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TECHNICAL MEMORANDUM

Contract No.: **T4541-AV**
Tech Memo No.: **405160-40**
Project Name: **W-Beam Bridge Rail for Temporary Timber Deck Bridge Installations**
Sponsor: **Roadside Safety Research Program Pooled Fund Study**

DATE: **August 22, 2013**

TO: **Rod Erickson**
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SUMMARY REPORT:

INTRODUCTION

Many locations in Alaska are remote and without highway access. To minimize shipping weight, timber decked bridges are often used. The Alaska Department of Transportation and Public Facilities (DOT&PF) policy for temporary timber bridge decks requires portable concrete barrier (PCB) as bridge rail meeting Test Level 3 (TL-3). Transporting PCBs to villages and communities off the road system can be expensive and another bridge rail solution is sought for temporary construction on low-volume roads that meets crashworthiness standards. The current specification requirements for temporary bridges in Alaska are provided as follows.

Alaska's standard specification for temporary bridge rail is 520-2.04.3.h: (1)

> Provide a concrete F Shape barrier system on the bridge and bridge approaches. Anchor barrier system to prevent deflection when impacted. Locate barrier so outside edge is setback a minimum of 12 horizontal inches from outside edge of bridge deck.

Timber deck bridges are sometimes installed as temporary structures until a permanent structure can be built. Because of seasonal working conditions, construction may require two construction seasons. A light-weight cost-effective alternative to transport of PCBs is sought.

W-beam and thrie beam bridge rails have been crash-tested, but neither system has been approved for use on a timber deck bridge structure. However, the recent Roadside Safety Pooled Fund (TPF-5(114)) projects Crash Testing and Evaluation of W-Beam Guardrail on Box Culvert Phase I and Phase II have provided good results for using a W-beam bridge railing system anchored to a rigid concrete culvert system with shallow soil cover. (2,3)

BACKGROUND

In 1988, Hirsch and Beggs reported on a study using a W6×9 steel guardrail post with a base plate anchored to a 6-inch thick culvert slab.(4) Static load tests and a full-scale crash test were performed on this design as part of this study. The testing performed on this design was successful with respect to National Cooperative Highway Research Program (NCHRP) *Report 230* performance level 2. In 2002, Polivka, Reid, Faller, Rohde, and Sicking reported on a similar design bolted to a box culvert with approximately 9 inches of fill on top of the box culvert.(5) The objective of this research was to develop a strong-post, W-beam guardrail system that can be rigidly attached to the surface of concrete box culverts. This new guardrail system with one-half post spacing (3 ft-1-1/2 inches) was designed to meet the Test Level 3 (TL-3) performance criteria found in *NCHRP Report 350*. Dynamic pendulum and full scale crash testing on this design was also successful.

In 2008, Texas A&M Transportation Institute (TTI) designed and full-scale crash tested a new W-beam guardrail system that anchored to the top of a concrete box culvert with 9 inches of fill cover (minimum cover).(2) In this pooled fund study, information from the above studies, as well as other research, was used to develop a new box culvert guardrail post design that meets TL-3 requirements. *NCHRP Report 350* test 3-11 was performed to evaluate this new guardrail system across low-fill culvert. During this test, the W-beam rail element was ruptured by the impact from the vehicle. Even though the rail element was ruptured, the vehicle was contained and redirected without penetrating, underriding, or overriding the installation. The rail element ruptured after the vehicle was redirected and while it was exiting out of the barrier system. The adhesive anchoring system worked as designed with the new W6×9 post and welded baseplate detail. No damage to the deck or failure of the adhesive anchors was observed. Due to the rupturing of the rail, Federal Highway Administration (FHWA) ruled that the test did not meet the requirements of *NCHRP Report 350* TL-3.

In November 2011, TTI made modifications to the design tested in 2008.(3) This design was the same as that tested in 2008 except the rail height was 31 inches above finished grade and the splices were moved away from the posts (in the center of the 6 ft-3 inch post spacing). The design was crash tested and was successful with respect to American Association of State Highway and Transportation Officials (AASHTO) *Manual for Assessing Safety Hardware* (*MASH*) Test 3-11.

The crash test performed on the W-beam guardrail on low-fill box culvert was in accordance with test 3-11 of *MASH*, which involves the 2270P vehicle (a 5000 lb (1/2-ton) 4-door pickup). Included in this report are the details of the installation used in the crash testing, details of the full-scale crash testing, and evaluation of the crash test.

The box culvert guardrail installation consisted of a 12 gage W-beam guardrail system supported by W6×9 steel posts anchored to a simulated box culvert. Standard 6-inch × 8-inch × 14-inch long wood blockouts were used to block out the W-beam guardrail from the steel posts. The height of the W-beam guardrail system was 31 inches from finished grade. The posts were spaced on 6 ft-3 inches on centers. The W-beam rail splices were located in the center of the 6 ft-3-inch post spacing. The posts were anchored to the top of a simulated box culvert slab using Hilti RE500 epoxy anchoring system. For this test installation, 9 inches of compacted standard soil material was constructed on top of the simulated box culvert slab. The W-beam guardrail system was anchored on each end using ET Plus extruder terminals. The W6×9 steel posts were welded to 12-inch × 12-inch × ⅞-inch thick base plate. The total length of the posts was 40⅛ inches. Each steel post with base plate was anchored to the 9-inch thick simulated box culvert slab using four ⅞-inch diameter A193 Super HAS all-thread rods, 8½ inches in length. These threaded rods were embedded approximately 6 inches in the box culvert slab and were anchored using HILTI RE500 epoxy anchoring system.

The crash test performed on the W-beam guardrail on low-fill box culvert met all the requirements of *MASH* Test 3-11. The guardrail design contained and redirected the 2270P vehicle. The vehicle did not penetrate, underride, or override the installation. Design and testing information from this project were used and considered for the design of the W-beam bridge rail for temporary timber deck bridges.

In 1998, Williams reported on new breakaway Texas Department of Transportation (TxDOT) Type T6 Posts with reduced welds between the posts and the baseplates.[(6)] Several different weld sizes and configurations were tested. The W6×8.5 posts were welded to 6-inch × 9½-inch × 5/8-inch thick base plates. Transverse loading was applied to the posts at a height of approximately 18 inches above the pavement surface. It all cases tested, when subjected to ultimate transverse loading, the posts broke away from the anchored baseplates due to dynamic rupture of the welds located on the tension flanges of the posts. The ultimate transverse resistances of the posts were dependent of the size and location of the post welds. In all cases tested, failure occurred in the welds with no significant signs of distress or failure of the base metal, tension failure of the bolts, or bending of the baseplates. Information obtained from this testing were reviewed for this project.

In 2000, Buth, Williams, and Bligh reported on a new breakaway TxDOT Type T6 post with two slots in the tension flange of the post.[(7)] Several different slot sizes were tested for this project. One size was selected for full-scale crash testing. Information obtained from this testing was also reviewed for this project.

OBJECTIVE

Several bridge rail options were considered for this project. Many of these options considered strong posts with flexible and stiff railing systems. The option of mounting W6×9 steel posts on base plates through-bolted to solid timber plank deck could be shown to be equivalent to the W-beam on box culvert with some failure or yielding mechanism for the post. For this project, a top of rail height of 31 inches was selected since this height has been successfully crash tested for *MASH* TL-3. Typical details of a W-beam bridge rail deign with posts bolted to a 12-inch thick timber deck are shown in Figure 1. It is understood that these details were previously proposed by a contractor for a timber bridge in Alaska. Considering this proposed bridge rail design, a crashworthy transition would be required if the details shown in Figure 1 are acceptable with respect to *MASH* TL-3 specifications. This transition would be required to transition this stiff post design to a flexible W-beam guardrail system off the bridge.

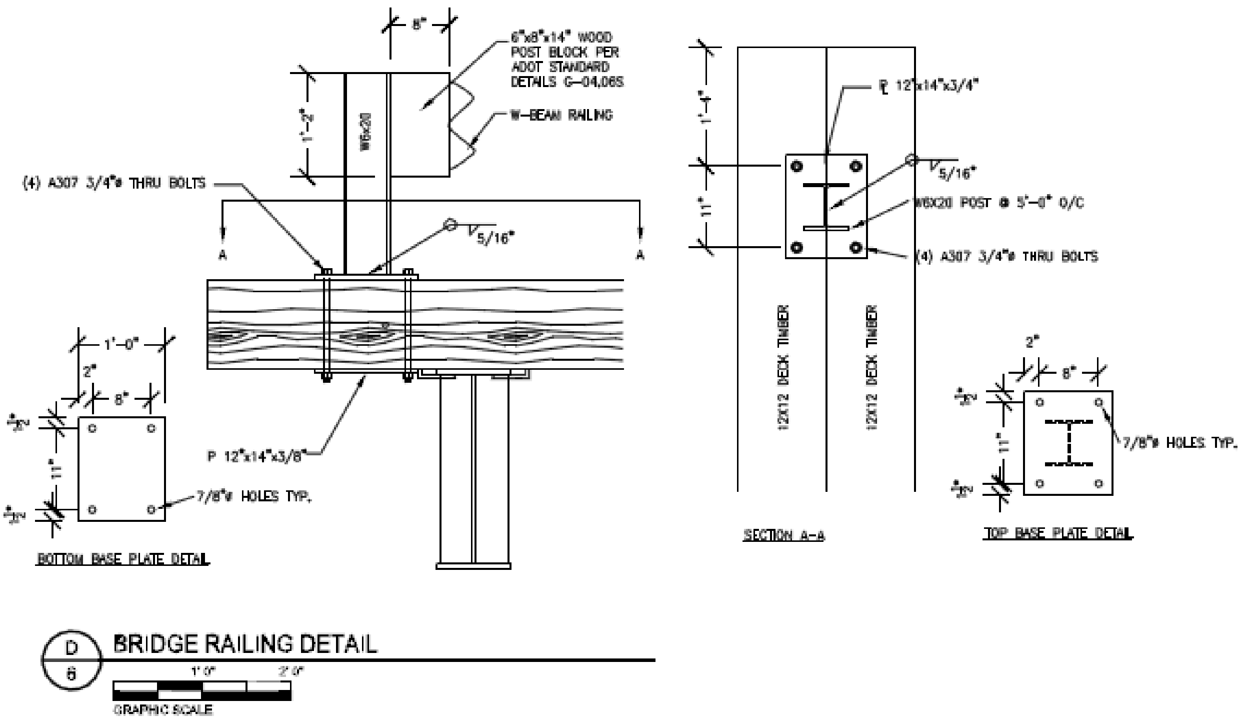


Figure 1 – W-Beam Bridge Rail for Temporary Timber Deck Bridge Installations

The purpose of the study was to perform engineering strength calculations and develop details of a W-beam guardrail system that utilizes steel posts with steel base plates bolted through a nominal 6-inch thick timber deck. It is understood that the deck will have timbers laminated in the transverse direction and the design will be used in TL-3 applications. However, due to the 6-inch deck thickness and the condition of the deck system, the design may be limited to TL-2 applications. However, 8-inch deck thickness or greater will be considered if the 6-inch thick deck is not acceptable for TL-3. The deck systems are laminated bolt-through systems. It is understood that 6-inch thick transverse laminated deck panels are more available in remote areas in Alaska.

BENEFITS

W-beam bridge rail that can be bolted to a timber deck is easier to transport than PCBs to remote areas in Alaska. Transporting PCBs to remote villages and communities off the road system is expensive. A crashworthy W-beam bridge rail design that utilizes steel posts with base plates would be cost effective and provide a good solution to barriers in remote areas.

PRODUCTS

For this phase of the project, it is understood that a detailed design of a W-beam guardrail system for use on temporary timber deck bridge installations was developed. TTI has developed several options for consideration and has performed detailed engineering on the design considered best suited for this application. Information such as crash performance, weight, ease of installation and the use of standard hardware for roadside applications were considered. Engineering calculations and details of the recommended design are included in this report. Details developed for this project are suitable for fabrication and construction of the W-bean guardrail design on temporary timber deck bridges. A timber deck thickness of 6 inches was considered in the engineering analyses performed. Component and/or full-scale crash testing of this design is recommended in a separate phase (Phase II).

WORK PLAN

Task 1 –Results from Literature Review of State of the Art Practice for the Design And Details of Bridge Railing Anchored to Timber Decks

A literature search was performed on the use of W-beam bridge railing systems anchored to concrete and timber deck systems. Systems utilizing W-beam bridge rail and other railing systems to timber deck bridges were reviewed. In addition, TTI has performed extensive full-scale testing of several different W6×8.5 base plated steel breakaway post designs. Considering past performance and experience with similar designs using steel guardrail posts attached to a rigid deck system, a W6×8.5 breakaway post design or a weak post design is required for this application. Previous research and testing on breakaway post design and weak post bridge railing systems were investigated as part of this task. Information on several bridge rail systems was collected for this project. A summary of several relevant designs collected from the literature review are provided below:

Development of a Low-Cost, Energy- Absorbing Bridge Rail, Midwest Regional Pooled Fund Research Program Fiscal Years 2008-2009 (Years 18 and 19), Research Project Numbers SPR-3(0017) and TPF-5(193), MwRSF Research Report No. TRP-03-226-10, August 11, 2010 [8]. For this project, a new low-cost bridge rail was designed to be compatible with the Midwest Guardrail System (MGS) such that an approach transition would not be required between the approach guardrail and the bridge rail system on the bridge. It was desired that the system minimize bridge deck and rail costs.

Several concepts for an energy-absorbing bridge post were developed and tested. These concepts included strong-post systems designed with plastic hinges and weak-post systems designed to bend near the attachment to the bridge deck. The final post concept incorporated S3×5.7 steel sections which were designed to bend at their bases. Each post was housed in a socket placed at the vertical edge of the deck and anchored to the deck with one through-deck bolt. A W-beam section was used as the rail element and was attached to the posts with a bolt that was designed to break during an impact event.

Two full-scale crash tests were performed according to the TL-3 impact conditions provided in *MASH*. The barrier system successfully met all the performance and safety criteria of *MASH*.

Test 12 – NCHRP Report 350 Test 3-11 of the Modified Texas Type T6 Bridge Rail on Bridge Deck, Texas Department of Transportation Project No. 0-1804, Texas Transportation Institute Project No. 418040-12, dated February 2000 [(7)]. For this project, a new breakaway bridge rail post was designed and tested. The Texas Type T6 Bridge Rail was developed under a previous TxDOT project and crash tested and evaluated under *NCHRP Report 230* guidelines. However, with the adoption of *NCHRP Report 350*, the Texas Type T6 was reevaluated using the 2000-kg pickup specified in *NCHRP Report 350* Test 3-11. As part of this project, the Texas Type T6 bridge rail post was redesigned to include the following:

1.) A larger and thicker base plate.
2.) Two ¼-inch wide by ½-inch long machined slots on the tension flange of the post.
3.) A 2-inch high × 3¼-inch high × ½-inch thick plate welded on the field side of the post flange to improve the break-away characteristics.

The modified Texas Type T6 Bridge Rail contained and redirected the vehicle. However, the vehicle rolled onto its side after the crash test. The test was unsatisfactory with respect to *NCHRP Report 350* evaluation criteria. The modified posts designed and tested for the T6 Bridge Rail performed well (broke away from the baseplate).

MASH Test 3-11 of The W-Beam Guardrail on Low Fill Box Culvert, Roadside Safety Research Program Pooled Fund Study No. TPF-5(114), Texas Transportation Institute Project Number 405160-23-2, February 2012 [(2)]. The primary objective of this study was to design and test a guardrail design with standard post spacing (6 ft-3 inch spacing) for use across low-fill box culverts in accordance with *MASH* TL-3. A second objective of this study was to develop a W6×9 post with a welded base plate for use with an epoxy anchoring system that would simplify installation.

The crash test on the W-beam guardrail on low-fill box culvert was performed in accordance with *MASH* Test 3-11. The W-beam guardrail on low-fill box culvert performed acceptably according to the specifications for *MASH* Test 3-11. Design information and details from this project were used for the design of the post base plate connection to timber deck for this project.

<u>Task 2 – W-Beam Bridge Rail for Temporary Timber Deck Bridge Installations Design, Analyses, and Detailing</u>

Information from literature was used to develop a recommended design for the temporary timber deck bridge rail for this project. For this task, information gathered from the literature search performed in Task 1 and previous full-scale crash testing of base plated W6×8.5 breakaway guardrail posts was considered for the design of the W-beam bridge rail anchored to a timber deck. A 6-inch thick transverse laminated Douglas Fir timber deck was considered in the analyses. TTI received details for a proposed timber bridge in Marshall, Alaska from Jeff Jeffers, with Alaska Department of Transportation and Public Facilities. These drawings (shown in Figure 1 above) are entitled "M.A.A.R.B.R. Temporary Bridge Design" and dated August 12, 2011. These drawings show details of a W-beam bridge rail anchored to a 12-inch thick timber deck. The proposed design planned for this structure incorporates W6×20 steel base plated posts anchored to the timber deck using through-bolts with steel anchor plates. The details planned for this project were considered in the analyses and design of the new W-beam bridge rail developed for this project.

The crash performance of the weak post guardrail system tested under MsRSF Project TRP-03-226-10 was reviewed very closely for this project. This weak post system consisted of a 31-inch high guardrail system attached to S3×5.7 posts spaced at 3 ft-1½ inches on centers. These posts were anchored to the edge of an 8-inch thick reinforced concrete deck. Each post was anchored to the concrete deck using a 1-inch diameter through-deck bolt. The posts were socketed into a fabricated steel bracket that was attached to the edge of the concrete deck. Each post was inserted into the socket approximately 14½ inches and was bolted to the base of the socket with a 5/8-inch diameter A325 bolt. Standard 12-gauge 12 ft -6 inch long sections of W-beam rail elements with post bolt slots at 37½-inch intervals were used as the rail element. The height of the rail elements was 31 inches above the bridge deck surface. Rail splices were located at bridge rail post locations. Rail block-outs were not used at the post locations. W-beam back-up plates were positioned between the rail and the post. The rail was connected to the post with 5/16-inch diameter ASTM A307 Grade A bolts and nuts and 1¾-inch × 1¾-inch × 1/8-inch square washers positioned on the traffic-side face of the bridge rail. The total length of the installation on the 8-inch thick simulated concrete deck cantilever was 75 ft. The bridge rail was anchored on each end using BCT cable anchors. The total length of the test installation was approximately 175 ft.

Full-scale crash testing was performed on the test installation in June 2009. The new bridge rail successfully met all the safety performance criteria recommended by *MASH* during full-scale crash testing. The bridge rail posts successfully broke away from the W-beam rail in the impact areas. The posts did not adversely affect the performance of the impacting vehicles by excessive "snagging" interaction with the tires of the vehicles. This information was used for the design of the W-beam bridge rail system for this project.

Engineering analyses were performed on a modified weak post design tested under <u>MwRSF Research Report No. TRP-03-226-10</u>. Calculations were performed on the anchor connection to the deck. For this project, a four bolt base plate design with through bolts and an anchor plate was designed and detailed. Many of the details used in the MwRSF weak post bridge rail system were incorporated. These details were incorporated based on the successful crash performance of the bridge rail system for MwRSF Project TRP-03-226-10. For this project, the S3×5.7 posts were designed to be welded to a four bolt base plate. Based on engineering calculations performed, the recommended base plate for the S3×5.7 post consist of a 10-inch × 10-inch ×5/8-inch thick A992 welded baseplate. It is recommended that each post be anchored to the 6-inch laminated timber deck using four 5/8-inch diameter A325 anchor bolts with a 10-inch ×10-inch × ¼-inch thick anchor plate. The S3×5.7 post should be welded to the base plate using a ¼-inch fillet weld all around. In addition to the post welds, two 3-inches × 2½-inches × 3/8-inch thick stiffeners are welded to the post and base plate (one each flange). These welded stiffeners would improve the anchorage and bearing strength performance of post anchorage to the 6-inch thick transverse laminated Douglas Fir timber deck. For additional information, please refer to the engineering details of the recommended design shown in Figure 2. Engineering calculations are provided in Appendix A.

IMPLEMENTATION

Additional full-scale testing of this design is needed to determine if this design is acceptable for *MASH* TL-3. Full-scale component testing of the post connection to a 6-inch thick transverse laminated timber deck is needed to validate the post design. The condition of the timber deck could greatly impact the performance of this design with respect to the *MASH* specifications. It is recommended that full-scale component testing be performed in the next phase to determine the strength of the post connection to the timber deck. It is understood that full-scale testing of these details will be performed in another phase (Phase 2). If the full-scale testing is successful with respect to the *MASH* specifications, the design can be implemented for timber bridges with the required deck thickness for TL-3 requirements. After successful testing in Phase 2, the details and drawings developed for this project and validated through Phase 2 can be used to develop standard sheets. After successful crash testing is completed in Phase 2, details of the successful design will be provided in the Task Force 13 format for submittal to AASHTO to be included in the AASHTO/ARTBA/AGC Bridge Rail Guide.

REFERENCES

1. Alaska Department of Transportation and Public Facilities, Standard Specification for Temporary Bridge Rail 520-2.04.3.h.
2. W. F. Williams, R. P. Bligh, D. L. Bullard, Jr., and W. L. Menges. *Crash Testing and Evaluation of W-Beam Guardrail on Box Culvert*. Test Report No. 405160-5-1, Texas A&M Transportation Institute, College Station, TX, August 2008.
3. W. F. Williams and W. L. Menges. *MASH Test 3-11 of the W-Beam Guardrail on Low-Fill Box Culvert*. Test Report No. 405160-23-2, Texas A&M Transportation Institute, College Station, TX, February 2012.
4. Hirsch, T.J., Beggs, Dale, *Use of Guardrails on Low Fill Bridge Length Culverts*, Report No. 405-2F, Texas Transportation Institute, August 1987.
5. Polivka, K.A., et. al., *A Guardrail Connection for Low-Fill Culverts*, Transportation Research Board paper, July 31, 2002.
6. W. F. Williams, "Texas Department of Transportation Type T6 Bridge Rail Post to Baseplate Weld Investigation", TTI Contract No. 418048, July 1998.

7. C. E. Buth, W. F. Williams, R. P. Bligh, and W. L. Menges. *Test 12—NCHRP Report 350 Test 3-11 of the Modified Texas Type T6 Bridge Rail on Bridge Deck*, Letter Report 1804-10, Texas A&M Transportation Institute, College Station, TX, February 2000.
8. Thiele, J.C., Sicking, D.L., Faller, R.K., Bielenberg, R.W., Lechtenberg, K.A., Reid, J.D., and Rosenbaugh, S.K., *Development of a Low-Cost, Energy-Absorbing Bridge Rail, Final Report to the Midwest State's Regional Pooled Fund Program*, Transportation Research Report No. TRP-03-226-10, Project No.: SPR-3(017) and TPF-5(193), Project Codes: RPFP-08-09 - Year 18 and RPFP-09-06 - Year 19, Midwest Roadside Safety Facility, University of Nebraska-Lincoln, Lincoln, Nebraska, August 11, 2010.

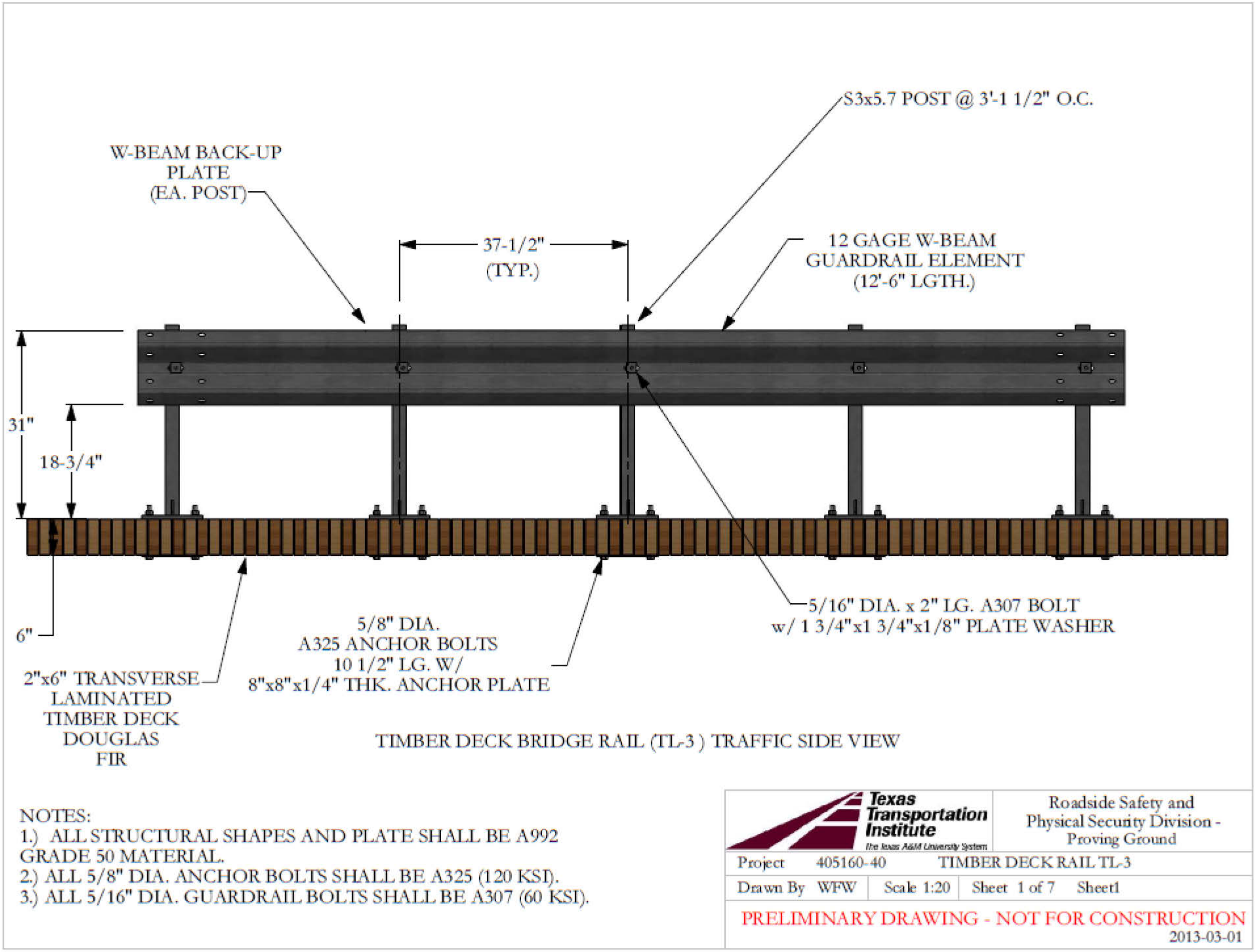


Figure 2 – Details of W-Beam Bridge Rail for Temporary Timber Deck Bridge

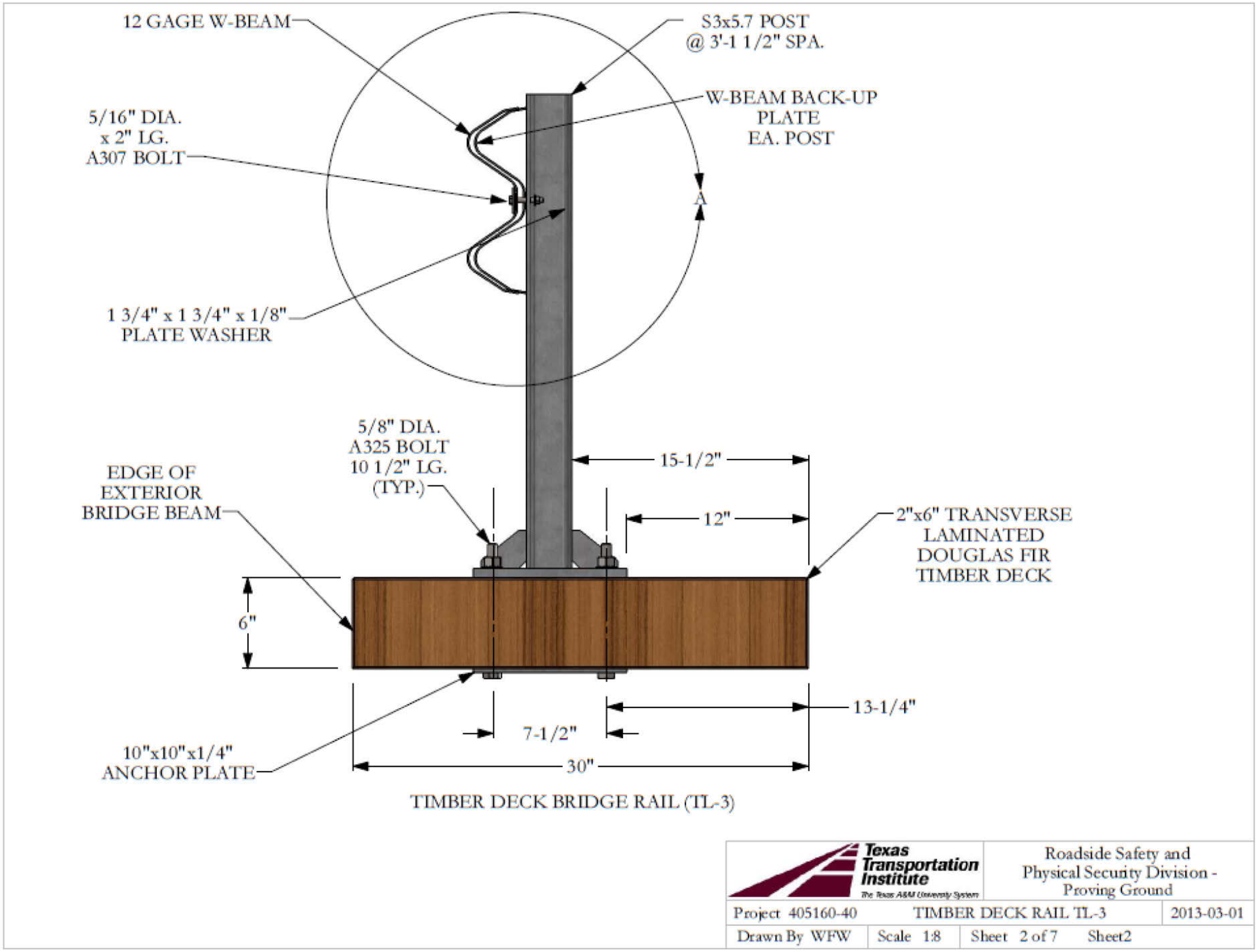


Figure 2 Cont'd - Details of W-Beam Bridge Rail for Temporary Timber Deck Bridge

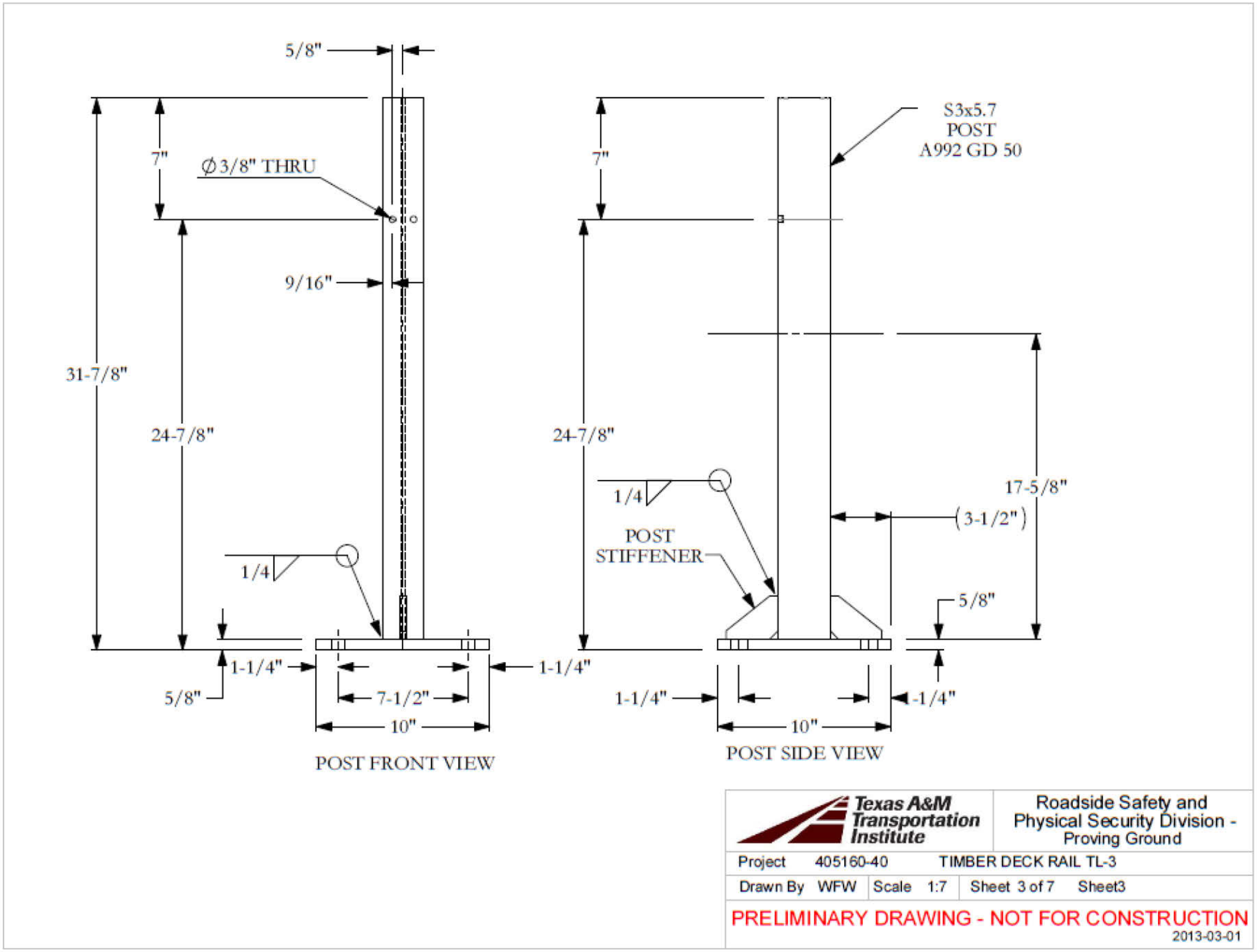


Figure 2 Cont'd - Details of W-Beam Bridge Rail for Temporary Timber Deck Bridge

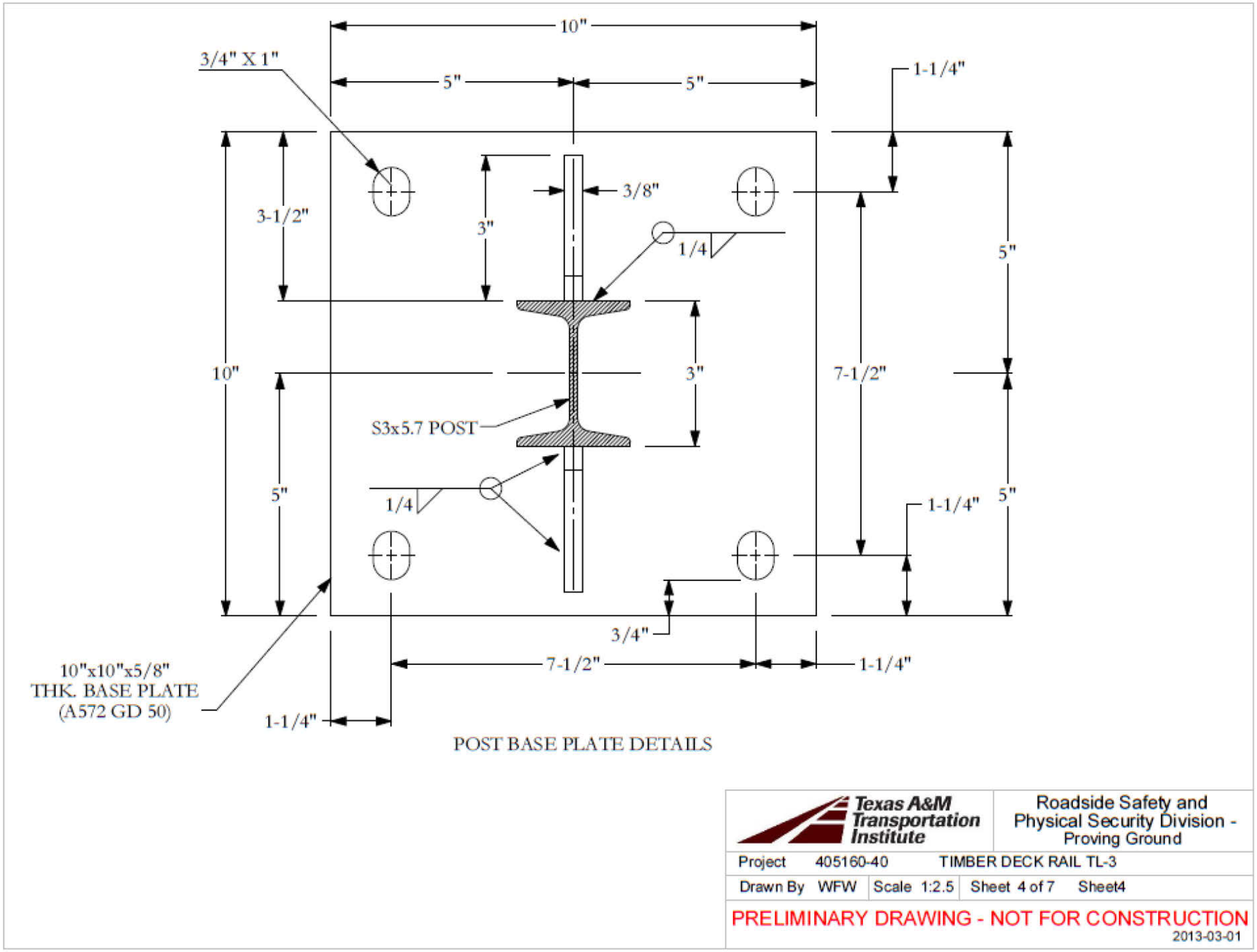
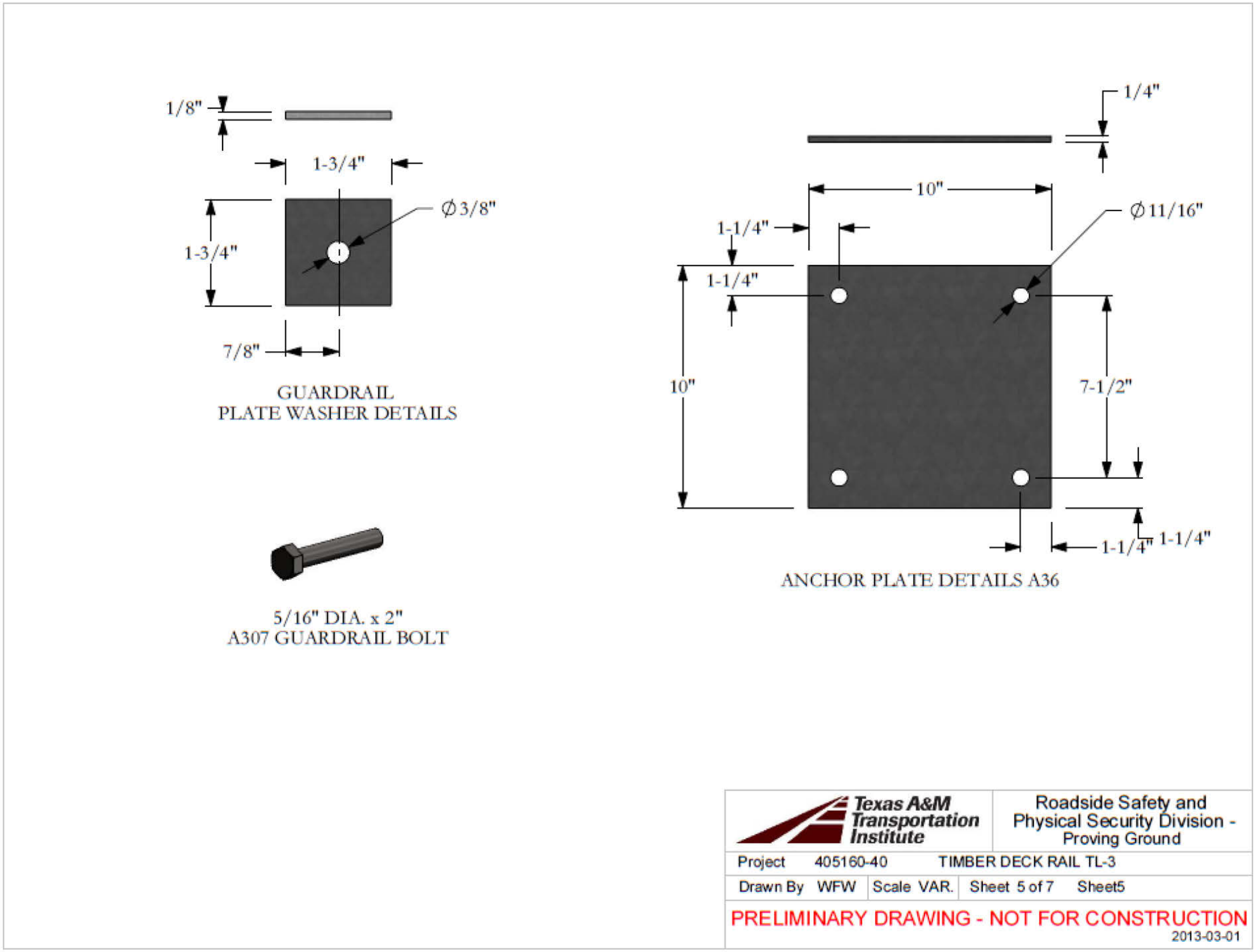


Figure 2 Cont'd - Details of W-Beam Bridge Rail for Temporary Timber Deck Bridge



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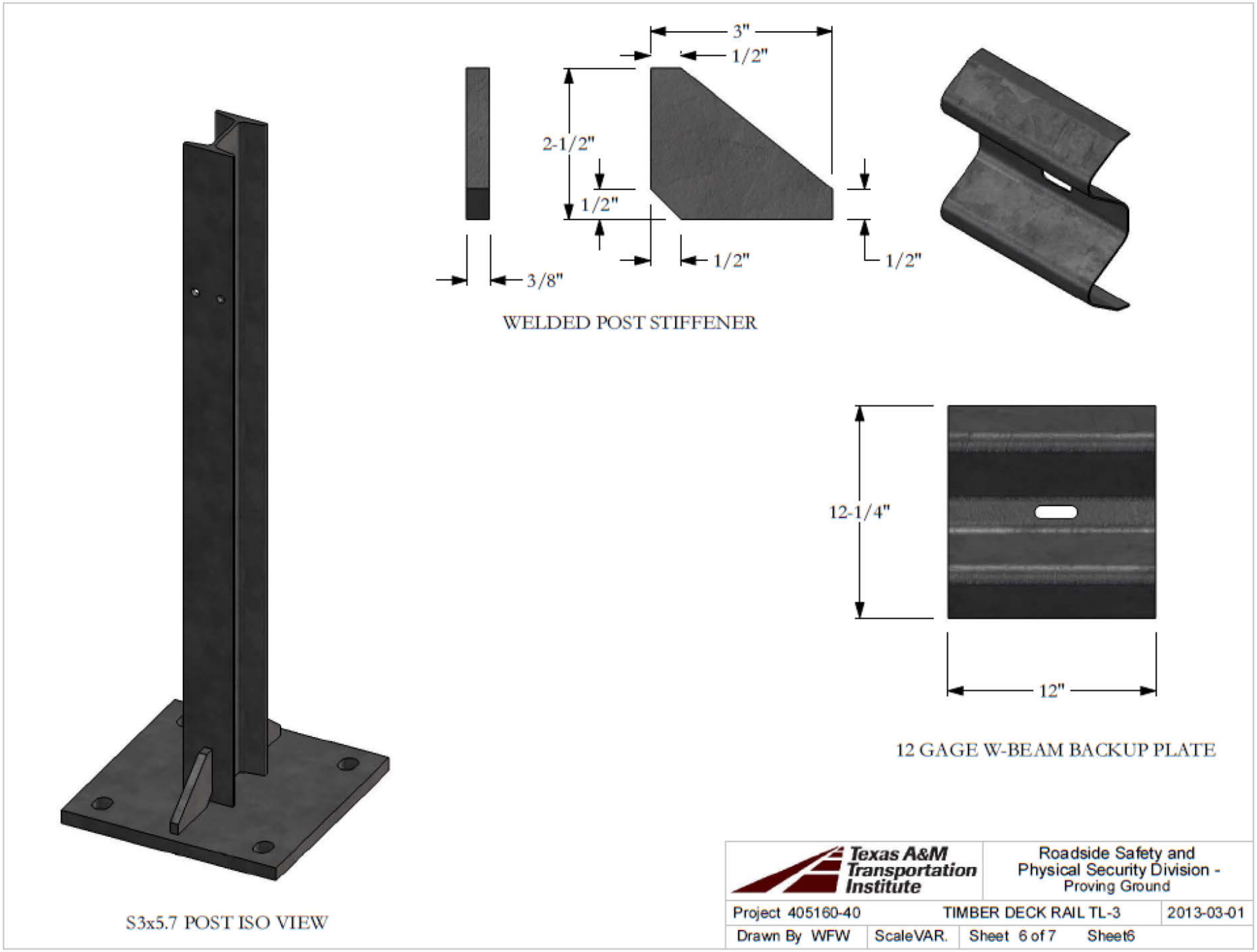


Figure 2 Cont'd - Details of W-Beam Bridge Rail for Temporary Timber Deck Bridge

APPENDIX A. ENGINEERING CALCULATIONS

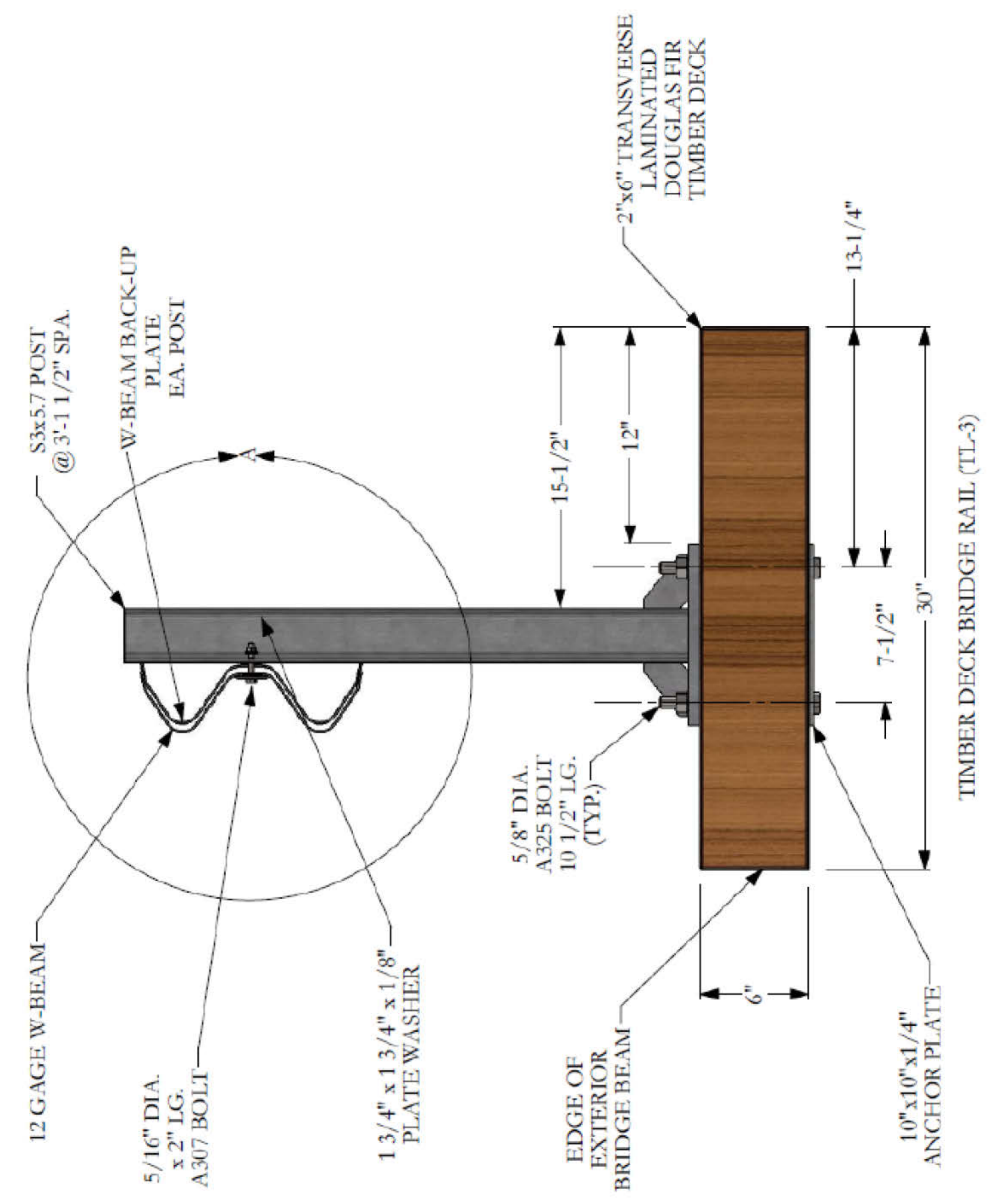
A1. W-Beam Bridge Rail for Temporary Timber Deck Bridge Rail Calculations

Texas A&M Transportation Institute

Subject: **Timber Rail Plate Design**

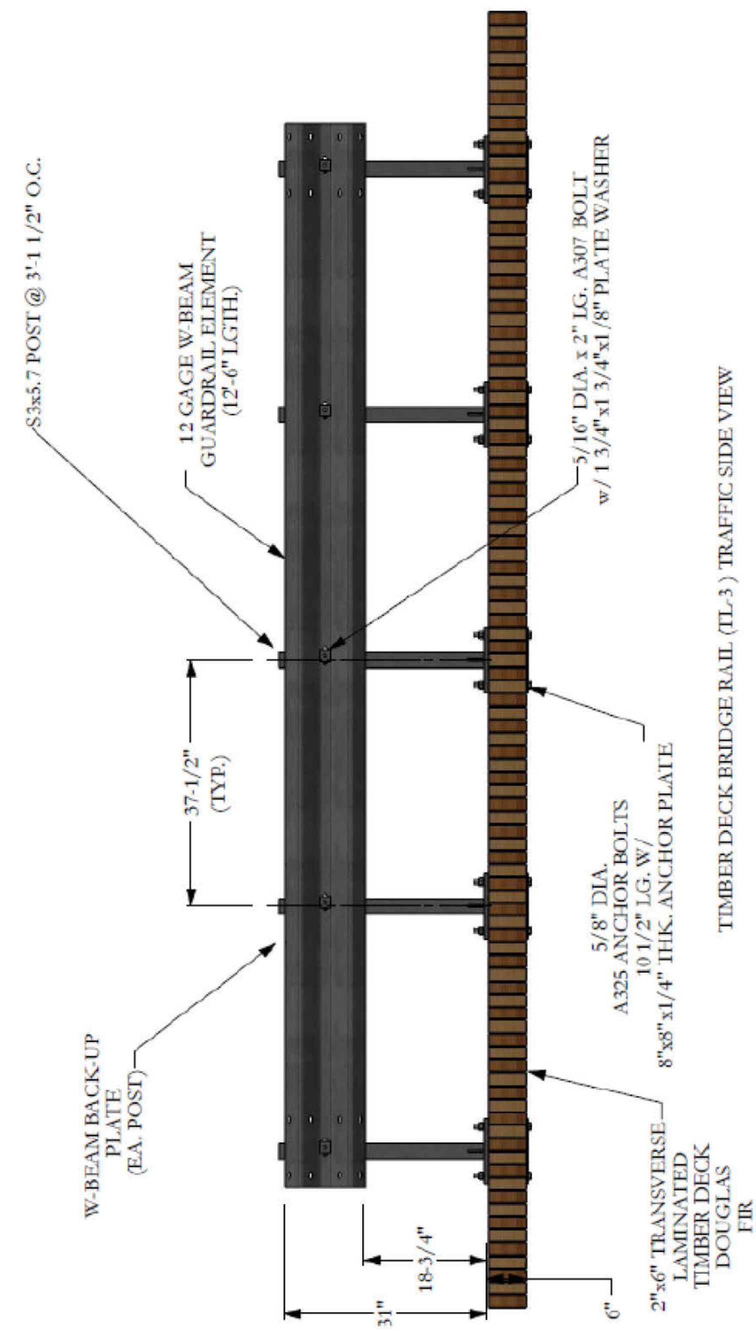
Sponsor: **WADOT Pooled Fund Project 405160-40**

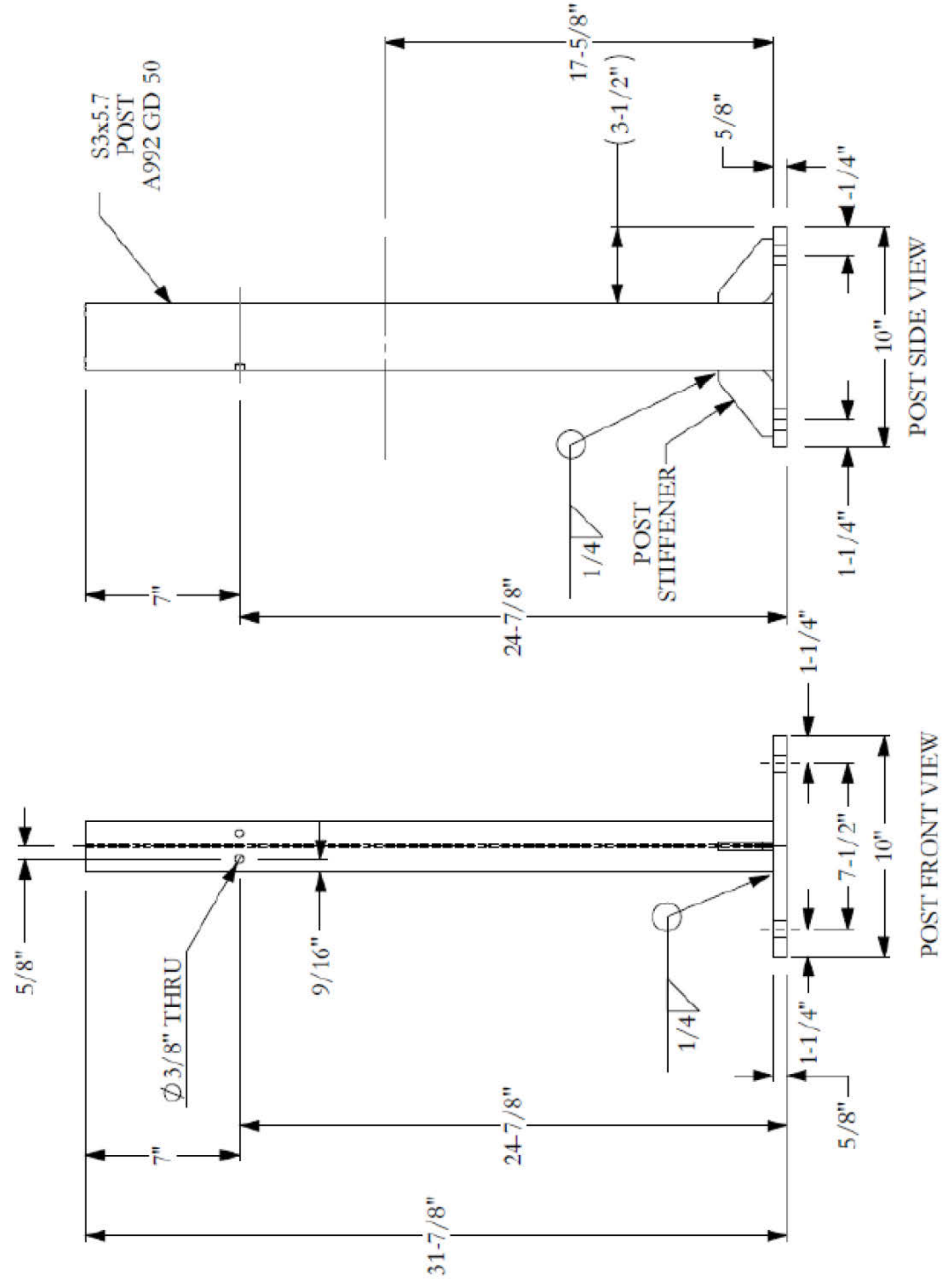
1.) Given: 1.) Basic Uplift Procedure as shown in Blodgett, "Design of Welded Structures" pages 3-3-8 through 10. and sketch w/ nomenclature showing Baseplate Geometry and distribution of force.
2.) Details of Timber Rail Base plate on Timber Deck
FIND: required thickness and anchor bolt force to acheive plastic failure of post

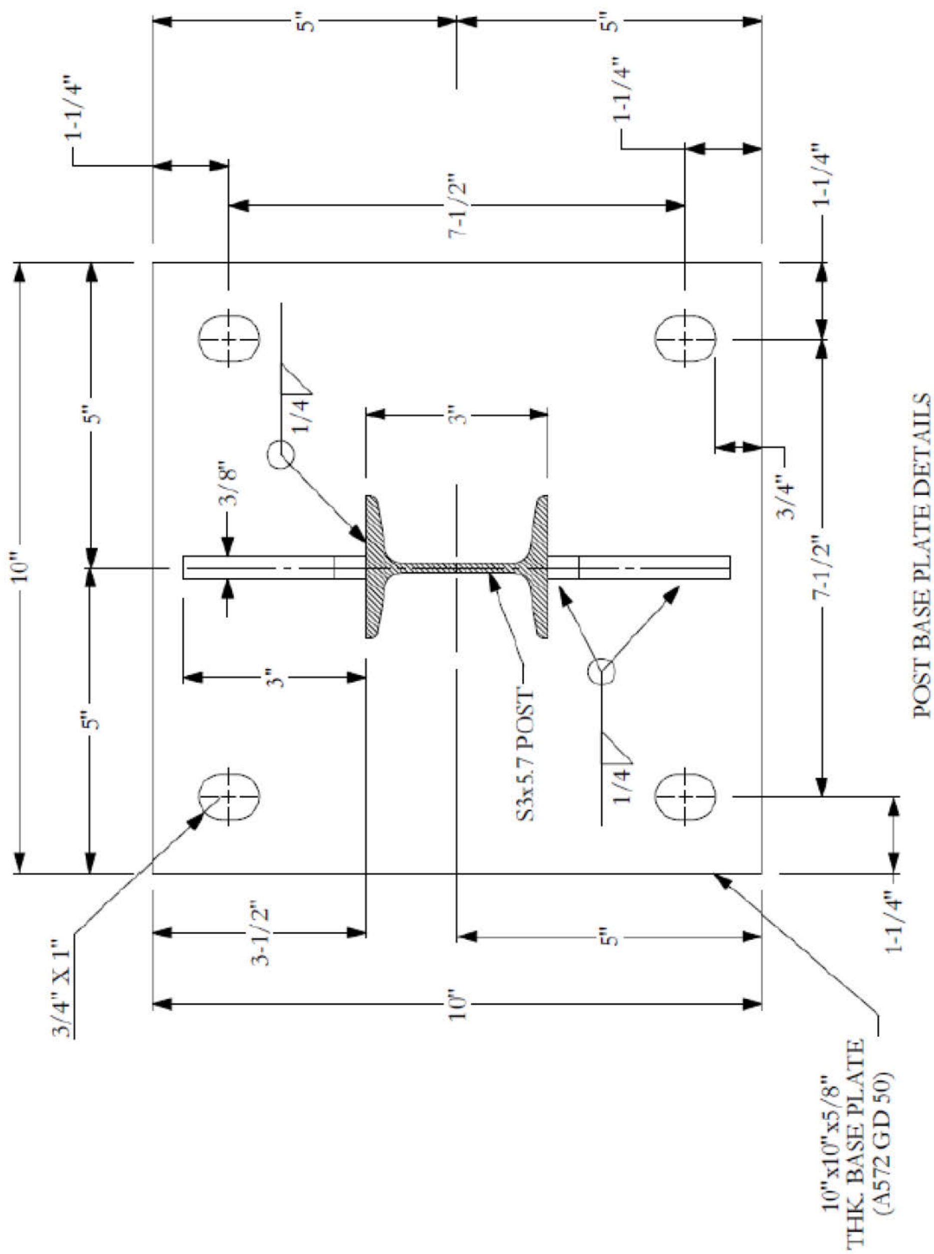


Subject: **Timber Rail Plate Design**

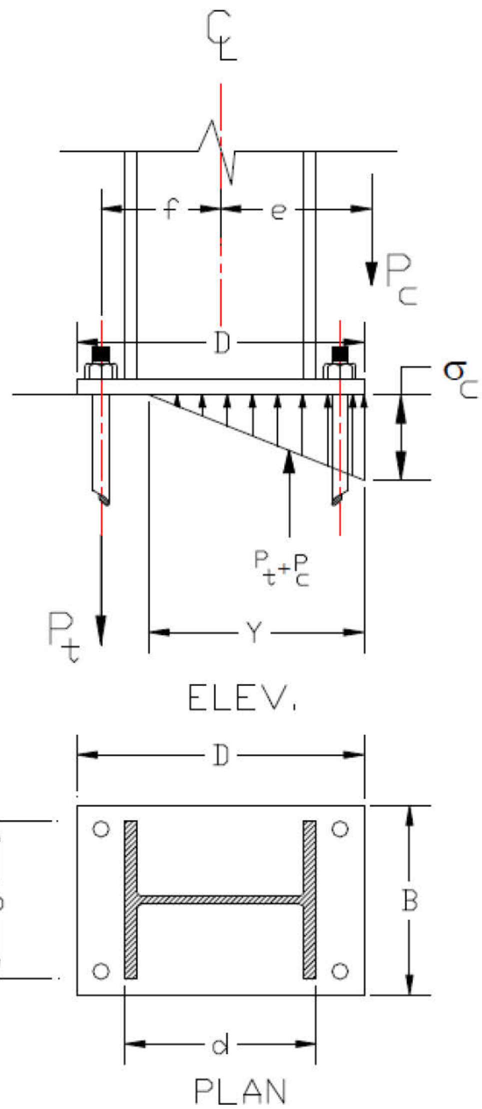
Sponsor: **WADOT Pooled Fund Project 405160-40**




S3x5.7
POST
A992 GD 50
17-5/8"
(3-1/2")
5/8"
1-1/4"
10"
1-1/4"
POST SIDE VIEW
POST
STIFFENER
1/4
7"
24-7/8"
1-1/4"
7-1/2"
10"
POST FRONT VIEW
5/8"
9/16"
∅3/8" THRU
1/4
1-1/4"
5/8"
7"
24-7/8"
31-7/8"


POST BASE PLATE DETAILS
S3x5.7 POST
10"x10"x5/8"
THK. BASE PLATE
(A572 GD 50)
3/4" X 1"
5"
5"
1-1/4"
1-1/4"
1-1/4"
1-1/4"
7-1/2"
7-1/2"
10"
10"
3"
3"
3/8"
3/4"
1/4
1/4
3-1/2"

Find: Maximum Stress (σ_c), "Y", and force in the bolts (P_t) for applied force as shown.



Subject: **Timber Rail Plate Design**

Sponsor: **WADOT Pooled Fund Project 405160-40**

This procedure uses a basic uplift procedure as shown in Blodget's "Design of Welded Structures" pages 3-3-8 through 10. It solves three equations for three unknowns for any combination of vertical & applied moment to the column. You have to combine the vertical load and moment to a single vertical load at some eccentricity "e".

Post Type: **S3x5.7 w/ 8"x8"x5/8" Baseplate, 4 Bolts ~ 5/8" Dia. (2 tension face):**

$P_c := \mathbf{0.1} \cdot \text{kips}$ Vertical Load on Post (kips) $Z := \mathbf{1.94}\text{in}^3$ S3x5.7

$F_y := \mathbf{50}\text{ksi}$ A992 Yield of Mat'L.

$M_1 := Z \cdot F_y$ Applied Moment (k-ft.) $M_1 = \mathbf{8.08} \cdot \text{kip} \cdot \text{ft}$

$d_{post} := \mathbf{3.0}\text{in}$

$e := \dfrac{M_1}{P_c}$ $e = \mathbf{970} \cdot \text{in}$ eccentricity (in.)

$b_{fpost} := \mathbf{2.33}\text{in}$

$N := \mathbf{2}$ ...... Number of Tension Bolts

$f_c := \mathbf{3600} \cdot \text{psi}$ Compressive Strength of Concrete (psi)

$B := \mathbf{10} \cdot \text{in}$ BP Width (in.) $f := \mathbf{2.75} \cdot \text{in}$ Distance from Col. Centerline to tension bolts.

$D := \mathbf{10} \cdot \text{in}$ BP Length (in.) $D_{bolts} := \dfrac{5}{8} \cdot \text{in}$ Dia. of anchor bolts (in.)

$d := \mathbf{3.0} \cdot \text{in}$ Col. Flange Depth (in.)

$b := \mathbf{2.33} \cdot \text{in}$ Col. Flange Width (in.) $E_s := 29 \cdot 10^6 \cdot \text{psi}$ Modulus of Elasticity (in.)

$A_s := \dfrac{\pi \cdot D_{bolts}^{\,2}}{4} \cdot N$ Area of tension bolts $A_s = \mathbf{0.614} \cdot \text{in}^2$

$E_w := \mathbf{1600000}\text{psi}$ $\text{kips} \equiv \text{kip}$

$\text{psi} \equiv \dfrac{\text{lbf}}{\text{in}^2}$ $\text{ksi} \equiv \dfrac{\text{kips}}{\text{in}^2}$ $n := \dfrac{E_s}{E_w}$ $n = \mathbf{18.13}$

From static, there are Three Equations & Three Unknowns, P_t, "Y", & s_c:

Use Mathcad's Solve Block to find solutions. Solve Block requires "Initial guesses and uses these guesses to converge on solutions for the three unknowns, s_c, Y, P_t:

Initial Guesses for unknowns: $\sigma_c := 1000 \cdot psi$ $\quad Y := .3 \cdot ft$ $\quad P_t := 1 \cdot kip$

Given

$$\frac{1}{2} \cdot Y \cdot \sigma_c \cdot B - P_t - P_c = 0$$

Equation 1

$$P_t \cdot f + (P_c + P_t) \cdot \left(\frac{D}{2} - \frac{Y}{3} \right) - P_c \cdot e = 0$$

Equation 2

$$\sigma_c = \frac{P_t \cdot Y}{A_s \cdot n \cdot \left(\frac{D}{2} - Y + f \right)}$$

Equation 3

$$\begin{pmatrix} Y \\ \sigma_c \\ P_t \end{pmatrix} := Find(Y, \sigma_c, P_t)$$

$Y = 3.1943 \cdot in$ Distance/length of pressure distribution

$\sigma_c = 911 \cdot psi$ Compressive stress @ the Edge of the Baseplate on Compression side.

$P_t = 14 \cdot kips$ Tension Force in (N) Anchor Bolts

$P_{Bolt} := \frac{P_t}{N}$ $\quad P_{Bolt} = 7.23 \cdot kips$ Tension per Bolt (kips)

Check Baseplate bending/thickness using forces & stress above separately.

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2. Calculate the moment in the baseplate and the required thickness

$$F_{bp} := \frac{\sigma_c \cdot Y}{2} \cdot 1in$$

$$F_{bp} = 1.46 \cdot kips$$

$$M_{pl} := \frac{F_{bp} \cdot \left[3.5in - \left(\frac{1}{3} \cdot Y\right)\right]}{in}$$

$$M_{pl} = 3.54 \cdot \frac{kip \cdot in}{in}$$

$$t_{pl} := \sqrt{\frac{4 \cdot M_{pl}}{0.90 \cdot F_y}}$$

$t_{pl} = 0.56 \cdot in$ use 5/8" THK. Plate... ok w/o stiffeners

3.) Check/size anchor bolts

$P_{Bolt} = 7.23 \cdot kips$

$\phi_{bolt} := 0.75$

$d_{bolt} := \frac{5}{8} in$

$F_{ubolt} := 105ksi$ Tension strength A325 bolt

$$A_{bolt} := \frac{\pi \cdot d_{bolt}^2}{4}$$

$$\phi R_{1bolt} := \phi_{bolt} \cdot F_{ubolt} \cdot (0.75 \cdot A_{bolt})$$

$\phi R_{1bolt} = 18.12 \cdot kips$ Use A325 5/8" dia. bolts

4.) Check Weld Around S3x5.7 Post

Use Blodgett Weld Design Procedure for welds treated as line:

$ksi \equiv \frac{1000lbf}{in^2}$

$t_{weld} := \frac{4}{16} in$ $\phi_{weld} := 0.75$ $F_{EXX} := 70ksi$

$t_e := 0.707 \cdot t_{weld}$ $d_{welds} := d_{post} + (t_{weld})$

$t_e = 0.18 \cdot in$

$\phi R_{weld} := \phi_{weld} \cdot t_e \cdot (0.60 \cdot F_{EXX})$

$\phi R_{weld} = 5.57 \cdot \frac{kips}{in}$

$S_w := 2 \cdot b_{fpost} \cdot d_{welds} + \frac{d_{welds}^2}{3}$

$\phi R_{weldneeded} := \frac{M_1}{S_w}$

$\phi R_{weldneeded} = 5.2 \cdot \frac{kips}{in}$

Use 1/4" fillet weld all around post
Add additional 3/8" Stiffeners for added stiffness
and additional weld strength

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5.) Check bearing stress from baseplate on timber deck

$f_{cperp} := 385 psi \cdot \phi_{impact}$ $\sigma_{avg} := \frac{\sigma_c \cdot 1}{2}$ $\sigma_{avg} = 455.53 \cdot psi$

$f_{cperp} = 512.05 \cdot psi$ Use 10x10x 5/8" baseplate size .... ok

6.) Check bending in Deck from baseplate loading

Use commercial decking for Douglas fir
Reference: Structural Engineering Handbook, Section 16
Table 3, Page 16-7, Commercial Dex Decking Repetitive Member Uses

$f_{bdeck} := 1650 \cdot psi$

$b_{deck} := 10in + 10in$ Width of section contributing

$t_{deck} := 6in$ $\phi_{impact} \equiv 1.33$

$S_{deck} := \frac{b_{deck} \cdot t_{deck}^2}{6}$

$S_{deck} = 120 \cdot in^3$

$M_{allowed} := S_{deck} \cdot f_{bdeck}$

$M_{allowed} = 16.5 \cdot kip \cdot ft$

$M_1 = 8.08 \cdot kip \cdot ft$

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7.) Check Horizontal shear from anchor bolts

$f_v := \mathbf{95}psi$ shearing stress on timber $t_{deck} = \mathbf{6} \cdot in$

$F_v := t_{deck} \cdot (\mathbf{13.25}in + \mathbf{5.5}in) \cdot f_v \cdot \mathbf{4}$ four planes here

$F_v = \mathbf{42.75} \cdot kips$ ... ok

8.) Design Summary:

1.) Use Post details as shown in the details shown above for MASH TL-3.
2.) Post spacing 3'- 1 1/2" (1/2 post spacing) for TL-3 similiar to MwRSF Report No. TRP-03-226-10.
3.) Use 10"x10"x5/8" THK. Base plate.
4.) Use 5/8" Dia. A325 Anchor Bolts.
5.) Use 1/4" fillet welds around posts using F_{EXX} 70 KSI welding Rods.
6.) Add 2 1/2" x 3" x 3/8" thick stiffeners (2) each post welded to post flange.
7.) Consider bolting w-beam back-up plates to posts or w-beam rail to prevent flying debris from crash.
8.) Use 6-inch thick laminated douglas fir timber deck in good condition.
9.) Use 5/16" Dia. A307 Guardrail bolt as tested in MwRSF Report.