Research Project Number TPF-5(193) Supplement #88

PERFORMANCE EVALUATION OF NEW JERSEY'S PORTABLE CONCRETE BARRIER WITH A FREE-STANDING CONFIGURATION AND GROUTED TOES – TEST NO. NJPCB-4

Submitted by

Surajkumar K. Bhakta, M.S.M.E.
Former Graduate Research Assistant

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

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

John D. Reid, Ph.D.
Professor

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

Erin L. Urbank, B.A.
Research Communication Specialist

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

NEW JERSEY DEPARTMENT OF TRANSPORTATION
1035 Parkway Avenue,
Trenton, New Jersey 08625

MwRSF Research Report No. TRP-03-371-18

December 12, 2018

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.
TRP-03-371-18

2.

3. Recipient's Accession No.

4. Title and Subtitle
Performance Evaluation of New Jersey's Portable Concrete Barrier with a Free-Standing Configuration and Grouted Toes – Test No. NJPCB-4

5. Report Date
December 12, 2018

6.

7. Author(s)
Bhakta, S.K., Lechtenberg, K.A., Faller, R.K., Reid, J.D., Bielenberg, R.W., and Urbank, E.L.

8. Performing Organization Report No.
TRP-03-371-18

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. Project/Task/Work Unit No.

11. Contract © or Grant (G) No.
TPF-5(193) Supplement #88

12. Sponsoring Organization Name and Address
New Jersey Department of Transportation
1035 Parkway Avenue
Trenton, New Jersey 08625

13. Type of Report and Period Covered
Final Report: 2015 -2018

14. Sponsoring Agency Code

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

16. Abstract

This report documents a full-scale crash test conducted in support of a study to investigate the performance of New Jersey Department of Transportation's (NJDOT's) Precast Concrete Curb, Construction Barrier, which will be referred as portable concrete barrier (PCB) in various configurations. This represents the fourth system as part of this study.

The primary objective of this research effort was to evaluate the safety performance of the NJDOT PCB, Type 4 (Alternative B) with a free-standing configuration and grouted toes, corresponding to joint class B in the 2013 NJDOT *Roadway Design Manual*. Barrier nos. 1 and 10 were anchored to a concrete tarmac through the pin anchor recesses with nine 1-in. (25-mm) diameter by 15-in. (381-mm) long ASTM A36 steel pins inserted into 1¼-in. (32-mm) diameter drilled holes in the concrete tarmac. Non-shrink grout wedges were placed at the toe of each barrier segment in every joint between adjacent barrier segments. The barrier was evaluated according to the Test Level 3 (TL-3) criteria set forth in the *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016). The research study included one full-scale vehicle crash test with a 2270P pickup truck. Following the successful redirection of the pickup truck, the safety performance of the system was determined to be acceptable according to the test designation no. 3-11 evaluation criteria specified in MASH 2016. The 1100C small car crash test was deemed unnecessary due to previous testing. The barrier successfully met MASH 2016 TL-3 criteria. This report is the fourth of nine documents in the nine-test series.

17. Document Analysis/Descriptors
Highway Safety, Roadside Appurtenances, Crash Test, Compliance Test, MASH 2016, Longitudinal Barrier, Portable Concrete Barrier, PCB, Free-standing, Grout Wedges, Pinned, and Barrier Curb

18. Availability Statement

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

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	125	

DISCLAIMER STATEMENT

This report was completed with funding from the New Jersey Department of Transportation. 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 New Jersey Department of Transportation nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of 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 Schmidt, Research Assistant Professor.

ACKNOWLEDGEMENTS

The authors wish to acknowledge several sources that made a contribution to this project: (1) New Jersey Department of Transportation for sponsoring this project and (2) MwRSF personnel for constructing the barrier and conducting the crash test.

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

Midwest Roadside Safety Facility

J.C. Holloway, M.S.C.E., E.I.T., Assistant Director – Physical Testing Division
J.D. Schmidt, Ph.D., P.E., Research Assistant Professor
C.S. Stolle, Ph.D., Research Assistant Professor
S.K. Rosenbaugh, M.S.C.E., E.I.T., Research Engineer
M. Asadollahi Pajouh, Ph.D., former Post-Doctoral Research Associate
S.A. Ranjha, Ph.D., former Post-Doctoral Research Associate
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
M.A. Rasmussen, Construction and Testing Technician I
M.T. Ramel, B.S.C.M., former Construction and Testing Technician I
R.M. Novak, Construction and Testing Technician I
J.E. Kohtz, B.S.M.E., CAD Technician
Undergraduate and Graduate Research Assistants

New Jersey Department of Transportation

Dave Bizuga, former Senior Executive Manager, Roadway Design Group 1
Giri Venkiteela, Research Project Manager, NJDOT Bureau of Research
Hung Tang, Design Standards Bureau, Roadway Standards Unit
Lee Steiner, Project Engineer, Bureau of Traffic Engineering

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

The New Jersey Department of Transportation (NJDOT) currently uses a New Jersey shape, Precast Concrete Curb, Concrete Barrier, which will be referred to as portable concrete barrier (PCB), with a vertical, I-beam connection pin to attach barriers end to end within their work zones and construction areas. The 2013 NJDOT *Roadway Design Manual* [1] provided guidance on allowable barrier deflections for various classes of PCB joint treatments, as shown in Table 1. The current 2015 NJDOT *Roadway Design Manual* [2] provides guidance on allowable deflections for various connection types, as shown in Table 2.

Table 1. 2013 NJDOT Roadway Design Manual PCB Guidance [1]

Joint Class	Use	Joint Treatment
A	Allowable movement over 16 to 24 inches	Connection Key only
B	Allowable movement over 11 to 16 inches	Connection Key and grout in every joint
C	Allowable movement of 11 inches	Connection Key and grout in every joint and pin every other unit. In units to be anchored, pin should be required in every recess
D	No allowable movement (i.e., bridge parapet)	Connection Key and grout in every joint and bolt every anchor pocket hole in every unit

Table 2. Current 2015 NJDOT Roadway Design Manual PCB Guidance [2]

Connection Type	Use	Joint Treatment*
A	Maximum allowable deflection of 41 inches	Connection Key and barrier end sections fully pinned
B	Maximum allowable deflection of 28 inches (Cannot be used with traffic on both sides of the barrier.)	Connection Key, 6” by 6” box beam, and barrier end sections fully pinned
C	Maximum allowable deflection of 11 inches	Connection Key, construction side of all sections pinned, and barrier end sections fully pinned

* Barrier end sections fully pinned – first and last barrier segments of the entire run regardless of connection type have pins in every anchor recess on both sides.

The guidance provided in both the 2013 and 2015 *Roadway Design Manual* was based on test data obtained from previous testing standards, which needs to be updated to be consistent with current crash testing standards and a changing vehicle fleet. Crash testing of other PCB systems under the Test Level 3 (TL-3) criteria of the *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) [3] has indicated that dynamic barrier deflections can increase significantly when compared to dynamic deflections based on older crash test data. Thus, a need exists to investigate the performance of the NJDOT PCB system in various configurations in order to provide updated design guidance. The NJDOT PCB standard plans are shown in Appendix A.

1.2 Objective

The objective of this research effort was to evaluate the safety performance of NJDOT's PCB, Type 4 (Alternative B) system with a free-standing configuration and grouted toes, corresponding to joint class B in the 2013 NJDOT *Roadway Design Manual* [1]. The system was to be evaluated according to the Test Level 3 (TL-3) criteria of the *Manual for Assessing Safety Hardware, Second Edition* (MASH 2016) [3].

1.3 Scope

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

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as PCBs, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [3]. Note that there is no difference between MASH 2009 [4] and MASH 2016 for most longitudinal barriers, such as the PCB system tested in this project, except that additional occupant compartment deformation measurements are required by MASH 2016. According to TL-3 of MASH 2016, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 3. However, only the 2270P crash test was deemed necessary as other prior small car tests were used to support a decision to deem the 1100C crash test not critical.

Table 3. MASH 2016 TL-3 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight, lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed, mph (km/h)	Angle, deg.	
Longitudinal Barrier	3-10	1100C	2,420 (1,100)	62 (100)	25	A,D,F,H,I
	3-11	2270P	5,000 (2,268)	62 (100)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 4.

In test no. 7069-3, a rigid, F-shape, concrete bridge rail was successfully impacted by a small car weighing 1,800 lb (816 kg) at 60.1 mph (96.7 km/h) and 21.4 degrees according to the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings* [5-6]. In the same manner, test nos. CMB-5 through CMB-10, CMB-13, and 4798-1 showed that rigid, New Jersey, concrete safety shape barriers struck by small cars have been shown to meet safety performance standards [7-8]. In addition, in test no. 2214NJ-1, a rigid, New Jersey, ½-section, concrete safety shape barrier was impacted by a passenger car weighing 2,579 lb (1,170 kg) at 60.8 mph (97.8 km/h) and 26.1 degrees according to the TL-3 standards set forth in MASH 2009 [9]. Furthermore, temporary, New Jersey safety shape, concrete median barriers have experienced only slight barrier deflections when impacted by small cars and behave similarly to rigid barriers as seen in test no. 47 [10]. As such, the 1100C passenger car test was deemed not critical for testing and evaluating this PCB system.

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

2.2 Evaluation Criteria

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the PCB system to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 4 and defined in greater detail in MASH 2016. The full-scale vehicle crash test documented herein was conducted and reported in accordance with the procedures provided in MASH 2016.

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

Table 4. MASH 2016 Evaluation Criteria for Longitudinal Barrier

<table>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td rowspan="12">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>

3 DESIGN DETAILS

The test installation consisted of ten 20-ft (6.1-m) long NJDOT PCBs with a free-standing configuration and grouted toes, as shown in Figures 1 through 14. This system uses NJDOT barriers, Type 4 (Alternative B) with joint class B, as specified in the 2013 NJDOT *Roadway Design Manual*. Photographs of the test installation are shown in Figures 15 through 17. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix B.

The concrete mix for the barrier sections required a minimum 28-day compressive strength of 3,700 psi (25.5 MPa). A minimum concrete cover of 1½ in. (38 mm) was used along all rebar in the barrier. All of the steel reinforcement in the barrier was ASTM A615 Grade 60 rebar and consisted of four No. 6 longitudinal bars, eight No. 4 bars for the vertical stirrups, four No. 6 lateral bars, and nine No. 4 bars for the anchor hole reinforcement loops. The section reinforcement details are shown in Figures 5 and 6.

The barrier sections used a connection key, as shown in Figures 7 through 11, and 16. The connection key assembly consisted of ½-in. (13-mm) thick ASTM A36 steel plates welded together to form the key shape. A connection socket was configured at each end of the barrier section, as shown in Figures 2, 16, and 17. The connection socket consisted of three ASTM A36 steel plates welded on the sides of ASTM A500 Grade B or C steel tube, as shown in Figures 9 and 10. The connection key was inserted into the steel tubes of two adjoining PCBs to form the connection, as shown in Figure 10.

Barrier nos. 1 and 10 were anchored to the concrete tarmac through the pin anchor recesses with nine 1-in. (25-mm) diameter by 15-in. (381-mm) long, ASTM A36 steel pins inserted into 1¼-in. (32-mm) diameter drilled holes in the concrete tarmac, as shown in Figures 1 and 17. The steel pins were embedded to a depth of 5 in. (127 mm), as shown in Figure 1. During installation, the barrier segments were pulled in a direction parallel to their longitudinal axes, and slack was removed from all joints. After slack was removed from all the joints, 1¼-in. (32-mm) diameter holes were drilled for pin anchors at pin recess locations. Five samples of concrete tarmac were tested from five different locations of MwRSF's Outdoor Test Site. The concrete tarmac had a compressive strength between 5,970 and 7,040 psi (41.2 and 48.5 MPa), as shown in Appendix C. Non-shrink grout wedges were placed at the toe of each barrier segment in every joint between adjacent barrier segments on both traffic and back sides, as shown in Figures 1, 2, and 16. The grout wedges consisted of a grout mix with a minimum 1-day compressive strength of 1,000 psi (6.9 MPa).

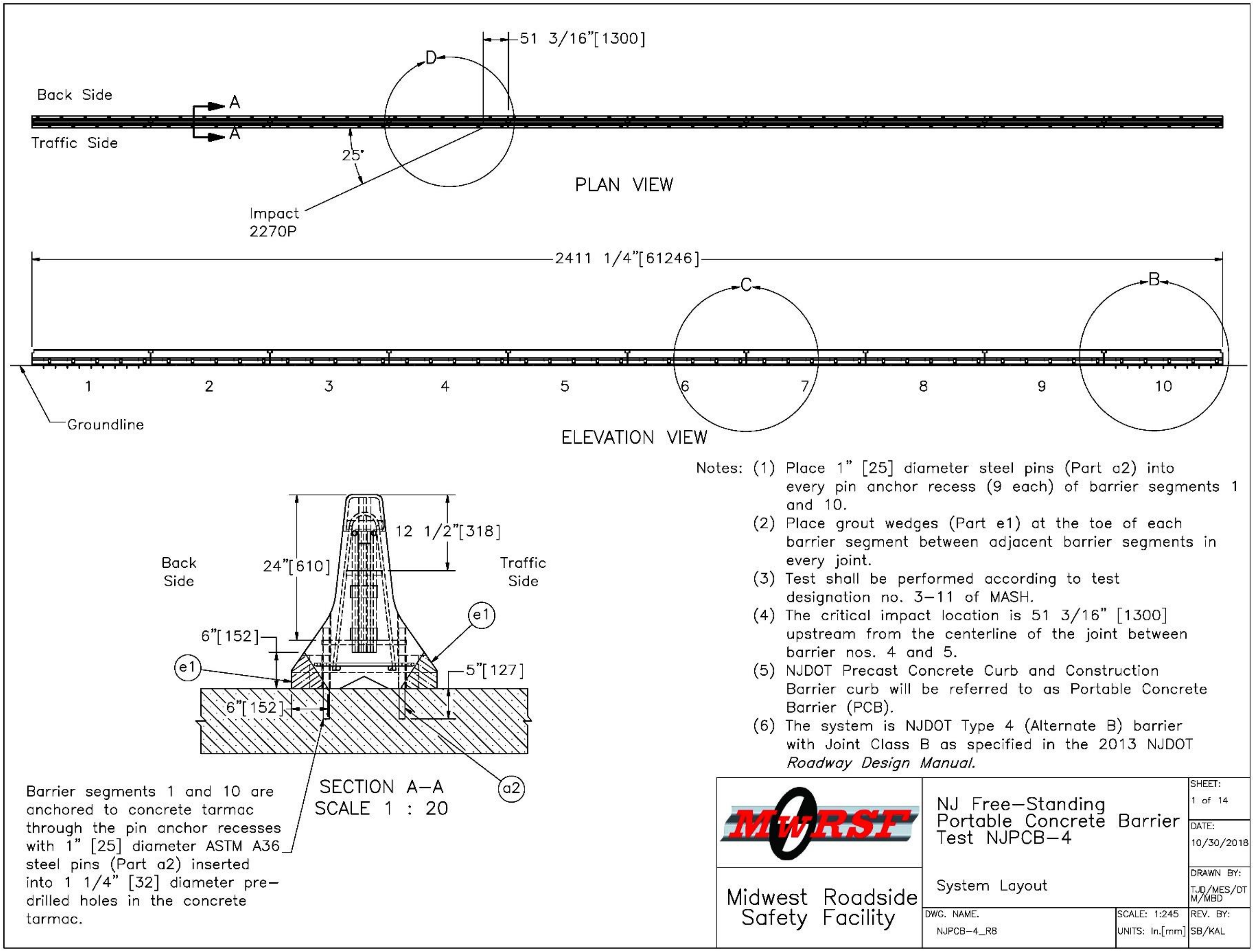


Figure 1. Test Installation Layout, Test No. NJPCB-4

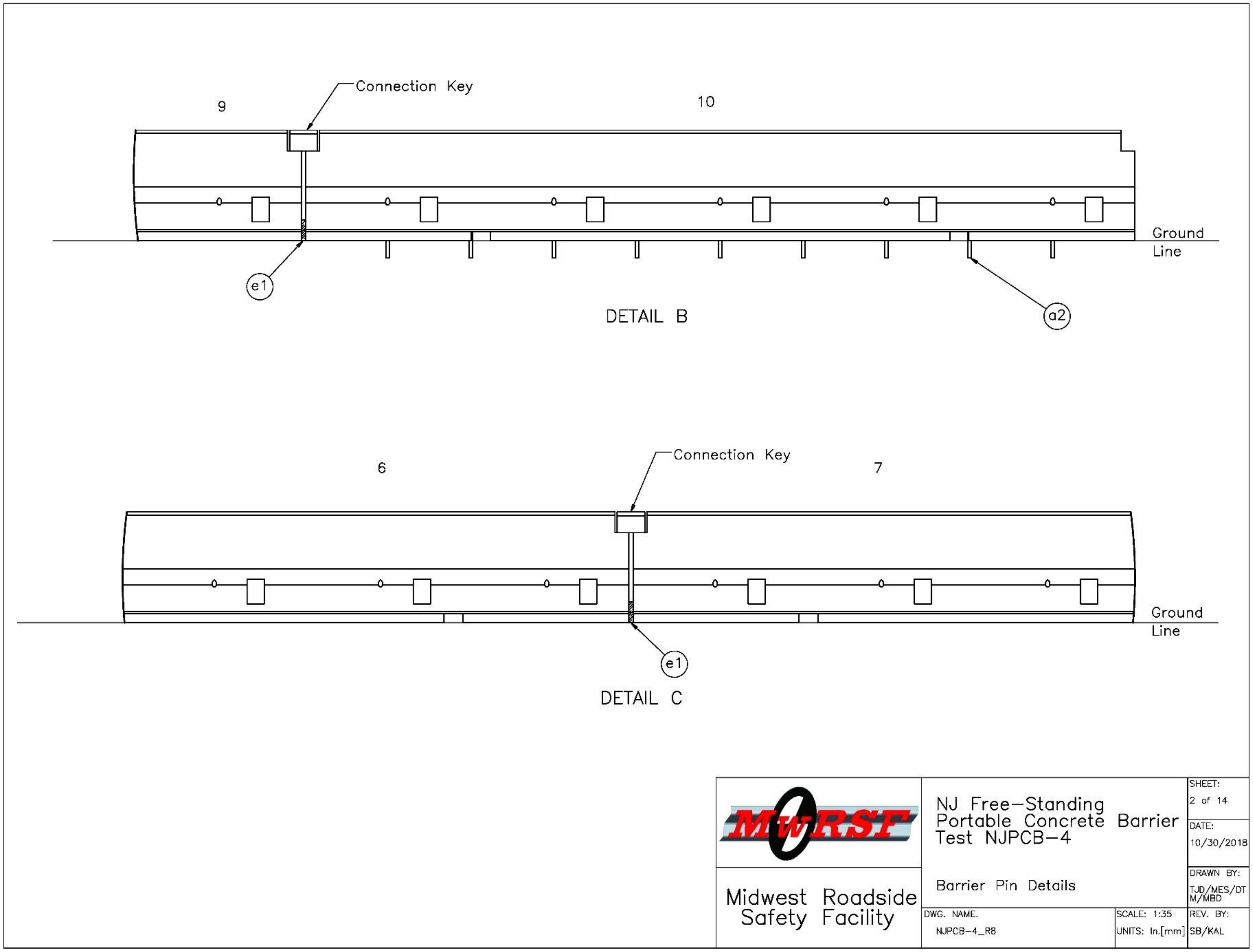


Figure 2. PCB Pin Anchor Details, Test No. NJPCB-4

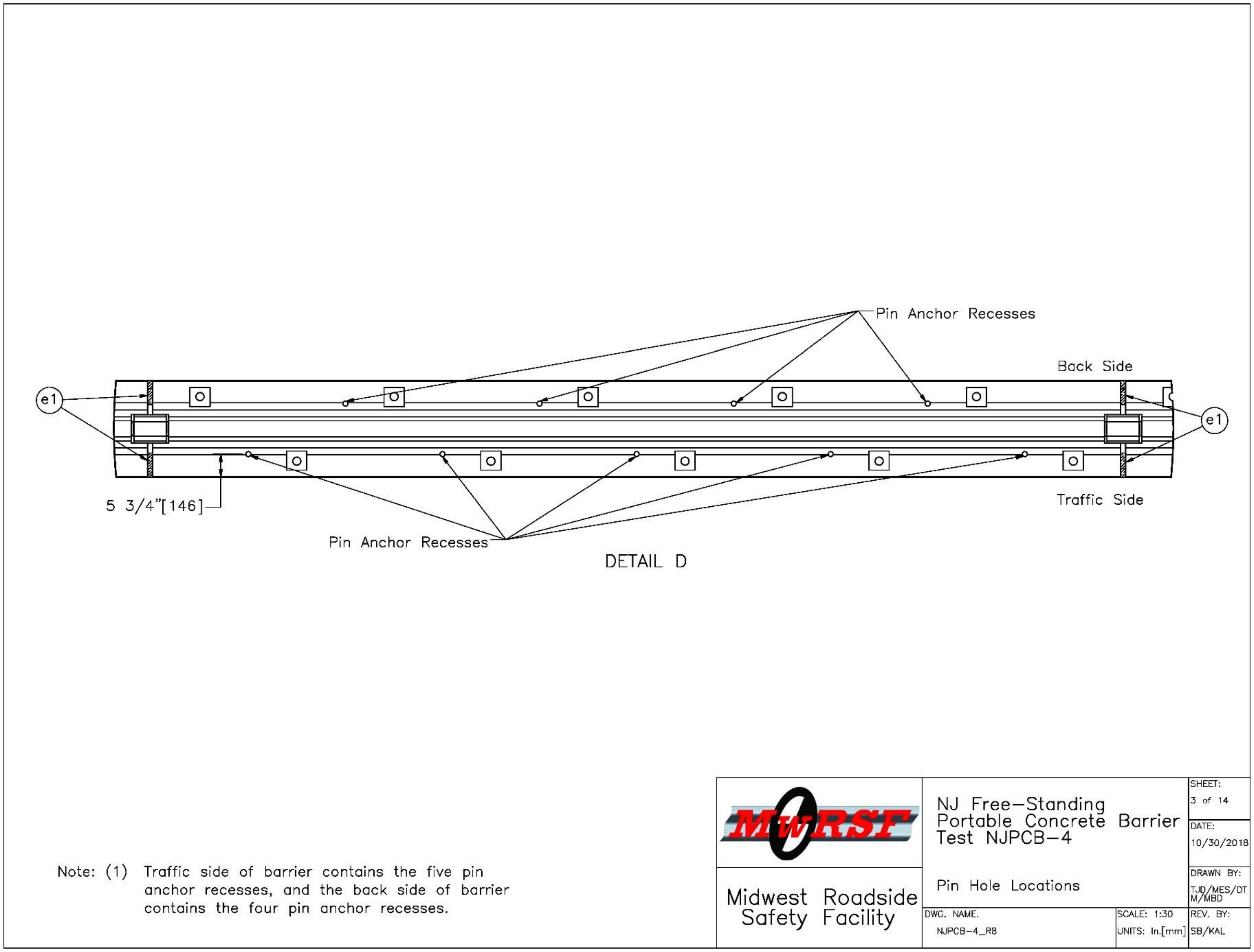


Figure 3. PCB Pin Anchor Recess Locations, Test No. NJPCB-4

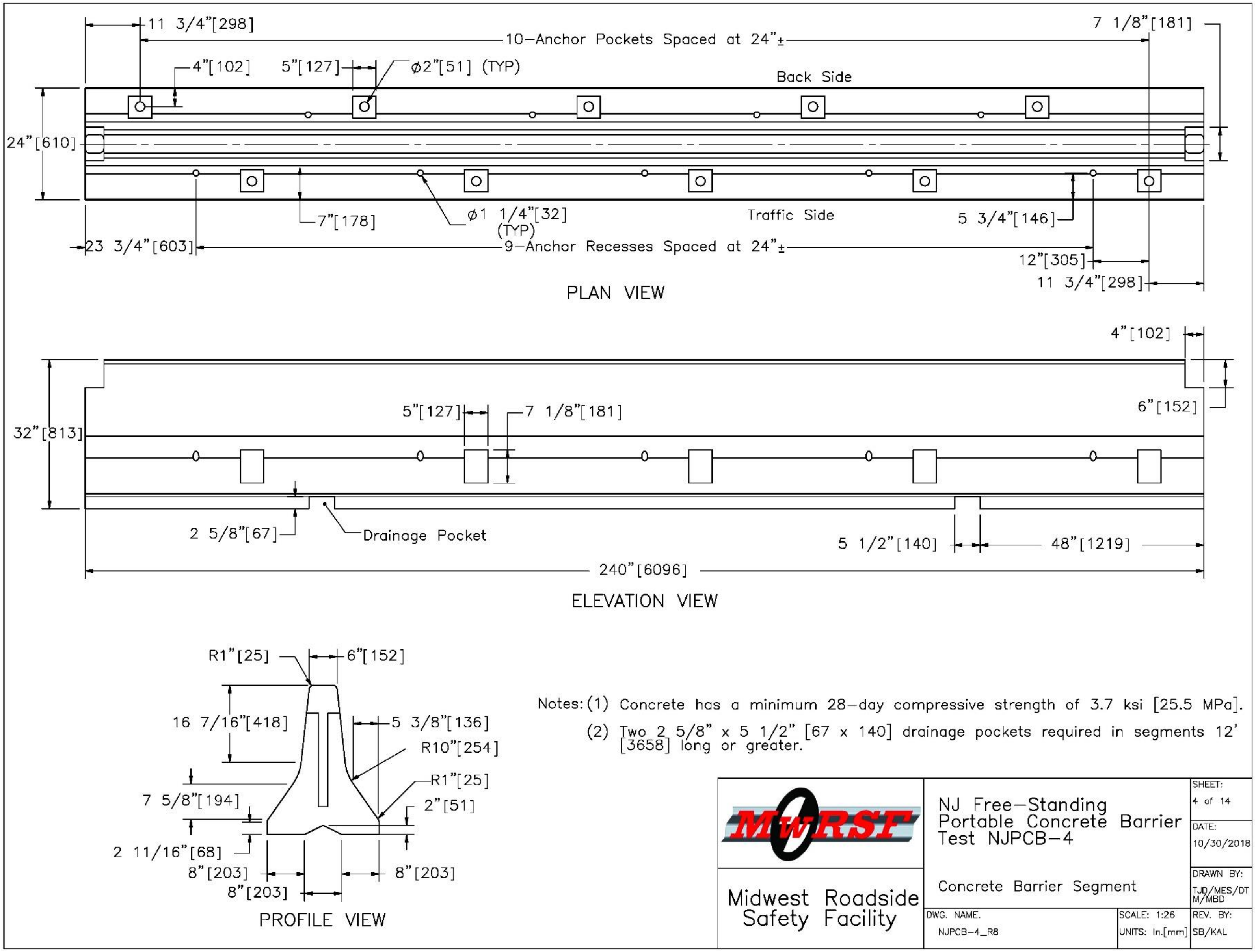


Figure 4. PCB Details, Test No. NJPCB-4

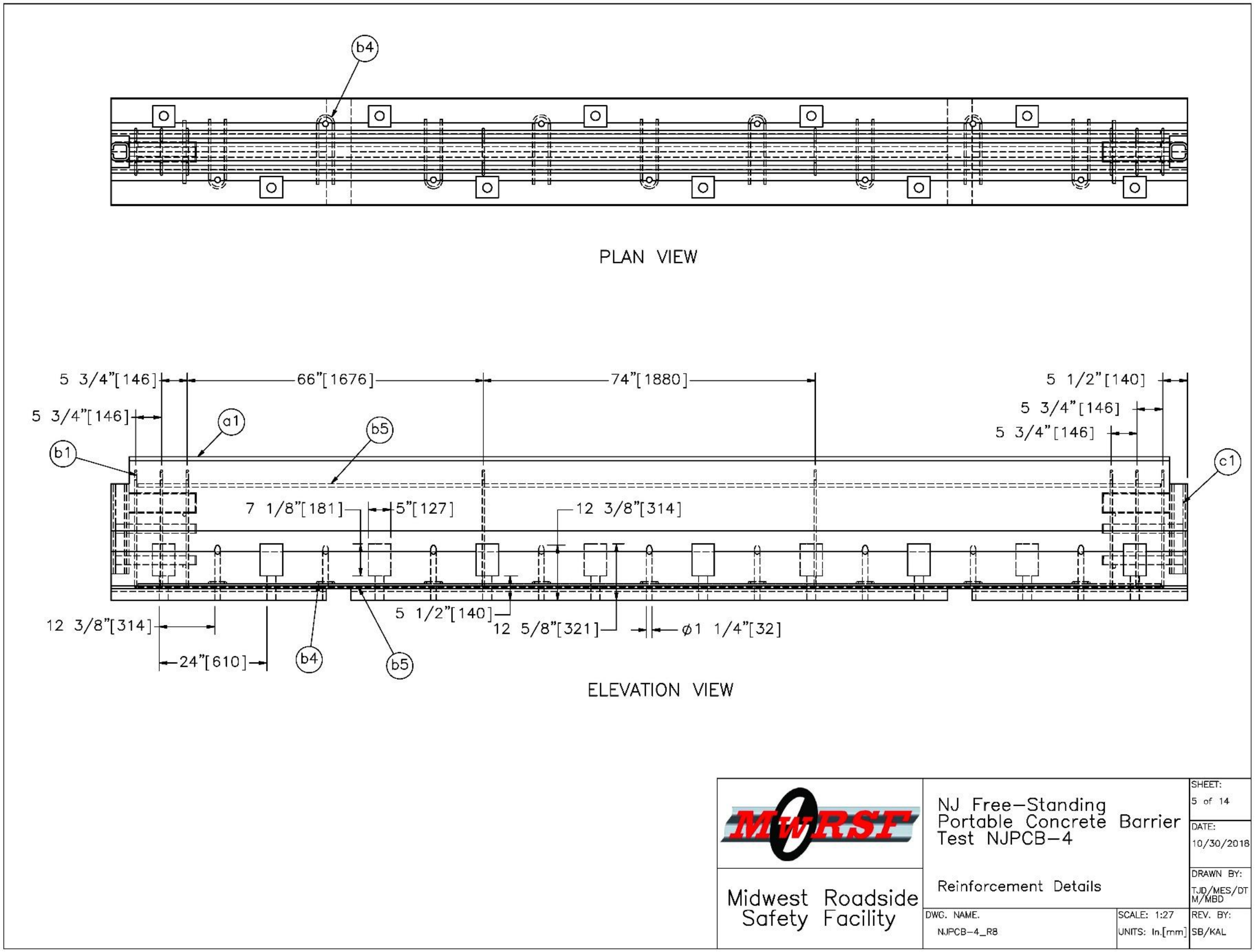


Figure 5. PCB Reinforcement Details, Test No. NJPCB-4

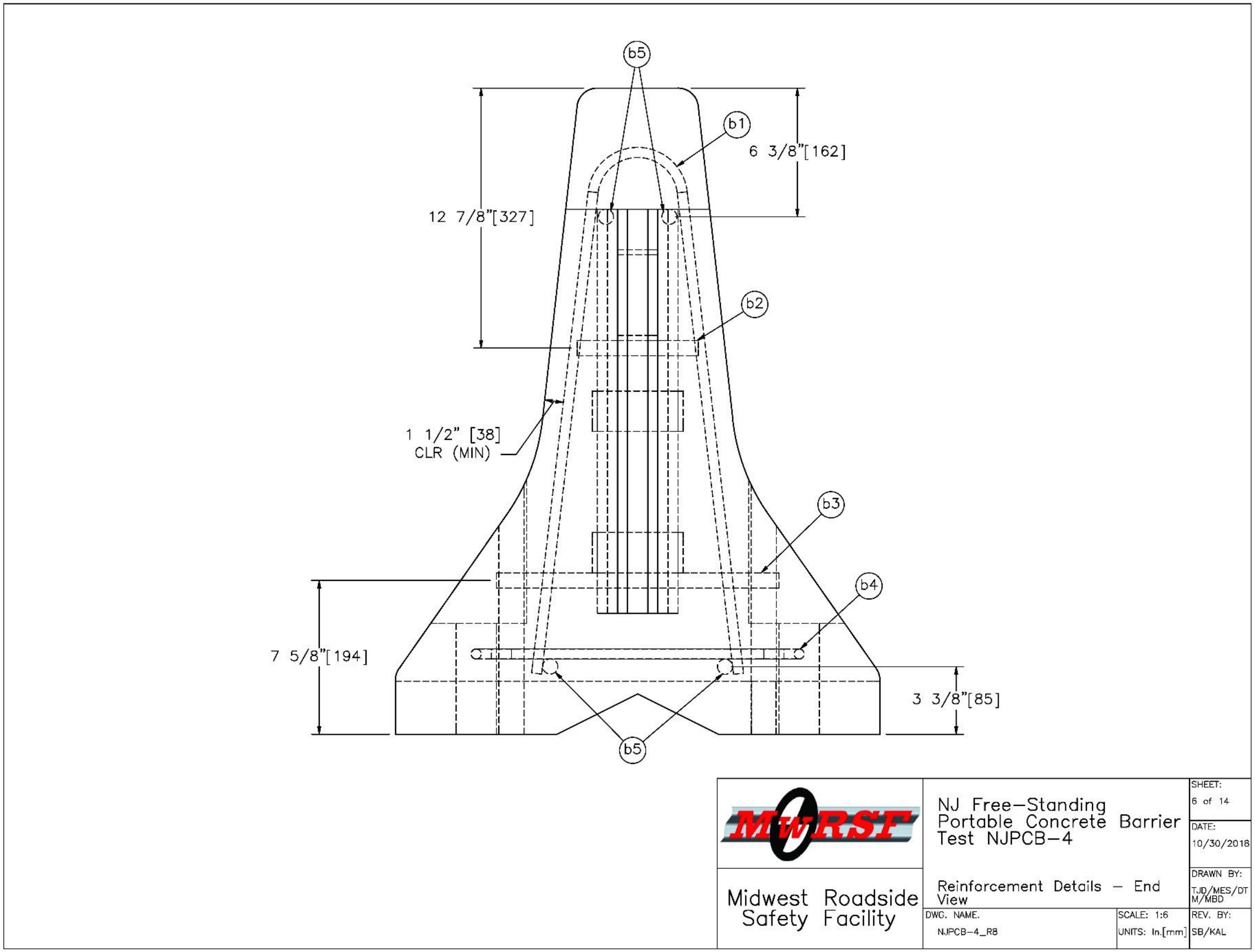


Figure 6. PCB Reinforcement Details – End View, Test No. NJPCB-4

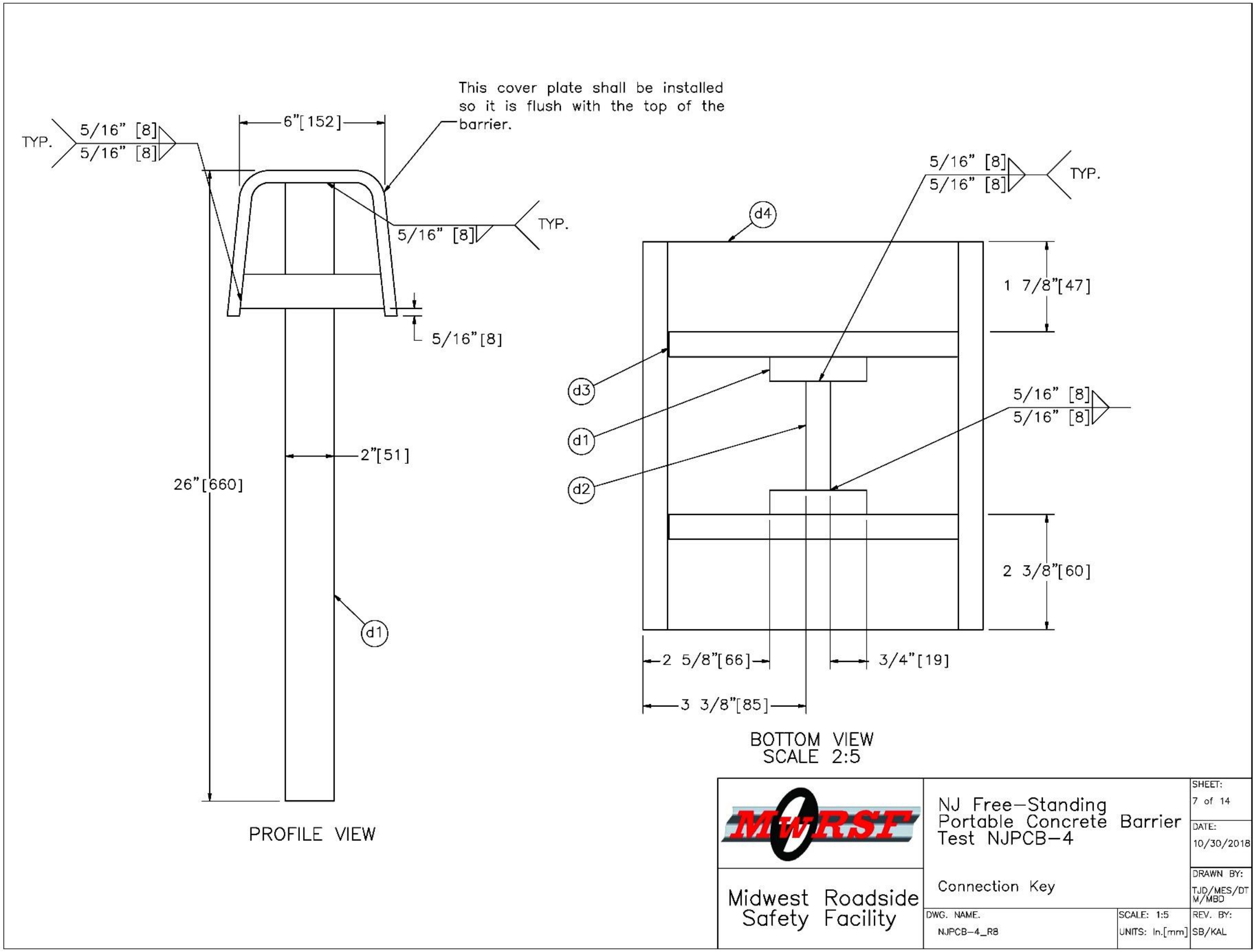


Figure 7. Connection Key Assembly Details, Test No. NJPCB-4

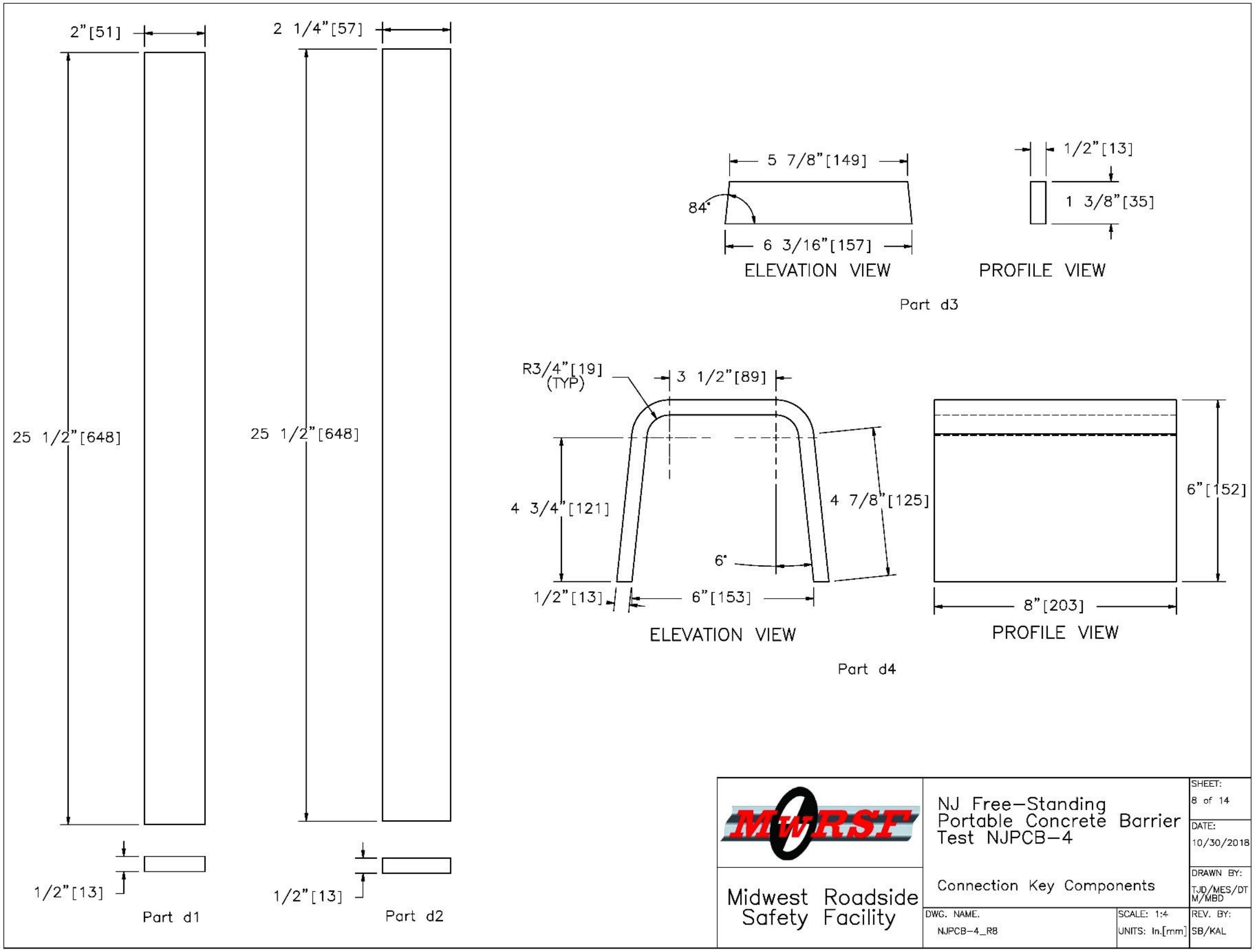


Figure 8. Connection Key Component Details, Test No. NJPCB-4

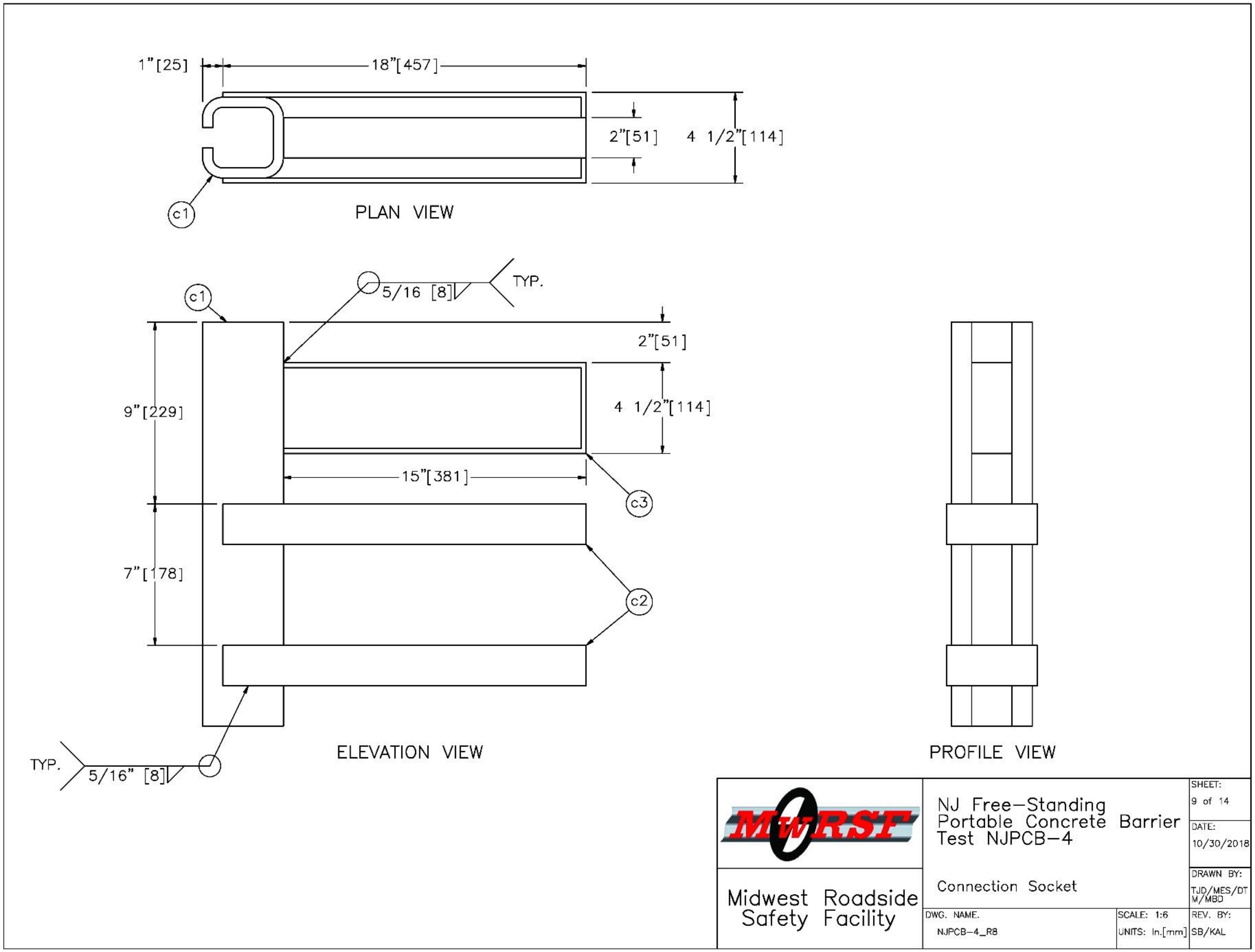


Figure 9. PCB Connection Socket Details, Test No. NJPCB-4

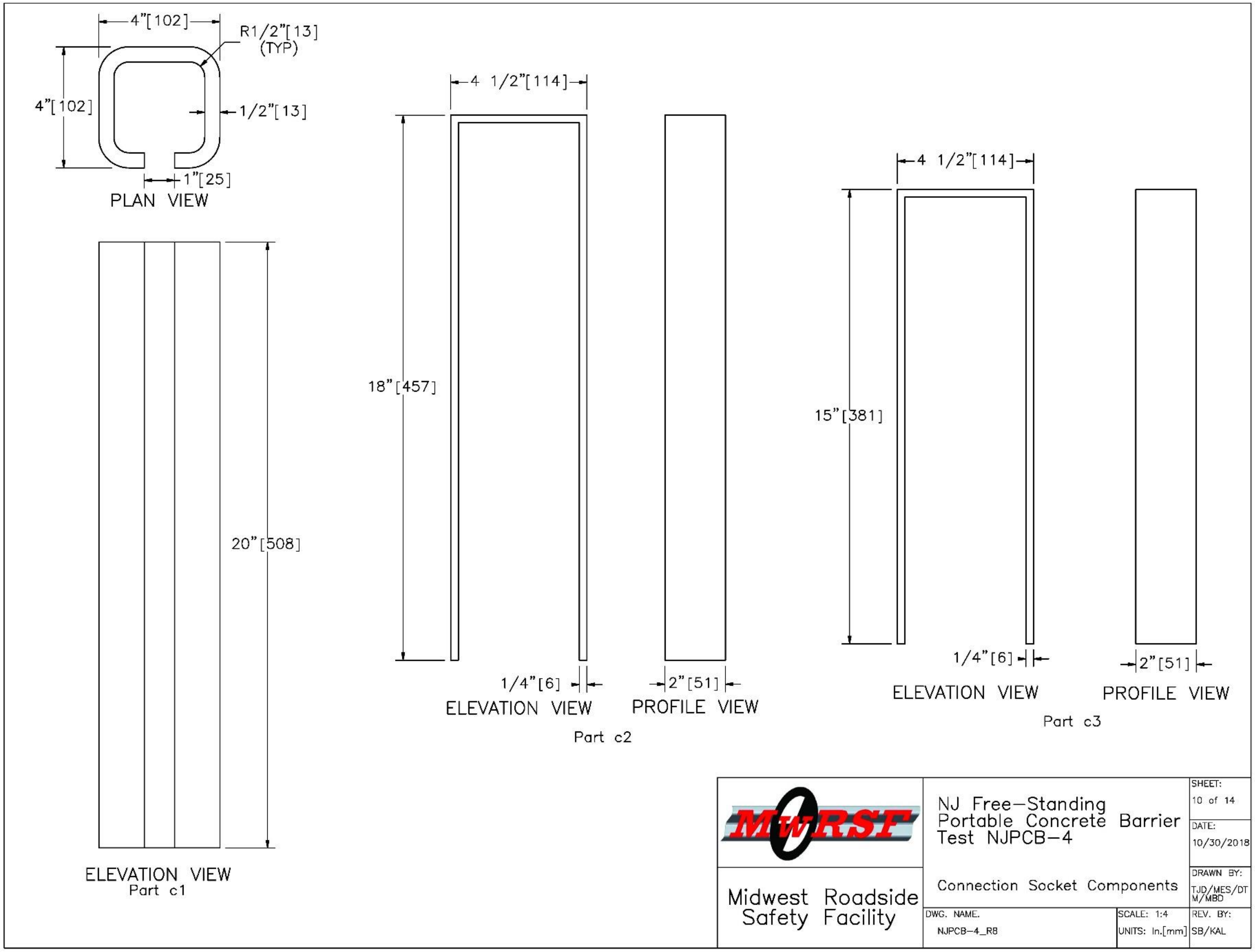


Figure 10. PCB Connection Socket Component Details, Test No. NJPCB-4

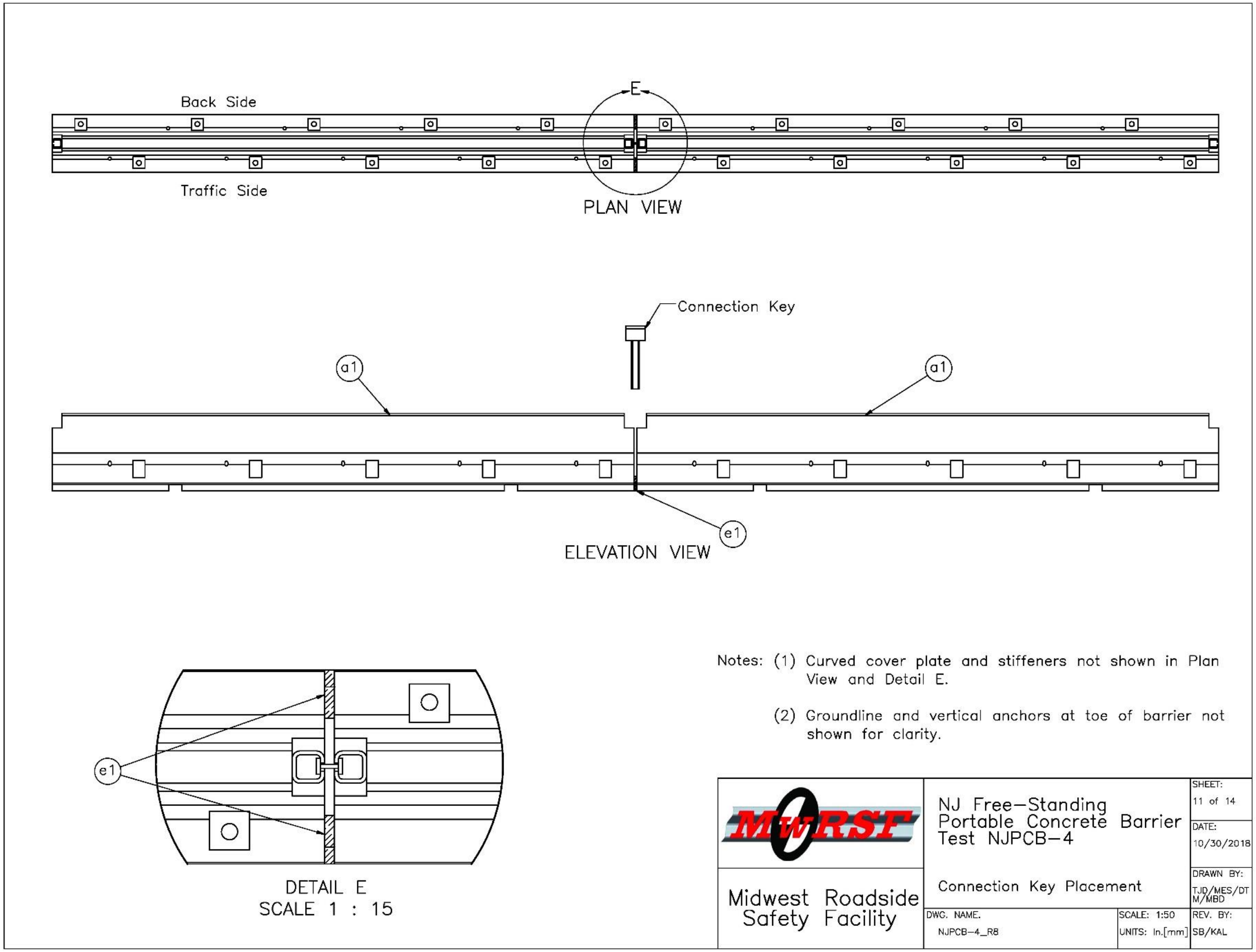
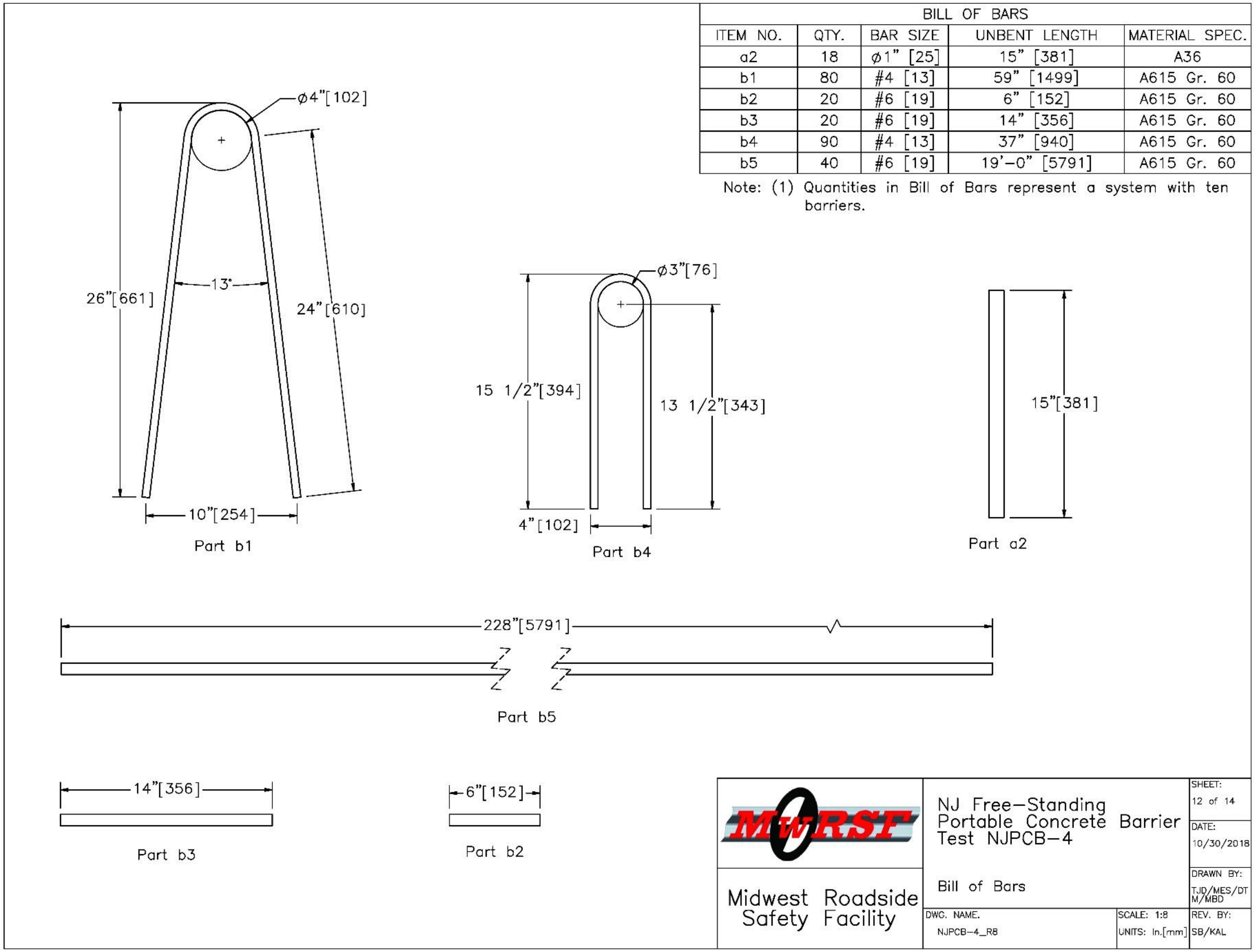


Figure 11. Connection Key Placement Details, Test No. NJPCB-4



BILL OF BARS				
ITEM NO.	QTY.	BAR SIZE	UNBENT LENGTH	MATERIAL SPEC.
a2	18	ø1" [25]	15" [381]	A36
b1	80	#4 [13]	59" [1499]	A615 Gr. 60
b2	20	#6 [19]	6" [152]	A615 Gr. 60
b3	20	#6 [19]	14" [356]	A615 Gr. 60
b4	90	#4 [13]	37" [940]	A615 Gr. 60
b5	40	#6 [19]	19'-0" [5791]	A615 Gr. 60

Note: (1) Quantities in Bill of Bars represent a system with ten barriers.

Figure 12. PCB Reinforcement Details, Test No. NJPCB-4

(1) Minimum concrete clear cover for reinforcement steel shall be 1 1/2" [38 mm].

(2) All end segments shall be pinned.

(3) After a segment has been placed and the connection key inserted, pull the unit in a direction parallel to its longitudinal axis to remove any slack in the joint.

(4) The portable concrete barrier shall be cast in steel forms.

(5) The portable concrete barrier shall be barrier segments of 20 feet [6,096 mm]. However, other lengths may be used to meet field conditions. The number and placement of the b2 and b3 reinforcement steel will vary with the length of the barrier segment as shown on the table of variable reinforcement steel. The b5 reinforcement steel shall be 10" [254 mm] shorter than the nominal length of the barrier segments.

(6) Reinforcing shown is the minimum required. Additional reinforcing necessary for handling shall be the option and responsibility of the contractor.

(7) Welding and fabrication of steel structures shall be in accordance with sections 1 thru 6 of the ANSI/AASHTO/AWS D1.5 bridge welding code and section 10 of the ANSI/AWS D1 structural welding code. Surfaces to be welded shall be free of scale, slag, rust, moisture, grease or any other material that will prevent proper welding or produce objectional fumes. Welding shall be shielded metal arc welding using properly dried 5/32" [4 mm] dia. E7018 electrodes.

(8) The length of the pins shall be such that a minimum embedment length of 5" [127 mm] is obtained when embedded into concrete pavement. When anchor pins are in place, they shall not project above the plane of the concrete surface of the barrier. Holes in bridge decks shall be 1 1/4" [32 mm] diameter maximum and made with a core drill or any other approved rotary drilling device that does not impart an impact force.

(9) Use non–shrink grout of a plastic consistency that is listed on the QPL and conforms to ASTM C 1107 with the following amendments:
1. Ensure that the grout has a working time of at least 30 minutes from the time the water is added.
2. Match the color of the hardened grout, where visible, to the color of the adjacent hardened concrete.
3. Include 1–day strength tests as part of the performance requirements of ASTM C 1107.
4. Ensure that the grout contains no more than 0.05 percent chlorides or 5.0 percent sulfates by weight.
5. Minimum 1–day compressive strength of 1,000 psi [6.9 MPa]

(10) Use connection key in every joint. Pin end segments with pins in every anchor pin recess.

MwRSF	NJ Free–Standing Portable Concrete Barrier Test NJPCB–4		SHEET: 13 of 14
			DATE: 10/30/2018
Midwest Roadside Safety Facility	General Notes		DRAWN BY: TJD/MES/DTM/MBD
	DWG. NAME. NJPCB–4_R8	SCALE: None UNITS: in.[mm]	REV. BY: SB/KAL

Figure 13. General Notes, Test No. NJPCB-4

Item No.	QTY.	Description	Material Spec	Galvanization Spec
a1	10	Concrete Barrier Segment – NJDOT Type 4 Barrier (Alternate B)	Min. f'c = 3,700 psi [25.5 MPa]	–
a2	18	1" [25] Dia., 15" [381] Long Anchor Steel Pin	ASTM A36	ASTM A123*
b1	80	1/2" [13] Dia., 59" [1,499] Long Bent Rebar	ASTM A615 Gr. 60	–
b2	20	3/4" [19] Dia., 6" [152] Long Rebar	ASTM A615 Gr. 60	–
b3	20	3/4" [19] Dia., 14" [356] Long Rebar	ASTM A615 Gr. 60	–
b4	90	1/2" [13] Dia., 37" [940] Long Bent Rebar	ASTM A615 Gr. 60	–
b5	40	3/4" [19] Dia., 228" [5,791] Long Rebar	ASTM A615 Gr. 60	–
c1	20	4"x4"x1/2" [102x102x13] x 20" [508] Long Tube	ASTM A500 Gr. B or C	–
c2	40	40 1/2"x2"x1/4" [1,029x51x6] Bent Steel Plate	ASTM A36	–
c3	20	34 1/2"x2"x1/4" [876x51x6] Bent Steel Plate	ASTM A36	–
d1	18	25 1/2"x2"x1/2" [648x51x13] Steel Plate	ASTM A36	–
d2	9	25 1/2"x2 1/4"x1/2" [648x57x13] Steel Plate	ASTM A36	–
d3	18	6 3/16"x1 3/8"x1/2" [157x35x13] Steel Plate – Stiffener	ASTM A36	–
d4	9	17"x8"x1/2" [432x203x13] Bent Steel Plate – Top Plate	ASTM A36	–
e1	18	Non–Shrink Grout	Min. 1–day Compressive Strength 1,000 psi [6.9 MPa]	–

*Component does not need to be galvanized for testing purposes.

Midwest Roadside Safety Facility	NJ Free–Standing Portable Concrete Barrier Test NJPCB–4 Bill of Materials		SHEET: 14 of 14 DATE: 10/30/2018 DRAWN BY: TJD/MES/DTM/MBD
	DWG. NAME. NJPCB–4_R8	SCALE: None UNITS: in.[mm]	REV. BY: SB/KAL

Figure 14. Bill of Materials, Test No. NJPCB-4

Figure 15. NJDOT PCB with Free-Standing Configuration and Grouted Toes Test Installation, Test No. NJPCB-4

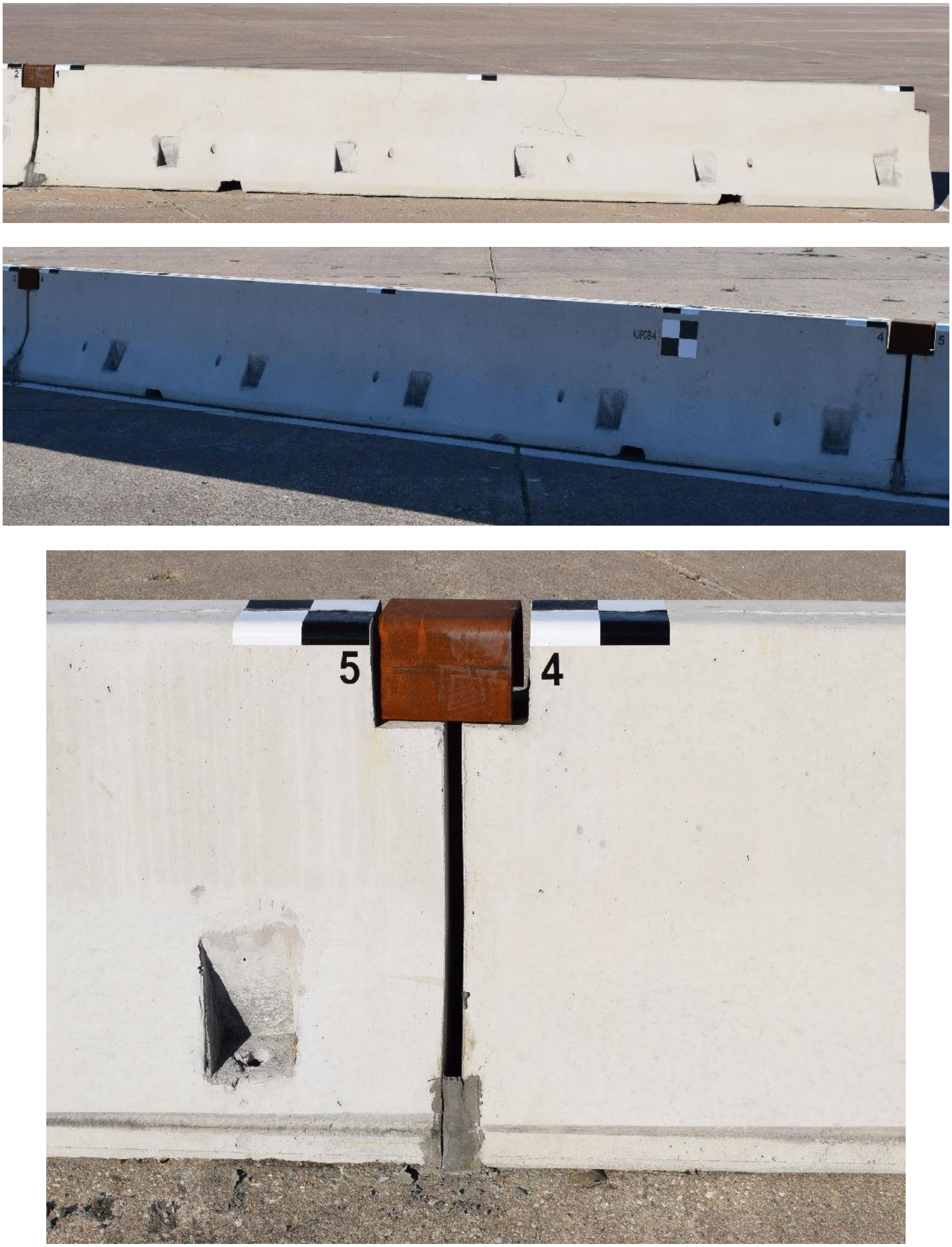


Figure 16. PCB Connection Key, Connection Socket, and Grout at Toes Between Barriers, Test No. NJPCB-4

Figure 17. PCB Pin Anchor Recesses – Barrier Nos. 1 and 10, Test No. NJPCB-4

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

4.3 Test Vehicle

For test no. NJPCB-4, a 2011 Dodge Ram 1500 quad cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,029 lb (2,281 kg), 5,000 lb (2,268 kg), and 5,156 lb (2,339 kg), respectively. The test vehicle is shown in Figures 18 and 19, and vehicle dimensions are shown in Figure 20. Note that pre-test photographs of the vehicle's undercarriage are not available.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [12] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The location of the final c.g. is shown in Figures 20 and 21. Data used to calculate the location of the c.g. and ballast information are shown in Appendix D.

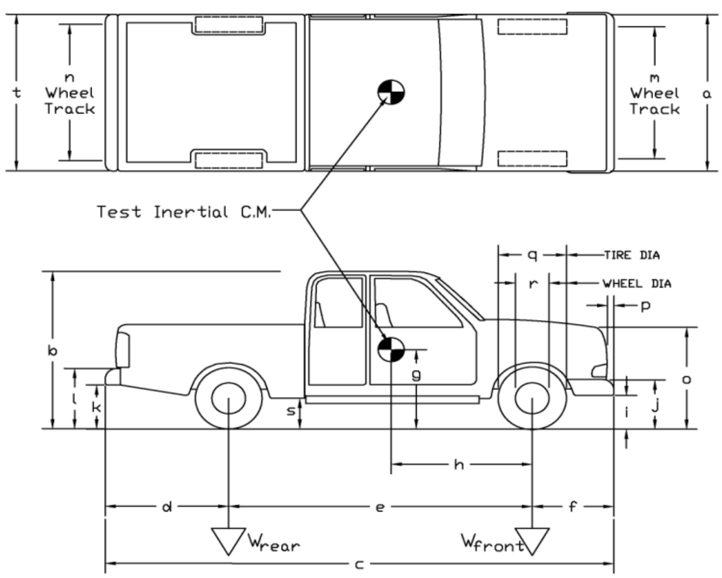
Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure 21. Round, checkered targets were placed on the c.g. on the left-side door, the right-side door, and the roof of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

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

Figure 18. Test Vehicle, Test No. NJPCB-4

Figure 19. Test Vehicle's Interior Floorboards, Test No. NJPCB-4

Date:	11/9/2016	**Test Name:**	NJPCB-4	**VIN No:**	1D7R1GP1BS554669
Year:	2011	**Make:**	Dodge	**Model:**	Ram 1500
Tire Size:	P265/70R17	**Tire Inflation Pressure:**	40 Psi	**Odometer:**	175692



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

a:	76 1/2 (1943) 78±2 (1950±50)		b:	74 5/8 (1895)
c:	230 3/4 (5861) 237±13 (6020±325)		d:	49 3/8 (1254)
e:	140 1/2 (3569) 148±12 (3760±300)		f:	40 7/8 (1038) 39±3 (1000±75)
g:	28 3/16 (716) min: 28 (710)		h:	61 11/16 (1567) 63±4 (1575±100)
i:	11 5/8 (295)		j:	26 (660)
k:	21 (533)		l:	30 (762)
m:	67 3/4 (1721) 67±1.5 (1700±38)		n:	67 3/4 (1721) 67±1.5 (1700±38)
o:	44 1/2 (1130) 43±4 (1100±75)		p:	5 1/2 (140)
q:	31 1/2 (800)		r:	18 1/2 (470)
s:	14 (356)		t:	75 1/2 (1918)

Wheel Center Height (Front):	15 (381)
Wheel Center Height (Rear):	15 3/8 (391)
Wheel Well Clearance (Front):	35 1/8 (892)
Wheel Well Clearance (Rear):	38 (965)
Bottom Frame Height (Front):	18 1/8 (460)
Bottom Frame Height (Rear):	25 1/4 (641)
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**	1473 (668)	**RF**	1428 (648)
	LR	1160 (526)	**RR**	1095 (497)

Weights lb (kg)	**Curb**	**Test Inertial**	**Gross Static**
W-front	2853 (1294)	2805 (1272)	2901 (1316)
W-rear	2176 (987)	2195 (996)	2255 (1023)
W-total	5029 (2281)	5000 (2268) 5000±110 (2270±50)	5156 (2339) 5165±110 (2343±50)

GVWR Ratings lb

Front	3700
Rear	3900
Total	6700

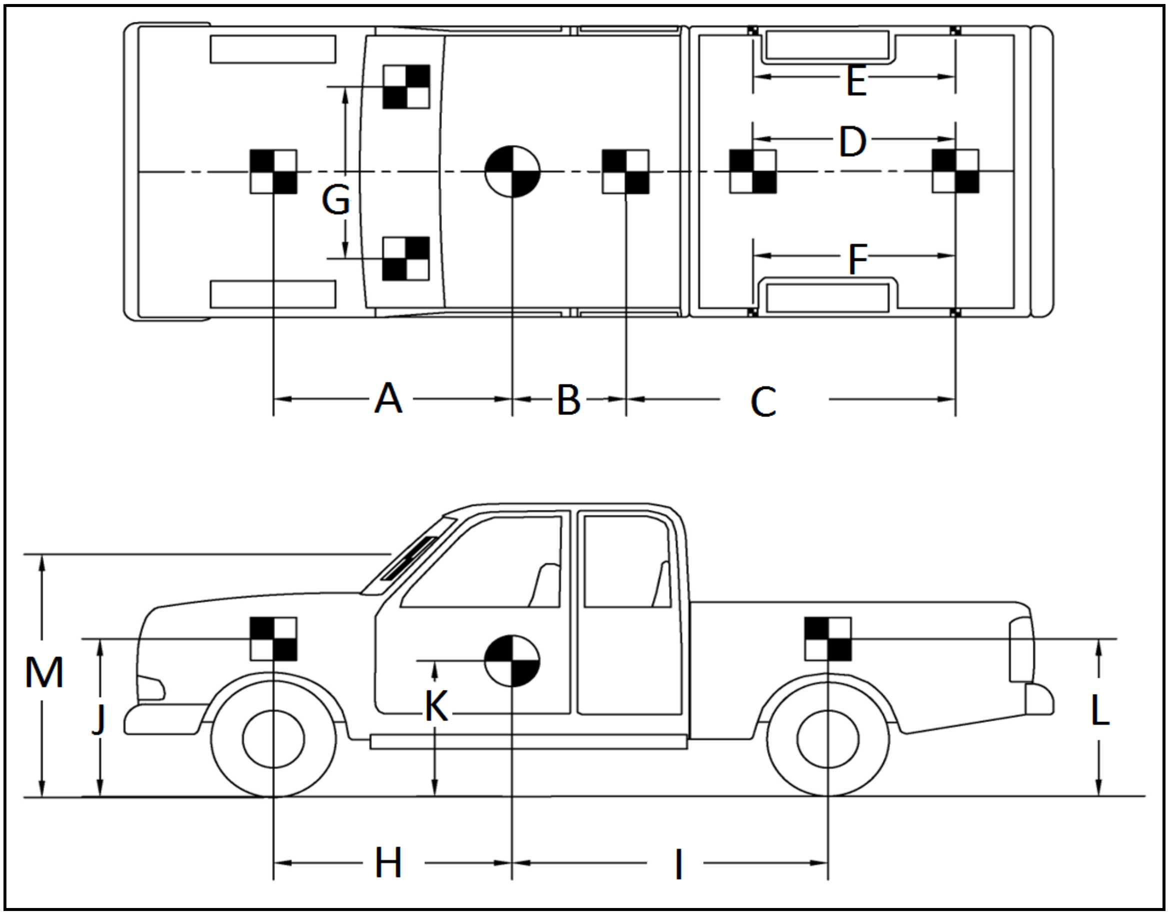
Dummy Data

Type:	Hybrid II
Mass:	156 lb
Seat Position:	Driver

Note any damage prior to test: minor dents and scratches, tail gate cap missing.

Figure 20. Vehicle Dimensions, Test No. NJPCB-4

Date:	**11/9/2016**	**Test Name:**	**NJPCB-4**	**VIN:**	**1D7R1GP1BS554669**
Year:	**2011**	**Make:**	**Dodge**	**Model:**	**Ram 1500**



TARGET GEOMETRY-- in. (mm)

A:	**73 1/8**	**(1857)**	**E:**	**63 1/2**	**(1613)**	**J:**	**39 1/4**	**(997)**
B:	**27**	**(686)**	**F:**	**63 1/2**	**(1613)**	**K:**	**28 1/8**	**(714)**
C:	**84 1/4**	**(2140)**	**G:**	**34 3/4**	**(883)**	**L:**	**41 7/8**	**(1064)**
D:	**44**	**(1118)**	**H:**	**61 3/4**	**(1568)**	**M:**	**65 1/4**	**(1657)**
			I:	**78 1/2**	**(1994)**			

Figure 21. Target Geometry, Test No. NJPCB-4

4.4 Simulated Occupant

For test no. NJPCB-4, A Hybrid II 50^{th}-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, which had a final weight of 156 lb (71 kg), was represented by model no. 572, serial no. 451, and was manufactured by Android Systems of Carson, California. As recommended by MASH 2016, the dummy was not included in calculating the c.g. location.

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 vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [13].

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

4.5.2 Rate Transducers

Two identical angular rate sensor systems, which were mounted inside the bodies of the SLICE-1 and SLICE-2 event data recorders, measured 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.

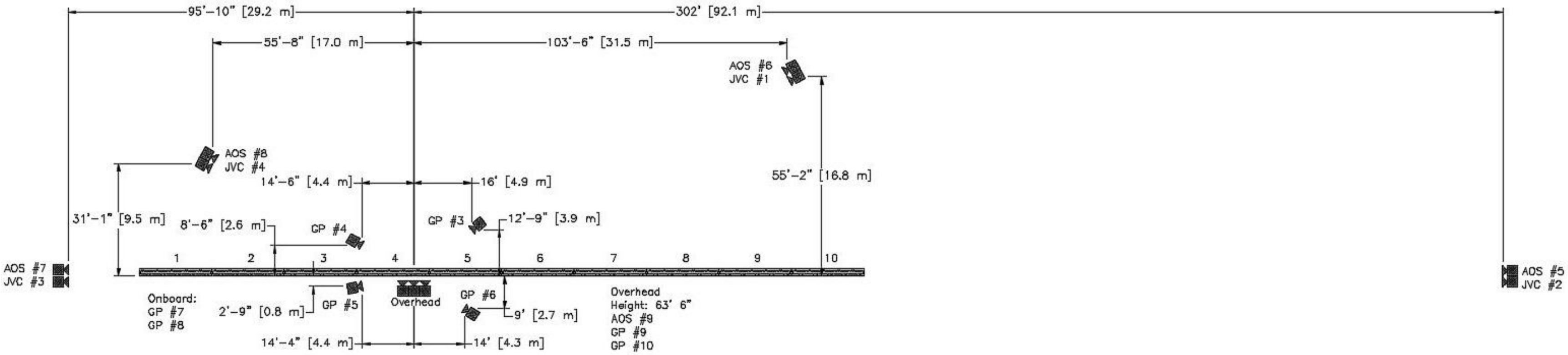
4.5.3 Retroreflective Optic Speed Trap

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. NJPCB-4. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 22.

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



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI Gigabit	500	Telesar 135 mm Fixed	-
AOS-6	AOS X-PRI Gigabit	500	Sigma 28-70 DG	50
AOS-7	AOS X-PRI Gigabit	500	Sigma 28-70	50
AOS-8	AOS S-VIT 1531	500	Fujinon 35 mm Fixed	-
AOS-9	AOS TRI-VIT 2236	1000	KOWA 12 mm Fixed	-
GP-3	GoPro Hero 3+	120		
GP-4	GoPro Hero 3+	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	240		
GP-10	GoPro Hero 4	120		
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 22. Camera Locations, Speeds, and Lens Settings, Test No. NJPCB-4

5 FULL-SCALE CRASH TEST NO. NJPCB-4

5.1 Weather Conditions

Test no. NJPCB-4 was conducted on November 9, 2016 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 5.

Table 5. Weather Conditions, Test No. NJPCB-4

Temperature	60° F
Humidity	41%
Wind Speed	11 mph
Wind Direction	230° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.05 in.
Previous 7-Day Precipitation	0.05 in.

5.2 Test Description

The 5,000-lb (2,268-kg) pickup truck impacted the NJDOT PCB, Type 4 (Alternative B) with a free-standing configuration and grouted toes, corresponding to joint class B in the 2013 NJDOT *Roadway Design Manual*, at a speed of 62.8 mph (101.1 km/h) and at an angle of 24.5 degrees. A sequential description of the impact events is contained in Table 6. A summary of the test results and sequential photographs are shown in Figure 24. Additional sequential photographs are shown in Figures 25 and 26. Documentary photographs of the crash test are shown in Figure 27.

Initial vehicle impact was to occur 4 ft – $3^{3}/_{16}$ in. (1.3 m) upstream from the centerline of the joint between barrier nos. 4 and 5, as shown in Figure 28, which was selected using Table 2.7 of MASH 2016. The actual point of impact was $5^{11}/_{16}$ in. (145 mm) downstream from the target location. The vehicle came to rest 187 ft – 5 in. (57.1 m) downstream from impact point and 15 ft (4.6 m) laterally away from the traffic side of the system after brakes were applied. The vehicle trajectory and final position are shown in Figures 24 and 29.

Table 6. Sequential Description of Impact Events, Test No. NJPCB-4

TIME (sec)	EVENT
0.000	Vehicle’s left-front tire impacted barrier no. 4 at 3 ft – 9½ in. (1.2 m) upstream from centerline of joint between barrier nos. 4 and 5.
0.002	Vehicle’s left-front bumper contacted barrier no. 4.
0.004	Vehicle’s left-front bumper deformed.
0.008	Vehicle’s left fender contacted barrier no. 4 and plastic fascia deformed.

0.010	Vehicle’s left headlight contacted downstream end of barrier no. 4.
0.012	Vehicle’s left headlight and left fender deformed.
0.020	Vehicle’s hood and grille deformed.
0.024	Downstream end of barrier no. 4 deflected backward.
0.030	Upstream end of barrier no. 5 deflected backward.
0.034	Vehicle pitched upward and rolled away from system.
0.039	Vehicle yawed away from system.
0.042	Upstream end of barrier no. 4 cracked, and vehicle’s left-front airbag deployed.
0.046	Vehicle’s right-front airbag deployed.
0.058	Vehicle’s left-front door deformed.
0.062	Vehicle rolled toward system.
0.066	Downstream end of barrier no. 5 cracked, and upstream end of barrier no. 4 spalled.
0.084	Downstream end of barrier no. 5 spalled.
0.090	Vehicle’s right-front tire became airborne.
0.160	Barrier no. 5 fractured between upstream end and midspan.
0.189	Barrier no. 5 deflected backward andupstream end of barrier no. 6 deflected backward.
0.207	Vehicle was parallel to system at a speed of 52.8 mph (84.9 km/h).
0.218	Vehicle’s left-front door contacted barrier no. 5.
0.226	Vehicle’s left taillight contacted barrier no. 4.
0.232	Vehicle’s left quarter panel deformed.
0.234	Vehicle pitched downward.
0.240	Vehicle’s left taillight deformed.
0.248	Vehicle’s left-rear door contacted barrier no. 5.
0.276	Vehicle’s left-rear tire became airborne.
0.278	Vehicle’s right-rear tire became airborne.
0.310	Vehicle exited system at a speed of 51.3 mph (82.6 km/h) and angle of 8.4 degrees.
0.348	Downstream end of barrier no. 6 cracked.
0.352	Downstream end of barrier no. 6 spalled.
0.361	Downstream end of barrier no. 7 cracked.
0.364	Upstream end of barrier no. 7 spalled.
0.474	Vehicle’s left-front tire regained contact with ground.
0.562	Vehicle’s bumper contacted ground.
0.622	Vehicle’s right-front tire regained contact with ground and mud flap disengaged.
0.638	Vehicle’s left headlight cover contacted ground.
0.648	Vehicle pitched upward.
0.876	System came to rest.
0.920	Vehicle’s left-rear tire regained contact with ground.
0.968	Vehicle’s right-rear tire regained contact with ground.
1.008	Vehicle yawed toward system.
1.066	Vehicle rolled toward system.
1.094	Vehicle pitched downward.

5.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 30 through 36. Barrier damage consisted of contact marks on the front face of the PCB segments, spalling of the concrete, and concrete cracking. The length of vehicle contact along the barrier was approximately 25 ft (7.6 m), which spanned from 5 ft – 9¼ in. (1.76 m) upstream from the centerline of the joint between barrier nos. 4 and 5 to 19 ft – 2¾ in. (5.86 m) downstream from the centerline of the joint between barrier nos. 4 and 5.

Tire marks and scrape marks were visible on the front face of barrier nos. 4 and 5 with additional scrape marks on the top faces of the barriers. Grout between barrier nos. 4 and 5 crumbled. A 54½-in. (1,384-mm) long crack was found on the front face of barrier no. 3 that started at the upstream end toe. A vertical crack was found on the front, top, and back faces of barrier no. 3, located 35¾ in. (908 mm) downstream from center. A 14-in. (356-mm) long vertical crack was found on the front face of barrier no. 3, 7 in. (178 mm) upstream from the downstream end of the barrier. A 19-in. long by 7½-in. wide (483-mm by 191-mm) scrape mark was found at the downstream end of the front face of barrier no. 4. Minor cracks were also found on the front and back faces of barrier nos. 3, 6, and 7.

Concrete spalling occurred on the back face of barrier no. 2 at the downstream end. Concrete spalling also occurred on barrier nos. 3 through 8. A 19-in. × 3-in. × ½-in. (483-mm × 76-mm × 13-mm) piece of concrete disengaged from barrier no. 3 at the lower-downstream corner on the back face. A 57-in. × 12-in. × 6½-in. (1,448-mm × 305-mm × 165-mm) piece of concrete was removed from the lower-downstream end of the front face of barrier no. 4. Concrete spalling, measuring 22 in. × 9 in. × 2½ in. (559 mm × 229 mm × 64 mm), occurred on the back face of barrier no. 4 at the downstream end. The front face of barrier no. 5 experienced 20½ in. × 10½ in. × 5 in. (521 mm × 267 mm × 127 mm) concrete spalling at the lower-upstream corner. Concrete spalling, measuring 26½ in. × 10 in. × 5¾ in. (673 mm × 254 mm × 146 mm), occurred on the back face of the downstream end of barrier no. 5. A 4-in. × 4½-in. (102-mm × 114-mm) piece of concrete disengaged from the lower-upstream edge of the back face of barrier no. 6. An 8-in × 4-in. (203-mm × 102-mm) piece of concrete spalled from the back face of barrier no. 6 and was located approximately 46 in. (1,168 mm) downstream from the upstream edge.

The maximum permanent set deflection of the barrier system was 38 in. (965 mm) at the upstream end of barrier no. 5, as measured in the field. The maximum lateral dynamic barrier deflection, including tipping of the barrier along the top surface, was 40.7 in. (1,034 mm) at the upstream end of barrier no. 5, as determined from high-speed digital video analysis. The working width of the system was found to be 64.7 in. (1,644 mm), also determined from high-speed digital video analysis. A schematic of the permanent set deflection, dynamic deflection, and working width is shown in Figure 23. In addition, NJDOT identifies the clear space behind the barrier, which is defined as the maximum deflection of the back of the barrier from its original position. For this test, the clear space behind the barrier was 40.7 in. (1,034 mm).

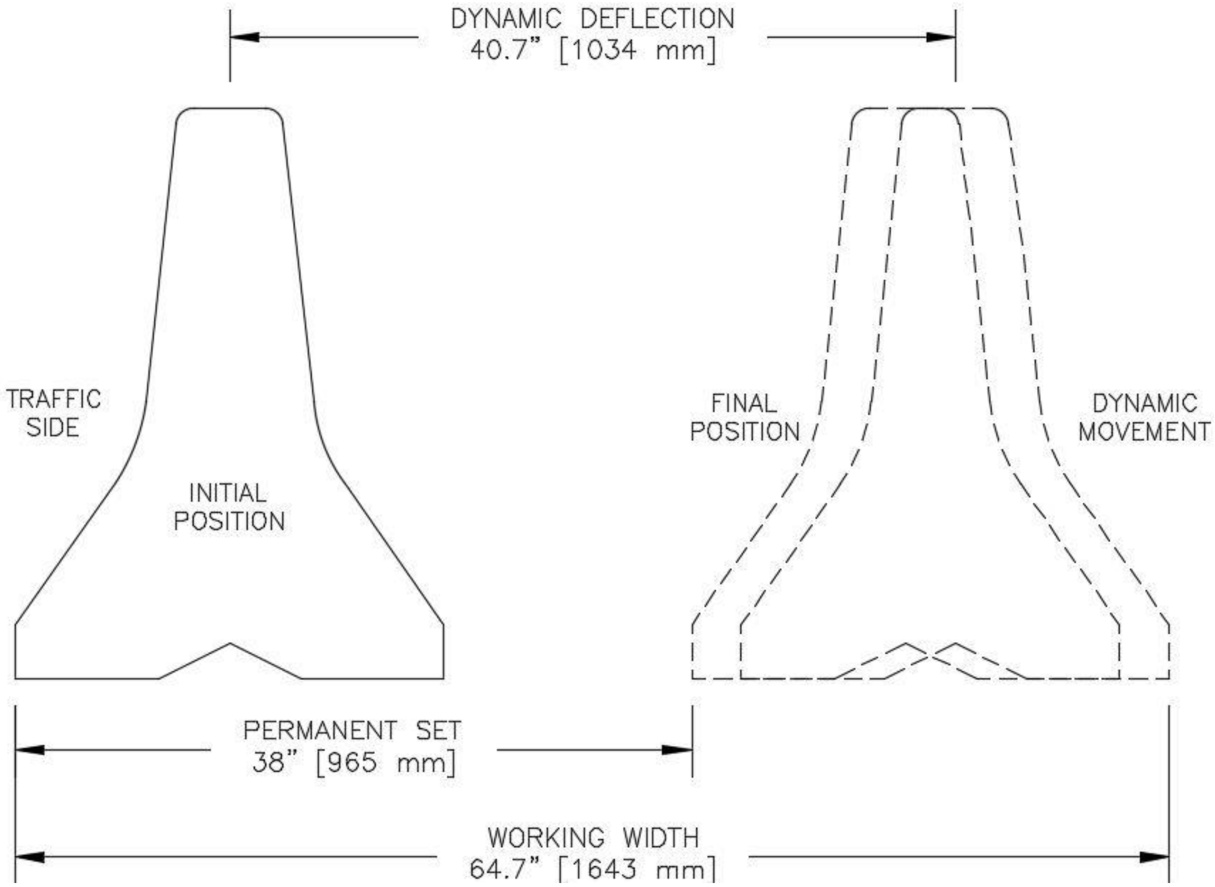


Figure 23. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. NJPCB-4

5.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 37 through 41. The maximum occupant compartment deformations are listed in Table 7 along with the deformation 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 deformations and the corresponding locations are provided in Appendix E.

The majority of damage was concentrated on the left-front corner and left side of the vehicle where the impact had occurred. The left side of the bumper was crushed inward and back. The left-front fender was deformed upward near the door panel and was dented and torn behind the left-front wheel. The left headlight was partially disengaged. The left corner of the front bumper was bent inward approximately 30 in. (762 mm) from the left side. The left-front corner of the frame rail buckled inward. The left side of the lower plastic fascia was partially disengaged. A 1-in (25-mm) gap occurred between the grille and the front bumper. A 2-in. (51-mm) gap was found between the hood and the left-front fender. The left-front tire's steel rim was deformed and torn. Denting and scraping were observed on the entire left side. A 10-in. × 22-in. (254-mm × 559-mm) dent was found at the middle of left-front door. A 2½-in. (64-mm) tear was found on the outer metal sheet of the left-front door. Dents and scraping were found on the left-side of the quarter panel. The tailgate disengaged from its connections, but remained attached to left-upper connection point.

The joint of the front sway bar disconnected from the end. The left-front lower control arm was dented ½ in. (13 mm). The left-front control arm deformed at the connection to the engine cross member. The steering rack fractured at the input shaft, and the left-front tie rod was bent. A 10-in. (254-mm) diameter spider web crack was found in the lower-right corner of the windshield. The spider web crack extended 40 in. (1,016 mm) toward the lower-left corner of the windshield. The left-front and right-front airbags deployed. The roof and remaining window glass remained undamaged.

Table 7. Maximum Occupant Compartment Deformations by Location

LOCATION	MAXIMUM DEFORMATION in. (mm)	MASH 2016 ALLOWABLE DEFORMATION in. (mm)
Wheel Well & Toe Pan	¾ (19)	≤ 9 (229)
Floor Pan & Transmission Tunnel	¾ (19)	≤ 12 (305)
A-Pillar	⅞ (22)	≤ 5 (127)
A-Pillar (Lateral)	⅛ (3)	≤ 3 (76)
B-Pillar	⅝ (16)	≤ 5 (127)
B-Pillar (Lateral)	⅜ (10)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	¼ (6)	≤ 12 (305)
Side Door (Above Seat)	−⅞ (−22)	≤ 9 (229)
Side Door (Below Seat)	⅜ (10)	≤ 12 (305)
Roof	−½ (−13)	≤ 4 (102)
Windshield	0 (0)	≤ 3 (76)
Side Window	Shattered due to contact with dummy's head	No shattering resulting from contact with structural member of test article
Dash	¾ (19)	N/A

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

5.5 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 8. 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 8. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 24. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix F.

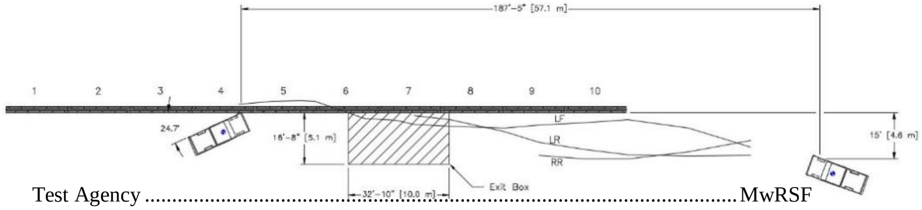
Table 8. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. NJPCB-4

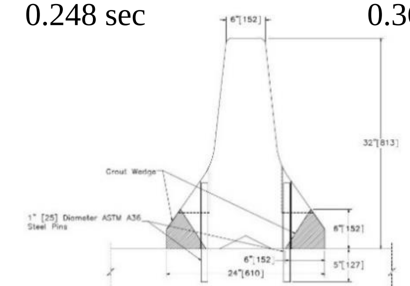
Evaluation Criteria		**Transducer**		**MASH 2016 Limits**
		SLICE-1	**SLICE-2 (primary)**	
OIV ft/s (m/s)	Longitudinal	-12.11 (-3.69)	-12.10 (-3.68)	±40 (12.2)
	Lateral	16.07 (4.89)	18.66 (5.69)	±40 (12.2)
ORA g's	Longitudinal	-3.95	-3.95	±20.49
	Lateral	13.09	12.09	±20.49
MAX. ANGULAR DISPL. deg.	Roll	-19.6	-16.2	±75
	Pitch	-13.1	-14.2	±75
	Yaw	-46.5	-47.4	not required
THIV ft/s (m/s)		18.54 (5.65)	22.41 (6.83)	not required
PHD g's		13.19	12.22	not required
ASI		1.11	1.26	not required

5.6 Discussion

The analysis of the test results for test no. NJPCB-4 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. 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 8.4 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. NJPCB-4 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.

0.000 sec | 0.164 sec | 0.207 sec | 0.248 sec | 0.364 sec





- Test Agency .... MwRSF
- Test Number NJPCB-4
- Date 11/9/2016
- MASH 2016 Test Designation 3-11
- Test Article .... NJDOT PCB with Free-Standing and Grouted Toes Configuration
- Total Length .... 200 ft (61.0 m)
- Key Component – NJDOT PCB
  - Length .... 20 ft (6.1 m)
  - Width .... 24 in. (610 mm)
  - Height .... 32 in. (813 mm)
- Key Component – Anchor Pins
  - Pin Size .... 1-in. (25-mm) Diameter Unthreaded Rod
  - Pin Material .... ASTM A36 Steel
  - Pin Length .... 15 in. (381 mm)
  - Embedment Depth .... 5 in. (127 mm)
  - Number of Pins per Barrier 9
  - Pinned Barrier Nos. .... 1 and 10
- Key Component – Grout
  - Specification .... Min. 1-day compressive strength 1,000 psi (6.9 MPa)
  - Location .... Toes at joints between barrier nos. 1-10 on traffic and back sides
- Type of Support Surface .... Concrete Tarmac
- Vehicle Make /Model .... 2011 Dodge Ram 1500 quad cab pickup truck
  - Curb .... 5,029 lb (2,281 kg)
  - Test Inertial .... 5,000 lb (2,268 kg)
  - Gross Static .... 5,156 lb (2,339 kg)
- Impact Conditions
  - Speed .... 62.8 mph (101.1 km/h)
  - Angle .... 24.5 deg
  - Impact Location .... 3 ft – 9½ in. (1.2 m) upstream from joint 4-5
- Impact Severity .... 113.4 kip-ft (153.7 kJ) > 105.6 kip-ft (143.1 kJ) limit in MASH 2016
- Exit Conditions
  - Speed .... 51.3 mph (82.6 km/h)
  - Angle .... 8.4 deg
  - Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Test Article Damage .... Moderate
- Vehicle Stopping Distance .... 187 ft – 5 in. (57.1 m) downstream
  15 ft (4.6 m) laterally in front
- Vehicle Damage .... Moderate
  - VDS [14] 11-LFQ-4
  - CDC [15] 11-LYEW-4
  - Maximum Interior Deformation .... ⅞ in. (22 mm)
- Maximum Test Article Deflections
  - Permanent Set .... 38 in. (965 mm)
  - Dynamic .... 40.7 in. (1,034 mm)
  - Working Width .... 64.7 in. (1,643 mm)
- Transducer Data

Evaluation Criteria		Transducer SLICE-1	Transducer SLICE-2 (primary)	MASH 2016 Limit
OIV ft/s (m/s)	Longitudinal	-12.11 (-3.69)	-12.10 (-3.68)	±40 (12.2)
	Lateral	16.07 (4.89)	18.66 (5.69)	±40 (12.2)
ORA g's	Longitudinal	-3.95	-3.95	±20.49
	Lateral	13.09	12.09	±20.49
MAX ANGULAR DISP. deg.	Roll	-19.6	-16.2	±75
	Pitch	-13.1	-14.2	±75
	Yaw	-46.5	-47.4	Not required
THIV – ft/s (m/s)		18.54 (5.65)	22.41 (6.83)	Not required
PHD – g's		13.19	12.22	Not required
ASI		1.11	1.26	Not required

Figure 24. Summary of Test Results and Sequential Photographs, Test No. NJPCB-4

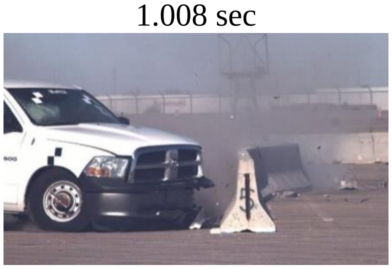

0.000 sec


0.190 sec


0.352 sec


0.562 sec


1.008 sec


1.804 sec


0.000 sec


0.164 sec


0.226


0.622 sec


1.008 sec

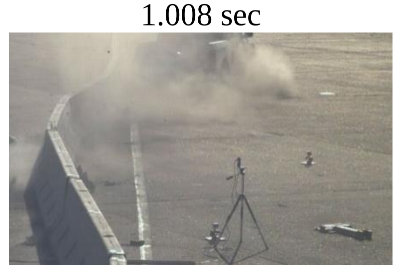
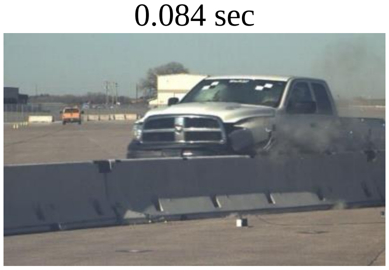

1.094 sec

Figure 25. Additional Sequential Photographs, Test No. NJPCB-4

0.000 sec

0.058 sec

0.084 sec



0.164 sec

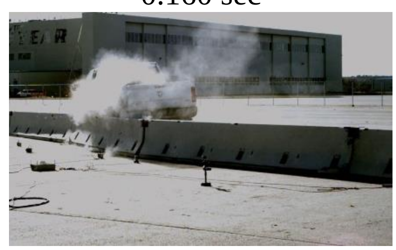
0.218 sec

0.310 sec

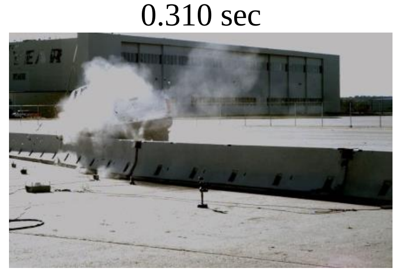
0.000 sec

0.066 sec

0.160 sec



0.310 sec



0.364 sec

Figure 26. Additional Sequential Photographs, Test No. NJPCB-4

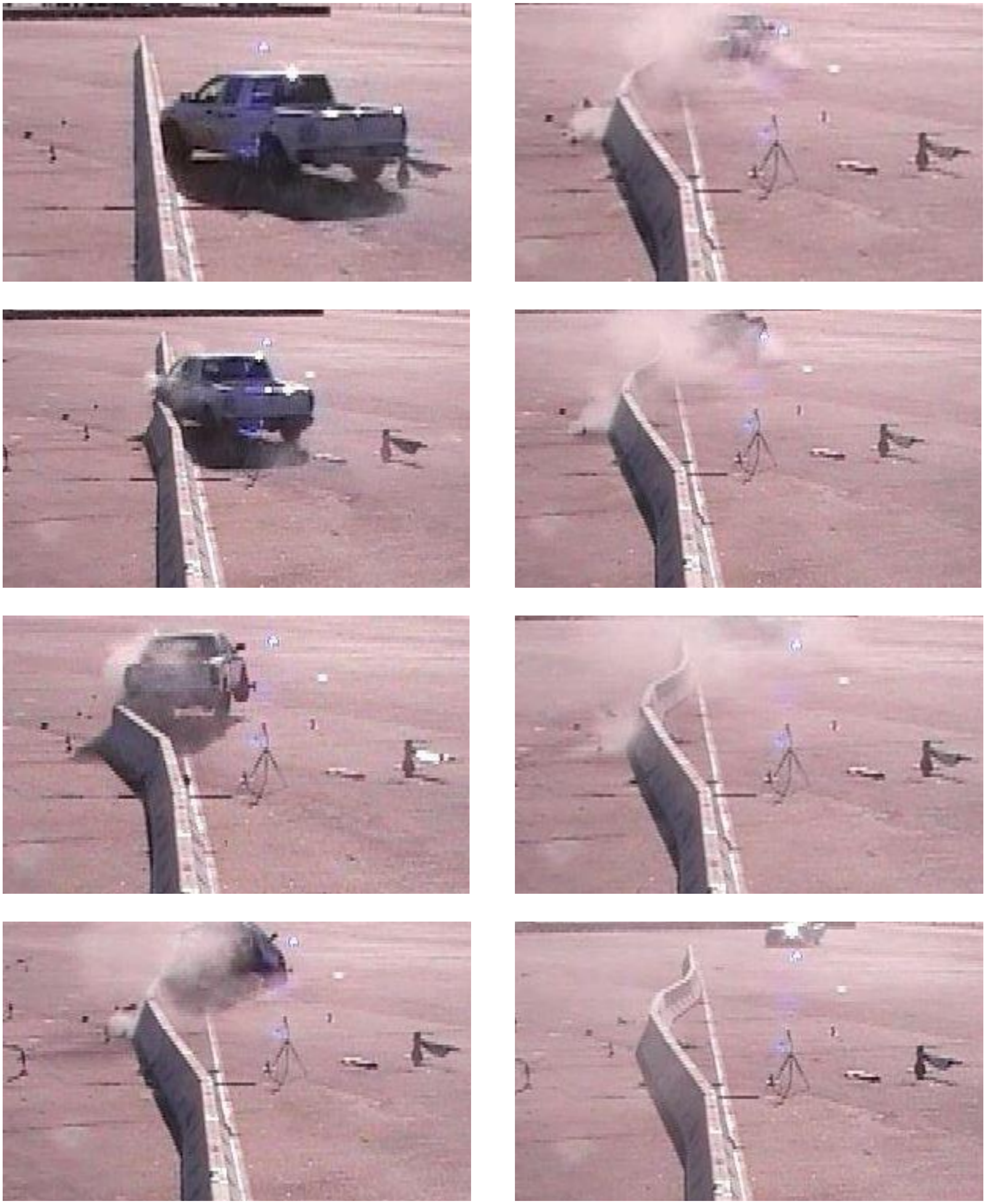


Figure 27. Documentary Photographs, Test No. NJPCB-4

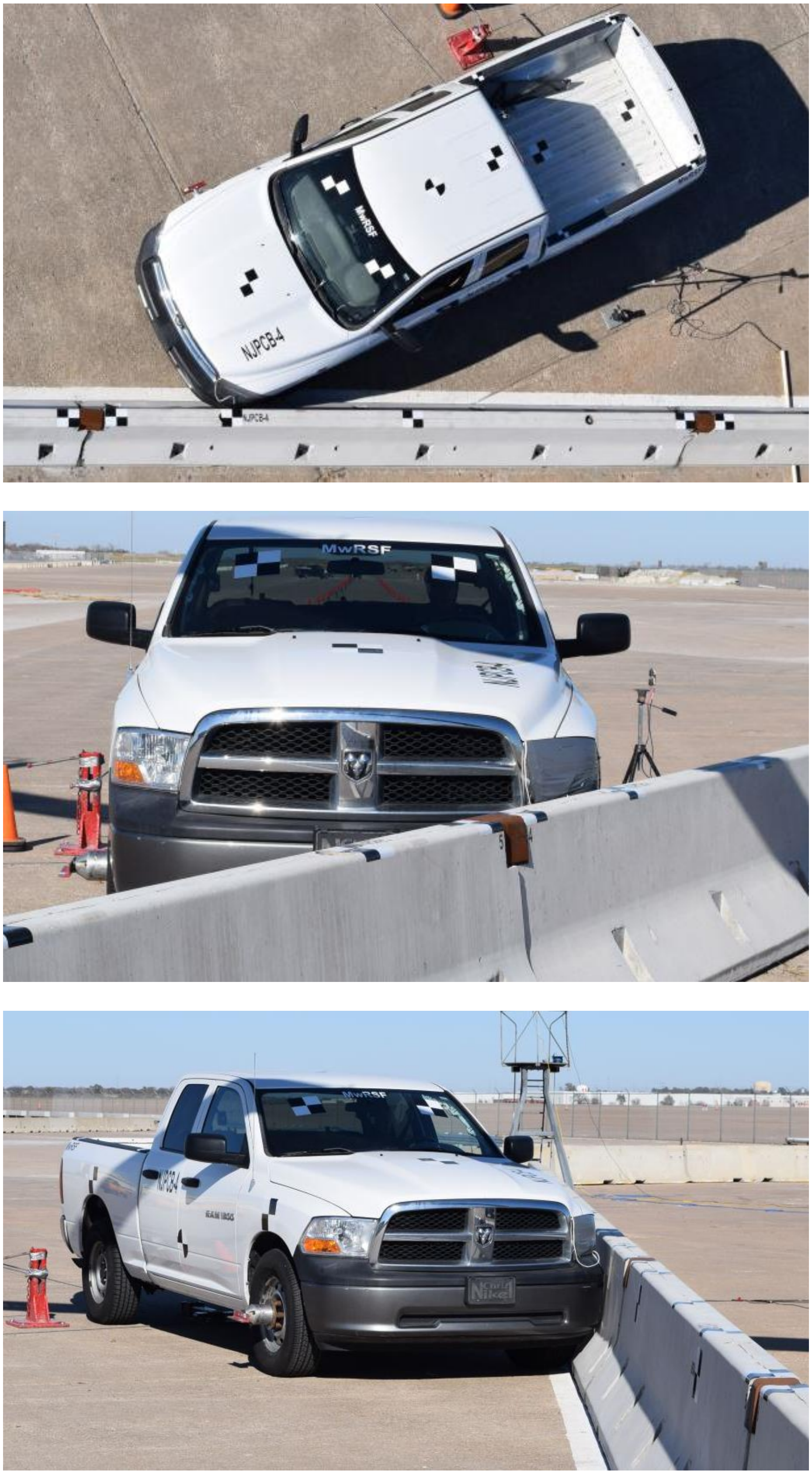


Figure 28. Impact Location, Test No. NJPCB-4

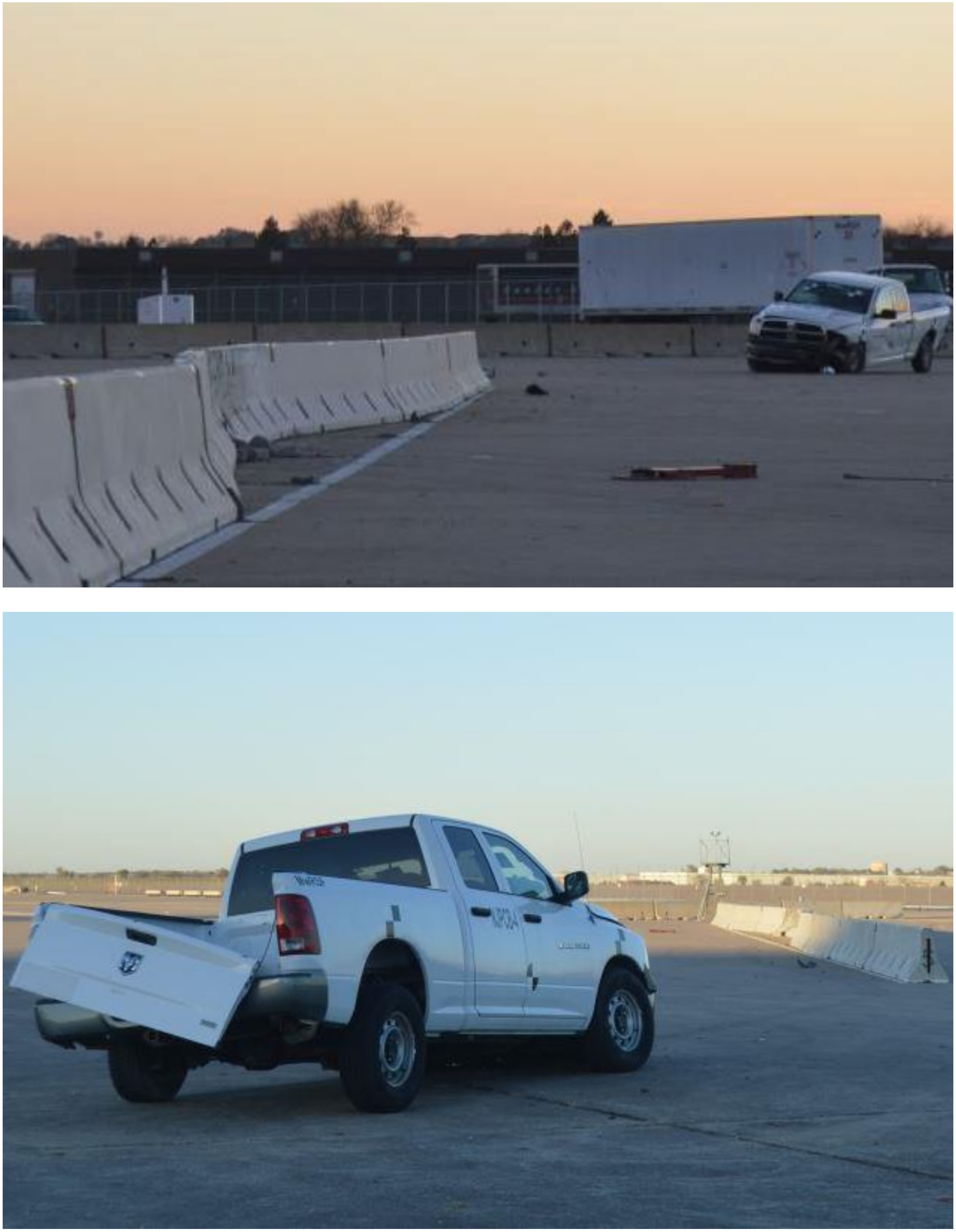
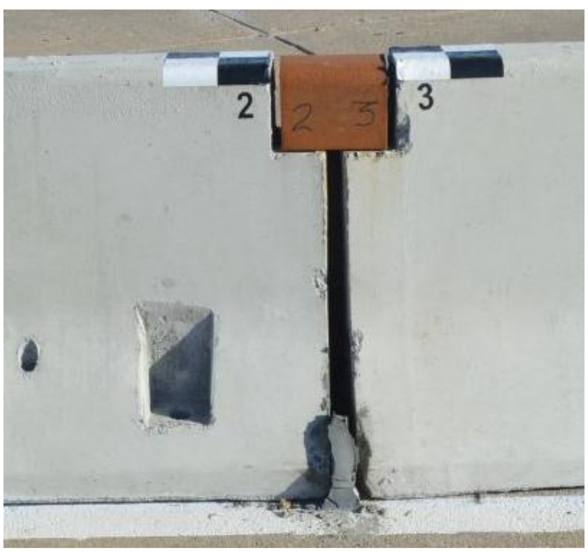


Figure 29. Vehicle Final Position and Trajectory Marks, Test No. NJPCB-4

Figure 30. System Damage – Front, Back, Upstream, and Downstream End, Test No. NJPCB-4

(a) Traffic Side

(b) Traffic Side



(c) Traffic Side

(d) Back Side

Figure 31. Barrier Nos. 2 and 3 – Traffic and Back Side Damage, Test No. NJPCB-4

Figure 32. Barrier Nos. 4 and 5 Damage, Test No. NJPCB-4

(a) Traffic Side

(b) Back Side

(c) Traffic Side

(d) Back Side

Figure 33. Barrier No. 4 – Traffic and Back Side Damage, Test No. NJPCB-4

(a) Traffic Side

(b) Back Side

(c) Traffic Side

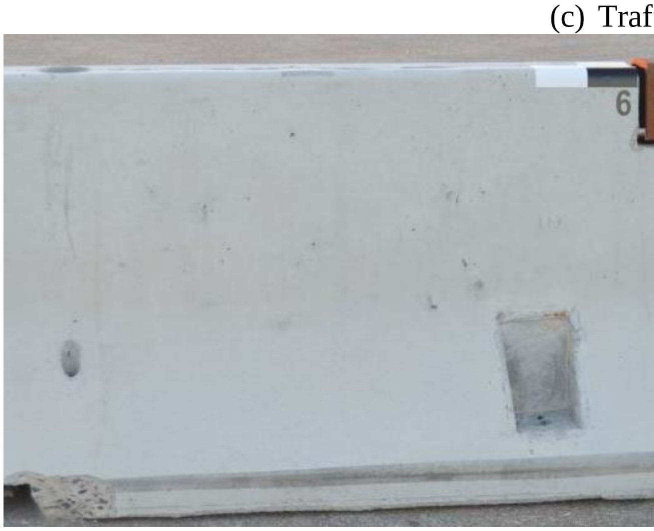
(d) Back Side

Figure 34. Barrier No. 5 – Traffic and Back Side Damage, Test No. NJPCB-4

(a) Traffic Side

(b) Back Side

(c) Traffic Side



(d) Back Side

(e) Back Side

Figure 35. Barrier No. 6 - Traffic and Back Side Damage, Test No. NJPCB-4

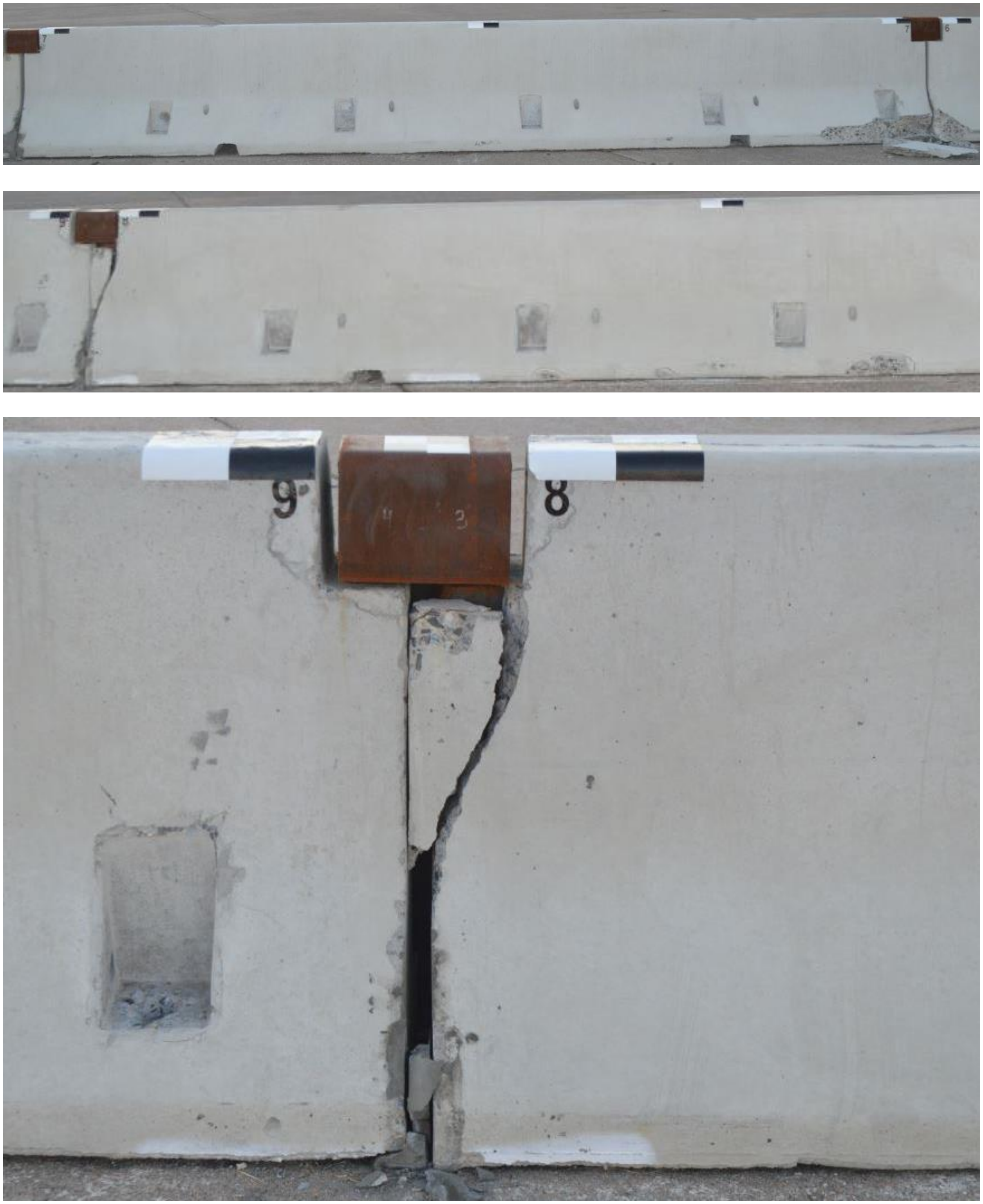


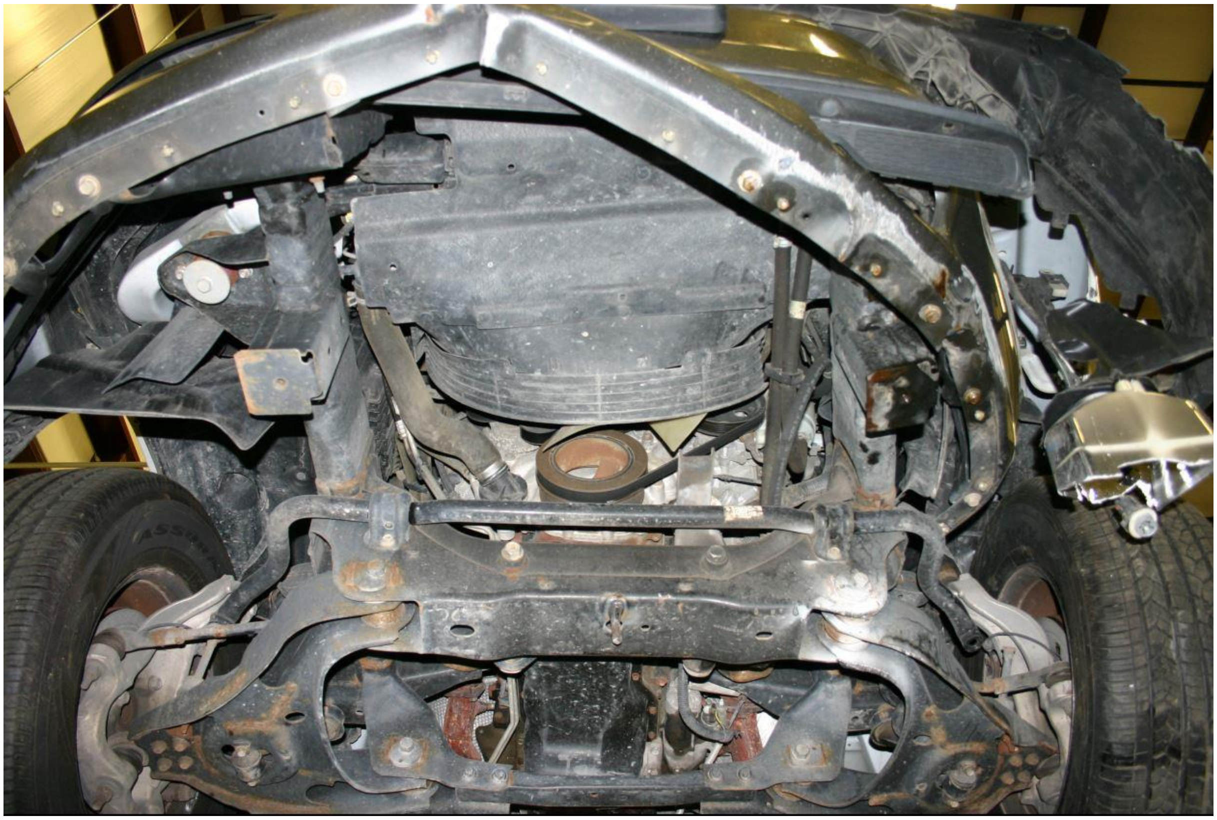
Figure 36. Barrier Nos. 7 and 8 – Back Side Damage, Test No. NJPCB-4

Figure 37. Vehicle Damage, Test No. NJPCB-4

Figure 38. Vehicle Damage, Test No. NJPCB-4

Figure 39. Vehicle Windshield, Quarter Panel, and Tailgate Damage, Test No. NJPCB-4

Figure 40. Occupant Compartment Deformation, Test No. NJPCB-4



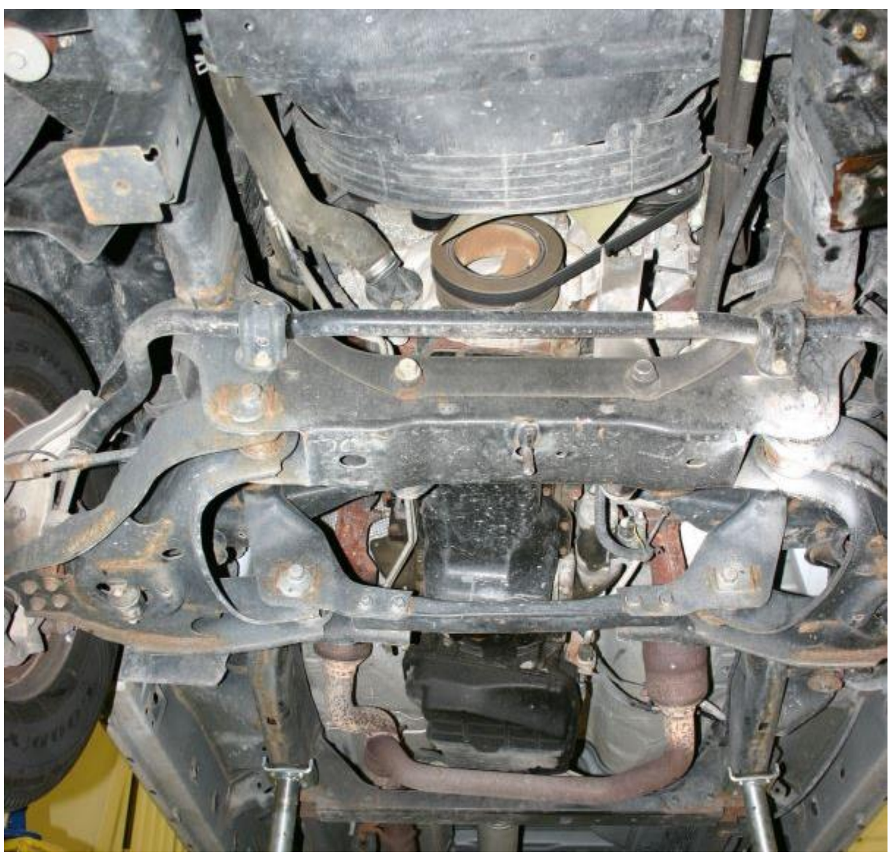


Figure 41. Undercarriage Damage, Test No. NJPCB-4

6 SUMMARY AND CONCLUSIONS

Test no. NJPCB-4 was conducted on the NJDOT PCB system with a free-standing configuration and grouted toes according to MASH 2016 test designation no. 3-11. This system used NJDOT barriers, Type 4 (Alternative B) with joint class B, as specified in the 2013 NJDOT *Roadway Design Manual*. Barrier nos. 1 and 10 were anchored to the concrete tarmac through the nine pin anchor recesses with 1-in. (25-mm) diameter by 15-in. (381-mm) long ASTM A36 steel pins. Non-shrink grout wedges were placed at the toe of each barrier segment in every joint between adjacent barrier segments.

During test no. NJPCB-4, the 5,000-lb (2,268 kg) pickup truck impacted the NJDOT PCB system at a speed of 62.8 mph (101.0 km/h) and at an angle of 24.5 degrees, resulting in an impact severity of 113.4 kip-ft (153.7 kJ). After impacting the barrier system, the vehicle exited the system at a speed of 51.3 mph (82.6 km/h) and at an angle of 8.4 degrees. The vehicle was successfully contained and smoothly redirected with moderate damage to both the barrier and the vehicle. Barrier nos. 4 and 5 experienced concrete spalling and cracking. A dynamic deflection of 40.7 in. (1,034 mm) and a working width of 64.7 in. (1,643 mm) were observed during the test, as shown in Figure 23. All occupant risk values were found to be within limits, and the occupant compartment deformations were also deemed acceptable. Subsequently, test no. NJPCB-4 was determined to satisfy the safety performance criteria for MASH test designation no. 3-11. A summary of the test evaluation is shown in Table 9.

Table 9. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. NJPCB-4</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td></tr>
<tr><td rowspan="10">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></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></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td></tr>
<tr><td 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></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></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>3-11</td></tr>
<tr><td colspan="5">Final Evaluation (Pass or Fail)</td><td>Pass</td></tr>
</table>

S – Satisfactory   U – Unsatisfactory   NA - Not Applicable

7 COMPARISON TO TEST NO. NYTCB-2

A summary of full-scale crash testing of the two free-standing configurations of the NJ PCB system is shown in Table 10. One system included removing the joint slack (test no. NJPCB-3) [16]. The other system consisted of removing joint slack and grouted toes (test no. NJPCB-4), as described herein. These tests were compared to the full-scale crash testing of a similar New York PCB system without removal of joint slack or grouted toes (test no. NYTCB-2) [17]. Results from these tests included the actual impact conditions and impact severity as well as dynamic barrier deflection, permanent set barrier deflection, working width (as measured from the original front face of the barrier), and the clear space behind the barrier. The clear space behind the barrier is used by NJDOT to define the maximum deflection of the back of the barrier from its original position. In addition, the schematic diagrams shown in Figure 42 indicate how the dynamic deflection, permanent set deflection, and working width for each crash test was defined.

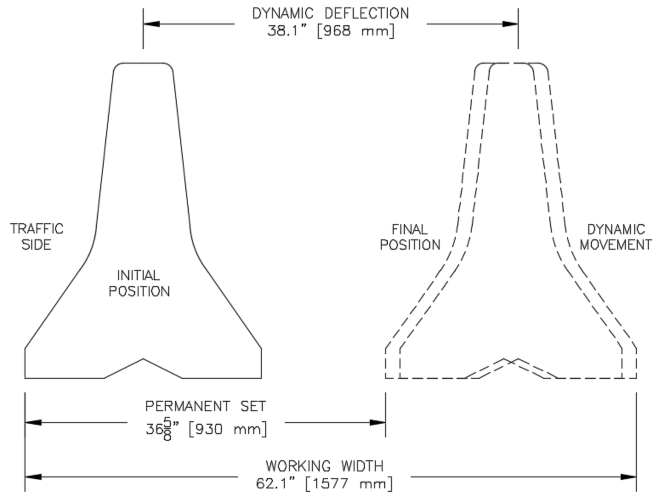
A review of the results from test nos. NJPCB-3, NJPCB-4, and NYTCB-2 revealed little to no benefit in terms of barrier deflection and clear space requirements for free-standing PCBs due to the removal of joint slack and/or the use of grouted barrier toes. This finding can be seen in the fact that dynamic deflections and the clear space behind barrier for all three tests are very similar. The primary cause of the lack of observed benefit for the modified PCB joints was the absence of barrier reinforcement in the toes of both the New York and New Jersey PCB segments. The lack of reinforcement led to disengagement of the barrier toes when they were loaded by adjacent barrier segments, which caused increased rotation and motion of the barrier joints. This toe disengagement overcomes the expected benefit that would have been provided by the removal of joint slack and use of grouted toes, which resulted in similar joint rotation and displacement for both the New Jersey and New York PCB crash tests. Secondly, the PCB segments used in these tests have a relatively small gap between adjacent barrier segments. Thus, improvement of the joint response through removal of joint slack and use of grouted toes provided less benefit than would be expected for other PCB systems, which utilize joint spacings up to 4 inches. Finally, barrier system behavior and associated barrier deflections can vary from test to test due to the natural variability of a wide variety of factors involved in full-scale crash testing. These factors would include slight differences in impact conditions, differing test vehicle model years, slight variations in steel and concrete strengths, and variation of the cracking and damage observed on the barrier segment, among others. Thus, some variability would be expected in barrier performance even for basically identical systems.

Smaller reductions in PCB deflections and clear space behind the barrier were observed with the removal of joint slack and use of grouted toes. This finding was primarily due to the fracture and disengagement of the barrier toes. If larger reductions in PCB deflections and clear space are desired, PCB redesign or modification would be required, including reinforcement of the barrier toes, which may improve effectiveness of joint slack removal and the use of grouted toes.

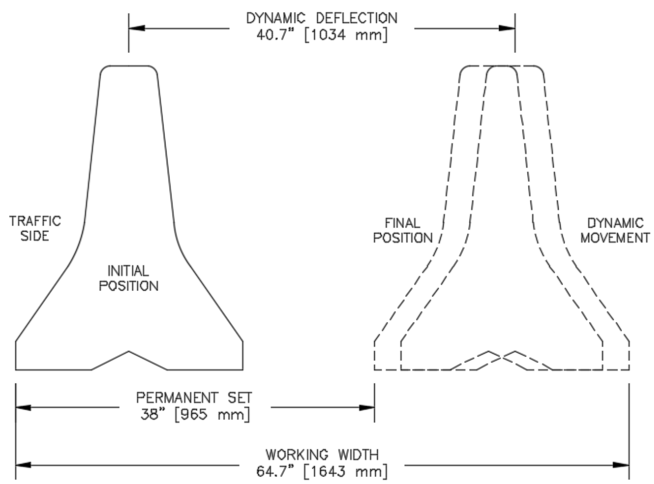
Table 10. Comparison of Free-Standing Systems

Test No.	Joint Class [1]	Connection Type [2]	System Details	Permanent Set	Dynamic Deflection (DD)	Working Width (WW)	Clear Space Behind Barrier	Vehicle Roll (deg)	Vehicle Pitch (deg)	Vehicle Mass lb (kg)	Impact Speed mph (km/h)	Impact Angle (deg)	Impact Severity kip-ft (kJ)
NJPCB-3 [16]	A	A	Free-standing system, barriers 1 and 10 pinned, remove slack, no grouted toes	36⅝ in. (930 mm)	38.1 in. (968 mm)	62.1 in. (1,577 mm)	38.1 in. (968 mm)	-17.2	-9.0	4,999 (2,268)	62.3 (100.2)	25.8	122.9 (166.6)
NJPCB-4	B	N/A	Free-standing system, barriers 1 and 10 pinned, remove slack, grouted toes	38 in. (962 mm)	40.7 in. (1,034 mm)	64.7 in. (1,643 mm)	40.7 in. (1,034 mm)	-16.2	-14.2	5,000 (2,268)	62.8 (101.3)	24.5	113.4 (153.7)
NYTCB-2 [17]	A	A	Free-standing system, barriers 1 and 10 pinned, slack not removed, no grouted toes	39½ in. (1,003 mm)	40.3 in. (1,023 mm)	64.3 in. (1,633 mm)	40.3 in. (1,023 mm)	-12.4	-10.6	5,024 (2,279)	61.2 (98.5)	25.8	119.2 (161.6)

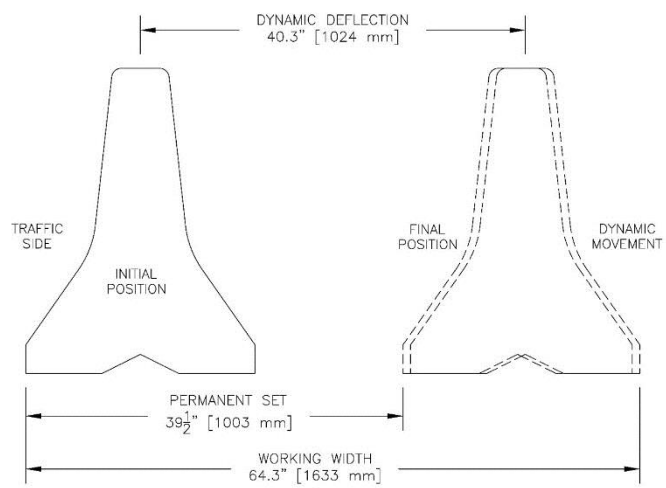
N/A = Not Applicable



NJPCB-3 – Free-Standing, Joint Slack Removed, No Grouted Toes



NJPCB-4 – Free-Standing, Joint Slack Removed, Grouted Toes



NYTCB-2 – Free-Standing, Joint Slack Not Removed, No Grouted Toes

Figure 42. Deflection Comparisons – Test Nos. NJPCB-3, NJPCB-4, and NYTCB-2

8 MASH IMPLEMENTATION

The objective of this research was to evaluate the safety performance of NJDOT's PCB, Type 4 (Alternative B) system with a free-standing configuration and grouted toes, corresponding to joint class B in the 2013 NJDOT *Roadway Design Manual*. The NJDOT barriers consisted of NJDOT PCBs joined with a connection key. Barrier nos. 1 and 10 were anchored to the concrete roadway surface through the nine pin anchor recesses with 1-in. (25-mm) diameter by 15-in. (381-mm) long, ASTM A36 steel pins. The barrier segments were pulled in a direction parallel to their longitudinal axes, and slack was removed from all joints prior to installation of the steel anchor pins. A wedge of grout was placed at the toe of each joint on both the traffic side and back side of the system.

According to TL-3 evaluation criteria in MASH 2016, two tests are required for evaluation of longitudinal barrier systems: (1) test designation no. 3-10 – an 1100C small car and (2) test designation no. 3-11 – a 2270P pickup truck. However, only the 2270P crash test was deemed necessary as other prior small car tests were used to support a decision to deem the 1100C crash test not critical.

In test no. 7069-3, a rigid, F-shape bridge rail was successfully impacted by a small car weighing 1,800 lb (816 kg) at 60.1 mph (96.7 km/h) and 21.4 degrees according to the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings* [5-6]. In the same manner, test nos. CMB-5 through CMB-10, CMB-13, and 4798-1 showed that rigid, New Jersey, concrete safety shape barriers struck by small cars have been shown to meet safety performance standards [7-9]. In addition, in test no. 2214NJ-1, a rigid, New Jersey, ½-section, concrete safety shape barrier was impacted by a passenger car weighing 2,579 lb (1,170 kg) at 60.8 mph (97.8 km/h) and 26.1 degrees according to the TL-3 standards set forth in MASH 2009 [9]. Furthermore, temporary, New Jersey safety shape, concrete median barriers have experienced only slight barrier deflections when impacted by small cars and behave similarly to rigid concrete barriers as seen in test no. 47 [10]. Therefore, the 1100C passenger car test was deemed not critical for testing and evaluating this PCB 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.

During test no. NJPCB-4, a 5,000-lb (2,268 kg) pickup truck with a simulated occupant seated in the left-front seat impacted the NJDOT PCB system with joint class B, as specified in the 2013 NJDOT *Roadway Design Manual*, at a speed of 62.8 mph (101.0 km/h) and at an angle of 24.5 degrees, resulting in an impact severity of 113.4 kip-ft (153.7 kJ). At 0.207 sec after impact, the vehicle became parallel to the system with a speed of 52.8 mph (84.9 km/h). At 0.310 sec, the vehicle was airborne as it exited the system at a speed of 51.3 mph (82.6 km/h) and at an angle of 8.4 degrees. The vehicle was successfully contained and smoothly redirected.

Exterior vehicle damage was moderate. Interior occupant compartment deformations were minimal with a maximum of ⅞ in. (22 mm), which did not violate the limits established in MASH 2016. Damage to the barrier was also moderate, consisting of contact marks on the front face of the PCB segments, concrete spalling, and concrete cracking on barrier nos. 4 and 5. The maximum dynamic barrier deflection was 40.7 in. (1,034 mm), which included minor tipping of the barrier at the top surface. The working width of the PCB system was 64.7 in. (1,643 mm). All occupant risk measures were within the recommended limits, and the occupant compartment deformations were also deemed acceptable. Therefore, NJDOT barriers, Type 4 (Alternative B) with joint class B, as specified in the 2013 NJDOT *Roadway Design Manual*, successfully met all the safety performance criteria of MASH 2016 test designation no. 3-11.

The NJDOT barriers, Type 4 (Alternative B) with joint class B, as specified in the 2013 NJDOT *Roadway Design Manual*, consisting of NJDOT PCB barriers joined with a connection key, joint slack removed, grouted toes, and barrier nos. 1 and 10 pinned on both the traffic side and back side, was successfully crash tested and evaluated according to the AASHTO MASH 2016 TL-3 criteria. This barrier successfully met all the requirements of MASH 2016 test designation no. 3-11. In addition, the researchers consider the system MASH 2016 compliant based on the successful test designation no. 3-11 test and the previous justification for test designation no. 3-10 being deemed not critical.

A comparison of similar systems for the free-standing configuration included three systems: (1) a NJ PCB system with the joint slack removed (test no. NJPCB-3) [16]; (2) a NJ PCB system with the joint slack removed and grouted toes (test no. NJPCB-4); and (3) a New York PCB system without removal of joint slack or grouted toes (test no. NYTCB-2) [17]. A review of these test results (test nos. NJPCB-3, NJPCB-4, and NYTCB-2) revealed little to no benefit would be observed in reduced barrier deflections and clear space requirements for free-standing PCBs due to joint slack removal and/or use of grouted toes as dynamic deflections and the clear space behind barrier for all three tests are very similar. The finding is primarily due to no barrier reinforcement in the toes of both the New York and New Jersey PCB segments. The lack of steel reinforcement led to concrete fracture near the barrier toes when they were loaded by adjacent barrier segments, which caused increased rotation of the barrier joints. This concrete toe disengagement reduced the expected benefit that would have been provided by the removal of joint slack and use of grouted toes. Second, the PCB segments used in these tests have a relatively small gap between adjacent barrier segments. Thus, improvement of the joint response through removal of joint slack and use of grouted toes provided less benefit than would be expected for other PCB systems, which utilize joint spacings up to 4 in. (102 mm). Finally, barrier system behavior and associated barrier deflections can vary from test to test due to the natural variability of a wide variety of factors involved in full-scale crash testing. These factors would include slight differences in impact conditions, differing test vehicle model years, slight variations in steel and concrete strengths, and variation of the cracking and damage observed on the barrier segments, among other. Thus, some variability would be expected in barrier performance even for basically identical systems.

In both the 2013 and 2015 NJDOT *Roadway Design Manual*, the allowable deflection is determined by the clear space behind the barrier, which is defined as the maximum deflection of the back of the barrier from its original position. For joint class B, as specified in the 2013 NJDOT *Roadway Design Manual* and utilized in this system, the NJDOT allowable movement guidance is 11 to 16 in. (279 to 406 mm). For this test, the clear space behind the barrier was 40.7 in. (1,034 mm). Limited reductions in PCB deflections and clear space behind the barrier were observed with joint slack removal and use of grouted toes. Again, this finding is primarily due to the fracture and disengagement of the barrier toes. If larger reductions in PCB deflections and clear space are desired, PCB redesign or modification would be required, including reinforcement of the barrier toes, which may improve the effectiveness of joint slack removal and the use of grouted toes.

9 REFERENCES

1. New Jersey Department of Transportation, *Roadway Design Manual*, Revised May 10, 2013.

2. New Jersey Department of Transportation, *Roadway Design Manual*, Revised 2015.

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

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

5. Buth, C. E., Hirsch, T. J., and McDevitt, C. F., *Performance Level 2 Bridge Railings*, Transportation Research Record No. 1258, Transportation Research Board, National Research Council, Washington, D.C., 1990.

6. *Guide Specifications for Bridge Railings*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 1989

7. Bronstad, M. E., Calcote, L. R., and Kimball Jr, C. E., *Concrete Median Barrier Research-Vol.2 Research Report*, Report No. FHWA-RD-77-4, Submitted to the Office of Research and Development, Federal Highway Administration, Performed by Southwest Research Institute, San Antonio, TX, March 1976.

8. Buth, C. E., Campise, W. L., Griffin III, L. I., Love, M. L., and Sicking, D. L., *Performance Limits of Longitudinal Barrier Systems-Volume I: Summary Report,* FHWA/RD-86/153, Final Report to the Federal Highway Administration, Office of Safety and Traffic Operations R&D, Performed by Texas Transportation Institute, Texas A&M University, College Station, TX, May 1986.

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

10. Fortuniewicz, J. S., Bryden, J. E., and Phillips, R. G., *Crash Tests of Portable Concrete Median Barrier for Maintenance Zones,* Report No. FHWA/NY/RR-82/102, Final Report to the Office of Research, Development, and Technology, Federal Highway Administration, Performed by the Engineering Research and Development Bureau, New York State Department of Transportation, December 1982.

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

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

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

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

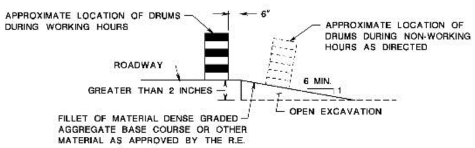
15. *Collision Deformation Classification – Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

16. Bhakta, S.K., Lechtenberg, K.A., Faller, R.K., Reid, J.D., Bielenberg, R.W., and Urbank, E.L., *Performance Evaluation of New Jersey's Portable Concrete Barrier with a Free-Standing Configuration and Grouted Toes – Test No. NJPCB-3*, Report No. TRP-03-355-18, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, December 2018.

17. Stolle, C.J., Polivka, K.A., Faller, R.K., Sicking, D.L., Bielenberg, R.W., Reid, J.D., Rohde, J.R., Allison, E.M., and Terpsma, R.J., *Evaluation of Box Beam Stiffening of Unanchored Temporary Concrete Barriers*, Research Report No. TRP-03-202-08, Project No. C-06-17, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, March 14, 2008.

10 APPENDICES

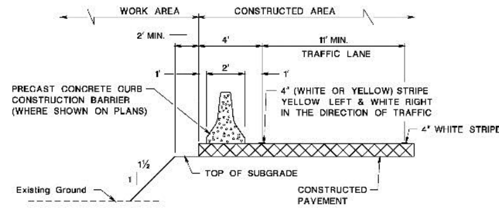
Appendix A. NJDOT PCB Standard Plans



NOTE:

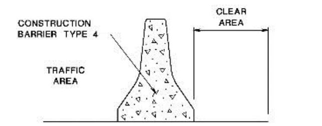
ESCAPE RAMPS MUST BE CONSTRUCTED AND MAINTAINED DURING NON-WORKING HOURS WHERE A VERTICAL DROP GREATER THAN 2 INCHES EXISTS ADJACENT TO TRAVELED LANE.

ESCAPE RAMP DETAIL



TYPICAL SECTION

PLACEMENT OF PRECAST CONCRETE CONSTRUCTION BARRIER



NOTES:

1. CHANGES TO THE PROPOSED JOINT CLASS AT ANY LOCATION MUST BE APPROVED BY THE DEPT.
2. NO ROADWAY DROP OFFS, OBSTRUCTIONS, STORAGE OF MATERIALS OR WORK WILL BE PERMITTED IN THE CLEAR AREA UNLESS APPROVED BY THE R.E.

STAGE	LOCATION	JOINT CLASS
	RTE. STA. TO STA.	

JOINT CLASS	CLEAR AREA
A	20 INCHES
B	18 INCHES
C	11 INCHES

CONSTRUCTION BARRIER, TYPE 4 JOINT CLASS AND CLEAR AREA

REGULATORY APPROACH SPEED OF TRAFFIC MILES/HOUR	RECOMMENDED SIGHT DISTANCE TO BEGINNING OF CHANNELIZING TAPERS		
	DESIRABLE		MINIMUM
	RURAL FEET	URBAN FEET	RURAL AND URBAN FEET
25	375	525	150
30	450	625	200
35	525	725	250
40	600	825	325
45	675	925	400
50	750	1025	475
55	875	1150	550
60	1000	1275	650
65	1050		725

NOTES:

1. AVOIDANCE MANEUVER IS FOR A SPEED, PATH, AND/OR DIRECTION CHANGE PRIOR TO THE BEGINNING OF CHANNELIZING TAPERS.
2. RECOMMENDED DISTANCES BETWEEN TWO SEPARATE LANE CLOSURES SHALL BE DOUBLE THE VALUES SHOWN ABOVE.
3. RURAL AND URBAN ROAD DESIGNATIONS SHALL BE AS DEFINED IN THE NJDOT STATE HIGHWAY STRAIGHT LINE DIAGRAMS.
4. DESIRABLE VALUES SHALL BE PROVIDED WHEREVER POSSIBLE. IF IT IS NOT FEASIBLE OR PRACTICAL TO PROVIDE DESIRABLE VALUES BECAUSE OF HORIZONTAL OR VERTICAL CURVATURE OR IF RELOCATION OF THE TAPER IS NOT POSSIBLE, THEN MINIMUM VALUES CAN BE APPLIED. WHEN MINIMUM VALUES ARE USED, SPECIAL ATTENTION SHOULD BE GIVEN TO THE USE OF SUITABLE TRAFFIC CONTROL DEVICES FOR PROVIDING ADVANCED WARNING OF THE CONDITIONS THAT ARE LIKELY TO BE ENCOUNTERED.
5. TAPERS SHALL BE LOCATED TO MAXIMIZE THE VISIBILITY OF THEIR TOTAL LENGTH.

RECOMMENDED TAPER LENGTH AND SPACING FOR CHANNELIZING TAPERS						RECOMMENDED SPACING ALONG TANGENTS
REGULATORY APPROACH SPEED OF TRAFFIC MILES/HOUR	MINIMUM TAPER RATIO IN LENGTH PER FOOT OF WIDTH	MINIMUM TAPER LENGTH L – FOR LANE WIDTHS			MAXIMUM DEVICE (B) SPACING ALONG TAPERS IN FEET	MAXIMUM DEVICE (D) SPACING ALONG TANGENTS IN FEET
		10'	11'	12'		
25	10.5:1	105	115	125	25	50
30	15:1	150	165	180	30	60
35	20.5:1	205	225	245	35	70
40	27:1	270	300	325	40	80
45	45:1	450	495	540	45	90
50	50:1	500	550	600	50	100
55	55:1	550	605	660	55	110
60	60:1	600	660	720	60	120
65	65:1	650	715	780	65	130

NOTE:

THE MAXIMUM DEVICE SPACING ALONG CURVES SHALL BE AS DEFINED FOR TAPERS (B) IN THE ABOVE TABLE.

NOTE TO DESIGNER:

THIS SHEET REQUIRES DESIGN SPECIFIC INFORMATION TO BE ADDED AND INCLUDED IN THE CONTRACT PLANS.

REMOVE THIS NOTE AFTER DESIGN SPECIFIC INFORMATION IS ADDED.

N.T.S.

TCD-2

NEW JERSEY DEPARTMENT OF TRANSPORTATION

TRAFFIC CONTROL DETAILS

101
146

Figure A-1. NJDOT PCB Standard Plans

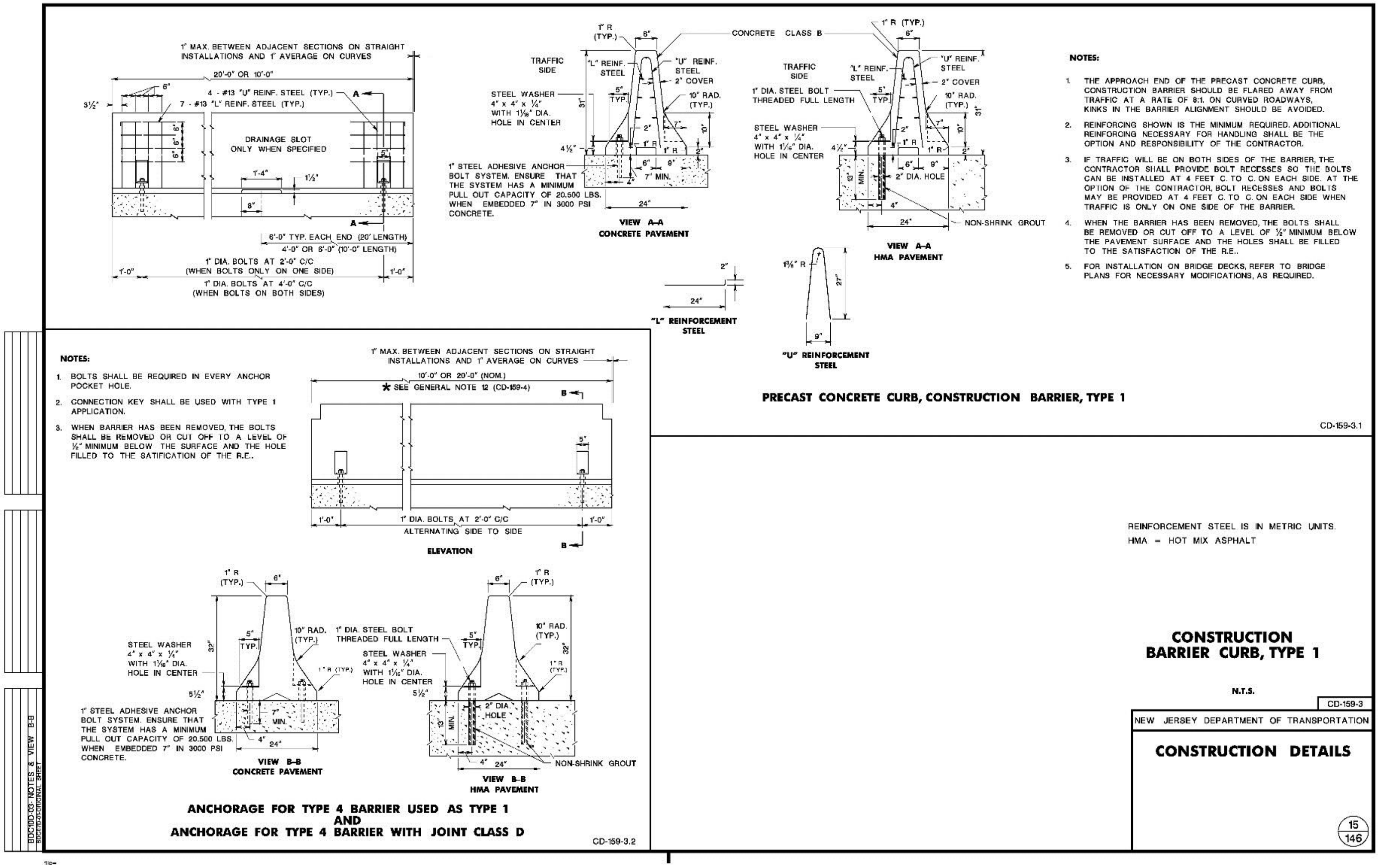


Figure A-2. NJDOT PCB Standard Plans

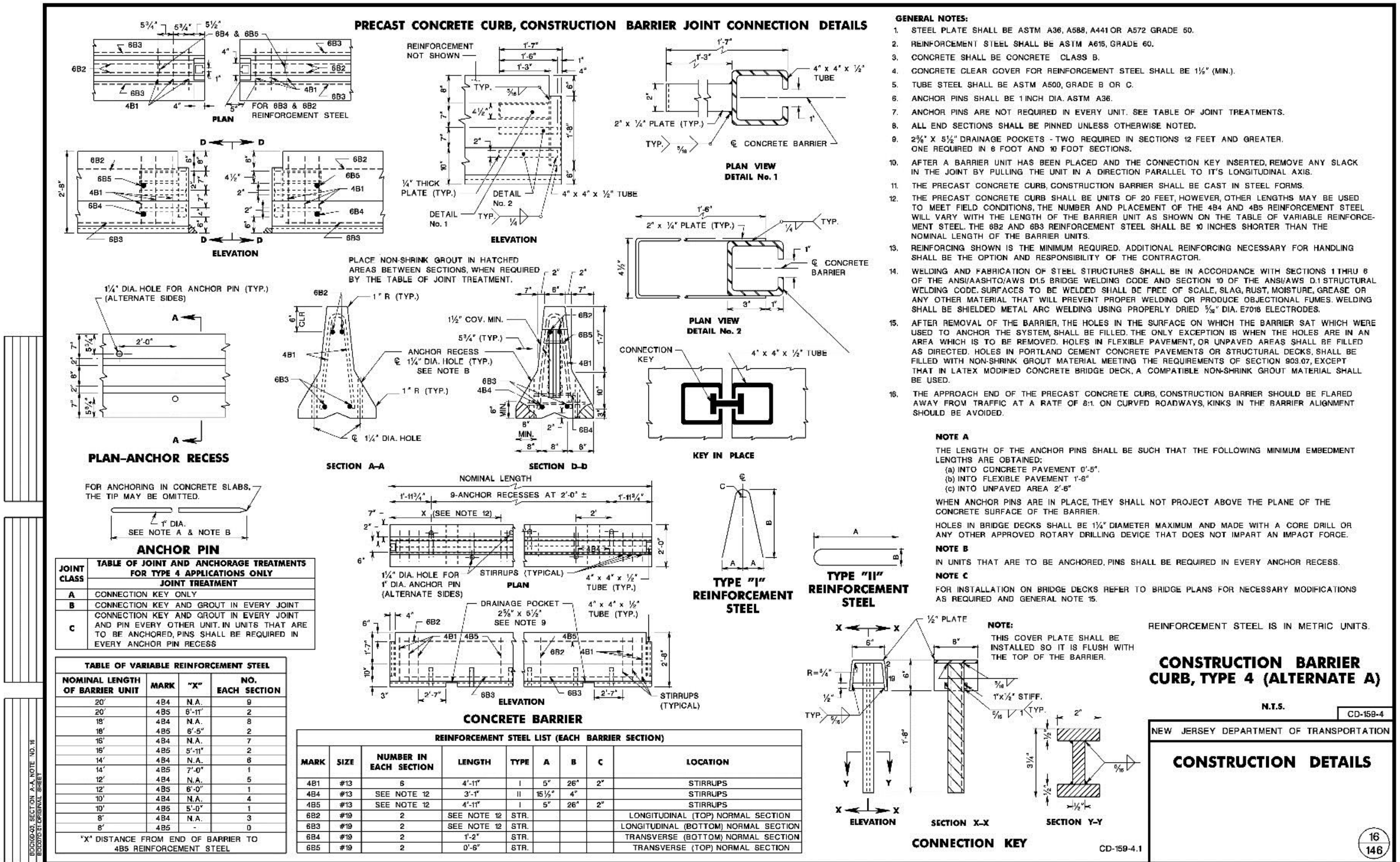


Figure A-3. NJDOT PCB Standard Plans

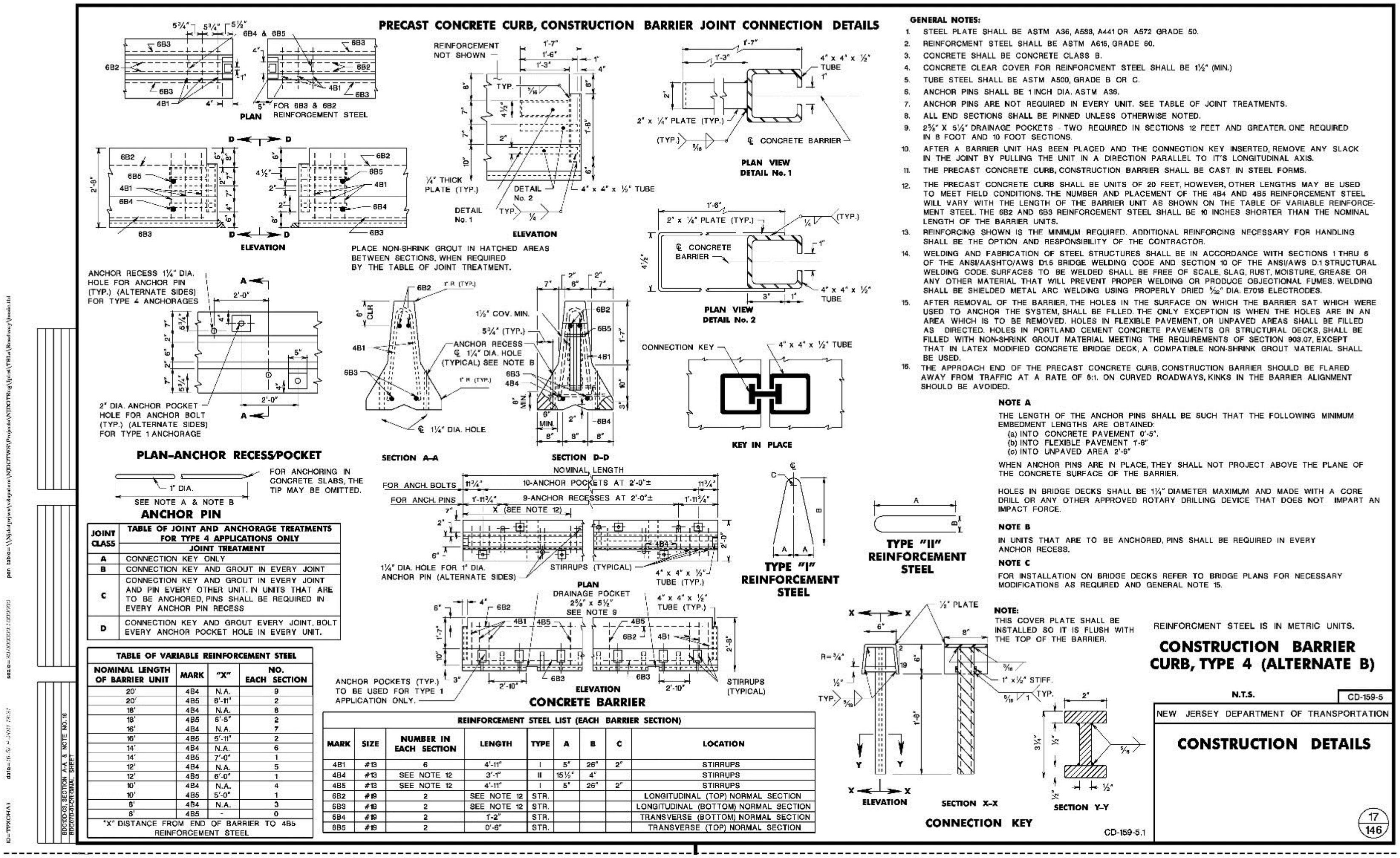


Figure A-4. NJDOT PCB Standard Plans

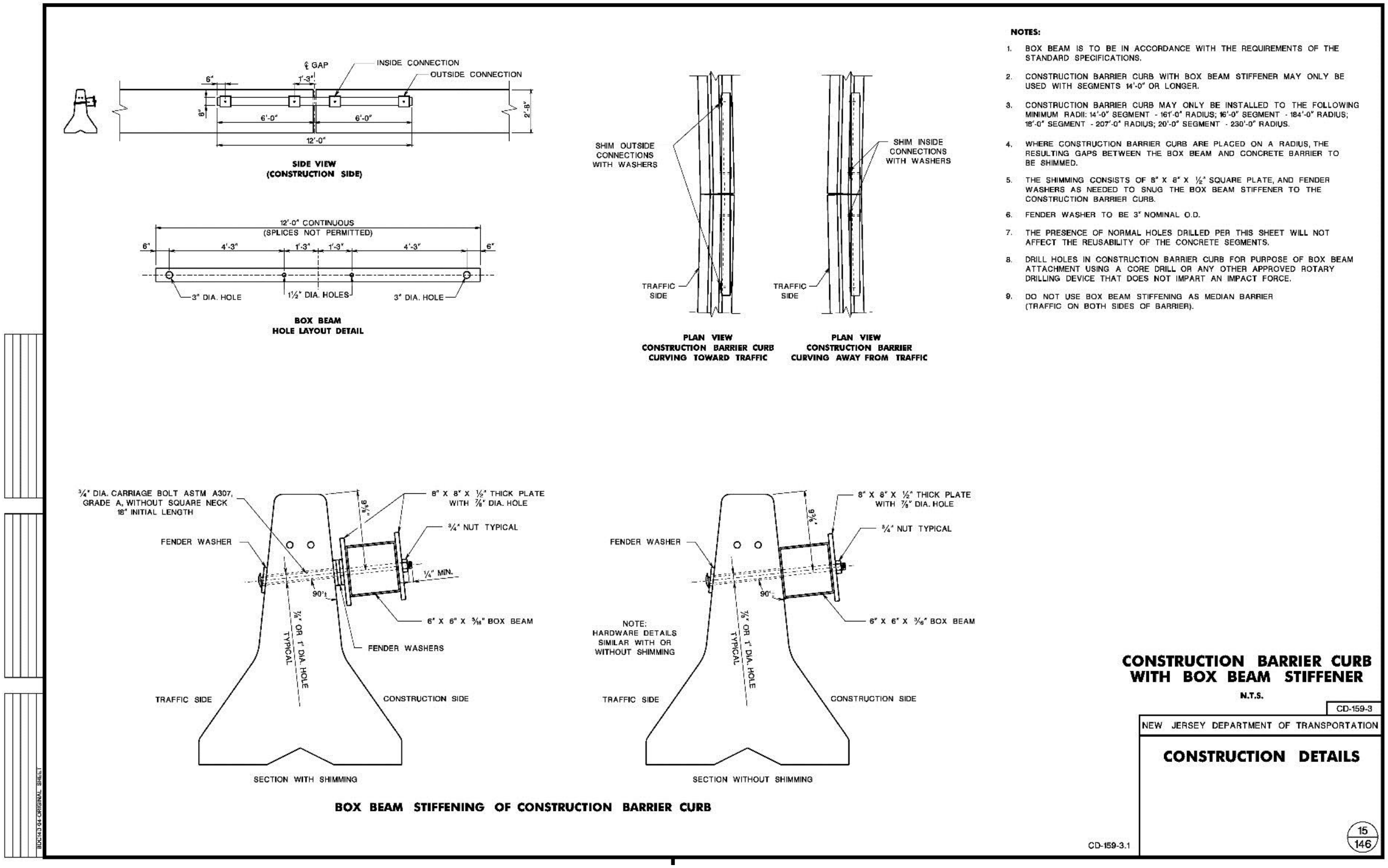


Figure A-5. NJDOT PCB Standard Plans

Appendix B. Material Specifications

Table B-1. Bill of Materials, Test No. NJPCB-4

Item No.	Description	Material Specification	Reference
A1	Concrete Barrier Segment	Min. f 'c = 3,700 psi (25.5 MPa)	University of Nebraska 15-563
A2	Anchor Steel Pins	ASTM A36	H #54141812
B1	Rebar - #4 Vertical Stirrup	ASTM A615 Gr. 60	Heat #61101274, 61101493, 61101510, 61101492, 61101499, 61101772
B2, B3	Rebar - #6 Longitudinal Bar	ASTM A615 Gr. 60	Heat #6115448, 61105472
B4	Rebar - #4 Horizontal Anchor Recess, Reinforcement Stirrup	ASTM A615 Gr. 60	Heat #61101274, 61101493, 61101510, 61101492, 61101499, 61101772
B5	Rebar - #6 Top and Bottom Cross Bar	ASTM A615 Gr. 60	Heat #6115448, 61105472
C1	Steel Tube – 4”×4”×½” (102×102×12.7) thick × 20” (508) long	ASTM A500 Gr. B and C	Heat #821597, 1422428, M04495_1, T83539, SD5020
C2	Bent Steel Plate 1, 2”×¼” (51×6)	ASTM A36	Heat #1129849
C3	Bent Steel Plate 2, 2”×¼” (51×6)	ASTM A36	Heat #1129849
D1	Steel Plate 1, 2”×½” (51×13)	ASTM A36	Heat #L99837
D2	Steel Plate 2, 2¼”×½” (57×13)	ASTM A36	Heat #54144612
D3	½” (13) Steel Plate – Stiffener	ASTM A36	Heat #54144612, L99837
D4	½” (13) Steel Plate – Top Plate	ASTM A36	Heat #54144612, L99837
E1	Non-Shrink Grout	Min. 1-day Compressive Strength 1,000 psi (6.9 MPa)	Advantage Grout ASTM C1107 Product Code: 67435

UNIVERSITY OF NEBRASKA

15-563

Cast Date	Age (days)	Cylinder 1	Cylinder 2	Average	Age (days)	Cylinder 1	Cylinder 2	Average	Age (days)	Cylinder 1	Cylinder 2	Average	Air	Slump	Concrete Temp.	Ambient Temp	EMAIL, Mailed, etc
10/26/2015	1	4171	3869	4020	7	7805	7800	7803	28			0	5.5	6 3/4	60	58	
10/27/2015	1	3539	3883	3711	7	7343	7624	7484	28			0	6.8	5 3/4	62	60	
10/28/2015	1	4116	4311	4214	7	6223	6340	6282	28			0	6.0	6 1/2	64	64	
10/29/2015	1	3831	3544	3688	7	7046	6998	7022	28			0	5.8	6 1/2	67	68	
10/30/2015	3	4571	4608	4590	7	6337	6235	6286	28			0	6.0	6 1/2	64	63	
11/2/2015	1	3125	3062	3094	7	6887	6748	6818	28			0	6.2	5 3/4	64	62	
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					
	1			0	7			0	28			0					

Figure B-2. Concrete Barrier Segment – Concrete Strength, Test No. NJPCB-4

CERTIFIED MATERIAL TEST REPORT Page 1/1

GERDAU

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

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
STEEL & PIPE SUPPLY CO INC JONESBURG INDUSTRIAL PARK JONESBURG,MO 63351 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	A36/44W	Round Bar / 1"

LENGTH	WEIGHT	HEAT / BATCH
20'00"	14,968 LB	54141812/02

SALES ORDER	CUSTOMER MATERIAL N°
1384530/000040	000000000009010020

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500233654	1321-0000027245	12/18/2014

SPECIFICATION / DATE or REVISION
1-ASTM A6/A6M-11, A36/A36M-08
2-A709/A709M-11 GR36
3-CSA G40.21-04(R2009) 44W

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Sn %
0.17	0.69	0.018	0.031	0.19	0.41	0.13	0.11	0.030	0.001	0.001	0.014

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
23.20	8.000	77428	534	54195	374

GEOMETRIC CHARACTERISTICS

R:R
32.00

COMMENTS / NOTES

R#16-0230 ASTM A36 1"x15" Round Bar
New Jersey TCB Barrer Anchor Dowel Pins
H#54141812 R#16-0230 December 2015

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

JORDAN FOSTER
QUALITY ASSURANCE MGR.

Figure B-3. Anchor Pins Material Certificate, Test No. NJPCB-4

CERTIFIED MATERIAL TEST REPORT — Page 1/1

GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)	
		LENGTH: 40'00"	WEIGHT: 5,050 LB	HEAT / BATCH: 61101274/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.43	0.66	0.012	0.048	0.23	0.43	0.16	0.05	0.046	0.019	0.017	0.56

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
66850	461	93950	648	8.000	200.0
67400	465	95100	656	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
13.50	OK
13.50	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
4.10	0.030	0.099	0.320
3.20	0.030	0.099	0.320

COMMENTS / NOTES

This grade meets the requirements for the following grades:

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

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-4. Rebar No. 4 Material Certificate, Test No. NJPCB-4

CERTIFIED MATERIAL TEST REPORT

Page 1/1

GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	5,023 LB	61101493/04

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.42	0.65	0.012	0.058	0.19	0.43	0.15	0.09	0.056	0.020	0.009	0.56

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
71350	492	104900	723	8.000	200.0
71250	491	105600	728	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
13.00	OK
11.50	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
2.70	0.032	0.098	0.321
1.40	0.034	0.099	0.321

COMMENTS / NOTES

This grade meets the requirements for the following grades:

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

JOSEPH T HOMOC
QUALITY ASSURANCE MGR.

Figure B-5. Rebar No. 4 Material Certificate, Test No. NJPCB-4

GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	5,050 LB	61101510/03

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqvA706 %
0.42	0.66	0.018	0.046	0.21	0.30	0.11	0.06	0.035	0.018	0.015	0.55

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
73400	506	107150	739	8.000	200.0
75600	521	110500	762	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
12.00	OK
13.00	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
2.40	0.032	0.080	0.322
2.30	0.032	0.080	0.322

COMMENTS / NOTES

This grade meets the requirements for the following grades:

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

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-6. Rebar No. 4 Material Certificate, Test No. NJPCB-4

GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	10,020 LB	61101492/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.43	0.67	0.014	0.054	0.20	0.43	0.21	0.10	0.064	0.018	0.017	0.57

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
65150	449	96100	663	8.000	200.0
68450	472	99600	687	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
15.00	OK
15.50	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
3.60	0.031	0.078	0.322
1.70	0.029	0.090	0.322

COMMENTS / NOTES

This grade meets the requirements for the following grades:

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

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-7. Rebar No. 4 Material Certificate, Test No. NJPCB-4

GERDAU

CERTIFIED MATERIAL TEST REPORT

Page 1/1

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	5,050 LB	61101499/04

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.43	0.68	0.026	0.064	0.21	0.33	0.21	0.19	0.066	0.016	0.012	0.58

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
70900	489	105500	727	8.000	200.0
68950	475	103200	712	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
11.00	OK
11.00	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
1.90	0.032	0.088	0.321
1.90	0.032	0.086	0.321

COMMENTS / NOTES

This grade meets the requirements for the following grades:

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

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-8. Rebar No. 4 Material Certificate, Test No. NJPCB-4

GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #4 (13MM)	
		LENGTH 40'00"	WEIGHT 4,008 LB	HEAT / BATCH 61101772/04

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
1785955/000010		ASTM A615/A615M-14

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB 22777	1331-0000029243	01/23/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.44	0.67	0.019	0.059	0.20	0.38	0.16	0.06	0.047	0.017	0.016	0.57

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
66400	458	96900	668	8.000	200.0
65850	454	97700	674	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
16.00	OK
17.00	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
1.10	0.025	0.099	0.320
0.80	0.029	0.115	0.320

COMMENTS / NOTES

This grade meets the requirements for the following grades:

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

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-9. Rebar No. 4 Material Certificate, Test No. NJPCB-4

CERTIFIED MATERIAL TEST REPORT

Page 1/1

GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #6 (19MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	30,282 LB	**61105448**/03

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
2886827/000020		ASTM A615/A615M-15

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB-23635	1331-0000038904	10/08/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.48	0.75	0.010	0.064	0.23	0.33	0.18	0.09	0.036	0.028	0.018	0.65

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
70159	484	107318	740	8.000	200.0
70590	487	108364	747	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
14.00	OK
13.00	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
5.80	0.040	0.090	0.477
5.80	0.040	0.090	0.477

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

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-10. Rebar No. 6 Material Certificate, Test No. NJPCB-4

Page 1/1

CERTIFIED MATERIAL TEST REPORT

GERDAU

US-ML-SAYREVILLE
NORTH CROSSMAN ROAD
SAYREVILLE, NJ 08872
USA

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022 USA	RE STEEL SUPPLY CO INC 2000 EDDYSTONE INDUSTRIAL PARK EDDYSTONE,PA 19022-1588 USA	60 (420)	Rebar / #6 (19MM)

LENGTH	WEIGHT	HEAT / BATCH
40'00"	4,987 LB	**61105472**/03

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
2886827/000020		ASTM A615/A615M-15

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
BB-23635	1331-0000038904	10/08/2015

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.46	0.72	0.019	0.048	0.21	0.38	0.15	0.14	0.036	0.017	0.022	0.63

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
73296	505	106977	738	8.000	200.0
73386	506	107455	741	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
13.00	OK
15.00	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
4.20	0.058	0.072	0.481
4.50	0.058	0.072	0.481

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

JOSEPH T HOMIC
QUALITY ASSURANCE MGR.

Figure B-11. Rebar No. 6 Material Certificate, Test No. NJPCB-4

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	821597

Atlas Tube Canada ULC
200 Clark St.
Harrow, Ontario, Canada
N0R 1G0
Tel: 519-738-3541
Fax: 519-738-3537

Atlas Tube
JMC STEEL GROUP

Ref.B/L: 80664351
Date: 05.08.2015
Customer: 1497

MATERIAL TEST REPORT

Sold to

Triad Metals International
1 Village Road
HORSHAM PA 19044-3812
USA

Shipped to

Triad Metals International
3507 Grand Avenue
PITTSBURGH PA 15225
USA

Material: 3.0x3.0x125x24'0"0(7x7). Material No: 300301252400 Made In: Canada

Sales order: 989576 Purchase Order: 75461 Melted in: Canada

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
821195	0.190	0.810	0.009	0.007	0.019	0.044	0.060	0.006	0.006	0.026	0.045	0.002	0.002	0.000	0.003

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101451859	49	063780 Psi	077160 Psi	26.6 %	ASTM A500-13 GRADE B&C	0.34

Material Note:
Sales Or.Note:

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: Canada

Sales order: 995107 Purchase Order: 76312 Melted in: Canada

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
775533	0.200	0.810	0.012	0.010	0.015	0.031	0.032	0.006	0.002	0.011	0.032	0.002	0.002	0.000	0.003

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101454130	1	066980 Psi	075080 Psi	27.0 %	ASTM A500-13 GRADE B&C	0.35

Material Note:
Sales Or.Note:

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: Canada

Sales order: 995107 Purchase Order: 76312 Melted in: Canada

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
821597	0.210	0.780	0.011	0.009	0.013	0.040	0.026	0.006	0.004	0.013	0.031	0.002	0.002	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101454130	7	069700 Psi	078390 Psi	27.2 %	ASTM A500-13 GRADE B&C	0.35

Material Note:
Sales Or.Note:

Marvin Phillips

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.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 1 Of 4

Metals Service Center Institute

Figure B-12. Steel Tube Material Certificate, Test No. NJPCB-4

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	821597

Atlas Tube Canada ULC
200 Clark St.
Harrow, Ontario, Canada
N0R 1G0
Tel: 519-738-3541
Fax: 519-738-3537

Atlas *Tube* JMC STEEL GROUP

Ref.B/L: 80664351
Date: 05.08.2015
Customer: 1497

MATERIAL TEST REPORT

Sold to
Triad Metals International
1 Village Road
HORSHAM PA 19044-3812
USA

Shipped to
Triad Metals International
3507 Grand Avenue
PITTSBURGH PA 15225
USA

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: Canada Melted in: Canada
Sales order: 995107 Purchase Order: 76312

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
821597	0.210	0.780	0.011	0.009	0.013	0.040	0.026	0.006	0.004	0.013	0.031	0.002	0.002	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101454131	8	069700 Psi	078390 Psi	27.2 %	ASTM A500-13 GRADE B&C	CE: 0.35

Material Note:
Sales Or.Note:

Material: 6.0x2.0x188x24'0"0(3x9). Material No: 600201882400 Made in: Canada Melted in: Canada
Sales order: 995107 Purchase Order: 76312

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
821679	0.180	0.790	0.010	0.008	0.015	0.040	0.047	0.002	0.005	0.023	0.038	0.002	0.002	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101453723	27	058410 Psi	069080 Psi	33.3 %	ASTM A500-13 GRADE B&C	CE: 0.33

Material Note:
Sales Or.Note:

Material: 6.0x6.0x188x40'0"0(3x3). Material No: 600601884000 Made in: Canada Melted in: Canada
Sales order: 1001173 Purchase Order: 77498

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
821531	0.190	0.810	0.013	0.006	0.017	0.059	0.051	0.005	0.004	0.015	0.036	0.002	0.002	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M101456164	9	063160 Psi	078380 Psi	30.5 %	ASTM A500-13 GRADE B&C	CE: 0.34

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 4

Metals Service Center Institute

Figure B-13. Steel Tube Material Certificate, Test No. NJPCB-4

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	1422428

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

Atlas Tube
JMC STEEL GROUP

Ref.B/L: 80660765
Date: 04.15.2015
Customer: 1497

MATERIAL TEST REPORT

Sold to

Triad Metals International
1 Village Road
HORSHAM PA 19044-3812
USA

Shipped to

Triad Metals International
3507 Grand Avenue
PITTSBURGH PA 15225
USA

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: USA
Sales order: 989623 Purchase Order: 75462 Melted in: Russian Fed.

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
1422428	0.200	0.930	0.007	0.010	0.013	0.043	0.040	0.000	0.000	0.020	0.030	0.000	0.000	0.000	0.006

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800549020	3	070619 Psi	081004 Psi	36 %	ASTM A500-13 GRADE B&C	0.37

Material Note:
Sales Or.Note:

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: USA
Sales order: 989623 Purchase Order: 75462 Melted in: Russian Fed.

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
1422428	0.200	0.930	0.007	0.010	0.013	0.043	0.040	0.000	0.000	0.020	0.030	0.000	0.000	0.000	0.006

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800549017	8	070619 Psi	081004 Psi	36 %	ASTM A500-13 GRADE B&C	0.37

Material Note:
Sales Or.Note:

Material: 20.0x4.0x313x48'0"0(1x4). Material No: 2000403134800 Made in: USA
Sales order: 994677 Purchase Order: 75051-replacement Melted in: USA

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
A73575	0.200	0.490	0.009	0.002	0.030	0.034	0.120	0.000	0.020	0.060	0.050	0.001	0.002	0.000	0.009

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M900754817	4	057121 Psi	074148 Psi	30 %	ASTM A500-13 GRADE B&C	0.31

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.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 3 Of 3

Metals Service Center Institute

Figure B-14. Steel Tube Material Certificate, Test No. NJPCB-4

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	M04495_1

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

Atlas Tube
JMC STEEL GROUP

Ref.B/L: 80665303
Date: 05.18.2015
Customer: 1497

MATERIAL TEST REPORT

Sold to
Triad Metals International
1 Village Road
HORSHAM PA 19044-3812
USA

Shipped to
Triad Metals International
3507 Grand Avenue
PITTSBURGH PA 15225
USA

Material: 4.0x4.0x500x48'0"0(3x2). Material No: 400405004800 Made in: USA
Melted in: USA

Sales order: 989623 Purchase Order: 75462

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
M04495_1	0.190	0.750	0.014	0.010	0.019	0.050	0.050	0.004	0.004	0.010	0.040	0.001	0.001	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800554030	2	072918 Psi	082550 Psi	35 %	ASTM A500-13 GRADE B&C	0.33

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 : 4 Of 4

Metals Service Center Institute

Figure B-15. Steel Tube Material Test Certificate, Test No. NJPCB-4

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	T83539

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

Atlas *Tube*
JMC STEEL GROUP

Ref.B/L: 80619794
Date: 08.22.2014
Customer: 1497

MATERIAL TEST REPORT

Sold to
Triad Metals International
1 Village Road
HORSHAM PA 19044-3812
USA

Shipped to
Triad Metals International
3500 Neville Road
NEVILLE ISLAND PA 15225
USA

Material: 4.0x4.0x375x48'0"0(4x2). Material No: 400403754800 Made in: USA
Melted in: USA
Sales order: 934921 Purchase Order: 67358

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
E84203	0.190	0.800	0.015	0.011	0.021	0.050	0.040	0.005	0.006	0.010	0.040	0.001	0.001	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.34
M800504131	8	071476 Psi	081675 Psi	32 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 4.0x4.0x500x40'0"0(4x2). Material No: 400405004000 Made in: USA
Melted in: USA
Sales order: 934921 Purchase Order: 67358

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
T83539	0.200	0.820	0.012	0.007	0.015	0.054	0.020	0.007	0.004	0.010	0.040	0.001	0.001	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.35
M800500342	8	072654 Psi	085933 Psi	29 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 12.0x12.0x250x40'0"0(2x2). Material No: 1201202504000 Made in: USA
Melted in: USA
Sales order: 933979 Purchase Order: 67228

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
T84047	0.180	0.800	0.008	0.007	0.015	0.045	0.020	0.003	0.003	0.010	0.040	0.001	0.001	0.000	0.007

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.33
M900697115	4	055286 Psi	073956 Psi	28 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Marvin Phillips

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.
CE calculated using the AWS D1.1 method.

Steel Tube Institute OF NORTH AMERICA

Page : 1 Of 4

Metals Service Center Institute

Figure B-16. Steel Tube Material Certificate, Test No. NJPCB-4

Customer Name	Customer PO#	Shipper No	Heat Number
Seibel Modern Mfg.	Leon	273924	SD5020

Independence Tube

6226 W. 74th St
Chicago, IL 60638
708-496-0380
Fax: 708-563-1950

independencetube.com
itctube.com
Certificate Number: DCR 250913

Sold By:
INDEPENDENCE TUBE CORPORATION
6226 W. 74th St.
Chicago, IL 60638
Tel: 708-496-0380
Fax: 708-563-1950

Purchase Order No: 70783
Sales Order No: DCR 64130 - 5
Bill of Lading No: DCR 43787 - 94
Invoice No:

Shipped: 1/16/2015
Invoiced:

Sold To:
2103 - TRIAD METALS
1 VILLAGE ROAD
HORSHAM, PA 19044-3812

Ship To:
39 - TRIAD METALS BARGE
MILE MARKER 7.3
OHIO RIVER
NEVILLE ISLAND, PA 15225

CERTIFICATE of ANALYSIS and TESTS

Customer Part No:

TUBING A500 GRADE B(C)
4" SQ X 1/2" X 48'

Certificate No: DCR 250913
Test Date: 1/14/2015

Total Pieces	Total Weight
36	37,376

Bundle Tag	Mill	Heat	Pieces	Weight
844458	40	SD5020	9	9,344
844459	40	SD5020	9	9,344
844460	40	SD5020	9	9,344
844461	40	SD5020	9	9,344

Mill #: 40 Heat #: SD5020 Yield: 72,300 psi Tensile: 78,800 psi Elongation: 28.50 % Y/T Ratio: 0.9175 Carbon Eq: 0.1352

C	Mn	P	S	Si	Al	Cu	Cr	Mo	V	Ni	Nb
0.0500	0.3900	0.0090	0.0040	0.2240	0.0260	0.0900	0.0400	0.0200	0.0010	0.0300	0.0080

Certification:

I certify that the above results are a true and correct copy of records prepared and maintained by Independence Tube Corporation. Sworn this day, 1/14/2015

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

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

Jose Martinez, QMS Manager

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

Figure B-17. Steel Tube Material Certificate, Test No. NJPCB-4

MID-AMERICA STEEL CORPORATION
TEST REPORT

No. F33822

TO: SEIBEL MODERN MFG & WELDING

DATE: 02/19/13
P.O. #: SBJ-40

ATTN:

TAG#	SIZE	SPEC
K78419	1/4 x 48.000 x 144.000	A-36
K78420	1/4 x 48.000 x 144.000	A-36
K78421	1/4 x 48.000 x 144.000	A-36
K78422	1/4 x 48.000 x 144.000	A-36

CHEMICAL ANALYSIS

TAG#	HEAT#	C	Mn	P	S
K78419	1129849	0.063	0.760	0.012	0.004
K78420	1129849	0.063	0.760	0.012	0.004
K78421	1129849	0.063	0.760	0.012	0.004
K78422	1129849	0.063	0.760	0.012	0.004

PHYSICAL ANALYSIS

TAG#	HEAT#	TENSILE	YIELD	ELONGATION
K78419	1129849	75,102	58,422	26%
K78420	1129849	75,102	58,422	26%
K78421	1129849	75,102	58,422	26%
K78422	1129849	75,102	58,422	26%

All material made and melted in the U.S.

Thank you,

JOHN RATICA
MID-AMERICA STEEL CORPORATION

Figure B-18. 2-in. × ¼-in. (51-mm × 6-mm) Bent Steel Plate, Test No. NJPCB-4

ArcelorMittal

ArcelorMittal LaPlace
(HARRIMAN)
2404 S. ROANE STREET
HARRIMAN, TENNESSEE 37748
Telephone (865) 882-5100

MATERIAL CERTIFICATION REPORT
METAL TRADER INC. (TRIAD METAL)
1 Village Road
HORSHAM PA 19044
ETATS-UNIS

TRIAD METALS INTERNATIONAL
(WASSELL LAND)
3507 Grand Avenue
PITTSBURGH PA 15225
USA

Tested in Accordance
With: ASTM A6

Sales Order 148953-4
Product Flat bars
Heat NO. L99837
Cust.Mat.
Size 2" X1/2" X3.404

Date 09/09/2015
Cust 40008882
Grade A3652950
Length 20' 00"

PO: 81536
Ref. 80833851
Pieces 288
Weight 19607.04

CHEMICAL ANALYSIS	
C	0.13
Mn	0.88
P	0.007
S	0.018
Si	0.19
Cu	0.24
Ni	0.17
Cr	0.14
Mo	0.065
Cb	0.020
V	0
B	
Al	
Sn	0.012
N	
Ti	
Ci	
CE	

MECHANICAL PROPERTIES	TEST 1 IMPERIAL	TEST 1 METRIC	TEST 2 IMPERIAL	TEST 2 METRIC	TEST 3 IMPERIAL	TEST 3 METRIC
YIELD STRENGTH	52710 PSI	363 MPa	53770 PSI	371 MPa		
TENSILE STRENGTH	72220 PSI	498 MPa	74560 PSI	514 MPa		
ELONGATION	25 %	25 %	25 %	25 %		
GAUGE LENGTH	8 IN	203 mm	8 IN	203 mm		
BEND TEST DIAMETER						
BEND TEST RESULTS						
SPECIMEN AREA						
REDUCTION OF AREA						
IMPACT STRENGTH						

IMPACT STRENGTH	IMPERIAL	METRIC	INTERNAL CLEANLINESS		GRAIN SIZE	
AVERAGE			SEVERITY		HARDNESS	
TEST TEMP			FREQUENCY		~~GRAIN PRACTICE~~	
ORIENTATION			RATING		REDUCTION RATIO	

This heat makes the following grades: A36-08,A52950-05,G40.21-CSA50W,CSA44W,A70936-09a, ASME SA36-2010, A57250-07, A70950-10, AASHTO M270 Grade 36,AASHTO M270 Grade 50, AASHTO M270M Grade 345.

I hereby certify that the material test results presented here are from the reported heat and are correct. All tests were performed in accordance to the specification reported above. All steel is electric arc furnace melted (billets), manufactured, processed, tested in the U.S.A with satisfactory results. No weld repair was performed on this heat.

Notarized upon request:
Sworn to and subscribed before me on 9th day of September, 2015
MANAGER

Notary Public County

Signed Keith D Limburg
KEITH D. LIMBURG, QUALITY ASSURANCE

Direct any questions or necessary clarifications concerning this report to the Sales Department 1-800-535-7692(USA)

Figure B-19. ½-in. (13-mm) Thick Steel Plate Material Certificate

GERDAU

CERTIFIED MATERIAL TEST REPORT

Page 1/1

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

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE
TRIAD METALS 3507 GRAND AVE PITTSBURGH,PA 15225 USA	TRIAD METALS INTERNATIONAL MET 1 VILLAGE RD HORSHAM,PA 19044-3800 USA	GGMULTI	Flat / 1/2 X 2 1/4

LENGTH	WEIGHT	HEAT / BATCH
20'00"	4,979 LB	54144612/03

SALES ORDER	CUSTOMER MATERIAL N°
2819476/000010	

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
83055W	1321-0000034345	09/24/2015

SPECIFICATION / DATE or REVISION
A6-13A,A36-12, ASME SA36-13
ASTM A529-05(2009), A572-13A
ASTM A709-13A, AASHTO M270-12
CSA G40.20-13/G40.21-13

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Sn %
0.17	0.71	0.011	0.033	0.20	0.47	0.14	0.17	0.030	0.015	0.002	0.013

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
29.40	8.000	74174	511	51422	355

GEOMETRIC CHARACTERISTICS

R:R
22.00

COMMENTS / NOTES

This grade meets the requirements for the following grades:
ASTM Grades: A36, A529-50; A572-50; A709-36, A709-50
CSA Grades; 44W; 50W
AASHTO Grades: M270-36; M270-50
ASME Grades: SA36

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

JORDAN FOSTER
QUALITY ASSURANCE MGR.

Figure B-20. ½-in. (13-mm) Thick Steel Plate Material Certificate, Test No. NJPCB-4

DAYTON SUPERIOR

1107 Advantage Grout

Cement Based Grout

TECHNICAL DATA SHEET

DESCRIPTION
The 1107 Advantage Grout is a non-shrink, non-metallic, non-corrosive, cementitious grout that is designed to provide a controlled, positive expansion to ensure an excellent bearing area. The 1107 Advantage Grout can be mixed from a fluid to a dry pack consistency.

USE
Exterior grouting of structural column base plates, pump and machinery bases, anchoring bolts, dowels, bearing pads and keyway joints. It finds applications in paper mills, oil refineries, food plants, chemical plants, sewage and water treatment plants etc.

FEATURES
- Controlled, net positive expansion
- Non shrink
- Non metallic/non corrosive
- Pourable, pumpable or dry pack consistency
- Interior/exterior applications

PROPERTIES
Corps of Engineers Specification for non-shrink grout:

CRD-C 621 Grades A, B, C

ASTM C-1107 Grades A, B, C

ASTM C-827 - 1107 Advantage Grout yielded a controlled positive expansion

Expansion - ASTM C-1090:

1 day: 0-0.3

3 days: 0-0.3

14 days: 0-0.3

28 days: 0-0.3

Test Results

	@ 1 Day		@ 3 Days		@ 7 Days		@ 28 Days	
Fluidity	PSI	MPa	PSI	MPa	PSI	MPa	PSI	MPa
Dry-Pack	5000	34.5	7000	48.2	9000	62.0	10000	68.9
Flowable	2500	17.2	5000	34.5	6000	41.4	8000	55.1
Fluid	2000	13.8	4000	27.6	5000	34.5	7500	51.7

Note:
The data shown is typical for controlled laboratory conditions. Reasonable variation from these results can be expected due to interlaboratory precision and bias. When testing the field mixed material, other factors such as variations in mixing, water content, temperature and curing conditions should be considered.

Estimating Guide
Yield (Flowable Consistency):
0.43 cu. ft./50 lbs. (0.0122 cu. M/22.67 kg) bag
0.59 cu. ft./50 lbs. (0.017 cu. M/22.67 kg) bag extended with 25 lbs. (11.34 kg) of washed 3/8 in. (1cm) pea gravel

Packaging

PRODUCT CODE	PACKAGE	SIZE	
		lbs	kg
67435	Bag	50	22.67
67437	Supersack	3,000	1,360.78

STORAGE
Store in a cool, dry area free from direct sunlight. Shelf life of unopened bags, when stored in a dry facility, is 12 months. Excessive temperature differential and /or high humidity can shorten the shelf life expectancy.

APPLICATION

Surface Preparation:
Thoroughly clean all contact surfaces. Existing concrete should be strong and sound. Surface should be roughened to insure bond. Metal base plates should be clean and free of oil and other contaminants. Maintain contact areas between 45°F (7°C) and 90°F (32°C) before grouting and during curing period.

Thoroughly wet concrete contact area 24 hours prior to grouting, keep wet and remove all surface water just prior to placement. If 24 hours is not possible, then saturate with water for at least 4 hours. Seal forms to prevent water or grout loss. On the placement side, provide an angle in the form high enough to assist in grouting and to maintain head pressure on the grout during the entire grouting process. Forms should be at least 1 in. (2.5 cm) higher than the bottom of the base plate.

Water Requirements:
Desired Mix Water / 50 lbs. (22.67 kg) Bag
Dry Pack: 5 pints (2.4 L)
Flowable: 8 pints (3.8 L)
Fluid: 9 pints (4.2 L)

Mixing:
A mechanical mixer with rotating blades like a mortar mixer is best. Small quantities can be mixed with a drill and paddle. When mixing less than a full bag, always first agitate the bag thoroughly so that a representative sample is obtained.

Sec 16 Grouts

Figure B-21. Non-Shrink Grout Specifications, Test No. NJPCB-4

DAYTON SUPERIOR

1107 Advantage Grout

Cement Based Grout

TECHNICAL DATA SHEET

Place approximately 3/4 of the anticipated mix water into the mixer and add the grout mix, adding the minimum additional water necessary to achieve desired consistency.
Mix for a total of five minutes ensuring uniform consistency. For placements greater in depth than 3 in. (7.6 cm), up to 25 lbs. (11.34 kg) of washed 3/8 in. (1 cm) pea gravel must be added to each 50 lbs. (22.67 kg) bag of grout. The approximate working time (pot life) is 30 minutes but will vary somewhat with ambient conditions.

For hot weather conditions, greater than 85°F (29°C), mix with cold water approximately 40°F (4°C).
For cold weather conditions, less than 50°F (10°C), mix with warm water, approximately 90°F (29°C). For additional hot and cold weather applications, contact Dayton Superior.

Placement:
Grout should be placed preferably from one side using a grout box to avoid entrapping air. Grout should not be over-worked or over-watered causing segregation or bleeding. Vent holes should be provided where necessary.
When possible, grout bolt holes first. Placement and consolidation should be continuous for any one section of the grout. When nearby equipment causes vibration of the grout, such equipment should be shut down for a period of 24 hours. Forms may be removed when grout is completely self-supporting. For best results, grout should extend downward at a 45 degree angle from the lower edge of the steel base plates or similar structures.

Sec 16 Grouts

CLEAN UP
Use clean water. Hardened material will require mechanical removal methods.

CURING
Exposed grout surfaces must be cured. Dayton Superior recommends using a Dayton Superior curing compound, cure & seal or a wet cure for 3 days. Maintain the temperature of the grout and contact area at 45°F (7°C) to 90°F (32°C) for a minimum of 24 hours.

LIMITATIONS

FOR PROFESSIONAL USE ONLY
Do not re-temper after initial mixing
Do not add other
cements or additives
Setting time for the 1107 Advantage Grout will slow during cooler weather, less than 50°F (10°C) and speed up during hot weather, greater than 80°F (27°C)
Prepackaged material segregates while in the bag, thus when mixing less than a full bag it is recommended to first agitate the bag to assure it is blended prior to sampling.

PRECAUTIONS

READ SDS PRIOR TO USING PRODUCT
- Product contains Crystalline Silica and Portland Cement Avoid breathing dust Silica may cause serious lung problems
- Use with adequate ventilation
n Wear protective clothing, gloves and eye protection (goggles, safety glasses and/or face shield)
- Keep out of the reach of children
- Do not take internally
- In case of ingestion, seek medical help immediately
- May cause skin irritation upon contact, especially prolonged or repeated. If skin contact occurs, wash immediately with soap and water and seek medical help as needed.
- If eye contact occurs, flush immediately with clean water and seek medical help as needed
- Dispose of waste material in accordanc

MANUFACTURER
Dayton Superior Corporation
1125 Byers Road
Miamisburg, OH 45342
Customer Service: 888-977-9600
Technical Services: 877-266-7732
Website: www.daytonsuperior.com

WARRANTY
Dayton Superior Corporation ("Dayton") warrants for 12 months from the date of manufacture or for the duration of the published product shelf life, whichever is less, that at the time of shipment by Dayton, the product is free of manufacturing defects and conforms to Dayton's product properties in force on the date of acceptance by Dayton of the order. Dayton shall only be liable under this warranty if the product has been applied, used, and stored in accordance with Dayton's instructions, especially surface preparation and installation, in force on the date of acceptance by Dayton of the order. The purchaser must examine the product when received and promptly notify Dayton in writing of any non-conformity before the product is used and no later than 30 days after such non-conformity is first discovered. If Dayton, in its sole discretion, determines that the product breached the above warranty, it will, in its sole discretion, replace the non-conforming product, refund the purchase price or issue a credit in the amount of the purchase price. This is the sole and exclusive remedy for breach of this warranty. Only a Dayton officer is authorized to modify this warranty. The information in this data sheet supersedes all other sales information received by the customer during the sales process. THE FOREGOING WARRANTY SHALL BE EXCLUSIVE AND IN LIEU OF ANY OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, AND ALL OTHER WARRANTIES OTHERWISE ARISING BY OPERATION OF LAW, COURSE OF DEALING, CUSTOM, TRADE OR OTHERWISE.

Visit www.daytonsuperior.com for the most up to date technical information
Page 2 of 3
File Date: 3/27/2015

Figure B-22. Non-Shrink Grout Specifications, Test No. NJPCB-4

benesch
engineers · scientists · planners

LINCOLN OFFICE
825 "M" Street Suite 100
Lincoln, NE 68508
Phone: (402) 479-2200
Fax: (402) 479-2276

COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 6x12

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility **Date** 08-Nov-16
Project Name: NJPCB-4
Placement Location: None Given
Mix Designation: n/a **Required Strength:** n/a

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area, sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
NJP- 1	A	11/8/2016	11/8/2016	11/8/2016	0	0	0	8	4.01	12.60	95,185	7,560	1,000	3	C 1231
NJP- 2	B	11/8/2016	11/8/2016	11/8/2016	0	0	0	8	4.00	12.59	85,934	6,830	1,000	5	C 1231
NJP- 3	C	11/8/2016	11/8/2016	11/8/2016	0	0	0	8	4.01	12.62	94,298	7,470	1,000	2	C 1231

1 cc: Shaun Tighe
Midwest Roadside Safety Facility

Remarks: Cast date unknown

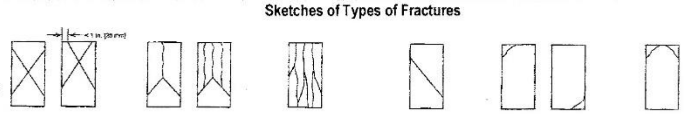
All concrete test data in this report was produced by Benesch personnel using ASTM Standard Methods and Practices unless otherwise noted.

Test results presented relate only to the concrete sampled by Benesch personnel as referenced above.

This report shall not be reproduced except in full, without the written approval of Alfred Benesch & Company.

Report Number 2147368938
Page 1

Sketches of Types of Fractures



Type 1 Reasonably well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps
Type 2 Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end
Type 3 Columnar vertical cracking through both ends, no well-formed cones
Type 4 Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type 1
Type 5 Side fractures at top or bottom (occur commonly with unbonded caps)
Type 6 Similar to Type 5 but end of cylinder is pointed

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By
Brant Wells, Field/Lab Operations Manager

Figure B-23. Non-shrink Grout Compressive Test Certificate, Test No. NJPCB-4

Appendix C. Concrete Tarmac Strength

benesch
engineers · scientists · planners

LINCOLN OFFICE
825 J Street
Lincoln, NE 68508
402/479-2200

COMPRESSION TEST OF Cylindrical CONCRETE SPECIMENS
ASTM Designation: C39-03

Client:	UNL			Date:	December 10, 2010	
Project:	MwRSF					
Placement Location:	WI - East 1, 2, 3					
Mix Type:	Class:			Mix No.:		
Type of Forms			Cement Factor, Sks/Yd		na	
			Water-Cement Ratio		na	
Admixture Quantity	na		Slump Inches		na	
Admixture Type	na		Unit Wt, lbs/cu. Ft.		na	
Admixture Quantity	na		Air Content, %		na	
Average Field Temperature	na		Batch Volume, Cu. Yds.		na	
Temperature of Concrete F	na		Ticket No.		na	
Identification Laboratory	East 1	East 2	East 3			
Date Cast						
Date Received in Laboratory	11/30/2010	11/30/2010	11/30/2010			
Date Tested						
Days Cured in Field						
Days Cured in Laboratory						
Age of Test, Days						
Length, in.	7.78	7.81	7.75			
Average Width (1), in.	3.72	3.72	3.72			
Cross-Sectional Area, sq. in.	10.874	10.869	10.874			
Maximum Load, lbf	71,030	76,470	73,310			
Compressive Stength, psi	6,530	7,040	6,740			
Length/Diameter Ratio	2.091	2.099	2.083			
Correction						
Corrected Compressive Strength,psi	0	0	0			
Type of Fracture	4	4	4			
Required Strength,psi						

Remarks:

All concrete break data in this report was produced by Benesch personnel using ASTM Standard Methods and Practices unless otherwise noted.

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By: Raymond E. Delka
Raymond E. Delka, Manager

Figure C-1. Concrete Tarmac Strength Test, Test No. NJPCB-4

benesch
engineers · scientists · planners

LINCOLN OFFICE
825 J Street
Lincoln, NE 68508
402/479-2200

COMPRESSION TEST OF Cylindrical CONCRETE SPECIMENS
ASTM Designation: C39-03

Client:	UNL			Date:	December 13, 2010	
Project:	MwRSF					
Placement Location:	WI - Epoxy West 4 &5					
Mix Type:	Class:			Mix No.:		
Type of Forms			Cement Factor, Sks/Yd		na	
			Water-Cement Ratio		na	
Admixture Quantity	na		Slump Inches		na	
Admixture Type	na		Unit Wt, lbs/cu. Ft.		na	
Admixture Quantity	na		Air Content, %		na	
Average Field Temperature	na		Batch Volume, Cu. Yds.		na	
Temperature of Concrete F	na		Ticket No.		na	
Identification Laboratory	4	5				
Date Cast						
Date Received in Laboratory	12/13/2010	12/13/2010				
Date Tested						
Days Cured in Field						
Days Cured in Laboratory						
Age of Test, Days	na	na				
Length, in.	8.05	8.06				
Average Width (1), in.	3.91	3.90				
Cross-Sectional Area, sq. in.	11.977	11.952				
Maximum Load, lbf	71,500	71,630				
Compressive Stength, psi	5,970	5,990				
Length/Diameter Ratio	2.061	2.065				
Correction						
Corrected Compressive Strength,psi	0	0				
Type of Fracture	3	3				
Required Strength,psi						

Remarks:

All concrete break data in this report was produced by Benesch personnel using ASTM Standard Methods and Practices unless otherwise noted.

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By: Raymond E. Delka, Manager

Figure C-2. Concrete Tarmac Strength Test, Test No. NJPCB-4

Appendix D. Vehicle Center of Gravity Determination

Date:	**11/9/2016**	**Test Name:**	**NJPCB-4**	**VIN:**	**1D7R1GP1BS554669**
Year:	**2011**	**Make:**	**Dodge**	**Model:**	**Ram 1500**

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	5029	28 1/3	142383.56
+	Hub	19	15	285
+	Brake activation cylinder & frame	7	26 3/4	187.25
+	Pneumatic tank (Nitrogen)	27	26 1/2	715.5
+	Strobe/Brake Battery	5	24 5/8	123.125
+	Brake Receiver/Wires	5	51 7/8	259.375
+	CG Plate including DAS	43	30 1/4	1300.75
-	Battery	-47	39 1/4	-1844.75
-	Oil	-8	23	-184
-	Interior	-86	27 1/2	-2365
-	Fuel	-149	18	-2682
-	Coolant	-11	31	-341
-	Washer fluid	-6	34 1/2	-207
+	Water Ballast (In Fuel Tank)	147	18	2646
+	Onboard Supplemental Battery	12	24 5/8	295.5
				0
Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle				140572.31

Estimated Total Weight (lb)	4987
Vertical CG Location (in.)	28.1878

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140 1/2 in.
Front Track Width: 67 3/4 in.
Rear Track Width: 67 3/4 in.

Center of Gravity	**2270P MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)	5000 ± 110	5000	0.0
Longitudinal CG (in.)	63 ± 4	61.6795	-1.32050
Lateral CG (in.)	NA	-0.1084	NA
Vertical CG (in.)	28 or greater	28.19	0.18775

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	1445	1408
Rear	1115	1061

FRONT	2853	lb
REAR	2176	lb
TOTAL	5029	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	1390	1415
Rear	1118	1077

FRONT	2805	lb
REAR	2195	lb
TOTAL	5000	lb

Figure D-1. Vehicle Mass Distribution, Test No. NJPCB-4

Appendix E. Vehicle Deformation Records

Date: 2/27/2018 Test Name: NJPCB-4 VIN: 1D7R1GP1BS554669
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
1	28.570	-28.025	4.869	28.263	-27.785	5.171	-0.307	0.240	0.302	0.493	0.431
2	31.186	-22.060	2.423	30.984	-21.874	2.707	-0.202	0.186	0.285	0.396	0.349
3	30.504	-15.554	0.817	30.505	-15.465	1.069	0.001	0.089	0.252	0.267	0.252
4	28.772	-11.356	1.763	28.835	-11.243	1.846	0.062	0.112	0.083	0.153	0.104
5	26.117	-28.521	0.347	26.023	-28.477	0.439	-0.094	0.043	0.093	0.139	0.132
6	26.319	-22.654	-0.395	26.315	-22.590	-0.196	-0.004	0.064	0.200	0.210	0.200
7	26.333	-16.390	-1.085	26.339	-16.321	-0.868	0.006	0.069	0.218	0.228	0.218
8	26.168	-12.297	-1.504	26.211	-12.332	-1.435	0.043	-0.036	0.069	0.089	0.082
9	23.323	-28.631	-1.371	23.326	-28.542	-1.335	0.003	0.089	0.036	0.096	0.036
10	23.253	-22.885	-2.001	23.213	-22.759	-1.732	-0.040	0.126	0.270	0.300	0.270
11	23.185	-16.811	-2.738	23.149	-16.733	-2.567	-0.035	0.078	0.172	0.192	0.172
12	23.198	-12.855	-3.168	23.154	-12.810	-3.092	-0.044	0.045	0.076	0.098	0.076
13	19.961	-29.241	-3.350	19.916	-29.158	-3.327	-0.045	0.083	0.023	0.097	0.023
14	19.927	-23.352	-3.630	19.936	-23.342	-3.431	0.009	0.010	0.199	0.200	0.199
15	19.866	-16.738	-4.372	19.881	-16.636	-4.205	0.015	0.102	0.167	0.196	0.167
16	19.808	-13.354	-4.766	19.843	-13.318	-4.648	0.035	0.036	0.118	0.128	0.118
17	16.351	-28.505	-3.241	16.243	-28.438	-3.247	-0.108	0.067	-0.005	0.127	-0.005
18	16.185	-22.863	-3.807	16.202	-22.748	-3.671	0.017	0.115	0.136	0.179	0.136
19	16.225	-17.020	-4.456	16.225	-16.927	-4.346	-0.001	0.093	0.110	0.144	0.110
20	15.962	-13.126	-4.904	16.054	-13.109	-4.845	0.092	0.016	0.058	0.110	0.058
21	10.448	-28.487	-3.259	10.391	-28.394	-3.312	-0.057	0.093	-0.053	0.121	-0.053
22	10.419	-23.220	-3.769	10.510	-23.276	-3.764	0.091	-0.056	0.004	0.107	0.004
23	10.366	-17.349	-4.428	10.396	-17.270	-4.386	0.030	0.080	0.042	0.095	0.042
24	10.273	-13.453	-4.868	10.290	-13.335	-4.868	0.017	0.118	0.000	0.119	0.000
25	0.148	-26.503	0.264	0.113	-26.443	0.236	-0.035	0.059	-0.029	0.074	-0.029
26	0.036	-20.920	-0.323	0.152	-20.969	-0.321	0.116	-0.049	0.002	0.126	0.002
27	0.025	-15.919	-0.875	0.050	-15.930	-0.877	0.026	-0.011	-0.002	0.028	-0.002
28	0.113	-11.540	-1.361	0.099	-11.546	-1.361	-0.014	-0.006	0.000	0.015	0.000

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

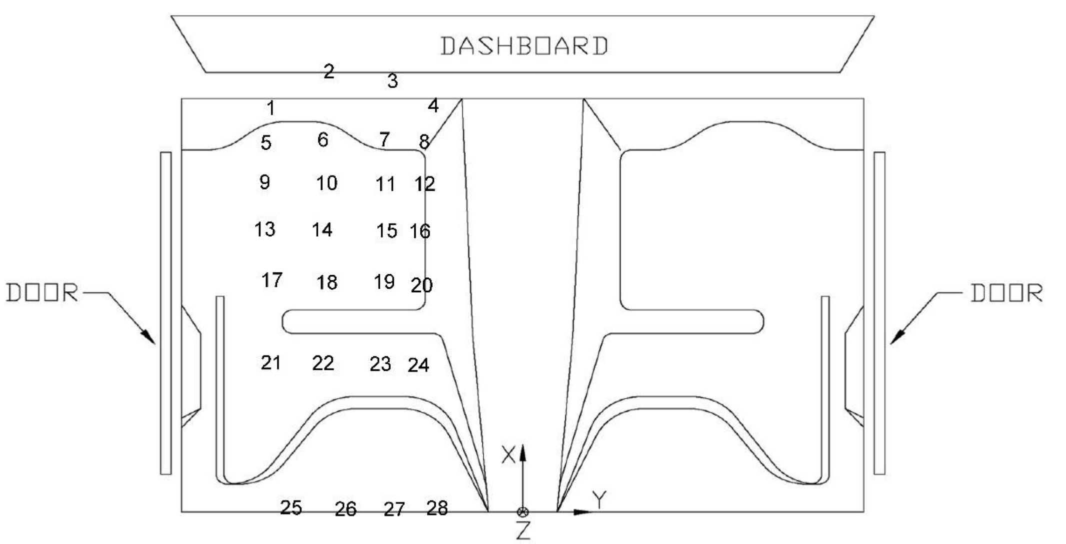


Figure E-1. Floor Pan Deformation Data – Set 1, Test No. NJPCB-4

Date: 2/27/2018 Test Name: NJPCB-4 VIN: 1D7R1GP1BS554669
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
1	50.884	-35.085	1.283	50.503	-35.013	0.722	-0.382	0.072	-0.561	0.682	0.686
2	53.306	-28.861	-0.835	53.116	-28.831	-1.219	-0.191	0.031	-0.385	0.431	0.432
3	52.667	-22.289	-1.594	52.600	-22.373	-2.040	-0.067	-0.084	-0.446	0.459	0.466
4	50.994	-18.188	-0.141	51.058	-18.148	-0.621	0.064	0.040	-0.480	0.486	0.487
5	48.143	-35.142	-3.218	47.997	-35.115	-3.938	-0.146	0.027	-0.721	0.736	0.737
6	48.355	-29.242	-3.341	48.308	-29.223	-3.892	-0.047	0.019	-0.551	0.553	0.554
7	48.378	-22.989	-3.376	48.310	-22.984	-3.830	-0.068	0.005	-0.453	0.458	0.458
8	48.156	-18.925	-3.265	48.223	-18.884	-3.893	0.067	0.041	-0.628	0.633	0.634
9	45.237	-35.010	-4.814	45.151	-35.008	-5.581	-0.086	0.002	-0.767	0.772	0.772
10	45.180	-29.231	-4.834	45.126	-29.179	-5.258	-0.054	0.052	-0.425	0.431	0.431
11	45.165	-23.145	-4.907	45.073	-23.084	-5.358	-0.092	0.061	-0.451	0.464	0.464
12	45.162	-19.309	-4.934	45.153	-19.190	-5.371	-0.009	0.119	-0.438	0.454	0.454
13	41.765	-35.479	-6.691	41.663	-35.356	-7.425	-0.103	0.123	-0.734	0.751	0.751
14	41.939	-29.701	-6.298	41.791	-29.611	-6.813	-0.148	0.090	-0.515	0.543	0.543
15	41.813	-22.891	-6.374	41.638	-22.765	-6.793	-0.175	0.126	-0.419	0.471	0.471
16	41.741	-19.566	-6.403	41.638	-19.454	-6.822	-0.103	0.112	-0.420	0.447	0.447
17	38.220	-34.724	-6.323	38.083	-34.563	-7.053	-0.137	0.162	-0.730	0.761	0.761
18	38.161	-29.016	-6.287	38.044	-28.963	-6.789	-0.117	0.052	-0.502	0.518	0.518
19	38.122	-23.150	-6.314	38.034	-23.111	-6.756	-0.087	0.039	-0.442	0.452	0.452
20	37.941	-19.277	-6.333	37.832	-19.201	-6.788	-0.109	0.076	-0.455	0.474	0.474
21	32.320	-34.682	-6.058	32.198	-34.577	-6.782	-0.123	0.105	-0.724	0.742	0.742
22	32.381	-29.451	-6.001	32.262	-29.389	-6.614	-0.120	0.061	-0.613	0.628	0.628
23	32.285	-23.475	-6.041	32.198	-23.366	-6.507	-0.087	0.110	-0.466	0.487	0.487
24	32.231	-19.551	-6.064	32.144	-19.446	-6.507	-0.087	0.105	-0.444	0.464	0.464
25	22.191	-32.985	-1.848	22.140	-32.936	-2.460	-0.051	0.049	-0.613	0.617	0.617
26	22.153	-27.430	-1.845	22.081	-27.381	-2.370	-0.072	0.050	-0.525	0.532	0.532
27	22.155	-22.423	-1.869	22.031	-22.365	-2.309	-0.124	0.058	-0.440	0.461	0.461
28	22.229	-18.005	-1.897	22.091	-17.972	-2.268	-0.138	0.033	-0.371	0.398	0.398

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

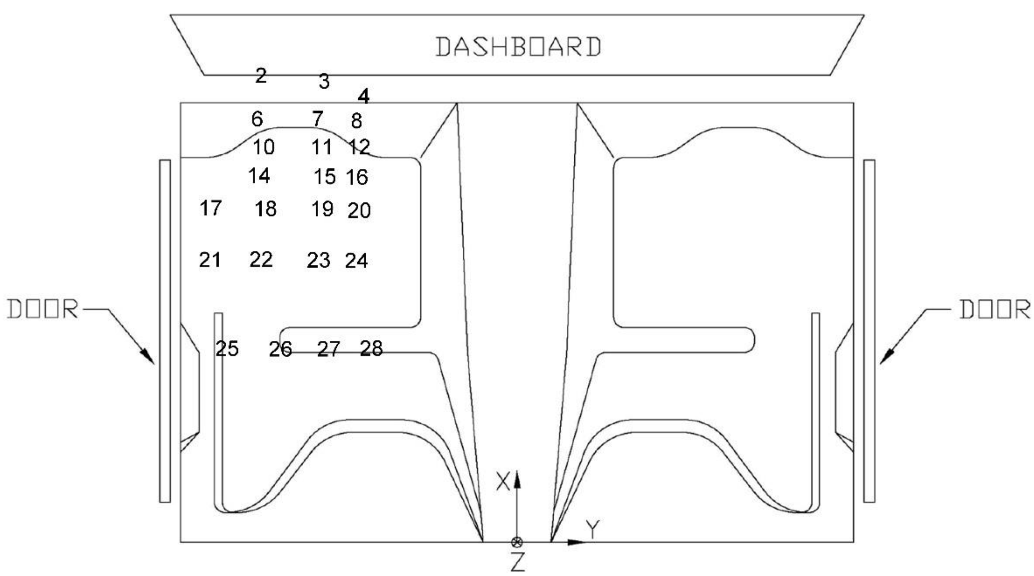


Figure E-2. Floor Pan Deformation Data – Set 2, Test No. NJPCB-4

Date: 2/27/2018 Test Name: NJPCB-4 VIN: 1D7R1GP1BS554669
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
DASH	1	14.357	-25.184	27.279	14.133	-25.023	27.301	-0.225	0.161	0.021	0.277	0.277
	2	12.523	-14.642	29.895	12.207	-14.467	29.836	-0.315	0.176	-0.060	0.366	0.366
	3	11.254	3.486	25.087	11.098	3.545	25.018	-0.156	0.059	-0.069	0.180	0.180
	4	11.983	-26.454	16.289	11.816	-26.385	16.330	-0.167	0.069	0.042	0.185	0.185
	5	9.931	-16.308	15.387	9.794	-16.293	15.355	-0.137	0.015	-0.032	0.141	0.141
	6	8.562	2.623	13.792	8.457	2.626	13.729	-0.105	0.002	-0.064	0.123	0.123
SIDE PANEL	7	20.737	-30.958	7.856	20.638	-30.667	7.938	-0.098	0.292	0.083	0.319	0.292
	8	24.082	-31.135	7.053	24.001	-30.926	7.201	-0.081	0.209	0.149	0.269	0.209
	9	22.362	-31.410	3.376	22.261	-31.180	3.492	-0.101	0.231	0.116	0.277	0.231
IMPACT SIDE DOOR	10	-13.005	-31.632	23.395	-13.268	-32.207	23.361	-0.263	-0.575	-0.035	0.633	-0.575
	11	-3.070	-31.275	23.300	-3.358	-31.678	23.358	-0.288	-0.403	0.058	0.499	-0.403
	12	8.545	-31.635	22.559	8.180	-31.828	22.694	-0.365	-0.193	0.135	0.434	-0.193
	13	-10.715	-33.703	8.295	-10.983	-33.700	8.357	-0.267	0.003	0.062	0.275	0.003
	14	1.642	-34.049	8.331	1.308	-33.977	8.443	-0.333	0.072	0.112	0.359	0.072
	15	12.760	-30.950	9.828	12.321	-30.576	9.886	-0.439	0.374	0.058	0.580	0.374
ROOF	16	3.083	-19.517	43.099	2.807	-19.337	43.098	-0.276	0.180	-0.001	0.329	-0.001
	17	5.246	-13.093	42.683	4.986	-12.881	42.666	-0.261	0.212	-0.017	0.336	-0.017
	18	6.515	-6.626	42.140	6.255	-6.347	42.103	-0.260	0.279	-0.037	0.383	-0.037
	19	7.095	-0.305	41.587	6.789	-0.213	41.555	-0.307	0.092	-0.032	0.322	-0.032
	20	7.296	5.125	40.996	6.975	5.346	40.938	-0.321	0.221	-0.057	0.394	-0.057
	21	-8.267	-15.678	46.543	-8.665	-15.622	46.482	-0.398	0.057	-0.062	0.407	-0.062
	22	-7.555	-8.526	46.121	-8.006	-8.401	46.031	-0.451	0.125	-0.090	0.477	-0.090
	23	-6.956	-3.548	45.749	-7.253	-3.326	45.604	-0.297	0.222	-0.145	0.398	-0.145
	24	-6.549	1.268	45.369	-6.990	1.388	45.219	-0.441	0.121	-0.150	0.481	-0.150
	25	-6.749	5.603	44.936	-7.122	5.750	44.756	-0.372	0.147	-0.180	0.439	-0.180
	26	-13.862	-15.652	46.908	-14.032	-15.445	46.779	-0.170	0.207	-0.129	0.297	-0.129
	27	-13.636	-9.298	46.614	-13.936	-9.168	46.440	-0.300	0.130	-0.174	0.371	-0.174
	28	-13.242	-3.322	46.178	-13.522	-3.239	45.983	-0.280	0.083	-0.195	0.351	-0.195
	29	-13.447	1.513	45.761	-13.719	1.545	45.548	-0.272	0.032	-0.213	0.347	-0.213
	30	-13.371	6.007	45.283	-13.692	6.147	45.041	-0.321	0.139	-0.242	0.426	-0.242
A PILLAR	31	3.532	-22.369	42.010	3.186	-22.191	42.039	-0.346	0.178	0.030	0.390	0.178
	32	9.271	-24.001	38.863	8.930	-23.836	38.793	-0.341	0.165	-0.070	0.385	0.165
	33	15.145	-25.705	34.800	14.876	-25.582	34.885	-0.268	0.123	0.084	0.307	0.123
	34	18.175	-26.612	32.664	17.872	-26.481	32.765	-0.303	0.132	0.102	0.346	0.132
B PILLAR	35	-22.623	-30.174	15.425	-22.726	-29.759	15.163	-0.104	0.415	-0.262	0.501	0.415
	36	-18.458	-30.149	15.540	-18.590	-29.875	15.326	-0.132	0.274	-0.215	0.372	0.274
	37	-22.995	-29.197	22.776	-23.147	-28.853	22.684	-0.151	0.343	-0.092	0.387	0.343
	38	-19.076	-29.122	23.042	-19.214	-28.858	22.900	-0.138	0.264	-0.142	0.330	0.264
	39	-23.376	-25.829	35.196	-23.636	-25.614	35.014	-0.260	0.214	-0.181	0.383	0.214
	40	-20.446	-25.727	35.310	-20.638	-25.556	35.141	-0.192	0.171	-0.169	0.308	0.171

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

Figure E-3. Occupant Compartment Deformation Data – Set 1, Test No. NJPCB-4

Date: 2/27/2018 Test Name: NJPCB-4 VIN: 1D7R1GP1BS554669
Year: 2011 Make: Dodge Model: Ram 1500

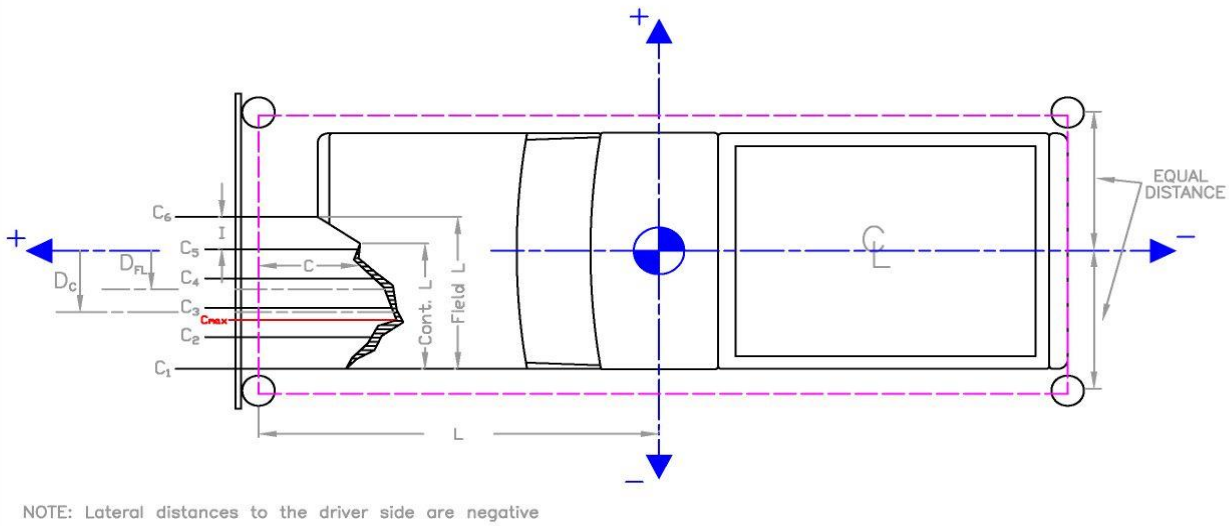
VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
DASH	1	37.685	-34.636	24.452	37.555	-34.950	23.741	-0.129	-0.314	-0.711	0.788	0.788
	2	35.957	-24.334	28.116	35.914	-24.753	27.592	-0.043	-0.419	-0.524	0.672	0.672
	3	34.718	-5.881	25.441	34.748	-6.276	25.087	0.030	-0.395	-0.354	0.531	0.531
	4	34.772	-34.708	13.541	34.684	-34.894	12.842	-0.088	-0.186	-0.699	0.729	0.729
	5	32.760	-24.537	13.785	32.689	-24.746	13.261	-0.071	-0.209	-0.525	0.569	0.569
	6	31.448	-5.532	14.314	31.477	-5.801	13.880	0.029	-0.269	-0.433	0.511	0.511
SIDE PANEL	7	43.106	-38.318	4.193	43.044	-38.178	3.436	-0.062	0.139	-0.758	0.773	0.139
	8	46.346	-38.415	3.266	46.361	-38.362	2.591	0.015	0.053	-0.675	0.677	0.053
	9	44.519	-38.298	-0.365	44.399	-38.162	-1.099	-0.120	0.136	-0.734	0.755	0.136
IMPACT SIDE DOOR	10	10.191	-40.535	21.133	9.941	-41.463	20.557	-0.250	-0.929	-0.576	1.121	-0.929
	11	20.084	-40.191	20.660	19.782	-40.980	20.130	-0.302	-0.790	-0.530	0.998	-0.790
	12	31.634	-40.509	19.322	31.363	-41.076	18.635	-0.270	-0.567	-0.687	0.931	-0.567
	13	11.685	-41.030	5.889	11.396	-41.134	5.318	-0.289	-0.104	-0.571	0.648	-0.104
	14	24.103	-41.366	5.325	23.785	-41.461	4.707	-0.318	-0.095	-0.618	0.701	-0.095
	15	35.268	-38.482	6.579	34.797	-38.298	5.916	-0.471	0.184	-0.664	0.834	0.184
ROOF	16	27.302	-30.594	41.240	27.253	-31.138	40.691	-0.049	-0.544	-0.548	0.774	-0.548
	17	29.497	-24.161	41.401	29.457	-24.708	40.925	-0.041	-0.547	-0.476	0.726	-0.476
	18	30.817	-17.541	41.477	30.732	-18.108	41.104	-0.085	-0.568	-0.373	0.684	-0.373
	19	31.422	-11.301	41.548	31.497	-11.888	41.167	0.075	-0.587	-0.381	0.703	-0.381
	20	31.479	-5.808	41.599	31.600	-6.317	41.268	0.121	-0.509	-0.330	0.619	-0.330
	21	16.083	-27.130	45.633	16.183	-27.752	45.119	0.100	-0.623	-0.514	0.814	-0.514
	22	16.738	-19.922	45.949	16.865	-20.429	45.512	0.126	-0.507	-0.437	0.681	-0.437
	23	17.420	-14.925	46.045	17.511	-15.549	45.662	0.090	-0.624	-0.383	0.738	-0.383
	24	17.779	-10.192	46.156	17.960	-10.736	45.814	0.181	-0.544	-0.342	0.668	-0.342
	25	17.678	-5.841	46.172	17.787	-6.353	45.897	0.108	-0.513	-0.275	0.592	-0.275
	26	10.528	-27.134	46.251	10.696	-27.674	45.747	0.169	-0.540	-0.504	0.758	-0.504
	27	10.741	-20.749	46.602	10.888	-21.349	46.165	0.147	-0.600	-0.437	0.757	-0.437
	28	11.145	-14.849	46.775	11.271	-15.401	46.409	0.127	-0.552	-0.366	0.674	-0.366
	29	10.991	-10.005	46.873	11.058	-10.595	46.565	0.067	-0.589	-0.308	0.668	-0.308
	30	11.105	-5.459	46.868	11.202	-6.004	46.606	0.097	-0.546	-0.262	0.613	-0.262
A PILLAR	31	27.570	-33.332	39.862	27.501	-33.824	39.300	-0.069	-0.492	-0.563	0.750	-0.492
	32	33.158	-34.627	36.241	33.064	-35.103	35.610	-0.094	-0.476	-0.631	0.796	-0.476
	33	38.794	-35.929	31.868	38.743	-36.394	31.203	-0.051	-0.464	-0.665	0.813	-0.464
	34	41.784	-36.610	29.394	41.645	-37.042	28.774	-0.140	-0.432	-0.620	0.768	-0.432
B PILLAR	35	0.235	-38.233	13.828	0.088	-38.006	13.217	-0.148	0.227	-0.611	0.669	0.227
	36	4.346	-38.228	13.786	4.317	-38.155	13.154	-0.028	0.073	-0.632	0.637	0.073
	37	0.195	-38.030	21.333	0.160	-38.015	20.803	-0.035	0.015	-0.530	0.531	0.015
	38	4.158	-37.996	21.337	4.071	-38.062	20.713	-0.087	-0.066	-0.623	0.633	-0.066
	39	0.394	-35.998	33.976	0.301	-36.291	33.417	-0.094	-0.293	-0.559	0.638	-0.293
	40	3.318	-35.916	33.960	3.376	-36.253	33.395	0.058	-0.337	-0.565	0.661	-0.337

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

Figure E-4. Occupant Compartment Deformation Data – Set 2, Test No. NJPCB-4

Date:	11/9/2016	Test Name:	NJPCB-4	VIN:	1D7R1GP1BS554669
Year:	2011	Make:	Dodge	Model:	Ram 1500



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	110	(2794)
Total Vehicle Width:	76 1/2	(1943)
Width of contact and induced crush - Field L:	59	(1499)
Crush measurement spacing interval (L/5) - I:	11 3/4	(298)
Distance from center of vehicle to center of Field L - D_{FL}:	-8 1/2	-(216)
Width of Contact Damage:	21	(533)
Distance from center of vehicle to center of contact damage - D_C:	-27 3/4	-(705)

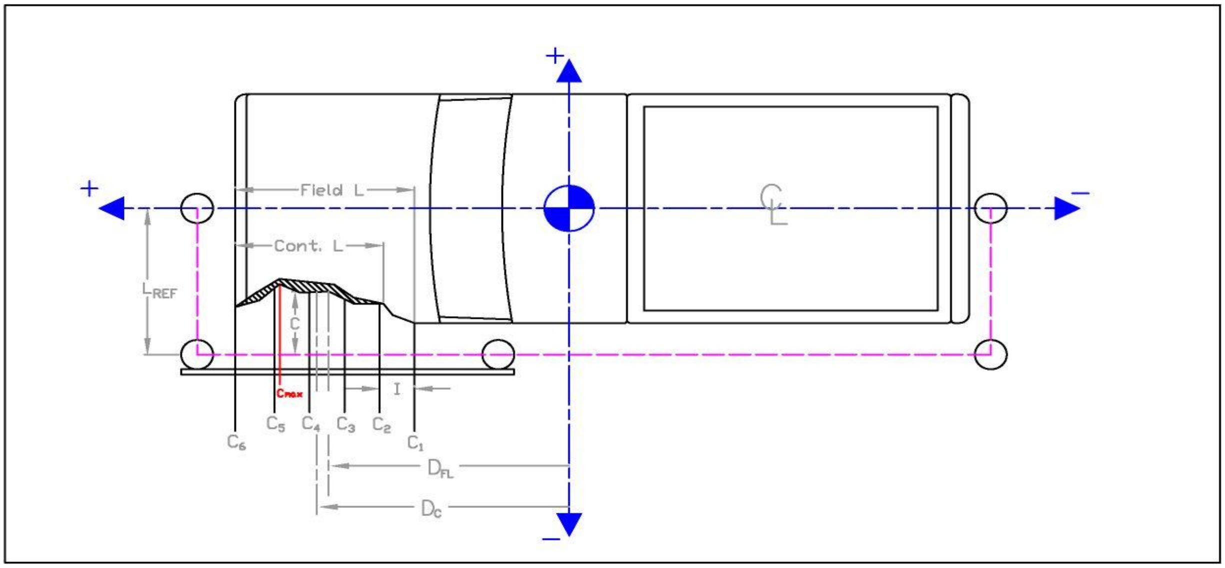
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)
NOTE: All values must be filled out above before crush measurements are filled out.

	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	-38	-(965)	22 1/2	(572)	4 1/3	(110)	NA	NA
C_2	28	(711)	-26 1/4	-(667)	7 1/8	(181)			16 4/7	(421)
C_3	10	(254)	-14 1/2	-(368)	4 7/8	(124)			4/5	(21)
C_4	6 1/4	(159)	-2 3/4	-(70)	4	(102)			-2	-(52)
C_5	7 3/4	(197)	9	(229)	4 3/8	(111)			-1	-(24)
C_6	9 1/4	(235)	20 3/4	(527)	5 3/4	(146)			- 4/5	-(21)
C_{MAX}	29	(737)	-26	-(660)	7	(178)			17 2/3	(449)

Figure E-5. Exterior Vehicle Crush (NASS) - Front, Test No. NJPCB-4

Date: 11/9/2016 **Test Name:** NJPCB-4 **VIN:** 1D7R1GP1BS554669

Year: 2011 **Make:** Dodge **Model:** Ram 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	46	(1168)
Total Vehicle Length:	230 3/4	(5861)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-12 4/5	-(325)
Width of contact and induced crush - Field L:	230 3/4	(5861)
Crush measurement spacing interval (L/5) - I:	46 1/8	(1172)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-12 4/5	-(325)
Width of Contact Damage:	230 3/4	(5861)
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	NA	NA	-128 1/4	-(3258)	33 1/2	(851)	2	(51)	NA	NA
C_2	NA	NA	-82 1/8	-(2086)	5 3/8	(137)			NA	NA
C_3	8 1/2	(216)	-36	-(914)	5 3/4	(146)			3/4	(19)
C_4	7 1/2	(191)	10 1/8	(257)	5 1/8	(130)			3/8	(10)
C_5	NA	NA	56 1/4	(1429)	5 1/8	(130)			NA	NA
C_6	33 1/4	(845)	102 3/8	(2600)	30	(762)			1 1/4	(32)
C_{MAX}	26	(660)	93	(2362)	8 3/8	(213)			15 5/8	(397)

Figure E-6. Exterior Vehicle Crush (NASS) - Side, Test No. NJPCB-4

Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. NJPCB-4

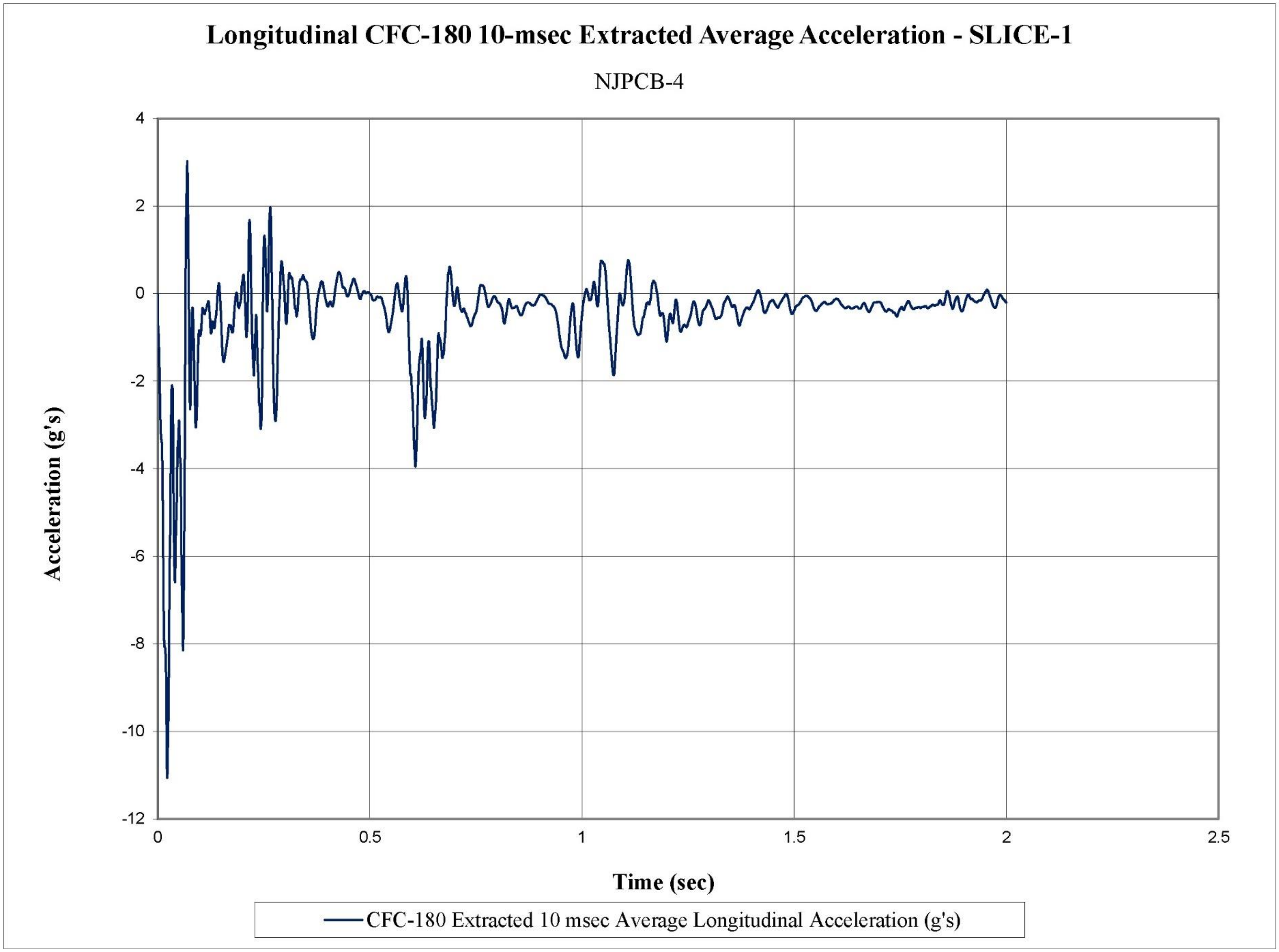


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. NJPCB-4

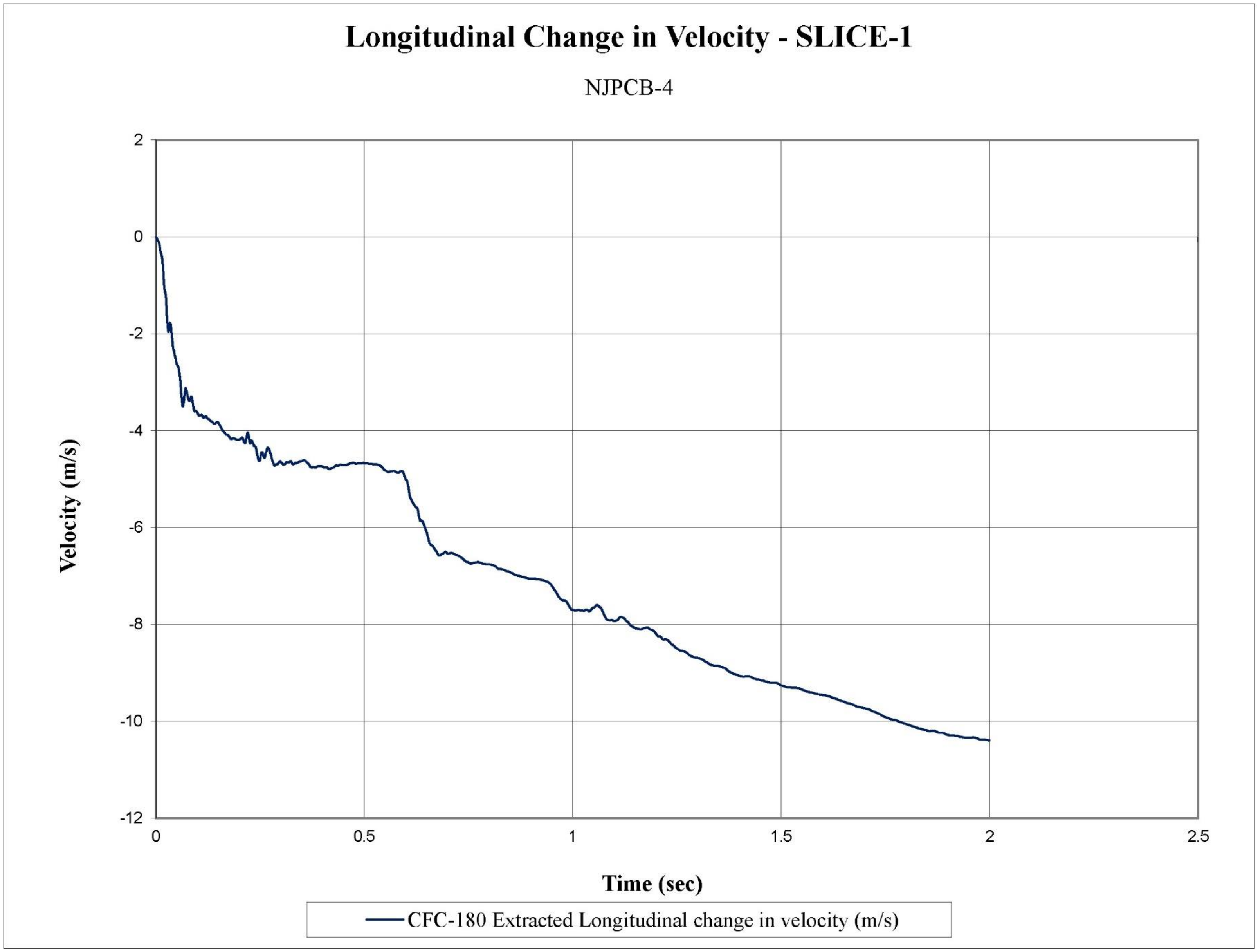


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. NJPCB-4

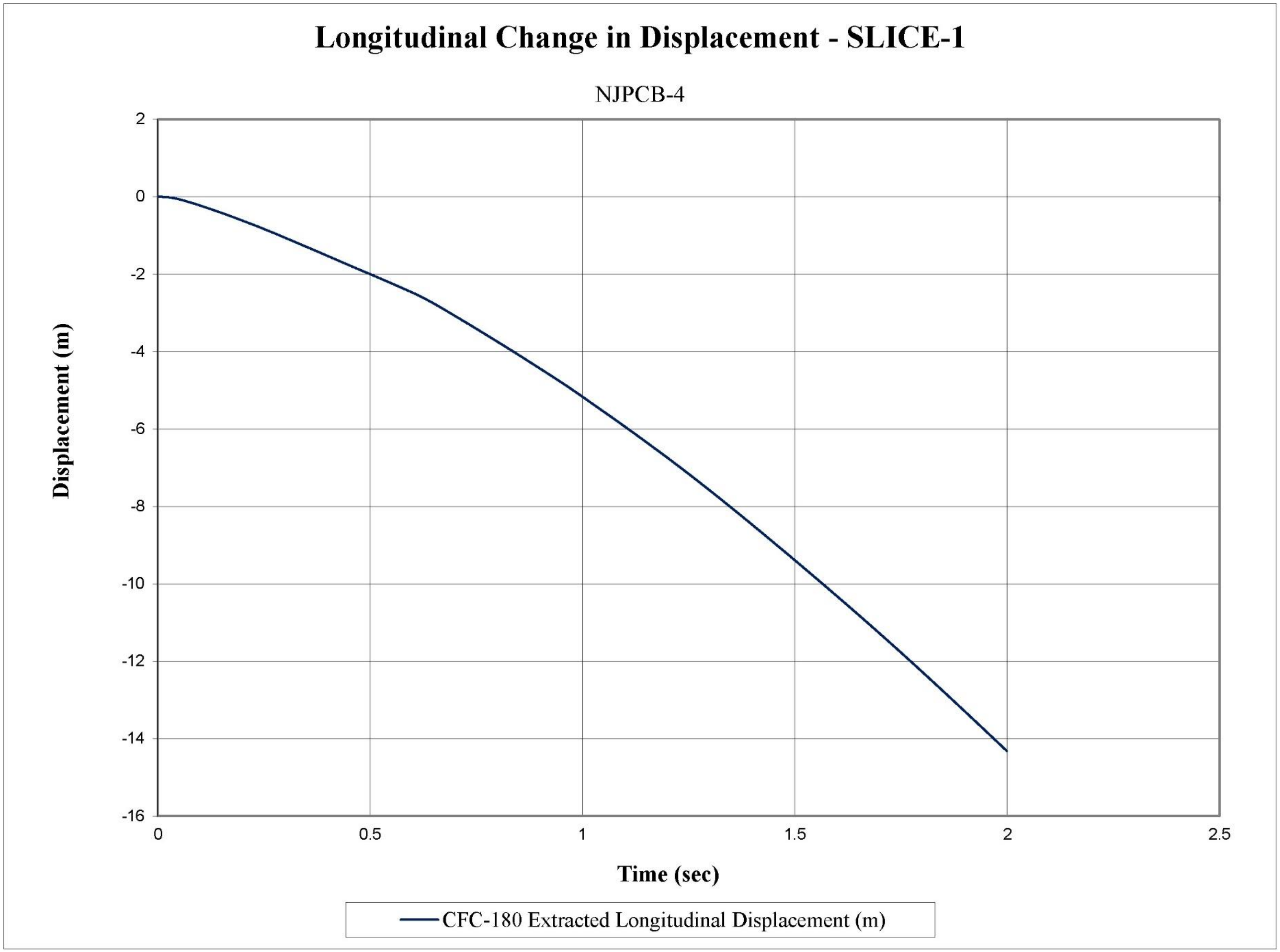


Figure F-3. Longitudinal Occupant Displacement (SLICE-1), Test No. NJPCB-4

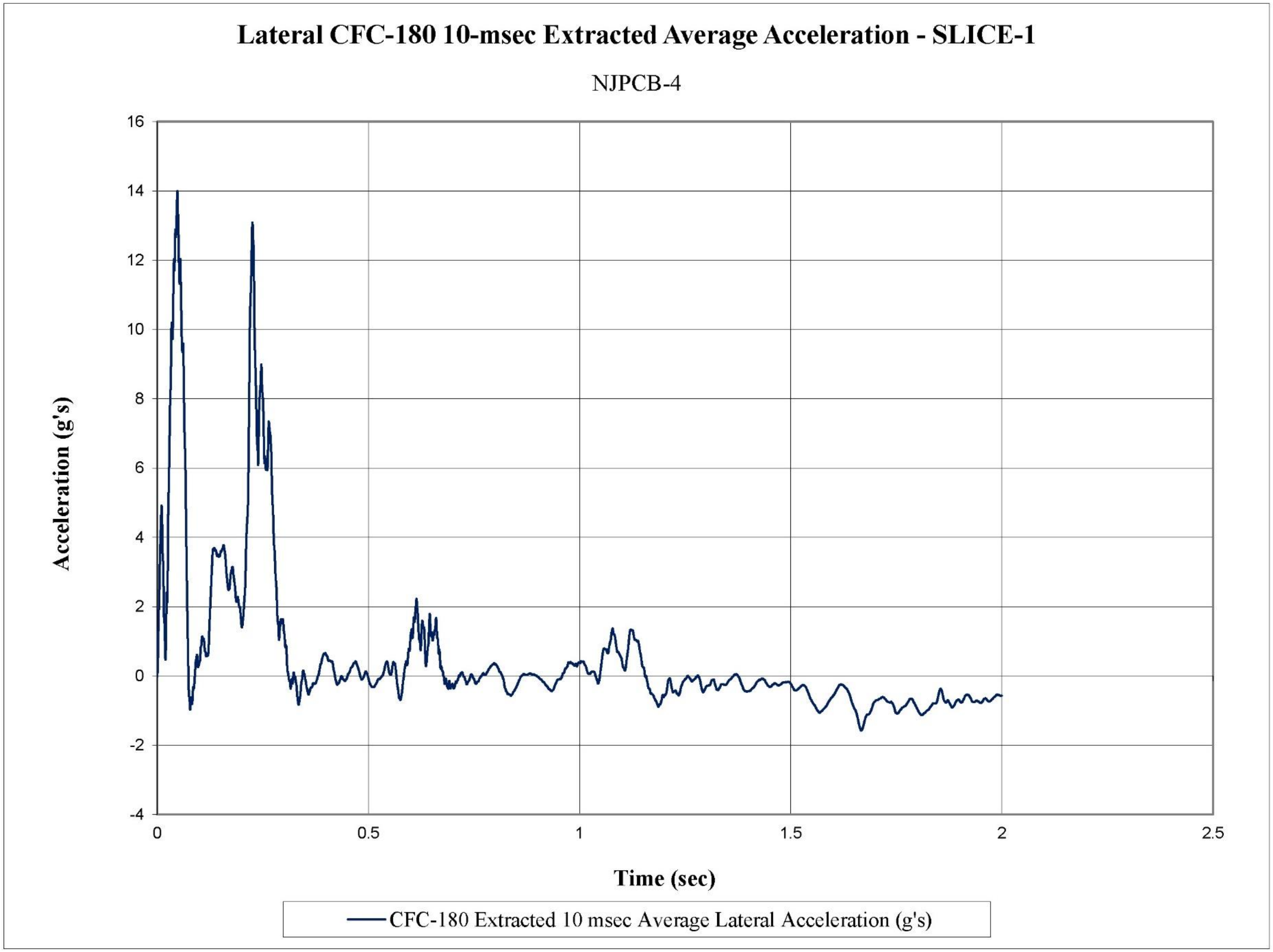


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. NJPCB-4

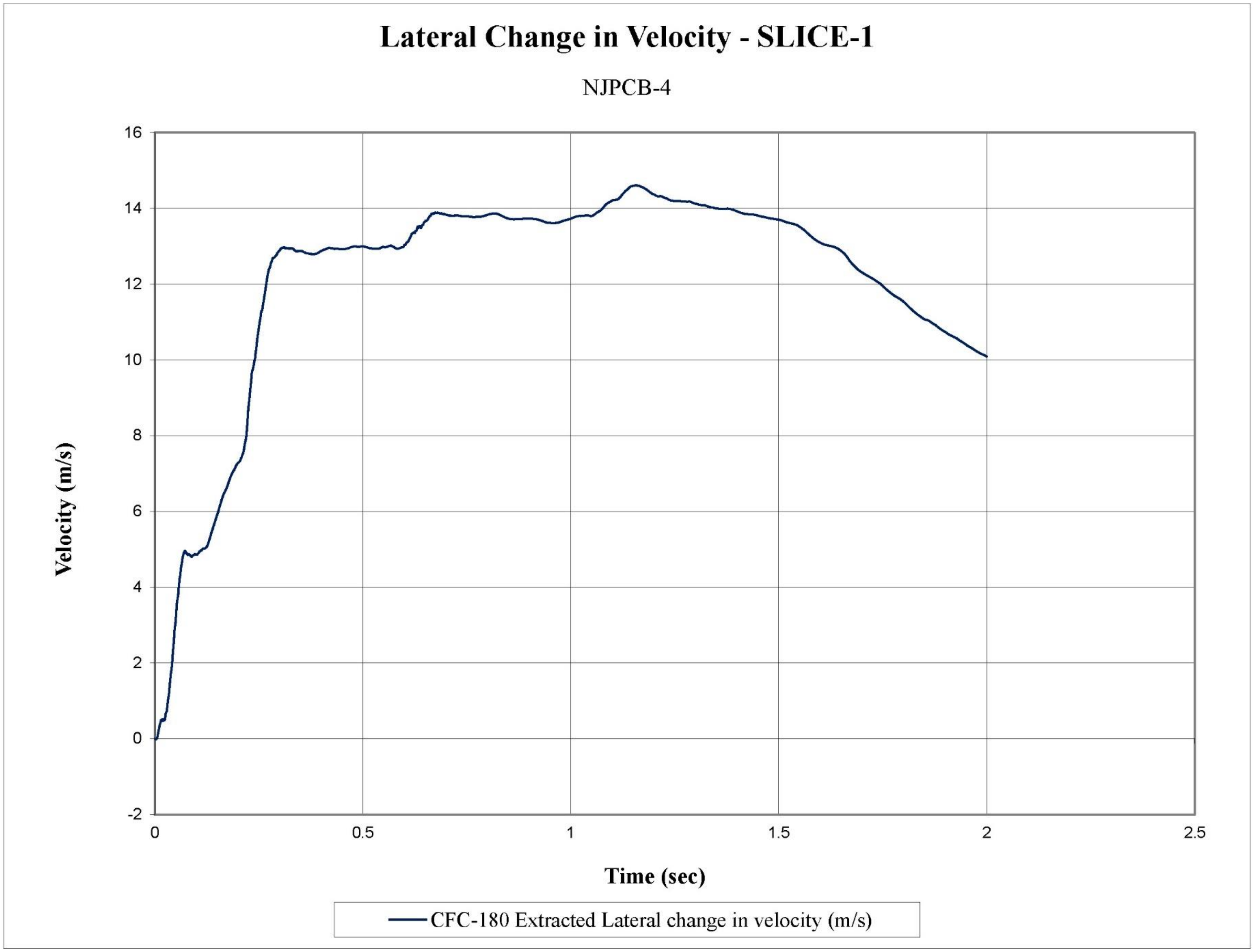


Figure F-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. NJPCB-4

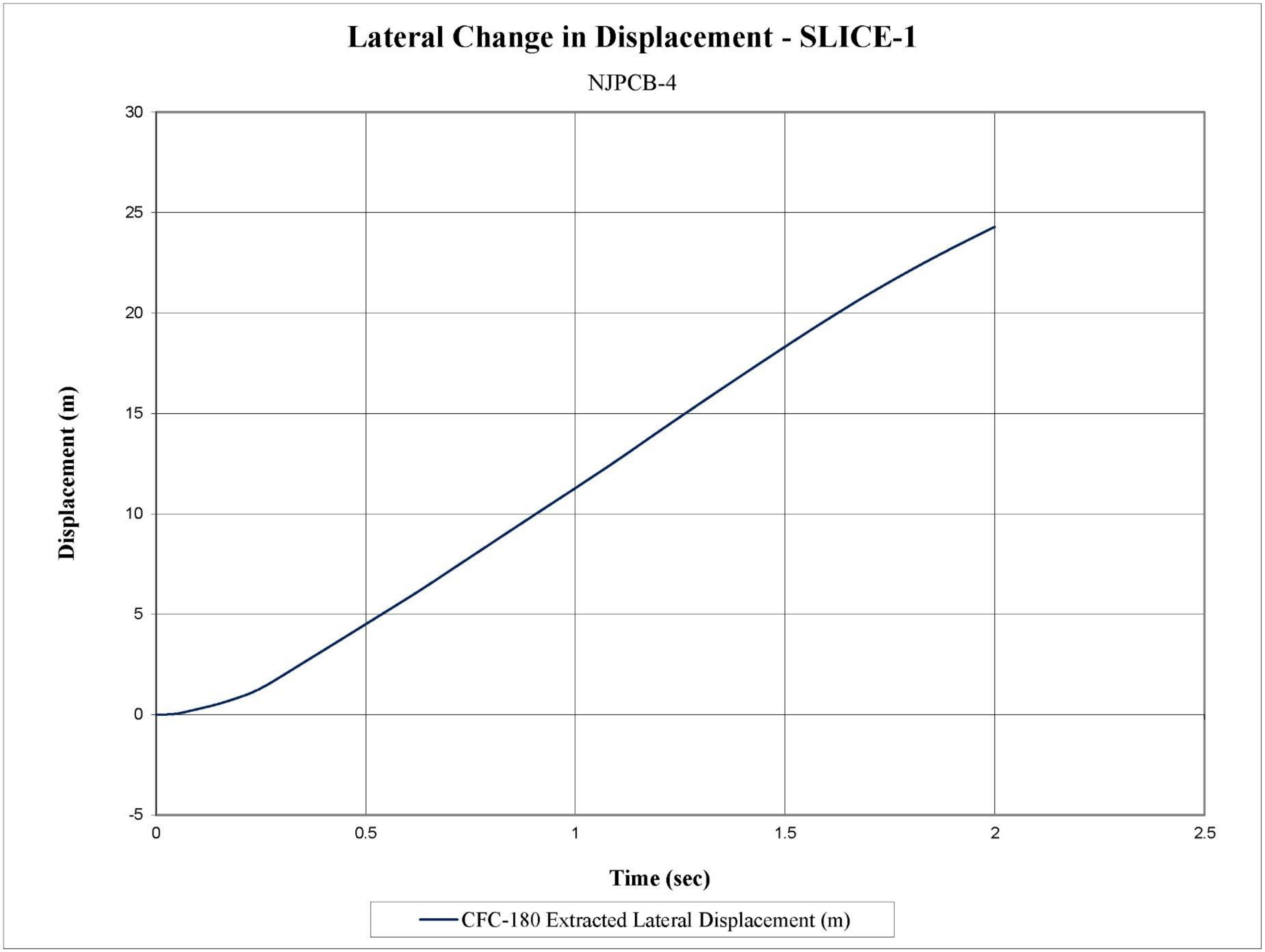


Figure F-6. Lateral Occupant Displacement (SLICE-1), Test No. NJPCB-4

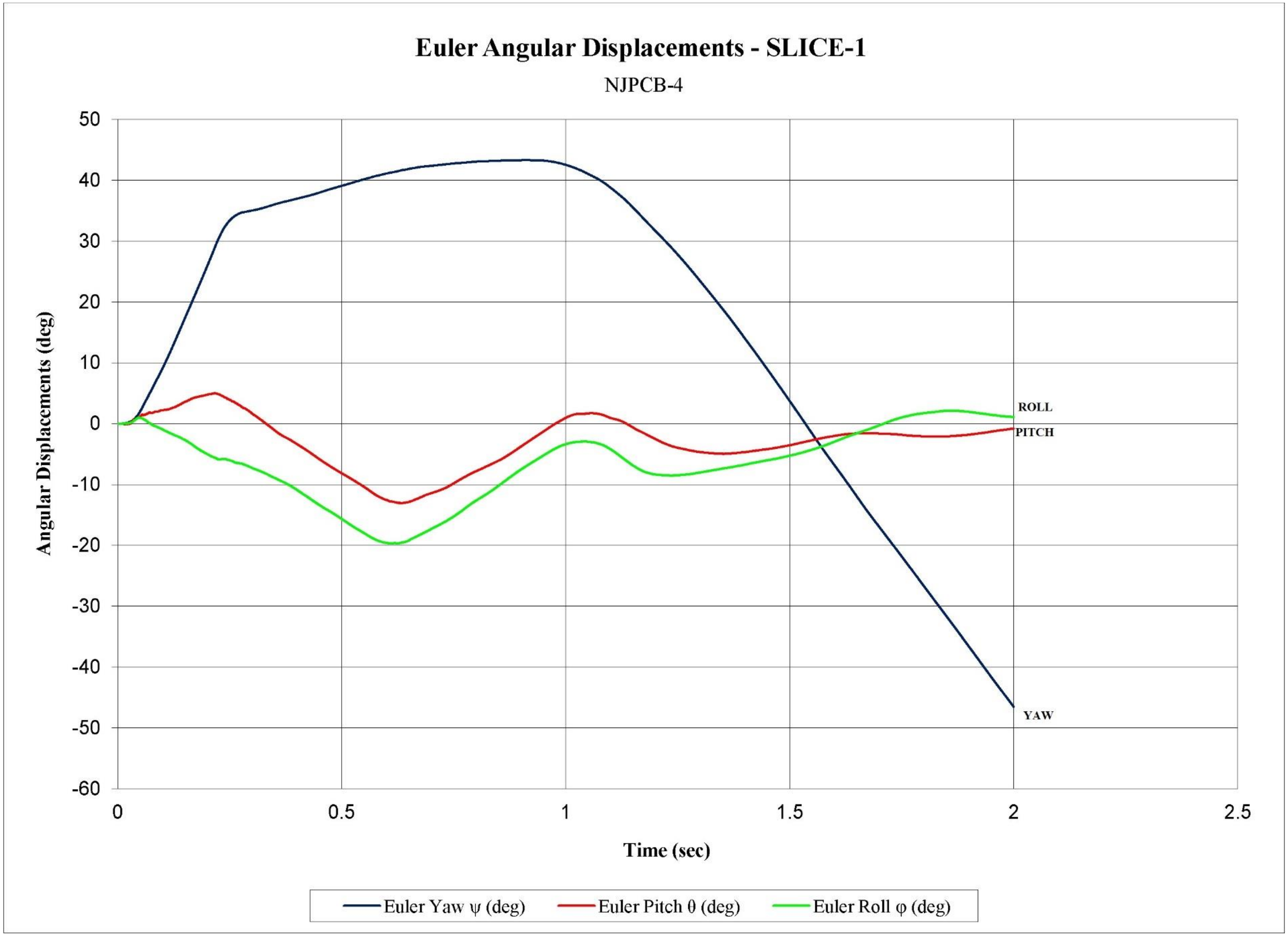


Figure F-7. Vehicle Angular Displacements (SLICE-1), Test No. NJPCB-4

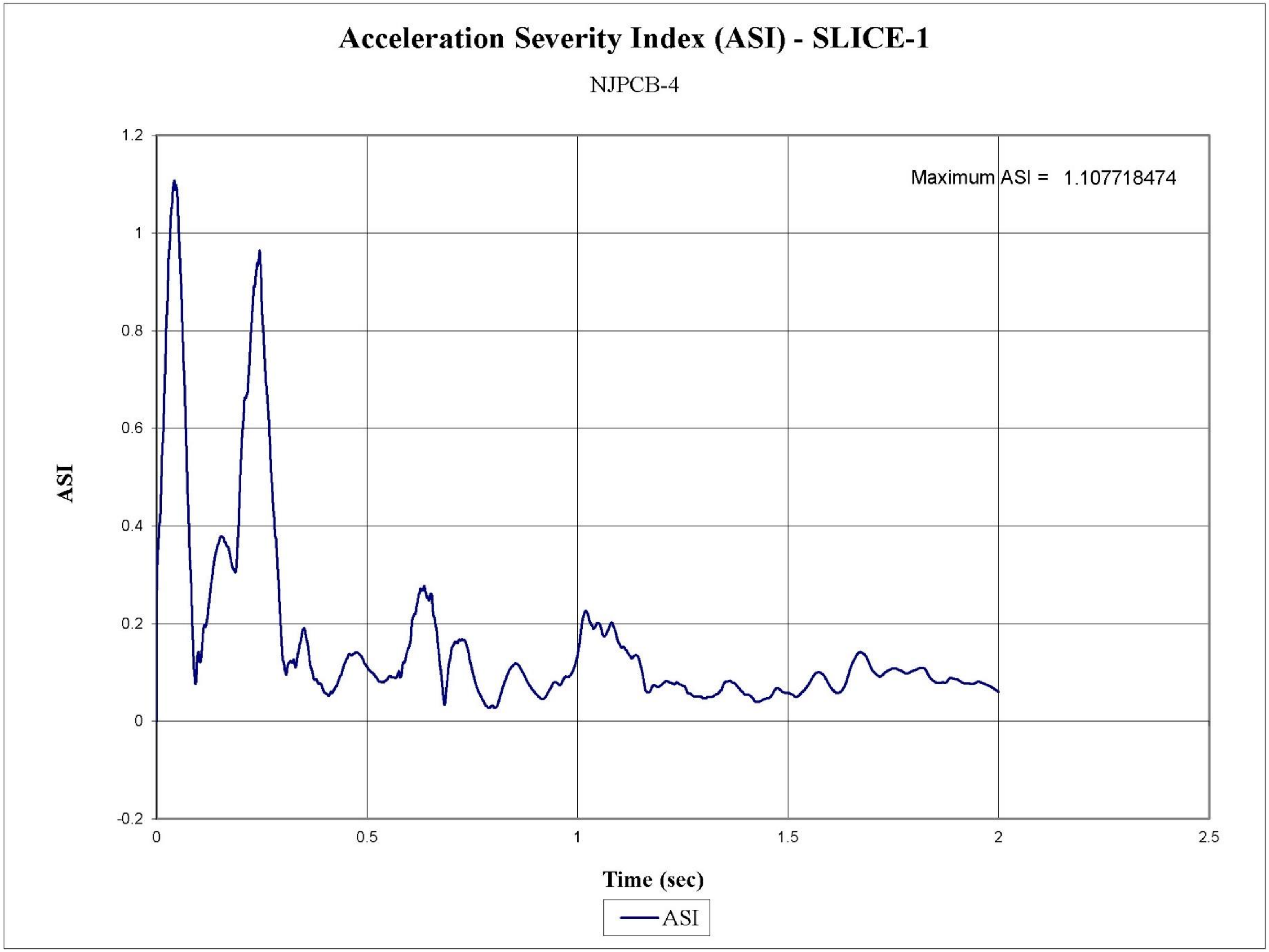


Figure F-8. Acceleration Severity Index (SLICE-1), Test No. NJPCB-4

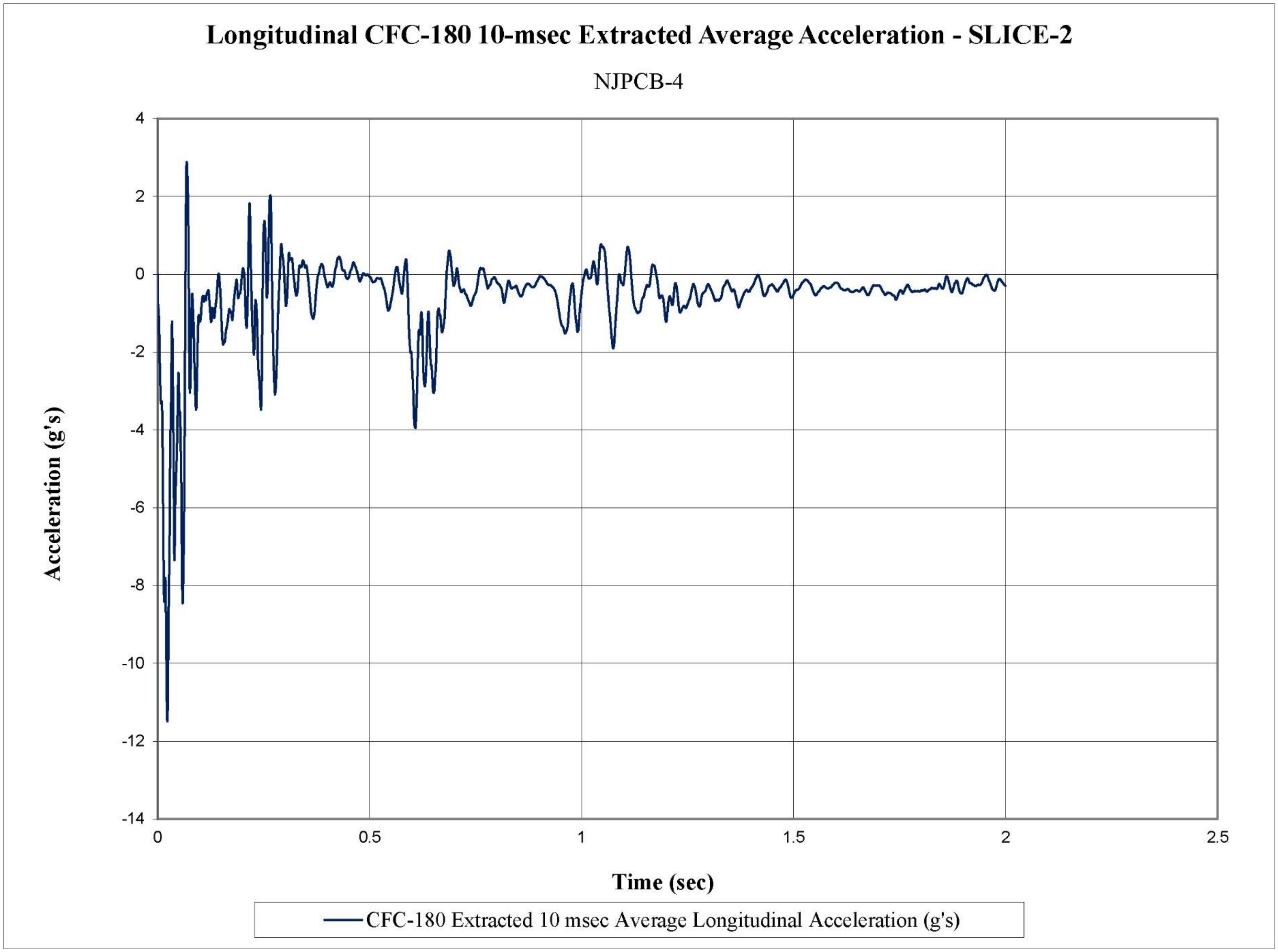


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. NJPCB-4

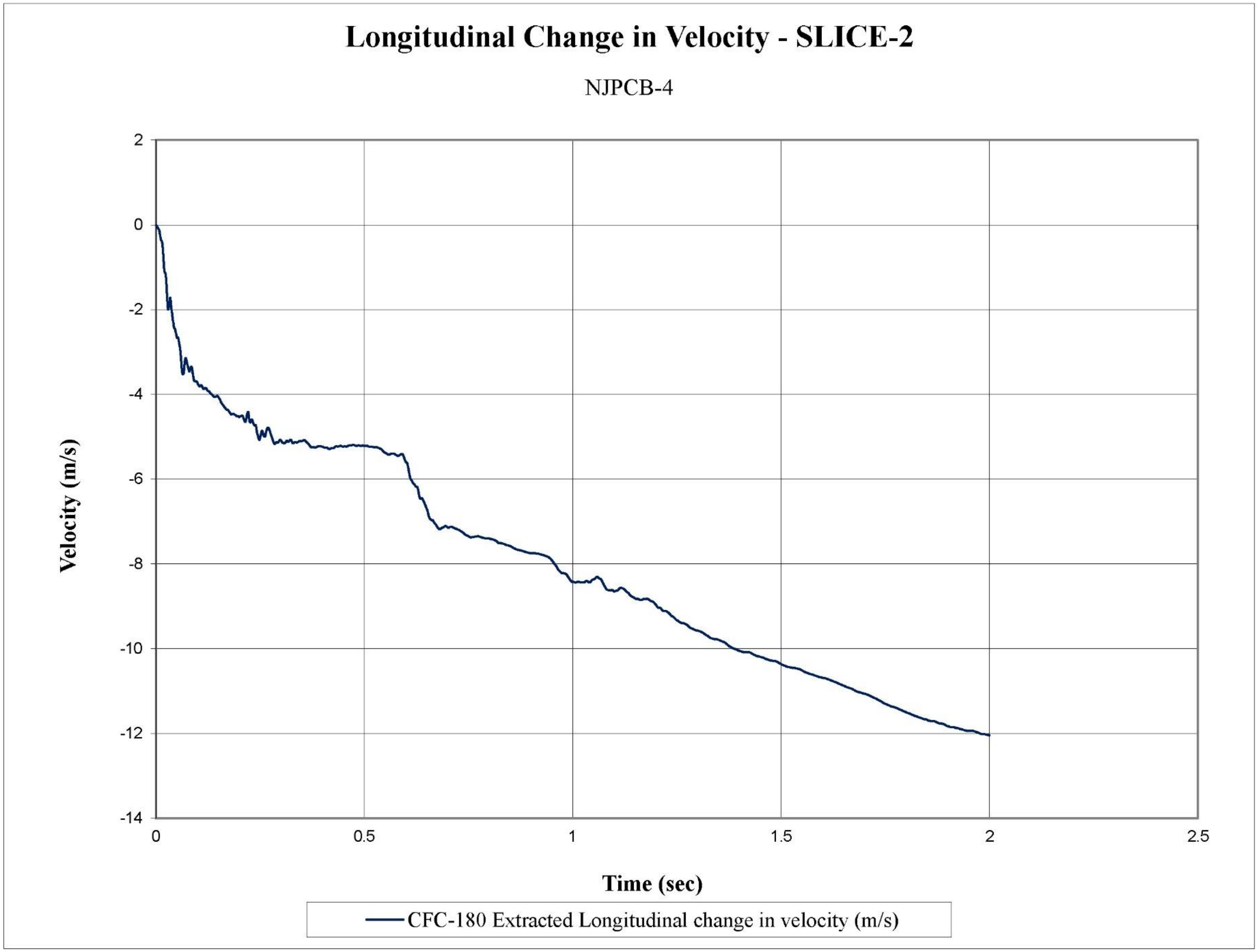


Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. NJPCB-4

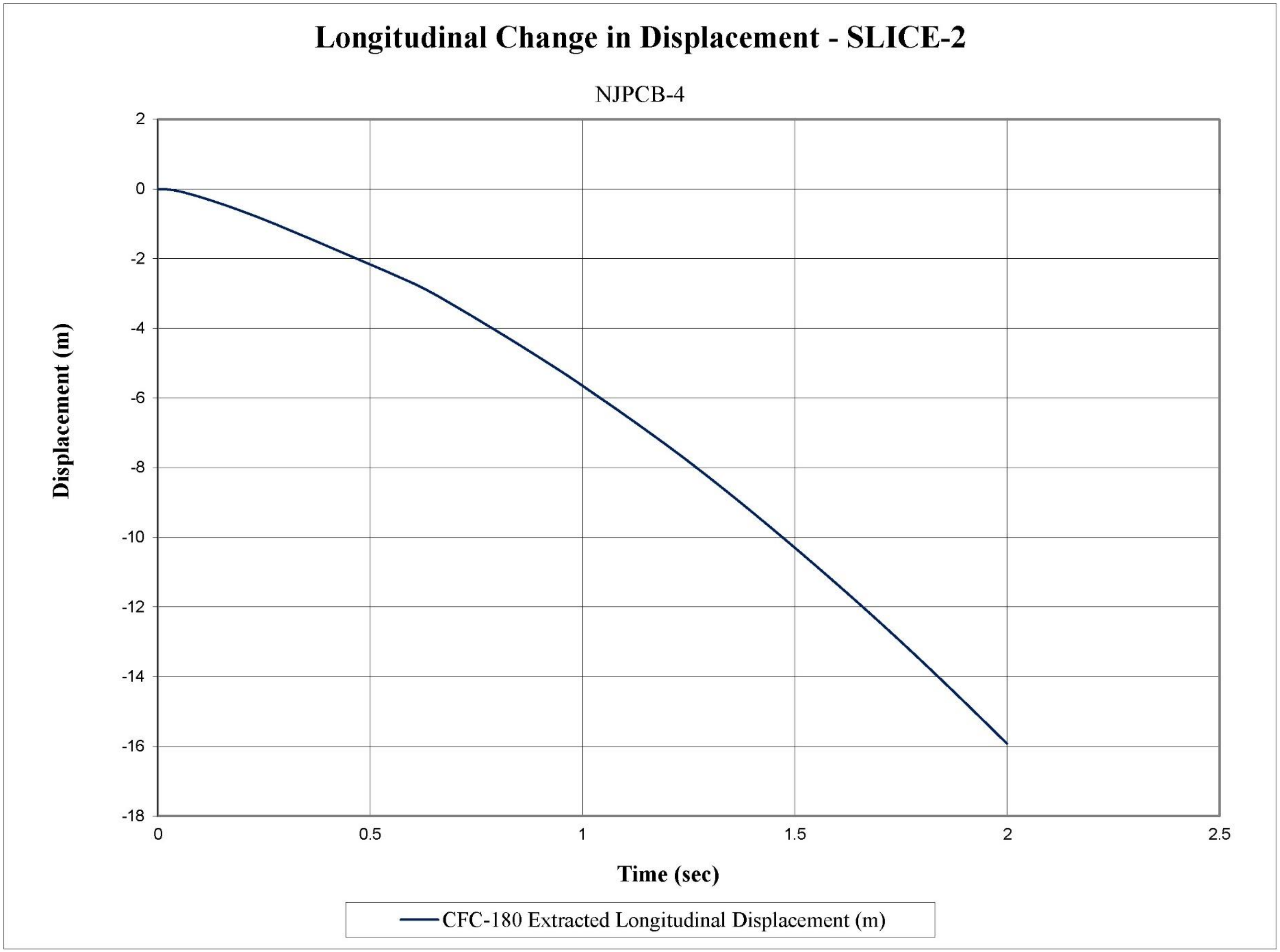


Figure F-11. Longitudinal Occupant Displacement (SLICE-2), Test No. NJPCB-4

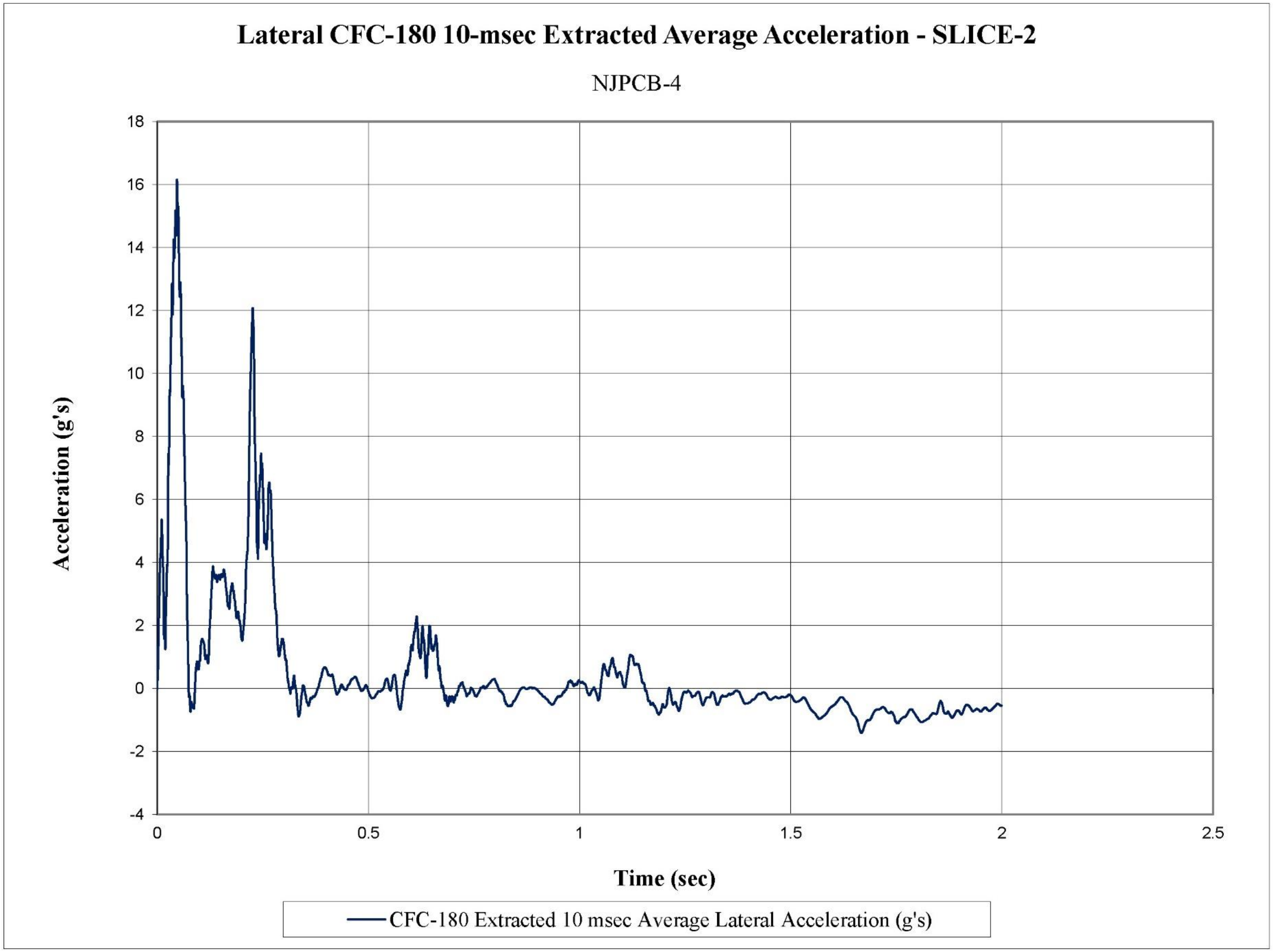


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. NJPCB-4

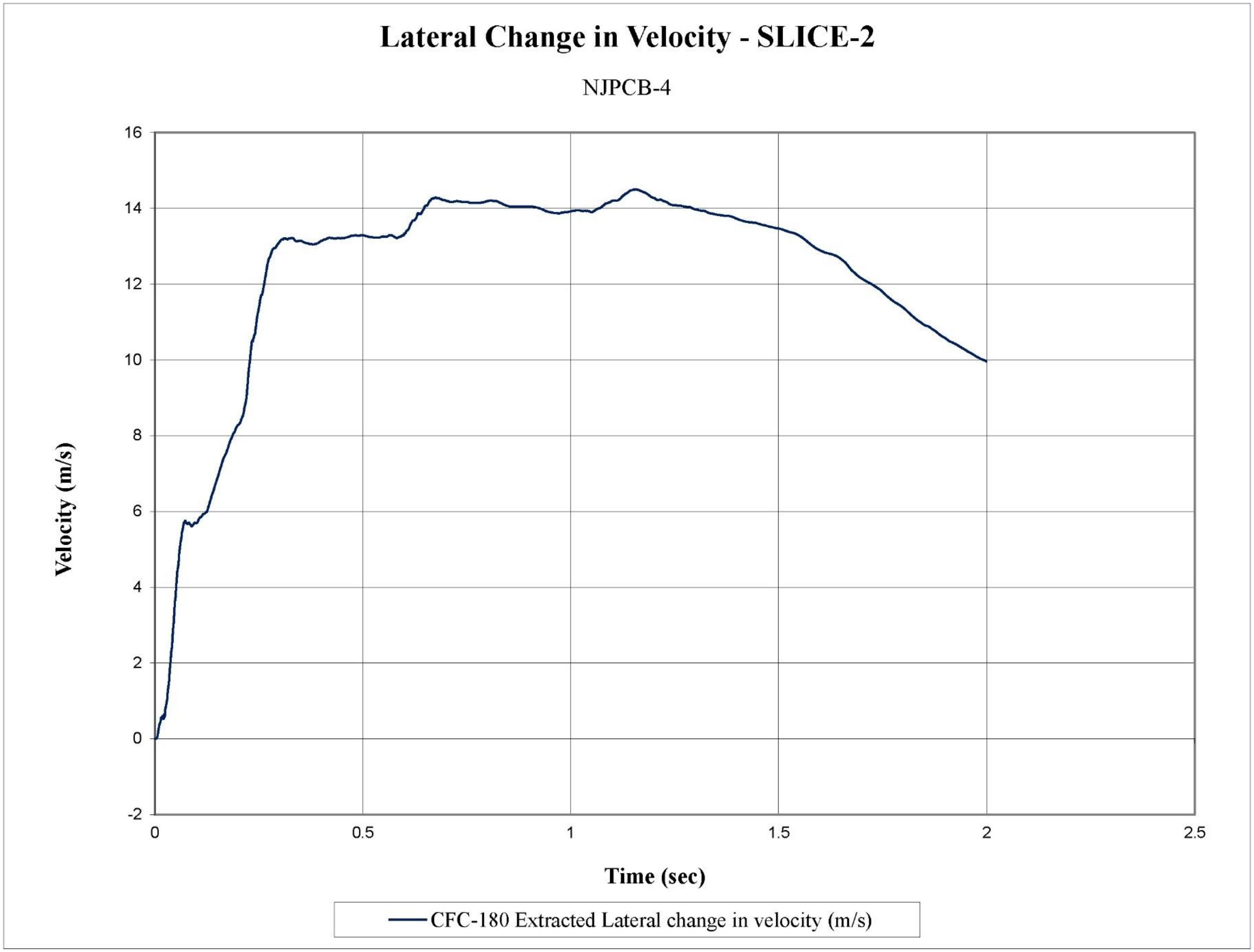


Figure F-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. NJPCB-4

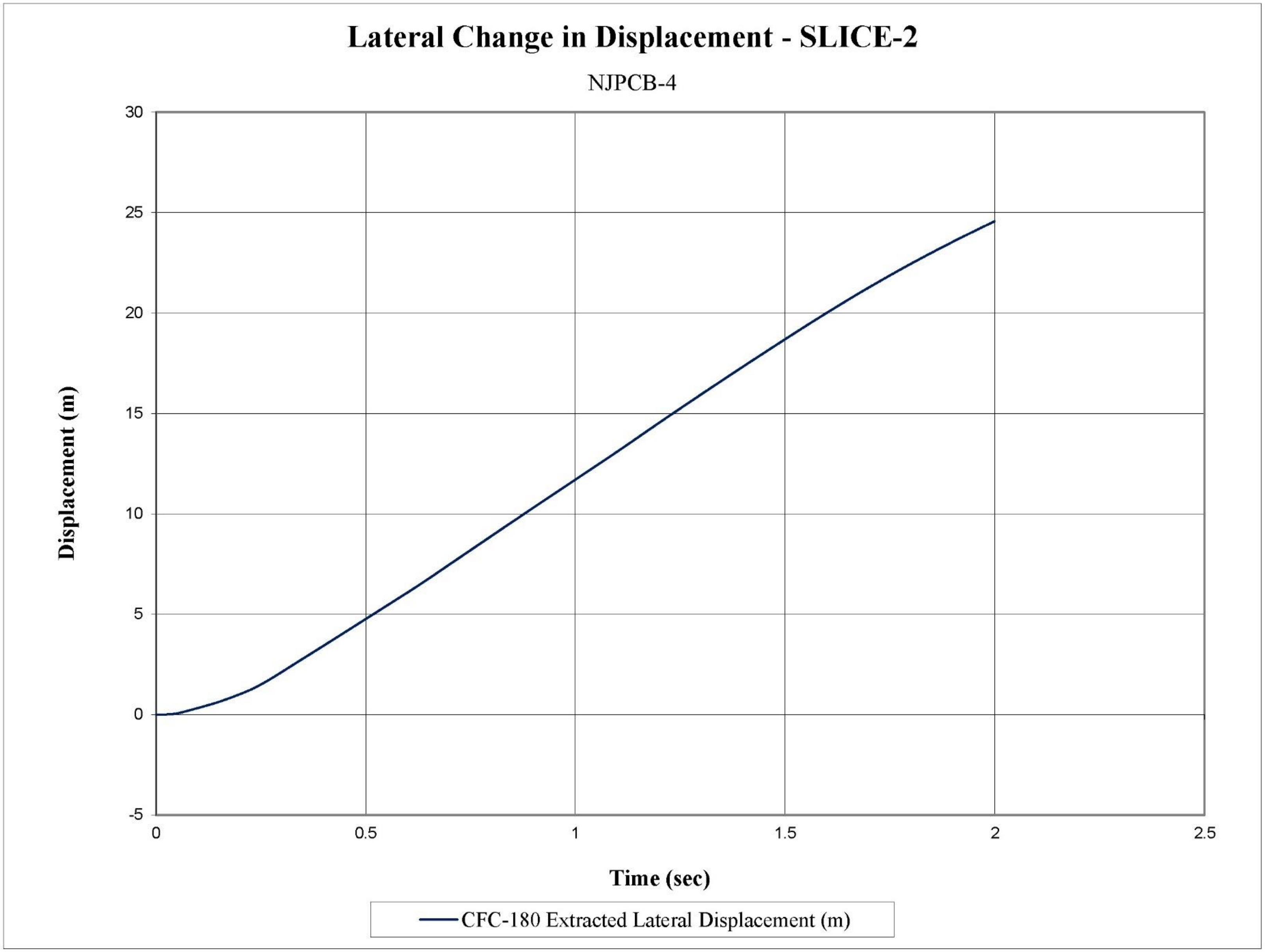


Figure F-14. Lateral Occupant Displacement (SLICE-2), Test No. NJPCB-4

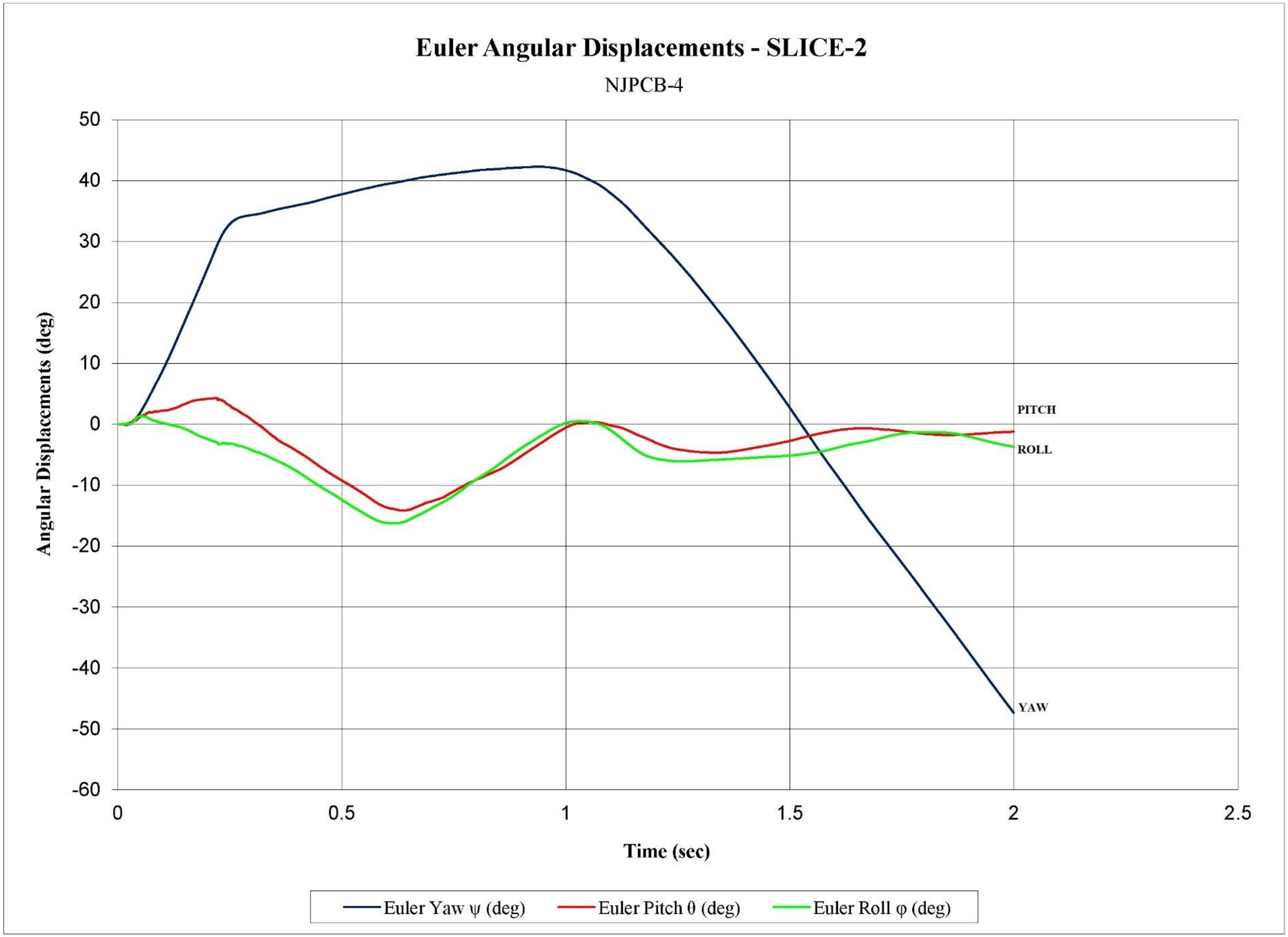


Figure F-15. Vehicle Angular Displacements (SLICE-2), Test No. NJPCB-4

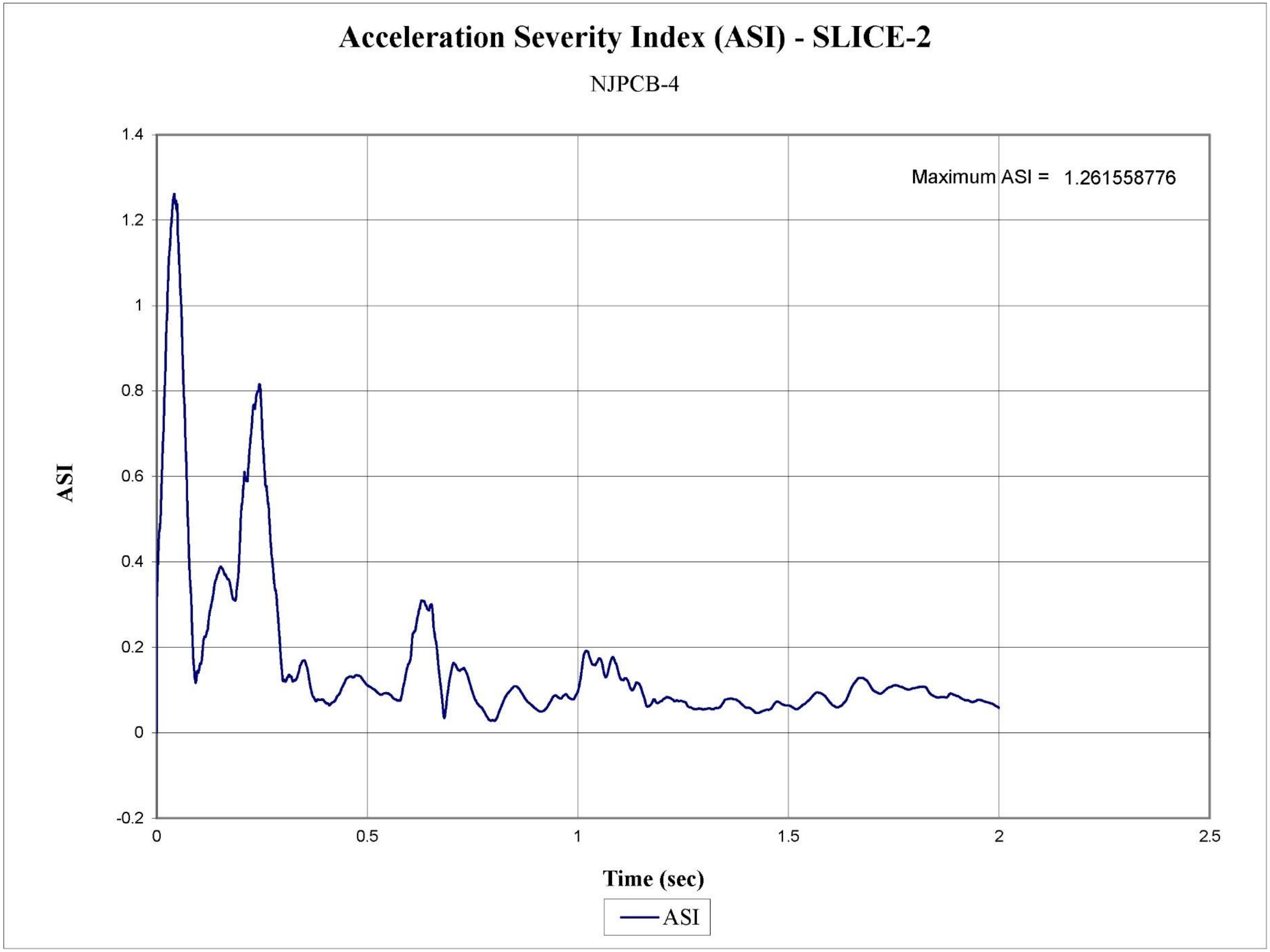


Figure F-16. Acceleration Severity Index (SLICE-2), Test No. NJPCB-4

END OF DOCUMENT