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DEVELOPMENT AND TESTING OF A BRIDGE RAIL FOR LOW-VOLUME ROADS

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16. Abstract

A new steel bridge rail was developed for use on low-volume bridges. The railing consisted 31-in. tall, 12-gauge W-beam guardrail mounted on S3x5.7 posts, which were supported by steel square-tube sockets attached to the side of the bridge deck. The sockets were to be attached to the steel C-channel that is typically placed along the edges of rural bridge decks in the state of Nebraska. The bridge railing was developed for use on both 7-in. thick cast in place decks and 12-in. thick pre-stressed concrete beam slabs.

Various welded and bolted socket-to-channel attachment designs were evaluated through dynamic bogie testing on both deck types. Posts were impacted both laterally and longitudinally to evaluate the strength of the attachments and the potential for deck damage during vehicle impacts. Upon reviewing the bogie testing results, the project sponsor selected the bolted attachment using embedded coupling nuts and threaded rods as the desired attachment design for full-scale testing.

Full-scale crash testing was conducted according to test designation no. 2-11 of the American Association of State Highway Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware (MASH 2016)*. The 2270P vehicle impacted the bridge rail at 25.5 degrees and 44.2 mph and was successfully contained and redirected. Damage to the bridge rail consisted of bent posts and deformed guardrail. No damage to the deck or sockets was observed. Thus, the tests passed all evaluation criteria of MASH 2016 test designation no. 2-11. The new railing was deemed MASH TL-2 crashworthy with a post spacing of 75 in. and MASH TL-3 crashworthy with a post spacing of 37.5 in. BARRIER VII simulations showed that the new railing could be directly connected to the Midwest Guardrail System (MGS) without a transition. Guidance was provided pertaining to the length of guardrail required adjacent to the bridge rail.

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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. Test nos. N2B-1 through N2B-6 were non-certified component tests conducted for research and development purposes only and are outside the scope of the MwRSF's A2LA Accreditation.

INDEPENDENT APPROVING AUTHORITY

The Independent Approving Authority for the data contained herein was Dr. Jennifer Rasmussen, Research Associate Professor.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

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

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in.
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yard	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliter	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or “metric ton”)	1.103	short ton (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela per square meter	0.2919	foot-Lamberts	fl
		FORCE & PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

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1 INTRODUCTION

1.1 Problem Statement

In 2016, the Nebraska State Legislature passed bill LB960 to adopt the Transportation Innovation Act. A portion of this act created a voluntary county bridge match assistance program intended to aid Nebraska counties in replacing deteriorated bridges. This program was targeted for the numerous bridges located on rural, low-volume roadways that needed immediate attention. With the replacement of these bridges, new bridge rails and approach guardrail systems were also necessary to ensure the safety of the motoring public.

Due to the large number of deficient bridges slated for replacement, these new bridges needed to be constructed in a timely and cost-efficient manner. It was also desired that the associated bridge railings be optimized to minimize costs while satisfying current safety standards. Additionally, side-mounted bridge rails were desired to maximize the traversable width of the bridge, and the bridge railings needed to prevent damage to the deck during an impact event to prevent costly repairs. For convenience, one bridge rail design was desired to treat all future installation sites for these rural bridges. Due to the low traffic volume associated with these bridges (50 – 500 average daily traffic (ADT)), a bridge railing that satisfied the Test Level 2 (TL-2) performance criteria of the 2016 edition of the *Manual for Assessing Safety Hardware* (MASH 2016) [1] was warranted rather than using more expensive TL-3 systems typically used on higher-speed, higher-volume roadways. Thus, a new MASH 2016 TL-2 bridge rail was desired to provide an economical treatment for rural, low volume roads.

1.2 Background

National Cooperative Highway Research Program (NCHRP) project 22-12(03) recently provided guidelines for the selection of bridge rails based on roadway characteristics such as traffic volume, percentage of heavy trucks, speed, lane width, curvature, and perceived risk of a railing failure [2]. In general terms, it was found that a TL-2 system would be warranted for nearly all roadways with a traffic volume less than 1,000 vehicles per day due to the low risk of vehicle encroachment. TL-1 barriers were not considered in the NCHRP analysis. However, the cost difference between a TL-1 and a TL-2 system is often minimal. Thus, bridges located on rural, low-volume roadways would likely warrant a TL-2 bridge railing.

Two W-beam bridge rails have previously been designed for use on low volume roads that satisfy MASH TL-2 and TL-3 safety standards. Both systems utilized a 31-in. tall W-beam rail supported by S3x5.7 weak posts, thereby limiting both the loads transferred to the bridge deck and the associated risk for deck damage. The first system, the Midwest Guardrail System (MGS) Bridge Rail, was a MASH TL-3 side-mounted system that was supported by steel sockets placed adjacent to the side of the deck [3], as shown in Figure 1. The system utilized a 37.5-in. post spacing, and the sockets were attached to the bridge deck with a 1-in. diameter bolt that went through the thickness of the deck. A steel angle was mounted below the deck to provide additional length for the force couple which resisted post bending. The system was full-scale crash tested according to MASH test designation nos. 3-10 and 3-11 with a small car and pickup truck, respectively.

Figure 1. MGS Bridge Rail Test Installation [3]

Texas Department of Transportation's (TxDOT) T631 bridge rail was mounted to the top of the bridge deck with a ⅝-in. thick base plate bolted to the top of the bridge deck with four ⅝-in. diameter bolts [4-5], as shown in Figure 2. The posts were welded to the base plates with continuous ¼-in. thick fillet welds. The system satisfied MASH TL-2 criteria and was successfully tested under MASH test designation nos. 2-10 and 2-11 with a 75-in. post spacing. A modified version of the system with a 37.5-in. post spacing was also crash tested and satisfied MASH TL-3 criteria. MASH test designation no. 3-11 was conducted on the system with a 75-in. post spacing, but the test resulted in failure due to rail tearing. Thus, the 75-in. post spacing is only crashworthy at MASH TL-2.

Figure 2. TxDOT T631 Test Installation [4-5]

These existing systems required attachment hardware on the top surface of the bridge deck. However, it was believed that a similar system could be developed with the posts and attachment hardware only on the side of the deck, such that the top surface of the deck remained clear of obstructions.

1.3 Objective

The research objectives for this project included the development and full-scale crash testing of a TL-2 bridge railing for use on rural, low-volume roadways. The bridge railing was to be compatible with both 7-in. thick cast-in-place (CIP) decks and 12-in. thick precast beam slabs, and the system needed to limit damage to the bridge deck during impact events. A railing incorporating side-mounted posts was desired to limit encroachment of the system over the bridge deck and maximize the traversable width of the bridge. A detailed analysis of the required length of need was required to identify the minimum length of the guardrail adjacent to the bridge and limit the total installation costs. All crash testing was to be conducted and reported according to the TL-2 safety requirements found in MASH 2016.

1.4 Scope

The development of the optimized MASH 2016 TL-2 bridge rail began with a literature review of previous crash-tested W-beam bridge rails evaluated according to MASH TL-2 and TL-3 were reviewed. The performance of various post attachment designs and anchorage to concrete bridge decks were a focus of this review.

Following this review, multiple design concepts were developed for attaching guardrail support posts to the concrete bridge decks. Efforts were made to mount the posts to the side of the bridge deck, leaving the top surface of the deck clear of any attachment hardware. Several design concepts were then selected for evaluation through dynamic component testing. Simulated bridge decks were constructed, and guardrail posts were mounted to the simulated deck utilizing the selected attachment designs. Each attachment design was subjected to both lateral and longitudinal impacts from a bogie vehicle to evaluate both the strong- and weak-axis performance of the post and anchorage assembly. Evaluations focused on both the strength of the post assembly as well as the damage imparted to the deck. Results from the dynamic bogie testing guided the selection of a bridge rail concept for further evaluation through full-scale crash testing in accordance with MASH TL-2 criteria.

Although MASH 2016 specifies two full-scale crash tests to satisfy TL-2 safety criteria, the greater mass of the 2270P pickup truck was expected to produce higher rail loads and system deflections than the 1100C small car. Additionally, two similar systems had previously been successfully crash tested with the 1100C vehicle, as discussed in Section 1.2. Therefore, test designation no. 2-10 with the small car was not considered critical, and only test designation no. 2-11 was conducted to evaluate the MASH TL-2 bridge rail.

In order to minimize the cost of barrier installations, the run-out-length of the guardrail adjacent to the bridge must also be optimized. After the bridge rail system was proven crashworthy to MASH TL-2, an analysis was conducted to evaluate whether a stiffness transition was necessary between the bridge rail and the adjacent roadside guardrail. Additionally, an analysis was conducted to calculate the minimum length of MGS required adjacent to the bridge railing based on anchorage requirements and guardrail terminal characteristics.

2 POST-TO-DECK CONNECTION DESIGNS

2.1 Deck Configurations

Historically, bridges on rural, low-volume roads in the state of Nebraska were built with CIP decks. However, the use of precast, prestressed beam slabs has become popular in recent years as they allow for rapid construction of the bridge. Thus, the Nebraska Department of Transportation (NDOT) desired the new bridge railing to be compatible with both deck types.

CIP decks in Nebraska are typically 7 to 8 in. thick and are reinforced with upper and lower steel rebar mats. These decks are supported by wide-flange steel girders, and the exterior girders are commonly placed directly below the edges of the deck. As such, there are no overhang or cantilevered portions of deck along the sides of the bridge. Steel channels are commonly placed along the edges of the deck. These channels are tack welded to the tops of the exterior girders and serve as formwork while pouring the deck. Additionally, the channels provided a steel surface along the edge of the deck where bridge rail posts could be welded onto the bridge. Rebar are welded to the inside face of the channel and tied to both the top and bottom steel mats to anchor the channels to the side of the deck. Example details from a typical CIP bridge deck are shown in Figure 3.

Through discussions with NDOT, a 7-in. thick deck reinforced with #4 lateral rebar at 6-in. spacings and #4 longitudinal rebar at 12-in. spacings in both the upper and lower steel mats was selected as a critical CIP deck for use in the development and evaluation of the new bridge railing. This configuration represented the thinnest CIP deck and utilized typical reinforcing steel. A C7x9.8 channel was selected for use along the deck edge as it was the weakest of the standard 7-in. C-channels.

Precast, pre-stressed, beam-slabs can be fabricated in a variety of sizes and configurations, but they have a minimum thickness of 12 in. and are typically around 3 ft to 4 ft wide. Similar to the CIP decks, steel channels are embedded into the sides of the precast beam-slabs to provide a steel surface for the attachment of bridge rail posts. However, since the channels are not needed as formwork, the side channels in beam-slab may be continuous along the edge or used intermittently only at post locations. Example details from a typical beam-slab bridge are shown in Figure 4, while pictures of short channel segments used in a recent bridge deck are shown in Figure 5. Through discussions with NDOT, a 12-in. thick beam-slab reinforced with #3 stirrups at 5-in. spacings, three #4 longitudinal rebar at the top, a combination of prestressing strands and rebar at the bottom, and a C12x20.7 side channel was selected as the critically small/weak beam-slab configuration for use in development and evaluation of the new bridge rail.

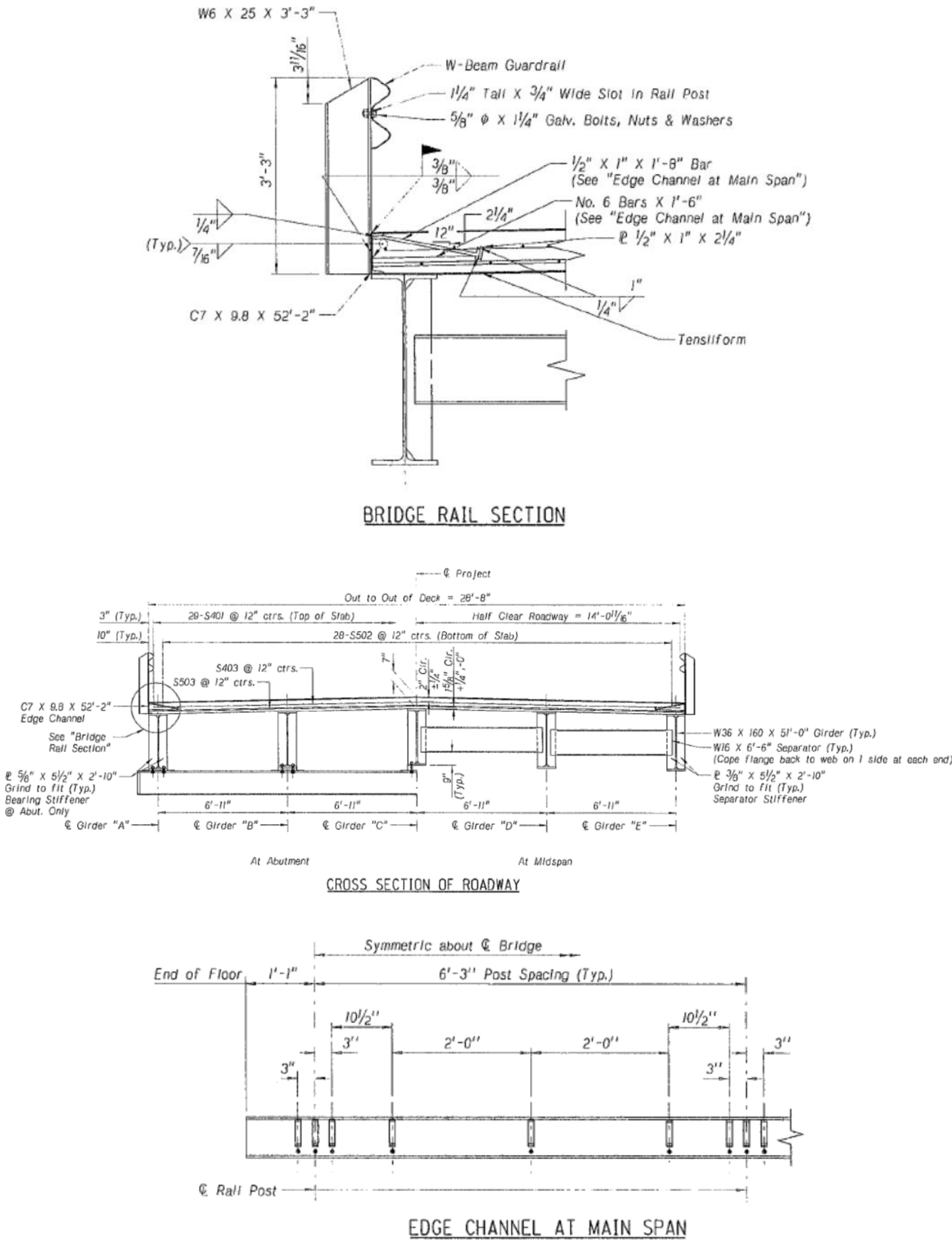


Figure 3. Example Details for 7-in. Thick CIP Deck

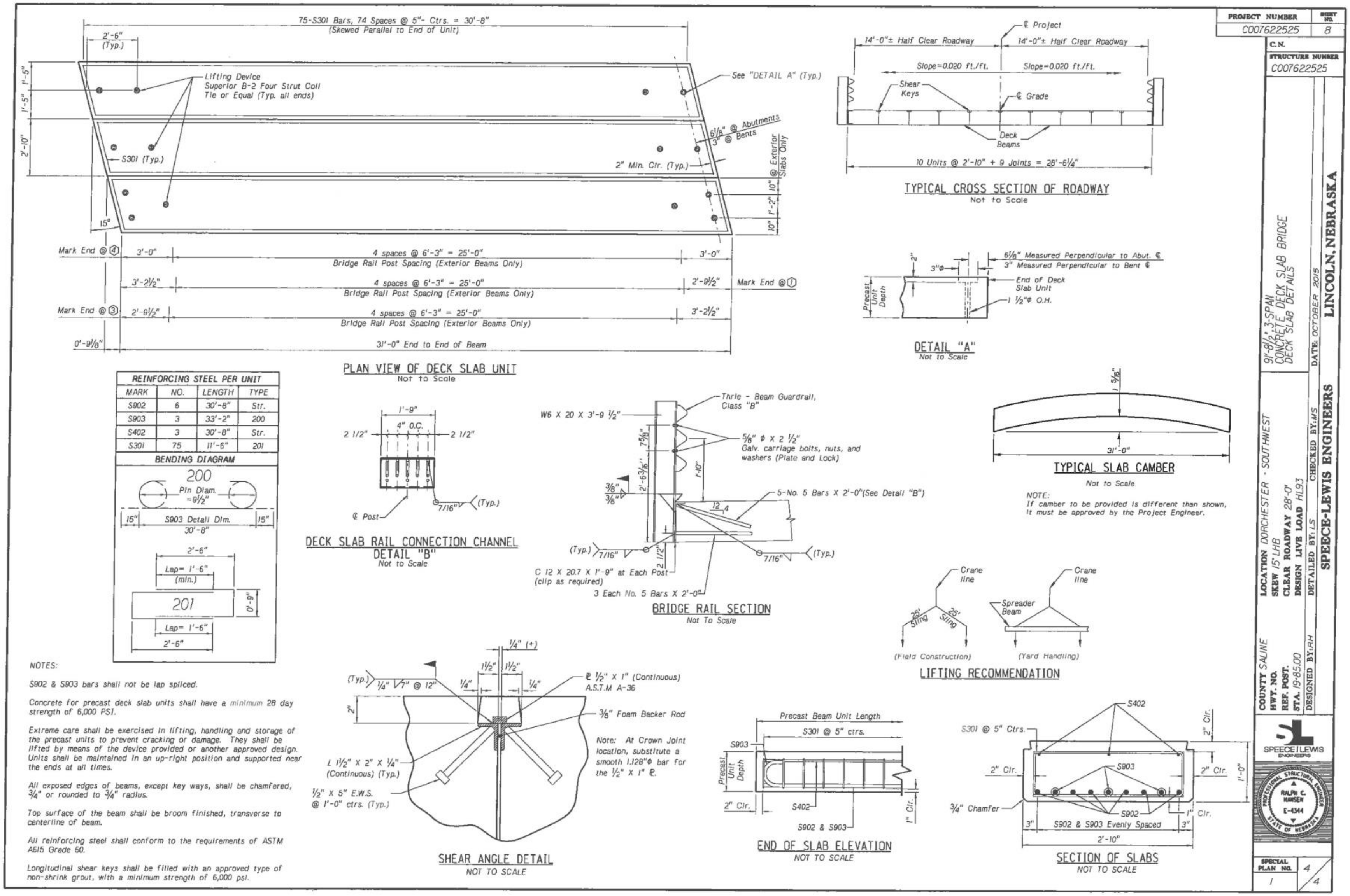


Figure 4. Example Details for 12-in. Thick Precast Beam-Slab Deck

Figure 5. Short Channel Segments Used Within a 12-in. Thick Beam-Slab Deck

2.2 Socket and Post Sections

It was desired for the new bridge rail to be a side-mounted, weak-post system with a socketed post-to-deck attachment. As such, the same steel post and socket sections used in the previously developed, MASH TL-3, MGS bridge rail were selected for use in the new system. The posts were S3x5.7 sections and the sockets consisted of HSS4x4x⅜ sections, as shown in Figure 6. The post standoffs, or shims, welded to the sides of the post within the socket were desired for use in the new bridge railing as well. These standoffs created a tighter fit for the post within the socket and prevented posts from leaning to the side. Additionally, the welded connections of the standoffs to the post create a stress concentrator that causes the post flanges to tear when a vehicle bumper impacts a post and bends it over longitudinally, as shown in Figure 7. With the flanges torn, a post will bend over easily and will not spring back upward to contact and potentially tear the vehicle floor pan, as observed in previous tests with S3x5.7 posts.

The socket assembly from the MGS bridge rail was to be reconfigured for use on the selected bridge decks. The only components that were to remain the same were the HSS square tube section and the keeper bolt that ran longitudinally through the center of the post's web to prevent the post from pulling out of the socket during impact events. In previous socketed systems utilizing S3x5.7 posts, like the MGS bridge rail and weak-post MGS attachments to concrete culverts [3, 6-7], the sockets extended 2 in. above the deck/ground surface. However, the CIP decks discussed in Section 2.1 are often poured with the paver running on top of the C-channel and extending off the edge of the deck. Thus, the top of the socket was desired to be slightly below the surface of the deck to prevent interference with this construction technique. Subsequently, all sockets designed and evaluated herein stopped ⅜ in. below the surface of the deck.

Two different socket-to-deck attachment methods were to be explored: (1) a welded attachment with the socket welded directly to the deck's side C-channel, and (2) a bolted attachment with the socket assembly bolted to the side of the deck. These attachment methods and their corresponding socket assemblies are discussed in the following sections.

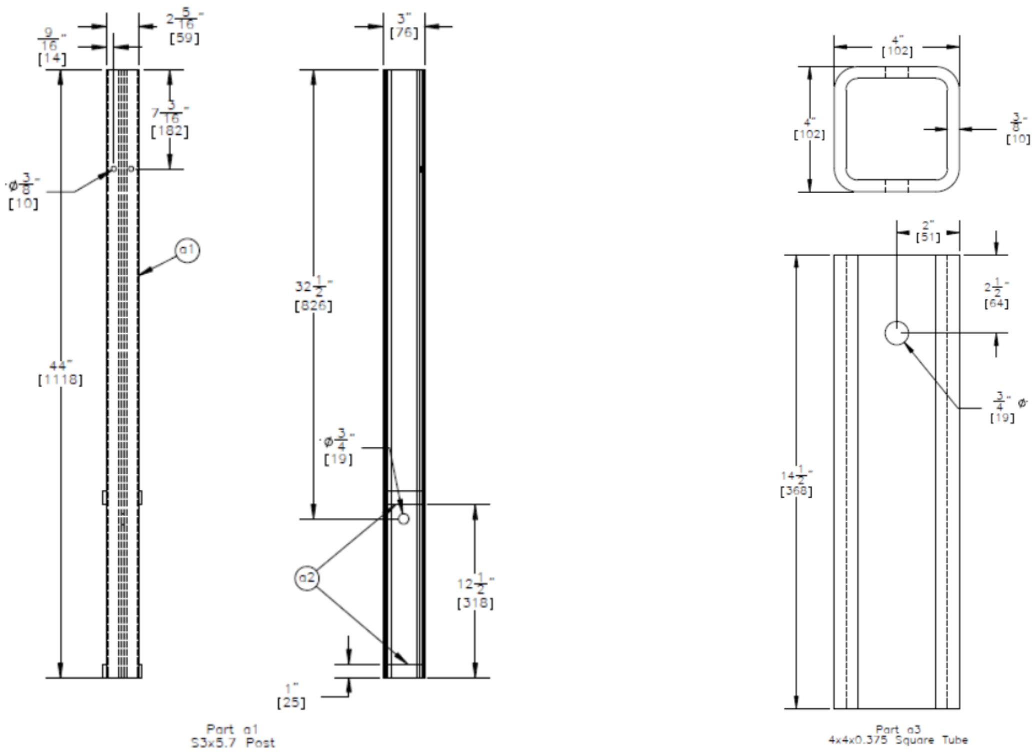


Figure 6. Post Assembly and Socket Tube from the MGS Bridge Rail [3]

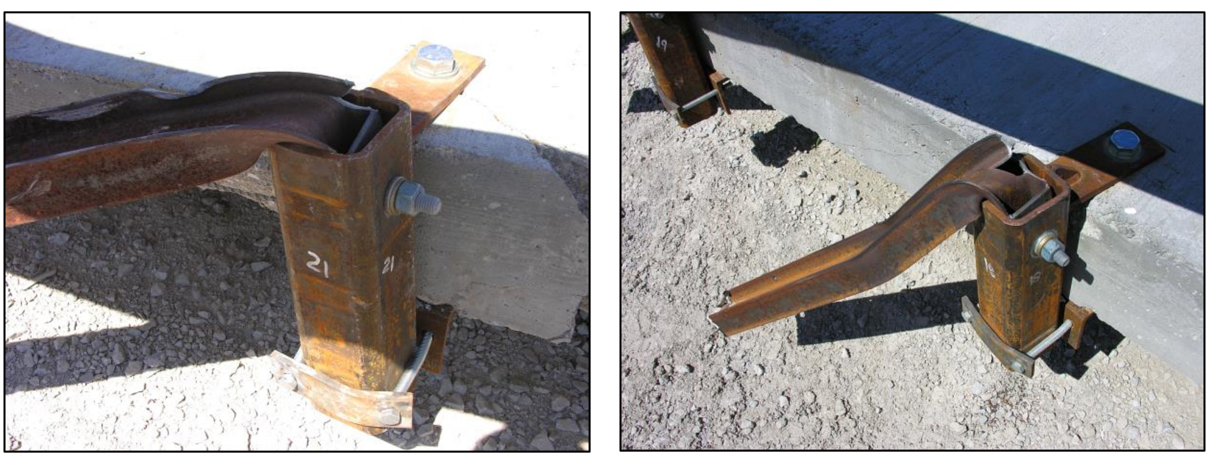


Figure 7. Post Flange Tearing adjacent to Post Standoffs [3]

2.3 Welded Socket Attachments

A welded attachment of the tube socket to the side channel of the deck was an option explored for use in the new bridge railing design. Directly welding the socket to the channel, as shown in Figure 8, minimized the number of components in the socket assembly by eliminating the need for an attachment plate. Also, many of the installers that work on rural bridges have experience with welding posts to deck edges. Thus, a welded attachment would provide a simple and cost-efficient mechanism for attaching the sockets to the bridge deck.

Figure 8. Socket Welded Directly to a 7-in. CIP Deck

A few concerns were identified with field welding the sockets. First, field welds require black, or galvanized, steel components. As such, both the socket and the side channel could not be galvanized and would be susceptible to rusting. Second, field welding would take longer to assemble the bridge railing compared to a bolted attachment. Finally, a welded attachment results in all of the impact load being transferred to the side channel of the deck. Even though the new bridge rail system used weak S3x5.7 posts, the impact loads could pry the top flange of the channel away from the bridge deck if the channel was not sufficiently anchored to the deck. This concern is illustrated in Figure 9.

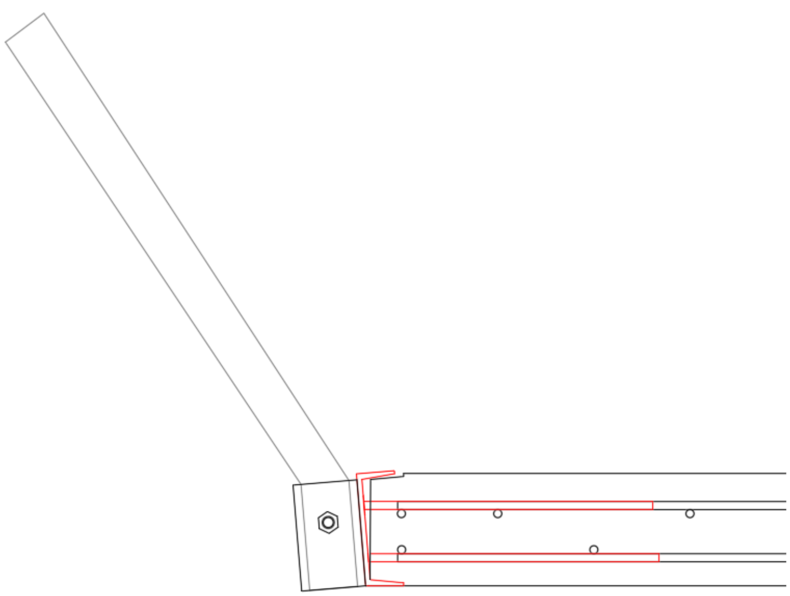


Figure 9. Channel Flange Prying off Deck During Loading

To mitigate the concerns of the channel being pried from the side of the bridge deck during impacts, multiple reinforcement configurations were developed to anchor the side channel to the deck. These anchorage configurations are shown in Figure 10. The first anchorage option utilized straight #4 rebar segments welded to the inside face of the channel that extended into the deck and tied into the upper and lower steel mats. ASTM A615 steel is the most common steel material used for rebar, but there were concerns that the butt welds at the end of the rebar to the channel would not fully develop the strength of the rebar. Thus, ASTM A706 steel rebar was also investigated for use in the channel anchorage as its chemical properties were designed to enhance weldability.

The second anchorage option utilized a #5 U-bar with its base located at the upper corner of the channel and its legs extending diagonally down and into the deck. Flare-bevel welds would be used to attach the base of the U-bar to the flange and web of the channel. This welded connection has significantly increased strength over the butt welds form the previous anchorage option and would be more likely to develop the full capacity of the U-bar. A few straight #4 rebar were also used in this anchorage option to help further anchor the channel and tie into the deck reinforcing steel.

The third anchorage option used gusset plates to reinforce the top flange and web of the channel, and #4 rebar were welded to the gussets using the stronger flare-bevel welds. The interior ends of the rebar were hooked down at 90 degrees to increase the anchorage capacity of the bars. A few straight #4 rebar were still used at the bottom of the channel to tie in with the lower steel mat of the deck. This anchorage design was considered the strongest of the options and would only be used if the other options failed to adequately anchor the channel to the edge of the deck.

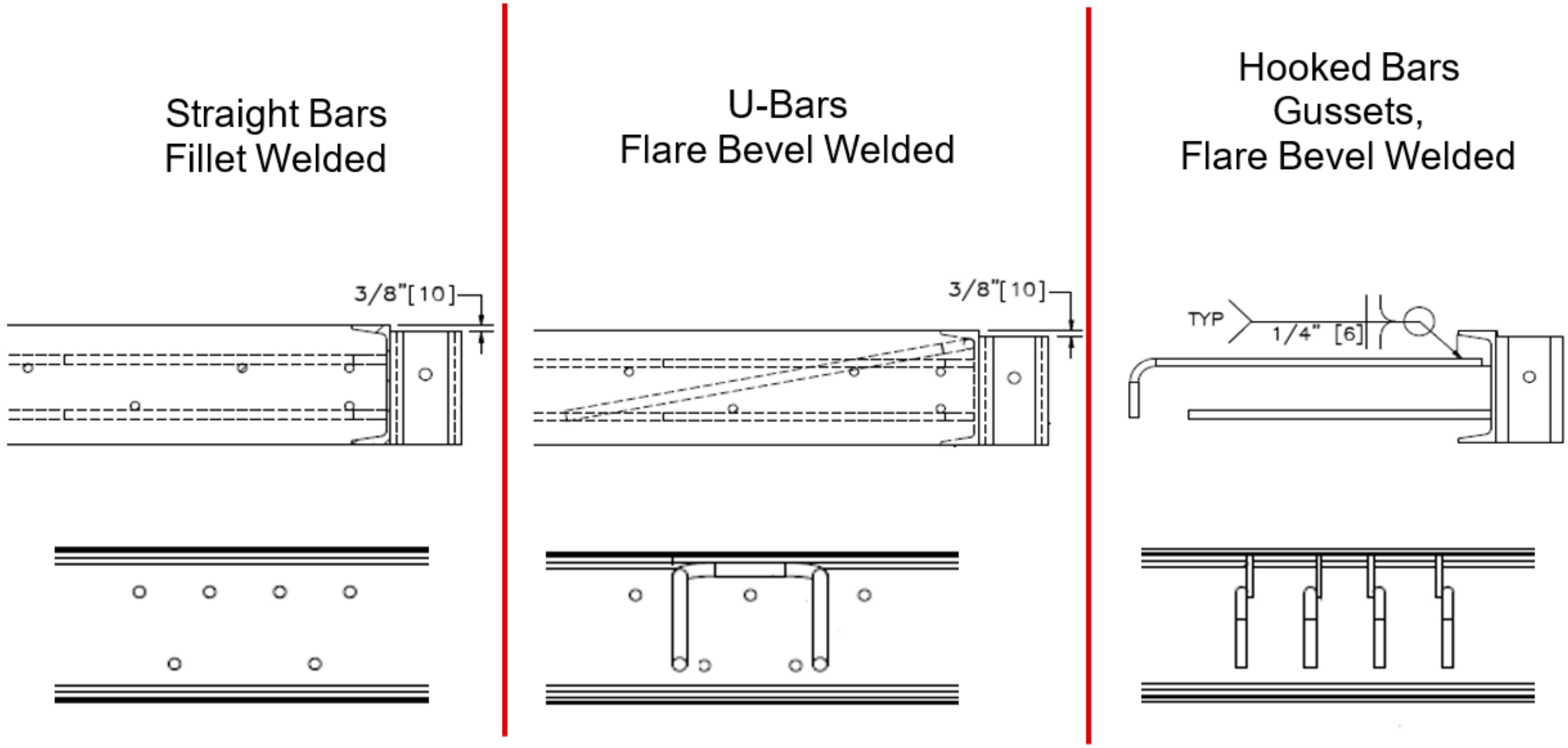


Figure 10. Welded Socket Attachment with (a) Straight Bar Anchorage, (b) U-bar Anchorage, and (c) Gussets and Hook Bar Anchorage

2.4 Bolted Socket Attachments

A bolted socket-to-deck attachment was desired to address many of the concerns raised with a welded attachment. Bolted attachments can use all galvanized components, thereby minimizing the risk of rusting. To create a bolted socket-to-deck attachment, the socket had to first be welded to a mounting plate. However, this socket assembly could be welded in the shop and galvanized prior to installation. Bolted attachments can also be assembled quickly on site and do not require the skilled/certified labor or extra equipment associated with welding. Finally, damaged components are much easier to replace in a bolted attachment in comparison to welded joints.

One of the objectives of the project was that the deck edge remained smooth without any hardware extending outward that would interfere with formwork. Thus, the socket assembly had to be bolted on from the outside with an internally threaded component cast within the deck. To satisfy these constraints, a new post-to-deck attachment method was developed using coupling nuts and threaded rods. Coupling nuts are commonly used to connect the ends of threaded hardware and directly transfer loads from one component to the other. For the new bolted attachment, holes were drilled in the web of the channel and coupling nuts were placed on the inside surface of the channel. Threaded rods were partially inserted into the coupling nuts and extended into the deck. These components would be embedded into the bridge deck when the concrete is poured. This allows the socket assemblies to be easily attached to the edge of the deck by bolting through the mounting plate and side channel and into the coupling nut, as shown in Figure 11.

During an impact, this new post-to-deck attachment design directly transfers the tensile loads from the attachment bolts through the coupling nuts and into the threaded rod anchors. The impact loads are never transferred to the channels (except for compression as part of the force couple resisting the moment created from post bending), so there would be minimal risk of damage to the side channels or the deck. Finally, the coupling nuts, threaded rods, and bolts would all be standard hardware, so only the socket assembly would need to be fabricated as part of the socket-to-deck attachment.

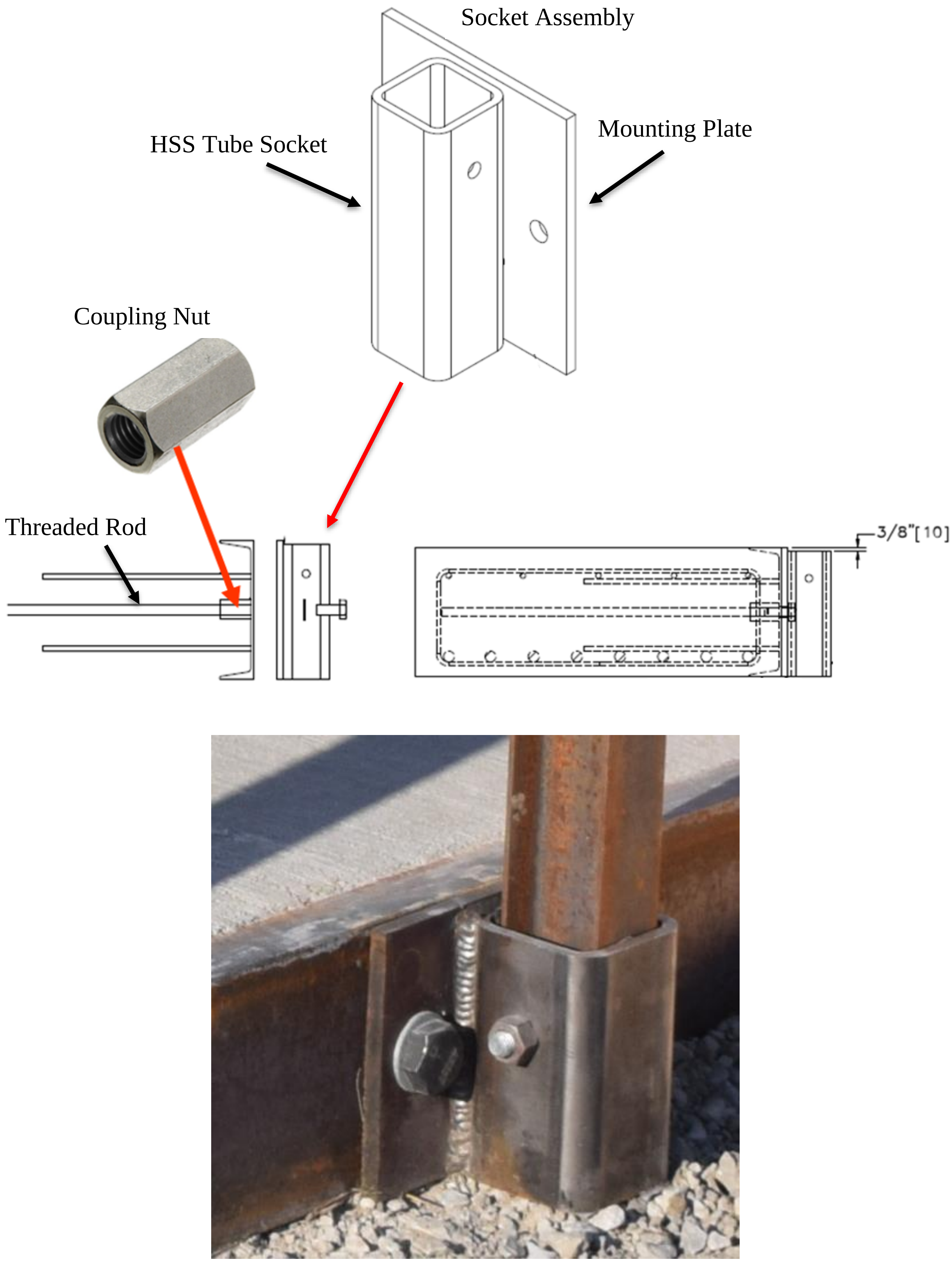


Figure 11. Coupling Nut and Threaded Rod Attachment of Socket Assembly to Deck

3 COMPONENT TESTING CONDITIONS

3.1 Purpose

Several side-mounted, post-to-deck connections were evaluated with dynamic component tests in order to evaluate the strength and behavior of the connections as well as potential damage to both deck types during an impact event.

3.2 Scope

Six dynamic component tests were conducted on S3x5.7 steel posts mounted to the side of simulated bridge decks with various socket-to-deck attachment designs. The socket-to-deck attachments consisted of the welded and bolted options discussed in Sections 2.3 and 2.4, respectively. A total of eight different socket-to-deck attachment designs were constructed on two simulated bridge decks, and each design, or location on the simulated decks, was denoted with a letter, as shown in Figures 12 through 35. Designs A through F were located on a simulated 7-in. thick, CIP deck and spaced at 51-in. intervals, on-center. Designs G and H were located on a simulated 12-in. thick, precast concrete beam-slab and were spaced 48 in. apart. Each of the socket-to-deck attachment designs had a unique combination of deck type, socket welds, bolt and threaded rod diameter, and internal reinforcement welded to the inside of the channel. Differences in the socket and post length were only due to the thickness of the deck and not necessarily a design feature desired for evaluation.

All of the socket-to-deck attachments were constructed on short channel segments embedded into the simulated decks. The short segments were utilized instead of a continuous channel so that any damage to a particular attachment location would not affect the adjacent locations. Additionally, testing short channel segments was seen as a worst-case scenario for anchoring the channel to the deck as a continuous channel should have increased strength and resistance to damage. Thus, if the component tests were successful with short channel segments, designs with continuous channels along the deck edge would also be acceptable.

Although eight test installations were constructed, only six dynamic component tests were conducted. Testing was conducted using an iterative approach where the design selected for evaluation in a specific test was based on the results of the previous tests. Eight different designs were constructed so that the researchers had design options available for continued testing without having to construct new test articles. Thus, the extra test articles provided multiple testing possibilities and a construction time savings at minimal additional installation costs.

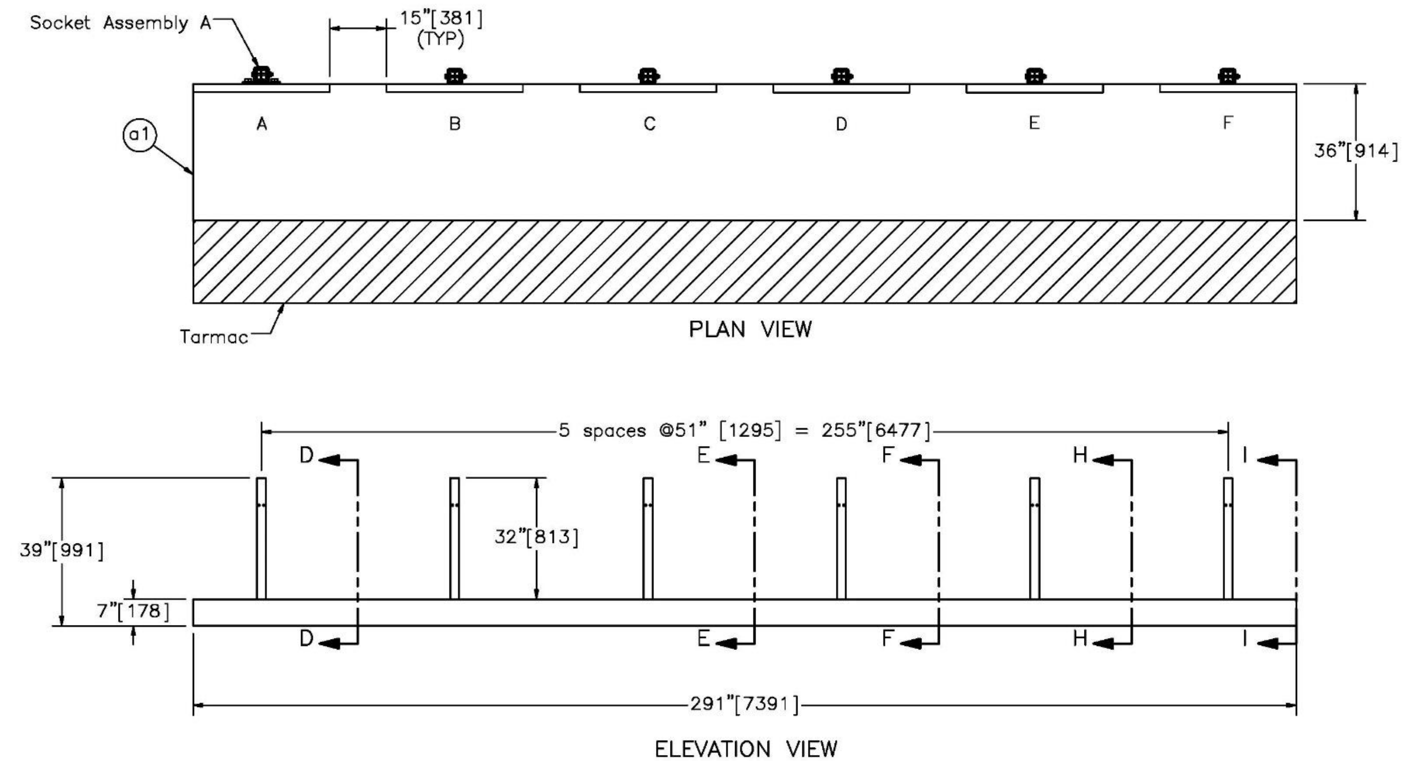
Two different impact conditions were used. The first involved a lateral impact (90-degree impact angle) on the post at a height of 25 in. subjecting it to strong-axis bending. These impact conditions were selected to match the height to the center of the W-beam rail and represent maximum lateral loading into the guardrail system. Similar impact conditions are routinely used to observe the performance of guardrail posts installed in soil. The second critical test condition involved a longitudinal impact (0-degree impact angle) where a post was subjected to weak-axis bending. The longitudinal impacts were conducted with a load height of 12 in. to simulate a small car bumper impacting posts during a redirection. This second impact was deemed critical because it induces high shear loads into the socket and may cause the socket to rotate. The target impact speed for both test conditions was 20 mph. These two critical impact conditions have previously been used to evaluate socket attachments to culverts for weak-post MGS installations [6-7]. Table 1 shows the design/location and impact conditions for each of the six dynamic component tests conducted during the study.

The simulated concrete decks were designed to replicate typical CIP and pre-stressed concrete beam-slabs used on rural Nebraska roadways. Note, the simulated concrete beam-slab was not pre-stressed and only utilized standard rebar reinforcement. This change saved on installation costs without affecting the results of the component tests. Both concrete decks had a targeted minimum compressive strength of 6,000 psi. The actual concrete compressive strength was 5,660 psi. Design details for the test installations are shown in Figures 12 through 35, and installation photographs are shown in Figure 36. Material specifications, mill certifications, and certificates of conformity for the simulated decks, posts, and attachment hardware used for the component tests are shown in Appendix A.

Table 1. Component Testing Details

Test No.	Target Impact Speed mph	Impact Angle degrees	Impact Height in.	Deck	Deck Location	Attachment Type	Attachment Details	C-Channel Section	C-Channel Assembly
N2B-1	20	90	25	7” CIP	A	Bolted	1-in. diameter fasteners	C7x9.8	A
N2B-2	20	90	25	12” Precast Beam-Slab	G	Bolted	¾-in. diameter fasteners	C12x20.7	F
N2B-3	20	90	25	7” CIP	B	Welded	Straight A706 rebar	C7x9.8	B
N2B-4	20	90	25	7” CIP	E	Welded	#5 U-bar	C7x9.8	D
N2B-5	20	0	12	12” Precast Beam-Slab	G	Bolted	¾-in. diameter fasteners	C12x20.7	F
N2B-6	20	0	12	7” CIP	C	Welded	Straight A615 rebar	C7x9.8	B

Test No.	Location	Deck Thickness	Bogie No.	Impact Head	Impact Height	Impact Speed mph [km/h]	Impact Angle
N2B–1	A	7" [178]	3	MGS	25" [632]	20 [32.2]	90°
N2B–2	G	12" [305]	3	MGS	25" [632]	20 [32.2]	90°
N2B–3	B	7" [178]	3	MGS	25" [632]	20 [32.2]	90°
N2B–4	E	7" [178]	3	MGS	25" [632]	20 [32.2]	90°
N2B–5	G	12" [305]	3	SHEAR	12" [305]	20 [32.2]	0°
N2B–6	C	7" [178]	3	SHEAR	12" [305]	20 [32.2]	0°



Notes: (1) Details for test nos. N2B–2 through N2B–6 will be determined following results from previous test(s).
(2) Test nos. N2B–2 through N2B–6 may incorporate weak–axis testing (0°) with the shear impact head at a 12" [305] impact height and/or testing of locations G and H on the 12" [305] deck.

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TL–2 Bridge Rail for Low–Volume Roads

7" Thick Deck System Overview

SHEET: 1 of 24
DATE: 2/19/2018
DRAWN BY: KJW/JEK/DTM/JWB
DWG. NAME. TL2BR_BogieDeck_R11
SCALE: 1:40
UNITS: in.[mm]
REV. BY: JEK/SKR/KAL/JCH

Figure 12. Bogie Testing Matrix and Setup, 7-in. Thick Deck System Overview

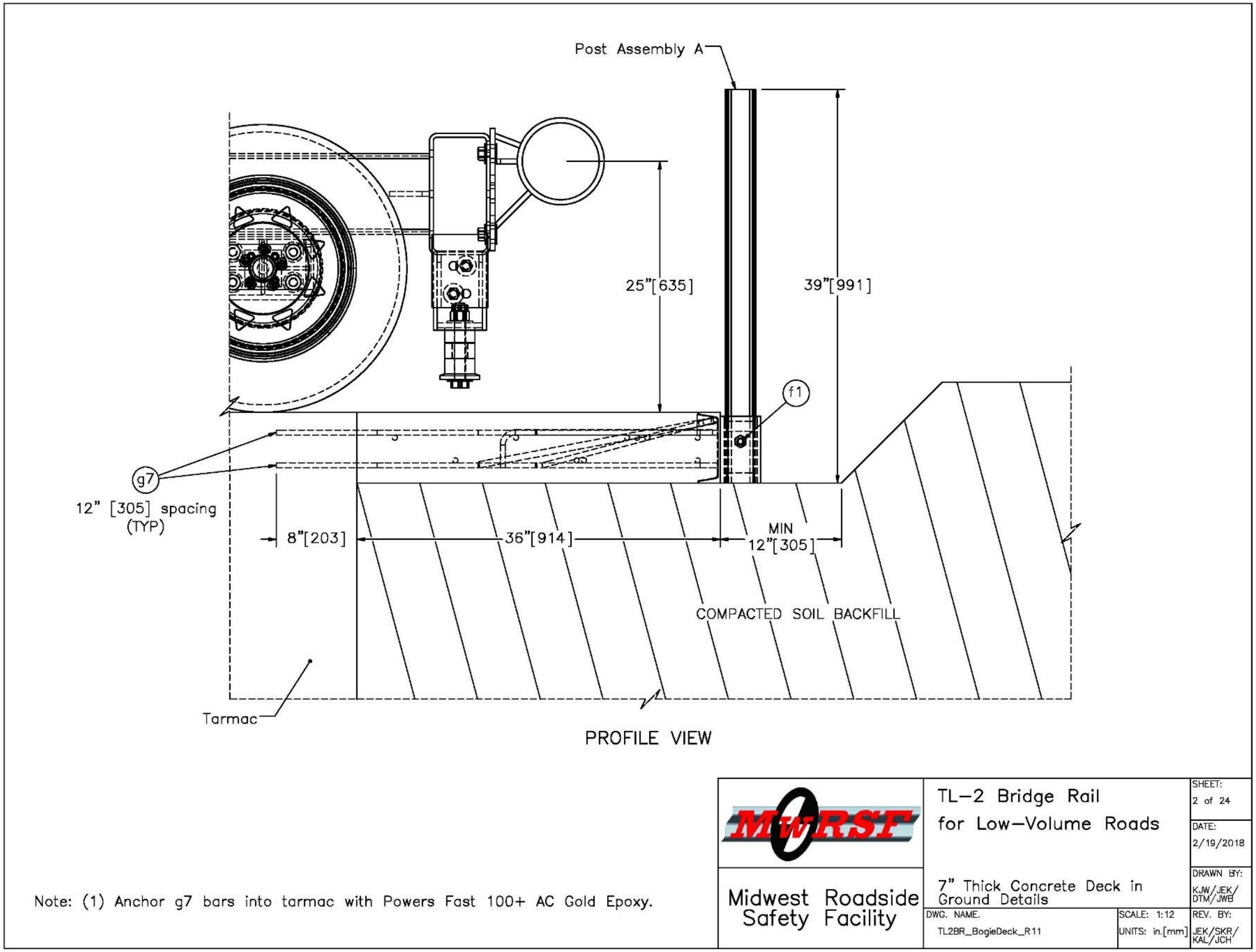


Figure 13. Bogie Testing Matrix and Setup, 7-in. Thick Concrete Deck in Ground Details

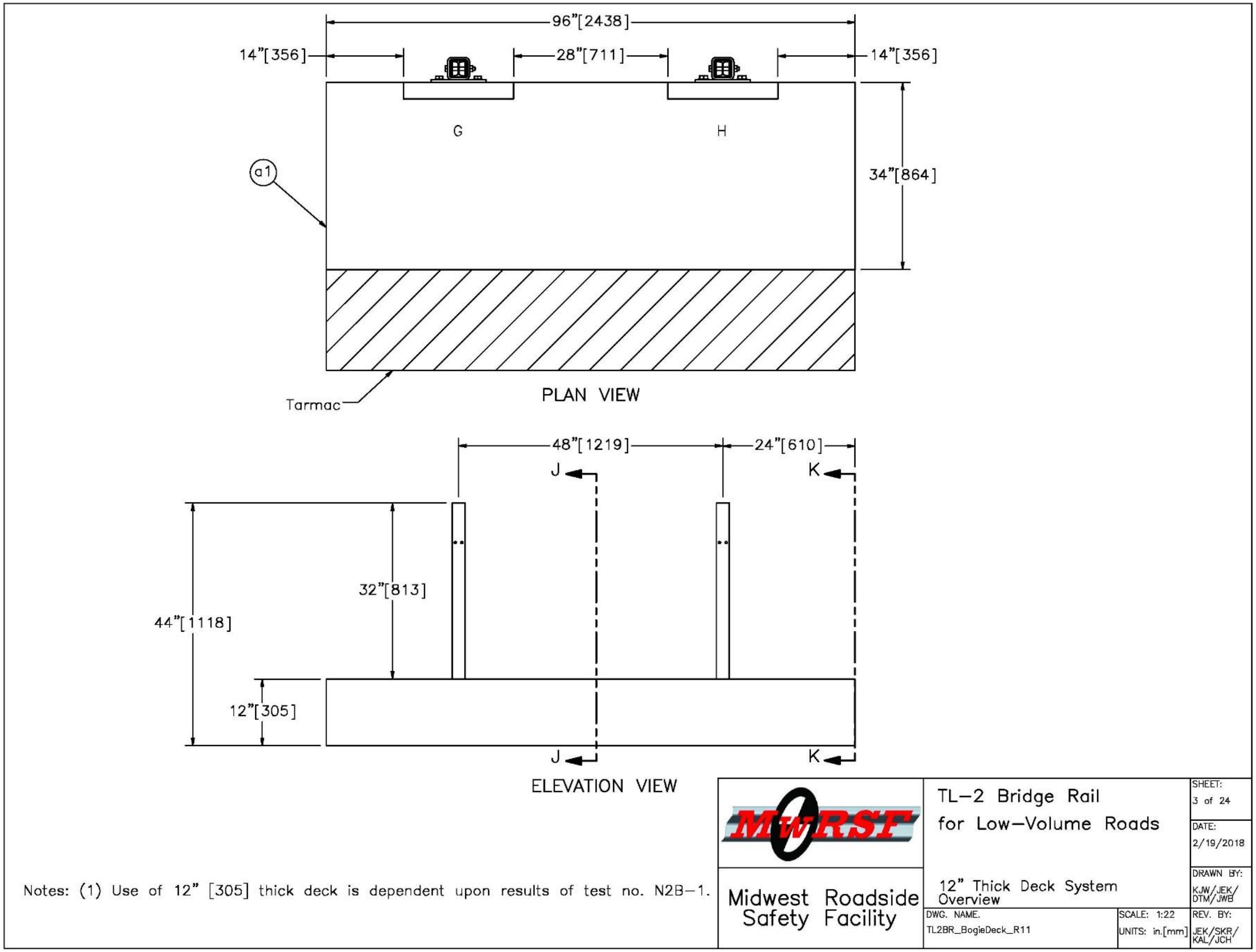


Figure 14. Bogie Testing Matrix and Setup, 12-in. Thick Deck System Overview

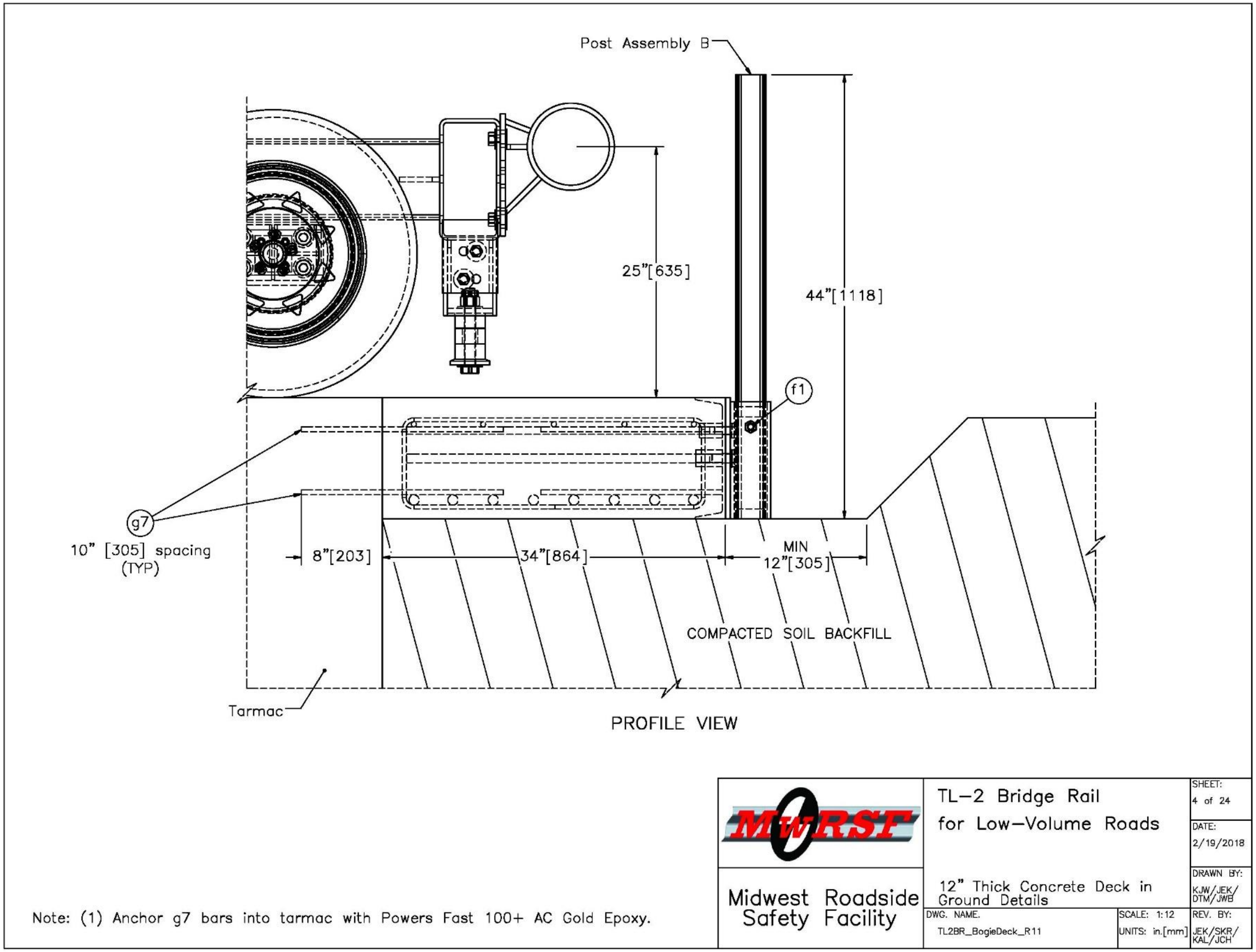


Figure 15. Bogie Testing Matrix and Setup, 12-in. Thick Concrete Deck in Ground Details

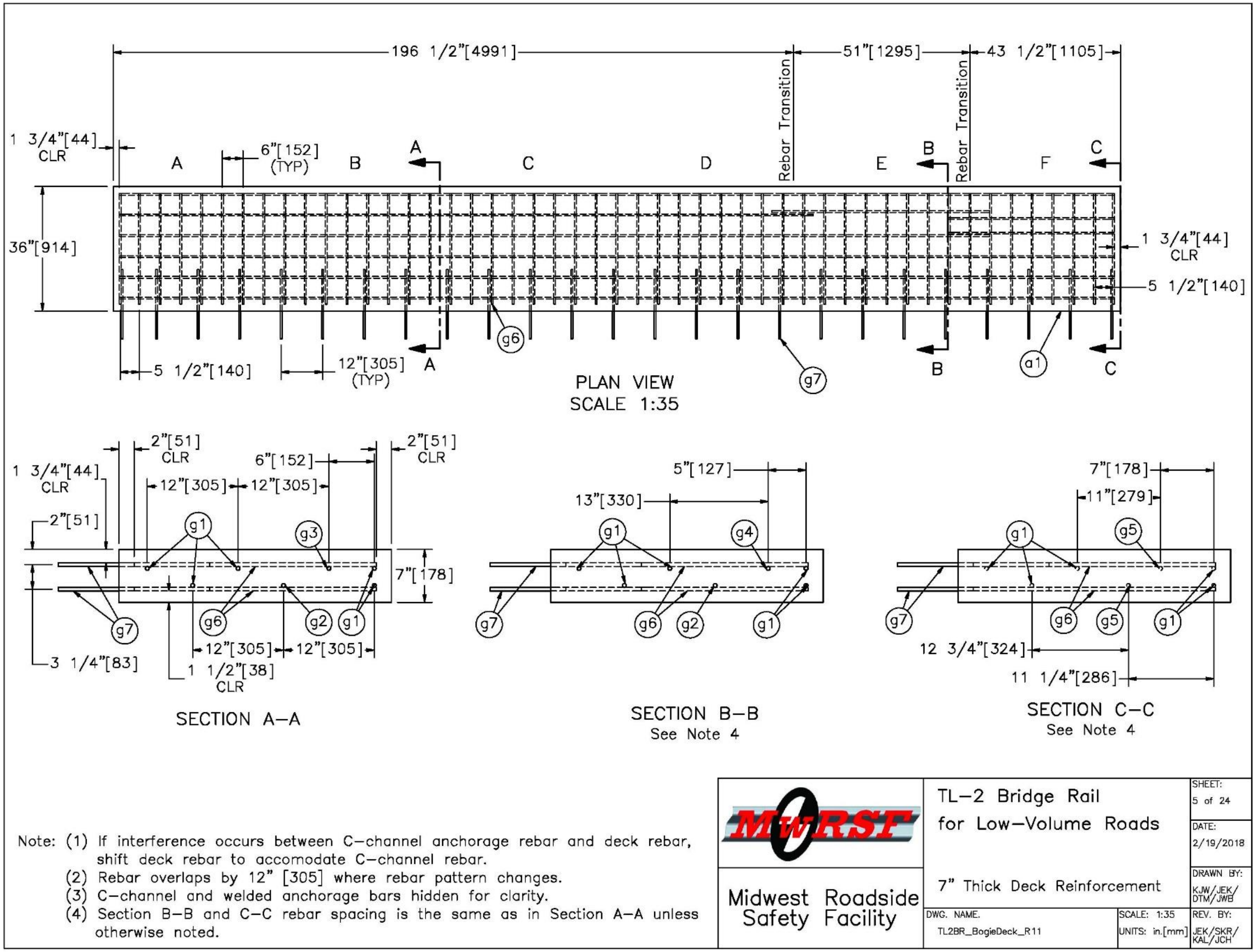


Figure 16. Bogie Testing Matrix and Setup, 7-in. Thick Deck Reinforcement

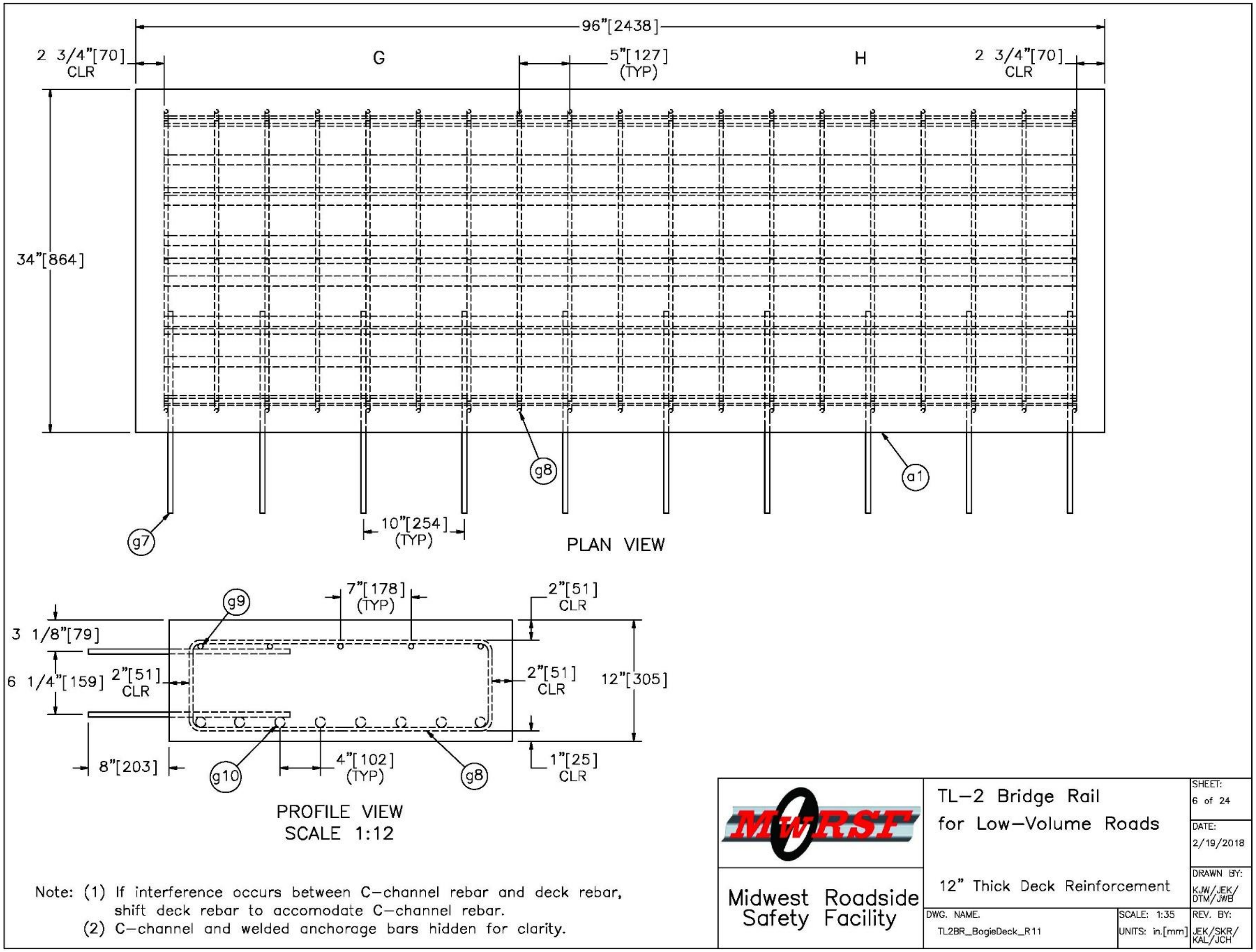


Figure 17. Bogie Testing Matrix and Setup, 12-in. Thick Deck Reinforcement

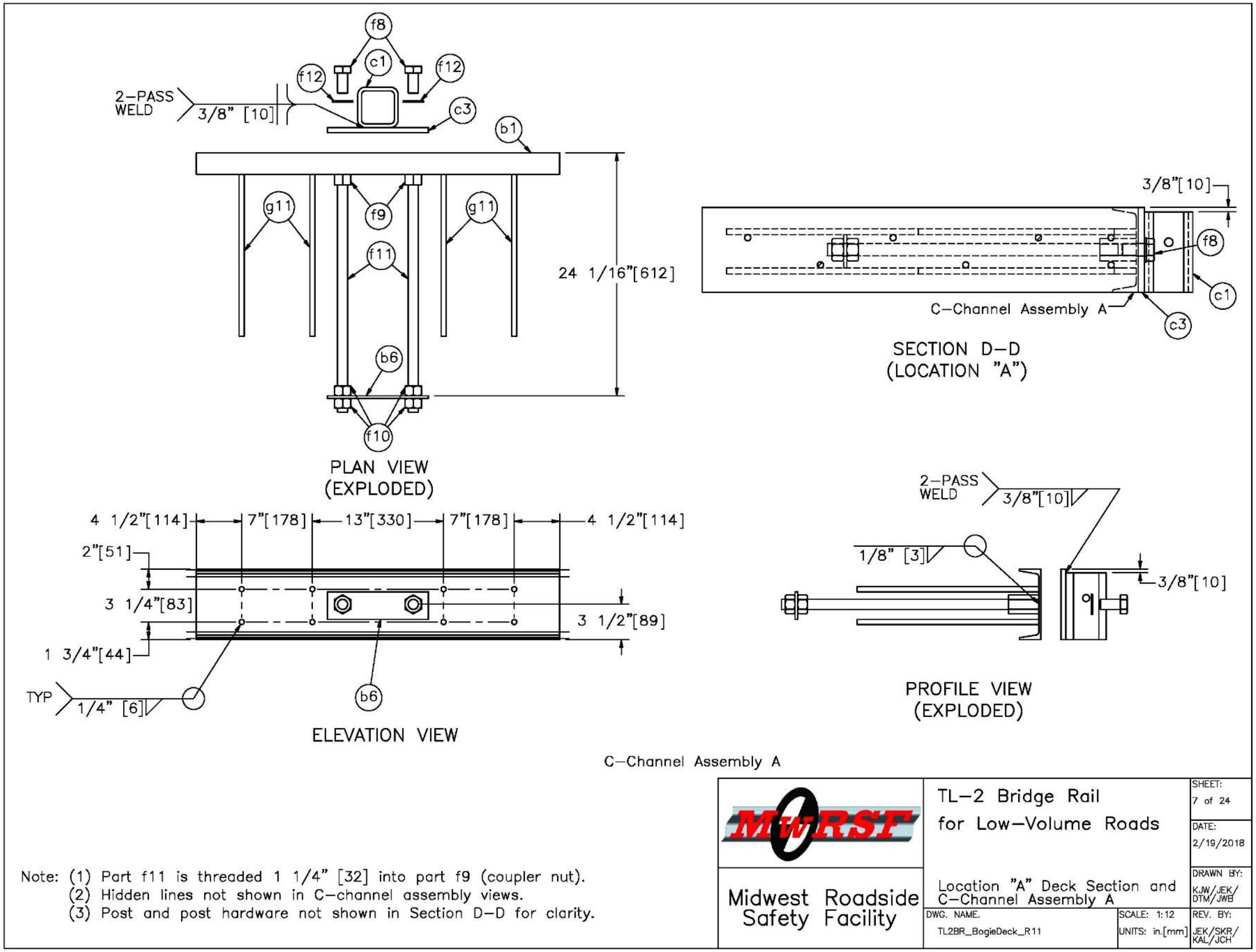


Figure 18. Bogie Testing Matrix and Setup, Location "A" Deck Section and C-Channel Assembly A

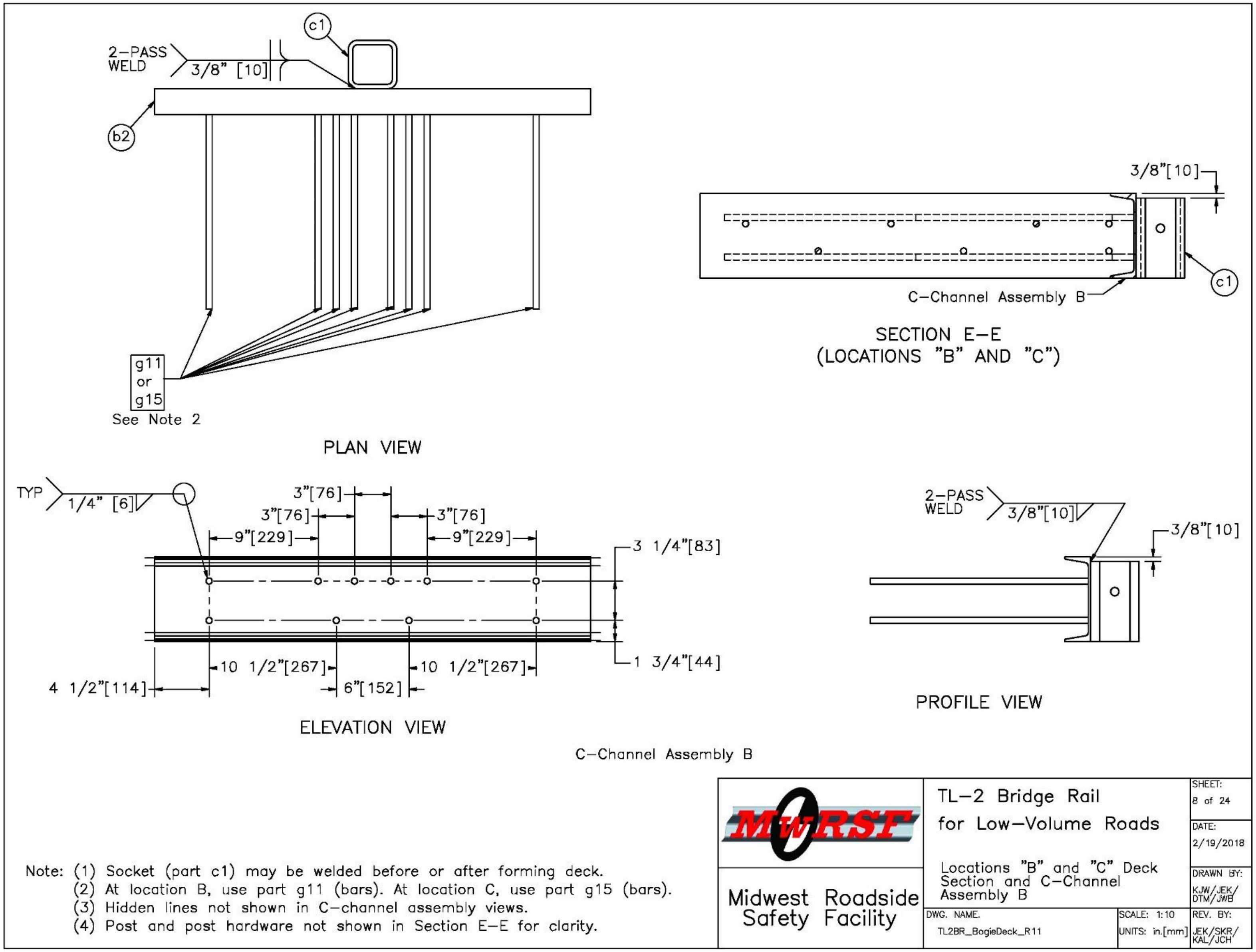


Figure 19. Bogie Testing Matrix and Setup, Locations "B" and "C" Deck Section and C-Channel Assembly B

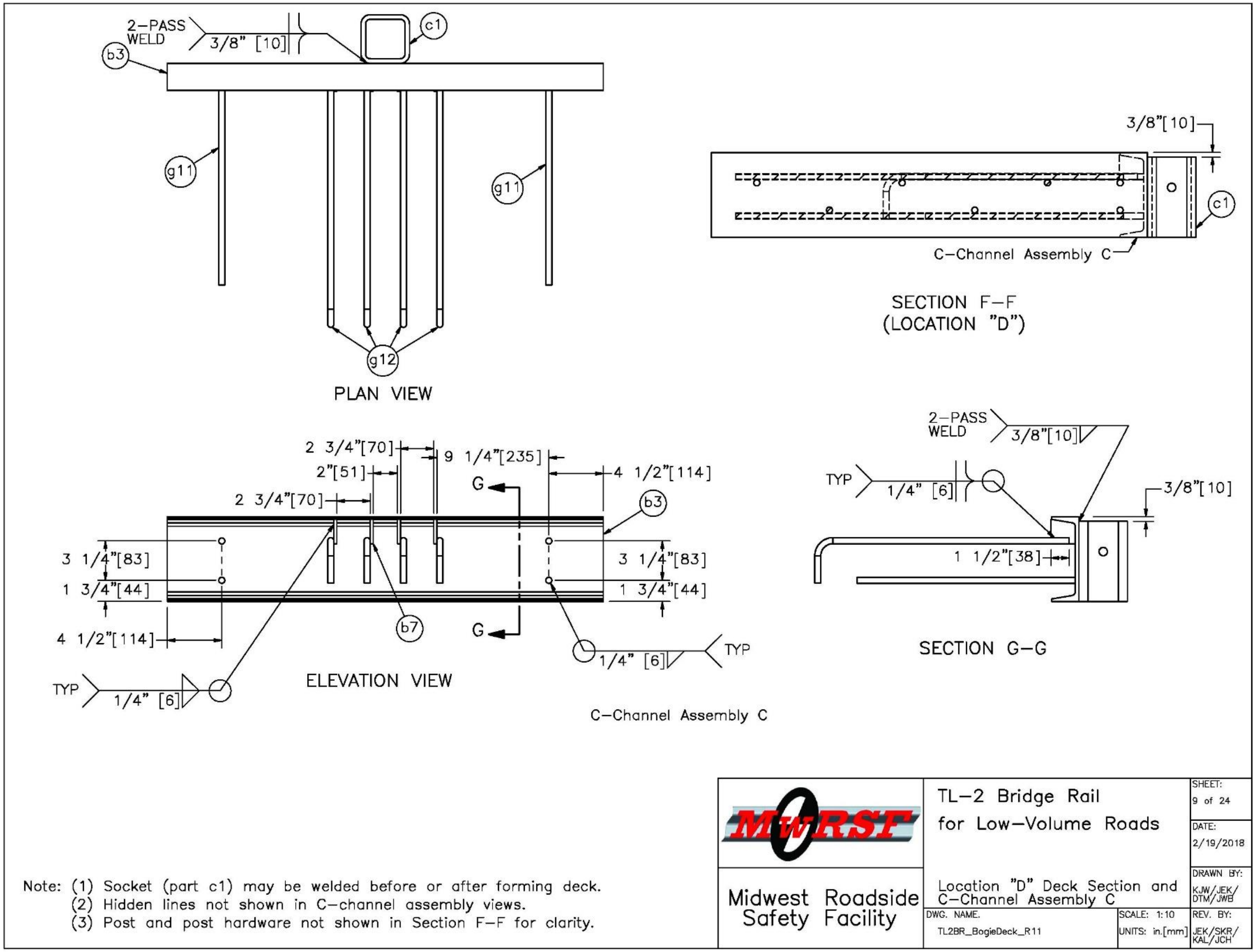


Figure 20. Bogie Testing Matrix and Setup, Location "D" Deck Section and C-Channel Assembly C

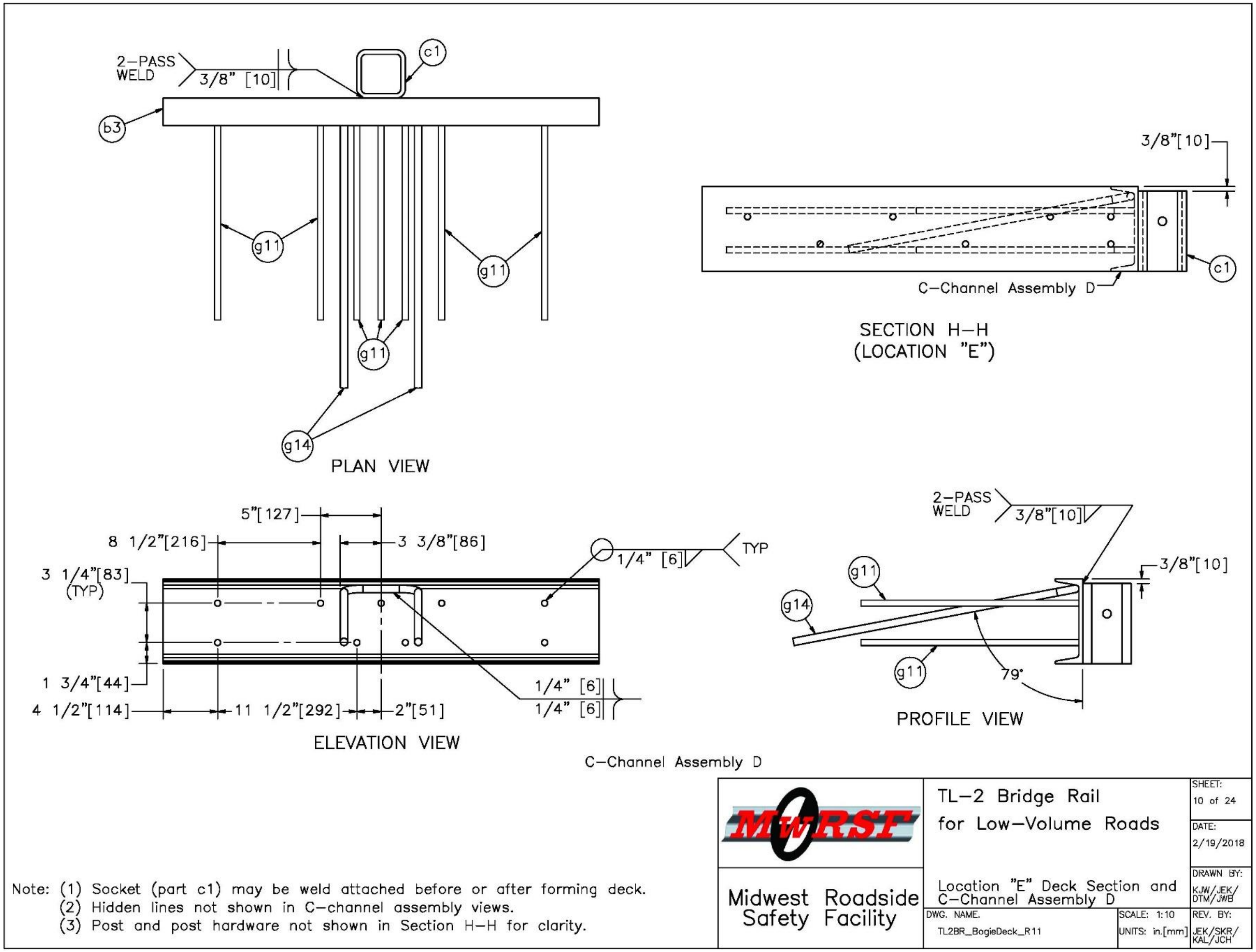


Figure 21. Bogie Testing Matrix and Setup, Location "E" Deck Section and C-Channel Assembly D

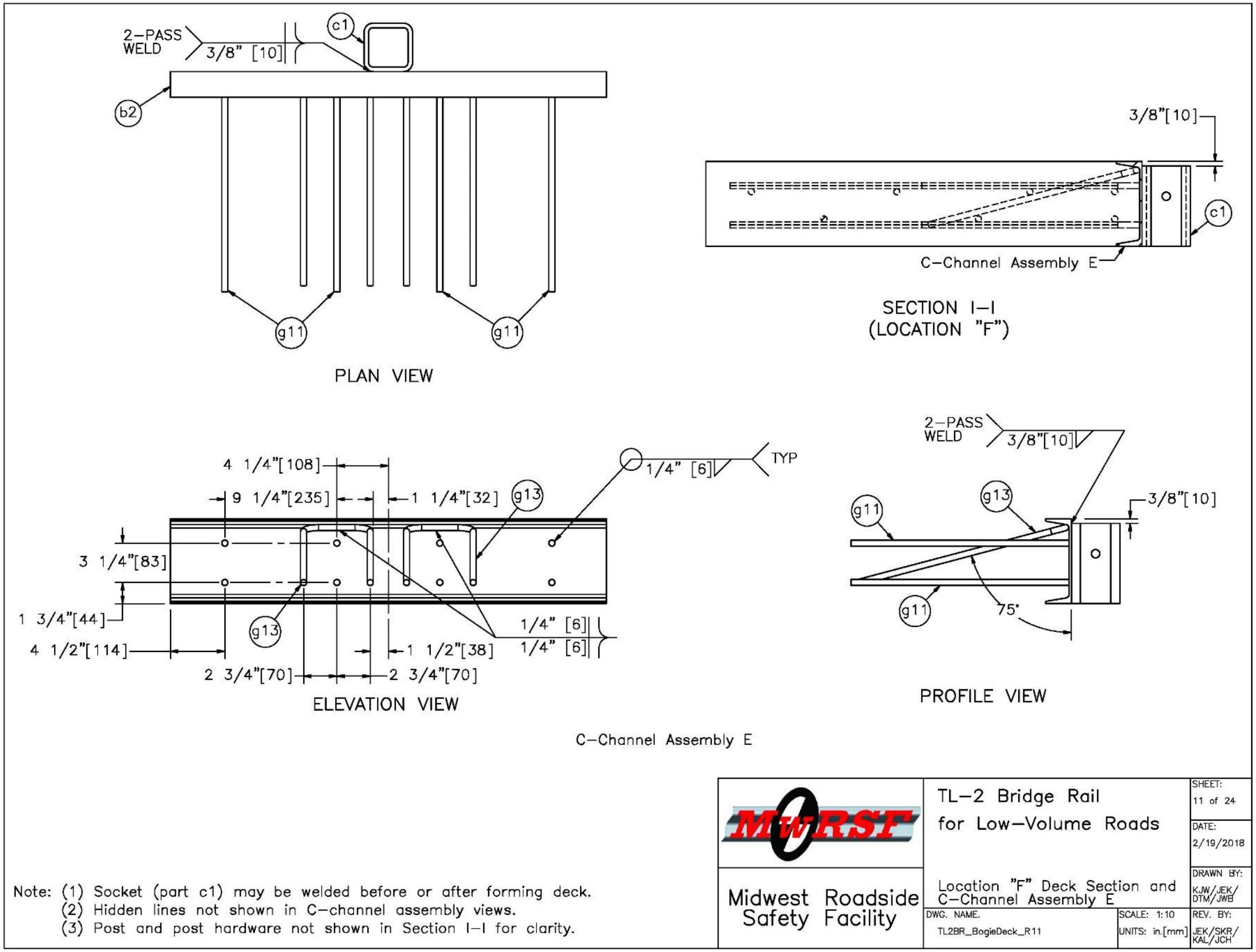


Figure 22. Bogie Testing Matrix and Setup, Location "F" Deck Section and C-Channel Assembly E

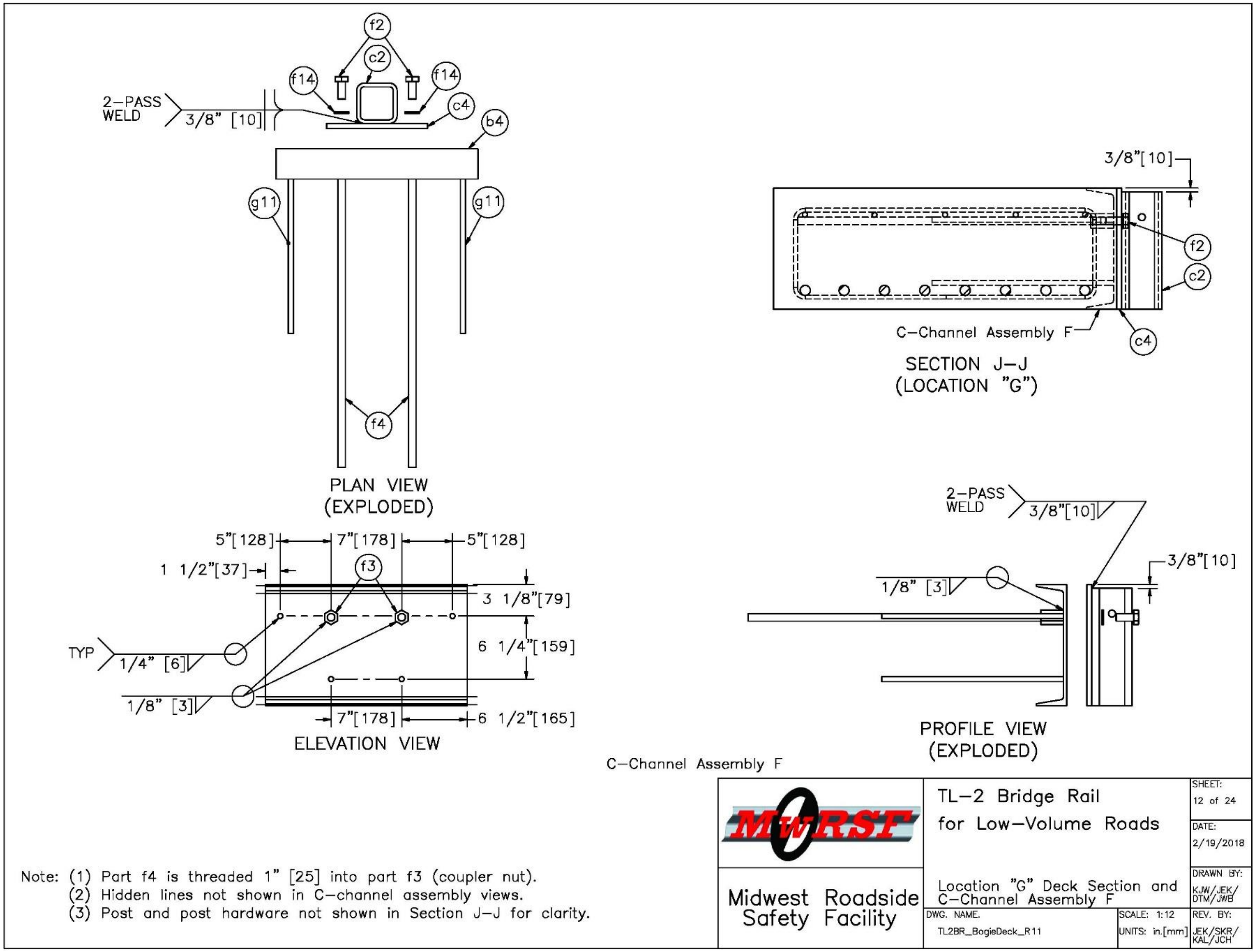


Figure 23. Bogie Testing Matrix and Setup, Location "G" Deck Section and C-Channel Assembly F

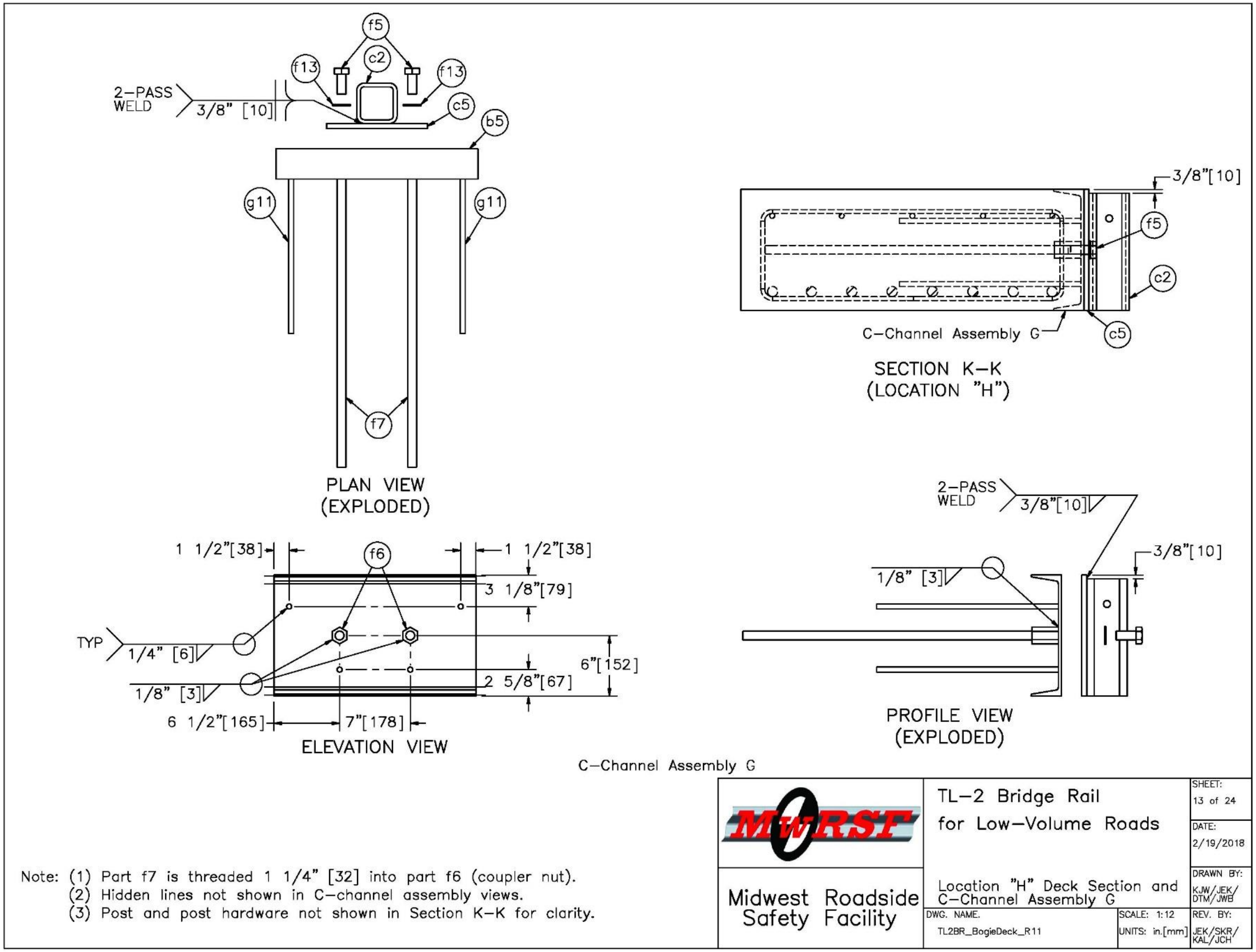


Figure 24. Bogie Testing Matrix and Setup, Location "H" Deck Section and C-Channel Assembly G

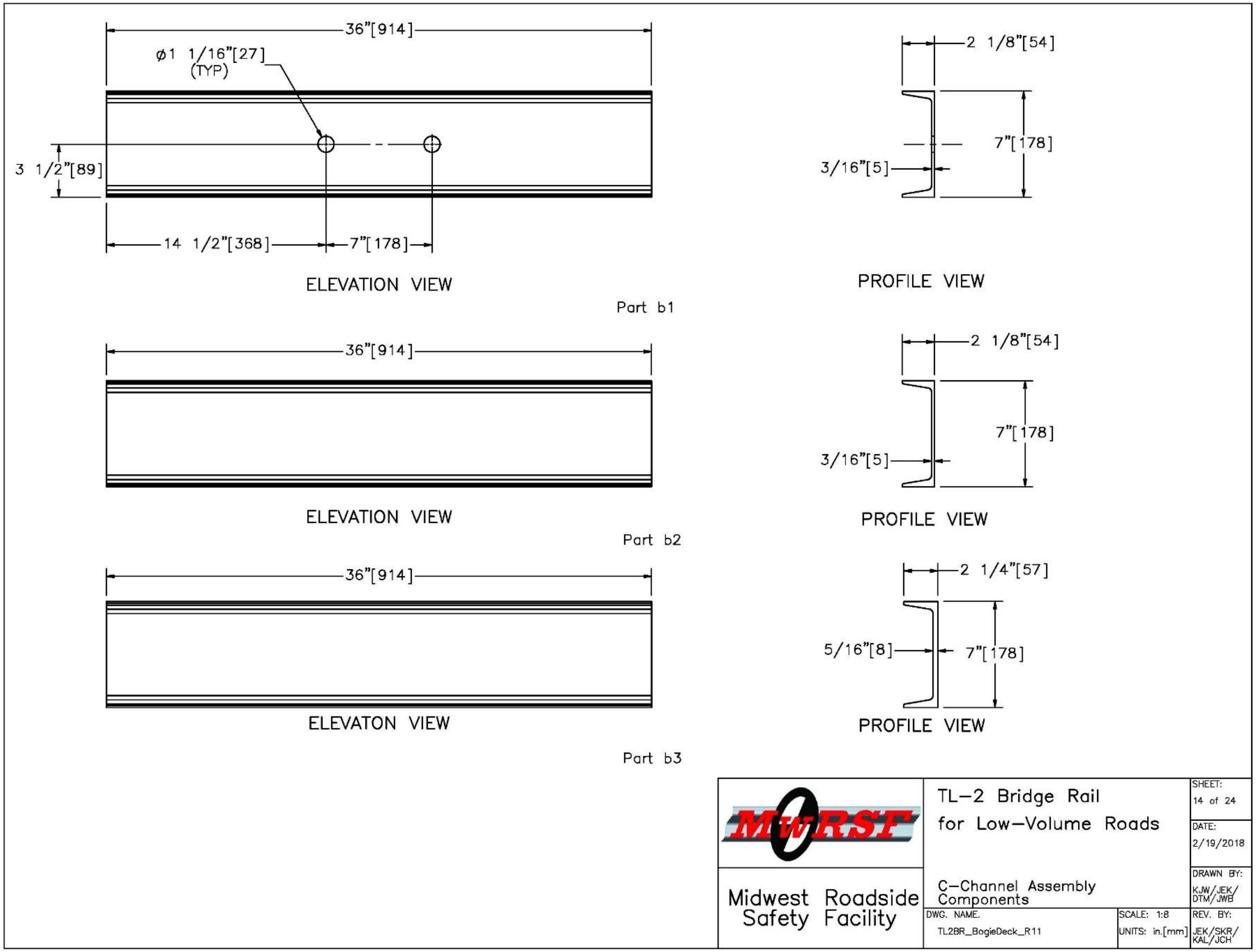


Figure 25. Bogie Testing Matrix and Setup, C-Channel Assembly Components

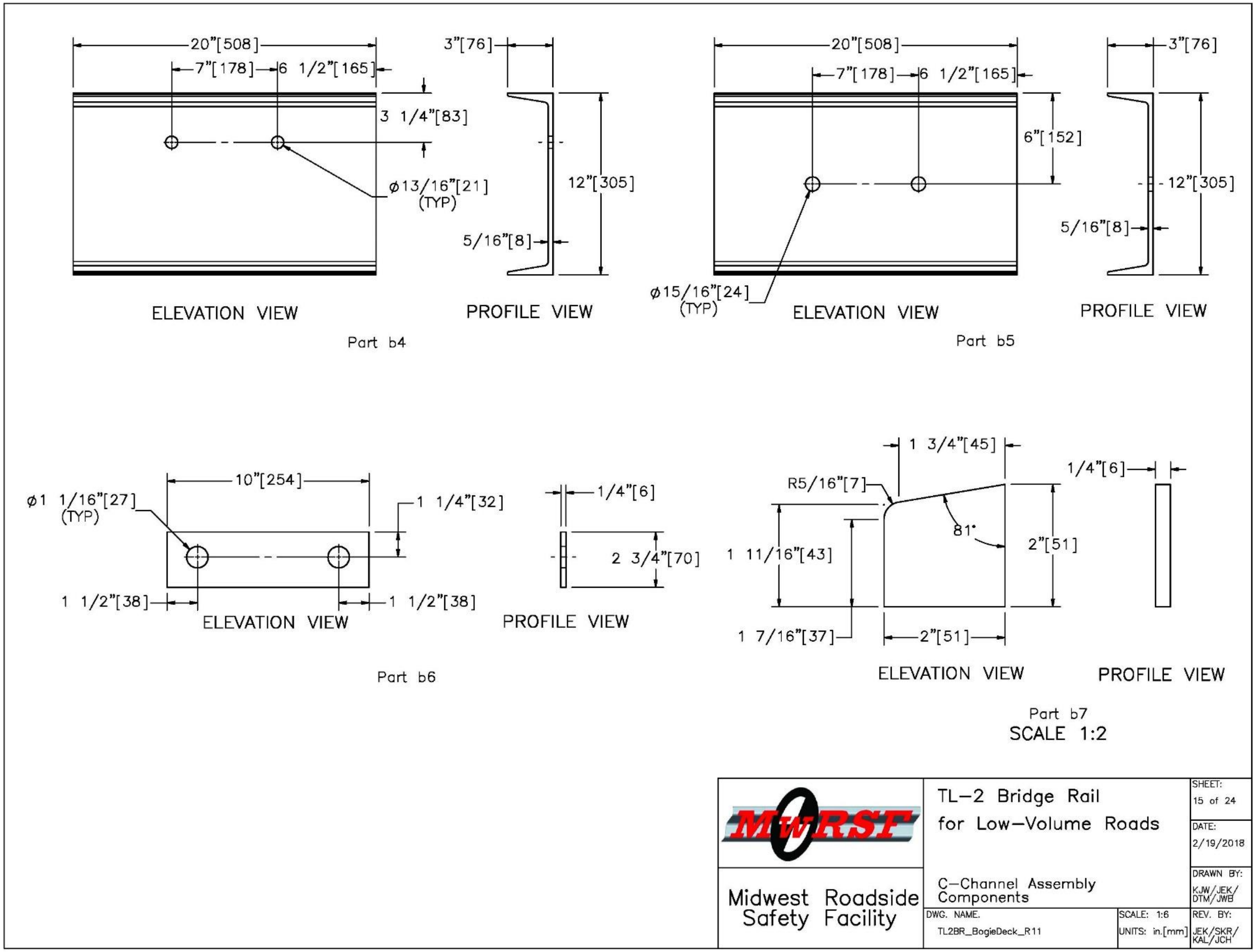


Figure 26. Bogie Testing Matrix and Setup, C-Channel Assembly Components

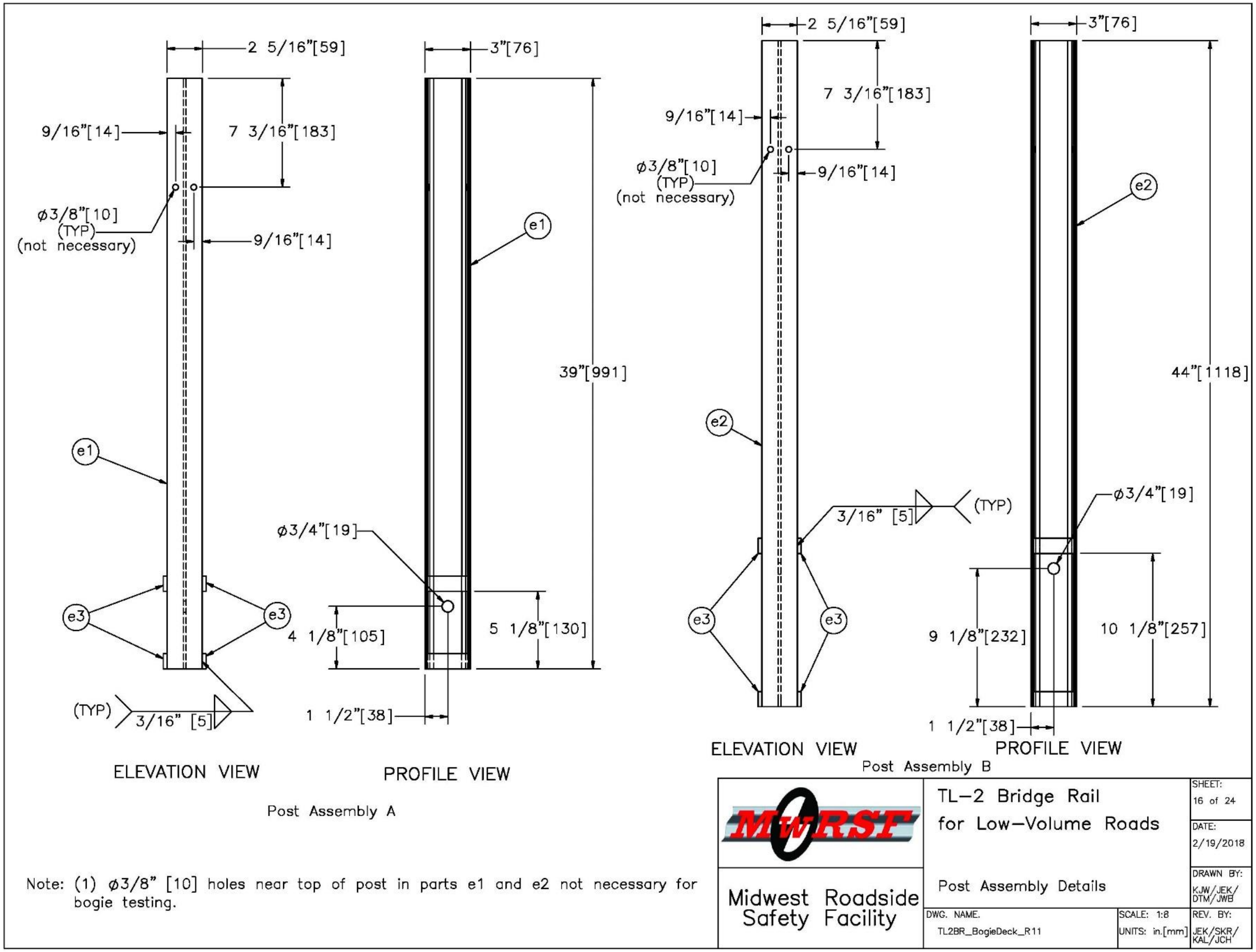


Figure 27. Bogie Testing Matrix and Setup, Post Assembly Details

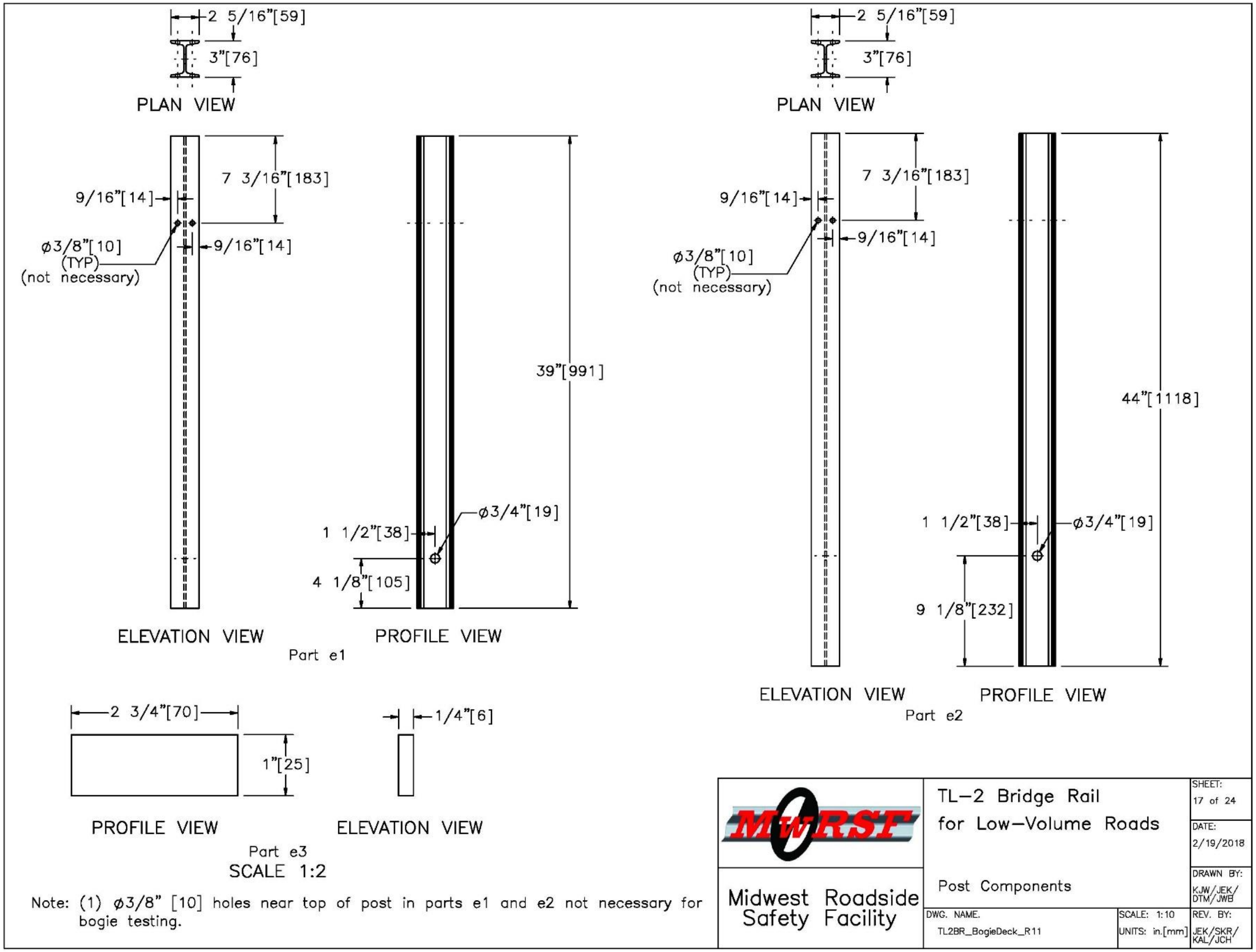


Figure 28. Bogie Testing Matrix and Setup, Post Components

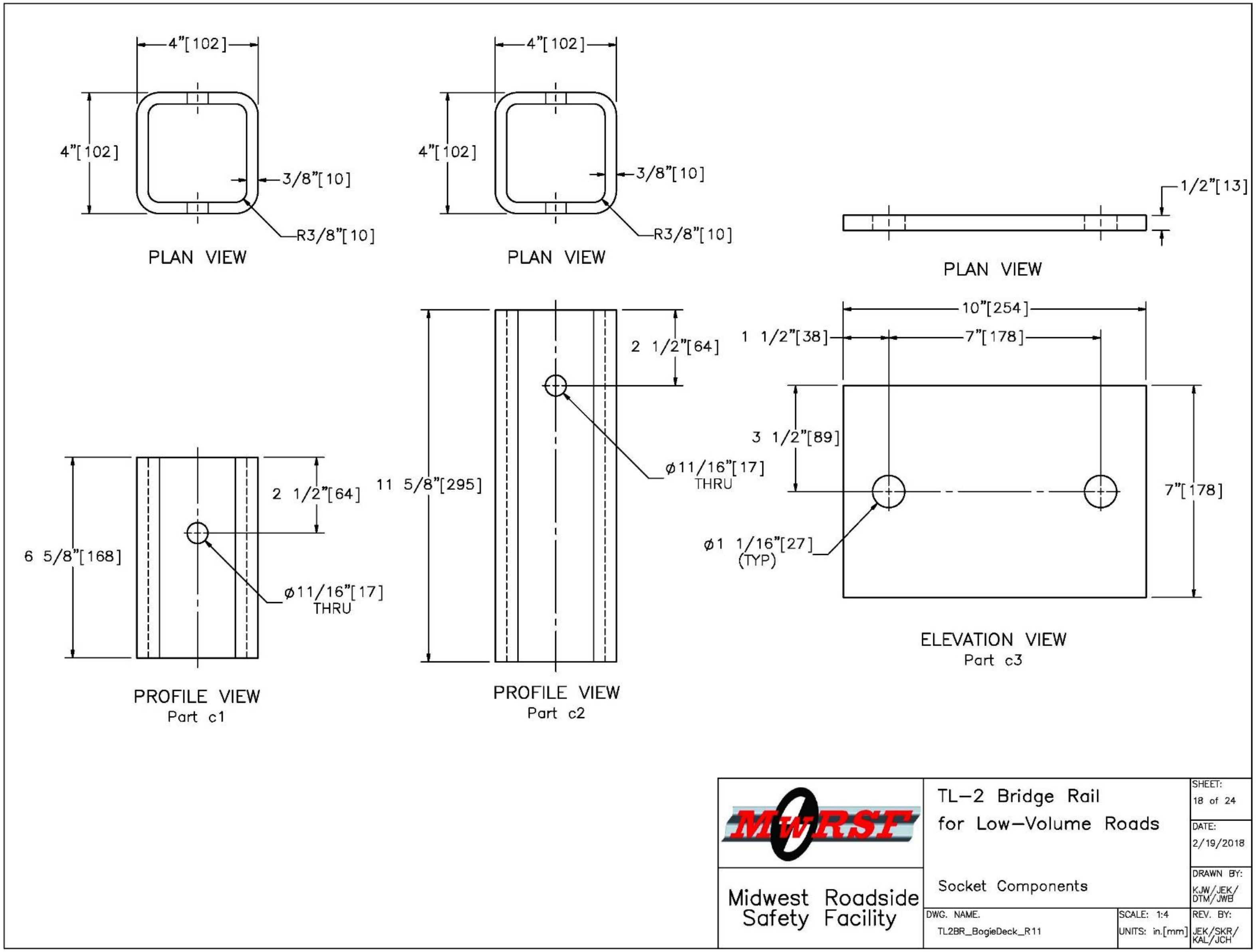


Figure 29. Bogie Testing Matrix and Setup, Socket Components

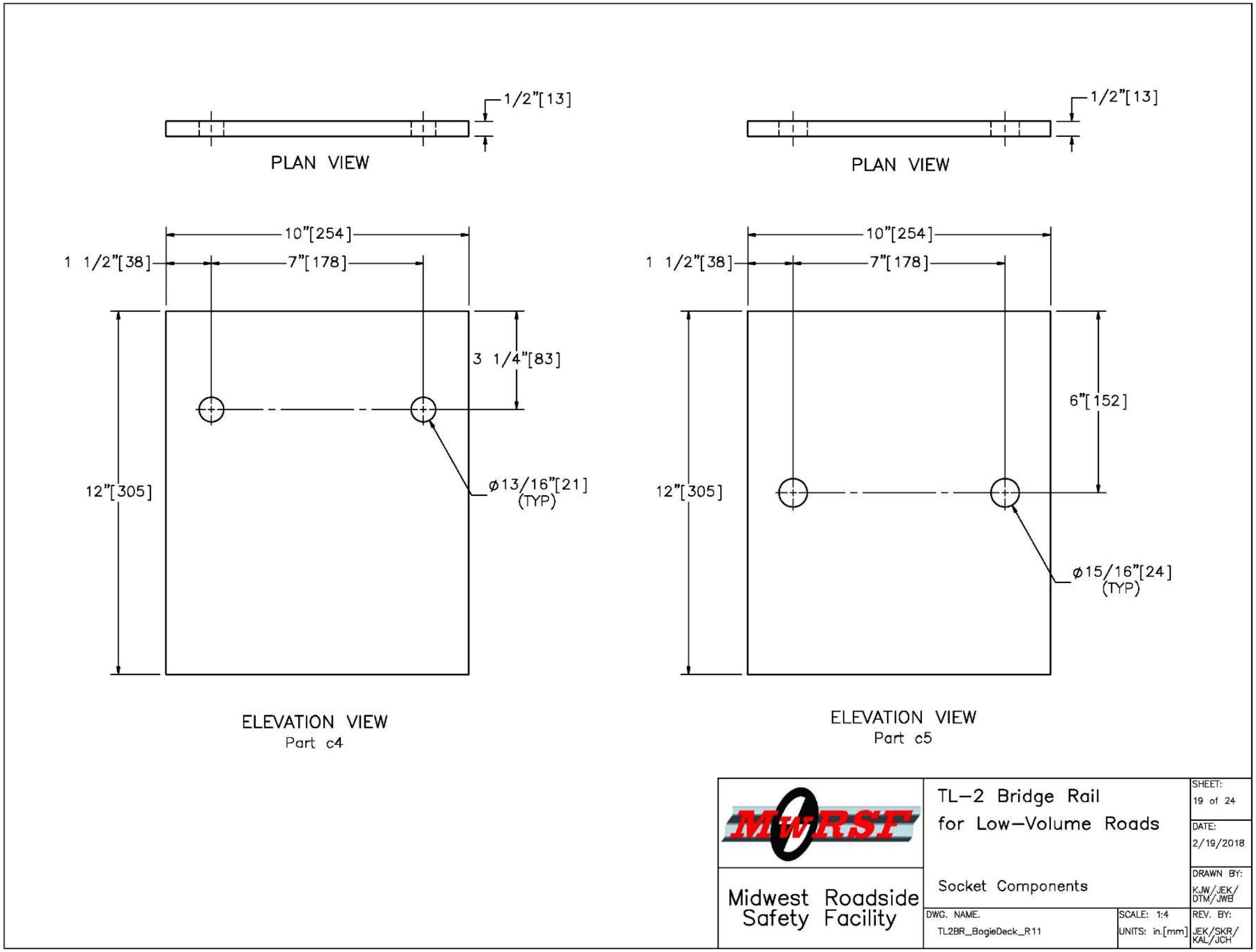
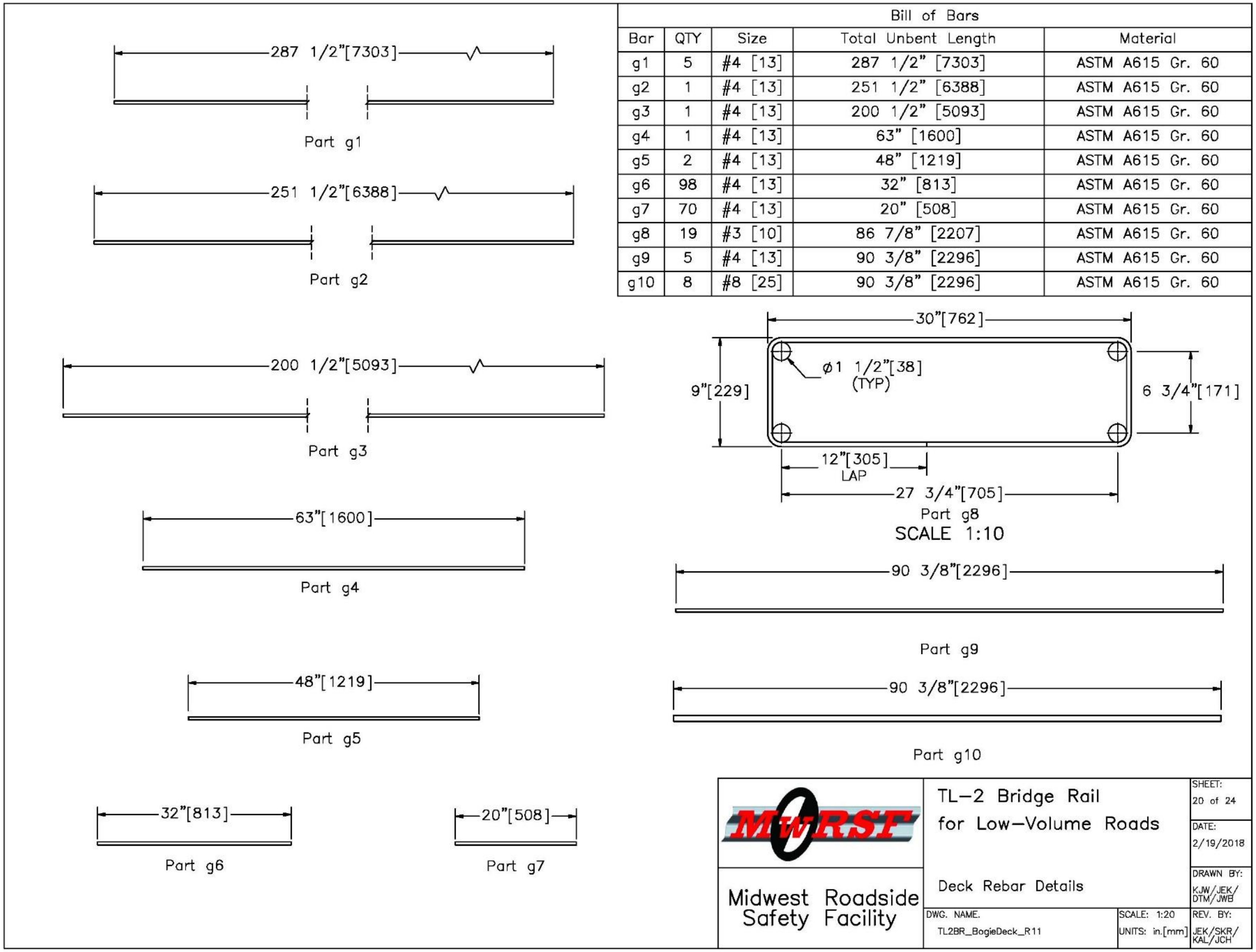


Figure 30. Bogie Testing Matrix and Setup, Socket Components



Bill of Bars				
Bar	QTY	Size	Total Unbent Length	Material
g1	5	#4 [13]	287 1/2" [7303]	ASTM A615 Gr. 60
g2	1	#4 [13]	251 1/2" [6388]	ASTM A615 Gr. 60
g3	1	#4 [13]	200 1/2" [5093]	ASTM A615 Gr. 60
g4	1	#4 [13]	63" [1600]	ASTM A615 Gr. 60
g5	2	#4 [13]	48" [1219]	ASTM A615 Gr. 60
g6	98	#4 [13]	32" [813]	ASTM A615 Gr. 60
g7	70	#4 [13]	20" [508]	ASTM A615 Gr. 60
g8	19	#3 [10]	86 7/8" [2207]	ASTM A615 Gr. 60
g9	5	#4 [13]	90 3/8" [2296]	ASTM A615 Gr. 60
g10	8	#8 [25]	90 3/8" [2296]	ASTM A615 Gr. 60

Figure 31. Bogie Testing Matrix and Setup, Deck Rebar Details

Bill of Bars				
Bar	QTY	Size	Total Unbent Length	Material
g11	47	#4 [13]	18" [1219]	ASTM A706 Gr. 60
g12	4	#4 [13]	23 11/16" [602]	ASTM A706 Gr. 60
g13	2	#4 [13]	40" [1016]	ASTM A706 Gr. 60
g14	1	#5 [16]	52 3/16" [1325]	ASTM A706 Gr. 60
g15	10	#4 [13]	18" [1219]	ASTM A615 Gr. 60

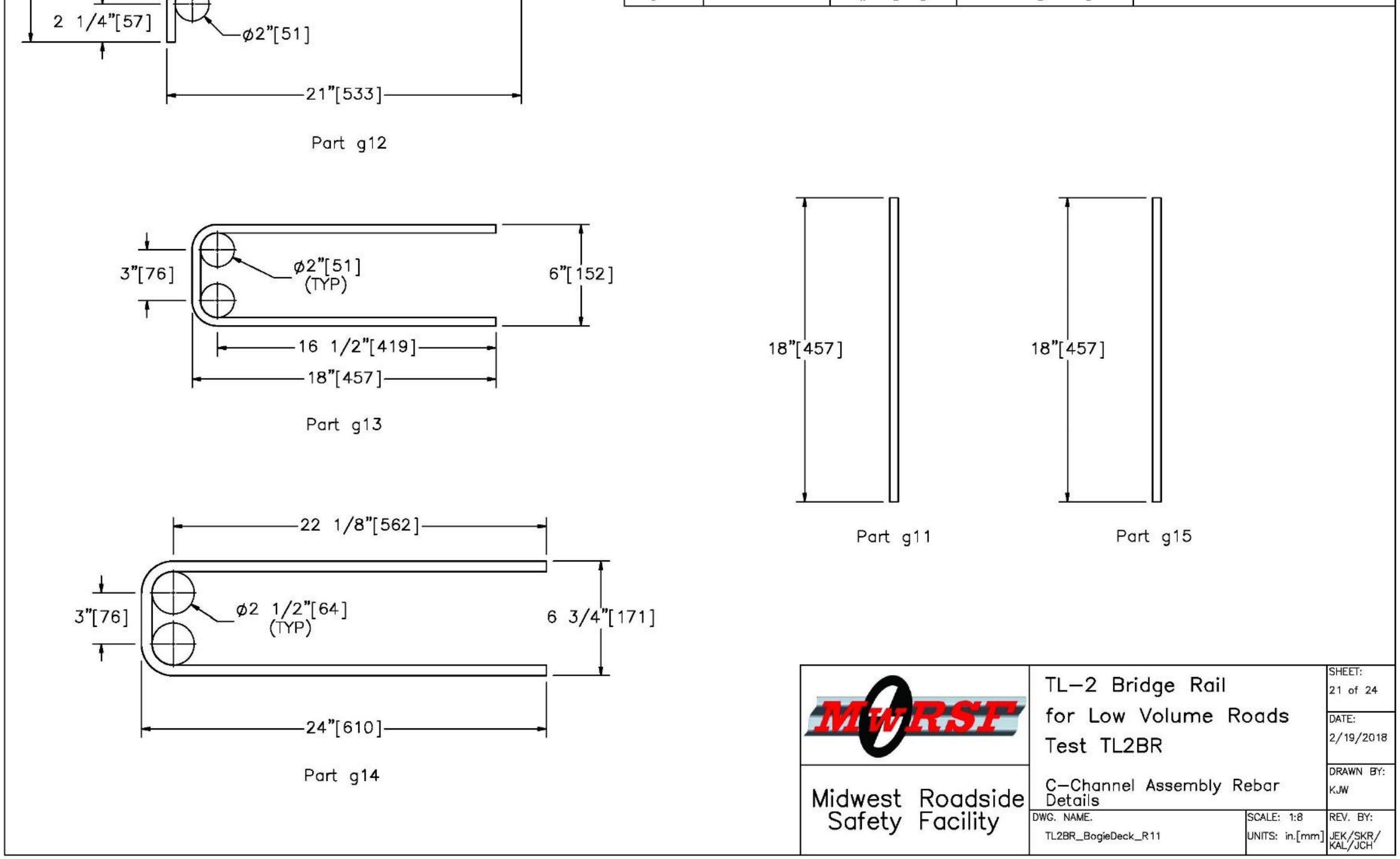


Figure 32. Bogie Testing Matrix and Setup, C-Channel Assembly Rebar Details

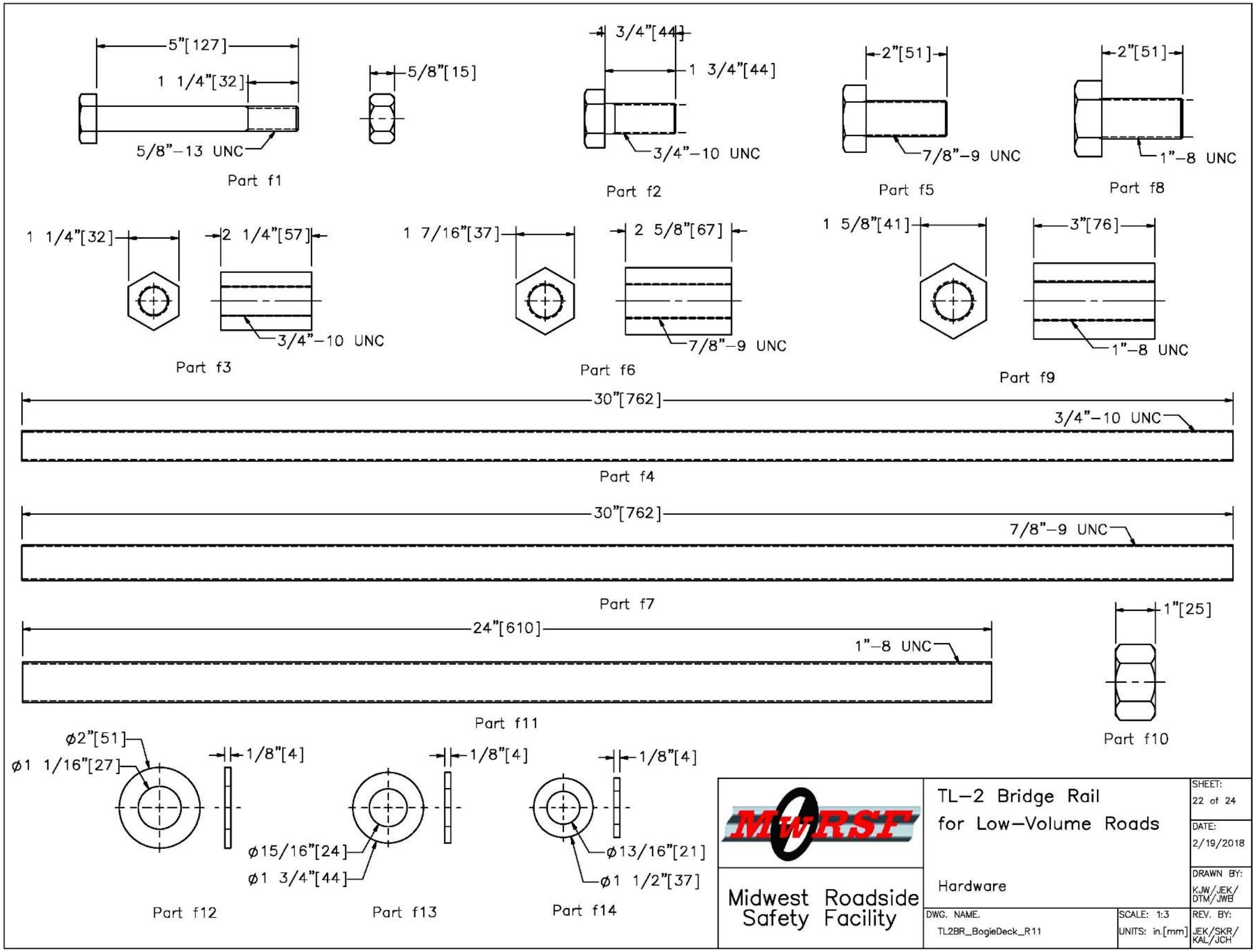


Figure 33. Bogie Testing Matrix and Setup, Hardware

Item No.	QTY.	Description	Material Spec	Galvanization Spec	Hardware Guide
a1	2	Concrete	Min. f'c = 6,000 psi [41.4 MPa] NE Mix 47BD	–	–
b1	1	C7x9.8 [C178x14.3], 36" [914] Long C-Channel	ASTM A36	–	–
b2	3	C7x9.8 [C178x14.3], 36" [914] Long C-Channel	ASTM A36	–	–
b3	2	C7x12.25 [C178x18.2], 36" [914] Long C-Channel	ASTM A36	–	–
b4	1	C12x20.7 [C305x30.8], 20" [508] Long C-Channel	ASTM A36	–	–
b5	1	C12x20.7 [C305x30.8], 20" [508] Long C-Channel	ASTM A36	–	–
b6	1	10"x2 3/4"x1/4" [254x70x6] Plate Washer	ASTM A36	ASTM A123	–
b7	4	2x2x1/4" [51x51x6] Gusset	ASTM A36	ASTM A123*	–
c1	6	HSS4x4x3/8" [102x102x10], 6 5/8" [168] Long Square Tube	ASTM A500 Gr. B	ASTM A123*	–
c2	2	HSS4x4x3/8" [102x102x10], 11 5/8" [295] Long Square Tube	ASTM A500 Gr. B	ASTM A123*	–
c3	1	10"x7"x1/2" [254x178x13] Steel Plate	ASTM A572 Gr. 50	ASTM A123*	–
c4	1	12"x10"x1/2" [305x254x13] Steel Plate	ASTM A572 Gr. 50	ASTM A123*	–
c5	1	12"x10"x1/2" [305x254x13] Steel Plate	ASTM A572 Gr. 50	ASTM A123*	–
e1	6	S3x5.7 [S76x8.5], 39" [991] Long Steel Post	ASTM A992	ASTM A123*	–
e2	2	S3x5.7 [S76x8.5], 44" [1118] Long Steel Post	ASTM A992	ASTM A123*	–
e3	32	2 3/4"x1"x1/4" [70x25x6] Post Standoff	ASTM A36	ASTM A123*	–
f1	8	5/8" [16] Dia. UNC, 5" [127] Long Heavy Hex Head Bolt and Nut	Bolt – ASTM F3125 Gr. A325 Type 1 Nut – ASTM A563DH	ASTM A153 or B633 or B695 Class 55 or F1136 Gr. 3 or F1941 or F2329 or F2833 Gr. 1	FBX16b
f2	2	3/4" [19] Dia. UNC, 1 3/4" [44] Long Heavy Hex Head Bolt	ASTM A449	ASTM A153 or B695 Class 55 or F2329	FBX20b
f3	2	3/4" [19] Dia. Heavy Hex Coupling Nut	ASTM A563DH or A194 Gr. 2H	ASTM A153 or B633 or B695 Class 55 or F1941 or F2329	–
f4	2	3/4" [19] Dia., 30" [762] Long Threaded Rod	ASTM A449	ASTM A153 or B695 Class 55 or F2329	FRR20b
f5	2	7/8" [22] Dia. UNC, 2" [51] Long Heavy Hex Head Bolt	ASTM A449	ASTM A153 or B695 Class 55 or F2329	FBX22b
f6	2	7/8" [22] Dia. Hex Coupling Nut	ASTM A563DH or A194 Gr. 2H	ASTM A153 or B633 or B695 Class 55 or F1941 or F2329	–

* Galvanization should occur after welding.

Midwest Roadside Safety Facility

TL-2 Bridge Rail for Low-Volume Roads

Bill of Materials

SHEET: 23 of 24
DATE: 2/19/2018
DRAWN BY: KJW/JEK/DTM/JWB
DWG. NAME. TL2BR_BogieDeck_R11
SCALE: 1:96
UNITS: in.[mm]
REV. BY: JEK/SKR/KAL/JCH

Figure 34. Bogie Testing Bill of Materials

Item No.	QTY.	Description	Material Spec	Galvanization Spec	Hardware Guide
f7	2	7/8" [22] Dia., 30" [762] Long Threaded Rod	ASTM A449	ASTM A153 or B695 Class 55 or F2329	–
f8	2	1" [24] Dia. UNC, 2" [51] Long Heavy Hex Head Bolt	ASTM A449	ASTM A153 or B695 Class 55 or F2329	FBX24b
f9	2	1" [25] Dia. Heavy Hex Coupling Nut	ASTM A563DH or A194 Gr. 2H	ASTM A153 or B633 or B695 Class 55 or F1941 or F2329	–
f10	4	1" [29] Dia. Heavy Hex Nut	ASTM A563DH or A194 Gr. 2H	ASTM A153 or B633 or B695 Class 55 or F1941 or F2329	FNX24b
f11	2	1" [25] Dia., 24" [610] Long Threaded Rod	ASTM A449	ASTM A153 or B695 Class 55 or F2329	FRR24b
f12	2	1" [25] Dia. Hardened Flat Washer	ASTM F436	ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329	FWC24b
f13	2	7/8" [22] Dia. Hardened Flat Washer	ASTM F436	ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329	FWC22b
f14	2	3/4" [19] Dia. Hardened Flat Washer	ASTM F436	ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329	FWC20b
g1	5	#4 [13] Bar, 287 1/2" [7,303] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)**	–
g2	1	#4 [13] Bar, 251 1/2" [6,388] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)**	–
g3	1	#4 [13] Bar. 200 1/2" [5,093] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)**	–
g4	1	#4 [13] Bar, 63" [1,600] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)**	–
g5	2	#4 [13] Bar, 48" [1,219] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)**	–
g6	98	#4 [13] Bar, 32" [813] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)**	–
g7	70	#4 [13] Bar, 20" [508] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)**	–
g8	19	#3 [10] Bar, 86 7/8" [2,207] Long Unbent	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)**	–
g9	5	#4 [13] Bar, 90 3/8" [2,296] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)**	–
g10	8	#8 [25] Bar, 90 3/8" [2,296] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)**	–
g11	47	#4 [13] Bar, 18" [457] Long	ASTM A706 Gr. 60	–	–
g12	4	#4 [13] Bar, 23 11/16" [602] Long Unbent	ASTM A706 Gr. 60	–	–
g13	2	#4 [13] Bar, 40" [1,016] Long Unbent	ASTM A706 Gr. 60	–	–
g14	1	#5 [16] Bar, 52 3/16" [1,325] Long Unbent	ASTM A706 Gr. 60	–	–
g15	10	#4 [13] Bar, 18" [457] Long	ASTM A615 Gr. 60	–	–

** Component does not need to be epoxy-coated for testing purposes.

Midwest Roadside Safety Facility

TL-2 Bridge Rail for Low-Volume Roads

Bill of Materials

SHEET: 24 of 24
DATE: 2/19/2018
DRAWN BY: KJW/JEK/DTM/JWB
DWG. NAME. TL2BR_BogieDeck_R11
SCALE: 1:96
UNITS: in.[mm]
REV. BY: JEK/SKR/KAL/JCH

Figure 35. Bogie Testing Bill of Materials

(a)

(b)

Figure 36. Installation Photographs for the (a) 7-in. CIP Deck and (b) 12-in. Precast Beam-Slab

3.3 Equipment and Instrumentation

Equipment and instrumentation utilized to collect and record data during the dynamic bogie tests included a bogie vehicle, accelerometers, a retroreflective speed trap, and high-speed and standard-speed digital video cameras.

3.3.1 Bogie Vehicle

A rigid-frame bogie was used to impact the post and socket assemblies. Two different impact heads were used in the testing. For lateral impacts, the bogie head was constructed of 8-in. diameter, ½-in. thick standard steel pipe, with ¾-in. neoprene belting wrapped around the pipe. The lateral impact head was bolted to the bogie vehicle at a height of 25 in. for test nos. N2B-1 through N2B-4. The combined weight of the bogie used in test nos. N2B-1 through N2B-4, with the addition of the mountable impact head and accelerometers, was 1,786 lb. For longitudinal impacts, the bogie head consisted of a 2½-in. x 2½-in. x $^{5}/_{16}$-in. square tube mounted on the outside flange of a W6x25 steel beam with reinforcing gussets. The longitudinal impact head was bolted to the bogie vehicle at a height of 12 in. for test nos. N2B-5 and N2B-6. The combined weight of the bogie used in test nos. N2B-5 and N2B-6, with the addition of the mountable impact head and accelerometers, was 1,690 lb. Photographs of the bogie with both impact heads are shown in Figure 37.

The tests were conducted using a steel corrugated beam guardrail to guide the bogie vehicle. A pickup truck was used to push the bogie vehicle to the required impact velocity. After reaching the target velocity, the push vehicle braked, allowing the bogie to be free rolling as it came off the track. A remote braking system was installed on the bogie allowing it to be brought safely to rest after the test.

(a) Lateral Impact Head - Test Nos. N2B-1 Through N2B-4

(b) Longitudinal Impact Head - Test Nos. N2B-5 and N2B-6

Figure 37. Bogie Vehicle with (a) Lateral Impact Head and (b) Longitudinal Impact Head

3.3.2 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. All of the accelerometer systems were mounted near the center of gravity (c.g.) of the bogie vehicle.

The two systems, the SLICE-1 and SLICE-2 units, were modular data acquisition systems manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The acceleration sensors were mounted inside the body of a custom-built, SLICE 6DX event data recorder and recorded data at 10,000 Hz to the onboard microprocessor. The 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.

3.3.3 Retroreflective Optic Speed Trap

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

3.3.4 Digital Photography

One AOS high-speed digital video camera and three GoPro digital video cameras were used to document each test. The AOS high-speed camera had a frame rate of 500 frames per second and the GoPro video camera had a frame rate of 120 frames per second. The cameras were placed laterally from the post, with a view perpendicular to the bogie's direction of travel. A digital still camera was also used to document pre- and post-test conditions for all tests.

3.4 End of Test Determination

When the impact head initially contacts the test article, the force exerted by the surrogate test vehicle is directly perpendicular. However, as the post rotates, the surrogate test vehicle's orientation and path moves further from perpendicular. This introduces two sources of error: (1) the contact force between the impact head and the post has a vertical component and (2) the impact head slides upward along the test article. Therefore, only the initial portion of the accelerometer trace should be used since variations in the data become significant as the system rotates and the surrogate test vehicle overrides the system. Additionally, guidelines were established to define the end of test time using the high-speed video of the impact. The first occurrence of either of the following events was used to determine the end of the test: (1) the test article fractures; or (2) the surrogate vehicle overrides/loses contact with the test article.

3.5 Data Processing

The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications [8]. The pertinent acceleration signal was extracted from the bulk of the data signals. The processed acceleration data was then multiplied by the mass of the bogie to get the impact force using Newton’s Second Law. Next, the acceleration trace was integrated to find the change in velocity versus time. Initial velocity of the bogie, calculated from the retroreflective optic speed trap data, was then used to determine the bogie velocity, and the calculated velocity trace was integrated to find the bogie’s displacement. Combining the previous results, a force vs. deflection curve was plotted for each test. Finally, integration of the force vs. deflection curve provided the energy vs. deflection curve for each test.

4 COMPONENT TESTING RESULTS AND DISCUSSION

4.1 Results

A total of six dynamic component tests were conducted with the bogie vehicle impacting posts and socket assemblies attached to simulated bridge decks. Descriptions of each test, including sequential and post-test photographs, are contained in the following sections. The accelerometer data for each test was processed to obtain acceleration, velocity, and deflection curves, as well as force vs. deflection and energy vs. deflection curves. Although the individual transducers produced similar results, the values described herein were calculated from the SLICE-1 data curves in order to provide common basis for comparing results from multiple tests. Test results for all transducers are provided in Appendix B.

4.1.1 Test No. N2B-1

The test article for test no. N2B-1 used Deck Location A and Channel Assembly A. The test article consisted of a bolted socket attachment utilizing 1-in. diameter bolts and a 7-in. thick simulated CIP bridge deck. See Section 3.2 for further details. Test no. N2B-1 was conducted with the bogie impacting the S3x5.7 post at a height of 25 in. and an angle of 90 degrees (through the strong axis of the post) at a speed of 21.2 mph. The impact caused the post to deflect backward as a plastic hinge formed in the post near the top of the socket and the post twisted. The bogie ultimately overrode the post at a displacement of 30.2 in. No damage occurred to the bridge deck, socket assembly, or attachment hardware. Time sequential photographs and post-test photographs are shown in Figure 38.

Force-displacement and energy-displacement curves were created from the accelerometer data and are shown in Figure 39. A peak force of 7.0 kips occurred at a displacement of 9.8 in., and an average force of 5.6 kips occurred through 20 in. of displacement. The test article had absorbed 138.9 k-in. of energy at the time the bogie overrode the post.

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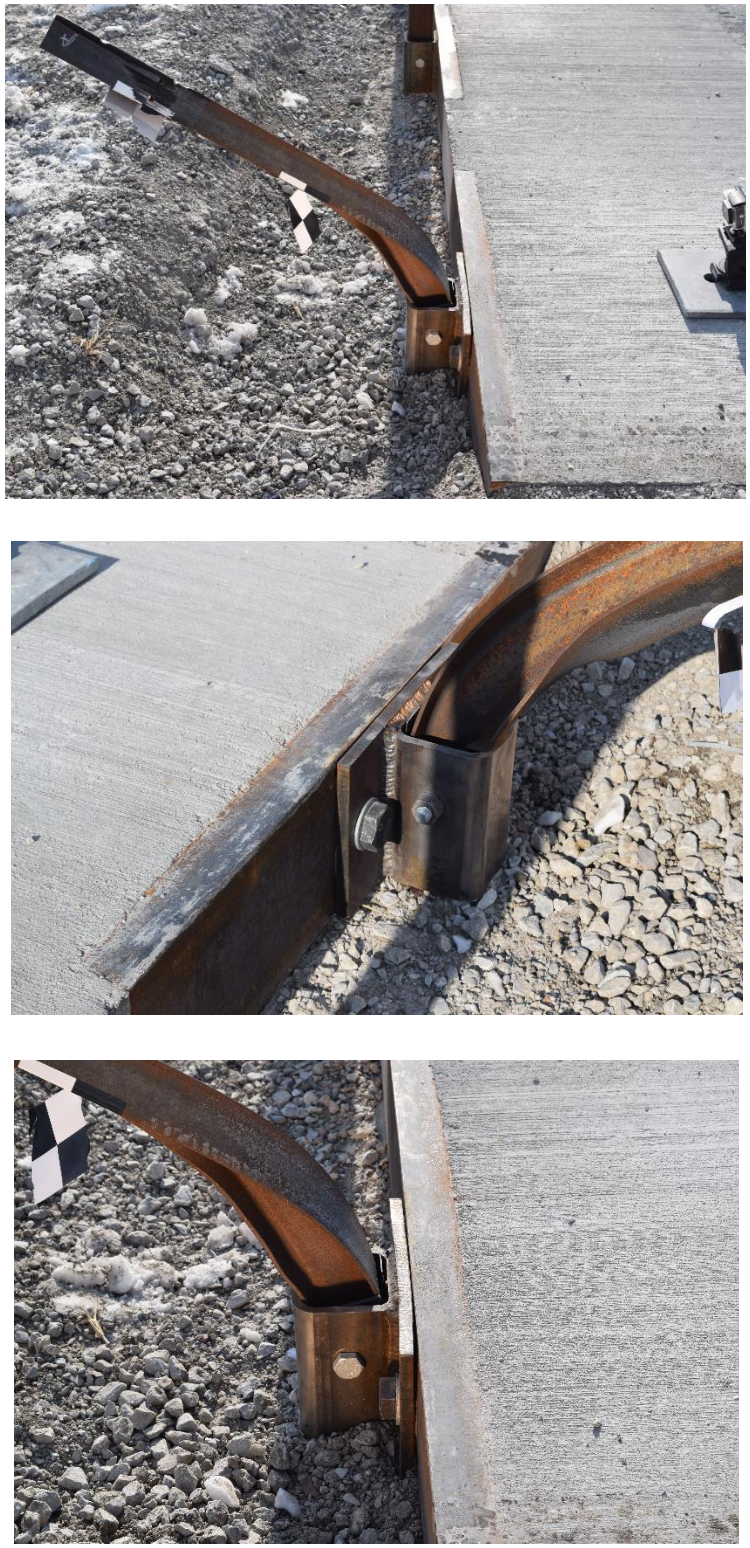

Figure 38. Time-Sequential and Post-Impact Photographs, Test No. N2B-1

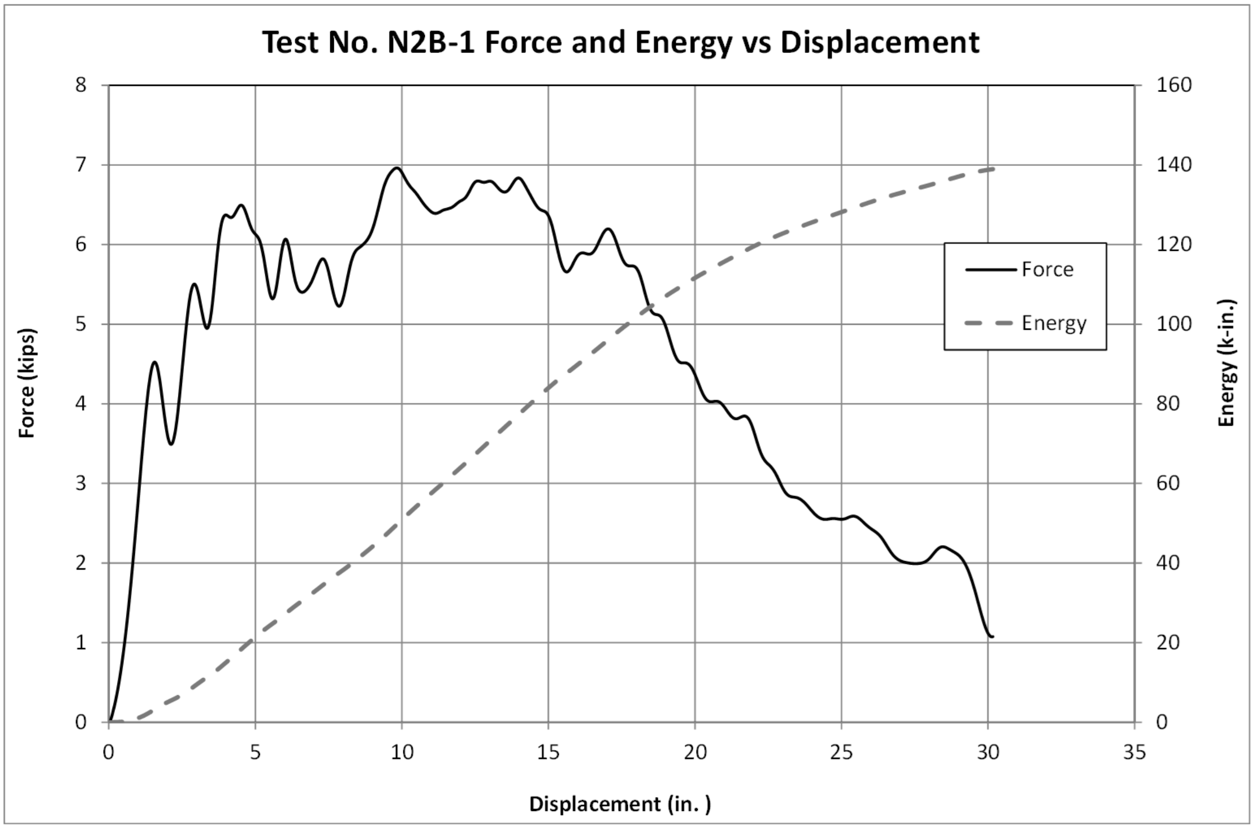

Figure 39. Force vs. Displacement and Energy vs. Displacement, Test No. N2B-1

4.1.2 Test No. N2B-2

The test article for test no. N2B-2 used Deck Location G and Channel Assembly F. The test article consisted of a bolted socket attachment utilizing ¾-in. diameter bolts and a 12-in. thick simulated precast beam-slam bridge deck. See Section 3.2 for further details. Test no. N2B-2 was conducted with the bogie impacting the S3x5.7 post at a height of 25 in. and an angle of 90 degrees (through the strong axis of the post) at a speed of 21.4 mph. The impact caused the post to deflect backward as a plastic hinge formed in the post near the top of the socket and the post twisted. The bogie ultimately overrode the post at a displacement of 29.6 in. No damage occurred to the deck, socket assembly, or attachment hardware. Time sequential photographs and post-test photographs are shown in Figure 40.

Force-displacement and energy-displacement curves were created from the accelerometer data and are shown in Figure 41. A peak force of 7.1 kips on the system occurred at a displacement of 2.6 in., and the average force through 20 in. of displacement was 5.2 kips. The test article had absorbed 124.5 k-in. of energy at the time the bogie overrode the post.

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Figure 40. Time-Sequential and Post-Impact Photographs, Test No. N2B-2

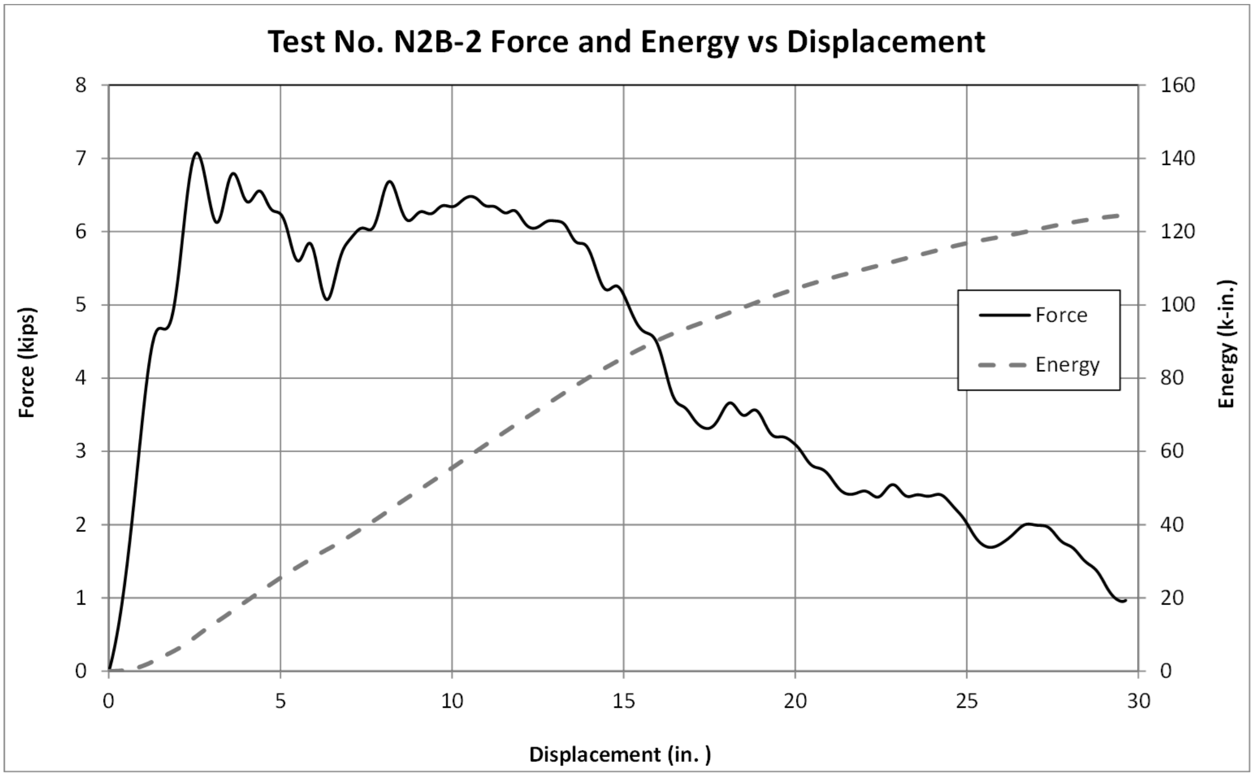

Figure 41. Force vs. Displacement and Energy vs. Displacement, Test No. N2B-2

4.1.3 Test No. N2B-3

The test article for test no. N2B-3 used Deck Location B and Channel Assembly B. The test article consisted of a welded socket attachment to the 7-in. thick simulated CIP bridge deck. The channel was anchored to the deck using straight segments of ASTM A706 rebar. See Section 3.2 for further details. Test no. N2B-3 was conducted with the bogie impacting the S3x5.7 post at a height of 25 in. and an angle of 90 degrees (through the strong axis of the post) at a speed of 21.2 mph. The impact caused the post to deflect backward as a plastic hinge formed in the post near the top of the socket. The bogie ultimately overrode the post at a displacement of 30.6 in. Due to the impact loads, the top flange of the socket had begun to pry away from the deck, and a ⅛-in. wide crack was found between the channel and the concrete. Additionally, some concrete spalling was found on the top edge of the deck adjacent to the channel. The socket and welds remained undamaged. Time sequential photographs and post-test photographs are shown in Figure 42.

Force-displacement and energy-displacement curves were created from the accelerometer data and are shown in Figure 43. A peak force of 7.4 kips on the system occurred at a displacement of 12.2 in., and the average force through 20 in. of displacement was 5.2 kips. The test article had absorbed 148.9 k-in. of energy at the time the bogie overrode the post.

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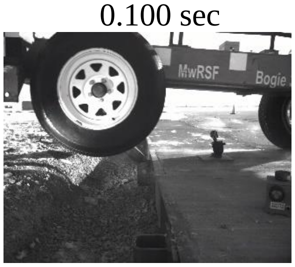

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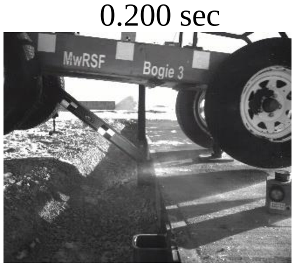

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Figure 42. Time-Sequential and Post-Impact Photographs, Test No. N2B-3

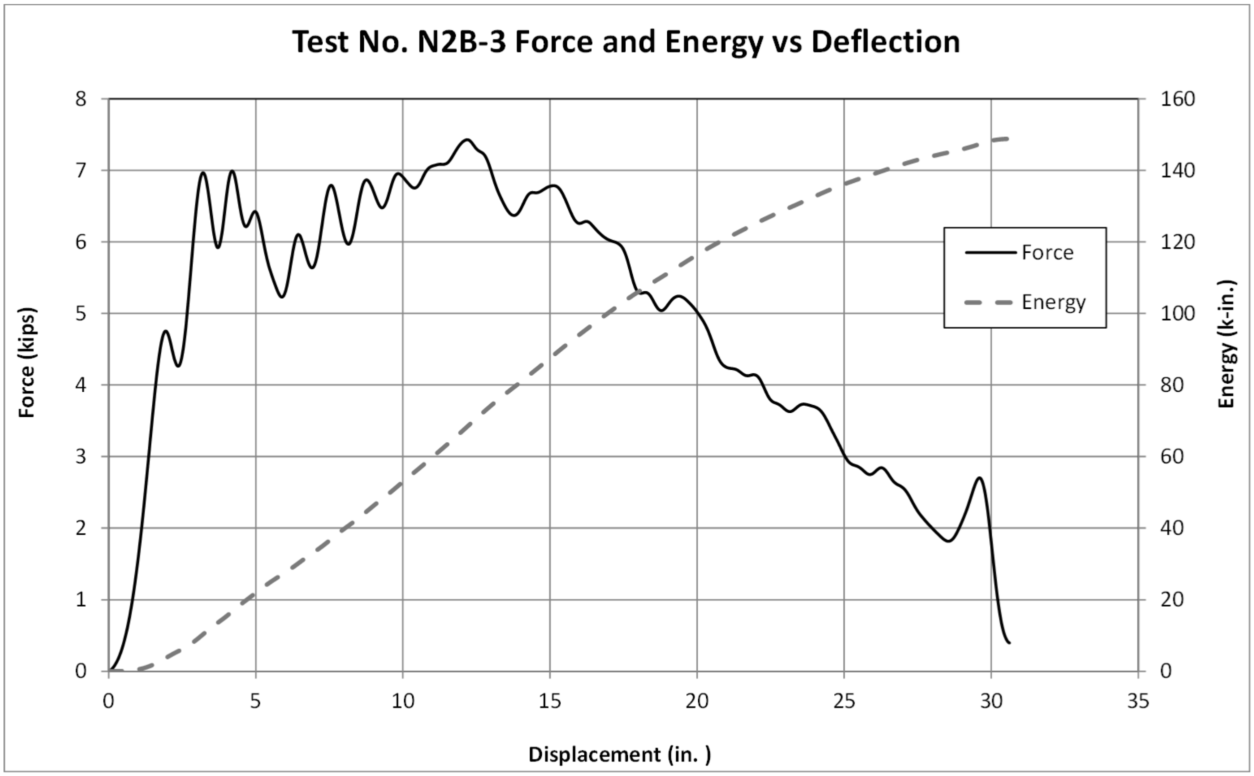

Figure 43. Force vs. Displacement and Energy vs. Displacement, Test No. N2B-3

4.1.4 Test No. N2B-4

The test article for test no. N2B-4 used Deck Location E and Channel Assembly D. The test article consisted of a welded socket attachment to the 7-in. thick simulated CIP bridge deck. The channel was anchored to the deck using a U-bar welded to the upper bend of the channel and additional #4 straight bars. See Section 3.2 for further details. Test no. N2B-4 was conducted with the bogie impacting the S3x5.7 post at a height of 25 in. and an angle of 90 degrees (through the strong axis of the post) at a speed of 21.5 mph. The impact caused the post to deflect backward as a plastic hinge formed in the post near the top of the socket. The bogie ultimately overrode the post at a displacement of 30.8 in. No damage was observed to the bridge deck or socket assembly. Time sequential photographs and post-test photographs are shown in Figure 44.

Force-displacement and energy-displacement curves were created from the accelerometer data and are shown in Figure 45. A peak force of 7.5 kips on the system occurred at a displacement of 11.5 in., and the average force through 20 in. of displacement was 5.9 kips. The test article had absorbed 156.6 k-in. of energy at the time the bogie overrode the post.

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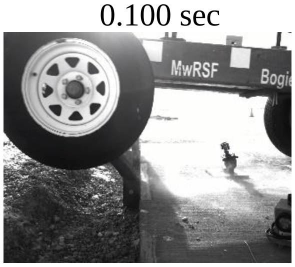

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Figure 44. Time-Sequential and Post-Impact Photographs, Test No. N2B-4

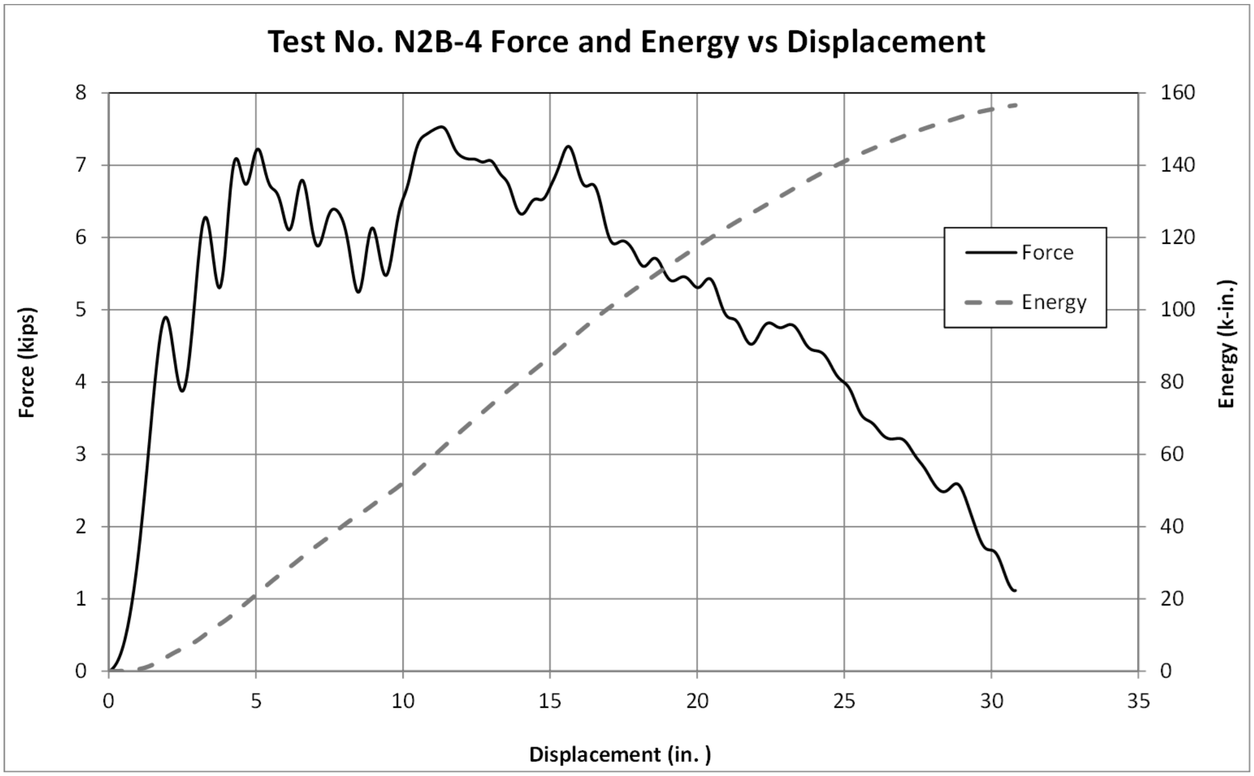

Figure 45. Force vs. Displacement and Energy vs. Displacement, Test No. N2B-4

4.1.5 Test No. N2B-5

The test article for test no. N2B-5 used Deck Location G and Channel Assembly F. The test article consisted of a bolted socket attachment utilizing ¾-in. diameter bolts and a 12-in. thick simulated precast beam-slab bridge deck. See Section 3.2 for further details. Test no. N2B-5 was conducted with the bogie impacting the S3x5.7 post at a height of 12 in. and an angle of 0 degrees (through the weak axis of the post) at a speed of 20.1 mph. The impact caused the post to deflect downstream as a plastic hinge formed in the post near the top of the socket. The bogie overrode the post at 34.0 in. of displacement. No damage occurred to the deck, socket assembly, or attachment hardware. Time sequential photographs and post-test photographs are shown in Figure 46.

Force-displacement and energy-displacement curves were created from the accelerometer data and are shown in Figure 47. A peak force of 10.3 kips on the system occurred at a displacement of 2.5 in., and the average force through 20 in. of displacement was 4.0 kips. The test article had absorbed 100.5 k-in. of energy at the time the bogie overrode the post.

Figure 46. Time-Sequential and Post-Impact Photographs, Test No. N2B-5

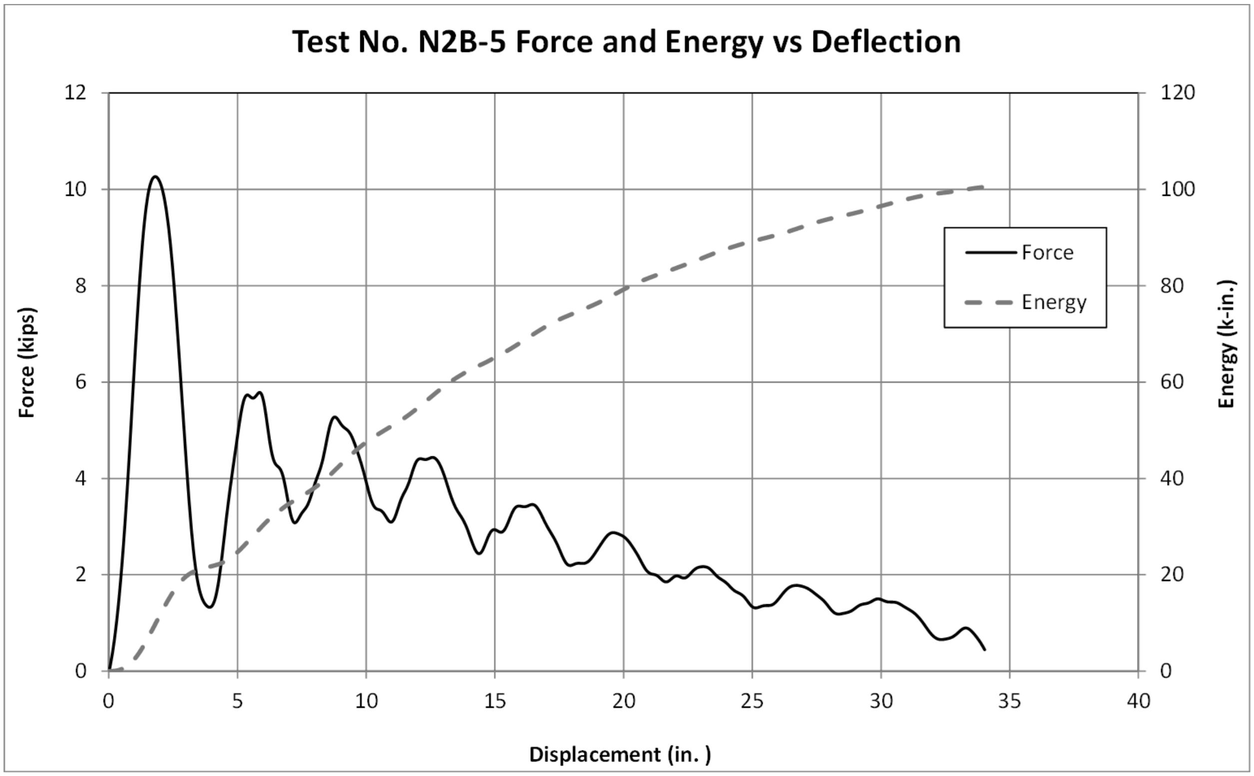

Figure 47. Force vs. Displacement and Energy vs. Displacement, Test No. N2B-5

4.1.6 Test No. N2B-6

The test article for test no. N2B-6 used Deck Location C and Channel Assembly B. The test article consisted of a welded socket attachment to the 7-in. thick simulated CIP bridge deck. The channel was anchored to the deck using straight segments of ASTM A615 rebar. See Section 3.2 for further details. Test no. N2B-6 was conducted with the bogie impacting the S3x5.7 post at a height of 12 in. and an angle of 0 degrees (through the strong axis of the post) at a speed of 21.6 mph. The impact caused the post to deflect downstream as a plastic hinge formed in the post near the top of the socket. The bogie ultimately overrode the post at a displacement of 33.6 in. No damage was observed on the bridge deck or socket assembly. Time sequential photographs and post-test photographs are shown in Figure 48.

Force-displacement and energy-displacement curves were created from the accelerometer data and are shown in Figure 49. A peak force of 9.4 kips on the system occurred at a displacement of 3.2 in., and the average force through 20 in. of displacement was 4.1 kips. The test article had absorbed 103.7 k-in. of energy at the time the bogie overrode the post.

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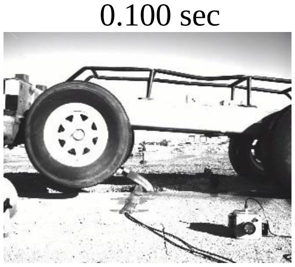

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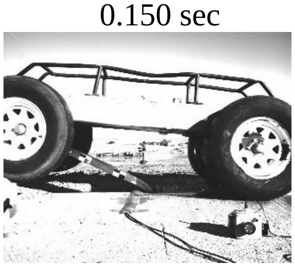

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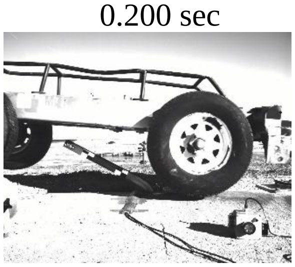

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Figure 48. Time-Sequential and Post-Impact Photographs, Test No. N2B-6

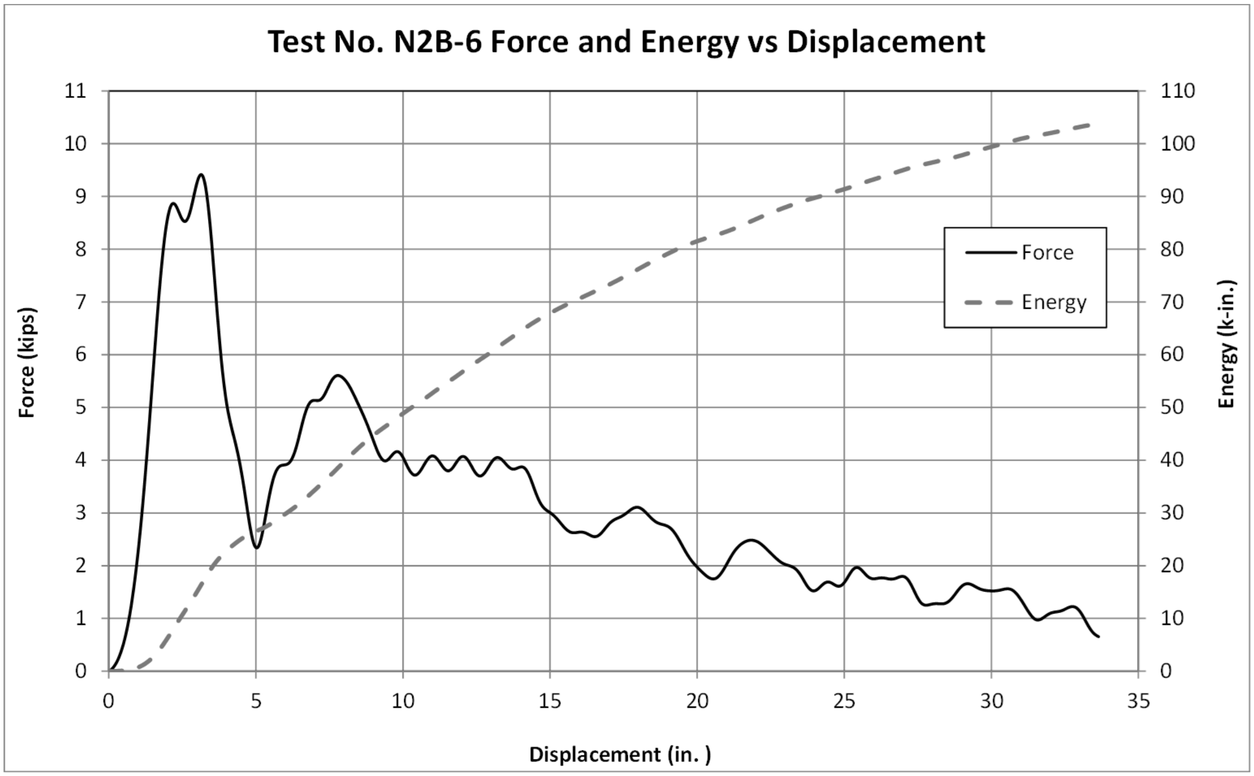


Figure 49. Force vs. Displacement and Energy vs. Displacement, Test No. N2B-6

4.2 Discussion

The results from all six component tests are summarized in Table 2. The impact speeds remained consistent throughout all the tests, and all tests resulted in plastic bending of the posts at the top of the sockets. Force displacement and energy displacement curves for the lateral impacts are shown in Figures 50 and 51, respectively. In all four tests, the force increased sharply to about 7 kips over the first 2.5 to 5 in. of displacement. The forces held steady around 6 to 7 kips until a displacement of about 15 in. and then began to gradually decrease to zero. The peak forces and the average forces calculated during the impact events were all very similar for the lateral impact tests, as would be expected with consistent post bending observed in each test. Test no. N2B-2 showed a slightly reduced resistance after about 12 in. of capacity. This was likely due to increased twisting of the post during the impact event as compared to the other test articles.

Force displacement and energy displacement curves for the longitudinal impacts are shown in Figures 52 and 53, respectively. In both tests, the force peaked sharply over the first few inches of displacement before quickly falling to around 5 kips. The forces declined steadily over the rest of the impact event. The peak forces and the average forces calculated during the impact events were all very similar for the lateral impact tests, as would be expected when both tests resulted in weak-axis bending of the posts. Plastic hinges formed near the top of the sockets in both tests. Both the deck and socket assemblies remained free from damage during the longitudinal tests.

Throughout all six tests, only test no. N2B-3, where the top flange of the channel was pulled outward ⅛ in. and minor concrete spalling was observed adjacent to the channel, resulted in any damage to the simulated decks. Thus, the straight rebar anchorage design did not provide adequate anchorage strength to the side channel for a welded socket-to-channel attachment. If a welded attachment was desired, the side channels should be anchored with the angled U-bars evaluated in test no. N2B-4.

After the bogie testing program was competed, NDOT and contractors specializing in rural bridges reviewed the results and selected the bolted attachment as the optimal attachment design. The bolted attachment was desired for its rapid and simple installation method, the ability for all components to be galvanized, and due to the direct transition of impact loads from the bolts to the threaded anchors thereby minimizing the risk of deck damage during an impact event. Therefore, the new bridge rail using a bolt, coupling nut, and threaded anchor attachment design was selected for further evaluation through full-scale crash testing.

Table 2. Dynamic Testing Results

Test No.	Attachment Details	Deck	Impact Velocity mph	Impact Angle deg.	Average Force kips			Peak Force kips	Damage Description
					@10”	@15"	@20”		
Lateral Impacts with 25-in. Impact Height									
N2B-1	Bolted: 1-in. diameter fasteners	7” CIP	21.2	90	5.1	5.6	5.6	7.0	N/A
N2B-2	Bolted: ¾-in. diameter fasteners	12” Precast Beam-Slab	21.4	90	5.6	5.7	5.2	7.1	N/A
N2B-3	Welded: #4 straight bar ASTM A706	7” CIP	21.2	90	5.3	5.8	5.8	7.4	⅛-in. crack along top edge of channel, concrete spalling
N2B-4	Welded: #5 U-bar ASTM A615	7” CIP	21.5	90	5.2	5.8	5.9	7.5	N/A
Longitudinal Impacts with 12-in. Impact Height									
N2B-5	Bolted: ¾-in. diameter fasteners	12” Precast Beam-Slab	20.2	0	4.8	4.3	4.0	10.3	N/A
N2B-6	Welded: #4 straight bar ASTM A615	7” CIP	21.6	0	4.9	4.5	4.1	9.4	N/A

Figure 50. Strong Axis, 90-Degree Impacts, Force vs. Deflection Comparison

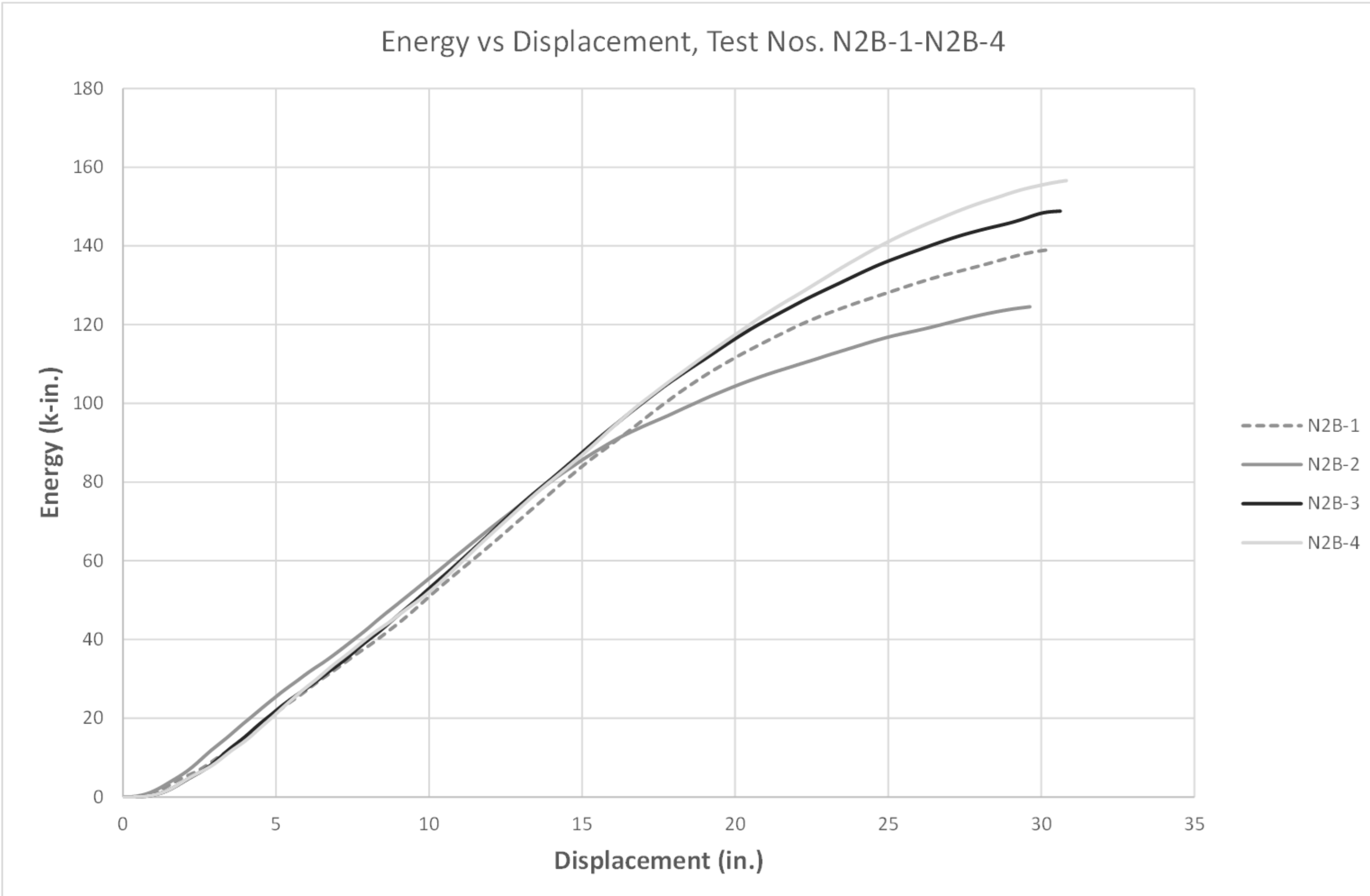


Figure 51. Strong Axis, 90-Degree Impacts, Energy vs Displacement Comparison

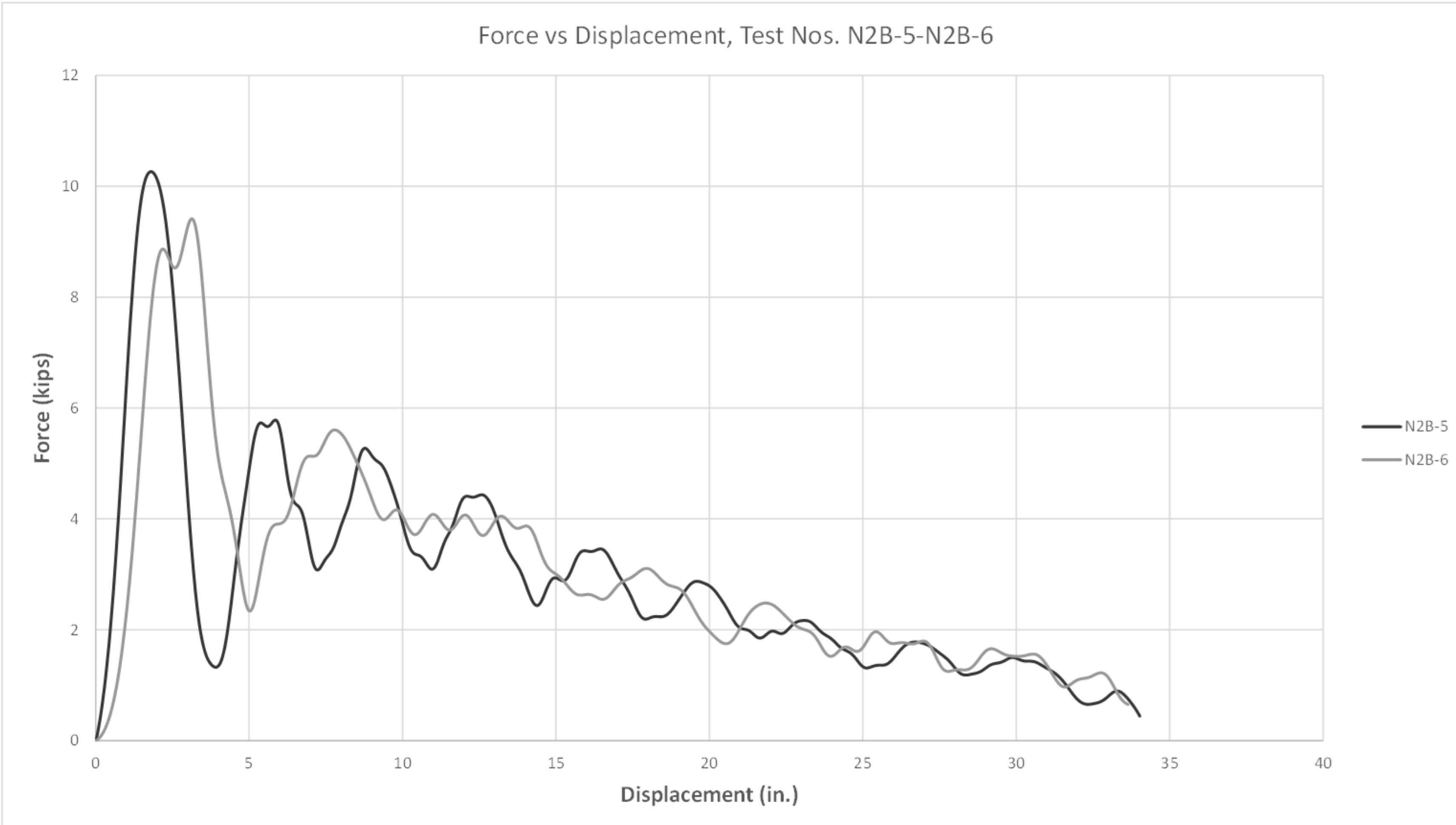


Figure 52. Weak Axis, 0-Degree Impacts, Force vs. Deflection Comparison

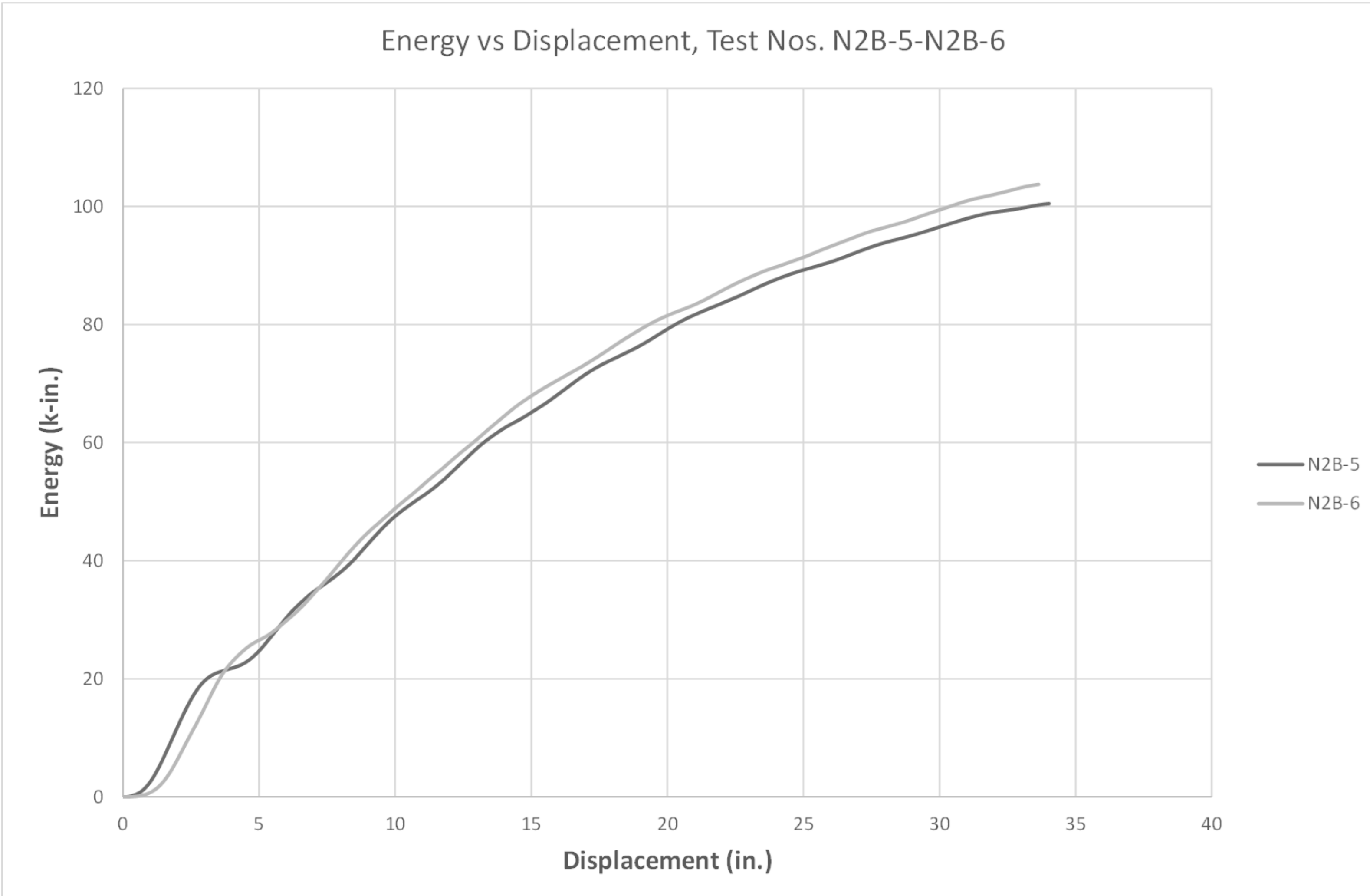


Figure 53. Weak Axis, 0-Degree Impacts, Energy vs Displacement Comparison

5 DESIGN DETAILS

5.1 Selection of Critical System Configurations for Testing

The new TL-2 bridge railing was to be compatible with both CIP and precast, beam-slab decks. After reviewing both deck types, a 7-in. thick CIP deck was identified as the thinnest and weakest of the bridge decks, which made it more susceptible to damage and anchor pullout than the thicker and stronger decks. Thus, a simulated 7-in. thick CIP deck was selected for use in full-scale crash testing. Component testing demonstrated the ability of the new coupling nut and threaded anchor attachment design to directly transfer impact loads to the interior of the deck and prevent damage to the edge of the deck, even with short channel segments at post locations. Thus, a continuous C7x9.8 channel was installed along the edge of the simulated bridge deck to represent the most common configuration for 7-in. thick decks. Note, a C7x9.8 represented the thinnest and weakest of the standard 7-in. C-channels, so use of any other 7-in. channel would also be acceptable.

As mentioned previously, CIP bridges on rural roads in Nebraska are typically constructed with the side channel located directly above the exterior bridge girders. In fact, the channels are often tack welded to the steel girders and used as formwork for pouring the deck. In recognition of this design characteristic, the full-scale test installation was constructed without a deck overhang. Instead, the edge of the simulated bridge deck was installed on a small concrete grade beam meant to represent a bridge girder. Bridges utilizing precast beam-slabs would not be directly supported at the edges the bridge. However, the increased thickness and reinforcement of precast beam-slabs results in significantly higher bending, shear, torsion, and anchor breakout strength compared to the thinner CIP decks. Therefore, precast beam-slabs would be expected to have the strength to support the new bridge rail as well.

Component testing of the bolted attachments on 7-in. CIP decks utilized 1-in. diameter bolts and threaded rods. However, an analysis of the loads observed during the component tests and the attachment design revealed that smaller ⅞-in. diameter hardware was strong enough to resist the impact loads. Subsequently, the attachment design was modified to use ⅞-in. diameter bolts, threaded rods, and coupling nuts.

5.2 Test Installation Details

A 75-ft long section of the new bridge railing was placed in the middle of a 182 ft – 3½ in. long MGS test installation, which included guardrail anchorages at both ends, as shown in Figures 54 through 81. The bridge railing consisted of 31-in. tall, 12-gauge, W-beam guardrail supported by S3x5.7 posts spaced at 75 in. on–center. A $^{5}/_{16}$-in. diameter hex bolt and a 1¾-in. square washer were used to attach the guardrail to the posts. The side-mounted posts were inserted into socket assemblies consisting of HSS4x4x⅜ tube sockets and a 10-in. x 7-in. mounting plate. Standoff plates were welded to the bottom of the posts to create a tighter fit between the post and the socket and force the posts to stand vertical after installation. A 1-in. wide steel strap was welded to the bottom of each socket to prevent the post from falling through the socket during installation. A ⅝-in. diameter keeper bolt was used to prevent the post from pulling out of the socket during impact events.

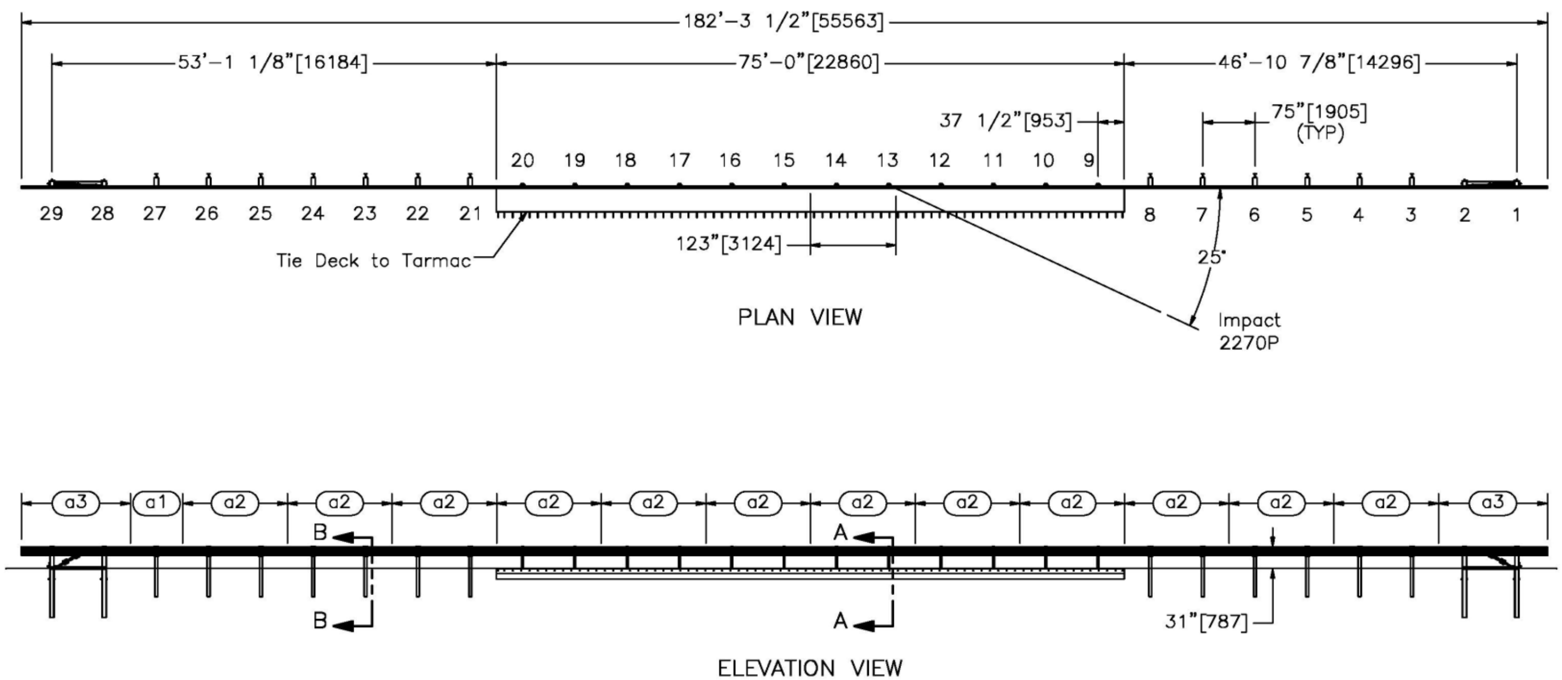
The socket assemblies were attached to the deck using two $^{7}/_{8}$-in. diameter bolts that threaded into coupling nuts embedded into the side of the bridge deck. All-thread steel rods were threaded into the opposite side of the coupling nuts and extended into the simulated deck where they were secured to a ¼-in. thick plate washer. The mounting plates of the socket assembly contained vertical slots to allow for slight height adjustments to the system during installation.

The simulated 7-in. thick, CIP bridge deck was 75 ft long, 36 in. wide, and was reinforced with #4 rebar in both the lateral and longitudinal directions for both the upper and lower steel mats. A C7x9.8 steel channel was cast into the outer edge of the deck. The channel assembly contained #4 rebar welded to the inside of its web that extended into the deck and tied into the upper and lower steel mats. The edge of the deck was supported by an unreinforced 8-in. x 12-in. grade beam meant to replicate an exterior bridge girder. The interior of the bridge deck was anchored to the existing tarmac by #4 rebar dowels. The concrete deck was constructed with a targeted minimum compressive strength of 6,000 psi. The concrete's actual 29-day compressive strength was 5,795 psi.

Standard MGS, consisting of 31-in. tall W-beam guardrail and W6x8.5 posts spaced at 75 in. on-center, was installed on both sides of the bridge railing. The systems were connected with adjacent S3x5.7 bridge posts and W6x8.5 MGS posts spaced 75 in. apart. Thus, a constant post spacing was used throughout the entire test installation.

A guardrail anchorage system typically utilized as a trailing end terminal was utilized to anchor the upstream end of the test installation. The guardrail anchorage system was originally designed to simulate the strength of other crashworthy end terminals. The anchorage system consisted of timber posts, foundation tubes, anchor cables, bearing plates, rail brackets, and channel struts, which closely resembled the hardware used in the Modified BCT system. The guardrail anchorage system has been MASH TL-3 crash tested as a downstream trailing end terminal [9-12]. Material specifications, mill certifications, and certificates of conformity for the full-scale test installation are shown in Appendix C.

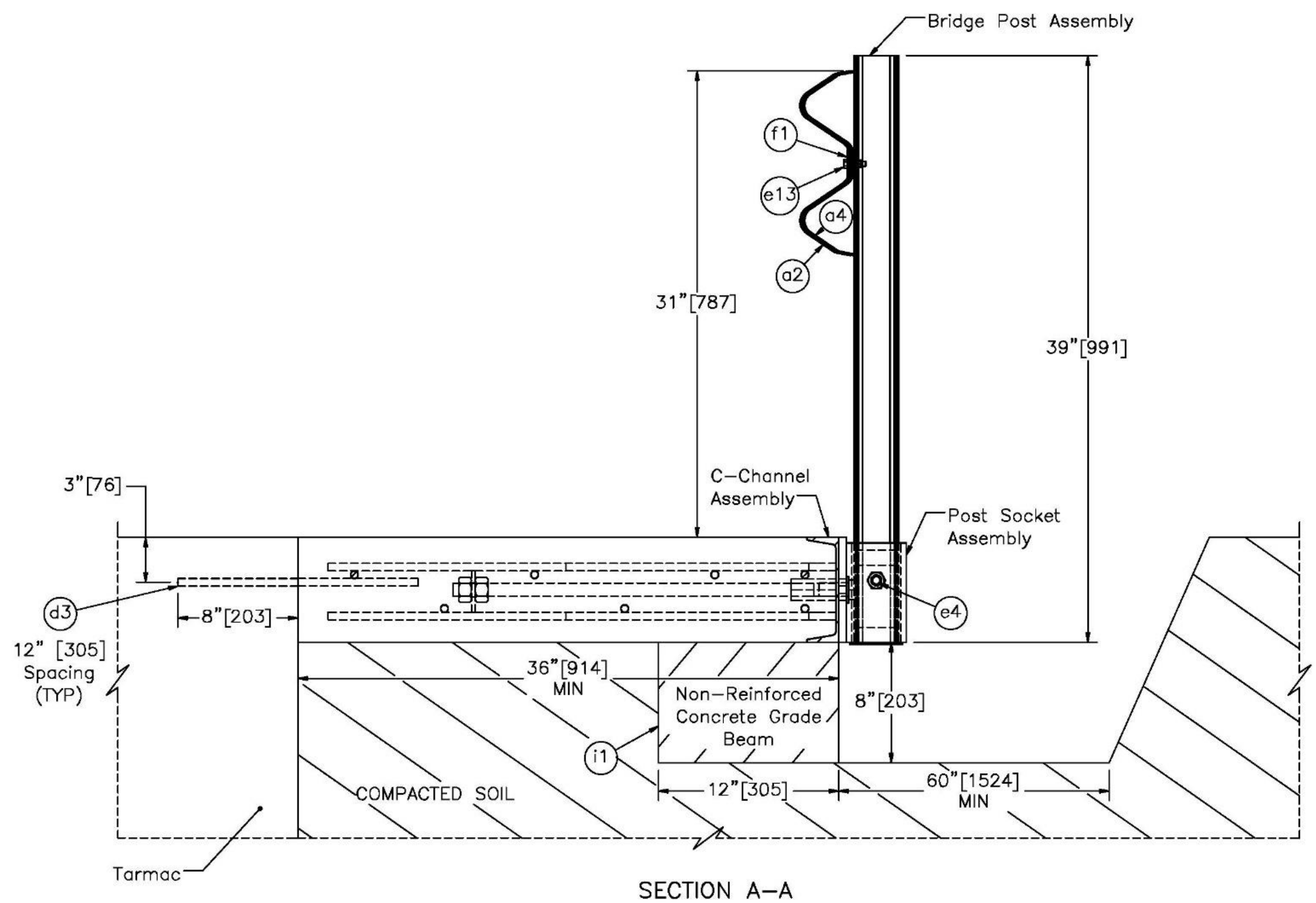
The original design intent was for 12-in. backup plates to be installed behind the W-beam at every bridge post location, as shown in Figures 55 and 75. Due to an oversight, these backup plates were not installed within the test installation. Although the test was conducted without backup plates, it is still recommended they be utilized in non-blocked, weak-post guardrail systems to prevent the rail tearing observed in other full-scale crash tests on similar systems [4-5, 13].



Notes: (1) Test shall be performed according to test designation no. 2–11 using MASH 2016 criteria.
(2) The impact location is 123" [3,124] upstream from the center of splice between post nos. 14 and 15.
(3) BCT anchors are placed in ⌀3' [914] holes, then backfilled and tamped with soil.

Midwest Roadside Safety Facility	TL–2 Bridge Rail Test No. N2BR–1 System Layout	SHEET: 1 of 27 DATE: 8/4/2020 DRAWN BY: MES/JEK/SBW
DWG. NAME. NDOR_TL2BR_R11	SCALE: 1:220 UNITS: in.[mm]	REV. BY: JK/SR/RB/RF/KL/JH

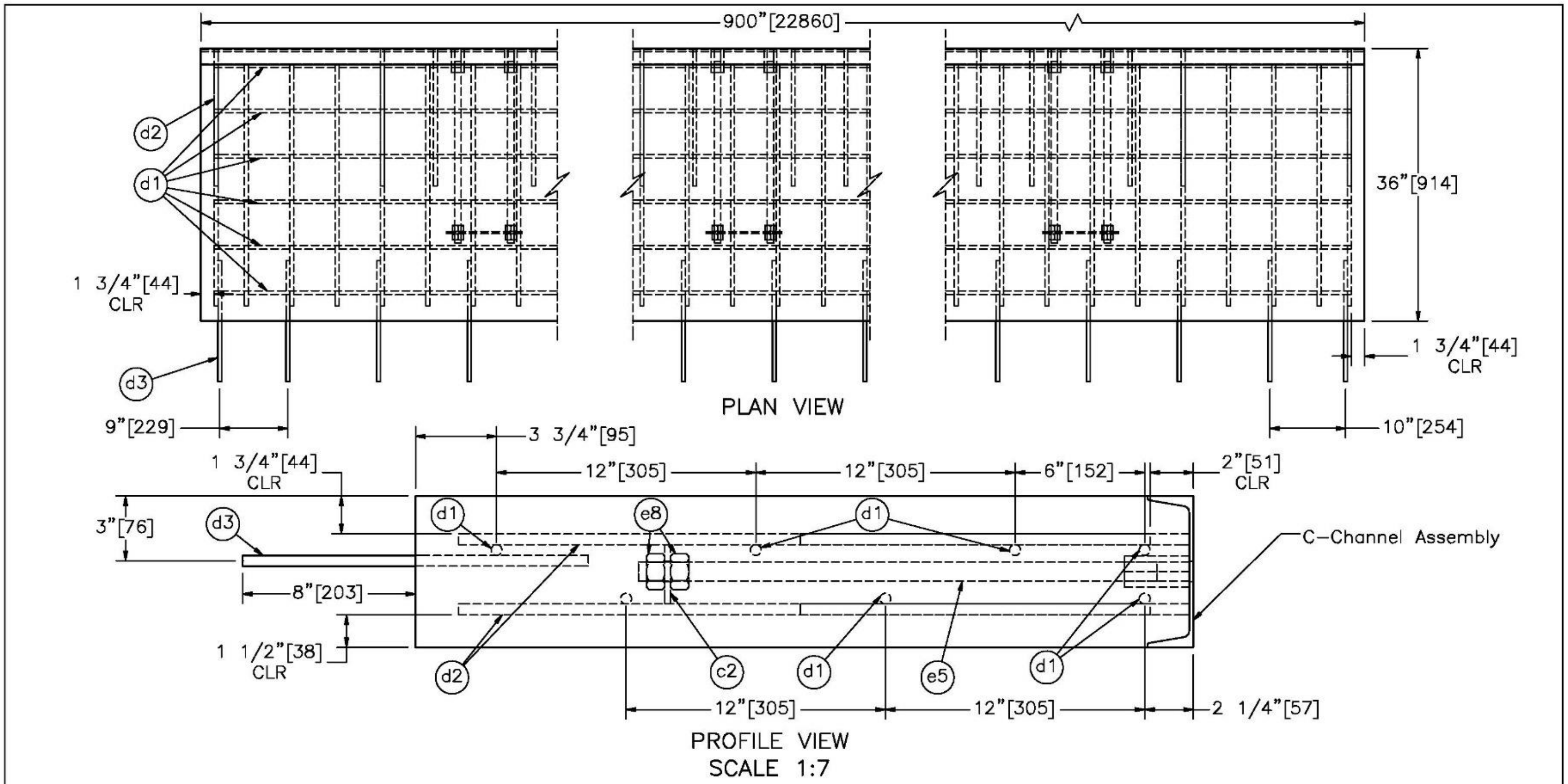
Figure 54. Test Installation Layout, Test No. N2BR-1



Notes: (1) Shim posts in deck region with shim plates (part c6) on front and back side, as necessary.
(2) Embed part no. d3 bars into tarmac with Powersfast 100+ AC gold epoxy.

Midwest Roadside Safety Facility	TL–2 Bridge Rail Test No. N2BR–1 Bridge Deck Cross Section	SHEET: 2 of 27
		DATE: 8/4/2020
		DRAWN BY: MES/JEK/SBW
	DWG. NAME. NDOR_TL2BR_R11	SCALE: 1:10 UNITS: in.[mm]
		REV. BY: JK/SR/RB/RF/KL/JH

Figure 55. Bridge Deck Cross Section, Test No. N2BR-1



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	1	Deck Assembly	–	–
–	4	C–Channel Assembly	–	ASTM A123
c2	12	10"x2 3/4"x1/4" [254x70x6] Plate Washer	ASTM A36	ASTM A123
d1	7	#4 [13] Bar, 896 1/2" [22,771] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
d2	302	#4 [13] Bar, 32" [813] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
d3	76	#4 [13] Bar, 16" [406] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)
e5	24	7/8"–9 UNC [M22x2.5], 24" [610] Long Threaded Rod	ASTM A449 or Equivalent	ASTM A153 or B695 Class 55 or F2329
e8	48	7/8" [22] Dia. Heavy Hex Nut	ASTM A563DH or Equivalent	ASTM A153 or B695 Class 55 or F2329

Notes: (1) C–Channel Assembly and reinforcement is hidden for clarity.
(2) Part e5 is threaded 1 1/4" [32] into part e7 (coupler nut).
(3) Part e7 held in place by external bolt during casting of deck.

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TL–2 Bridge Rail
Test No. N2BR–1

Concrete Deck Assembly Details

SHEET: 3 of 27
DATE: 8/4/2020
DRAWN BY: MES/JEK/S BW
REV. BY: JK/SR/RB/ RF/KL/JH
DWG. NAME. NDOR_TL2BR_R11
SCALE: 1:20
UNITS: in.[mm]

Figure 56. Concrete Deck Assembly Details, Test No. N2BR-1

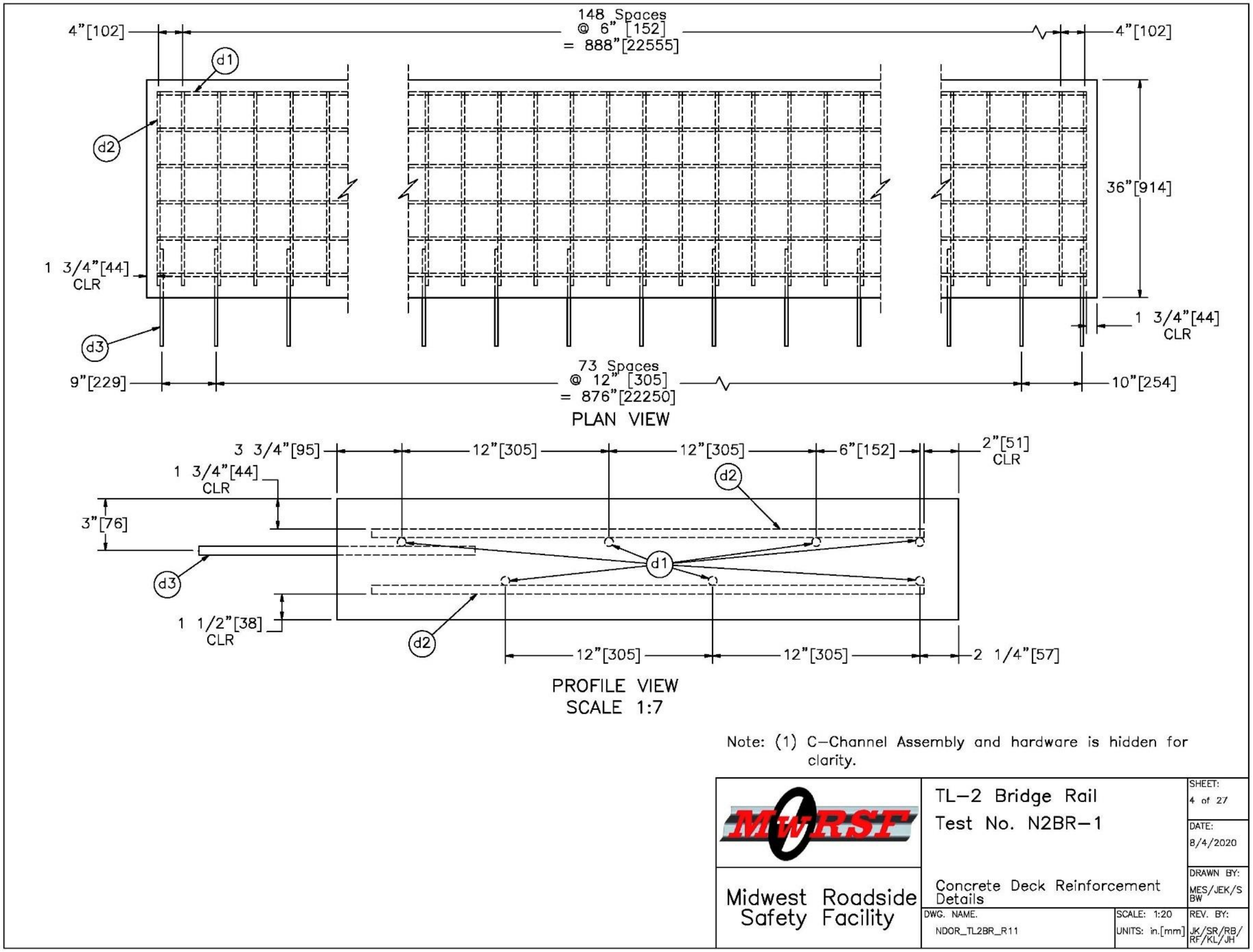


Figure 57. Concrete Deck Reinforcement, Test No. N2BR-1

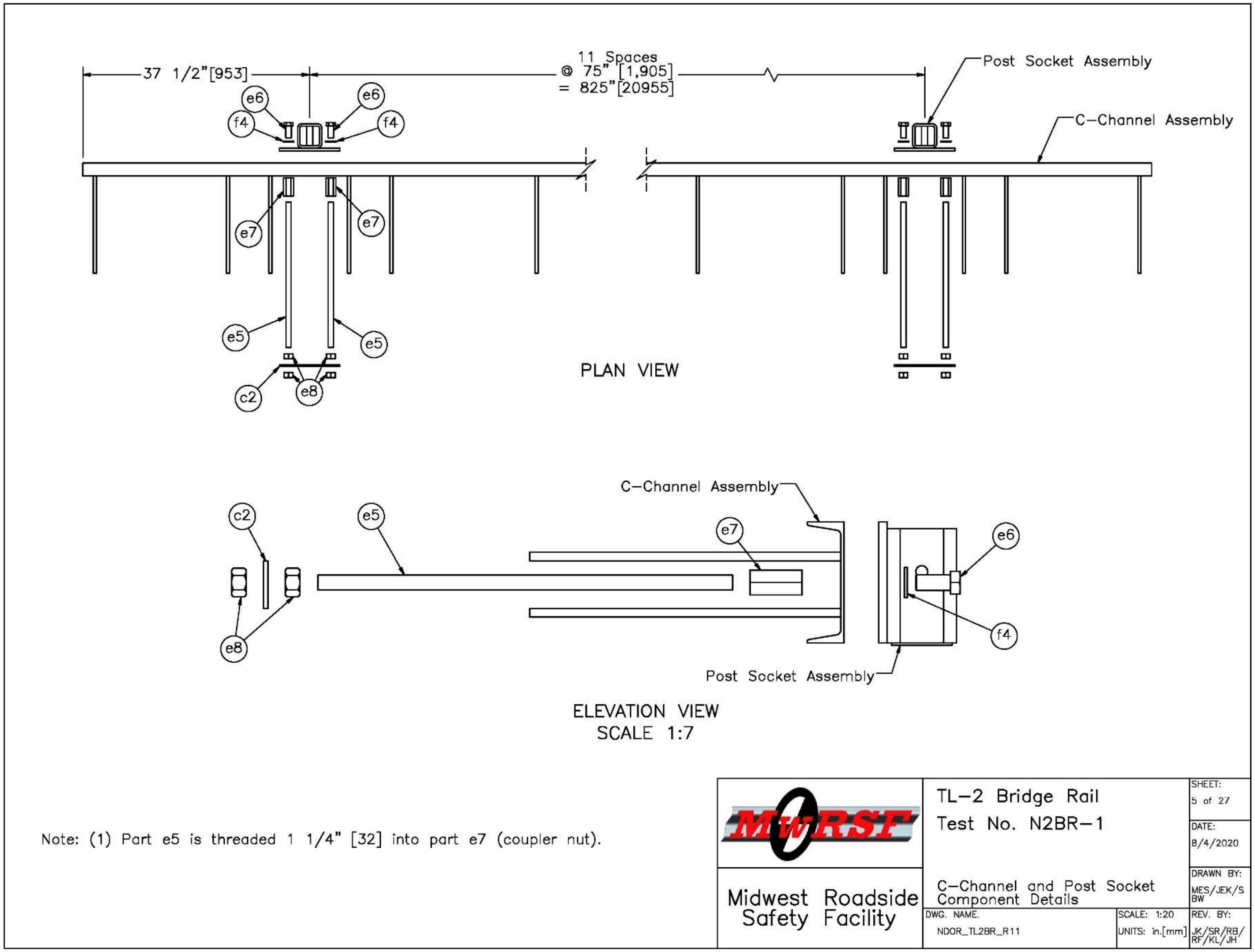


Figure 58. C-Channel and Post Socket Component Details, Test No. N2BR-1

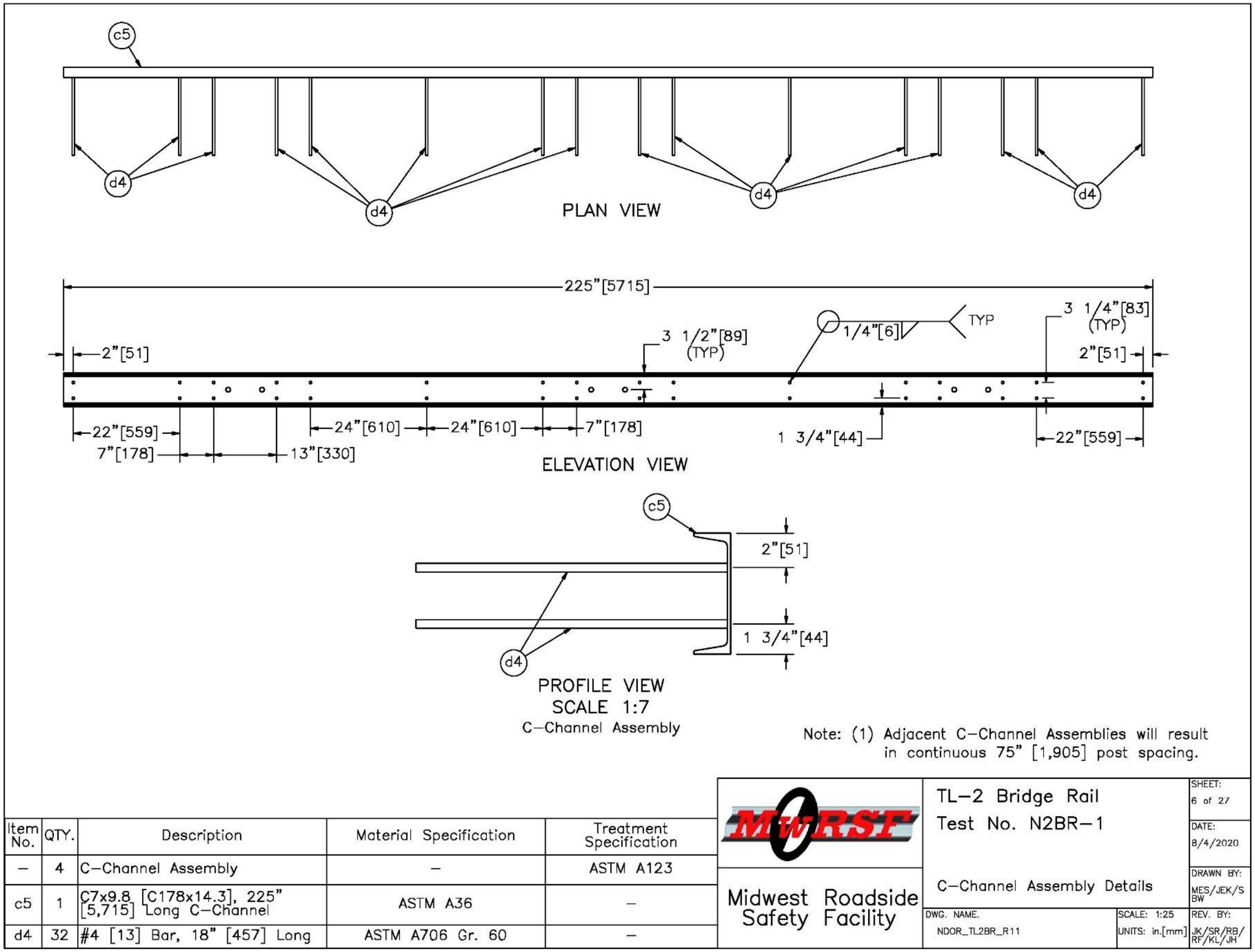


Figure 59. C-Channel Assembly Details, Test No. N2BR-1

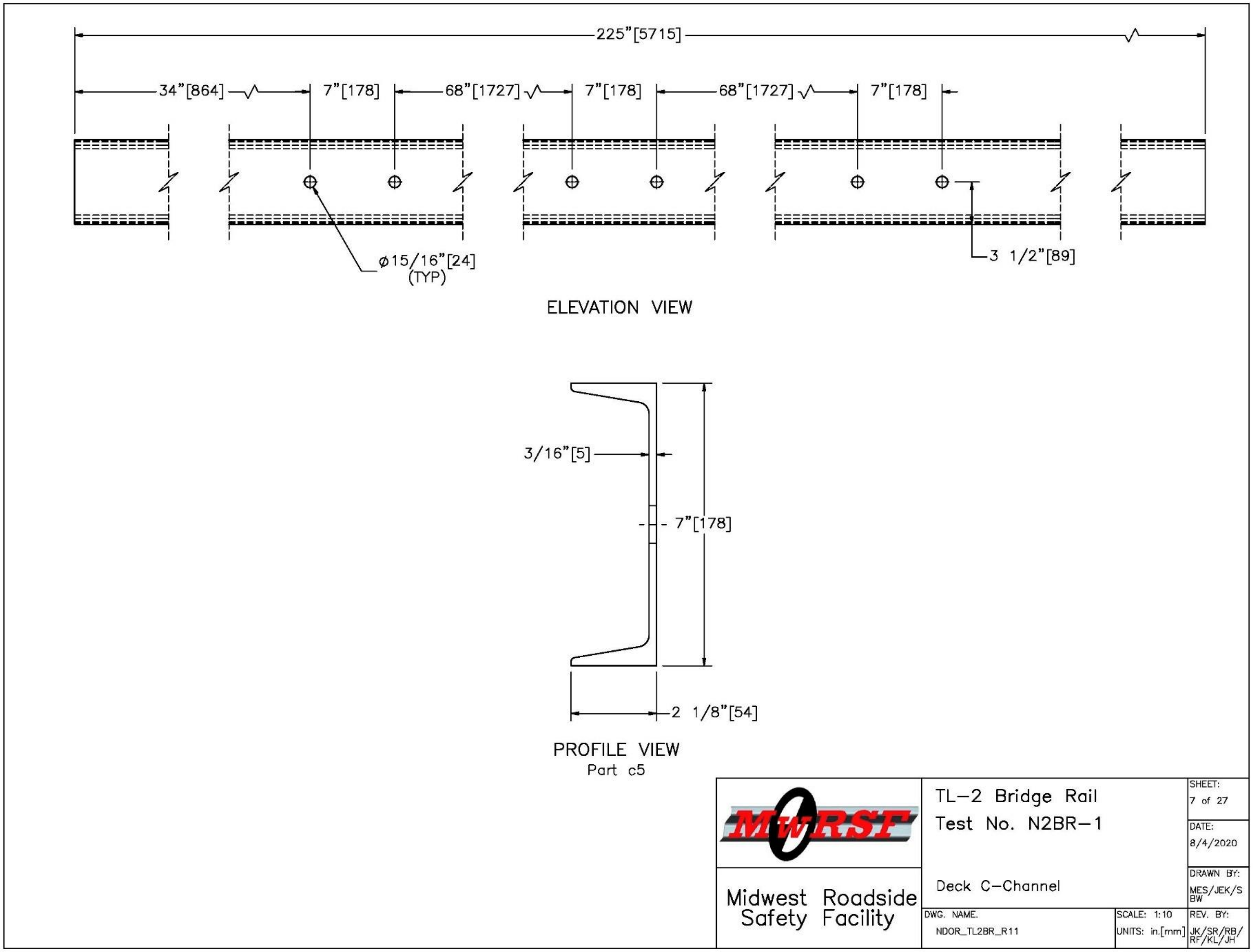
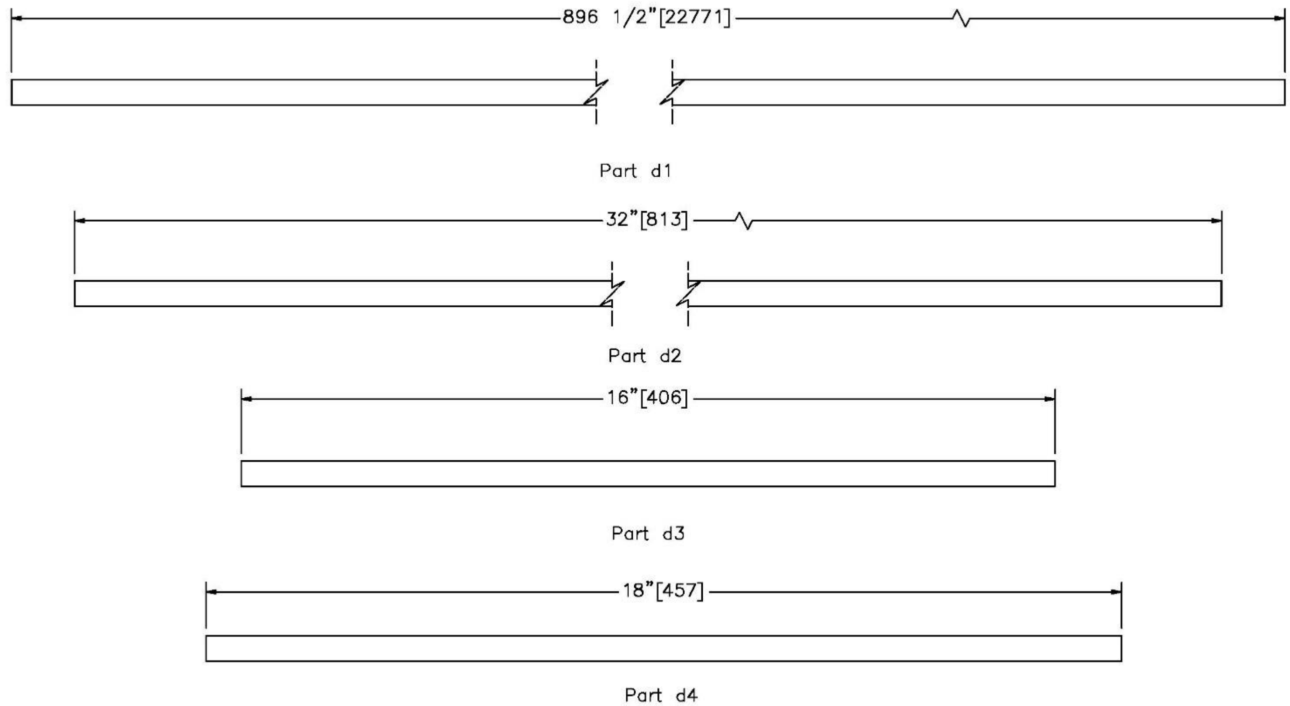


Figure 60. Deck C-Channel, Test No. N2BR-1

Bill of Bars				
Bar	QTY	Size	Total Unbent Length	Material
d1	7	#4 [13]	896 1/2" [22,771]	ASTM A615 Gr. 60
d2	302	#4 [13]	32" [813]	ASTM A615 Gr. 60
d3	76	#4 [13]	16" [406]	ASTM A615 Gr. 60
d4	128	#4 [13]	18" [457]	ASTM A706 Gr. 60



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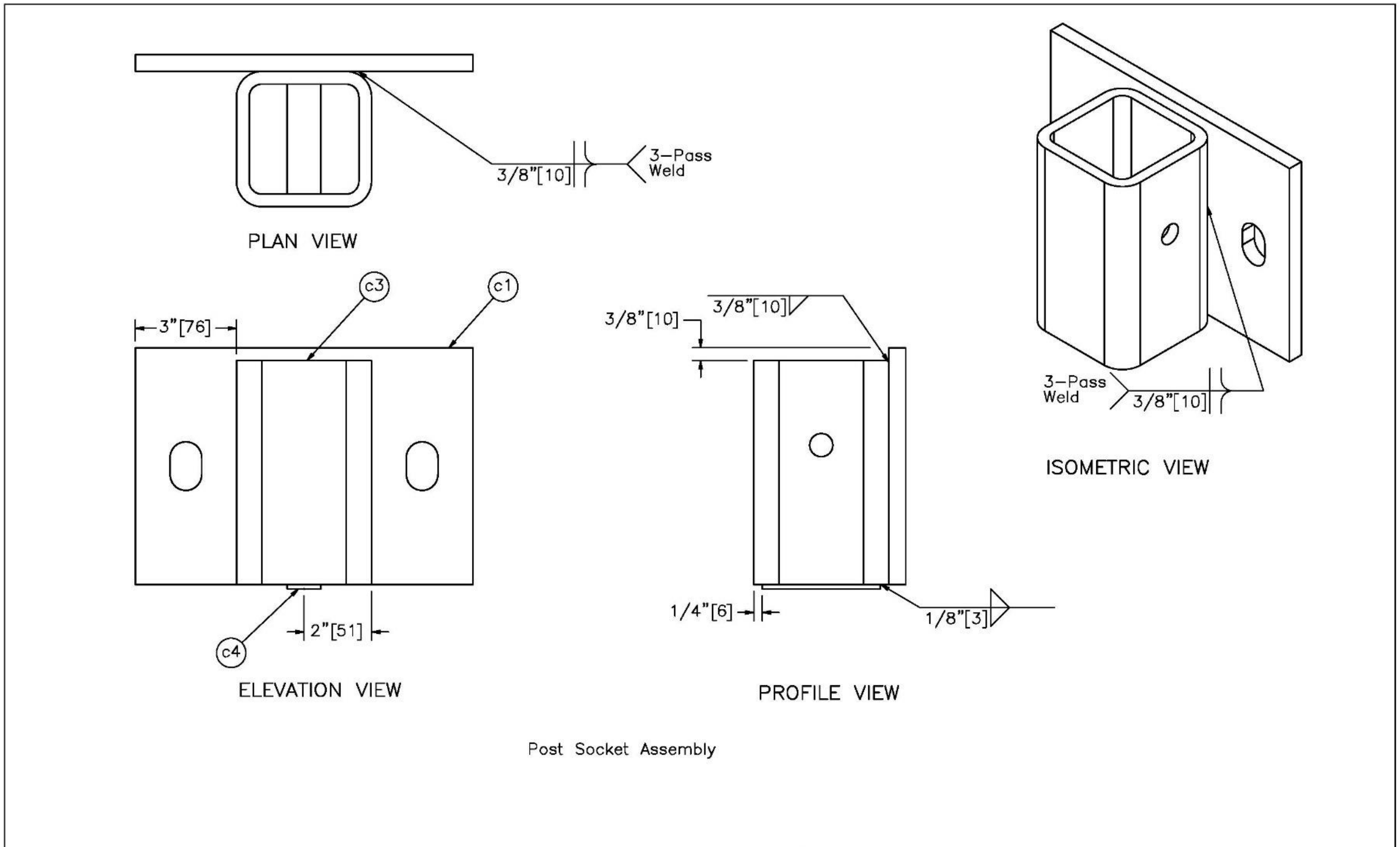
TL-2 Bridge Rail
Test No. N2BR-1

Deck Reinforcement

SHEET: 8 of 27
DATE: 8/4/2020
DRAWN BY: MES/JEK/SBW
DWG. NAME. NDOR_TL2BR_R11
SCALE: 1:3
UNITS: in.[mm]
REV. BY: JK/SR/RB/RF/KL/JH

Figure 61. Deck Reinforcement, Test No. N2BR-1



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	12	Post Socket Assembly	–	ASTM A123
c1	1	10"x7"x1/2" [254x178x13] Steel Plate	ASTM A572 Gr. 50	–
c3	1	HSS4"x4"x3/8" [102x102x10], 6 5/8" [168] Long Square Tube	ASTM A500 Gr. B	–
c4	1	3 1/2"x1"x1/8" [89x25x4]	ASTM A36	–

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TL-2 Bridge Rail
Test No. N2BR-1

Post Socket Assembly

SHEET: 9 of 27
DATE: 8/4/2020
DRAWN BY: MES/JEK/S BW
DWG. NAME. NDOR_TL2BR_R11
SCALE: 1:4
UNITS: in.[mm]
REV. BY: JK/SR/RB/ RF/KL/JH

Figure 62. Post Socket Assembly, Test No. N2BR-1

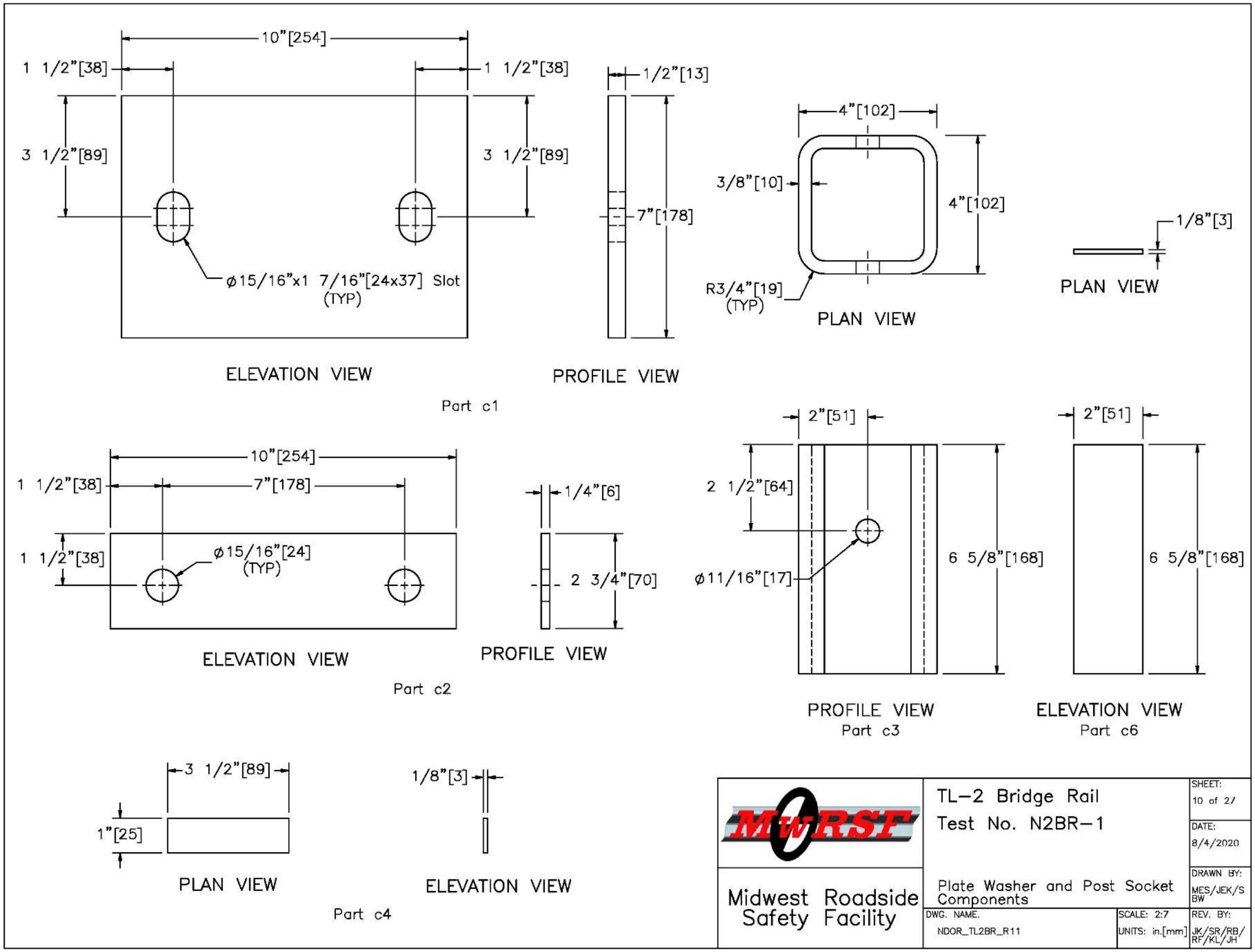
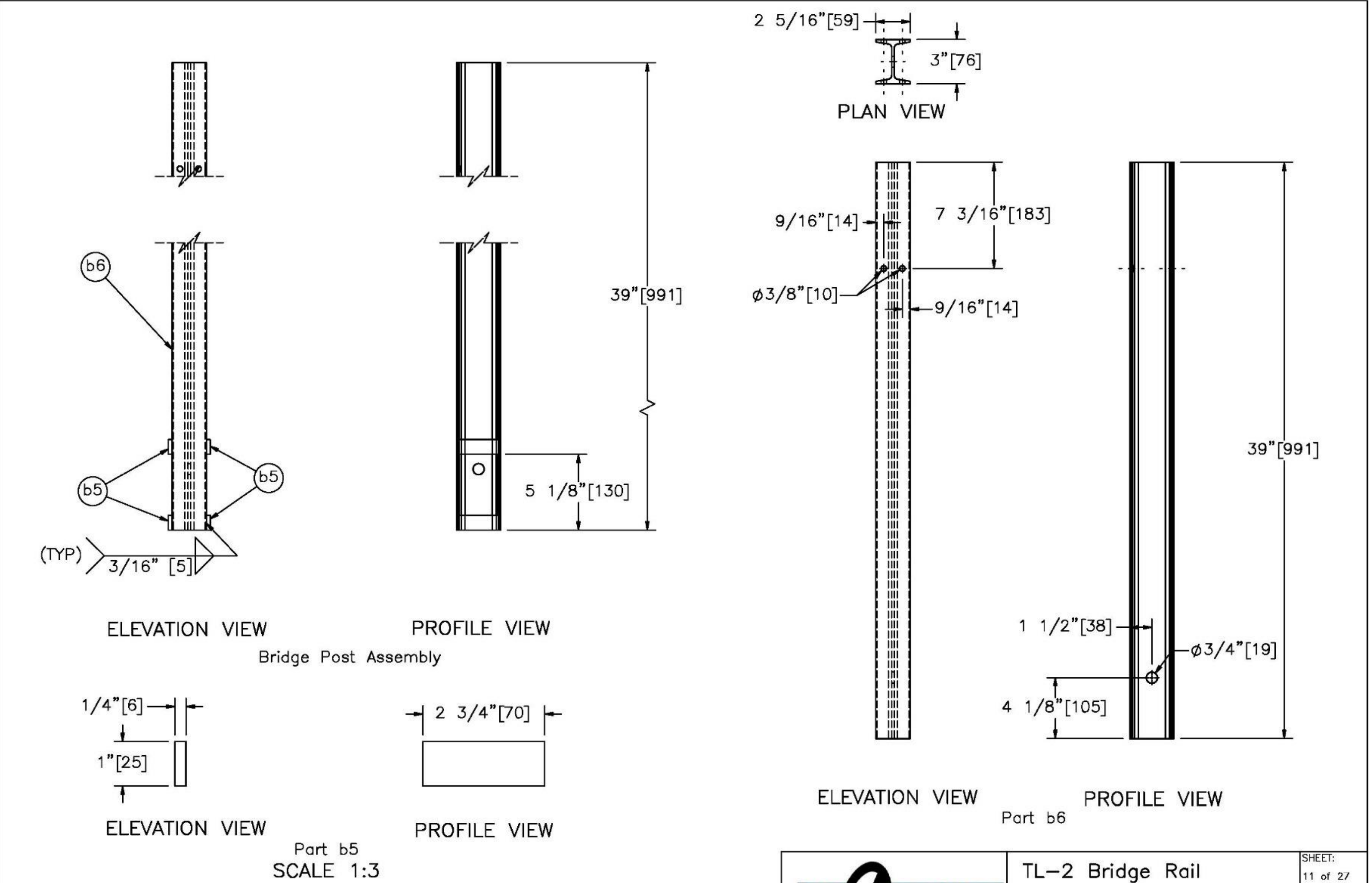


Figure 63. Plate Washer and Post Socket Components, Test No. N2BR-1



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	12	Bridge Post Assembly	–	ASTM A123
b6	1	S3x5.7 [S76x8.5], 39" [991] Long Steel Post	ASTM A992 Gr. 50	–
b5	4	2 3/4"x1"x1/4" [70x25x6] Post Standoff	ASTM A36	–

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TL–2 Bridge Rail
Test No. N2BR–1

Bridge Post Assembly and Components

SHEET: 11 of 27
DATE: 8/4/2020
DRAWN BY: MES/JEK/SBW
DWG. NAME. NDOR_TL2BR_R11
SCALE: 1:9
UNITS: in.[mm]
REV. BY: JK/SR/RB/RF/KL/JH

Figure 64. Bridge Post Assembly and Components, Test No. N2BR-1

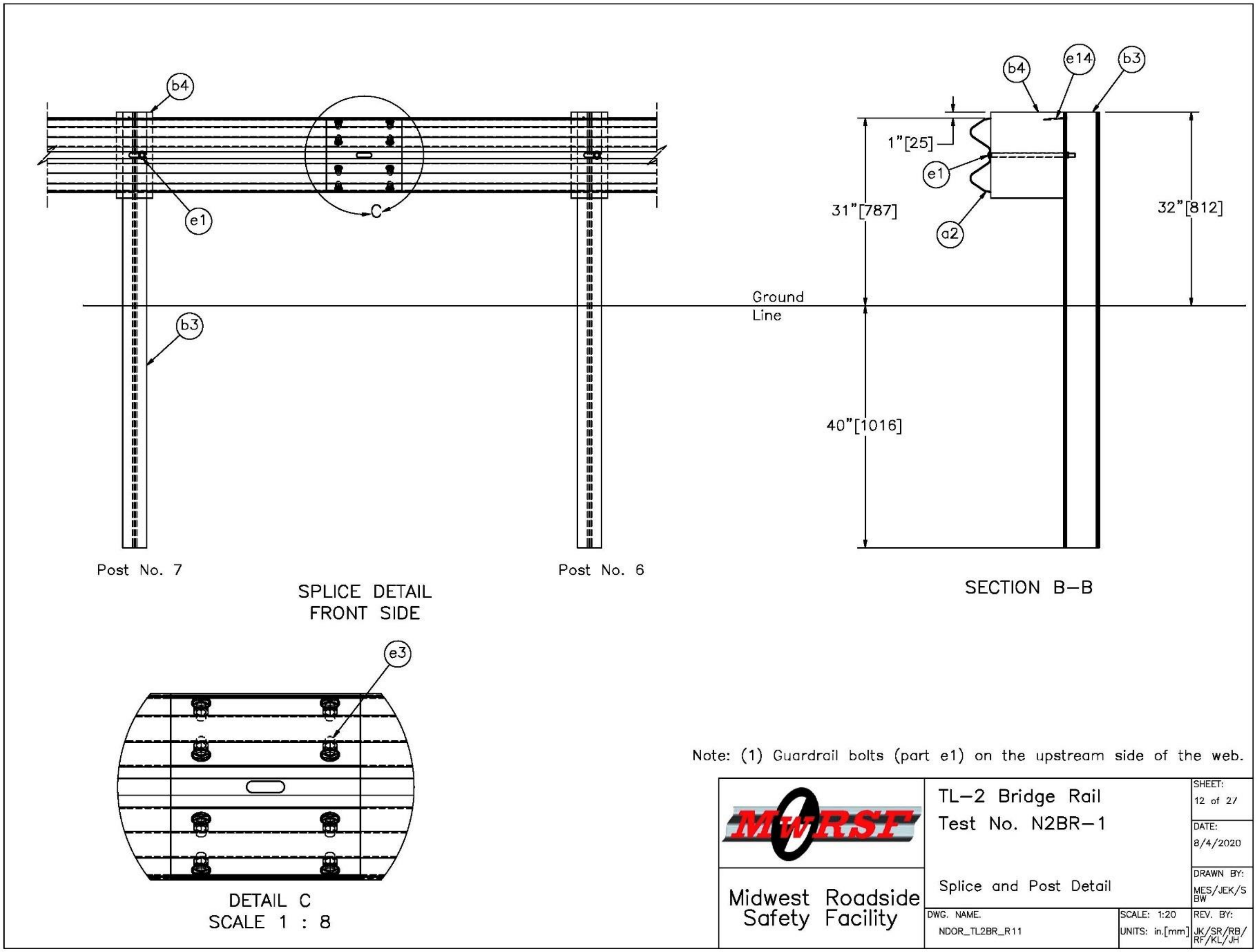


Figure 65. Splice and Post Detail, Test No. N2BR-1

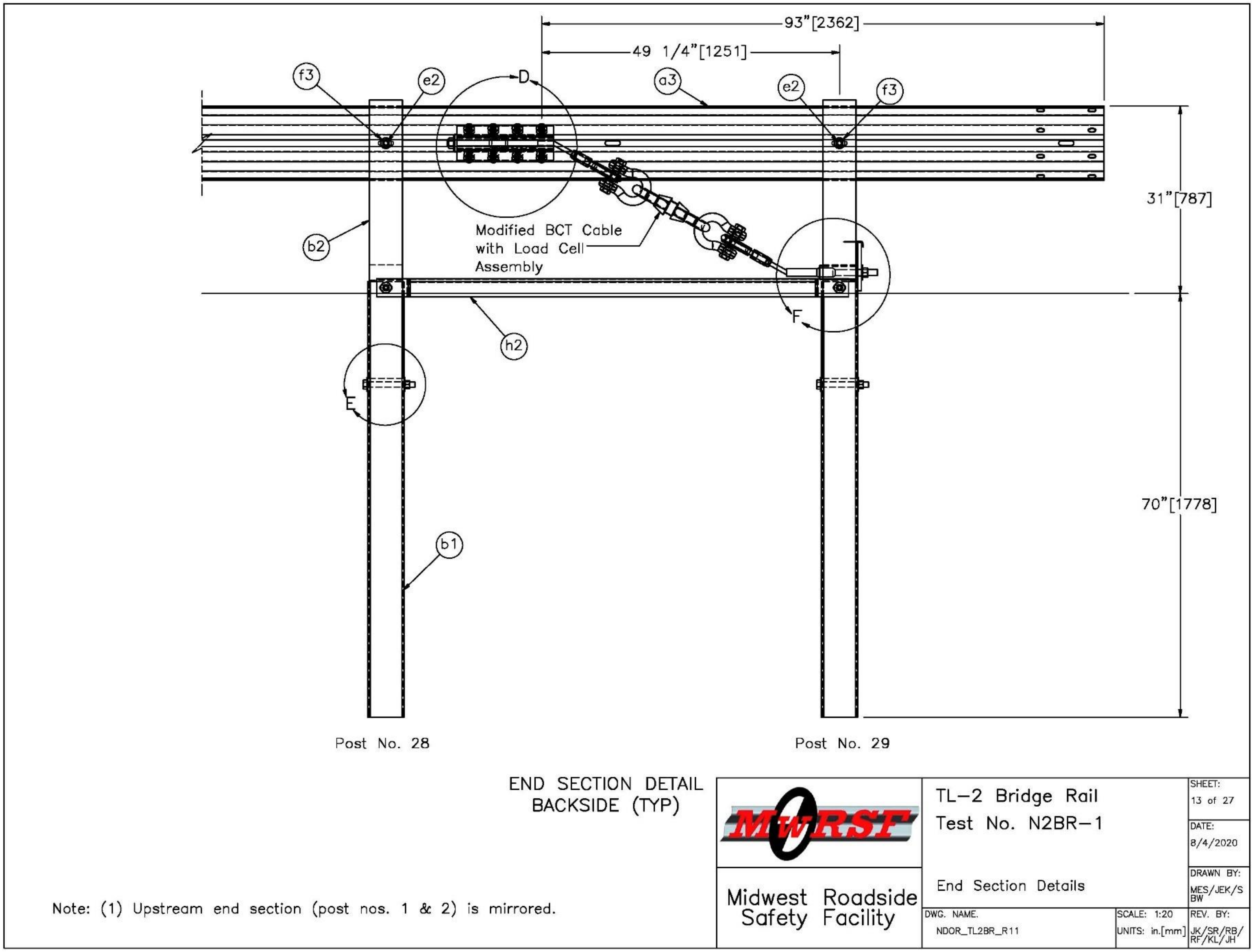


Figure 66. End Section Details, Test No. N2BR-1

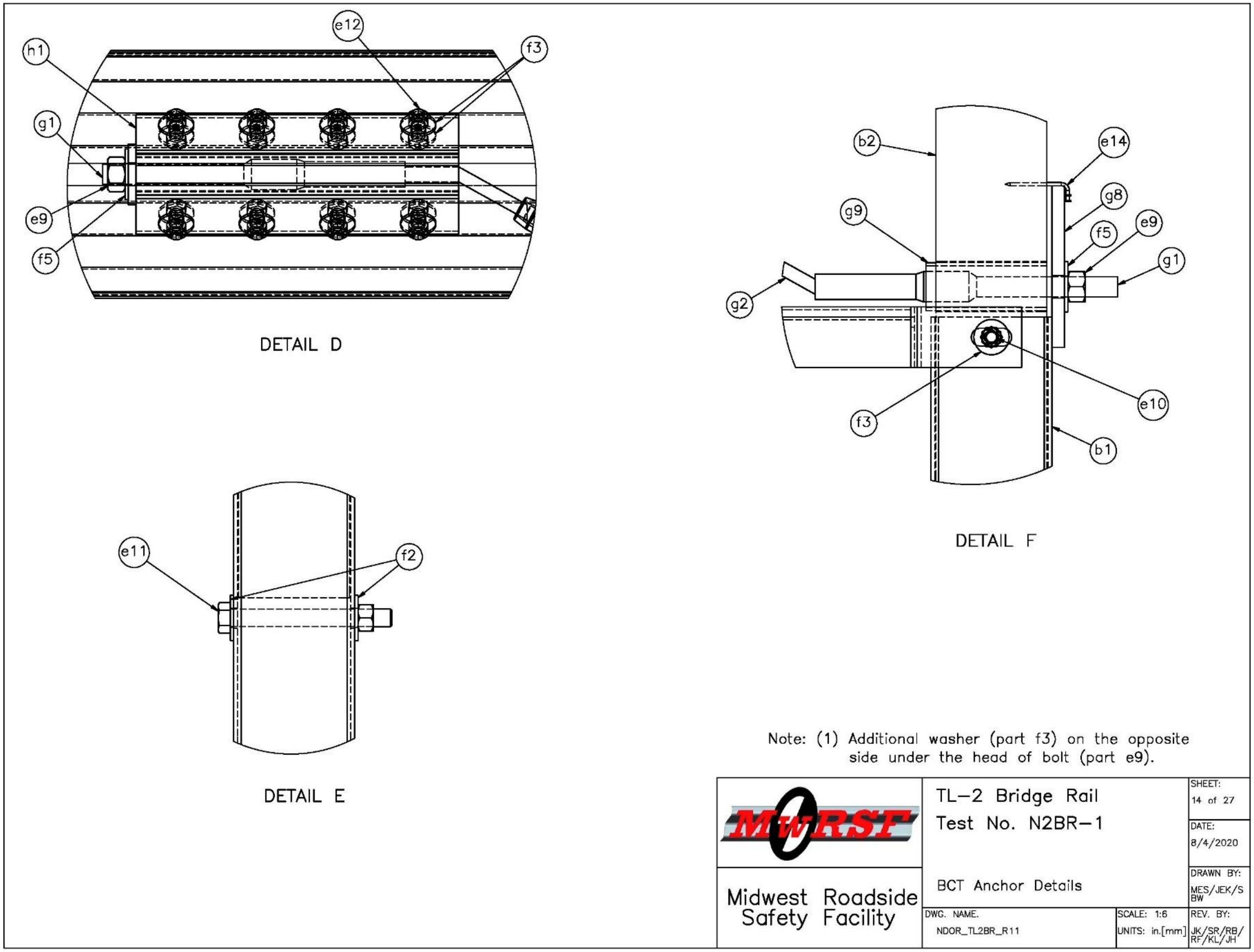


Figure 67. BCT Anchor Details, Test No. N2BR-1

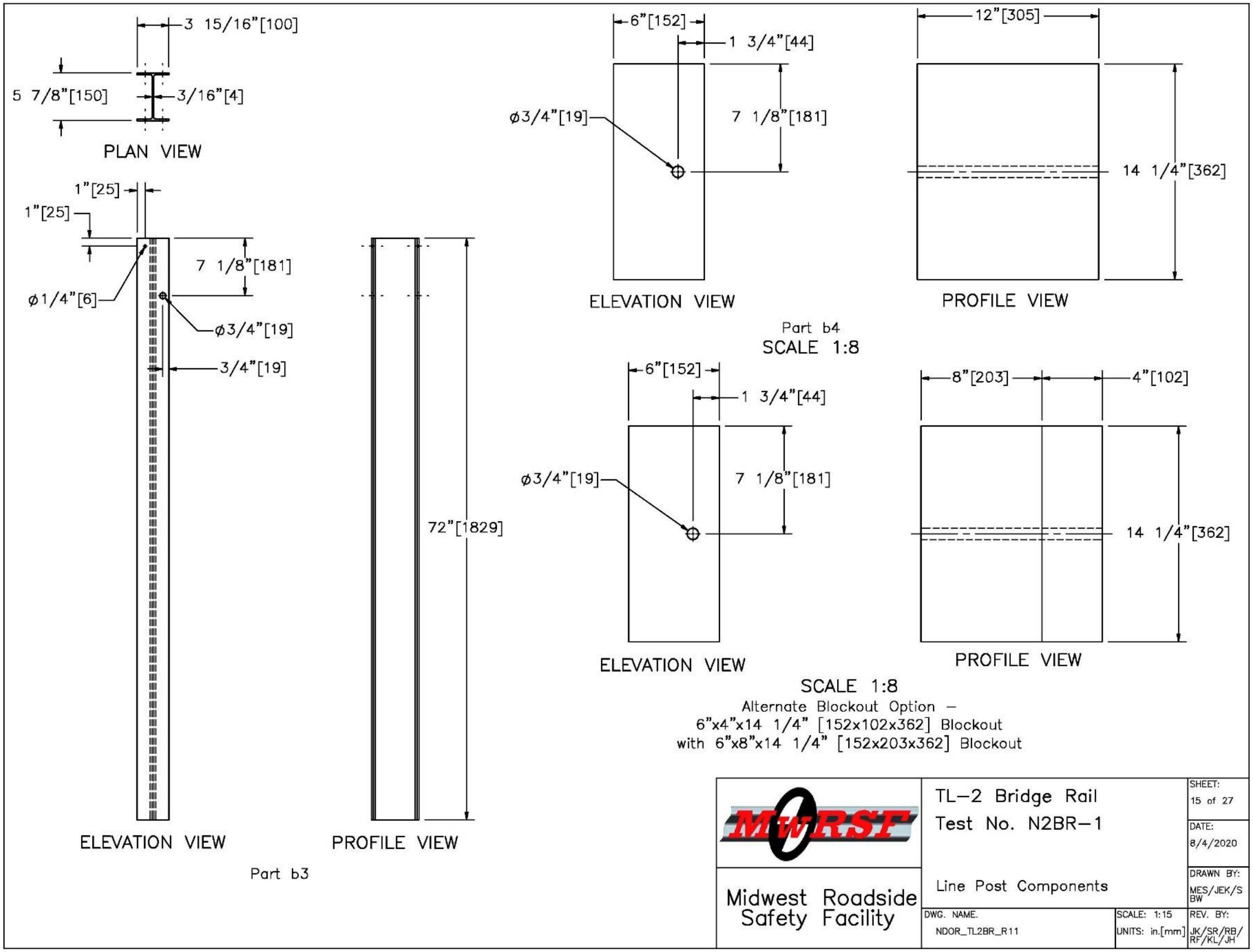


Figure 68. Line Post Components, Test No. N2BR-1

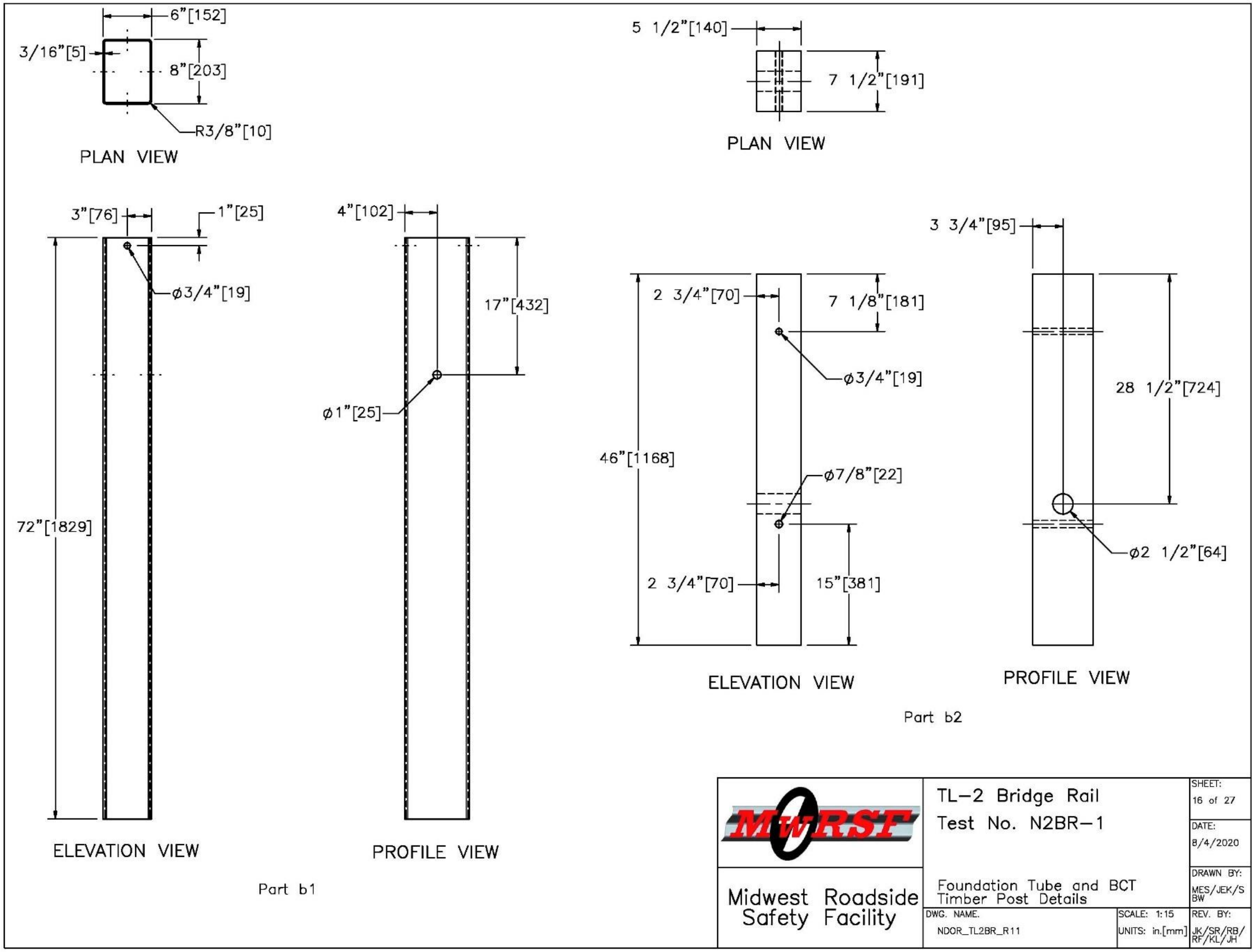
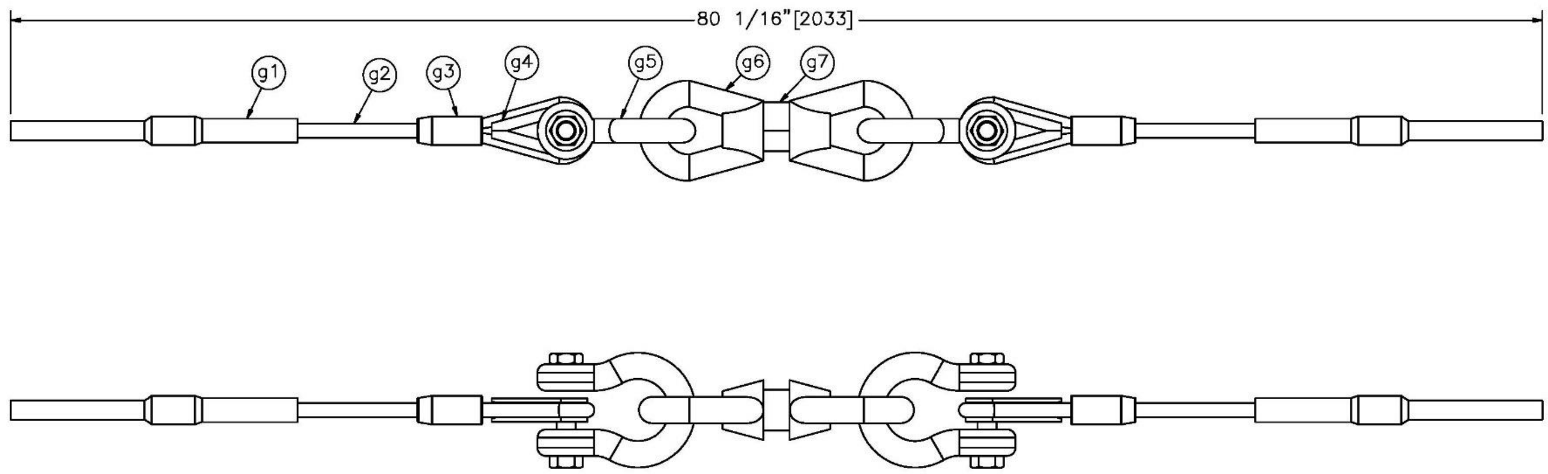


Figure 69. Foundation Tube and BCT Timber Post Details, Test No. N2BR-1



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	2	Load Cell Assembly	–	–
g1	2	BCT Anchor Cable End Swaged Fiting	Fitting – ASTM A576 Gr. 1035 Stud – ASTM F568 Class C	Fitting – ASTM A153 Stud – ASTM A153 or B695
g2	2	3/4" 6x19, 24 1/2" [622] Long IWRC IPS Wire Rope	IPS	ASTM A741 Type II Class A
g4	2	Crosby Heavy Duty HT – 3/4" [19] Dia. Cable Thimble	Stock No. 1037773	As Supplied
g3	2	115-HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–
g5	2	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 – As Supplied	–
g6	2	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNC 6 [M36x4]	Stock No. 107 – As Supplied	–
g7	1	TLL-50K-PTB Load Cell	–	–

Note: (1) 6x25 IWRC IPS cables meet the minimum breaking strength of 42.7 kips [190 kN] and may be substitued for the 6x19 IWRC IPS cables.

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TL-2 Bridge Rail
Test No. N2BR-1

BCT Anchor Cable & Load Cell Detail

SHEET: 17 of 27
DATE: 8/4/2020
DRAWN BY: MES/JEK/SBW
DWG. NAME. NDOR_TL2BR_R11
SCALE: 1:8
UNITS: in.[mm]
REV. BY: JK/SR/RB/RF/KL/JH

Figure 70. BCT Anchor Cable and Load Cell Detail, Test No. N2BR-1

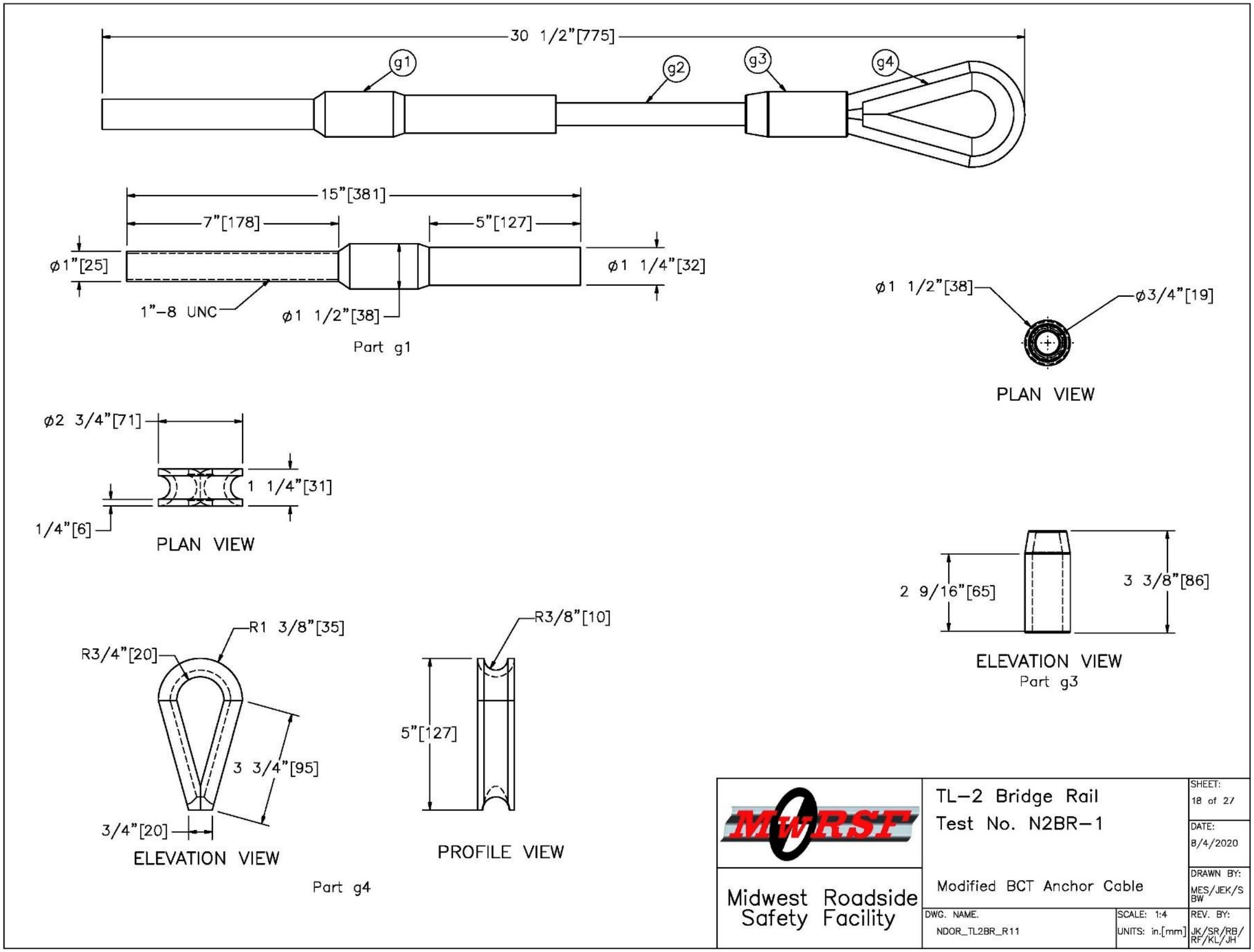


Figure 71. Modified BCT Anchor Cable, Test No. N2BR-1

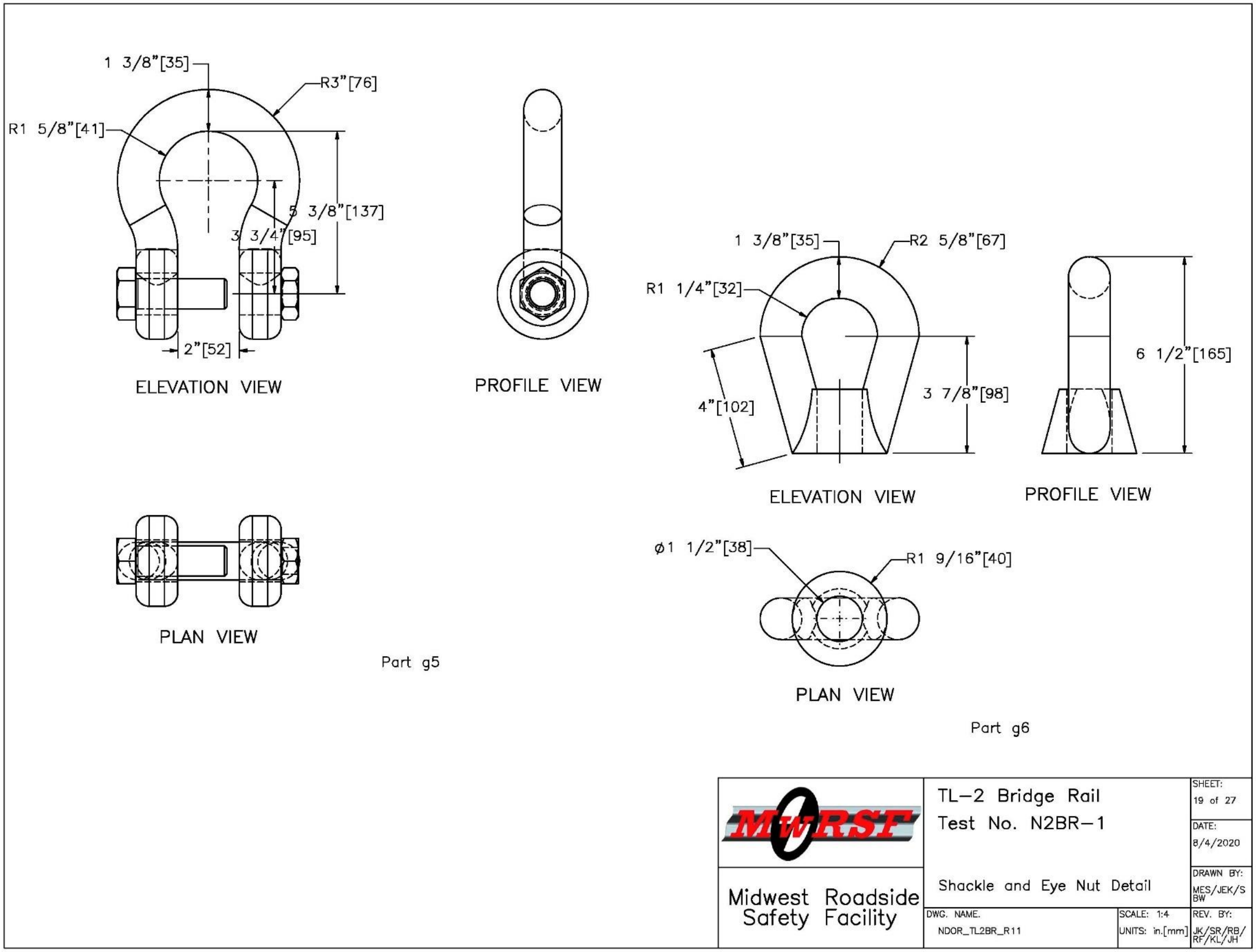
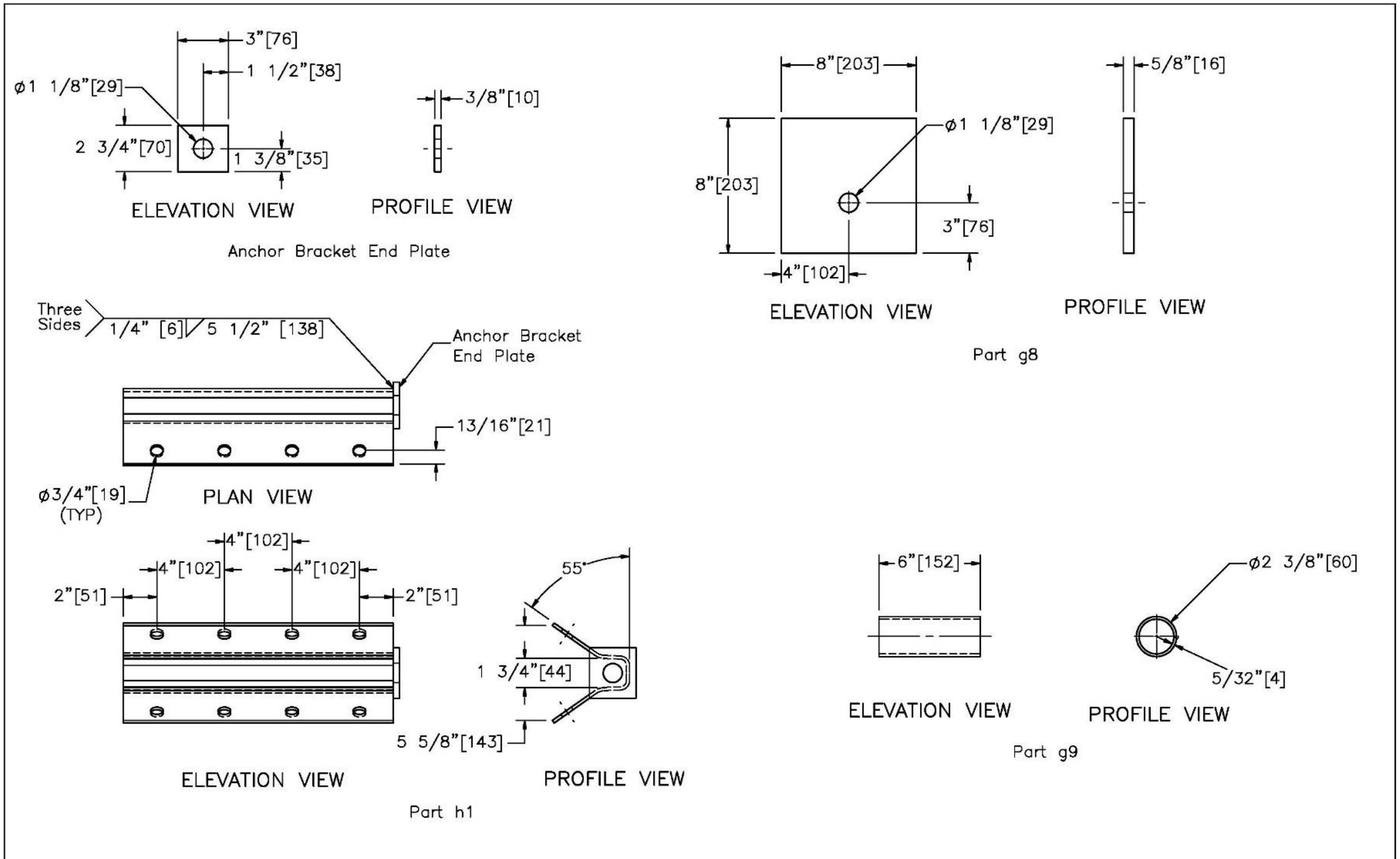


Figure 72. Shackle and Eye Nut Detail, Test No. N2BR-1



Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
h1	2	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
–	1	Anchor Bracket	ASTM A36	–	–
–	1	End Plate	ASTM A36	–	–

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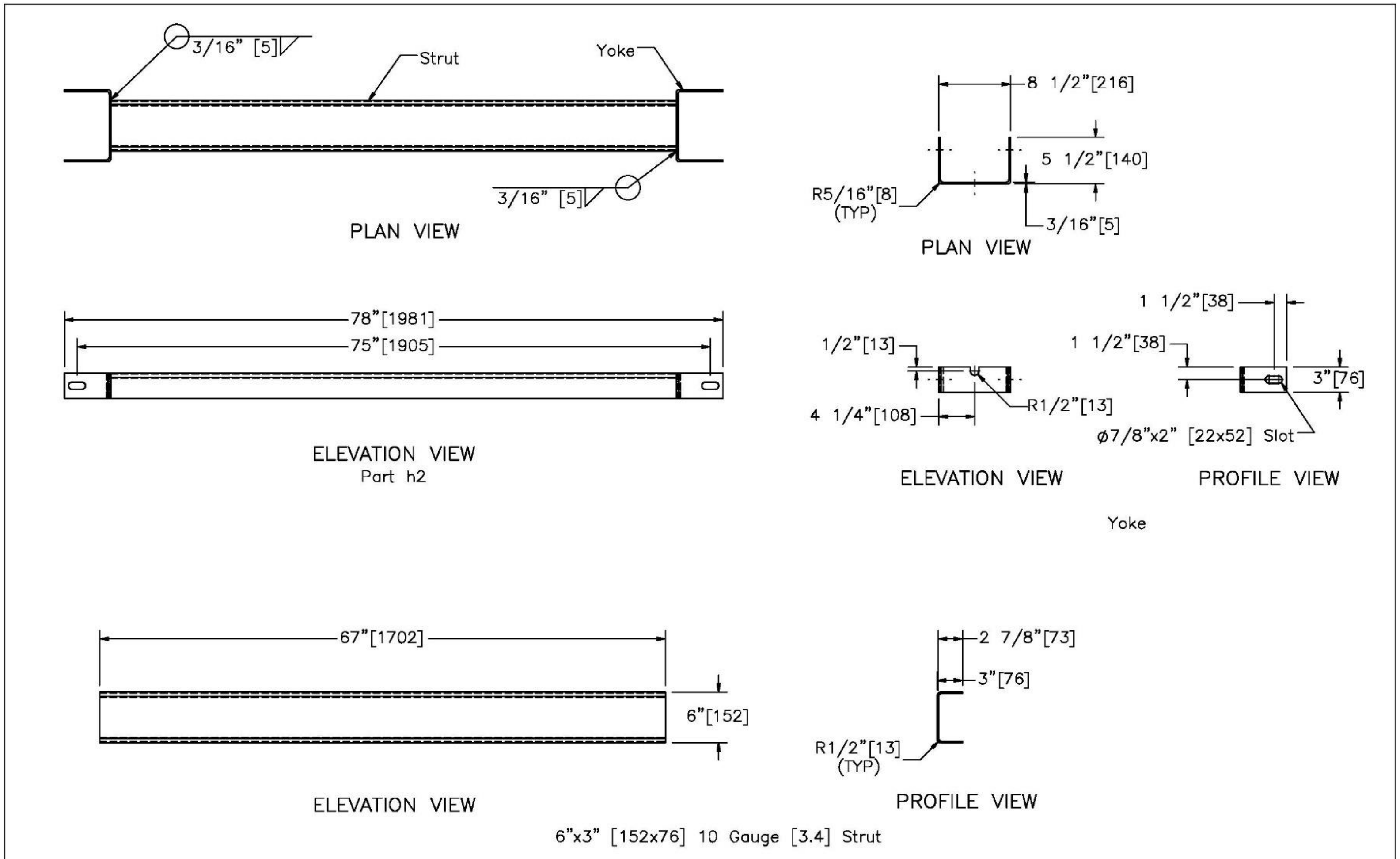
TL–2 Bridge Rail
Test No. N2BR–1

BCT Post Components & Anchor Bracket

SHEET: 20 of 27
DATE: 8/4/2020
DRAWN BY: MES/JEK/SBW
DWG. NAME. NDOR_TL2BR_R11
SCALE: 1:8
UNITS: in.[mm]
REV. BY: JK/SR/RB/RF/KL/JH

Figure 73. BCT Post Components and Anchor Bracket, Test No. N2BR-1



Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
h2	2	Ground Strut Assembly	ASTM A36	ASTM A123	PFP02
–	1	6"x3" [152x76] 10 Gauge [3.4] Strut	ASTM A36	–	–
–	2	8 1/2"x5 1/2"x3" [216x140x76] Yoke	ASTM A36	–	–

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TL–2 Bridge Rail
Test No. N2BR–1

Ground Strut and Bearing Plate

SHEET: 21 of 27
DATE: 8/4/2020
DRAWN BY: MES/JEK/S BW
DWG. NAME. NDOR_TL2BR_R11
SCALE: 1:16
UNITS: in.[mm]
REV. BY: JK/SR/RB/RF/KL/JH

Figure 74. Ground Strut and Bearing Plate, Test No. N2BR-1

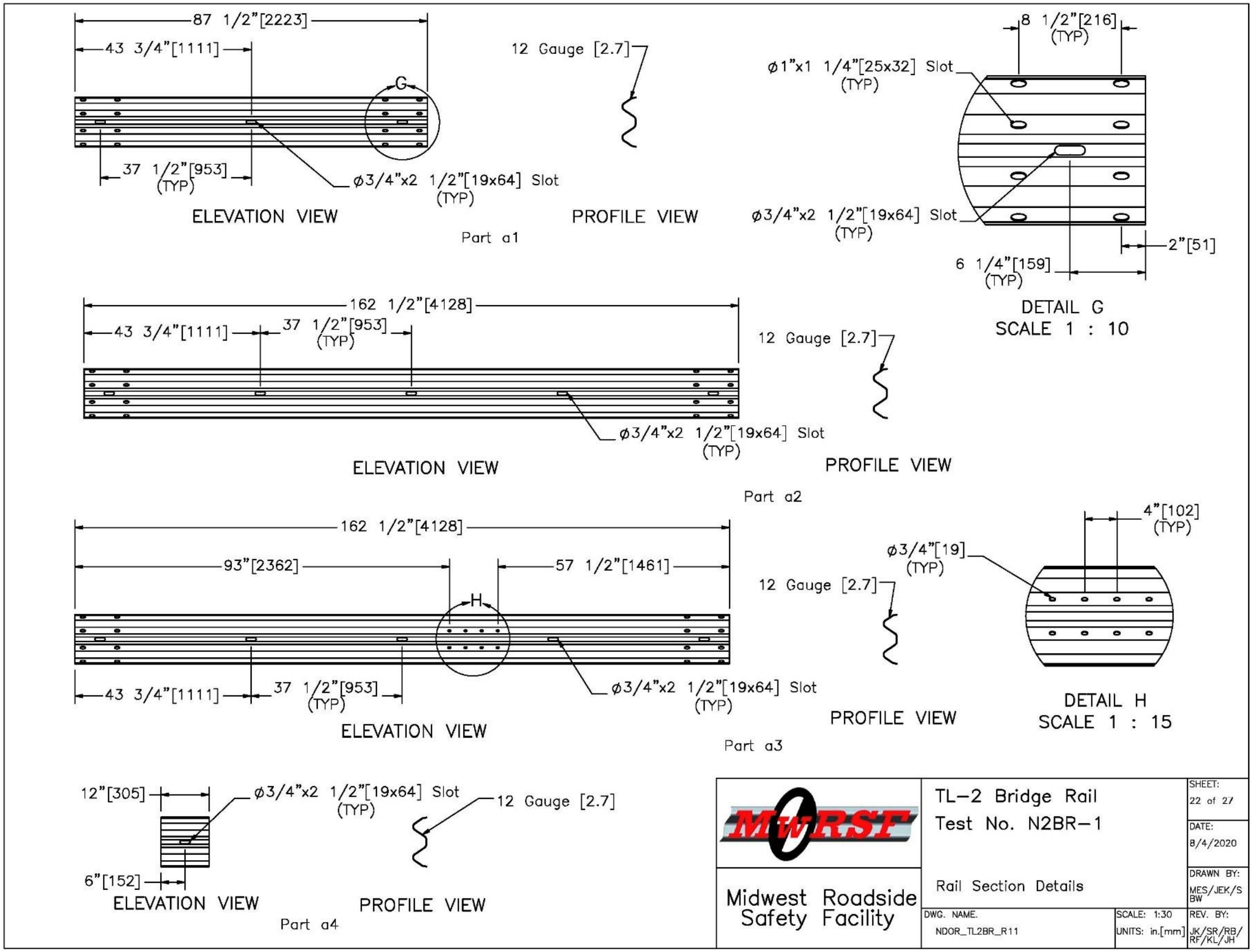

Figure 75. Rail Section Details, Test No. N2BR-1

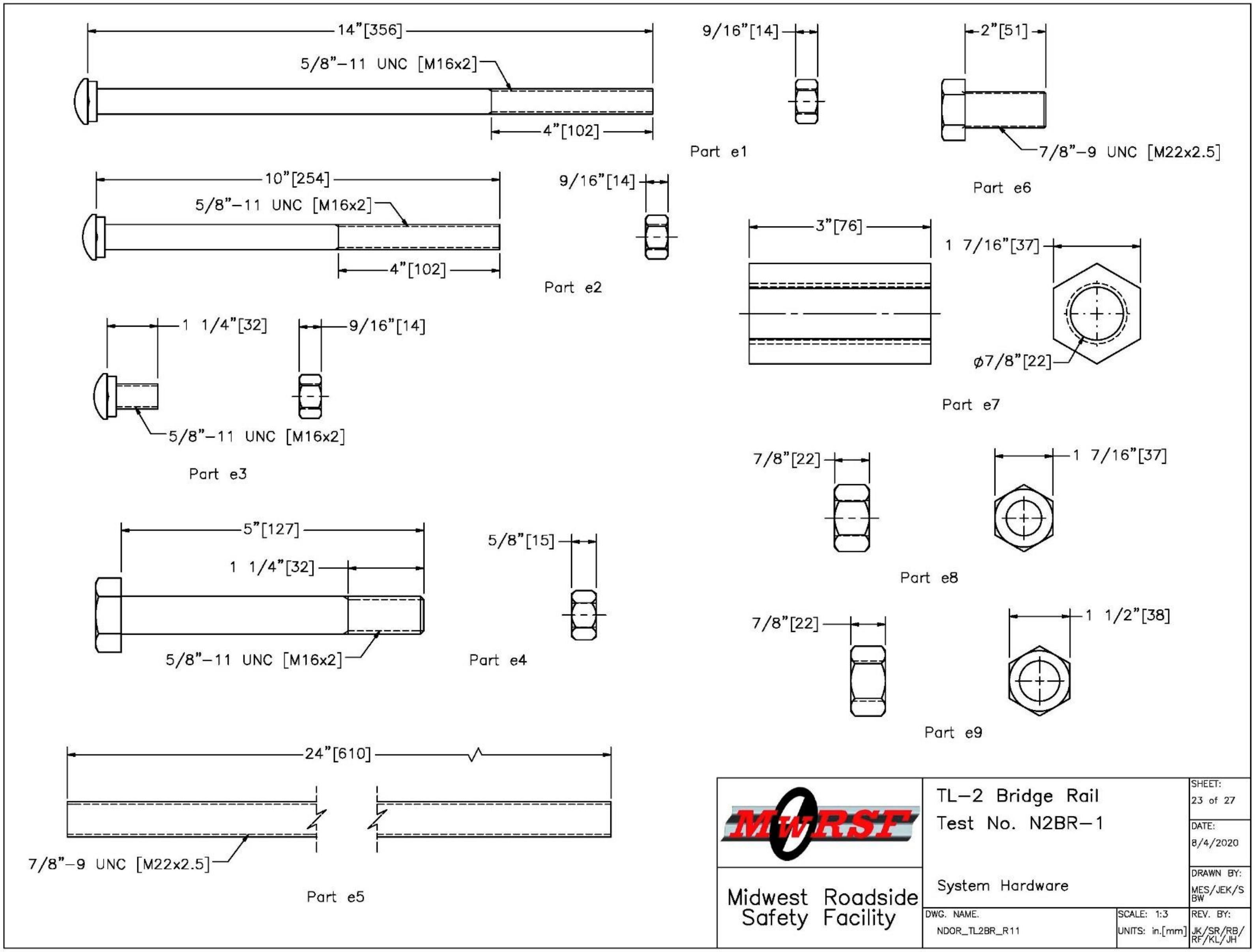

Figure 76. System Hardware, Test No. N2BR-1

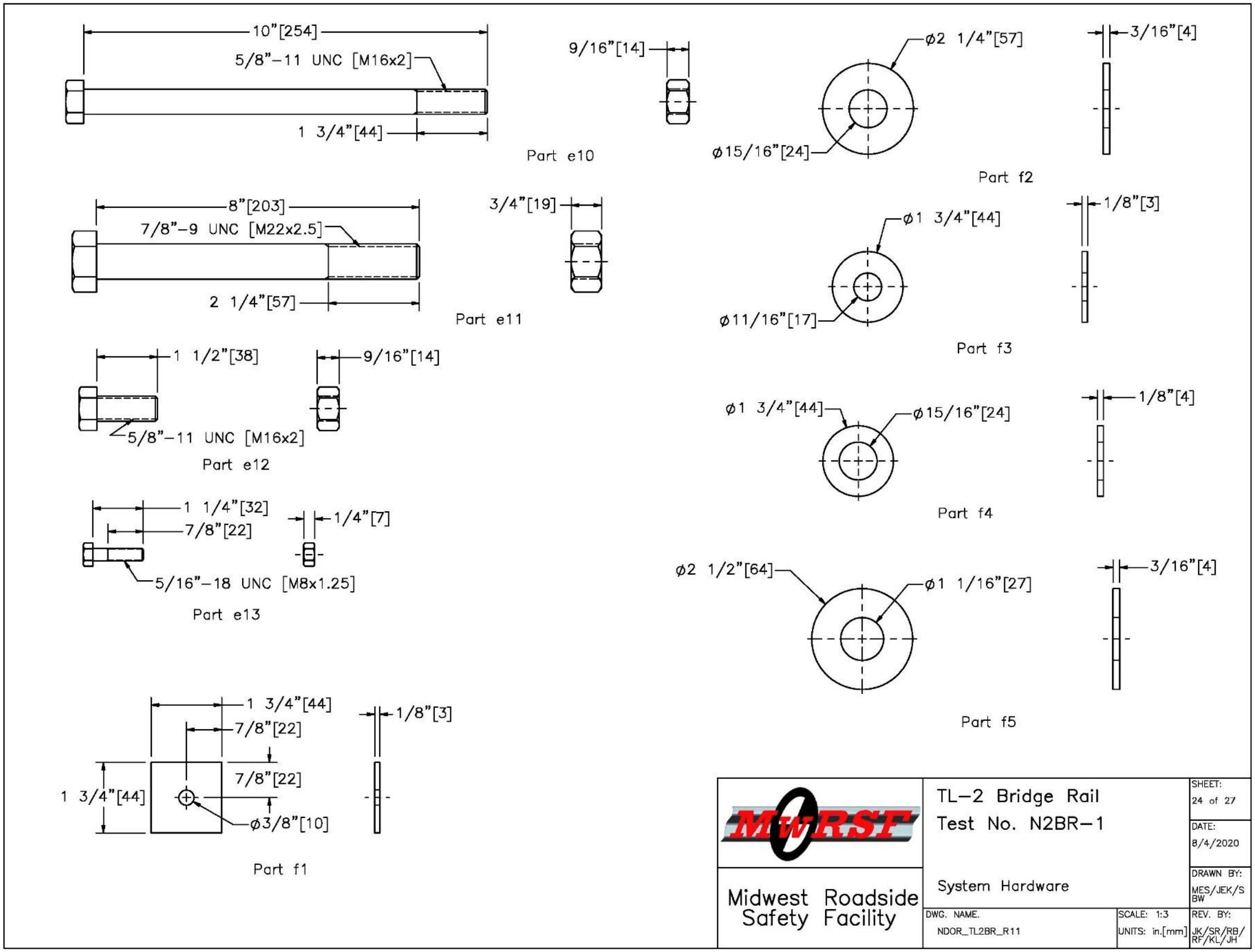

Figure 77. System Hardware, Test No. N2BR-1

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
a1	1	6'–3" [1,905] 12–gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
a2	12	12'–6" [3,810] 12–gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
a3	2	12'–6" [3,810] 12–gauge [2.7] W–Beam MGS End Section	AASHTO M180	ASTM A123 or A653	RWM14a
a4	12	1' [305] 12–gauge [2.7] W–Beam MGS Section	AASHTO M180	ASTM A123 or A653	RWM04a
b1	4	72" [1,829] Long Foundation Tube	ASTM A500 Gr. B	ASTM A123	PTE06
b2	4	BCT Timber Post – MGS Height	SYP Grade No. 1 or better (No knots 18" [457] above or below ground tension face)	–	–
b3	13	W6x8.5 [W152x12.6] or W6x9 [W152x13.4], 72" Long [1,829] Steel Post	ASTM A992 Gr. 50	ASTM A123	PWE06
b4	13	6"x12"x14 1/4" [152x305x368] Timber Blockout for Steel Posts	SYP Grade No.1 or better	–	PDB10a
b5	48	2 3/4"x1"x1/4" [70x25x6] Post Standoff	ASTM A36	–	–
b6	12	S3x5.7 [S76x8.5], 39" [991] Long Steel Post	ASTM A992 Gr. 50	–	–
c1	12	10"x7"x1/2" [254x178x13] Steel Plate	ASTM A572 Gr. 50	–	–
c2	12	10"x2 3/4"x1/4" [254x70x6] Plate Washer	ASTM A36	ASTM A123	–
c3	12	HSS4"x4"x3/8" [102x102x10], 6 5/8" [168] Long Square Tube	ASTM A500 Gr. B	–	–
c4	12	3 1/2"x1"x1/8" [89x25x4]	ASTM A36	–	–
c5	4	C7x9.8 [C178x14.3], 225" [5,715] Long C–Channel	ASTM A36	–	–
c6	24*	6 5/8"x2"x1/8" [168x51x3] Shim Plate	ASTM A36	ASTM A123	–
d1	7	#4 [13] Bar, 896 1/2" [22,771] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)	–
d2	302	#4 [13] Bar, 32" [813] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)	–
d3	76	#4 [13] Bar, 16" [406] Long	ASTM A615 Gr. 60	Epoxy Coated (ASTM A775 or A934)	–
d4	128	#4 [13] Bar, 18" [457] Long	ASTM A706 Gr. 60	–	–
e1	13	5/8"–11 UNC [M16x2], 14" [356] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB06
e2	4	5/8"–11 UNC [M16x2], 10" [254] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB03
e3	112	5/8"–11 UNC [M16x2], 1 1/4" [32] Long Guardrail Bolt and Nut	Bolt – ASTM A307 Gr. A Nut – ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBB01

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Midwest Roadside Safety Facility

TL–2 Bridge Rail
Test No. N2BR–1

Bill of Materials

SHEET: 25 of 27

DATE: 8/4/2020

DRAWN BY: MES/JEK/SBW

DWG. NAME. NDOR_TL2BR_R11

SCALE: None
UNITS: in.[mm]

REV. BY: JK/SR/RB/RF/KL/JH

Figure 78. Bill of Materials, Test No. N2BR-1

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
e4	12	5/8"–11 UNC [M16x2], 5" [127] Long Heavy Hex Head Bolt and Nut	Bolt – ASTM F3125 Gr. A325 Type 1 or Equivalent Nut – ASTM A563DH or Equivalent	ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329 or F2833 Gr. 1	FBX16b
e5	24	7/8"–9 UNC [M22x2.5], 24" [610] Long Threaded Rod	ASTM A449 or Equivalent	ASTM A153 or B695 Class 55 or F2329	–
e6	24	7/8"–9 UNC [M22x2.5], 2" [51] Long Heavy Hex Head Bolt	ASTM A449 or Equivalent	ASTM A153 or B695 Class 55 or F2329	FBX22b
e7	24	7/8" [22] Dia. Heavy Hex Coupling Nut	ASTM A563DH or Equivalent	ASTM A153 or B695 Class 55 or F2329	–
e8	48	7/8" [22] Dia. Heavy Hex Nut	ASTM A563DH or Equivalent	ASTM A153 or B695 Class 55 or F2329	FNX22b
e9	4	1" [25] Dia. Hex Nut	ASTM A563A	ASTM A153 or B695 Class 55 or F2329	FBX24a
e10	4	5/8"–11 UNC [M16x2], 10" [254] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A or Equivalent Nut – ASTM A563A or Equivalent	ASTM A153 or B695 Class 55 or F2329	FBX16a
e11	4	7/8"–9 UNC [M22x2.5], 8" [203] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A or Equivalent Nut – ASTM A563A or Equivalent	ASTM A153 or B695 Class 55 or F2329	–
e12	16	5/8"–11 UNC [M16x2], 1 1/2" [38] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A or Equivalent Nut – ASTM A563A or Equivalent	ASTM A153 or B695 Class 55 or F2329	FBX16a
e13	12	5/16"–18 UNC [M8x1.25], 1 1/4" [32] Long Hex Head Bolt and Nut	Bolt – ASTM A307 Gr. A or Equivalent Nut – ASTM A563A or Equivalent	ASTM A153 or B695 Class 55 or F2329	FBX08a
e14	15	16D Double Head Nail	–	–	–
f1	12	1 3/4"x1 3/4"x1/8" [44x44x3] Square Washer	ASTM A36	ASTM A123	FWR01
f2	8	7/8" [22] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	–
f3	44	5/8" [16] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC16a
f4	24	7/8" [22] Dia. Hardened Flat Washer	ASTM F436	ASTM A153 or B695 Class 55 or F1136 Gr. 3 or F2329	FWC24b
f5	4	1" [25] Dia. Plain Round Washer	ASTM F844	ASTM A123 or A153 or F2329	FWC24a
g1	2	BCT Anchor Cable End Swaged Fiting	Fitting – ASTM A576 Gr. 1035 Stud – ASTM F568 Class C	Fitting – ASTM A153 Stud – ASTM A153 or B695	–
g2	2	3/4" [190] Dia. 6x19, 24 1/2" [622] Long IWRC IPS Wire Rope	IPS	ASTM A741 Type II Class A	–
g3	4	115–HT Mechanical Splice – 3/4" [19] Dia.	As Supplied	–	–
g4	4	Crosby Heavy Duty HT – 3/4" [19] Dia. Cable Thimble	Stock No. 1037773	As Supplied	–

Midwest Roadside Safety Facility

TL–2 Bridge Rail
Test No. N2BR–1

Bill of Materials

SHEET: 26 of 27
DATE: 8/4/2020
DRAWN BY: MES/JEK/SBW
REV. BY: JK/SR/RB/RF/KL/JH
DWG. NAME. NDOR_TL2BR_R11
SCALE: None
UNITS: in.[mm]

Figure 79. Bill of Materials, Test No. N2BR-1

Item No.	QTY.	Description	Material Specification	Treatment Specification	Hardware Guide
g5	4	Crosby G2130 or S2130 Bolt Type Shackle – 1 1/4" [32] Dia. with thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 – As Supplied	–	–
g6	4	Chicago Hardware Drop Forged Heavy Duty Eye Nut – Drilled and Tapped 1 1/2" [38] Dia. – UNC 6 [M36x4]	Stock No. 107 – As Supplied	–	–
g7	2	TLL-50K-PTB Load Cell	–	–	–
g8	2	8"x8"x5/8" [203x203x16] Anchor Bearing Plate	ASTM A36	ASTM A123	FPB01
g9	2	2 3/8" [60] O.D. x 6" [152] Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	ASTM A123	FMM02
h1	2	Anchor Bracket Assembly	ASTM A36	ASTM A123	FPA01
h2	2	Ground Strut Assembly	ASTM A36	ASTM A123	PFP02
i1	1	Grade Beam	Min f'c = 4,000 psi [27.6 MPa]	–	–
–	1	Concrete	Min. f'c = 6,000 psi [41.4 MPa] NE Mix 47BD	–	–

Midwest Roadside Safety Facility

TL-2 Bridge Rail
Test No. N2BR-1

Bill of Materials

SHEET: 27 of 27

DATE: 8/4/2020

DRAWN BY: MES/JEK/SBW

DWG. NAME. NDOR_TL2BR_R11

SCALE: None
UNITS: in.[mm]

REV. BY: JK/SR/RB/RF/KL/JH

Figure 80. Bill of Materials, Test No. N2BR-1

Figure 81. Test Installation Photographs, Test No. N2BR-1

6 TEST REQUIREMENTS AND EVALUATION CRITERIA

6.1 Test Requirements

Longitudinal barrier systems, such as bridge rails, must satisfy impact safety standards in order to be declared eligible for federal reimbursement by the Federal Highway Administration (FHWA) for use on the National Highway System (NHS). For new hardware, these safety standards consist of the guidelines and procedures published in MASH 2016 [1]. Note that there are no differences between MASH 2009 and MASH 2016 for longitudinal barriers, such as the bridge rail developed herein, except that additional occupant compartment deformation measurements, photographs, and documentation are required by MASH 2016. According to TL-2 of MASH 2016, longitudinal barrier systems must be subjected to two full-scale vehicle crash tests, as summarized in Table 3.

Table 3. MASH 2016 TL-2 Crash Test Conditions for Longitudinal Barriers

Test Article	Test Designation No.	Test Vehicle	Vehicle Weight lb	Impact Conditions		Evaluation Criteria [1]
				Speed, mph	Angle, deg.	
Longitudinal Barrier	2-10	1100C	2,425	44	25	A,D,F,H,I
	2-11	2270P	5,000	44	25	A,D,F,H,I

[1] Evaluation Criteria Explained in Table 4

Although MASH requires two full-scale crash tests, testing with the 1100C test vehicle was not deemed critical for the evaluation of the new bridge rail. Previous MASH crash testing has been conducted with both the 2270P and the 1100C vehicles on the MGS Bridge Rail and the TxDOT T631 bridge rail [3-5]. Similar to the NDOT TL-2 Bridge Rail developed herein, both of these previous bridge rails consist of 31-in. tall, 12-gauge, W-beam guardrail supported by S3x5.7 posts. Further, all three bridge rails were designed to absorb impact energy through bending of the weak S3x5.7 posts while the attachment of the post to the deck remains rigid and intact. The TxDOT T631 bridge rail was successfully tested to MASH test designation nos. 2-10 and 2-11 with a 75-in. post spacing, which is the same as the new NDOT TL-2 bridge rail. Additionally, the MGS Bridge Rail was successfully tested to MASH test designation nos. 3-10 and 3-11 with a 37.5-in. post spacing utilizing the same post assembly and HSS4x4x⅜ steel sockets incorporated into the new NDOT TL-2 bridge rail. Thus, if the socket assembly remained undamaged and intact throughout an impact event, the new TL-2 bridge rail would be expected to perform very similarly to the TL-2 version of the TxDOT T631. The increased mass of the 2270P test vehicle results in a higher impact severity, higher impact loads, and higher system deflections than observed during tests with the 1100C test vehicle. Therefore, MASH test designation no. 2-11 was deemed necessary to evaluate the post-to-deck connection strength of the new system, and MASH test designation no. 2-10 was determined to be non-critical. Should future knowledge gained from testing of this bridge rail or similar systems raise concerns regarding the new bridge railing’s performance with small cars, it may become necessary to evaluate the bridge rail with the MASH 1100C vehicle.

6.2 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 bridge railing to contain and redirect impacting vehicles. In addition, controlled lateral deflection of the test article is acceptable. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Post-impact vehicle trajectory is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. These evaluation criteria are summarized in Table 4 and defined in greater detail in MASH 2016. The full-scale vehicle crash test was conducted and reported in accordance with the procedures provided in MASH 2016.

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

Table 4. MASH 2016 Evaluation Criteria for Longitudinal Barriers

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

6.3 Soil Strength Requirements

In accordance with Chapter 3 and Appendix B of MASH 2016, foundation soil strength must be verified before any full-scale crash testing can occur. During the installation of a soil dependent system, W6x16 posts are installed near the impact region utilizing the same installation procedures as the system. Prior to full-scale testing, a dynamic impact test must be conducted to verify a minimum dynamic soil resistance of 7.5 kips at post deflections between 5 and 20 in. measured at a height of 25 in. 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. Further details can be found in Appendix B of MASH 2016.

7 TEST CONDITIONS

7.1 Test Facility

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

7.2 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 [14] was used to steer the test vehicle. A guide flag, attached to the left-front wheel and the guide cable, was sheared off before impact with the barrier system. The ⅜-in. diameter guide cable was tensioned to approximately 3,500 lb and supported both laterally and vertically every 100 ft by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide flag struck and knocked each stanchion to the ground.

7.3 Test Vehicles

For test no. N2BR-1, a 2011 Dodge Ram 1500 was used as the test vehicle. The curb, test inertial, and gross static vehicle weights were 5,111 lb, 4,999 lb, and 5,160 lb, respectively. The test vehicle is shown in Figures 82 and 83, and vehicle dimensions are shown in Figure 84. Note that the test vehicle was within six model years of the 2017 research project contract date.

The longitudinal component of the center of gravity (c.g.) was determined using the measured axle weights. The Suspension Method [15] was used to determine the vertical component of the c.g. for the pickup truck. This method is based on the principle that the c.g. of any freely suspended body is in the vertical plane through the point of suspension. The vehicle was suspended successively in three positions, and the respective planes containing the c.g. were established. The intersection of these planes pinpointed the final c.g. location for the test inertial condition. The location of the final c.g. is shown in Figures 84 and 85. Data used to calculate the location of the c.g. and ballast information are shown in Appendix D.

Square, black- and white-checkered targets were placed on the vehicle for reference to be viewed from the high-speed digital video cameras and aid in the video analysis, as shown in Figure 85. Round, checkered targets were placed on the c.g. on the left-side door, the right-side door, and the roof of the vehicle.

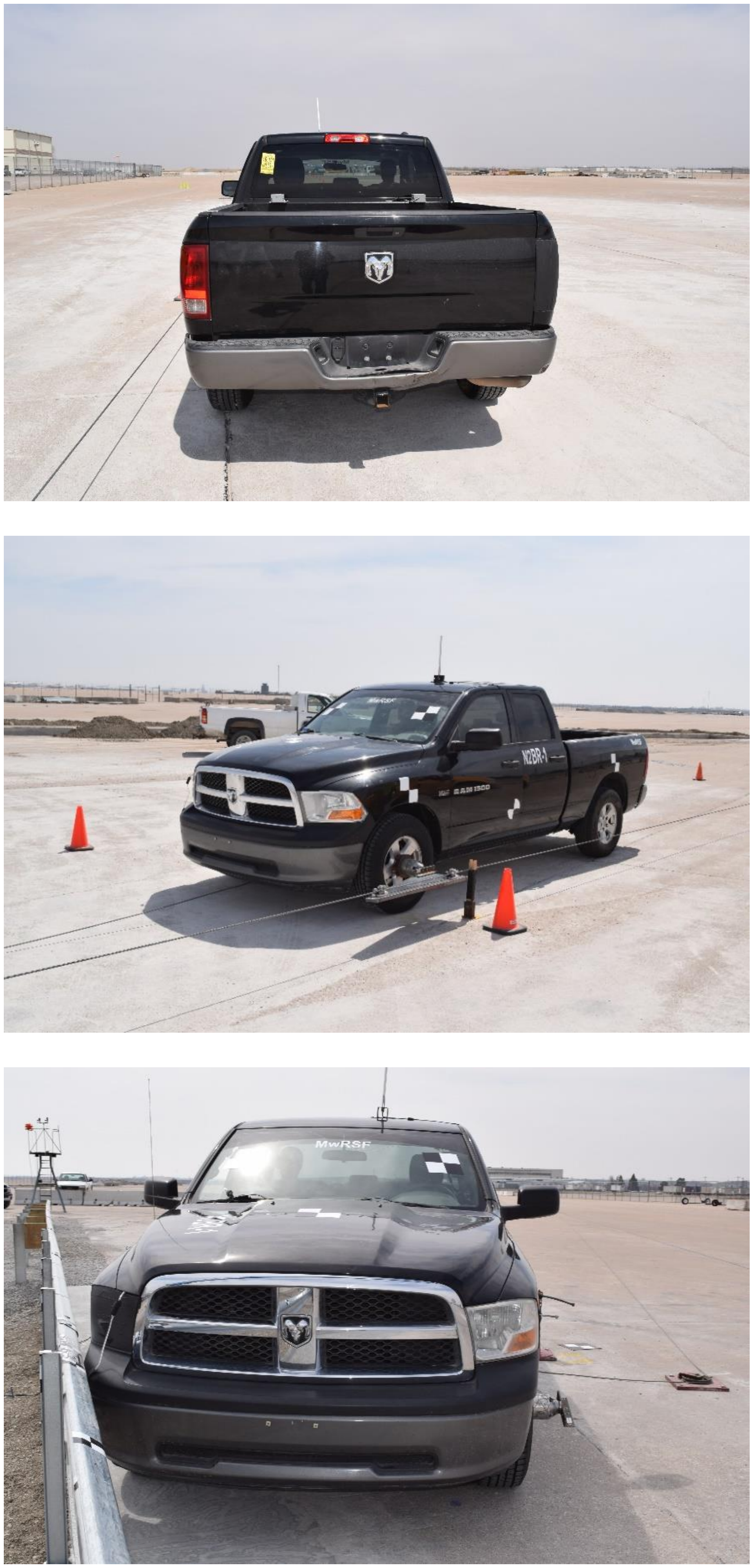


Figure 82. Test Vehicle, Test No. N2BR-1

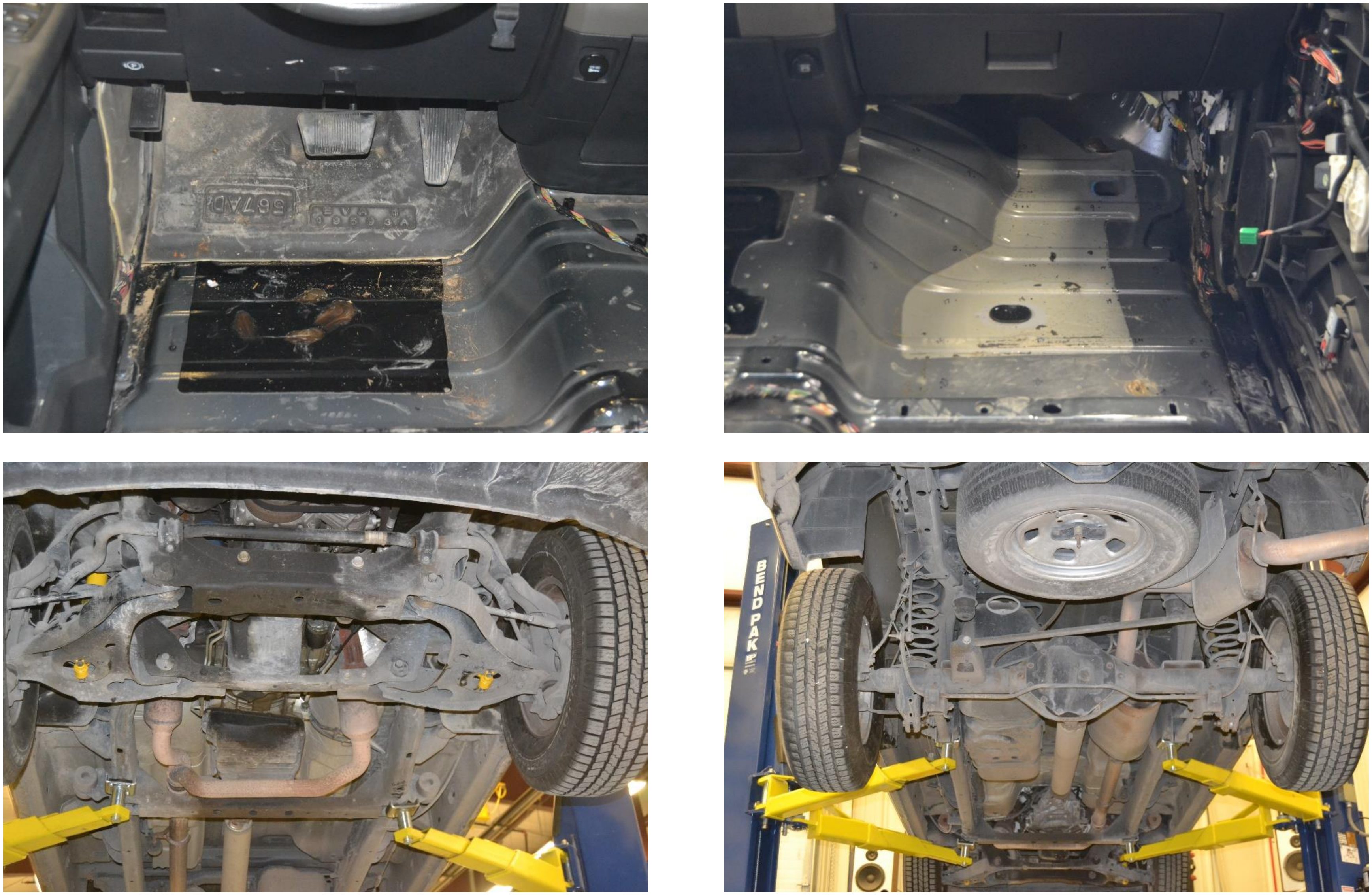
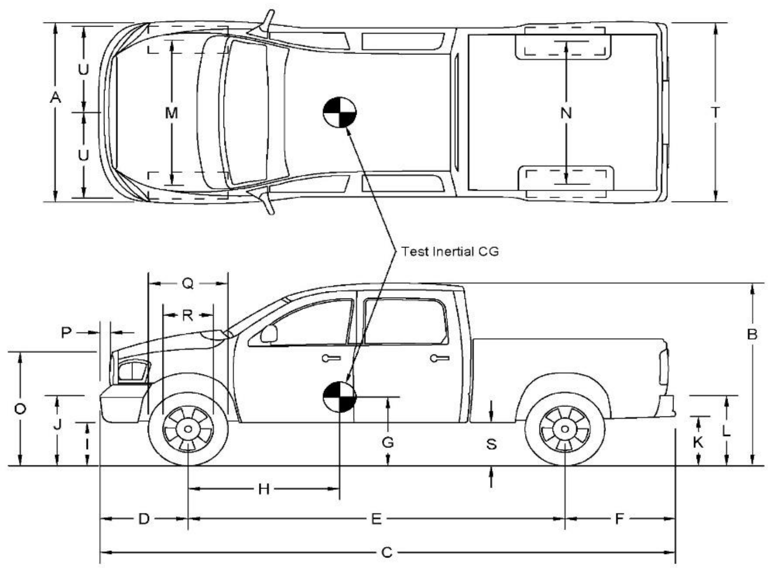


Figure 83. Vehicle Floor Pan and Undercarriage Prior to Test No. N2BR-1

Date:	4/12/2018	Test Name:	2NBR-1	VIN No:	1D7RB1DG4BS514230
Year:	2011	Make:	Dodge	Model:	Ram 1500
Tire Size:	P265/79R17	Tire Inflation Pressure:	40 Psi	Odometer:	152320



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

A:	76 (1930) 78±2 (1950±50)	B:	74 3/4 (1899)		
C:	229 1/2 (5829) 237±13 (6020±325)	D:	42 3/8 (1076) 39±3 (1000±75)		
E:	140 3/8 (3566) 148±12 (3760±300)	F:	46 3/4 (1187)		
G:	28 1/4 (718) min: 28 (710)	H:	60 7/8 (1546) 63±4 (1575±100)		
I:	12 (305)	J:	25 1/4 (641)		
K:	20 1/2 (521)	L:	29 1/4 (743)		
M:	67 3/4 (1721) 67±1.5 (1700±38)	N:	67 3/4 (1721) 67±1.5 (1700±38)		
O:	44 (1118) 43±4 (1100±75)	P:	4 1/2 (114)		
Q:	31 1/2 (800)	R:	18 1/2 (470)		
S:	14 1/2 (368)	T:	76 1/2 (1943)		

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

Wheel Center Height (Front):	15	(381)
Wheel Center Height (Rear):	15 1/8	(384)
Wheel Well Clearance (Front):	34 3/4	(883)
Wheel Well Clearance (Rear):	38	(965)
Bottom Frame Height (Front):	18	(457)
Bottom Frame Height (Rear):	25 3/4	(654)
Engine Type:	Gasoline	
Engine Size:	5.7L	
Transmission Type:	automatic	
Drive Type:	RWD	
Cab Style:	Quad Cab	
Bed Length:	67"	

Mass Distribution lb (kg)

Gross Static	LF	1459 (662)	RF	1469 (666)
	LR	1096 (497)	RR	1136 (515)

Weights lb (kg)	Curb	Test Inertial	Gross Static
W-front	2894 (1313)	2831 (1284)	2928 (1328)
W-rear	2217 (1006)	2168 (983)	2232 (1012)
W-total	5111 (2318)	4999 (2268) 5000±110 (2270±50)	5160 (2341) 5165±110 (2343±50)

GVWR Ratings lb

Front	3700
Rear	3900
Total	6700

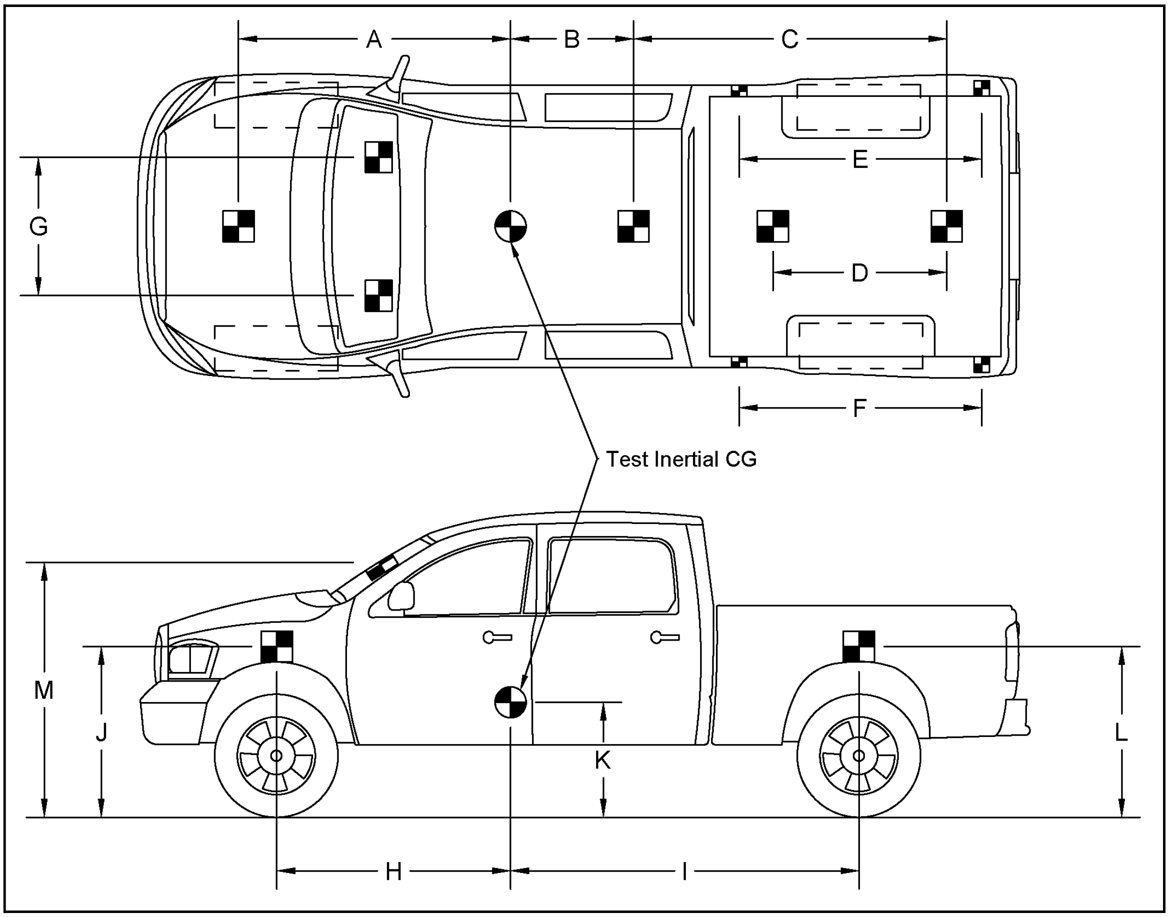
Surrogate Occupant Data

Type:	Hybrid II
Mass:	159 lb
Seat Position:	Right Front

Note any damage prior to test: Minor hail dents all over

Figure 84. Vehicle Dimensions, Test No. N2BR-1

Date: 4/12/2018 **Test Name:** 2NBR-1 **VIN:** 1D7RB1DG4BS514230
Year: 2011 **Make:** Dodge **Model:** Ram 1500



TARGET GEOMETRY-- in. (mm)

A:	71 1/2 (1816)	E:	63 5/16 (1608)	J:	39 (991)
B:	29 3/8 (746)	F:	63 3/8 (1610)	K:	28 1/4 (718)
C:	70 7/8 (1800)	G:	44 1/16 (1119)	L:	42 1/4 (1073)
D:	39 (991)	H:	60 7/8 (1546)	M:	61 (1549)
		I:	76 1/2 (1943)		

Figure 85. Target Geometry, Test No. N2BR-1

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

7.4 Simulated Occupant

For test no. N2BR-1, a Hybrid II 50th-Percentile, Adult Male Dummy equipped with footwear was placed in the right-front seat of the test vehicle with the seat belt fastened. The simulated occupant had a final weight of 159 lb. As recommended by MASH 2016, the simulated occupant was not included in calculating the c.g. location.

7.5 Data Acquisition Systems

7.5.1 Accelerometers

Two environmental shock and vibration sensor/recorder systems were used to measure the accelerations in the longitudinal, lateral, and vertical directions. Both accelerometer systems were mounted near the c.g. of the test vehicle. The electronic accelerometer data obtained in dynamic testing was filtered using the SAE Class 60 and the SAE Class 180 Butterworth filters conforming to the SAE J211/1 specifications [8].

The primary system, the SLICE-1 unit, was a modular data acquisition system manufactured by Diversified Technical Systems, Inc. (DTS) of Seal Beach, California. The SLICE-1 unit was designated as the primary system. The acceleration sensors were mounted inside the body of a custom-built, SLICE 6DX event data recorder and recorded data at 10,000 Hz to the onboard microprocessor. The 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.

The second accelerometer system, the DTS unit, was a two-arm piezoresistive accelerometer system manufactured by Endevco of San Juan Capistrano, California. Three accelerometers were used to measure each of the longitudinal, lateral, and vertical accelerations independently at a sample rate of 10,000 Hz. The accelerometers were configured and controlled using a system developed and manufactured by DTS of Seal Beach, California. More specifically, data was collected using a DTS Sensor Input Module (SIM), Model TDAS3-SIM-16M. The SIM was configured with 16 MB SRAM and 8 sensor input channels with 250 kB SRAM/channel. The SIM was mounted on a TDAS3-R4 module rack. The module rack was configured with isolated power/event/communications, 10BaseT Ethernet and RS232 communication, and an internal backup battery. Both the SIM and module rack were crashworthy. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the accelerometer data.

7.5.2 Rate Transducers

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

A second angular rate sensor, the DTS ARS-1500, with a range of 1,500 degrees/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rates of rotation of the test vehicles. The angular rate sensor was mounted on an aluminum block inside the test vehicle near the c.g. and recorded data at 10,000 Hz to the DTS SIM. The raw data measurements were then downloaded, converted to the proper Euler angles for analysis, and plotted. The "DTS TDAS Control" computer software program and a customized Microsoft Excel worksheet were used to analyze and plot the angular rate sensor data.

7.5.3 Retroreflective Optic Speed Trap

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

7.5.4 Load Cells and String Potentiometers

Load cells were installed in the upstream and downstream anchor cables for test no. N2BR-1 but did not record data due to technical difficulties. The load cells were Transducer Techniques model no. TLL-50K with a load range up to 50 kips. During testing, output voltage signals were sent from the transducers to a National Instruments PCI-6071E data acquisition board, acquired with LabView software, and stored on a personal computer at a sample rate of 10,000 Hz.

7.5.5 Digital Photography

Six high-speed AOS digital video cameras, ten GoPro digital video cameras, and three JVC digital video cameras were utilized to film test no. N2BR-1. Camera details, camera operating speeds, lens information, and a schematic of the camera locations relative to the system are shown in Figure 86 and Table 5. The high-speed videos were analyzed using TEMA Motion and Redlake MotionScope software programs. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed videos. A digital still camera was also used to document pre- and post-test conditions of the system and vehicle.

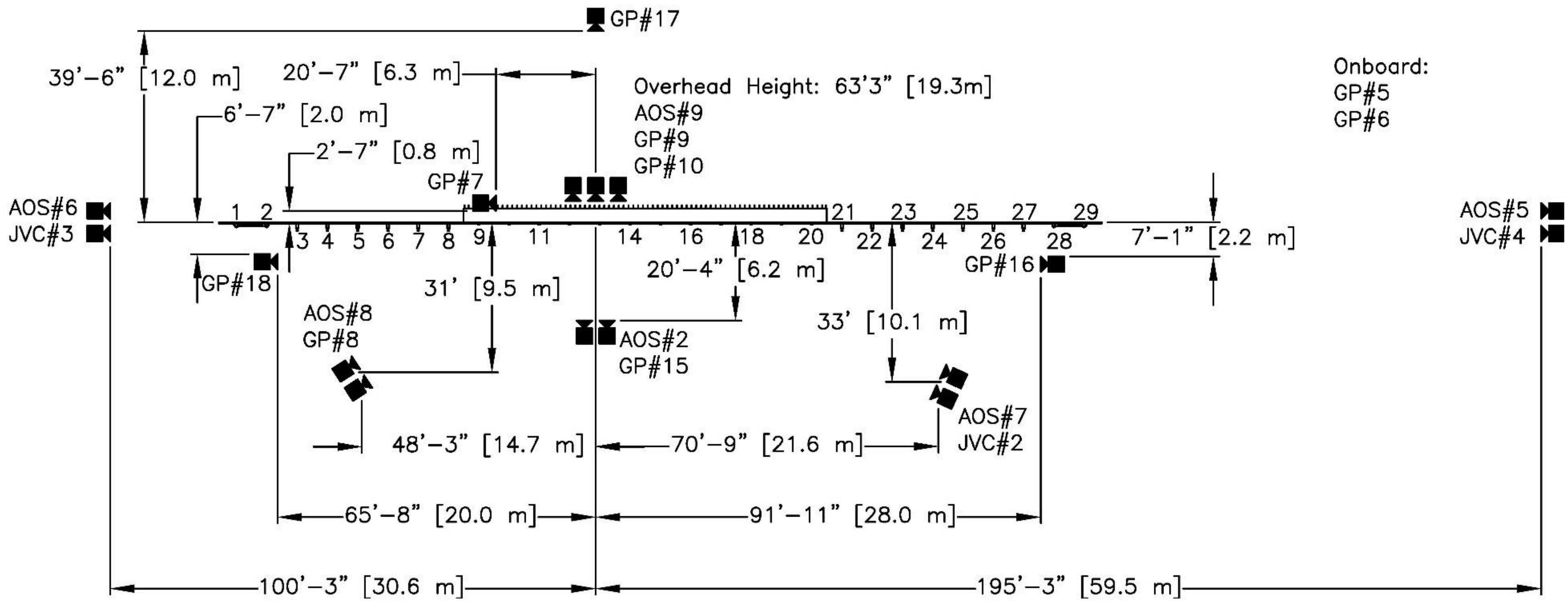


Figure 86. Camera Location Diagram, Test No. N2BR-1

Table 5. Camera Locations, Speeds, and Lens Settings, Test No. N2BR-1

No.	Type	Operating Speed frames/sec	Lens	Lens Setting
AOS-2	AOS Vitcam CTM	500	Kowa 16 mm Fixed	-
AOS-5	AOS Vitcam CTM	500	Telesar 135 mm Fixed	-
AOS-6	AOS X PRI Gigabit	500	Fujinon 50 mm Fixed	-
AOS-7	AOS X-PRI Gigabit	500	Sigma 28-70 #2	35
AOS-8	AOS S-VIT 1531	500	Sigma 28-70 #1	28
AOS-9	AOS X-TRI-VIT 2236	1000	Kowa 12 mm 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	120		
GP-17	GoPro Hero 4	120		
GP-18	GoPro Hero 4	120		
JVC-2	JVC 2	29		
JVC-3	JVC 3	29		
JVC-4	JVC 4	29		

8 FULL-SCALE CRASH TEST NO. N2BR-1

8.1 Static Soil Test

Before full-scale crash test no. N2BR-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 E, 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.

8.2 Weather Conditions

Test no. N2BR-1 was conducted on April 12, 2018 at approximately 1:15 p.m. The weather conditions as per the National Oceanic and Atmospheric Administration (station 14939/LNK) were reported and are shown in Table 6.

Table 6. Weather Conditions, Test No. N2BR-1

Temperature	70° F
Humidity	37%
Wind Speed	16 mph
Wind Direction	90°
Sky Conditions	Windy Partly Cloudy
Visibility	10.0 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0 in.
Previous 7-Day Precipitation	0.2 in.

8.3 Test Description

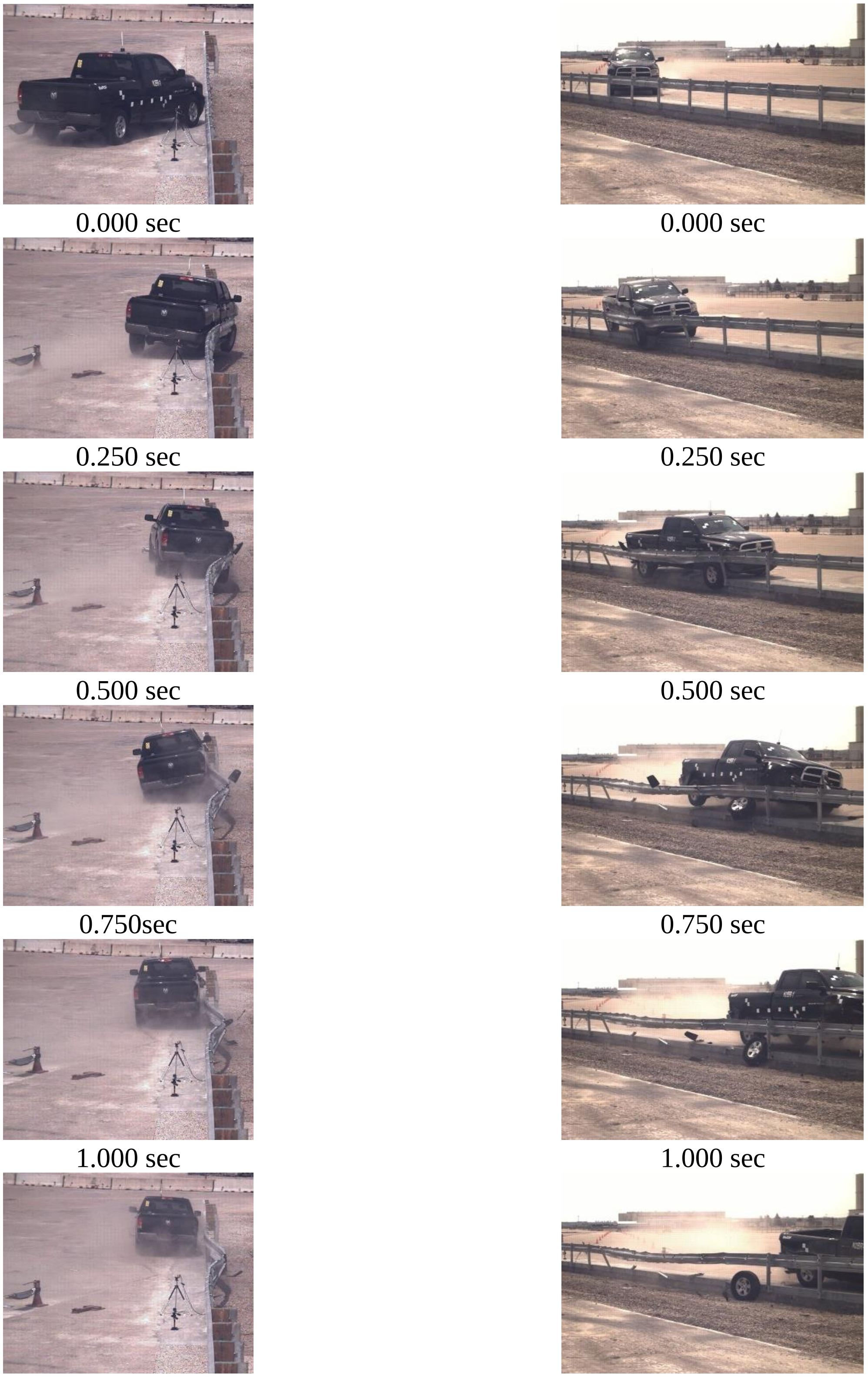
Initial vehicle impact was to occur 123 in. upstream from the centerline of the splice between post nos. 14 and 15, as shown in Figure 87. This impact point was selected using the CIP plots found in Section 2.3 of MASH 2016. The 4,999-lb pickup truck impacted the new TL-2 bridge rail at a speed of 44.2 mph and at an angle of 25.5 degrees. The actual point of impact was 2.6 in. downstream from the targeted location. During the impact event, the bridge railing contained the pickup truck and smoothly redirected it back onto the bridge. The vehicle's right-front tire extended over the edge of the deck, but the vehicle remained stable with minimal roll. The front-right tire snagged on the socket supporting post no. 17, causing the wheel to disengage. The tire snag resulted in about a 10-g longitudinal acceleration pulse, which remained well within the MASH limits, and only minor pitch and roll displacements. After exiting the system, the brakes were applied, and the vehicle veered back toward the system and impacted the MGS downstream of the bridge rail. The vehicle came to rest adjacent to the downstream anchorage 104 ft – 5 in. downstream from the initial impact point after brakes were applied.

A detailed description of the sequential impact events is contained in Table 7. Sequential photographs are shown in Figures 88 and 89. Documentary photographs of the crash test are shown in Figure 90. The vehicle trajectory and final position are shown in Figure 91.

Figure 87. Impact Location, Test No. N2BR-1

Table 7. Sequential Description of Impact Events, Test No. N2BR-1

TIME sec	EVENT
0.000	Vehicle's front bumper impacted the system 120.4 in. upstream from the centerline of the splice between post nos. 14 and 15 at 44.2 mph.
0.006	System began to deflect backward.
0.016	Vehicle's right-front tire contacted system.
0.030	Vehicle's hood began to deform and post nos. 13 and 14 began to deflect backward.
0.038	Post no. 15 began to deflect backward.
0.060	Vehicle pitched downward.
0.080	Vehicle's right-front tire passed over the edge of the bridge deck.
0.108	Vehicle's bumper impacted post no. 14 and bent it downstream.
0.162	Post no. 16 began to deflect backward.
0.172	Post no. 17 began to deflect backward.
0.206	Vehicle's bumper impacted post no. 15 and bent it downstream.
0.218	Vehicle began to roll toward system.
0.290	Rear of vehicle impacted rail near post no. 13.
0.310	Vehicle's right-rear tire passed over the edge of the bridge deck.
0.336	Vehicle's bumper impacted post no. 16 and bent it downstream.
0.349	Vehicle was parallel to the system at a velocity of 31.2 mph.
0.380	Vehicle reached maximum positive roll value of 12.1 degrees and began to roll away from the system.
0.510	Vehicle's right-front tire impacted the socket supporting post no. 17.
0.548	Vehicle's right-front tire detached from vehicle.
0.680	Vehicle's right-front tire was on top of post no. 17, which was bent downstream.
0.723	Vehicle reached maximum negative roll of -11.2 degrees.
0.846	Vehicle's left-front tire became airborne.
0.860	Vehicle became airborne.
0.952	Vehicle exited system at a velocity of 19.7 mph.
0.970	Vehicle's right-front tire impacted post and socket no. 18 and bounced backward.
1.064	Vehicle's right-rear tire contacted ground.
1.120	Vehicle's left-front tire returned to the ground.
1.270	Vehicle's right-front corner impacted ground.
1.710	Vehicle began to yaw and veer toward system.
1.840	Vehicle's right-front fender contacted system between post nos. 23 and 24.
1.996	Vehicle yawed away from system.
2.710	Vehicle exited system again traveling nearly parallel to rail.
3.400	Vehicle contacted rail near downstream anchorage
5.340	Vehicle came to a stop.



0.000 sec | 0.000 sec
0.250 sec | 0.250 sec
0.500 sec | 0.500 sec
0.750sec | 0.750 sec
1.000 sec | 1.000 sec
1.250 sec | 1.250 sec

Figure 88. Sequential Photographs, Test No. N2BR-1


0.000 sec


0.000 sec


0.250 sec


0.250 sec


0.500 sec


0.500 sec

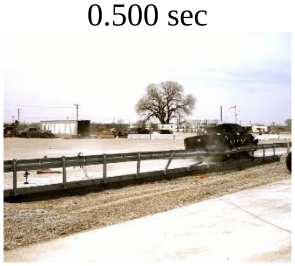

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Figure 89. Additional Sequential Photographs, Test No. N2BR-1

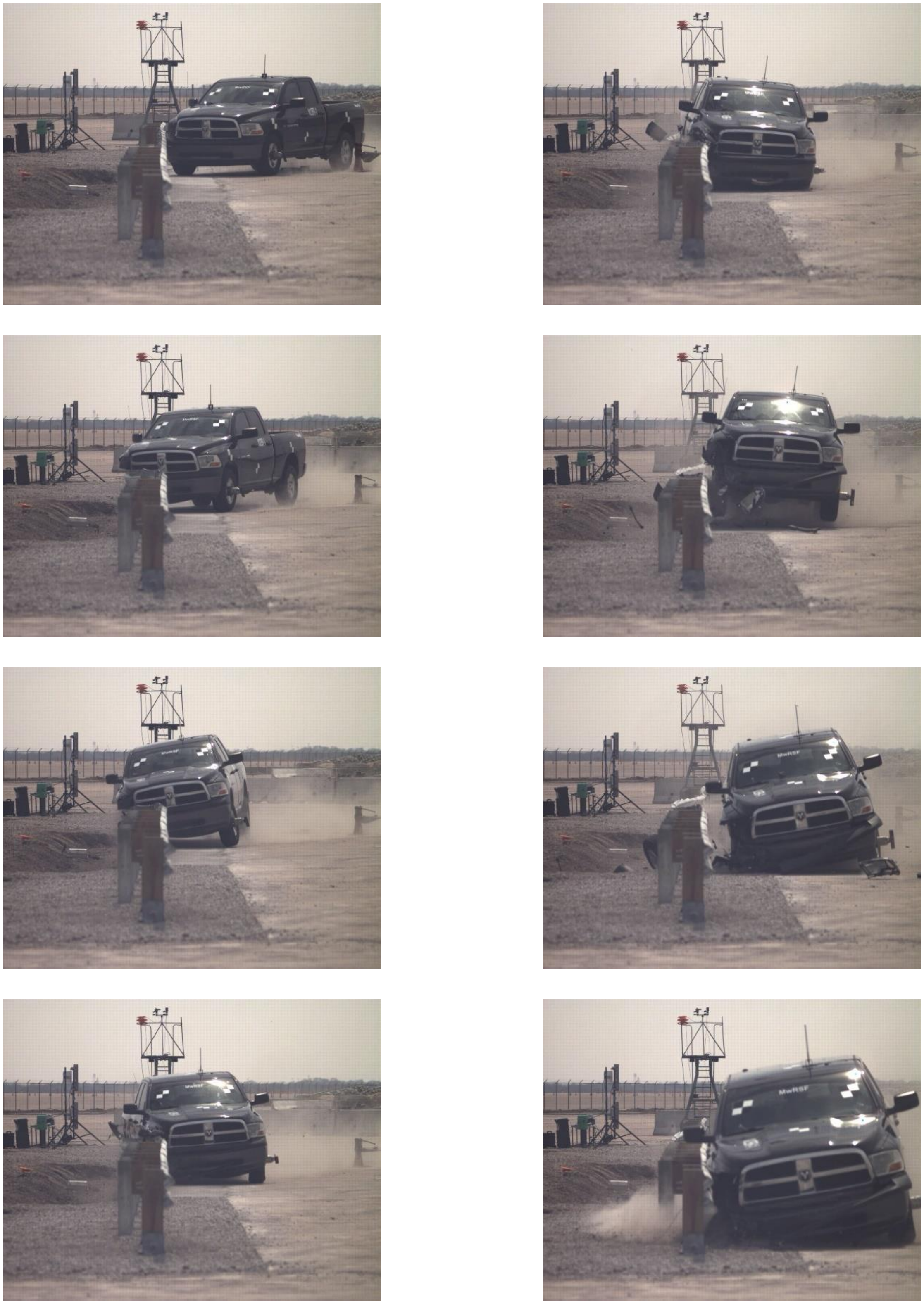


Figure 90. Documentary Photographs, Test No. N2BR-1

Figure 91. Vehicle Trajectory Marks and Final Position, Test No. N2BR-1

8.4 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 92 through 95. Barrier damage consisted of contact marks extending from post nos. 13 to 17, as well as rail deformations, post bending and tearing, and guardrail bolt release. The length of vehicle contact along the barrier was approximately 27 ft which spanned from 6½ in. upstream from the impact point to 5 in. downstream from post no. 17. Guardrail scrapes and deformations in the form of kinking and flattening were observed throughout the contact region. Four additional kinks were observed downstream from post no. 17, outside of the contact region. Guardrail bolt fracture occurred in post nos. 13 through 17.

Post no. 12 was bent slightly backward and post no. 13 was bent backward and downstream. Post nos. 14 through 17 were bent downstream approximately 90 degrees, and the upstream flanges of these posts were torn adjacent to the welded post standoffs. Tears extended through the upstream edge of the flange and through the web, with tears in post nos. 14 through 16 extending 1¼ in., and the tear in post no. 17 extending 2 in. Scrapes were located on the upstream edge of the flange and front face of the flange on post nos. 13 through 17, beginning near the base of the post and extending upward.

Little to no damage occurred to the post socket assemblies. Only very minor deformations on the top edges were found on the sockets at post nos. 14 through 17. The sockets at post nos. 14 through 17 were rotated downstream, but not damaged. The tolerance provided by the vertical slots in the mounting plate allowed for the small rotations of these socket assemblies. The attachment bolts and the bridge deck were undamaged. Damage to the test installation due to the secondary impacts was negligible, consisting mostly of contact marks.

The maximum lateral permanent set of the barrier system was 20 in., which occurred on the guardrail located at mid-span between post nos. 14 and 15, as measured in the field. The maximum lateral dynamic barrier deflection was 32.6 in. measured on the guardrail at mid-span between post nos. 14 and 15, as determined from high-speed digital video analysis. The working width of the system was found to be 38.4 in., also determined from high-speed digital video analysis.


Overall System Damage, Upstream View


Overall System Damage, Front View


Overall System Damage, Upstream Behind View

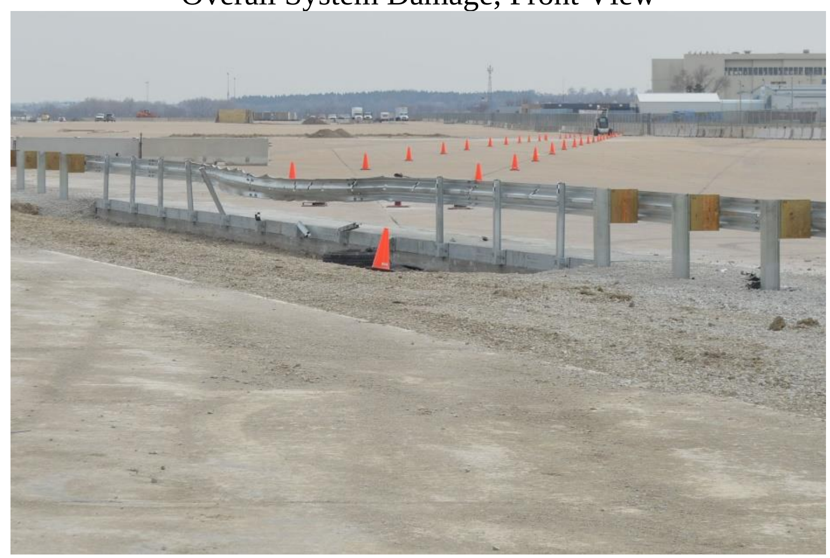

Overall System Damage, Downstream Behind View

Figure 92. System Damage, Test No. N2BR-1

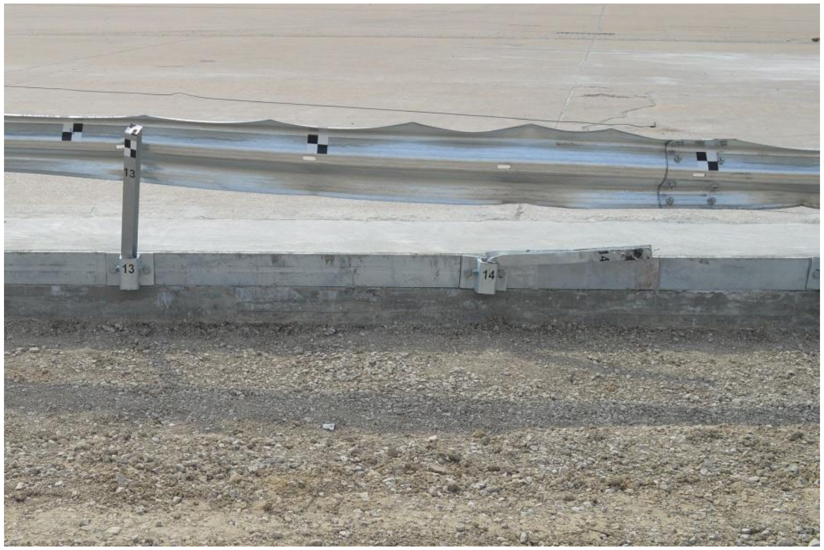
Post Nos. 13 and 14 Damage

Post Nos. 14 and 15 Damage

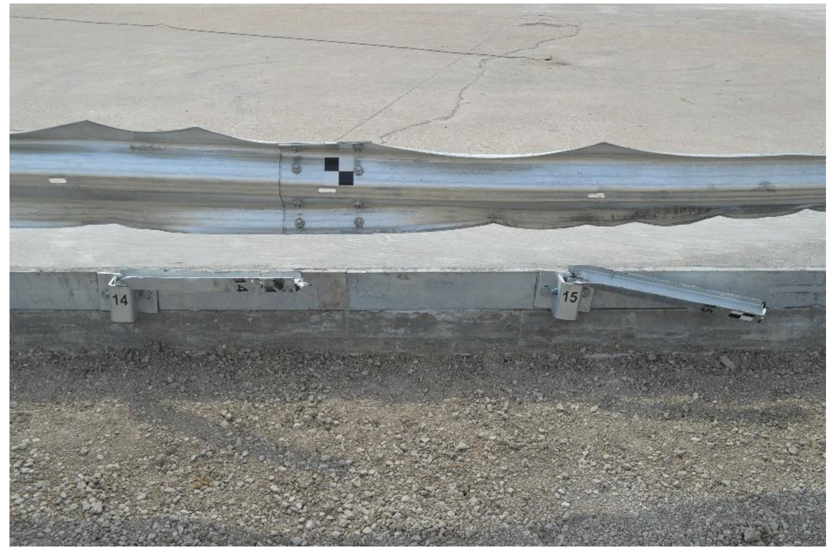
Post Nos. 15 and 16 Damage

Post Nos 16 and 17 Damage

Figure 93. System Damage, Front-Side Views, Test No. N2BR-1



Post Nos. 13 and 14 Rear Damage



Post Nos. 14 and 15 Rear Damage

Post Nos. 15 and 16 Rear Damage

Post Nos. 16 and 17 Rear Damage

Figure 94. System Damage, Back-Side Views, Test No. N2BR-1

Post No. 14 Tearing

Post No. 15 Tearing

Post No. 16 Tearing

Post No. 17 Tearing

Figure 95. System Damage, Post Bending and Tearing, Test No. N2BR-1

8.5 Vehicle Damage

The damage to the vehicle was moderate, as shown in Figures 96 through 98. The maximum occupant compartment deformations are listed in Table 8 along with the intrusion limits established in MASH 2016 for various areas of the occupant compartment. Complete occupant compartment and vehicle deformations and the corresponding locations are provided in Appendix F. 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. Outward deformations, which are denoted as negative numbers in Appendix F, are not considered crush toward the occupant, and are not evaluated by MASH 2016 criteria.

The majority of the damage was concentrated on the right-front corner of the vehicle where the impact had occurred. The right-front bumper and fender were crushed inward. The right-front tire and right-front headlight were disengaged from the vehicle, and the bumper bent back and under the vehicle. Scraping was observed along the vehicle's entire right side. Denting was observed on the right-rear fender. Scraps and minor dents were observed to undercarriage components on the right side of the vehicle. Damage to the suspension consisted of scrapes to the right front and right rear shocks, as well as to the lower control arm. The steering knuckle assemblies, tie rod, and lower control arm all disengaged from the right side of the vehicle. Damage to the chassis consisted of minor scrapes on the lower rear end shock mount. The drive train remained undamaged.

Figure 96. Vehicle Damage, Test No. N2BR-1

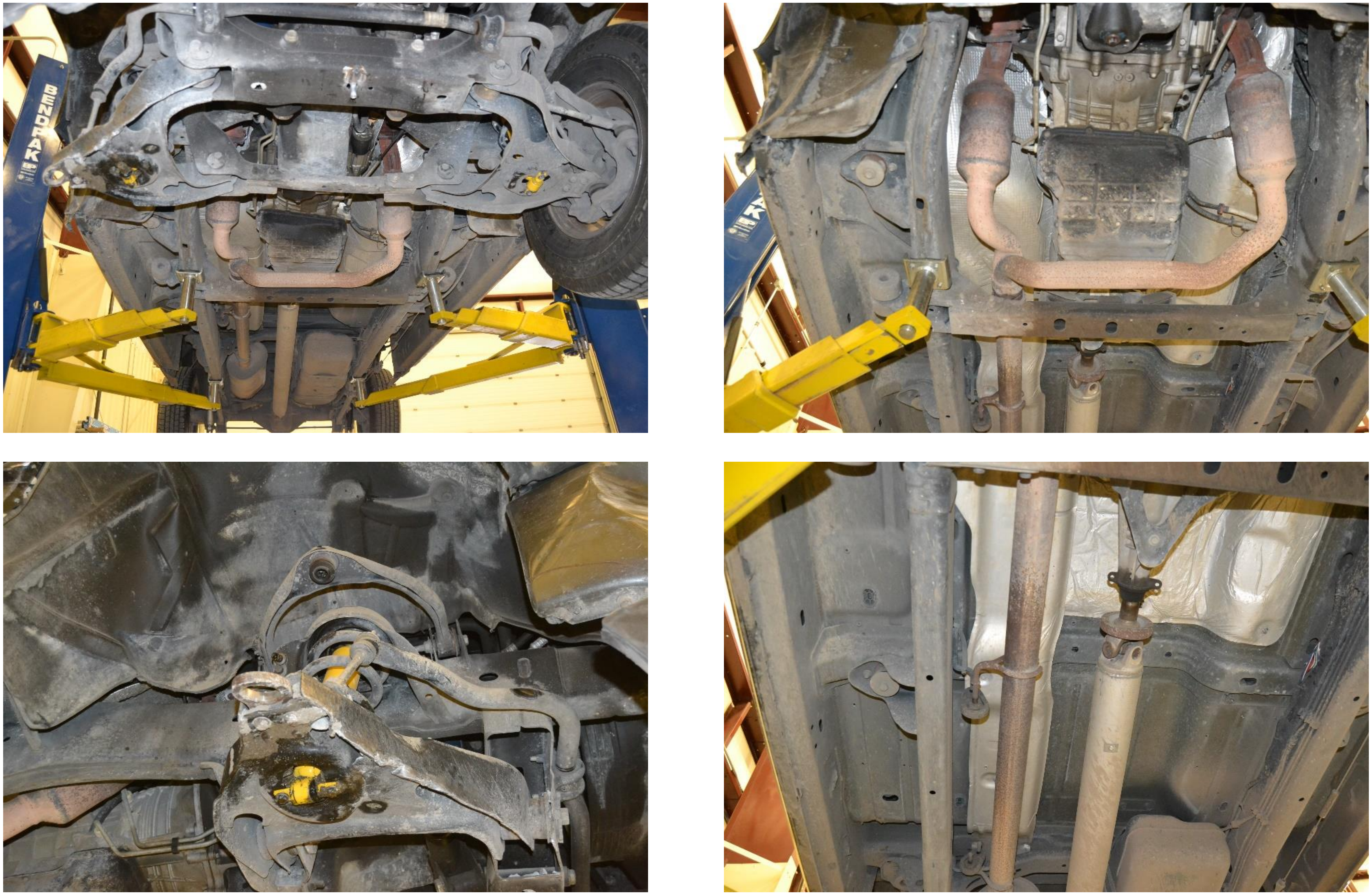


Figure 97. Vehicle Undercarriage Damage, Test No. N2BR-1

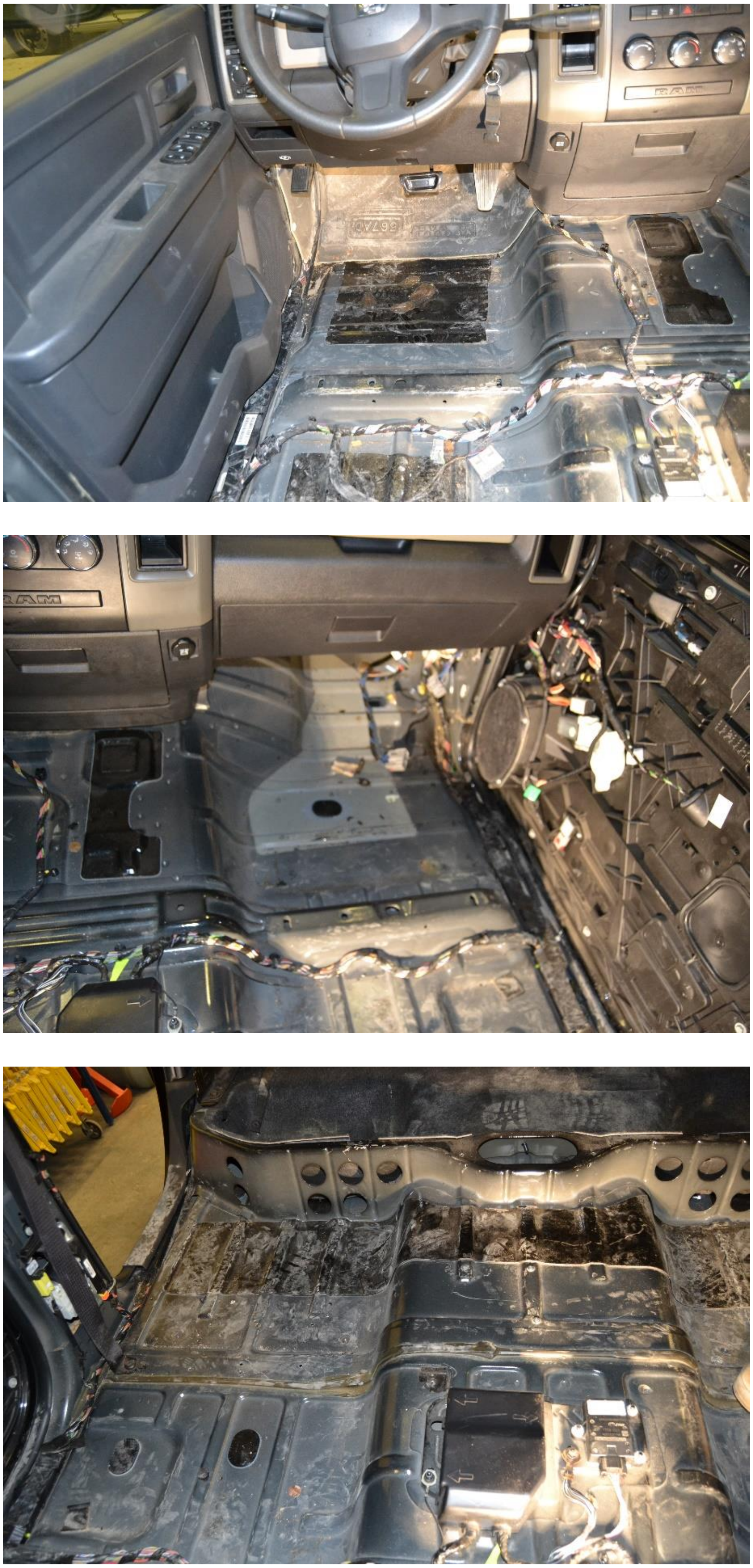


Figure 98. Vehicle Interior Damage, Test No. N2BR-1

Table 8. Maximum Occupant Compartment Deformations by Location, Test No. N2BR-1

LOCATION	MAXIMUM INTRUSION in.	MASH 2016 ALLOWABLE INTRUSION in.
Wheel Well & Toe Pan	0.1	≤ 9
Floor Pan & Transmission Tunnel	-0.2	≤ 12
A-Pillar	0.1	≤ 5
A-Pillar (Lateral)	0.1	≤ 3
B-Pillar	0.4	≤ 5
B-Pillar (Lateral)	0.4	≤ 3
Side Front Panel (in Front of A-Pillar)	0.2	≤ 12
Side Door (Above Seat)	0.3	≤ 9
Side Door (Below Seat)	0.4	≤ 12
Roof	0	≤ 4
Windshield	0	≤ 3
Side Window	Intact	No shattering resulting from contact with structural member of test article
Dash	0.3	N/A

Note: Negative values denote outward deformation
N/A – No MASH 2016 criteria exist for this location

8.6 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 9. 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 9. The recorded data from the accelerometers and the rate transducers are shown graphically in Appendix G.

Table 9. Summary of OIV, ORA, THIV, PHD, and ASI Values, Test No. N2BR-1

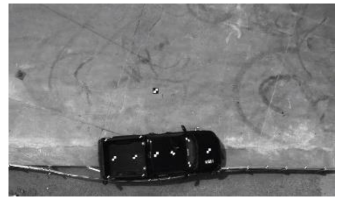
Evaluation Criteria		Transducer		MASH 2016 Limits
		SLICE-1 (primary)	DTS	
OIV ft/s	Longitudinal	-11.52	-12.50	±40
	Lateral	-11.55	-10.53	±40
ORA g's	Longitudinal	-10.98	-10.34	±20.49
	Lateral	5.74	-4.93	±20.49
MAX. ANGULAR DISPL. deg.	Roll	12.1	-11.2	±75
	Pitch	1.9	3.2	±75
	Yaw	-32.3	-32.4	not required
THIV ft/s		15.58	15.55	not required
PHD g's		11.66	10.74	not required
ASI		0.48	0.49	not required

8.7 Discussion

The analysis of the test results for test no. N2BR-1 showed that the bridge rail 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 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 -1.0 degrees, and its trajectory did not violate the bounds of the exit box. Therefore, test no. N2BR-1 was determined to be acceptable according to the MASH 2016 safety performance criteria for test designation no. 2-11. A summary of the test results and sequential photographs are shown in Figure 99.

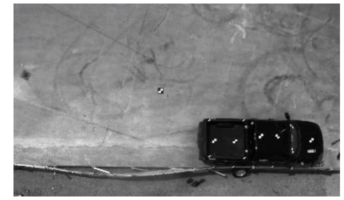
0.000 sec

0.250 sec

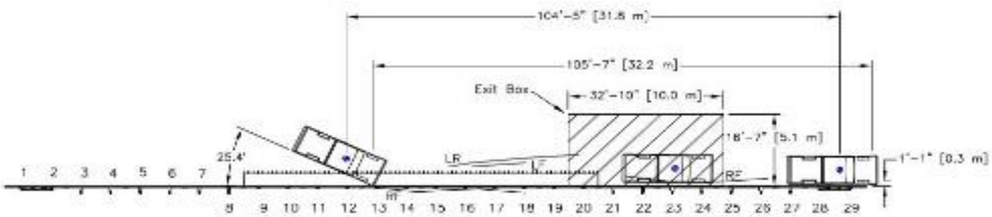


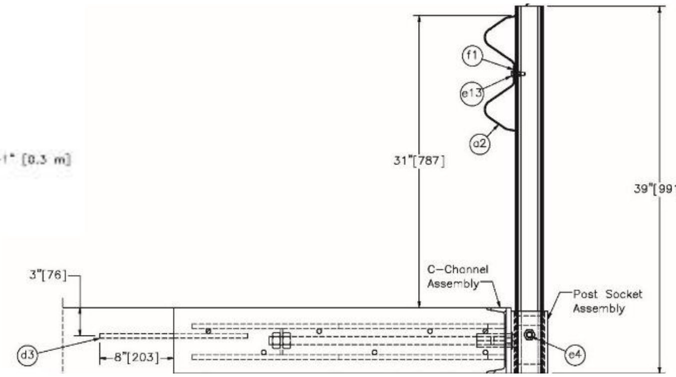
0.500 sec

0.750 sec



1.000 sec





- Test Agency .... MwRSF
- Test Number N2BR-1
- Date 4/12/2018
- MASH 2016 Test Designation No 2-11
- Test Article .... Test-Level 2 Side Mounted Bridge Rail
- Total Length .... 182 ft – 3½ in.
- Key Component - Rail
  - Length .... 225 ft
  - Thickness .... 12 Gauge
- Key Component – Bridge Rail Post
  - Length .... 39 in.
  - Type S3x5.7
  - Spacing .... 75 in.
- Deck Type .... 7-in. thick CIP deck
- Vehicle Make /Model .... 2011 Dodge Ram 1500
  - Curb .... 5,111 lb
  - Test Inertial .... 4,999 lb
  - Gross Static .... 5,160 lb
- Impact Conditions
  - Speed .... 44.2 mph
  - Angle .... 25.5 deg.
  - Impact Location .... 120.4 in. upstream from splice between post nos. 14 and 15
- Impact Severity (IS) .... 60.5 kip-ft > 51 kip-ft limit from MASH 2016
- Exit Conditions
  - Speed .... 19.7 mph
  - Angle .... -1.0 deg.
- Exit Box Criterion .... Pass
- Vehicle Stability .... Satisfactory
- Vehicle Stopping Distance .... 104 ft – 5 in.
- Vehicle Damage .... Moderate
  - VDS [16] 1-RFQ-3
  - CDC [17] 01-RFME1
  - Maximum Interior Deformation .... 0.4 in.

- Test Article Damage .... Moderate
- Maximum Test Article Deflections
  - Permanent Set .... 20 in.
  - Dynamic .... 32.6 in.
  - Working Width .... 38.4 in.
- Transducer Data

Evaluation Criteria		Transducer		MASH 2016 Limit
		SLICE-1 (primary)	DTS	
OIV ft/s	Longitudinal	-11.52	-12.50	±40
	Lateral	-11.55	-10.53	±40
ORA g's	Longitudinal	-10.98	-10.34	±20.49
	Lateral	5.74	-4.93	±20.49
MAX ANGULAR DISP. deg.	Roll	12.1	-11.2	±75
	Pitch	1.9	3.2	±75
	Yaw	-32.2	-32.4	Not required
THIV – ft/s		15.7	15.4	Not required
PHD – g's		11.7	10.7	Not required
ASI		0.48	0.49	Not required

Figure 99. Summary of Test Results and Sequential Photographs, Test No. N2BR-1

9 BRIDGE RAIL TRANSITION TO MGS

9.1 Background and Scope

Barrier transitions are often required to safely connect longitudinal barrier systems of different components and/or lateral stiffnesses. The new TL-2 bridge rail developed herein utilizes the same guardrail, barrier height, and post spacing as standard MGS. However, the difference between the S3x5.7 bridge rail post and the W6x8.5/W6x9 of the MGS results in a different lateral stiffness. Thus, the connection between the two guardrail systems was required.

To evaluate if a transition was necessary between the MGS and the new TL-2 bridge rail, vehicle crash test simulations were performed with BARRIER VII. BARRIER VII is a computer program used extensively to model and analyze vehicle crashes into guardrail systems [18-19]. In this program, the barrier and vehicle are idealized as two-dimensional structures in the horizontal plane, meaning that vertical displacements of the barrier or the vehicle are not considered. BARRIER VII models post and beam systems using a rail that yields at nodal locations and elastic, perfectly-plastic posts. Thus, component models of W6x9 posts, S3x5.7 posts, anchor posts, and 12-gauge W-beam guardrail were required to perform the analysis. The vehicle was idealized as a rigid body of prescribed shape surrounded by a cushion of discrete springs.

The primary purpose of the transition analysis was to evaluate guardrail pocketing angles at the transition from the weaker S3x5.7 TL-2 bridge rail posts to stiffer W6x9 MGS posts. Large guardrail pocketing angles in front of an impacting vehicle have been associated with vehicle instabilities, vehicle snag, excessive decelerations, high rail loads, and even rail rupture. Pocketing angles less than 30 degrees are typically considered safe for guardrail systems, while pocketing angles greater than 30 degrees run a higher risk of failure [3]. Barrier deflections and forces were also determined through the analysis.

9.2 BARRIER VII Model

To simulate test no. N2BR-1, a BARRIER VII model with a system length of 225 ft was used, consisting of 75 ft of MGS upstream and downstream from a 75-ft section of the TL-2 bridge rail. The upstream and downstream portions of the MGS were intentionally made longer than the full-scale crash test because it was not desired to significantly load the anchor posts due to BARRIER VII's limitations in accurately depicting their behavior. The barrier consisted of a updated 12-gauge W-beam rail model, which spanned the entire length of the system, and four different post sections: 1) a simulated strong anchor post, 2) a second BCT post at upstream and downstream ends of the system, 3) W6x9 posts for the MGS, and 4) S3x5.7 posts for the bridge rail.

Initially, properties for the posts and W-beam were obtained from previous BARRIER VII studies and from nominal cross-section properties of the components. However, after conducting initial simulations and comparing the result to full-scale crash tests, the properties were modified to provide more accurate results. These modifications are described in the following sections.

9.2.1 Post Models

Force versus deflection characteristics observed from previous bogie tests provided the basis for the post models. Data obtained from bogie testing of the S3x5.7 posts determined the initial bending moments about the strong and weak axis at the base of the post were 142.9 and 46.9 kips/in., respectively. These strengths were reduced by a factor of 0.7 to 32.8 and 100 kips/in., respectively, to account for rail twisting commonly observed in guardrail tests, including test no. N2BR-1. Bending strengths for the W6x9 posts were obtained in a similar manner with guidance from previous BARRIER VII models evaluating the MGS. A deflection of 15 in. was established as the failure limit for both posts. Calibrated post parameters for the W6x9 and S3x5.7 posts used in the BARRIER VII simulations are shown in Table 10.

Table 10. BARRIER VII Post Input Parameters

BARRIER VII Parameters		W6x9 Input Values	S3x5.7 Input Values
K_B - Post Stiffness Along B (strong axis)	kip/in.	5.0	2.5
K_A - Post Stiffness Along A (weak axis)	kip/in.	3.0	2.5
M_A - Moment About A (strong axis)	kip-in.	180.0	100.0
M_B - Moment About B (weak axis)	kip-in.	92.0	32.8
δ_A - Failure Displacement Along B	in.	15	15
δ_B - Failure Displacement Along B	in.	15	15

9.2.2 Anchor Models

Two modified BCT posts were utilized within the guardrail anchorages positioned at each end of the test installations. These posts were inserted into 6-ft long steel foundation tubes, and a ground line strut was positioned between the anchor posts, and a cable anchor was attached between the end post and the guardrail section.

In BARRIER VII, the ground line strut and cable were not modeled for simplicity. To accommodate for this, the two end anchor posts were modeled with significantly stiffer post parameters to compensate for the lack of the ground line strut and cable [20-21]. Calibrated post parameters for the anchor and BCT posts used in the BARRIER VII simulations are shown in Table 11

Table 11. BARRIER VII Anchor Post Input Parameters

BARRIER VII Parameters		Strong Anchor Post Values	Second BCT Post Input Values
K_B - Post Stiffness Along B (strong axis)	kip/in.	6.0	3.0
K_A - Post Stiffness Along A (weak axis)	kip/in.	6.0	3.0
M_A - Moment About A (strong axis)	kip-in.	180.0	225.0
M_B - Moment About B (weak axis)	kip-in.	92.0	150
δ_F - Failure Displacement Along B	in.	15	15

9.2.3 W-Beam Guardrail Model

Previous W-beam guardrail models were based on the material and geometrical properties of undamaged guardrail. However, these nominal values were believed to be the source of error in the simulations. During an impact event, W-beam guardrail is flattened and stretched. Flattened W-beam sections have much less bending strength than undamaged rail due to the change in the cross-section shape. BARRIER VII is incapable of altering the cross-sectional properties of a component during a simulation. As such, the cross section and bending strength of the W-beam in BARRIER VII had to be reduced from the nominal values to better replicate reality. Further, tensile loads in guardrail systems result in the W-beam segments shifting relative to one another at splice locations, effectively elongating the guardrail. BARRIER VII does not model splices, so the cross-sectional area of the W-beam had to be reduced to allow the rail to elongate during impacts. The nominal and adjusted properties for the W-beam guardrail in BARRIER VII are shown in Table 12.

Table 12. Adjusted W-beam Properties in BARRIER VII

Property	Nominal W-beam Value	Adjusted W-beam Value
Rail I_x	2.29 in.^{4}	0.75 in.^{4}
Rail P_y	99.5 kip	99.5 kip
Rail My	68.5 kip-in.	17 kip-in.
Rail A	1.99 in.^{2}	0.5 in.^{2}

A uniform mesh density was used across the entire length of the guardrail. A node spacing of 9⅜ in. was used, requiring 289 nodes for the 225-ft long system.

9.2.4 Coefficient of Friction

Contact interfaces between the vehicle and barrier were defined within BARRIER VII with a coefficient of friction. This global coefficient of friction was utilized to account for vehicle-rail friction, vehicle-post friction, and wheel snag during the impact event. The kinetic friction value was calibrated according to the physical test's exit time, parallel time, and length of contact in order to provide the most accurate results. The selected coefficient of friction was 0.27.

9.3 TL-2 Bridge Rail Model Verification

Validation of the BARRIER VII model was conducted through comparison of BARRIER VII results to that of full-scale crash test no. N2BR-1. The simulated 2270P vehicle was given the same impact speed, impact angle, and impact point as the full-scale test. The model was evaluated on a number of parameters, including vehicle time to parallel, vehicle speed at parallel, maximum displacement, and maximum pocketing angle. Pocketing angles for both the simulation and the physical test where calculated over a 37.5-in. distance, or half post spacing. A comparison of the results in shown in Table 13.

Table 13. Comparison of BARRIER VII Results to Test No. N2BR-1

Parameter	Test No. N2BR-1	BARRIER VII Model
Vehicle Parallel		
Time	0.349 sec	0.357 sec
Speed	31.16 mph	32.1 mph
Displacement		
Maximum	32.1 in.	32.2 in.
Location	Post 15	Post 15
Tim e	0.290 sec	0.250 sec
Pocketing Angle		
Max. Angle	17°	15°
Location	Mid-span Post 15-16	Mid-span Post 15-16
Time	0.300 sec	0.280 sec

The BARRIER VII simulation matched the results of the full-scale crash test rather well over the first 0.400 sec of the impact. The vehicle parallel time and speed where very similar, the system displacements were nearly identical, and the maximum pocketing angles were within 2 degrees. Post failure was defined in the BARRIER VII simulations as post displacements greater than 15 in. BARRIER VII determined 4 posts failed according to this failure criteria, and post nos. 14 through 17 had bent completely over in the physical test. A graphical comparison of the simulation to the physical test is shown in Figures 100 through 106. After approximately 0.400 s, the model began to deviate from the full-scale test. BARRIER VII is known for having difficulties simulating system rebound and restoration forces. As such, the results do not match up as well as the vehicle exits the system. Fortunately, all the evaluation metrics for the simulations (e.g., maximum displacements and pocketing angles) occur before the vehicle reaches parallel and starts to exit the system. Therefore, based on the comparison to the physical test described herein, the model of the new TL-2 bridge rail was considered validated.

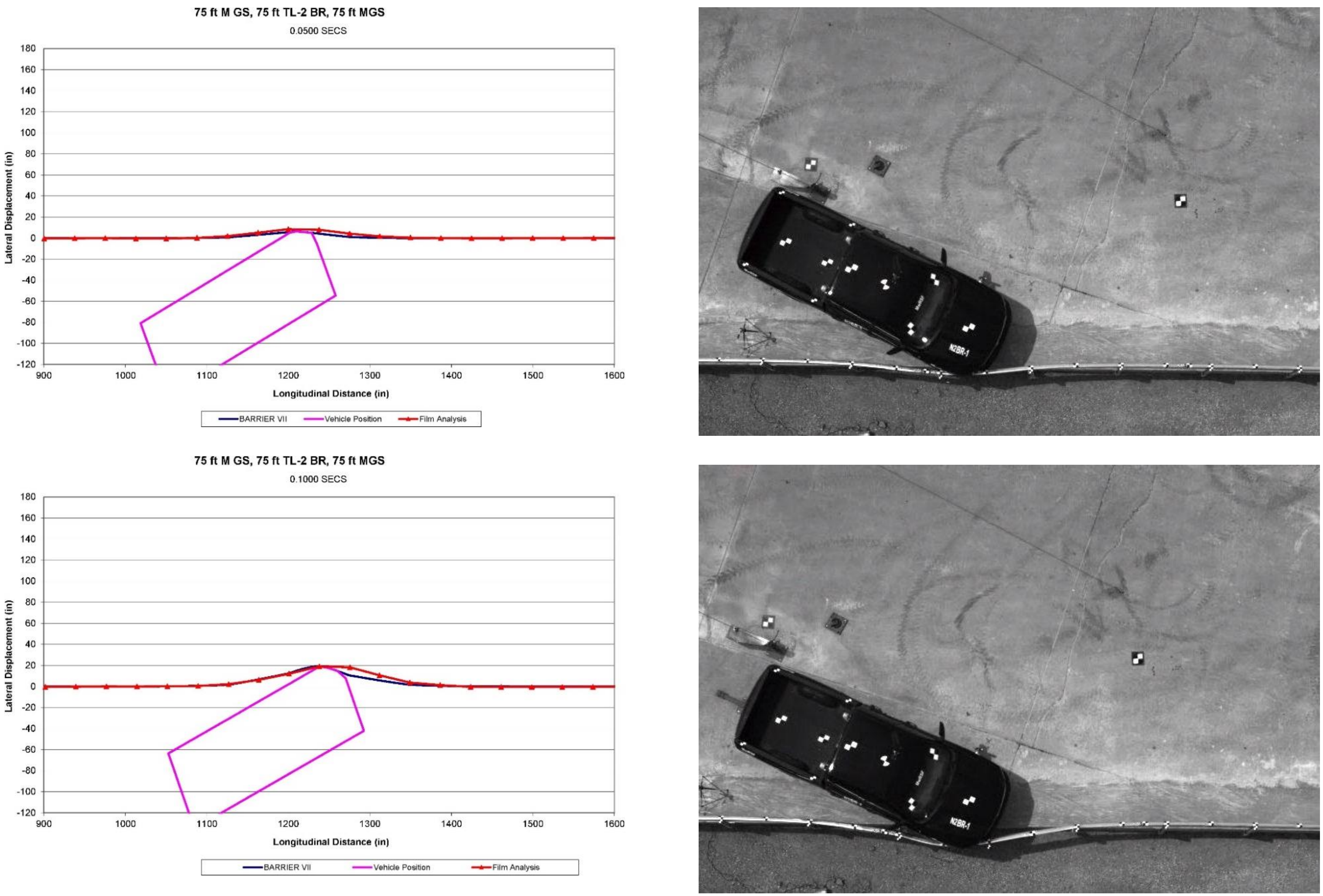


Figure 100. Sequential Figures from BARRIER VII Simulation and Test No. N2BR-1

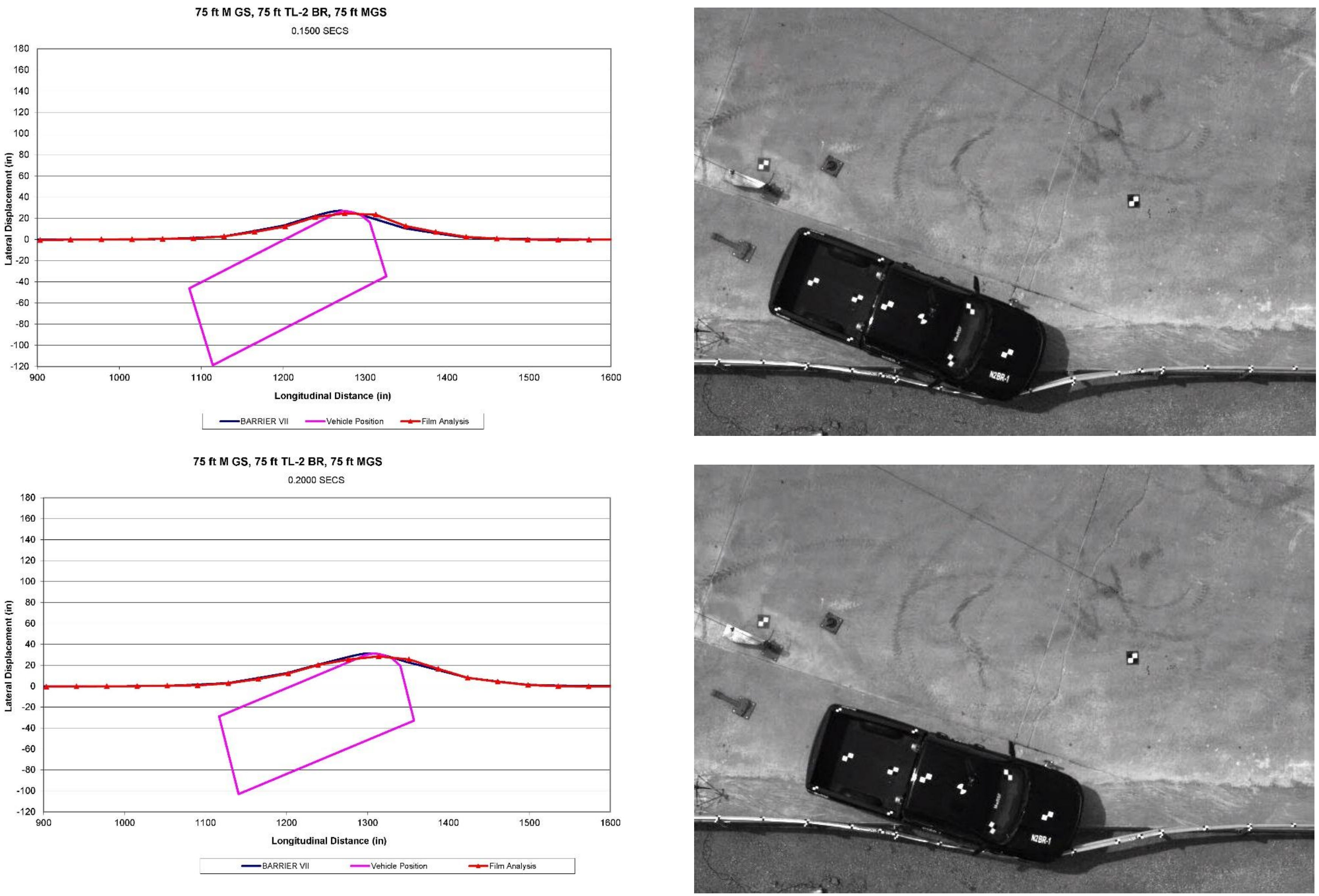


Figure 101. Sequential Figures from BARRIER VII Simulation and Test No. N2BR-1

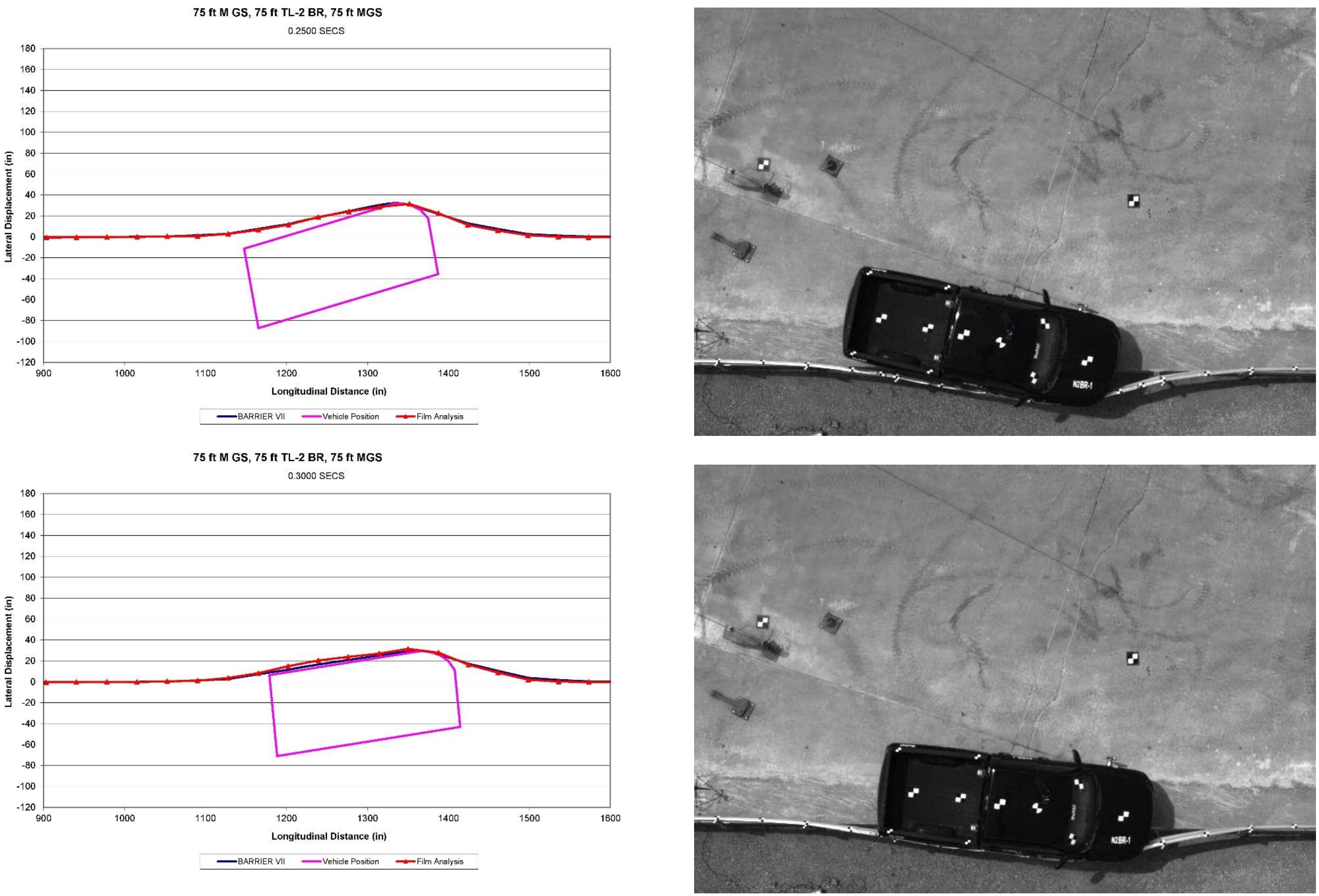


Figure 102. Sequential Figures from BARRIER VII Simulation and Test No. N2BR-1

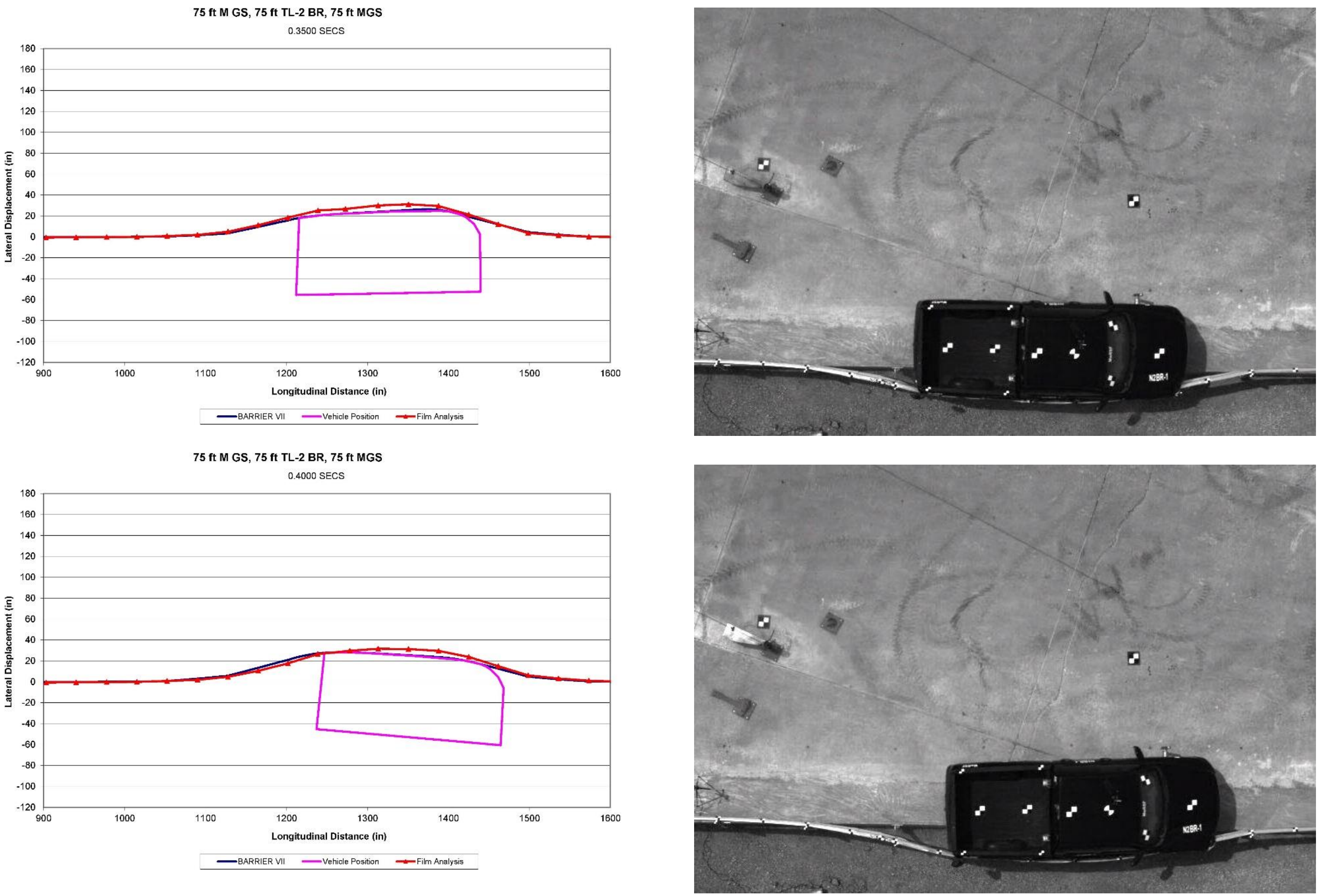


Figure 103. Sequential Figures from BARRIER VII Simulation and Test No. N2BR-1

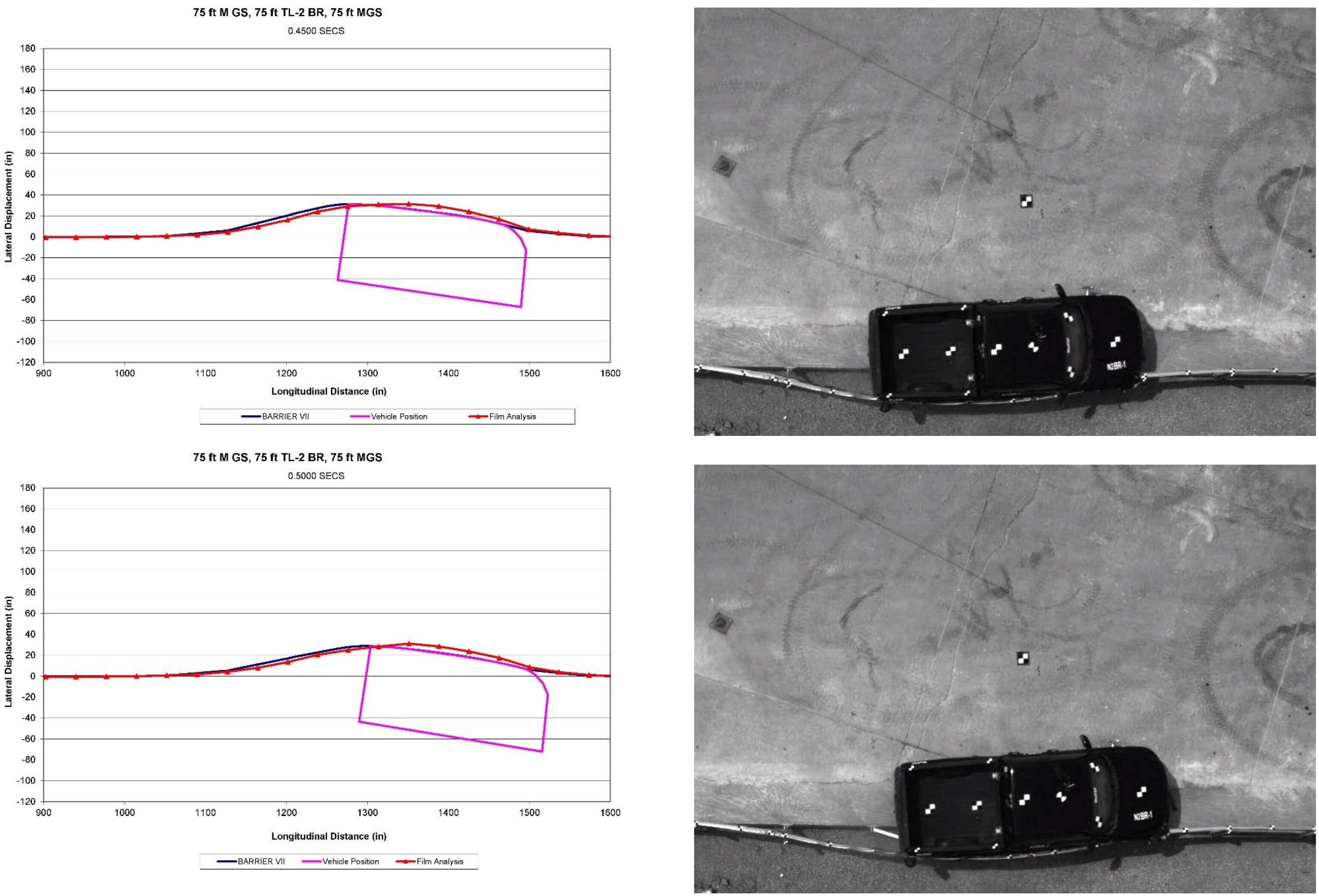


Figure 104. Sequential Figures from BARRIER VII Simulation and Test No. N2BR-1

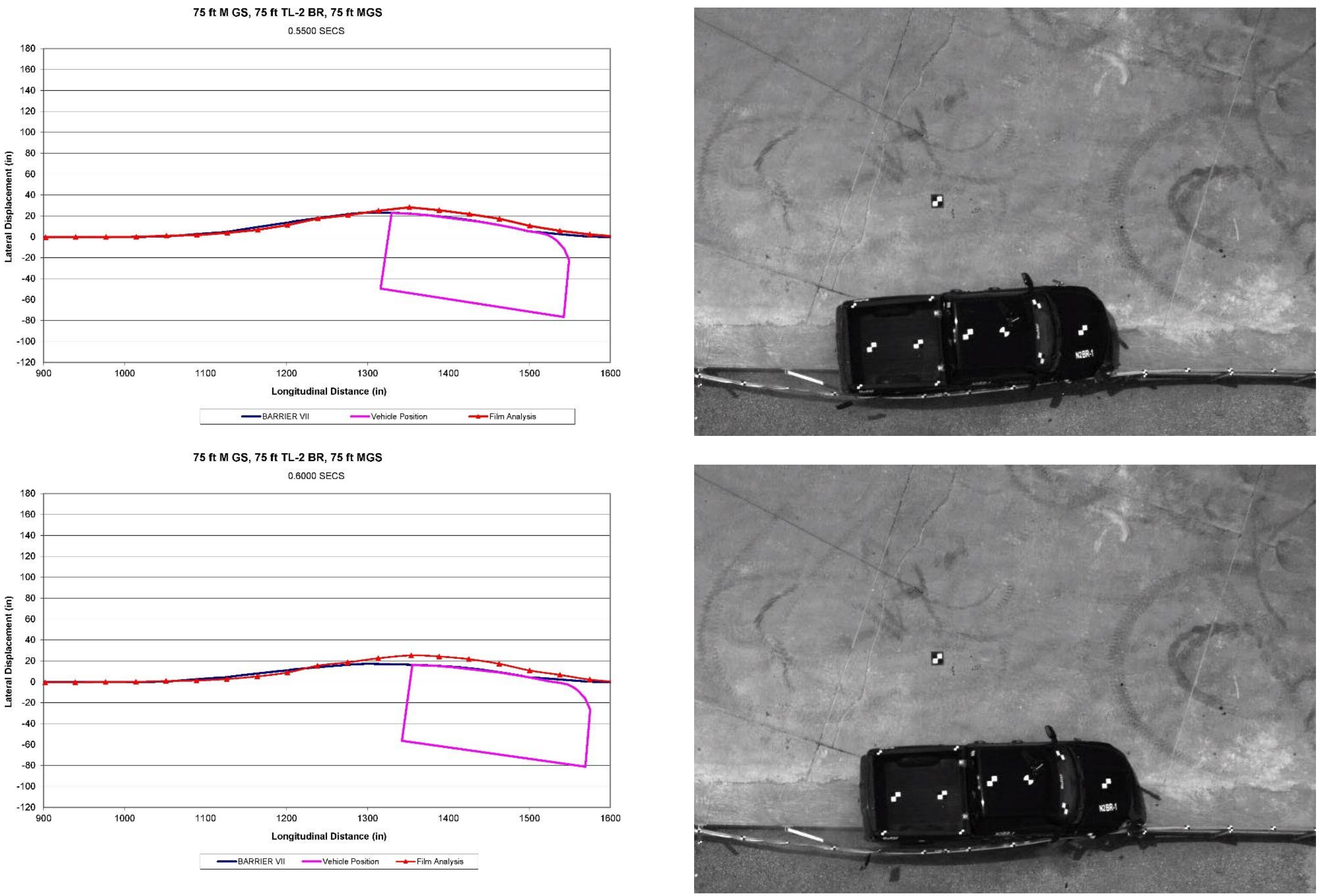


Figure 105. Sequential Figures from BARRIER VII Simulation and Test No. N2BR-1

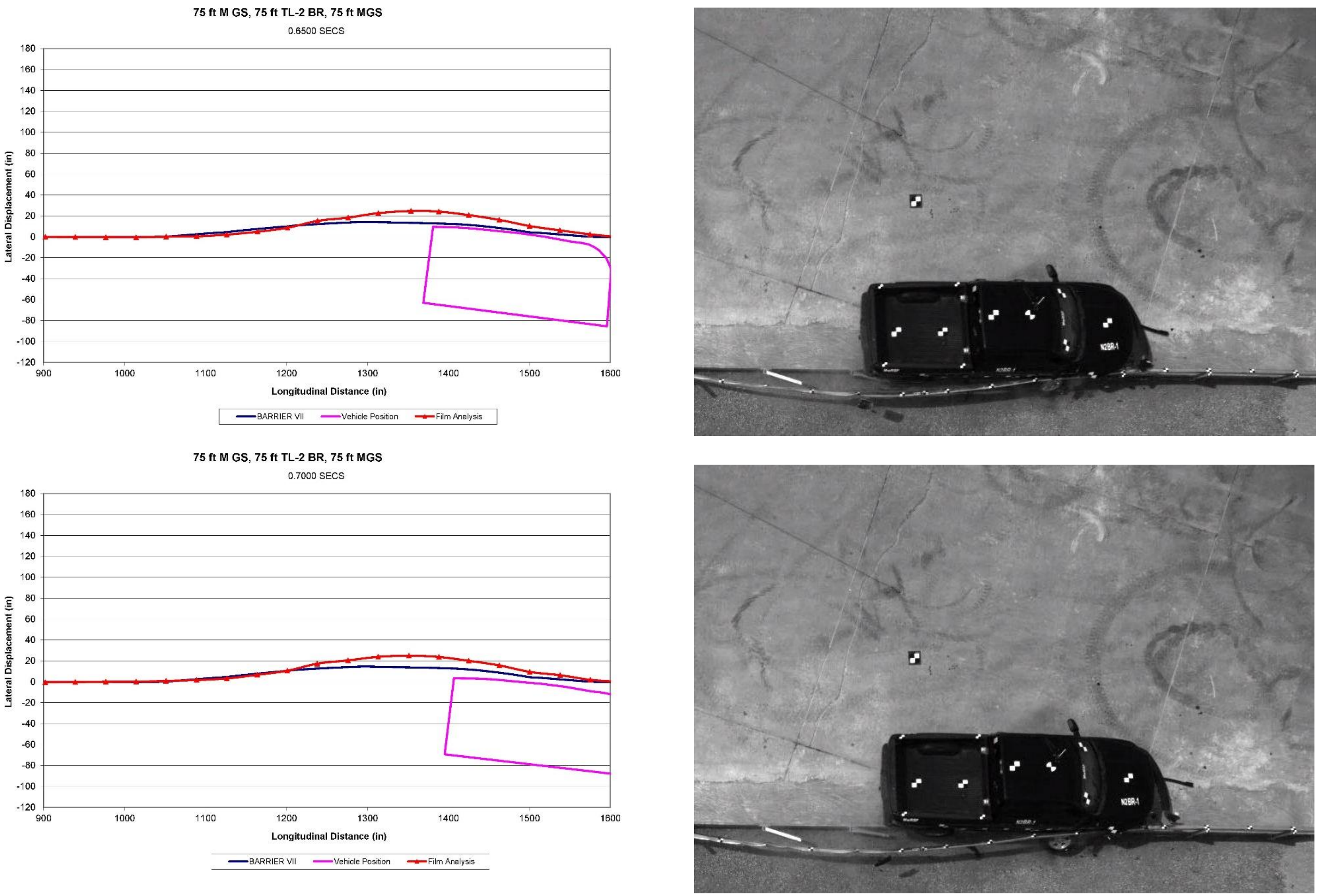


Figure 106. Sequential Figures from BARRIER VII Simulation and Test No. N2BR-1

9.4 MGS Model Validation

At the time of this study, there had not been a MASH TL-2 test conducted on a standard MGS installation. Thus, the BARRIER VII MGS model was validated against a TL-3 crash test, test no. ILT-1, which evaluated the MGS placed in front of a breakaway luminaire pole [22]. Additionally, to evaluate the new W-beam properties in a more rigorous test, the new BARRIER VII model components were also validated against test no. MGSMP-1, which was an MGS system with a missing post [23]

9.4.1 Simulation of MGS at TL-3

Test no. ILT-1 was conducted to evaluate the performance of the MGS when a breakaway light pole is placed behind the guardrail [22]. The BARRIER VII model to replicate test no. ILT-1 consisted of 175 ft of W-beam guardrail comprised of 225 nodes spaced at 9⅜ in. The model had 25 W6x9 posts spaced at 75 in. and was anchored on both ends by two simulated strong BCT anchor posts. All guardrail and anchor post properties used in the validation of the new TL-2 bridge rail remained the same, even the coefficient of friction of 0.27.

The simulation was conducted with the 2270P vehicle impacting the system with the same impact speed, impact angle, and impact point as test no. ILT-1. A comparison of the BARRIER VII results to the physical test is shown in Table 16. Parallel times, pocketing angles, and the locations of the pocketing angle were very similar. The maximum system displacement was also similar, though the location of the displacement and the time of displacement were slightly different. Overall, the simulation results matched well with the crash test.

Table 14. Comparison of BARRIER VII Results to Test No. ILT-1

Parameter	Test No. ILT-1	BARRIER VII Model
Vehicle Parallel		
Time	0.323 sec	0.308 sec
Speed	37.9 mph	44.5 mph
Displacement		
Maximum	44.1 in.	42.2 in.
Location	Post 14	Mid-span Post 13-14
Time	0.300 sec	0.250 sec
Pocketing Angle		
Max. Angle	21.2°	19.6°
Location	Mid-span Post 14-15	Mid-span Post 14-15
Time	0.230 sec	0.270 sec

9.4.2 Simulation of MGS with Missing Post at TL-3

Test no. MGSMP-1 was conducted to evaluate the performance of the MGS when one post is not installed at a given point, leaving a 150-in. gap between two posts [23]. The BARRIER VII model used to replicate test no. MGSMP-1 was identical to the model used for replicating test no. ILT-1, except a single post was removed from the model. The simulation was conducted with the

2270P vehicle impacting the system at the same speed, angle, and impact point as the physical test. A comparison of the BARRIER VII results to the physical test is shown in Table 17. Parallel times, pocketing angles, and the locations of the pocketing angle were very similar. The maximum system displacements did not match as well but were still less than 8 percent different. Overall, the simulation results matched well with the crash test.

Table 15. Comparison of BARRIER VII Results to Test no. MGSMP-1

Parameter	Test No. MGSMP-1	BARRIER VII Model
Vehicle Parallel		
Time	0.310 sec	0.298 sec
Speed	43.1 mph	46 mph
Displacement		
Maximum	49 in.	45.3 in.
Location	Post 14	Mid-span Post 13-14
Time	0.330 sec	0.350 sec
Pocketing Angle		
Max. Angle	23.8°	21.3°
Location	Mid-span Post 14-15	Mid-span Post 14-15
Time	0.270 sec	0.290 sec

9.5 Baseline TL-2 MGS Simulations

For comparison purposes, baseline simulations were conducted on the validated BARRIER VII models of both the new bridge rail and the standard MGS with the prescribed MASH TL-2 impact conditions. The baseline models were both impacted at the mid span of the guardrail at a speed of 44 mph and an impact angle of 25 degrees. The TL-2 bridge rail had a maximum deflection of 31.01 in., while the MGS only had a deflection of 20.4 in. The MGS baseline produced a maximum pocketing angle of 16.6 degrees between post nos. 14 and 15 at 200 ms, and the TL-2 bridge rail baseline produced a maximum pocketing angle of 15.8 degrees between post nos. 15 and 16. Parallel time in the MGS baseline simulation occurred at 354 ms when the vehicle was traveling at 31.4 mph, and occurred at 326 ms when the vehicle was traveling at 31.1 mph.

9.6 Simulation of Transition from MGS to TL-2 Bridge Rail

Once the BARRIER VII model was validated, simulations were run to evaluate the connection of the new TL-2 bridge rail to standard MGS. Similar to the crash test, the model had a 75-in. spacing between adjacent bridge posts and MGS posts, thus maintaining a constant 75-in. post spacing through the system. A total of 25 impacts over an 18.75-ft long span were simulated with the vehicle impacting the system according to MASH TL-2 conditions. The 25 impact points correspond to nodes nos. 169 to 185 in the BARRIER VII model shown in Figures 107 through 109. These nodes correspond to the mid-span between post nos. 21 and 22 to the midspan between post nos. 24 and 25, with post no. 25 being the first MGS post downstream of the bridge rail. Note, these post numbers do not correlate to the full-scale test installation as the model had a different system length than the test article. All node and post numbers discussed in this section refer only to the model.

The simulations were run with the vehicle impacting the bridge rail and traveling into the MGS. These impact points were chosen because the transition from the less rigid TL-2 bridge rail to the more rigid MGS is the most likely location for large pocketing angles to develop. The results of these simulations are summarized in Table 16.

The pocketing angles do increase from the 15 to 17 degree baseline values to a maximum of 23.5 degrees. As expected, the majority of the maximum pocketing angles occurred just upstream of post no. 25, which is the first W6x9 post adjacent to the bridge rail. None of the pocketing angles in the simulations approached the 30-degree limit where concerns for vehicle snag and instabilities exist. Maximum displacements show a gradual decrease as the impacts are moved closer to and into the MGS region of the model, so system deflections were also deemed acceptable. Finally, the maximum rail tension loads were also documented, but the forces saw only a minimal increase through the 25 simulations. The maximum force of 49.4 kips was only half of the 99-kip tensile yield capacity of 12-gauge W-beam.

As there were no concerns regarding the minor increases in pocketing angle and rail forces, the direct connection of the new TL-2 bridge rail to standard MGS was considered crashworthy. There is no need for a transition between the two systems, and a constant post spacing of 75 in. should be used throughout the installation.

Table 16. BARRIER VII Maximum Pocketing Angles, Displacements, and Forces

Impact Node	Pocketing Angle		Displacement		Force	
	Maximum (deg.)	Location (post no.)	Maximum (in.)	Location (node)	Maximum	Location (node)
TL-2 BR Baseline	15.75	20	31.01	142	42.65	129
165	19.73	25	32.27	179	47.55	174
166	21.32	25	32.34	180	48.18	173
167	21.23	25	29.9	180	46.71	177
168	22.15	25	29.8	181	47.69	175
169	22.92	25	30.05	182	49.11	177
170	23.3	25	30.63	183	49.42	172
171	22.72	25	29.95	184	49.42	172
172	22.73	25	30.13	185	49.17	174
173	23.04	25	30.29	186	49.35	175
174	23.04	25	29.94	186	47.9	175
175	22.52	25	27.82	187	48.88	180
176	22.56	25	28.44	188	48.22	181
177	22.84	25	27.73	189	48.11	182
178	22.72	25	27.04	190	46.75	181
179	23.17	25	27.65	191	47.42	181
180	23.51	25	27.71	192	46.1	185
181	23.48	25	27.82	193	44.51	184
182	22.22	25	25.2	194	42.73	187
183	21.28	25	25.36	195	40.6	188
184	19.93	27	25.5	196	40.04	187
185	19.61	27	25.93	198	39.28	189
186	19.43	27	26.05	199	38.72	193
187	18.9	27	25.52	200	37.32	187
188	18.07	26	22.12	200	37.85	195
189	17.84	27	21.99	200	38.68	196
MGS Baseline	16.62	18	20.4	22.82	46.4	130

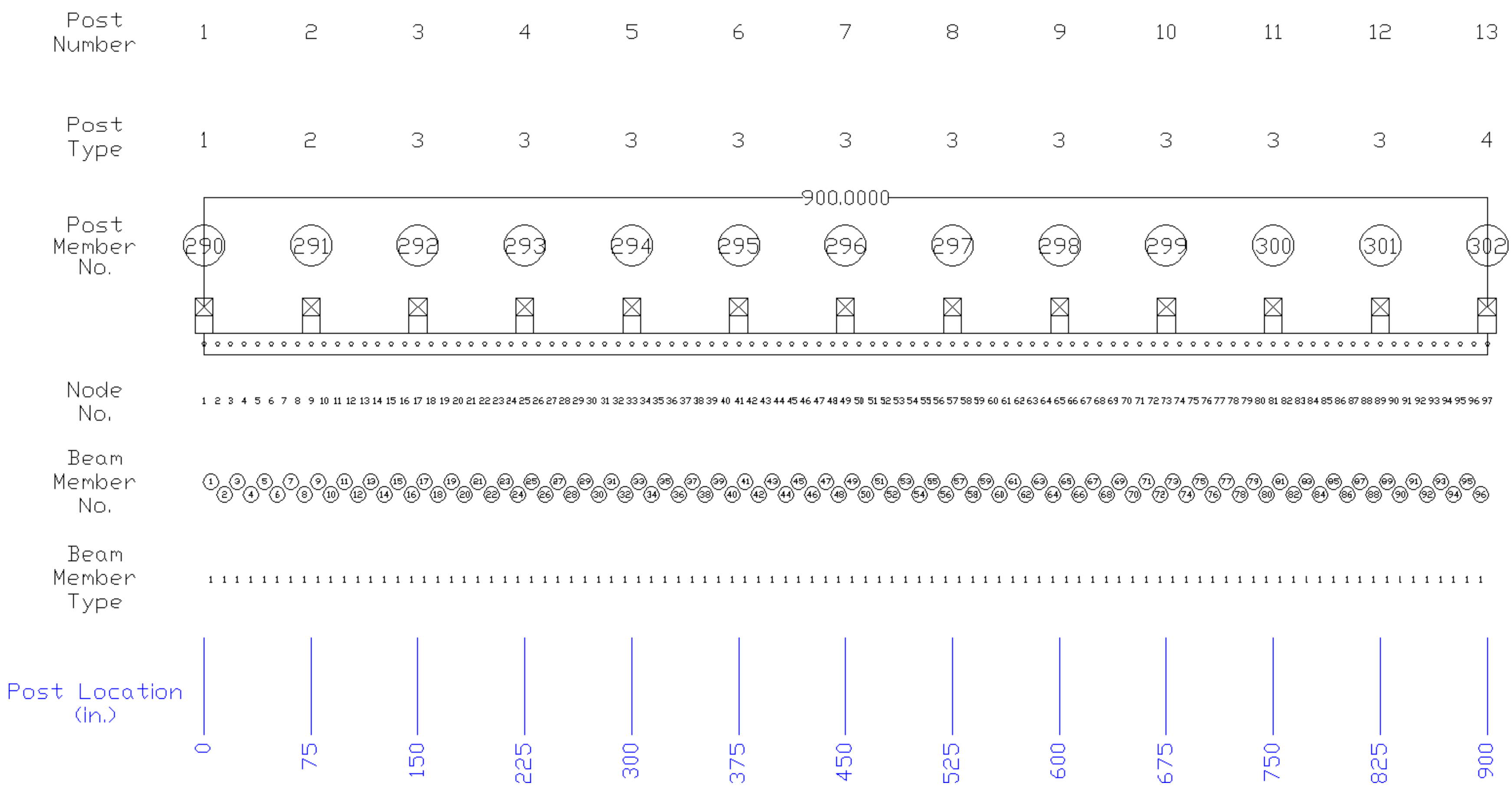


Figure 107. Model of Test No. N2BR-1 Post Nos. 1 through 13

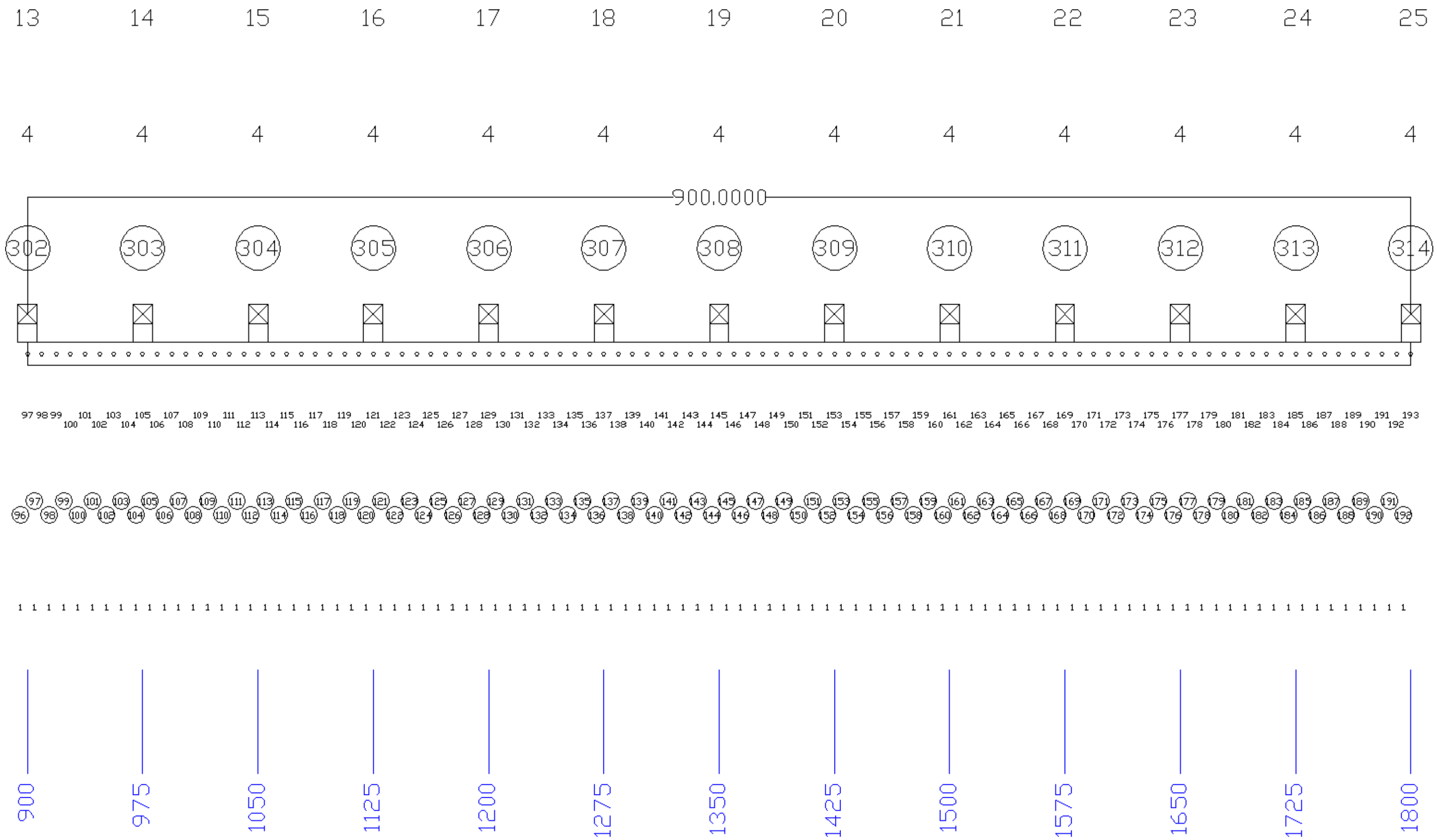


Figure 108. Model of Test No. N2BR-1 Post Nos. 13 through 25

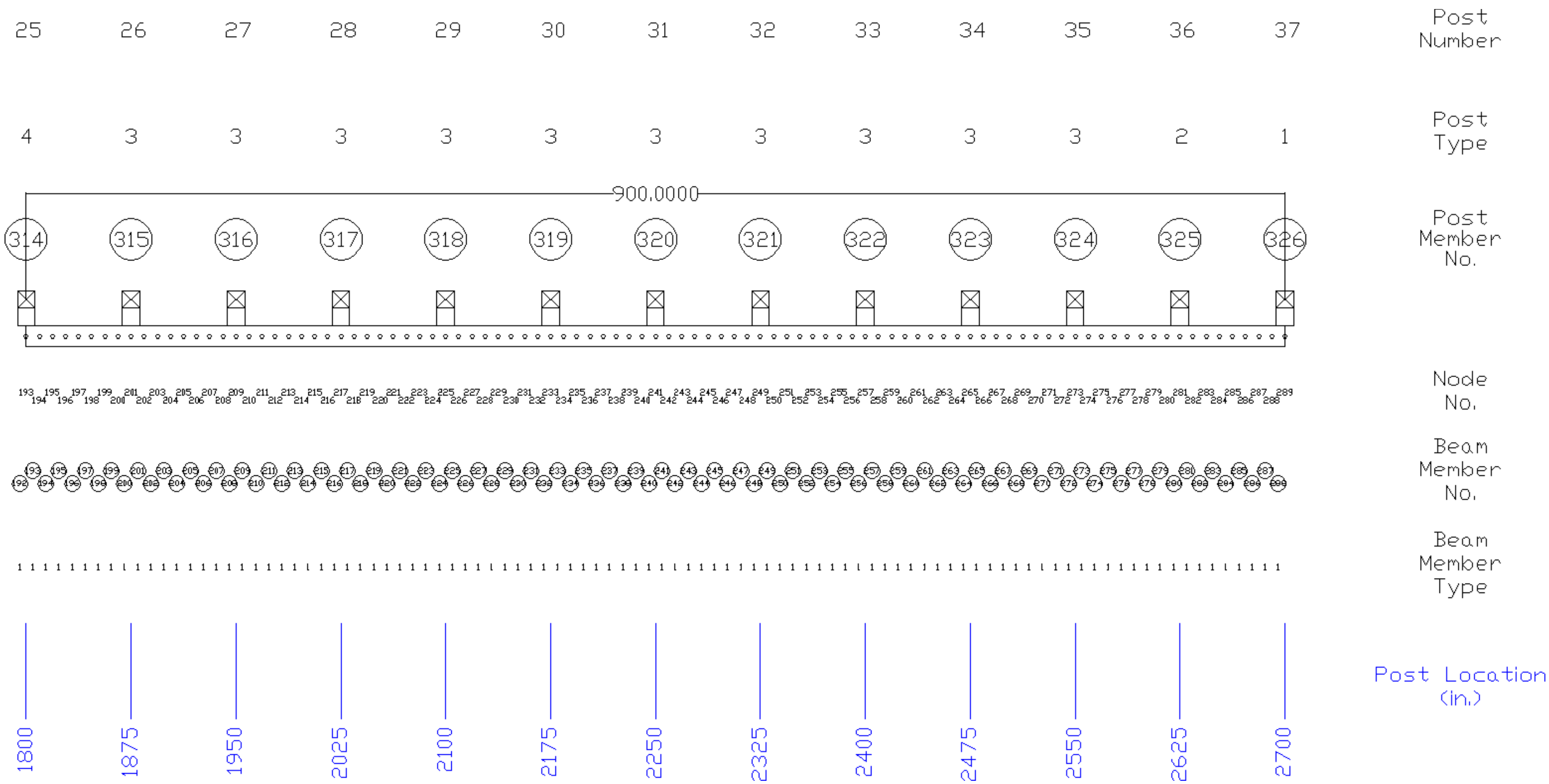


Figure 109. Model of Test No. N2BR-1 Post Nos. 25 through 37

10 MINIMUM GUARDRAIL LENGTH

10.1 Background and Scope

For the new TL-2 bridge rail to function properly, additional guardrail and guardrail anchorage is needed adjacent to the bridge rail on both the upstream and downstream ends, similar to the as-tested configuration. Factors that should be considered to determine the minimum length of guardrail include the guardrail length of need required to shield the hazard, terminal stroke length, guardrail anchorage requirements, and the minimum length needed to resist compression forces from crashworthy end terminals. When determining the minimum length of guardrail required adjacent to the bridge rail, all four of the factors should be considered. Depending on the site conditions, any one factor may control the installation length. These factors are discussed independently in the following sections.

10.2 Length of Need to Shield Roadside Hazards

Roadside hazards within the clear zone require a certain length of guardrail upstream from the hazard to properly shield them from errant motorists. The *AASHTO Roadside Design Guide* (RDG) provides equations for determining the length of guardrail necessary to shield hazards [24]. In addition to these equations, the RDG also provides guidance to determine the variables required to calculate the required length of need, such as runout length and the lateral extent of the area of concern. If the guardrail installation is not sufficient in length, the hazard is not truly shielded and still poses a risk to motorists.

10.3 Terminal Stroke Length

Terminal stroke length is defined as the maximum longitudinal vehicle stopping distance during head-on impacts on the end terminal. Sufficient stroke length is necessary to ensure proper end terminal energy dissipation and that the vehicle comes to a stop before reaching the bridge, where it could roll off the edge of the deck. Terminal stroke length varies for each end terminal system. Roadside engineers should refer to manufacturer specifications to determine the required stroke length for the end terminal desired for installation. It is recommended that the TL-2 stroke length for the end terminal be used when evaluating system lengths in order to be consistent with the test level of the bridge rail system.

Previously, 12.5 ft of standard guardrail has been recommended between a terminal and any MGS special applications, such as the new TL-2 bridge rail, to separate the different systems and ensure they do not negatively affect the performance of the other system. This 12.5 ft of separation guardrail has been recommended for both tangent and flared end terminals, as shown in Figure 110 [6]. However, the additional 12.5 ft of MGS is a conservative approach that may not be applicable in all cases. For example, the additional guardrail may not be cost effective for very low-volume roads where the risk of crashes is minimal and installation funds are limited.

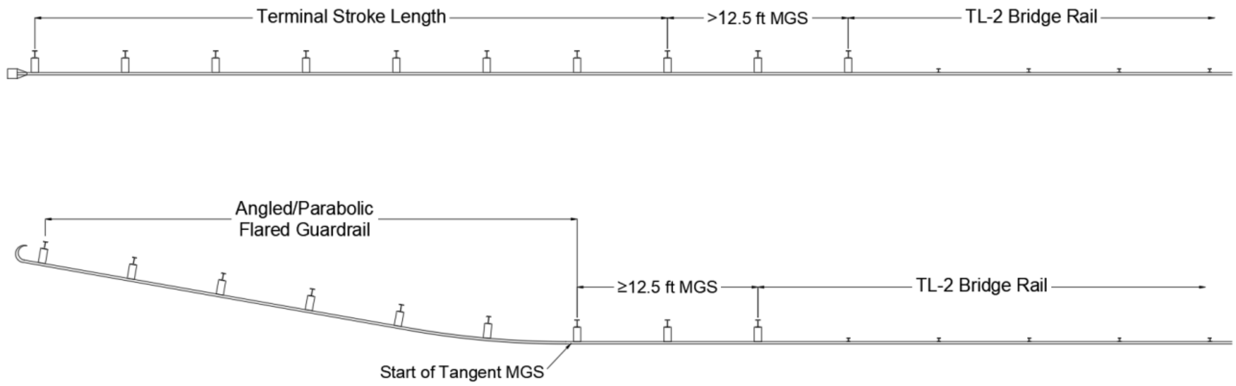


Figure 110. Separation of Manufacturer Specified End Terminal Stroke Length and Bridge Rail

10.4 Anchorage Requirements

For the TL-2 bridge rail and the guardrail to function as intended, sufficient guardrail anchorage is required for the W-beam to develop the tensile forces required to redirect a vehicle. Typical guardrail installations are installed with terminals or trailing end anchorages, which typically consist of two anchorage posts that provide adequate tensile capacity for the rail. However, impacts too close to the guardrail ends will result in anchorage failure and, subsequently, the vehicle won't be contained and redirected. Thus, one needs to consider the beginning and end of the length of need for the anchorages to remain effective.

Under TL-3 conditions, the beginning of the length of need for end terminals is typically at the third post from the upstream end, and end of the length of need for a standard trailing end anchorage has been defined as the sixth post from the downstream end [9-10]. The beginning of length of need for TL-2 terminals is typically defined as the same point for a TL-3 installation, and the end of length of need for a TL-2 installation has not yet been evaluated. The length of need points are potentially closer to their respective ends for a TL-2 installation, but until further research is conducted, these points will remain unknown. As such, design should consider the third post from the end of an end terminal as the beginning of the redirective length of the system when designing the system length needed to shield the hazard unless the selected end terminal was crash tested with the beginning of length of need point upstream of the third post. On the downstream end of the bridge rail, it is recommended that a minimum of six posts, including the two anchorage posts, be used in order to develop adequate system anchorage and ensure that vehicle redirection is achieved throughout the entire length of the bridge rail.

10.5 Compression Terminal Force Resistance

Compression terminals require the guardrail to resist a certain amount of compressive forces as the vehicle is brought to a stop. After the guardrail anchorage is released at the beginning of an end-on impact, only the downstream support posts are left to provide resistance to the guardrail and prevent the entire installation (and vehicle) from translating downstream. Note, tension based end terminals would not require downstream posts to resist impact loads, so this concern only applies to compression terminals.

The resistance applied to the guardrail by a post can be defined as the minimum between the post's longitudinal (weak-axis) bending strength, the post's torsional strength, and the shear capacity of the guardrail attachment bolt. Weak-axis bending capacity was calculated based on a load application height, H, of 25 in. Post sockets and soil were assumed to act as a fixed end supports. The yield strength, F_y, of both posts was 50 ksi, and a strength reduction factor, φ, of 0.9 was applied to the yield strength. The capacity of the posts, P, was determined using the equation $P = \frac{\varphi F_y Z_y}{H}$, where Z_y is the weak axis section modulus of the post.

S3x5.7 posts utilized 5/16-in. diameter A307 Gr. A bolts, while W6x8.5 posts utilized ⅝-in. diameter A307 Gr. A bolts. The factored yield strength, φF_{nv}, of the bolts obtained from the *AISC Steel Construction Manual* was 20.3 ksi [25]. The force required to achieve bolt shear capacity, P, was calculated using the equation $P = \varphi F_{nv} A_b$, where A_b is the nominal cross sectional area of the bolt.

The torsional capacity of the posts was determined by assuming the post sockets and soil would leave the posts unrestrained from warping and the posts would only be loaded in pure torsion. Load applied via the W-beam rail would have an eccentricity, l, equal to the blockout depth plus half of the post depth. Yield stress, F_y, for both posts was 50 ksi, and a strength reduction factor, φ, of 0.9 was applied to the yield strength. The force acting at the face of a post required to cause torsional yielding, P, was calculated by determining the applied load acting at the face of the post using the equation $P = \frac{\varphi F_y J}{t_f l \theta'}$, where θ', which describes the rate of change of the angle of rotation about the longitudinal axis of the member, was obtained from *AISC Design Guide 9* [26]. The term t_f is defined as the flange thickness of the post, and J is defined as the polar moment of inertia of the post.

All three failure strengths were calculated for both the S3x5.7 bridge rail and a typical W6x8.5 MGS post and are shown in Table 17. The capacity of an S3x5.7 post was limited to 1.1 kips through the shear capacity of the 5/16-in. diameter A307 Gr. A bolt, while the strength of a W6x8.5 was found to be 2.4 kips through torsion failure with a 12-in. blockout. For shorter blockouts, the capacity of a W6x8.5 post would be limited by its weak-axis bending capacity of 2.8 kips. Posts used within the end terminals on the downstream side of an installation would also resist the compressive forces in the W-beam. However, many terminal posts are weakened or breakaway posts, so the capacity of these posts would require further analysis to determine their capacities.

Table 17. TL-2 Bridge Rail and MGS Post Compressive Capacity Loads

Post	Weak Axis Bending Load kips	Bolt Shear Load kips	Post Torsion Load kips
TL-2 Bridge Rail Posts (S3x5.7)	1.2	1.5	6.75
MGS Posts (W6x8.5)	2.8	6.2	2.4 (12-in. block) 11.9 (no block)

The magnitude of the compressive forces applied to the guardrail varies by compression terminal due to the differences in energy absorbing mechanisms. Average compressive forces were previously determined through an analysis of full-scale crash testing, and are shown in Table 18 [27]. Peak end terminal compressive forces have the potential to be greater than the average end terminal forces. Should the designer wish to design for the case of peak end terminal forces, a factor of safety may be utilized.

Table 18. End Terminal Average Compressive Forces [27]

End Terminal System	Average Compressive Force kips
BEST-350	18.-22.5
ET-2000	12-21.3
ET-2000 Plus	12-21.3
FLEAT-350	13.5-16.7
SKT-350	10.5-15.2
SKT-MGS	10.5
ET-Plus (27¾ in.)	15
ET-Plus (31 in.)	12.7
SGET	15.2
MSKT	12.6

The length of MGS adjacent to the bridge required to resist the terminal compression force depends on multiple site-specific factors, such as the type of terminal and the length and number of posts in the bridge rail. However, for the guardrail installation to resist the compression loads of the terminal, the following equation must be satisfied;

$$N_s P_s + N_w P_w > C$$

where N_S is the number of S3x5.7 bridge rail posts, P_S is the strength of an S3x5.7 post, N_w is the number of W6x8.5 MGS posts, P_w is the strength of a W6x8.5 post, and C is the compressive load for a given terminal. Values for the post strengths and terminal compression forces can be found in Tables 17 and 18, while the number of bridge rail posts will be site specific. The only remaining variable is the number of MGS posts, which can be solved for and translated into a required length of MGS by multiplying by a 75-in. spacing per post. Note, the posts within the upstream terminal's stroke length should not be counted as part of N_w or the guardrail resistance, as these posts would be overrun by the impacting vehicle and disengage from the rail. Example calculations are shown in Appendix H.

11 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The objective of this project was to develop a new side-mounted, TL-2 bridge rail for low-volume roads. The bridge railing was to utilize 31-in. W-beam guardrail and S3x5.7 posts, similar to previously developed bridge rails and guardrail systems attached to concrete culverts [3-7]. The bridge railing was to be completely side-mounted (i.e., no hardware on the deck surface) and incorporate a socketed post attachment for ease of installation and repair. Finally, the bridge railing was to be compatible with both 7-in. thick CIP decks and 12-in. thick precast beam-slab decks. Both deck types utilize steel channels along the deck edge that could be used as part of the post-to-deck attachment.

Two different types of socket-to-deck attachments were explored. Welded attachments involved the HSS4x4x⅜ steel tube sockets being welded directly to the steel channels along the edge of the deck. Welded attachments required the channels to be strongly anchored to the deck or the channels would be pried off during impact events. Thus, multiple channel anchorage designs were explored, including straight bars butt-welded to the inside surface of the channel, U-bars flare-bevel welded to the upper corner of the channel, and hooked rebar flare-bevel welded to gussets located in the upper corner of the channel. A bolted attachment involved a prefabricated socket assembly being bolted to the side the deck. The bolts were inserted through the steel channels and threaded into coupling nuts embedded into the deck. Threaded rods were threaded into the other end of the coupling nuts and extended into the interior of the deck. When loaded, the tensile loads in the bolts would be directly transferred through the coupling nuts to the threaded anchors. Thus, the channel was not directly loaded and the chance of damage to the edge of the deck was minimal.

Six dynamic component tests were conducted on both welded and bolted attachment designs and on both CIP and precast beam-slab decks. Testing was also conducted in both the lateral and longitudinal directions to evaluate both loading conditions. During the tests, the novel bolt, coupling nut, and threaded rod anchorage design performed as intended. The posts were bent over while the socket assemblies, attachment hardware, and decks remained undamaged. Lateral testing of a welded attachment with the channel anchored by straight bars welded to the channel's web resulted in the channel being pulled slightly off the deck edge. A ⅛-in. crack opened between the top of the channel and the concrete deck, and minor concrete spalling was observed adjacent to the channel. Testing of the U-bar channel anchorage proved strong enough to prevent the channel from prying away from the deck and prevented any damage to the socket and deck. Both the welded and bolted designs performed satisfactorily in longitudinal tests as the posts bent over and no damage was found to the deck or attachment hardware.

Following a review of the component testing results, the bolted attachment with coupling nut and threaded rod anchors was selected for further evaluation though full-scale crash testing. Although MASH 2016 specifies two full-scale crash tests to satisfy TL-2 safety criteria, the greater mass of the 2270P pickup truck was expected to produce higher system deflections and anchorage loads than the 1100C small car. Additionally, two similar systems had previously been successfully crash tested with the 1100C vehicle [3-5]. Therefore, test designation no. 2-10 with the small car was not considered critical, and only test designation no. 2-11 was conducted to evaluate the MASH TL-2 bridge rail.

The test article for the full-scale crash test was built on a simulated 7-in. thick CIP, as this represented the weaker of the two deck options and was more susceptible to damage. A 75-ft long bridge rail installation was constructed in the middle of a 182-ft long MGS guardrail installation equipped with guardrail anchors on each end. During test no. N2BR-1 the 4,999-lb pickup truck impacted the TL-2 bridge rail at a speed of 44.2 mph and an angle of 25.5 degrees. The vehicle was successfully contained and smoothly redirected with moderate damage to vehicle. All vehicle decelerations, ORAs, and OIVs fell within the recommended safety limits established in MASH 2016. Therefore, test no. N2BR-1 was successful according to the safety criteria of MASH 2016 test designation no. 2-11. A summary of the test evaluation is shown in Table 19.

Although MASH requires two full-scale crash tests, testing with the 1100C test vehicle was not deemed critical for the evaluation of the new bridge rail. Previous MASH crash testing has been conducted with both the 2270P and the 1100C vehicles on the MGS Bridge Rail and the TxDOT T631 bridge rail [3-5]. Similar to the NDOT TL-2 Bridge Rail developed herein, both of these previous bridge rails consist of 31-in. tall, 12-gauge, W-beam guardrail supported by S3x5.7 posts. Further, all three bridge rails were designed to absorb impact energy through bending of the weak S3x5.7 posts while the attachment of the post to the deck remains rigid and intact. The TxDOT T631 bridge rail was successfully tested to MASH test designation nos. 2-10 and 2-11 with a 75-in. post spacing, which is the same as the new NDOT TL-2 bridge rail. Additionally, the MGS Bridge Rail was successfully tested to MASH test designation nos. 3-10 and 3-11 with a 37.5-in. post spacing utilizing the same post assembly and HSS4x4x⅜ steel sockets incorporated into the new NDOT TL-2 bridge rail. Since the socket assembly remained undamaged and intact throughout an impact event, the new TL-2 bridge rail would be expected to perform very similarly to the TL-2 version of the TxDOT T631 during a MASH 2-10 test. Therefore, MASH test designation no. 2-10 was determined to be non-critical, and the new, NDOT side-mounted bridge rail was considered crashworthy to MASH TL-2 criteria.

The simulated bridge deck and all of the socket assemblies remained undamaged during test no. N2BR-1. A few of the socket assemblies rotated downstream during the test, but this was only due to the vertical slots in the mounting plate that were included to allow height adjustments during installation, and they could easily be straightened. None of the attachment bolts or coupling nuts were damaged. As such, repairs to the system would only include the removal and replacement of damaged W-beam and posts.

The TL-2 bridge rail design included 12-in. backup plates to be installed behind the W-beam at every bridge post location, as shown previously on Figures 55 and 75. Due to an oversight, these backup plates were not installed within the full-scale test installation. Although the test was conducted successfully without them, it is still recommended to utilize backup plates in non-blocked, weak-post guardrail systems to prevent the rail tearing as observed in other full-scale crash tests on similar systems [4-5, 13].

Following the full-scale crash test, crash simulations were conducted to evaluate the connection between the TL-2 bridge rail and the standard MGS. BARRIER VII models were constructed and validated against the TL-2 full-scale crash test documented herein as well as TL-3 impacts into the MGS and the MGS with an omitted post. The validated model was then subjected to 25 different crash tests with the vehicle impacting the TL-3 bridge rail and approaching the adjacent MGS. A 75-in. spacing was used between the outermost bridge rail post and the adjacent MGS post. All simulations were conducted with impact conditions in accordance with MASH test designation no. 2-11. The BARRIER VII analysis showed only minor increases in the guardrail pocketing angles and tensile rail forces due to the transition from TL-2 bridge rail to MGS. Thus, the direct connection of the new TL-2 bridge rail to adjacent MGS while maintaining a consistent 75-in. post spacing was determined to be crashworthy under MASH TL-2 conditions.

The minimum length of MGS installed adjacent to the guardrail was also investigated. Factors to be considered when defining the minimum system length include guardrail length of need to shield the hazard, terminal stroke length, guardrail anchorage requirements, and the installation length necessary to resist the terminal compression forces. Guidance pertaining to these factors was provided in Chapter 10 and example calculations are provided in Appendix H.

The new TL-2 bridge rail was designed to be compatible with both 7-in. thick CIP decks and 12-in. thick precast beam-slabs. The 7-in. CIP deck was selected as the critical deck for full-scale crash testing due to its thinner and weaker structure. As such, details for attaching the bridge rail to a 7-in. CIP deck are shown in Chapter 5.

Three different options were developed for attaching the bridge rail to 12-in. precast beam-slabs. Option 1 includes keeping as many components as possible identical to the as-tested configuration with a 7-in. CIP deck. The socket assemblies, bolts, coupling nuts, threaded rods, and embedded plates would all remain the same. Holes in the C12x20.7 side channel would be centered 3.5 in. from the top to accommodate the unmodified socket assembly. The only different component would be the steel channel assembly, which would increase in size to match the deck thickness. Details for the Option 1 attachment of the bridge rail to a 12-in. precast beam-slab deck are shown in Figures 111 through 115.

Option 2 was modeled after the configuration subjected to dynamic component testing as part of the early attachment development efforts (see attachment location G and channel assembly F). This configuration optimizes the attachment hardware by incorporating slightly smaller ¾-in. diameter bolts, coupling nuts, and threaded rods as compared to the ⅞-in. diameter hardware in the as-tested configuration. However, it also requires a longer socket assembly and longer posts. Details for the Option 2 attachment of the bridge rail to a 12-in. precast beam-slab deck are shown in Figures 116 through 120.

Option 3 incorporates the same attachment hardware as the as-tested configuration and keeps the location of the hardware in the middle of the deck thickness. Like Option 2, this configuration requires an elongated socket assembly and post compared to the as-tested system. Details for the Option 3 attachment of the bridge rail to a 12-in precast beam-slab deck are shown in Figures 121 through 125.

Although a continuous steel channels was used along the side of the simulated bridge deck in the full-scale crash test, some bridges are constructed with channels located only at post locations. Since the attachment bolts are directly linked to threaded anchors embedded in the deck, loading to the side-channels is minimal. Thus, implementing the new TL-2 bridge rail system on a deck with short segments of steel channels is not expected to affect the performance of the system. The short channel segments should be at least 20 in. long to match the channel lengths tested during the component testing phase of this project. Details for short channel segments for both 7-in. CIP decks and 12-in. precast beam-slab decks are shown in Figures 126 and 127.

Bridge posts should not be placed too close to the upstream or downstream ends of a bridge deck as the attachment anchors may not be able to develop the required shear and/or tension loads. Thus, a post should be no closer than 10 in. from the ends of a deck, as measured to the center of the post. Note, this corresponds to half of the short channel segment length, so the short segments can be placed at the ends of the deck and the corresponding post would be 10 in. away.

Finally, the bridge railing system developed herein utilizes the same 31-in. tall W-beam and S3x5.7 weak posts as two other MASH crash tested TL-3 bridge railings. Additionally, all three bridge rails perform the same way with post bending absorbing the impact energy while the deck and post-to-deck-attachment remain undamaged. The only difference between NDOT’s new TL-2 bridge rail and these other two MASH TL-3 railings is the post spacing for the TL-3 railings was reduced to 37.5 in. on-center. Therefore, if the post spacing of the new bridge railing developed herein were reduced to 37.5 in. on-center, the system would be expected to perform similarly to the other systems and be crashworthy to MASH TL-3 evaluation criteria.

Table 19. Summary of Safety Performance Evaluation

<table>
<tr><th>Evaluation Factors</th><th colspan="4">Evaluation Criteria</th><th>Test No. N2BR-1</th></tr>
<tr><td>Structural Adequacy</td><td>A.</td><td colspan="3">Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td><td>S</td></tr>
<tr><td rowspan="13">Occupant Risk</td><td rowspan="2">D.</td><td colspan="3">1. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone.</td><td>S</td></tr>
<tr><td colspan="3">2. Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E of MASH 2016.</td><td>S</td></tr>
<tr><td>F.</td><td colspan="3">The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees.</td><td>S</td></tr>
<tr><td rowspan="4">H.</td><td colspan="3">Occupant Impact Velocity (OIV) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td>S</td></tr>
<tr><td colspan="3">Occupant Impact Velocity Limits</td><td rowspan="3">S</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>30 ft/s</td><td>40 ft/s</td></tr>
<tr><td rowspan="4">I.</td><td colspan="3">The Occupant Ridedown Acceleration (ORA) (see Appendix A, Section A5.2.2 of MASH 2016 for calculation procedure) should satisfy the following limits:</td><td>S</td></tr>
<tr><td colspan="3">Occupant Ridedown Acceleration Limits</td><td rowspan="3">S</td></tr>
<tr><td>Component</td><td>Preferred</td><td>Maximum</td></tr>
<tr><td>Longitudinal and Lateral</td><td>15.0 g’s</td><td>20.49 g’s</td></tr>
<tr><td colspan="5">MASH 2016 Test Designation No.</td><td>2-11</td></tr>
<tr><td colspan="5">Final Evaluation (Pass or Fail)</td><td>Pass</td></tr>
</table>

S – Satisfactory U – Unsatisfactory NA - Not Applicable

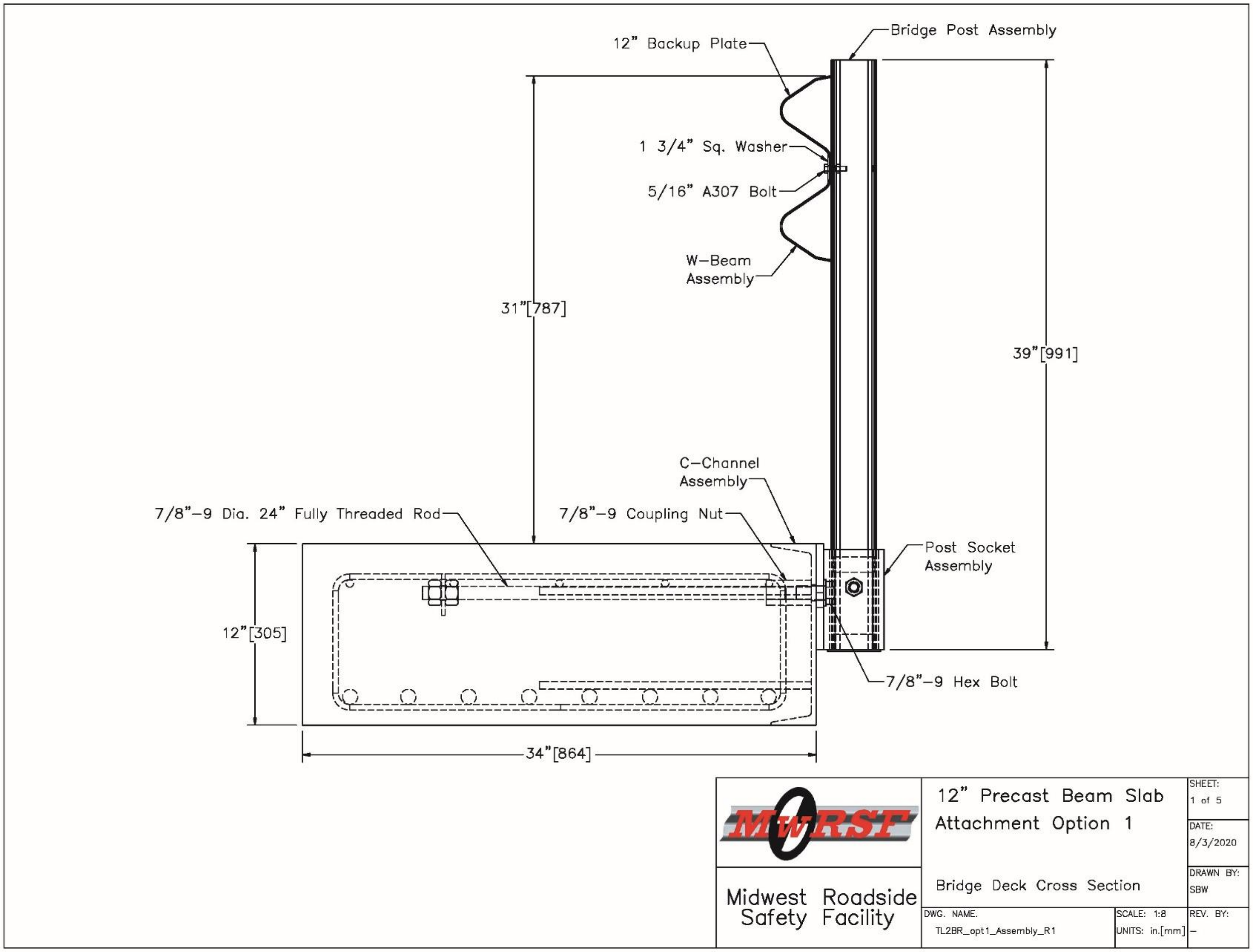
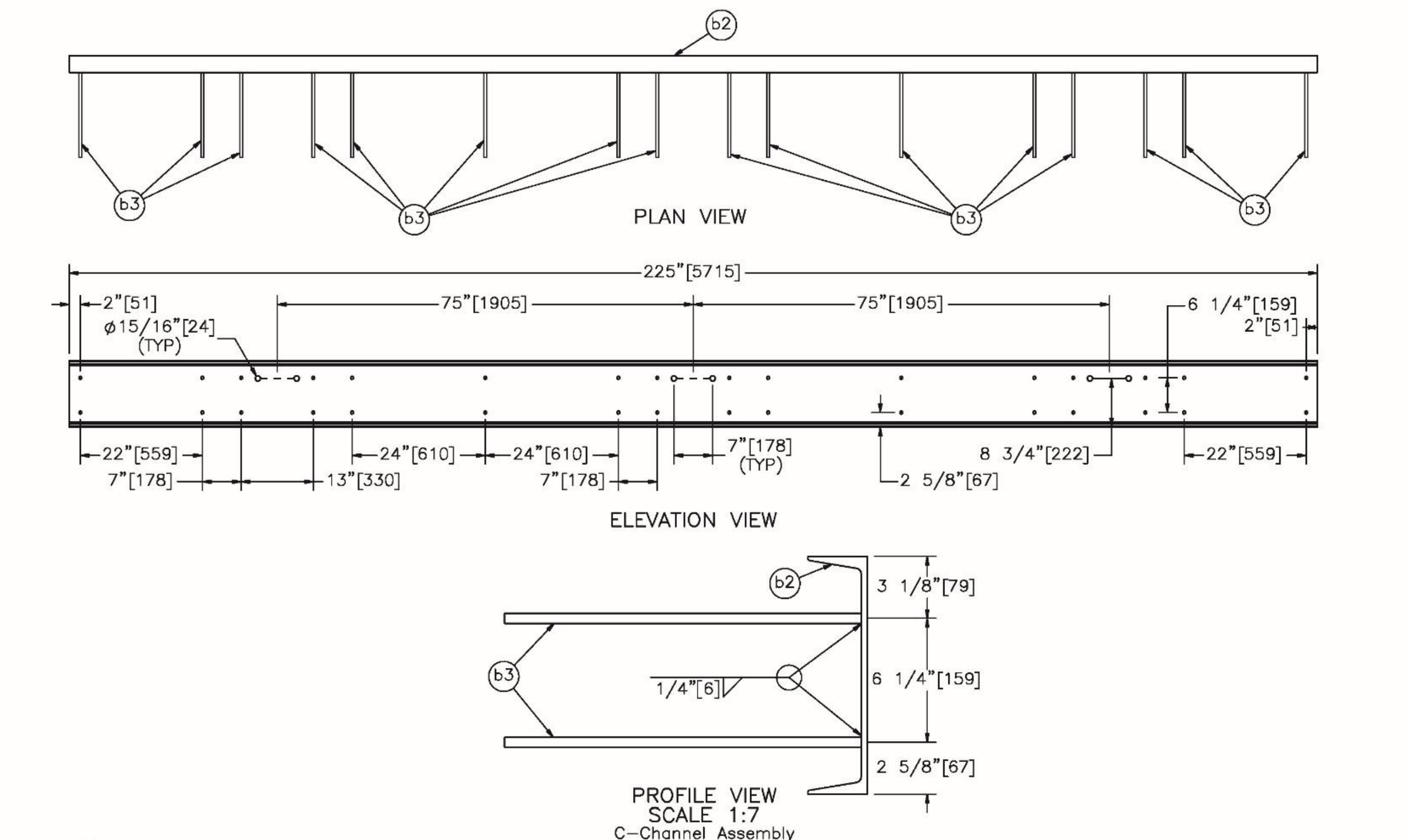


Figure 111. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 1, Cross Section



Notes: (1) Adjacent C–Channel Assemblies will result in Continuous 75" spacing.

Item No.	QTY.	Description	Material Specification	Treatment Specification
–	–	C–Channel Assembly	–	ASTM A132
b2	1	C12x20.7 [C305x30.8], 20" [508] Long C–Channel	ASTM A36	See Assembly
b3	32	#4 [13] Bar, 18" [457] Long	ASTM A706 Gr. 60	–

Midwest Roadside Safety Facility

12" Precast Beam Slab Attachment Option 1

C–Channel Assembly Details

SHEET: 2 of 5
DATE: 8/3/2020
DRAWN BY: SBW
DWG. NAME. TL2BR_opt1_Assembly_R1
SCALE: 1:25
UNITS: in.[mm]
REV. BY: –

Figure 112. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 1, Channel Assembly

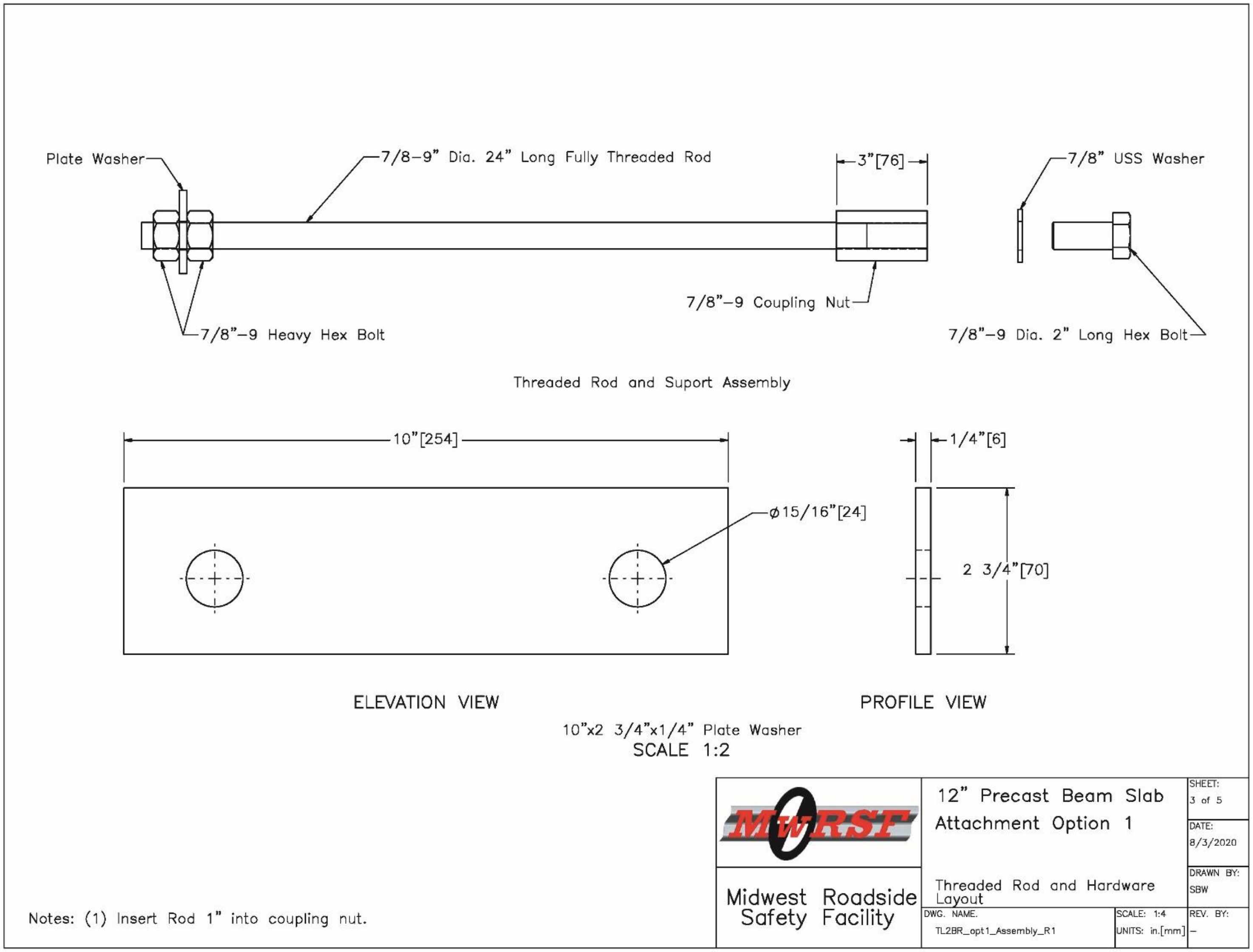
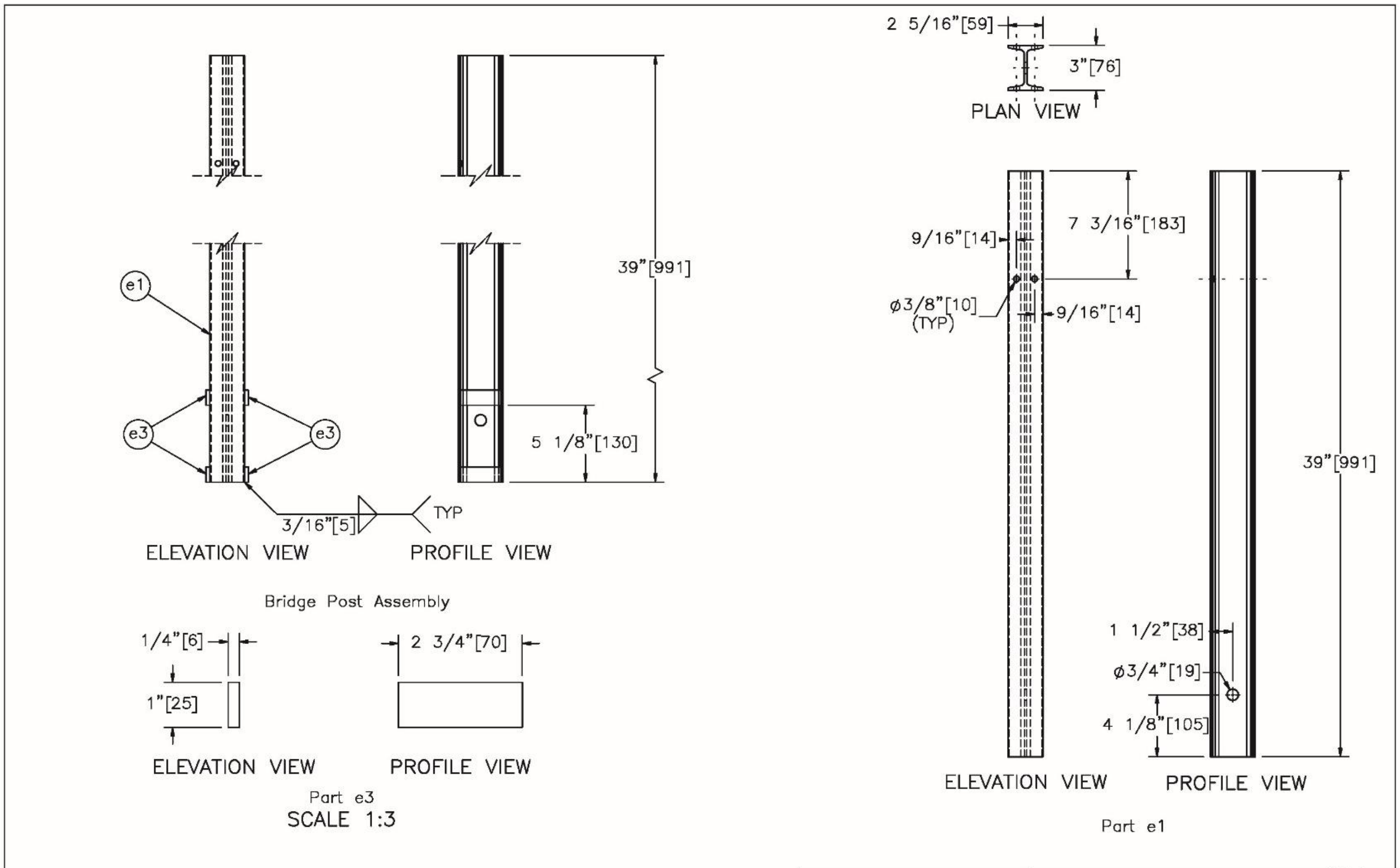


Figure 113. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 1, Embedded Anchorage



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	–	Bridge Post Assembly	–	ASTM A123
e1	1	S3x5.7 [S76x8.5], 39" [991] Long Steel Post	ASTM A992	See Assembly
e3	4	2 3/4"x1"x1/4" [70x25x6] Post Standoff	ASTM A36	See Assembly

MwRSF

Midwest Roadside Safety Facility

12" Precast Beam Slab Attachment Option 1

Bridge Post Assembly and Components

SHEET: 4 of 5

DATE: 8/3/2020

DRAWN BY: SBW

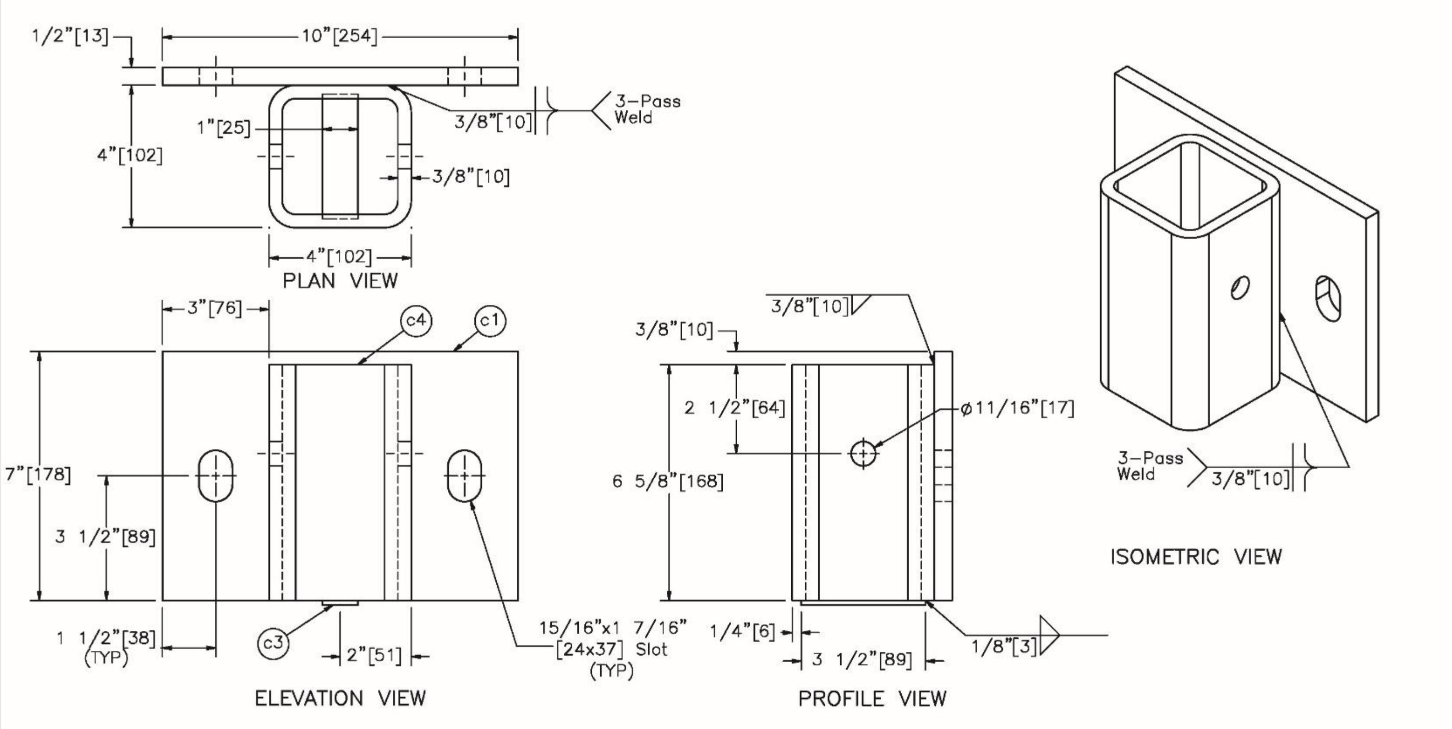
DWG. NAME. TL2BR_opt1_Assembly_R1

SCALE: 1:9

UNITS: in.[mm]

REV. BY: –

Figure 114. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 1, Post Assembly



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	–	Post Socket Assembly	–	ASTM A123
c1	1	10"x7"x1/2" [254x178x13] Steel Plate	ASTM A572 Gr. 50	See Assembly
c3	1	3 1/2"x1"x1/8" [89x25x4]	ASTM A36	See Assembly
c4	1	HSS4"x4"x3/8" [102x102x10], 6 5/8" [168] Long Square Tube	ASTM A500 Gr. B	See Assembly

Midwest Roadside Safety Facility	12" Precast Beam Slab Attachment Option 1	SHEET: 5 of 5
		DATE: 8/3/2020
	Post Socket Assembly	DRAWN BY: SBW
	DWG. NAME. TL2BR_opt1_Assembly_R1 — SCALE: 1:4 UNITS: in.[mm]	REV. BY: –

Figure 115. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 1, Socket Assembly

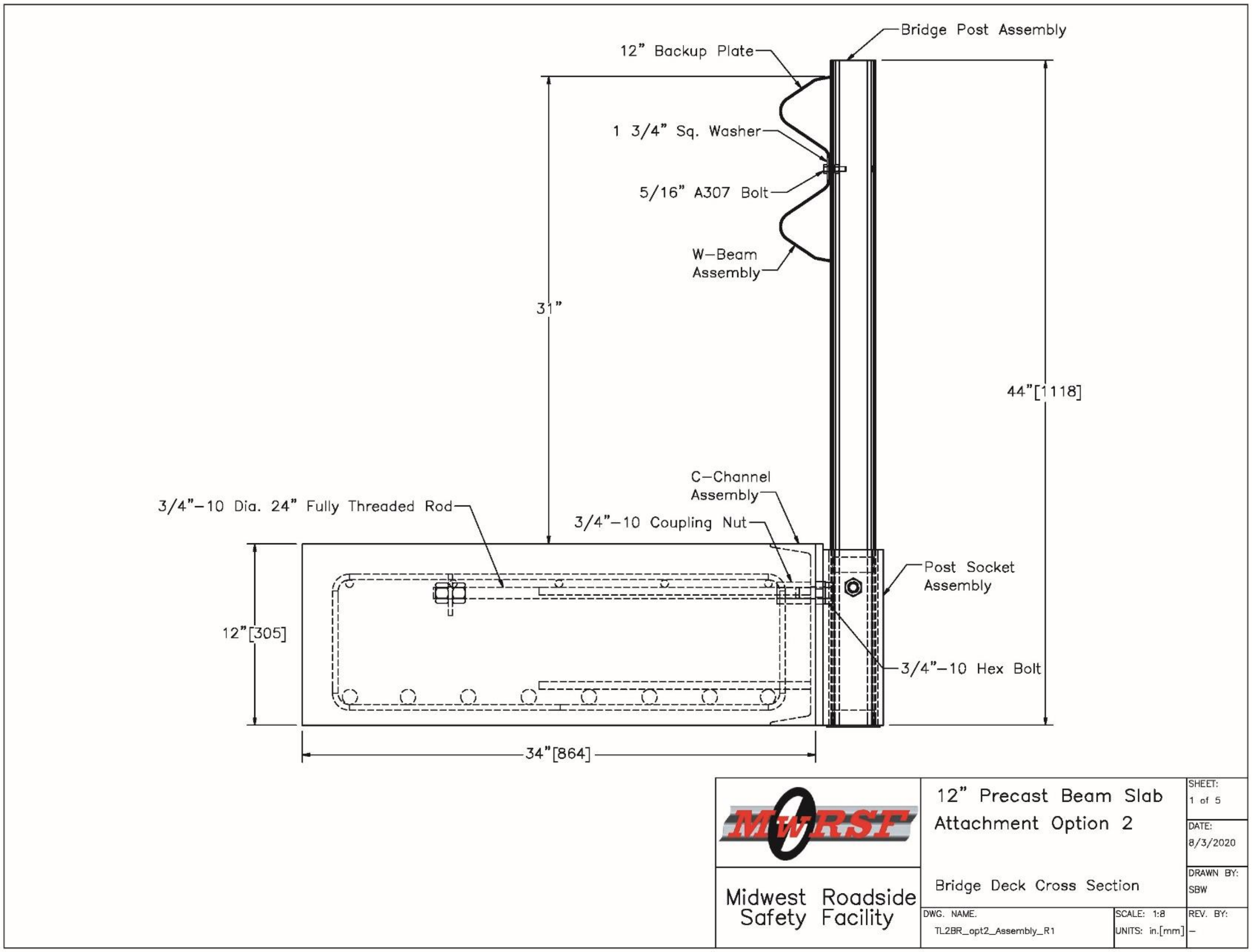
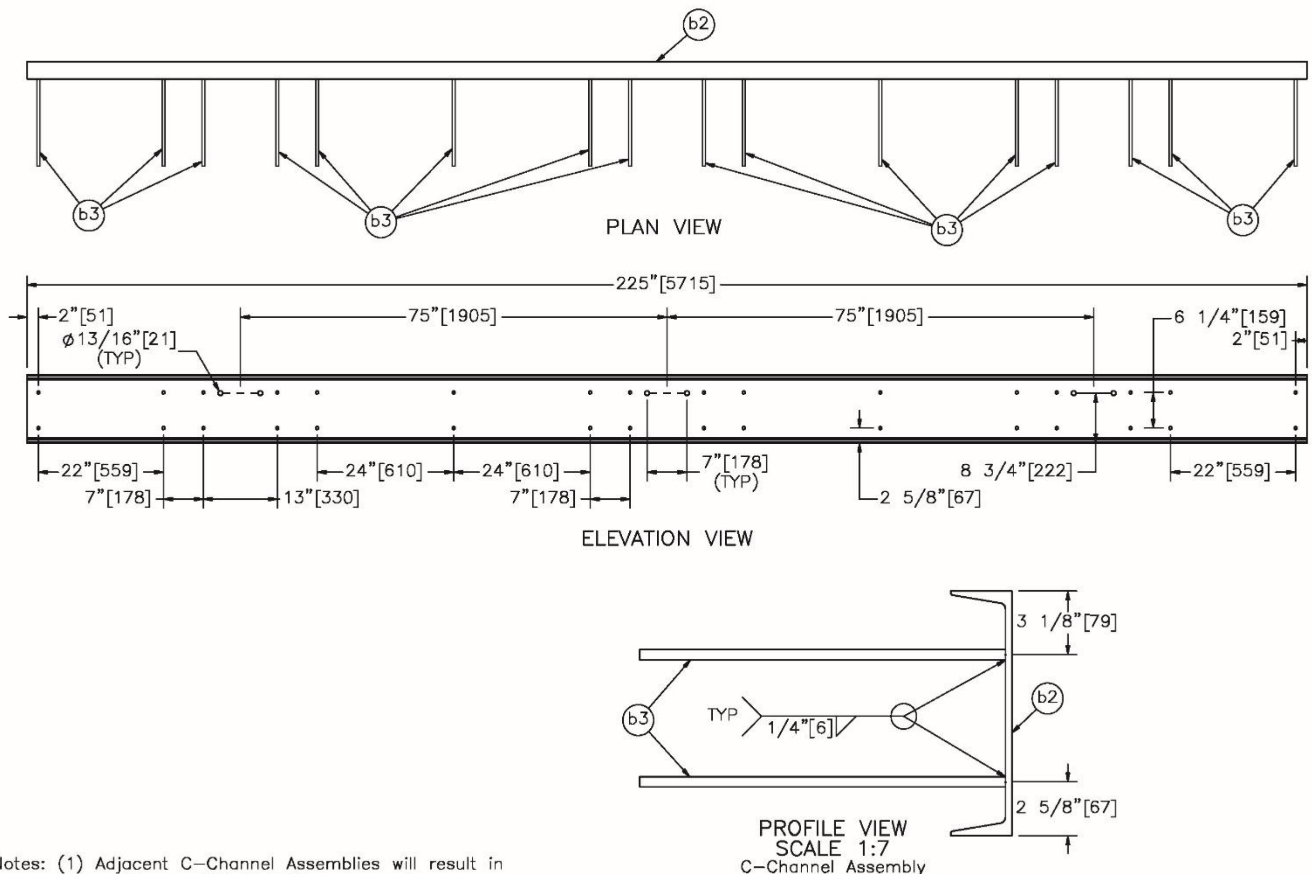


Figure 116. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 2, Cross Section



Notes: (1) Adjacent C-Channel Assemblies will result in continuous 75" [1,905] post spacing.

Item No.	QTY.	Description	Material Specification	Treatment Specification
–	–	C-Channel Assembly	–	ASTM A132
b2	1	C12x20.7 [C305x30.8], 225" [508] Long C-Channel	ASTM A36	See Assembly
b3	32	#4 [13] Bar, 18" [457] Long	ASTM A706 Gr. 60	–

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12" Precast Beam Slab Attachment Option 2

C-Channel Assembly Details

SHEET: 2 of 5
DATE: 8/3/2020
DRAWN BY: SBW
DWG. NAME. TL2BR_opt2_Assembly_R1
SCALE: 1:25
UNITS: in.[mm]
REV. BY: –

Figure 117. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 2, Channel Assembly

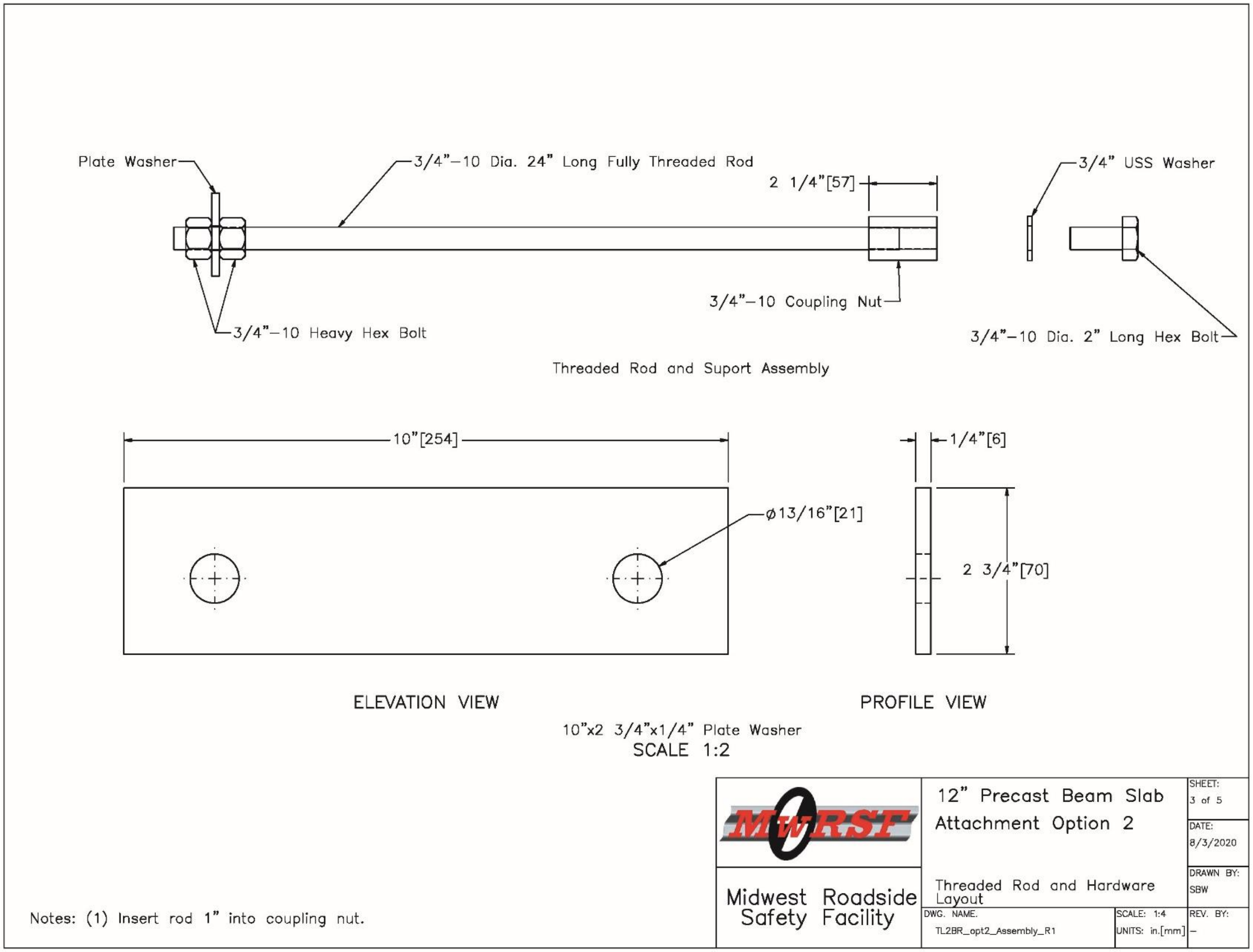
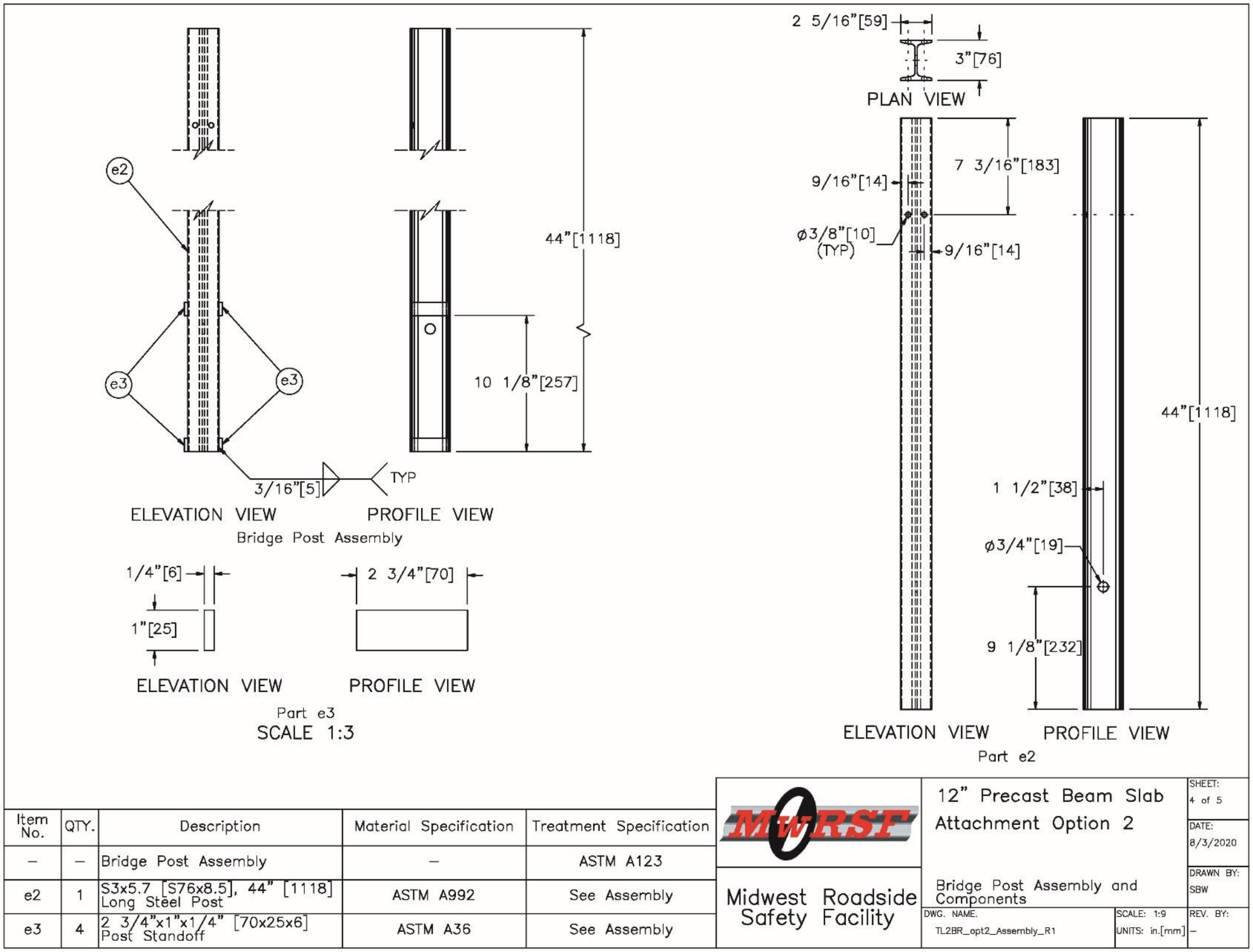
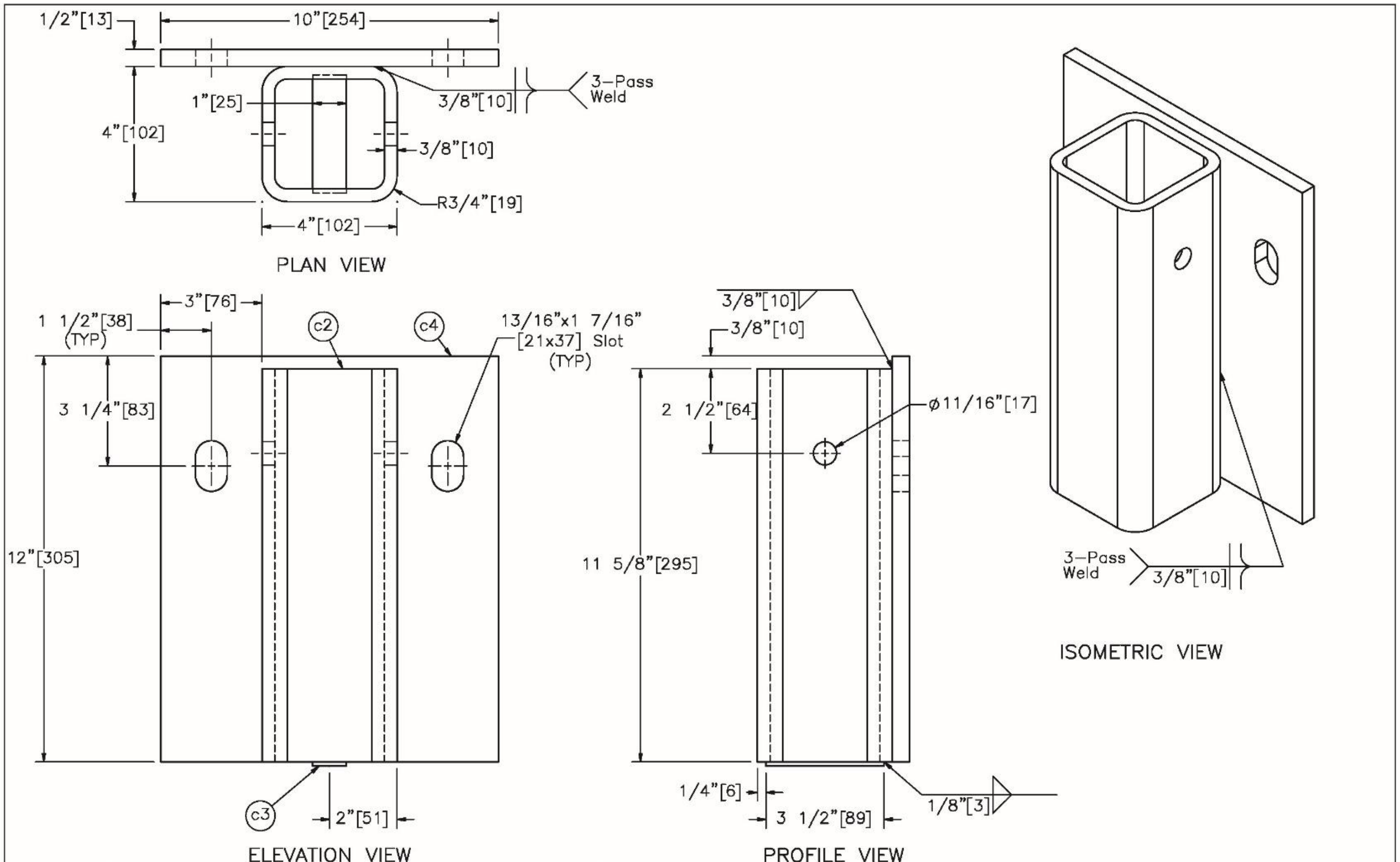


Figure 118. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 2, Embedded Anchorage



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	–	Bridge Post Assembly	–	ASTM A123
e2	1	S3x5.7 [S76x8.5], 44" [1118] Long Steel Post	ASTM A992	See Assembly
e3	4	2 3/4"x1"x1/4" [70x25x6] Post Standoff	ASTM A36	See Assembly

Figure 119. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 2, Post Assembly



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	–	Post Socket Assembly	–	ASTM A123
c2	1	HSS4x4x3/8" [102x102x10], 11 5/8" [295] Long Square Tube	ASTM A500 Gr. B	See Assembly
c3	1	3 1/2"x1"x1/8" [89x25x4]	ASTM A36	See Assembly
c4	1	12"x10"x1/2" [305x254x13] Steel Plate	ASTM A572 Gr. 50	See Assembly

Midwest Roadside Safety Facility

12" Precast Beam Slab Attachment Option 2

Post Socket Assembly

SHEET: 5 of 5

DATE: 8/3/2020

DRAWN BY: SBW

DWG. NAME. TL2BR_opt2_Assembly_R1

SCALE: 1:4

UNITS: in.[mm]

REV. BY: –

Figure 120. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 2, Socket Assembly

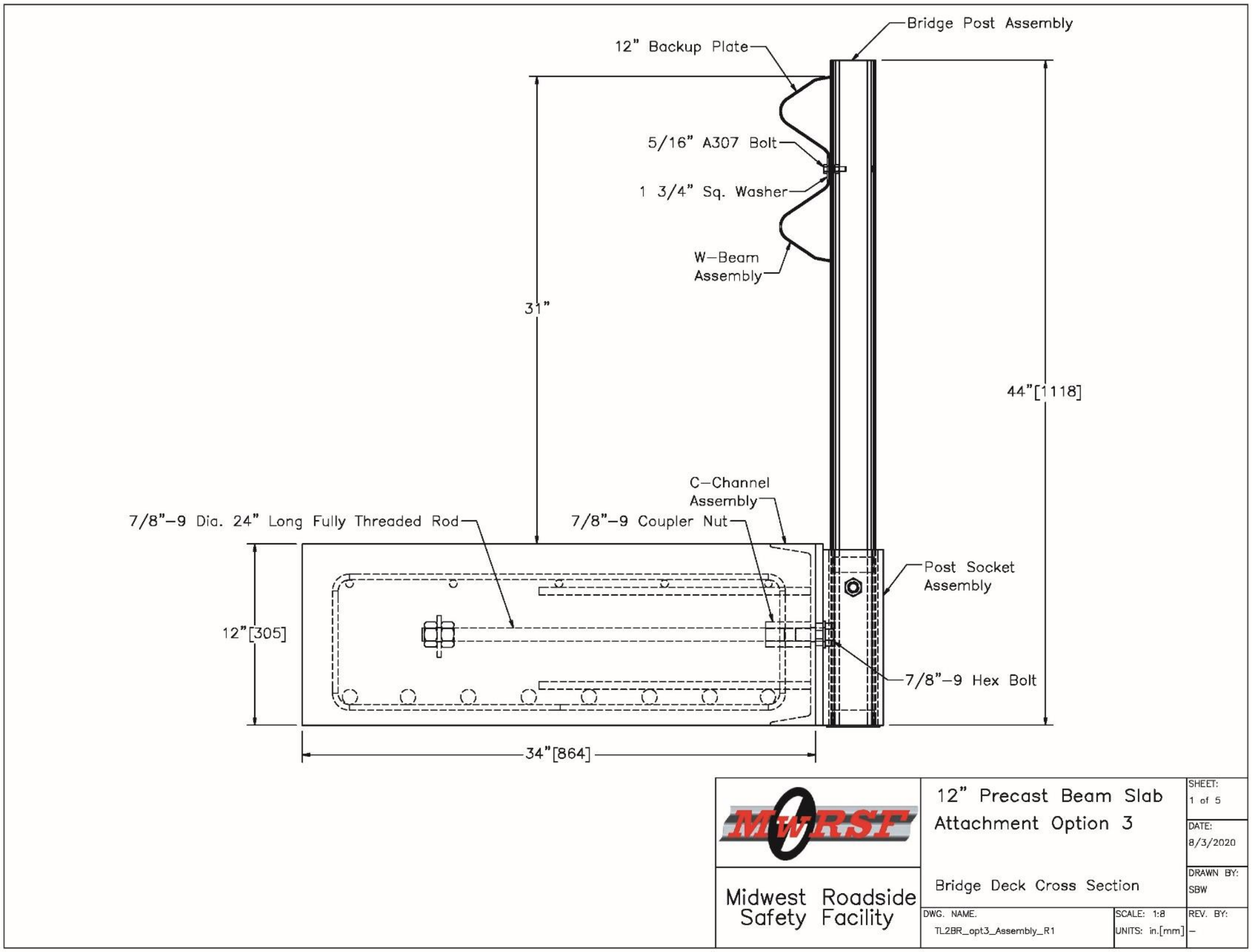
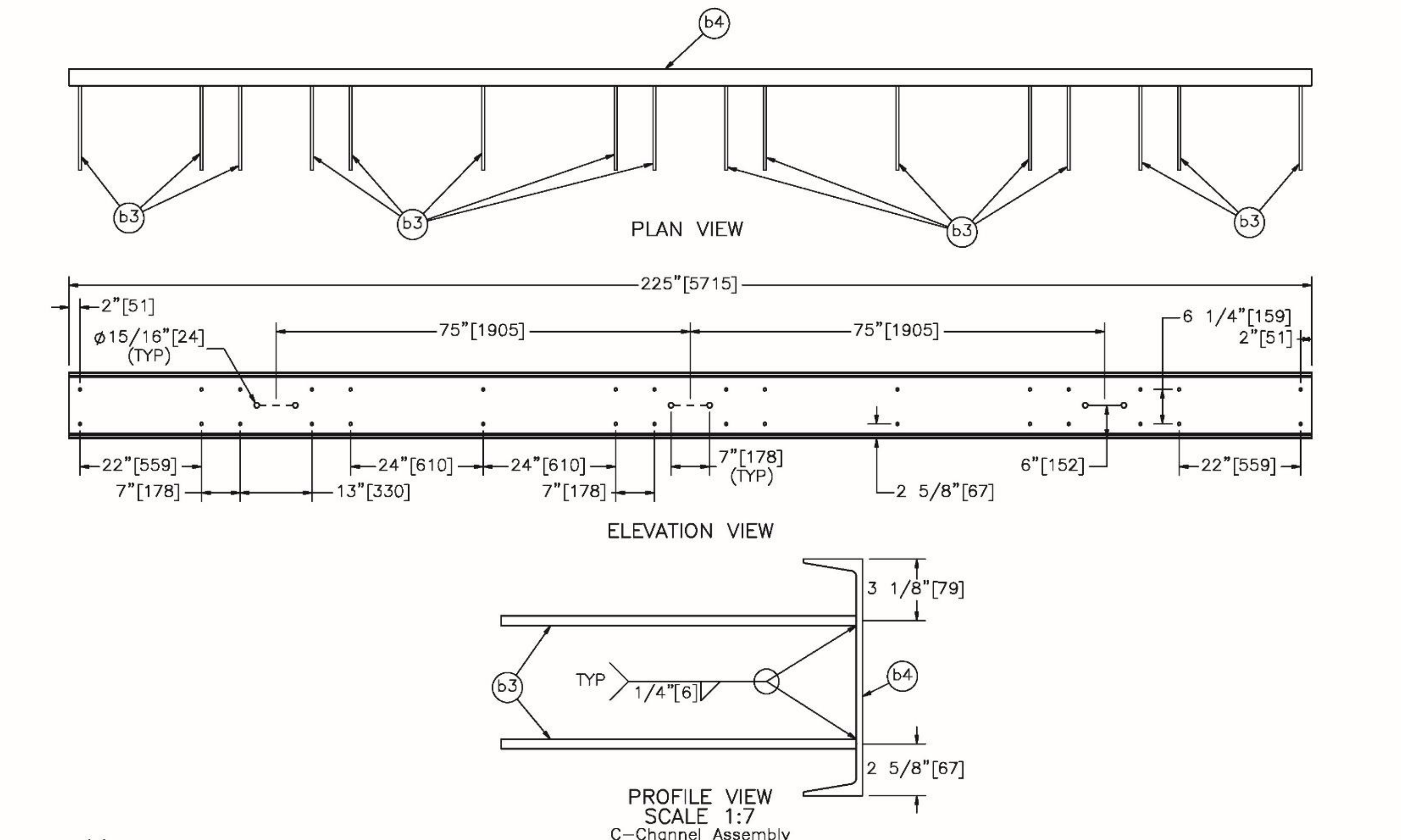


Figure 121. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 3, Cross Section



Notes: (1) Adjacent C-Channel Assemblies will result in continuous 75" [1,905] post spacing.

Item No.	QTY.	Description	Material Specification	Treatment Specification
–	–	C-Channel Assembly	–	ASTM A132
b4	1	C12x20.7 [C305x30.8], 20" [508] Long C-Channel	ASTM A36	See Assembly
b3	32	#4 [13] Bar, 18" [457] Long	ASTM A706 Gr. 60	–

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12" Precast Beam Slab Attachment Option 3

C-Channel Assembly Details

SHEET: 2 of 5
DATE: 8/3/2020
DRAWN BY: SBW
DWG. NAME. TL2BR_opt3_Assembly_R1
SCALE: 1:25
UNITS: in.[mm]
REV. BY: –

Figure 122. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 3, Channel Assembly

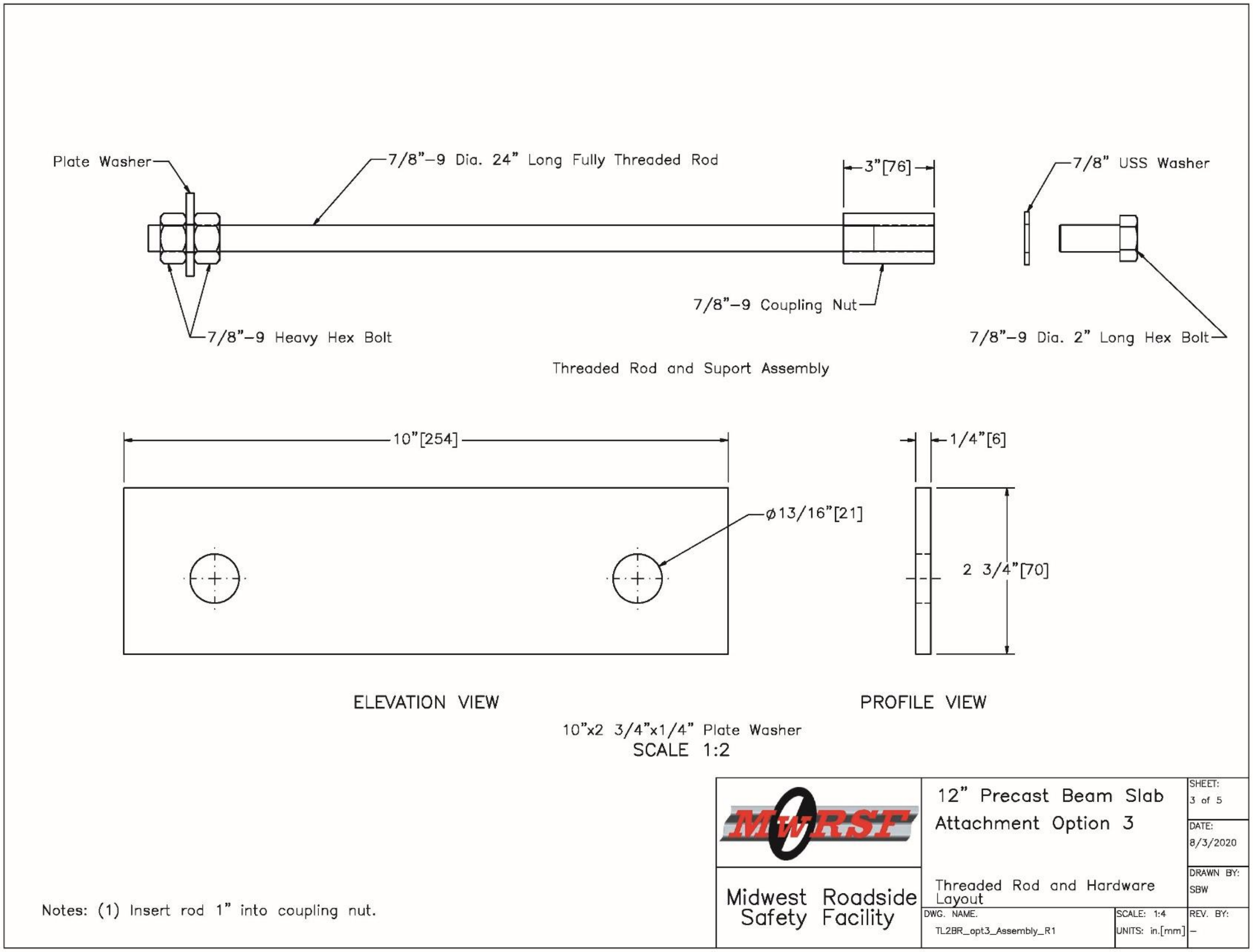
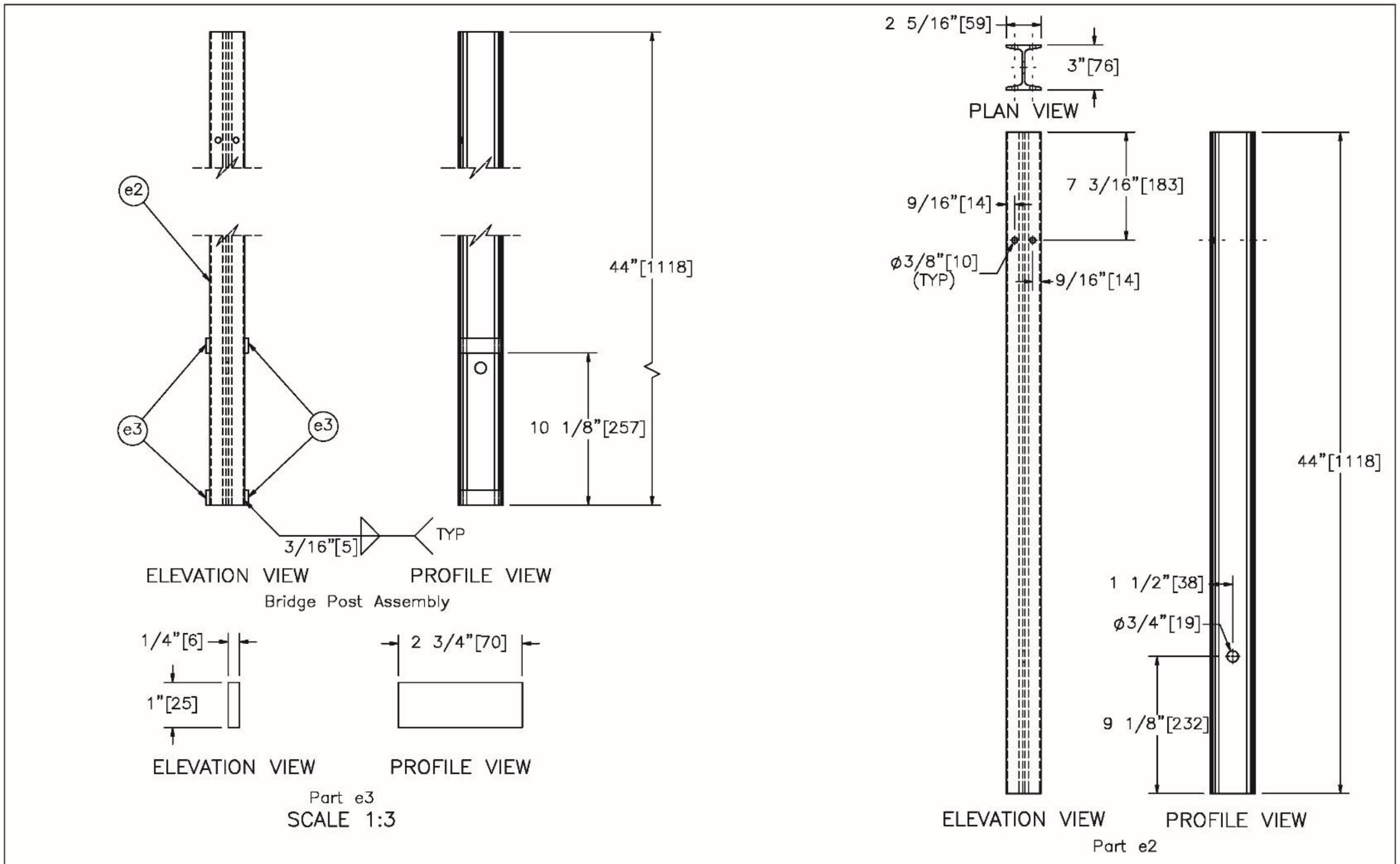


Figure 123. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 3, Embedded Anchorage



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	–	Bridge Post Assembly	–	ASTM A123
e2	1	S3x5.7 [S76x8.5], 44" [1118] Long Steel Post	ASTM A992	See Assembly
e3	4	2 3/4"x1"x1/4" [70x25x6] Post Standoff	ASTM A36	See Assembly

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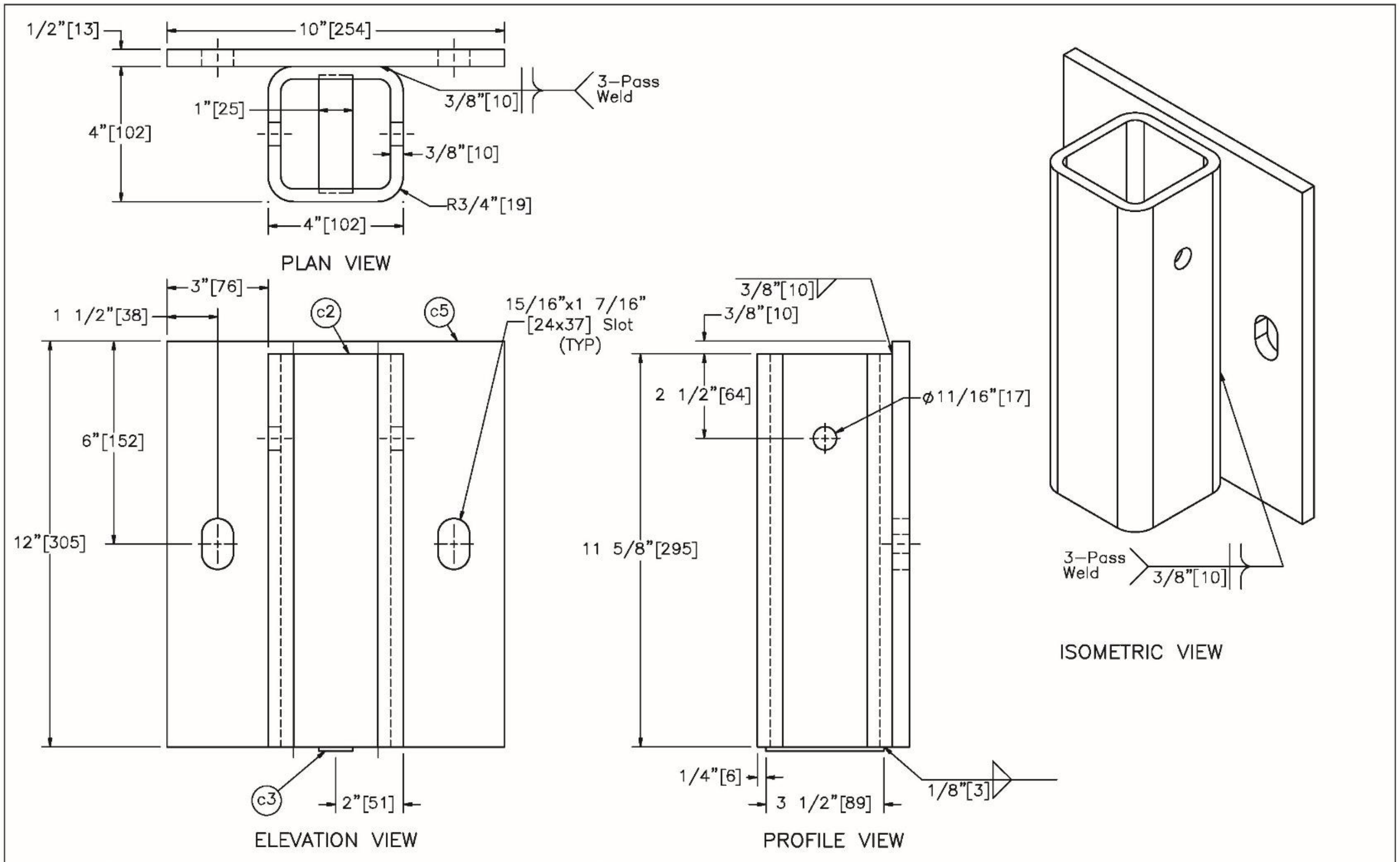
12" Precast Beam Slab Attachment Option 3

Bridge Post Assembly and Components

SHEET: 4 of 5
DATE: 8/3/2020
DRAWN BY: SBW
DWG. NAME. TL2BR_opt3_Assembly_R1
SCALE: 1:9
UNITS: in.[mm]
REV. BY: –

Figure 124. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 3, Post Assembly



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	–	Post Socket Assembly	–	ASTM A123
c2	1	HSS4x4x3/8" [102x102x10], 11 5/8" [295] Long Square Tube	ASTM A500 Gr. B	See Assembly
c3	1	3 1/2"x1"x1/8" [89x25x4]	ASTM A36	See Assembly
c5	1	12"x10"x1/2" [305x254x13] Steel Plate	ASTM A572 Gr. 50	See Assembly

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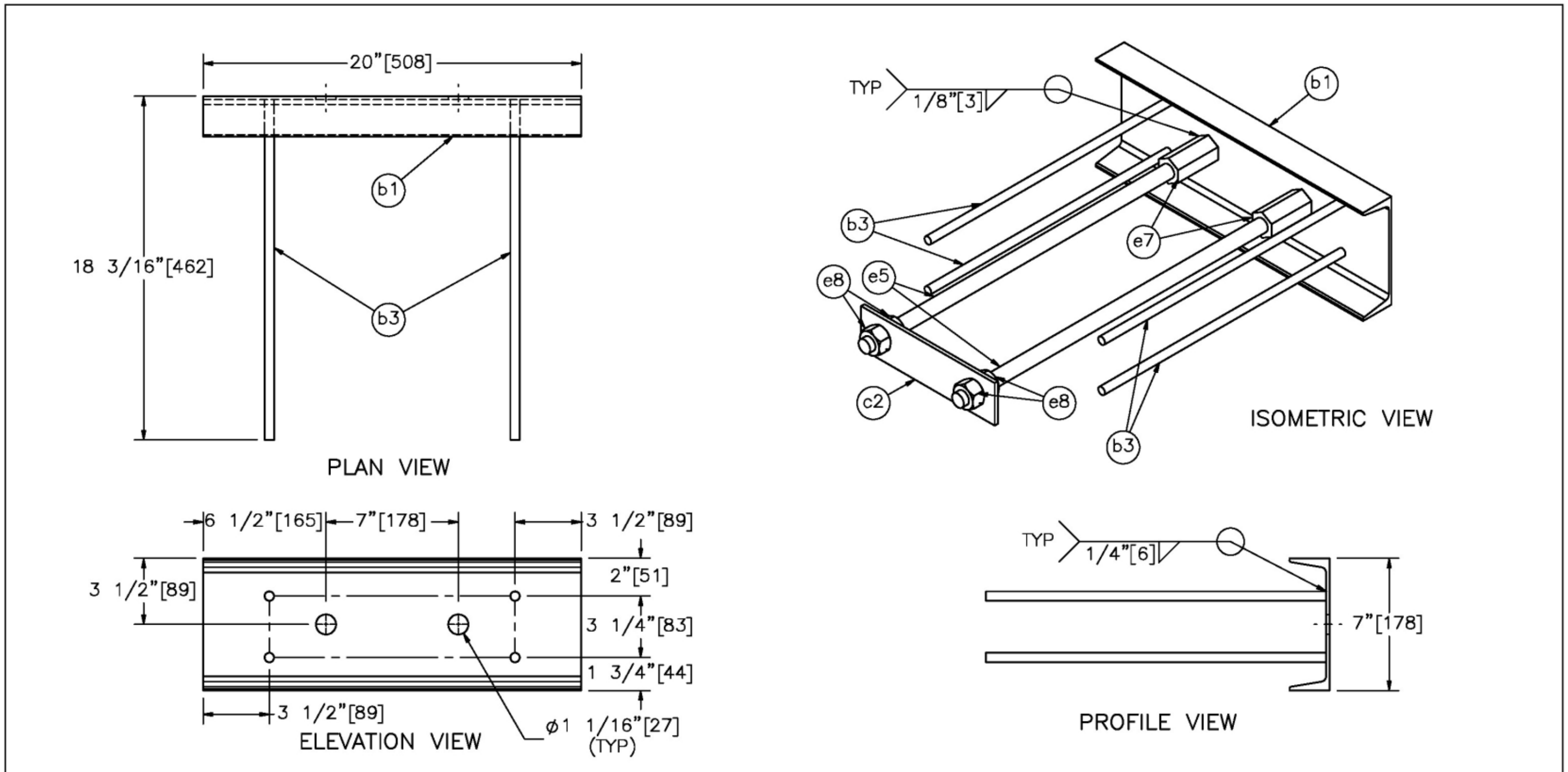
Midwest Roadside Safety Facility

12" Precast Beam Slab Attachment Option 3

Post Socket Assembly

SHEET: 5 of 5
DATE: 8/3/2020
DRAWN BY: SBW
DWG. NAME. TL2BR_opt3_Assembly_R1
SCALE: 1:4
UNITS: in.[mm]
REV. BY: –

Figure 125. System Details, TL-2 Bridge Rail Attachment to 12-in. Deck, Option 3, Socket Assembly

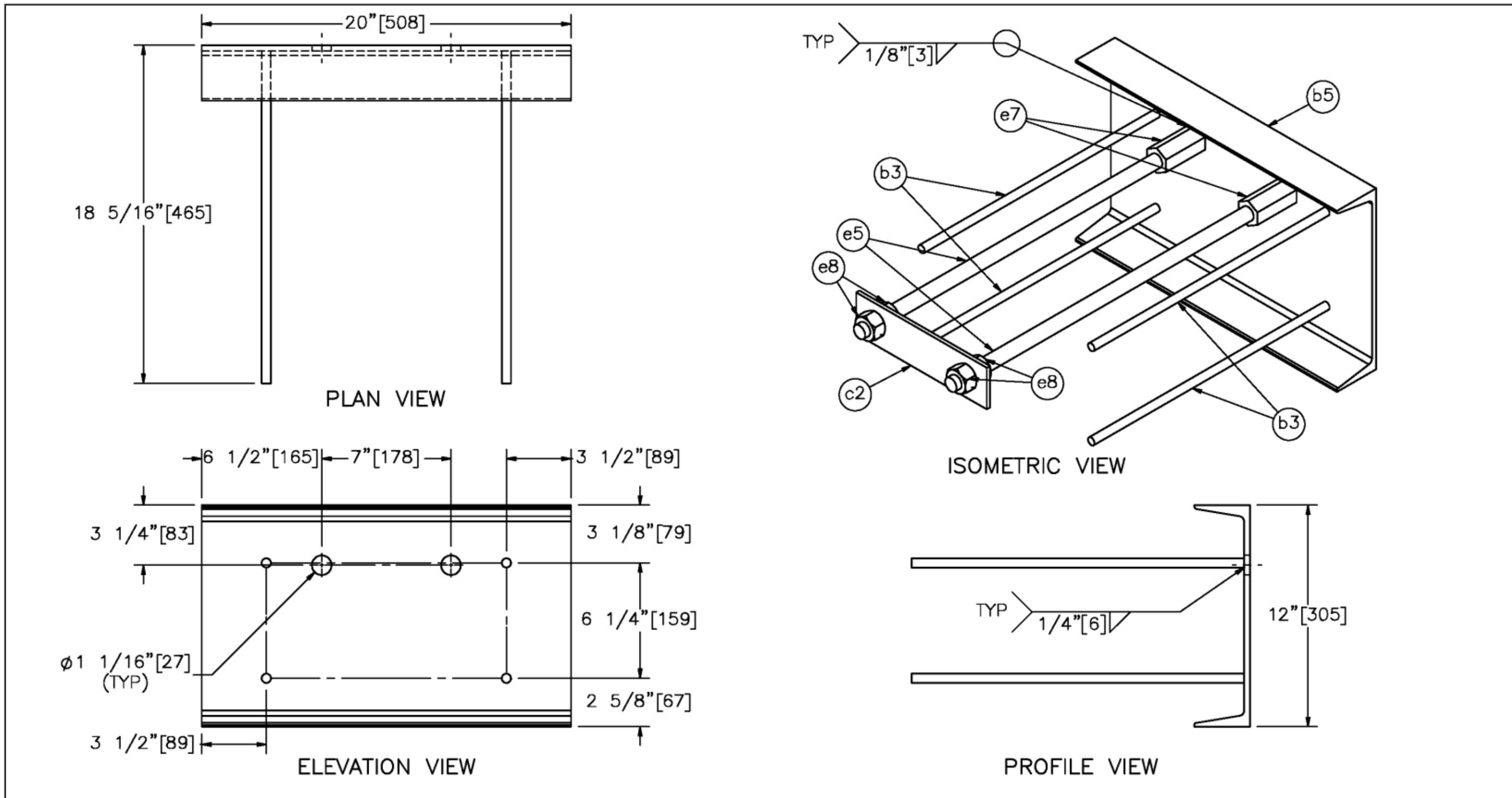


Item No.	QTY.	Description	Material Specification	Treatment Specification
–	–	7"x20" Long C–Channel Assembly	–	–
b1	1	C7x9.8 [C178x14.3], 20" [914] Long C–Channel	ASTM A36	–
b3	4	#4 [13] Bar, 18" [457] Long	ASTM A706 Gr. 60	–
c2	1	10"x2 3/4"x1/4" [254x70x6] Plate Washer	ASTM A36	ASTM A123
e5	2	7/8"–9 UNC [M22x2.5], 24" [610] Long Threaded Rod	ASTM A449 or Equivalent	ASTM A153 or B695 Class 55 or F2329
e7	2	7/8" [22] Dia. Heavy Hex Coupling Nut	ASTM A563DH or Equivalent	ASTM A153 or B695 Class 55 or F2329
e8	4	7/8" [22] Dia. Heavy Hex Nut	ASTM A563DH or Equivalent	ASTM A153 or B695 Class 55 or F2329

Notes: (1) Threaded rods and coupling nuts hidden from non isometrics views for clairity.
(2) Coupling nuts can either be spot welded or bolted in place during casting.

MwRSF Midwest Roadside Safety Facility	7" and 12" C–Channel Assemblies	SHEET: 1 of 2
		DATE: 8/3/2020
	7" C–Channel Assembly	DRAWN BY: SBW
	DWG. NAME. TL2BR_C–Channel_Assembly_R1 / SCALE: 1:8 UNITS: in.[mm]	REV. BY: –

Figure 126. Details for 20-in. Long C7x9.8 Channel Assembly for Use on 7-in. CIP decks



Item No.	QTY.	Description	Material Specification	Treatment Specification
–	–	12"x20" Long C–Channel Assembly	–	–
b5	1	C12x20.7 [C305x30.8], 20" [508] Long C–Channel	ASTM A36	–
c2	1	10"x2 3/4"x1/4" [254x70x6] Plate Washer	ASTM A36	ASTM A123
b3	4	#4 [13] Bar, 18" [457] Long	ASTM A706 Gr. 60	–
e5	2	7/8"–9 UNC [M22x2.5], 24" [610] Long Threaded Rod	ASTM A449 or Equivalent	ASTM A153 or B695 Class 55 or F2329
e7	2	7/8" [22] Dia. Heavy Hex Coupling Nut	ASTM A563DH or Equivalent	ASTM A153 or B695 Class 55 or F2329
e8	4	7/8" [22] Dia. Heavy Hex Nut	ASTM A563DH or Equivalent	ASTM A153 or B695 Class 55 or F2329

Notes: (1) Threaded rods and coupling nuts hidden from non isometrics views for clairity.
(2) Coupling nuts can either be spot welded or bolted in place during casting.

Midwest Roadside Safety Facility

7" and 12" C–Channel Assemblies

12" C–Channel Assembly

SHEET: 2 of 2

DATE: 8/3/2020

DRAWN BY: SBW

DWG. NAME. TL2BR_C–Channel_Assembly_R1

SCALE: 1:8

UNITS: in.[mm]

REV. BY: –

Figure 127. Details for 20-in. Long C12x20.7 Channel Assembly for Use on 12-in. CIP decks

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13 APPENDICES

Appendix A. Bogie Test Material Specifications

Table A-1. Bill of Materials, Test Nos. N2B-1 through N2B-6

Item No.	Part Description	Material Specification	Reference No.
a1	Concrete	Min. f'c = 6,000 psi NE Mix 47BD	R#2147369871
b1	C7x9.8, 36" Long C-Channel	ASTM A36	H#1047907
b2	C7x9.8, 36" Long C-Channel	ASTM A36	H#1047907
b3	C7x12.25, 36" Long C-Channel	ASTM A36	H#63142712
b4	C12x20.7, 20" Long C-Channel	ASTM A36	H#55049945
b5	C12x20.7, 20" Long C-Channel	ASTM A36	H#55049945
b6	10"x2 3/4"x1/4" Plate Washer	ASTM A36	H#B707407
b7	2x2x1/4" Gusset	ASTM A36	H#B707407
c1	HSS4x4x3/8", 6 5/8" Long Square Tube	ASTM A500 Gr. B	H#W45369
c2	HSS4x4x3/8", 11 5/8" Long Square Tube	ASTM A500 Gr. B	H#W45369
c3	10"x7"x1/2" Steel Plate	ASTM A572 Gr. 50	H#A7D898
c4	12"x10"x1/2" Steel Plate	ASTM A572 Gr. 50	H#A7D898
c5	12"x10"x1/2" Steel Plate	ASTM A572 Gr. 50	H#A7D898
e1	S3x5.7, 39" Long Steel Post	ASTM A992	H#59070748
e2	S3x5.7, 44" Long Steel Post	ASTM A992	H#59070748
e3	2 3/4"x1"x1/4" Post Standoff	ASTM A36	H#64055041
f1	5/8" Dia. UNC, 5" Long Heavy Hex Head Bolt and Nut	Bolt - ASTM F3125 Gr. A325 Type 1 Nut - ASTM A563DH	BOLT: H#C20373 NUT: H#C114376
f2	3/4" Dia. UNC, 1 3/4" Long Heavy Hex Head Bolt	ASTM A449	H#NF14204233
f3	3/4" Dia. Heavy Hex Coupling Nut	ASTM A563DH or A194 Gr. 2H	H#NF16203911
f4	3/4" Dia., 30" Long Threaded Rod	ASTM A449	H#DL1610487601

Table A-2. Bill of Materials, Test Nos. N2B-1 through N2B-6, Cont.

Item No.	Part Description	Material Specification	Reference No.
f5	7/8" Dia. UNC, 2" Long Heavy Hex Head Bolt	ASTM A325 HVY HEX	H#331704677
f6	7/8" Dia. Hex Coupling Nut	ASTM A563DH or A194 Gr. 2H	H#NF14103504
f7	7/8" Dia., 30" Long Threaded Rod	ASTM A449	H#DL1610686802
f8	1" Dia. UNC, 2" Long Heavy Hex Head Bolt	ASTM A449	H#NF16103170
f9	1" Dia. Heavy Hex Coupling Nut	ASTM A563DH or A194 Gr. 2H	H#NF14103504
f10	1" Dia. Heavy Hex Nut	ASTM A563DH or A194 Gr. 2H	H#DL15105591
f11	1" Dia., 24" Long Threaded Rod	ASTM A449	H#A164782
f12	1" Dia. Hardened Flat Washer	ASTM F436	H#276190
f13	7/8" Dia. Hardened Flat Washer	ASTM F436	H#274703
f14	3/4" Dia. Hardened Flat Washer	ASTM F436	H#273699
g1	#4 Bar, 287 1/2" Long	ASTM A615 Gr. 60	H#58028860
g2	#4 Bar, 251 1/2" Long	ASTM A615 Gr. 60	H#58028860
g3	#4 Bar. 200 1/2" Long	ASTM A615 Gr. 60	H#58028860
g4	#4 Bar, 63" Long	ASTM A615 Gr. 60	H#58028860
g5	#4 Bar, 48" Long	ASTM A615 Gr. 60	H#58028860
g6	#4 Bar, 32" Long	ASTM A615 Gr. 60	H#58028860
g7	#4 Bar, 20" Long	ASTM A615 Gr. 60	H#58028860
g8	#3 Bar, 86 7/8" Long Unbent	ASTM A615 Gr. 60	H#587796
g9	#4 Bar, 90 3/8" Long	ASTM A615 Gr. 60	H#58028860
g10	#8 Bar, 90 3/8" Long	ASTM A615 Gr. 60	H#KN14104453
g11	#4 Bar, 18"] Long	ASTM A706 Gr. 60	H#53145629
g12	#4 Bar, 23 11/16" Long Unbent	ASTM A706 Gr. 60	H#53145629
g13	#4 Bar, 40" Long Unbent	ASTM A706 Gr. 60	H#53145629
g14	#5 Bar, 52 3/16" Long Unbent	ASTM A706 Gr. 60	H#53145629
g15	#4 Bar, 18" Long	ASTM A615 Gr. 60	H#58028860

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COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 6x12

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility | **Date** 30-Nov-17
Project Name: Miscellaneous Concrete Testing
Placement Location: TL-2

Mix Designation: | **Required Strength:**

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area, sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
URR- 46	D	10/20/2017	11/30/2017	11/30/2017	41	0	41	12	5.99	28.20	155,217	5,500		5	C 1231
URR- 47	E	10/20/2017	11/30/2017	11/30/2017	41	0	41	12	6.01	28.35	163,635	5,770		5	C 1231
URR- 48	F	10/20/2017	11/30/2017	11/30/2017	41	0	41	12	6.00	28.24	161,598	5,720		5	C 1231

1 cc: Ms. Karla Lechtenberg
Midwest Roadside Safety Facility

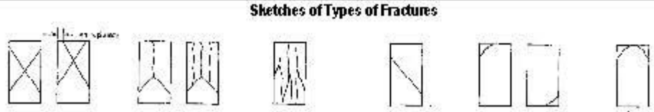
Remarks:

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

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

Report Number 2147369871
Page 1

Sketches of Types of Fractures



ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By ______
Brant Wells, Field/Lab Operations Manager

Figure A-1. Concrete, Test Nos. N2B-1 through N2B-6

CMC

1SERIES-BPS ®

CMC STEEL ALABAMA
101 S 50TH STREET
BIRMINGHAM AL 35212-3525

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800-637-3227

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

Marcus W. McCluney - CMC Steel AL
Quality Assurance Manager

HEAT NO.:1047907 SECTION: CHANNEL 7"x9.8# 40'0" A36/572T1 GRADE: ASTM A36-14/A572-15 Gr 50 Tp1 ROLL DATE: 06/09/2017 MELT DATE: 06/06/2017 Cert. No.: 82115015 / 047907B840	S O L D T O: Steel & Pipe Supply Co Inc 555 Poyntz Ave Manhattan KS US 66502-6085 7855875182 7855872282	S H I P T O: Steel & Pipe Supply Co 401 New Century Pkwy New Century KS US 66031-0000 9137684333 7855875381	Delivery#: 82115015 BOL#: 72094677 CUST PO#: 4500287306 CUST P/N: 25798040 DLVRY LBS / HEAT: 10976.000 LB DLVRY PCS / HEAT: 28 EA

Characteristic	Value	Characteristic	Value	Characteristic	Value
C	0.13%	Elongation Gage Lgth test 1	8IN		
Mn	0.73%	Yield to tensile ratio test1	0.76		
P	0.015%	Yield Strength test 2	58.7ksi		
S	0.032%	Tensile Strength test 2	76.8ksi		
Si	0.20%	Elongation test 2	25%		
Cu	0.26%	Elongation Gage Lgth test 2	8IN		
Cr	0.20%	Yield to tensile ratio test2	0.76		
Ni	0.12%				
Mo	0.063%				
V	0.005%				
Cb	0.010%				
Sn	0.009%				
B	0.0000%				
Ti	0.002%				
N	0.0095%				
Carbon Eq A6	0.33%				
Yield Strength test 1	57.6ksi				
Tensile Strength test 1	75.6ksi				
Elongation test 1	23%				

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

REMARKS :
ALSO MEETS A709 GR. 36, ASME SA36-08 ADDEND A, M270 GR. 36, A709 GR. 50 TYP 1, A529-50, A992, CAN 44W, CAN 50W

06/22/2017 14:48:49
Page 1 OF 1

Figure A-2. C7x9.8, 36-in. Long C-Channel, Test Nos. N2B-1 through N2B-6

GERDAU

US-ML-CALVERT CITY
1035 SHAR-CAL ROAD
CALVERT CITY, KY 42029
USA

CERTIFIED MATERIAL TEST REPORT

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CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
STEEL & PIPE SUPPLY CO INC 401 NEW CENTURY PKWY NEW CENTURY,KS 66031-1127 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	GGMULTI	Channel / 7 X 12.25#	0000010926

LENGTH	WEIGHT	HEAT / BATCH
40'00"	17,640 LB	63142712/02

SALES ORDER	CUSTOMER MATERIAL N°
3842668/000010	000000000257122540

SPECIFICATION / DATE or REVISION
ASTM A529-14, A572-15
ASTM A6-14,A36-14, ASME SA-36
ASTM A709-15, AASHTO M270-12
CSA G40.20-13/G40.21-13

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500268004	1322-0000021503	08/10/2016

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Al %	N %
0.11	0.74	0.012	0.033	0.23	0.24	0.08	0.11	0.028	0.018	0.001	0.001	0.0127

CHEMICAL COMPOSITION

Sn %
0.011

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
24.00	8.000	72300	499	55400	382
24.00	8.000	72550	500	55340	382

GEOMETRIC CHARACTERISTICS

CSA Squa
0.468
0.466

COMMENTS / NOTES

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

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

MICHAEL HERNDON
QUALITY ASSURANCE MGR.

Figure A-3. C7x12.25, 36-in. Long C-Channel, Test Nos. N2B-1 through N2B-6

GERDAU

CERTIFIED MATERIAL TEST REPORT

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

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID
STEEL & PIPE SUPPLY CO INC JONESBURG INDUSTRIAL PARK JONESBURG,MO 63351 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	GGMULTI	Channel / 12 X 20.7#	0000091740

LENGTH	WEIGHT	HEAT / BATCH
40'00"	19,872 LB	55049945/02

SALES ORDER	CUSTOMER MATERIAL N°
5121870/000030	000000002512207040

SPECIFICATION / DATE or REVISION
ASTM A529-14, A572-15
ASTM A6-14,A36-14, ASME SA-36
ASTM A709-15, AASHTO M270-12
CSA G40.20-13/G40.21-13

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
G450023237	1323-0000090662	05/31/2017

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	N %	Sn %
0.08	1.16	0.016	0.021	0.26	0.28	0.10	0.10	0.026	0.036	0.002	0.0100	0.009

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS 0.2% PSI	YS MPa
22.50	8.000	71900	496	54900	379
21.50	8.000	72700	501	55800	385

COMMENTS / NOTES

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

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

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

YAN WANG
QUALITY ASSURANCE MGR.
Phone: (770) 387 5718 Email: yan.wang@gerdau.com

Figure A-4. C7x20.7, 36-in. Long C-Channel, Test Nos. N2B-1 through N2B-6

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 06/27/2017
TIME 22:09:18
USER GIANGRER

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
40287387-0030	70872120TM	1/4 72 X 120 A36 TEMPERPASS STPMLPL	12	7,351.200			06/27/2017

Chemical Analysis

Heat No. B707407 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS **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
0.0700	0.8100	0.0130	0.0030	0.0200	0.0400	0.0500	0.0100	0.0001	0.1000	0.0270	0.0030	0.0030	0.0010	0.0070	0.0050

Mechanical / Physical Properties

Mill Coil No. 17B761473

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
59600.000	44600.000	39.00			0	NA			
59600.000	44700.000	35.10			0	NA			
61295.000	43391.000	32.90			0	NA			
59828.000	42127.000	40.85			0	NA			

Batch 0004826149 12 EA 7,351.200 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 A-5. 10-in. x 2¾-in. x ¼-in. Plate Washer, Test Nos. N2B-1 through N2B-6

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 06/27/2017
TIME 22:09:18
USER GIANGRER

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
40287387-0030	70872120TM	1/4 72 X 120 A36 TEMPERPASS STPMLPL	12	7,351.200			06/27/2017

Chemical Analysis

Heat No. B707407 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS 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
0.0700	0.8100	0.0130	0.0030	0.0200	0.0400	0.0500	0.0100	0.0001	0.1000	0.0270	0.0030	0.0030	0.0010	0.0070	0.0050

Mechanical / Physical Properties

Mill Coil No. 17B761473

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
59600.000	44600.000	39.00			0	NA			
59600.000	44700.000	35.10			0	NA			
61295.000	43391.000	32.90			0	NA			
59828.000	42127.000	40.85			0	NA			

Batch 0004826149 12 EA 7,351.200 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 A-6. 2-in. x 2-in. x ¼-in. Gusset, Test Nos. N2B-1 through N2B-6

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

Atlas *Tube*
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80773104
Date: 07.24.2017
Customer: 179

MATERIAL TEST REPORT

Sold to

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

Shipped to

Steel & Pipe Supply Company
1020 West Fort Gibson
CATOOSA OK 74015
USA

Material: 4.0x4.0x375x40'0"0(5x2). **Material No:** 400403754000 **Made in:** USA **Melted in:** USA

Sales order: 1196766 **Purchase Order:** 4500290927 **Cust Material #:** 6540037540

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
W45369	0.190	0.790	0.011	0.007	0.020	0.039	0.040	0.004	0.003	0.010	0.050	0.002	0.001	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800718467	10	061632 Psi	073060 Psi	30 %	ASTM A500-13 GRADE B&C	0.34

Material Note:
Sales Or.Note:

Material: 4.0x4 0x375x40'0"0(5x2). **Material No:** 400403754000 **Made in:** USA **Melted in:** USA

Sales order: 1196766 **Purchase Order:** 4500290927 **Cust Material #:** 6540037540

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
W45369	0.190	0.790	0.011	0.007	0.020	0.039	0.040	0.004	0.003	0.010	0.050	0.002	0.001	0.000	0.005

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800718474	10	061632 Psi	073060 Psi	30 %	ASTM A500-13 GRADE B&C	0.34

Material Note:
Sales Or.Note:

Material: 6.0x4.0x375x40'0"0(3x2). **Material No:** 600403754000 **Made in:** USA **Melted in:** USA

Sales order: 1198462 **Purchase Order:** C450006656 **Cust Material #:** 6660040037540

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
V2570	0.190	0.620	0.013	0.010	0.020	0.031	0.160	0.009	0.020	0.060	0.090	0.002	0.001	0.000	0.008

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800717340	6	071646 Psi	082892 Psi	29 %	ASTM A500-13 GRADE B&C	0.33

Material Note:
Sales Or.Note:

Jason Richard

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

Steel Tube Institute OF NORTH AMERICA

Page : 1 Of 3

Metals Service Center Institute

Figure A-7. HSS4x4x⅜ Square Tube, Test Nos. N2B-1 through N2B-6

SSAB

Preliminary Test Certificate

Form TC1: Revision 2: Date 23 Apr 2014

1770 Bill Sharp Boulevard, Muscatine, IA 52761-9412, US **Official copy to follow**

Customer: STEEL & PIPE SUPPLY P.O. BOX 1688 MANHATTAN KS 66502	Customer P.O. No.: 4500287649	Mill Order No.: 41-504804-02	Shipping Manifest : MT318692
	Product Description: ASTM A572-50/M345(15)/A709-50/M345(16A)	Ship Date: 21 Jun 17 Cert Date: 21 Jun 17	Cert No: 061649975 (Page 1 of 1)
	Size: 0.500 X 96.00 X 240.0 (IN)		

Tested Pieces				Tensiles						Charpy Impact Tests					
Heat Id	Piece Id	Tested Thickness	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1 2 3 Avg	% Shear 1 2 3 Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp %Shr
A7D898	D19	0.496 (DISCRT)	L	61	73		38	T							
A7F058	D31	0.497 (DISCRT)	L	55	68		37	T							
B7D657	D18	0.507 (DISCRT)	L	57	77		28	T							

Chemical Analysis

Heat Id	C	Mn	P	S	Si	Tot Al	Cu	Ni	Cr	Mo	Cb	V	Ti	ORGN
A7D898	.05	1.32	.014	.004	.10	.034	.30	.14	.15	.03	.024	.027	.008	USA
A7F058	.05	1.21	.012	.006	.02	.028	.31	.14	.10	.04	.002	.053	.001	USA
B7D657	.16	1.14	.013	.007	.03	.029	.30	.15	.17	.04	.002	.033	.006	USA

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

B7D657	D18	PCES: 2, LBS:	6534	A7F058	D31	PCES: 1, LBS:	3267
A7D898	D19	PCES: 3, LBS:	9801				

Cust Part # : 721696240A2

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

SENIOR METALLURGIST - PRODUCT

Figure A-8. ½-in. Thick Steel Plate, Test Nos. N2B-1 through N2B-6

GERDAU

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

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
STEEL & PIPE SUPPLY CO INC 401 NEW CENTURY PKWY NEW CENTURY,KS 66031-1127 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	A36/A572-50	Standard I-Beam / 3 X 5.7# / 75 X 8.5	0000050470

LENGTH	WEIGHT	HEAT / BATCH
40'00"	8,208 LB	S9070748/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
4082394/000030	000000000035357040	ASME SA36 ASTM A572-15 ASTM A6-14, A36-14 ASTM A709-13A

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500271337	1327-0000209580	09/02/2016

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.14	0.91	0.020	0.035	0.21	0.32	0.17	0.16	0.036	0.009	0.003	0.013	0.002

CHEMICAL COMPOSITION

CEqyA6 %
0.36

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	G/L Inch	G/L mm
61464	78321	424	540	8.000	200.0
61487	78301	424	540	8.000	200.0

MECHANICAL PROPERTIES

Elong. %
23.40
21.30

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

TOM HARRINGTON
QUALITY ASSURANCE MGR.

Figure A-9. S3x5.7 Steel Post, Test Nos. N2B-1 through N2B-6

GERDAU

US-ML-WILTON
1500-2500 WEST 3RD STREET
WILTON, IA 52778
USA

CERTIFIED MATERIAL TEST REPORT

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CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
STEEL & PIPE SUPPLY CO INC 401 NEW CENTURY PKWY NEW CENTURY,KS 66031-1127 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	A36/44W	Flat Bar / 1/4 X 1	0000011110

LENGTH	WEIGHT	HEAT / BATCH
20'00"	19,584 LB	64055041/02

SALES ORDER	CUSTOMER MATERIAL N°
4190352/000010	000000000010810020

SPECIFICATION / DATE or REVISION
ASME SA36
ASTM A6-14, A36-14
ASTM A709-15, AASHTO M270-12
CSA G40.20-13/G40.21-13

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500272853	1334-0000034941	09/20/2016

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Al %	Pb %
0.15	0.57	0.007	0.021	0.21	0.26	0.09	0.07	0.020	0.001	0.014	0.002	0.0000

CHEMICAL COMPOSITION

CEqyA529 %	Sn %
0.33	0.018

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
22.50	8.000	74300	512	58000	400
22.50	8.000	74400	513	57600	397

GEOMETRIC CHARACTERISTICS

R:R
123.14

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

BHASKAR YALAMANCHILI
QUALITY DIRECTOR

BRETT KRAUSE
QUALITY ASSURANCE MGR.

Figure A-10. 2¾-in. x 1-in. x ¼-in. Post, Test Nos. N2B-1 through N2B-6

INFASCO

LOT NO.: 1610-58099
3023G

ISO 9001, ISO/TS16949
ISO / IEC 17025
ISO 14001

A325 △

FASTENER TEST REPORT

(THIS DOCUMENT MAY ONLY BE REPRODUCED IN ITS ENTIRETY, WITH PRIOR WRITTEN APPROVAL BY THE INFASCO LABORATORY)
(THE INFASCO LABORATORY IS ACCREDITED BY THE CCN FOR THE TESTS LISTED AT WWW.CCN.CA)
COMPLIES WITH EN10204 2004 INSPECTION CERTIFICATE 3.1

DATE 2016-10-19

DESCRIPTION AND MARKING: A325-1 STRUCTURAL BOLT UNC N HDG
HOLLOW TRIANGLE & "A325"

SIZE	GRADE	QUANTITY
5/8-11 X 5	1036M	5,800

HEAT CHEMICAL ANALYSIS (provided by steel supplier)

HEAT NO.	C %	Mn %	P %	S %	Si %				
C20373	0.36	0.96	0.007	0.013	0.25				

METHOD		ASTM F606	ASTM F606			ASTM F606		ASTM E376
		PROOF LOAD (psi)	WEDGE TENSILE STRENGTH (psi)	SHEAR STRENGTH	SURFACE HARDNESS (HR 30N)	CORE HARDNESS (ROCKWELL)	MICRO HARDNESS	COATING THICKNESS (0.001 in)
SPEC. MIN.		85,000	120,000			HRC 25.0		2.00
SPEC. MAX:						HRC 34.0		
S	NO.1	87,000	147,000			HRC 32.2		3.52
A	NO.2	87,000	146,000			32.7		3.63
M	NO.3	87,000	147,000			32.0		3.98
P	NO.4					32.4		2.92
L	NO.5							3.41
E	NO.6							3.41
	NO.7							4.09
	NO.8							3.28
	NO.9							3.95
	NO.10							2.66
	NO.11							3.07
	NO.12							2.65
	NO.13							3.30
	NO.14							3.50
	NO.15							3.42

THE ABOVE TESTED SAMPLES HAVE BEEN INSPECTED FOR VISUAL DISCONTINUITIES AND FOUND ACCEPTABLE.
THEY COMPLY IN ALL RESPECTS WITH THE LATEST EDITION OF THE FOLLOWING SPECS:
ASTM A325 TYPE 1 ASME B18.2.6, THREADS PER ASME B1.1 CLASS 2A. UNLESS OTHERWISE SPECIFIED.
MEETS THE SURFACE DISCONTINUITIES REQUIREMENTS
ASTM F2329, ASTM-A-153 Class C
THESE FASTENERS WERE OIL QUENCHED AND TEMPERED AT A TEMP. ABOVE 800°F.
NO BISMUTH, SELENIUM, TELLURIUM OR LEAD HAVE BEEN INTENTIONALLY ADDED

COATING THICKNESS VALUES PROVIDED BY COATING SUPPLIER.

MANUFACTURED IN: CANADA
The steel was melted and rolled
in North America and is mercury and asbestos-free.

Isabelle Parent, Eng., M.A.Sc.
Quality Assurance Foreman

INFASCO
A division of Ifastgroupe LP
A Heico Company
700 Ouellette, Marieville (Quebec) J3M 1P6
Tel.: (450) 658-8741 Fax: (450) 460-5496

FQ-019-2 Rev. 09 Revision date of test report: 2017-01-09 Page 1 of 1

Figure A-11. ⅝-in. Dia., 5-in. Long Heavy Hex Head Bolt, Test Nos. N2B-1 through N2B-6

INFASCO

ISO 9001, ISO/TS16949
ISO / IEC 17025
ISO 14001

LOT NO.: 1604-53117
8441G

FASTENER TEST REPORT

(THIS DOCUMENT MAY ONLY BE REPRODUCED IN ITS ENTIRETY, WITH PRIOR WRITTEN APPROVAL BY THE INFASCO LABORATORY)
(THE INFASCO LABORATORY IS ACCREDITED BY THE CCN FOR THE TESTS LISTED AT WWW.CCN.CA)
COMPLIES WITH EN10204:2004 INSPECTION CERTIFICATE 3.1

DATE 2016-05-25

DESCRIPTION AND MARKING: HVY HEX NUT A563-DH FNA OS. UNC OS HDG+L
TRIANGLE & "DH"

SIZE	GRADE	QUANTITY
5/8-11 .020 O/S	1046	131,000

HEAT CHEMICAL ANALYSIS (provided by steel supplier)

HEAT NO.	C %	Mn %	P %	S %	Si %	Cu %	Ni %		
C114376	0.44	0.84	0.010	0.009	0.22	0.12	0.06		

METHOD	ASTM F606				ASTM F606		ASTM E376
	PROOF LOAD (psi)	WEDGE TENSILE STRENGTH	SHEAR STRENGTH	SURFACE HARDNESS (HR 30N)	CORE HARDNESS (ROCKWELL)	MICRO HARDNESS	COATING THICKNESS (0.001 in)
SPEC. MIN. / SPEC. MAX:	150,000				HRC 24.0 / HRC 38.0		2.00
SAMPLE NO.1	157,000				HRC 30.6		3.38
NO.2	155,000				29.8		3.23
NO.3	156,000				30.7		3.06
NO.4	156,000				29.9		2.59
NO.5	155,000				31.9		2.68
NO.6							2.68
NO.7							2.88
NO.8							2.60
NO.9							2.20
NO.10							2.50
NO.11							2.76
NO.12							2.83
NO.13							2.94
NO.14							2.16
NO.15							2.35

THE ABOVE TESTED SAMPLES HAVE BEEN INSPECTED FOR VISUAL DISCONTINUITIES AND FOUND ACCEPTABLE.
THEY COMPLY IN ALL RESPECTS WITH THE LATEST EDITION OF THE FOLLOWING SPECS:
ASTM A563 DH AND ASME B18.2.2, THREADS PER ASME B1.1 CLASS 2B UNLESS OTHERWISE SPECIFIED.

ASTM F2329, ASTM-A-153 CLASS C + LUBRICANT

COATING THICKNESS VALUES PROVIDED BY COATING SUPPLIER.

MANUFACTURED IN : CANADA
The steel was melted and rolled
in North America and is mercury and asbestos-free.

Daniel Guilbault
Quality Assurance Foreman

INFASCO
A division of Ifastgroupe LP
A Heico Company
700 Ouellette, Marieville (Quebec) J3M 1P5
Tel.: (450) 658-8741 Fax: (450) 460-5496

FQ-019-2 Rev. 09 Revision date of test report: 2016-06-17 Page 1 of 1

Figure A-12. ⅝-in. Dia. 5-in. Long Heavy Hex Head Nut, Test Nos. N2B-1 through N2B-6

NUCOR
FASTENER DIVISION

LOT NO.
353485A

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

CUSTOMER NO/NAME
143 CORDOVA BOLT INC

TEST REPORT SERIAL#	F8444739	NUCOR ORDER #	970775
TEST REPORT ISSUE DATE	11/26/14	CUST PART #	
DATE SHIPPED	5/23/16	CUSTOMER P.O. #	055645
NAME OF LAB SAMPLER:	RYAN UNGER, LAB TECHNICIAN		

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

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
160556	650	353485A	3/4-10 X 1 3/4 A325-T HVY HX STRUC SCREW PLAIN LESS NUT

MANUFACTURE DATE 11/17/14

--CHEMISTRY MATERIAL GRADE -1039ML1
**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER NUCOR STEEL - NEBRASKA

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM029564	NF14204233	.40	.88	.006	.016	.25

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM A325-14

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 28400 LBS	TENSILE STRENGTH 6 DEG-WEDGE (LBS)	STRESS (PSI)
N/A	30.0	PASS	49490	148174
N/A	31.6	PASS	48610	145539
N/A	31.0	PASS	49240	147425
N/A	31.1			
AVERAGE VALUES FROM TESTS				
	30.9		49113	147046

PRODUCTION LOT SIZE 6800 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM A325-14 4 PCS. SAMPLED LOT PASSED
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.399	1.402
Head Height	8	0.468	0.475
Threads	8	PASS	PASS

ALL TESTS ARE IN ACCORDANCE WITH THE LATEST REVISIONS OF THE METHODS PRESCRIBED IN THE APPLICABLE SAE AND ASTM SPECIFICATIONS. THE SAMPLES TESTED CONFORM TO THE SPECIFICATIONS AS DESCRIBED/LISTED ABOVE AND WERE MANUFACTURED FREE OF MERCURY CONTAMINATION. NO HEATS TO WHICH BISMUTH, SELENIUM, TELLURIUM, OR LEAD WAS INTENTIONALLY ADDED HAVE BEEN USED TO PRODUCE THE BOLTS.
THE STEEL WAS MELTED AND MANUFACTURED IN THE U.S.A. AND THE PRODUCT WAS MANUFACTURED AND TESTED IN THE U.S.A. PRODUCT COMPLIES WITH DFARS 252.225-7016. WE CERTIFY THAT THIS DATA IS A TRUE REPRESENTATION OF INFORMATION PROVIDED BY THE MATERIAL SUPPLIER AND OUR TESTING LABORATORY. THIS CERTIFIED MATERIAL TEST REPORT RELATES ONLY TO THE ITEMS LISTED ON THIS DOCUMENT AND MAY NOT BE REPRODUCED EXCEPT IN FULL.

ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/15

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

Figure A-13. ¾-in. Dia. 1¾-in. Long Heavy Hex Head Bolt, Test Nos. N2B-1 through N2B-6

Customer: WECALL INC   Ord #: T803092 Part #: 507373   Cust PO#: 21642   Page 1 of 2

Provided By : EARLE M. JORGENSEN COMPANY

NUCOR
NUCOR COLD FINISH WISCONSIN, INC.

Mill Certification
1/13/2017

MTR #: E1-135435
7200 S 6th St
OAK CREEK, WI 53154
(414) 764-0220
Fax: (414) 764-2073

Sold To: EARLE M JORGENSEN CO
1900 MITCHELL BLVD
PO BOX 1900
SCHAUMBURG, IL 60194
(847) 301-2346
Fax: (847) 891-2203

Ship To: EARLE M JORGENSEN CO
1900 MITCHELL BLVD
SCHAUMBURG, IL 60194
(847) 301-6118
Fax: (847) 891-2203

R 135982

Customer P.O.	P764144-423	Sales Order	634243.1
Product Group	Cold Finish Bar	Part Number	321499
Grade	4140/4142 ASTM A108 (REPLACES ASTM A331)	Lot #	E1177188
Size	Hex 1.2500 (.0050)	Heat #	NF16203911
Product	HX 1.2500" 4140DH 12-R AN.CD	B.L. Number	E1-235907
Description	CF Grade 4140DH	Load Number	E1-135435
Customer Spec	4140	Customer Part #	507373

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.

Part Detail: HX 1.2500" 4140 12-R Cold Drawn Annealed
Process: Annealed, Cold Drawn

Melt Date: 11/3/2016

C	Mn	P	S	Si	Cu	Cr	Ni	Mo	Sn	V	Cb
0.42%	0.96%	0.008%	0.027%	0.27%	0.13%	0.98%	0.10%	0.180%	0.007%	0.0060%	0.004%
Al	Pb										
0.030%	0.000%										

DI value: 5.75   Melting Mill: Nucor Bar NE   Country of Melting: USA

Simulated Hardenability Band

J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14	J15	J16	J18	J20	J22	J24	J26	J28	J30	J32
57	57	57	57	57	57	57	57	55	54	52	50	50	50	49	48	48	47	46	45	44	43	42	40

Reduction Ratio 29.0 :1   Country of Rolling: USA   Rolling Mill: Nucor Bar NE

Grain Size per ASTM E112 = 0

ASTM E381
Surface: 1   Mid Radius: 1   Center: 3

ASTM E45 Method A (Worst)
Sulfides: T: 2.0 H: 0.5 Alumina: T: 1.0 H: 0.5 Silicates: T: 0.5 H: 0.0 Globular: T: 1.0 H: 0.5

1. All products produced are weld free.
2. Mercury, in any form, has not been used in the production or testing of this material.

Nicholas Schultz

Nick Schultz
Sales Manager

NBMG-10 January 1, 2012   Page 5 of 6

Figure A-14. ¾-in. Dia. Heavy Hex Coupling Nut, Test Nos. N2B-1 through N2B-6

Vulcan
THREADED PRODUCTS, INC.

Vulcan Threaded Products
10 Cross Creek Trail
Pelham, AL 35124
Tel (205) 620-5100
Fax (205) 620-5150

JOB MATERIAL CERTIFICATION

Job No: 498848 — **Job Information** — **Certified Date:** 10/26/16

Containers: S11682725 S11695467 S11695486 S11695508

Customer: Conklin and Conklin

Ship To: 34201 Seventh Street, Union City, CA 94587

Vulcan Part No: BAR B7 .6813x144

Customer Part No: BAR B7 .680x144

Customer PO No: 017803

Shipped Qty: 12384 lbs

Order No: 301952

Line No: 2

Note:

Applicable Specifications

Type	Specification	Rev	Amend	Option
-	ASTM F1554 Gd 105 S4	2015		
Heat Treat	ASME SA-193/SA-193M B7	2013		
	ASTM A193 B7	2016		

Test Results

See following pages for tests

Certified Chemical Analysis

Heat No: DL1610487601 — Origin: USA

C	Mn	P	S	Si	Cr	Mo	Ni	V	Cu	Al	Cb
0.420	0.93	0.004	0.007	0.26	0.86	0.17	0.05	0.009	0.13	0.030	0.005
N	**DI**	**G.S.**	**Macro S**	**Macro R**	**Macro C**	**J1**	**J2**	**J3**	**J4**	**J5**	**J6**
0.0080	4.89	9	2	2	2	57	57	57	57	57	56
J7	**J8**	**J9**	**J10**	**J12**	**J14**	**J16**	**J18**	**J20**	**J24**	**J28**	**J32**
55	53	52	50	47	46	43	42	41	40	37	35

Notes

Material was manufactured, tested and inspected in accordance with Vulcan Threaded Products Inc. Quality Assurance Program and Manual Rev. A, dated 8/23/11. Processed material is Quenched and Tempered - Stress Free. No weld repair performed on the material. No Mercury used in the production of this material. Melted and Manufactured in the USA.
Document is in accordance with EN 10204 - 3.1B of 2004 (3.1).

Plex 10/26/16 4:15 PM vulc.mgut Page 1 of 2

19520 3/4 B7/G105 ATR

PORTLAND BOLT
PO 30712
INV 73419
98 3/4" X 144" B7 ATR, BLK 1OF2
JUNE 1, 2017

NOV 16 2016

30712

Figure A-15. ¾-in. Dia. 30-in. Long Threaded Rod, Test Nos. N2B-1 through N2B-6

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 : 2018/03/28

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 110254885
COMMODITY : FINISHED HEX NUT GR-A
SIZE : 7/8-9 NC O/T 0.56MM
LOT NO : 1N1810005
SHIP QUANTITY : 9,000 PCS
LOT QUANTITY 55,748 PCS
HEADMARKS :

PACKING NO : GEM180115010
INVOICE NO : GEM/FNL-180201WI-1
PART NO : 36717
SAMPLING PLAN : ASME B18.18-2011(Category.2)/ASTM F1470-2012
HEAT NO : 331704677
MATERIAL : XGML08
FINISH : HOT DIP GALVANIZED PER ASTM A153-2009/ASTM F2329-2013

MANUFACTURE DATE : 2018/01/05
COUNTRY OF ORIGIN : CHINA

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO ASTM A563-2015

Chemistry	AL%	C%	MN%	P%	S%	SI%
Spec. : MIN.						
MAX.		0.5800		0.1300	0.2300	
Test Value	0.0360	0.0600	0.4500	0.0140	0.0030	0.0300

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18.2.2-2015

SAMPLED BY : WDANDAN

INSPECTIONS ITEM	SAMPLE	SPECIFIED		ACTUAL RESULT	ACC.	REJ.
WIDTH ACROSS CORNERS	5PCS		1.4470-1.5160 inch	1.4850-1.4930 inch	5	0
FIM	15PCS	ASME B18.2.2-2015	Max. 0.0250 inch	0.0110-0.0200 inch	15	0
THICKNESS	5PCS		0.7240-0.7760 inch	0.7460-0.7570 inch	5	0
WIDTH ACROSS FLATS	5PCS		1.2690-1.3120 inch	1.2930-1.2980 inch	5	0
SURFACE DISCONTINUITIES	29PCS		ASTM F812-2012	PASSED	29	0
THREAD	15PCS		GAGING SYSTEM 21	PASSED	15	0

MECHANICAL PROPERTIES : ACCORDING TO ASTM A563-2015

SAMPLED BY : TANGHAO

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	15PCS	ASTM F606-2014		68-107 HRB	86-90 HRB	15	0
PROOF LOAD	5PCS	ASTM F606-2014		Min. 31,416 LBF	OK	5	0
PLATING THICKNESS(μm)	29PCS	ASTM B568-1998		>=53	62.38-62.57	29	0

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

Quality Supervisor: [signature]

page 1 of 1

Figure A-16. ⅞-in. Dia. 2-in. Long Heavy Hex Head Bolt, Test Nos. N2B-1 through N2B-6

NUCOR
NUCOR COLD FINISH WISCONSIN, INC.

Mill Certification
4/16/2015

MTR #: 0000008756
7200 S 6th St
OAK CREEK, WI 53154
(414) 764-0220
Fax: (414) 764-2073

Sold To: ALRO STEEL CORP
PO BOX 927
JACKSON, MI 49204-0927
(517) 787-5500
Fax: (517) 787-6399

Ship To: ALRO - AKRON
4787 STATE RD
CUYAHOGA FALLS, OH 44223-3555
(330) 929-4660
Fax: (517) 787-6399

Customer P.O.	AK11262453	Sales Order	606726.1
Product Group	Cold Finish Bar	Part Number	321503
Grade	4140/4142 ASTM A108 (REPLACES ASTM A331)	Lot #	E1164321
Size	Hex 1.5000 (.0050)	Heat #	NF14103504
Product	HX 1.5000" 4140DH 12-R AN.CD	B.L. Number	E1-229548
Description	CF Grade 4140DH	Load Number	E1-129098
Customer Spec	4140	Customer Part #	32563000

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.

Part Detail: HX 1.5000" 4140 12-R Cold Drawn Annealed
Process: Annealed, Cold Drawn

Melt Date: 10/3/2014

C	Mn	P	S	Si	Cu	Cr	Ni	Mo	Sn	V	Cb
0.40%	0.95%	0.006%	0.022%	0.31%	0.16%	0.95%	0.08%	0.190%	0.007%	0.0060%	0.004%
Al	Pb										
0.028%	0.000%										

DI value: 5.70 Melting Mill: Nucor Bar NE Country of Melting: USA

Grain Practice: FINE

Simulated Hardenability Band

J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14	J15	J16	J18	J20	J22	J24	J26	J28	J30	J32
58	58	58	58	58	58	58	58	54	53	51.0	49	49	49	48	47	47	46	45	45	43	42	41	39

Reduction Ratio 21.0 :1 Country of Rolling: USA Rolling Mill: Nucor Bar NE

ASTM E381
Surface: 1 Mid Radius: 1 Center: 2

ASTM E45 Method A (Worst)
Sulfides: T: 1.5 H: 0.5 Alumina: T: 1.5 H: 0.0 Silicates: T: 0.5 H: 0.0 Globular: T: 1.5 H: 0.5

1. All products produced are weld free.
2. Mercury, in any form, has not been used in the production or testing of this material.

ALRO STEEL/METAL
RT07900927

RECEIVED
APR 16 2015
ALRO STEEL PV

Nick Schultz
Sales Manager

NBMG-10 January 1, 2012 Page 2 of 5

Figure A-17. ⅞-in. Dia. Hex Coupling Nut, Test Nos. N2B-1 through N2B-6

Vulcan THREADED PRODUCTS, INC.

Vulcan Threaded Products
10 Cross Creek Trail
Pelham, AL 35124
Tel (205) 620-5100
Fax (205) 620-5150

JOB MATERIAL CERTIFICATION

Job No: 513030 **Job Information** **Certified Date:** 1/27/17

Containers: S12022849

Customer: Portland Bolt & Mfg., Inc. **Ship To:** 3441 NW Guam Street Portland, OR 97210

Vulcan Part No: ATR B7 7/8x12

Customer Part No: ATR B7 7/8x12

Customer PO No: 29600 **Shipped Qty:** 142 pcs

Order No: 311935 **Line No:** 1

Note:

Applicable Specifications

Type	Specification	Rev	Amend	Option
-	ASTM F1554 Gd 105 S4	2015		
Heat Treat	ASME SA-193/SA-193M B7	2013		
	ASTM A193 B7	2016		

Test Results

See following pages for tests

Certified Chemical Analysis

Heat No: DL1610686802 Origin: USA

C	Mn	P	S	Si	Cr	Mo	Ni	V	Cu	Al	Cb	N
0.420	0.91	0.004	0.007	0.26	0.87	0.16	0.06	0.008	0.18	0.039	0.005	0.0100
DI	**RR**	**G.S.**	**Macro S**	**Macro R**	**Macro C**	**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**
4.89	120.6:1	7	2	2	2	57	57	57	57	57	56	55
J8	**J9**	**J10**	**J12**	**J14**	**J16**	**J18**	**J20**	**J24**	**J28**	**J32**		
53	52	50	47	46	43	42	41	40	37	35		

Notes

Material was manufactured, tested and inspected in accordance with Vulcan Threaded Products Inc. Quality Assurance Program and Manual Rev. A, dated 8/23/11. Processed material is Quenched and Tempered - Stress Free. No weld repair performed on the material. No Mercury used in the production of this material. Melted and Manufactured in the USA.
Document is in accordance with EN 10204 - 3.1B of 2004 (3.1).

Plex 1/27/17 4:10 PM vulc.mgn Page 1 of 2

19571 7/8 B7/6105 ATR

Figure A-18. ⅞-in. Dia. 30-in. Long Threaded Rod, Test Nos. N2B-1 through N2B-6

NUCOR
FASTENER DIVISION

LOT NO.
383920A

32405

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

CUSTOMER NO/NAME
143 CORDOVA BOLT INC
NUCOR ORDER # 16888

TEST REPORT SERIAL#	FB511122	CUST PART #	
TEST REPORT ISSUE DATE	11/03/16		
DATE SHIPPED	7/10/17	CUSTOMER P.O. #	061576
NAME OF LAB SAMPLER:	RYAN UNGER, LAB TECHNICIAN		

A325T
n

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

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION	
162296	574	383920A	1-8 X 2	A325T HVY HX
MANUFACTURE DATE 10/26/16			PLAIN ASTM F3125 TY1	

--CHEMISTRY MATERIAL GRADE -1037ML

**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI	CR	
RM031035	NF16103170	.38	.78	.008	.016	.23	.34	NUCOR STEEL - NEBRASKA

--MECHANICAL PROPERTIES IN ACCORDANCE WITH ASTM F3125-15a

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 51500 LBS	TENSILE STRENGTH 0 DEG-WEDGE (LBS)	STRESS (PSI)
N/A	28.7	PASS	89860	148284
N/A	29.9	PASS	90730	149719
N/A	31.9			
AVERAGE VALUES FROM TESTS				
	30.2		90295	149002

PRODUCTION LOT SIZE 2700 PCS

--VISUAL INSPECTION IN ACCORDANCE WITH ASTM F3125-15a 3 PCS. SAMPLED LOT PASSED
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	4	1.840	1.843
Head Height	4	0.605	0.610
Threads	4	PASS	PASS

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

A2LA ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/17

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

32405-1

Figure A-19. 1-in. Dia. 2-in. Long Heavy Hex Head Bolt, Test Nos. N2B-1 through N2B-6

Wecall Inc.

P.O. Box 39 • 64 Penniman Rd. • Orwell, OH 44076
(440) 437-8202 • Fax: (440) 437-8208
Fastener Insignia: 01OH

Record of Conformance

Sold To:
Portland Bolt & Mfg. Co., Inc
3441 NW Guam St.
Portland OR 97210

Shipped To:
Portland Bolt & Mfg.
3441 NW Guam St.
Portland OR 97210

Customer PO Number	Order Date	Order Quantity	Customer Part Number
32404/2	20-Sep-17	2	55555

Fastener Type	Description	Thread Description
Coupling Nut	1-1/2" Hex x 2-5/8" Long	7/8" - 9 UNC 2B RH

Fastener Specification	Coating Specification	Fastener Lot Number
ASTM A563 Gr DH		4142

Raw Material Lot Code	Raw Material Grade	Heat Number
20465-2	ASTM A108 Gr 4140	NF14103504

Cold Finish Source	Cold Finish Country	Melt Source	Melt Country
Nucor Cold Finish	USA	Nucor Bar NE	USA

Heat Analysis per Material Supplier:

%C	%MN	%P	%S	%SI	%CR	%NI	%MO
0.400%	0.950%	0.006%	0.022%	0.310%	0.950%	0.08%	0.190%

Heat Treatment Process:
Harden @ 1550 F for 2.5 Hrs.
Temper @ 1175 F for 2.5 Hrs.

Test #1	Test #2	Test #3
Proof Load	Hardness	
Results	**Results**	**Results**
Pass	Pass	

We certify that this data is a true representation of information provided by our material supplier and testing laboratory and that these fasteners were manufactured, sampled, tested and inspected in accordance with the specifications listed.

These fasteners were manufactured and tested in the USA, from steel which was melted and manufactured in the USA.

Paul Doherty
Wecall Inc.

25-Sep-17

Figure A-20. 1-in. Dia. Heavy Hex Coupling Nut, Test Nos. N2B-1 through N2B-6

NUCOR
FASTENER DIVISION

LOT NO.
3711238

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

CUSTOMER NO/NAME
8001 FASTENAL COMPANY-KS — NUCOR ORDER # 978943
TEST REPORT SERIAL# FB488556 — CUST PART # 38210
TEST REPORT ISSUE DATE 3/04/16
DATE SHIPPED 8/17/16 — CUSTOMER P.O. # 210117217
NAME OF LAB SAMPLER: SANDRA NEUMANN-PLUMMER, LAB TECHNICIAN

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

NUCOR PART NO	QUANTITY	LOT NO.	DESCRIPTION
175647	3600	3711238	1-8 GR DH HV H.D.G. HEX NUT H.D.G./GREEN LUBE

MANUFACTURE DATE 1/07/16

--CHEMISTRY MATERIAL GRADE -1045L
**CHEMISTRY COMPOSITION (WT% HEAT ANALYSIS) BY MATERIAL SUPPLIER — NUCOR STEEL - SOUTH CAROL

MATERIAL NUMBER	HEAT NUMBER	C	MN	P	S	SI
RM030412	DL15105591	.44	.64	.005	.020	.20

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

SURFACE HARDNESS (R30N)	CORE HARDNESS (RC)	PROOF LOAD 90900 LBS	TENSILE STRENGTH (LBS)	DEG-WEDGE STRESS (PSI)
N/A	26.6	PASS	N/A	N/A
N/A	27.0	PASS	N/A	N/A
N/A	27.6	PASS	N/A	N/A
N/A	28.9	PASS	N/A	N/A
N/A	26.7	PASS	N/A	N/A

AVERAGE VALUES FROM TESTS
27.4
PRODUCTION LOT SIZE 90800 PCS

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

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

1. 0.00294 2. 0.00311 3. 0.00346 4. 0.00235 5. 0.00218 6. 0.00270 7. 0.00353
8. 0.00322 9. 0.00406 10. 0.00269 11. 0.00275 12. 0.00315 13. 0.00487 14. 0.00253
15. 0.00416

AVERAGE THICKNESS FROM 15 TESTS .00318
HEAT TREATMENT - AUSTENITIZED, OIL QUENCHED & TEMPERED (MIN 800 DEG F)

--DIMENSIONS PER ASME B18.2.6-2010

CHARACTERISTIC	#SAMPLES TESTED	MINIMUM	MAXIMUM
Width Across Corners	8	1.824	1.844
Thickness	32	0.980	1.001

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

ACCREDITED

MECHANICAL FASTENER
CERTIFICATE NO. A2LA 0139.01
EXPIRATION DATE 12/31/17

NUCOR FASTENER
A DIVISION OF NUCOR CORPORATION

John W. Ferguson
JOHN W. FERGUSON
QUALITY ASSURANCE SUPERVISOR

Page 1 of 1

Figure A-21. 1-in. Dia. Heavy Hex Nut, Test Nos. N2B-1 through N2B-6

Vulcan THREADED PRODUCTS, INC.

Vulcan Threaded Products
10 Cross Creek Trail
Pelham, AL 35124
Tel (205) 620-5100
Fax (205) 620-5150

JOB MATERIAL CERTIFICATION

Job No: 522717 **Job Information** **Certified Date:** 3/29/17

Containers: S12299838 S12299871 S12299878

Customer: Conklin and Conklin **Ship To:** 34201 Seventh Street Union City, CA 94587

Vulcan Part No: BAR B7 .9144x144

Customer Part No: RAWSTEEL-.910-B

Customer PO No: 018032 **Shipped Qty:** 7486 lbs

Order No: 312995 **Line No:** 1

Note:

Applicable Specifications

Type	Specification	Rev	Amend	Option
-	ASTM F1554 Gd 105 S4	2015		
Heat Treat	ASME SA-193/SA-193M B7	2013		
	ASTM A193 B7	2016		

Test Results

See following pages for tests

Certified Chemical Analysis

Heat No: A164782 Lot: .9688 Origin: USA

C	Mn	P	S	Si	Cr	Mo	Ni	V	Cu	Al
0.420	0.87	0.010	0.012	0.25	1.01	0.21	0.13	0.004	0.21	0.038
Cb	**Sn**	**Ti**	**N**	**B**	**Ca**	**As**	**Sb**	**H, ppm**	**DI**	**RR**
0.001	0.009	0.001	0.0089	0.0003	0.0005	0.005	0.004	1.2	5.90	196.9:1
G.S.	**Macro S**	**Macro R**	**Macro C**	**J1**	**J2**	**J3**	**J4**	**J5**	**J6**	**J7**
7	1	1	2	57	57	57	57	57	57	57
J8	**J9**	**J10**	**J12**	**J14**	**J16**	**J18**	**J20**	**J24**	**J28**	**J32**
57	57	55	51	51	49	48	47	46	44	41

Notes

Material was manufactured, tested and inspected in accordance with Vulcan Threaded Products Inc. Quality Assurance Program and Manual Rev. A, dated 8/23/11. Processed material is Quenched and Tempered - Stress Free. No weld repair performed on the material. No Mercury used in the production of this material. Melted and Manufactured in the USA.
Document is in accordance with EN 10204 - 3.1B of 2004 (3.1).

Plex 3/29/17 1:26 PM vulc.mgri Page 1 of 2

19572 1" B7/6105 ATR

PORTLAND BOLT
PO 31961
INV 73947
100 1" X 144" B7 ATR, BLK 1OF2
AUGUST 21, 2017

APR 25 2017

Figure A-22. 1-in. Dia. 24-in. Long Threaded Rod, Test Nos. N2B-1 through N2B-6

STAMPING THE FUTURE

WROUGHT WASHER MFG., INC.

September 6, 2017

Certification of Compliance

003280
FASTENAL COMPANY PURCHASING
P.O. BOX 978
WINONA, MN 55987

Wrought Washer Ordr/Lot Number
304915

HT ORDER 303714

Heat Number	**C**	**Mn**	**P**	**S**	**Si**
276190	0.330	0.840	0.008	0.005	0.243

(Chemical Analysis)

Purchase Order Number	**Part Description**	**Date Shipped**	**Quantity Shipped**
110246277	1" F436 S MARK HDG 0156034	09/06/2017	2,100

We hereby certify that the subject parts conform to the requirements of the applicable specification indicated for the subject parts and are in complete conformance to F436-11. We hereby certify that the subject parts were hardened to RC 26-45. We hereby certify that the subject parts were hot dip galvanized in accordance with specification ASTM A153 CLASS D and ASTM F2329.

We hereby certify that all statutory requirements as to American Production and Labor Standards and all conditions of purchase applicable to the transaction have been complied with and that the subject parts were melted and manufactured in the U.S.A. No weld repairs were made to the material.

Truly yours,
Wrought Washer Mfg., Inc.

Paul Schaefer
Q.C. Manager

Sworn and subscribed before me on September 6, 2017
My commission expires April 24, 2021

SUSAN M. DAOUST NOTARY PUBLIC STATE OF WISCONSIN

(032) SMARK, HT, HDG, F436
WW INTERNAL USE : 64814602/008/017315/59500

1901 CHICORY RD. • MOUNT PLEASANT, WI 53403 • PHONE (262) 554-9550 • FAX (262) 554-9584
VISIT OUR WEBSITE: www.wroughtwasher.com

Figure A-23. 1-in. Dia. Hardened Flat Washer, Test Nos. N2B-1 through N2B-6

STAMPING THE FUTURE

WROUGHT WASHER MFG., INC.

August 30, 2017

Certification of Compliance

003280
FASTENAL COMPANY PURCHASING
P.O. BOX 978
WINONA, MN 55987

Wrought Washer Ordr/Lot Number
304151

HT ORDER 302984

Heat Number		**Chemical Analysis**			
	C	**Mn**	**P**	**S**	**Si**
274703	0.340	0.830	0.008	0.002	0.227

Purchase Order Number	**Part Description**	**Date Shipped**	**Quantity Shipped**
110246277	7/8 F436 S MARK HDG 0156031	08/30/2017	11,000

We hereby certify that the subject parts conform to the requirements of the applicable specification indicated for the subject parts and are in complete conformance to F436-11. We hereby certify that the subject parts were hardened to RC 26-45. We hereby certify that the subject parts were hot dip galvanized in accordance with specification ASTM A153 CLASS D and ASTM F2329.

We hereby certify that all statutory requirements as to American Production and Labor Standards and all conditions of purchase applicable to the transaction have been complied with and that the subject parts were melted and manufactured in the U.S.A. No weld repairs were made to the material.

Truly yours,
Wrought Washer Mfg., Inc.

Paul Schaefer
Q.C. Manager

Sworn and subscribed before me on August 30, 2017
My commission expires April 24, 2021

SUSAN M. DAOUST NOTARY PUBLIC STATE OF WISCONSIN

(032) SMARK, HT, HDG, F436
WW INTERNAL USE : 64814601/007/017305/59091

1901 CHICORY RD. • MOUNT PLEASANT, WI 53403 • PHONE (262) 554-9550 • FAX (262) 554-9584
VISIT OUR WEBSITE: www.wroughtwasher.com

Figure A-24. ⅞-in. Dia. Hardened Flat Washer, Test Nos. N2B-1 through N2B-6

STAMPING THE FUTURE

WROUGHT WASHER MFG., INC.

July 12, 2017

Certification of Compliance

003280
FASTENAL COMPANY PURCHASING
P.O. BOX 978
WINONA, MN 55987

Wrought Washer Ordr/Lot Number
303708

HT ORDER 302794

Heat Number	Chemical Analysis C	Mn	P	S	Si
273699	0.520	0.650	0.009	0.002	0.026

Purchase Order Number	Part Description	Date Shipped	Quantity Shipped
110242728	3/4 F436 S MARK HDG 0156028 PO 110242728	07/11/2017	10,200

We hereby certify that the subject parts conform to the requirements of the applicable specification indicated for the subject parts and are in complete conformance to F436-11. We hereby certify that the subject parts were hardened to RC 26-45. We hereby certify that the subject parts were hot dip galvanized in accordance with specification ASTM A153 CLASS D and ASTM F2329.

We hereby certify that all statutory requirements as to American Production and Labor Standards and all conditions of purchase applicable to the transaction have been complied with and that the subject parts were melted and manufactured in the U.S.A. No weld repairs were made to the material.

Truly yours,
Wrought Washer Mfg., Inc.

Paul H. Schaefer

Susan M. Daoust

Paul Schaefer
Q.C. Manager

Sworn and subscribed before me on July 12, 2017
My commission expires April 24, 2021

SUSAN M. DAOUST NOTARY PUBLIC STATE OF WISCONSIN

(032) SMARK, HT, HDG, F436
WW INTERNAL USE : 64693002/004/017295/59089

1901 CHICORY RD. • MOUNT PLEASANT, WI 53403 • PHONE (262) 554-9550 • FAX (262) 554-9584
VISIT OUR WEBSITE: www.wroughtwasher.com

Figure A-25. ¾-in. Dia. Hardened Flat Washer, Test Nos. N2B-1 through N2B-6

GERDAU

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

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
NEBCO INC STEEL DIVISION HAVELOCK,NE 68529 USA	CONCRETE INDUSTRIES INC LINCOLN,NE 68529-0529 USA	60 (420)	Rebar / #4 (13MM)	0000000000

LENGTH	WEIGHT	HEAT / BATCH
60'00"	60,120 LB	58028860/02

SALES ORDER	CUSTOMER MATERIAL Nº	SPECIFICATION / DATE or REVISION
4767685/000010		ASTM A615/A615M-15 E1

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
123815	1327-0000228798	03/16/2017

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.43	0.89	0.013	0.040	0.21	0.27	0.10	0.13	0.018	0.006	0.019	0.011	0.003

CHEMICAL COMPOSITION

CEqyA706 %
0.60

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
68350	471	108860	751	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
14.20	OK

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

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

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

Figure A-26. No. 4 Rebar Mill Certification, Test Nos. N2B-1 through N2B-6

EVRAZ ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

2100 S. Freeway
Pueblo, CO 81004 USA

MATERIAL TEST REPORT

Date Printed: 09–SEP–16

Date Shipped: 09–SEP–16

Product: BAR #3 (3/8")

Specification: ASTM A706/A615 Gr 60

FWIP: 52815366

Customer: CONCRETE INDUSTRIES INC
P O BOX 29529
LINCOLN, NE 68529

Cust. PO: 121420

CHEMICAL ANALYSIS (In Weight %, uncertainty of measurement 0.005%) (Heat cast 07/25/16)

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ti
587796	0.28	1.22	0.014	0.023	0.21	0.25	0.09	0.21	0.019	0.003	0.037	0.0003	0.000	0.010	0.0089	0.001

Carbon Equivalent = 0.511

MECHANICAL PROPERTIES (Tensiles test date 08/26/16)

Heat Number	Sample No.		Yield (Psi)	Ultimate (Psi)	Elongation (%)	Reduction (%)	Bend	Wt/ft
587796	01		68469	103770	15.2		OK	0.363
		(MPa)	472.1	715.5				
587796	02		68592	101150	14.2		OK	0.365
		(MPa)	472.9	697.4				

All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.

ERMS also certifies this material to be free from Mercury contamination.

This material has been produced, tested and conforms to the requirements of the applicable specifications. We hereby certify that the above test results represent those contained in the records of the Company.

Valoree Varick
General Supervisor of Quality

Figure A-27. No. 3 Rebar Mill Certification, Test Nos. N2B-1 through N2B-6

SOLD TO: ADELPHIA METALS I LLC
411 MAIN ST E
NEW PRAGUE, MN 56071-

NUCOR
NUCOR STEEL KANKAKEE, INC.

CERTIFIED MILL TEST REPORT

Page: 2

SHIP TO: ADELPHIA METALS - TRK
411 MAIN STREET EAST
NEW PRAGUE, MN 56071-

Ship from:
MTR #: 0000024491
Nucor Steel Kankakee, Inc.
One Nucor Way
Bourbonnais, IL 60914
815-937-3131

Date: 25-Jul-2014
B.L. Number: 484645
Load Number: 251220

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					CHEMICAL TESTS						
		YIELD P.S.I.	TENSILE P.S.I.	ELONG % IN 8"	BEND	WT% / DEF	C / Ni	Mn / Cr	P / Mo	S / V	Si / Cb	Cu / Sn	C.E.
PO# =>	811627												
KN1410445301	Nucor Steel - Kankakee Inc	67,451	97,059	14.6%	OK	-3.9%	.26	1.20	.020	.036	.22	.36	.50
KN14104453	16/#5 Rebar	465MPa	669MPa			.044	.20	.27	.069	.044	.001		
	40' A706M(A706) WELDABLE												
	ASTM A706/A706M-09b GR60 [420] A												
	ASHTO M322												
	TEN/YD = 1.44												
	Melted 07/22/14 Rolled 07/24/14												

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 A-28. No. 8 Rebar Mill Certification, Test Nos. N2B-1 through N2B-6

GERDAU

US-ML-BEAUMONT
100 OLD HIGHWAY 90 WEST
VIDOR, TX 77662
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
CONCRETE INDUSTRIES INC 6300 CORNHUSKER HWY LINCOLN,NE 68507-3112 USA	CONCRETE INDUSTRIES INC LINCOLN,NE 68529-0529 USA	60/A706-60	Rebar / #4 (13MM)	0000000000

LENGTH	WEIGHT	HEAT / BATCH
0	47,498 LB	53145629/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
5290798/000010		ASTM A615/A615M-15 E1 ASTM A706/A706M-15

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
126067	4785-0000000192	06/30/2017

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.27	1.11	0.022	0.010	0.21	0.31	0.12	0.22	0.043	0.012	0.047	0.49

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	Elong. %
67685	467	101935	703	8.000	14.20

MECHANICAL PROPERTIES

BendTest	T/Y
OK	1.51

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
-1.30	0.023	0.100	0.323

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

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

LEONARDO RADICCHI
QUALITY ASSURANCE MGR.
Phone: 409-769-1086 Email: Leonardo.Cunha@gerdau.com

Figure A-29. No. 4 Rebar Mill Certification, Test Nos. N2B-1 through N2B-6

Appendix B. Bogie Test Results

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	
Test Description:	S3x5.7 post in steel sleeve
Test Number:	n2b-1
Test Date:	1/4/2018
Failure Type:	Post and tube yield

Post Properties	
Post Type:	Steel
Post Size:	S3x5.7 Post
Post Length:	39 in.
Embedment Depth:	6.625 in.
Orientation:	Strong

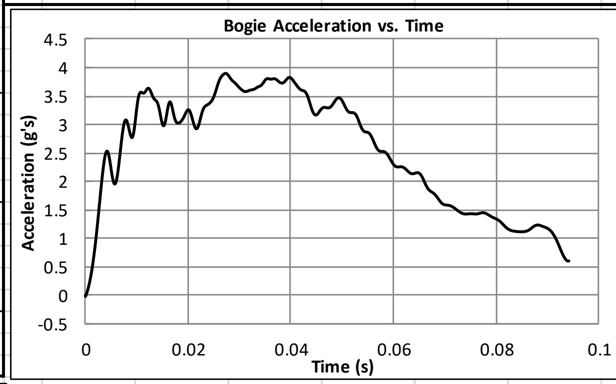
Soil Properties	
Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

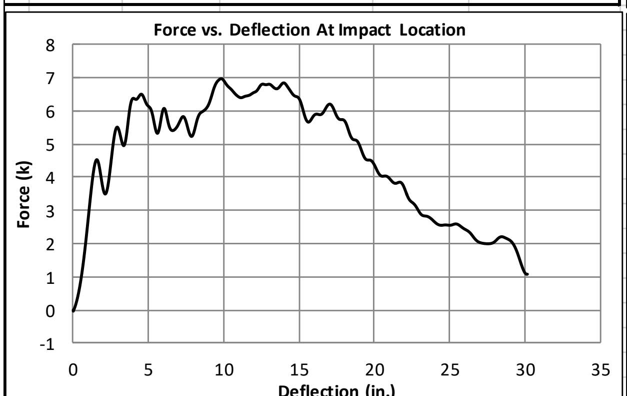
Bogie Properties		
Impact Velocity:	21.17 mph	(31.06 ft/s)
Impact Height:	25 in.	
Bogie Mass:	1786 lb	

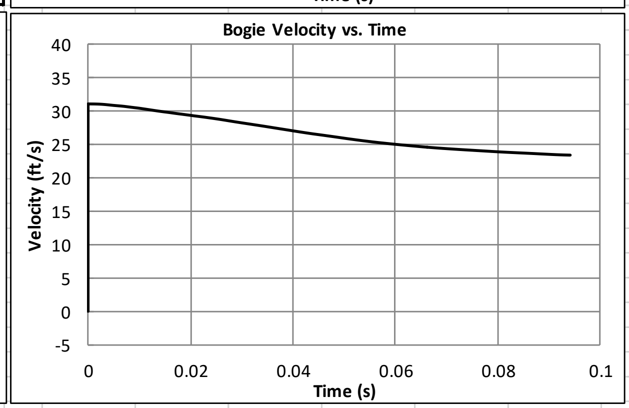
Data Acquired	
Accelerometer:	SLICE1
Camera Data:	AOS2, gp15, gp16, gp18

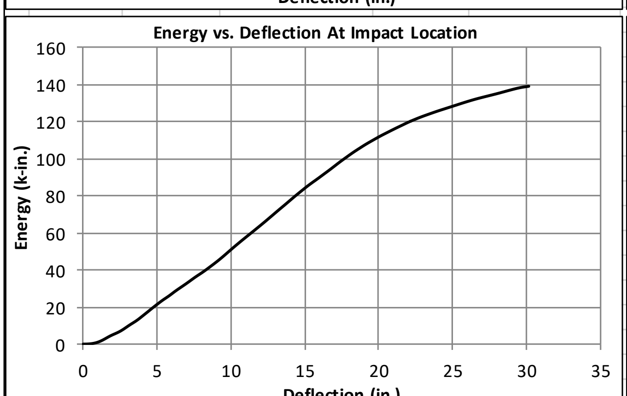
Test Results Summary		
Event Duration:	0.0942	sec
Max. Deflection:	30.2	in.
Peak Force:	7.0	k
Initial Linear Stiffness:	0.7	k/in.
Total Energy:	139.0	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	4.24	5.08	5.60	5.58
Energy (k-in.)	21.2	50.8	83.9	111.6









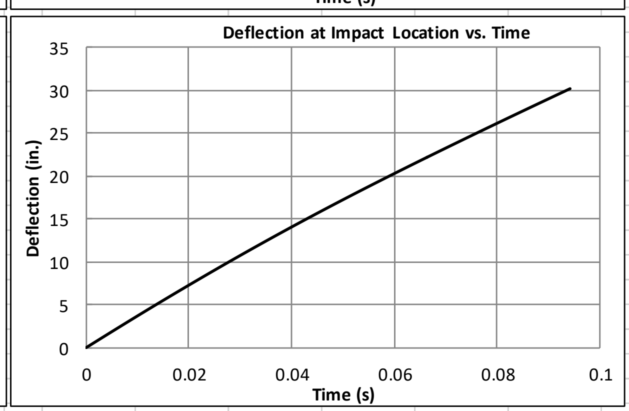


Figure B-1. Test No. N2B-1 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	
Test Description:	S3x5.7 post in steel sleeve
Test Number:	n2b-1
Test Date:	1/4/2018
Failure Type:	Post and tube yield

Post Properties	
Post Type:	Steel
Post Size:	S3x5.7 Post
Post Length:	39 in.
Embedment Depth:	6.625 in.
Orientation:	Strong

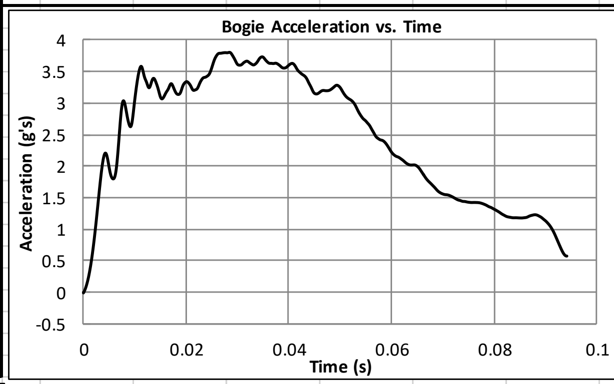
Soil Properties	
Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

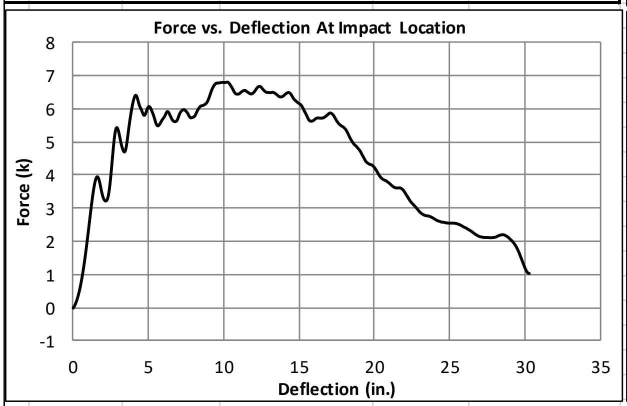
Bogie Properties		
Impact Velocity:	21.17 mph	(31.06 ft/s)
Impact Height:	25 in.	
Bogie Mass:	1786 lb	

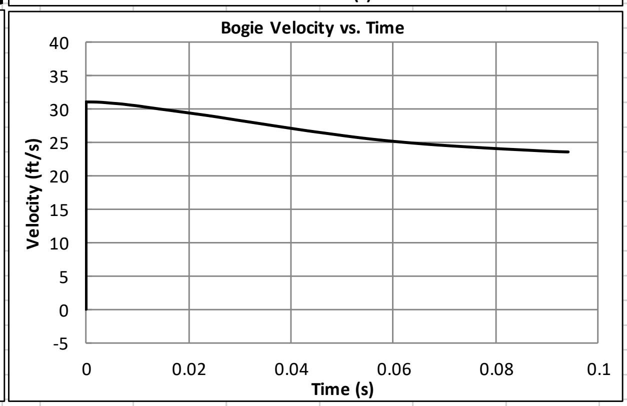
Data Acquired	
Accelerometer:	SLICE2
Camera Data:	AOS2, gp15, gp16, gp18

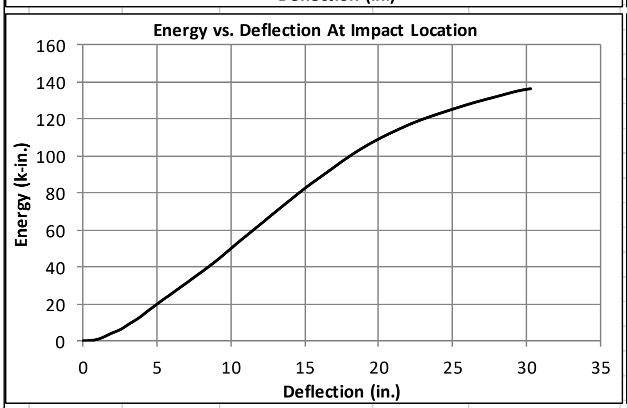
Test Results Summary		
Event Duration:	0.0942	sec
Max. Deflection:	30.3	in.
Peak Force:	6.8	k
Initial Linear Stiffness:	0.7	k/in.
Total Energy:	136.1	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	3.93	4.96	5.48	5.44
Energy (k-in.)	19.6	49.6	82.2	108.9









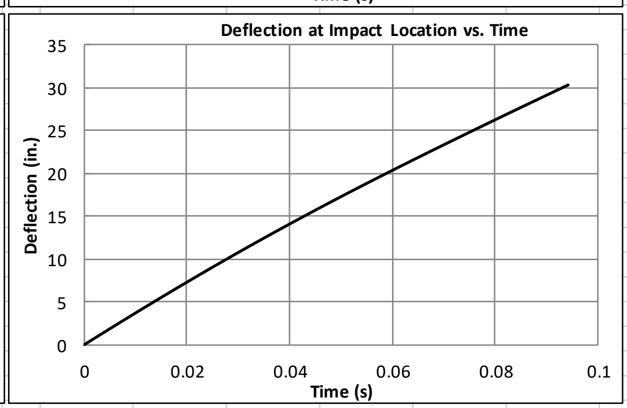


Figure B-2. Test No. N2B-1 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	
Test Description:	S3x5.7 post in steel sleeve
Test Number:	n2b-2
Test Date:	1/4/2018
Failure Type:	Post and tube yield

Post Properties	
Post Type:	Steel
Post Size:	S3x5.7
Post Length:	44 in.
Embedment Depth:	11.625 in.
Orientation:	Strong

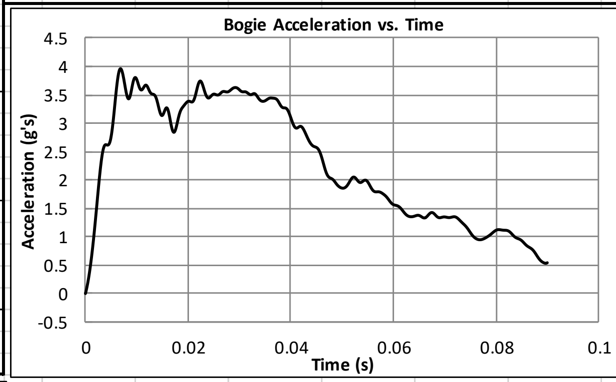
Soil Properties	
Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

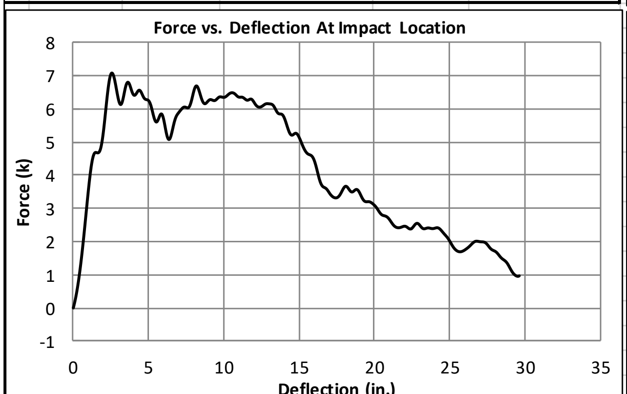
Bogie Properties		
Impact Velocity:	21.44 mph	(31.45 ft/s)
Impact Height:	25 in.	
Bogie Mass:	1786 lb	

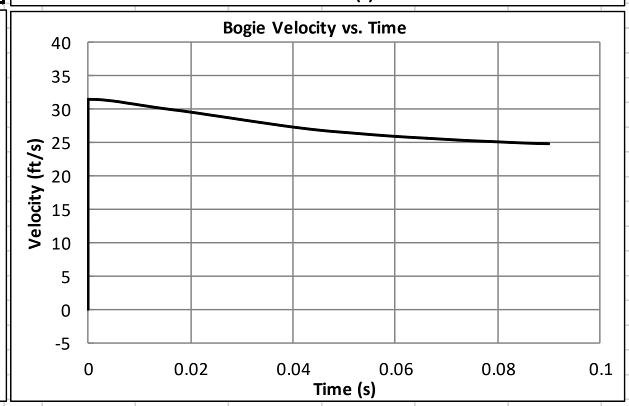
Data Acquired	
Accelerometer:	SLICE1
Camera Data:	gp16, gp17, gp18

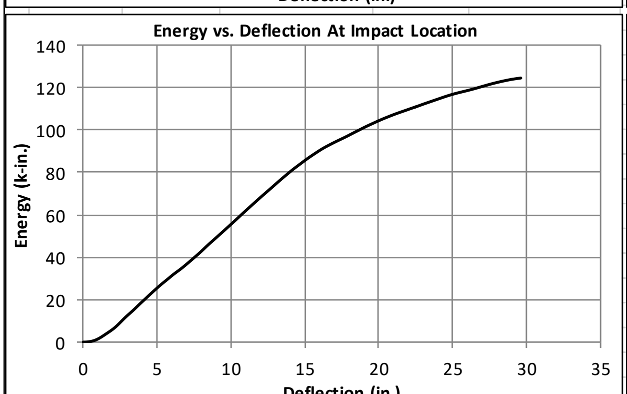
Test Results Summary		
Event Duration:	0.0900	sec
Max. Deflection:	29.6	in.
Peak Force:	7.1	k
Initial Linear Stiffness:	2.8	k/in.
Total Energy:	124.5	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	5.07	5.55	5.70	5.22
Energy (k-in.)	25.3	55.5	85.5	104.4









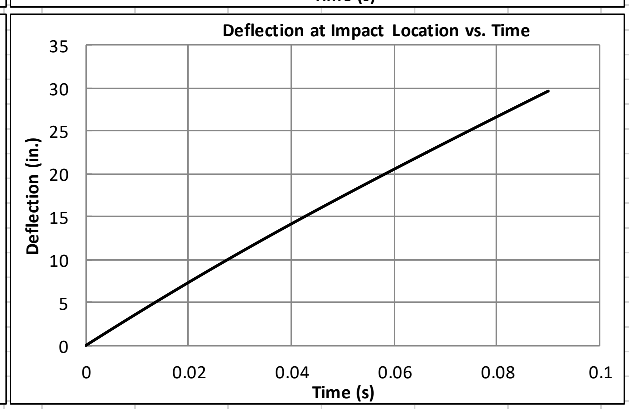


Figure B-3. Test no. N2B-2 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	S3x5.7 post in steel sleeve
Test Number:	n2b-2
Test Date:	1/4/2018
Failure Type:	Post and tube yield

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	44 in.
Embedment Depth:	11.625 in.
Orientation:	Strong

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	21.44 mph	(31.45 ft/s)
Impact Height:	25 in.	
Bogie Mass:	1786 lb	

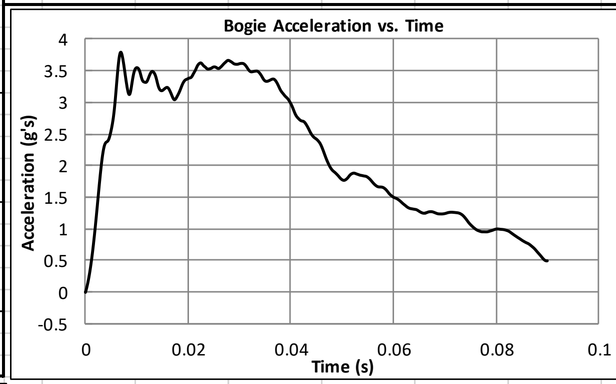
Data Acquired

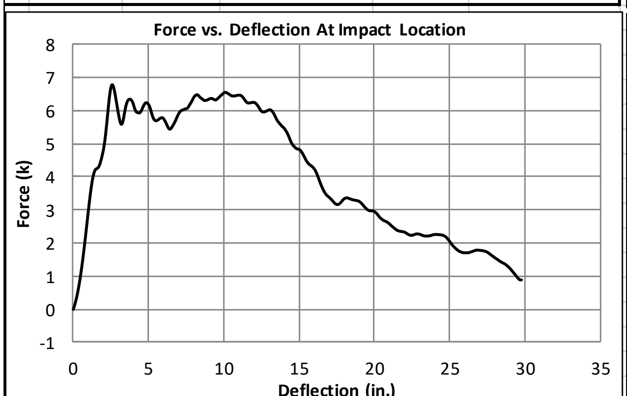
Accelerometer:	SLICE2
Camera Data:	gp16, gp17, gp18

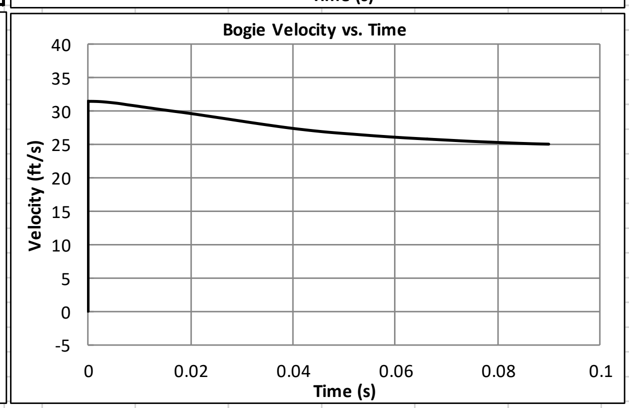
Test Results Summary

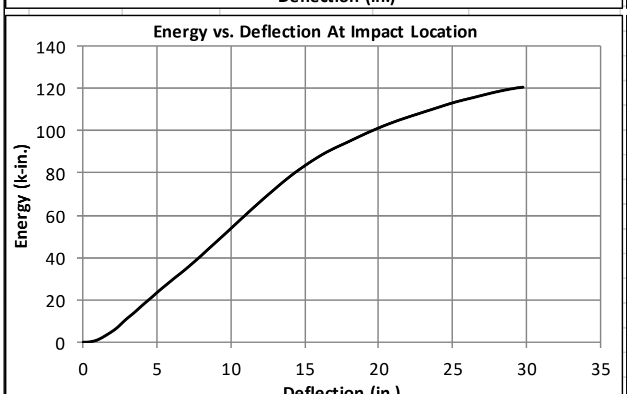
Event Duration:	0.0900	sec
Max. Deflection:	29.8	in.
Peak Force:	6.8	k
Initial Linear Stiffness:	2.6	k/in.
Total Energy:	120.6	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	4.68	5.37	5.56	5.07
Energy (k-in.)	23.4	53.7	83.3	101.3









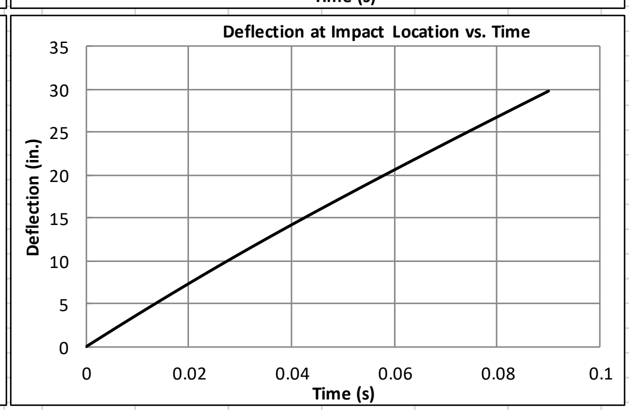


Figure B-4. Test No. N2B-2 Results (SLICE-2)

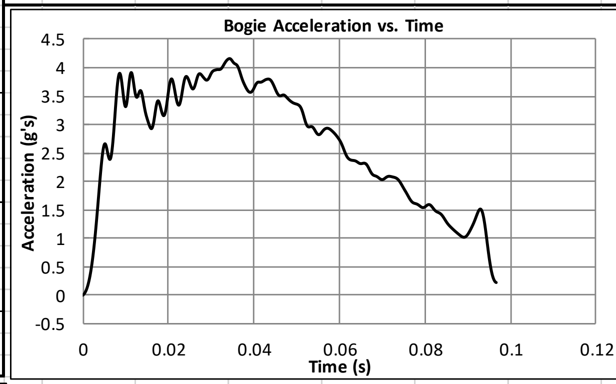
MIDWEST ROADSIDE SAFETY FACILITY

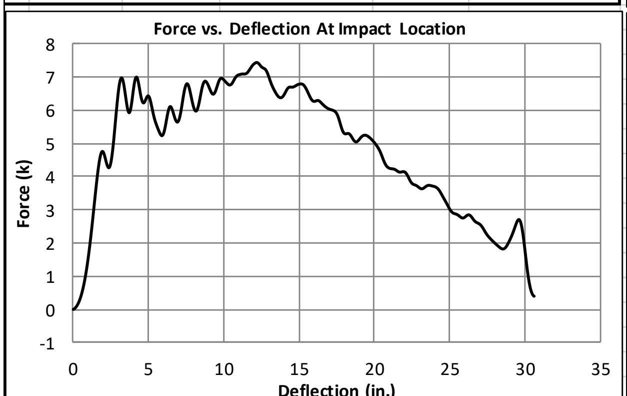
Bogie Test Summary

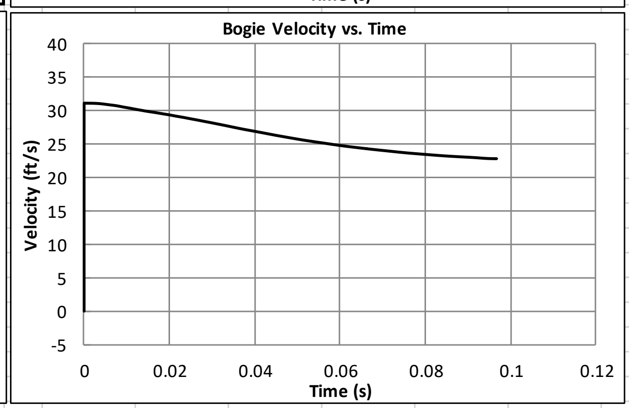
Test Information	
Test Description:	S3x5.7 post in steel sleeve
Test Number:	n2b-3
Test Date:	1/4/2018
Failure Type:	Post and tube yield
Post Properties	
Post Type:	Steel
Post Size:	S3x5.7
Post Length:	39 in.
Embedment Depth:	6.625
Orientation:	Strong
Soil Properties	
Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA
Bogie Properties	
Impact Velocity:	21.2 mph (31.09 ft/s)
Impact Height:	25 in.
Bogie Mass:	1786 lb
Data Acquired	
Accelerometer:	SLICE1
Camera Data:	AOS2, gp15, gp16, gp18

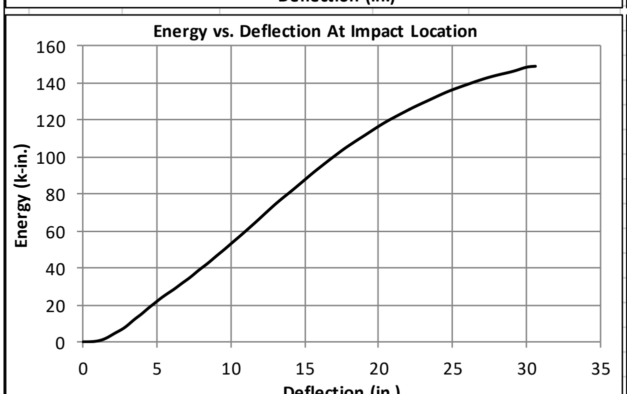
Test Results Summary		
Event Duration:	0.0967	sec
Max. Deflection:	30.6	in.
Peak Force:	7.4	k
Initial Linear Stiffness:	0.6	k/in.
Total Energy:	148.9	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	4.35	5.29	5.82	5.82
Energy (k-in.)	21.8	52.9	87.3	116.3









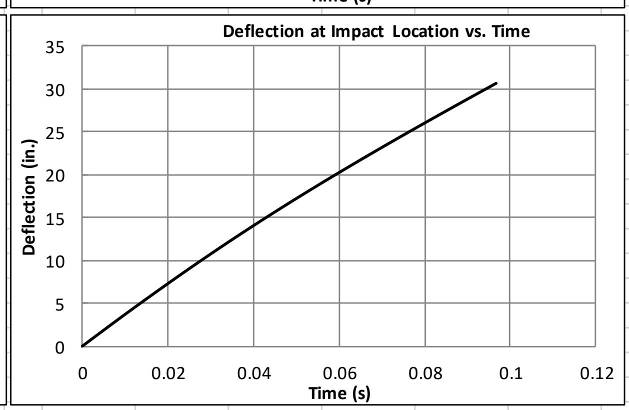


Figure B-5. Test No. N2B-3 Results (SLICE-1)

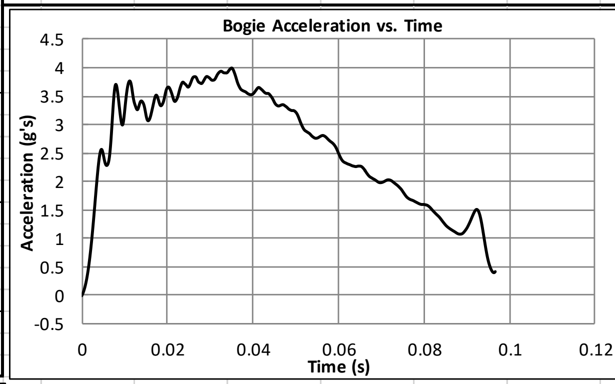
MIDWEST ROADSIDE SAFETY FACILITY

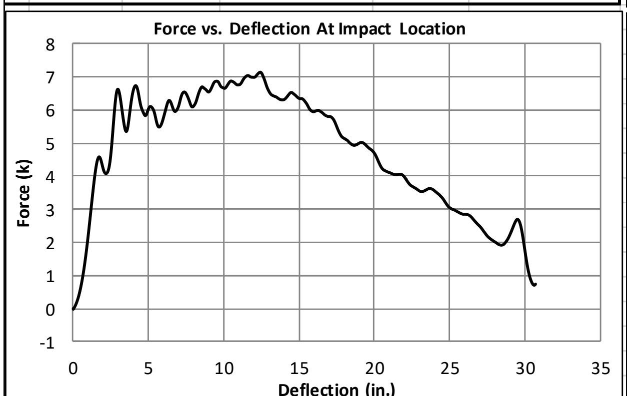
Bogie Test Summary

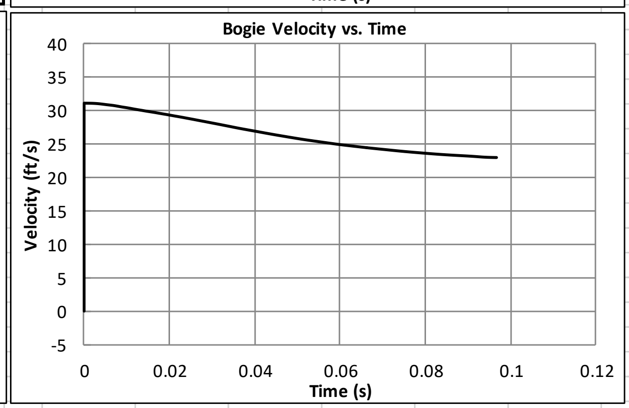
Test Information	
Test Description:	S3x5.7 post in steel sleeve
Test Number:	n2b-3
Test Date:	1/4/2018
Failure Type:	Post and tube yield
Post Properties	
Post Type:	Steel
Post Size:	S3x5.7
Post Length:	39 in.
Embedment Depth:	6.625
Orientation:	Strong
Soil Properties	
Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA
Bogie Properties	
Impact Velocity:	21.2 mph (31.09 ft/s)
Impact Height:	25 in.
Bogie Mass:	1786 lb
Data Acquired	
Accelerometer:	SLICE2
Camera Data:	AOS2, gp15, gp16, gp18

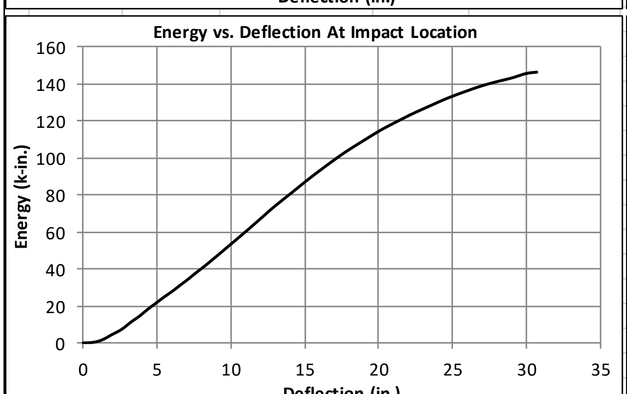
Test Results Summary		
Event Duration:	0.0967	sec
Max. Deflection:	30.7	in.
Peak Force:	7.1	k
Initial Linear Stiffness:	0.6	k/in.
Total Energy:	146.2	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	4.34	5.32	5.79	5.71
Energy (k-in.)	21.7	53.2	86.8	114.2









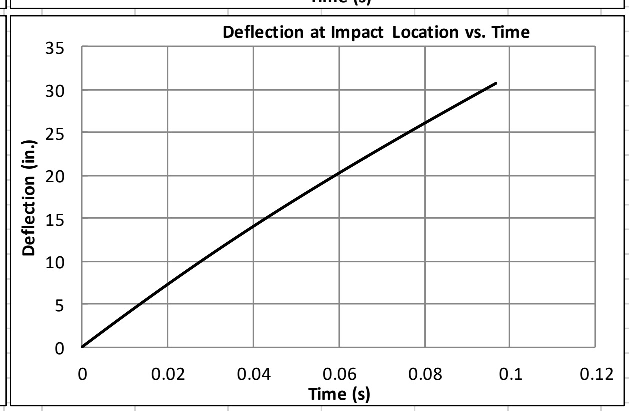


Figure B-6. Test No. N2B-3 Results (SLICE-2)

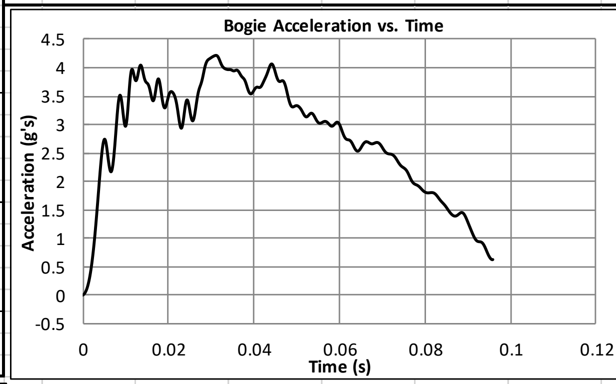
MIDWEST ROADSIDE SAFETY FACILITY

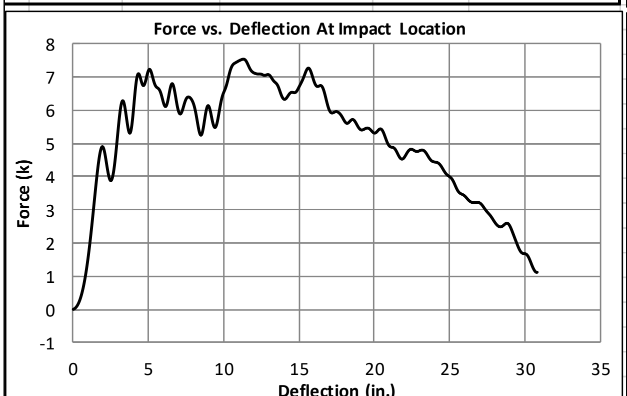
Bogie Test Summary

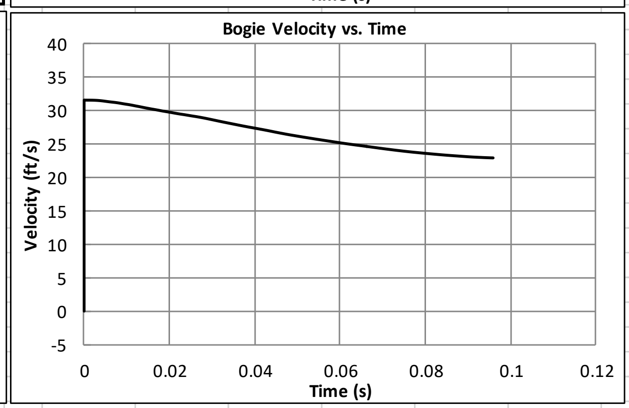
Test Information		
Test Description:	S3x5.7 post in steel sleeve	
Test Number:	n2b-4	
Test Date:	1/5/2018	
Failure Type:	post yield	
Post Properties		
Post Type:	Steel	
Post Size:	S3x5.7	
Post Length:	39 in.	
Embedment Depth:	6.625 in.	
Orientation:	Strong	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Bogie Properties		
Impact Velocity:	21.51 mph	(31.55 ft/s)
Impact Height:	25 in.	
Bogie Mass:	1786 lb	
Data Acquired		
Accelerometer:	SLICE1	
Camera Data:	AOS9, gp16, gp17, gp18	

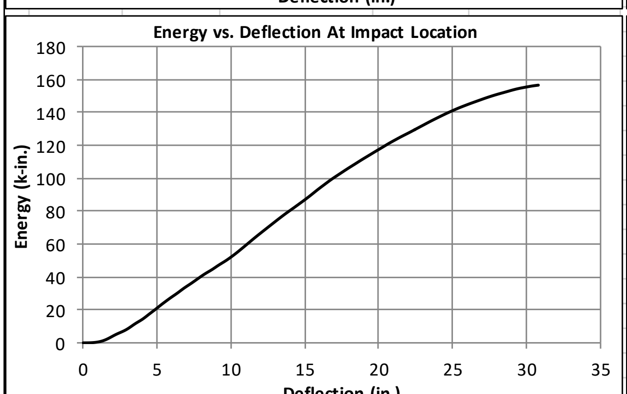
Test Results Summary		
Event Duration:	0.0959	sec
Max. Deflection:	30.8	in.
Peak Force:	7.5	k
Initial Linear Stiffness:	0.7	k/in.
Total Energy:	156.6	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	4.20	5.19	5.79	5.87
Energy (k-in.)	21.0	51.9	86.8	117.3









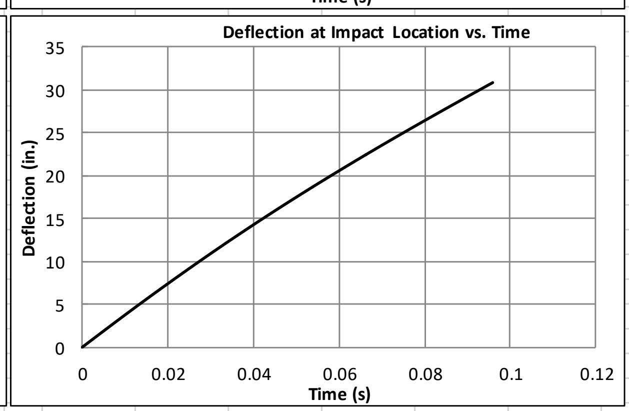


Figure B-7. Test No. N2B-4 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	S3x5.7 post in steel sleeve
Test Number:	n2b-4
Test Date:	1/5/2018
Failure Type:	post yield

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	39 in.
Embedment Depth:	6.625 in.
Orientation:	Strong

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	21.51 mph	(31.55 ft/s)
Impact Height:	25 in.	
Bogie Mass:	1786 lb	

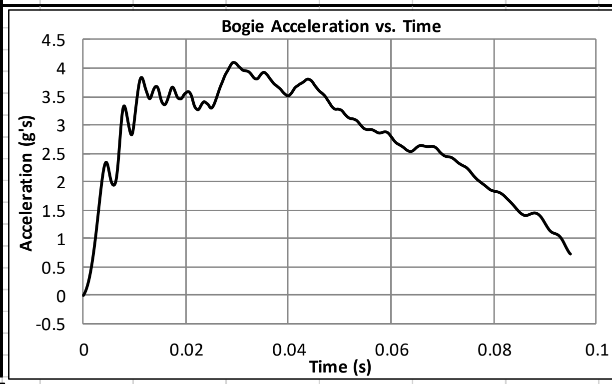
Data Acquired

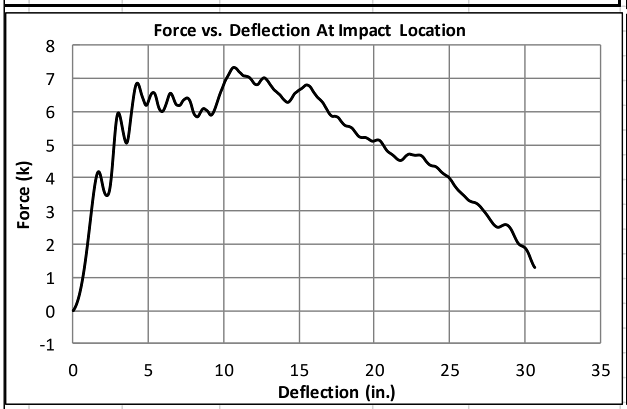
Accelerometer:	SLICE2
Camera Data:	AOS9, gp16, gp17, gp18

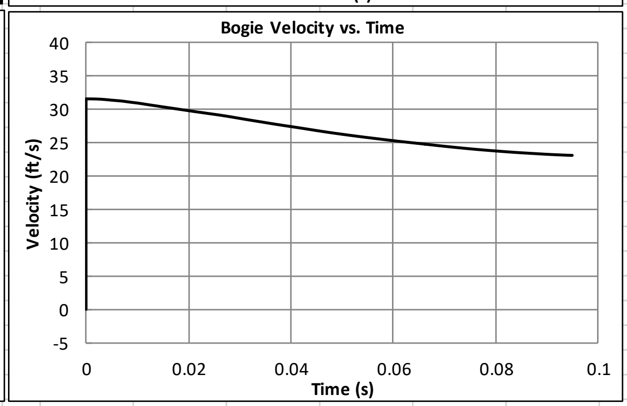
Test Results Summary

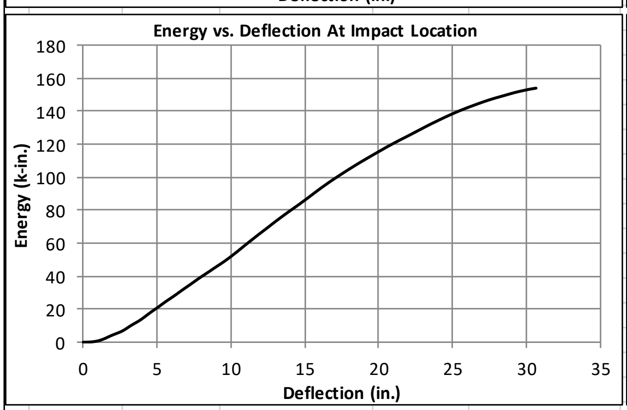
Event Duration:	0.0950	sec
Max. Deflection:	30.7	in.
Peak Force:	7.3	k
Initial Linear Stiffness:	0.7	k/in.
Total Energy:	154.0	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	4.13	5.18	5.73	5.77
Energy (k-in.)	20.7	51.8	86.0	115.5









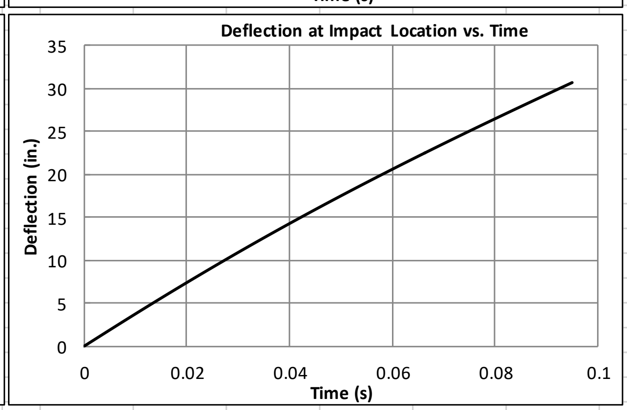


Figure B-8. Test No. N2B-4 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	S3x5.7 post in steel sleeve	
Test Number:	n2b-5	
Test Date:	1/5/2018	
Failure Type:	Post yield	

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	44 in.
Embedment Depth:	11.625
Orientation:	Weak

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	20.19 mph	(29.62 ft/s)
Impact Height:	12 in.	
Bogie Mass:	1690 lb	

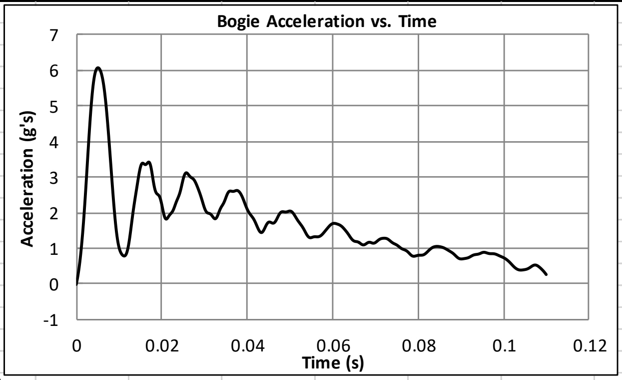
Data Acquired

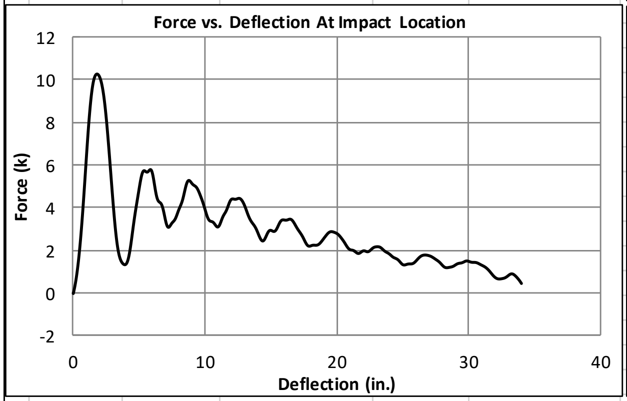
Accelerometer:	SLICE1
Camera Data:	aos9, gp15, gp16, gp17

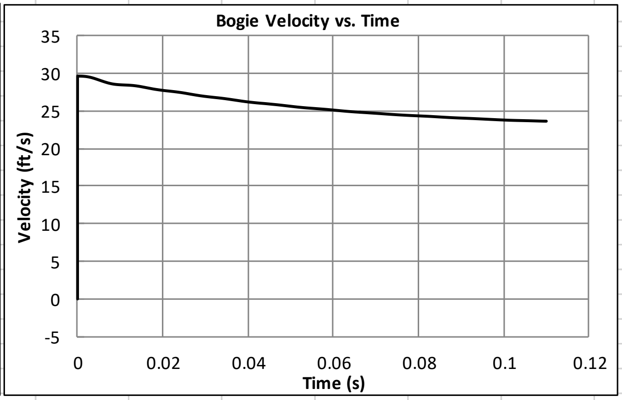
Test Results Summary

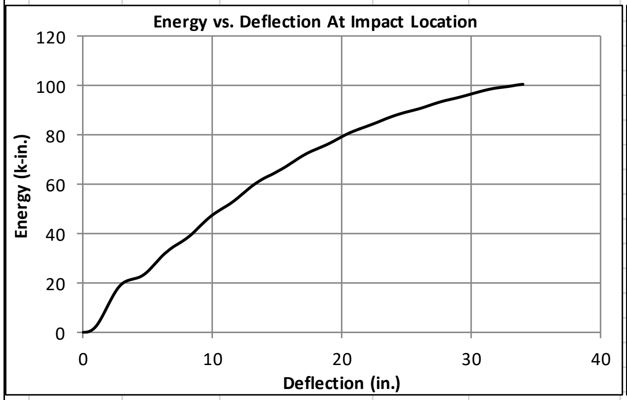
Event Duration:	0.1100	sec
Max. Deflection:	34.0	in.
Peak Force:	10.3	k
Initial Linear Stiffness:	5.7	k/in.
Total Energy:	100.5	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	4.93	4.75	4.34	3.96
Energy (k-in.)	24.7	47.5	65.1	79.2









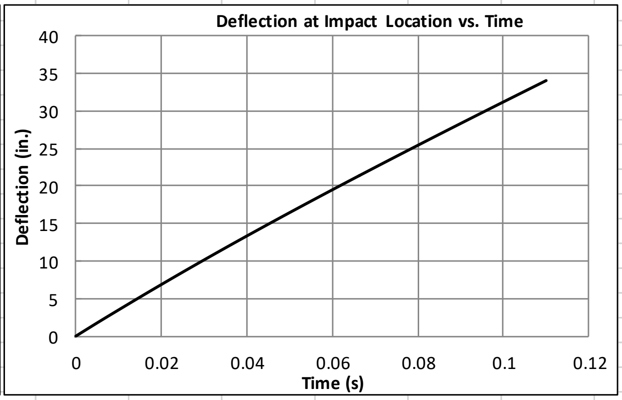


Figure B-9. Test No. N2B-5 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	S3x5.7 post in steel sleeve attached to simulated bri
Test Number:	n2b-5
Test Date:	1/5/2018
Failure Type:	Post yield

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	44 in.
Embedment Depth:	11.625
Orientation:	Weak

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	20.19 mph	(29.62 ft/s)
Impact Height:	12 in.	
Bogie Mass:	1690 lb	

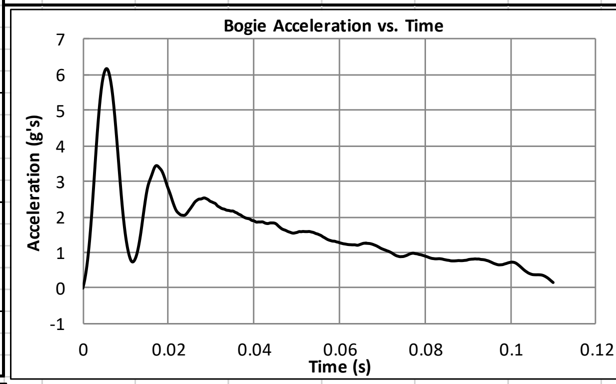
Data Acquired

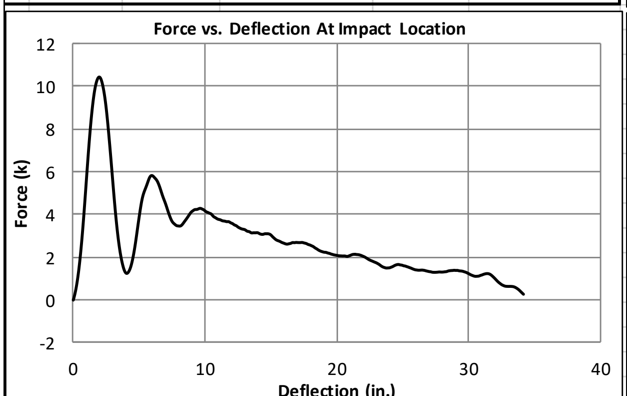
Accelerometer:	SLICE1
Camera Data:	aos9, gp15, gp16, gp17

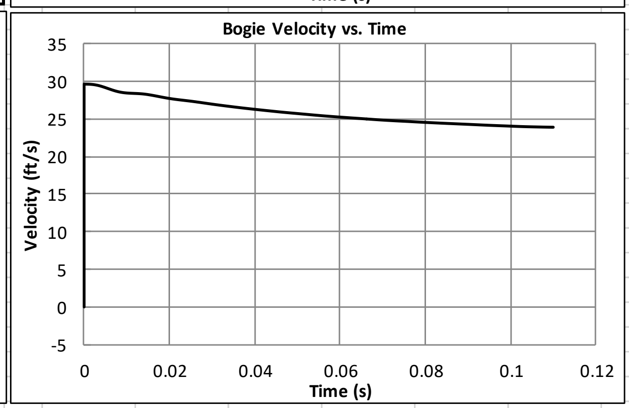
Test Results Summary

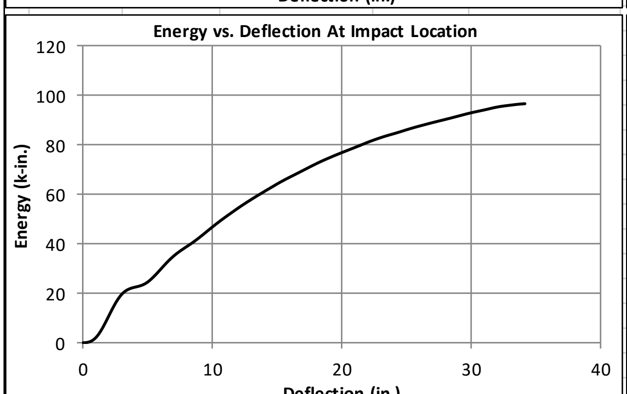
Event Duration:	0.1100	sec
Max. Deflection:	34.2	in.
Peak Force:	10.4	k
Initial Linear Stiffness:	5.3	k/in.
Total Energy:	96.6	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	4.91	4.67	4.27	3.84
Energy (k-in.)	24.5	46.7	64.1	76.8









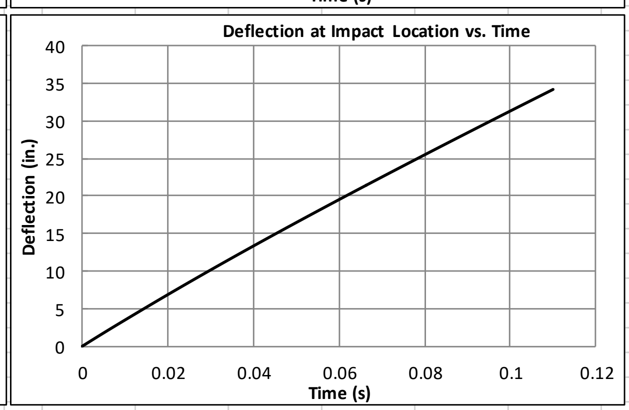


Figure B-10. Test No. N2B-5 Results (SLICE-2)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	S3x5.7 post in steel sleeve
Test Number:	n2b-6
Test Date:	1/8/2018
Failure Type:	Post yield

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	44 in.
Embedment Depth:	11.625
Orientation:	Weak

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	21.58 mph	(31.65 ft/s)
Impact Height:	12 in.	
Bogie Mass:	1690 lb	

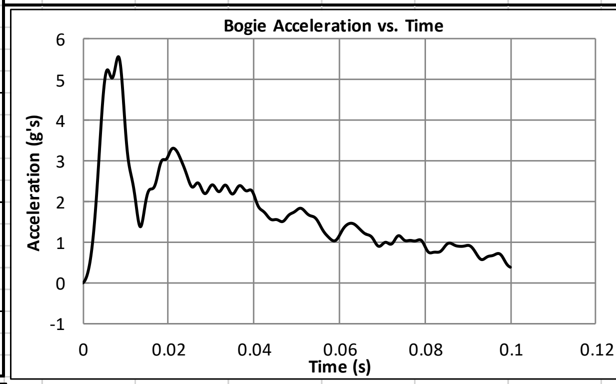
Data Acquired

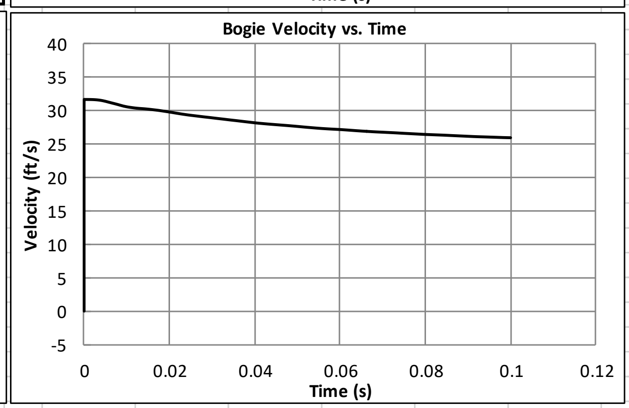
Accelerometer:	SLICE1
Camera Data:	aos9, gp16, gp17

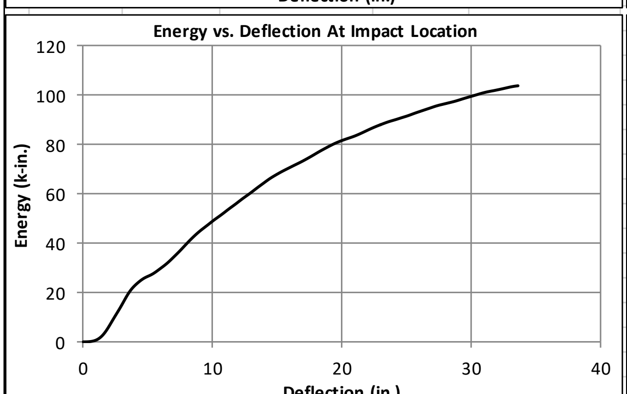
Test Results Summary

Event Duration:	0.1000	sec
Max. Deflection:	33.6	in.
Peak Force:	9.4	k
Initial Linear Stiffness:	3.0	k/in.
Total Energy:	103.7	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	5.30	4.88	4.52	4.08
Energy (k-in.)	26.5	48.8	67.9	81.5







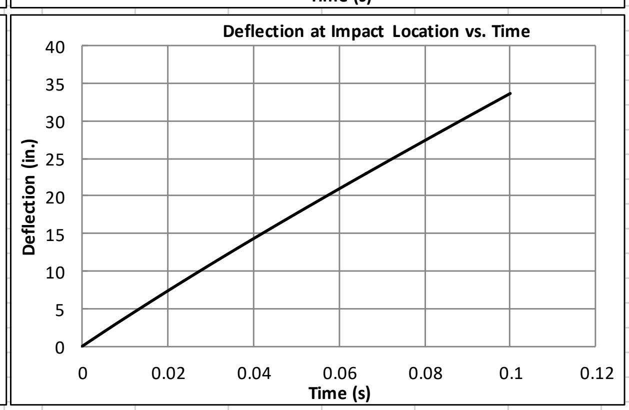


Figure B-11. Test No. N2B-6 Results (SLICE-1)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information

Test Description:	S3x5.7 post in steel sleeve
Test Number:	n2b-6
Test Date:	1/8/2018
Failure Type:	Post yield

Post Properties

Post Type:	Steel
Post Size:	S3x5.7
Post Length:	39 in.
Embedment Depth:	6.625 in.
Orientation:	Weak

Soil Properties

Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA

Bogie Properties

Impact Velocity:	21.58 mph	(31.65 ft/s)
Impact Height:	12 in.	
Bogie Mass:	1690 lb	

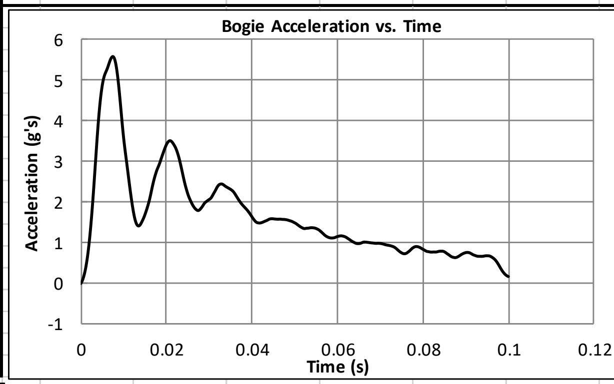
Data Acquired

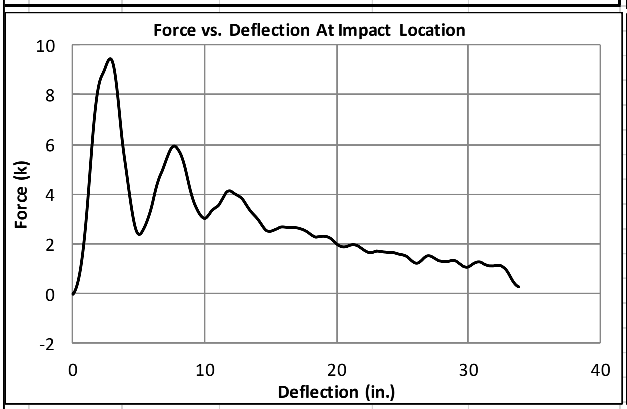
Accelerometer:	SLICE2
Camera Data:	aos9, gp16, gp17

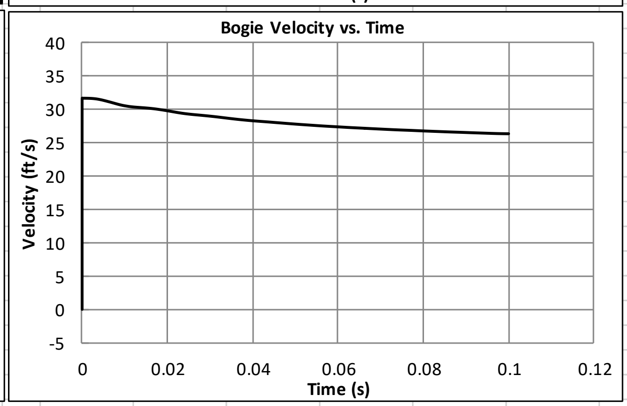
Test Results Summary

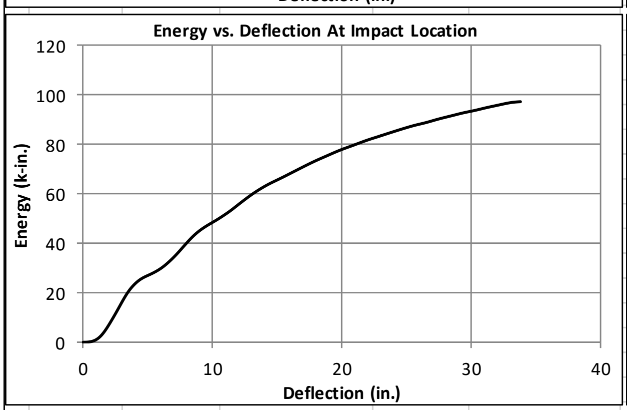
Event Duration:	0.1000	sec
Max. Deflection:	33.8	in.
Peak Force:	9.4	k
Initial Linear Stiffness:	3.3	k/in.
Total Energy:	97.2	k-in.

	@ 5"	@ 10"	@ 15"	@20"
Average Force (k)	5.39	4.83	4.37	3.89
Energy (k-in.)	26.9	48.3	65.5	77.9









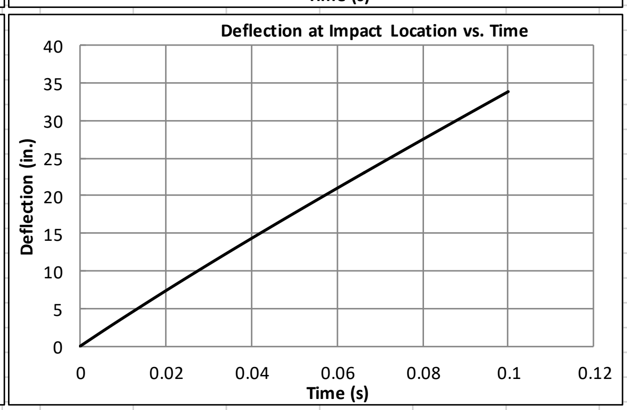


Figure B-12. Test No. N2B-6 Results (SLICE-2)

Appendix C. Full-Scale Test Material Specifications

Table C-1. Bill of Materials, Test No. N2BR-1

Item No.	Description	Material Specification	Reference No.
a1	6'-3" 12-gauge W-Beam MGS Section	AASHTO M180	HTCode#9760 H#31631800
a2	12'-6" 12-gauge W-Beam MGS Section	AASHTO M180	H#9411949
a3	12'-6" 12-gauge W-Beam MGS End Section	AASHTO M180	HTCode#1207 H#C84187
b1	72" Long Foundation Tube	ASTM A500 Gr. B	HTCode#811T08220
b2	BCT Timber Post - MGS Height	SYP Grade No. 1 or better (No knots within 18" of ground on tension face)	Charge#24096
b3	W6x8.5 or W6x9, 72" Long Steel Post	ASTM A992 Gr. 50	H#55048942
b4	6"x12"x14 1/4" Timber Blockout for Steel Posts	SYP Grade No.1 or better	Ch#23888 LIGHT BLUE, White Paint Post#27, Post#25
b5	2 3/4"x1"x1/4" Post Standoff	ASTM A36	H#64055041/02
b6	S3x5.7, 39" Long Steel Post	ASTM A992 Gr. 50	H#59076269/02
c1	10"x7"x1/2" Steel Plate	ASTM A572 Gr. 50	H#A7D898
c2	10"x2 3/4"x1/4" Plate Washer	ASTM A36	H#17126641
c3	HSS4"x4"x3/8", 6 5/8" Long Square Tube	ASTM A500 Gr. B	H#W46930
c4	3 1/2"x1"x1/8"	ASTM A36	H#62213
c5	C7x9.8, 225" Long C-Channel	ASTM A36	H#52080955/02
c6	6 5/8"x2"x1/8" Shim Plate	ASTM A36	H#1164312
d1	#4 Bar, 896 1/2" Long	ASTM A615 Gr. 60	H#5716646
d2	#4 Bar, 32" Long	ASTM A615 Gr. 60	H#57166635
d3	#4 Bar, 16" Long	ASTM A615 Gr. 60	H#17-00688
d4	#4 Bar, 18" Long	ASTM A706 Gr. 60	H#594643
e1	5/8"-11 UNC, 14"] Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	H#100886654
e2	5/8"-11 UNC, 10" Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	H#DL16102715
e3	5/8"-11 UNC, 1 1/4" Long Guardrail Bolt and Nut	Bolt - ASTM A307 Gr. A Nut - ASTM A563A	Bolts: H#20455760 Nuts: 20479830

Table C-2. Bill of Materials, Test No. N2BR-1, Cont.

Item No.	Description	Material Specification	Reference No.
e4	5/8"-11 UNC, 5" Long Heavy Hex Head Bolt and Nut	Bolt - ASTM F3125 Gr. A325 Type 1 Nut - ASTM A563DH	Bolt: H#CR10456700-41 Nut: H#75068952 L#27160
e5	7/8"-9 UNC, 24" Long Threaded Rod	ASTM A449 or Equivalent COC says A449	Job#542344
e6	7/8"-9 UNC, 2"Long Heavy Hex Head Bolt	ASTM A449 or Equivalent ASTM A325	P#0129028BO C#180083637 H#331313371
e7	7/8" Dia. Heavy Hex Coupling Nut	ASTM A563DH	H#NF100884291
e8	7/8" Dia. Heavy Hex Nut	ASTM A563DH or Equivalent	H#6214369204
e9	1" Dia. Hex Nut	ASTM A563A	P#36119 C#110207371 H#15306714-3
e10	5/8"-11 UNC, 10" Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A or Equivalent, Nut - ASTM A563A or Equivalent	Bolts: H#DL16102715 Nuts: P#36713 C#210101523
e11	7/8"-9 UNC, 8" Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A or Equivalent, Nut - ASTM A563A or Equivalent	FASTENAL COC
e12	5/8"-11 UNC, 1 1/2" Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A or Equivalent, Nut - ASTM A563A or Equivalent	Bolts: H#816070039 Nuts: P#36713 C#210101523
e13	5/16"-18 UNC, 1 1/4" Long Hex Head Bolt and Nut	Bolt - ASTM A307 Gr. A or Equivalent, Nut - ASTM A563A or Equivalent	Bolts: P#91830 C#120263056 H#G4604921 Nut: P#1136703 C#120200536 H#183425
e14	16D Double Head Nail	-	McMaster-Carr PO E000357170
f1	1 3/4"x1 3/4"x1/8" Square Washer	11GA A1011 -CS-TYB TEMP HS	H#B707141
f2	7/8" Dia. Plain Round Washer	ASTM F844	FASTENAL COC

Table C-3. Bill of Materials, Test No. N2BR-1, Cont.

Item No.	Description	Material Specification	Reference No.
f3	5/8" Dia. Plain Round Washer	ASTM F844	N/A
f4	7/8" Dia. Hardened Flat Washer	ASTM F436	H#173583
f5	1" Dia. Plain Round Washer	ASTM F844	N/A
g1	BCT Anchor Cable End Swaged Fitting	Fitting - ASTM A576 Gr. 1035 Stud - ASTM F568 Class C	CGLP Order# 256284
g2	3/4" Dia. 6x19, 24 1/2" Long IWRC IPS Wire Rope	IPS	CGLP Order# 256284
g3	115-HT Mechanical Splice - 3/4" Dia.	As Supplied	N/A
g4	Crosby Heavy Duty HT - 3/4" Dia. Cable Thimble	Stock No. 1037773	N/A
g5	Crosby G2130 or S2130 Bolt Type Shackle - 1¼" Dia. w/ thin head bolt, nut, and cotter pin, Grade A, Class 3	Stock Nos. 1019597 and 1019604 - As Supplied	N/A
g6	Chicago Hardware Drop Forged Heavy Duty Eye Nut - Drilled and Tapped 1 1/2" Dia. - UNC 6	Stock No. 107 - As Supplied	N/A
g7	TLL-50K-PTB Load Cell	As Supplied	N/A
g8	8"x8"x5/8" Anchor Bearing Plate	ASTM A36	H#4181496
g9	2 3/8" O.D. x 6" Long BCT Post Sleeve	ASTM A53 Gr. B Schedule 40	H#A79999
h1	Anchor Bracket Assembly	ASTM A36	South: H#4153095 North: R#17-282
h2	Ground Strut Assembly	ASTM A36	H#195070
	Deck Concrete	Min. f'c = 6,000 psi NE Mix 47BD	Ticket#1222277, 1222285 PC#485030000
i1	Grade Beam Concrete	Min f'c = 4,000 psi	Ticket#4202504 PC#470031PF

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Test Report

Customer:	GUARDRAIL SYSTEMS 8000 SERUM AVE. RALSTON,NE,68127-4213	Ship Date; Customer P O Shipped to: Project: GHP Order No.:	10/12/2016 EMAIL 6-21-2016 GUARDRAIL SYSTEMS STOCK 9386AJ

HT # code	Heat #	C.	MN.	P.	S.	Si.	Tensile	Yield	Elong.	Quanity	Class	Type	Description
9760	31631800	0.2	0.85	0.01	0.001	0.04	79600	62100	25	6	A	1	12GA 15FT7.5IN WB T13FT1.5IN
9761	4152233	0.22	0.74	0.011	0.006	0.01	79057	59958	25.33	6	A	1	12 GA 12FT6IN WB T1 FLEAT-SKT COMBO PAN
9760	31631800	0.2	0.85	0.01	0.001	0.04	79600	62100	25	5	A	1	12GA 25FT0IN 3FT1 1/2IN WB T1
9692	31629790	0.2	0.82	0.012	0.002	0.04	81442	58556	17.56	1	A	1	12GA 25FT0IN 3FT1 1/2IN WB T1
9760	31631800	0.2	0.85	0.01	0.001	0.04	79600	62100	25	40	A	1	12GA 6FT 3IN WB T1 HS@ 3FT 1.5IN

R#17-402 QTY 2
For Georgia MGS though only one will be used there.
February 2017 SMT

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
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska & Iowa Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4

By __________
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 13 day of October, 2016

Notary Public, State of Ohio

Figure C-1. 6-ft 3-in. 12-Gauge W-Beam MGS Section Material Certification, Test No. N2BR-1

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Customer:	UNIVERSITY OF NEBRASKA-LINCOLN 401 CANFIELD ADMIN BLDG P O BOX 880439 LINCOLN,NE,68588-0439	Test Report	
		Ship Date:	7/9/2015
		Customer P.O.:	4500274709/ 07/07/2015
		Shipped to:	UNIVERSITY OF NEBRASKA-LINCOLN
		Project:	TESTING COIL
		GHP Order No.:	183306

HT # code	Heat #	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	10	A	2	12GA 25FT WB T2 MGS ANCHOR PANEL
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	100	A	2	12GA 12FT6IN/3FT1 1/2IN WB T2
8534	9411949	0.21	0.75	0.01	0.006	0.01	75774	56527	27.15	20	A	2	12GA 25FT0IN 3FT1 1/2IN WB T2

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.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: ____________________
Andrew Artar, VP of Sales & Marketing
Gregory Highway Products, Inc.

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public by Andrew Artar this 17 day of July 2015
Notary Public, State of Ohio

NOTARIAL SEAL
STATE OF OHIO

DAWN R. BATTON
NOTARY PUBLIC
STATE OF OHIO
Comm. Expires
March 03, 2018
Recorded in
Portage County

Figure C-2. 12-ft 6-in. 12-Gauge W-Beam MGS Section Material Certification, Test No. N2BR-1

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

Customer: UNIVERSITY OF NEBRASKA-LINCOLN
401 CANFIELD ADMIN BLDG
P O BOX 880439
LINCOLN,NE,68588-0439

Test Report
Ship Date: 1/26/2018
Customer P O: 36263
Shipped to: UNIVERSITY OF NEBRASKA-LINCOLN
Project:
GHP Order No.: 319AA

HT # code	Heat #	C.	MN.	P.	S.	Si.	Tensile	Yield	Elong.	Quanity	Class	Type	Description
1207	C85187	0.2	0.48	0.008	0.003	0.03	80433	59371	16.35	150	A	2	12GA 12FT6IN/3FT1 1/2IN WB T2

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.
All other galvanized material conforms with ASTM-123 & ASTM-653
All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: Jeffery L Grover
Jeffery Grover, VP of Highway Products Sales & Marketing
Gregory Highway Products, Inc.

NOTARIAL SEAL — STATE OF OHIO

James P Dehnke
Notary Public - State of Ohio
My Commission Expires
October 19, 2019

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Jeffery Grover this 29 day of January, 2018

Notary Public, State of Ohio

Figure C-3. 12-ft 6-in. 12-Gauge W-Beam MGS End Section Material Certification, Test No. N2BR-1

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

MIDWEST MACHINERY & SUPPLY CO.
P. O. BOX 703

MILFORD,NE,68405

Test Report
Ship Date: 10/26/2017
Customer P.O.: 3501
Shipped to: MIDWEST MACHINERY & SUPPLY CO.
Project: STOCK
GHP Order No: 7044AA

HT # code	LOT#	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
616137		0.21	0.93	0.011	0.003	0.02	73148	58210	32	15		2	3/16IN X 6IN X 8IN X 5FT0IN TUBE SLEEVE
811T08220		0.22	0.81	0.013	0.006	0.005	71412	56323	35	10		2	3/16IN X 6IN X 8IN X 6FT0IN TUBE SLEEVE
214482		0.04	0.83	0.014	0.005	0.02	75275	68023	28.6	25			10GA MGS TB TRAN APPROACH END-RIGHT
214143		0.04	0.81	0.015	0.006	0.02	75565	69618	29.7	18			10GA MGS TB TRAN DEPARTURE END-LEFT

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: ______________________

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by
Andrew Artar this 31 day of October, 2017

Notary Public, State of Ohio

Figure C-4. 72-in. Long Foundation Tube Material Certification, Test No. N2BR-1

CNWP
CENTRAL NEBRASKA WOOD PRESERVERS

1098 East Maple St
Sutton, NE 68979
Phone: 402.773.4319
Email: nick@nebraskawood.com

CERTIFICATE OF COMPLIANCE

Shipped To: Midwest Machinery and Supply
BOL# 10057336
Customer PO# 3460
Preservative: CCA – C 0.60D pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
GR6806.5CRT	6x8-6.5′ CRT	105	24080	.603
GR61222BLK	6x12-22″ Block	56	24003	.700
GR6822CH	6x8-22″ Block	84	24108	.666
GS6846PST	5.5x7.5-46″ BCT	42	24096	.661
GS6806.5PST	5.5x7.5-6.5′ Rub Post	126	24080	.603
GS6823BLK	5.5x7.5-23″ Rub Block	84	24075	.654
GR61219BLK	6x12-19″ Routered Blk	168	24074	.676

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

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

Nicholas Sowl, General Counsel

7/24/2017
Date

Figure C-5. BCT Timber Post – MGS Height, Test No. N2BR-1

HIGHWAY SAFETY CORP

P.O. BOX 358
GLASTONBURY, CT 06033

CERTIFICATE OF COMPLIANCE/ANALYSIS REPORT

SOLD TO:
MIDWEST MACHINERY & SUPPLY
974-238th Road

Milford, NE, USA

SHIP TO:
MIDWEST MACHINERY & SUPPLY
974 238TH ROAD
MILFORD,

INVOICE / S.O.: 0201778 / 0148102
CUSTOMER P.O.: 3508

REFERENCE: STOCK
DATE SHIPPED: 10/23/2017

QTY:	HEAT/LOT NO:	ITEM NUMBER: YIELD:	CC: TENSILE: %ELONG:	DESCRIPTION: C: Mn: P: S: Si: Cl: Type ACW
550		T-POG060080600	IB-B0600800	THRIE POST W06 x 008.5# x 06'00 GALV
(200)	1702411			
(350)	55048942			
400	1703040	PSG030050503-20	IBSB03005000	POST S03@05.7 x 05'03.0 3 HL 2 SD W/PLT 3.5-3-3 SPGLV
	B76746		PL-B025-080240	

ALL STEEL USED IN MANUFACTURING IS MADE AND MELTED IN THE USA, INCLUDING HARDWARE FASTENERS, AND COMPLIES WITH THE BUY AMERICA ACT. ALL COATINGS PROCESSES ARE PERFORMED IN THE USA AND COMPLY WITH THE BUY AMERICA ACT. BOLTS COMPLY WITH ASTMA-307 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. NUTS COMPLY WITH ASTMA-563 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. WASHERS COMPLY WITH ASTM F-436 AND/OR F-844 SPECIFICATIONS AND ARE GALVANIZED IN ACCORDANCE WITH ASTMA-153, UNLESS OTHERWISE STATED. ALL GUARDRAIL MEETS AASHTO M-180 AND ALL STRUCTURAL STEEL MEETS AASHTO M-270. ALL OTHER GALVANIZED MATERIAL CONFORMS WITH ASTMA-123. ALL OTHER ITEMS COMPLY WITH AASHTO M-111, M-166, M-133, M-265, ASTM A36, ASTMA-709, ASTMA-123, ASTM A606, AND ASTMA588 SPECIFICATIONS IF APPLICABLE. COMPLIANCE WITH ALL SPECIFICATIONS OF DEPARTMENT OF PUBLIC WORKS, DEPARTMENT OF HIGHWAYS AND TRANSPORTATION, DIVISION OF ROADS AND BRIDGES AND STATE HIGHWAY ADMINISTRATION IS MET IN ALL RESPECTS.

HIGHWAY SAFETY CORPORATION

QUALITY ASSURANCE MANAGER

NOTARIZED UPON REQUEST:
STATE OF CONNECTICUT COUNTY OF HARTFORD
SWORN AND SUBSCRIBED BEFORE ME THIS 3rd DAY OF Nov, 2017

Margaret J Satalino
Notary Public

MARGARET J. SATALINO
NOTARY PUBLIC
MY COMMISSION EXPIRES OCT. 31, 2021

Page 1 - 0148102

Figure C-6. W6x8.5, 72-in. Long Steel Post Certificate of Compliance, Test No. N2BR-1

CNWP
CENTRAL NEBRASKA WOOD PRESERVERS

1098 East Maple St
Sutton, NE 68979
Phone: 402.773.4319
Email: nick@nebraskawood.com

CERTIFICATE OF COMPLIANCE

Shipped To: Midwest Machinery and Supply
BOL# 100588715
Customer PO# 3528
Preservative: CCA - C 0.60D pcf AWPA UC4B

Part #	Physical Description	# of Pieces	Charge #	Tested Retention
4075b	6x8-14" Block	126	24683	.665
6120b	6x12-14" Block	84	23888	.678
GS6806.5 PST	5.5x7.5-6.5' Rub Post	84	24604	.652
GS6806.5 PST	5.5x7.5-6.5' Rub Post	42	24603	.643
GS6814 BLK	5.5x7.5-14' Block	126	24194	.633

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

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

Nick Sowl, General Counsel

1/11/2018
Date

Figure C-7. 6-in. x 12-in. x 14¼-in. Timber Blockouts for Steel Posts Certificates of Compliance, Test No. N2BR-1

GERDAU

US-ML-WILTON
1500-2500 WEST 3RD STREET
WILTON, IA 52778
USA

CERTIFIED MATERIAL TEST REPORT

Page 1/1

CUSTOMER SHIP TO STEEL & PIPE SUPPLY CO INC 401 NEW CENTURY PKWY NEW CENTURY,KS 66031-1127 USA	CUSTOMER BILL TO STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	GRADE A36/44W	SHAPE / SIZE Flat Bar / 1/4 X 1	DOCUMENT ID: 0000011110
		LENGTH 20'00"	WEIGHT 19,584 LB	HEAT / BATCH 64055041/02
SALES ORDER 4190352/000010	CUSTOMER MATERIAL N° 000000000010810020	SPECIFICATION / DATE or REVISION ASME SA36 ASTM A6-14, A36-14 ASTM A709-15, AASHTO M270-12 CSA G40.20-13/G40.21-13	H#64055041/02	

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500272853	1334-0000034941	09/20/2016

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	V %	Nb %	Al %	Pb %
0.15	0.57	0.007	0.021	0.21	0.26	0.09	0.07	0.020	0.001	0.014	0.002	0.0000

CHEMICAL COMPOSITION

CEqyA529 %	Sn %
0.33	0.018

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS PSI	YS MPa
22.50	8.000	74300	512	58000	400
22.50	8.000	74400	513	57600	397

GEOMETRIC CHARACTERISTICS

R:R
123.14

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

Bhaskar
BHASKAR YALAMANCHILI
QUALITY DIRECTOR

Brett Krause
BRETT KRAUSE
QUALITY ASSURANCE MGR.

Figure C-8. 2¾-in. x 1-in. x ¼-in. Post Standoff Mill Certification, Test No. N2BR-1

GERDAU

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

CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
STEEL & PIPE SUPPLY CO INC 4750 W MARSHALL AVE LONGVIEW,TX 75604-4817 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	A36/A572-50	Standard I-Beam / 3 X 5.7# / 75 X 8.5	0000184326

LENGTH	PCS	WEIGHT	HEAT / BATCH
40'00"	36	8,208 LB	59076269/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
5937305/000050	000000000035357040	ASME SA36 ASTM A572-15 ASTM A6-14, A36-14 ASTM A709-15 H#59076269/02

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500299528	1327-0000263916	01/15/2018

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	Nb %	Al %
0.10	0.84	0.014	0.024	0.18	0.33	0.11	0.18	0.013	0.007	0.001	0.012	0.003

CHEMICAL COMPOSITION

CEqyA6 %
0.31

MECHANICAL PROPERTIES

YS 0.2% PSI	UTS PSI	YS MPa	UTS MPa	G/L Inch	G/L mm
56532	68686	390	474	8.000	200.0
56815	69000	392	476	8.000	200.0

MECHANICAL PROPERTIES

Elong. %
22.70
21.80

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

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WADE LUMPKINS
QUALITY ASSURANCE MGR.
Phone: 972-779-3118 Email: Wade.Lumpkins@gerdau.com

Figure C-9. S3x5.7 Post Mill Certification, Test No. N2BR-1 Mill Certification, Test No. N2BR-1

SSAB

Preliminary Test Certificate

1770 Bill Sharp Boulevard, Muscatine, IA 52761-9412, US **Official copy to follow**

Form TC1: Revision 2: Date 23 Apr 2014

Customer: STEEL & PIPE SUPPLY P.O. BOX 1688 MANHATTAN KS 66502	Customer P.O. No.: 4500287649	Mill Order No.: 41-504804-02	Shipping Manifest: MT318692
	Product Description: ASTM A572-50/M345(15)/A709-50/M345(16A)	Ship Date: 21 Jun 17 Cert Date: 21 Jun 17	Cert No: 061649975 (Page 1 of 1)
	Size: 0.500 X 96.00 X 240.0 (IN)		

Tested Pieces				Tensiles							Charpy Impact Tests												
Heat Id	Piece Id	Tested Thickness	Tst Loc	YS (KSI)	UTS (KSI)	%RA	Elong % 2in	Elong % 8in	Tst Dir	Hardness	Abs. Energy(FTLB) 1	2	3	Avg	% Shear 1	2	3	Avg	Tst Tmp	Tst Dir	Tst Siz (mm)	BDWTT Tmp	%Shr
A7D898	D19	0.496 (DISCRT)	L	61	73		38		T														
A7F058	D31	0.497 (DISCRT)	L	55	68		37		T														
B7D657	D18	0.507 (DISCRT)	L	57	77		28		T														

Chemical Analysis

Heat Id	C	Mn	P	S	Si	Tot Al	Cu	Ni	Cr	Mo	Cb	V	Ti	ORGN
A7D898	.05	1.32	.014	.004	.10	.034	.30	.14	.15	.03	.024	.027	.008	USA
A7F058	.05	1.21	.012	.006	.02	.028	.31	.14	.10	.04	.002	.053	.001	USA
B7D657	.16	1.14	.013	.007	.03	.029	.30	.15	.17	.04	.002	.033	.006	USA

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

B7D657	D18	PCES:	2, LBS:	6534		A7F058	D31	PCES:	1, LBS:	3267
A7D898	D19	PCES:	3, LBS:	9801						

(H) Cust Part # : 721696240A2

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

SENIOR METALLURGIST - PRODUCT

Figure C-10. 10-in. x 7-in. x ½-in. Steel Plate Mill Certification, Test No. N2BR-1

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 12/19/2017
TIME 12:50:41
USER WILLIAMR

SOLD TO
66031-1127

SHIP TO
18271
SPS Warehouse 0045
401 New Century Parkway
NEW CENTURY KS

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40299425-0020	70872178	1/4 72 X 178 A36 STP MIL PLT	6	5452.140			12/19/2017

H#17126641

Chemical Analysis

DOMESTIC

Heat No. 17126641 Vendor BIG RIVER STEEL LLC 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	0.8200	0.0070	0.0020	0.0300	0.0400	0.0500	0.0120	0.0001	0.1100	0.0260	0.0010	0.0040	0.0020	0.0077	0.0055

Mechanical / Physical Properties

Mill Coil No. 17126641-05

Tensile	Yield	Elong	Rckwl	Grain	Charpy	Charpy Dr	Charpy Sz	Temperature	Olsen
75700.000	54100.000	28.10			0	NA			
71300.000	52000.000	30.60			0	NA			
71800.000	52000.000	33.20			0	NA			
74300.000	55400.000	28.70			0	NA			

Batch 0005075120 6 EA 5,452.140 LB

Batch 0005075119 7 EA 6,360.830 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-11. 10-in. x 2¾-in. x ¼-in. Plate Washer Mill Certification, Test No. N2BR-1

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

Atlas Tube
A DIVISION OF ZEKELMAN INDUSTRIES

Ref.B/L: 80796107
Date: 12.07.2017
Customer: 179

MATERIAL TEST REPORT

Sold to

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

H#W46930

Shipped to

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

Material: 4.0x4.0x375x40'0"0(5x2). **Material No:** 400403754000 **Made in:** USA **Melted in:** USA

Sales order: 1238969 **Purchase Order:** C450006892 **Cust Material #:** 6540037540

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
W46930	0.190	0.790	0.010	0.008	0.014	0.050	0.040	0.004	0.005	0.010	0.050	0.002	0.001	0.000	0.004

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M800748374	10	067450 Psi	078686 Psi	29 %	ASTM A500-13 GRADE B&C	0.34

Material Note:
Sales Or.Note:

Material: 8.0x8.0x250x40'0"0(3x3). **Material No:** 800802504000 **Made in:** USA **Melted in:** USA

Sales order: 1238966 **Purchase Order:** C450006892 **Cust Material #:** 6580025040

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
M47546	0.200	0.850	0.012	0.009	0.012	0.040	0.030	0.005	0.005	0.010	0.040	0.002	0.001	0.000	0.007

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M900959981	9	064500 Psi	077500 Psi	32 %	ASTM A500-13 GRADE B&C	0.36

Material Note:
Sales Or.Note:

Material: 8.0x8.0x313x40'0"0(3x2). **Material No:** 800803134000 **Made in:** USA **Melted in:** USA

Sales order: 1238971 **Purchase Order:** C450006892 **Cust Material #:** 6580031340

Heat No	C	Mn	P	S	Si	Al	Cu	Cb	Mo	Ni	Cr	V	Ti	B	N
17118861	0.210	0.750	0.007	0.003	0.020	0.027	0.120	0.001	0.013	0.040	0.040	0.003	0.000	0.000	0.006

Bundle No	PCs	Yield	Tensile	Eln.2in	Certification	CE
M900959865	6	064000 Psi	077500 Psi	32 %	ASTM A500-13 GRADE B&C	0.36

Material Note:
Sales Or.Note:

Jason Richard

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

Steel Tube Institute OF NORTH AMERICA

Page : 1 Of 3

Metals Service Center Institute

Figure C-12. HSS4x4x⅜, 6⅝-in. Long Square Tube Mill Certification, Test No. N2BR-1

CERTIFICATE OF ANALYSIS

1020 Niedringhaus Ave
PO BOX 366
Granite City, IL 62040
Phone: (618) 452-2833 Fax: (618) 452-8780

THE STEEL WORKS

Date: 03/01/2016
Time: 13:34:43
Page: 5 of 5

Release #: 6599 Customer: STEEL & PIPE SUPPLY CO. INC. Customer PO:

Chemistry Heat Number 62213

nValue: rValue:

C:	.14	Mn:	.68	P:	.021	S:	.016	Si:	.19
Cu:	.04	Al:		CB:		V:		Ni:	
Cr:		Ti:		N:		Mo:		Ca:	
Zr:		Sb:		B:		Sn:		Nb:	

Melted and Manufactured Outside of the USA TURKEY

Tag No	Product	Gage	Width	Length	Weight	Storage Tag No	Part Number	Rb	Tensile	Yield	Elong
748003	HR FL	0.1250	1.0000	240.0000	4,352 Grade A36		SPSC 1/8 X 1.0 X 2		67000	42900	36.0

Cust PO: 4500260308

Authorized Signatory

Mary Macko

Mary Macko

The above stated information is an exact copy of test reports provided by our supplier or independent laboratory and contained in our permanent records, or that the absence of same, the steel listed above was purchased by us to comply with the above stated.

psdata cc-484 3

Figure C-13. 3½-in. x 1-in. x ⅛-in. Plate Mill Certification, Test No. N2BR-1

Steel & Pipe Supply Co.
Midwest Steel Works, Inc.
Customer PO: 50247
Heat: 52080955
Shipment: 0018004574

GERDAU

CA-ML-WHITBY
1 GERDAU CT
WHITBY, ON L1N 5T1
Canada

CERTIFIED MATERIAL TEST REPORT

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CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
STEEL & PIPE SUPPLY CO INC 401 NEW CENTURY PKWY NEW CENTURY,KS 66031-1127 USA	STEEL & PIPE SUPPLY CO INC MANHATTAN,KS 66505-1688 USA	GGMULTI	Channel / 7 X 9.8#	0000060224

LENGTH	WEIGHT	HEAT / BATCH
40'00"	18,816 LB	52080955/02

SALES ORDER	CUSTOMER MATERIAL Nº
5780975/000020	000000000025798040

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
4500297143	1302-0000068002	12/04/2017

SPECIFICATION / DATE or REVISION H#52080955/02
ASTM A529-14, A572-15
ASTM A6-14,A36-14, ASME SA-36
ASTM A709-15, AASHTO M270-12
CSA G40.20-13/G40.21-13

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	V %	Nb %
0.14	0.75	0.017	0.032	0.17	0.32	0.12	0.12	0.013	0.001

MECHANICAL PROPERTIES

Elong. %	G/L Inch	UTS PSI	UTS MPa	YS 0.2% PSI	YS MPa
25.00	8.000	69800	481	51200	353
25.00	8.000	71400	492	51100	352

COMMENTS / NOTES

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

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in Canada. CMTR complies with EN 10204 3.1.

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QUALITY ASSURANCE MGR.
Phone: (905) 668-8811 EXT 4055 Email: Leonardo.Nunes@gerdau.com

Figure C-14. C7x9.8, 225-in. Long C-Channel Mill Certification, Test No. N2BR-1

CERTIFICATE OF ANALYSIS

1020 Niedringhaus Ave
PO BOX 366
Granite City, IL 62040
Phone: (618) 452-2833 Fax: (618) 452-8780

THE STEEL WORKS

Date: 08/26/2016
Time: 12:47:57
Page: 7 of 8

Release #: 7226 Customer: STEEL & PIPE SUPPLY CO. INC. Customer PO:

Chemistry Heat Number 1164312

nValue: rValue:

C:	.22	Mn:	.47	P:	.008	S:	.0015	Si:	.02
Cu:	.11	Al:	.03	CB:		V:	.002	Ni:	.04
Cr:	.05	Ti:	.003	N:	.007	Mo:	.01	Ca:	.003
Zr:		Sb:		B:		Sn:	.005	Nb:	.002

Melted and Manufactured in the USA

Tag No	Product	Gage	Width	Length	Weight	Storage Tag No	Part Number	Rb	Tensile	Yield	Elong
754064	HR PL Mill Tag No: 1165949.0	0.1250	2.0000	240.0000	2,651 Grade A36		SPSC 1/8 X 2.0 X 240	Cust PO: 4500270667	74200	50800	28.0
754071	HR PL Mill Tag No: 1165949.0	0.1250	1.5000	240.0000	2,549 Grade A36		SPSC 1/8 X 1.5 X 240	Cust PO: 4500270667	74200	50800	28.0
754072	HR PL Mill Tag No: 1165949.0	0.1250	1.5000	240.0000	2,027 Grade A36		SPSC 1/8 X 1.5 X 240	Cust PO: 4500270667	74200	50800	28.0
754061	HR PL Mill Tag No: 1165949.0	0.1250	2.0000	240.0000	2,651 Grade A36		SPSC 1/8 X 2.0 X 240	Cust PO: 4500270667	74200	50800	28.0
754062	HR PL Mill Tag No: 1165949.0	0.1250	2.0000	240.0000	2,651 Grade A36		SPSC 1/8 X 2.0 X 240	Cust PO: 4500270667	74200	50800	28.0
754063	HR PL Mill Tag No: 1165949.0	0.1250	2.0000	240.0000	2,651 Grade A36		SPSC 1/8 X 2.0 X 240	Cust PO: 4500270667	74200	50800	28.0

The above stated information is an exact copy of test reports provided by our supplier or independent laboratory and contained in our permanent records, or that the absence of same, the steel listed above was purchased by us to comply with the above stated.

pssdata.co-484.3

Figure C-15. 6⅝-in. x 2-in. x ⅛-in. Shim Plate Mill Certification, Test No. N2BR-1

GERDAU

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

CERTIFIED MATERIAL TEST REPORT

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CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
METAL PARTNERS REBAR LLC 13535 S TORRENCE AVE CHICAGO,IL 60633-2164 USA	METAL PARTNERS INTERNATIONAL 55 S MAIN STREET NAPERVILLE,IL 60540-8500 USA	60 (420) TMX	Rebar / #4 (13MM)	0000000000

LENGTH	WEIGHT	HEAT / BATCH
20'00"	2,004 LB	57166646/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
5354816/000010	X-13-42-2000	ASTM A615/A615M-15 E1

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
11046	4751-0000020526	07/17/2017

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.28	0.55	0.007	0.065	0.17	0.31	0.12	0.11	0.020	0.007	0.003	0.39

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
77120	532	92280	636	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
11.90	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
4.49	0.029	0.104	0.323

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

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JIM HALL
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Figure C-16. No. 4 Rebar Mill Certification, Test No. N2BR-1

GERDAU

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

CERTIFIED MATERIAL TEST REPORT

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CUSTOMER SHIP TO	CUSTOMER BILL TO	GRADE	SHAPE / SIZE	DOCUMENT ID:
MIDWEST PIPE COATING 925 KENNEDY AVE SCHERERVILLE,IN 46375-1325 USA	METAL PARTNERS INTERNATIONAL 47 E CHICAGO AVE NAPERVILLE,IL 60540-5360 USA	60 (420) TMX	Rebar / #4 (13MM)	0000000000

LENGTH	WEIGHT	HEAT / BATCH
40'00"	6,012 LB	57166635/02

SALES ORDER	CUSTOMER MATERIAL N°	SPECIFICATION / DATE or REVISION
5371122/000240	X-13-42-4000	ASTM A615/A615M-15 E1

CUSTOMER PURCHASE ORDER NUMBER	BILL OF LADING	DATE
11095	4751-0000021408	09/07/2017

CHEMICAL COMPOSITION

C %	Mn %	P %	S %	Si %	Cu %	Ni %	Cr %	Mo %	Sn %	V %	CEqyA706 %
0.29	0.54	0.010	0.072	0.20	0.32	0.11	0.09	0.010	0.010	0.002	0.41

MECHANICAL PROPERTIES

YS PSI	YS MPa	UTS PSI	UTS MPa	G/L Inch	G/L mm
79010	545	95020	655	8.000	200.0

MECHANICAL PROPERTIES

Elong. %	BendTest
11.30	OK

GEOMETRIC CHARACTERISTICS

%Light %	Def Hgt Inch	Def Gap Inch	DefSpace Inch
4.19	0.030	0.108	0.324

COMMENTS / NOTES

The above figures are certified chemical and physical test records as contained in the permanent records of company. We certify that these data are correct and in compliance with specified requirements. This material, including the billets, was melted and manufactured in the USA. CMTR complies with EN 10204 3.1.

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JIM HALL
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Figure C-17. No. 4 Rebar Mill Certification, Test No. N2BR-1

KAPTAN DEMIR CELIK ENDUSTRISI ve TICARET A.S.
FAHRETTIN KERIM GOKAY CAD. BESTEKAR SAADETTIN KAYNAK
SOKAK NO:2 34662 ALTUNIZADE/USKUDAR /ISTANBUL/TURKEY
Tel : +90.216. 547 49 00 , Fax :+90.216. 428 74 74

ORIGINAL

TO WHOM IT MAY CONCERN

13.02.2017
PAGE 1/1

DESCRIPTION OF GOODS:

ACE-USA-322/RDB
REINFORCING DEFORMED STEEL BARS
QUALITY :ASTM A 615-GR 40/ASTM A 615-GR 60/AIR COOLED

KAPTAN DEMIR CELIK ENDUSTRISI VE TICARET A.S.
www.kaptandemir.com.tr
MERSIS NO: 0499004945800015

MILL TEST CERTIFICATE

LOT 1

Size (Inch)	Length (Feet)	GRADE	Heat Number	NUMBER OF BUNDLES	PHYSICAL PROPERTIES: Yield Point Mpa	Tensile Strength Mpa	Rm / ReH	Elng. %	Bend Test	CHEMICAL ANALYSIS %: C	Mn	Si	P	S	Ni	Cr	Mo	Cu	V	N	Ceq
(#3) 3/8"	20	60	17-00528	26	466	672	1,44	13,0	OK	0,41	0,62	0,14	0,019	0,039	0,09	0,08	0,023	0,33	0,017	0,0099	0,57
(#3) 3/8"	20	60	17-00524	78	469	678	1,45	13,9	OK	0,42	0,66	0,16	0,030	0,030	0,13	0,15	0,027	0,40	0,018	0,0087	0,60
(#4) 1/2"	20	40	17-00687	55	335	510	1,52	19,3	OK	0,29	0,56	0,14	0,030	0,034	0,12	0,14	0,030	0,32	0,003	0,0080	0,45
(#4) 1/2"	20	40	17-00688	114	342	505	1,48	17,9	OK	0,28	0,63	0,14	0,034	0,036	0,10	0,18	0,024	0,29	0,005	0,0079	0,45
(#4) 1/2"	20	40	17-00689	39	343	505	1,47	19,4	OK	0,30	0,55	0,13	0,023	0,038	0,11	0,10	0,022	0,27	0,003	0,0083	0,44
(#4) 1/2"	20	60	17-00506	37	497	707	1,42	13,5	OK	0,45	0,61	0,15	0,032	0,034	0,12	0,12	0,019	0,44	0,024	0,0080	0,62
(#4) 1/2"	20	60	17-00507	92	465	656	1,41	13,0	OK	0,45	0,63	0,18	0,030	0,032	0,13	0,12	0,021	0,41	0,025	0,0071	0,62
(#4) 1/2"	20	60	17-00508	130	468	677	1,45	13,0	OK	0,44	0,65	0,18	0,034	0,023	0,13	0,13	0,025	0,41	0,024	0,0082	0,62
(#4) 1/2"	20	60	17-00509	47	467	677	1,45	13,4	OK	0,47	0,63	0,15	0,027	0,044	0,12	0,10	0,023	0,40	0,023	0,0080	0,64
(#4) 1/2"	20	60	17-00510	118	487	678	1,39	12,8	OK	0,45	0,64	0,16	0,030	0,045	0,12	0,11	0,028	0,36	0,023	0,0084	0,62
(#4) 1/2"	20	60	17-00511	83	508	708	1,39	11,4	OK	0,44	0,62	0,17	0,046	0,012	0,14	0,19	0,030	0,43	0,024	0,0092	0,63
(#4) 1/2"	20	60	17-00512	105	489	699	1,43	11,2	OK	0,45	0,61	0,17	0,031	0,040	0,12	0,14	0,031	0,40	0,024	0,0073	0,62
(#4) 1/2"	20	60	17-00513	111	479	685	1,43	12,6	OK	0,44	0,61	0,17	0,035	0,035	0,11	0,12	0,023	0,42	0,023	0,0077	0,61
(#4) 1/2"	20	60	17-00514	50	492	690	1,40	12,4	OK	0,44	0,62	0,16	0,032	0,027	0,12	0,16	0,023	0,45	0,024	0,0081	0,62
(#4) 1/2"	20	60	17-00515	91	488	683	1,40	11,9	OK	0,44	0,62	0,16	0,032	0,027	0,12	0,16	0,023	0,45	0,024	0,0081	0,62
(#4) 1/2"	20	60	17-00516	21	480	681	1,42	12,5	OK	0,44	0,61	0,15	0,031	0,028	0,13	0,13	0,023	0,44	0,023	0,0091	0,62
(#5) 5/8"	20	60	17-00834	54	477	670	1,40	13,9	OK	0,45	0,61	0,16	0,028	0,031	0,11	0,15	0,028	0,29	0,022	0,0097	0,61
(#5) 5/8"	20	60	17-00842	70	476	676	1,42	13,7	OK	0,45	0,60	0,13	0,016	0,028	0,10	0,09	0,025	0,27	0,024	0,0096	0,60
(#5) 5/8"	20	60	17-00843	50	452	656	1,45	13,3	OK	0,44	0,62	0,13	0,017	0,040	0,10	0,10	0,028	0,28	0,023	0,0090	0,60
(#5) 5/8"	20	60	17-00844	34	474	661	1,39	14,1	OK	0,44	0,59	0,13	0,021	0,031	0,10	0,10	0,032	0,29	0,023	0,0091	0,60
(#6) 3/4"	20	60	17-00885	23	470	670	1,43	13,1	OK	0,46	0,62	0,15	0,017	0,038	0,12	0,10	0,029	0,31	0,023	0,0098	0,62
(#6) 3/4"	20	60	17-00886	27	468	679	1,45	13,2	OK	0,45	0,61	0,13	0,016	0,029	0,13	0,09	0,023	0,30	0,023	0,0096	0,61
			TOTAL	1.455																	

Customer Name	Customer PO#	Shipper No	Heat Number
Carroll Distributing & Construction S	LI104261	219957	17-00688

Figure C-18. No. 4 Rebar Mill Certification, Test No. N2BR-1

EVRAZ | ROCKY MOUNTAIN STEEL
A DIVISION OF EVRAZ INC. NA

2100 S. Freeway
Pueblo, CO 81004 USA

MATERIAL TEST REPORT

Date Printed: 28-AUG-17

Date Shipped: 28-AUG-17 | Product: DEF #4 (1/2") | Specification: ASTM A706/A615 GR 60

FWIP: 52815348 | Customer: HARRIS SUPPLY SOLUTIONS INC | Cust. PO: P147717

318 ARVIN AVE
STONEY CREEK, L8E 2M2

CHEMICAL ANALYSIS (In Weight %, uncertainty of measurement 0.005%) (Heat cast 08/14/17)

Heat Number	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	Al	V	B	Cb	Sn	N	Ti
594643	0.27	1.24	0.014	0.015	0.24	0.27	0.08	0.18	0.015	0.002	0.039	0.0003	0.000	0.011	0.0087	0.001

Carbon Equivalent = 0.501

MECHANICAL PROPERTIES (Tensiles test date 08/16/17)

Heat Number	Sample No.		Yield (Psi)	Ultimate (Psi)	Elongation (%)	Reduction (%)	Bend	Wt/ft
594643	01		67804	96380	15.0		OK	0.663
		(MPa)	467.5	664.5				
594643	02		61540	96040	14.5		OK	0.662
		(MPa)	424.3	662.2				

All melting and manufacturing processes of the material subject to this test certificate occurred in the United States of America.
ERMS also certifies this material to be free from Mercury contamination.

This material has been produced, tested and conforms to the requirements of the applicable specifications. We hereby certify that the above test results represent those contained in the records of the Company.

Methods used: ASTM A370, A510, A615, A706.

Material test report shall not be reproduced except in full, without approval of the company.

Bryce Lakamp
Process Control Engineer

Figure C-19. No. 4 Rebar Mill Certification, Test No. N2BR-1

NUCOR
Nucor Steel Nebraska

Mill Certification
05/08/2017

MTR#: 16101
Lot #: 10088865421
2911 E NUCOR ROAD
PO BOX 309
NORFOLK, NE 68701 US
402-644-0200
Fax: 402-644-0329

Sold To: KING STEEL CORPORATION
5225 E COOK RD
GRAND BLANC, MI 48439 US

Ship To: KING STEEL WAREHOUSE
4608 S 25TH ST
NORFOLK, NE 68701 US

Customer P.O	022420-MS-T	Sales Order #	10003125 - 1.2
Product Group	Wire Rod - Industrial Quality	Product #	1035146
Grade	1010M1	Lot #	10088865421
Size	0.594"	Heat #	100888654
BOL #	BOL-113346	Load #	16101
Description	WR-IQ RD 0.594" 1010M1 COIL 4300 lbs	Customer Part #	
Production Date	05/04/2017	Qty Shipped LBS	156830
Product Country Of Origin	United States	Qty Shipped EA	38
Original Item Description		Original Item Number	

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.

Melt Country of Origin : United States — Melting Date: 04/30/2017

C (%)	Mn (%)	P (%)	S (%)	Si (%)	Ni (%)	Cr (%)	Mo (%)	Cu (%)	Ti (%)	V (%)	B (%)
0.12	0.51	0.008	0.026	0.15	0.08	0.10	0.03	0.23	0.000	0.002	0.000
Nb (%)	Sn (%)	Al (%)	Pb (%)	Ca (%)							
0.002	0.008	0.00	0.000	0.000							

Reduction Ratio 158.38 : 1

Other Test Results
Yield (PSI) : 49200 — Tensile (PSI) : 83800 — Elongation in 8" (%) : 27.0

Comments:
All manufacturing processes of the steel materials in this product, including melting, have been performed in the United States.
All products produced are weld free.
Mercury, in any form, has not been used in the production or testing of this material.
Test conform to ASTM A29-15, ASTM E415 and ASTM E1019-resulphurized grades or applicable customer requirements.
All material melted at Nucor Steel Nebraska is produced in an Electric Arc Furnace.
Strand Cast
ISO-17025 LAB accreditation cert available upon request.
Exporting Country-USA
Sales@nucorne.com

NBMG-10 January 1, 2012 — Jim Hill, Division Metallurgist — Page 1 of 1

Figure C-20. ⅝-in. Dia. 14-in. Long Bolt Mill Certification, Test No. N2BR-1

CERTIFICATE OF COMPLIANCE

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

CUSTOMER NAME: TRINITY INDUSTRIES

CUSTOMER PO: 183621

SHIPPER #: 060458
DATE SHIPPED: 05/11/2017

LOT#: 29783-B

SPECIFICATION: ASTM A307, GRADE A MILD CARBON STEEL BOLTS

TENSILE:	SPEC:	60,000 psi*min	RESULTS:	72,977 72,530
HARDNESS:		100 max		84.70 85.00

*Pounds Per Square Inch.

COATING: ASTM SPECIFICATION F-2329 HOT DIP GALVANIZE
ROGERS GALVANIZE:: 29783-B

CHEMICAL COMPOSITION

MILL	GRADE	HEAT#	C	Mn	P	S	Si
NUCOR	1010	DL16102715	.11	.45	.004	.018	.13

7,875 PCS 5/8" X 10" GUARD RAIL BOLT
P/N 3500G

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

STATE OF ILLINOIS
COUNTY OF WINNEBAGO
SIGNED BEFORE ME ON THIS
11th DAY OF May 20 17 — Linda McComas — APPROVED SIGNATORY — 5/11/17 DATE

Merry F Shane

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

Figure C-21. ⅝-in. Dia. 10-in. Long Bolt Certificate of Compliance, Test No. N2BR-1

10016
Bennett Bolt
38196

Conformance Certificate

Issued to:

AUTO BOLT

QUALITY BOLT MAKING
SINCE 1948

Bennett Bolt Works, Inc.

Report Number: PS31836AH
Date of Testing: 09/01/17
Lot Number: 31836AH-1
Lot Quantity: 192,761
Page: 1 of 5

Cust part # 62C125BSP3H **Cust po #** 6014494 **Auto Bolt part #** GARD7125
Description: GARD 5/8-11x1-1/4, ASTM 307A, Hot dip galvanized, Head - ABN/307A/USA/Lot Id, Oval Shoulder Splice Bolt
Mechanical and Material Requirements: ASTM A307A
Finish Specification: HOT DIP GALVANIZED PER ASTM A 153/F2329 OR ASTM A 123
Material Grade: 1015-US **Heat Number:** 20455760 CERT ATTACHED
Hardness: 69-100 HRB **Case Depth:** NA
Surface Hardness: NA
Tensile Test per: SAE J 429 ASTM F606 ASTM F 606M ISO-898-1 OTHER
Tensile Test Requirements: 60,000 PSI Min N/A **Method:** Axial

Test results using sampling plan ASME / ASTM B18.18.2M

	1	2	3	4	5	6	7	8
Hardness HRB	83.0	82.0	83.0	81.0	82.0			
Ultimate Tensile in PSI	80,163	74,309	79,787	80,066	80,243			

Visual Inspection: 100 Samples were inspected for surface discontinuities per the above mentioned specification.

* Denotes tests sub-contracted to an outside accredited laboratory or results provided by vendor.

Amendments: n-a

www.autobolt.net
4740 Manufacturing Ave
Cleveland, OH 44135

APPROVAL: [signature]

QUALITY MANAGER:
ASSIGNED SIGNATORY: X

THE AUTO BOLT COMPANY IS AN ISO-9001-2008 CERTIFIED COMPANY. CERTIFICATE # US04/3795

THIS PRODUCT MANUFACTURED IN THE UNITED STATES OF AMERICA.
FORM #F 8.2.4-1
ISSUE DATE JAN 31, 2005 REV. E
Removed SGS logo 4-10-2007

Figure C-22. ⅝-in. Dia. 1¼-in. Long Heavy Hex Head Bolt Certificate of Conformance, Test No. N2BR-1

TFI
Telefast Industries
A Division of EFG

CERTIFICATION

DATE: 4/3/2017

CUSTOMER	CUSTOMER P.O.	INVOICE
Bennett Bolt Works, Inc.	6015438 BLANKET	58432
12 Elbridge Street	**LOT NUMBER**	**SHIP DATE**
Jordan, NY 13080	0068078-124590	4/3/2017
DESCRIPTION	**MATERIAL**	**HEAT NUMBER**
Nut Guardrail 5/8-11 + .031	1018	20479830
A563 GrA HDG	**CUSTOMER PART NUMBER**	**QUANTITY**
EFG PART NUMBER: T3400	62CNDR0H	36000

HARDNESS: B 85.4
PROOF LOAD: 5 samples passed at 75,000 psi min.
PLATING: Hot Dip Galvanized - Pass

All parts processed Mercury free and without Welds.

We hereby certify that to our actual knowledge the information contained herein is correct. We also certify that all parts substantially conform to SAE, ASTM, or customer specifications as agreed upon. The product has been manufactured and tested in accordance with our Quality Assurance manual. The above data accurately represents values provided by our suppliers or values generated in the EFG – Berea Plant laboratory. All manufacturing processes for these parts occurred in the United States of America.

This document may only be reproduced without alteration and only for the purpose of certifying the same or lesser quantity of the product specified here.

The recording of false, fictitious or fraudulent statements or entries on this document may be punishable as a felony under Federal Statutes.

Joe Kilpatrick

Joe Kilpatrick
Quality Assurance Technician

ENGINEERED FASTENING SOLUTIONS

Figure C-23. ⅝-in. Dia. 1¼-in. Long Heavy Hex Head Nut Certificate of Conformance, Test No. N2BR-1

FONTANA FASTENERS PLANT FRANKFORT

TEST REPORT

Operations Center
3281 West County Road 0 NS
Frankfort, IN 46041-6966
T. 765.654.0477
F. 765.654.0857

Ship Date	
Certification	542314*15*1
Report Date	12-28-16

Cust PO	U39876
Lot Nbr	776663
Quantity	1000
Mfg Date	11-04-16

BRIGHTON-BEST INTL SUWANEE GA
250 HORIZON DRIVE
SUWANEE, GA 30024

PART INFORMATION

Part Number	480144
Description	5/8-11 X 5 F3125 A325-1 HEAVY HEX STRUCTURAL DOUBLE MADE IN USA
Finish	HOT DIP ZINC PER ASTM A153 CLASS C
Head Marking	A325 LE USA

RAW MATERIAL ANALYSIS

Steel Heat Nbr	Steel Supplier	Steel Grade	Code	Element	Rqd Min Pct	Rqd Max Pct	Percent
CR10456700-41	Charter Steel	30MnB3	C	Carbon	0.30	0.33	0.33
			Mn	Manganese	0.80	0.95	0.93
			P	Phosphorus	0.000	0.020	0.007
			S	Sulfur	0.000	0.015	0.007
			Si	Silicon	0.150	0.250	0.230
			Ni	Nickel	0.00	0.10	0.04
			Cr	Chromium	0.10	0.20	0.15
			Mo	Molybdenum	0.00	0.04	0.02
			Cu	Copper	0.00	0.15	0.08
			Al	Aluminum	0.020	0.050	0.024
			B	Boron	0.0010	0.0030	0.0028
			Ti	Titanium	0.010	0.050	0.020

Certification test results include those reported by the following laboratories:
Charter Steel, A2LA, 01-31-17
Fontana Fasteners, Inc., ISO17025-A2LA Cert#0122.02, 05-31-18

MECHANICAL PROPERTIES

Wedge Angle	10
Proof Load	19200/85000 (lbs/Psi)

Test Performed	Required	High	Low	Average	Samples
Tensile, PSI	120000 / 160000	143000	143000	143000	4
Proof Load Elongation	0.0000 / 0.0005	0.0002	0	0.0001	3
Superficial R30N	45 / 54	46	45	46	4
Core Hardness, HRC	25 / 34	30	27	29	4

Figure C-24. ⅝-in. Dia. 5-in. Long Heavy Hex Head Bolt Material Certification, Test No. N2BR-1

FONTANA FASTENERS PLANT FRANKFORT

TEST REPORT

Operations Center
3281 West County Road 0 NS
Frankfort, IN 46041-6966
T. 765.654.0477
F. 765.654.0857

Ship Date	
Certification	542314*15*1
Report Date	12-28-16

Cust PO	U39876
Lot Nbr	778663
Quantity	1000
Mfg Date	11-04-16

BRIGHTON-BEST INTL SUWANEE GA
250 HORIZON DRIVE
SUWANEE, GA 30024

PART INFORMATION

Part Number	480144
Description	5/8-11 X 5 F3125 A325-1 HEAVY HEX STRUCTURAL DOUBLE MADE IN USA
Finish	HOT DIP ZINC PER ASTM A153 CLASS C
Head Marking	A325 LE USA

RAW MATERIAL ANALYSIS

Steel Heat Nbr	Steel Supplier	Steel Grade	Code	Element	Rqd Min Pct	Rqd Max Pct	Percent
CR10456700-41	Charter Steel	30MnB3	C	Carbon	0.30	0.33	0.33
			Mn	Manganese	0.80	0.95	0.93
			P	Phosphorus	0.000	0.020	0.007
			S	Sulfur	0.000	0.015	0.007
			Si	Silicon	0.150	0.250	0.230
			Ni	Nickel	0.00	0.10	0.04
			Cr	Chromium	0.10	0.20	0.15
			Mo	Molybdenum	0.00	0.04	0.02
			Cu	Copper	0.00	0.15	0.08
			Al	Aluminum	0.020	0.050	0.024
			B	Boron	0.0010	0.0030	0.0028
			Ti	Titanium	0.010	0.050	0.020

Certification test results include those reported by the following laboratories:
Charter Steel, A2LA, 01-31-17
Fontana Fasteners, Inc., ISO17025-A2LA Cert#0122.02, 05-31-18

MECHANICAL PROPERTIES

Wedge Angle	10
Proof Load	19200/85000 (lbs/Psi)

Test Performed	Required	High	Low	Average	Samples
Tensile, PSI	120000 / 160000	143000	143000	143000	4
Proof Load Elongation	0.0000 / 0.0005	0.0002	0	0.0001	3
Superficial R30N	45 / 54	46	45	46	4
Core Hardness, HRC	25 / 34	30	27	29	4

Figure C-25. ⅝-in. Dia. 5-in. Long Heavy Hex Head Nut Material Certification, Test No. N2BR-1

Job Material Certification

Page 3 of 4

Vulcan THREADED PRODUCTS, INC.

Vulcan Threaded Products
10 Cross Creek Trail
Pelham, AL 35124
Tel (205) 620-5100
Fax (205) 620-5150

JOB MATERIAL CERTIFICATION

Job No: 542344 **Job Information** **Certified Date:** 8/18/17

Containers: S12833344 S12833366 S12833557 S12833725 S12833952 S12833953 S12847504

Customer: Conklin and Conklin **Ship To:** 34201 Seventh Street Union City, CA 94587

Vulcan Part No: BAR B7 .7987x144 SC

Customer Part No: RAWSTEEL-.796-B

Customer PO No: 018290 **Shipped Qty:** 16341 lbs

Order No: 326755 **Line No:** 1

Note:

Applicable Specifications

Type	Specification	Rev	Amend	Option
-	ASTM F1554 Gd 105 S4	2015		
	ASTM F1554 Gr 105	2015		
Heat Treat	ASME SA-193/SA-193M B7	2013		
	ASTM A193 B7	2016		
Quality	EN 10204 3.1	2004		

Test Results

See following pages for tests

Certified Chemical Analysis

Heat No: 10496110 Origin: USA

C	Mn	P	S	Si	Cr	Mo	Ni	V	Cu
0.410	0.87	0.007	0.025	0.28	0.91	0.21	0.06	0.003	0.13
Al	Nb	Sn	Ti	N	B	DI	RR	G.S.	Macro S
0.026	0.001	0.008	0.002	0.0070	0.0001	5.29	54:1	Fine	2
Macro R	Macro C	J1	J2	J3	J4	J5	J6	J7	J8
2	2	57	57	57	57	57	57	56	55
J9	J10	J12	J14	J16	J18	J20	J24	J28	J32
54	52	50	48	46	45	44	42	40	38

Notes

Material was manufactured, tested and inspected in accordance with Vulcan Threaded Products Inc. Quality Assurance Program and Manual Rev. A, dated 8/23/11. Processed material is Quenched and Tempered - Stress Free. No weld repair performed on the material. No Mercury used in the production of this material. Melted and Manufactured in the USA.
Depth of decarburization meets ASTM A962/A962M-16b spec requirements
Document is in accordance with EN 10204 - 3.1B of 2004 (3.1).

Plex 8/18/17 7:58 AM vulc.mgri Page 1 of 2

PORTLAND BOLT
PO 34081
INV 75014
50 7/8" X 144" B7 ATR, BLK 1OF2
JANUARY 26, 2018

19571 7/8 B7 5105 ATR

https://www.plexonline.com/2c198e84-2955-405d-9c9d-45872c8b79e3/Sales/Report_Job_Cert.asp?Mode... 9/21/2017

Figure C-26. ⅞-in. 24-in. Long Threaded Material Certification, Test No. N2BR-1

autocraft Product Inspection Report				Shanghai autocraft Co., Ltd. 168 Nanlu Highway, Nanhui Industrial Zone, Shanghai 201300, China Tel: +86 21 3818 1100			
Confirm Item	■Appearance	■Size	■ Material	■ (ES)	Confirmation		
						Inspection	Check	Approval
Part Name	Heavy Hex Structural Bolt	Part Number	0129028BO	Customer	AF-FAST	Customer			
Part Size	7/8-9UNC*2"	Quantity	3375PCS	Lot/Order No.	180083637 B14017826				
REFE. STD	ASME B 18.2.6 ASTM A325	Sampling plan	B18.18	Heat Number	331313371	Supplier	李沙沙	常真	左加林
Product Description	Dimensions according to ANSI/ASME B18.2.6 Mechanical properties according to ASTM A325	Manufacturing date	2014 4 28	■Accept	_Reject				

序号 No.	Item	Standard	Sampling Qty	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	Results
1	Head Mark	ATC A325	29pcs	ATC A325															OK
2	Width across flats	1.394"-1.438" (35.41~36.52)	5pcs	1.406	1.408	1.407	1.406	1.407	---	---	---	---	---	---	---	---	---	---	OK
3	Width across corners	1.589"-1.660" (40.37-42.16)	5pcs	1.603	1.604	1.610	1.603	1.609	---	---	---	---	---	---	---	---	---	---	OK
4	true position of head with shank	0.086" MAX (2.18 MAX)	5pcs	0.010	0.008	0.010	0.012	0.010	---	---	---	---	---	---	---	---	---	---	OK
5	Head height	0.531-0.563 (13.49~14.30)	5pcs	0.555	0.545	0.553	0.548	0.546	---	---	---	---	---	---	---	---	---	---	OK
6	total runout of bearing surface with shank	0.025" MAX (0.63 MAX)	5pcs	0.011	0.010	0.007	0.009	0.006	---	---	---	---	---	---	---	---	---	---	OK
7	Overall length	1.81"-2.00" (45.98-50.80)	15pcs	1.974	1.957	1.973	1.963	1.962	1.966	1.972	1.957	1.969	1.972	1.975	1.960	1.966	1.976	1.958	OK
8	Grip length	0.277" MAX (7.05 MAX)	15pcs	0.261	0.254	0.249	0.259	0.261	0.251	0.253	0.256	0.252	0.247	0.251	0.258	0.247	0.246	0.263	OK
9	Incomplete threads length	0.22" MAX (5.64 MAX)	5pcs	0.173	0.165	0.163	0.171	0.176	---	---	---	---	---	---	---	---	---	---	OK
10	Bearing thickness	0.015"~0.035" (0.39~0.88)	5pcs	0.022	0.020	0.017	0.017	0.019	---	---	---	---	---	---	---	---	---	---	OK
11	Bearing dia.	Φ1.297" MIN (Φ32.87 MIN)	5pcs	1.300	1.300	1.300	1.300	1.302	---	---	---	---	---	---	---	---	---	---	OK
12	Under head Radius	R0.031"-0.062" (R0.79-1.57)	5pcs	0.050	0.044	0.048	0.048	0.040	---	---	---	---	---	---	---	---	---	---	OK
13	major dia.	Φ0.8592"-0.8951" (Φ21.83-22.73)	15pcs	0.883	0.881	0.882	0.884	0.882	0.883	0.882	0.884	0.883	0.882	0.882	0.883	0.883	0.881	0.884	OK
14	Hardness(Per standard ASTM F606 13)	25-34 HRC	15pcs	29.0	29.5	29.5	29.0	28.5	29.5	30.0	29.0	29.5	29.5	29.0	30.0	28.5	29.5	29.0	OK
15	Wedge Tensile Strength(Per standard ASTM F606-13)	120,000 psi MIN (825MPa) MIN	5pcs	134725	135353	135128	135395	134398	---	---	---	---	---	---	---	---	---	---	OK
16	Stress under proof load(Per standard ASTM F606-13)	85,000 psi (585MPa)	5pcs	4.0um	5.0um	4.0um	4.5um	3.0um	---	---	---	---	---	---	---	---	---	---	OK
17	Decarburization and microstructure (ASTM F2328-11)	high temperd M Complete decarburized depth:0.015mm Non-decarburized height:0.864mm min	5pcs	OK	OK	OK	OK	OK	---	---	---	---	---	---	---	---	---	---	OK
18	surface discontinuities	ASTM F788-13	5pcs	OK	OK	OK	OK	OK	---	---	---	---	---	---	---	---	---	---	OK
19	Coating thickness(ASTM A153-05)	53um MIN	15pcs	65.2	73.2	64.1	66.3	64.3	63.8	70.4	72.5	65.5	73.1	73.3	71.8	71.0	70.4	68.7	OK
20	Appearance	Gray,Hot dip galvanized	29pcs	Gray,Hot dip galvanized															OK
备注 Note																			

ATC-QR-QAD824-1-013(A1)

Figure C-27. ⅞-in. Dia. 2-in. Long Heavy Hex Head Bolt Material Certification, Test No. N2BR-1

Wecall Inc.

P.O. Box 39 • 64 Penniman Rd. • Orwell, OH 44076
(440) 437-8202 • Fax: (440) 437-8208
Fastener Insignia: 01OH

Record of Conformance

Sold To:
Portland Bolt & Mfg. Co., Inc
3441 NW Guam St.
Portland OR 97210

Shipped To:
Portland Bolt & Mfg. Co., Inc
3441 NW Guam St.
Portland OR 97210

Customer PO Number	Order Date	Order Quantity	Customer Part Number
31472	18-Jul-17	100	19502

Fastener Type	Description	Thread Description
Coupling Nut	1-1/2" Hex x 3" Long	7/8" - 9 UNC O/S RH

Fastener Specification	Coating Specification	Fastener Lot Number
ASTM A563 Gr DH	ASTM F2329	4878

Raw Material Lot Code	Raw Material Grade	Heat Number
21787-1	ASTM A108 Gr 4140	NF100884291

Cold Finish Source	Cold Finish Country	Melt Source	Melt Country
Nucor	USA	Nucor Bar NE	USA

Heat Analysis per Material Supplier:

%C	%MN	%P	%S	%SI	%CR	%NI	%MO
0.430%	0.910%	0.011%	0.023%	0.250%	0.990%	0.06%	0.170%

Heat Treatment Process:
Harden @ 1550 F for 2 Hrs. Oil Quench
Temper @ 1175 F for 2.5 Hrs. Air Cool

Test #1	Test #2	Test #3
Proof Load	Hardness	
Results	**Results**	**Results**
Pass	Pass	

We certify that this data is a true representation of information provided by our material supplier and testing laboratory and that these fasteners were manufactured, sampled, tested and inspected in accordance with the specifications listed.

These fasteners were manufactured and tested in the USA, from steel which was melted and manufactured in the USA.

Paul Doherty
Wecall Inc.

24-Jul-17

Figure C-28. ⅞-in. Diameter Heavy Hex Coupling Nut Certificate of Conformance, Test No. N2BR-1

UNYTITE INC.
INNOVATIVE FASTENING SYSTEMS

Unytite, Inc.
One Unytite Drive
Peru, IL 61354
Tel 815-224-2221
Fax 815-224-3434

INSPECTION CERTIFICATE

Job No: 26357 | **Job Information** | **Certified Date:** 8/31/17

Customer:
Customer PO No:
Lot Number: 26357-6214369204
Ship To:
Shipped Qty:

Part Information

Part No: A563 7/8-9 +0.022 DH HHN HDG BLUE DYE-0

Description: ASTM A563 HHN, Grade DH, Hot Dipped Galv, Blue Dye

Manufactured Quantity: 33,763

Applicable Specifications

Specification	Amend	Specification	Amend
ASME B1.1	2003	ASME B18.2.2	2015
ASME B18.2.6	2010	ASTM A563	2015
ASTM F2329	2013	ASTM F606/606M	2014
ASTM F812/F812M	2012		

Test Results
Test No: 15662 Test: A563 DH Mechanical Properties

Description	Hardness (HRC)	Tempering Temp (800 degree F Min)	Proof Load (Pass/Fail) (ASTM Min)	Shape & Dimension ASME B18.2.2	Thread Precision ASME B18.1.1	Visual ASTM F812
Sample Inspection	27.95	1,175	69,200	Pass	Pass	Pass

Certified Chemical Analysis

Heat No	Grade	Manufacturer	Origin	C	Mn	P	S	Si	Cr	Ni	Cu
6214369204	1045	Gerdau Ameristeel	USA	0.4400	0.7200	0.007	0.0270	0.2100	0.1800	0.0700	0.1300

Notes

All tests are in accordance with the latest revisions of the methods prescribed in the applicable SAE and ASTM Specifications.

The samples tested conform the specifications as described/listed above and were manufactured free of mercury contamination and there is no welding performed in the production of the products. No heats to which Bismuth, Selenium, Tellurium, or Lead was intentionally added have been used to produce products.
The steel was melted and manufactured in the U.S.A. and the product was manufactured and tested in the U.S.A.

We certify that this data is true representation of information provided by the material supplier and our testing laboratory. This certified material test report relates only to the items listed on this document and may not be reproduced except in full.

OFFICIAL SEAL
JEAN MARGHERIO
NOTARY PUBLIC - STATE OF ILLINOIS
MY COMMISSION EXPIRES:10/18/17

D Savage | 8/31/17
Savage, Dan - Supervisor, Quality | Date

Plex 8/31/17 2:53 PM dsavage Page 1

Figure C-29. ⅞-in. Diameter Heavy Hex Nut Material Certification, Test No. N2BR-1

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 : 2017/12/04

PURCHASER : FASTENAL COMPANY PURCHASING
PO. NUMBER : 110207371
COMMODITY : FINISHED HEX NUT GR-A
SIZE : 1-8 NC
LOT NO : 1N1640157
SHIP QUANTITY : 10, 800 PCS
LOT QUANTITY 27, 604 PCS
HEADMARKS :
MANUFACTURE DATE : 2016/04/26
COUNTRY OF ORIGIN : CHINA

PACKING NO : GEM160426014
INVOICE NO : GEM/FNL-160512WI-1
PART NO : 36119
SAMPLING PLAN : ASME B18. 18-2011(Category. 2)/ASTM F1470-2012
HEAT NO : 15306714-3
MATERIAL : X1008A
FINISH : PLAIN

PERCENTAGE COMPOSITION OF CHEMISTRY:ACCORDING TO ASTM A563-2015

Chemistry	AL%	C%	MN%	P%	S%	SI%
Spec. : MIN.						
MAX.		0. 5800		0. 1300	0. 2300	
Test Value	0. 0340	0. 0700	0. 2700	0. 0100	0. 0090	0. 0400

DIMENSIONAL INSPECTIONS :ACCORDING TO ASME B18. 2. 2-2015

SAMPLED BY : ZHANG XIA

INSPECTIONS ITEM	SAMPLE	SPECIFIED		ACTUAL RESULT	ACC.	REJ.
WIDTH ACROSS CORNERS	4PCS		1. 6530-1. 7320 inch	1. 6740-1. 6770 inch	4	0
FIM	15PCS	ASME B18. 2. 2-2015	Max. 0. 0270 inch	0. 0140-0. 0210 inch	15	0
THICKNESS	4PCS		0. 8310-0. 8870 inch	0. 8600-0. 8640 inch	4	0
WIDTH ACROSS FLATS	4PCS		1. 4500-1. 5000 inch	1. 4570-1. 4610 inch	4	0
SURFACE DISCONTINUITIES	29PCS		ASTM F812-2012	PASSED	29	0
THREAD	15PCS		GAGING SYSTEM 21	PASSED	15	0

MECHANICAL PROPERTIES : ACCORDING TO ASTM A563-2015

SAMPLED BY : GDAN LIAN

INSPECTIONS ITEM	SAMPLE	TEST METHOD	REF	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
CORE HARDNESS	15PCS	ASTM F606-2014		68-107 HRB	80-82 HRB	15	0
PROOF LOAD	4PCS	ASTM F606-2014		Min. 90 KSI	OK	4	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: Erin

Figure C-30. 1-in. Diameter Hex Nut Material Certification, Test No. N2BR-1

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

STELFAST® INC.

22979 Stelfast Parkway
Strongsville, Ohio 44149

CERTIFICATE OF CONFORMANCE

DESCRIPTION OF MATERIAL AND SPECIFICATIONS

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

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

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

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

David Biss
Quality Manager

December 07, 2015

Page 1 of 1

Figure C-31. ⅝-in. Dia. Hex Nut Certificate of Conformance, Test No. N2BR-1

Apr. 12. 2018 4:32PM . Fastenal-NELIN No. 4682 P. 3

FASTENAL®

Certificate of Compliance

Sold To:

UNL TRANSPORTATION

Purchase Order:

Job: TL-2 and Bullnose

Invoice Date: 03/27/2018

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

5 PCS 7/8"-9 x 8" ASTM A307 Grade A Hot Dipped Galvanized Hex Bolt SUPPLIED UNDER OUR TRACE NUMBER line35042 AND UNDER PART NUMBER 92005

20 PCS 7/8"-9 Hot Dip Galvanized Finish Grade A Finished Hex Nut SUPPLIED UNDER OUR TRACE NUMBER 110254885 AND UNDER PART NUMBER 36717

5 PCS 7/8"-9 x 8" ASTM A307 Grade A Hot Dipped Galvanized Hex Bolt SUPPLIED UNDER OUR TRACE NUMBER line35042 AND UNDER PART NUMBER 92005

5 PCS 7/8"-9 x 8" ASTM A307 Grade A Hot Dipped Galvanized Hex Bolt SUPPLIED UNDER OUR TRACE NUMBER line35042 AND UNDER PART NUMBER 92005

5 PCS 7/8"-9 x 8" ASTM A307 Grade A Hot Dipped Galvanized Hex Bolt SUPPLIED UNDER OUR TRACE NUMBER line35042 AND UNDER PART NUMBER 92005

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

Fastenal Account Representative Signature

Printed Name

4/12/18

Date

Please check current revision to avoid using obsolete copies.

This document was printed on 04/12/2018 and was current at that time.

Fastenal Store Location/Address

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

Page 1 of 1

Figure C-32. ⅞-in. Dia. 8-in. Long Hex Head Bolt and Nut Certificate of Compliance, Test No. N2BR-1

CERTIFIED MATERIAL TEST REPORT
FOR ASTM A307, GRADE A - MACHINE BOLTS

FACTORY: NINGBO ECONOMIC & TECHNICAL DEVELOPMENT ZONE YONGGANG FASTENERS CO., LTD.
REPORT DATE:2016/12/29
R#17-507 H#816070039
ADDRESS: FuShan South Road No.17,BeiLun NingBo China
BCT Cable Bracket Bolts
MANUFACTURE DATE:2016/12/2
TEL#(852)25423366
CUSTOMER: FASTENAL
MFG LOT NUMBER:M-2016HT927-9
SAMPE SIZE: ACC.TO Dimension:ASME B18.18-11;Mechanical Properties:ASTM F1470-12
MANU QTY: 4800PCS
SHIPPED QTY: 4800PCS
SIZE: 5/8-11X1 1/2 HDG
HEADMARKS: 307A PLUS NY
PO NUMBER:220023115
PART NO:1191919

STEEL PROPERTIES:
MATERIAL TYPE:Q195
HEAT NUMBER: 816070039

CHEMISTRY SPEC:	C %*100	Mn%*100	P %*1000	S %*1000
Grade A ASTM A307-12	0.29max	1.20 max	0.04max	0.15max
TEST:	0.07	0.28	0.016	0.003

DIMENSIONAL INSPECTIONS Unit:inch SPECIFICATION: ASME B18.2.1 - 2012

CHARACTERISTICS	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
********************	**********************************	*****************	********	********
VISUAL	ASTM F788-2013	PASSED	22	0
THREAD	ASME B1.1-2003,3A GO,2A NOGO	PASSED	15	0
WIDTH FLATS	0.906-0.938	0.915-0.928	4	0
WIDTH A/C	1.033-1.083	1.048-1.057	4	0
HEAD HEIGHT	0.378-0.444	0.394-0.424	4	0
THREAD LENGTH	1.420-1.560	1.435-1.541	15	0
LENGTH	1.420-1.560	1.435-1.541	15	0

MECHANICAL PROPERTIES: SPECIFICATION: ASTM A307-2012 GR-A

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
********************	*****************	*****************	*****************	********	********
CORE HARDNESS :	ASTM F606-2014	69-100 HRB	76-79 HRB	4	0
WEDGE TENSILE:	ASTM F606-2014	Min 60 KSI	65-69 KSI	4	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
COATINGS OF ZINC:	SPECIFIATION:ASTM F2329-2013				
HOT DIP GALVANIZED	ASTM B568-98(2104)	Min 0.0017"	0.0017" -0.0018"	4	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.

Maker's ISO# 00109Q16722R3M/3302

NINGBO ECONOMIC & TECHNICAL DEVELOPMENT ZONE YONGGANG FASTENERS CO.,LTD

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

Figure C-33. ⅝-in. Dia. 1½-in. Long Hex Head Bolt Certificate of Conformance, Test No. N2BR-1

JINAN STAR FASTENER CO., LTD

NO.75 CUIPING STREET PINGYIN JINAN CHINA
TEL: 0086 531 87896380 FAX: 0086 531 87871032
E-mail: zhangyuhua@star-fastener.com

CERTIFICATE OF INSPECTION

HY038.1.3-12

Manufacturering Date:2016-7-10 **DATE: 2016-7-17**

Customer Part Number客户编码	91830
Customer Control (PO) Number客户订单号	120263056
Product Description产品描述	5/16-18x1-1/4 307A G
Surface Condition表面处理	HDG
Head Marking头部标记	307A and 01RL
Lot Size (Manufactured QTY):生产数量	17870pcs
Lot Size (QTY Shipped):装运数量	17860pcs
Lot Number订单号	FAS16161
Mechanical properties机械性能要求	ASTM A307-2014 GrA

Material type原材料名称:	Q235				Heat Number		G4604921			
	C%	Mn%	Si%	S%	P%	Ni%	Cr%		Cu%	
Chemical composition化学成份:标准	max0.33	max1.25		max0.051	max0.041					
Chemical composition化学成份:实测值	0.14	0.49	0.17	0.019	0.026	0.008	0.034		0.007	
Sampling Plan Used 使用的抽样方案	**Dimensional as per ASME B18.18-2011/Mechanical Property as per F1470-2012**									

Specification技术要求:	specification 检测标准	Test method 检测方法	Standard 标准值	单位	Test value 实测值	Sampling Plan 抽样方案	ACC 合格	REJ 不合格
Width across Flat对边尺寸	ASME B18.2.1-2012		0.484-0.500	in	0.488-0.491	5/0	5	0
Width across Corners对角尺寸	ASME B18.2.1-2012		0.552-0.577	in	0.568-0.571	5/0	5	0
Height高度	ASME B18.2.1-2012		0.195-0.235	in	0.205-0.209	5/0	5	0
Length总长度	ASME B18.2.1-2012		1.21-1.27	in	1.249-1.251	15/0	15	0
Radius under head头下R角	ASME B18.2.1-2012		0.01-0.03	in	0.012-0.014	15/0	15	0
Head Chamfer头部顶圆角度	ASME B18.2.1-2012		15-30°	°	22.5-22.7	5/0	5	0
Concentricity 同轴度	ASME B18.2.1-2012		0.03	in	0.011-0.013	5/0	5	0
Max Distance from under head to thread 头下间距max	ASME B18.2.1-2012		0.139	in	0.106-0.108	15/0	15	0
Major 大径	ANSI B1.1-2003		0.303-0.311	in	0.305-0.306	15/0	15	0
Thread 螺纹	ANSI B1.1-2003		NUT GO		NUT GO	15/0	15	0
Core Hardness芯部硬度	ASTM A307-2014	ASTM F606-2016	69-100	HRB	91.5-93.3	15/0	15	0
Tensile Strength抗拉强度	ASTM A307-2014	ASTM F606-2016	min60	KSI	89.3-91.5	5/0	5	0
Plating thickness镀层厚度	ASTM F2329-2013		0.002	in	0.0030-0.0047	29/0	29	0
Appearance外观	ASTM F788-2013		Visual		OK	29/0	29	0

Parts are manufactured and tested according to above specification, we certify that this is a true representation of information provided by manufacturer
产品是按照上述要求进行生产和检测的，我们证明厂家提供的信息是真实的

Signature: Fu Yan Jun The requirements are fulfilled

Title: Quality Manager Inspector（终检员）:马付彬

Figure C-34. $^{5}/_{16}$-in. 1¼-in. Long Hex Head Bolt Material Certification, Test No. N2BR-1

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

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

DATE: 29.Oct.2014

MFG LOT NUMBER: GL14023-2

CUSTOMER: FASTELNAL

PO NUMBER:120200536

SAMPLE PLAN : ACC. TO ASME B18.18 - 2011
SIZE: 5/16"-18 HDG QNTY: 75000 PCS

PART NO: 1136703

STEEL PROPERTIES
STEEL GRADE: Q195

HEAT NUMBER: 183425

	C %*100	Mn%*100	P %*1000	S %*1000
CHEMISTRY SPEC:	0.55max	min	0.12max	0.15max
TEST:	0.09	0.41	0.022	0.035

DIMENSIONAL INSPECTIONS — SPECIFICATION: ASME B18.2.2-2010

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
APPEARANCE	ASTM F812/F812M-07		PASSED	100	0
THREAD	ASME B1.3		PASSED	32	0
WIDTH A/F		0.500-0.489	0.497-0.491	32	0
WIDTH A/C		0.577-0.557	0.571-0.563	8	0
HEIGHT		0.273-0.258	0.269-0.260	8	0
MARK	NO MARKING		PASSED	100	0

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

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
HARDNESS :	ASTM F606-2010a	B68-C32 Max(107HRB)	86-88HRB	8	0
PROOF LOAD :	ASTM F606-2010a	Min80 Ksi	PASSED	4	0

CHARACTERISTICS	TEST METHOD	SPECIFIED	ACTUAL RESULT	ACC.	REJ.
HOT DIP GALVANIZED	ASTM F2329-05	MIN 0.0017"	0.0021"	4	0

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

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

Figure C-35. $^{5}/_{16}$-in. Hex Nut Material Certification, Test No. N2BR-1

McMASTER-CARR. Certificate of Compliance

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

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

Purchase Order
E000357170

Order Placed By
Shaun M Tighe

McMaster-Carr Number
2098331-01

Page 1 of 1

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

Certificate of compliance

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

Sarah Weinberg
Compliance Manager

Figure C-36. 16D Double Head Nail Certificate of Compliance, Test No. N2BR-1

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 07/12/2017
TIME 18:07:21
USER J.DUBOIS

SOLD TO

SHIP TO
17238
Longview Warehouse
4750 West Marshall Ave
LONGVIEW TX 75604

Washers

Order	Material No.	Description	Quantity	Weight	Customer Part	Customer PO	Ship Date
40288806-0030	80117296TM	11GA 72 X 96 A1011-CS-TYB TEMP HS	21	5,040			07/12/2017

Chemical Analysis

Heat No. B707141 Vendor STEEL DYNAMICS COLUMBUS DOMESTIC Mill STEEL DYNAMICS COLUMBUS Melted and Manufactured in the USA

Carbon	Manganese	Phosphorus	Sulphur	Silicon	Nickel	Chromium	Molybdenum	Boron	Copper	Aluminum	Titanium	Vanadium	Columbium	Nitrogen	Tin
0.0500	0.3200	0.0100	0.0030	0.0200	0.0300	0.0500	0.0100	0.0001	0.1100	0.0220	0.0020	0.0020	0.0030	0.0063	0.0060

Mechanical / Physical Properties

Mill Coil No. 17B759735

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

Batch 0004845086 21 EA 5,040 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-37. 1¾-in. x 1¾-in. x ⅛-in. Square Washer, Test No. N2BR-1

Apr. 12. 2018 4:32PM Fastenal-NELIN No. 4682 P. 2

FASTENAL®

Certificate of Compliance

Sold To:

UNL TRANSPORTATION

Purchase Order:

Job: TL-2 and Bullnose

Invoice Date: 03/27/2018

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

40 PCS 7/8" x 2.250" OD Low Carbon Hot Dipped Galvanized Finish Steel USS General Purpose Flat Washer SUPPLIED UNDER OUR TRACE NUMBER 170077928 AND UNDER PART NUMBER 33187

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

Fastenal Account Representative Signature

Jeremiah Morehead

Printed Name

4/12/18

Date

Please check current revision to avoid using obsolete copies.

This document was printed on 04/12/2018 and was current at that time.

Fastenal Store Location/Address

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

Page 1 of 1

Figure C-38. ⅞-in. Diameter Plain Round Washer Certificate of Compliance, Test No. N2BR-1

TSI EST. 1991 TECHNICAL STAMPING

TECHNICAL STAMPING, INC.

50600 E. RUSSELL SCHMIDT BLVD.
CHESTERFIELD TWP., MI 48051
PH(586)948-3285 / FX(586)948-3286

MATERIAL CERTIFICATION

CUSTOMER NAME	CUSTOMER ORDER NUMBER	DATE
Portland Bolt & Mfg. Co.	30701	11/30/2017

PART NUMBER - CUSTOMER LOT NO.	LOT NUMBER	QUANTITY
7/8" F436 Hdg 16447	0917-627	2,400

STEEL GRADE	HEAT	C	MN	P	S	SI	AL	REVISION
	173583	.52	.82	.012	.002	.239	.027	ASTM F-436-10

SPECIFICATION		ACTUAL	GAUGE
O.D -	1.718 - 1.782	1.722 - 1.725	CALIPER
I.D -	.938 - .970	.948 - .951	CALIPER, PIN GAUGE
THICKNESS-	.136 - .177	.142 - .145	MICROMETER
FLAT-	Max .010	.002	CALIPER
HEAT TREAT -	38 - 45 HRC	41 - 44	
PLATING-		See Attached Cert	
OTHER		N/A	

WE HEARBY CERTIFY THIS PRODUCT WAS PRODUCED UNDER A ISO-9001:2008 QUALITY ASSURANCE SYSTEM. ISO-9001:2008 CERTIFICATION NUMBER-1265 - DATE OF REGIS. JAN. 3, 2003 ALL MATERIALS ARE MADE AND MELTED IN THE U.S.A. THIS PRODUCT WAS MANUFACTURED IN CHESTERFIELD, MICHIGAN, U.S.A. THIS PRODUCT CONFORMS TO ALL REQUIREMENTS FOR WASHERS AS PRODUCED ACCORDING TO A.S.T.M. F-436-10. THE ABOVE TEST RESULTS APPLY ONLY TO THE ITEMS TESTED. THIS TEST REPORT MUST NOT BE REPRODUCED EXCEPT IN FULL WITHOUT PRIOR WRITTEN APPROVAL.

CERTIFIED
ISO 9001:

AUTHORIZED SIGNATURE

Qity 3008 Rev. 2 11/26/01

Figure C-39. ⅞-in. Diameter Hardened Flat Washer Material Certification, Test No. N2BR-1

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

CERTIFICATON BCT Cables Yellow Paint

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

Figure C-40. BCT Anchor Cable End Swaged Fitting and ¾-in. Diameter 6x19 24½-in. Long IWRC IPS Wire Rope Material Certification, Test No. N2BR-1

GREGORY HIGHWAY PRODUCTS, INC.
4100 13th St. SW
Canton, Ohio 44710

MIDWEST MACHINERY & SUPPLY CO.
P. O. BOX 703

MILFORD,NE,68405

Test Report
Ship Date: 11/17/2017
Customer P.O.: 3515
Shipped to: MIDWEST MACHINERY & SUPPLY CO.
Project:
GHP Order No: 128AA

HT # code	LOT#	C.	Mn.	P.	S.	Si.	Tensile	Yield	Elong.	Quantity	Class	Type	Description
A74070		0.21	0.46	0.012	0.002	0.03	76100	58800	25.2	4	A	2	12GA TB TRANS.
4181496		0.24	0.84	0.014	0.01	0.01	72400	44800	34	4		2	5/8IN X 8IN X 8IN BRG. PL.
4181489		0.09	0.45	0.012	0.004	0.01	58000	43100	27	4		2	350 STRUT & YOKE
196828BM		0.04	0.84	0.014	0.003		76000	74000	25			2	350 STRUT & YOKE
E22985		0.17	0.51	0.013	0.008	0.008	72510	64310	29.5	4		2	2IN X 5 1/2IN PIPE SLEEVE
811T08220		0.22	0.81	0.013	0.006	0.005	71412	56323	35	8		2	3/16IN X 6IN X 8IN X 6FT0IN TUBE SLEEVE

All Galvanizing has occurred in the United States
All steel used in the manufacture is of Domestic Origin, "Made and Melted in the United States"
All Steel used meets Title 23CFR 635.410 - Buy America
All Guardrail and Terminal Sections meets AASHTO M-180, All structural steel meets AASHTO M-183 & M270
All Bolts and Nuts are of Domestic Origin
All material fabricated in accordance with Nebraska Department of Transportation
All controlled oxidized/corrosion resistant Guardrail and terminal sections meet ASTM A606, Type 4.

By: ______________

James P. Dehnke
Notary Public, State of Ohio
My Commission Expires 10-19-2019

STATE OF OHIO: COUNTY OF STARK
Sworn to and subscribed before me, a Notary Public, by Andrew Artar this 21 day of November, 2017

Notary Public, State of Ohio

Figure C-41. 8-in. x 8-in. x ⅝-in. Anchor Bearing Plate Material Certification, Test No. N2BR-1

EXLTUBE

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

STEEL VENTURES, LLC dba EXLTUBE

Certified Test Report

Customer:	Size:	Customer Order No:	Date:
SPS - New Century 401 New Century Parkway NEW CENTURY KS 66031-1127	02.375	4500269918	07/25/2016
	Gauge: .154	Delivery No: 82798116 Load No. 3774661	
	Specification: ASTM A500-13 Gr.B/C, ASTM A53-12 Gr.B BNT*, ASME SA53 Gr.B BNT*		

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

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

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

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

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

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

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

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

STEEL VENTURES, LLC dba EXLTUBE

Jonathan Wolfe
Quality Assurance Manager

Figure C-42. 2⅜-in. O.D. x 6-in. Long BCT Post Sleeve Material Certification, Test No. N2BR-1

Certified Analysis

Trinity Highway Products, LLC
2548 N.E. 28th St.
Ft Worth, TX
Customer: MIDWEST 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	6'0 TUBE SL/.188X8X6	A-500			A8F1160	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	0.180	0.830	0.010	0.005	0.020	0.230	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 Onal.a

Figure C-43. Anchor Bracket Assembly Material Certification, Test No. N2BR-1

Certifieа ₋nalysis

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: 1275017
Customer PO: 3400
BOL Number: 99202
Document #: 1
Shipped To: NE
Use State: NE

Prod Ln Grp: 3-Guardrail (Dom)

Ship Date:

As of: 3/22/17

Qty	Part #	Description	Spec	CL	TY	Heat Code/ Heat	Yield	TS	Elg	C	Mn	P	S	Si	Cu	Cb	Cr	Vn	ACW
400	3380G	5/8"X1.5" HEX BOLT A307	HW			0052429-113200													
600	3400G	5/8"X2" GR BOLT	HW			29221													
500	3480G	5/8"X8" GR BOLT A307	HW			29369													
450	3500G	5/8"X10" GR BOLT A307	HW			29550-B													
700	3540G	5/8"X14" GR BOLT A307	HW			29567													
300	3580G	5/8"X18" GR BOLT A307	HW			29338													
600	4235G	3/16"X1.75"X3" WSHR	HW			C7001													
10	9852A	STRUT & YOKE ASSY	A-36			195070	52,940	69,970	31.1	0.190	0.520	0.014	0.004	0.020	0.110	0.000	0.050	0.000	4
	9852A		A-36			A82292	54,000	73,300	31.0	0.200	0.460	0.010	0.003	0.020	0.150	0.000	0.060	0.001	4
	9852A		A-36			645887	39,900	62,500	32.0	0.190	0.400	0.009	0.015	0.009	0.054	0.001	0.038	0.001	4
	9852A		A-36			645887	39,900	62,500	32.0	0.190	0.400	0.009	0.015	0.009	0.054	0.001	0.038	0.001	4
	9852A		HW			15056184													
20	12173G	T12/6'3/4@1'6.75"/S			2	L35216													
			M-180	A	2	209331	62,090	81,500	28.1	0.190	0.720	0.013	0.002	0.020	0.110	0.000	0.070	0.002	4
			M-180	A	2	209332	61,400	81,290	25.3	0.190	0.730	0.014	0.003	0.020	0.120	0.000	0.060	0.001	4
			M-180	A	2	209333	61,200	80,050	25.8	0.200	0.740	0.016	0.005	0.010	0.120	0.000	0.070	0.002	4

2 of 4

Figure C-44. Ground Strut Assembly Material Certification, Test No. N2BR-1

Ready Mixed Concrete Company
6200 Cornhusker Hwy, Lincoln, NE 68529
Phone: (402) 434-1844 Fax: (402) 434-1877

Customer's Signature:

PLANT	TRUCK	DRIVER	CUSTOMER	PROJECT	TAX	PO NUMBER	DATE	TIME	TICKET
01	0118	3058	3	3		TL2	3/13/18	11:45 AM	1222277

Customer	Delivery Address	Special Instructions
CIA---MIDWEST ROADSIDE SAFETY	4630 NW 36TH STREET	NORTH OF THE GOODYEAR HANGER

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
5.50	5.50	5.50	48503000	PR 8 1/2 SK 3	yd	$134.00	$737.00
				MINIMUM HAUL			$15.00
				WINTER SERVICE			$24.75

Water Added On Job At Customer's Request:

SLUMP: 4.00 in

Notes:

TICKET SUBTOTAL	$776.75
SALES TAX	$0.00
TICKET TOTAL	$776.75
PREVIOUS TOTAL	
GRAND TOTAL	$776.75

CAUTION FRESH CONCRETE
KEEP CHILDREN AWAY

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

Terms & Conditions

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

MATERIAL	DESCRIPTION	DESIGN QTY	REQUIRED	BATCHED	% VAR	% MOISTURE	ACTUAL WATER
G47B	47B GRAVEL	1785 lb	10014 lb	9980 lb	-0.34%	2.00% M	23 gl
L47B	47B ROCK	777 lb	4316 lb	4300 lb	-0.11%	1.00% M	5 gl
CEM3	CEMENT TYPE:	799 lb	4395 lb	4405 lb	0.24%		
WATER	WATER	40.2 GL	198.0 GL	196.5 GL	-0.72%		196.5 gl
LRWR	POZZ 322N LOV	32.00 oz	176.00 oz	176.00 oz	0.00%		
AIR	MICRO AIR 200	8.40 oz	46.20 oz	46.00 oz	-0.43%		

Actual Load: 20339 lb | Num Batches: 1 | Design W/C: 0.42 | Water/Cement: 0.43 A | Design Water: 221.1 gl | Manual | Actual: 225.1 gl
Slump: 4.00 in # | Water in Truck: 0.0 GL | Adjust Water: 0.0 GL / Load | Trim Water: 0.0 GL / CYDS
Actual W/C Ratio 0.43 | Actual Water: 225 gl | Batched Cement: 4405 lb | Allowable Water: 0 lb | To Add: 0.0 gl

Figure C-45. Concrete Deck Material, Test No. N2BR-1

Ready Mixed Concrete Company
6200 Cornhusker Hwy, Lincoln, NE 68529
Phone: (402) 434-1844 Fax: (402) 434-1877

Customer's Signature: ____________________

PLANT	TRUCK	DRIVER	CUSTOMER	PROJECT	TAX	PO NUMBER	DATE	TIME	TICKET
01	0131	8890	3	3		TL2	3/13/18	12:56 PM	1222285

Customer	Delivery Address	Special Instructions
CIA---MIDWEST ROADSIDE SAFETY	4630 NW 36TH STREET	NORTH OF THE GOODYEAR HANGER

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
1.00	1.00	1.00	**48503000**	**PR 8 1/2 SK 3**	yd	$134.00	$134.00
				MINIMUM HAUL			$60.00
				WINTER SERVICE			$4.50

Water Added On Job At Customer's Request: ____________

SLUMP: 4.00 in

Notes:

TICKET SUBTOTAL	$198.50
SALES TAX	$0.00
TICKET TOTAL	**$198.50**
PREVIOUS TOTAL	
GRAND TOTAL	**$198.50**

CAUTION FRESH CONCRETE
KEEP CHILDREN AWAY

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

Terms & Conditions

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

MATERIAL	DESCRIPTION	DESIGN QTY	REQUIRED	BATCHED	% VAR	% MOISTURE	ACTUAL WATER
G47B	47B GRAVEL	1785 lb	1821 lb	2000 lb	+ 9.96%	2.00% M	5 gl
L47B	47B ROCK	777 lb	785 lb	780 lb	-0.17%	1.00% M	1 gl
CEM3	CEMENT TYPE:	799 lb	799 lb	810 lb	1.38%		
WATER	WATER	40.2 GL	36.0 GL	36.0 GL	-0.11%		36.0 gl
LRWR	POZZ 322N LOV	32.00 oz	32.00 oz	33.00 oz	3.13%		
AIR	MICRO AIR 200	8.40 oz	8.40 oz	8.00 oz	-4.76%		

Actual | Num Batches: 1 | Manual

Load: 3893 lb	**Design W/C: 0.42**	Water/Cement: 0.43 A	Design Water: 40.2 gl	Actual: 41.6 gl
Slump: 4.00 in #	Water in Truck: 0.0 GL	Adjust Water: 0.0 GL / Load	Trim Water: 0.0 GL / CYDS	
Actual W/C Ratio 0.43	Actual Water: 42 gl	Batched Cement: 810 lb	Allowable Water: 0 lb	To Add: 0.0 gl

Figure C-46. Concrete Deck Material, Test No. N2BR-1

Ready Mixed Concrete Company
6200 Cornhusker Hwy, Lincoln, NE 68529
Phone: (402) 434-1844 Fax: (402) 434-1877

Customer's Signature:

PLANT	TRUCK	DRIVER	CUSTOMER	PROJECT	TAX	PO NUMBER	DATE	TIME	TICKET
4	0241	6580	00003	3		BUNKY 560-1716	2/1/18	10:48 AM	4202504

Customer
CIA--MIDWEST ROADSIDE SAFETY

Delivery Address
4630 NW 36TH STREET

Special Instructions

LOAD QUANTITY	CUMULATIVE QUANTITY	ORDERED QUANTITY	PRODUCT CODE	PRODUCT DESCRIPTION	UOM	UNIT PRICE	EXTENDED PRICE
2.50	2.50	2.50	470031PF	47BD (1PF) WO/R	yd	$118.91	$297.28
				MINIMUM HAUL			$45.00
				WINTER SERVICE			$11.25

Water Added On Job At Customer's Request:

SLUMP: 4.00 in

Notes:

TICKET SUBTOTAL	$353.53
SALES TAX	$0.00
TICKET TOTAL	$353.53
PREVIOUS TOTAL	
GRAND TOTAL	$353.53

CAUTION FRESH CONCRETE
KEEP CHILDREN AWAY

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

Terms & Conditions

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

MATERIAL	DESCRIPTION	DESIGN QTY	REQUIRED	BATCHED	% VAR	% MOISTURE	ACTUAL WATER
G47B	47B GRAVEL	1975.0 lb	5020.2 lb	5040.0 lb	0.39%	1.68% A	10.0 gl
L47B	47B ROCK	840.0 lb	2128.5 lb	2140.0 lb	0.16%	1.36% A	3.4 gl
CEM1PF	1PF CEMENT	658.0 lb	1645.0 lb	1640.0 lb	-0.30%		
WATER	WATER	31.6 gl	68.2 gl	68.5 gl	-0.74%		68.5 gl
LRWR	POZZ 322N LOV	20.0 oz	50.0 oz	50.0 oz	0.00%		
AIR	MB AE 200 air e	5.9 oz	14.8 oz	14.0 oz	-5.08%		

Actual — Num Batches: 1 — Manual

Load: 9396 lb — Design W/C: 0.40 — Water/Cement: 0.42 A — Design Water: 79.0 gl — Actual: 81.9 gl

Slump: 4.00 in # — Water in Truck: 0.0 gl — Adjust Water: 0.0 gl / Load — Trim Water: 0.0 gl / CYDS

Actual W/C Ratio 0.42 — Actual Water: 82 gl — Batched Cement: 1640 lb — Allowable Water: 0 lb — To Add: 0.0 gl

Figure C-47. Grade Beam Concrete, Test No. N2BR-1

benesch
engineers · scientists · planners

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

COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 6x12

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility **Date** 03-Apr-18
Project Name: Miscellaneous Concrete Testing
Placement Location: TL2, Test A (Grade Beam)

Mix Designation: N/A **Required Strength:** N/A

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area, sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
URR- 54		2/1/2018	4/2/2018	4/3/2018	60	1	61	12	5.98	28.09	161,742	5,760		6	C 1231

1 cc: Ms. Karla Lechtenberg
Midwest Roadside Safety Facility

Remarks:

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

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

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

Report Number 2147370069
Page 1

Sketches of Types of Fractures

Type 1 — Reasonably well-formed cones on both ends, less than 1 in. [25 mm] of cracking through caps

Type 2 — Well-formed cone on one end, vertical cracks running through caps, no well-defined cone on other end

Type 3 — Columnar vertical cracking through both ends, no well-formed cones

Type 4 — Diagonal fracture with no cracking through ends; tap with hammer to distinguish from Type 1

Type 5 — Side fractures at top or bottom (occur commonly with unbonded caps)

Type 6 — Similar to Type 5 but end of cylinder is pointed

ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By [signature]
Brant Wells, Field/Lab Operations Manager

Figure C-48. Concrete Grade Beam Material Certification, Test No. N2BR-1

benesch
engineers · scientists · planners

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

COMPRESSION TEST OF CYLINDRICAL CONCRETE SPECIMENS - 6x12

ASTM Designation: C 39

Client Name: Midwest Roadside Safety Facility **Date** 11-Apr-18
Project Name: Miscellaneous Concrete Testing
Placement Location: TL2 Test B Deck

Mix Designation: **Required Strength:**

Laboratory Test Data

Laboratory Identification	Field Identification	Date Cast	Date Received	Date Tested	Days Cured in Field	Days Cured in Laboratory	Age of Test, Days	Length of Specimen, in.	Diameter of Specimen, in.	Cross-Sectional Area, sq.in.	Maximum Load, lbf	Compressive Strength, psi.	Required Strength, psi.	Type of Fracture	ASTM Practice for Capping Specimen
URR- 56	TestB Deck	3/13/2018	4/11/2018	4/11/2018	29	0	29	12	5.99	28.15	166,071	5,900		5	C 1231
URR- 57	TestC Deck	3/13/2018	4/11/2018	4/11/2018	29	0	29	12	5.98	28.11	159,963	5,690		4	C 1231

1 cc: Ms. Karla Lechtenberg
Midwest Roadside Safety Facility

Remarks:

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

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

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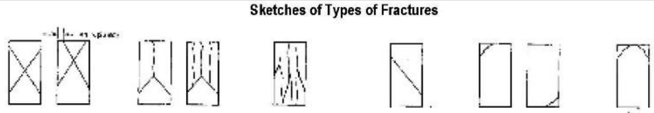
Sketches of Types of Fractures



ALFRED BENESCH & COMPANY
CONSTRUCTION MATERIALS LABORATORY

By Brant Wells
Brant Wells, Field/Lab Operations Manager

Figure C-49. Concrete Deck Material Certification, Test No. N2BR-1

Appendix D. Vehicle Center of Gravity Determination

Date: 4/12/2018 **Test Name:** 2NBR-1 **VIN:** 1D7RB1DG4BS514230
Year: 2011 **Make:** Dodge **Model:** Ram 1500

Vehicle CG Determination

VEHICLE	Equipment	Weight (lb.)	Vertical CG (in.)	Vertical M (lb.-in.)
+	Unballasted Truck (Curb)	5111	28 3/8	145053.13
+	Hub	19	15	285
+	Brake activation cylinder & frame	7	27	189
+	Pneumatic tank (Nitrogen)	28	26	728
+	Strobe/Brake Battery	5	25	125
+	Brake Receiver/Wires	5	51	255
+	CG Plate including DAS	38	24	912
-	Battery	-46	41	-1886
-	Oil	-13	19	-247
-	Interior	-87	32	-2784
-	Fuel	-166	20	-3320
-	Coolant	-11	31	-341
-	Washer fluid	0	31	0
+	Water Ballast (In Fuel Tank)	63	17	1071
+	Onboard Supplemental Battery	12	26	312
+	Smart Barrier Stuff	10	25	250
+	TDAS	17	25	425
Note: (+) is added equipment to vehicle, (-) is removed equipment from vehicle				141027.13

Estimated Total Weight (lb.) 4992
Vertical CG Location (in.) 28.2506

Vehicle Dimensions for C.G. Calculations

Wheel Base: 140 3/8 in. Front Track Width: 67 3/4 in.
Rear Track Width: 67 3/4 in.

Center of Gravity	**2270P MASH Targets**	**Test Inertial**	**Difference**
Test Inertial Weight (lb.)	5000 ± 110	4999	-1.0
Longitudinal CG (in.)	63 ± 4	60.878776	-2.12122
Lateral CG (in.)	NA	-0.386252	NA
Vertical CG (in.)	28 or greater	28.25	0.25063

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	1457	1437
Rear	1123	1094

FRONT	2894	lb.
REAR	2217	lb.
TOTAL	5111	lb.

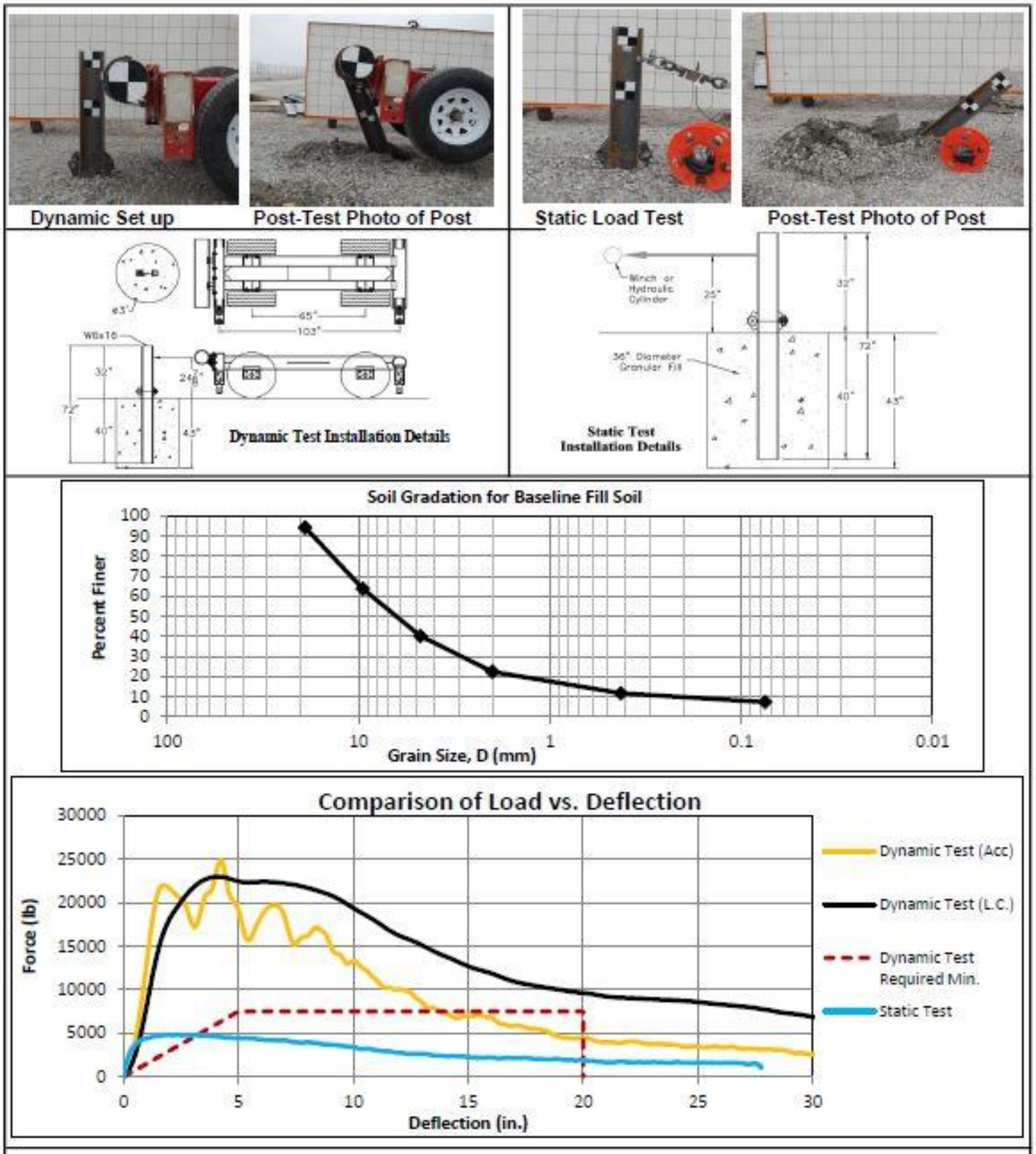
TEST INERTIAL WEIGHT (lb.)

	Left	Right
Front	1451	1380
Rear	1077	1091

FRONT	2831	lb.
REAR	2168	lb.
TOTAL	4999	lb.

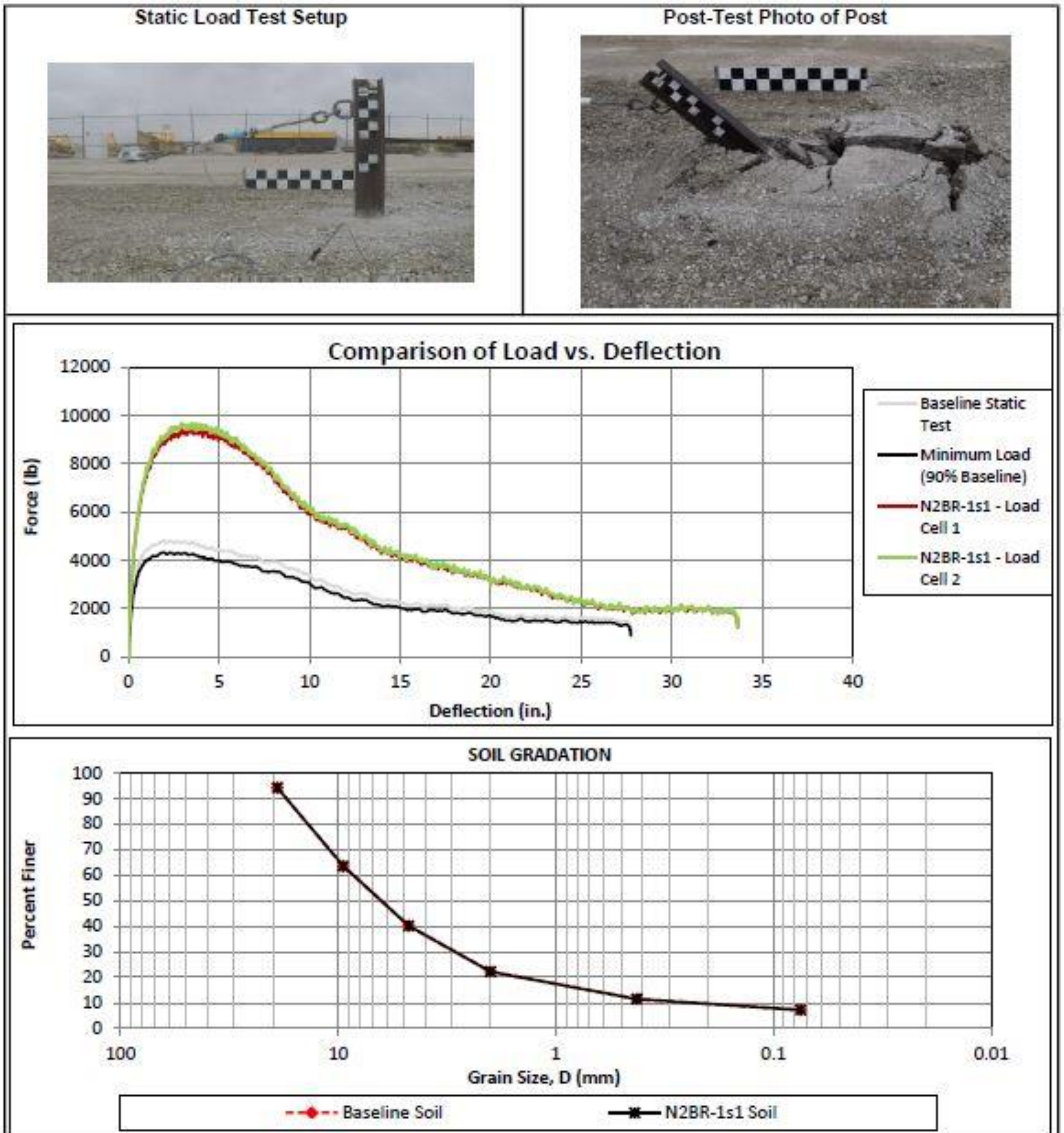
Figure D-1. Vehicle Mass Distribution, Test No. N2BR-1

Appendix E. 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 E-1. Soil Strength, Initial Calibration Tests



Date..	4/11/2018
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 E-2. Static Soil Test, Test No. N2BR-1

Appendix F. Vehicle Deformation Records

Date: 4/12/2018 Test Name: 2NBR-1 VIN: 1D7RB1DG4BS514230
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	48.0	14.8	-3.8	47.9	14.8	-4.0	0.1	0.0	-0.1	0.2	0.1	X
	2	48.2	18.1	-1.4	48.7	18.1	-1.8	-0.5	-0.1	-0.5	0.7	0.0	
	3	49.6	20.8	1.0	49.6	20.8	0.9	0.0	0.0	-0.1	0.1	0.0	X
	4	49.7	25.4	0.9	49.7	25.3	0.7	0.0	0.0	-0.2	0.2	0.0	
	5	49.2	29.1	-0.1	49.2	29.1	-0.3	0.0	0.0	-0.2	0.2	0.0	X
	6	43.2	13.4	-1.9	43.3	13.5	-2.1	0.0	0.0	-0.2	0.2	0.0	
	7	44.0	17.4	0.5	44.1	17.5	0.4	0.0	-0.1	-0.2	0.2	0.0	
	8	45.0	20.8	3.4	45.0	20.8	3.2	0.0	0.0	-0.2	0.2	0.0	X
	9	44.8	26.1	3.3	44.8	26.1	3.1	0.0	0.0	-0.2	0.2	0.0	
	10	44.6	29.6	3.3	44.6	29.7	3.1	0.0	-0.1	-0.2	0.2	0.0	X
FLOOR PAN (Z)	11	39.4	12.1	0.5	39.4	12.1	0.3	0.0	0.0	-0.2	0.2	-0.2	Z
	12	40.4	16.5	4.0	40.4	16.5	3.8	0.0	0.0	-0.2	0.2	-0.2	Z
	13	40.7	20.8	5.4	40.7	20.8	5.2	0.0	0.0	-0.2	0.2	-0.2	Z
	14	40.4	26.4	5.3	40.4	26.5	5.1	0.0	-0.1	-0.2	0.2	-0.2	Z
	15	40.3	30.0	5.3	40.2	30.0	5.1	0.1	-0.1	-0.2	0.2	-0.2	Z
	16	35.9	11.0	2.0	35.9	11.0	1.8	0.0	0.0	-0.2	0.2	-0.2	Z
	17	36.9	16.1	5.4	36.8	16.1	5.2	0.0	0.0	-0.2	0.2	-0.2	Z
	18	36.8	20.8	5.4	36.9	20.8	5.2	0.0	0.0	-0.2	0.2	-0.2	Z
	19	36.6	26.4	5.3	36.5	26.4	5.2	0.0	-0.1	-0.1	0.2	-0.1	Z
	20	36.7	30.2	5.3	36.6	30.2	5.1	0.1	0.0	-0.2	0.2	-0.2	Z
	21	32.3	10.6	2.2	32.3	10.6	2.0	0.0	0.0	-0.2	0.2	-0.2	Z
	22	32.3	15.5	5.1	32.3	15.5	5.0	0.0	0.0	-0.2	0.2	-0.2	Z
	23	32.2	20.5	5.1	32.2	20.6	5.0	0.0	0.0	-0.1	0.2	-0.1	Z
	24	32.1	26.5	5.1	32.0	26.4	4.9	0.1	0.0	-0.1	0.2	-0.1	Z
	25	31.9	30.8	5.0	31.9	30.8	4.9	0.0	0.0	-0.1	0.1	-0.1	Z
	26	28.4	10.4	2.0	28.5	10.5	1.8	-0.1	0.0	-0.2	0.2	-0.2	Z
	27	28.4	15.1	5.4	28.4	15.1	5.2	0.0	0.0	-0.2	0.2	-0.2	Z
	28	28.4	20.3	5.3	28.4	20.3	5.2	0.0	0.0	-0.1	0.1	-0.1	Z
	29	27.4	27.2	5.2	27.3	27.3	5.1	0.0	-0.1	-0.1	0.1	-0.1	Z
	30	28.0	30.4	5.3	27.9	30.4	5.2	0.0	0.0	-0.1	0.1	-0.1	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 F-1. Floor Pan Deformation Data – Set 1, Test No. N2BR-1

Date: 4/12/2018
Year: 2011

Test Name: 2NBR-1
Make: Dodge

VIN: 1D7RB1DG4BS514230
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	48.8	32.2	-6.0	48.8	32.1	-6.2	0.1	0.0	-0.3	0.3	0.1	X
	2	49.1	35.4	-5.5	49.7	35.4	-6.1	-0.5	0.0	-0.6	0.8	0.0	
	3	50.8	38.1	-3.1	50.7	38.0	-3.4	0.0	0.0	-0.3	0.3	0.0	X
	4	51.0	42.6	-3.3	51.0	42.5	-3.6	0.0	0.0	-0.3	0.3	0.0	
	5	50.7	46.4	-4.2	50.7	46.4	-4.6	0.0	0.0	-0.3	0.3	0.0	
	6	44.0	31.0	-6.1	44.1	31.0	-6.4	-0.1	0.0	-0.3	0.3	0.0	
	7	45.0	34.9	-3.6	45.1	34.9	-3.9	-0.1	0.0	-0.3	0.3	0.0	
	8	46.1	38.2	-0.8	46.1	38.2	-1.1	0.0	0.0	-0.3	0.3	0.0	X
	9	46.1	43.6	-0.8	46.2	43.6	-1.2	-0.1	0.0	-0.4	0.4	0.0	
	10	46.1	47.1	-0.8	46.2	47.2	-1.2	0.0	0.0	-0.4	0.4	0.0	
FLOOR PAN (Z)	11	40.1	29.8	-3.7	40.1	29.8	-4.0	0.0	0.0	-0.3	0.3	-0.3	Z
	12	41.4	34.2	-0.1	41.4	34.1	-0.4	0.0	0.0	-0.3	0.3	-0.3	Z
	13	41.8	38.4	1.2	41.8	38.4	0.9	0.0	0.0	-0.3	0.3	-0.3	Z
	14	41.8	44.1	1.2	41.8	44.1	0.8	0.0	0.0	-0.3	0.3	-0.3	Z
	15	41.9	47.6	1.1	41.8	47.7	0.8	0.1	0.0	-0.3	0.3	-0.3	Z
	16	36.6	28.9	-2.2	36.6	28.9	-2.5	0.0	0.0	-0.3	0.3	-0.3	Z
	17	37.8	33.9	1.2	37.7	33.9	0.9	0.0	0.0	-0.3	0.3	-0.3	Z
	18	37.9	38.7	1.2	38.0	38.7	0.9	-0.1	0.0	-0.3	0.3	-0.3	Z
	19	37.9	44.2	1.1	37.9	44.3	0.9	0.0	0.0	-0.3	0.3	-0.3	Z
	20	38.3	48.0	1.1	38.2	48.1	0.8	0.1	0.0	-0.3	0.3	-0.3	Z
	21	32.9	28.7	-2.0	33.0	28.7	-2.3	0.0	0.0	-0.3	0.3	-0.3	Z
	22	33.2	33.6	1.0	33.2	33.6	0.7	0.0	0.0	-0.3	0.3	-0.3	Z
	23	33.4	38.6	0.9	33.3	38.6	0.7	0.0	0.0	-0.3	0.3	-0.3	Z
	24	33.5	44.5	0.9	33.4	44.5	0.6	0.1	0.1	-0.3	0.3	-0.3	Z
	25	33.5	48.8	0.9	33.5	48.8	0.6	0.0	0.0	-0.3	0.3	-0.3	Z
	26	29.1	28.7	-2.2	29.2	28.7	-2.4	-0.1	0.0	-0.3	0.3	-0.3	Z
	27	29.3	33.4	1.2	29.3	33.4	0.9	0.0	0.0	-0.3	0.3	-0.3	Z
	28	29.5	38.6	1.1	29.5	38.5	0.9	0.0	0.0	-0.3	0.3	-0.3	Z
	29	28.8	45.5	1.0	28.8	45.6	0.8	0.0	0.0	-0.2	0.2	-0.2	Z
	30	29.5	48.7	1.1	29.5	48.6	0.9	0.0	0.0	-0.2	0.2	-0.2	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 F-2. Floor Pan Deformation Data – Set 2, Test No. N2BR-1

Date: 4/12/2018 Test Name: 2NBR-1 VIN: 1D7RB1DG4BS514230
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	37.9	0.5	-27.6	38.0	0.5	-27.7	-0.2	0.0	-0.1	0.2	0.2	X, Y, Z
	2	38.0	11.3	-27.6	38.1	11.1	-27.7	-0.1	0.2	-0.1	0.3	0.3	X, Y, Z
	3	38.6	26.9	-26.7	38.7	26.9	-26.9	-0.1	0.0	-0.2	0.2	0.2	X, Y, Z
	4	32.0	0.4	-21.9	32.2	0.4	-21.9	-0.2	0.0	-0.1	0.2	0.2	X, Y, Z
	5	35.6	11.3	-24.5	35.8	11.2	-24.6	-0.2	0.0	-0.1	0.2	0.2	X, Y, Z
	6	36.0	27.0	-24.3	36.1	27.0	-24.5	-0.1	0.0	-0.2	0.2	0.2	X, Y, Z
SIDE PANEL (Y)	7	42.1	33.7	-4.4	42.0	33.5	-4.6	0.1	0.2	-0.2	0.3	0.2	Y
	8	42.6	33.7	-0.1	42.5	33.6	-0.3	0.0	0.1	-0.2	0.3	0.1	Y
	9	46.5	33.7	-3.2	46.4	33.7	-3.3	0.1	0.0	-0.2	0.2	0.0	Y
IMPACT SIDE DOOR (Y)	10	33.7	34.7	-22.5	33.4	34.4	-22.7	0.3	0.3	-0.2	0.4	0.3	Y
	11	23.7	34.4	-22.7	23.4	34.2	-22.9	0.3	0.2	-0.2	0.4	0.2	Y
	12	9.5	34.1	-23.0	9.2	34.0	-23.1	0.2	0.1	-0.1	0.3	0.1	Y
	13	30.1	36.1	1.2	29.9	35.6	1.1	0.2	0.4	-0.2	0.5	0.4	Y
	14	22.8	35.8	1.2	22.5	35.4	1.0	0.3	0.4	-0.2	0.5	0.4	Y
	15	9.5	35.1	0.9	9.3	34.8	0.8	0.3	0.3	-0.1	0.4	0.3	Y
ROOF - (Z)	16	29.9	0.8	-42.6	30.0	0.7	-42.6	-0.1	0.2	0.0	0.2	0.0	Z
	17	29.6	6.4	-42.6	29.7	6.3	-42.6	-0.1	0.1	-0.1	0.1	-0.1	Z
	18	29.0	11.3	-42.5	29.1	11.2	-42.6	-0.1	0.1	0.0	0.2	0.0	Z
	19	28.0	16.2	-42.4	28.1	16.0	-42.5	-0.1	0.2	-0.1	0.2	-0.1	Z
	20	26.5	21.4	-42.2	26.6	21.3	-42.3	0.0	0.2	-0.1	0.2	-0.1	Z
	21	24.1	0.4	-45.2	24.2	0.2	-45.3	-0.1	0.2	0.0	0.2	0.0	Z
	22	23.7	5.3	-45.3	23.9	5.1	-45.3	-0.1	0.1	0.0	0.2	0.0	Z
	23	23.1	10.0	-45.2	23.2	9.8	-45.3	-0.1	0.2	-0.1	0.2	-0.1	Z
	24	21.8	14.9	-45.2	21.9	14.8	-45.3	0.0	0.2	-0.1	0.2	-0.1	Z
	25	20.9	19.5	-45.0	20.8	19.4	-45.1	0.1	0.1	-0.1	0.2	-0.1	Z
	26	21.6	0.8	-45.8	21.7	0.6	-45.8	-0.1	0.2	0.0	0.2	0.0	Z
	27	21.2	5.3	-45.8	21.2	5.2	-45.8	0.0	0.2	0.0	0.2	0.0	Z
	28	20.9	9.7	-45.7	20.9	9.6	-45.8	-0.1	0.2	-0.1	0.2	-0.1	Z
	29	19.9	14.7	-45.6	20.0	14.5	-45.7	0.0	0.2	-0.1	0.2	-0.1	Z
	30	18.8	19.2	-45.4	18.7	19.0	-45.5	0.0	0.2	-0.1	0.2	-0.1	Z
A-PILLAR Maximum (X, Y, Z)	31	42.4	32.4	-28.4	42.5	32.4	-28.6	0.0	0.0	-0.2	0.2	0.0	Y
	32	40.5	31.9	-29.9	40.6	31.9	-30.1	0.0	0.1	-0.2	0.2	0.1	Y
	33	38.9	31.5	-31.0	39.0	31.5	-31.2	-0.1	0.0	-0.2	0.2	0.0	Y
	34	35.9	30.8	-33.7	36.0	30.8	-33.9	-0.1	0.0	-0.2	0.2	0.0	Y
	35	33.7	30.2	-35.2	33.7	30.2	-35.4	-0.1	0.1	-0.2	0.2	0.1	Y
	36	31.3	29.6	-36.9	31.3	29.5	-37.0	-0.1	0.1	-0.1	0.2	0.1	Y
A-PILLAR Lateral (Y)	31	42.4	32.4	-28.4	42.5	32.4	-28.6	0.0	0.0	-0.2	0.2	0.0	Y
	32	40.5	31.9	-29.9	40.6	31.9	-30.1	0.0	0.1	-0.2	0.2	0.1	Y
	33	38.9	31.5	-31.0	39.0	31.5	-31.2	-0.1	0.0	-0.2	0.2	0.0	Y
	34	35.9	30.8	-33.7	36.0	30.8	-33.9	-0.1	0.0	-0.2	0.2	0.0	Y
	35	33.7	30.2	-35.2	33.7	30.2	-35.4	-0.1	0.1	-0.2	0.2	0.1	Y
	36	31.3	29.6	-36.9	31.3	29.5	-37.0	-0.1	0.1	-0.1	0.2	0.1	Y
B-PILLAR Maximum (X, Y, Z)	37	0.6	27.7	-39.4	0.7	27.3	-39.5	-0.2	0.4	-0.1	0.4	0.4	Y
	38	0.9	29.0	-36.2	1.1	28.6	-36.2	-0.1	0.4	-0.1	0.4	0.4	Y
	39	1.4	30.3	-32.6	1.5	30.0	-32.6	-0.1	0.3	0.0	0.4	0.3	Y
	40	1.7	31.3	-29.0	1.8	30.9	-29.0	-0.1	0.3	0.0	0.3	0.3	Y
B-PILLAR Lateral (Y)	37	0.6	27.7	-39.4	0.7	27.3	-39.5	-0.2	0.4	-0.1	0.4	0.4	Y
	38	0.9	29.0	-36.2	1.1	28.6	-36.2	-0.1	0.4	-0.1	0.4	0.4	Y
	39	1.4	30.3	-32.6	1.5	30.0	-32.6	-0.1	0.3	0.0	0.4	0.3	Y
	40	1.7	31.3	-29.0	1.8	30.9	-29.0	-0.1	0.3	0.0	0.3	0.3	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 F-3. Occupant Compartment Deformation Data – Set 1, Test No. N2BR-1

Date:	4/12/2018	Test Name:	2NBR-1	VIN:	1D7RB1DG4BS514230
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	38.1	18.3	-31.8	38.3	18.5	-31.8	-0.2	-0.2	-0.1	0.3	0.3	X, Y, Z
	2	38.7	29.1	-31.8	38.9	29.1	-31.9	-0.2	0.0	-0.1	0.3	0.3	X, Y, Z
	3	40.0	44.7	-30.9	40.2	44.8	-31.1	-0.2	-0.1	-0.2	0.3	0.3	X, Y, Z
	4	32.2	18.5	-26.0	32.5	18.6	-26.1	-0.3	-0.1	-0.1	0.3	0.3	X, Y, Z
	5	36.3	29.2	-28.7	36.6	29.3	-28.8	-0.3	-0.1	-0.1	0.3	0.3	X, Y, Z
	6	37.5	44.9	-28.5	37.7	45.0	-28.7	-0.2	-0.1	-0.2	0.3	0.3	X, Y, Z
SIDE PANEL (Y)	7	43.8	51.2	-8.6	43.8	51.3	-8.8	0.0	0.0	-0.2	0.2	0.0	Y
	8	44.3	51.2	-4.3	44.3	51.3	-4.5	0.0	-0.1	-0.2	0.3	-0.1	Y
	9	48.2	51.1	-7.3	48.2	51.2	-7.5	0.1	-0.1	-0.2	0.2	-0.1	Y
IMPACT SIDE DOOR (Y)	10	35.5	52.7	-26.6	35.3	52.6	-26.9	0.2	0.1	-0.3	0.3	0.1	Y
	11	25.5	52.8	-26.9	25.3	52.8	-27.2	0.2	0.0	-0.3	0.4	0.0	Y
	12	11.2	53.2	-27.2	11.1	53.3	-27.4	0.1	0.0	-0.2	0.2	0.0	Y
	13	31.9	54.2	-3.0	31.7	54.0	-3.2	0.2	0.3	-0.2	0.4	0.3	Y
	14	24.6	54.3	-3.0	24.4	54.1	-3.3	0.2	0.2	-0.3	0.4	0.2	Y
	15	11.4	54.2	-3.3	11.1	54.1	-3.5	0.2	0.1	-0.2	0.3	0.1	Y
ROOF - (Z)	16	30.1	19.0	-46.8	30.4	19.0	-46.8	-0.2	0.0	-0.1	0.3	-0.1	Z
	17	30.1	24.6	-46.7	30.3	24.6	-46.8	-0.2	-0.1	-0.1	0.2	-0.1	Z
	18	29.7	29.5	-46.7	30.0	29.5	-46.8	-0.2	0.0	-0.1	0.3	-0.1	Z
	19	29.0	34.4	-46.6	29.2	34.4	-46.7	-0.2	0.0	-0.1	0.3	-0.1	Z
	20	27.7	39.7	-46.4	27.9	39.7	-46.6	-0.2	0.0	-0.2	0.2	-0.2	Z
	21	24.3	18.8	-49.4	24.6	18.8	-49.5	-0.2	0.1	-0.1	0.2	-0.1	Z
	22	24.2	23.7	-49.4	24.5	23.7	-49.5	-0.2	0.0	-0.1	0.3	-0.1	Z
	23	23.8	28.5	-49.4	24.0	28.4	-49.5	-0.2	0.1	-0.1	0.2	-0.1	Z
	24	22.8	33.4	-49.4	22.9	33.4	-49.5	-0.1	0.0	-0.1	0.2	-0.1	Z
	25	22.0	38.1	-49.2	22.1	38.1	-49.3	-0.1	0.0	-0.1	0.2	-0.1	Z
	26	21.8	19.3	-50.0	22.0	19.3	-50.0	-0.2	0.0	-0.1	0.2	-0.1	Z
	27	21.7	23.9	-50.0	21.8	23.9	-50.1	-0.2	0.0	-0.1	0.2	-0.1	Z
	28	21.5	28.3	-49.9	21.7	28.3	-50.0	-0.2	0.0	-0.1	0.2	-0.1	Z
	29	20.8	33.3	-49.8	21.0	33.2	-49.9	-0.2	0.1	-0.1	0.2	-0.1	Z
	30	19.9	37.8	-49.6	20.0	37.8	-49.8	-0.1	0.0	-0.1	0.2	-0.1	Z
A-PILLAR Maximum (X, Y, Z)	31	44.1	50.0	-32.6	44.3	50.1	-32.8	-0.2	-0.1	-0.2	0.3	0.0	
	32	42.2	49.6	-34.1	42.3	49.7	-34.3	-0.2	-0.1	-0.2	0.3	0.0	
	33	40.6	49.2	-35.2	40.8	49.3	-35.4	-0.2	-0.1	-0.3	0.3	0.0	
	34	37.6	48.7	-37.9	37.8	48.8	-38.1	-0.2	-0.1	-0.2	0.3	0.0	
	35	35.3	48.2	-39.4	35.5	48.3	-39.6	-0.2	-0.1	-0.2	0.3	0.0	
	36	32.8	47.7	-41.1	33.0	47.7	-41.2	-0.2	0.0	-0.2	0.2	0.0	
A-PILLAR Lateral (Y)	31	44.1	50.0	-32.6	44.3	50.1	-32.8	-0.2	-0.1	-0.2	0.3	-0.1	Y
	32	42.2	49.6	-34.1	42.3	49.7	-34.3	-0.2	-0.1	-0.2	0.3	-0.1	Y
	33	40.6	49.2	-35.2	40.8	49.3	-35.4	-0.2	-0.1	-0.3	0.3	-0.1	Y
	34	37.6	48.7	-37.9	37.8	48.8	-38.1	-0.2	-0.1	-0.2	0.3	-0.1	Y
	35	35.3	48.2	-39.4	35.5	48.3	-39.6	-0.2	-0.1	-0.2	0.3	-0.1	Y
	36	32.8	47.7	-41.1	33.0	47.7	-41.2	-0.2	0.0	-0.2	0.2	0.0	Y
B-PILLAR Maximum (X, Y, Z)	37	2.1	47.2	-43.6	2.4	46.9	-43.8	-0.3	0.2	-0.2	0.4	0.2	Y
	38	2.5	48.4	-40.4	2.7	48.2	-40.6	-0.3	0.2	-0.2	0.4	0.2	Y
	39	3.0	49.8	-36.8	3.3	49.6	-36.9	-0.2	0.2	-0.1	0.3	0.2	Y
	40	3.4	50.7	-33.2	3.5	50.5	-33.3	-0.2	0.1	-0.1	0.3	0.1	Y
B-PILLAR Lateral (Y)	37	2.1	47.2	-43.6	2.4	46.9	-43.8	-0.3	0.2	-0.2	0.4	0.2	Y
	38	2.5	48.4	-40.4	2.7	48.2	-40.6	-0.3	0.2	-0.2	0.4	0.2	Y
	39	3.0	49.8	-36.8	3.3	49.6	-36.9	-0.2	0.2	-0.1	0.3	0.2	Y
	40	3.4	50.7	-33.2	3.5	50.5	-33.3	-0.2	0.1	-0.1	0.3	0.1	Y

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

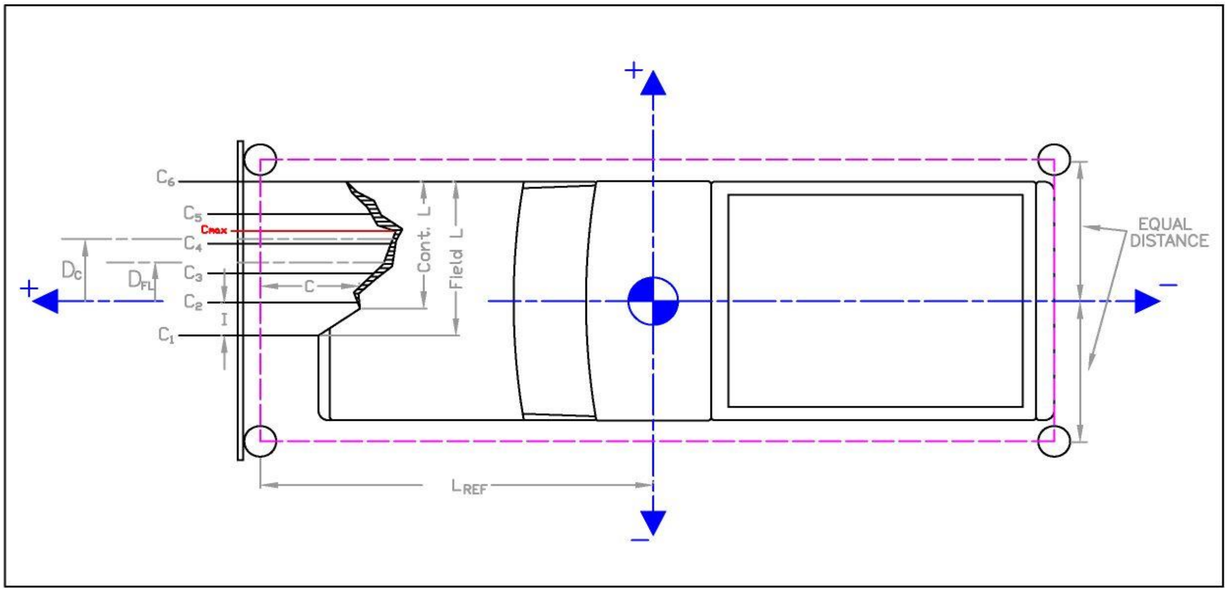
[B] Crush calculations that use multiple directional components will disregard components that are negative and only include positive values where the component is deforming inward toward the occupant compartment.

[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 F-4. Occupant Compartment Deformation Data – Set 2, Test No. N2BR-1

Date: 4/12/2018 **Test Name:** 2NBR-1 **VIN:** 1D7RB1DG4BS514230

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



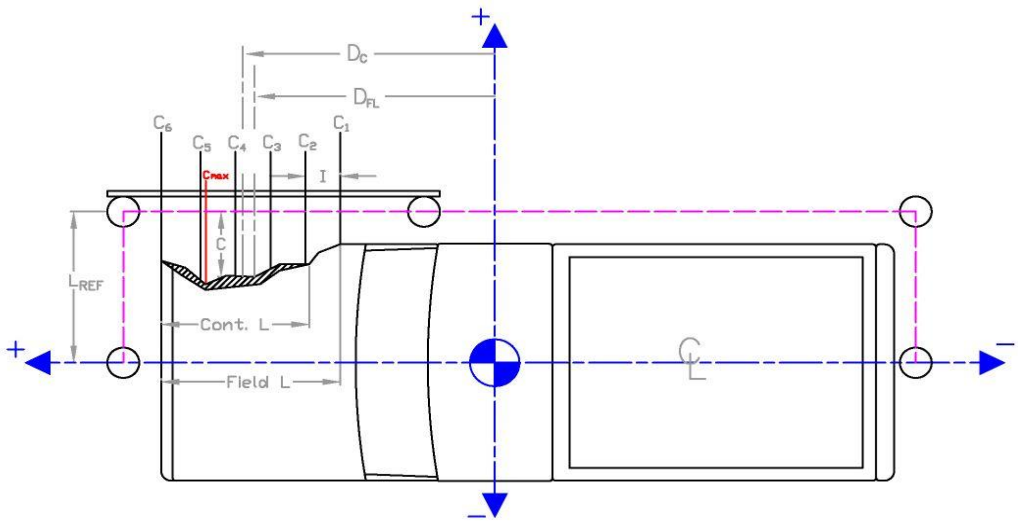
	in.	(mm)
Distance from C.G. to reference line - L_{REF}:	114 1/4	(2902)
Total Vehicle Width:	76	(1930)
Width of contact and induced crush - Field L:	54	(1372)
Crush measurement spacing interval (L/5) - I:	10 3/4	(273)
Distance from center of vehicle to center of Field L - D_{FL}:	0	()
Width of Contact Damage:	20 1/2	(521)
Distance from center of vehicle to center of contact damage - D_C:	48 1/4	(1226)

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	15 1/4	(387)	-27	-(686)	7 1/2	(191)	9 1/4	(235)	-1 1/2	-(38)
C_2	14 1/4	(362)	-16 1/4	-(413)	5	(127)			0	()
C_3	13 1/3	(338)	-5 1/2	-(140)	4 1/8	(105)			-0	-(2)
C_4	13 1/4	(337)	5 1/4	(133)	4 1/8	(105)			- 1/8	-(3)
C_5	14 1/4	(362)	16	(406)	5	(127)			0	()
C_6	25 1/2	(648)	26 3/4	(679)	7 3/8	(187)			8 7/8	(225)
C_{MAX}	25 1/2	(648)	26 3/4	(679)	7 3/8	(187)			8 7/8	(225)

Figure F-5. Exterior Vehicle Crush (NASS) - Front, Test No. N2BR-1

Date:	4/12/2018	**Test Name:**	2NBR-1	**VIN:**	1D7RB1DG4BS514230
Year:	2011	**Make:**	Dodge	**Model:**	Ram 1500



	in.	(mm)
Distance from centerline to reference line - L_{REF}:	76	(1930)
Total Vehicle Length:	229 1/2	(5829)
Distance from vehicle c.g. to 1/2 of Vehicle total length:	-7 1/8	-(181)
Width of contact and induced crush - Field L:	70 1/2	(1791)
Crush measurement spacing interval (L/5) - I:	14 1/8	(359)
Distance from vehicle c.g. to center of Field L - D_{FL}:	66 1/4	(1683)
Width of Contact Damage:	64 1/2	(1638)
Distance from vehicle c.g. to center of contact damage - D_C:	69 1/4	(1759)

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	35 3/4	(908)	31	(787)	5 1/8	(130)	32	(813)	-1 3/8	-(35)
C_2	na	NA	45 1/8	(1146)	5 1/8	(130)			NA	NA
C_3	na	NA	59 1/4	(1505)	5 1/2	(140)			NA	NA
C_4	45 3/4	(1162)	73 3/8	(1864)	5 7/8	(149)			7 7/8	(200)
C_5	48 1/2	(1232)	87 1/2	(2223)	5 7/8	(149)			10 5/8	(270)
C_6	57 1/4	(1454)	101 5/8	(2581)	12 1/2	(318)			12 3/4	(324)
C_{MAX}	57 1/4	(1454)	101 5/8	(2581)	12 1/2	(318)			12 3/4	(324)

Figure F-6. Exterior Vehicle Crush (NASS) - Side, Test No. N2BR-1

Appendix G. Accelerometer and Rate Transducer Data Plots, Test No. N2BR-1

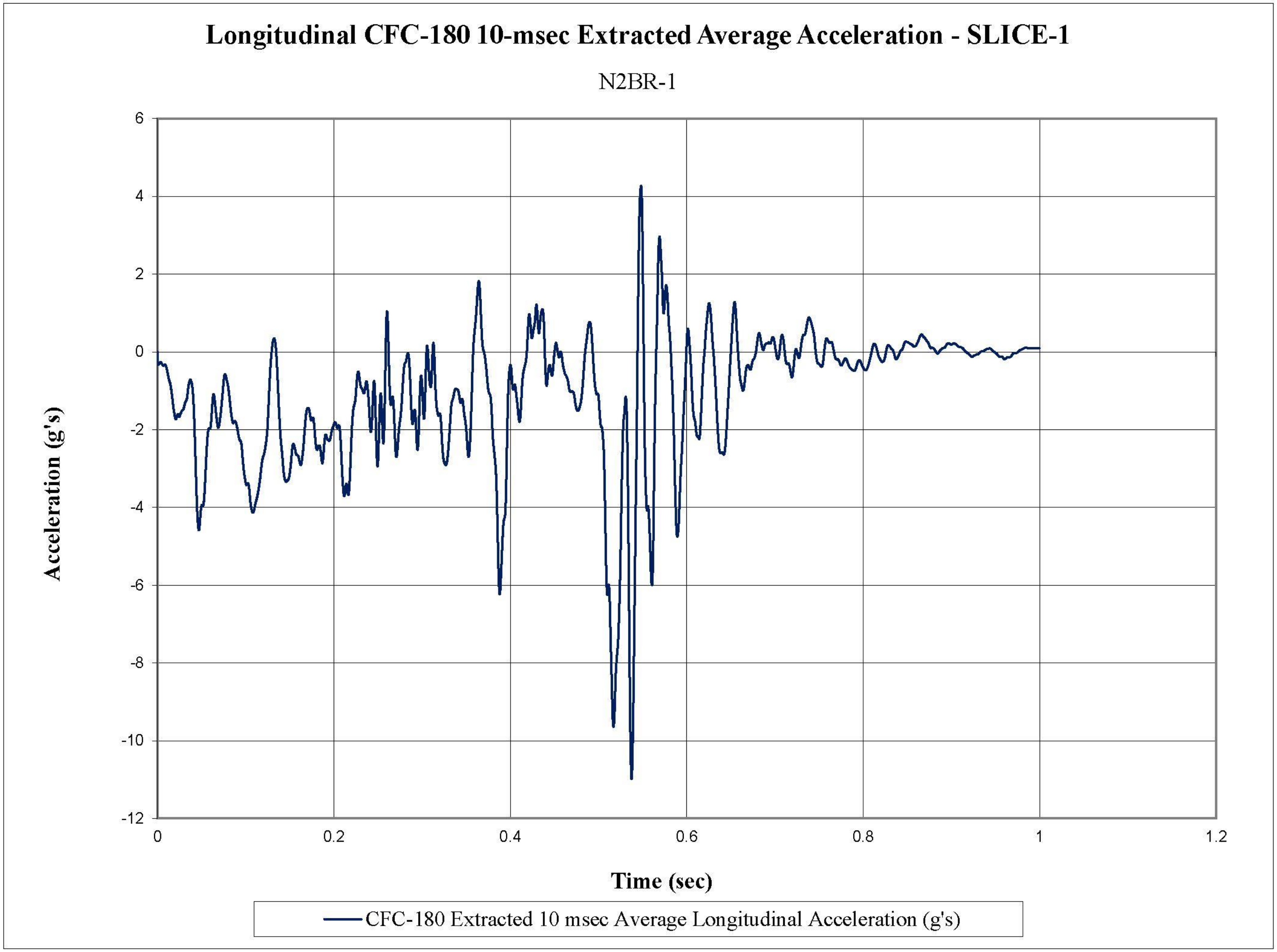


Figure G-1. Longitudinal CFC-180 10-msec Extracted Average Acceleration (SLICE-1), Test No. N2BR-1

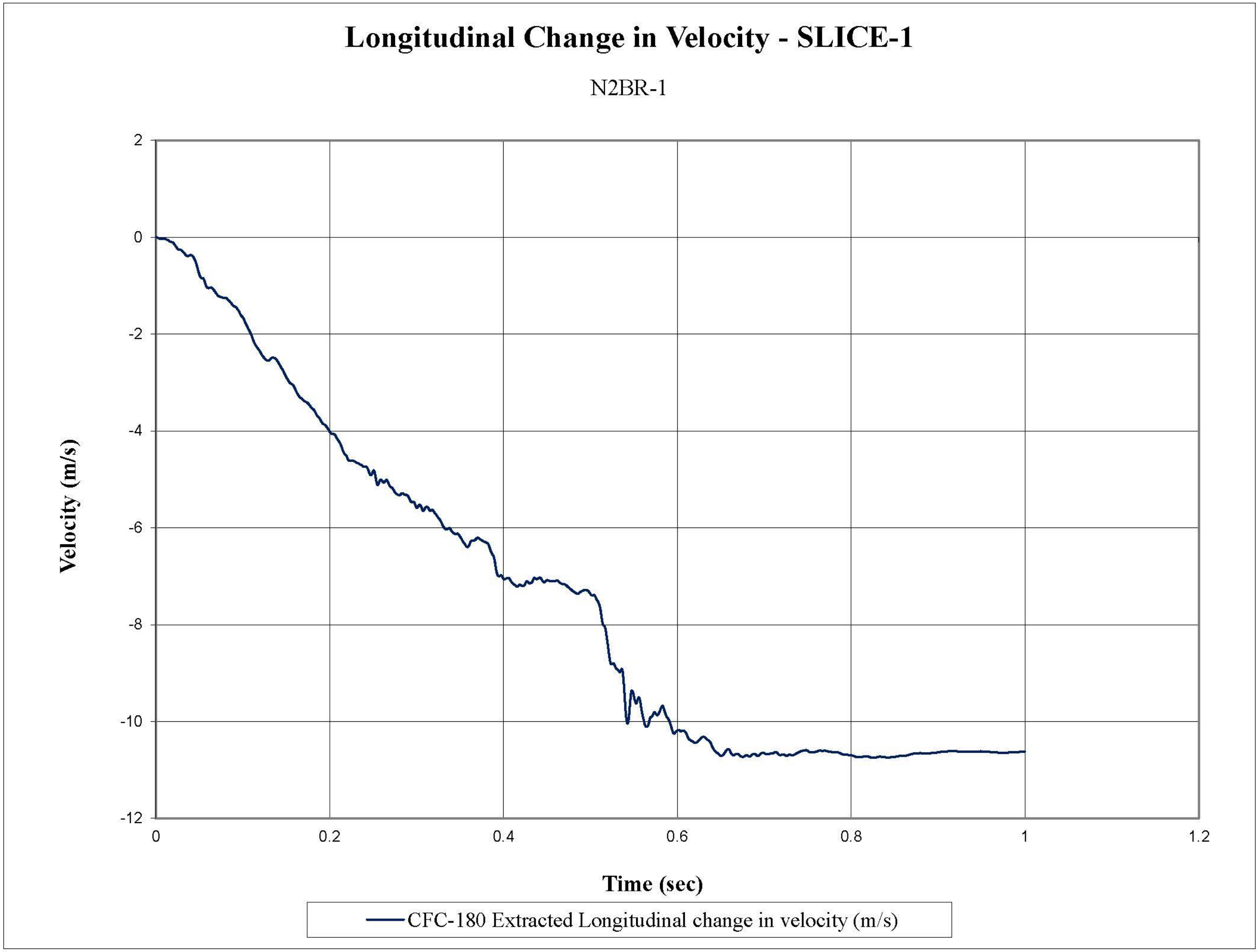


Figure G-2. Longitudinal Change in Velocity (SLICE-1), Test No. N2BR-1

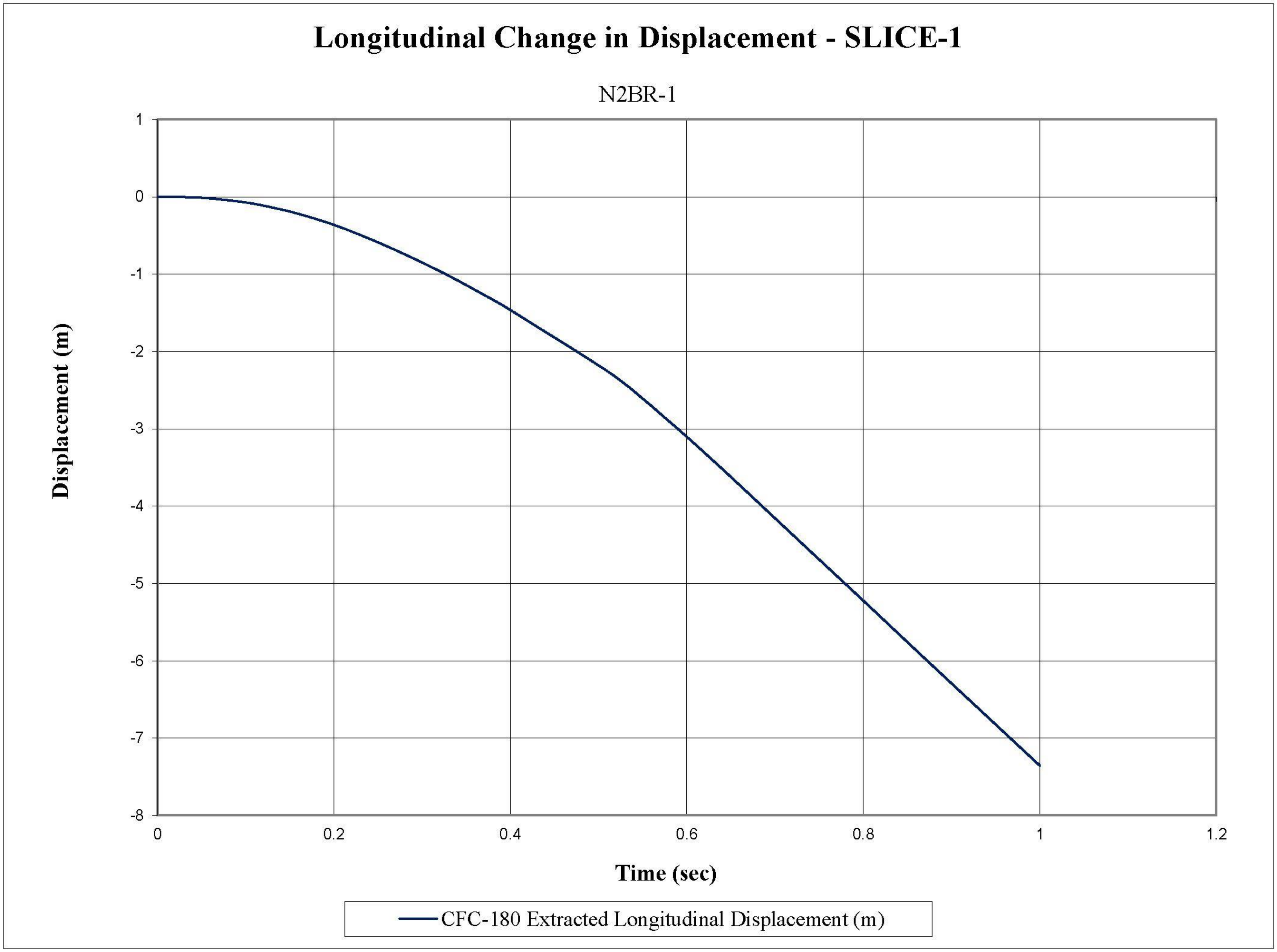


Figure G-3. Longitudinal Change in Displacement (SLICE-1), Test No. N2BR-1

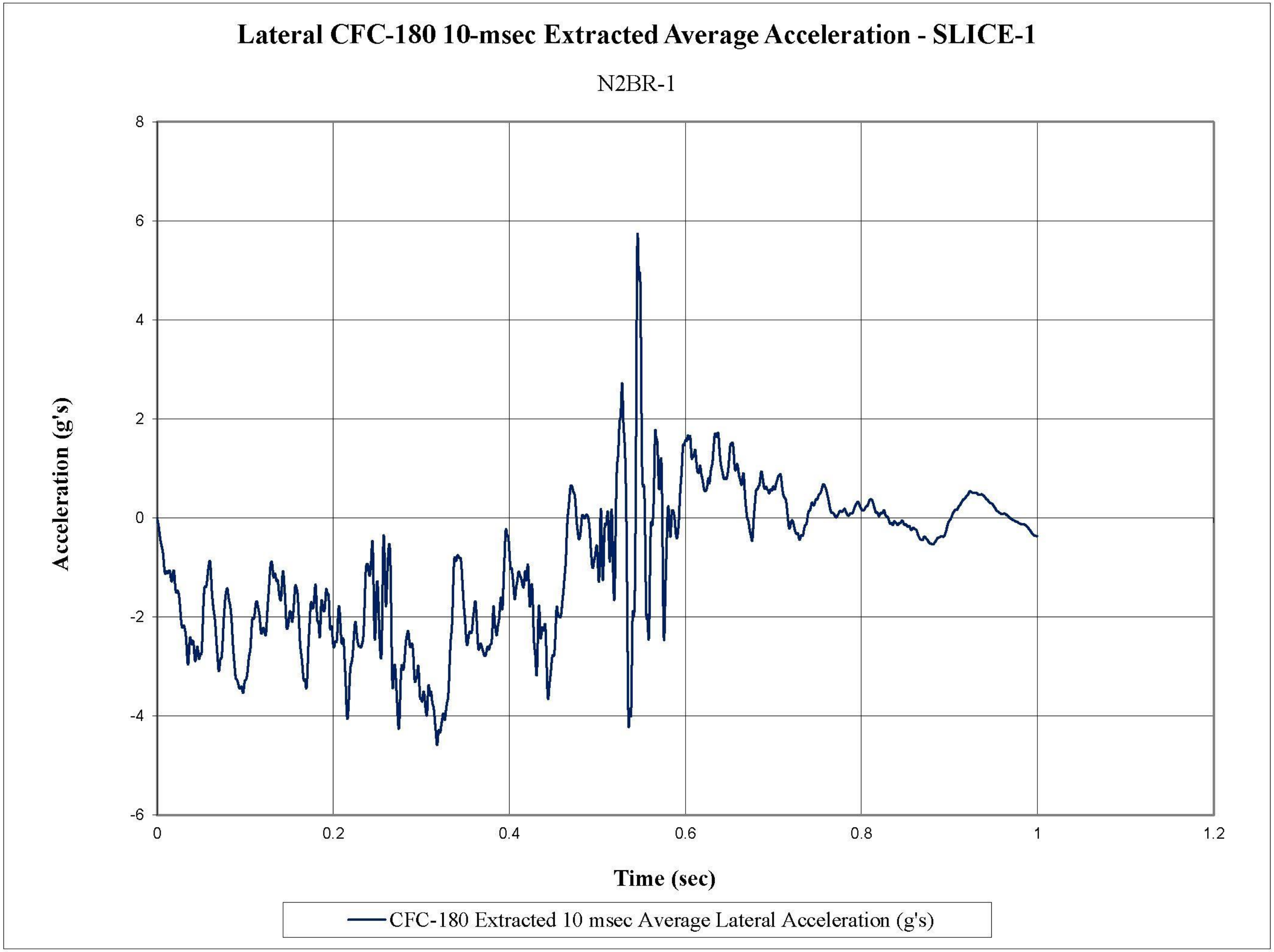


Figure G-4. Lateral CFC-180 10-msec Extracted Average Acceleration (SLICE-1), Test No. N2BR-1

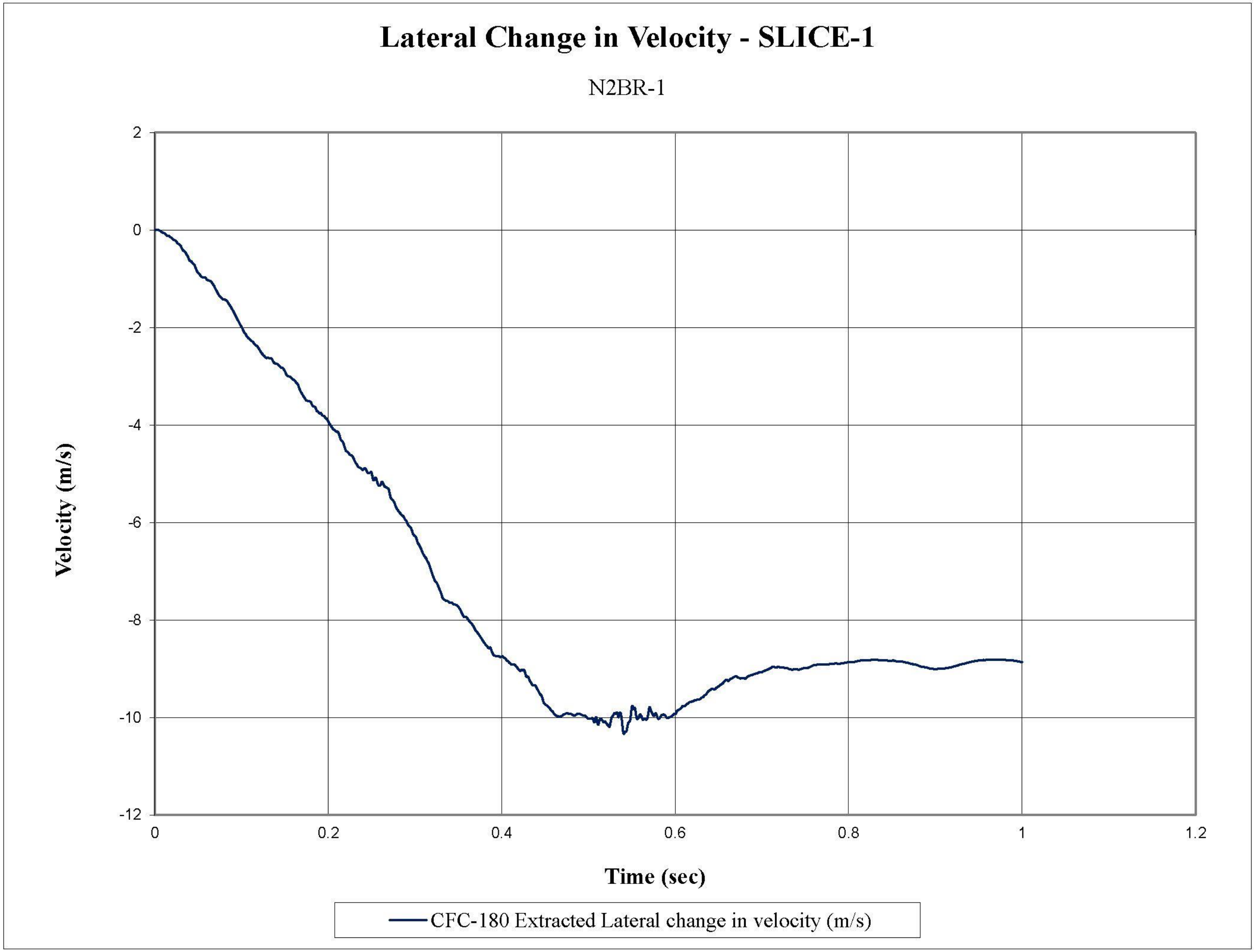


Figure G-5. Lateral Change in Velocity (SLICE-1), Test No. N2BR-1

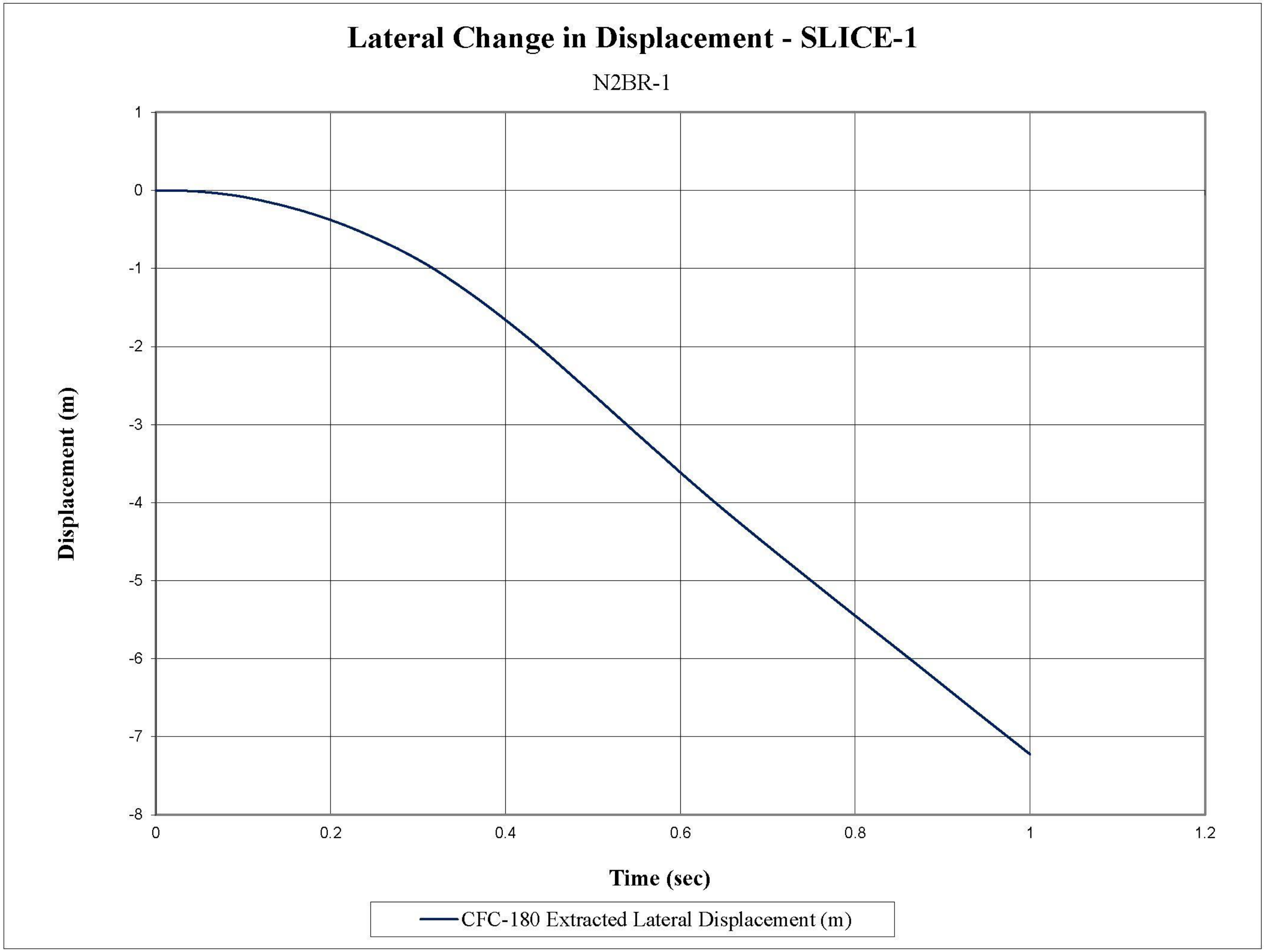


Figure G-6. Lateral Change in Displacement (SLICE-1), Test No. N2BR-1

Figure G-7. Vehicle Angular Displacements (SLICE-1), Test No. N2BR-1

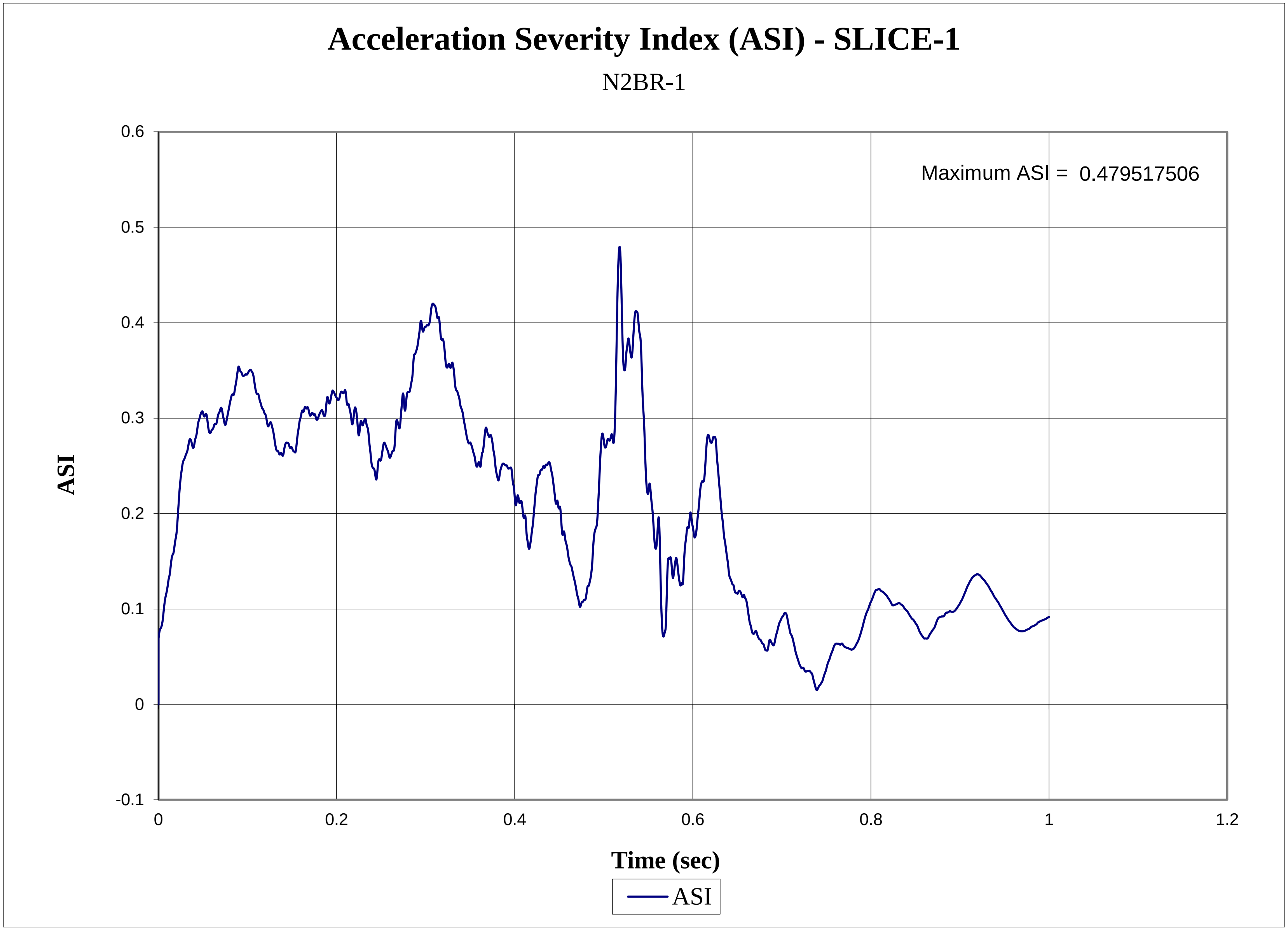


Figure G-8. Acceleration Severity Index (SLICE-1), Test No. N2BR-1

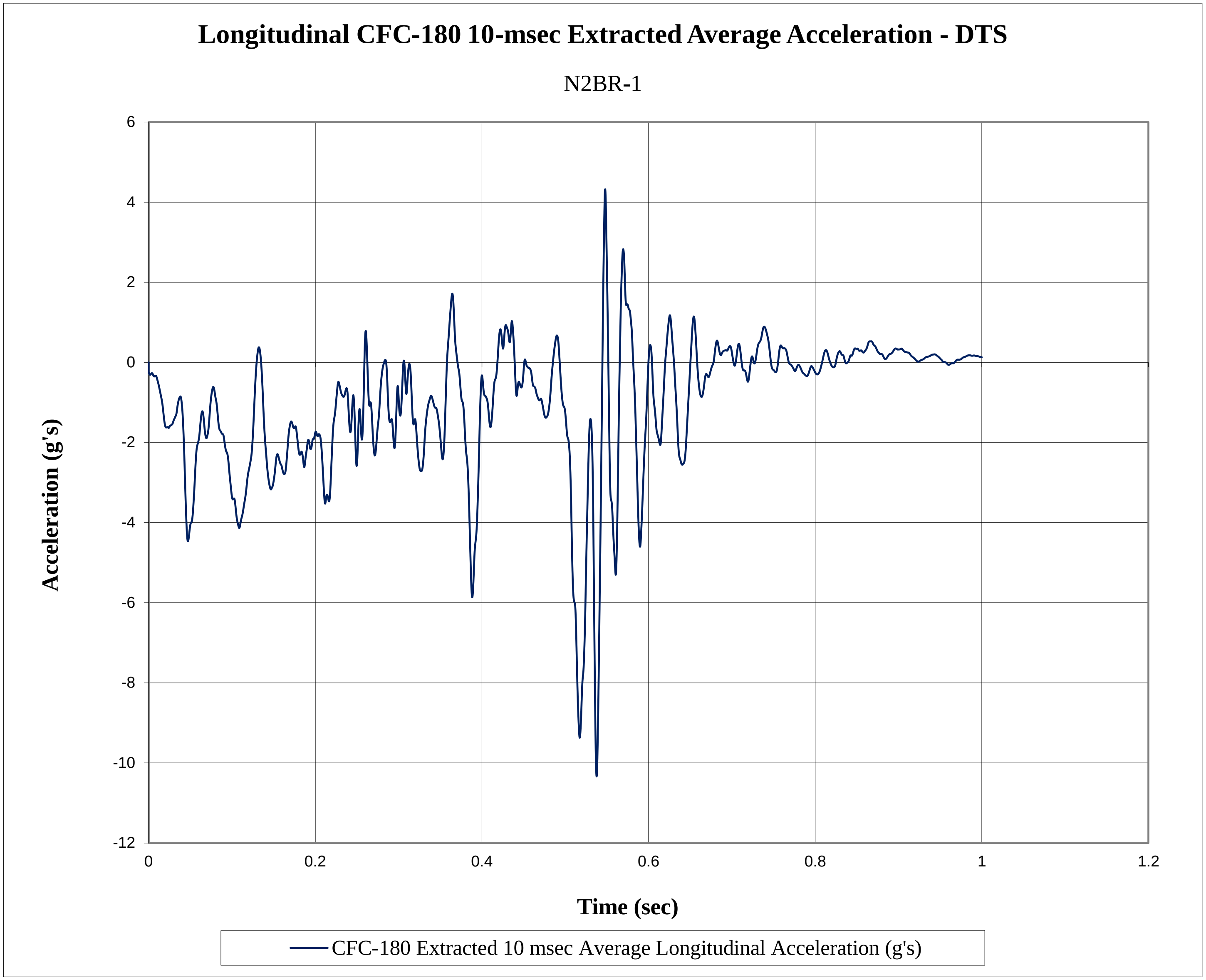


Figure G-9. 10-ms Average Longitudinal Deceleration (DTS), Test No. N2BR-1

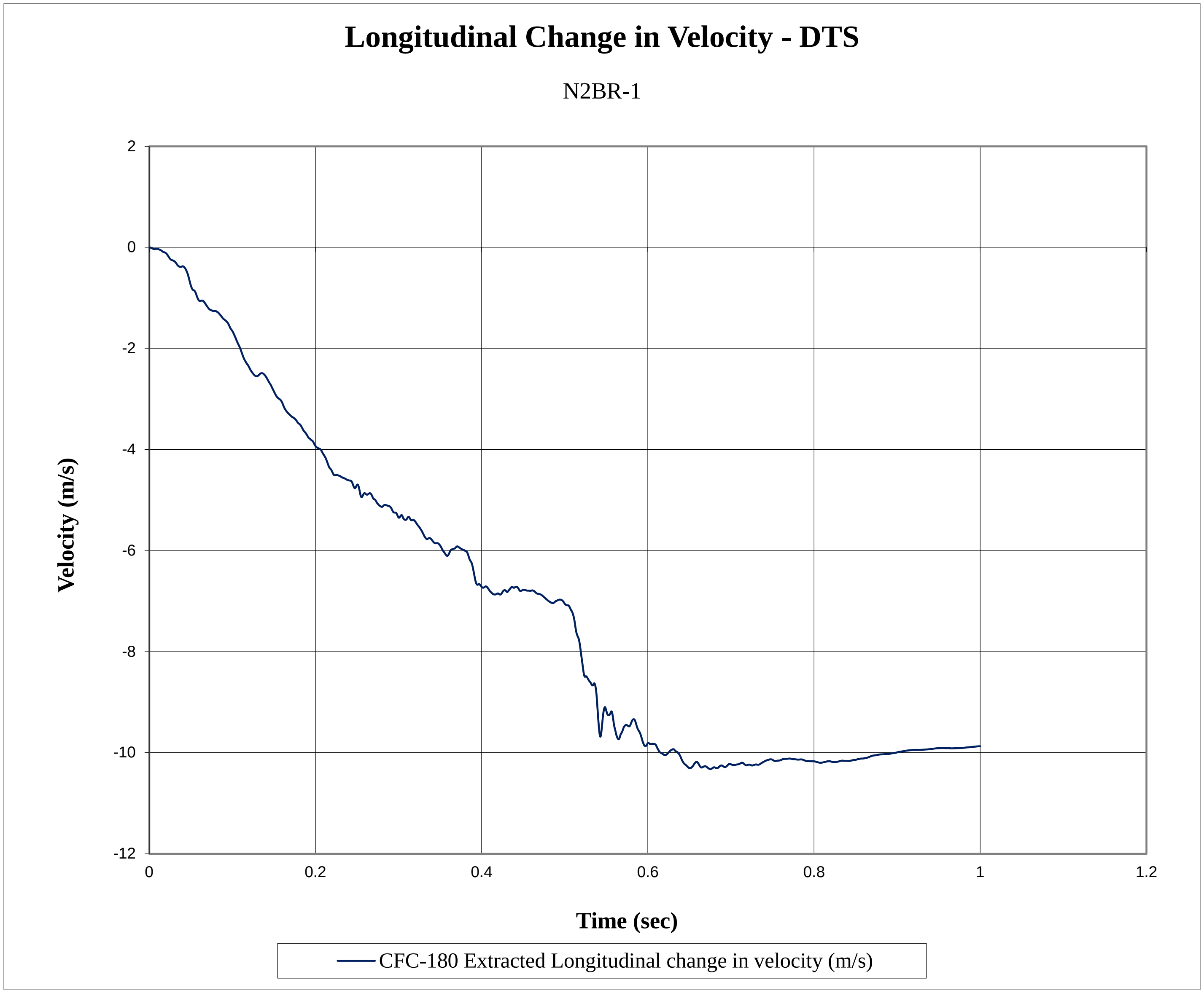


Figure G-10. Longitudinal Occupant Impact Velocity (DTS), Test No. N2BR-1

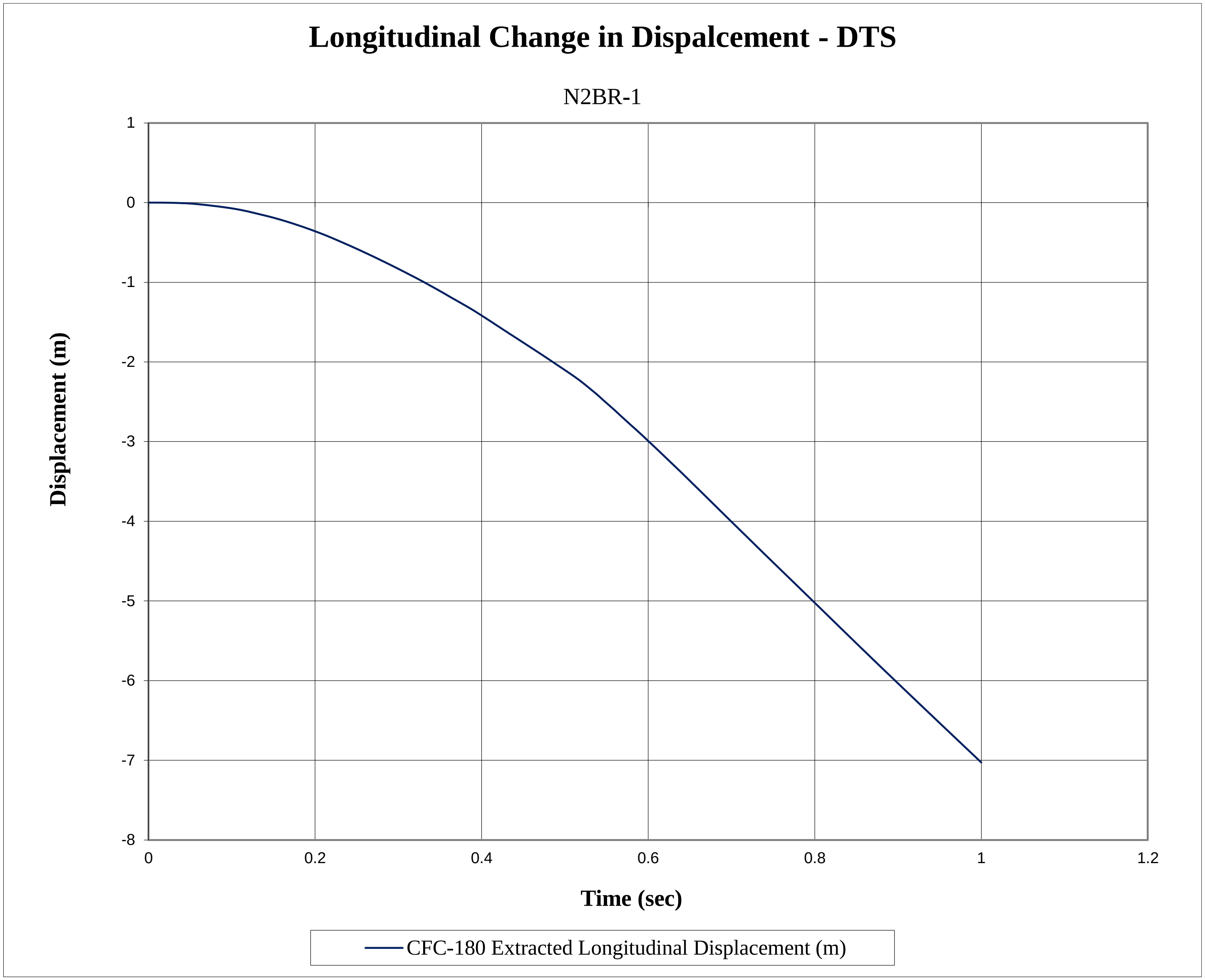


Figure G-11. Longitudinal Occupant Displacement (DTS), Test No. N2BR-1

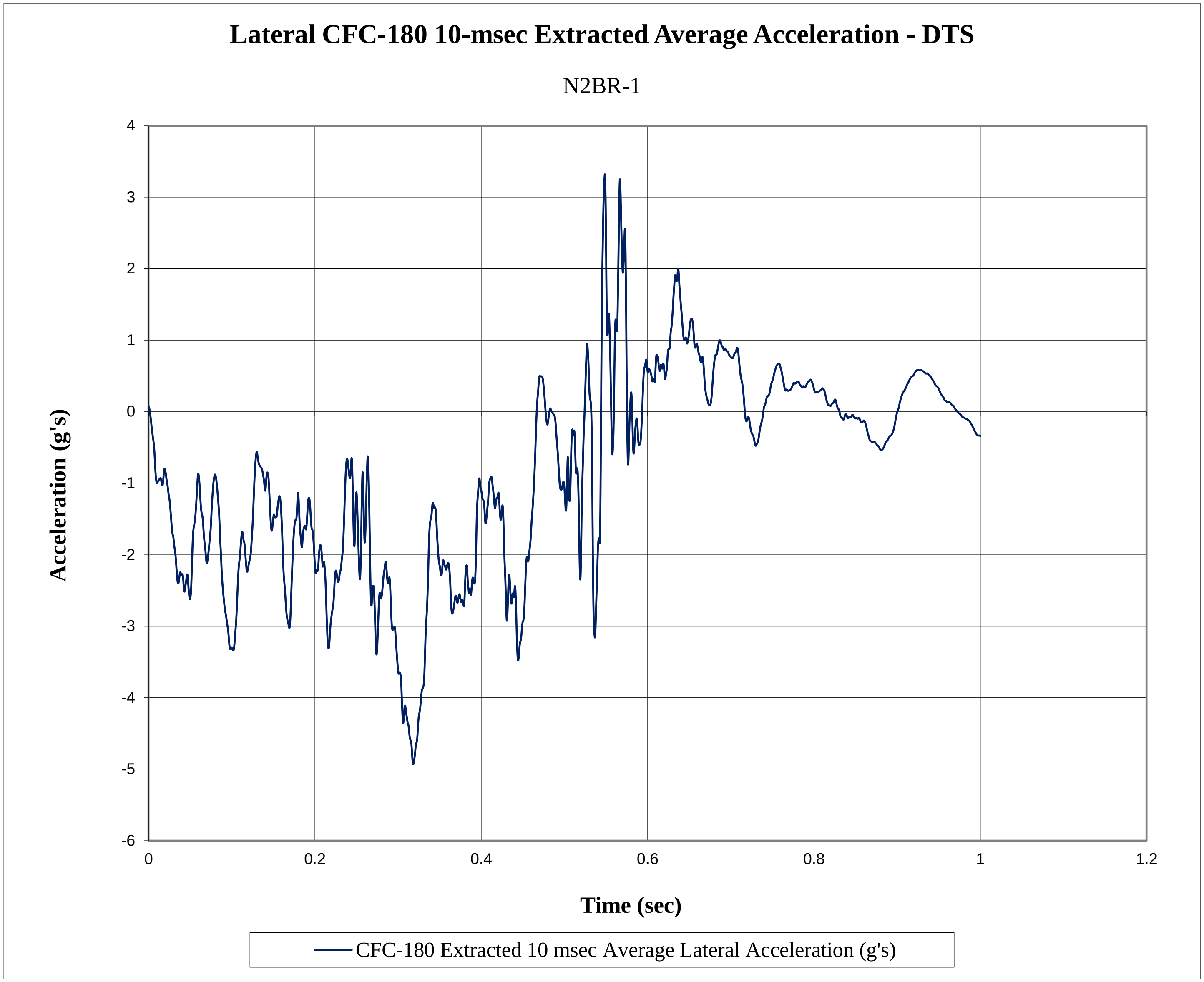


Figure G-12. 10-ms Average Lateral Deceleration (DTS), Test No. N2BR-1

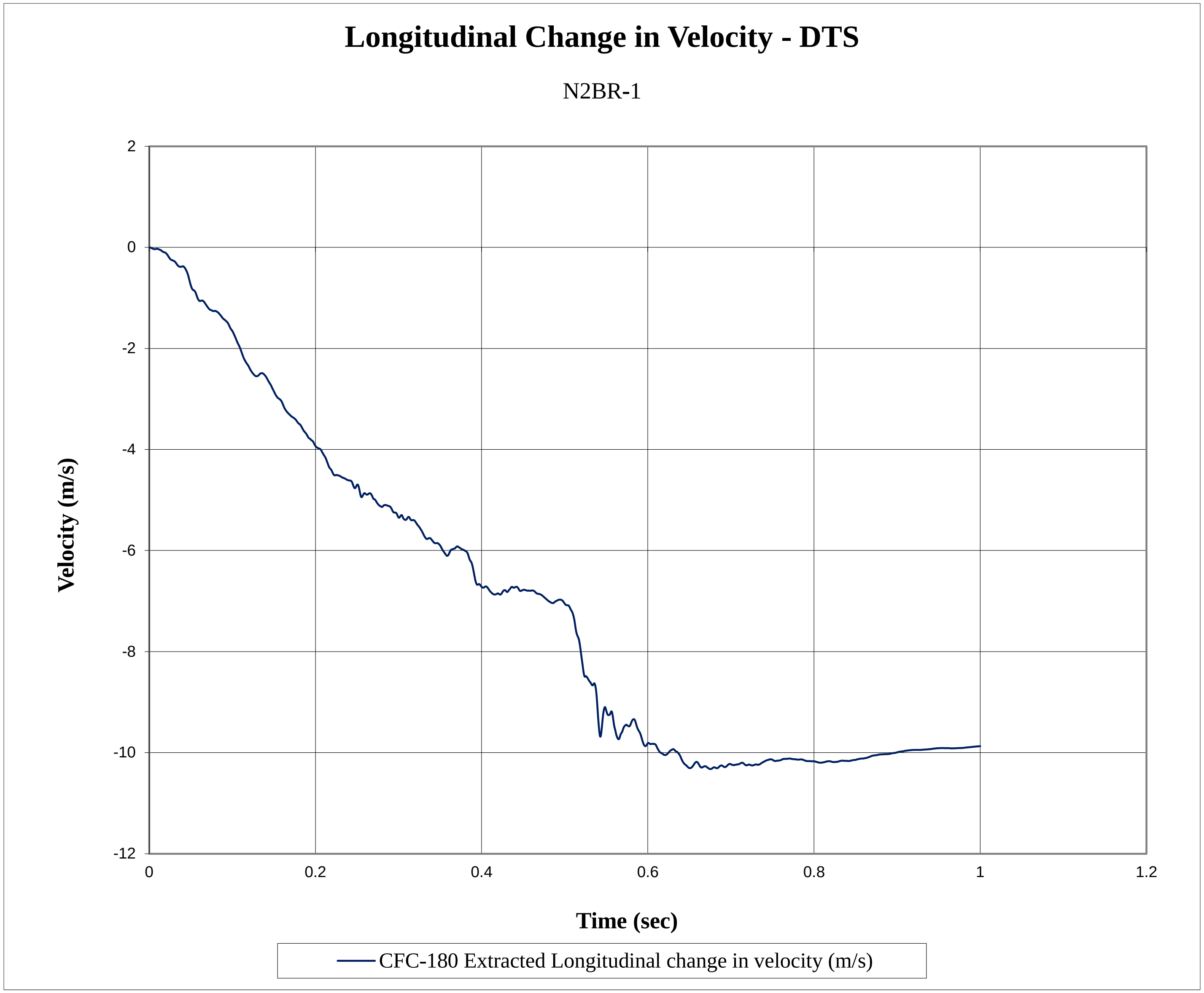


Figure G-13. Lateral Occupant Impact Velocity (DTS), Test No. N2BR-1

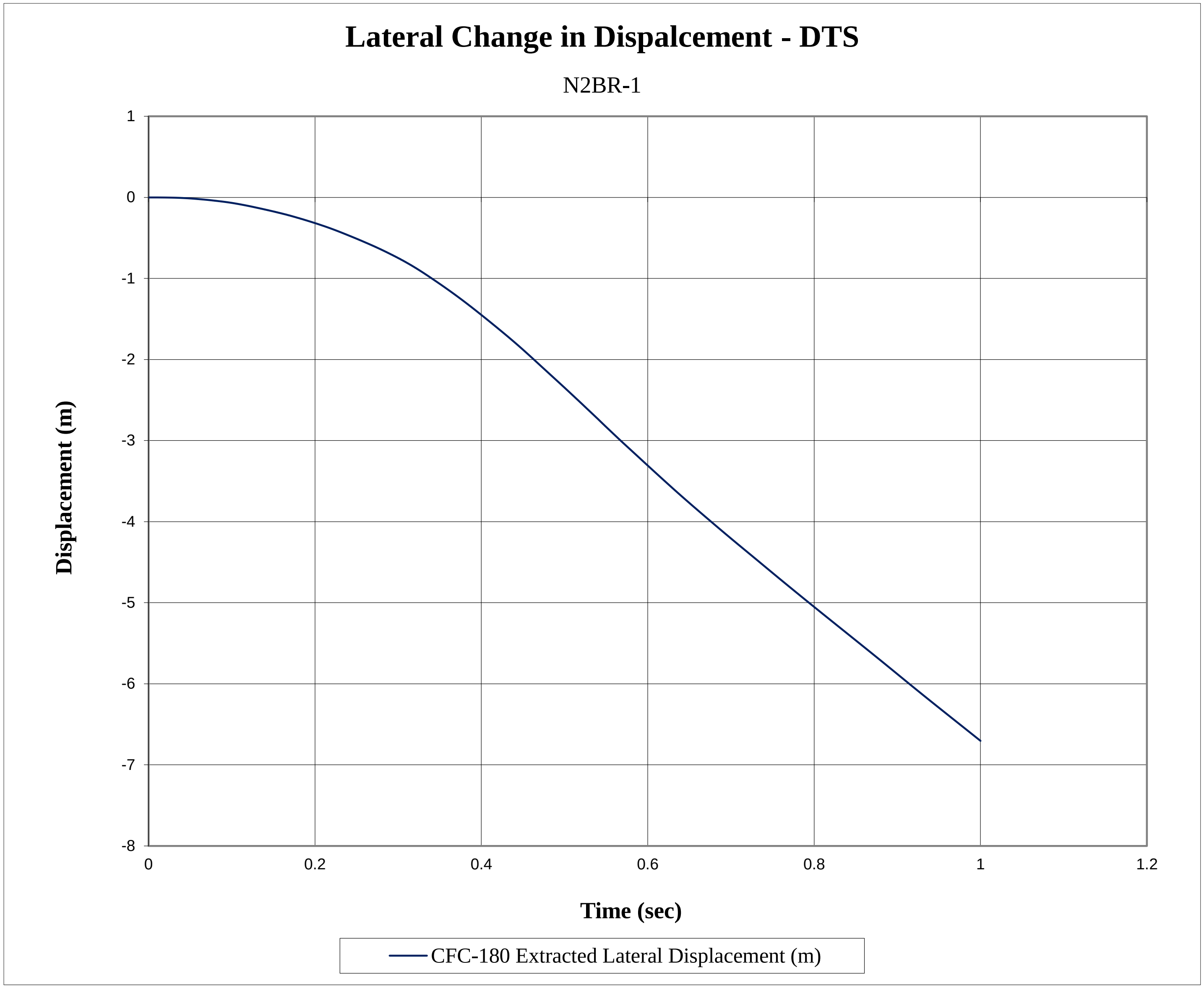


Figure G-14. Lateral Occupant Displacement (DTS), Test No. N2BR-1

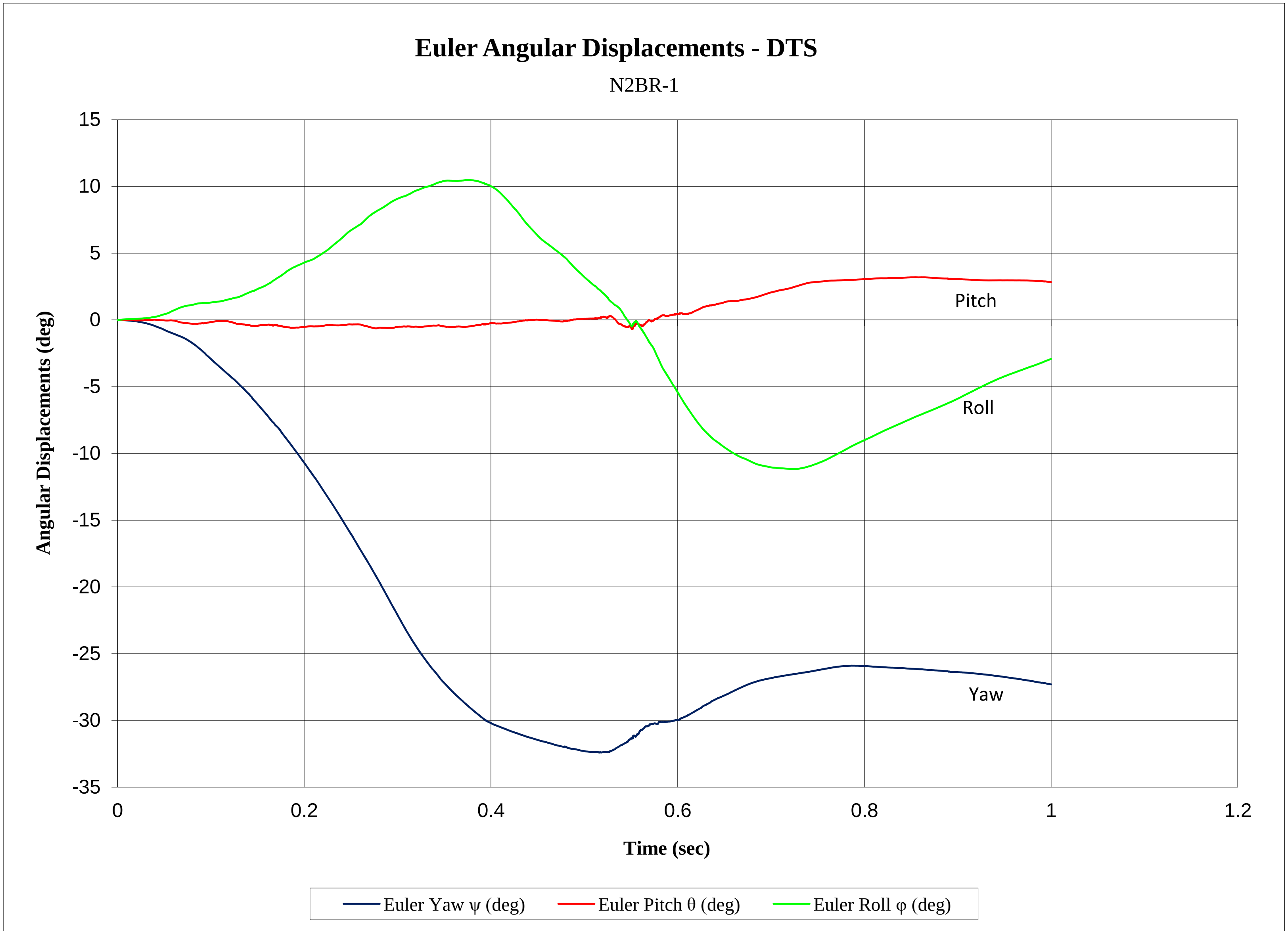


Figure G-15. Vehicle Angular Displacements (DTS), Test No. N2BR-1

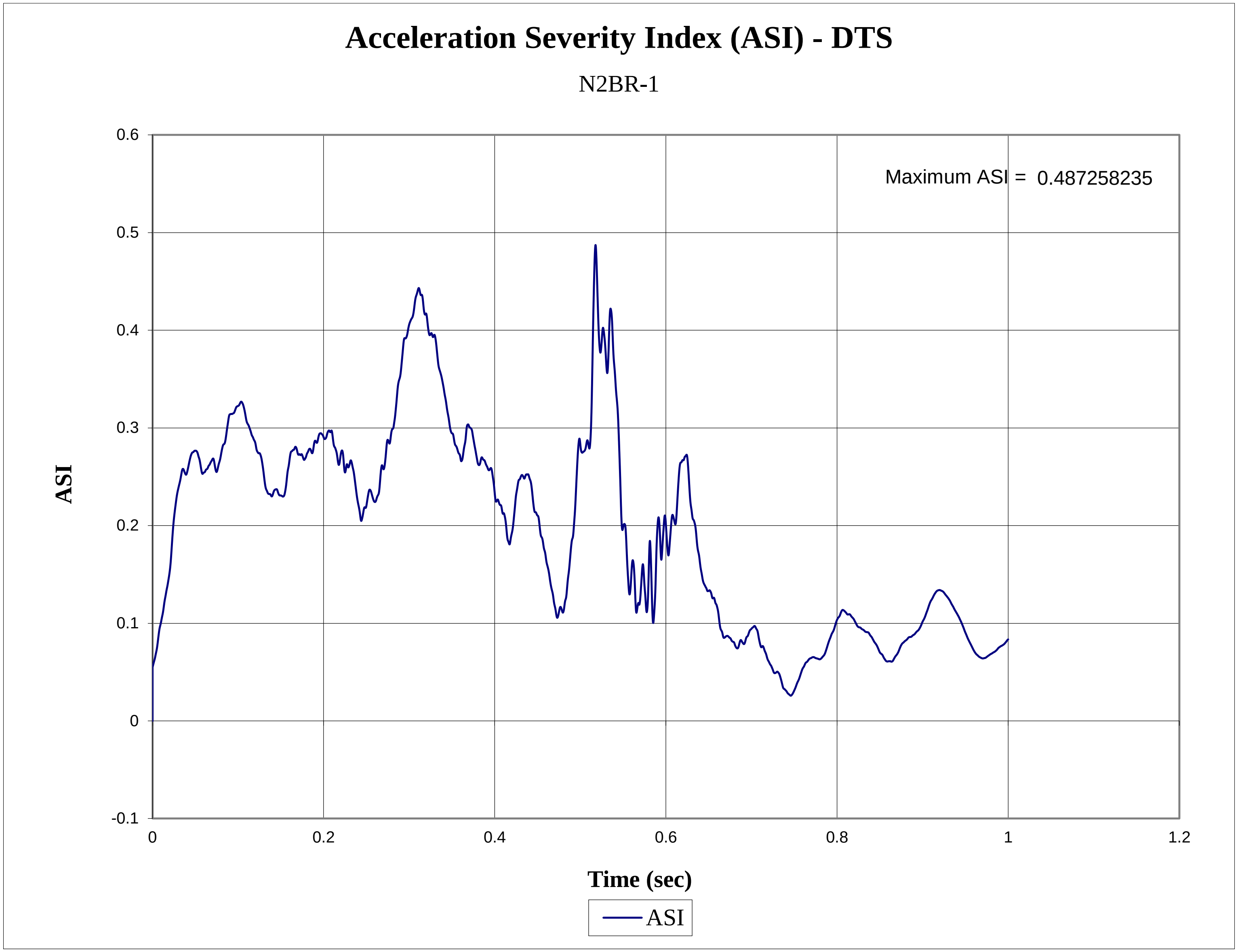
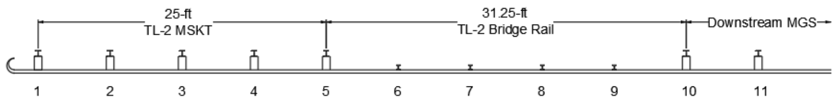


Figure G-16. Acceleration Severity Index (DTS), Test No. N2BR-1

Appendix H. Example Calculations for Minimum Installation Lengths

The following pages contain a few example calculations for the length of MGS required adjacent to the bridge rail based on the forces applied to the W-beam guardrail by a compression terminal. Please note that these calculations are only for the resistance needed to support proper function of a compression and do not include consideration for the length of need required to shield the hazard, terminal stroke length, or guardrail anchorage requirements. All of these factors should be considered when determining the minimum MGS length adjacent to the bridge rail.

EXAMPLE #1



- TL-2 installation
- 25-ft bridge
    - 31.25 ft of bridge rail (between W6x8.5 posts)
    - (4) S3x5.7 bridge rail posts
- MSKT on upstream end of guardrail
    - TL-2 stroke length of 25 ft
- 25 ft of guardrail upstream of bridge rail
- Downstream MGS posts to utilize 12-in. blockouts

Compression load from Table 18 in Section 10.5:
For an MSKT, C = 12.6 kips

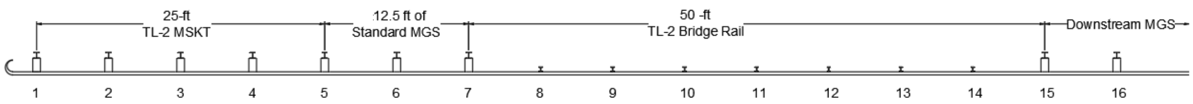
Post capacities from Table 17 in Section 10.5:
S3x5.7 bridge posts, P_s = 1.2 kips
W6x8.5 MGS posts with 12" blockout, P_w = 2.4 kips

Use equation from Section 10.5 to find minimum number of MGS posts downstream of bridge

$$N_s P_s + N_w P_w > C$$
$$(4)(1.2) + N_w(2.4) > 12.6$$
$$N_w > 3.25\ posts$$

TL-2 MSKT has a stroke length of 25 ft, so all of the posts on the upstream side of the bridge rail are within the stroke length and should not be counted as resisting the terminal compression force. Thus, four W6x8.5 MGS posts are required on the downstream end of the bridge rail to resist the terminal compression forces. This corresponds to 18.75-ft of MGS beginning at post no. 10 of the installation.

EXAMPLE #2



- TL-2 installation
- 45-ft bridge
    - 50 ft of bridge rail (between W6x8.5 posts)
    - (7) S3x5.7 bridge rail posts
- MSKT on upstream end of guardrail
    - TL-2 stroke length of 25 ft
- 37.5-ft of guardrail upstream of bridge rail
- Downstream MGS posts to utilize 12-in. blockouts

Compression load from Table 18 in Section 10.5:
For an MSKT, C = 12.6 kips

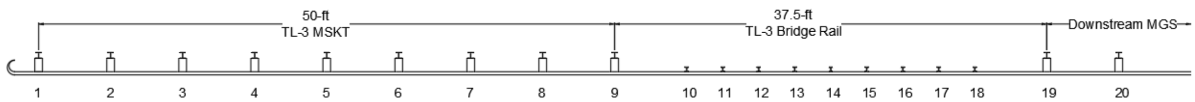
Post capacities from Table 17 in Section 10.5:
S3x5.7 bridge posts, P_s = 1.2 kips
W6x8.5 MGS posts with 12" blockout, P_w = 2.4 kips

Use equation from Section 10.5 to find minimum number of MGS posts downstream of bridge

$$N_s P_s + N_w P_w > C$$
$$(7)(1.2) + N_w(2.4) > 12.6$$
$$N_w > 1.75 \ posts$$

TL-2 MSKT has a stroke length of 25 ft, so two of the posts on the upstream side of the bridge rail are outside the stroke length and would resist the terminal compression force. Thus, the additional 12.5-ft of MGS installed adjacent to the TL-2 MSKT and the 50-ft long bridge rail are sufficient to resist the terminal compression forces. No additional MGS is required on the downstream end to account for terminal compression forces, so the length of the MGS required on the downstream end would be likely be determined from anchorage requirements (see Section 10.5).

EXAMPLE #3



- TL-3 installation
- 35-ft bridge
    - 37.5 ft of bridge rail (between W6x8.5 posts)
    - (9) S3x5.7 bridge rail posts
- MSKT on upstream end of guardrail
    - TL-3 stroke length of 50 ft
- 50-ft of guardrail upstream of bridge rail
- Downstream MGS posts to utilize 12-in. blockouts

Compression load from Table 18 in Section 10.5:
For an MSKT, C = 12.6 kips

Post capacities from Table 17 in Section 10.5:
S3x5.7 bridge posts, P_s = 1.2 kips
W6x8.5 MGS posts with 12" blockout, P_w = 2.4 kips

Use equation from Section 10.5 to find minimum number of MGS posts downstream of bridge

$$N_s P_s + N_w P_w > C$$
$$(9)(1.2) + N_w(2.4) > 12.6$$
$$N_w > 0.75 \; posts$$

TL-3 MSKT has a stroke length of 50 ft, so all of the posts on the upstream side of the bridge rail are within the stroke length and should not be counted as resisting the terminal compression force. Thus, only one W6x8.5 MGS post is required on the downstream end to account for terminal compression forces. As such, the length of MGS required on the downstream end would be likely be determined from anchorage requirements (see Section 10.5).

EXAMPLE #4

What length of bridge rail would be sufficient to resist the terminal compression forces of an MSKT? In such an installation, the length of the MGS on downstream end of the installation would be determined by anchorage requirements only.

$$N_s P_s + N_w P_w > C$$
$$N_s(1.2) + (0)(2.4) > 12.6$$
$$N_s > 10.5 \ posts$$

Eleven posts spaced at 6.25 ft intervals would cover a distance of 62.5 ft. Assuming there was at least 1 ft of distance between the outer posts and the ends of the bridge, any bridge longer than 65 ft should have enough posts to resist the compression forces in an MSKT terminal.

END OF DOCUMENT