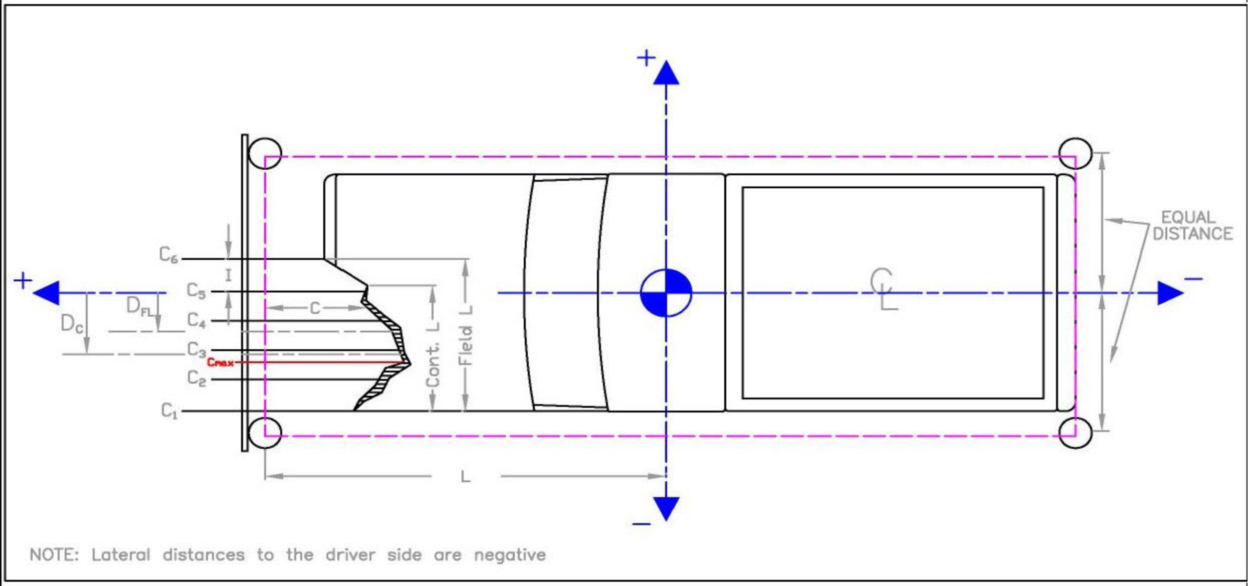
Date: 3/3/2017 Test Name: MSPBN-1 VIN: 1D7RB1GP9AS171061
Year: 2010 Make: Dodge Model: Ram TRX

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	37.637	-29.278	27.023	37.891	-29.221	27.036	0.255	0.056	0.013	0.261
	2	35.590	-16.796	30.200	35.870	-16.672	30.219	0.280	0.124	0.019	0.307
	3	34.535	0.927	26.701	34.819	1.009	26.666	0.284	0.082	-0.036	0.298
	4	34.743	-29.288	17.008	35.000	-29.176	17.007	0.257	0.112	0.000	0.281
	5	33.004	-18.129	15.797	33.282	-18.023	15.778	0.278	0.106	-0.019	0.298
	6	31.904	0.110	15.225	32.174	0.189	15.299	0.269	0.079	0.074	0.290
SIDE PANEL	7	43.861	-32.160	5.876	44.082	-31.974	5.905	0.221	0.186	0.029	0.290
	8	46.799	-32.291	5.290	47.022	-32.179	5.332	0.222	0.111	0.042	0.252
	9	45.392	-32.282	2.822	45.624	-32.171	2.844	0.231	0.111	0.022	0.257
IMPACT SIDE DOOR	10	8.600	-32.775	24.615	8.688	-32.852	24.531	0.088	-0.077	-0.084	0.144
	11	19.554	-32.706	24.484	19.607	-32.662	24.452	0.053	0.044	-0.032	0.076
	12	33.797	-32.618	24.234	33.797	-32.429	24.207	0.000	0.189	-0.027	0.190
	13	8.526	-33.712	11.278	8.624	-33.752	11.240	0.098	-0.039	-0.037	0.112
	14	19.991	-34.313	11.372	20.033	-34.167	11.275	0.042	0.146	-0.097	0.180
	15	34.427	-33.481	10.767	34.468	-33.115	10.731	0.041	0.366	-0.036	0.370
ROOF	16	25.874	-23.953	43.199	26.092	-23.974	43.204	0.218	-0.021	0.005	0.219
	17	28.349	-16.713	43.203	28.627	-16.766	43.163	0.278	-0.052	-0.040	0.286
	18	29.389	-11.246	43.177	29.637	-11.210	43.156	0.248	0.036	-0.021	0.252
	19	30.259	-4.712	43.010	30.569	-4.609	42.944	0.310	0.104	-0.066	0.334
	20	30.524	1.876	42.780	30.829	1.944	42.705	0.305	0.068	-0.075	0.322
	21	20.223	-21.764	45.999	20.522	-21.684	45.956	0.299	0.079	-0.042	0.312
	22	21.361	-16.075	46.140	21.656	-16.081	46.088	0.296	-0.005	-0.052	0.300
	23	21.861	-10.175	46.205	22.213	-10.154	46.142	0.352	0.021	-0.063	0.359
	24	22.592	-4.795	46.050	22.946	-4.719	45.981	0.354	0.076	-0.070	0.369
	25	22.728	1.653	45.814	23.071	1.734	45.738	0.343	0.082	-0.076	0.360
	26	16.040	-20.768	46.601	16.361	-20.712	46.554	0.322	0.056	-0.047	0.330
	27	16.473	-16.119	46.757	16.692	-16.124	46.715	0.218	-0.004	-0.042	0.222
	28	17.114	-8.868	46.836	17.418	-8.828	46.786	0.305	0.040	-0.050	0.311
	29	18.726	-4.082	46.609	18.983	-4.124	46.554	0.258	-0.042	-0.055	0.267
	30	19.487	2.725	46.286	19.540	2.101	46.282	0.053	-0.624	-0.004	0.626
A PILLAR	31	27.341	-25.779	41.337	27.639	-25.753	41.275	0.298	0.026	-0.062	0.306
	32	33.307	-27.313	38.301	33.587	-27.285	38.285	0.281	0.028	-0.016	0.283
	33	36.890	-28.221	35.903	37.234	-28.209	35.853	0.344	0.012	-0.050	0.348
	34	40.506	-29.125	33.066	40.770	-29.088	33.055	0.264	0.036	-0.012	0.267
B PILLAR	35	1.291	-31.875	8.104	1.562	-31.859	8.086	0.271	0.017	-0.017	0.272
	36	4.878	-31.879	8.284	5.109	-31.870	8.277	0.231	0.009	-0.008	0.231
	37	0.219	-31.195	18.745	0.465	-31.186	18.697	0.246	0.009	-0.049	0.251
	38	4.660	-31.191	19.287	4.864	-31.192	19.260	0.204	-0.001	-0.027	0.206
	39	-0.068	-29.904	30.249	0.208	-29.900	30.186	0.276	0.003	-0.063	0.283
	40	3.251	-29.838	30.484	3.492	-29.844	30.409	0.241	-0.006	-0.075	0.252

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

Date:	3/8/2017	Test Name:	MSPBN-1	VIN:	1D7RB1GP9AS171061
Year:	2010	Make:	Dodge	Model:	Ram TRX



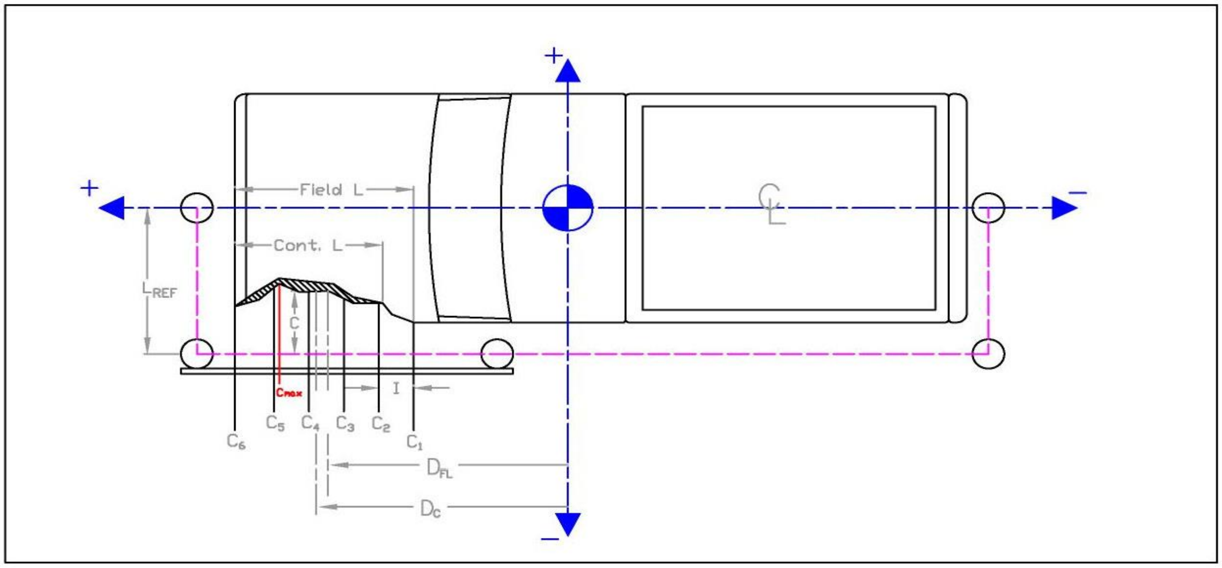
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	106 1/4	(2699)
Total Vehicle Width:	79 1/8	(2010)
Width of contact and induced crush - Field L:	32	(813)
Crush measurement spacing interval (L/5) - I:	6 3/8	(162)
Distance from center of vehicle to center of Field L - D_{FL}:	-20	-(508)
Width of Contact Damage:	21	(533)
Distance from center of vehicle to center of contact damage - D_C:	-25 1/2	-(648)

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	na	NA	-36	-(914)	15 1/8	(384)	1 4/9	(37)	NA	NA
C_2	na	NA	-29 5/8	-(752)	9 1/8	(232)			NA	NA
C_3	15	(381)	-23 1/4	-(591)	6 1/2	(165)			7	(179)
C_4	8 1/2	(216)	-16 7/8	-(429)	5 1/8	(130)			2	(49)
C_5	6	(152)	-10 1/2	-(267)	4 1/2	(114)			0	(2)
C_6	5 1/4	(133)	-4 1/8	-(105)	4	(102)			- 1/5	-(5)
C_{MAX}	27 1/2	(699)	-27 1/2	-(699)	7 3/4	(197)			18 1/3	(465)

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

Date:	3/8/2017	**Test Name:**	MSPBN-1	**VIN:**	1D7RB1GP9AS171061
Year:	2010	**Make:**	Dodge	**Model:**	Ram TRX



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	42	(1067)
Total Vehicle Length:	229 1/4	(5823)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-12 4/5	-(325)
Width of contact and induced crush - Field L:	229 1/4	(5823)
Crush measurement spacing interval (L/5) - I:	45 7/8	(1165)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-12 4/5	-(325)
Width of Contact Damage:	229 1/4	(5823)
Distance from vehicle c.g. to center of contact damage - D_C:	-12 4/5	-(325)

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	31	(787)	-127 1/2	-(3239)	33 1/2	(851)	-2	-(51)	- 1/2	-(13)
C_2	5	(127)	-81 5/8	-(2073)	5 1/4	(133)			1 3/4	(44)
C_3	2 1/2	(64)	-35 3/4	-(908)	5 5/8	(143)			-1 1/8	-(29)
C_4	2 1/2	(64)	10 1/8	(257)	5 1/8	(130)			- 5/8	-(16)
C_5	na	NA	56	(1422)	5	(127)			NA	NA
C_6	32 1/2	(826)	101 7/8	(2588)	33 1/2	(851)			1	(25)
C_{MAX}	16 3/4	(425)	70	(1778)	5	(127)			13 3/4	(349)

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

Date: 3/22/2017 | Test Name: MSPBN-2 | VIN: KNADH4A34A6680510
Year: 2010 | Make: Kia | Model: Rio

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	26.713	-22.041	1.815	26.849	-22.115	1.816	0.136	-0.074	0.001	0.155
2	29.140	-15.940	-1.232	29.416	-15.979	-1.215	0.277	-0.039	0.017	0.280
3	28.523	-9.065	-1.885	28.765	-9.043	-1.870	0.242	0.022	0.015	0.243
4	27.904	-5.806	-2.226	28.153	-5.862	-2.167	0.249	-0.056	0.060	0.262
5	25.273	-22.119	-1.745	25.447	-22.149	-1.818	0.174	-0.030	-0.072	0.191
6	25.553	-15.627	-3.057	25.782	-15.679	-3.067	0.229	-0.052	-0.010	0.235
7	25.426	-10.469	-3.386	25.640	-10.515	-3.392	0.214	-0.046	-0.006	0.219
8	25.054	-6.030	-3.670	25.263	-6.067	-3.687	0.209	-0.037	-0.017	0.213
9	18.830	-21.972	-4.674	19.017	-22.050	-4.727	0.187	-0.077	-0.053	0.209
10	17.917	-15.139	-4.666	18.126	-15.128	-4.729	0.209	0.011	-0.063	0.219
11	16.926	-9.904	-4.952	17.163	-9.884	-4.894	0.237	0.021	0.058	0.245
12	16.673	-6.138	-4.959	16.861	-6.103	-4.961	0.187	0.035	-0.002	0.190
13	15.985	-21.920	-5.011	16.119	-21.946	-5.068	0.134	-0.026	-0.057	0.148
14	15.016	-15.242	-4.490	15.238	-15.234	-4.553	0.223	0.008	-0.063	0.232
15	14.426	-10.317	-4.971	14.615	-10.285	-4.935	0.188	0.032	0.036	0.194
16	13.856	-6.342	-5.064	14.068	-6.331	-5.069	0.213	0.011	-0.005	0.213
17	12.100	-21.897	-5.047	12.333	-21.919	-5.100	0.233	-0.021	-0.053	0.240
18	12.002	-15.245	-4.281	12.210	-15.191	-4.327	0.208	0.054	-0.047	0.220
19	10.942	-10.453	-4.839	11.226	-10.433	-4.838	0.284	0.021	0.001	0.284
20	10.418	-6.226	-4.874	10.634	-6.202	-4.863	0.216	0.024	0.012	0.218
21	7.195	-21.692	-4.553	7.458	-21.634	-4.592	0.262	0.057	-0.039	0.271
22	7.397	-15.085	-4.009	7.635	-15.132	-4.035	0.237	-0.047	-0.027	0.243
23	6.555	-9.692	-4.540	6.828	-9.685	-4.595	0.273	0.007	-0.055	0.278
24	6.231	-6.458	-4.451	6.451	-6.506	-4.392	0.220	-0.048	0.059	0.233
25	-0.078	-21.472	0.198	0.147	-21.431	0.183	0.225	0.041	-0.016	0.229
26	-0.089	-14.616	-0.013	0.139	-14.597	-0.018	0.227	0.019	-0.006	0.228
27	-0.070	-9.674	-0.072	-1.748	-9.781	1.036	-1.678	-0.107	1.108	2.014
28	-0.019	-5.709	-0.058	0.165	-5.711	-0.062	0.184	-0.003	-0.004	0.184

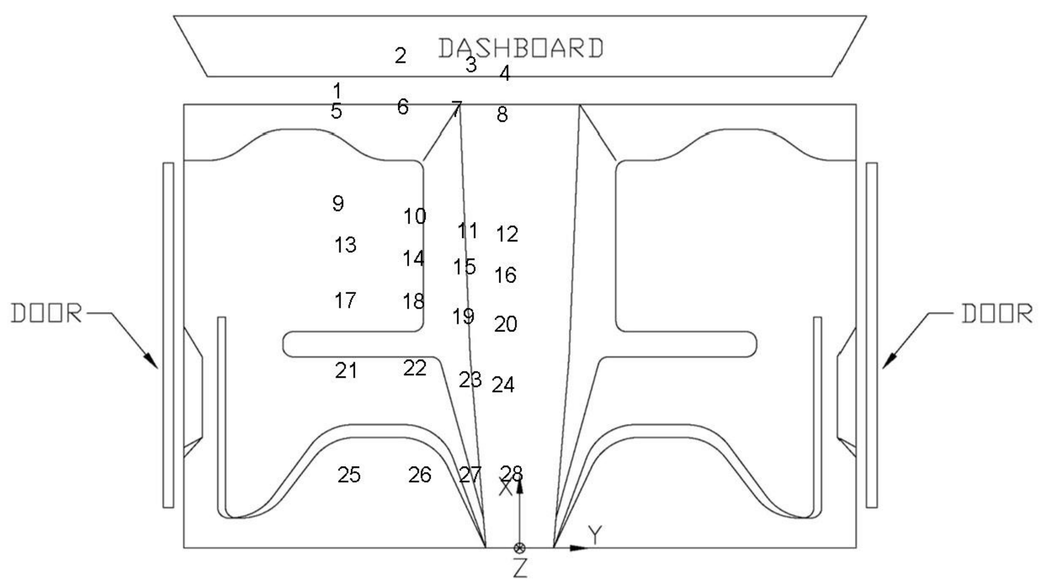


Figure D-7. Floor Pan Deformation Data – Set 1, Test No. MSPBN-2

Date: 3/22/2017 Test Name: MSPBN-2 VIN: KNADH4A34A6680510
Year: 2010 Make: Kia Model: Rio

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	46.098	-25.769	2.665	45.932	-26.113	2.939	-0.166	-0.345	0.274	0.471
2	48.747	-19.768	-0.253	48.632	-20.081	-0.036	-0.115	-0.313	0.217	0.398
3	48.302	-12.896	-0.896	48.186	-13.330	-0.705	-0.116	-0.435	0.191	0.488
4	47.736	-9.520	-1.263	47.696	-9.809	-1.015	-0.041	-0.289	0.248	0.383
5	44.757	-25.806	-0.878	44.616	-26.172	-0.704	-0.141	-0.366	0.174	0.430
6	45.210	-19.298	-2.164	45.095	-19.692	-1.970	-0.116	-0.394	0.194	0.454
7	45.180	-14.159	-2.499	45.083	-14.526	-2.304	-0.097	-0.367	0.195	0.426
8	44.847	-9.699	-2.816	44.810	-10.100	-2.624	-0.037	-0.401	0.192	0.447
9	38.387	-25.540	-3.946	38.281	-25.931	-3.794	-0.106	-0.391	0.153	0.433
10	37.583	-18.678	-3.954	37.562	-18.992	-3.835	-0.021	-0.314	0.120	0.337
11	36.710	-13.397	-4.267	36.756	-13.754	-4.031	0.047	-0.356	0.236	0.430
12	36.529	-9.635	-4.267	36.492	-9.918	-4.114	-0.037	-0.283	0.153	0.324
13	35.498	-25.395	-4.352	35.395	-25.711	-4.222	-0.103	-0.316	0.130	0.357
14	34.727	-18.727	-3.847	34.657	-19.050	-3.744	-0.070	-0.323	0.103	0.346
15	34.200	-13.819	-4.335	34.138	-14.097	-4.160	-0.062	-0.279	0.176	0.335
16	33.721	-9.854	-4.451	33.681	-10.151	-4.319	-0.040	-0.298	0.132	0.328
17	31.691	-25.340	-4.474	31.613	-25.688	-4.361	-0.078	-0.349	0.113	0.375
18	31.695	-18.658	-3.708	31.580	-18.929	-3.605	-0.114	-0.271	0.103	0.312
19	30.763	-13.887	-4.283	30.714	-14.155	-4.160	-0.049	-0.268	0.123	0.299
20	30.274	-9.625	-4.330	30.234	-9.930	-4.213	-0.040	-0.305	0.117	0.330
21	26.791	-25.020	-4.094	26.706	-25.292	-3.991	-0.086	-0.272	0.102	0.303
22	27.101	-18.421	-3.539	27.096	-18.806	-3.455	-0.005	-0.385	0.085	0.394
23	26.375	-12.997	-4.095	26.291	-13.313	-4.030	-0.084	-0.317	0.065	0.334
24	26.066	-9.761	-3.997	26.087	-10.185	-3.878	0.021	-0.425	0.119	0.441
25	19.389	-24.674	0.495	19.319	-24.947	0.565	-0.070	-0.273	0.070	0.290
26	19.547	-17.892	0.286	19.436	-18.093	0.355	-0.111	-0.200	0.069	0.239
27	19.648	-12.940	0.232	19.563	-13.189	0.285	-0.085	-0.249	0.053	0.268
28	19.723	-8.948	0.254	19.698	-9.191	0.280	-0.026	-0.243	0.026	0.245

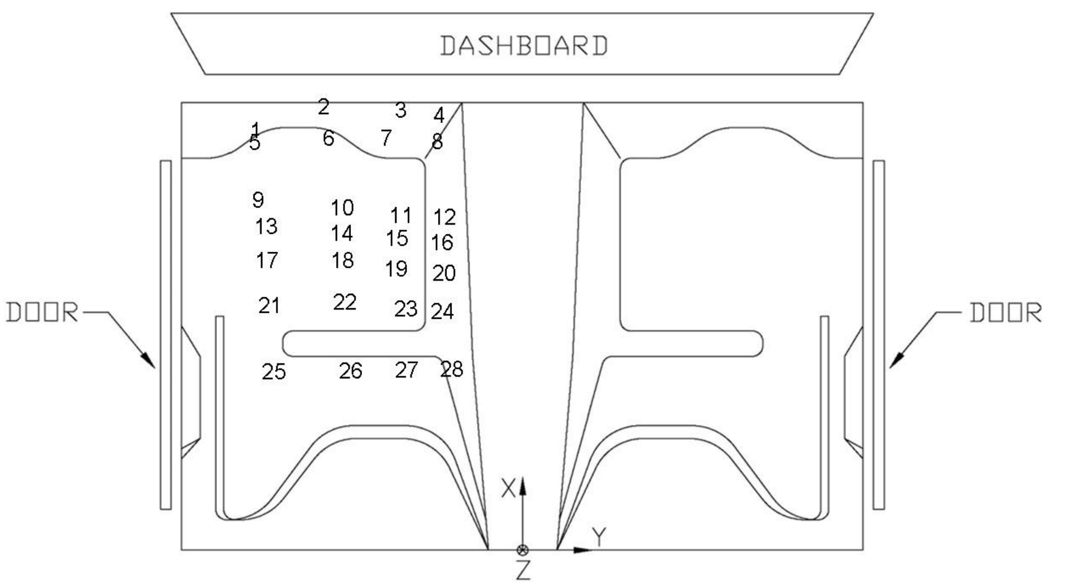


Figure D-8. Floor Pan Deformation Data – Set 2, Test No. MSPBN-2

Date: 3/22/2017 Test Name: MSPBN-2 VIN: KNADH4A34A6680510
Year: 2010 Make: Kia Model: Rio

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	15.382	-22.600	22.824	15.641	-22.530	22.790	0.259	0.069	-0.034	0.271
	2	12.052	-12.225	26.495	12.320	-12.107	26.476	0.268	0.117	-0.019	0.293
	3	14.215	2.053	23.534	14.585	2.119	23.726	0.370	0.066	0.192	0.422
	4	13.986	-21.425	12.807	14.238	-21.228	12.774	0.252	0.197	-0.033	0.322
	5	13.207	-11.613	12.220	13.463	-11.419	12.233	0.256	0.194	0.013	0.321
	6	9.520	0.296	12.120	9.794	0.400	12.233	0.275	0.103	0.113	0.314
SIDE PANEL	7	18.685	-26.209	3.186	18.932	-25.982	3.111	0.248	0.226	-0.075	0.344
	8	21.123	-26.192	0.814	21.415	-26.089	0.753	0.293	0.103	-0.061	0.316
	9	23.227	-26.049	6.834	23.451	-25.808	6.768	0.224	0.242	-0.066	0.336
IMPACT SIDE DOOR	10	-13.340	-27.439	25.728	-13.462	-28.209	25.868	-0.122	-0.770	0.141	0.792
	11	0.396	-27.074	24.037	0.233	-27.483	24.063	-0.163	-0.409	0.027	0.441
	12	12.657	-26.975	22.027	12.383	-26.871	22.157	-0.274	0.103	0.131	0.320
	13	-11.733	-27.669	14.678	-11.834	-28.394	14.804	-0.101	-0.725	0.125	0.743
	14	0.589	-27.815	13.202	0.497	-28.987	13.277	-0.091	-1.172	0.075	1.178
	15	12.670	-27.437	10.823	12.466	-27.791	10.969	-0.204	-0.355	0.146	0.435
ROOF	16	2.311	-20.371	39.369	2.669	-20.559	39.518	0.357	-0.188	0.149	0.430
	17	3.287	-13.793	39.758	3.628	-13.946	39.907	0.341	-0.153	0.148	0.402
	18	3.748	-8.295	39.836	4.123	-8.493	39.963	0.375	-0.199	0.127	0.443
	19	3.903	-4.116	39.855	4.258	-4.325	39.994	0.355	-0.210	0.139	0.435
	20	3.838	0.619	39.862	4.205	0.456	39.997	0.367	-0.164	0.135	0.424
	21	-3.575	-19.079	42.454	-3.242	-19.266	42.584	0.333	-0.187	0.130	0.403
	22	-3.402	-13.455	42.902	-3.076	-13.621	43.041	0.325	-0.166	0.139	0.391
	23	-3.328	-8.440	43.134	-2.954	-8.625	43.270	0.374	-0.185	0.136	0.439
	24	-3.373	-4.026	43.244	-3.039	-4.278	43.400	0.335	-0.252	0.156	0.447
	25	-3.500	0.441	43.259	-3.172	0.170	43.437	0.328	-0.271	0.178	0.461
	26	-7.925	-17.244	43.690	-7.535	-17.401	43.802	0.389	-0.157	0.112	0.434
	27	-7.762	-13.055	43.962	-7.460	-13.255	44.113	0.302	-0.200	0.151	0.392
	28	-7.654	-8.521	44.148	-7.320	-8.777	44.304	0.334	-0.256	0.157	0.449
	29	-7.594	-4.077	44.233	-7.167	-4.242	44.385	0.427	-0.165	0.152	0.482
	30	-7.484	0.097	44.208	-7.213	-0.159	44.400	0.272	-0.256	0.192	0.419
A PILLAR	31	2.597	-20.857	38.136	2.897	-21.007	38.282	0.300	-0.149	0.146	0.365
	32	7.808	-22.012	34.881	8.078	-22.086	35.083	0.270	-0.073	0.203	0.345
	33	12.767	-23.167	31.517	13.053	-23.219	31.657	0.285	-0.052	0.140	0.322
	34	18.373	-24.376	27.356	18.618	-24.390	27.367	0.246	-0.013	0.012	0.246
B PILLAR	35	-18.275	-26.312	10.719	-17.960	-26.298	10.848	0.315	0.014	0.129	0.341
	36	-14.585	-26.310	10.919	-14.320	-26.296	10.984	0.265	0.015	0.066	0.273
	37	-19.603	-26.474	19.675	-19.342	-26.415	19.850	0.261	0.059	0.175	0.320
	38	-15.327	-26.486	19.598	-14.993	-26.478	19.730	0.334	0.009	0.133	0.360
	39	-19.836	-26.096	27.375	-19.569	-26.083	27.493	0.268	0.013	0.118	0.293
	40	-15.778	-25.915	27.422	-15.492	-25.924	27.526	0.286	-0.009	0.104	0.305

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

Date: 3/22/2017 Test Name: MSPBN-2 VIN: KNADH4A34A6680510
Year: 2010 Make: Kia Model: Rio

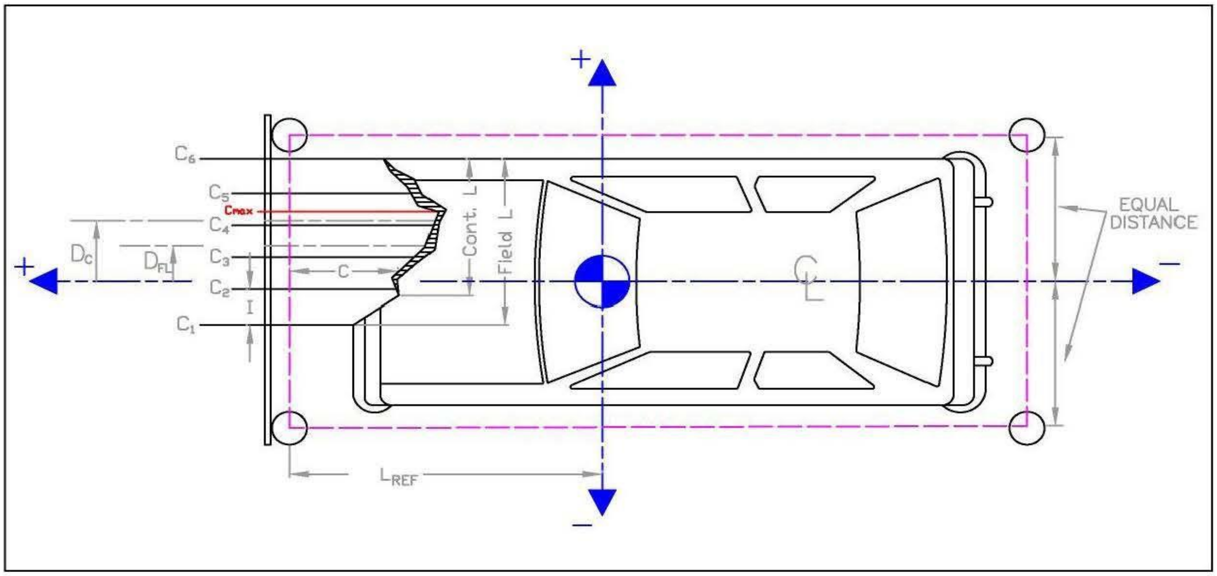
VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	34.303	-26.101	23.488	34.089	-26.300	23.575	-0.214	-0.199	0.087	0.305
	2	31.076	-15.676	27.001	30.887	-15.755	27.153	-0.189	-0.078	0.153	0.255
	3	33.640	-1.482	24.248	33.539	-1.629	24.414	-0.101	-0.147	0.166	0.244
	4	33.173	-24.905	13.383	33.030	-24.998	13.521	-0.143	-0.092	0.137	0.219
	5	32.593	-15.096	12.806	32.440	-15.179	12.997	-0.153	-0.082	0.191	0.258
	6	29.142	-3.065	12.613	29.087	-3.216	12.799	-0.055	-0.151	0.186	0.246
SIDE PANEL	7	37.965	-29.776	3.854	37.807	-29.855	4.030	-0.158	-0.079	0.177	0.250
	8	40.515	-29.805	1.614	40.407	-29.991	1.818	-0.108	-0.186	0.204	0.296
	9	42.453	-29.702	7.669	42.374	-29.771	7.891	-0.079	-0.069	0.221	0.245
IMPACT SIDE DOOR	10	5.419	-30.386	25.750	4.737	-31.619	25.713	-0.682	-1.233	-0.037	1.410
	11	19.249	-30.289	24.337	18.418	-31.084	24.453	-0.831	-0.794	0.116	1.156
	12	31.467	-30.423	22.581	30.754	-30.640	22.851	-0.713	-0.217	0.270	0.793
	13	7.294	-30.643	14.666	6.736	-31.764	14.794	-0.558	-1.121	0.128	1.259
	14	19.650	-31.025	13.477	19.042	-32.559	13.624	-0.608	-1.534	0.146	1.657
	15	31.787	-30.877	11.454	31.101	-31.564	11.651	-0.686	-0.688	0.197	0.991
ROOF	16	20.924	-23.655	39.681	20.737	-24.084	39.921	-0.187	-0.429	0.240	0.526
	17	22.012	-17.032	40.109	21.825	-17.400	40.337	-0.187	-0.368	0.228	0.472
	18	22.602	-11.584	40.183	22.357	-11.971	40.444	-0.246	-0.387	0.261	0.528
	19	22.806	-7.396	40.225	22.667	-7.859	40.429	-0.139	-0.463	0.204	0.524
	20	22.767	-2.603	40.267	22.700	-3.039	40.436	-0.067	-0.436	0.169	0.472
	21	15.005	-22.205	42.641	14.669	-22.548	42.856	-0.336	-0.344	0.215	0.527
	22	15.222	-16.651	43.105	15.010	-16.924	43.291	-0.212	-0.273	0.186	0.392
	23	15.425	-11.591	43.338	15.205	-11.938	43.519	-0.220	-0.347	0.181	0.449
	24	15.379	-7.142	43.468	15.287	-7.536	43.623	-0.092	-0.394	0.156	0.433
	25	15.350	-2.657	43.492	15.149	-3.036	43.673	-0.201	-0.380	0.180	0.466
	26	10.709	-20.307	43.781	10.491	-20.652	43.930	-0.217	-0.345	0.149	0.434
	27	10.812	-16.089	44.081	10.645	-16.475	44.225	-0.167	-0.385	0.144	0.444
	28	11.002	-11.609	44.270	10.809	-11.938	44.429	-0.192	-0.330	0.159	0.413
	29	11.243	-7.125	44.342	11.047	-7.405	44.505	-0.196	-0.280	0.163	0.379
	30	11.367	-2.976	44.330	11.179	-3.314	44.493	-0.188	-0.338	0.163	0.419
A PILLAR	31	21.178	-24.100	38.489	20.987	-24.438	38.736	-0.191	-0.338	0.247	0.460
	32	26.442	-25.355	35.360	26.238	-25.655	35.620	-0.205	-0.300	0.260	0.447
	33	31.488	-26.611	32.102	31.229	-26.902	32.339	-0.259	-0.291	0.237	0.456
	34	37.154	-27.926	28.086	36.945	-28.194	28.283	-0.208	-0.268	0.198	0.393
B PILLAR	35	0.875	-29.155	10.673	0.717	-29.327	10.689	-0.157	-0.173	0.016	0.234
	36	4.585	-29.227	10.900	4.425	-29.408	10.974	-0.160	-0.182	0.074	0.253
	37	-0.710	-29.290	19.511	-0.890	-29.410	19.603	-0.180	-0.120	0.092	0.235
	38	3.692	-29.386	19.556	3.492	-29.550	19.636	-0.200	-0.164	0.080	0.270
	39	-1.139	-28.908	27.186	-1.298	-29.025	27.324	-0.159	-0.117	0.139	0.241
	40	2.988	-28.805	27.338	2.772	-28.962	27.457	-0.216	-0.157	0.119	0.293

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

Date: 3/24/2017 Test Number: MSPBN-2

Year: 2010 Make: Kia Model: Rio



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	72 1/2	(1842)
Total Width of Vehicle:	65 1/4	(1657)
Width of contact and induced crush - Field L:	65 1/4	(1657)
Crush measurement spacing interval (L/5) - I:	13	(330)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	65 1/4	(1657)
Distance from center of vehicle to center of contact damage - D_C:	0	()

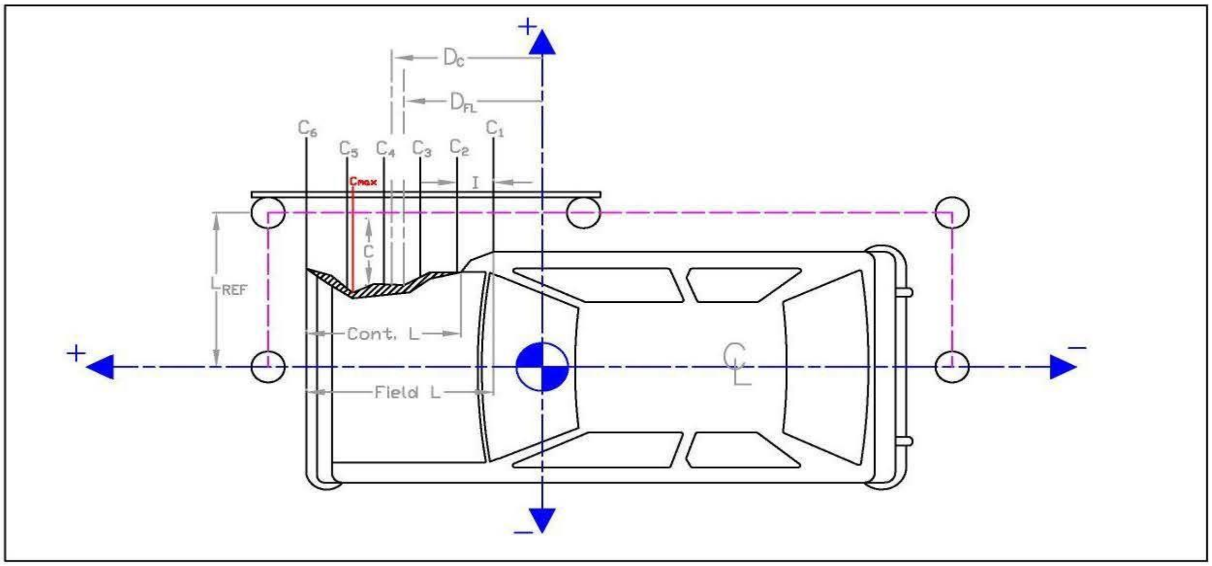
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	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	NA	NA	-32 5/8	-(829)	24	(610)	-2 4/5	-(71)	NA	NA
C_2	5 1/4	(133)	-19 5/8	-(498)	8 1/2	(216)			- 4/9	-(11)
C_3	3	(76)	-6 5/8	-(168)	6 1/8	(156)			- 1/3	-(8)
C_4	3 1/4	(83)	6 3/8	(162)	6 1/8	(156)			-0	-(2)
C_5	6 1/2	(165)	19 3/8	(492)	8 3/8	(213)			1	(24)
C_6	NA	NA	32 3/8	(822)	24	(610)			NA	NA
C_{MAX}	12 1/2	(318)	24	(610)	10 3/8	(264)			5	(125)

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

Date: 3/24/2017 Test Number: MSPBN-2

Year: 2010 Make: Kia Model: Rio



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	35 1/2	(902)
Total Vehicle Length:	167 1/8	(4245)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-14 1/8	-(359)
Width of contact and induced crush - Field L:	167 1/8	(4245)
Crush measurement spacing interval (L/5) - I:	33 3/8	(848)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-14 1/8	-(359)
Width of Contact Damage:	167 1/8	(4245)
Distance from vehicle c.g. to center of contact damage - D_C:	-14 1/8	-(359)

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	NA	NA	-97 3/4	-(2483)	26	(660)	- 1/2	-(13)	NA	NA
C_2	4	(102)	-64 3/8	-(1635)	4	(102)			1/2	(13)
C_3	3 1/4	(83)	-31	-(787)	3 5/8	(92)			1/8	(3)
C_4	3 3/4	(95)	2 3/8	(60)	3 3/4	(95)			1/2	(13)
C_5	4 1/2	(114)	35 3/4	(908)	3 1/4	(83)			1 3/4	(44)
C_6	NA	NA	69 1/8	(1756)	20 1/4	(514)			NA	NA
C_{MAX}	8	(203)	54	(1372)	4 7/8	(124)			3 5/8	(92)

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

Date: 4/11/2017 Test Name: MSPBN-3 VIN: KMHCN4AC5BU612118
Year: 2011 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	26.721	-22.627	1.826	26.771	-22.625	2.104	0.050	0.002	0.279	0.283
2	30.307	-15.094	-1.185	30.544	-15.161	-0.993	0.237	-0.067	0.192	0.312
3	29.527	-7.110	-1.590	29.717	-7.070	-1.510	0.190	0.040	0.080	0.210
4	20.439	-20.543	-5.313	20.636	-20.513	-5.251	0.197	0.030	0.062	0.209
5	21.189	-13.829	-5.173	21.430	-13.833	-5.059	0.241	-0.004	0.114	0.267
6	21.091	-6.851	-5.040	21.325	-6.929	-4.992	0.234	-0.078	0.047	0.251
7	14.651	-20.408	-5.172	14.842	-20.343	-5.057	0.191	0.065	0.114	0.232
8	14.316	-13.463	-4.893	14.536	-13.414	-4.820	0.220	0.049	0.072	0.237
9	14.502	-6.691	-5.217	14.770	-6.715	-5.170	0.268	-0.024	0.047	0.273
10	7.709	-20.259	-4.764	7.906	-20.228	-4.816	0.197	0.031	-0.053	0.206
11	7.444	-14.244	-4.537	7.678	-14.220	-4.489	0.234	0.025	0.048	0.240
12	7.660	-7.116	-4.899	7.881	-7.084	-4.860	0.221	0.032	0.039	0.227
13	0.509	-20.665	-0.502	0.703	-20.639	-0.408	0.194	0.026	0.094	0.217
14	0.840	-7.421	-0.392	1.108	-7.326	-0.395	0.269	0.095	-0.002	0.285
15	30.416	7.957	-1.077	30.699	7.874	-1.081	0.283	-0.083	-0.004	0.295
16	31.129	14.207	-0.762	31.452	14.122	-0.794	0.323	-0.086	-0.032	0.336
17	28.484	20.303	2.113	28.721	20.306	2.120	0.237	0.003	0.007	0.238
18	23.255	6.182	-4.756	23.461	6.125	-4.755	0.206	-0.057	0.001	0.214
19	24.729	14.772	-3.701	24.949	14.672	-3.735	0.220	-0.100	-0.034	0.244
20	25.065	22.321	-3.745	25.259	22.317	-3.815	0.194	-0.004	-0.070	0.206
21	17.383	6.687	-5.026	17.547	6.582	-5.012	0.165	-0.105	0.014	0.196
22	18.650	14.969	-4.653	18.883	14.907	-4.702	0.233	-0.062	-0.049	0.246
23	18.468	23.343	-4.807	18.764	23.317	-4.864	0.296	-0.025	-0.057	0.303
24	9.224	6.710	-4.793	9.532	6.680	-4.800	0.308	-0.029	-0.007	0.310
25	9.429	15.197	-4.275	9.717	15.215	-4.315	0.288	0.018	-0.041	0.292
26	9.132	23.496	-4.493	9.395	23.575	-4.495	0.263	0.078	-0.003	0.274
27	1.283	7.838	-0.152	1.630	7.795	-0.172	0.347	-0.044	-0.021	0.350
28	1.679	20.979	-0.074	1.953	20.959	-0.099	0.274	-0.019	-0.025	0.275

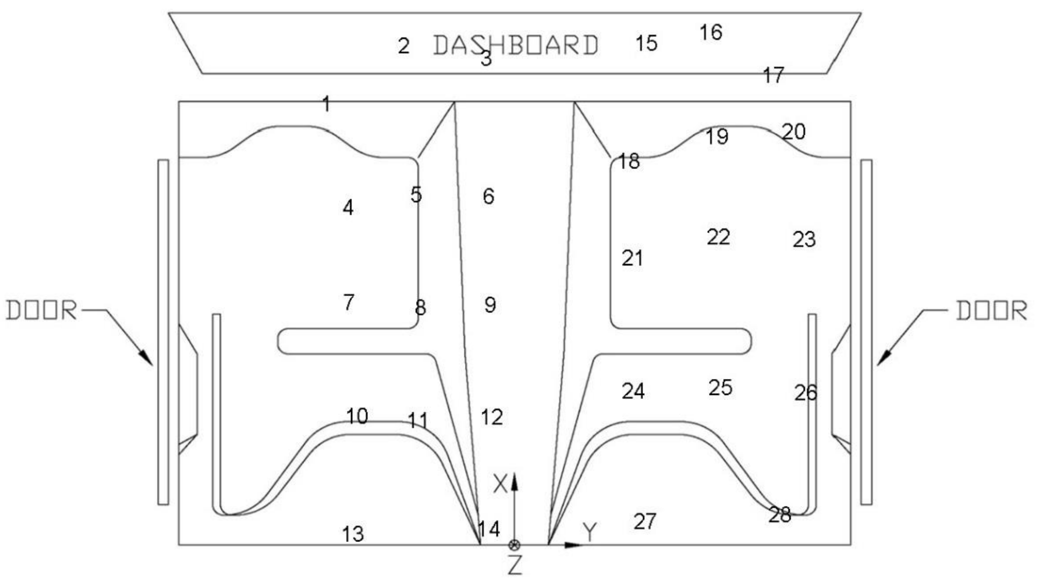


Figure D-13. Floor Pan Deformation Data – Set 1, Test No. MSPBN-3

Date: 4/11/2017 Test Name: MSPBN-3 VIN: KMHCN4AC5BU612118
Year: 2011 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
1	48.087	-18.524	2.578	47.890	-18.715	2.763	-0.197	-0.191	0.185	0.331
2	51.398	-10.744	-0.373	51.380	-11.047	-0.169	-0.018	-0.304	0.204	0.366
3	50.235	-2.832	-0.777	50.213	-3.102	-0.648	-0.022	-0.270	0.129	0.300
4	41.810	-16.642	-4.760	41.815	-16.905	-4.689	0.005	-0.263	0.071	0.272
5	42.253	-9.883	-4.584	42.219	-10.117	-4.458	-0.034	-0.234	0.126	0.268
6	41.861	-3.055	-4.434	41.850	-3.279	-4.351	-0.011	-0.224	0.083	0.239
7	36.047	-16.801	-4.751	36.049	-17.077	-4.629	0.002	-0.276	0.122	0.302
8	35.408	-9.911	-4.445	35.374	-10.088	-4.373	-0.034	-0.178	0.072	0.195
9	35.218	-3.154	-4.748	35.303	-3.396	-4.694	0.085	-0.242	0.053	0.262
10	29.059	-16.950	-4.524	29.170	-17.212	-4.568	0.111	-0.262	-0.044	0.288
11	28.549	-11.006	-4.250	28.563	-11.252	-4.222	0.014	-0.246	0.028	0.248
12	28.415	-3.865	-4.574	28.405	-4.016	-4.529	-0.010	-0.151	0.045	0.158
13	21.856	-17.707	-0.400	21.856	-17.937	-0.326	0.000	-0.231	0.074	0.242
14	21.609	-4.513	-0.240	21.561	-4.757	-0.227	-0.049	-0.244	0.013	0.249
15	50.468	12.191	-0.220	50.475	11.976	-0.110	0.007	-0.216	0.110	0.242
16	50.887	18.360	0.079	50.874	18.191	0.198	-0.013	-0.169	0.119	0.207
17	47.857	24.390	2.972	47.798	24.228	3.042	-0.058	-0.163	0.070	0.186
18	43.386	10.113	-4.045	43.400	9.857	-3.983	0.013	-0.256	0.062	0.264
19	44.470	18.742	-2.914	44.443	18.511	-2.885	-0.026	-0.231	0.029	0.235
20	44.416	26.353	-2.957	44.372	26.161	-2.926	-0.044	-0.191	0.031	0.199
21	37.563	10.297	-4.432	37.539	10.117	-4.385	-0.023	-0.181	0.047	0.188
22	38.382	18.691	-4.001	38.383	18.454	-4.011	0.000	-0.236	-0.010	0.237
23	37.855	27.052	-4.126	37.864	26.841	-4.116	0.010	-0.211	0.009	0.212
24	29.443	10.055	-4.403	29.379	9.738	-4.363	-0.064	-0.317	0.040	0.326
25	29.209	18.574	-3.831	29.221	18.298	-3.837	0.012	-0.276	-0.007	0.276
26	28.469	26.857	-4.001	28.537	26.600	-3.999	0.068	-0.257	0.002	0.266
27	21.423	10.748	0.063	21.341	10.490	0.077	-0.082	-0.258	0.014	0.271
28	21.086	23.820	0.214	21.096	23.645	0.215	0.009	-0.175	0.000	0.175

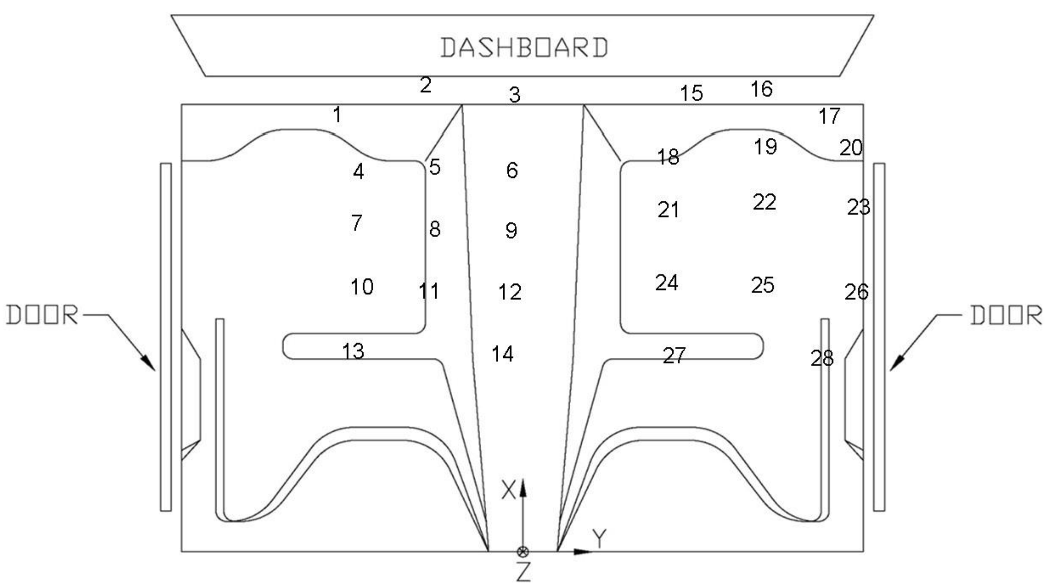


Figure D-14. Floor Pan Deformation Data – Set 2, Test No. MSPBN-3

Date: 4/11/2017 Test Name: MSPBN-3 VIN: KMHCN4AC5BU612118
Year: 2011 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	12.343	-13.854	26.564	12.718	-13.706	26.725	0.374	0.149	0.161	0.434
	2	14.454	0.573	24.083	14.903	0.736	24.185	0.449	0.163	0.102	0.489
	3	16.422	23.929	23.147	16.917	24.112	23.171	0.494	0.183	0.024	0.528
	4	12.696	-24.749	13.209	12.956	-24.585	13.438	0.260	0.164	0.229	0.383
	5	10.562	0.045	17.854	10.879	0.131	17.928	0.317	0.086	0.074	0.337
	6	13.439	23.968	17.667	13.794	24.105	17.587	0.355	0.137	-0.080	0.388
SIDE PANEL	7	18.173	-27.020	2.688	18.364	-26.824	2.930	0.191	0.195	0.241	0.365
	8	24.983	-27.587	2.951	25.245	-27.413	3.175	0.262	0.174	0.223	0.386
	9	20.502	-27.402	-0.186	20.656	-27.108	0.012	0.154	0.293	0.198	0.386
IMPACT SIDE DOOR	10	7.570	-27.741	21.798	7.829	-27.489	21.973	0.260	0.252	0.174	0.402
	11	-0.337	-27.517	22.978	0.000	-27.327	23.234	0.337	0.190	0.256	0.464
	12	-11.754	-27.206	24.663	-11.584	-27.115	24.811	0.169	0.091	0.148	0.243
	13	8.118	-28.332	7.753	8.378	-28.030	8.011	0.260	0.303	0.258	0.475
	14	0.423	-28.077	3.720	0.618	-27.734	3.848	0.195	0.344	0.127	0.415
	15	-10.848	-27.624	12.774	-10.571	-27.390	12.977	0.278	0.234	0.204	0.416
ROOF	16	1.957	-20.885	39.197	2.408	-20.779	39.350	0.451	0.105	0.153	0.487
	17	3.664	-10.870	39.926	4.078	-10.657	40.064	0.414	0.213	0.138	0.486
	18	4.415	-0.378	40.195	4.872	-0.170	40.265	0.457	0.208	0.069	0.507
	19	4.327	9.195	40.130	4.739	9.303	40.183	0.411	0.107	0.054	0.428
	20	3.134	20.340	39.635	3.551	20.491	39.616	0.417	0.151	-0.018	0.444
	21	-3.825	-19.010	42.131	-3.370	-18.835	42.301	0.454	0.175	0.170	0.516
	22	-3.142	-11.335	42.825	-2.749	-11.180	42.978	0.393	0.155	0.154	0.449
	23	-3.058	-0.163	43.377	-2.623	-0.044	43.471	0.436	0.119	0.094	0.461
	24	-3.918	10.151	43.455	-3.487	10.220	43.512	0.431	0.069	0.057	0.440
	25	-5.449	16.598	43.392	-5.011	16.818	43.414	0.438	0.220	0.021	0.491
	26	-10.477	-16.130	43.908	-10.107	-15.954	44.098	0.370	0.176	0.189	0.451
	27	-10.273	-9.953	44.459	-9.903	-9.855	44.612	0.371	0.098	0.153	0.413
	28	-10.020	-0.342	44.857	-9.647	-0.164	44.983	0.373	0.178	0.127	0.432
	29	-9.750	8.254	44.739	-9.349	8.400	44.829	0.401	0.146	0.090	0.436
	30	-9.742	15.921	44.297	-9.295	16.116	44.336	0.447	0.194	0.039	0.489
A PILLAR	31	20.562	-26.473	24.550	20.837	-26.350	24.712	0.274	0.124	0.162	0.342
	32	15.303	-25.367	28.886	15.638	-25.249	29.110	0.335	0.118	0.224	0.420
	33	8.575	-23.696	33.561	9.009	-23.583	33.737	0.434	0.113	0.176	0.482
	34	2.377	-22.118	37.376	2.717	-21.959	37.639	0.341	0.160	0.264	0.459
B PILLAR	35	-18.213	-21.056	39.906	-17.850	-20.853	40.180	0.362	0.203	0.273	0.497
	36	-20.418	-21.094	39.980	-20.061	-20.911	40.213	0.356	0.183	0.233	0.463
	37	-17.149	-24.209	32.580	-16.813	-24.026	32.848	0.336	0.183	0.268	0.467
	38	-20.616	-24.105	32.943	-20.284	-23.976	33.032	0.332	0.129	0.090	0.367
	39	-16.750	-25.831	24.025	-16.433	-25.679	24.151	0.317	0.151	0.126	0.373
	40	-20.267	-25.747	24.143	-19.950	-25.592	24.370	0.317	0.155	0.227	0.419

Figure D-15. Driver Occupant Compartment Deformation Data – Set 1, Test No. MSPBN-3

Date: 4/11/2017 Test Name: MSPBN-3 VIN: KMHCN4AC5BU612118
Year: 2011 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	12.372	-13.815	26.570	12.673	-13.710	26.741	0.301	0.105	0.171	0.362
	2	14.429	0.531	24.076	14.893	0.685	24.228	0.464	0.154	0.152	0.512
	3	16.476	24.011	23.199	16.922	24.110	23.187	0.446	0.099	-0.012	0.457
	4	12.694	-24.752	13.193	12.971	-24.633	13.353	0.277	0.119	0.160	0.341
	5	10.564	-0.012	17.848	10.885	0.153	17.968	0.321	0.165	0.120	0.380
	6	13.450	23.912	17.728	13.807	24.065	17.636	0.358	0.153	-0.091	0.399
SIDE PANEL	7	21.159	26.017	6.000	21.654	26.008	5.838	0.495	-0.010	-0.163	0.521
	8	19.828	26.249	1.536	20.157	26.216	1.439	0.329	-0.033	-0.097	0.345
	9	24.397	26.146	1.050	24.757	26.127	0.953	0.360	-0.020	-0.097	0.373
IMPACT SIDE DOOR	10	13.757	27.102	21.940	14.035	27.154	21.933	0.278	0.052	-0.007	0.283
	11	1.811	27.386	23.742	2.091	27.434	23.700	0.280	0.048	-0.042	0.287
	12	-9.742	27.708	25.393	-9.473	27.809	25.442	0.269	0.101	0.049	0.291
	13	10.805	27.966	8.246	11.092	27.971	8.246	0.287	0.005	0.001	0.287
	14	1.925	28.304	4.229	2.159	28.272	4.217	0.235	-0.032	-0.012	0.237
	15	-8.784	28.304	12.779	-8.630	28.395	12.677	0.154	0.091	-0.102	0.206
ROOF	16	1.958	-20.878	39.194	2.357	-20.800	39.369	0.399	0.078	0.174	0.442
	17	3.619	-10.819	39.948	4.067	-10.740	40.062	0.448	0.079	0.114	0.469
	18	4.459	-0.298	40.175	4.806	-0.211	40.295	0.346	0.087	0.120	0.377
	19	4.386	9.172	40.100	4.752	9.313	40.171	0.366	0.141	0.071	0.399
	20	3.185	20.290	39.604	3.517	20.471	39.637	0.332	0.181	0.033	0.380
	21	-3.827	-19.052	42.123	-3.389	-18.774	42.319	0.439	0.278	0.196	0.555
	22	-3.204	-11.391	42.837	-2.790	-11.191	42.992	0.414	0.200	0.156	0.485
	23	-2.971	-0.136	43.355	-2.577	-0.029	43.463	0.394	0.107	0.107	0.422
	24	-3.916	10.093	43.461	-3.518	10.275	43.512	0.398	0.182	0.052	0.441
	25	-5.517	16.525	43.415	-5.019	16.789	43.417	0.498	0.264	0.002	0.564
	26	-10.509	-16.160	43.908	-10.063	-15.953	44.095	0.446	0.207	0.187	0.526
	27	-10.271	-10.003	44.454	-9.920	-9.774	44.624	0.351	0.229	0.170	0.452
	28	-10.055	-0.297	44.866	-9.626	-0.157	44.978	0.429	0.141	0.111	0.465
	29	-9.763	8.225	44.746	-9.363	8.398	44.827	0.400	0.173	0.081	0.444
	30	-9.812	15.883	44.314	-9.270	16.110	44.330	0.542	0.228	0.015	0.588
A PILLAR	31	22.937	25.221	24.518	23.172	25.244	24.508	0.236	0.023	-0.010	0.237
	32	17.175	24.255	29.171	17.583	24.310	29.150	0.407	0.055	-0.020	0.412
	33	9.886	22.772	34.259	10.242	22.862	34.238	0.356	0.090	-0.021	0.368
	34	3.914	21.559	37.675	4.297	21.674	37.700	0.383	0.115	0.025	0.401
B PILLAR	35	-16.829	21.483	40.467	-16.488	21.553	40.563	0.340	0.070	0.096	0.361
	36	-19.279	21.464	40.918	-18.932	21.608	40.899	0.347	0.144	-0.020	0.376
	37	-15.846	24.719	33.446	-15.419	24.758	33.449	0.427	0.040	0.003	0.429
	38	-19.252	24.674	34.102	-18.957	24.683	34.220	0.296	0.009	0.118	0.318
	39	-14.520	26.584	24.540	-14.119	26.563	24.640	0.401	-0.021	0.100	0.413
	40	-18.627	26.561	26.636	-18.365	26.549	26.585	0.262	-0.012	-0.051	0.267

Figure D-16. Passenger Occupant Compartment Deformation Data – Set 1, Test No. MSPBN-3

Date: 4/11/2017 Test Name: MSPBN-3 VIN: KMHCN4AC5BU612118
Year: 2011 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	32.726	-10.531	26.952	32.769	-10.623	27.111	0.043	-0.092	0.158	0.188
	2	34.274	4.002	24.591	34.344	3.875	24.696	0.069	-0.127	0.104	0.178
	3	35.188	27.470	23.814	35.315	27.263	23.869	0.127	-0.207	0.055	0.249
	4	33.883	-21.348	13.571	33.901	-21.483	13.813	0.018	-0.135	0.242	0.277
	5	30.524	3.296	18.280	30.584	3.183	18.375	0.061	-0.113	0.095	0.160
	6	32.289	27.298	18.197	32.327	27.220	18.227	0.038	-0.078	0.030	0.092
SIDE PANEL	7	39.737	-23.304	3.181	39.740	-23.308	3.407	0.003	-0.004	0.226	0.226
	8	46.423	-23.559	3.718	46.515	-23.563	3.777	0.092	-0.004	0.058	0.109
	9	42.237	-23.527	0.380	42.154	-23.417	0.591	-0.083	0.109	0.211	0.252
IMPACT SIDE DOOR	10	28.654	-24.603	22.066	28.651	-24.706	22.255	-0.004	-0.104	0.189	0.215
	11	20.880	-24.751	23.086	20.823	-24.997	23.308	-0.056	-0.246	0.222	0.336
	12	9.266	-24.970	24.443	9.242	-25.464	24.473	-0.024	-0.494	0.030	0.495
	13	29.611	-25.100	7.987	29.624	-25.120	8.201	0.012	-0.020	0.214	0.215
	14	21.993	-25.178	3.773	22.060	-25.223	3.948	0.068	-0.045	0.175	0.193
	15	10.562	-25.282	12.594	10.604	-25.582	12.687	0.041	-0.300	0.093	0.316
ROOF	16	22.450	-18.134	39.296	22.510	-18.311	39.492	0.061	-0.177	0.196	0.271
	17	23.640	-7.988	40.131	23.715	-8.145	40.270	0.075	-0.157	0.139	0.223
	18	23.950	2.551	40.431	24.051	2.390	40.523	0.101	-0.161	0.092	0.211
	19	23.413	12.046	40.403	23.414	11.879	40.515	0.002	-0.167	0.111	0.201
	20	21.665	23.141	39.945	21.708	23.009	39.978	0.044	-0.132	0.033	0.143
	21	16.510	-16.474	42.127	16.572	-16.580	42.297	0.062	-0.106	0.170	0.209
	22	16.799	-8.822	42.866	16.844	-8.981	43.015	0.045	-0.158	0.149	0.222
	23	16.398	2.321	43.455	16.533	2.277	43.543	0.135	-0.043	0.089	0.167
	24	15.081	12.525	43.554	15.115	12.391	43.626	0.034	-0.134	0.072	0.156
	25	13.217	19.032	43.481	13.300	18.913	43.525	0.083	-0.119	0.044	0.152
	26	9.675	-13.939	43.765	9.739	-14.066	43.917	0.064	-0.127	0.152	0.208
	27	9.561	-7.802	44.346	9.684	-7.997	44.459	0.122	-0.195	0.113	0.256
	28	9.390	1.812	44.787	9.480	1.739	44.880	0.090	-0.073	0.093	0.148
	29	9.237	10.415	44.715	9.298	10.342	44.789	0.060	-0.073	0.075	0.121
	30	8.940	18.145	44.291	8.969	17.961	44.350	0.029	-0.184	0.059	0.196
A PILLAR	31	41.522	-22.734	25.073	41.670	-22.871	25.150	0.148	-0.137	0.077	0.216
	32	36.202	-21.918	29.307	36.339	-22.056	29.516	0.137	-0.138	0.208	0.285
	33	29.323	-20.579	33.861	29.455	-20.730	33.997	0.132	-0.151	0.136	0.242
	34	22.812	-19.299	37.565	22.935	-19.443	37.713	0.123	-0.144	0.148	0.240
B PILLAR	35	2.196	-19.206	39.589	2.393	-19.318	39.791	0.197	-0.112	0.201	0.303
	36	0.055	-19.366	39.564	0.135	-19.477	39.772	0.080	-0.111	0.208	0.249
	37	3.622	-22.261	32.285	3.783	-22.401	32.430	0.161	-0.140	0.145	0.258
	38	0.096	-22.328	32.515	0.261	-22.473	32.672	0.165	-0.145	0.157	0.270
	39	4.316	-23.830	23.668	4.421	-23.964	23.812	0.105	-0.134	0.144	0.223
	40	0.746	-23.910	23.712	0.815	-24.057	23.790	0.069	-0.147	0.078	0.180

Figure D-17. Driver Occupant Compartment Deformation Data – Set 2, Test No. MSPBN-3

Date: 4/11/2017 Test Name: MSPBN-3 VIN: KMHCN4AC5BU612118
Year: 2011 Make: Hyundai Model: Accent

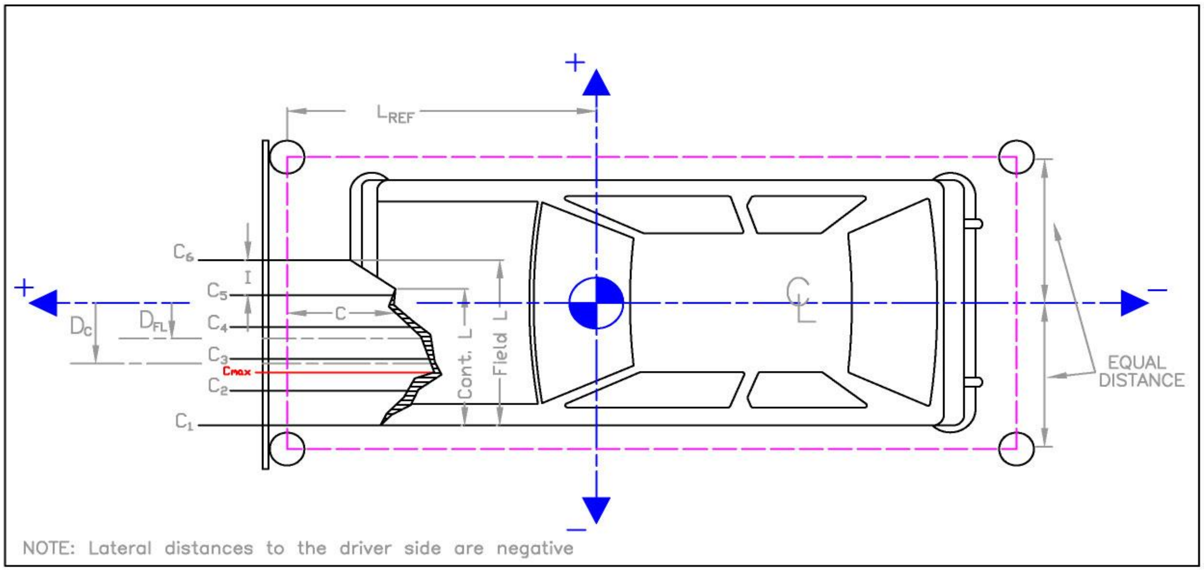
VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)
DASH	1	32.701	-10.571	26.940	32.832	-10.650	27.145	0.131	-0.079	0.205	0.255
	2	34.239	3.971	24.580	34.419	3.847	24.762	0.180	-0.124	0.182	0.284
	3	35.199	27.460	23.828	35.292	27.330	23.882	0.093	-0.131	0.054	0.169
	4	33.904	-21.305	13.548	33.961	-21.424	13.683	0.057	-0.119	0.136	0.189
	5	30.500	3.289	18.241	30.575	3.153	18.381	0.075	-0.136	0.140	0.209
	6	32.290	27.311	18.225	32.338	27.206	18.261	0.049	-0.104	0.036	0.121
SIDE PANEL	7	40.226	29.796	6.706	40.317	29.586	6.695	0.090	-0.210	-0.011	0.229
	8	38.878	29.984	2.375	38.990	29.754	2.293	0.112	-0.230	-0.082	0.269
	9	43.555	30.097	1.922	43.608	29.889	1.905	0.054	-0.207	-0.017	0.215
IMPACT SIDE DOOR	10	32.328	30.461	22.581	32.283	30.273	22.497	-0.045	-0.188	-0.084	0.211
	11	20.349	30.192	24.007	20.333	29.969	24.038	-0.015	-0.223	0.032	0.226
	12	8.733	29.973	25.492	8.752	29.781	25.443	0.019	-0.192	-0.049	0.198
	13	29.743	31.258	8.806	29.656	31.027	8.735	-0.087	-0.232	-0.070	0.257
	14	20.926	31.206	4.530	20.827	30.933	4.484	-0.100	-0.273	-0.046	0.294
	15	9.880	30.673	12.756	9.816	30.480	12.731	-0.064	-0.193	-0.025	0.205
ROOF	16	22.459	-18.129	39.295	22.609	-18.272	39.442	0.151	-0.143	0.147	0.255
	17	23.659	-8.003	40.121	23.777	-8.163	40.244	0.118	-0.160	0.123	0.233
	18	23.902	2.534	40.456	24.035	2.406	40.534	0.133	-0.128	0.077	0.200
	19	23.343	11.946	40.451	23.431	11.888	40.506	0.088	-0.058	0.054	0.118
	20	21.709	23.128	39.922	21.713	22.955	39.983	0.003	-0.173	0.062	0.184
	21	16.521	-16.454	42.119	16.672	-16.542	42.282	0.151	-0.088	0.163	0.238
	22	16.822	-8.830	42.862	16.938	-8.887	43.000	0.116	-0.057	0.138	0.189
	23	16.337	2.293	43.470	16.446	2.283	43.567	0.109	-0.010	0.097	0.146
	24	15.037	12.583	43.565	15.113	12.497	43.624	0.076	-0.085	0.059	0.129
	25	13.168	19.029	43.496	13.249	18.888	43.535	0.081	-0.141	0.039	0.167
	26	9.657	-13.965	43.769	9.758	-14.130	43.914	0.101	-0.165	0.145	0.242
	27	9.530	-7.805	44.353	9.698	-7.838	44.471	0.168	-0.033	0.118	0.208
	28	9.401	1.871	44.787	9.444	1.762	44.890	0.043	-0.109	0.103	0.156
	29	9.255	10.428	44.711	9.269	10.282	44.798	0.014	-0.146	0.087	0.170
	30	8.887	18.098	44.302	8.996	17.966	44.347	0.109	-0.132	0.044	0.177
A PILLAR	31										
	32										
	33	N/A compromised data									
	34										
B PILLAR	35										
	36										
	37	N/A compromised data									
	38										
	39										
	40										

Figure D-18. Passenger Occupant Compartment Deformation Data – Set 2, Test No. MSPBN-3

Date: 4/11/2017 Test Number: MSPBN-3

Year: 2011 Make: Hyundai Model: Accent



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	68	(1727)
Total Width of Vehicle:	65 3/4	(1670)
Width of contact and induced crush - Field L:	65 3/4	(1670)
Crush measurement spacing interval (L/5) - I:	13 1/8	(333)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	65 3/4	(1670)
Distance from center of vehicle to center of contact damage - D_C:	0	()

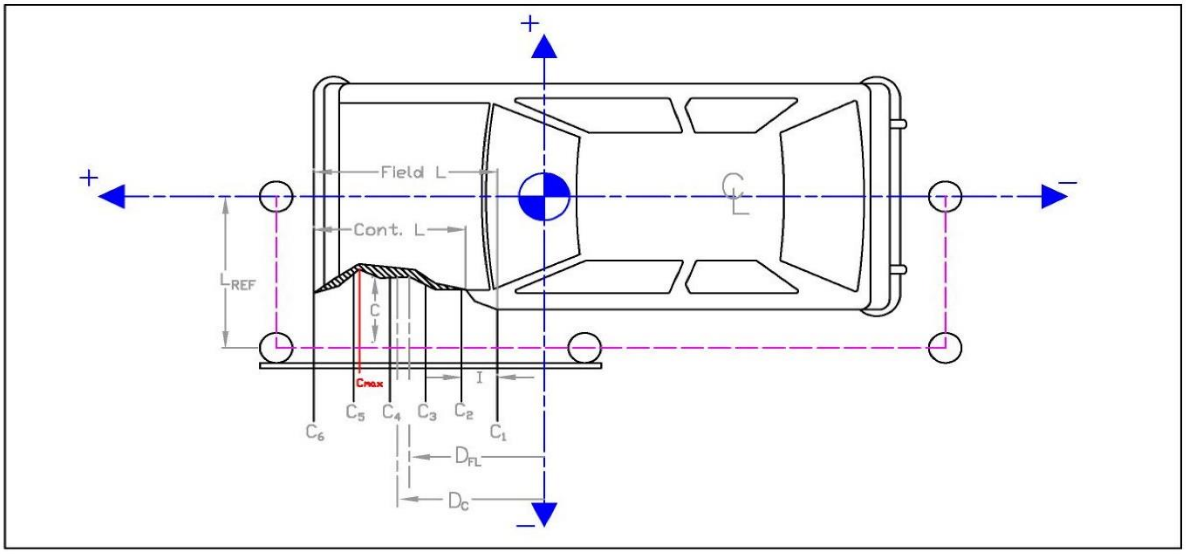
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

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	41 1/4	(1048)	-32 7/8	-(835)	20 1/4	(514)	-4	-(103)	25	(637)
C_2	3	(76)	-19 3/4	-(502)	4 3/4	(121)			2 1/3	(59)
C_3	11 1/4	(286)	-6 5/8	-(168)	2 3/8	(60)			13	(329)
C_4	10	(254)	6 1/2	(165)	2 3/8	(60)			11 2/3	(297)
C_5	2	(51)	19 5/8	(498)	4 3/4	(121)			1 1/3	(33)
C_6	44	(1118)	32 3/4	(832)	19 7/8	(505)			28 1/5	(716)
C_{MAX}	12	(305)	0	()	1 3/4	(44)			14 1/3	(364)

Figure D-19. Exterior Vehicle Crush (NASS) - Front, Test No. MSPBN-3

Date: 42836 | Test Number: MSPBN-3

Year: 2011 | Make: Hyundai | Model: Accent



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	37	(940)
Total Vehicle Length:	168 1/4	(4274)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-14 4/7	-(370)
Width of contact and induced crush - Field L:	168 1/4	(4274)
Crush measurement spacing interval (L/5) - I:	33 5/8	(854)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-14 4/7	-(370)
Width of Contact Damage:	71	(1803)
Distance from vehicle c.g. to center of contact damage - D_C:	34	(865)

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	18 1/2	(470)	-98 3/4	-(2508)	36	(914)	1	(25)	-18 1/2	-(470)
C_2	5 3/4	(146)	-65 1/8	-(1654)	4	(102)			3/4	(19)
C_3	4	(102)	-31 1/2	-(800)	3 3/8	(86)			- 3/8	-(10)
C_4	4	(102)	2 1/8	(54)	3 1/4	(83)			- 1/4	-(6)
C_5	3/4	(19)	35 3/4	(908)	3 1/2	(89)			-3 3/4	-(95)
C_6	NA	NA	69 3/8	(1762)	31 7/8	(810)			NA	NA
C_{MAX}	15 1/2	(394)	54	(1372)	4 3/4	(121)			9 3/4	(248)

Figure D-20. Exterior Vehicle Crush (NASS) - Side, Test No. MSPBN-3

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

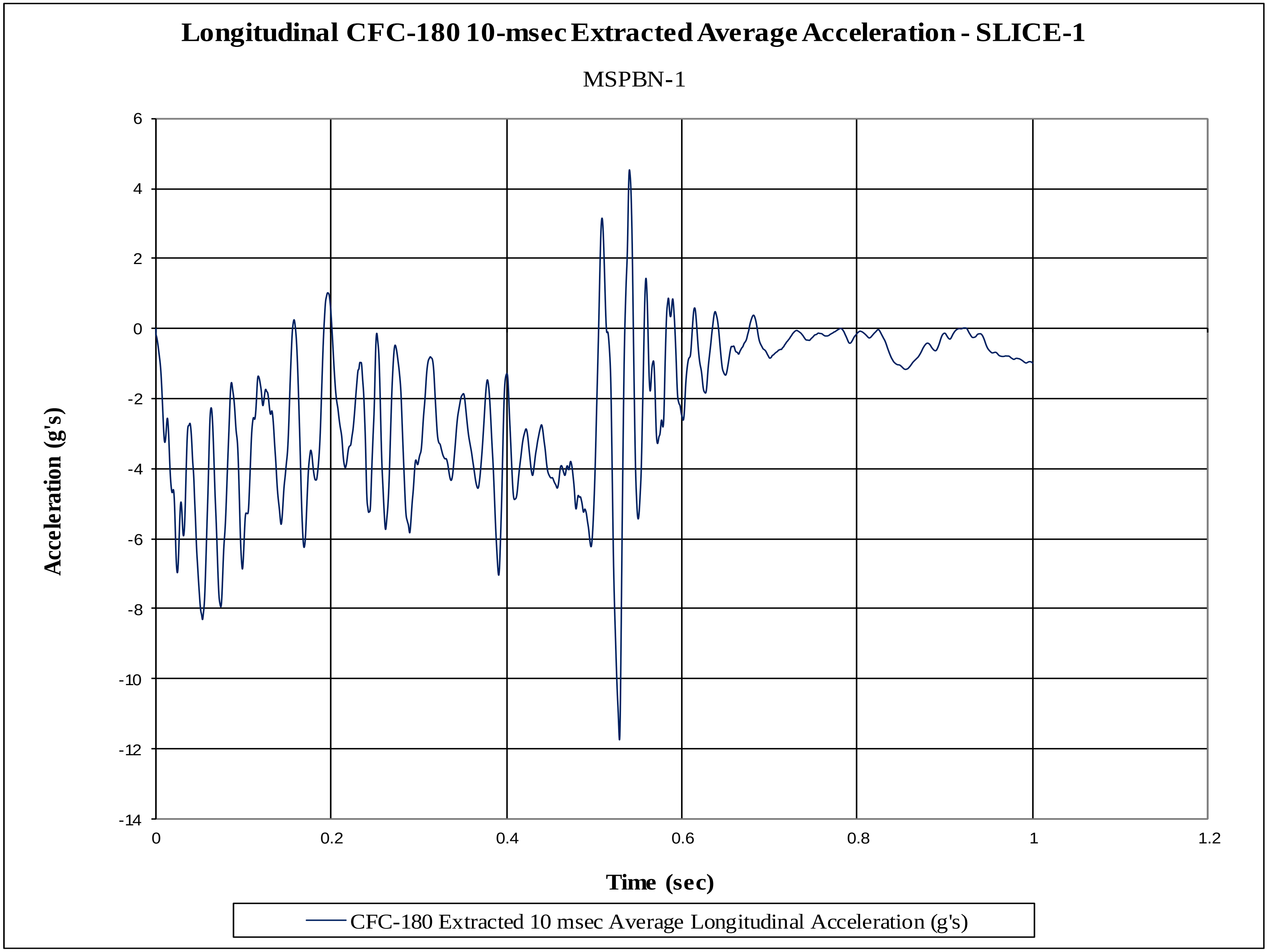


Figure E-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MSPBN-1

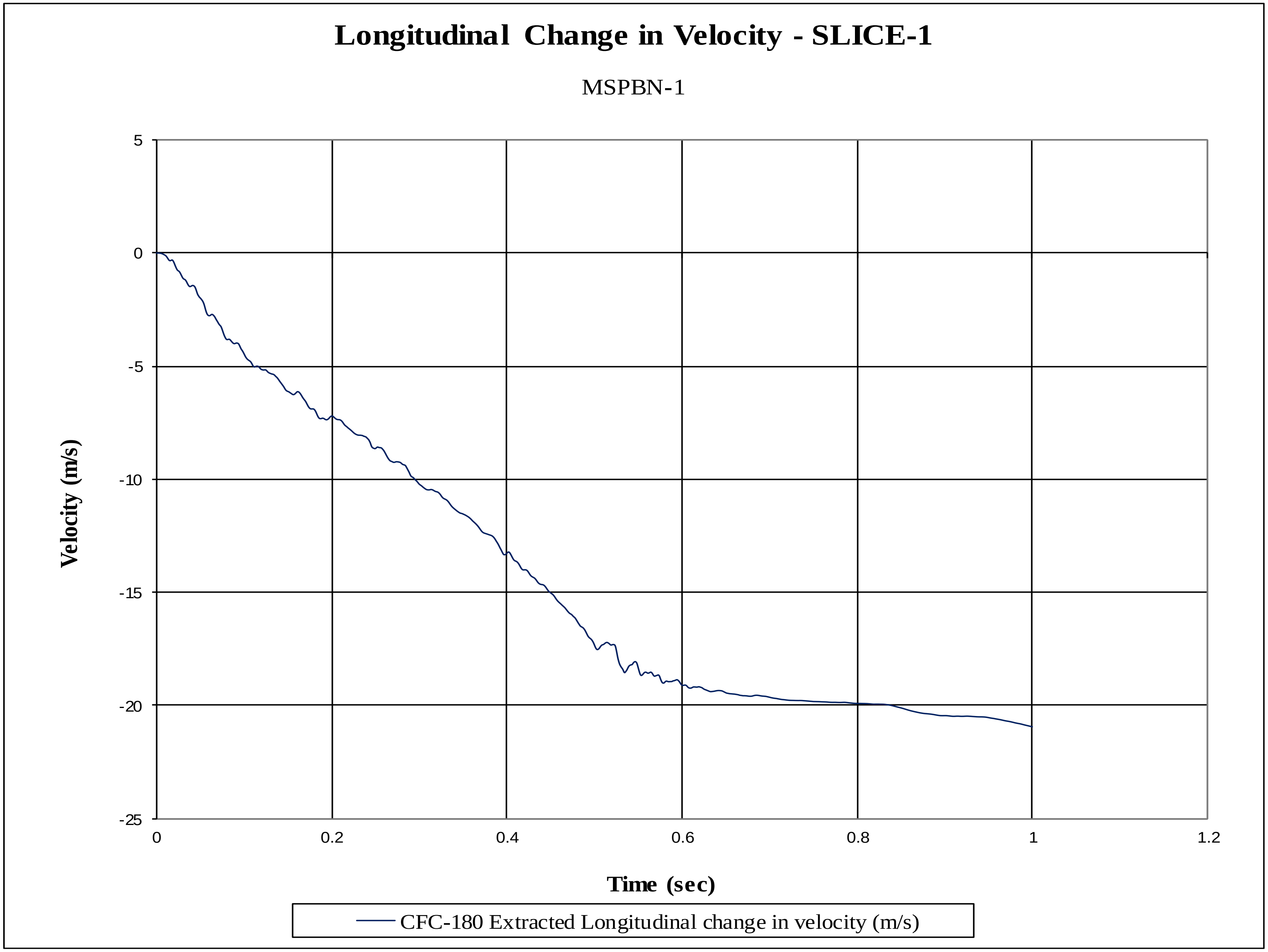


Figure E-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MSPBN-1

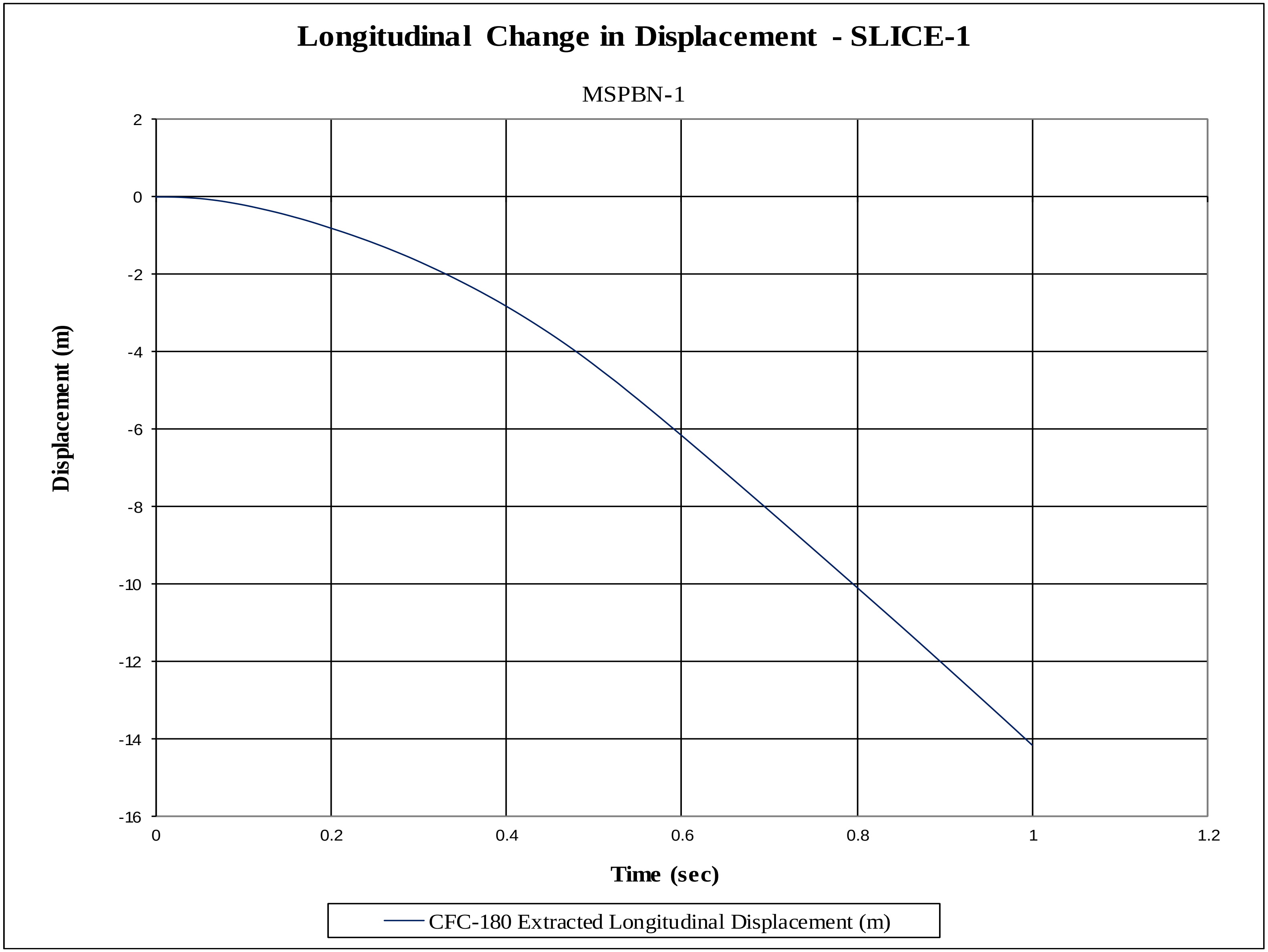


Figure E-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MSPBN-1

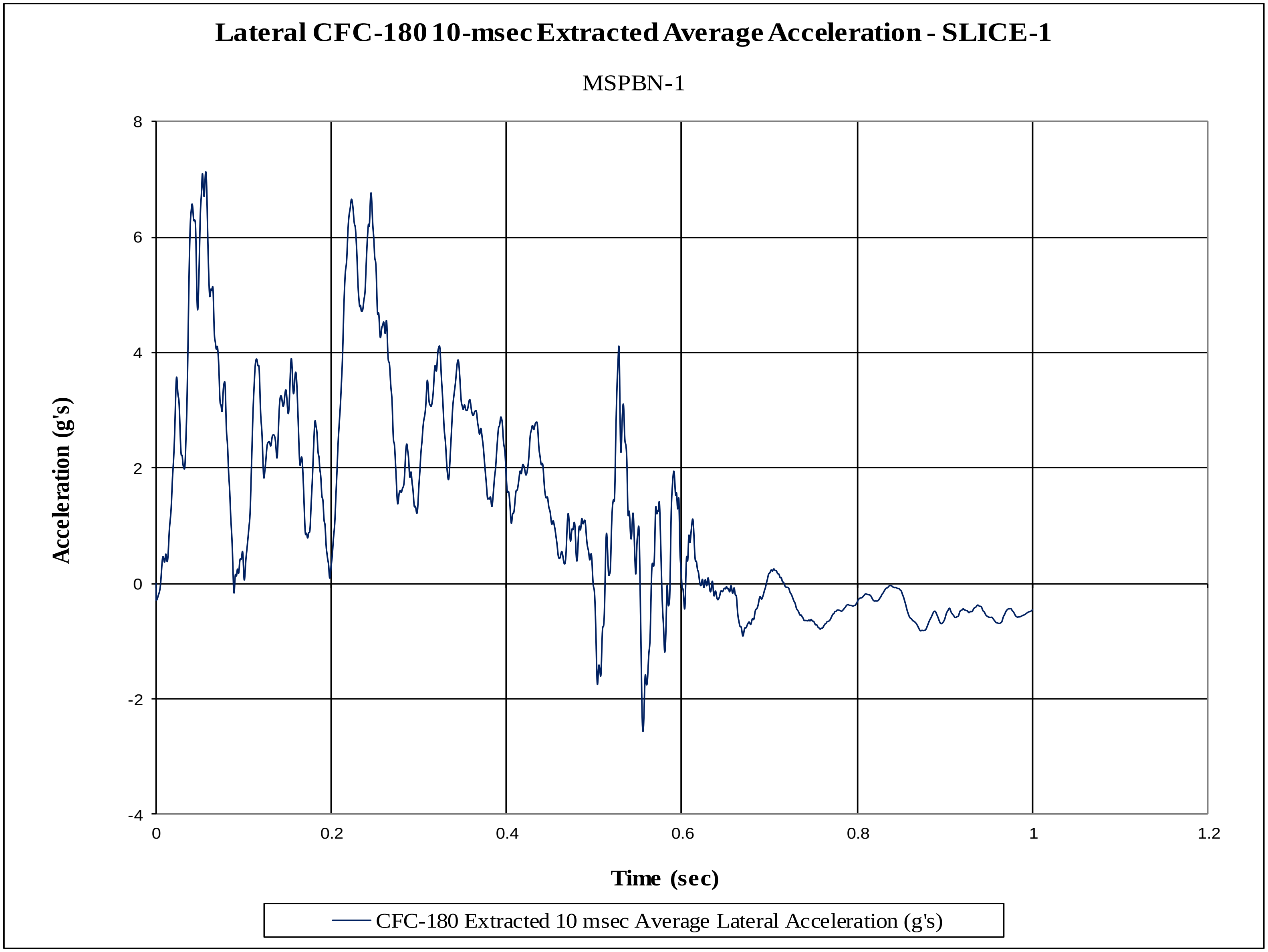


Figure E-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MSPBN-1

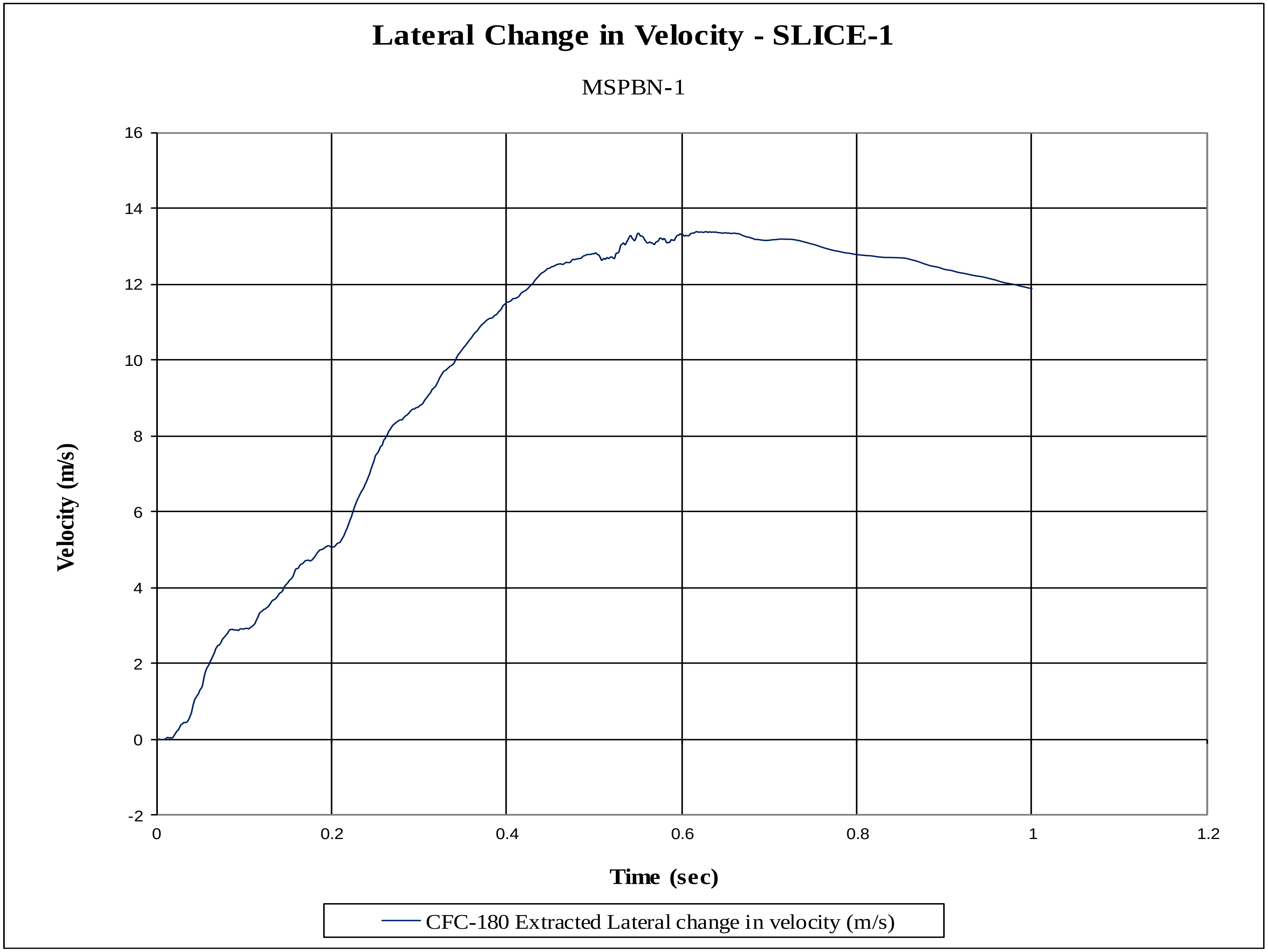


Figure E-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MSPBN-1

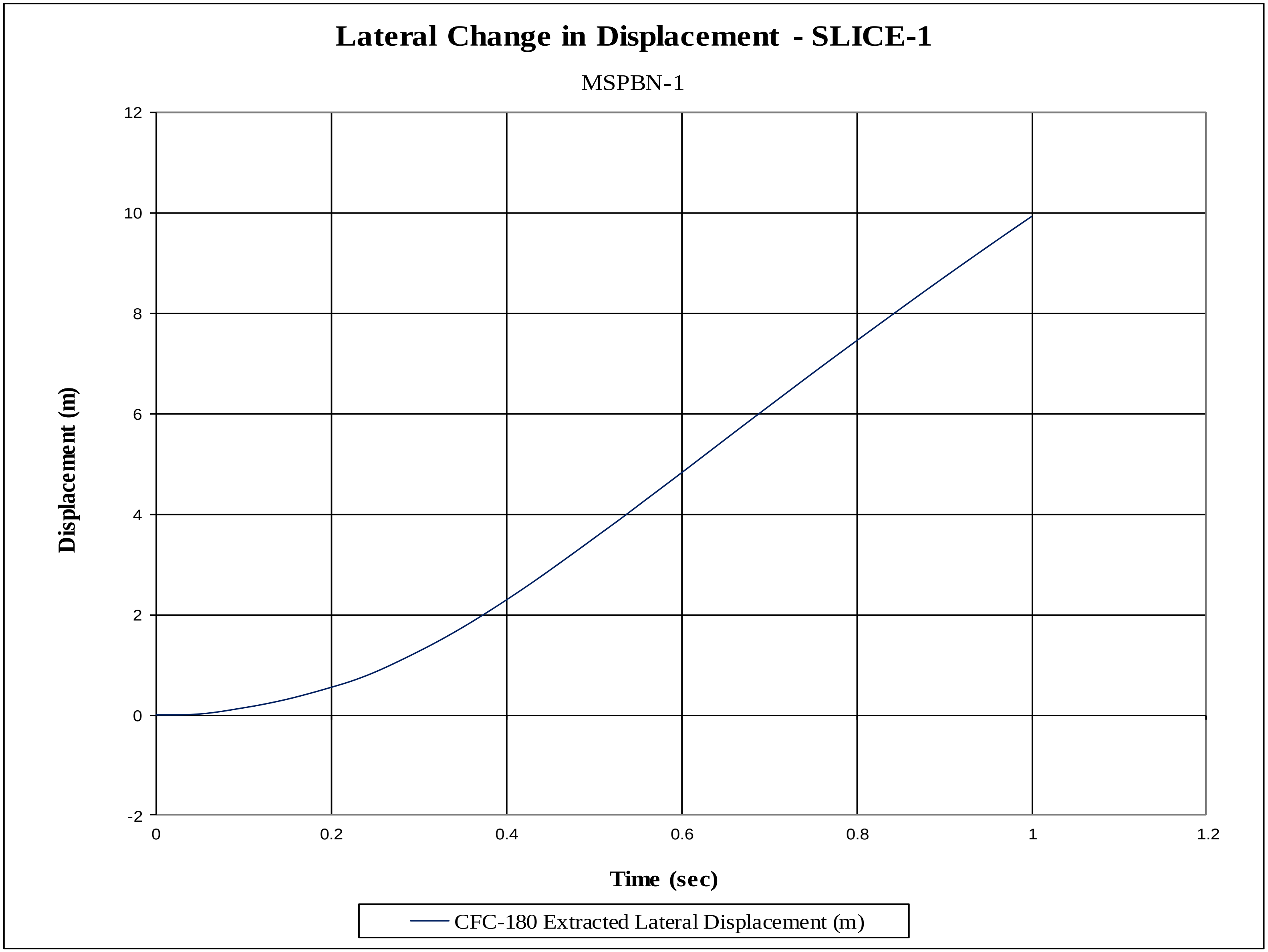


Figure E-6. Lateral Occupant Displacement (SLICE-1), Test No. MSPBN-1

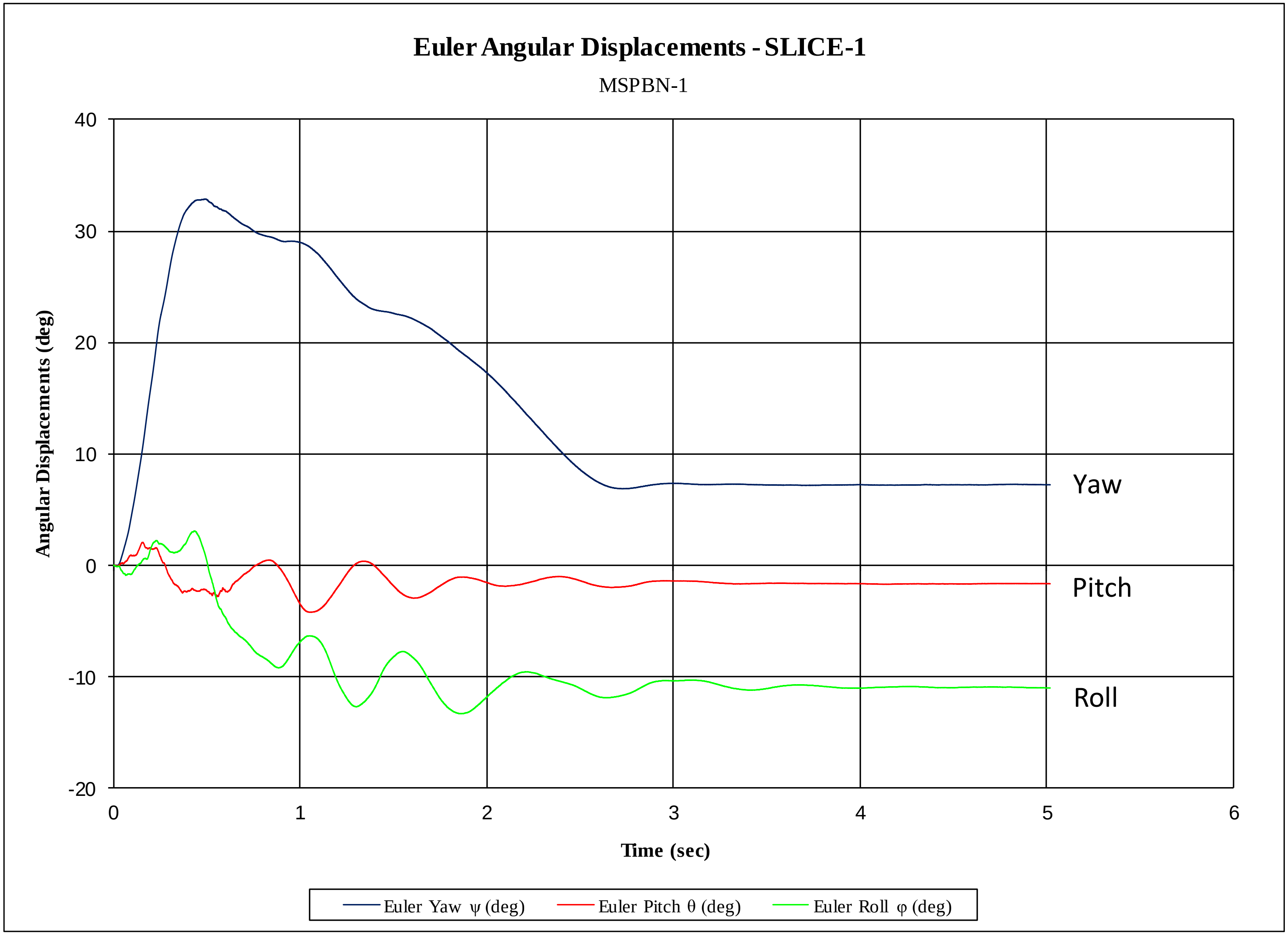


Figure E-7. Vehicle Yaw, Pitch and Roll Angular Displacements (SLICE-1), Test No. MSPBN-1

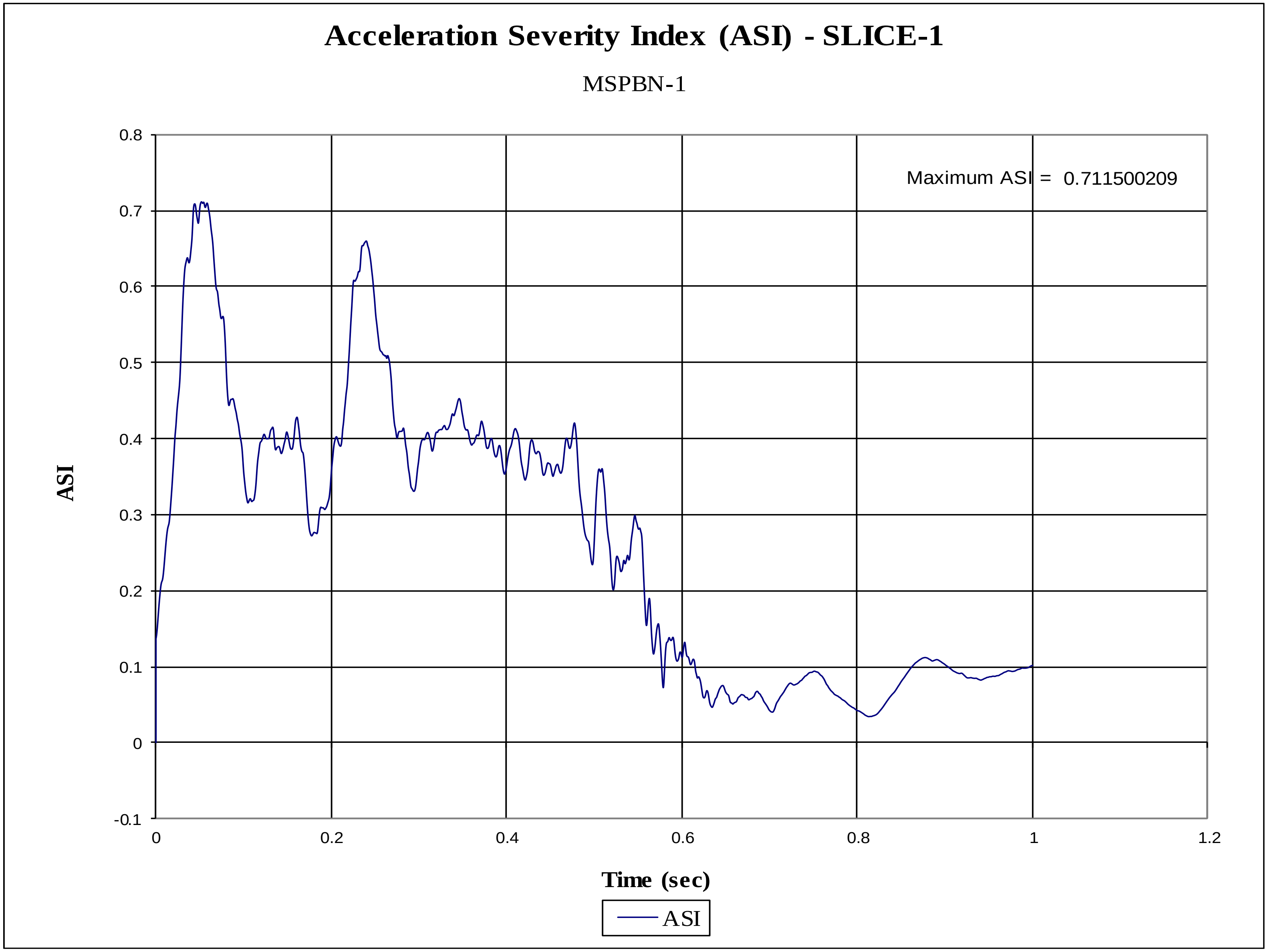


Figure E-8. Acceleration Severity Index (SLICE-1), Test No. MSPBN-1

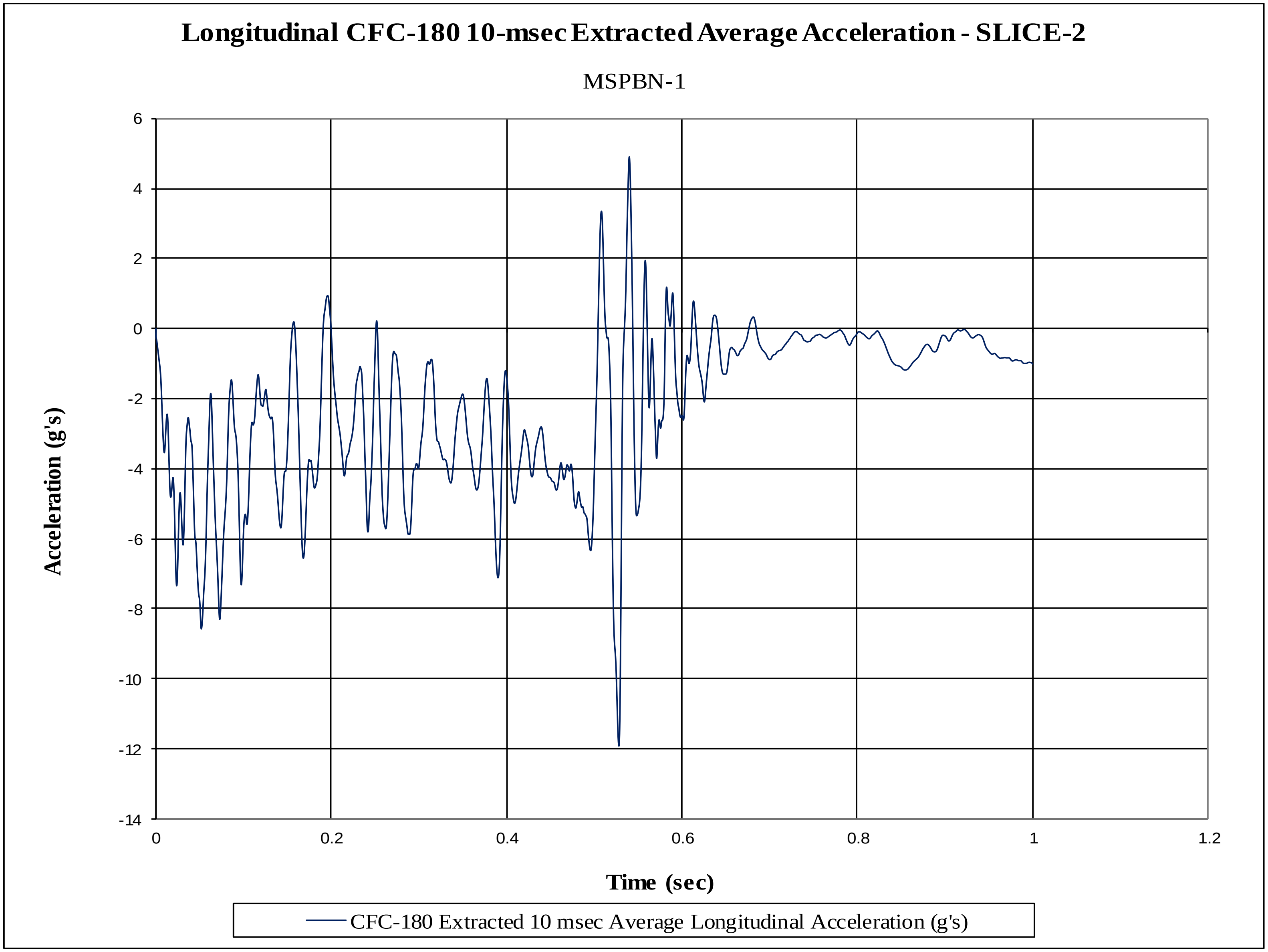


Figure E-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MSPBN-1

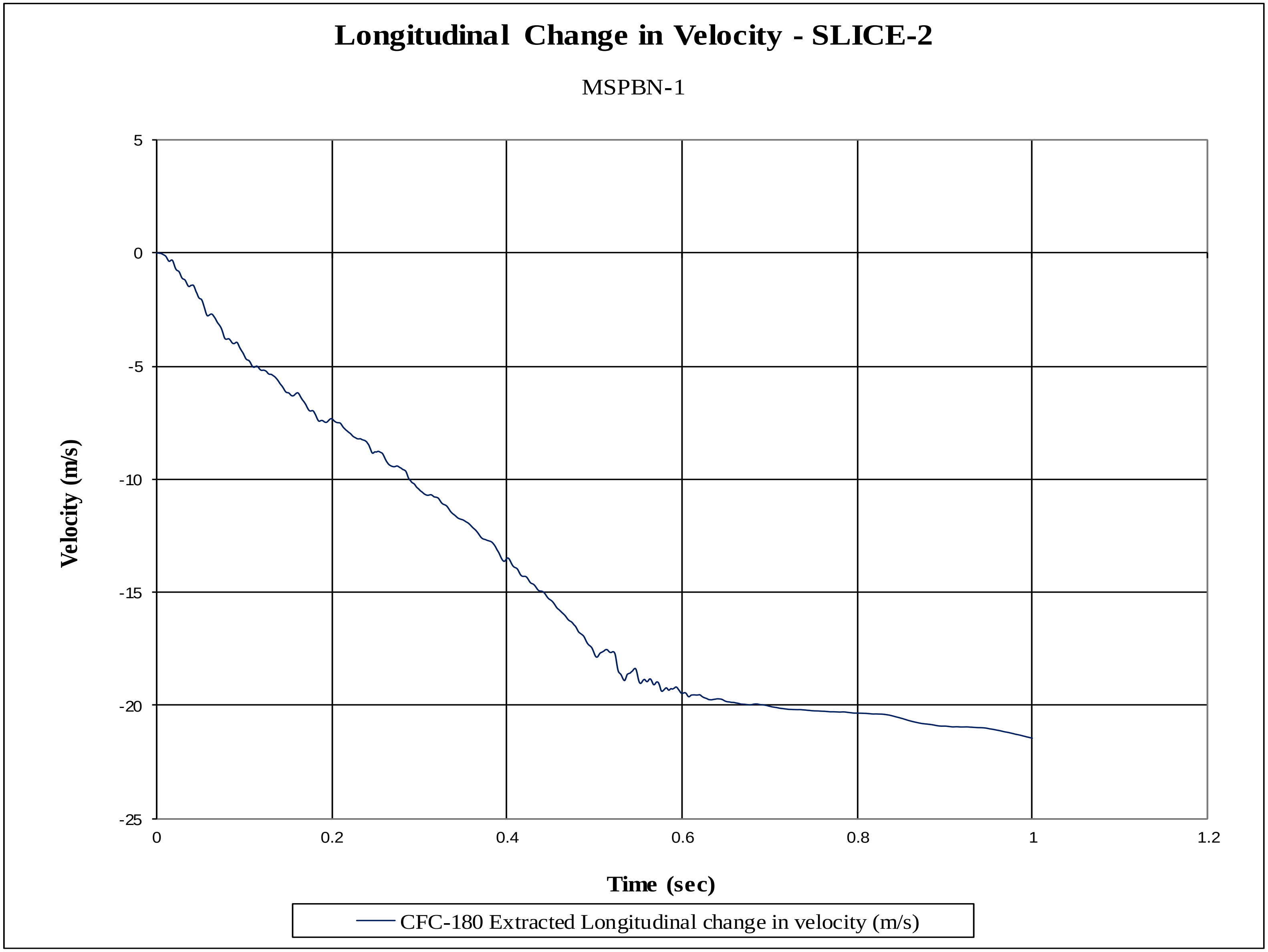


Figure E-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MSPBN-1

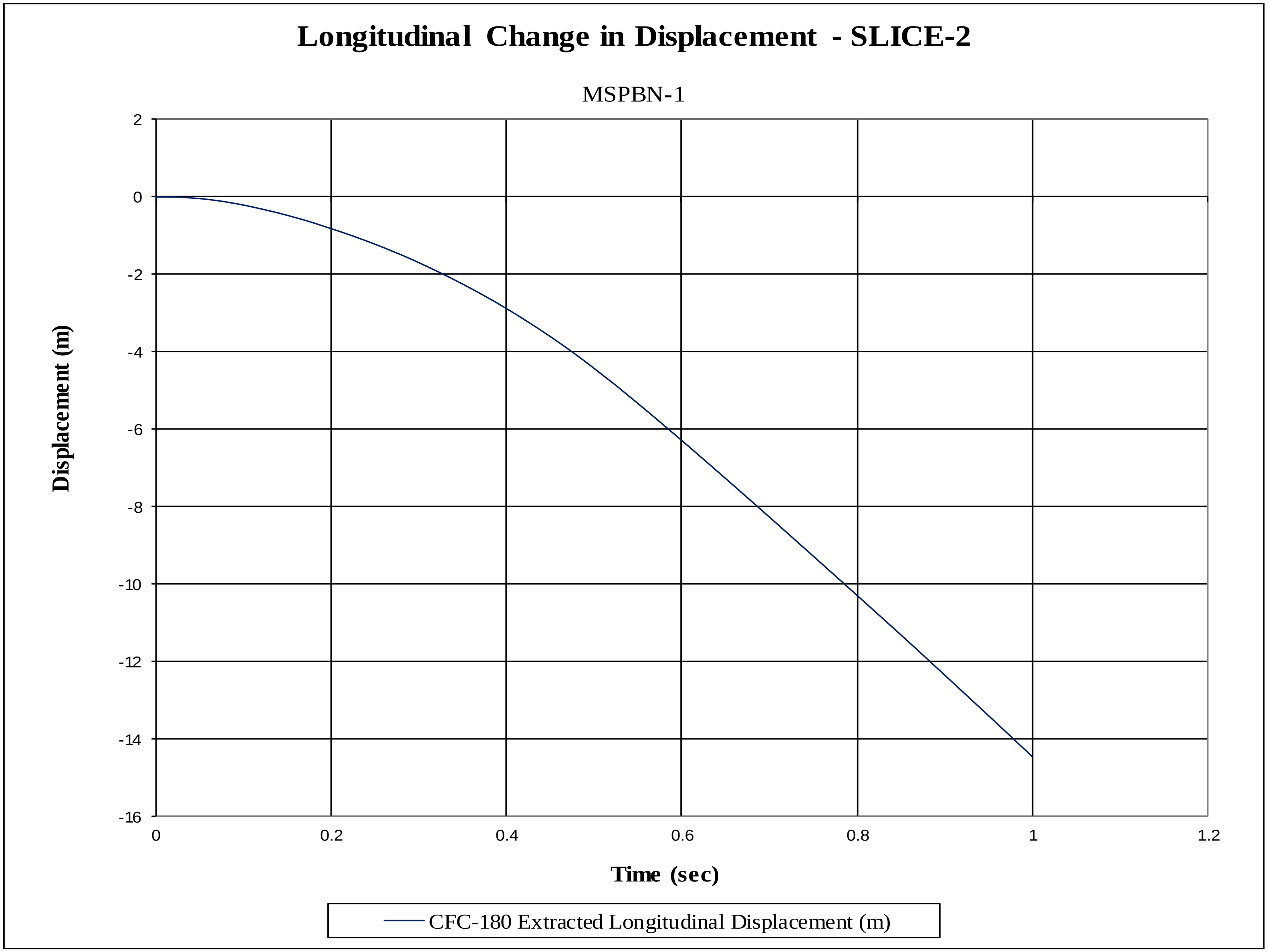


Figure E-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MSPBN-1

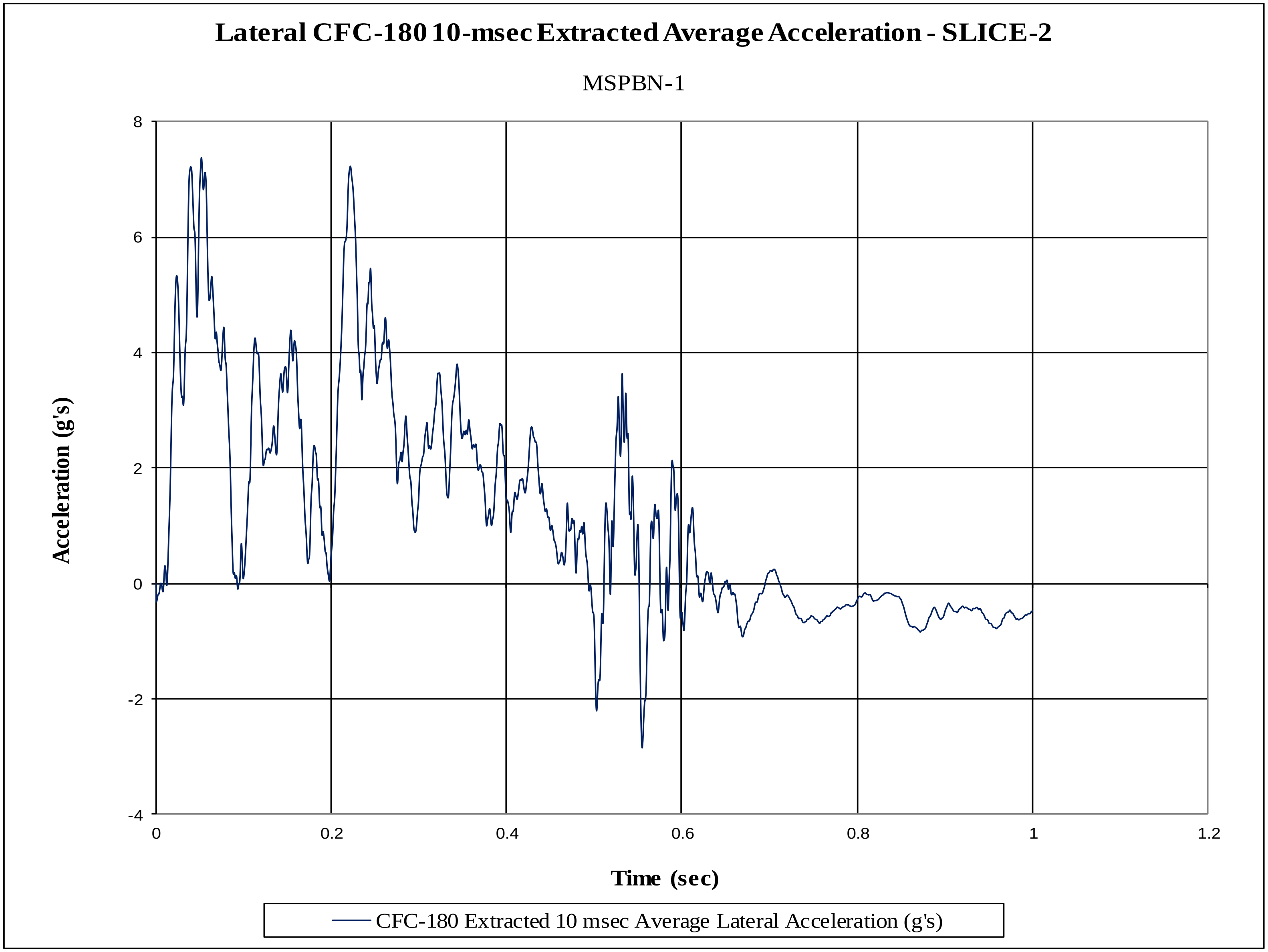


Figure E-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MSPBN-1

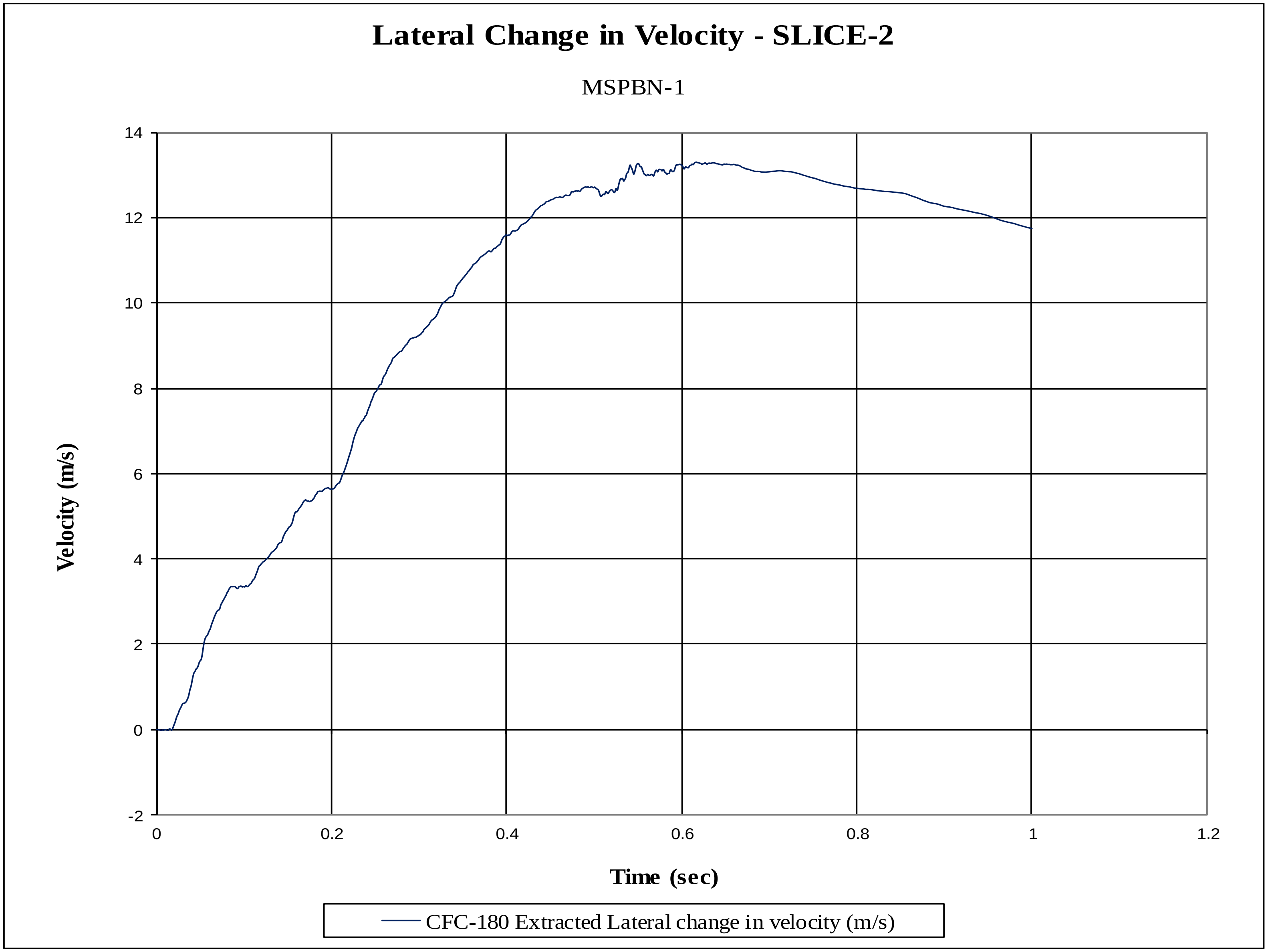


Figure E-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MSPBN-1

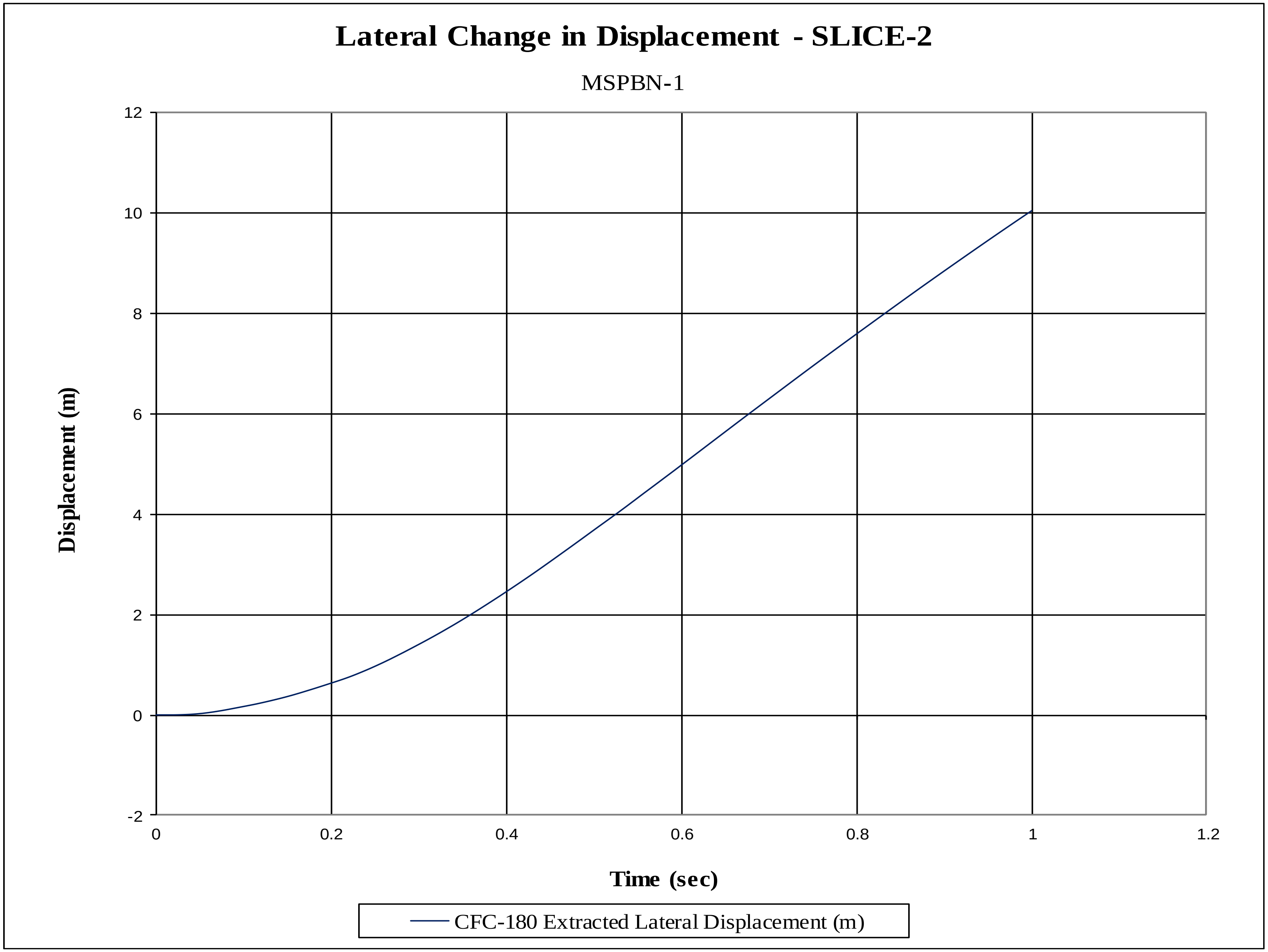


Figure E-14. Lateral Occupant Displacement (SLICE-2), Test No. MSPBN-1

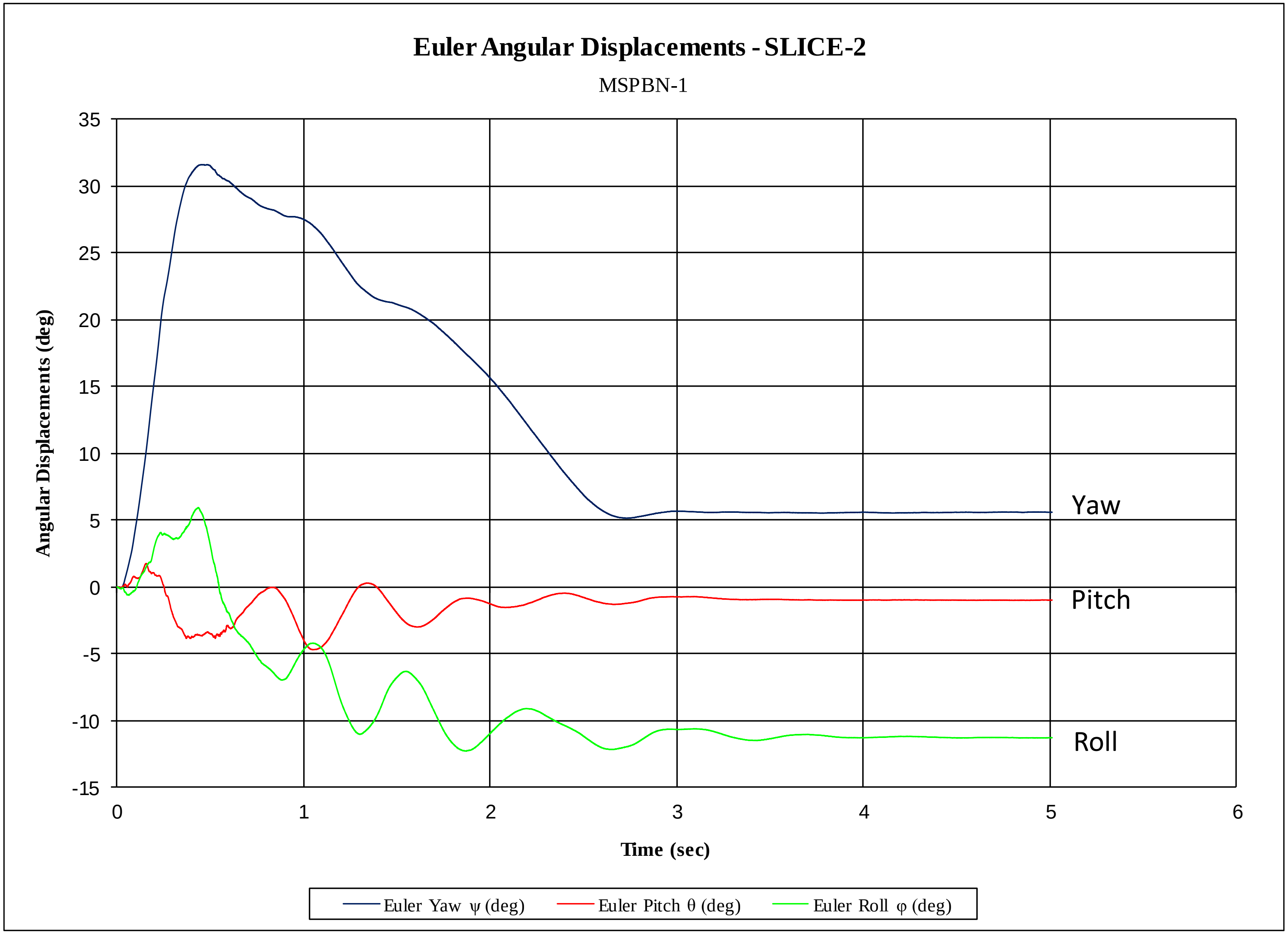


Figure E-15. Vehicle Yaw, Pitch, and Roll Angular Displacements (SLICE-2), Test No. MSPBN-1

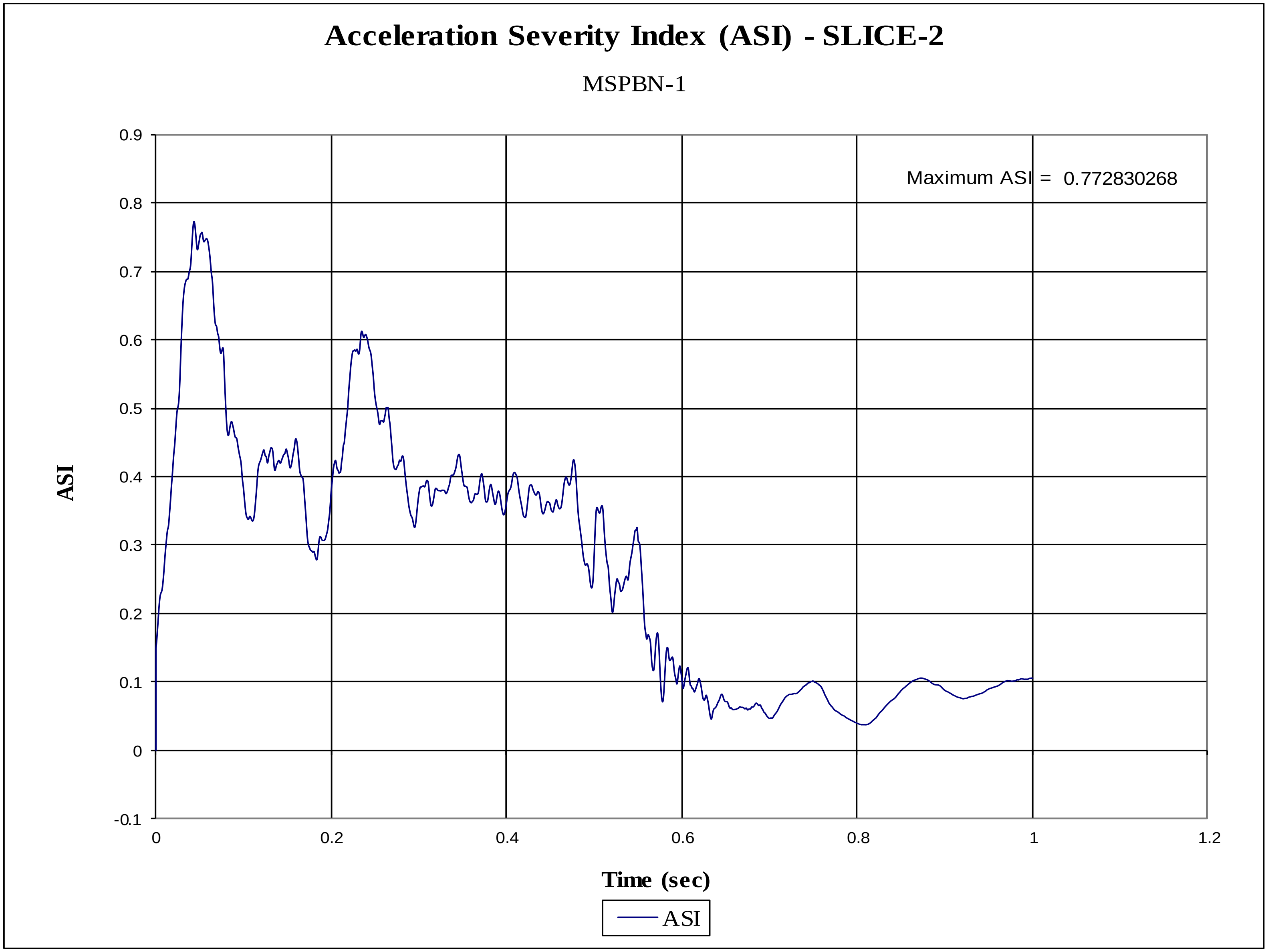


Figure E-16. Acceleration Severity Index (SLICE-2), Test No. MSPBN-1

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

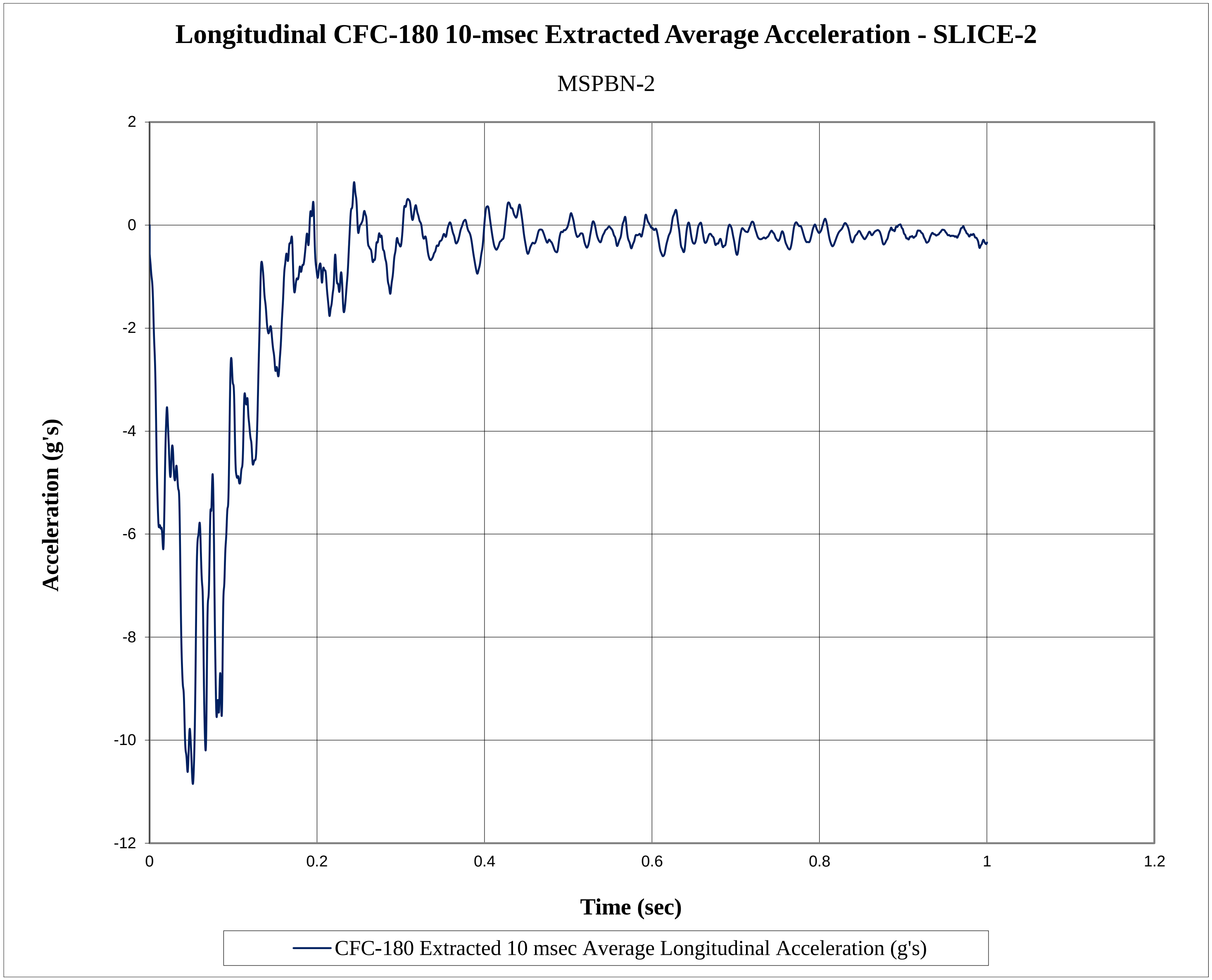


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MSPBN-2

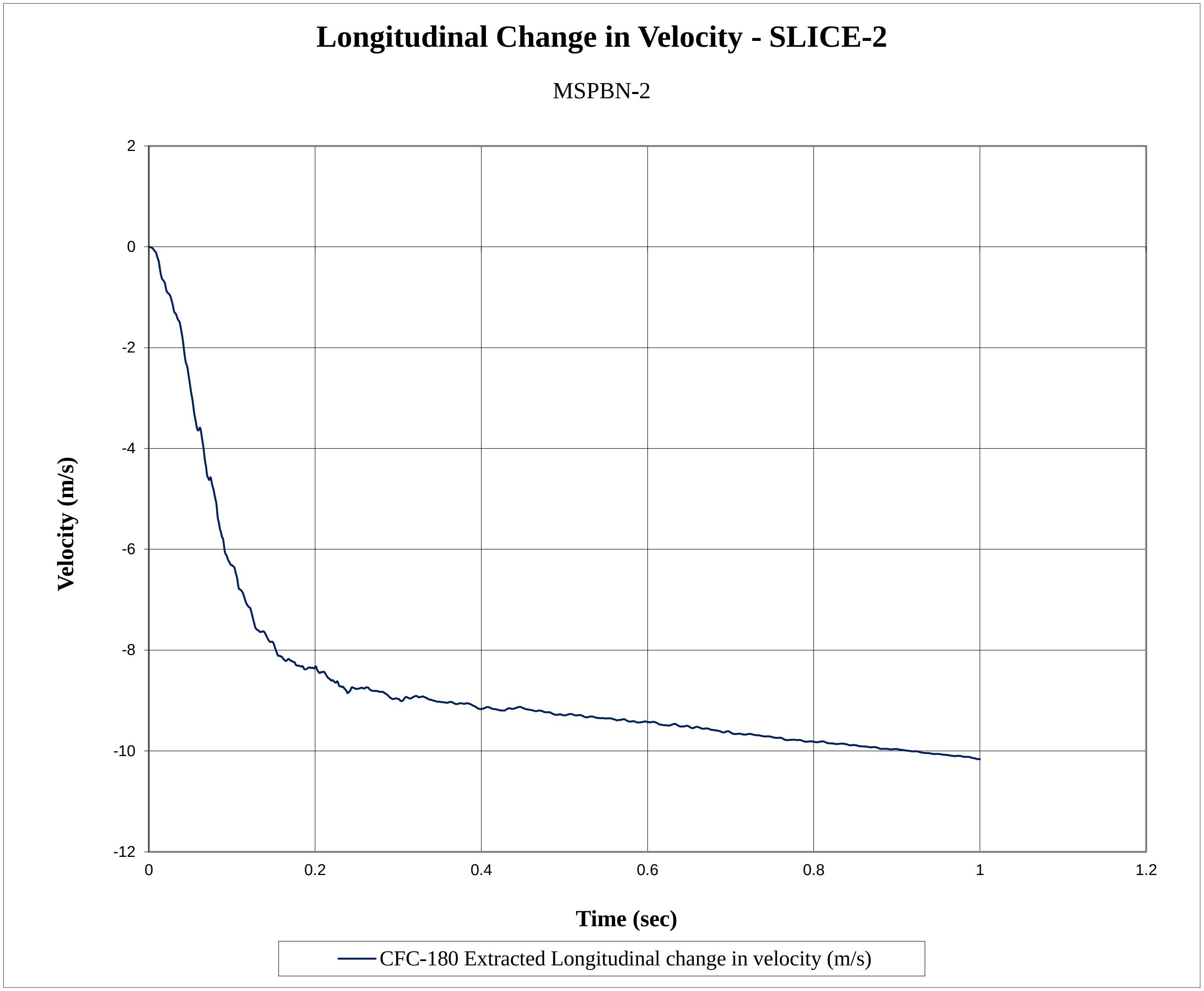


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MSPBN-2

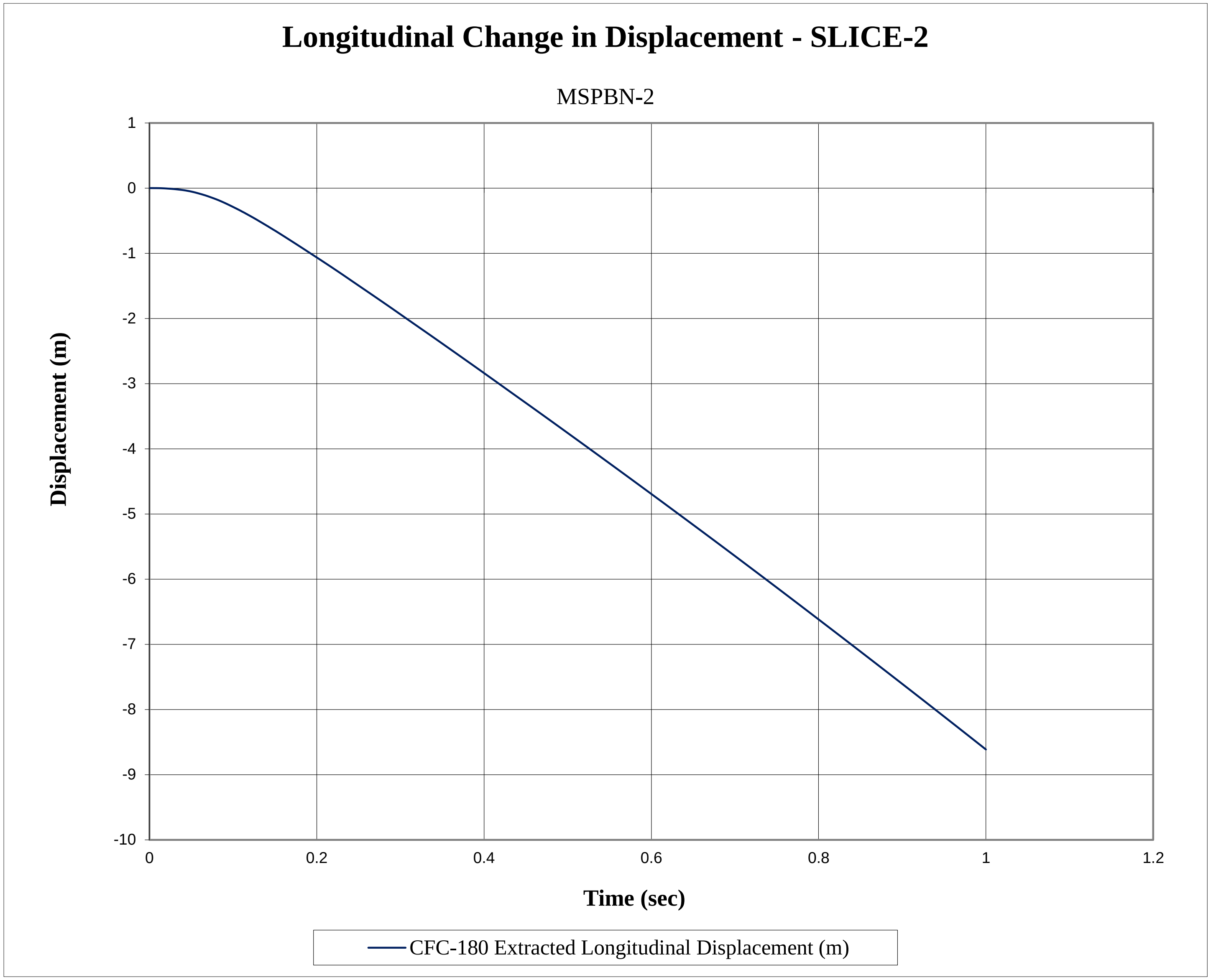


Figure F-3. Longitudinal Occupant Displacement (SLICE-2), Test No. MSPBN-2

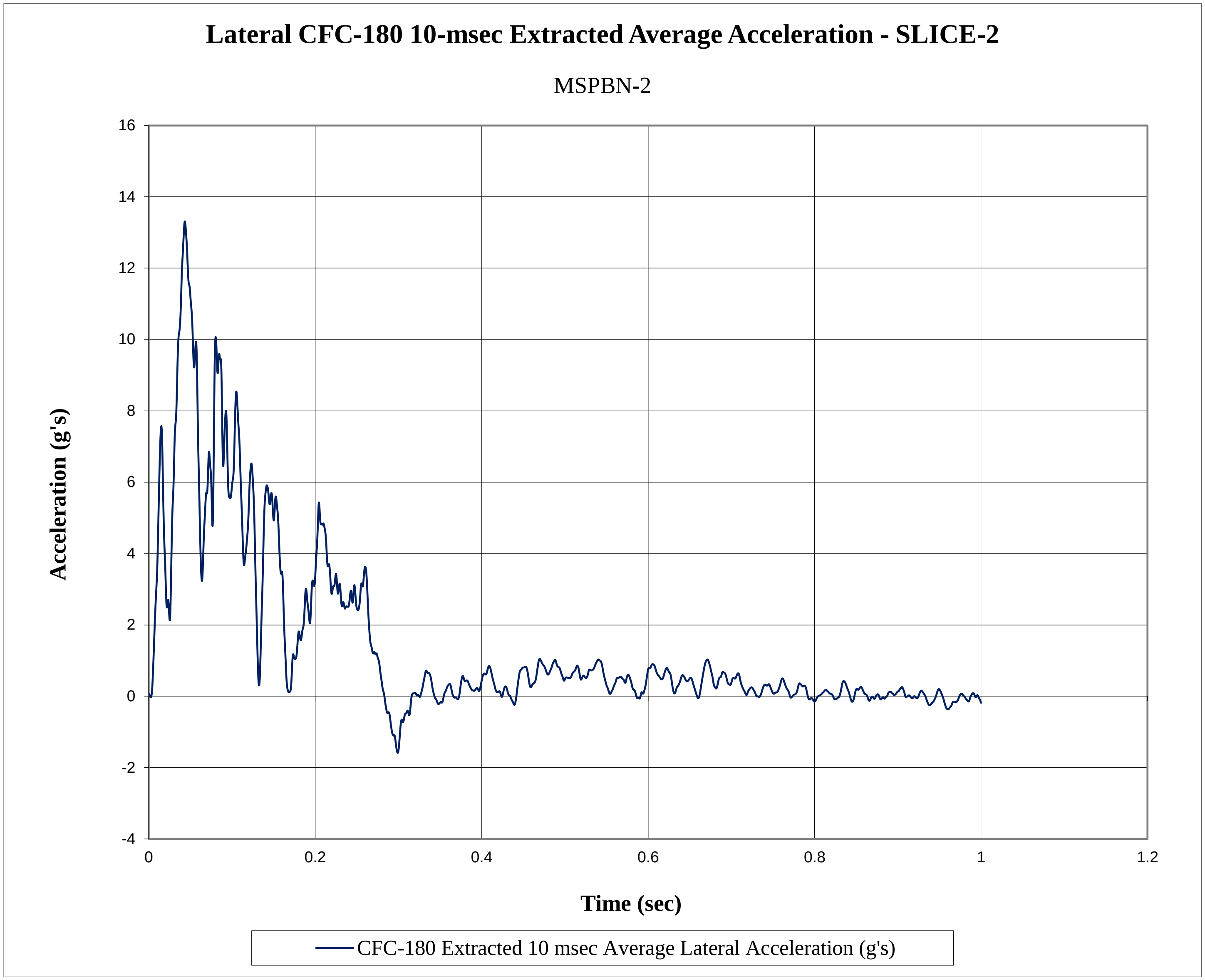


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MSPBN-2

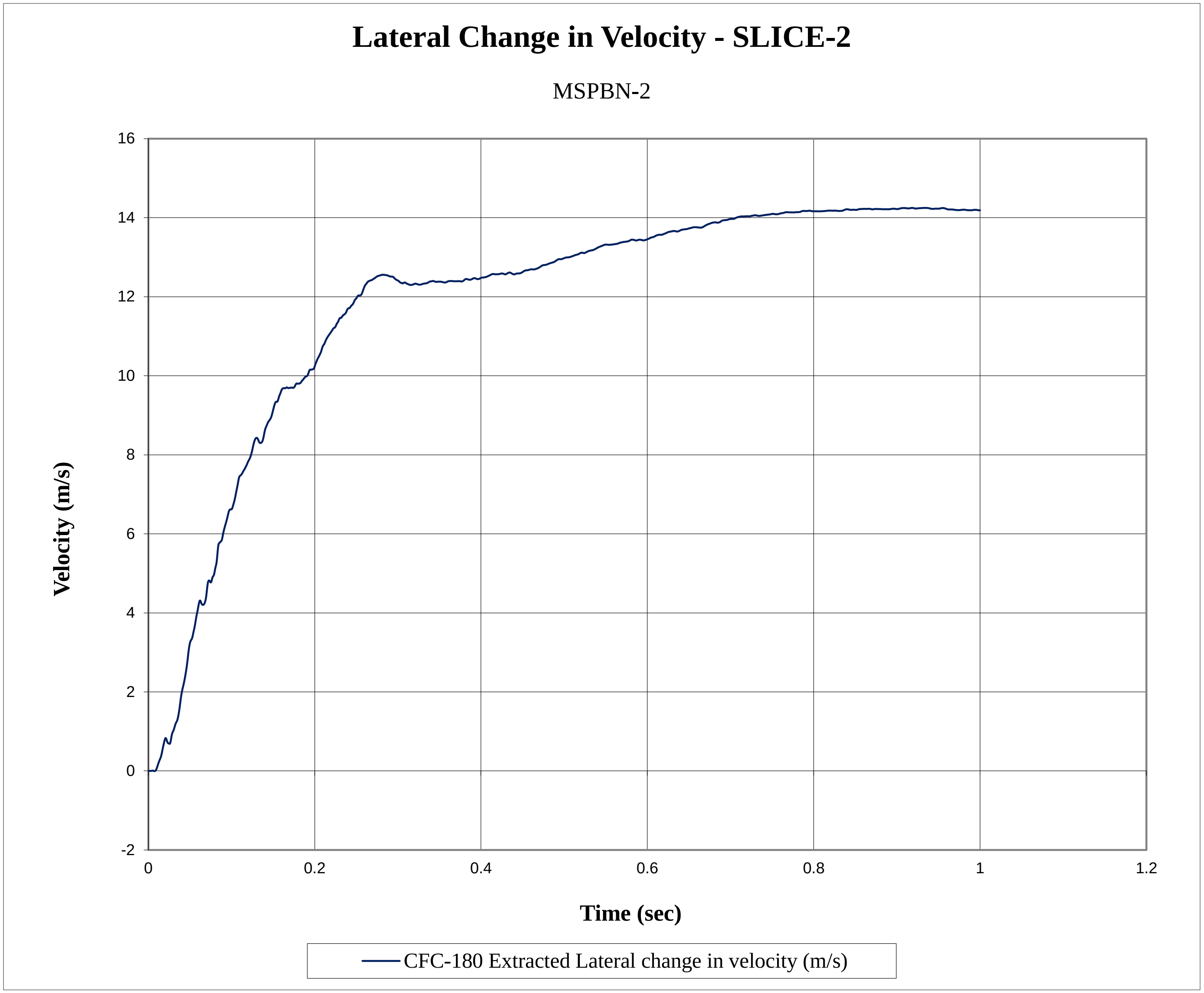


Figure F-5. Lateral Occupant Impact Velocity (SLICE-2), Test No. MSPBN-2

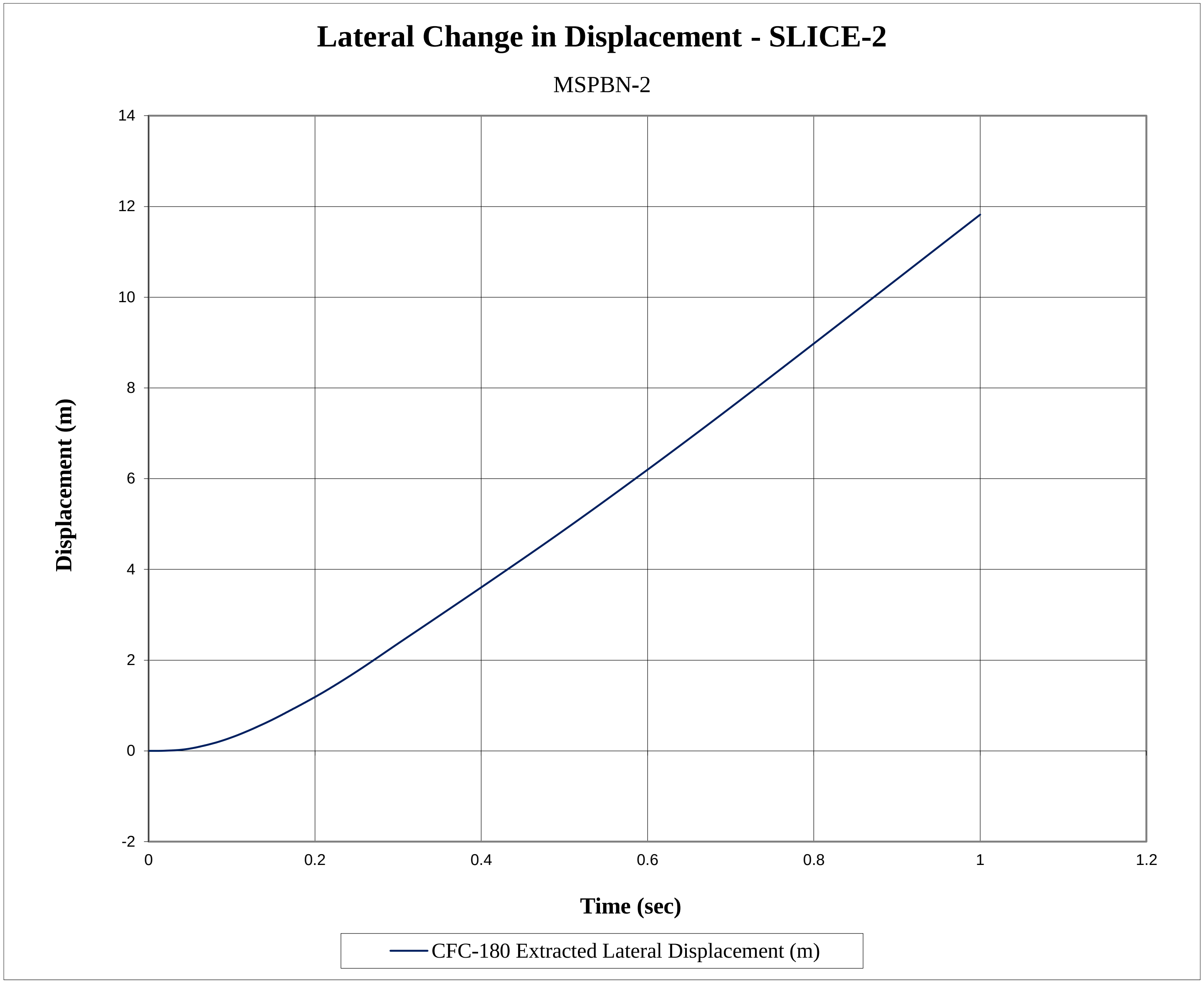


Figure F-6. Lateral Occupant Displacement (SLICE-2), Test No. MSPBN-2

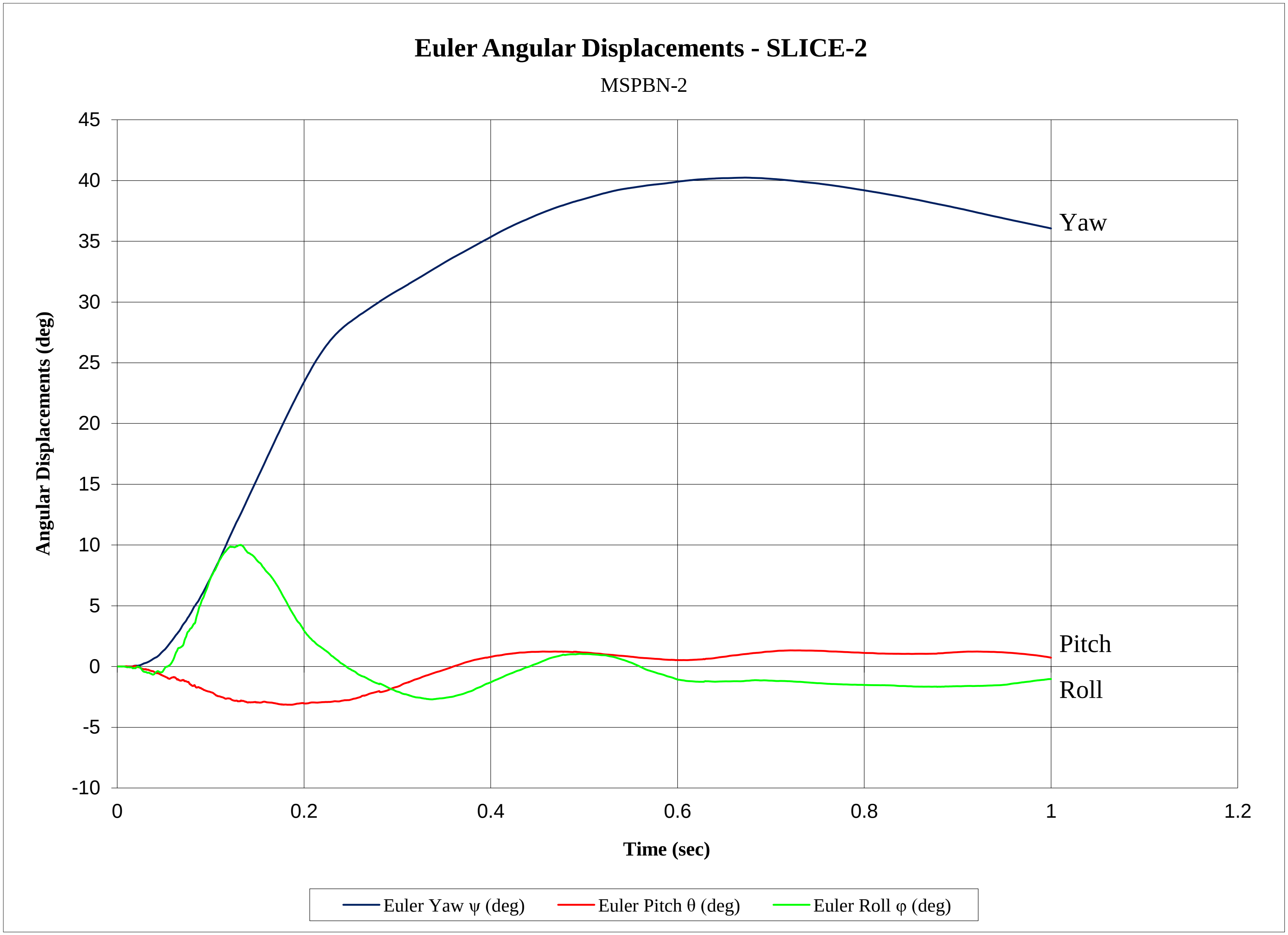


Figure F-7. Vehicle Yaw, Pitch, and Roll Angular Displacements (SLICE-2), Test No. MSPBN-2

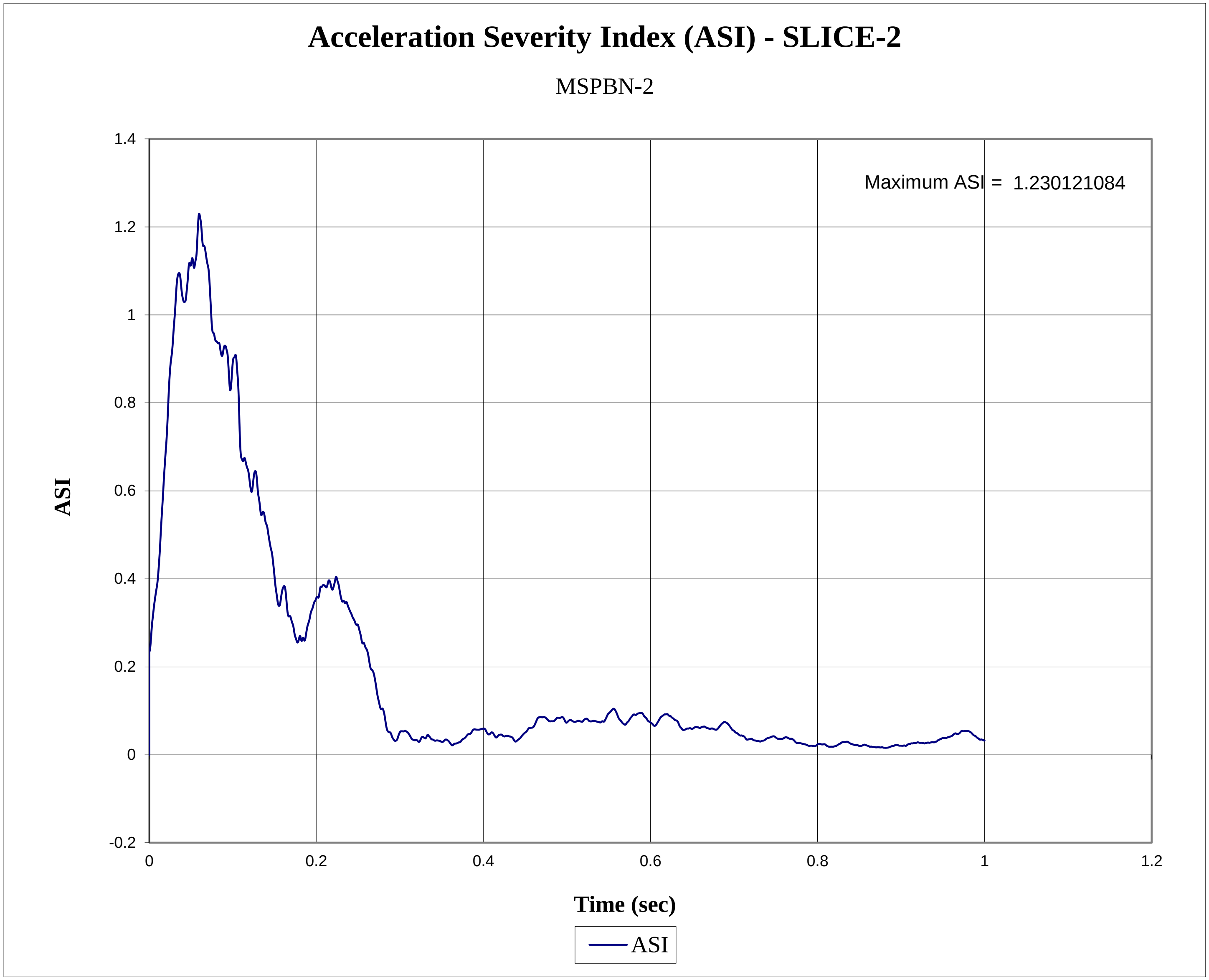


Figure F-8. Acceleration Severity Index (SLICE-2), Test No. MSPBN-2

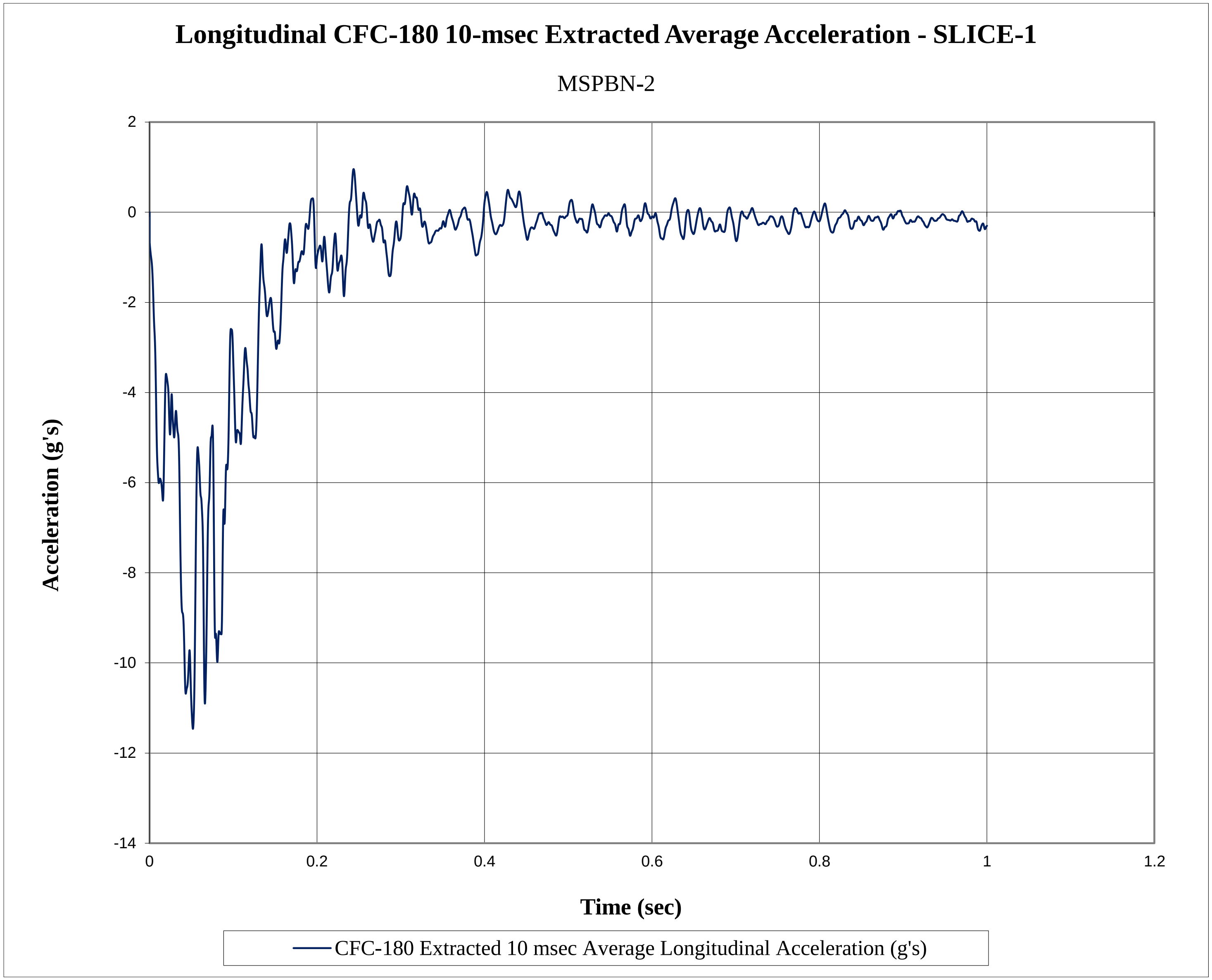


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MSPBN-2

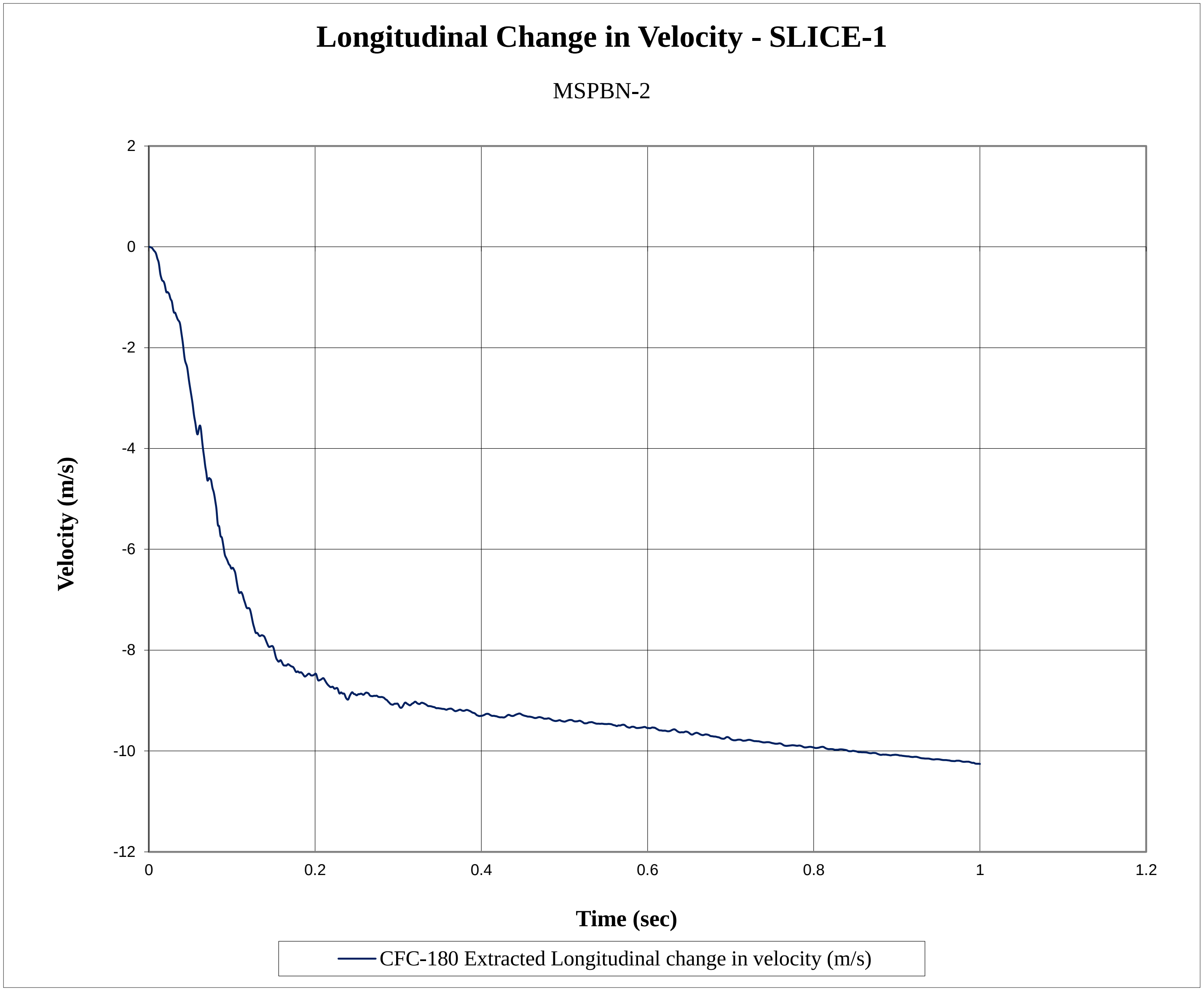


Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MSPBN-2

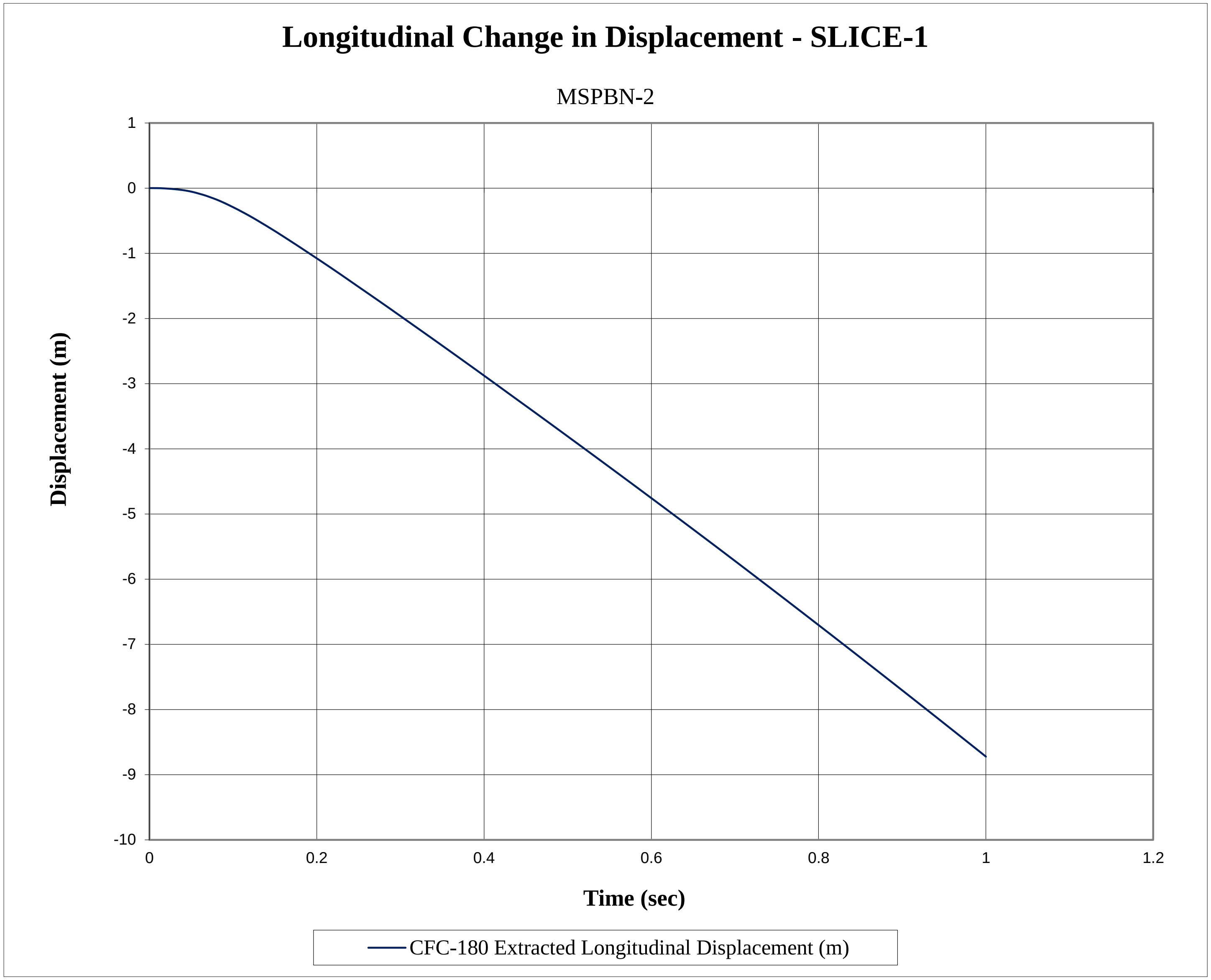


Figure F-11. Longitudinal Occupant Displacement (SLICE-1), Test No. MSPBN-2

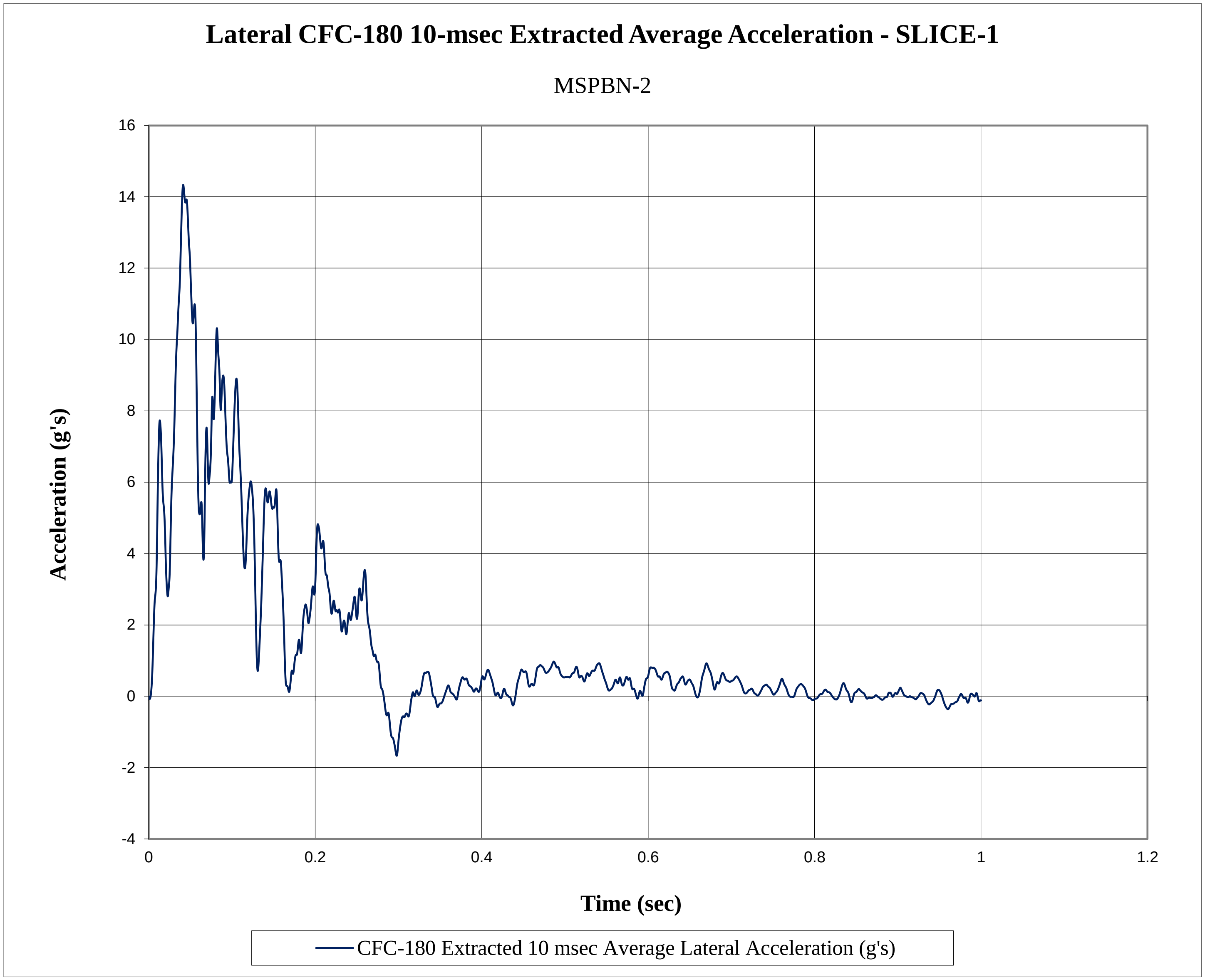


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MSPBN-2

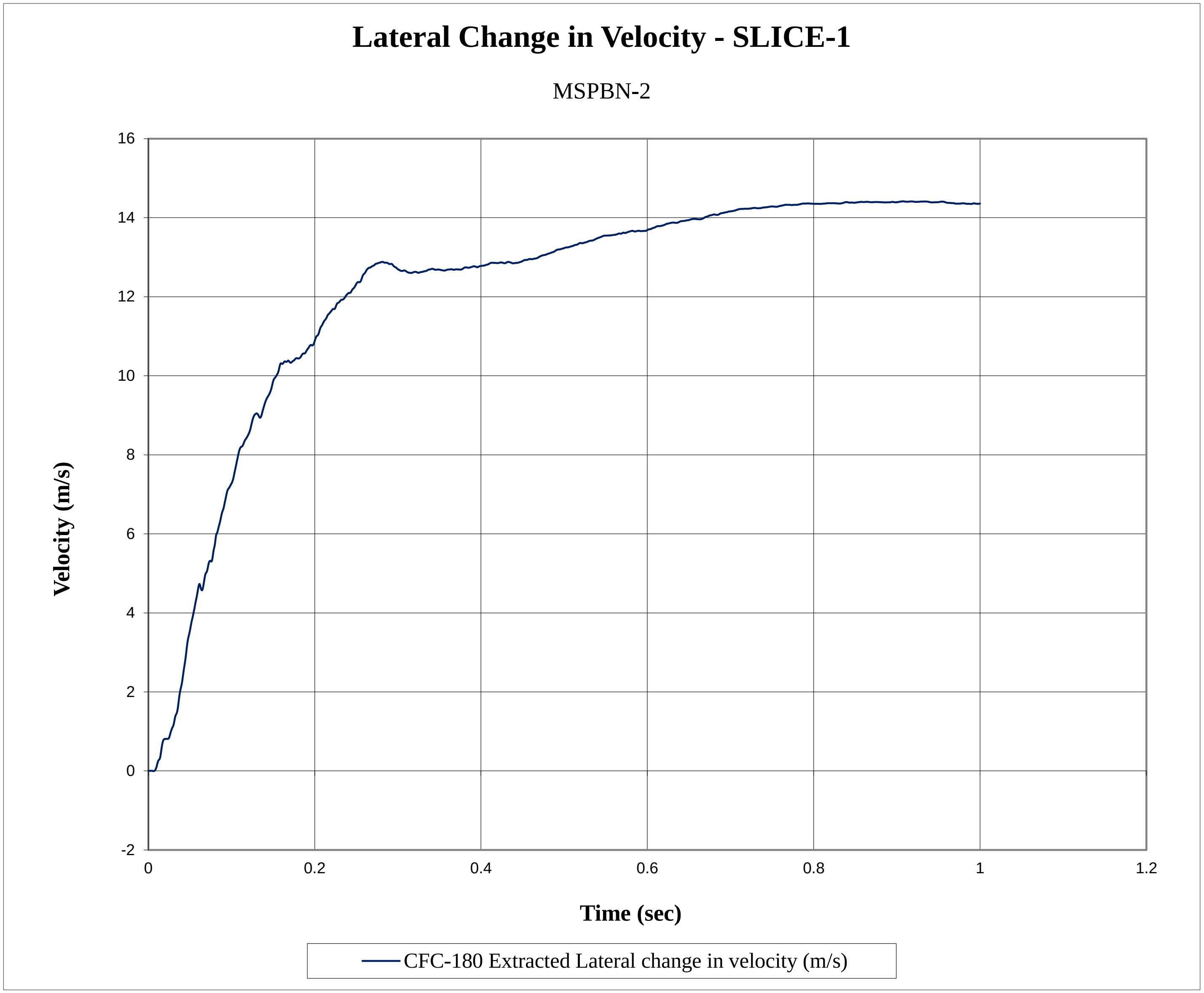


Figure F-13. Lateral Occupant Impact Velocity (SLICE-1), Test No. MSPBN-2

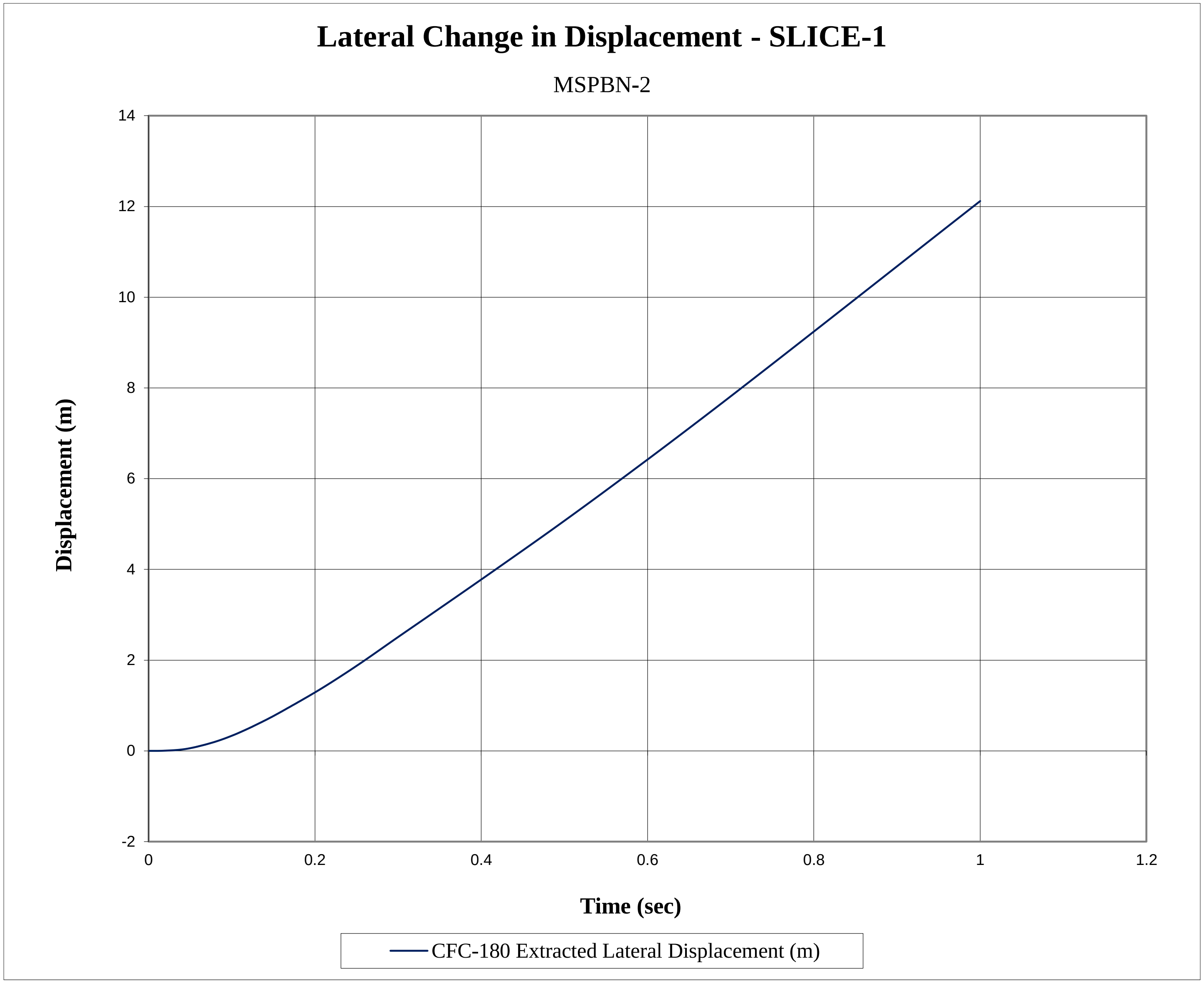


Figure F-14. Lateral Occupant Displacement (SLICE-1), Test No. MSPBN-2

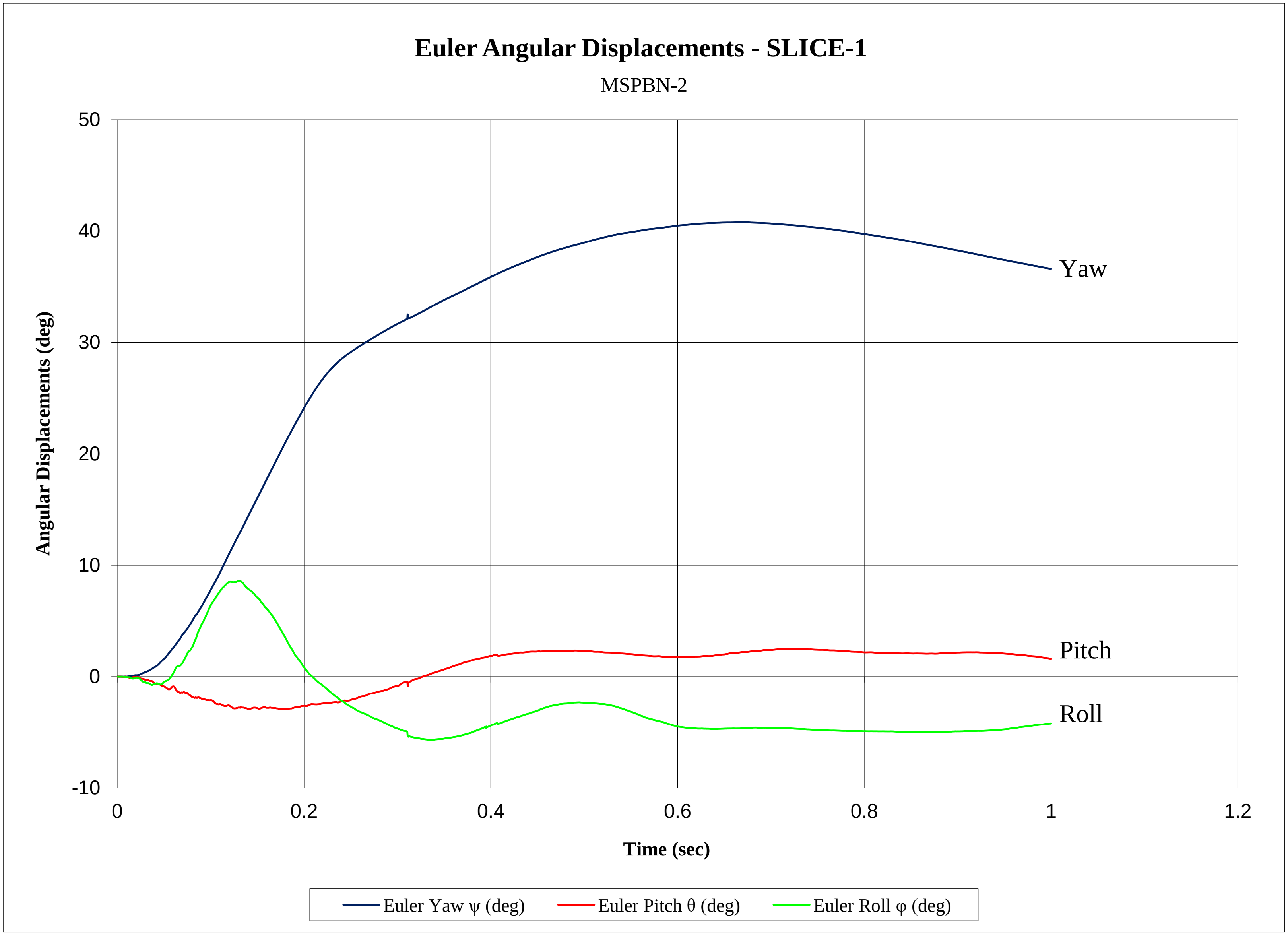


Figure F-15. Vehicle Yaw, Pitch and Roll Angular Displacements (SLICE-1), Test No. MSPBN-2

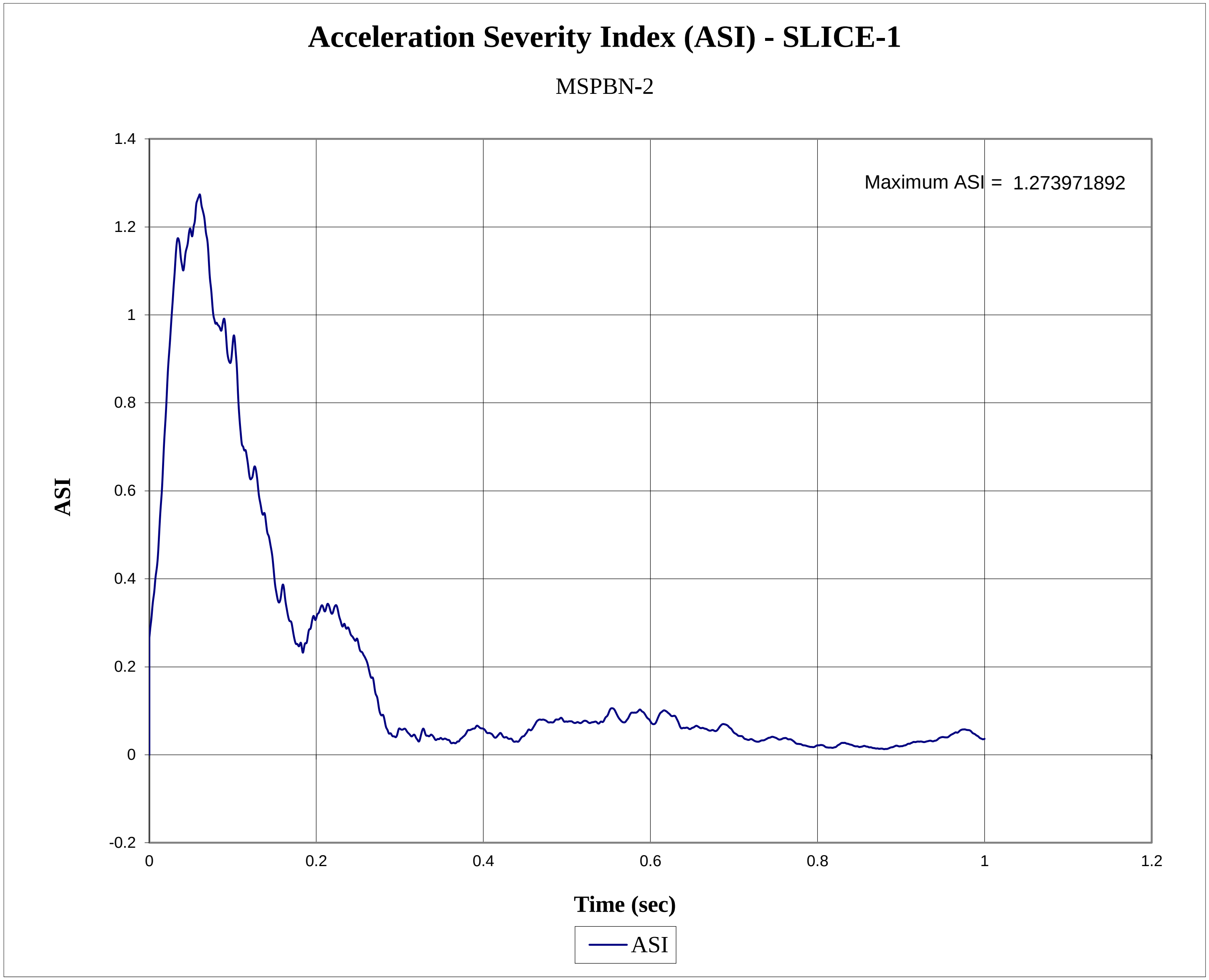


Figure F-16. Acceleration Severity Index (SLICE-1), Test No. MSPBN-2

Appendix G. Accelerometer and Rate Transducer Data Plots, Test No. MSPBN-3

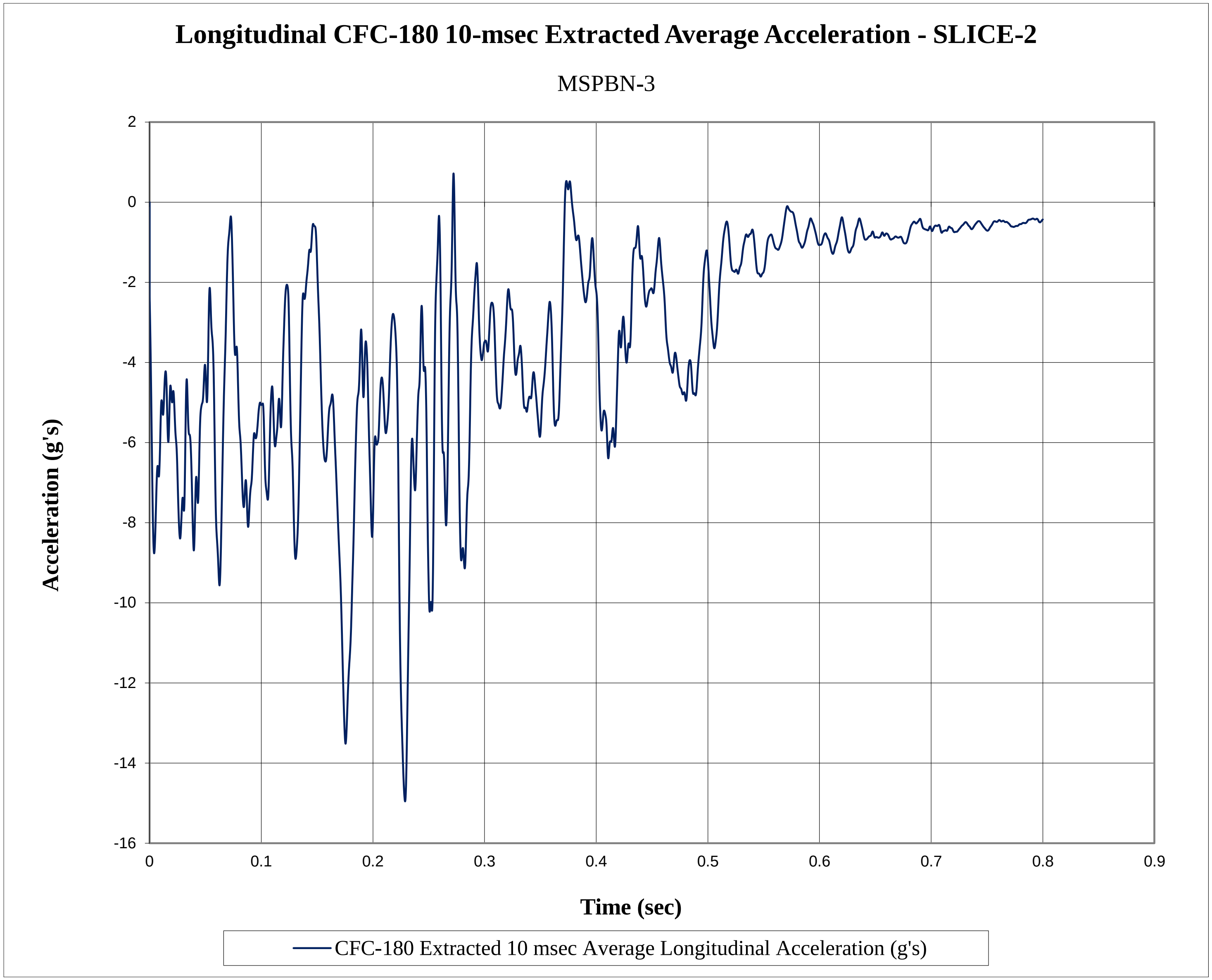


Figure G-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MSPBN-3

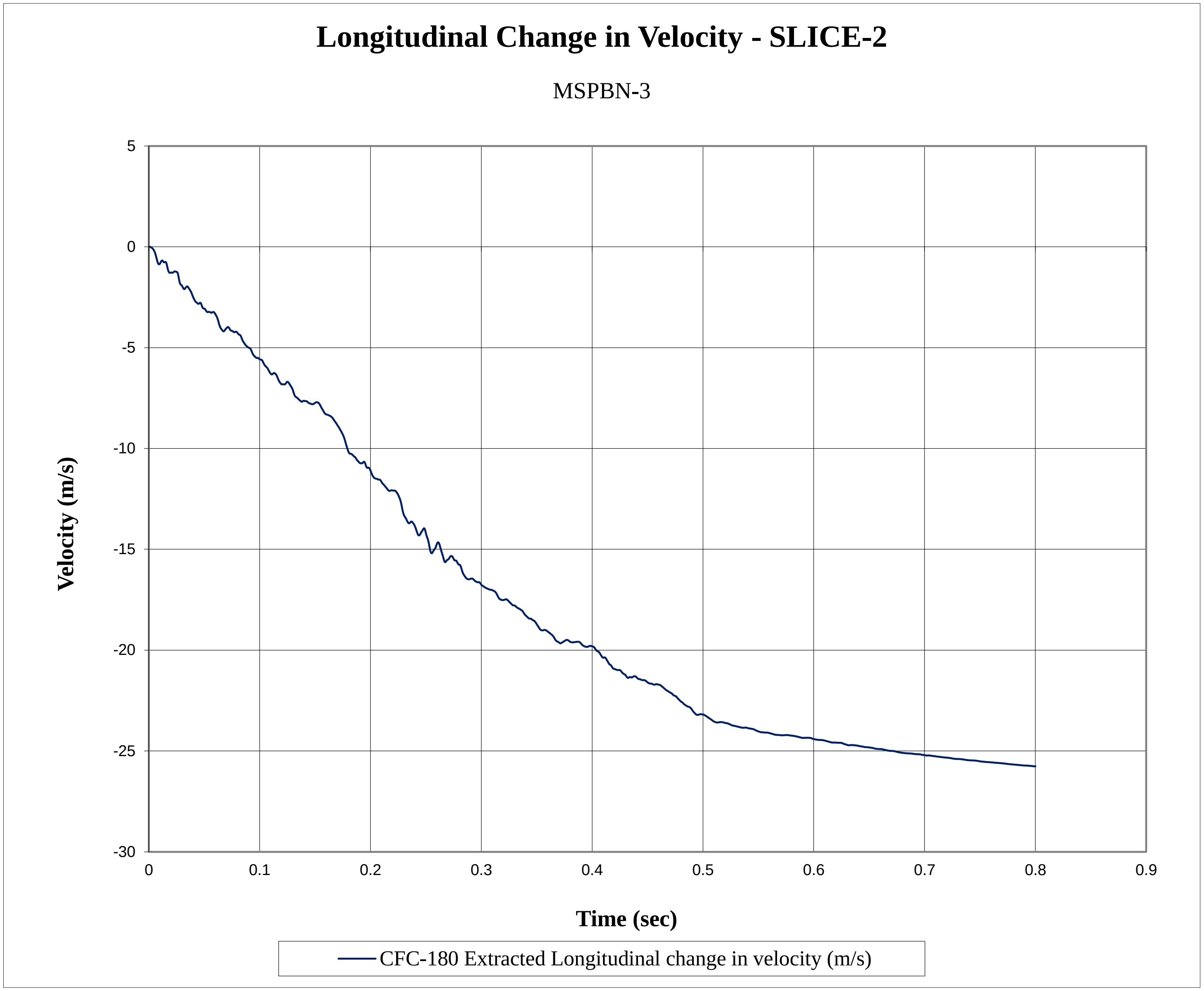


Figure G-2. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MSPBN-3

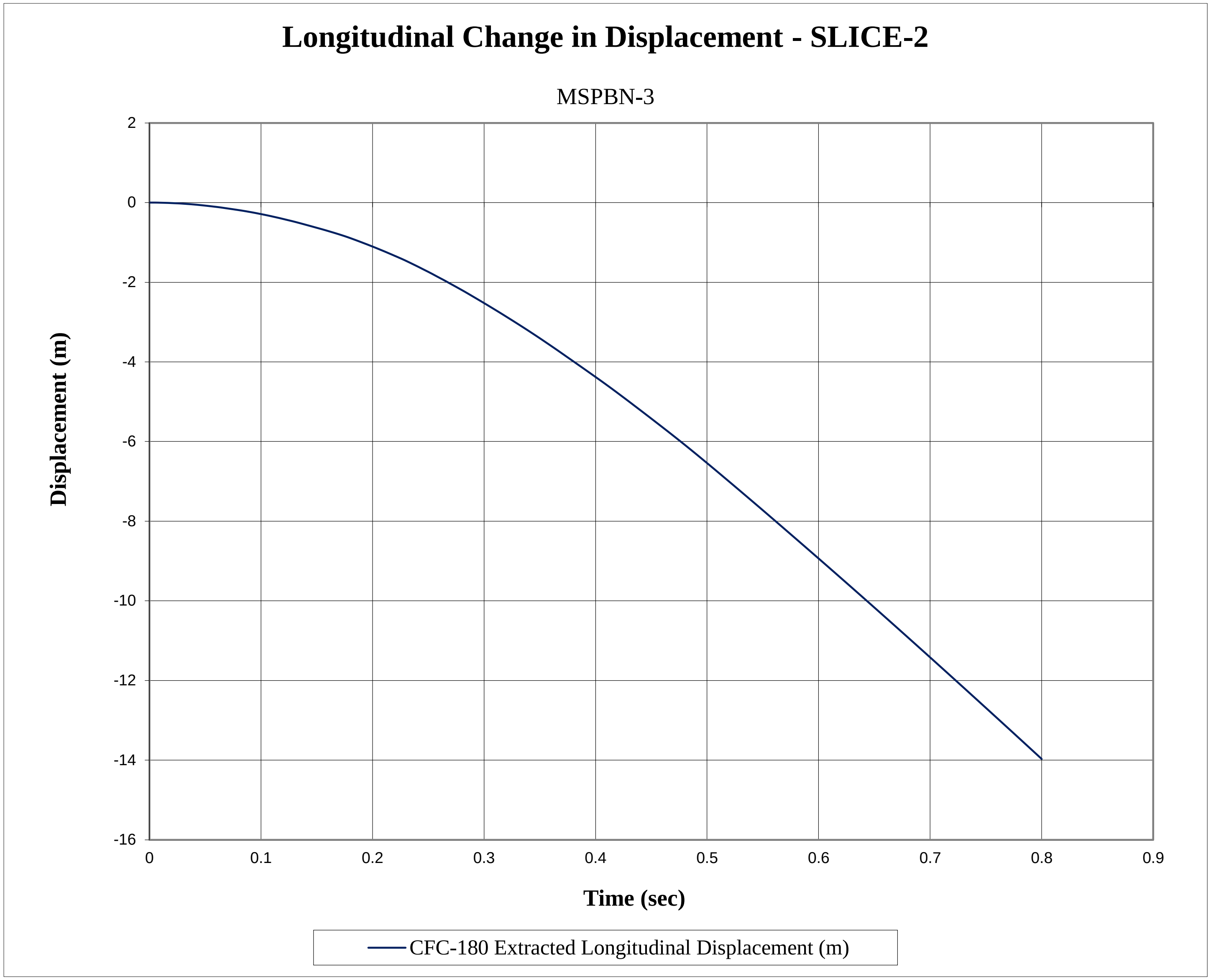


Figure G-3. Longitudinal Occupant Displacement (SLICE-2), Test No. MSPBN-3

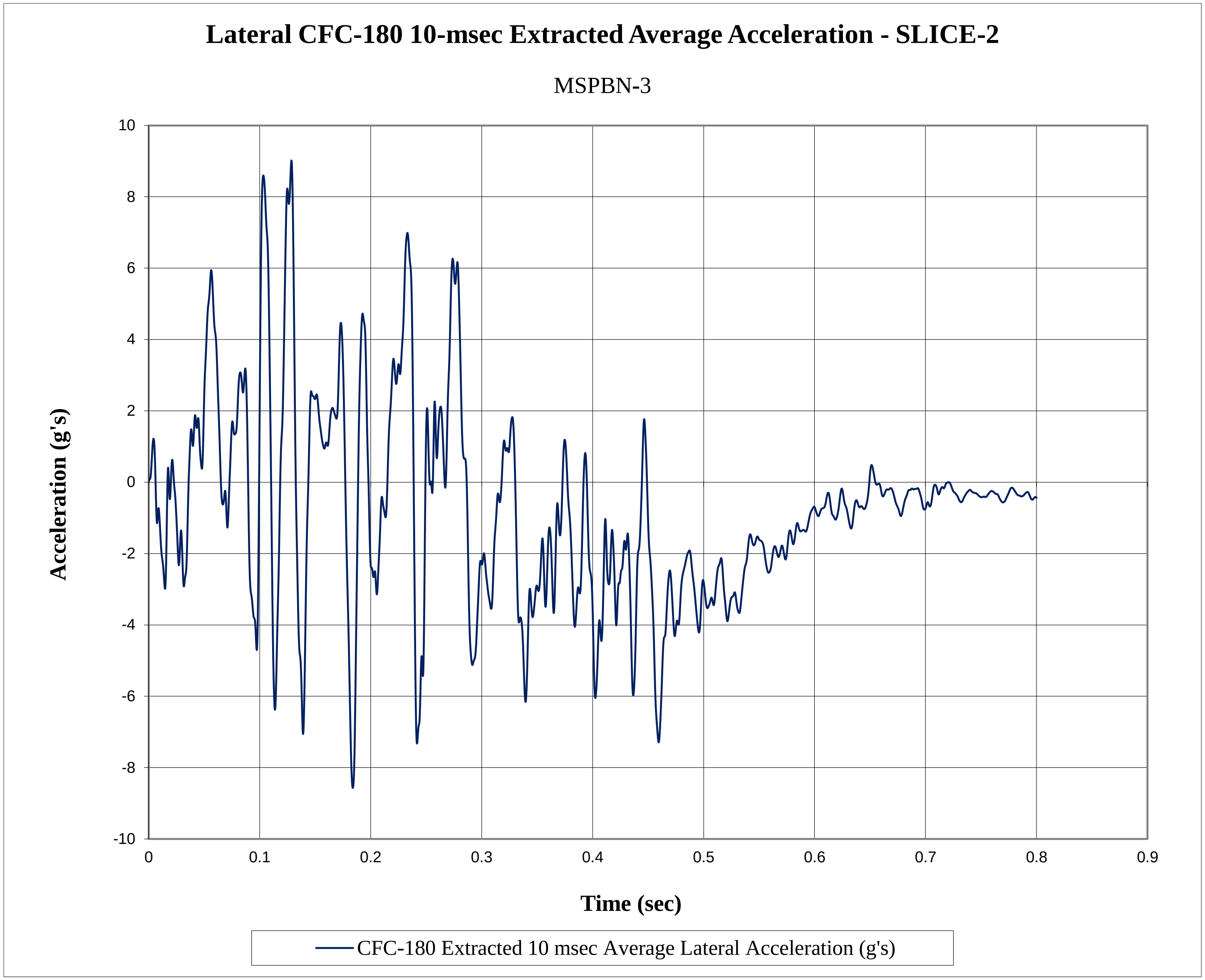


Figure G-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MSPBN-3

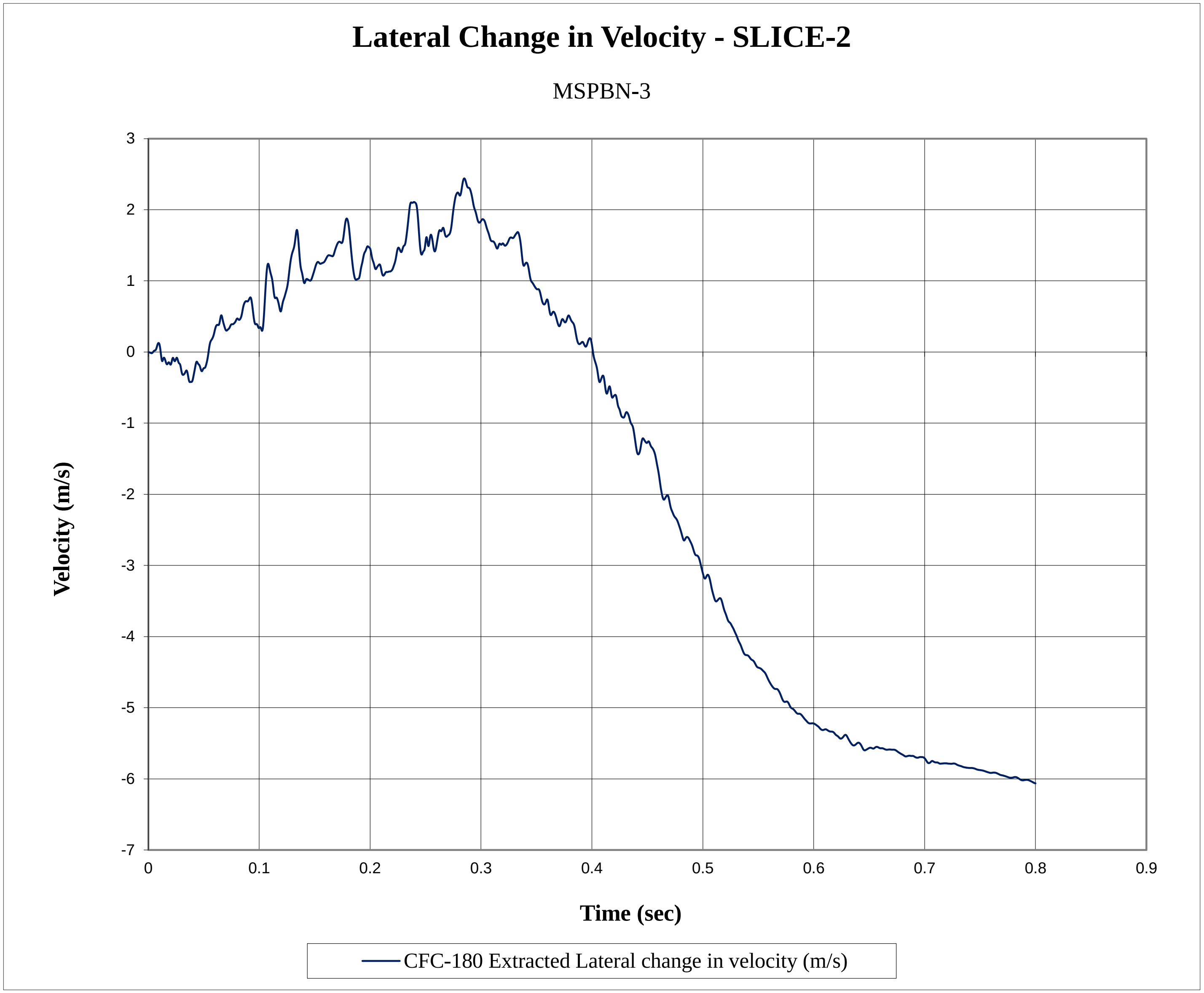


Figure G-5. Lateral Occupant Impact Velocity (SLICE-2), Test No. MSPBN-3

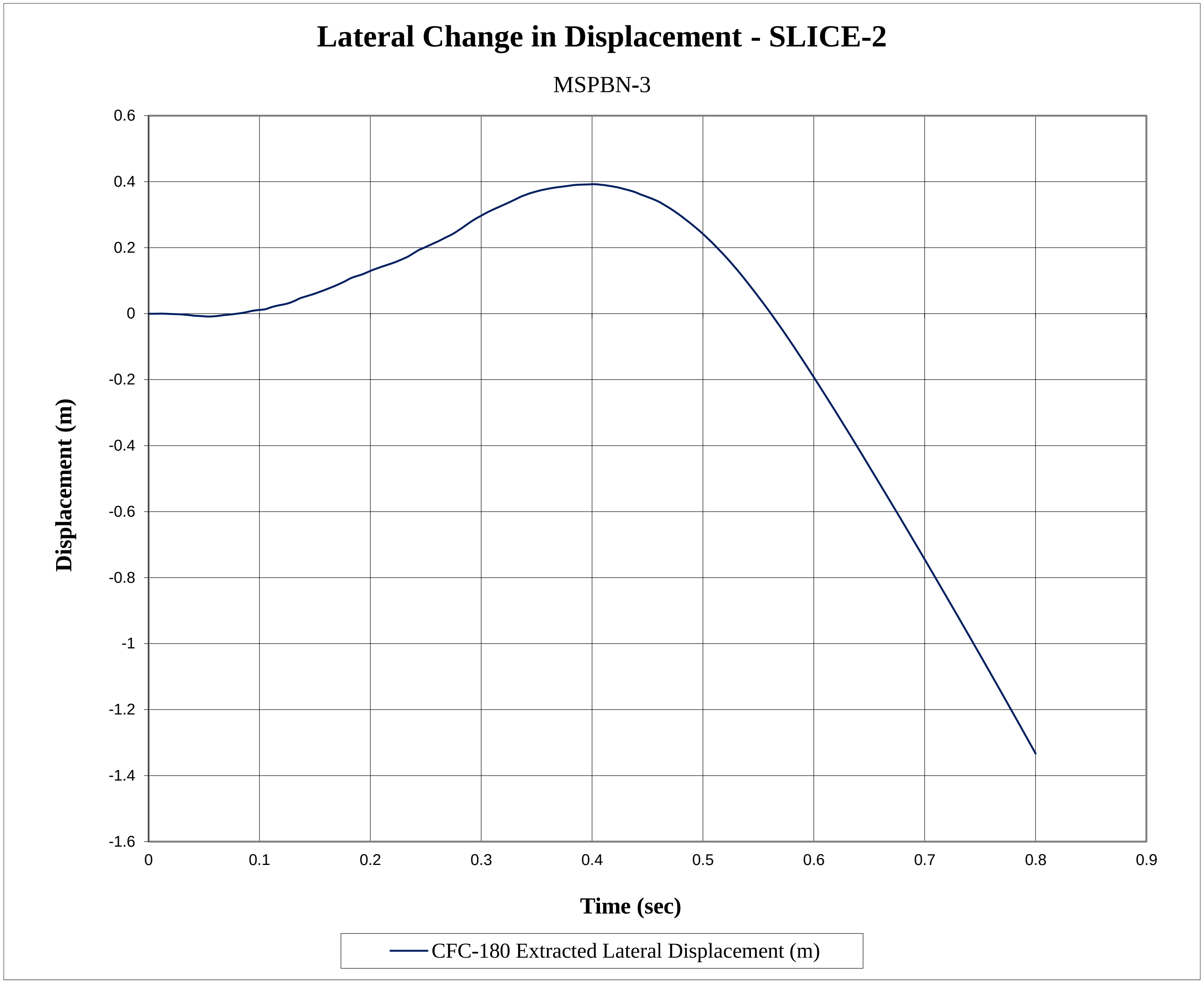


Figure G-6. Lateral Occupant Displacement (SLICE-2), Test No. MSPBN-3

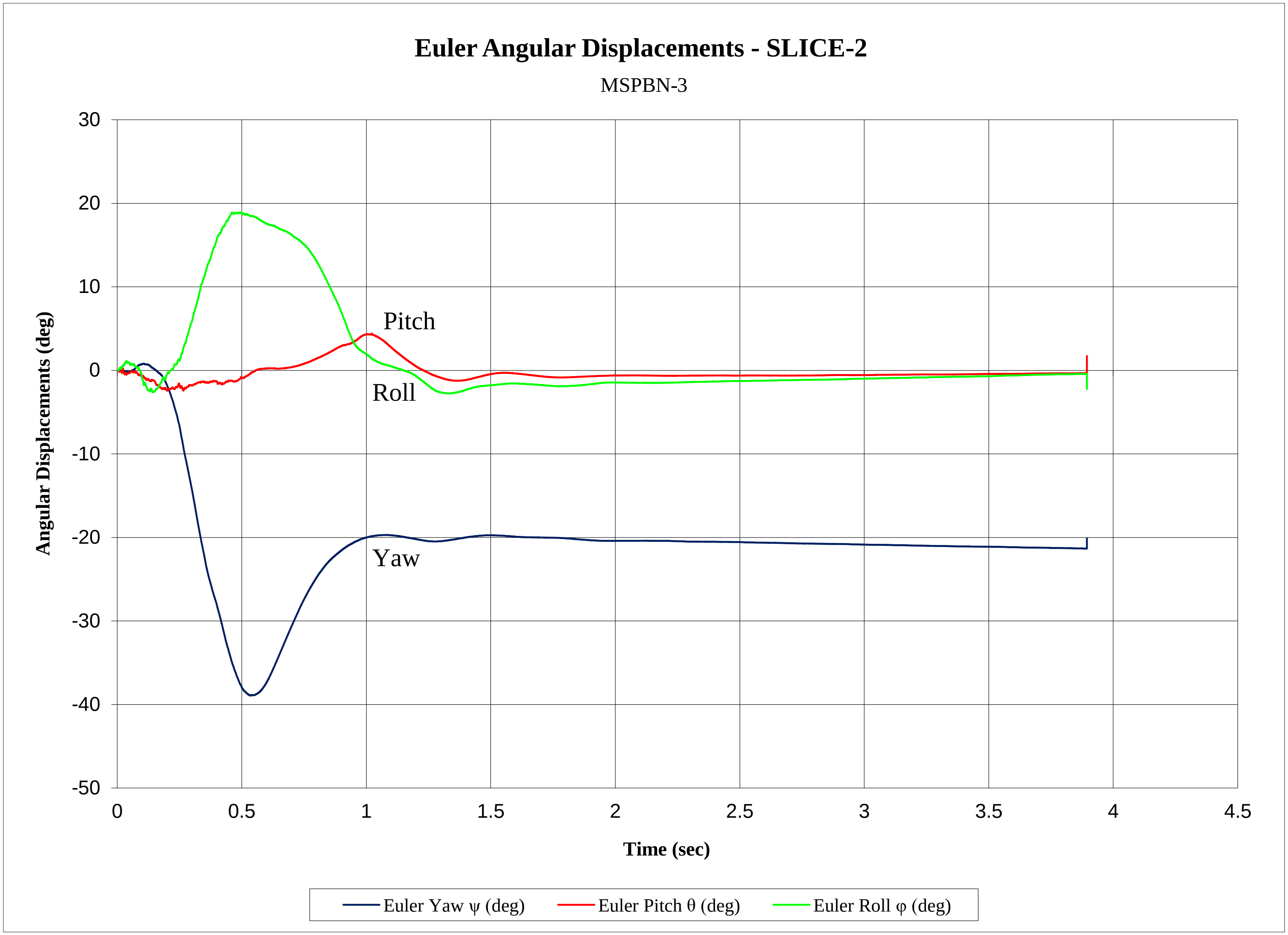


Figure G-7. Vehicle Yaw, Pitch, and Roll Angular Displacements (SLICE-2), Test No. MSPBN-3

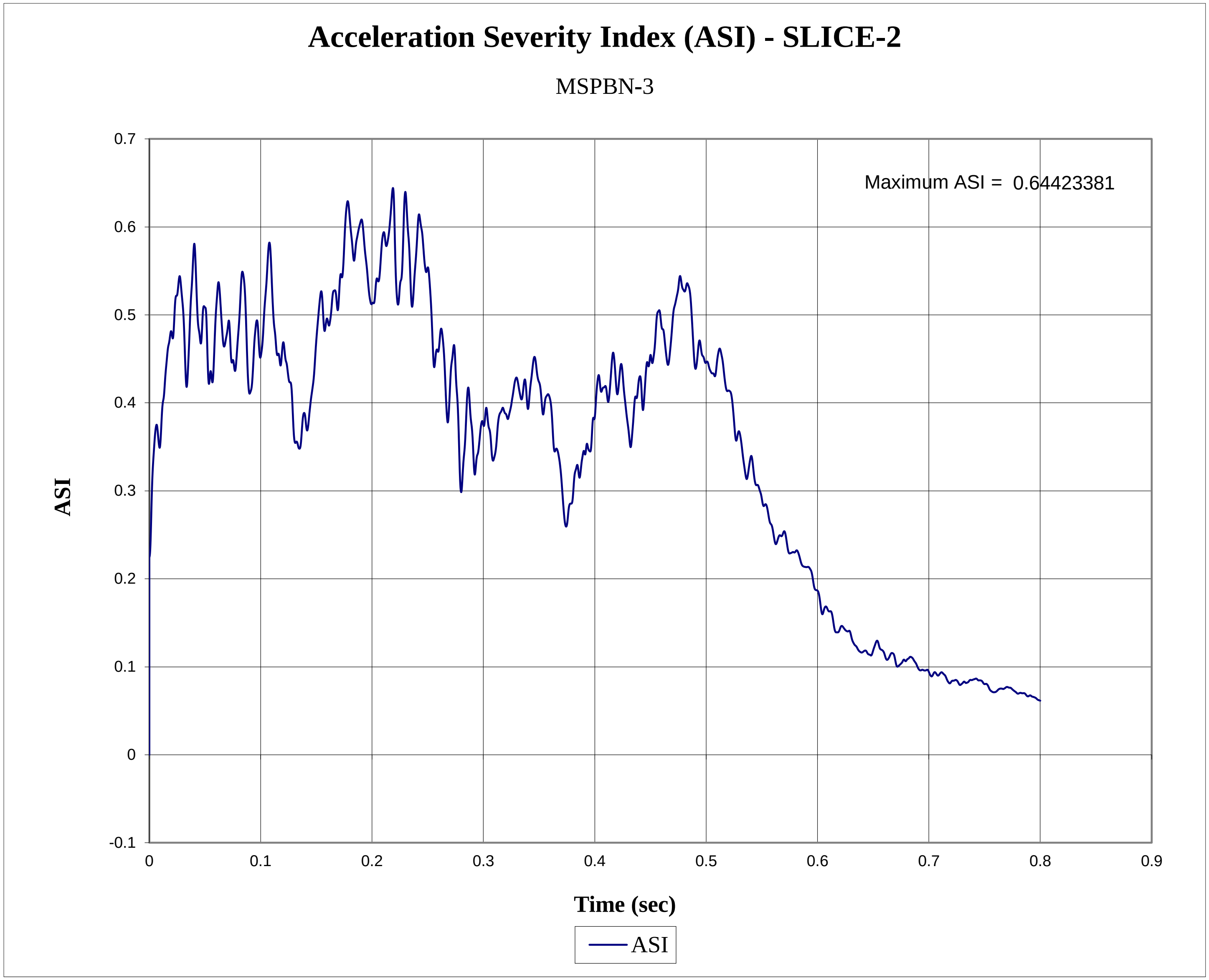


Figure G-8. Acceleration Severity Index (SLICE-2), Test No. MSPBN-3

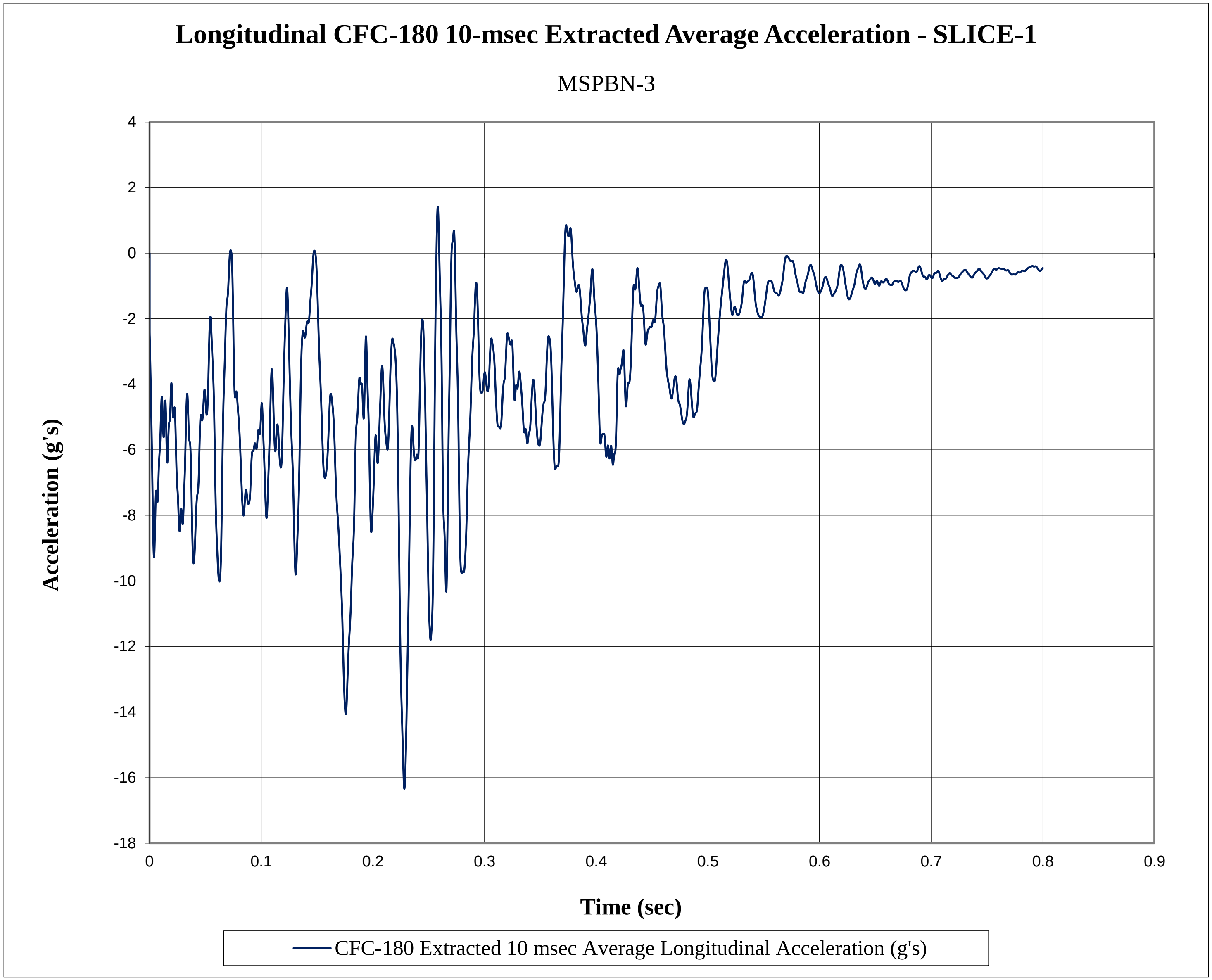


Figure G-9. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MSPBN-3

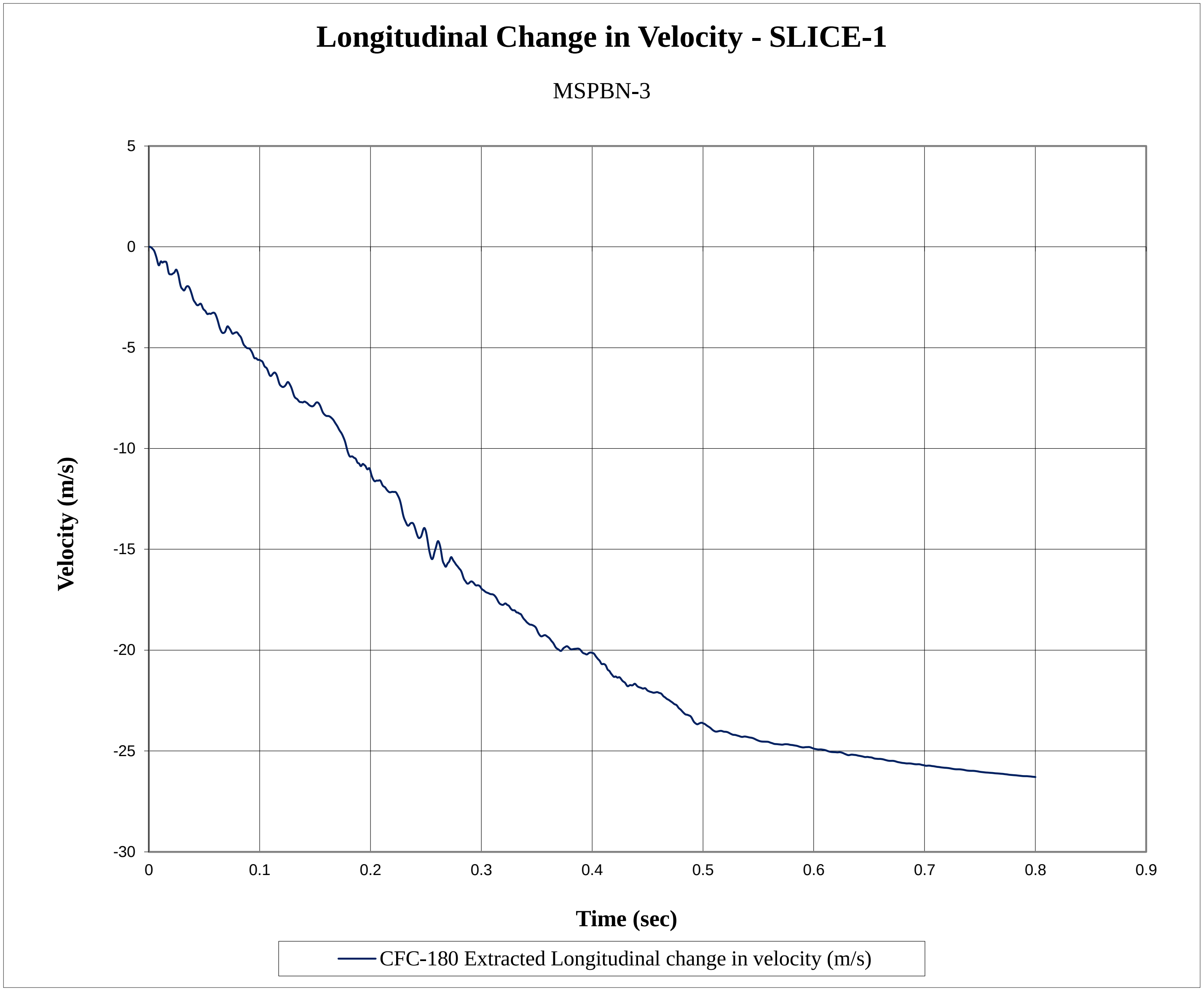


Figure G-10. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MSPBN-3

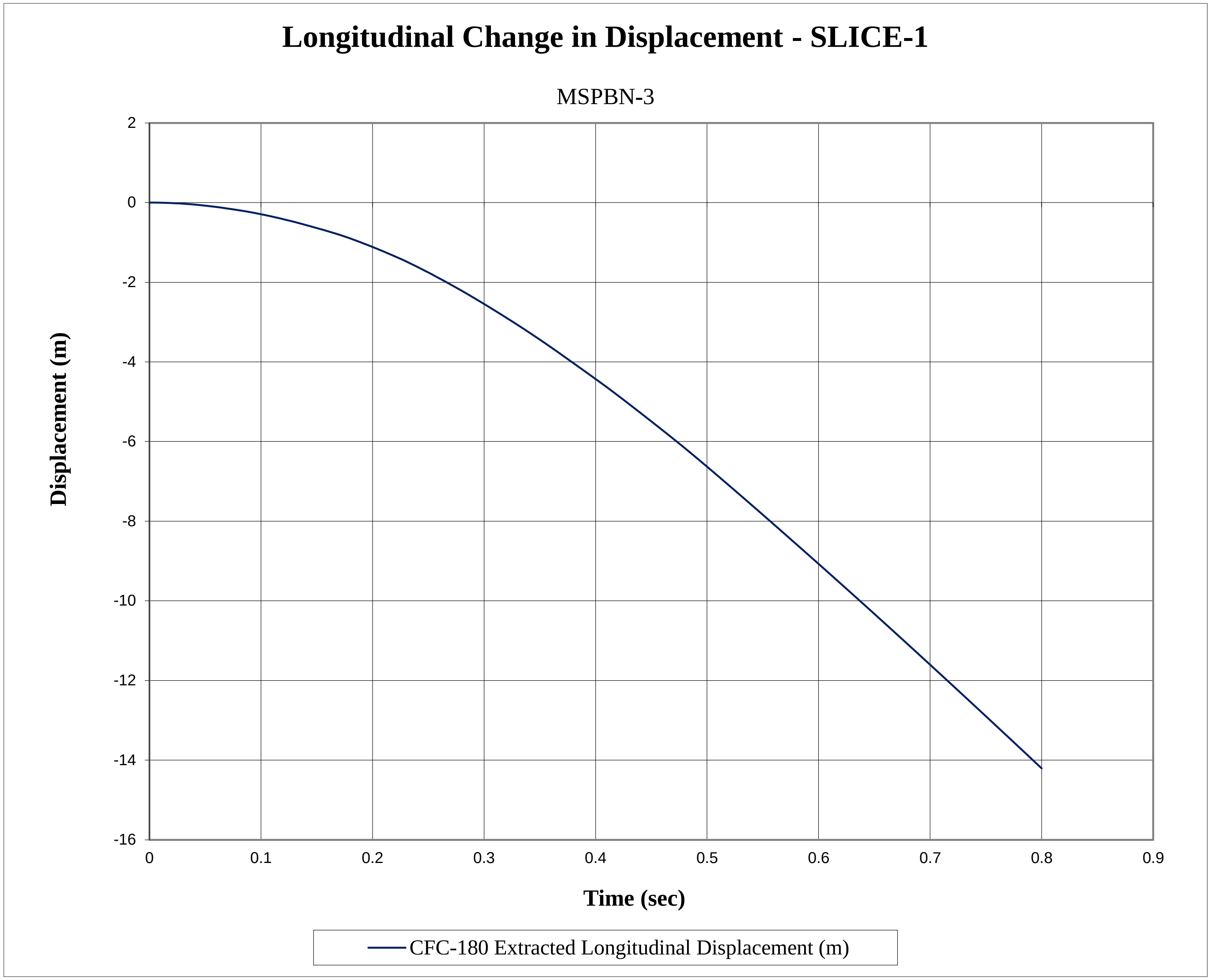


Figure G-11. Longitudinal Occupant Displacement (SLICE-1), Test No. MSPBN-3

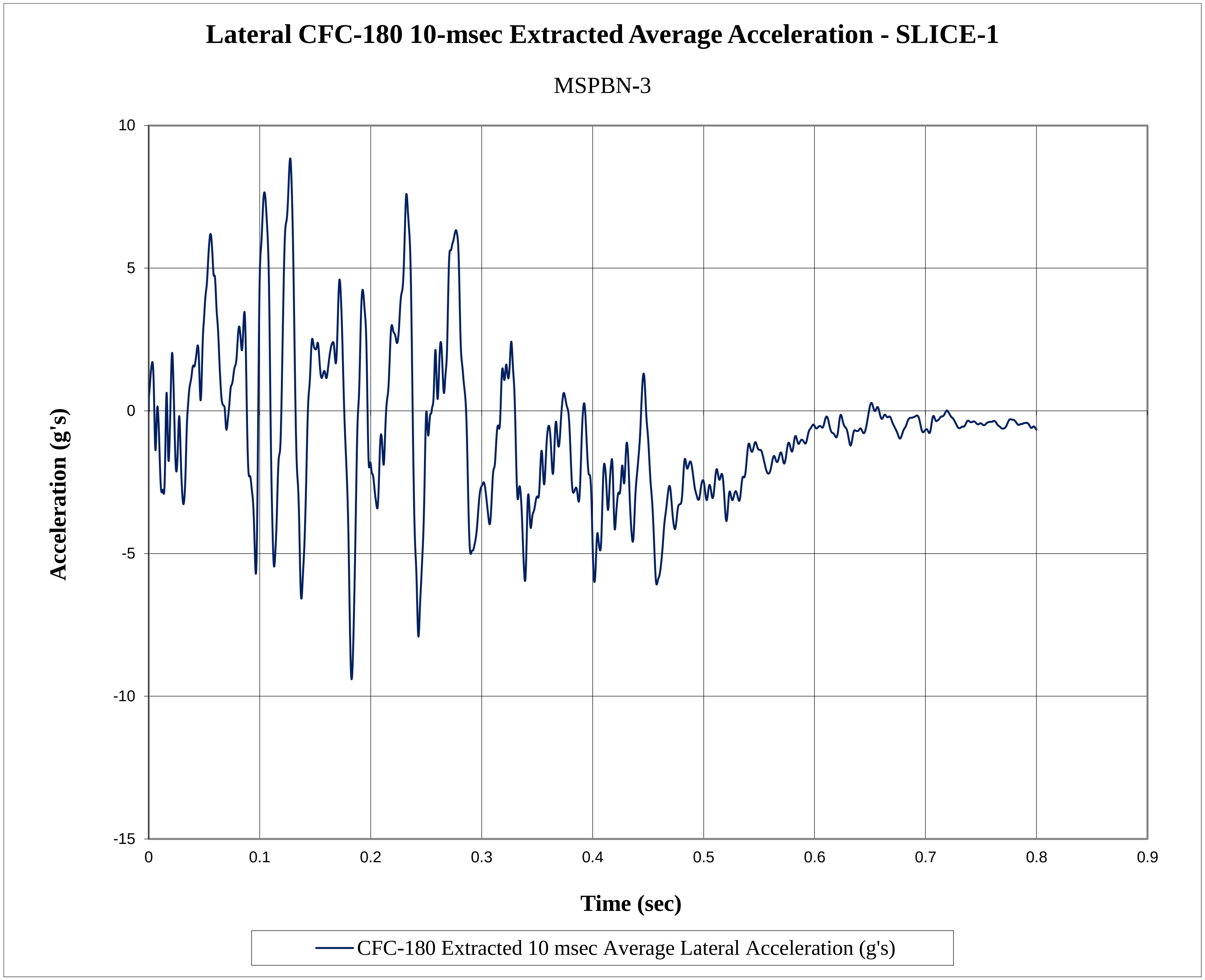


Figure G-12. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MSPBN-3

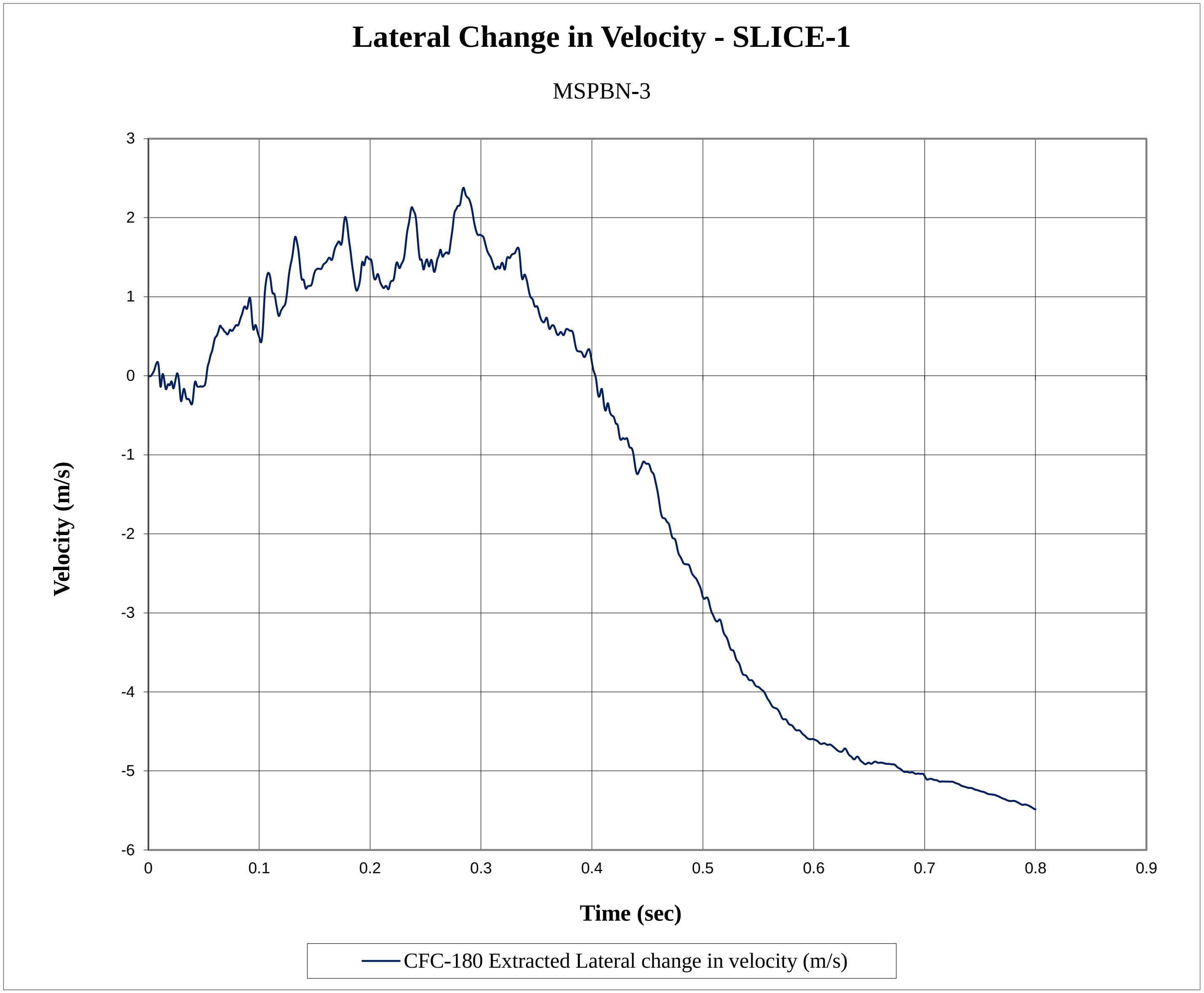


Figure G-13. Lateral Occupant Impact Velocity (SLICE-1), Test No. MSPBN-3

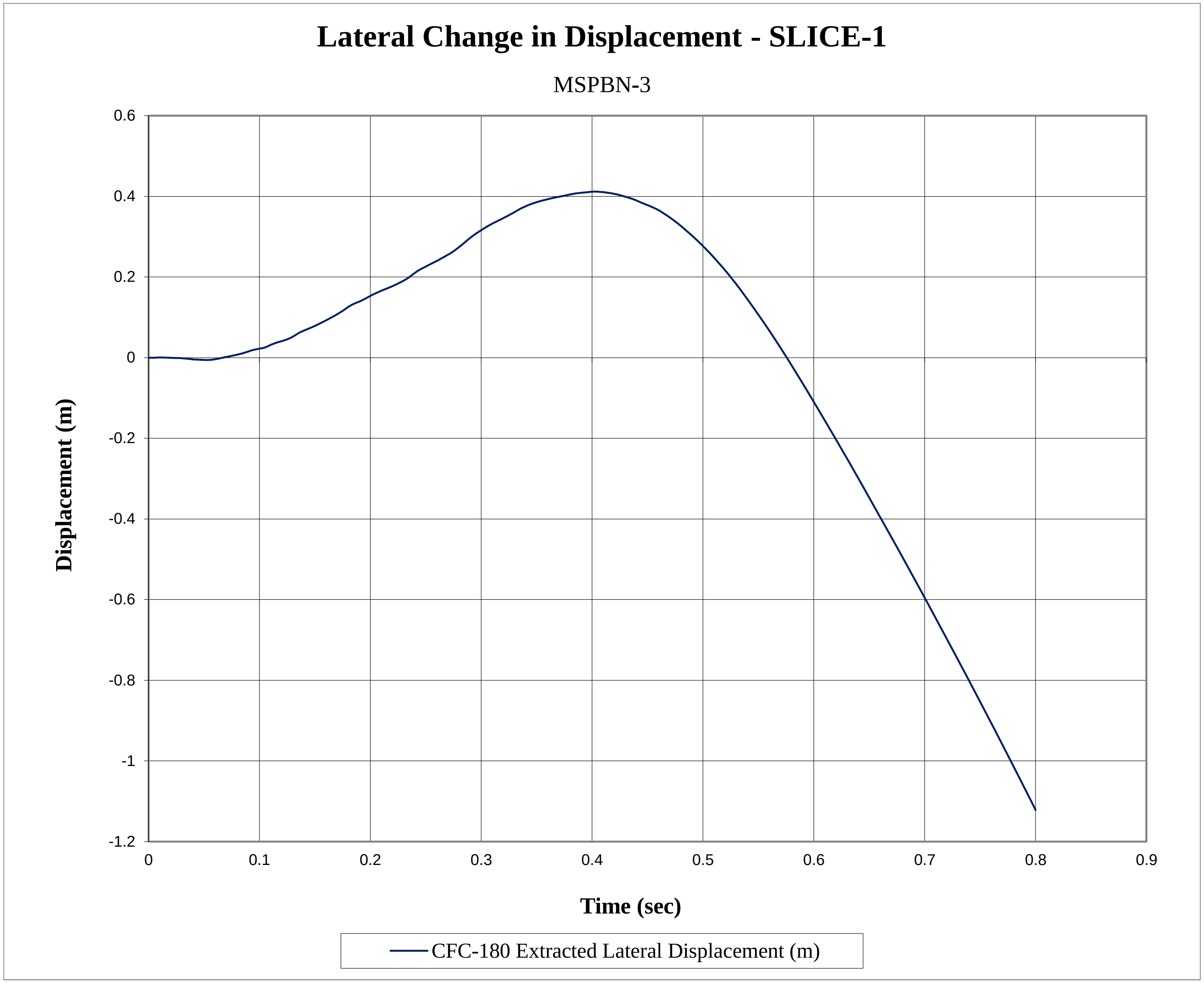


Figure G-14. Lateral Occupant Displacement (SLICE-1), Test No. MSPBN-3

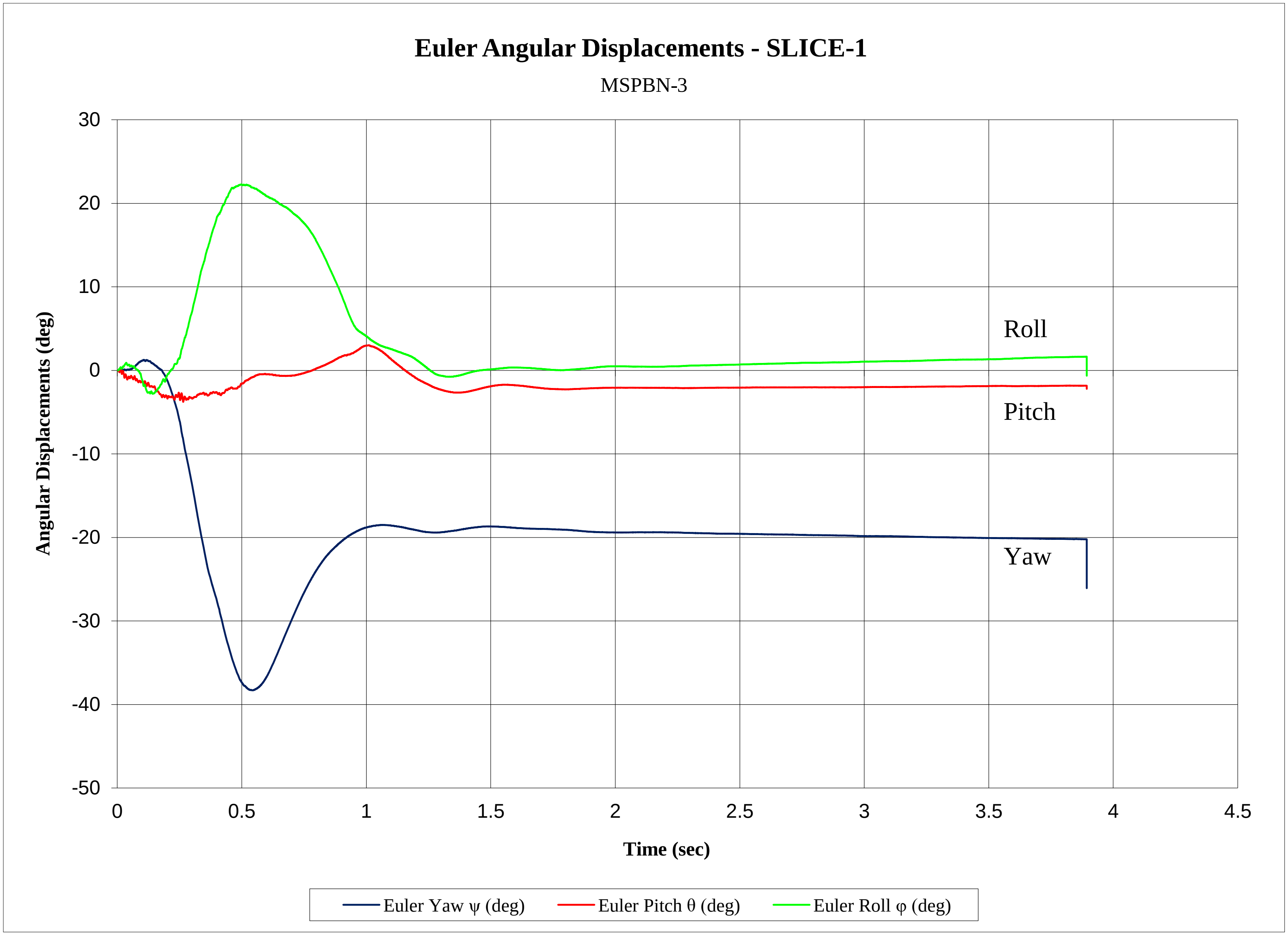


Figure G-15. Vehicle Yaw, Pitch, and Roll Angular Displacements (SLICE-1), Test No. MSPBN-3

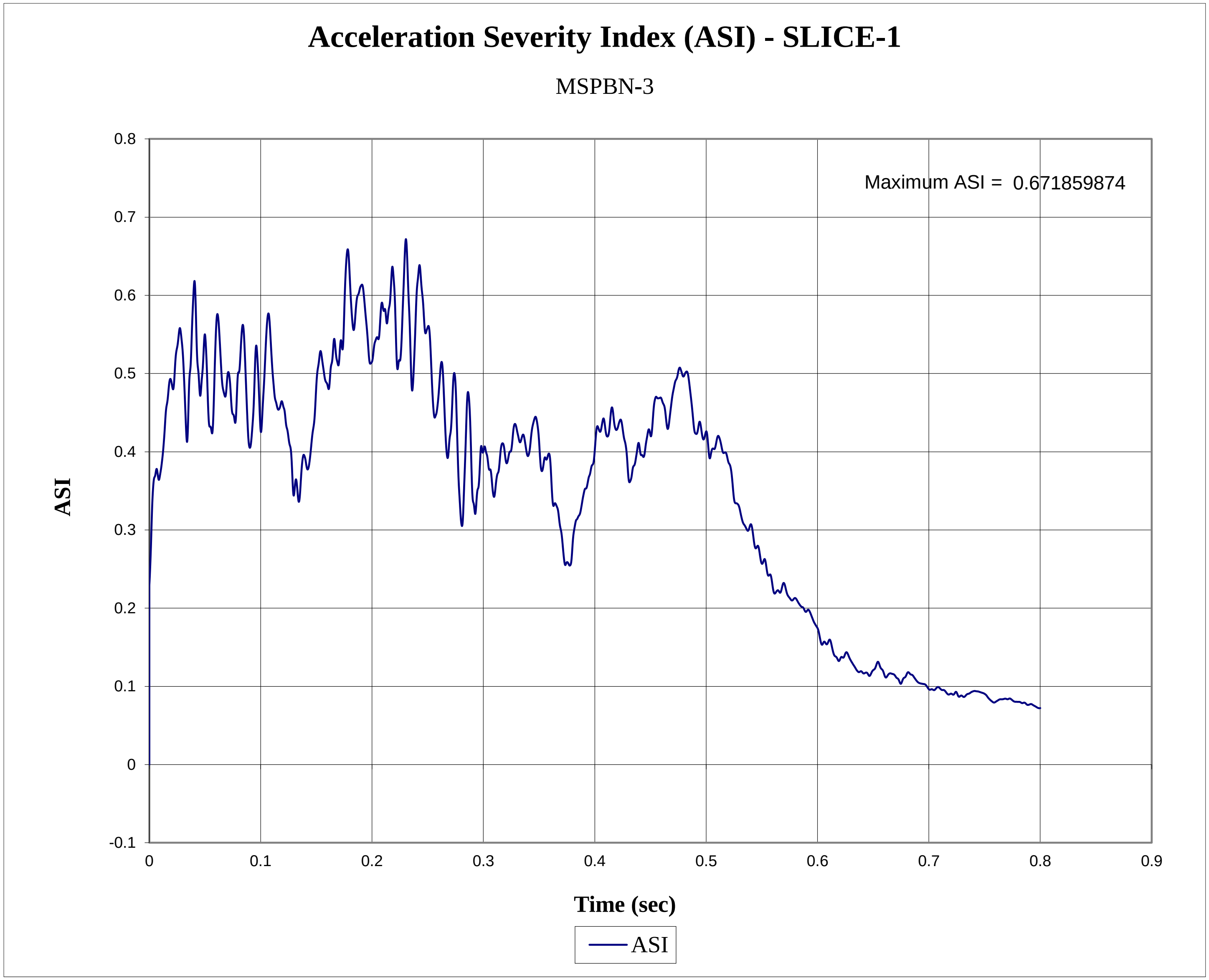


Figure G-16. Acceleration Severity Index (SLICE-1), Test No. MSPBN-3

END OF DOCUMENT