Final Report

DEVELOPMENT OF A TL-2 STEEL BRIDGE RAILING AND TRANSITION FOR USE ON TRANSVERSE, NAIL-LAMINATED, TIMBER BRIDGES

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16. Abstract (Limit: 200 words)

A previously designed and full-scale vehicle crash tested, thrie beam and channel bridge railing was adapted for use on transverse, nail-laminated, timber deck bridges used by the West Virginia Department of Transportation. The original bridge railing and transition systems were developed and crash tested for transverse, glue-laminated, timber decks using the Test Level 2 (TL-2) requirements found in NCHRP Report No. 350. For this study, the steel bridge posts and post-to-deck attachment hardware were fastened to the new timber deck. Four dynamic bogie tests were used to evaluate the structural capacity of the steel hardware as well as the timber deck. The use of timber shear connectors was evaluated in two of the four tests. For all of the tests, the bridge posts were plastically deformed, bent backward, and twisted. No rupture was observed in the steel bridge hardware or within the timber deck. Timber deck damage consisted of slight bearing deformations surrounding a few of the vertical bolt holes. The timber deck, posts, and post-to-deck attachment hardware withstood peak impact loading and provided sufficient structural capacity to support the TL-2 thrie beam and channel bridge railing system. Although the timber shear connectors reduced the minor bearing deformations, their use was not deemed necessary for actual bridges.

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DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the West Virginia Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

UNCERTAINTY OF MEASUREMENT STATEMENT

The Midwest Roadside Safety Facility (MwRSF) has determined the uncertainty of measurements for several parameters involved in non-standard testing of roadside safety hardware as well as in standard full-scale crash 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.

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1 INTRODUCTION

1.1 Problem Statement

Historically, the District Offices of the West Virginia Department of Transportation, Division of Highways have been responsible for the construction, maintenance, and repair of many bridges that utilize transverse, timber, nail-laminated deck systems placed on steel wide-flange girders. Many of these bridges utilize a combination bridge railing systems consisting of 6-in. x 6-in. (152-mm x 152-mm) timber curb rails, steel support posts, and an upper W-beam railing.

According to Section 3.2.2 of the West Virginia Bridge Design Manual, all new or retrofit bridge railings shall meet or exceed the current crash testing criteria. Unfortunately, no crashworthy bridge railing systems have been developed for use on transverse, nail-laminated, timber bridge decks. The current combination W-beam with curb bridge railing systems used by the district offices of the West Virginia Division of Highways (WVDOH) have not been crash tested and do not meet current impact safety standards. If a crash-tested, steel, deck-mounted bridge railing is not developed for these structures, then the districts will no longer be allowed to construct this economical bridge system. In addition, the continued use of non-crashworthy railings would result in safety concerns for the motoring public. Therefore, there exists a need to develop a crashworthy bridge railing system for use on transverse, timber, nail-laminated deck systems.

Transverse, nail-laminated bridge decks are an asset to the overall bridge program in the State of West Virginia for several reasons. First, these bridge deck systems are relatively inexpensive and are known to have quick installation times. In addition, these systems can be installed while maintaining intermittent traffic on the bridge. Third, new bridges with transverse, nail-laminated decks placed on steel structural girders usually cost approximately one-third of a concrete box beam bridge. Finally, a crashworthy bridge railing which uses standardized barrier components should allow maintenance personnel to easily remove and replace any damaged components in a timely and efficient manner without requiring long periods of lane closure.

1.2 Background

In 1998, researchers at the Midwest Roadside Safety Facility (MwRSF) developed two bridge railing systems for transverse, glue-laminated, timber deck bridges [1-2]. For the first railing, a steel system was constructed with a thrie beam rail, an upper structural channel rail, wide-flange post and blockouts, and upper and lower deck mounting plates. A second railing was configured mostly as a wood system using rectangular rail sections, posts, and blockouts, all manufactured from glue-laminated timber, and upper and lower post-to-deck mounting plates. Approach guardrail transition systems were developed for both railing systems.

During this testing program, both of the MwRSF bridge railing and transition systems safely redirected 3/4-ton pickup trucks impacting at the target conditions of 43.5 mph (70 km/h) and 25 degrees. The crash testing and evaluation efforts were conducted according to Test Level 2 (TL-2) criteria found in the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* [3].

1.3 Research Objectives

For this project, the research objectives included the modification of MwRSF's crashworthy, TL-2 steel thrie beam and channel bridge railing for use on a transverse, nail-laminated, timber bridge deck supported by steel wide-flange beams. The bridge railing system was evaluated using dynamic bogie testing on the steel bridge posts attached to an alternative nail-laminated, timber deck. The dynamic component testing program was used to verify that the post-to-deck attachment hardware and timber deck would remain intact under peak impact loading deemed representative of a pickup truck crash test conducted under the TL-2 impact safety standards of NCHRP Report No. 350. In addition, the testing was used to demonstrate that the peak impact loading would not result in significant deck damage. If the dynamic component testing provided acceptable results, then MwRSF researchers would seek acceptance from the Federal Highway Administration (FHWA) for allowing the use of the previously crash-tested bridge railing system on transverse, nail-laminated, timber deck bridges. Finally, the testing program evaluated the benefits for utilizing timber shear plates within the post-to-deck connection.

1.4 Research Approach

Dynamic bogie impact tests were conducted in order to evaluate the structural capacity of the post-to-deck attachment as well as the transverse, nail-laminated, timber bridge deck. A total of four bogie impact tests were performed. For two tests, the bogie vehicle impacted the posts head-on and with the rigid head aligned with the centerline of each post. For the remaining two tests, the bogie vehicle impacted the posts with the rigid head offset from the centerline of each post in order to induce both torsion and bending loads into the post, post-to-deck attachment hardware, and timber deck. The bogie test results obtained from the posts attached to the nail-laminated timber deck were then compared to those results obtained from the actual TL-2 crash test performed on the original bridge railing system using the impact safety criteria published in NCHRP Report No. 350.

During the full-scale vehicle crash testing (test no. STCR-1) of the original thrie beam and channel rail bridge railing system attached to a transverse, glue-laminated, timber deck, the maximum dynamic and permanent set thrie beam rail deflections were 6 $^{3}/_{16}$ in. (157 mm) and 4 in. (102 mm), respectively [1-2]. Yielding of steel bridge posts was also observed as depicted by posts leaning backward. However, there was no visible damage to the timber bridge deck or rupture of the post-to-deck attachment hardware.

Therefore, if the bogie tests demonstrate that the steel posts can withstand peak impact loading and yield without damaging the nail-laminated timber deck or rupturing the post-to-deck attachment hardware, then it is deemed appropriate to adapt the thrie beam and channel bridge rail system to transverse, nail-laminated, timber bridge decks. This same methodology, combined with bogie testing, was previously used to adapt a TL-4 steel thrie beam and steel tube bridge railing system to a fiber reinforced plastic (FRP) bridge deck after the railing system had been crash tested and evaluated on a transverse, glue-laminated, timber deck [4-6].

The test results were later analyzed and documented. Conclusions were then drawn that pertain to the behavior of the steel bridge posts, steel post-to-deck attachment hardware, and timber deck when subjected to direct lateral and torsion loading. Finally, recommendations were made pertaining to use of the TL-2 steel thrie beam and channel bridge railing on the transverse, nail-laminated, timber deck bridges.

2 BRIDGE RAILING HISTORY

2.1 Original Simulated Test Bridge (1998)

In 1998, the crash testing of the thrie beam and channel bridge railing and approach guardrail transition systems was conducted at MwRSF's outdoor test site located in Lincoln, Nebraska [1,6]. A full-size test bridge was constructed to perform all of the barrier testing. The test bridge measured approximately 13 ft (3.96 m) wide and 120 ft (36.58 m) long and consisted of three simply-supported spans measuring approximately 40 ft (12.19 m) each. The transverse deck system was constructed of 5⅛-in. (130-mm) thick by 48-in. (1.22-m) wide glulam timber panels. The glulam timber for the deck was Combination No. 47 Southern Yellow Pine, as specified in the AASHTO LRFD Bridge Design Specifications [7]. The timber was treated according to the American Wood Preservers' Association (AWPA) Standard C14 [8]. Thirty glulam timber panels were placed side by side to achieve the 120 ft (36.58 m) length and were attached to the longitudinal glulam beams with standard aluminum deck brackets. The test bridge was positioned on concrete supports that were placed in a 6-ft 11⅞-in. (2.13-m) deep excavated test pit. The concrete supports were placed so that the top of the test bridge was 2 in. (51 mm) below the concrete surface to allow for placement of the bridge deck wearing surface.

2.2 Original Bridge Railing and Transition Design Details

The bridge railing system was designed with a thrie beam rail, an upper structural channel rail, wide-flange bridge posts and rail blockouts, and deck mounting plates. Specific details of this system are provided in References [1,6]. For the steel system, a 10-gauge, thrie beam rail was blocked away from wide-flange posts with wide-flange spacers. A structural channel rail was then attached to the top of the posts. The lower end of each post was bolted to two steel plates that were connected to the top and bottom surfaces of the bridge deck with vertical bolts. A TL-2 approach guardrail transition system was designed for attachment to each end of the bridge railing system. The system was constructed using a steel thrie beam rail, a sloped structural channel end rail, guardrail posts, and rail blockouts. Specific details of the approach guardrail transition are provided in References [1,6].

2.3 Prior Full-Scale Crash Testing Program

The steel bridge railing system was subjected to one full-scale vehicle crash test. Test no. STCR-1 was successfully performed with a 1990 Chevrolet 2500 pickup truck with a test inertial weight (mass) of 4,334 lbs (1,966 kg) and at the impact conditions of 41.4 mph (66.6 km/hr) and 25.6 degrees. Following an analysis of the test results, it was determined that the steel bridge railing system met the TL-2 safety performance criteria provided in NCHRP Report No. 350. No significant damage to the test bridge was evident from the vehicle impact test. For the bridge railing system, damage consisted primarily of permanent deformation of the thrie beam rail, channel rail, wide-flange posts, and rail spacers. Although visual permanent set deformations of the steel components were found in the vicinity of the impact, all of the steel members remained intact and serviceable after the test. Thus, replacement of bridge railing components would be based more on aesthetics versus structural integrity.

The approach guardrail transition that was used with the steel bridge railing system was also subjected to one full-scale vehicle crash test. Test no. STCR-2 was successfully performed with a 1990 Chevrolet 2500 pickup truck with a test inertial weight (mass) of 4,486 lbs (2,035 kg) and at the impact conditions of 43.4 mph (69.9 km/hr) and 25.8 degrees. Following an analysis of the test results, it was determined that the approach guardrail transition for use with the steel bridge railing system met the TL-2 safety performance criteria provided in NCHRP Report No. 350. No significant damage to the upstream end of the test bridge was evident from the vehicle impact test. For the approach guardrail transition system, damage consisted primarily of deformed thrie beam rail and bridge posts as well as displaced guardrail posts. Although visual permanent set deformations of the thrie beam rail were found in the vicinity of the impact, the rail remained intact and serviceable after the test. Thus, replacement of the guardrail would be based more on aesthetics versus structural integrity.

3 PHYSICAL TESTING OVERVIEW

3.1 Purpose

Physical testing of components is an important aspect of any design process. Using this method, the researcher is able to gain practical insight and experience for both component and system behavior. Physical testing can accurately represent a system's behavior, thus allowing the researcher to gain a better understanding of the design and its limits.

3.2 Test Facility

Physical testing of W6x12 (W152x17.9) steel bridge posts and the associated post-to-deck hardware components was performed at MwRSF's outdoor testing facility located at the Lincoln Air Park, on the northwest side of the Lincoln Municipal Airport. The outdoor test facility is configured with a full-size bridge test pit which allows for the construction, testing, and evaluation of actual bridge decks and railing systems.

3.3 Testing Matrix

The research objectives were achieved by performing dynamic bogie impact tests on steel bridge posts that were attached to a transverse, nail-laminated, timber deck. A total of four bogie impact tests, test nos. WVTL2-1 through WVTL2-4, were conducted with the bridge posts and post-to-deck hardware mounted to the outer edge of a timber bridge deck. The target impact conditions for the crash tests consisted of an impact speed of 16 mph (25.7 km/h) and an impact angle of 90 degrees relative to the post's strong axis of bending. A rigid, vertical, cylinder was mounted to the front of the bogie vehicle, while a 4-in. x 4-in. x ½-in. (102-mm x 102-mm x 13-mm) steel tube was horizontally-mounted to the front of the posts at a height of 21⅝ in. (550 mm) above the bridge deck. For test nos. WVTL2-1 and WVTL2-3, the bogie vehicle and impact head contacted the horizontal steel tube with the vehicle aligned with the centerline of each post for a classical "head-on" impact event. For test nos. WVTL2-2 and WVTL2-4, the bogie vehicle and impact head contacted the horizontal steel tube with the vehicle laterally offset 9 in. (229 mm) away from the centerline of each post. These offset impacts were desired to evaluate the structural capacity of the post, post-to-deck attachment hardware, and the timber bridge deck under a combined lateral and torsion loading. The test matrix is shown in Table 1.

It was also desired to investigate the use of timber shear plates within the post-to-deck connection in order to quantify whether their use provided any additional structural capacity to the bridge railing system. Therefore, test nos. WVTL2-3 and WVTL2-4 utilized shear plates in the pos-to-deck attachment, while test nos. WVTL2-1 and WVTL2-2 did not use shear plates. Complete design details for the post assemblies used in the bogie testing program are provided in Chapter 4. However, it should be noted that the thrie beam and channel rails were not incorporated into post assemblies as they were not deemed necessary for evaluating post yield, rupture of the post-to-deck hardware, and timber deck damage.

Table 1. Dynamic Bogie Impact Testing Matrix – Bridge Posts and Attachment Hardware

Test No.	Target Impact Speed mph (km/h)	Impact Orientation (deg.)	Impact Location	Shear Connectors	Additional Torsion Stiffeners on Post
WVTL2-1	16 (25.7)	90	Centered on Post	None	None
WVTL2-2	16 (25.7)	90	9-In. Lateral Offset	None	Gussets Near Impact Height
WVTL2-3	16 (25.7)	90	Centered on Post	Shear Plates	None
WVTL2-4	16 (25.7)	90	9-In. Lateral Offset	Shear Plates	Gussets Near Impact Height

4 SYSTEM DETAILS FOR COMPONENT TESTING

4.1 Introduction

Each test article was comprised of a steel bridge post, block out, horizontal impact tube, and top and bottom steel deck mounting plates. The bridge posts were assembled and attached to the edge of a transverse, nail-laminated, timber bridge deck. Descriptions of these components can be found in the following sections. Design drawings for the test articles are shown in Figures 1 through 12.

4.2 Steel Bridge Posts

The steel bridge posts were 42¾-in. (1,086-mm) long, W6x12 (W152x17.9) beams made from ASTM A992 or ASTM A572 Grade 50 steel, as shown in Figures 7 through 9. Near the top of the post, four ¾-in. (19-mm) diameter bolt holes were placed within the front flange. The blockouts were bolted to the posts using these bolt holes. Slots were cut into the front flange near the bottom of each post and used to fasten the bottom deck plate to the post. The hole and slot locations in the posts are shown in Figure 9.

In addition to the fabricated holes and slots, a steel post plate was welded to the front flange 9 in. (229 mm) from the bottom of the post. Each post plate measured 10⅜ in. x 4 in. x ½ in. (264 mm x 102 mm x 13 mm). Two slots were cut into the post plate and used to bolt the top deck plate to the post. To provide stiffness and resistance to buckling, gusset plates and stiffeners were also welded to the posts. The geometries of the gussets and the stiffeners are shown in Figure 10. Gussets were placed on both sides of the web at the bottom of the post and directly behind the top of the post plate, while the post wing stiffeners were located along the top of the post plate and adjacent to the gusset plates, as shown in Figures 7 and 8. These gussets and stiffeners were designed to provide additional stiffness to the post and to prevent localized bucking near the deck plate attachments.

4.3 Top and Bottom Deck Plate Assemblies

Deck plate assemblies were utilized to attach the bridge posts to the bridge deck. The top deck plate was ½ in. (13 mm) thick, while the bottom deck plate was ⅜ in. (10 mm) thick. The deck plates were fabricated from ASTM A36 steel and contained eight 1-in. (25-mm) diameter holes, as shown in Figures 5 and 6. Eight ⅞-in. (22.2-mm) diameter by 7¾-in. (197-mm) long, ASTM A307 hex bolts were to be used to fasten the deck plates to the edge of the timber bridge deck, as shown in Figures 1 through 4. However, an error in the material ordering process led to fact that Grade 5 bolts were used in lieu of the A307 bolts. Regretfully, this error was not discovered until after the bogie testing program had been completed and documentation and reporting had been initiated.

Steel rectangular end plates were welded to the back side of the deck plates and provided the locations where the bridge post bolted to the plates. The end plates were welded to the deck plates using triangular-shaped plate stiffeners, as shown in Figure 5. The dimensions of the top end plate, bottom end plate, and the plate stiffeners are shown in Figure 6.

The steel fastening hardware used to attach the posts to the deck plates and the deck plates to the bridge deck is shown in Figure 11. Two ⅞-in. (22.2-mm) diameter ASTM A325 hex head bolts were used to fasten the top deck plate to each post, while two ⅝-in. (15.9-mm) diameter ASTM A325 hex head bolts were used to fasten the bottom deck plate to each post.

4.4 Post Blockouts and Impact Tube Assembly

Post blockouts were configured with ASTM A992 or ASTM A572 Grade 50, W6x12 (W152x17.9) steel sections that attached to the front face of the bridge posts. Eight ¾-in. (19-

mm) holes, four in the front flange and four in the back flange, were placed into each blockout. Four ⅝-in. (15.9-mm) diameter by 2-in. (51-mm) long, ASTM A490 heavy hex head bolts were used to secure each blockout to each post. Details for the steel blockout are provided in Figures 7 through 9. The higher grade bolts were selected for use in the bogie testing program in order to prevent premature bolt failure and blockout release during the off-center impact tests, thus resulting in a higher loading imparted to the steel hardware and timber deck. However, it should be noted that the higher grade bolts would not be used to attach the blockouts to the posts in the actual bridge railing system.

The horizontal impact tube assembly consisted of a 30-in. (762-mm) long section of 4-in. x 4-in. x ½-in. (102-mm x 102-mm x 13-mm) steel tube that was welded to a 6-in. x 12-in. x ½-in. (152-mm x 305-mm x 13-mm) steel plate, as shown in Figure 10. The impact tube assembly was bolted to the front face of the post blockout using four additional ⅝-in. (15.9-mm) diameter by 2-in. (51-mm) long, ASTM A490 heavy hex head bolts. The horizontal impact tube was used in all four bogie tests in order to ensure that the bogie vehicle did not slip off of the posts during loading. In addition, the horizontal impact tube was especially necessary to impart an eccentric load to the post and deck hardware, thus resulting in the combined lateral and torsion load condition for test nos. WVTL2-2 and WVTL2-4.

4.5 Special Gusset Hardware (Off-Centered Impact Testing)

For the two off-center impact tests, test nos. WVTL2-2 and WVTL2-4, four extra gussets were used to prevent premature twisting and buckling of the blockout and bridge post. Gussets were welded to both sides of web for both the posts and the blockouts. All of the gussets were placed at the same height as the center of the impact tube. Gusset placement and geometry are shown in Figures 8 and 10, respectively.

4.6 Timber Shear Plates

For test nos. WVTL2-3 and WVTL2-4, circular shear plates were used to enhance the bolted attachment between the top and bottom deck plates and the timber bridge deck. The 4-in. (102-mm) diameter shear plates were made from galvanized steel and were used to distribute shear forces over a larger area of the upper and lower deck surfaces, reducing the possibility for the vertical steel bolts to tearing through the wood holes located near the edge of the timber deck.

4.7 Timber Bridge Deck

In order to simulate real world conditions, a transverse, nail-laminated, timber bridge deck was constructed at MwRSF's outdoor test facility for both this research project as well as for a previous WVDOH research study [9]. The bridge deck was constructed from 14-ft (4.3-m) long, 2-in. x 6-in. (51-mm x 152-mm) treated, dimensional lumber and covered by a 2-in. (51-mm) thick concrete wearing surface. The timber boards were manufactured from Grade No. 1 Southern Yellow Pine and treated with ACQ-D to a minimum net retention of 0.40 lbs/ft^3 (6.41 kg/m^3) satisfying AWPA U1, UC4A [10]. For actual bridge installations, it is recommended that the dimensional lumber boards be treated to a net retention of 0.60 lbs/ft^3 (9.61 kg/m^3) satisfying AWPA U1, UC4B. The boards were placed on end and nailed together through and perpendicular to the wide face of the board using 20d or 20 penny "common" nails. A specific nail pattern, which repeated every four boards, was used to ensure that a nail did not contact a previously driven nail. Special care was given to the nail pattern near the deck edge to ensure the nails did not occupy space where the vertical bolt holes for the bridge rail would later be drilled. During deck assembly, two beads of Liquid Nails Heavy Duty Construction Adhesive (Item No. LN-901) were applied to the sides of the boards and over the outer 3 ft (0.9 m) of deck. The adhesive was used to provide additional punching shear resistance in the deck as well as improved load transfer between boards. Detailed drawings depicting the nailing pattern for both exterior and interior regions of the bridge deck are provided in Reference [9].

Steel deck anchor brackets were sandwiched between adjacent deck boards and were used to attach the bridge deck to the steel girders. The deck anchor brackets were fabricated from 11-gauge (3.04-mm thick), ASTM A36 G90 galvanized steel sheet and were cut to the dimensions noted in Reference [9]. The anchor brackets hooked onto the top flange of the steel bridge girders and were nailed to the adjacent deck boards using two 20d or 20 penny “common” nails. The anchor brackets were installed on 1-ft (305-mm) centers on both girders. The brackets on the exterior girder were all placed on the top-inside flange, while the brackets on the interior girder alternated sides.

4.8 Bridge Substructure

The support structure for the bridge deck consisted of two rows of wide-flange, steel girders, four transverse concrete supports (two bents and two abutments), and lateral bracing between girders. The two rows of three girders were positioned along the entire length of the 120-ft (36.58-m) long, bridge deck. The girders were supported by simulated bridge abutments at each end and two simulated bridge piers spaced approximately 40 ft (12.2 m) apart. In addition to these four rigid supports, three intermediate concrete platform supports with wood shim blocks were used to vertically support the steel girders at the midpoint of each 40-ft (12.2-m) span. Finally, steel C-channel diaphragms were used as lateral bracing for the girders and spaced approximately on 12.5-ft (3.8-m) intervals. The entire substructure is described in detail in Reference [9].

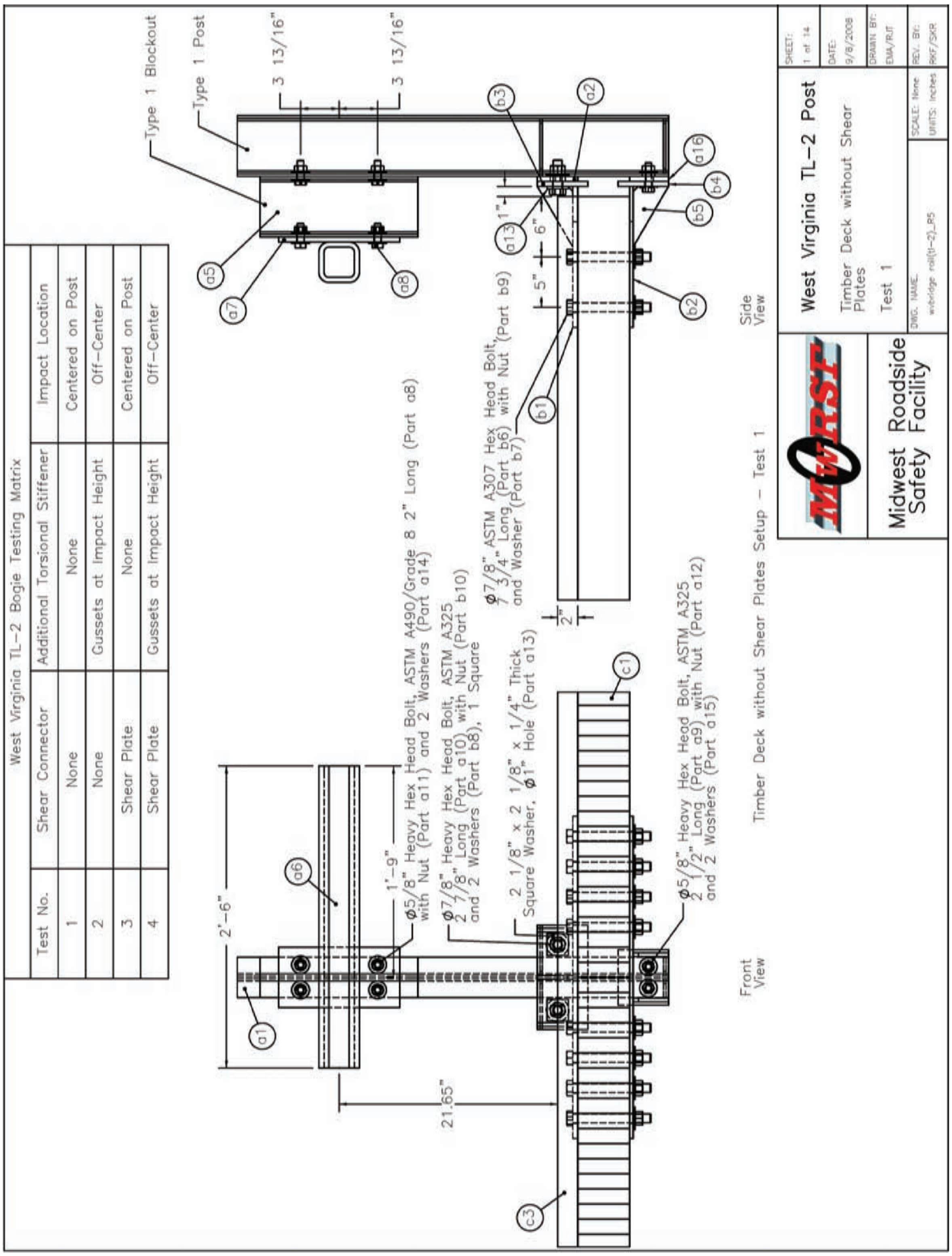


Figure 1. Post Testing Schematic, Test No. WVTL2-1

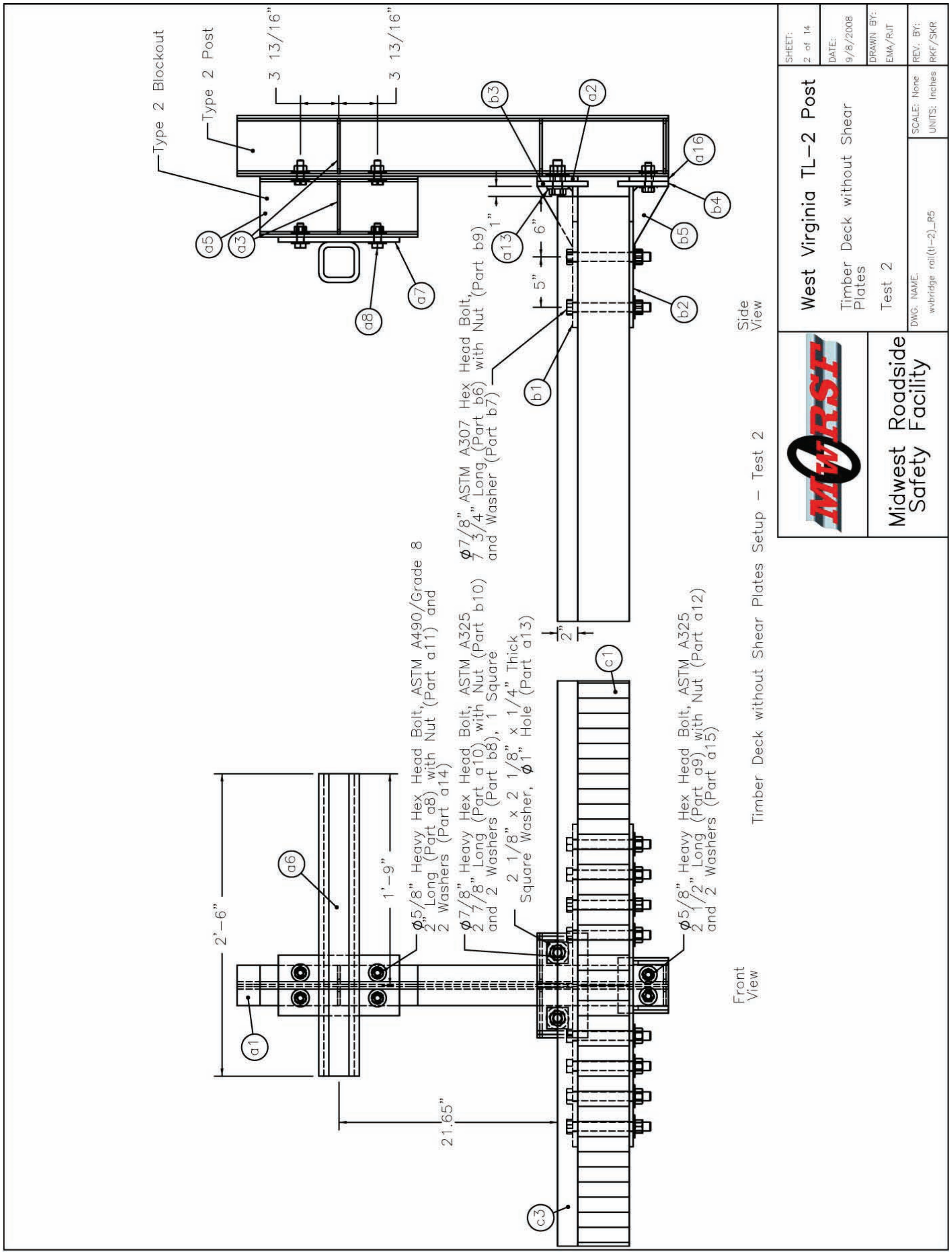


Figure 2. Post Testing Schematic, Test No. WVTL2-2

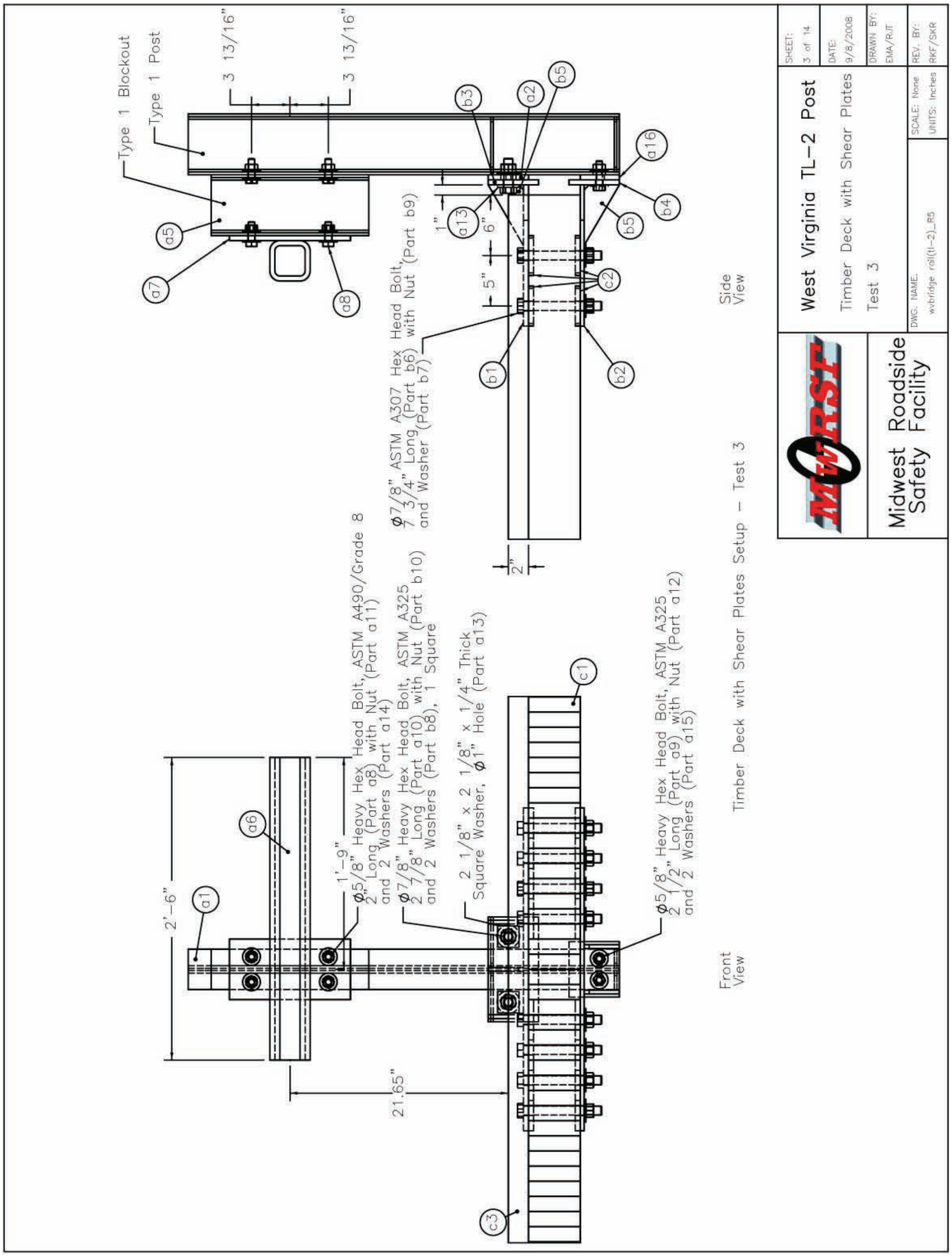


Figure 3. Post Testing Schematic, Test No. WVTL2-3

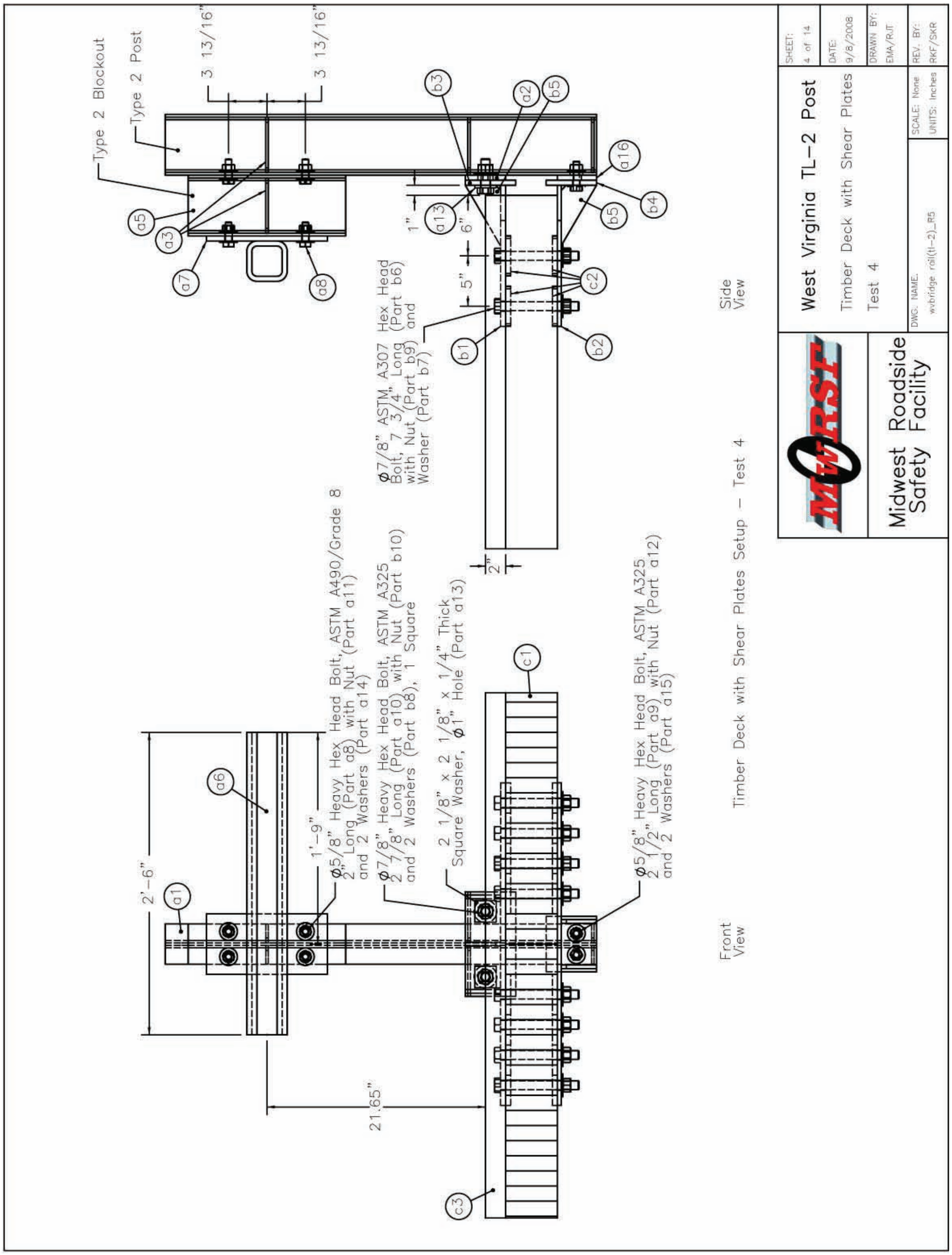


Figure 4. Post Testing Schematic, Test No. WVTL2-4

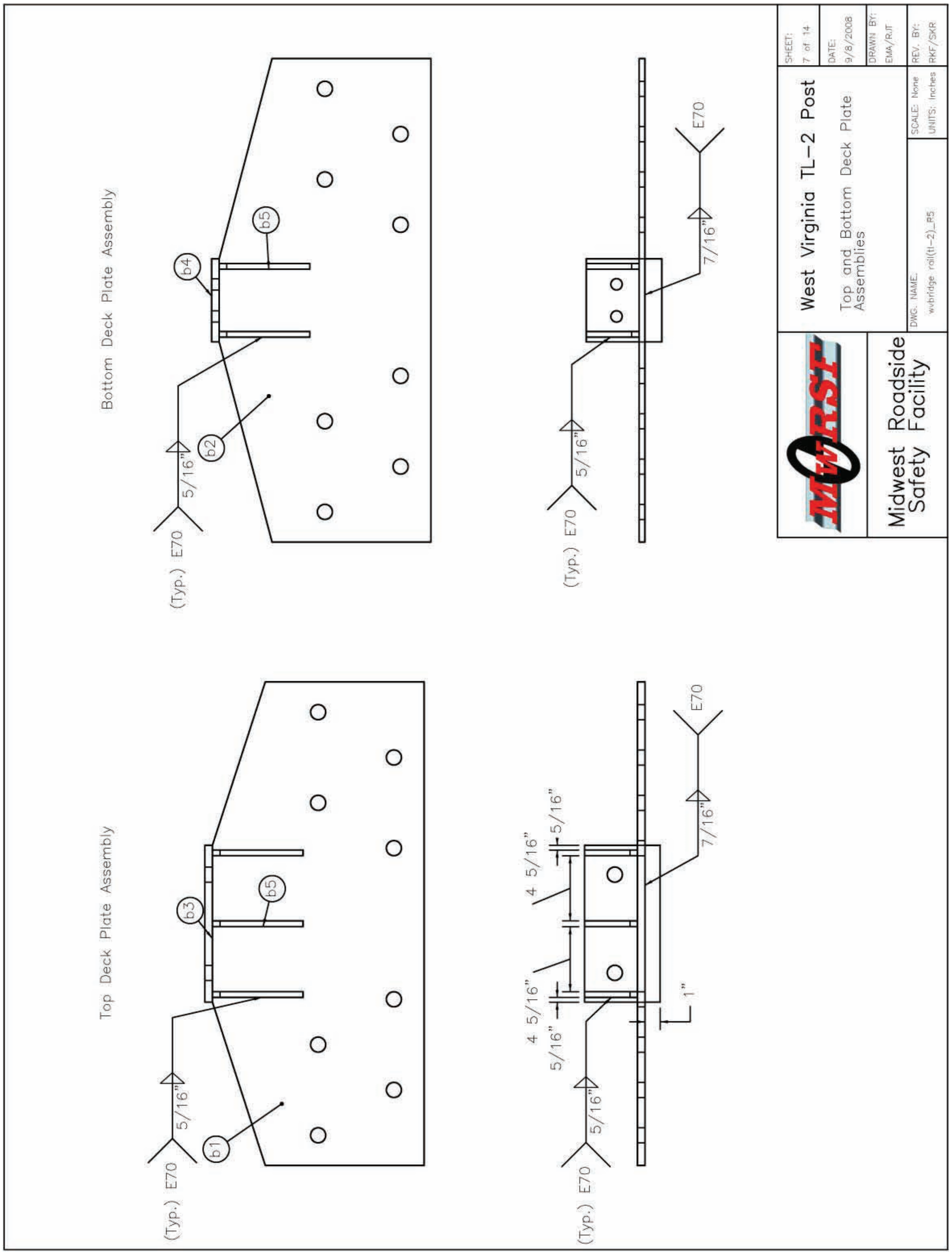


Figure 5. Top and Bottom Deck Plate Assemblies

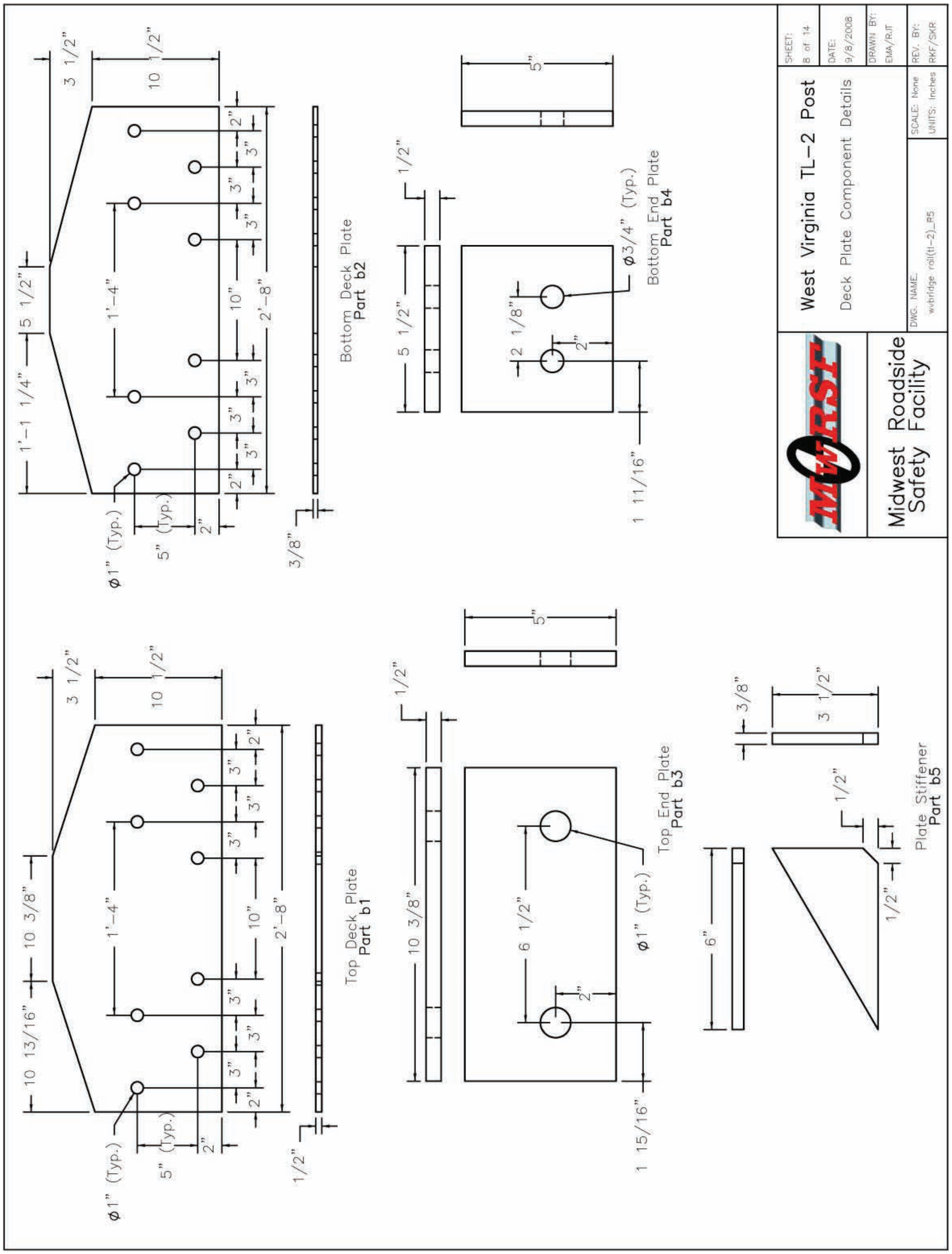


Figure 6. Component Details for Deck Plates

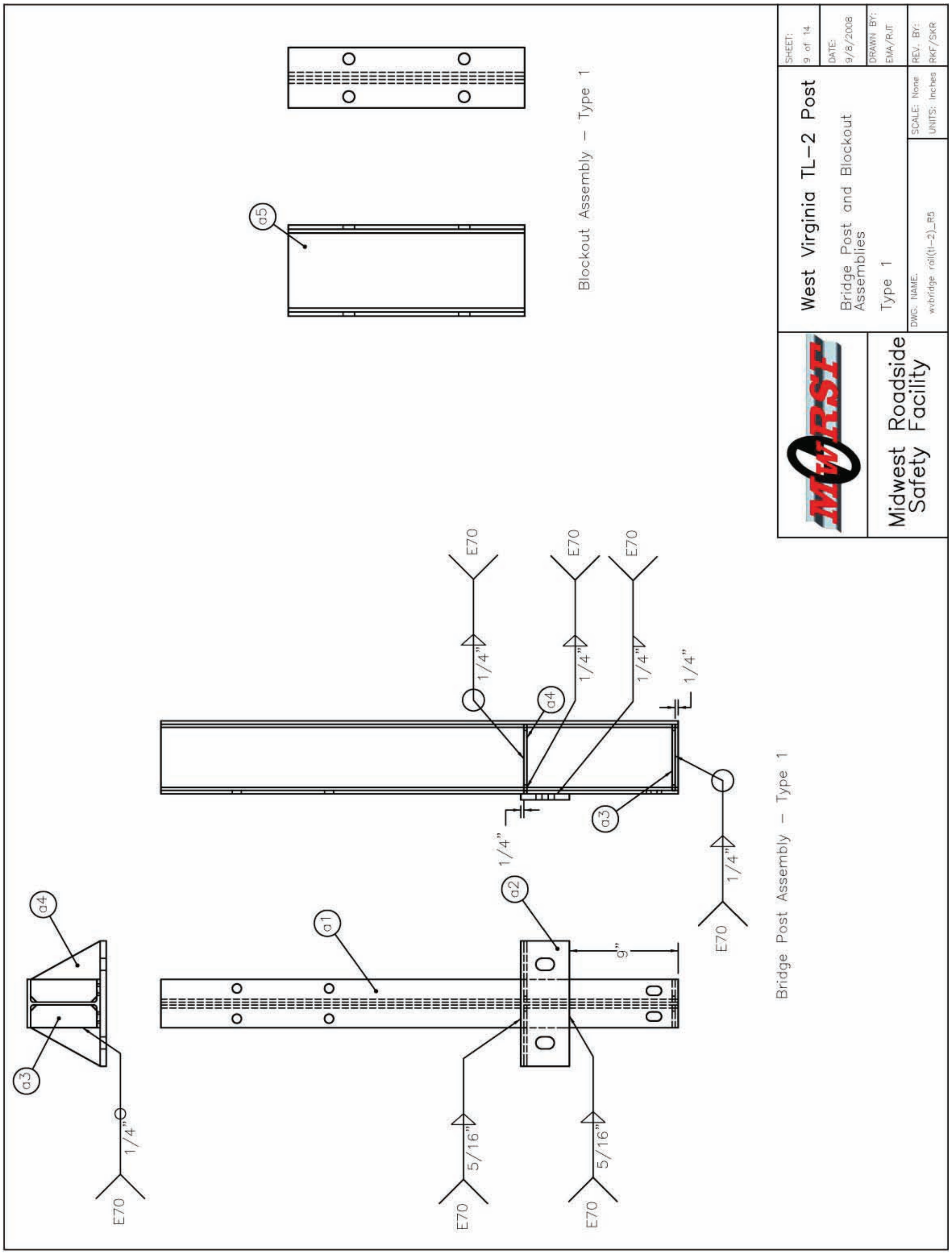


Figure 7. Bridge Post and Blockout Assemblies, Test Nos. WVTL2-1 and WVTL2-3

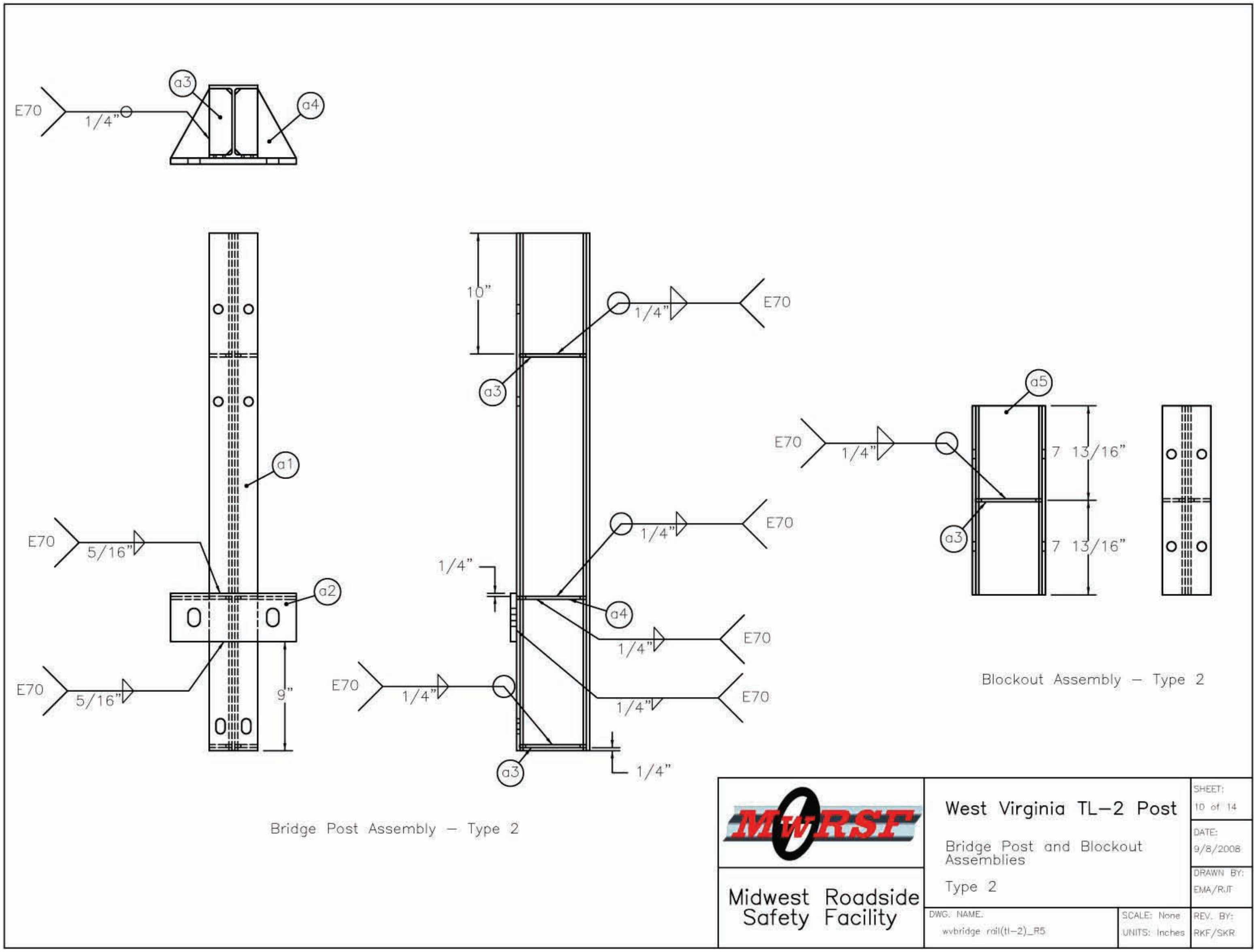


Figure 8. Bridge Post and Blockout Assemblies, Test Nos. WVTL2-2 and WVTL2-4

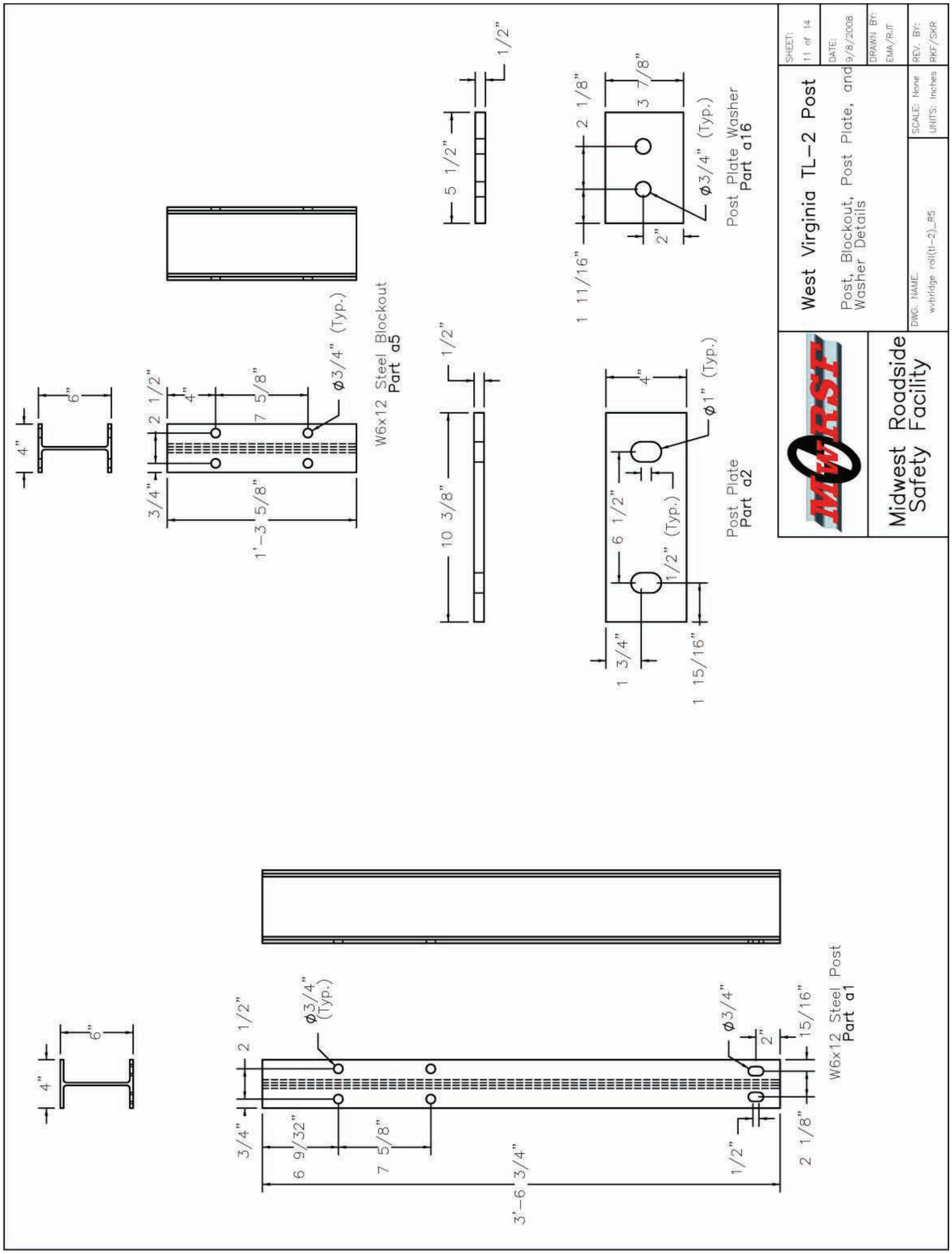


Figure 9. Post, Blockout, Post Plate, and Washer Details

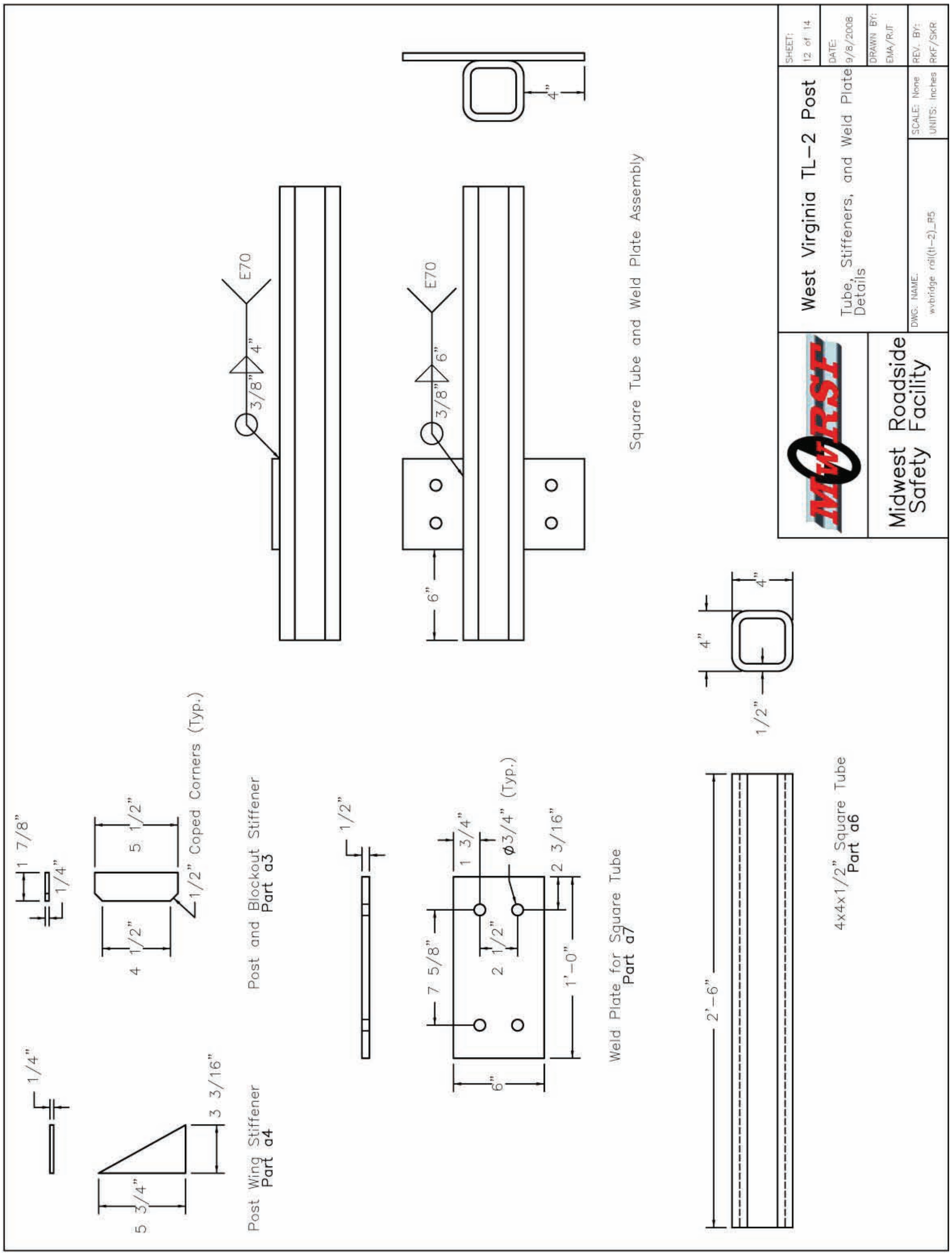


Figure 10. Horizontal Impact Tube Assembly and Post Stiffeners

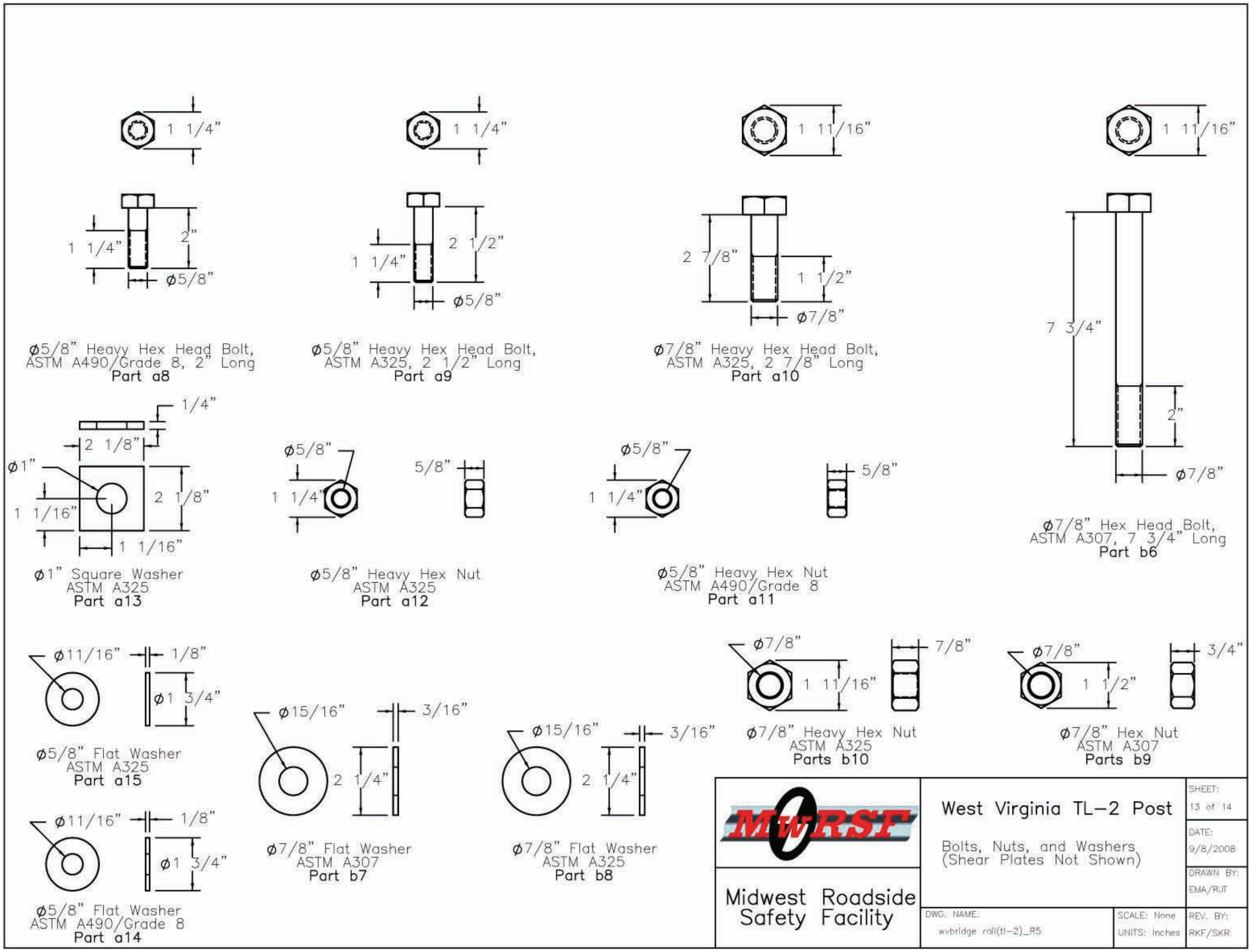


Figure 11. Steel Fastener Hardware – Bolts, Nuts, and Washers

West Virginia Bridge Rail – TL-2			
Item No.	QTY.	Description	Material Specification
a1	4	W6x12x42 3/4" Post	A992 or A572 Grade 50
a2	4	Post Plate	A36
a3	24	Post Stiffener	A36
a4	8	Post Wing Stiffener	A36
a5	4	W6x12x15 5/8" Steel Blockout	A992 or A572 Grade 50
a6	2	4x4x0.5" Square Tube 30" Long (One per test series)	A500 Grade B or C
a7	2	Weld Plate for Square Tube	A36
a8	32	5/8" Heavy Hex Head Bolt 2" Long	A490/Grade 8
a9	8	5/8" Heavy Hex Head Bolt 2 1/2" Long	A325
a10	8	7/8" Heavy Hex Head Bolt 2 7/8" Long	A325
a11	32	5/8" Heavy Hex Nut	A490/Grade 8
a12	8	5/8" Heavy Hex Nut	A325
a13	8	Square Washer	A36
a14	64	5/8" Flat Washer	A490/Grade 8
a15	16	5/8" Flat Washer	A325
a16	4	Post Plate Washer	A36
b1	4	Top Deck Plate	A36
b2	4	Bottom Deck Plate	A36
b3	4	Top End Plate	A36
b4	4	Bottom End Plate	A36
b5	20	Plate Stiffener	A36
b6	32	7/8" Hex Head Bolt 7 3/4" Long	A307
b7	32	7/8" Flat Washer	A307
b8	8	7/8" Flat Washer	A325
b9	32	7/8" Hex Nut	A307
b10	8	7/8" Heavy Hex Nut	A325
c1	960	2"x6"x14' Long Treated, Dimensional Lumber (0.60 lbs retention)	Southern Yellow Pine No. 1
c2	32	ø4" Shear Plate for ø7/8" bolts	Galvanized Steel
c3	1	Asphalt	–

Midwest Roadside Safety Facility

West Virginia TL-2 Post

Bill of Materials for Four Post Tests

SHEET:	14 of 14
DATE:	9/8/2008
DRAWN BY:	EMA/RJT
DWG. NAME.	wvbridge rail(tl-2)_R5
SCALE:	None
UNITS:	Inches
REV. BY:	RKF/SKR

Figure 12. Bill of Materials

5 TEST PARAMETERS

5.1 Bogie Vehicle

A rigid-frame bogie, weighing 1,711 lbs (776 kg), was used to impact the steel bridge posts. The bogie head was constructed with a 3½-in. (89-mm) diameter by 0.3-in. (7.6-mm) thick steel pipe which was secured vertically to a mounting plate. The rigid impact head, used for numerous bogie testing programs, was welded to the mounting plate and braced using 4 sets of gussets spaced evenly along the length of the steel pipe. The mounting plate was then bolted to the front of the bogie vehicle using four ¾-in (19-mm) diameter by 7½-in. (191-mm) long, hex head bolts. Photographs of the bogie vehicle as the bogie impact head are shown in Figure 13.

Figure 13. Bogie Vehicle and Bogie Impact Head

5.2 Bogie Propulsion and Guidance System

The bogie vehicle was directed to the targeted impact point using a steel corrugated B-beam guardrail to guide the right-side tires of the bogie. The B-beam segments were aligned parallel with the targeted impact angle and positioned such that the impact head contacted the targeted impact point, as shown in Figure 14.

A pickup truck was used to push the bogie vehicle to the required impact velocity. As the bogie reached the end of the guide track, the pickup truck slowed, released away from the bogie, and allowed the bogie to be “free-wheeling” as it impacted the test article. A digital speedometer was located in the tow vehicle to increase the accuracy of the bogie’s impact speed.

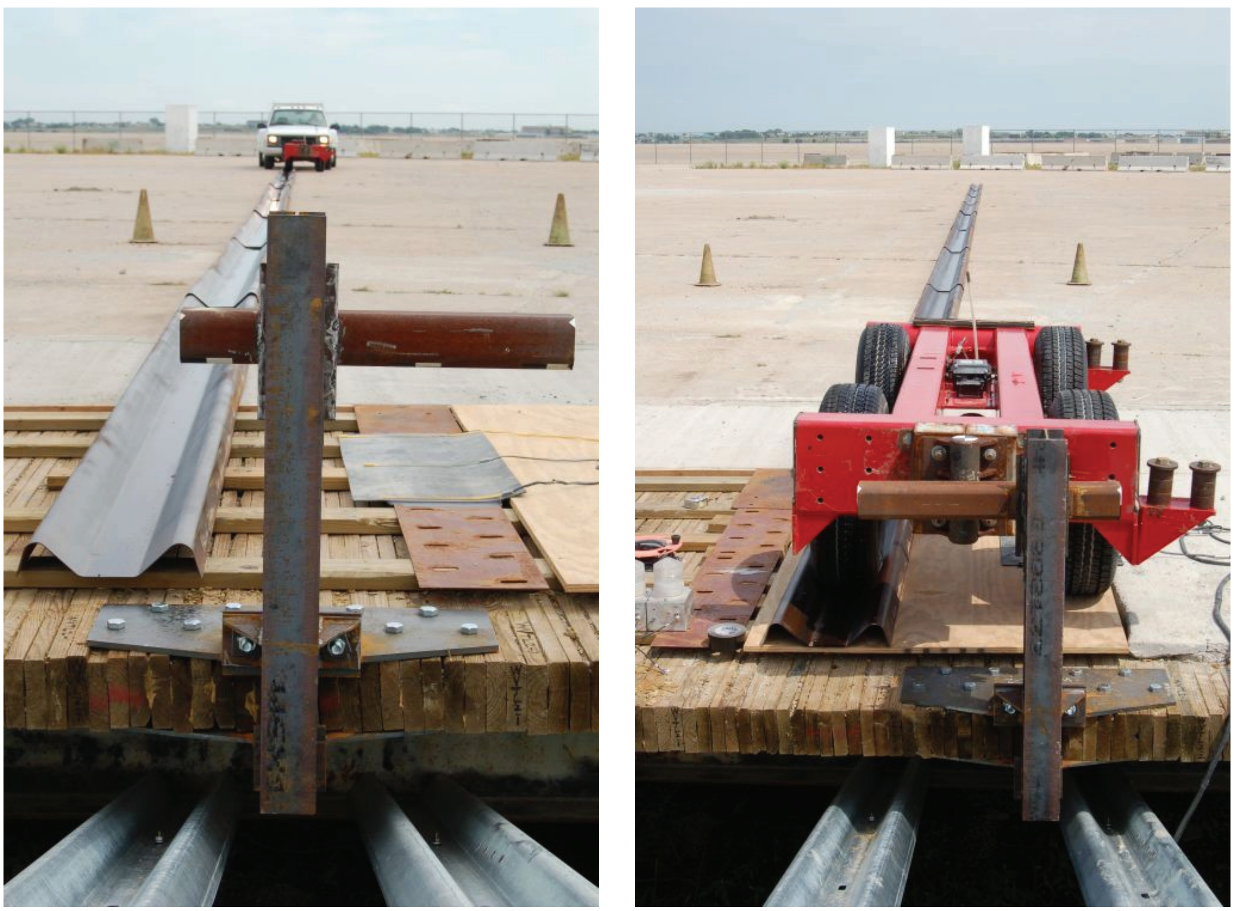


Figure 14. Bogie Vehicle Guidance System

5.3 Data Acquisition Systems

5.3.1 Accelerometers

One triaxial piezoresistive accelerometer system with a range of ±500 g's was used to measure the acceleration in the longitudinal direction at a sample rate of 10,000 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-4 6DOF-500/1200, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels. The EDR-4 6DOF-500/1200 was configured with 6 MB of RAM memory and a 1,500 Hz lowpass filter.

Another triaxial piezoresistive accelerometer system with a range of ± 200 G's was also used to measure the acceleration in the longitudinal direction at a sample rate of 3200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3M6, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan and includes three differential channels as well as three single-ended channels. The EDR-3 was configured with 256 Kb of RAM memory and a 1,120 Hz lowpass filter. Computer software programs "DynaMax 1 (DM-1)", "DADiSP," and a customized Excel spreadsheet were used to analyze and plot the data from both accelerometers.

5.4 High-Speed Photography

For test nos. WVTL2-1 through WVTL2-4, one high-speed AOS VITcam digital video camera and two JVC digital video cameras were used to record the impact events. One AOS VITcam video camera and one JVC video camera were placed perpendicular to impact to record movement of each bridge post. Another JVC camera was used to record movement and/or deformation of deck plates and the attachment to the deck.

The AOS VITcam videos were analyzed using the Image Express MotionPlus and Redlake Motion Scope computer software. Due to technical difficulties, no high-speed data was captured for test nos. WVTL2-1 or WVTL2-2.

5.4.1 Pressure Tape Switches

For all of the bogie tests, three pressure-activated tape switches, spaced at 3.28-ft (1-m) intervals, were used to determine the speed of the bogie vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the left-front tire of the bogie vehicle passed over it. The test vehicle speed was then determined from the electronic timing mark data recorded using the “Test Point” or “LabVIEW” software packages. Strobe lights and high-speed video analysis were to be used only as a backup in the event that vehicle speed could not be determined from the electronic data.

5.5 Test Methodology

Four tests were conducted on the bridge post assemblies that were fastened to a transverse, nail-laminated, timber bridge deck. For two of the tests, test nos. WVTL2-1 and WVTL2-3, the bogie vehicle’s impact head contacted the centerline of the posts, as shown in Figure 15. For the remaining two tests, test nos. WVTL2-2 and WVTL2-4, the bogie vehicle’s impact head contacted the post and horizontal beam with a 9 in. (229 mm) lateral offset from the centerline of the posts, as shown in Figure 16. The test matrix was shown previously in Table 1.

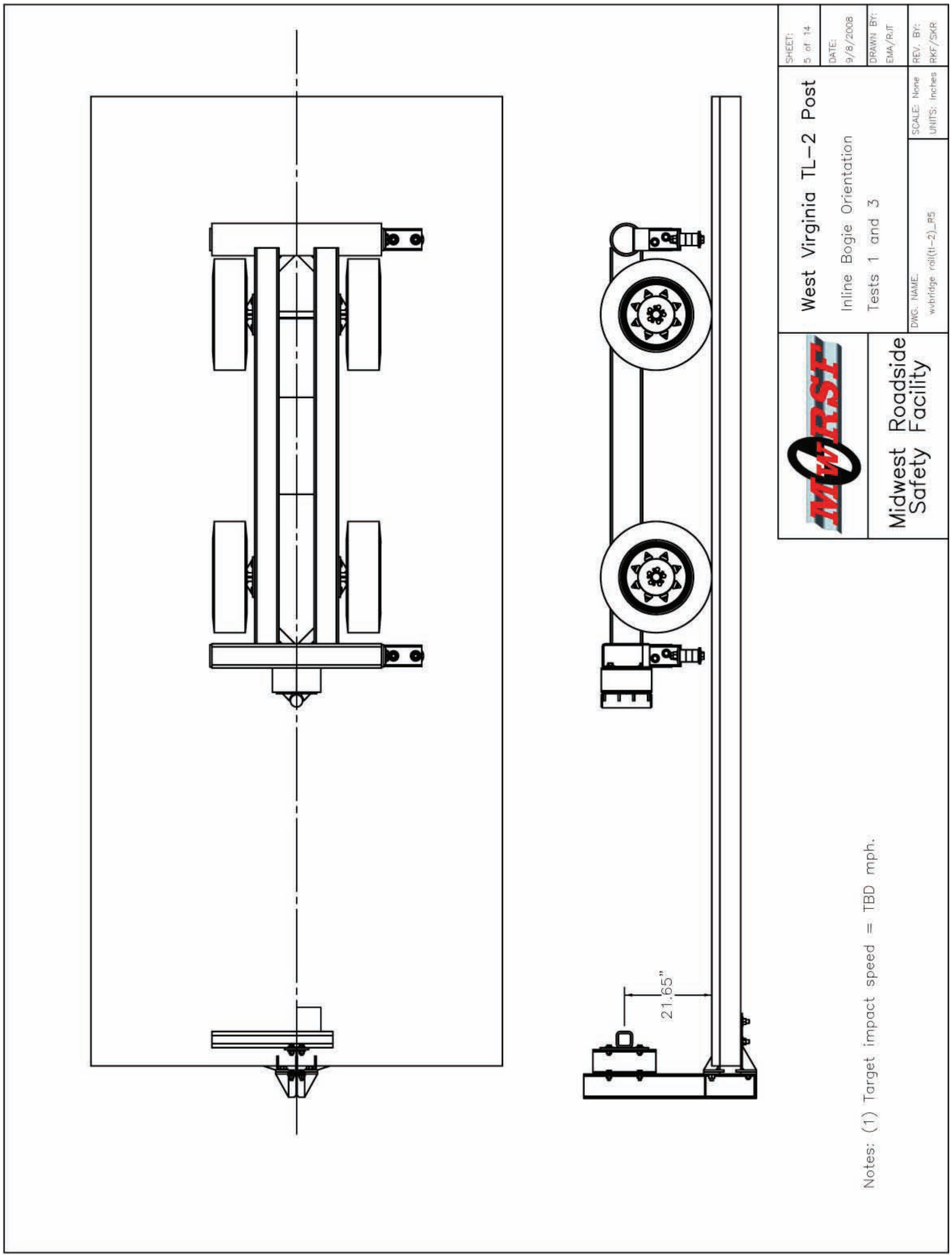


Figure 15. Impact Orientation, Test Nos. WVTL2-1 and WVTL2-3

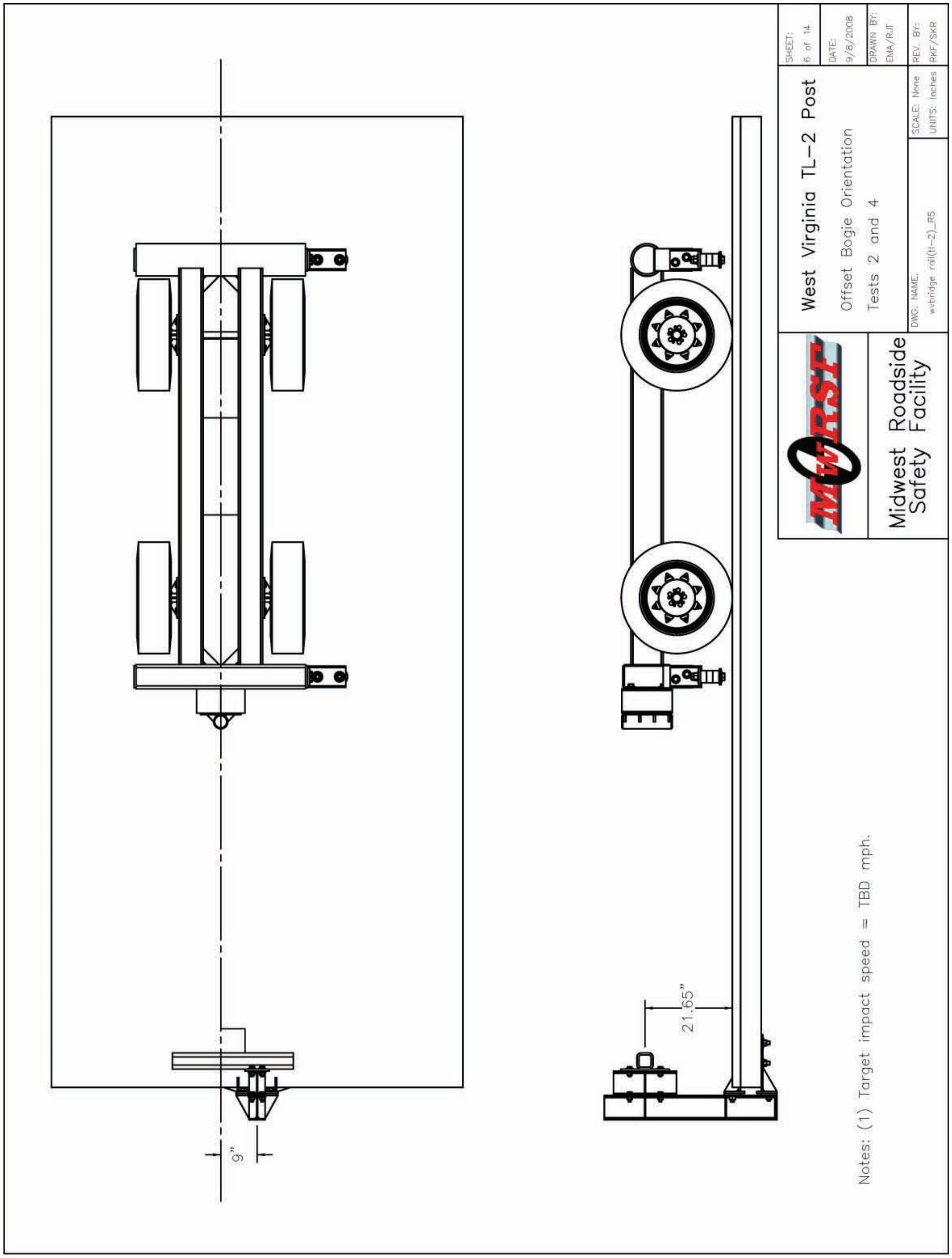


Figure 16. Impact Orientation, Test Nos. WVTL2-2 and WVTL2-4

5.6 End of Test Determination

During an impact event, the data acquisition system records the bogie vehicle accelerations observed from all sources, not just the post. Because of this, vibrations in the bogie vehicle impact head and accelerometer mounting assembly are also recorded, thus potentially resulting in a high-frequency acceleration trace. Since the bogie vehicle may still be vibrating after the impact event, the data may extend beyond the failure of the post. For this reason, it was necessary to define the end of the test.

In general, the end of test time was identified as the time that the vibration peaks in the acceleration trace subsided back toward zero, and it was clear that the continuation of vibrations were not caused by the interaction with the post. Additionally, the test duration times were limited by the bogie-post contact time so that there were no unreasonably long test durations. For each test, the high-speed video was used to establish the length of time that the bogie was actually in contact with the post, and this time was then used to define the end of the test.

5.7 Data Processing

Initially, the electronic accelerometer data was filtered using the SAE Class 60 Butterworth filter conforming to the SAE J211/1 specifications. The pertinent acceleration signal was extracted from the entire data signal. The processed acceleration data was then multiplied by the mass of the bogie to determine the impact force using Newton's Second Law. Next, the acceleration trace was integrated to find the change in velocity versus time. The initial velocity of the bogie, as calculated from the pressure tape switch data, was then combined with the change in velocity data in order to determine the actual bogie velocity versus time curve. The calculated bogie velocity curve was then integrated to find the bogie's displacement versus time, which was also the post displacement. Using the prior results as well as an integration of the force versus displacement curve, the energy versus displacement curve was determined for each bogie test.

6 DYNAMIC POST TESTING

6.1 Introduction

In 1998, the steel thrie beam and channel bridge railing system was crash tested and evaluated according to the TL-2 safety performance criteria provided in NCHRP Report No. 350. Test no. STCR-1 was successfully performed with a 1990 Chevrolet 2500 pickup truck with a test inertial weight (mass) of 4,334 lbs (1,966 kg) and at the impact conditions of 41.4 mph (66.6 km/h) and 25.6 degrees. Following the test, it was determined that the steel bridge railing system met the TL-2 safety performance criteria when attached to a transverse, glue-laminated (glulam), timber bridge deck. The maximum dynamic and permanent set thrie beam rail deflections were 6 $^{3}/_{16}$ in. (157 mm) and 4 in. (102 mm), respectively [1-2]. Several steel bridge posts had yielded, as depicted by posts leaning backward. There was no visible damage to the timber bridge deck or rupture of the post-to-deck attachment hardware. Since post yield was observed in the original crash testing program, it was demonstrated that the steel bridge posts achieved their peak load capacity without damaging the glulam timber deck or rupturing the post-to-deck attachment hardware.

As discussed previously, the West Virginia Department of Transportation contracted with MwRSF to modify the thrie beam and channel bridge railing system so that it could be safely used on transverse, nail-laminated, timber bridge decks. It is widely known that full-scale vehicle crash testing is the primary method used to evaluate the safety performance of a bridge railing system. However, MwRSF researchers deemed it appropriate to use dynamic component testing to determine whether the prior crashworthy bridge rail could be adapted to an alternative bridge deck configuration. This opinion was based on several factors. First, if post yielding was observed in the component testing program, then the steel posts, post-to-deck attachment hardware, and timber deck would likely have withstood a peak load event, similar to the loading imparted during vehicular crash tests. Second, if the peak load was reached without damaging the timber deck and without rupture of the post-to-deck attachment hardware, then it was reasoned that the prior crashworthy bridge railing system would also have performed in an acceptable manner when attached to transverse, nail-laminated, timber deck bridges. Once again, this same methodology, combined with bogie testing, was previously used to adapt a TL-4 steel thrie beam and steel tube bridge railing system to a fiber reinforced plastic (FRP) bridge deck after the railing system had been crash tested and evaluated on a transverse, glue-laminated, timber deck system [4-6].

Therefore, dynamic bogie testing was utilized to determine the bogie acceleration, velocity, and displacement as well as the force versus deflection (F vs. D) and energy versus deflection (E vs. D) behaviors for the steel bridge posts attached to the nail-laminated timber deck. These behaviors were obtained for posts subjected to two load conditions – strong-axis bending under cantilevered loading as well as combined torsion and bending. The results presented within Chapter 6 were calculated using the accelerometer data obtained from the EDR-3 data recorder. However, test results are provided in Appendix A for both the EDR-3 and EDR-4 data recorders.

6.2 Dynamic Test Results

The following sub-sections present the results for test nos. WVTL2-1 through WVTL2-4. For this testing program, two impact conditions were investigated – centered and off-centered post impacts. In addition, the research team evaluated the use of timber shear connectors placed between the top mounting plate and the upper deck surface as well as between the bottom mounting plate and the lower deck surface.

6.2.1 Test No. WVTL2-1: Centered Impact – No Shear Plates

The 1711.3-lb (776.2-kg) bogie impacted the West Virginia bridge post assembly at a speed of 16.6 mph (26.7 km/h) and at an angle of 0 degrees. A summary of the test results can be found below and sequential photographs are shown in Figure 17. Additional post test photos are shown in Figure 18 and Figure 19.

6.2.1.1 Weather Conditions, Test No. WVTL2-1

Test No. WVTL2-1 was conducted on August 26, 2008 at approximately 1:22 pm. The weather conditions were reported as shown in Table 2.

Table 2. Weather Conditions, Test No. WVTL2-1

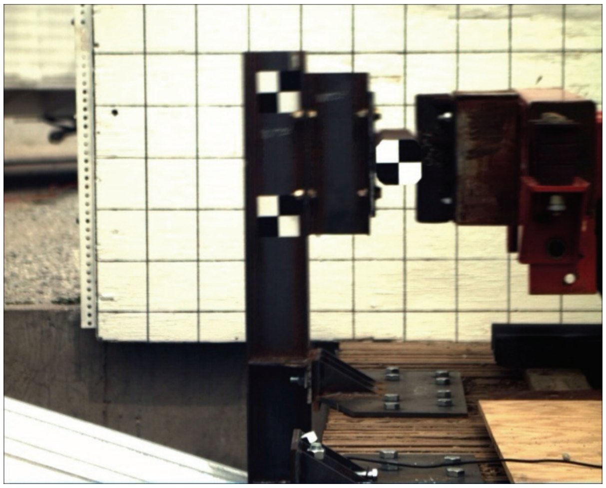
Temperature	80° F
Humidity	49%
Wind Speed	17 mph
Wind Direction	140° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.46 in.
Previous 7-Day Precipitation	0.46 in.

6.2.1.2 Test Description, Test No. WVTL2-1

During test no. WVTL2-1, the bogie head impacted the centerline of the bridge post assembly at a speed of 16.6 mph (26.7 kph). Sequential photographs of the impact event are shown in Figure 17. At 0.002 seconds after impact, the post began to pull away from the mounting plate attached to the top deck plate. At 0.006 sec, the timber bridge deck began to deflect downward due to the moment applied to the deck edge as well as the rotation of the post assembly. At 0.014 sec, the post began to bend backward above the welded post plate. At 0.036 sec, the W6x12 (W152x17.9) post and blockout began to twist clockwise, and the bogie head began to slide along the horizontal impact tube. At 0.070 sec, the post reached its maximum deflection of 10.5 in. (267 mm) and began to recoil. At 0.136 sec, the bogie lost contact with the horizontal impact tube as it continued to travel away from the post.

Damage to the post assembly included plastic bending and minor buckling, as shown in Figure 18. The top deck plate was bent downward near its attachment to the post. The post had minor buckling along its compression flange, and a gap had opened between the post plate and the top end plate. Also, the web of the post blockout was bent, resulting in the impact tube rotating approximately 20 degrees. Damage to the timber bridge deck consisted of only minor bearing deformations to the bolt holes, as shown in Figure 19.

Force versus deflection and energy versus deflection curves are shown in Figure 20. Initially, a high peak force of 29.7 kips (132.1 kN) was observed at 1.3 in. (33 mm), likely resulting from the inertial effects. The inertial spike dropped off to 1.4 kips (6.2 kN) at 2.4 in. (61 mm). The force level climbed and spiked again at 3.4 in. (86 mm) with a magnitude of 22.2 kips (98.8 kN). From 3.2 in. (81 mm) to 9.1 in. (231 mm), the post's average resistive force was approximately 20 kips (89 kN). Subsequently, the force level increased to 29.1 kips (129.4 kN) at 9.4 in. (239 mm). At a maximum deflection of 10.5 in. (267 mm), the post assembly had absorbed 189.2 kip-in. (21.4 kJ) of energy. For comparison purposes, the energy dissipated at 5 in. (127 mm) and 10 in. (254 mm) was 73.2 kip-in. (8.3 kJ) and 176.8 kip-in (20.0 kJ), respectively.



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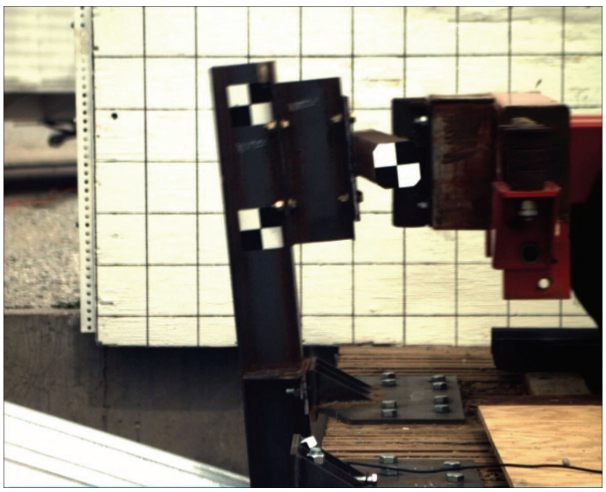

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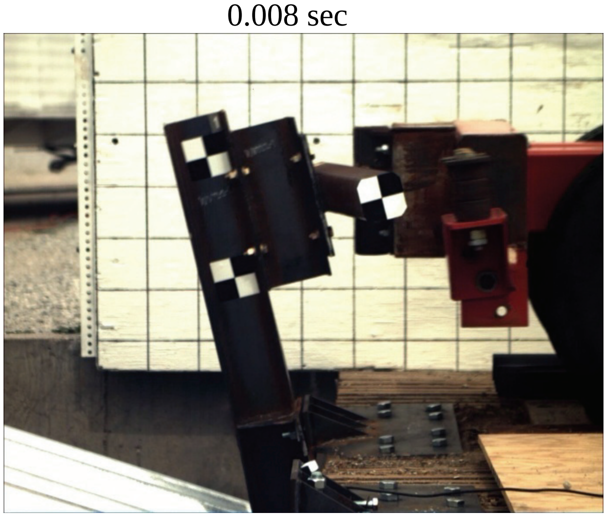

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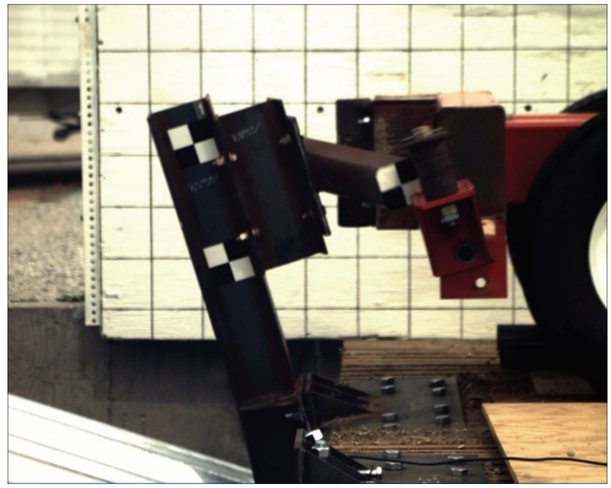

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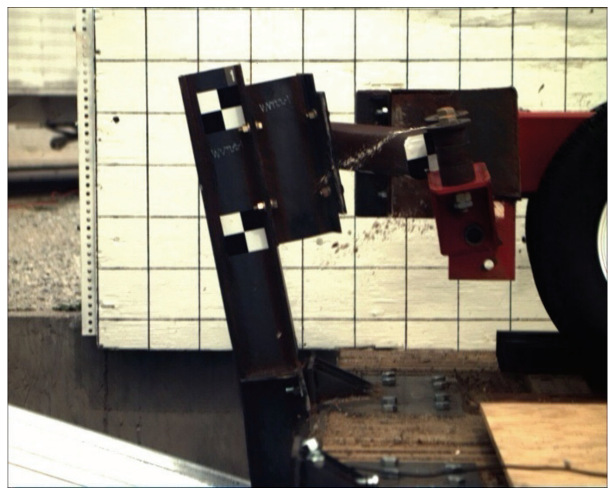

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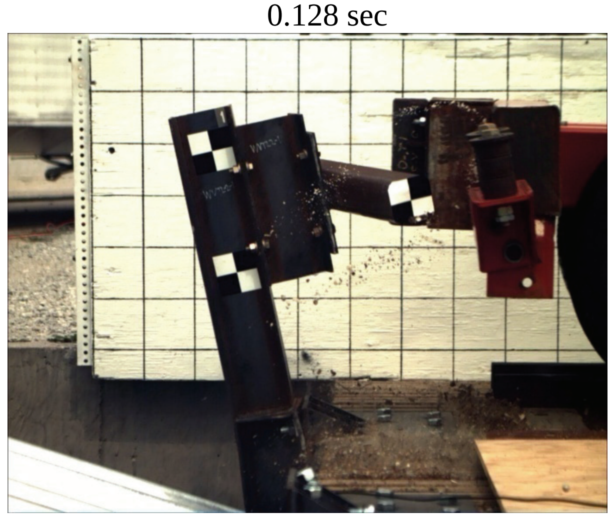

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Figure 17. Sequential Photographs, Test No. WVTL2-1

Figure 18. Post Assembly Damage, Test No. WVTL2-1

Figure 19. Deck Damage, Test No. WVTL2-1

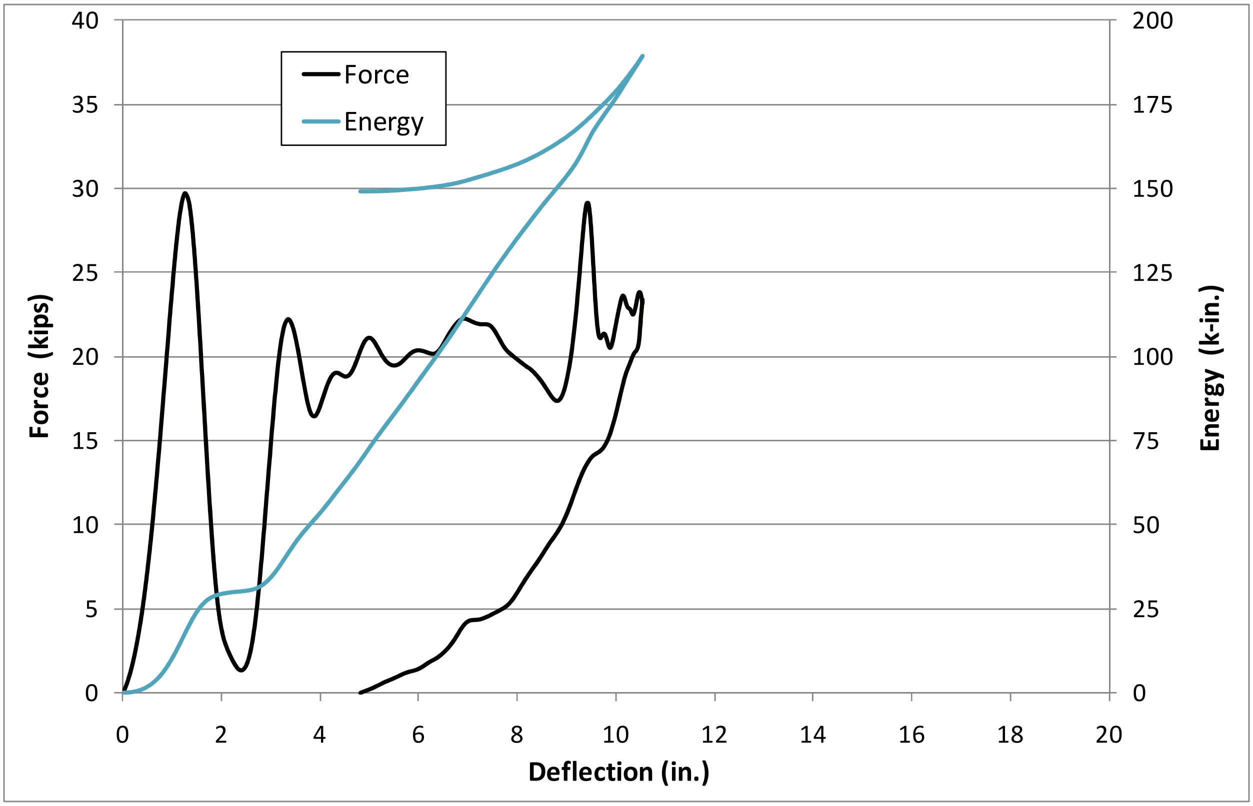


Figure 20. Force vs. Deflection and Energy vs. Deflection, Test No. WVTL2-1

6.2.2 Test No. WVTL2-2: Eccentric Impact – No Shear Plates

The 1711.3-lb (776.2-kg) bogie impacted the West Virginia bridge post assembly at a speed of 17.0 mph (27.4 km/h) and at an angle of 0 degrees. A summary of the test results can be found below and sequential photographs are shown in Figure 21. Additional post test photos are shown in Figure 22 and Figure 23.

6.2.2.1 Weather Conditions, Test No. WVTL2-2

Test No. WVTL2-2 was conducted on August 26, 2008 at approximately 3:13 pm. The weather conditions were reported as shown in Table 3.

Table 3. Weather Conditions, Test No. WVTL2-2

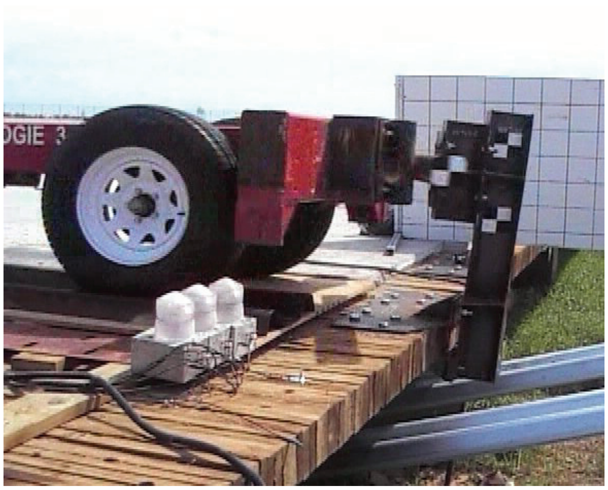
Temperature	80° F
Humidity	45%
Wind Speed	16 mph
Wind Direction	140° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.46 in.
Previous 7-Day Precipitation	0.46 in.

6.2.2.2 Test Description, Test No. WVTL2-2

During test no. WVTL2-2, the bogie head impacted the bridge post assembly using a 9-in. (229-mm) lateral offset away from the centerline of the post and at a speed of 17.0 mph (27.4 km/h). It should be noted that the AOS high-speed video camera did not trigger properly and did not record the impact event. Thus, the sequential photographs were taken from one of the JVC digital video cameras, as shown in Figure 21. At 0.033 seconds after impact, the post and blockout were twisting counter-clockwise due to the eccentric loading condition. At 0.067 sec, the entire post assembly was bending backward as the post buckled. At 0.133 sec, the bogie was rebounding and was no longer in contact with the post assembly.

The post experienced severe plastic deformations, resulting from twisting and bending of the post, as shown in Figure 22. The post was bent backward and twisted nearly 90 degrees about its vertical axis. Localized buckling was found on the rear post flange, just above the connection to the deck plates. Also, the top deck plate was bent downward off of the edge of the timber bridge deck. The upper post region (portion above the bottom end of the blockout) and the blockout sustained limited deformation due to the additional gussets placed in these regions to prevent premature collapse or failure under eccentric loading. The timber bridge deck sustained only minor bearing deformations to the bolt holes, as shown in Figure 23.

Force versus deflection and energy versus deflection curves are shown in Figure 24. At the beginning of the impact event, a large peak load of 26.3 kips (117.0 kN) was recorded at 1.3 in. (33 mm), likely resulting from the inertial effects. The inertial spike dropped to zero at 2.2 in. (56 mm). Subsequently, the force climbed and spiked again at 4.3 in. (109 mm) with a magnitude of 15.4 kips (68.5 kN). From 3.8 in. (97 mm) to 8.8 in. (224 mm), the post's average resistive force was under 10 kips (44.5 kN). Later, the average resistive force increased to an approximate level of 16 kips (71.4 kN) between of 10 in. (254 mm) and 15 in. (381 mm). The post resistance then decreased until the bogie vehicle reached its maximum deflection of 18.2 in. (462 mm). The post absorbed 199.0 kip-in. (22.5 kJ) of energy at the maximum deflection of 18.2 in. (462 mm). For comparison purposes, the energy dissipated at 5 in. (127 mm), 10 in. (254 mm), and 15 in. (381 mm) was 40.6 kip-in. (4.6 kJ), 82.3 kip-in. (9.3 kJ), and 164.3 kip-in. (18.6 kJ), respectively. It should be noted that the displacements noted above pertain to the longitudinal movement of the rigid bogie vehicle.



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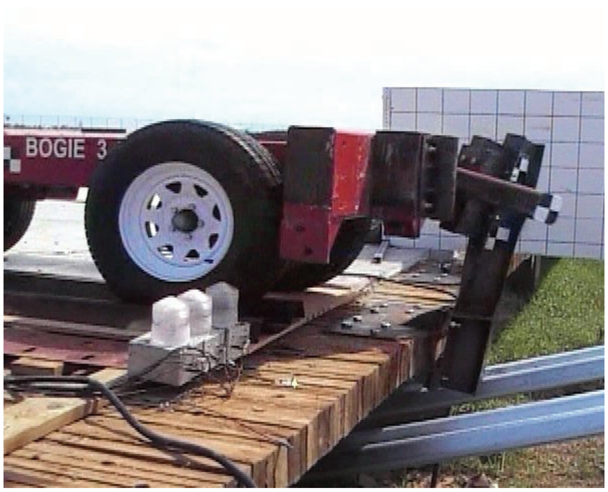

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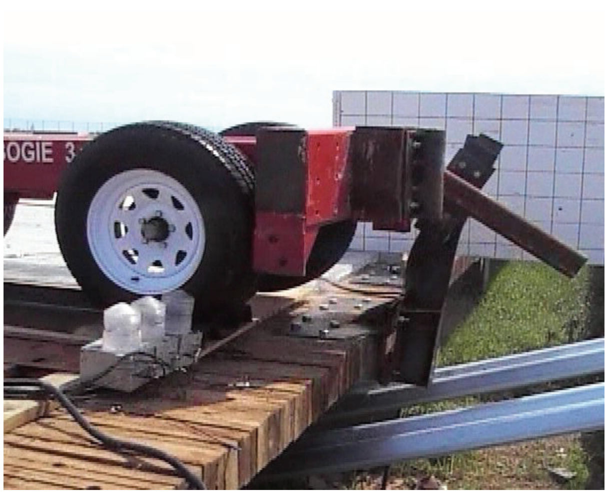

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Figure 21. Sequential Photographs, Test No. WVTL2-2

Figure 22. Post Assembly Damage, Test No. WVTL2-2

Figure 23. Deck Damage, Test No. WVTL2-2

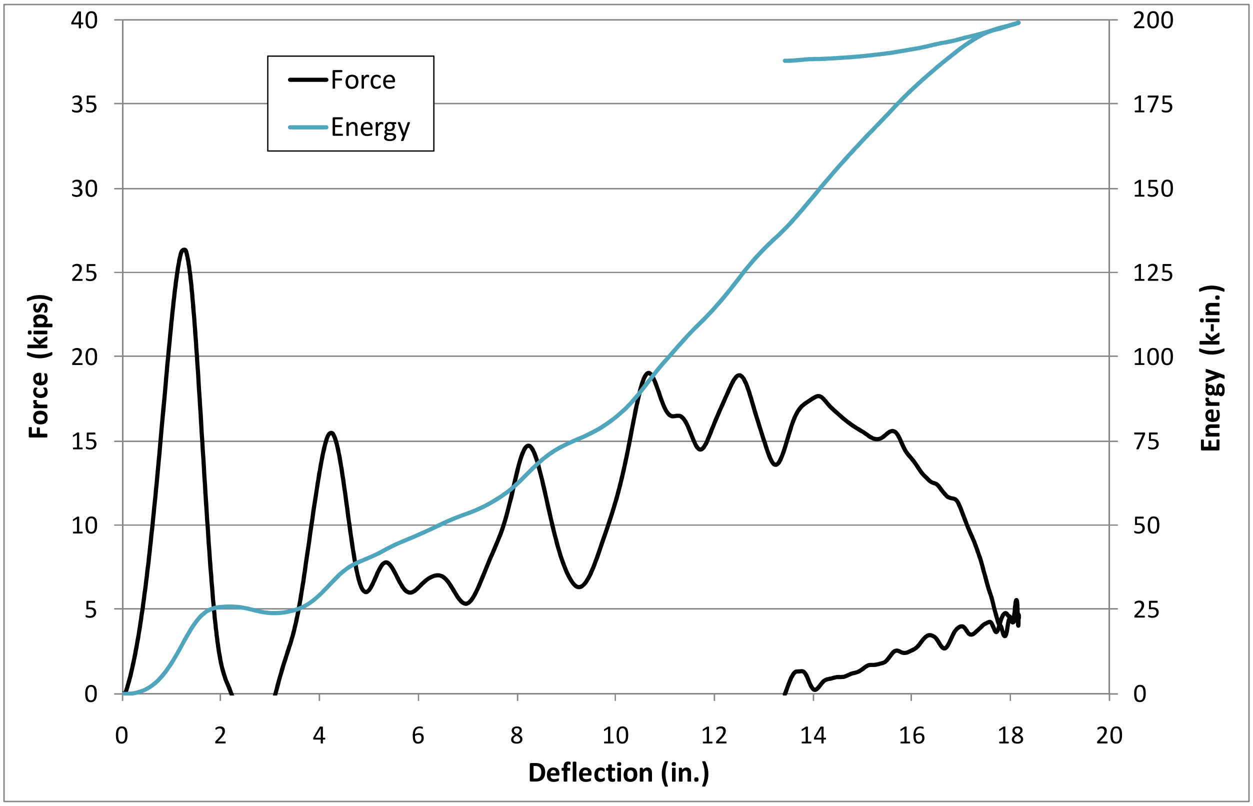


Figure 24. Force vs. Deflection and Energy vs. Deflection, Test No. WVTL2-2

6.2.3 Test No. WVTL2-3: Centered Impact – Shear Plates

The 1711.3-lb (776.2-kg) bogie impacted the West Virginia bridge post assembly at a speed of 16.7 mph (26.9 km/h) and at an angle of 0 degrees. A summary of the test results can be found below and sequential photographs are shown in Figure 25. Additional post test photos are shown in Figure 26 and Figure 27.

6.2.3.1 Weather Conditions, Test No. WVTL2-3

Test No. WVTL2-3 was conducted on August 26, 2008 at approximately 4:00 pm. The weather conditions were reported as shown in Table 4.

Table 4. Weather Conditions, Test No. WVTL2-3

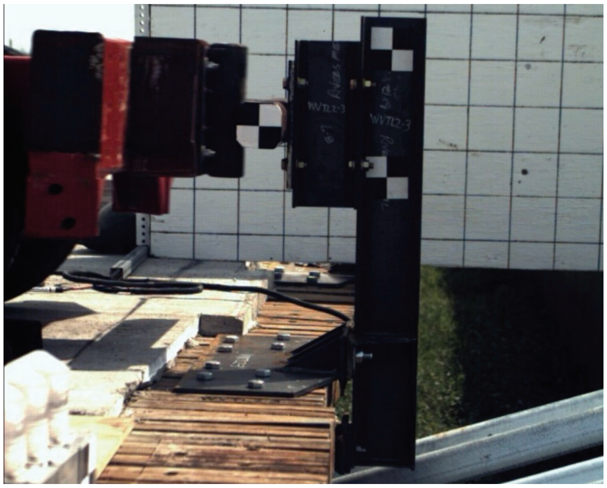
Temperature	81° F
Humidity	42%
Wind Speed	15 mph
Wind Direction	150° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.46 in.
Previous 7-Day Precipitation	0.46 in.

6.2.3.2 Test Description, Test No. WVTL2-3

During test no. WVTL2-3, the bogie head impacted the centerline of the bridge post assembly at a speed of 16.7 mph (26.9 km/h). Sequential photographs of the impact event are shown in Figure 25. At 0.002 seconds after impact, the bridge post began to rotate backward. At 0.004 sec, the bridge deck began to deflect downward due to the moment applied to the deck edge as well as rotation of the post assembly. At 0.020 sec, the post began to twist as the bogie impact head slid along the horizontal impact tube. At 0.028 sec, the post continued to bend backward, and the web of the blockout began to buckle. At 0.066 sec, the bogie head had completely slid off of the horizontal impact tube. At 0.072 sec, the bogie head mounting block contacted the post assembly and began to drive the post assembly backward once again. At 0.124 sec, the bogie reached its maximum deflection of 16.6 in. (422 mm) and began to rebound.

Damage to the bridge post assembly consisted of plastic bending, twisting, and localized buckling, as shown in Figure 26. The post was bent backward, and a gap had opened between the post plate and the top end plate. The post was also twisted clockwise resulting in localized flange buckling and bending of the web. The web of the post blockout was bent in the opposite direction as the web of the post, which resulted in the horizontal impact tube remaining normal to the path of the bogie. The deck plates and the timber bridge deck sustained no visual damage, as shown in Figures 26 and 27.

Force versus deflection and energy versus deflection curves are shown in Figure 28. Initially, a high peak force of 30.1 kips (133.9 kN) was observed at 1.3 in. (33 mm), likely resulting from the inertial effects. The inertial spike dropped off to zero at 2.4 in. (61 mm). The force level climbed and spiked again at 3.4 in. (86 mm) with a magnitude of 24.8 kips (110.3 kN). From 3.1 in. (79 mm) to 6.1 in. (155 mm), the post's average resistive force was approximately 19 kips (84.5 kN). Subsequently, the force level began to significantly drop off when the impact head began to slide down the horizontal impact tube, thus causing the assembly to twist. At a maximum deflection of 16.6 in. (422 mm), the post assembly had absorbed 192.9 kip-in. (21.7 kJ) of energy. For comparison purposes, the energy dissipated at 5 in. (127 mm), 10 in. (254 mm), and 15 in. (381 mm) was 72.4 kip-in. (8.2 kJ), 139.2 kip-in. (15.7 kJ), and 175.0 kip-in (19.8 kJ), respectively.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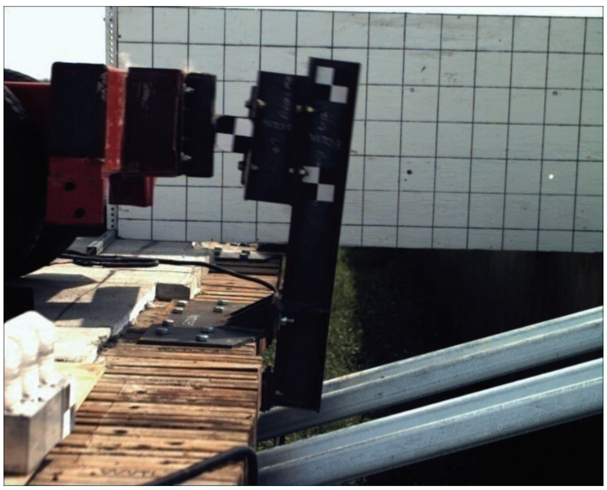
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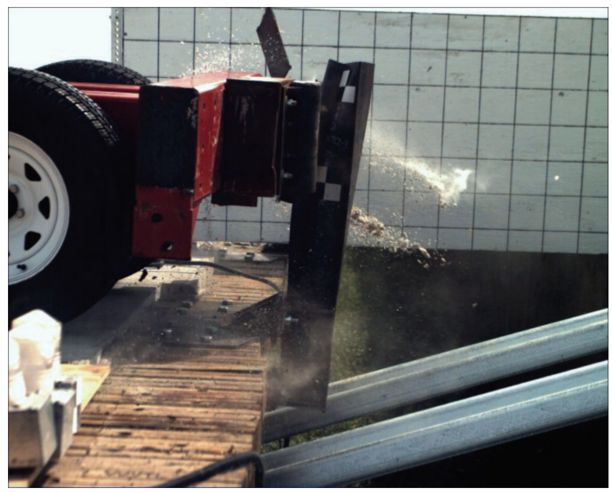
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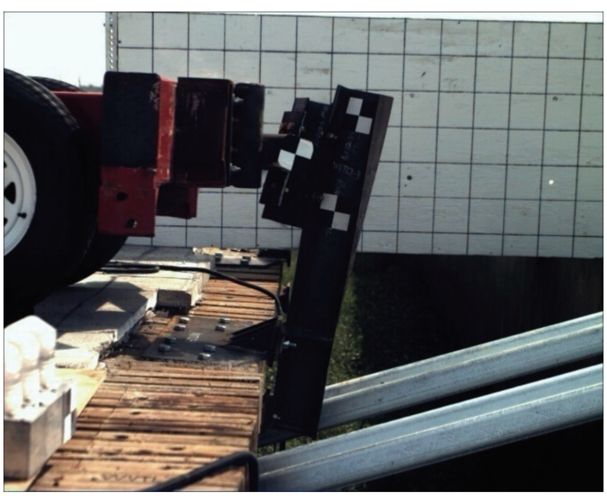
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Figure 25. Sequential Photographs, Test No. WVTL2-3

Figure 26. Post Assembly Damage, Test No. WVTL2-3

Figure 27. Deck Damage, Test No. WVTL2-3

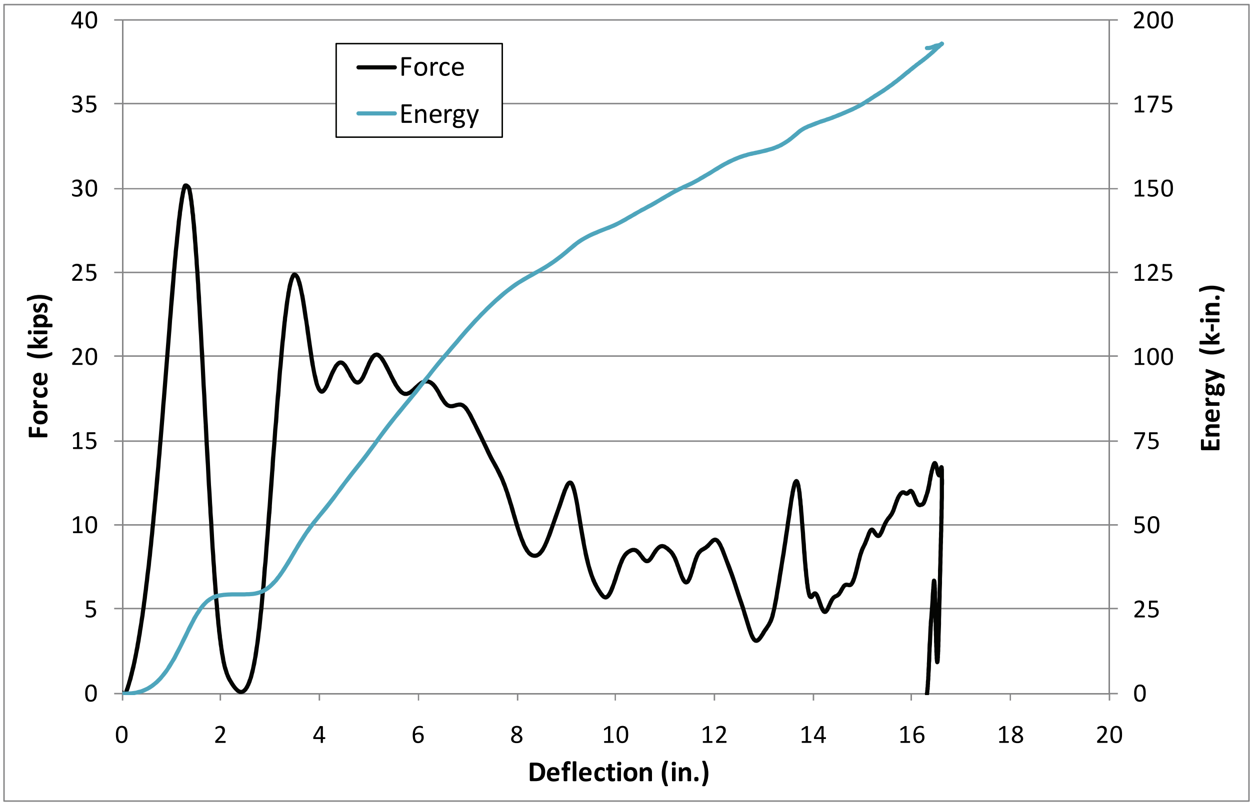


Figure 28. Force vs. Deflection and Energy vs. Deflection, Test No. WVTL2-3

6.2.4 Test No. WVTL2-4: Eccentric Impact – Shear Plates

The 1711.3-lb (776.2-kg) bogie impacted the West Virginia bridge post assembly at a speed of 17.0 mph (27.4 km/h) and at an angle of 0 degrees. A summary of the test results can be found below and sequential photographs are shown in Figure 29. Additional post test photos are shown in Figure 30 and Figure 31.

6.2.4.1 Weather Conditions, Test No. WVTL2-4

Test No. WVTL2-4 was conducted on August 26, 2008 at approximately 4:45 pm. The weather conditions were reported as shown in Table 5.

Table 5. Weather Conditions, Test No. WVTL2-4

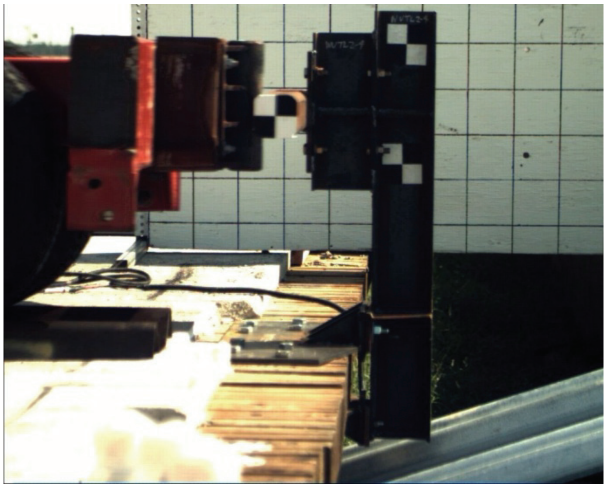
Temperature	81° F
Humidity	44%
Wind Speed	17 mph
Wind Direction	150° from True North
Sky Conditions	Sunny
Visibility	10 Statute Miles
Pavement Surface	Dry
Previous 3-Day Precipitation	0.46 in.
Previous 7-Day Precipitation	0.46 in.

6.2.4.2 Test Description, Test No. WVTL2-4

During test no. WVTL2-4, the bogie head impacted the bridge post assembly using a 9-in. (229-mm) lateral offset away from the centerline of the post and at a speed of 17.0 mph (27.4 km/h). Sequential photographs of the impact event are shown in Figure 29. At 0.004 seconds after impact, the post began to rotate backward. At 0.006 sec, the post assembly began to twist counter-clockwise, and the timber bridge deck began to deflect downward. At 0.030 sec, while the horizontal impact tube was rotating, the short end appeared to contact the bogie frame, thus potentially causing the rate of post rotation to decrease. At this same time, the post assembly began to deflect backward more rapidly. At 0.060 sec, the post began to rotate more rapidly while still deflecting backward. At 0.158 sec, the post reached its maximum deflection of 18.1 in. (460 mm), and the bogie began to rebound.

Damage to the post assembly included plastic bending and twisting, as shown in Figure 30. The post was twisted nearly 90 degrees between the deck connection and the impact height. Flange and web buckling were evident throughout this region of the post. A small gap had opened between the post plate and the top end plate, but there did not appear to be any damage to the deck plates. The post blockout did not appear to be damaged or deformed. Also, the timber deck did not sustain any visual damage, as shown in Figure 31.

Force versus deflection and energy versus deflection curves are shown in Figure 32. At the beginning of the impact event, a large peak load of 25.3 kips (112.5 kN) was recorded at 1.2 in. (31 mm), likely resulting from the inertial effects. The inertial spike dropped to zero at 2.3 in. (58 mm). Subsequently, the force climbed and spiked again at 3.9 in. (99 mm) with a magnitude of 16.5 kips (73.4 kN). From 3.4 in. (86 mm) to 8.7 in. (221 mm), the post's average resistive force was approximately 10 kips (44.5 kN). Later, the resistive force increased and spiked at 11.3 in. (287 mm) with a magnitude of 22.3 kips (99.2 kN). From 10.9 in. (277 mm) to 15.8 in. (401 mm), the post's average resistive force was in excess of 15 kips (66.7 kN). The post resistance then decreased until the bogie vehicle reached its maximum deflection of 18.1 in. (460 mm). The post absorbed 199.6 kip-in. (22.6 kJ) of energy at the maximum deflection of 18.1 in. (460 mm). For comparison purposes, the energy dissipated at 5 in. (127 mm), 10 in. (254 mm), and 15 in. (381 mm) was 45.1 kip-in. (5.1 kJ), 89.8 kip-in (10.1 kJ), and 165.5 kip-in. (18.7 kJ), respectively. It should be noted that the displacements noted above pertain to the longitudinal movement of the rigid bogie vehicle.



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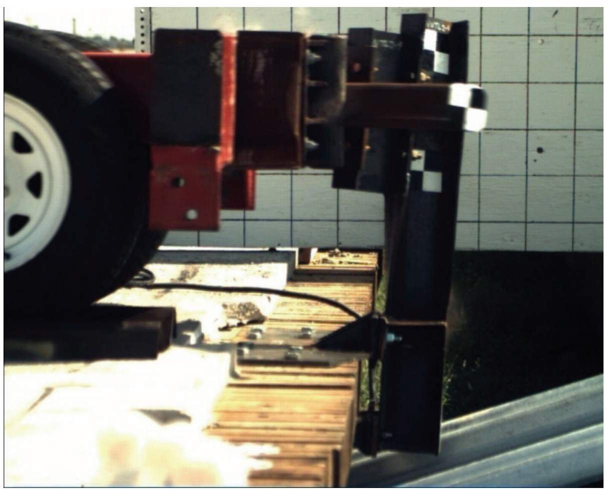

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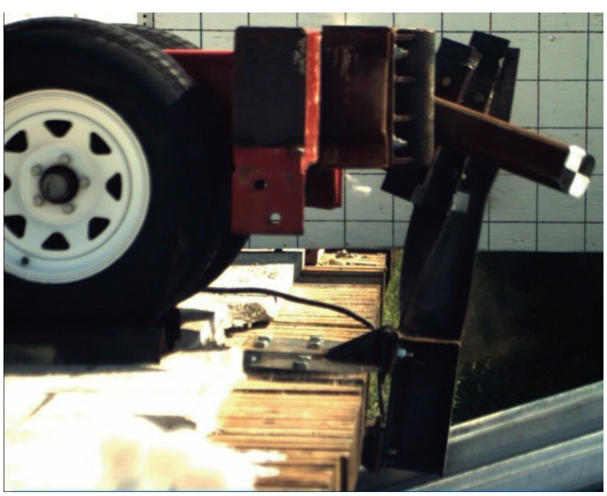

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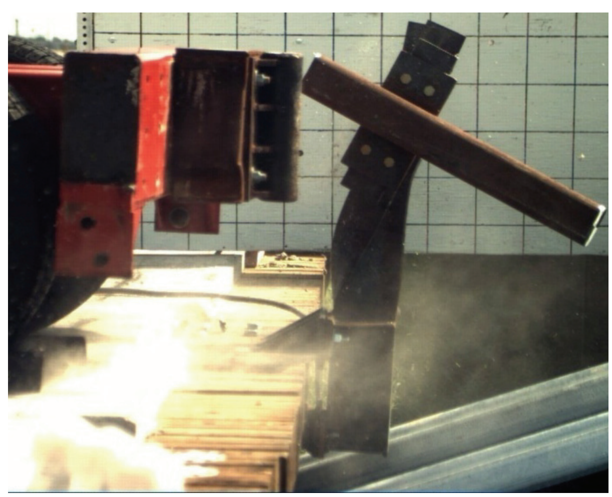

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Figure 29. Sequential Photographs, Test No. WVTL2-4

Figure 30. Post Assembly Damage, Test No. WVTL2-4

Figure 31. Deck Damage, Test No. WVTL2-4

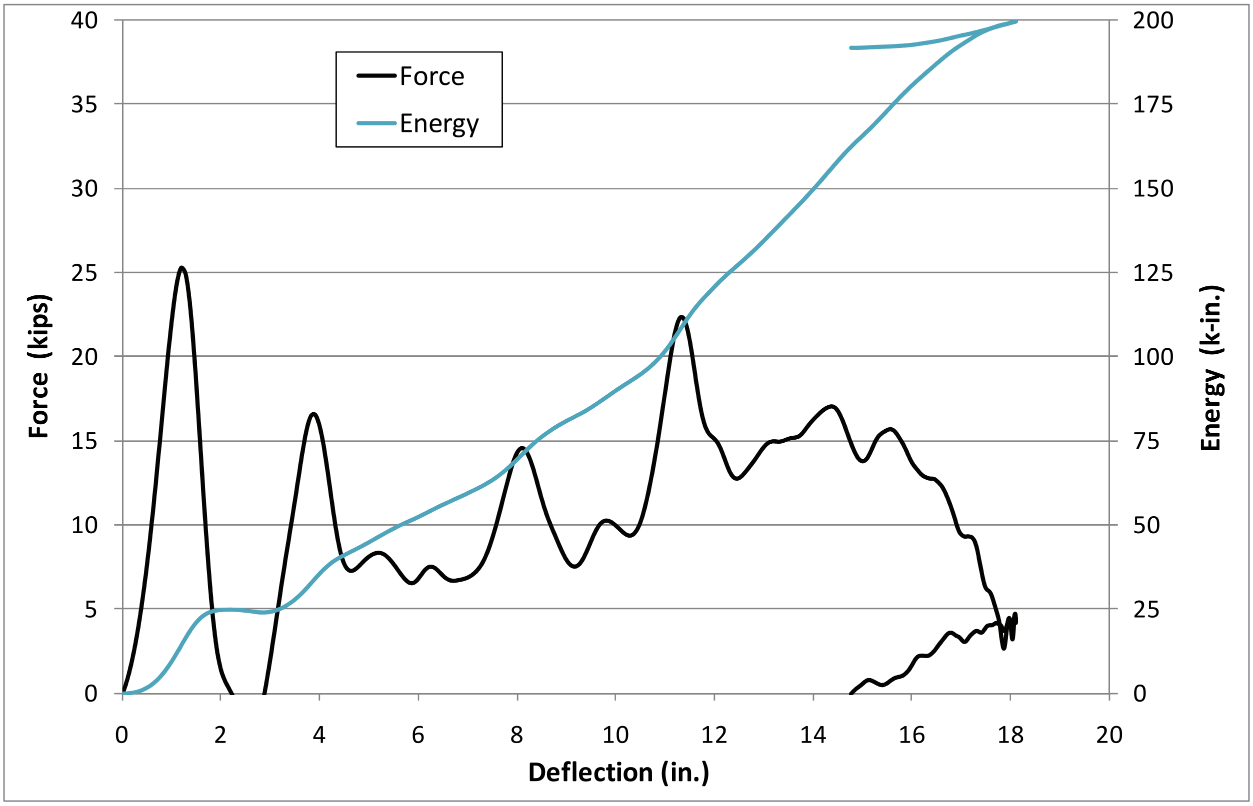

Figure 32. Force vs. Deflection and Energy vs. Deflection, Test No. WVTL2-4

6.3 Discussion and Comparison of Test Results

The results from the bogie testing program are summarized in Table 6. For the four tests, the bogie impact speeds were relatively consistent as the speed only varied from 16.6 to 17.0 mph (26.7 to 27.4 kph). As a result, the peak energy absorbed by each post assembly was also rather consistent, varying from 189.2 to 199.6 k-in. (21.4 to 22.6 kJ). However, the forces versus deflection behavior observed for the each of the four tests were quite different and were found to be dependent on the test setup, more specifically, the targeted impact point. After the inertial spikes had ended, the average resistive forces for the centerline impact events were found to be approximately twice those observed for the eccentrically loaded post assemblies. For example, the bogie impacts conducted into the centerline of the post resulted in an average force level ranging between 19 and 20 kips (84.5 and 89.0 kN) over the early portion of the event. However, the bogie impacts conducted with a 9-in. (229-mm) lateral offset resulted in an average force level of approximately 10 kips (44.5 kN). This result can be explained by the differences in stiffness and strength between a load scenario involving strong-axis bending and one involving a combination of torsion and strong-axis bending. A comparison of the force versus deflection curves for the four tests is provided in Figures 33.

As noted above, the average force levels were greater for the centerline impacts as compared to the eccentric impacts. Thus, it would be expected that the energy dissipated over the early portion of the events would also be greater for the centerline impacts as compared to the eccentric impacts. For test nos. WVTL2-1 and WVTL2-3 (centerline impacts), the energy dissipated at 5 in. (127 mm) was 73.2 kip-in. (8.3 kJ) and 72.4 kip-in. (8.2 kJ), respectively, while the energy dissipated at 10 in. (254 mm) was 176.8 kip-in. (20.0 kJ) and 139.2 kip-in. (15.7 kJ), respectively. For test nos. WVTL2-2 and WVTL2-4 (eccentric impacts), the energy dissipated at 5 in. (127 mm) was 40.6 kip-in. (4.6 kJ) and 45.1 kip-in. (5.1 kJ), respectively, while the energy dissipated at 10 in. (254 mm) was 82.3 kip-in. (9.3 kJ) and 89.8 kip-in. (10.1 kJ), respectively. A comparison of the energy versus deflection curves for the four tests is shown in Figure 34.

For all four bogie tests, inertial effects were observed in the beginning of the impact events. As illustrated in Figure 33, the recorded data from each test showed a large force spike approximately over the first 2 in. (51 mm) of deflection. For the centerline impact events, the peak force of the inertial spoke ranged between 29.7 and 30.1 kips (132.1 and 133.9 kN). For the eccentric impact events, the peak force of the inertial spike ranged between 25.3 and 26.3 kips (112.5 and 117.0 kN). The displacements corresponding to the peak load values and to the zero, or nearly non-zero, force values after the peak load were nearly identical for the four bogie tests.

Test nos. WVTL2-1 and WVTL2-3 were conducted with the bogie head impacting through the centerline of each post. As shown in Figure 33, the force versus deflection curves for these two tests were very similar through the first 6 in. (152 mm) of deflection. After this deflection, the resistive force for test no. WVTL2-1 remained relatively constant, while the force observed in test no. WVTL2-3 decreased significantly. As discussed in Section 6.2.3, it was at a deflection of approximately 6 in. (152 mm) when the post assembly for test no. WVTL2-3 began to twist.

As noted previously, test nos. WVTL2-1 and WVTL2-3 were centerline impacts that were used to evaluate the benefits for using timber shear connectors between the top and bottom mounting plates and the timber deck surfaces. Although timber shear connectors are used to provide improved load distribution to timber surfaces as well as a reduction in bolt bearing failures in wood material, these two bogie tests (test nos. WVTL2-1 and WVTL2-3) revealed little to no difference in the observed force versus deflection behaviors before the post twisted in test no. WVTL2-3. In fact, the average forces through 5 in. (127 mm) of deflection were nearly identical at 14.6 kips (64.9 kN) and 14.5 kips (64.5 kN), as shown in Table 6. In addition, the average force level observed at 10 in. (254 mm) of deflection was greater for the option without shear plates [17.7 kips (78.7 kN)] as compared to the shear plate option [14.0 kips (62.3 kN)]. Therefore, the inclusion of the timber shear connectors within the post-to-deck attachment did not provide any significant increase in strength for the centerline impacts. Although the timber shear connectors reduced the bearing deformations in wood surrounding the bolt holes, it would not appear that their use would be required in actual bridge railing installations unless their use can be justified solely for reducing future maintenance costs.

Test nos. WVTL2-2 and WVTL2-4 were eccentric impacts with the bogie head contacting the horizontal impact beam and post assemblies 9 in. (229 mm) laterally away from the centerline of the posts. As shown in Figure 33, the force versus deflection curves for these two tests were very similar throughout the impact events. As shown in Table 6, the average forces observed at deflections of 5, 10, and 15 in. (127, 254, and 381 mm) were similar, and both tests resulted in a maximum deflection of just over 18 in. (457 mm). Accordingly, the energy versus deflection curves for these two tests were also very similar, as shown in Figure 34.

The eccentric impact tests (test nos. WVTL2-2 and WVTL2-4) were also used to evaluate the benefits of using timber shear connectors between the top and bottom mounting plates and the timber deck surfaces. From these tests, the average force observed over the first 10 in. (254 mm) of deflection was approximately 9 percent greater for the shear connector option [9.0 kips (40.0 kN)] as compared to the option without shear connectors [8.2 kips (36.5 kN)]. Therefore, the inclusion of the timber shear connectors within the post-to-deck attachment provided only a limited increase in strength for the off-center impacts. Although the timber shear connectors once again reduced the bearing deformations in wood surrounding the bolt holes, it would not appear that their use would be required in actual bridge railing installations unless their use can be justified solely for reducing future maintenance costs.

Finally, it should be noted that all of the steel bridge posts were loaded beyond yield as each post was deformed and bent backward. However, the post-to-deck attachment hardware did not sustain any visible damage, and the timber bridge deck sustained only very minor bearing deformations around a few bolt holes. Therefore, the timber deck, posts, and post-to-deck attachment hardware withstood peak impact loading and provided sufficient structural capacity in order to support the thrie beam and channel bridge railing system.

As noted previously, the deck mounting plates were to be anchored to the top and bottom surfaces of the timber deck using eight ⅞-in. (22.2-mm) diameter by 7¾-in. (197-mm) long, ASTM A307 (Grade 2 equivalent) hex head bolts. During the documentation and reporting phase, it was uncovered that the deck plates were placed using ⅞-in. (22.2-mm) diameter by 8-in. (203-mm) long, Grade 5 hex head bolts (cap screws) due to an error in material ordering. As a result, the vertical fasteners were installed and tested using a higher grade of steel (Grade 5 versus Grade 2) than required.

In 1998, the original thrie beam and channel bridge railing system was successfully crash tested on a 5⅛-in. (130-mm) thick, transverse, glulam, timber deck system. For this TL-2 testing and evaluation program, eight ⅞-in. (22.2-mm) diameter by 7¾-in. (197-mm) long, ASTM A307 (Grade 2 equivalent) hex head bolts with timber shear connectors were used to anchor the posts and deck plates to the glulam timber deck panels. Timber shear connectors are typically installed using ASTM A307 grade fasteners since the connection strength is often controlled by the capacity of wood member(s). During crash testing, no deck damage was reported. In addition, the combination of the ASTM A307 vertical hex head bolts and 4-in. (102-mm) diameter timber shear connectors did not result in bolt damage and thus provided adequate shear capacity while the posts plastically deformed and withstood peak impact loading.

Based on the prior successful crash testing program as well as the current bogie testing program, the MwRSF researchers believe that the bridge post, post-to-deck attachment hardware, and timber deck would have performed in a similar manner if the connection would have utilized ASTM A307 hex head bolts in combination with 4-in. (102-mm) diameter timber shear connectors.

Table 6. Bogie Testing Results

Test No.	Impact Velocity (mph)	Impact Point	Shear Plates	Average Force (kips)			Maximum Deflection (in.)	Peak Energy (k-in.)
				@ 5"	@ 10"	@ 15"		
WVTL2-1	16.6	Center of Post	No	14.6	17.7	N.A.	10.5	189.2
WVTL2-2	17.0	Offset 9"	No	8.1	8.2	11.0	18.2	199.0
WVTL2-3	16.7	Center of Post	Yes	14.5	14.0	11.7	16.6	192.9
WVTL2-4	17.0	Offset 9"	Yes	9.0	9.0	11.1	18.1	199.6

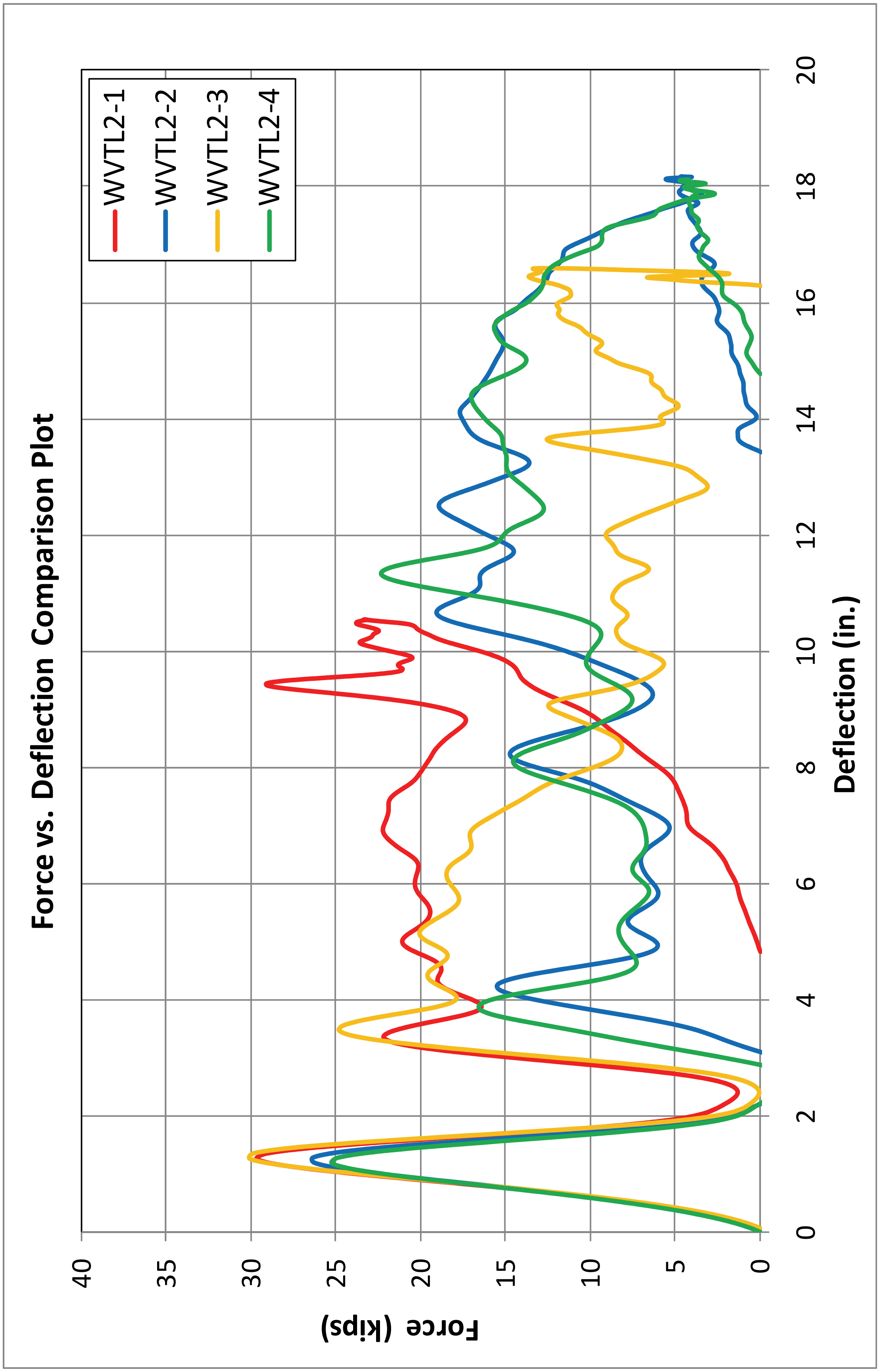

Figure 33. Force vs. Deflection – Test Nos. WVTL2-1 through WVTL2-4

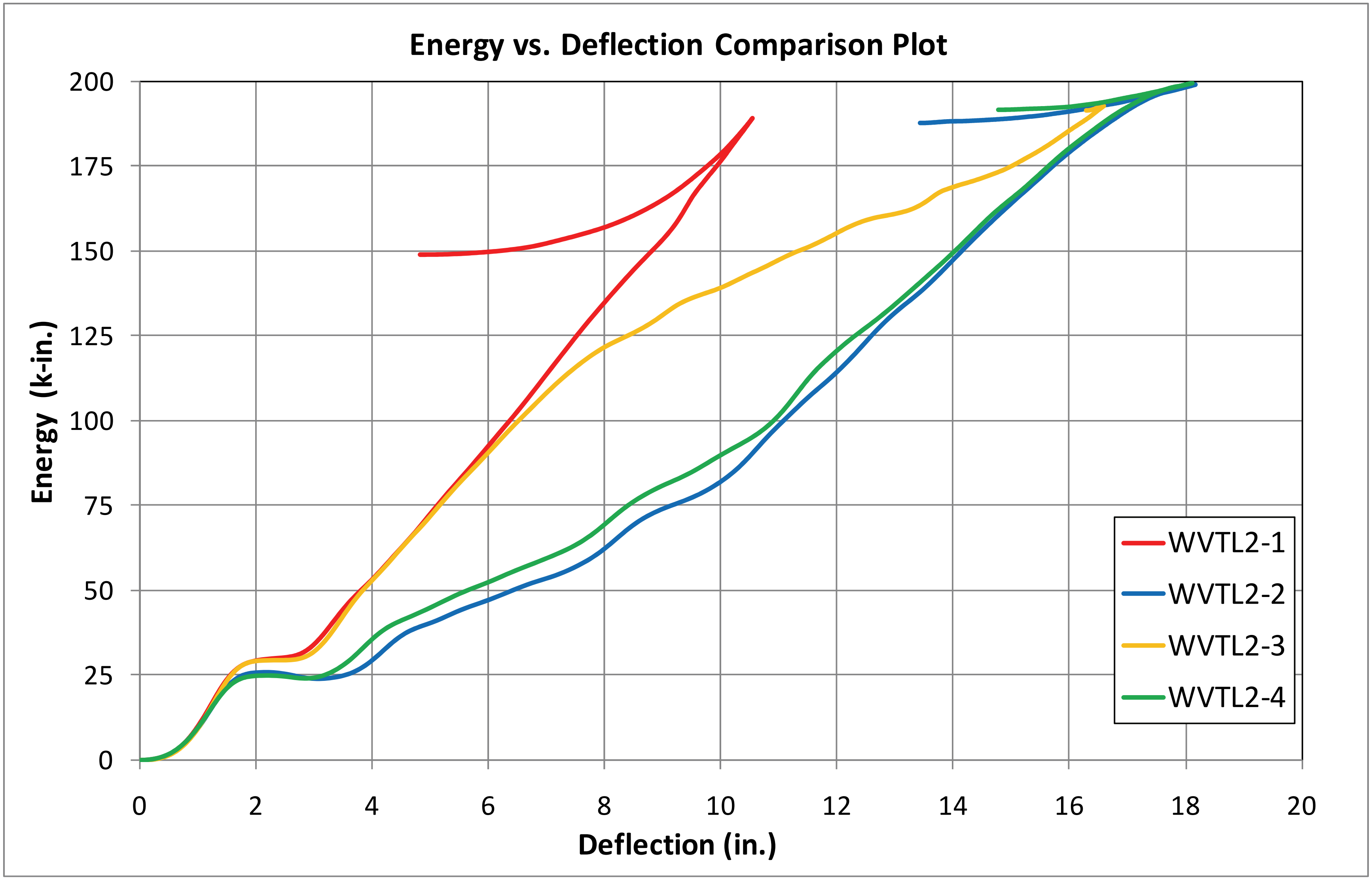

Figure 34. Energy vs. Deflection – Test Nos. WVTL2-1 through WVTL2-4

7 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

For this research study, the West Virginia Department of Transportation (WVDOT) contracted with MwRSF to modify an existing, crashworthy bridge railing system for use on transverse, nail-laminated, timber decks that are commonly used on rural bridges. As such, WVDOT personnel selected the thrie beam and channel bridge railing system that was originally developed for use on transverse, glue-laminated, timber deck bridges [1-2]. The original bridge railing and associated approach guardrail transition systems were successfully crash tested and evaluated to the TL-2 safety performance criteria provided in NCHRP Report No. 350 and accepted for use on the national highway system by FHWA [11].

During the original full-scale vehicle crash testing (test no. STCR-1) of the bridge railing system attached to a transverse, glue-laminated, timber deck, the maximum dynamic and permanent set thrie beam rail deflections were 6 $^{3}/_{16}$ in. (157 mm) and 4 in. (102 mm), respectively [1-2]. In addition, yielding of steel bridge posts was also observed as depicted by posts leaning backward. However, there was no visible damage to the timber bridge deck or rupture of the post-to-deck attachment hardware.

Historically, full-scale vehicle crash testing has primarily been used to evaluate the safety performance of a bridge railing system. However, MwRSF researchers deemed it appropriate to use dynamic component testing to determine whether the prior crashworthy bridge rail could be adapted to an alternative bridge deck configuration. This opinion was based on several factors. First, if post yielding and plastic deformations were observed in the component testing program, then the steel posts, post-to-deck attachment hardware, and timber deck would likely have withstood a peak load event, similar to the loading imparted during vehicular crash tests. Second, if the peak load was reached without damaging the timber deck and without rupture of the post-to-deck attachment hardware, then it was reasoned that the prior crashworthy bridge railing system would also have performed in an acceptable manner when attached to transverse, nail-laminated, timber deck bridges. As noted previously, this same methodology was used to adapt a TL-4 steel thrie beam and steel tube bridge railing system to a fiber reinforced plastic (FRP) bridge deck after the railing system had been crash tested and evaluated on a transverse, glue-laminated, timber deck system [4-6].

Therefore, dynamic component testing was utilized to evaluate whether the TL-2 steel thrie beam and channel bridge railing could be installed on transverse, nail-laminated, timber deck bridges. In addition, this testing was used to evaluate the benefits for using timber shear connectors between the top and bottom mounting plates and the timber deck surfaces. Four bogie impact tests were conducted. For two tests, the bogie vehicle impacted the posts head-on and with the rigid head aligned with the centerline of each post. For the remaining two tests, the bogie vehicle impacted the posts with the rigid head laterally offset 9 in. (229 mm) away from the centerline of each post in order to induce both torsion and bending loads into the post, post-to-deck attachment hardware, and timber deck. For each of the bogie tests, post yielding was observed, and the posts were plastically deformed through bending, torsion, or a combination of both. During the testing program, the timber deck did not sustain any significant damage. Only slight bearing damage was observed surrounding a few of the bolt holes in those tests where the shear connectors were not used. Finally, the post-to-deck attachment hardware did not rupture or pull away from the deck edge. Since plastic deformations were observed in all four steel bridge posts, MwRSF researchers believed that the timber deck, posts, and post-to-deck attachment hardware withstood peak impact loading and provided sufficient structural capacity in order to support the TL-2 thrie beam and channel bridge railing system.

Timber shear connectors were utilized within the post-to-deck attachment hardware for two of the four bogie tests (test nos. WVTL2-3 and WVTL2-4) in order to evaluate their ability to transfer shear into the deck and mitigate deck damage. For the centerline impact events, the inclusion of the timber shear connectors did not provide any significant increase in strength. For the eccentric impact events, the inclusion of the timber shear connectors provided only a limited increase in strength. Although the timber shear connectors reduced the minor bearing deformations in wood surrounding a few of the bolt holes, it would not appear that their use would be required in actual bridge railing installations unless their use can be justified solely for reducing future maintenance costs. Design details for the TL-2 thrie beam and channel bridge railing and approach guardrail transition system are provided in Appendix B.

As noted previously and for the bogie testing program, the deck mounting plates were attached to the timber deck using eight ⅞-in. (22.2-mm) diameter by 8-in. (203-mm) long, Grade 5 hex head bolts in lieu of the specified ASTM A307 (Grade 2 equivalent) hex head bolts. As a result of this unanticipated deviation from the project plan, the deck mounting plates can be anchored to the transverse, nail-laminated, timber deck using three options: (1) ⅞-in. (22.2-mm) diameter ASTM A307 (Grade 2 equivalent) bolts in combination with 4-in. (102-mm) diameter timber shear connectors; (2) ⅞-in. (22.2-mm) diameter ASTM A325 (Grade 5 equivalent) bolts in combination with 4-in. (102-mm) diameter timber shear connectors; or (3) ⅞-in. (22.2-mm) diameter ASTM A325 (Grade 5 equivalent) bolts without the use of timber shear connectors if minor bearing deformations around some of the vertical holes is acceptable. It should be noted that Option 3 is depicted in Appendix B.

Based on the successful bogie testing of the steel bridge posts attached to the transverse, nail-laminated, timber bridge deck and in lieu of full-scale vehicle crash testing, MwRSF researchers believe that the bogie tests are a valid indicator of the dynamic performance for the posts and post-to-deck attachment hardware. It is the opinion of MwRSF researchers that the TL-2 steel thrie beam and channel bridge railing can be adapted for use on transverse, nail-laminated, timber deck bridges using the design details tested and provided herein. Therefore, MwRSF will seek FHWA acceptance for the bridge railing system when anchored to a transverse, nail-laminated, timber bridge deck according to the TL-2 safety performance criteria provided in NCHRP Report No. 350.

8 REFERENCES

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9 APPENDICES

APPENDIX A – TEST RESULTS

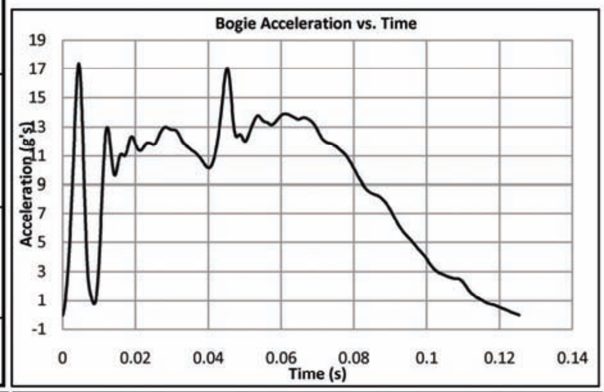
A summary sheet for each dynamic bogie test is provided in this section. Summary sheets include acceleration, velocity, and displacement versus time plots, as well as force and energy versus displacement plots.

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	West Virginia TL-2 Timber Deck Post	
Test Number:	WVTL2-1	
Test Date:	26-Aug-2008	
Failure Type:	Flange Buckling	
Post Properties		
Post Type:	Timber Deck Steel Post	
Post Size:	W150x18	W6x12
Post Length:	108.6 cm	42.75 in.
Embedment Depth:	#VALUE!	NA in.
Orientation:	Strong Axis - Centered on Post	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	7.4040486 m/s	16.6 mph (24.3 fps)
Impact Height:	63.2 cm	24.875 in.
Bogie Mass:	776.2 kg	1711.3 lbs
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 22'	

Test Results Summary		
Max. Deflection:	26.8	cm
Peak Force:	132.2	kN
Initial Linear Stiffness:	41.3	kN/cm
Total Energy:	21.4	kJ



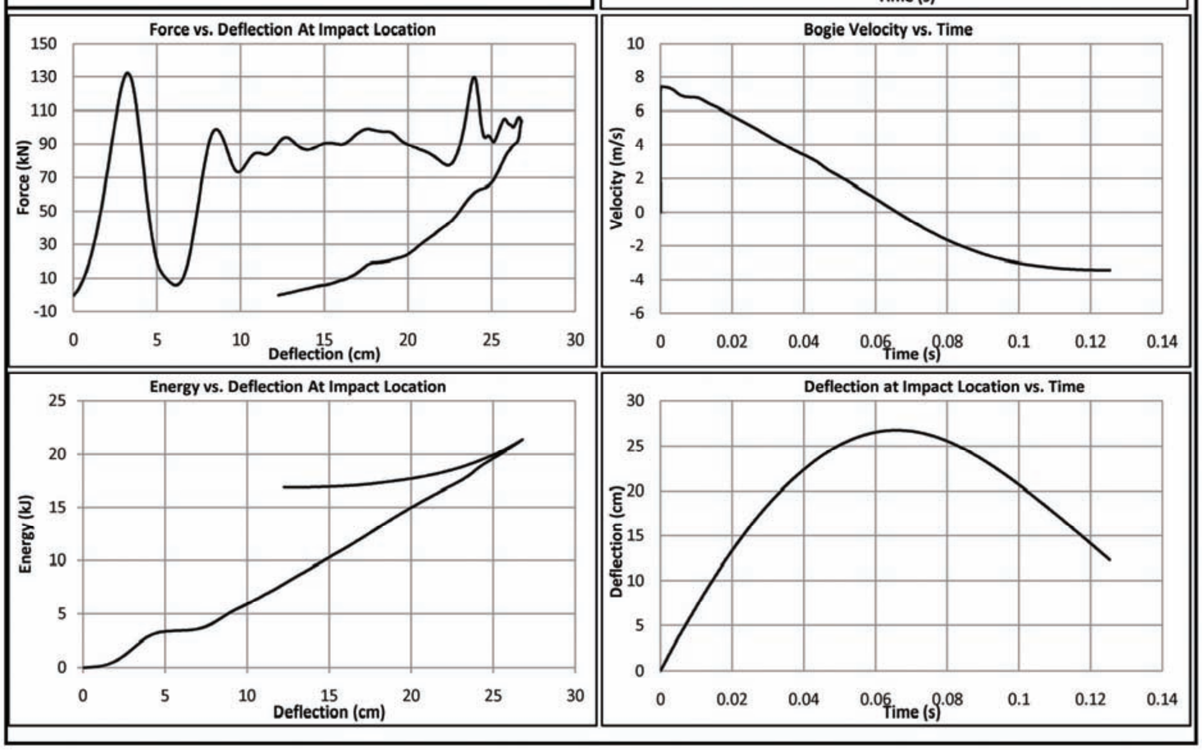


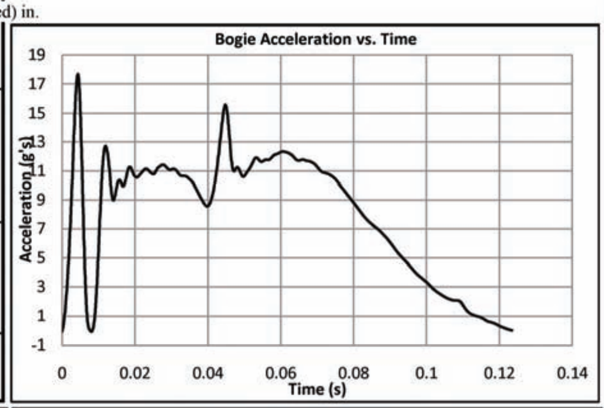
Figure A - 1. Results of Test No. WVTL2-1 (EDR3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	West Virginia TL-2 Timber Deck Steel Post	
Test Number:	WVTL2-1	
Test Date:	26-Aug-2008	
Failure Type:	Flange Buckling	
Post Properties		
Post Type:	Timber Deck Steel Post	
Post Size:	W150x18	W6x12
Post Length:	108.6 cm	42.75 in.
Embedment Depth:	#VALUE!	NA (Timber Deck Mounted) in.
Orientation:	Strong Axis - Centered On Post	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	7.4040486 m/s	16.6 mph (24.3 fps)
Impact Height:	63.2 cm	24.875 in.
Bogie Mass:	776.2 kg	1711.3 lbs
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-5 Perpendicular - 22'	

Test Results Summary		
Max. Deflection:	28.7	cm
Peak Force:	134.5	kN
Initial Linear Stiffness:	#DIV/0!	kN/cm
Total Energy:	21.3	kJ



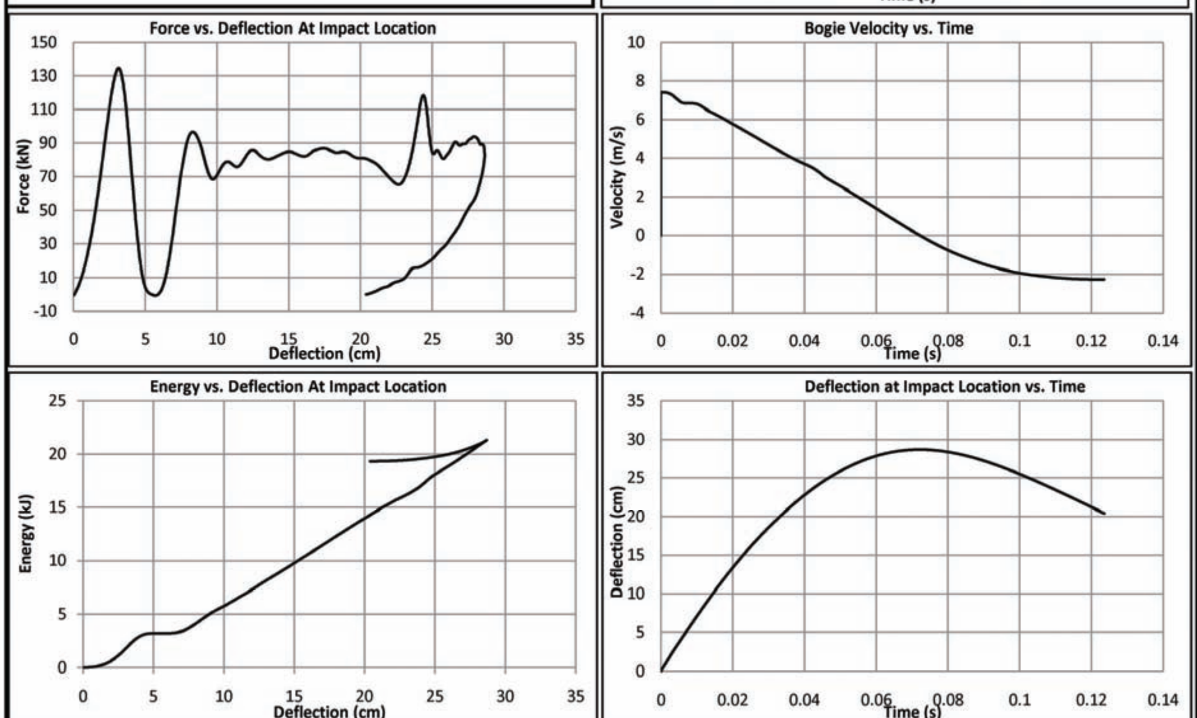


Figure A - 2. Results of Test No. WVTL2-1 (EDR4)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information — West Virginia TL-2 Timber Deck Post

Test Number:	WVTL2-2	
Test Date:	26-Aug-2008	
Failure Type:	Torsional	

Test Results Summary

Max. Deflection:	46.1	cm
Peak Force:	117.1	kN
Initial Linear Stiffness:	35.6	kN/cm
Total Energy:	22.5	kJ

Post Properties

Post Type:	Timber Deck Steel Post with Gussets @ Impact Height	
Post Size:	W150x18	W6x12
Post Length:	108.6 cm	42.75 in.
Embedment Depth:	#VALUE!	NA in.
Orientation:	Strong Axis - Off Center	

Soil Properties

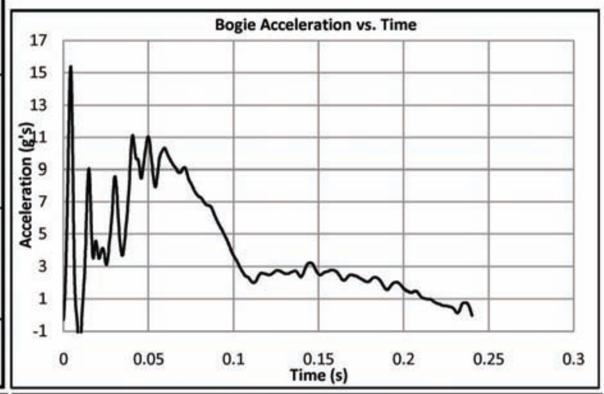
Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA
Soil Density, γd:	NA

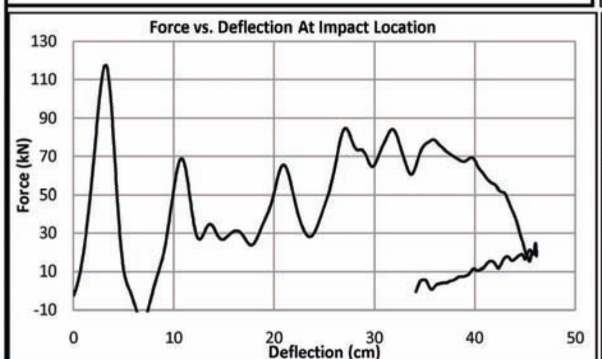
Bogie Properties

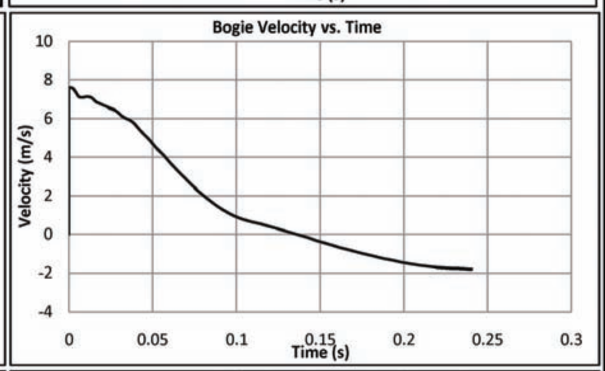
Impact Velocity:	7.601 m/s	17 mph (24.9 fps)
Impact Height:	63.2 cm	24.875 in.
Bogie Mass:	776.2 kg	1711.3 lbs

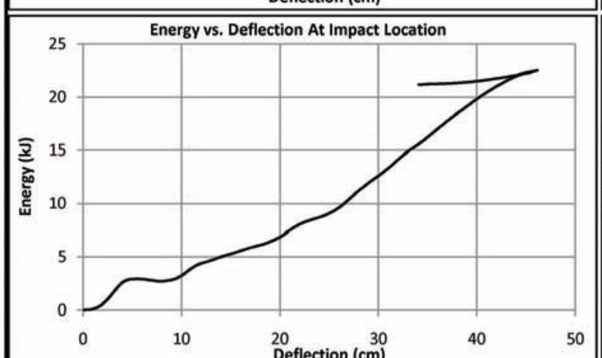
Data Acquired

Acceleration Data:	EDR-3
Camera Data:	AOS-5 Perpendicular - 22'









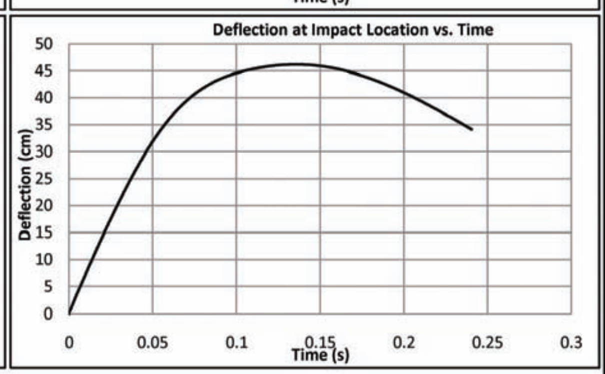


Figure A - 3. Results of Test No. WVTL2-2 (EDR3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	West Virginia TL-2 Timber Deck Steel Post	
Test Number:	WVTL2-2	
Test Date:	26-Aug-2008	
Failure Type:	Torsional	

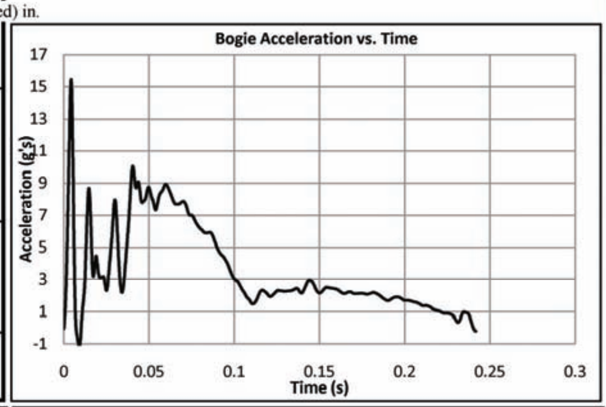
Test Results Summary		
Max. Deflection:	54.3	cm
Peak Force:	117.6	kN
Initial Linear Stiffness:	38.0	kN/cm
Total Energy:	22.4	kJ

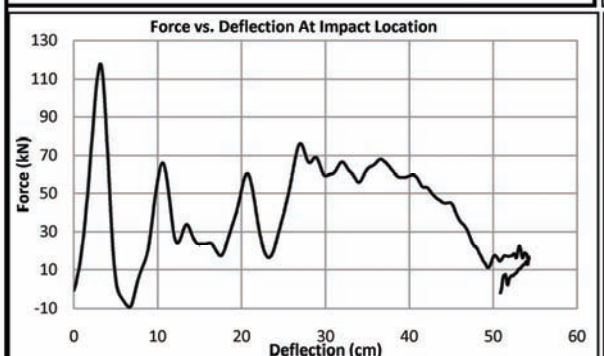
Post Properties		
Post Type:	Timber Deck Steel Post with Gussets @ Impact Height	
Post Size:	W150x18	W6x12
Post Length:	108.6 cm	42.75 in.
Embedment Depth:	#VALUE!	NA (Timber Deck Mounted) in.
Orientation:	Strong Axis - Off Center	

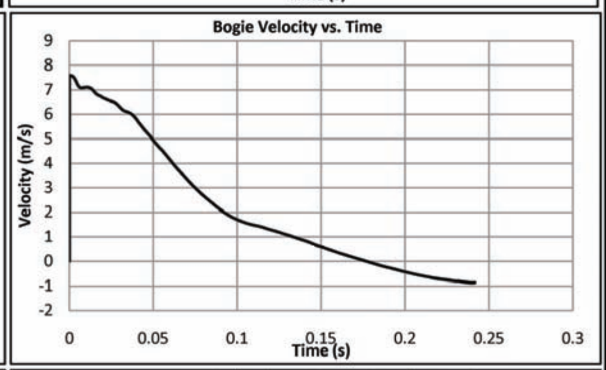
Soil Properties	
Gradation:	NA
Moisture Content:	NA
Compaction Method:	NA
Soil Density, γd:	NA

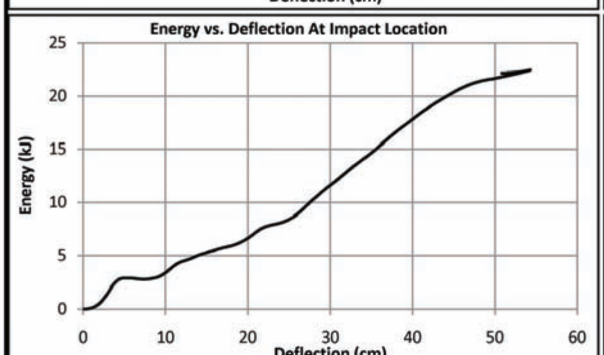
Bogie Properties		
Impact Velocity:	7.601 m/s	17 mph (24.9 fps)
Impact Height:	63.2 cm	24.875 in.
Bogie Mass:	776.2 kg	1711.3 lbs

Data Acquired	
Acceleration Data:	EDR-4
Camera Data:	AOS-5 Perpendicular - 11'









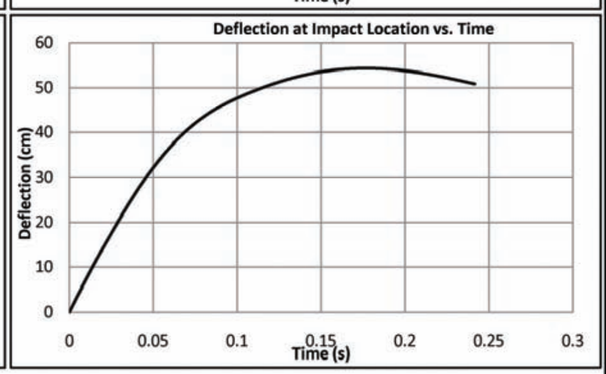


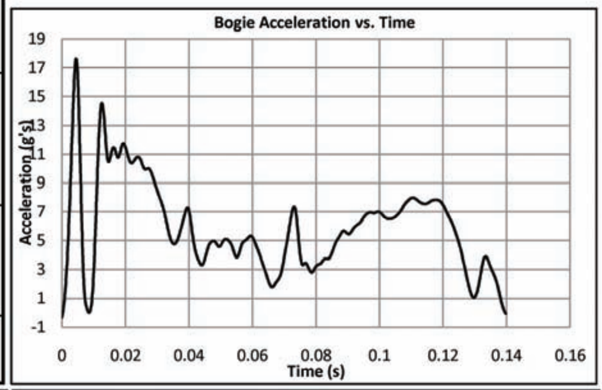
Figure A - 4. Results of Test No. WVTL2-2 (EDR4)

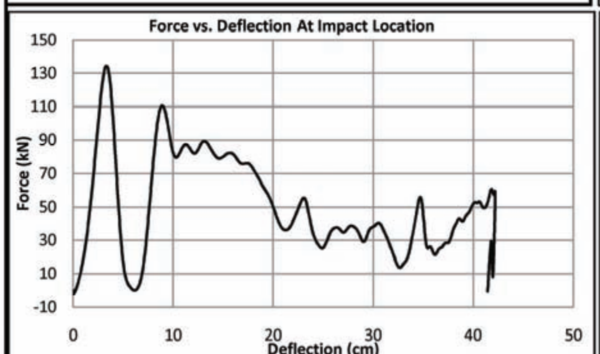
MIDWEST ROADSIDE SAFETY FACILITY

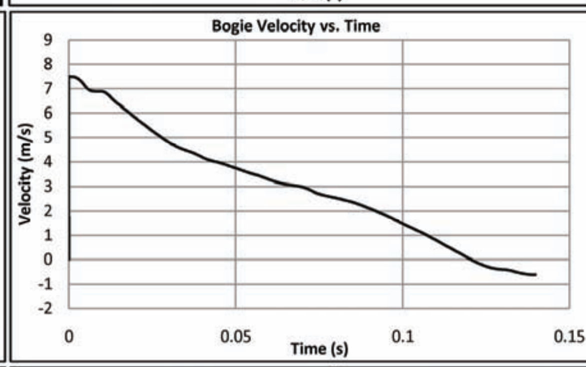
Bogie Test Summary

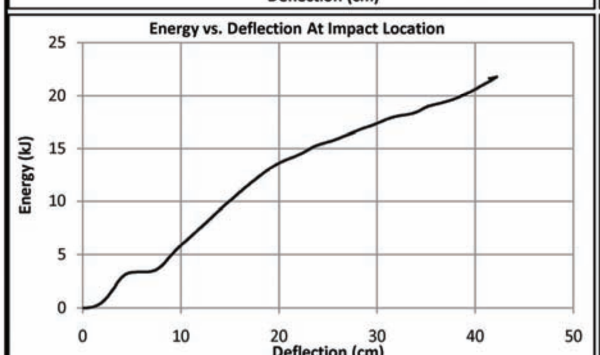
Test Information	West Virginia TL-2 Timber Deck Post	
Test Number:	WVTL2-3	
Test Date:	26-Aug-2008	
Failure Type:	Torsional	
Post Properties		
Post Type:	Timber Deck Steel Post with Shear Plates	
Post Size:	W150x18	W6x12
Post Length:	108.6 cm	42.75 in.
Embedment Depth:	#VALUE!	NA in.
Orientation:	Strong Axis - Centered on Post	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	7.4828 m/s	16.7 mph (24.5 fps)
Impact Height:	63.2 cm	24.875 in.
Bogie Mass:	776.2 kg	1711.3 lbs
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 22'	

Test Results Summary		
Max. Deflection:	42.2	cm
Peak Force:	134.0	kN
Initial Linear Stiffness:	41.4	kN/cm
Total Energy:	21.8	kJ









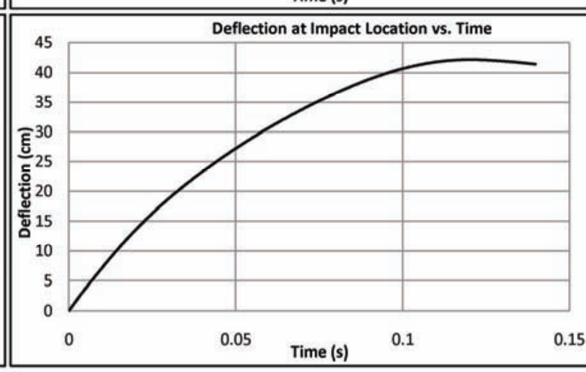


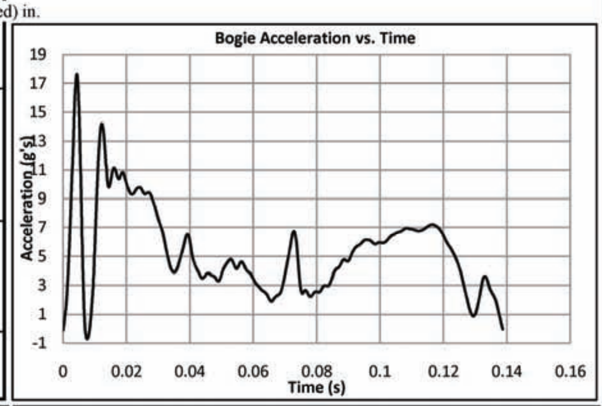
Figure A - 5. Results of Test No. WVTL2-3 (EDR3)

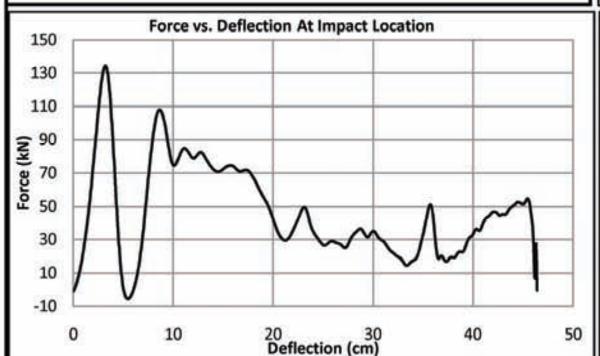
MIDWEST ROADSIDE SAFETY FACILITY

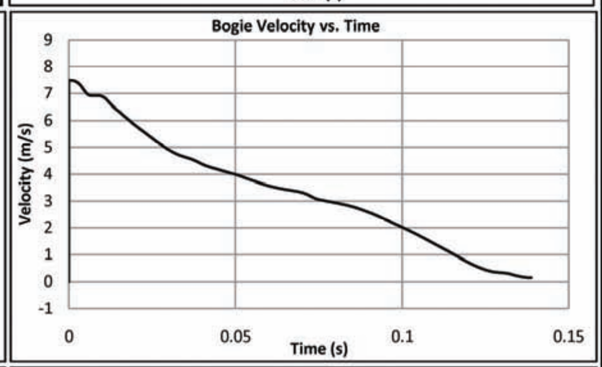
Bogie Test Summary

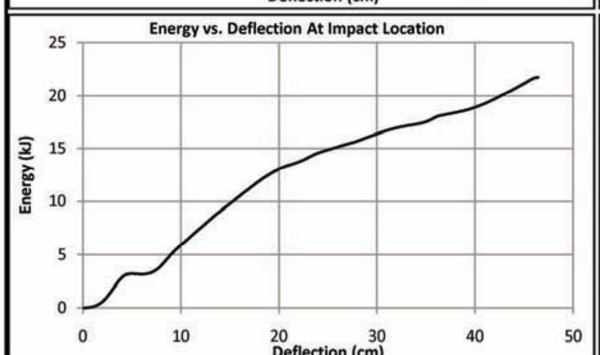
Test Information	West Virginia TL-2 Timber Deck Steel Post	
Test Number:	WVTL2-3	
Test Date:	26-Aug-2008	
Failure Type:	Torsional	
Post Properties		
Post Type:	Timber Deck Steel Post with Shear Plates	
Post Size:	W150x18	W6x12
Post Length:	108.6 cm	42.75 in.
Embedment Depth:	#VALUE!	NA (Timber Deck Mounted) in.
Orientation:	Strong Axis - Centered on Post	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	7.4828 m/s	16.7 mph (24.5 fps)
Impact Height:	63.2 cm	24.875 in.
Bogie Mass:	776.2 kg	1711.3 lbs
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-5 Perpendicular - 15'	

Test Results Summary		
Max. Deflection:	46.4	cm
Peak Force:	134.3	kN
Initial Linear Stiffness:	42.3	kN/cm
Total Energy:	21.7	kJ









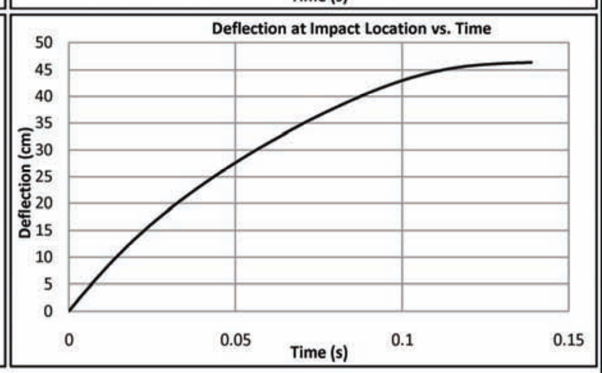


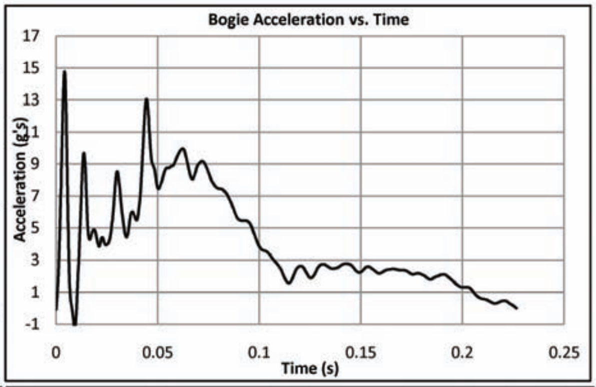
Figure A - 6. Results of Test No. WVTL2-3 (EDR4)

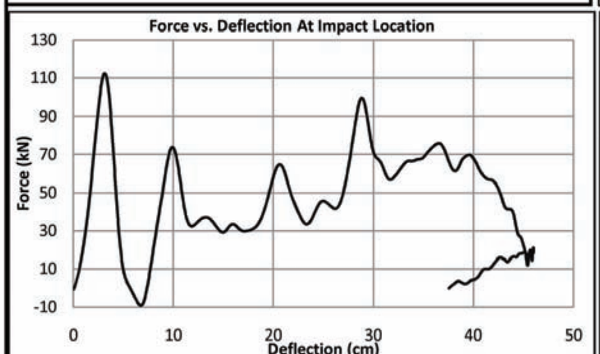
MIDWEST ROADSIDE SAFETY FACILITY

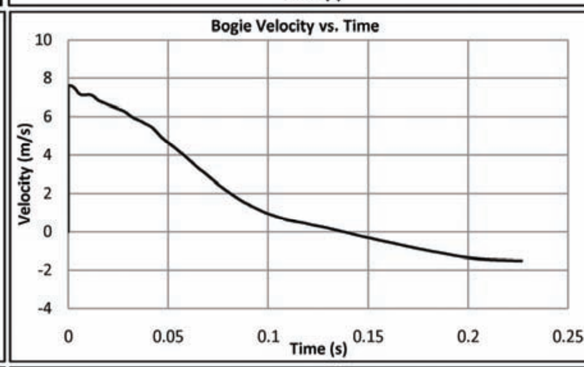
Bogie Test Summary

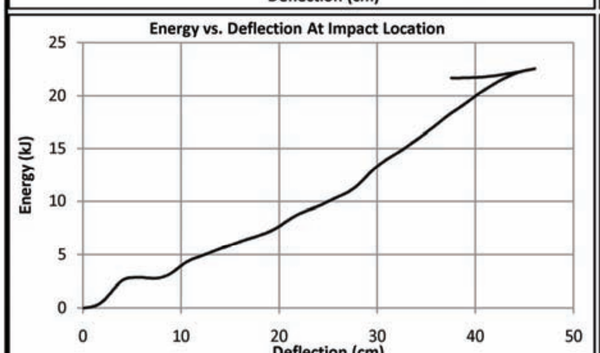
Test Information	West Virginia TL-2 Timber Deck Post	
Test Number:	WVTL2-4	
Test Date:	26-Aug-2008	
Failure Type:	Torsional	
Post Properties		
Post Type:	Timber Deck Steel Post with Shear Plates and Gussets @ Impact Height	
Post Size:	W150x18	W6x12
Post Length:	108.6 cm	42.75 in.
Embedment Depth:	#VALUE!	NA in.
Orientation:	Strong Axis - Centered on Post	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	7.61365528 m/s	17 mph (25 fps)
Impact Height:	63.2 cm	24.875 in.
Bogie Mass:	776.2 kg	1711.3 lbs
Data Acquired		
Acceleration Data:	EDR-3	
Camera Data:	AOS-5 Perpendicular - 22'	

Test Results Summary		
Max. Deflection:	46.0	cm
Peak Force:	112.4	kN
Initial Linear Stiffness:	36.7	kN/cm
Total Energy:	22.6	kJ









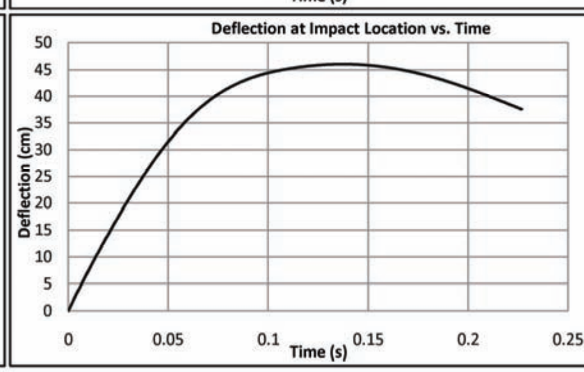


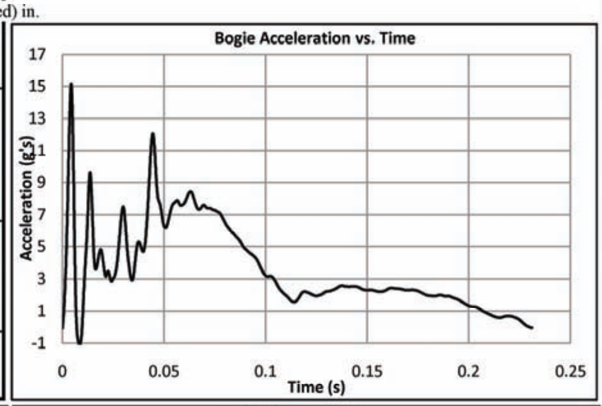
Figure A - 7. Results of Test No. WVTL2-4 (EDR3)

MIDWEST ROADSIDE SAFETY FACILITY

Bogie Test Summary

Test Information	West Virginia TL-2 Timber Deck Steel Post	
Test Number:	WVTL2-4	
Test Date:	26-Aug-2008	
Failure Type:	Torsional	
Post Properties		
Post Type:	Timber Deck Steel Post with Shear Plates and Gussets @ Impact Height	
Post Size:	W150x18	W6x12
Post Length:	108.6 cm	42.75 in.
Embedment Depth:	#VALUE!	NA (Timber Deck Mounted) in.
Orientation:	Strong Axis - Off Center	
Soil Properties		
Gradation:	NA	
Moisture Content:	NA	
Compaction Method:	NA	
Soil Density, γd:	NA	
Bogie Properties		
Impact Velocity:	7.61365528 m/s	17 mph (25 fps)
Impact Height:	63.2 cm	24.875 in.
Bogie Mass:	776.2 kg	1711.3 lbs
Data Acquired		
Acceleration Data:	EDR-4	
Camera Data:	AOS-5 Perpendicular - 19'	

Test Results Summary		
Max. Deflection:	55.2	cm
Peak Force:	115.3	kN
Initial Linear Stiffness:	36.3	kN/cm
Total Energy:	22.5	kJ



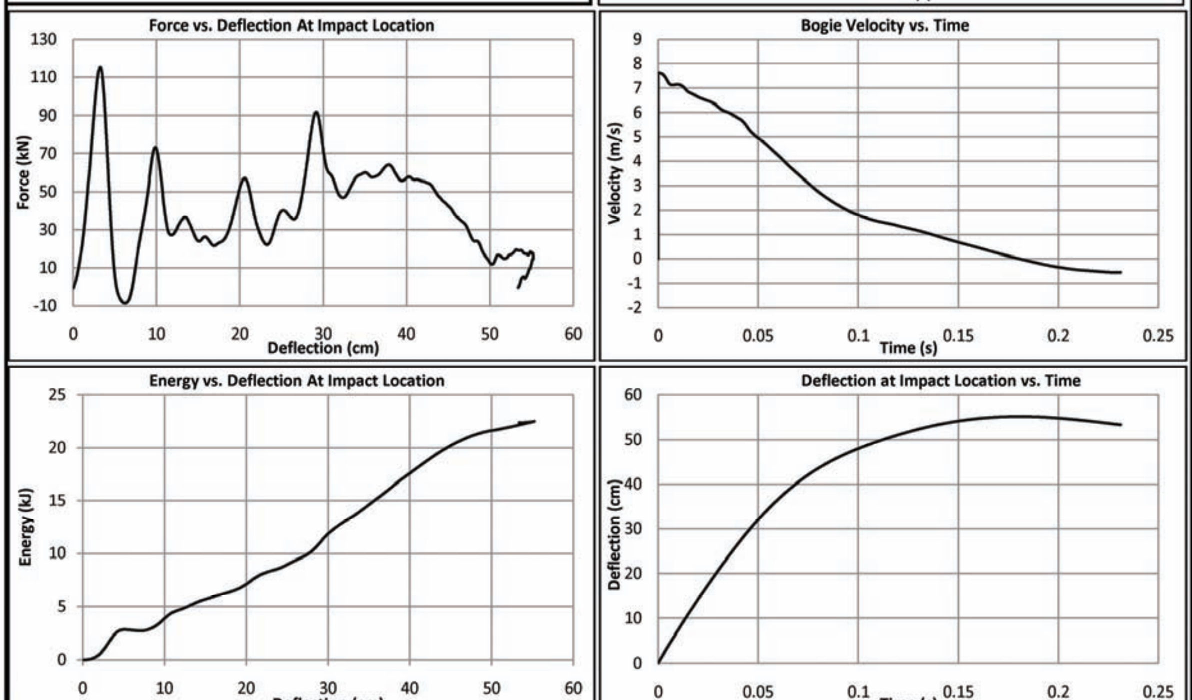


Figure A - 8. Results of Test No. WVTL2-4 (EDR4)

APPENDIX B – FINAL BRIDGE RAILING AND TRANSITION SYSTEM DRAWINGS

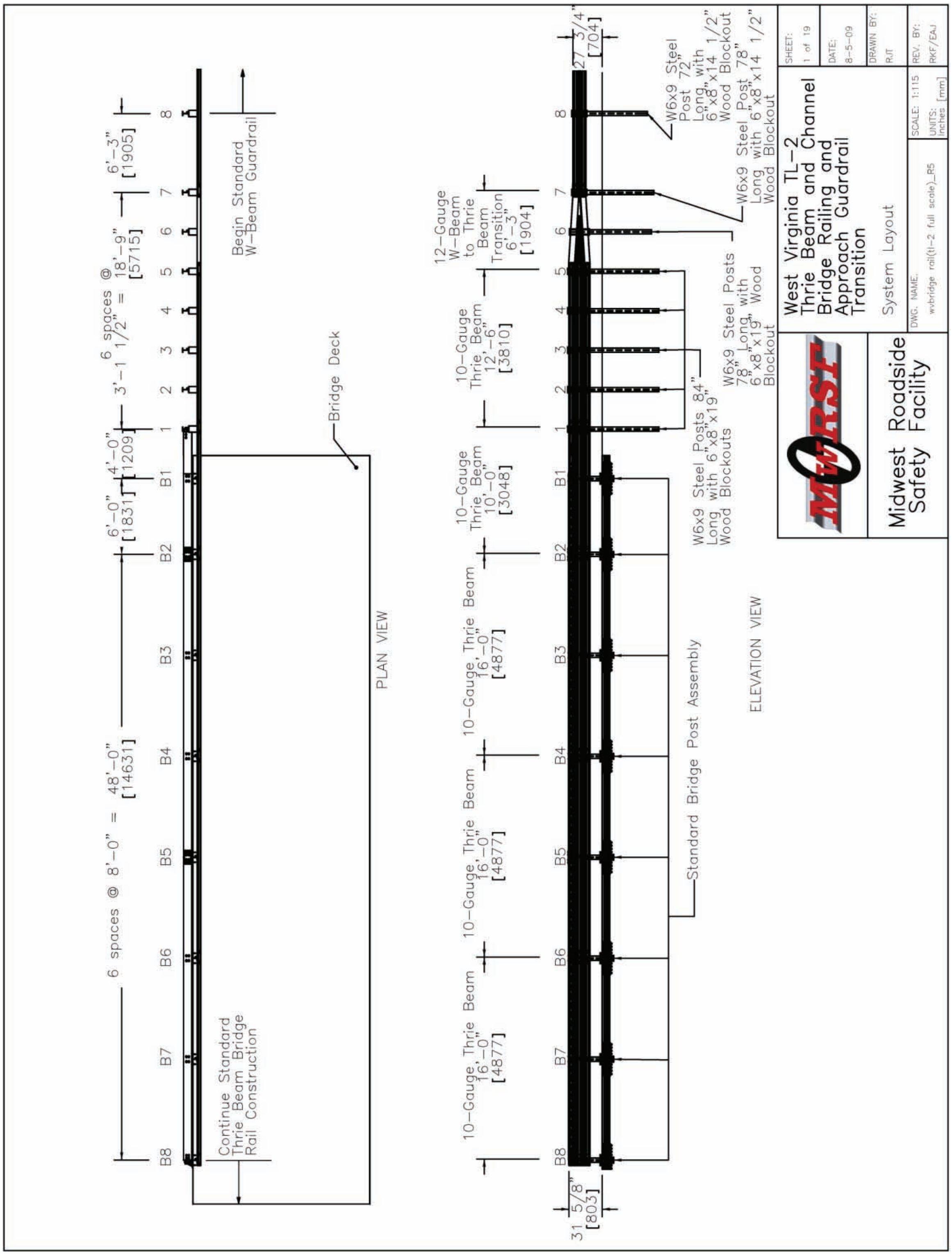


Figure B - 1. System Layout

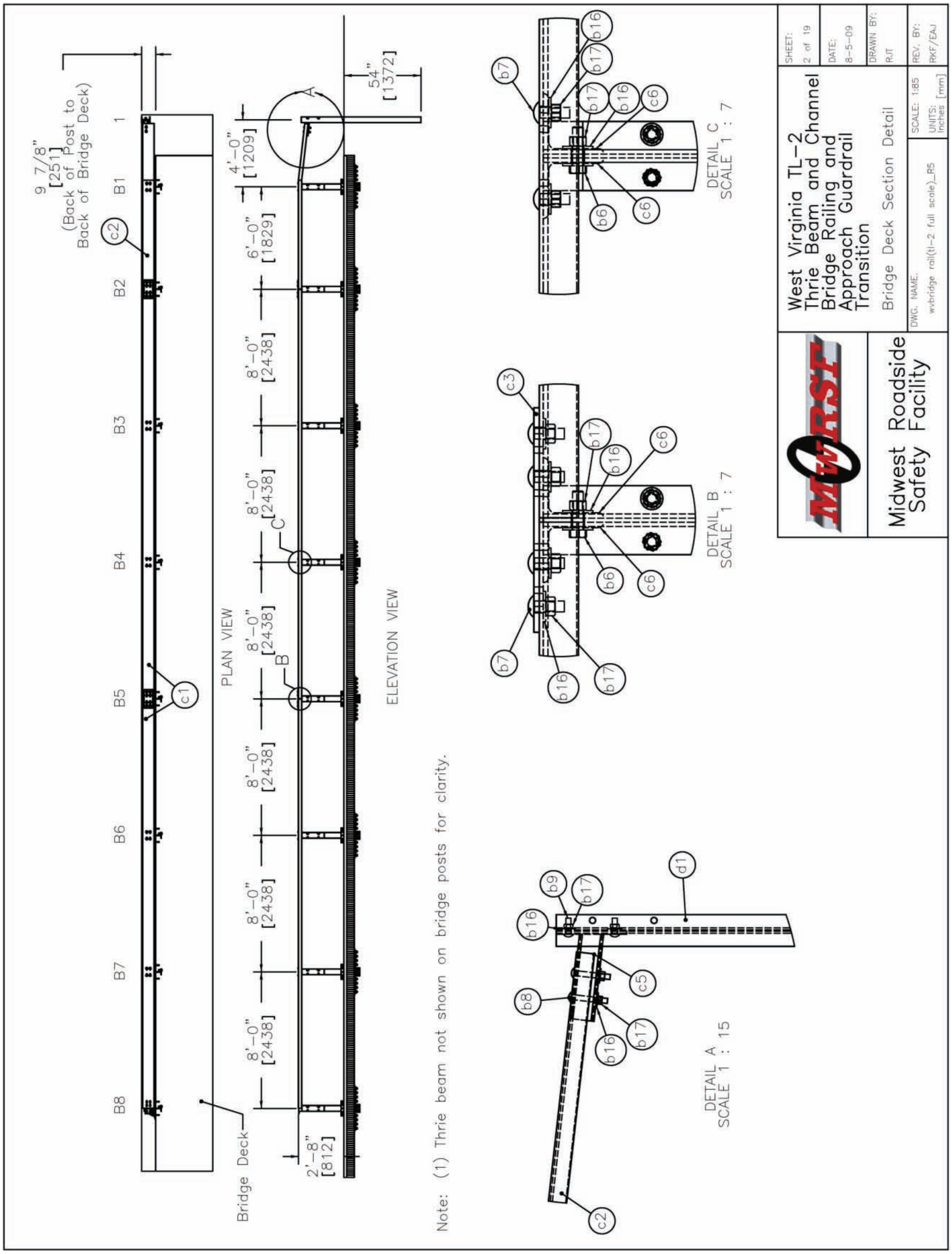


Figure B - 2. Bridge Deck Section Detail

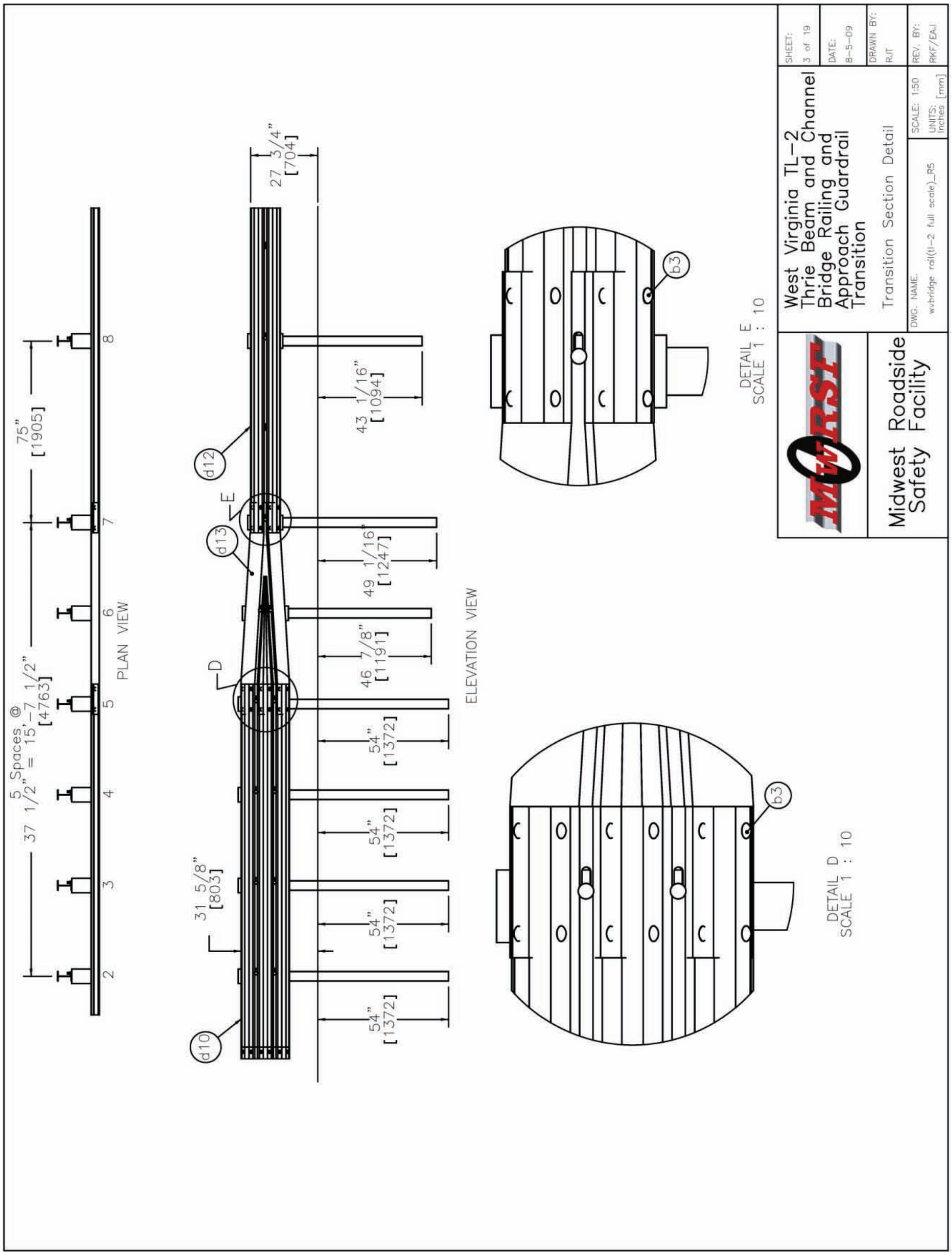


Figure B - 3. Transition Section Detail

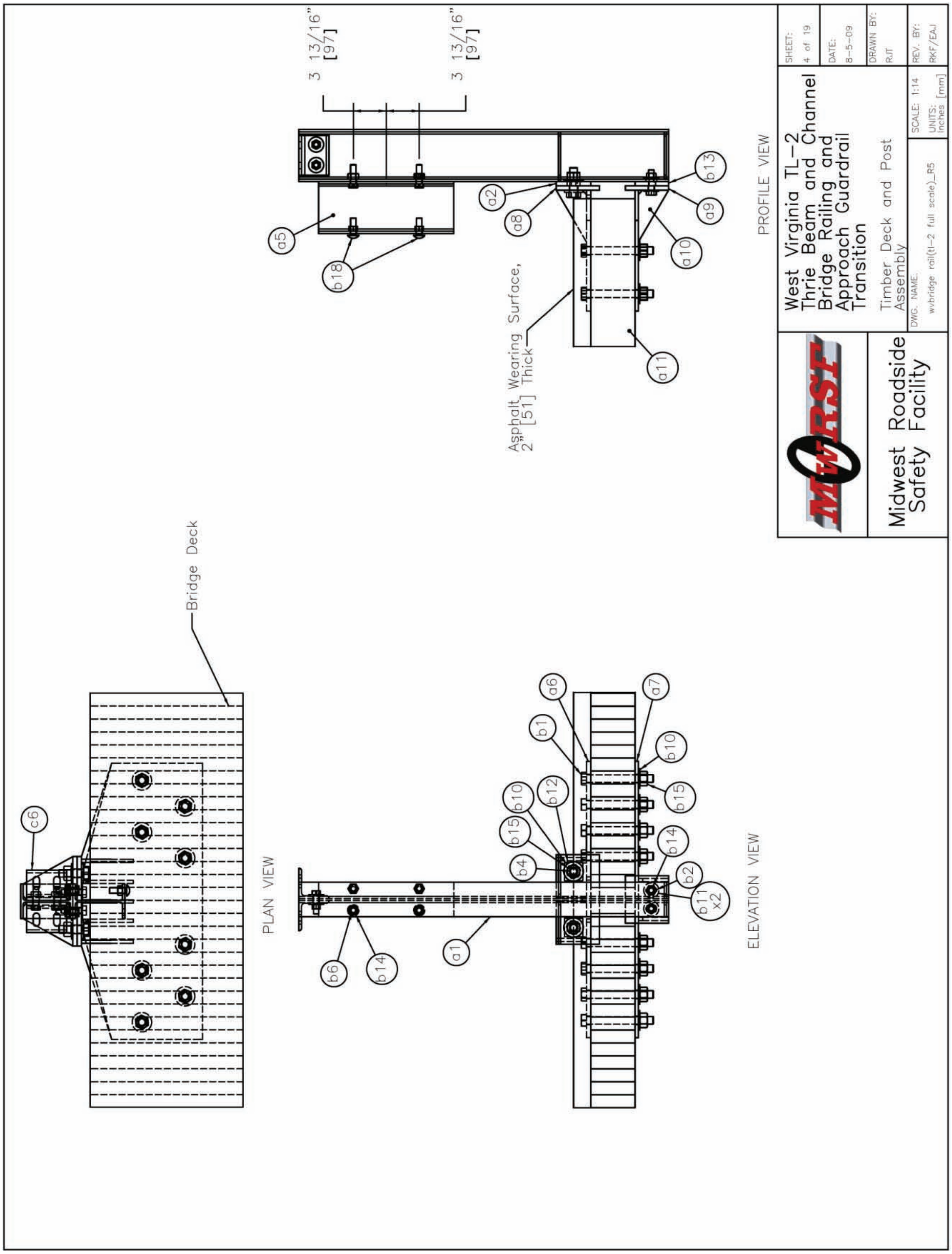


Figure B - 4. Timber Deck and Post Assembly

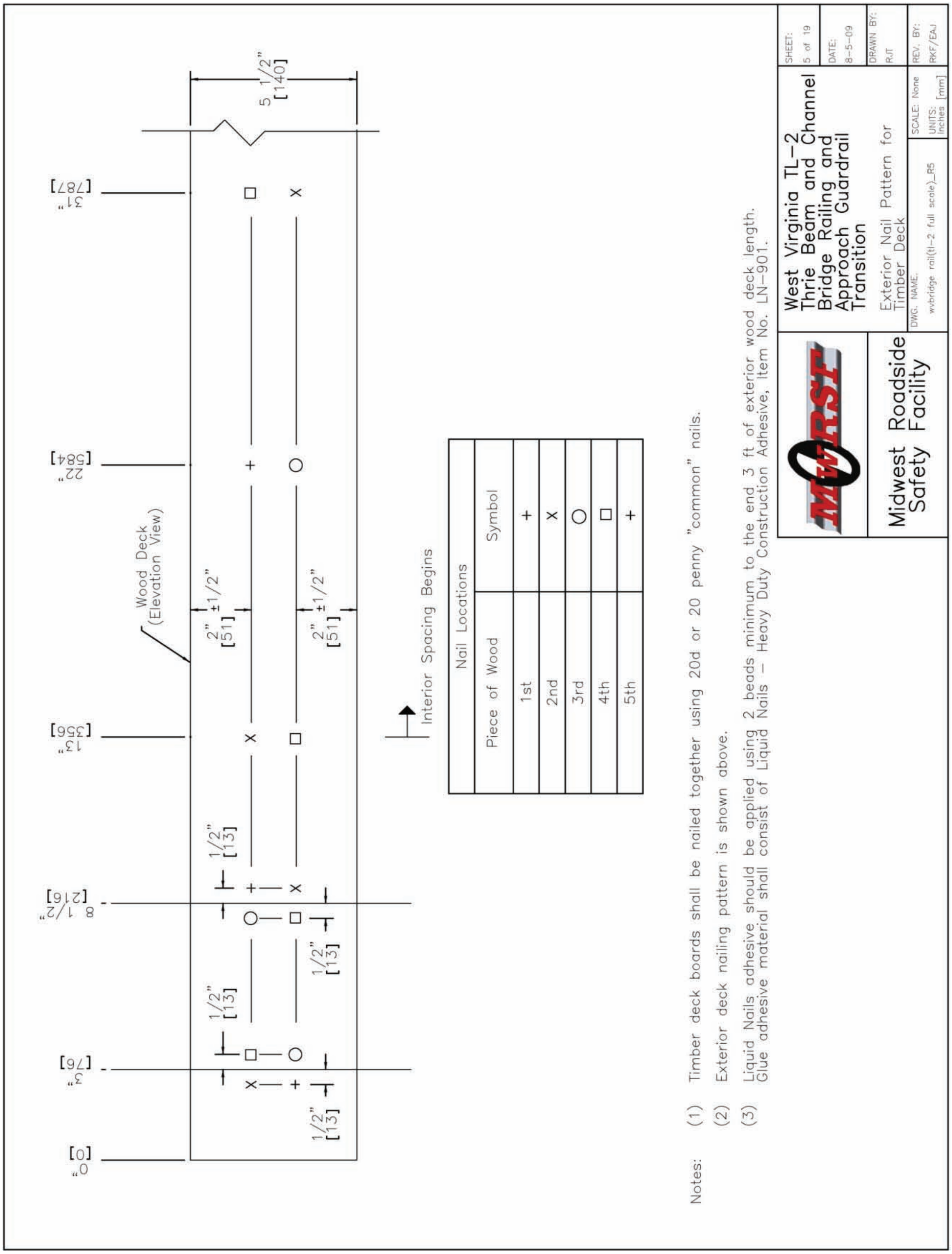


Figure B - 5. Exterior Nail Pattern for Timber Deck

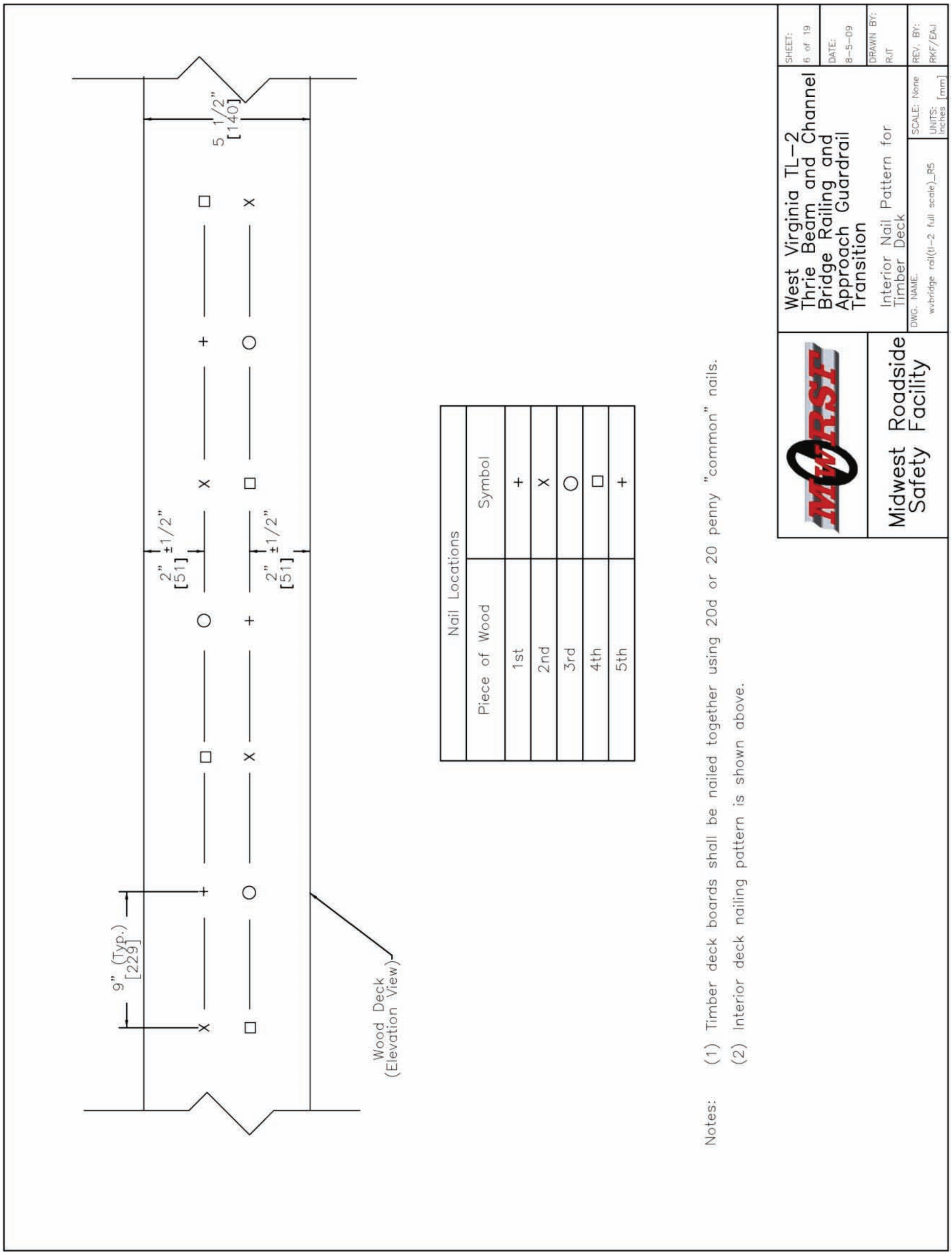


Figure B - 6. Interior Nail Pattern for Timber Deck

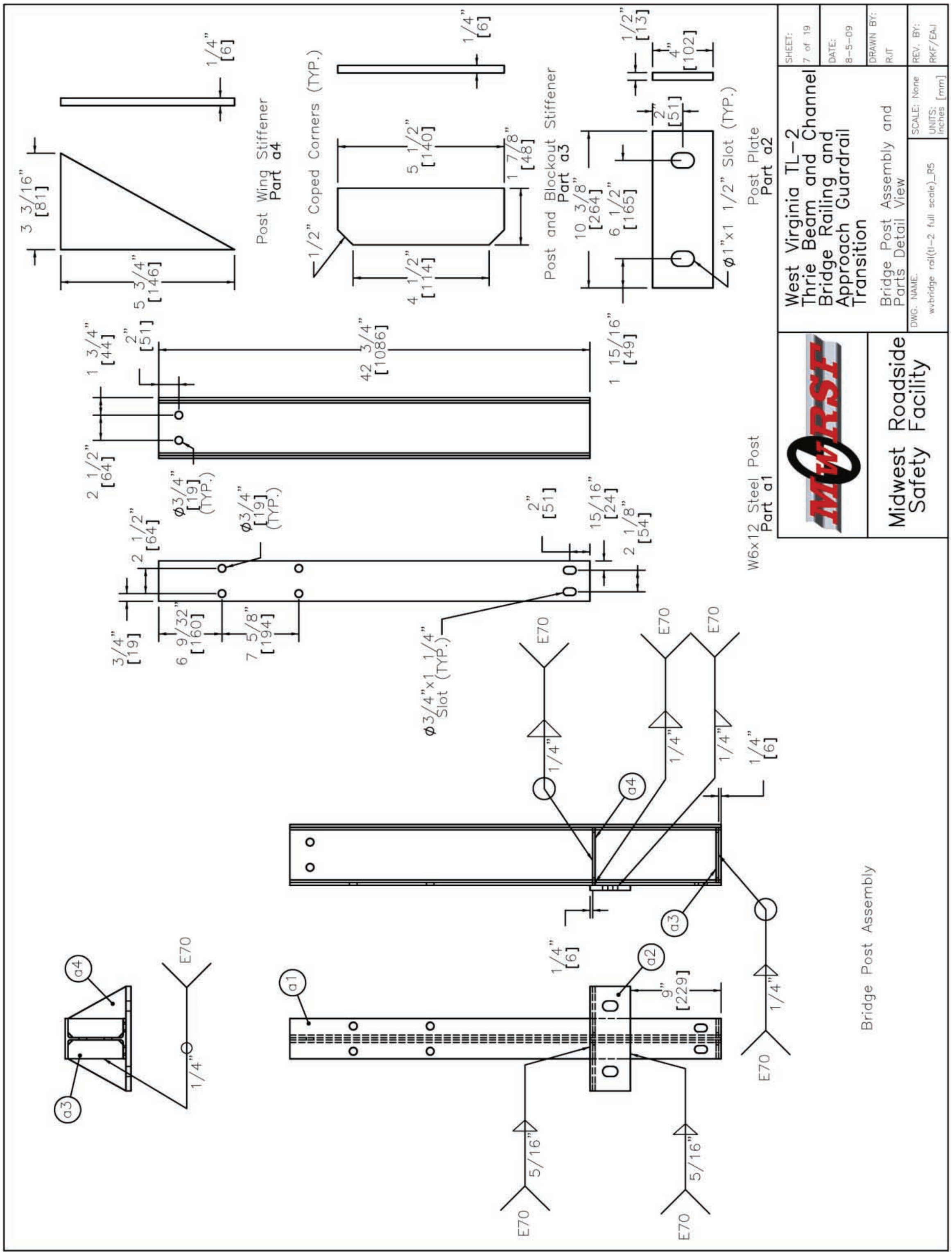


Figure B - 7. Bridge Post Assembly and Parts Detail View

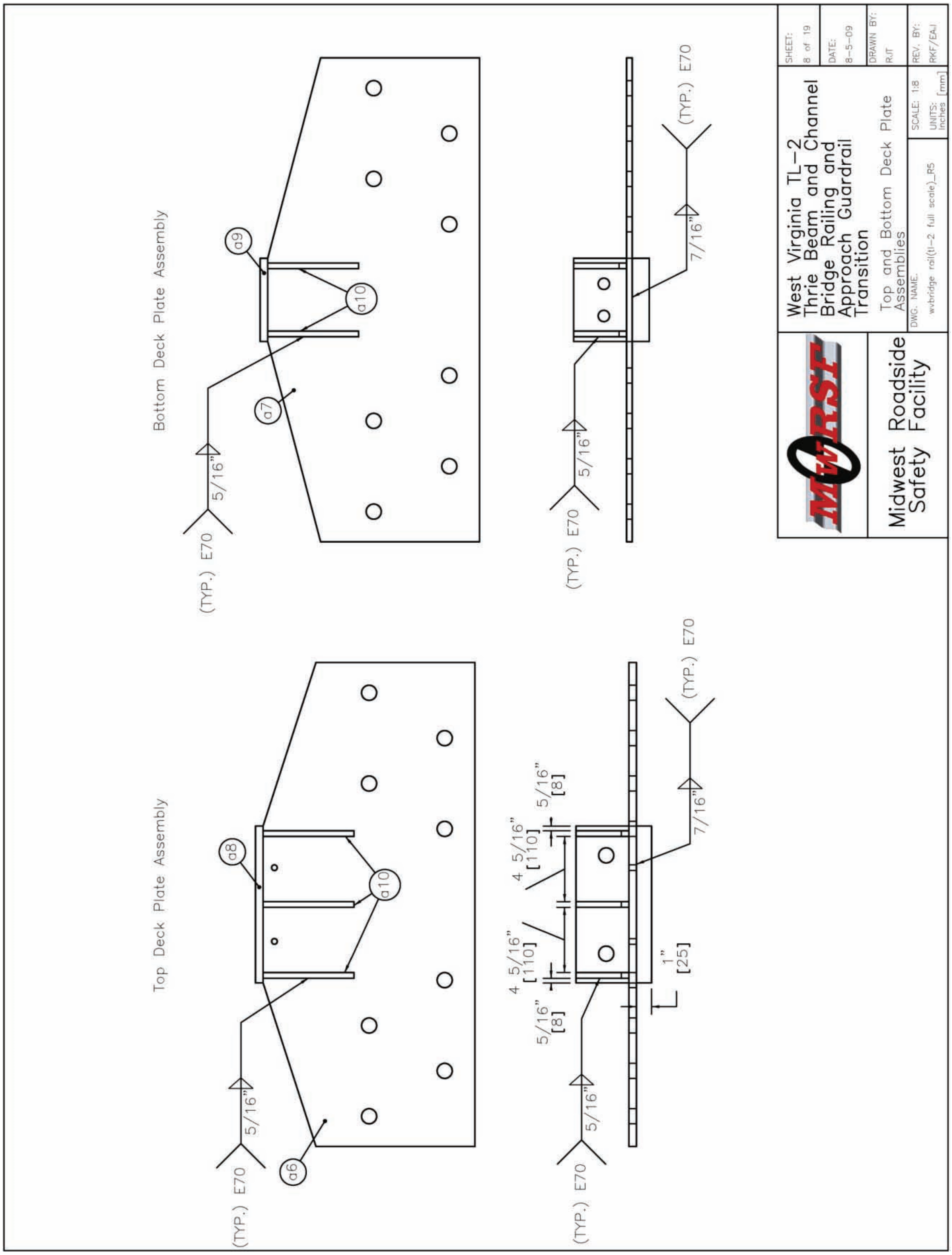


Figure B - 8. Top and Bottom Deck Plate Assemblies

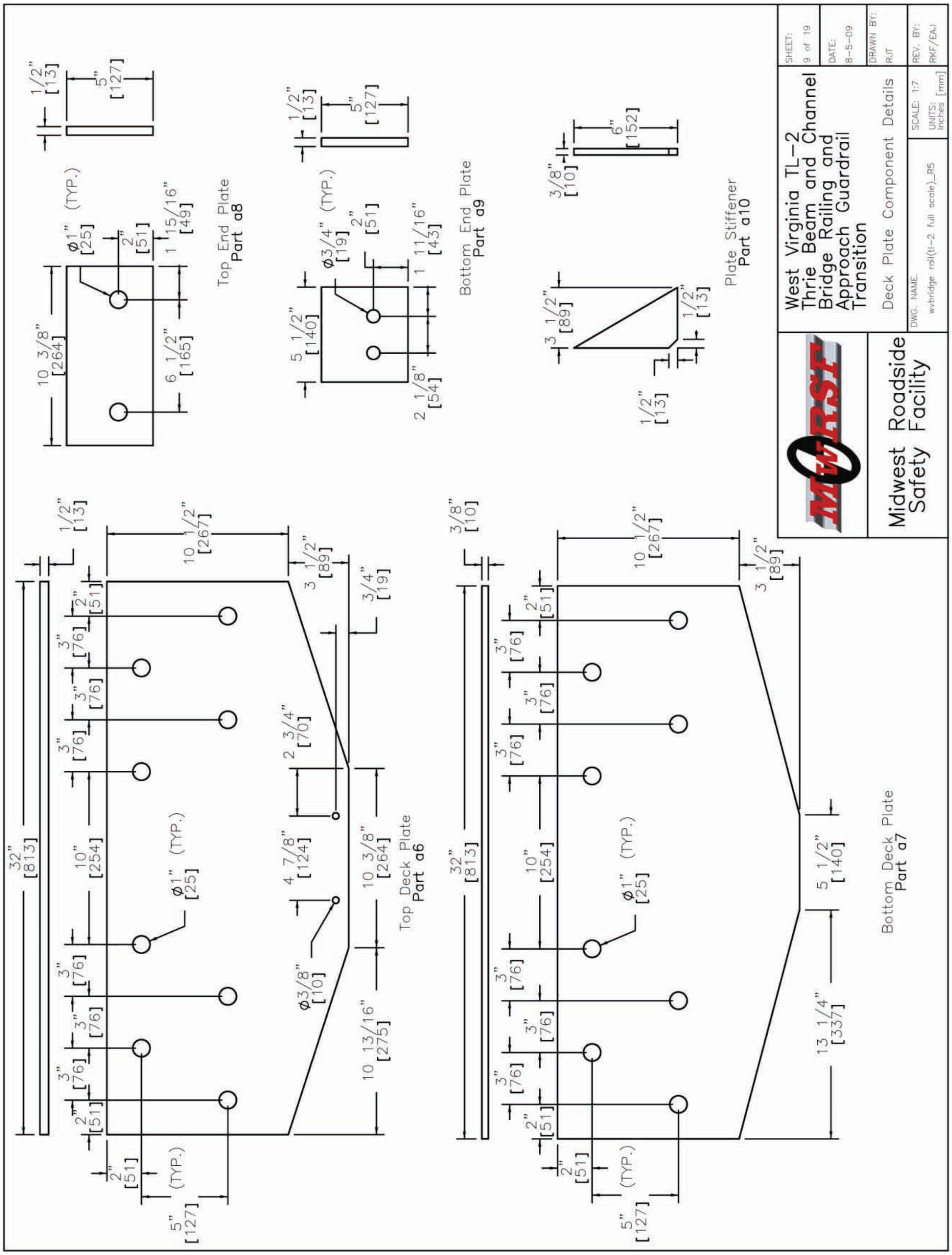


Figure B - 9. Deck Plate Component Details

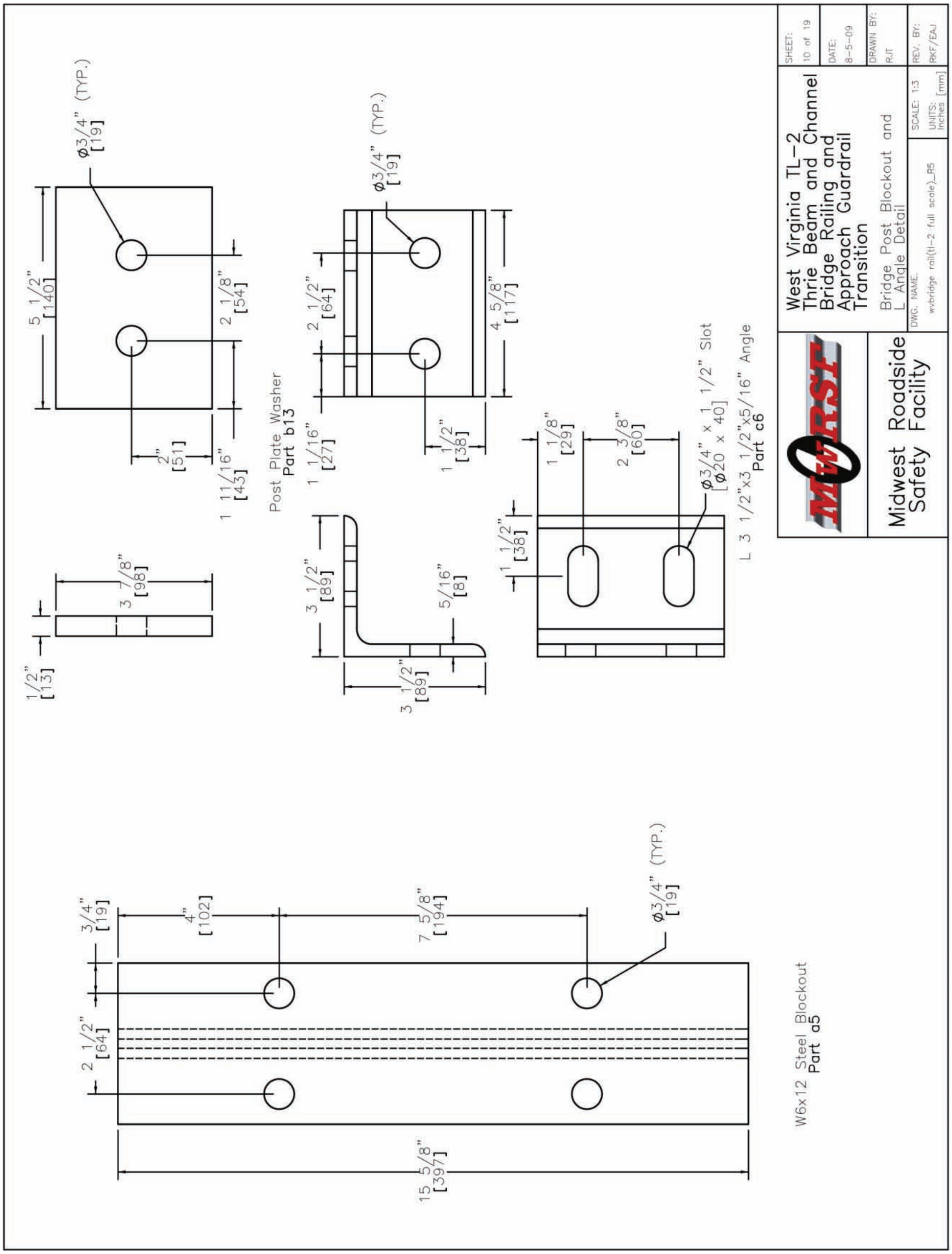


Figure B - 10. Bridge Post Blockout and L Angle Detail

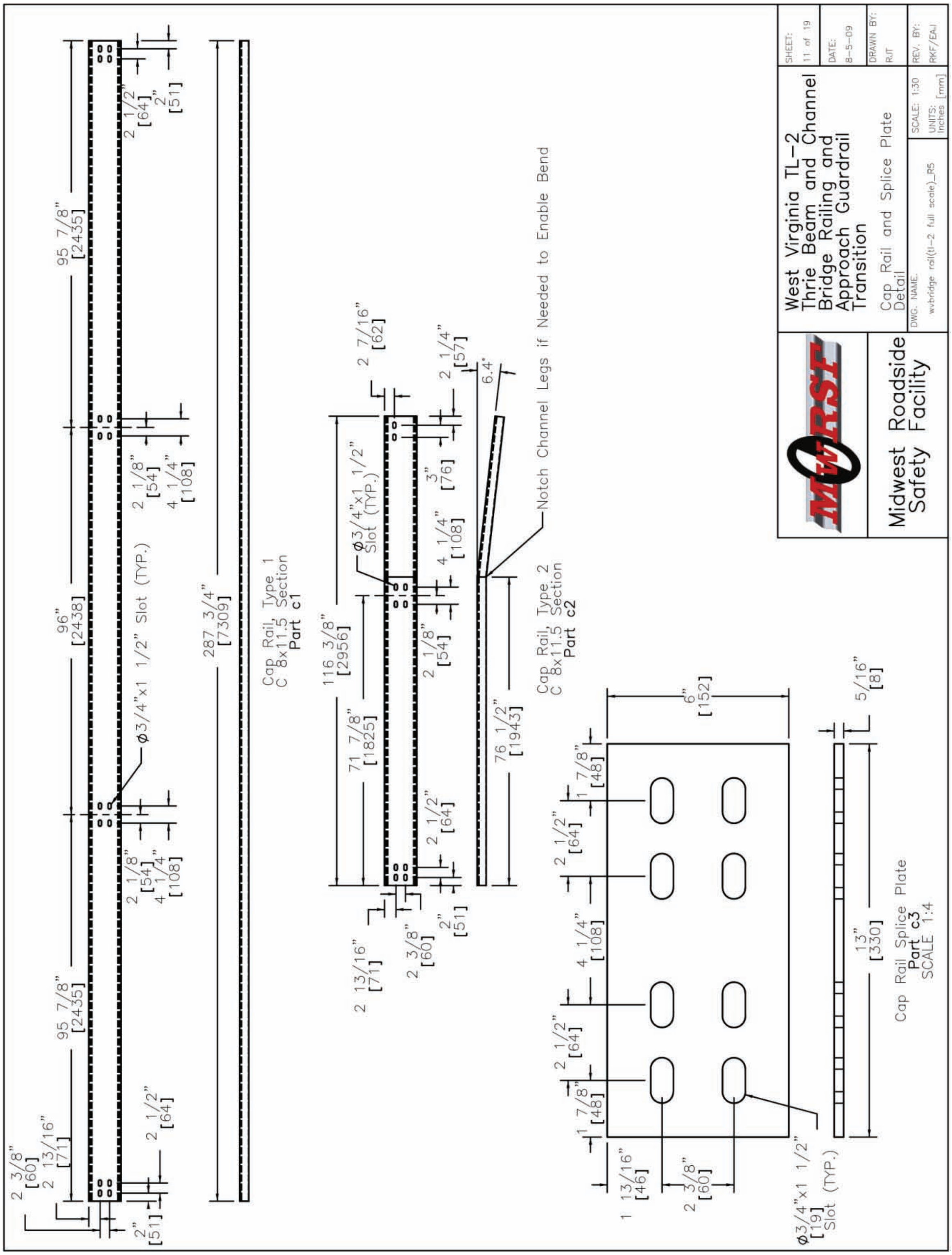


Figure B - 11. Cap Rail and Splice Plate Detail

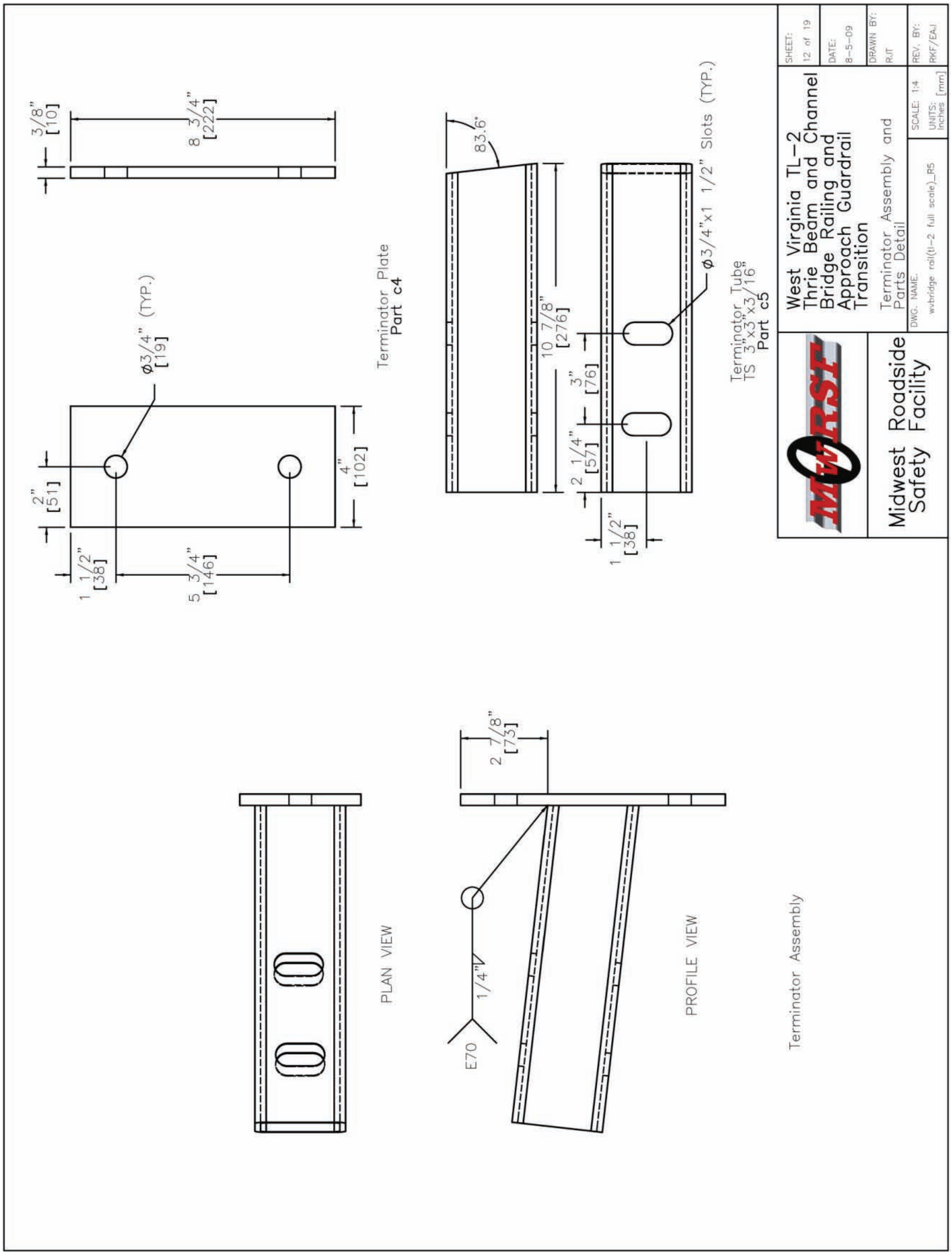


Figure B - 12. Terminator Assembly and Parts Detail

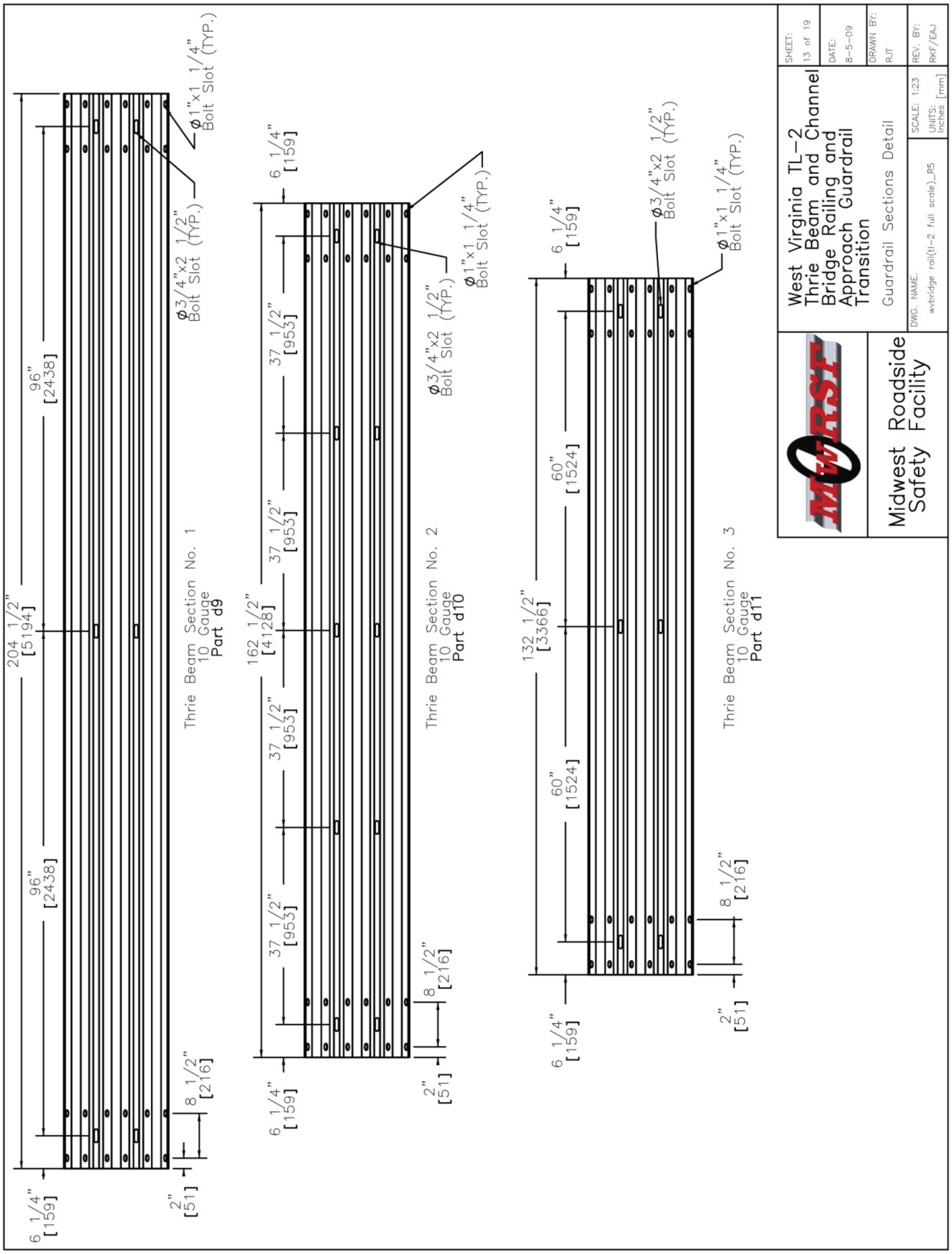


Figure B - 13. Guardrail Sections Detail

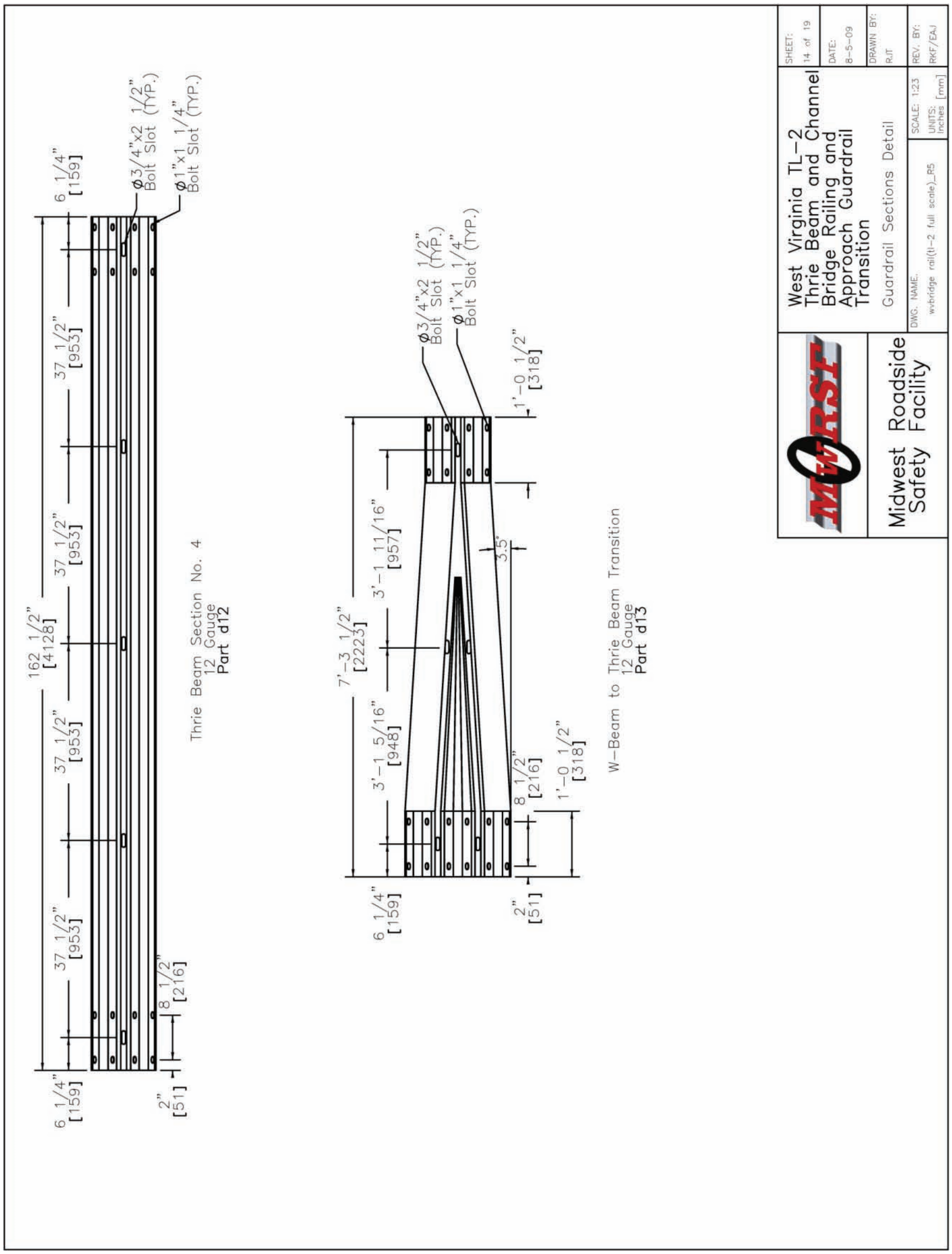


Figure B - 14. Guardrail Sections Detail

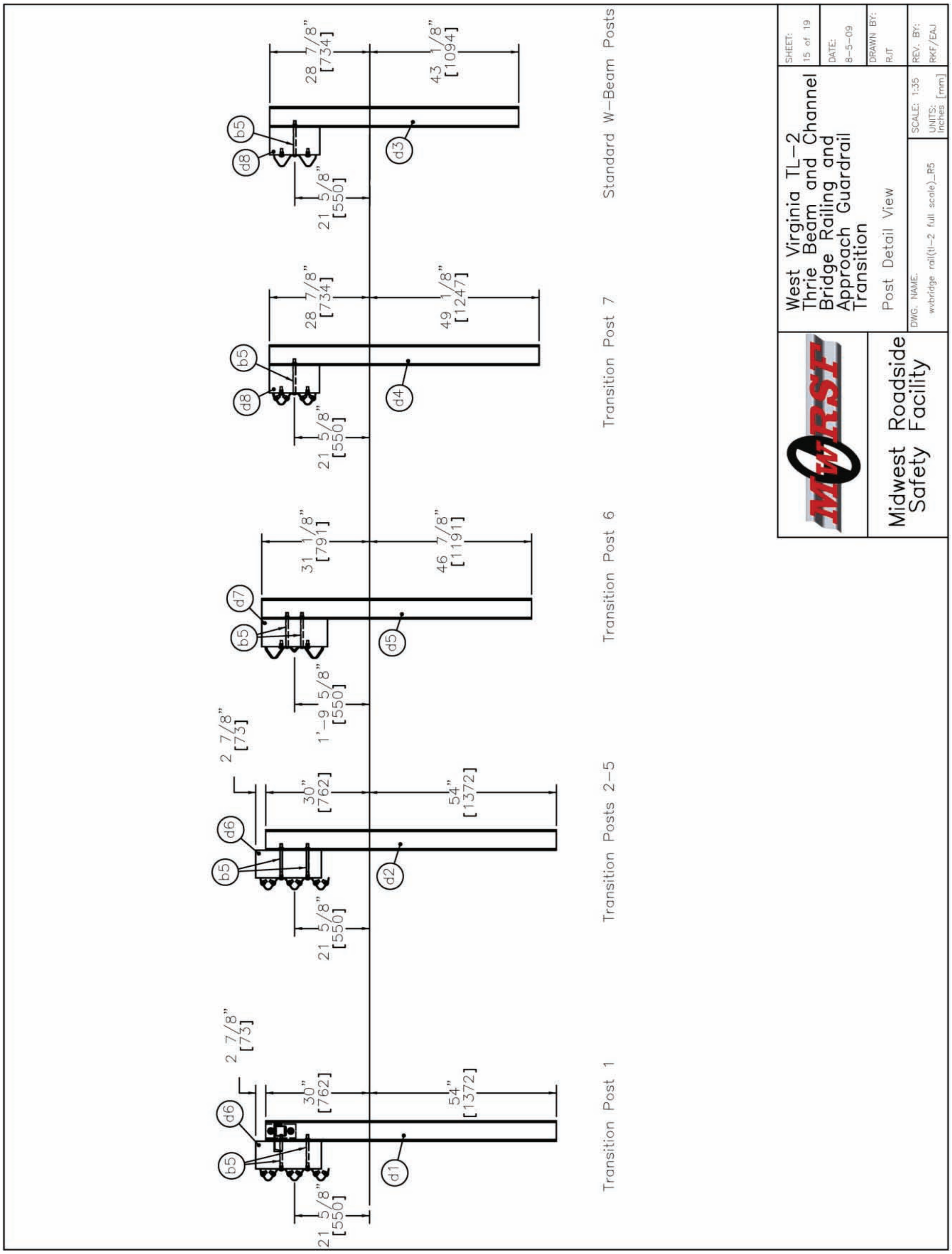


Figure B - 15. Post Detail View

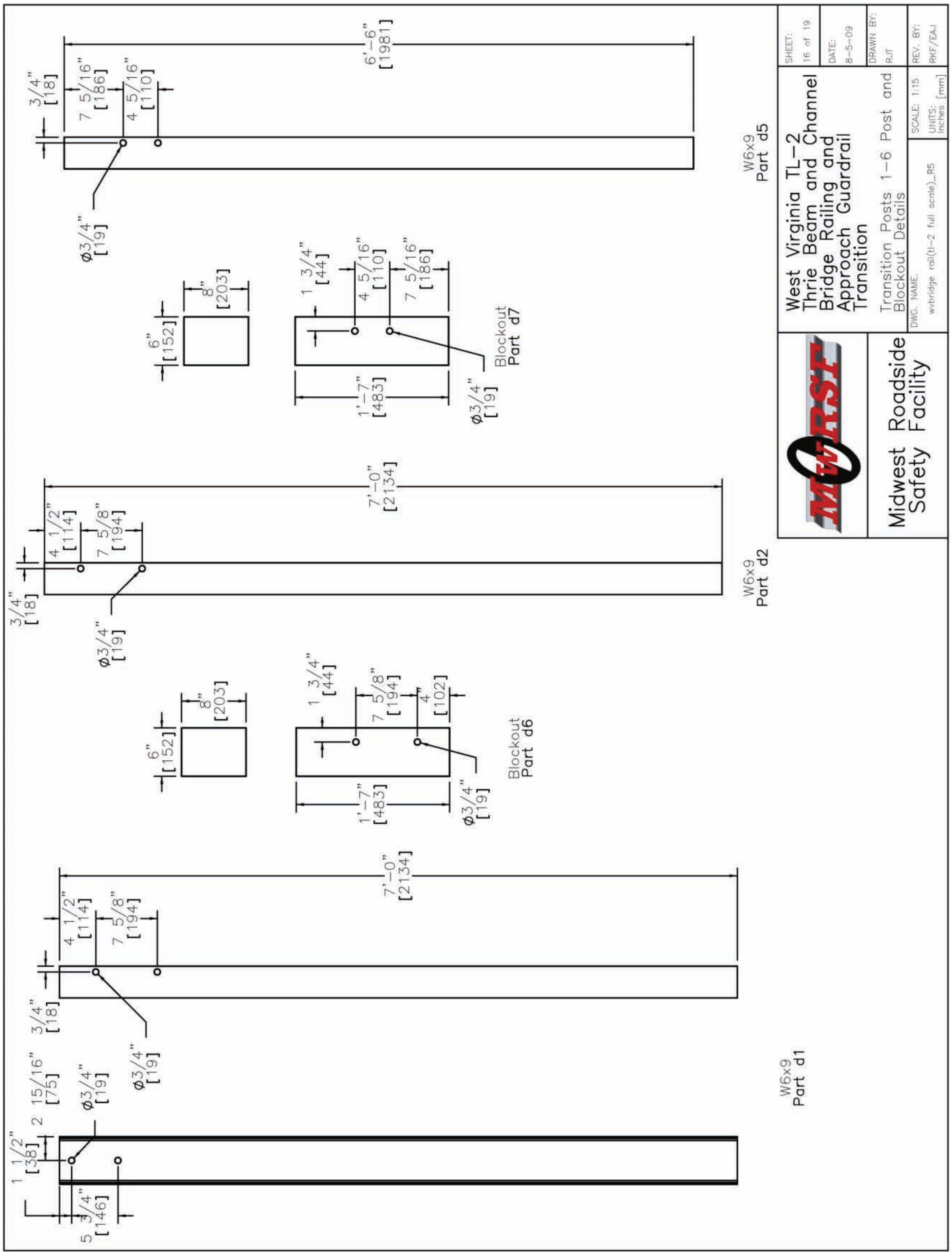


Figure B - 16. Transition Posts 1-6 and Blockout Details

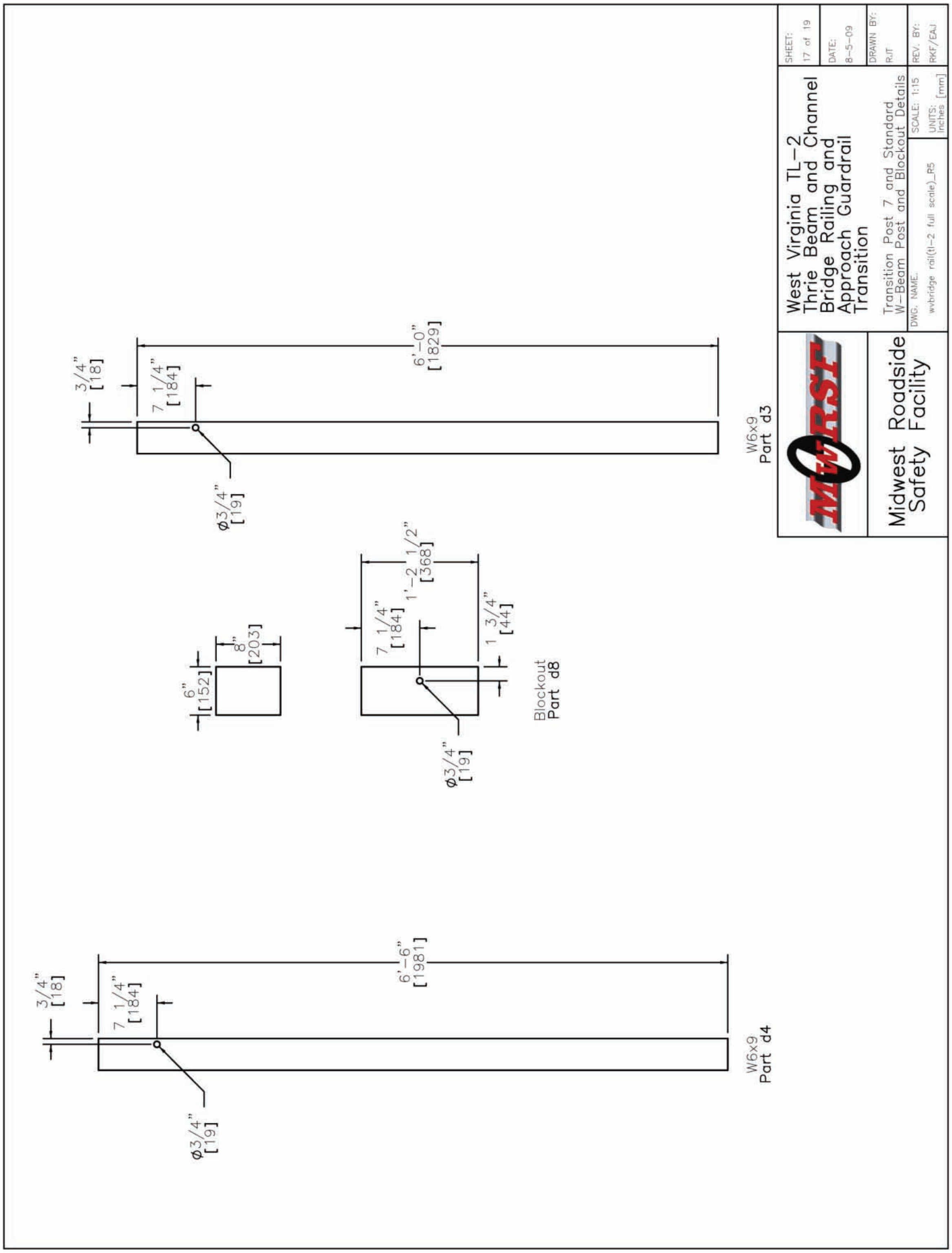


Figure B - 17. Transition Post 7, Standard W-Beam Post, and Blockout Details

West Virginia TL-2 Bridge Railing and Approach Transition				
Item No.	QTY.	Description	Material Specification	Hardware Guide
a1	8	W6x12x42 3/4" Post	A992 or A572 Grade 50	–
a2	8	Post Plate	A36	–
a3	32	Post Stiffener	A36	–
a4	16	Post Wing Stiffener	A36	–
a5	8	W6x12x15 5/8" Steel Blockout	A992 or A572 Grade 50	–
a6	8	Top Deck Plate	A36	–
a7	8	Bottom Deck Plate	A36	–
a8	8	Top End Plate	A36	–
a9	8	Bottom End Plate	A36	–
a10	40	Plate Stiffener	A36	–
a11	1000	2"x6"x14' Long Treated, Dimensional Lumber (0.60 lbs retention)	Southern Yellow Pine No. 1	–
b1	64	ø7/8" Heavy Hex Head Bolt 7 3/4" Long	A325 Type 1	–
b2	16	ø5/8" Heavy Hex Head Bolt 2 1/2" Long	A325 Type 1	–
b3	80	ø5/8"x1 1/2" Guardrail Bolt and Nut	A307 Grade A	FBB01
b4	16	ø7/8" Heavy Hex Head Bolt 2 7/8" Long	A325 Type 1	–
b5	14	ø5/8"x10" Guardrail Bolt and Nut	A307 Grade A	FBB03
b6	48	ø5/8"x2 1/4" Long Hex Bolt	A307 Grade A	–
b7	36	ø5/8"x1 3/4" Round Head Bolt	A307 Grade A	–
b8	2	ø5/8"x4 1/2" Round Head Bolt	A307 Grade A	–
b9	2	ø5/8"x2" Round Head Bolt	A307 Grade A	–
b10	80	ø7/8" Flat Washer	F436 Gr. 1	FWC22a
b11	32	ø5/8" Flat Washer	F436 Gr. 1	FWC16a
b12	16	ø1" Square Washer	A36	–
b13	8	Post Plate Washer	A36	–
b14	16	ø5/8" Hex Nut	A563DH	–
b15	80	ø7/8" Hex Nut	A563DH	–
b16	72	ø5/8" Flat Washer	F844	–
b17	88	ø5/8" Hex Nut	A563A	–
b18	16	ø5/8"x2" Guardrail Bolt and Nut	A307 Grade A	FBB02
c1	2	C8x11.5 Cap Rail	A36	–
c2	1	C8x11.5 Bent Cap Rail	A36	–
c3	2	Cap Rail Splice Plate	A36	–
c4	1	Terminator Plate	A36	–
c5	1	Terminator Tube	A500 Grade B	–
c6	16	3 1/2"x3 1/2"x5/16" L Angle	A36	–

Midwest Roadside Safety Facility

West Virginia TL-2 Thrie Beam and Channel Bridge Railing and Approach Guardrail Transition

Bill of Materials

SHEET: 18 of 19	DATE: 8-5-09	DRAWN BY: RJT	DWG. NAME. wvbridge rail(tl-2 full scale)_R5	SCALE: None	UNITS: Inches [mm]	REV. BY: RKF/EAJ

Figure B - 18. Bill of Materials

West Virginia TL-2 Bridge Railing and Approach Transition				
Item No.	QTY.	Description	Material Specification	Hardware Guide
d1	1	W6x9 84" Long, Post 1	A36	–
d2	4	W6x9 84" Long, Posts 2–5	A36	–
d3	1	W6x9 72" Long, Post 8	A36	–
d4	1	W6x9 78" Long, Post 7	A36	–
d5	1	W6x9 78" Long, Post 6	A36	–
d6	5	6x8x19" Blockout	Southern Yellow Pine No. 1	–
d7	1	6x8x19" Blockout	Southern Yellow Pine No. 1	–
d8	2	6x8x14 1/2" Blockout	Southern Yellow Pine No. 1	PDB09
d9	3	12'–6" Thrie Beam Section	10 gauge AASHTO M180	RTM02b
d10	1	12'–6" Thrie Beam Section – 1/2 Post Spacing	10 gauge AASHTO M180	RTM04b
d11	1	10' Thrie Beam Section	10 gauge AASHTO M180	RTM02b
d12	1	12'–6" W–Beam Section – 1/2 Post Spacing	12 gauge AASHTO M180	RWM04a
d13	1	6'–3" W–Beam to Thrie Beam Transition Section	12 gauge AASHTO M180	RWT01a

Midwest Roadside Safety Facility

West Virginia TL–2 Thrie Beam and Channel Bridge Railing and Approach Guardrail Transition

Bill Of Materials (Continued)

SHEET: 19 of 19 | DATE: 8–5–09 | DRAWN BY: RJT | REV. BY: RKF/EAJ | DWG. NAME: wvbridge rail(tl–2 full scale)_R5 | SCALE: None | UNITS: Inches [mm]

Figure B - 19. Bill of Materials (Continued)

APPENDIX C – MATERIAL SPECIFICATIONS AND DOCUMENTATION

Figure C-23. Grainger Packing List

LINCOLN LUMBER COMPANY

LUMBERYARD
932 NORTH 23rd
LINCOLN, NEBRASKA
(402) 474-4488

MAILING ADDRESS
P.O. BOX 30373
LINCOLN, NE 68503-0373
FAX NO. (402) 474-3749

LUMBER YARD

A FINANCE CHARGE will be assessed on any past due balances computed at a **PERIODIC RATE OF 2% PER MONTH (ANNUAL PERCENTAGE RATE OF 24%)** on the outstanding balance. Mechanics Liens will be filed automatically as lien date approaches.

SOLD TO

UNIVERSITY OF NEBR
ACCOUNTING
401 ADM BLDG.
LINCOLN, NE 68588-0439

SHIP TO

MIDWEST ROADSIDE SAFETY
4800 NW 35TH STREET.
MWRSF
LINCOLN, NE 68524

ACCOUNT NO.	CUSTOMER P.O. NO.	TERMS	ORDER NO.	ORDER DATE	SLSM	LUMBER INV. NO.	INVOICE DATE
U7500	45001	DUE NET 20 DAYS	28070	03/03/08	MAK	L	0 / / 0

ORDERED	BACK ORDERED	SHIPPED	✓	DESCRIPTION	U/M	U/PRICE	AMOUNT
1024	0	1024		2X6X14' .40 #1 WSYP TREATED V /TREATED LUMBER	EA		

MAR 3, 2008 13:47:22 OT:

FILLED BY | CHECKED BY | SHIPPED BY

****
* DELIVERY TICKET *
****

SHIP VIA LINCOLN LUMBER

PAGE# 1 OF 1

PO# 4500185288

MERCHANDISE	
OTHER	
TAX	
FREIGHT	
TOTAL	

Figure C - 1. Deck Lumber Invoice

TMCO

TMCO Inc
535 "J" Street
Lincoln, NE 68508
Phone: 402-476-0013
Fax: 402-817-2050

Quotation

Quote To: UNIVERSITY
MIDWEST ROADSIDE SAFETY
LINCOLN, NE
United States

Quote Number:	18394			**Contact:**	
Quote Date:	05/04/08	**Expires:**	06/03/08	**Inquiry:**	
Customer:	UNL001			**Terms:**	Net 30 Days
Salesman:	HOUSE SALES			**Phone:**	472-4767
Ship Via:				**FAX:**	472-8080
FOB:	Lincoln, NE 68508			**Delivery:**	Standard Delivery 4 weeks FRO.

Thank you for the opportunity to submit this quote. Please be aware that it is our standard practice to fill each order to plus or minus 10% of the ordered quantity. Please specify if exact quantities are required. All deliveries made by TMCO are subject to a delivery charge. Please contact customer service for current delivery charge.

Item	Part Number	Description	Revision	Quantity	Price
1	DECK BRACKET	WEST VIRGINIA TL-1 CURB-TYPE TIMBER BRIDGE RAIL (MADE FROM 11GA A36 GALVANIZED SHEET)		260	$2.2400/EA
				Total:	***$582.40***

By Shane Jackson
TMCO Inc

Figure C - 2. Deck Anchor Bracket Invoice

ANCHOR BRACKET
MILL CERT.

C121380
Print Date: 05/30/2007

Page: 2 of 3

NUCOR
SHEET MILL GROUP
Nucor Steel-Crawfordsville
4537 South Nucor Road
Crawfordsville, IN 47933-9450

Customer Name: STATE STEEL SUPPLY CO., INC.
Customer Address: P.O. BOX 3224
SIOUX CITY IA 51102

Order Number: 172734 - 0001
Order Dimensions: 0.1150 X 48.0000
GVHR,CUT,A653CS,1005A1,690

Customer PO Number: P703308L003

Coil Number	Heat	Slab
1186606.000	272616	06

Chemical Analysis

Heat	C	Mn	P	S	Si	Cu	Sn	Ni	Cr	Mo	Al	N	V	Nb	Ti	B	Sb
272616	0.04	0.240	0.015	0.001	0.026	0.109	0.010	0.037	0.087	0.015	0.045	0.008	0.002	0.001	0.003	<0.001	0.002

Coil Number	Heat	Slab
1188198.000	272618	01

Chemical Analysis

Heat	C	Mn	P	S	Si	Cu	Sn	Ni	Cr	Mo	Al	N	V	Nb	Ti	B	Sb
272618	0.04	0.240	0.010	<0.001	0.026	0.063	0.003	0.017	0.040	0.012	0.046	0.008	0.002	0.001	0.003	<0.001	0.002

MELTED AND ROLLED IN THE USA

THIS IS NOT A CERTIFIED TEST REPORT

05/30/2007 03:49PM Nucor Steel, Inc PAGE 2 OF 3

Figure C - 3. Deck Anchor Bracket Certification

Cleveland Steel
SPECIALTY COMPANY
SINCE 1924

INVOICE

No : 00015341

ISO 9001 CERTIFIED

26001 RICHMOND ROAD
BEDFORD HTS., OHIO 44146
PHONE: 216-464-9400 FAX: 216-464-9404

To: MWRFF/UNL
4800 NORTHWEST 35TH ST.
LINCOLN, NE 68524

ShipTo: MWRFF/UNL
4800 NORTHWEST 35TH ST.
LINCOLN, NE 68524

Ship VIA	P.O. #	FOB	Terms	Date	Customer No	Page
UPS NEXT DAY	W.V.	ORIGIN	CREDIT CARD	08/20/2008	004050	1

Quantity	Job #	Part Number	Rev	Price/Unit	Extended Price
50	00020724	SP 4SG SHEAR PLATE 7/8" BOLT	A	$6.53	$326.50
1	00020725	Pilot 938 Pilot	A	$50.25	$50.25
1		UPS-NEXT DAY AIR		$218.41	$218.41

PAID
AUG 20 2008

Sub-Total :	$376.75
Freight :	$218.41
Tax :	$0.00
Total Amount :	$595.16

Figure C - 4. Cleveland Steel Invoice

Cleveland Steel
SPECIALTY COMPANY
SINCE 1924

26001 RICHMOND ROAD
BEDFORD HTS., OHIO 44146
PHONE: 216-464-9400 FAX: 216-464-9404

PACKING SLIP

No : 00015341

ISO 9001 CERTIFIED

To: MWRFF/UNL
4800 NORTHWEST 35TH ST.
LINCOLN, NE 68524

ShipTo: MWRFF/UNL
4800 NORTHWEST 35TH ST.
LINCOLN, NE 68524

Ship VIA	P.O. #	FOB	Terms:	Date	Page
UPS NEXT DAY	W.V.	ORIGIN	CREDIT CARD	8/20/2008	1

Quantity	Part Number	Rev	Job #
50	SP 4SG SHEAR PLATE 7/8" BOLT	A	00020724
1	Pilot 938 Pilot	A	00020725

Received By: ______________________ Date: ______________________

Figure C - 5. Cleveland Steel Invoice

08/20/2008 07:42 2164649404 CLEVESTEEL PAGE 01/01

Cleveland Steel
SPECIALTY COMPANY

26001 RICHMOND ROAD
BEDFORD HTS., OHIO 44146
PHONE: 216-464-9400 FAX: 216-464-9404

Sales Order Date Stamp : 08/20/2008
Job # :00020724 Change No. : 1

MWRFF/UNL
4800 NORTHWEST 35TH ST.
LINCOLN, NE 68524

402-770-9121
402-472-9464

Shipping Address : MWRFF/UNL
4800 NORTHWEST 35TH ST.
LINCOLN, NE 68524

P.O:	Ship Via	Terms	FOB	Confirmed : / /
W.V.	UPS NEXT DAY	CREDIT CARD	ORIGIN	Closed : / /
	Buyer	Sales Person		
	KEN KRENK	HOUSE		

Job #	Part Number	Rev #	Qty Ordered	Price	Extended Amount
00020724	SP 4SG Due Date: 08/20/2008	A	50	$6.53	326.50
00020725	Pilot 938 Due Date: 08/20/2008	A	1	$50.25	50.25
				Total:	376.75

216-
464-
9723-

ORDER CONFIRMATION

THANK YOU FOR YOUR RECENT ORDER.

PLEASE REVIEW THE ABOVE INFORMATION. IF THERE IS A DISCREPANCY, PLEASE ADVISE US IMMEDIATELY.

YOUR CREDIT CARD WILL BE CHARGED 376 75 PLUS FREIGHT

08/20/2008 Page 1

Figure C - 6. Cleveland Steel Invoice

02/06/2000 07:23 4729464 MWRSF-FIELD PAGE 01

44030262

DOVEL & DOVEL FABRICATION
(402)-785-7180

DD FABRICATION

TO: MwRSF DATE: 8-18-08

MATERIALS	LABOR & CONSUMABLES	HRS.	SUB-TOTAL
West Virginia TL-2	Post		
Labor	37 1/2 hrs. @ $35.00/hr.		$1,295.00
4 top plates.			$500.00
4 bottom Plates			$400.00
4 bridge posts w/ blocks			$350.00
2 Tube Stiffenrs			$355.00
		TAX	—
SIGNATURE: Shannon Nut[illegible]		TOTAL	2900.00

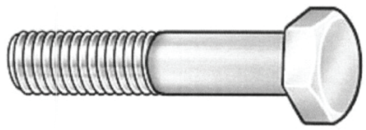
OWNER: GOERGE DOVEL

Figure C - 7. Post Fabrication Invoice

Grainger Industrial Supply Page 1 of 2

GRAINGER
FOR THE ONES WHO GET IT DONE

printed August 3, 2009



Hex Cap Screw,Steel,7/8-9 x 3,PK10

Hex Head Cap Screw, Standard Head Type, Medium Strength, Grade 5, Steel, Zinc Plated Finish, Thread Size 7/8-9, Thread Type UNC, Length Under Head 3 In, Thread Length 2 In Min, Head Height 35/64 In, Head Width 1 5/16 In, Partially Threaded, Right Hand Thread Direction, Thread Class 2A, Proof Load 39,300 PSI, Tensile Strength 55,400 PSI, Rockwell Hardness C25-C34, Meets/Exceeds SAE J429, Package 10

Grainger Item #	1KB83
Price (pk.)	**$23.68**
Package Qty.	10
Brand	APPROVED VENDOR
Mfr. Model #	1KB83
Ship Qty.	1
Sell Qty. (Will-Call)	1
Ship Weight (lbs.)	6.55
Usually Ships	Today
Catalog Page No.	2492

Price shown may not reflect your price. Log in or register.

Additional Info

Grade 5 Hex Head Cap Screws

Tech Specs

Item: Hex Head Cap Screw
Head Type: Standard
Type: Medium Strength
Grade: 5
Comparable To: Property Class 8.8
Material: Steel
Finish: Zinc Plated
Thread Size: 7/8-9
Thread Type: UNC
Length under Head: 3"
Thread Length: 2"
Head Height: 35/64"
Head Width: 1 5/16"
Thread Style: Partially Threaded
Thread Direction: Right Hand
Class: 2A
Proof Load (PSI): 39,300
Tensile Strength (PSI): 120,000
Rockwell Hardness: C25 to C34
Meets/Exceeds: SAE J429 and ASME B18.2.1
Package Quantity: 10

Notes & Restrictions

There are currently no notes or restrictions for this item.

Optional Accessories

Split Lock Washer,0.894 ID,PK 100

Item #: 2DB15
Brand: APPROVED VENDOR
Usually Ships: Today
Price (ea): $29.95

Hex Nut,Full,7/8-9,1 5/16 In,PK 25

Item #: 1EU55
Brand: APPROVED VENDOR
Usually Ships: While Stock Lasts
Price (ea): $12.35

Flat Washer,15/16 IDx2 1/4 OD,PK25

Item #: 2DA38
Brand: APPROVED VENDOR
Usually Ships: Today
Price (ea): $10.61

Primerless Threadlocker 2760 (TM),10 ml

http://www.grainger.com/Grainger/wwg/itemDetails.shtml 8/3/2009

Figure C - 8. Grainger Hex Cap Screw Specification Sheet

MSDS

This item does not require a **Material Safety Data Sheet (MSDS).**

Required Accessories

There are currently no required accessories for this item.

Item #: 1LLP8
Brand: LOCTITE
Usually Ships: Today
Price (ea): $18.87

Primerless Threadlocker 2760 (TM),50 ml

Item #: 1LLP9
Brand: LOCTITE
Usually Ships: Today
Price (ea): $70.40

Primerless Threadlocker 2760 (TM),250 ml

Item #: 1LLR1
Brand: LOCTITE
Usually Ships: Today
Price (ea): $177.50

Alternate Products

Hex Cap Screw,Stl,7/8-9x3 1/2,PK10

Item #: 1KB84
Brand: APPROVED VENDOR
Usually Ships: Today
Price (ea): $30.50

Repair Parts

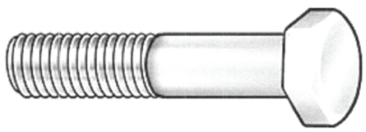
A Repair Part may be available for this item. Visit our Repair Parts Center or contact your local branch for more information.

Figure C - 9. Grainger Hex Cap Screw Specification Sheet

Grainger Industrial Supply Page 1 of 2

GRAINGER
FOR THE ONES WHO GET IT DONE

printed August 3, 2009



Hex Cap Screw,Steel,7/8-9 x 8,PK10

Hex Head Cap Screw, Standard Head Type, Medium Strength, Grade 5, Steel, Zinc Plated Finish, Thread Size 7/8-9, Thread Type UNC, Length Under Head 8 In, Thread Length 2 1/4 In Min, Head Height 35/64 In, Head Width 1 5/16 In, Partially Threaded, Right Hand Thread Direction, Thread Class 2A, Proof Load 39,300 PSI, Tensile Strength 55,400 PSI, Rockwell Hardness C25-C34, Meets/Exceeds SAE J429, Package 10

Grainger Item #	1KB92
Price (pk.)	**$67.35**
Package Qty.	10
Brand	APPROVED VENDOR
Mfr. Model #	1KB92
Ship Qty.	1
Sell Qty. (Will-Call)	1
Ship Weight (lbs.)	15.05
Usually Ships	1-3 Days
Catalog Page No.	2492

Price shown may not reflect your price. Log in or register.

Additional Info

Grade 5 Hex Head Cap Screws

Tech Specs

Item: Hex Head Cap Screw
Head Type: Standard
Type: Medium Strength
Grade: 5
Comparable To: Property Class 8.8
Material: Steel
Finish: Zinc Plated
Thread Size: 7/8-9
Thread Type: UNC
Length under Head: 8"
Thread Length: 2 1/4"
Head Height: 35/64"
Head Width: 1 5/16"
Thread Style: Partially Threaded
Thread Direction: Right Hand
Class: 2A
Proof Load (PSI): 39,300
Tensile Strength (PSI): 120,000
Rockwell Hardness: C25 to C34
Meets/Exceeds: SAE J429 and ASME B18.2.1
Package Quantity: 10

Notes & Restrictions

There are currently no notes or restrictions for this item.

Optional Accessories

Split Lock Washer,0.894 ID,PK 100

Item #: 2DB15
Brand: APPROVED VENDOR
Usually Ships: Today
Price (ea): $29.95

Hex Nut,Full,7/8-9,1 5/16 In,PK 25

Item #: 1EU55
Brand: APPROVED VENDOR
Usually Ships: While Stock Lasts
Price (ea): $12.35

Flat Washer,15/16 IDx2 1/4 OD,PK25

Item #: 2DA38
Brand: APPROVED VENDOR
Usually Ships: Today
Price (ea): $10.61

Primerless Threadlocker 2760 (TM),10 ml

http://www.grainger.com/Grainger/wwg/itemDetails.shtml 8/3/2009

Figure C - 10. Grainger Hex Cap Screw Specification Sheet

MSDS

This item does not require a **Material Safety Data Sheet (MSDS).**

Required Accessories

There are currently no required accessories for this item.

Item #: 1LLP8
Brand: LOCTITE
Usually Ships: Today
Price (ea): $18.87

Primerless Threadlocker 2760 (TM),50 ml

Item #: 1LLP9
Brand: LOCTITE
Usually Ships: Today
Price (ea): $70.40

Primerless Threadlocker 2760 (TM),250 ml

Item #: 1LLR1
Brand: LOCTITE
Usually Ships: Today
Price (ea): $177.50

Alternate Products

There are currently no alternate products for this item.

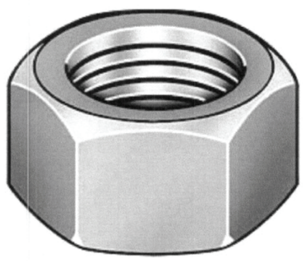
Repair Parts

A Repair Part may be available for this item. Visit our Repair Parts Center or contact your local branch for more information.

Figure C - 11. Grainger Hex Cap Screw Specification Sheet

GRAINGER
FOR THE ONES WHO GET IT DONE

printed August 3, 2009



Hex Nut,Full,7/8-9,1 5/16 In,PK 15

Hex Nut, Nut Type Full, Low Carbon Steel, Plain Finish, Grade 2, Thread Size 7/8-9, Thread Type UNC, Right Hand Thread Direction, Width 1 5/16 In, Height 3/4 In, Rockwell Hardness B68-C32, General Purpose, Meets/Exceeds ASME/ANSI B18.2.2, ASTM A563 and SAE J995, Package 15

Grainger Item #	2FE89
Price (pk.)	**$10.34**
Package Qty.	15
Brand	APPROVED VENDOR
Mfr. Model #	2FE89
Ship Qty.	1
Sell Qty. (Will-Call)	1
Ship Weight (lbs.)	2.7
Usually Ships	1-3 Days
Catalog Page No.	2521

Price shown may not reflect your price. Log in or register.

Additional Info

Grade 2 Full Hex Nuts

General-purpose hex nuts (also known as finished hex nuts) meet ASME/ANSI B18.2.2, ASTM A563, and SAE J995 standards.
Right-hand thread direction.

Tech Specs

Item: Hex Nut
Type: Full
Material: Low Carbon Steel
Finish: Plain
Grade: 2
Thread Size: 7/8-9
Thread Type: UNC
Thread Direction: Right Hand
Width: 1 5/16"
Height: 3/4"
Rockwell Hardness: B68-C32
Application: General Purpose
Meets/Exceeds: ASME/ANSI B18.2.2, ASTM A563, and SAE J995
Package Quantity: 15

Notes & Restrictions

There are currently no notes or restrictions for this item.

MSDS

This item does not require a **Material Safety Data Sheet (MSDS).**

Required Accessories

Optional Accessories

Threadlocker,10 Ml,Red

Item #: 3KE48
Brand: LOCTITE
Usually Ships: Today
Price (ea): $15.45

Threadlocker,50 Ml,Red

Item #: 3KE49
Brand: LOCTITE
Usually Ships: Today
Price (ea): $36.15

Threadlocker,250 Ml

Item #: 3KE50
Brand: LOCTITE
Usually Ships: Today
Price (ea): $126.20

Threadlocker,50 Ml,Red

Figure C - 12. Grainger Hex Nut Specification Sheet

There are currently no required accessories for this item.

Item #: 4KL51
Brand: LOCTITE
Usually Ships: Today
Price (ea): $42.20

Threadlocker,250 Ml

Item #: 4KL52
Brand: LOCTITE
Usually Ships: Today
Price (ea): $164.25

Threadlocker,Capillary

Item #: 4KL55
Brand: LOCTITE
Usually Ships: Today
Price (ea): $147.40

Threadlocker,10 Ml

Item #: 5E216
Brand: LOCTITE
Usually Ships: Today
Price (ea): $13.71

Threadlocker,50 Ml

Item #: 5E217
Brand: LOCTITE
Usually Ships: Today
Price (ea): $38.30

Alternate Products

Hex Nut,Full,7/8-9,1 5/16 In,PK 15

Item #: 2FE91
Brand: APPROVED VENDOR
Usually Ships: Today
Price (ea): $9.43

Repair Parts

A Repair Part may be available for this item. Visit our Repair Parts Center or contact your local branch for more information.

Figure C - 13. Grainger Hex Nut Specification Sheet

GRAINGER
FOR THE ONES WHO GET IT DONE

August 04, 2008

Order # : 022499914

Here is your order detail.

Final Shipping Destination

First Name: kenneth
Last Name: krenk
Company: MidWest Roadside Safety Facility
Address: 4800 nw 35th st
Address2:
City: lincoln
State/Province: NE
Zip Code: 68524
Country: US
Phone: 4025409221
Fax: 4024729464
E-mail: kkrenk@uni.edu

Billing Information

First Name: kenneth
Last Name: krenk
Company: MidWest Roadside Safety Facility
Address: 4800 nw 35th st
Address2:
City: lincoln
State: NE
Zip Code: 68524
Country: US
Phone: 4025409221
Fax: 4024729464
E-mail: kkrenk@unl.edu

Delivery Options

Shipping Method: UPS Ground - Standard Shipping

Payment Information

Payment method: Visa
Name on card: kenneth krenk
Card number: 4xxxxxxxxxxx3570
Expiration Date: 09 / 2010

Product Selection

Qty.	Item #	Description	Brand Mfr. Model #	Available Quantity	Backorder Quantity	Your Price	Extended Price
2	2XJ41	Hex Cap Screw,Stl,5/8-11 x 2,PK 25	APPROVED VENDOR 2XJ41	2	0	$27.09	$54.18
1	1KB51	Hex Cap Screw,5/8-11 x 2 1/2,PK 25	APPROVED VENDOR 1KB51	1	0	$16.45	$16.45
2	1EE45	Hex Nut,Full,5/8-11,15/16 In,PK 25	APPROVED VENDOR 1EE45	2	0	$6.20	$12.40
1	1KB83	Hex Cap Screw,Steel,7/8-9 x 3,PK10	APPROVED VENDOR 1KB83	1	0	$19.38	$19.38
4	1KB92	Hex Cap Screw,Steel,7/8-9 x 8,PK10	APPROVED VENDOR 1KB92	0	4	$53.46	$213.84
1	1EU79	Hex Nut,Full,5/8-11,15/16 In,PK 25	APPROVED VENDOR 1EU79	1	0	$4.92	$4.92
3	2FE89	Hex Nut,Full,7/8-9,1 5/16 In,PK 15	APPROVED VENDOR 2FE89	3	0	$8.32	$24.96
3	5RY70	Flat Washer,21/32 x 1 5/16 In,PK25	APPROVED VENDOR 5RY70	3	0	$16.63	$49.89
2	5RU62	Flat Washer,21/32ID x 1 3/8OD,PK10	APPROVED VENDOR 5RU62	2	0	$4.87	$9.74
4	5RY72	Flat Washer,15/16ID x 1	APPROVED VENDOR	4	0	$14.09	$56.36

https://www.grainger.com/Grainger/wwg/printablePO.shtml?ordernumber=022499914 8/4/2008

Figure C - 14. Grainger Packing List

Page 2 of 2

		3/4OD,PK10	5RY72				
2	5RU68	Flat Washer,29/32ID x 1 3/4 OD,PK5	APPROVED VENDOR 5RU68	2	0	$4.95	$9.90
1	5RU59	Flat Washer,17/32ID x 1 1/8OD,PK25	APPROVED VENDOR 5RU59	1	0	$9.13	$9.13
6	1VKB6	Spray Paint,Gloss,Safety Orange,10 Oz	DEM-KOTE GR1VKB6000	6	0	$2.44	$14.64

Promotion Code:

Subtotal:	$495.79
Freight:	$0.00
*Total Cost:	$495.79

***Total Cost includes an estimated tax amount, if applicable. Your invoice will reflect final tax charges on the items shipped.**

You have been given free freight on this order.

https://www.grainger.com/Grainger/wwg/printablePO.shtml?ordernumber=022499914 8/4/2008

Figure C - 15. Grainger Packing List

GRAINGER

Page 1 of 2

11200 E. 210 Highway
Kansas City 64161

Ship To:

MIDWEST ROADSIDE SAFETY FACILITY

4800 nw 35th st
LINCOLN NE 68524

Sold To:

UNL

401 ADMINISTRATION
LINCOLN NE 68588-0000

PACKING LIST

BOX ID U771108228 +

PO Number	022499914
A/P Delivery Number	6079774983
Grainger Account Number	0807879150
Caller	KENNETH KRENK
PO Release Number	
Project /Job Number	
Department	
Order Date & Time	08/04/2008 11:09:24
Ship Date	08/04/2008
Requisitioner	
Vendor Number	
Employee Contact	WMCONNGEN
Carrier	UPS CWT BREAK 3
Order Type	SH
Debit / Credit Code	VISA
Cartons in this shipment	2

Please reference **A/P DELIVERY NUMBER** on all remittance and correspondence

For questions about this order or your account call: (402) 476-9014

PO Line #	Item #	Description	Quantity Shipped	Shipped from other location	Back-ordered	Tax	Unit Price	TOTAL
000001	2XJ41	Hex Cap Screw Stl 5/8-11	2	0	0	E	27.09	54.18
000002	1KB51	Hex Cap Screw 5/8-11 x 2	1	0	0	E	16.45	16.45
000003	1EE45	Hex Nut Full 5/8-11 15/16	2	0	0	E	6.20	12.40
000004	1KB83	Hex Cap Screw Steel 7/8-9	1	0	0	E	19.38	19.38
000007	2FE89	Hex Nut Full 7/8-9 1 5/16	3	0	0	E	8.32	24.96
000010	5RY72	Flat Washer 15/16ID x 1 3	4	0	0	E	14.09	56.36
000013	1VKB6	Spray Paint Gloss Safety	6	0	0	E	2.44	14.64
	1EU79	Hex Nut Full 5/8-11 15/16	0	1	0		.00	.00
	1KB92	Hex Cap Screw Steel 7/8-9	0	0	4		.00	.00
	5RU59	Flat Washer 17/32ID x 1 1	0	1	0		.00	.00
	5RU62	Flat Washer 21/32ID x 1 3	0	2	0		.00	.00

continued

THANK YOU FOR YOUR ORDER!
Visit us at grainger.com
See Sales Terms and Conditions on the Reverse

Figure C - 16. Grainger Packing List

GRAINGER

Page 2 of 2

11200 E. 210 Highway
Kansas City 64161

Ship To:

MIDWEST ROADSIDE SAFETY FACILITY

4800 nw 35th st
LINCOLN NE 68524

Sold To:

UNL

401 ADMINISTRATION
LINCOLN NE 68588-0000

PACKING LIST

BOX ID U771108228 +

PO Number	022499914
A/P Delivery Number	**6079774983**
Grainger Account Number	0807879150
Caller	KENNETH KRENK
PO Release Number	
Project /Job Number	
Department	
Order Date & Time	08/04/2008 11:09:24
Ship Date	08/04/2008
Requisitioner	
Vendor Number	
Employee Contact	WMCONNGEN
Carrier	UPS CWT BREAK 3
Order Type	SH
Debit / Credit Code	VISA
Cartons in this shipment	2

Please reference **A/P DELIVERY NUMBER** on all remittance and correspondence

For questions about this order or your account call: (402) 476-9014

PO Line #	Item #	Description	Quantity Shipped	Shipped from other location	Back-ordered	Tax	Unit Price	TOTAL
	5RU68	Flat Washer 29/32ID x 1 3	0	2	0		.00	.00
	5RY70	Flat Washer 21/32 x 1 5/1	0	3	0		.00	.00

Subtotal 198.37

TOTAL 198.37

THANK YOU FOR YOUR ORDER!
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Figure C - 17. Grainger Packing List

GRAINGER

Page 1 of 2

5959 W. Howard St.
Niles 60714

PACKING LIST

BOX ID U218467624-A +

Ship To:

MIDWEST ROADSIDE SAFETY FACILITY

4800 nw 35th st
LINCOLN NE 68524

Sold To:

UNL

401 ADMINISTRATION
LINCOLN NE 68588-0000

PO Number	022499914
A/P Delivery Number	6079796124
Grainger Account Number	0807879150
Caller	KENNETH KRENK
PO Release Number	
Project /Job Number	
Department	
Order Date & Time	08/04/2008 11:17:50
Ship Date	08/04/2008
Requisitioner	
Vendor Number	
Employee Contact	WMCONNGEN
Carrier	UPS GROUND
Order Type	SH
Debit / Credit Code	VISA
Cartons in this shipment	2

Please reference A/P DELIVERY NUMBER on all remittance and correspondence

For questions about this order or your account call: (402) 476-9014

PO Line #	Item #	Description	Quantity Shipped	Shipped from other location	Back-ordered	Tax	Unit Price	TOTAL
000006	1EU79	Hex Nut Full 5/8-11 15/16	1	0	0	E	4.92	4.92
000009	5RU62	Flat Washer 21/32ID x 1 3	2	0	0	E	4.87	9.74
000011	5RU68	Flat Washer 29/32ID x 1 3	2	0	0	E	4.95	9.90
000012	5RU59	Flat Washer 17/32ID x 1 1	1	0	0	E	9.13	9.13
	1KB92	Hex Cap Screw Steel 7/8-9	0	4	0		.00	.00
	5RY70	Flat Washer 21/32 x 1 5/1	0	0	3		.00	.00
	2XJ41	Hex Cap Screw Stl 5/8-11	0	2	0		.00	.00
	1KB51	Hex Cap Screw 5/8-11 x 2	0	1	0		.00	.00
	1EE45	Hex Nut Full 5/8-11 15/16	0	2	0		.00	.00
	1KB83	Hex Cap Screw Steel 7/8-9	0	1	0		.00	.00
	2FE89	Hex Nut Full 7/8-9 1 5/16	0	3	0		.00	.00

continued

THANK YOU FOR YOUR ORDER!
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Figure C - 18. Grainger Packing List

GRAINGER

Page 1 of 1

5959 W. Howard St.
Niles 60714

PACKING LIST

BOX ID U218389924-A

Ship To:

MIDWEST ROADSIDE SAFETY FACILITY

4800 nw 35th st
LINCOLN NE 68524

Sold To:

UNL

401 ADMINISTRATION
LINCOLN NE 68588-0000

PO Number	022499914
A/P Delivery Number	6079862637
Grainger Account Number	0807879150
Caller	KENNETH KRENK
PO Release Number	
Project /Job Number	
Department	
Order Date & Time	08/05/2008 05:04:24
Ship Date	08/05/2008
Requisitioner	
Vendor Number	
Employee Contact	WMCONNGEN
Carrier	UPS GROUND
Order Type	SH
Debit / Credit Code	VISA
Cartons in this shipment	1

Please reference **A/P DELIVERY NUMBER** on all remittance and correspondence

For questions about this order or your account call: (402) 476-9014

PO Line #	Item #	Description	Quantity Shipped	Shipped from other location	Back-ordered	Tax	Unit Price	TOTAL
000008	5RY70	Flat Washer 21/32 x 1 5/1	3	0	0	E	16.63	49.89
	1KB92	Hex Cap Screw Steel 7/8-9	0	4	0		.00	.00

Subtotal 49.89

TOTAL 49.89

THANK YOU FOR YOUR ORDER!

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Figure C - 19. Grainger Packing List

GRAINGER

Page 1 of 1

101 Southchase blvd
Fountain Inn 29644

PACKING LIST

BOX ID U222406052-A

Ship To:

MIDWEST ROADSIDE SAFETY FACILITY

4800 nw 35th st
LINCOLN NE 68524

Sold To:

UNL

401 ADMINISTRATION
LINCOLN NE 68588-0000

PO Number	022499914
A/P Delivery Number	6079997987
Grainger Account Number	0807879150
Caller	KENNETH KRENK
PO Release Number	
Project /Job Number	
Department	
Order Date & Time	08/06/2008 14:31:15
Ship Date	08/06/2008
Requisitioner	
Vendor Number	
Employee Contact	WMCONNGEN
Carrier	UPS GROUND
Order Type	SH
Debit / Credit Code	VISA
Cartons in this shipment	1

Please reference **A/P DELIVERY NUMBER** on all remittance and correspondence

For questions about this order or your account call: (402) 476-9014

PO Line #	Item #	Description	Quantity Shipped	Shipped from other location	Back-ordered	Tax	Unit Price	TOTAL
000005	1KB92	Hex Cap Screw Steel 7/8-9	4	0	0	E	53.46	213.84

Subtotal 213.84

TOTAL 213.84

THANK YOU FOR YOUR ORDER!
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Figure C - 20. Grainger Packing List

Page 1 of 1

GRAINGER
FOR THE ONES WHO GET IT DONE

August 06, 2008
Order # : 022556131
Here is your order detail.

Final Shipping Destination

First Name: kenneth
Last Name: krenk
Company: MidWest Roadside Safety Facility
Address: 4800 nw 35th st
Address2:
City: lincoln
State/Province: NE
Zip Code: 68524
Country: US
Phone: 4025409221
Fax: 4024729464
E-mail: kkrenk@unl.edu

Billing Information

First Name: kenneth
Last Name: krenk
Company: MidWest Roadside Safety Facility
Address: 4800 nw 35th st
Address2:
City: lincoln
State: NE
Zip Code: 68524
Country: US
Phone: 4025409221
Fax: 4024729464
E-mail: kkrenk@unl.edu

Delivery Options

Shipping Method: UPS Ground - Standard Shipping

Payment Information

Payment method: Visa
Name on card: kenneth krenk
Card number: 4xxxxxxxxxxx3570
Expiration Date: 09 / 2010

Product Selection

Qty.	Item #	Description	Brand Mfr. Model #	Available Quantity	Your Price	Extended Price
1	2DA69	Flat Washer,15/16IDx1 3/4 OD,PK100	APPROVED VENDOR 2DA69	1	$15.11	$15.11
1	2DA63	Flat Washer,19/32 x 1 5/32,PK 100	APPROVED VENDOR 2DA63	1	$6.10	$6.10
1	1RA75	Thumb Screw,Knurl,10-24x1/2 L,Pk5	APPROVED VENDOR 1RA75	1	$11.13	$11.13

Promotion Code:

Subtotal:	**$32.34**
Freight:	**$0.00**
*Total Cost:	**$32.34**

***Total Cost includes an estimated tax amount, if applicable. Your invoice will reflect final tax charges on the items shipped.**
You have been given free freight on this order.

https://www.grainger.com/Grainger/wwg/printablePO.shtml?ordernumber=022556131 8/6/2008

Figure C - 21. Grainger Packing List

GRAINGER

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PACKING LIST

BOX ID U879743244-A

11200 E. 210 Highway
Kansas City 64161

Ship To:

MIDWEST ROADSIDE SAFETY FACILITY

4800 nw 35th st
LINCOLN NE 68524

Sold To:

UNL

401 ADMINISTRATION
LINCOLN NE 68588-0000

PO Number	022556131
A/P Delivery Number	6080069187
Grainger Account Number	0807879150
Caller	KENNETH KRENK
PO Release Number	
Project /Job Number	
Department	
Order Date & Time	08/06/2008 14:40:58
Ship Date	08/06/2008
Requisitioner	
Vendor Number	
Employee Contact	WMCONNGEN
Carrier	UPS CWT BREAK 3
Order Type	SH
Debit / Credit Code	VISA
Cartons	1

Please reference **A/P DELIVERY NUMBER** on all remittance and correspondence

For questions about this order or your account call: (402) 476-9014

PO Line #	Item #	Description	Quantity Shipped	Shipped from other location	Back-ordered	Tax	Unit Price	TOTAL
000001	2DA69	Flat Washer 15/16IDx1 3/4	1	0	0	E	15.11	15.11
000002	2DA63	Flat Washer 19/32 x 1 5/3	1	0	0	E	6.10	6.10
	1RA75	Thumb Screw Knurl 10-24x1	0	1	0		.00	.00
							Subtotal	21.21
							TOTAL	21.21

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Figure C - 22. Grainger Packing List

GRAINGER

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5959 W. Howard St.
Niles 60714

PACKING LIST

BOX ID U218102355-A

Ship To:

MIDWEST ROADSIDE SAFETY FACILITY

4800 nw 35th st
LINCOLN NE 68524

Sold To:

UNL

401 ADMINISTRATION
LINCOLN NE 68588-0000

PO Number	022556131
A/P Delivery Number	6080062839
Grainger Account Number	0807879150
Caller	KENNETH KRENK
PO Release Number	
Project /Job Number	
Department	
Order Date & Time	08/06/2008 14:49:17
Ship Date	08/06/2008
Requisitioner	
Vendor Number	
Employee Contact	WMCONNGEN
Carrier	UPS GROUND
Order Type	SH
Debit / Credit Code	VISA
Cartons in this shipment	1

Please reference **A/P DELIVERY NUMBER** on all remittance and correspondence

For questions about this order or your account call: (402) 476-9014

PO Line #	Item #	Description	Quantity Shipped	Shipped from other location	Back-ordered	Tax	Unit Price	TOTAL
000003	1RA75	Thumb Screw Knurl 10-24x1	1	0	0	E	11.13	11.13
	2DA69	Flat Washer 15/16IDx1 3/4	0	1	0		.00	.00
	2DA63	Flat Washer 19/32 x 1 5/3	0	1	0		.00	.00

Subtotal 11.13

TOTAL 11.13

THANK YOU FOR YOUR ORDER!

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Figure C - 23. Grainger Packing List

END OF DOCUMENT