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EVALUATION OF THE MINNESOTA NOISE WALL AND RUBRAIL SYSTEM

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The Minnesota Department of Transportation had previously successfully evaluated a noise wall and rubrail system under the NCHRP Report No. 350 safety performance criteria. The rubrail in this system was re-sized, and the system was evaluated with the latest crash testing standard, the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH 2016). The noise wall and timber rubrail system consisted of an 89-ft (27.1-m) long timber rubrail in front of twelve 18-ft (5.5-m) tall concrete posts with a wooden noise wall.
During test no. MNNW-1, with the noise wall installed on the back side of the posts, the 2270P pickup truck impacted the barrier at a 24.7-degree angle at a speed of 63.0 mph (101.4 km/h). The vehicle was captured and redirected by the system and satisfied the safety performance criteria for MASH 2016 test designation no. 3-11. In test no. MNNW-2, with the noise wall installed on the back side of the posts, the 1100C small car impacted the barrier at a 25.4-degree angle with a speed of 63.1 mph (101.5 km/h). The vehicle was captured and redirected by the system and satisfied the safety performance criteria for MASH 2016 test designation no. 3-10. During test no. MNNW-3, with the noise wall installed on the front side of the posts, the 2270P pickup truck impacted the barrier at a 25.9 degree angle with a speed of 61.2 mph (98.5 km/h). The vehicle was captured and redirected by the system and satisfied the safety performance criteria for MASH 2016 test designation no. 3-11.</td></tr>
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This report was completed with funding from 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 Minnesota Department of Transportation nor the Federal Highway Administration, U.S. Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

UNCERTAINTY OF MEASUREMENT STATEMENT

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

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority (IAA) for the data contained herein was Mr. Scott K. Rosenbaugh, Research Engineer.

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1 INTRODUCTION

1.1 Background and Problem Statement

The Minnesota Department of Transportation's (MnDOT's) glue-laminated timber rubrail was developed for situations where a noise wall will be located within the clear zone and when other types of protection are not considered desirable [1]. An example of an installed configuration is shown in Figure 1, and the standard plans are shown in Appendix A.

Figure 1. MnDOT Noise Wall and Rubrail Installation

The crashworthiness of this combination noise wall and barrier system was previously evaluated according to the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* [2]. The test installation consisted of 81 ft (24.7 m) of glulam timber rail sections that were supported by eleven reinforced concrete posts [1]. The noise wall wood planks were not installed. Test no. MNTR-1 was conducted using a 4,386-lb (1,989-kg) pickup truck impacting at a speed of 61.8 mph (99.5 km/h) and at an angle of 25.3 degrees. The glulam rail and noise wall barrier system successfully contained and redirected the pickup truck according to the Test Level 3 (TL-3) criteria published in NCHRP Report No. 350. However, the noise wall and rubrail system had not been evaluated with the latest crash testing standard, the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware (MASH 2016)* [3]. Therefore, a need existed to evaluate the rubrail design according the TL-3 requirements found in MASH 2016.

1.2 Objective

The objective of the research project was to modify an existing design and evaluate the safety performance of the MnDOT noise wall system with glulam timber rubrail. The system was to be evaluated according to the TL-3 safety performance criteria set forth in MASH 2016. In addition, the glulam rubrail was to be analyzed and modified, if necessary. Two configurations were to be evaluated – one with the wood noise wall planks installed on the back side of the concrete posts and another with planks installed on the front side of the concrete posts. The successful crash testing of the noise wall system will allow for its continued use on Minnesota highways and roadways, thus ensuring the safety of the motoring public with the current vehicle fleet.

1.3 Scope

The research objective was achieved through the completion of several tasks. First, an analysis phase was conducted in order to evaluate the capacity of the existing timber rubrail, and the timber rail was redesigned. After the final design was completed, the system was fabricated and constructed at the Midwest Roadside Safety Facility (MwRSF) Outdoor Test Site. Three full scale vehicle crash tests were performed with a 5,000-lb (2,270-kg) pickup truck using back-side sound panels, a 2,420-lb (1,100-kg) small passenger car using back-side sound panels, and a 5,000-lb (2,270 kg) pickup truck using front-side sound panels. Each of the tests utilized a target impact speed of 62 mph (100.0 km/h) and a target impact angle of 25 degrees for MASH 2016 TL-3 impact conditions. Finally, the test results were analyzed, evaluated, and documented. Conclusions and recommendations were then made pertaining to the safety performance of the noise wall and glulam timber rubrail system.

2 BARRIER DESIGN

Minnesota's existing standard plans for the noise wall and rubrail system are shown in Appendix A. The rubrail is currently specified as a glue-laminated wood rubrail fabricated with Combination No. 48 Southern Pine or Combination No. 2 Western Species material, measuring 8¾ in. (222 mm) deep by 13½ in. (343 mm) tall. The rubrail configuration was successfully tested under NCHRP Report No. 350 test designation no. 3-11 impact conditions, and the rail sustained no major damage [1]. However, the nominal impact severity of test designation no. 3-11 has increased 13.3 percent, from 101.5 kip-ft (137.6 kJ) under NCHRP Report No. 350 to 115.1 kip-ft (156.1 kJ) under MASH 2016. This increase is due to an increase in vehicle mass in the modern vehicle fleet. The lateral design force for a NCHRP Report No. 350 TL-3 bridge rail, which is commonly used for roadside barriers as well, has historically been 54.0 kips (240 kN) applied over a 4-ft (1.2-m) length [4]. Recently, the final report on NCHRP Project 22-20 [5] recommended a 70-kip (311-kN) load applied over a 4-ft (1.2 m) length for barrier design under MASH 2016 TL-3 [5]. With the increased impact severity and lateral force, the existing rubrail may not have a sufficient capacity under MASH test designation no. 3-11 impact conditions. Thus, the capacity of the rail was evaluated.

The American Wood Council's *National Design Specification (NDS) for Wood Construction* was utilized to evaluate the capacity of the glue-laminated rubrail [6]. The allowable bending stress to use for design was 4.49 ksi (31.0 MPa) and 4.04 ksi (27.9 MPa) for Combination No. 48 Southern Pine and Combination No. 2 Western Species, respectively. Utilizing the 70-kip (311-kN) load distributed over 4 ft (1.2 m) and assuming a simply-supported connection at the posts spaced 8 ft (2.4 m) apart, the calculated bending stress was 7.31 ksi (50.4 MPa), which is much greater than the allowable bending stress. Utilizing the 54-kip (240-kN) load distributed over 4 ft (1.2 m) and assuming a simply-supported connection at the posts spaced 8 ft (2.4 m) apart, the calculated bending stress was 5.64 ksi (38.9 MPa), which was 25.6 percent greater than the allowable bending stress for Combination No. 48 Southern Pine and 39.6 percent greater than the allowable bending stress for Combination No. 2 Western Species. Since the rubrail in the original crash test did not fail due to excessive bending stress, the calculations were believed to be conservative.

The researchers believed that the same ratios of actual/allowable bending stress with the 54-kip (240-kN) load (1.256 for Combination No. 48 Southern Pine and 1.396 for Combination No. 2 Western Species) could be utilized for the rail design with the 70-kip (311.4-kN) load without excessive bending stress occurring in the MASH 2016 test designation no. 3-11 crash test. A 10-in. (254-mm) deep by 13½-in. (343-mm) tall rubrail was calculated to produce similar actual/allowable bending stress ratios and was anticipated to perform acceptably. However, a 10-in. (254-mm) deep beam is considered to be non-standard size. Therefore, a 10¾-in. (273-mm) deep by 13½-in. (343-mm) tall rubrail, which is a standard glue-laminated size, was calculated to produce an actual/allowable bending stress ratio of 1.112 and 1.234 percent for the Combination No. 48 Southern Pine and Combination No. 2 Western Species, respectively. Since these ratios are less than the ratios of the prior crash-tested rubrail, the research team believed that they would perform acceptably, and that the rubrail section would not fail due to excessive bending stress. Therefore, a 10¾-in. (273-mm) deep by 13½-in. (343-mm) tall glue-laminated wood rubrail fabricated with Combination No. 48 Southern Pine or Combination No. 2 Western Species material was recommended for the crash testing program.

3 TEST REQUIREMENTS AND EVALUATION CRITERIA

3.1 Test Requirements

Longitudinal barriers, such as the noise wall and timber rubrail system, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [3]. 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 and MASH 2016 for longitudinal barriers, such as the system tested in this project, except additional occupant compartment deformation measurements and documentation are required by MASH 2016. For the evaluation of the back-side noise wall configuration, both test designation nos. 3-10 and 3-11 were conducted. For the evaluation of the front-side noise wall configuration, only test designation no. 3-11 was conducted. Test designation no. 3-10 with the front-side noise wall configuration was deemed to be non-critical if test designation no. 3-11 with the front-side configuration and both back-side configuration tests were successful. The system was expected to have a similar stiffness with the front-side and back-side configurations and the car could potentially extend farther under or over top of the rail with the back-side configuration. Thus, the back-side wall configuration was used for test designation no. 3-10.

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

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight lb (kg)	Impact Conditions		Evaluation Criteria [1]
				Speed mph (km/h)	Angle deg.	
Longitudinal Barrier	3-10	1100C	2,420 (1,100)	62 (100.0)	25	A,D,F,H,I
	3-11	2270P	5,000 (2,270)	62 (100.0)	25	A,D,F,H,I

[1] Evaluation criteria explained in Table 2

3.2 Evaluation Criteria

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

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

3.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH 2016, foundation soil strength must be verified before any full-scale crash testing can occur for any soil-dependent system. Due to the large post section, heavy mass, and significant post embedment depth, the system should have adequate strength in varying soil types and was not considered to have soil dependence under TL-3 impact loading. However, the soil strength was still evaluated prior to the first full-scale crash test, but it was not re-evaluated before subsequent tests. A W6x16 (W152x23.8) post was installed near the impact region utilizing a similar installation procedure as the system itself. Prior to full-scale crash testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips (33.4 kN) at post deflections between 5 and 20 in. (127 and 508 mm), as measured at a height of 25 in. (635 mm) above the ground line. If dynamic testing near the system is not desired, MASH 2016 permits a static test to be conducted instead and compared against the results of a previously established baseline test. In this situation, the soil must provide a resistance of at least 90% of the static baseline test at deflections of 5, 10, and 15 in. (127, 254, and 381 mm). Further details can be found in Appendix B of MASH 2016.

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="12">Occupant Risk</td><td>D.</td><td colspan="3">Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s
(9.1 m/s)</td><td>40 ft/s
(12.2 m/s)</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
</table>

4 TEST CONDITIONS

4.1 Test Facility

The Outdoor Test Site is located at the Lincoln Air Park on the northwest side of the Lincoln Municipal Airport and is approximately 5 miles (8.0 km) northwest of the University of Nebraska-Lincoln.

4.2 Vehicle Tow and Guidance System

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

A vehicle guidance system developed by Hinch [7] 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. (9.5-mm) diameter guide cable was tensioned to approximately 3,500 lb (15.6 kN) and supported both laterally and vertically every 100 ft (30.5 m) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

4.3 Test Vehicles

For test no. MNNW-1, a 2010 Dodge Ram 1500 Crew Cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,264 lb (2,388 kg), 5,056 lb (2,293 kg), and 5,214 lb (2,365 kg), respectively. The test vehicle is shown in Figures 2 and 3, and vehicle dimensions are shown in Figure 4.

For test no. MNNW-2, a 2010 Hyundai Accent was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 2,476 lb (1,123 kg), 2,431 lb (1,103 kg), and 2,595 lb (1,177 kg), respectively. The test vehicle is shown in Figures 5 and 6, and vehicle dimensions are shown in Figure 7.

For test no. MNNW-3, a 2011 Dodge Ram 1500 Crew Cab pickup truck was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,265 lb (2,388 kg), 5,028 lb (2,281 kg), and 5,188 lb (2,353 kg), respectively. The test vehicle is shown in Figures 8 and 9, and vehicle dimensions are shown in Figure 10.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [8] was used to determine the vertical component of the c.g. for the pickup trucks. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The 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 vertical component of the c.g. for the 1100C vehicle was determined utilizing a procedure published by SAE [9]. The location of the final c.g. is shown in Figures 4 and 11 for test no. MNNW-1, Figures 7 and 12 for test no. MNNW-2, and Figures 10 and 13 for test no. MNNW-3. Data used to calculate the location of the c.g. and ballast information are shown in Appendix B.

Square, black- and white-checkered targets were placed on the vehicles for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in 11 through 13. Round, checkered targets were placed at the c.g. on the left-side door, the right-side door, and the roof of the vehicles.

The front wheels of the test vehicles were aligned to vehicle standards except the toe-in value was adjusted to zero such that the vehicles would track properly along the guide cable. A 5B flash bulb was mounted on each vehicle's right-side windshield wiper and was fired by a pressure tape switch mounted at the impact corner of the front bumper. The flash bulb was fired upon initial impact with the test article to create a visual indicator of the precise time of impact on the high-speed digital videos. A remote-controlled brake system was installed in the test vehicles so the vehicles could be brought safely to a stop after each test.

4.4 Simulated Occupants

For test nos. MNNW-1, MNNW-2, and MNNW-3, a Hybrid II 50th-Percentile, Adult Male Dummy, equipped with clothing and footwear, was placed in the right-front seat of each test vehicle with the seat belt fastened. The three dummies, which had final weights of 161 lb (73 kg), 161 lb (73 kg), and 160 lb (73 kg) for test nos. MNNW-1, MNNW-2, and MNNW-3, respectively, were represented by model no. 572 and were manufactured by Android Systems of Carson, California. As recommended by MASH 2016, the dummies were not included in calculating the c.g. location.

4.5 Data Acquisition Systems

4.5.1 Accelerometers

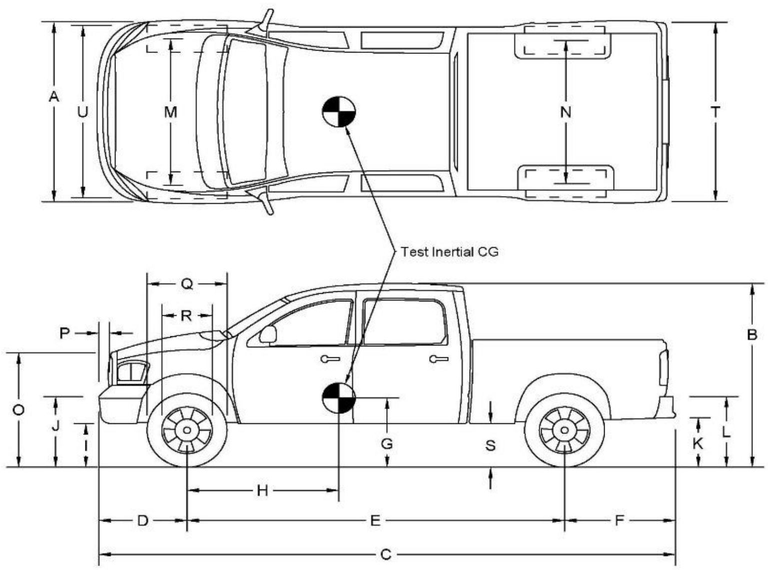
Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. All accelerometer systems were mounted near the c.g. of the test vehicles. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filter conforming to the SAE J211/1 specifications [10].

The two systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. For test nos. MNNW-1 and MNNW-3, the SLICE-2 unit was designated as the primary system. For test no. MNNW-2, the SLICE-1 unit was designated as the primary system. The acceleration sensors were mounted inside the bodies of custom-built, SLICE 6DX event data recorders and recorded data at 10,000 Hz to the onboard microprocessor. Each SLICE 6DX was configured with 7 GB of non-volatile flash memory, a range of ±500 g's, a sample rate of 10,000 Hz, and a 1,650 Hz (CFC 1000) anti-aliasing filter. The "SLICEWare" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

Figure 2. Test Vehicle, Test No. MNNW-1

Figure 3. Test Vehicle’s Interior Floorboard and Undercarriage, Test No. MNNW-1

Date:	2/27/2018	Test Name:	MNNW-1	VIN No:	1D7RB1CT0AS214480
Year:	2010	Make:	Dodge	Model:	RAM 1500 Crew
Tire Size:	275-60 R20	Tire Inflation Pressure:	35 Psi	Odometer:	11598



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

A:	76 1/2 (1943) 78±2 (1950±50)	B:	75 3/4 (1924)
C:	229 3/8 (5826) 237±13 (6020±325)	D:	70 7/8 (1800) 39±3 (1000±75)
E:	140 1/2 (3569) 148±12 (3760±300)	F:	48 (1219)
G:	29 9/16 (751) min: 28 (710)	H:	61 (1549) 63±4 (1575±100)
I:	13 3/4 (349)	J:	25 1/2 (648)
K:	22 (559)	L:	30 1/2 (775)
M:	68 1/4 (1734) 67±1.5 (1700±38)	N:	68 3/8 (1737) 67±1.5 (1700±38)
O:	45 1/4 (1149) 43±4 (1100±75)	P:	4 3/4 (121)
Q:	32 3/4 (832)	R:	21 1/2 (546)
S:	16 (406)	T:	76 1/2 (1943)

U (impact width): 35 3/4 (908)

Mass Distribution lb (kg)

Gross Static	LF	1471 (667)	RF	1490 (676)
	LR	1097 (498)	RR	1156 (524)

Wheel Center Height (Front):	15 1/2 (394)
Wheel Center Height (Rear):	15 3/4 (400)
Wheel Well Clearance (Front):	36 (914)
Wheel Well Clearance (Rear):	39 1/4 (997)
Bottom Frame Height (Front):	19 (483)
Bottom Frame Height (Rear):	26 3/4 (679)
Engine Type:	Gasoline
Engine Size:	5.7L
Transmission Type:	Automatic
Drive Type:	RWD
Cab Style:	Crew Cab
Bed Length:	67"

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2955 (1340)	2860 (1297)	2961 (1343)
W-rear	2309 (1047)	2196 (996)	2253 (1022)
W-total	5264 (2388)	5056 (2293) 5000±110 (2270±50)	5214 (2365) 5165±110 (2343±50)

GVWR Ratings lb

Front	3700
Rear	3900
Total	6700

Surrogate Occupant Data

Type:	Hybrid II
Mass:	161 lb
Seat Position:	Right Front

Note any damage prior to test: Left box side above and behind rear wheel is scraped dand dented.

Figure 4. Vehicle Dimensions, Test No. MNNW-1

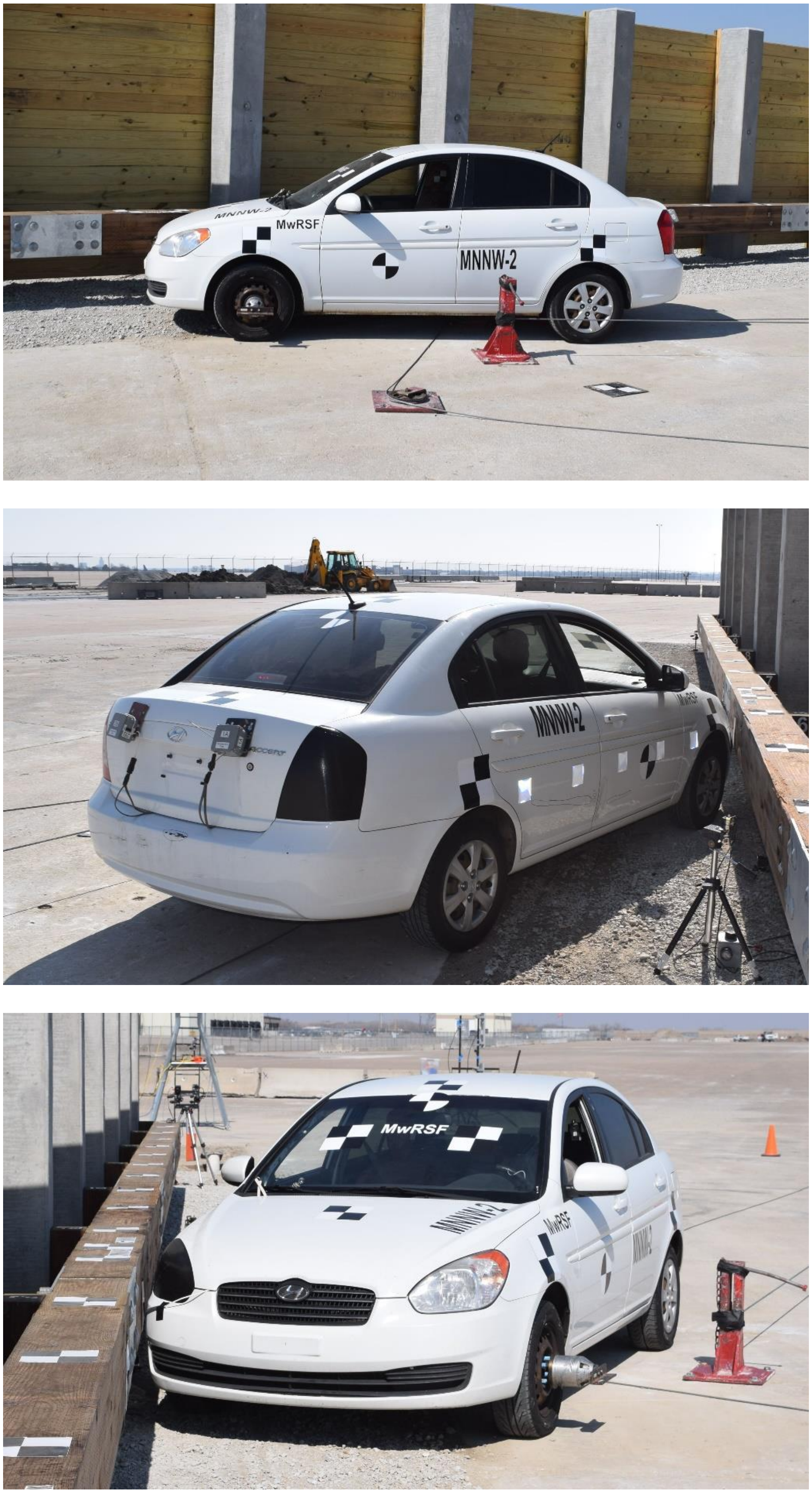
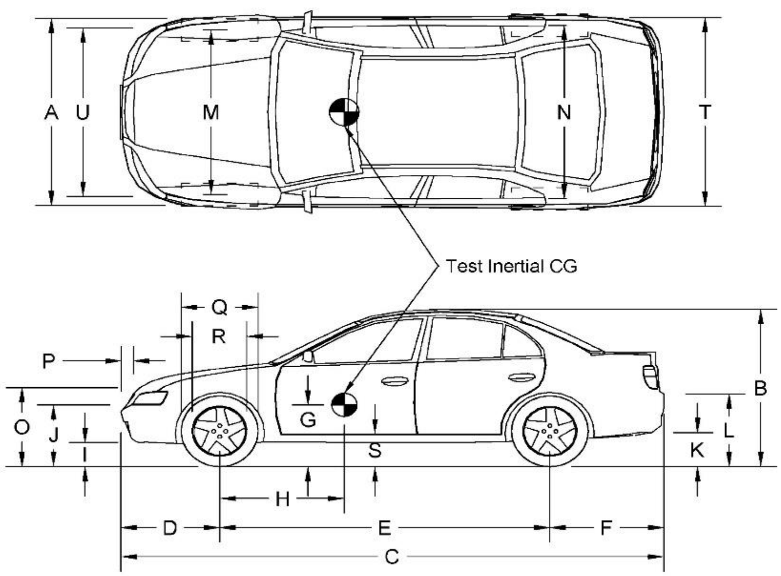


Figure 5. Test Vehicle, Test No. MNNW-2

Figure 6. Test Vehicle's Interior Floorboard and Undercarriage, Test No. MNNW-2

Date:	2/27/2018	Test Name:	MNNW-2	VIN No:	KMHCN4ACXBU610901
Year:	2010	Make:	Hyundai	Model:	Accent
Tire Size:	185/65R14	Tire Inflation Pressure:	32 Psi	Odometer:	200164



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

A:	65 3/4	(1670)	B:	57	(1448)
	65±3 (1650±75)				
C:	168 3/8	(4277)	D:	34 1/2	(876)
	169±8 (4300±200)			35±4 (900±100)	
E:	98 3/4	(2508)	F:	35 3/4	(908)
	98±5 (2500±125)				
G:	22 7/16	(570)	H:	36 5/8	(930)
				39±4 (990±100)	
I:	7 1/2	(191)	J:	21	(533)
K:	11 1/8	(283)	l:	23 1/2	(597)
M:	57 7/8	(1470)	N:	57	(1448)
	56±2 (1425±50)			56±2 (1425±50)	
O:	27 1/2	(699)	P:	4 1/2	(114)
	24±4 (600±100)				
Q:	22 1/2	(572)	R:	15 1/2	(394)
S:	11 3/4	(298)	T:	64 1/2	(1638)

U (impact width):	28 7/8	(733)
Top of radiator core support:	28 1/2	(724)
Wheel Center Height (Front):	10 3/4	(273)
Wheel Center Height (Rear):	11	(279)
Wheel Well Clearance (Front):	3 1/4	(83)
Wheel Well Clearance (Rear):	2 3/4	(70)
Bottom Frame Height (Front):	6	(152)
Bottom Frame Height (Rear):	9 5/8	(244)
Engine Type:	Gasoline	
Engine Size:	1.6L 4 cyl	
Transmission Type:	Automatic	
Drive Type:	FWD	

Mass Distribution lb (kg)

Gross Static	LF	804	(365)	RF	809	(367)
	LR	479	(217)	RR	503	(228)

Weights lb (kg)	Curb		Test Inertial		Gross Static	
W-front	1577	(715)	1530	(694)	1613	(732)
W-rear	899	(408)	901	(409)	982	(445)
W-total	2476	(1123)	2431	(1103)	2595	(1177)
			2420±55 (1100±25)		2585±55 (1175±50)	

GVWR Ratings lb

Front	1918
Rear	1874
Total	3638

Surrogate Occupant Data

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

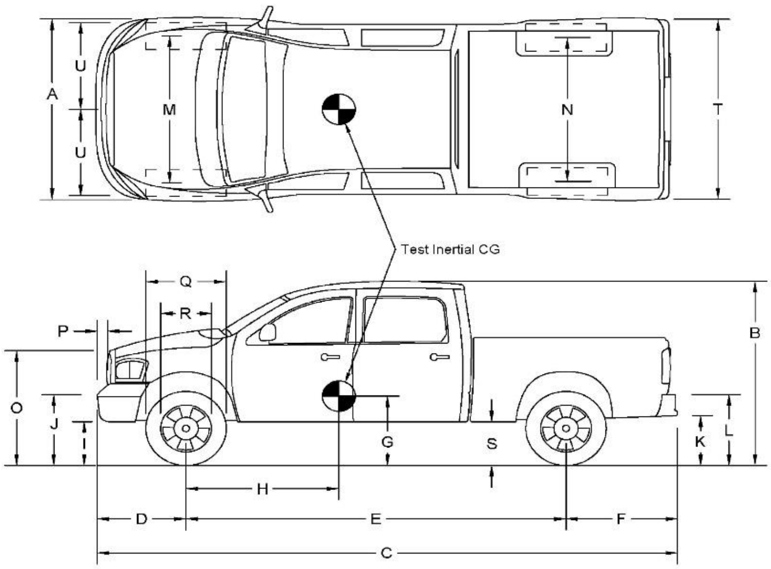
Note any damage prior to test: Small dents and scrapes along the right side rear door.

Figure 7. Vehicle Dimensions, Test No. MNNW-2

Figure 8. Test Vehicle, Test No. MNNW-3

Figure 9. Test Vehicle's Interior Floorboard and Undercarriage, Test No. MNNW-3

Date:	4/4/2018	Test Name:	MNNW-3	VIN No:	1D7RB1CP7BX646567
Year:	2011	Make:	Dodge	Model:	Ram 1500
Tire Size:	265/70 R17	Tire Inflation Pressure:	37 Psi	Odometer:	182968



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

A:	76 1/2	(1943)	B:	74	(1880)
	78±2 (1950±50)				
C:	229 7/8	(5839)	D:	42 3/8	(1076)
	237±13 (6020±325)			39±3 (1000±75)	
E:	140 1/2	(3569)	F:	47	(1194)
	148±12 (3760±300)				
G:	28 5/8	(727)	H:	61 3/16	(1554)
	min: 28 (710)			63±4 (1575±100)	
I:	12	(305)	J:	23 3/4	(603)
K:	21	(533)	L:	29 1/2	(749)
M:	66 1/4	(1683)	N:	67 3/4	(1721)
	67±1.5 (1700±38)			67±1.5 (1700±38)	
O:	44 1/8	(1121)	P:	5	(127)
	43±4 (1100±75)				
Q:	31	(787)	R:	18 1/2	(470)
S:	15 3/8	(391)	T:	75 5/8	(1921)

U (impact width):	35 1/2	(902)
Wheel Center Height (Front):	15	(381)
Wheel Center Height (Rear):	15 1/4	(387)
Wheel Well Clearance (Front):	34 1/2	(876)
Wheel Well Clearance (Rear):	38	(965)
Bottom Frame Height (Front):	18 1/2	(470)
Bottom Frame Height (Rear):	26 1/2	(673)
Engine Type:	8cyl. Gas	
Engine Size:	4.7	
Transmission Type:	Automatic	
Drive Type:	RWD	
Cab Style:	Crew Cab	
Bed Length:	67"	

Mass Distribution lb (kg)

Gross Static	LF	1444 (655)		RF	1492 (677)	
	LR	1161 (527)		RR	1091 (495)	

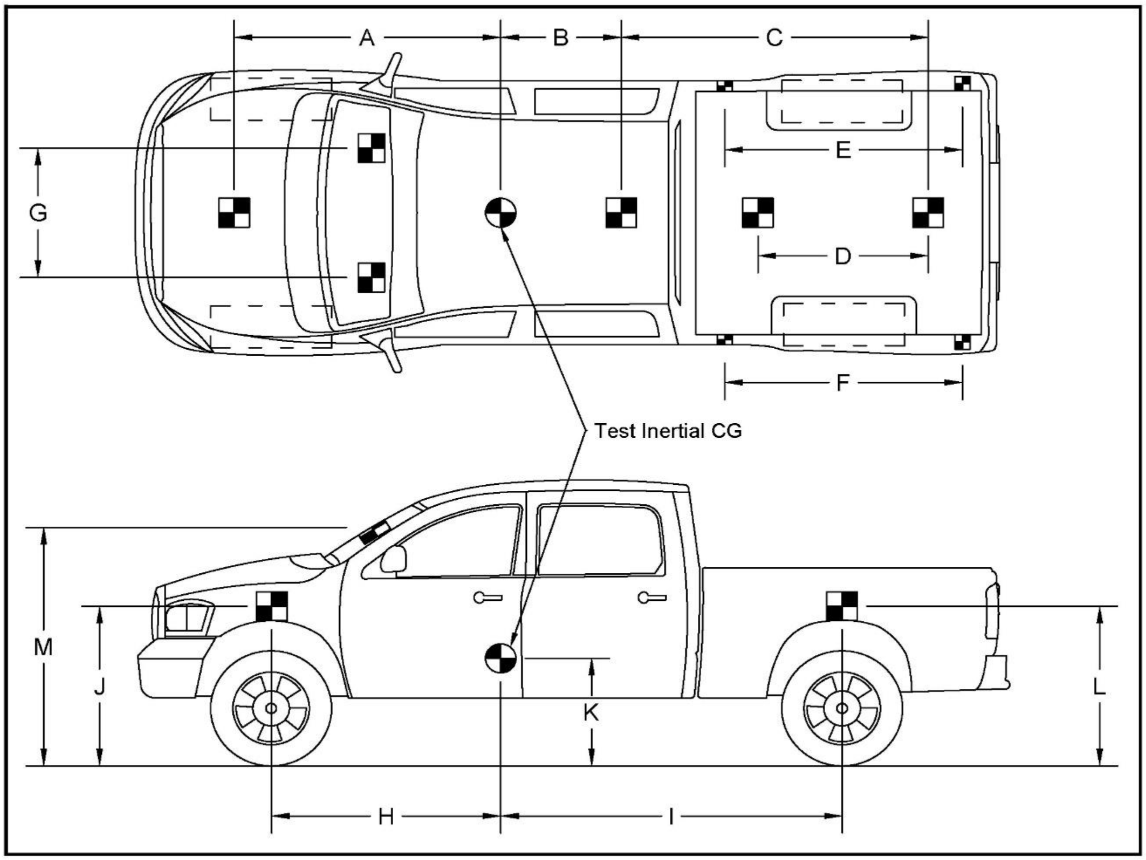
Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2940 (1334)	2839 (1288)	2936 (1332)
W-rear	2325 (1055)	2189 (993)	2252 (1021)
W-total	5265 (2388)	5028 (2281) 5000±110 (2270±50)	5188 (2353) 5165±110 (2343±50)

GVWR Ratings lb		Surrogate Occupant Data	
Front	3700	Type:	Hybrid II
Rear	3900	Mass:	160 lb
Total	6800	Seat Position:	Right

Note any damage prior to test: None

Figure 10. Vehicle Dimensions, Test No. MNNW-3

Date:	2/28/2018	Test Name:	MNNW-1	VIN:	1D7RB1CT0AS214480
Year:	2010	Make:	Dodge	Model:	RAM 1500 Crew

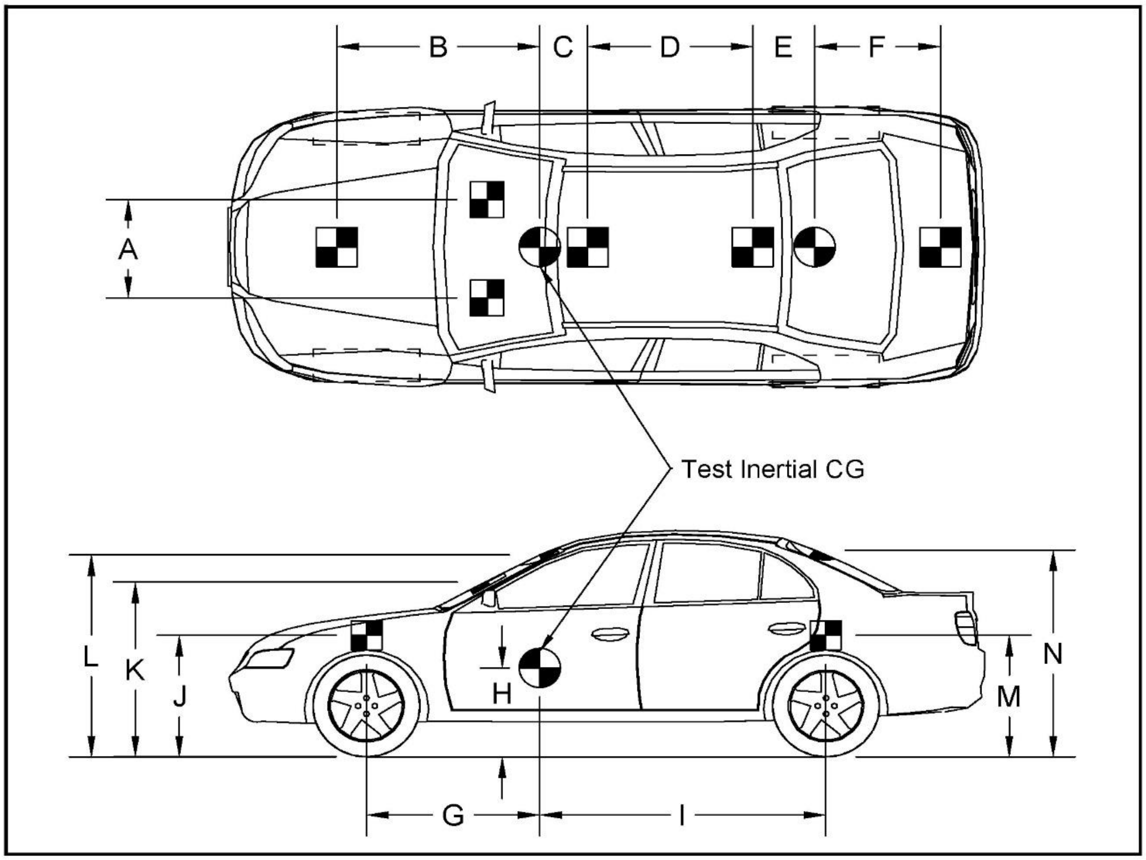


TARGET GEOMETRY-- in. (mm)

A:	73	(1854)	E:	54 1/8	(1375)	J:	40	(1016)
B:	34	(864)	F:	54 1/4	(1378)	K:	29 1/2	(749)
C:	77 1/2	(1969)	G:	31 1/8	(791)	L:	43 3/8	(1102)
D:	43 3/4	(1111)	H:	79 1/2	(2019)	M:	63 3/4	(1619)
			I:	79 1/2	(2019)			

Figure 11. Target Geometry, Test No. MNNW-1

Date:	2/27/2018	Test Name:	MNNW-2	VIN:	KMHCN4ACXBU610901
Year:	2010	Make:	Hyundai	Model:	Accent

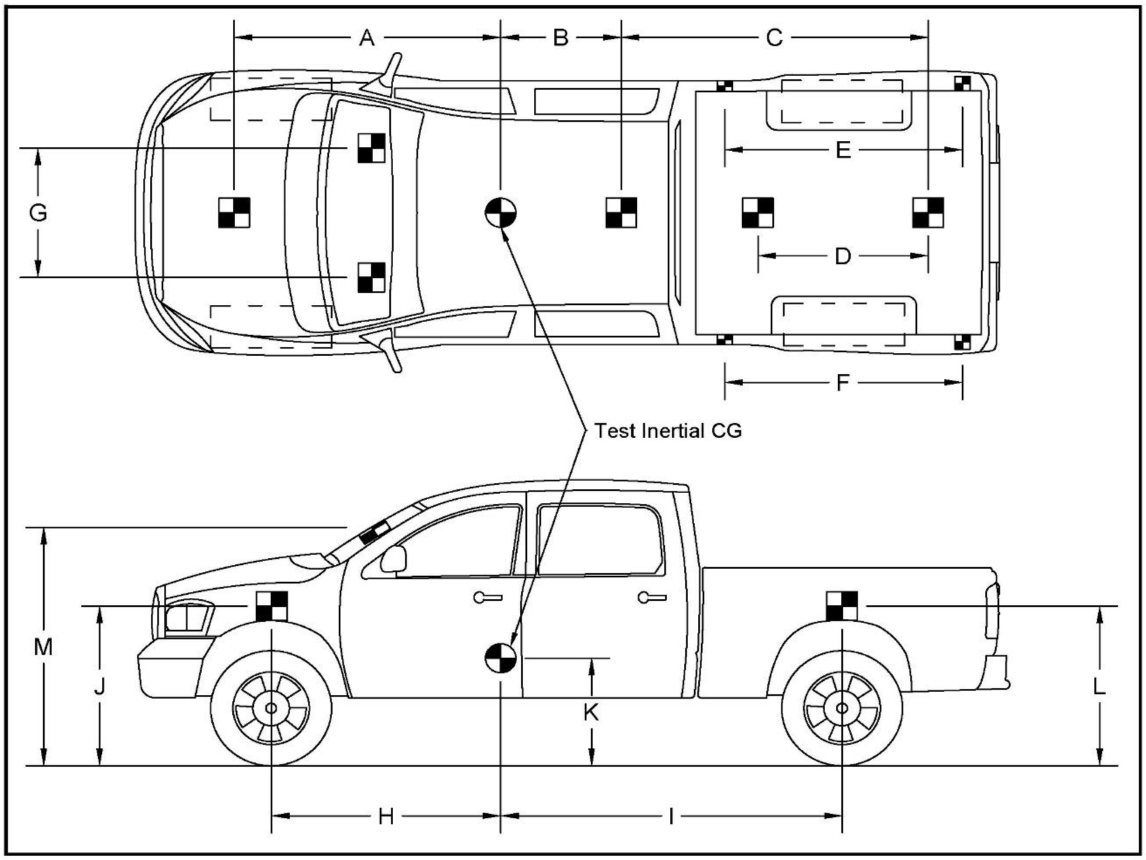


TARGET GEOMETRY-- in. (mm)

A:	24 1/8	(613)	F:	25 1/4	(641)	K: Windshield Target	46 3/4	(1187)
B:	43 1/2	(1105)	G:	36 7/8	(937)	L: Front round CG target	52 7/8	(1343)
C:	8 1/2	(216)	H:	22 5/8	(575)	M:	28 3/4	(730)
D:	38	(965)	I:	61 7/8	(1572)	N: Rear Round target	53 3/8	(1356)
E:	14	(356)	J:	29	(737)			

Figure 12. Target Geometry, Test No. MNNW-2

Date:	4/4/2018	Test Name:	MNNW-3	VIN:	1D7RB1CP7BX646567
Year:	2011	Make:	Dodge	Model:	Ram 1500



TARGET GEOMETRY-- in. (mm)

A:	65 1/2	(1664)	E:	74 1/2	(1892)	J:	39	(991)
B:	33 1/2	(851)	F:	74 1/2	(1892)	K:	28 1/4	(718)
C:	100 1/2	(2553)	G:	31 7/8	(810)	L:	42 1/4	(1073)
D:	29	(737)	H:	61 1/16	(1551)	M:	61	(1549)
			I:	79 11/16	(2024)			

Figure 13. Target Geometry, Test No. MNNW-3

4.5.2 Rate Transducers

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

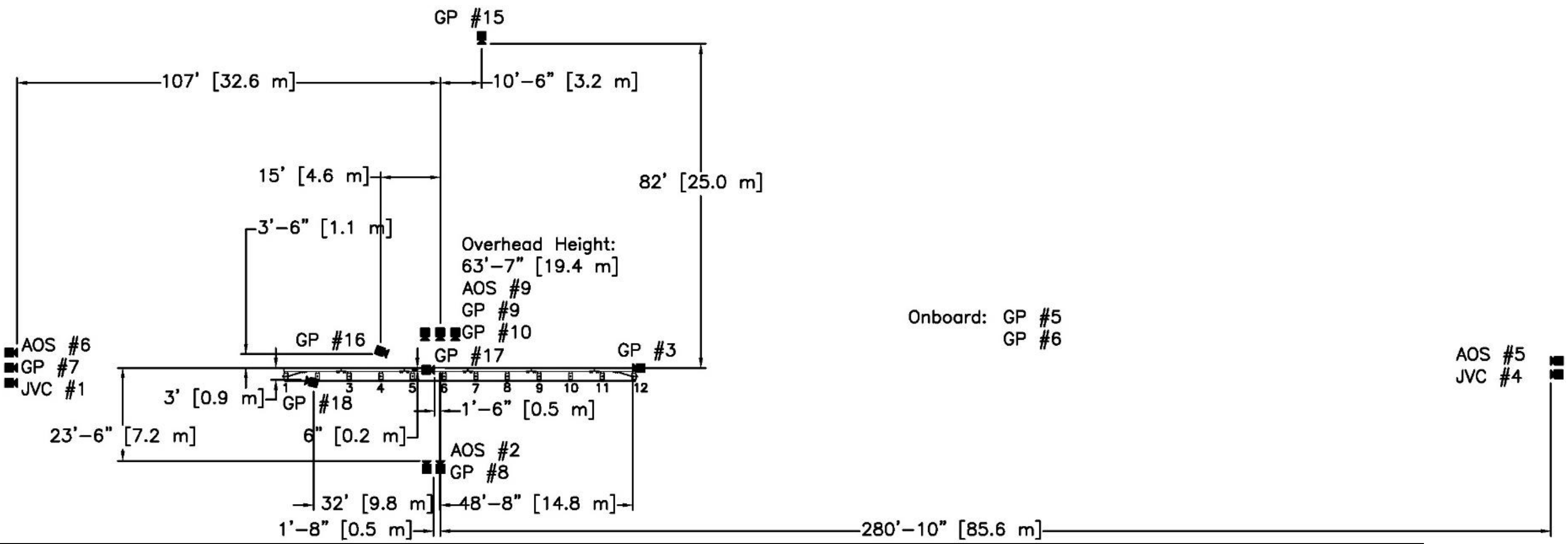
4.5.3 Retroreflective Optic Speed Trap

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

4.5.4 Digital Photography

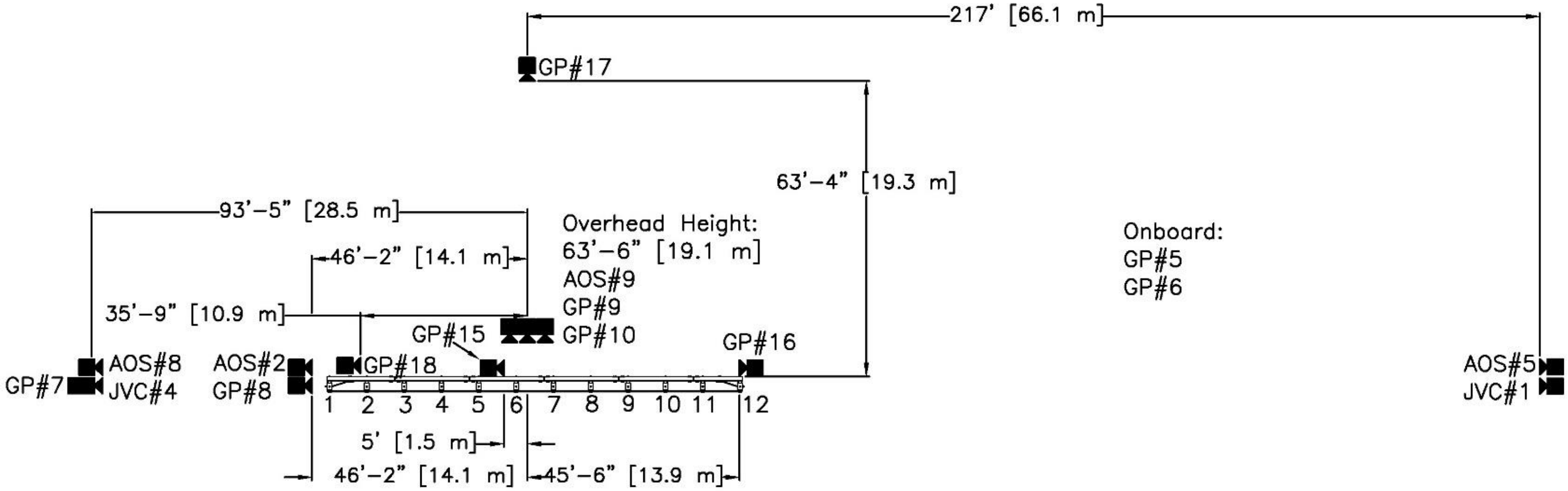
Four AOS high-speed digital video cameras, eleven GoPro digital video cameras, and two JVC digital video cameras were utilized to film test no. MNNW-1. Four AOS high-speed digital video cameras, ten GoPro digital video cameras, and two JVC digital video cameras were utilized to film test no. MNNW-2. Three AOS high-speed digital video cameras, ten GoPro digital video cameras, and two JVC digital video cameras were used to film test no. MNNW-3. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figures 14 through 16 for test nos. MNNW-1 through MNNW-3, respectively.

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



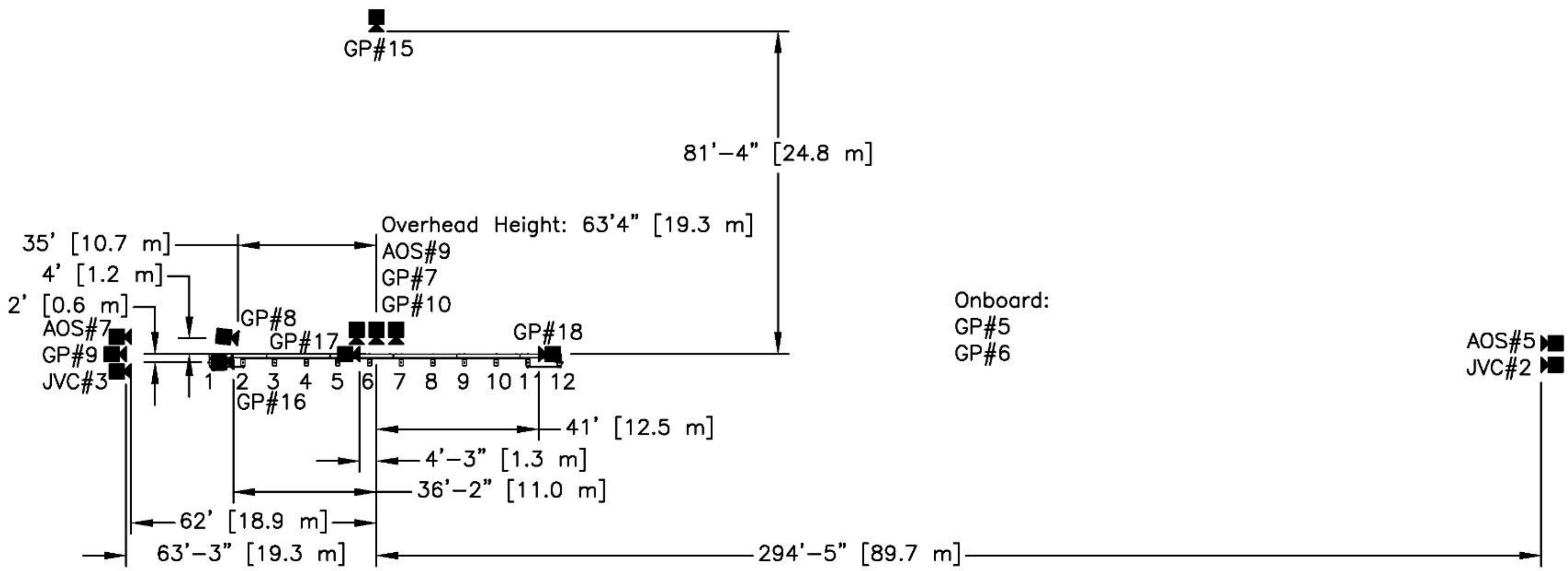
No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam	500	KOWA 16mm Fixed	-
AOS-5	AOS X-PRI	500	Telesar 135mm Fixed	-
AOS-6	AOS X-PRI	500	Fujinon 50 Fixed	-
AOS-9	AOS TRI-VIT 2236	1000	KOWA 12mm Fixed	-
GP-3	GoPro Hero 3+ w/ Cosmicar 12.5mm	120		
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
GP-15	GoPro Hero 4	120		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	120		
GP-18	GoPro Hero 4	120		
JVC-1	JVC – G2-MC500 (Everio)	30		
JVC-4	JVC – G2-MG27u (Everio)	30		

Figure 14. Camera Locations, Speeds, and Lens Settings, Test No. MNNW-1



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-2	AOS Vitcam	500	KOWA 16mm Fixed	-
AOS-5	AOS X-PRI	500	Telesar 135mm Fixed	-
AOS-8	AOS S-VIT 1531	500	Sigma 28-70	50
AOS-9	AOS TRI-VIT 2236	1000	KOWA 12mm Fixed	-
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
GP-15	GoPro Hero 4	120		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	120		
GP-18	GoPro Hero 4	120		
JVC-1	JVC – G2-MC500 (Everio)	30		
JVC-4	JVC – G2-MG27u (Everio)	30		

Figure 15. Camera Locations, Speeds, and Lens Settings, Test No. MNNW-2



No.	Type	Operating Speed (frames/sec)	Lens	Lens Setting
AOS-5	AOS X-PRI	500	Telesar 135mm	-
AOS-7	AOS X-PRI	500	Sigma 28-70	28
AOS-9	AOS TRI-VIT 2236	500	Kowa 12mm	-
GP-5	GoPro Hero 3+	120		
GP-6	GoPro Hero 3+	120		
GP-7	GoPro Hero 4	120		
GP-8	GoPro Hero 4	240		
GP-9	GoPro Hero 4	120		
GP-10	GoPro Hero 4	240		
GP-15	GoPro Hero 4	120		
GP-16	GoPro Hero 4	240		
GP-17	GoPro Hero 4	120		
GP-18	GoPro Hero 4	120		
JVC-2	JVC – G2-MC500 (Everio)	30		
JVC-3	JVC – G2-MG27u (Everio)	30		

Figure 16. Camera Locations, Speeds, and Lens Settings, Test No. MNNW-3

5 DESIGN DETAILS – TEST NOS. MNNW-1 AND MNNW-2

MnDOT utilizes several different post sizes, embedment depths, and wall heights to meet the noise wall requirements for various areas. A noise wall system with the same height as used in test no. MNTR-1 was selected for evaluation herein. This system was configured with one of the smaller wall heights and embedment depths utilized by MnDOT, which still provided a very stiff and strong system when placed in soil. Based on prior testing, the selected test configuration parameters were believed to serve as a valid indicator of performance for the other configurations.

The test installation consisted of a wood plank noise wall with concrete posts and a glulam timber rubrail, as shown in Figures 17 through 34 for test nos. MNNW-1 and MNNW-2. Photographs of the test installation are shown in Figures 35 and 36 for test no. MNNW-1 and Figures 37 and 38 for test no. MNNW-2. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix C.

The test installation for the barrier system was composed of a wood plank noise wall, which spanned across twelve concrete support posts and was protected by 89 ft (27.1 m) of glulam timber rail sections, as shown in Figures 17 and 18. The total width of the system from the front of the glulam timber rail to the back of the wood batten was 40¾ in. (1,035 mm). The glulam timber for the rail members and spacer blocks was fabricated with Combination No. 2 West Coast Douglas Fir material, as specified in AASHTO's *LRFD Bridge Design Specifications* [4], which was slightly weaker than Combination no. 48 Southern Pine. The glulam was treated with pentachlorophenol in heavy oil to a minimum net retention of 0.6 lb/ft^3 (9.6 kg/m^3), as specified in AWPA Standard U1 to the requirements of Use Category 4A (UC4A) [11]. The rail members were 13½ in. (343 mm) wide by 10¾ in. (273 mm) deep with a 30-in. (762-mm) top mounting height, as measured from the ground line to the top of the rubrail. Five H-shaped steel assemblies were used to splice together the rail ends, thus resulting in the total rail length. The H-shaped, welded splice plates consisted of two ASTM A36 steel plates measuring 13½ in. wide x 29¼ in. long x ⅜ in. thick (343 mm x 743 mm x 10 mm) and one orthogonal ASTM A36 steel plate measuring 13½ in. wide x 10 in. long x ⅜ in. thick (343 mm x 254 mm x 10 mm) welded together as shown in Figure 28. At all rail splice locations, eight 1¼-in. (32-mm) diameter by 14-in. (356-mm) long ASTM A307 Grade A galvanized dome head bolts with a 1¼-in. (32-mm) diameter flat washer and a 1¼-in. (32-mm) diameter hex nut were used to attach to rail sections to the splice plates, as shown in Figures 17 through 19 and 28. The rubrail was offset away from the posts with spacer blocks measuring 9 in. wide x 6 in. deep x 13½ in. long (229 mm x 152 mm x 343 mm), as shown in Figures 17 through 19 and 30.

Although it was preferred to use dome head bolts to attach the rubrail and spacer blocks to the concrete posts, round head bolts in combination with a washer, equivalent in diameter to the dome head bolts, were used instead of dome head bolts. Through this substitution, the two post-to-rail bolts were ¾-in. (19-mm) diameter by 18-in. (457-mm) long ASTM A307 Grade A galvanized round head bolts with a flat head key with a ¾-in. (19-mm) diameter washer that had an outer diameter of 2 in. (51 mm). The post-to-rail bolts were attached to the concrete posts with field-installed threaded inserts.

A wood plank noise wall system was attached to the back side of the concrete posts. The noise wall planks consisted of 2-in. x 8-in. x 16-ft (51-mm x 203-mm x 4.9-m) tongue and groove wood planks with a minimum bending stress of 1,500 psi (10.3 MPa). The planks were attached to the concrete posts with a 2-in. x 8-in. x 10-ft (51-mm x 203-mm x 3.0-m) wood batten with a minimum bending stress of 1,500 psi (10.3 MPa) and a 3-in. x 10-in. x 10-ft (76-mm x 254-mm x 3.0-m) wood nailer with a minimum bending stress of 1,200 psi (8.3 MPa). The noise wall planks, nailer, and batten were obtained at a lower grade than specified. However, the reduced strength of these timber products was deemed non-critical to the crashworthiness of the noise wall system.

The entire system was constructed with twelve prestressed concrete posts, as shown in Figures 17, 26, 27, and 29. All twelve posts were concrete sections measuring 12 in. wide x 18 in. deep x 18 ft long (305 mm x 457 mm x 5.5 m), as shown in Figure 26. The concrete posts were spaced 8 ft (2.4 m) on center along the length of the system with a soil embedment depth of 8 ft (2.4 m), as shown in Figures 17 and 18. The posts were installed in a compacted coarse crushed limestone soil. The concrete used for the prestressed concrete posts had a minimum compressive strength of 5,500 psi (37.9 MPa).

The concrete posts utilized in the test installation were configured with the longitudinal prestressing strands in lieu of longitudinal reinforcement bars, as shown in Figure 26. The steel prestressing strands consisted of ½-in. (12.7-mm) diameter, 270-ksi (1,862-MPa) LO-LAX prestress strands extending the length of the post. The loop bars were no. 3 reinforcing bars, 53 in. (1.3 m) long, bent into a rectangular shape, and were spaced 18 in. (457 mm) on center. A minimum concrete cover of 2 in. (51 mm) was used for all the rebar and strands placed within the posts. The reinforcing bars in the post were ASTM A615 Grade 60 epoxy-coated rebar. The post reinforcement details are shown in Figures 26 and 27.

A BCT anchor cable assembly attached the end post to a cable anchor bracket on the back of the rubrail. Each cable anchor bracket was attached to the rail section with eight 1¼-in. (32-mm) diameter by 14-in. (356-mm) long ASTM A307 Grade A galvanized dome head bolts and a 1¼-in. (32-mm) diameter hex nut.

During installation of the test article, a few items were modified to ease construction, including:

(1) The slots in the rubrail were not in the correct location. Thus, some slots in the rail were enlarged to align post-to-rail bolts with the threaded inserts in the concrete posts. At post no. 5, a 2½-in. (64-mm) outer diameter washer was utilized due to an oversized hole in the rail.

(2) The galvanized post-to-rail bolt threads were not compatible with the threads in the zinc-plated, threaded inserts that were installed in the posts. Thus, the galvanization was stripped from the threaded ends of bolts so that they could be installed.

(3) The ends of the timber rubrails required planing to fit within the H-shaped splice plates.

(4) For testing purposes only, double-headed nails were used instead of part g3 to allow the noise wall sections to remain intact when switching from the back-side noise wall configuration to the front-side noise wall configuration.

After construction of the system, a few modifications were identified that would ease construction of future installations. Although the noise wall and rubrail system can be installed in the as-tested configuration shown in Figures 17 through 34, MwRSF would recommend future installations utilize the modified system details shown in Chapter 12.

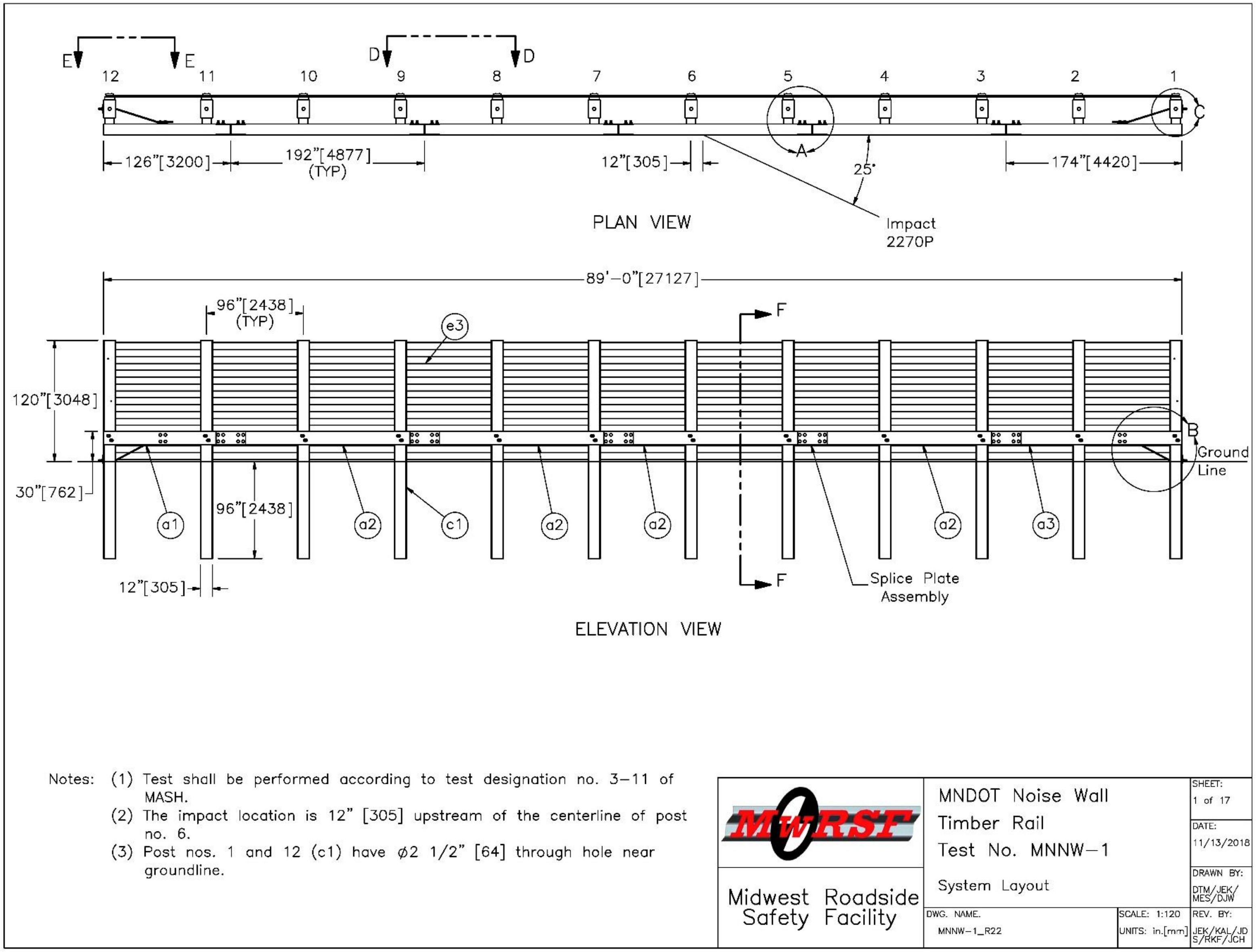


Figure 17. System Layout, Test No. MNNW-1 (Recommended updates provided in Chapter 12)

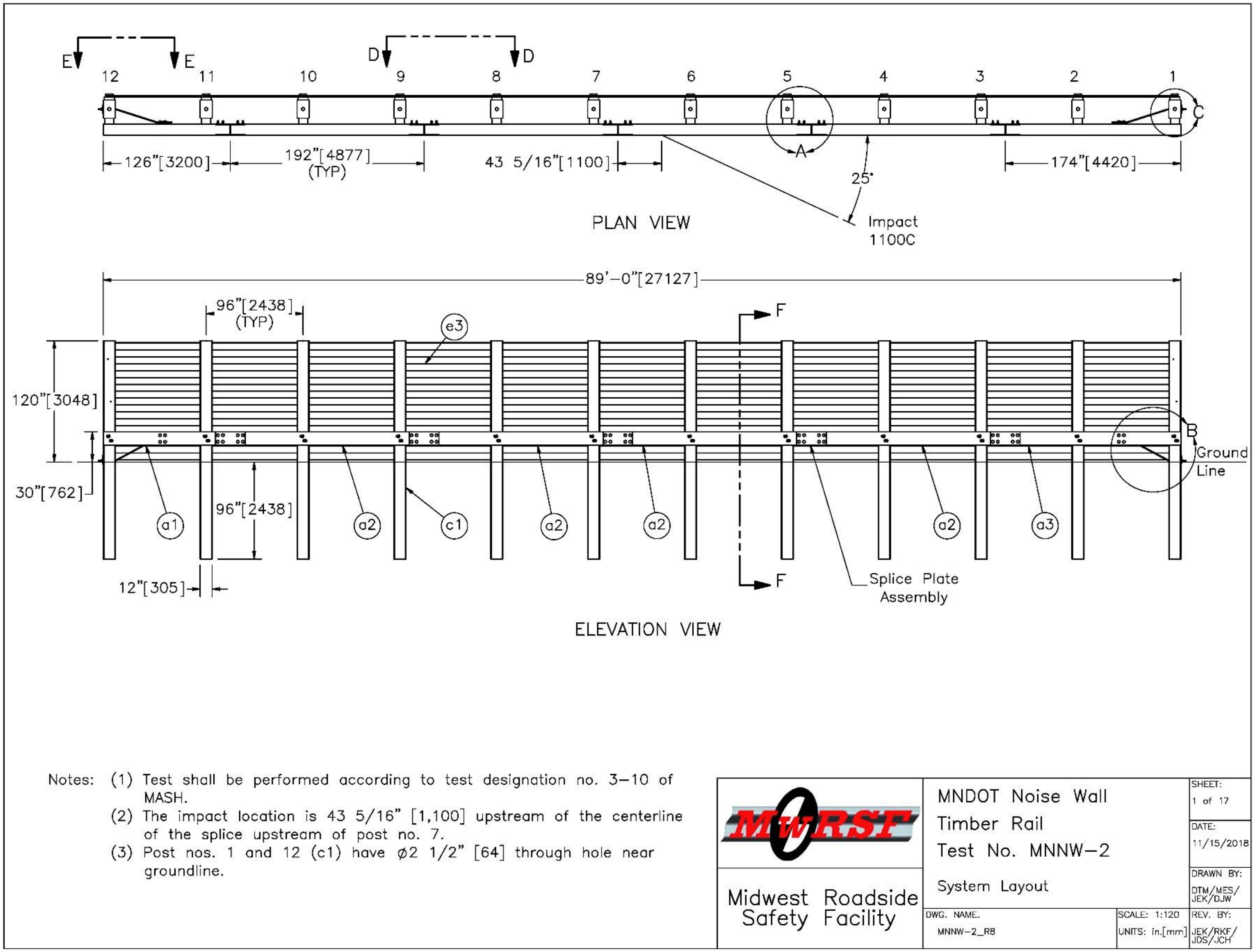


Figure 18. System Layout, Test No. MNNW-2 (Recommended updates provided in Chapter 12)

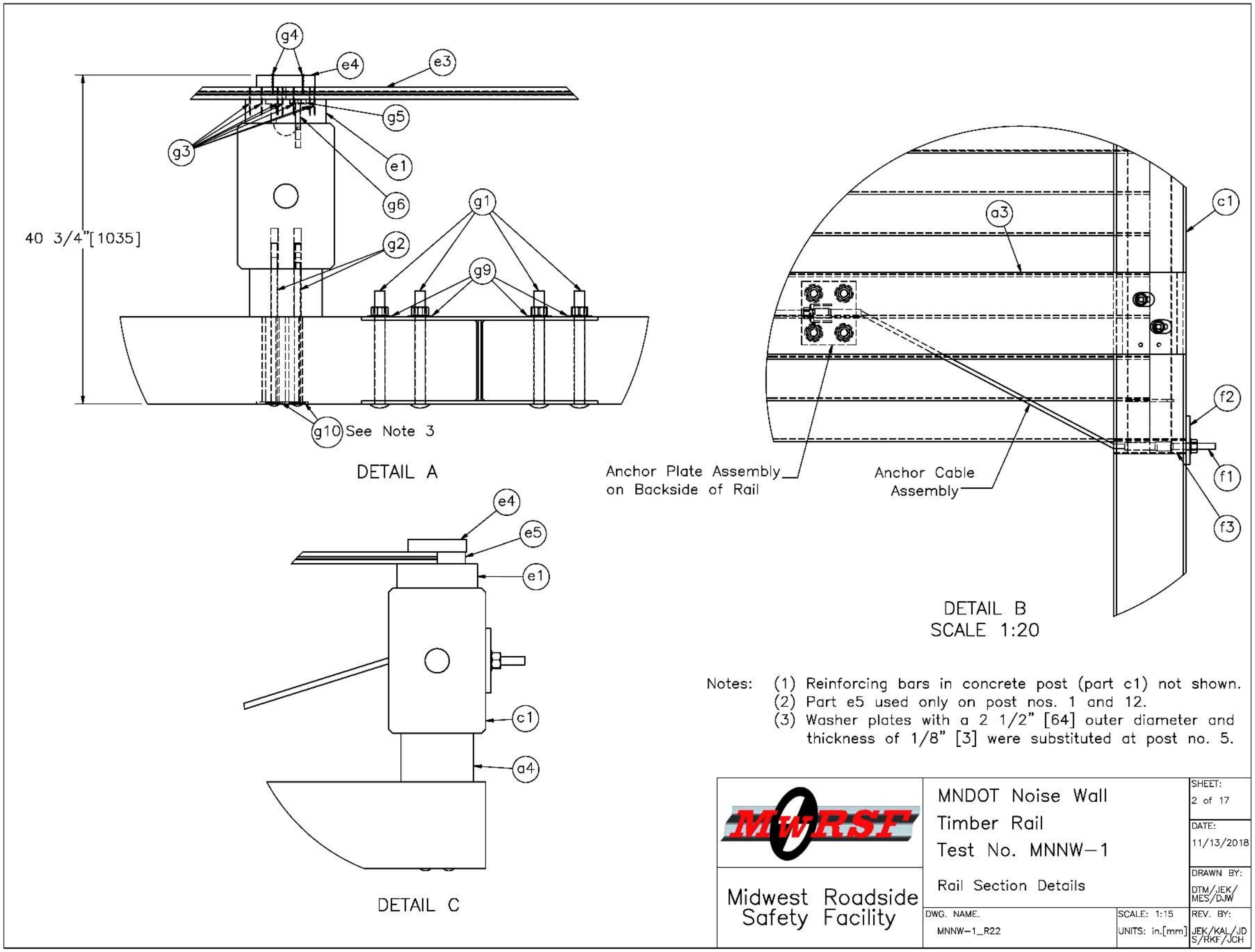


Figure 19. Rail Section Details, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

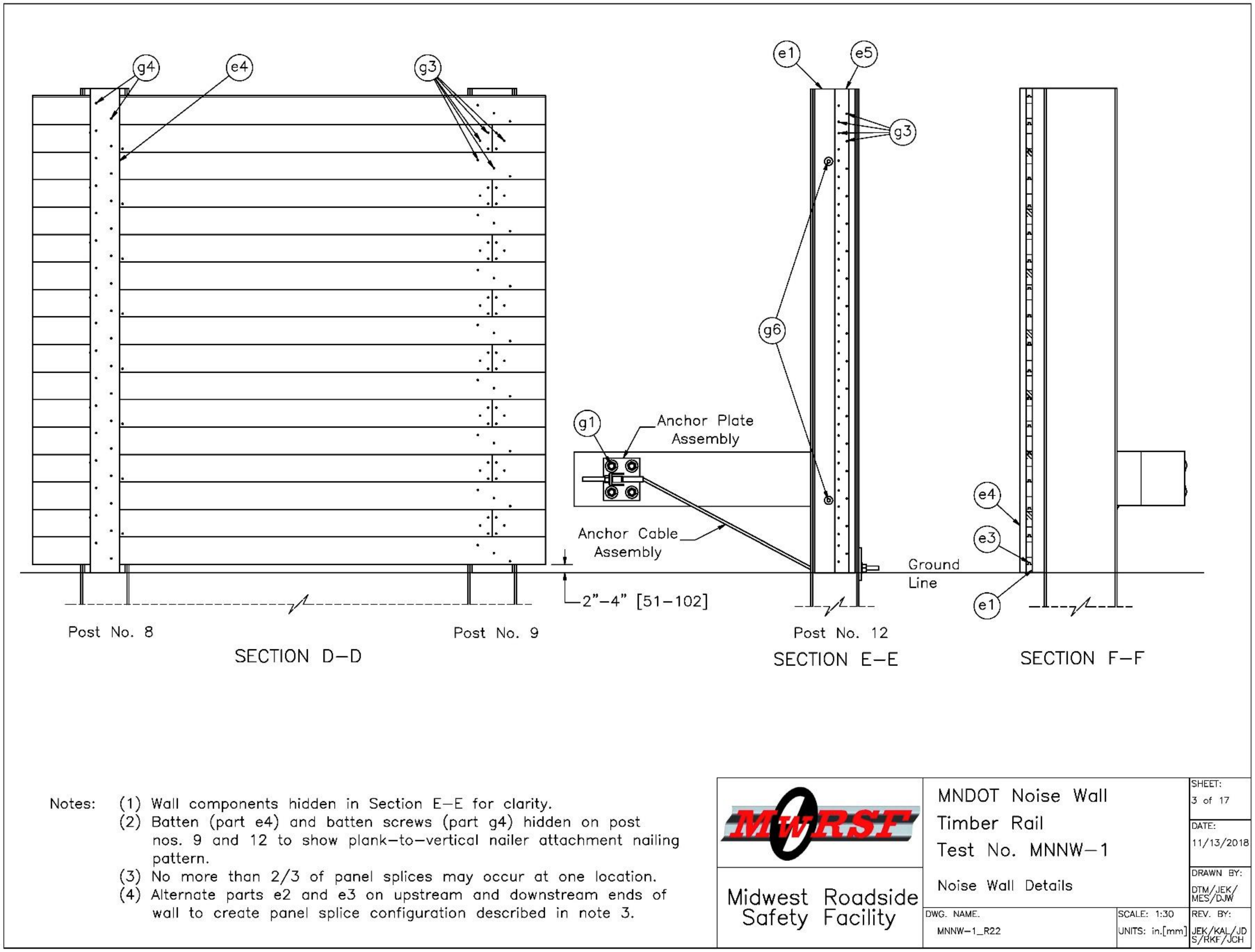


Figure 20. Noise Wall Details, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

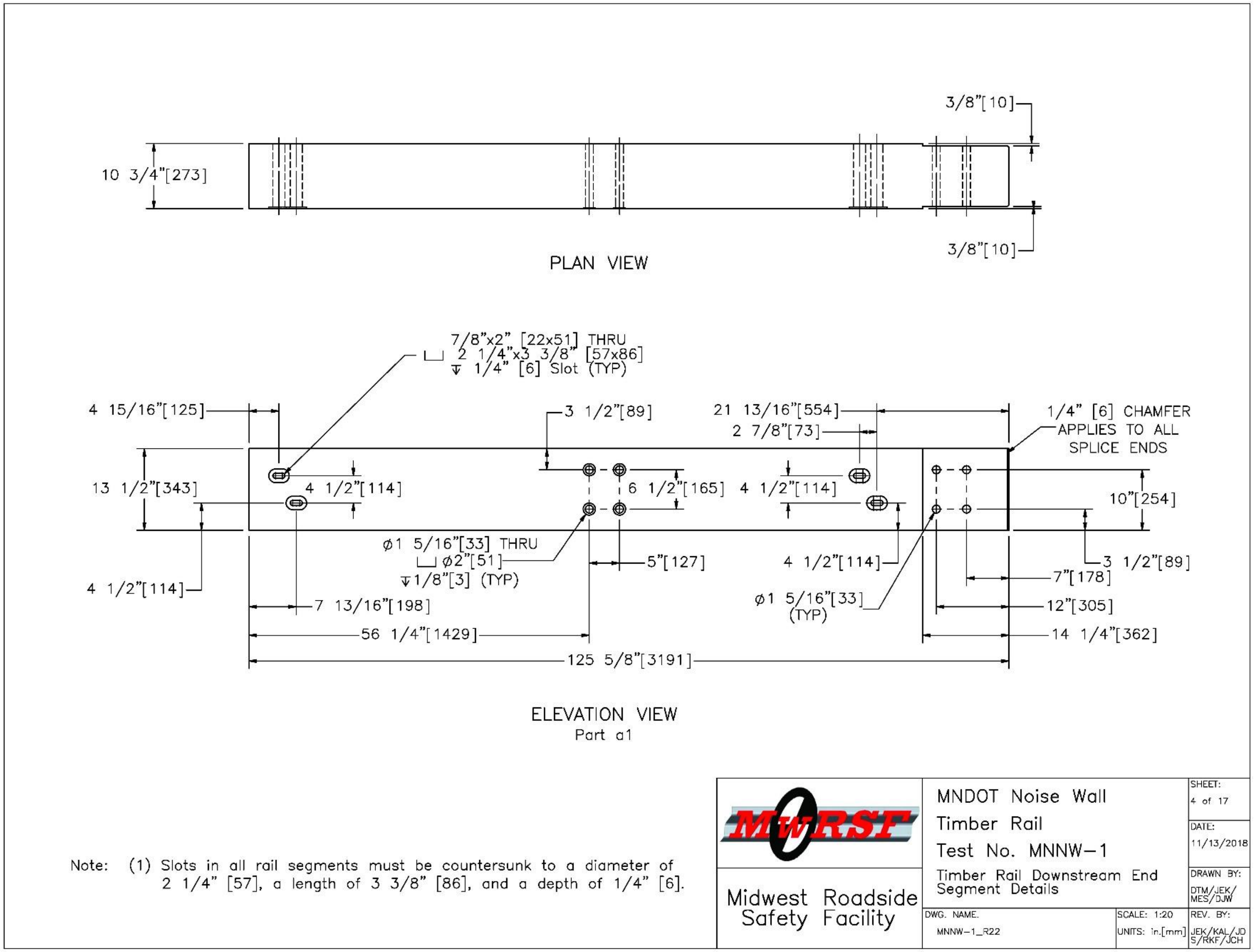


Figure 21. Timber Rail Downstream End Segment Details, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

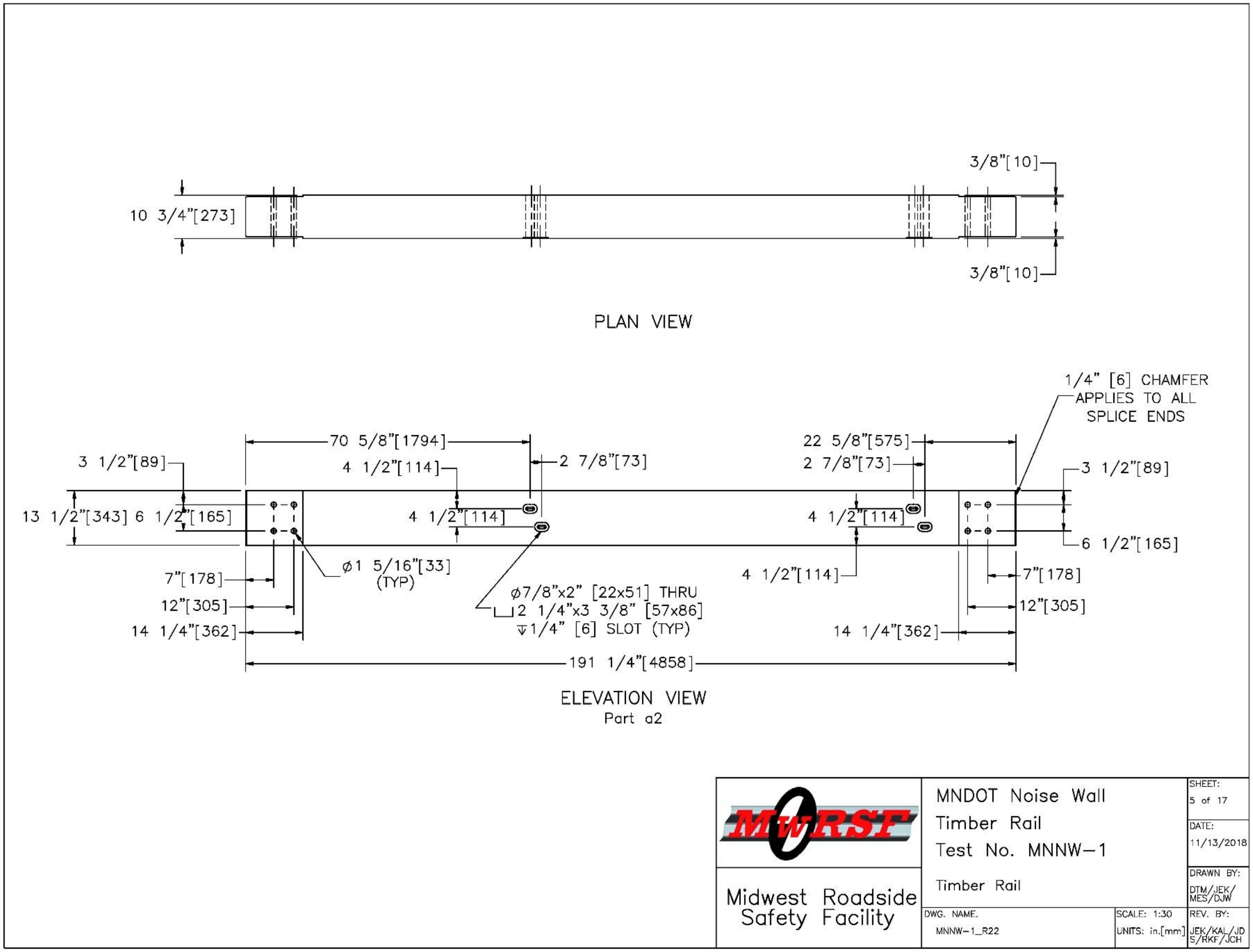


Figure 22. Timber Rail, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

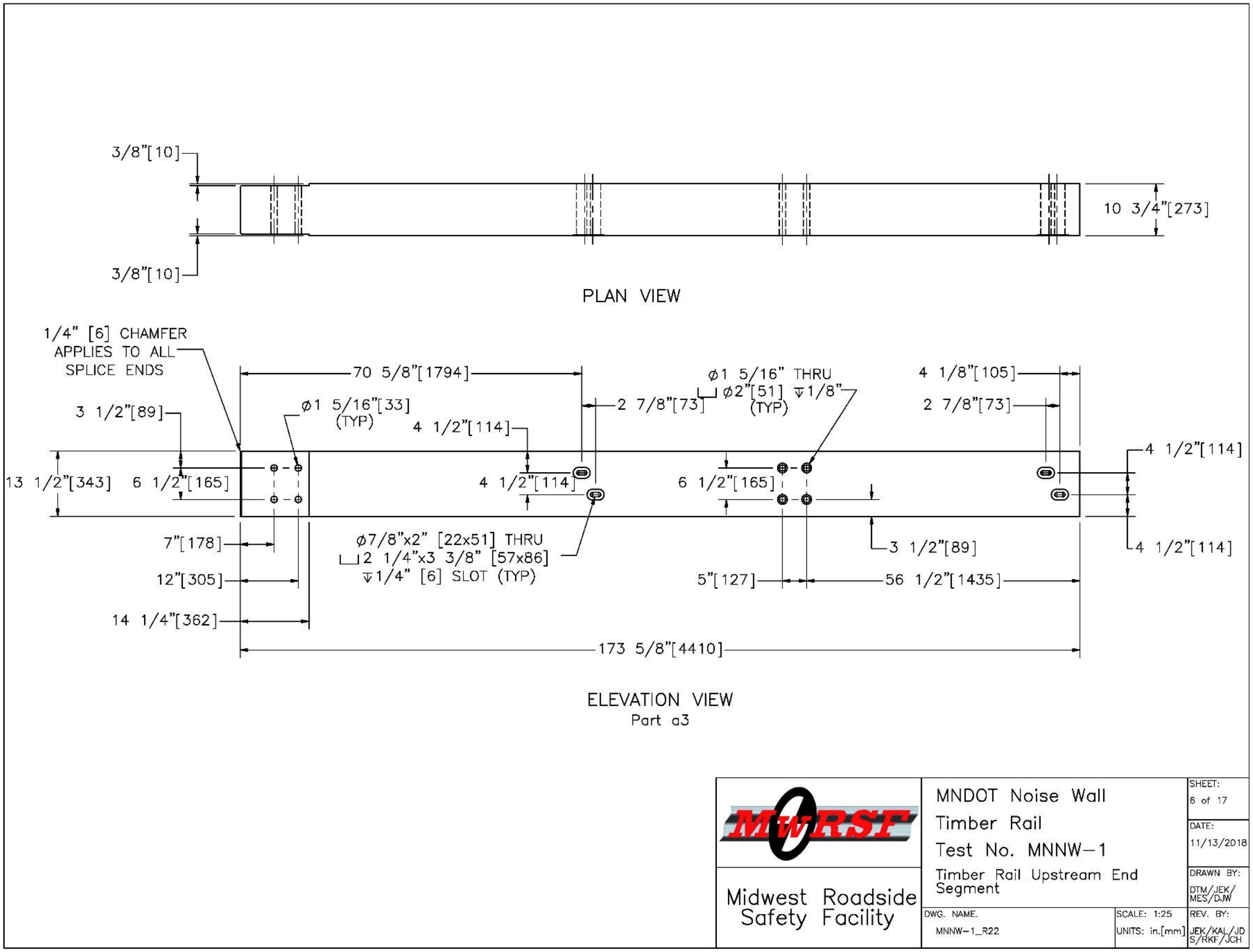


Figure 23. Timber Rail Upstream End Segment, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

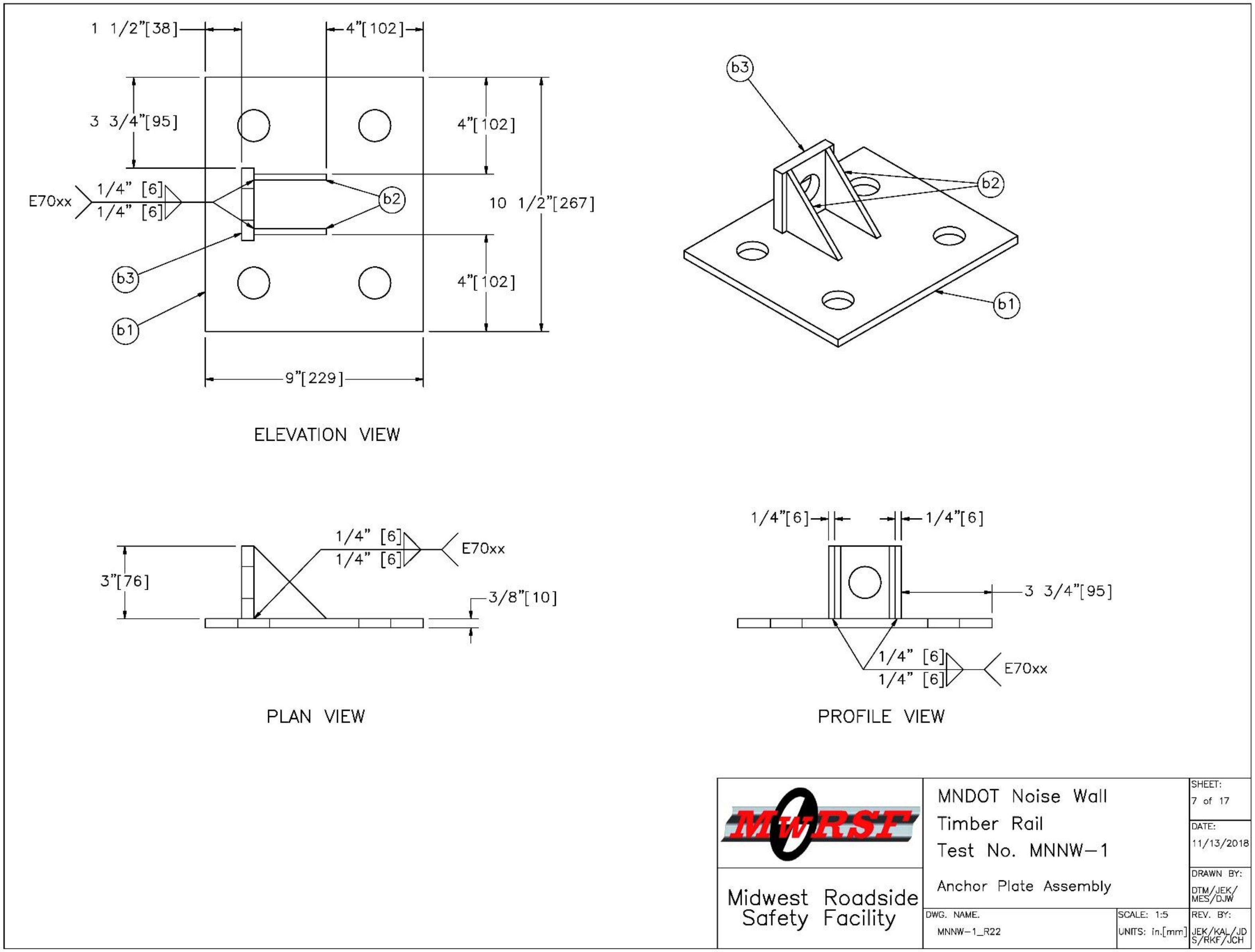


Figure 24. Anchor Plate Assembly, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

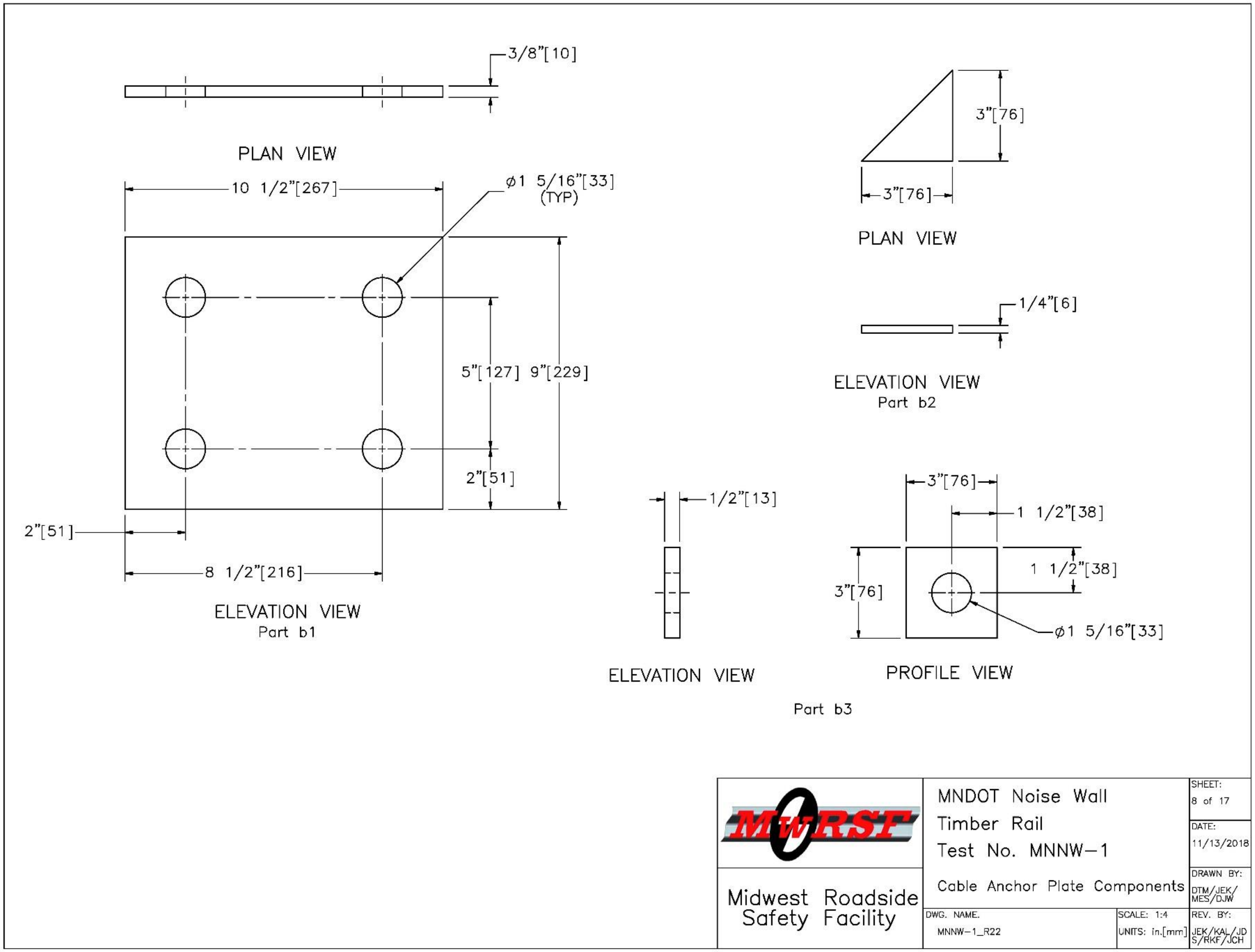


Figure 25. Cable Anchor Plate Components, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

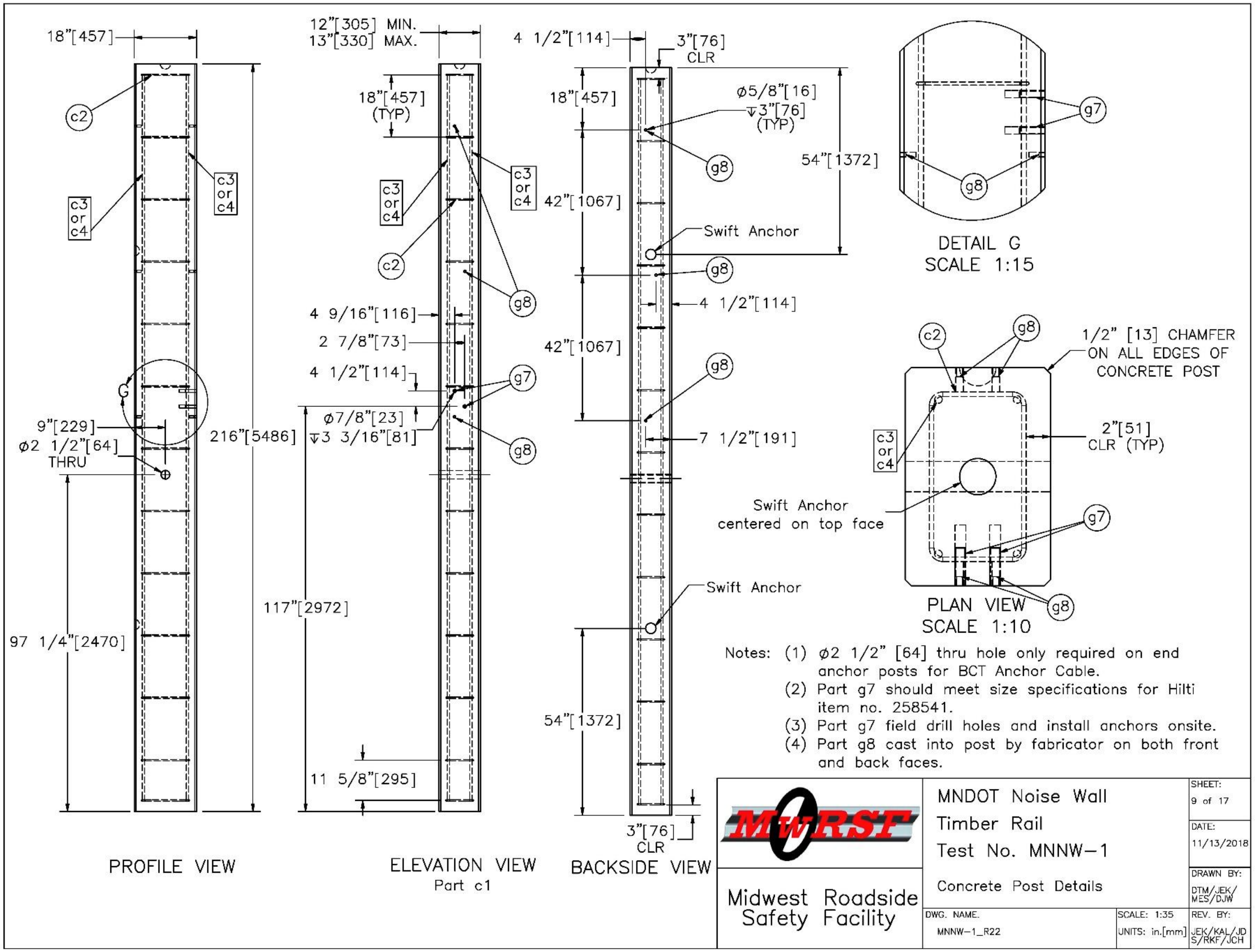
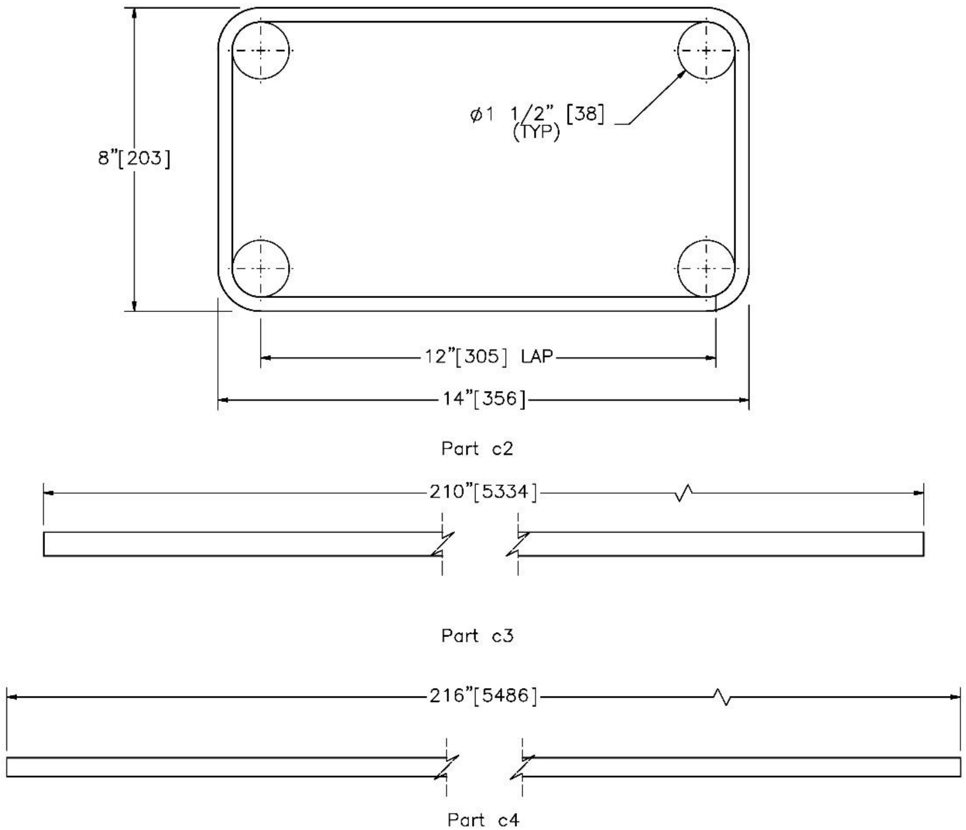


Figure 26. Concrete Post Details, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)



BILL OF BARS			
ITEM NO.	QTY. PER POST	BAR SIZE	TOTAL LENGTH
c2	13	#3	53" [1,346]
c3	4	#5	210" [5,334]
c4	4	1/2" [13]	216" [5,486]

Notes: (1) Splices not allowed in part c3.
(2) Prestressed strands (part c4) may be used in lieu of c3 reinforcement bars. ϕ1/2" [13] low-relaxation, 270 ksi [1,862 MPa] ultimate strength Initial prestress = 30,900 lb [137.5 kN] per strand; cut strands flush with concrete.

Midwest Roadside Safety Facility	MNDOT Noise Wall Timber Rail Test No. MNNW-1	SHEET: 10 of 17 DATE: 11/13/2018
	Concrete Post Reinforcement	DRAWN BY: DTM/JEK/MES/DJW
	DWG. NAME. MNNW-1_R22 | SCALE: 1:4 UNITS: in.[mm]	REV. BY: JEK/KAL/JDS/RKF/JCH

Figure 27. Concrete Post Reinforcement, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

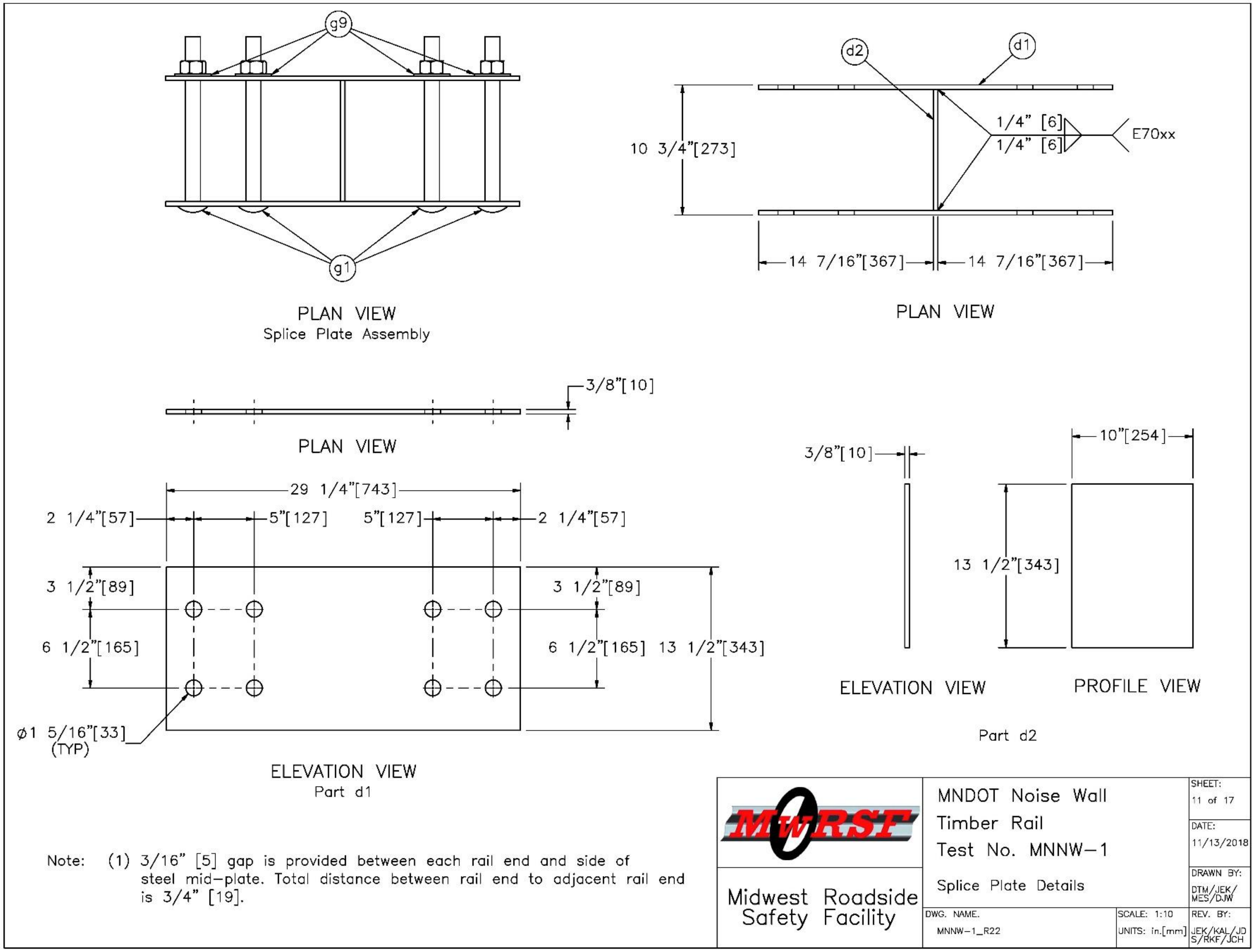


Figure 28. Splice Plate Details, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

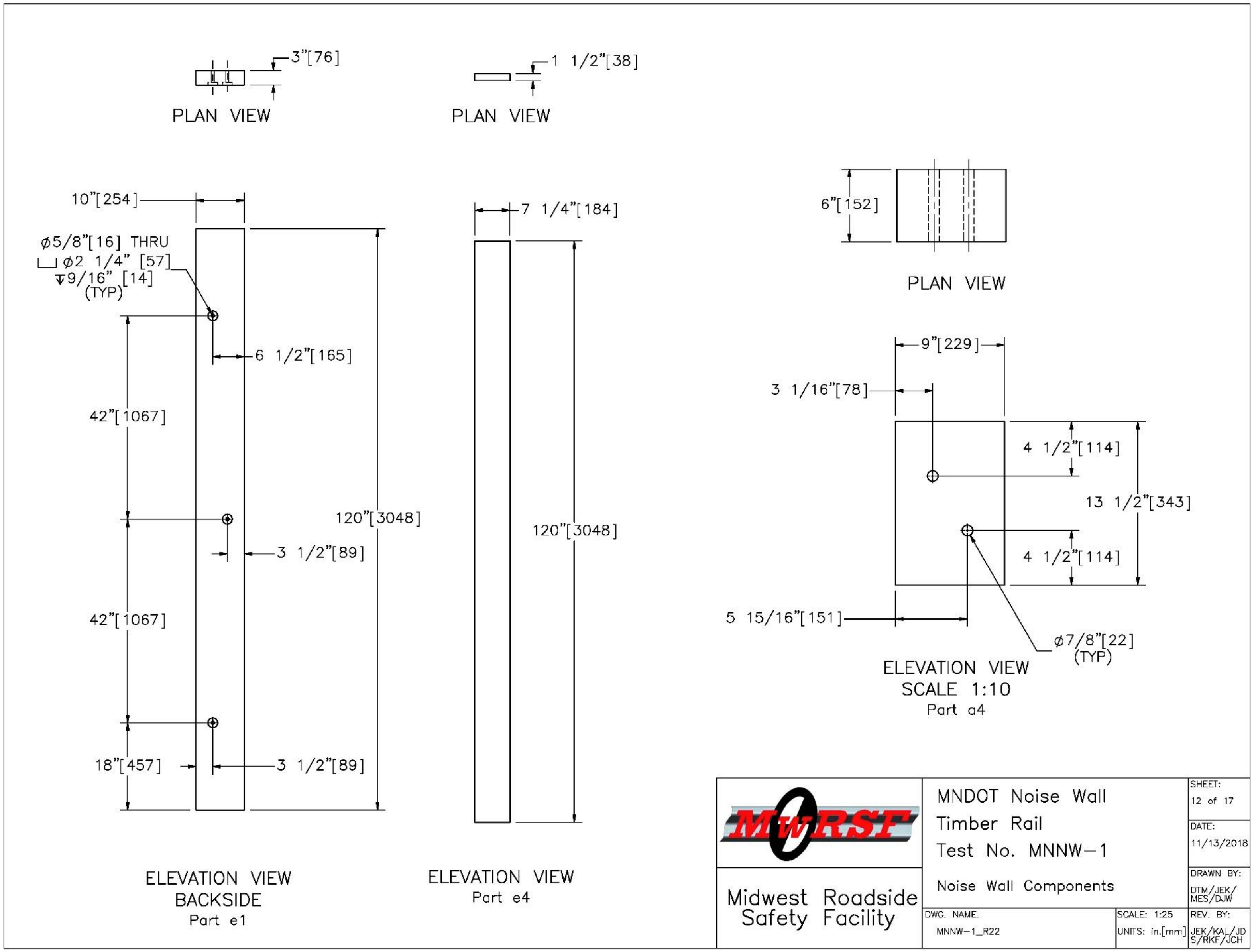


Figure 29. Noise Wall Components, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

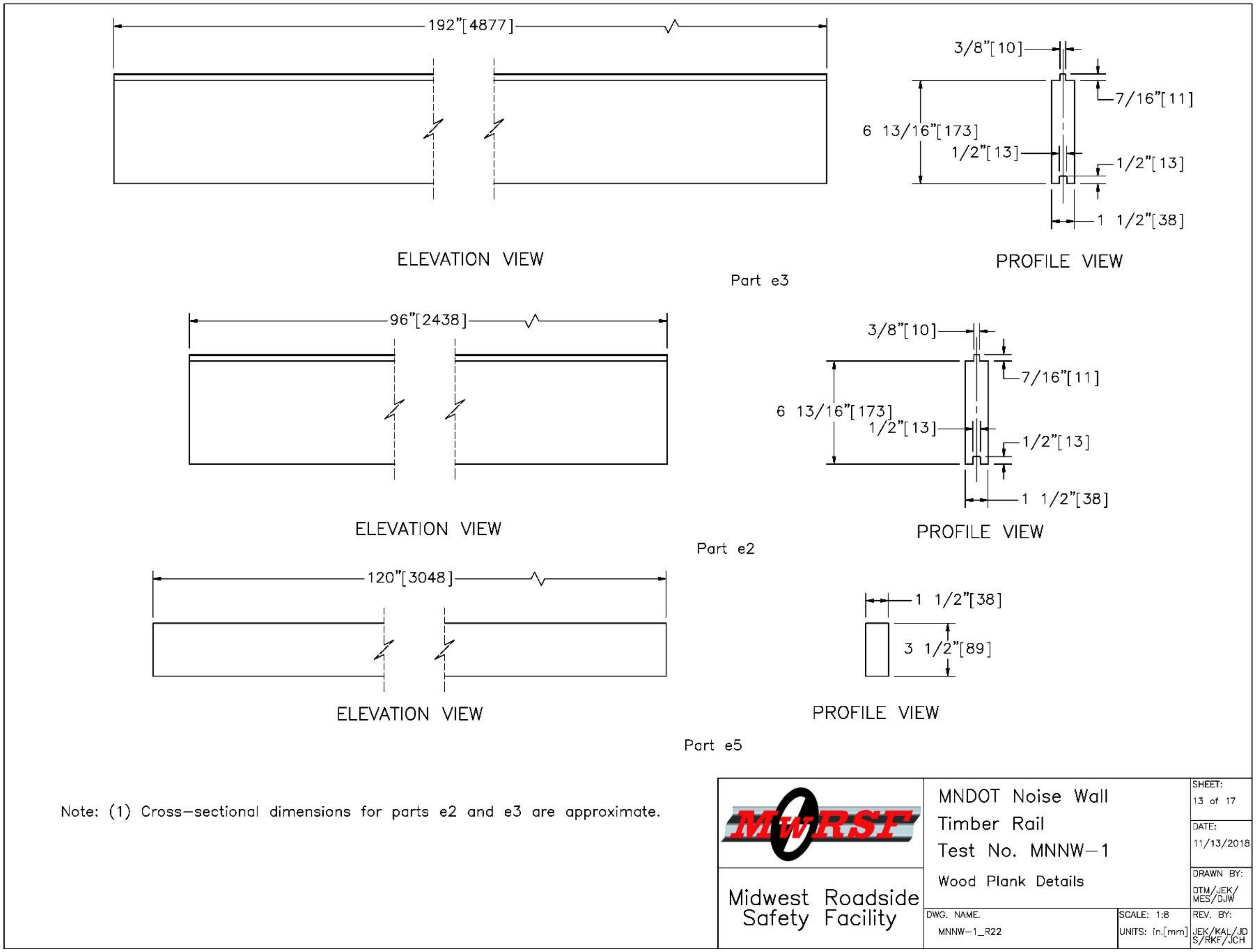


Figure 30. Wood Plank Details, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

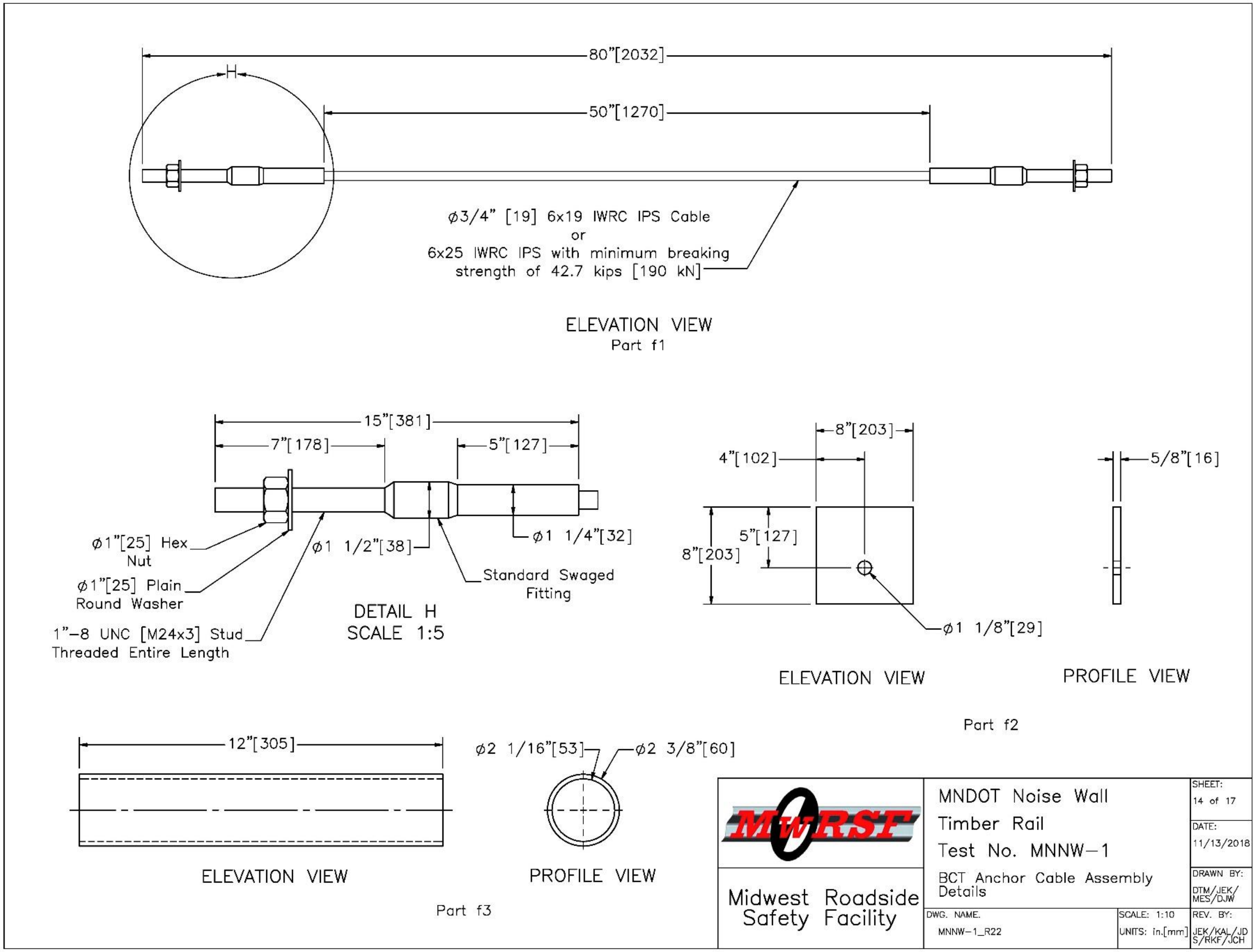


Figure 31. BCT Anchor Cable Assembly Details, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

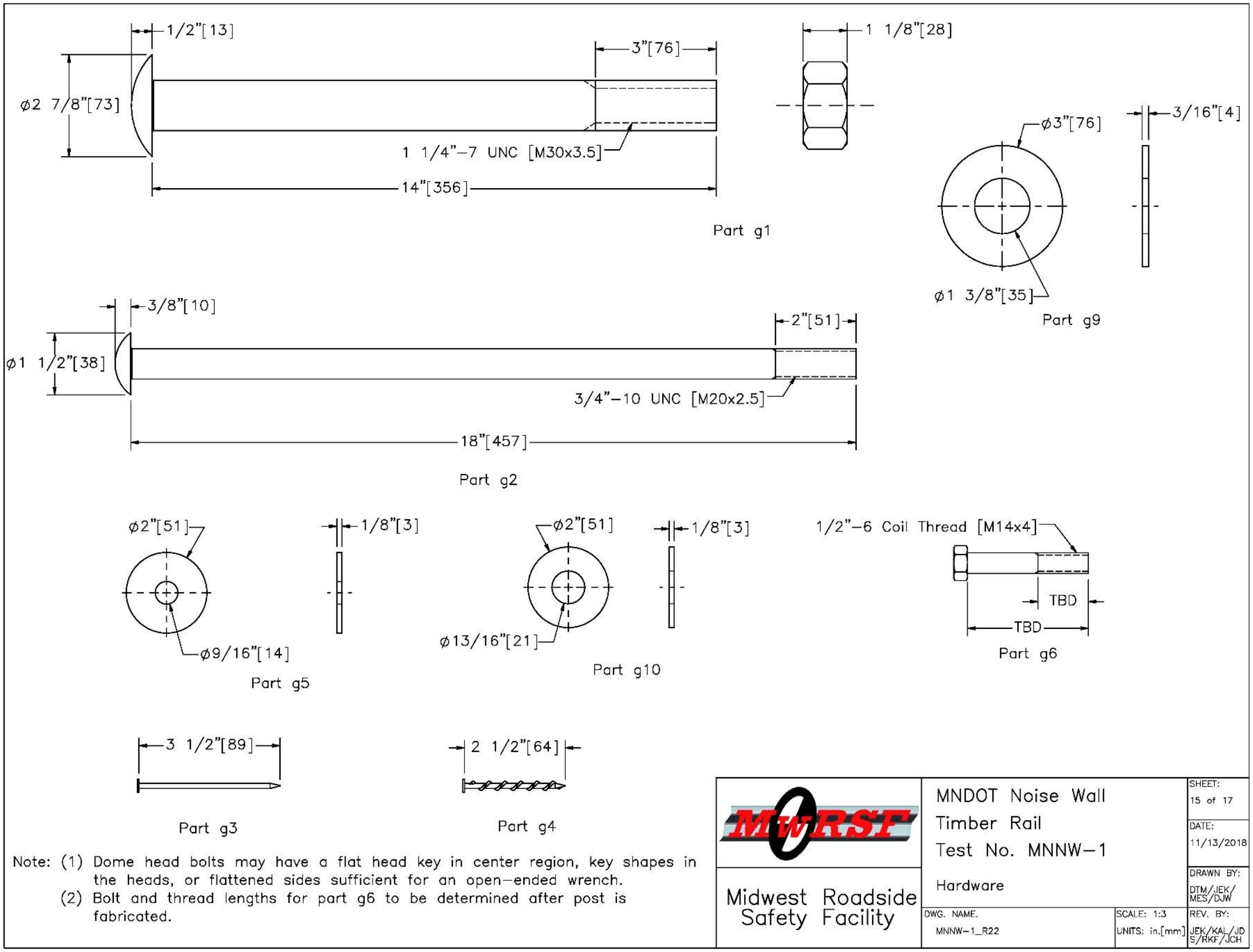


Figure 32. Hardware, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	1	125 5/8"x13 1/2"x10 3/4" [3,191x343x273] Timber Rail End Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a2	4	191 1/4"x13 1/2"x10 3/4" [4,858x343x273] Timber Rail Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a3	1	173 5/8"x13 1/2"x10 3/4" [4,410x343x273] Timber Rail End Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a4	12	13 1/2"x9"x6" [343x229x152] Wood Blockout	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
b1	2	10 1/2"x9"x3/8" [229x267x10] Steel Plate	ASTM A36	ASTM A123**	–
b2	4	3"x3"x1/4" [76x76x6] Steel Gusset	ASTM A36	ASTM A123**	–
b3	2	3"x3"x1/2" [76x76x13] Steel Plate	ASTM A36	ASTM A123**	–
c1	12	12"x18" [305x457], 18' [5,486] Long Concrete Post	Min. f'c = 5,500 psi [37.9 MPa] MnDOT mix 3W82	–	–
c2	156	3/8" [10] Dia., 53" [1,346] Long Rebar	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)	–
c3*	48	5/8" [16] Dia., 210" [5,334] Long Rebar	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)	–
c4*	48	1/2" [13] Dia, 7–Wire Pre–Stressing Strand, 216" [5,486] Long	ASTM A416 Gr. 270	–	–
d1	10	29 1/4"x13 1/2"x3/8" [743x343x10] Steel Plate	ASTM A36	ASTM A123**	–
d2	5	13 1/2"x10"x3/8" [343x254x10] Steel Plate	ASTM A36	ASTM A123**	–
e1	12	3"x10" [76x254], 10' [3,048] Long Vertical Wood Nailer	SYP Gr. No. 1 Dense or better standard rough sawn or Douglas Fir–Larch No. 1 or Douglas Fir–Larch (North) Select Structural or Douglas Fir–South Select Structural or equivalent with min F'b = 1,200 psi [8.3 MPa]	See Note 4	–
e2	17	2"x8" [51x203], 8' [2,438] Long Tongue and Groove Wood Plank	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e3	85	2"x8" [51x203], 16' [4,877] Long Tongue and Groove Wood Plank	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e4	12	2"x8" [51x203], 10' [3,048] Long Wood Batten	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e5	2	2"x4" [51x102], 10' [3,048] Long Wood Plank	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–

*Use either part c3 or c4.

** Weld before galvanization.

Notes:
(1) Timber rail sections and blockouts shall be treated with pentachlorophenol (PCP–A) in heavy oil to a minimum net retention of 0.6 lb/ft^3 (9.6 kg/m^3) in accordance with AWPA Standard U1 to the requirements of Use Category 4A (UC4A).
(2) Wood shall be cut, drilled, and completely fabricated prior to treatment with preservative. Drain excess chemicals and dry all treated wood at the place of manufacture.
(3) All field cuts, bore holes, and damages shall be treated with material acceptable to the engineer prior to installation.
(4) Provide preservative treated timber products per Spec. 3491.

Midwest Roadside Safety Facility

MNDOT Noise Wall Timber Rail Test No. MNNW–1

Bill of Materials

SHEET:	16 of 17
DATE:	11/13/2018
DRAWN BY:	DTM/JEK/MES/DJW
DWG. NAME.	MNNW–1_R22
SCALE:	None
UNITS:	in.[mm]
REV. BY:	JEK/KAL/JDS/RKF/JCH

Figure 33. Bill of Materials, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
f1	2	BCT Anchor Cable	–	–	FCA01
f2	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
f3	2	2 3/8" [60] O.D. x 12" [305] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	–
g1	48	1 1/4"–7 UNC [M30x3.5], 14" [356] Long Round Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB09a
g2	24	3/4"–10 UNC [M20x2.5], 18" [457] Long Round Head Bolt with Flat Head Key	ASTM A307 Gr. A	ASTM A153 or B695 Class 55 or F2329	FBB08a
g3	969	16D Ring Shank Nail	–	–	–
g4	408	No. 8 x 2 1/2" [64] Long Bugle Head Exterior Screw	–	ASTM A153 or B695 Class 55	–
g5	36	1/2" [13] Dia. Round Plate Washer	ASTM F844	ASTM A123 or A153 or F2329	–
g6	36	1/2"–6 Coil Thread [M14x4], 3" [76] Long Hex Head Bolt	ASTM A307 Gr. A	ASTM A153 or B695 Class 55 or F2329	–
g7	24	3/4"–10 UNC [M20x2.5] Drop–In Concrete Anchor	Hilti Item No. 258541	Zinc–Plated	–
g8	72	1/2"–6 Coil Thread [M14x4] Concrete Anchor	As Supplied	Galvanize per spec. 3392 or electroplate per ASTM B633 SC4 Type II	–
g9	48	1 1/4" [32] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC30a
g10*	24	3/4" [19] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC20a

* Washer plates with a 2 1/2" [64] outer diameter and thickness of 1/8" [3] were substituted at post no. 5.

Midwest Roadside Safety Facility

MNDOT Noise Wall
Timber Rail
Test No. MNNW–1

Bill of Materials

SHEET: 17 of 17
DATE: 11/13/2018
DRAWN BY: DTM/JEK/MES/DJW
REV. BY: JEK/KAL/JD S/RKF/JCH
DWG. NAME. MNNW–1_R22
SCALE: None
UNITS: in.[mm]

Figure 34. Bill of Materials, Test Nos. MNNW-1 and MNNW-2 (Recommended updates provided in Chapter 12)

Figure 35. Test Installation Photographs, Test No. MNNW-1

Figure 36. Test Installation Photographs, Test No. MNNW-1

Figure 37. Test Installation Photographs, Test No. MNNW-2

Figure 38. Test Installation Photographs, Test No. MNNW-2

6 FULL-SCALE CRASH TEST NO. MNNW-1

6.1 Static Soil Test

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

6.2 Weather Conditions

Test no. MNNW-1 was conducted on February 28, 2018 at approximately 2:30 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 3.

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

Temperature	44° F
Humidity	68%
Wind Speed	17 mph
Wind Direction	20° from True North
Sky Conditions	Overcast
Visibility	7 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.00 in.
Previous 7-Day Precipitation	0.25 in.

6.3 Test Description

Since minimal deflection was expected near the ground line, the noise wall system was thought to behave similarly to a rigid barrier. Table 2.7 of MASH 2016 recommends using an impact point approximately 4.3 ft (1.3 m) upstream from a post or splice for rigid barriers. However, due to similarities between the noise wall previously evaluated under NCHRP Report No. 350 in test no. MNTR-1 and the modified noise wall in test no. MNNW-1, the same impact point utilized in test no. MNTR-1 was selected to maximize vehicle snag on a post [1]. Initial vehicle impact was to occur 12 in. (305 mm) upstream from the centerline of post no. 6, as shown in Figure 46, which was selected as the same impact point in test no. MNTR-1 as it produced the maximum vehicle extent behind the barrier to snag on the concrete posts.

The 5,056-lb (2,293-kg) crew cab pickup truck impacted the noise wall system at a speed of 63.0 mph (101.4 km/h) and at an angle of 24.7 degrees. The actual point of impact was about $^{7}/_{16}$ in. (11 mm) downstream from the targeted impact point. A sequential description of the impact events is contained in Table 4. A summary of the test results and sequential photographs are shown in Figure 39. Additional sequential photographs are shown in Figure 40. Documentary photographs of the crash test are shown in Figure 41. The vehicle came to rest 117 ft – 9 in. (35.9 m) downstream and 4 ft – 4 in. (1.3 m) laterally behind the barrier after brakes were applied. The vehicle trajectory and final position are shown in Figures 39 and 47.

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

TIME (sec)	EVENT
0.000	Vehicle's front bumper contacted rail between post nos. 5 and 6.
0.008	Vehicle's right fender contacted rail.
0.010	Vehicle's right-front tire contacted rail.
0.024	Post no. 6 deflected backward.
0.026	Vehicle's grille contacted rail.
0.036	Vehicle's right headlight contacted rail.
0.042	Post no. 7 deflected backward.
0.052	Vehicle rolled toward system.
0.066	Vehicle's upper right-front and right-rear doors deformed.
0.068	Vehicle yawed away from system and vehicle's right-front wheel disengaged.
0.073	Vehicle's grille became disengaged.
0.078	Vehicle's windshield cracked.
0.087	Vehicle's plastic fascia became disengaged.
0.088	Vehicle's grille contacted post no. 7, and post no. 7 deflected backward.
0.110	Post no. 6 deflected forward.
0.122	Vehicle pitched downward, and vehicle's left-rear tire became airborne.
0.136	Post no. 7 deflected forward.
0.138	Vehicle's left-front tire became airborne.
0.156	Vehicle's right-rear door contacted rail, and vehicle's grille contacted post no. 8.
0.162	Vehicle's right-side mirror contacted post no. 7 and shattered.
0.202	Vehicle's right quarter panel contacted rail.
0.204	Vehicle's right-rear tire contacted rail.
0.210	Vehicle's rear bumper contacted rail.
0.224	Vehicle was parallel to system at a speed of 40.9 mph (65.8 km/h).
0.244	Vehicle's right-rear tire became airborne.
0.266	Vehicle yawed toward system.
0.294	Vehicle exited system at a speed of 38.3 mph (61.6 km/h), and at an angle of 3.7 degrees.
0.396	Vehicle's front bumper contacted ground.
0.414	System came to rest.
0.438	Vehicle rolled away from system.
0.478	Vehicle's right headlight became disengaged.
0.802	Vehicle's left-front tire regained contact with ground.
0.824	Vehicle pitched upward.
0.920	Vehicle's left headlight became disengaged.
1.196	Vehicle's left-rear tire regained contact with ground.
1.212	Vehicle's right-rear tire regained contact with ground.
1.238	Vehicle's right-rear wheel became disengaged.

6.4 Barrier Damage

Damage to the barrier was minimal, as shown in Figure 49. Barrier damage consisted of contact marks, splinters, and gouges on the front face of the timber rubrail. The length of vehicle contact along the barrier was approximately 14 ft – 8 in. (4.5 m), which spanned from 1 ft – 5¾ in. (0.5 m) upstream from post no. 6 to 3 ft – 8¼ in. (1.1 m) upstream from post no. 8.

The majority of the splinters on the front face of the rail were located around post nos. 5, 6, and 7, where initial impact occurred. The largest splinter was 72 in. (1,829 mm) long and began 23 in. (584 mm) upstream from post no. 6. A 54-in. (1,372-mm) long splinter and a 49-in. (1,245-mm) long splinter ran nearly parallel to each other, starting at the same point 40 in. (1,016 mm) downstream from post no. 6. The farthest upstream splinter was located 17 in. (432 mm) upstream from post no. 5, but it only measured 5 in. (127 mm) in length, 2 in. (51 mm) in width, and ⅛ in. (3 mm) in height. The farthest downstream splinter was 47½ in. (1,207 mm) long and began 17 in. (432 mm) downstream from post no. 7.

A 10-in. (254-mm) x 7½-in. (191-mm) x 3½-in. (89-mm) gouge was located 13 in. (330 mm) upstream from post no. 6. A smaller gouge was also found on the upstream face of the blockout at post no. 7 and located 2 in. (51 mm) from the bottom. A thin piece of the rail, measuring 47 in. (1,194 mm) in length, detached from its initial location at 24 in. (610 mm) downstream from post no. 6. Concrete spalled on the upstream face of post no. 7 at 49 in. (1,245 mm) from the bottom, but the noise wall itself remained undamaged.

Three post-to-rail bolts on the front face of the rail were embedded and shifted different lengths. The top post-to-rail bolt at post no. 6 was shifted 1 in. (25 mm) downstream, the top post-to-rail bolt at post no. 7 was shifted ½ in. (13 mm) upstream, and the top post-to-rail bolt at post no. 9 was shifted ½ in. (13 mm) downstream.

The maximum lateral permanent set of the barrier system was ⅞ in. (22 mm), which occurred at the midspan of the rail between post nos. 6 and 7, as measured in the field. The maximum permanent set of the posts was ¼ in. (6 mm) at rail height of post nos. 6 and 7, as measured in the field. The maximum permanent set of the top of the posts was approximately 0.3 in. (8 mm) and 0.5 in. (13 mm) at the top of post nos. 6 and 7, respectively, as determined from high-speed digital video analysis. The maximum lateral dynamic post and rail deflections were 3.8 in. (96 mm) at the top of post no. 7 and 1.1 in. (28 mm) at the top of the rail at post no. 6, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 44.5 in. (1,132 mm) at the top of post no. 7, also determined from high-speed digital video analysis.

6.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figure 51. The maximum occupant compartment intrusion values are listed in Table 5 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment and none of the established MASH 2016 deformation limits were violated. The entire A-pillar (lateral), side door above seat, floor pan, and roof deformed slightly outward, which is not considered crush toward the occupant, is denoted as negative numbers in Table 5, and is not evaluated by MASH 2016 criteria. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix E.

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

Location	**MAXIMUM INTRUSION in. (mm)**	**MASH 2016 ALLOWABLE INTRUSION in. (mm)**
Wheel Well & Toe Pan	1.5 (38)	≤ 9 (229)
Floor Pan & Transmission Tunnel	-2.0 (-51)	N/A
A-Pillar	0.4 (10)	≤ 5 (127)
A-Pillar (Lateral)	-1.0 (-25)	N/A
B-Pillar	0.3 (8)	≤ 5 (127)
B-Pillar (Lateral)	0.2 (5)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	6.1 (156)	≤ 12 (305)
Side Door (Above Seat)	-1.3 (-33)	N/A
Side Door (Below Seat)	2.6 (66)	≤ 12 (305)
Roof	-1.1 (-28)	N/A
Windshield	0 (0)	≤ 3 (76)
Side Window	No shattering	No shattering resulting from contact with structural member of test article
Dash	1.1 (28)	N/A

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

The majority of damage was concentrated on the right-front corner and right side of the vehicle where the impact had occurred. The right side of the bumper was crushed inward and back, while the left side buckled outward. The size of the crush was 78 in. (1,981 mm) in length, 14 in. (356 mm) in width, and 30 in. (762 mm) in height. The right-front quarter panel was crushed 7 in. (178 mm) into the engine compartment and the cab of the vehicle. The right-front door was also crushed inward. Beginning at the front edge of the door, the area of crush was 45 in. x 20 in. (1,143 mm x 508 mm). A 39-in. (991-mm) long rip in the sheet metal also ran the length of the right-front door. The right-rear door also had a large, 42-in. (1,067-mm) long dent spanning the entire length of the door. The right side of the vehicle bed was crushed inward, causing it to bend outward 3 in. (76 mm) behind the right-rear tire. The vehicle grille disengaged upon impact with the barrier. The right side of the windshield was cracked. All other components of the vehicle were undamaged.

6.6 Occupant Risk

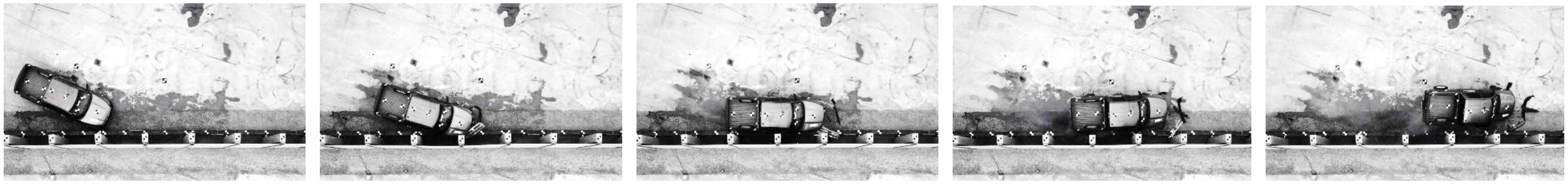
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 6. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 6. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 39. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix F.

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

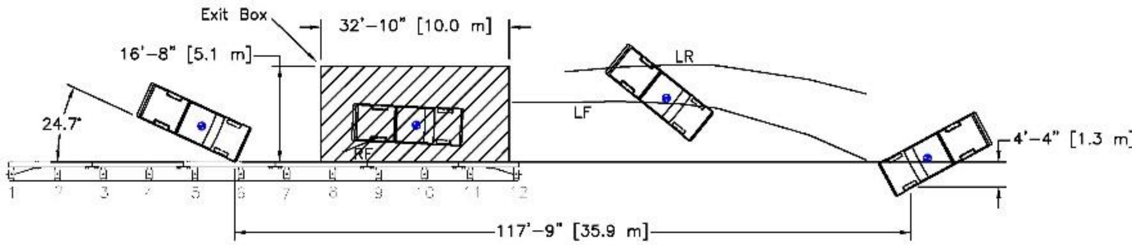
Evaluation Criteria		**Transducer**		**MASH 2016 Limits**
		SLICE-1	**SLICE-2 (primary)**	
OIV ft/s (m/s)	Longitudinal	-24.43 (-7.45)	-24.08 (-7.34)	±40 (12.2)
	Lateral	-23.87 (-7.27)	-26.09 (-7.95)	±40 (12.2)
ORA g's	Longitudinal	-7.63	-7.59	±20.49
	Lateral	-8.63	-7.33	±20.49
MAX. ANGULAR DISPL. deg.	Roll	27.7	26.7	±75
	Pitch	-19.9	-21.0	±75
	Yaw	30.3	30.1	not required
THIV ft/s (m/s)		33.26 (10.13)	33.93 (10.34)	not required
PHD g's		9.97	9.14	not required
ASI		1.34	1.46	not required

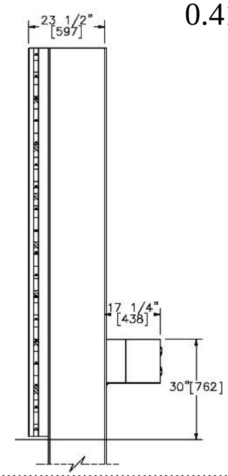
6.7 Discussion

The analysis of the test results for test no. MNNW-1 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix F, were deemed acceptable because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 3.7 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. MNNW-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.



0.000 sec 0.110 sec 0.204 sec 0.294 sec 0.414 sec





- Test Agency .... MwRSF
- Test Number MNNW-1
- Date 2/28/2018
- MASH 2016 Test Designation No. 3-11
- Test Article .... MN Noise Wall
- Total Length .... 89 ft (27.1 m)
- Key Component - Rail
  - Length .... 89 ft (27.1 m)
  - Width .... 13½ in. (343 mm)
  - Depth .... 10¾ in. (273 mm)
- Key Component - Concrete Post
  - Length .... 18 ft (5.5 m)
  - Width .... 18 in. (457 mm)
  - Spacing .... 8 ft (2.4 m)
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... 2010 Dodge Ram 1500 Crew Cab
  - Curb .... 5,264 lb (2,388 kg)
  - Test Inertial .... 5,056 lb (2,293 kg)
  - Gross Static .... 5,214 lb (2,365 kg)
- Impact Conditions
  - Speed .... 63.0 mph (101.4 km/h)
  - Angle .... 24.7 deg.
  - Impact Location .... $11^{9}/_{16}$ in. (294 mm) US from centerline of post no. 6
- Impact Severity ......117.2 kip-ft (158.9 kJ) > 106 kip-ft (144 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 38.3 mph (61.6 km/h)
  - Angle .... 3.7 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 117 ft – 9 in. (35.9 m) downstream
  .... 4 ft – 4 in. (1.3 m) laterally behind

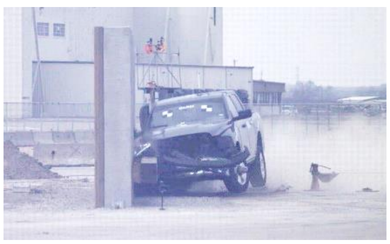
- Vehicle Damage .... Moderate
  - VDS [12] 01-RFQ-4
  - CDC [13] 01-RYEW-3
  - Maximum Interior Deformation .... 6.1 in. (155 mm)
- Test Article Damage .... Minimal
- Maximum Test Article Deflections
  - Permanent Set .... ⅞ in. (22 mm) at midspan of rail between post nos. 6 and 7
  - Dynamic .... 3.8 in. (96 mm) at top of post no. 7
  - Working Width .... 44.5 in. (1,132 mm) at top of post no. 7
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-24.43 (-7.45)	-24.08 (-7.34)	±40 (12.2)
	Lateral	-23.87 (-7.27)	-26.09 (-7.95)	±40 (12.2)
ORA g's	Longitudinal	-7.63	-7.59	±20.49
	Lateral	-8.63	-7.33	±20.49
MAX ANGULAR DISP. deg.	Roll	27.7	26.7	±75
	Pitch	-19.9	-21.0	±75
	Yaw	30.3	30.1	not required
THIV – ft/s (m/s)		33.26 (10.13)	33.93 (10.34)	not required
PHD – g's		9.97	9.14	not required
ASI		1.34	1.46	not required

Figure 39. Summary of Test Results and Sequential Photographs, Test No. MNNW-1


0.000 sec


0.088 sec


0.162 sec


0.294 sec


0.396 sec


0.802 sec


0.000 sec


0.088 sec


0.162 sec


0.294 sec


0.414 sec


0.802 sec

Figure 40. Additional Sequential Photographs, Test No. MNNW-1

Figure 41. Documentary Photographs, Test No. MNNW-1

Figure 42. Documentary Photographs, Test No. MNNW-1

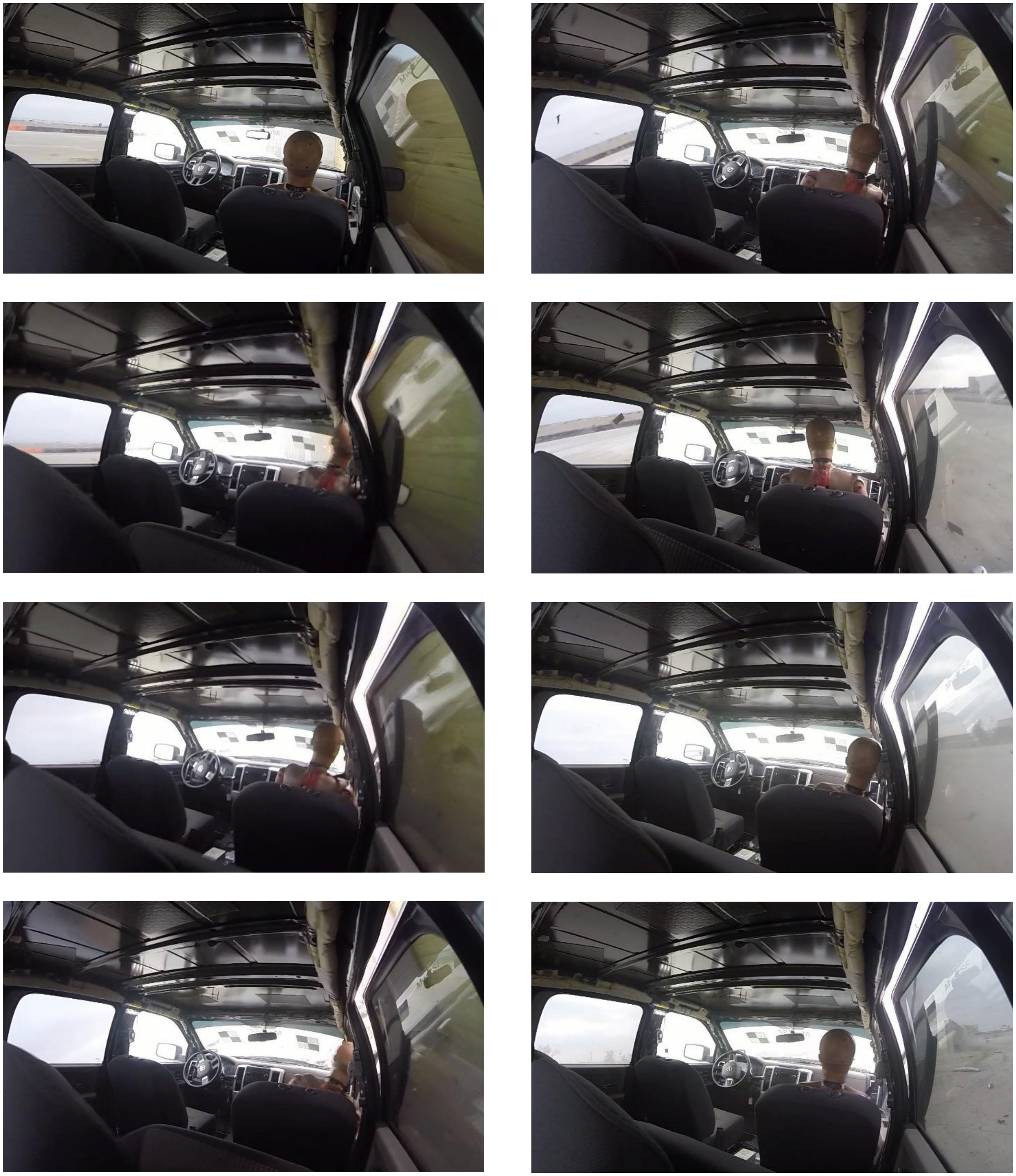


Figure 43. Documentary Photographs, Test No. MNNW-1

Figure 44. Documentary Photographs, Test No. MNNW-1

Figure 45. Documentary Photographs, Test No. MNNW-1

Figure 46. Impact Location, Test No. MNNW-1

Figure 47. Vehicle Final Position and Trajectory Marks, Test No. MNNW-1

Figure 48. System Damage, Test No. MNNW-1

Figure 49. System Damage, Test No. MNNW-1

Figure 50. Vehicle Undercarriage and Occupant Compartment Damage, Test No. MNNW-1

Figure 51. Vehicle Damage, Test No. MNNW-1

7 FULL-SCALE CRASH TEST NO. MNNW-2

7.1 Static Soil Test

A static soil test was conducted before test no. MNNW-1, which demonstrated a soil resistance above the baseline test limits. Since the system was not deemed to have significant soil dependence as discussed previously due to large posts, heavy mass, and deep post embedment depth, a static soil test was not conducted before test no. MNNW-2.

7.2 Weather Conditions

Test no. MNNW-2 was conducted on March 9, 2018 at approximately 2:00 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 7.

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

Temperature	52° F
Humidity	34%
Wind Speed	15 mph
Wind Direction	60° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.05 in.
Previous 7-Day Precipitation	0.09 in.

7.3 Test Description

The noise wall system was thought to behave similarly to a rigid barrier since minimal deflection was expected near the ground line. Table 2.7 of MASH 2016 recommends using an impact point approximately 3.6 ft (1.1 m) upstream from a post or splice for rigid barriers. Initial vehicle impact was to occur 43$^{5}/_{16}$ in. (1,100 mm) upstream from the center of the rail splice between post nos. 6 and 7, as shown in Figure 59, which was selected using Table 2.7 of MASH 2016 to maximize the probability of wheel snag.

The 2,431-lb (1,103-kg) small car impacted the noise wall system at a speed of 63.1 mph (101.5 km/h) and at an angle of 25.4 degrees. The actual point of impact was about 2⅞ in. (73 mm) upstream from the targeted impact point. A sequential description of the impact events is contained in Table 8. A summary of the test results and sequential photographs are shown in Figure 52. Additional sequential photographs are shown in Figure 53. Documentary photographs of the crash test are shown in Figure 54. The vehicle came to rest 144 ft – 6 in. (44.0 m) downstream and 56 ft – 5 in. (17.2 m) laterally in front of the barrier after brakes were applied. The vehicle trajectory and final position are shown in Figures 52 and 60.

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

TIME (sec)	EVENT
0.000	Vehicle's front bumper contacted rail between post nos. 6 and 7.
0.006	Vehicle's front bumper deformed, and vehicle's right headlight contacted rail.
0.012	Vehicle's right-front hood contacted rail.
0.014	Vehicle's right fender contacted rail.
0.018	Vehicle's right headlight shattered.
0.020	Rail between post nos. 6 and 7 splintered.
0.024	Post no. 7 deflected backward.
0.032	Vehicle's right side grille contacted rail, and vehicle yawed away from system.
0.034	Vehicle's right-front door deformed, and vehicle pitched downward.
0.036	Post no. 6 deflected backward, and vehicle's grille deformed.
0.040	Vehicle's windshield cracked.
0.044	Vehicle's right-front door contacted rail.
0.054	Vehicle rolled away from system.
0.058	Post no. 8 deflected backward, and vehicle's roof deformed.
0.068	Vehicle's right-front tire contacted post no. 7.
0.090	Post no. 6 deflected forward.
0.098	Post no. 7 deflected forward.
0.128	Vehicle's front bumper cover deformed and contacted ground.
0.142	Post no. 8 deflected forward.
0.146	Vehicle's right-rear door contacted rail.
0.150	Vehicle rolled toward system.
0.152	Vehicle pitched upward.
0.178	Vehicle was parallel to system at a speed of 43.6 mph (70.1 km/h).
0.198	Vehicle's right quarter panel contacted rail.
0.248	Vehicle's front bumper contacted ground.
0.250	Vehicle's rear bumper contacted rail.
0.336	Vehicle exited system at a speed of 43.0 mph (69.1 km/h) and at an angle of 5.6 degrees.
0.420	Vehicle pitched downward.
0.640	Vehicle's front bumper cover contacted ground.

7.4 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 62 and 61. Barrier damage consisted of contact marks on the front face of the rail, gouging of the rail, and spacer block rotation. The length of vehicle contact along the barrier was approximately 12 ft – 7½ in. (3.8 m), which spanned 21¼ in. (540 m) downstream from the centerline of post no. 6 to 19½ in. (495 mm) upstream from the centerline of post no. 8.

The largest gouge, found on top of the rail, was 66¾ in. (1,695 mm) long and began 7 in. (178 mm) upstream from the centerline of post no. 7. Another large gouge was found toward the bottom of the rail at the centerline of post no. 7 and extended 58½ in. (1,486 mm) downstream. Three more gouges were seen near the point of impact. Those gouges measured 47 in. (1,194 mm), 29 in. (737 mm), and 22 in. (559 mm) in length and began 6 in. (152 mm) upstream, 1 in. (25 mm) upstream, and 10 in. (254 mm) downstream from the impact point, respectively. The smallest gouge was located on the wood spacer at post no. 7 and 2½ in. (64 mm) from the front of the concrete post. The gouge was 4½ in. (114 mm) long, running from the bottom of the spacer block upward. The spacer blocks at post nos. 5 and 7 were both rotated ⅛ in. (3 mm) upstream.

The maximum lateral permanent set of the barrier system was ⅛ in. (3 mm), which occurred both at rail height of post no. 7 and at the midspan of the rail between post nos. 5 and 6, as measured in the field. The maximum lateral permanent set of the top of the posts was approximately 0.1 in. (3 mm), which occurred at the top of post no. 6, as determined from high-speed digital video analysis. The maximum lateral dynamic post and rail deflections were 4.5 in. (114 mm) at the top of post no. 7 and 1.9 in. (48 mm) at the midspan of the rail between post nos. 6 and 7, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 45.2 in. (1,148 mm) at the top of post no. 7, also determined from high-speed digital video analysis.

7.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 62 and 61. The maximum occupant compartment intrusion values are listed in Table 9 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment and none of the established MASH 2016 deformation limits were violated. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix E.

The majority of damage was concentrated on the right-front corner and right side of the vehicle where the impact had occurred. The right side of the front bumper was torn off 24 in. (610 mm) from the centerline of the vehicle. The right headlight was completely disengaged. The right side of the hood was crushed inward and back toward the center of the vehicle. The right fender was also crushed inward. The crushed area of the fender was 44 in. (1,118 mm) long, 23 in. (584 mm) wide, and 8 in. (203 mm) deep. An 8-in. (203-mm) section of the outer rim of the right-front wheel was bent inward toward the center axis of the wheel. The right-front door and the right-rear door were both crushed along their entire length and shifted 1 in. (25 mm) toward the back of the vehicle, although the crushing on the right-front door was more extensive than the crushing on the right-rear door. Minor crushing was also found on the right quarter panel, just above the right-rear wheel well. The right side of the windshield was cracked, and the remainder of the vehicle was undamaged.

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

Location	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	0.5 (13)	≤ 9 (229)
Floor Pan & Transmission Tunnel	1.3 (32)	≤ 12 (305)
A-Pillar	1.0 (25)	≤ 5 (127)
A-Pillar (Lateral)	0.5 (13)	≤ 3 (76)
B-Pillar	0.4 (10)	≤ 5 (127)
B-Pillar (Lateral)	0.2 (5)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	1.9 (48)	≤ 12 (305)
Side Door (Above Seat)	1.0 (25)	≤ 9 (229)
Side Door (Below Seat)	1.2 (30)	≤ 12 (305)
Roof	0.7 (18)	≤ 4 (102)
Windshield	0 (0)	≤ 3 (76)
Side Window	No shattering	No shattering resulting from contact with structural member of test article
Dash	1.1 (28)	N/A

N/A – Not applicable

7.6 Occupant Risk

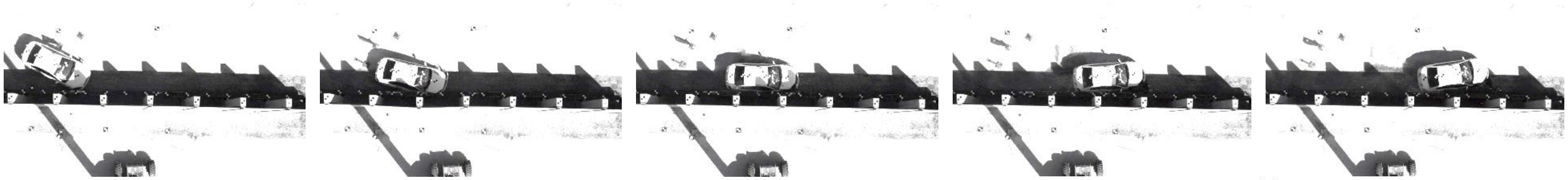
The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 10. Note that the OIVs and ORAs were within suggested limits, as provided in MASH 2016. The calculated THIV, PHD, and ASI values are also shown in Table 10. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 52. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix G.

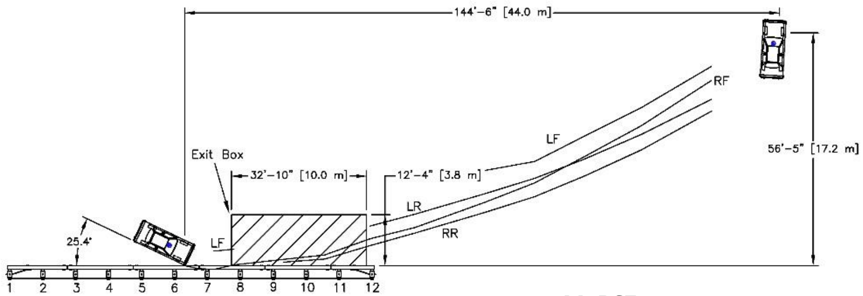
Table 10. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MNNW-2

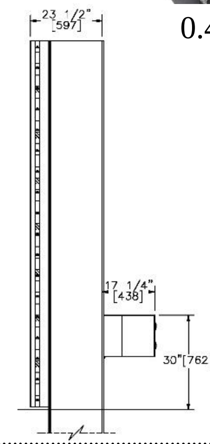
Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 (primary)	**SLICE-2**	
OIV ft/s (m/s)	Longitudinal	-24.30 (-7.41)	-23.73 (-7.23)	±40 (12.2)
	Lateral	-29.79 (-9.08)	-28.42 (-8.66)	±40 (12.2)
ORA g's	Longitudinal	-6.78	-6.20	±20.49
	Lateral	-3.97	-4.55	±20.49
MAX. ANGULAR DISPL. deg.	Roll	6.0	-3.3	±75
	Pitch	-4.1	-2.9	±75
	Yaw	-37.0	-37.2	not required
THIV ft/s (m/s)		33.17 (10.11)	32.46 (9.90)	not required
PHD g's		6.83	6.17	not required
ASI		2.25	2.14	not required

7.7 Discussion

The analysis of the test results for test no. MNNW-2 showed that the system adequately contained and redirected the 1100C vehicle with controlled lateral displacements of the barrier. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix G, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 5.6 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. MNNW-2 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-10.







- Test Agency .... MwRSF
- Test Number MNNW-2
- Date 3/9/2018
- MASH 2016 Test Designation No. 3-10
- Test Article .... MN Noise Wall
- Total Length .... 89.0 ft (27.1 m)
- Key Component - Rail
  - Length .... 89 ft (27.1 m)
  - Width .... 13½ in. (343 mm)
  - Depth .... 10¾ in. (273 mm)
- Key Component - Concrete Post
  - Length .... 18 ft (5.5 m)
  - Width .... 18 in. (457 mm)
  - Spacing .... 8 ft (2.4 m)
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make/Model .... 2010 Hyundai Accent
  - Curb .... 2,476 lb (1,123 kg)
  - Test Inertial .... 2,431 lb (1,103 kg)
  - Gross Static .... 2,595 lb (1,177 kg)
- Impact Conditions
  - Speed .... 63.1 mph (101.5 km/h)
  - Angle .... 25.4 deg.
  - Impact Location ... 46 3/16 in. (1,173 mm) US from rail splice between post nos. 6 & 7
- Impact Severity .... 59.7 kip-ft (80.9 kJ) > 51 kip-ft (69.7 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 43.0 mph (70.0 km/h)
  - Angle .... 5.6 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 144 ft – 6 in. (44.0 m) downstream
  56 ft – 5 in. (17.2 m) laterally in front

- Test Article Damage .... Minimal
- Vehicle Damage .... Moderate
  - VDS [12] 01-RFQ-4
  - CDC [13] 01-RYEW-3
  - Maximum Interior Deformation .... 1.9 in. (48 mm)
- Maximum Test Article Deflections
  - Permanent Set ..... ⅛ in. (3 mm) at post no. 7 and midspan between post nos. 5 and 6
  - Dynamic .... 4.5 in. (114 mm) at top of post no. 7
  - Working Width .... 45.2 in. (1,148 mm) at top of post no. 7
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1 (primary)	SLICE-2	
OIV ft/s (m/s)	Longitudinal	-24.30 (-7.41)	-23.73 (-7.23)	±40 (12.2)
	Lateral	-29.79 (-9.08)	-28.42 (-8.66)	±40 (12.2)
ORA g's	Longitudinal	-6.78	-6.20	±20.49
	Lateral	-3.97	-4.55	±20.49
MAX ANGULAR DISP. deg.	Roll	6.0	-3.3	±75
	Pitch	-4.0	-2.9	±75
	Yaw	-37.0	-37.2	not required
THIV – ft/s (m/s)		33.17 (10.11)	32.46 (9.90)	not required
PHD – g's		6.83	6.17	not required
ASI		2.25	2.14	not required

Figure 52. Summary of Test Results and Sequential Photographs, Test No. MNNW-2

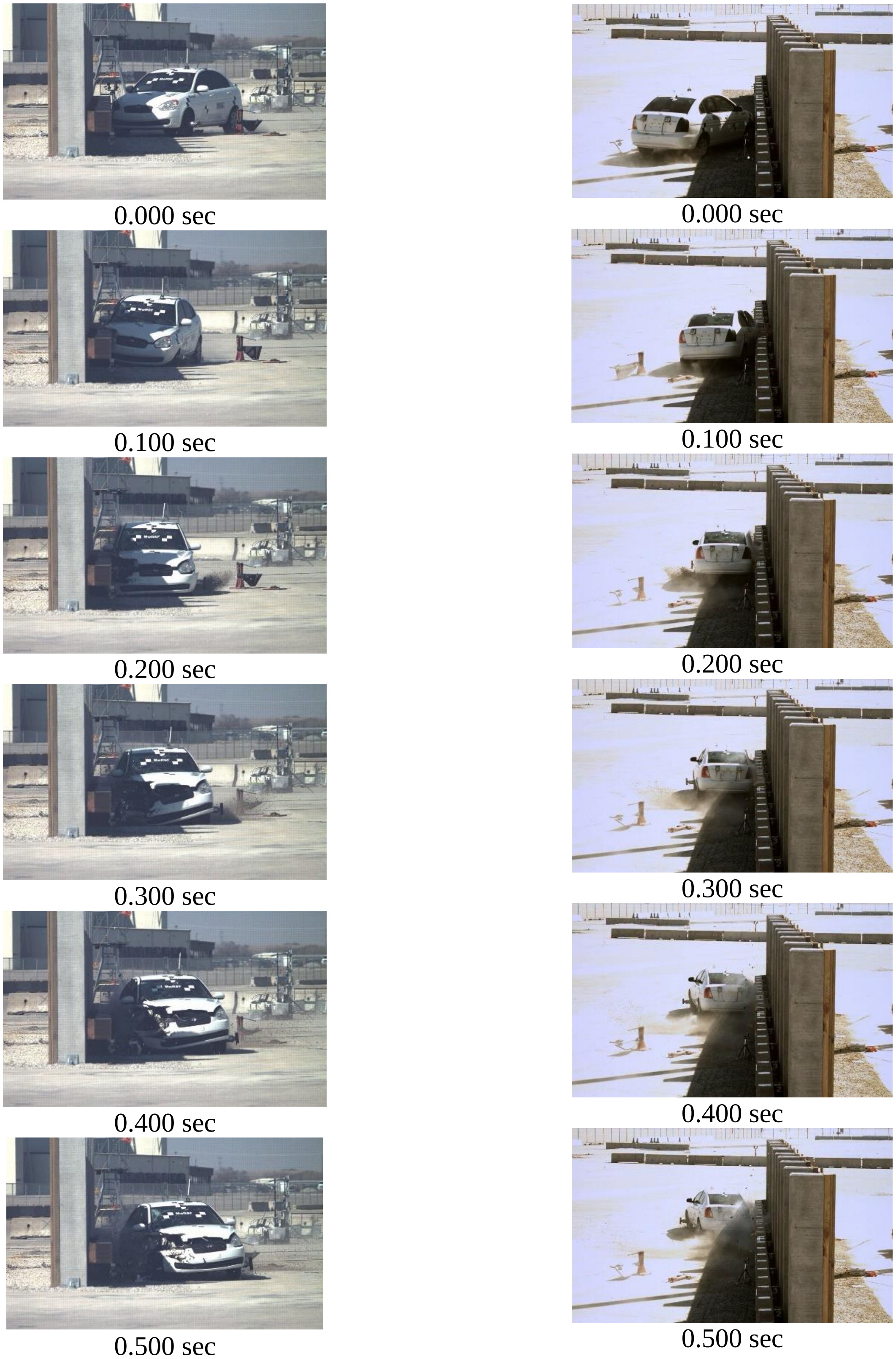


Figure 53. Additional Sequential Photographs, Test No. MNNW-2

Figure 54. Documentary Photographs, Test No. MNNW-2

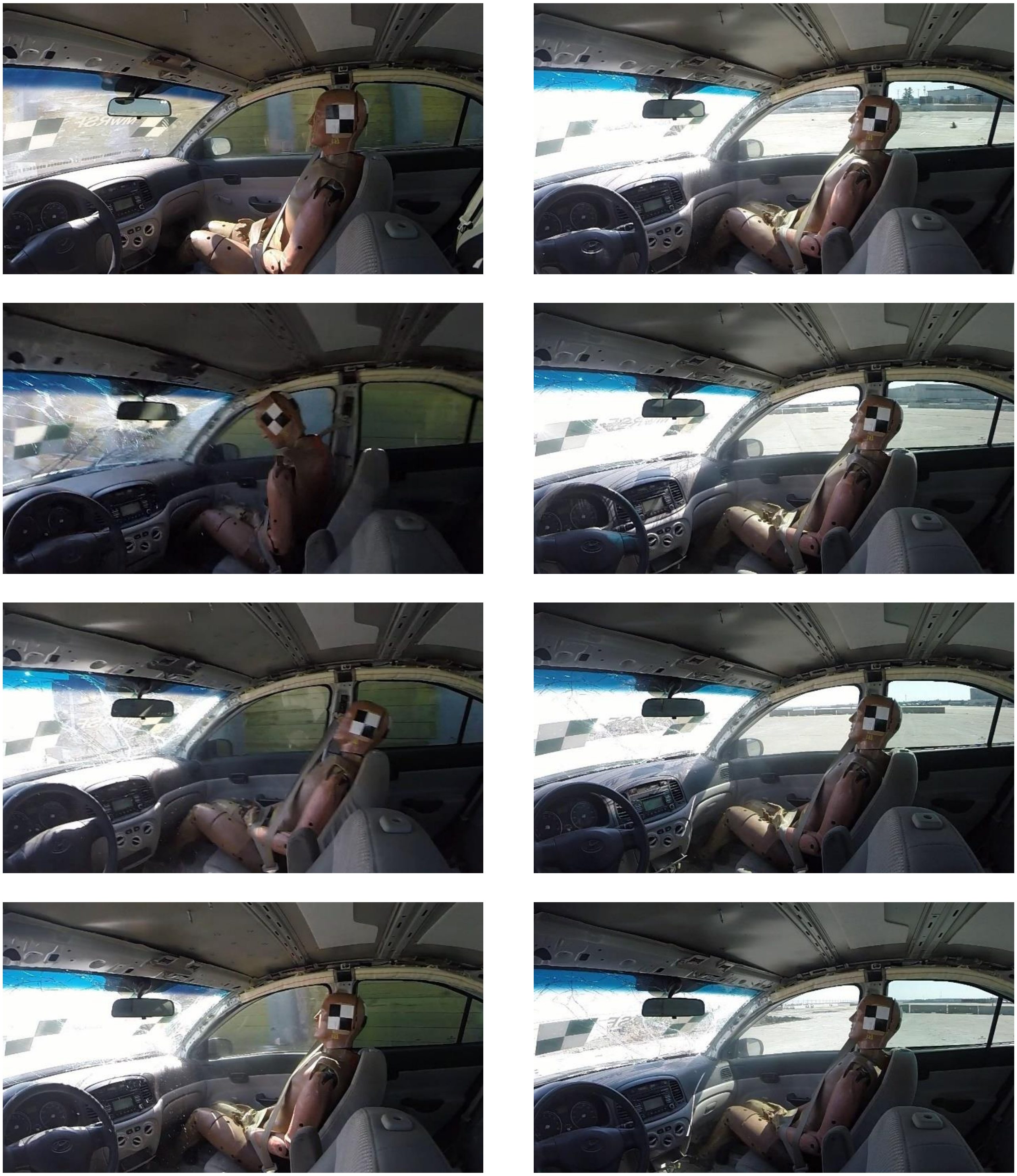


Figure 55. Documentary Photographs, Test No. MNNW-2

Figure 56. Documentary Photographs, Test No. MNNW-2

Figure 57. Documentary Photographs, Test No. MNNW-2

Figure 58. Documentary Photographs, Test No. MNNW-2

Figure 59. Impact Location, Test No. MNNW-2

Figure 60. Vehicle Final Position and Trajectory Marks, Test No. MNNW-2

Figure 61. System Damage, Test No. MNNW-2

Figure 62. System Damage, Test No. MNNW-2

Figure 63. Vehicle Undercarriage and Occupant Compartment Damage, Test No. MNNW-2

Figure 64. Vehicle Damage, Test No. MNNW-2

Figure 65. Vehicle Damage, Test No. MNNW-2

8 DESIGN DETAILS – TEST NO. MNNW-3

The test installation consisted of a wood plank noise wall with concrete posts and a glulam timber rubrail, as shown in Figures 66 through 83 for test no. MNNW-3. The test installation was similar to the system evaluated in test nos. MNNW-1 and MNNW-2. Test no. MNNW-3 had the noise wall installed on the front side of the posts, utilized shorter splice bolts, and utilized hex-head bolts for the post-to-rail connection rather than using round head bolts with washers or dome head bolts. Photographs of the test installation are shown in Figures 84 and 85 for test no. MNNW-3. Material specifications, mill certifications, and certificates of conformity for the system materials are shown in Appendix C.

The test installation for the barrier system was constructed of a wood plank noise wall, which spanned across twelve concrete support posts, and was protected by 89 ft (27.1 m) of glulam timber rail sections, as shown in Figure 66. The total width of the system from the front of the glulam timber rail to the back of the concrete post was 34¾ in. (883 mm). The glulam timber for the rail members was fabricated with Combination No. 2 West Coast Douglas Fir material, as specified in AASHTO's *LRFD Bridge Design Specifications* [4], and it was treated with pentachlorophenol in heavy oil to a minimum net retention of 0.6 lb/ft^3 (9.61 kg/m^3), as specified in AWPA Standard U1 to the requirements of Use Category 4A (UC4A) [11]. The rail members were 13½ in. (343 mm) wide by 10¾ in. (273 mm) deep with a 30-in. (762-mm) top mounting height, as measured from the top of the soil surface to the top of the rubrail. Five H-shaped assemblies were used to splice together the rail ends, thus resulting in the total rail length. The H-shaped, welded splice plates consisted of two ASTM A36 steel plates measuring 13½ in. wide x 29¼ in. long x ⅜ in. thick (343 mm x 743 mm x 10 mm) and one orthogonal ASTM A36 steel plate 13½ in. wide x 10 in. long x ⅜ in. thick (343 mm x 254 mm x 10 mm), as shown in Figure 77. At all rail splice locations, eight 1¼-in. (32-mm) diameter by 12-in. (305-mm) long ASTM A307 Grade A galvanized dome head bolts with a 1¼-in. (32-mm) diameter flat washer and a 1¼-in. (32-mm) diameter hex nut were used to attach to rail sections to the splice plates, as shown in Figures 66, 67, and 77. The rubrail was offset away from the posts by 6 in. (152 mm) with the wood batten, noise wall planks, and wood nailer, as shown in Figures 66, 67, and 78.

A wood plank noise wall system was attached to the front side of the concrete posts. The noise wall planks consisted of 2-in. x 8-in. x 16-ft (51-mm x 203-mm x 4.9-m) tongue and groove wood planks with a minimum bending stress of 1,500 psi (10.3 MPa). The planks were attached to the concrete posts with a 2-in. x 8-in. x 10-ft (51-in. x 203-mm x 3.0-m) wood batten with a minimum bending stress of 1,500 psi (10.3 MPa) and a 3-in. x 10-in. x 10-ft (76-mm x 254-mm x 3.0-m) wood nailer with a minimum bending stress of 1,200 psi (8.3 MPa). To allow for the attachment of the anchor cable, the end two sections of noise wall planks were installed on the back side of the concrete posts.

For the third crash test, the sponsors requested that hex-head bolts be used for the post-to-rail connection in lieu of the specified dome head bolts. Two post-to-rail bolts were attached to the concrete posts with field-installed, threaded inserts. The hex-head bolts were ¾-in. (19-mm) diameter ASTM A307 Grade A by 18 in. (457 mm) long with a ¾-in. (19-mm) washer that had a 2-in. (51-mm) outer diameter. The hex-head bolts and washers were recessed ⅝ in. (16 mm) inward from the front face of the rail so that the bolt head was flush with the front face of the rail.

The entire system was constructed with twelve prestressed concrete posts, as shown in Figures 66, 74, 75, and 77. All twelve posts were concrete sections measuring 12 in. wide x 18 in. deep x 18 ft long (305 mm x 457 mm x 5.5 m), as shown in Figure 75. The concrete posts were spaced 8 ft (2.4 m) on center along the length of the system with a soil embedment depth of 8 ft (2.4 m), as shown in Figure 66. The concrete used for the prestressed concrete posts had a minimum compressive strength of 5,500 psi (37.9 MPa).

The concrete posts utilized in the test installation were configured with the longitudinal prestressing strands in lieu of longitudinal reinforcement bars, as shown in Figure 75. The steel prestressing strands consisted of ½-in. (12.7-mm) diameter, 270 ksi (1,862 MPa) LO-LAX prestress strands extending the length of the post. The loop bars were no. 3 reinforcing bars, 53 in. (1.3 m) long, bent into a rectangular shape, and were spaced 18 in. (457 mm) on center. A minimum concrete cover of 2 in. (51 mm) was used for all the rebar and strands placed within the posts. The reinforcing bars in the post were ASTM A615 Grade 60 epoxy-coated rebar. The post reinforcement details are shown in Figures 75 and 76.

A BCT anchor cable assembly attached the end post to a cable anchor bracket on the back of the rubrail. Each cable anchor bracket was attached to the rail section with eight 1¼-in. (32-mm) diameter by 14-in. (356-mm) long ASTM A307 Grade A galvanized dome head bolts and a 1¼-in. (32-mm) diameter hex nut.

During installation of the test article, a few items were modified to ease construction, including:

(1) The slots in the rubrail were not in the correct location. Thus, some slots in the rail were enlarged to align post-to-rail bolts with the threaded inserts in the concrete posts. At post no. 5, a 2½-in. (64-mm) outer diameter washer was utilized due to an oversized hole in the rail.

(2) The galvanized post-to-rail bolt threads were not compatible with the threads in the zinc-plated, threaded inserts that were installed in the posts. Thus, the galvanization was stripped from the threaded ends of the bolts so that they could be installed.

(3) The ends of the timber rubrails required planning to fit within the H-shaped splice plates.

(4) For testing purposes only, double-headed nails were used instead of part g3 to allow the noise wall sections to remain intact when switching from the back-side noise wall configuration to the front-side noise wall configuration.

After construction of the system, a few modifications were identified that would ease construction of future installations. Although the noise wall and rubrail system can be installed in the as-tested configuration shown in Figures 66 through 83, MwRSF would recommend future installations utilize the modified system details shown in Chapter 12.

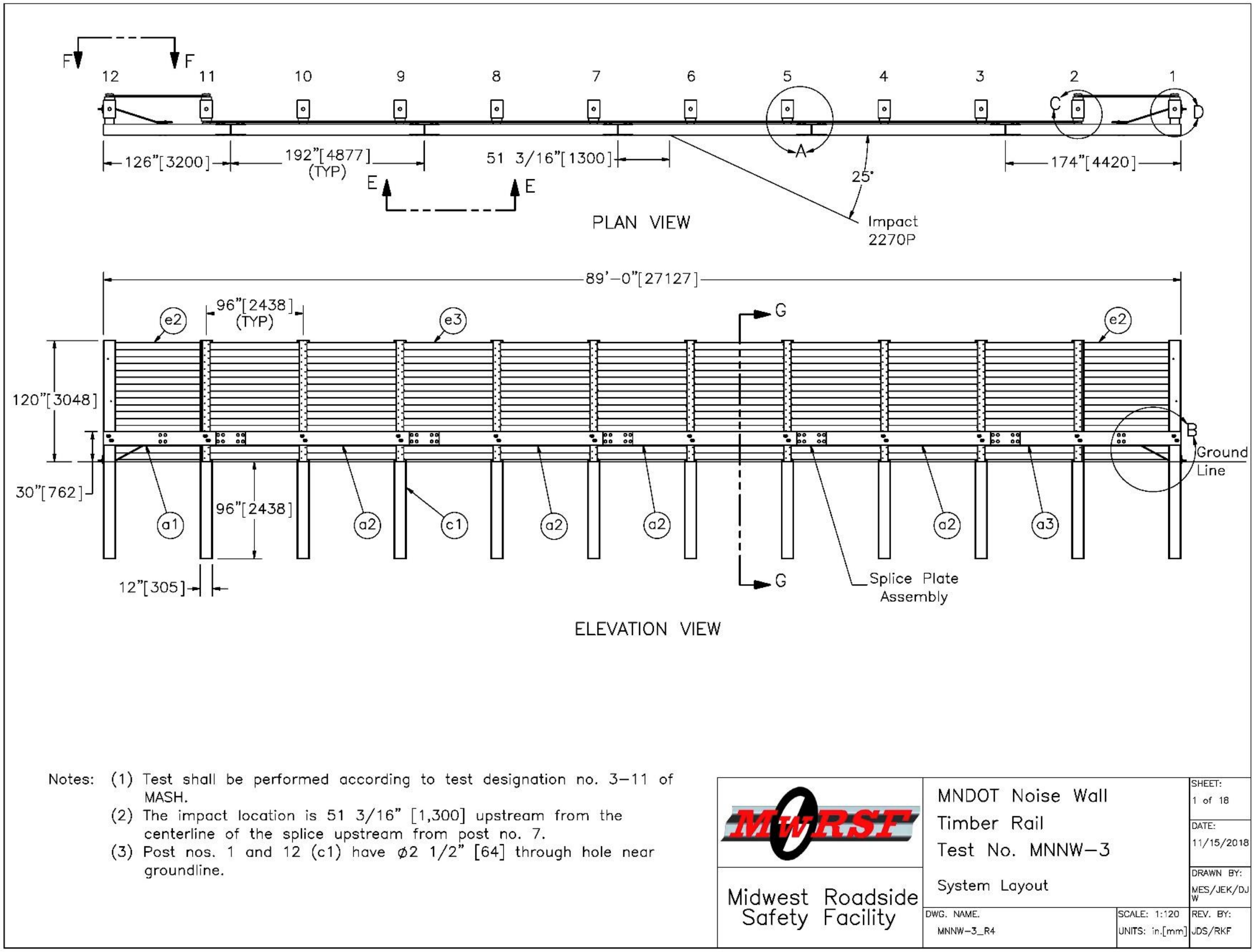


Figure 66. System Layout, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

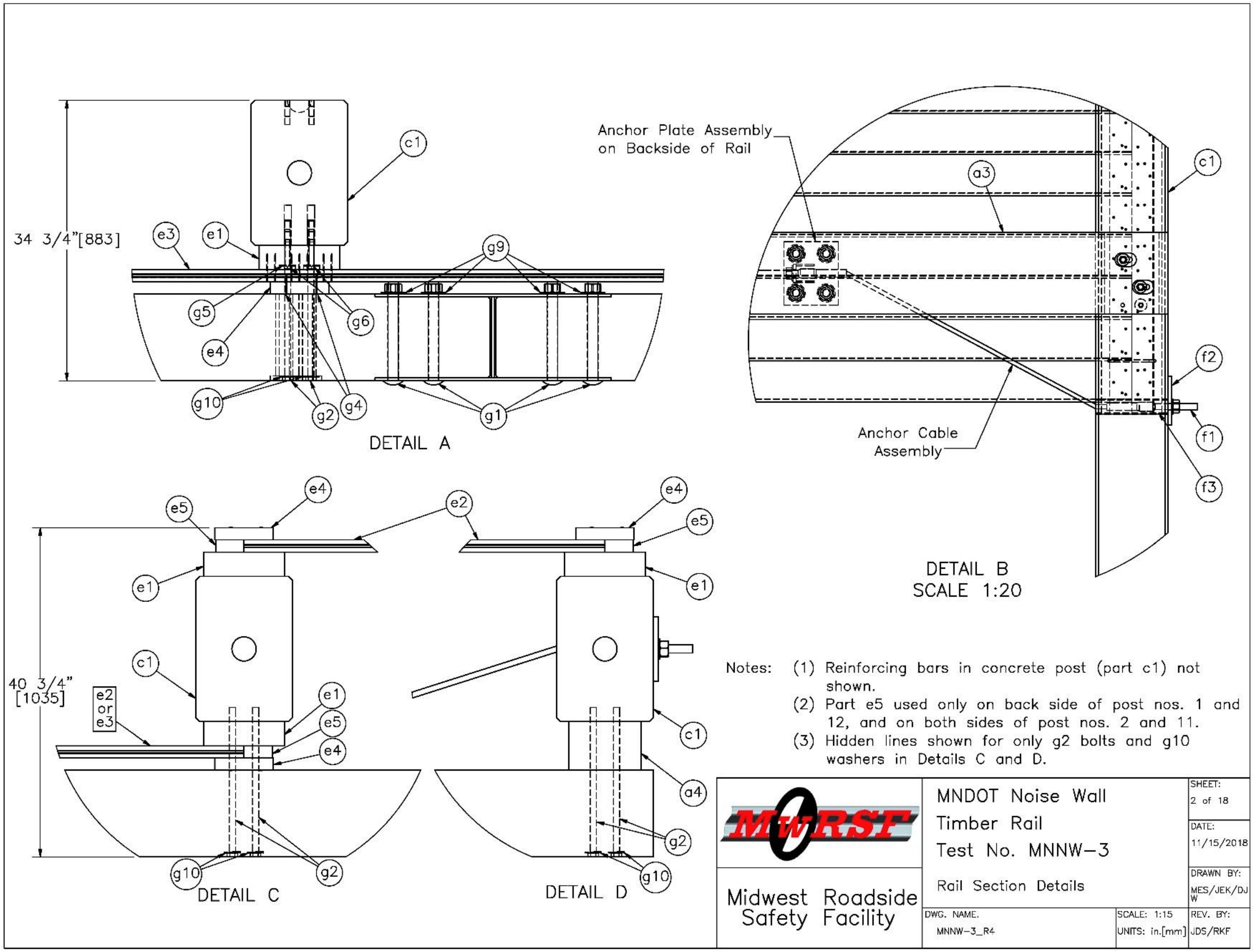


Figure 67. Rail Section Details, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

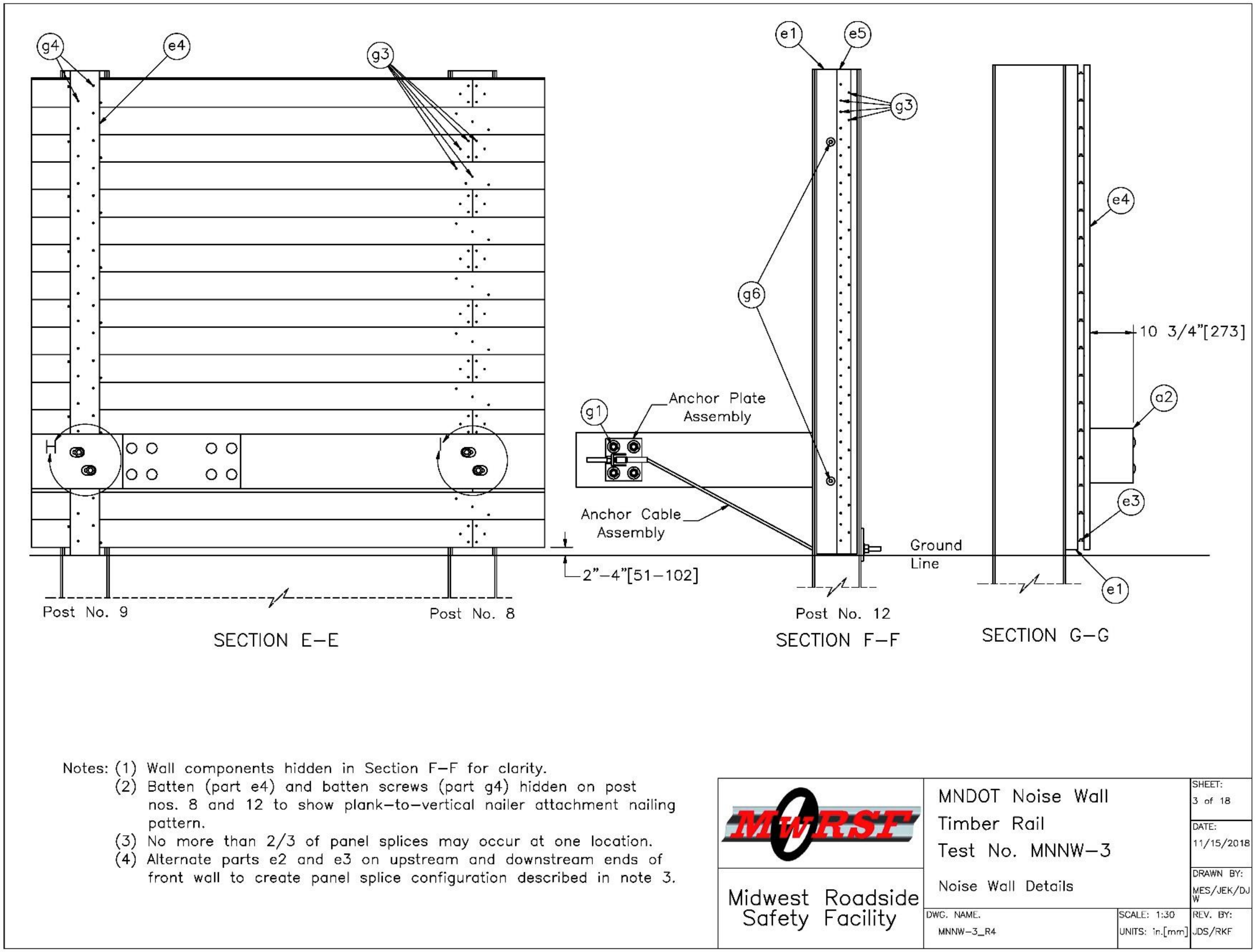


Figure 68. Noise Wall Details, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

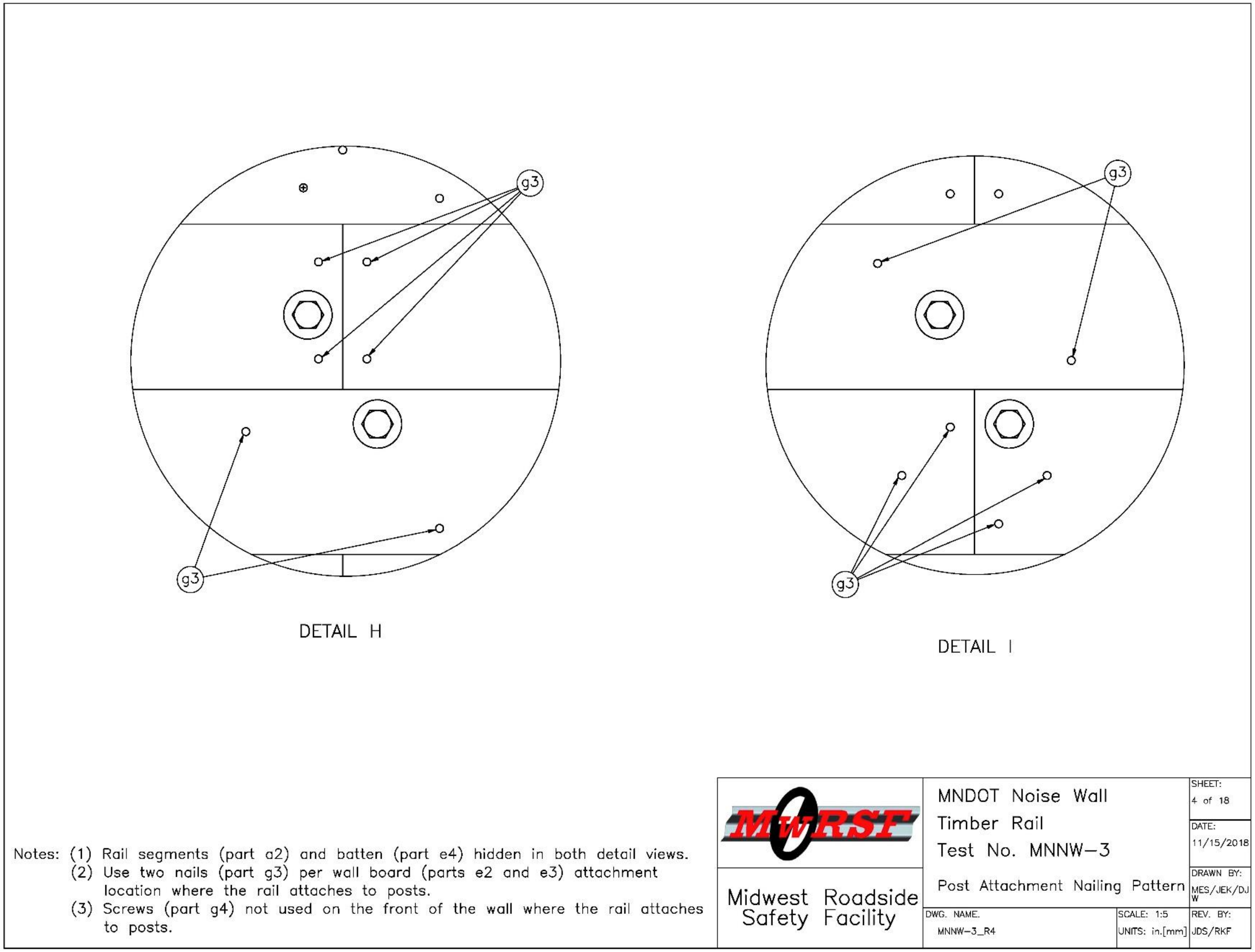


Figure 69. Post Attachment Nailing Pattern, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

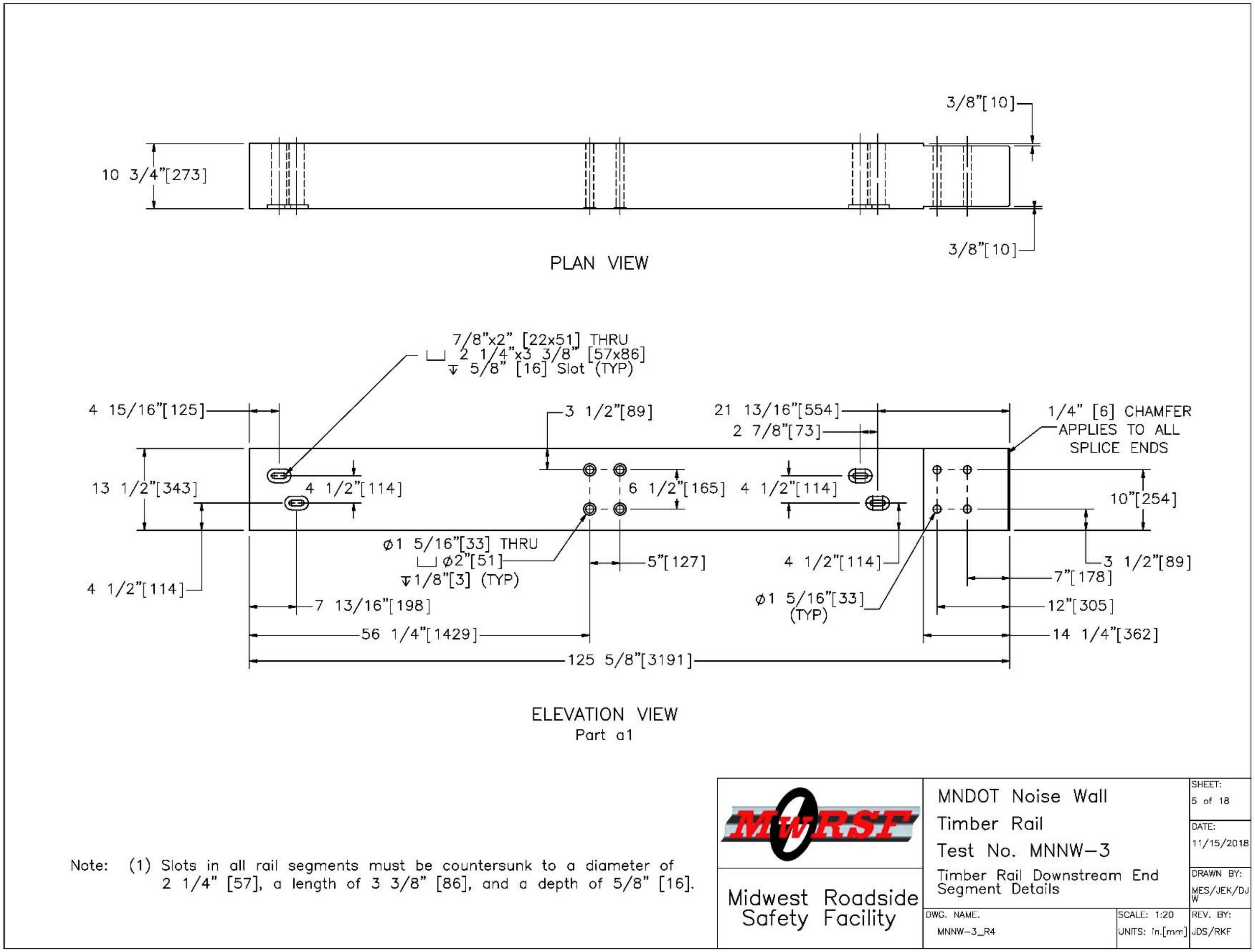


Figure 70. Timber Rail Downstream End Segment Details, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

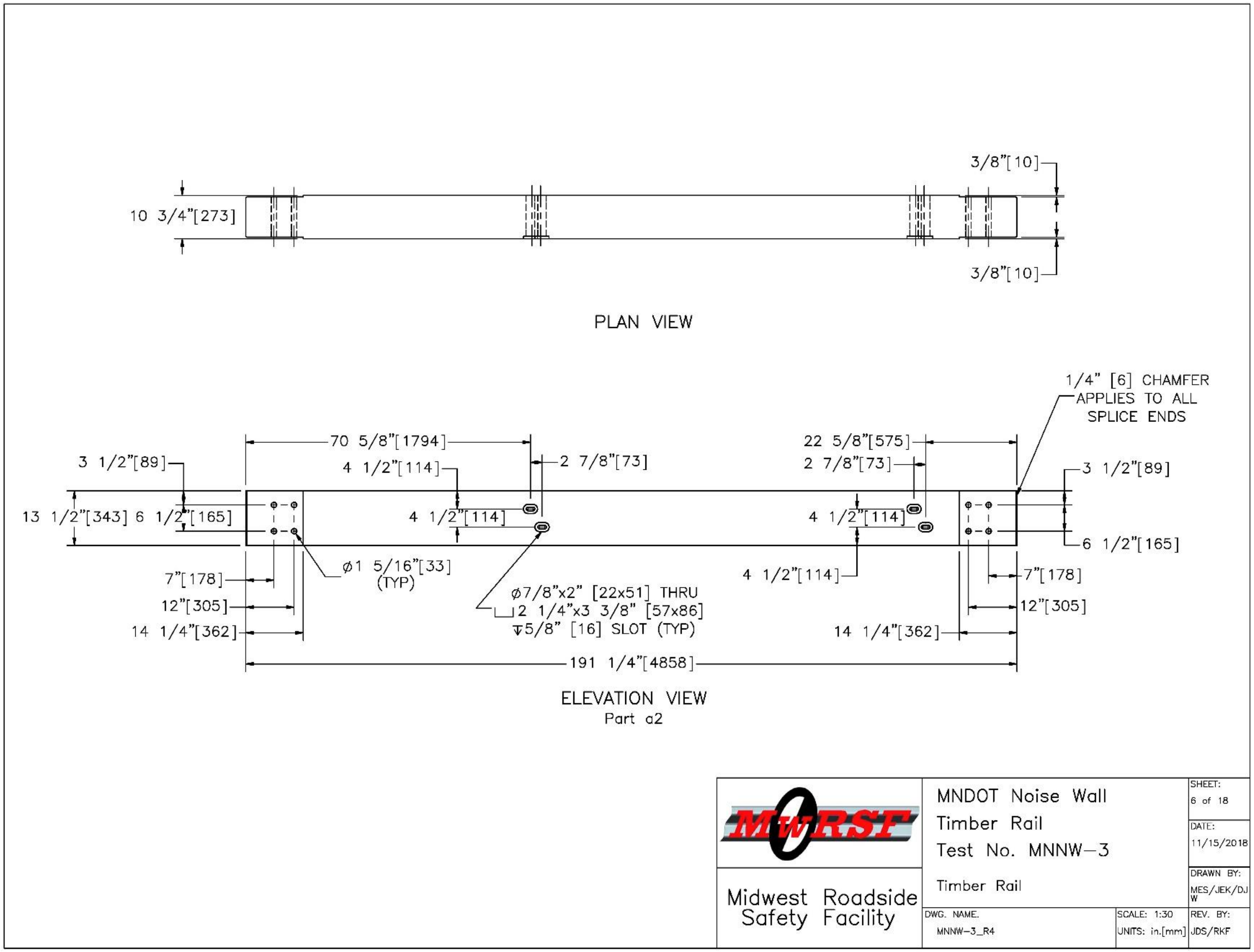


Figure 71. Timber Rail, Test Nos. Test No. MNNW-3 (Recommended updates provided in Chapter 12)

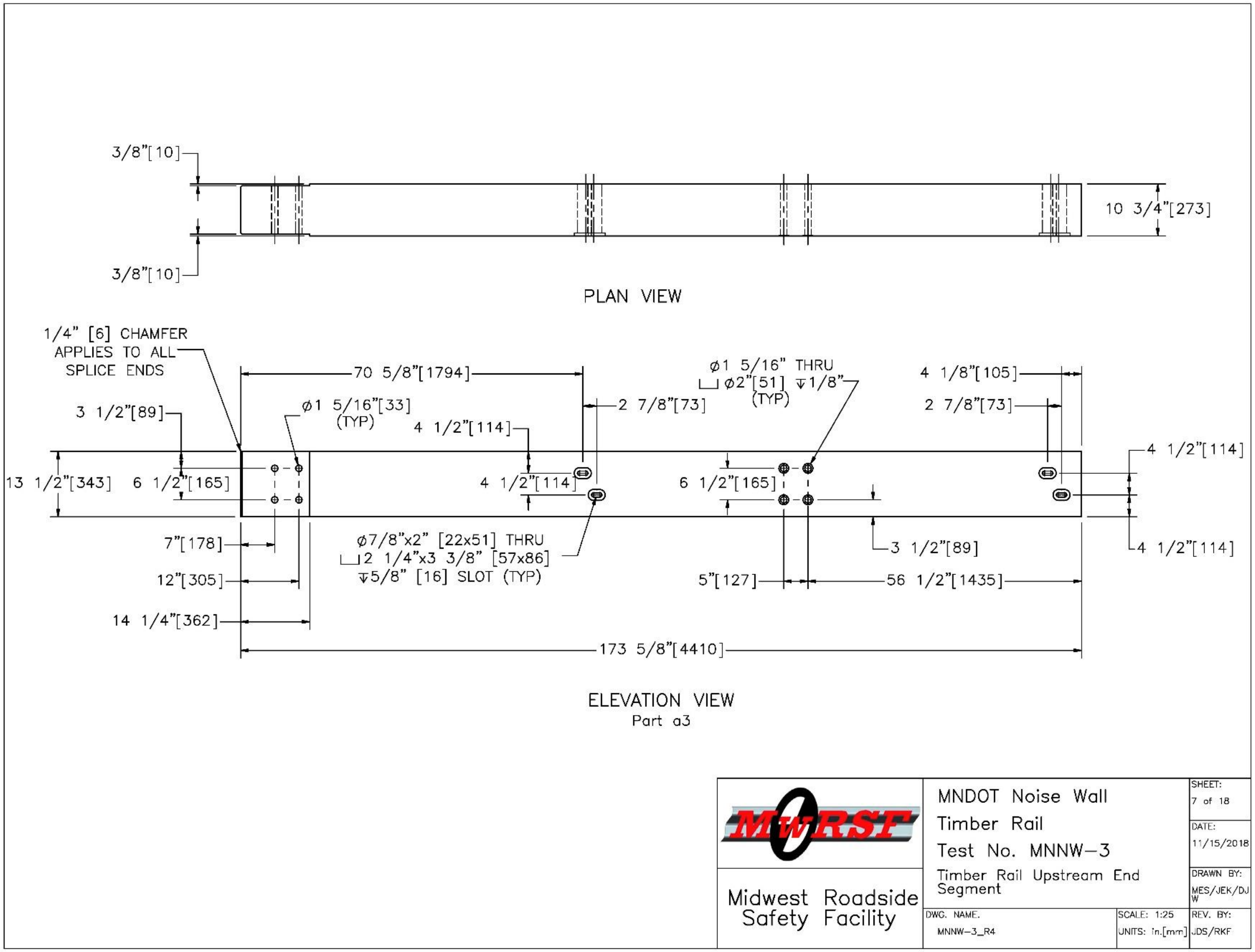


Figure 72. Timber Rail Upstream End Segment, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

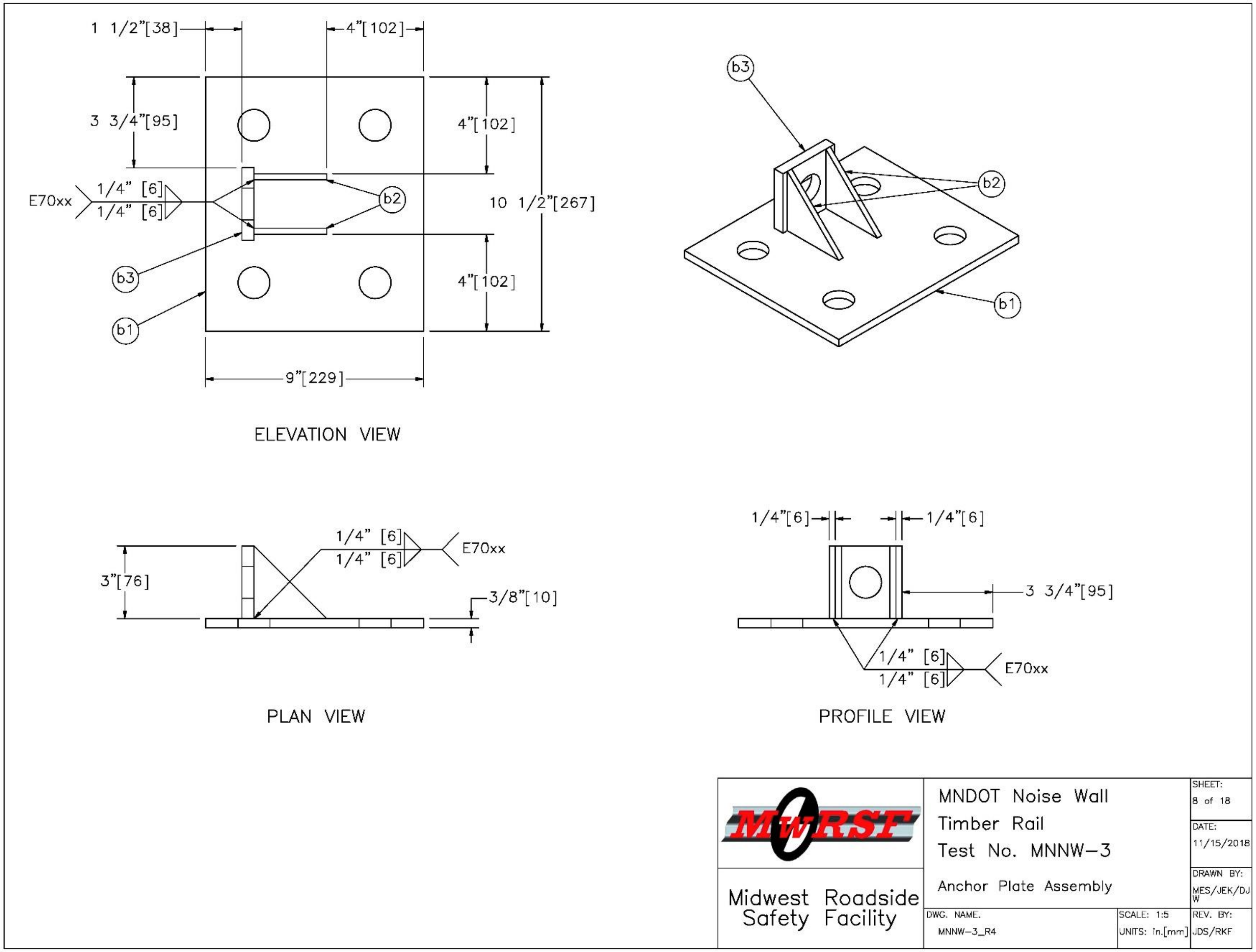


Figure 73. Anchor Plate Assembly, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

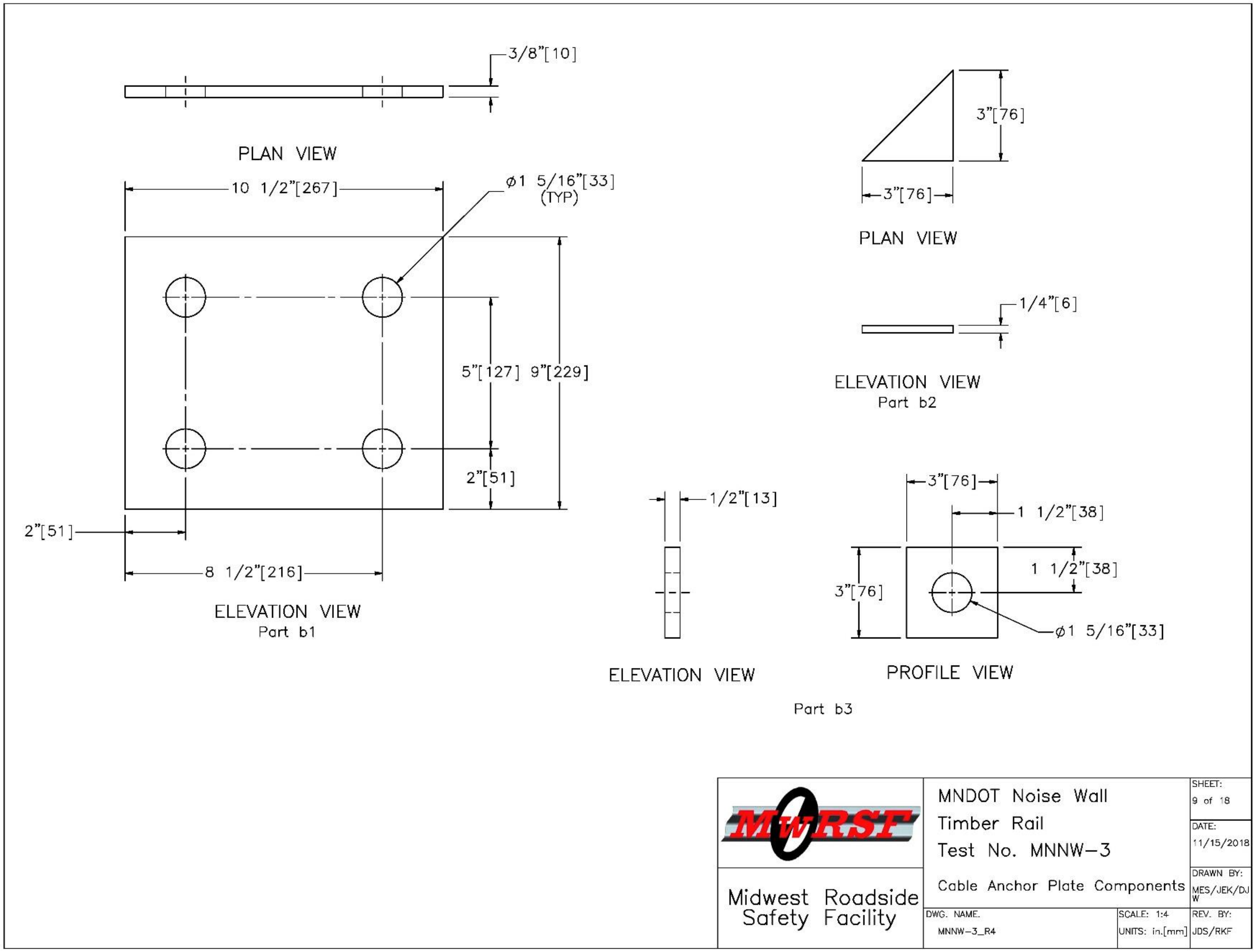


Figure 74. Cable Anchor Plate Components, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

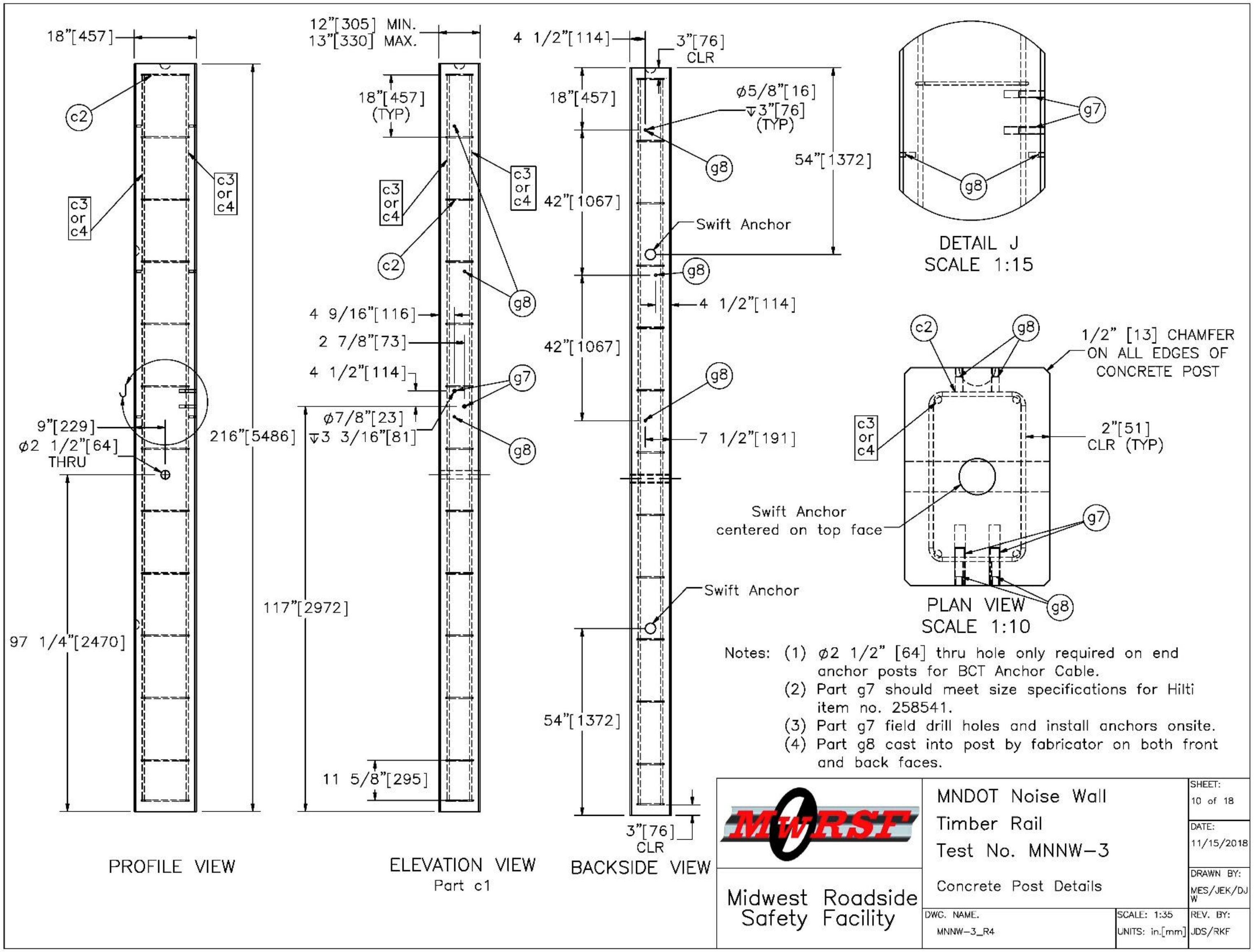
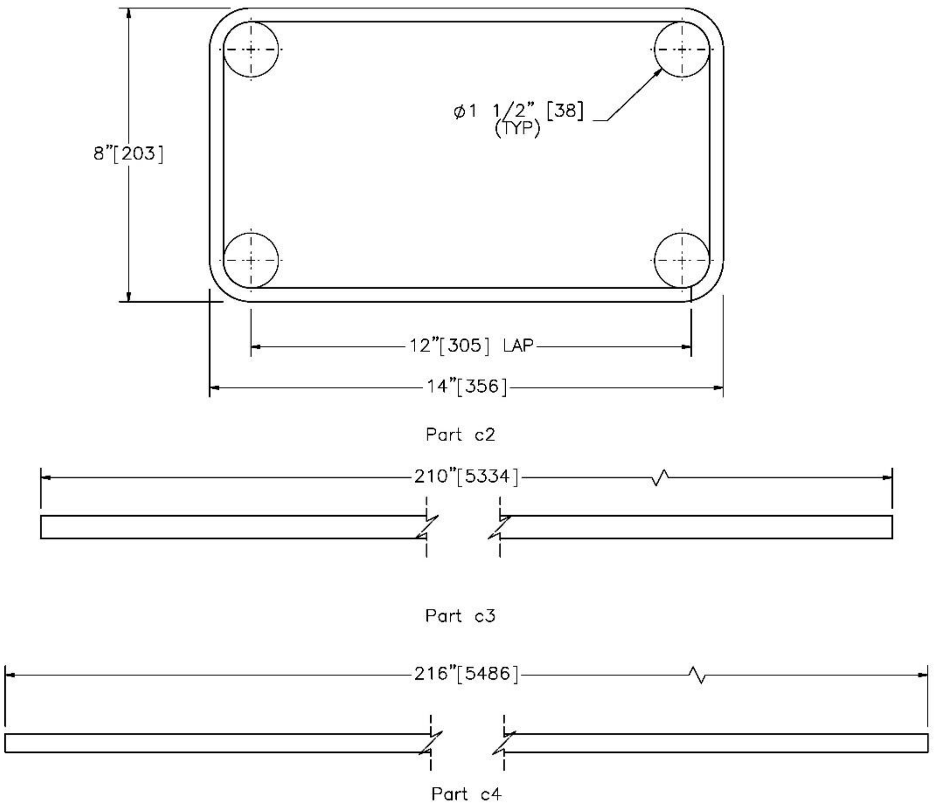


Figure 75. Concrete Post Details, Test No. MNNW-3 (Recommended updates provided in Chapter 12)



BILL OF BARS			
ITEM NO.	QTY. PER POST	BAR SIZE	TOTAL LENGTH
c2	13	#3	53" [1,346]
c3	4	#5	210" [5,334]
c4	4	1/2" [13]	216" [5,486]

Notes: (1) Splices not allowed in part c3.
(2) Prestressed strands (part c4) may be used in lieu of c3 reinforcement bars. ϕ1/2" [13] low-relaxation, 270 ksi [1,862 MPa] ultimate strength Initial prestress = 30,900 lb [137.5 kN] per strand; cut strands flush with concrete.

Midwest Roadside Safety Facility

MNDOT Noise Wall
Timber Rail
Test No. MNNW-3

Concrete Post Reinforcement

SHEET: 11 of 18
DATE: 11/15/2018
DRAWN BY: MES/JEK/DJW
DWG. NAME. MNNW-3_R4
SCALE: 1:4
UNITS: in.[mm]
REV. BY: JDS/RKF

Figure 76. Concrete Post Reinforcement, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

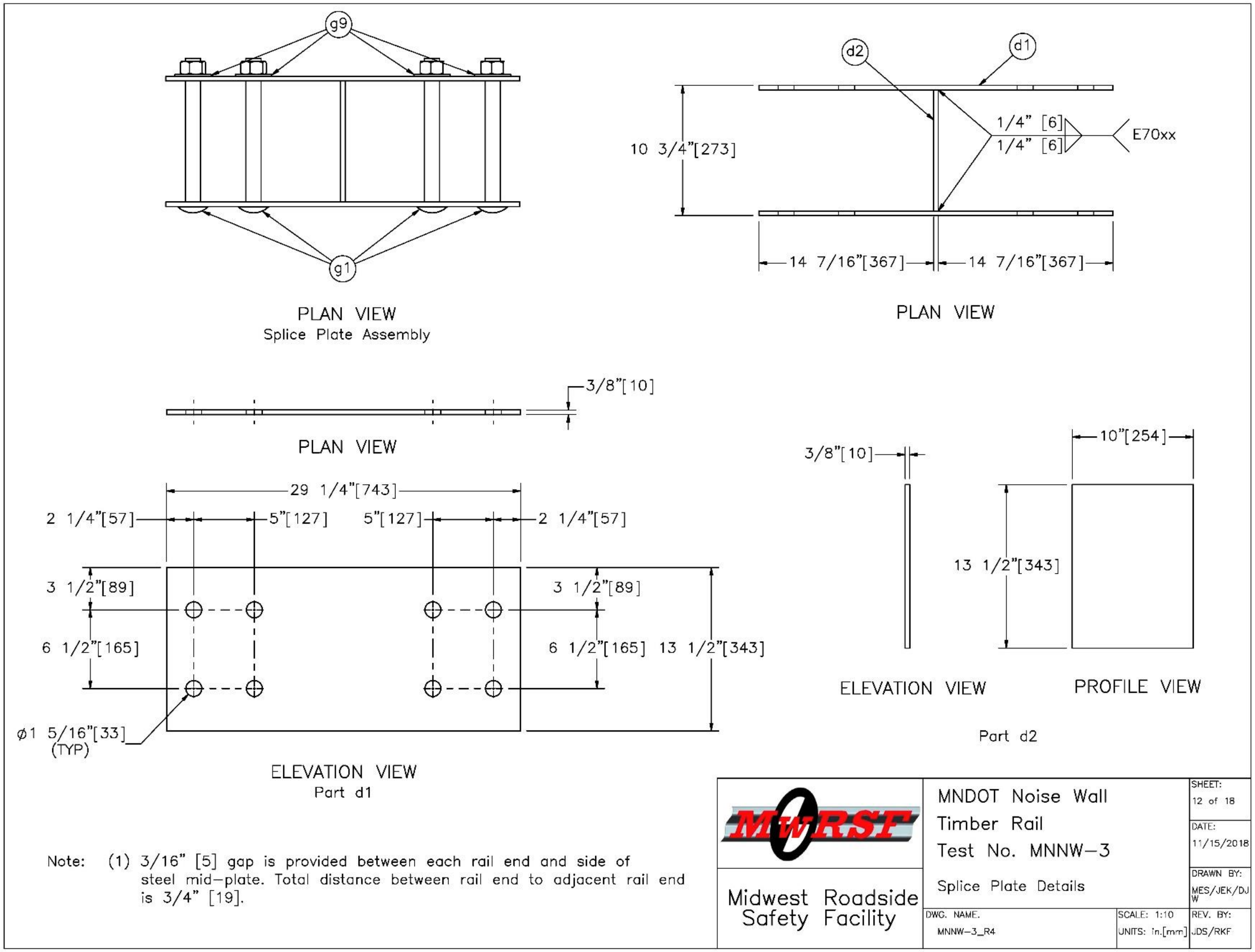


Figure 77. Splice Plate Details, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

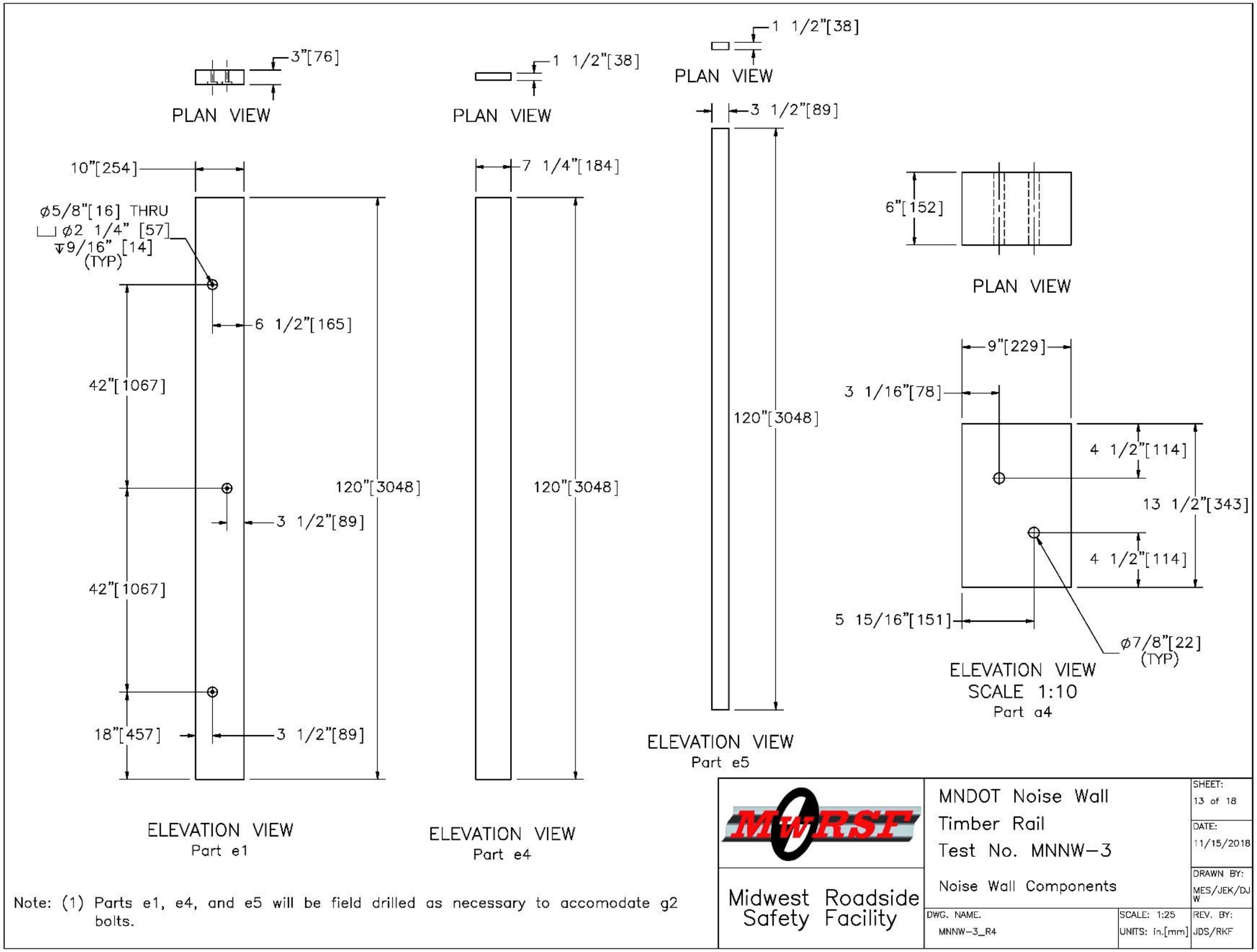


Figure 78. Noise Wall Components, Test Nos. Test No. MNNW-3 (Recommended updates provided in Chapter 12)

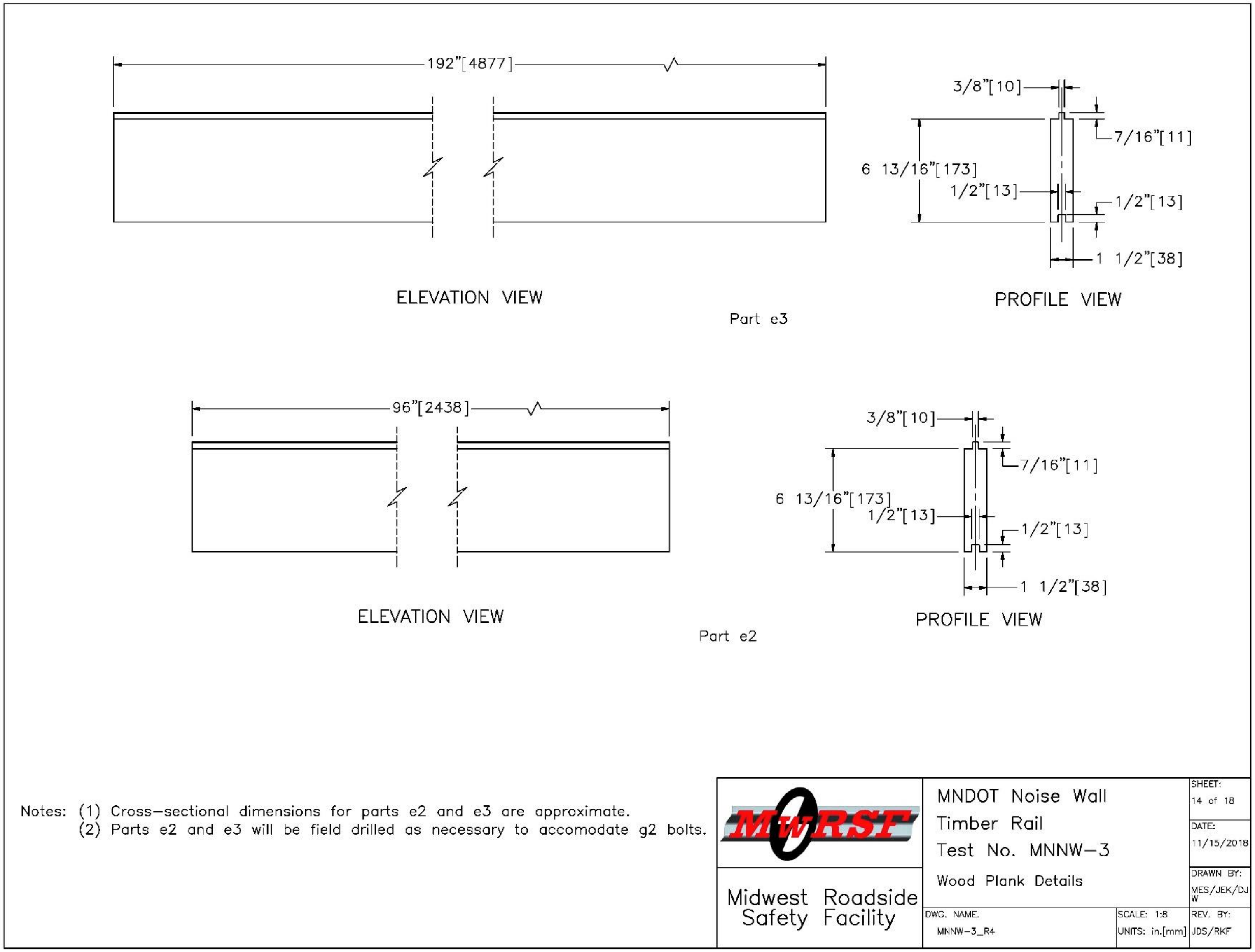


Figure 79. Wood Plank Details, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

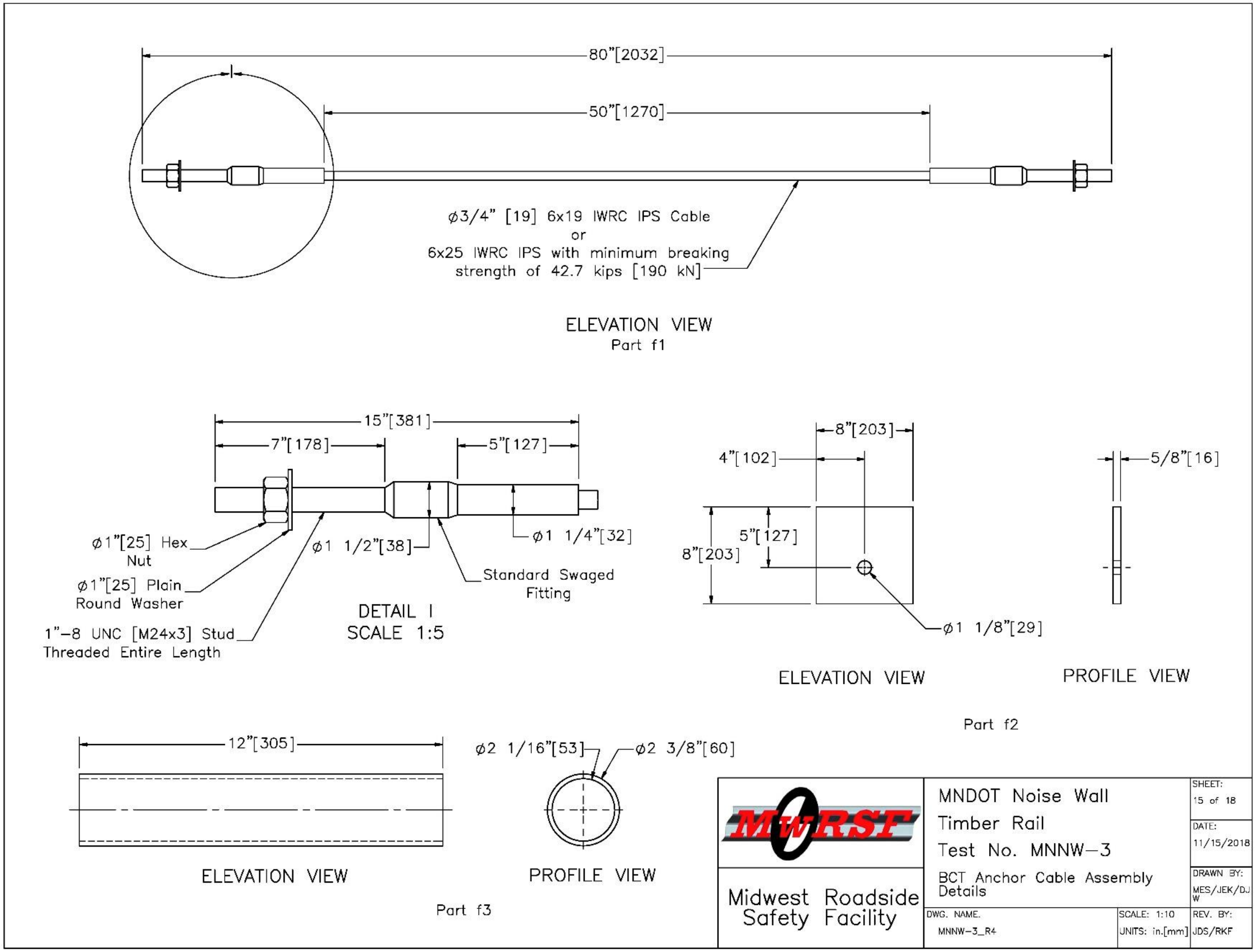


Figure 80. BCT Anchor Cable Assembly Details, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

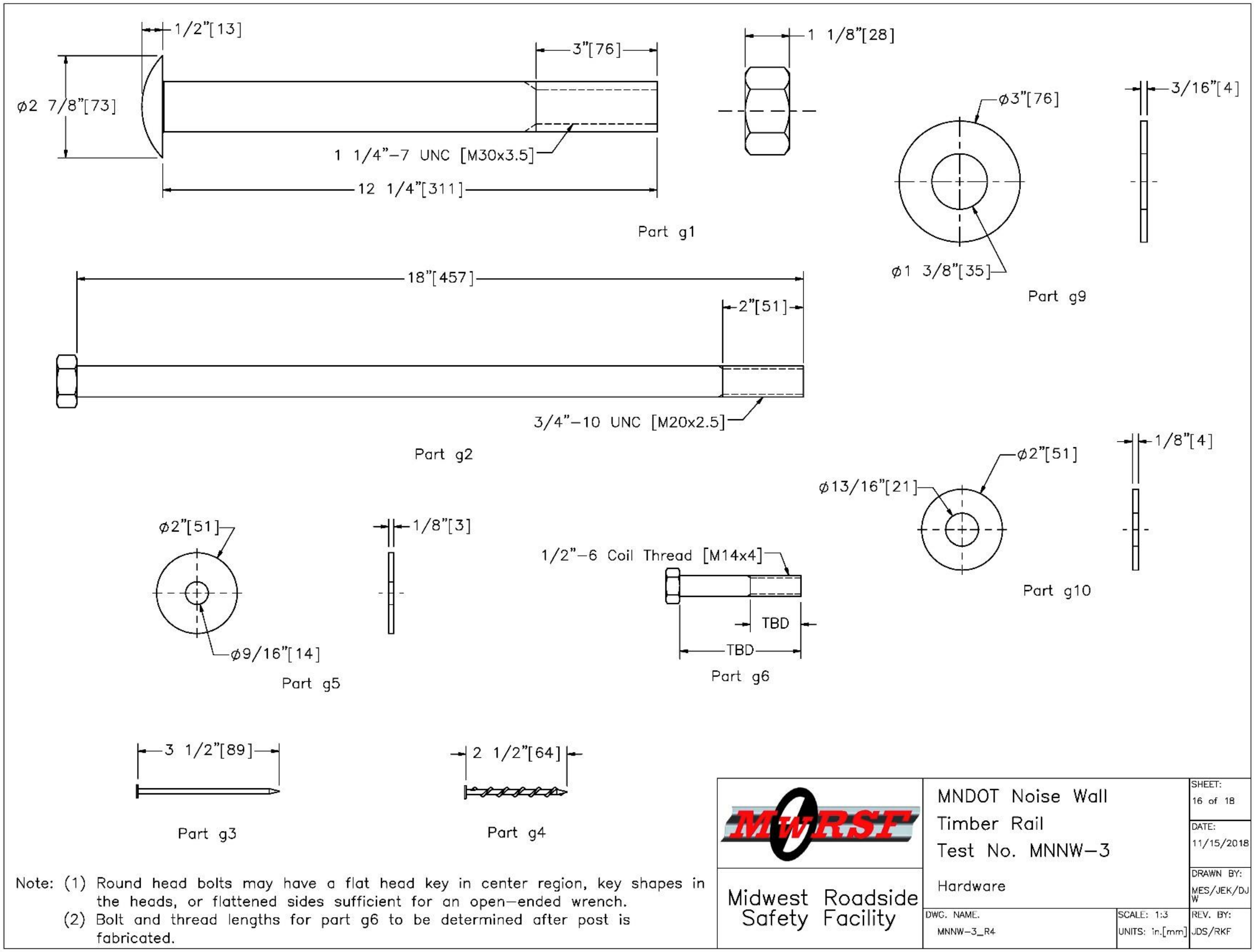


Figure 81. Hardware, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	1	125 5/8"x13 1/2"x10 3/4" [3,191x343x273] Timber Rail End Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a2	4	191 1/4"x13 1/2"x10 3/4" [4,858x343x273] Timber Rail Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a3	1	173 5/8"x13 1/2"x10 3/4" [4,410x343x273] Timber Rail End Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a4	2	13 1/2"x9"x6" [343x229x152] Wood Blockout	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
b1	2	10 1/2"x9"x3/8" [229x267x10] Steel Plate	ASTM A36	ASTM A123**	–
b2	4	3"x3"x1/4" [76x76x6] Steel Gusset	ASTM A36	ASTM A123**	–
b3	2	3"x3"x1/2" [76x76x13] Steel Plate	ASTM A36	ASTM A123**	–
c1	12	12"x18" [305x457], 18' [5,486] Long Concrete Post	Min. f'c = 4,000 ksi [27.6 MPa]	–	–
c2	156	3/8" [10] Dia., 53" [1,346] Long Rebar	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)	–
c3*	48	1/2" [13] Dia., 210" [5,334] Long Rebar	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)	–
c4*	48	1/2" [13] Dia, 7-Wire Pre-Stressing Strand, 216" [5,486] Long	ASTM A416 Gr. 270	–	–
d1	10	29 1/4"x13 1/2"x3/8" [743x343x10] Steel Plate	ASTM A36	ASTM A123**	–
d2	5	13 1/2"x10"x3/8" [343x254x10] Steel Plate	ASTM A36	ASTM A123**	–
e1	14	3"x10" [76x254], 10' [3,048] Long Vertical Wood Nailer	SYP Gr. No. 1 Dense or better standard rough sawn or Douglas Fir-Larch No. 1 or Douglas Fir-Larch (North) Select Structural or Douglas Fir-South Select Structural or equivalent with min F'b = 1,200 psi [8.3 MPa]	See Note 4	–
e2	51	2"x8" [51x203], 8' [2,438] Long Tongue and Groove Wood Plank	SYP Gr. Select Structural Douglas Fir-Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e3	68	2"x8" [51x203], 16' [4,877] Long Tongue and Groove Wood Plank	SYP Gr. Select Structural Douglas Fir-Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e4	14	2"x8" [51x203], 10' [3,048] Long Wood Batten	SYP Gr. Select Structural Douglas Fir-Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e5	6	2"x4" [51x102], 10' [3,048] Long Wood Plank	SYP Gr. Select Structural Douglas Fir-Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–

*Use either part c3 or c4. ** Weld before galvanization.

Notes:
(1) Timber rail sections and blockouts shall be treated with pentachlorophenol (PCP-A) in heavy oil to a minimum net retention of 0.6 lb/ft^3 (9.6 kg/m^3) in accordance with AWPA Standard U1 to the requirements Use Category 4A (UC4A).
(2) Wood shall be cut, drilled, and completely fabricated prior to treatment with preservative. Drain excess chemicals and dry all treated wood at the place of manufacture.
(3) All field cuts, bore holes, and damages shall be treated with material acceptable to the engineer prior to installation.
(4) Provide preservative treated timber products per Spec. 3491.

Midwest Roadside Safety Facility

MNDOT Noise Wall
Timber Rail
Test No. MNNW-3
Bill of Materials

SHEET: 17 of 18
DATE: 11/15/2018
DRAWN BY: MES/JEK/DJW
DWG. NAME. MNNW-3_R4
SCALE: None
UNITS: in.[mm]
REV. BY: JDS/RKF

Figure 82. Bill of Materials, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
f1	2	BCT Anchor Cable	–	–	FCA01
f2	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
f3	2	2 3/8" [60] O.D. x 12" [305] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	–
g1	48	1 1/4"–7 UNC [M30x3.5], 12 1/4" [311] Long Round Head Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB09a
g2	24	3/4"–10 UNC [M20x2.5], 18" [457] Long Hex Head Bolt	ASTM A307 Gr. A or Equivalent	ASTM A153 or B695 Class 55 or F2329	FBX20a
g3	1192	16D Ring Shank Nail	–	–	–
g4	436	No. 8 x 2 1/2" [64] Long Bugle Head Exterior Screw	–	ASTM A153 or B695 Class 55	–
g5	42	1/2" [13] Dia. Round Plate Washer	ASTM F844	ASTM A123 or A153 or F2329	–
g6	42	1/2"–6 Coil Thread [M14x4], 3" [76] Long Hex Head Bolt	ASTM A307 Gr. A or Equivalent	ASTM A153 or B695 Class 55 or F2329	–
g7	24	3/4"–10 UNC [M20x2.5] Drop–In Concrete Anchor	Hilti Item No. 258541	Zinc–Plated	–
g8	72	1/2"–6 Coil Thread [M14x4] Concrete Anchor	As Supplied	Galvanize per spec. 3392 or electroplate per ASTM B633 SC4 Type II	–
g9	48	1 1/4" [32] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC30a
g10	24	3/4" [19] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC20a

Midwest Roadside Safety Facility

MNDOT Noise Wall
Timber Rail
Test No. MNNW–3

Bill of Materials

SHEET:	18 of 18
DATE:	11/15/2018
DRAWN BY:	MES/JEK/DJW
DWG. NAME.	MNNW–3_R4
SCALE:	None
UNITS:	in.[mm]
REV. BY:	JDS/RKF

Figure 83. Bill of Materials, Test No. MNNW-3 (Recommended updates provided in Chapter 12)

Figure 84. Test Installation Photographs, Test No. MNNW-3

Figure 85. Test Installation Photographs, Test No. MNNW-3

9 FULL-SCALE CRASH TEST NO. MNNW-3

9.1 Static Soil Test

A static soil test was conducted before test no. MNNW-1, which demonstrated a soil resistance above the baseline test limits. Since the system was not deemed to have significant soil dependence, as discussed previously, due to large posts, heavy mass, and deep post embedment depth, a static soil test was not conducted before test no. MNNW-3. Additionally, it was noted that a very shallow frostline existed. Since the system was not believed to have soil dependence and had deflected less than 1 in. (25 mm) at the ground line in both test nos. MNNW-1 and MNNW-2, it was determined that the shallow frost would not affect the performance of the system.

9.2 Weather Conditions

Test no. MNNW-3 was conducted on April 4, 2018 at approximately 2:45 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 11.

Table 11. Weather Conditions, Test No. MNNW-3

Temperature	43° F
Humidity	38%
Wind Speed	13 mph
Wind Direction	170° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.08 in.
Previous 7-Day Precipitation	0.14 in.

9.3 Test Description

The noise wall system was thought to behave similarly to a rigid barrier since minimal deflection was expected near the ground line. Table 2.7 of MASH 2016 recommends an impact point approximately 4.3 ft (1.3 m) upstream from a post or splice for rigid barriers. In test no. MNNW-1, the impact point was selected to be the same as used in test no. MNTR-1 to maximize vehicle snag on a post [1], which was 12 in. (305 mm) upstream from post no. 6, or 9 ft (2.7 m) upstream from post no. 7. After video analysis of test no. MNNW-1, the maximum vehicle extent over the rail was very near the same time that the vehicle reached post no. 7. Thus, the critical impact point for test no. MNNW-3 was believed to be in the range of a minimum of 4.3 ft (1.3 m) upstream from post no. 7 and a maximum of 9 ft (2.7 m) upstream from post no. 7. Since the pickup truck in test no. MNNW-3 would not be able to reach the concrete posts with the noise wall installed on the front side of the posts, the maximum vehicle extent would occur over a shorter longitudinal length than observed in test no. MNNW-1. Thus, the critical impact point was selected near the center of the range and also 4.3 ft (1.3 m) upstream from the rail splice between post nos. 6 and 7, or 6.3 ft (1.9 m) upstream from the centerline of post no. 6. Initial vehicle impact was to occur 51$^{3}/_{16}$ in. (1,300 mm) upstream from the center of the rail splice between post nos. 6 and 7, as shown in Figure 93, which was selected to maximize vehicle snag on the batten and splice.

The 5,028-lb (2,281-kg) crew cab pickup truck impacted the noise wall system at a speed of 61.2 mph (98.5 km/h) and at an angle of 25.9 degrees. The actual point of impact was about 1$^{13}/_{16}$ in. (46 mm) downstream from the target impact point. A sequential description of the impact events is contained in Table 12. A summary of the test results and sequential photographs are shown in Figure 86. Additional sequential photographs are shown in Figure 87. Documentary photographs of the crash test are shown in Figure 88. The vehicle came to rest 74 ft – 7 in. (22.7 m) downstream and 56 ft – 11 in. (17.3 m) laterally behind the barrier after brakes were applied. The vehicle trajectory and final position are shown in Figures 86 and 94.

Table 12. Sequential Description of Impact Events, Test No. MNNW-3

TIME (sec)	EVENT
0.000	Vehicle's front bumper contacted rail between post nos. 6 and 7.
0.004	Vehicle's front bumper deformed, and vehicle's right headlight contacted rail.
0.010	Vehicle's right-front tire contacted rail.
0.022	Vehicle's grille deformed.
0.026	Vehicle's right-front wheel rim deformed.
0.028	Post no. 6 deflected backward.
0.032	Post no. 7 deflected backward.
0.034	Vehicle's right-front door deformed.
0.038	Post no. 8 deflected backward.
0.044	Vehicle's hood contacted wall and deformed.
0.050	Vehicle's grille contacted wall.
0.060	Vehicle yawed away from system and pitched downward.
0.064	Vehicle rolled toward system.
0.068	Vehicle's right-side mirror contacted wall and deformed.
0.072	Vehicle's grille became disengaged.
0.078	Vehicle's hood contacted post batten no. 7.
0.088	Vehicle's right-front door contacted wall.
0.104	Vehicle's left headlight became disengaged.
0.124	Post no. 6 deflected forward.
0.126	Post no. 7 deflected forward.
0.140	Vehicle's left-rear tire became airborne.
0.142	Vehicle's right-rear door contacted rail.

0.156	Post no. 8 deflected forward.
0.232	Vehicle's right quarter panel contacted rail.
0.290	Vehicle was parallel to system at a speed of 35.0 mph (56.3 km/h).
0.304	Vehicle's right-rear tire contacted rail.
0.402	Vehicle's front bumper contacted ground.
0.450	Vehicle rolled away from system.
0.454	Vehicle's right-rear tire became airborne and exited system at a speed of 30.8 mph (49.5 km/h) and an angle of 8.4 degrees.
0.556	Vehicle yawed toward system.
0.596	Vehicle pitched upward.
0.798	Vehicle's right-rear tire regained contact with ground.
0.830	Vehicle rolled toward system.
0.832	Vehicle's left-rear tire regained contact with ground.
0.970	Vehicle pitched downward.
1.090	Vehicle's left-rear tire became airborne.
1.264	Vehicle pitched upward.
1.508	Vehicle's left-rear tire regained contact with ground.

9.4 Barrier Damage

Damage to the barrier was minimal, as shown in Figures 96 and 95. Barrier damage consisted of contact marks on the front face of the rail, splintering of the timber rail, and bolt displacement. The length of vehicle contact along the barrier was approximately 12 ft – 4½ in. (3.8 m), which spanned 14¾ in. (375 mm) downstream from the centerline of post no. 6 to 28¾ in. (730 mm) upstream from the centerline of post no. 8.

Contact marks were also visible on the front face of the noise wall and the wooden battens. Contact marks on the wall measured 30 in. (762 mm), 42 in. (1,067 mm), and 45 in. (1,143 mm) in length, respectively. The 30-in. (762-mm) mark began 20 in. (508 mm) above the top face of the rail and 16 in. (406 mm) upstream from the centerline between post nos. 6 and 7. The 42-in. (1,067-mm) mark began 8 in. (203 mm) above the top face of the rail and 22½ in. (572 mm) upstream from the centerline between post nos. 6 and 7. The 45-in. (1,143-mm) long mark began 2½ in. (64 mm) below the bottom face of the rail and 39 in. (991 mm) upstream from the centerline between post nos. 6 and 7. An 8-in. (203-mm) contact mark was also found on the wooden batten at post no. 7, about 21½ in. (546 mm) above the top face of the rail. The wood batten at post no. 7 also fractured approximately 18 in. (457 mm) from the bottom. The top and bottom post-to-rail bolts of post no. 7 were torn out of their respective holes and bent 2 in. (51 mm) downstream, and the rail splice between post nos. 6 and 7 was bent ¼ in. (6 mm) outward at its top upstream corner.

Splintering was common along the timber rail. The longest splinter damage on the rail began 8 in. (203 mm) downstream from the centerline between post nos. 6 and 7 and measured

103 in. (2,616 mm) in length. Two long splinters and a large gouge in the rail were found about 16 in. (406 mm) downstream from post no. 6 on the bottom front corner of the rail. The splinters were 26 in. (660 mm) long and 30½ in. (775 mm) long, and the gouge was 6 in. (152 mm) long and 2 in. (51 mm) deep. On the bottom front corner of the rail, a 63-in. (1,600-mm) splinter was located 16 in. (406 mm) downstream from the centerline between post nos. 6 and 7. A 60½-in. (1,537-mm) long splinter began 12½ in. (318 mm) downstream from post no. 6 and ran along the top front corner of the rail. Splintering also occurred on the top face of the rail. Three splinters measuring 74 in. (1,880 mm), 41 in. (1,041 mm), and 9 in. (229 mm) in length were found 74 in. (1,880 mm), 28 in. (711 mm), and 17½ in. (445 mm) downstream from the rail splice between post nos. 6 and 7, respectively. An 8-in. (203-mm) splinter was also found on the wood batten at post no. 7, about 39 in. (991 mm) from the bottom of the board.

The maximum lateral permanent set of the barrier system was ⅜ in. (10 mm), which occurred both at the rail height of post no. 7 and at the midspan of the rail between post nos. 6 and 7, as measured in the field. The maximum lateral permanent set of the top of the posts was approximately 0.5 in. (13 mm), which occurred at the top of post no. 7, as determined from high-speed digital video analysis. The maximum lateral dynamic post and rail deflection was 7.0 in. (178 mm) at the top of post no. 7 and 1.3 in. (32.3 mm) at the midspan of the rail between post nos. 6 and 7, respectively, as determined from high-speed digital video analysis. The working width of the system was found to be 41.75 in. (1,060 mm) at the top of post no. 7, also determined from high-speed digital video analysis.

9.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 98 and 99. The maximum occupant compartment intrusion values are listed in Table 13 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. MASH 2016 defines intrusion or deformation as the occupant compartment being deformed and reduced in size with no observed penetration. There were no penetrations into the occupant compartment and none of the established MASH 2016 deformation limits were violated. The entire A-pillar (lateral) and side door above the seat deformed outward, which is not considered crush toward the occupant, is denoted as negative numbers in Table 13, and is not evaluated by MASH 2016 criteria. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix E.

The majority of damage was concentrated on the right-front corner and right side of the vehicle where the impact occurred. The grille and the right-front quarter panel were disengaged from the vehicle. The front bumper was crushed inward and back on the right side and bent outward in the middle. The crush on the right side of the bumper covered an area of 73 in. x 17 in. (1,854 mm x 432 mm) and penetrated to a depth of 20 in. (508 mm). A 35-in. x 14-in. (889-mm x 356-mm) section on the right side of the hood was crushed inward toward the center of the vehicle. The entire length of the right-front door was torn and crushed inward. The sheet metal tear on the right-front door was 2 in. (51 mm) wide, and the crush on the right-front door was 29 in. (737 mm). The force of impact caused the top frame of the right-front door to extend outward away from the vehicle. The right-rear door was also left ajar, but to a lesser extent. The right side of the windshield was cracked. The right-front windows shattered due to contact with the dummy's head.

Table 13. Maximum Occupant Compartment Intrusion by Location, Test No. MNNW-3

Location	MAXIMUM INTRUSION in. (mm)	MASH 2016 ALLOWABLE INTRUSION in. (mm)
Wheel Well & Toe Pan	1.9 (48)	≤ 9 (229)
Floor Pan & Transmission Tunnel	1.2 (30)	≤ 12 (305)
A-Pillar	0.6 (15)	≤ 5 (127)
A-Pillar (Lateral)	-0.8 (-20)	N/A
B-Pillar	0.1 (3)	≤ 5 (127)
B-Pillar (Lateral)	0.1 (3)	≤ 3 (76)
Side Front Panel (in Front of A-Pillar)	5.5 (140)	≤ 12 (305)
Side Door (Above Seat)	-4.0 (-102)	N/A
Side Door (Below Seat)	1.6 (41)	≤ 12 (305)
Roof	0.3 (8)	≤ 4 (102)
Windshield	0 (0)	≤ 3 (76)
Side Window	Shattered due to contact with dummy's head	No shattering resulting from contact with structural member of test article
Dash	0.4 (10)	N/A

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

9.6 Occupant Risk

The calculated occupant impact velocities (OIVs) and maximum 0.010-sec average occupant ridedown accelerations (ORAs) in both the longitudinal and lateral directions are shown in Table 14. 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 14. The results of the occupant risk analysis, as determined from the accelerometer data, are summarized in Figure 86. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix H.

Table 14. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. MNNW-3

Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1	SLICE-2 (primary)	
OIV ft/s (m/s)	Longitudinal	-27.45 (-8.37)	-26.65 (-8.12)	±40 (12.2)
	Lateral	-23.47 (-7.15)	-24.46 (-7.46)	±40 (12.2)
ORA g's	Longitudinal	-7.74	-8.20	±20.49
	Lateral	-7.32	-6.64	±20.49
MAX. ANGULAR DISPL. deg.	Roll	11.1	6.7	±75
	Pitch	-7.2	6.1	±75
	Yaw	-33.9	-33.7	not required
THIV ft/s (m/s)		34.77 (10.60)	35.37 (10.78)	not required
PHD g's		8.92	11.47	not required
ASI		1.45	1.53	not required

9.7 Discussion

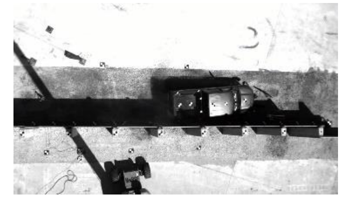
The analysis of the test results for test no. MNNW-3 showed that the system adequately contained and redirected the 2270P vehicle with controlled lateral displacements of the barrier. Detached elements, fragments, or other debris from the test article did not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or work-zone personnel. Deformations of, or intrusions into, the occupant compartment that could have caused serious injury did not occur. The test vehicle did not penetrate nor ride over the barrier and remained upright during and after the collision. Vehicle roll, pitch, and yaw angular displacements, as shown in Appendix H, were deemed acceptable, because they did not adversely influence occupant risk nor cause rollover. After impact, the vehicle exited the barrier at an angle of 8.4 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. MNNW-3 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 3-11.

0.000 sec

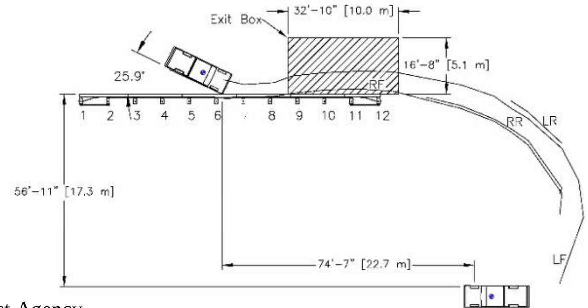
0.100 sec

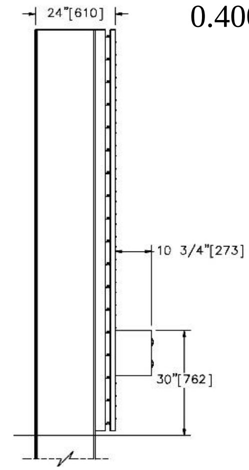
0.200 sec

0.300 sec



0.400 sec





- Test Agency .... MwRSF
- Test Number MNNW-3
- Date 4/4/2018
- MASH 2016 Test Designation No. 3-11
- Test Article .... MN Noise Wall
- Total Length .... 89.0 ft (27.1 m)
- Key Component - Rail
  - Length .... 89 ft (27.1 m)
  - Width .... 13½ in. (343 mm)
  - Depth .... 10¾ in. (273 mm)
- Key Component - Concrete Post
  - Length .... 18 ft (5.5 m)
  - Width .... 18 in. (457 mm)
  - Spacing .... 8 ft (2.4 m)
- Soil Type .... Coarse Crushed Limestone
- Vehicle Make /Model .... 2011 Dodge Ram 1500 Crew Cab
  - Curb .... 5,265 lb (2,388 kg)
  - Test Inertial .... 5,028 lb (2,281 kg)
  - Gross Static .... 5,188 lb (2,353 kg)
- Impact Conditions
  - Speed .... 61.2 mph (98.5 km/h)
  - Angle .... 25.9 deg.
  - Impact Location ..... 49⅜ in. (1,254 mm) US from rail splice between post nos. 6 & 7
- Impact Severity ...... 120.4 kip-ft (163.3 kJ) > 106 kip-ft (144 kJ) limit from MASH 2016
- Exit Conditions
  - Speed .... 30.8 mph (49.5 km/h)
  - Angle .... 8.4 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 74 ft – 7 in. (22.7 m) Downstream
  56 ft – 11 in. (17.3 m) Laterally Behind
- Test Article Damage .... Minimal
- Vehicle Damage .... Moderate
  - VDS [12] 01-RFQ-5
  - CDC [13] 01-RYEW-5
  - Maximum Interior Deformation .... 5.5 in. (140 mm)
- Maximum Test Article Deflections
  - Permanent Set ... ⅜ in. (10 mm) at post no. 7 and midspan between post nos. 6 and 7
  - Dynamic .... 7.0 in. (178 mm) at the top of post no. 7
  - Working Width .... 41.8 in. (1,060 mm) at the top of post no. 7
- Transducer Data

Evaluation Criteria		Transducer SLICE-1	Transducer SLICE-2 (primary)	MASH 2016 Limit
OIV ft/s (m/s)	Longitudinal	-27.45 (-8.37)	-26.65 (-8.12)	±40 (12.2)
	Lateral	-23.47 (-7.15)	-24.46 (-7.46)	±40 (12.2)
ORA g's	Longitudinal	-7.74	-8.20	±20.49
	Lateral	-7.32	-6.64	±20.49
MAX ANGULAR DISP. deg.	Roll	11.1	6.7	±75
	Pitch	-7.2	6.1	±75
	Yaw	-33.9	-33.7	not required
THIV – ft/s (m/s)		34.77 (10.60)	35.37 (10.78)	not required
PHD – g's		8.92	11.47	not required
ASI		1.45	1.53	not required

Figure 86. Summary of Test Results and Sequential Photographs, Test No. MNNW-3


0.000 sec


0.100 sec


0.200 sec


0.300 sec

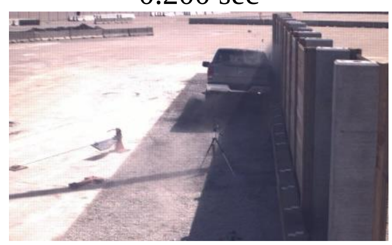

0.400 sec


0.500 sec


0.000 sec


0.100 sec


0.200 sec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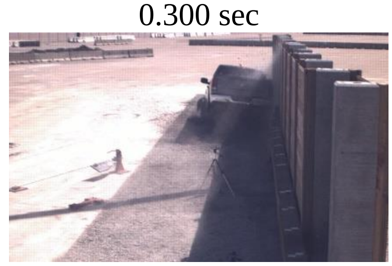
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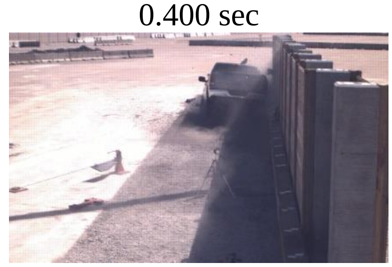

0.500 sec

Figure 87. Additional Sequential Photographs, Test No. MNNW-3

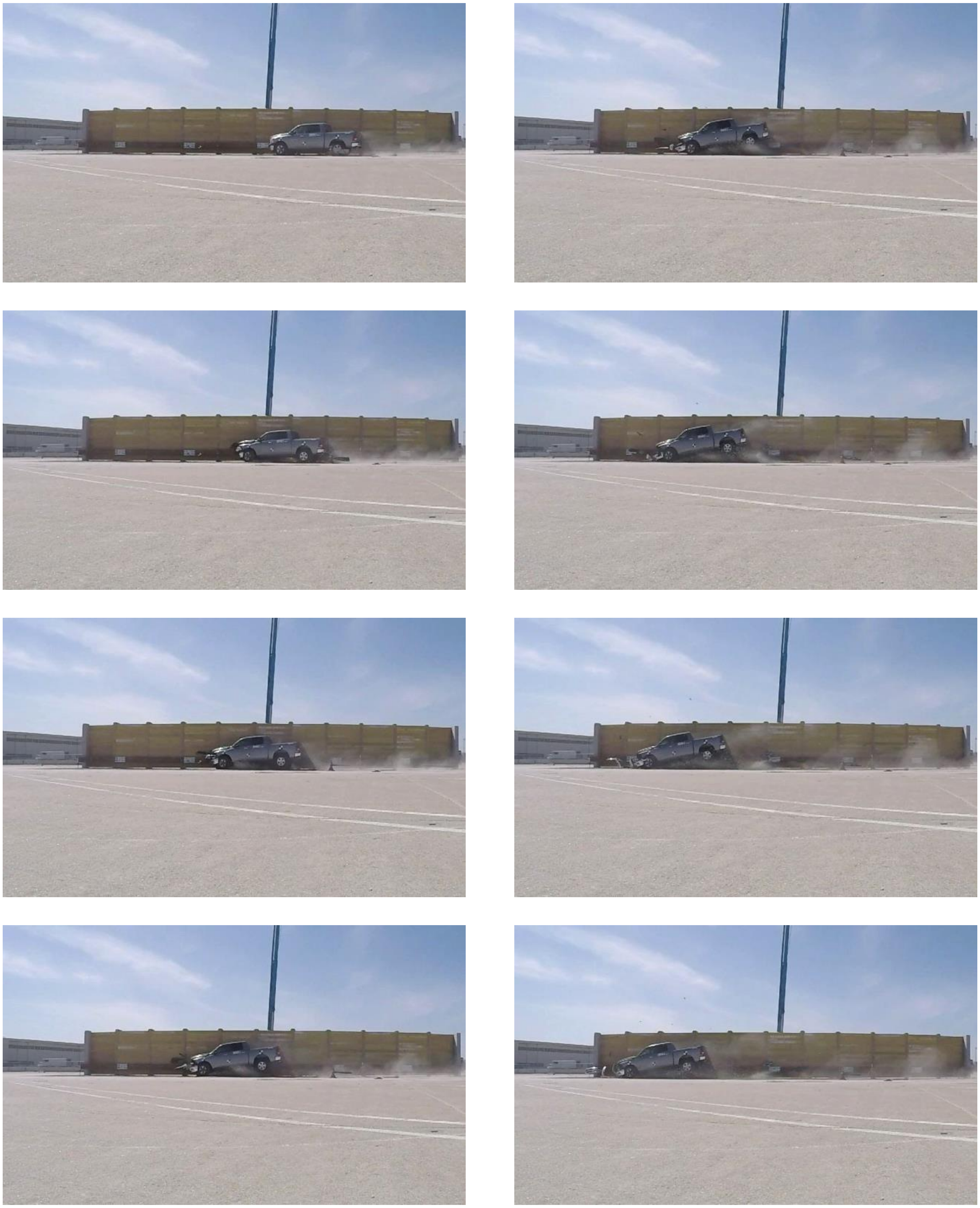


Figure 88. Documentary Photographs, Test No. MNNW-3

Figure 89. Documentary Photographs, Test No. MNNW-3

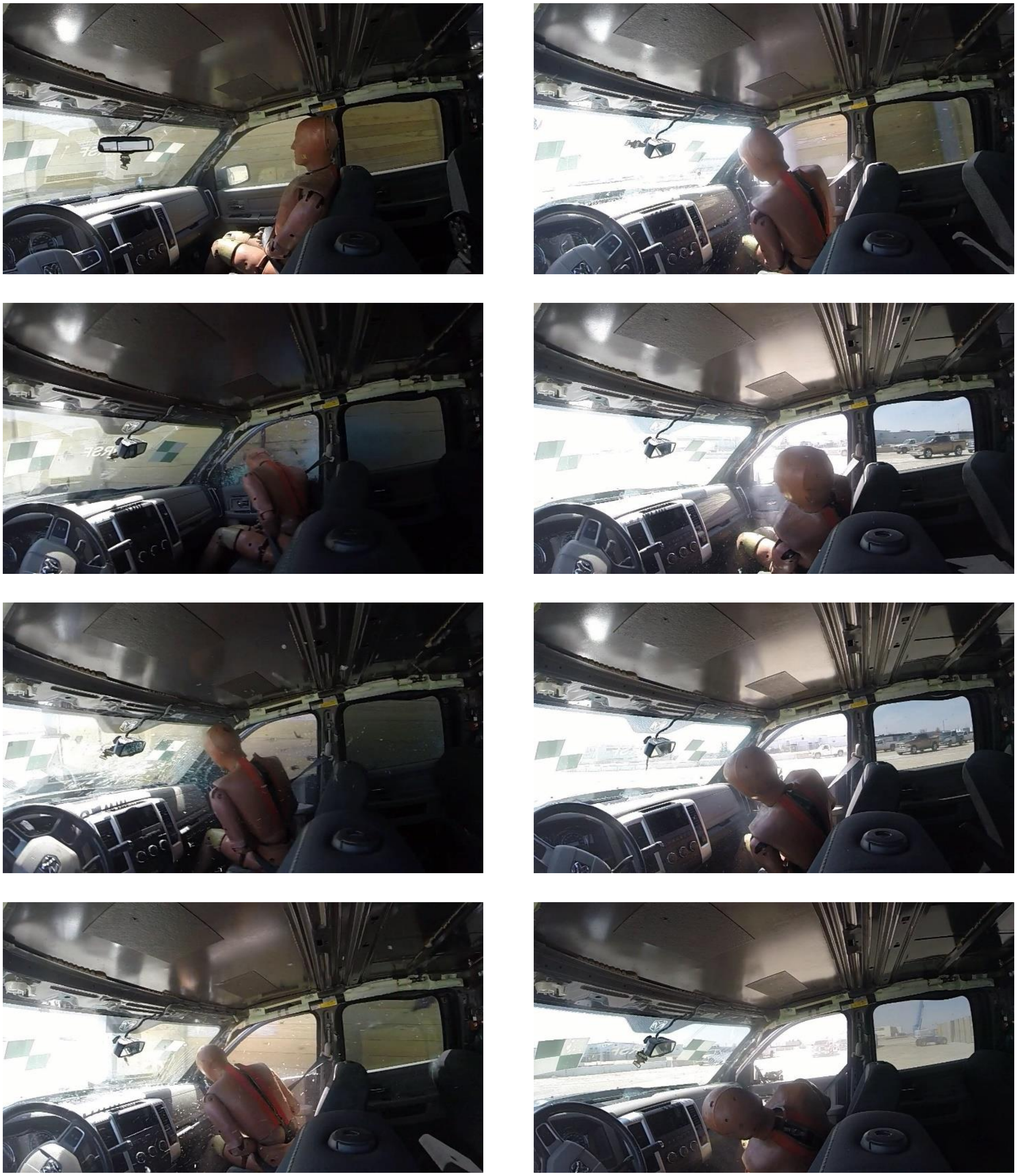


Figure 90. Documentary Photographs, Test No. MNNW-3

Figure 91. Documentary Photographs, Test No. MNNW-3

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

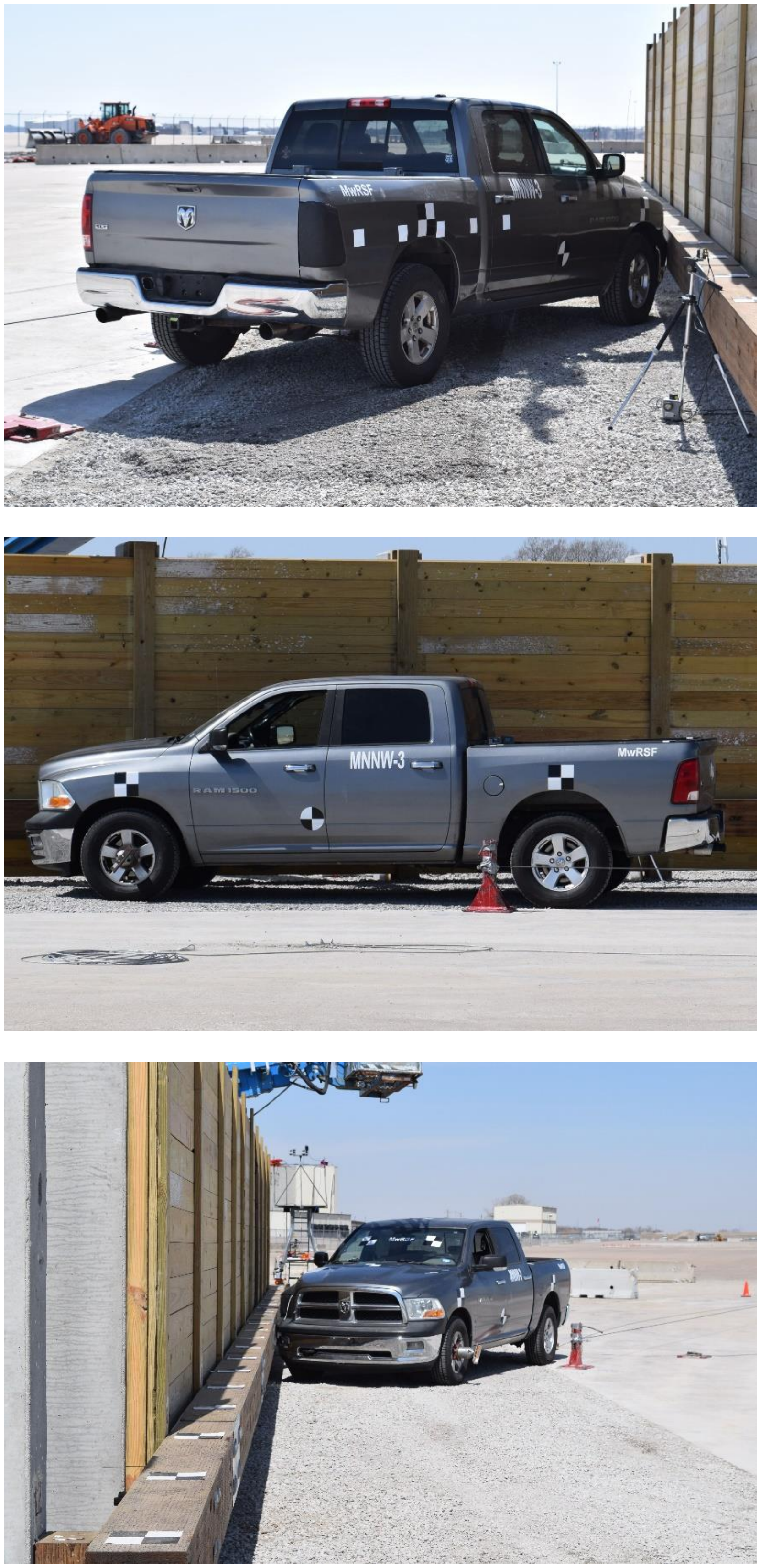


Figure 93. Impact Location, Test No. MNNW-3

Figure 94. Vehicle Final Position and Trajectory Marks, Test No. MNNW-3

Figure 95. System Damage, Test No. MNNW-3

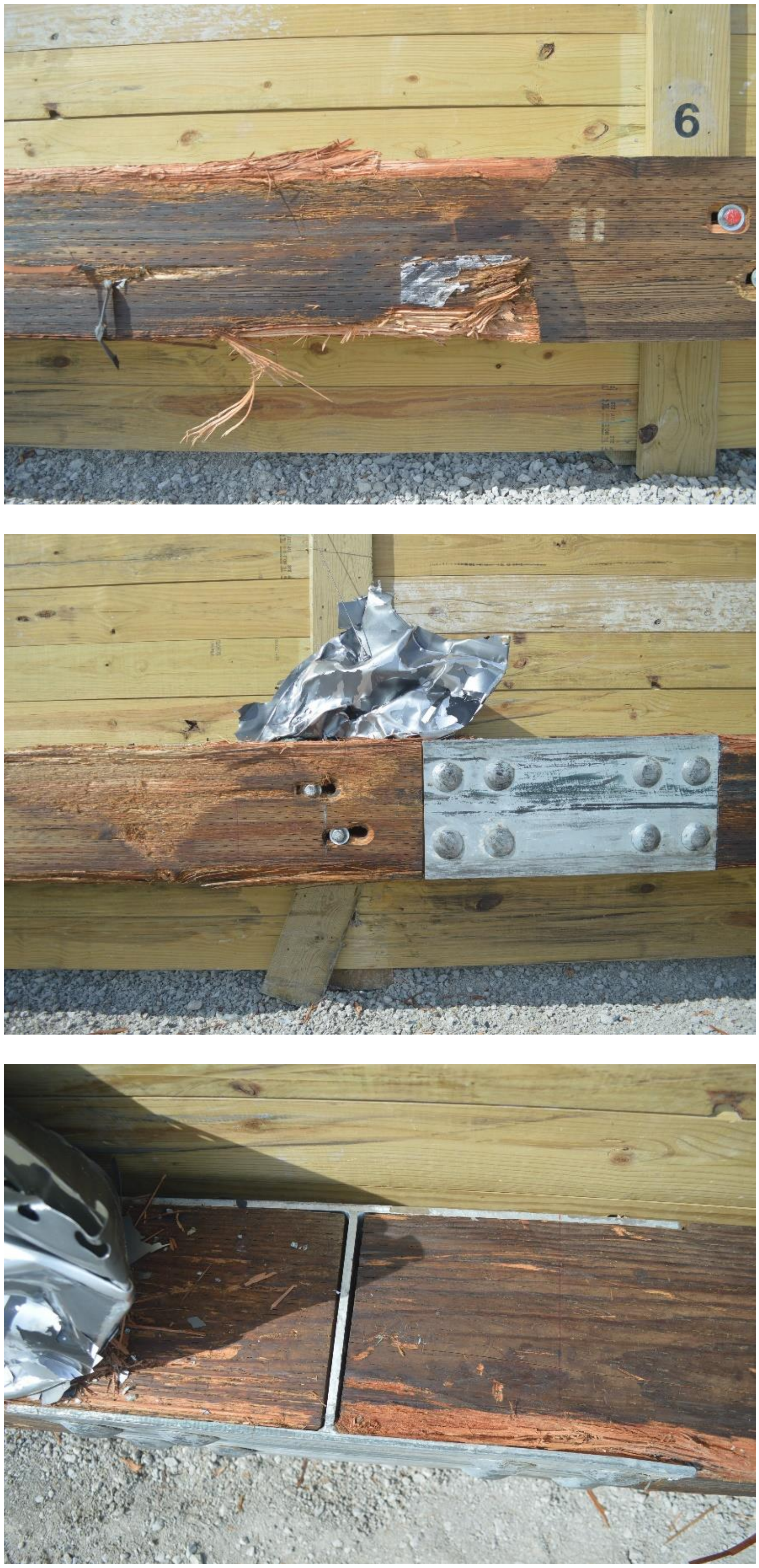


Figure 96. System Damage, Test No. MNNW-3

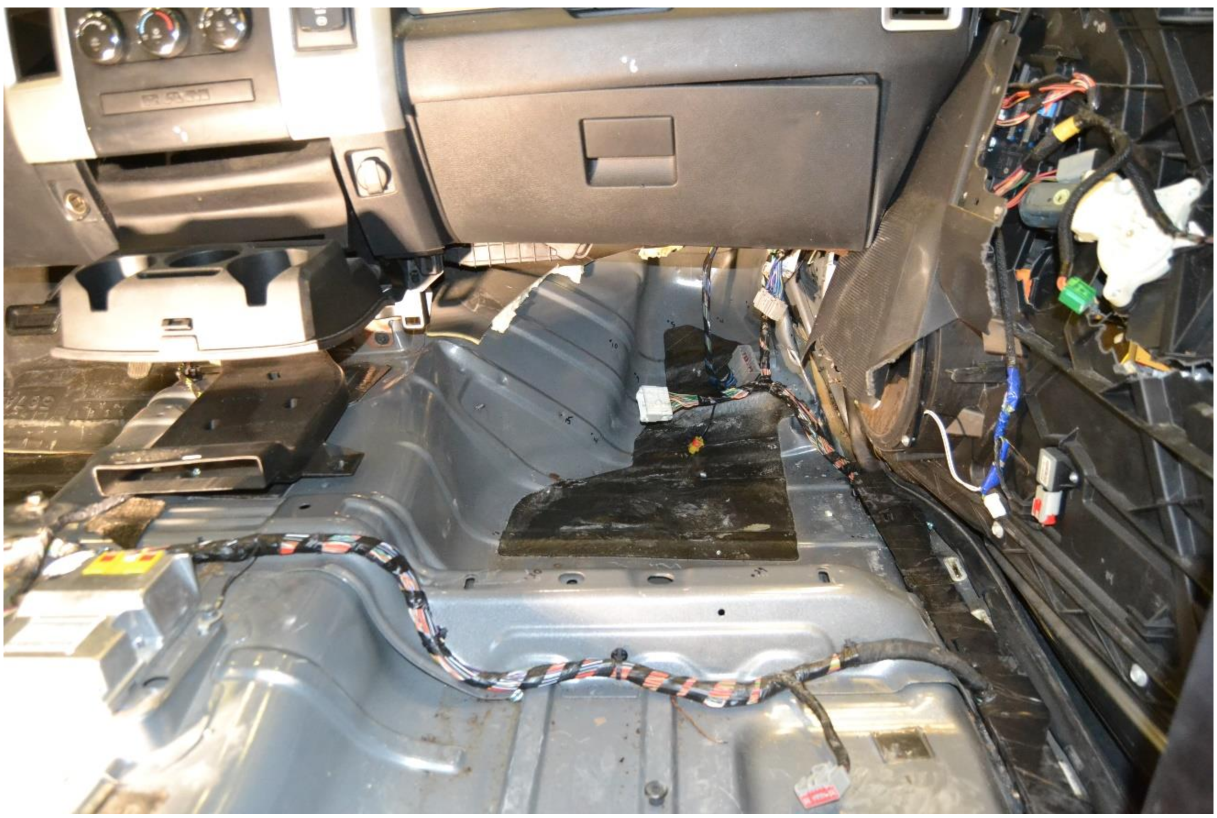


Figure 97. Vehicle Undercarriage and Occupant Compartment Damage, Test No. MNNW-3

Figure 98. Vehicle Damage, Test No. MNNW-3

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

10 DISCUSSION

The three crash tests were compared, and some general conclusions were drawn. The lateral barrier force during each crash test was estimated using the primary vehicle accelerometer data. The longitudinal and lateral vehicle accelerations from each test, as measured at the vehicles' c.g., were processed using a 50-msec moving average. The 50-msec moving average vehicle accelerations were then combined with the uncoupled yaw angle versus time data in order to estimate the lateral vehicular loading imparted to the barrier system. The estimated lateral barrier forces are shown in Figure 100.

Test nos. MNNW-1 and MNNW-3 were both conducted with the 2270P pickup truck and had impact severities of 117.2 kip-ft (158.9 kJ) and 120.4 kip-ft (163.3 kJ), respectively. Test nos. MNNW-1 and MNNW-3 showed very similar peak lateral forces of 69.8 kips (310.5 kN) and 72.9 kips (324.3 kN), respectively, which indicates that the back-side and front-side noise wall configurations performed in a very similar manner. In test no. MNNW-1, the secondary impact with the rear axle of the pickup was more significant than the secondary impact observed in test no. MNNW-3. The test no. MNNW-1 pickup truck also had much more rear axle damage than observed on the test no. MNNW-3 pickup truck. In test no. MNNW-2, the small car exerted an estimated 52.1-kip (231.8-kN) lateral impact force to the barrier. Note that the small car impact event had a noticeably shorter time duration than observed for the pickup truck crash events.

Since the pickup truck impact events revealed an estimated lateral barrier force that was much greater than observed in the small car impact, the lateral dynamic barrier deflections observed in the pickup truck tests were expected to be much greater than observed for the small car test. However, this outcome did not occur. Dynamic deflection at the top of the posts was 3.8 in. (96.5 mm), 4.5 in. (114.3 mm), and 7.0 in. (177.8 mm) for test nos. MNNW-1, MNNW-2, and MNNW-3, respectively. The increased lateral dynamic barrier deflections between tests was believed to be partially due to an accumulation of soil damage between crash tests. For this research program, all of the deeply-embedded, vertical concrete posts were reused between tests. Further, the surrounding soil was not re-compacted around the 8-ft (2.4 m) deep posts after each test. Instead, the soil was only filled in as needed to reset and plumb the posts. Thus, the soil below grade would not likely be as firmly compacted against the posts for the two later tests. Rather, slight soil gaps may have been present below grade, followed by a stiff, compacted soil interface, which would have occurred after the first impact events. Based on the lateral barrier impact forces provided in Figure 100, it is estimated that the lateral dynamic barrier deflections that would occur in test nos. MNNW-1 and MNNW-3 would be nearly identical if installed in identical soil conditions. Following this testing program, it is evident that the selected vertical concrete posts for this noise wall and glulam timber rubrail system could be impacted several times by errant vehicles before requiring resetting. However, system repair may be required for design variations that utilize smaller post cross-sections and/or shallower post embedment depths.

The maximum dynamic deflection and working width measured from high-speed video analysis occurred at the top of the posts, which were 10 ft (3.0 m) above ground. The dynamic deflection and working width near the ground line was minimal.

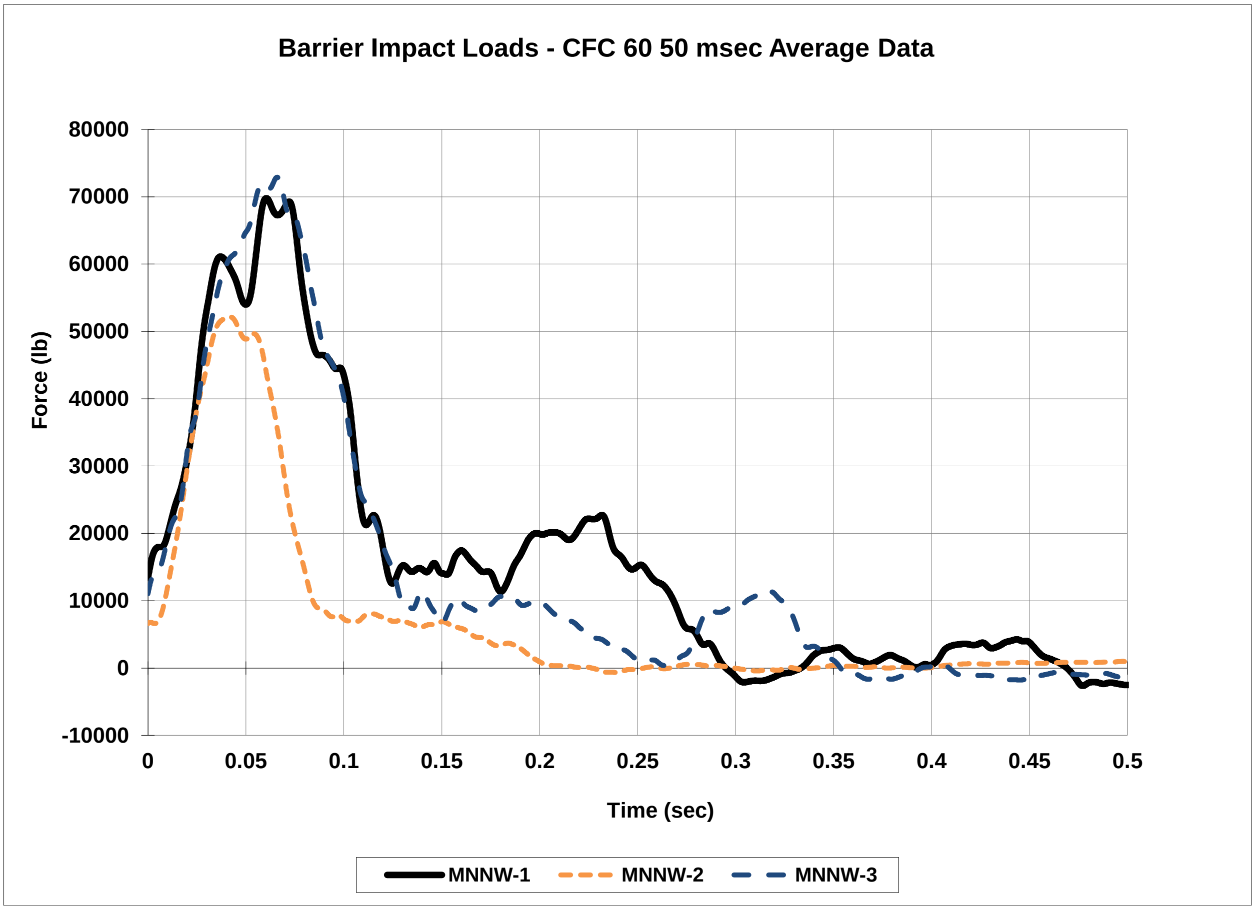


Figure 100. Estimated Lateral Barrier Loads, Test Nos. MNNW-1 through MNNW-3

11 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Test nos. MNNW-1, MNNW-2, and MNNW-3 were conducted on a noise wall system according to MASH 2016 test designation nos. 3-10 and 3-11. A summary of the test evaluations is shown in Table 15.

Test no. MNNW-1 was conducted according to MASH 2016 test designation no. 3-11. The barrier consisted of an 89-ft (27.1-m) timber glulam rubrail in front of twelve 18-ft (5.5-m) long concrete posts with a wooden noise wall attached to the back side of the posts. In test no. MNNW-1, the 5,056-lb (2,293-kg) pickup truck impacted the noise wall at a speed of 63.0 mph (101.4 km/h), an angle of 24.7 degrees, and at a location $11^9/_{16}$ in. (294 mm) upstream from the centerline of post no. 6, thus resulting in an impact severity of 117.2 kip-ft (158.9 kJ). After impacting the barrier system, the vehicle exited the system at a speed of 38.3 mph (61.6 km/h) and an angle of 3.7 degrees. The vehicle was successfully contained and smoothly redirected with minimal damage to the barrier and moderate damage to the vehicle. All vehicle decelerations, ORAs, and OIVs fell below the recommended safety limits established in MASH 2016. Therefore, test no. MNNW-1 was successful according to the safety criteria of MASH 2016 test designation no. 3-11.

Test no. MNNW-2 was conducted according to MASH 2016 test designation no. 3-10. The barrier consisted of an 89-ft (27.1-m) timber glulam rubrail in front of twelve 18-ft (5.5-m) long concrete posts with a wooden noise wall attached to the back side of the posts. In test no. MNNW-2, the 2,431-lb (1,103-kg) small car impacted the noise wall at a speed of 63.1 mph (101.5 km/h), an angle of 25.4 degrees, and at a location $46^3/_{16}$ in. (1,173 mm) upstream from the centerline of the rail splice between post nos. 6 and 7, thus resulting in an impact severity of 59.7 kip-ft (80.9 kJ). After impacting the barrier system, the vehicle exited the system at a speed of 43.0 mph (69.1 km/h) and an angle of 5.6 degrees. The vehicle was successfully contained and smoothly redirected with minimal damage to the barrier and moderate damage to the vehicle. All vehicle decelerations, ORAs, and OIVs fell below the recommended safety limits established in MASH 2016. Therefore, test no. MNNW-2 was successful according to the safety criteria of MASH 2016 test designation no. 3-10.

Test no. MNNW-3 was conducted according to MASH 2016 test designation no. 3-11. The barrier consisted of an 89-ft (27.1-m) timber glulam rubrail in front of twelve 18-ft (5.5-m) long concrete posts with a wooden noise wall attached to the front side of the posts. In test no. MNNW-3, the 5,028-lb (2,281-kg) pickup truck impacted the barrier at a speed of 61.2 mph (98.5 km/h), an angle of 25.9 degrees, and at a location $49^3/_8$ in. (1,254 mm) upstream from the centerline of the rail splice between post nos. 6 and 7, thus resulting in an impact severity of 120.4 kip-ft (163.3 kJ). After impacting the barrier system, the vehicle exited the system at a speed of 30.8 mph (49.5 km/h) and an angle of 8.4 degrees. The vehicle was successfully contained and smoothly redirected with minimal damage to the barrier and moderate damage to the vehicle. All vehicle decelerations, ORAs, and OIVs fell below the recommended safety limits established in MASH 2016. Therefore, test no. MNNW-3 was successful according to the safety criteria of MASH 2016 test designation no. 3-11.

A few modifications are recommended for ease of installation:

(1) The field-installed threaded anchors should be installed by setting the rail in place and then field drilling the holes in the concrete posts at the proper location to align with the slots in the rubrail.

(2) The galvanized post-to-rail bolt threads were not compatible with the threads in the zinc-plated, threaded inserts that were installed in the posts. It recommended that the bolts and threads have the same coating to ensure compatibility. Further, galvanized or plated female anchors should incorporate properly cut threads to accept galvanized bolts.

(3) The ends of the glulam timber rubrails required minor planning to allow them to fit within the galvanized H-shaped splice plates. With the addition of galvanization and fabrication tolerances, it is recommended that additional planning tolerance be added to the timber rubrail ends. Thus, the notches in the timber rubrails were increased from a ⅜-in. (9.5-mm) depth to a $^{7}/_{16}$-in. (11.1-mm) depth in Figures 101 through 135. Additionally, the corners of rubrails were chamfered ¼-in. (6.4-mm) to fit around the welds in the H-shaped splice plates. However, due to some variations in the welds, a $^{5}/_{16}$-in. (7.9-mm) chamfer would allow for easier installation, as denoted in Figures 101 through 135.

The final drawing set for use in system implementation is shown in Chapter 12 in Figures 101 through 117 for the back-side noise wall configuration and Figures 118 through 135 for the front-side noise wall configuration.

Table 15. Summary of Safety Performance Evaluations

Evaluation Factors	Evaluation Criteria		Test No. MNNW-1 (2270P)	Test No. MNNW-2 (1100C)	Test No. MNNW-3 (2270P)
Structural Adequacy	A.	Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	S	S	S
Occupant Risk	D.	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.	S	S	S
		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.	S	S	S
	F.	The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.	S	S	S
	H.	Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits: Occupant Impact Velocity Limits Component / Preferred / Maximum Longitudinal and Lateral / 30 ft/s (9.1 m/s) / 40 ft/s (12.2 m/s)	S	S	S
	I.	The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits: Occupant Ridedown Acceleration Limits Component / Preferred / Maximum Longitudinal and Lateral / 15.0 g's / 20.49 g's	S	S	S
MASH 2016 Test Designation No.			3-11	3-10	3-11
Final Evaluation (Pass or Fail)			Pass	Pass	Pass

S – Satisfactory U – Unsatisfactory NA - Not Applicable

12 MASH EVALUATION

The MnDOT noise wall and glulam timber rubrail system was evaluated to determine its compliance with MASH 2016 TL-3 evaluation criteria. The test installation of the barrier system was constructed of a wood plank noise wall, which spanned across concrete support posts, and was protected by glulam timber rail sections.

MASH 2016 currently requires two full-scale crash tests for evaluation of longitudinal barrier systems to TL-3. The back-side noise wall configuration passed both MASH 2016 TL-3 tests for longitudinal barriers, test nos. 3-10 and 3-11, and is considered acceptable for use on the roadside. The front-side noise wall configuration passed one crash test, MASH 2016 test designation no. 3-11. MASH 2016 test designation no. 3-11 was deemed more critical for evaluating vehicle snag on posts as well as investigating lateral dynamic barrier loading with the noise wall mounted to the front side of the posts. Test designation no. 3-10 was deemed unnecessary for the noise wall mounted to the front side of the posts. Both crash tests under test designation no. 3-11 (test nos. MNNW-1 and MNNW-3) with the noise wall installed on the back- and front-side faces of the posts provided similar results, and the barriers experienced very similar lateral loading. Similar to the pickup truck tests, it was expected that test designation no. 3-10 would result in similar loading with the front-side noise wall configuration as the back-side noise wall configuration. Additionally, there was minimal concern for vehicle snag as the vehicle would not be able to extend as far underneath or over top of the rubrail. Thus, the overall barrier system should also provide similar performance under MASH test designation no. 3-10 impact events using back- and front-side noise wall configurations.

Test no. MNNW-1 was conducted according to MASH 2016 test designation no. 3-11 with a 5,056-lb (2,293-kg) pickup truck impacting the noise wall (back-side configuration) at a speed of 63.0 mph (101.4 km/h), an angle of 24.7 degrees, and at a location $11^{9}/_{16}$ in. (294 mm) upstream from the centerline of post no. 6, thus resulting in an impact severity of 117.2 kip-ft (158.9 kJ). Maximum dynamic deflection and working width was 3.8 in. (97 mm) and 44.5 in. (1,130 mm), respectively, at the top of post no. 7. Test no. MNNW-1 was successful according to the safety criteria of MASH 2016 test designation no. 3-11.

Test no. MNNW-2 was conducted according to MASH 2016 test designation no. 3-10 with a 2,431-lb (1,103-kg) small car impacting the noise wall (back-side configuration) at a speed of 63.1 mph (101.5 km/h), an angle of 25.4 degrees, and at a location $46^{3}/_{16}$ in. (1,173 mm) upstream from the centerline of the rail splice between post nos. 6 and 7, thus resulting in an impact severity of 59.7 kip-ft (80.9 kJ). Maximum dynamic deflection and working width was 4.5 in. (114 mm) and 44.5 in. (1,148 mm), respectively, at the top of post no. 7. Test no. MNNW-2 was successful according to the safety criteria of MASH 2016 test designation no. 3-10.

Test no. MNNW-3 was conducted according to MASH 2016 test designation no. 3-11 with a 5,028-lb (2,281-kg) pickup truck impacting the noise wall (front-side configuration) at a speed of 61.2 mph (98.5 km/h), an angle of 25.9 degrees, and at a location $49^{3}/_{8}$ in. (1,254 mm) upstream from the centerline of the rail splice between post nos. 6 and 7, thus resulting in an impact severity of 120.4 kip-ft (163.3 kJ). Maximum dynamic deflection and working width was 7.0 in. (178 mm) and 41.8 in. (1,062 mm), respectively, at the top of post no. 7.

The glulam timber for the rail members and spacer blocks was fabricated with Combination no. 2 Western Species, but any wood species with a stronger bending strength, including Combination No. 48 Southern Pine material, is an acceptable and equivalent alternative.

The concrete posts utilized in the test installation were configured with longitudinal prestressing strands in lieu of longitudinal reinforcement bars. However, reinforced concrete posts of equivalent strength are an acceptable alternative

The noise wall configurations with deeper embedment depths and taller noise walls are all expected to be stiffer than the as-tested systems due to increased soil resistance. All evaluation criteria in the crash tests were far from the limits published in MASH 2016. Thus, a stiffer system should also be a crashworthy configuration. Additionally, an embedment depth of 6 ft (1.8 m), which is the minimum embedment depth allowed by MnDOT, was previously tested to NCHRP Report 350 evaluation criteria and performed acceptably. Even with the increased impact severity with MASH 2013 test designation no. 3-11, it is believed that the noise wall system with 12-in. (305-mm) x 18-in. (457-mm) concrete posts with embedment depths of 6 ft (1.8 m) and greater should be crashworthy. However, the dynamic deflections may increase slightly with shallower embedment depths.

Both recessed round-head bolts and recessed hex-head bolts were evaluated in the test series and performed acceptably. Round-head bolts with a washer equivalent to size of a dome-head bolt head are believed to perform the same since they have the same sized contact area with the rubrail. Thus, round-head bolts with a washer and dome-head bolts with an ⅛-in. (3-mm) recess in the timber rubrail are both acceptable for use in the rail-to-post connection. Additionally, hex-head bolts with a ⅝-in. (16-mm) recess are also acceptable for use in the rail-to-post connection based on test no. MNNW-3. Details for the dome-head bolts are shown in the back-side noise wall configuration in Figures 101 through 117. Details for the hex-head bolts are shown in the front-side noise wall configuration in Figures 118 through 135. However, either bolt can be use with either the back- or front-side configuration.

In test nos. MNNW-1 and MNNW-2, 14-in. (356-mm) long splice bolts were utilized and performed acceptably. In test no. MNNW-3, 12-in. (305-mm) long splice bolts were utilized and performed acceptably. The 14-in. (356-mm) long splice bolts could be utilized only in the back-side noise wall configuration. Due to the similarities in performance in both the back-side and front-side noise wall configurations, the 12-in. (305-mm) long splice bolts could be utilized in either configuration.

MnDOT may utilize 32-ft (9.8-m) long rubrails in lieu of 16-ft (4.9-m) long rubrails. Utilizing a long rubrail would decrease the number of splice plates and splice bolts necessary for construction. The capacity of the splices is similar to the capacity of the rubrail, so 32-ft (9.8-m) long rubrails used in lieu of 16-ft (4.9-m) long rubrails would also result in a crashworthy system.

The transition point from a back-side to a front-side noise wall could present a concern for vehicle snag. In test no. MNNW-1, the vehicle almost contacted the concrete post, which is located 16¾ in. (425 mm) behind the front face of the timber rubrail. For the noise wall configuration attached to the front side of the posts, the noise wall's vertical battens were located

10¾ in. (273 mm) behind the front face of the timber rubrail. Thus, a narrow exposure existed where the engine hood or front fender panel could snag on vertical components with an overlap of approximately 6 in. (152 mm). The snag likely would not be too severe, but the alternating noise wall placement from the back side to the front side of posts would pose greater snag risk. The severity of this snag could be evaluated with additional crash testing to confirm its crashworthiness. Further, the end of the noise wall and glulam timber rubrail barrier system could present a snag hazard if left unprotected. It is recommended that the ends of the system be protected with an appropriate crashworthy system or extended beyond the clear zone.

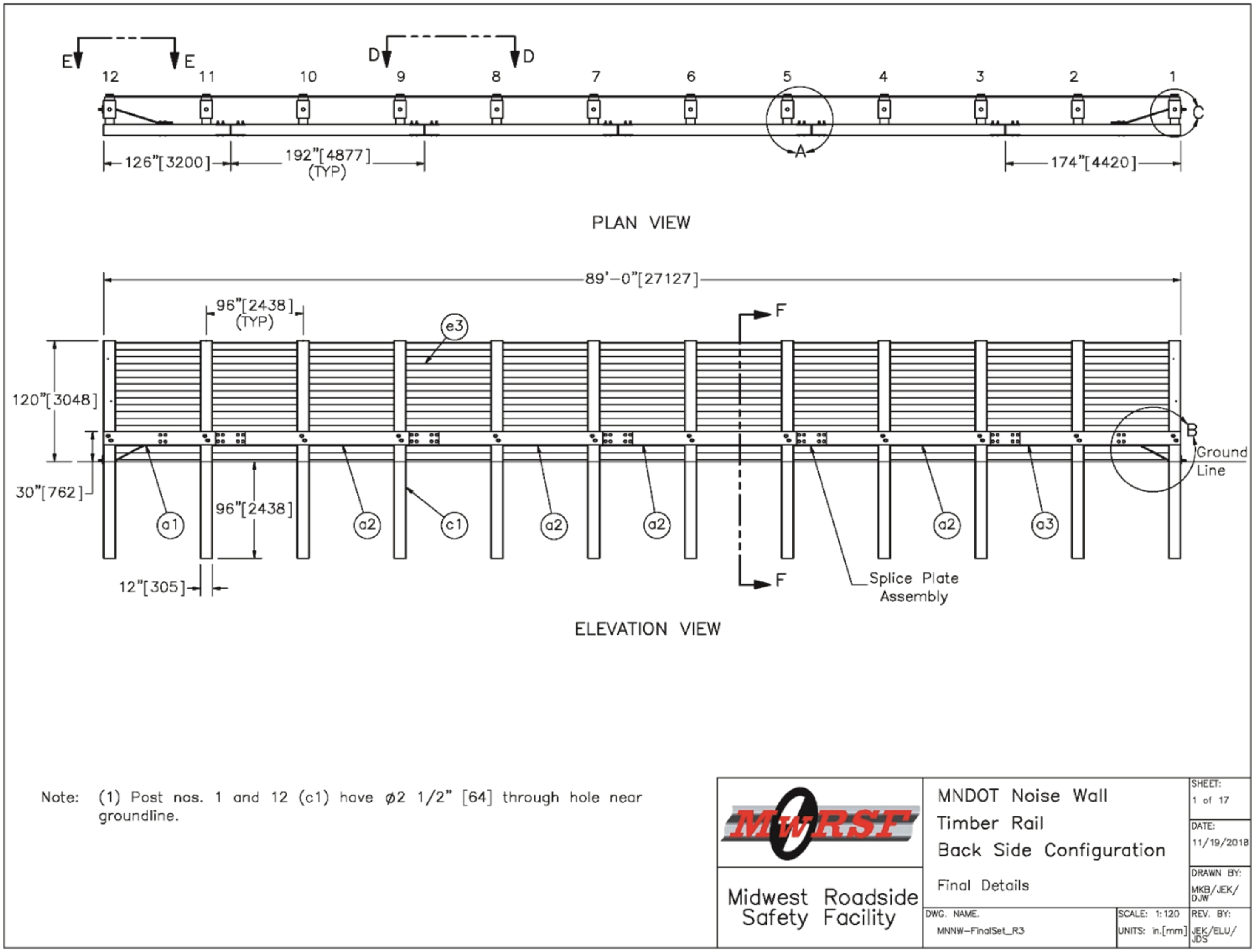


Figure 101. Final Details, Back-Side Noise Wall

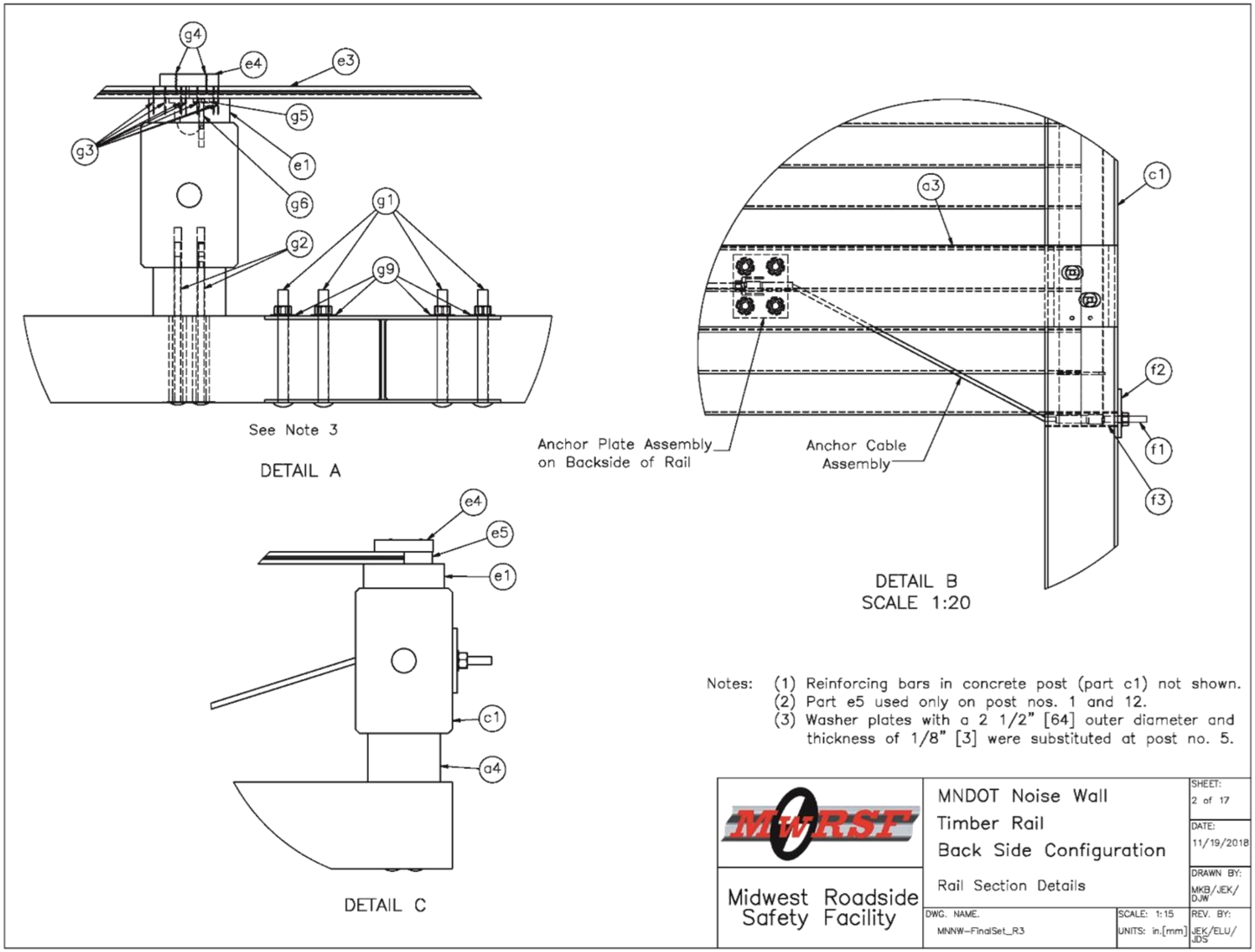


Figure 102. Rail Section Details, Back-Side Noise Wall

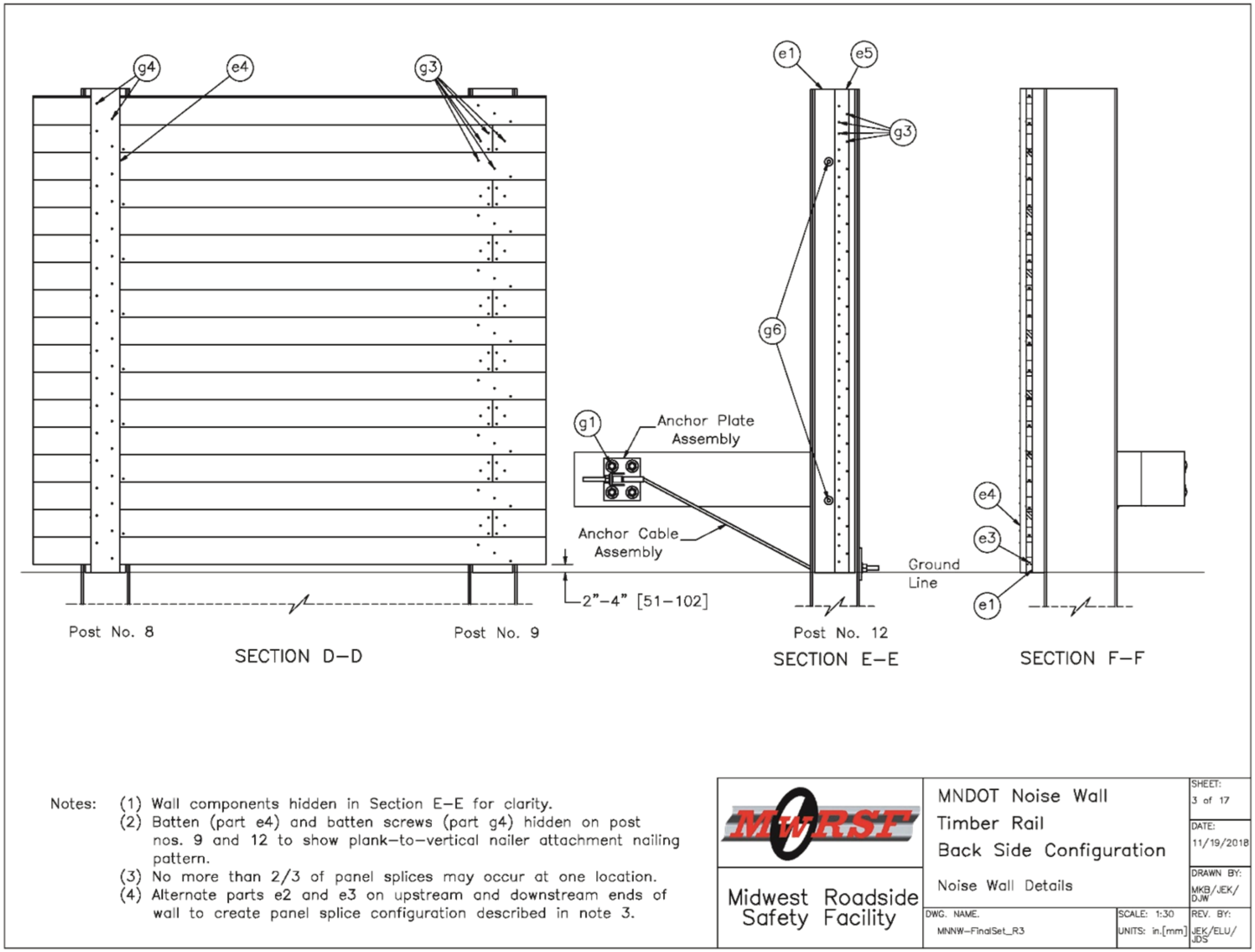


Figure 103. Noise Wall Details, Back-Side Noise Wall

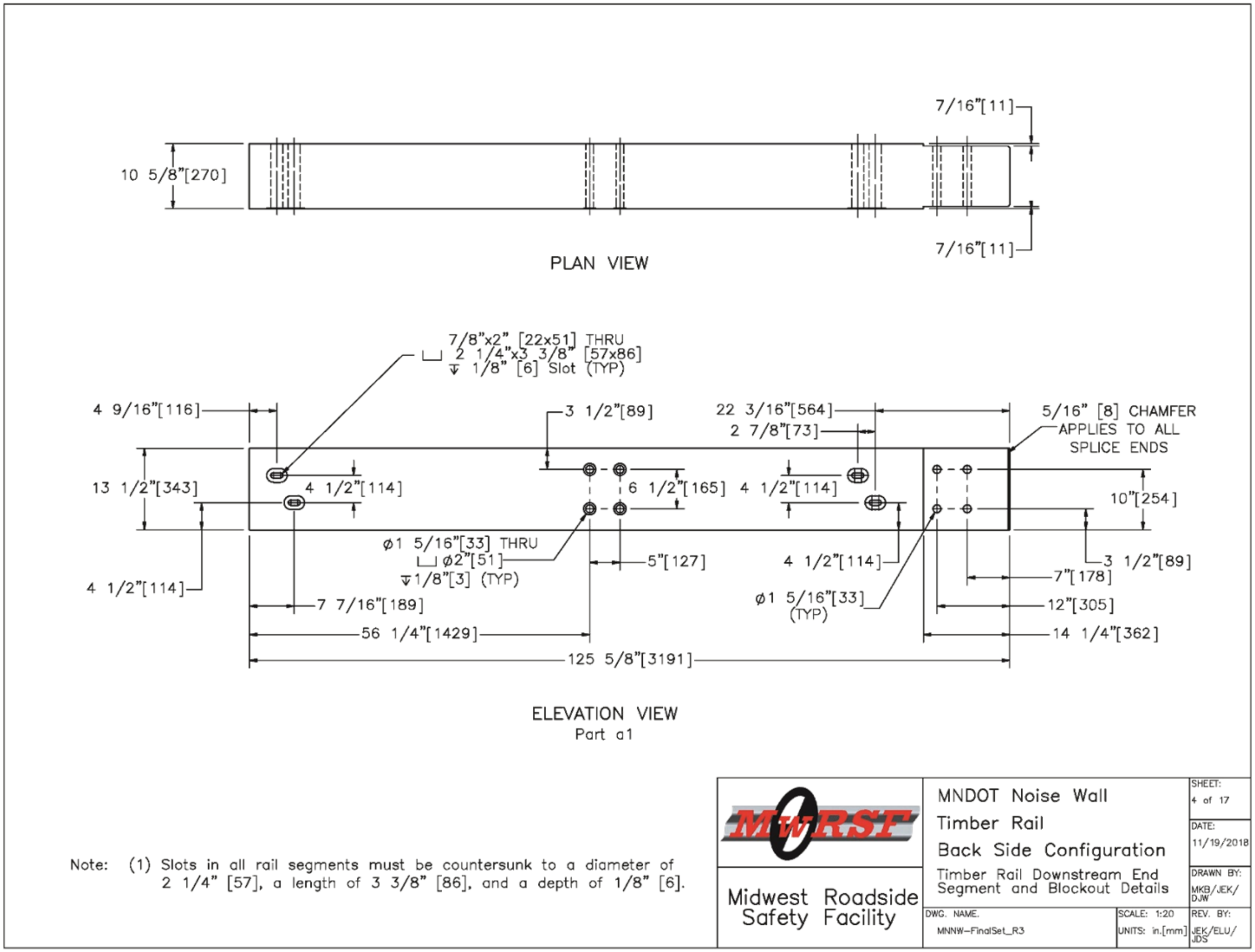


Figure 104. Timber Rail Downstream End Segment and Blockout Details, Back-Side Noise Wall

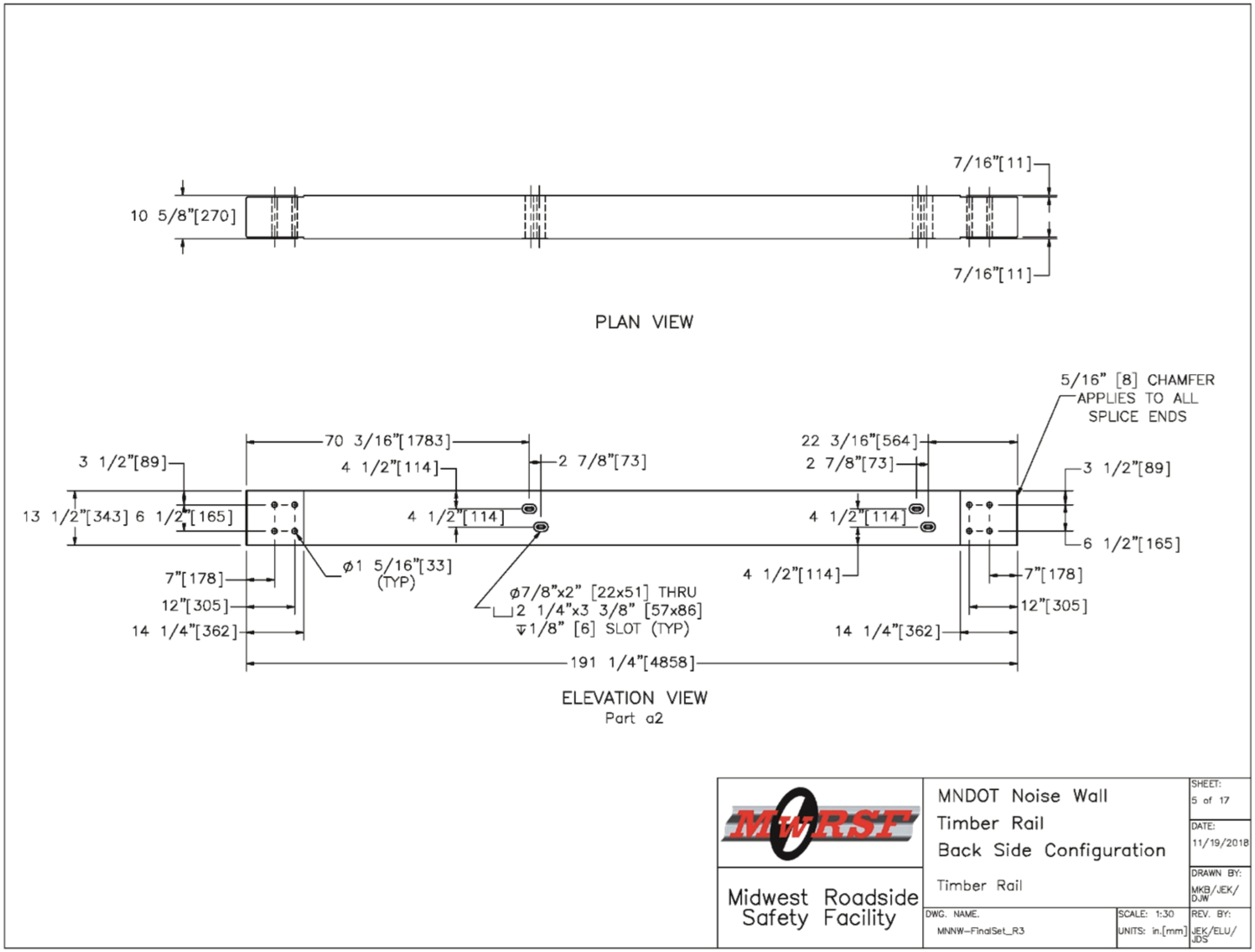


Figure 105. Timber Rail, Back-Side Noise Wall

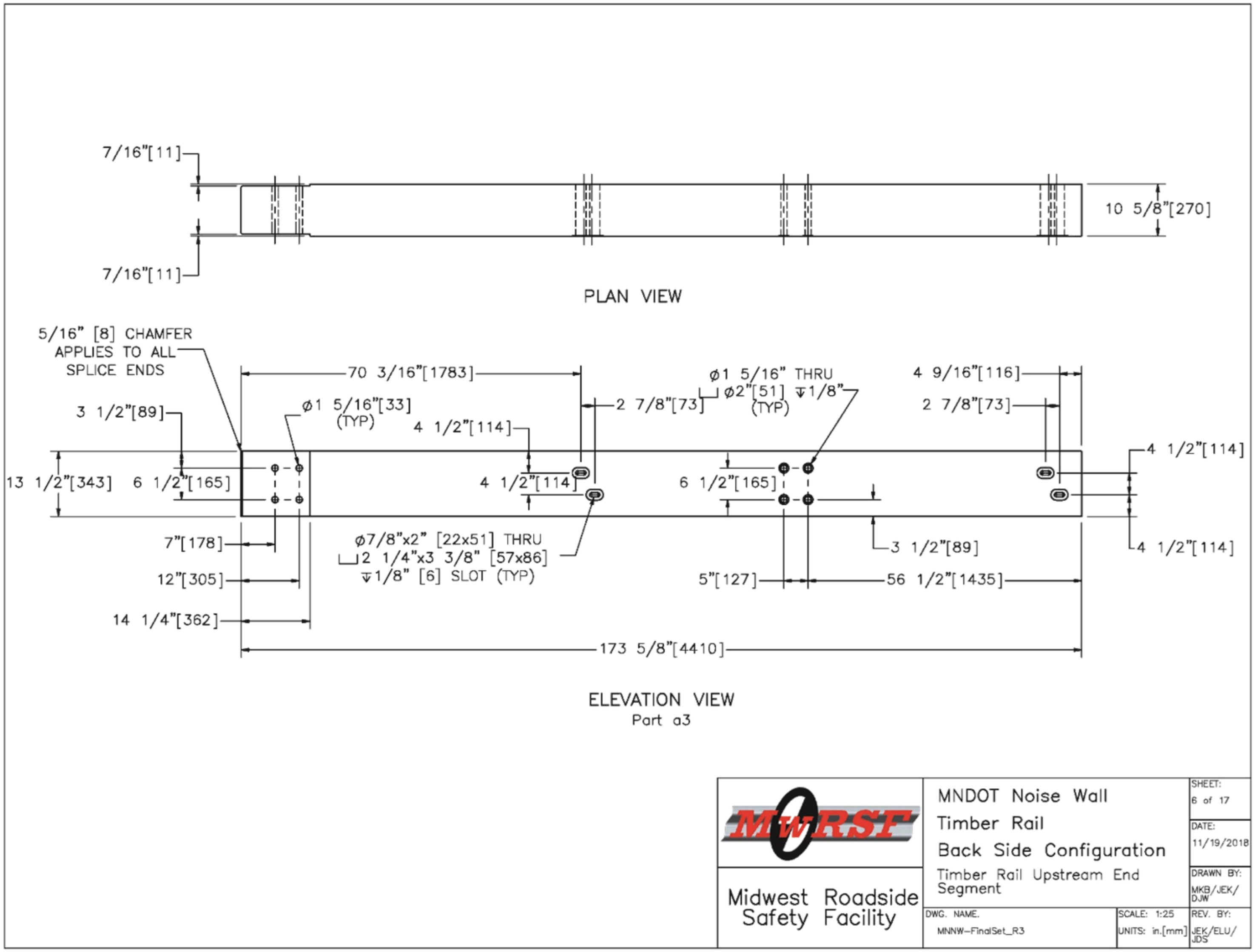


Figure 106. Timber Rail Upstream End Segment, Back-Side Noise Wall

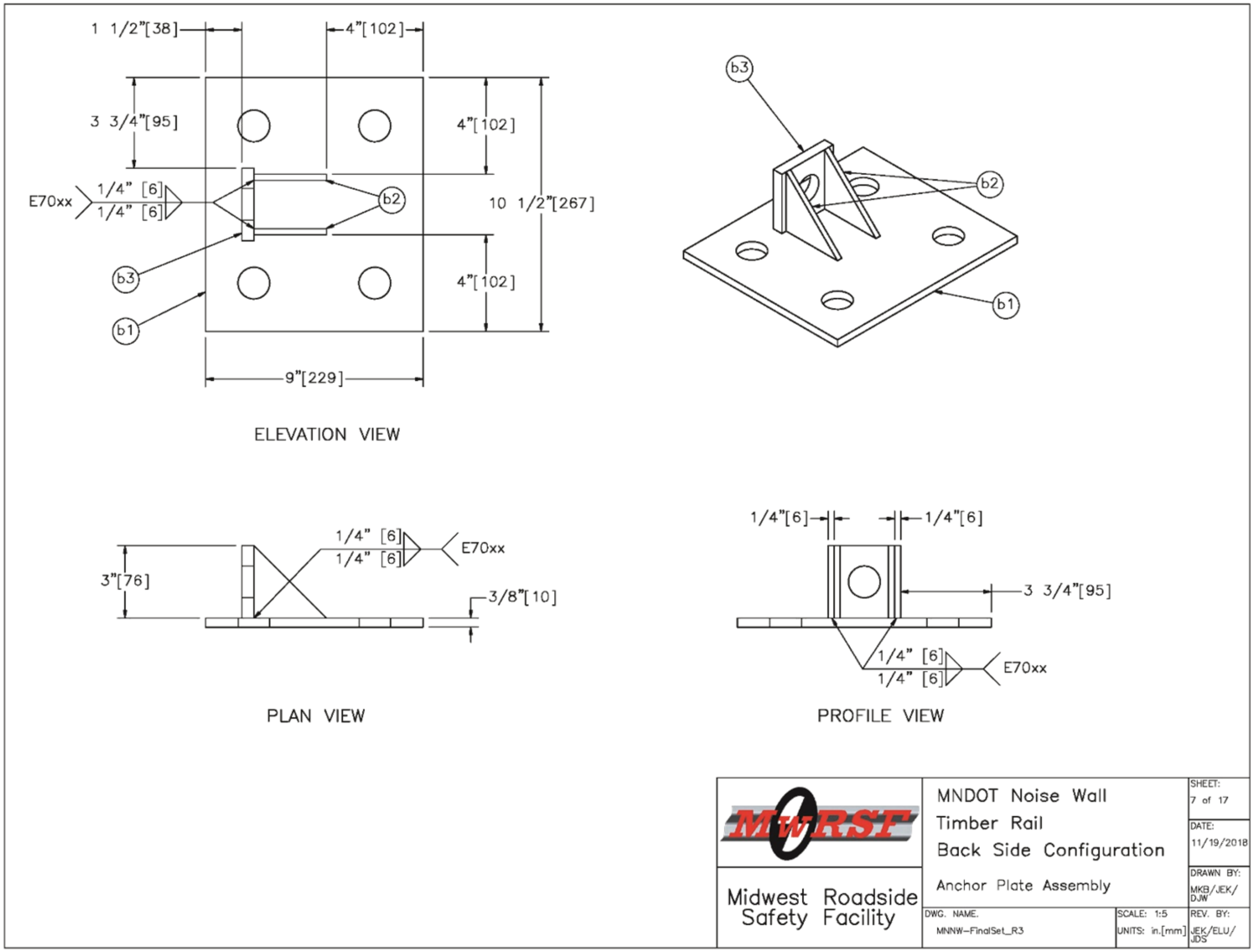


Figure 107. Anchor Plate Assembly, Back-Side Noise Wall

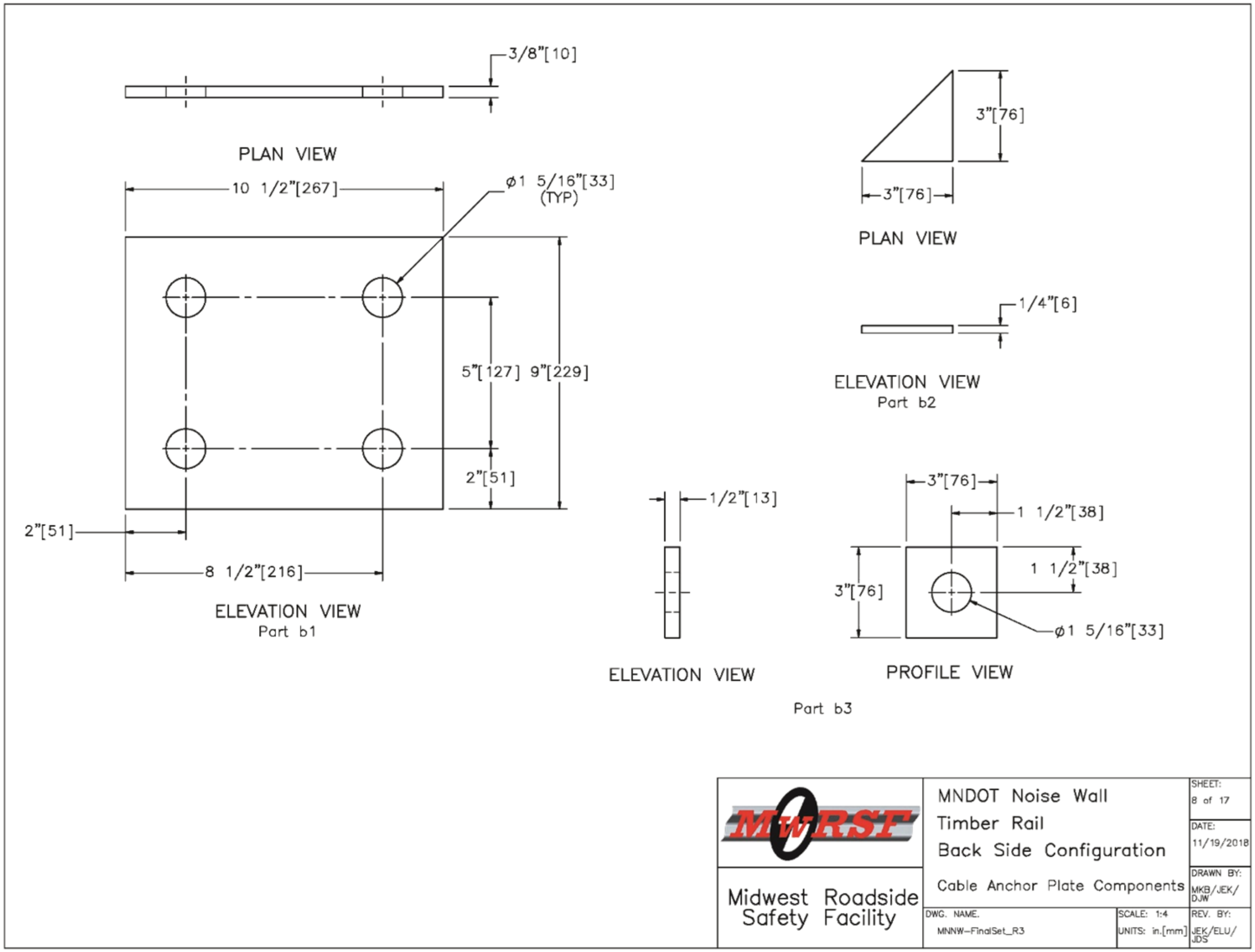


Figure 108. Cable Anchor Plate Components, Back-Side Noise Wall

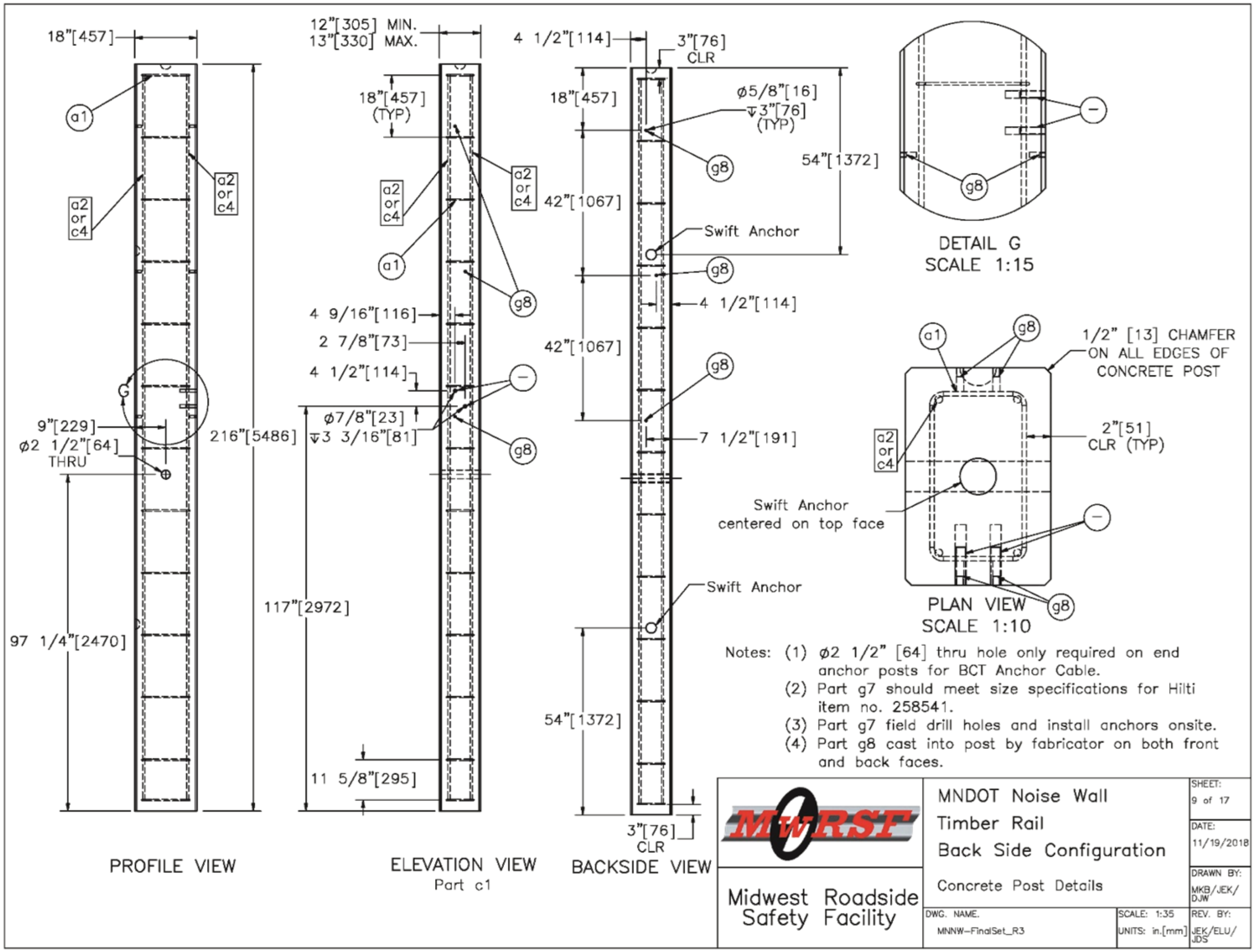
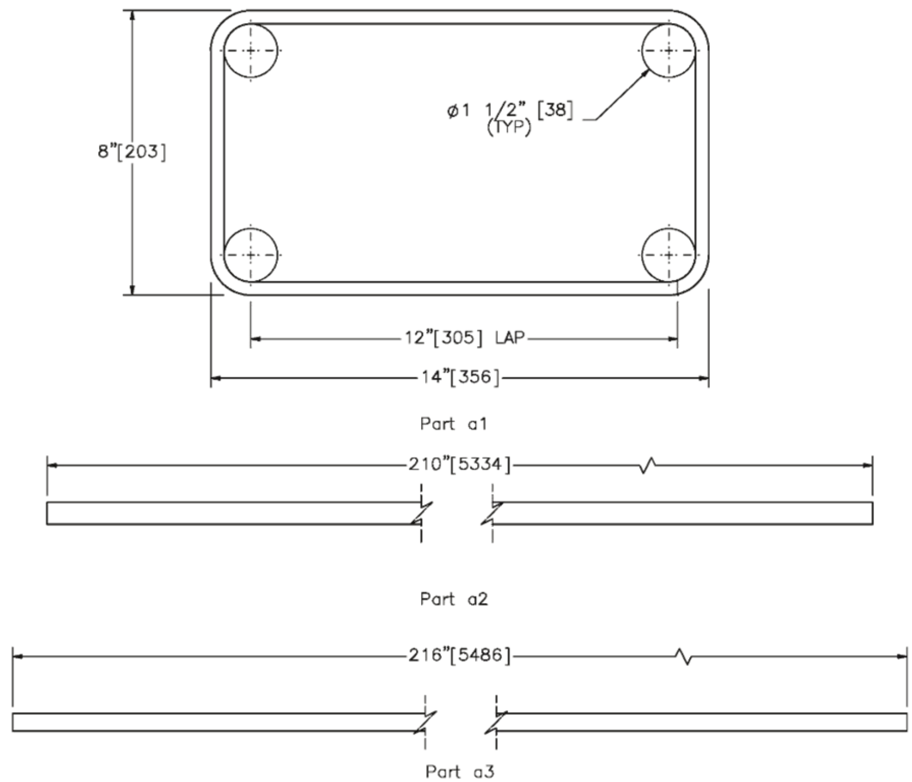


Figure 109. Concrete Post Details, Back-Side Noise Wall



BILL OF BARS			
ITEM NO.	QTY. PER POST	BAR SIZE	TOTAL LENGTH
c2	13	#3	53" [1,346]
c3	4	#5	210" [5,334]
c4	4	1/2" [13]	216" [5,486]

Notes: (1) Splices not allowed in part c3.
(2) Prestressed strands (part c4) may be used in lieu of c3 reinforcement bars. ø1/2" [13] low–relaxation, 270 ksi [1,862 MPa] ultimate strength Initial prestress = 30,900 lb [137.5 kN] per strand; cut strands flush with concrete.

Midwest Roadside Safety Facility

MNDOT Noise Wall
Timber Rail
Back Side Configuration

Concrete Post Reinforcement

SHEET: 10 of 17
DATE: 11/19/2018
DRAWN BY: MKB/JEK/DJW
DWG. NAME. MNNW–FinalSet_R3
SCALE: 1:4
UNITS: in.[mm]
REV. BY: JEK/ELU/JDS

Figure 110. Concrete Post Reinforcement, Back-Side Noise Wall

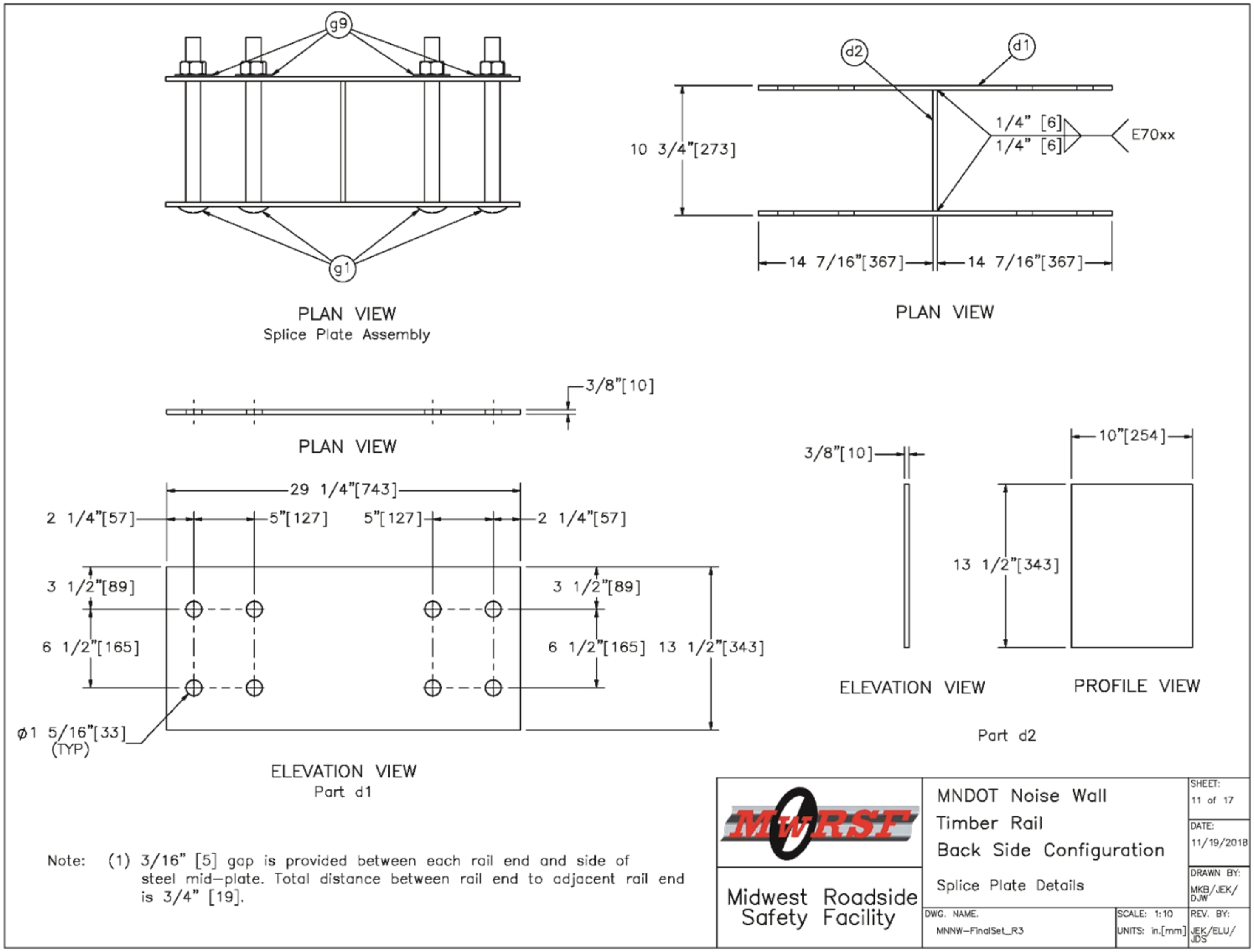


Figure 111. Splice Plate Details, Back-Side Noise Wall

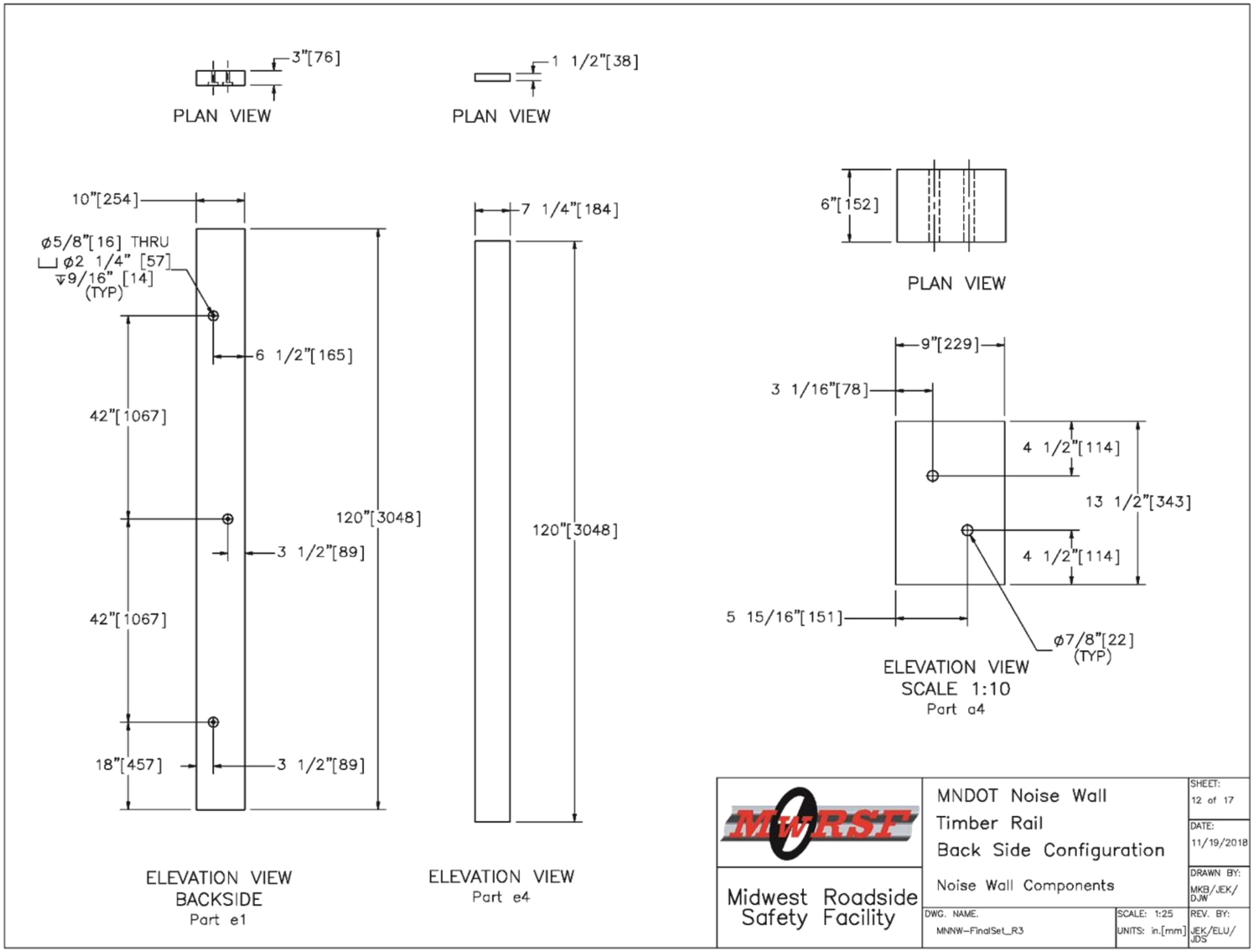


Figure 112. Noise Wall Components, Back-Side Noise Wall

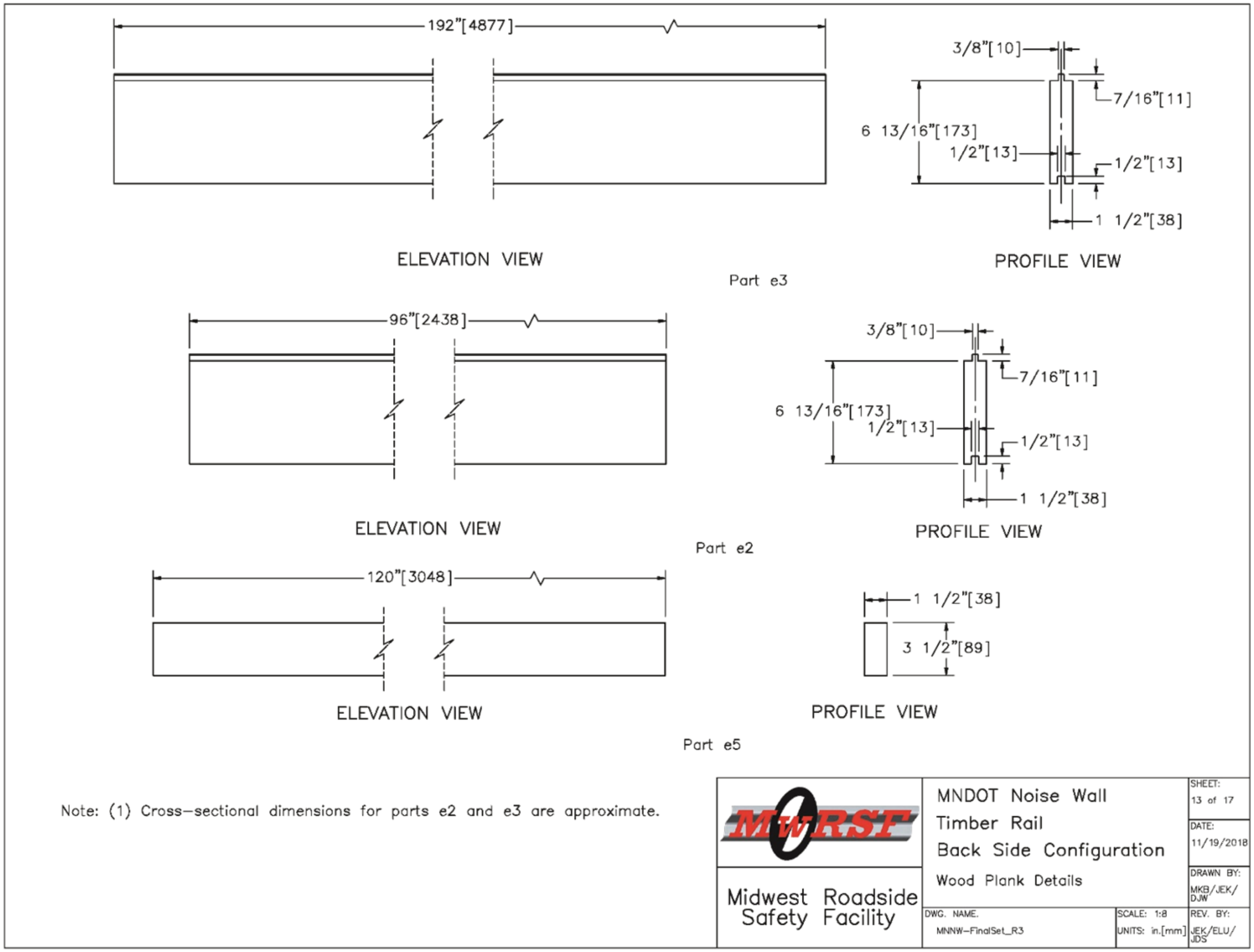


Figure 113. Wood Plank Details, Back-Side Noise Wall

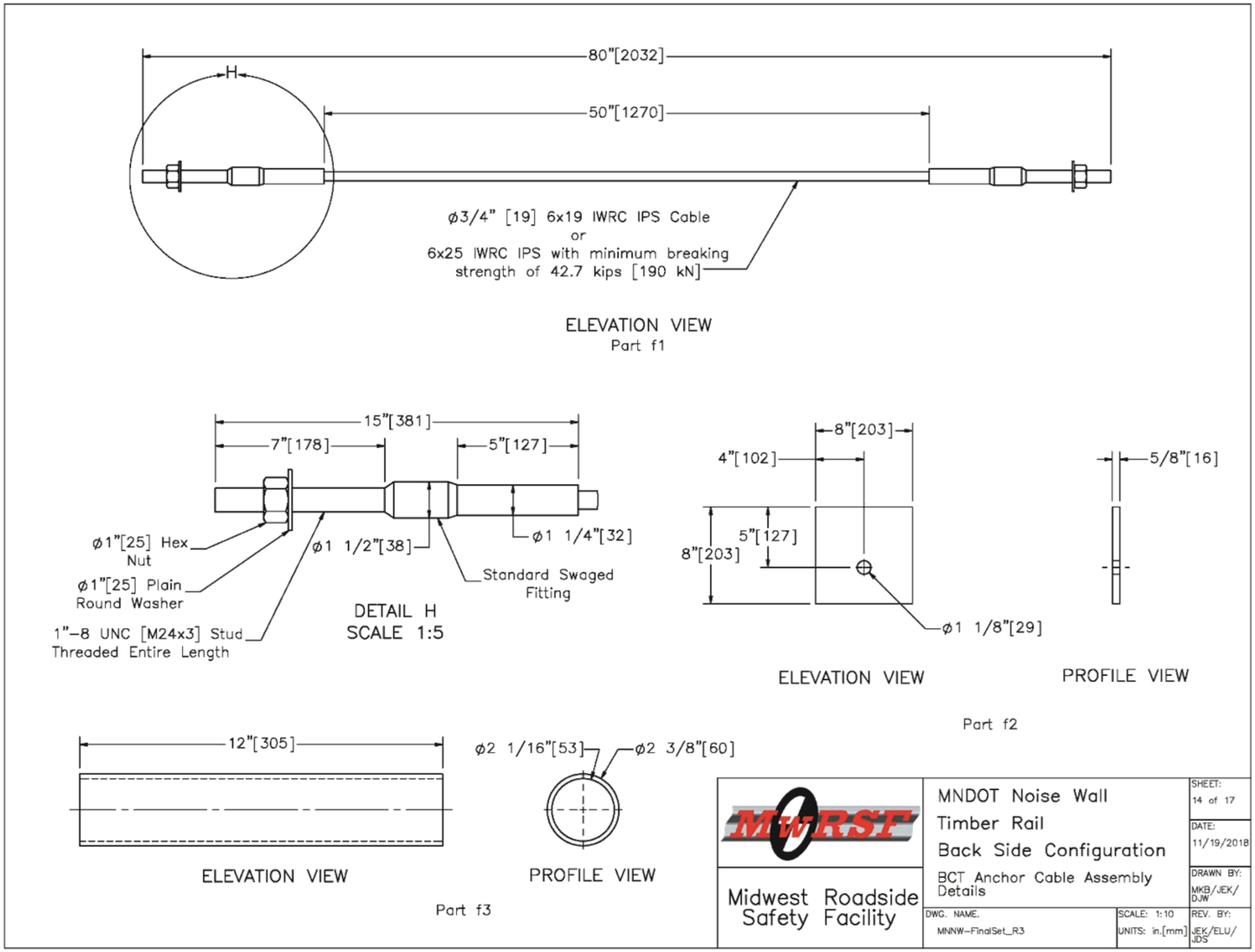


Figure 114. BCT Anchor Cable Assembly Details, Back-Side Noise Wall

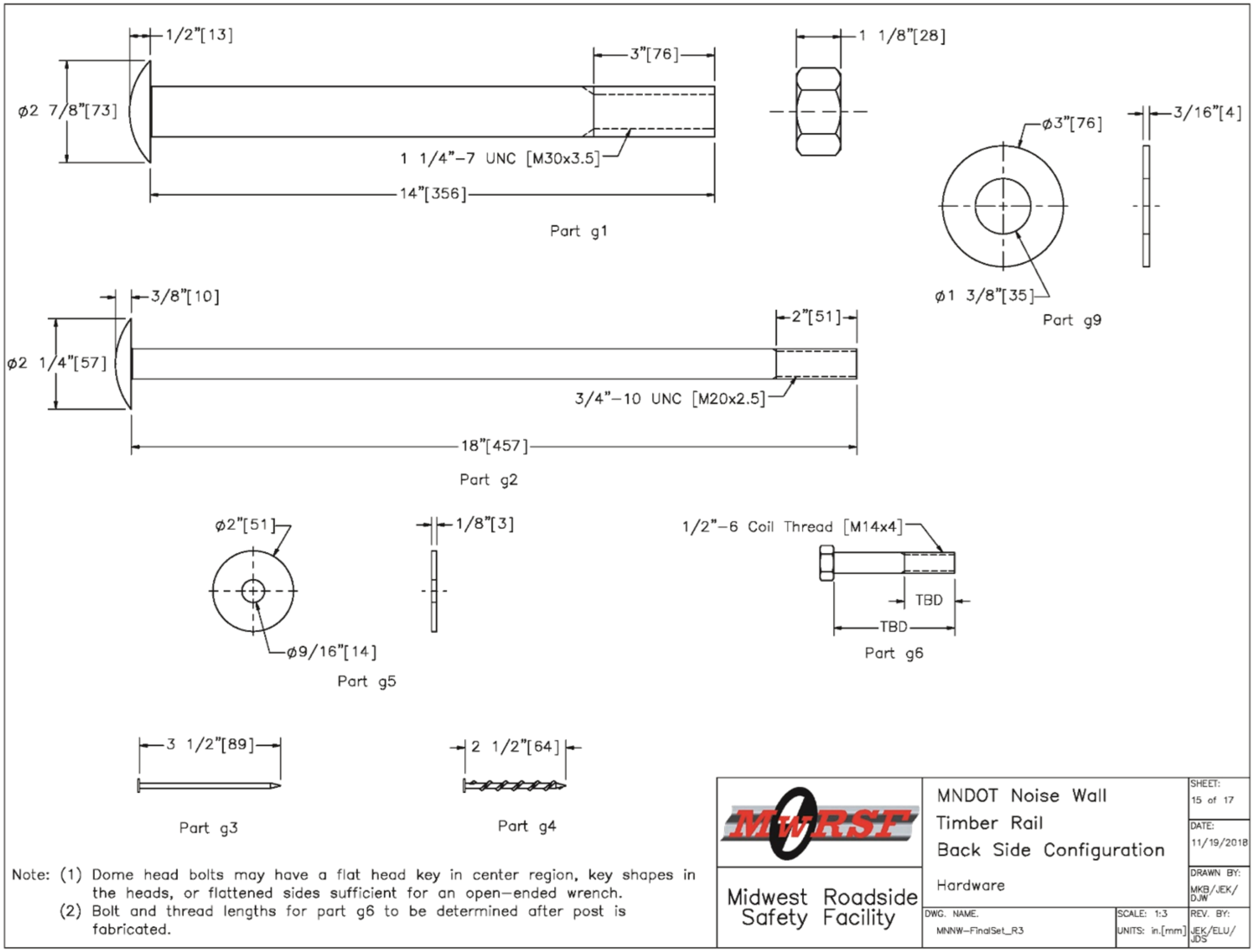


Figure 115. Hardware, Back-Side Noise Wall

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	1	125 5/8"x13 1/2"x10 3/4" [3,191x343x273] Timber Rail End Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a2	4	191 1/4"x13 1/2"x10 3/4" [4,858x343x273] Timber Rail Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a3	1	173 5/8"x13 1/2"x10 3/4" [4,410x343x273] Timber Rail End Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a4	12	13 1/2"x9"x6" [343x229x152] Wood Blockout	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
b1	2	10 1/2"x9"x3/8" [229x267x10] Steel Plate	ASTM A36	ASTM A123**	–
b2	4	3"x3"x1/4" [76x76x6] Steel Gusset	ASTM A36	ASTM A123**	–
b3	2	3"x3"x1/2" [76x76x13] Steel Plate	ASTM A36	ASTM A123**	–
c1	12	12"x18" [305x457], 18' [5,486] Long Concrete Post	Min. f'c = 5,500 psi [37.9 MPa] MnDOT mix 3W82	–	–
a1	156	3/8" [10] Dia., 53" [1,346] Long Rebar	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)	–
a2*	48	5/8" [16] Dia., 210" [5,334] Long Rebar	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)	–
c4*	48	1/2" [13] Dia, 7–Wire Pre–Stressing Strand, 216" [5,486] Long	ASTM A416 Gr. 270	–	–
d1	10	29 1/4"x13 1/2"x3/8" [743x343x10] Steel Plate	ASTM A36	ASTM A123**	–
d2	5	13 1/2"x10"x3/8" [343x254x10] Steel Plate	ASTM A36	ASTM A123**	–
e1	12	3"x10" [76x254], 10' [3,048] Long Vertical Wood Nailer	SYP Gr. No. 1 Dense or better standard rough sawn or Douglas Fir–Larch No. 1 or Douglas Fir–Larch (North) Select Structural or Douglas Fir–South Select Structural or equivalent with min F'b = 1,200 psi [8.3 MPa]	See Note 4	–
e2	17	2"x8" [51x203], 8' [2,438] Long Tongue and Groove Wood Plank	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e3	85	2"x8" [51x203], 16' [4,877] Long Tongue and Groove Wood Plank	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e4	12	2"x8" [51x203], 10' [3,048] Long Wood Batten	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e5	2	2"x4" [51x102], 10' [3,048] Long Wood Plank	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–

*Use either part c3 or c4.

** Weld before galvanization.

Notes:
(1) Timber rail sections and blockouts shall be treated with pentachlorophenol (PCP–A) in heavy oil to a minimum net retention of 0.6 lb/ft^3 (9.6 kg/m^3) in accordance with AWPA Standard U1 to the requirements of Use Category 4A (UC4A).
(2) Wood shall be cut, drilled, and completely fabricated prior to treatment with preservative. Drain excess chemicals and dry all treated wood at the place of manufacture.
(3) All field cuts, bore holes, and damages shall be treated with material acceptable to the engineer prior to installation.
(4) Provide preservative treated timber products per Spec. 3491.

Midwest Roadside Safety Facility

MNDOT Noise Wall
Timber Rail
Back Side Configuration

Bill of Materials

SHEET: 16 of 17
DATE: 11/19/2018
DRAWN BY: MKB/JEK/DJW
DWG. NAME. MNNW–FinalSet_R3
SCALE: None
UNITS: in.[mm]
REV. BY: JEK/ELU/JDS

Figure 116. Bill of Materials, Back-Side Noise Wall

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
f1	2	BCT Anchor Cable	–	–	FCA01
f2	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
f3	2	2 3/8" [60] O.D. x 12" [305] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	–
g1*	48	1 1/4"–7 UNC [M30x3.5], 14" [356] Long Dome Head Bolt and Nut	Bolt – ASTM A307 Gr. A or equivalent Nut – ASTM A563A or equivalent	ASTM A153 or B695 Class 55 or F2329	FBB09a
g2	24	3/4"–10 UNC [M20x2.5], 18" [457] Long Dome Head Bolt with a Flat Head or Other Key Shape in Center Region or Flattened Sides	ASTM A307 Gr. A or equivalent	ASTM A153 or B695 Class 55 or F2329	FBB08a
g3	969	16D Ring Shank Nail	–	–	–
g4	408	No. 8 x 2 1/2" [64] Long Bugle Head Exterior Screw	–	ASTM A153 or B695 Class 55	–
g5	36	1/2" [13] Dia. Round Plate Washer	ASTM F844	ASTM A123 or A153 or F2329	–
g6	36	1/2"–6 Coil Thread [M14x4], 3" [76] Long Hex Head Bolt	ASTM A307 Gr. A or equivalent	ASTM A153 or B695 Class 55 or F2329	–
g7	24	3/4"–10 UNC [M20x2.5] Drop–In Concrete Anchor	Hilti Item No. 258541 or similiar	Zinc–Plated or Galvanized	–
g8	72	1/2"–6 Coil Thread [M14x4] Concrete Anchor	As Supplied	Galvanize per spec. 3392 or electroplate per ASTM B633 SC4 Type II	–
g9	48	1 1/4" [32] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC30a

*Anchor plate bolts can have fins or lugs. Splice bolts should not have lugs or fins.

Note: (1) Hilti Item No. 258541 (Part g7) is not compatible with hot–dipped galvanized bolts. Recommend using inserts and bolts that are both zinc–plated or both galvanized so that thread patterns are compatible.

Midwest Roadside Safety Facility

MNDOT Noise Wall Timber Rail Back Side Configuration

Bill of Materials

SHEET: 17 of 17
DATE: 11/19/2018
DRAWN BY: MKB/JEK/DJW
DWG. NAME. MNNW–FinalSet_R3
SCALE: None
UNITS: in.[mm]
REV. BY: JEK/ELU/JDS

Figure 117. Bill of Materials, Back-Side Noise Wall (continued)

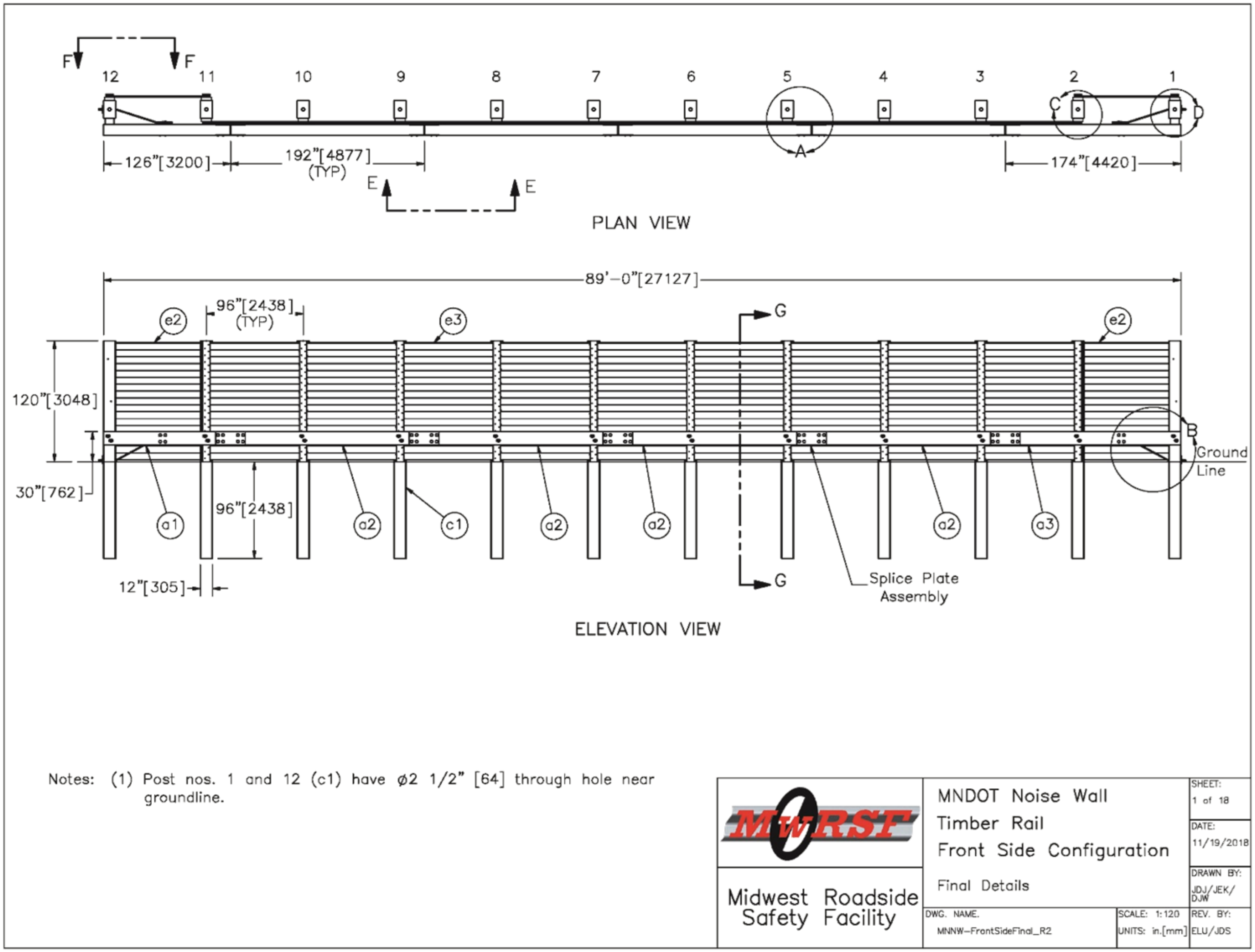


Figure 118. Final Details, Front-Side Noise Wall

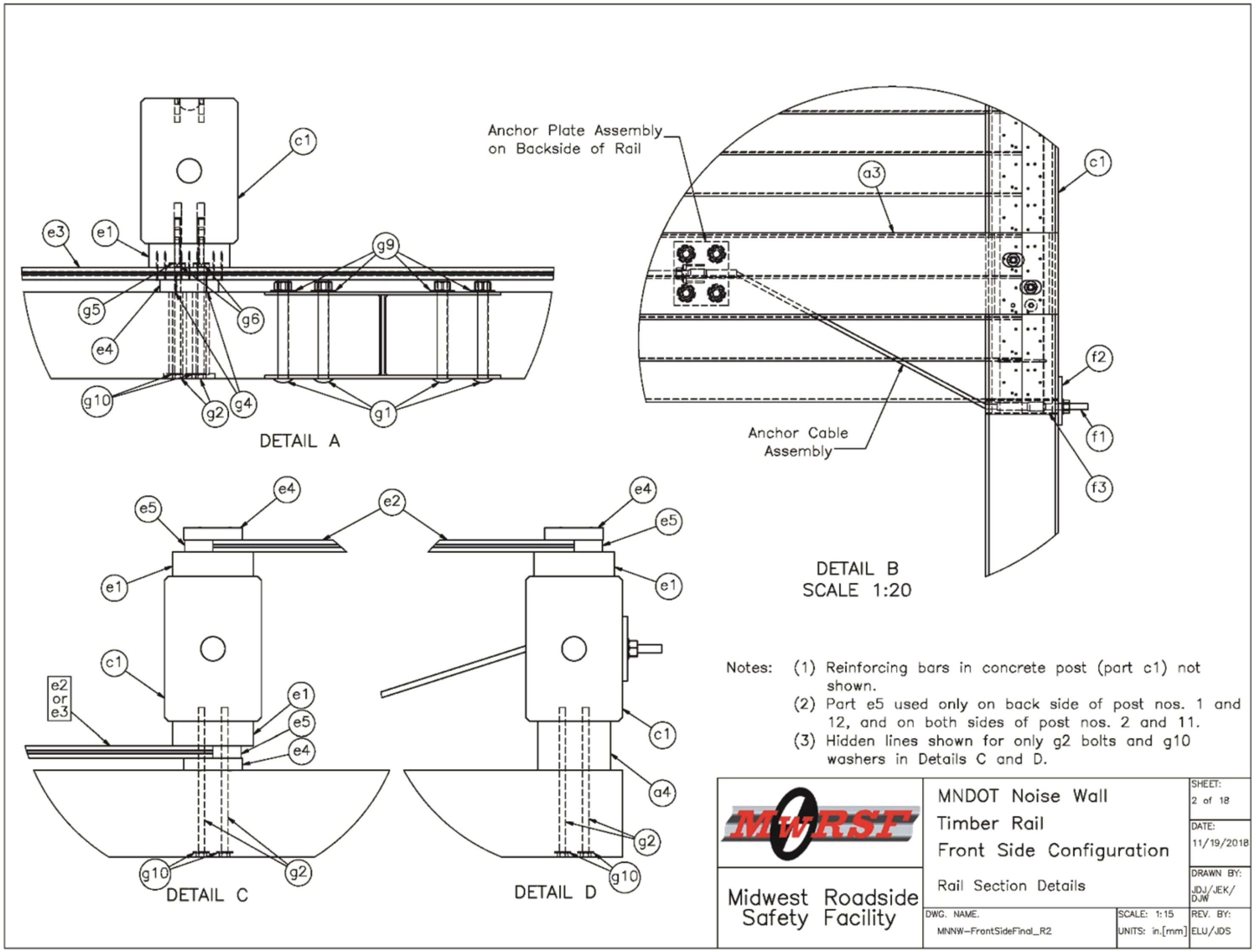


Figure 119. Rail Section Details, Front-Side Noise Wall

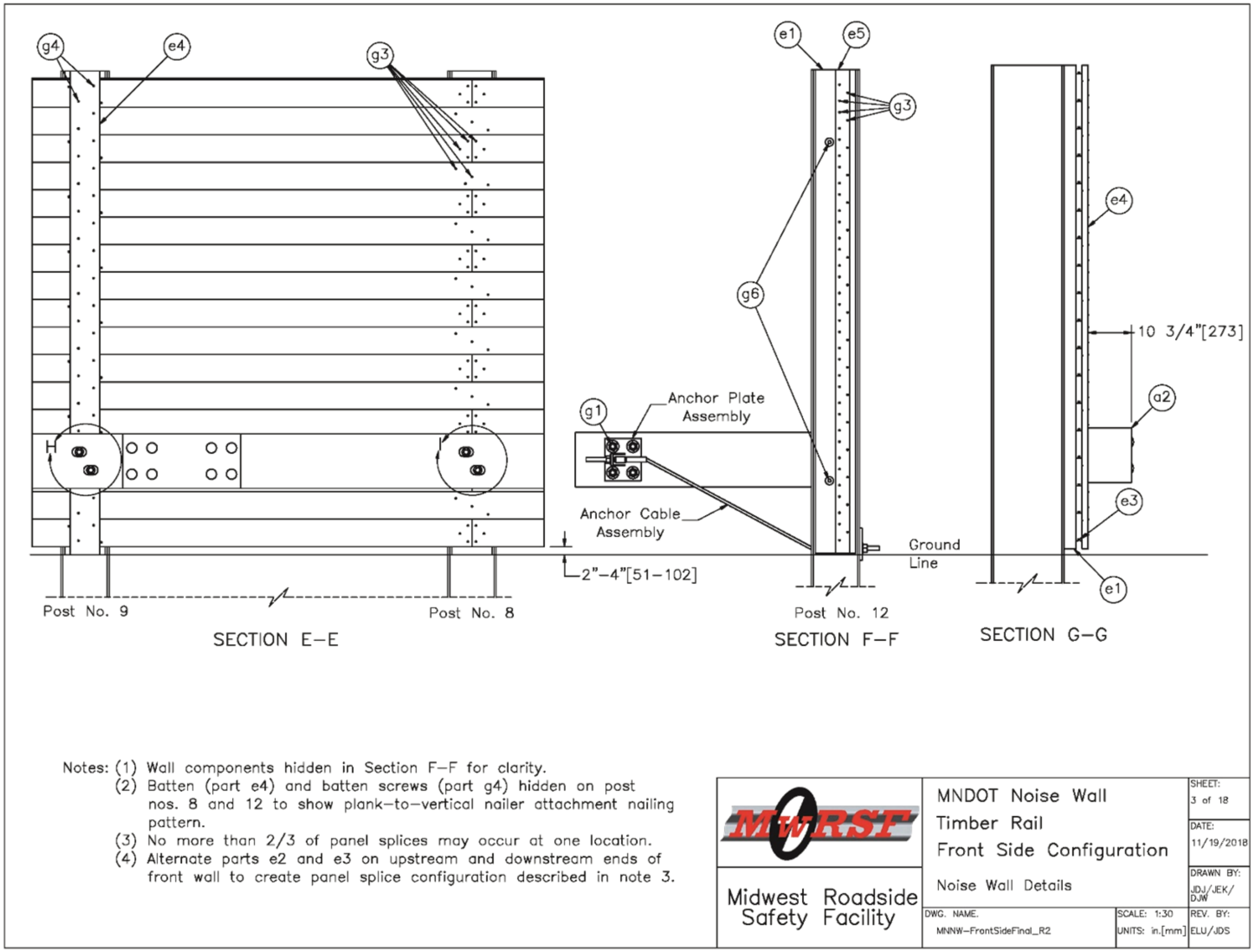
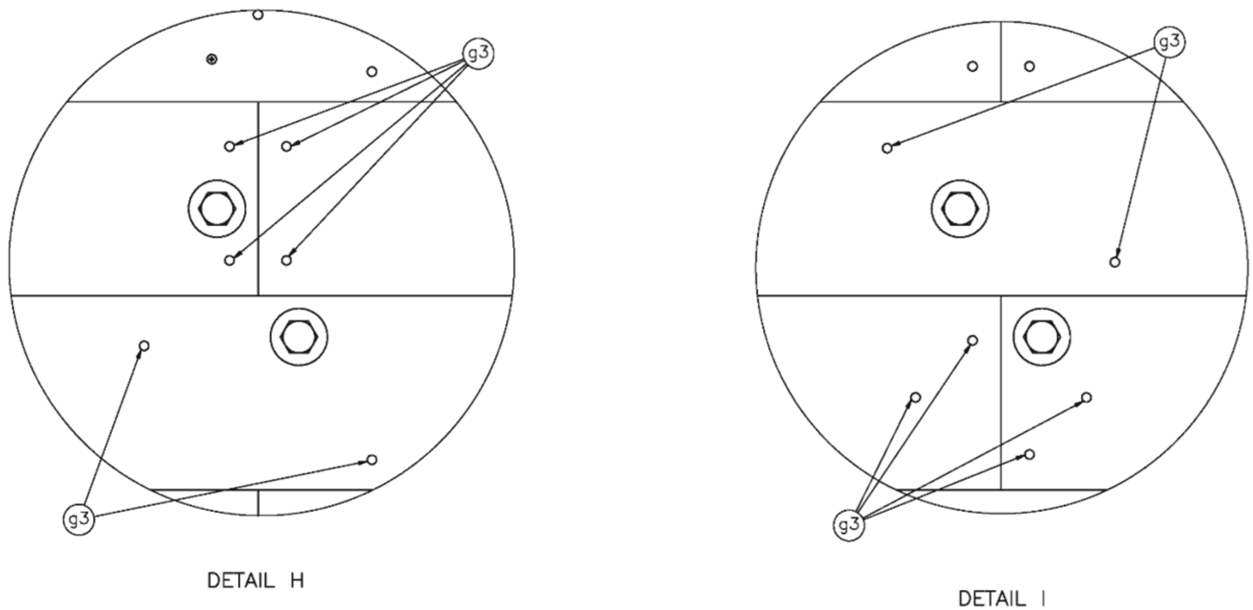


Figure 120. Noise Wall Details, Front-Side Noise Wall



Notes: (1) Rail segments (part a2) and batten (part e4) hidden in both detail views.
(2) Use two nails (part g3) per wall board (parts e2 and e3) attachment location where the rail attaches to posts.
(3) Screws (part g4) not used on the front of the wall where the rail attaches to posts.

MwRSF Midwest Roadside Safety Facility	MNDOT Noise Wall Timber Rail Front Side Configuration Post Attachment Nailing Pattern	SHEET: 4 of 18
		DATE: 11/19/2018
		DRAWN BY: JDJ/JEK/DJW
	DWG. NAME. MNNW–FrontSideFinal_R2 / SCALE: 1:5 UNITS: in.[mm]	REV. BY: ELU/JDS

Figure 121. Post Attachment Nailing Pattern, Front-Side Noise Wall

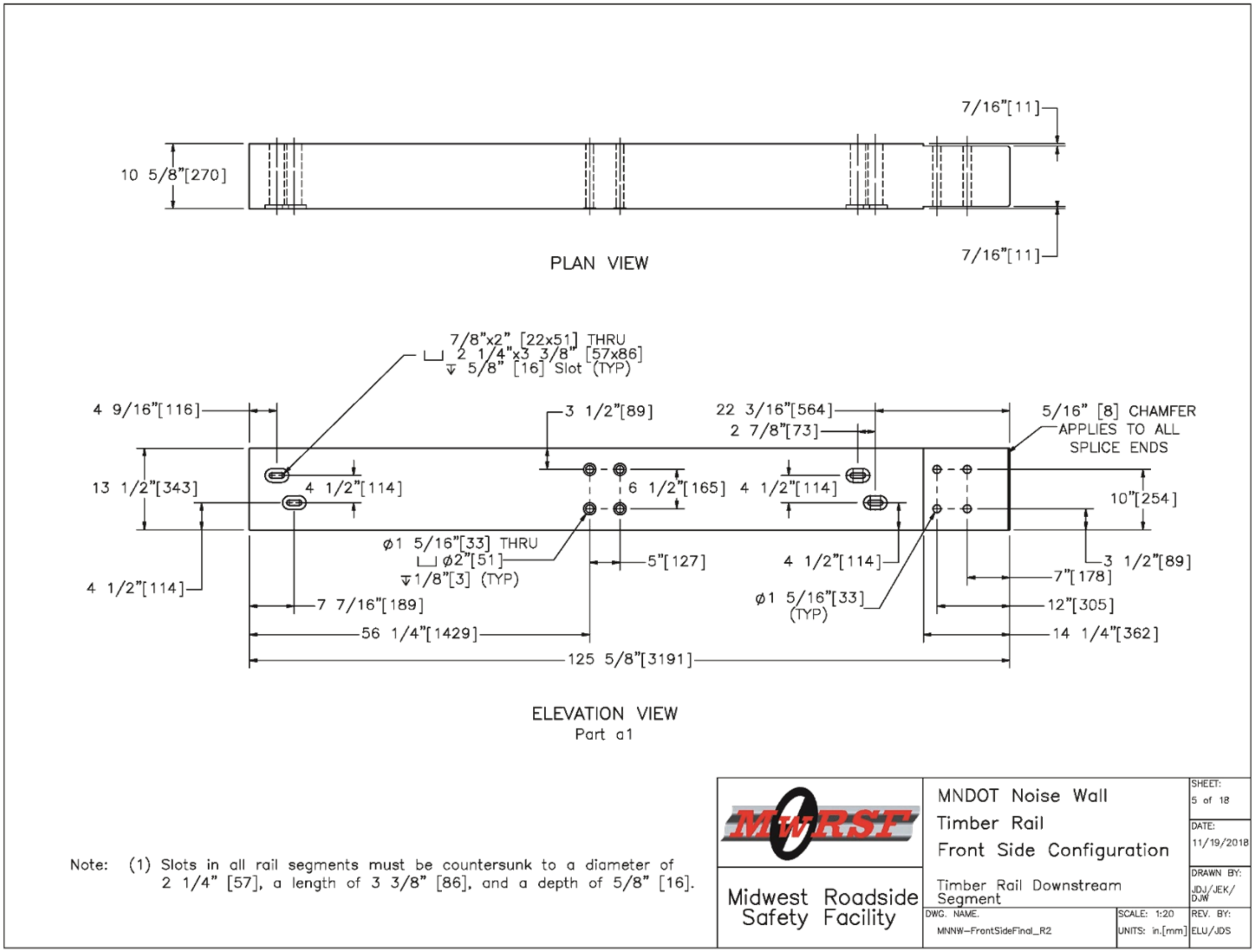


Figure 122. Timber Rail Downstream Segment, Front-Side Noise Wall

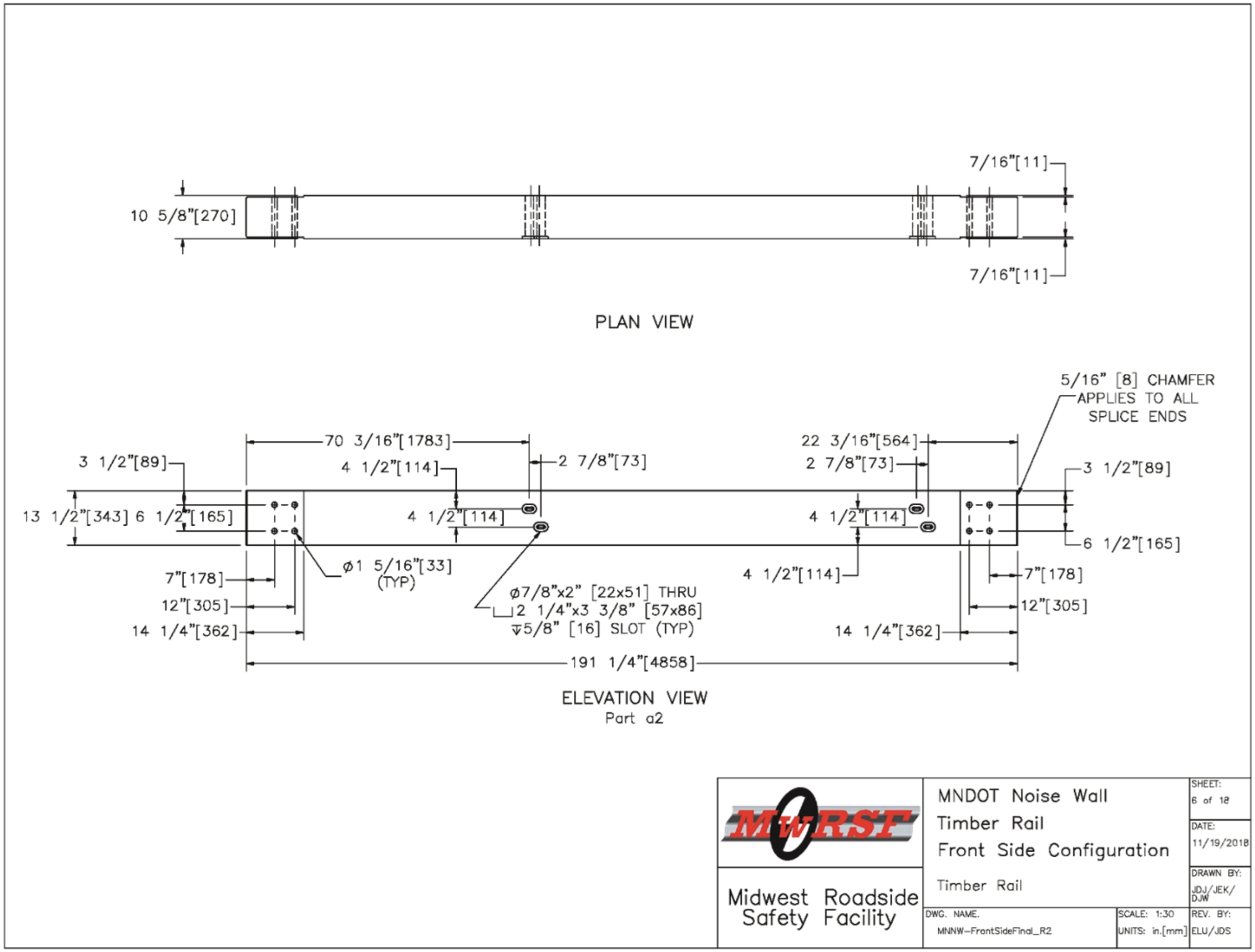


Figure 123. Timber Rail, Front-Side Noise Wall

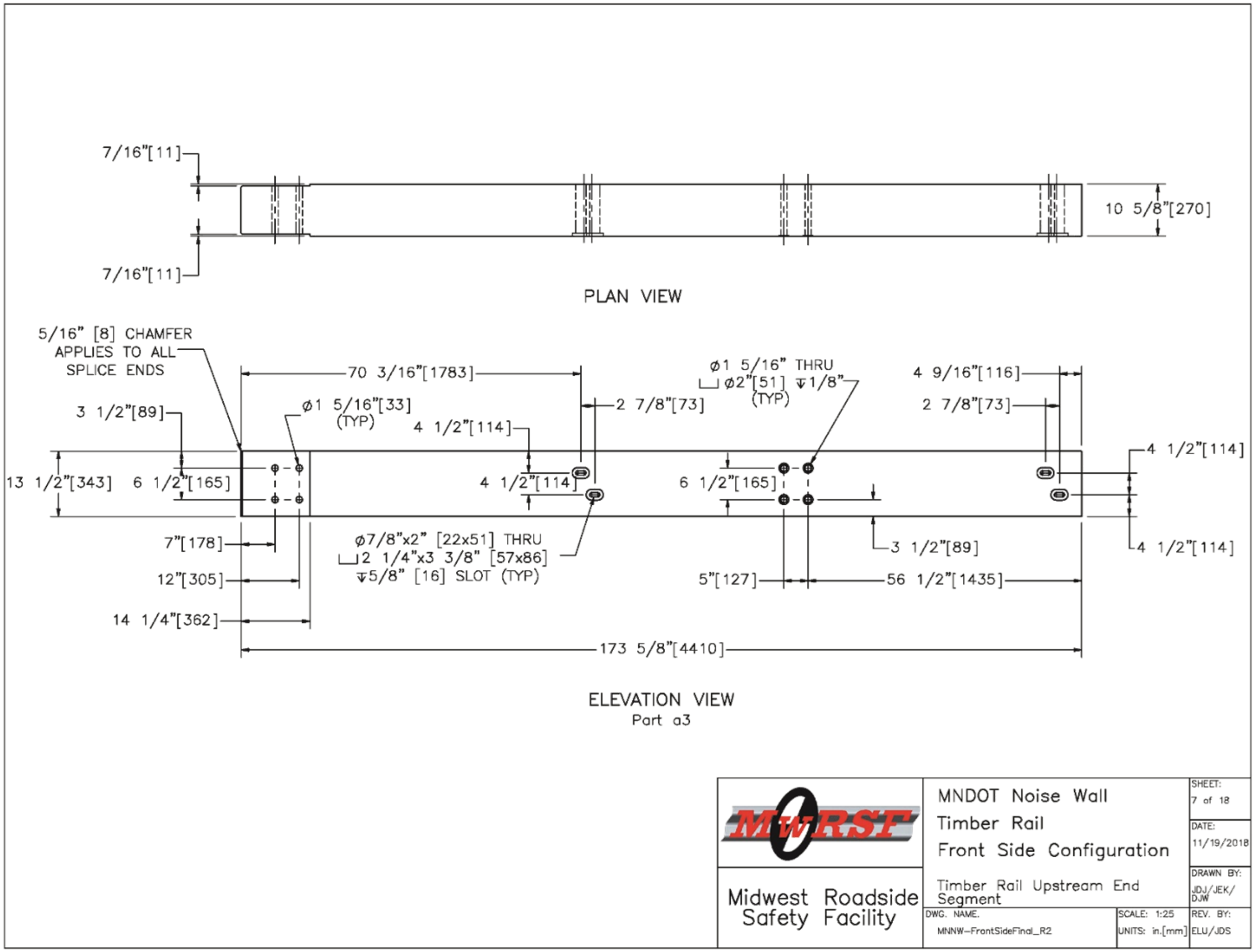


Figure 124. Timber Rail Upstream End Segment, Front-Side Noise Wall

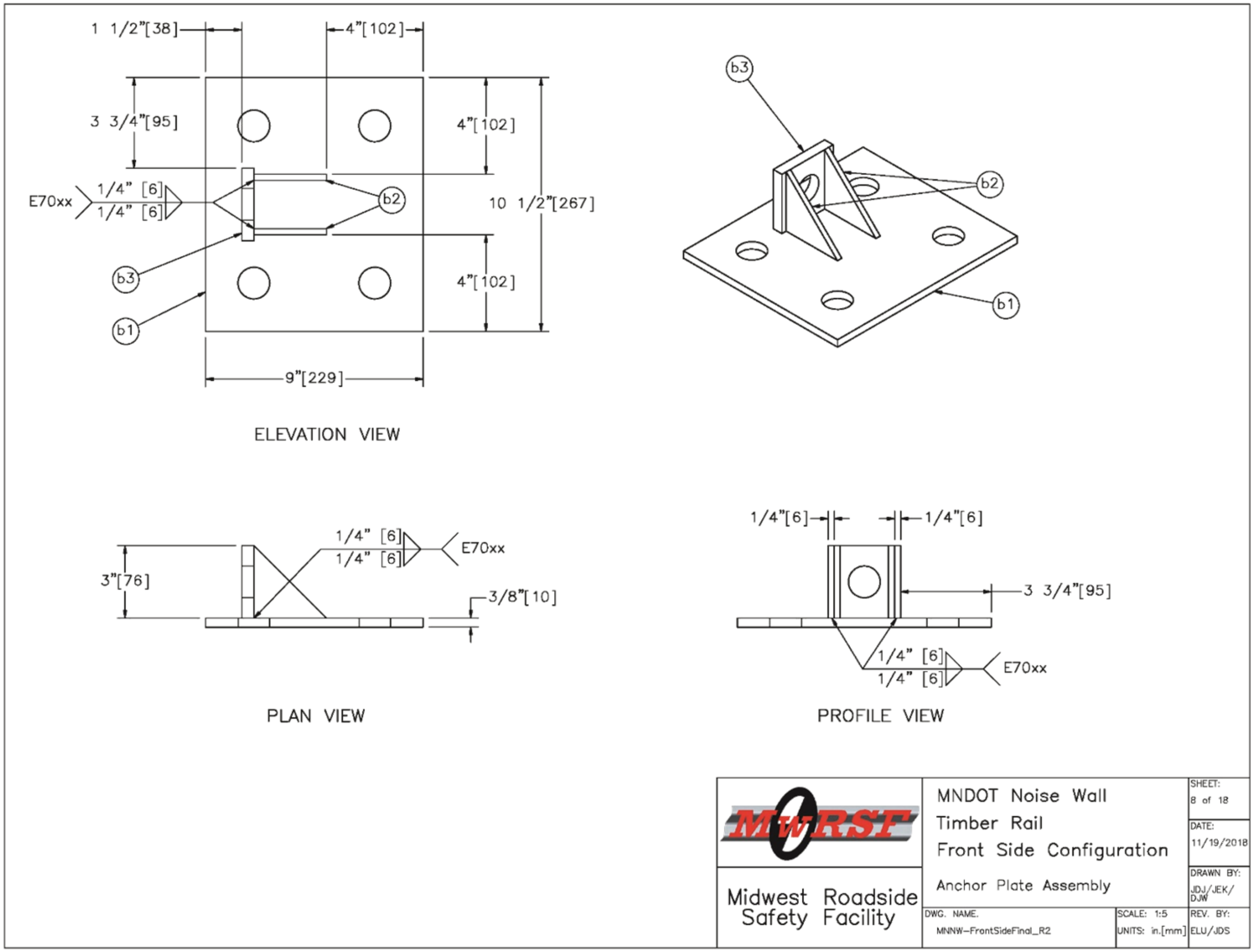


Figure 125. Anchor Plate Assembly, Front-Side Noise Wall

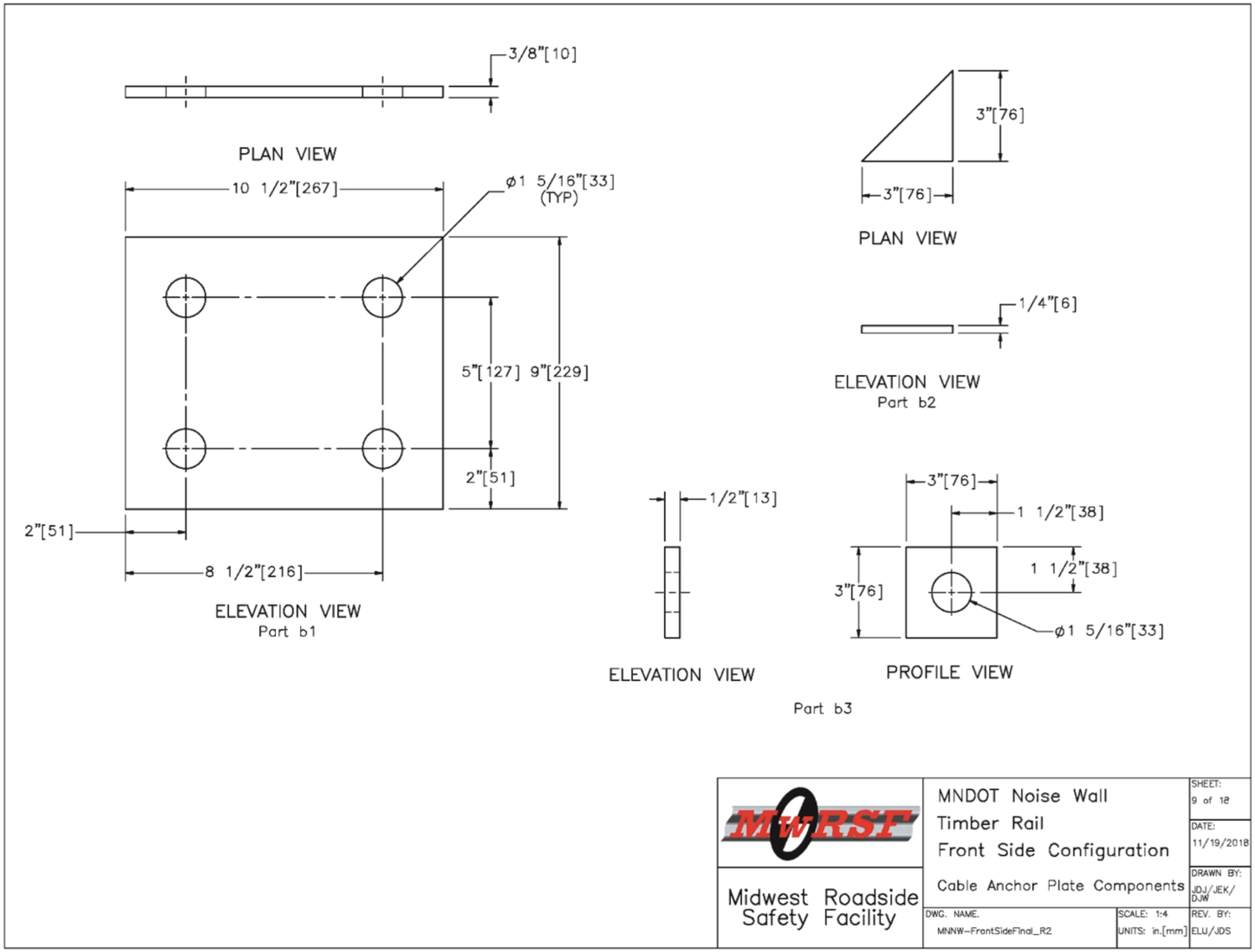


Figure 126. Cable Anchor Plate Components, Front-Side Noise Wall

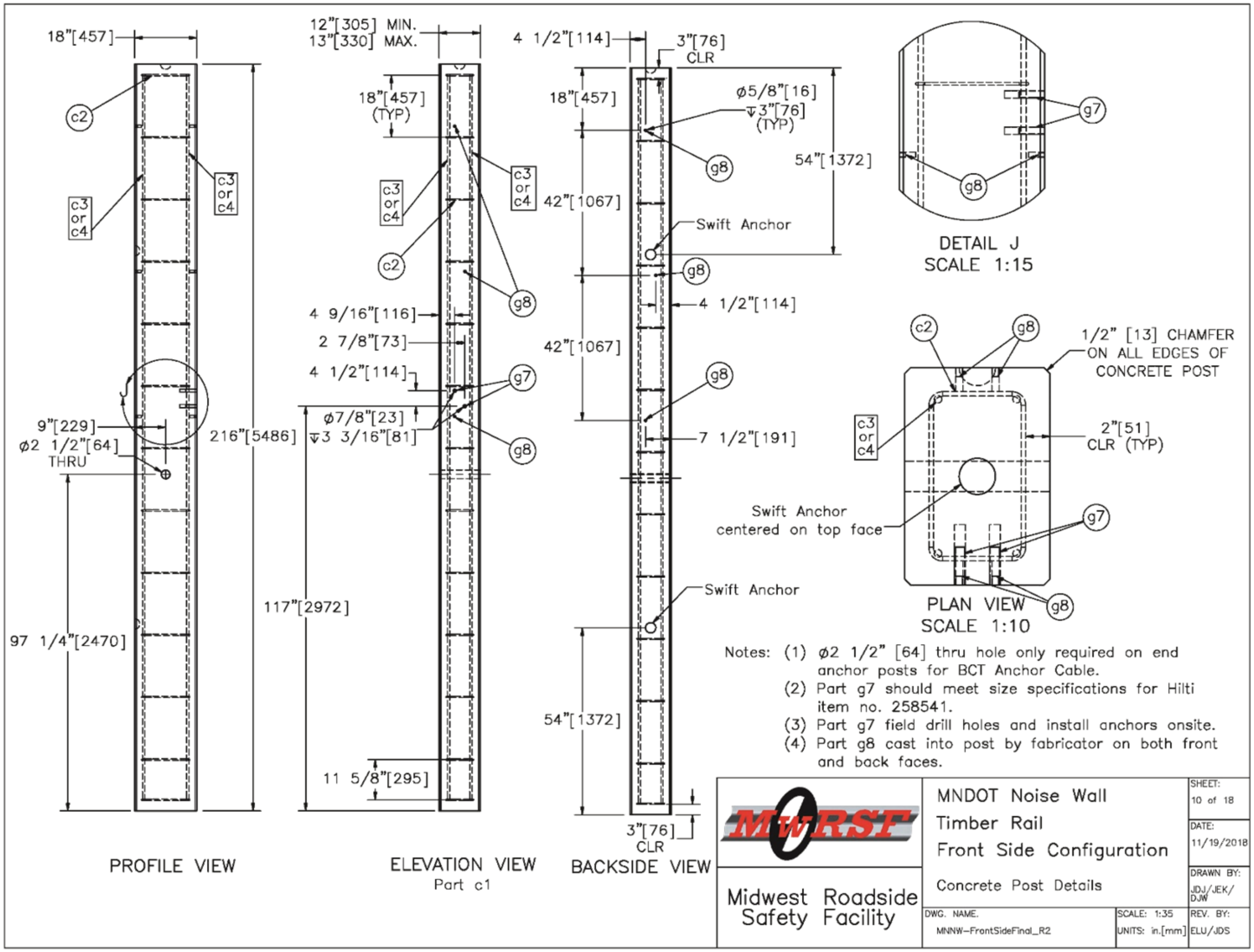
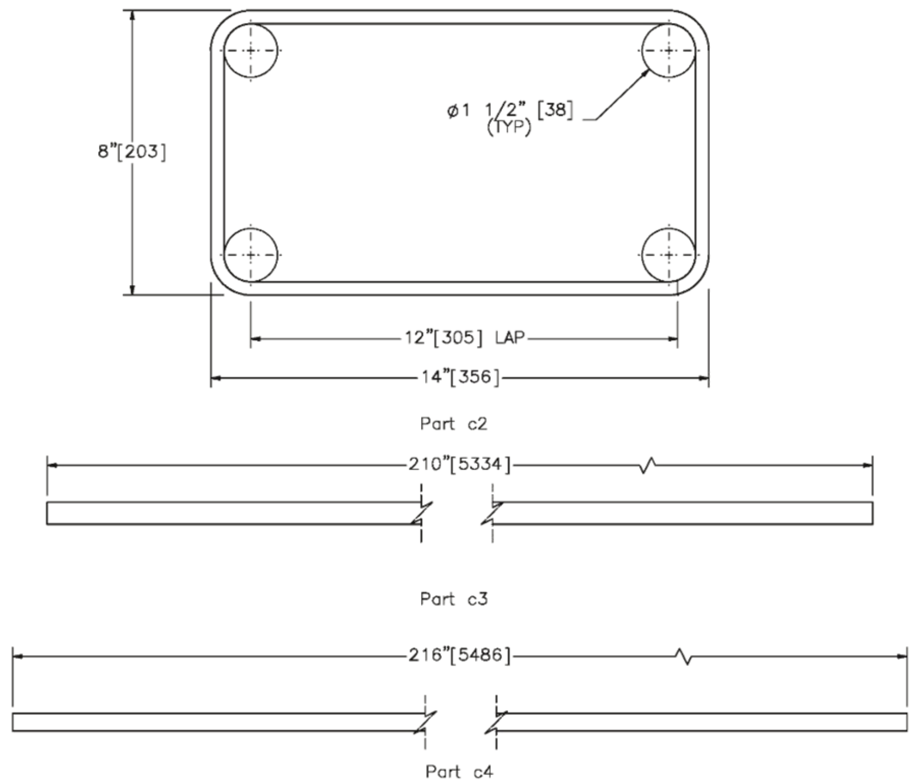


Figure 127. Concrete Post Details, Front-Side Noise Wall



BILL OF BARS			
ITEM NO.	QTY. PER POST	BAR SIZE	TOTAL LENGTH
c2	13	#3	53" [1,346]
c3	4	#5	210" [5,334]
c4	4	1/2" [13]	216" [5,486]

Notes: (1) Splices not allowed in part c3.
(2) Prestressed strands (part c4) may be used in lieu of c3 reinforcement bars. ø1/2" [13] low-relaxation, 270 ksi [1,862 MPa] ultimate strength Initial prestress = 30,900 lb [137.5 kN] per strand; cut strands flush with concrete.

Midwest Roadside Safety Facility

MNDOT Noise Wall
Timber Rail
Front Side Configuration

Concrete Post Reinforcement

SHEET: 11 of 18
DATE: 11/19/2018
DRAWN BY: JDJ/JEK/DJW
DWG. NAME. MNNW-FrontSideFinal_R2
SCALE: 1:4
UNITS: in.[mm]
REV. BY: ELU/JDS

Figure 128. Concrete Post Reinforcement, Front-Side Noise Wall

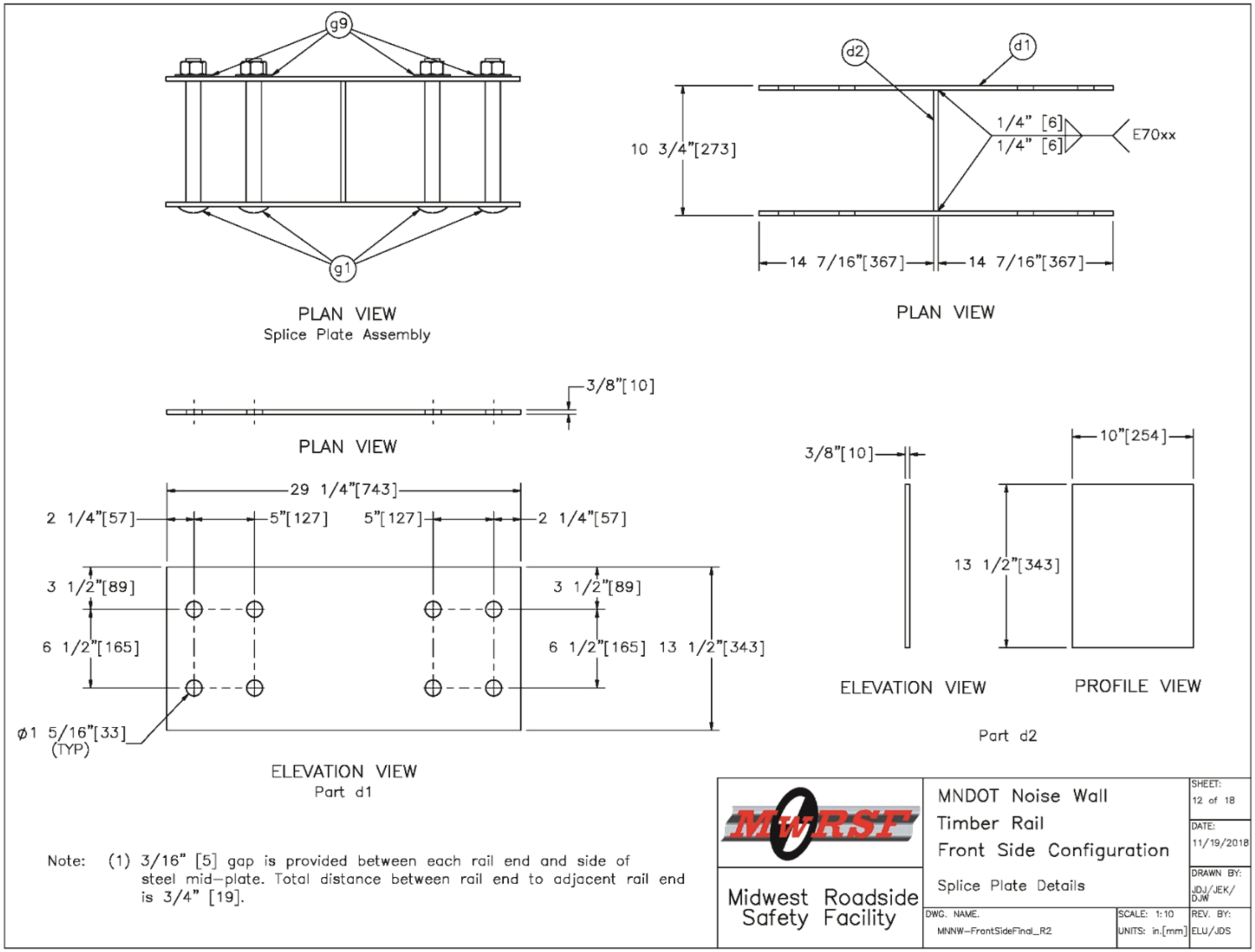


Figure 129. Splice Plate Details, Front-Side Noise Wall

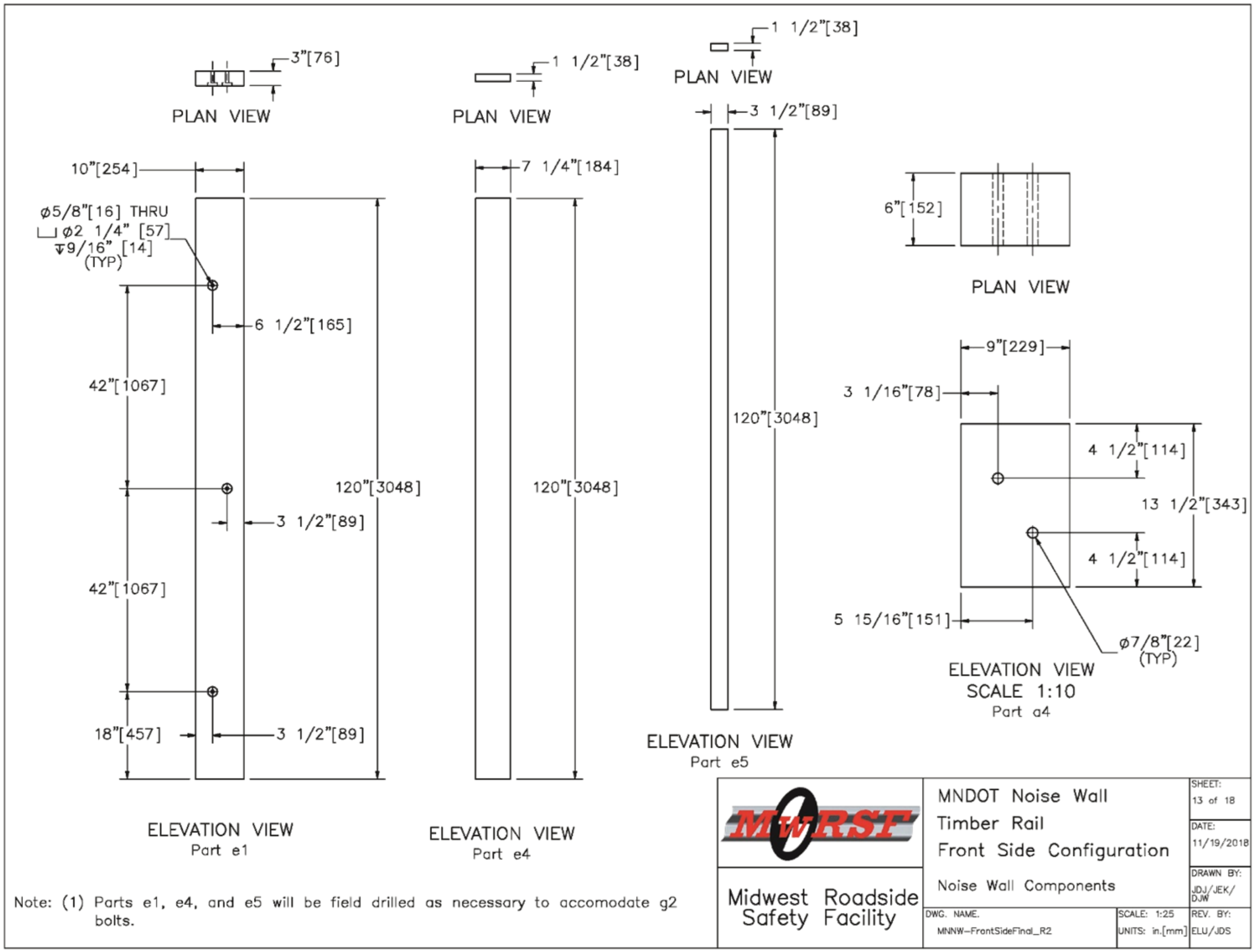


Figure 130. Noise Wall Components, Front-Side Noise Wall

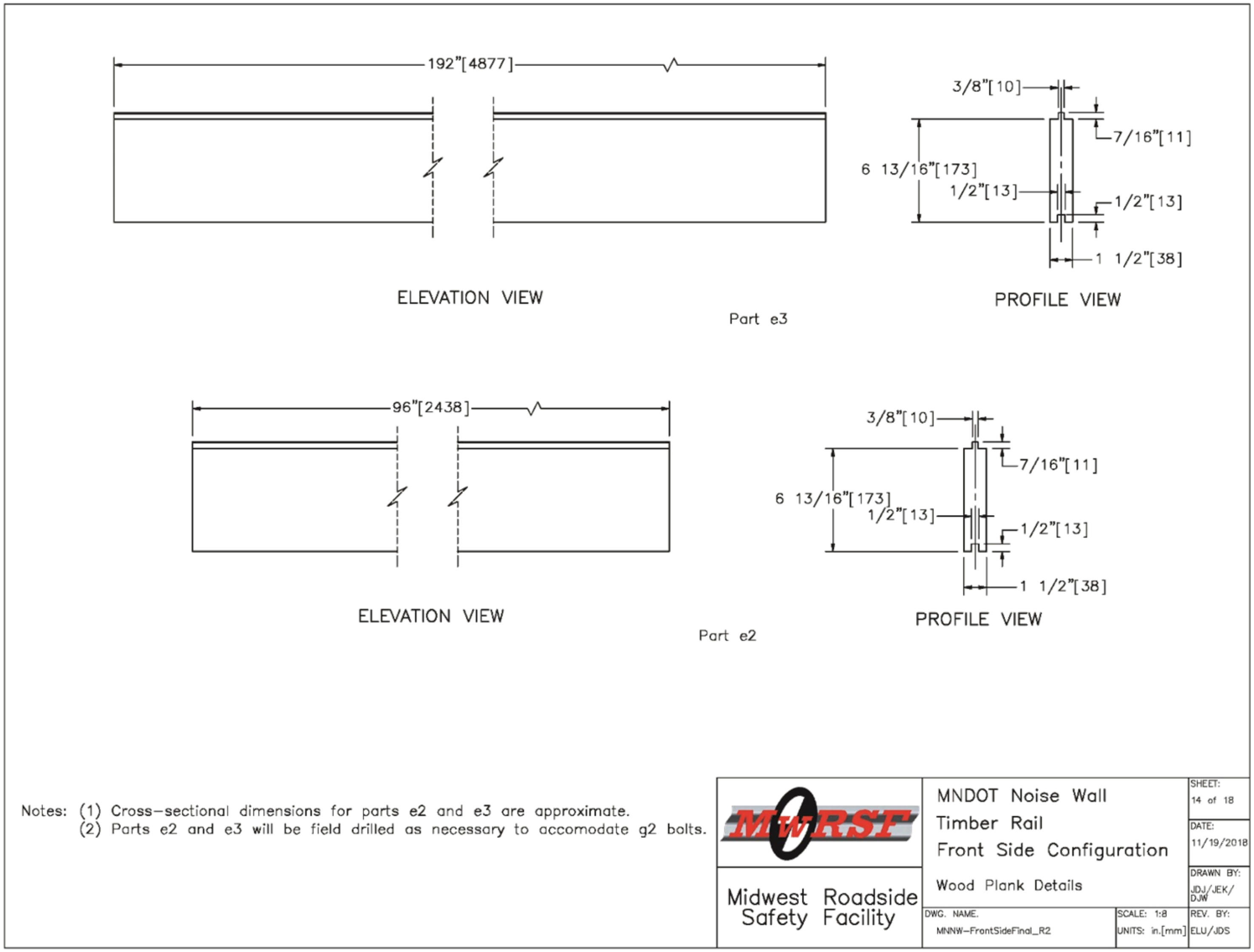


Figure 131. Wood Plank Details, Front-Side Noise Wall

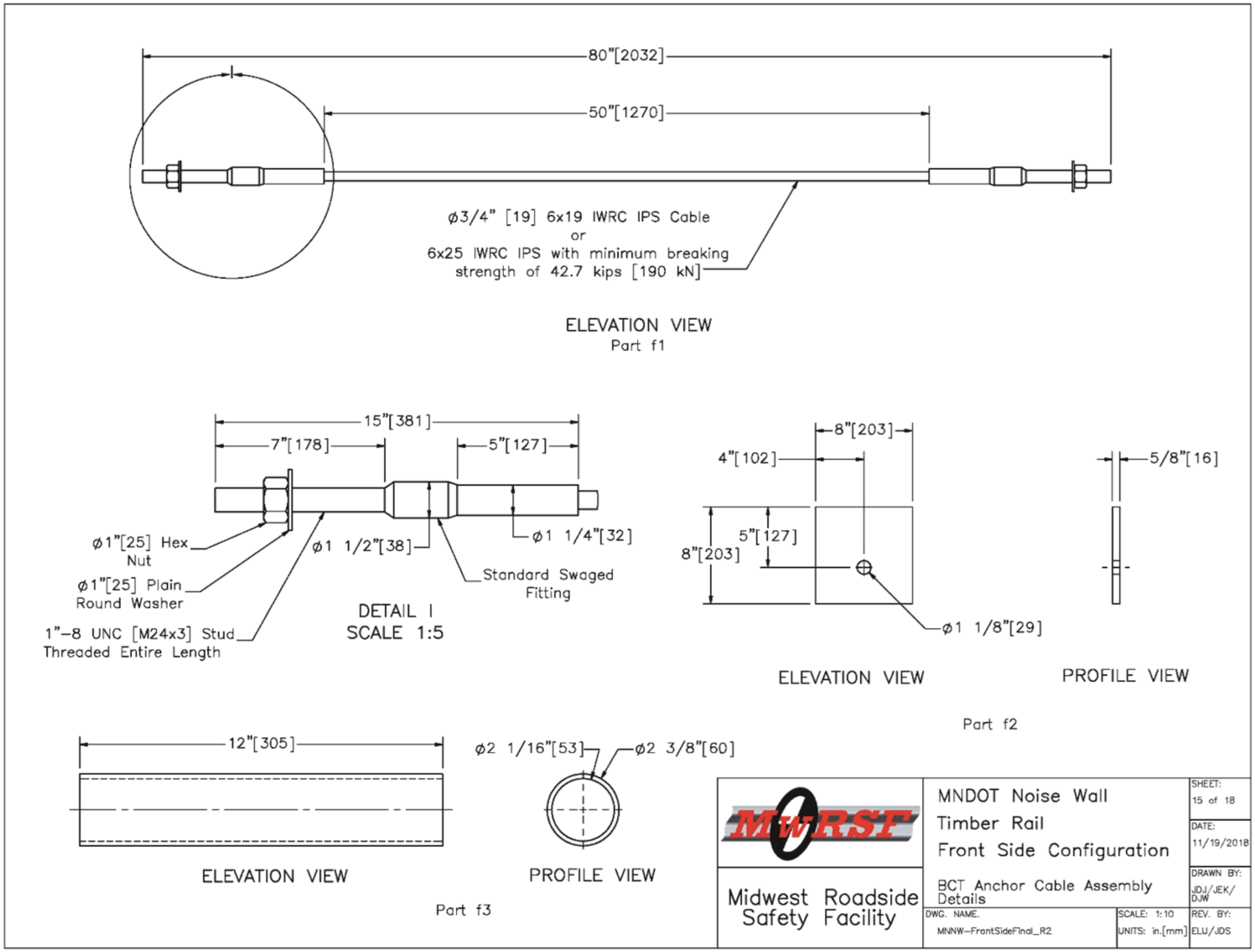


Figure 132. BCT Anchor Cable Assembly Details, Front-Side Noise Wall

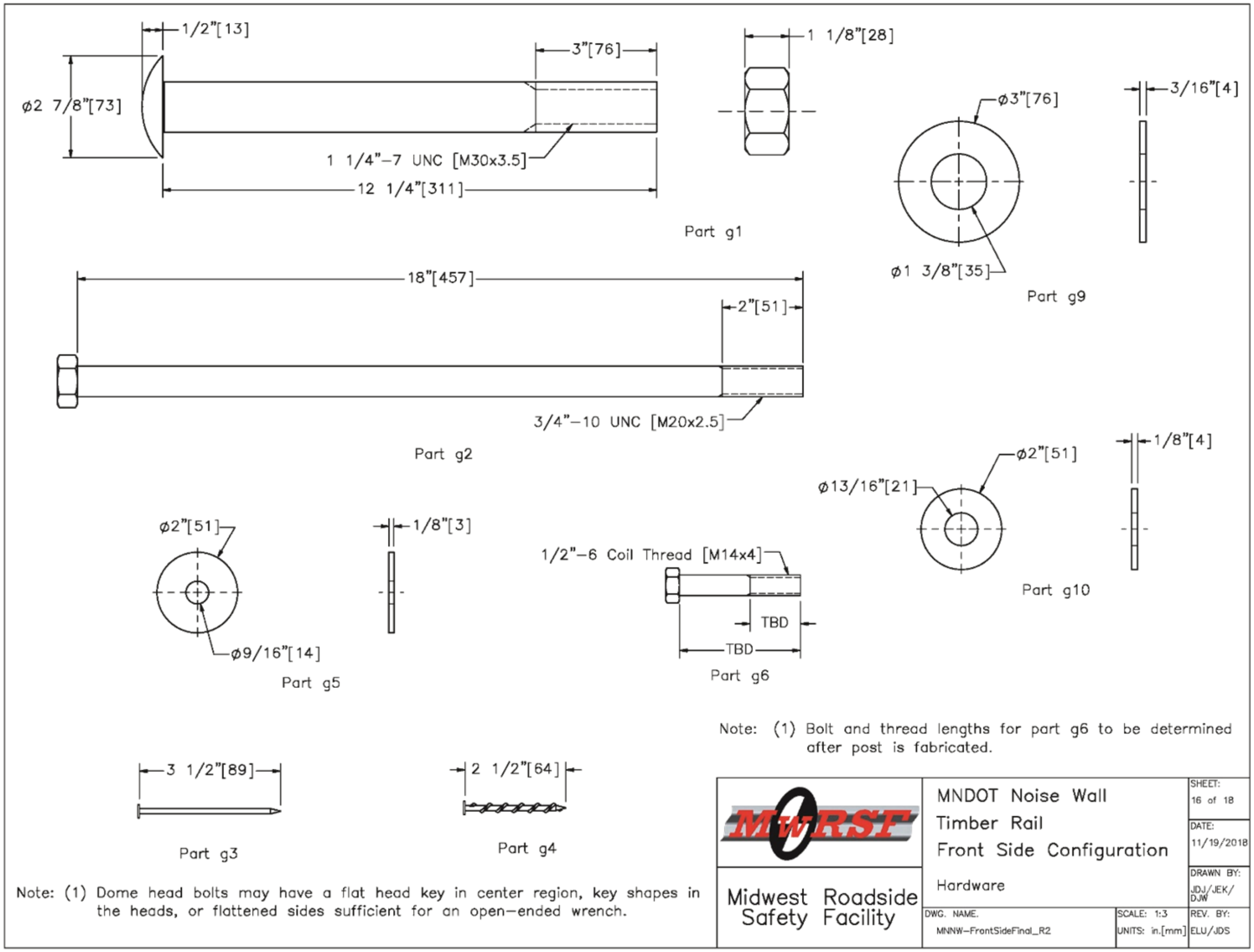


Figure 133. Hardware, Front-Side Noise Wall

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	1	125 5/8"x13 1/2"x10 3/4" [3,191x343x273] Timber Rail End Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a2	4	191 1/4"x13 1/2"x10 3/4" [4,858x343x273] Timber Rail Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a3	1	173 5/8"x13 1/2"x10 3/4" [4,410x343x273] Timber Rail End Section	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
a4	2	13 1/2"x9"x6" [343x229x152] Wood Blockout	GLULAM – Comb. 48(SP) or Comb. 2(Western species)	See Notes 1–3	–
b1	2	10 1/2"x9"x3/8" [229x267x10] Steel Plate	ASTM A36	ASTM A123**	–
b2	4	3"x3"x1/4" [76x76x6] Steel Gusset	ASTM A36	ASTM A123**	–
b3	2	3"x3"x1/2" [76x76x13] Steel Plate	ASTM A36	ASTM A123**	–
c1	12	12"x18" [305x457], 18' [5,486] Long Concrete Post	Min. f'c = 4,000 ksi [27.6 MPa]	–	–
c2	156	3/8" [10] Dia., 53" [1,346] Long Rebar	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)	–
c3*	48	1/2" [13] Dia., 210" [5,334] Long Rebar	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)	–
c4*	48	1/2" [13] Dia, 7–Wire Pre–Stressing Strand, 216" [5,486] Long	ASTM A416 Gr. 270	–	–
d1	10	29 1/4"x13 1/2"x3/8" [743x343x10] Steel Plate	ASTM A36	ASTM A123**	–
d2	5	13 1/2"x10"x3/8" [343x254x10] Steel Plate	ASTM A36	ASTM A123**	–
e1	14	3"x10" [76x254], 10' [3,048] Long Vertical Wood Nailer	SYP Gr. No. 1 Dense or better standard rough sawn or Douglas Fir–Larch No. 1 or Douglas Fir–Larch (North) Select Structural or Douglas Fir–South Select Structural or equivalent with min F'b = 1,200 psi [8.3 MPa]	See Note 4	–
e2	51	2"x8" [51x203], 8' [2,438] Long Tongue and Groove Wood Plank	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e3	68	2"x8" [51x203], 16' [4,877] Long Tongue and Groove Wood Plank	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e4	14	2"x8" [51x203], 10' [3,048] Long Wood Batten	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–
e5	6	2"x4" [51x102], 10' [3,048] Long Wood Plank	SYP Gr. Select Structural Douglas Fir–Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	See Note 4	–

*Use either part c3 or c4. ** Weld before galvanization.

Notes:
(1) Timber rail sections and blockouts shall be treated with pentachlorophenol (PCP–A) in heavy oil to a minimum net retention of 0.6 lb/ft³ (9.6 kg/m³) in accordance with AWPA Standard U1 to the requirements Use Category 4A (UC4A).
(2) Wood shall be cut, drilled, and completely fabricated prior to treatment with preservative. Drain excess chemicals and dry all treated wood at the place of manufacture.
(3) All field cuts, bore holes, and damages shall be treated with material acceptable to the engineer prior to installation.
(4) Provide preservative treated timber products per Spec. 3491.

Midwest Roadside Safety Facility

MNDOT Noise Wall
Timber Rail
Front Side Configuration
Bill of Materials

SHEET: 17 of 18
DATE: 11/19/2018
DRAWN BY: JDJ/JEK/DJW
DWG. NAME: MNNW–FrontSideFinal_R2
SCALE: 1:256
UNITS: in.[mm]
REV. BY: ELU/JDS

Figure 134. Bill of Materials, Front-Side Noise Wall

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
f1	2	BCT Anchor Cable	–	–	FCA01
f2	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
f3	2	2 3/8" [60] O.D. x 12" [305] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	–
g1*	48	1 1/4"–7 UNC [M30x3.5], 12 1/4" [311] Long Dome Head Bolt and Nut	Bolt – ASTM A307 Gr. A or Equivalent Nut – ASTM A563A or Equivalent	ASTM A153 or B695 Class 55 or F2329	FBB09a
g2	24	3/4"–10 UNC [M20x2.5], 18" [457] Long Hex Head Bolt	ASTM A307 Gr. A or Equivalent	ASTM A153 or B695 Class 55 or F2329	FBX20a
g3	1192	16D Ring Shank Nail	–	–	–
g4	436	No. 8 x 2 1/2" [64] Long Bugle Head Exterior Screw	–	ASTM A153 or B695 Class 55	–
g5	42	1/2" [13] Dia. Round Plate Washer	ASTM F844	ASTM A123 or A153 or F2329	–
g6	42	1/2"–6 Coil Thread [M14x4], 3" [76] Long Hex Head Bolt	ASTM A307 Gr. A or Equivalent	ASTM A153 or B695 Class 55 or F2329	–
g7	24	3/4"–10 UNC [M20x2.5] Drop–In Concrete Anchor	Hilti Item No. 258541 or Similar	Zinc–Plated or Galvanized	–
g8	72	1/2"–6 Coil Thread [M14x4] Concrete Anchor	As Supplied	Galvanize per spec. 3392 or electroplate per ASTM B633 SC4 Type II	–
g9	48	1 1/4" [32] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC30a
g10	24	3/4" [19] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC20a

*Anchor plate bolts can have fins or lugs. Splice bolts should not have lugs or fins.

Note: Hilti Item No. 258541 (part g7) is not compatible with hot–dipped galvanized bolts. Recommend using inserts and bolts that are both zinc–plated or both galvanized so that thread patterns are compatible.

Midwest Roadside Safety Facility

MNDOT Noise Wall
Timber Rail
Front Side Configuration

Bill of Materials

SHEET: 18 of 18
DATE: 11/19/2018
DRAWN BY: JDJ/JEK/DJW
DWG. NAME. MNNW–FrontSideFinal_R2
SCALE: 1:256
UNITS: in.[mm]
REV. BY: ELU/JDS

Figure 135. Bill of Materials, Front-Side Noise Wall (continued)

13 REFERENCES

1. Polivka, K.A., Rohde, J.R., Faller, R.K., Holloway, J.C., and Sicking, D.L., *Design and Evaluation of Minnesota's Timber Rub-Rail Noise Barriers*, Report No. TRP-03-156-05, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, March 8, 2005.

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

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

4. *AASHTO LRFD Bridge Design Specifications, Eighth Edition*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., November 2017.

5. Bligh, R.P., Briaud, J.L., Abu-Odeh, A., Saez. B., D.O., Maddah, L.S., and Mi Kim, K., *Design Guidelines for Test Level 3 (TL-3) Through Test Level 5 (TL-5) Roadside Barrier Systems Placed on Mechanically Stabilized Earth (MSE) Retaining Wall*, Final Report for the National Cooperative Highway Research Program, Transportation Research Board, Project No. 22-20(2), Texas Transportation Institute, College Station, Texas, June 2017.

6. *National Design Specification for Wood Construction*, 2015 Edition Third Electronic Version, ANSI/AWC NDS-2015, American Wood Council, October 2016.

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

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

9. MacInnis, D., Cliff, W., and Ising, K., *A Comparison of the Moment of Inertia Estimation Techniques for Vehicle Dynamics Simulation*, SAE Technical Paper Series – 970951, Society of Automotive Engineers, Inc., Warrendale, Pennsylvania, 1997.

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

11. *Use Category System: User Specification for Treated Wood*, Specification No. U1-17, American Wood Protection Association Standard, 2017.

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.

14 APPENDICES

Appendix A. Noise Wall and Rubrail with Concrete Posts Standard Plans

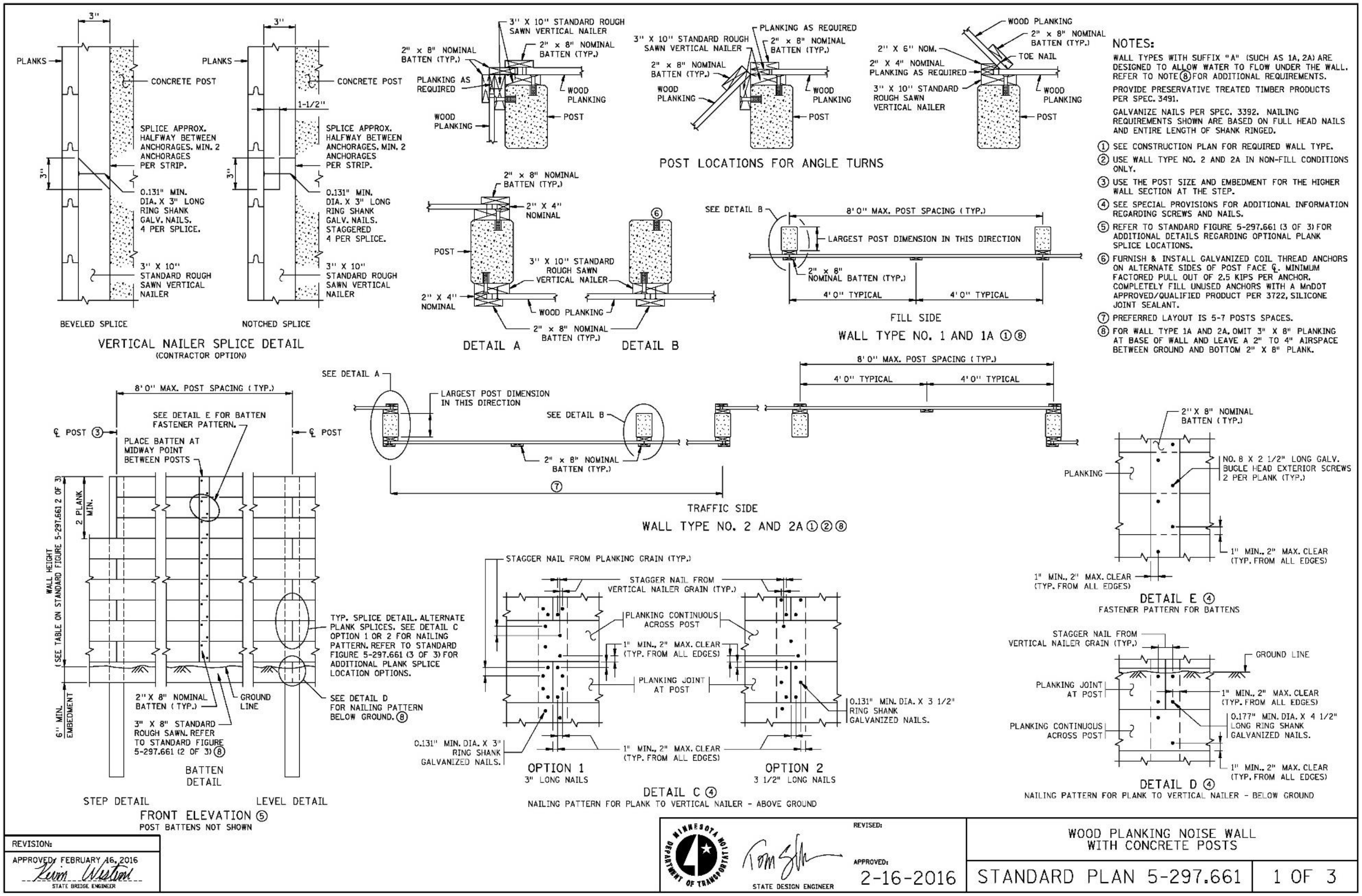
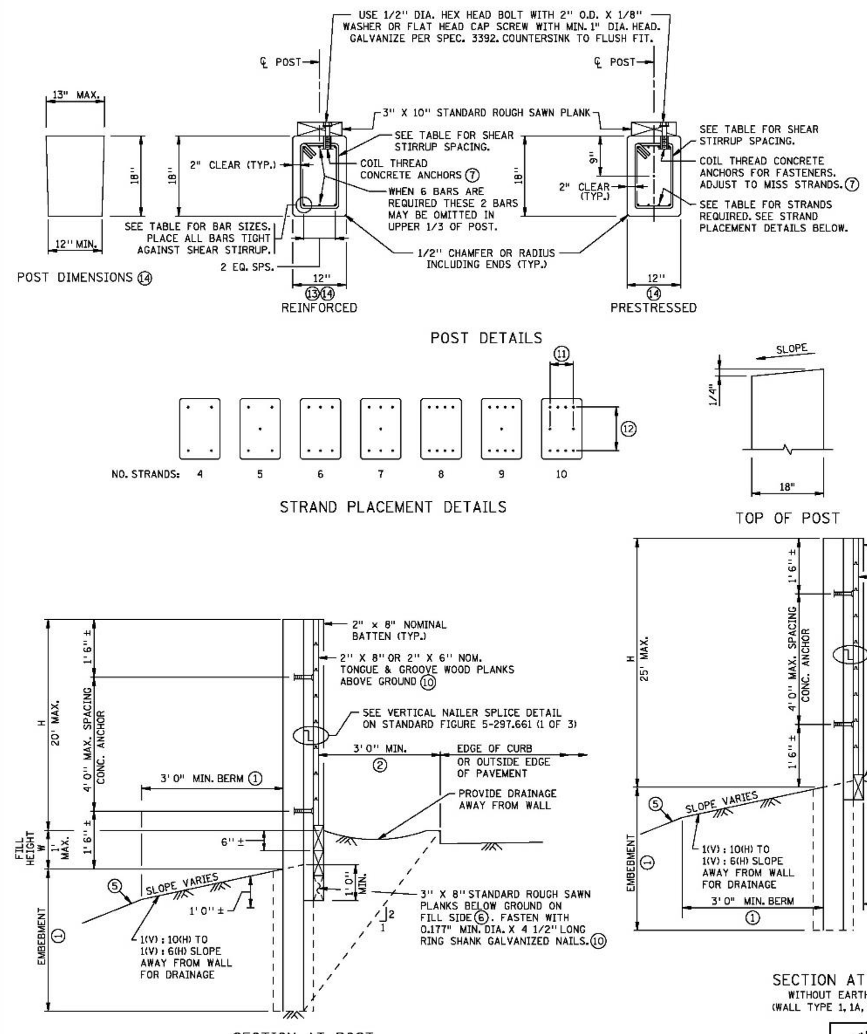


Figure A-1. Wood Planking Noise Wall with Concrete Posts



POST EMBEDMENT TABLE
FILL HEIGHT W = 1 FT. MAXIMUM

"H" WALL HEIGHT (FT.)	POST SPACING (FT.)	POST SIZE (IN.)	REINF. BARS ⑬	SHEAR STIRRUP SPACING (IN.) ⑨	PRE-STRESSED STRANDS	POST EMBEDMENT ① LEVEL GROUND	1(V):4(H) SLOPE	1(V):3(H) SLOPE	1(V):2(H) SLOPE
5	8	12 X 18	4 NO. 4	18	4	6' 0"	6' 0"	7' 0"	8' 0"
6	8	12 X 18	4 NO. 4	18	4	7' 0"	7' 0"	7' 0"	8' 0"
7	8	12 X 18	4 NO. 4	18	4	7' 0"	7' 0"	8' 0"	9' 0"
8	8	12 X 18	4 NO. 5	18	4	7' 0"	8' 0"	8' 0"	9' 0"
9	8	12 X 18	4 NO. 5	18	4	8' 0"	8' 0"	8' 0"	9' 0"
10	8	12 X 18	4 NO. 5	18	4	8' 0"	8' 0"	9' 0"	10' 0"
11	8	12 X 18	4 NO. 5	10	4	8' 0"	9' 0"	9' 0"	10' 0"
12	8	12 X 18	6 NO. 5	10	4	8' 0"	9' 0"	9' 0"	10' 0"
13	8	12 X 18	6 NO. 5	10	4	9' 0"	9' 0"	10' 0"	10' 0"
14	8	12 X 18	6 NO. 5	10	4	9' 0"	10' 0"	10' 0"	11' 0"
15	8	12 X 18	6 NO. 6	10	4	9' 0"	10' 0"	10' 0"	11' 0"
16	8	12 X 18	6 NO. 6	10	4	10' 0"	10' 0"	11' 0"	12' 0"
17	8	12 X 18	6 NO. 6	10	4	10' 0"	10' 0"	11' 0"	12' 0"
18	8	12 X 18	6 NO. 6	10	4	10' 0"	11' 0"	11' 0"	13' 0"
19	8	12 X 18	6 NO. 7	10	5	11' 0"	11' 0"	12' 0"	13' 0"
20	8	12 X 18	6 NO. 7	10	6	11' 0"	11' 0"	12' 0"	13' 0"
21	8	12 X 18	6 NO. 7	10	6	11' 0"	12' 0"	12' 0"	14' 0"
22	8	12 X 18	6 NO. 8	10	7	12' 0"	12' 0"	13' 0"	14' 0"
23	8	12 X 18	6 NO. 8	10	8	12' 0"	12' 0"	13' 0"	15' 0"
24	8	12 X 18	6 NO. 8	10	9	12' 0"	13' 0"	14' 0"	15' 0"
25	8	12 X 18	6 NO. 8	10	10	12' 0"	13' 0"	14' 0"	17' 0"

DESIGN CRITERIA:

2012 AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS, INCLUDING 2013 INTERIMS.

2012 NATIONAL DESIGN SPECIFICATION (NDS) FOR WALL CONSTRUCTION - LRFD

ϕ = 30° (GRANULAR)
γ = 110 P.C.F.
WIND LOAD = 19 P.S.F.
F_b = 1500 P.S.I. WOOD PLANKING AND BATTEN.
F_b = 1200 P.S.I. ALL OTHER WOOD MEMBERS.

POST DESIGN CRITERIA

NO. OF STRANDS	f'ci ③	f'c ④
6 OR LESS	4000 PSI	5500 PSI
7 OR MORE	4000 PSI	6000 PSI

NOTES:

USE OF THIS STANDARD ASSUMES SOIL TESTS AT MAXIMUM 200 FT. INTERVALS AT EACH SITE AND SOILS ENGINEER REVIEWED RESULTS AND CONCURS WITH USE OF THIS STANDARD.

POST EMBEDMENT DEPTH IS BASED ON THE WATER TABLE BEING BELOW THE BOTTOM OF EACH POST, OTHER CONDITIONS REQUIRE A SPECIAL DESIGN.

REFER TO SPECIAL PROVISIONS FOR ADDITIONAL INFORMATION.

FOR SLOPES BETWEEN THOSE SHOWN, USE THE POST EMBEDMENT FOR THE STEEPER SLOPE OR USE INTERPOLATION.

FOR SLOPES 1 (V):6(H) OR FLATTER, USE POST EMBEDMENT SHOWN FOR LEVEL GROUND.

REFER TO SPECIAL PROVISIONS FOR REINFORCEMENT OF POSTS LOCATED WITHIN 20 FT. OF THE OUTSIDE EDGE OF A ROADWAY SHOULDER AND POSTS SUPPORTING GLUE LAMINATED RUB RAIL (STANDARD FIGURE 5-297.678). FABRICATOR TO IDENTIFY THESE POSTS WITH PERMANENT MARK ON BOTTOM OF POST.

FOR CONCRETE POSTS WITH THE SAME LENGTH, USE THE LARGEST NUMBER OF PRESTRESSED STRANDS OR REBARS REQUIRED FOR THAT POST LENGTH. USE MIX 3W82 FOR ALL POSTS. REFER TO SPEC. 2462 FOR ADDITIONAL REQUIREMENTS.

USE A MIN. OF 4, ½" DIA. (AREA = 0.153 SQ. IN.) LOW-RELAXATION PRESTRESSED STEEL STRANDS PER SPEC. 3348, WITH 270 KSI ULTIMATE STRENGTH, INITIAL PRESTRESS = 30,900 LBS. PER STRAND. CUT STRANDS FLUSH WITH CONCRETE. COVER ENDS WITH SEALANT PER APPROVED PRODUCTS LIST "BRIDGE - PRESTRESSED BEAMS - CUT STRAND SEALANT."

USE EPOXY COATED GRADE 60 REINFORCING BARS PER SPEC. 3301.

① POST EMBEDMENT DEPTH IN THE TABLE IS BASED ON A 3 FT. MIN. BERM IN FRONT OF THE WALL.
② WHEN THE CURB LINE IS CLOSER THAN 1(V):2(H) SLOPE, A SPECIAL DESIGN IS REQUIRED.
③ MINIMUM CONCRETE STRENGTH AT TIME OF PRESTRESS TRANSFER.
④ MIN. CONCRETE STRENGTH AT WHICH THE POST CAN BE TRANSPORTED AND PLACED.
⑤ SEE POST EMBEDMENT TABLES FOR MAXIMUM SLOPE.
⑥ SEE SPEC. 3491 FOR ADDITIONAL PRESERVATIVE TREATMENT REQUIREMENTS FOR LUMBER PLACED BELOW GRADE.
⑦ PLACE COIL THREAD ANCHORS ON ALTERNATE SIDES OF POST FACE CENTERLINE. MINIMUM FACTORED PULL OUT OF 2.5 KIPS PER ANCHOR. GALVANIZE ANCHORS PER SPEC. 3392 OR ELECTROPLATE PER ASTM B633 SC4 TYPE II. COMPLETELY FILL UNUSED ANCHORS WITH A MnDOT APPROVED/QUALIFIED PRODUCT PER 3372, SILICONE JOINT SEALANT.
⑧ FOR WALL TYPE 1A AND 2A, OMIT 3" X 8" PLANKING AT BASE OF WALL AND LEAVE A 2" TO 4" AIRSPACE BETWEEN GROUND AND BOTTOM 2" X 8" PLANK.
⑨ USE NO. 3 BARS FOR SHEAR STIRRUPS. PLACE FIRST STIRRUP 3" FROM EACH END.
⑩ REFER TO STANDARD FIGURE 5-297.661 (1 OF 3) FOR NAILING PATTERN.
⑪ MINIMUM CENTER-TO-CENTER SPACING OF 6", WITH INTERMEDIATE STRANDS PLACED SYMMETRICALLY (TYP. FOR ALL CONFIGURATIONS).
⑫ MINIMUM CENTER-TO-CENTER SPACING OF 12", WITH INTERMEDIATE STRANDS PLACED SYMMETRICALLY (TYP. FOR ALL CONFIGURATIONS).
⑬ NO REINFORCEMENT SPLICES ALLOWED.
⑭ 12" MIN, 13" MAX. TO ALLOW FOR DRAFT OF FORM.

REVISION:
APPROVED: FEBRUARY 16, 2016
Kevin Western
STATE BRIDGE ENGINEER

STATE DESIGN ENGINEER
REVISED: 8-10-2016
APPROVED: 2-16-2016

WOOD PLANKING NOISE WALL WITH CONCRETE POSTS

STANDARD PLAN 5-297.661 | 2 OF 3

Figure A-2. Wood Planking Noise Wall with Concrete Posts

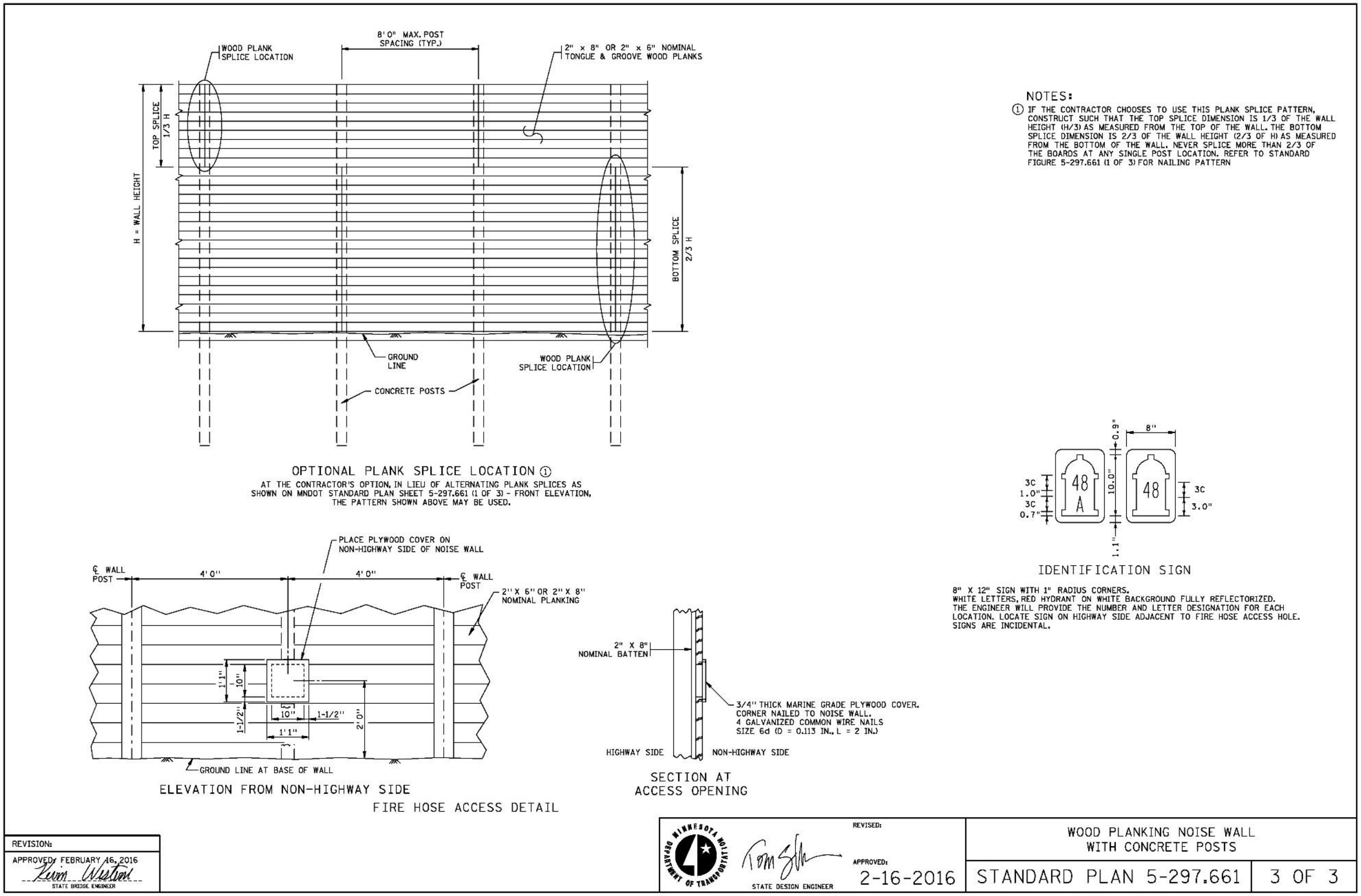


Figure A-3. Wood Planking Noise Wall with Concrete Posts

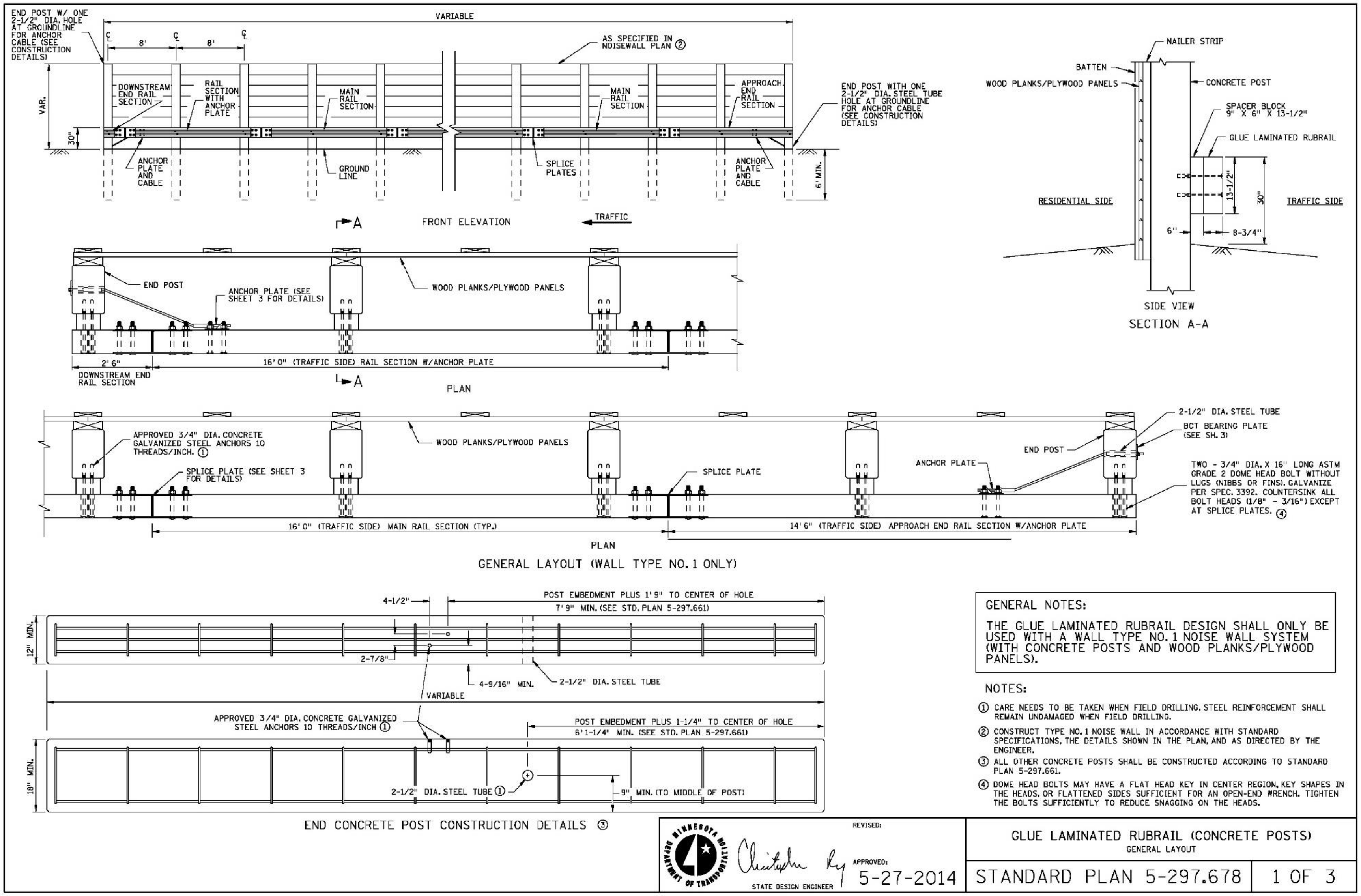


Figure A-4. Glue Laminated Rubrail (Concrete Posts) – General Layout

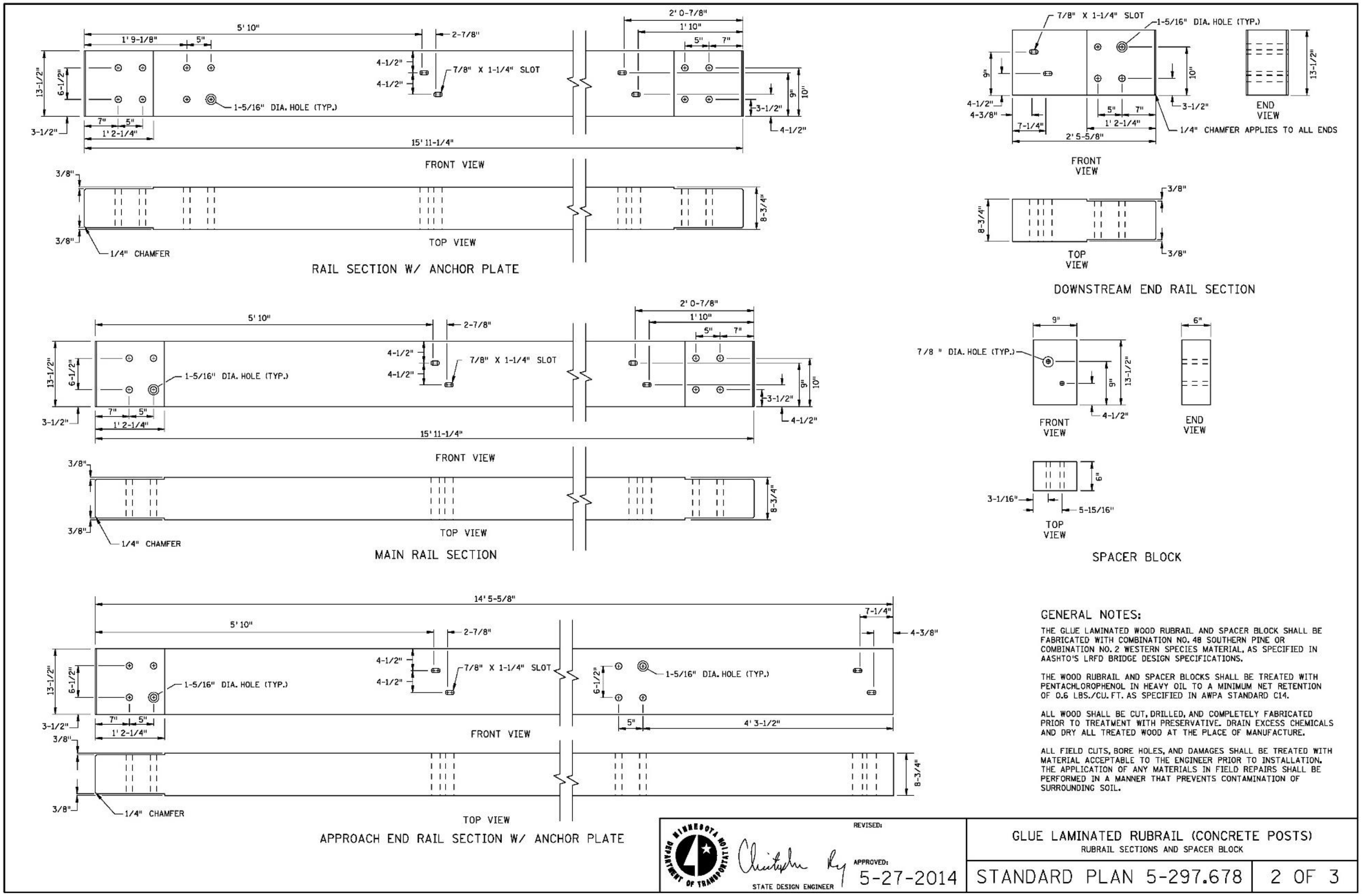


Figure A-5. Glue Laminated Rubrail (Concrete Posts) – Rubrail Sections and Spacer Block

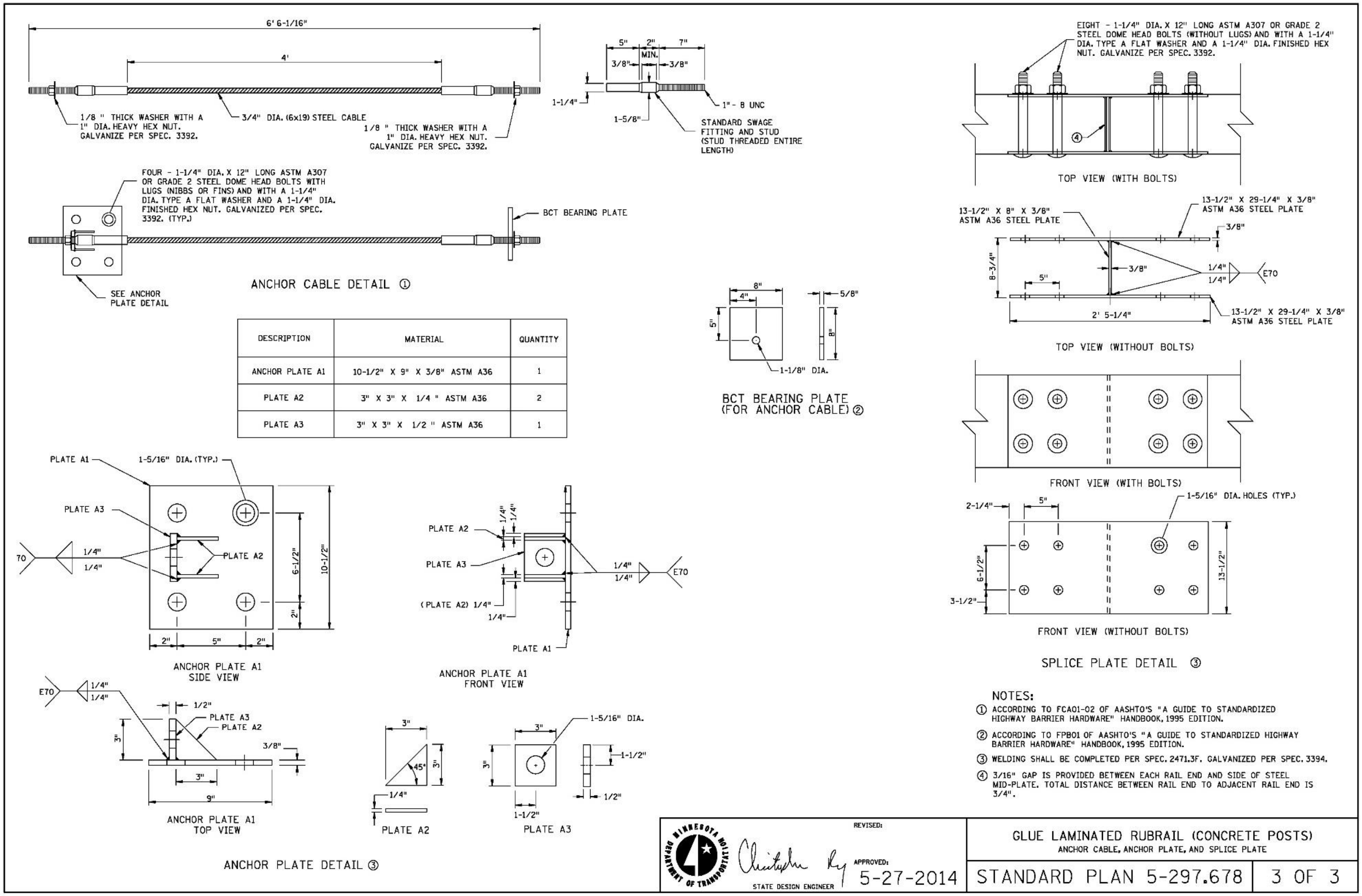


Figure A-6. Glue Laminated Rubrail (Concrete Posts) – Anchor Cable, Anchor Plate, and Splice Plate

Appendix B. Vehicle Center of Gravity Determination

Date:	2/28/2018	Test Name:	MNNW-1	VIN:	1D7RB1CT0AS214480
Year:	2010	Make:	Dodge	Model:	RAM 1500 Crew

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	5264	29 1/4	154009.5
+	Hub	19	15 1/2	294.5
+	Brake activation cylinder & frame	19	15 3/4	299.25
+	Pneumatic tank (Nitrogen)	7	28	196
+	Strobe/Brake Battery	28	29	812
+	Brake Receiver/Wires	5	28	140
+	CG Plate including DAS	6	54	324
-	Battery	42	50	2100
-	Oil	-41	36	-1476
-	Interior	-11	22	-242
-	Fuel	-96	36	-3456
-	Coolant	-188	18	-3384
-	Washer fluid	-12	39	-468
+	Water Ballast (In Fuel Tank)	-1	40	-40
+	Onboard Supplemental Battery	0	0	0
		14	27	378
				0
Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle				149487.25

Estimated Total Weight (lb)	5055
Vertical CG Location (in.)	29.5722

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140 1/2 in. Front Track Width: 68 1/4 in.
Rear Track Width: 68 3/8 in.

Center of Gravity	2270P MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	5000 ± 110	5056	56.0
Longitudinal CG (in.)	63 ± 4	61.02413	-1.97587
Lateral CG (in.)	NA	-0.189156	NA
Vertical CG (in.)	28 or greater	29.57	1.57216

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	1518	1437
Rear	1159	1150

FRONT	2955	lb
REAR	2309	lb
TOTAL	5264	lb

TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1459	1401
Rear	1083	1113

FRONT	2860	lb
REAR	2196	lb
TOTAL	5056	lb

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

Date:	2/28/2018	Test Name:	MNNW-2	VIN:	KMHCN4ACXBU610901
Year:	2010	Make:	Hyundai	Model:	Accent

Vehicle CG Determination

	Vehicle Equipment	Weight (lb)
+	Unballasted Car (Curb)	2476
+	Hub	19
+	Brake activation cylinder & frame	7
+	Pneumatic tank (Nitrogen)	22
+	Strobe/Brake Battery	5
+	Brake Receiver/Wires	5
+	CG Plate including DAS	13
-	Battery	-38
-	Oil	-5
-	Interior	-41
-	Fuel	-12
-	Coolant	-5
-	Washer fluid	-8
+	Water Ballast (In Fuel Tank)	0
+	Onboard Supplemental Battery	13
-		
-	Trunk carpet	-4

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

Estimated Total Weight (lb) 2447

Vehicle Dimensions for C.G. Calculations

Wheel Base:	98 3/4	in.	Front Track Width:	57 7/8	in.
Roof Height:	57	in.	Rear Track Width:	57	in.

Center of Gravity	1100C MASH Targets	Test Inertial	Difference
Test Inertial Weight (lb)	2420 ± 55	2431	11.0
Longitudinal CG (in.)	39 ± 4	36.59965	-2.40035
Lateral CG (in.)	NA	-0.602491	NA
Vertical CG (in.)	NA	22.41	NA

Note: Long. CG is measured from front axle of test vehicle

Note: Lateral CG measured from centerline - positive to vehicle right (passenger) side

CURB WEIGHT (lb)

	Left	Right
Front	802	775
Rear	450	449

FRONT	1577	lb
REAR	899	lb
TOTAL	2476	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	784	746
Rear	457	444

FRONT	1530	lb
REAR	901	lb
TOTAL	2431	lb

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

Date:	**4/4/2018**	**Test Name:**	**MNNW-3**	**VIN:**	**1D7RB1CP7BX646567**
Year:	**2011**	**Make:**	**Dodge**	**Model:**	**Ram 1500**

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb)	Vertical CG (in.)	Vertical M (lb-in.)
+	Unballasted Truck (Curb)	5265	28 3/8	149352.88
+	Hub	19	15	285
+	Brake activation cylinder & frame	7	29 7/8	209.125
+	Pneumatic tank (Nitrogen)	22	27 1/2	605
+	Strobe/Brake Battery	5	27	135
+	Brake Receiver/Wires	6	51 1/2	309
+	CG Plate including DAS	50	30 1/8	1506.25
-	Battery	-44	39 1/2	-1738
-	Oil	-9	18	-162
-	Interior	-118	25 3/4	-3038.5
-	Fuel	-196	20 3/8	-3993.5
-	Coolant	-9	31 1/4	-281.25
-	Washer fluid	-1	32	-32
+	Water Ballast (In Fuel Tank)	0		0
+	Onboard Supplemental Battery	13	27 3/8	355.875
+	Smart Barrier Provisions	10	25 1/5	252
				0
				143764.88

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

Estimated Total Weight (lb)	5020
Vertical CG Location (in.)	28.6384

Vehicle Dimensions for C.G. Calculations

Wheel Base:	140 1/2 in.	Front Track Width:	66 1/4 in.
		Rear Track Width:	67 3/4 in.

Center of Gravity	**2270P MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb)	5000 ± 110	5028	28.0
Longitudinal CG (in.)	63 ± 4	61.168357	-1.83164
Lateral CG (in.)	NA	-0.732896	NA
Vertical CG (in.)	28 or greater	28.64	0.63842

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	1490	1450
Rear	1179	1146

FRONT	2940	lb
REAR	2325	lb
TOTAL	5265	lb

TEST INERTIAL WEIGHT (lb)

	Left	Right
Front	1431	1408
Rear	1138	1051

FRONT	2839	lb
REAR	2189	lb
TOTAL	5028	lb

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

Appendix C. Material Specifications

Table C-1. Bill of Materials, Test Nos. MNNW-1, MNNW-2, and MNNW-3

Item No.	Description	Material Specification	Reference
a1	125 5/8"x13 1/2"x10 3/4" [3,191x343x273] Timber Rail End Section	GLULAM - Comb. 48 (SP) or Comb. 2 (Western species)	CO#174067 MO#162115
a2	191 1/4"x13 1/2"x10 3/4" [4,858x343x273] Timber Rail Section	GLULAM - Comb. 48 (SP) or Comb. 2 (Western species)	CO#174067 MO#162115
a3	173 5/8"x13 1/2"x10 3/4" [4,410x343x273] Timber Rail End Section	GLULAM - Comb. 48 (SP) or Comb. 2 (Western species)	CO#174067 MO#162115
a4	13 1/2"x9"x6" [343x229x152] Wood Blockout	GLULAM - Comb. 48 (SP) or Comb. 2 (Western species)	CO#174067 MO#162115
b1	10 1/2"x9"x3/8" [229x267x10] Steel Plate	ASTM A36	H#17043961
b2	3"x3"x1/4" [76x76x6] Steel Gusset	ASTM A36	H#A7P1312
b3	3"x3"x1/2" [76x76x13] Steel Plate	ASTM A36	H#17073161
c1	12"x18" [305x457], 18' [5,486] Long Concrete Post	Min. f'c = 5,500 psi [37.9 MPa] MnDOT mix 3W82	Wieser Concrete Test, Avg. Result: 7457 ACI Grade 1
c2	3/8" [10] Dia., 53" [1,346] Long Rebar	ASTM A615 Gr. 60	H#KN16105651
c3	5/8" [16] Dia., 210" [5,334] Long Rebar	ASTM A615 Gr. 60	Not Used - Item c4 USED INSTEAD
c4	1/2" [13] Dia, 7-Wire Pre-Stressing Strand, 216" [5,486] Long	ASTM A416 Gr. 270	Coil#2344-3 H#5314572502
d1	29 1/4"x13 1/2"x3/8" [743x343x10] Steel Plate	ASTM A36	H#17043961
d2	13 1/2"x10"x3/8" [343x254x10] Steel Plate	ASTM A36	H#17043961
e1	3"x10" [76x254], 10' [3,048] Long Vertical Wood Nailer	SYP Gr. No. 1 Dense or better standard rough sawn or Douglas Fir-Larch No. 1 or Douglas Fir-Larch (North) Select Structural or Douglas Fir-South Select Structural or equivalent with min F'b = 1,200 psi [8.3 MPa]	Millard Lumber Order#3658140
e2	2"x8" [51x203], 8' [2,438] Long Tongue and Groove Wood Plank	SYP Gr. Select Structural Douglas Fir-Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	Millard Lumber Order#3658140
e3	2"x8" [51x203], 16' [4,877] Long Tongue and Groove Wood Plank	SYP Gr. Select Structural Douglas Fir-Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	Millard Lumber Order#3658140
e4	2"x8" [51x203], 10' [3,048] Long Wood Batten	SYP Gr. Select Structural Douglas Fir-Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	Millard Lumber Order#3658140
e5	2"x4" [51x102], 10' [3,048] Long Wood Plank	SYP Gr. Select Structural Douglas Fir-Larch Select Structural or equivalent with min F'b = 1,500 psi [10.3 MPa]	Millard Lumber Order#3658140
f1	BCT Anchor Cable	-	R#17-700 Yellow OR H#119048*

Table C-2. Bill of Materials, Test Nos. MNNW-1, MNNW-2, and MNNW-3 (Cont.)

Item No.	Description	Material Specification	Reference
f2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	South: H#DL15103543 North: H#6106195 R#090453-9
f3	2 3/8" [60] O.D. x 12" [305] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	H#B712810
g1	1 1/4" [32] Dia. UNC, 14" [356] Long Round Head Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Invoice#103293 H#278117
g2	3/4" [19] Dia. UNC, 18" [457] Long Round Head Bolt	ASTM A307 Gr. A	Invoice#103293 H#145417 OR H#17308059-3 Red Paint;* H#184335 Unpainted;*
g3	16D Ring Shank Nail	-	Lowes Trans#9000581
g4	No. 8 x 2 1/2" [64] Long Bugle Head Exterior Screw	-	Grainger COC, Item#31JJ25
g5	1/2" [13] Dia. Round Plate Washer	ASTM F844	PCI and CONAC COC
g6	1/2"-6 [13] Coil Thread, 3" [76] Long Hex Head Bolt	ASTM A307 Gr. A	PCI and CONAC COC
g7	3/4"-10 UNC [19] Drop-In Concrete Anchor	Hilti Item No. 258541	Hilti COC
g8	1/2"-6 [13] Coil Thread Concrete Anchor	As Supplied	PO#0000017781 L#0000097318
g9	1 1/4" [32] Dia. Plain Round Washer	ASTM A844	P#33189 PO#220024755 L#M-SWE0411982-34
g10	3/4" [19] Dia. Plain Round Washer	ASTM F844	P#1133018 PO#210136785 L#17H168220-3

*test no. MNNW-3 only

APA

Certificate of Conformance

THE UNDERSIGNED MANUFACTURER HEREBY CERTIFIES that the structural wood products identified below and marked with a collective mark of **APA – The Engineered Wood Association (APA)** were manufactured in accordance with the specifications indicated below.

☑ ANSI Standard A190.1-2012, for Structural Glued Laminated Timber

Job Name:

Job Location:

Customer's Order No.: 174067 Date: 12-5-2017 Mfgr's Order No.: 162115

Distributor: WESTERN WOOD STRUCTURES

Order Description:

Signature: Ron Jubber [signature] Name: Ron Jubber

Company: Zip-O-Laminators, LLC Position: Quality Assurance

Address: 2701 W. 1st Ave, Eugene OR 97402 Date: 12-5-2017

IT IS HEREBY CERTIFIED that the structural glued laminated timber production of the above-named manufacturer which carries a collective mark of *APA* is subject to regular audit by *APA – The Engineered Wood Association,* such audit consisting of the inspection of the manufacturing process, with sampling to verify the quality of glulam construction and the adequacy of glue bond.

by [signature]
Steve Zylkowski
Director, Quality Services

REPRESENTING THE ENGINEERED WOOD INDUSTRY

7011 South 19th Street • Tacoma, Washington 98466-5333 • Phone: (253) 565-6600 • Fax: (253) 565-7265 • www.apawood.org

EWS Cert Conformance.pdf

Figure C-1. Timber Rail Material Certificate of Conformance, Test Nos. MNNW-1, MNNW-2, and MNNW-3

Consumer Information Sheet

PENTACHLOROPHENOL PRESSURE-TREATED WOOD

CONSUMER INFORMATION

This wood has been preserved by pressure-treatment with an EPA-registered pesticide containing pentachlorophenol to protect it from insect attack and decay. Wood treated with pentachlorophenol should be used only where such protection is important.

Pentachlorophenol penetrates deeply into and remains in the pressure-treated wood for a long time. Exposure to pentachlorophenol may present certain hazards. Therefore, the following precautions should be taken both when handling the treated wood and in determining where to use and dipose of the treated wood.

USE SITE PRECAUTIONS

______Logs treated with pentachlorophenol should not be used for log homes.

Wood treated with pentachlorophenol should not be used where it will be in frequent or prolonged contact with bare skin (for example, chairs and other outdoor furniture), unless an effective sealer has been applied.

Pentachlorophenol-treated wood should not be used in residential, industrial, or commercial interiors except for laminated beams or building components which are in ground contact and are subject to decay or insect infestation and where two coats of an appropriate sealer are applied. Sealers may be applied at the installation site.

Wood treated with pentachlorophenol should not be used in the interiors of farm buildings where there may be direct contact with domestic animals or livestock which may crib (bite) or lick the wood.

In interiors of farm buildings where domestic animals or livestock are unlikely to crib (bite) or lick the wood, pentachlorophenol-treated wood may be used for building components which are in ground contact and are subject to decay or insect infestation and where two coats of an appropriate sealer are applied. Sealers may be applied at the installation site.

Do not use pentachlorophenol-treated wood for farrowing or brooding facilities.

Do not use treated wood under circumstances where the preservative may become a component of food or animal feed. Examples of such sites would be structures or containers for storing silage or food.

Do not use treated wood for cutting boards or countertops.

Only treated wood that is visibly clean and free of surface residue should be used for patios, decks and walkways.

Do not use treated wood for construction of those portions of beehives which may come into contact with the honey.

Pentachlorophenol-treated wood should not be used where it may come into direct or indirect contact with public drinking water, except for uses involving incidental contact such as docks and bridges.

Do not use pentachlorophenol-treated wood where it may come into direct or indirect contact with drinking water for domestic animals or livestock, except for uses involving incidental contact such as docks and bridges.

HANDLING PRECAUTIONS

Dispose of treated wood by ordinary trash collection or burial. Treated wood should not be burned in open fires or in stoves, fireplaces, or residential boilers because toxic chemicals may be produced as part of the smoke and ashes. Treated wood from commercial or industrial use (e.g., construction sites) may be burned only in commercial or industrial incinerators or boilers rated at 20 million BTU/hour or greater heat input or its equivalent in accordance with state and federal regulations.

Avoid frequent or prolonged inhalation of sawdust from treated wood. When sawing and machining treated wood, wear a dust mask. Whenever possible, these operations should be performed outdoors to avoid indoor accumulations of airborne sawdust from treated wood.

Avoid frequent or prolonged skin contact with pentachlorophenol-treated wood; when handling the treated wood, wear long-sleeved shirts and long pants and use gloves impervious to the chemicals (for example, gloves that are vinyl-coated).

When power-sawing and machining, wear goggles to protect eyes from flying particles.

After working with the wood, and before eating, drinking, and use of tobacco products, wash exposed areas thoroughly.

If oily preservatives or sawdust accumulate on clothes, launder before reuse. Wash work clothes separately from other household clothing.

Figure C-2. Timber Rail Material Certificate of Conformance, Test Nos. MNNW-1, MNNW-2, and MNNW-3

TREATED WOOD HAZARD LABEL

HEALTH/SAFETY ALERT

HANDLING MAY CAUSE SPLINTERS

WOOD DUST MAY CAUSE EYE AND SKIN IRRITATION

OBSERVE GOOD HYGIENE AND SAFETY PRACTICES WHEN HANDLING THIS PRODUCT

DO NOT USE THIS PRODUCT UNTIL MSDS AND CIS HAVE BEEN READ AND UNDERSTOOD

WARNING: Some forms of components of the liquid preservatives used to manufacture these products have caused lung, skin and possibly other cancers in humans occupationally or environmentally overexposed. Such hazards have not been associated with treated wood use.

THIS PRODUCT CONTAINS A CHEMICAL KNOWN TO THE STATE

OF CALIFORNIA TO CAUSE CANCER

FOR MORE INFORMATION ON PROPOSITION 65, VISIT
http://oehha.ca.gov/prop65.html

Figure C-3. Timber Rail Material Certificate of Conformance, Test Nos. MNNW-1, MNNW-2, and MNNW-3

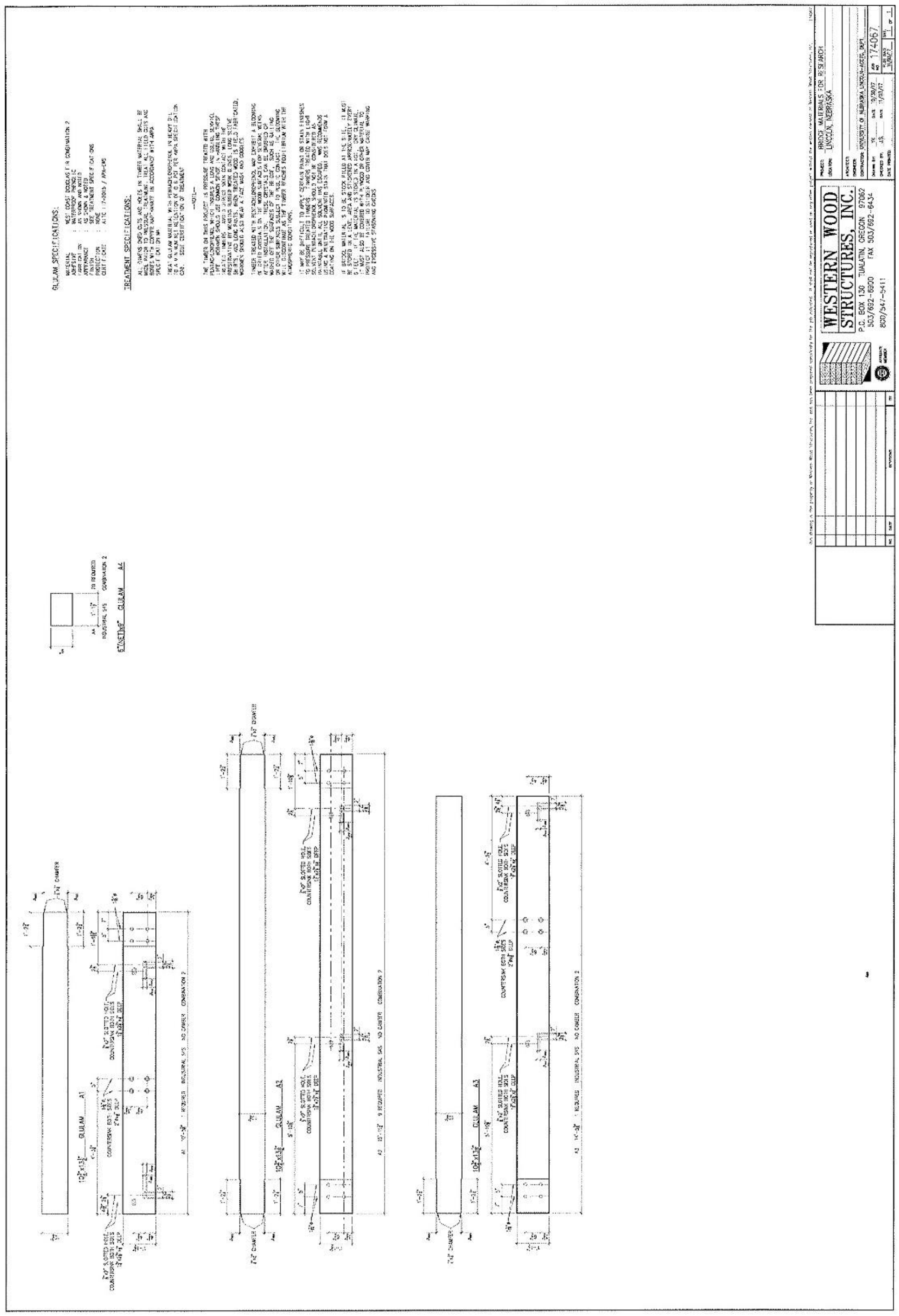


Figure C-4. Timber Rail Material Certificate of Conformance, Test Nos. MNNW-1, MNNW-2, and MNNW-3

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

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 07/05/2017
TIME 11:18:56
USER H.ZAVALA

SOLD TO
66031-1127

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

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40288406-0010	701272120TM	3/8 72 X 120 A36 TEMPERPASS STPMLPL	8	7,353.600			07/05/2017

Chemical Analysis

Heat No. 17043961 Vendor BIG RIVER STEEL LLC DOMESTIC Mill BIG RIVER STEEL LLC Melted and Manufactured in the USA
Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.1900	0.8500	0.0100	0.0030	0.0300	0.0400	0.0700	0.0130	0.0001	0.1400	0.0380	0.0000	0.0030	0.0010	0.0075	0.0062

Mechanical / Physical Properties

Mill Coil No. 17043961-04

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
72770.000	48824.000	35.20			0	NA			
70521.000	48659.000	33.20			0	NA			
70725.000	45986.000	32.00			0	NA			
70499.000	47266.000	32.20			0	NA			

Batch 0004833970 8 EA 7,353.600 LB Batch 0004833973 8 EA 7,353.600 LB Batch 0004833990 7 EA 6,434.400 LB

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

Figure C-5. Steel Plate Material Certificate, Test Nos. MNNW-1, MNNW-2, and MNNW-3

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

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 05/25/2017
TIME 19:57:33
USER J. DUBOIS

SOLD TO

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

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40285879-0010	72896240	1/4 96 X 240 A36 MILL PLATE	5	8,168			05/25/2017

Chemical Analysis

Heat No. A7P1312 Vendor NUCOR STEEL TUSCALOOSA INC DOMESTIC Mill NUCOR STEEL TUSCALOOSA INC Melted and Manufactured in the USA
Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.1900	0.8700	0.0090	0.0090	0.0300	0.0800	0.0700	0.0240	0.0001	0.1900	0.0270	0.0010	0.0030	0.0020	0.0080	0.0000

Mechanical / Physical Properties

Mill Coil No. 7D0068

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
72963.000	50286.000	32.75			0	NA			
67801.000	45536.000	30.65			0	NA			
71995.000	49738.000	31.35			0	NA			

Batch 0004782696 5 EA 8,168 LB

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

Figure C-6. Steel Gusset Material Certificate, Test Nos. MNNW-1, MNNW-2, and MNNW-3

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

METALLURGICAL TEST REPORT

PAGE 1 of 1
DATE 09/25/2017
TIME 11:26:58
USER WILLIAMR

SOLD TO
66[illegible]31-1127

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

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
4029232[illegible]-0010	70167212OTM	72 X 120 A36 TEMPERPASS STPMLPL	1	1,225.200			09/25/2017

Chemical Analysis

Heat No. 17073161 Vendor BIG RIVER STEEL LLC DOMESTIC Mill BIG RIVER STEEL LLC Melted and Manufactured in the USA

Produced from Coil

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.1900	0.8100	0.0060	0.0010	0.0200	0.0300	0.0300	0.0100	0.0001	0.1000	0.0250	0.0000	0.0030	0.0020	0.0080	0.0061

Mechanical / Physical Properties

Mill Coil No. 17073161-03

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
7260[illegible].000	48900.000	33.00			0	NA			
7150[illegible].000	48000 000	34.50			0	NA			
7170[illegible].000	45700.000	34.20			0	NA			
7170[illegible].000	47700.000	34.00			0	NA			

Batch 0004949996 1 EA 1,225 200 LB

Figure C-7. Steel Plate Material Certificate, Test Nos. MNNW-1, MNNW-2, and MNNW-3

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

CONCRETE TEST RESULTS

PROJECT: Nebraska Posts

Testing By: Jason Hendricks

CONCRETE SUPPLIER Wieser Concrete

ACI GRADE 1

SET	TEST	POUR DATE	RESULTS	AVERAGE	TEST TYPE
1	1		7348		
	2	10/19/2017	7566	**7457**	28 Day
	3				
2	1				
	2				28 Day
	3				
3	1				
	2				
	3				
4	1				
	2				
	3				
5	1				
	2				
	3				
6	1				
	2				
	3				
7	1				
	2				
	3				

Signature

Figure C-8. Concrete Post Material Certificate, Test Nos. MNNW-1, MNNW-2, and MNNW-3

SOLD TO:	ABC COATING CO INC PO BOX 9693 TULSA, OK 74157-
SHIP TO:	ABC COATING CO - MN 2500 W COUNTY ROAD B DOOR 16A ROSEVILLE, MN 55113-

NUCOR
NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT Page: 1

Ship from:
MTR #: 0000146382
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

Date: 25-Oct-2016
B.L. Number: 529492
Load Number: 279240

Material Safety Data Sheets are available at www.nucorbar.com or by contacting your inside sales representative. NBMG-08 January 1, 2012

LOT # / HEAT #	DESCRIPTION	PHYSICAL TESTS: YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	CHEMICAL TESTS: C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	102016-MINN												
KN1610511501	Nucor Steel - Kankakee Inc	68,025	105,418	14.3%	OK	-3.2%	.37	1.08	.022	.048	.21	.36	
KN16105115	10/#3 Rebar	469MPa	727MPa			.023	.13	.20	.036	.004	.001		
	40' A615M GR420 (Gr60)												
	ASTM A615/A615M-14 GR 60[420]												
	AASHTO M31-07												
	Melted 08/23/16 Rolled 08/27/16												
PO# =>	102016-MINN												
KN1610511601	Nucor Steel - Kankakee Inc	73,054	109,049	13.6%	OK	-2.1%	.38	.99	.014	.048	.19	.39	
KN16105116	10/#3 Rebar	504MPa	752MPa			.023	.13	.12	.037	.003	.001		
	40' A615M GR420 (Gr60)												
	ASTM A615/A615M-14 GR 60[420]												
	AASHTO M31-07												
	Melted 08/23/16 Rolled 08/26/16												
PO# =>	102016-MINN												
KN1610565101	Nucor Steel - Kankakee Inc	67,275	101,464	14.1%	OK	-2.7%	.38	1.00	.012	.040	.17	.36	
KN16105651	10/#3 Rebar	464MPa	700MPa			.026	.18	.15	.059	.003	.001		
	40' A615M GR420 (Gr60)												
	ASTM A615/A615M-14 GR 60[420]												
	AASHTO M31-07												
	Melted 09/29/16 Rolled 10/13/16												

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

QUALITY ASSURANCE: Matt Luymes

Figure C-9. Rebar Material Certificate, Test Nos. MNNW-1, MNNW-2, and MNNW-3

WMC

18490 MAIN STREET, CONROE, TX 77385
678-633-7091

PRODUCT TEST CERTIFICATION

CUSTOMER: Wieser Concrete Products

DATE: 4/24/2017

LOCATION: 3716 US Hwy 10
Maiden Rock, WI 54750
Ph 715-647-2311

CERTIFICATION # 7702755

PURCHASE ORDER # **W01205**

CERTIFICATION STANDARD: ASTM A416/A416M-12

WMC HEREBY CERTIFIES THAT THE SPECIMENS TAKEN FROM PRODUCTION LOT(S) CONSISTING OF ONE OR MORE OF THE FOLLOWING LOT/SERIAL NUMBERS WERE TESTED IN ACCORDANCE WITH AND MET THE SPECIFICATION REQUIREMENTS OF ASTM A 416-10.
THE ATTACHED TEST REPORT(S) REPRESENTS THE RESULT OF SUCH TEST(S).

SIZE: 0.500 " DIAMETER

GRADE: 270K GRADE LR SEVEN WIRE STRAND ASTM A416:

COIL NUMBERS	HEAT NUMBER
2346 -1	5314572502
2346 -2	5314572502
2346 -4	5314572502
2346 -6	5314572502
2346 -8	5314572502
2344 -1	5314572502
2344 -3	5314572502

THE PRODUCTS LISTED IN THIS CERTIFICATION WERE MANUFACTURED AND FABRICATED IN THE UNITED STATES OF AMERICA

WMC HEREBY CERTIFIES THAT THE PRESTRESSING STRAND DESCRIBED ABOVE MEETS OR EXCEEDS THE MINIMUM BONDING REQUIREMENTS AS CURRENTLY ACCEPTED IN THE NASP (NORTH AMERICAN STRAND PRODUCERS) PULL-OUT TEST AND THE MOUSTAFFA BLOCK PULL-OUT TEST.

ALL DOMESTIC PRESTRESSING STRAND WAS MADE FROM STEEL ROD THAT WAS MANUFACTURED AND PROCESSED COMPLETELY IN AMERICA. THE ROD WAS THEN MANUFACTURED INTO PC STRAND IN THE UNITED STATED AT WMC LLC, 18490 MAIN STREET CONROE, TX 77385, **WITH AN AVERAGE MODULUS OF 28.8.**

THE MATERIAL MEETS THE "BUY AMERICA" REQUIREMENTS OF 23 CFR 635.410.

THE PRODUCTS LISTED IN THIS CERTIFICATION WERE MANUFACTURED IN THE USA FROM WIRE ROD WHICH WAS MANUFACTURED IN THE USA.

CERTIFICATION PREPARED BY:

Figure C-10. Pre-Stressed Strand Material Certificate, Test Nos. MNNW-1, MNNW-2, and MNNW-3

Picking Note G1 12-4 5 UNITS DB

Order No	Date	Date Required	Branch	Sales Rep	Taken By	Customer	Customer Ref
3658140	11/06/2017	~~On 11/28/2017~~ 6	Waverly	Jan Badura	Jan Badura	Cod/Cash Sales - Jan Badura	Lumber

Special Instructions	Picking & Order Notes	Delivery Address
Contact Info: Eugene (Bunky) Krier 402-560-1716	Accepted from quote #363680	Midwest Roadside Safety Facility College of Engineering, University of Nebraska-Lincoln 4630 NW 36th Street Lincoln, Nebraska, 68524 Area:

Line No	Product Code - Description	Quantity	Weight	Qty Picked
1	3 X 12X 12' Rough Sawn Treated ** .40**	P 15 ea	15.000	15
2	Vendor did not have any 3x10 10's		0.000	
3	2x8 12' treated **.60**	P 25 ea	25.000	25
4	2x4 12' treated **.60**	P 5 ea	5.000	5
5	ABOVE ITEMS SOL RACK TB 11/15		0.000	
6	.		0.000	
7	.		0.000	
8	items below sol dock tb 11/16/17		0.000	
9	2 x 8 x 16 TNG SYP **.40**	P 120 ea	120.000	120
10	Sold in 12 pc. bundles.		0.000	
Picked By:			165.000	

11/21/2017 3: 12:34PM Page 1 of 1

Figure C-11. Wood Plank, Nailer, and Batten Material Specification, Test Nos. MNNW-1, MNNW-2, and MNNW-3

SPRENGER MIDWEST
WHOLESALE LUMBER

QUOTE

Account: DOIT01 0096
Branch: SPRENGERSF

SHIP TO:
Millard Lumber Inc 0355
Waverly Yard/Mfg
11200 N 148th St
Waverly NE 68462

Page 1 of 1

PO:	REF:	JOB:
EXP DELV DATE:	TYPE: WH	SHIP VIA: WE ARRANGE FRT TERM:
ACTIVATION DATE:	QUOTED FOR: Jan	
CLOSE DATE:	QUOTED BY: Brianc	

QUANTITY	UOM	ITEM/DESCRIPTION	PRICE/UOM	AMOUNT
	BF	204YTFDN 2X4 .60 FDN CCA TREATED #2 SYP		
X	(PC)	5/12'		
	BF	208YTFDN 2X8 .60 FDN CCA TREATED #2 SYP		
X	(PC)	25/12'		
	BF	312YT 3X12 GROUND CONTACT TRT SYP		
X	(PC)	~~20~~/12' 15 We're actually sold out of 3x12x20 for a month or so. Offering 3x12x12 in lieu of the 10's you'd asked for. Please note that they are GROUND CONTACT grade treatment (= old .40 level) vs BELOW GRADE grade of treatment (= of .60 level). We have NO way to get them in the Below Grade level.		
	BF	208YTTGM1 2X8 new style T&G #1 SYP GROUND CONTACTMCA		
X	(PC)	~~182~~/16' 120 This is the only options we stock for 2x8x16 T&G. It is Ground Contact grade (= old .40) and is sold in 12-pc increments only.		

PAYMENT TERMS:

Total

Figure C-12. Wood Plank, Nailer, and Batten Material Specification, Test Nos. MNNW-1, MNNW-2, and MNNW-3

COMMERCIAL GROUP LIFTING PRODUCTS

Feb 15th 2017

SOLD TO:
GREGORY INDUSTRIES, INC.
4100 13TH ST. SW
CANTON, OH. 44710

SHIP TO:
HIGHWAY – FINISHED GOODS
GREGORY INDUSTRIES, INC.
ATTN: STEVE PENNINGTON
CANTON, OH 44710

R#17-700
BCT Cables Yellow Paint

CERTIFICATON

CGLP ORDER# 256284
GREGORY PO# 36454

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

1,330 PCS, PART# 3012G, 3/4IN X 6FT 6IN DOUBLE SWAGE GUARD RAIL ASSEMBLYS.

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

ATTACHMENTS:

(WIRE ROPE) WIRECO WORLD GROUP REEL# 428-671806-1; HEAT# .15R582807; 16R584001; 72987C; 16R586548; 73253F; 16R588160; 16R584967; 16R585464; 16R586547; 14R574048; 14R571682; 16R586549; 16R586401; (ROCKY MOUNTAIN STEEL / EVRAZ)

(END FITTINGS) REMLINGER MFG: HEAT#S 75063022; 75062074; 765063075 (GERDAU NORTH AMERICA)

VERY TRULY YOURS

BILL KOTARSKI
GEN MGR CLEV OFFICE

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

Figure C-13. BCT Anchor Cable Material Certificate, Test Nos. MNNW-1 and MNNW-2

Certified Analysis

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

MILFORD, NE 68405
Project: RESALE

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

As of: 11/7/16

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

3 of 5

Figure C-14. Anchor Bearing Plate (South) and BCT Anchor Cable Material Certificate, Test Nos. MNNW-1, MNNW-2, and MNNW-3

Certified Analysis

Trinity Highway Products, LLC
2548 N.E. 28th St.
Ft Worth, TX

Customer: MID WEST MACH.& SUPPLY CO.
P. O. BOX 81097

LINCOLN, NE 68501-1097

Project: RESALE

Order Number: 1095199
Customer PO: 2041
BOL Number: 24481
Document #: 1
Shipped To: NE
Use State: KS

As of: 6/20/08

Qty	Part#	Description	Spec	CL	TY	Heat Code/ Heat #	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
25	6G	12/6'3/S	M-180	A		84964	64,230	81,300	25.4	0.180	0.720	0.012	0.001	0.040	0.080	0.000	0.060	0.000	4
20	701A	.25X11.75X16 CAB ANC	A-36			4153095	44,900	60,800	34.0	0.240	0.750	0.012	0.003	0.020	0.020	0.000	0.040	0.002	4
10	742G	60 TUBE SL/.188X8X6	A-500			A8P1160	74,000	87,000	25.2	0.050	0.670	0.013	0.005	0.030	0.220	0.000	0.060	0.021	4
20	782G	5/8"X8"X8" BEAR PL/OF	A-36			6106195	46,700	69,900	23.5	0.120	0.830	0.010	0.005	0.020	0.330	0.000	0.070	0.006	4
40	907G	12/BUFFER/ROLLED	M-180	A		L0049	54,200	73,500	25.0	0.160	0.700	0.011	0.008	0.020	0.200	0.000	0.100	0.000	4

Upon delivery, all materials subject to Trinity Highway Products, LLC Storage Stain Policy No. LG-002.

ALL STEEL USED WAS MELTED AND MANUFACTURED IN USA AND COMPLIES WITH THE BUY AMERICA ACT.
ALL GUARDRAIL MEETS AASHTO M-180, ALL STRUCTURAL STEEL MEETS ASTM A36
ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTM-123.
BOLTS COMPLY WITH ASTM A-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.
NUTS COMPLY WITH ASTM A-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTM A-153, UNLESS OTHERWISE STATED.

3/4" DIA CABLE 6X19 ZINC COATED SWAGED END AISI C-1035 STEEL ANNEALED STUD 1" DIA ASTM 449 AASHTO M30, TYPE II BREAKING STRENGTH – 49100 LB

State of Texas, County of Tarrant. Sworn and subscribed before me this 20th day of June, 2008

Notary Public:
Commission Expires

RACHEL R. MEDINA
Notary Public
State of Texas
My Commission Expires

Trinity Highway Products, LLC
Certified By:

Stefanie Ornel.a

MIDWEST MACHINERY 402-761-3288 06/04/2009 16:36

Figure C-15. Anchor Bearing Plate (North) Material Certificate, Test Nos. MNNW-1, MNNW-2, and MNNW-3

Atlas Tube (Alabama), Inc.
171 Cleage Dr
Birmingham, Alabama, USA
35217
Tel:
Fax:

Atlas Tube
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80791452
Date: 11.10.2017
Customer: 179

MATERIAL TEST REPORT

Sold to

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

Shipped to

Steel & Pipe Supply Compan
401 New Century Parkway
NEW CENTURY KS 66031
USA

Material: 3.0x2.0x188x40'0"0(5x4). Material No: 0300201884000-B Made in: USA Melted in: USA

Sales order: 1226976 Purchase Order: 4500296656 Cust Material #: 6630020018840

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
B704212	0.200	0.450	0.010	0.004	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.28
40867002	20	064649 Psi	087652 Psi	24 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 2.375x154x42'0"0(34x1). Material No: R023751544200 Made in: USA Melted in: USA

Sales order: 1226976 Purchase Order: 4500296656 Cust Material #: 642004042

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
B712810	0.210	0.460	0.012	0.002	0.020	0.024	0.100	0.002	0.020	0.030	0.060	0.004	0.002	0.000	0.008

Bundle No	PCs	Yield	Tensile	Eln.2in	Rb	Certification	CE: 0.32
MC00005947	34	063688 Psi	083220 Psi	25 %	91	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

Material: 2.375x154x42'0"0(34x1). Material No: R023751544200 Made in: USA Melted in: USA

Sales order: 1226976 Purchase Order: 4500296656 Cust Material #: 642004042

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
17037261	0.210	0.810	0.005	0.004	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE: 0.35
41532001	34	066144 Psi	082159 Psi	27 %	ASTM A500-13 GRADE B&C	

Material Note:
Sales Or.Note:

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

Steel Tube Institute OF NORTH AMERICA

Page : 3 Of 4

Metals Service Center Institute

Figure C-16. BCT Post Sleeve Material Certificate, Test Nos. MNNW-1, MNNW-2, and MNNW-3

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

CERTIFICATE OF CONFORMANCE

For: CASH SALE
PB Invoice#: 103293
Cust PO#: MIDWEST ROADSIDE
Date: 9/29/2017
Shipped: 10/03/2017

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.

Description: 1-1/4 X 14 GALV ASTM A307A ROUND HEAD BOLT

Heat#: 278117 **Base Steel:** A36 **Diam:** 1-1/4

Source: CASCADE STEEL RLG MILL **Proof Load:** 0

C :	.180	**Mn:**	.680	**P :**	.016	**Hardness:**	0		
S :	.018	**Si:**	.220	**Ni:**	.080	**Tensile:**	70,000 PSI	**RA:**	65.00%
Cr:	.150	**Mo:**	.024	**Cu:**	.240	**Yield:**	41,200 PSI	**Elon:**	32.00%
Pb:	.000	**V :**	.000	**Cb:**	.000	**Sample Length:**	8 INCH		
N :	.000			**CE:**	.3178	**Charpy:**		**CVN Temp:**	

Description: 3/4 X 18 GALV ASTM A307A ROUND HEAD BOLT

Heat#: 145417 **Base Steel:** A36 **Diam:** 3/4

Source: CASCADE STEEL RLG MILL **Proof Load:** 0

C :	.170	**Mn:**	.680	**P :**	.012	**Hardness:**	0		
S :	.012	**Si:**	.270	**Ni:**	.060	**Tensile:**	73,500 PSI	**RA:**	42.00%
Cr:	.100	**Mo:**	.021	**Cu:**	.240	**Yield:**	49,200 PSI	**Elon:**	27.00%
Pb:	.000	**V :**	.002	**Cb:**	.000	**Sample Length:**	8 INCH		
N :	.000			**CE:**	.3017	**Charpy:**		**CVN Temp:**	

Figure C-17. Round Head Bolts Material Certificate, Test Nos. MNNW-1 and MNNW-2

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

CERTIFICATE OF CONFORMANCE

For: CASH SALE
PB Invoice#: 103293
Cust PO#: MIDWEST ROADSIDE
Date: 9/29/2017
Shipped: 10/03/2017

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.

Nuts:
ASTM A563A HEX

Coatings:
ITEMS HOT DIP GALVANIZED PER ASTM F2329/A153C

By:
Certification Department Quality Assurance
Dane McKinnon

Figure C-18. Hex Nut Certificate of Conformance, Test Nos. MNNW-1 and MNNW-2

Certified Material Test Report to BS EN 10204-2004 3.1
FOR ASTM A307, GRADE A HEX MACHINE BOLTS

FACTORY: IFI & Morgan Ltd. Haiyan Office
ADDRESS: Haiyan, Zhejiang, China
TEL:(00852)25423366
CUSTOMER: FASTENAL

DATE: SEP 10 2016
MANU DATE: SEP 01 2016
MFG LOT NUMBER: GL16088-5
PO NUMBER: 220021131
PART NO: 91986

SAMPE SIZE: ASME B18.8 CATEGORY 2-2011; ASTM F1470-2012 TABLE 2
MANU QTY: 720 PCS
SHIPPED QTY: 720 PCS
SIZE: 3/4-10 x 18 HDG
HEADMARKS: 307A + ⋈

STEEL PROPERTIES:
STEEL GRADE: Q195LD
HEAT NUMBER: 184335

CHEMISTRY SPEC:	C %	Mn%	P %	S %
	0.29 max	1.20 max	0.04max	0.15max
TEST:	0.08	0.37	0.028	0.026

DIMENSIONAL INSPECTIONS — SPECIFICATION: ASME B18.2.1 - 2015

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
APPEARANCE	ASTM F788/F788M-13	PASSED	18	0
THREAD	ANSI B1.1-2003(R08)-2A	PASSED	13	0
WIDTH FLATS	1.125-1.088	1.112-1.110	3	0
WIDTH A/C	1.299-1.240	1.245-1.243	3	0
HEAD HEIGHT	0.524-0.455	0.476-0.474	3	0
BODY DIA.	0.768-0.729	0.738-0.736	3	0
THREAD LENGTH	Min 2.000	PASSED	3	0
LENGTH	18.140-17.820	18.998-17.983	3	0

MECHANICAL PROPERTIES: — SPECIFICATION: ASTM A307-2014 GR-A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS :	ASTM F606-2013	Max 100 HRB	79-84 HRB	3	0
WEDGE TENSILE:	ASTM F606-2013	Min 60 KSI	70-74 KSI	3	0
ELONGATION IN 2 in.	ASTM F606-2013	Min 18 %	19-21%	3	0

COATINGS OF HOT DIP ZINC — SPECIFIATION: ASTM F2329-2013

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
Coating thickness	ASTM B568-98(201	Min0.0017"	0.0020"	13	0

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

IFI MORGAN LTD. 检验专用章 QUALITY CONTROL

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

Figure C-19. Round Head Bolt Material Certificate, Test No. MNNW-3

ISO/TS 16949 BUREAU VERITAS Certification

GEM-YEAR TESTING LABORATORY
CERTIFICATE OF INSPECTION

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

Tel: (0573)84185001(48Lines)
Fax: (0573)84184488 84184567
DATE : 2018/02/05

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 220025818
COMMODITY : HOT FORM HEX MACHINE BOLT GR-A
SIZE : 3/4-10X18 NC
LOT NO : 1B1782484
SHIP QUANTITY : 480 PCS
LOT QUANTITY 481 PCS
HEADMARKS : CYI & 307A
MANUFACTURE DATE : 2017/09/16
COUNTRY OF ORIGIN : CHINA

PACKING NO : GEM170930008
INVOICE NO : GEM/FNL-171026IN-1
PART NO : 91986
SAMPLING PLAN : ASME B18.18-2011(Category.2)/ASTM F1470-2012
HEAT NO : 17308059-3
MATERIAL : X1008A
FINISH : HOT DIP GALVANIZED PER ASTM A153-2009/ASTM F2329-2013

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO ASTM A307-2014

Chemistry	AL%	C%	MN%	P%	S%	SI%
Spec. : MIN.						
MAX.		0.3300	1.2500	0.0410		
Test Value	0.0380	0.0800	0.2700	0.0160	0.0060	0.0300

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.2.1-2012

SAMPLED BY : CLYAN

INSPECTIONS ITEM	SAMPLE	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
THREAD LENGTH	9PCS	2.0000 inch	6.2260-6.2300 inch	9	0
MAJOR DIAMETER	9PCS	0.7370-0.7500 inch	0.7440-0.7460 inch	9	0
BODY DIAMETER	3PCS	0.7290-0.7680 inch	0.7450-0.7460 inch	3	0
WIDTH ACROSS CORNERS	3PCS	1.2400-1.2990 inch	1.2760-1.2780 inch	3	0
HEIGHT	3PCS	0.4550-0.5240 inch	0.4960-0.4970 inch	3	0
NOMINAL LENGTH	9PCS	17.8200-18.1400 inch	17.9190-17.9270 inch	9	0
WIDTH ACROSS FLATS	3PCS	1.0880-1.1250 inch	1.1080-1.1100 inch	3	0
SURFACE DISCONTINUITIES	11PCS	ASTM F788-2013	PASSED	11	0
THREAD	9PCS	ASME B1.1-2003 nut	PASSED	9	0

MECHANICAL PROPERTIES : ACCORDING TO ASTM A 307-2014

SAMPLED BY : LUYI

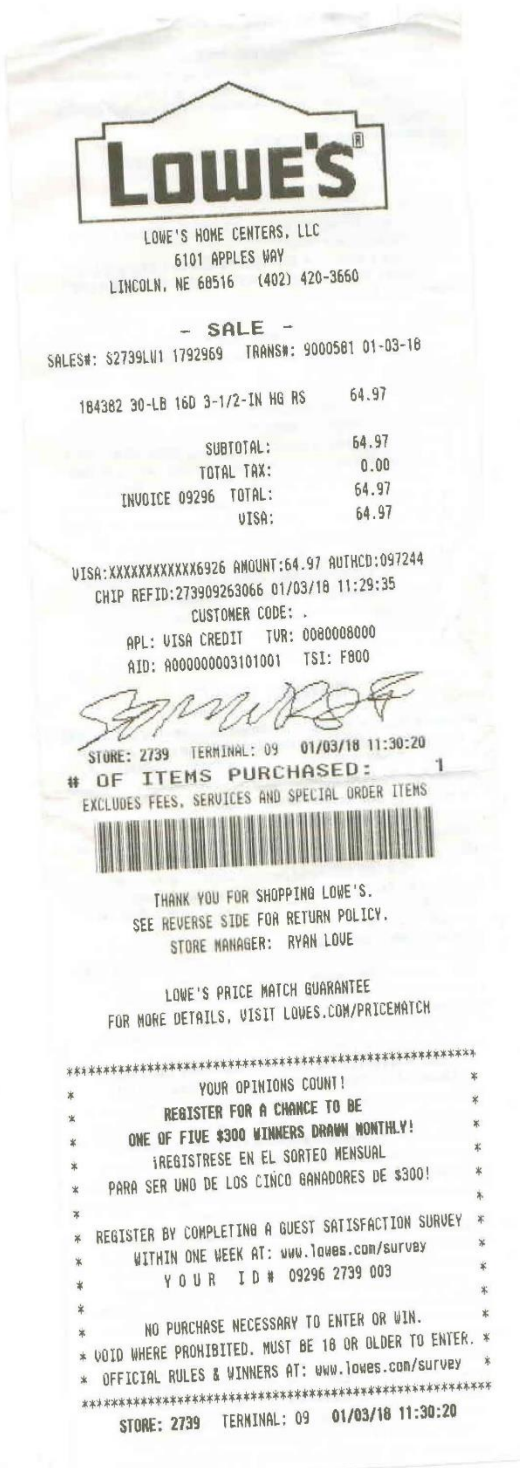
INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	9PCS	ASTM F606-2016		Max. 100 HRB	76-84 HRB	9	0
TENSILE STRENGTH	3PCS	ASTM F606-2016		Min. 60 KSI	72-77 KSI	3	0
PLATING THICKNESS(μm)	5PCS	ASTM B568-1998		>=53	78.03-85.9	5	0

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

Quality Supervisor: Brin

page 1 of 1

Figure C-20. Round Head Bolt Material Certificate, Test No. MNNW-3



LOWE'S

LOWE'S HOME CENTERS, LLC
6101 APPLES WAY
LINCOLN, NE 68516 (402) 420-3660

- SALE -

SALES#: S2739LW1 1792969 TRANS#: 9000581 01-03-18

184382 30-LB 16D 3-1/2-IN HG RS 64.97

SUBTOTAL:	64.97
TOTAL TAX:	0.00
INVOICE 09296 TOTAL:	64.97
VISA:	64.97

VISA:XXXXXXXXXXXX6926 AMOUNT:64.97 AUTHCD:097244
CHIP REFID:273909263066 01/03/18 11:29:35
CUSTOMER CODE: .
APL: VISA CREDIT TVR: 0080008000
AID: A000000003101001 TSI: F800

STORE: 2739 TERMINAL: 09 01/03/18 11:30:20
OF ITEMS PURCHASED: 1
EXCLUDES FEES, SERVICES AND SPECIAL ORDER ITEMS

THANK YOU FOR SHOPPING LOWE'S.
SEE REVERSE SIDE FOR RETURN POLICY.
STORE MANAGER: RYAN LOVE

LOWE'S PRICE MATCH GUARANTEE
FOR MORE DETAILS, VISIT LOWES.COM/PRICEMATCH

YOUR OPINIONS COUNT!
REGISTER FOR A CHANCE TO BE
ONE OF FIVE $300 WINNERS DRAWN MONTHLY!
¡REGISTRESE EN EL SORTEO MENSUAL
PARA SER UNO DE LOS CINCO GANADORES DE $300!

REGISTER BY COMPLETING A GUEST SATISFACTION SURVEY
WITHIN ONE WEEK AT: www.lowes.com/survey
Y O U R I D # 09296 2739 003

NO PURCHASE NECESSARY TO ENTER OR WIN.
VOID WHERE PROHIBITED. MUST BE 18 OR OLDER TO ENTER.
OFFICIAL RULES & WINNERS AT: www.lowes.com/survey

STORE: 2739 TERMINAL: 09 01/03/18 11:30:20

Figure C-21. Shank Nail Receipt, Test Nos. MNNW-1, MNNW-2, and MNNW-3

GRAINGER
FOR THE ONES WHO GET IT DONE

Certificate of Conformance

W.W. Grainger, Inc.
100 Grainger Parkway
Lake Forest, IL. 60045-5201

February 15 2018

Attn: SHAUN M TIGHE
SHAUN M TIGHE
CANFIELD ADMINISTRATION
BLDG
LINCOLN, NE, 68588-0439

Fax #

Grainger Sales Order #: 1309088366
Customer PO #: E000480344

Dear SHAUN M TIGHE
As you requested, we are providing you with the following information. We certify that, to the best of Grainger's actual knowledge, the products described below conform to the respective manufacturer's specifications as described and approved by the manufacturer.

Item #	Description	Vendor Part #	Catalog Page #	Order Quantity
31JJ25	Deck Screw,Bugle,#8,2-1/2,Star,SST,PK2	U30250.016.0250	2107	5.000

Shea Gallup
Process Management Analyst
Compliance Team
Grainger Industrial Supply

Figure C-22. Screw Certificate of Conformance, Test Nos. MNNW-1, MNNW-2, and MNNW-3

CONAC
Concrete Product Solutions

January 1, 2018

CERTIFICATE OF COMPLIANCE

Product Name or Description:

All CONAC Lifting Devices including DR Anchors, A-Anchors, Flat System Anchors and Clutches, Coil Inserts, Wire Rope Anchors and Threaded Lifting System Inserts.

This is to certify that the above lifting and handling products have been manufactured and tested in accordance with the quality control plan established by ISO 9001 certified manufacturers and meet or exceed OSHA 29 CFR 1926.704 when compared to the listed catalog rating for the lifting device.

This document certifies each manufactured product can be related to a quality control plan. The manufacturing quality control tests can be made available upon written request and when appropriate.

The rated capacities are for mechanical capacity of the listed anchor or insert only. Placement, edge distances, embedment depth, concrete strength, attachment device, sling angles, and rigging consideration are not part of this certificate of compliance.

Michael Azarin, President
CONAC, Concrete Accessories of GA Inc.
Date: 1/1/2018

QMF-029 Rev. 0 New 11-14-13 (11.0)
Lifting Insert Certificate of Compliance 127

Figure C-23. Bolt and Washer Certificate of Compliance, Test Nos. MNNW-1, MNNW-2, and MNNW-3

HILTI
P.O. Box 21148
Tulsa, OK 74121
P: 800-879-8000
F: 800-879-7000

Date: 2/19/2018

Customer: UNIVERSITY OF NEBRASKA-LINCOLN

Customer PO: MnDOT Noise Wall

Subject: Certificate of Conformance - Hilti HDI Anchors

Quantity: 100 PCS / 336429 / Flush anchor HDI 3/4

To Whom it May Concern:

This is to certify that Hilti HDI Drop in Expansion Anchors, supplied on the above purchase order, are manufactured of mild carbon steel and are plated in accordance with the requirements of **Federal Specification** QQ Z 325C, superseded by **ASTM** B633 85,**Type** III, **Class** Fe/Zn 5.

The anchors conform to the description provided in **Federal Specification** FF S 325, **Group** VIII, **Type** I.

Sincerely,

B. Mitchell

B. Mitchell, Certification Specialist

HILTI, Inc.
coc7

Figure C-24. Concrete Anchor Certificate of Conformance, Test Nos. MNNW-1, MNNW-2, and MNNW-3

31362

2490 Arbor Blvd.
Moraine, Ohio 45439

SUMMIT FINISHING TECHNOLOGIES, INC.

Phone: (937)424-5512
Fax: (937) 424-5519

Certificate of Conformance

Date: 3-30-17

P.O. #: 0000017781

Company: CONTRACTORS MATERIALS

Part Number: B16-1/2" X 4" 0.223 \ Lot: 0000097318

Part Description: COIL INSERTS

Summit Finishing Technologies Inc. does hereby certify that all processed material shipped against the above Purchase Order were processed in compliance with the all of the specifications detailed on the said Purchase Order.

Specifications Number: ASTM B633 FeZn25 TYPE III SC4 & BAKE

Process: 25 μm Barrel Zinc Electroplate Yellow Di-Chromate Post Treatment

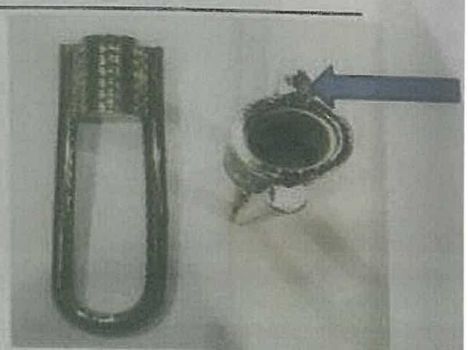
Quantity Tested: 10 Lot Quantity: 10,000

at:/Release/Bin Number(s)

Thickness checks at P-point:

Barrel 1-1	27.82 μm	Barrel 2-1	32.16 μm
Barrel 1-2	25.93 μm	Barrel 2-2	29.81 μm
Barrel 1-3	26.34 μm	Barrel 2-3	28.72 μm
Barrel 1-4	27.38 μm	Barrel 2-4	28.27 μm
Barrel 1-5	27.57 μm	Barrel 2-5	28.44 μm

Authorized Representative



Photo

Figure C-25. Concrete Anchor Certificate of Conformance, Test Nos. MNNW-1, MNNW-2, and MNNW-3

TEST REPORT

USS FLAT WASHER, HDG

CUSTOMER:

DATE: **2017-07-12**

PO NUMBER: **220024755**

MFG LOT NUMBER: **M-SWE0411982-34**

SIZE: **1-1/4**

PART NO: **33189**

HEADMARKS:

QNTY: **9,000 PCS**

DIMENSIONAL INSPECTIONS

SPECIFICATION: **ASME B18.21.1(2009)**

CHARACTERISTICS	SPECIFIED		ACTUAL RESULT	ACC.	REJ.
**********************	************************************		*******************	********	********
APPEARANCE	**ASTM F788-07**		**PASSED**	**100**	**0**
OUTSIDE DIA	**2.993-3.030**		**2.998-3.001**	**8**	**0**
INSIDE DIA	**1.368-1.405**		**1.393-1.395**	**8**	**0**
THICKNESS	**0.136-0.192**		**0.141-0.146**	**8**	**0**
HOT DIP GALVANIZED	**ASTM A153 class C. RoHS Compliant**	**Min 0.0017"**	**Min 0.0018In**	**8**	**0**

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION.
WE CERTIFY THAT THIS DAIA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
MFG ISO 9001:2015 SGS Certificate # HK04/0105

IFI & MORGAN LTD.
检验专用章
QUANLITY CONTROL

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

IFI & MORGAN LTD. ***ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China***

Figure C-26. Round Washer Material Certificate, Test Nos. MNNW-1, MNNW-2 and MNNW-3

3/4" x 2.000" OD Low Carbon Zinc Finish Steel USS General Purpose Flat Washer

CERTIFIED MATERIAL TEST REPORT
FOR USS FLAT WASHERS ZP

FACTORY: IFI & MORGAN LTD
ADDRESS: Chang'an North Road, Wuyuan Town, Haiyan, Zhejiang, China

REPORT DATE: 2017-12-04

MANUFACTURE DATE: 2017-12-04

COUNTRY OF ORIGIN: CHINA
CUSTOMER: **FASTENAL**

MFG LOT NUMBER: 17H168220-3

SAMPLING PLAN PER ASME B18.18-11
SIZE: 3/4 ZP QNTY(Lot size): 33600PCS
HEADMARKS: NO MARK

PO NUMBER:210136785

PART NO: 1133018

DIMENSIONAL INSPECTIONS SPECIFICATION: ASTM B18.21.1-2011

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
**********************	*************************************	******************	********	********
APPEARANCE	ASTM F844	PASSED	100	0
OUTSIDE DIA	1.993-2.030	1.999-2.015	10	0
INSIDE DIA	0.805-0.842	0.819-0.828	10	0
THICKNESS	0.122-0.177	0.128-0.157	10	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
*********************	*****************	******************	******************	********	********
ZINC PLATED	ASTM F1941	Min 3 um	3.9-5.1um	8	0

ALL TESTS IN ACCORDANCE WITH THE METHODS PRESCRIBED IN THE APPLICABLE ASTM SPECIFICATION. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY.
MFG ISO9002 CERTIFICATE NO.HK04/0105

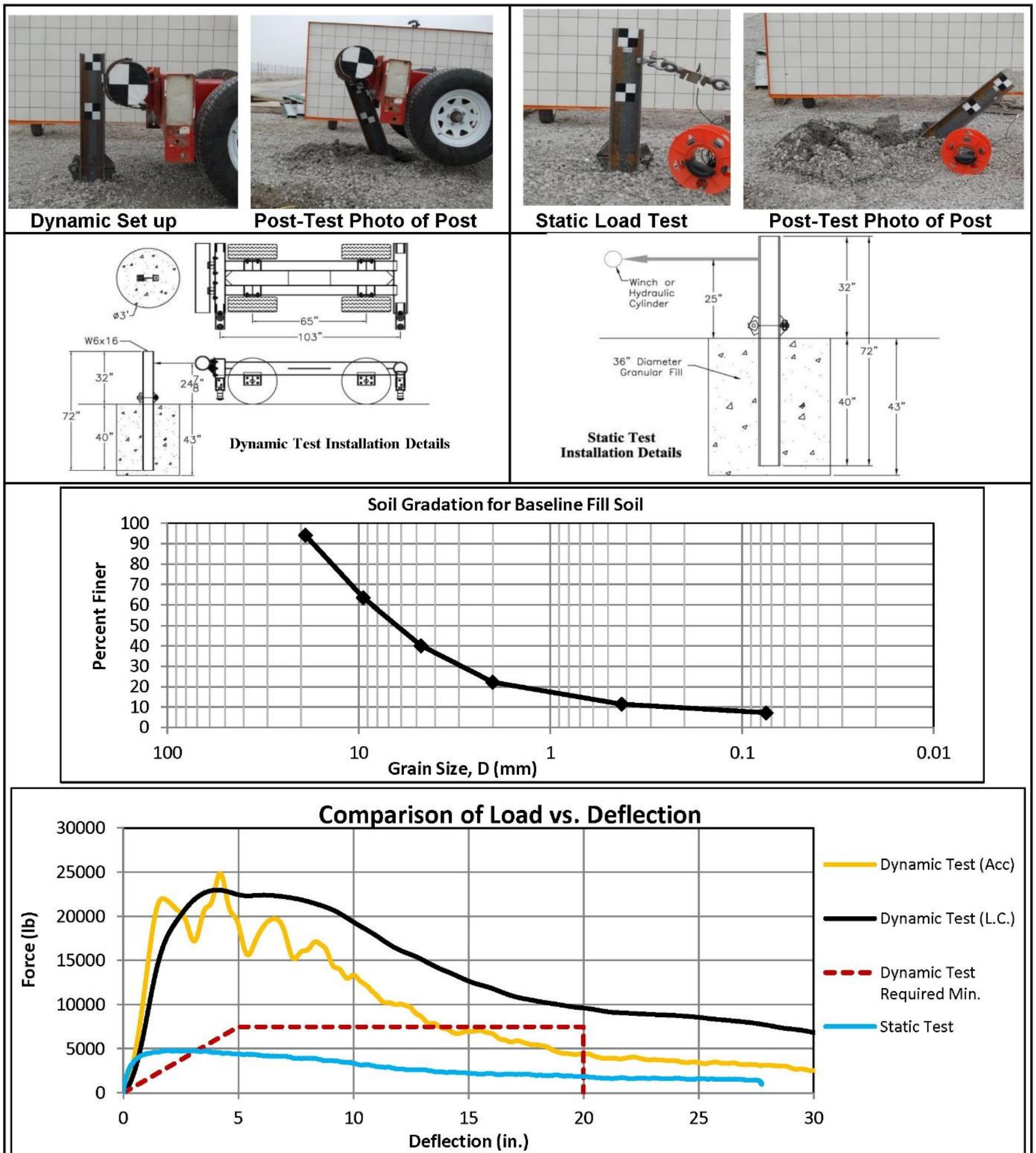
IFI & MORGAN LTD.
检验专用章
QUANLITY CONTROL

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

由 扫描全能王 扫描创建

Figure C-27. Round Washer Material Certificate, Test Nos. MNNW-1, MNNW-2 and MNNW-3

Appendix D. Static Soil Tests

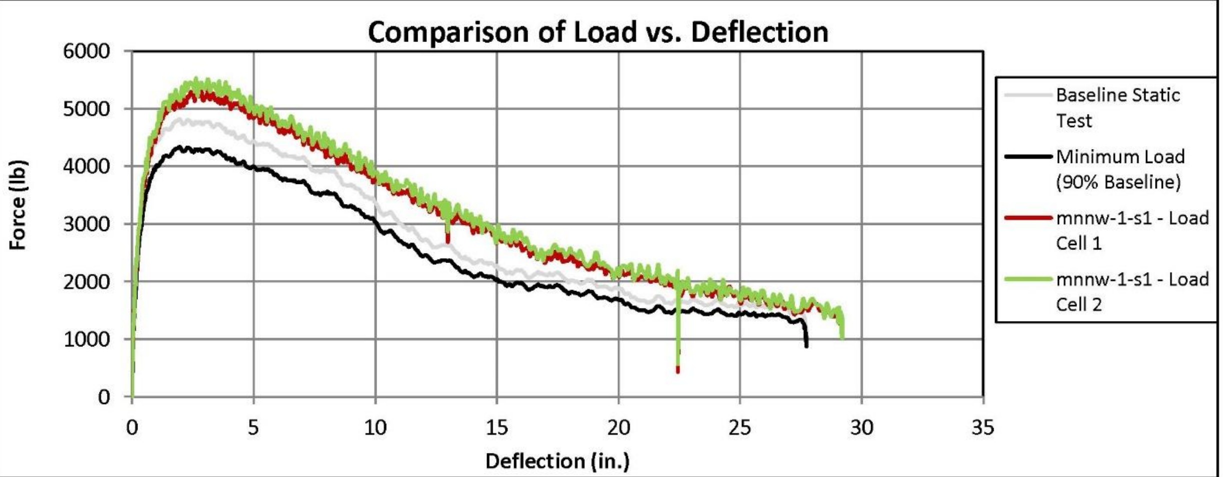


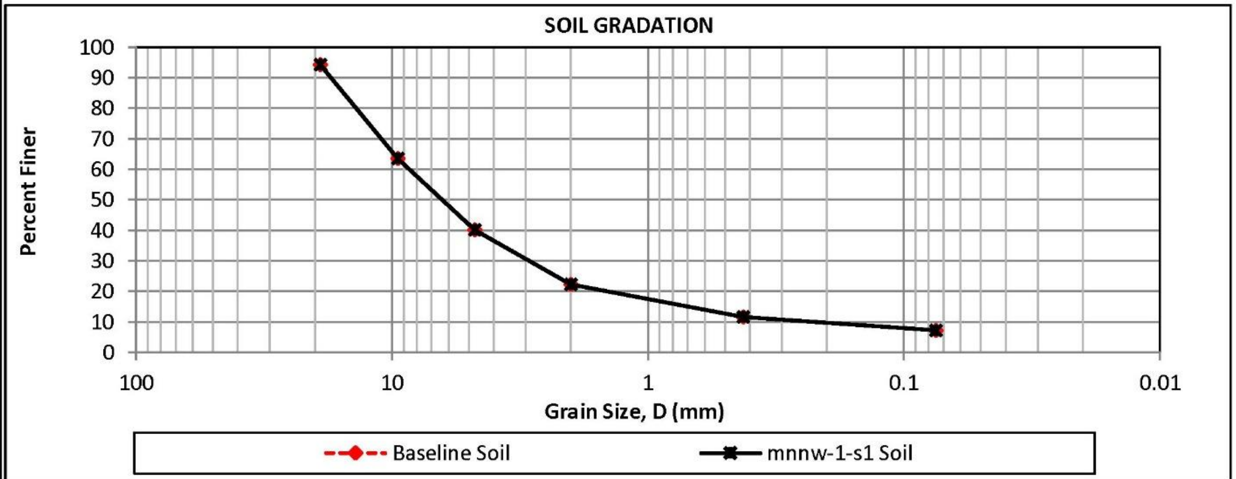
Date..	2/16/2018
Test Facility & Site Location.......................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)..........	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)........	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.......	H.E.-8
Bogie Weight...	1786 lb 810 kg
Impact Velocity..	20.9 mph 33.7 km/h

Figure D-1. Soil Strength, Initial Calibration Tests, Test No. MNNW-1

Static Load Test Setup

Post-Test Photo of Post





Date..	2/27/2018
Test Facility & Site Location.......................	Midwest Roadside Safety Facility
In situ soil description (ASTM D2487)..........	Well-Graded Gravel (GW)
Fill material description (ASTM D2487)........	Well-Graded Gravel (GW) (see sieve analyses above)
Description of fill placement procedure.......	8-inch lifts tamped with a pneumatic compactor

Figure D-2. Static Soil Test, Test No. MNNW-1

Appendix E. Vehicle Deformation Records

Date: 2/27/2018 Test Name: MNNW-1 VIN: 1D7RB1CT0AS214480
Year: 2010 Make: Dodge Model: RAM 1500 Crew

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Crush (in.)
TOE PAN - WHEEL WELL	1	62.399	44.043	7.112	61.704	42.753	7.149	0.694	1.290	0.038	0.696
	2	62.873	42.163	5.941	62.632	41.612	5.705	0.241	0.551	-0.236	0.337
	3	63.176	39.956	4.667	62.694	39.400	4.063	0.482	0.556	-0.604	0.773
	4	63.255	36.168	4.779	62.887	35.546	4.247	0.368	0.623	-0.532	0.647
	5	62.078	33.799	6.451	61.372	34.305	6.154	0.706	-0.506	-0.297	0.766
	6	60.988	32.213	7.467	60.240	32.624	7.152	0.748	-0.411	-0.316	0.812
	7	60.482	44.199	4.192	59.457	41.729	4.209	1.026	2.469	0.018	1.026
	8	60.503	42.564	3.281	59.902	41.762	2.844	0.600	0.802	-0.437	0.743
FLOOR PAN	9	60.365	40.144	3.062	59.864	39.448	2.495	0.502	0.696	-0.567	-0.567
	10	60.325	37.635	3.119	59.824	36.442	2.692	0.501	1.194	-0.427	-0.427
	11	60.055	34.393	3.875	59.692	34.028	3.331	0.363	0.366	-0.544	-0.544
	12	59.128	32.562	6.231	58.411	32.812	5.943	0.716	-0.251	-0.289	-0.289
	13	56.066	45.797	0.949	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data
	14	55.979	43.582	1.010	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data
	15	56.179	39.819	1.082	55.633	38.833	0.974	0.546	0.986	-0.109	-0.109
	16	56.365	37.240	1.163	55.860	36.383	0.497	0.505	0.857	-0.666	-0.666
	17	56.208	34.439	1.673	55.774	33.787	0.762	0.434	0.652	-0.911	-0.911
	18	55.300	31.997	4.308	54.706	31.868	3.680	0.594	0.129	-0.628	-0.628
	19	49.143	45.715	-0.827	48.727	45.054	-0.834	0.416	0.661	-0.007	-0.007
	20	49.212	42.990	-0.697	48.833	42.482	-1.054	0.378	0.508	-0.358	-0.358
	21	49.343	39.749	-0.689	48.927	39.270	-1.309	0.417	0.480	-0.620	-0.620
	22	49.270	37.779	-0.678	48.929	37.330	-1.279	0.341	0.449	-0.601	-0.601
	23	49.444	34.849	-0.692	48.985	34.312	-1.238	0.459	0.537	-0.545	-0.545
	24	49.383	30.343	-0.500	49.029	29.884	-1.015	0.354	0.460	-0.515	-0.515
	25	39.337	44.951	-1.108	38.992	44.418	-2.423	0.345	0.534	-1.315	-1.315
	26	39.319	41.171	-1.078	39.105	40.718	-1.798	0.214	0.453	-0.720	-0.720
	27	39.337	35.681	-1.046	38.991	35.287	-1.664	0.346	0.393	-0.618	-0.618
	28	39.166	31.678	-1.005	38.816	31.318	-1.465	0.350	0.360	-0.461	-0.461
	29	33.153	40.319	2.876	32.983	40.041	2.400	0.170	0.277	-0.476	-0.476
	30	33.374	30.343	2.929	33.108	30.143	2.660	0.266	0.199	-0.269	-0.269

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

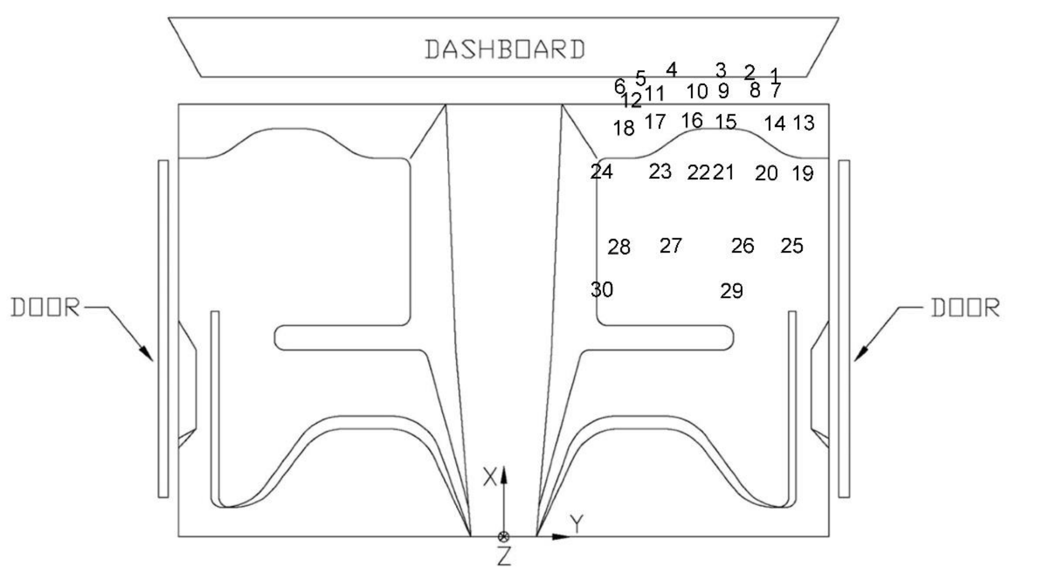


Figure E-1. Floor Pan Deformation Data – Set 1, Test No. MNNW-1

Date: 2/27/2018 Test Name: MNNW-1 VIN: 1D7RB1CT0AS214480
Year: 2010 Make: Dodge Model: RAM 1500 Crew

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Crush (in.)
TOE PAN - WHEEL WELL	1	62.867	22.673	2.963	62.475	21.347	2.067	0.392	1.326	-0.896	0.978
	2	63.286	20.781	1.791	63.350	20.168	0.620	-0.064	0.613	-1.171	1.173
	3	63.525	18.567	0.516	63.325	17.943	-1.006	0.200	0.624	-1.521	1.534
	4	63.500	14.778	0.628	63.405	14.086	-0.794	0.095	0.692	-1.422	1.425
	5	62.262	12.442	2.302	61.878	12.906	1.141	0.384	-0.464	-1.161	1.223
	6	61.130	10.886	3.320	60.708	11.266	2.165	0.422	-0.380	-1.155	1.230
	7	60.948	22.882	0.048	60.160	20.369	-0.837	0.788	2.513	-0.885	1.185
	8	60.921	21.248	-0.863	60.590	20.379	-2.208	0.332	0.869	-1.345	1.386
FLOOR PAN	9	60.717	18.833	-1.083	60.478	18.064	-2.539	0.239	0.768	-1.456	-1.456
	10	60.608	16.326	-1.025	60.351	15.062	-2.318	0.257	1.264	-1.292	-1.292
	11	60.250	13.093	-0.269	60.155	12.658	-1.659	0.095	0.435	-1.390	-1.390
	12	59.278	11.287	2.088	58.871	11.501	0.977	0.407	-0.214	-1.111	-1.111
	13	56.570	24.603	-3.184	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data
	14	56.422	22.391	-3.124	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data	Bad Data
	15	56.518	18.624	-3.052	56.212	17.565	-4.003	0.307	1.059	-0.951	-0.951
	16	56.633	16.041	-2.973	56.359	15.106	-4.464	0.274	0.935	-1.492	-1.492
	17	56.401	13.245	-2.463	56.199	12.516	-4.178	0.201	0.729	-1.715	-1.715
	18	55.431	10.829	0.174	55.111	10.652	-1.233	0.320	0.177	-1.406	-1.406
	19	49.643	24.712	-4.944	49.472	23.977	-5.773	0.171	0.735	-0.829	-0.829
	20	49.637	21.987	-4.814	49.499	21.402	-5.974	0.138	0.585	-1.161	-1.161
	21	49.679	18.743	-4.807	49.493	18.186	-6.206	0.186	0.557	-1.399	-1.399
	22	49.551	16.776	-4.797	49.438	16.247	-6.161	0.113	0.529	-1.364	-1.364
	23	49.644	13.842	-4.811	49.404	13.230	-6.097	0.240	0.613	-1.286	-1.286
	24	49.459	9.340	-4.620	49.319	8.804	-5.841	0.141	0.536	-1.221	-1.221
	25	39.819	24.220	-5.201	39.704	23.621	-7.236	0.115	0.598	-2.035	-2.035
	26	39.697	20.442	-5.172	39.713	19.925	-6.585	-0.017	0.517	-1.413	-1.413
	27	39.564	14.953	-5.141	39.439	14.501	-6.407	0.124	0.452	-1.266	-1.266
	28	39.282	10.956	-5.100	39.148	10.541	-6.176	0.133	0.416	-1.076	-1.076
	29	33.519	19.759	-1.203	33.628	19.463	-2.306	-0.109	0.296	-1.102	-1.102
	30	33.465	9.780	-1.153	33.460	9.567	-1.972	0.005	0.213	-0.819	-0.819

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

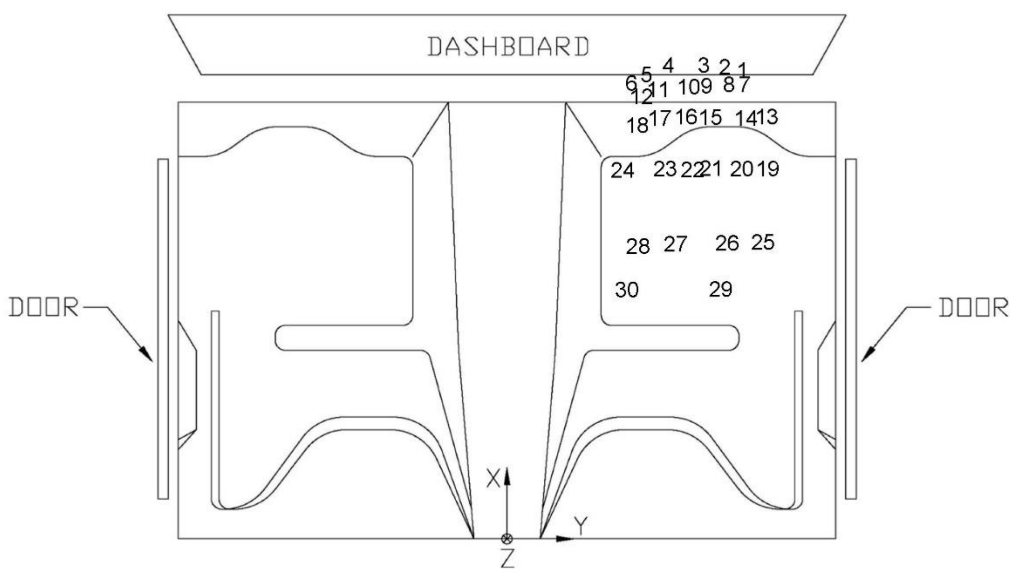


Figure E-2. Floor Pan Deformation Data – Set 2, Test No. MNNW-1

Date: 2/27/2018 Test Name: MNNW-1 VIN: 1D7RB1CT0AS214480
Year: 2010 Make: Dodge Model: RAM 1500 Crew

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Crush (in.)
DASH	1	48.955	15.740	32.214	48.807	16.019	32.170	0.149	-0.280	-0.044	0.320
	2	48.324	27.034	31.717	48.105	27.281	31.810	0.219	-0.246	0.093	0.342
	3	48.437	33.033	31.424	48.036	33.217	31.435	0.401	-0.184	0.011	0.442
	4	48.685	38.828	31.048	48.321	39.058	31.128	0.363	-0.230	0.080	0.438
	5	43.919	28.545	20.783	43.562	28.602	21.008	0.357	-0.058	0.224	0.425
	6	44.236	40.486	20.736	43.521	40.483	20.927	0.714	0.003	0.192	0.740
SIDE PANEL	7	53.686	48.791	3.989	52.536	43.781	4.430	1.150	5.010	0.441	5.010
	8	53.785	48.809	7.777	52.286	43.384	8.325	1.499	5.426	0.548	5.426
	9	57.803	48.899	8.242	56.301	42.790	8.903	1.502	6.110	0.661	6.110
IMPACT SIDE DOOR	10	44.177	50.608	24.059	42.895	51.716	24.003	1.281	-1.108	-0.055	-1.108
	11	33.716	50.328	23.266	32.322	51.642	23.196	1.395	-1.314	-0.071	-1.314
	12	22.015	50.767	22.203	20.642	52.070	22.071	1.373	-1.304	-0.133	-1.304
	13	38.886	51.646	7.303	37.339	49.090	7.445	1.547	2.557	0.142	2.557
	14	32.925	51.074	3.066	31.254	48.852	3.270	1.670	2.222	0.204	2.222
	15	23.262	50.507	6.641	21.652	49.589	6.911	1.610	0.918	0.270	0.918
ROOF	16	37.722	15.164	47.755	37.667	15.768	47.430	0.055	-0.604	-0.325	-0.325
	17	37.156	25.950	47.397	36.934	26.577	47.139	0.222	-0.627	-0.258	-0.258
	18	37.048	37.146	46.815	36.860	37.791	46.525	0.188	-0.645	-0.290	-0.290
	19	33.554	15.077	49.994	33.493	15.618	49.842	0.061	-0.541	-0.152	-0.152
	20	32.293	24.342	50.016	32.109	24.912	49.857	0.183	-0.570	-0.159	-0.159
	21	30.761	34.804	49.566	30.624	35.361	49.368	0.136	-0.557	-0.198	-0.198
	22	29.562	14.873	50.616	29.392	15.436	50.491	0.170	-0.563	-0.125	-0.125
	23	29.368	20.516	50.569	29.233	21.125	50.418	0.135	-0.609	-0.151	-0.151
	24	27.860	27.948	50.435	27.687	28.582	50.291	0.173	-0.634	-0.144	-0.144
	25	27.188	36.171	49.917	26.931	36.748	49.776	0.256	-0.577	-0.141	-0.141
	26	25.757	15.688	50.935	25.601	16.194	50.837	0.156	-0.506	-0.098	-0.098
	27	25.273	21.553	50.887	25.131	22.065	50.772	0.142	-0.513	-0.115	-0.115
	28	24.814	28.874	50.568	24.547	29.500	50.439	0.267	-0.626	-0.129	-0.129
	29	23.813	36.112	50.226	23.585	36.691	50.092	0.228	-0.579	-0.135	-0.135
	30	18.790	23.494	51.150	18.830	23.922	51.043	-0.040	-0.428	-0.107	-0.107
A PILLAR	31	51.751	47.310	32.789	51.352	48.149	32.452	0.399	-0.840	-0.337	0.399
	32	45.446	45.540	38.552	45.141	46.223	38.223	0.305	-0.684	-0.330	0.305
	33	41.372	44.443	41.008	41.043	45.059	40.702	0.329	-0.616	-0.306	0.329
	34	37.371	43.720	43.779	37.041	44.339	43.506	0.330	-0.619	-0.274	0.330
B PILLAR	35	9.239	43.819	42.046	9.031	44.075	41.917	0.208	-0.256	-0.129	0.330
	36	12.511	44.571	40.562	12.241	44.932	40.527	0.271	-0.361	-0.035	0.271
	37	8.663	45.505	36.083	8.467	45.488	35.916	0.196	0.016	-0.168	0.196
	38	13.325	46.567	34.746	13.039	46.822	34.621	0.286	-0.255	-0.126	0.286
	39	10.018	47.333	28.589	9.761	47.177	28.419	0.256	0.156	-0.170	0.300
	40	14.183	47.676	24.265	14.002	47.623	24.101	0.180	0.053	-0.164	0.188

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

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

Date: 2/27/2018 Test Name: MNNW-1 VIN: 1D7RB1CT0AS214480
Year: 2010 Make: Dodge Model: RAM 1500 Crew

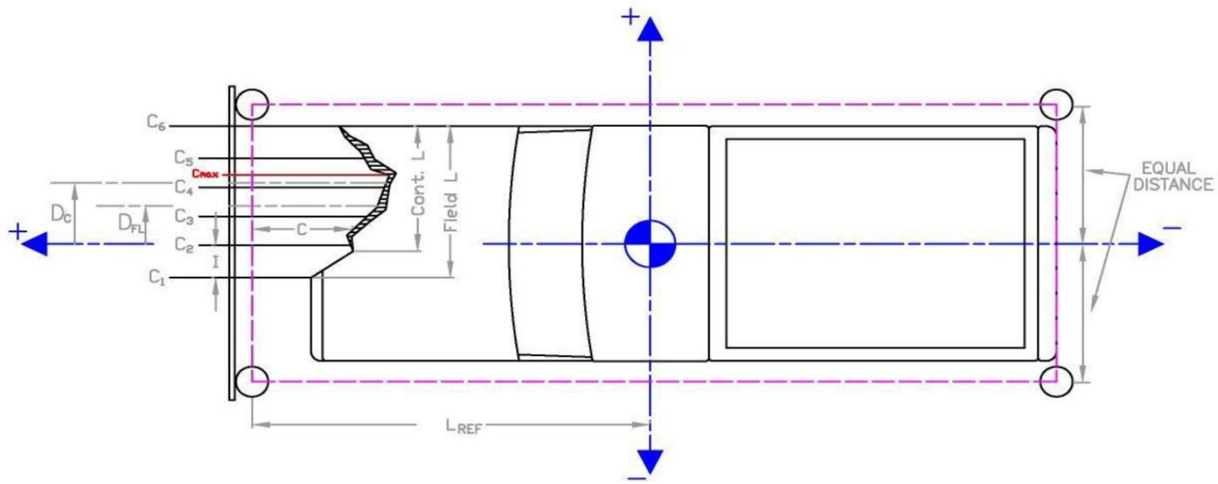
VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Crush (in.)
DASH	1	48.729	-5.224	28.048	48.624	-4.777	27.177	0.105	0.447	-0.871	0.985
	2	48.408	6.083	27.543	48.242	6.497	26.748	0.165	-0.414	-0.796	0.912
	3	48.685	12.076	27.244	48.338	12.430	26.332	0.347	-0.354	-0.913	1.039
	4	49.092	17.862	26.863	48.788	18.259	25.980	0.304	-0.397	-0.883	1.014
	5	44.013	7.707	16.621	43.598	7.878	15.996	0.415	-0.172	-0.625	0.769
	6	44.659	19.634	16.563	43.898	19.754	15.834	0.761	-0.120	-0.729	1.060
SIDE PANEL	7	54.285	27.663	-0.219	52.788	22.682	-0.803	1.496	4.981	-0.584	4.981
	8	54.395	27.682	3.569	52.578	22.318	3.098	1.818	5.364	-0.471	5.364
	9	58.416	27.661	4.022	56.581	21.612	3.627	1.835	6.049	-0.394	6.049
IMPACT SIDE DOOR	10	44.889	29.756	19.877	43.636	31.020	18.840	1.254	-1.264	-1.037	-1.264
	11	34.422	29.765	19.116	33.054	31.247	18.172	1.368	-1.482	-0.945	-1.482
	12	22.734	30.525	18.088	21.378	32.004	17.197	1.356	-1.479	-0.891	-1.479
	13	39.579	30.928	3.137	37.790	28.447	2.375	1.788	2.481	-0.762	2.481
	14	33.591	30.517	-1.082	31.647	28.357	-1.718	1.944	2.160	-0.637	2.160
	15	23.928	30.220	2.523	22.119	29.395	2.044	1.809	0.825	-0.479	0.825
ROOF	16	37.531	-5.478	43.623	37.681	-4.607	42.583	-0.151	0.872	-1.040	-1.040
	17	37.261	5.319	43.257	37.256	6.217	42.227	0.005	-0.898	-1.031	-1.031
	18	37.461	16.514	42.666	37.497	17.424	41.535	-0.036	-0.910	-1.131	-1.131
	19	33.369	-5.449	45.874	33.537	-4.621	45.050	-0.168	0.828	-0.824	-0.824
	20	32.363	3.848	45.892	32.422	4.710	45.019	-0.058	-0.862	-0.874	-0.874
	21	31.119	14.347	45.438	31.231	15.193	44.476	-0.112	-0.846	-0.961	-0.961
	22	29.374	-5.542	46.508	29.441	-4.680	45.754	-0.067	0.862	-0.753	-0.753
	23	29.336	0.105	46.457	29.445	1.011	45.644	-0.110	-0.906	-0.813	-0.813
	24	28.033	7.575	46.321	28.112	8.508	45.485	-0.080	-0.934	-0.836	-0.836
	25	27.586	15.813	45.798	27.586	16.689	44.923	0.001	-0.876	-0.875	-0.875
	26	25.594	-4.622	46.838	25.678	-3.811	46.144	-0.084	0.812	-0.693	-0.693
	27	25.272	1.254	46.786	25.377	2.071	46.045	-0.104	-0.818	-0.741	-0.741
	28	25.015	8.584	46.462	25.003	9.517	45.668	0.012	-0.933	-0.794	-0.794
	29	24.212	15.847	46.118	24.244	16.731	45.284	-0.031	-0.884	-0.834	-0.834
	30	18.846	3.374	47.067	19.136	4.110	46.385	-0.290	-0.737	-0.681	-0.681
A PILLAR	31	52.396	26.257	28.588	52.096	27.267	27.201	0.300	-1.010	-1.386	0.300
	32	46.061	24.666	34.371	45.908	25.559	33.067	0.154	-0.893	-1.305	0.154
	33	41.966	23.684	36.840	41.811	24.530	35.608	0.156	-0.846	-1.233	0.156
	34	37.956	23.074	39.624	37.827	23.944	38.468	0.129	-0.870	-1.156	0.129
B PILLAR	35	9.832	23.947	37.975	9.802	24.478	37.249	0.030	-0.531	-0.726	0.030
	36	13.119	24.607	36.480	13.017	25.232	35.811	0.102	-0.625	-0.669	0.102
	37	9.285	25.644	32.012	9.201	25.867	31.247	0.083	-0.224	-0.766	0.083
	38	13.970	26.576	30.661	13.792	27.060	29.882	0.178	-0.483	-0.778	0.178
	39	10.666	27.429	24.513	10.445	27.469	23.722	0.221	-0.040	-0.791	0.221
	40	14.827	27.653	20.176	14.641	27.764	19.345	0.186	-0.111	-0.831	0.186

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

Figure E-4. Occupant Compartment Deformation Data – Set 2, Test No. MNNW-1

Date:	2/27/2018	Test Name:	MNNW-1	VIN:	1D7RB1CT0AS214480
Year:	2010	Make:	Dodge	Model:	RAM 1500 Crew



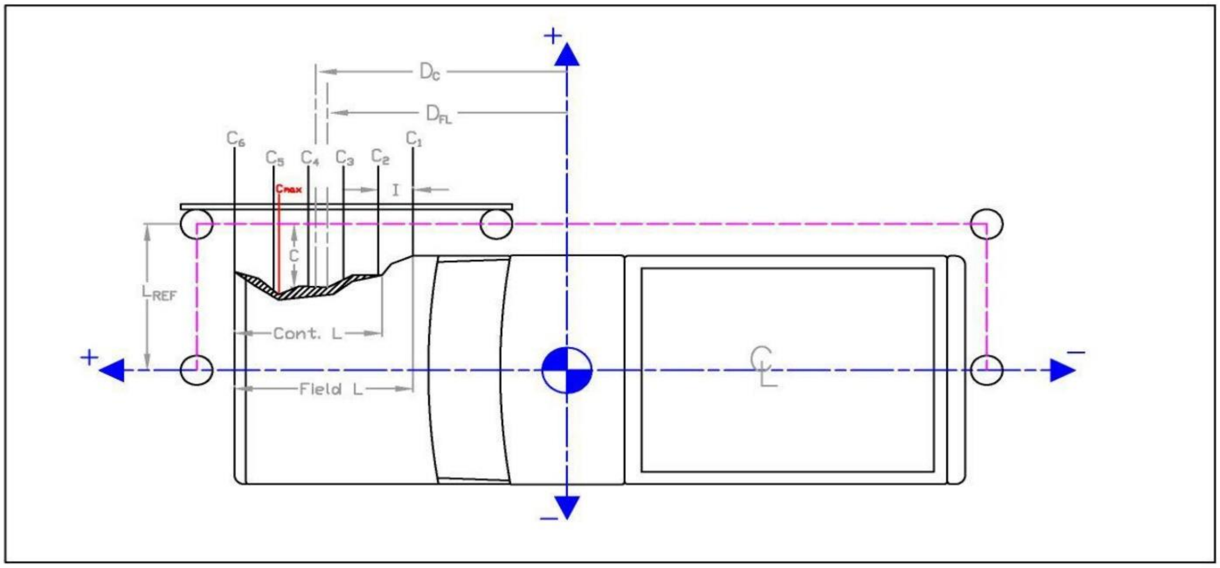
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	123	(3124)
Total Vehicle Width:	76 1/2	(1943)
Width of contact and induced crush - Field L:	76 1/2	(1943)
Crush measurement spacing interval (L/5) - I:	15 1/4	(387)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	24	(610)
Distance from center of vehicle to center of contact damage - D_C:	25	(635)

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	#VALUE!	-38 1/4	-(972)	22 1/2	(572)	18	(457)	#VALUE!	#VALUE!
C_2	29 1/2	(749)	-23	-(584)	6 1/2	(165)			5	(127)
C_3	18	(457)	-7 3/4	-(197)	4 1/4	(108)			-4 1/4	-(108)
C_4	19 1/4	(489)	7 1/2	(191)	4 1/4	(108)			-3	-(76)
C_5	37	(940)	22 3/4	(578)	6 1/8	(156)			12 7/8	(327)
C_6	N/A	#VALUE!	38	(965)	20 1/2	(521)			#VALUE!	#VALUE!
C_{MAX}	37	(940)	22 3/4	(578)	6 1/8	(156)			12 7/8	(327)

Figure E-5. Exterior Vehicle Crush (NASS) - Front, Test No. MNNW-1

Date:	2/27/2018	**Test Name:**	MNNW-1	**VIN:**	1D7RB1CT0AS214480
Year:	2010	**Make:**	Dodge	**Model:**	RAM 1500 Crew



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	49	(1245)
Total Vehicle Length:	229 3/8	(5826)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-5 2/3	-(144)
Width of contact and induced crush - Field L:	229 3/8	(5826)
Crush measurement spacing interval (L/5) - I:	45 7/8	(1165)
Distance from vehicle c.g. to center of Field L - D_{FL}:	-48 3/4	-(1238)
Width of Contact Damage:	229 3/8	(5826)
Distance from vehicle c.g. to center of contact damage - D_C:	-48 3/4	-(1238)

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

	Crush Measurement		Longitudinal Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual	Crush
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	N/a	#VALUE!	-163 1/2	-(4153)	33 1/2	(851)	5	(127)	#VALUE!	#VALUE!
C_2	N/A	#VALUE!	-117 5/8	-(2988)	26 5/8	(676)			#VALUE!	#VALUE!
C_3	N/A	#VALUE!	-71 3/4	-(1822)	5 3/8	(137)			#VALUE!	#VALUE!
C_4	7 1/2	(191)	-25 7/8	-(657)	5 1/4	(133)			-2 3/4	-(70)
C_5	7 1/4	(184)	20	(508)	5 1/8	(130)			-2 7/8	-(73)
C_6	21	(533)	65 7/8	(1673)	5 3/8	(137)			10 5/8	(270)
C_{MAX}	22	(559)	75	(1905)	5 7/8	(149)			11 1/8	(283)

Figure E-6. Exterior Vehicle Crush (NASS) - Side, Test No. MNNW-1

Date: 2/27/2018 Test Name: MNNW-2 VIN: KMHCN4ACXBU610901
Year: 2010 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
TOE PAN - WHEEL WELL	1	54.298	7.532	1.865	54.288	7.466	1.507	0.010	0.066	-0.357	0.363	0.010
	2	55.156	11.802	2.442	55.038	11.724	2.021	0.118	0.078	-0.421	0.444	0.118
	3	55.577	14.904	2.677	55.473	14.877	2.255	0.104	0.027	-0.423	0.436	0.104
	4	54.960	19.622	2.444	54.831	19.570	1.916	0.129	0.052	-0.528	0.546	0.129
	5	51.721	9.715	0.369	51.648	9.744	0.073	0.073	-0.029	-0.296	0.306	0.073
	6	52.305	14.074	0.709	52.137	13.935	0.265	0.168	0.139	-0.444	0.495	0.168
	7	51.727	20.015	0.461	51.644	19.979	-0.064	0.083	0.036	-0.525	0.533	0.083
	8	51.367	23.427	1.532	51.138	23.245	0.859	0.229	0.181	-0.674	0.735	0.229
FLOOR PAN	9	46.431	9.515	-1.913	46.256	9.359	-2.184	0.176	0.155	-0.271	0.358	-0.271
	10	46.119	14.284	-1.824	45.980	14.204	-2.221	0.138	0.080	-0.397	0.428	-0.397
	11	46.001	19.730	-1.793	45.914	19.507	-2.284	0.087	0.222	-0.491	0.546	-0.491
	12	46.093	23.978	-1.639	45.967	23.811	-2.164	0.125	0.167	-0.526	0.566	-0.526
	13	42.613	8.983	-2.270	42.597	8.928	-2.478	0.016	0.055	-0.207	0.215	-0.207
	14	42.250	13.671	-2.103	42.136	13.520	-2.283	0.114	0.151	-0.180	0.261	-0.180
	15	42.182	18.954	-1.926	42.041	18.720	-2.398	0.141	0.234	-0.473	0.546	-0.473
	16	42.167	23.887	-1.795	42.094	23.761	-2.411	0.073	0.126	-0.616	0.633	-0.616
	17	39.486	8.719	-2.555	39.449	8.643	-2.836	0.037	0.076	-0.281	0.293	-0.281
	18	39.940	13.348	-2.266	39.777	13.250	-2.202	0.163	0.097	0.064	0.200	0.064
	19	39.553	18.456	-2.059	39.469	18.418	-2.501	0.084	0.038	-0.442	0.452	-0.442
	20	39.235	23.357	-2.245	39.121	23.185	-2.910	0.114	0.172	-0.665	0.696	-0.665
	21	35.354	8.570	-2.617	35.280	8.583	-2.895	0.074	-0.013	-0.279	0.289	-0.279
	22	35.483	12.905	-2.469	35.435	12.757	-2.606	0.048	0.148	-0.136	0.207	-0.136
	23	35.094	18.205	-2.170	35.062	18.091	-2.641	0.031	0.114	-0.471	0.485	-0.471
	24	34.831	23.115	-2.588	34.697	23.021	-3.160	0.134	0.094	-0.572	0.595	-0.572
	25	31.170	8.479	-2.285	31.134	8.424	-2.575	0.037	0.055	-0.290	0.297	-0.290
	26	31.278	12.995	-2.280	31.232	12.948	-2.765	0.046	0.048	-0.485	0.490	-0.485
	27	31.465	18.241	-2.210	31.403	18.146	-2.673	0.062	0.095	-0.463	0.477	-0.463
	28	31.478	23.568	-2.432	31.408	23.431	-3.008	0.070	0.137	-0.576	0.596	-0.576
	29	26.021	12.267	1.349	26.033	12.239	1.001	-0.012	0.027	-0.348	0.349	-0.348
	30	26.045	20.624	1.393	26.024	20.620	0.906	0.021	0.004	-0.488	0.488	-0.488

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

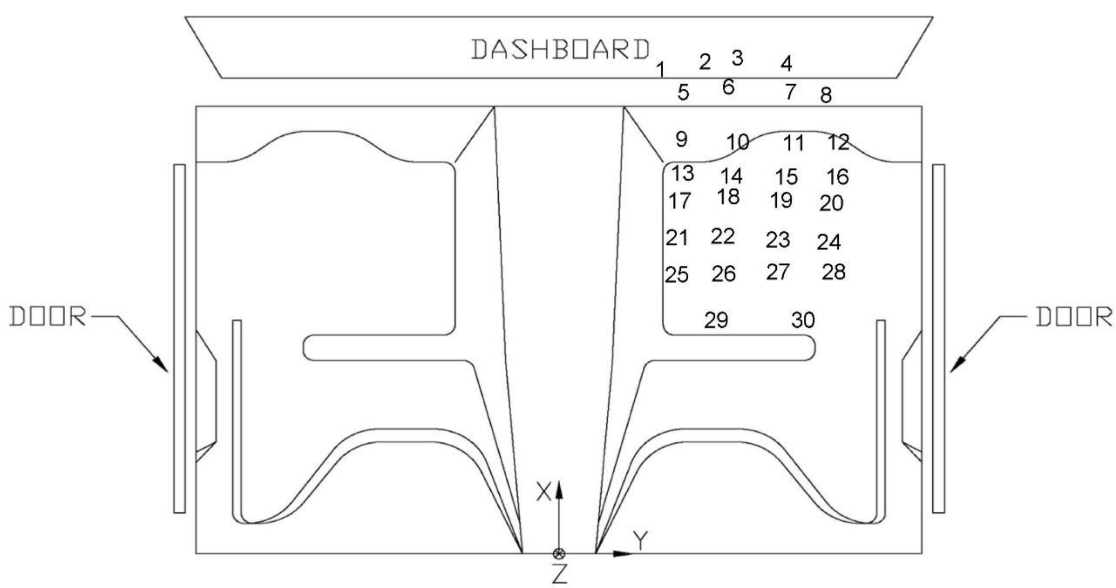


Figure E-7. Floor Pan Deformation Data – Set 1, Test No. MNNW-2

Date: 2/27/2018 Test Name: MNNW-2 VIN: KMHCN4ACXBU610901
Year: 2010 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
FLOORPAN - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
TOE PAN - WHEEL WELL	1	64.304	17.061	-3.971	64.333	16.717	-3.637	-0.029	0.344	0.335	0.481	0.335
	2	65.117	21.341	-3.411	65.070	20.924	-3.027	0.047	0.418	0.384	0.569	0.387
	3	65.506	24.449	-3.188	65.456	24.011	-2.743	0.051	0.438	0.445	0.627	0.448
	4	64.841	29.158	-3.440	64.834	28.686	-2.978	0.006	0.472	0.462	0.661	0.462
	5	61.705	19.210	-5.477	61.701	18.877	-5.063	0.005	0.333	0.413	0.531	0.413
	6	62.244	23.577	-5.154	62.235	23.112	-4.732	0.008	0.464	0.422	0.627	0.422
	7	61.604	29.510	-5.426	61.632	29.123	-4.993	-0.028	0.387	0.433	0.581	0.433
	8	61.209	32.922	-4.368	61.100	32.432	-3.987	0.109	0.490	0.381	0.631	0.396
FLOOR PAN	9	56.419	18.946	-7.760	56.485	18.588	-7.354	-0.066	0.357	0.406	0.545	0.406
	10	56.057	23.712	-7.690	56.099	23.421	-7.306	-0.042	0.291	0.384	0.483	0.384
	11	55.882	29.156	-7.681	55.912	28.754	-7.272	-0.030	0.403	0.408	0.574	0.408
	12	55.930	33.406	-7.543	55.936	32.972	-7.079	-0.007	0.434	0.465	0.635	0.465
	13	52.606	18.373	-8.116	52.720	18.076	-7.696	-0.114	0.297	0.420	0.527	0.420
	14	52.195	23.058	-7.967	52.121	28.049	-7.442	0.074	-4.991	0.526	5.019	0.526
	15	52.072	28.341	-7.812	51.643	29.178	-6.524	0.429	-0.837	1.288	1.595	1.288
	16	52.005	33.273	-7.701	52.093	33.003	-7.375	-0.088	0.271	0.326	0.432	0.326
	17	49.483	18.076	-8.401	49.681	17.913	-8.094	-0.199	0.163	0.307	0.400	0.307
	18	49.888	22.710	-8.130	49.917	22.418	-7.356	-0.029	0.291	0.774	0.827	0.774
	19	49.448	27.814	-7.943	49.528	27.565	-7.573	-0.080	0.249	0.370	0.454	0.370
	20	49.079	32.711	-8.150	49.133	32.359	-7.893	-0.053	0.352	0.256	0.439	0.256
	21	45.352	17.884	-8.463	45.468	17.640	-8.181	-0.115	0.244	0.282	0.391	0.282
	22	45.436	22.220	-8.333	45.495	21.788	-7.856	-0.059	0.432	0.477	0.646	0.477
	23	44.991	27.517	-8.055	45.072	27.171	-7.768	-0.081	0.346	0.288	0.457	0.288
	24	44.678	32.422	-8.493	44.707	32.128	-8.203	-0.029	0.294	0.290	0.413	0.290
	25	41.170	17.750	-8.133	41.253	17.492	-7.913	-0.083	0.258	0.220	0.349	0.220
	26	41.230	22.267	-8.145	41.284	22.032	-8.022	-0.054	0.235	0.123	0.271	0.123
	27	41.363	27.515	-8.097	41.401	27.185	-7.843	-0.038	0.330	0.253	0.418	0.253
	28	41.320	32.841	-8.340	41.366	32.507	-8.076	-0.045	0.334	0.264	0.428	0.264
	29	35.979	21.499	-4.516	36.086	21.229	-4.331	-0.107	0.270	0.185	0.344	0.185
	30	35.917	29.856	-4.505	36.036	29.477	-4.276	-0.120	0.379	0.230	0.459	0.230

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

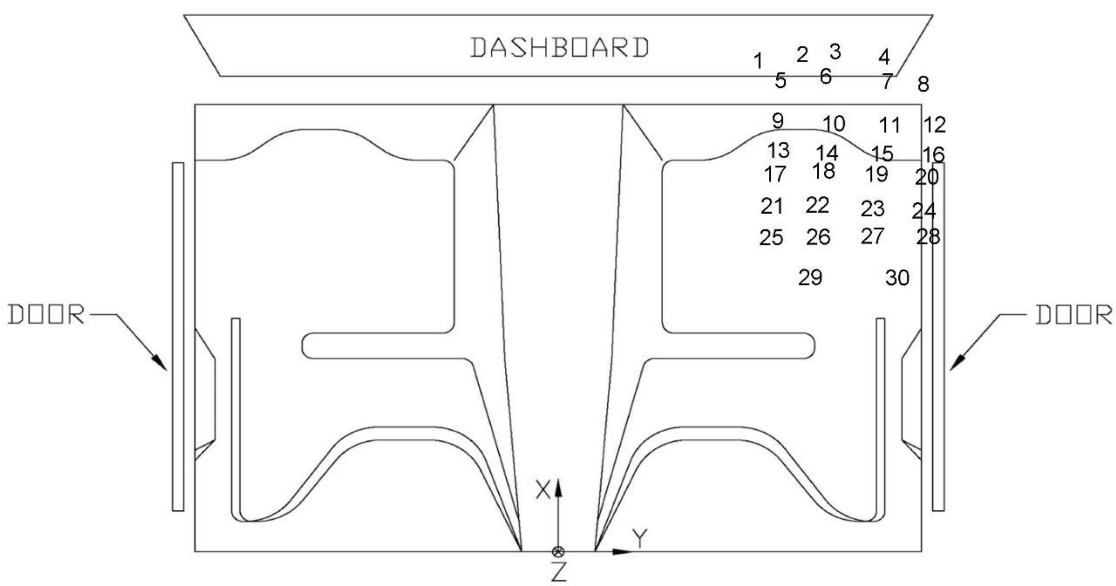


Figure E-8. Floor Pan Deformation Data – Set 2, Test No. MNNW-2

Date: 2/27/2018 Test Name: MNNW-2 VIN: KMHCN4ACXBU610901
Year: 2010 Make: Hyundai Model: Accent

VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 1

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
DASH	1	38.580	2.111	26.760	38.436	2.184	26.841	0.144	-0.073	0.081	0.180	0.180
	2	38.185	9.293	26.193	37.900	9.417	26.125	0.285	-0.124	-0.068	0.318	0.318
	3	39.276	15.347	25.399	38.995	15.441	25.209	0.281	-0.094	-0.191	0.352	0.352
	4	39.233	22.286	25.253	38.839	22.366	24.713	0.394	-0.080	-0.540	0.673	0.673
	5	34.113	6.612	19.901	33.897	6.528	19.906	0.215	0.084	0.006	0.231	0.231
	6	37.124	23.172	20.121	36.617	23.042	19.587	0.507	0.130	-0.534	0.748	0.748
SIDE PANEL	7	43.797	28.642	4.325	43.575	27.880	3.461	0.221	0.762	-0.864	1.173	0.762
	8	45.846	28.449	8.593	45.262	26.978	7.799	0.583	1.471	-0.794	1.771	1.471
	9	49.133	28.618	8.386	48.625	27.125	7.748	0.509	1.493	-0.638	1.701	1.493
IMPACT SIDE DOOR	10	38.262	29.843	21.793	37.117	29.594	20.907	1.145	0.248	-0.886	1.469	0.248
	11	25.362	30.572	19.539	24.525	32.177	18.695	0.837	-1.604	-0.844	1.997	-1.604
	12	13.372	29.934	23.522	12.659	31.347	23.006	0.713	-1.414	-0.515	1.665	-1.414
	13	38.881	29.825	14.500	37.699	29.215	13.663	1.182	0.610	-0.838	1.572	0.610
	14	26.520	30.659	7.258	25.660	30.789	6.521	0.860	-0.130	-0.737	1.140	-0.130
	15	15.365	29.937	14.100	14.620	31.485	13.517	0.745	-1.547	-0.583	1.814	-1.547
ROOF	16	25.259	1.664	41.376	25.069	2.890	41.339	0.190	-1.226	-0.036	1.241	-0.036
	17	24.893	6.627	41.444	24.803	7.951	41.382	0.091	-1.324	-0.063	1.329	-0.063
	18	24.661	12.448	41.210	24.623	13.767	41.194	0.038	-1.319	-0.016	1.320	-0.016
	19	23.534	20.362	40.799	23.529	21.686	40.866	0.005	-1.324	0.067	1.325	0.067
	20	20.340	1.715	44.098	20.192	2.982	44.096	0.148	-1.267	-0.002	1.276	-0.002
	21	20.030	6.008	44.126	19.915	7.391	44.168	0.114	-1.383	0.042	1.389	0.042
	22	19.699	11.419	43.990	19.593	12.785	44.060	0.106	-1.366	0.070	1.371	0.070
	23	19.004	18.331	43.590	18.855	19.654	43.632	0.149	-1.323	0.042	1.332	0.042
	24	16.581	1.752	44.741	16.508	3.019	44.927	0.073	-1.267	0.186	1.283	0.186
	25	16.345	5.580	44.753	16.326	6.908	44.878	0.019	-1.329	0.125	1.335	0.125
	26	16.505	11.188	44.532	16.431	12.439	44.623	0.074	-1.251	0.091	1.257	0.091
	27	15.964	17.652	44.146	15.797	18.917	43.992	0.167	-1.265	-0.153	1.285	-0.153
	28	13.422	3.877	45.126	13.329	5.113	45.255	0.093	-1.235	0.129	1.246	0.129
	29	13.488	8.850	45.006	13.400	10.051	45.110	0.087	-1.201	0.104	1.209	0.104
	30	13.589	14.159	44.708	13.491	15.419	44.562	0.098	-1.260	-0.146	1.272	-0.146
A PILLAR	31	42.898	27.404	29.021	42.470	27.805	28.431	0.428	-0.401	-0.590	0.832	0.428
	32	38.141	26.423	32.394	38.003	27.140	32.074	0.138	-0.717	-0.319	0.797	0.138
	33	33.240	25.345	35.374	33.245	26.206	35.359	-0.005	-0.860	-0.016	0.860	0.000
	34	25.885	23.941	38.480	25.989	24.931	38.714	-0.104	-0.990	0.233	1.023	0.233
B PILLAR	35	4.770	23.333	39.536	4.718	24.491	39.164	0.053	-1.159	-0.372	1.218	0.053
	36	2.586	25.307	35.556	2.405	26.200	35.147	0.181	-0.893	-0.410	0.999	0.181
	37	6.496	26.265	33.106	6.347	27.201	32.747	0.149	-0.936	-0.359	1.013	0.149
	38	3.515	27.526	28.720	3.298	28.176	28.192	0.217	-0.650	-0.528	0.865	0.217
	39	7.882	27.892	26.174	7.647	28.787	25.703	0.235	-0.895	-0.471	1.038	0.235
	40	4.624	28.221	20.415	4.548	28.645	19.850	0.077	-0.424	-0.566	0.711	0.077

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

Figure E-9. Occupant Compartment Deformation Data – Set 1, Test No. MNNW-2

Date:	2/27/2018	Test Name:	MNNW-2	VIN:	KMHCN4ACXBU610901
Year:	2010	Make:	Hyundai	Model:	Accent

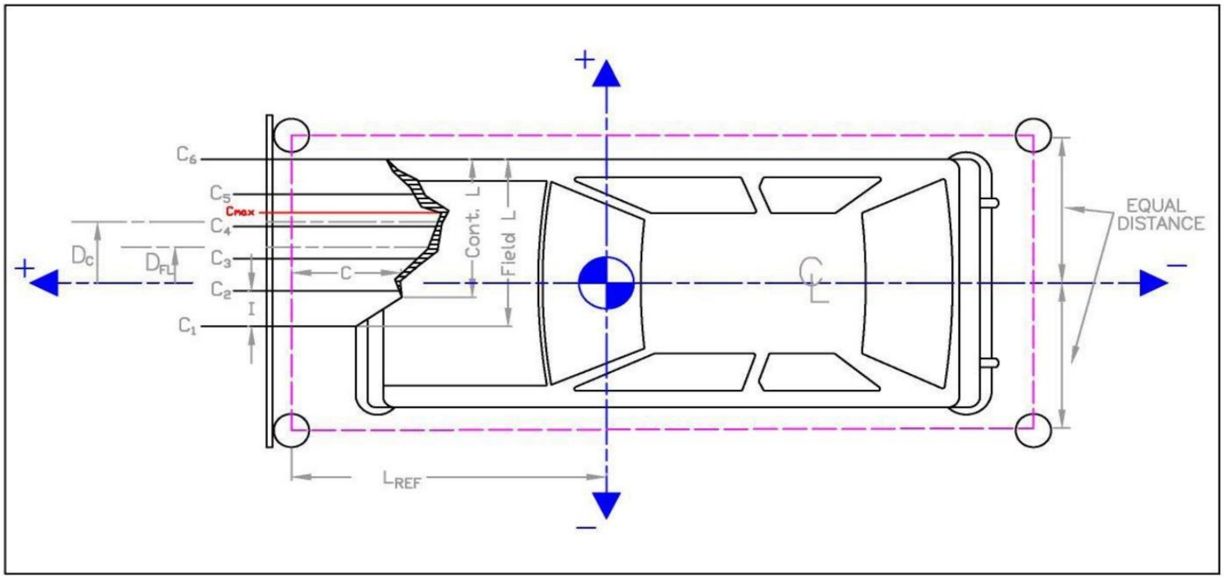
VEHICLE PRE/POST CRUSH
INTERIOR CRUSH - SET 2

	POINT	X (in.)	Y (in.)	Z (in.)	X' (in.)	Y' (in.)	Z' (in.)	ΔX (in.)	ΔY (in.)	ΔZ (in.)	Total Δ (in.)	Crush (in.)
DASH	1	48.636	11.558	20.943	48.386	10.813	21.470	0.250	0.745	0.527	0.946	0.946
	2	48.167	18.734	20.351	47.808	18.008	20.914	0.360	0.727	0.564	0.987	0.987
	3	49.196	24.797	19.537	48.751	24.087	20.018	0.445	0.709	0.481	0.966	0.966
	4	49.081	31.734	19.366	48.594	30.945	19.728	0.487	0.789	0.361	0.995	0.995
	5	44.125	15.990	14.067	43.844	15.193	14.600	0.281	0.797	0.533	0.999	0.999
	6	46.966	32.580	14.231	46.409	31.653	14.609	0.557	0.927	0.378	1.145	1.145
SIDE PANEL	7	53.588	38.065	-1.582	53.468	36.946	-1.435	0.120	1.119	0.147	1.135	1.119
	8	55.637	37.908	2.688	55.119	35.981	2.931	0.518	1.927	0.243	2.010	1.927
	9	58.923	38.110	2.482	58.398	36.173	2.872	0.525	1.937	0.390	2.044	1.937
IMPACT SIDE DOOR	10	48.034	39.268	15.880	46.821	38.288	16.071	1.212	0.981	0.191	1.571	0.981
	11	35.128	39.857	13.619	34.225	40.788	13.678	0.904	-0.932	0.059	1.299	-0.932
	12	23.144	39.108	17.600	22.263	39.789	17.883	0.880	-0.681	0.283	1.149	-0.681
	13	48.656	39.232	8.588	47.534	38.039	8.751	1.122	1.193	0.163	1.646	1.193
	14	36.290	39.913	1.338	35.526	39.623	1.508	0.764	0.289	0.170	0.834	0.289
	15	25.140	39.100	8.179	24.409	40.091	8.419	0.731	-0.991	0.241	1.255	-0.991
ROOF	16	35.315	11.025	35.555	34.846	11.165	35.803	0.469	-0.140	0.247	0.548	0.247
	17	34.898	15.984	35.607	34.528	16.192	35.924	0.370	-0.208	0.318	0.530	0.318
	18	34.606	21.801	35.352	34.264	22.015	35.854	0.341	-0.214	0.502	0.644	0.502
	19	33.397	29.702	34.913	33.101	29.955	35.648	0.296	-0.254	0.734	0.831	0.734
	20	30.394	11.034	38.276	29.903	11.170	38.548	0.491	-0.136	0.272	0.578	0.272
	21	30.040	15.323	38.288	29.547	15.493	38.685	0.493	-0.170	0.396	0.655	0.396
	22	29.654	20.730	38.134	29.180	20.933	38.659	0.474	-0.202	0.525	0.736	0.525
	23	28.887	27.633	37.710	28.456	27.773	38.335	0.431	-0.140	0.626	0.773	0.626
	24	26.635	11.034	38.917	26.206	11.091	39.322	0.429	-0.057	0.404	0.592	0.404
	25	26.360	14.859	38.916	26.024	14.886	39.334	0.336	-0.027	0.418	0.537	0.418
	26	26.462	20.468	38.675	26.026	20.521	39.183	0.436	-0.052	0.508	0.671	0.508
	27	25.854	26.925	38.267	25.369	27.061	38.655	0.485	-0.137	0.388	0.636	0.388
	28	23.454	13.128	39.293	23.003	13.265	39.658	0.451	-0.136	0.365	0.596	0.365
	29	23.468	18.101	39.156	23.034	18.197	39.592	0.434	-0.096	0.435	0.622	0.435
	30	23.515	23.410	38.840	23.087	23.491	39.146	0.428	-0.081	0.306	0.532	0.306
A PILLAR	31	52.692	36.902	23.119	52.147	36.425	23.564	0.545	0.477	0.446	0.850	0.850
	32	47.944	35.884	26.492	47.608	35.643	27.105	0.337	0.241	0.612	0.739	0.739
	33	43.053	34.766	29.475	42.790	34.598	30.306	0.263	0.168	0.831	0.887	0.887
	34	35.711	33.297	32.583	35.526	33.206	33.581	0.185	0.091	0.998	1.019	1.019
B PILLAR	35	14.604	32.474	33.634	14.283	32.542	33.852	0.321	-0.069	0.218	0.394	0.388
	36	12.401	34.411	29.646	11.997	34.336	29.770	0.404	0.076	0.124	0.430	0.430
	37	16.302	35.401	27.193	15.995	35.421	27.418	0.307	-0.019	0.224	0.381	0.380
	38	13.310	36.616	22.803	12.975	36.420	22.989	0.335	0.197	0.186	0.431	0.431
	39	17.673	37.018	20.257	17.343	37.113	20.427	0.331	-0.095	0.170	0.384	0.372
	40	14.415	37.294	14.496	14.218	37.047	14.623	0.197	0.247	0.128	0.341	0.341

Note: A positive value for ΔX, ΔY, and ΔZ will denote crushing inward toward the occupant compartment

Figure E-10. Occupant Compartment Deformation Data – Set 2, Test No. MNNW-2

Date:	2/27/2018	**Test Name:**	MNNW-2	**VIN:**	KMHCN4ACXBU610901
Year:	2010	**Make:**	Hyundai	**Model:**	Accent



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	89	(2261)
Total Width of Vehicle:	65 3/4	(1670)
Width of contact and induced crush - Field L:	32 7/8	(835)
Crush measurement spacing interval (L/5) - I:	6 5/8	(168)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	22 7/8	(581)
Distance from center of vehicle to center of contact damage - D_C:	0	()

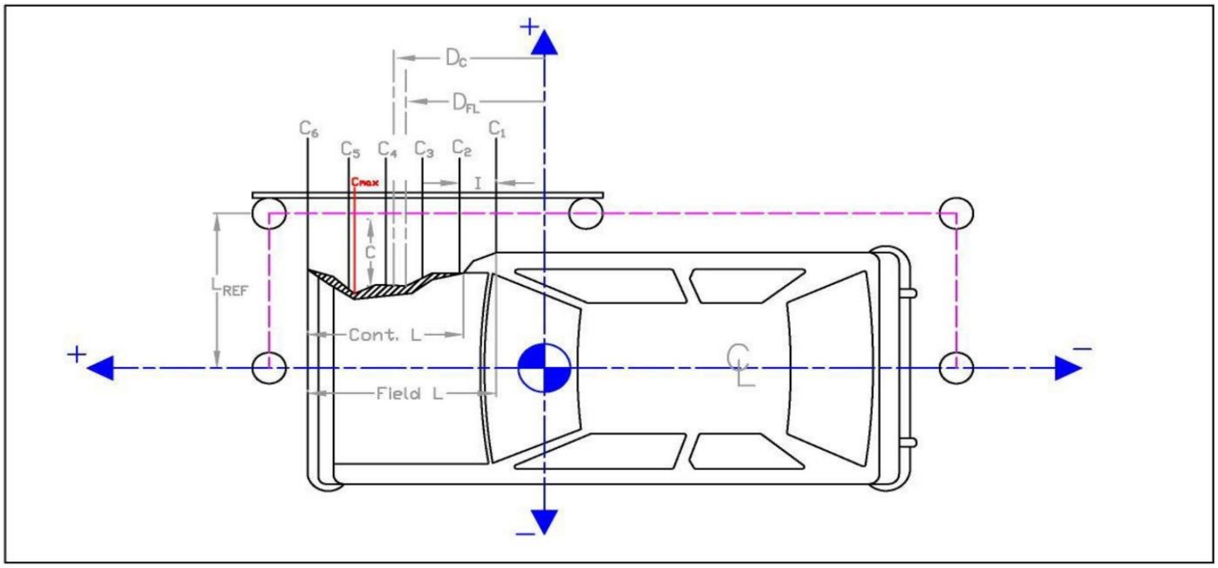
NOTE: Enter "NA" for crush measurement if distance can not be measured (i.e., side of vehicle has been pushed inward)

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

Crush Measurement			Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	19	(483)	-16 1/2	-(419)	3 7/8	(98)	17 3/8	(441)	-2 1/4	-(57)
C_2	18 1/2	(470)	-9 7/8	-(251)	2 3/4	(70)			-1 5/8	-(41)
C_3	18	(457)	-3 1/4	-(83)	1 3/4	(44)			-1 1/8	-(29)
C_4	19	(483)	3 3/8	(86)	1 3/4	(44)			- 1/8	-(3)
C_5	20 3/4	(527)	10	(254)	2 3/4	(70)			5/8	(16)
C_6	37	(940)	16 5/8	(422)	3 7/8	(98)			15 3/4	(400)
C_{MAX}	43 1/4	(1099)	12	(305)	3	(76)			22 7/8	(581)

Figure E-11. Exterior Vehicle Crush (NASS) - Front, Test No. MNNW-2

Date:	2/27/2018	Test Name:	MNNW-2	VIN:	KMHCN4ACXBU610901
Year:	2010	Make:	Hyundai	Model:	Accent



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	43	(1092)
Total Vehicle Length:	168 3/8	(4277)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-11 4/5	-(300)
Width of contact and induced crush - Field L:	140 3/8	(3566)
Crush measurement spacing interval (L/5) - I:	28 1/8	(714)
Distance from vehicle c.g. to center of Field L - D_{FL}:	5	(127)
Width of Contact Damage:	140 3/8	(3566)
Distance from vehicle c.g. to center of contact damage - D_C:	5	(127)

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	12	(305)	-65 1/4	-(1657)	4	(102)	7	(178)	1	(25)
C_2	11 1/2	(292)	-37 1/8	-(943)	3 1/2	(89)			1	(25)
C_3	12	(305)	-9	-(229)	3 1/4	(83)			1 3/4	(44)
C_4	15	(381)	19 1/8	(486)	3 1/4	(83)			4 3/4	(121)
C_5	26 1/2	(673)	47 1/4	(1200)	4	(102)			15 1/2	(394)
C_6	NA	NA	75 3/8	(1915)	36	(914)			NA	NA
C_{MAX}	26 1/2	(673)	47 1/4	(1200)	4	(102)			15 1/2	(394)

Figure E-12. Exterior Vehicle Crush (NASS) - Side, Test No. MNNW-2

Date: 4/4/2018 Test Name: MNNW-3 VIN: 1D7RB1CP7BX646567
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
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	61.8348	33.3253	-2.6982	59.9450	29.4505	-3.2749	1.8898	3.8748	-0.5767	4.3495	1.8898	X
	2	62.2693	31.2544	-1.5966	61.2724	29.3262	-1.2807	0.9969	1.9282	0.3159	2.1935	1.0458	X, Z
	3	62.8402	29.7849	-0.9496	62.3078	28.6385	-0.1183	0.5324	1.1464	0.8313	1.5129	0.9872	X, Z
	4	62.9440	27.8081	-0.0158	62.5648	26.9299	0.9500	0.3792	0.8782	0.9658	1.3593	1.0376	X, Z
	5	62.9025	24.6086	0.0318	62.6564	23.7449	1.2138	0.2461	0.8637	1.1820	1.4845	1.2073	X, Z
	6	59.2622	34.5090	1.6317	BAD DATA	BAD DATA	BAD DATA	BAD DATA	BAD DATA	BAD DATA	BAD DATA	BAD DATA	X, Z
	7	58.9947	29.8356	1.8407	58.3343	28.3932	2.1788	0.6604	1.4424	0.3381	1.6220	0.7419	X, Z
	8	58.8947	26.7287	2.0202	58.8020	25.4234	2.9810	0.0927	1.3053	0.9608	1.6234	0.9653	X, Z
	9	58.6783	22.5736	1.8299	58.5952	21.7746	3.1298	0.0831	0.7990	1.2999	1.5281	1.3026	X, Z
	10	57.5577	20.5099	-0.5605	57.0550	20.4621	0.4179	0.5027	0.0478	0.9784	1.1010	1.1000	X, Z
FLOOR PAN (Z)	11	53.2310	33.3278	4.9748	53.0944	32.1373	5.2944	0.1366	1.1905	0.3196	1.2402	0.3196	Z
	12	53.2880	30.3505	4.8556	53.0681	29.3892	5.6418	0.2199	0.9613	0.7862	1.2612	0.7862	Z
	13	53.2866	25.0368	4.8636	53.2030	24.1057	6.0261	0.0836	0.9311	1.1625	1.4918	1.1625	Z
	14	52.6165	20.2609	3.1583	52.4198	19.4753	4.3896	0.1967	0.7856	1.2313	1.4738	1.2313	Z
	15	52.1464	18.5228	1.8881	51.9422	17.8807	2.9446	0.2042	0.6421	1.0565	1.2531	1.0565	Z
	16	49.5424	33.4697	5.0764	49.5286	32.5721	6.0784	0.0138	0.8976	1.0020	1.3453	1.0020	Z
	17	49.6122	30.4326	4.9469	49.5008	29.5056	5.9858	0.1114	0.9270	1.0389	1.3968	1.0389	Z
	18	49.5489	24.9253	4.9721	49.4554	24.1189	6.0071	0.0935	0.8064	1.0350	1.3154	1.0350	Z
	19	49.5803	19.4561	4.9597	49.4122	18.5610	5.9227	0.1681	0.8951	0.9630	1.3255	0.9630	Z
	20	48.5382	15.3992	2.2494	48.4180	14.6687	2.9781	0.1202	0.7305	0.7287	1.0388	0.7287	Z
	21	43.6235	33.3737	5.0703	43.6441	32.6086	6.1082	-0.0206	0.7651	1.0379	1.2896	1.0379	Z
	22	43.6460	30.1319	4.9557	43.6478	29.4204	5.9415	-0.0018	0.7115	0.9858	1.2157	0.9858	Z
	23	43.6963	25.0961	4.9409	43.5172	24.3009	5.7601	0.1791	0.7952	0.8192	1.1556	0.8192	Z
	24	43.7037	20.1351	4.9912	43.5210	19.3905	5.6434	0.1827	0.7446	0.6522	1.0066	0.6522	Z
	25	43.7801	16.0378	4.9917	43.4994	15.2476	5.5302	0.2807	0.7902	0.5385	0.9966	0.5385	Z
	26	39.8361	33.7275	5.3106	39.9074	33.0272	6.1508	-0.0713	0.7003	0.8402	1.0961	0.8402	Z
	27	39.9195	30.5588	5.3013	39.9313	29.6997	6.0599	-0.0118	0.8591	0.7586	1.1462	0.7586	Z
	28	39.9183	24.7673	5.2964	39.8246	24.0273	5.9626	0.0937	0.7400	0.6662	1.0001	0.6662	Z
	29	33.5472	27.5811	1.3377	33.6634	27.0485	1.7370	-0.1162	0.5326	0.3993	0.6757	0.3993	Z
	30	33.6096	19.1444	1.3679	33.5726	18.5736	1.6837	0.0370	0.5708	0.3158	0.6534	0.3158	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 no direction listed, then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan

Posttest Floor Pan

Figure E-13. Floor Pan Deformation Data – Set 1, Test No. MNNW-3

Date: 4/4/2018 Test Name: MNNW-3 VIN: 1D7RB1CP7BX646567
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
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	61.1396	48.1965	-6.7376	59.2824	44.6865	-8.4099	1.8572	3.5100	-1.6723	4.3088	1.8572	X
	2	61.5566	46.1228	-5.6347	60.6259	44.5722	-6.4259	0.9307	1.5506	-0.7912	1.9740	0.9307	X
	3	62.1153	44.6490	-4.9866	61.6667	43.8887	-5.2658	0.4486	0.7603	-0.2792	0.9259	0.4486	X
	4	62.2026	42.6720	-4.0517	61.9215	42.1887	-4.1833	0.2811	0.4833	-0.1316	0.5744	0.2811	X
	5	62.1352	39.4729	-4.0025	61.9941	39.0058	-3.8898	0.1411	0.4671	0.1127	0.5008	0.1806	X, Z
	6	58.5742	49.4032	-2.4098	bad data	bad data	bad data	bad data	bad data	bad data	bad data	bad data	bad data
	7	58.2687	44.7323	-2.1985	57.7115	43.6922	-2.9327	0.5572	1.0401	-0.7342	1.3897	0.5572	X
	8	58.1435	41.6263	-2.0174	58.1663	40.7271	-2.1060	-0.0228	0.8992	-0.0886	0.9038	0.0000	
	9	57.8937	37.4731	-2.2057	57.9365	37.0814	-1.9204	-0.0428	0.3917	0.2853	0.4865	0.2853	Z
	10	56.7578	35.4172	-4.5956	56.3644	35.7533	-4.6064	0.3934	-0.3361	-0.0108	0.5175	0.3934	X
FLOOR PAN (Z)	11	52.5317	48.2726	0.9305	52.5235	47.5010	0.1912	0.0082	0.7716	-0.7393	1.0686	-0.7393	Z
	12	52.5647	45.2948	0.8129	52.4818	44.7566	0.5652	0.0829	0.5382	-0.2477	0.5982	-0.2477	Z
	13	52.5204	39.9813	0.8237	52.5849	39.4762	0.9991	-0.0645	0.5051	0.1754	0.5386	0.1754	Z
	14	51.8126	35.2101	-0.8794	51.7569	34.8358	-0.5862	0.0557	0.3743	0.2932	0.4787	0.2932	Z
	15	51.3292	33.4752	-2.1490	51.2564	33.2307	-2.0116	0.0728	0.2445	0.1374	0.2898	0.1374	Z
	16	48.8443	48.4443	1.0300	48.9675	47.9672	1.0013	-0.1232	0.4771	-0.0287	0.4936	-0.0287	Z
	17	48.8896	45.4067	0.9020	48.9185	44.9003	0.9384	-0.0289	0.5064	0.0364	0.5085	0.0364	Z
	18	48.7818	39.9002	0.9301	48.8375	39.5144	1.0118	-0.0557	0.3858	0.0817	0.3983	0.0817	Z
	19	48.7690	34.4309	0.9206	48.7566	33.9565	0.9812	0.0124	0.4744	0.0606	0.4784	0.0606	Z
	20	47.6957	30.3811	-1.7881	47.7113	30.0430	-1.9173	-0.0156	0.3381	-0.1292	0.3623	-0.1292	Z
	21	42.9248	48.3962	1.0206	43.0838	48.0437	1.0808	-0.1590	0.3525	0.0602	0.3914	0.0602	Z
	22	42.9212	45.1543	0.9077	43.0650	44.8541	0.9447	-0.1438	0.3002	0.0370	0.3349	0.0370	Z
	23	42.9308	40.1182	0.8956	42.8987	39.7341	0.8136	0.0321	0.3841	-0.0820	0.3941	-0.0820	Z
	24	42.8981	35.1574	0.9485	42.8688	34.8228	0.7441	0.0293	0.3346	-0.2044	0.3932	-0.2044	Z
	25	42.9414	31.0595	0.9512	42.8187	30.6793	0.6708	0.1227	0.3802	-0.2804	0.4881	-0.2804	Z
	26	39.1403	48.7807	1.2585	39.3506	48.4878	1.1511	-0.2103	0.2929	-0.1074	0.3762	-0.1074	Z
	27	39.1981	45.6115	1.2509	39.3515	45.1595	1.0920	-0.1534	0.4520	-0.1589	0.5031	-0.1589	Z
	28	39.1501	39.8201	1.2491	39.2062	39.4873	1.0501	-0.0561	0.3328	-0.1990	0.3918	-0.1990	Z
	29	32.8042	42.6832	-2.7148	33.0293	42.5094	-3.1517	-0.2251	0.1738	-0.4369	0.5213	-0.4369	Z
	30	32.7983	34.2464	-2.6801	32.8816	34.0352	-3.1228	-0.0833	0.2112	-0.4427	0.4975	-0.4427	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 no direction listed, then no intrusion is recorded, and Crush will be 0.

Pretest Floor Pan

Posttest Floor Pan

Figure E-14. Floor Pan Deformation Data – Set 2, Test No. MNNW-3

Date: 4/4/2018 Test Name: MNNW-3 VIN: 1D7RB1CP7BX646567

Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
INTERIOR CRUSH - SET 1

	POINT	Pretest X (in.)	Pretest Y (in.)	Pretest Z (in.)	Posttest X (in.)	Posttest Y (in.)	Posttest Z (in.)	ΔX^A (in.)	ΔY^A (in.)	ΔZ^A (in.)	Total Δ (in.)	Crush[B] (in.)	Directions for Crush[C]
DASH (X, Y, Z)	1	42.1861	4.2953	-14.7973	41.9147	4.5541	-14.5863	0.2714	-0.2588	0.2110	0.4303	0.4303	X, Y, Z
	2	44.8225	4.7014	-26.5067	44.9969	4.9453	-26.1864	-0.1744	-0.2439	0.3203	0.4387	0.4387	X, Y, Z
	3	48.1277	18.2022	-26.6980	48.3039	18.4761	-26.5302	-0.1762	-0.2739	0.1678	0.3664	0.3664	X, Y, Z
	4	48.7786	26.4635	-26.5310	48.7759	26.7780	-26.3198	0.0027	-0.3145	0.2112	0.3788	0.3788	X, Y, Z
	5	46.3741	22.7477	-22.4328	46.3328	22.9613	-22.3352	0.0413	-0.2136	0.0976	0.2384	0.2384	X, Y, Z
	6	44.2273	22.9275	-15.9147	43.9673	23.0229	-15.8944	0.2600	-0.0954	0.0203	0.2777	0.2777	X, Y, Z
SIDE PANEL (Y)	7	58.4633	36.7887	-3.9477	56.8394	31.4753	-4.1275	1.6239	5.3134	-0.1798	5.5589	5.3134	Y
	8	55.9373	37.0014	-3.3273	54.4571	32.1295	-3.3995	1.4802	4.8719	-0.0722	5.0923	4.8719	Y
	9	56.1118	36.7021	-0.3703	54.8487	32.2855	-0.4112	1.2631	4.4166	-0.0409	4.5938	4.4166	Y
IMPACT SIDE DOOR (Y)	10	42.8978	39.0887	-16.4459	41.5054	40.7124	-16.6118	1.3924	-1.6237	-0.1659	2.1454	-1.6237	Y
	11	25.1852	39.5037	-16.7560	24.1514	43.5515	-16.7348	1.0338	-4.0478	0.0212	4.1778	-4.0478	Y
	12	32.5791	40.0137	-8.3153	31.6560	42.4316	-8.6162	0.9231	-2.4179	-0.3009	2.6056	-2.4179	Y
	13	41.2470	39.6125	1.0418	39.1966	38.0998	0.5972	2.0504	1.5127	-0.4446	2.5865	1.5127	Y
	14	33.6949	39.5023	0.7643	31.8228	39.5364	0.3595	1.8721	-0.0341	-0.4048	1.9157	-0.0341	Y
	15	24.5481	38.9539	0.2067	22.7001	41.0436	-0.1423	1.8480	-2.0897	-0.3490	2.8114	-2.0897	Y
ROOF - (Z)	16	28.7946	25.7562	-45.3135	29.2454	26.2092	-45.1638	-0.4508	-0.4530	0.1497	0.6564	0.1497	Z
	17	28.8741	22.2064	-45.6470	29.3881	22.7203	-45.4454	-0.5140	-0.5139	0.2016	0.7543	0.2016	Z
	18	29.4845	17.8384	-45.8584	29.9629	18.3194	-45.6287	-0.4784	-0.4810	0.2297	0.7162	0.2297	Z
	19	29.7181	13.8322	-46.0231	30.2795	14.4100	-45.7576	-0.5614	-0.5778	0.2655	0.8482	0.2655	Z
	20	29.7734	9.8263	-46.1382	30.3376	10.4055	-45.8536	-0.5642	-0.5792	0.2846	0.8572	0.2846	Z
	21	24.9369	26.0690	-45.7447	25.4277	26.5074	-45.6252	-0.4908	-0.4384	0.1195	0.6688	0.1195	Z
	22	25.0953	22.1594	-45.9809	25.6324	22.6008	-45.8238	-0.5371	-0.4414	0.1571	0.7127	0.1571	Z
	23	25.2927	17.7026	-46.2337	25.8713	18.2199	-46.0431	-0.5786	-0.5173	0.1906	0.7992	0.1906	Z
	24	25.5737	13.6570	-46.3856	26.1357	14.2256	-46.1673	-0.5620	-0.5686	0.2183	0.8287	0.2183	Z
	25	26.0358	9.8735	-46.5188	26.7463	10.4210	-46.2802	-0.7105	-0.5475	0.2386	0.9282	0.2386	Z
	26	19.5230	25.8925	-46.0869	20.1322	26.3694	-46.0129	-0.6092	-0.4769	0.0740	0.7772	0.0740	Z
	27	19.3191	21.8082	-46.4165	20.0399	22.2900	-46.3170	-0.7208	-0.4818	0.0995	0.8727	0.0995	Z
	28	19.4386	17.3172	-46.6515	20.2114	17.7478	-46.5292	-0.7728	-0.4306	0.1223	0.8931	0.1223	Z
	29	19.7678	13.0692	-46.8024	20.4231	13.5530	-46.6675	-0.6553	-0.4838	0.1349	0.8256	0.1349	Z
	30	19.9845	9.9952	-46.8830	20.5701	10.3882	-46.7314	-0.5856	-0.3930	0.1516	0.7214	0.1516	Z
A-PILLAR Maximum (X, Y, Z)	31	52.0648	35.0489	-29.8442	52.1533	35.8585	-29.2450	-0.0885	-0.8096	0.5992	1.0111	0.5992	Z
	32	48.8736	34.2634	-32.3626	49.0630	35.0024	-31.8608	-0.1894	-0.7390	0.5018	0.9131	0.5018	Z
	33	45.3024	33.5704	-35.1339	45.7045	34.3172	-34.7360	-0.4021	-0.7468	0.3979	0.9369	0.3979	Z
	34	41.5974	32.6006	-37.3103	42.0220	33.2900	-37.0704	-0.4246	-0.6894	0.2399	0.8445	0.2399	Z
	35	39.1565	32.0903	-38.9148	39.5633	32.6879	-38.6078	-0.4068	-0.5976	0.3070	0.7854	0.3070	Z
	36	36.0180	31.2642	-40.6843	36.4934	31.8752	-40.5143	-0.4754	-0.6110	0.1700	0.7926	0.1700	Z
A-PILLAR Lateral (Y)	31	52.0648	35.0489	-29.8442	52.1533	35.8585	-29.2450	-0.0885	-0.8096	0.5992	1.0111	-0.8096	Y
	32	48.8736	34.2634	-32.3626	49.0630	35.0024	-31.8608	-0.1894	-0.7390	0.5018	0.9131	-0.7390	Y
	33	45.3024	33.5704	-35.1339	45.7045	34.3172	-34.7360	-0.4021	-0.7468	0.3979	0.9369	-0.7468	Y
	34	41.5974	32.6006	-37.3103	42.0220	33.2900	-37.0704	-0.4246	-0.6894	0.2399	0.8445	-0.6894	Y
	35	39.1565	32.0903	-38.9148	39.5633	32.6879	-38.6078	-0.4068	-0.5976	0.3070	0.7854	-0.5976	Y
	36	36.0180	31.2642	-40.6843	36.4934	31.8752	-40.5143	-0.4754	-0.6110	0.1700	0.7926	-0.6110	Y
B-PILLAR Maximum (X, Y, Z)	37	11.0229	32.4520	-39.1354	11.4401	32.7412	-39.2535	-0.4172	-0.2892	-0.1181	0.5212	0.0000	
	38	13.5380	35.5036	-29.3105	13.8800	35.7155	-29.3296	-0.3420	-0.2119	-0.0191	0.4028	0.0000	
	39	10.1763	36.0647	-25.3679	10.4646	36.1620	-25.3923	-0.2883	-0.0973	-0.0244	0.3053	0.0000	
	40	14.1014	36.2129	-23.4456	14.3658	36.3498	-23.4441	-0.2644	-0.1369	0.0015	0.2977	0.0015	Z
B-PILLAR Lateral (Y)	37	11.0229	32.4520	-39.1354	11.4401	32.7412	-39.2535	-0.4172	-0.2892	-0.1181	0.5212	-0.2892	Y
	38	13.5380	35.5036	-29.3105	13.8800	35.7155	-29.3296	-0.3420	-0.2119	-0.0191	0.4028	-0.2119	Y
	39	10.1763	36.0647	-25.3679	10.4646	36.1620	-25.3923	-0.2883	-0.0973	-0.0244	0.3053	-0.0973	Y
	40	14.1014	36.2129	-23.4456	14.3658	36.3498	-23.4441	-0.2644	-0.1369	0.0015	0.2977	-0.1369	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 no direction listed, then no intrusion is recorded, and Crush will be 0.

Figure E-15. Occupant Compartment Deformation Data – Set 1, Test No. MNNW-3

Date: 4/4/2018 Test Name: MNNW-3 VIN: 1D7RB1CP7BX646567
Year: 2011 Make: Dodge Model: Ram 1500

VEHICLE DEFORMATION
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	41.2592	19.3295	-18.8351	41.0636	19.3805	-19.3269	0.1956	-0.0510	-0.4918	0.5317	0.5317	X, Y, Z
	2	43.9043	19.7089	-30.5434	44.0474	19.6240	-30.9566	-0.1431	0.0849	-0.4132	0.4454	0.4454	X, Y, Z
	3	47.3147	33.1834	-30.7400	47.5131	33.1099	-31.4596	-0.1984	0.0735	-0.7196	0.7501	0.7501	X, Y, Z
	4	48.0300	41.4395	-30.5769	48.0863	41.4072	-31.3333	-0.0563	0.0323	-0.7564	0.7592	0.7592	X, Y, Z
	5	45.5946	37.7447	-26.4780	45.6331	37.6584	-27.2910	-0.0385	0.0863	-0.8130	0.8185	0.8185	X, Y, Z
	6	43.4462	37.9446	-19.9610	43.3256	37.8099	-20.8306	0.1206	0.1347	-0.8696	0.8882	0.8882	X, Y, Z
SIDE PANEL (Y)	7	57.7841	51.7005	-7.9942	56.4017	46.2181	-9.2586	1.3824	5.4824	-1.2644	5.7937	5.4824	Y
	8	55.2596	51.9333	-7.3752	54.0339	46.9079	-8.5162	1.2257	5.0254	-1.1410	5.2971	5.0254	Y
	9	55.4302	51.6341	-4.4179	54.4538	47.0876	-5.5331	0.9764	4.5465	-1.1152	4.7820	4.5465	Y
IMPACT SIDE DOOR (Y)	10	42.2430	54.1154	-20.5011	41.0696	55.5202	-21.6968	1.1734	-1.4048	-1.1957	2.1863	-1.4048	Y
	11	24.5343	54.6683	-20.8200	23.7504	58.5671	-21.6955	0.7839	-3.8988	-0.8755	4.0721	-3.8988	Y
	12	31.9279	55.1249	-12.3759	31.3126	57.4341	-13.6325	0.6153	-2.3092	-1.2566	2.7000	-2.3092	Y
	13	40.5880	54.6611	-3.0144	38.8821	53.0997	-4.4440	1.7059	1.5614	-1.4296	2.7188	1.5614	Y
	14	33.0354	54.6096	-3.2955	31.5242	54.6228	-4.6311	1.5112	-0.0132	-1.3356	2.0169	-0.0132	Y
	15	23.8848	54.1322	-3.8573	22.4161	56.2351	-5.0677	1.4687	-2.1029	-1.2104	2.8363	-2.1029	Y
ROOF - (Z)	16	28.0501	40.8783	-49.3687	28.3844	40.8945	-49.9996	-0.3343	-0.0162	-0.6309	0.7142	-0.6309	Z
	17	28.1021	37.3279	-49.7004	28.4827	37.4017	-50.2488	-0.3806	-0.0738	-0.5484	0.6716	-0.5484	Z
	18	28.6785	32.9551	-49.9092	29.0031	32.9926	-50.3948	-0.3246	-0.0375	-0.4856	0.5853	-0.4856	Z
	19	28.8809	28.9472	-50.0718	29.2717	29.0787	-50.4887	-0.3908	-0.1315	-0.4169	0.5864	-0.4169	Z
	20	28.9050	24.9408	-50.1847	29.2810	25.0730	-50.5466	-0.3760	-0.1322	-0.3619	0.5384	-0.3619	Z
	21	24.1951	41.2210	-49.8019	24.5665	41.2344	-50.4304	-0.3714	-0.0134	-0.6285	0.7302	-0.6285	Z
	22	24.3231	37.3102	-50.0360	24.7226	37.3239	-50.5932	-0.3995	-0.0137	-0.5572	0.6858	-0.5572	Z
	23	24.4859	32.8518	-50.2865	24.9072	32.9385	-50.7724	-0.4213	-0.0867	-0.4859	0.6489	-0.4859	Z
	24	24.7354	28.8040	-50.4362	25.1226	28.9403	-50.8604	-0.3872	-0.1363	-0.4242	0.5903	-0.4242	Z
	25	25.1681	25.0170	-50.5672	25.6865	25.1278	-50.9420	-0.5184	-0.1108	-0.3748	0.6492	-0.3748	Z
	26	18.7802	41.0865	-50.1467	19.2666	41.1566	-50.7705	-0.4864	-0.0701	-0.6238	0.7941	-0.6238	Z
	27	18.5447	37.0037	-50.4743	19.1227	37.0759	-51.0345	-0.5780	-0.0722	-0.5602	0.8082	-0.5602	Z
	28	18.6292	32.5118	-50.7069	19.2379	32.5302	-51.2044	-0.6087	-0.0184	-0.4975	0.7864	-0.4975	Z
	29	18.9254	28.2614	-50.8555	19.3981	28.3320	-51.3041	-0.4727	-0.0706	-0.4486	0.6555	-0.4486	Z
	30	19.1182	25.1857	-50.9343	19.5067	25.1651	-51.3389	-0.3885	0.0206	-0.4046	0.5613	-0.4046	Z
A-PILLAR Maximum (X, Y, Z)	31	51.3846	49.9973	-33.8929	51.5462	50.4180	-34.3753	-0.1616	-0.4207	-0.4824	0.6602	0.0000	
	32	48.1886	49.2354	-36.4124	48.4228	49.5744	-36.9556	-0.2342	-0.3390	-0.5432	0.6818	0.0000	
	33	44.6135	48.5688	-39.1851	45.0310	48.9024	-39.7946	-0.4175	-0.3336	-0.6095	0.8106	0.0000	
	34	40.9021	47.6269	-41.3628	41.3160	47.8975	-42.0867	-0.4139	-0.2706	-0.7239	0.8767	0.0000	
	35	38.4579	47.1348	-42.9683	38.8367	47.3105	-43.5967	-0.3788	-0.1757	-0.6284	0.7545	0.0000	
	36	35.3140	46.3322	-44.7388	35.7406	46.5168	-45.4685	-0.4266	-0.1846	-0.7297	0.8652	0.0000	
A-PILLAR Lateral (Y)	31	51.3846	49.9973	-33.8929	51.5462	50.4180	-34.3753	-0.1616	-0.4207	-0.4824	0.6602	-0.4207	Y
	32	48.1886	49.2354	-36.4124	48.4228	49.5744	-36.9556	-0.2342	-0.3390	-0.5432	0.6818	-0.3390	Y
	33	44.6135	48.5688	-39.1851	45.0310	48.9024	-39.7946	-0.4175	-0.3336	-0.6095	0.8106	-0.3336	Y
	34	40.9021	47.6269	-41.3628	41.3160	47.8975	-42.0867	-0.4139	-0.2706	-0.7239	0.8767	-0.2706	Y
	35	38.4579	47.1348	-42.9683	38.8367	47.3105	-43.5967	-0.3788	-0.1757	-0.6284	0.7545	-0.1757	Y
	36	35.3140	46.3322	-44.7388	35.7406	46.5168	-45.4685	-0.4266	-0.1846	-0.7297	0.8652	-0.1846	Y
B-PILLAR Maximum (X, Y, Z)	37	10.3281	47.7157	-43.2026	10.7116	47.6969	-43.9972	-0.3835	0.0188	-0.7946	0.8825	0.0188	Y
	38	12.8623	50.7526	-33.3780	13.2747	50.7359	-34.1241	-0.4124	0.0167	-0.7461	0.8527	0.0167	Y
	39	9.5031	51.3420	-29.4374	9.8999	51.2611	-30.1615	-0.3968	0.0809	-0.7241	0.8296	0.0809	Y
	40	13.4284	51.4605	-27.5132	13.8202	51.4204	-28.2494	-0.3918	0.0401	-0.7362	0.8349	0.0401	Y
B-PILLAR Lateral (Y)	37	10.3281	47.7157	-43.2026	10.7116	47.6969	-43.9972	-0.3835	0.0188	-0.7946	0.8825	0.0188	Y
	38	12.8623	50.7526	-33.3780	13.2747	50.7359	-34.1241	-0.4124	0.0167	-0.7461	0.8527	0.0167	Y
	39	9.5031	51.3420	-29.4374	9.8999	51.2611	-30.1615	-0.3968	0.0809	-0.7241	0.8296	0.0809	Y
	40	13.4284	51.4605	-27.5132	13.8202	51.4204	-28.2494	-0.3918	0.0401	-0.7362	0.8349	0.0401	Y

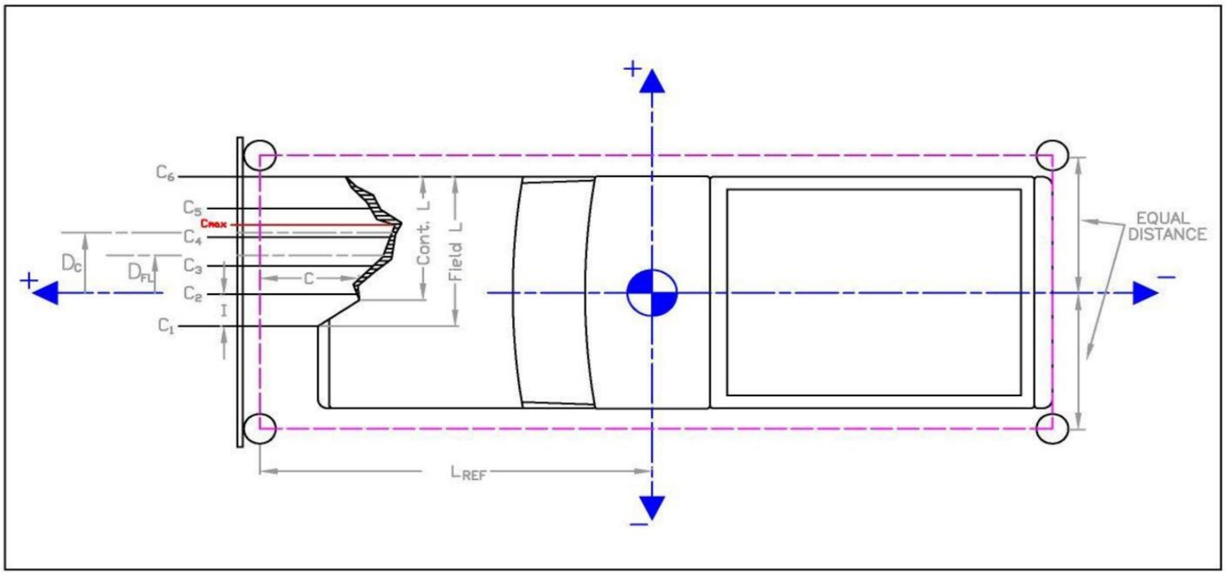
[A] Positive values denote deformation as inward toward the occupant compartment, negative values denote deformations outward away from the occupant compartment.

[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 no direction listed, then no intrusion is recorded, and Crush will be 0.

Figure E-16. Occupant Compartment Deformation Data – Set 2, Test No. MNNW-3

Date:	4/4/2018	Test Name:	MNNW-3	VIN:	1D7RB1CP7BX646567
Year:	2011	Make:	Dodge	Model:	Ram 1500



	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	125 1/2	(3188)
Total Vehicle Width:	76 1/2	(1943)
Width of contact and induced crush - Field L:	76 1/2	(1943)
Crush measurement spacing interval (L/5) - I:	15 1/4	(387)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	32	(813)
Distance from center of vehicle to center of contact damage - D_C:	30	(762)

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

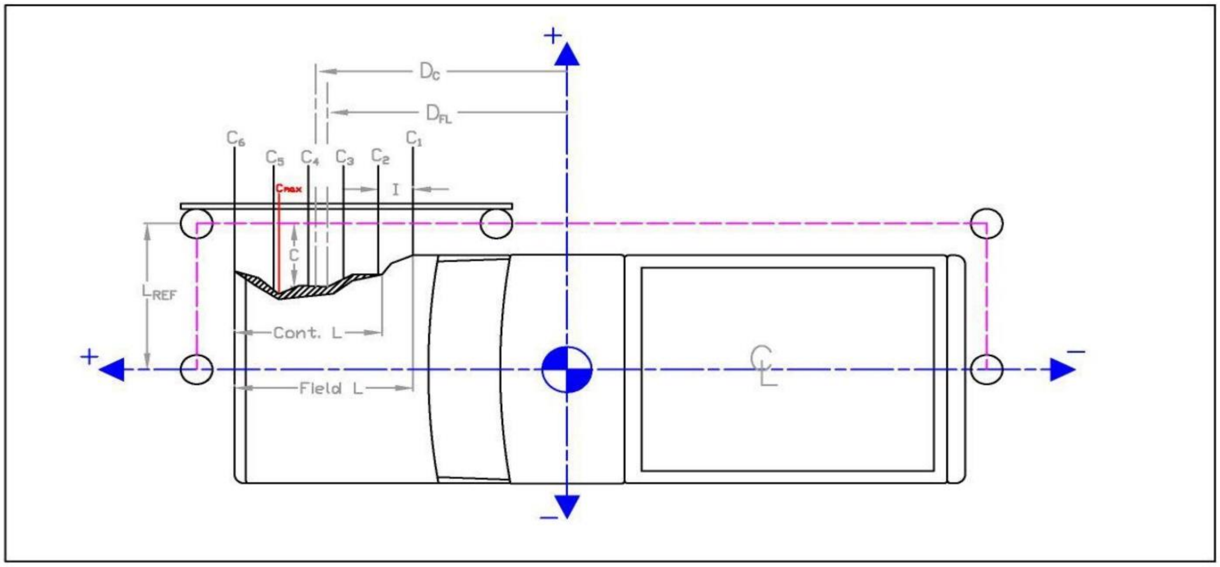
NOTE: All values must be filled out above before crush measurements are filled out.

	Crush Measurement		Lateral Location		Original Profile Measurement		Dist. Between Ref. Lines		Actual Crush	
	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)	in.	(mm)
C_1	NA	NA	-38 1/4	-(972)	22 1/2	(572)	20 1/3	(516)	NA	NA
C_2	26	(660)	-23	-(584)	6 1/2	(165)			- 4/5	-(21)
C_3	20	(508)	-7 3/4	-(197)	4 1/4	(108)			-4 4/7	-(116)
C_4	25 1/4	(641)	7 1/2	(191)	4 1/4	(108)			2/3	(17)
C_5	44	(1118)	22 3/4	(578)	6 1/8	(156)			17 4/7	(446)
C_6	NA	NA	38	(965)	20 1/2	(521)			NA	NA
C_{MAX}	44	(1118)	22 3/4	(578)	6 1/8	(156)			17 4/7	(446)

Figure E-17. Exterior Vehicle Crush (NASS) - Front, Test No. MNNW-3

Date: 4/4/2018 | Test Name: MNNW-3 | VIN: 1D7RB1CP7BX646567

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



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	52	(1321)
Total Vehicle Length:	229 7/8	(5839)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-6 3/4	-(171)
Width of contact and induced crush - Field L:	114	(2896)
Crush measurement spacing interval (L/5) - I:	22 3/4	(578)
Distance from vehicle c.g. to center of Field L - D_{FL}:	46	(1168)
Width of Contact Damage:	114	(2896)
Distance from vehicle c.g. to center of contact damage - D_C:	46	(1168)

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	13	(330)	-11	-(279)	5	(127)	8	(203)	0	()
C_2	13 3/8	(340)	11 3/4	(298)	5	(127)			3/8	(10)
C_3	17 3/8	(441)	34 1/2	(876)	5 1/8	(130)			4 1/4	(108)
C_4	NA	NA	57 1/4	(1454)	5 5/8	(143)			NA	NA
C_5	31 1/2	(800)	80	(2032)	5 3/8	(137)			18 1/8	(460)
C_6	41 1/4	(1048)	102 3/4	(2610)	13 1/4	(337)			20	(508)
C_{MAX}	41 1/4	(1048)	102 3/4	(2610)	13 1/4	(337)			20	(508)

Figure E-18. Exterior Vehicle Crush (NASS) - Side, Test No. MNNW-2

Appendix F. Accelerometer and Rate Transducer Data Plots, Test No. MNNW-1

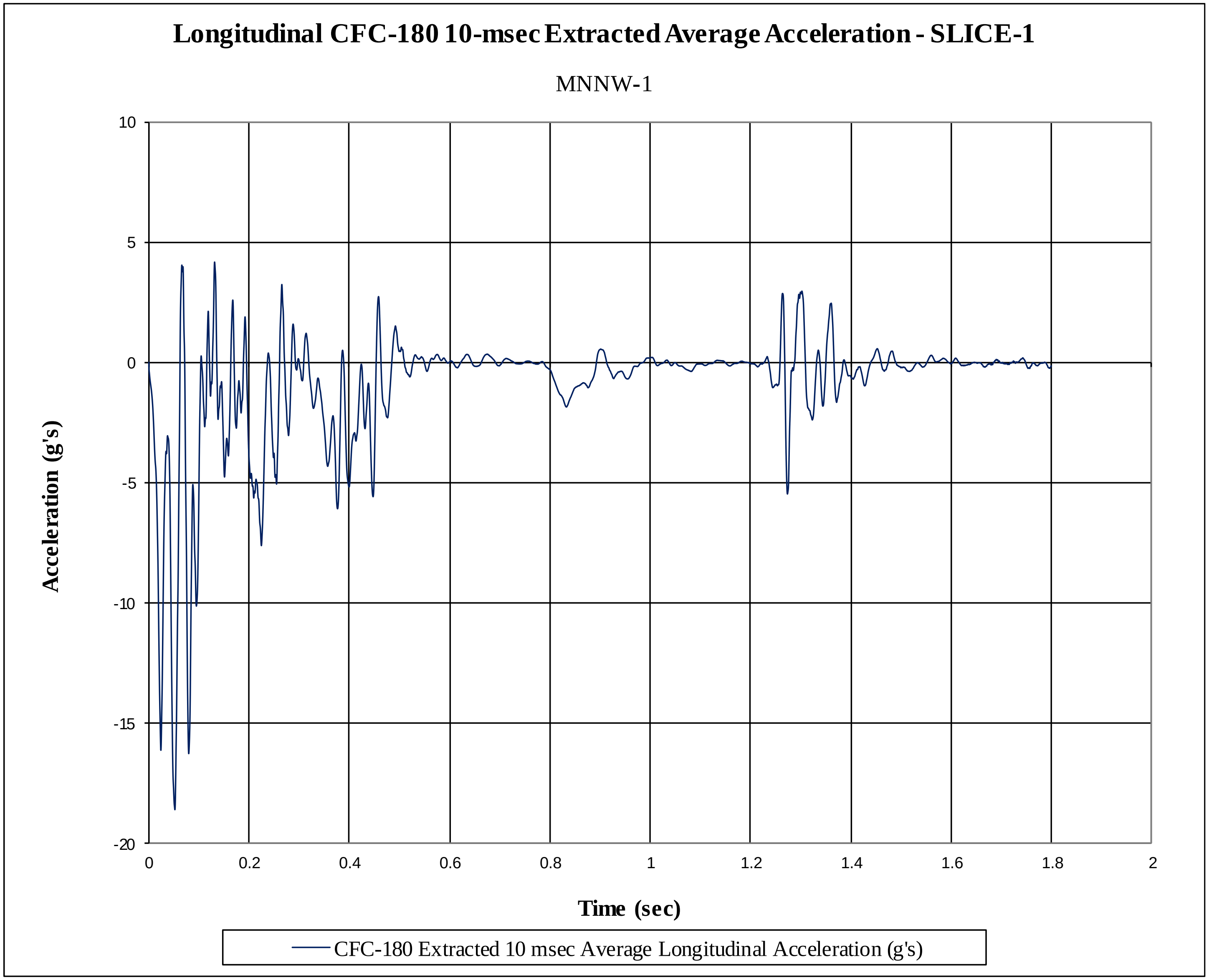


Figure F-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MNNW-1

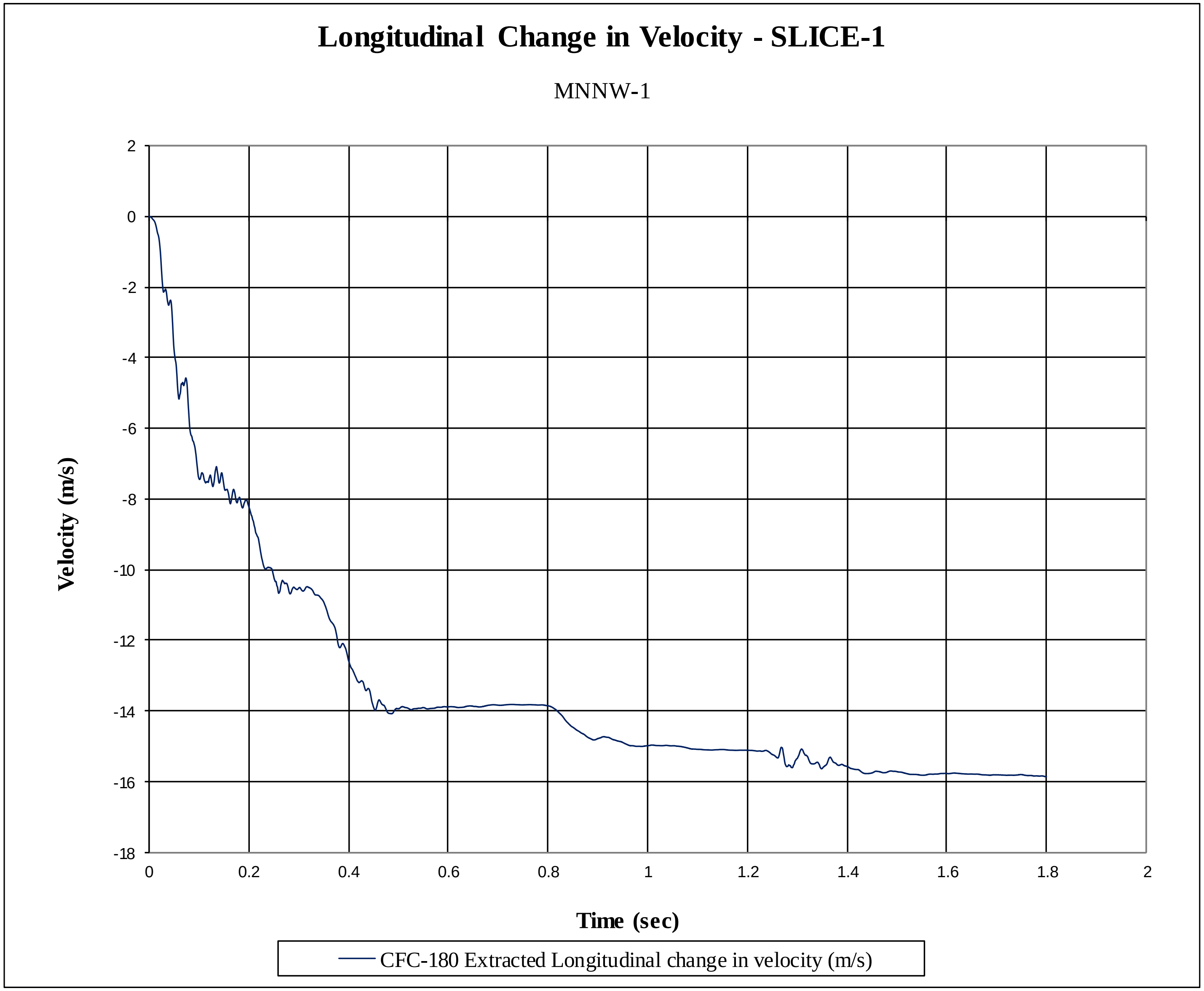


Figure F-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MNNW-1

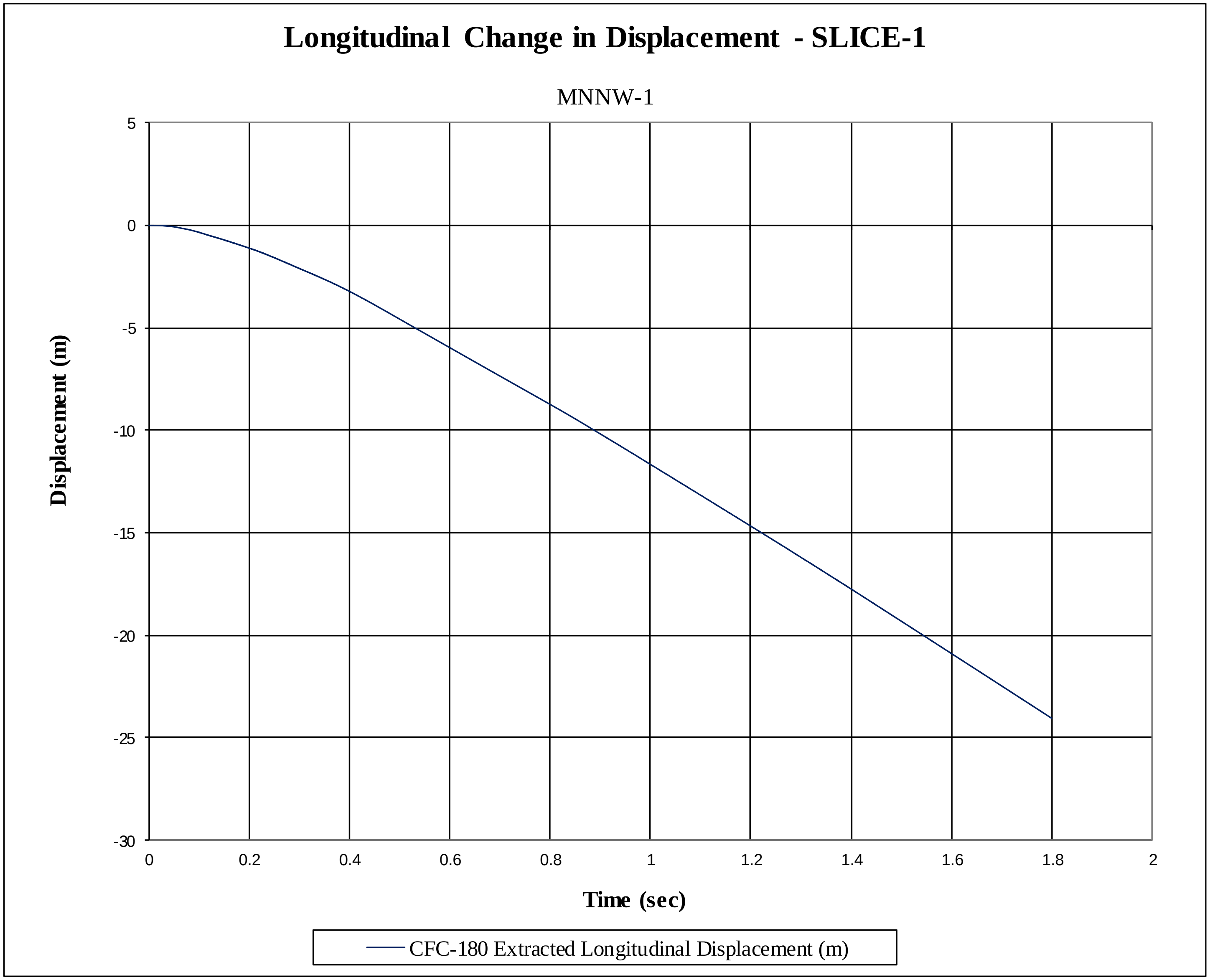


Figure F-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MNNW-1

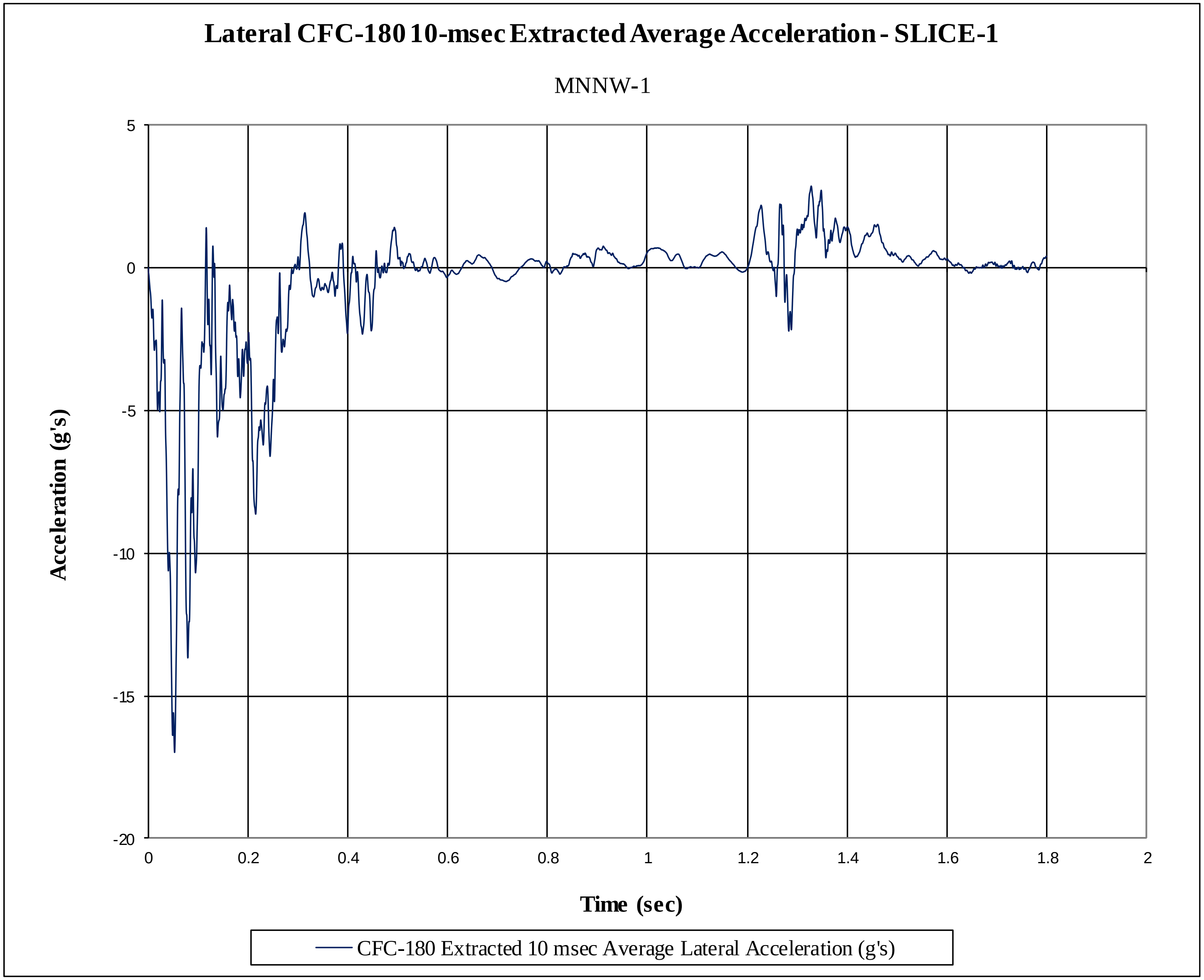


Figure F-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MNNW-1

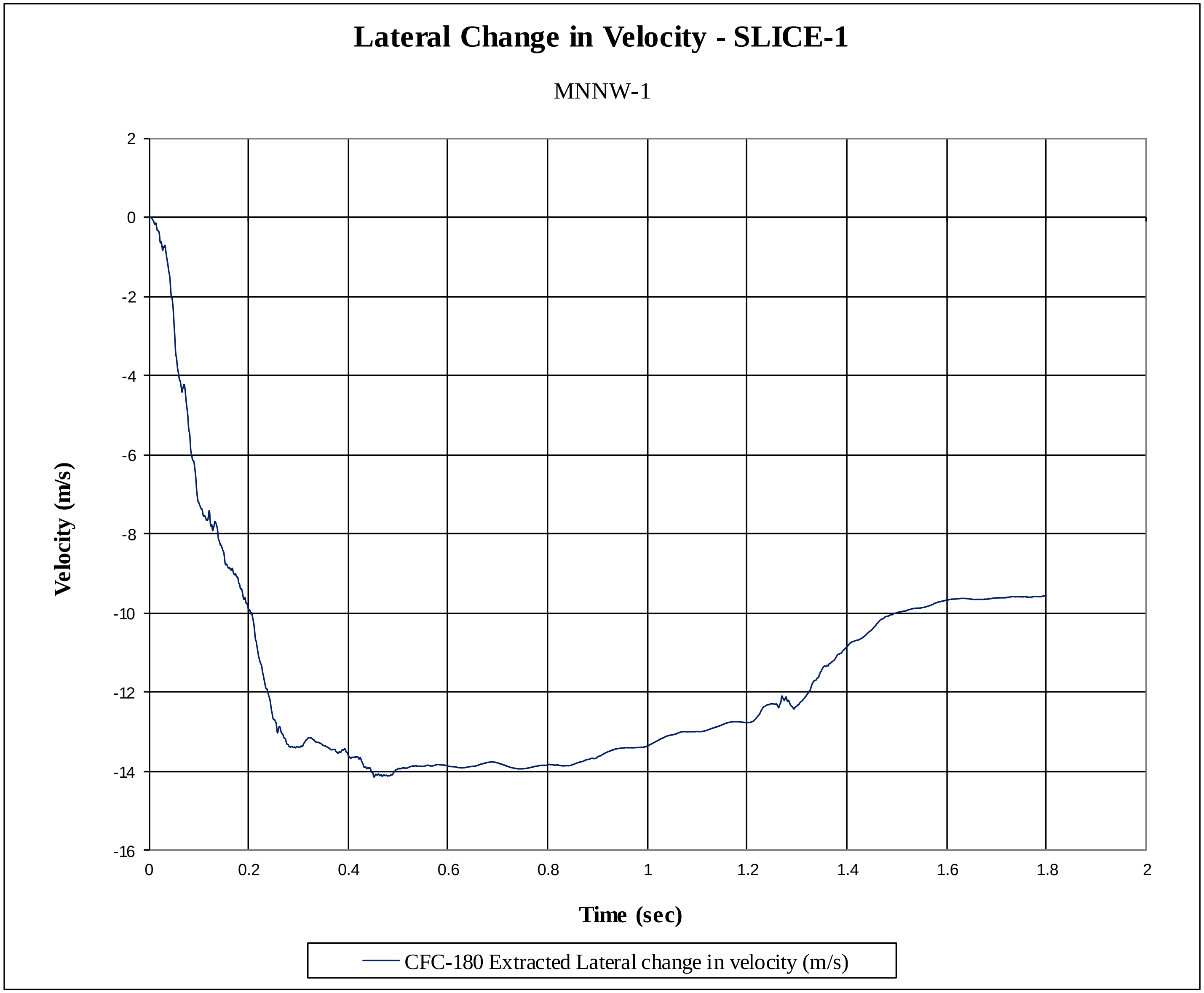


Figure F-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MNNW-1

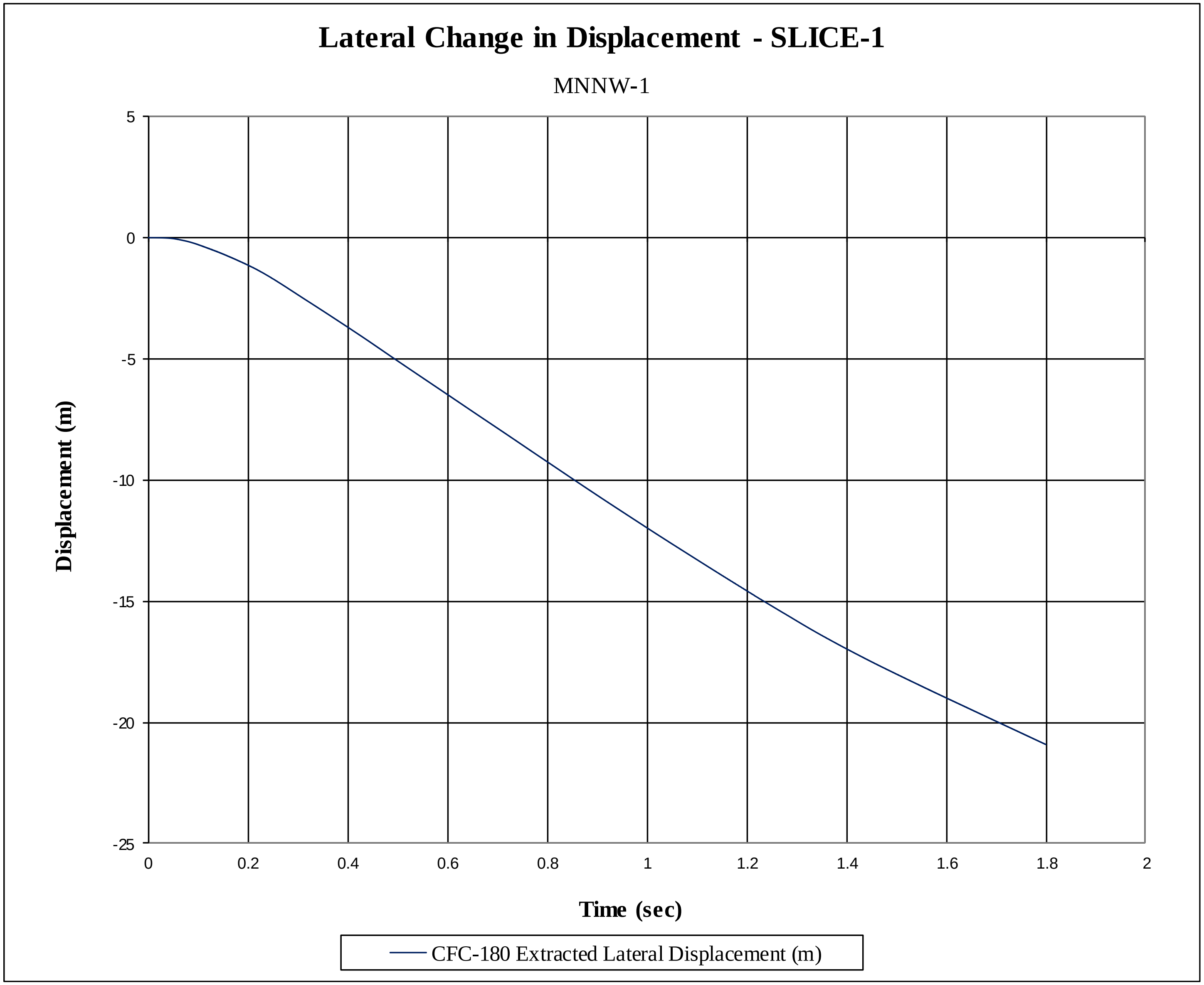


Figure F-6. Lateral Occupant Displacement (SLICE-1), Test No. MNNW-1

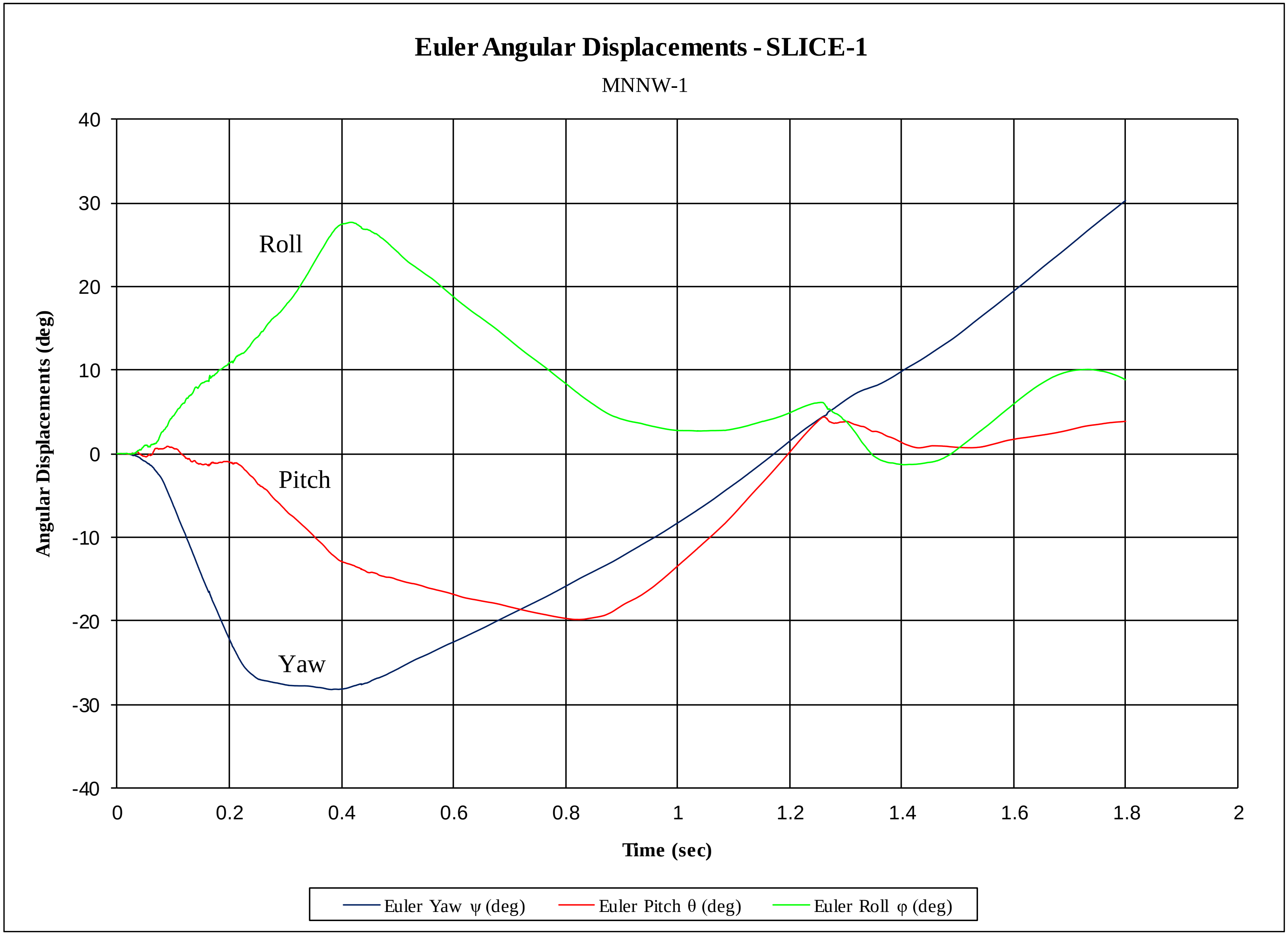


Figure F-7. Vehicle Angular Displacements (SLICE-1), Test No. MNNW-1

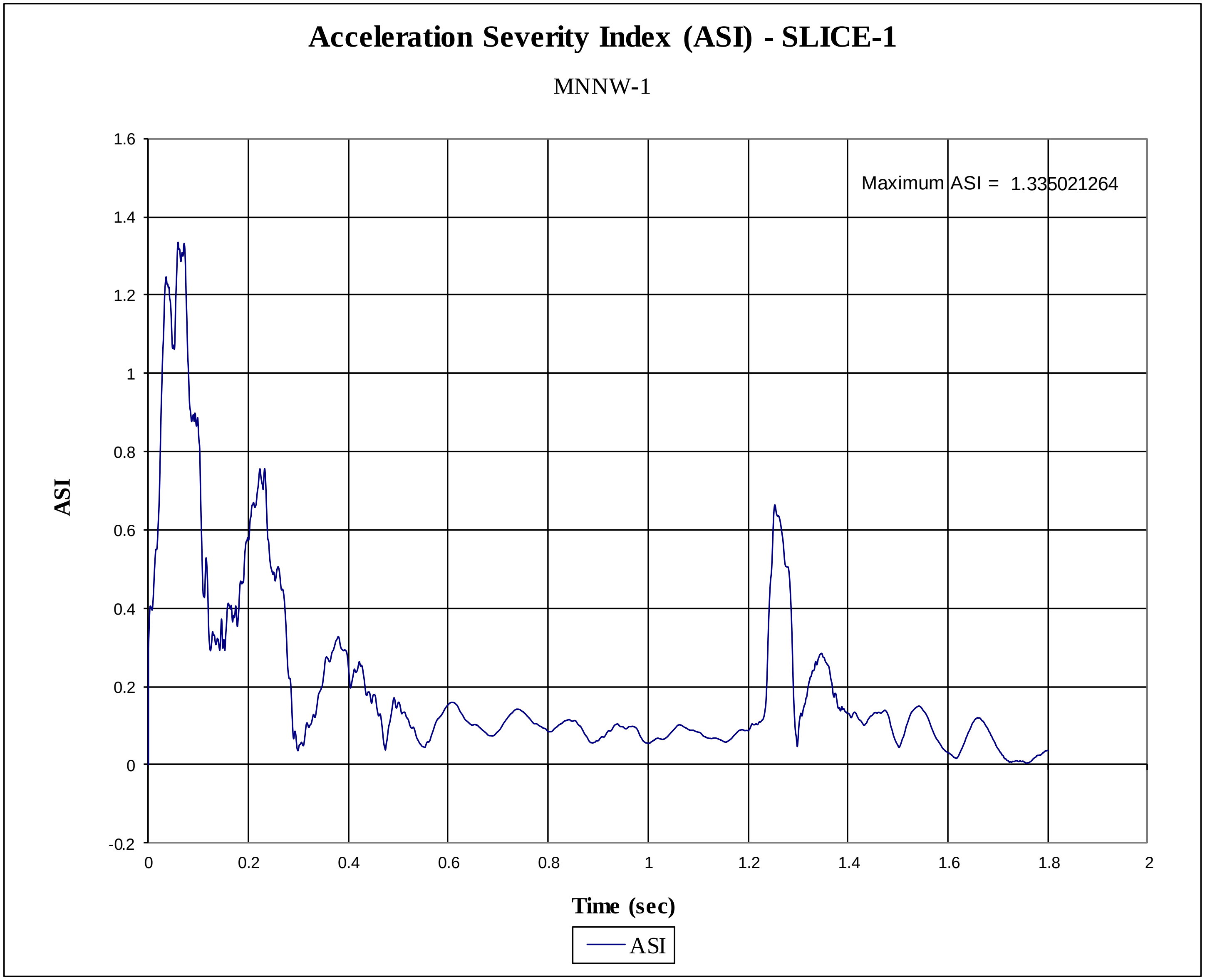


Figure F-8. Acceleration Severity Index (SLICE-1), Test No. MNNW-1

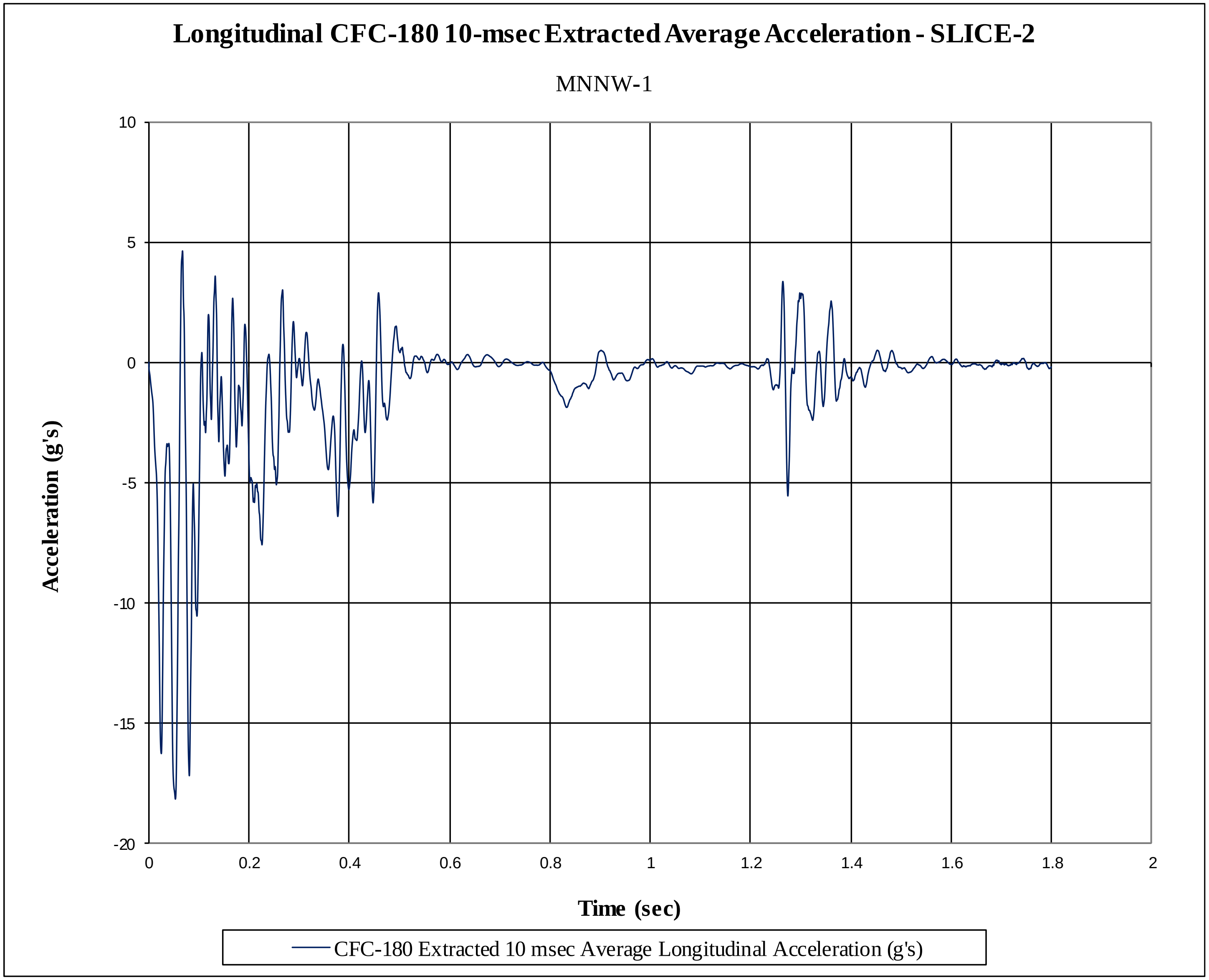


Figure F-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MNNW-1

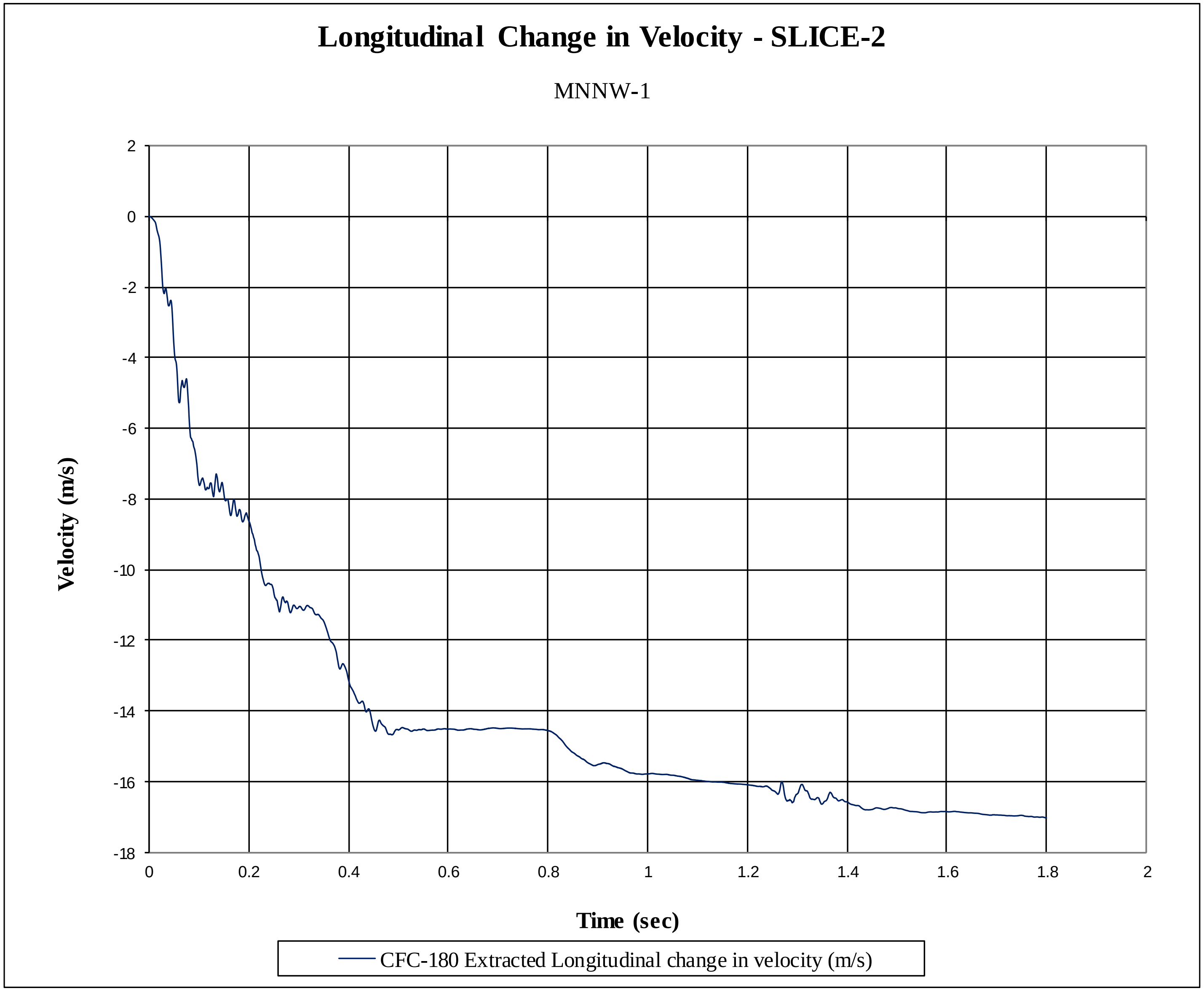


Figure F-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MNNW-1

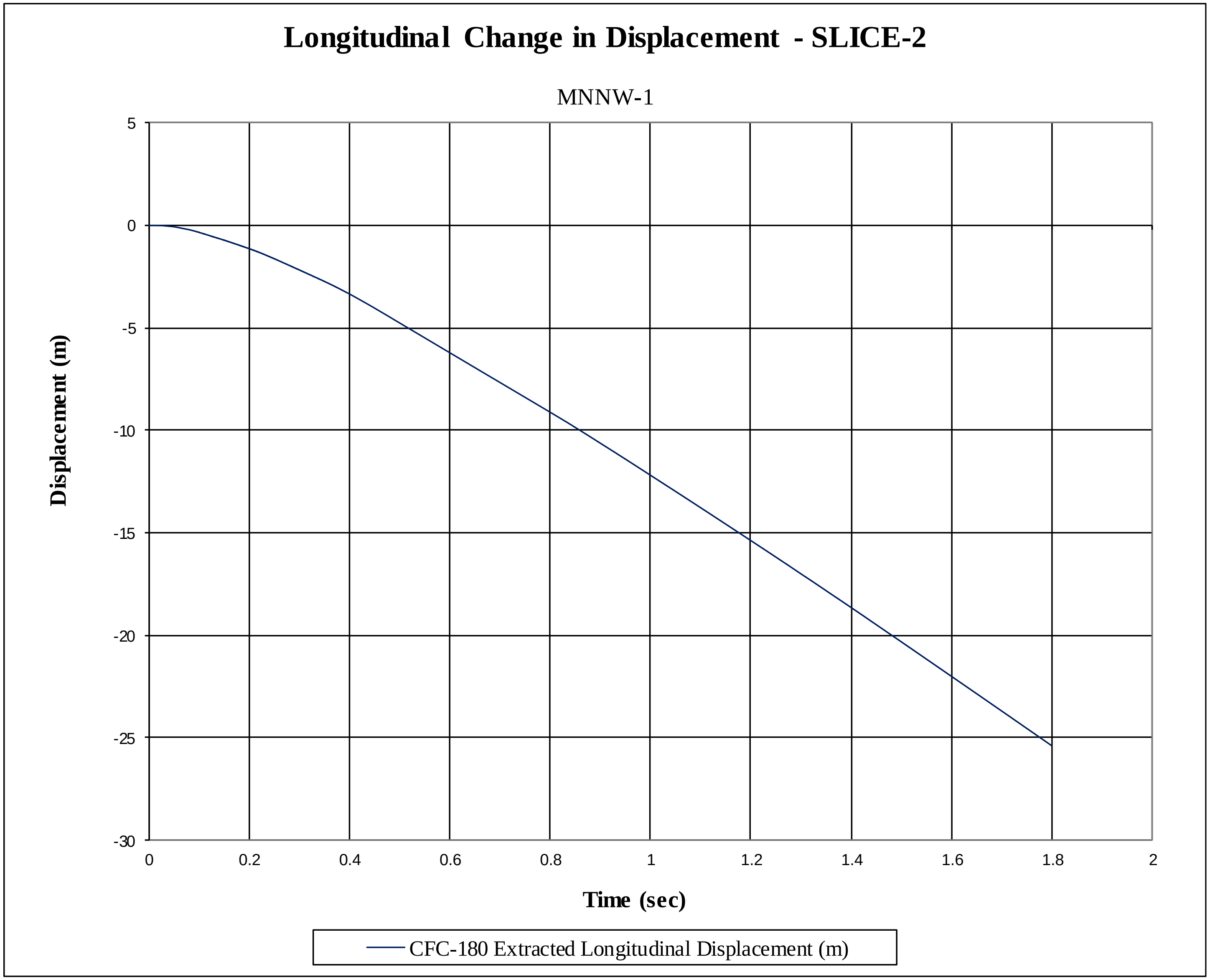


Figure F-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MNNW-1

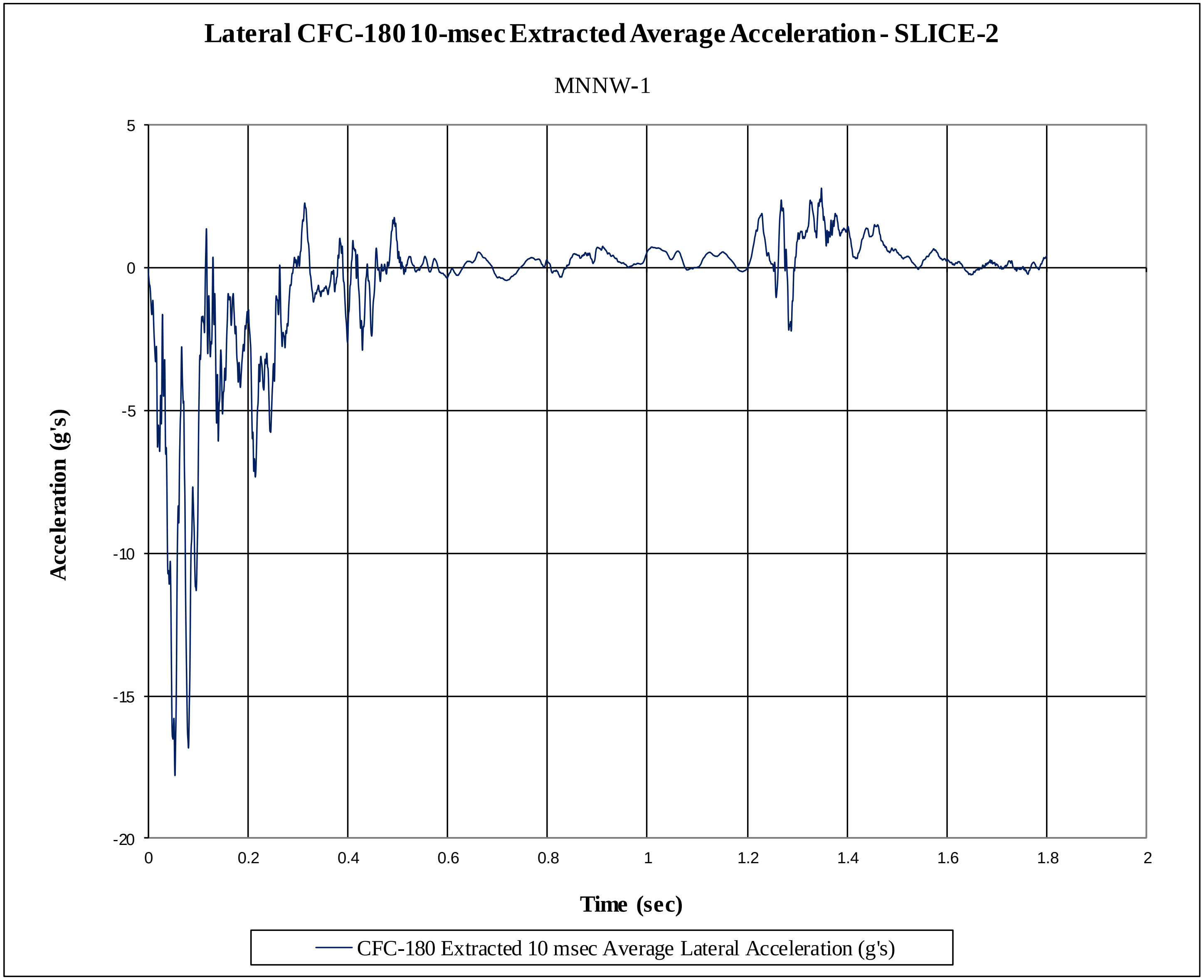


Figure F-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MNNW-1

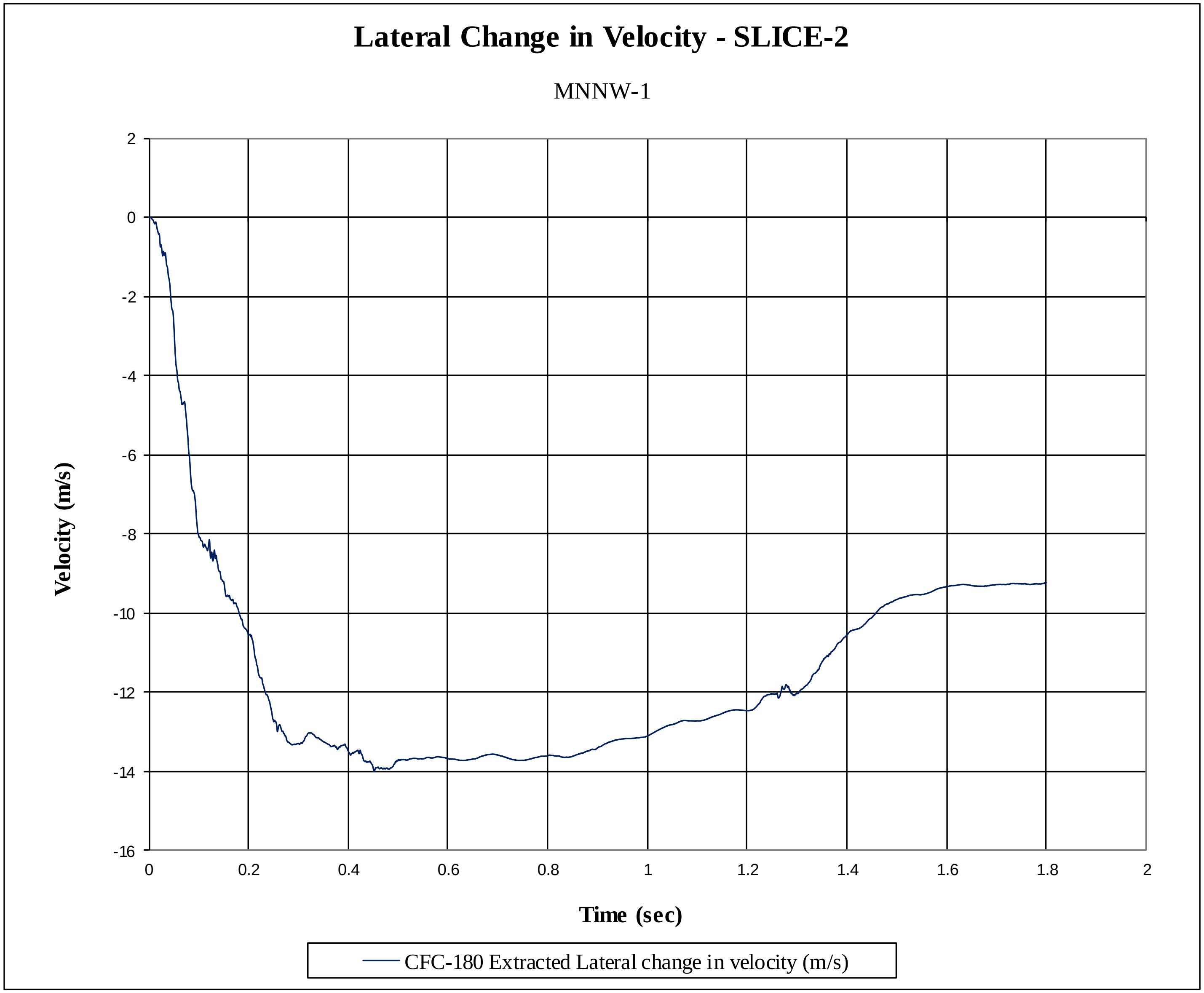


Figure F-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MNNW-1

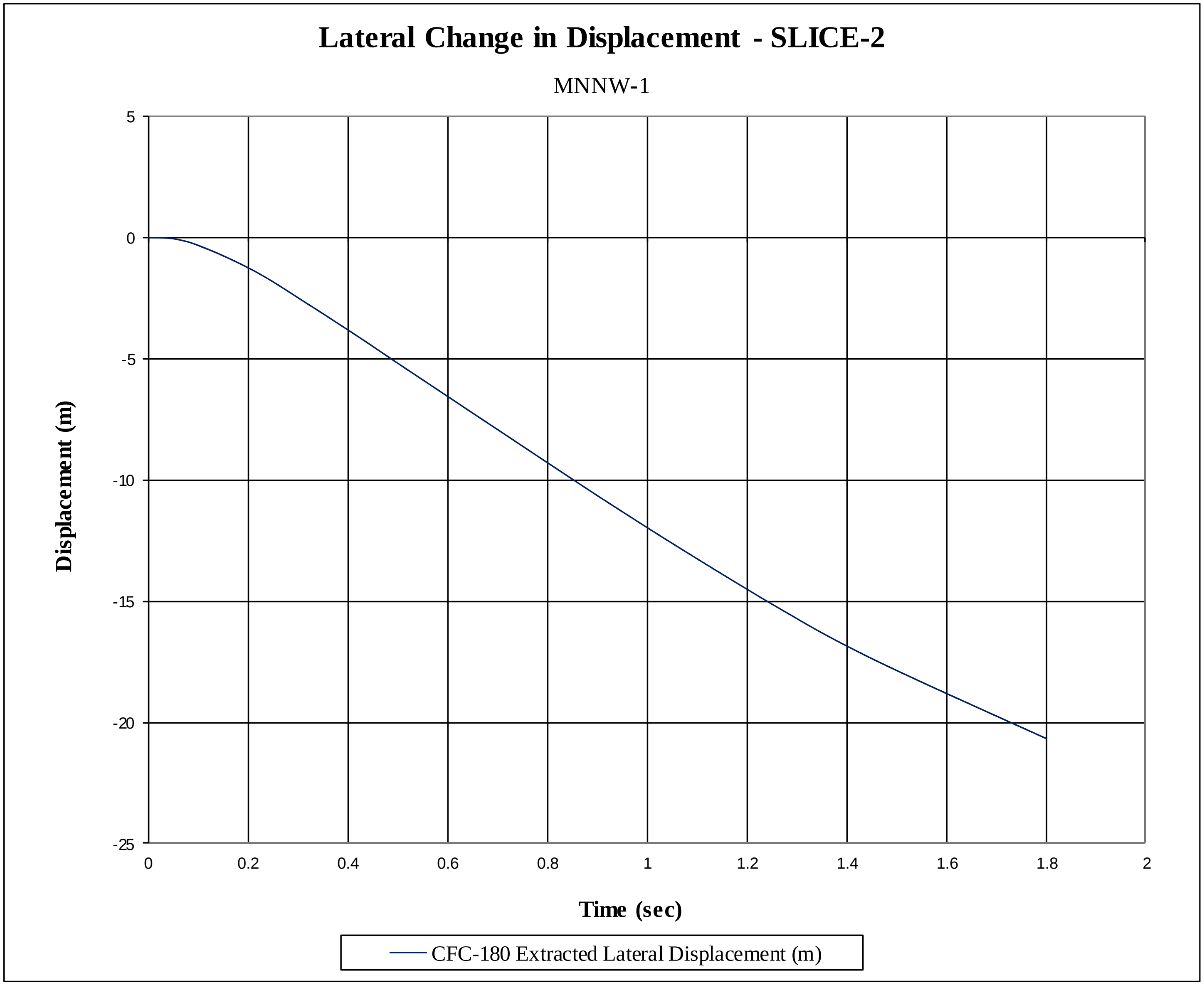


Figure F-14. Lateral Occupant Displacement (SLICE-2), Test No. MNNW-1

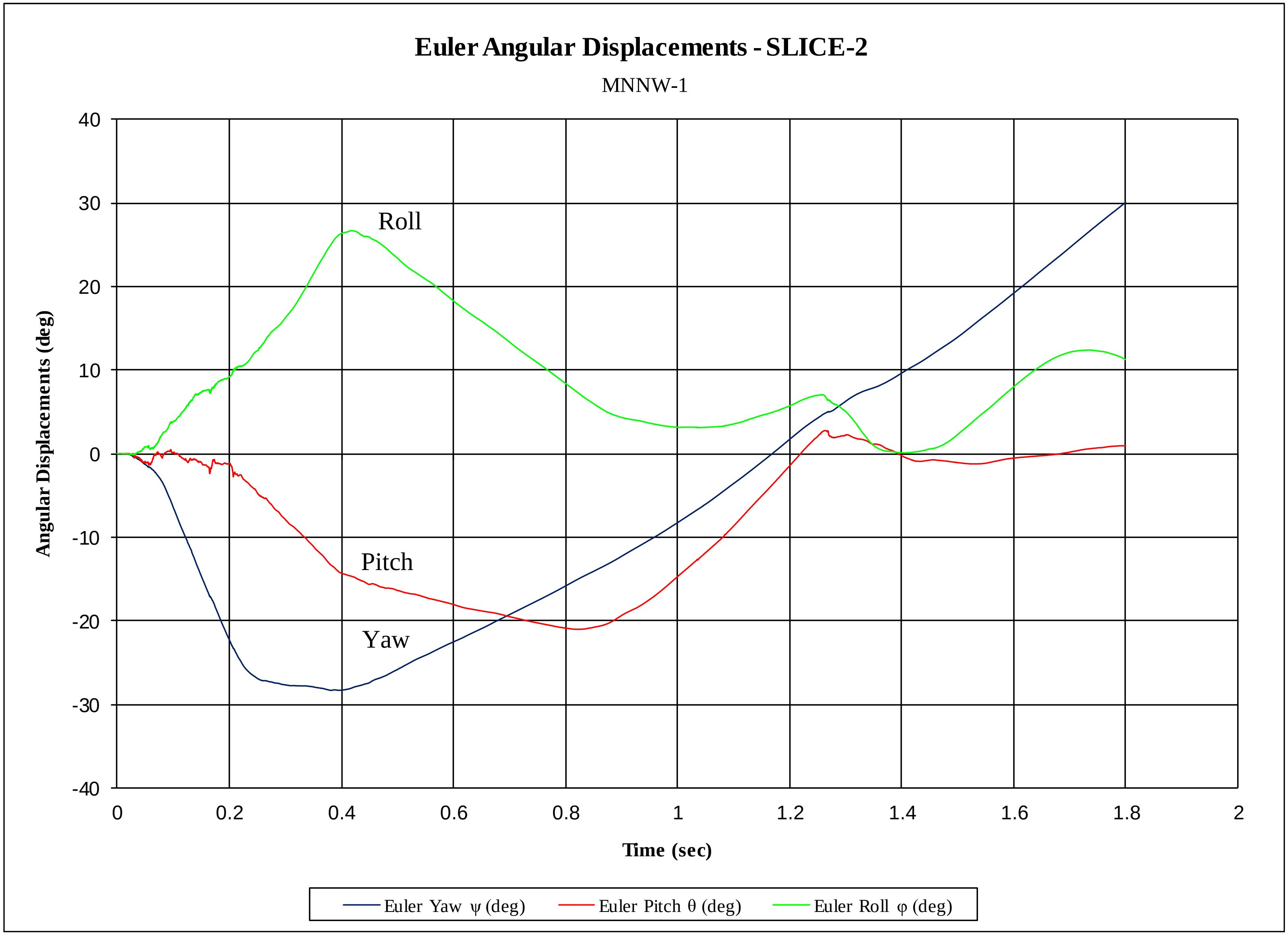


Figure F-15. Vehicle Angular Displacements (SLICE-2), Test No. MNNW-1

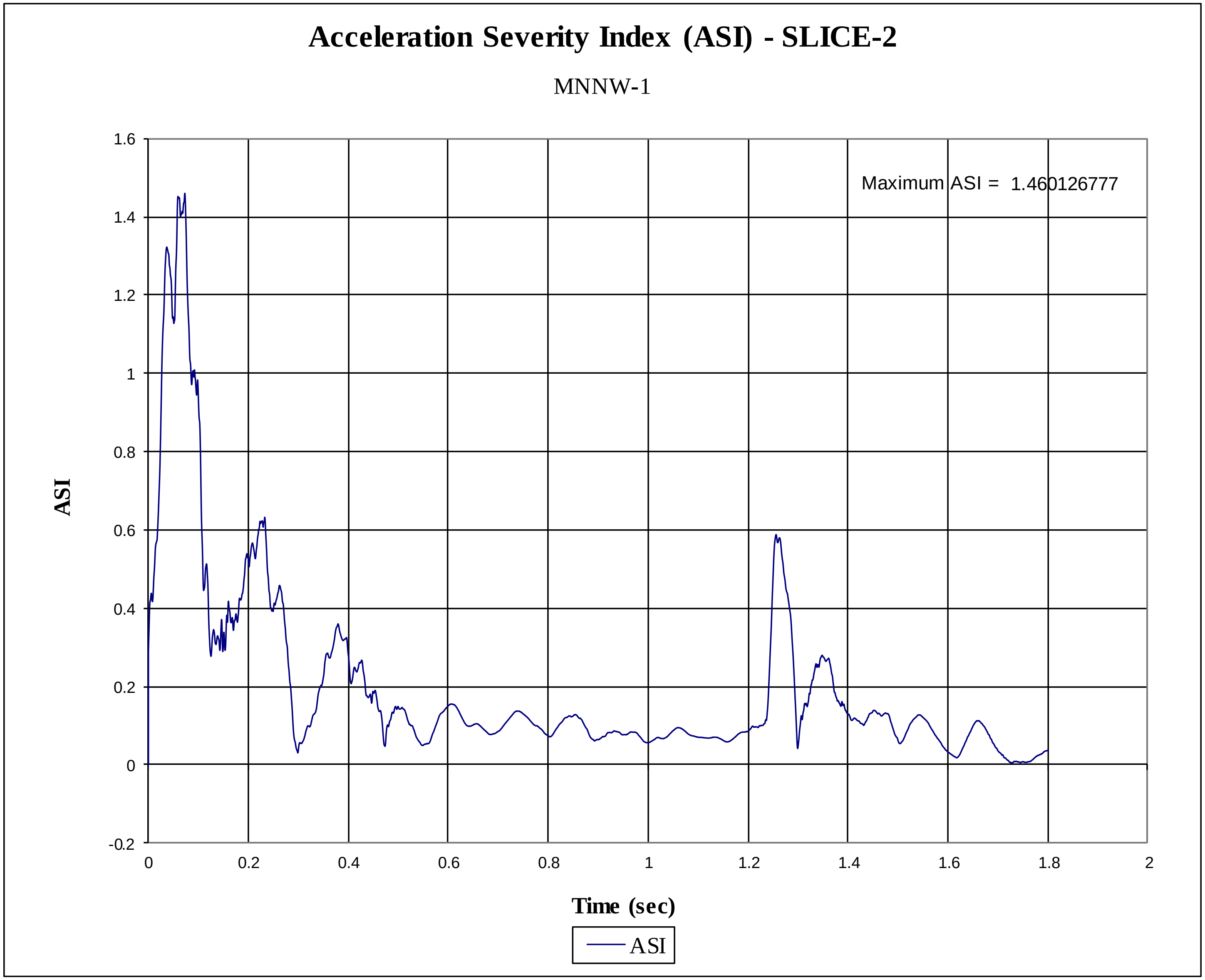


Figure F-16. Acceleration Severity Index (SLICE-2), Test No. MNNW-1

Appendix G. Accelerometer and Rate Transducer Data Plots, Test No. MNNW-2

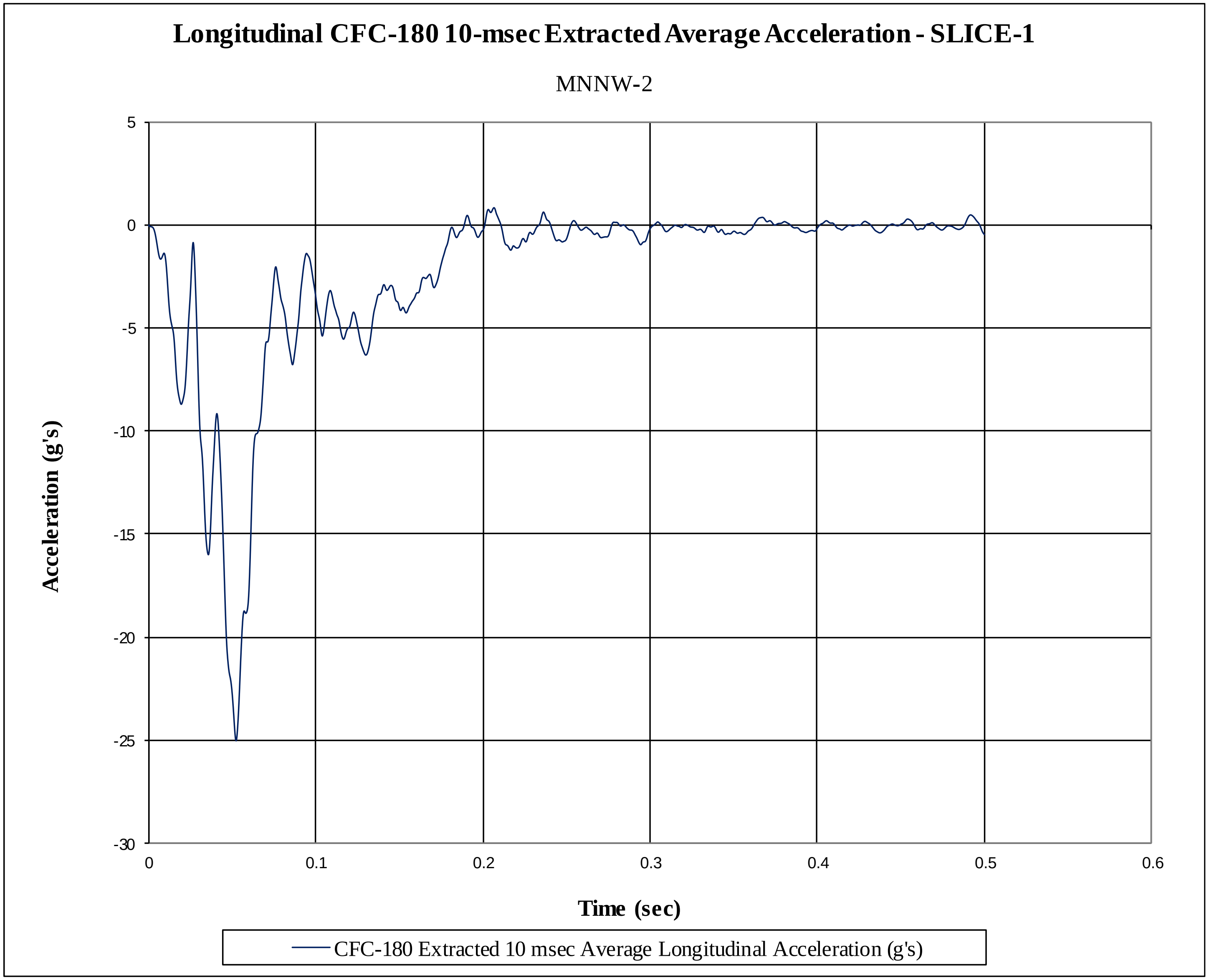


Figure G-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MNNW-2

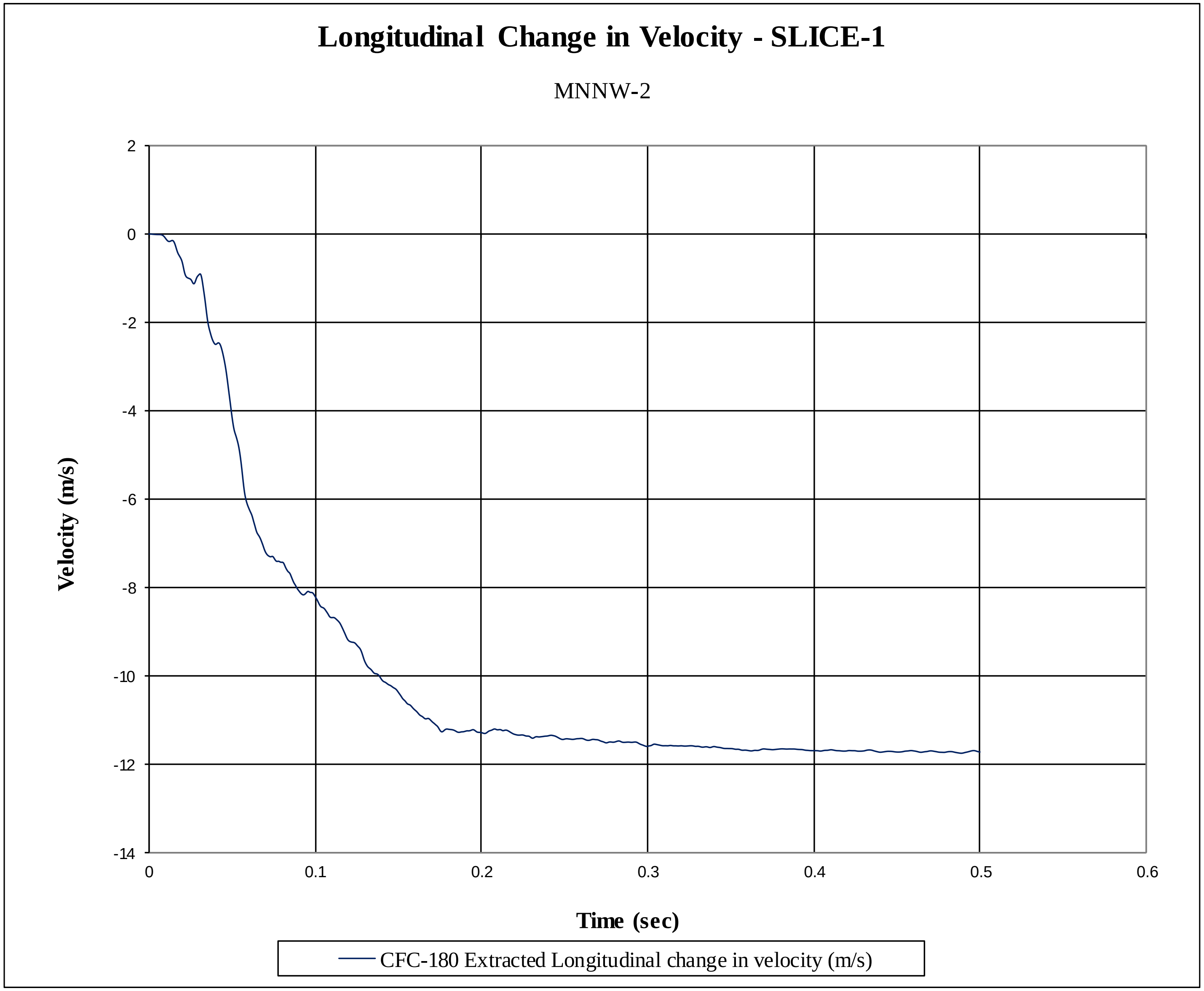


Figure G-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MNNW-2

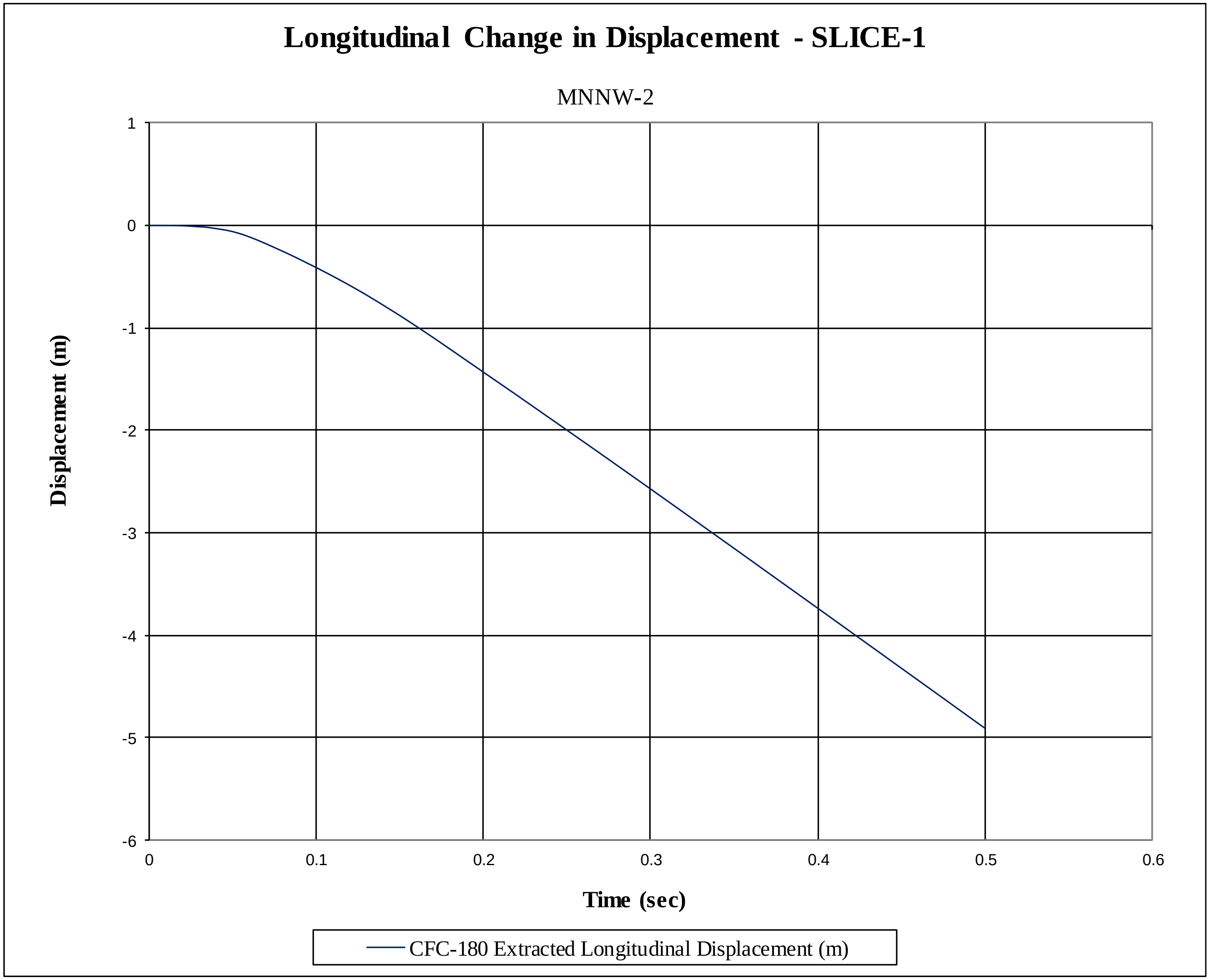


Figure G-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MNNW-2

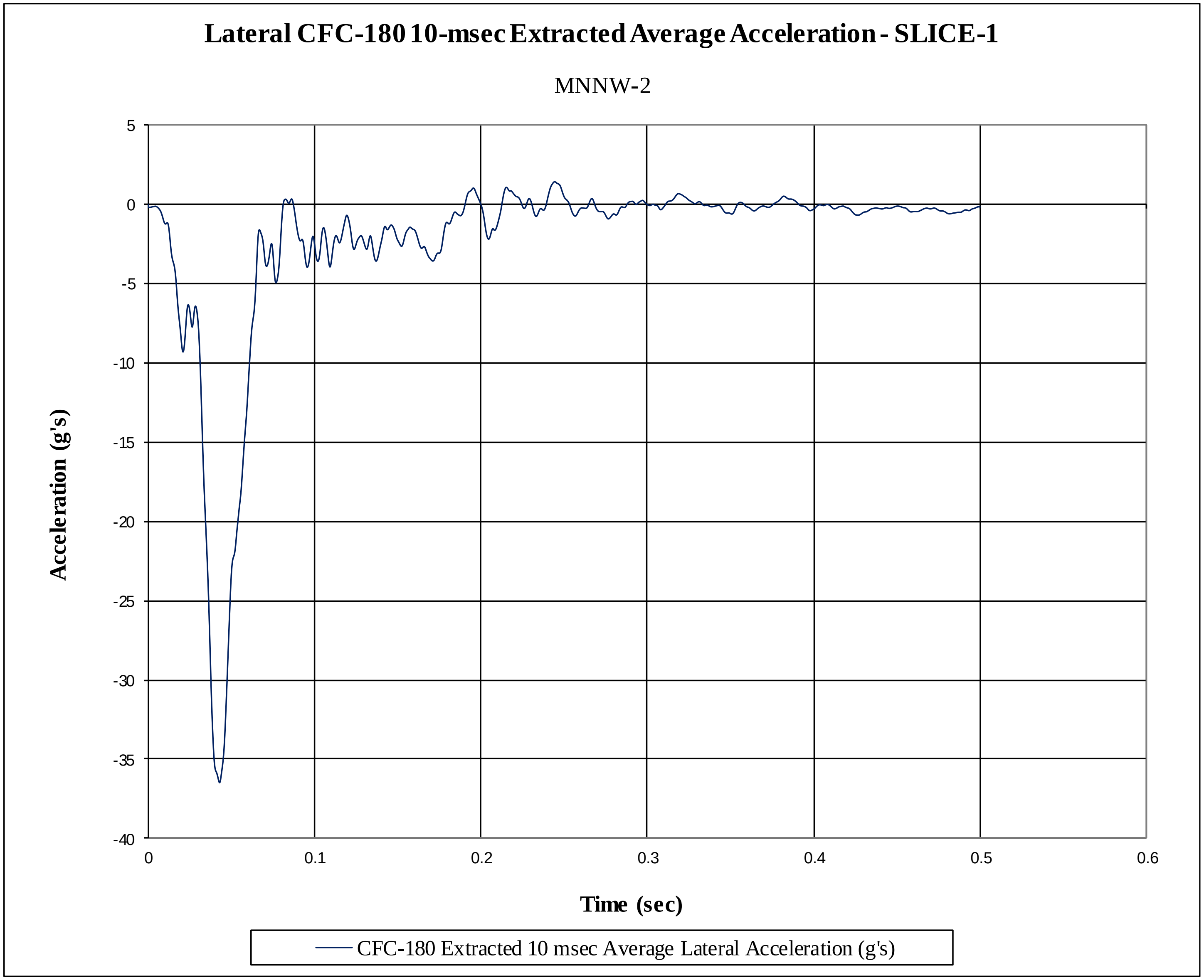


Figure G-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MNNW-2

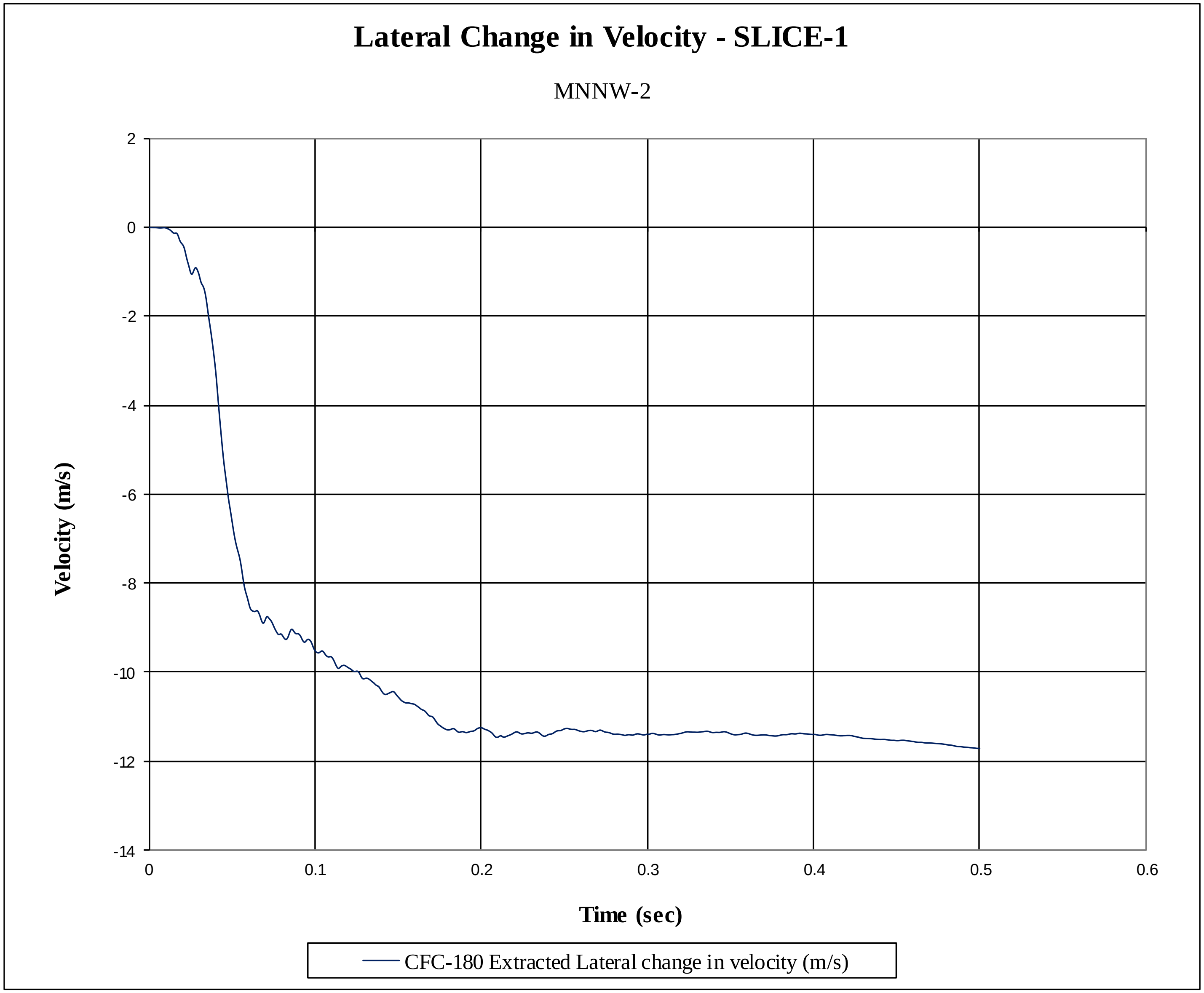


Figure G-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MNNW-2

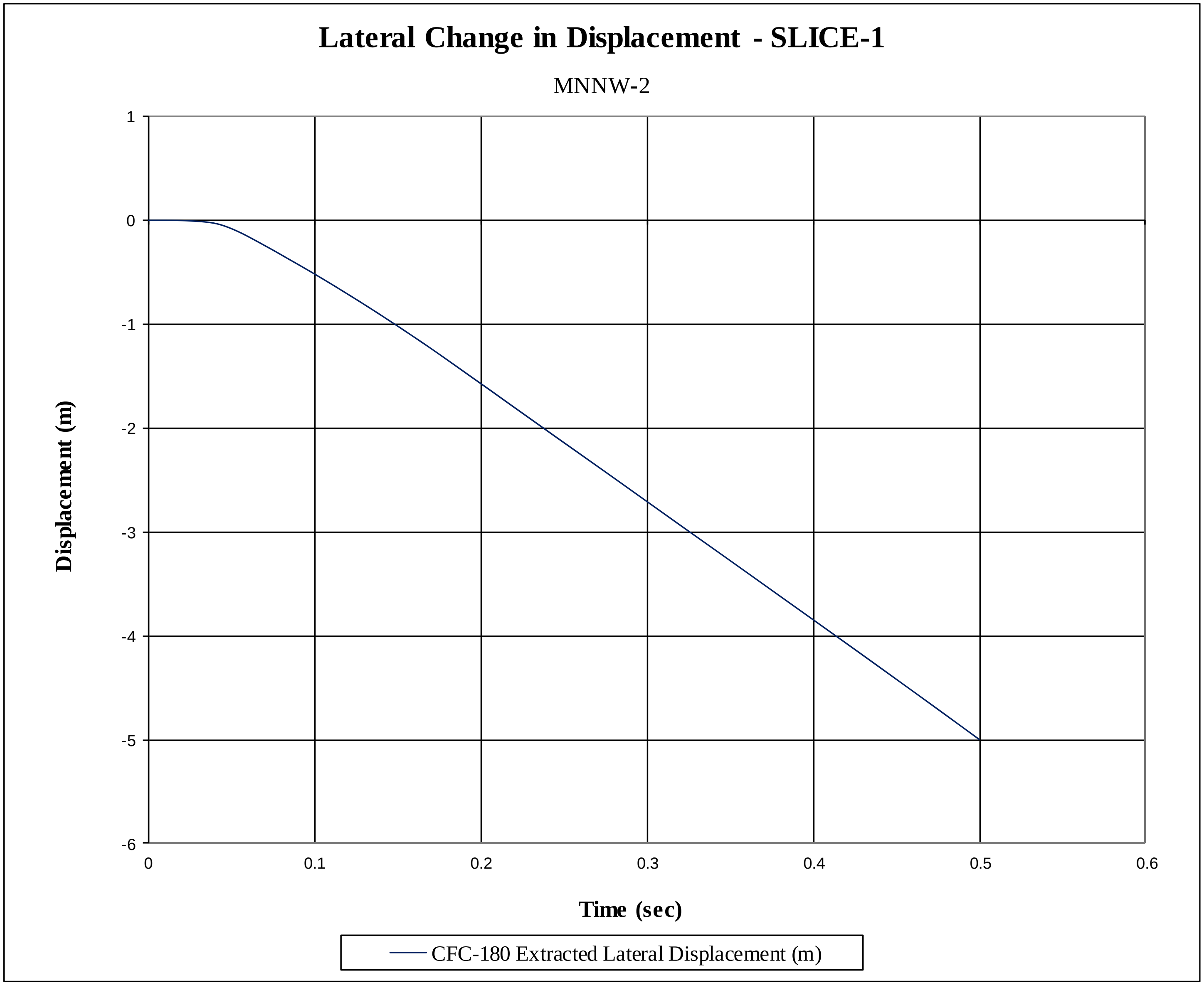


Figure G-6. Lateral Occupant Displacement (SLICE-1), Test No. MNNW-2

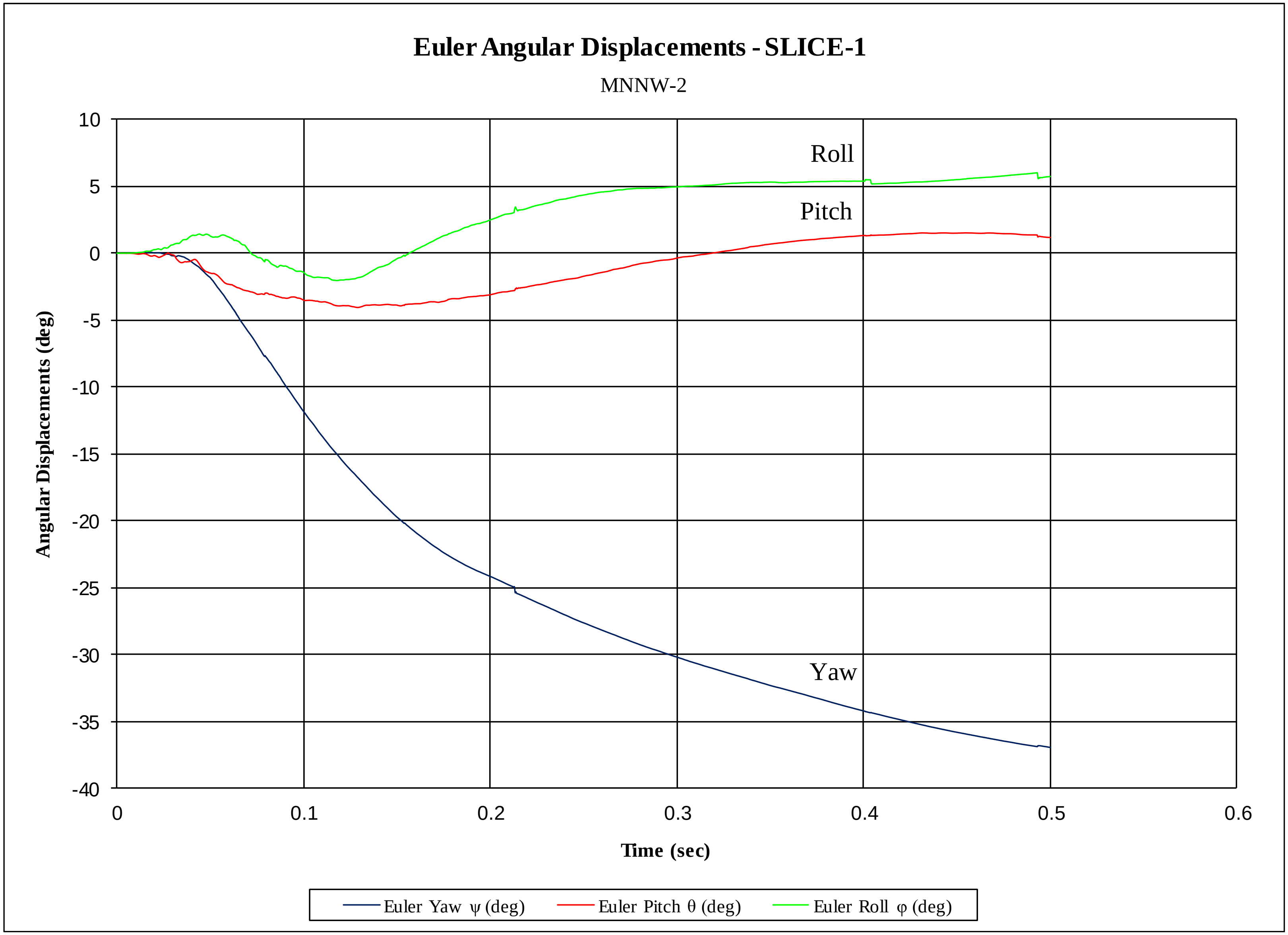


Figure G-7. Vehicle Angular Displacements (SLICE-1), Test No. MNNW-2

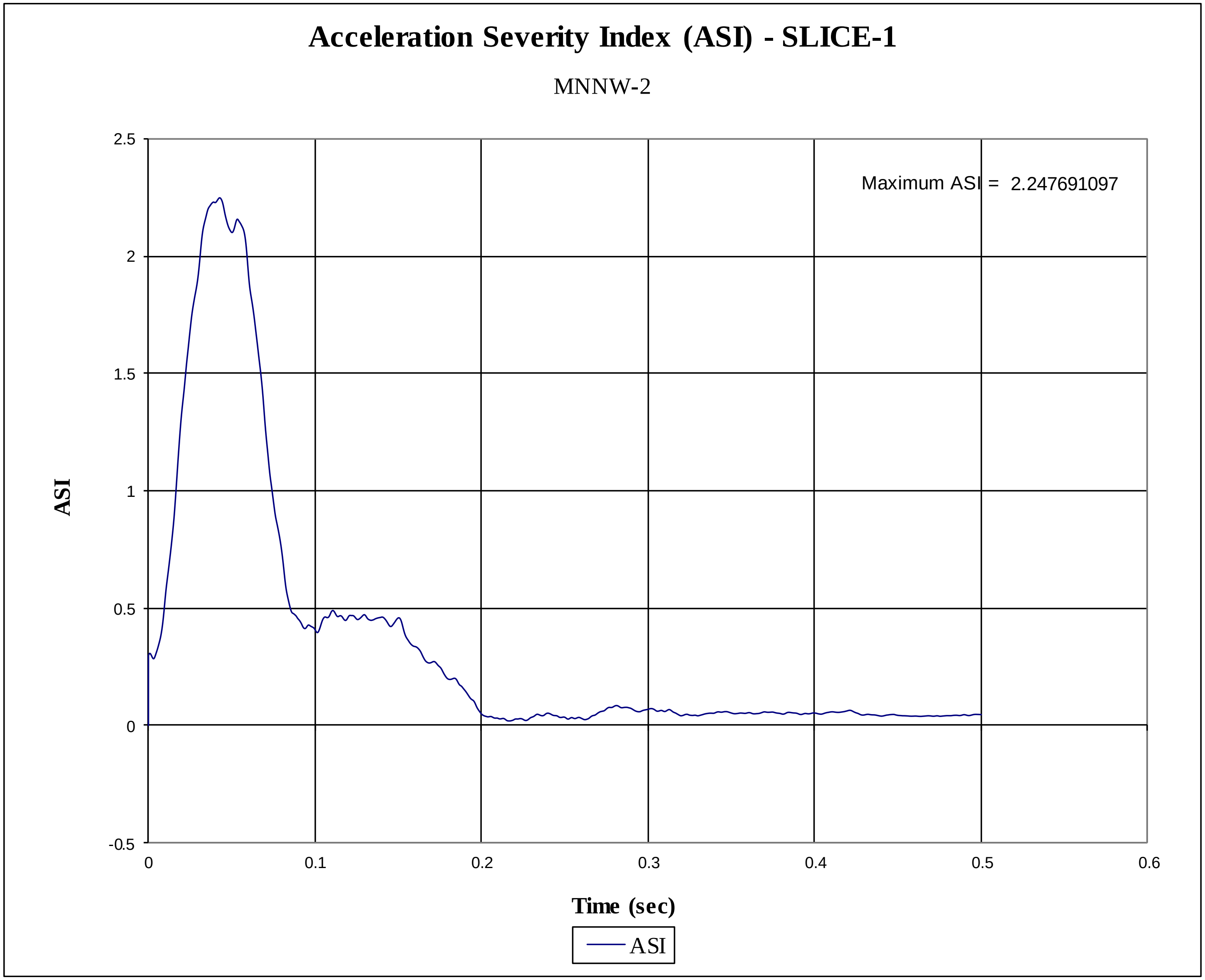


Figure G-8. Acceleration Severity Index (SLICE-1), Test No. MNNW-2

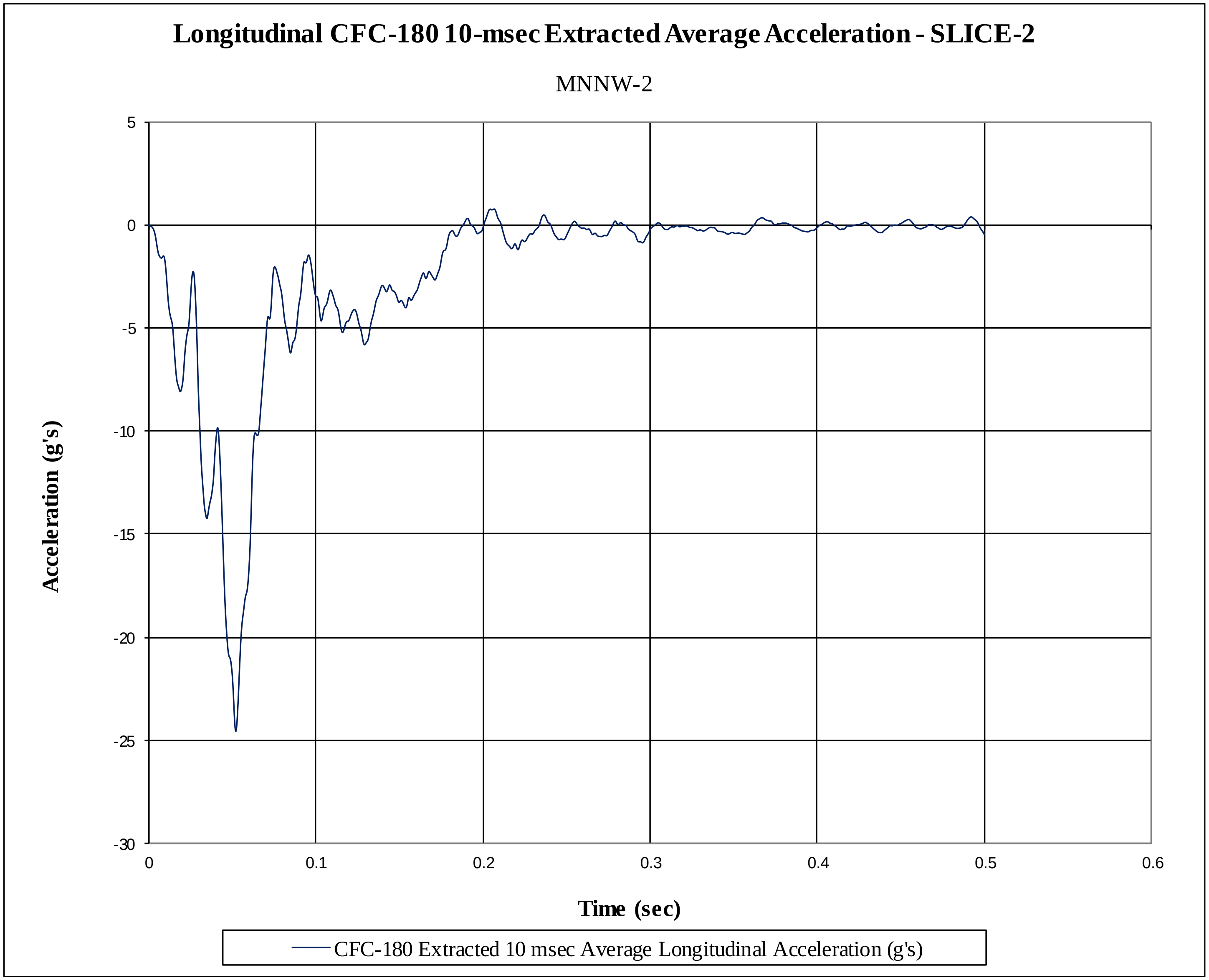


Figure G-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MNNW-2

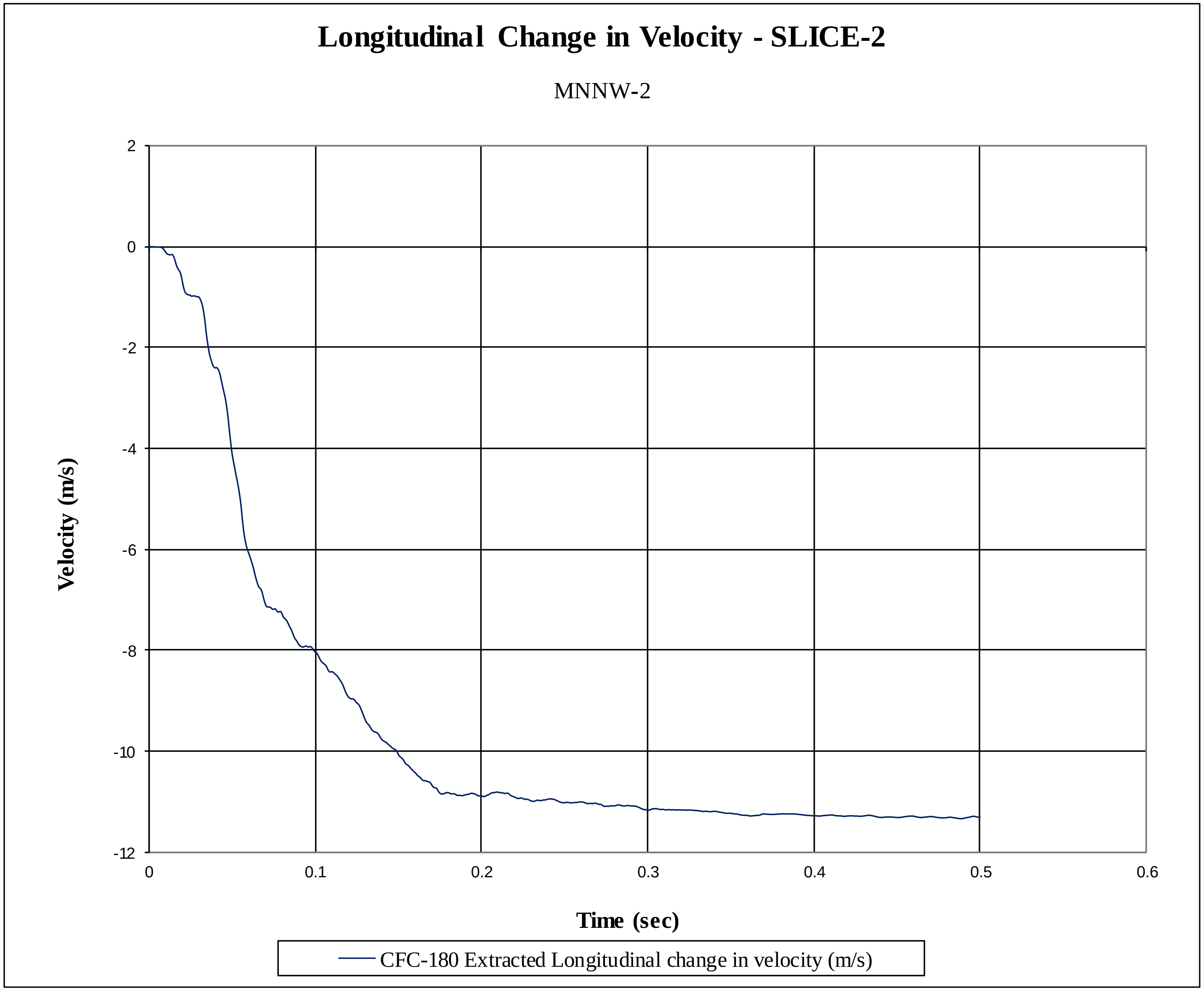


Figure G-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MNNW-2

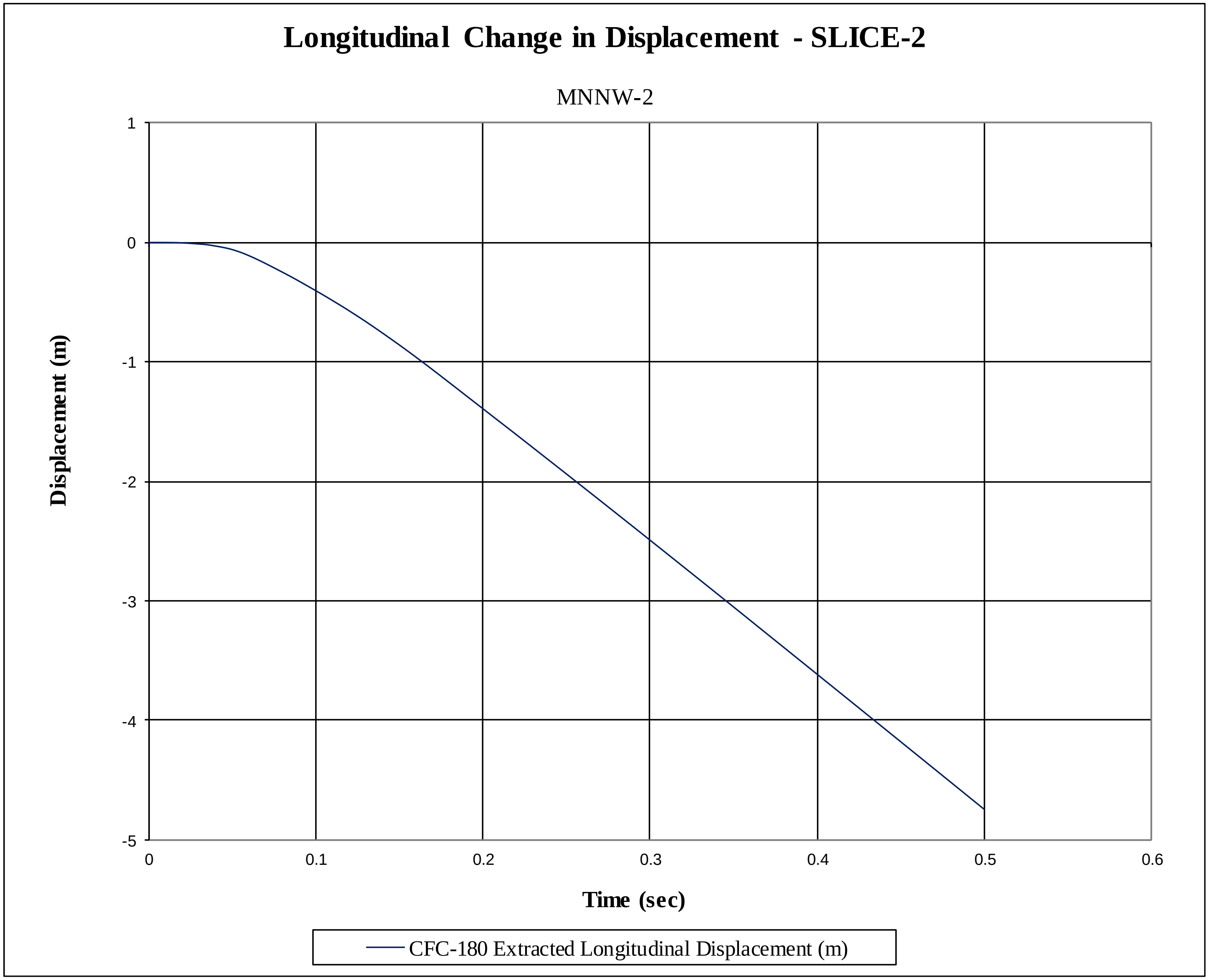


Figure G-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MNNW-2

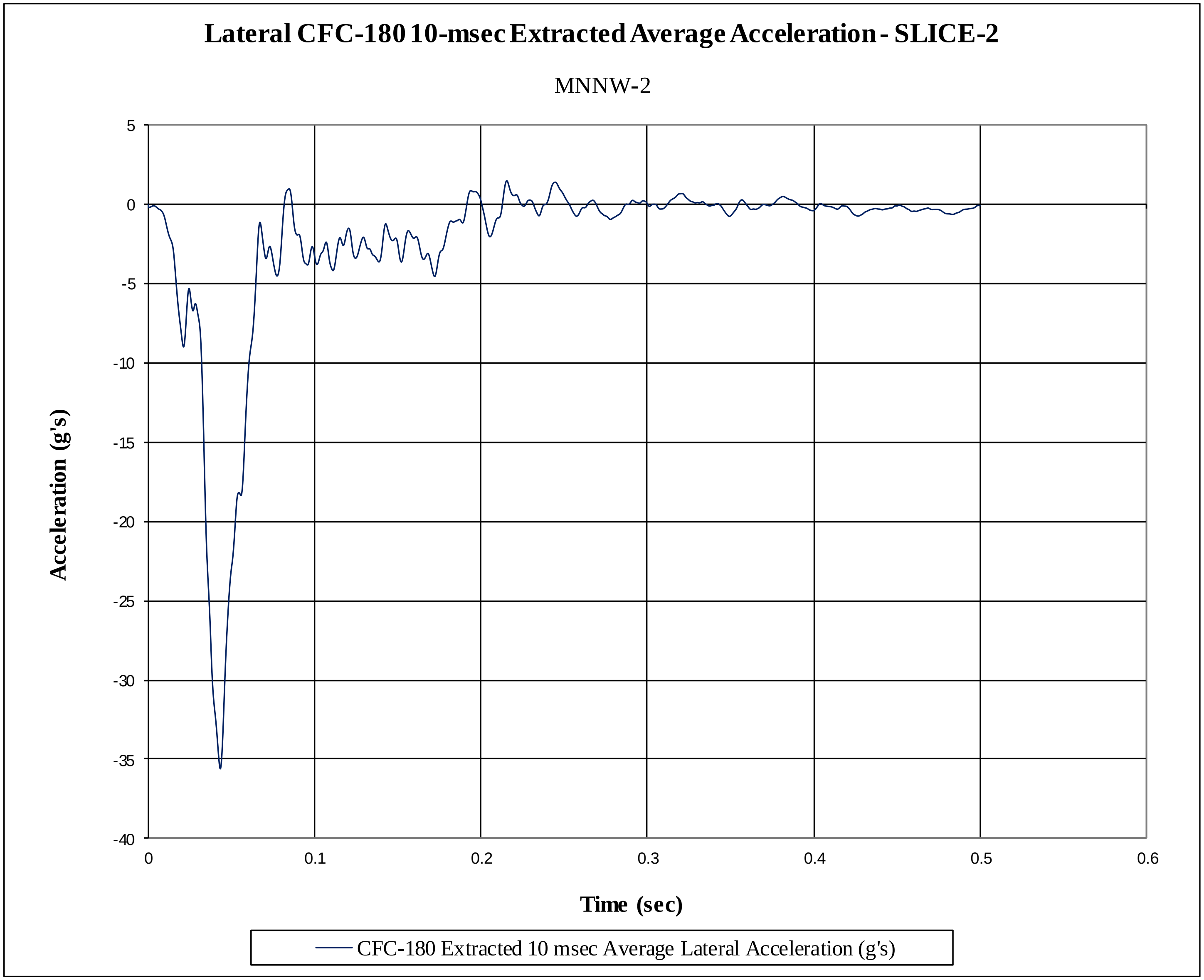


Figure G-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MNNW-2

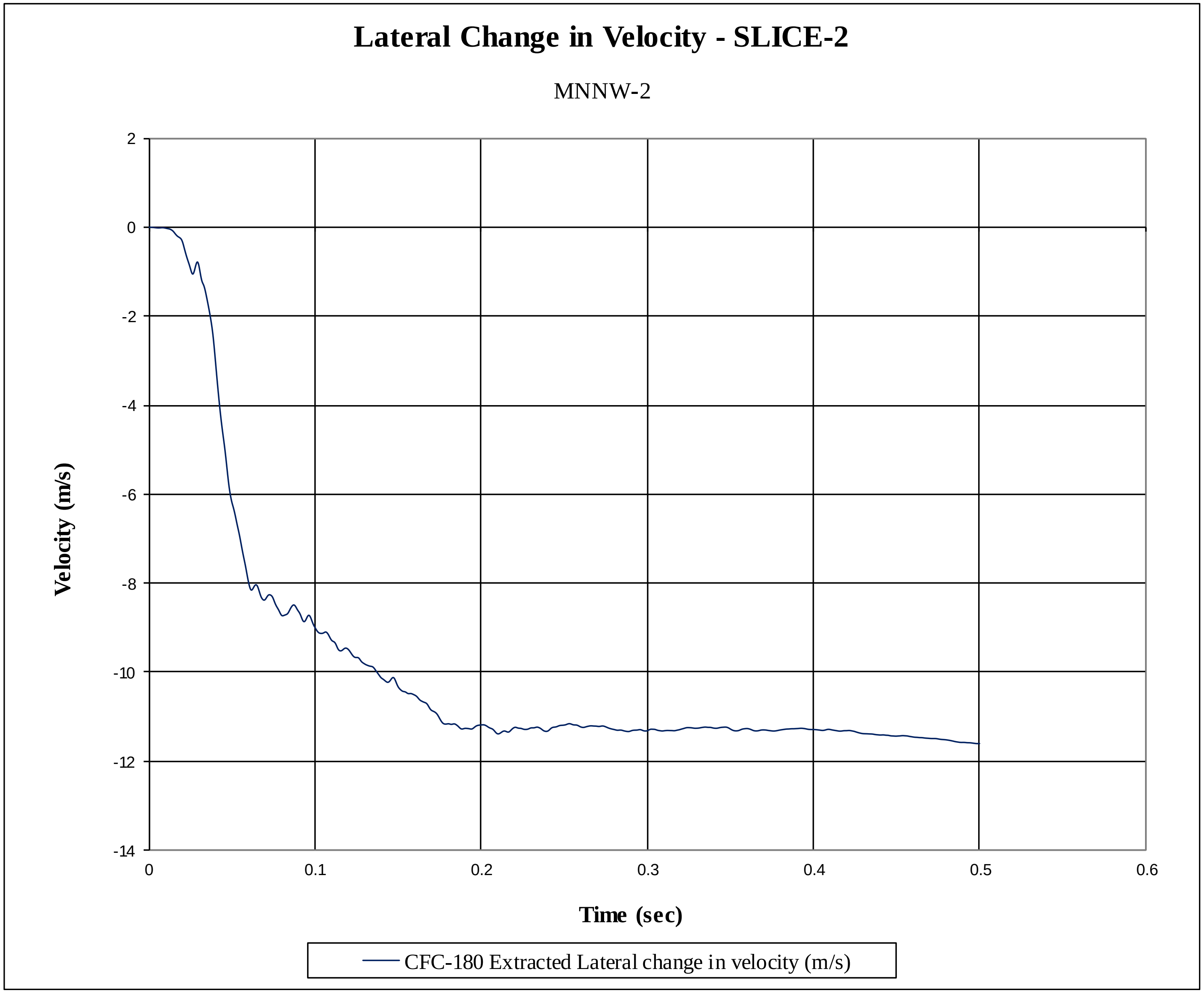


Figure G-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MNNW-2

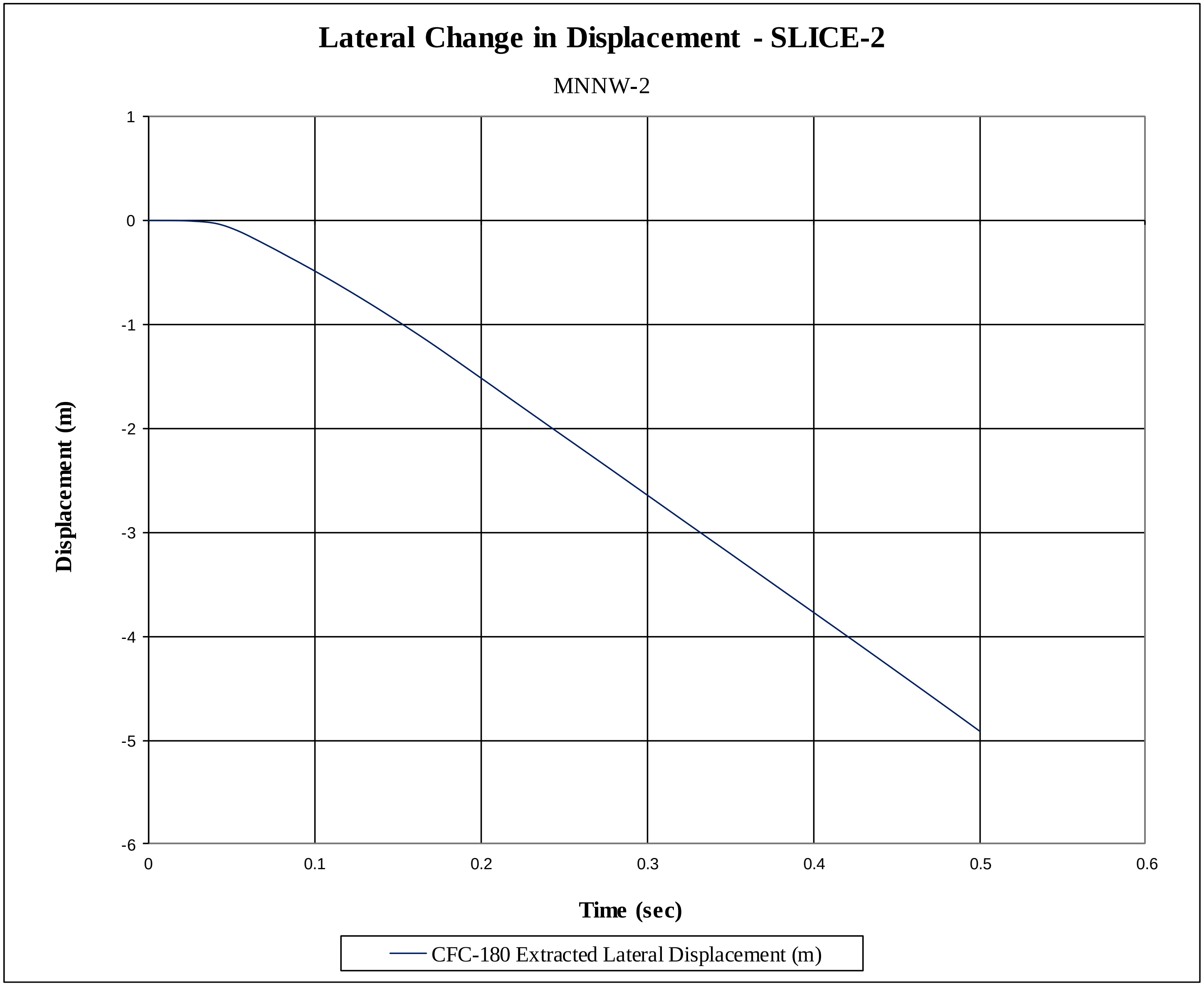


Figure G-14. Lateral Occupant Displacement (SLICE-2), Test No. MNNW-2

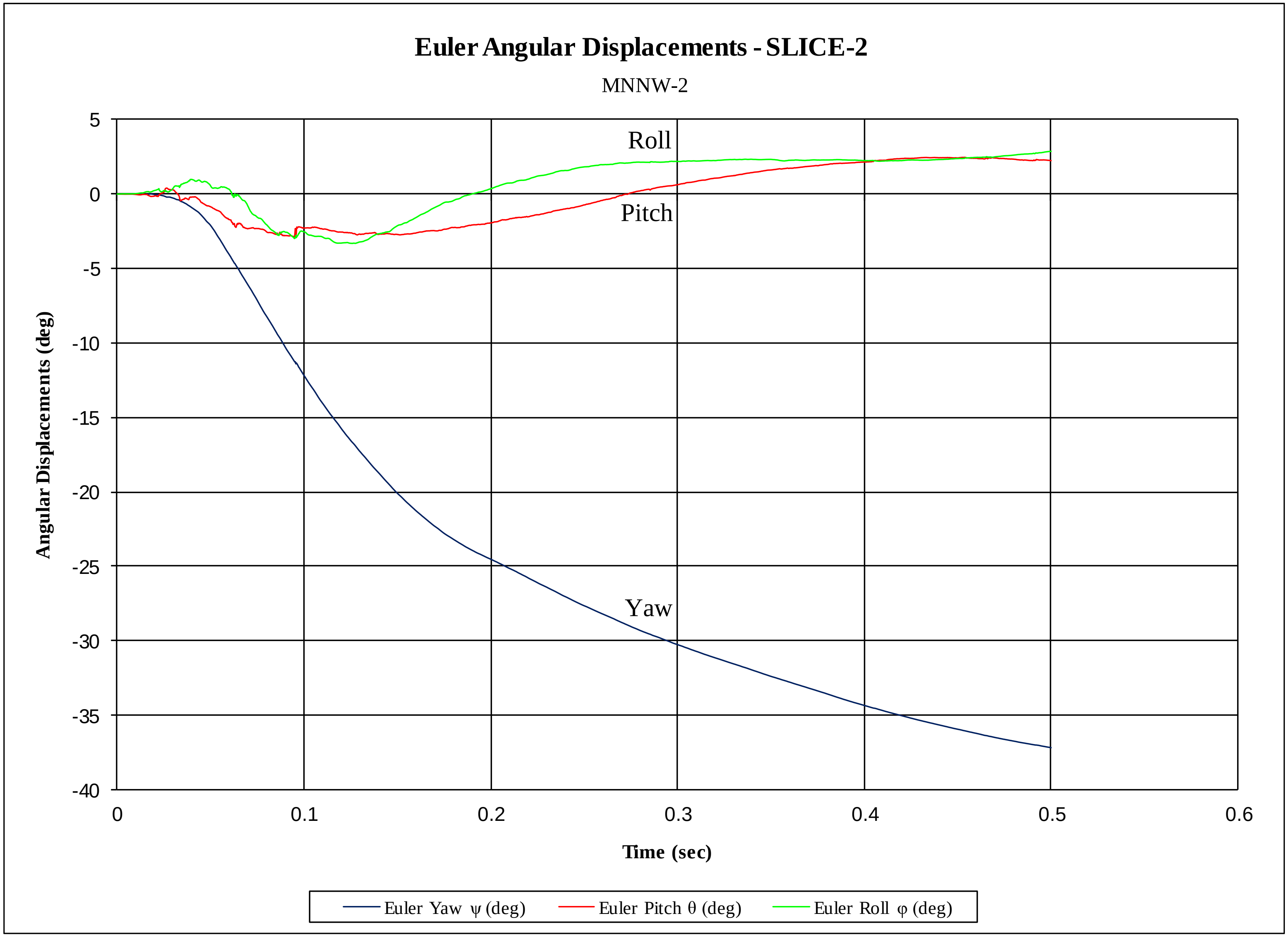


Figure G-15. Vehicle Angular Displacements (SLICE-2), Test No. MNNW-2

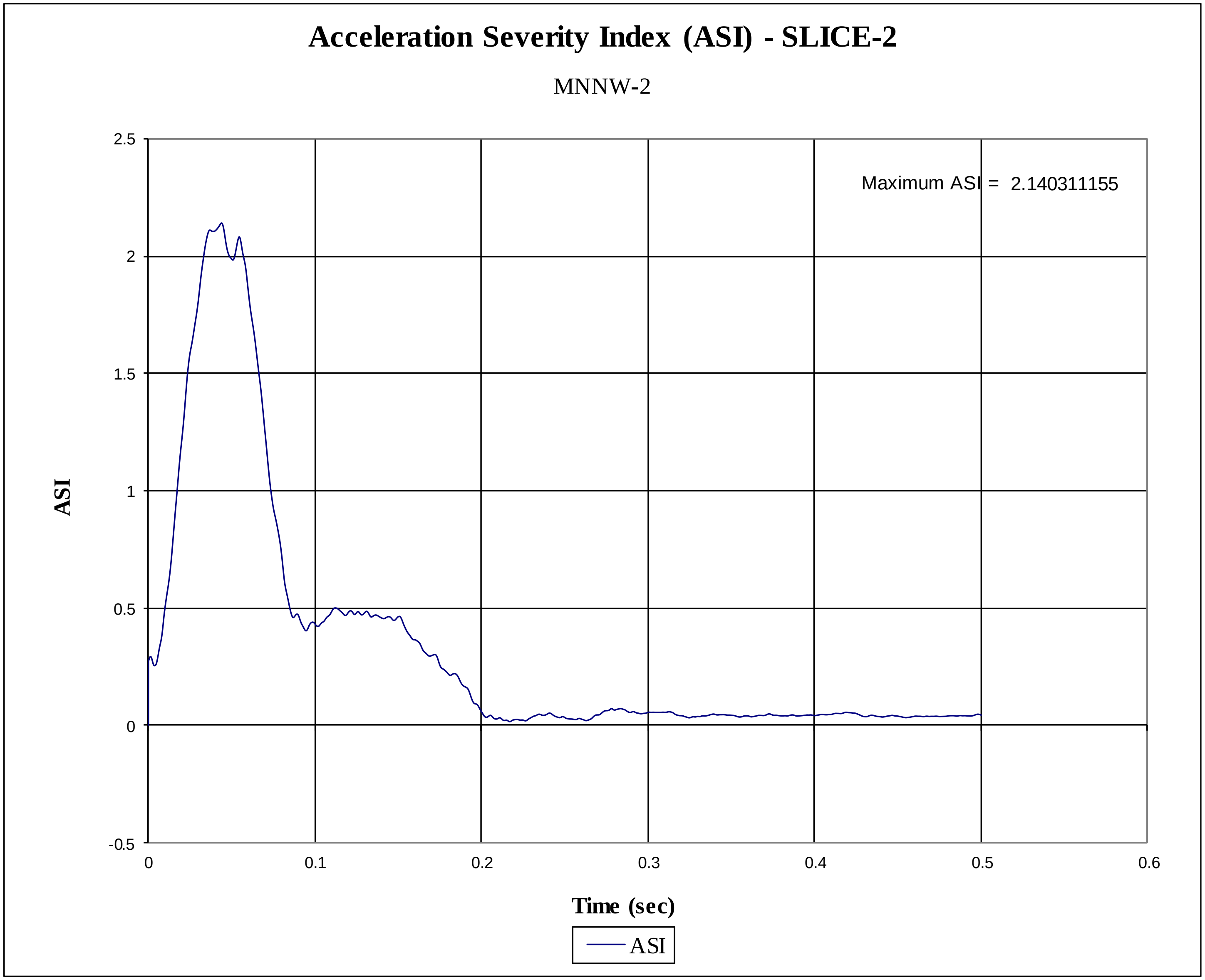


Figure G-16. Acceleration Severity Index (SLICE-2), Test No. MNNW-2

Appendix H. Accelerometer and Rate Transducer Data Plots, Test No. MNNW-3

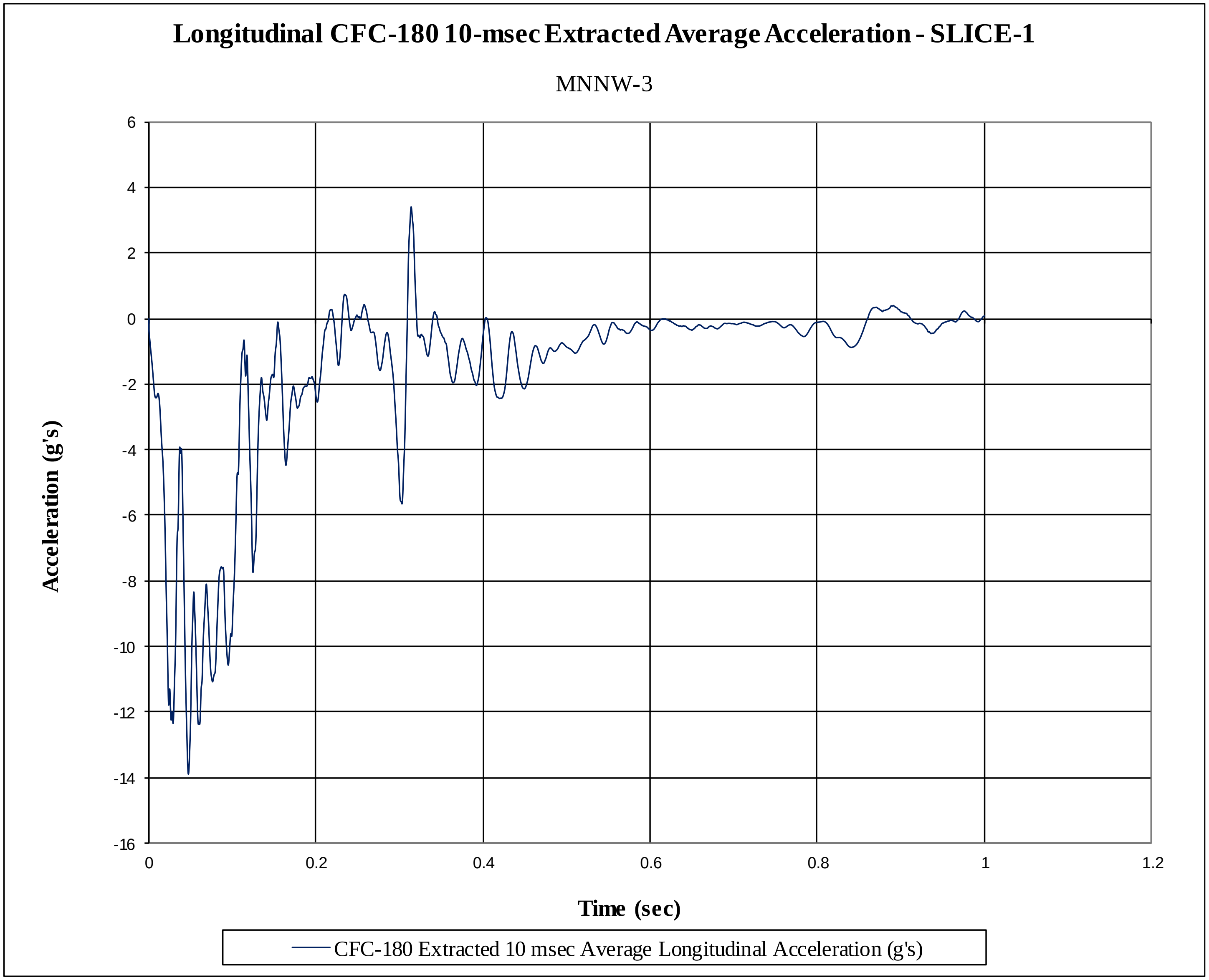


Figure H-1. 10-ms Average Longitudinal Deceleration (SLICE-1), Test No. MNNW-3

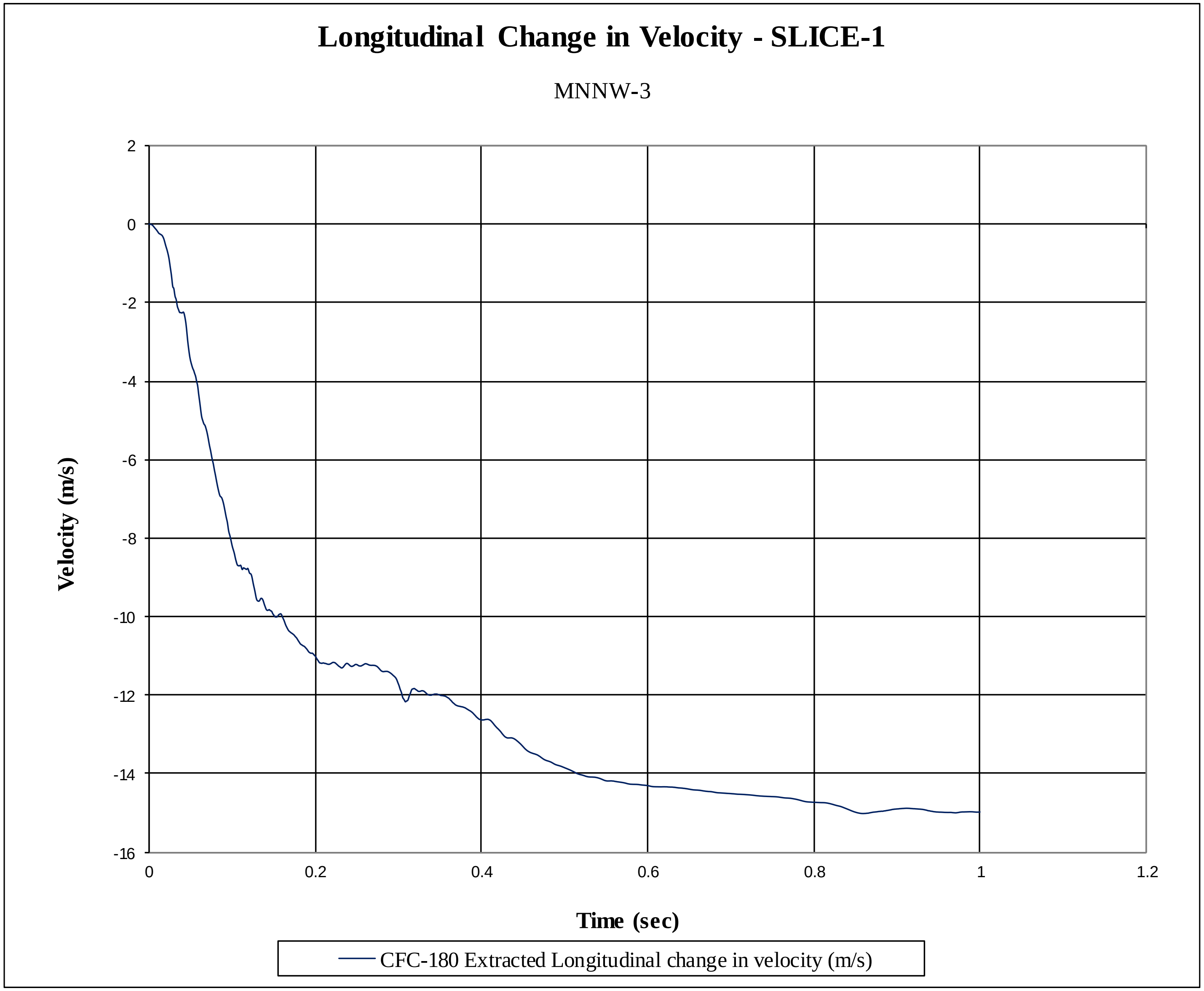


Figure H-2. Longitudinal Occupant Impact Velocity (SLICE-1), Test No. MNNW-3

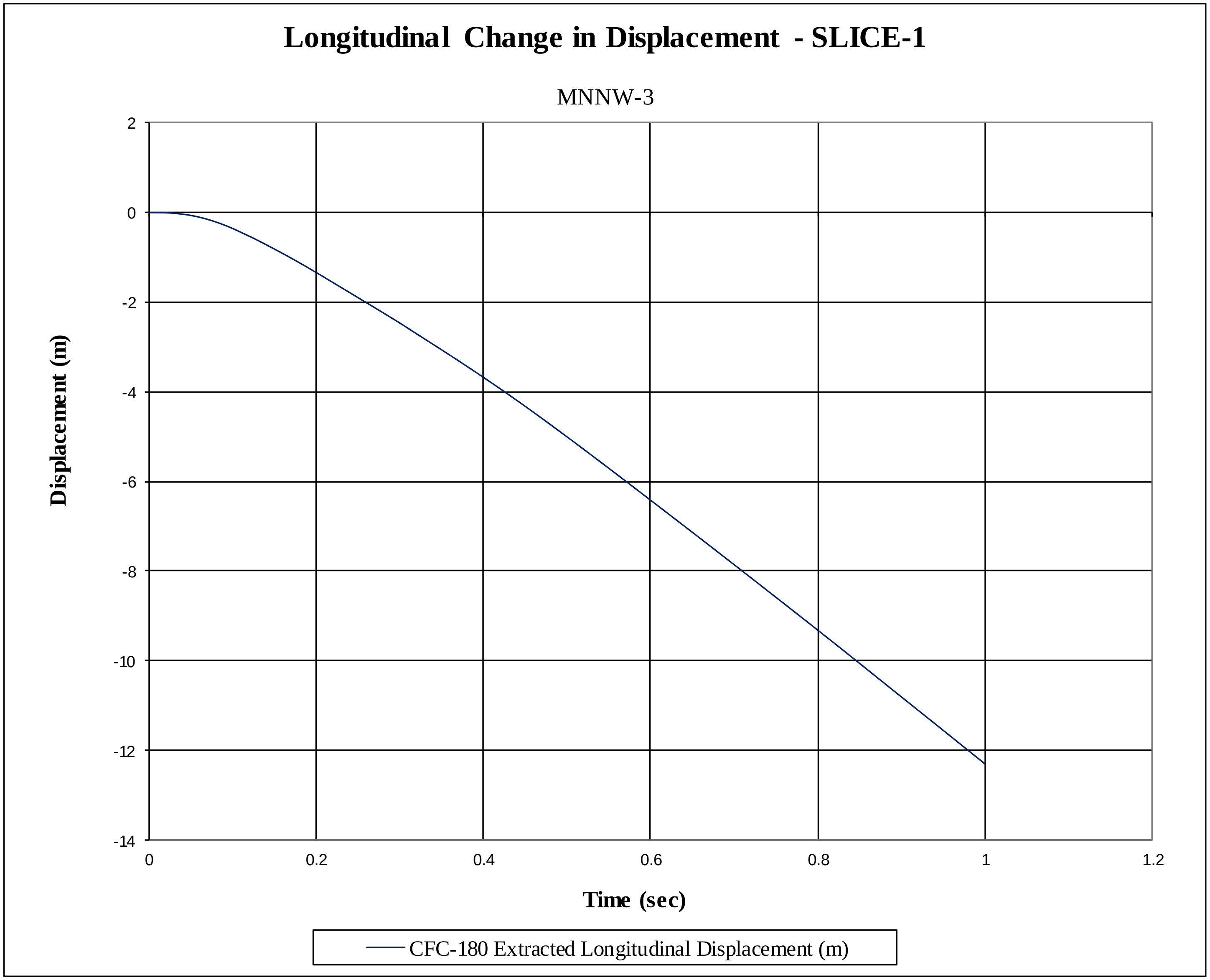


Figure H-3. Longitudinal Occupant Displacement (SLICE-1), Test No. MNNW-3

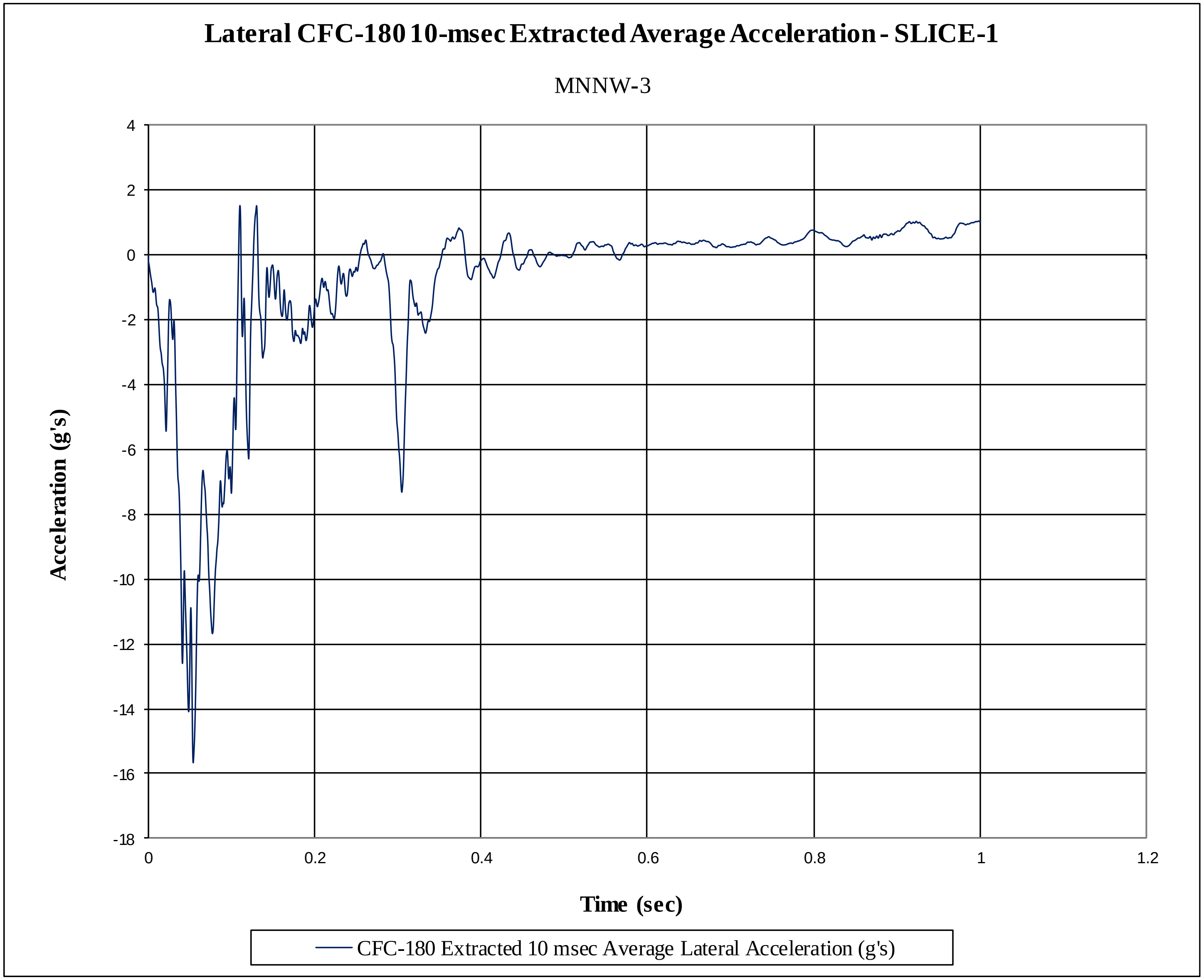


Figure H-4. 10-ms Average Lateral Deceleration (SLICE-1), Test No. MNNW-3

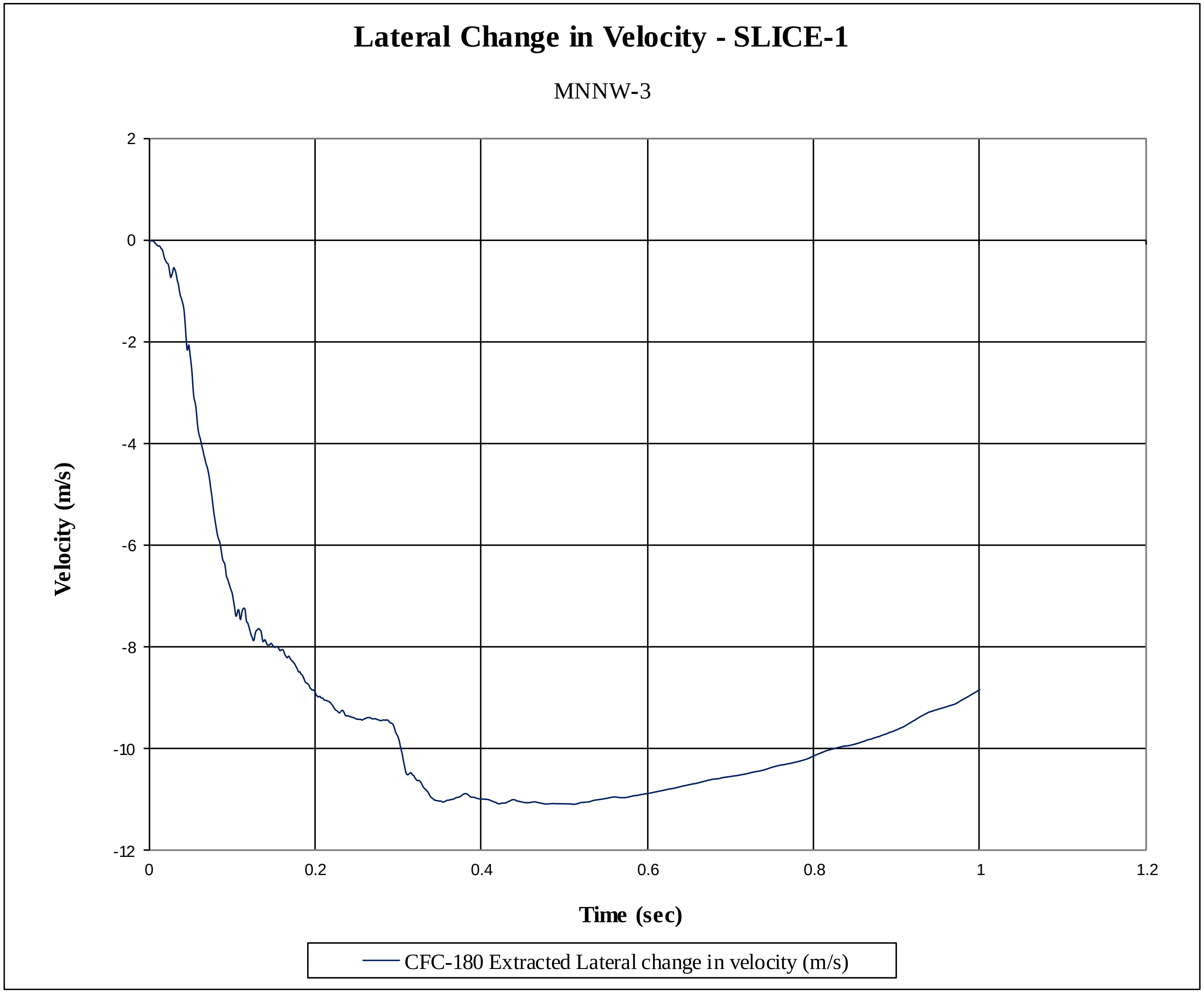


Figure H-5. Lateral Occupant Impact Velocity (SLICE-1), Test No. MNNW-3

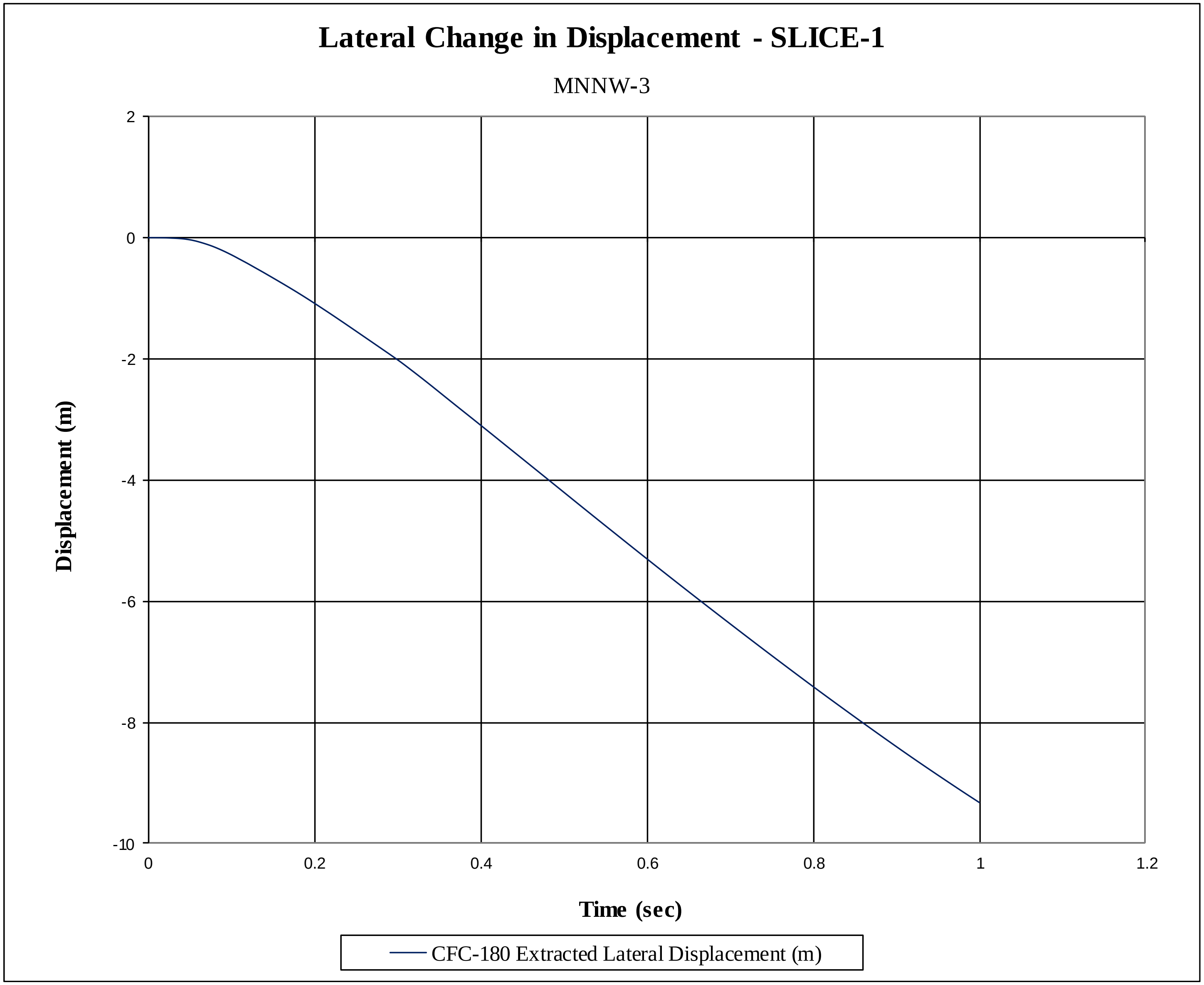


Figure H-6. Lateral Occupant Displacement (SLICE-1), Test No. MNNW-3

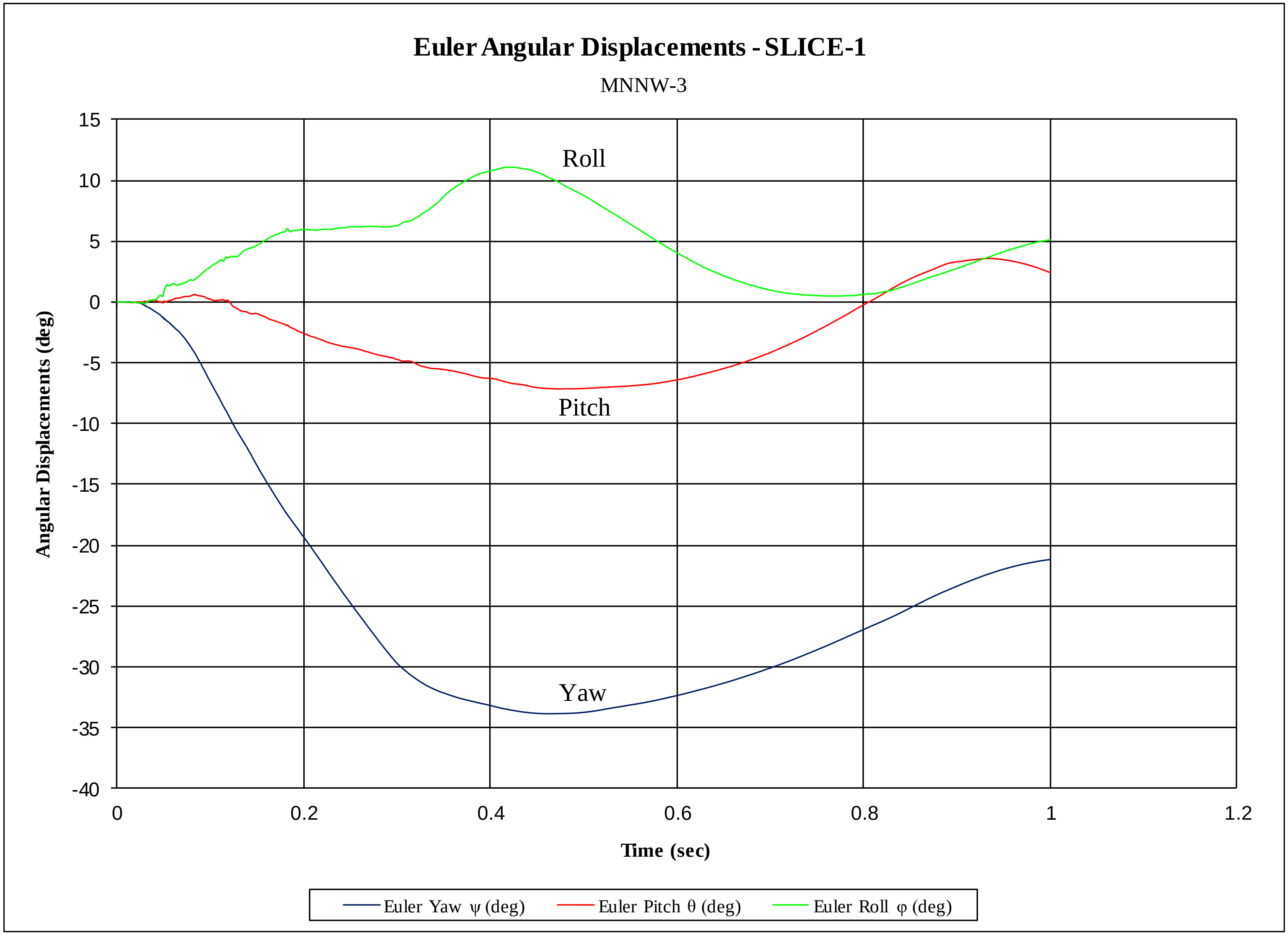


Figure H-7. Vehicle Angular Displacements (SLICE-1), Test No. MNNW-3

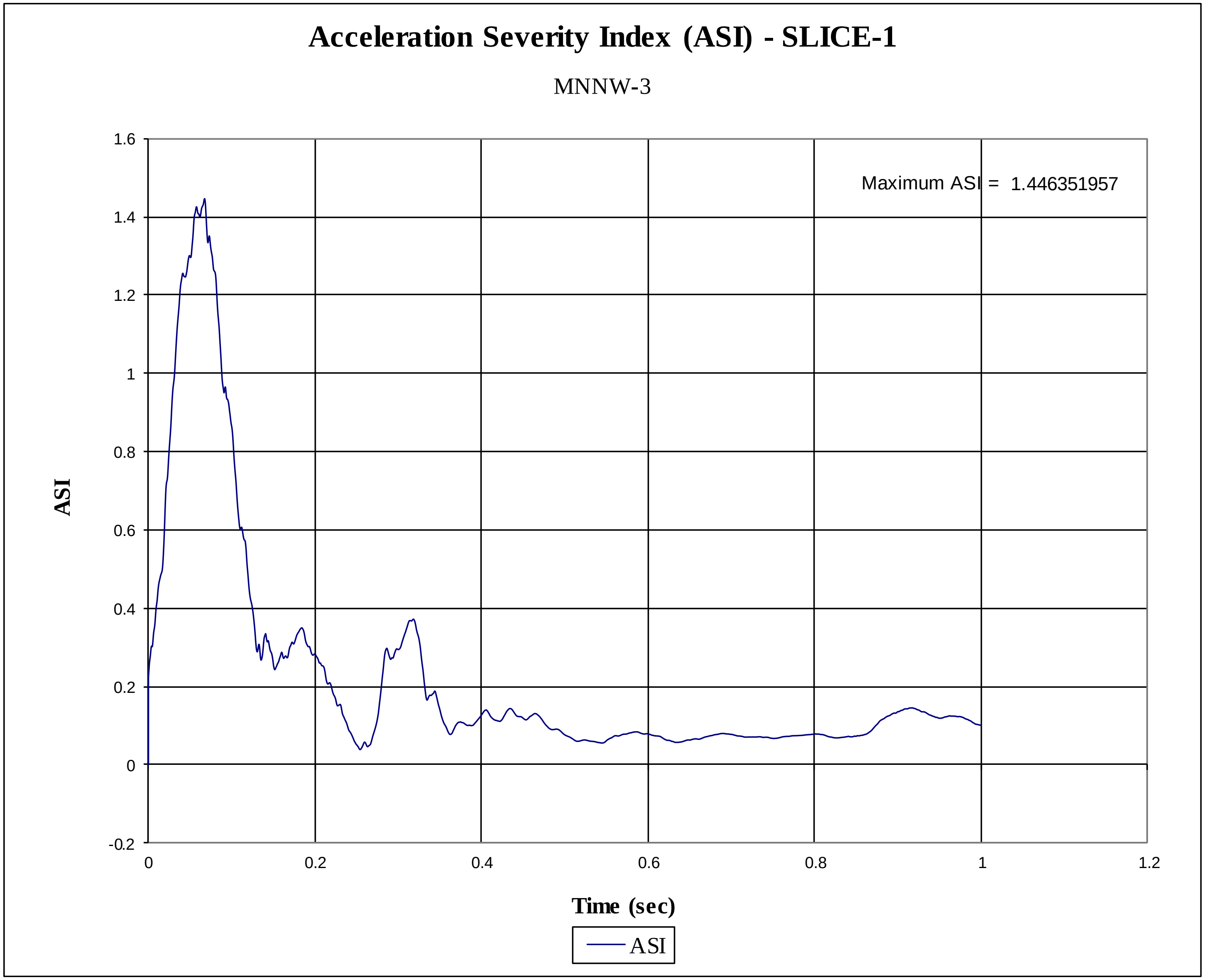


Figure H-8. Acceleration Severity Index (SLICE-1), Test No. MNNW-3

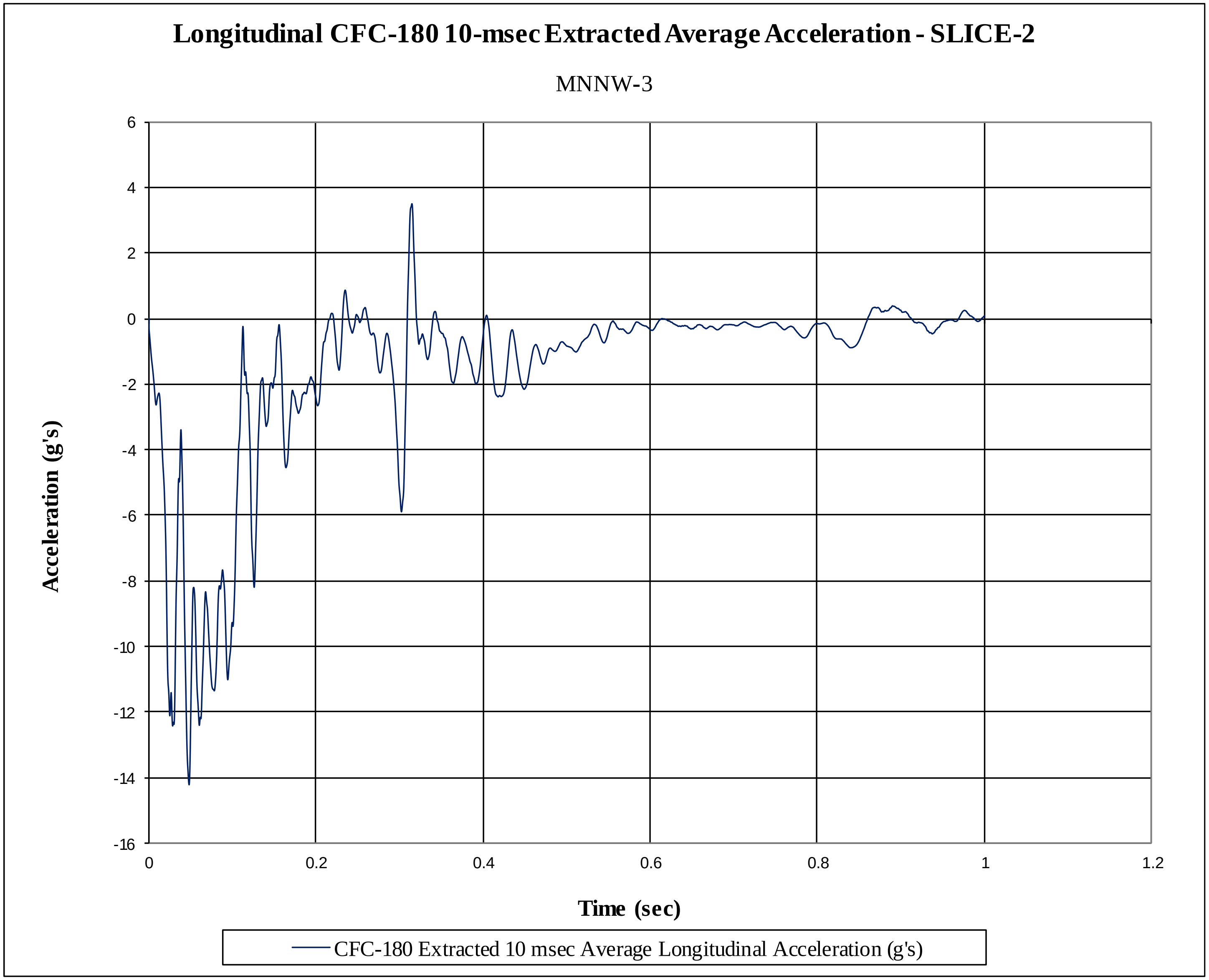


Figure H-9. 10-ms Average Longitudinal Deceleration (SLICE-2), Test No. MNNW-3

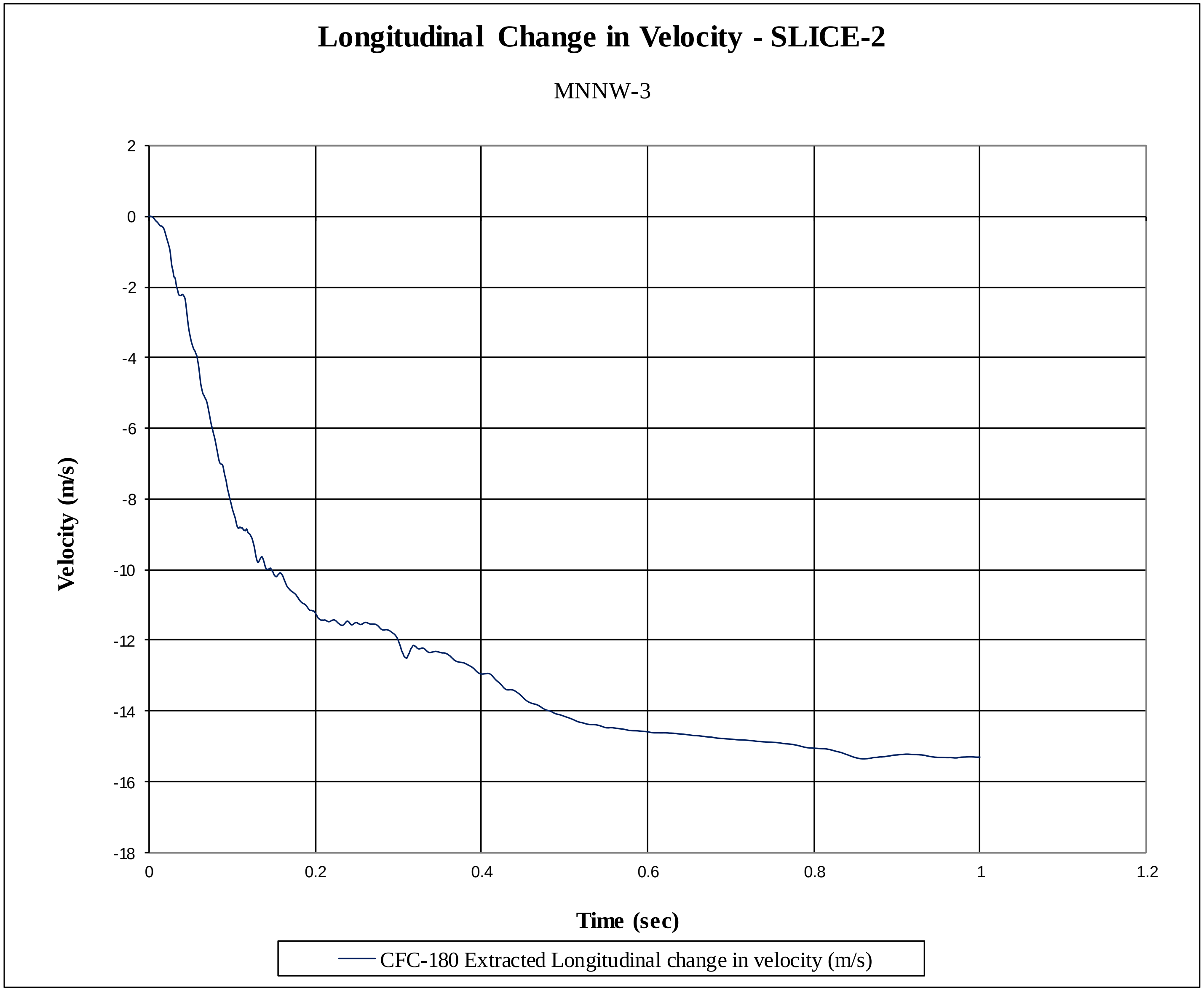


Figure H-10. Longitudinal Occupant Impact Velocity (SLICE-2), Test No. MNNW-3

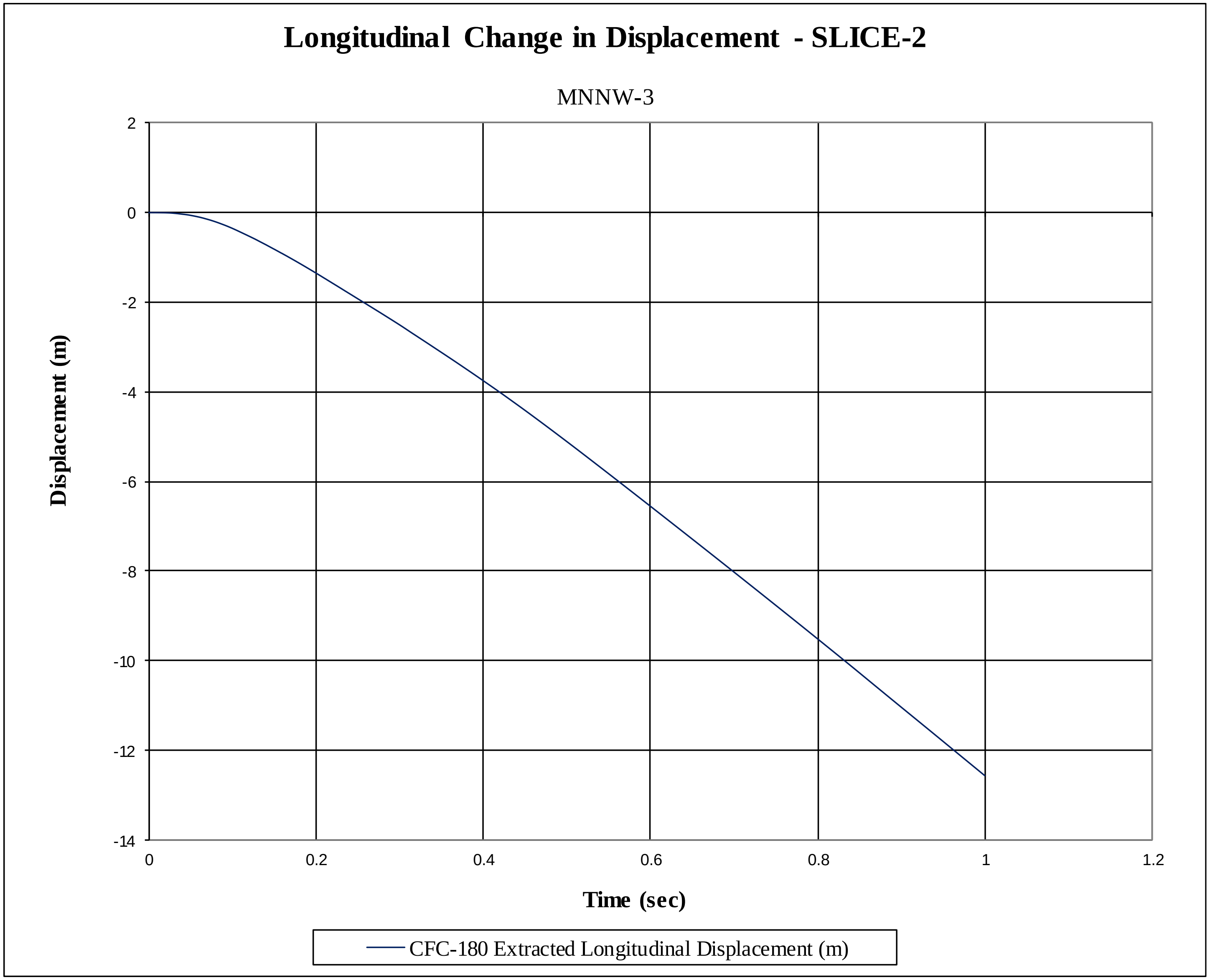


Figure H-11. Longitudinal Occupant Displacement (SLICE-2), Test No. MNNW-3

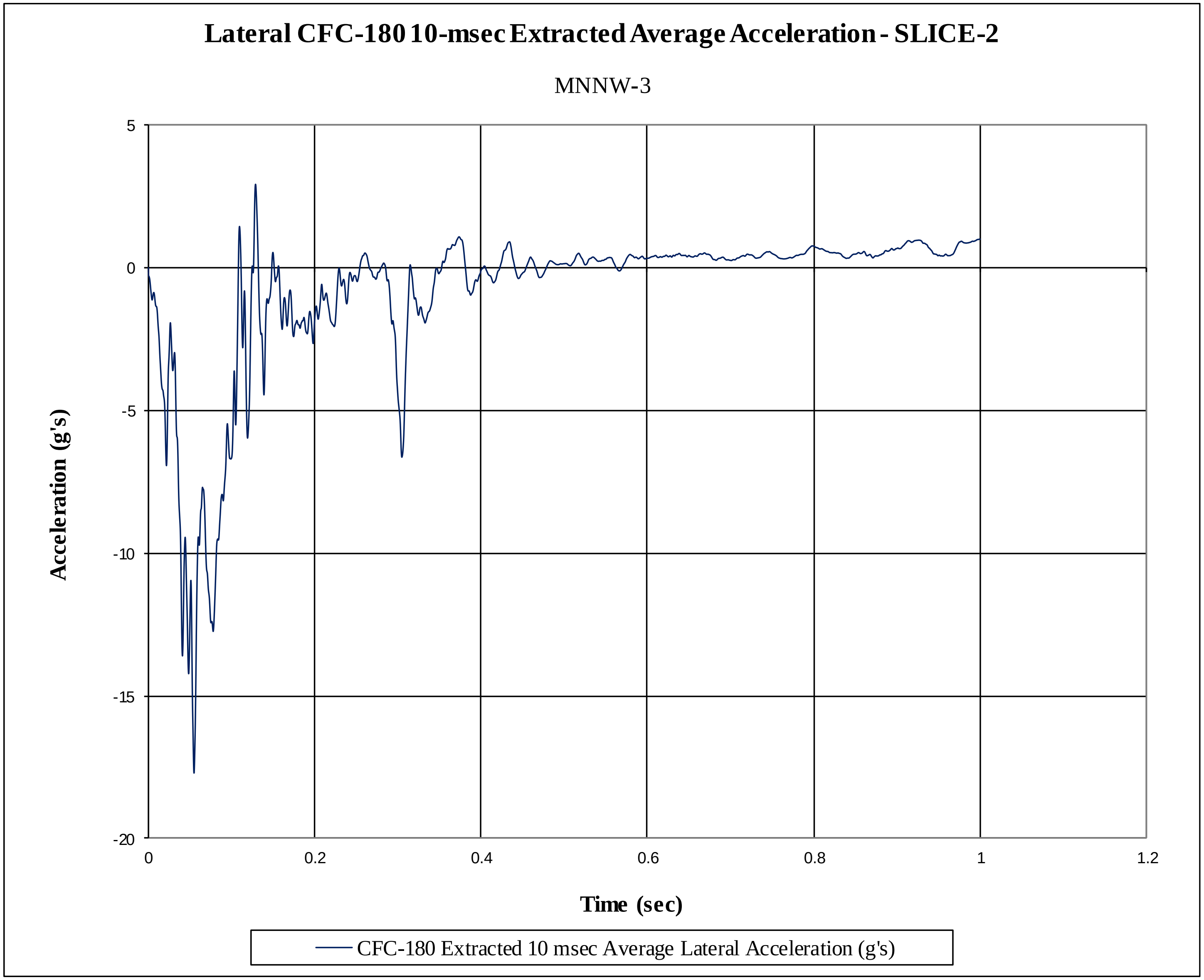


Figure H-12. 10-ms Average Lateral Deceleration (SLICE-2), Test No. MNNW-3

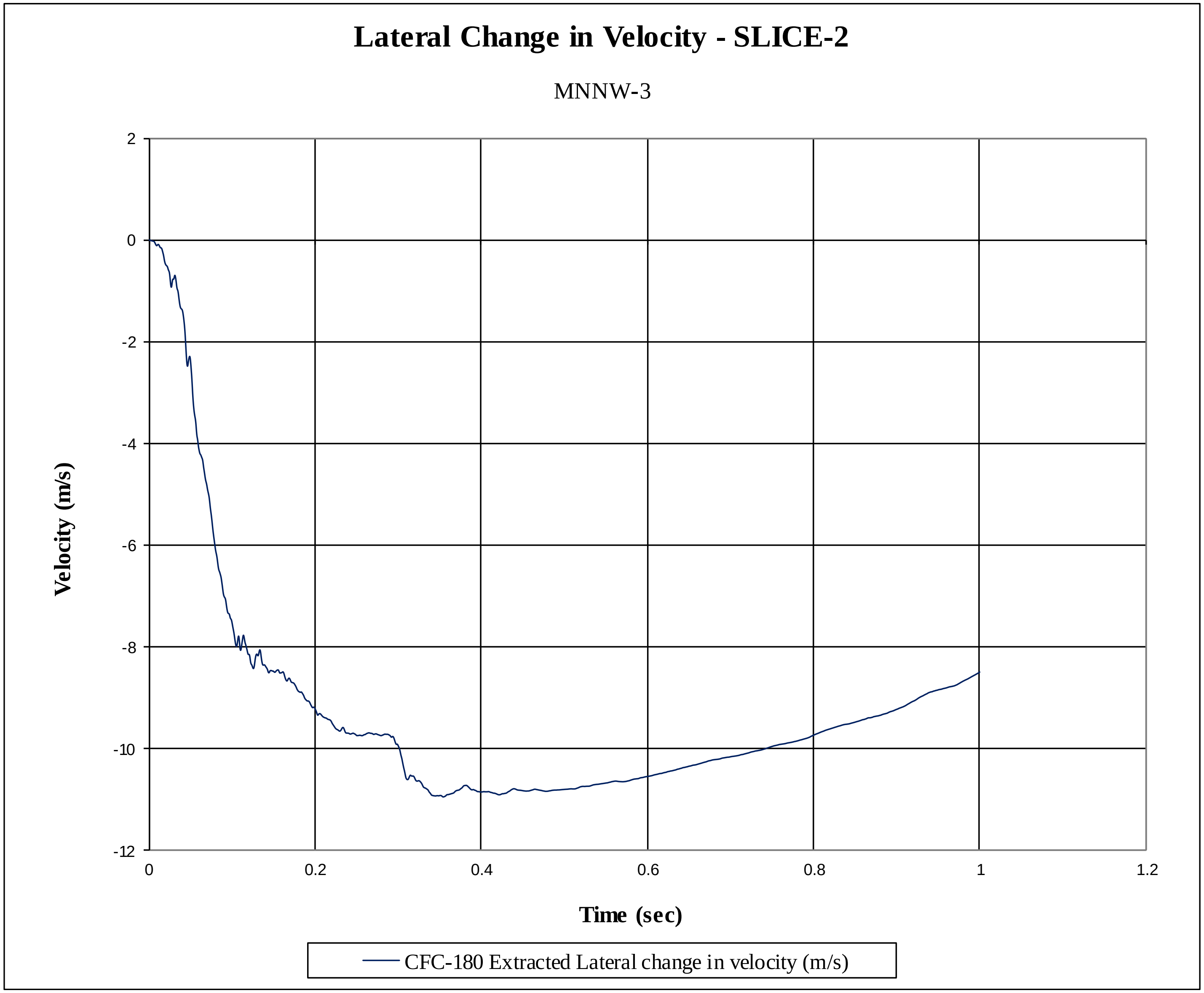


Figure H-13. Lateral Occupant Impact Velocity (SLICE-2), Test No. MNNW-3

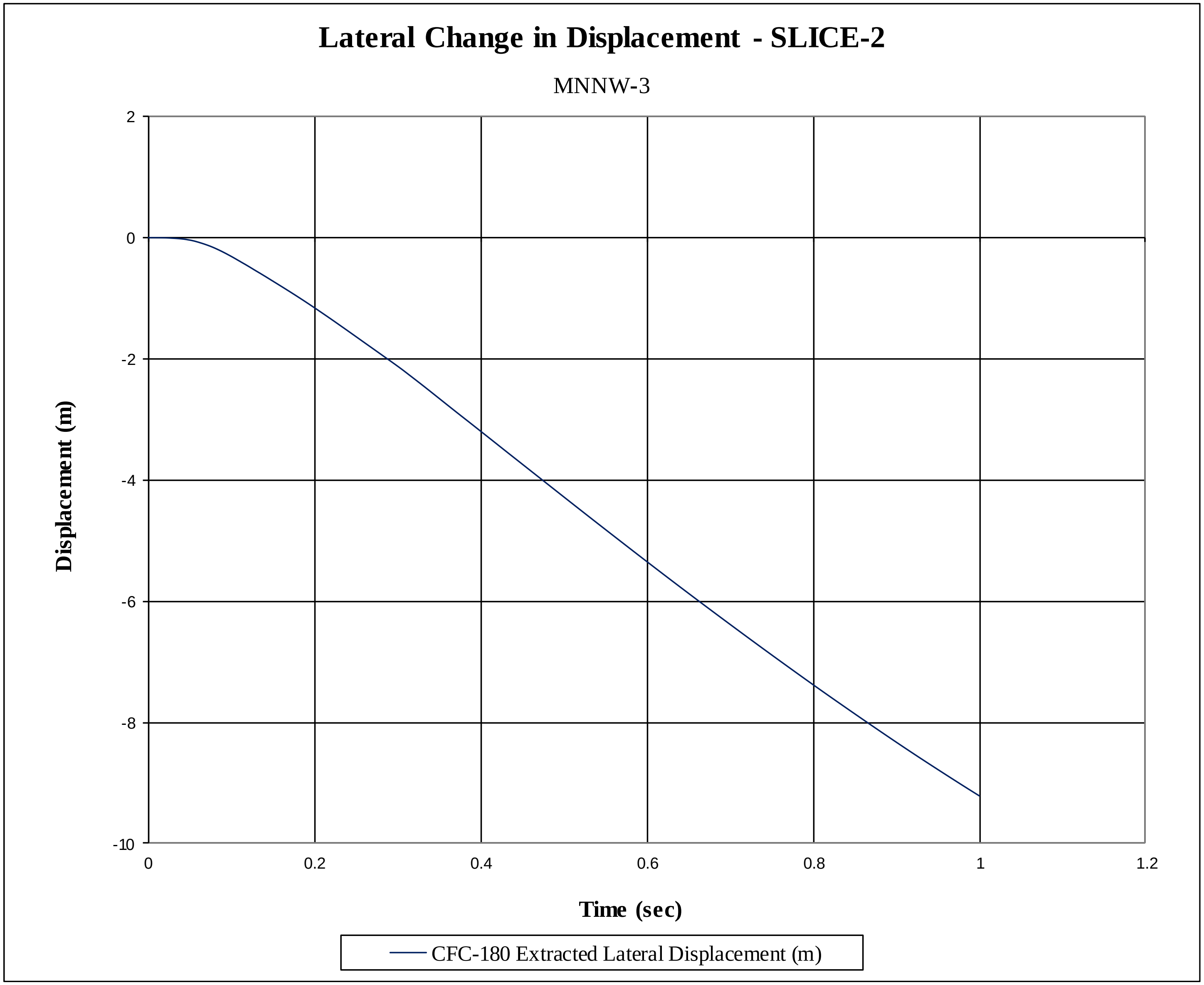


Figure H-14. Lateral Occupant Displacement (SLICE-2), Test No. MNNW-3

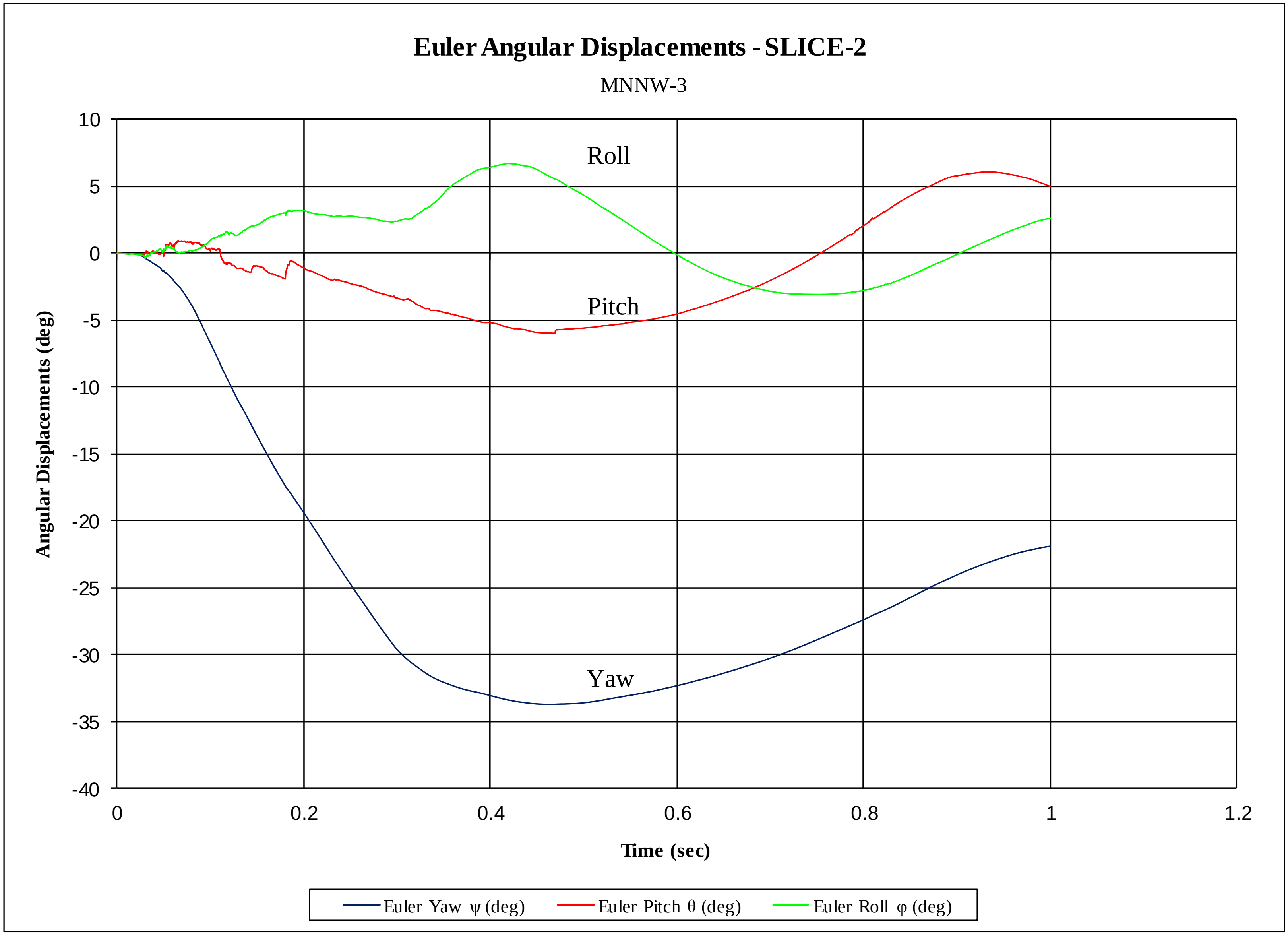


Figure H-15. Vehicle Angular Displacements (SLICE-2), Test No. MNNW-3

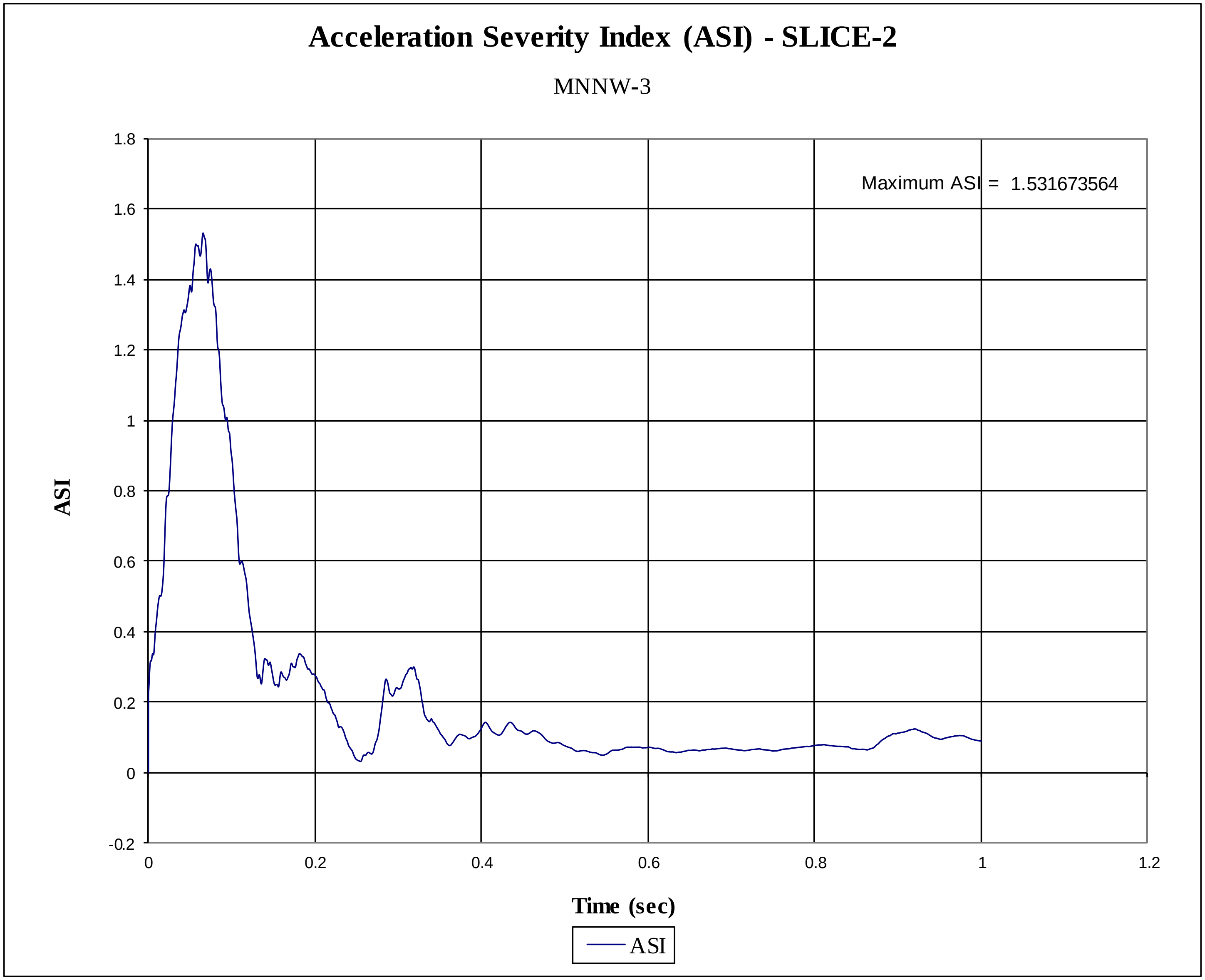


Figure H-16. Acceleration Severity Index (SLICE-2), Test No. MNNW-3

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