Research Project Number TPF-5(193) Supplement #153

MASH 2016 TEST LEVEL 3 EVALUATION OF MNDOT BICYCLE AND PEDESTRIAN RAIL

Submitted by

Miguel A. Hinojosa, B.S.M.E.
Graduate Research Assistant

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

Scott Rosenbaugh, M.S.C.E.
Research Engineer

Cody S. Stolle, Ph.D.
Research Assistant Professor

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

Jennifer D. Rasmussen, Ph.D., P.E.
Research Associate Professor

Joshua S. Steelman, Ph.D., P.E.
Associate Professor

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

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

MINNESOTA DEPARTMENT OF TRANSPORTATION
395 John Ireland Blvd
St. Paul, Minnesota 55155

MwRSF Research Report No. TRP-03-443-20

December 11, 2020

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
TRP-03-443-20		

4. Title and Subtitle MASH 2016 Test Level 3 Evaluation of MnDOT Bicycle and Pedestrian Rail	**5. Report Date** December 11, 2020
	6. Performing Organization Code
7. Author(s) Hinojosa, M.A., Faller, R.K., Rosenbaugh, S.K., Stolle, C.S., Bielenberg, R.W, Rasmussen J.D., Steelman, J.S., and Holloway, J.C.	**8. Performing Organization Report No.** TRP-03-443-20
9. Performing Organization Name and Address Midwest Roadside Safety Facility (MwRSF) Nebraska Transportation Center University of Nebraska-Lincoln	**10. Work Unit No.**
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	**11. Contract** TPF-5(193) Suppl. #153
12. Sponsoring Agency Name and Address Minnesota Department of Transportation 395 John Ireland Blvd St. Paul, Minnesota 55155	**13. Type of Report and Period Covered** Final Report: 2019-2020
	14. Sponsoring Agency Code TPF-5(193) Suppl. #153

15. Supplementary Notes

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

16. Abstract

The Minnesota Department of Transportation (MnDOT) desires to use a vehicle, bicycle, and pedestrian combination bridge railing system along pedestrian and bicycle bridge paths. A variation of the MnDOT combination bicycle and pedestrian railing was full-scale crash tested according to the Test Level 3 (TL-3) procedures described in the *Manual for Assessing Safety Hardware* (MASH 2016). The combination bicycle and pedestrian railing included a 32-in. tall concrete barrier consistent with the MnDOT "J"-shaped barrier and a steel rail constructed from upper and lower longitudinal rails, welded vertical spindles, and steel posts mounted to the backside of the concrete barrier. Two longitudinal cables were threaded through the longitudinal rail elements and anchored to the backside of the concrete barrier at the upstream and downstream ends. For the tested system, an existing New Jersey (NJ) safety shape concrete barrier was modified for use as a J-shape barrier, and the steel rail was fastened to the back-side face of the barrier using a welded post and plate assembly.

In full-scale crash test no. MNPD-3, the system was evaluated according to MASH test designation no. 3-11. The 2014 Dodge Ram 1500 crew cab pickup truck impacted the system 71¼ in. upstream from the centerline of post no. 4 with a speed of 63.4 mph at an angle of 25.3 degrees. The vehicle was successfully redirected, resulting in minimal plastic deformation to the steel rail and minimal scraping and gouging to the concrete barrier. This bicycle and pedestrian railing system minimized the potential for vehicle snag on the vertical spindles by welding them on the back-side faces of the top and bottom longitudinal tubular rails. The combination railing system was found to meet the AASHTO MASH 2016 TL-3 impact safety criteria.

17. Key Words	18. Distribution Statement
Highway Safety, Crash Test, Roadside Appurtenances, Compliance Test, MASH 2016, Test Level 3, TL-3, Bicycle Rail, Pedestrian Rail, Concrete Safety Shape, and Bridge Rail	No restrictions. This document is available through the National Technical Information Service. 5285 Port Royal Road Springfield, VA 22161

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	150	

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

DISCLAIMER STATEMENT

This material is based upon work supported by the Federal Highway Administration, U.S. Department of Transportation and the Minnesota 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 University of Nebraska-Lincoln, Minnesota Department of Transportation, nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, or regulation. Trade or manufacturers' names, which may appear in this report, are cited only because they are considered essential to the objectives of the report. The United States (U.S.) government, the State of Nebraska, and the State of Minnesota do not endorse products or manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

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

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Dr. John Reid, Professor.

ACKNOWLEDGEMENTS

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

Midwest Roadside Safety Facility
J.D. Reid, Ph.D., Professor
K.A. Lechtenberg, M.S.M.E., Research Engineer
M. Asadollahi Pajouh, Ph.D., P.E., Research Assistant Professor
A.T. Russell, B.S.B.A., Testing and Maintenance Technician II
E.W. Krier, B.S., Construction and Testing Technician II
S.M. Tighe, Construction and Testing Technician I
D.S. Charroin, Construction and Testing Technician I
R.M. Novak, Construction and Testing Technician I
T.C. Donahoo, Construction and Testing Technician I
J.T. Jones, Construction and Testing Technician I
J.E. Kohtz, B.S.M.E., CAD Technician
E.L. Urbank, B.A., Research Communication Specialist
Z.Z. Jabr, Engineering Technician
Undergraduate and Graduate Research Assistants

Minnesota Department of Transportation
Michael Elle, P.E., Design Standards Engineer
Paul Rowekamp, P.E., Bridge Standards and Research Engineer
Joe Black, P.E., Bridge Standards Unit
David Dahlberg, P.E., Bridge Design Manual & Policy Unit
Jihshya Lin, P.E., Bridge Evaluation and Fabrication Methods Engineer

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in.	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short ton (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5(F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela per square meter	cd/m^2
		FORCE & PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in.
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliter	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or “metric ton”)	1.103	short ton (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE & PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Background

The Minnesota Department of Transportation (MnDOT) currently uses a concrete barrier with an upper steel bicycle and pedestrian railing system, a test installation of which was constructed for research purposes at the Midwest Roadside Safety Facility (MwRSF) located in Lincoln, Nebraska, as shown in Figure 1. The crashworthiness of this bridge rail was previously recognized as meeting National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* [1], Test Level 4 (TL-4) safety performance standards. NCHRP Report No. 350 has since been superseded by the American Association of State Highway and Transportation Officials' (AASHTO) *Manual for Assessing Safety Hardware* (MASH 2016) [2]. Thus, MnDOT desired to evaluate the bridge rail according to the MASH 2016 impact safety standards. In an effort to encourage state departments of transportation (DOTs) and hardware developers to advance their designs, the Federal Highway Administration (FHWA) and AASHTO developed an implementation policy that included sunset dates for various categories of roadside safety hardware [3]. The new policy recommended that all bridge rails installed on federal-aid roadways were to be tested and evaluated under MASH 2016 by December 31, 2019. As a result, MnDOT began to plan for this crash testing effort in 2018.

MnDOT plans to use the combination bridge railing system under two different scenarios: (1) as a retrofit attachment to existing 32-in. tall, New Jersey and F-shaped concrete barriers, as shown in Figure 1, which is derived from the system that was developed and crash tested by MwRSF in 1998 [4] and shown in Figures 2 and 3 and (2) in combination with new installations of MASH 2016 TL-4 36-in. tall, single-slope concrete barriers. The bridge rail system attached to a concrete barrier is provided in MnDOT Standard Plan Fig. 5 – 397.158(A) (32-in. tall, J-shaped concrete barrier) [5], as shown in Figure 4.

Figure 1. 2020 MwRSF Combination Bicycle and Pedestrian Bridge Railing Installation

MnDOT updated its combination bridge railing system in two ways prior to conducting this research effort. In test no. MNPD-1 [4], the spindles were welded at the centerlines of the top face of the bottom tube rail and the bottom face of the top tube rail, as shown in Figures 3 and 5. Currently, the spindles are welded to the back-side face of both longitudinal rails, as shown in Figures 1, 4, and 6, which increased the lateral spindle setback by $1^{13}/_{16}$ in. The total lateral spindle setback is measured from the top front corner of the J-shape concrete barrier to the front face of the spindles. Additionally, the sloped end treatment on the upstream and downstream ends of the steel railing system was flattened from a 1V:1H slope (Figures 2 and 7) to a 1V:2H slope (Figures 4 and 7).

MnDOT installs the steel bicycle and pedestrian railing system on multiple concrete barrier shapes and heights. The 32-in. tall, New Jersey-shape concrete barrier was historically associated with higher Zone of Intrusion values (ZOIs) (or lateral vehicle extent over the barrier) during MASH crash testing as compared to observed ZOIs for 32-in. tall, F-shape and 36-in. tall, single slope concrete barriers [6]. Thus, the 32-in. tall, New Jersey (NJ) shape concrete barrier was identified as the critical concrete barrier for use in evaluating the bicycle and pedestrian railing system as it would accentuate the risk for vehicle snag on the upper steel railing, specifically the vertical support posts and spindles.

1.2 Research Objective

The objective of this research effort was to conduct a MASH 2016 TL-3 safety performance evaluation on MnDOT's bicycle and pedestrian railing system installed on a surrogate 32-in. tall, J-shape concrete barrier.

1.3 Scope

The research effort included the construction of a test installation consisting of a steel bicycle and pedestrian railing system mounted to an existing 32-in. tall, NJ-shape concrete barrier [7], which was modified to meet MnDOT’s J-shape concrete barrier dimensions. The test installation was full-scale crash tested and evaluated according to MASH 2016 test designation no. 3-11. The critical impact point was selected using MASH guidance [2], which is discussed herein. A summary of test results is provided herein, along with conclusions.

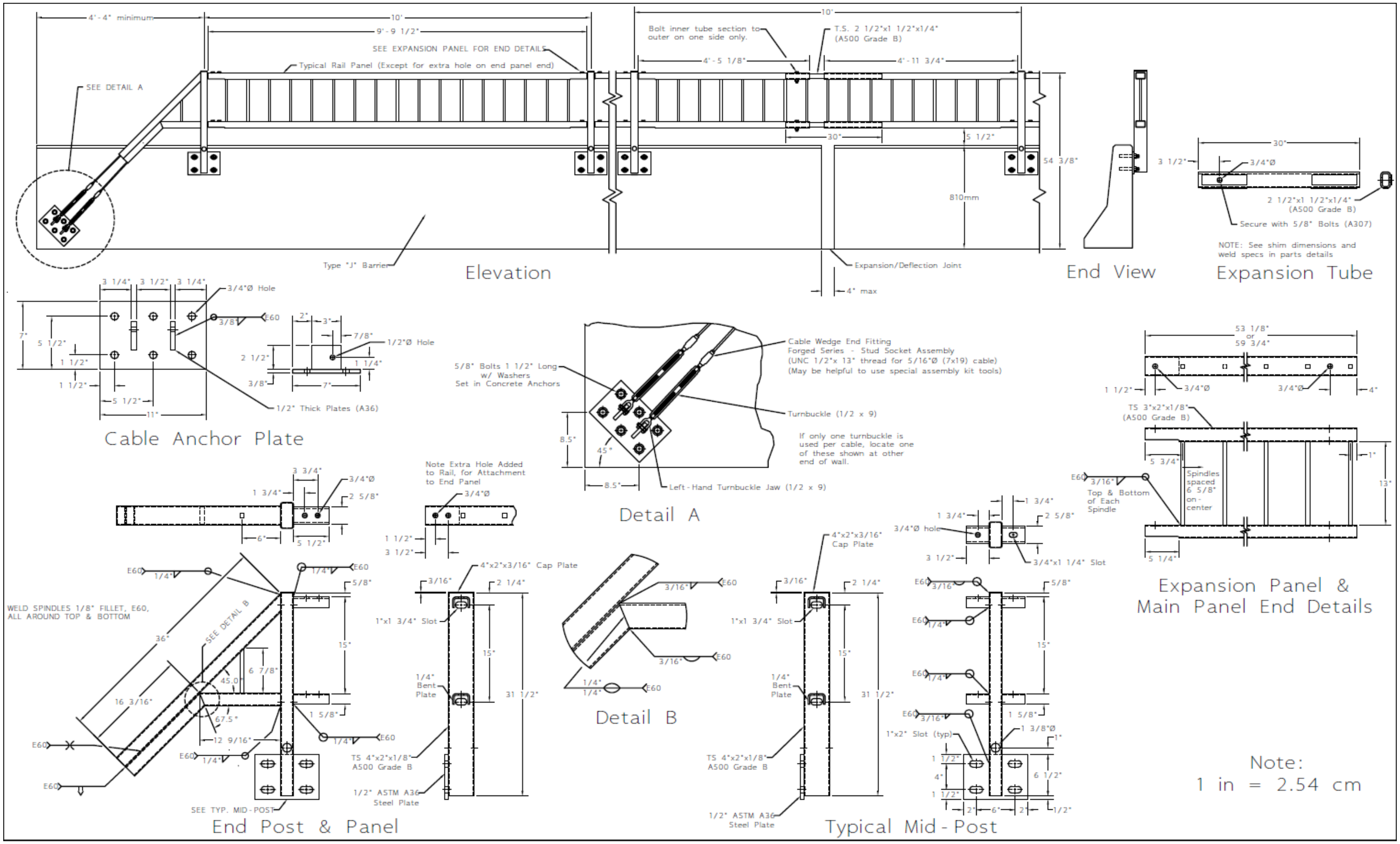


Figure 2. 1998 MwRSF Construction Plans [4], Test No. MNPD-1

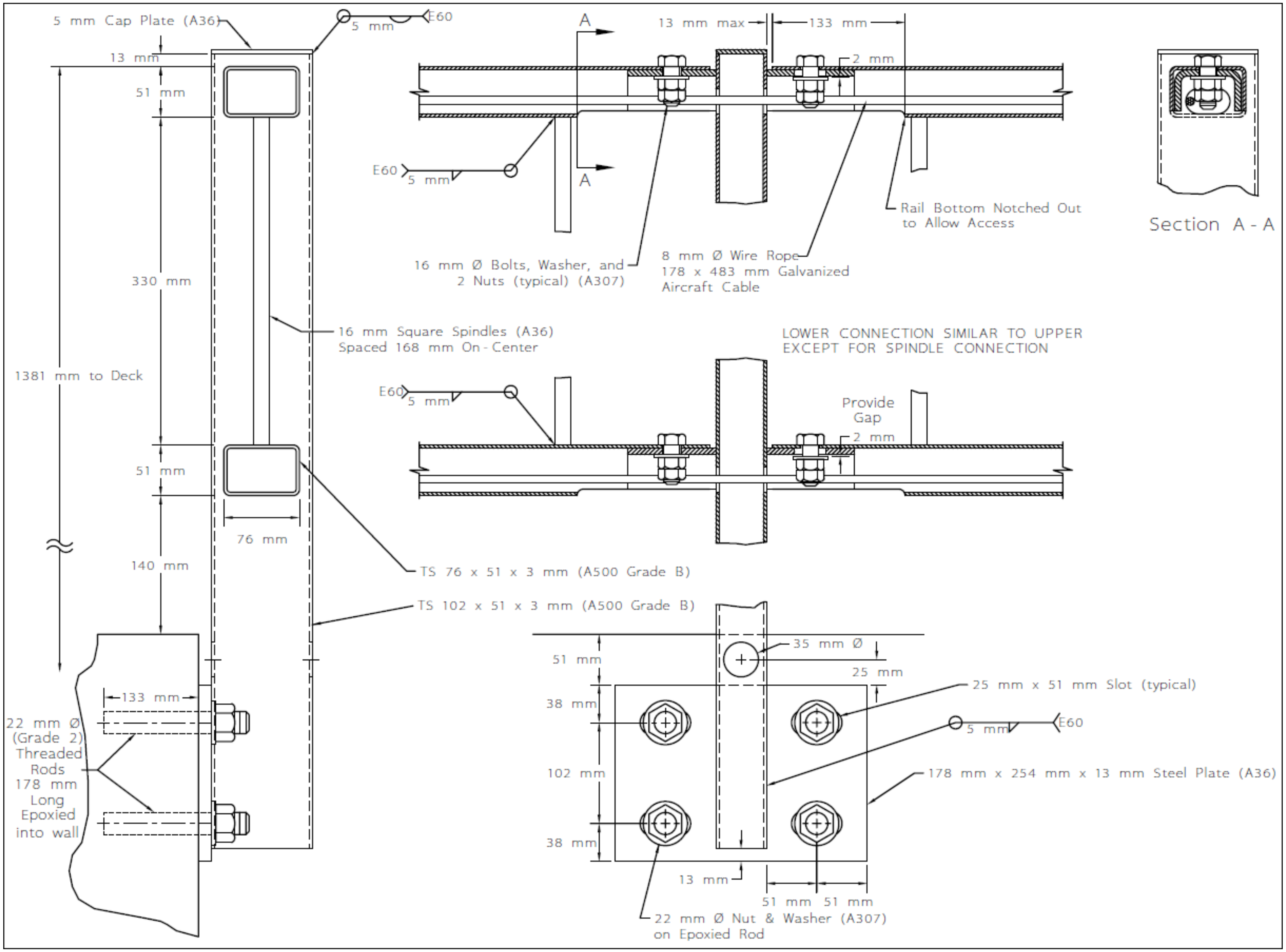


Figure 3. 1998 MwRSF Construction Plans [4], Test No. MNPD-1

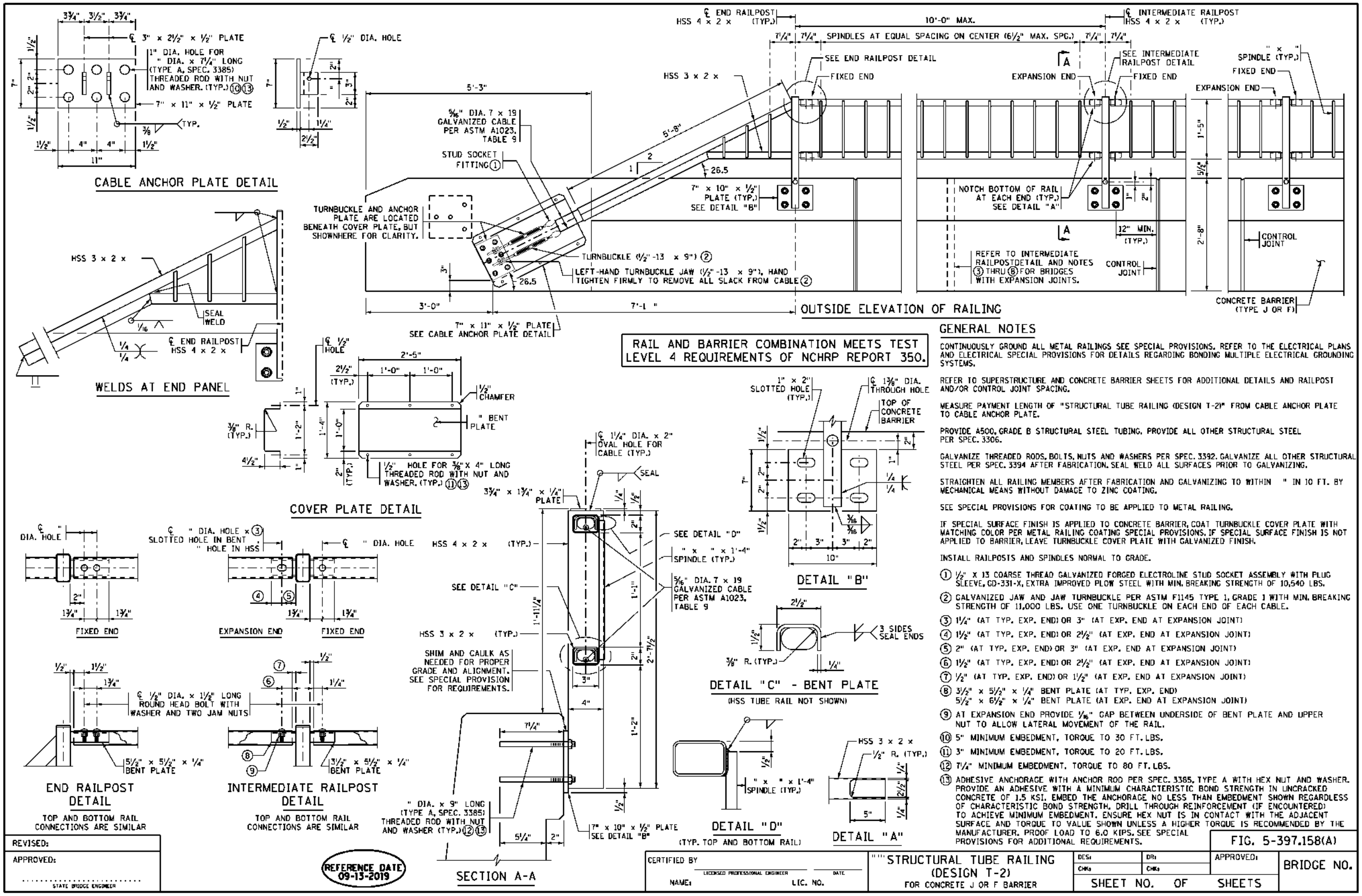


Figure 4. 2020 MnDOT Bicycle and Pedestrian Rail Standard Plans [5], Test No. MNPD-3

Figure 5. 1998 MnDOT Bicycle and Pedestrian Rail with Mid-Tube Spindle Positioning [4], Test No. MNPD-1

Figure 6. 2020 MnDOT Bicycle and Pedestrian Rail Spindle with Back of Tube Positioning, Test No. MNPD-3

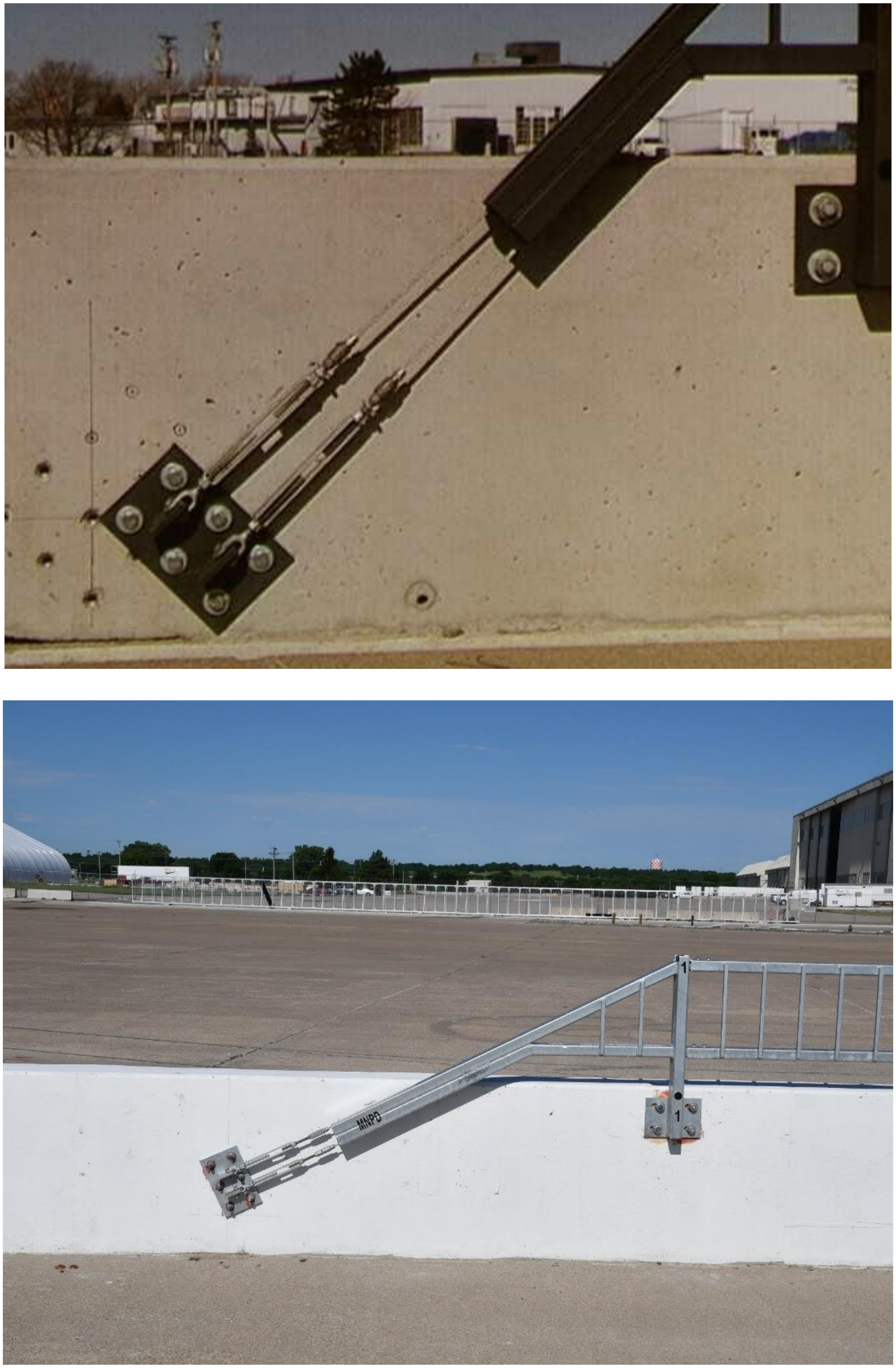


Figure 7. Slope End Section Comparison, Test Nos. MNPD-1 and MNPD-3

2 TEST REQUIREMENTS AND EVALUATION CRITERIA

2.1 Test Requirements

Longitudinal barriers, such as bicycle and pedestrian rails, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the 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 [2]. According to TL-3 of MASH 2016, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 1. Note that there is no difference between MASH 2009 [8] and MASH 2016 [2] for longitudinal barriers, such as the system tested in this project, except that additional occupant compartment deformation measurements, photographs, and documentation are required by MASH 2016.

Table 1. MASH 2016 TL-3 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight lb	Impact Conditions		Evaluation Criteria [1]
				Speed mph	Angle degrees	
Longitudinal Barrier	3-11	2270P	5,000	62	25	A,D,F,H,I
Longitudinal Barrier	3-10	1100C	2,425	62	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2.

MASH 2016 test designation no. 3-10, which involves an 1100C vehicle, was deemed unnecessary or non-critical for two reasons. First, this NJ-shape concrete barrier passed test no. 2214NJ-1 under the test designation no. 3-10 impact conditions as a part of NCHRP Project No. 22-14(2) [7]. The 1100C vehicle impacted 18 ft – 6 in. downstream from the upstream end of the New Jersey concrete barrier at 60.8 mph and at a 26.1-degree angle. The New Jersey barrier sustained no permanent set deflection, no dynamic deflection, and a working width of approximately 16 in. The vehicle exited the barrier at 49.3 mph and at a 6.6-degree angle. The occupant risk summary for test no. 2214NJ-1 consisted of occupant impact velocities (OIVs) of 16.47 ft/s longitudinally and 35 ft/s laterally, and occupant ride-down accelerations (ORAs) of 5.49 g’s longitudinally and 8.08 g’s laterally [7]. Second, the ZOI value for test no. 2214NJ-1 was approximately 7 in. MnDOT’s J-shape concrete bridge railing has a top width of 9¼ in. with the nearest exposed metal railing component (i.e., support posts) positioned 9¾ in. away from the top front corner of the barrier. Consequently, no 1100C small car contact would occur with the attached bicycle and pedestrian railing system. Therefore, test no. 2214NJ-1 was deemed sufficient for use as a test designation no. 3-10 evaluation of the MnDOT bicycle and pedestrian railing system installed on a J-concrete barrier and would not need to be rerun. Therefore, only test designation no. 3-11 was deemed critical for evaluating the MASH 2016 TL-3 safety performance of the MnDOT bicycle and pedestrian railing system installed on a J-shape concrete barrier.

Table 2. MASH 2016 Evaluation Criteria for Longitudinal Barrier

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

2.2 Critical Impact Point

In MASH 2016 [2], the impact point refers to the location at which the test vehicle first contacts the test article. The impact point for a redirective, longitudinal barrier can affect its overall safety performance. The potential for vehicle instability, rollover, snag, pocketing, excessive interior occupant deformation, elevated occupant risk, test article penetration, and structural failure is often associated with the selection of the impact point used to evaluate the barrier system. Within practical limits, the impact location should be selected to represent the point along the barrier system that will maximize the risk for test failure. The impact location that maximizes the risk of test failure is known as the critical impact point (CIP).

The MnDOT bridge railing system is configured with a lower, rigid, reinforced-concrete barrier along with an upper, metal, beam and post railing. MASH 2016 specifies that post-and-beam longitudinal barriers may have two potential CIPs: one associated with wheel snagging and pocketing on a post (i.e., hard point) and another that induces maximum loading to a critical portion of the system, such as a rail splice [2]. For the MnDOT bridge railing system, wheel snag on lower posts would not be a concern as no openings exist within the 32-in. tall concrete barrier. As such, maximum loading to the rigid concrete barrier may more likely be associated with an increase in vehicle deformation. For shorter width concrete barrier, the engine hood and front fender panel may extend over the top of the rigid barrier, where vehicle-to-barrier contact may occur if the metal railing system is located near the front face of the barrier. If the upper metal railing is located farther away from the front face of the rigid concrete barrier, then additional longitudinal distance and time may be appropriate to allow for the vehicle to maximize its lateral extent over the top of the barrier. At this point, the vehicle's upper structure may be able to contact the metal structure, snag on vertical elements, and laterally load elements at splice locations.

When splices are coincident with a hard point, such as at a vertical support post, a single test can be conducted to evaluate both critical points. If splices are spaced away from a hard point, it may be necessary to conduct two full-scale crash tests with a particular vehicle to properly evaluate CIPs. However, it should be noted that only the 2270P vehicle crash test needs to be run as it produces the greatest splice loading and hence the greatest chance for structural failure. Due to the fact that rail splices within the new bicycle and pedestrian railing are located near the vertical support posts, it was believed that vehicle snagging on a post, which is near a splice, as well as maximum loading on a post or splice above the parapet could be evaluated with one test with the 2270P passenger vehicle.

The CIP for a rigid barrier under test designation no. 3-11 is noted as 4.3 ft (51.2 in.) upstream from the component that maximizes the snag severity of the railing system, as provided in Table 2.7 of MASH 2016 [2]. For the MnDOT bicycle and pedestrian railing system, a post was determined to be the component that maximizes the snag severity. Each metal post and mounting plate assembly is attached to the back-side vertical face of the concrete barrier, which provides a lateral offset of the 9¾ in. between the front barrier face and the front face of each post. As noted above, it may be prudent to provide additional longitudinal distance and time for the vehicle to maximize its lateral extent over the top of the barrier. Using a 25-degree impact angle in combination with a 9¾-in. lateral post offset, the additional longitudinal distance to maximize lateral vehicle extent over the top of barrier would be approximately 20.9 in. When combining the two lengths of 51.2 in. and 20.9 in., one would arrive at a CIP distance of approximately 72.1 in., which would be measured upstream from the upstream face of a vertical support post. Since the vertical support posts are 2 in. wide, the CIP distance to the centerline of a post would actually be around 73.1 in. Based on an approximate calculation early in the project, the CIP for test no. MNPD-3 was chosen to be $73^{3}/_{16}$ in., which was measured upstream from the centerline of post no. 4.

For comparison purposes, test no. MNPD-1 [4] was conducted on the original combination bridge railing system according to TL-3 of the NCHRP Report No. 350 impact safety standards [1]. For test no. MNPD-1 with a 2000P pickup truck (test designation no. 3-11), the CIP was 78.7 in. upstream from the centerline of post no. 4, which is very similar to the CIP selected for use in the MASH 2016 crash testing program with a 2270P pickup truck.

2.3 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 bridge railing to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 2 and defined in greater detail in MASH 2016. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in MASH 2016.

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

3 DESIGN DETAILS – TEST NO. MNPD-3

The test installation consisted of a 100-ft long concrete barrier with a back-mounted, bicycle and pedestrian bridge railing system. The test plan and construction drawings are shown in Figures 8 through 32. Photographs of the test installation are shown in Figures 33 through 38. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix A.

For the test no. MNPD-3 crash testing program, the modified reinforced-concrete barrier was consistent with MnDOT's 32-in. tall, J-shape concrete barrier with a 9¼-in. top width and an 18¼-in. bottom width, as shown in Figure 9. All steel reinforcing bars conformed to ASTM A615 Grade 60 and were epoxy-coated according to ASTM A775. The J-shape concrete barrier was constructed from two pieces: (1) an existing New Jersey profile barrier system measuring 120 ft – 2 in. long and 32 in. tall, with a 6-in. top width and 15-in. base width that provided the correct front profile of the concrete barrier [7], and (2) a 3¼-in. wide by 32-in. tall by 100-ft long, reinforced-concrete wall that was retrofitted to the back side of the existing, NJ-shape concrete barrier to achieve the minimum 9¼-in. barrier top width, as shown in Figures 9 and 33. The downstream end of the retrofit wall was flush with the downstream end of the New Jersey-shape concrete barrier, thus creating a retrofit length equal to 100 ft, as shown in Figures 7 and 35.

Note that the standard MnDOT J-barrier was later determined to have a top width and a bottom width of 9 in. and 18 in., respectively. Thus, the rectangular retrofit wall should have been 3 in. wide versus 3¼-in. wide. In summary, the concrete barrier was constructed to be ¼ in. wider than intended.

The retrofit wall used a series of rebar assemblies that consisted of three L-shaped No. 4 rebar tied to a 30¼-in. tall, vertical No. 4 stirrup, as shown in Figure 11. To anchor the retrofit wall, the three L-shaped No. 4 rebar were anchored with an epoxy adhesive 5 in. deep into the existing NJ-shape concrete barrier [7] by drilling a ⅝-in. diameter hole at heights of 2 in., 10⅝ in., and 24⅝ in. from the top of the concrete barrier. The retrofit wall used five horizontal No. 4 rebar tied through a length of 100 ft at heights of 1¾ in., 3 13/16 in., 9¾ in., 16 13/16 in., and 25 11/16 in. from the top of the concrete barrier, as shown in Figures 11 and 12. The retrofit wall consisted of three horizontal spacing patterns, as shown in Figure 11. The downstream end's pattern is shown in Detail B in Figure 11, the post-to-post pattern is shown in Detail C in Figure 11, and the upstream end pattern is shown in Detail D in Figure 11.

The bicycle and pedestrian railing system utilized nine post assemblies which were anchored to the back-side, vertical face of the concrete barrier. Each post was fabricated from ASTM A500 Grade B HSS steel tubing, measuring 4 in. x 2 in. x ⅛ in., which were treated according to ASTM A123 hot-dip galvanizing. Two 3½-in. x 4 9/16-in. x ¼-in. bent plates, configured with ASTM A709 Grade 36 steel, were welded to the post at the upper and lower rail heights of 54½ in. and 37½ in. above the ground, as shown in Figures 9, 17, 18, and 19. The lower bent plates were welded onto each post using a three-sided sealed ends weld of ⅛ in. The bent plates were used to attach the rail panels to the posts using ½-in. diameter, 13 UNC by 1½-in. long SAE J2484 round head machine screws, zinc-plated in accordance to ASTM F1941 with two ASTM F436 ½-in. diameter hardened SAE washers zinc-plated in accordance to ASTM F2329, and ½-in. diameter, 13 UNC ASTM A563A jam nuts zinc-plated in accordance to ASTM F1941 for both downstream and upstream post assemblies, as shown Figures 15, 37, and 38. MnDOT's standard plan [5] specified the use of ASTM A307 Grade B round head bolts, each measuring ½ in. diameter x 1½ in. long with an ASTM F436 ½-in. diameter hardened SAE washer and two ASTM A563A ½-in.-13 UNC jam nuts, as shown in Figure 4.

MnDOT specified the use of round head bolts for attaching rail panels to vertical posts. For these round head bolts, it is necessary to acquire a special treatment on each head for holding the bolt while tightening the lower two nuts. These special treatments may include: (1) flat, Philips, torx, hex, or other key shapes within the center region of head or (2) two flattened sides sufficient for holding each head with an open-end wrench. Note that the original bicycle and pedestrian railing system was developed and successfully crash tested under TL-4 impact conditions of NCHRP Report No. 350 using hex head bolts to attached rail panels to posts [4].

Each ASTM A500 Grade B HSS 4-in. x 2-in. x ⅛-in. steel post was welded onto a 10-in. x 7-in. x ½-in. ASTM A709 Grade 36 steel mounting plate with a ¼-in. fillet weld on the sides, a ⅛-in. fillet weld on the bottom, and a 3⁄16-in. fillet weld on the top of the plate. Each post assembly was anchored to the backside of the barrier using four ASTM F1554 Grade 36 galvanized ⅞-in. diameter – 9 UNC by 9-in. long, threaded rods; ⅞-in. diameter – 9 UNC hex nuts; and a ⅞-in. diameter hardened washer. The post assemblies were treated according to ASTM A123 hot-dip galvanizing.

The longitudinal upper and lower rails consisted of ASTM A500 Grade B HSS 3 in. x 2 in. x ⅛ in. sections measuring 117½ in. long. The termination end rail assemblies consisted of two ASTM A500 Grade B HSS 3-in. x 2-in. x ⅛-in. tubes welded together with a ¼-in. fillet weld along the length of the tubes, as shown in Figures 17 and 18. The top angled rail was welded onto the top of the post using a ⅛-in. fillet weld at an angle of 26.6 degrees. The lower angled rail was welded onto an ASTM A500 Grade B HSS 3-in. x 2-in. x ⅛-in. post using a ⅛-in. fillet weld at the lower bent plate height, as shown in Figures 17 and 18. For each rail assembly, 16-in. x ⅝-in. x ⅝-in. vertical spindles spaced at 6-in. centers, were welded to the back sides of the longitudinal rails with a ⅛-in. fillet weld, as shown in Figures 20 and 21.

The cable assembly used for test nos. MNPD-1 and MNPD-2, as detailed in MwRSF report, *Design and Evaluation of the TL-4 Minnesota Combination Traffic/Bicycle Bridge Rail* [4], consisted of a ½-in. diameter, UNJ, Crosby HG 4037 jaw; a ½-in. UNC Crosby threaded turnbuckle; an Electroline stud socket GD-331-X; and $^{5}/_{16}$-in. diameter by 7x19 wire rope, as shown in Figure 28. The cable assembly used for test no. MNPD-3 consisted of an Electroline Forged Series Open body Clevis and Socket Turnbuckle with an Electroline part no. XD-4031-BX and a 3⁄16-in. diameter by 7x19 wire rope, as shown in Figures 28, 29, and 32.

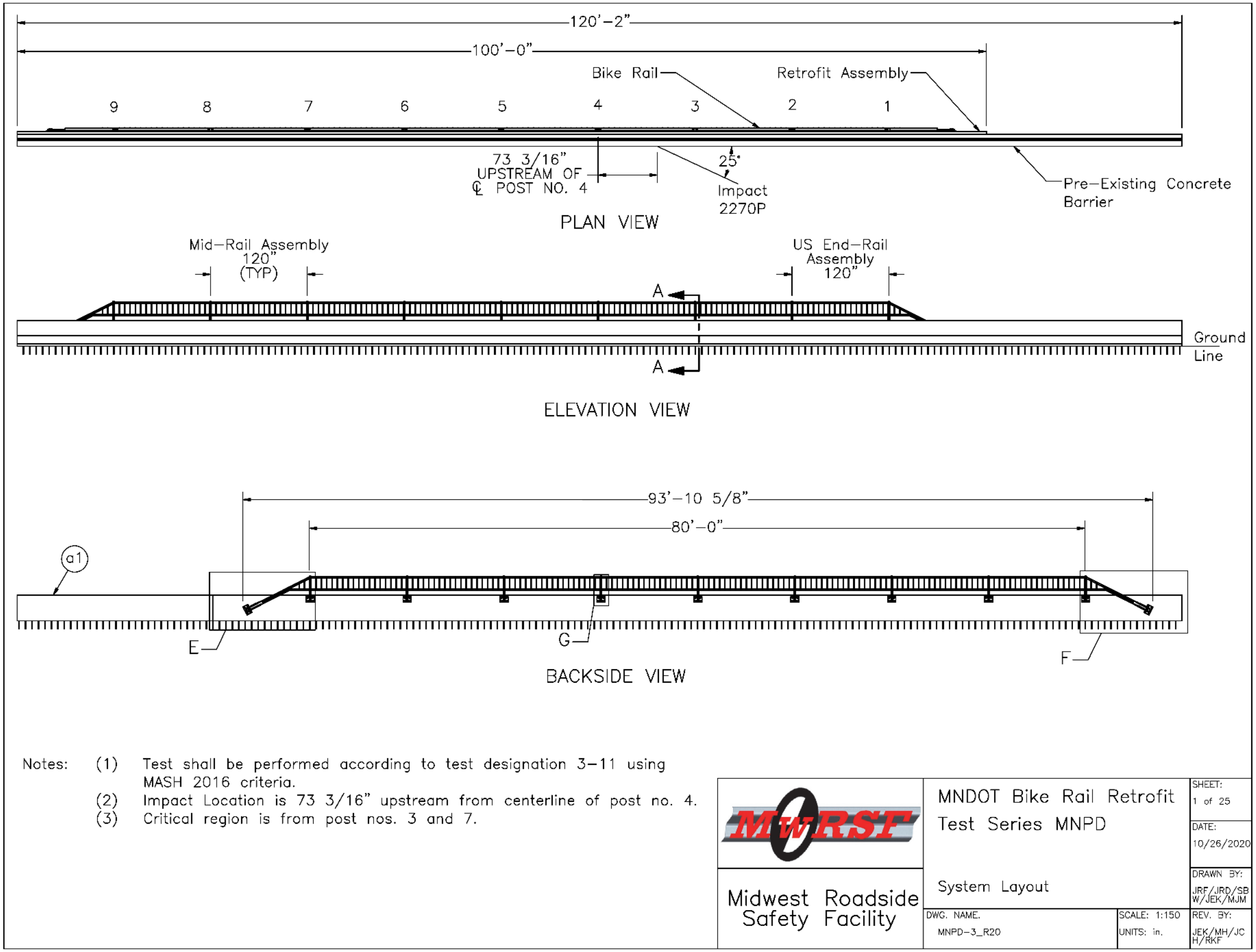


Figure 8. System Layout, Test No. MNPD-3

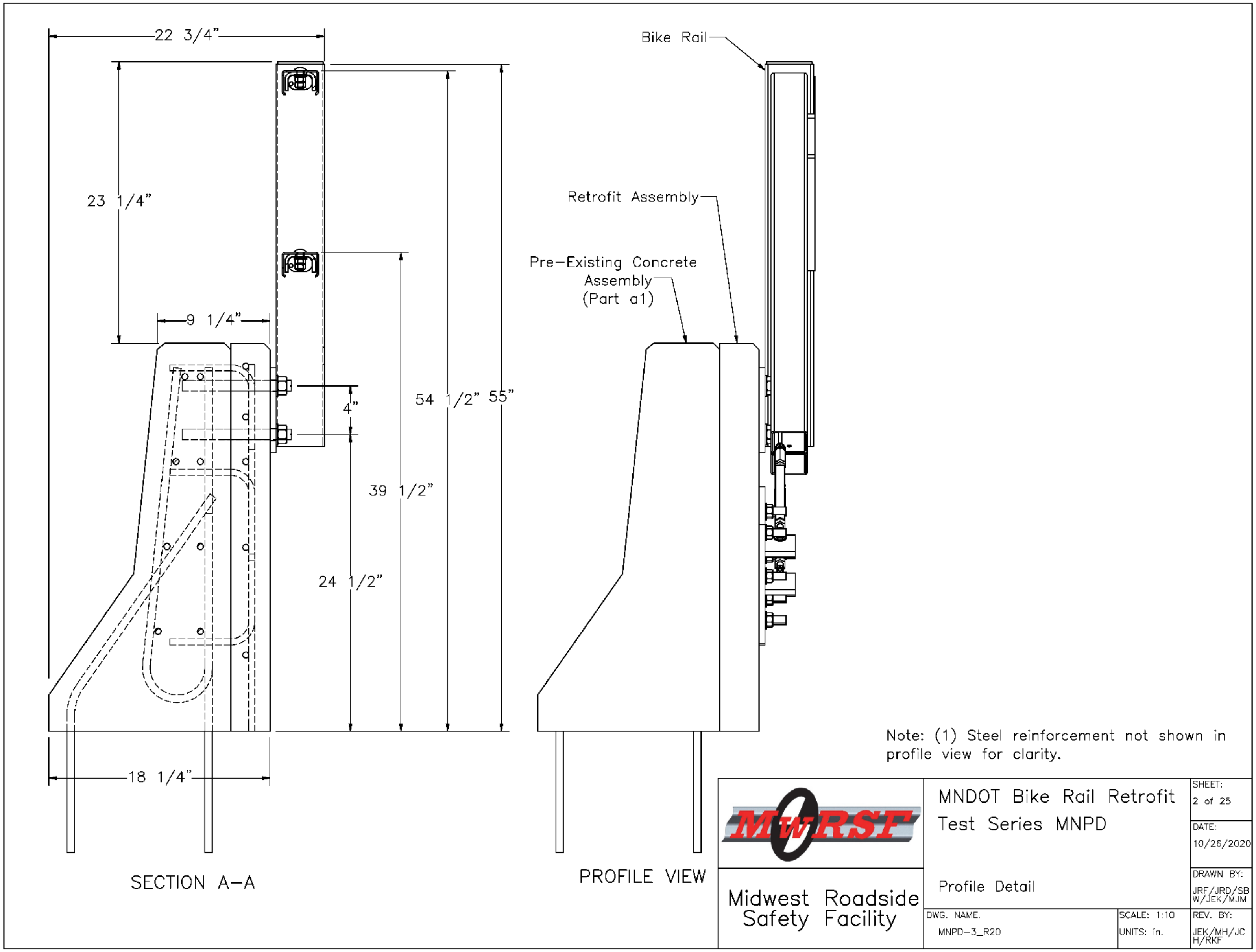


Figure 9. Profile Detail, Test No. MNPD-3

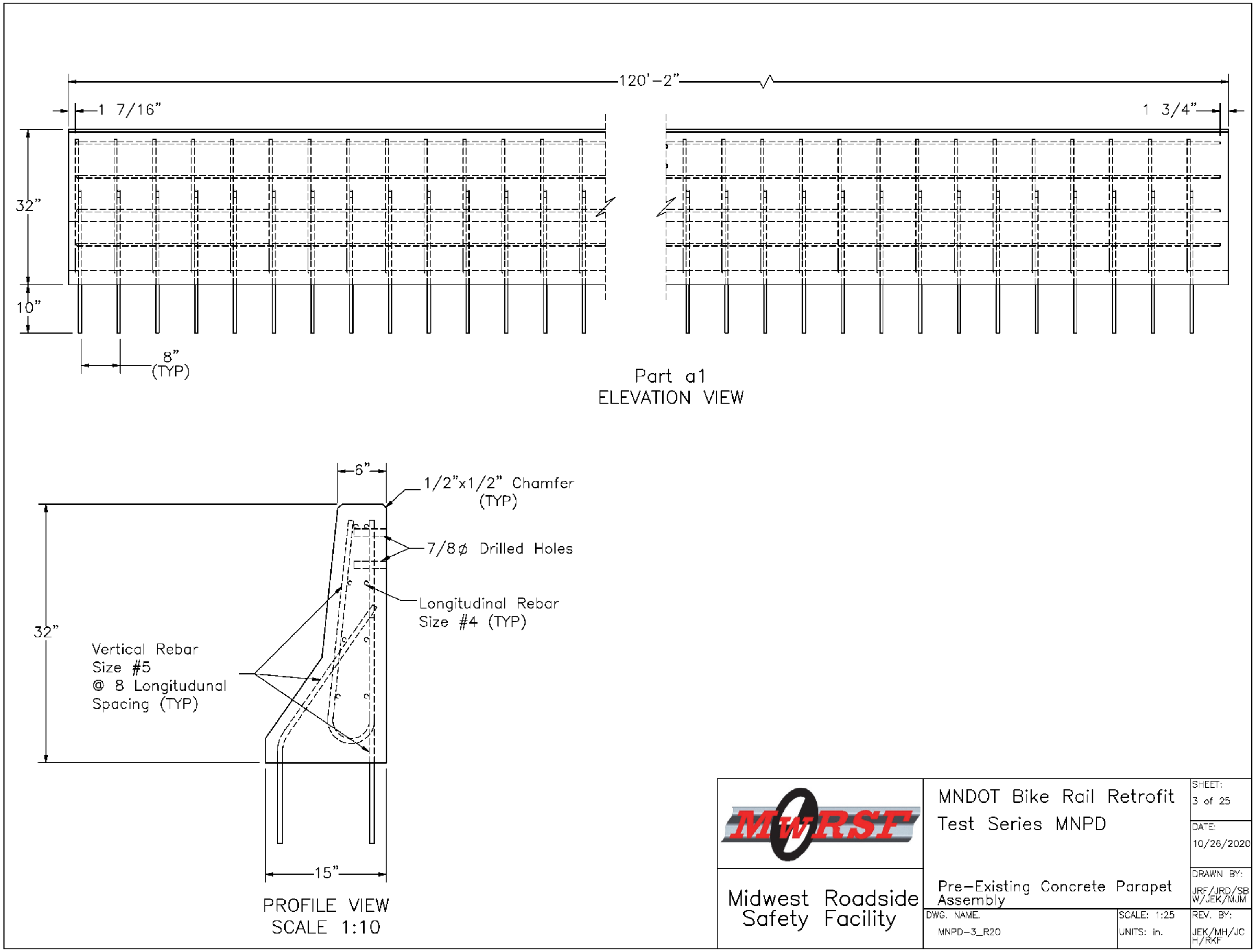
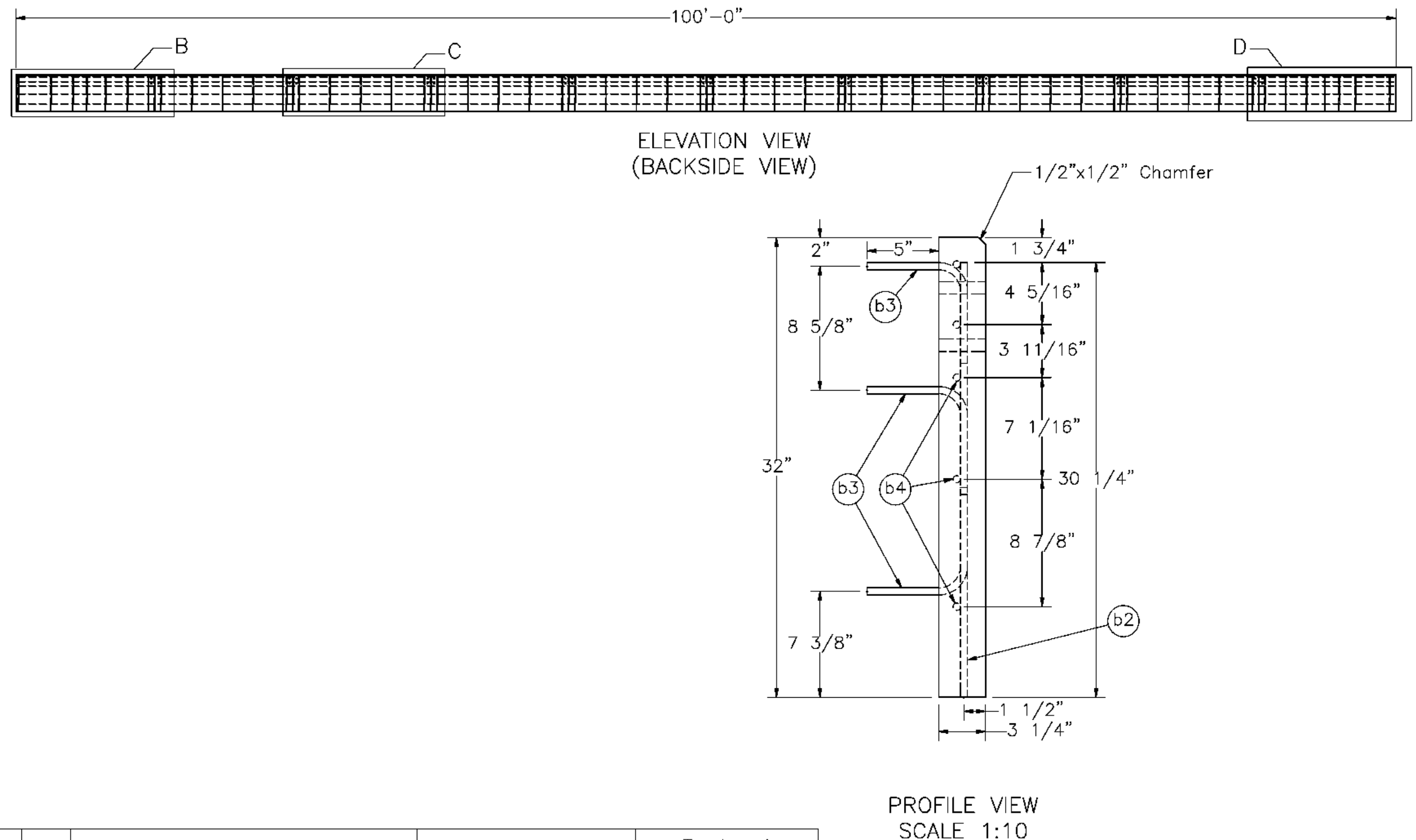


Figure 10. Pre-Existing Concrete Barrier Assembly, Test No. MNPD-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Retrofit Assembly	–	–
b1	1	Concrete for Retrofit	5,000 psi minimum	–
b2	63	#4 Bar, 30 1/4" Total Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775)
b3	189	#4 Bar, 12 3/4" Total Unbent Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775)
b4	5	#4 Bar, 1196 1/2" Total Length	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775)

Midwest Roadside Safety Facility

MNDOT Bike Rail Retrofit Test Series MNPD

Retrofit Assembly

SHEET: 4 of 25
DATE: 10/26/2020
DRAWN BY: JRF/JRD/SB W/JEK/MJM
DWG. NAME. MNPD-3_R20
SCALE: 1:125
UNITS: in.
REV. BY: JEK/MH/JC F/RKF

Figure 11. Retrofit Assembly, Test No. MNPD-3

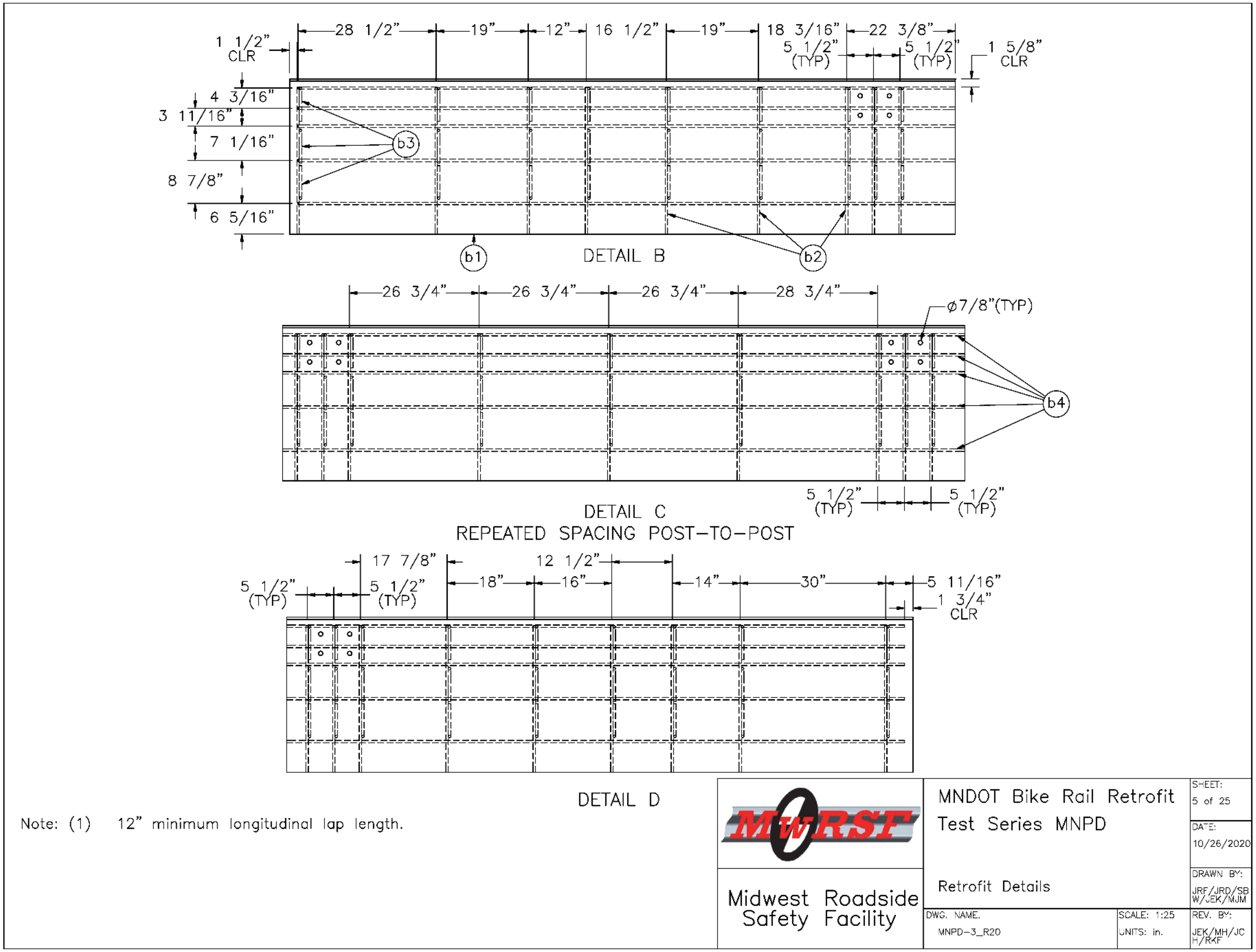
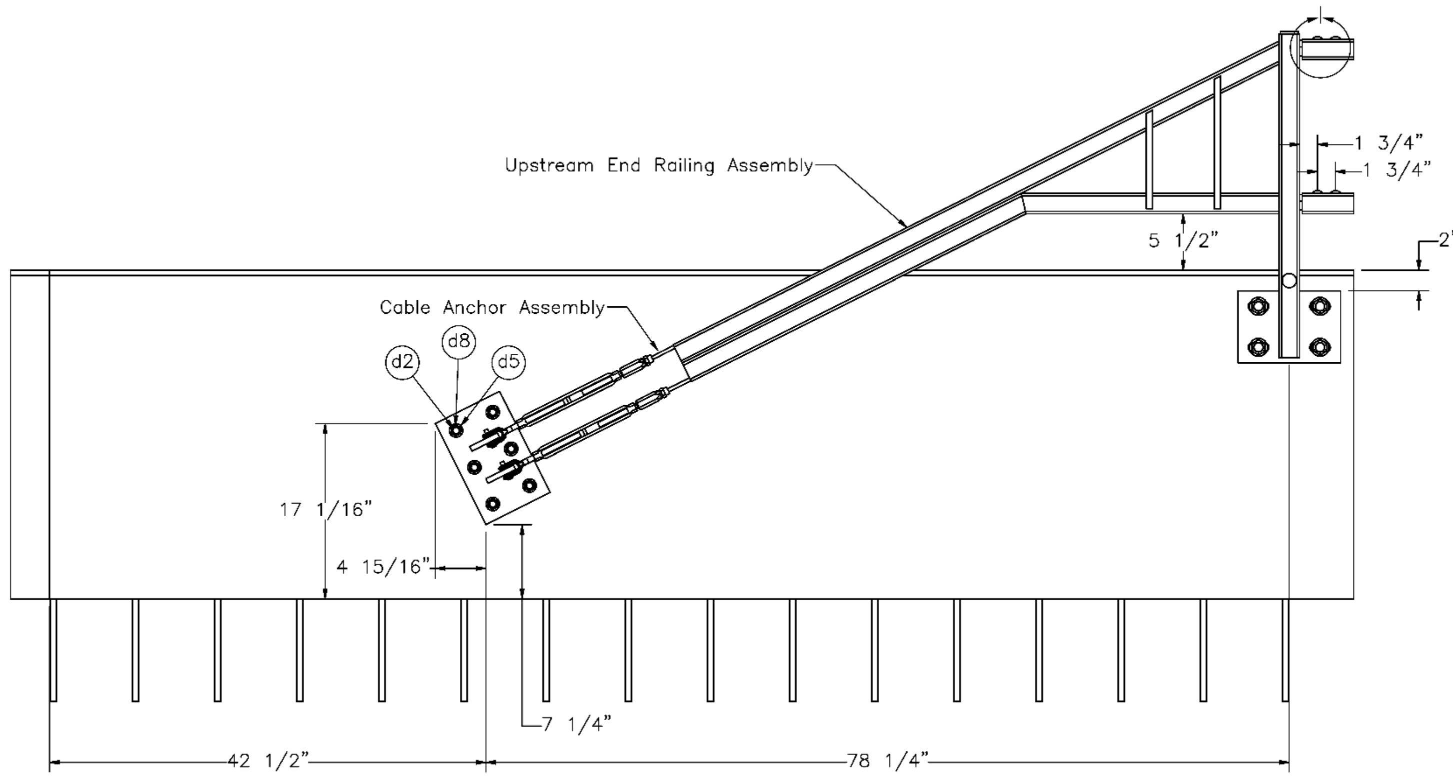


Figure 12. Retrofit Wall Reinforcement Details, Test No. MNPD-3



DETAIL E

Note: (1) At each cable anchor bolt: 5" minimum embedment, and torque to 30 ft–lb.

(2) Provide an adhesive with a minimum characteristic bond strength in uncracked concrete of 1.5 ksi. Embed the anchorage no less than embedment shown regardless of characteristic bond strength. Drill through reinforcement (If encountered) to achieve minimum embedment. Ensure hex nut is in contact with the adjacent surface and torque to value specified unless a higher torque is recommended by the manufacturer.

Midwest Roadside Safety Facility	MNDOT Bike Rail Retrofit Test Series MNPD Upstream End Rail Details	SHEET: 6 of 25 DATE: 10/26/2020 DRAWN BY: JRF/JRD/SB W/JEK/MJM
	DWG. NAME. MNPD–3_R20	SCALE: 1:15 UNITS: in. REV. BY: JEK/MH/JC F/RKF

Figure 13. Upstream End Rail Details, Test No. MNPD-3

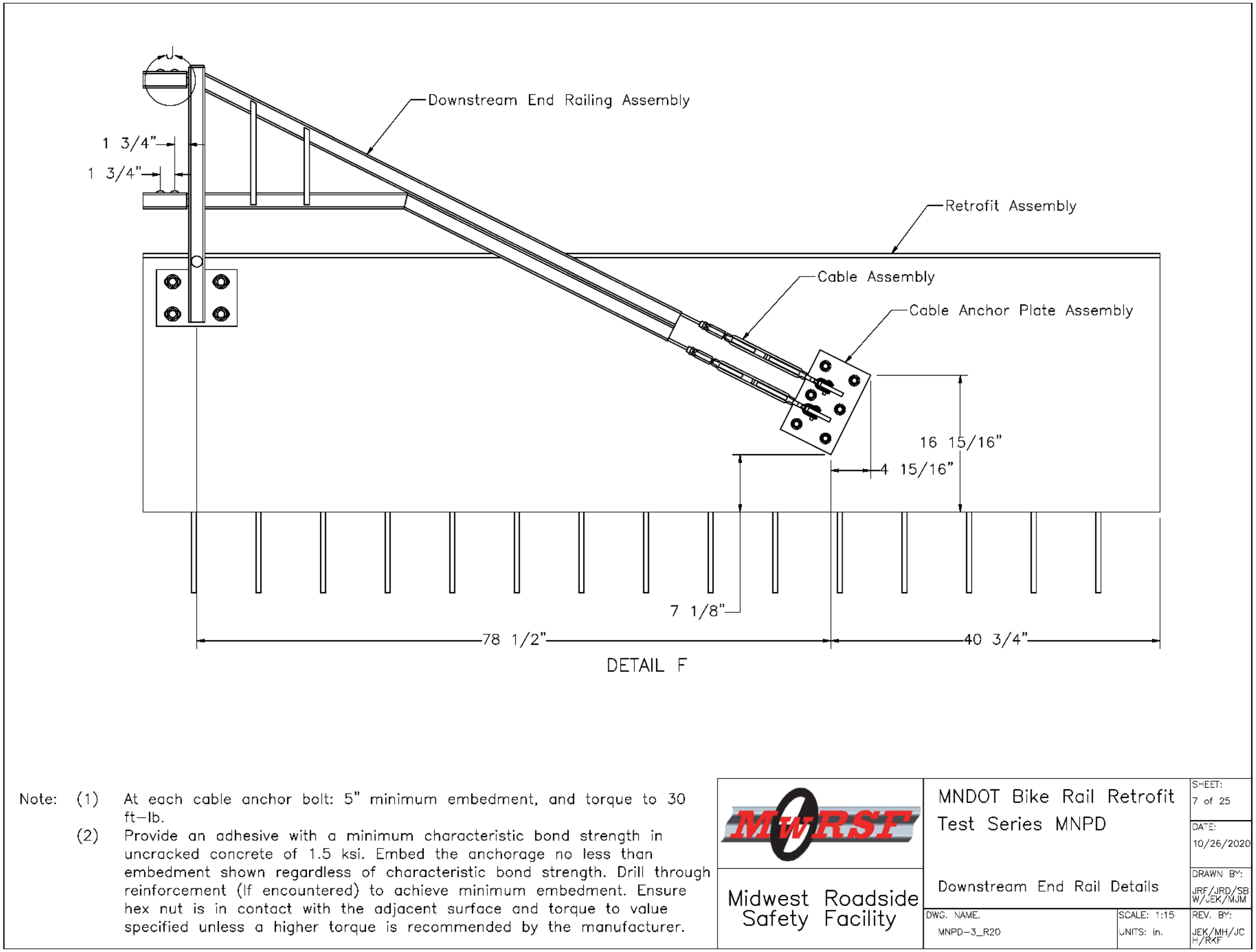


Figure 14. Downstream End Rail Details, Test No. MNPD-3

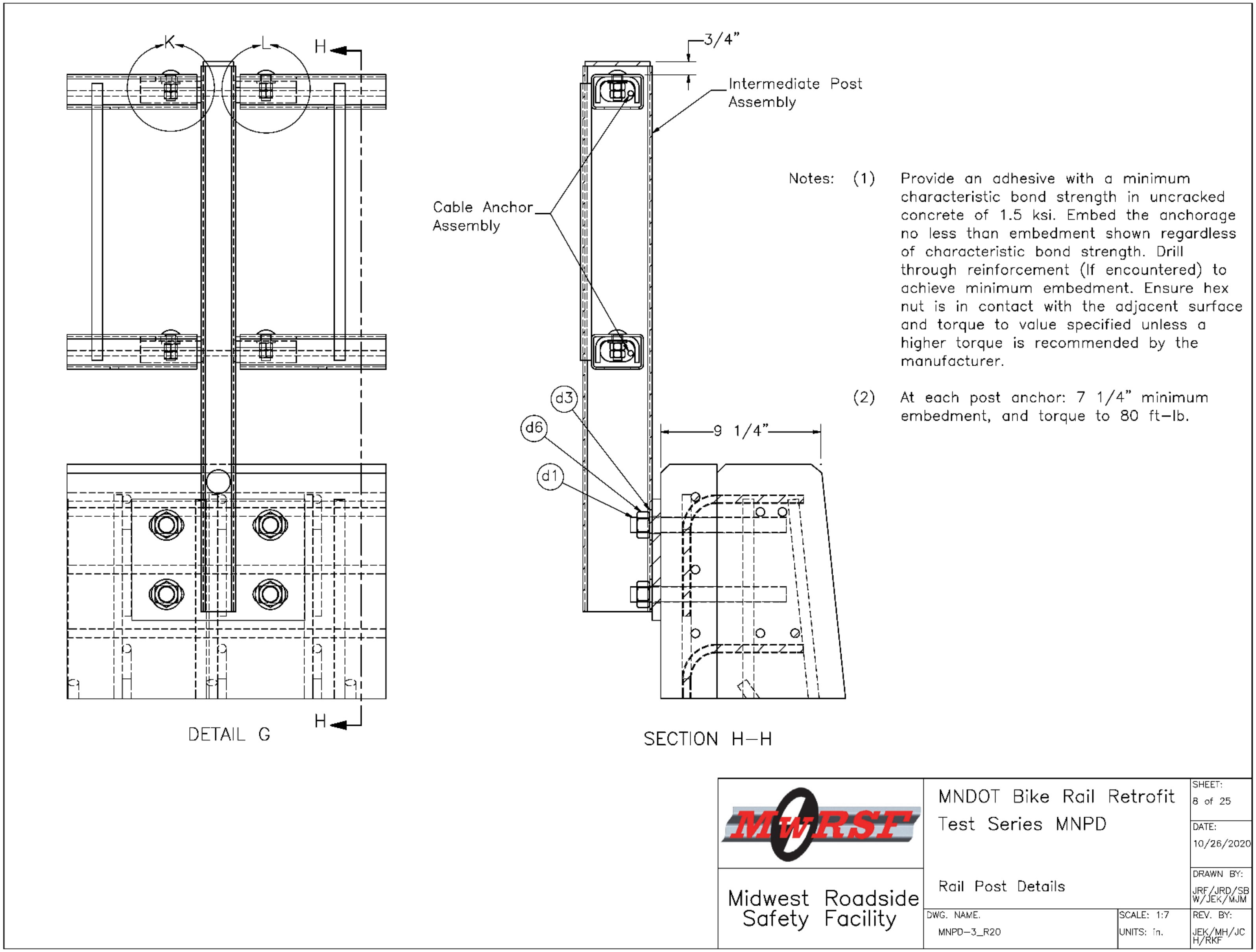


Figure 15. Rail Post Details, Test No. MNPD-3

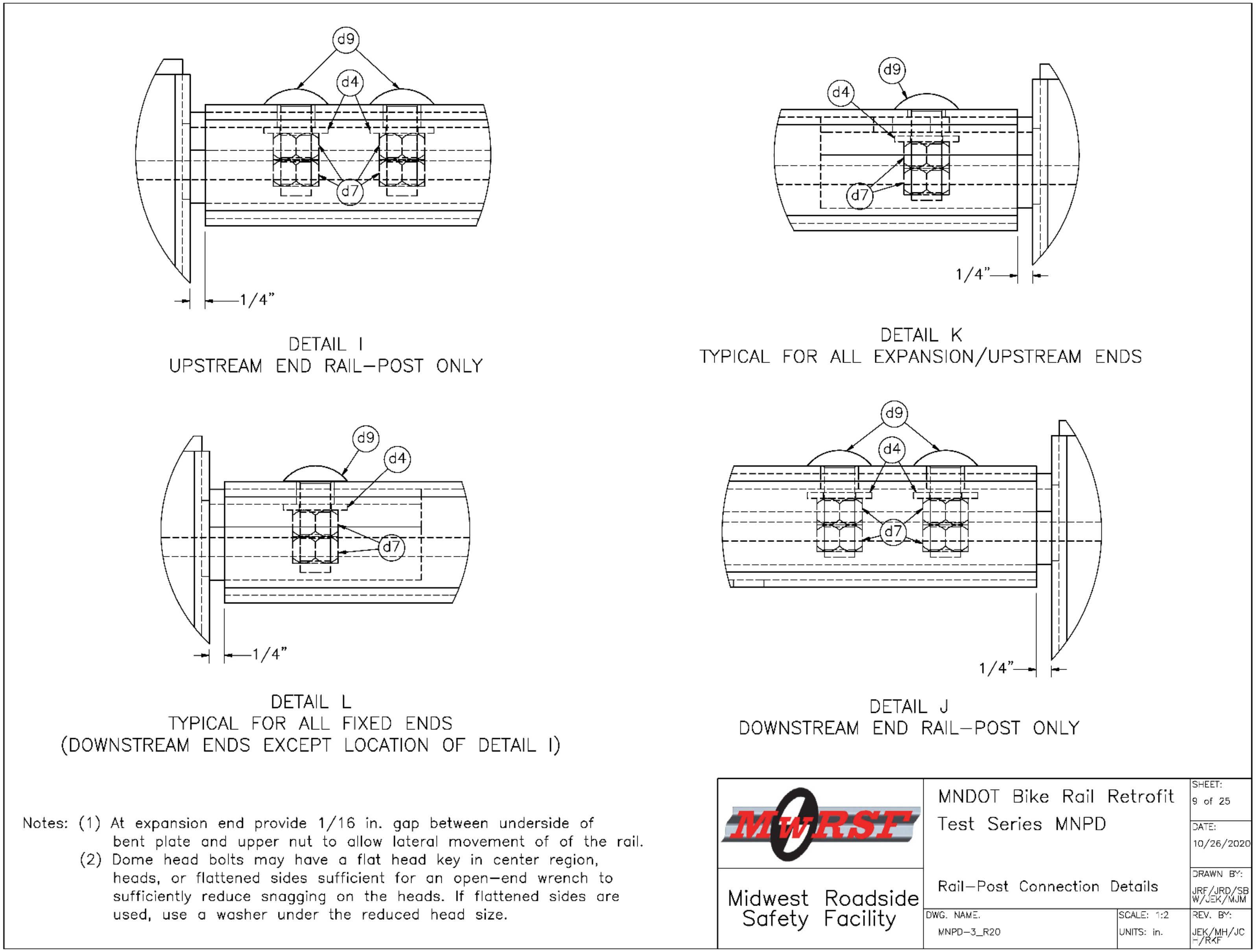
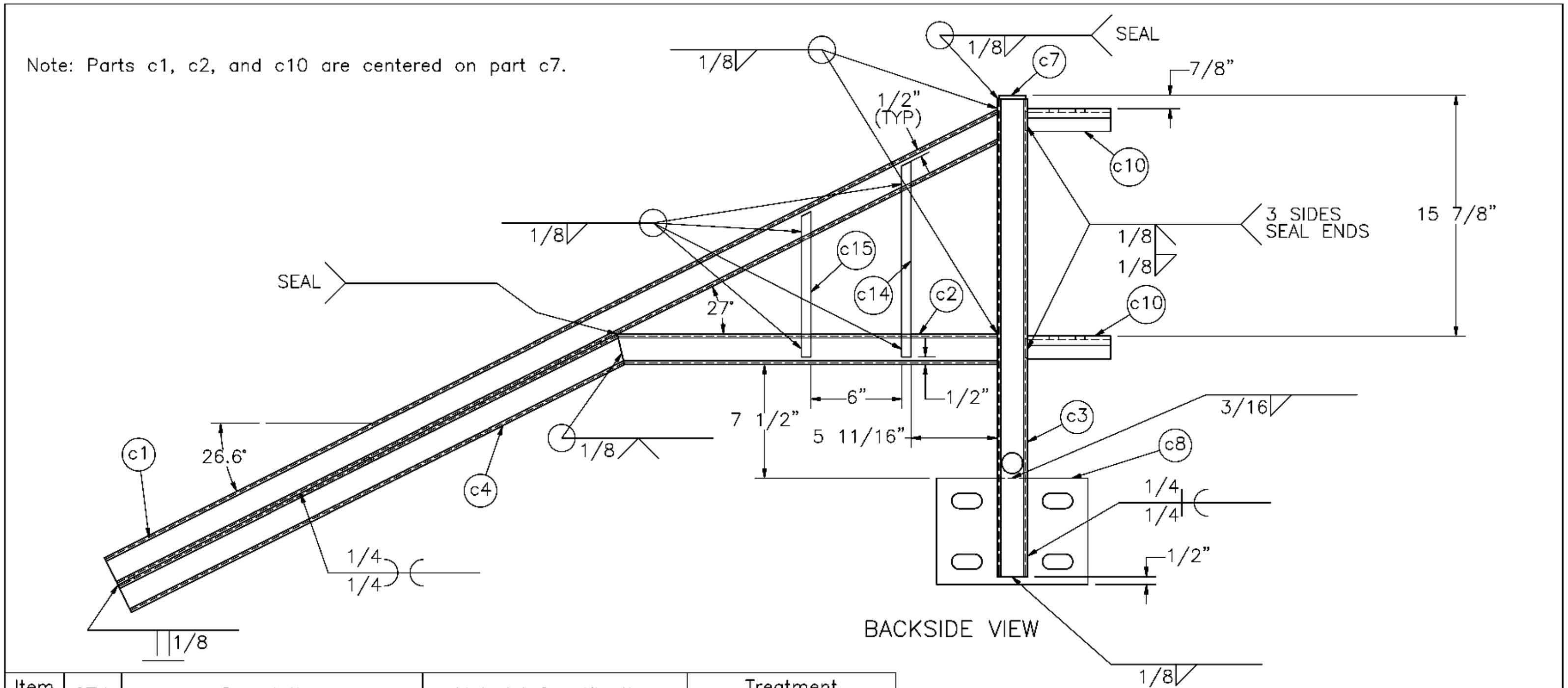


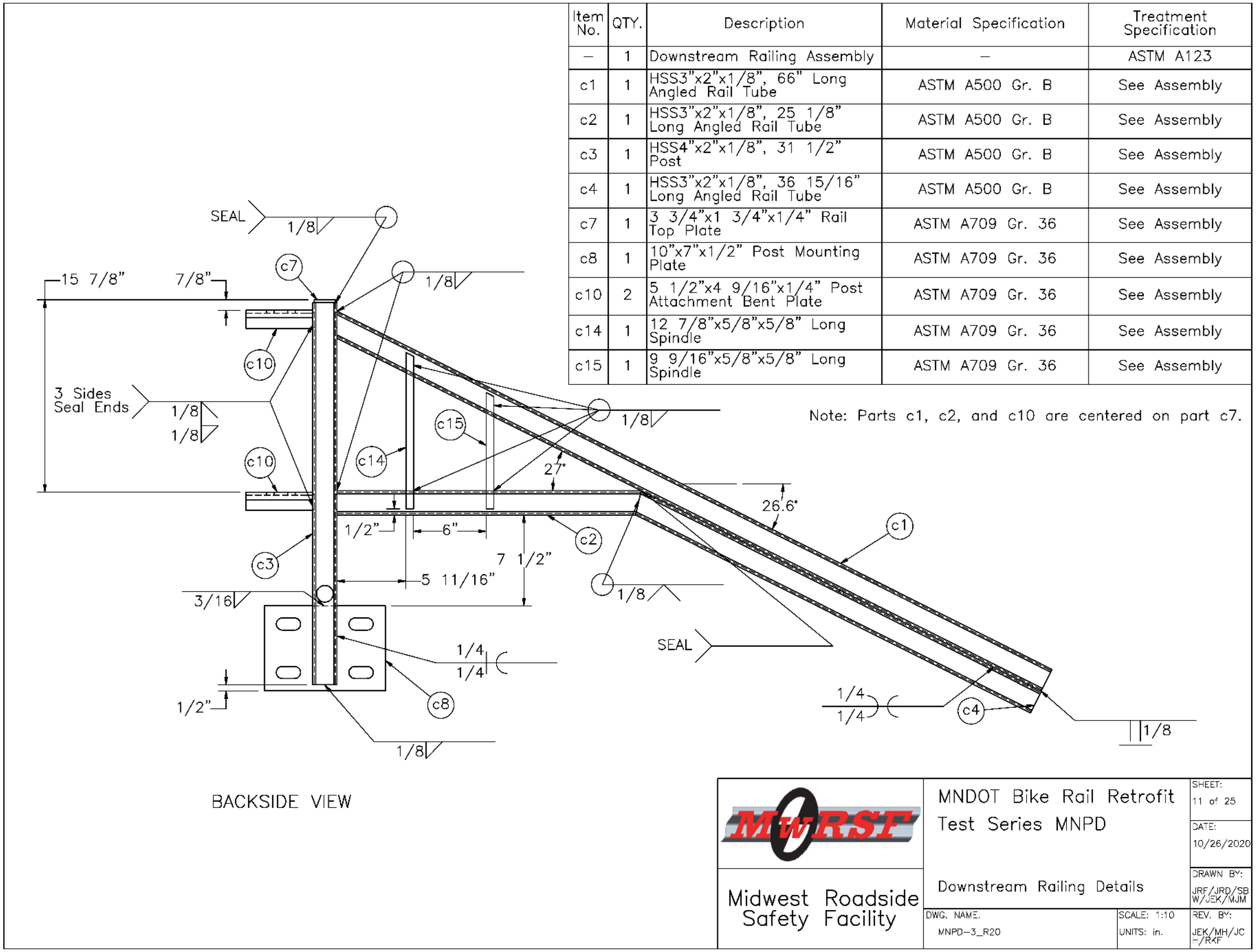
Figure 16. Rail-Post Connection Details, Test No. MNPD-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Upstream Railing Assembly	–	ASTM A123
c1	1	HSS3"x2"x1/8", 66" Long Angled Rail Tube	ASTM A500 Gr. B	See Assembly
c2	1	HSS3"x2"x1/8", 25 1/8" Long Angled Rail Tube	ASTM A500 Gr. B	See Assembly
c3	1	HSS4"x2"x1/8", 31 1/2" Post	ASTM A500 Gr. B	See Assembly
c4	1	HSS3"x2"x1/8", 36 15/16" Long Angled Rail Tube	ASTM A500 Gr. B	See Assembly
c7	1	3 3/4"x1 3/4"x1/4" Rail Top Plate	ASTM A709 Gr. 36	See Assembly
c8	1	10"x7"x1/2" Post Mounting Plate	ASTM A709 Gr. 36	See Assembly
c10	2	5 1/2"x4 9/16"x1/4" Post Attachment Bent Plate	ASTM A709 Gr. 36	See Assembly
c14	1	12 7/8"x5/8"x5/8" Long Spindle	ASTM A709 Gr. 36	See Assembly
c15	1	9 9/16"x5/8"x5/8" Long Spindle	ASTM A709 Gr. 36	See Assembly

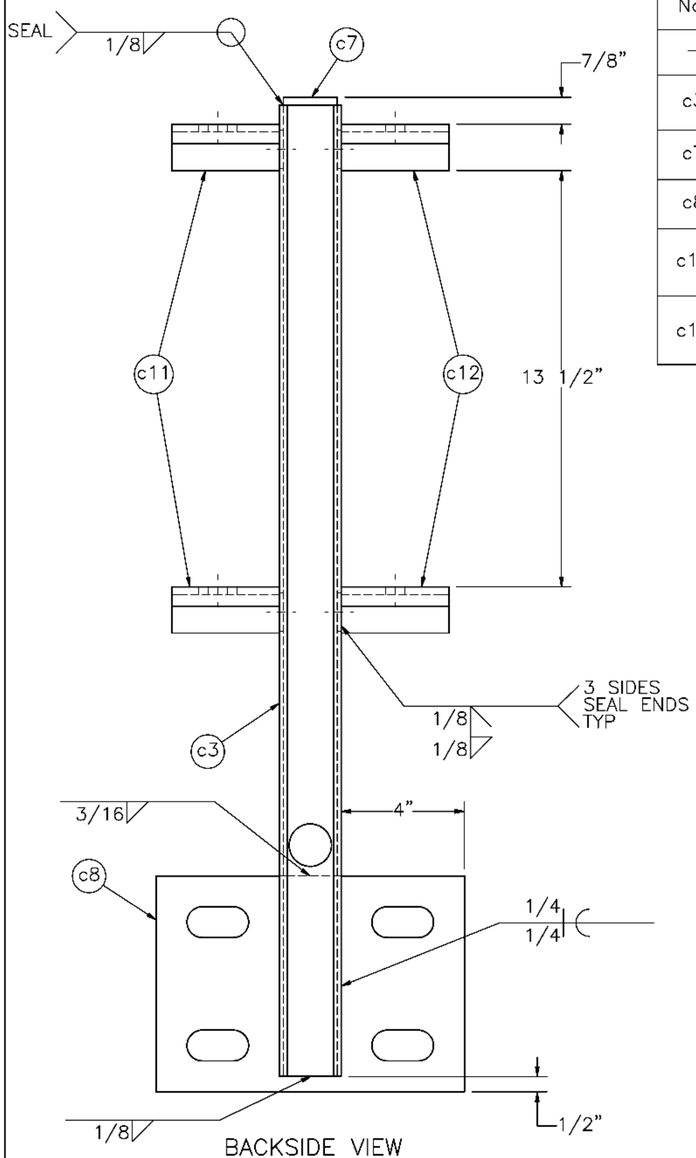
MwRSF Midwest Roadside Safety Facility	MNDOT Bike Rail Retrofit Test Series MNPD	SHEET: 10 of 25
		DATE: 10/26/2020
	Upstream Railing Assembly	DRAWN BY: JRF/JRD/SBW/JEK/MJM
	DWG. NAME. MNPD-3_R20	SCALE: 1:10 UNITS: in.
		REV. BY: JEK/MH/JCH/RKF

Figure 17. Upstream Railing Assembly, Test No. MNPD-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Downstream Railing Assembly	–	ASTM A123
c1	1	HSS3"x2"x1/8", 66" Long Angled Rail Tube	ASTM A500 Gr. B	See Assembly
c2	1	HSS3"x2"x1/8", 25 1/8" Long Angled Rail Tube	ASTM A500 Gr. B	See Assembly
c3	1	HSS4"x2"x1/8", 31 1/2" Post	ASTM A500 Gr. B	See Assembly
c4	1	HSS3"x2"x1/8", 36 15/16" Long Angled Rail Tube	ASTM A500 Gr. B	See Assembly
c7	1	3 3/4"x1 3/4"x1/4" Rail Top Plate	ASTM A709 Gr. 36	See Assembly
c8	1	10"x7"x1/2" Post Mounting Plate	ASTM A709 Gr. 36	See Assembly
c10	2	5 1/2"x4 9/16"x1/4" Post Attachment Bent Plate	ASTM A709 Gr. 36	See Assembly
c14	1	12 7/8"x5/8"x5/8" Long Spindle	ASTM A709 Gr. 36	See Assembly
c15	1	9 9/16"x5/8"x5/8" Long Spindle	ASTM A709 Gr. 36	See Assembly

Figure 18. Downstream Railing Details, Test No. MNPD-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	9	Intermediate Rail Post Assembly	–	ASTM A123
c3	1	HSS4"x2"x1/8", 31 1/2" Post	ASTM A500 Gr. B	See Assembly
c7	1	3 3/4"x1 3/4"x1/4" Rail Top Plate	ASTM A709 Gr. 36	See Assembly
c8	1	10"x7"x1/2" Post Mounting Plate	ASTM A709 Gr. 36	See Assembly
c11	2	3 1/2"x4 9/16"x1/4" Post Attachment Bent Plate– Expansion End	ASTM A709 Gr. 36	See Assembly
c12	2	3 1/2"x4 9/16"x1/4" Post Attachment Bent Plate– Fixed End	ASTM A709 Gr. 36	ASTM A123

Note: Parts c11 and c12 are centered on part c7.

Midwest Roadside Safety Facility

MNDOT Bike Rail Retrofit Test Series MNPD

Intermediate Post Assembly

SHEET: 12 of 25

DATE: 10/26/2020

DRAWN BY: JRF/JRD/SBW/JEK/MJM

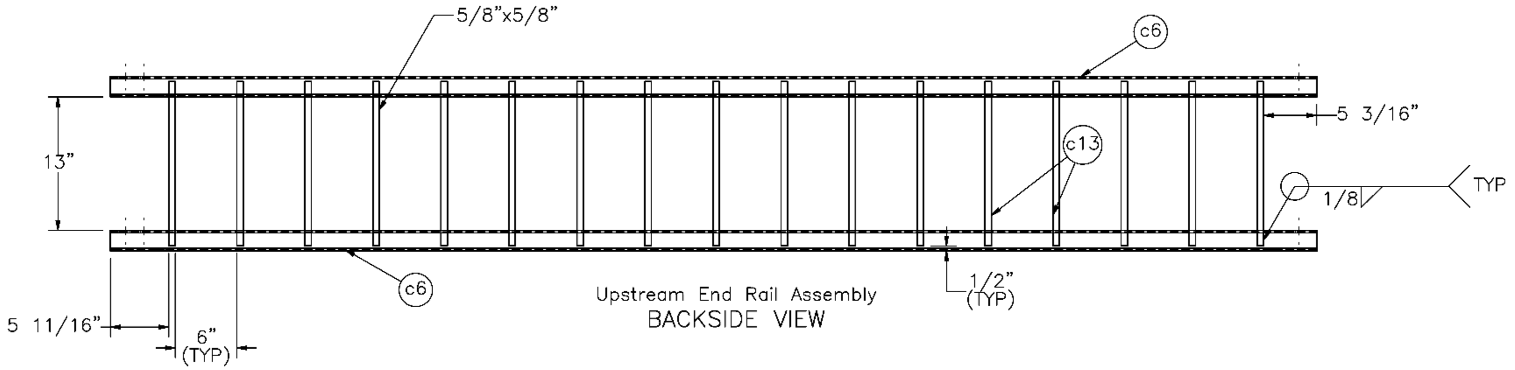
DWG. NAME. MNPD-3_R20

SCALE: 1:5

UNITS: in.

REV. BY: JEK/MH/JCH/RKF

Figure 19. Intermediate Post Assembly, Test No. MNPD-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Upstream End Rail Assembly	–	ASTM A123
c6	2	HSS3"x2"x1/8", 117 1/2" Long Endrail Tube	ASTM A500 Gr. B	See Assembly
c13	17	16"x5/8"x5/8" Long Rail Spindle	ASTM A709 Gr. 36	See Assembly

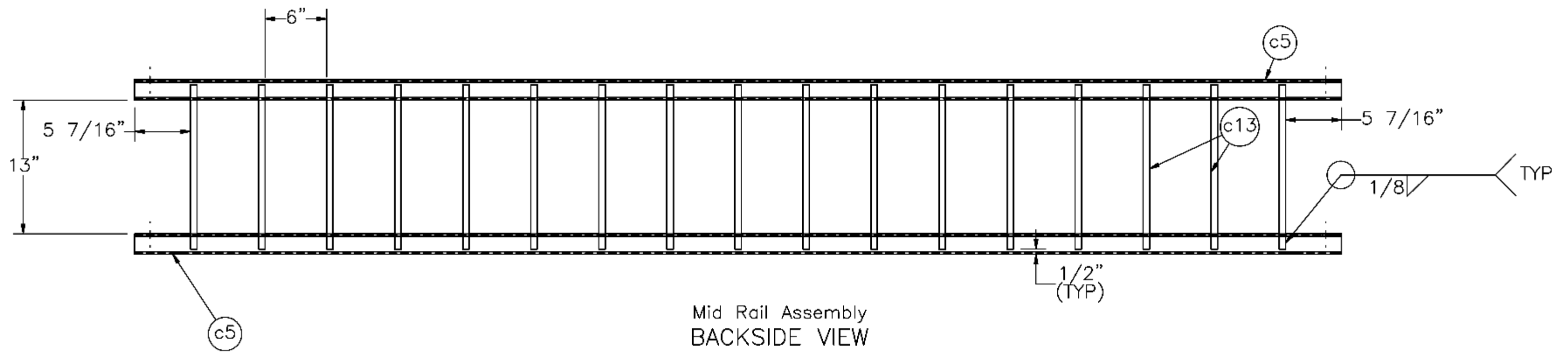
MwRSF
Midwest Roadside Safety Facility

MNDOT Bike Rail Retrofit
Test Series MNPD

Upstream End Rail Assembly

SHEET: 13 of 25
DATE: 10/26/2020
DRAWN BY: JRF/JRD/SBW/JEK/MJM
DWG. NAME. MNPD-3_R20
SCALE: 1:15
UNITS: in.
REV. BY: JEK/MH/JCH/RKF

Figure 20. Upstream End Rail Assembly, Test No. MNPD-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	7	Mid Rail Assembly	–	ASTM A123
c5	2	HSS3"x2"x1/8", 117 1/2" Long Rail Tube	ASTM A500 Gr. B	See Assembly
c13	17	16"x5/8"x5/8" Long Rail Spindle	ASTM A709 Gr. 36	See Assembly

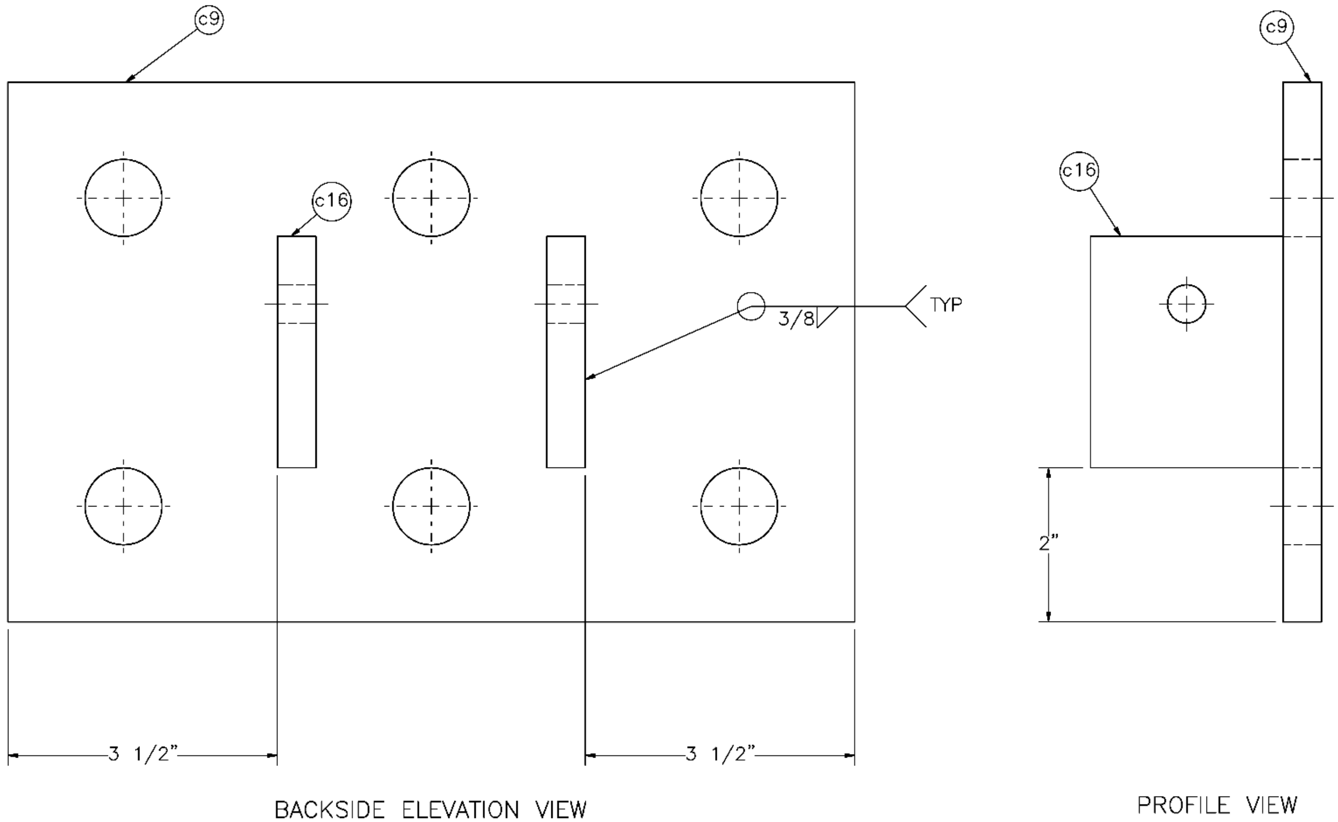
MwRSF
Midwest Roadside Safety Facility

MNDOT Bike Rail Retrofit
Test Series MNPD

Mid Rail Assembly

SHEET: 14 of 25
DATE: 10/26/2020
DRAWN BY: JRF/JRD/SBW/JEK/MJM
REV. BY: JEK/MH/JCH/RKF
DWG. NAME. MNPD–3_R20
SCALE: 1:15
UNITS: in.

Figure 21. Mid Rail Assembly, Test No. MNPD-3



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	2	Cable Anchor Plate Assembly	–	ASTM A123
c9	1	7"x11"x1/2" Cable Anchor Plate	ASTM A709 Gr. 36	See Assembly
c16	2	3"x2 1/2"x1/2" Cable Anchor Plate Flange	ASTM A709 Gr. 36	See Assembly

MwRSF Midwest Roadside Safety Facility	MNDOT Bike Rail Retrofit Test Series MNPD		SHEET: 15 of 25
			DATE: 10/26/2020
	Cable Anchor Plate Assembly		DRAWN BY: JRF/JRD/SB W/JEK/MJM
	DWG. NAME. MNPD-3_R20	SCALE: 1:2 UNITS: in.	REV. BY: JEK/MH/JC F/RKF

Figure 22. Cable Anchor Plate Assembly, Test No. MNPD-3

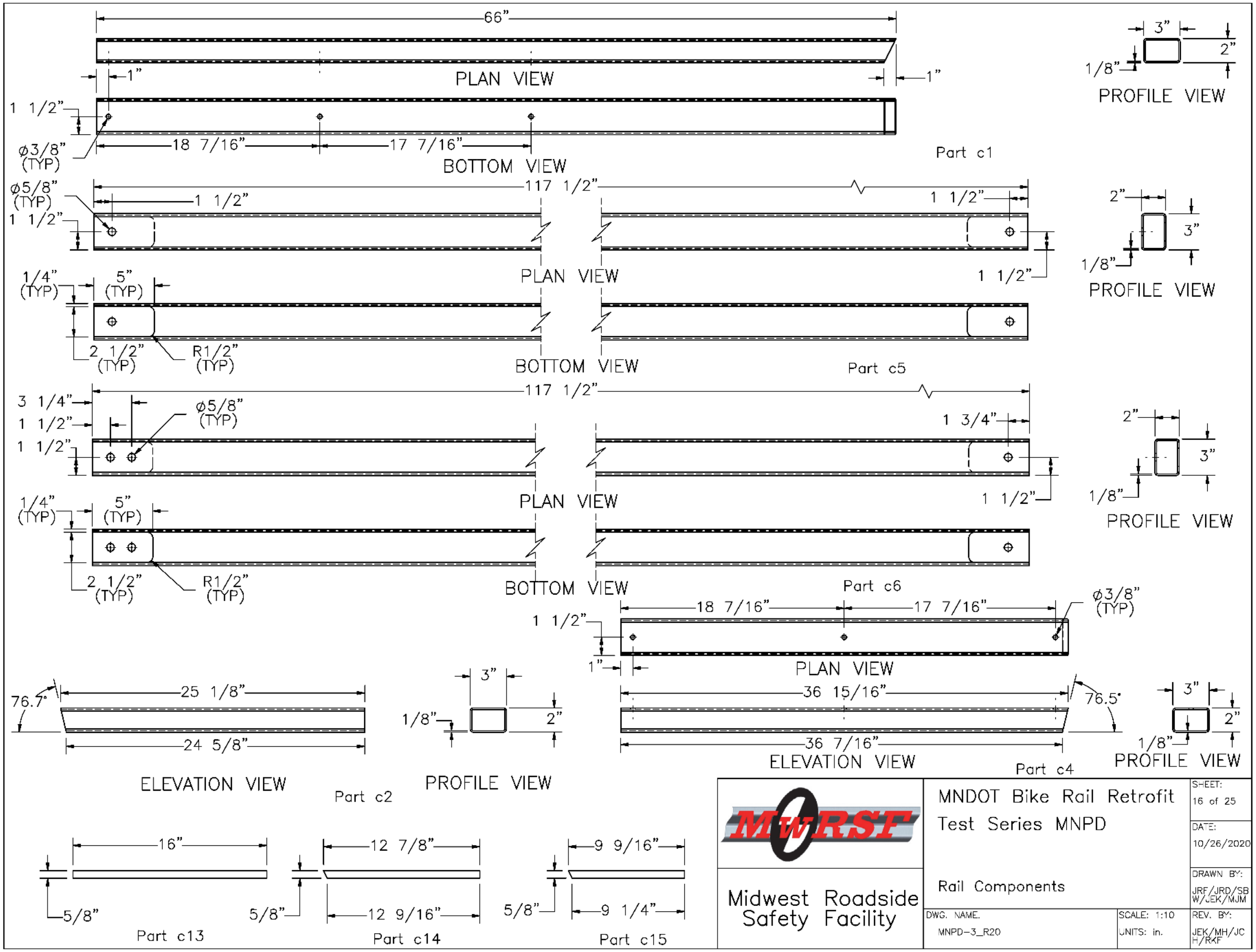


Figure 23. Rail Components, Test No. MNPD-3

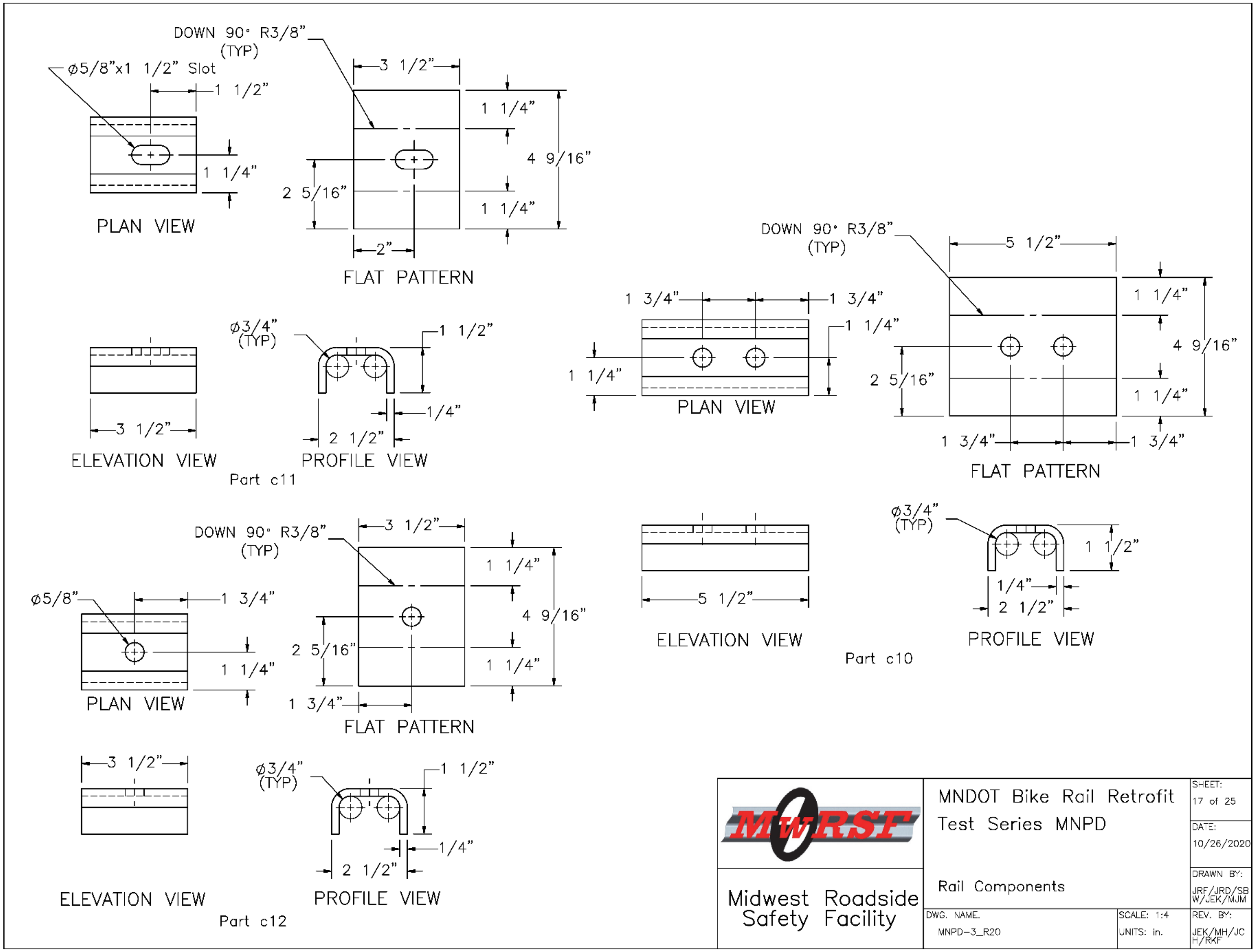


Figure 24. Rail Components, Test No. MNPD-3

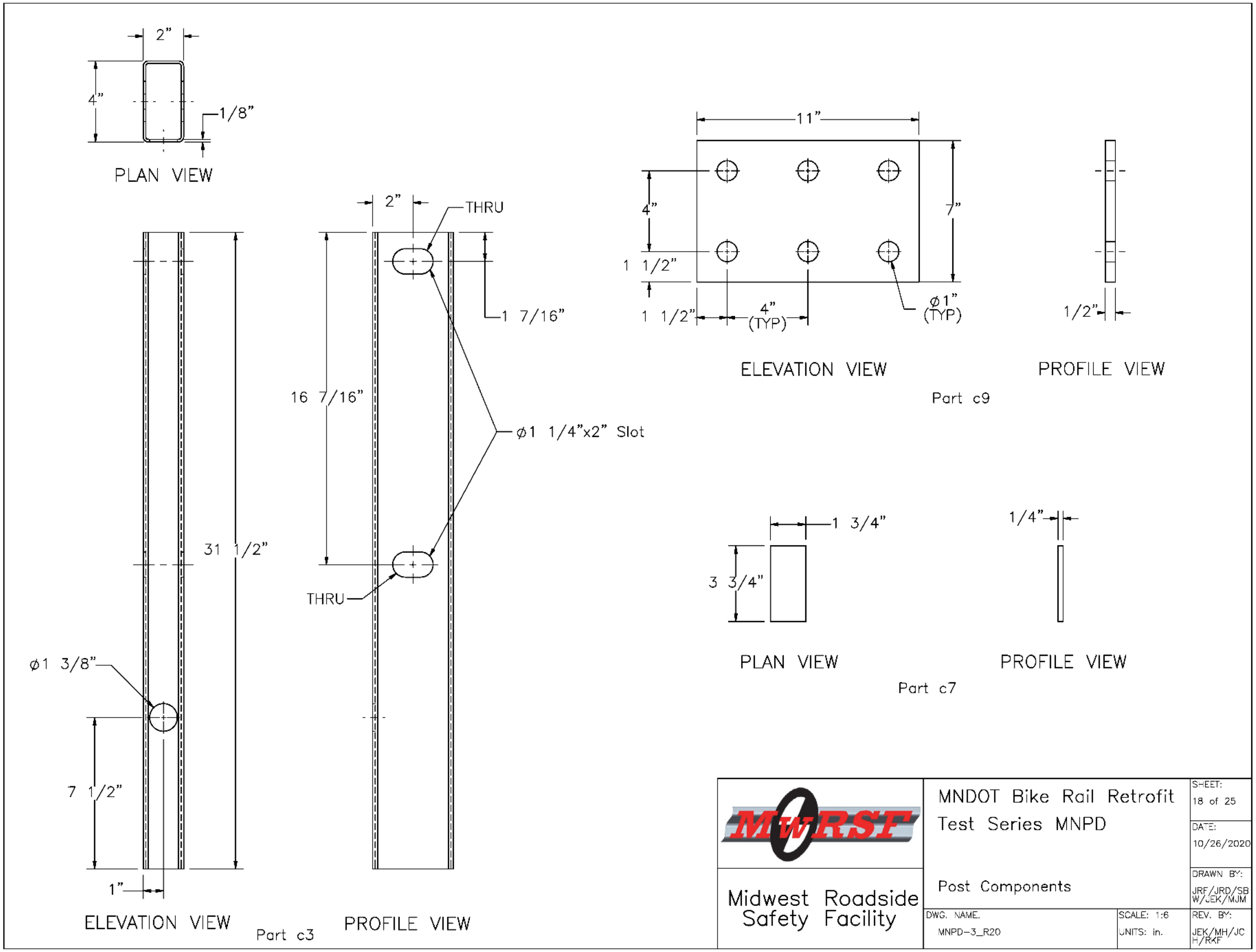


Figure 25. Post Components, Test No. MNPD-3

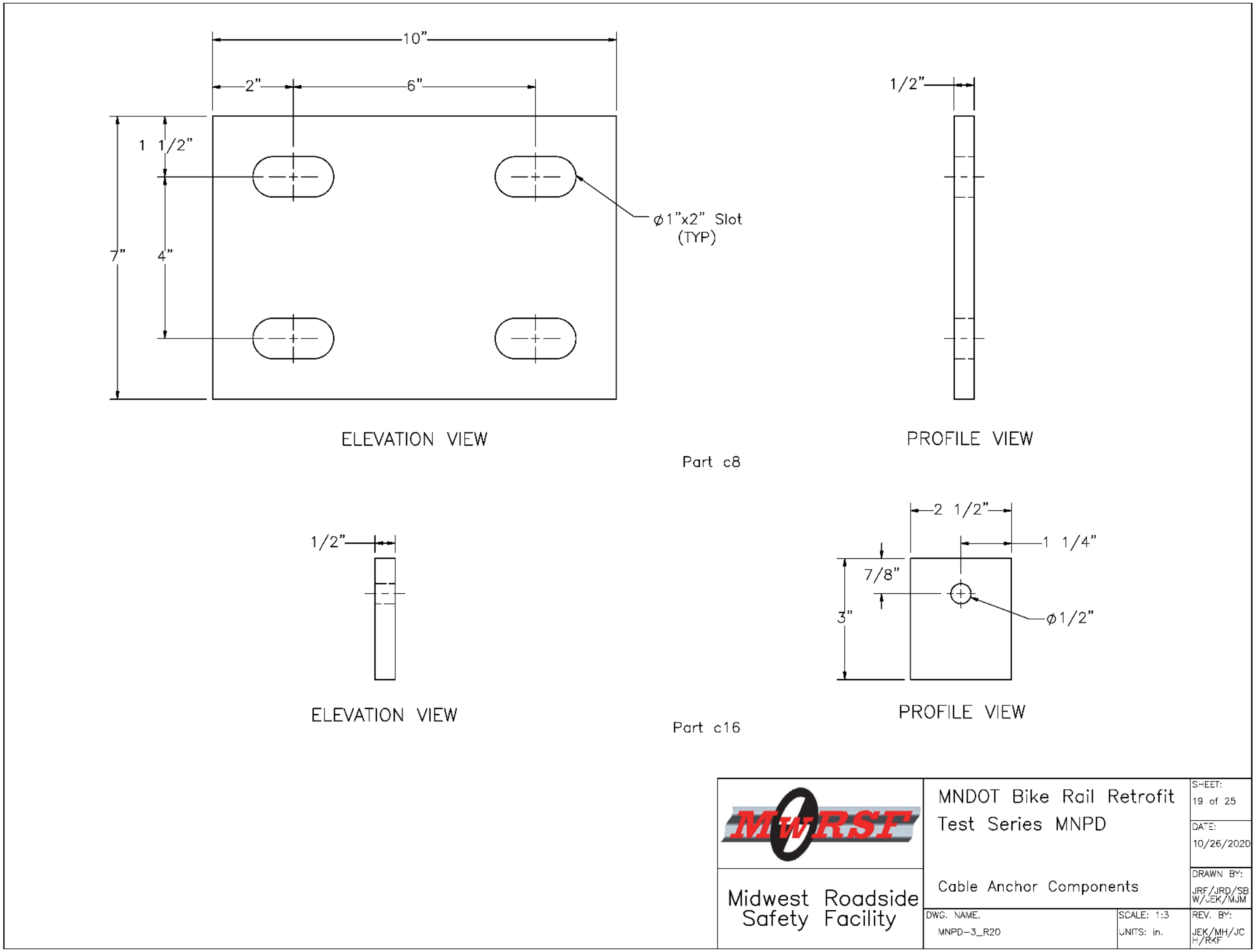
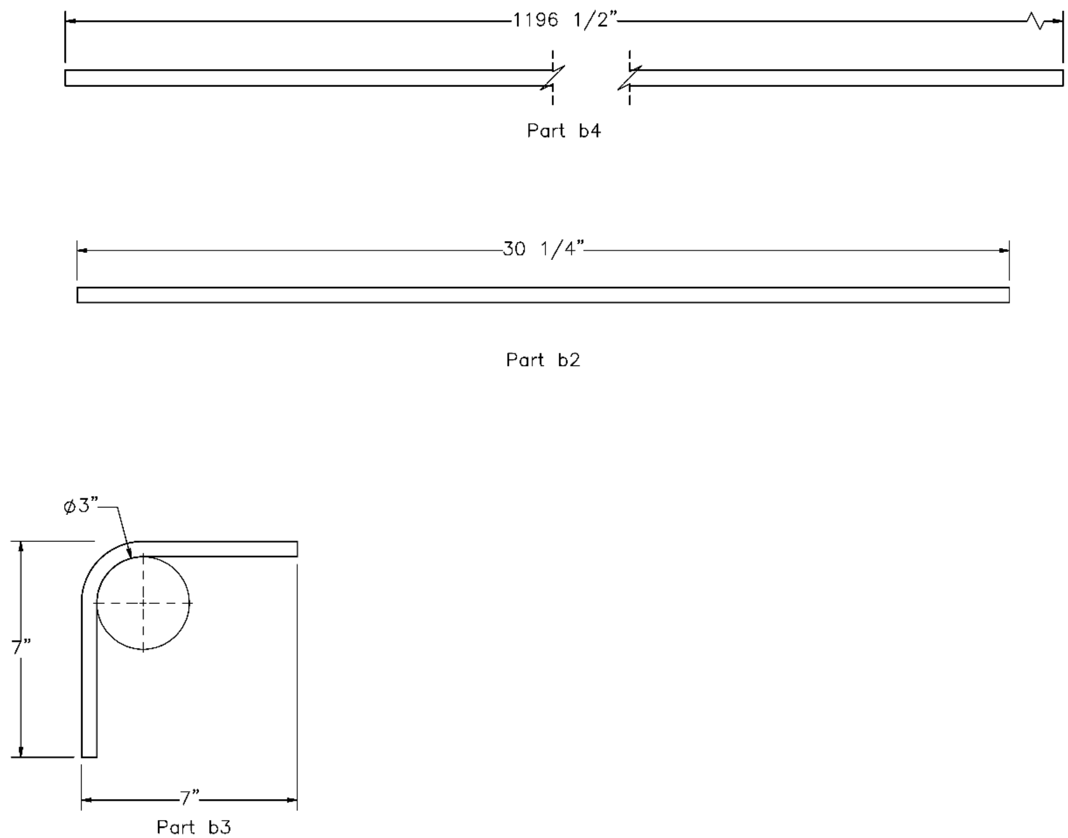


Figure 26. Cable Anchor Components, Test No. MNPD-3



Bar	QTY.	Size	Total Unbent Length	Material Specification	Treatment Specification
b2	63	#4	30 1/4"	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775)
b3	189	#4	12 3/4"	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775)
b4	5	#4	1196 1/2"	ASTM A615 Gr. 60	Epoxy-Coated (ASTM A775)

Midwest Roadside Safety Facility

MNDOT Bike Rail Retrofit Test Series MNPD

System Rebar

SHEET: 20 of 25

DATE: 10/26/2020

DRAWN BY: JRF/JRD/SBW/JEK/MJM

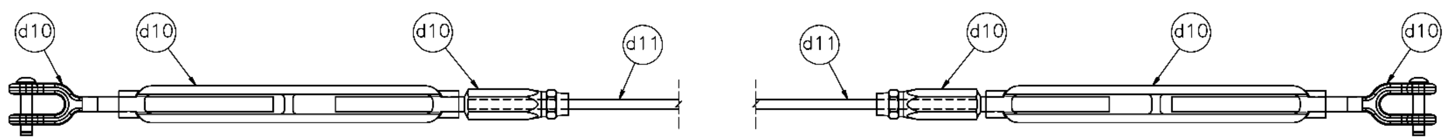
DWG. NAME. MNPD-3_R20

SCALE: 1:5

UNITS: in.

REV. BY: JEK/MH/JCH/RKF

Figure 27. System Rebar, Test No. MNPD-3



ELEVATION VIEW

Note: (1) For all turnbuckles, hand tighten firmly to remove all slack from cable

Item No.	QTY.	Description	Material Specification	Treatment Specification
–	2	Cable Assembly	–	
d10	2	Electroline XD–4031–BX Forged Series Open Body Clevis and Socket Turnbuckle	ASTM F1145 Type 1 Gr. 1 Min. Breaking Strength 9,160 lbs	ASTM A153
d11	1	5/16" Dia. 7x19 FC Wire Rope	ASTM A1023 Table 7 EIP MIN Breaking Strength 9800	ASTM A1007

Midwest Roadside Safety Facility

MNDOT Bike Rail Retrofit
Test Series MNPD

Cable Assembly

SHEET: 21 of 25
DATE: 10/26/2020
DRAWN BY: JRF/JRD/SBW/JEK/MJM
DWG. NAME. MNPD–3_R20
SCALE: 1:5
UNITS: in.
REV. BY: JEK/MH/JCH/RKF

Figure 28. Cable Assembly, Test No. MNPD-3

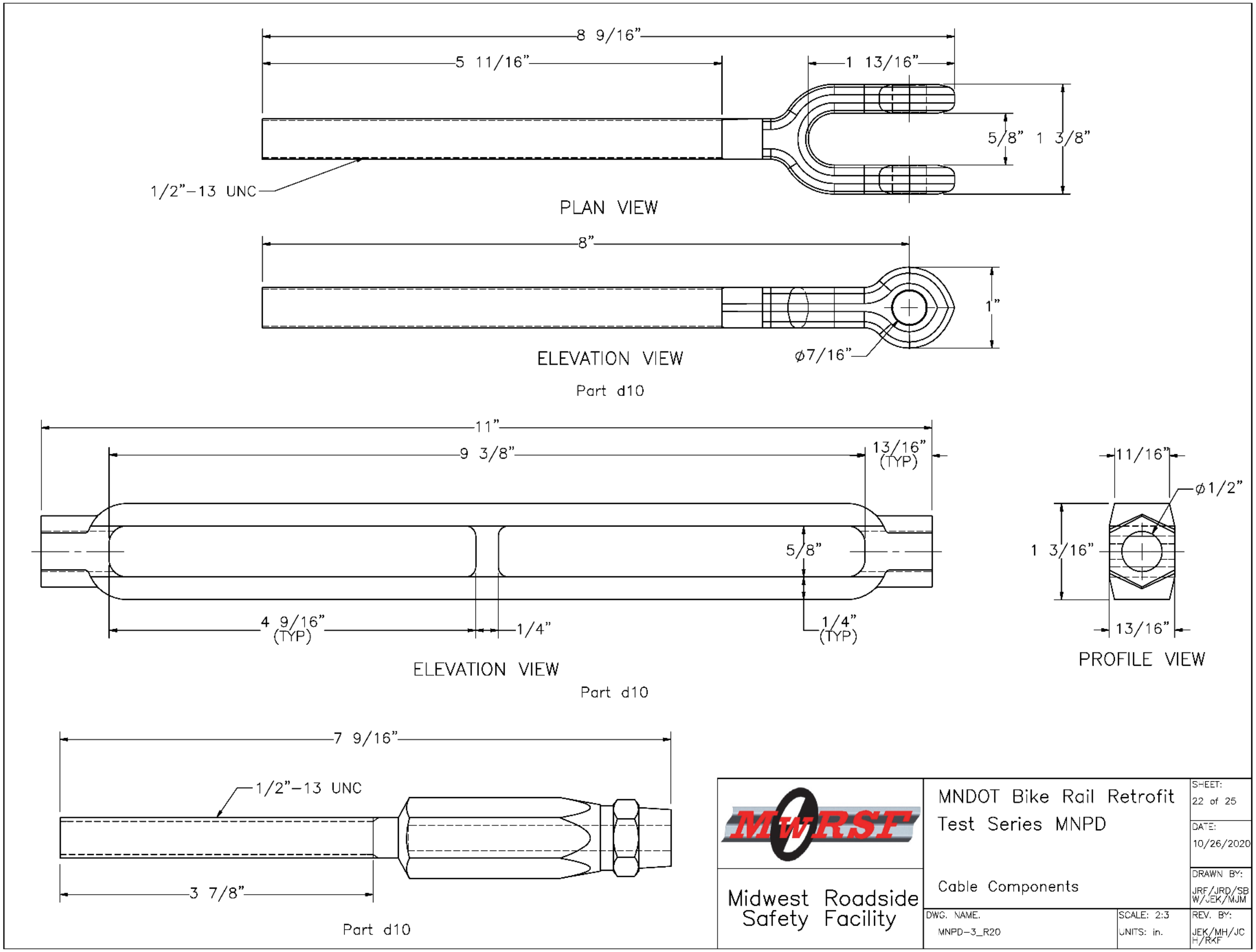


Figure 29. Cable Components, Test No. MNPD-3

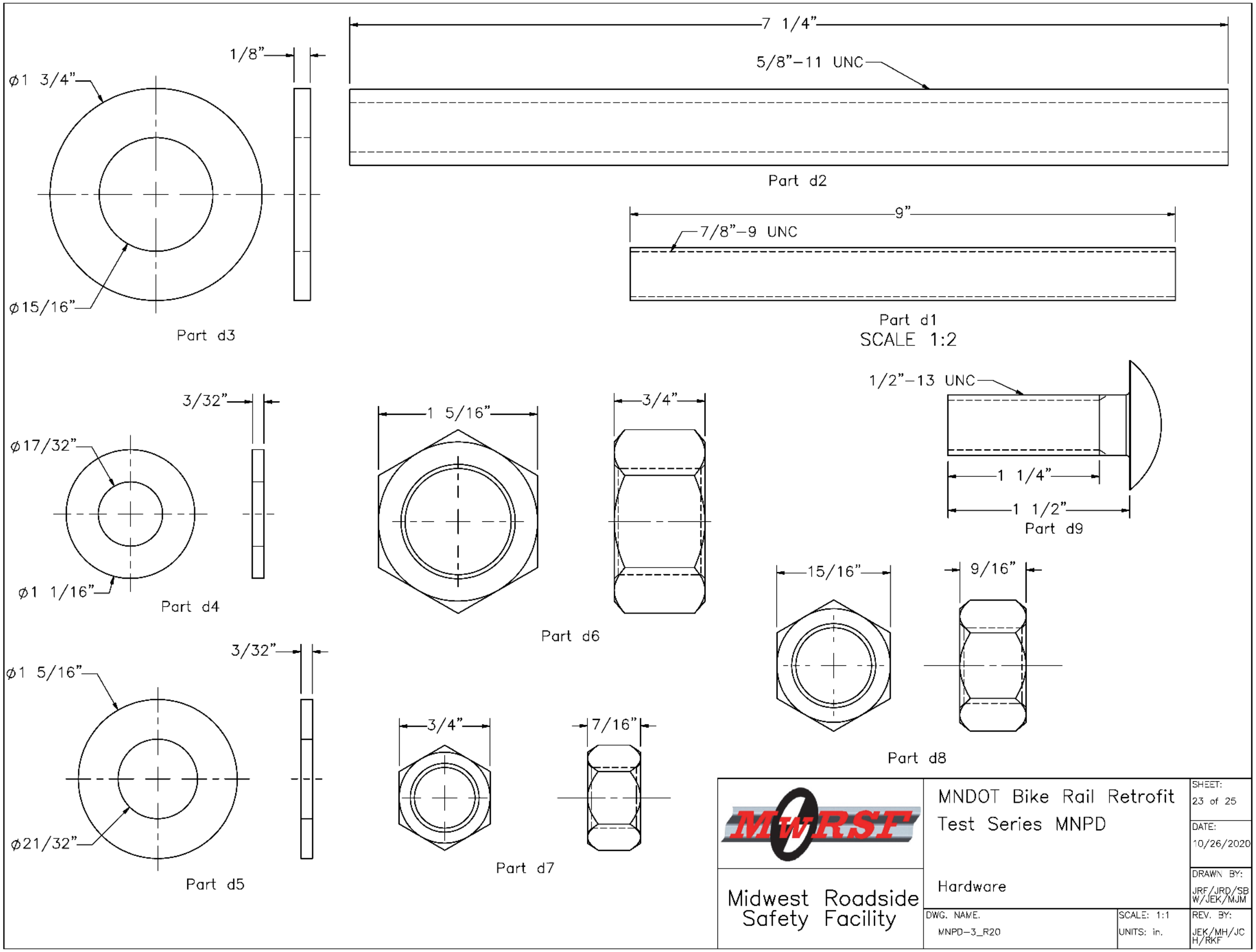


Figure 30. Hardware, Test No. MNPD-3

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	1	Pre-existing Concrete Barrier	–	–	–
b1	1	Concrete for Retrofit	5,000 psi minimum	–	–
b2	63	#4 Bar, 30 1/4" Total Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b3	189	#4 Bar, 12 3/4" Total Unbent Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
b4	5	#4 Bar, 1196 1/2" Total Length	ASTM A615 Gr. 60	Epoxy–Coated (ASTM A775)	–
c1	2	HSS3"x2"x1/8", 66" Long Angled Rail Tube	ASTM A500 Gr. B	See Assembly	–
c2	2	HSS3"x2"x1/8", 25 1/8" Long Angled Rail Tube	ASTM A500 Gr. B	See Assembly	–
c3	9	HSS4"x2"x1/8", 31 1/2" Post	ASTM A500 Gr. B	See Assembly	–
c4	2	HSS3"x2"x1/8", 36 15/16" Long Angled Rail Tube	ASTM A500 Gr. B	See Assembly	–
c5	12	HSS3"x2"x1/8", 117 1/2" Long Rail Tube	ASTM A500 Gr. B	See Assembly	–
c6	4	HSS3"x2"x1/8", 117 1/2" Long Endrail Tube	ASTM A500 Gr. B	See Assembly	–
c7	9	3 3/4"x1 3/4"x1/4" Rail Top Plate	ASTM A709 Gr. 36	See Assembly	–
c8	9	10"x7"x1/2" Post Mounting Plate	ASTM A709 Gr. 36	See Assembly	–
c9	2	7"x11"x1/2" Cable Anchor Plate	ASTM A709 Gr. 36	See Assembly	–
c10	4	5 1/2"x4 9/16"x1/4" Post Attachment Bent Plate	ASTM A709 Gr. 36	See Assembly	–
c11	14	3 1/2"x4 9/16"x1/4" Post Attachment Bent Plate–Expansion End	ASTM A709 Gr. 36	See Assembly	–
c12	14	3 1/2"x4 9/16"x1/4" Post Attachment Bent Plate–Fixed End	ASTM A709 Gr. 36	ASTM A123	–
c13	136	16"x5/8"x5/8" Long Rail Spindle	ASTM A709 Gr. 36	See Assembly	–
c14	2	12 7/8"x5/8"x5/8" Long Spindle	ASTM A709 Gr. 36	See Assembly	–
c15	2	9 9/16"x5/8"x5/8" Long Spindle	ASTM A709 Gr. 36	See Assembly	–
c16	4	3"x2 1/2"x1/2" Cable Anchor Plate Flange	ASTM A709 Gr. 36	See Assembly	–
d1	36	7/8"–9 UNC, 9" Long Threaded Rod	ASTM F1554 Gr. 36	ASTM A153 or B695 Class 55	–
d2	12	5/8"–11 UNC, 7 1/4" Long Threaded Rod	ASTM F1554 Gr. 36	ASTM A153 or B695 Class 55	–
d3	36	7/8" Dia. Hardened SAE Washer	ASTM F436	ASTM A153 or B695 Class 55	–
d4	36	1/2" Dia. Hardened SAE Washer	ASTM F436	ASTM A153 or B695 Class 55	–
d5	12	5/8" Dia. Hardened SAE Washer	ASTM F436	ASTM A153 or B695 Class 55	–
d6	36	7/8"–9 UNC Hex Nut	ASTM A563A	ASTM A153 or B695 Class 55	–
d7	72	1/2"–13 Jam Nut	ASTM A563A	ASTM A153 or B695 Class 55	–

Midwest Roadside Safety Facility

MNDOT Bike Rail Retrofit
Test Series MNPD

Bill of Materials

SHEET: 24 of 25
DATE: 10/26/2020
DRAWN BY: JRF/JRD/SBW/JEK/MJM
REV. BY: JEK/MH/JCH/RKF
DWG. NAME. MNPD–3_R20
UNITS: in.

Figure 31. Bill of Materials, Test No. MNPD-3

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
d8	12	5/8"-9 UNC Hex Nut	ASTM A563A	ASTM A153 or B695 Class 55	–
d9	36	1/2"-13 UNC, 1 1/2" Long Round Head Bolt	ASTM A307 Gr. A	ASTM A153 or B695 Class 55	–
d10	4	Electroline XD-4031-BX Forged Series Open Body Clevis and Socket Turnbuckle	ASTM F1145 Type 1 Gr. 1 Min. Breaking Strength 9,160 lbs	ASTM A153	–
d11	4	5/16" Dia. 7x19 FC Wire Rope	ASTM A1023 Table 7 EIP MIN Breaking Strength 9800	ASTM A1007	–
f1	–	Chemical Epoxy	Min. Bond Strength (1.5 ksi)	–	–

Midwest Roadside Safety Facility	MNDOT Bike Rail Retrofit Test Series MNPD		SHEET: 25 of 25 DATE: 10/26/2020
	Bill of Materials		DRAWN BY: JRF/JRD/SBW/JEK/MJM
	DWG. NAME. MNPD-3_R20	UNITS: in.	REV. BY: JEK/MH/JCH/RKF

Figure 32. Bill of Materials, Test No. MNPD-3

Figure 33. Concrete Barrier Modification, Test No. MNPD-3

Figure 34. Construction Process, Test No. MNPD-3

Figure 35. System Installation, Test No. MNPD-3

Figure 36. Mid-Rail Assembly, Test No. MNPD-3

Figure 37. Upstream Sloped End, Post No. 1, and Post-Rail Connection, Test No. MNPD-3

Figure 38. Upstream Sloped End, Post No. 1, and Post-Rail Connection, Test No. MNPD-3

4 TEST CONDITIONS

4.1 Test Facility

The Outdoor Test Site is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles 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, located on the tow vehicle, was used to increase the accuracy of the test vehicle's impact speed.

A vehicle guidance system developed by Hinch [9] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. diameter guide cable was tensioned to approximately 3,500 lb and supported both laterally and vertically every 100 ft 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.

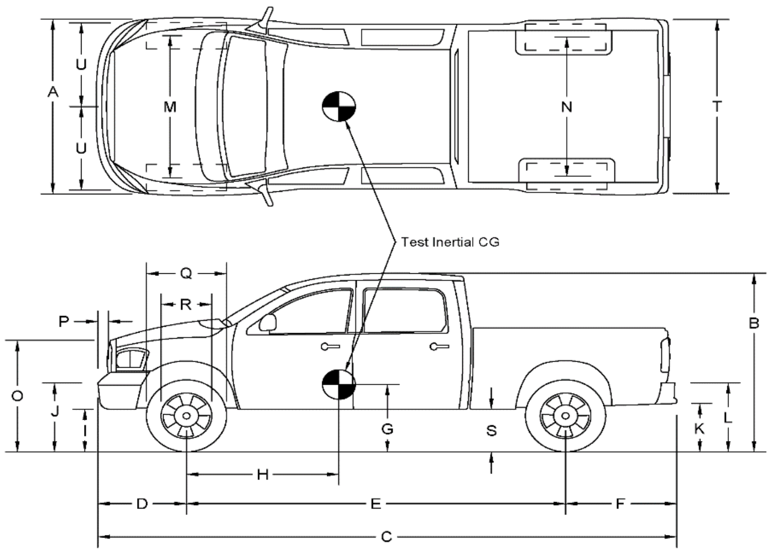
4.3 Test Vehicle

For test no. MNPD-3, a 2014 Dodge Ram 1500 crew cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 4,994 lb, 5,001 lb, and 5,182 lb, respectively. The test vehicle is shown in Figures 39 and 40, and vehicle dimensions are shown in Figure 41.

Figure 39. Test Vehicle, Test No. MNPD-3

Figure 40. Test Vehicle’s Interior Floorboards and Undercarriage, Test No. MNPD-3

		Test Name:	MNPD-3	**VIN No:**	1C6RR6LG9ES236433
Model Year:	2014	**Make:**	Dodge	**Model:**	RAM 1500
Tire Size:	P265/70 R17	**Tire Inflation Pressure:**	40 psi	**Odometer:**	188984



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

A: 77 5/8 (1972) 78±2 (1950±50)		B: 74 3/8 (1889)	
C: 228 5/8 (5807) 237±13 (6020±325)		D: 41 (1041) 39±3 (1000±75)	
E: 140 3/4 (3575) 148±12 (3760±300)		F: 47 1/8 (1197)	
G: 28 3/4 (730) min: 28 (710)		H: 65 15/16 (1675) 63±4 (1575±100)	
I: 12 1/2 (318)		J: 22 3/4 (578)	
K: 20 5/8 (524)		L: 28 5/8 (727)	
M: 68 (1727) 67±1.5 (1700±38)		N: 67 7/16 (1713) 67±1.5 (1700±38)	
O: 45 (1143) 43±4 (1100±75)		P: 2 5/16 (59)	
Q: 30 1/2 (775)		R: 18 1/2 (470)	
S: 15 1/4 (387)		T: 77 1/4 (1962)	

U (impact width): 37 (941)

Mass Distribution - lb (kg)

Gross Static	LF	1365 (619)	RF	1391 (631)
	LR	1244 (564)	RR	1182 (536)

Wheel Center Height (Front):	15 1/4 (387)
Wheel Center Height (Rear):	15 3/8 (391)
Wheel Well Clearance (Front):	35 1/8 (892)
Wheel Well Clearance (Rear):	37 1/2 (953)
Bottom Frame Height (Front):	11 3/8 (289)
Bottom Frame Height (Rear):	12 7/8 (327)
Engine Type:	Gasoline
Engine Size:	3.6L V6
Transmission Type:	Automatic
Drive Type:	RWD
Cab Style:	Crew Cab
Bed Length:	67"

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2701 (1225)	2658 (1206)	2756 (1250)
W-rear	2293 (1040)	2343 (1063)	2426 (1100)
W-total	4994 (2265)	5001 (2268) 5000±110 (2270±50)	5182 (2351) 5165±110 (2343±50)

GVWR Ratings - lb

Front	3700
Rear	3900
Total	6800

Surrogate Occupant Data

Type:	Hybrid II
Mass:	161 lb
Seat Position:	Right/Passenger

Note any damage prior to test: No Damage

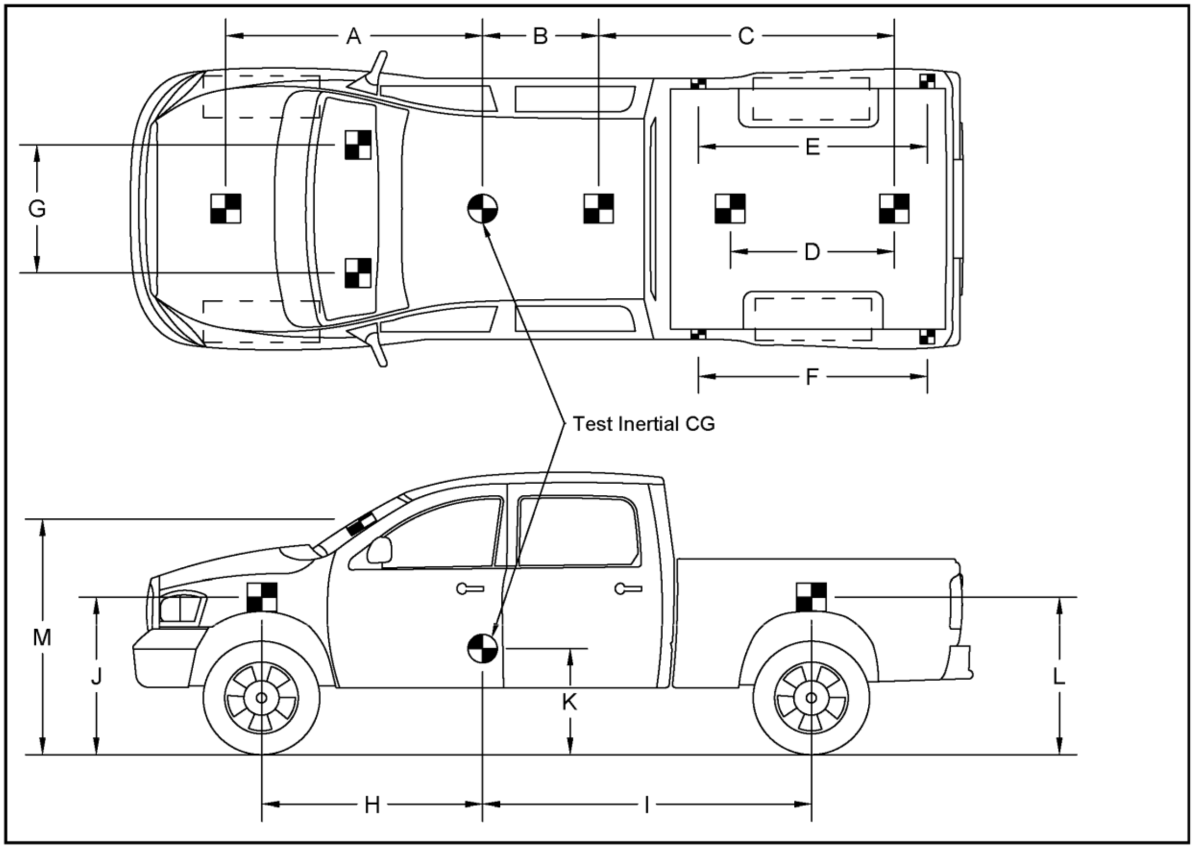
Figure 41. Vehicle Dimensions, Test No. MNPD-3

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [10] 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 Figure 42. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure 42. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicle.

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

		Test Name:	MNPD-3	VIN:	1C6RR6LG9ES236433
Model Year:	2014	Make:	Dodge	Model:	RAM 1500



TARGET GEOMETRY-- in. (mm)

A:	78 13/16	(2002)	E:	57 11/16	(1465)	J:	39 1/4	(997)
B:	34 1/4	(870)	F:	57 7/8	(1470)	K:	28 3/4	(730)
C:	71 3/8	(1813)	G:	28 1/2	(724)	L:	41 11/16	(1059)
D:	47 13/16	(1214)	H:	66	(1676)	M:	62	(1575)
			I:	74 1/2	(1892)			

Figure 42. Target Geometry, Test No. MNPD-3

4.4 Simulated Occupant

For test no. MNPD-3, a Hybrid II 50th-Percentile, Adult Male Dummy equipped with footwear was placed in the right-front seat of the test vehicle with the seat belt fastened. The simulated occupant had a final weight of 161 lb. As recommended by MASH 2016, the simulated occupant 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 systems were mounted near the c.g. of the test vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [11].

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 body of custom-built, SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

4.5.2 Rate Transducers

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

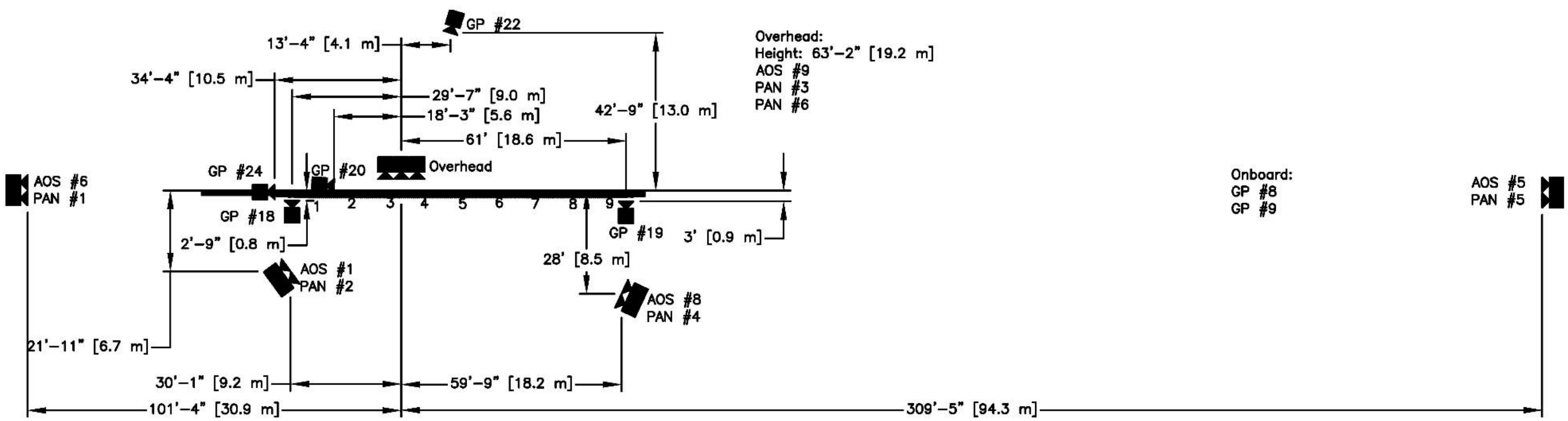
4.5.3 Retroreflective Optic Speed Trap

The retroreflective optic speed trap was used to determine the speed of the test vehicle before impact. Five retroreflective targets, spaced at approximately 18-in. 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, seven GoPro digital video cameras, and six Panasonic digital video cameras were utilized to film test no. MNPD-3. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 43.

The high-speed videos were analyzed using TEMA Motion and Redlake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A digital still camera was also used to document pre- and post-test conditions for test no. MNPD-3.



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-1	AOS Vitcam CTM	500	35 mm	
AOS-5	AOS X-PRI Gigabit	500	100 mm	
AOS-6	AOS X-PRI Gigabit	500	50 mm	
AOS-8	AOS S-VIT 1531	500	25 mm	
AOS-9	AOS TRI-VIT 2236	1000	KOWA 12 mm Fixed	
GP-8	GoPro Hero 4	120		
GP-9	GoPro Hero 4	120		
GP-18	GoPro Hero 6	240		
GP-19	GoPro Hero 6	240		
GP-20	GoPro Hero 6	240		
GP-22	GoPro Hero 7	120		
GP-24	GoPro Hero 7	120		
PAN-1	Panasonic HC-V770	120		
PAN-2	Panasonic HC-V770	120		
PAN-3	Panasonic HC-V770	120		
PAN-4	Panasonic HC-V770	120		
PAN-5	Panasonic HC-VX981	120		
PAN-6	Panasonic HC-VX981	120		

Figure 43. Camera Locations, Speeds, and Lens Settings, Test No. MNPD-3

5 FULL-SCALE CRASH TEST NO. MNPD-3

5.1 Weather Conditions

Test no. MNPD-3 was conducted on June 4, 2020 at approximately 12:00 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

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

Temperature	90° F
Humidity	51%
Wind Speed	11 mph
Wind Direction	190° from True North
Sky Conditions	Sunny
Visibility	9.94 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.48 in.
Previous 7-Day Precipitation	0.58 in.

5.2 Test Description

Test no. MNPD-3 was conducted on a steel bicycle and pedestrian railing system mounted to the existing 32-in. tall, New Jersey-shaped, concrete barrier under the MASH 2016 TL-3 guidelines for test designation no. 3-11. Test designation no. 3-11 involves an impact with a 2270P vehicle at 62 mph and 25 degrees on the bridge railing system. The CIP for this system was selected to maximize the potential for vehicle interaction and snag on the support posts of the metal railing, as discussed in Section 2.2.

Initial vehicle impact was to occur 73³⁄₁₆ in. upstream from the centerline of post no. 4, as shown in Figure 44. The 5,001-lb crew cab pickup truck impacted the combination bicycle pedestrian bridge railing system at a speed of 63.4 mph and at an angle of 25.3 degrees. The actual point of impact was 71¼ in. upstream from the centerline of post no. 4.

In the test, the vehicle was safely captured and smoothly redirected by the 32-in. tall, New Jersey-shape, concrete barrier with attached bicycle and pedestrian bridge railing system. During the redirection of the vehicle, the right-front fender and right-front corner of the engine hood snagged on the upstream corner of the first spindle upstream from post no. 4. The maximum vehicle-to-barrier contact occurred when the right-front corner of the engine hood and the right-front fender snagged on the upstream face of post no. 4, thus resulting in the quarter panel being torn rearward and away from the vehicle. However, this vehicle snag was not determined to pose a risk to the vehicle's occupant compartment nor did it pose any concerns for excessive change in velocity or deceleration of the vehicle. Vehicle redirection was primarily facilitated by the concrete barrier. Other vehicle contact with the steel bicycle and pedestrian bridge railing system occurred when the vehicle's right-front fender engaged the lower tube rail and the upstream corner of the first spindle upstream from post no. 4 as well as when the right-front rearview mirror made contact with the upper tube rail. The vehicle came to rest 204 ft – 6 in. downstream and 16 ft – 5 in. laterally in front of the barrier after brakes were applied.

A detailed description of the sequential impact events is contained in Table 4. Sequential photographs are shown in Figures 45 and 46. Documentary photographs of the crash test are shown in Figure 47. The vehicle trajectory and final position are shown in Figure 48.

Figure 44. Impact Location, Test No. MNPD-3

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

Time (sec)	Event
0.000	Vehicle's right-front tire impacted concrete barrier 71¼ in. upstream from post no. 4.
0.002	Vehicle’s bumper cover contacted concrete barrier.
0.008	Vehicle's right-front fender deformed, and vehicle's right headlight contacted concrete barrier.
0.012	Vehicle's right fender contacted concrete barrier.
0.022	Vehicle's engine hood and right-front door deformed.
0.034	Vehicle's right fender contacted metal rail.
0.042	Vehicle's right-rear door deformed.
0.044	Vehicle pitched upward.
0.054	Vehicle's right-front door contacted concrete barrier.
0.056	Vehicle's hood contacted post no. 4.
0.062	Vehicle’s right fender contacted post no.4
0.094	Vehicle's right-front window shattered, and simulated occupant's head passed through right-front window.
0.112	Vehicle's left-front tire became airborne.
0.114	Vehicle's grille became disengaged.
0.144	Vehicle's right-rear tire contacted concrete barrier.
0.172	Vehicle's rear bumper contacted concrete barrier.
0.178	Simulated occupant's head reentered through right-front window. Vehicle was parallel to the system. Parallel vehicle velocity was 51.8 mph.
0.220	Vehicle's left-rear tire became airborne.
0.260	Vehicle's right-front tire became airborne.
0.292	Vehicle's tailgate detached from left side.
0.312	System came to a rest.
0.358	Vehicle's right-rear tire became airborne.
0.362	Vehicle exited the system at a velocity of 53.0 mph.
0.476	Vehicle's right-front tire regained contact with ground.
0.594	Vehicle pitched upward.
0.628	Vehicle rolled away from system.
0.742	Vehicle's right-rear tire regained contact with ground.
0.796	Vehicle's left-front tire regained contact with ground.
0.938	Vehicle's left-rear tire regained contact with ground.
2.782	Vehicle's left-rear tire became disengaged.
4.558	Vehicle came to rest.

0.000 sec

0.000 sec

0.050 sec

0.050 sec

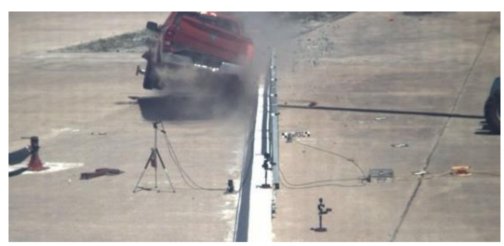
0.100 sec

0.100 sec

0.200 sec

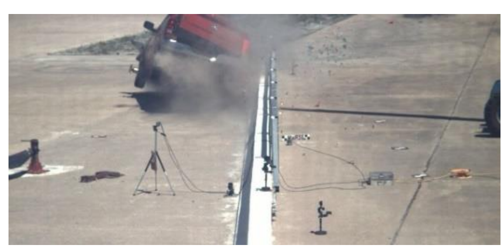
0.200 sec

0.300 sec



0.300 sec

0.450 sec

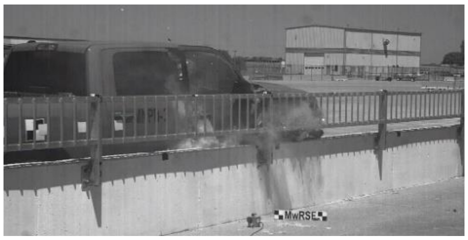


0.450 sec

Figure 45. Sequential Photographs, Test No. MNPD-3


0.000 sec


0.000 sec


0.025 sec


0.025 sec


0.050 sec


0.050 sec


0.100 sec


0.100 sec


0.150 sec


0.150 sec


0.225 sec


0.225 sec

Figure 46. Sequential Photographs, Test No. MNPD-3

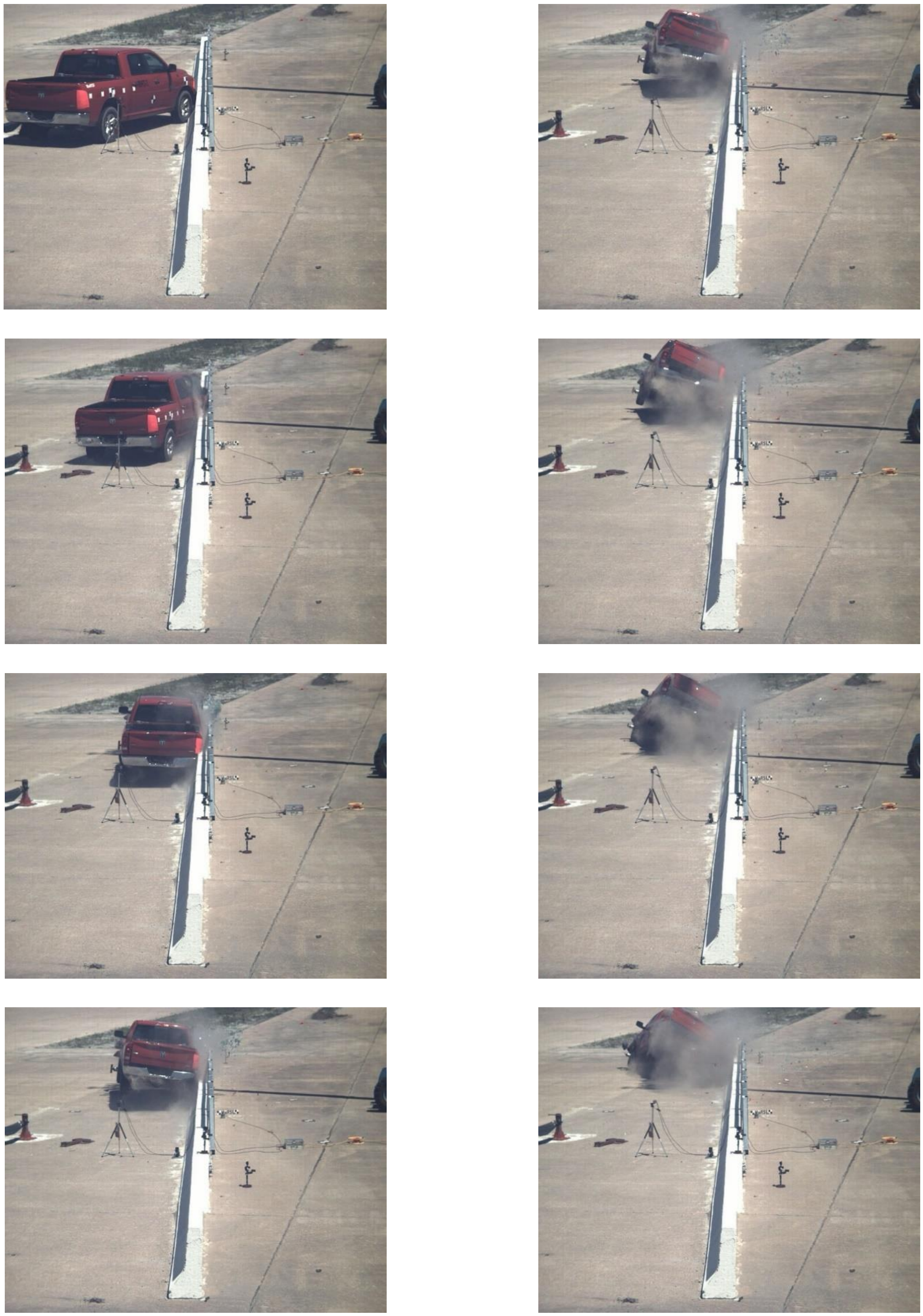


Figure 47. Documentary Photographs, Test No. MNPD-3

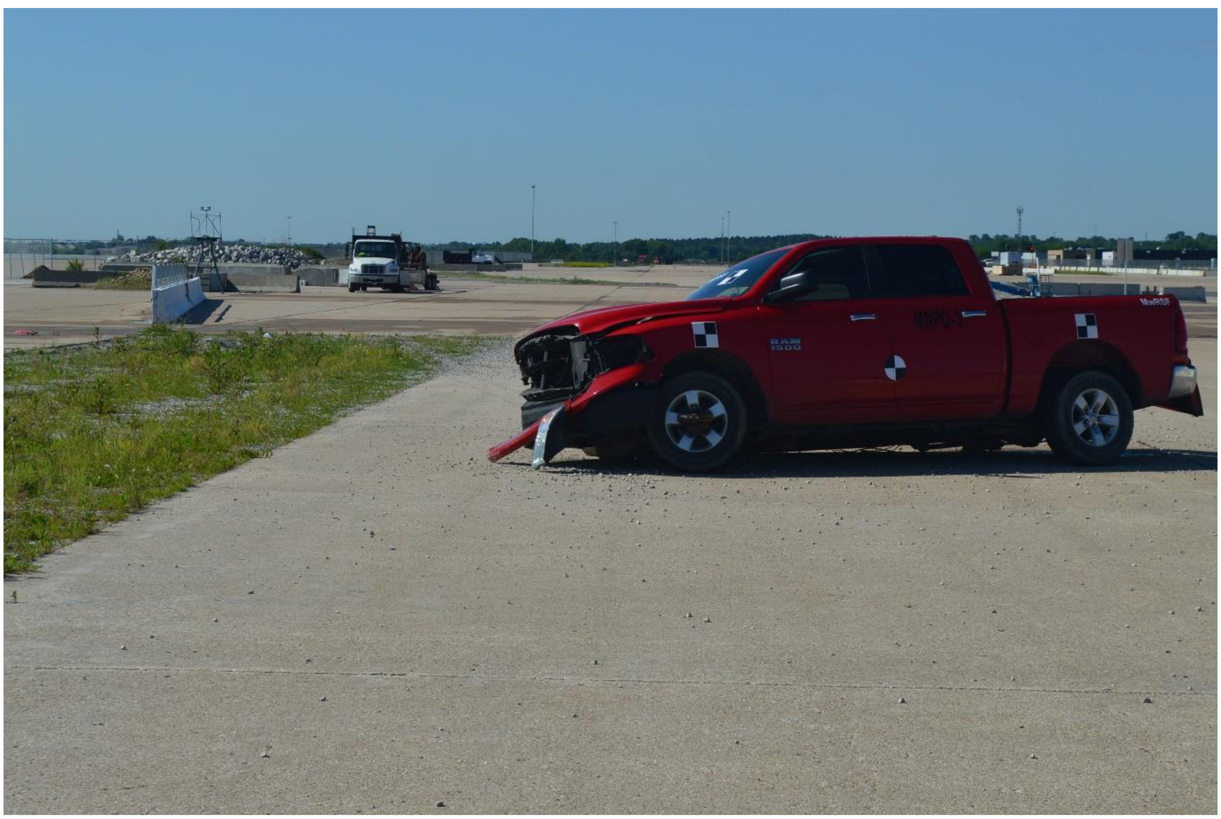


Figure 48. Vehicle Final Position and Trajectory Marks, Test No. MNPD-3.

5.3 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 49 through 58. Barrier damage largely consisted of contact marks, scraping, and gouging of the concrete barrier. The length of vehicle contact along the barrier extended downstream approximately 13 ft – 11 in., starting 14½ in. upstream from the impact point.

Contact marks measuring ¼ in. wide were found on the top corner of the lower rail, starting 23¼ in. upstream from post no. 4 and extending 31¾ in. downstream to the end of the rail. Contact marks ½ in. wide were found on the bottom corner of the lower rail, starting 10½ in. upstream from post no. 4 and extending 8½ in. downstream. Contact marks were found on the front face, near the top corner of the lower rail, starting 5¼ in. downstream from post no. 4 and extending 12 in. downstream. Minor vehicle contact occurred with the first vertical spindle located upstream from post no. 4, as shown in Figures 54 and 55. A small amount of vehicle debris remained on the spindle. Contact marks on the front face of the first spindle upstream from post no. 4 extended upward 7½ in. from the top face of the lower rail, as shown in Figure 53. Contact marks on the upstream face of post no. 4 began 7½ in. from the top and extended 11½ in. downward. A separate contact mark was observed on the downstream face of post no. 4, starting 4¾ in. from the top and extending 1¼ in. downward.

Tire marks were visible on the front face of the J-shape concrete barrier, starting 14½ in. upstream from impact and extending 167 in. downstream across the traffic side of the barrier. Scuff marks were also found along the length of vehicle contact. Gouging was found on the front face of the barrier measuring 4½ in. long and located 15 in. from the top edge and extending 5½ in. downstream from the impact point with a height of 4 in. and a width of ¼ in. Scraping measuring 10 in. long was located 31 in. downstream from the impact point and 7 in. from the top front corner of the concrete barrier with a width of ½ in. Chipping, measuring 2½ in. long, was located 17 in. downstream from the impact point and 13¼ in. below the top front corner of the concrete barrier with a width of ¾ in. Additional chipping, measuring 11¼ in. long, was located on the top traffic-side corner of the concrete barrier 24½ in. downstream from post no. 4 with a height of ¾ in.

The maximum lateral permanent set of the barrier system was 0.4 in. between post nos. 5 and 6, as measured in the field. The maximum lateral dynamic barrier deflection, including rotation of the metal railing, was 0.6 in. on the upper rail at post no. 6, as determined from high-speed digital video analysis. The working width of the system was found to be 23.2 in., also determined from high-speed digital video analysis. The ZOI was 12¾ in. Barrier deflections are shown schematically in Figure 59.

Figure 49. System Damage, Test No. MNPD-3

Figure 50. System Damage, Test No. MNPD-3

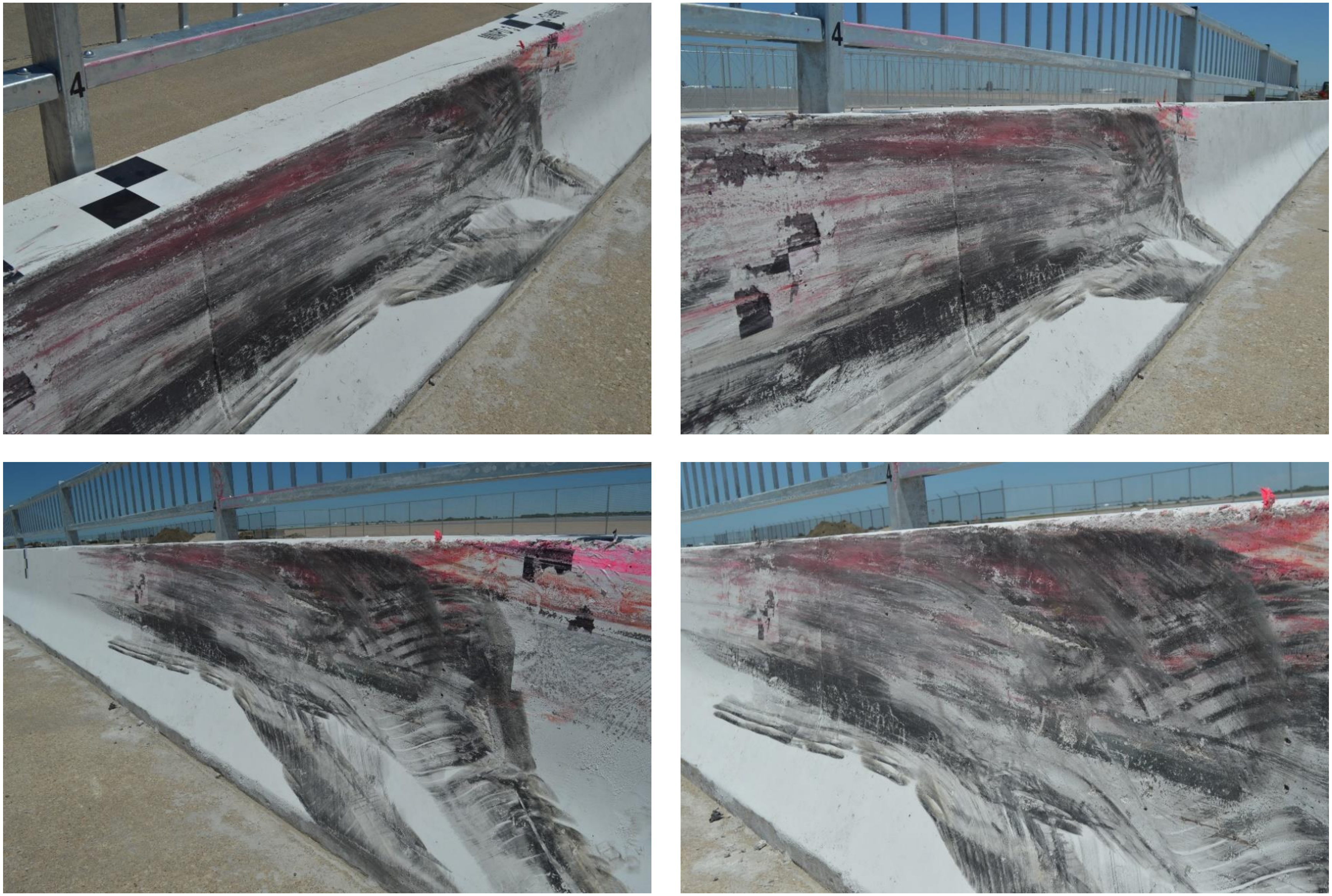


Figure 51. Tire Marks and Concrete Gouging, Test No. MNPD-3

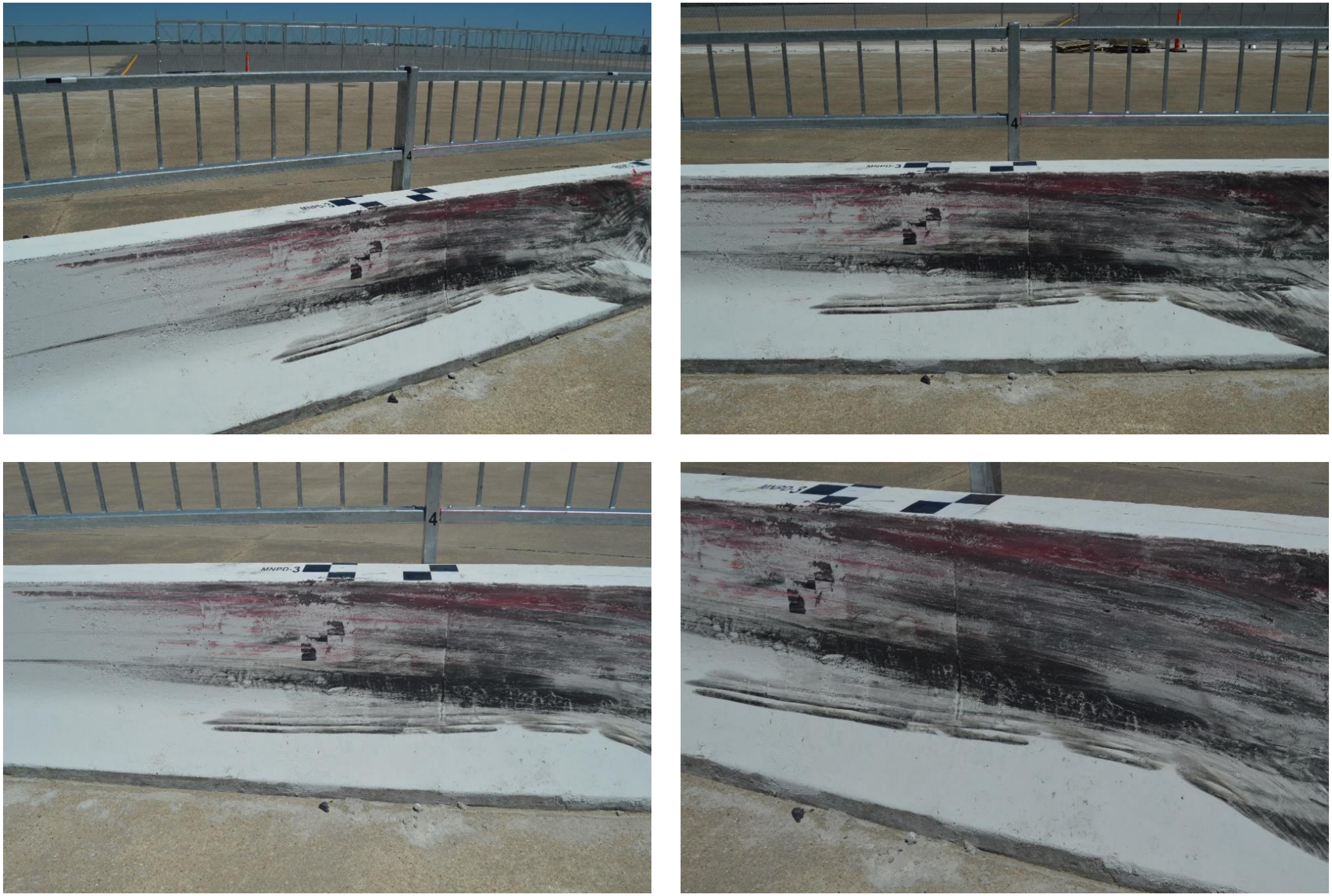


Figure 52. Tire Marks and Concrete Scraping, Test No. MNPD-3

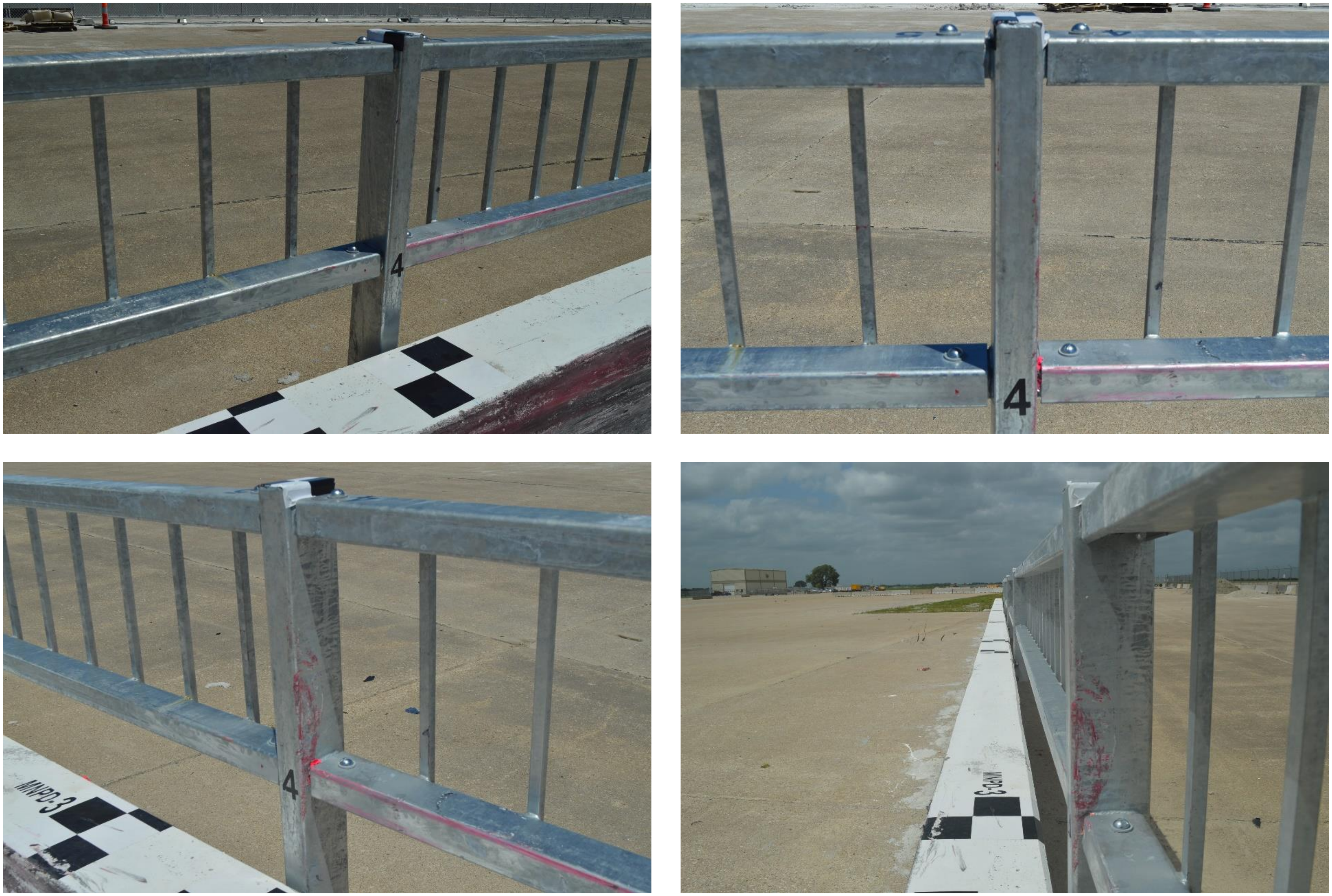


Figure 53. Rail and Post No. 4 Damage, Test No. MNPD-3

Figure 54. Rail and Post No. 4 Damage, Test No. MNPD-3

Figure 55. Spindle Contact and Debris, Test No. MNPD-3

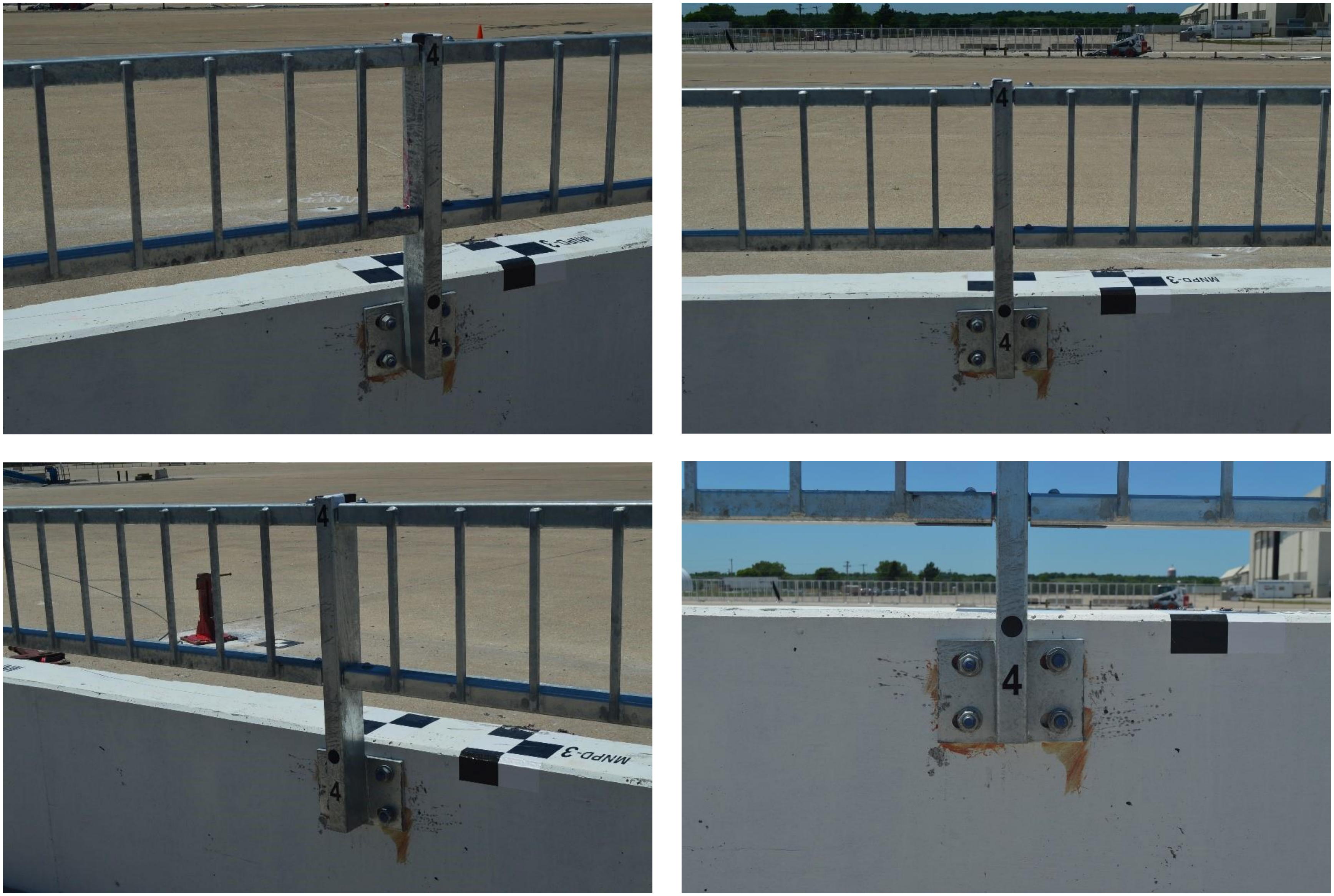


Figure 56. Rail and Post No. 4 Damage, Test No. MNPD-3

Figure 57. Rail and Post No. 4 Damage, Test No. MNPD-3

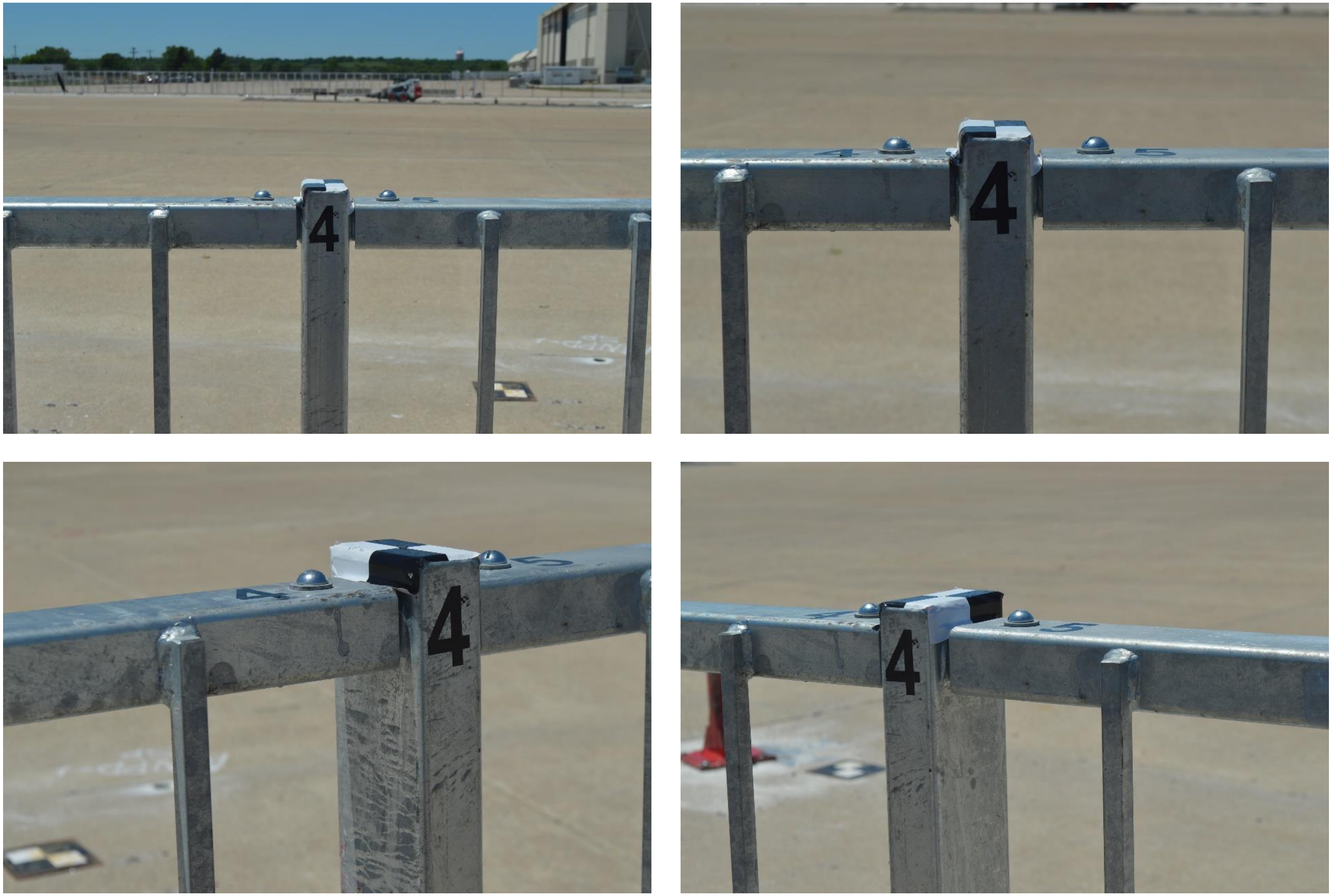


Figure 58. Rail and Post No. 4 Damage, Test No. MNPD-3

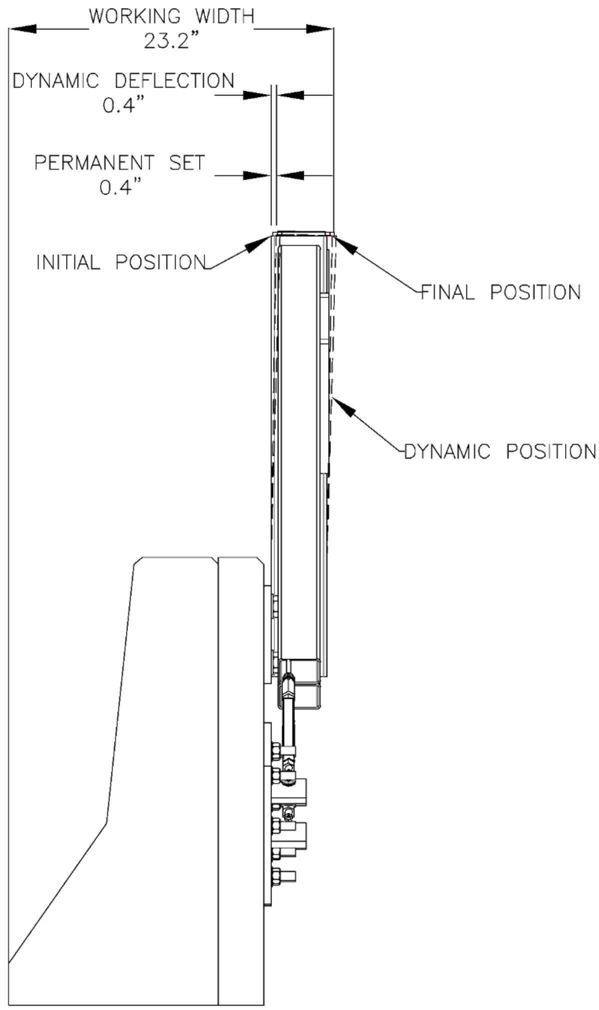


Figure 59. Permanent Set Deflection, Dynamic Deflection, and Working Width, Test No. MNPD-3

5.4 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 60 through 67. The maximum occupant compartment deformations are listed in Table 5 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment, and none of the established MASH 2016 deformation limits were violated. Occupant compartment deformations along with the corresponding locations are provided in Appendix C.

The majority of the damage was concentrated on the right-front corner and right side of the vehicle, where impact had occurred, as shown in Figure 60. The vehicle's steel engine hood was deformed across its entirety, and the right edge was deformed inward, as shown in Figures 60, 61, and 62. The left side of the front bumper was pushed downward. The right side of the bumper was crushed inward. The right-front fender was dented, torn front to back, and pushed upward near the right-front door, as shown in Figures 61 and 62. The right-front cast aluminum rim was severely deformed, fractured, and crushed, as shown in Figure 62. The grille was pushed backward and fractured around the right-side headlight assembly. The right-side headlight was disengaged from the vehicle, as shown in Figure 62. The right-side, upper control arm was fractured. The right side of the radiator was pushed backward. Denting and scraping were observed across the entire right side. The right-front door was slightly ajar, and creases were found in the door's sheet metal. The right-side window glass shattered, as shown in Figures 61, 62, and 63. The right-rear door was dented and ajar. The right side of the truck bed was dented, and the fuel hatch was ajar. The right-rear wheel detached, as shown in Figure 63. The right side of the rear bumper was torn and pushed downward. The right side of the windshield had a hairline crack, as shown in Figure 67. The roof and remaining window glass remained undamaged.

Figure 60. Vehicle Damage, Test No. MNPD-3

Figure 61. Vehicle Damage, Test No. MNPD-3

Figure 62. Vehicle Damage, Test No. MNPD-3

Figure 63. Vehicle Damage, Test No. MNPD-3

Figure 64. Vehicle Floor Pan, Test No. MNPD-3

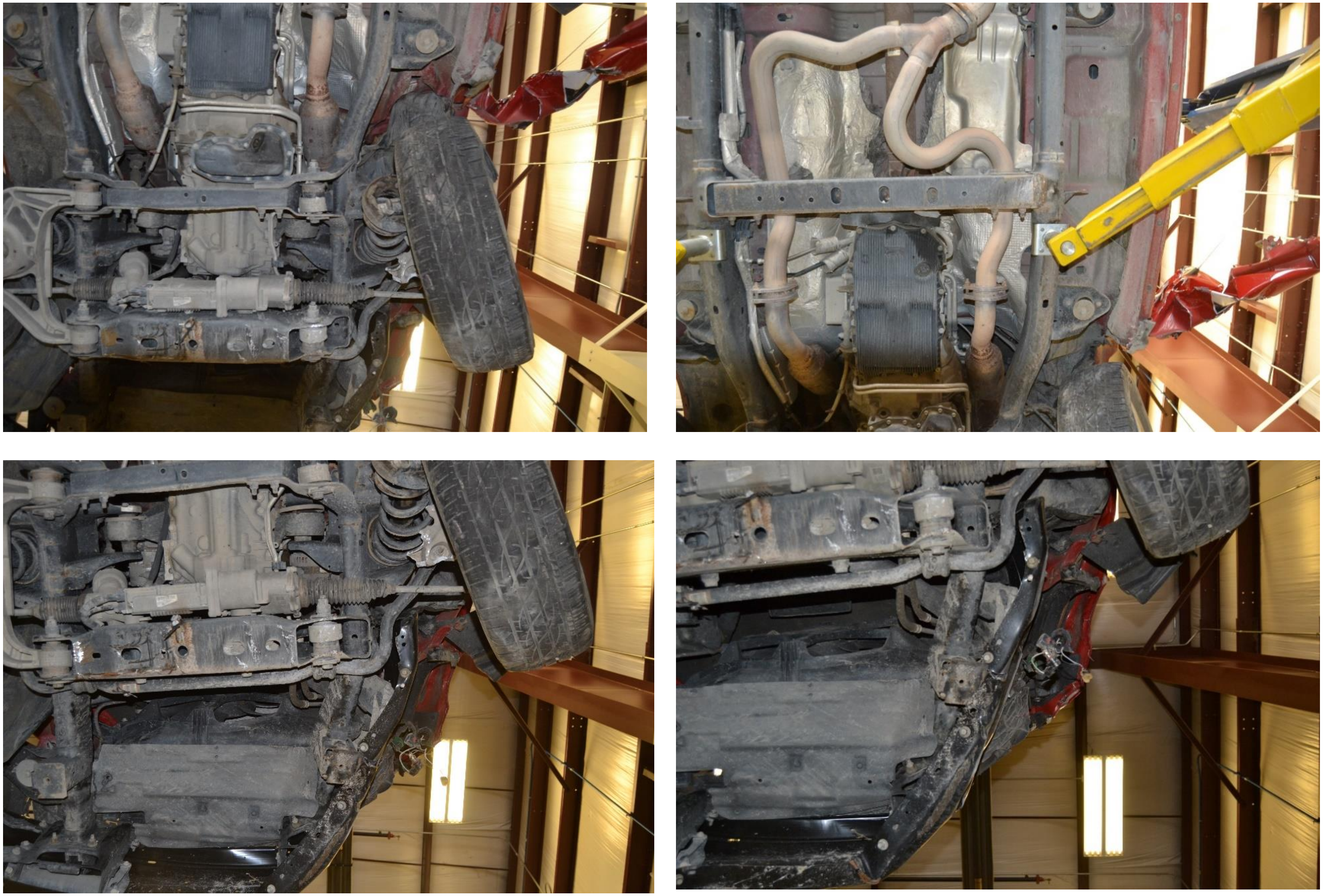


Figure 65. Undercarriage Damage, Test No. MNPD-3

Figure 66. Undercarriage Damage, Test No. MNPD-3

Figure 67. Windshield Damage (Post-Test), Test No. MNPD-3

Table 5. Maximum Occupant Compartment Deformations by Location, Test No. MNPD-3

LOCATION	MAXIMUM INTRUSION in.	MASH 2016 ALLOWABLE INTRUSION in.
Wheel Well & Toe Pan	2.4	≤ 9
Floor Pan & Transmission Tunnel	0.1	≤ 12
A-Pillar	1.7	≤ 5
A-Pillar (Lateral)	0.0	≤ 3
B-Pillar	0.9	≤ 5
B-Pillar (Lateral)	0.5	≤ 3
Side Front Panel (in Front of A-Pillar)	2.9	≤ 12
Side Door (Above Seat)	0.0	≤ 9
Side Door (Below Seat)	0.5	≤ 12
Roof	1.1	≤ 4
Windshield	0.0	≤ 3
Side Window	Shattered due to contact with dummy's head	No shattering resulting from contact with structural member of test article
Dash	1.6	N/A

N/A – Not applicable

5.5 Head Ejection

It is noted in MASH 2016 under the occupant risk evaluation criteria that no shattering of a side window from direct contact with a structural member of the test article should occur. This requirement is believed to extend to direct contact between a test article and the side window as an occupant's head would be considered to be at elevated risk of contacting the test article, thus increasing the potential for serious injury, even if an impact does not violate any other MASH 2016 evaluation criteria. Thus, occupant head ejection out of the occupant compartment should be tracked for tall longitudinal barriers and considered a pass/fail test evaluation criterion.

Onboard high-speed footage with camera views of the occupant's head movement for test no. MNPD-3 are shown in Figures 68 and 69. Video analysis of the positioning of the dummy's head during test no. MNPD-3 showed that head contact with the bridge railing system did not occur, as shown in Figures 70 through 73. Therefore, test no. MNPD-3 was deemed to have successfully passed the MASH 2016 evaluation criteria using a stringent interpretation of the occupant risk criteria.

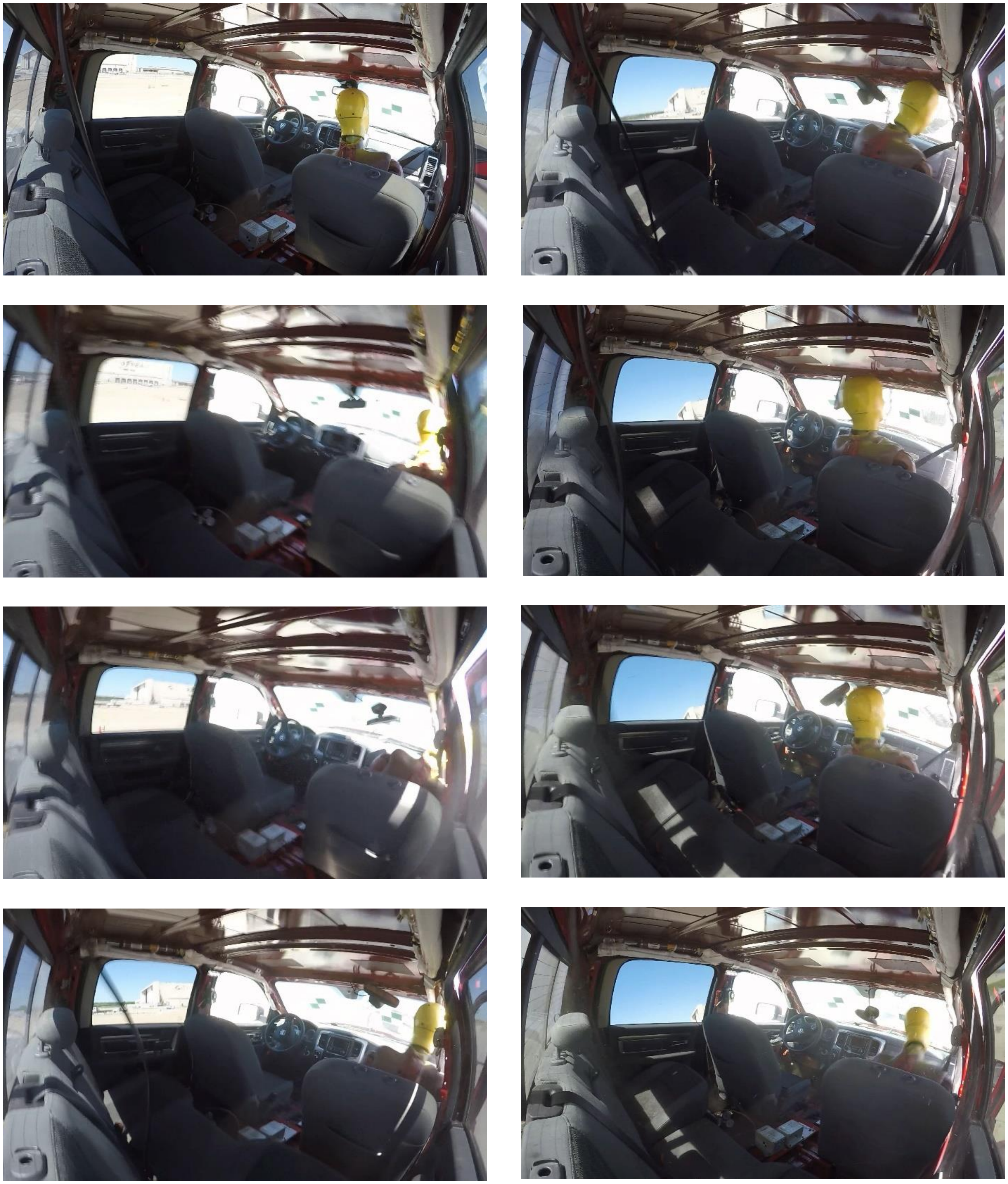


Figure 68. Documentary Photographs, Test No. MNPD-3

Figure 69. Documentary Photographs, Test No. MNPD-3

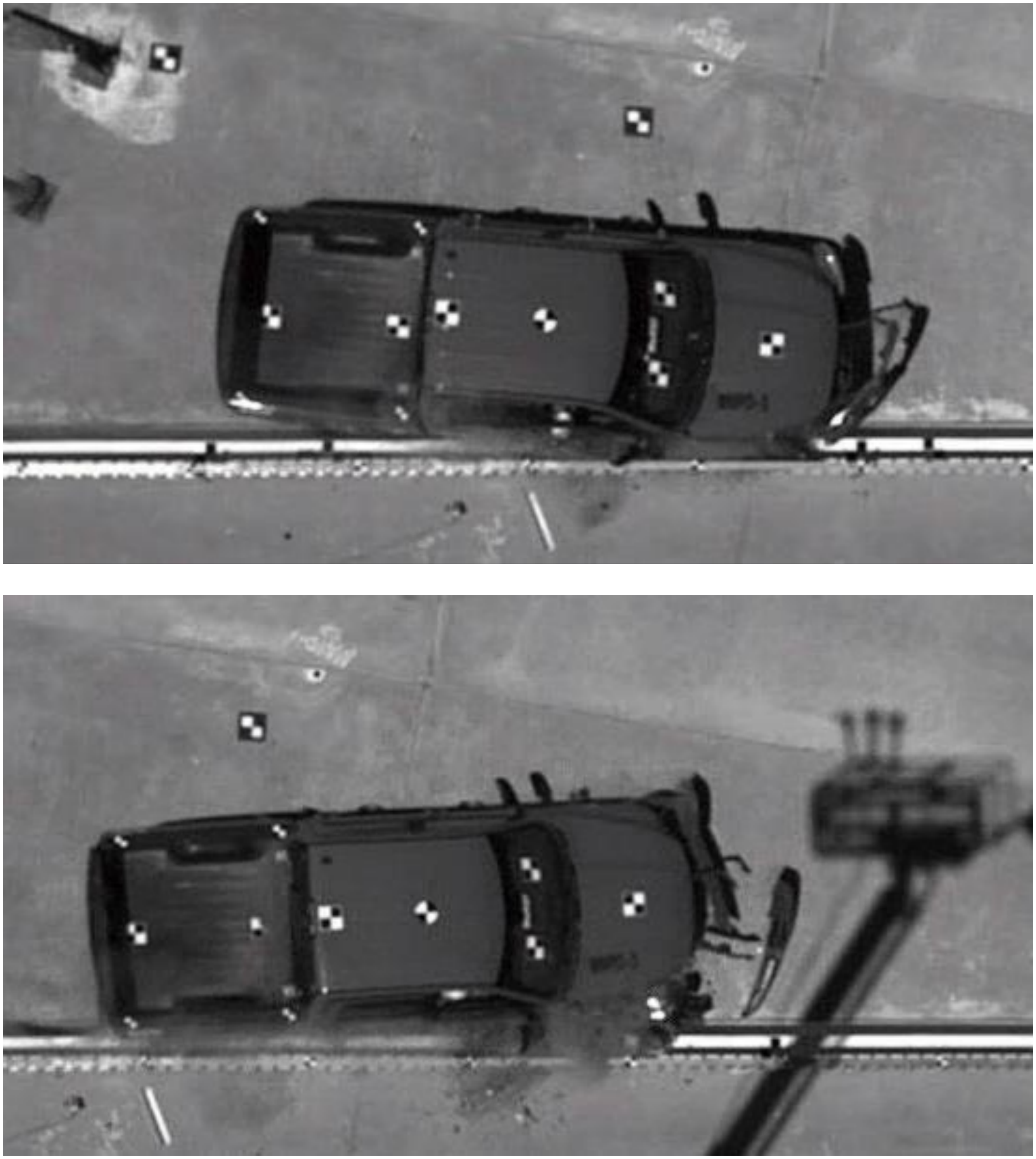


Figure 70. Overhead View of Head Ejection, Test No. MNPD-3

Figure 71. Upstream View of Head Ejection, Test No. MNPD-3

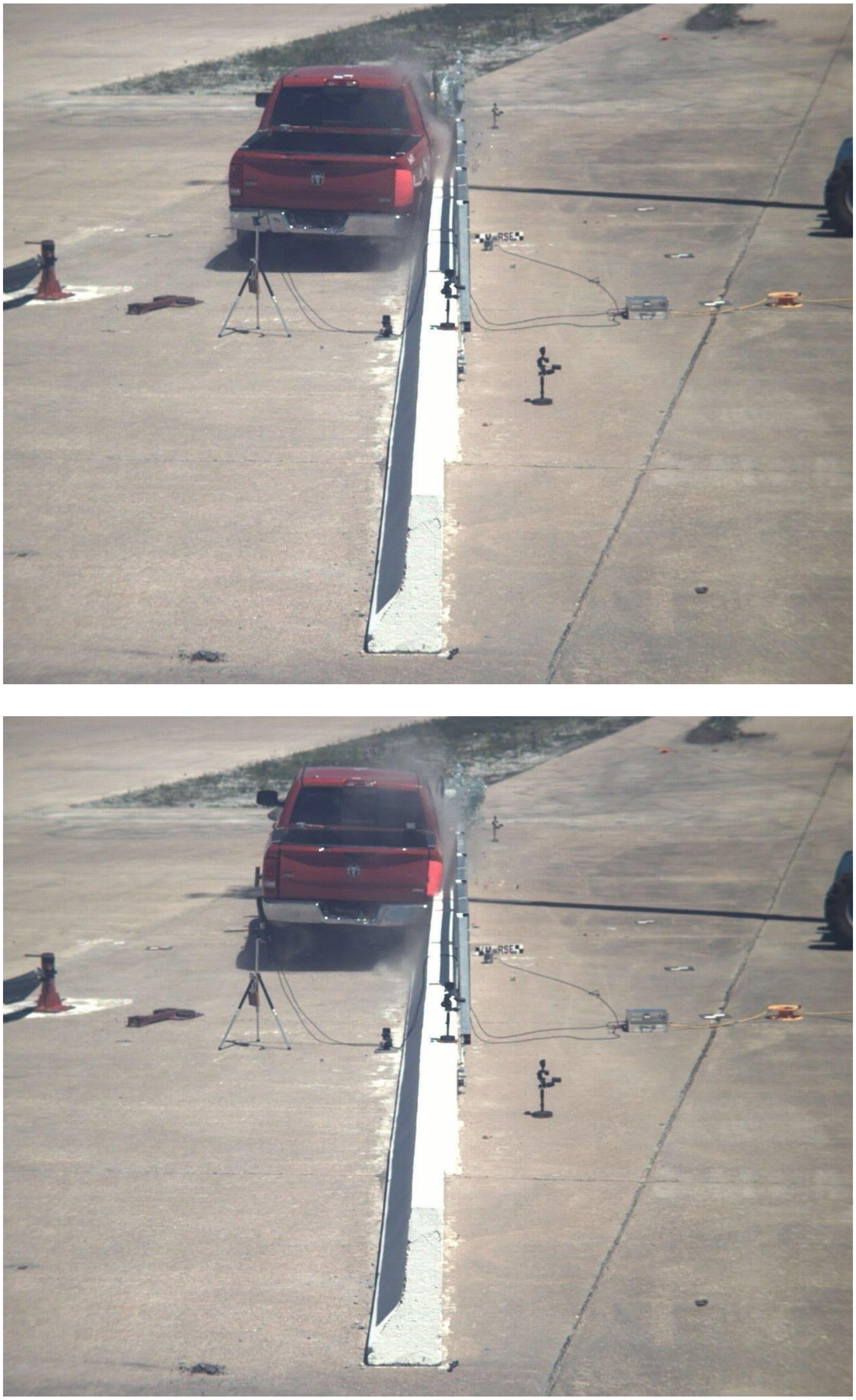


Figure 72. Downstream View of Head Ejection, Test No. MNPD-3

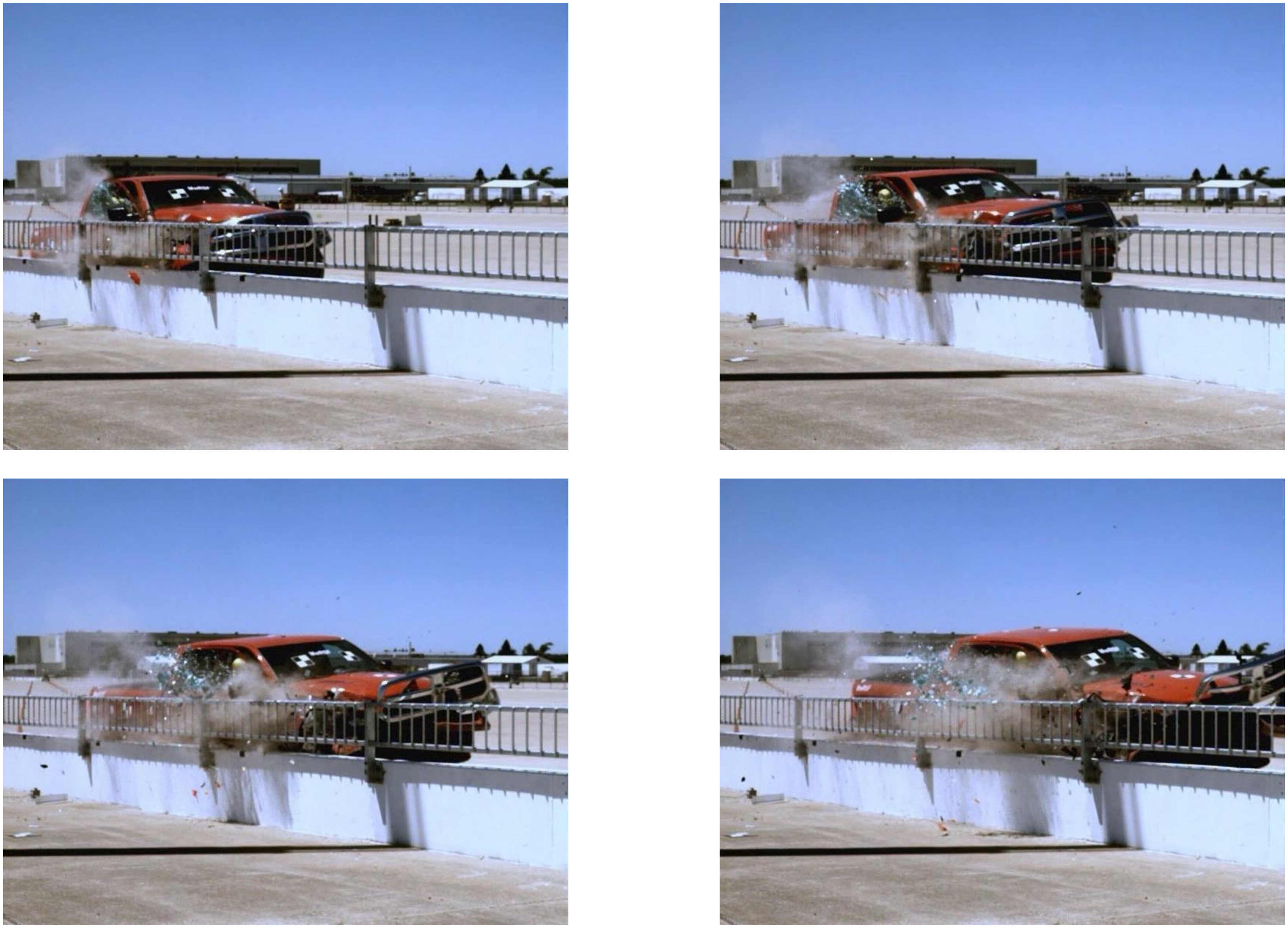


Figure 73. Angled Downstream View of Head Ejection, Test No. MNPD-3

5.6 Occupant Risk

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

Table 6. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MNPD-3

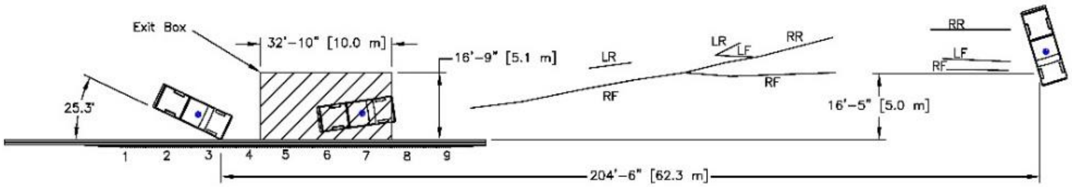
Evaluation Criteria		**Transducer**		**MASH 2016 Limits**
		SLICE-1	**SLICE-2 (primary)**	
OIV ft/s	Longitudinal	-14.77	-14.37	±40
	Lateral	-23.36	-24.87	±40
ORA g's	Longitudinal	-5.90	-5.87	±20.49
	Lateral	-11.21	-10.53	±20.49
Maximum Angular Displacement degrees	Roll	22.9	22.8	±75
	Pitch	-9.2	-10.3	±75
	Yaw	-43.7	-43.9	not required
THIV ft/s		28.31	29.26	not required
PHD g's		11.51	10.87	not required
ASI		1.41	1.51	not required

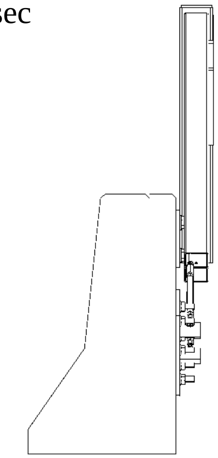
5.7 Discussion

The analysis of the results for test no. MNPD-3 showed that the system adequately contained and redirected the 2270P vehicle with negligible displacements of the barrier. A summary of the test results and sequential photographs are shown in Figure 74. 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 D, were deemed acceptable because they did not adversely influence occupant risk nor cause rollover. All occupant risk measures were within limits. After impact, the vehicle exited the barrier at an angle of 6.6 degrees, and its trajectory did not violate the bounds of the exit box. During the test, the simulated occupant's head protruded out of the right-side window and extended into the ZOI but did not contact the metal railing system. Therefore, test no. MNPD-3 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.

It should be noted that the top barrier width should have been 9 in. versus 9¼ in., as discussed in Section 3. Although the top barrier width was ¼ in. wider than used in MnDOT's standard J-barrier, vehicle contact between the 2200P pickup truck and the upper metal railing would likely provide similar barrier performance.

0.000 sec | 0.150 sec | 0.250 sec | 0.350 sec | 0.450 sec





- Test Agency .... MwRSF
- Test Number MNPD-3
- Date 6/4/2020
- MASH 2016 Test Designation No. 3-11
- Test Article .... Minnesota Bicycle and Pedestrian Bridge Railing System
- Total Length .... 120 ft – 2 in.
- Key Component - Post
  - Length .... 31½ in.
  - Width .... 4 in.
  - Spacing .... 2 in.
- Key Component – Concrete Barrier
  - Length .... 120 ft – 2 in.
  - Width .... 9 in.
  - Height .... 32 in.
- Vehicle Make /Model .... 2014 Dodge Ram
  - Curb .... 4,994 lb
  - Test Inertial .... 5,001 lb
  - Gross Static .... 5,182 lb
- Impact Conditions
  - Speed .... 63.4 mph
  - Angle .... 25.3 degrees
  - Impact Location .... 71¼ in. upstream from post no. 4
- Impact Severity .... 122.7 kip-ft > 52 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed .... 53.0 mph
  - Angle .... 5.1 degrees
- Exit Box Criterion .... Pass
  Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance ..... 204 ft – 6 in. downstream and 16 ft – 5 in. laterally in front
- Vehicle Damage .... Moderate
  - VDS [12] 01-RFQ-5
  - CDC [13] 01-RYEW-5
  - Maximum Interior Deformation .... 2.9 in.
- Test Article Damage .... minimal
- Maximum Test Article Deflections
  - Permanent Set .... 0.4 in.
  - Dynamic .... 0.6 in.
  - Working Width .... 23.2 in.
  - ZOI .... 12.75 in.
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s	Longitudinal	-14.77	-14.37	±40 (12.2)
	Lateral	-23.36	-24.87	±40 (12.2)
ORA g's	Longitudinal	-5.90	-5.87	±20.49
	Lateral	-11.21	-10.53	±20.49
Maximum Angular Displacement degrees	Roll	22.9	22.8	±75
	Pitch	-9.2	-10.3	±75
	Yaw	-43.7	-43.9	Not required
THIV – ft/s		28.31	29.26	Not required
PHD – g's		11.51	10.87	Not required
ASI		1.41	1.51	Not required

Figure 74. Summary of Test Results and Sequential Photographs, Test No. MNPD-3

6 SUMMARY AND CONCLUSIONS

6.1 Summary

The objective of this study was to crash test and evaluate a J-shape concrete traffic barrier with an attached metal bicycle and pedestrian railing according to the MASH 2016 TL-3 safety performance criteria. The combination bridge railing system could be used when pedestrians and bicycles are present on vehicular bridges. An early variation of the MnDOT bicycle and pedestrian railing system was previously crash tested by MwRSF according to NCHRP Report No. 350 safety standards [1,4]. Thus, it was desired to have the currently-used bridge rail system meet the MASH 2016 TL-3 standards [2,5]. The combination bridge railing system was evaluated through full-scale vehicle crash testing using only MASH 2016 test designation no. 3-11, which involves a 2270P pickup truck impacting the combination railing system at a speed of 62 mph at an angle of 25 degrees. Test designation no. 3-11 was deemed critical on the 32-in. tall, J-shape concrete barrier due to the anticipated vehicle-to-rail contact, vehicle snag on metal railing components, potential for vehicle instabilities, occupant risk, and peak lateral loading to the barrier system.

Test designation no. 3-10, which involves the 1100C vehicle, was not deemed necessary or critical for two reasons. First, the 1100C small car vehicle has already impacted this concrete barrier in NCHRP Project No. 22-14(2) with test no. 2214NJ-1 at the TL-3 impact conditions and with acceptable results [7]. The 1100C small car vehicle impacted 18 ft – 6 in. downstream from the upstream end of the New Jersey-shape concrete barrier at a speed of 60.8 mph at an angle of 26.1 degrees. For test no. 2214NJ-1 with an 1100C small car vehicle, the NJ-shape concrete barrier did not sustain any permanent set deflection or dynamic deflection, and the working width was approximately 16 in. [7]. Note that the barrier's top width and base width were 6 in. and 15 in., respectively [7]. The 1100C small car vehicle exited the concrete barrier at a speed of 49.3 mph with an angle of 6.6 degrees. For test no. 2214NJ-1, the longitudinal and lateral OIV were 16.47 ft/s and 35 ft/s, respectively. The longitudinal and lateral ORA were 5.49 g's and 8.08 g's, respectively. Second, the ZOI for test no. 2214NJ-1 was approximately 7 in. when the top barrier width was 6 in. In the current system, the MnDOT J-shape concrete barrier has a top width of 9¼ in., and the nearest metal railing component is positioned 9¾ in. away from the top-front corner of the concrete barrier. Therefore, no 1100C small car contact would occur with the bicycle and pedestrian railing system. Thus, the prior 1100C small car crash test would also serve as the successful test and evaluation for the NJ-shape or J-shape concrete barrier with an attached bicycle and pedestrian railing system.

As noted in Section 3, the top width of the MnDOT's J-barrier was to be 9 in. versus 9¼ in. Although the J-barrier was ¼ in. wider than intended, no small car contact with the metal railing would occur with a 9 in. top width.

Test no. MNPD-3 was conducted to evaluate a 32-in. tall, J-shape concrete barrier with an attached crashworthy bicycle and pedestrian metal railing. The critical impact point for test no. MNPD-3 was selected as 73³⁄₁₆ in. upstream from the centerline of post no. 4 to maximize vehicle snag on the bicycle and pedestrian railing system. The 5,001-lb crew cab pickup truck impacted the combination concrete barrier with bicycle and pedestrian rail at a speed of 63.4 mph and at an angle of 25.3 degrees. The vehicle was captured and redirected by the 32-in. tall, New Jersey-shape concrete barrier with upper metal railing.

During the redirection of the pickup truck vehicle, the right-front fender and right-front corner of the engine hood contacted the upstream side of the post downstream from the impact point. This contact resulted in sufficient snag to peel back the right-front fender and deform the engine hood. However, the vehicle snag did not penetrate the occupant compartment, violate crush limits, or result in elevated occupant risk measures. The vehicle exited the barrier in a stable manner and came to rest 204 ft – 6 in. downstream from and 16 ft – 5 in. laterally in front of the barrier. The dynamic barrier deflection was 0.6 in. The combination bridge railing system's working width was 23.2 in., and the ZOI value was 12¾ in. Again, all occupant risk values were found to be within evaluation limits, and the occupant compartment deformations were also deemed acceptable. Subsequently, test no. MNPD-3 was determined to satisfy the safety performance criteria for MASH 2016 test designation no. 3-11. A summary of the test evaluation is shown in Table 7.

It should be noted that the top barrier width should have been 9 in. versus 9¼ in., as discussed in Section 3. Although the top barrier width was ¼ in. wider than used in MnDOT's standard J-barrier, vehicle contact between the 2270P pickup truck and the upper metal railing would likely provide similar barrier performance.

6.2 Conclusions

MnDOT's bicycle and pedestrian railing attached to a 32-in. tall, reinforced, concrete barrier was evaluated through a full-scale vehicle crash test, test designation no. 3-11, according to the MASH 2016 TL-3 safety criteria. The 32-in. tall, reinforced-concrete, combination system was found to satisfy all evaluation criteria for MASH 2016 test designation no. 3-11.

Table 7. Summary of Safety Performance Evaluation

<table>
<tr><td>Evaluation Factors</td><td colspan="4">Evaluation Criteria</td><td>Test No. MNPD-3</td></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="12">Occupant Risk</td><td rowspan="2">D.</td><td colspan="3">1. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</td><td>S</td></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</td><td>40 ft/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 REFERENCES

1. Ross, H.E., Sicking, D.l., and Zimmer, R.A., *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program (NCHRP) Report No. 350, National Cooperative Highway Research Program, Washington, D.C., 1993.

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

3. *AASHTO/FHWA Joint Implementation Agreement for the AASHTO Manual for Assessing Safety Hardware,* American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 2015.

4. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Holloway, J.C., *Design and Evaluation of the TL-4 Minnesota Combination Traffic/Bicycle Bridge Rail,* Research Report No. TRP-03-74-98, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, November 30, 1998.

5. Minnesota Department of Transportation (DOT), Design – *Structural Tube Railing (Design T-2)*, Fig. 5-397.158e(A), https://www.dot.state.mn.us/bridge/bridgedetails2.html, October 15, 2020.

6. Stolle, C.J., Reid, J.D., and Faller, R.K., Zone of Intrusion for Permanent 9.1-Degree *Single-Slope Concrete Barriers*, Research Report No. TRP-03-292-13, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, March 14, 2014.

7. Polivka, K.A., Faller, R.K., Sicking, D.L., Rohde, J.R., Bielenberg, R.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)*, Research Report No. TRP-03-177-06, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, October 13, 2006.

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

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

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

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

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

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

8 APPENDICES

Appendix A. Material Specifications

Table A-1. Bill of Materials, Test No. MNPD-3

Item No.	Description	Material Specification	Material Specification used for Test No. MNPD-3	Reference
a1	Pre-existing Concrete Barrier	-	Gr 60 rebar. 28-day concrete compressive strength of 4,500 psi according to MwRSF CAD 2214 NJ-2 R3	n/a
b1	Concrete for Retrofit	5,000 psi minimum		Ticket #2003509
b2	#4 Bar, 30¼" Total Length	ASTM A615 Gr. 60		H#6008587
b3	#4 Bar, 12¾" Total Unbent Length	ASTM A615 Gr. 60		H#6007274
b4	#4 Bar, 1196 1/2" Total Length	ASTM A615 Gr. 60		H#B165038
b5	#4 Bar, 79'-6 13/16" Total Length	ASTM A706 Gr. 36		H#B165038
c1	HSS3"x2"x1/8", 66" Long Angled Rail Tube	ASTM A500 Gr. B		H#2100315
c2	HSS3"x2"x1/8", 25 1/8" Long Angled Rail Tube	ASTM A500 Gr. B		H#2100315
c3	HSS4"x2"x1/8", 31 1/2" Post	ASTM A500 Gr. B		H#1196498
c4	HSS3"x2"x1/8", 36 15/16" Long Angled Rail Tube	ASTM A500 Gr. B		H#2100315
c5	HSS3"x2"x1/8", 117 1/2" Long Rail Tube	ASTM A500 Gr. B		H#2100315
c6	HSS3"x2"x1/8", 117 1/2" Long End Rail Tube	ASTM A500 Gr. B		H#2100315
c7	3 3/4"x1¾"x¼" Rail Top Plate	ASTM A709 Gr. 36		H#813L65970
c8	10"x7"x1/2" Post Mounting Plate	ASTM A709 Gr. 36		H#Y0665
c9	7"x11"x1/2" Cable Anchor Plate	ASTM A709 Gr. 36		H#Y0665
c10	5 1/2"x4 9/16"x¼" Post Attachment Bent Plate	ASTM A709 Gr. 36		H#813L65970

Table A-2. Bill of Materials, Test No. MNPD-3, Cont.

Item No.	Description	Material Specification	Material Specification used for Test No. MNPD-3	Reference
c11	3 1/2"x4 9/16"x¼" Post Attachment Bent Plate-Expansion End	ASTM A709 Gr. 36		H#813L65970
c12	3 1/2"x4 9/16"x¼" Post Attachment Bent Plate-Fixed End	ASTM A709 Gr. 36		H#813L65970
c13	16"x5/8"x5/8" Long Rail Spindle	ASTM A709 Gr. 36		H#54171852/02
c14	12 7/8"x5/8"x5/8" Long Spindle	ASTM A709 Gr. 36		H#54171852/02
c15	9 9/16"x5/8"x5/8" Long Spindle	ASTM A709 Gr. 36		H#54171852/02
c16	3"x2 1/2"x1/2" Cable Anchor Plate Flange	ASTM A709 Gr. 36		H#Y0665
d1	7/8"-9 UNC, 9" Long Threaded Rod	ASTM F1554 Gr. 36		PB#129843
d2	5/8"-11 UNC, 7¼" Long Threaded Rod	ASTM F1554 Gr. 36		PB#130009
d3	7/8" Dia. Hardened SAE Washer	ASTM F436		H#B54780 PB#129843
d4	1/2" Dia. Hardened SAE Washer	ASTM F436	ZINC Plated ASTM F2329	P#0156022 T#120395440
d5	5/8" Dia. Hardened SAE Washer	ASTM F436		PB#130009
d6	7/8"-9 UNC Hex Nut	ASTM A563A		PB#129843
d7	1/2"-13 Jam Nut	ASTM F1941	ZINC Plated ASTM F1941	COC H#369406Z H#SF92856
d8	5/8"-9 UNC Hex Nut	ASTM A563A		P#36713 T#110315120
d9	1/2"-13 UNC, 1 1/2" Long Round Head Bolt	ASTM F1941	SAE J2484 MACHINE SCREW, ROUND HEAD SLOTTED, ZINC F1941	H#19B501513 L#U69581-583947 P#583947

Table A-3. Bill of Materials, Test No. MNPD-3, Cont.

Item No.	Description	Material Specification	Material Specification used for Test No. MNPD-3	Reference
d10	Clevis and Socket Turnbuckle Electroline XD-4031-BX Forged Series Open Body	ASTM F1145 Type 1 Gr. 1 Min. Breaking Strength 9,160 lbs		COC O#0109760
d11	5/16" DIA. 7x19 Wire Rope	ASTM A1023 Table 7 EIP Min. Breaking Strength 9,800 lbs	Applied Specification: RR-W-410	COC P#45507 T#210175509
f1	Chemical Adhesive	Min. Bond Strength (1.5 ksi)		Hilti

HUSKER READY-MIXED CONCRETE

Husker Concrete
201 S 1st Street, Lincoln, NE 68508
Phone: (402) 438-2147

Customer's Signature: X

PLANT	TRUCK	DRIVER	CUSTOMER	PROJECT	TAX	PO NUMBER	DATE	TIME	TICKET
11	2252	10435				MN PED	12/20/19	1:23 PM	2003509

Customer	Delivery Address	Special Instructions
UNL-MIDWEST ROADSIDE SAFETY	4630 NW 36TH ST	AIRPARK

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
3.50	3.50	3.50	250131PF	L5000 1PF	yd	$123.75	$433.13
				MINIMUM HAUL			$35.00
				WINTER SERVICE			$17.50

Water Added On Job At Customer's Request:	SLUMP	Notes:		
5.5	5.00 in		TICKET SUBTOTAL	$485.63
			SALES TAX	$0.00
			TICKET TOTAL	**$485.63**
			PREVIOUS TOTAL	
			GRAND TOTAL	**$485.63**

CAUTION FRESH CONCRETE
KEEP CHILDREN AWAY

Contains Portland cement. Freshly mixed cement, mortar, concrete or grout may cause skin injury. Avoid prolonged contact with skin. Always wear appropriate Personal Protective Equipment (PPE). In case of contact with eyes or skin, flush thoroughly with water. If irritation persists, seek medical attention promptly.

Terms & Conditions

This concrete is produced with the ASTM standard specifications for ready mix concrete. Strengths are based on a 3" slump. Drivers are not permitted to add water to the mix to exceed this slump, except under the authorization of the customer and their acceptance of any decrease in compressive strength and any risk of loss as a result thereof. Cylinder tests must be handled according to ACI/ASTM specifications and drawn by a licensed testing lab and/or certified technician.
Ready Mixed Concrete Company will not deliver any product beyond any curb lines unless expressly told to do so by customer and customer assumes all liability for any personal or property damage that may occur as a result of any such directive.
The purchaser's exceptions and claims shall be deemed waived unless made in writing within 3 days from time of delivery. In such a case, seller shall be given full opportunity to investigate any such claim. Seller's liability shall in no event exceed the purchase price of the materials against which any claims are made.

Figure A-1. Retrofit Concrete, Test No. MNPD-3 [b1]

CMC STEEL OKLAHOMA
584 Old Highway 70
Durant OK 74701-0000

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

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

Jacob Selzer – CMC Steel
Quality Assurance Manager

HEAT NO.:6008587 SECTION: REBAR 13MM (#4) 60'0" 420/60 GRADE: ASTM A615-18e1 Gr 420/60 ROLL DATE: 07/26/2019 MELT DATE: 07/26/2019 Cert. No.: 82787276 / 008587J265	S O L D T O	Concrete Industries Inc 6300 Cornhusker Hwy Lincoln NE US 68529-0529 4024341899 4024341899	S H I P T O	Nebco Inc 6300 Cornhusker Hwy Lincoln NE US 68507-3112 4024341800	Delivery#: 82787276 BOL#: 1804585 CUST PO#: 137490 CUST P/N: DLVRY LBS / HEAT: 98752.000 LB DLVRY PCS / HEAT: 2464 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.26%	Elongation test 1	12%		
Mn	1.03%	Elongation Gage Lgth test 1	8IN		
P	0.011%	Tensile to Yield ratio test1	1.22		
S	0.039%	Bend Test 1	Passed		
Si	0.20%	Rebar Deformation Avg. Spaci	0.333IN		
Cu	0.39%	Rebar Deformation Avg. Heigh	0.029IN		
Cr	0.13%	Rebar Deformation Max. Gap	0.113IN		
Ni	0.19%	Bend Test Diameter	1.750IN		
Mo	0.063%	Strain at Peak Stress test 1	9.0%		
V	0.006%				
Sn	0.013%				
Al	0.002%				
NB	0.001%				
N	0.0107%				
Carbon Eq A6	0.51%				
Yield Strength test 1	85.2ksi				
Yield Strength test 1 (metri	588MPa				
Tensile Strength test 1	104.2ksi				
Tensile Strength 1 (metric)	719MPa				

The Following is true of the material represented by this MTR:

**Material is fully killed*
**100% melted and rolled in the USA*
**EN10204:2004 3.1 compliant*
**Contains no weld repair*
**Contains no Mercury contamination*
**Manufactured in accordance with the latest version of the plant quality manual*
**Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661*
**Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov*

REMARKS : ALSO MEETS AASHTO M31

Page 1 OF 1 08/07/2019 10:47:38

Figure A-2. 30¼-in. Long No. 4 Reinforcement Bar, Test No. MNPD-3 [b2]

CMC STEEL OKLAHOMA
584 Old Highway 70
Durant OK 74701-0000

CERTIFIED MILL TEST REPORT
For additional copies call
830-372-8771

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

Jacob Selzer – CMC Steel

Quality Assurance Manager

HEAT NO.:6007274 SECTION: SPOOL REBAR 13MM (#4) A615/A706-60 3.5T GRADE: ASTM A615 GR A706-60 Dual Gr ROLL DATE: 05/21/2019 MELT DATE: 05/21/2019 Cert. No.: 82764426 / 007274J051	S O L D T O	Concrete Industries Inc 6300 Cornhusker Hwy Lincoln NE US 68529-0529 4024341899 4024341899	S H I P T O	Concrete Industries Inc 6300 Cornhusker Hwy Lincoln NE US 68529-0529 4024341899 4024341899	Delivery#: 82764426 BOL#: 73070333 CUST PO#: 137319 CUST P/N: DLVRY LBS / HEAT: 21000.000 LB DLVRY PCS / HEAT: 3 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.24%	Elongation Gage Lgth test 1	8IN		
Mn	1.22%	Tensile to Yield ratio test1	1.40		
P	0.006%	Bend Test 1	Passed		
S	0.019%	Rebar Deformation Avg. Spaci	0.339IN		
Si	0.19%	Rebar Deformation Avg. Heigh	0.030IN		
Cu	0.33%	Rebar Deformation Max. Gap	0.121IN		
Cr	0.15%	Bend Test Diameter	1.500IN		
Ni	0.12%	Strain at Peak Stress test 1	9.8%		
Mo	0.032%				
V	0.006%				
Sn	0.014%				
Al	0.000%				
N	0.0040%				
Carbon Eq A706	0.47%				
Yield Strength test 1	71.7ksi				
Yield Strength test 1 (metri	495MPa				
Tensile Strength test 1	100.2ksi				
Tensile Strength 1 (metric)	691MPa				
Elongation test 1	15%				

The Following is true of the material represented by this MTR:

**Material is fully killed*
**100% melted and rolled in the USA*
**EN10204:2004 3.1 compliant*
**Contains no weld repair*
**Contains no Mercury contamination*
**Manufactured in accordance with the latest version of the plant quality manual*
**Meets the "Buy America" requirements of 23 CFR635.410, 49 CFR 661*
**Warning: This product can expose you to chemicals which are known to the State of California to cause cancer, birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov*

REMARKS : ALSO MEETS AASHTO M31

Page 1 OF 1 07/08/2019 11:35:10

Figure A-3. 12¾-in. Long No. 4 Reinforcement Bar, Test No. MNPD-3 [b3]

Steel Dynamics, Inc.
Long Products Group
Structural and Rail Division
(260) 625-8100 (260) 625-8950 FAX
Quality Steel 100% EAF Melted
and Manufactured in the USA
Complies to Buy America requirements
ISO 9001:2015, NTPEP, and ABS Certified
CMTR complies with EN 10204 3.1.
Recycled content: PC = 75.0%, PI = 22.0%

CERTIFIED MILL TEST REPORT

Printed: 07 / 19 / 2019
Produced: 07 / 10 / 2019

Ship to:
ADELPHIA METALS (CPU)
411 Main Street
New Prague MN, 46580 US
Attn: Rob Hanes

Customer # 001611

Bill to:
ADELPHIA METALS
411 Main Street
New Prague MN, 56071 US
Attn: Brian Blue

GENERAL INFORMATION

Product Rebar
Size #4

Heat Number B165038
Condition(s) As-Rolled
Fine Grained
Fully Killed
No Weld Repair

SPECIFICATIONS

Standards	Grades
» ASTM A615/615M - 16	Grade 60

SHIPMENT DETAILS

BOL # 0000557122 - 12024.00 lbs

Bundle / ASN #	Length	pcs	Cust PO | Job/Reference
010051484	20' 0"	150	825239
010051485	20' 0"	150	825239
010051489	20' 0"	150	825239
010051490	20' 0"	150	825239
010051491	20' 0"	150	825239
010051464	20' 0"	150	825239

CHEMICAL ANALYSIS (weight percent)

C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	V	Nb/Cb	Al	N	B	*C11	Analysis Type
.19	.64	.009	.014	.15	.30	.11	.10	.04	.012	.002	.001	.002	.0098	.0002	.319	Heat

MECHANICAL TESTING

Test	Yield (fy) Strength ksi / MPa	Tensile (fu) Strength ksi / MPa	fu / fy ratio	% Elong. (8" gage)
1	84 / 580	101 / 695	1.20	10
2	84 / 580	102 / 705	1.21	12

REBAR BEND TEST

Test	Result
1	PASS

Notes: CE11 (ASTM A706) = C + (Mn/6) + (Cu/40) + (Ni/20) + (Cr/10) - (Mo/50) - (V/10)

I hereby certify that the material described herein has been made to the applicable specification by the electric arc furnace/continuous cast process and tested in accordance with the requirements of American Bureau of Shipping Rules with satisfactory results.
Signed:

ABS CERTIFICATION

I hereby certify that the content of this report are accurate and correct. All tests and operations performed by this material manufacturer are in compliance with the requirements of the material specifications and applicable purchaser designated requirements.

Signed: Todd Bashford
Quality Manager

Form F-6100-002-054 rev 6

State of Indiana, County of Whitley Sworn to and subscribed before me

this __________ day of ____________________

Signed: ____________________ My commission expires: __________
Notary Public

ASTM A6 - 14.6: A signature is not required on the test report; however, the document shall clearly identify the organization submitting the report. Notwithstanding the absence of a signature, the organization submitting the report is responsible for the content of the report

Page 3 of 5

Figure A-4. 1,196½-in. Long No. 4 Reinforcement Bar, Test No. MNPD-3 [b4, b5]

CERTIFICATE OF TESTING

IPSCO TUBULARS INC

TMK IPSCO

Page 1

Certificate Number:	363127-1
	Monday, March 2, 2020, 11:49:11 AM

Bill of Lading: 59897

Size: 3.000 X 2.000 in	Gage: 0.120 in	Grade: A500B	Mill Order No: 97428-02	Customer PO: P00220JT181

Specification: ASTM A500-18
PRODUCT MEETS SPECIFICATION REQUIREMENTS
FOR GRADES B AND C.

Customer: STATE STEEL SUPPLY CO.

Pieces: 105 Length: 24.00 (ft)

Heat	Product ID	Test Type			Orientation				Width (in)		YS (psi)		TS (psi)		Elong%(2 in)		Y/T	
		Wgt (%)	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	V	Cb	Ti	B	CEQ
2100315	G-970F 1519361/	HEAT QUALIFIER			PIPE LPA				1.504		69200		74200		31.0		0.93	
		Heat	0.22	0.78	0.010	0.002	0.02	0.08	0.03	0.05	0.010	0.003	0.030	0.003	0.000	0.001	0.0000	0.37

P00220JT18102

2100315

TPA - Transverse Pipe Axis
180° of Weld
LPA - Longitudinal Pipe Axis
90° of Weld
TWA - Transverse Weld Axis
FST - Full Section Testing
FBN - Full Body Normalized
Q&T - Quenched and Tempered
SR - Stress Relieved
form CRTR3001

Melted and Manufactured in the USA
EN 10204:2004 TYPE 3.1 CERT-
No Weld Repair Performed On This Product

We certify that the product described above has been manufactured, sampled, inspected, and tested in accordance to the referenced specification. The product has been found to be in compliance with all requirements.

Joseph A Casey
QA Coordinator

Monday, March 2, 2020, 11:49:50 AM

MILL ADDRESS - 1201-R ST., GENEVA, NE 68361 | PHONE: (402) 759-4401

Figure A-5. HSS3x2x⅛ ASTM A500 Grade B Rail Tube, Test No. MNPD-3 [c1, c2, c4, c5, c6]

TMK IPSCO

CERTIFICATE OF TESTING
IPSCO TUBULARS INC

Page 1

Certificate Number: 363890-1

Tuesday, March 10, 2020, 10:27:39 AM

Bill of Lading: 60555 | Customer Part No: 00845

Size: 4.000 X 2.000 in | Gage: 0.120 in | Grade: A500B | Mill Order No: 97504-02 | Customer PO: 01030997

Specification: ASTM A500-18
PRODUCT MEETS SPECIFICATION REQUIREMENTS
FOR GRADES B AND C.

Customer: NORFOLK IRON & METAL

Pieces: 28 Length: 24.00

Heat	Product ID	Test Type		Orientation				Width (in)		YS (psi)		TS (psi)		Elong%(2 in)		Y/T	
		Wgt (%)	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Sn	Al	V	Cb	Ti	B	CEC
1196498	G-965F 1491377-	HEAT QUALIFIER		PIPE LPA				1.508		69000		76200		33.0		0.91	
		Heat:	0.21	0.77	0.010	0.003	0.02	0.08	0.03	0.04	0.010	0.004	0.030	0.002	0.000	0.002	0.0000	0.35

TPA - Transverse Pipe Axis
180° of Weld
LPA - Longitudinal Pipe Axis
90° of Weld
TWA - Transverse Weld Axis
FST - Full Section Testing
FBN - Full Body Normalized
Q&T - Quenched and Tempered
SR - Stress Relieved
form CRTR3001

Melted and Manufactured in the USA
EN 10204:2004 TYPE 3.1 CERT
No Weld Repair Performed On This Product

We certify that the product described above has been manufactured, sampled, inspected, and tested in accordance to the referenced specification. The product has been found to be in compliance with all requirements.

Joseph A Casey
QA Coordinator

Tuesday, March 10, 2020, 10:27:49 AM

MILL ADDRESS - 1201-R ST., GENEVA, NE 68361 | PHONE: (402) 759-4401

Figure A-6. HSS4x2x⅛ 31½-in. Long ASTM A500 Grade B Post, Test No. MNPD-3 [c3]

NIM

Test Certificate

Document: 01125438

Norfolk Iron & Metal Co.

3001 North Victory Road
Norfolk, NE 68701
PH: (402) 371-1810

Product Information

25872 - PLATE 1/4 A36 COLD REDUCED

Thickness: .2500 Width: 48.0000 Length: 96.0000

Mill Coil: 363757 ARC BH

Heat: 813L65970 Supplier: ARCELORMITTAL

Specification(s):
ASTM A709 GR36,PLATE-18

Chemistry Data

C	MN	P	S	SI	AL	CB	V	CU	CR
.16	.87	.011	.004	.009	.039	.002	.001	.014	.02
NI	**MO**	**SN**	**TI**	**N**	**B**	**ZR**	**PB**	**MG**	**ZN**
.01	.002	.003	.002	.004	.0002	.00	.00	.00	.00

Mechanical Data

	Yield (PSI)	Tensile (PSI)	Elongation	Reduction Of Area	Sample Taken From
1	41580	64129	40.15 2"	53.4500	Head
2	42270	62242	42.52 2"	59.7600	Center

Produced From Coil

Melted In: UNITED STATES, Manufacured In: UNITED STATES

The Mechanical Data for the product described above reflect the results of tests made by us in accordance with applicable ASTM or ASME standards and our testing procedures, and we certify that the information included in this Test Certificate with respect to such Mechanical Data is accurate to the best of our knowledge.

The Chemistry Data shown above was reported to us by ARCELORMITTAL and have been included in this Test Certificate solely for your information.

Figure A-7. ¼-in. Plate, Test No. MNPD-3 [c7, c10, c11, c12]

Norfolk Iron & Metal Co.

3001 North Victory Road
Norfolk, NE 68701
PH: (402) 371-1810

Test Certificate

Document: 01125439

Product Information

01707 - PLATE 1/2 A36 COLD REDUCED

Thickness: .5000 Width: 48.0000 Length: 96.0000

Mill Coil: 5289162 NLMK IN

Heat: Y0665 Supplier: NLMK INDIANA

Specification(s):
ASTM A709 GR36,PLATE-18

Chemistry Data

C	MN	P	S	SI	AL	CB	V	CU	CR
.05	.93	.014	.006	.02	.031	.002	.003	.15	.07

NI	MO	SN	TI	N	B	ZR	PB	MG	ZN
.05	.01	.03	.002	.008	.0001	.00	.00	.00	.00

Mechanical Data

	Yield (PSI)	Tensile (PSI)	Elongation	Reduction Of Area	Sample Taken From
1	47661	60322	52.82 2"	69.2100	Head
2	48301	60667	51.78 2"	68.9500	Center

Produced From Coil

Melted In: UNITED STATES, Manufacured In: UNITED STATES

The Mechanical Data for the product described above reflect the results of tests made by us in accordance with applicable ASTM or ASME standards and our testing procedures, and we certify that the information included in this Test Certificate with respect to such Mechanical Data is accurate to the best of our knowledge.

The Chemistry Data shown above was reported to us by NLMK INDIANA and have been included in this Test Certificate solely for your information.

Figure A-8. ½-in. Plate, Test No. MNPD-3 [c8, c9, c16]

GERDAU

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

CERTIFIED MATERIAL TEST REPORT

Page 1 / 1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMEN
NORFOLK IRON & METAL CO INC 3001 N VICTORY RD NORFOLK,NE 68701-0833 USA	NORFOLK IRON & METAL CO INC NORFOLK,NE 68702-1129 USA	GGMULTI	Square Bar / 5/8"	0000086479

LENGTH	WEIGHT	HEAT / BATCH
20'00"	9,562 LB	54171852/02

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
8619907/000020	01479############	ASME SA36, ASTM A529-14 ASTM A6-17, A36-14, A572-15 ASTM A709-17, AASHTO M270-15 CSA G40.20-13/G40.21-13

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
01030331	1321-0000073829	01/31/2020

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %
0.13	0.65	0.012	0.022	0.18	0.37	0.11	0.13	0.030	0.002	0.007

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
25.00	8.000	73715	508	55357	382

GEOMETRIC CHARACTERISTICS

R:R
64.00

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. Weld repair has not been performed on this material. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

Bhaskar

BHASKAR YALAMANCHILI
QUALITY DIRECTOR
Phone: (409) 267-1071 Email: Bhaskar.Yalamanchili@gerdau.com

Rachel Warren

RACHEL WARREN
QUALITY ASSURANCE MGR.
Phone: (704) 596-0361 EX3039 Email: Rachel.Webster@gerdau.com

Figure A-9. 16-in. x ⅝-in. x ⅝-in. Long Rail Spindle, Test No. MNPD-3 [c13, c14, c15]

Portland Bolt
& MANUFACTURING COMPANY

Phone: 800-547-6758 | Fax: 503-227-4634
3441 NW Guam Street, Portland, OR 97210
Web: www.portlandbolt.com | Email: sales@portlandbolt.com

For: MIDWEST ROADSIDE SAFETY FACIL
PB Invoice#: 129843
Cust PO#: CHAT
Date: 3/18/2020
Shipped: 3/19/2020

CERTIFICATE OF CONFORMANCE

We certify that the following items were manufactured and tested in accordance with the chemical, mechanical, dimensional and thread fit requirements of the specifications referenced.

Product:
ASTM F1554G36 ALL THRD ROD

Nuts:
ASTM A563A HEX

Washers:
ASTM F436-1 RND

Coatings:
ITEMS HOT DIP GALVANIZED PER ASTM F2329/A153C

By:
Certification Department Quality Assurance
Dane McKinnon

Figure A-10. ⅞-in. Diameter – 9 UNC, 9-in. Long Threaded Rod, Washer, and Hex Nut, Test No. MNPD-3 [d1, d3, d6]

Portland Bolt
& MANUFACTURING COMPANY

Phone: 800-547-6758 | Fax: 503-227-4634
3441 NW Guam Street, Portland, OR 97210
Web: www.portlandbolt.com | Email: sales@portlandbolt.com

For: MIDWEST ROADSIDE SAFETY FACIL
PB Invoice#: 130009
Cust PO#: 6926
Date: 3/31/2020
Shipped: 3/27/2020

CERTIFICATE OF CONFORMANCE

We certify that the following items were manufactured and tested in accordance with the chemical, mechanical, dimensional and thread fit requirements of the specifications referenced.

Product:
ASTM F1554G36 ALL THRD ROD

Nuts:
ASTM A563A HEX

Washers:
ASTM F436-1 RND

Coatings:
ITEMS HOT DIP GALVANIZED PER ASTM F2329/A153C

By: ____________________
Certification Department Quality Assurance
Dane McKinnon

Figure A-11. ⅝-in. Diameter – 11 UNC 7¼-in. Long Threaded Rod and Washer, Test No. MNPD-3 [d2, d5]

FASTENAL®

Certificate of Compliance

Sold To:		**Purchase Order:**	MNPD-3 2020
UNL TRANSPORTATION/Midwest Roadside Safe		**Job:**	Item# d4
		Invoice Date:	04/10/2020

THIS IS TO CERTIFY THAT WE HAVE SUPPLIED YOU WITH THE FOLLOWING PARTS.
THESE PARTS WERE PURCHASED TO THE FOLLOWING SPECIFICATIONS.

40 PCS 1/2" ASTM F436 Type 1 Hot Dipped Galvanized Steel Structural Flat Washer Made in USA SUPPLIED UNDER OUR TRACE NUMBER 120395440 AND UNDER PART NUMBER 0156022

This is to certify that the above document is true and accurate to the best of my knowledge.

Please check current revision to avoid using obsolete copies.

This document was printed on 04/10/2020 and was current at that time.

Fastenal Account Representative Signature

Fastenal Store Location/Address

3201 N. 23rd Street STE 1
LINCOLN, NE 68521
Phone #: (402)476-7900
Fax #: 402/476-7958

Printed Name

Date

Page 1 of 1

Figure A-12. ½-in. Diameter Hardened SAE Washer, Test No. MNPD-3 [d4]

SUPER CHENG INDUSTRIAL CO., LTD.

CERTIFICATE OF INSPECTION

ISO 9001-2015
IATF 16949-2016

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

CERT NO : SC-S21180905 ISSUE DATE : 2018/11/08

CUSTOMER : FASTENAL COMPANY PURCHASING

P.O. NO : 120339166 LOT NO : S21180905

PART NO. : 1136210 HEAT NO. : 369406Z

COMMODITY : FIN HEX JAM NUT SAMPLING PLAN : ASME B18.18-17

SIZE : 1/2-13 DIMENSION SPEC : ASME B18.2.2-15

FINISH : TRIVALENT ZINC MECHANICAL SPEC : ASTM A563 GRADE A

QTY SHIPPED : 11250 PCS FINISH : ASTM F1941/F1941M-16

ITEM	SPECIFICATION	ACTUAL RESULT	ACC.	REJ.
APPEARANCE	ASTM F812-12(R17)	GOOD	V	
THREAD	ASME B1.1-03(R18)	GO/NOT GO GAUGE PASS	V	
W.A.F.	0.750 ~ 0.736 in	0.743 ~ 0.741 in	V	
W.A.C.	0.866 ~ 0.840 in	0.848 ~ 0.846 in	V	
THICKNESS	0.323 ~ 0.302 in	0.315 ~ 0.310 in	V	
HARDNESS	MAX 32 HRC	94.0 ~ 90.0 HRB	V	
PROOF LOAD	MIN 54000 PSI	PASS	V	
PLATING THICKNESS	MIN 0.0001 in	0.00016 ~ 0.00012 in	V	

TEST METHOD :
CORE HARDNESS / SURFACE HARDNESS : ASTM F606/F606M-16
PROOF LOAD : ASTM F606/F606M-16
PLATING THICKNESS : ASTM B568-98(R14) / ASTM F1941/F1941M-16
SALT SPRAY TEST : ASTM B117-18

ALL TESTS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN APPLICABLE FASTENER SPECIFICATION. WE CERTIFY THAT THIS DATA IS THE TRUE REPRESENTATION OF INFORMATION PROVIDED BY MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THE ABOVE PARTS ARE RoHS COMPLIANT.

AUTHORIZED SIGNATURE

Figure A-13. ½-in. Diameter -13 Threads Jam Nut, Test No. MNPD-3 [d7]

SUPER CHENG INDUSTRIAL CO., LTD.

CERTIFICATE OF INSPECTION

ISO 9001-2015
IATF 16949-2016

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

CERT NO : SC-S22180706 ISSUE DATE : 2018/08/16

CUSTOMER : FASTENAL COMPANY PURCHASING

P.O. NO : 210165866 LOT NO : S22180706

PART NO. : 36210 HEAT NO. : SF92856

COMMODITY : FIN HEX JAM NUT SAMPLING PLAN : ASME B18.18-17

SIZE : 1/2-13 DIMENSION SPEC : ASME B18.2.2-15

FINISH : TRIVALENT ZINC MECHANICAL SPEC : ASTM A563 GRADE A

QTY SHIPPED : 18000 PCS FINISH : ASTM F1941/F1941M-16

ITEM	SPECIFICATION	ACTUAL RESULT	ACC.	REJ.
APPEARANCE	ASTM F812-12(R17)	GOOD	V	
THREAD	ASME B1.1-03(R18)	GO/NOT GO GAUGE PASS	V	
W.A.F.	0.750 ~ 0.736 in	0.743 ~ 0.741 in	V	
W.A.C.	0.866 ~ 0.840 in	0.848 ~ 0.845 in	V	
THICKNESS	0.323 ~ 0.302 in	0.314 ~ 0.311 in	V	
HARDNESS	MAX 32 HRC	94.0 ~ 90.0 HRB	V	
PROOF LOAD	MIN 54000 PSI	PASS	V	
PLATING THICKNESS	MIN 0.0001 in	0.00016 ~ 0.00014 in	V	

TEST METHOD :
CORE HARDNESS / SURFACE HARDNESS : ASTM F606/F606M-16
PROOF LOAD : ASTM F606/F606M-16
PLATING THICKNESS : ASTM B568-98(R14) / ASTM F1941/F1941M-16
SALT SPRAY TEST : ASTM B117-18

ALL TESTS ARE IN ACCORDANCE WITH THE METHODS PRESCRIBED IN APPLICABLE FASTENER SPECIFICATION. WE CERTIFY THAT THIS DATA IS THE TRUE REPRESENTATION OF INFORMATION PROVIDED BY MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THE ABOVE PARTS ARE RoHS COMPLIANT.

AUTHORIZED SIGNATURE

Figure A-14. ½-in. Diameter -13 Threads Jam Nut, Test No. MNPD-3 [d7]

FASTENAL®

Certificate of Compliance

Sold To:		**Purchase Order:**	MNPD-3 2020
UNL TRANSPORTATION/Midwest Roadside Safe		**Job:**	Item# d8
		Invoice Date:	04/10/2020

THIS IS TO CERTIFY THAT WE HAVE SUPPLIED YOU WITH THE FOLLOWING PARTS.
THESE PARTS WERE PURCHASED TO THE FOLLOWING SPECIFICATIONS.

12 PCS 5/8"-11 Hot Dip Galvanized Finish Grade A Finished Hex Nut SUPPLIED UNDER OUR TRACE NUMBER 110315120 AND UNDER PART NUMBER 36713

This is to certify that the above document is true and accurate to the best of my knowledge.

Fastenal Account Representative Signature

Printed Name

Date

Please check current revision to avoid using obsolete copies.

This document was printed on 04/10/2020 and was current at that time.

Fastenal Store Location/Address

3201 N. 23rd Street STE 1
LINCOLN, NE 68521
Phone #: (402)476-7900
Fax #: 402/476-7958

Page 1 of 1

Figure A-15. ⅝-in. Diameter -9 UNC Hex Nut, Test No. MNPD-3 [d8]

CERTIFIED MATERIAL TEST REPORT
FOR MACHINE SCREWS

FACTORY: Hai Yan Booming Fastener Co. Ltd. DATE: 2020.01.02
ADDRESS: No.162 Chenxi North Road Hai Yan Zhejiang China PO NUMBER:U69581
COUNTRY OF ORIGIN: Hai Yan Zhejiang China LOT# U69581-583947
CUSTOMER: BRIGHTON-BEST INTERNATIONAL(TW), INC. PART NO: 583947
SAMPLE SIZE: ACC. TO ASME B18.18 CATEGORY 2-2017; ASTM F1470-12
DESCRIPTION: MACHINE SCREW,ROUND HEAD SLOTTED,ZINC CR+3(INCH)
SIZE: 1/2-13x1-1/2 QNTY:3,150 PCS
HEADMARKS: NO

STEEL PROPERTIES: Low Carbon Steel TEST FACILITY: S
STEEL GRADE: ML08A1(Dia 14.0 mm) HEAT NUMBER: 19B501513

CHEMISTRY SPEC:	C %*100	Si %*100	Mn%*100	P %*1000	S %*1000	A1%*1000
	5--10	10 max	30--60	35 max	35 max	20 min
TEST:	8	6	40	13	3	27

DIMENSIONAL INSPECTIONS SPECIFICATION: ASME B18.6.3-2013 TEST FACILITY: M

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
APPEARANCE	ASTM F788-13	PASSED	100	0
THREAD	ANSI B1.1-03(R08)-GO3A/NOGO2A	PASSED	32	0
Head Dia.	0.813--0.766	0.807--0.788	32	0
Head Height	0.355--0.332	0.350--0.340	32	0
Slot Width	0.106--0.091	0.102--0.096	32	0
Slot Depth	0.211--0.159	0.204--0.175	32	0
Major Dia.	0.498--0.488	0.490--0.488	32	0
Length	1.500--1.440	1.480--1.465	32	0

MECHANICAL PROPERTIES: SPECIFICATION: SAE J82-2016 GR-60M TEST FACILITY: M

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
WEDGE TENSILE:	ASTM F606/F606M-2016	MIN 60000 PSI	76000--79500	8	0

TEST FACILITY: S

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
COATINGS OF ZINC	SPECIFICATION: ASTM F1941/F1941M-2016 Fe/Zn 3AN				
COATING THICKNESS	ASTM B568-98(2014)	Min 3μm	3.5--5.5 μm	8	0
Salt Spray Test Result	ASTM B117-2016	6 Hr no white rust and 12 Hr no Red Rust	PASSED	8	0

ZINC ELECTROPLATING WITH TRIVALENT CHROMATE (CR+3) IN COMPLIANCE WITH ROHS REQUIREMENTS

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE SAE SPECIFICATION. WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
THE REPORT IS ISSUED ACCORDING TO ISO16228 F3.1(EN10204 3.1).
All parts meet the requirements of FQA and records of compliance are on file.
Maker's ISO# 12817Q20462R0M

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

Figure A-16. ½-in. Diameter -13 UNC, 1½-in. Long Round Head Bolt, Test No. MNPD-3 [d9]

Esmet
ELECTROLINE® TUFLOC®

1406 Fifth Street SW
Canton, Ohio 44702

P: 330-452-9132
F: 330-452-2557
info@esmet.com
www.esmet.com

CERTIFICATE OF COMPLIANCE

DATE: 04/01/2020

CERTIFICATION OF ORDER NUMBER: MNPD

ESMET FACTORY ORDER NUMBER: 0109760

PART NUMBER	QUANTITY
XD 4031 BX TURNBUCKLE W/MB731	8

Attn: Quality Control

This is to certify that the parts shipped on this order were inspected by First Piece, Patrol and Final Inspection procedures and conform to the requirements of Esmet's appropriate engineering drawings and/or customer requirements and specifications. The material is free from mercurial contamination.

These items are manufactured and inspected to meet the requirements of **MIL-S-21433A**. **Esmet operates a Quality Management System which complies with the requirements of ISO 9001:2015**

Made in the U.S.A.

Doug Craighead
Manager, Quality Control

Figure A-17. Forged Series Open Body Clevis and Socket Turnbuckle, Test No. MNPD-3 [d10]

FASTENAL®

Certificate of Compliance

Sold To:		**Purchase Order:**	MNPD-3 2020
UNL TRANSPORTATION/Midwest Roadside Safe		**Job:**	Item#d13
		Invoice Date:	03/31/2020

THIS IS TO CERTIFY THAT WE HAVE SUPPLIED YOU WITH THE FOLLOWING PARTS.
THESE PARTS WERE PURCHASED TO THE FOLLOWING SPECIFICATIONS.

500 PCS 5/16" (7x19) Minimum Break Strength 9800lb Galvanized Cable SUPPLIED UNDER OUR TRACE NUMBER 210175509 AND UNDER PART NUMBER 45507

This is to certify that the above document is true and accurate to the best of my knowledge.

Fastenal Account Representative Signature

Ross Schall

Printed Name

3/3/2020

Date

Please check current revision to avoid using obsolete copies.

This document was printed on 03/31/2020 and was current at that time.

Fastenal Store Location/Address

3201 N. 23rd Street STE 1
LINCOLN, NE 68521
Phone #: (402)476-7900
Fax #: 402/476-7958

Page 1 of 1

Figure A-18. 5⁄16-in. Diameter by 7 x 19 Wire Rope, Test No. MNPD-3 [d11]

P.O. Box 21148
Tulsa, OK 74121
Phone (918) 252-6000
Fax No. (918) 252-6520

Certified Quality and Environmental Systems
SGS
ISO 9001 / ISO 14001
Reg. No. 12455-03

Date: 12/13/2016

Subject: Certificate of Conformance

Product: HIT RE-500 V3 Adhesive

To Whom it May Concern:

This is to certify that the HIT-RE 500 V3 is a high-strength, slow cure two-part epoxy adhesive contained in two cartridges separating the resin from the hardener.

Additionally, this certifies that the product has been seismically and cracked concrete qualified as represented in ICC-ES report ESR- 3814.

Sincerely,

Hilti, Inc.

5400 South 122 East Avenue

Tulsa, Oklahoma 74146

800-879-8000

800-879-7000 fax

US-Sales@hilti.com

Figure A-19. Hilti Chemical Epoxy, Test No. MNPD-3 [f1]

Appendix B. Vehicle Center of Gravity Determination

	Test Name:	MNPD-3	VIN:	1C6RR6LG9ES236433	
Model Year: 2014	Make:	Dodge	Model:	RAM 1500	

Vehicle CG Determination

	Vehicle Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	4994	29.094401	145297.44
+	Hub	19	15.25	289.75
+	Brake activation cylinder & frame	8	27	216
+	Pneumatic tank (Nitrogen)	22	27.25	599.5
+	Strobe/Brake Battery	5	26.5	132.5
+	Brake Receiver/Wires	6	53.25	319.5
+	CG Plate including DAQ	38	30.875	1173.25
-	Battery	-45	44.5	-2002.5
-	Oil	-11	17	-187
-	Interior	-53	36	-1908
-	Fuel	-113	18	-2034
-	Coolant	-5	33	-165
-	Washer fluid	-3	36	-108
+	Water Ballast (In Fuel Tank)	156	18	2808
+	Onboard Supplemental Battery	5	27	135
				0
				0
	Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle			144566.44

Estimated Total Weight (lb)	5023
Vertical CG Location (in.)	28.7809

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140.75 in. Front Track Width: 68 in.
Rear Track Width: 67.4375 in.

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	5001	1.0
Longitudinal CG (in.)	63 ± 4	65.942262	2.94226
Lateral CG (in.)	NA	-0.670282	NA
Vertical CG (in.)	28 or greater	28.78	0.78090

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	1359	1342
Rear	1177	1116

FRONT	2701	lb
REAR	2293	lb
TOTAL	4994	lb

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1358	1300
Rear	1192	1151

FRONT	2658	lb
REAR	2343	lb
TOTAL	5001	lb

Figure B-1. Vehicle Mass Distribution, Test No. MNPD-3

Appendix C. Vehicle Deformation Records

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

Model Year: 2014 | Test Name: MNPD-3 | VIN: 1C6RR6LG9ES236433
Make: Dodge | Model: RAM 1500

VEHICLE DEFORMATION
PASSENGER SIDE FLOOR PAN - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	58.9351	34.1185	-5.8313	58.1830	34.2585	-5.7644	0.7521	-0.1400	-0.0669	0.7679	0.7521	X
	2	59.9849	36.6720	-4.2603	59.1576	36.7046	-4.2558	0.8273	-0.0326	-0.0045	0.8280	0.8273	X
	3	60.9922	39.2517	-1.6133	60.5880	38.2847	-1.3345	0.4042	0.9670	-0.2788	1.0845	0.4042	X
	4	60.9574	43.4980	-1.5548	59.3202	42.1549	-2.6329	1.6372	1.3431	1.0781	2.3763	1.9603	X, Z
	5	61.0104	47.7897	-1.4919	58.8717	45.8982	-2.5712	2.1387	1.8915	1.0793	3.0523	2.3956	X, Z
	6	55.8834	32.9858	-4.5308	55.3209	32.7521	-4.4596	0.5625	0.2337	-0.0712	0.6133	0.5625	X
	7	56.9867	36.3976	-2.3899	56.4446	35.9441	-2.0511	0.5421	0.4535	-0.3388	0.7838	0.5421	X
	8	57.7961	39.7322	0.1513	57.5709	38.7235	0.8103	0.2252	1.0087	-0.6590	1.2258	0.2252	X
	9	57.8868	44.0840	0.1726	56.9225	42.7919	-0.1747	0.9643	1.2921	0.3473	1.6492	1.0249	X, Z
	10	58.0881	48.2085	-0.1166	56.3036	46.6754	-1.2061	1.7845	1.5331	1.0895	2.5927	2.0908	X, Z
FLOOR PAN (Z)	11	52.4659	31.8660	-2.5295	52.1489	31.1587	-2.2163	0.3170	0.7073	-0.3132	0.8360	-0.3132	Z
	12	53.5790	34.9635	0.0699	53.3021	34.1517	0.5058	0.2769	0.8118	-0.4359	0.9621	-0.4359	Z
	13	53.8913	39.2692	1.4555	53.6408	38.2798	2.0504	0.2505	0.9894	-0.5949	1.1813	-0.5949	Z
	14	53.9649	44.1545	1.5391	53.6903	43.2257	2.0555	0.2746	0.9288	-0.5164	1.0976	-0.5164	Z
	15	54.4075	48.5849	1.6986	54.1244	47.6008	1.7725	0.2831	0.9841	-0.0739	1.0267	-0.0739	Z
	16	49.7320	30.9387	-0.7591	49.4665	30.0576	-0.5041	0.2655	0.8811	-0.2550	0.9549	-0.2550	Z
	17	50.1446	34.6524	1.4038	49.8528	33.8358	1.7940	0.2918	0.8166	-0.3902	0.9509	-0.3902	Z
	18	50.5894	38.7844	1.4696	50.3842	37.9415	2.1253	0.2052	0.8429	-0.6557	1.0874	-0.6557	Z
	19	50.6425	43.4283	1.5332	50.5212	42.5210	2.2788	0.1213	0.9073	-0.7456	1.1806	-0.7456	Z
	20	50.7931	48.6073	1.7113	50.6154	47.7165	1.8940	0.1777	0.8908	-0.1827	0.9265	-0.1827	Z
	21	46.1589	30.5396	0.1618	45.8683	29.8517	0.2380	0.2906	0.6879	-0.0762	0.7506	-0.0762	Z
	22	46.7083	34.5716	1.4096	46.4116	33.7565	1.7205	0.2967	0.8151	-0.3109	0.9215	-0.3109	Z
	23	46.8844	39.1015	1.4514	46.6895	38.3224	2.0894	0.1949	0.7791	-0.6380	1.0257	-0.6380	Z
	24	46.9552	43.5791	1.5504	46.8011	42.6916	2.5180	0.1541	0.8875	-0.9676	1.3220	-0.9676	Z
	25	47.0968	48.7451	1.7185	46.8488	47.8671	2.1930	0.2480	0.8780	-0.4745	1.0284	-0.4745	Z
	26	42.5812	30.5399	0.1203	42.2941	30.0127	0.0358	0.2871	0.5272	0.0845	0.6062	0.0845	Z
	27	42.6988	34.4391	1.4991	42.4110	33.7326	1.7197	0.2878	0.7065	-0.2206	0.7941	-0.2206	Z
	28	42.8244	38.8507	1.5589	42.6110	38.0809	2.1162	0.2134	0.7698	-0.5573	0.9740	-0.5573	Z
	29	43.2671	43.0450	1.6139	43.1442	42.2809	2.6117	0.1229	0.7641	-0.9978	1.2628	-0.9978	Z
	30	43.6311	48.3288	1.7132	43.5449	47.5483	3.0668	0.0862	0.7805	-1.3536	1.5649	-1.3536	Z

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

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

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

Pretest Floor Pan

Posttest Floor Pan

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

Model Year: 2014 | Test Name: MNPD-3 | VIN: 1C6RR6LG9ES236433
Make: Dodge | Model: RAM 1500

VEHICLE DEFORMATION
PASSENGER SIDE FLOOR PAN - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
TOE PAN - WHEEL WELL (X, Z)	1	53.8938	18.3224	-2.3460	53.2148	18.5882	-1.4066	0.6790	-0.2658	-0.9394	1.1892	0.6790	X
	2	54.9330	20.9073	-0.8198	54.1651	21.0410	0.1067	0.7679	-0.1337	-0.9265	1.2108	0.7679	X
	3	55.9383	23.5332	1.7821	55.5768	22.6299	3.0324	0.3615	0.9033	-1.2503	1.5843	0.3615	X
	4	55.8649	27.7794	1.7812	54.2765	26.4904	1.7370	1.5884	1.2890	0.0442	2.0461	1.5890	X, Z
	5	55.8789	32.0718	1.7832	53.7946	30.2294	1.8028	2.0843	1.8424	-0.0196	2.7819	2.0843	X
	6	50.8635	17.1805	-1.0042	50.3642	17.0547	-0.1083	0.4993	0.1258	-0.8959	1.0333	0.4993	X
	7	51.9530	20.6321	1.0792	51.4555	20.2534	2.3061	0.4975	0.3787	-1.2269	1.3770	0.4975	X
	8	52.7525	24.0095	3.5664	52.5525	23.0390	5.1729	0.2000	0.9705	-1.6065	1.8875	0.2000	X
	9	52.8033	28.3618	3.5257	51.8693	27.1028	4.1921	0.9340	1.2590	-0.6664	1.7034	0.9340	X
	10	52.9643	32.4834	3.1769	51.2175	30.9819	3.1648	1.7468	1.5015	0.0121	2.3035	1.7468	X, Z
FLOOR PAN (Z)	11	47.4730	16.0581	1.0411	47.2030	15.4301	2.1278	0.2700	0.6280	-1.0867	1.2838	-1.0867	Z
	12	48.5789	19.2020	3.5873	48.3251	18.4297	4.8556	0.2538	0.7723	-1.2683	1.5065	-1.2683	Z
	13	48.8630	23.5295	4.9095	48.6245	22.5586	6.4061	0.2385	0.9709	-1.4966	1.7998	-1.4966	Z
	14	48.8923	28.4160	4.9239	48.6299	27.5047	6.4177	0.2624	0.9113	-1.4938	1.7694	-1.4938	Z
	15	49.2954	32.8521	5.0173	49.0254	31.8839	6.1411	0.2700	0.9682	-1.1238	1.5077	-1.1238	Z
	16	44.7624	15.1311	2.8472	44.5278	14.3028	3.8342	0.2346	0.8283	-0.9870	1.3097	-0.9870	Z
	17	45.1586	18.8786	4.9541	44.8767	18.0814	6.1378	0.2819	0.7972	-1.1837	1.4547	-1.1837	Z
	18	45.5659	23.0150	4.9580	45.3710	22.1911	6.4753	0.1949	0.8239	-1.5173	1.7375	-1.5173	Z
	19	45.5768	27.6596	4.9559	45.4668	26.7715	6.6350	0.1100	0.8881	-1.6791	1.9027	-1.6791	Z
	20	45.6812	32.8418	5.0600	45.5152	31.9682	6.2571	0.1660	0.8736	-1.1971	1.4912	-1.1971	Z
	21	41.2008	14.7126	3.8034	40.9304	14.0639	4.5702	0.2704	0.6487	-0.7668	1.0401	-0.7668	Z
	22	41.7234	18.7666	4.9897	41.4364	17.9715	6.0587	0.2870	0.7951	-1.0690	1.3628	-1.0690	Z
	23	41.8581	23.2982	4.9664	41.6730	22.5391	6.4340	0.1851	0.7591	-1.4676	1.6626	-1.4676	Z
	24	41.8885	27.7771	5.0018	41.7449	26.9086	6.8684	0.1436	0.8685	-1.8666	2.0638	-1.8666	Z
	25	41.9839	32.9461	5.0961	41.7470	32.0848	6.5502	0.2369	0.8613	-1.4541	1.7066	-1.4541	Z
	26	37.6231	14.6798	3.7918	37.3552	14.1933	4.3625	0.2679	0.4865	-0.5707	0.7963	-0.5707	Z
	27	37.7162	18.5991	5.1146	37.4362	17.9119	6.0514	0.2800	0.6872	-0.9368	1.1951	-0.9368	Z
	28	37.8016	23.0120	5.1113	37.5968	22.2613	6.4539	0.2048	0.7507	-1.3426	1.5518	-1.3426	Z
	29	38.2061	27.2105	5.1037	38.0917	26.4652	6.9557	0.1144	0.7453	-1.8520	1.9996	-1.8520	Z
	30	38.5223	32.4983	5.1256	38.4447	31.7353	7.4182	0.0776	0.7630	-2.2926	2.4175	-2.2926	Z

[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.
[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.
[C] Direction for Crush column denotes which directions are included in the crush calculations. If "NA" then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan	Posttest Floor Pan
	

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

Model Year: 2014 | Test Name: MNPD-3 | VIN: 1C6RR6LG9ES236433
Make: Dodge | Model: RAM 1500

VEHICLE DEFORMATION
PASSENGER SIDE INTERIOR CRUSH - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	50.7013	20.4112	-31.9909	51.0955	20.5391	-31.7729	-0.3942	-0.1279	0.2180	0.4683	0.4683	X, Y, Z
	2	50.5199	32.0349	-31.4011	50.8462	32.2230	-31.2255	-0.3263	-0.1881	0.1756	0.4156	0.4156	X, Y, Z
	3	51.7625	49.1369	-30.3938	52.0437	49.3057	-30.0708	-0.2812	-0.1688	0.3230	0.4603	0.4603	X, Y, Z
	4	44.0617	20.7837	-24.1830	44.2939	20.9275	-24.0932	-0.2322	-0.1438	0.0898	0.2875	0.2875	X, Y, Z
	5	46.6182	32.6896	-21.7784	46.7418	32.8215	-21.7214	-0.1236	-0.1319	0.0570	0.1895	0.1895	X, Y, Z
	6	47.1664	49.4321	-21.9042	47.2414	49.5552	-21.7349	-0.0750	-0.1231	0.1693	0.2224	0.2224	X, Y, Z
SIDE PANEL (Y)	7	56.5139	52.6382	-3.1469	56.1060	49.7864	-2.8410	0.4079	2.8518	0.3059	2.8970	2.8518	Y
	8	61.4364	52.3245	-6.7823	60.9378	49.4977	-6.7174	0.4986	2.8268	0.0649	2.8712	2.8268	Y
	9	55.9040	52.7797	-9.7128	55.4892	50.2465	-9.5928	0.4148	2.5332	0.1200	2.5697	2.5332	Y
IMPACT SIDE DOOR (Y)	10	47.4860	55.1383	-23.5798	46.7430	56.0018	-23.2019	0.7430	-0.8635	0.3779	1.2002	-0.8635	Y
	11	35.7905	55.1002	-23.2382	35.1518	56.7703	-22.8863	0.6387	-1.6701	0.3519	1.8224	-1.6701	Y
	12	24.9666	55.1254	-23.0932	24.3664	56.8946	-22.9194	0.6002	-1.7692	0.1738	1.8763	-1.7692	Y
	13	47.6508	54.6385	-14.2605	46.4565	54.1705	-14.0009	1.1943	0.4680	0.2596	1.3087	0.4680	Y
	14	34.7456	56.2025	-12.6230	33.9877	57.0574	-12.3120	0.7579	-0.8549	0.3110	1.1841	-0.8549	Y
	15	25.2967	55.6159	-12.5215	24.5192	56.2830	-12.9811	0.7775	-0.6671	-0.4596	1.1228	-0.6671	Y
ROOF - (Z)	16	41.4298	21.2919	-46.6809	41.9312	21.5189	-46.3176	-0.5014	-0.2270	0.3633	0.6595	0.3633	Z
	17	41.6247	28.4731	-46.7680	42.0331	28.6740	-46.4135	-0.4084	-0.2009	0.3545	0.5769	0.3545	Z
	18	40.7554	34.7499	-46.6777	41.2404	35.0957	-46.3178	-0.4850	-0.3458	0.3599	0.6959	0.3599	Z
	19	39.5007	39.7604	-46.0344	40.0361	40.0065	-45.6810	-0.5354	-0.2461	0.3534	0.6871	0.3534	Z
	20	38.7607	44.9428	-45.7151	39.2593	45.1203	-45.4018	-0.4986	-0.1775	0.3133	0.6150	0.3133	Z
	21	36.7208	20.8871	-49.3451	37.1959	21.1397	-49.0452	-0.4751	-0.2526	0.2999	0.6160	0.2999	Z
	22	36.5764	26.4721	-49.2419	37.1258	26.6764	-48.9311	-0.5494	-0.2043	0.3108	0.6635	0.3108	Z
	23	35.9328	32.8137	-49.0427	36.4495	33.0435	-48.7507	-0.5167	-0.2298	0.2920	0.6364	0.2920	Z
	24	35.0791	37.5811	-48.8340	35.6743	37.7825	-48.5338	-0.5952	-0.2014	0.3002	0.6964	0.3002	Z
	25	33.4840	42.7291	-48.5924	34.0837	42.9181	-48.3196	-0.5997	-0.1890	0.2728	0.6854	0.2728	Z
	26	32.1147	21.3774	-50.1776	32.6443	21.5137	-49.9074	-0.5296	-0.1363	0.2702	0.6100	0.2702	Z
	27	31.3874	26.1626	-50.1524	31.9217	26.2710	-49.8970	-0.5343	-0.1084	0.2554	0.6020	0.2554	Z
	28	30.3166	31.7857	-50.0272	30.8675	31.9817	-49.7888	-0.5509	-0.1960	0.2384	0.6315	0.2384	Z
	29	29.5260	36.2676	-49.8209	29.9884	36.3422	-49.6158	-0.4624	-0.0746	0.2051	0.5113	0.2051	Z
	30	28.1529	41.5337	-49.4954	28.6117	41.6440	-49.3144	-0.4588	-0.1103	0.1810	0.5054	0.1810	Z
A-PILLAR Maximum (X, Y, Z)	31	55.4964	51.7180	-31.7127	55.6971	52.0616	-31.0946	-0.2007	-0.3436	0.6181	0.7351	0.6181	Z
	32	52.4084	51.1212	-33.9405	52.6184	51.3500	-33.5413	-0.2100	-0.2288	0.3992	0.5058	0.3992	Z
	33	48.7819	49.3606	-35.9901	49.0367	49.5623	-35.6147	-0.2548	-0.2017	0.3754	0.4965	0.3754	Z
	34	45.7332	49.1482	-38.4518	46.0609	49.3672	-38.0520	-0.3277	-0.2190	0.3998	0.5614	0.3998	Z
	35	41.8038	47.8785	-40.6060	42.1386	48.0440	-40.3122	-0.3348	-0.1655	0.2938	0.4752	0.2938	Z
	36	38.7000	48.3793	-44.0203	39.0857	48.5516	-43.7326	-0.3857	-0.1723	0.2877	0.5111	0.2877	Z
A-PILLAR Lateral (Y)	31	55.4964	51.7180	-31.7127	55.6971	52.0616	-31.0946	-0.2007	-0.3436	0.6181	0.7351	-0.3436	Y
	32	52.4084	51.1212	-33.9405	52.6184	51.3500	-33.5413	-0.2100	-0.2288	0.3992	0.5058	-0.2288	Y
	33	48.7819	49.3606	-35.9901	49.0367	49.5623	-35.6147	-0.2548	-0.2017	0.3754	0.4965	-0.2017	Y
	34	45.7332	49.1482	-38.4518	46.0609	49.3672	-38.0520	-0.3277	-0.2190	0.3998	0.5614	-0.2190	Y
	35	41.8038	47.8785	-40.6060	42.1386	48.0440	-40.3122	-0.3348	-0.1655	0.2938	0.4752	-0.1655	Y
	36	38.7000	48.3793	-44.0203	39.0857	48.5516	-43.7326	-0.3857	-0.1723	0.2877	0.5111	-0.1723	Y
B-PILLAR Maximum (X, Y, Z)	37	14.5842	48.4538	-44.7390	14.9981	48.5768	-44.6902	-0.4139	-0.1230	0.0488	0.4345	0.0488	Z
	38	15.5233	51.9305	-34.3868	15.7576	51.7984	-34.2595	-0.2343	0.1321	0.1273	0.2976	0.1835	Y, Z
	39	16.6986	52.9847	-24.0437	16.8706	52.6086	-23.8978	-0.1720	0.3761	0.1459	0.4385	0.4034	Y, Z
	40	17.6303	52.9604	-12.1803	17.8672	52.4194	-12.0799	-0.2369	0.5410	0.1004	0.5991	0.5502	Y, Z
B-PILLAR Lateral (Y)	37	14.5842	48.4538	-44.7390	14.9981	48.5768	-44.6902	-0.4139	-0.1230	0.0488	0.4345	-0.1230	Y
	38	15.5233	51.9305	-34.3868	15.7576	51.7984	-34.2595	-0.2343	0.1321	0.1273	0.2976	0.1321	Y
	39	16.6986	52.9847	-24.0437	16.8706	52.6086	-23.8978	-0.1720	0.3761	0.1459	0.4385	0.3761	Y
	40	17.6303	52.9604	-12.1803	17.8672	52.4194	-12.0799	-0.2369	0.5410	0.1004	0.5991	0.5410	Y

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

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

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

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

Model Year: 2014 | Test Name: MNPD-3 | VIN: 1C6RR6LG9ES236433
Make: Dodge | Model: RAM 1500

VEHICLE DEFORMATION
PASSENGER SIDE INTERIOR CRUSH - SET 2

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX[A] (in.)	ΔY[A] (in.)	ΔZ[A] (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	45.5740	4.1813	-28.2393	46.2570	4.8461	-27.4653	-0.6830	-0.6648	0.7740	1.2278	1.2278	X, Y, Z
	2	45.2921	15.8099	-27.8065	45.9024	16.5265	-26.9007	-0.6103	-0.7166	0.9058	1.3063	1.3063	X, Y, Z
	3	46.3879	32.9345	-27.0429	46.9459	33.6176	-25.7201	-0.5580	-0.6831	1.3228	1.5899	1.5899	X, Y, Z
	4	38.9961	4.6012	-20.3819	39.4486	5.1620	-19.7882	-0.4525	-0.5608	0.5937	0.9337	0.9337	X, Y, Z
	5	41.4643	16.5614	-18.1613	41.7885	17.0740	-17.3976	-0.3242	-0.5126	0.7637	0.9752	0.9752	X, Y, Z
	6	41.8596	33.3048	-18.5198	42.1378	33.8115	-17.3861	-0.2782	-0.5067	1.1337	1.2726	1.2726	X, Y, Z
SIDE PANEL (Y)	7	51.3322	36.8513	0.1130	50.9913	34.0942	1.5123	0.3409	2.7571	1.3993	3.1106	2.7571	Y
	8	56.2271	36.5318	-3.5589	55.8273	33.8547	-2.3623	0.3998	2.6771	1.1966	2.9595	2.6771	Y
	9	50.6668	36.8973	-6.4488	50.3735	34.5588	-5.2391	0.2933	2.3385	1.2097	2.6491	2.3385	Y
IMPACT SIDE DOOR (Y)	10	42.1136	38.9902	-20.2756	41.5821	40.2556	-18.8438	0.5315	-1.2654	1.4318	1.9834	-1.2654	Y
	11	30.4221	38.8521	-19.8355	29.9844	40.9194	-18.5324	0.4377	-2.0673	1.3031	2.4826	-2.0673	Y
	12	19.6000	38.7824	-19.6002	19.1983	40.9469	-18.5704	0.4017	-2.1645	1.0298	2.4304	-2.1645	Y
	13	42.3598	38.6197	-10.9521	41.3079	38.4080	-9.6457	1.0519	0.2117	1.3064	1.6906	0.2117	Y
	14	29.4549	40.0904	-9.2280	28.8130	41.1803	-7.9583	0.6419	-1.0899	1.2697	1.7922	-1.0899	Y
	15	20.0129	39.4206	-9.0393	19.3520	40.3219	-8.6329	0.6609	-0.9013	0.4064	1.1892	-0.9013	Y
ROOF - (Z)	16	36.1739	4.7775	-42.8618	37.0908	5.7652	-42.0128	-0.9169	-0.9877	0.8490	1.5928	0.8490	Z
	17	36.3030	11.9583	-43.0483	37.1284	12.9211	-42.0981	-0.8254	-0.9628	0.9502	1.5847	0.9502	Z
	18	35.3775	18.2277	-43.0363	36.2780	19.3353	-41.9932	-0.9005	-1.1076	1.0431	1.7680	1.0431	Z
	19	34.0828	23.2351	-42.4508	35.0294	24.2340	-41.3497	-0.9466	-0.9989	1.1011	1.7625	1.1011	Z
	20	33.2985	28.4146	-42.1960	34.2066	29.3402	-41.0632	-0.9081	-0.9256	1.1328	1.7218	1.1328	Z
	21	31.4470	4.2941	-45.4806	32.3604	5.3476	-44.7432	-0.9134	-1.0535	0.7374	1.5773	0.7374	Z
	22	31.2528	9.8785	-45.4523	32.2404	10.8832	-44.6209	-0.9876	-1.0047	0.8314	1.6358	0.8314	Z
	23	30.5534	16.2161	-45.3342	31.5069	17.2437	-44.4314	-0.9535	-1.0276	0.9028	1.6674	0.9028	Z
	24	29.6582	20.9782	-45.1833	30.6891	21.9753	-44.2078	-1.0309	-0.9971	0.9755	1.7345	0.9755	Z
	25	28.0185	26.1145	-44.9986	29.0523	27.0960	-43.9867	-1.0338	-0.9815	1.0119	1.7481	1.0119	Z
	26	26.8299	4.7317	-46.2811	27.8060	5.6820	-45.6070	-0.9761	-0.9503	0.6741	1.5200	0.6741	Z
	27	26.0594	9.5101	-46.3149	27.0406	10.4325	-45.5898	-0.9812	-0.9224	0.7251	1.5295	0.7251	Z
	28	24.9388	15.1245	-46.2574	25.9351	16.1334	-45.4737	-0.9963	-1.0089	0.7837	1.6201	0.7837	Z
	29	24.1093	19.6016	-46.1056	25.0169	20.4856	-45.2946	-0.9076	-0.8840	0.8110	1.5043	0.8110	Z
	30	22.6913	24.8591	-45.8404	23.5924	25.7743	-44.9860	-0.9011	-0.9152	0.8544	1.5426	0.8544	Z
A-PILLAR Maximum (X, Y, Z)	31	50.0872	35.5306	-28.4280	50.5748	36.4077	-26.7381	-0.4876	-0.8771	1.6899	1.9654	1.6899	Z
	32	46.9865	34.8758	-30.6215	47.5038	35.6720	-29.1873	-0.5173	-0.7962	1.4342	1.7200	1.4342	Z
	33	43.3593	33.0548	-32.6165	43.9392	33.8554	-31.2650	-0.5799	-0.8006	1.3515	1.6745	1.3515	Z
	34	40.2923	32.7814	-35.0494	40.9664	33.6372	-33.7040	-0.6741	-0.8558	1.3454	1.7312	1.3454	Z
	35	36.3570	31.4472	-37.1531	37.0572	32.2822	-35.9680	-0.7002	-0.8350	1.1851	1.6100	1.1851	Z
	36	33.2207	31.8734	-40.5477	34.0014	32.7674	-39.3891	-0.7807	-0.8940	1.1586	1.6586	1.1586	Z
A-PILLAR Lateral (Y)	31	50.0872	35.5306	-28.4280	50.5748	36.4077	-26.7381	-0.4876	-0.8771	1.6899	1.9654	-0.8771	Y
	32	46.9865	34.8758	-30.6215	47.5038	35.6720	-29.1873	-0.5173	-0.7962	1.4342	1.7200	-0.7962	Y
	33	43.3593	33.0548	-32.6165	43.9392	33.8554	-31.2650	-0.5799	-0.8006	1.3515	1.6745	-0.8006	Y
	34	40.2923	32.7814	-35.0494	40.9664	33.6372	-33.7040	-0.6741	-0.8558	1.3454	1.7312	-0.8558	Y
	35	36.3570	31.4472	-37.1531	37.0572	32.2822	-35.9680	-0.7002	-0.8350	1.1851	1.6100	-0.8350	Y
	36	33.2207	31.8734	-40.5477	34.0014	32.7674	-39.3891	-0.7807	-0.8940	1.1586	1.6586	-0.8940	Y
B-PILLAR Maximum (X, Y, Z)	37	9.1001	31.7221	-41.0652	9.9149	32.5776	-40.3578	-0.8148	-0.8555	0.7074	1.3770	0.7074	Z
	38	10.0931	35.3485	-30.7696	10.6408	35.7904	-29.9220	-0.5477	-0.4419	0.8476	1.1017	0.8476	Z
	39	11.3442	36.5549	-20.4521	11.7417	36.5951	-19.5586	-0.3975	-0.0402	0.8935	0.9788	0.8935	Z
	40	12.3740	36.7015	-8.5976	12.7346	36.3973	-7.7405	-0.3606	0.3042	0.8571	0.9784	0.9095	Y, Z
B-PILLAR Lateral (Y)	37	9.1001	31.7221	-41.0652	9.9149	32.5776	-40.3578	-0.8148	-0.8555	0.7074	1.3770	-0.8555	Y
	38	10.0931	35.3485	-30.7696	10.6408	35.7904	-29.9220	-0.5477	-0.4419	0.8476	1.1017	-0.4419	Y
	39	11.3442	36.5549	-20.4521	11.7417	36.5951	-19.5586	-0.3975	-0.0402	0.8935	0.9788	-0.0402	Y
	40	12.3740	36.7015	-8.5976	12.7346	36.3973	-7.7405	-0.3606	0.3042	0.8571	0.9784	0.3042	Y

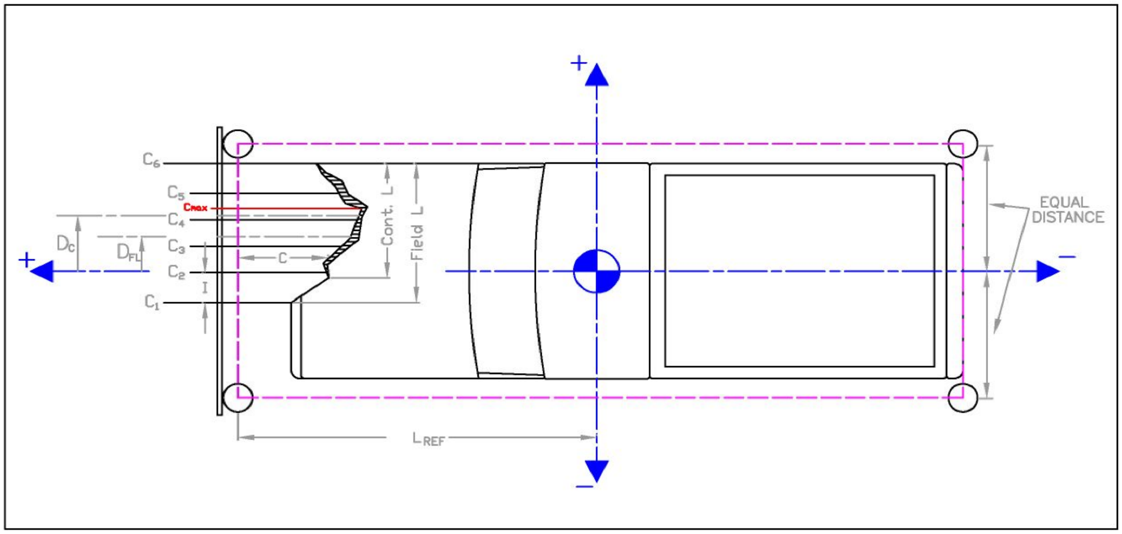
[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

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

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

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

Date Measured:	10/6/2020	Test Name:	MNPD-3	VIN:	1C6RR6LG9ES236433
Model Year:	2014	Make:	Dodge	Model:	RAM 1500



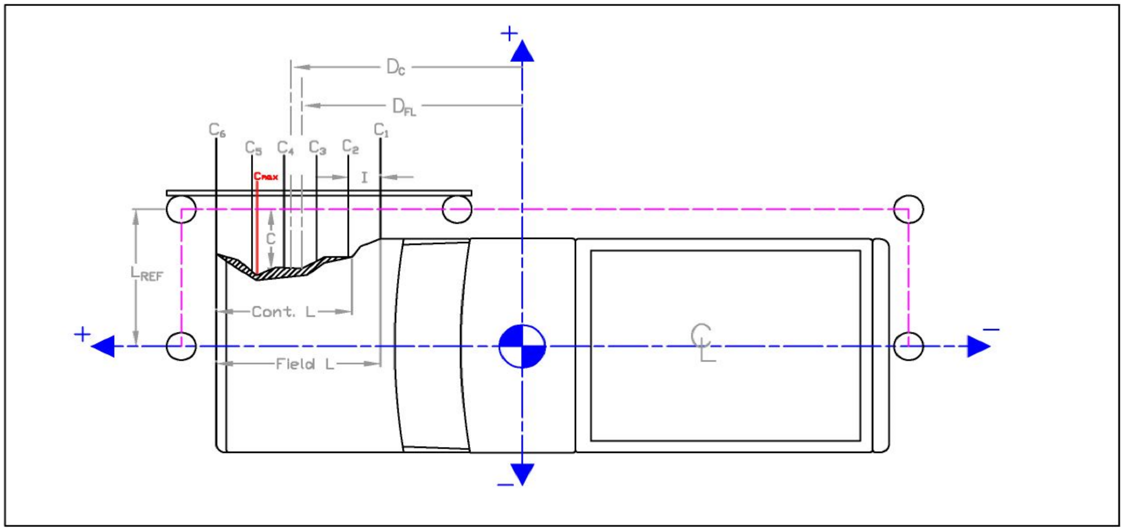
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	123 1/2	(3137)
Total Vehicle Width:	77 5/8	(1972)
Width of contact and induced crush - Field L:	77 5/8	(1972)
Crush measurement spacing interval (L/5) - I:	15 1/2	(394)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	23 1/3	(592)
Distance from center of vehicle to center of contact damage - D_C:	38 4/5	(986)

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

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	N/a	N/A	-38 7/8	-(987)	22 1/2	(572)	13 4/5	(351)	N/A	N/A
C_2	18 1/8	(460)	-23 3/8	-(594)	6 5/8	(168)			-2 1/3	-(59)
C_3	16 1/4	(413)	-7 7/8	-(200)	4 1/4	(108)			-1 4/5	-(46)
C_4	16 7/8	(429)	7 5/8	(194)	4 1/4	(108)			-1 1/5	-(30)
C_5	41 1/2	(1054)	23 1/8	(587)	6 1/8	(156)			21 4/7	(548)
C_6	N/a	N/A	38 5/8	(981)	20 1/2	(521)			N/A	N/A
C_{MAX}	41 1/2	(1054)	23 1/8	(587)	6 1/8	(156)			21 4/7	(548)

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

Date Measured:	10/6/2020	Test Name:	MNPD-3	VIN:	1C6RR6LG9ES236433
Model Year:	2014	Make:	Dodge	Model:	RAM 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	45 1/4	(1149)
Total Vehicle Length:	228 5/8	(5807)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-1 1/4	-(32)
Width of contact and induced crush - Field L:	228 5/8	(5807)
Crush measurement spacing interval (L/5) - I:	45 3/4	(1162)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-7 3/8	-(187)
Width of Contact Damage:	228 5/8	(5807)
Distance from vehicle c.g. to center of contact damage - D_C:	-7 3/8	-(187)

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

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	N/a	N/A	-121 3/4	-(3092)	33 1/2	(851)	1 1/4	(32)	N/A	N/A
C_2	N/a	N/A	-76	-(1930)	5 1/2	(140)			N/A	N/A
C_3	8	(203)	-30 1/4	-(768)	5 7/8	(149)			7/8	(22)
C_4	7 3/4	(197)	15 1/2	(394)	5	(127)			1 1/2	(38)
C_5	N/a	N/A	61 1/4	(1556)	5 7/8	(149)			N/A	N/A
C_6	N/a	N/A	107	(2718)	11 7/8	(302)			N/A	N/A
C_{MAX}	27 1/4	(692)	92	(2337)	5 7/8	(149)			20 1/8	(511)

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

Model Year: 2014	Test Name: MNPD-3	VIN: 1C6RR6LG9ES236433
	Make: Dodge	Model: RAM 1500

Passenger Side Maximum Deformation

Reference Set 1				Reference Set 2			
Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]	Location	Maximum Deformation[A,B] (in.)	MASH Allowable Deformation (in.)	Directions of Deformation[C]
Roof	0.4	≤ 4	Z	Roof	1.1	≤ 4	Z
Windshield[D]	0.0	≤ 3	X, Z	Windshield[D]	NA	≤ 3	X, Z
A-Pillar Maximum	0.6	≤ 5	Z	A-Pillar Maximum	1.7	≤ 5	Z
A-Pillar Lateral	-0.3	≤ 3	Y	A-Pillar Lateral	-0.9	≤ 3	Y
B-Pillar Maximum	0.6	≤ 5	Y, Z	B-Pillar Maximum	0.9	≤ 5	Y, Z
B-Pillar Lateral	0.5	≤ 3	Y	B-Pillar Lateral	0.3	≤ 3	Y
Toe Pan - Wheel Well	2.4	≤ 9	X, Z	Toe Pan - Wheel Well	2.1	≤ 9	X
Side Front Panel	2.9	≤ 12	Y	Side Front Panel	2.8	≤ 12	Y
Side Door (above seat)	-1.8	≤ 9	Y	Side Door (above seat)	-2.2	≤ 9	Y
Side Door (below seat)	0.5	≤ 12	Y	Side Door (below seat)	0.2	≤ 12	Y
Floor Pan	0.1	≤ 12	Z	Floor Pan	-2.3	≤ 12	Z
Dash - no MASH requirement	0.5	NA	X, Y, Z	Dash - no MASH requirement	1.6	NA	X, Y, Z

[A] Items highlighted in red do not meet MASH allowable deformations.

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

[C] For Toe Pan - Wheel Well the direction of defromation may include X and Z direction. For A-Pillar Maximum and B-Pillar Maximum the direction of deformation may include X, Y, and Z directions. The direction of deformation for Toe Pan -Wheel Well, A-Pillar Maximum, and B-Pillar Maximum only include components where the deformation is positive and intruding into the occupant compartment. If direction of deformation is "NA" then no intrusion is recorded and deformation will be 0.

[D] If deformation is observered for the windshield then the windshield deformation is measured posttest with an examplar vehicle, therefore only one set of reference is measured and recorded.

Notes on vehicle interior crush:

Figure C-7. Maximum Occupant Compartment Deformations by Location, Test No. MNPD-3

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

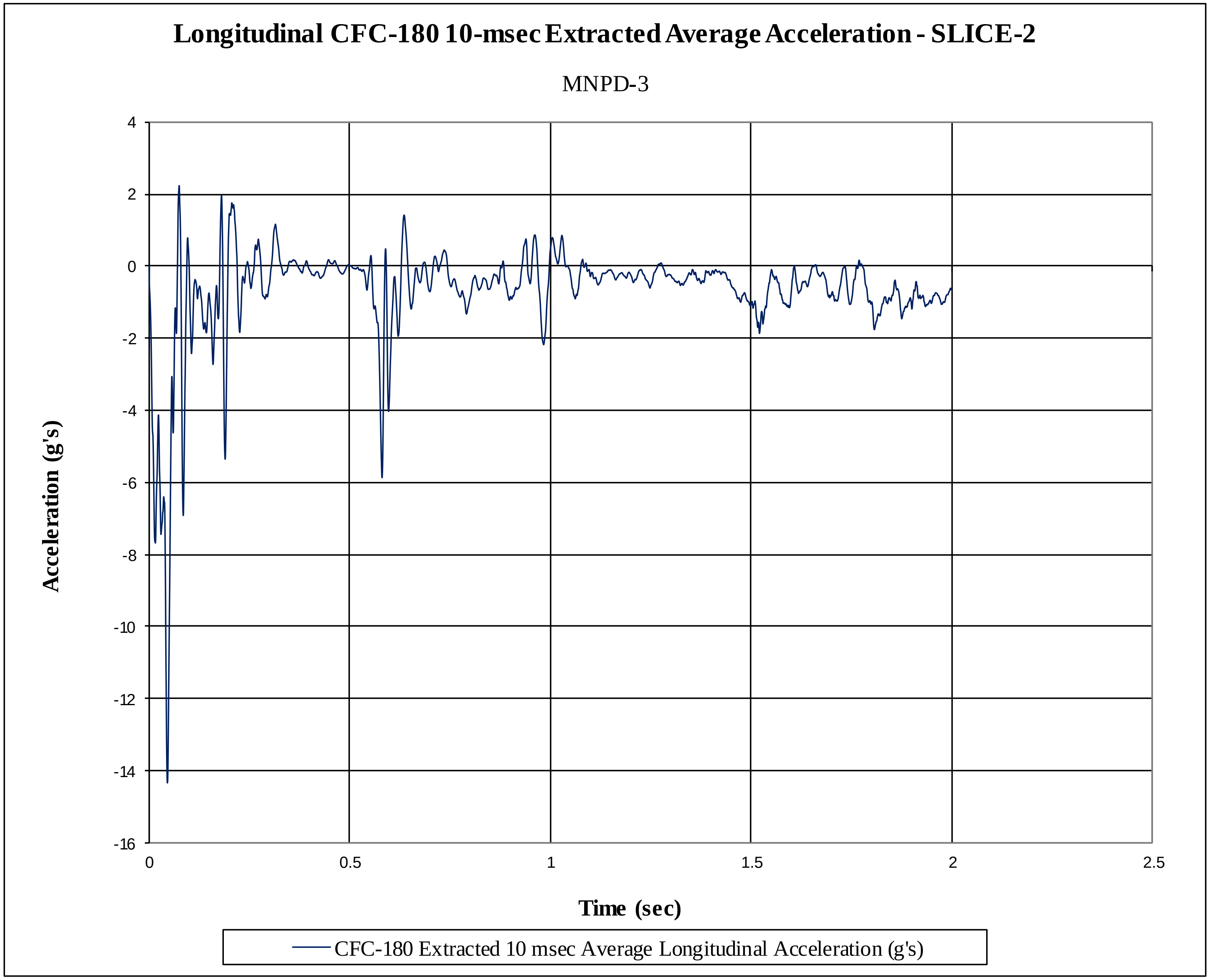


Figure D-1. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MNPD-3

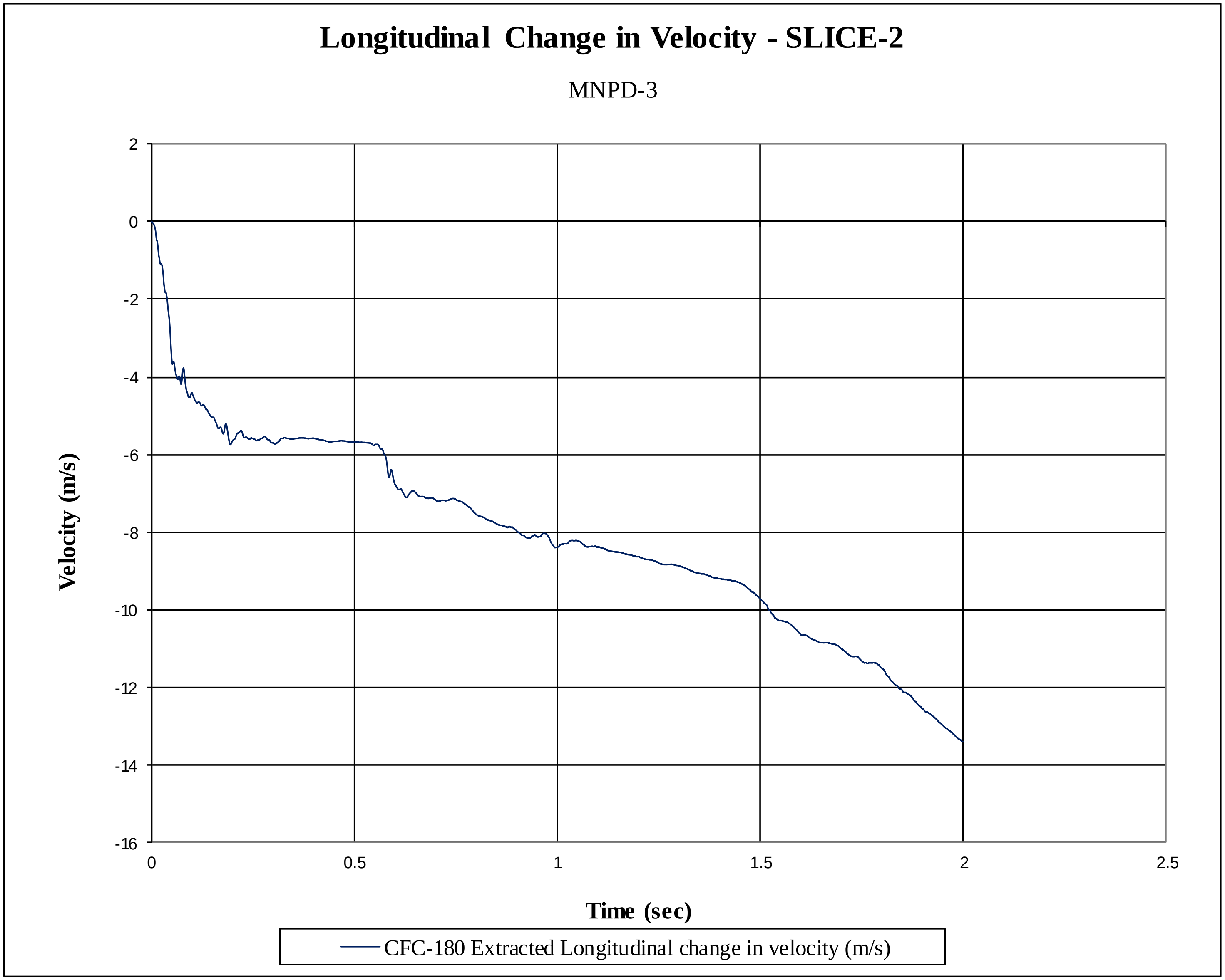


Figure D-2. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MNPD-3

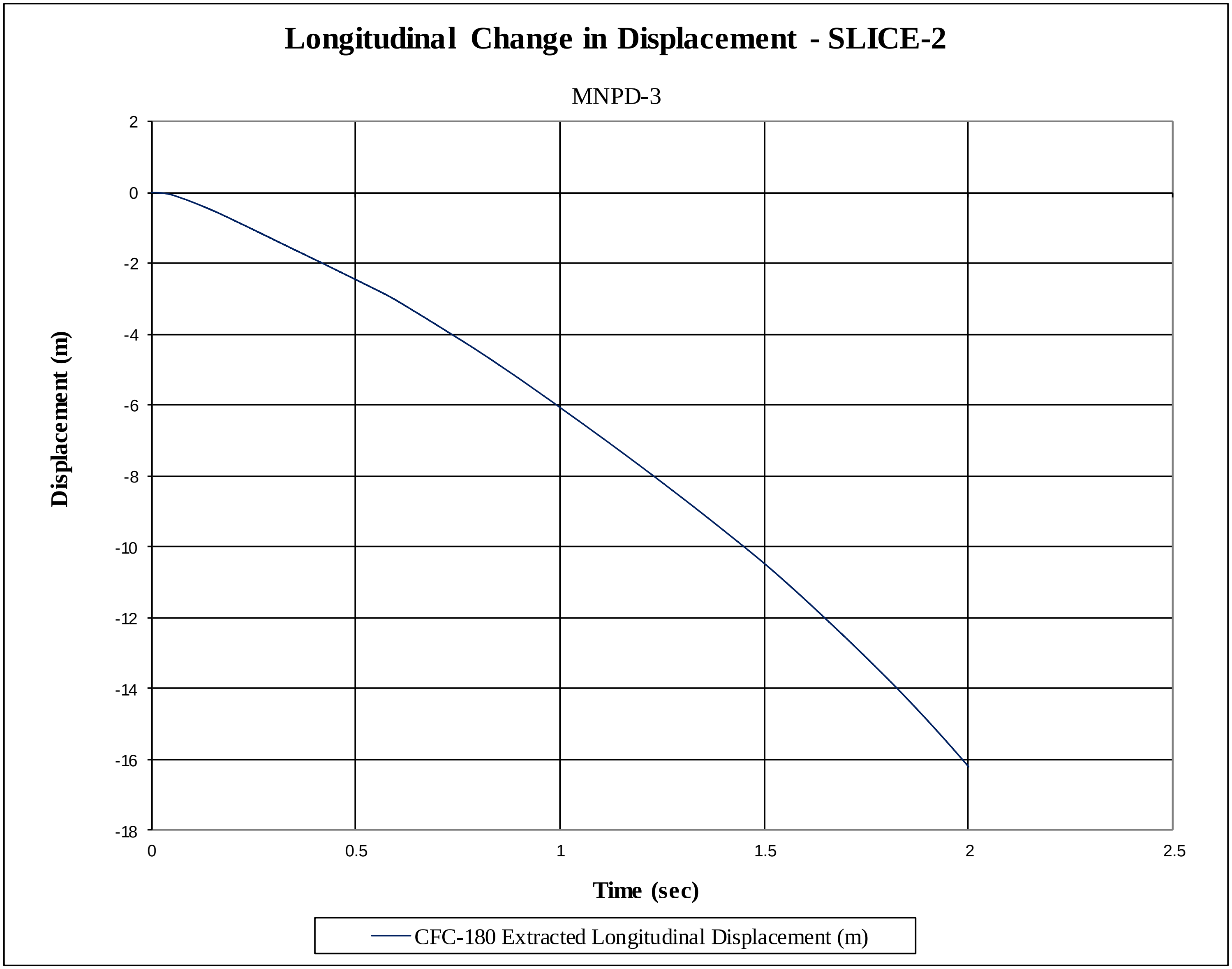


Figure D-3. Longitudinal Occupant Displacement (SLICE-2), Test No. MNPD-3

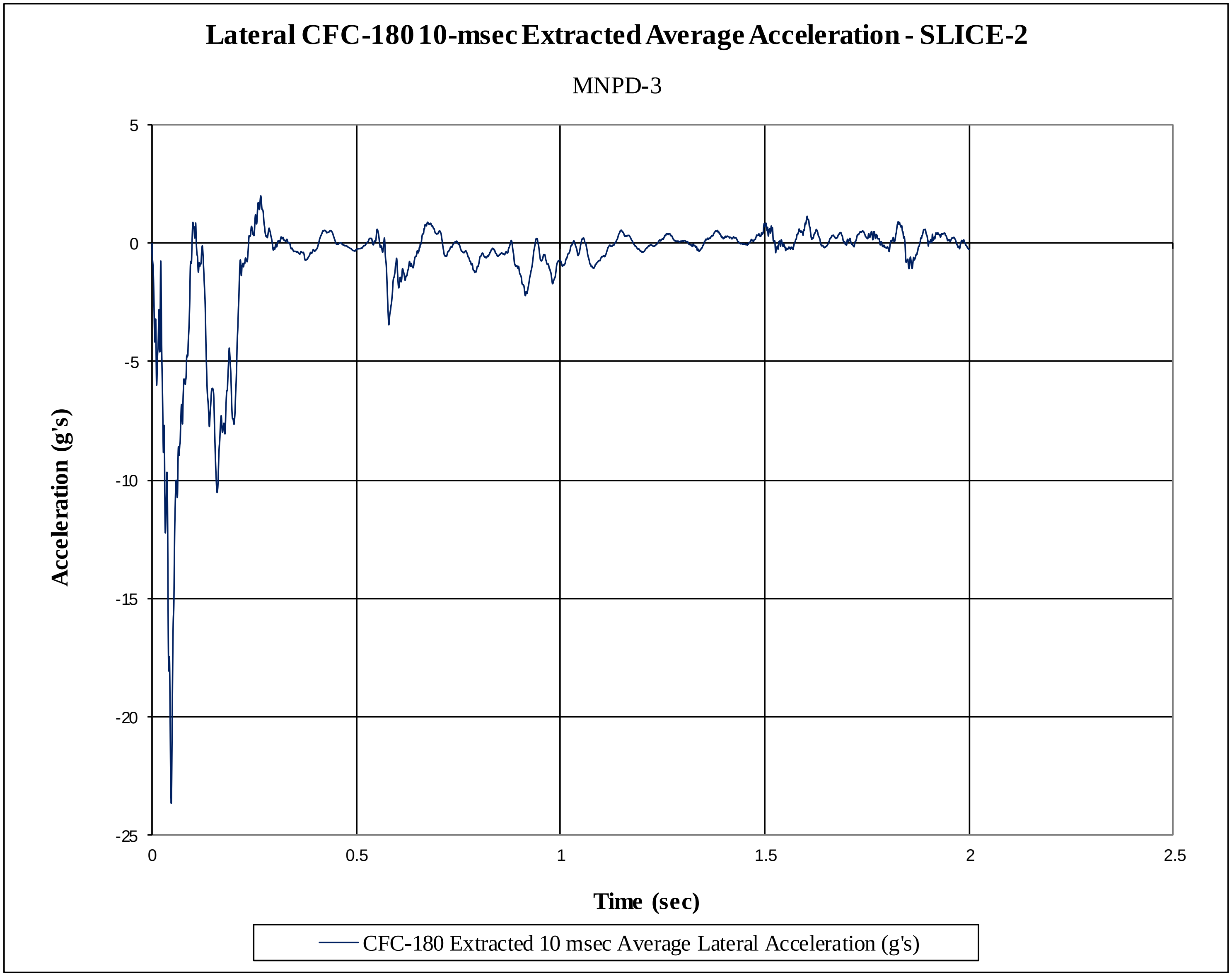


Figure D-4. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MNPD-3

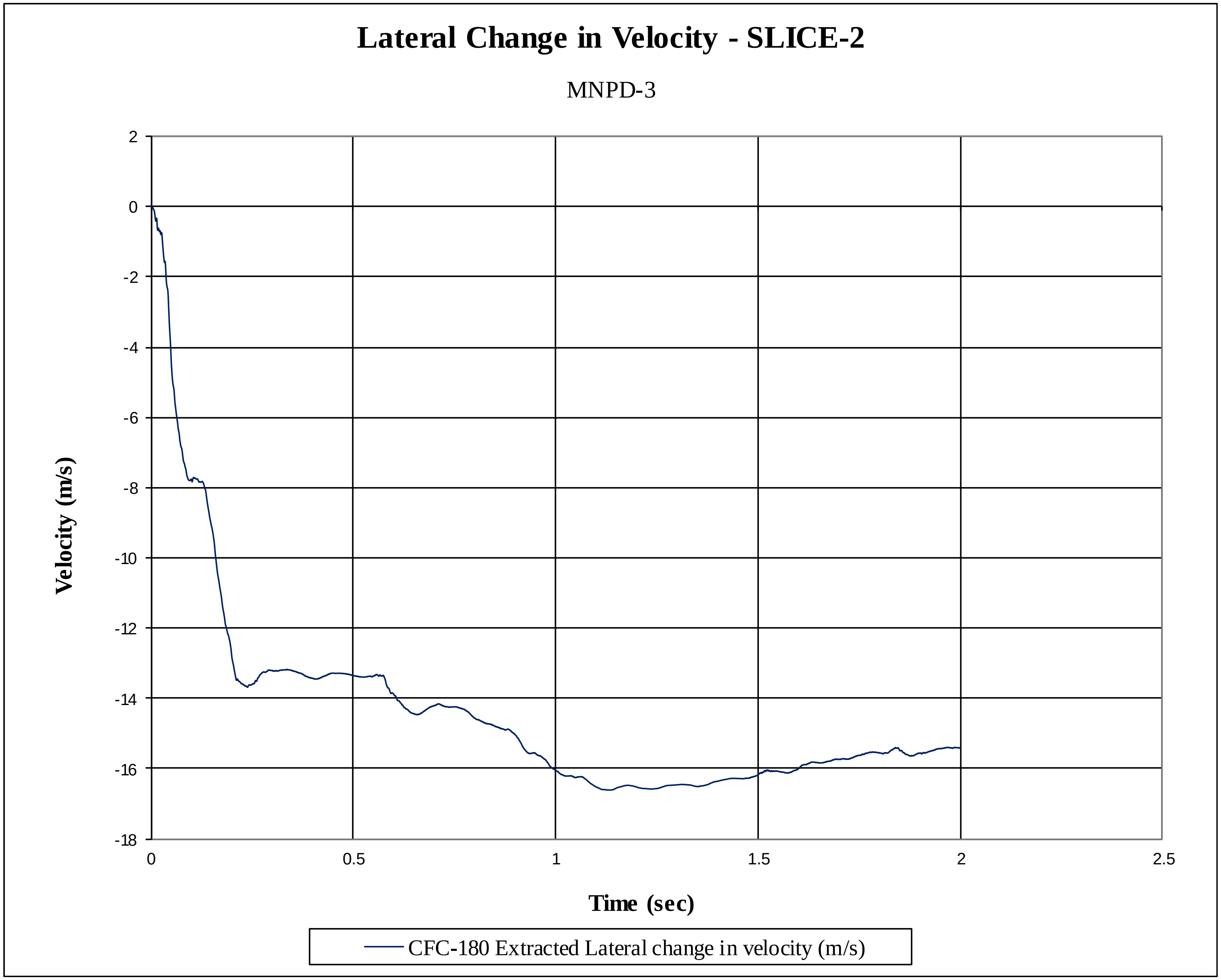


Figure D-5. Lateral Occupant Impact Velocity (SLICE-2), Test No. MNPD-3

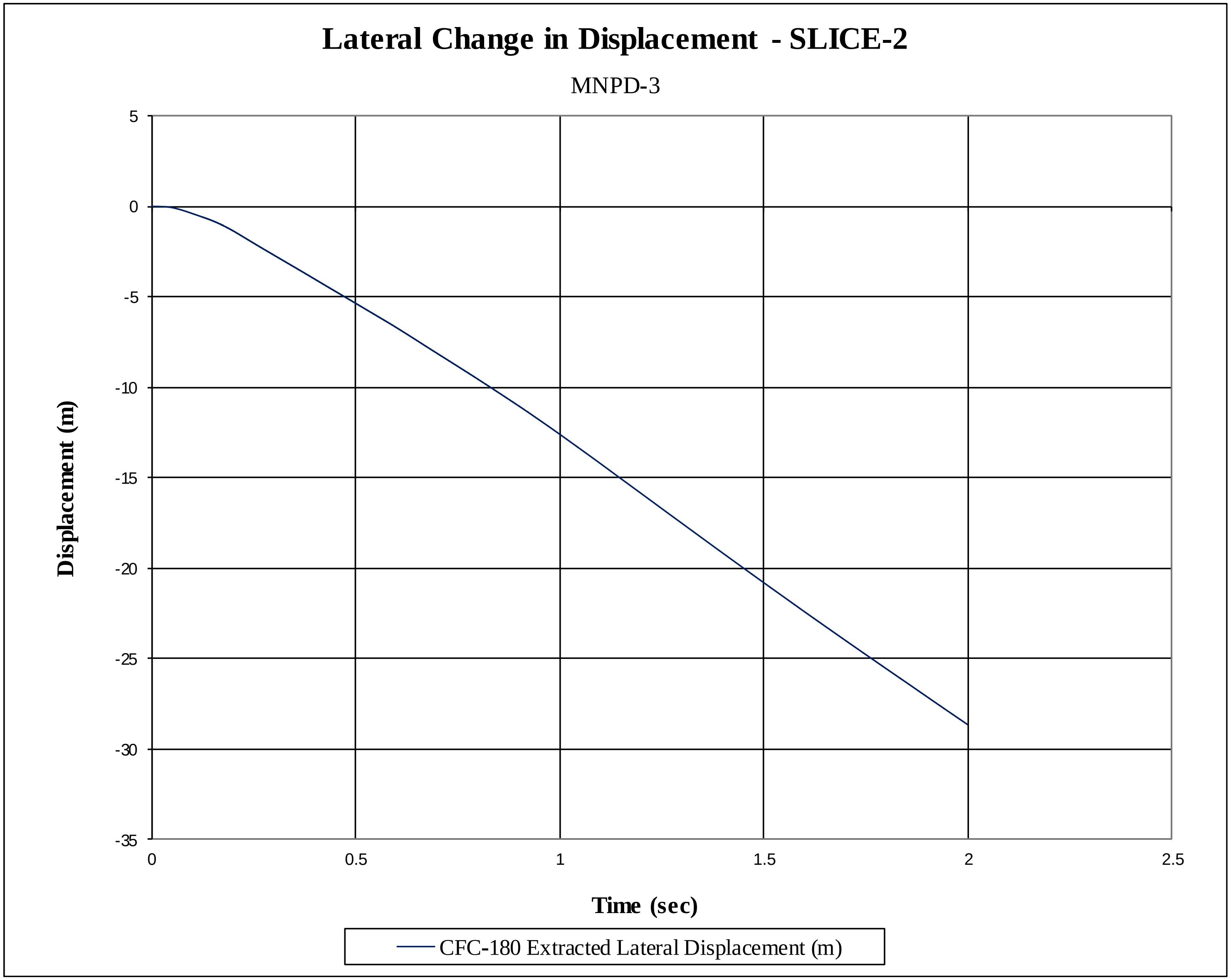


Figure D-6. Lateral Occupant Displacement (SLICE-2), Test No. MNPD-3

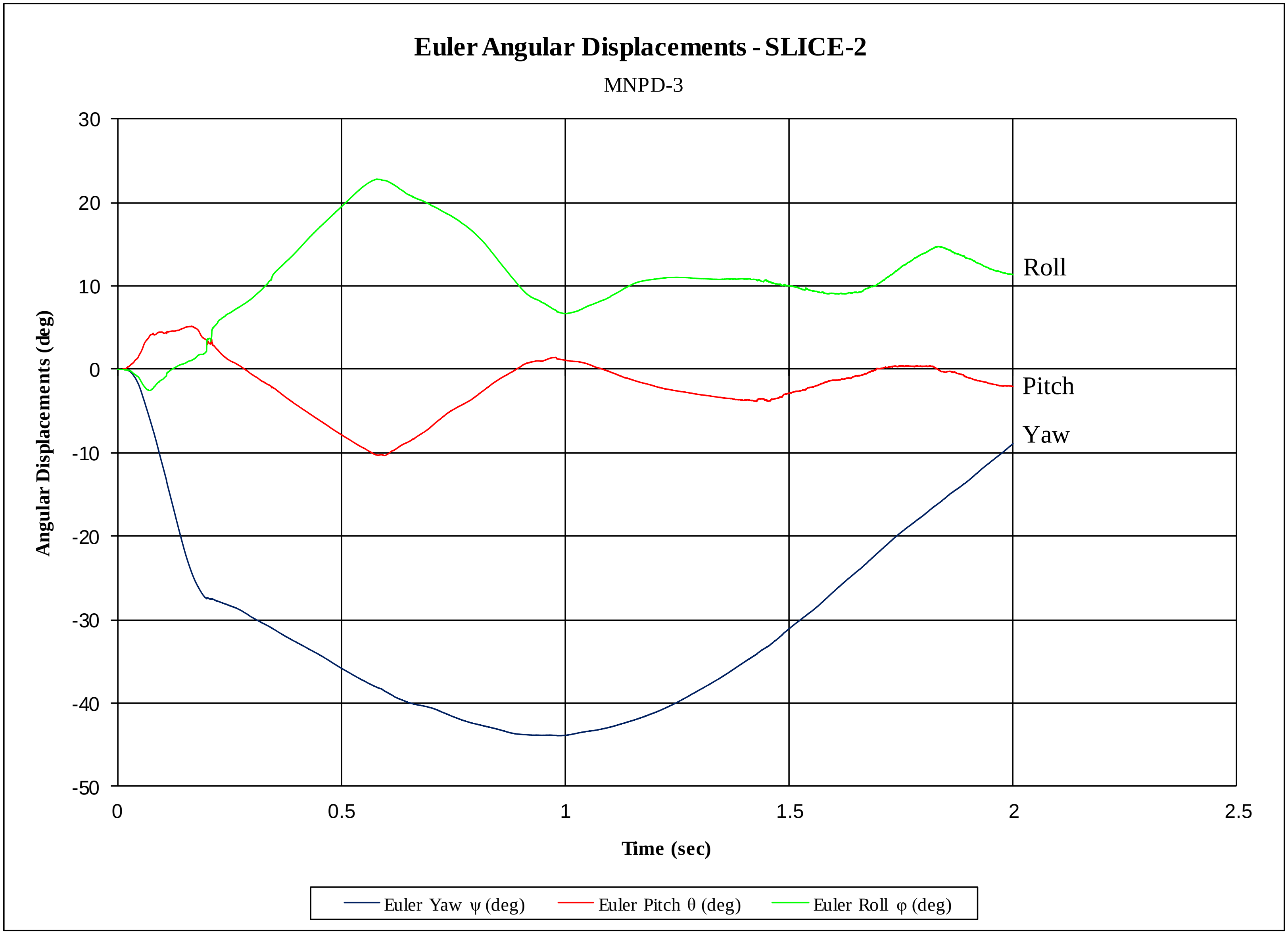


Figure D-7. Vehicle Angular Displacements (SLICE-2), Test No. MNPD-3

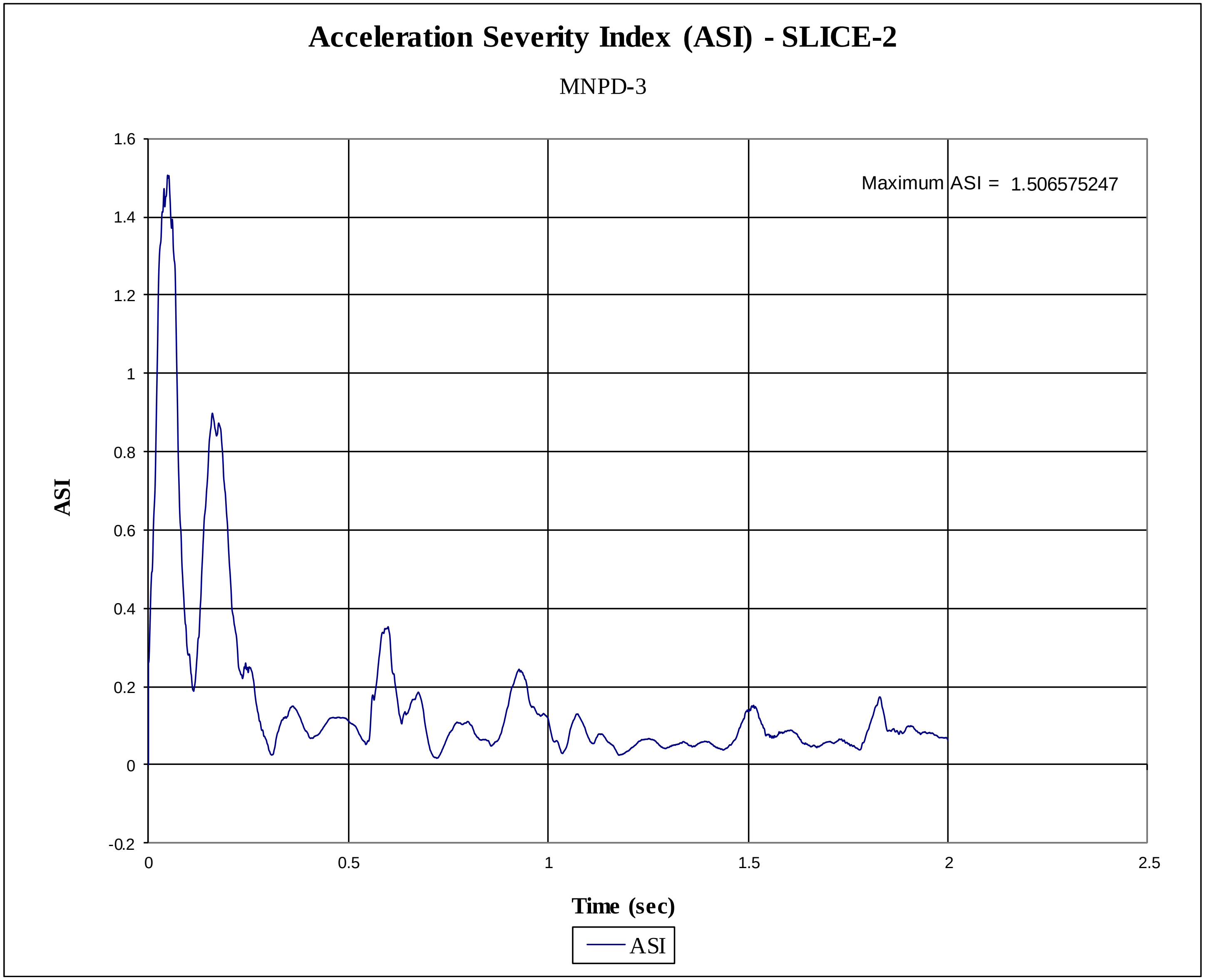


Figure D-8. Acceleration Severity Index (SLICE-2), Test No. MNPD-3

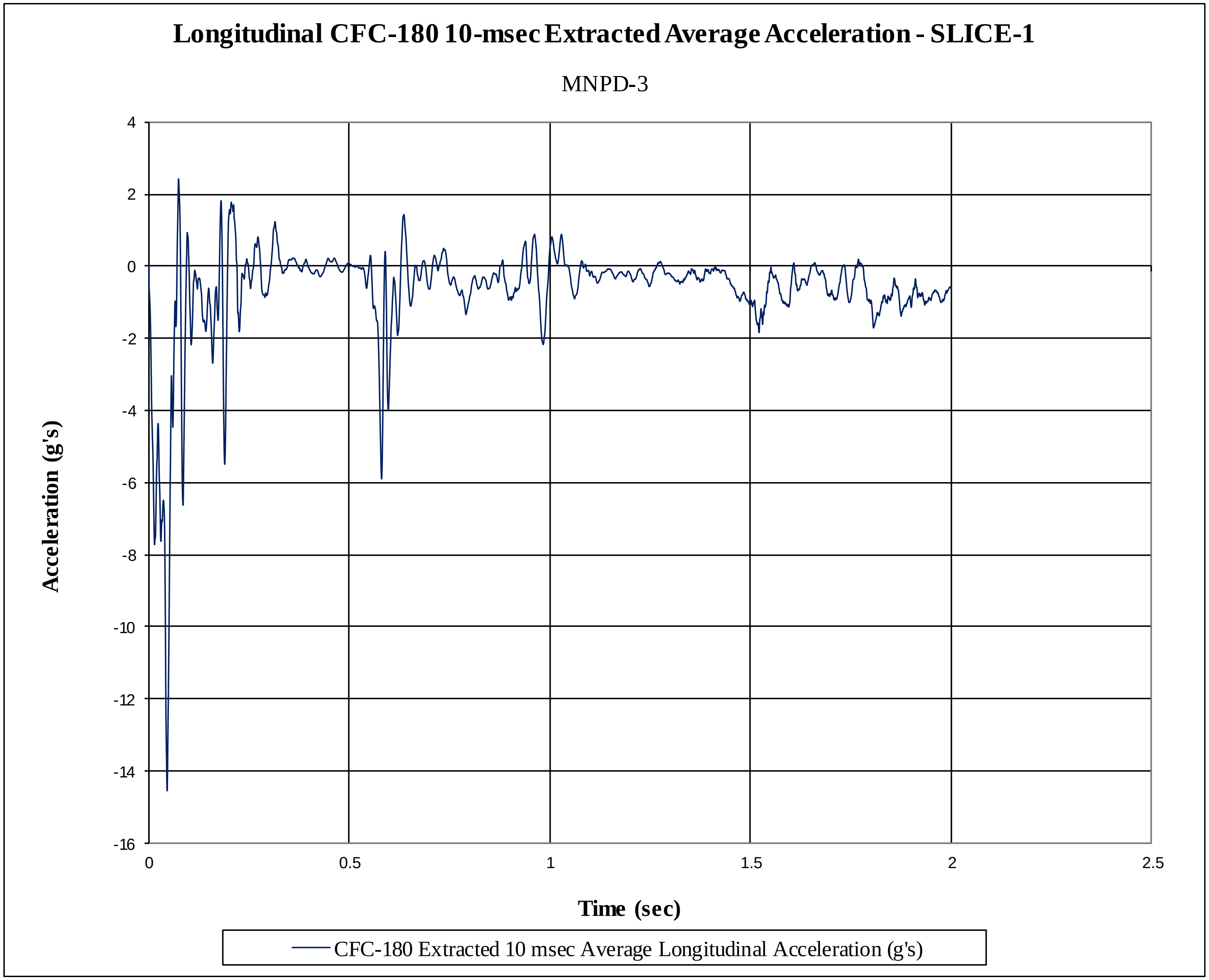


Figure D-9. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MNPD-3

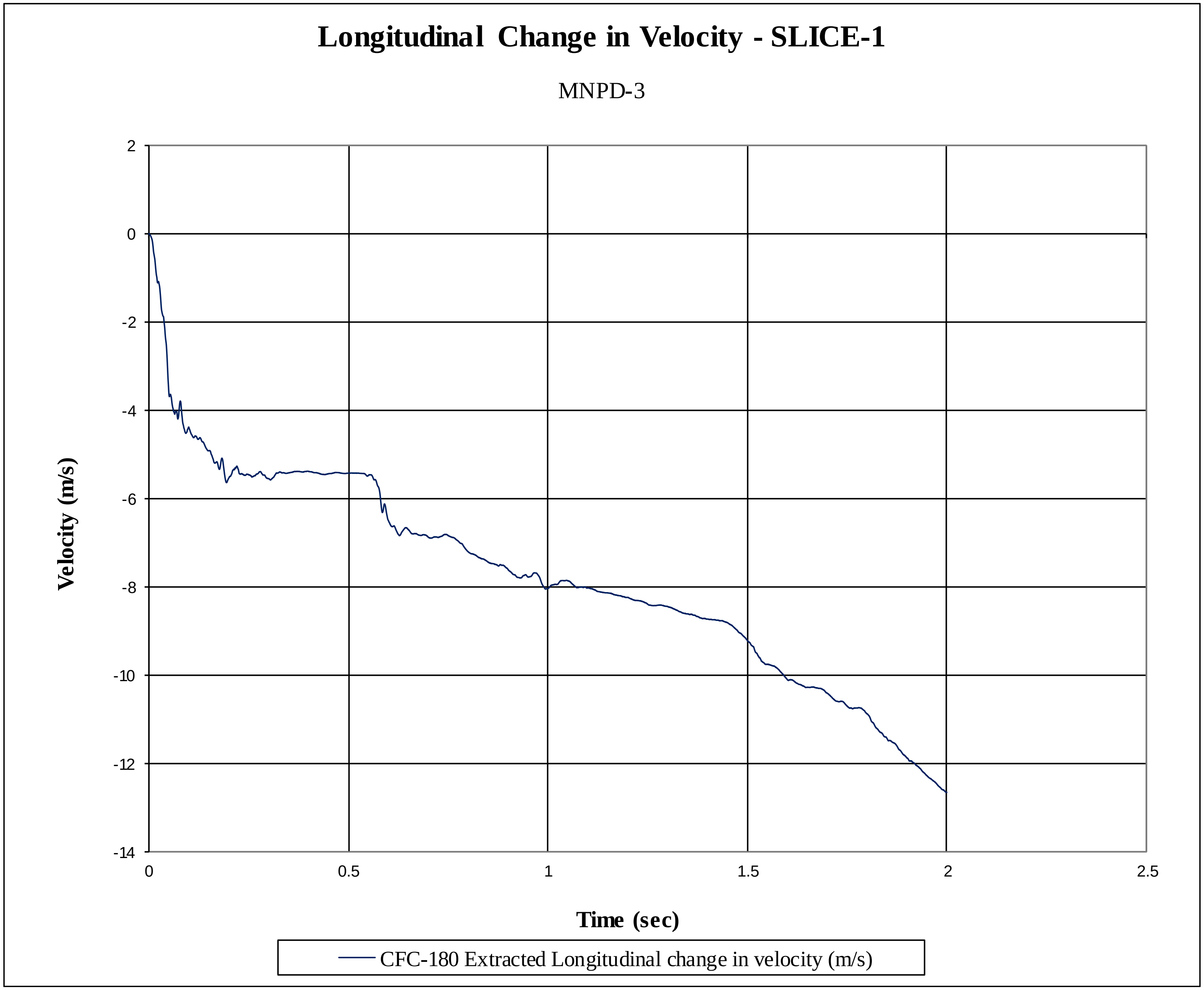


Figure D-10. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MNPD-3

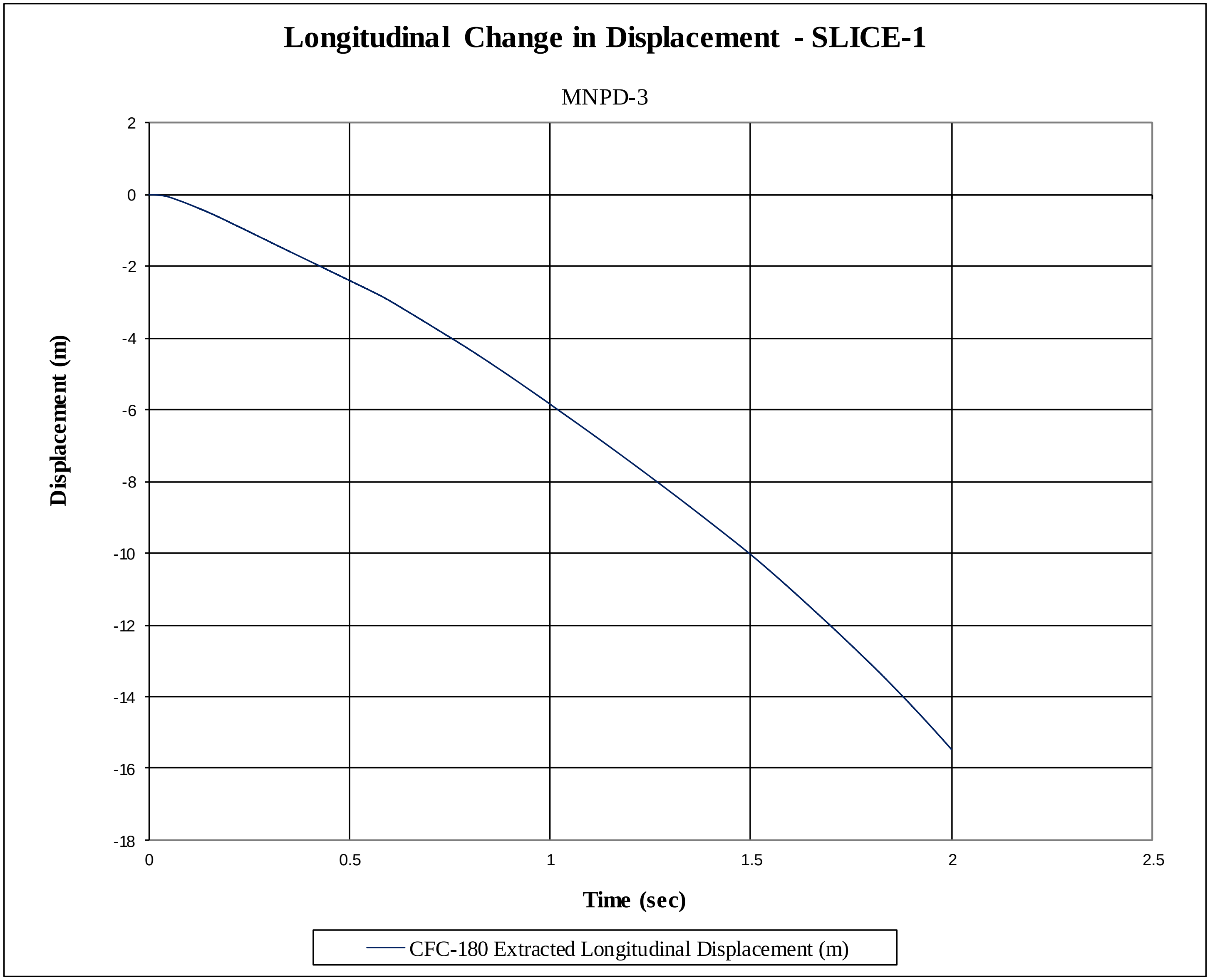


Figure D-11. Longitudinal Occupant Displacement (SLICE-1), Test No. MNPD-3

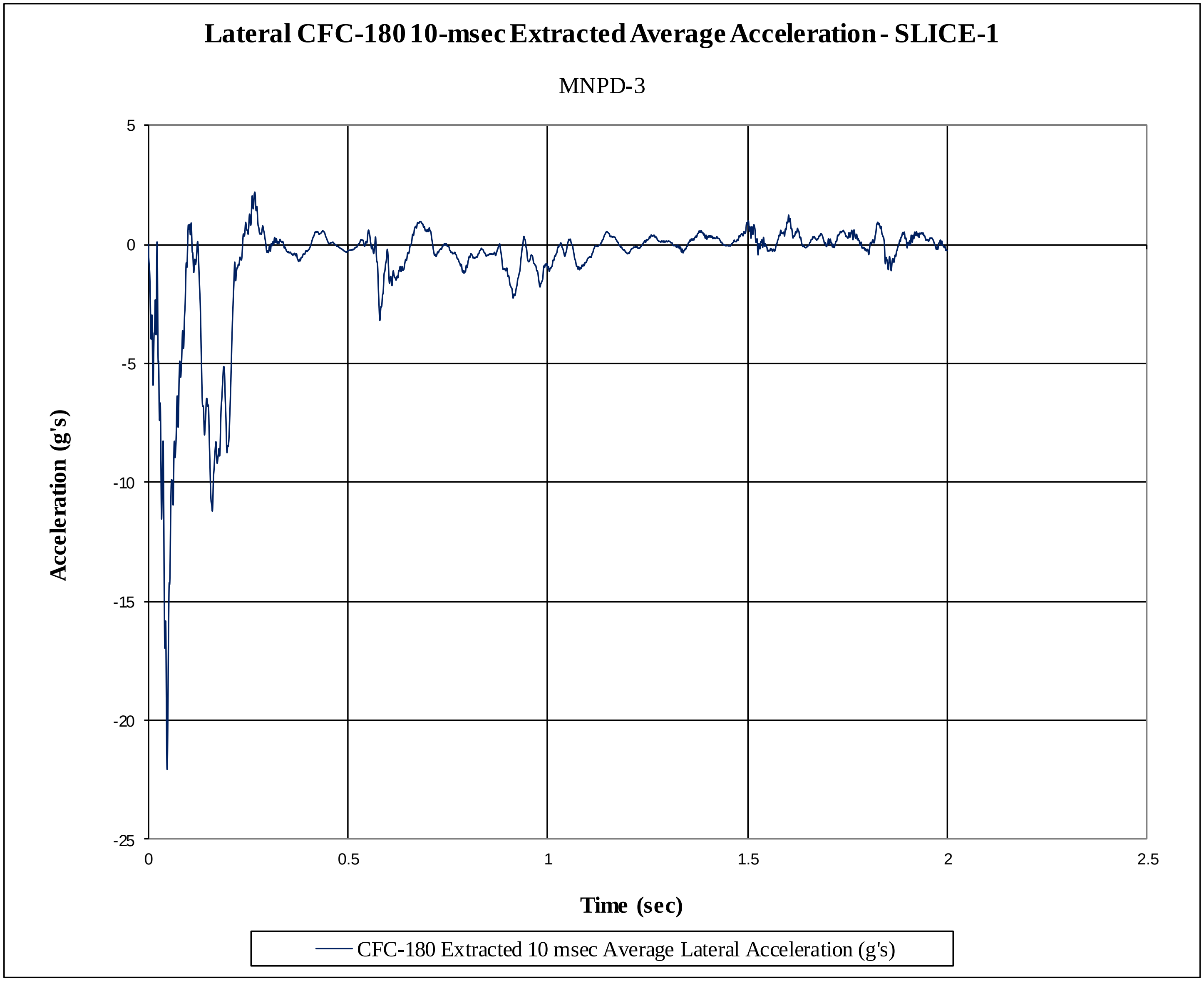


Figure D-12. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MNPD-3

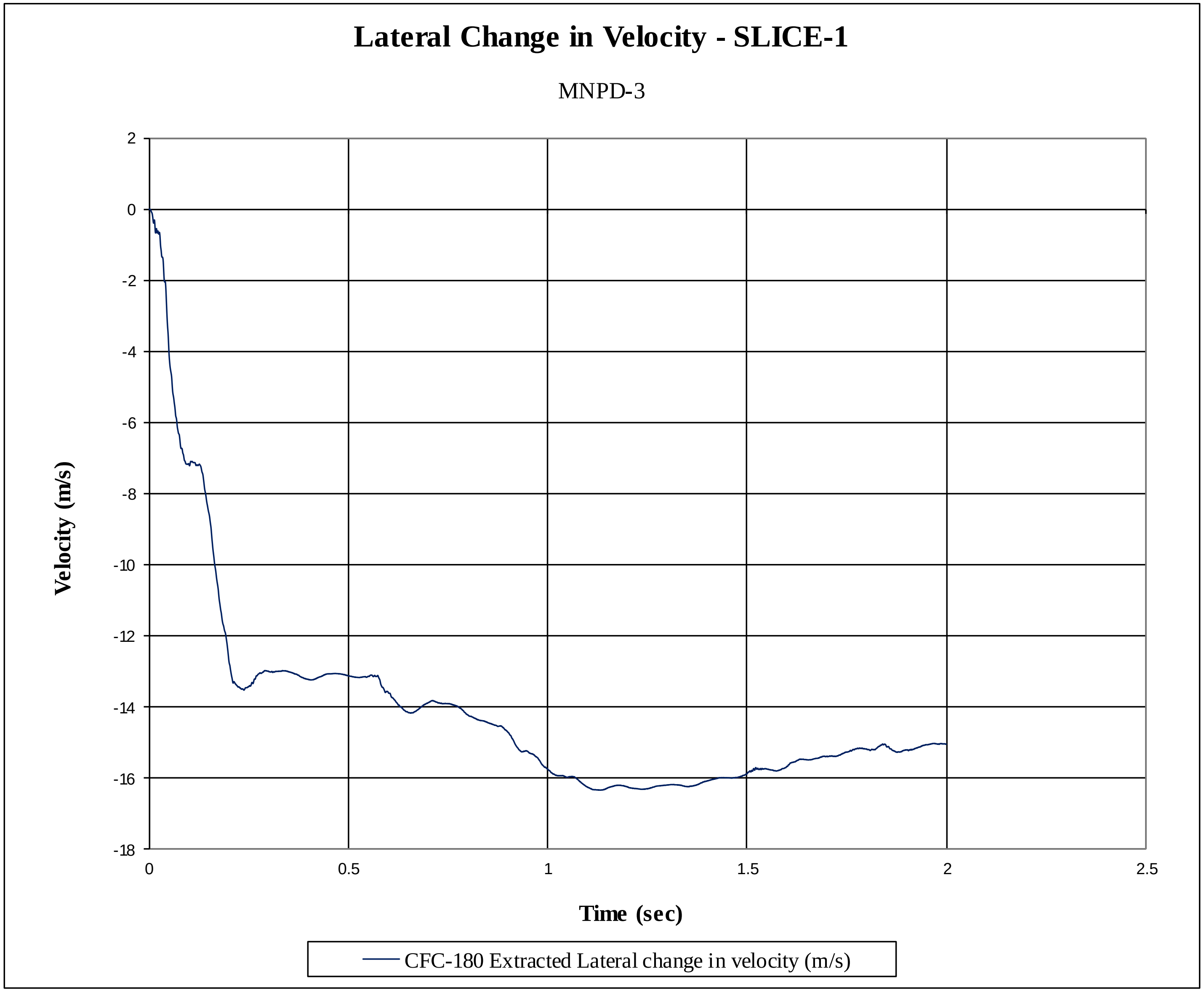


Figure D-13. Lateral Occupant Impact Velocity (SLICE-1), Test No. MNPD-3

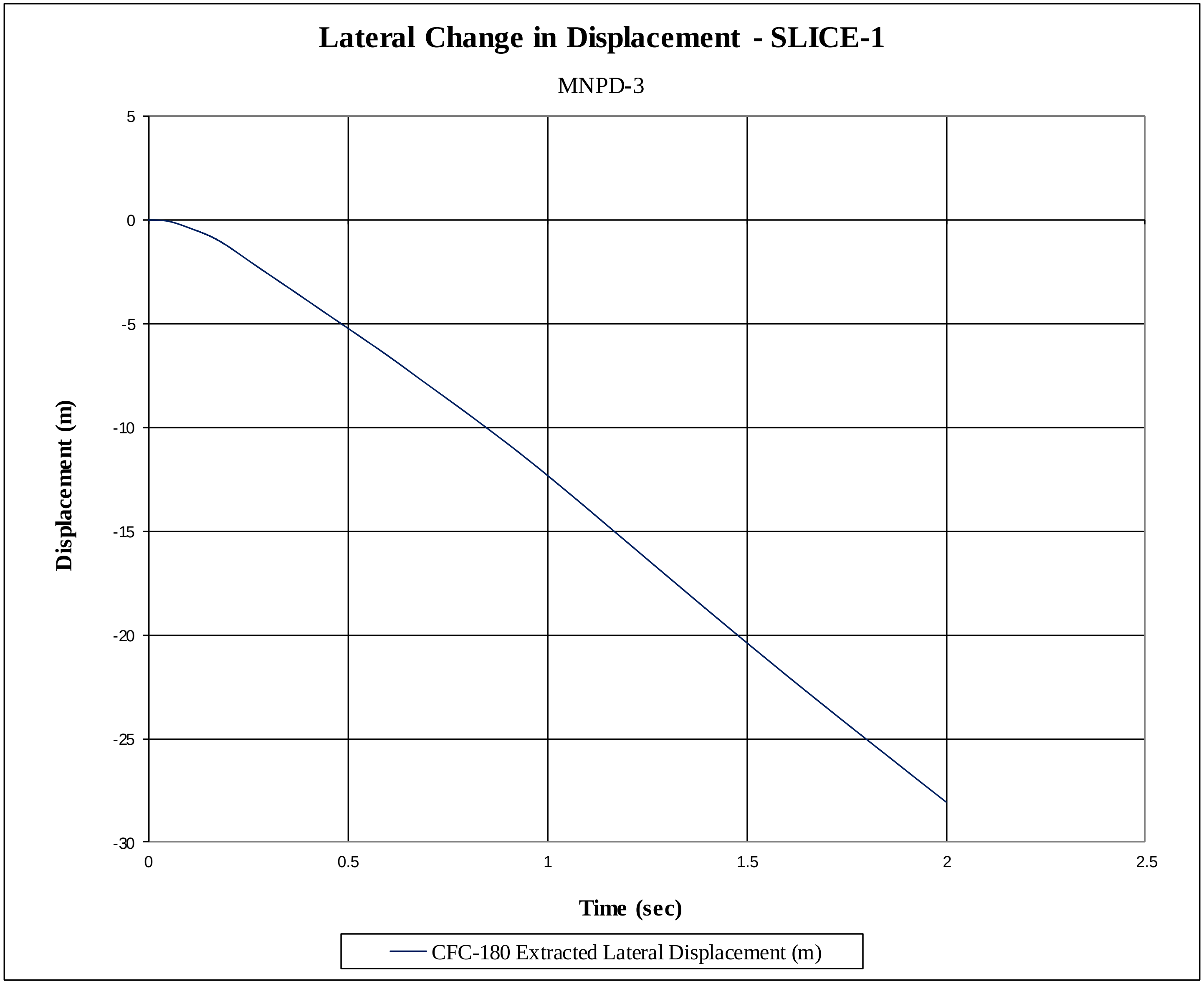


Figure D-14. Lateral Occupant Displacement (SLICE-1), Test No. MNPD-3

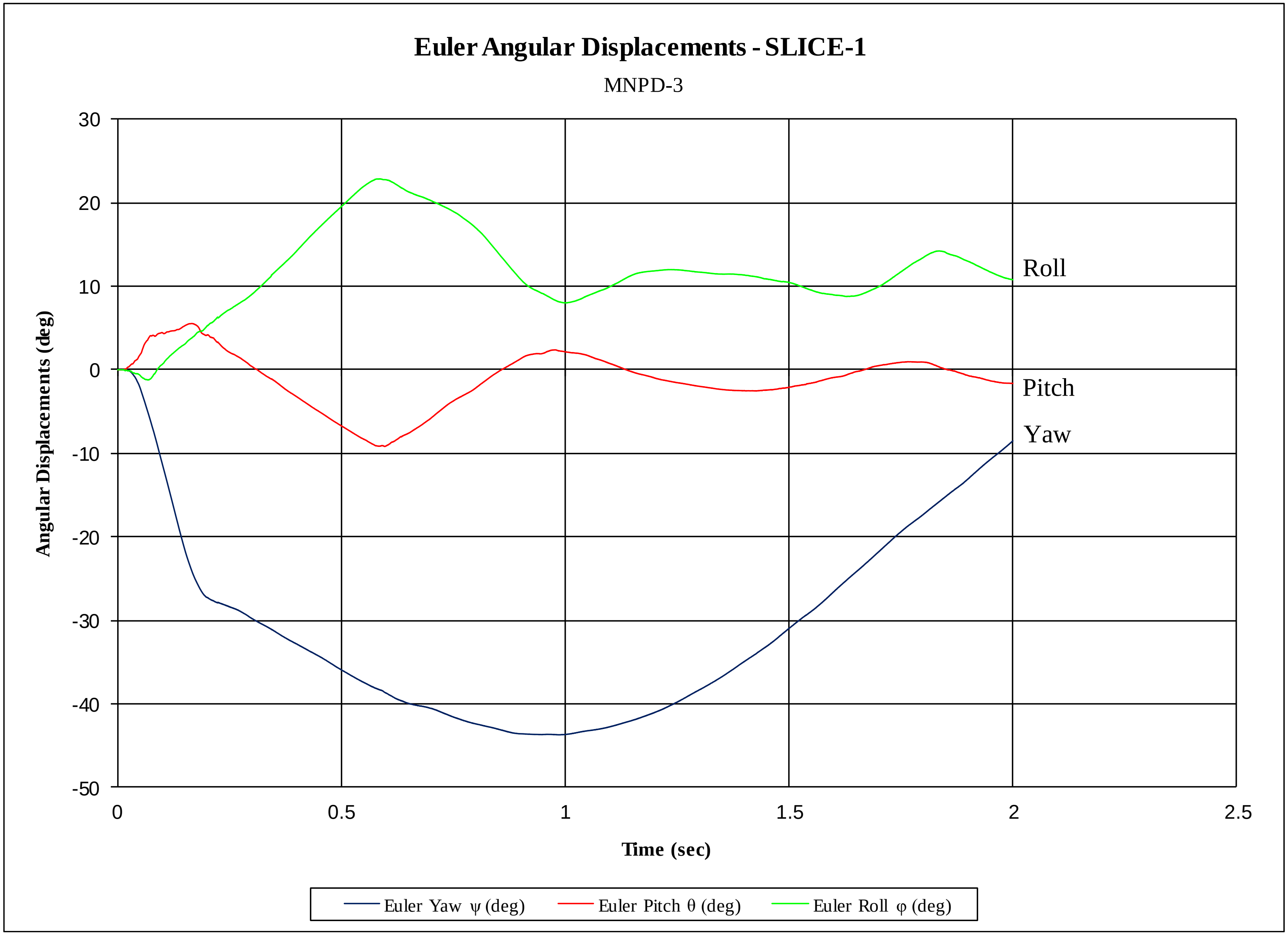


Figure D-15. Vehicle Angular Displacements (SLICE-1), Test No. MNPD-3

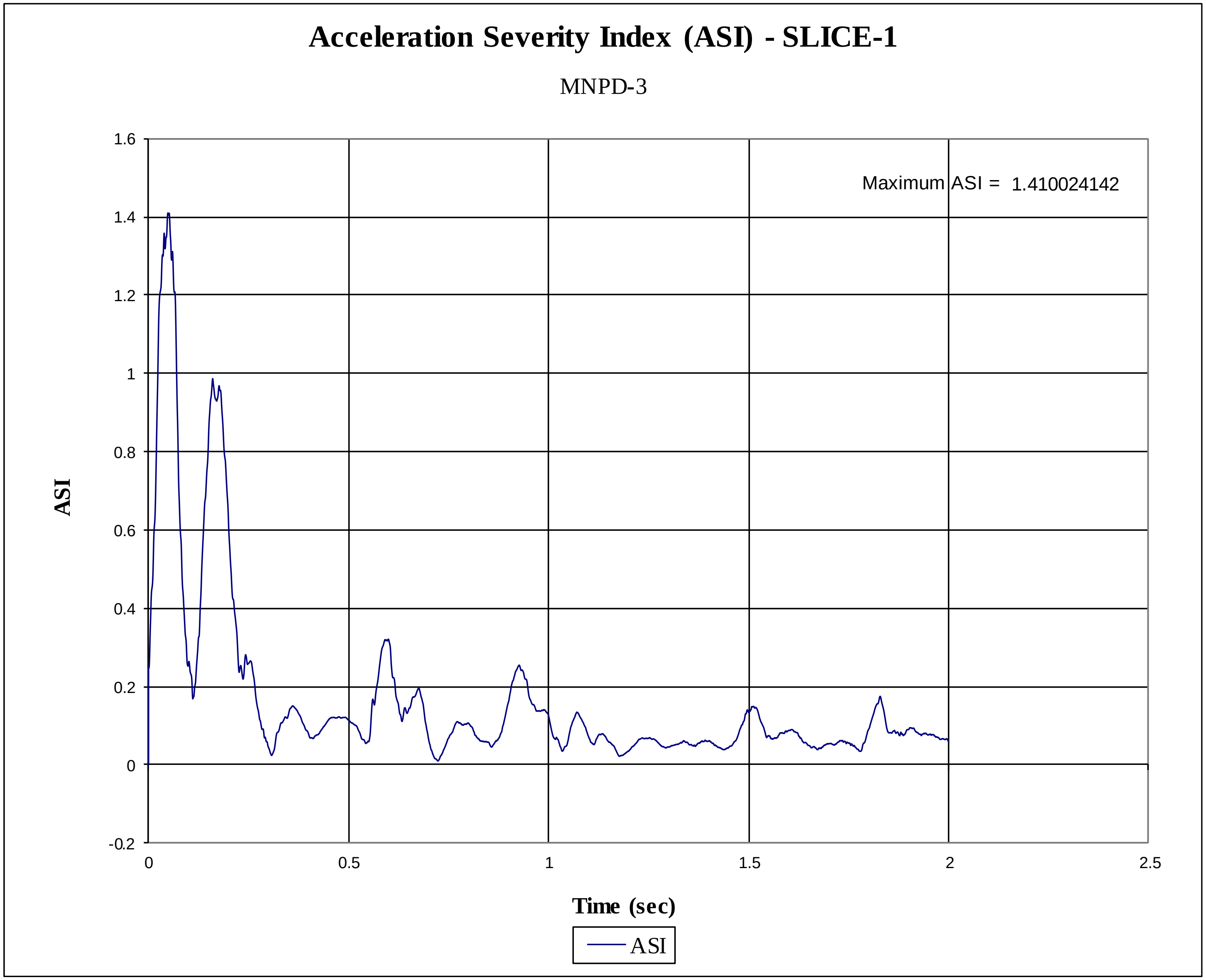


Figure D-16. Acceleration Severity Index (SLICE-1), Test No. MNPD-3

END OF DOCUMENT