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Guardrails for Use on Historic Bridges

Volume 1—Replacement Strategies




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16. Abstract

Bridges that are designated historic present a special challenge to bridge engineers whenever rehabilitation work or improvements are made to the bridges. Federal and state laws protect historically significant bridges, and railings on these bridges can be subject to protection because of the role they play in aesthetics. Unfortunately, original railings on historic bridges do not typically meet current crash-test requirements and typically do not meet current standards for railing height and size of permitted openings. The primary objective of this study is to develop strategies that can be used to address existing railings on historic bridges and to develop solutions that meet current design requirements. In addition to the modification, selection, and design of the bridge railing, the bridge deck is also impacted by changes made to the railing. Due to increased force levels recently required by AASHTO, deck overhangs require significantly more reinforcement than for past practice. These increases are being realized on all bridge decks and may pose particular challenges for the attachment of railing to historic bridges. Therefore, a secondary objective of this project is to investigate the design of the deck overhang and determine whether reduced amounts of reinforcement are possible. For Volume 1 (Replacement Strategies), three phases of research were conducted. First, an overview of current practice for addressing historic bridge railings was performed. Second, an investigation was conducted to document historic bridge railings in Indiana. Finally, rehabilitation solutions were developed to address the specific bridge railings found in Indiana. Based on this research, three retrofit strategies were developed which include an inboard railing, curb railing, and a simulated historic railing. These rehabilitation solutions can be used to address historic bridge railings not only in Indiana, but across the country. For Volume 2 (Bridge Deck Overhang Design), experimental testing of half-scale and full-scale overhang specimens was conducted, and the results were analyzed. Failures of in-service bridge railings were also evaluated. Based on this research, recommendations are provided for the more efficient and economic design of bridge deck overhangs. These recommendations are applicable not only for historic bridges, but for all concrete bridge decks.

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EXECUTIVE SUMMARY

GUARDRAILS FOR USE ON HISTORIC BRIDGES: VOLUME 1— REPLACEMENT STRATEGIES

Introduction

Bridges that are designated historic present a special challenge to bridge engineers whenever rehabilitation work or improvements are made to the bridges. Federal and state laws protect historically significant bridges, and railings on these bridges can be subject to protection because of the role they play in aesthetics. Unfortunately, original railings on historic bridges do not typically meet current crash-test requirements and typically do not meet current standards for railing height and size of permitted openings. The primary objective of this study is to develop strategies that can be used to address existing railings on historic bridges and to develop solutions that meet current design requirements. In addition to the modification, selection, and design of the bridge railing, the bridge deck is also impacted by changes made to the railing. Due to increased force levels recently required by AASHTO, deck overhangs must have significantly more reinforcement than in past practice. These increases are being realized on all bridge decks and may pose particular challenges for the attachment of railing to historic bridges. Therefore, a secondary objective of this project is to investigate the design of the deck overhang and determine whether reduced amounts of reinforcement are possible.

For Volume 1 (Replacement Strategies), three phases of research were conducted. First, an overview of current practice for addressing historic bridge railings was performed. Second, an investigation was conducted to document historic bridge railings in Indiana. Finally, rehabilitation solutions were developed to address the specific bridge railings found in Indiana. Based on this research, three retrofit strategies were developed: inboard railing, curb railing, and simulated historic railing. These rehabilitation solutions can be used to address historic bridge railings not only in Indiana, but also across the country.

For Volume 2 (Bridge Deck Overhang Design), experimental testing of half-scale and full-scale overhang specimens was conducted, and the results were analyzed. Failures of in-service bridge railings were also evaluated. Based on this research, recommendations are provided for the more efficient and economic design of bridge deck overhangs which are applicable not only for historic bridges, but for all concrete bridge decks.

Findings

Volume 1: Replacement Strategies

Indiana's historic bridge inventory was investigated to determine how many historic bridges remain in service as well as to document the types and variety of historic railings in existence. As of January 2014, 658 historic bridges remain in service in Indiana, on which 61 different historic railings were identified. Of these, 7 railing types, along with bridges with no railing, constitute two-thirds of the entire inventory. It is interesting that of the other railings, 25 occur on only one bridge and 11 occur on only two bridges. Therefore, 59% of the different railing types are unique. Based on this analysis, research focused on addressing the most common railings identified. However, an attempt was also made to address as many of the unique railings as possible.

Three different options utilizing modern, previously crash tested railings were identified to upgrade the railings on Indiana's historic bridges. The first option is to install a modern railing inside the original railing. When this option is exercised, the original railing may remain on a bridge. The second option is to install a special inboard railing on the curb. This special railing, which can be used if the bridge has a sidewalk, protects pedestrians on the sidewalk and allows the original railing to be retained. The third option is railing replacement. A collection of approved, crash-tested railings developed by a number of states was used as a baseline to design simulated railings to approximate the appearance of historic railings.

Simulated railings were developed to cover a variety of historic concrete and steel railings. These railings maintained the overall structure and crash-resistant geometry of the base railing while integrating geometric features of the historic railing. In all, it was possible to simulate 42 of the historic railings existing in Indiana. These railings cover 66.3% of all historic bridges in the state. Three timber railing types, which were not considered in the scope of this research, accounted for 8.4% of all historic bridges in the state. Sixteen railing types did not possess a historic look, did not possess acceptable geometry, or did not exemplify historic craftsmanship. These railings accounted for 25% of all historic bridges in the state.

Volume 2: Bridge Deck Overhang Design

Based on the experimental testing program, along with analysis of the results, the following findings were made:

1. A diagonal tension failure in the deck overhang/barrier joint is a potential failure mode. However, this failure mode is only possible for very short bridge lengths (<30 ft) and will not control the capacity of the overhang/barrier system of a typical bridge deck.
2. The strength of the overhang/barrier wall system is controlled by punching shear rather than the yield-line mechanism. This finding is significant in that design of the overhang according to AASHTO requirements is based on the yield line strength. Reviews of in-service barrier impacts support the finding that punching shear controls the capacity of the system, with field failures producing the same failure surfaces as observed in the laboratory.
3. Barrier impact loads are transferred to the bridge system through the deck overhang over a large distribution length. Load was found to be distributed to the overhang at least 10 times the horizontal loading dimension (L_t), significantly larger than considered by current design provisions. Because of this very effective distribution, there are significantly lower demands on the overhang reinforcement from the barrier impact force than considered using current design provisions. Consequently, a significant reduction in transverse reinforcement relative to that currently required by the AASHTO design specification can be achieved.

Implementation

There are two primary targets for implementation of the results of this research: recommendations regarding upgrading historic bridge railings and recommendations regarding design of bridge deck overhangs. The recommendations regarding bridge deck overhang are generally applicable for both new and rehabilitation projects.

Upgrading Railings

Through the use of the strategies developed in this research program, it is possible to retain historic railing appearance for the majority of historic bridges in Indiana. In many cases, it is also possible to improve aesthetics. Most importantly, however, these strategies allow for improvement in the safety of the traveling public.

Bridge Deck Overhangs

It is recommended that the bridge deck overhang be designed based on vertical forces. Considering the very effective lateral force transfer to the overhang and the maximum applied lateral force as limited through the punching shear capacity of the barrier, design of the overhang to resist the lateral impact force is not required. If the lateral impact force is to be considered, two modifications from current design requirements as specified by AASHTO are recommended:

1. Applied lateral force should be based on the lesser of the punching shear strength of the barrier and the yield line strength.
2. The deck overhang distribution length should be considered as $10L_t$, where L_t is the longitudinal length of distribution of impact force.

By implementing these recommendations, significant cost savings can be realized through the reduction of reinforcement required in the bridge deck overhang.

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1. INTRODUCTION

1.1 Background

The National Historic Preservation Act of 1966 authorized the creation of the National Register of Historic Places (NRHP). The passage of this law provided a legal means for recognizing historic assets, including bridges. The law also promoted awareness of preserving historic bridges (NPS, n.d.). Historic bridges are characterized by design philosophies, building techniques, and architectural styles that are uncommon today or sometimes no longer used. Therefore, it is advantageous to preserve historic bridges, which are considered rich cultural icons.

Although historic bridges are visual reminders of bygone eras, they generally do not meet current standards for roadway width, structural adequacy, and railing strength (Buth, Haug, Menges, & Williams, 2004). Considering railings in particular, the original railing on a historic bridge is not likely to meet current crash test requirements. Historic bridge railings are also not likely to meet current standards for railing height and size of permitted openings.

1.2 Objective and Scope

The objective of this research is to develop a toolbox of design and rehabilitation solutions that can be used to improve the safety of a variety of existing railings on historic bridges in Indiana without damaging the aesthetic qualities or historic value of the bridges. This research was conducted in three phases. First, current practice for addressing historic bridge railings was reviewed. Second, an investigation was conducted to document and inventory historic bridge railings in Indiana. Finally, rehabilitation solutions were developed to address the specific historic bridge railings found in Indiana.

2. REVIEW OF HISTORIC BRIDGE RAILING PRACTICE

2.1 History of Railing Design Standards

The American Association of State Highway and Transportation Officials (AASHTO) has published bridge design specifications since 1931, but the advent of standard safety and strength requirements for bridge railings occurred in the late 1980s (Barker & Puckett, 2013). Development of a set of standard strength and safety requirements for bridge railings was necessary to ensure the safe use of the nation's bridges.

Since August 1986, the Federal Highway Administration (FHWA) has required bridge railings used on projects funded fully or partially with federal money to meet full-scale crash-test criteria (FHWA, 1997). The National Cooperative Highway Research Program (NCHRP; Ross, Sicking, Zimmer, & Michie, 1993) published *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features* in 1993. This report synthesized previous research on the impact performance of highway barriers and set forth a scheme of Test Levels (TL) for rating the crashworthiness of highway barriers (including bridge railings). This report is the foundation for current crash test and impact performance standards for bridge railings (Ross et al., 1993).

In 1994, AASHTO published the *LRFD Bridge Design Specifications 1st Ed.* This was the first AASHTO bridge design code to contain strength requirements for bridge railings (AASHTO, 1994).

2.2 Current Railing Design Standards

The AASHTO *Manual for Assessing Safety Hardware* (MASH) contains current strength and safety requirements for bridge railings. AASHTO incorporated the content of NCHRP Report 350 into MASH (AASHTO, 2009). NCHRP Report 350 prescribed six Test Levels (Test Levels 1 through 6) to quantify the sturdiness of highway barriers against impact, and they are incorporated into MASH. Bridge railings are a subset of highway barriers and are therefore subject to these requirements (Ross et al., 1993). Consequently, a new bridge railing must be designed using prescribed forces, and it must be crash tested to determine its Test Level (AASHTO, 2009).

The requirements to meet a certain Test Level increase with the numeric value of the Test Level: Test Level 1 is the least demanding while Test Level 6 is the most demanding. Therefore, a railing rated at Test Level 1 has the weakest classification and a railing rated at Test Level 6 has the strongest classification. A new bridge railing is crash tested with multiple vehicles in separate tests, as shown in Table 2.1. Crash tests of a bridge railing are evaluated using three criteria: structural adequacy of the railing, occupant risk (to the impacting vehicle), and post-impact vehicular response. A Test Level is assigned to a railing based on the application of the criteria to the results of crash tests (Ross et al., 1993).

In the 16 years from the publication of NCHRP Report 350 to the publication of MASH, some changes were made to the Test Level requirements. The Test Level requirements are shown in Table 2.1 (AASHTO, 2014). In Table 2.1, W is vehicle weight, B is out-to-out wheel spacing on an axle, and G is height of the vehicle's center of gravity. As of 2014, bridge railings that were crash-tested and accepted under the NCHRP Report 350 criteria were considered appropriate as replacements or new installations (AASHTO, 2014).

In addition to structural rigidity requirements, bridge railings are required to have a minimum height above the wearing surface. Section 13.7.3.2 of AASHTO's (2014) *LRFD Bridge Design Specifications* lists bridge railing height requirements. Railings rated TL-3 or lower must be at least 27 in. tall. Railings rated at TL-4 must be at least 32 in. tall and railings rated at TL-5 must be at least 42 in. tall. Finally, railings rated at TL-6 must be at least 90 in. tall (AASHTO, 2014). A summary of these requirements is provided in Table 2.2.

TABLE 2.1
Changes from NCHRP Report 350 to AASHTO MASH (AASHTO, 2014)

	Vehicle Characteristics	Small Automobiles		Pickup Truck	Single-Unit Van Truck	Van-Type Tractor Trailer		Tractor-Tanker Trailer
NCHRP Report 350	W (kips)	1.55	1.8	4.5	18.0	50.0	80.0	80.0
	B (ft)	5.5	5.5	6.5	7.5	8.0	8.0	8.0
	G (in.)	22	22	27	49	64	73	81
	Crash angle, θ	20°	20°	25°	15°	15°	15°	15°
	Test Level	**Test Speeds (mph)**						
	TL-1	30	30	30	N/A	N/A	N/A	N/A
	TL-2	45	45	45	N/A	N/A	N/A	N/A
	TL-3	60	60	60	N/A	N/A	N/A	N/A
	TL-4	60	60	60	50	N/A	N/	N/A
	TL-5	60	60	60	N/A	N/A	50	N/A
	TL-6	60	60	60	N/A	N/A	N/A	50
AASHTO MASH	W (kips)	2.42	3.3	5.0	22.0	N/A	79.3	79.3
	B (ft)	5.5	5.5	6.5	7.5	N/A	8.0	8.0
	G (in.)	N/A	N/A	28	63	N/A	73	81
	Crash angle, θ	25°	N/A	25°	15°	N/A	15°	15°
	Test Level	**Test Speeds (mph)**						
	TL-1	30	N/A	30	N/A	N/A	N/A	N/A
	TL-2	45	N/A	45	N/A	N/A	N/A	N/A
	TL-3	60	N/A	60	N/A	N/A	N/A	N/A
	TL-4	60	N/A	60	N/A	N/A	N/A	N/A
	TL-5	60	N/A	60	N/A	N/A	50	N/A
	TL-6	60	N/A	60	N/A	N/A	N/A	50

TABLE 2.2
Summary of Railing Height Requirements

Rating	Minimum Railing Height (in.)
TL-3 or lower	27
TL-4	32
TL-5	42
TL-6	90

2.3 Historic Bridge Identification

The passage of the National Historic Preservation Act in 1966 authorized the creation of the National Register of Historic Places (NPS, n.d.). To be eligible for listing on the NHRP, a historic asset must retain sufficient integrity, be at least 50 years old, and have significance under one or more of the following criteria:

Criterion A: A resource may be eligible under this criterion if it is associated with events that have made a significant contribution to the broad patterns of history.

Criterion B: A resource may be eligible under this criterion if it is associated with the lives of persons significant in our past.

Criterion C: A resource may be eligible under this criterion if it embodies the distinctive characteristics of a type, period, or method of construction, or if it represents the work of a master, or if it possesses high artistic values.

Criterion D: A resource may be eligible under this criterion if it has yielded, or is likely to yield information important in prehistory or history.

Bridges are typically eligible under Criterion A or Criterion C (ODOT, 2007).

2.4 National Historic Bridge Management

In 1987, Congress passed the Surface Transportation & Uniform Relocation Assistance Act (STURAA). A stipulation of STURAA requires states to inventory their historic bridges. In 2012, the consulting firm Mead & Hunt (M&H) published *Historic Bridge Practices*

Nationwide: Inventory, Evaluation, and Management. The M&H report detailed historic bridge practices in the U.S. M&H surveyed the Departments of Transportation (DOTs) of all 50 states to determine the progress of the states' historic bridge inventories. M&H presented its survey results in the bar chart shown in Figure 2.1 (Mead & Hunt, 2012).

Although all 50 states have inventoried their historic bridges, Figure 2.1 indicates that only 38 states have completed historic bridge rehabilitation projects. The historic bridge rehabilitation projects ranged from minor repairs to multi-million-dollar projects. Additionally, fewer than half of the 50 states have initiated programmatic agreements or management plans. Programmatic agreements and management plans are methods for states to identify historic bridges, identify preservation options, and coordinate federal funding for proposed projects (Mead & Hunt, 2012).

Indiana is among the 19 states that have executed a programmatic agreement to manage its historic bridges. INDOT executed a programmatic agreement with FHWA, the Indiana State Historic Preservation Officer (SHPO), and the Advisory Council on Historic Preservation in July 2006 (INDOT, 2006).

Elsewhere, the Oregon Department of Transportation (ODOT) has completed a number of successful rehabilitations (Mead & Hunt, 2012). Kentucky, Ohio, Oregon, Tennessee, and Texas are a few states that have published documents outlining their historic bridge preservation efforts.

1. Kentucky: *Assessment of Kentucky's Historic Truss Bridges* (O'Connell, Gorssardt, & Ripy, 2010).
2. Ohio: *Ohio Historic Bridge Maintenance and Preservation Guide* (TranSystems, 2010).
3. Oregon: *Historic Bridge Preservation Plan* (ODOT, 2007).
4. Tennessee: *Tennessee's Survey Report for Historic Highway Bridges* (Carver, 2008).
5. Texas: *Historic Bridge Manual* (TxDOT, 2010).

More general guidance on historic bridge preservation is available in the following publications:

1. *Guidelines for Historic Bridge Rehabilitation and Replacement* (AASHTO, 2008).
2. *NCHRP Synthesis 275: Historic Highway Bridge Preservation Practices* (Chamberlin, 1999).
3. *Best Practices and Lessons Learned on the Preservation and Rehabilitation of Historic Bridges* (Parsons Brinckerhoff, TranSystems, & Gowan, 2012).

2.5 Bridge Railing Manual

The Texas Department of Transportation (TxDOT, 2012) developed a manual specifically for bridge railings (*Bridge Railing Manual*). The manual summarizes current policies governing the use of bridge railings in Texas and provides information on acceptable Texas bridge railing types. Of particular interest, a section of the manual is devoted to railings on historic bridges. It presents four options that can be used to upgrade the railings on historic bridges in Texas. These four options are summarized as:

1. Place an approved railing inboard of the existing railing and leave the existing railing undisturbed.

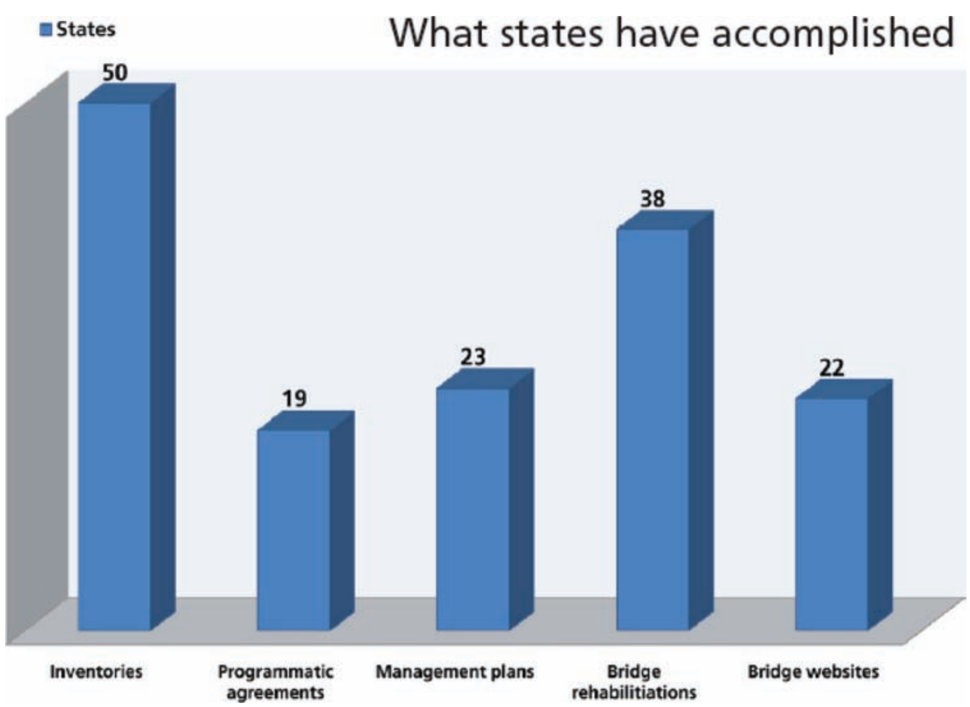


Figure 2.1 States' historic bridge management activities (Mead & Hunt, 2012).

2. Replace the existing railing with an acceptable approved railing, approximating the appearance of the old railing with the new railing.
3. Remove the existing railing and incorporate it into a new acceptable railing.
4. Design a special railing to closely match the appearance of the existing railing.

The difference between Options 2 and 4 is the degree to which a historic railing is approximated. Option 4 calls for a new railing to be designed to look almost exactly like the historic railing while Option 2 calls for finding an existing railing that resembles the historic railing. Option 2 may not be available for many types of railings (TxDOT, 2012).

2.6 Historic Bridge Railing Research

Texas leads the country in historic bridge railing research. The Texas Transportation Institute (TTI), with the support of the Texas Department of Transportation (TxDOT), has been at the forefront of historic bridge railing retrofit research. TTI engineers have designed, crash-tested, and implemented retrofit railings on some of Texas's on-system (carrying state highways) truss bridges (Buth et al., 2004).

TxDOT formed a Historic Bridge Task Force in 1996. The task force developed a methodology for evaluating preservation options for on-system truss bridges that are listed on or are eligible for listing on the National Register of Historic Places (NRHP). In 2003, TxDOT maintained 38 metal truss bridges aged 50 years or more on its state highway system. A total of 33 of the 38 bridges are listed on the NRHP. The existing railings on these bridges did not meet MASH requirements. In addition, these bridges have other problems common to many types of historic bridges, including narrow deck widths, low vertical clearance, and substandard load capacities (Buth et al., 2004).

TxDOT focused on developing solutions for its on-system truss bridges. A research program performed at TTI addressed the substandard attributes of the railings on the 38 truss bridges (Buth et al., 2004). In particular, they focused on two of their on-system truss bridges as outlined by the following research objectives:

1. Design/develop a retrofit railing for low-speed application on the Roy B. Inks Bridge in Llano, Texas. The Roy B. Inks Bridge has four main spans consisting of Parker thru trusses with a speed limit of 40 mph and is shown in Figure 2.2.
2. Design/develop a retrofit railing for high-speed application on the U.S. 281 bridge over the Brazos River in Palo Pinto County, Texas. The U.S. 281 bridge is a three-span Warren thru-truss bridge with a speed limit of 60 mph and is shown in Figure 2.3 (Buth et al., 2004).

In both bridges, a continuous steel channel served as the railing. In the original configuration, the channel member railing was mounted directly to the truss members as shown in Figure 2.4 for the Roy B. Inks Bridge. The U.S. 281 bridge had a similar railing connection detail. Engineers at TTI designed retrofit railings for these bridges using the impact conditions specified in the second edition of AASHTO's *LRFD Bridge Design Specifications* (Buth et al., 2004).

Each retrofit railing utilized the original channel member to maintain the historic appearance of the bridges. For the low-speed retrofit railing (40 mph, Roy B. Inks Bridge), a TS8x4x1/2 section was added to the

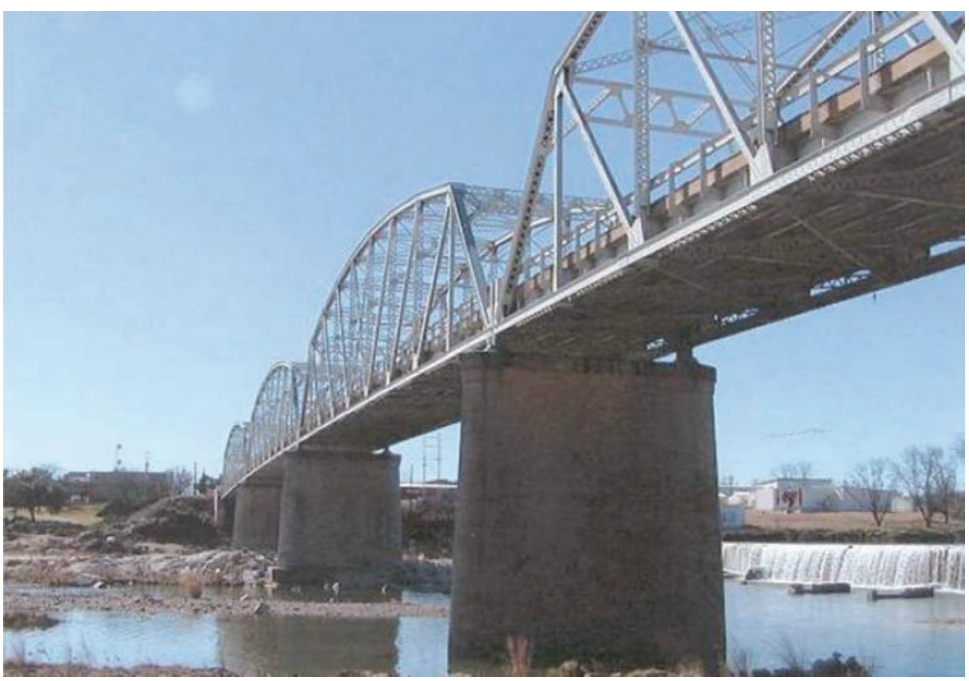


Figure 2.2 Roy B. Inks Bridge (Buth, 2004).

Figure 2.3 U.S. 281 bridge (Buth, 2004).

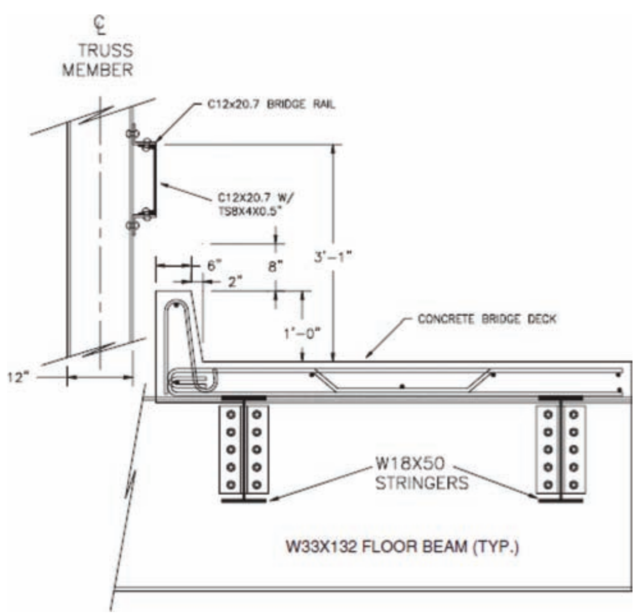


Figure 2.4 Typical railing connection to truss member on the Roy B. Inks Bridge (Williams, 2010).

C12x20.7 to increase the overall flexural capacity of the railing. Additionally, engineers placed crushable steel tube blockouts between the composite C12x20.7 and TS8x4x1/2 railing and the truss members to absorb impact forces and protect the truss members. Figure 2.5 shows the railing before it was tested while Figure 2.6 shows the railing after crash testing (Buth et al., 2004).

The steel blockout deformed during the test as expected. This railing was successfully crash-tested for Test Level 2 (Buth et al., 2004). Figure 2.7 shows the Roy B. Inks Bridge after the railing was retrofitted (Williams, 2010).

For the high-speed retrofit railing (60 mph, U.S. 281 bridge), the C12x20.7 was mounted on the front of a W6x20 section to improve the overall flexural strength of the railing. W6x20 steel posts anchored the new W6x20-C12x20.7 composite railing to the existing curb, rather than to the truss members as was done in the Roy B. Inks Bridge. Figure 2.8 shows the composite railing before the crash test while Figure 2.9 shows the railing after testing (Buth et al., 2004).

The railing was successfully crash-tested for Test Level 3 (Buth et al., 2004). According to John Holt of the Texas Department of Transportation, the retrofit railing had not yet been installed on the U.S. 281 bridge as of October 2014.

Considering that new truss bridges are being built in Texas, TxDOT wants to offer flexibility for designers to choose between railings supported by the concrete bridge deck or railings supported directly by the truss members. The successful completion of this research program not only resulted in suitable retrofit railings for historic metal truss bridges, it also resulted in additional design options for bridge engineers (Buth et al., 2004). These options are consistent with Option 3 discussed in the TxDOT (2012) *Bridge Railing Manual.*

2.7 Historic Replacement Railings

Texas has developed standardized railings that are designed to match the appearance of historic concrete railings (Option 4 of the historic railing option list in the TxDOT [2012] *Bridge Railing Manual*). The standardized railings include TxDOT T411, TxDOT

Figure 2.5 Test setup of the Roy B. Inks railing before crash testing (Buth et al., 2004).

Figure 2.6 Test setup of the Roy B. Inks railing after crash testing (Buth et al., 2004).

(a) Railing Profile (Google, 2013) **(b) Blockout (Williams, 2010)**

Figure 2.7 Roy B. Inks bridge with the retrofit railing developed at TTI.

C411, and TxDOT C412. Illustrations of these railings are shown in Figure 2.10 and Table 2.3 provides a summary of the TxDOT railings. The T411 was designed as a traffic railing while the C411 and C412 were designed as pedestrian/traffic combination railings (TxDOT 2012). Standard drawings of these railings are provided in Appendix A.

To provide a historic railing for use in Indiana, INDOT adopted the TxDOT C411 railing. In Indiana, the TxDOT C411 is known as the INDOT TX railing.

Figure 2.8 Test setup of the U.S. 281 railing before crash testing (Buth et al., 2004).

Figure 2.9 Test setup of the U.S. 281 railing after crash testing (Buth et al., 2004).

TABLE 2.3
TxDOT Standardized Historic Approximation Railings

Railing	Height (in.)	Rating
TxDOT T411	32	TL-2
TxDOT C411	42	TL-2
TxDOT C412	42	TL-4

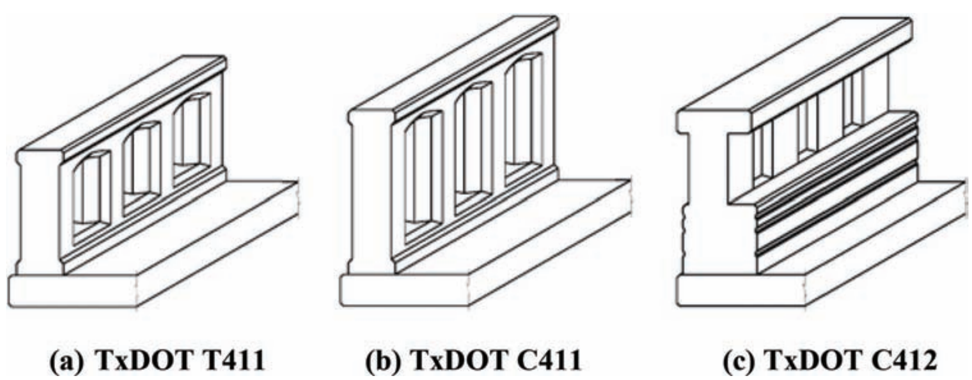


Figure 2.10 TxDOT approximation of historic bridge railings (TxDOT, 2012).

An illustration of the INDOT TX railing is shown in Figure 2.11 while Figure 2.12 shows an Indiana bridge that implemented this railing. Standard drawings of the INDOT TX railing are also provided in Appendix A.

2.8 Modern Aesthetic Railings

Other aesthetic bridge railings, in addition to railings that were designed to explicitly match a type of historic

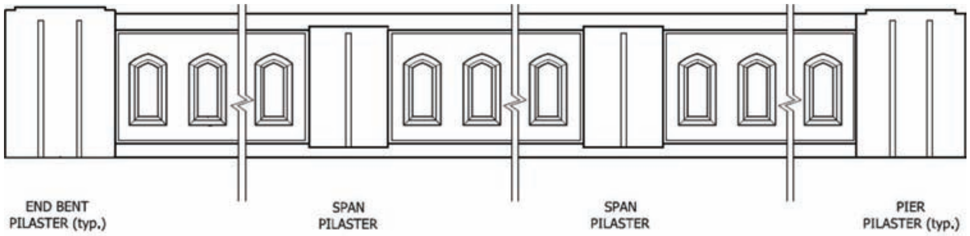


Figure 2.11 INDOT TX railing profile (INDOT, 2012).

Figure 2.12 INDOT TX railing installation.

Figure 2.13 Concrete railing with tribal design architectural texture (Caltrans, n.d.).

railing, have been developed and installed on bridges in the U.S. The California Department of Transportation (Caltrans) has numerous examples of aesthetic railings on its state highway system, as illustrated in Figures 2.13 through 2.16 (Caltrans, n.d.).

Caltrans discusses the possibilities for California bridge railings in its publication *Bridge Rails and Barriers* (Caltrans, n.d.). The artistry of the ornate railings on California bridges pays homage to historic bridges while satisfying modern strength and safety requirements

Figure 2.14 Concrete railing with tribal design architectural texture (Caltrans, n.d.).

Figure 2.15 Concrete railing with architectural treatment (Caltrans, n.d.).

(Caltrans, n.d.). These railings may also provide aesthetic solutions for historic bridges.

2.9 Railing Approval

Generally, a historical preservation agency has jurisdiction over proposed alterations to historic assets. In Indiana, alterations to historic assets must be approved by the Indiana State Historic Preservation Officer (SHPO). Therefore, for railing changes on a historic bridge, the responsible transportation agency must apply to Indiana SHPO for approval. While INDOT is directly responsible for historic bridges on state or U.S. highways, the majority of historic bridges in Indiana are on either municipal or county roads. When federal funding is utilized to alter a historic bridge on a municipal or county road, INDOT has oversight of the process.

Figure 2.16 Concrete railing with architectural treatment (Caltrans, n.d.).

3. DOCUMENTATION OF HISTORIC BRIDGES AND RAILINGS IN INDIANA

3.1 Indiana Historic Bridge Database

After INDOT began its programmatic agreement with FHWA in 2006, the historic bridges in Indiana were required to be identified. INDOT contracted Mead & Hunt (M&H) to apply the National Register of Historic Places (NRHP) criteria to all bridges in the state. Mead & Hunt completed a database, took photographs of Indiana's historic bridges, and delivered its findings to INDOT in March 2008. After two years of public input and revision, M&H delivered its final database to INDOT in December 2010. The database indicated that Indiana had 796 historic bridges as of December 2010. Of the 796 historic bridges, 705 were still in service in December 2010.

3.2 Analysis of the Historic Bridge Database

Using the database and photos compiled by M&H, a streamlined spreadsheet of Indiana's historic bridges was compiled. The spreadsheet was designed to include the following:

- Location by county
- National Bridge Inventory (NBI) number
- Structure type
- Railing type
- Railing-to-deck connection type
- Facility carried
- Facility crossed
- Qualifying historic significance parameter

As part of its programmatic agreement with the FHWA, INDOT is required to publish annual reports of its historic bridge activities. The first report covered the calendar year of 2010 and was published in January 2011. This report and subsequent annual reports (calendar years 2011, 2012, 2012 addendum, 2013) delivered under the programmatic agreement indicated that 47 of the 705 in-service historic bridges have been closed to traffic or replaced between December 2010 and January 2014 (INDOT, 2014). A list of historic bridges that have been removed from service between December 2010 and January 2014 is provided in Appendix B.

As of January 2014, there were 658 in-service historic bridges in Indiana (INDOT, 2014). Most of the railings on the 658 bridges do not meet the *Manual for Assessing Safety Hardware* (MASH) requirements for strength and impact performance due to differences in the design requirements of the time as well as varying states of disrepair.

The spreadsheet of historic bridges was analyzed to determine statistics for the following items:

1. Type of structure
2. Facility carried
3. Facility crossed
4. Railing type

Four breakdowns of the historic bridge inventory were generated for the historic bridges that remain in service (658 bridges). Information on numbers of each structure type, facility carried, and facility crossed are presented in Tables 3.1 through 3.3. The nomenclature in the left-most columns of Tables 3.1 to 3.3 is as presented by M&H. As indicated from review of the data, the majority of Indiana's in-service historic bridges (approximately 58%) are comprised of three types: concrete arch, metal pony truss, and metal thru truss bridges. The majority of Indiana's in-service historic bridges are on county roads or city streets with only a small percentage (13%) carrying either a state or a U.S. highway. Finally, the majority cross small waterways.

TABLE 3.1
In-Service Historic Bridges by Structure Type

	In-Service Bridges		Out-of-Service Bridges
Category	**Quantity**	**Percentage**	**Quantity**
Concrete Arch	175	26.6	9
Metal Arch	6	0.9	1
Metal Pony Truss	88	13.4	36
Metal Thru Truss	121	18.4	52
Prestressed Concrete Box Beam	11	1.7	1
Prestressed Concrete I-Beam	9	1.4	0
Reinforced Concrete Girder and Beam	79	12.0	4
Reinforced Concrete Rigid Frame and Box	6	0.9	1
Reinforced Concrete Slab	41	6.2	7
Steel Beam	17	2.6	1
Steel Deck Truss	8	1.2	0
Steel Girder	9	1.4	7
Steel Movable	1	0.1	0
Stone Arch	34	5.2	4
Timber Other	1	0.1	3
Timber Truss	52	7.9	12
Total	**658**	**100%**	**138**
Grand Total of Historic Bridges		**796**	

TABLE 3.2
In-Service Historic Bridges by Facility Carried

	In-Service Bridges	
Facility Carried	**Quantity**	**Percentage**
County Road	260	39.5
Named Street	317	48.2
State Highway	48	7.3
U.S. Highway	33	5.0
Total	**658**	**100%**

TABLE 3.3
In-Service Historic Bridges by Facility Crossed

	In-Service Bridges	
Facility Crossed	**Quantity**	**Percentage**
Named Street	3	0.5
State Highway	1	0.2
U.S. Highway	2	0.3
Creek	396	60.2
Ditch	28	4.3
Railroad	13	2.0
River	156	23.7
Canal	5	0.8
Other (Run, Branch, Fork, Hollow, Whitewater, Reservoir, Lake, Tunnel, Stream, Drain, Bayou)	54	8.2
Total	**658**	**100%**

The types of railings were not identified by M&H. Therefore, this study developed a naming system for the railings. This nomenclature is presented in Table 3.4 and images of each railing type are provided in Appendix C. In all, 61 different railing types were identified. Using this system, the railing types for each bridge were identified and the results are presented in Table 3.5.

TABLE 3.4
Historic Bridge Railing Types

Material	Railing Type	Description
Concrete	1 (Bush-Hammered Panel)	Concrete railing with sunk-in panels of aspect ratio greater than one (length / height)
	2	Concrete railing with rectangular outlines of aspect ratio greater than one (length / height)
	3	Concrete railing with sunk-in panels of aspect ratio approximately one (length / height)
	4	Concrete railing with capital block and posts
	5	Concrete railing with sunk-in archways
	6	Concrete railing with arch openings and posts
	7	Concrete railing with urn-shaped blocks and posts
	8	Concrete railing with diamond openings
	9	Concrete railing with ovular open blocks with capital blocks and posts
	10	Concrete railing with wide arch openings and posts
	11	Concrete railing with tall arch openings
	12	Concrete railing with rectangular openings of aspect ratio greater than one (length / height)
	13	Concrete railing with rectangular openings of aspect ratio greater than one (length / height) and posts
	14 (F-type)	F-type concrete railing
	15	Vertical face concrete parapet wall
	16	Two-tiered vertical face concrete railing with posts
	17	Two-tiered vertical face concrete railing without posts
	18	Three-tiered concrete railing with or without posts
	19	Three-tiered concrete railing with setbacks
	20	Three-tiered concrete railing with longitudinal outlines and end treatments
	21	Vertical face concrete parapet wall with capital block
	22	Concrete railing with thinner middle section
	23	Concrete railing with large blocks and posts and capital block
	24	Concrete railing consisting of trapezoidal sections with triangular openings
	25	Concrete railing with red brick facade and posts #1
	26	Concrete railing with red brick facade and posts #2
Metal	1	Three-tube semi-ovular metal railing
	2	Two-tube semi-ovular metal railing
	3	Two-bar rectangular metal railing without concrete parapet
	4	Single serif channel metal railing
	5 (Galvanized Beam)	Galvanized w-beam metal railing
	6	Metal lattice railing
	7	Single sans-serif channel metal railing
	8	Single rectangular tube metal railing
	9	Double rectangular tube metal railing
	10	Double angle metal railing
	11	Single angle metal railing
	12	Two-bar circular metal railing with posts
	13	Three-bar circular metal railing with posts
	14	Two-bar metal railing with fence posts
Metal and Concrete	1	Two-bar circular metal railing on top of a concrete parapet
	2	Two-bar square metal railing on top of a concrete parapet
	3	Two-bar circular metal railing with concrete posts
	4 (F-type w/ Handrail)	F-type concrete railing with a metal handrail on top
Pedestrian	1	Decorative metal fence railing #1 (with concrete posts)
	2	Decorative metal fence railing #2 (with concrete posts)
	3	Decorative metal fence railing #3 (with concrete posts)
	4	Decorative metal fence railing #4 (with concrete posts)
	5	Decorative metal fence railing #5 (without concrete posts or very few concrete posts)
	6	Decorative metal fence railing #6 (without concrete posts or very few concrete posts)
	7	Decorative metal fence railing #7 (without concrete posts or very few concrete posts)
	8	Decorative metal fence railing #8 (without concrete posts or very few concrete posts)
Stone	1	Round stone and mortar railing
	2	Rectangular stone vertical face railing
	3	Rectangular stone vertical face railing with capital stones
	4	Rectangular stone vertical face railing with capital stones and stone posts
	5	Rectangular interlocking stone blocks with rectangular openings
	6	Stone block railing with diamond openings (similar to Concrete 8)
Timber	1	Single-board timber railing
	2	Double-board timber railing
	3	Triple-board timber railing
	No Railing	No railing

TABLE 3.5
Historic Bridges by Railing Type

	Historic Bridge Railing Type	Quantity	Percentage
Concrete	1 (Bush-Hammered Panel)	74	11.25
	2	46	7.00
	3	2	0.31
	4	2	0.31
	5	1	0.15
	6	39	5.93
	7	12	1.82
	8	1	0.15
	9	1	0.15
	10	2	0.31
	11	1	0.15
	12	2	0.31
	13	1	0.15
	14 (F-type)	14	2.11
	15	24	3.65
	16	2	0.31
	17	6	0.91
	18	6	0.91
	19	4	0.61
	20	1	0.15
	21	3	0.46
	22	1	0.15
	23	2	0.31
	24	2	0.31
	25	1	0.15
	26	1	0.15
Metal	1	15	2.28
	2	9	1.37
	3	1	0.15
	4	1	0.15
	5 (Galvanized Beam)	75	11.40
	6	78	11.85
	7	9	1.37
	8	2	0.31
	9	24	3.65
	10	38	5.78
	11	1	0.15
	12	6	0.91
	13	1	0.15
	14	7	1.06
Metal and Concrete	1	8	1.22
	2	2	0.31
	3	1	0.15
	4 (F-type w/ Handrail)	1	0.15
Pedestrian	1	1	0.15
	2	1	0.15
	3	1	0.15
	4	1	0.15
	5	1	0.15
	6	2	0.31
	7	1	0.15
	8	1	0.15

(Continued)

TABLE 3.5
(Continued)

	Historic Bridge Railing Type	Quantity	Percentage
Stone	1	1	0.15
	2	10	1.51
	3	13	1.98
	4	1	0.15
	5	3	0.45
	6	1	0.15
Timber	1	47	7.14
	2	6	0.91
	3	2	0.31
Name	No Railing	35	5.32
	Total	**658**	**100%**

TABLE 3.6
Summary of Railing Types Observed on 5% or More of Bridges

Rank	Historic Bridge Railing Type	Quantity	Percentage
1	Metal 6	78	11.85
2	Metal 5 (Galvanized Beam)	75	11.40
3	Concrete 1 (Bush-Hammered Panel)	74	11.25
4	Timber 1	47	7.14
5	Concrete 2	46	7.00
6	Concrete 6	39	5.93
7	Metal 10	38	5.78
8	No Railing	35	5.32
	Total	**432**	**65.67%**

Figure 3.1 Metal 6 railing (Rank 1).

From review of Table 3.5, it is clear that some railing types are more common than others. Twenty-five railing types are evident on only a single historic bridge in the state, and 11 railing types are evident on only two historic bridges. Of particular interest is that only seven railing types have a percentage of 5% or greater. Furthermore, no railing whatsoever was observed on 5.3% of the bridges. The categories with more than 5% occurrence are highlighted in Table 3.5, summarized in Table 3.6, and illustrated in Figures 3.1 to 3.8. The railings are ranked in terms of the highest occurrence. While there were 61 different types of railings identified, the top 7 railings constitute two-thirds of all railings in use (Table 3.6). Based on this analysis, focusing retrofit strategies on a small number of railing types can have a significant impact. While the timber railings, and in particular Timber 1, constitute a large quantity of bridges, this railing type, which is predominantly on covered bridges, is considered outside the scope of this study and therefore will not be considered further.

Figure 3.2 Metal 5 (galvanized beam) railing (Rank 2).

Figure 3.3 Concrete 1 (bush-hammered panel) railing (Rank 3).

Figure 3.4 Timber 1 railing (Rank 4).

Figure 3.5 Concrete 2 railing (Rank 5).

Figure 3.6 Concrete 6 railing (Rank 6).

Figure 3.7 Metal 10 railing (Rank 7).

Figure 3.8 Bridges with no railing (Rank 8).

4. BRIDGE RAILING RETROFIT STRATEGIES

4.1 Introduction

Three different retrofit strategies for guardrails on Indiana's historic bridges were identified. Research focused on developing solutions that can be immediately used, rather than developing completely new railings that require crash-testing programs. Therefore, all solutions are based on previously crash-tested and accepted bridge railings.

Avoidance of crash testing is not unprecedented. Frederick G. Wright Jr. of the Federal Highway Administration (FHWA) discussed how guardrails may be admissible without crash test programs in a May 16, 2000, memorandum to FHWA Resource Center directors and division administrators. He discussed a railing design and analysis project undertaken by the Colorado Department of Transportation (CDOT). CDOT designed a new railing which was similar to a previously crash tested and accepted railing. CDOT then analyzed the capacity of the previously accepted railing and modified its design to ensure it possessed the same strength.

FHWA accepted the new CDOT railing without crash testing (Wright, 2000).

Bridge engineers could use this type of analysis as a basis for acceptance of bridge railings that are similar to a design that has been accepted under NCHRP Report 350/MASH guidelines. Mr. Wright expressed a desire to provide highway agencies a greater choice of railing designs without requiring unnecessary testing. He also cautioned that all possible railing failure modes must be considered carefully when this type of analysis is utilized (Wright, 2000).

4.2 Bridge Railing Design Parameters

Before a retrofit strategy can be chosen, two bridge railing design parameters must be considered. The two parameters are the Test Level (TL) required and the presence/absence of a sidewalk. In Indiana, all new bridges and bridge retrofits are subject to the requirements of the current edition of the *Indiana Design Manual* (IDM). Chapter 404, "Bridge Deck" provides details on the design of bridge railings.

The Test Level (TL) required is a function of the design speed of the facility carried, the Annual Average Daily Traffic (AADT), the percentage of trucks on the facility carried, the bridge railing offset, the geometry of the bridge and adjacent sections of roadway, the height of the bridge deck, and the type of land use below the bridge (INDOT, 2013). The AADT and percentage of trucks of the AADT must be known in order to use the IDM to ascertain the required railing Test Level (TL) for a bridge.

The presence or absence of a sidewalk also controls the type of railing that can be specified. If a sidewalk is present, a 42-in. tall railing is required. Additionally, the design speed on a bridge affects the type of required railing(s).

4.2.1 Required Test Level

The *Indiana Design Manual* (IDM) considers only three of the six AASHTO-prescribed Test Levels: TL-2, TL-4, and TL-5. The IDM contains the complete procedure for determining the required TL, and this procedure is provided in IDM Chapter 404 (INDOT, 2013).

TL-2: Generally appropriate on a bridge which is not on the state highway system or on a bridge that is on the state highway system and has a design speed of 45 mph or lower.

TL-4: Generally appropriate on a bridge which does not meet the criteria for a TL-2 railing or for a bridge that is on the state highway system and has a design speed of 50 mph or higher.

TL-5: Generally appropriate on a bridge that is on the state highway system and has a high AADT or a high percentage of truck traffic.

In the instance that a bridge railing is rated at TL-4, but the IDM procedure calls for a TL-5 railing, it is acceptable to leave the TL-4 railing in place "for a minor bridge rehabilitation project which does not include bridge deck replacement or deck widening." The TL-4 railing must be replaced by a TL-5 railing if the rehabilitation project involves deck replacement or deck widening (INDOT, 2013).

4.2.2 Presence/Absence of a Sidewalk

The presence/absence of a sidewalk on a bridge affects the type of railing that can be installed in a retrofit project. If a sidewalk is present, either of the two following conditions applies to the railing selection for a bridge, based on design speed (INDOT, 2013).

Design speed of 45 mph or lower. Only a railing shown to be crashworthy in the presence of a sidewalk may be chosen. A pedestrian/traffic combination railing must be selected. A pedestrian/traffic combination railing is a railing that satisfies the Test Level requirement due to the adjusted AADT and satisfies the height requirement for a pedestrian railing, which is at least 42 in., measured from the surface of the walkway. The railing is required to be placed at the coping. Furthermore, Section 13.11.2 of the AASHTO *LRFD Bridge Design Specifications* requires that a barrier curb, not exceeding 8 in. in height, separate the sidewalk from the roadway (AASHTO, 2014). Figure 4.1 shows a typical barrier curb and details the height limitation.

Design speed of 50 mph or higher. A bridge railing must be placed between the sidewalk and the roadway. An accompanying pedestrian railing is required to be placed at the coping. The sidewalk must be laterally protected on both sides. Both the outer pedestrian railing and the inner pedestrian/traffic combination railing shall be at least 42 in. in height, measured from the surface of the walkway. Indiana permits the sidewalk to be at the same elevation of the roadway surface in this instance (INDOT, 2013).

4.2.3 Horizontal Roadway Clearance on a Bridge

Although not a design parameter for railings on new bridges, the horizontal roadway clearance on a historic bridge can be restrictive to remedial efforts. A new

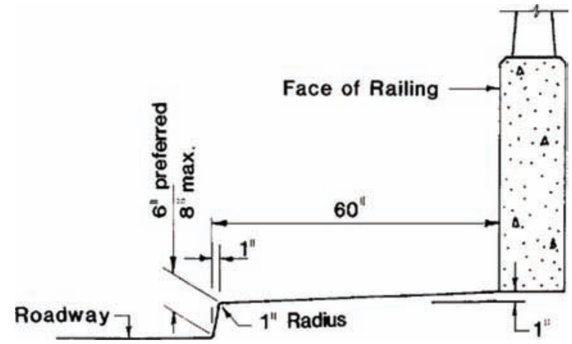


Figure 4.1 Typical barrier curb on a bridge with 8 in. height limitation (AASHTO, 2014).

bridge can simply be designed to be wide enough to accommodate any bridge railing, but a historic bridge generally cannot be widened. In both rural and urban environments, new bridges or bridges under reconstruction are required to have a horizontal clearance equal to the width of the traveled way plus additional clearance for shoulders. The traveled way typically consists of lanes 10 ft to 12 ft wide and shoulders are typically 2 ft to 10 ft wide (INDOT, 2013). Many historic bridges have lanes narrower than 12 ft and shoulders narrower than 4 ft. If a retrofit strategy for a historic bridge railing would infringe upon the horizontal roadway clearance, it cannot be implemented.

4.3 Inboard Retrofit

One retrofit option is to install a modern railing inside of the original railing, and the new railing is referred to as an inboard rail. This technique has previously been used in Indiana as shown in Figure 4.2. In the early 2000s, a metal thru truss carrying State Road 75 across Wildcat Creek in Carroll County, Indiana was retrofitted with the INDOT CF-1, which is equivalent to the Oregon Department of Transportation (ODOT) two-tube curb-mounted railing. The CF-1 railing is no longer a standard in Indiana, but is still standardized in Oregon. The metal tube railing was installed inside of the original railing.

Installing an inboard rail is an attractive option for a bridge that has the necessary horizontal clearance to accommodate it. Another benefit of installing an inboard railing is the ability to choose a railing through which drivers can see the original railing, thus maintaining the historic appearance of the bridge. Unfortunately, many historic bridges have narrow deck widths. An inboard railing cannot be installed on a bridge if it would exacerbate a lane width deficiency.

Figure 4.3 shows a rendering of another possible inboard rail. An existing Metal 6 railing can be protected by the ODOT two-tube railing without compromising the historic appearance of the bridge.

4.4 Curb Retrofit

A total of 113 historic bridges have sidewalks. In these cases, another retrofit option is to provide an inboard rail that is located at the curb. This railing is known as the Washington D.C. curb railing for its place of origin (FHWA, 2005). This option has the advantage of protecting the sidewalk from errant vehicles. Furthermore, INDOT does not require the original railing to be replaced if the curb railing option is exercised. A disadvantage of the Washington D.C. railing, however, is that it is rated at TL-2, meaning it cannot be used on bridges with design speeds of 50 mph or higher.

This may not be a severe disadvantage considering that many historic bridges are on lower design speed roadways. Figure 4.4 shows a rendering and implementation of the Washington D.C. curb railing.

4.5 Railing Replacement

A third retrofit option is to replace a historic railing with a simulated historic railing. The *Indiana Design Manual* (IDM) allows modern railings to be modified for project-specific use. An advantage of this option is that a railing can be designed to closely match the appearance of a historic railing, although in some cases it may not be possible to design a close approximation.

Figure 4.2 A metal thru truss with an inboard railing.

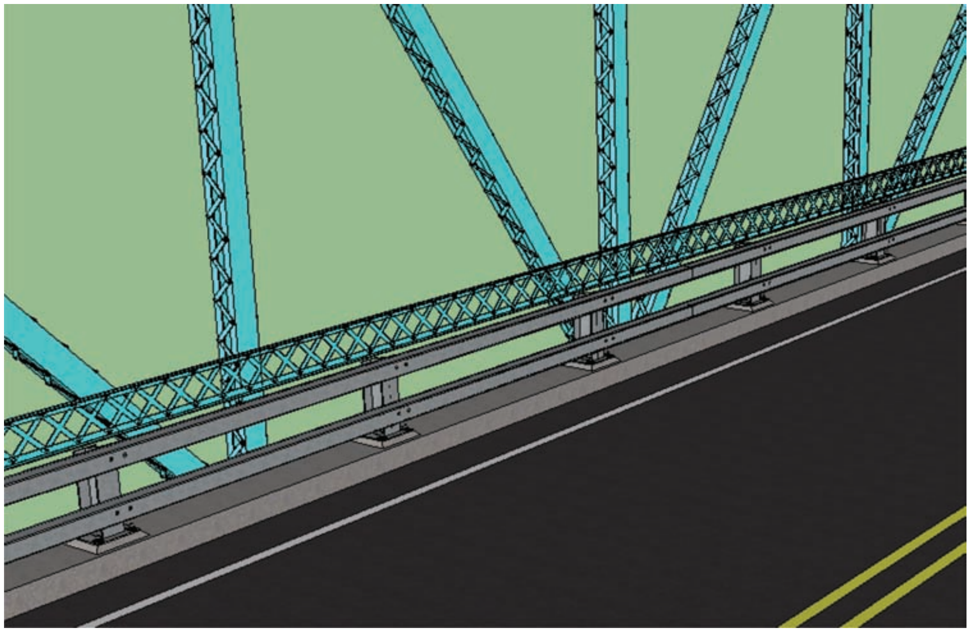


Figure 4.3 ODOT two-tube railing inside of a Metal 6 railing.

Figure 4.4 Washington D.C. curb railing (FHWA, 2005).

Modern crash-tested and approved reinforced concrete and metal tube railings were modified to match the appearance of 42 historic railings. Two approaches were used. For reinforced concrete railings, the approved railing cross-section was expanded and altered. For metal tube railings, attachments for the approved railings were designed. The 42 simulated historic railings were designed to satisfy the requirements of the IDM. Three of the historic railing types were timber, and therefore, were outside the scope of this research and not considered.

Sixteen of the observed railings on historic bridges did not possess a historic look, did not possess acceptable geometry under modern crash test standards, and did not exemplify historic craftsmanship; therefore, they were not replicated.

Drawings of the Concrete 1 railing (Bush-Hammered Panel) from circa 1940 were provided by INDOT. These drawings aided the design of a modern railing that approximated this railing. Unfortunately, detailed drawings of other railing types were not available.

Table 4.1 outlines the railings that were approximated as well as those that were not. For railings that were approximated, the crash-tested base railing is listed along with the modification required. For those that were not approximated, the reason for not replicating is provided. Renderings and drawings were produced for each of the 42 historic railings that were approximated with a modern railing. For some historic railings, two simulated railings were developed. A picture of each historic railing, paired with the modern base railing used to approximate it, as well as the simulated railing are provided in Appendix D. Drawings of each simulated railing are included in Appendix E.

4.5.1 Reinforced Concrete Railings

The primary functions of bridge railings are to keep vehicles from driving off the structure and to safely redirect vehicles during an impact with the railing. Therefore, bridge railings are designed to prevent vehicle snagging and to prevent the railing from protruding

TABLE 4.1
Historic Railing Approximation Methods

	Historic Railing	Base Railing	Approximation Method
Concrete	1 (Bush-Hammered Panel)	TxDOT T221	Custom forms
	2	TxDOT T221	Custom forms
	3	TxDOT T221	Custom forms
	4	TxDOT T221	Custom forms
	5	TxDOT T221	Custom forms
	6	INDOT TX	No modification necessary
	7	ODOT Concrete Beam and Post	Custom forms and infill
	8	ODOT Concrete Beam and Post	Custom forms and infill
	9	ODOT Concrete Beam and Post	Custom forms and infill
	10	ODOT Concrete Beam and Post	Custom forms and infill
	11	ODOT Concrete Beam and Post	Custom forms and infill
	12	ODOT Concrete Beam and Post	Custom forms and infill
	13	ODOT Concrete Beam and Post	Custom forms and infill
	14 (F-type)	None	This is a modern railing
	15	TxDOT T221	No modification necessary
	16	TxDOT T221	Custom forms and infill
	17	TxDOT T221	Custom forms and infill
	18	TxDOT T221	Custom forms and infill
	19	INDOT FC	Custom forms and infill
	20	TxDOT T221	Custom forms and infill
	21	None	Does not possess historic appearance
	22	ODOT Concrete Beam and Post	Custom forms and infill
	23	TxDOT T221	Custom forms and infill
	24	None	Unfavorable geometry, does not possess historic appearance
	25	TxDOT T221	Masonry attachments
	26	TxDOT T221	Masonry attachments
Metal	1	ODOT Three-Tube Railing	No modification necessary
	2	ODOT Two-Tube Railing	No modification necessary
	3	ODOT Two-Tube Railing	No modification necessary
	4	Caltrans Concrete Barrier Type 90	No modification necessary
	5 (Galvanized Beam)	None	Does not possess historic appearance
	6	ODOT Two-Tube Railing	Metal attachments
	7	None	Does not possess historic appearance
	8	None	Does not possess historic appearance
	9	ODOT Two-Tube Railing	No modification necessary
	10	None	Does not possess historic appearance
	11	None	Does not possess historic appearance
	12	None	Does not possess historic appearance
	13	None	Does not possess historic appearance
	14	ODOT Two-Tube Railing	Metal attachments
	1	None	This is a modern railing
	2	None	This is a modern railing
	3	None	Does not possess historic appearance
	4 (F-type w/ Handrail)	None	This is a modern railing
Pedestrian	1	TxDOT PR3	Metal attachments
	2	TxDOT PR3	Metal attachments
	3	TxDOT PR3	Metal attachments
	4	TxDOT PR3	Metal attachments
	5	ODOT Pedestrian Rail	Metal attachments
	6	TxDOT PR3	Metal attachments
	7	ODOT Pedestrian Rail	Metal attachments
	8	None	Special case

(Continued)

TABLE 4.1
(Continued)

	Historic Railing	Base Railing	Approximation Method
Stone	1	TxDOT T221	Formliners
	2	TxDOT T221	Formliners
	3	TxDOT T221	Formliners
	4	TxDOT T221	Formliners
	5	None	Does not possess acceptable geometry
	6	ODOT Concrete Beam and Post	Custom forms and infill
Timber	1	None	Special case: covered bridge
	2	None	Special case: covered bridge
	3	None	Special case: covered bridge

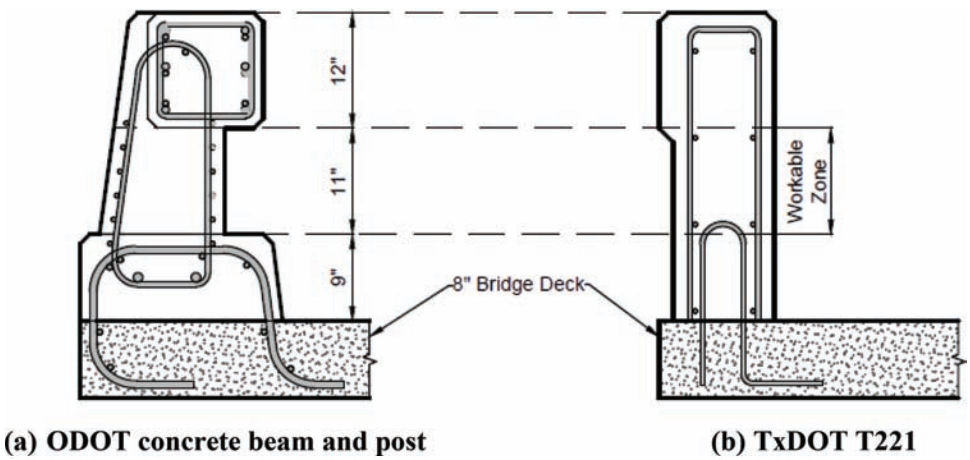


Figure 4.5 Workable zone of a reinforced concrete railing.

into a vehicle during an impact (Ross et al., 1993). The vehicle redirection features of the Oregon Department of Transportation (ODOT) concrete beam and post railing were investigated because of the versatility of its shape as well as its crash-resistant geometry. A cross-section of the ODOT concrete beam and post railing is shown in Figure 4.5(a). The railing has a 9-in. high parapet curb for stopping the advance of tires and a 12-in. beam for stopping the advance of bumpers. The parapet curb and the beam of the ODOT concrete beam and post railing are the vehicle-redirecting features of this railing.

The region between the curb and the beam provides strength, but is not part of the vehicle-redirecting features. Therefore, it was considered that railing geometry in this zone can be adjusted with limitations. First, an alteration in shape cannot protrude outside of the original cross-section in this zone. Second, the structural geometry of the approved railing cannot be reduced. Third, the reinforcement cannot be modified to reduce its capacity.

The concrete in this zone between the curb and beam was termed the "workable zone" which allowed for adjustments in geometry such that the geometry of historical railings could be approximated.

To approximate reinforced concrete historical bridge railings, the geometry of two approved railings was considered. These include the ODOT concrete beam and post and the TxDOT T221. Both are TL-4 rated which allow for use on essentially all historic bridges in the state. Figure 4.5 illustrates the workable zone for both railings. The ODOT concrete beam and post and the TxDOT T221 railings serve as the base form from which to replicate or approximate several historic railings (Table 4.2).

4.5.1.1 TxDOT T221 Railing. The TxDOT T221 was the basis for 17 of the 42 simulated railings (Table 4.2). The TxDOT T221 is a favorable baseline for modification because it possesses a simple geometry as shown in Figure 4.6 and is a crash-tested TL-4 railing. Therefore, this railing can be easily utilized and mobilized in a wide range of scenarios.

There are two primary approaches used to modify this railing. The first is through the use of formwork within the workable zone, and the second is through the use of formliners.

4.5.1.1.1 Approximation with Custom Formwork. A bridge with the Concrete 1 (Bush-Hammered Panel) railing is shown in Figure 4.7. A cross-section of an original Bush-Hammered Panel, taken from a 1937 drawing by the State Highway Commission of Indiana, is shown in Figure 4.8. This railing does not satisfy modern crash test standards; however, it is possible to

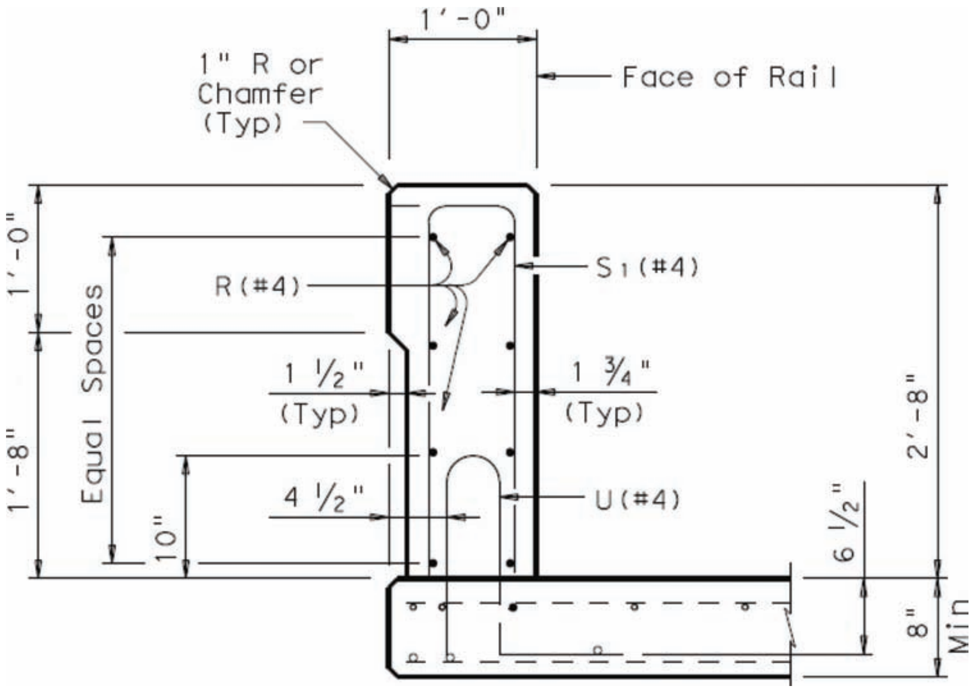


Figure 4.6 Cross-section of the TxDOT T221 railing (TxDOT, n.d.).

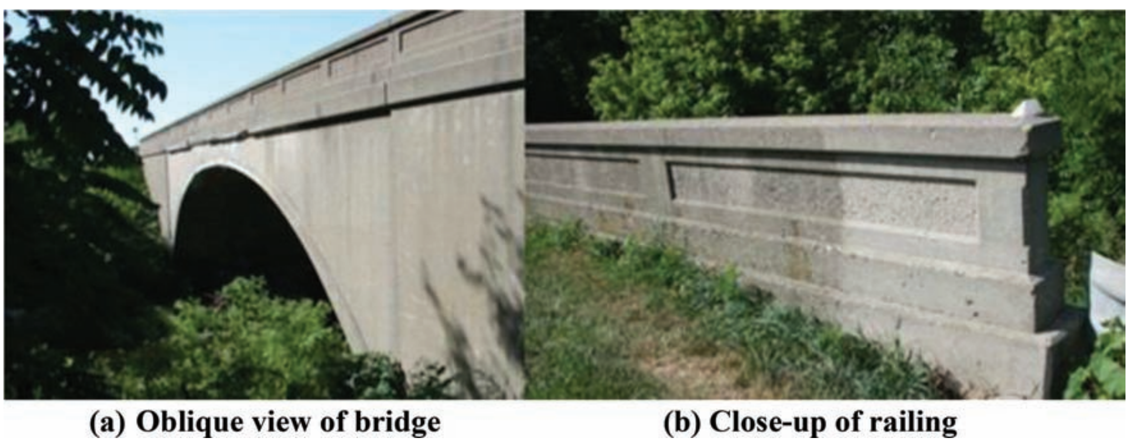


Figure 4.7 Historic bridge with a bush-hammered panel railing.

develop a modification of the TxDOT T221 railing to approximate the same appearance.

To maintain the appearance of the Bush-Hammered Panel railing and maintain the crash test acceptability of the T221, the T221 railing's cross-section was expanded to accommodate the sunk-in panels of the Bush-Hammered Panel railing, as shown in Figure 4.9. An elevation view is provided in Figure 4.10. There are three key features of the approximated railing. First, the retrofit Bush-Hammered Panel cross-section is sized such that it contains the full size and strength of the T221 railing. Second, the size and location of the reinforcement of the T221 railing were not altered. Third, the sunk-in panels of the new Bush-Hammered Panel railing are contained entirely within the workable zone to provide appropriate crash geometry.

A rendering of the retrofit Bush-Hammered Panel railing is shown in Figures 4.11 and 4.12 on a historic concrete arch bridge. It is important to note that the new Bush-Hammered Panel is an approximation of the original. The geometric characteristics of the workable zone limit the degree to which the original railing can be approximated in the interest of the safety of the impacting vehicle. A similar approach was used to construct approximations of 21 other historic reinforced concrete railings as outlined in Table 4.1.

4.5.1.1.2 Approximation with Formliners. Standard production formliners can be used in conjunction with the TxDOT T221 railing to approximate a number of railings, including Stone 1 (Figure 4.13), Stone 2 (Figure 4.14), Stone 3 (Figure 4.15), and Stone 4 (Figure 4.16). As an example, Custom Rock (n.d.a, n.d.b., n.d.c) produces a variety of formliners, three of which can be used to approximate a historic railing as listed in Table 4.2. Railing texture is created by the formliners while railing color, through the use of concrete stains or color added to the concrete mix, can be provided to enhance the appearance of the railing.

Relief is a unique characteristic of every formliner. The relief of a formliner is the formliner's maximum depth, and the relief of a particular formliner was accounted for when the simulated historic railings were designed. As shown in Figure 4.9, the size and shape of the cross-section of the base railing (TxDOT T221) is an absolute minimum that cannot be infringed upon.

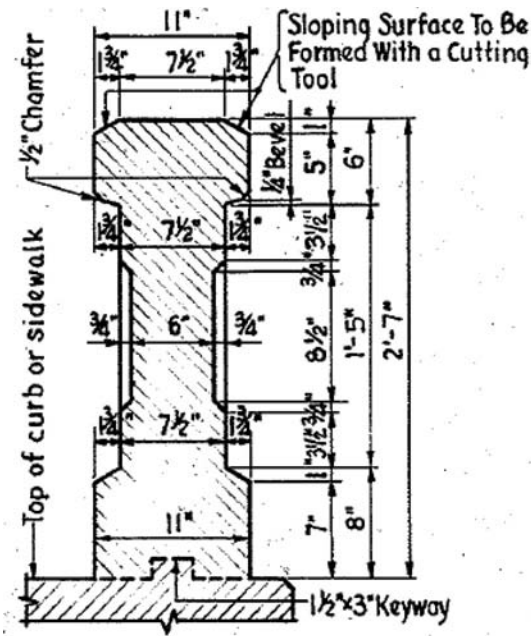


Figure 4.8 Cross-section of the bush-hammered panel railing.

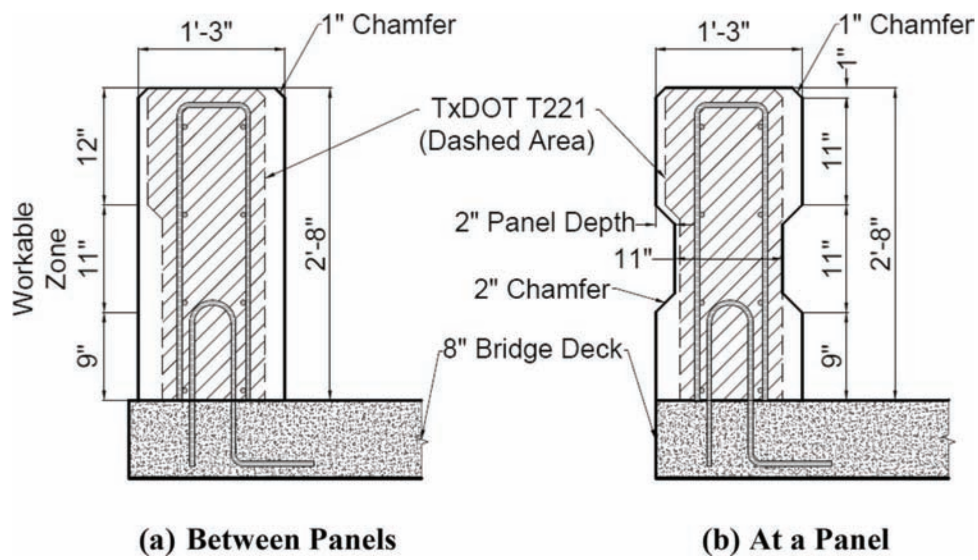


Figure 4.9 Cross-section of a retrofit bush-hammered panel railing.

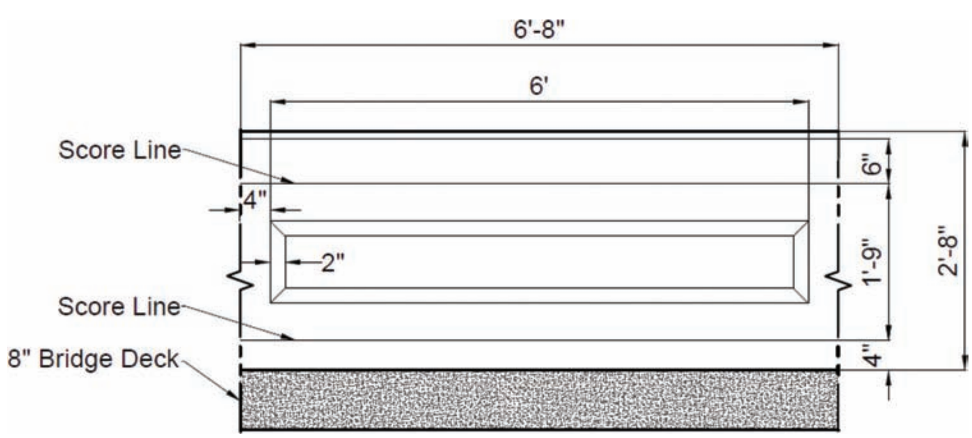


Figure 4.10 Elevation view of the retrofit bush-hammered panel railing.

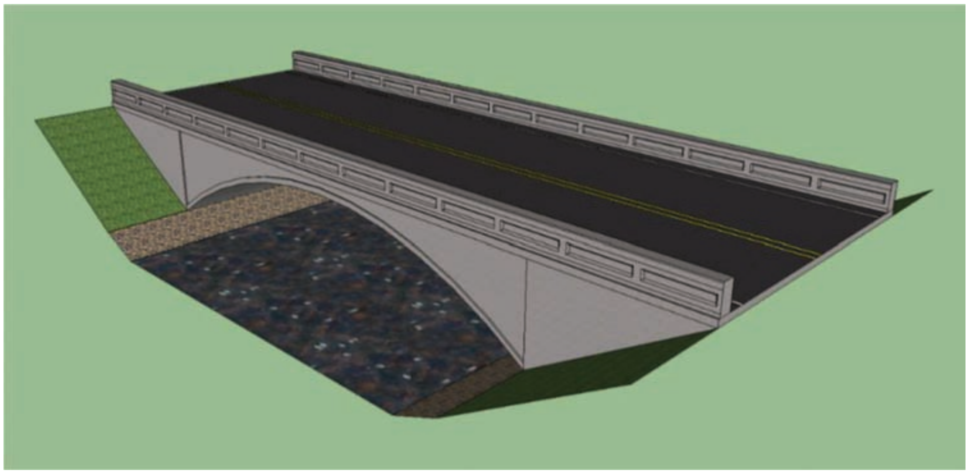


Figure 4.11 Retrofit bush-hammered panel on a historic concrete arch bridge.

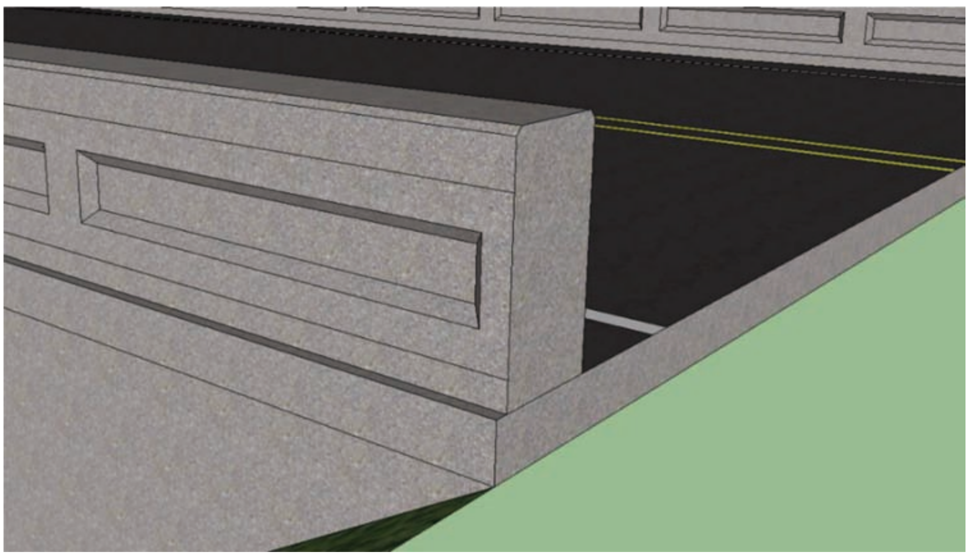


Figure 4.12 Close-up view of the retrofit bush-hammered panel railing.

TABLE 4.2
Historic Railings and Approximating Custom Rock Formliners

Historic Railing	Custom Rock Formliner Name
Stone 1	Yosemite Stone
Stone 2	New England Drystack
Stone 3	New England Drystack
Stone 4	Tollway Ashlar

(a) Railing Detail (b) Formliner: "Yosemite Stone"

Figure 4.13 Stone 1 railing.

(a) Railing Detail (b) Formliner: "New England Drystack"

Figure 4.14 Stone 2 railing.

(a) Railing Detail (b) Formliner: "New England Drystack"

Figure 4.15 Stone 3 railing.

(a) Railing Detail (b) Formliner: "Tollway Ashlar"

Figure 4.16 Stone 4 railing.

4.5.1.2 ODOT Concrete Beam and Post Railing. The ODOT concrete beam and post was the basis for 9 of the 42 simulated railings. Figure 4.17 shows a cross-section of the ODOT concrete beam and post railing. The concrete beam and post is a favorable baseline for modification because a variety of geometries can be constructed in its openings. The openings can also be filled to create a different appearance. Similar to the TxDOT T221, the concrete beam and post is a TL-4 railing, making it acceptable in low speed (45 mph or lower) or high speed (50 mph or higher) applications.

To provide an example of the use of the ODOT concrete beam and post railing, it can be modified to approximate the appearance of the railing shown in Figure 4.18. Figure 4.19(a) shows the ODOT concrete beam and post railing in its standard configuration, and Figure 4.19(b) shows it in its modified configuration. The arched openings of the Concrete 11 railing were recreated in the openings of the concrete beam and post. This modification does not reduce the structural strength of the railing or influence its crash resistance geometry.

4.5.2 Metal Tube Railings

Metal tube railings are very useful for use as base railings, especially for use on historic truss bridges. Metal attachments can be added to the back sides of the tubes to recreate 6 historic railings (Table 4.1). Both the two- and three-tube ODOT metal railings were selected for use. While both railings are rated as TL-4, the two-tube railing is 32.5 in. tall while the three-tube railing is 42 in. tall. Figure 4.20 compares the cross-sections of the different tube configurations.

The metal thru truss shown in Figure 4.21 carries State Road 11 across the East Fork White River in Jackson County, Indiana. The bridge has the Metal 5 (Galvanized Beam) railing type, a railing type which is not desired to replicate because it is neither sturdy enough to withstand an impact nor exemplary of a historic look. Metal thru truss bridges with railings such as the one shown in Figure 4.21 are strong candidates for use of a modified metal tube railing.

A similar metal thru truss bridge that still possesses its original railing is shown in Figure 4.22. The light green Metal 14 railing shown is a historically accurate railing for a metal thru truss and can be approximated as shown in Figure 4.23. In this manner, the Galvanized Beam railing used on the bridge in Figure 4.21 can be replaced with a more aesthetic railing, improving safety in the process.

Another retrofit is shown in Figures 4.24 and 4.25. The Metal 6 railing on the pony truss bridge shown in Figure 4.24 is characterized by metal strips arranged in a lattice pattern. Metal attachments can be added to the ODOT two-tube railing to match the appearance of a historic Metal 6 railing. This solution is desirable because it removes the railing from the truss members while also improving the overall aesthetics of the bridge.

4.5.3 Pedestrian Railings

Pedestrian railings are subject to different requirements than traffic railings. Section 13.8 of the

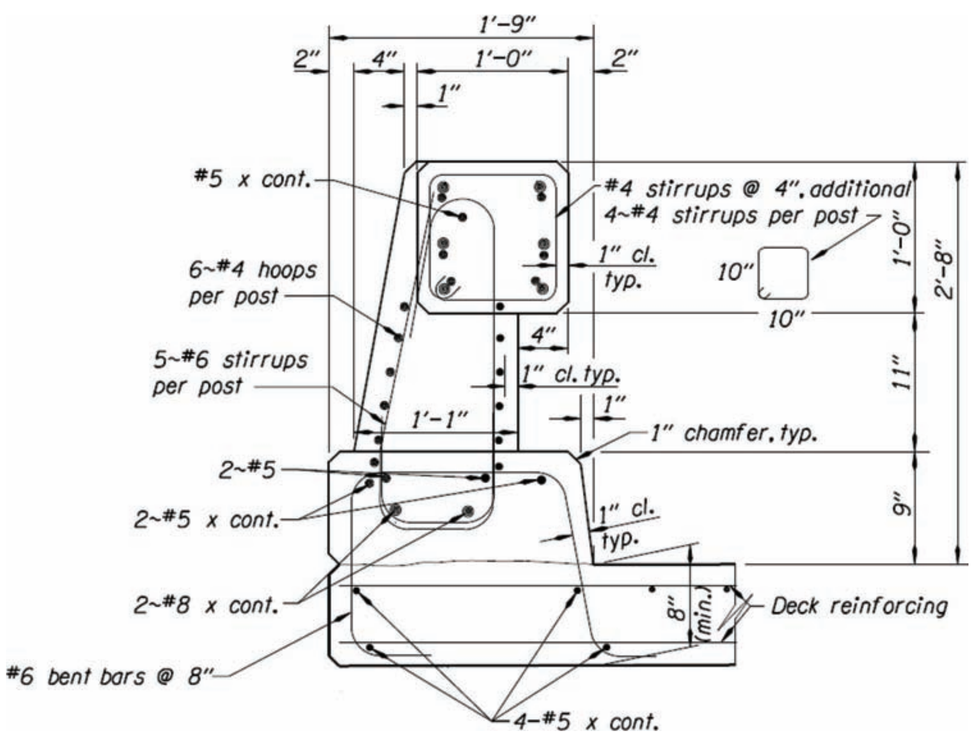
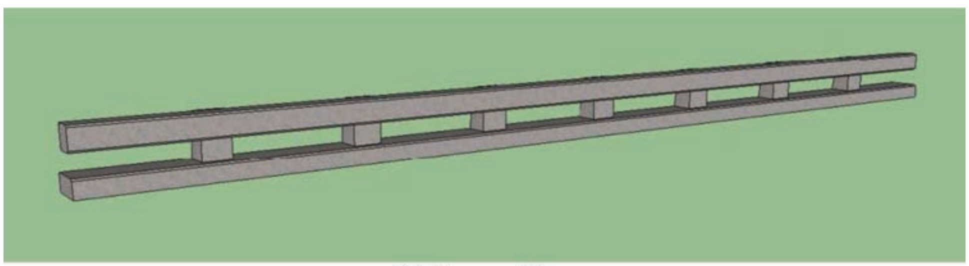
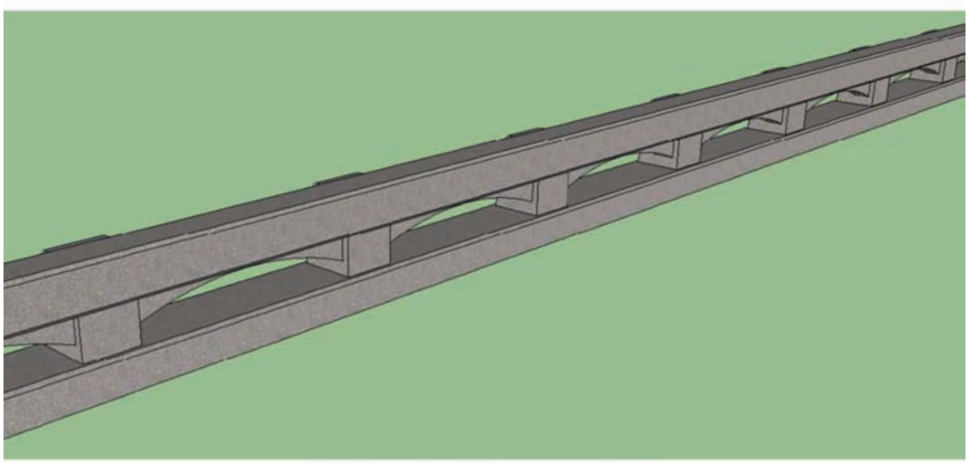


Figure 4.17 Cross-section of the concrete beam and post railing (ODOT, n.d.).

Figure 4.18 Concrete 11 railing.



(a) Base railing



(b) Simulated historic railing

Figure 4.19 ODOT concrete beam and post modified to approximate Concrete 11.

AASHTO *LRFD Bridge Design Specifications* contains the design requirements for pedestrian railings (AASHTO, 2014). In general, all pedestrian railings must be at least 42 in. tall. The openings in a pedestrian railing must be proportioned such that a 6 in. diameter sphere cannot pass through an opening in the lower 27 in. of the railing and that an 8 in. diameter sphere cannot pass through an opening above the lower 27 in.

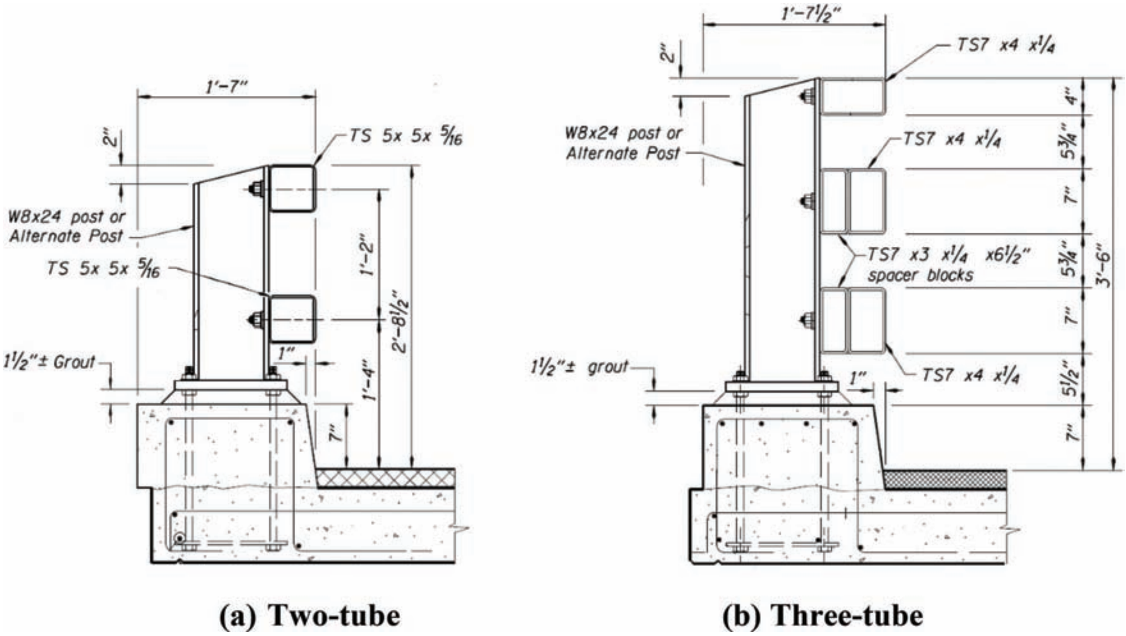


Figure 4.20 ODOT metal tube railing cross-sections (ODOT, n.d.).

Figure 4.21 Metal thru truss with a railing ineligible for replication.

of the railing. Furthermore, if a chain-link fence is used in a pedestrian railing, the openings of the mesh cannot exceed 2 in.

Contrary to traffic railings, pedestrian railings do not require crash testing; however, AASHTO still prescribes design forces. The design live load for a pedestrian railing is 50 lb/ft, acting horizontally and vertically on each longitudinal element of a railing, as shown in Figure 4.26. Additionally, a concentrated load of 200 lb is applied to a longitudinal element at any point in any direction, acting simultaneously with the distributed live load. Finally, the posts of pedestrian railings must be designed for a transverse concentrated load of at least 200 lb applied at the center of gravity of the upper longitudinal element or at a height of 5 ft, whichever is smaller (AASHTO, 2014).

Because pedestrian railings do not require crash testing, nearly perfect approximations of seven of the eight found in Indiana were possible (Pedestrian 1 through 7). The Pedestrian 8 railing was observed on only one bridge, a bascule bridge in LaPorte County. The bridge's counter-weights may have to be adjusted if a new railing is installed. For this reason, Pedestrian 8 is considered a special case and it was not replicated.

Figure 4.22 Close-up of Metal 14 railing (light green).

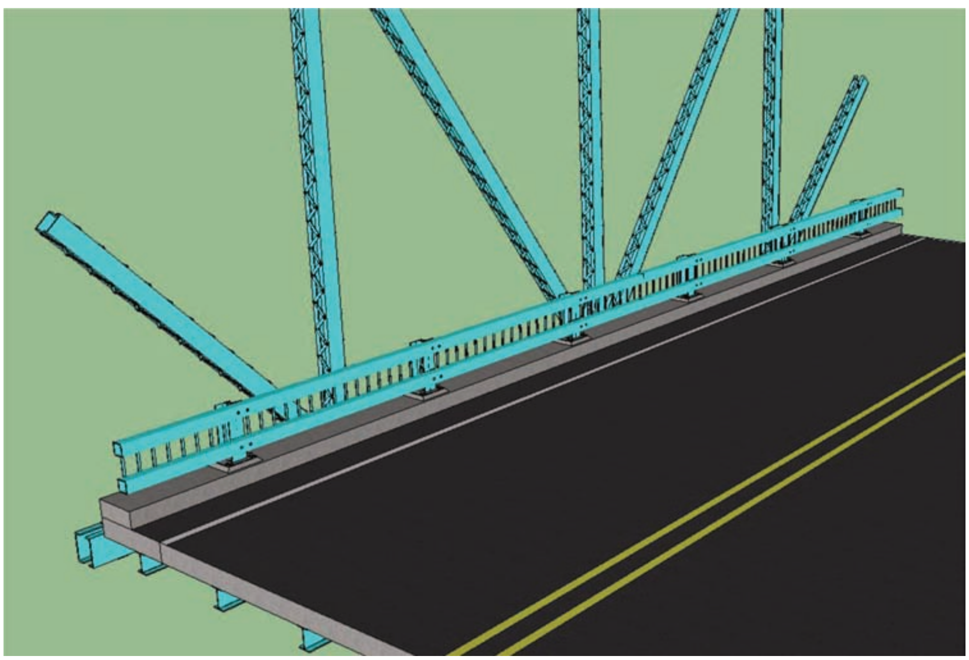


Figure 4.23 Modified ODOT two-tube railing on a metal thru truss.

The seven approximated pedestrian railings are loosely based on either the Texas Department of Transportation (TxDOT) PR3 railing (Figure 4.27) or the Oregon Department of Transportation (ODOT) Pedestrian Rail (Figure 4.28). Standard drawings of the pedestrian railings are shown in Appendix A, and photographs of the pedestrian railings are provided in Appendix D. Drawings of the simulated modern pedestrian railings are shown in Appendix E.

4.5.4 Summary of Design Methodology

The methodology for the development of a simulated historic railing is as follows:

1. Select a modern crash-tested traffic railing or pedestrian railing to serve as a baseline. These include TxDOT PR3, TxDOT T221, ODOT concrete beam and post, ODOT two-tube curb-mounted, ODOT pedestrian, and the INDOT FC.

Figure 4.24 Metal 6 railing on historic pony truss bridge.

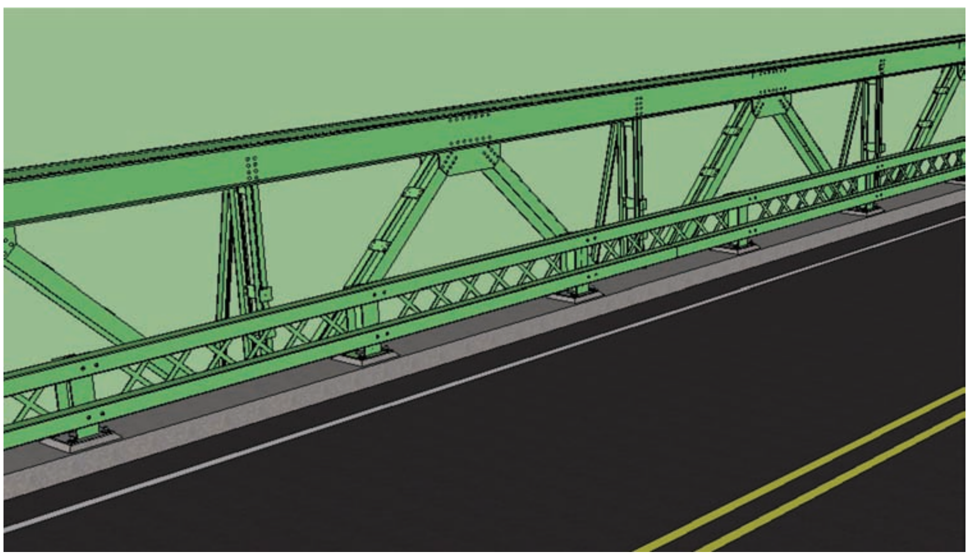


Figure 4.25 Modified ODOT two-tube railing.

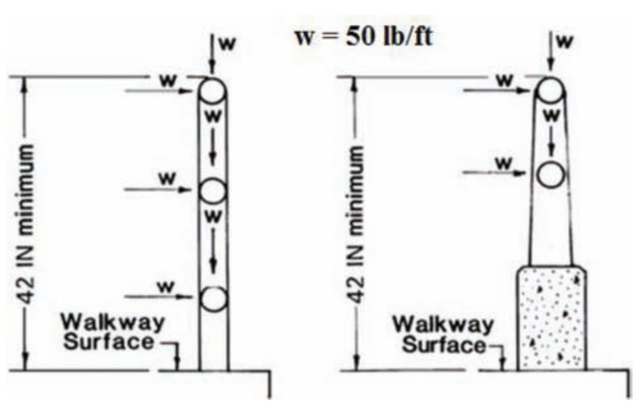


Figure 4.26 Application of distributed load on a pedestrian railing (AASHTO, 2014).

Figure 4.27 Rendering of the TxDOT PR3 railing.

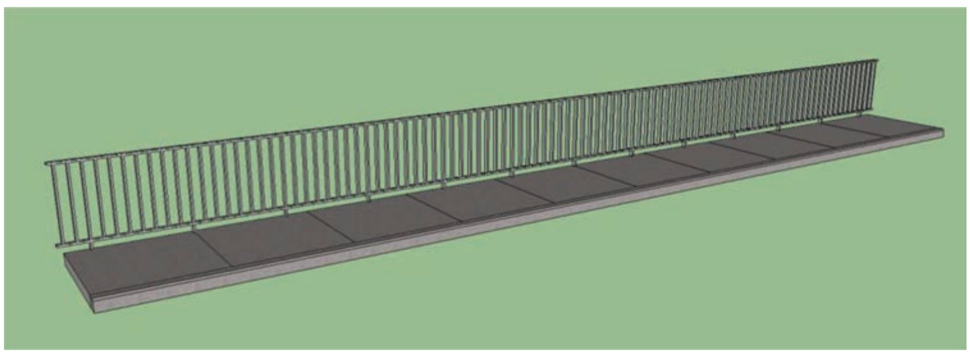


Figure 4.28 Rendering of the ODOT pedestrian rail.

2. Expand the cross-section, leave the reinforcement details exactly the same, and make desired geometric modifications in the "workable zone" (reinforced concrete railing) or add non-structural attachments (metal tube railing).
3. Develop drawings and renderings of the simulated historic railing. Because the cross-sections were expanded and the reinforcement was not altered, railing strength is considered to be adequate. This overall approach can be used to simulate any historic railing. The majority of railings used in Indiana were designed and are included in Appendix D (renderings) and Appendix E (design drawings).

4.6 Retrofit Selection Procedure

Figure 4.29 presents a visual guide to the process of selecting a retrofit. Orange boxes contain solution strategies. A distinction is made between TL-2 railings and TL-4 railings because the Washington D.C. curb railing is only applicable on bridges for which a TL-2 railing is appropriate.

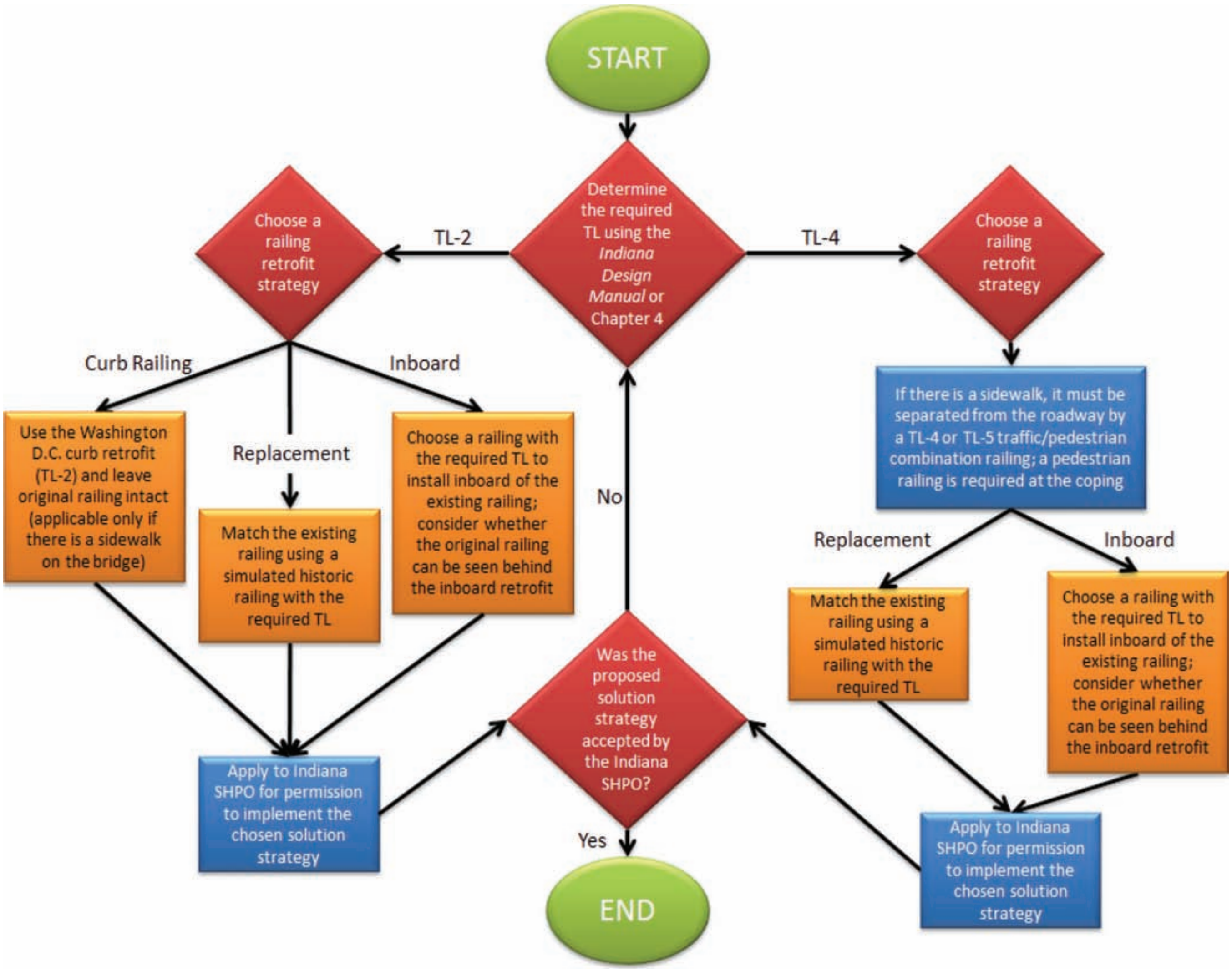


Figure 4.29 Flowchart for selecting a retrofit strategy.

5. SUMMARY AND CONCLUSION

5.1 Summary

In July 2006, the Indiana Department of Transportation (INDOT) began a programmatic agreement with the Federal Highway Administration (FHWA) to manage and maintain its historic bridges. This agreement signaled the beginning of Indiana's effort to preserve its historic bridges. As of January 2014, 658 historic bridges remain in service in Indiana. Preserving these historic bridges is important especially considering the rich cultural icons that these bridges represent.

Most of the 658 historic bridges in the state have railings that do not meet current strength and safety standards. The objective of this study was to develop strategies that can be used to address existing railings on historic bridges and to develop solutions that meet current design requirements. Previous research has focused on developing retrofit railings through rigorous design and crash-testing programs. Moreover, previous research has focused on developing railings for specific bridges. These methods were not preferred for use in Indiana due to the variety and range of historic bridges in the state's inventory.

5.2 Conclusions

Indiana is among 19 states that have a programmatic agreement to manage its historic bridges. Indiana's historic bridge inventory was investigated to determine how many historic bridges remain in service as well as to document the types and variety of historic railings in existence. As of January 2014, 658 historic bridges remain in service in Indiana. On these 658 historic bridges, 61 different historic railings were identified. Of these, 7 railing types, along with bridges with no railing, constitute two-thirds of the entire inventory. It is interesting that 25 of the other railings occur on only one single bridge and 11 of the other railings occur on only two bridges. Therefore, 59% of the different railing types are unique. Based on this analysis, research focused on addressing the most common railings identified. However, an attempt was also made to address as many of the unique railings as possible.

Three different options utilizing modern, previously crash tested railings were identified to upgrade the railings on Indiana's historic bridges. The first option is to install a modern railing inside of the original railing. When this option is exercised, the original railing may remain on a bridge. The second option is to install a special inboard railing on the curb. This special railing, which can be used if the bridge has a sidewalk, protects pedestrians on the sidewalk and allows the original railing to be retained. The third option is railing replacement. A collection of approved, crash-tested railings developed by a number of states was used as a baseline to design simulated railings to approximate the appearance of historic railings.

Simulated railings were developed to cover a variety of historic concrete and steel railings. These railings maintained the overall structure and crash resistant geometry of the base railing while integrating geometric features of the historic railing. In all, it was possible to simulate 42 of the historic railings existing in Indiana. These railings cover 66.3% of all historic bridges in the state. Three timber railing types, which were not considered in the scope of this research, accounted for 8.4% of all historic bridges in the state. Sixteen railing types did not possess a historic look, did not possess acceptable geometry, or did not exemplify historic craftsmanship. These railings accounted for 25% of all historic bridges in the state.

Through the use of strategies developed in this research, it is possible to retain historic railing appearance of the majority of historic bridges in Indiana. In many cases, it is also possible to improve aesthetics. More importantly, however, these strategies allow for improvement in the safety of the traveling public.

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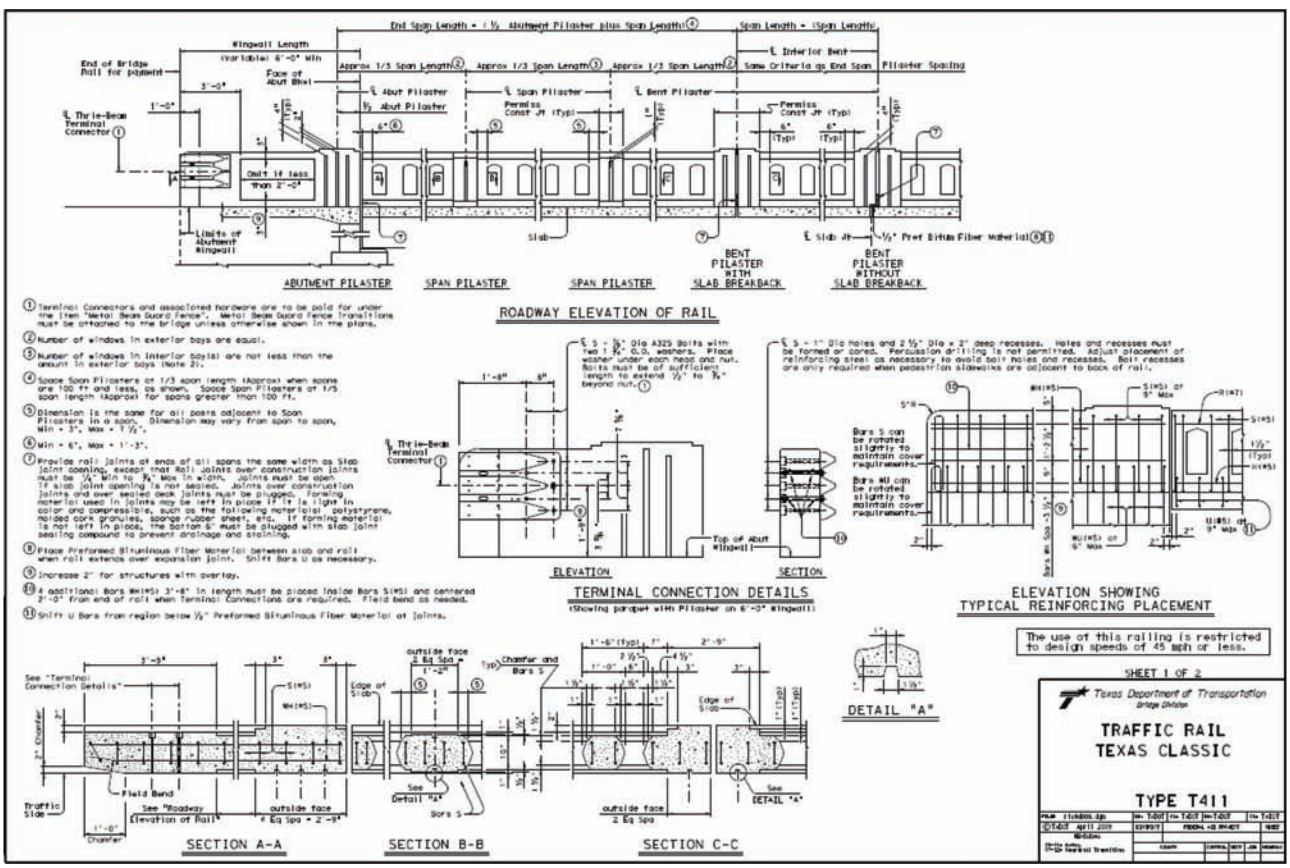
APPENDICES

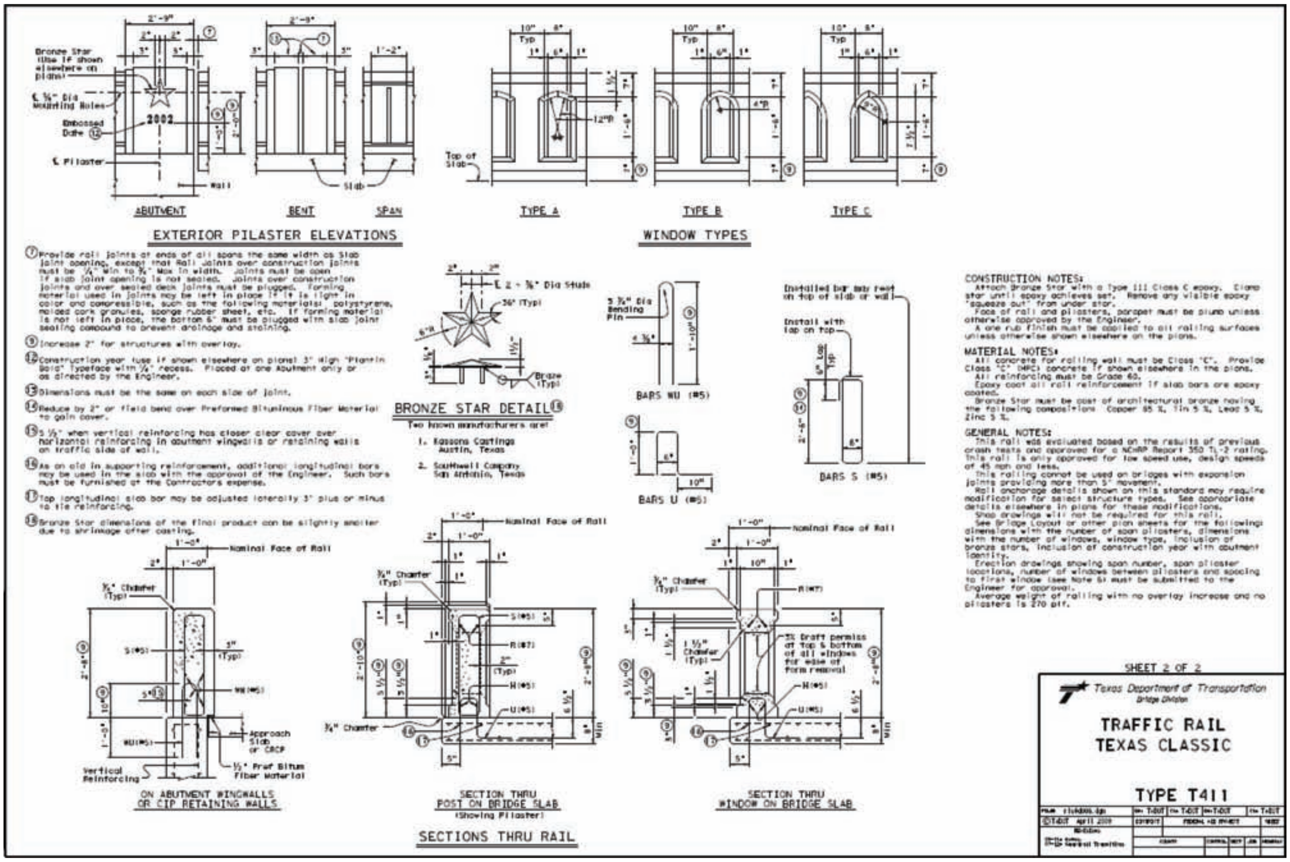
APPENDIX A. MODERN RAILING STANDARD DRAWINGS

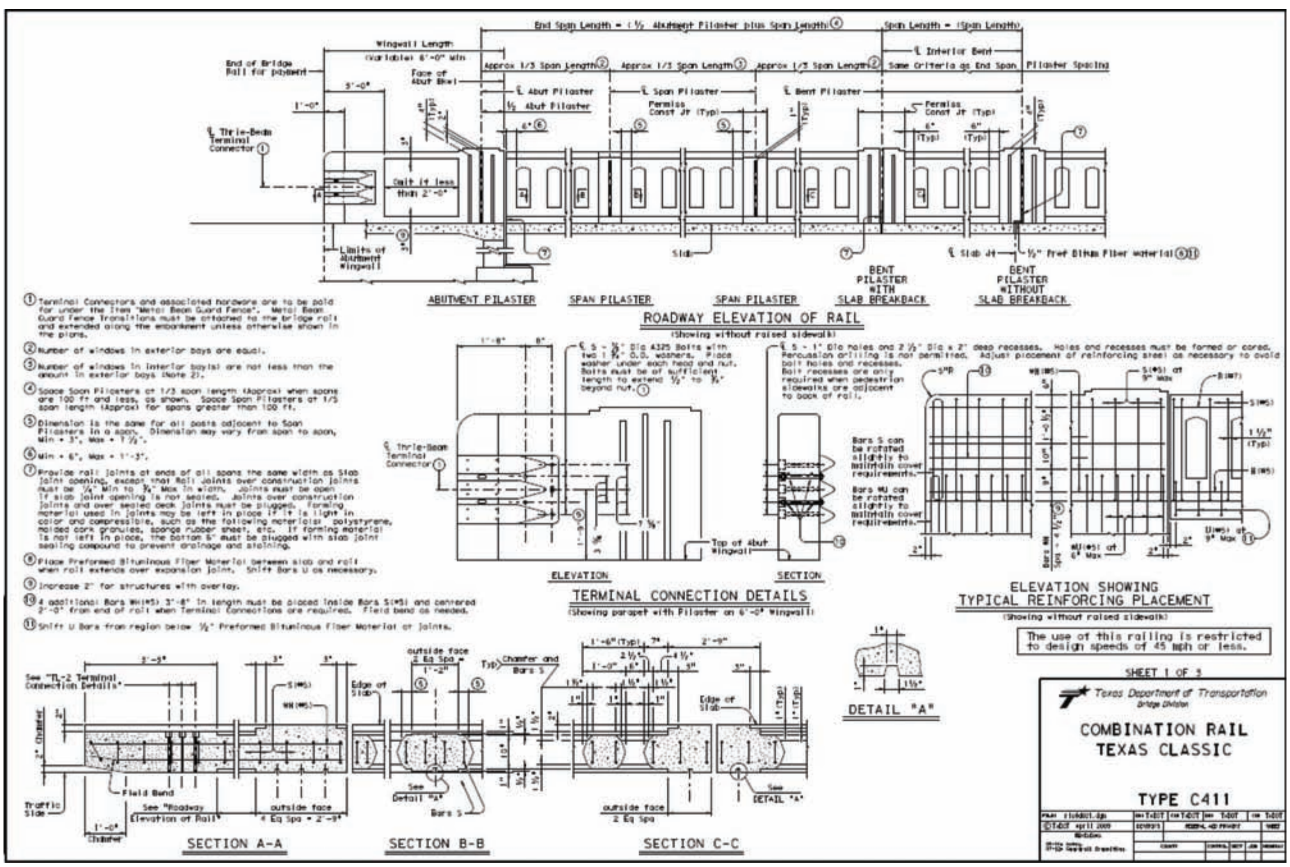
Standard drawings are provided for a variety of crash-tested railings. Table A.1 lists the railings included along with their Test Levels.

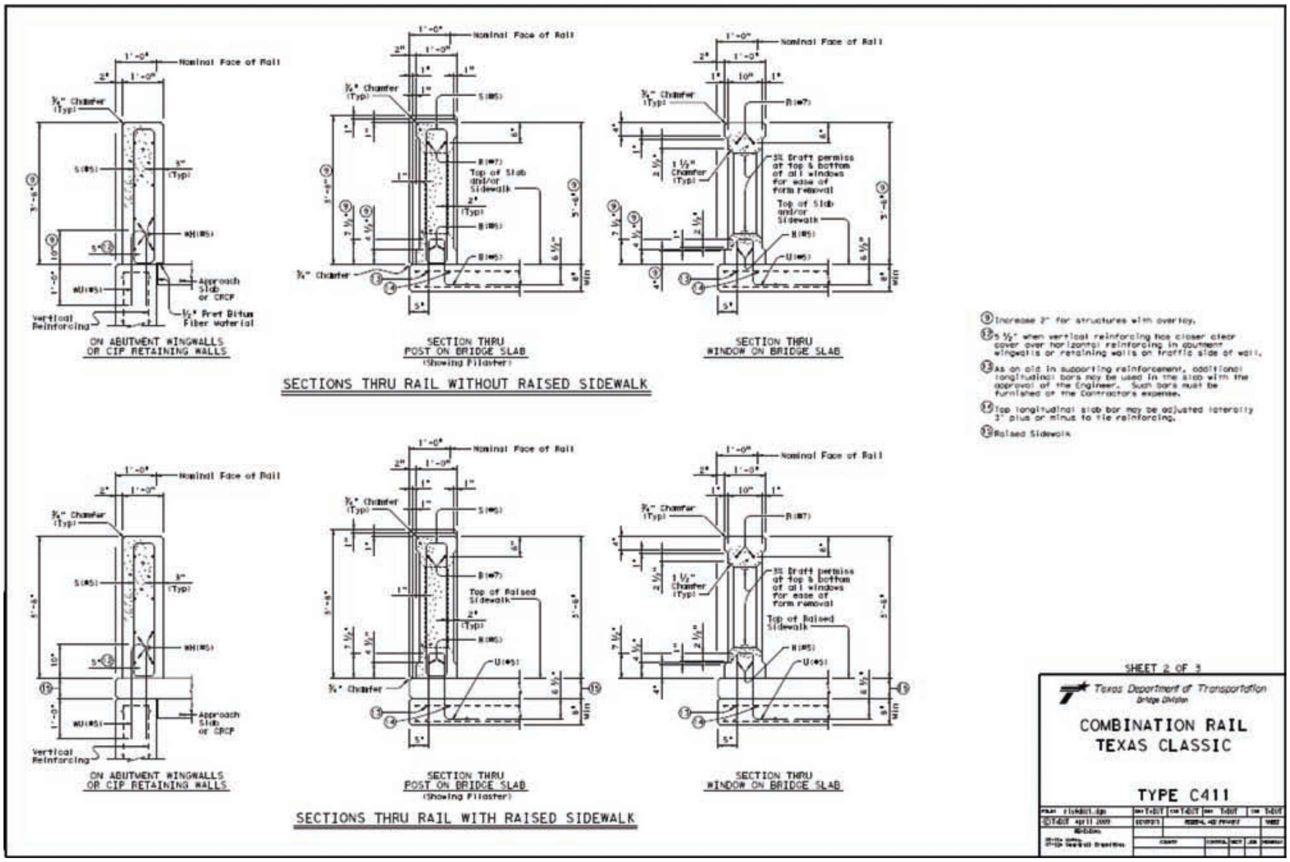
TABLE A.1
List of Standard Drawings Provided

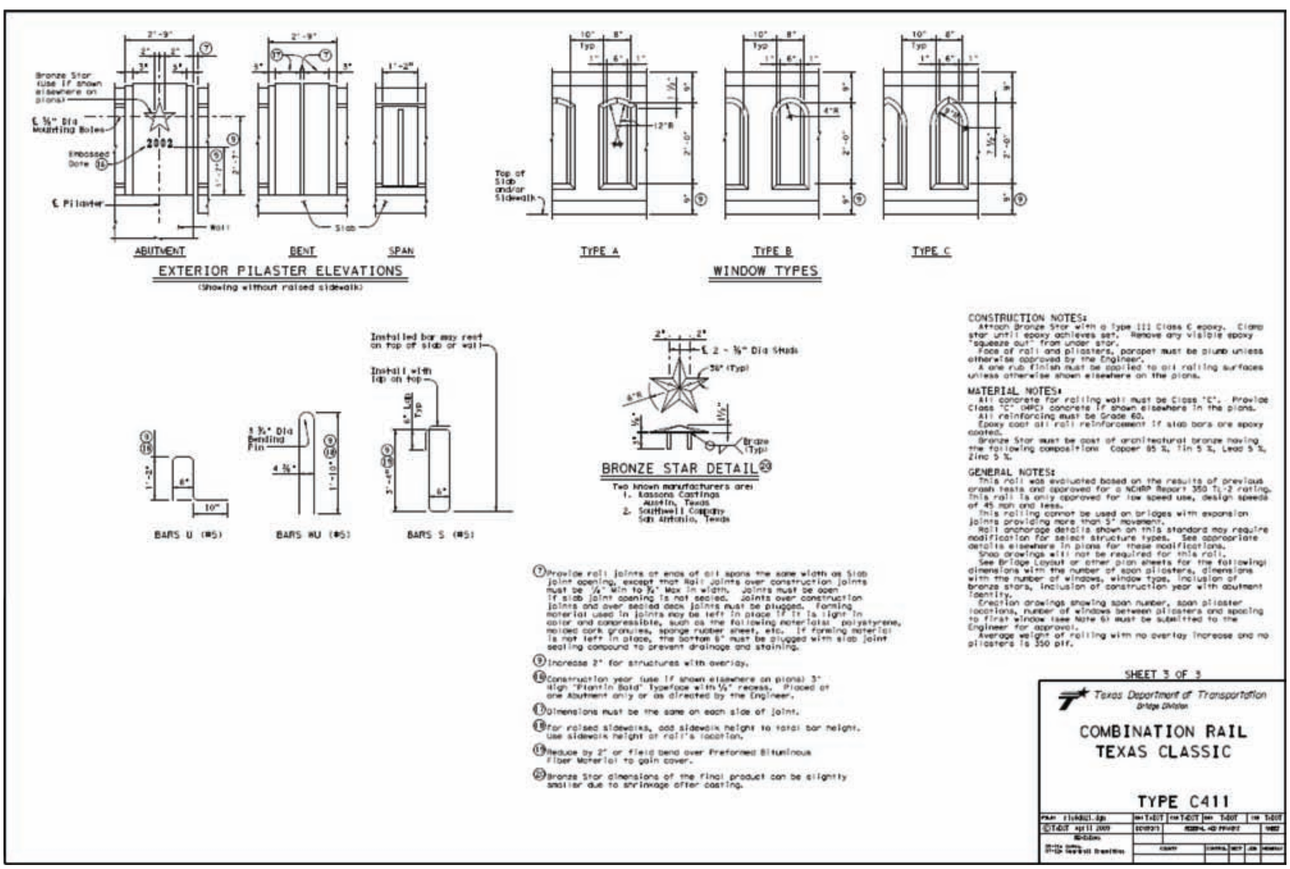
State DOT	Railing ID	Test Level	Pages
TxDOT	T411	2	74–75
TxDOT	C411	2	76–78
TxDOT	C412	4	79–82
INDOT	TX	2	83–86
TxDOT	T221	4	87–88
ODOT	Concrete Beam and Post	4	89
INDOT	FC	4	90–91
ODOT	Two-Tube Railing	4	92–93
ODOT	Three-Tube Railing	4	94–95
Caltrans	Type 90	4	96–98
TxDOT	PR3	N/A	99–100
ODOT	Pedestrian Rail	N/A	101
DDOT	Washington, D.C. Curb Railing	2	102

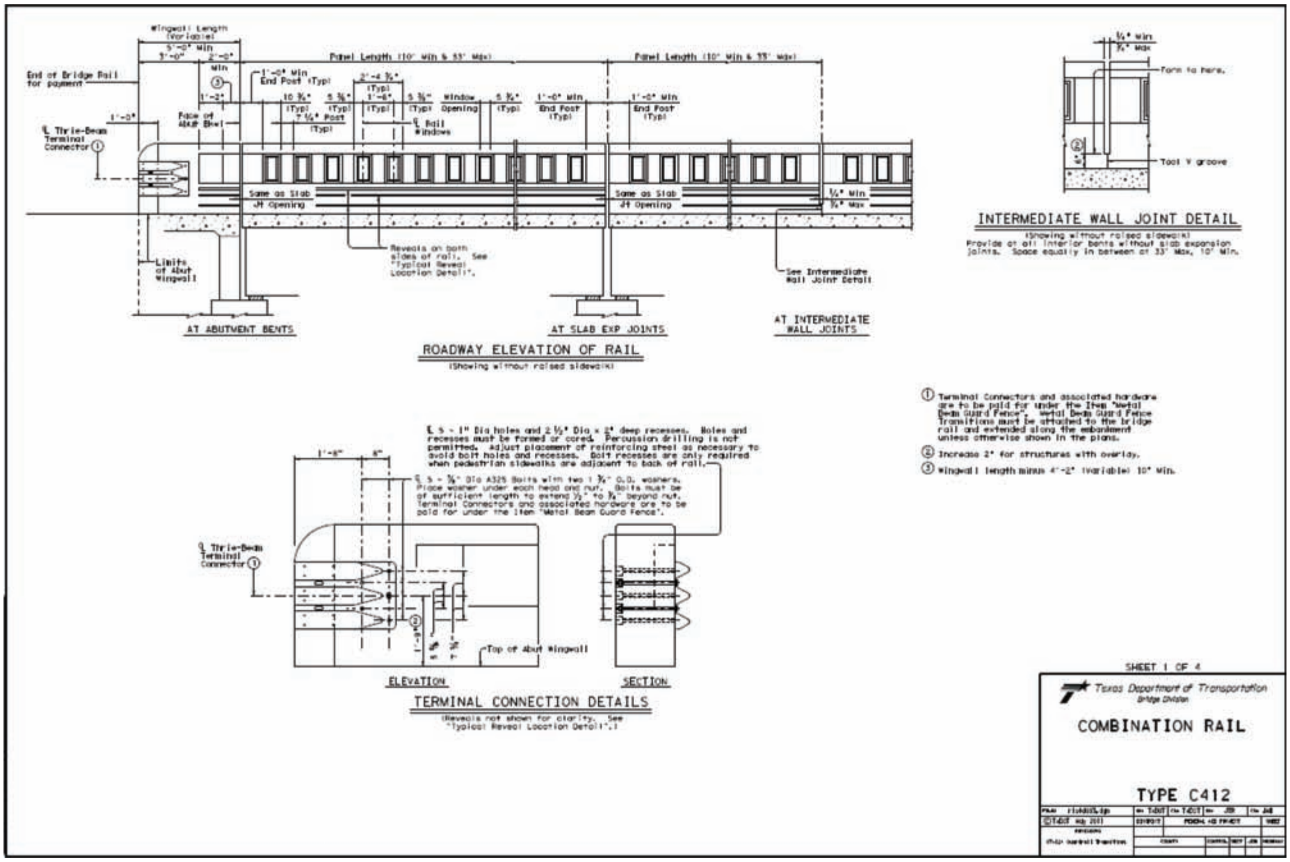


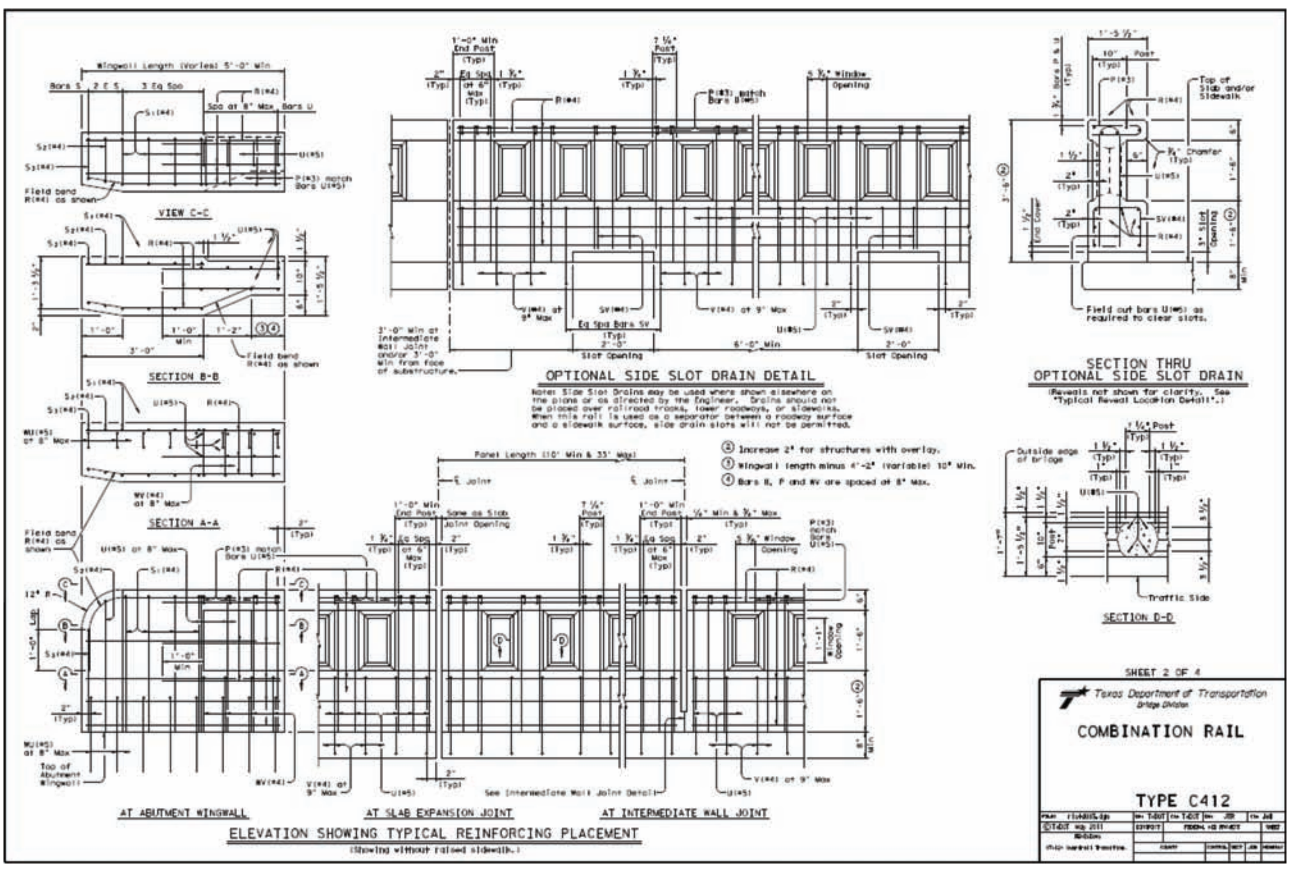

ABUTMENT
BENT
SPAN
EXTERIOR PILASTER ELEVATIONS
TYPE A
TYPE B
TYPE C
WINDOW TYPES
BRONZE STAR DETAIL
BARS WU (#5)
BARS U (#5)
BARS S (#5)
CONSTRUCTION NOTES:
MATERIAL NOTES:
GENERAL NOTES:
ON ABUTMENT WINGWALLS OR CIP RETAINING WALLS
SECTION THRU POST ON BRIDGE SLAB
SECTION THRU WINDOW ON BRIDGE SLAB
SECTIONS THRU RAIL
SHEET 2 OF 2
Texas Department of Transportation
Bridge Division
TRAFFIC RAIL
TEXAS CLASSIC
TYPE T411

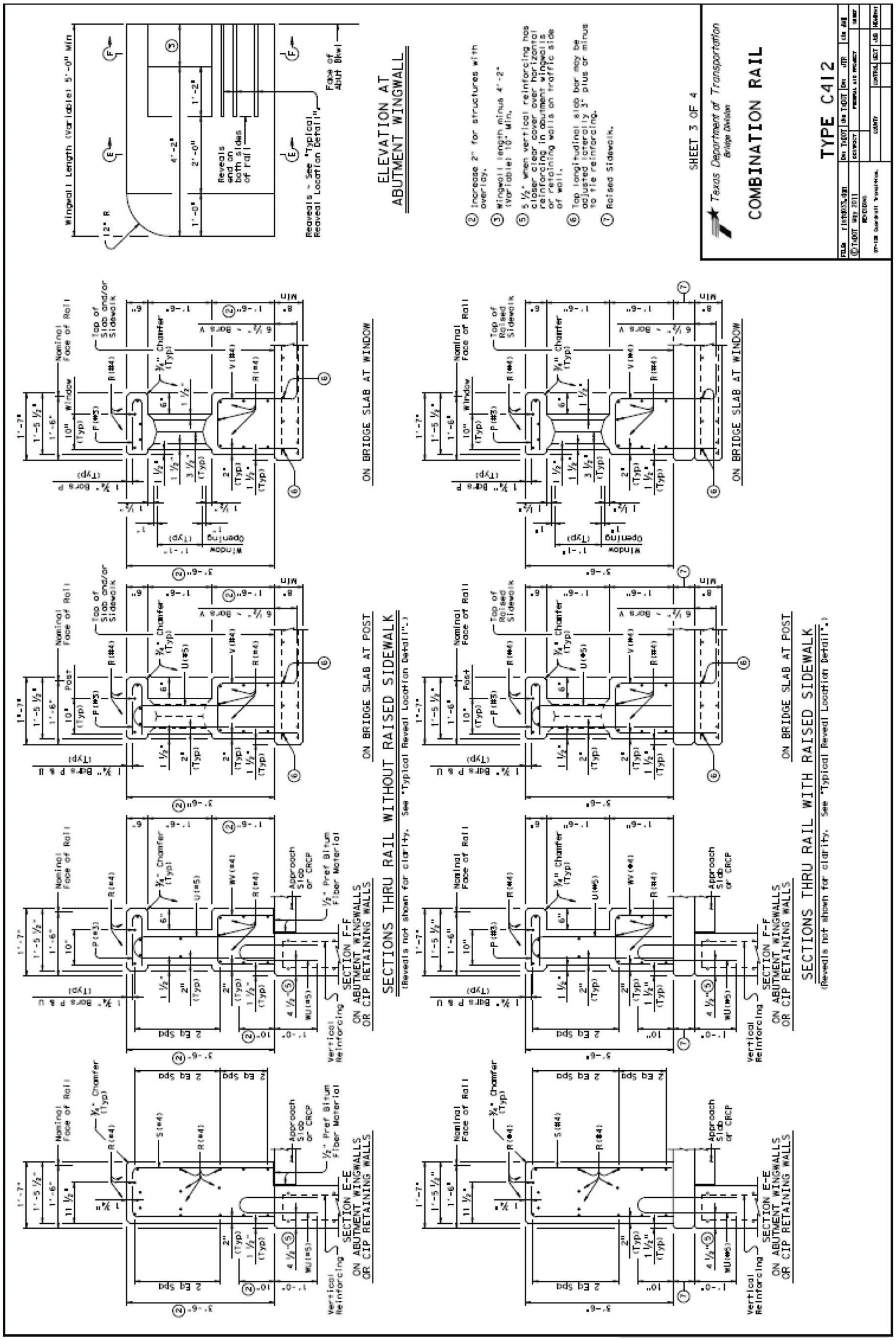

ABUTMENT PILASTER
SPAN PILASTER
SPAN PILASTER
BENT PILASTER WITH SLAB BREAKBACK
BENT PILASTER WITHOUT SLAB BREAKBACK
ROADWAY ELEVATION OF RAIL
(Showing without raised sidewalk)
ELEVATION
SECTION
TERMINAL CONNECTION DETAILS
ELEVATION SHOWING TYPICAL REINFORCING PLACEMENT
(Showing without raised sidewalk)
The use of this railing is restricted to design speeds of 45 mph or less.
DETAIL "A"
SECTION A-A
SECTION B-B
SECTION C-C
SHEET 1 OF 3
Texas Department of Transportation
Bridge Division
COMBINATION RAIL
TEXAS CLASSIC
TYPE C411

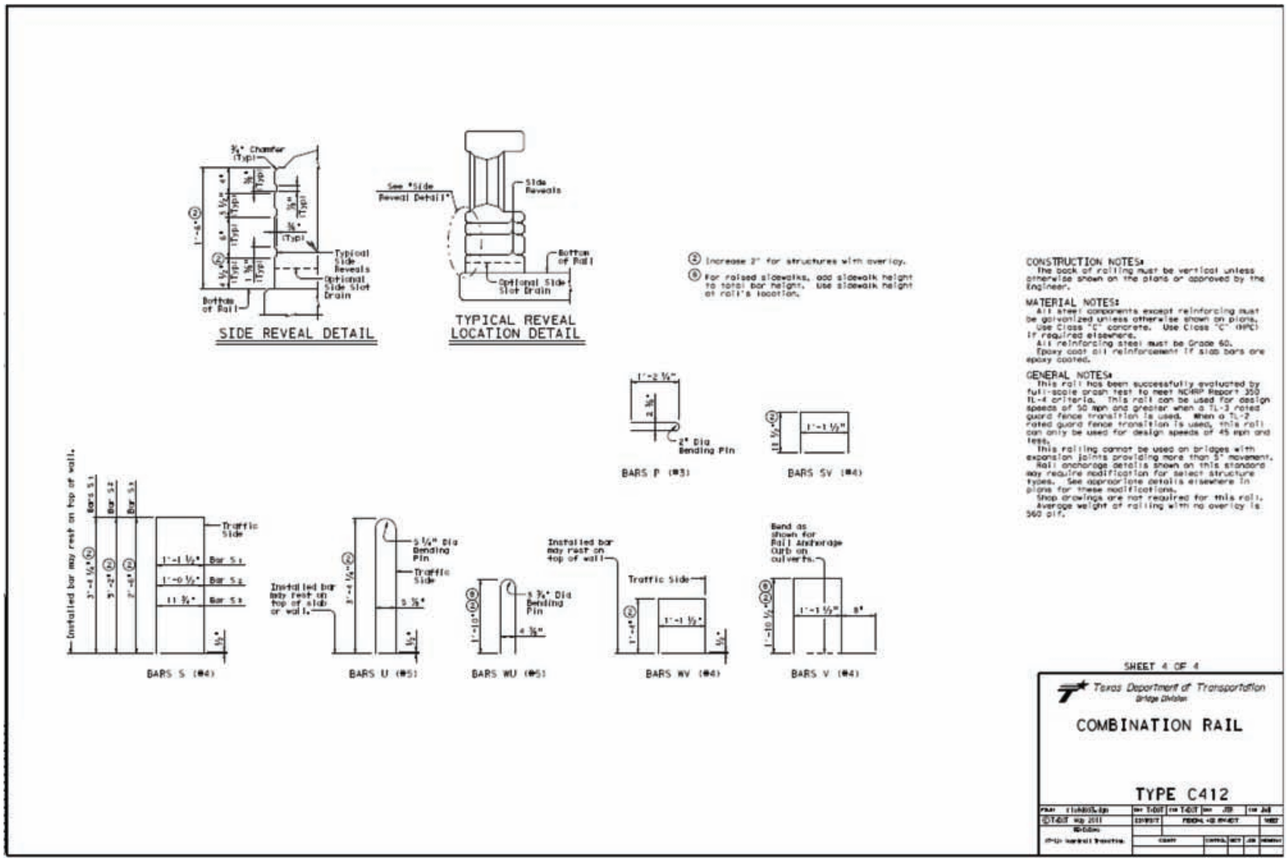


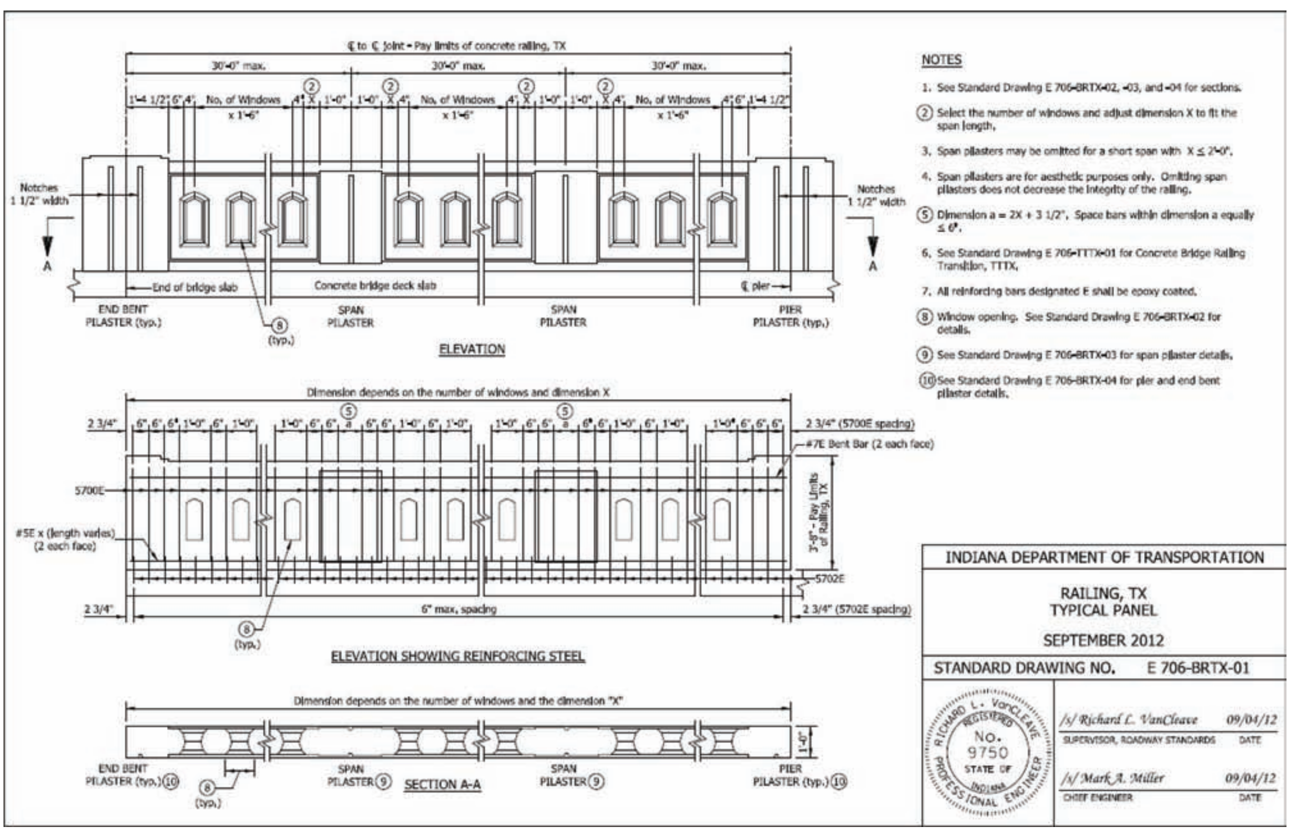


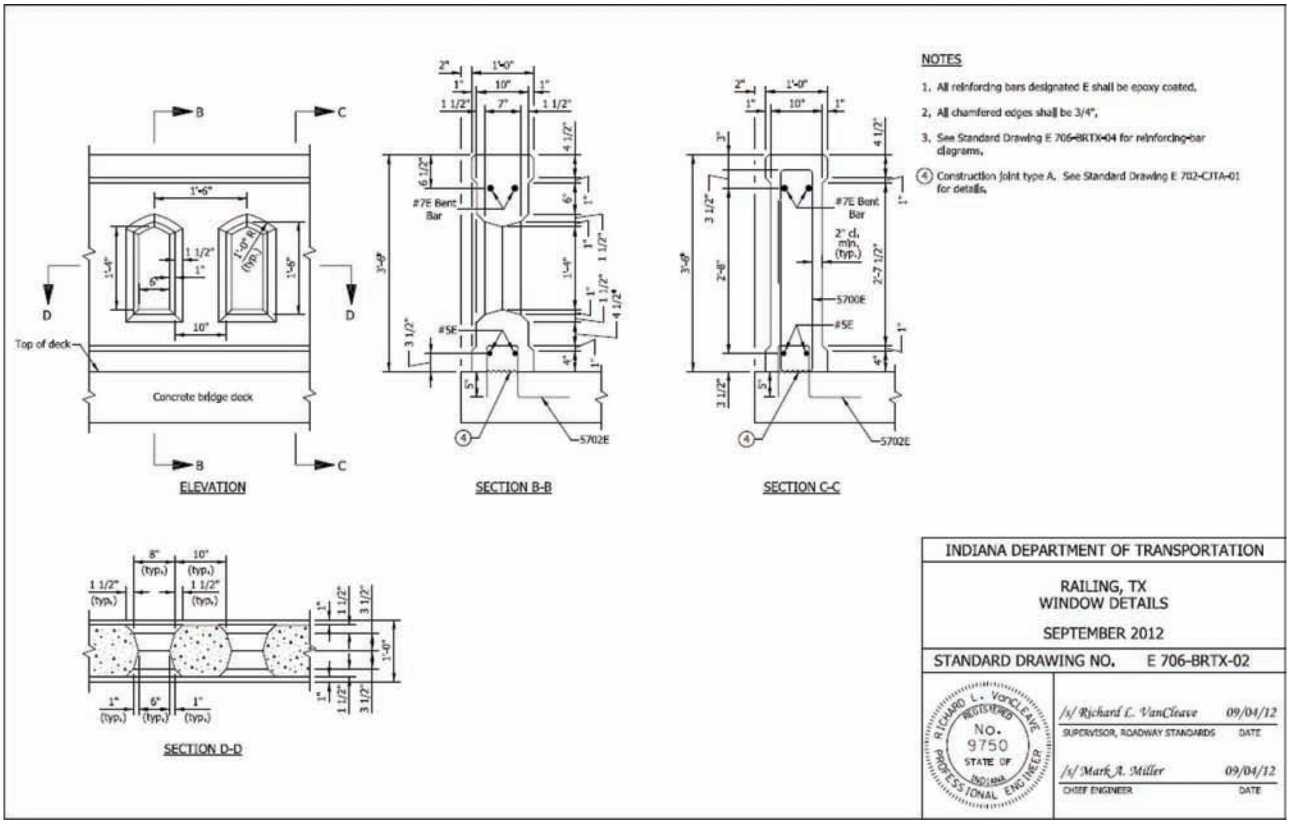

ROADWAY ELEVATION OF RAIL
(Showing without raised sidewalk)
AT ABUTMENT BENTS
AT SLAB EXP JOINTS
AT INTERMEDIATE WALL JOINTS
INTERMEDIATE WALL JOINT DETAIL
TERMINAL CONNECTION DETAILS
ELEVATION
SECTION
SHEET 1 OF 4
Texas Department of Transportation
Bridge Division
COMBINATION RAIL
TYPE C412

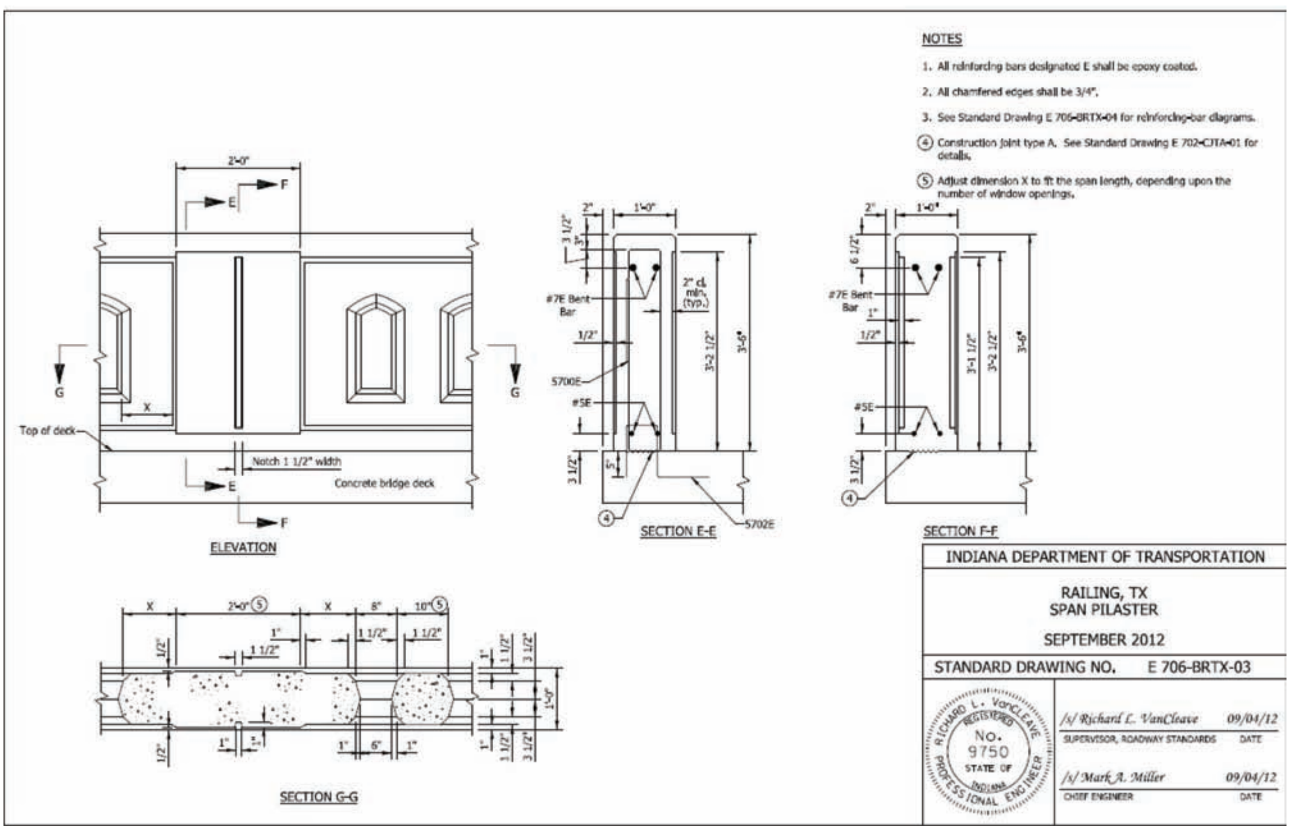

VIEW C-C
SECTION B-B
SECTION A-A
OPTIONAL SIDE SLOT DRAIN DETAIL
SECTION THRU OPTIONAL SIDE SLOT DRAIN
SECTION D-D
AT ABUTMENT WINGWALL
AT SLAB EXPANSION JOINT
AT INTERMEDIATE WALL JOINT
ELEVATION SHOWING TYPICAL REINFORCING PLACEMENT
(Showing without raised sidewalk.)
SHEET 2 OF 4
Texas Department of Transportation
Bridge Division
COMBINATION RAIL
TYPE C412

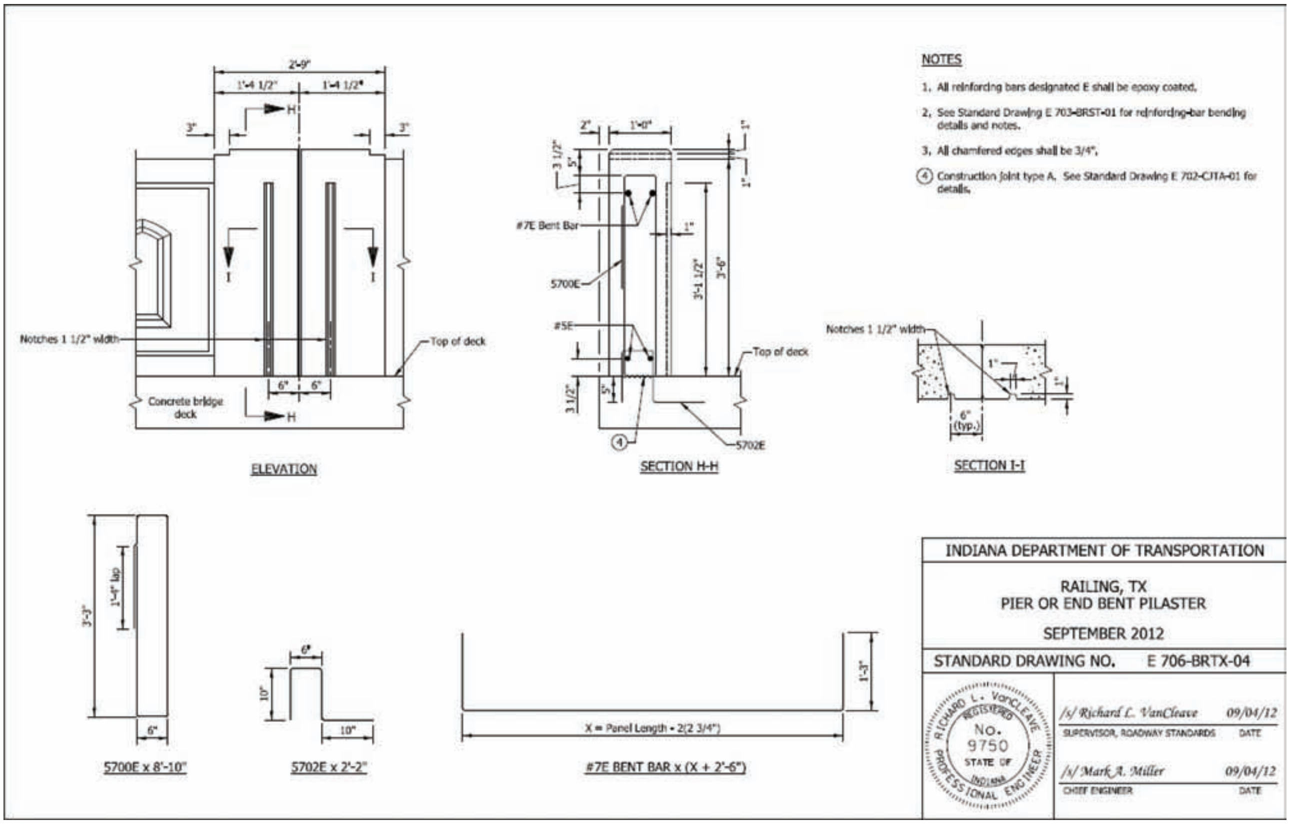

SECTIONS THRU RAIL WITHOUT RAISED SIDEWALK
SECTIONS THRU RAIL WITH RAISED SIDEWALK
ON BRIDGE SLAB AT POST
ON BRIDGE SLAB AT WINDOW
SECTION E-E
SECTION F-F
ON ABUTMENT WINGWALLS OR CIP RETAINING WALLS
ELEVATION AT ABUTMENT WINGWALL
SHEET 3 OF 4
Texas Department of Transportation
Bridge Division
COMBINATION RAIL
TYPE C412

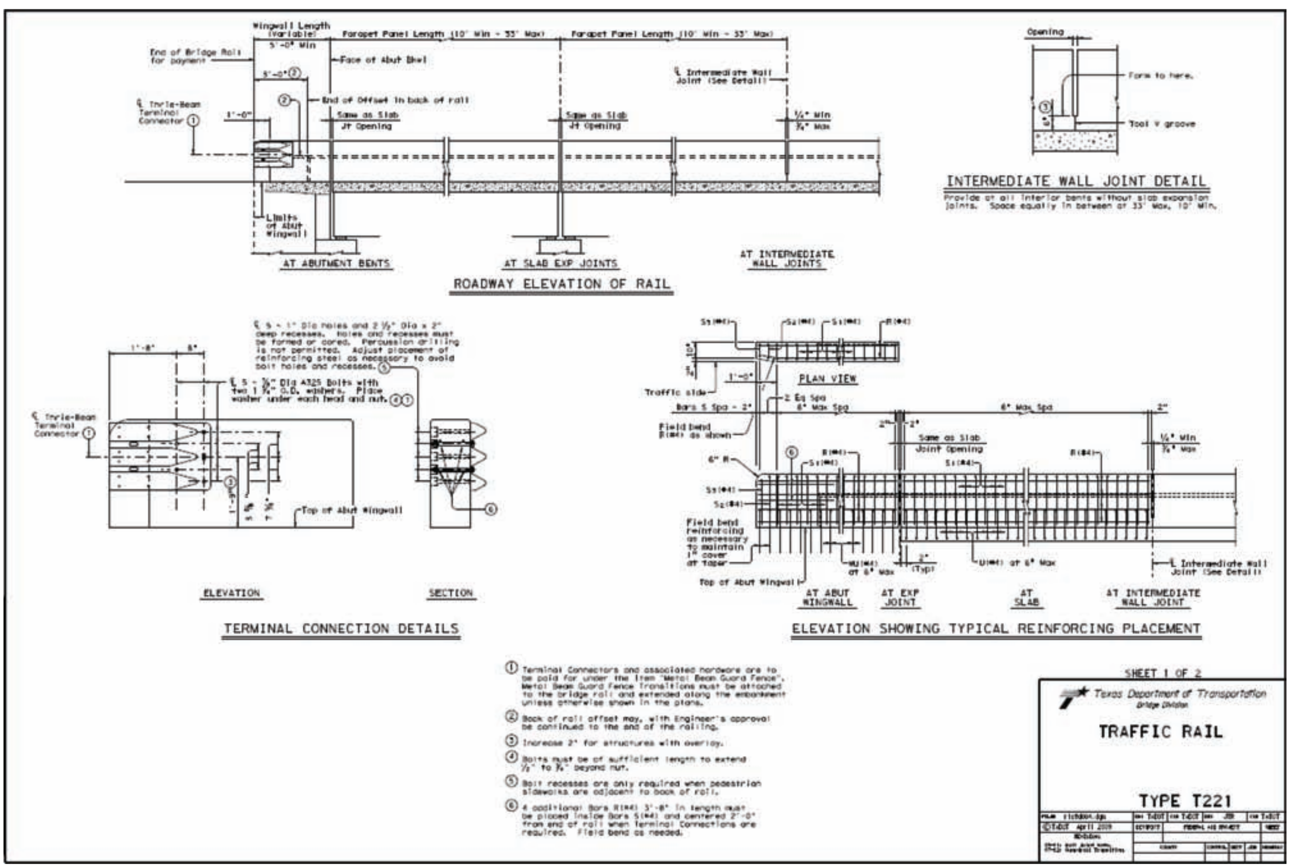

SIDE REVEAL DETAIL
TYPICAL REVEAL LOCATION DETAIL
CONSTRUCTION NOTES:
MATERIAL NOTES:
GENERAL NOTES:
BARS P (#3)
BARS SV (#4)
BARS S (#4)
BARS U (#5)
BARS WU (#5)
BARS WV (#4)
BARS V (#4)
SHEET 4 OF 4
Texas Department of Transportation
Bridge Division
COMBINATION RAIL
TYPE C412

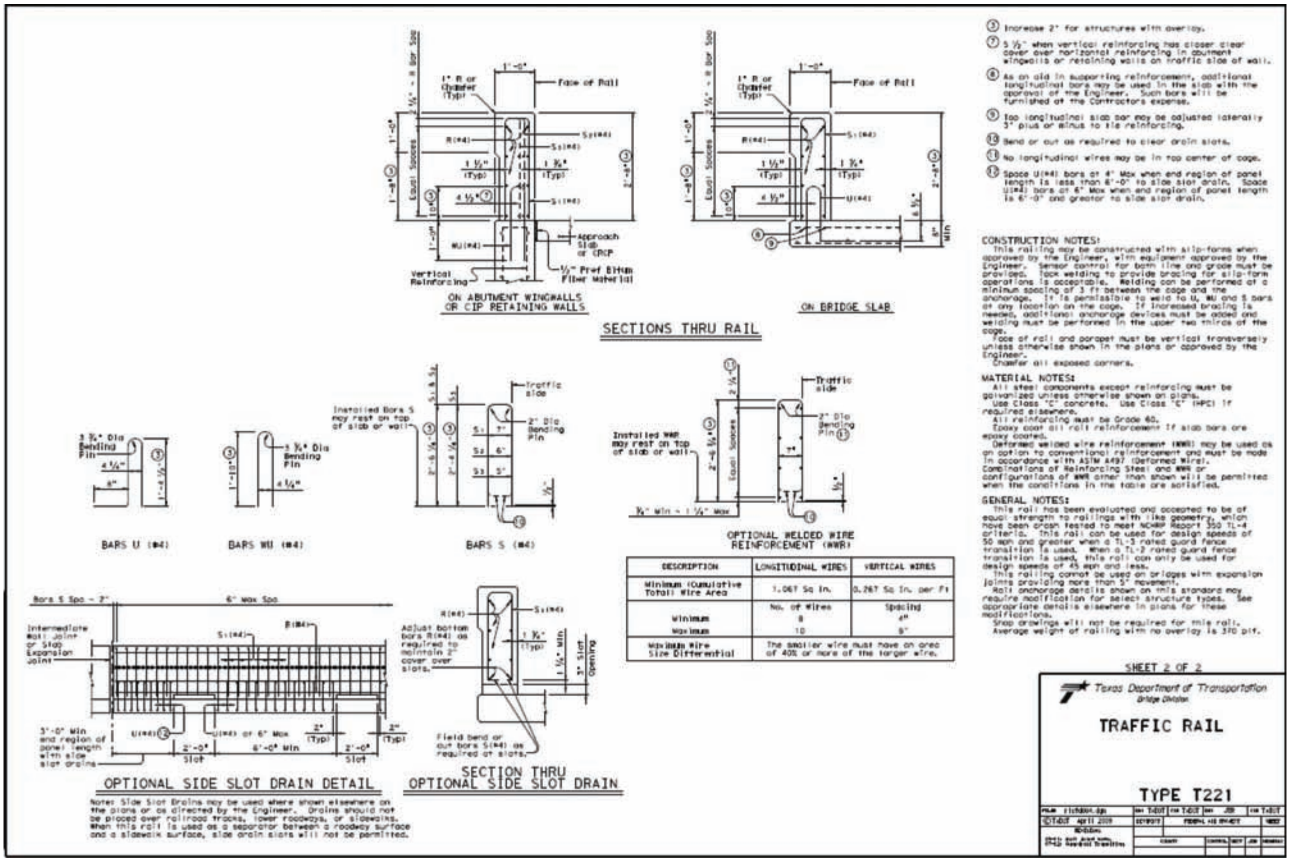

NOTES
1. See Standard Drawing E 706-BRTX-02, -03, and -04 for sections.
2 Select the number of windows and adjust dimension X to fit the span length.
3. Span pilasters may be omitted for a short span with X ≤ 2'-0".
4. Span pilasters are for aesthetic purposes only. Omitting span pilasters does not decrease the integrity of the railing.
5 Dimension a = 2X + 3 1/2". Space bars within dimension a equally ≤ 6".
6. See Standard Drawing E 706-TTTX-01 for Concrete Bridge Railing Transition, TTTX.
7. All reinforcing bars designated E shall be epoxy coated.
8 Window opening. See Standard Drawing E 706-BRTX-02 for details.
9 See Standard Drawing E 706-BRTX-03 for span pilaster details.
10 See Standard Drawing E 706-BRTX-04 for pier and end bent pilaster details.
ELEVATION
ELEVATION SHOWING REINFORCING STEEL
SECTION A-A
END BENT PILASTER (typ.)
SPAN PILASTER
PIER PILASTER (typ.)
Concrete bridge deck slab
End of bridge slab
INDIANA DEPARTMENT OF TRANSPORTATION
RAILING, TX
TYPICAL PANEL
SEPTEMBER 2012
STANDARD DRAWING NO. E 706-BRTX-01
/s/ Richard L. VanCleave 09/04/12
SUPERVISOR, ROADWAY STANDARDS DATE
/s/ Mark A. Miller 09/04/12
CHIEF ENGINEER DATE

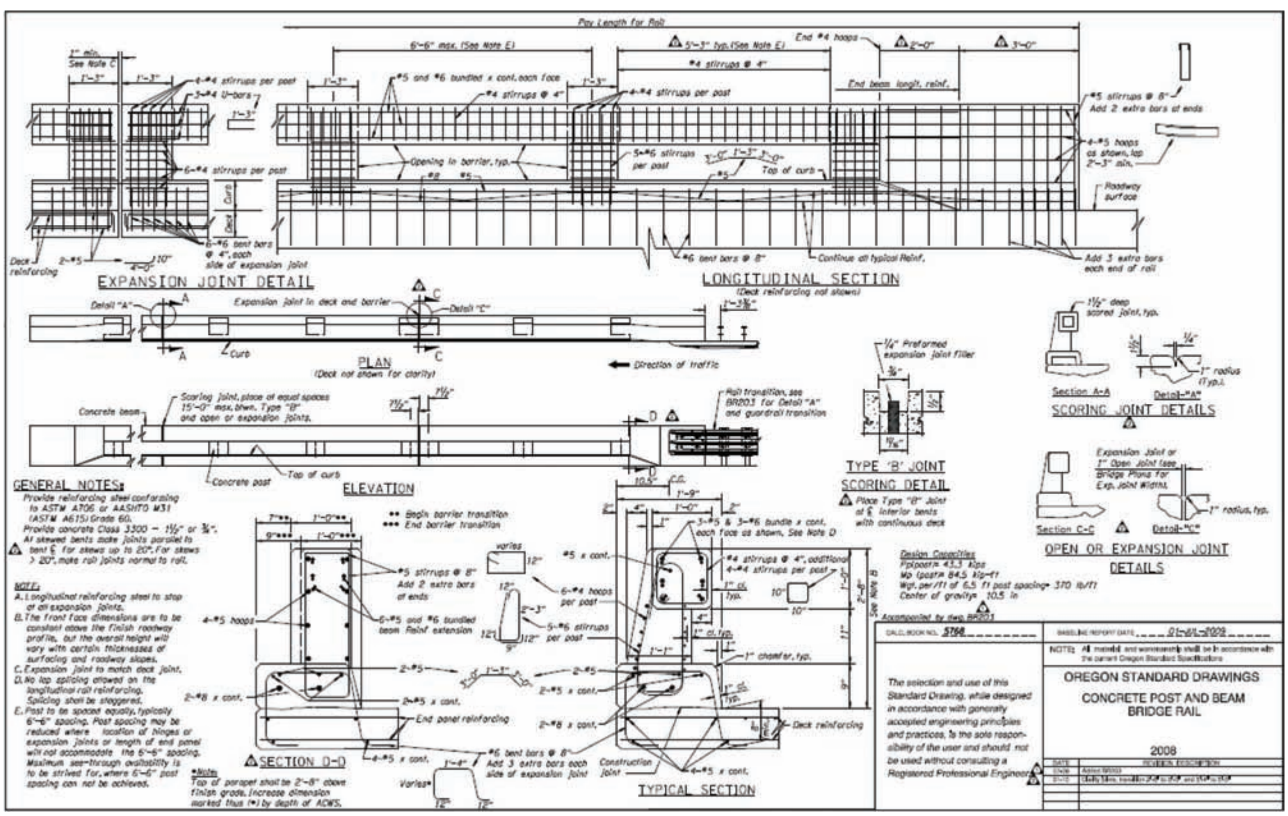

NOTES
1. All reinforcing bars designated E shall be epoxy coated.
2. All chamfered edges shall be 3/4".
3. See Standard Drawing E 706-BRTX-04 for reinforcing-bar diagrams.
(4) Construction joint type A. See Standard Drawing E 702-CJTA-01 for details.
ELEVATION
SECTION B-B
SECTION C-C
SECTION D-D
Top of deck
Concrete bridge deck
#7E Bent Bar
#5E
5700E
5702E
2" cl. min. (typ.)
INDIANA DEPARTMENT OF TRANSPORTATION
RAILING, TX
WINDOW DETAILS
SEPTEMBER 2012
STANDARD DRAWING NO. E 706-BRTX-02
/s/ Richard L. VanCleave 09/04/12
SUPERVISOR, ROADWAY STANDARDS DATE
/s/ Mark A. Miller 09/04/12
CHIEF ENGINEER DATE

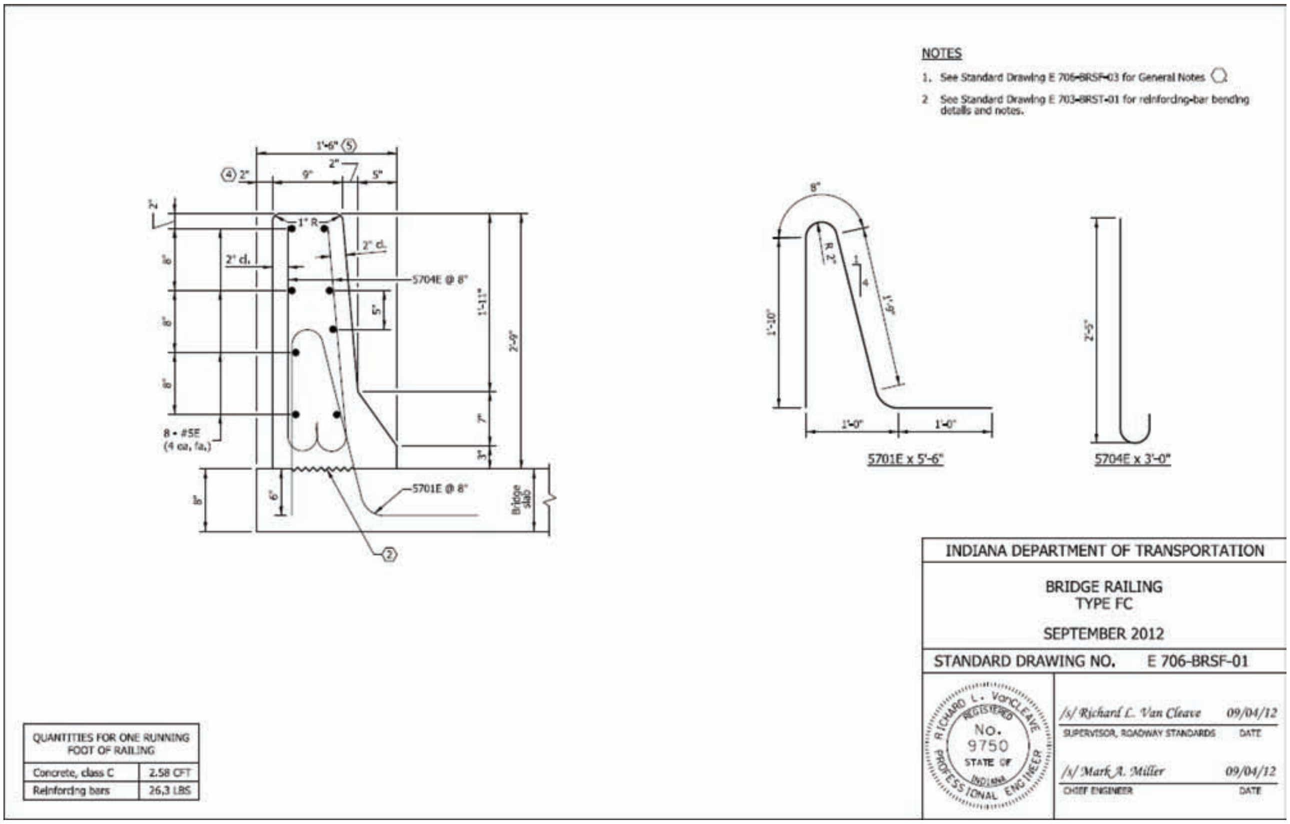

NOTES
1. All reinforcing bars designated E shall be epoxy coated.
2. All chamfered edges shall be 3/4".
3. See Standard Drawing E 706-BRTX-04 for reinforcing-bar diagrams.
(4) Construction joint type A. See Standard Drawing E 702-CJTA-01 for details.
(5) Adjust dimension X to fit the span length, depending upon the number of window openings.
ELEVATION
SECTION E-E
SECTION F-F
SECTION G-G
Top of deck
Notch 1 1/2" width
Concrete bridge deck
#7E Bent Bar
#5E
5700E
5702E
2" cl. min. (typ.)
INDIANA DEPARTMENT OF TRANSPORTATION
RAILING, TX
SPAN PILASTER
SEPTEMBER 2012
STANDARD DRAWING NO. E 706-BRTX-03
/s/ Richard L. VanCleave 09/04/12
SUPERVISOR, ROADWAY STANDARDS DATE
/s/ Mark A. Miller 09/04/12
CHIEF ENGINEER DATE

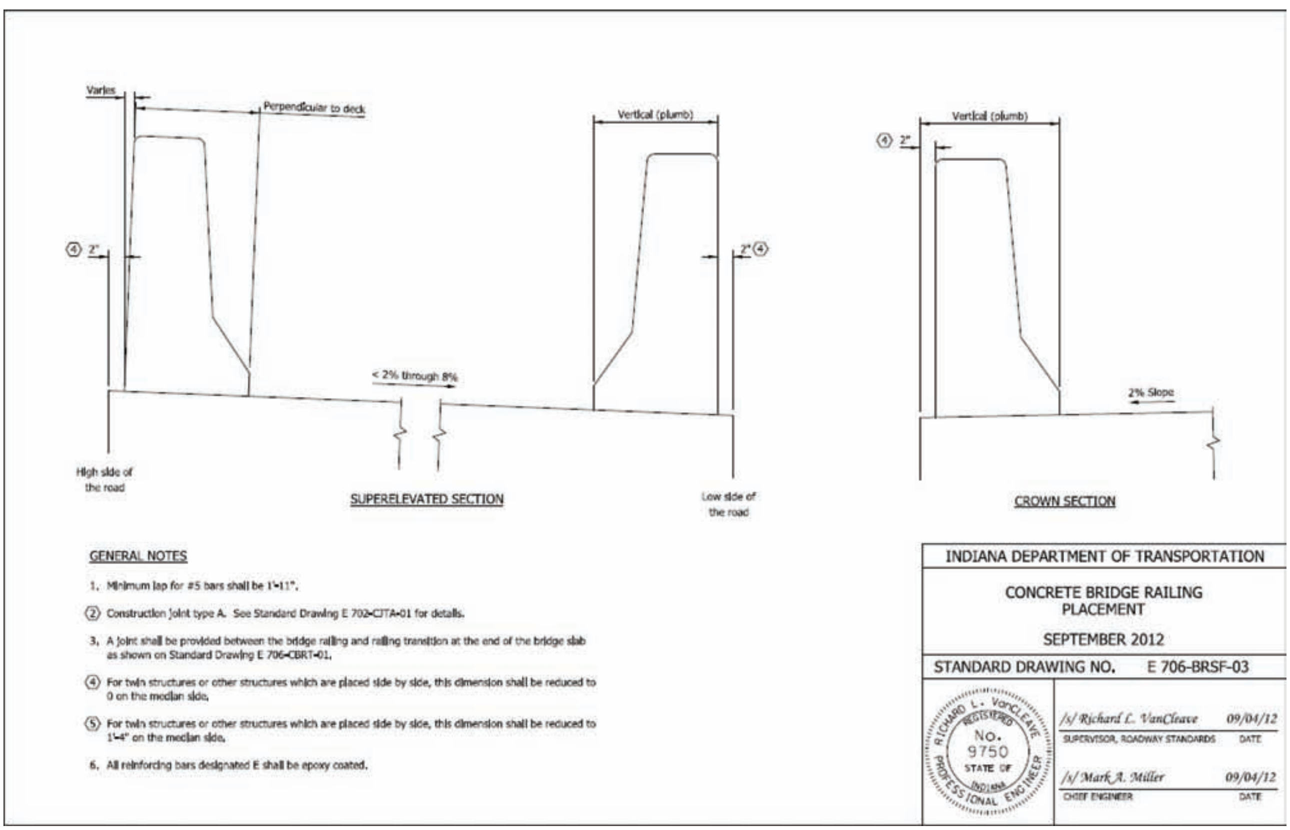

NOTES
1. All reinforcing bars designated E shall be epoxy coated.
2. See Standard Drawing E 703-BRST-01 for reinforcing-bar bending details and notes.
3. All chamfered edges shall be 3/4".
4 Construction joint type A. See Standard Drawing E 702-CJTA-01 for details.
2'-9"
1'-4 1/2"
1'-4 1/2"
Notches 1 1/2" width
Top of deck
Concrete bridge deck
ELEVATION
#7E Bent Bar
5700E
#5E
5702E
SECTION H-H
SECTION I-I
5700E x 8'-10"
5702E x 2'-2"
X = Panel Length - 2(2 3/4")
#7E BENT BAR x (X + 2'-6")
INDIANA DEPARTMENT OF TRANSPORTATION
RAILING, TX
PIER OR END BENT PILASTER
SEPTEMBER 2012
STANDARD DRAWING NO. E 706-BRTX-04
/s/ Richard L. VanCleave 09/04/12
SUPERVISOR, ROADWAY STANDARDS DATE
/s/ Mark A. Miller 09/04/12
CHIEF ENGINEER DATE

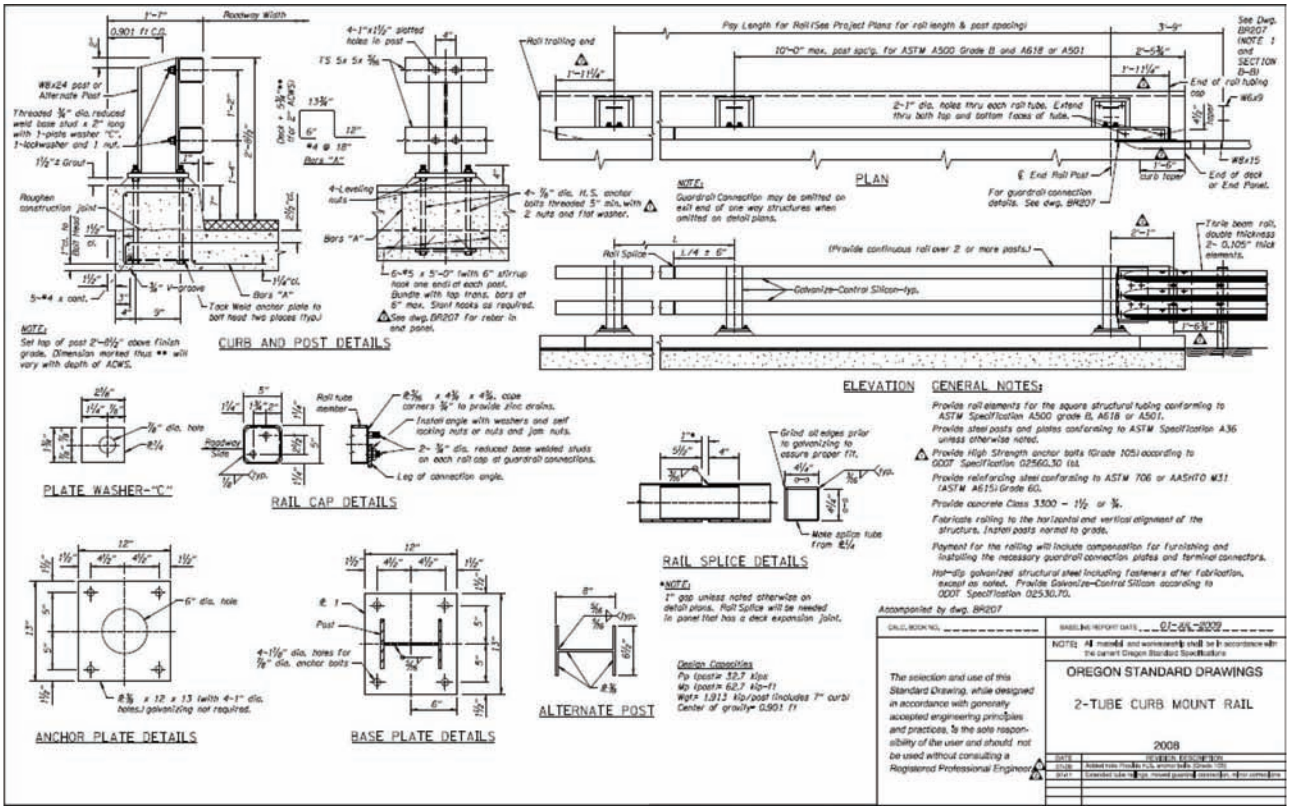

INTERMEDIATE WALL JOINT DETAIL
AT ABUTMENT BENTS
AT SLAB EXP JOINTS
AT INTERMEDIATE WALL JOINTS
ROADWAY ELEVATION OF RAIL
PLAN VIEW
ELEVATION
SECTION
TERMINAL CONNECTION DETAILS
ELEVATION SHOWING TYPICAL REINFORCING PLACEMENT
SHEET 1 OF 2
Texas Department of Transportation
Bridge Division
TRAFFIC RAIL
TYPE T221

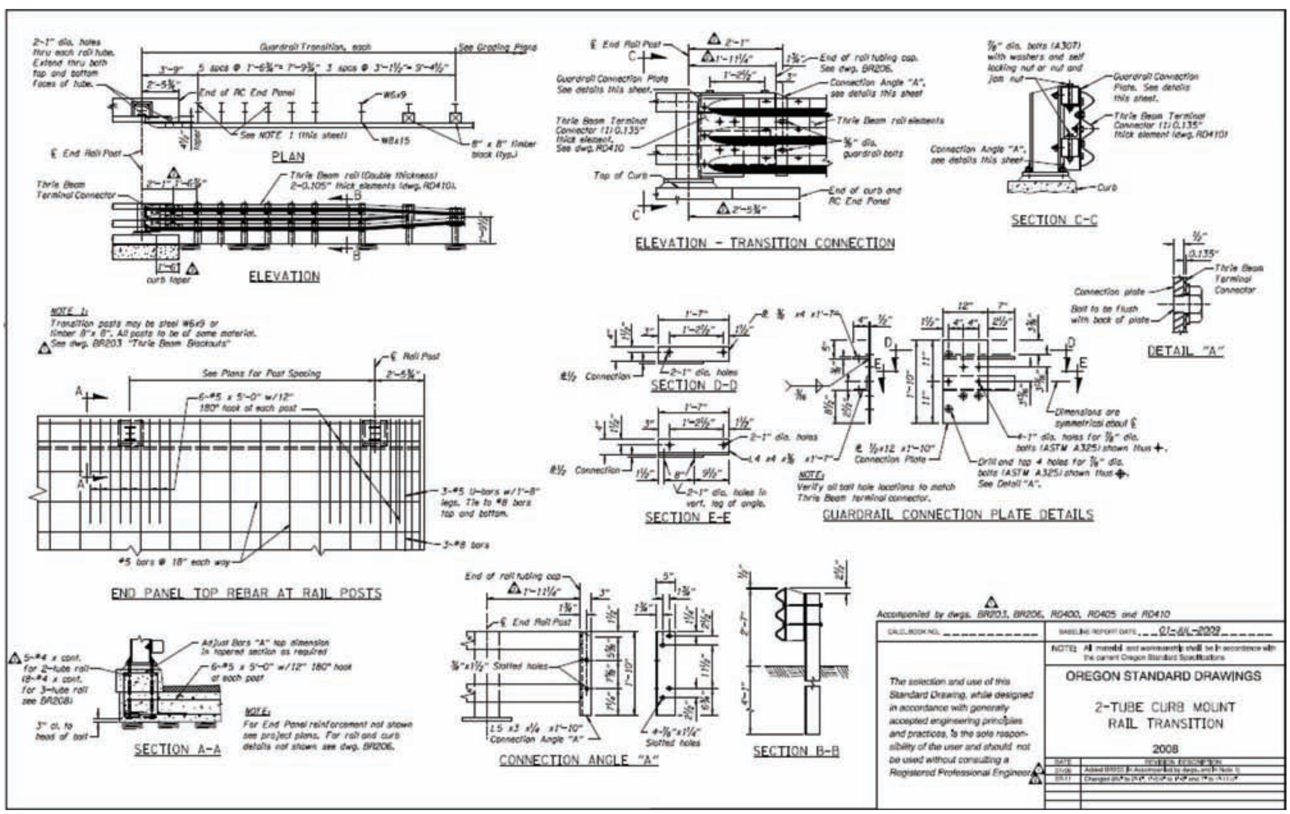

SECTIONS THRU RAIL
ON ABUTMENT WINGWALLS OR CIP RETAINING WALLS
ON BRIDGE SLAB
BARS U (#4)
BARS WU (#4)
BARS S (#4)
OPTIONAL WELDED WIRE REINFORCEMENT (WWR)
OPTIONAL SIDE SLOT DRAIN DETAIL
SECTION THRU OPTIONAL SIDE SLOT DRAIN
CONSTRUCTION NOTES:
MATERIAL NOTES:
GENERAL NOTES:
SHEET 2 OF 2
Texas Department of Transportation
TRAFFIC RAIL
TYPE T221

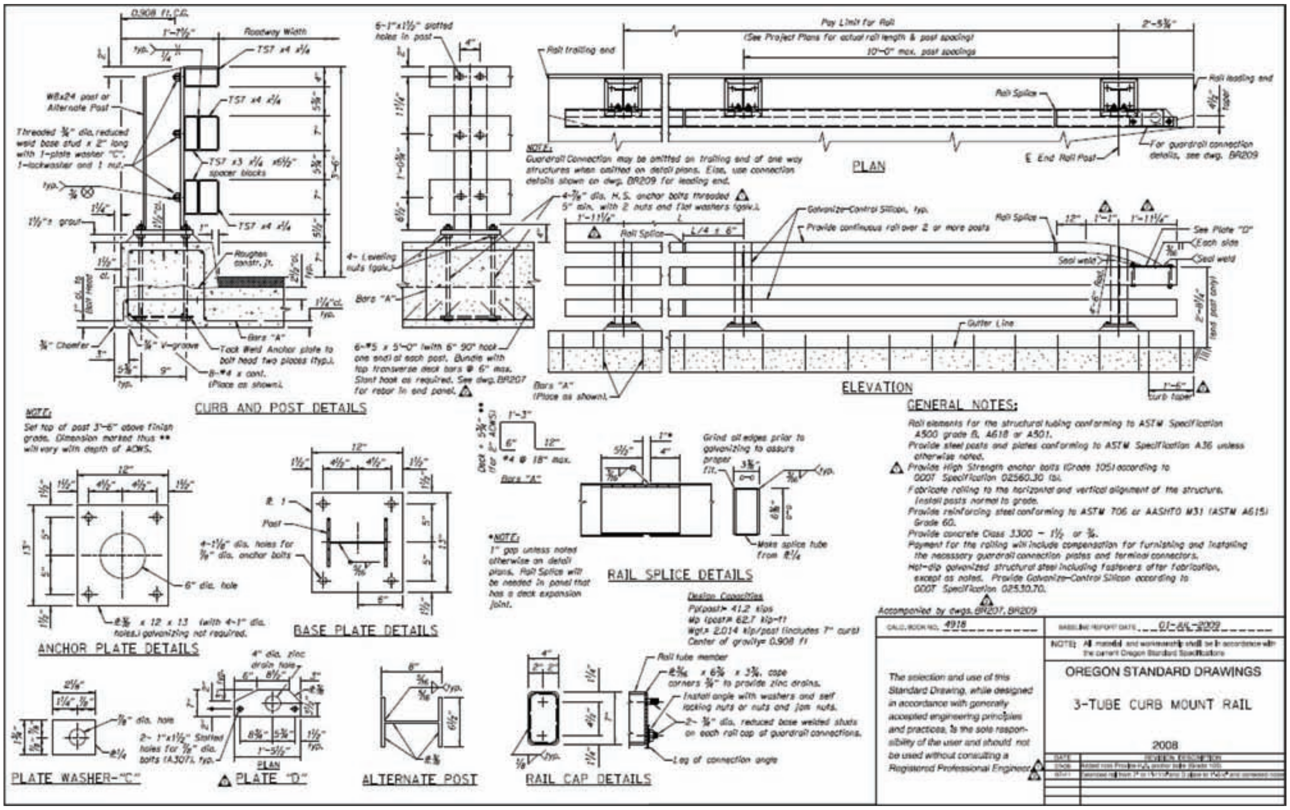

Pay Length for Rail
EXPANSION JOINT DETAIL
LONGITUDINAL SECTION
(Deck reinforcing not shown)
PLAN
(Deck not shown for clarity)
ELEVATION
GENERAL NOTES:
TYPE 'B' JOINT SCORING DETAIL
SCORING JOINT DETAILS
OPEN OR EXPANSION JOINT DETAILS
SECTION D-D
TYPICAL SECTION
OREGON STANDARD DRAWINGS
CONCRETE POST AND BEAM BRIDGE RAIL
2008

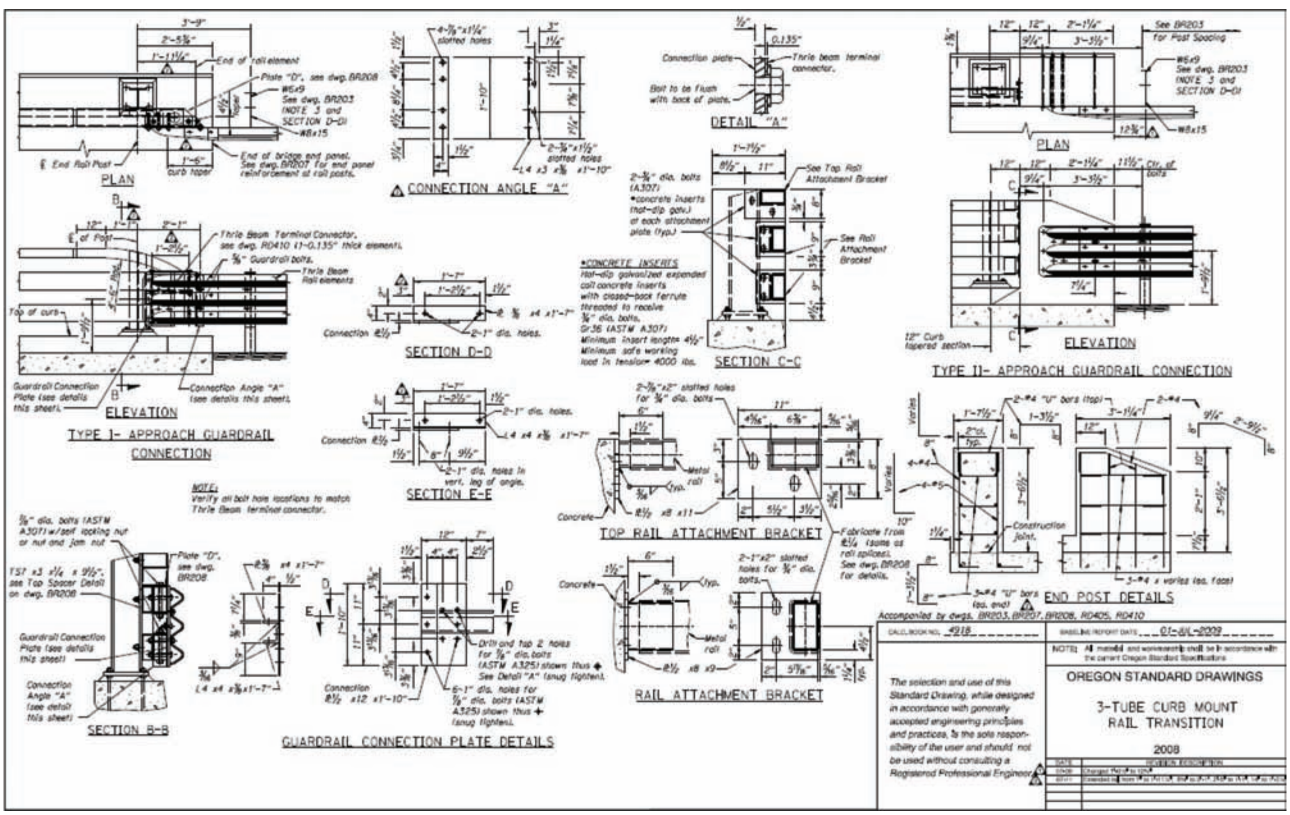

NOTES
1. See Standard Drawing E 706-BRSF-03 for General Notes
2. See Standard Drawing E 703-BRST-01 for reinforcing-bar bending details and notes.
1'-6" ⑤
④ 2"
9"
2"
5"
1" R
2" cl.
2" cl.
5704E @ 8"
1'-11"
2'-9"
8 - #5E
(4 ea. fa.)
5701E @ 8"
Bridge slab
②
8"
R 2"
1'-10"
1'-9"
1'-0"
1'-0"
5701E x 5'-6"
2'-5"
5704E x 3'-0"
QUANTITIES FOR ONE RUNNING FOOT OF RAILING
Concrete, class C 2.58 CFT
Reinforcing bars 26.3 LBS
INDIANA DEPARTMENT OF TRANSPORTATION
BRIDGE RAILING
TYPE FC
SEPTEMBER 2012
STANDARD DRAWING NO. E 706-BRSF-01
RICHARD L. VanCLEAVE REGISTERED No. 9750 STATE OF INDIANA PROFESSIONAL ENGINEER
/s/ Richard L. Van Cleave 09/04/12
SUPERVISOR, ROADWAY STANDARDS DATE
/s/ Mark A. Miller 09/04/12
CHIEF ENGINEER DATE

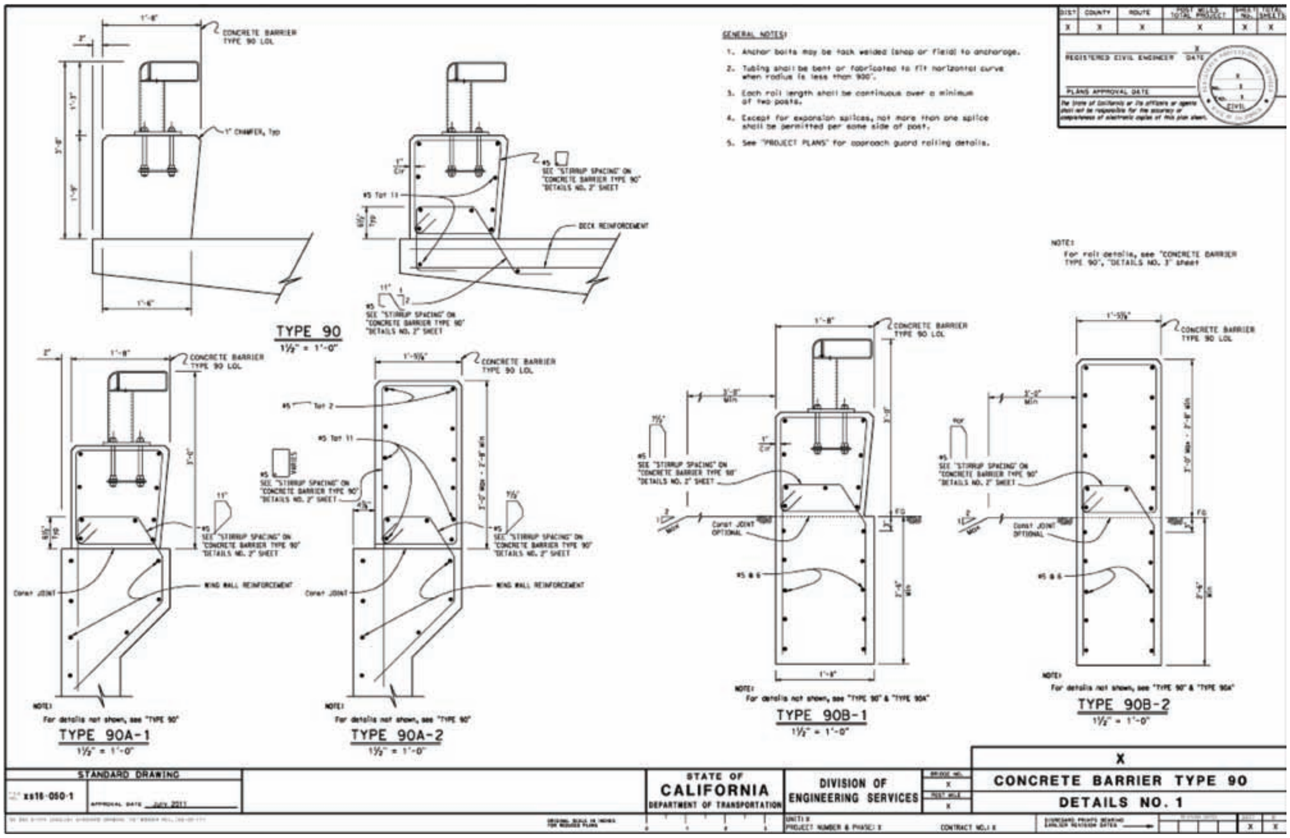

Varies
Perpendicular to deck
④ 2"
< 2% through 8%
High side of the road
SUPERELEVATED SECTION
Vertical (plumb)
2" ④
Low side of the road
Vertical (plumb)
④ 2"
2% Slope
CROWN SECTION
GENERAL NOTES
1. Minimum lap for #5 bars shall be 1'-11".
② Construction joint type A. See Standard Drawing E 702-CJTA-01 for details.
3. A joint shall be provided between the bridge railing and railing transition at the end of the bridge slab as shown on Standard Drawing E 706-CBRT-01.
④ For twin structures or other structures which are placed side by side, this dimension shall be reduced to 0 on the median side.
⑤ For twin structures or other structures which are placed side by side, this dimension shall be reduced to 1'-4" on the median side.
6. All reinforcing bars designated E shall be epoxy coated.
INDIANA DEPARTMENT OF TRANSPORTATION
CONCRETE BRIDGE RAILING
PLACEMENT
SEPTEMBER 2012
STANDARD DRAWING NO. E 706-BRSF-03
RICHARD L. VanCLEAVE REGISTERED No. 9750 STATE OF INDIANA PROFESSIONAL ENGINEER
/s/ Richard L. VanCleave 09/04/12
SUPERVISOR, ROADWAY STANDARDS DATE
/s/ Mark A. Miller 09/04/12
CHIEF ENGINEER DATE

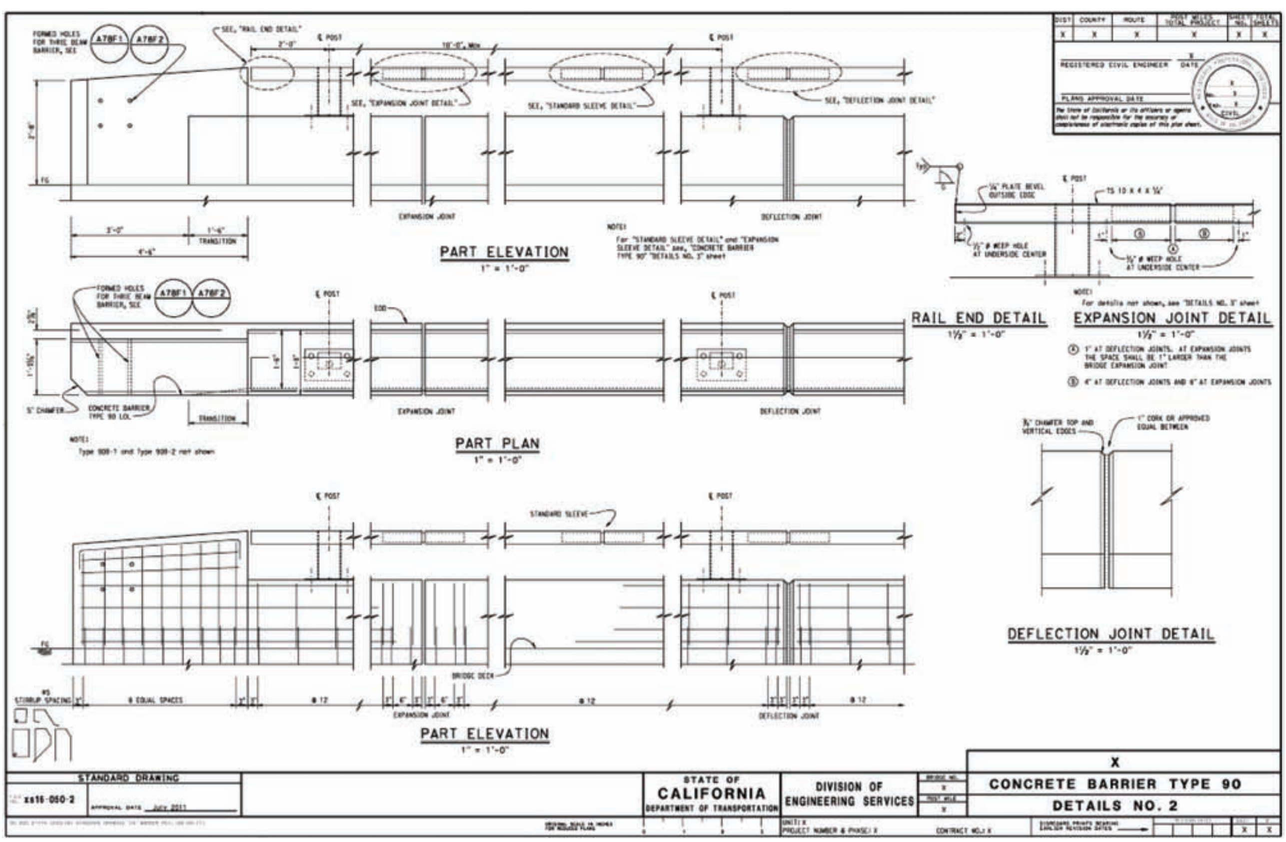


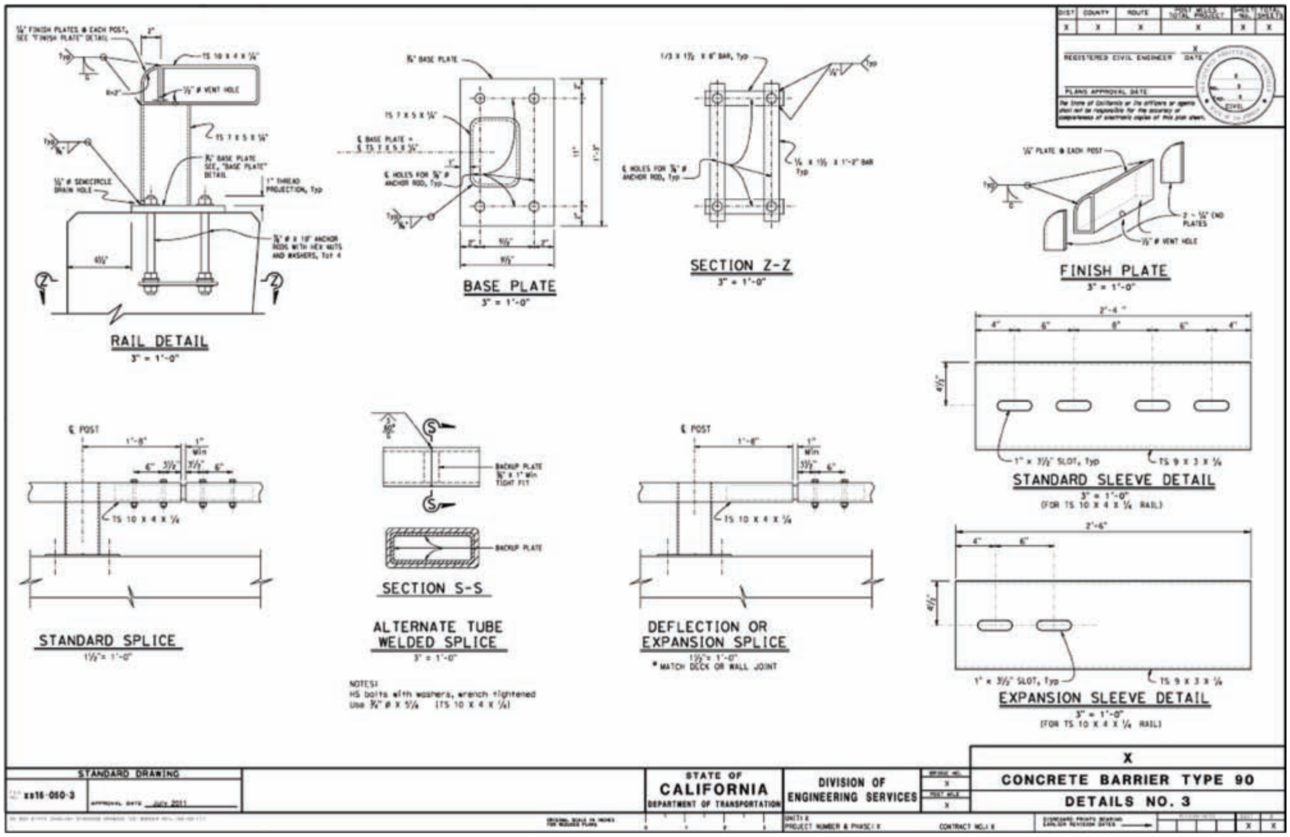


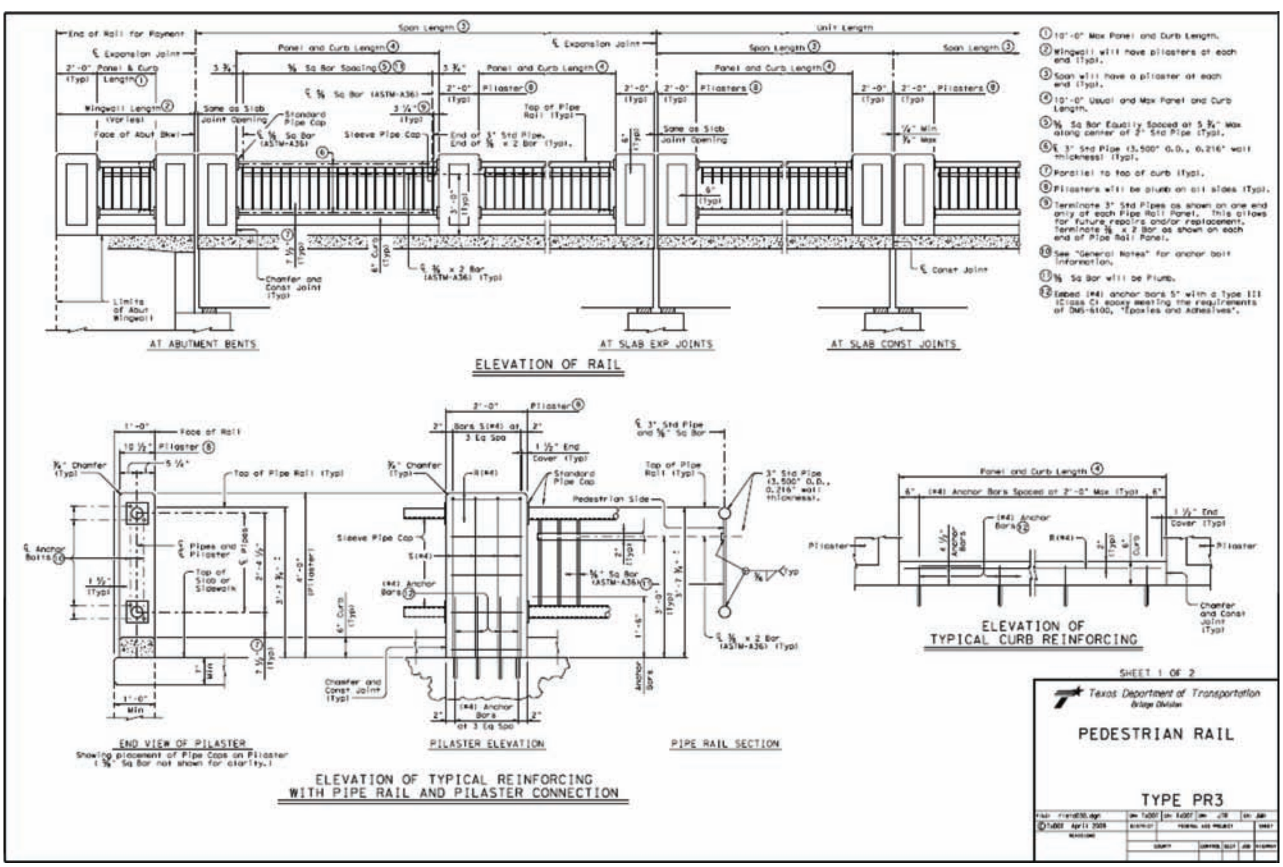

CURB AND POST DETAILS
ANCHOR PLATE DETAILS
BASE PLATE DETAILS
RAIL SPLICE DETAILS
PLAN
ELEVATION
GENERAL NOTES:
PLATE WASHER-"C"
PLATE "D"
ALTERNATE POST
RAIL CAP DETAILS
OREGON STANDARD DRAWINGS
3-TUBE CURB MOUNT RAIL
2008

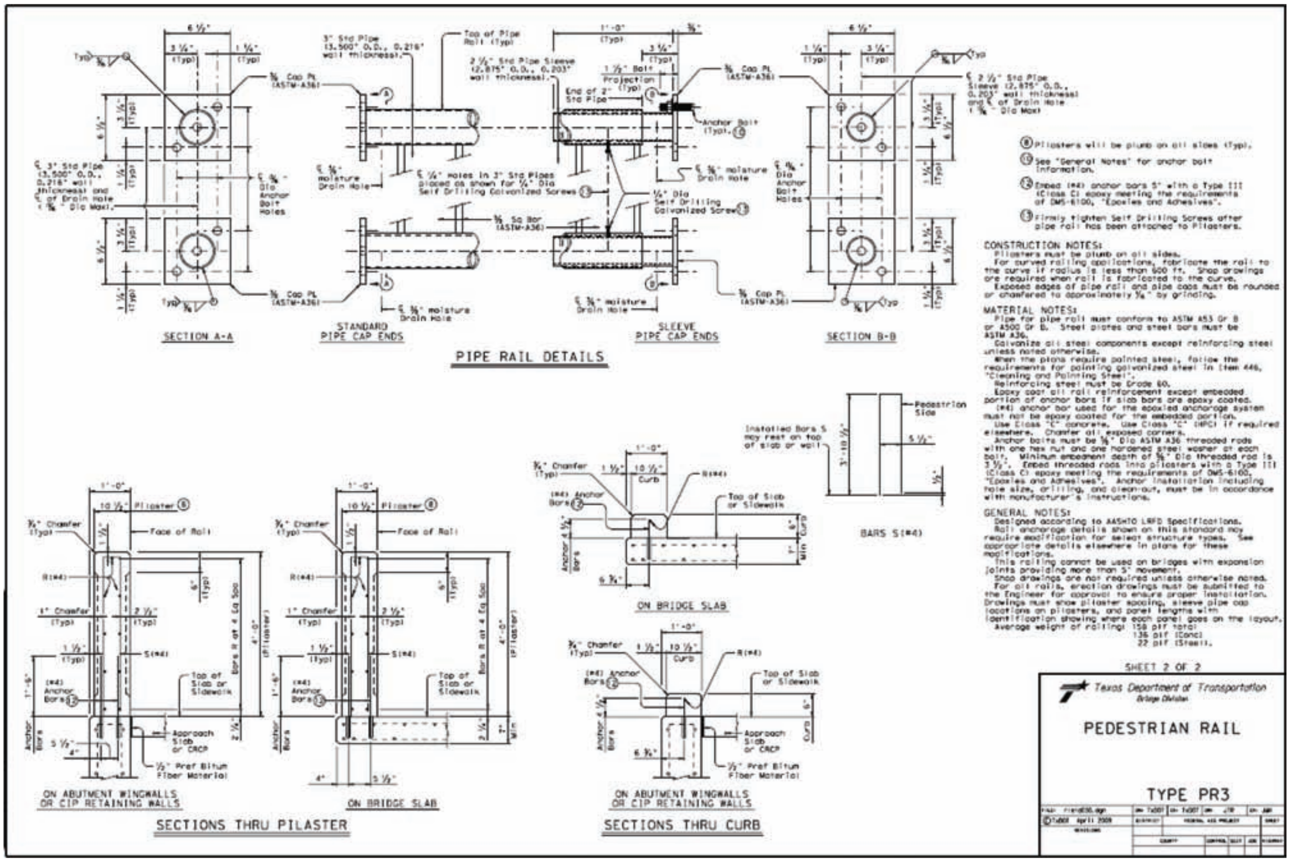

PLAN
ELEVATION
TYPE I- APPROACH GUARDRAIL CONNECTION
CONNECTION ANGLE "A"
SECTION D-D
SECTION E-E
DETAIL "A"
SECTION C-C
SECTION B-B
GUARDRAIL CONNECTION PLATE DETAILS
TOP RAIL ATTACHMENT BRACKET
RAIL ATTACHMENT BRACKET
TYPE II- APPROACH GUARDRAIL CONNECTION
END POST DETAILS
OREGON STANDARD DRAWINGS
3-TUBE CURB MOUNT RAIL TRANSITION
2008

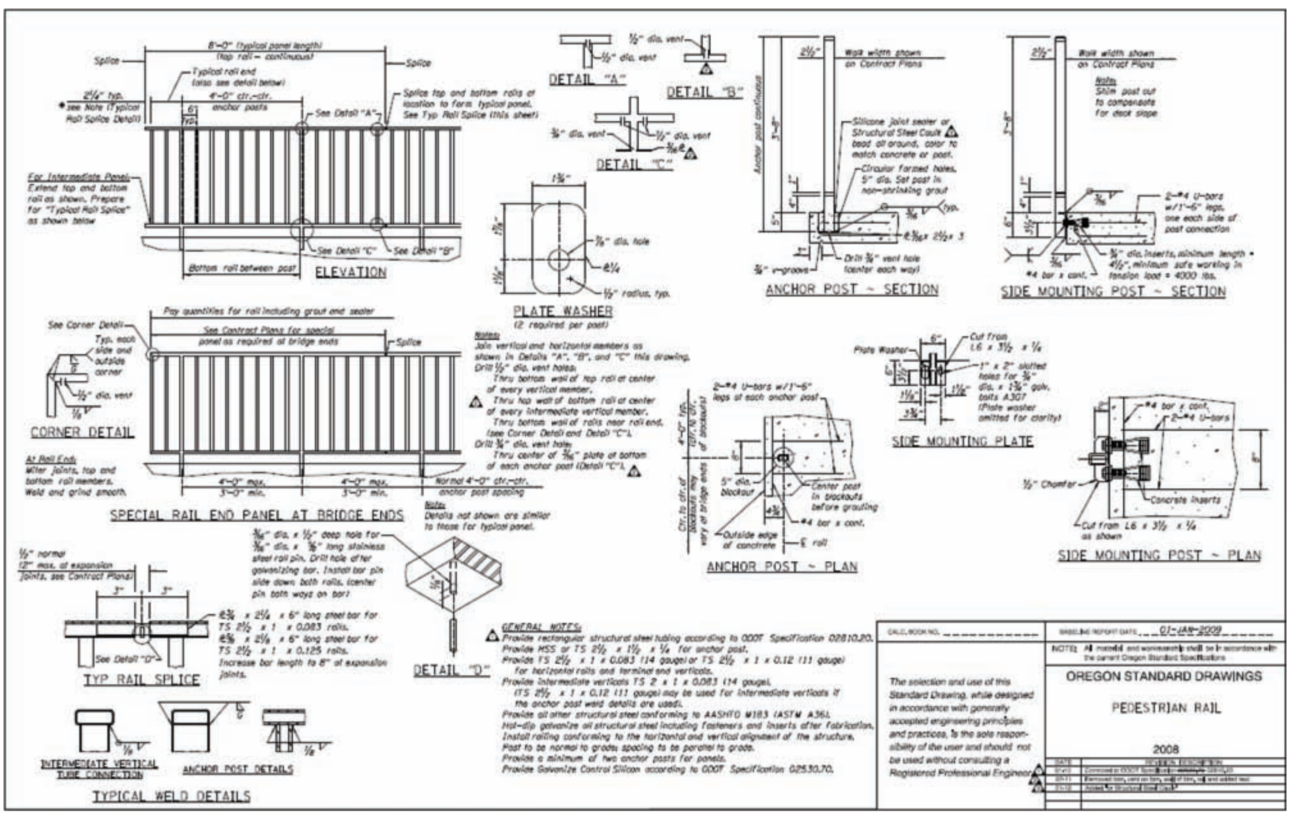

GENERAL NOTES:
TYPE 90
TYPE 90A-1
TYPE 90A-2
TYPE 90B-1
TYPE 90B-2
STANDARD DRAWING
STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
CONCRETE BARRIER TYPE 90
DETAILS NO. 1

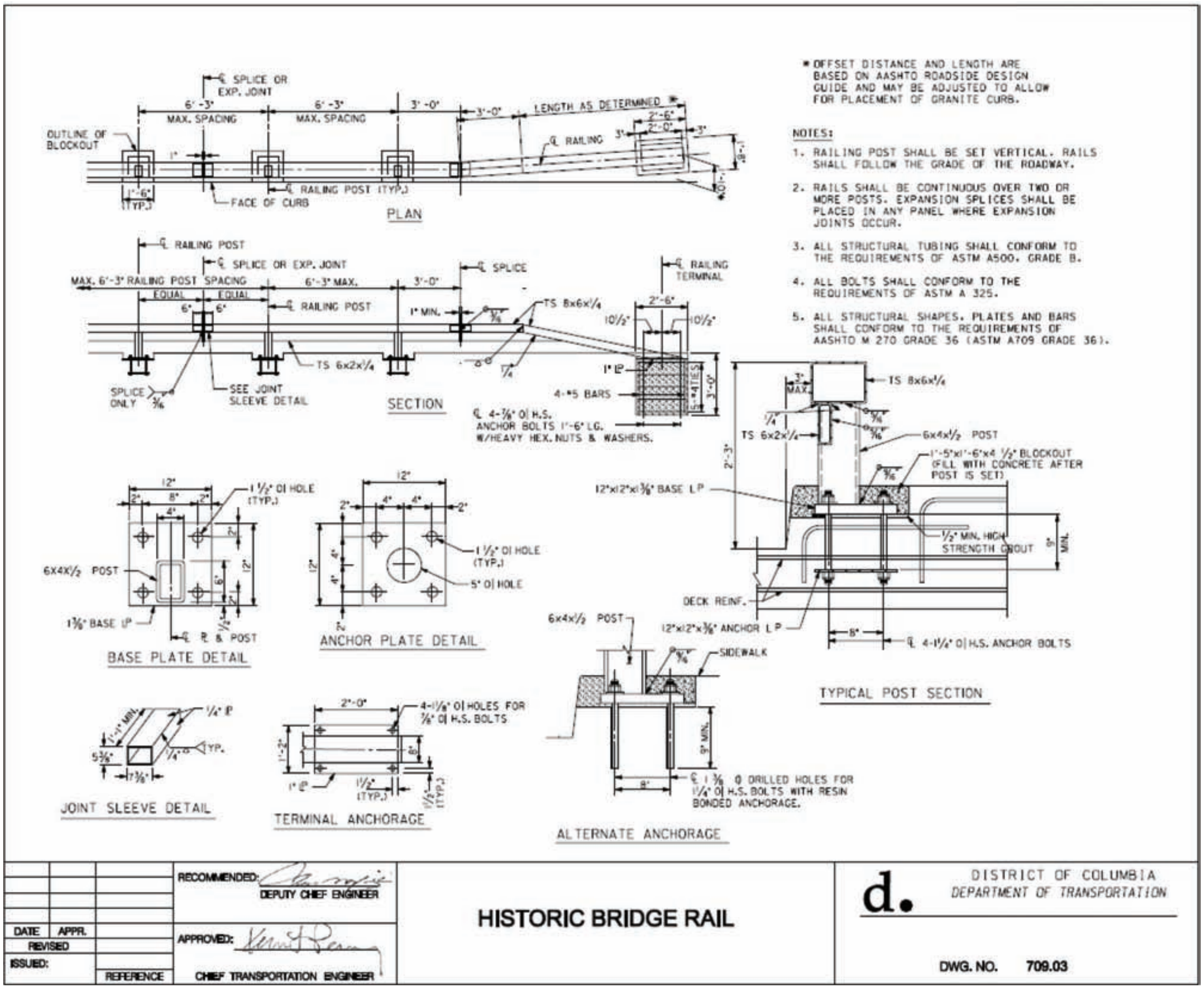

PART ELEVATION
RAIL END DETAIL
EXPANSION JOINT DETAIL
PART PLAN
DEFLECTION JOINT DETAIL
PART ELEVATION
STANDARD DRAWING
STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
CONCRETE BARRIER TYPE 90
DETAILS NO. 2


RAIL DETAIL
3" = 1'-0"
BASE PLATE
3" = 1'-0"
SECTION Z-Z
3" = 1'-0"
FINISH PLATE
3" = 1'-0"
STANDARD SLEEVE DETAIL
STANDARD SPLICE
SECTION S-S
ALTERNATE TUBE WELDED SPLICE
DEFLECTION OR EXPANSION SPLICE
EXPANSION SLEEVE DETAIL
STANDARD DRAWING
STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
CONCRETE BARRIER TYPE 90
DETAILS NO. 3


AT ABUTMENT BENTS
AT SLAB EXP JOINTS
AT SLAB CONST JOINTS
ELEVATION OF RAIL
ELEVATION OF TYPICAL CURB REINFORCING
END VIEW OF PILASTER
PILASTER ELEVATION
PIPE RAIL SECTION
ELEVATION OF TYPICAL REINFORCING WITH PIPE RAIL AND PILASTER CONNECTION
SHEET 1 OF 2
Texas Department of Transportation
PEDESTRIAN RAIL
TYPE PR3


PIPE RAIL DETAILS
SECTION A-A
STANDARD PIPE CAP ENDS
SLEEVE PIPE CAP ENDS
SECTION B-B
CONSTRUCTION NOTES:
MATERIAL NOTES:
GENERAL NOTES:
ON BRIDGE SLAB
BARS S(#4)
SECTIONS THRU PILASTER
SECTIONS THRU CURB
ON ABUTMENT WINGWALLS OR CIP RETAINING WALLS
SHEET 2 OF 2
Texas Department of Transportation
PEDESTRIAN RAIL
TYPE PR3


ELEVATION
DETAIL "A"
DETAIL "B"
DETAIL "C"
PLATE WASHER
ANCHOR POST ~ SECTION
SIDE MOUNTING POST ~ SECTION
CORNER DETAIL
SPECIAL RAIL END PANEL AT BRIDGE ENDS
SIDE MOUNTING PLATE
ANCHOR POST ~ PLAN
SIDE MOUNTING POST ~ PLAN
TYP RAIL SPLICE
DETAIL "D"
GENERAL NOTES:
TYPICAL WELD DETAILS
OREGON STANDARD DRAWINGS
PEDESTRIAN RAIL
2008


* OFFSET DISTANCE AND LENGTH ARE BASED ON AASHTO ROADSIDE DESIGN GUIDE AND MAY BE ADJUSTED TO ALLOW FOR PLACEMENT OF GRANITE CURB.
NOTES:
1. RAILING POST SHALL BE SET VERTICAL. RAILS SHALL FOLLOW THE GRADE OF THE ROADWAY.
2. RAILS SHALL BE CONTINUOUS OVER TWO OR MORE POSTS. EXPANSION SPLICES SHALL BE PLACED IN ANY PANEL WHERE EXPANSION JOINTS OCCUR.
3. ALL STRUCTURAL TUBING SHALL CONFORM TO THE REQUIREMENTS OF ASTM A500, GRADE B.
4. ALL BOLTS SHALL CONFORM TO THE REQUIREMENTS OF ASTM A 325.
5. ALL STRUCTURAL SHAPES, PLATES AND BARS SHALL CONFORM TO THE REQUIREMENTS OF AASHTO M 270 GRADE 36 (ASTM A709 GRADE 36).
PLAN
SECTION
BASE PLATE DETAIL
ANCHOR PLATE DETAIL
TYPICAL POST SECTION
JOINT SLEEVE DETAIL
TERMINAL ANCHORAGE
ALTERNATE ANCHORAGE
RECOMMENDED:
DEPUTY CHIEF ENGINEER
APPROVED:
CHIEF TRANSPORTATION ENGINEER
DATE
APPR.
REVISED
ISSUED:
REFERENCE
HISTORIC BRIDGE RAIL
d.
DISTRICT OF COLUMBIA
DEPARTMENT OF TRANSPORTATION
DWG. NO. 709.03

APPENDIX B. HISTORIC BRIDGES REMOVED FROM SERVICE UNDER INDIANA'S PROGRAMMATIC AGREEMENT

TABLE B.1
Historic Bridges Removed from Service

NBI #	County	Structural Type	Railing Type
0300003	Bartholomew	Metal Pony Truss	Metal 10
0300121	Bartholomew	Metal Pony Truss	Metal 10
0300024	Bartholomew	Metal Thru Truss	Metal 6
0400004	Benton	Reinforced Concrete Girder and Beam	Galvanized Beam
0600011	Boone	Metal Pony Truss	Metal 7
0600052	Boone	Reinforced Concrete Girder and Beam	Bush-Hammered Panel
0700031	Brown	Metal Pony Truss	None
0800129	Carroll	Reinforced Concrete Slab	None
1300067	Crawford	Metal Pony Truss	Galvanized Beam
1300008	Crawford	Metal Pony Truss	Metal 10
2800014	Greene	Metal Pony Truss	Metal 6
2800204	Greene	Timber Other	Timber 2
3600125	Jackson	Metal Pony Truss	None
3600103	Jackson	Metal Thru Truss	Metal 10
4000008	Jennings	Metal Pony Truss	Metal 6
4000015	Jennings	Reinforced Concrete Slab	None
4200147	Knox	Timber Other	Timber 2
4700122	Lawrence	Concrete Arch	Concrete 6
4700052	Lawrence	Metal Pony Truss	Metal 6
4700053	Lawrence	Metal Pony Truss	Metal 6
4700042	Lawrence	Metal Pony Truss	Metal 7
4800077	Madison	Metal Pony Truss	Metal 10
4900390	Marion	Prestressed Concrete Box Beam	Galvanized Beam
4900209	Marion	Reinforced Concrete Slab	Bush-Hammered Panel
5100061	Martin	Metal Pony Truss	Metal 10
5100006	Martin	Metal Pony Truss	Metal 10
5100040	Martin	Metal Pony Truss	Metal 10
5500125	Morgan	Concrete Arch	Bush-Hammered Panel
5500142	Morgan	Metal Pony Truss	Metal 10
5500024	Morgan	Reinforced Concrete Girder and Beam	Bush-Hammered Panel
5600093	Newton	Metal Thru Truss	Galvanized Beam
5900024	Orange	Steel Beam	Concrete 15
6300057	Pike	Metal Thru Truss	Metal 10
6500238	Posey	Metal Pony Truss	Metal 6
6500150	Posey	Metal Thru Truss	Metal 6
6700173	Putnam	Metal Pony Truss	Metal 10
6800181	Randolph	Metal Pony Truss	Metal 6
6900053	Ripley	Stone Arch	Stone 3
7300013	Shelby	Metal Thru Truss	Galvanized Beam
7400168	Spencer	Concrete Arch	Concrete 15
8000051	Tipton	Reinforced Concrete Girder and Beam	Concrete 21
8000009	Tipton	Reinforced Concrete Slab	Bush-Hammered Panel
8400113	Vigo	Metal Pony Truss	Metal 4
8800038	Washington	Metal Pony Truss	Galvanized Beam
8800040	Washington	Reinforced Concrete Slab	Concrete 2
9000058	Wells	Metal Pony Truss	Metal 6
5940	White	Concrete Arch	Concrete 6

APPENDIX C. PHOTOS OF HISTORIC BRIDGE RAILINGS

Photos of all railing types observed on historic bridges in Indiana are provided. Each photo is accompanied by the name of the railing and the number of in-service bridges on which it appears.

Concrete 1 (Bush-Hammered Panel) (74 bridges)

Concrete 2 (46 bridges)

Concrete 3 (2 bridges)

Concrete 4 (2 bridges)

Concrete 5 (1 bridge)

Concrete 6 (39 bridges)

Concrete 7 (12 bridges)

Concrete 8 (1 bridge)

Concrete 9 (1 bridge)

Concrete 10 (2 bridges)

Concrete 11 (1 bridge)

Concrete 12 (2 bridges)

Concrete 13 (1 bridge)

Concrete 14 (F-type) (14 bridges)

Concrete 15 (24 bridges)

Concrete 16 (2 bridges)

Concrete 17 (6 bridges)

Concrete 18 (6 bridges)

Concrete 19 (4 bridges)

Concrete 20 (1 bridge)

Concrete 21 (3 bridges)

Concrete 22 (1 bridge)

Concrete 23 (2 bridges)

Concrete 24 (2 bridges)

Concrete 25 (1 bridge)

Concrete 26 (1 bridge)

Metal 1 (15 bridges)

Metal 2 (9 bridges)

Metal 3 (1 bridge)

Metal 4 (1 bridge)

Metal 5 (Galvanized Beam) (75 bridges)

Metal 6 (78 bridges)

Metal 7 (9 bridges)

Metal 8 (2 bridges)

Metal 9 (24 bridges)

Metal 10 (38 bridges)

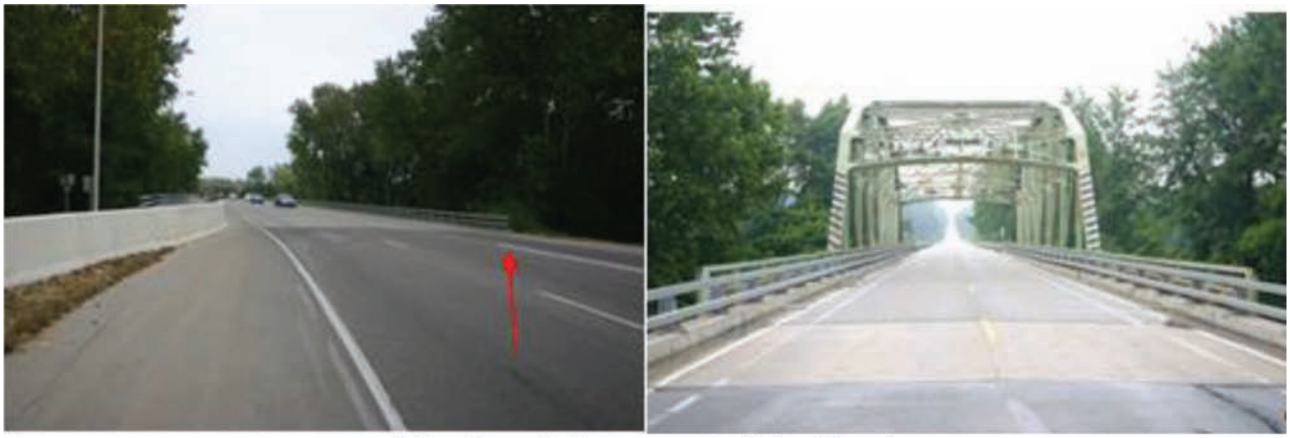
Metal 11 (1 bridge)

Metal 12 (6 bridges)

Metal 13 (1 bridge)

Metal 14 (7 bridges)

Metal and Concrete 1 (8 bridges)



Metal and Concrete 2 (2 bridges)

Metal and Concrete 3 (1 bridge)

Metal and Concrete 4 (F-type w/ Handrail) (1 bridge)

Pedestrian 1 (1 bridge)

Pedestrian 2 (1 bridge)

Pedestrian 3 (1 bridge)

Pedestrian 4 (1 bridge)

Pedestrian 5 (1 bridge)

Pedestrian 6 (2 bridges)

Pedestrian 7 (1 bridge)

Pedestrian 8 (1 bridge)

Stone 1 (1 bridge)

Stone 2 (10 bridges)

Stone 3 (13 bridges)

Stone 4 (1 bridge)

Stone 5 (3 bridges)

Stone 6 (1 bridge)

Timber 1 (47 bridges)

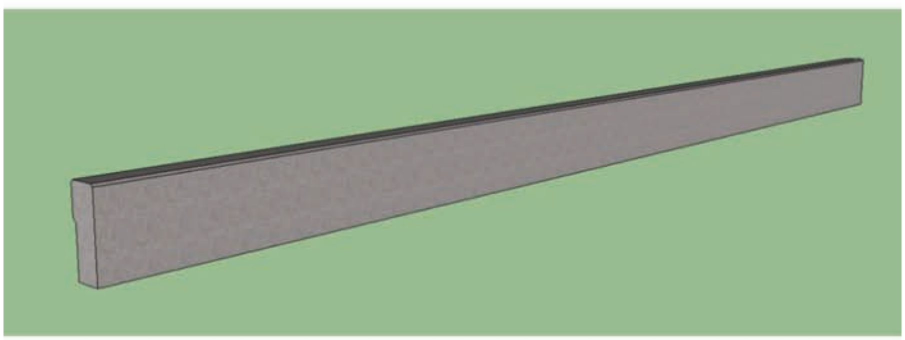
Timber 2 (6 bridges)

Timber 3 (2 bridges)

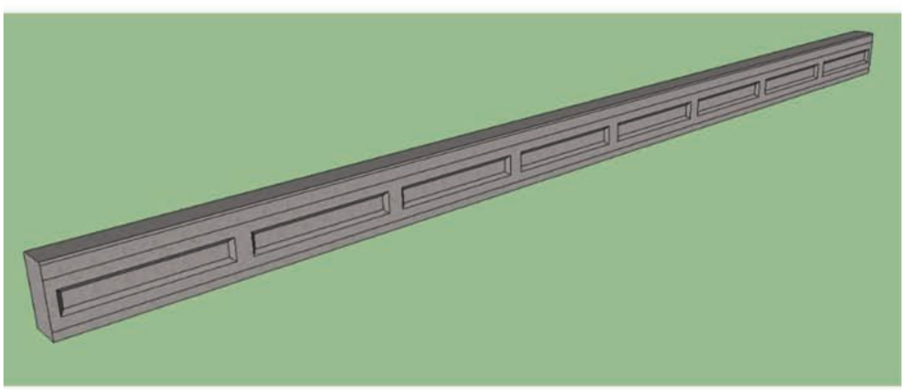
No Railing (35 bridges)

APPENDIX D. SIMULATED HISTORIC RAILING RENDERINGS

Concrete 1 (Bush-Hammered Panel)

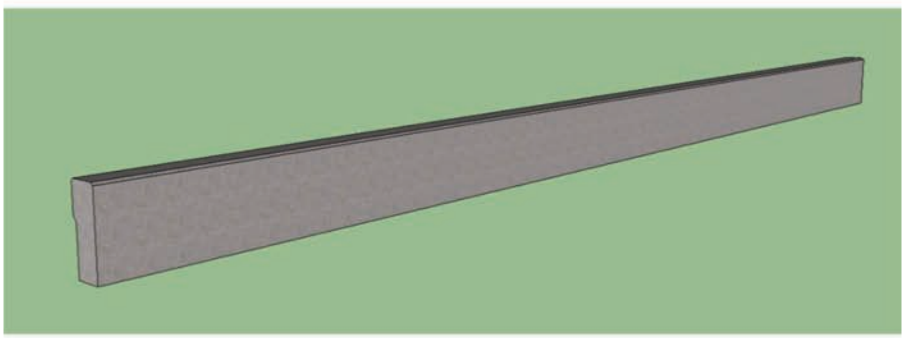


Parent Railing: TxDOT T221

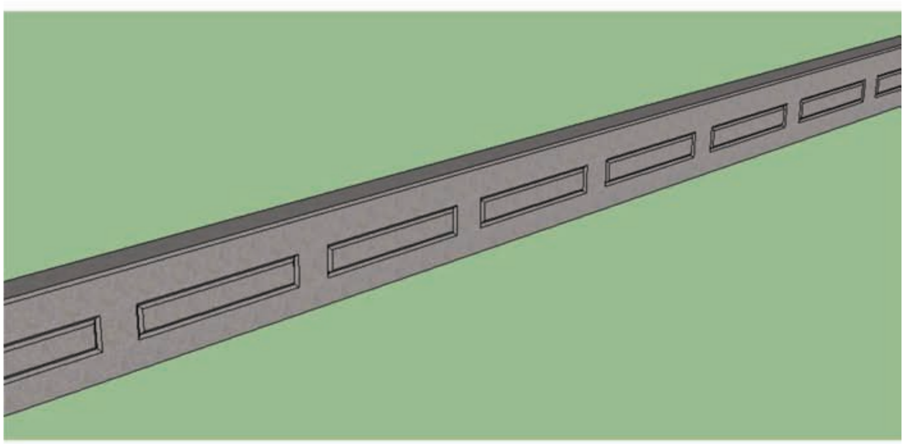


Modified Railing

Concrete 2

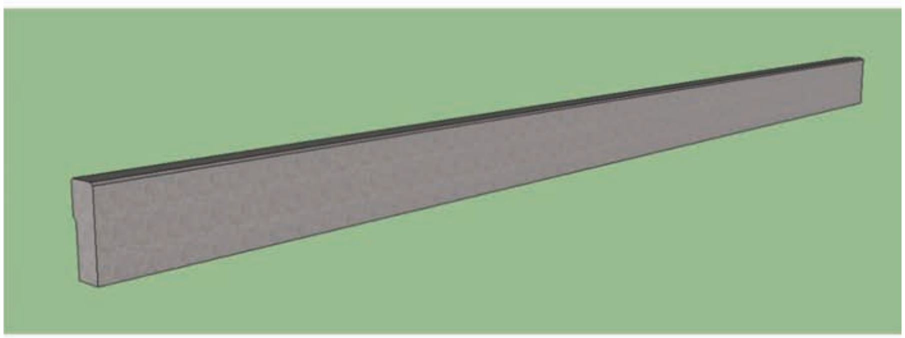


Parent Railing: TxDOT T221

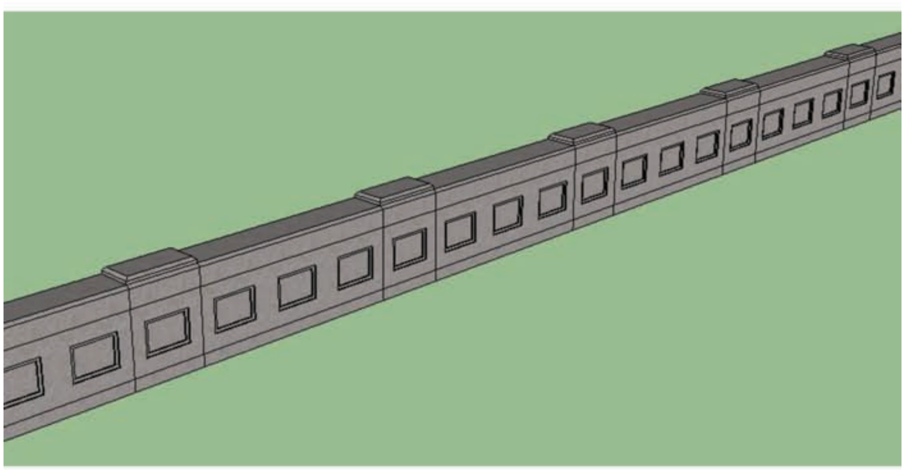


Modified Railing

Concrete 3

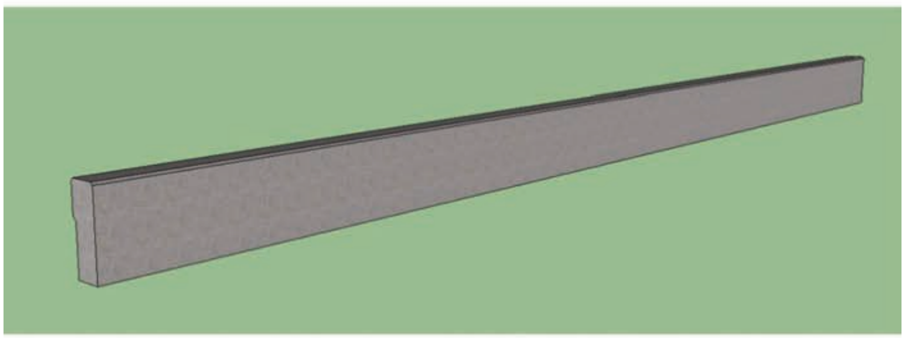


Parent Railing: TxDOT T221

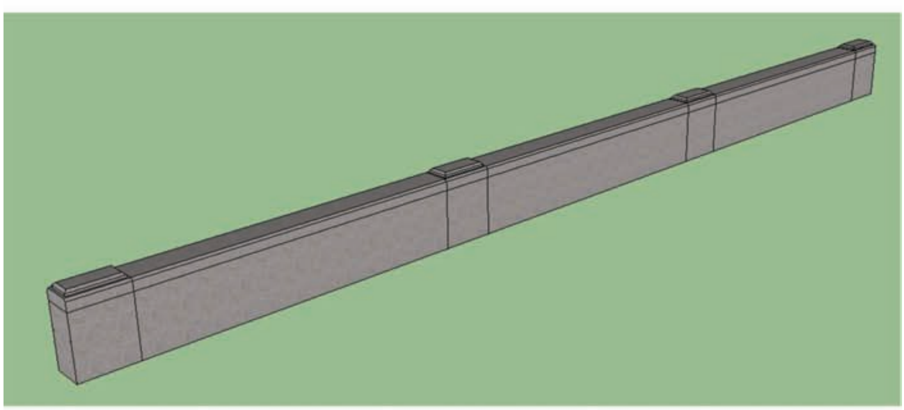


Modified Railing

Concrete 4

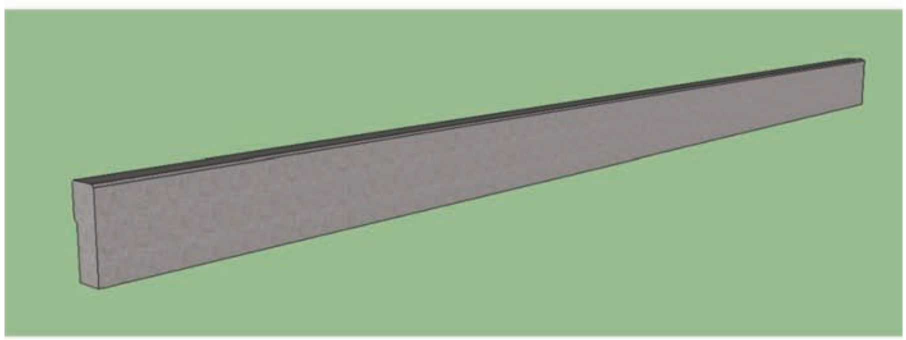


Parent Railing: TxDOT T221

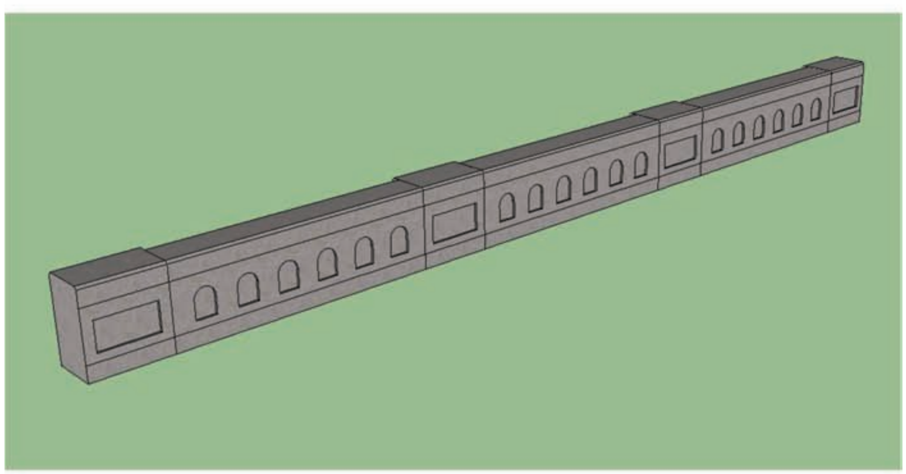


Modified Railing

Concrete 5

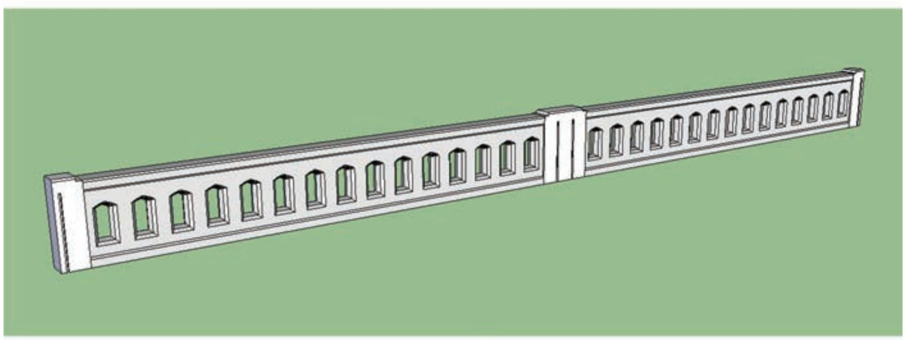


Parent Railing: TxDOT T221



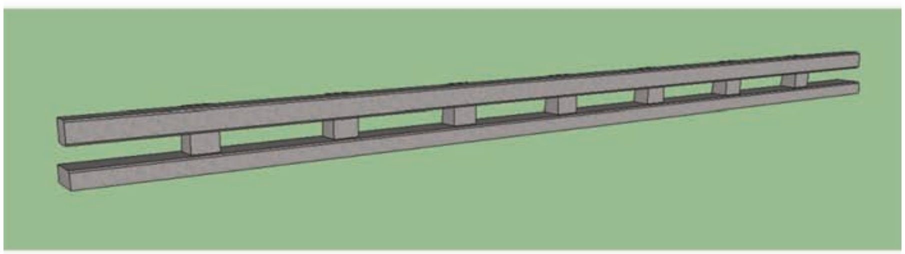
Modified Railing

Concrete 6

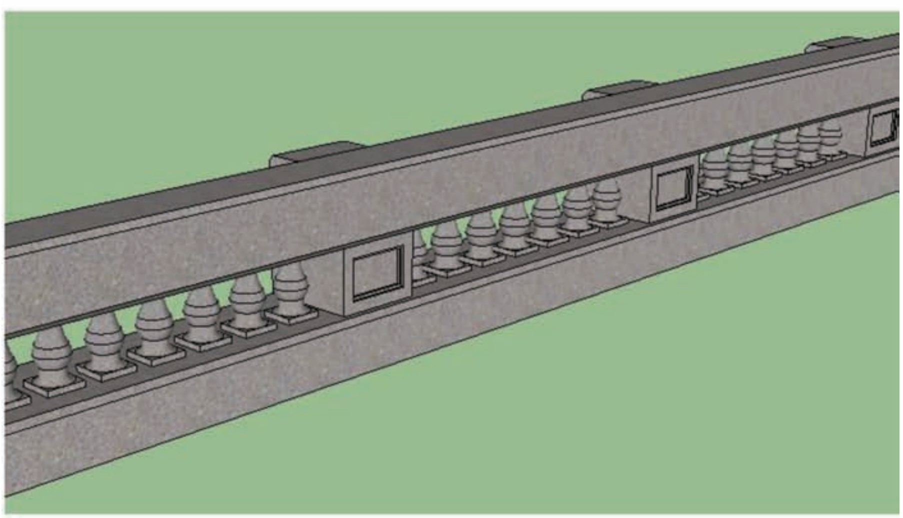


Nearly Exact Approximation: INDOT TX

Concrete 7

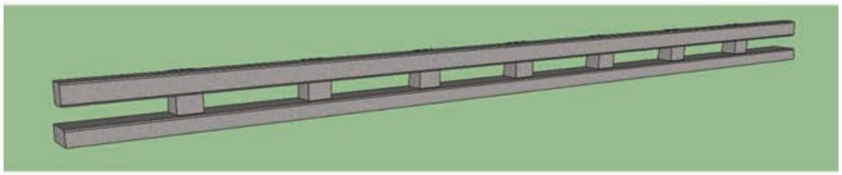


Parent Railing: ODOT Concrete Beam and Post

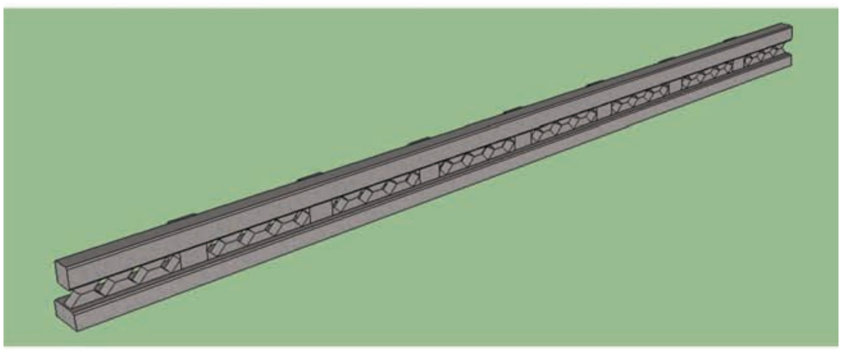


Modified Railing

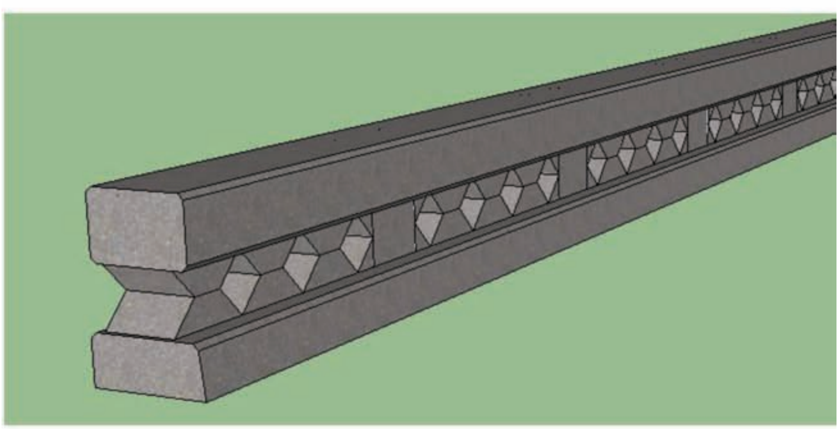
Concrete 8



Parent Railing: ODOT Concrete Beam and Post

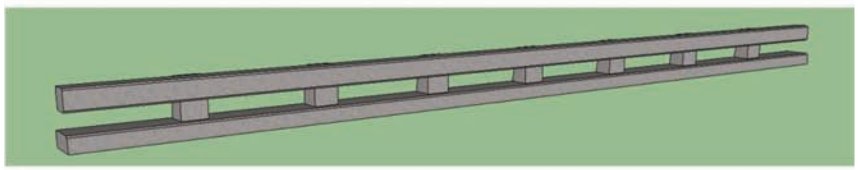


Modified Railing (Option 1)

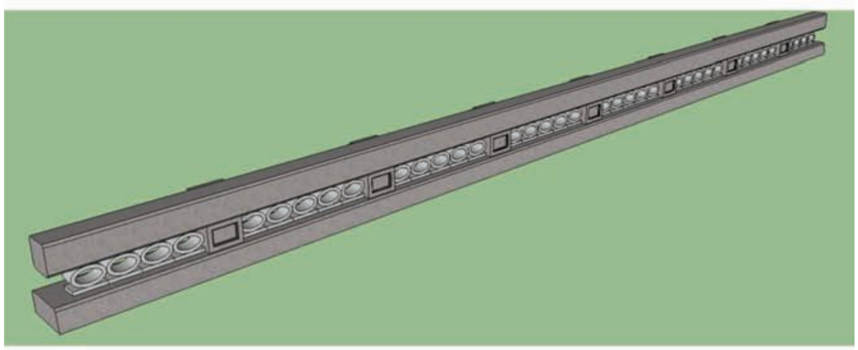


Modified Railing (Option 2 – Symmetric)

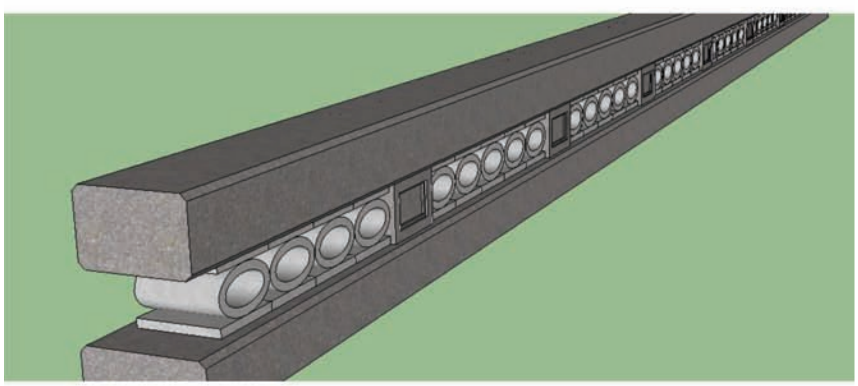
Concrete 9



Parent Railing: ODOT Concrete Beam and Post

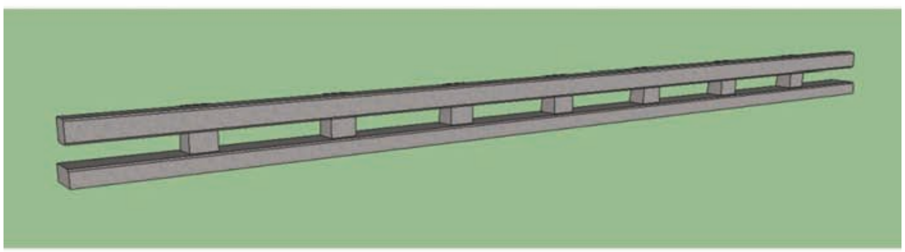


Modified Railing (Option 1)

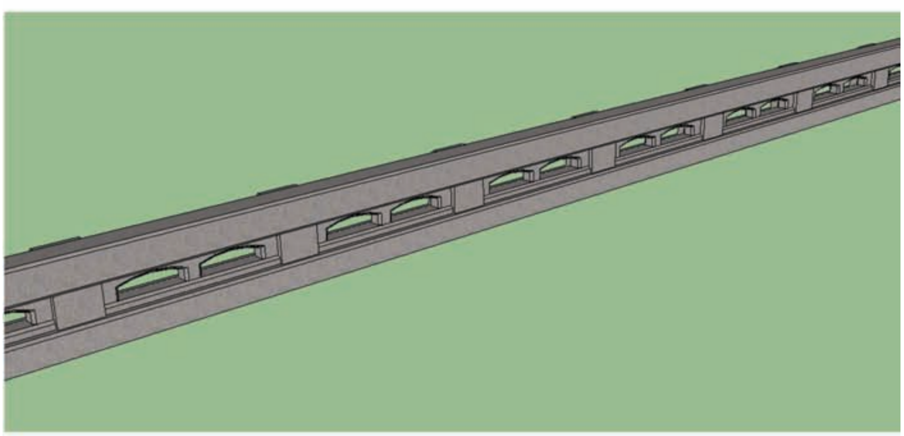


Modified Railing (Option 2 – Symmetric)

Concrete 10

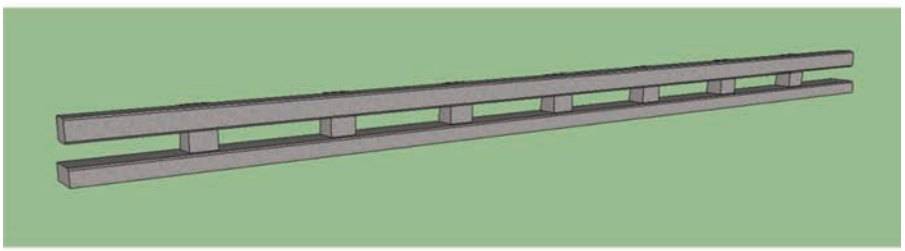


Parent Railing: ODOT Concrete Beam and Post

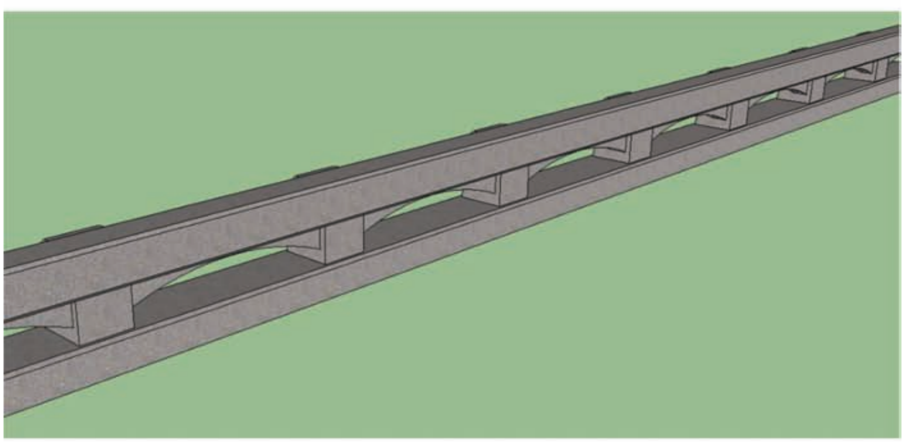


Modified Railing

Concrete 11

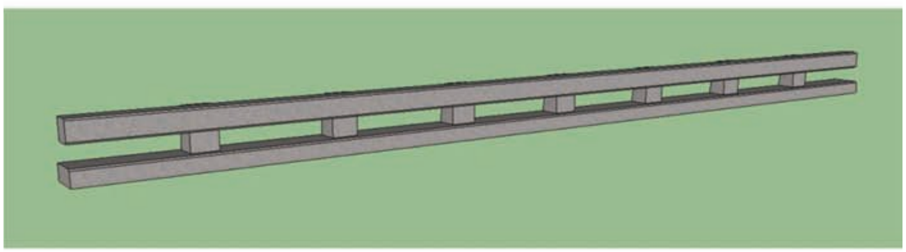


Parent Railing: ODOT Concrete Beam and Post

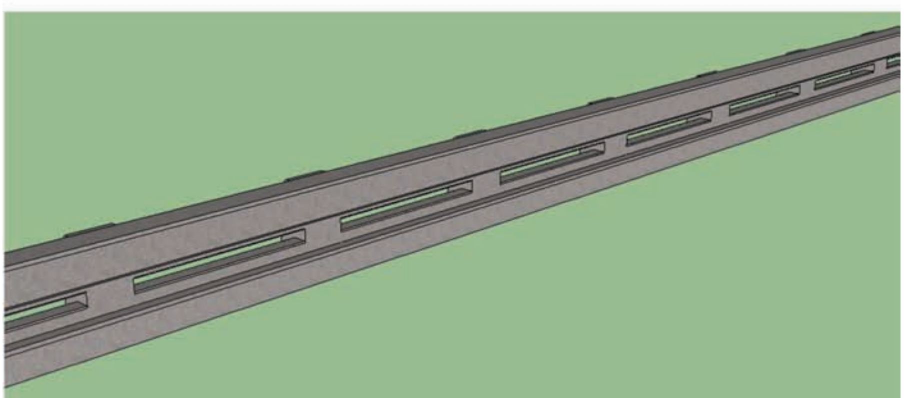


Modified Railing

Concrete 12

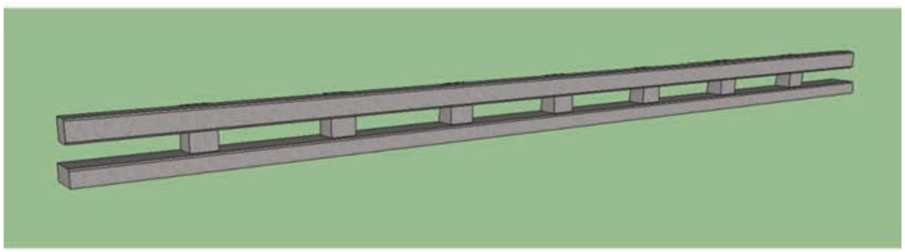


Parent Railing: ODOT Concrete Beam and Post

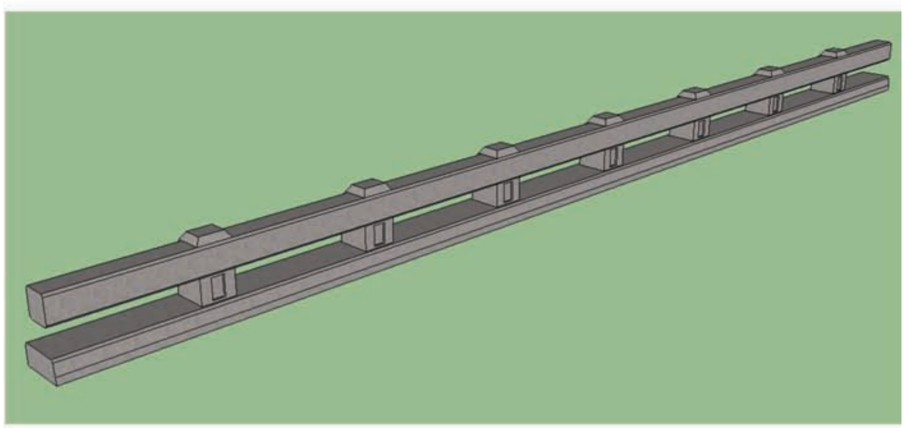


Modified Railing

Concrete 13

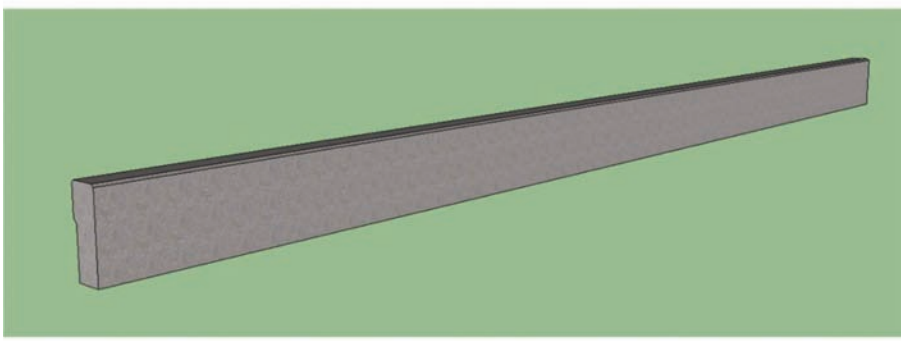


Parent Railing: ODOT Concrete Beam and Post



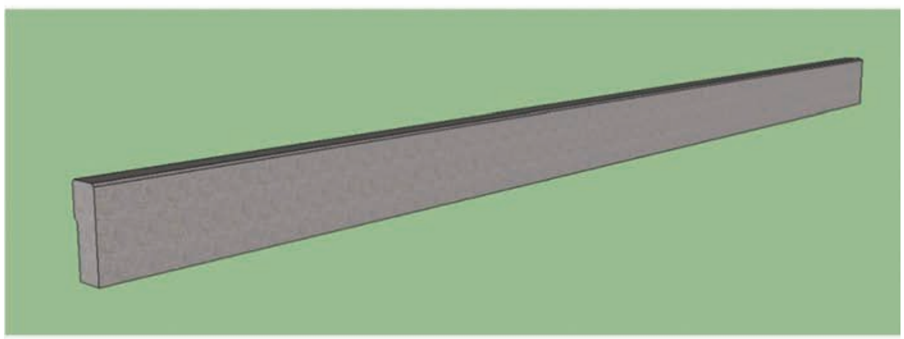
Modified Railing

Concrete 15

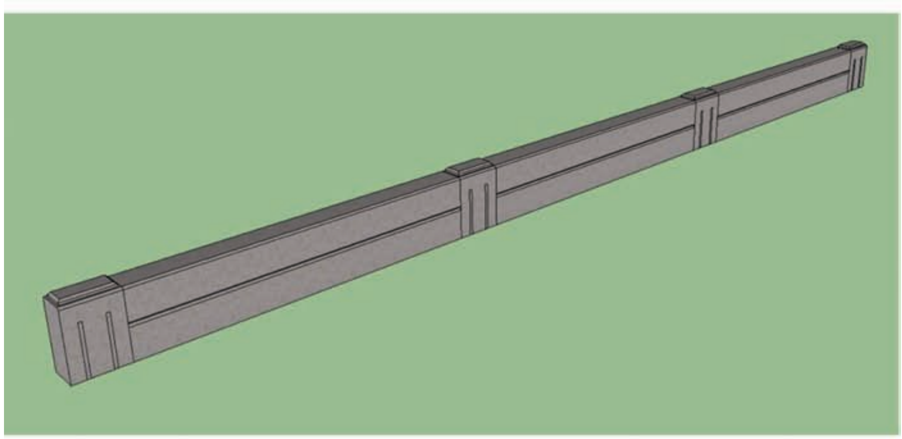


Nearly Exact Approximation: TxDOT T221

Concrete 16

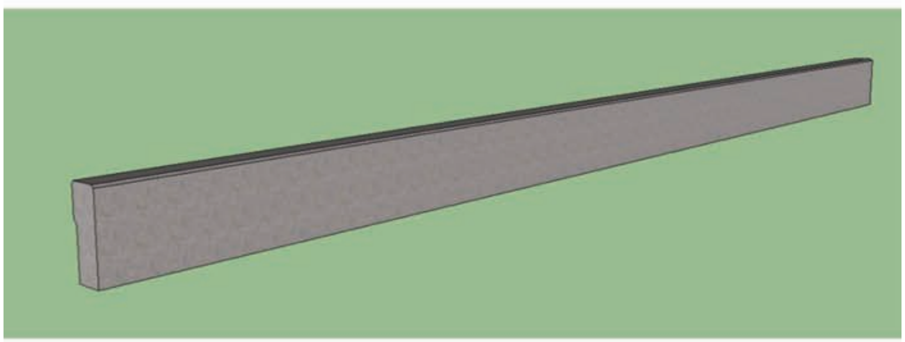


Parent Railing: TxDOT T221

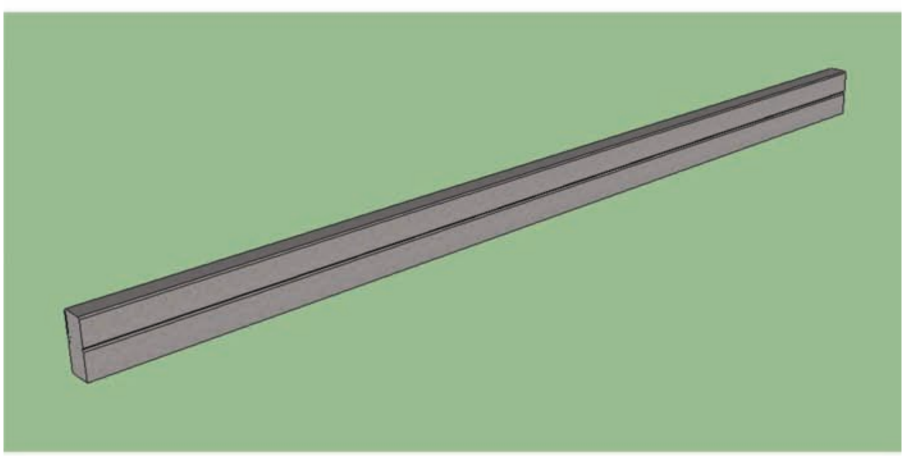


Modified Railing

Concrete 17

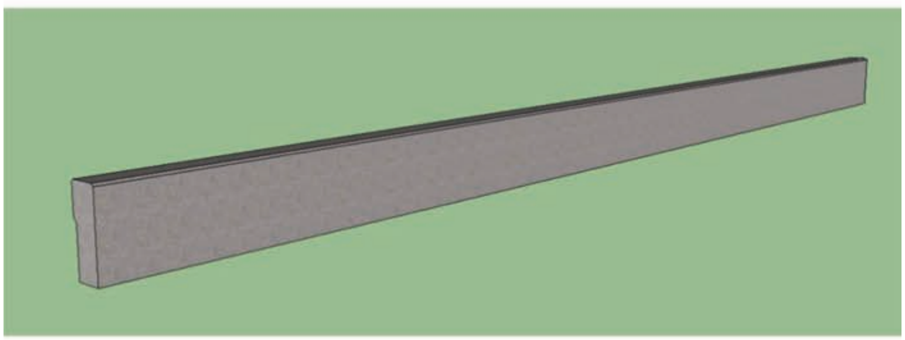


Parent Railing: TxDOT T221

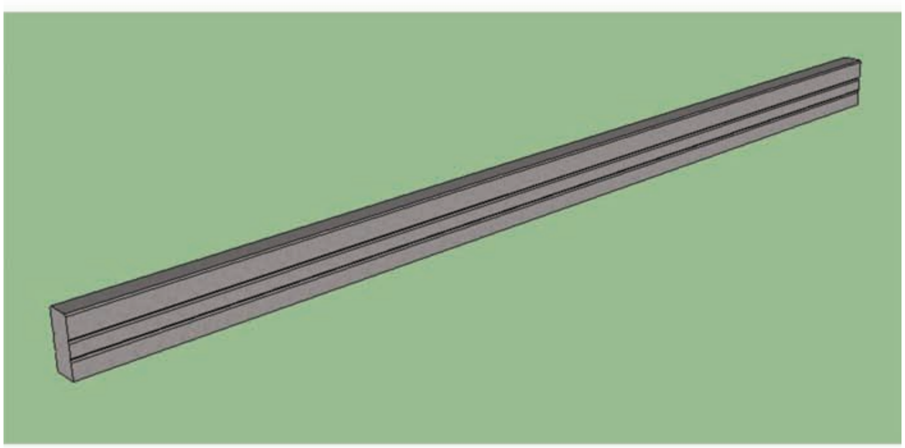


Modified Railing

Concrete 18

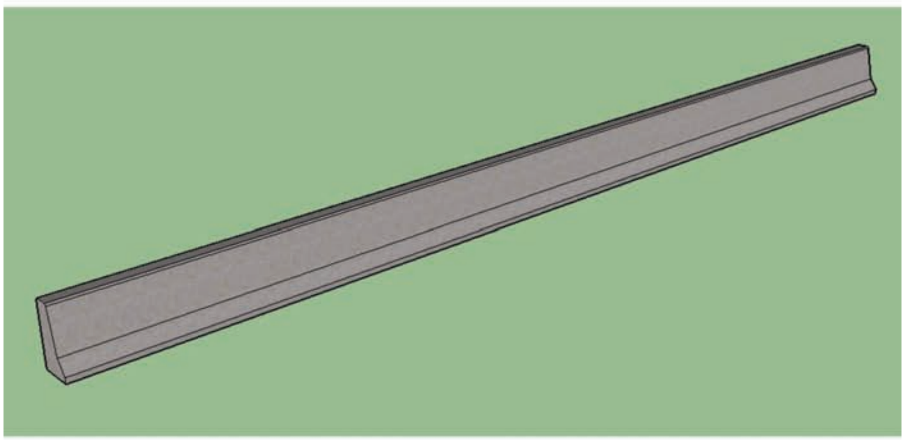


Parent Railing: TxDOT T221

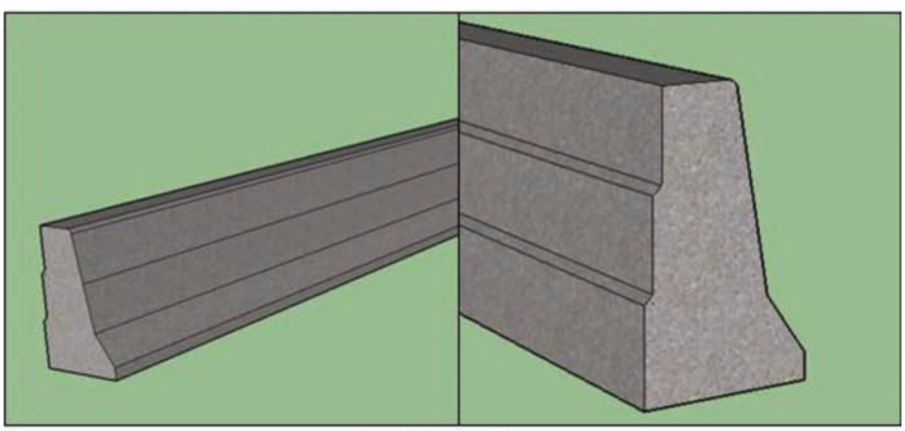


Modified Railing

Concrete 19

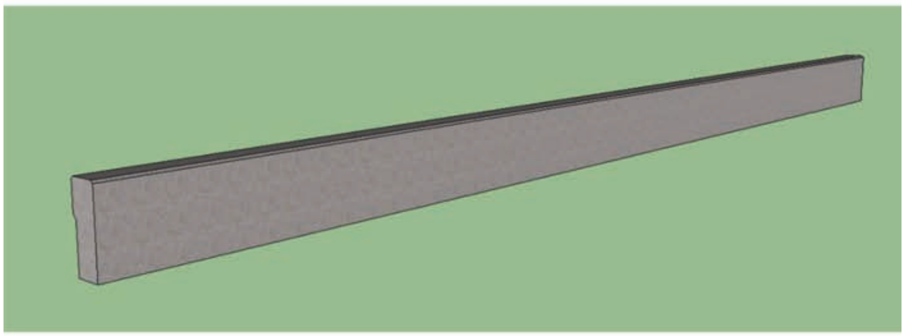


Parent Railing: INDOT FC

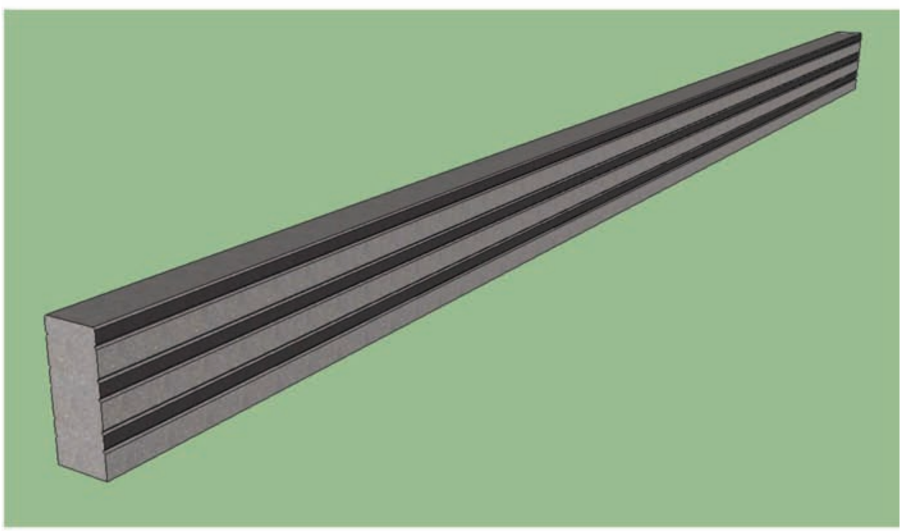


Modified Railing

Concrete 20

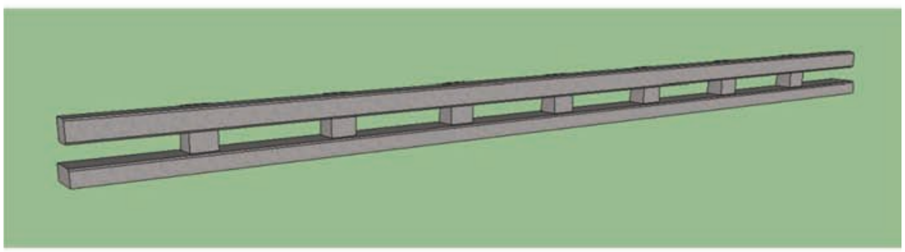


Parent Railing: TxDOT T221

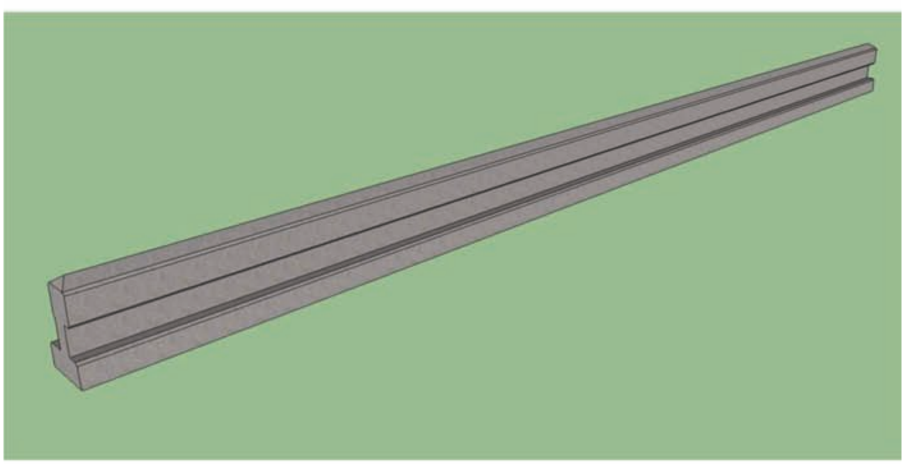


Modified Railing

Concrete 22

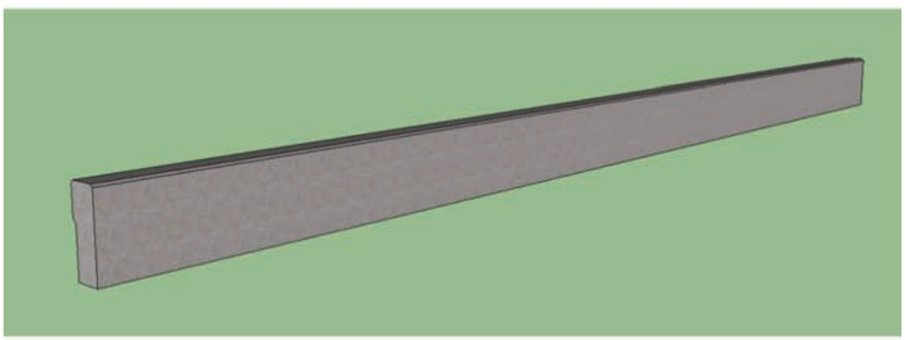


Parent Railing: ODOT Concrete Beam and Post

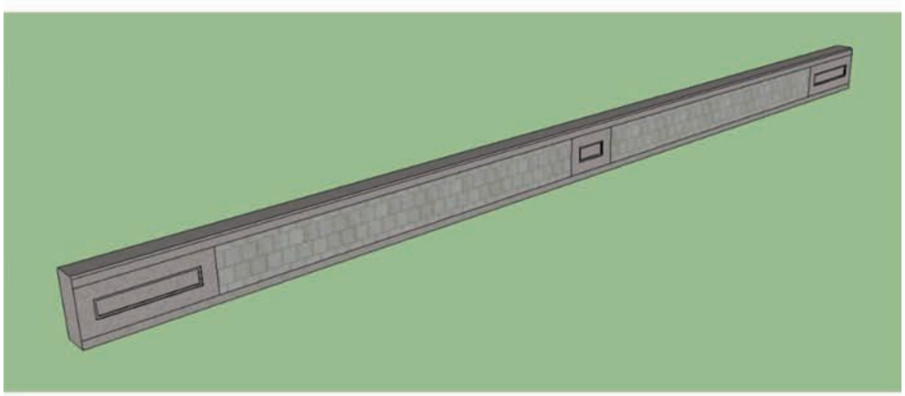


Modified Railing

Concrete 23

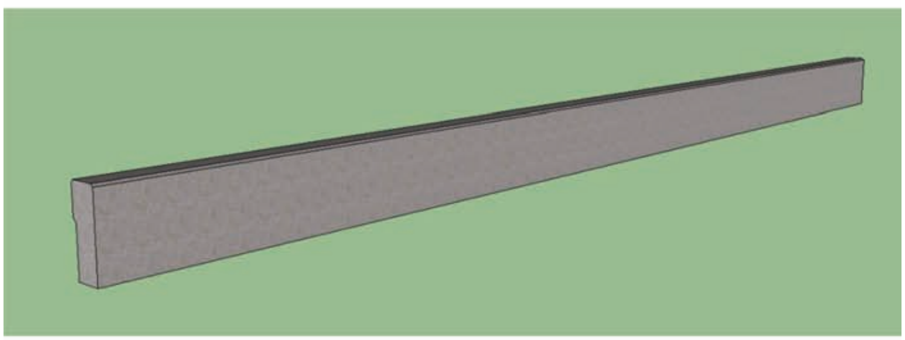


Parent Railing: TxDOT T221

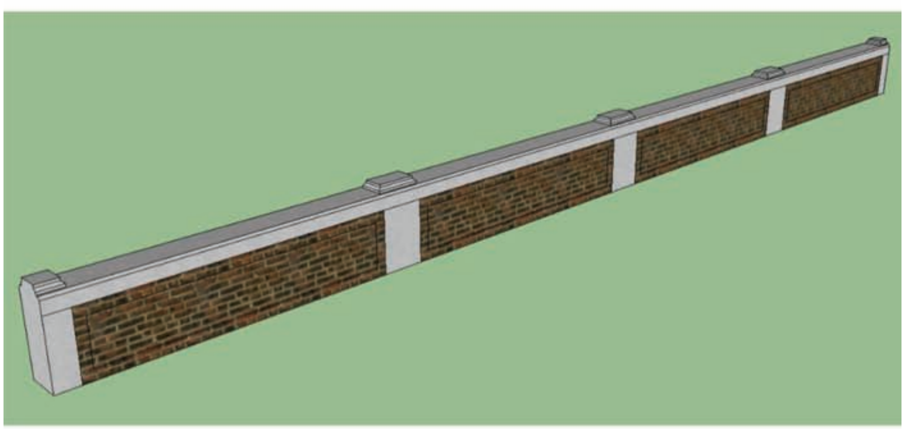


Modified Railing

Concrete 25

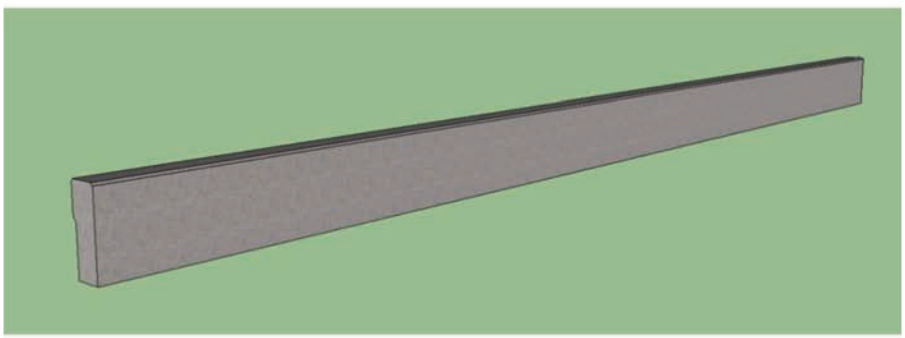


Parent Railing: TxDOT T221

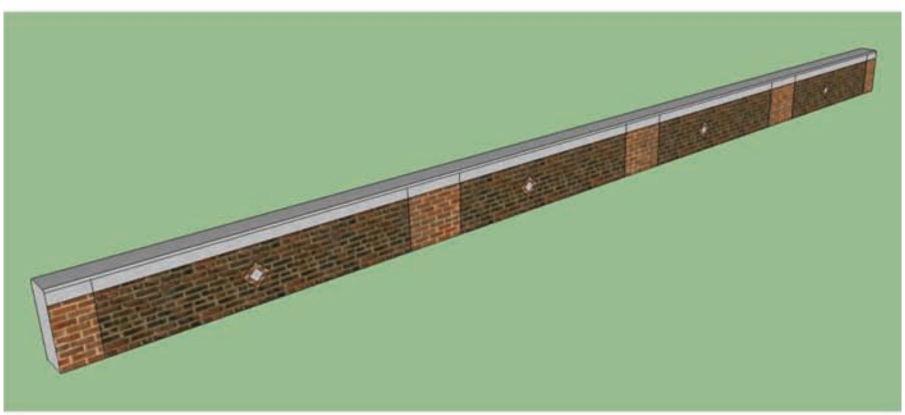


Modified Railing

Concrete 26

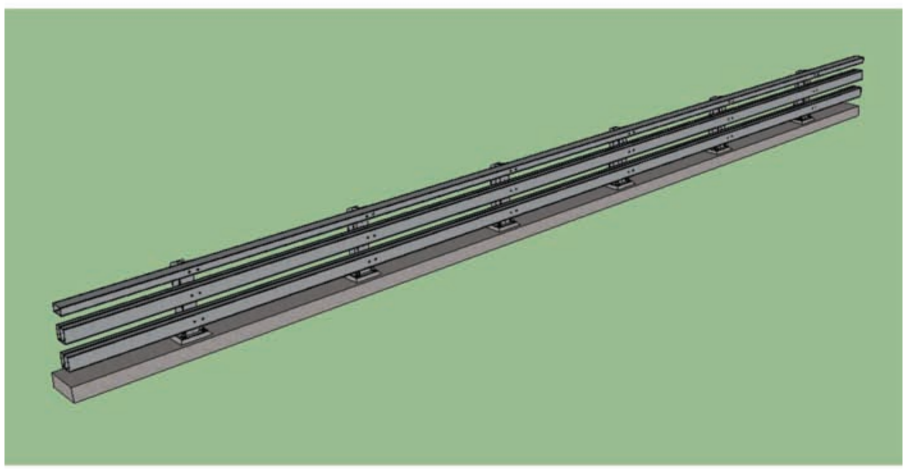


Parent Railing: TxDOT T221



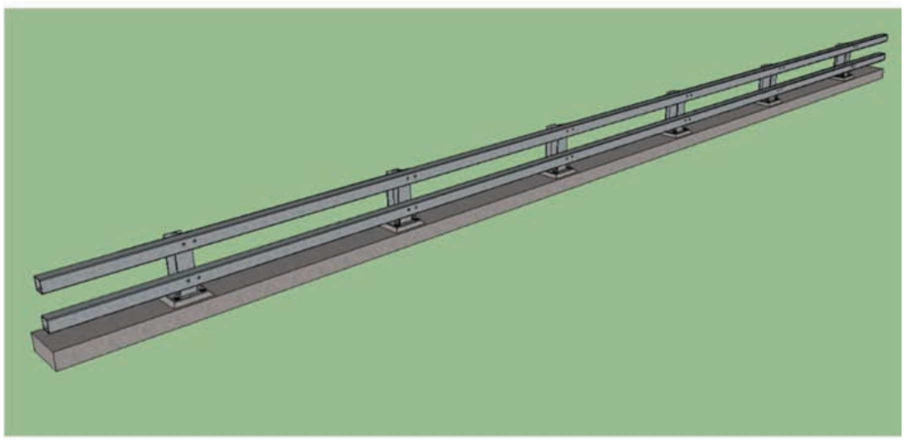
Modified Railing

Metal 1



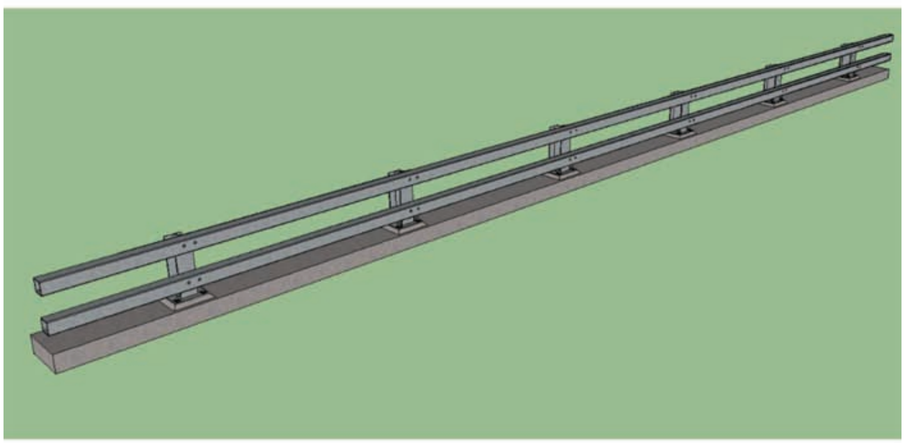
Nearly Exact Approximation: ODOT Three-Tube Curb-Mounted Railing

Metal 2



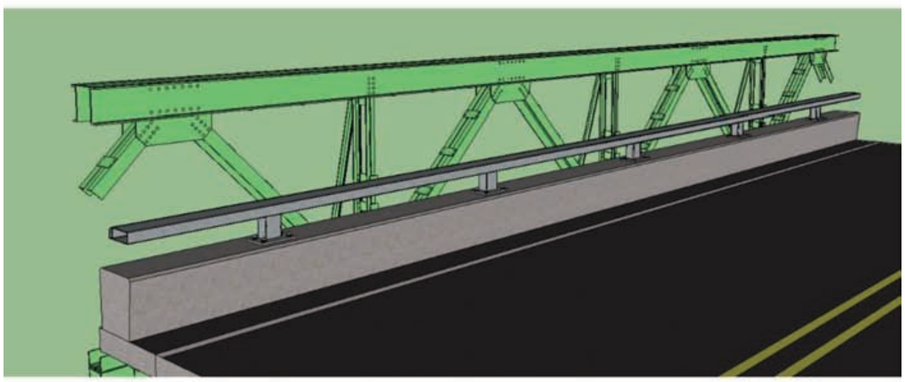
Nearly Exact Approximation: ODOT Two-Tube Curb-Mounted Railing

Metal 3



Nearly Exact Approximation: ODOT Two-Tube Curb-Mounted Railing

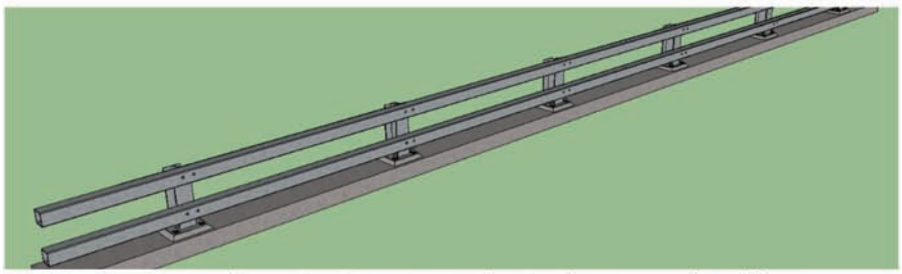
Metal 4



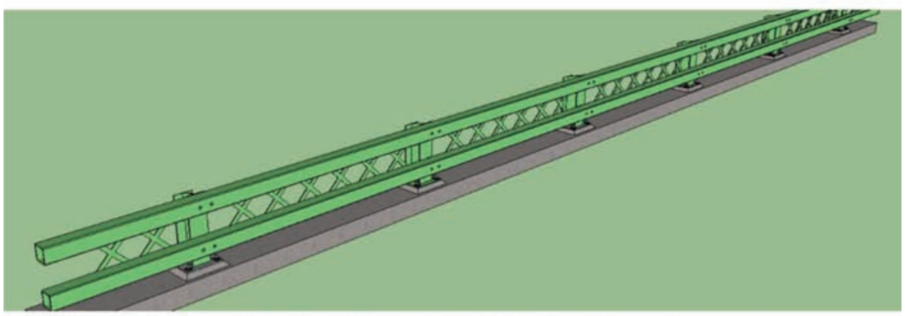
Approximation: CALTRANS Concrete Barrier Type 90 (Option 1)

Approximation: ODOT Two-Tube Curb-Mounted Railing (Option 2)

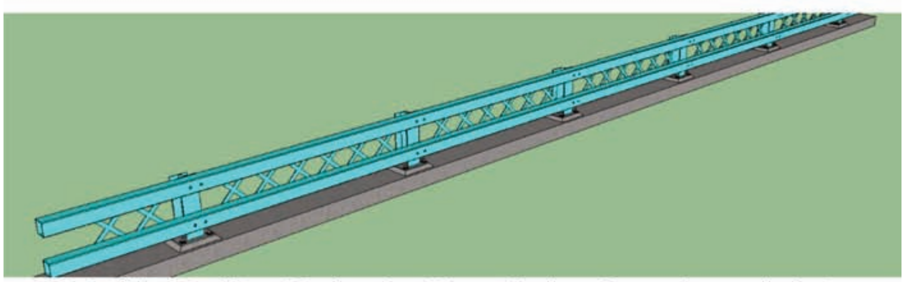
Metal 6



Parent Railing: ODOT Two-Tube Curb-Mounted Railing

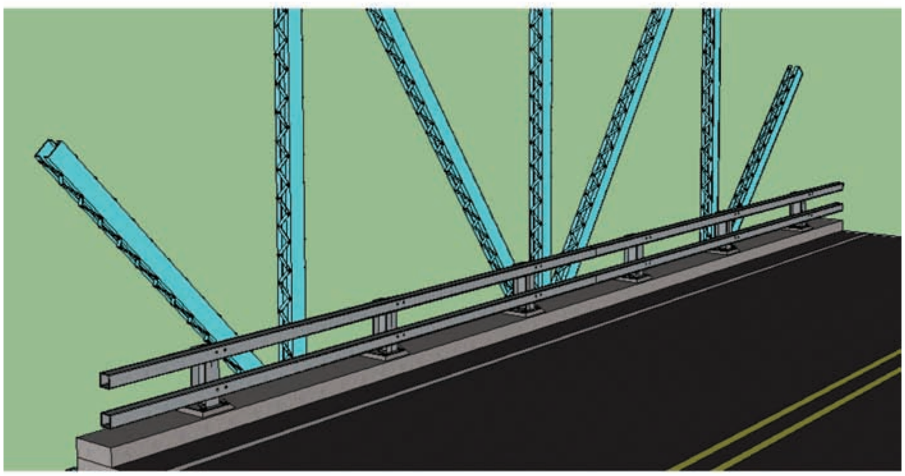


Modified Railing (Option 1 – Green)



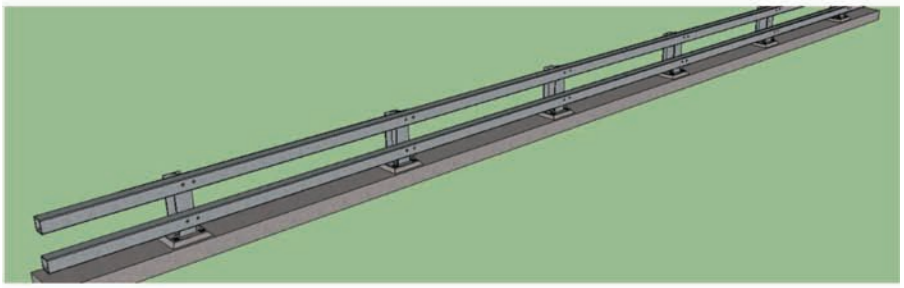
Modified Railing (Option 2 – Blue; this is only a color variation)

Metal 9

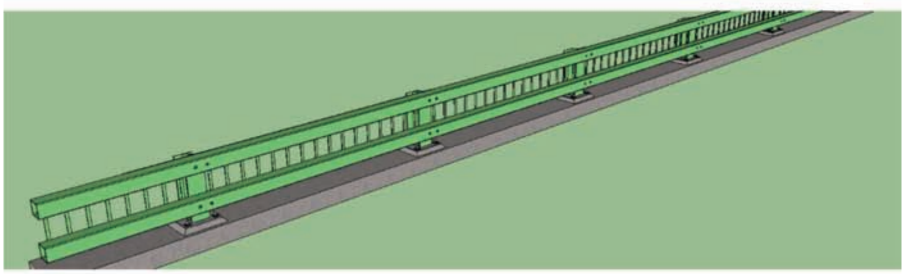


Nearly Exact Approximation: ODOT Two-Tube Curb-Mounted Railing

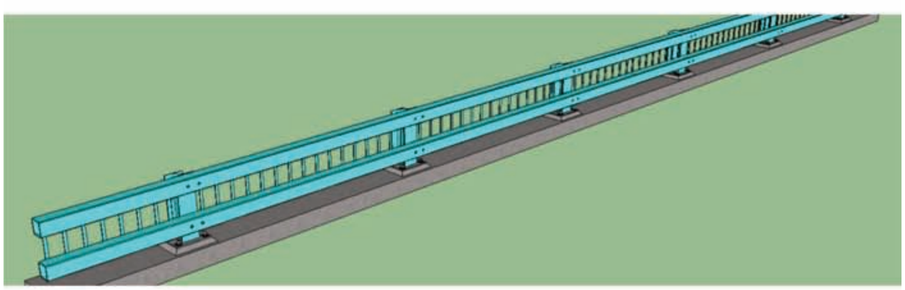
Metal 14



Parent Railing: ODOT Two-Tube Curb-Mounted Railing

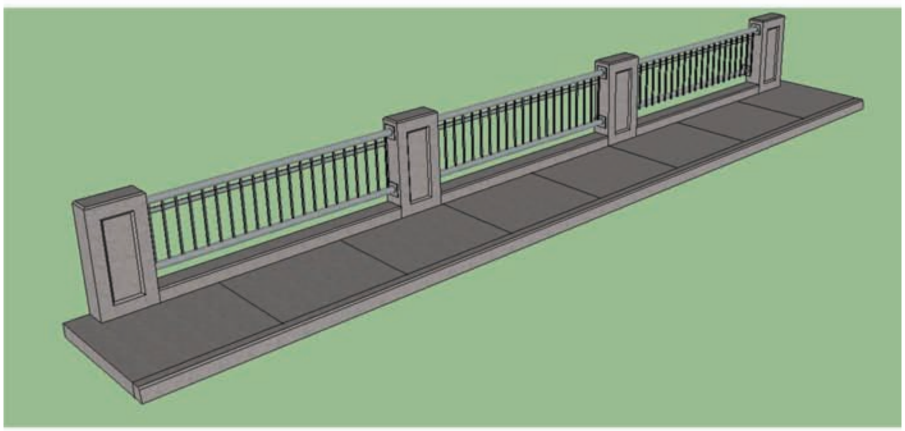


Modified Railing (Option 1 – Green)

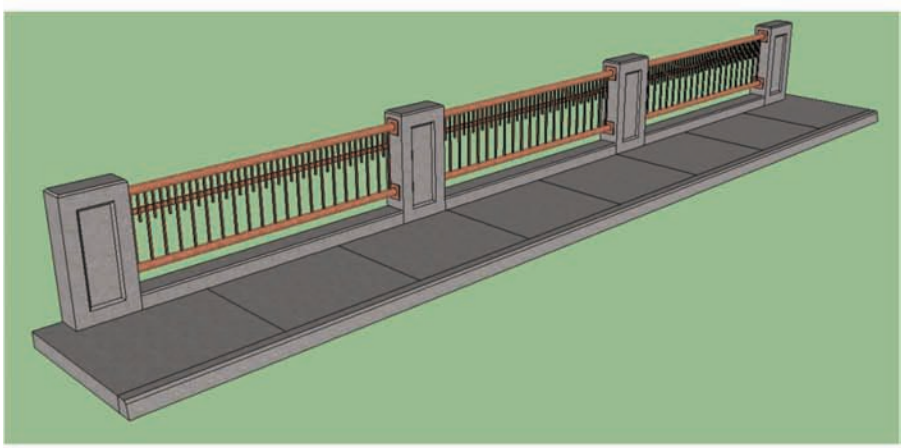


Modified Railing (Option 2 – Blue; this is only a color variation)

Pedestrian 1



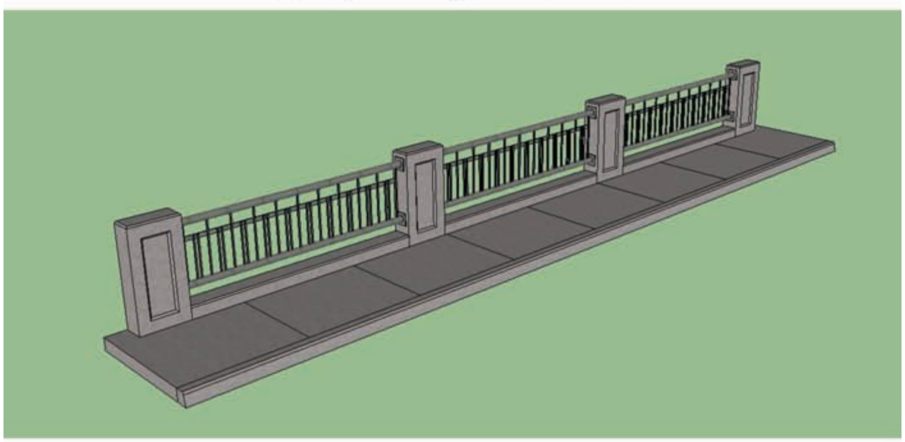
Concept Railing: TxDOT PR3



Modified Railing

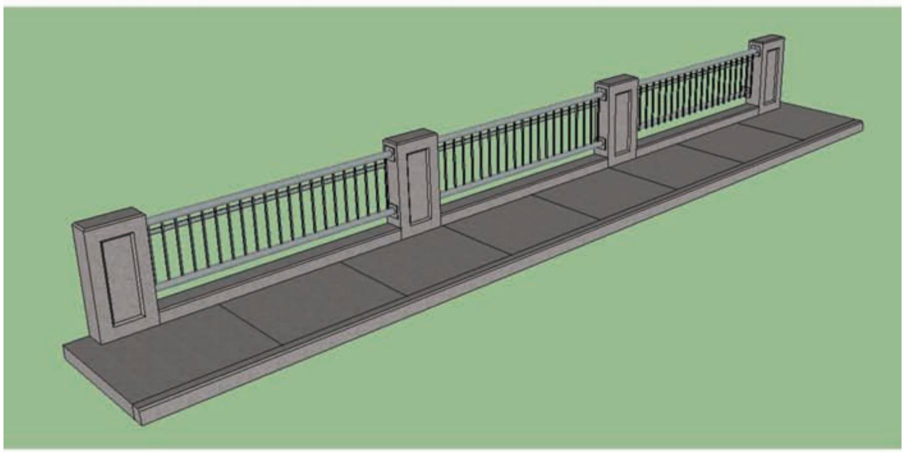
Pedestrian 2

Concept Railing: TxDOT PR3

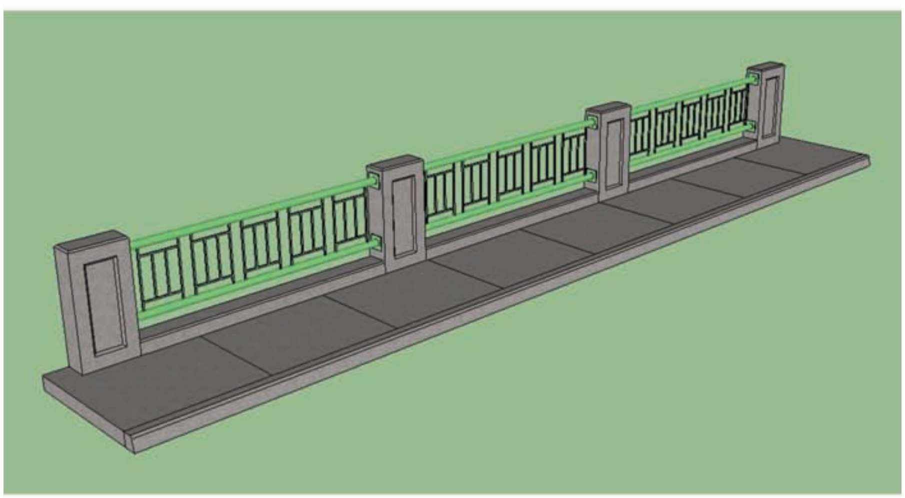


Modified Railing

Pedestrian 3

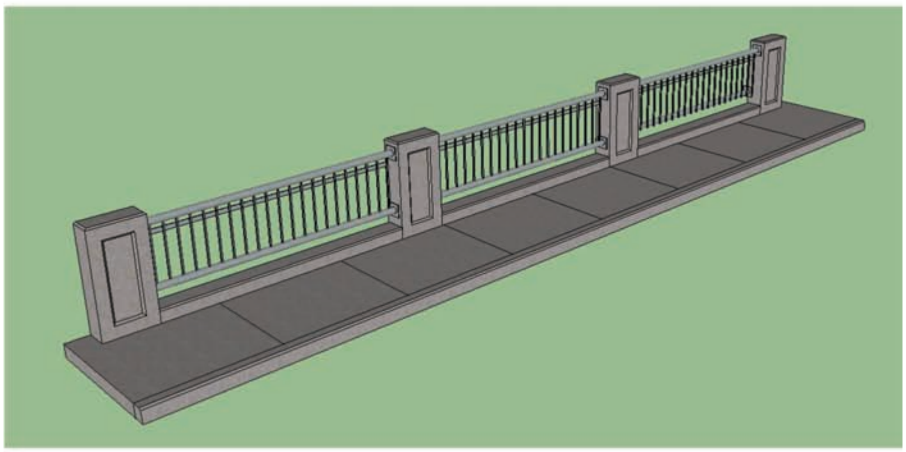


Concept Railing: TxDOT PR3



Modified Railing

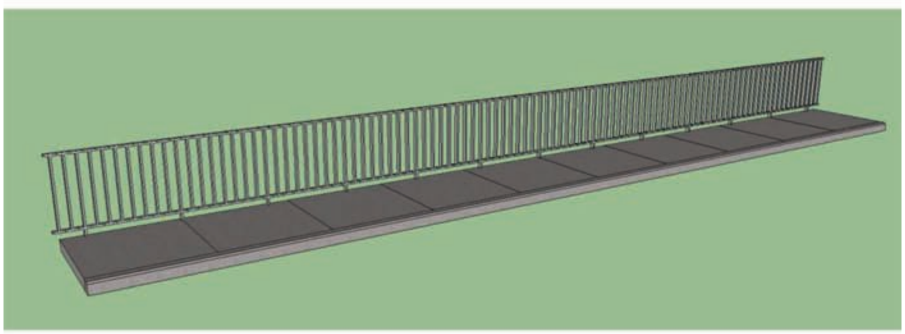
Pedestrian 4



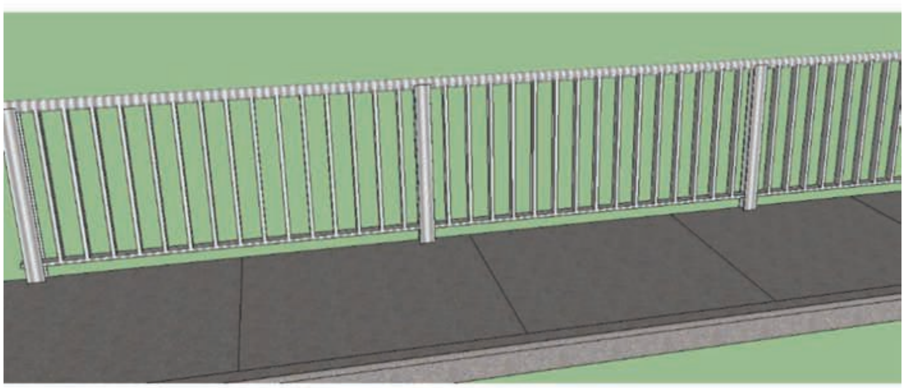
Concept Railing: TxDOT PR3

Modified Railing

Pedestrian 5

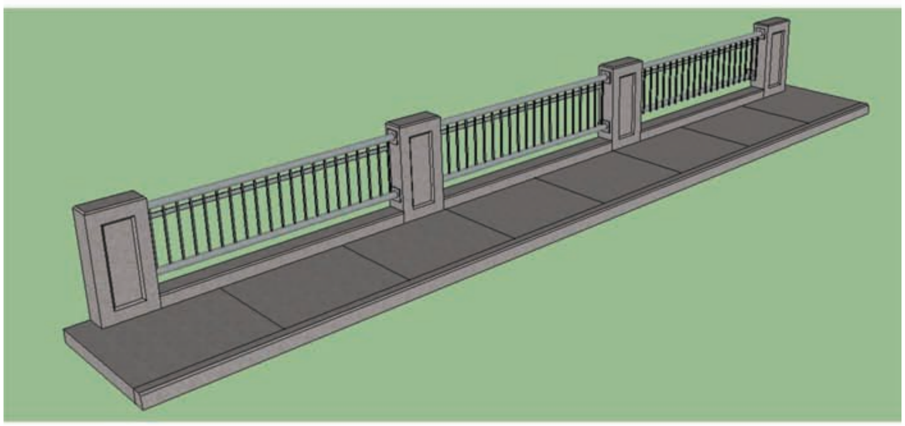


Concept Railing: ODOT Pedestrian Rail

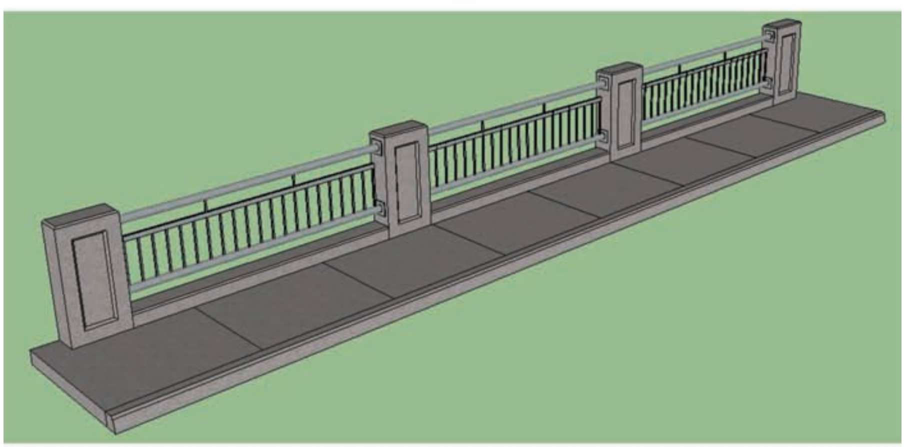


Modified Railing

Pedestrian 6

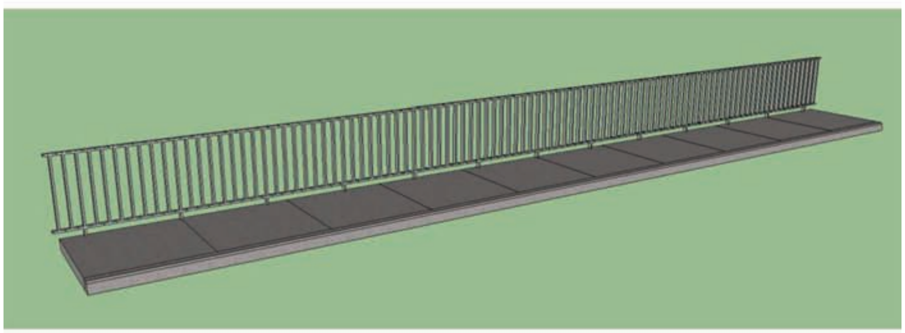


Concept Railing: TxDOT PR3

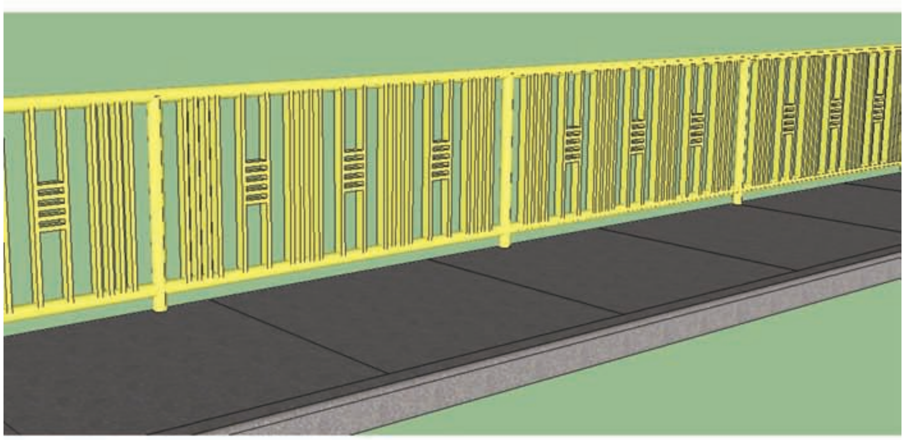


Modified Railing

Pedestrian 7

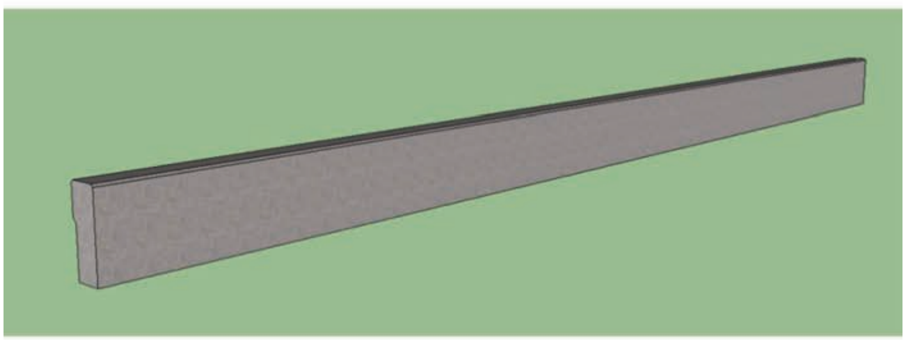


Concept Railing: ODOT Pedestrian Rail

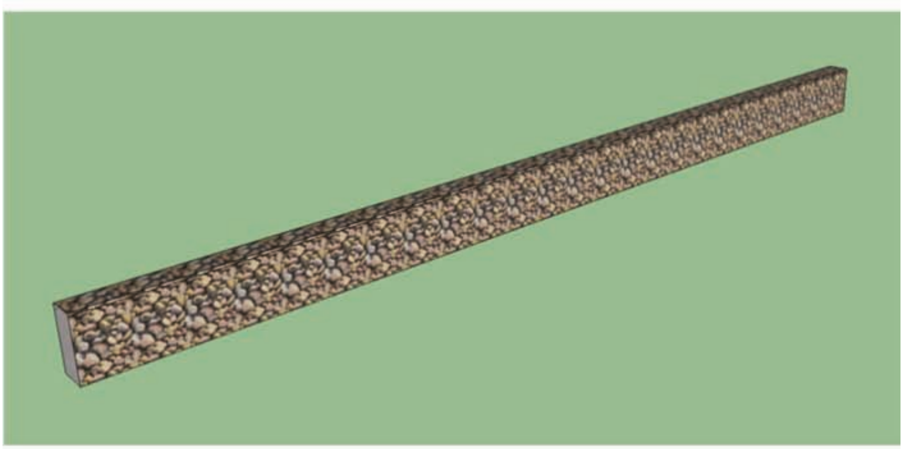


Modified Railing

Stone 1

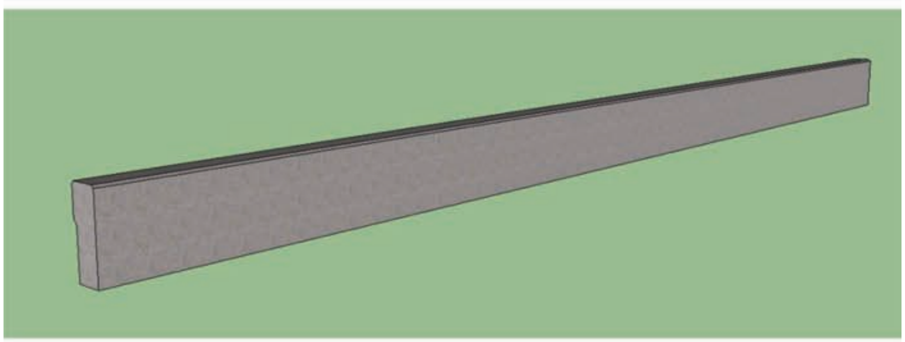


Parent Railing: TxDOT T221

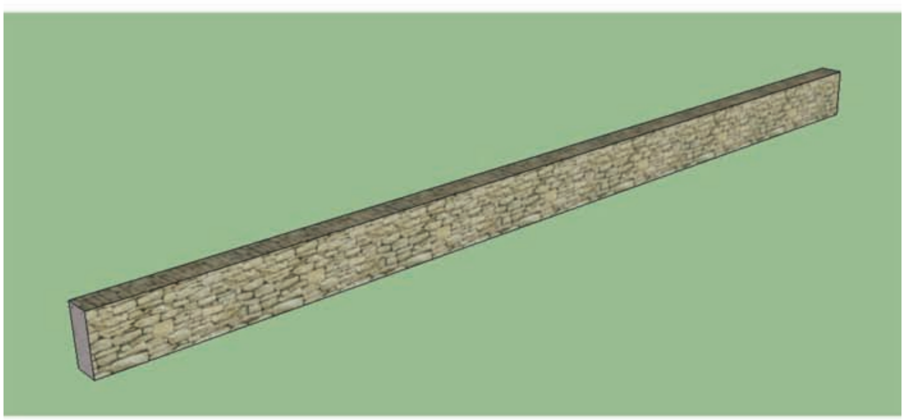


Modified Railing

Stone 2

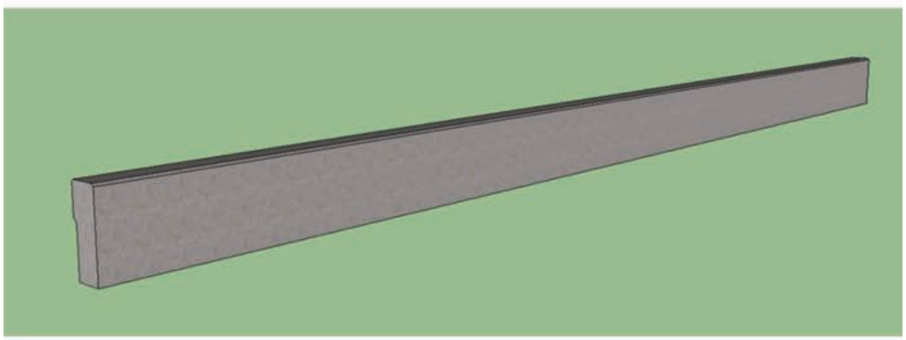


Parent Railing: TxDOT T221

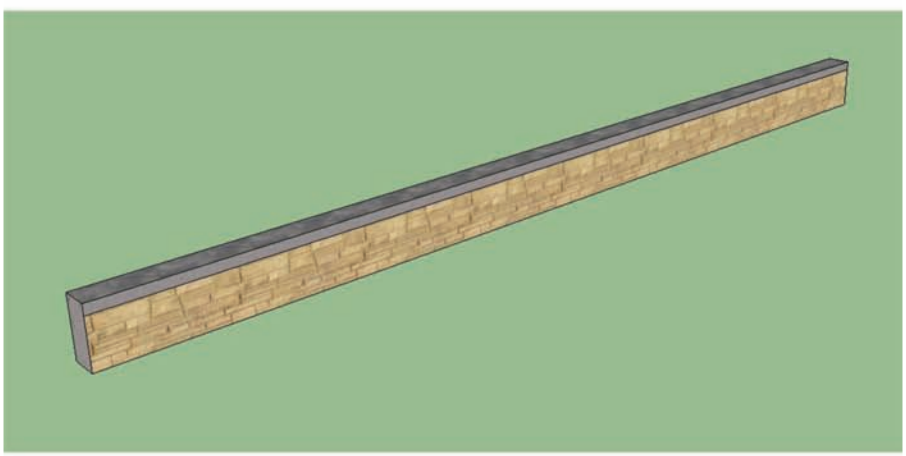


Modified Railing

Stone 3

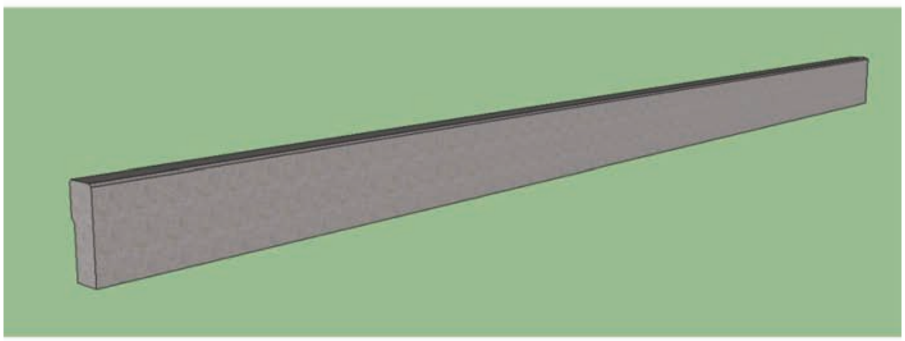


Parent Railing: TxDOT T221

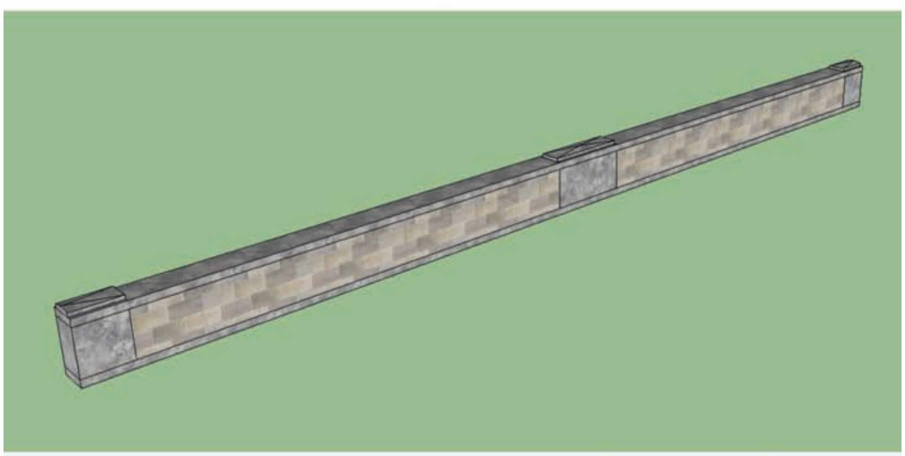


Modified Railing

Stone 4

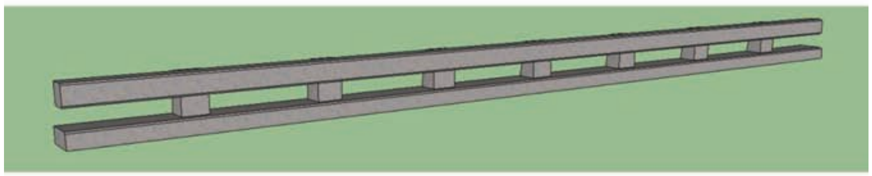


Parent Railing: TxDOT T221

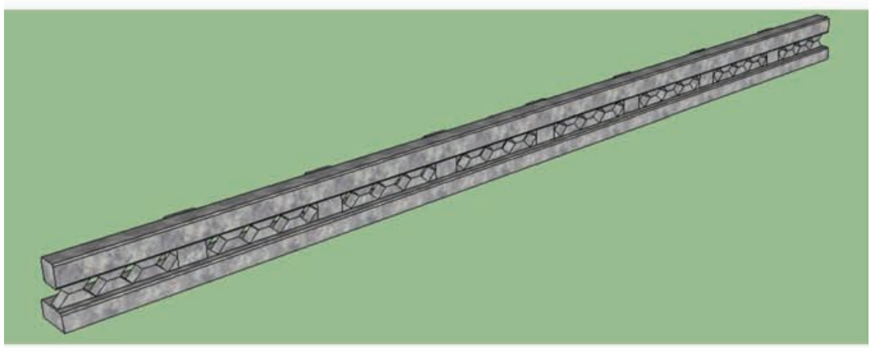


Modified Railing

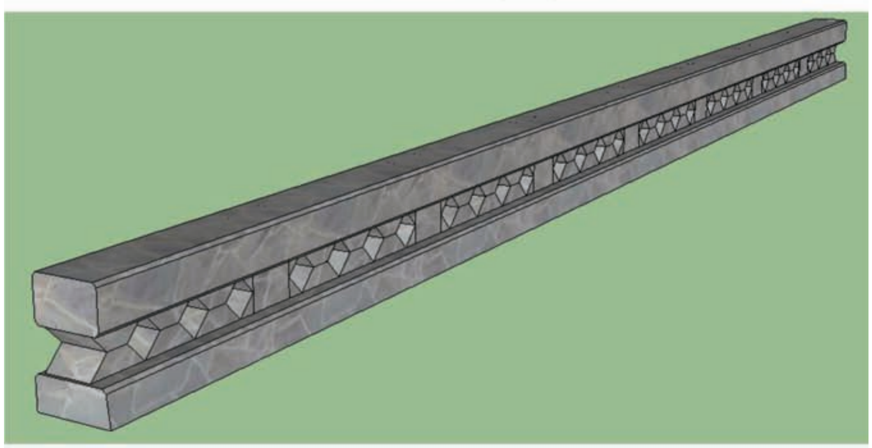
Stone 6



Parent Railing: ODOT Concrete Beam and Post

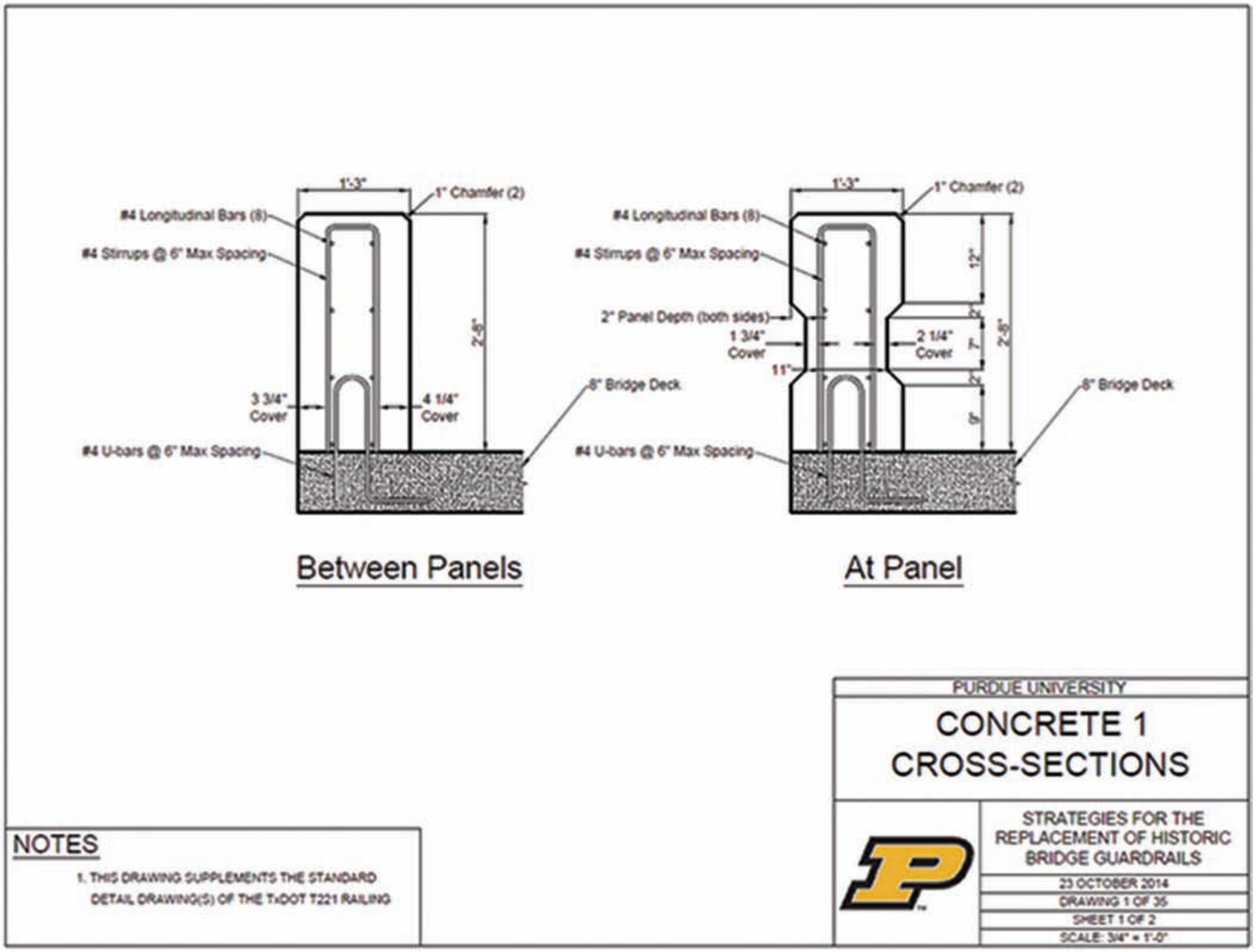


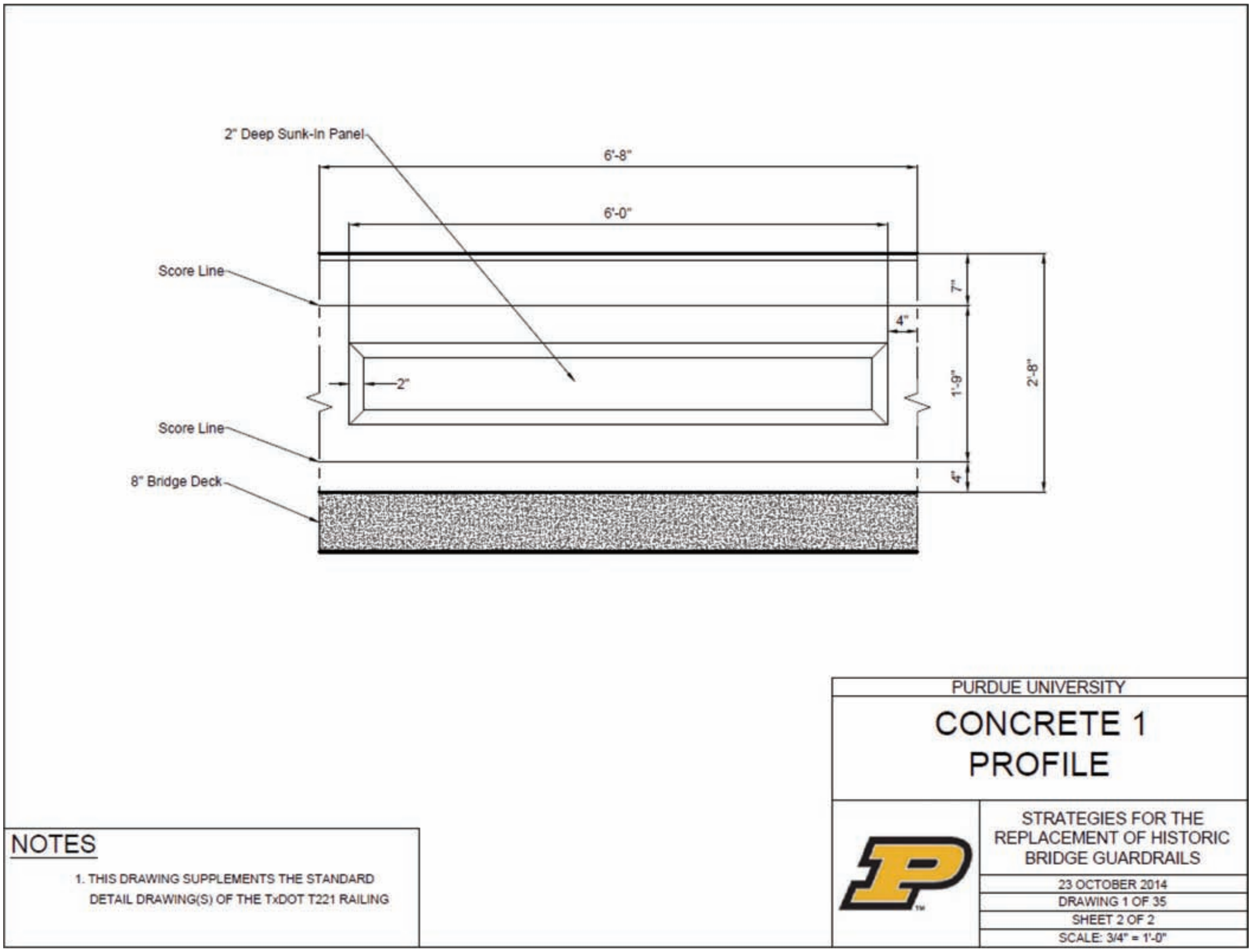
Modified Parent Railing (Option 1)

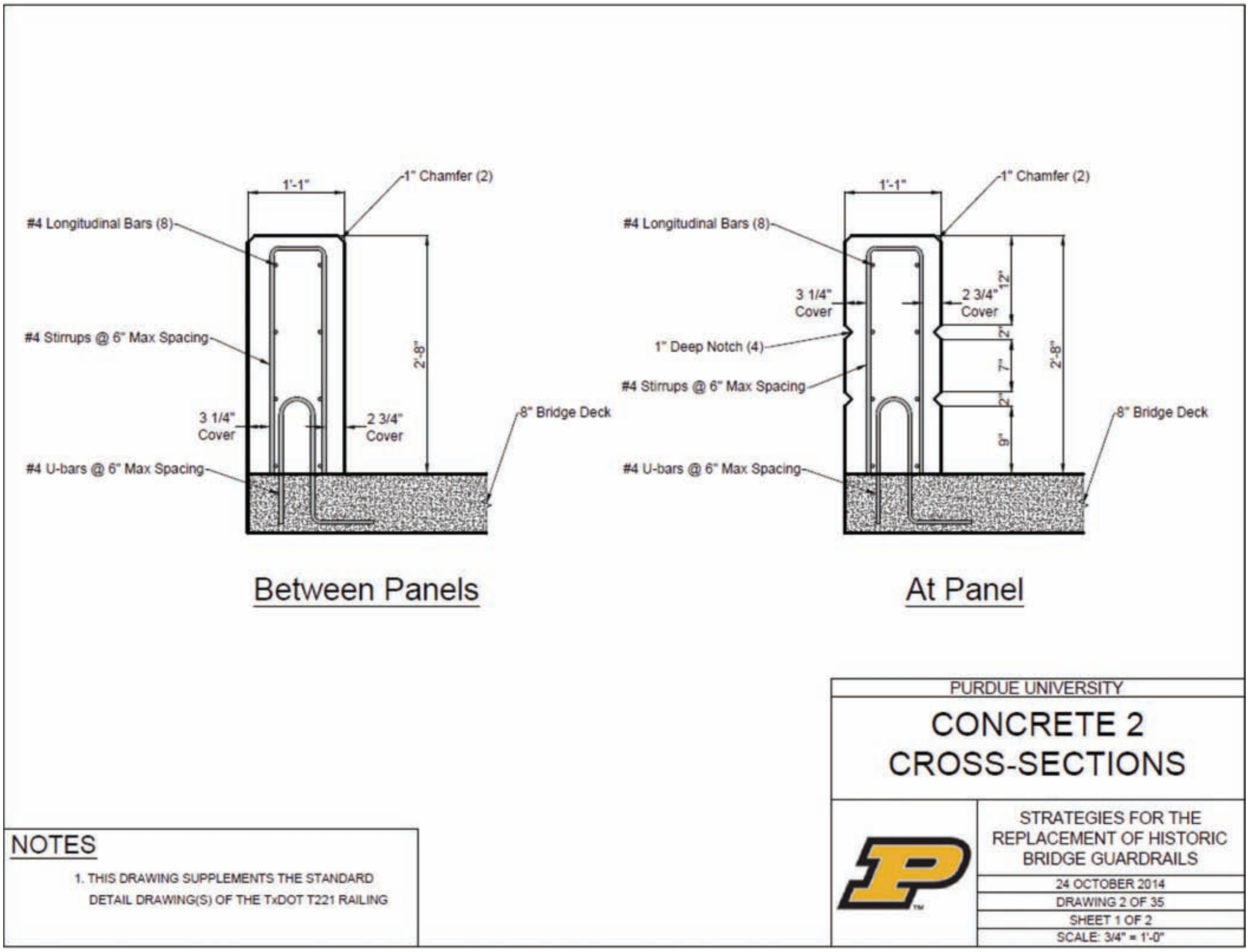


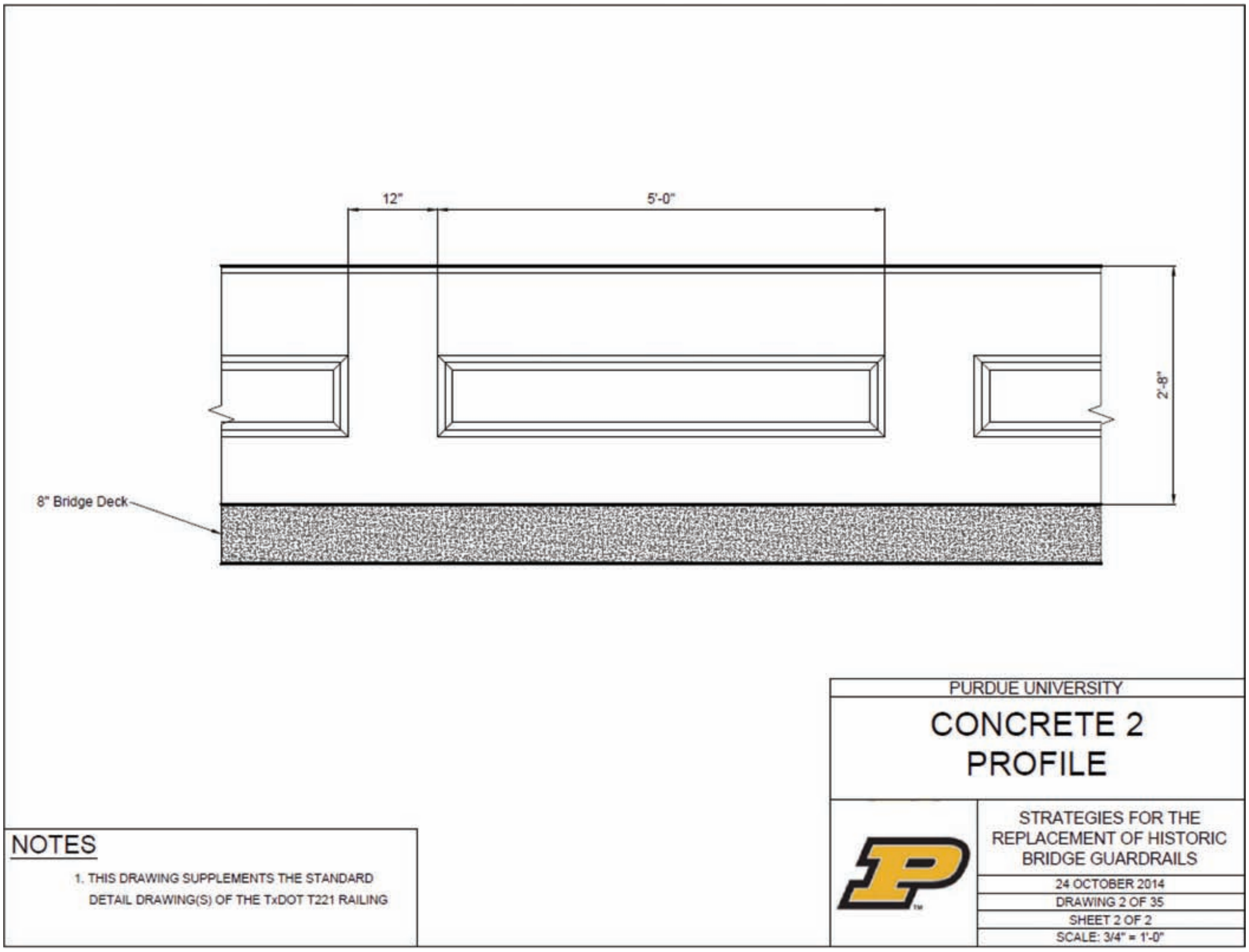
Modified Parent Railing (Option 2 – Symmetric)

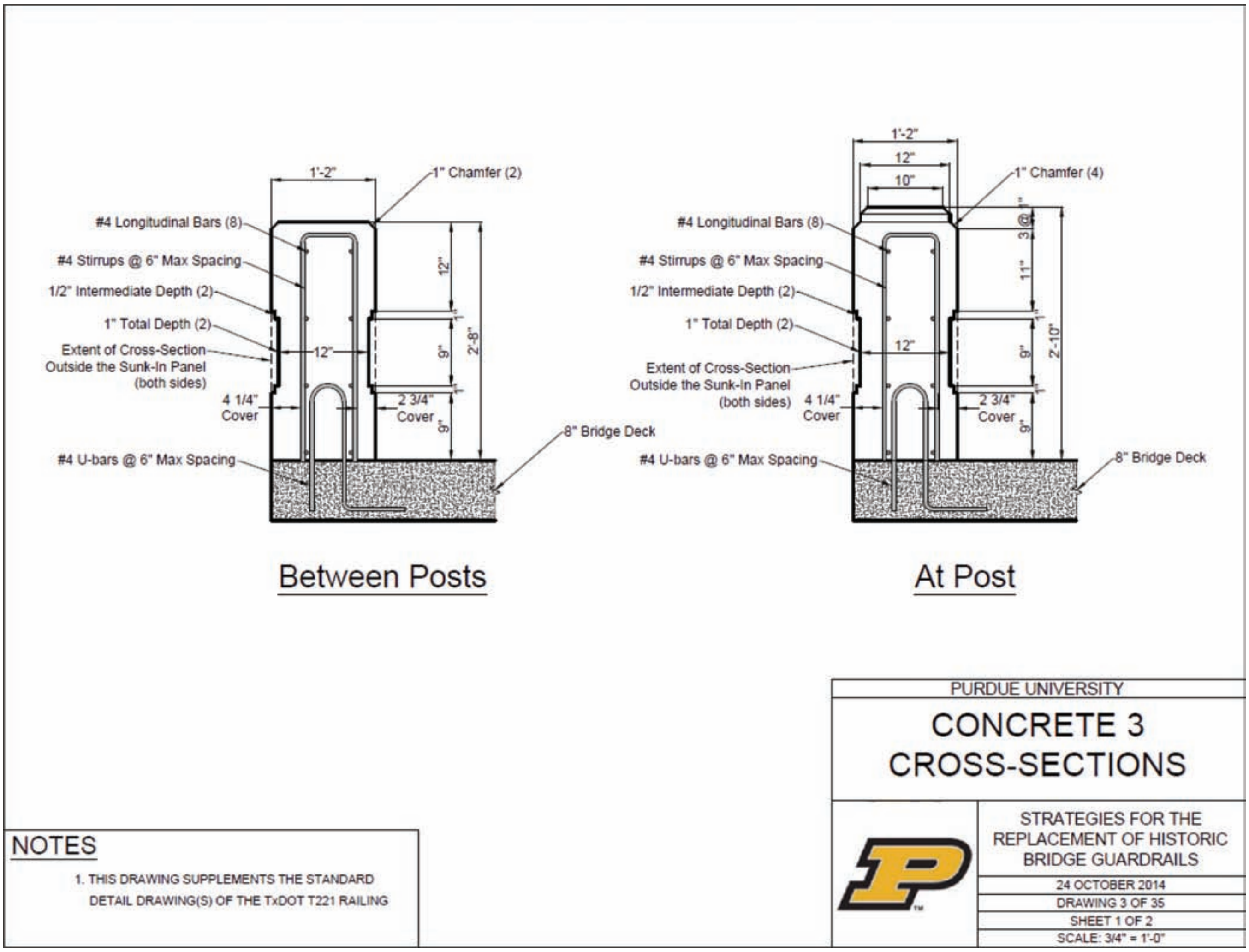
APPENDIX E. SIMULATED HISTORIC RAILING DRAWINGS

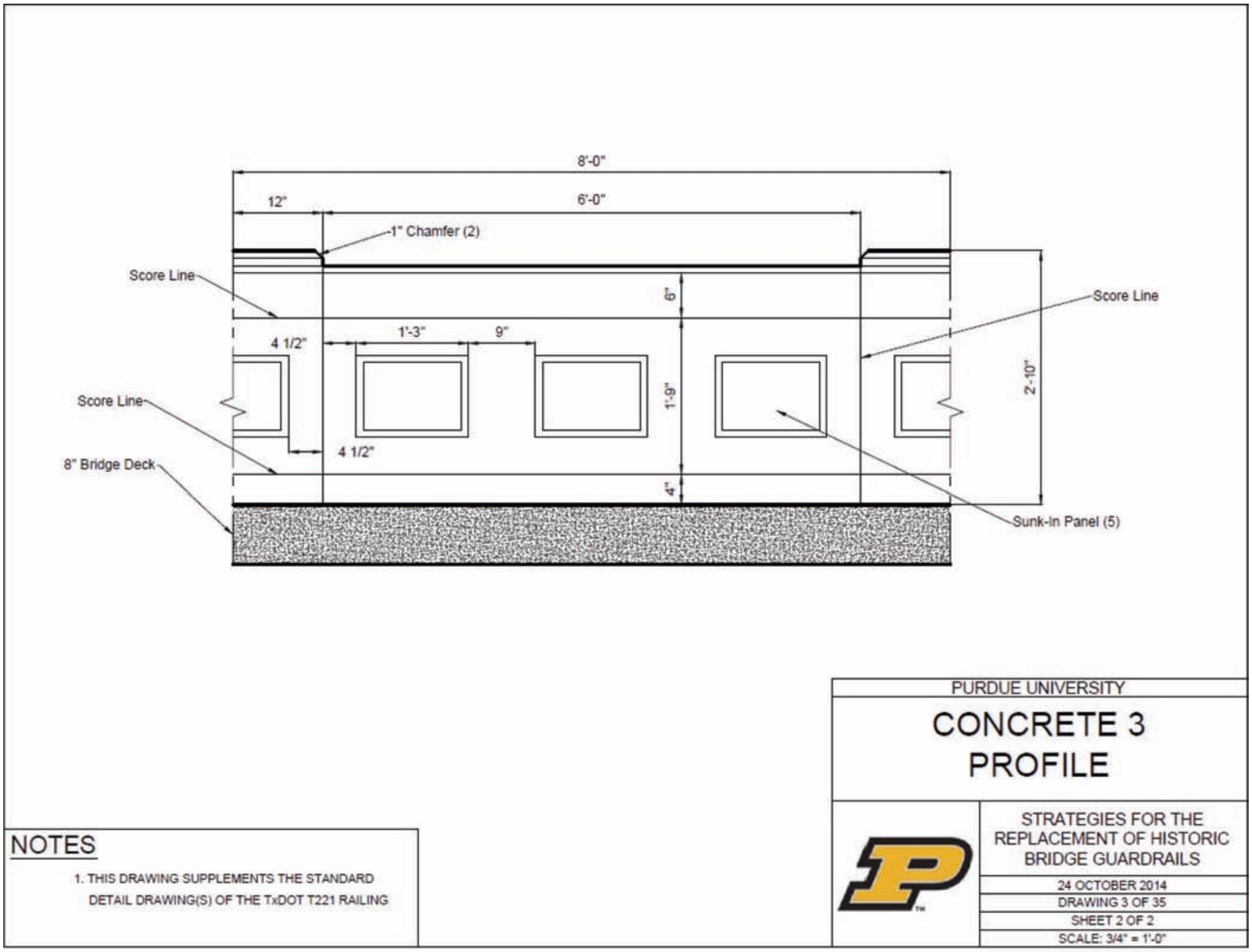


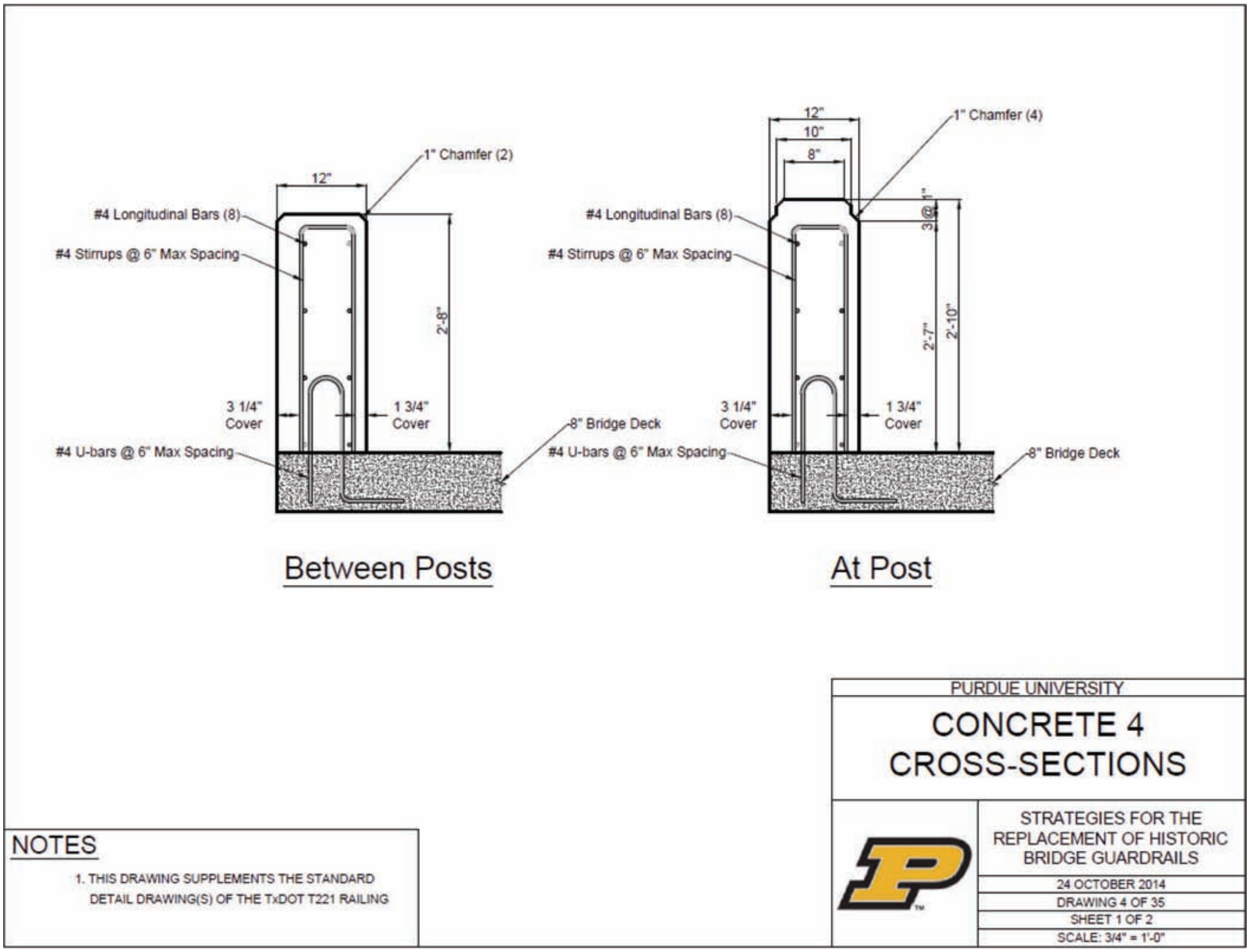

2" Deep Sunk-In Panel
6'-8"
6'-0"
Score Line
7"
4"
2"
1'-9"
2'-8"
Score Line
4"
8" Bridge Deck
PURDUE UNIVERSITY
CONCRETE 1
PROFILE
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
23 OCTOBER 2014
DRAWING 1 OF 35
SHEET 2 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT T221 RAILING


1'-1"
1" Chamfer (2)
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
3 1/4" Cover
2 3/4" Cover
2'-8"
8" Bridge Deck
#4 U-bars @ 6" Max Spacing
Between Panels
1'-1"
1" Chamfer (2)
#4 Longitudinal Bars (8)
3 1/4" Cover
2 3/4" Cover
1" Deep Notch (4)
#4 Stirrups @ 6" Max Spacing
12"
2"
7"
2"
9"
2'-8"
8" Bridge Deck
#4 U-bars @ 6" Max Spacing
At Panel
PURDUE UNIVERSITY
CONCRETE 2
CROSS-SECTIONS
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
24 OCTOBER 2014
DRAWING 2 OF 35
SHEET 1 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT T221 RAILING

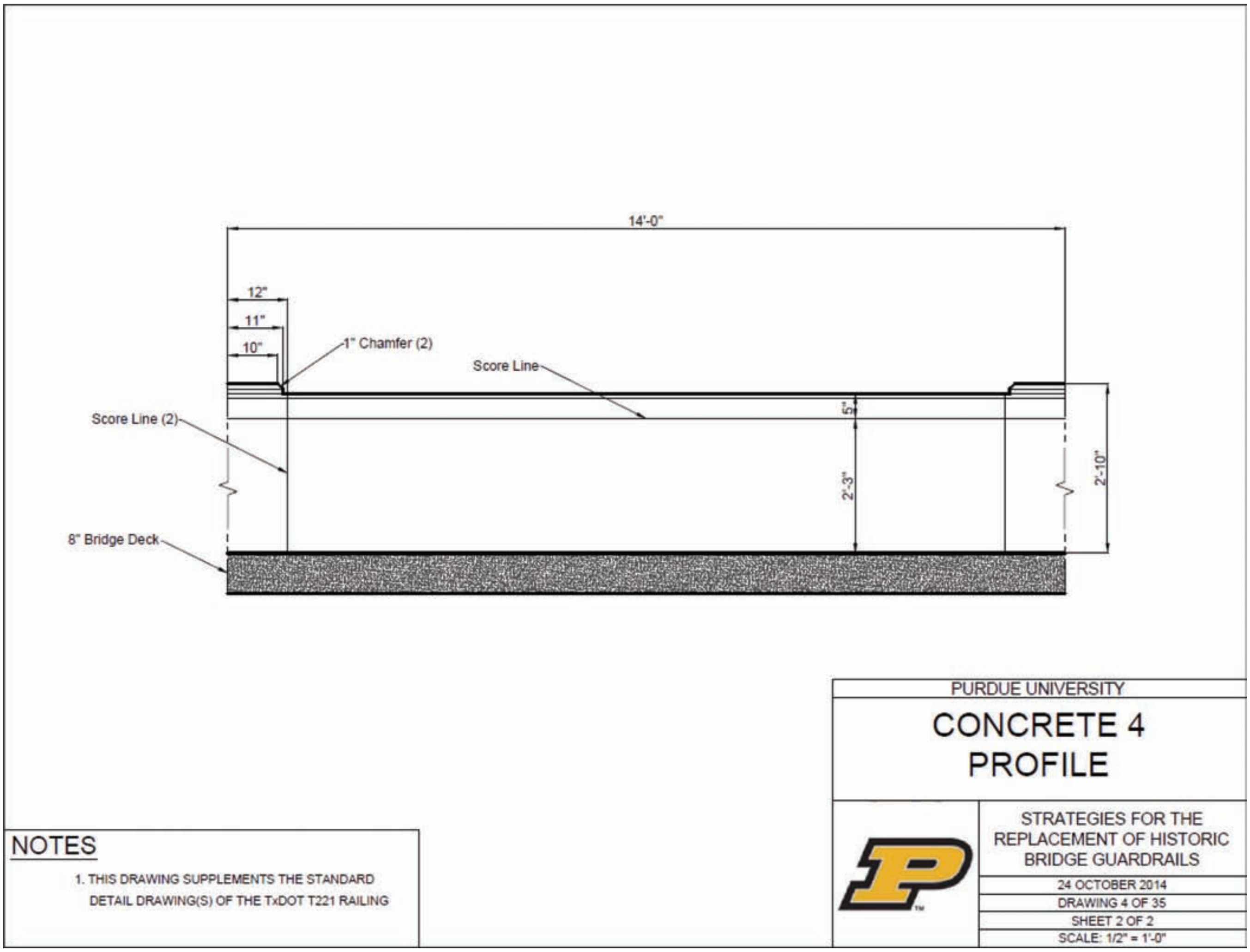

12"
5'-0"
2'-8"
8" Bridge Deck
PURDUE UNIVERSITY
CONCRETE 2
PROFILE
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
24 OCTOBER 2014
DRAWING 2 OF 35
SHEET 2 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT T221 RAILING

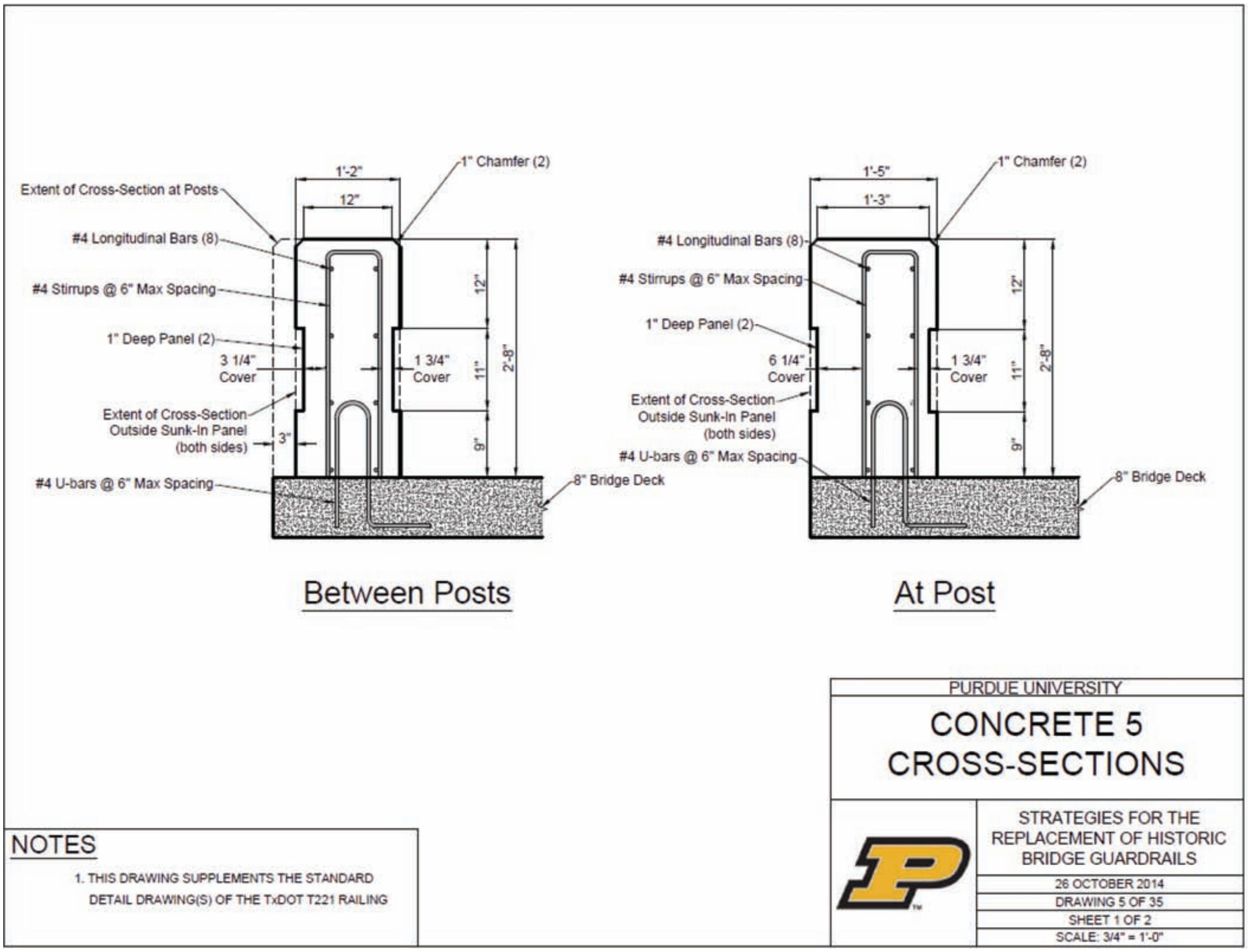

1'-2"
1" Chamfer (2)
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
1/2" Intermediate Depth (2)
1" Total Depth (2)
Extent of Cross-Section Outside the Sunk-In Panel (both sides)
12"
4 1/4" Cover
2 3/4" Cover
12"
1"
9"
1"
9"
2'-8"
8" Bridge Deck
#4 U-bars @ 6" Max Spacing
Between Posts
1'-2"
12"
10"
1" Chamfer (4)
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
1/2" Intermediate Depth (2)
1" Total Depth (2)
12"
Extent of Cross-Section Outside the Sunk-In Panel (both sides)
4 1/4" Cover
2 3/4" Cover
11"
1"
9"
1"
9"
2'-10"
8" Bridge Deck
#4 U-bars @ 6" Max Spacing
At Post
PURDUE UNIVERSITY
CONCRETE 3
CROSS-SECTIONS
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
24 OCTOBER 2014
DRAWING 3 OF 35
SHEET 1 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING

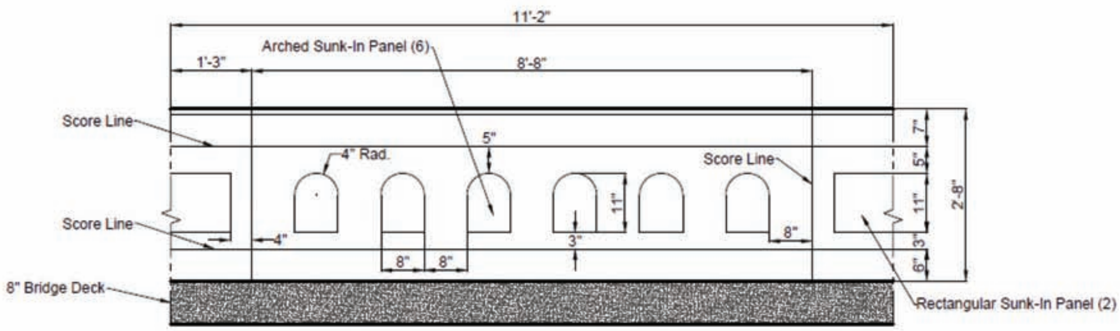

8'-0"
12"
6'-0"
1" Chamfer (2)
Score Line
Score Line
Score Line
4 1/2"
1'-3"
9"
6"
1'-9"
4"
2'-10"
4 1/2"
8" Bridge Deck
Sunk-In Panel (5)
PURDUE UNIVERSITY
CONCRETE 3
PROFILE
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
24 OCTOBER 2014
DRAWING 3 OF 35
SHEET 2 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT T221 RAILING



1" Chamfer (2)
12"
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
2'-8"
3 1/4" Cover
1 3/4" Cover
8" Bridge Deck
#4 U-bars @ 6" Max Spacing
Between Posts
12"
10"
8"
1" Chamfer (4)
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
3 @ 1"
2'-7"
2'-10"
3 1/4" Cover
1 3/4" Cover
#4 U-bars @ 6" Max Spacing
8" Bridge Deck
At Post
PURDUE UNIVERSITY
CONCRETE 4
CROSS-SECTIONS
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
24 OCTOBER 2014
DRAWING 4 OF 35
SHEET 1 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT T221 RAILING


14'-0"
12"
11"
10"
1" Chamfer (2)
Score Line
Score Line (2)
5"
2'-3"
2'-10"
8" Bridge Deck
PURDUE UNIVERSITY
CONCRETE 4
PROFILE
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
24 OCTOBER 2014
DRAWING 4 OF 35
SHEET 2 OF 2
SCALE: 1/2" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT T221 RAILING


1'-2"
12"
1" Chamfer (2)
Extent of Cross-Section at Posts
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
1" Deep Panel (2)
3 1/4"
Cover
1 3/4"
Cover
Extent of Cross-Section
Outside Sunk-In Panel
(both sides)
3"
#4 U-bars @ 6" Max Spacing
8" Bridge Deck
12"
11"
9"
2'-8"
Between Posts
1'-5"
1'-3"
1" Chamfer (2)
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
1" Deep Panel (2)
6 1/4"
Cover
1 3/4"
Cover
Extent of Cross-Section
Outside Sunk-In Panel
(both sides)
#4 U-bars @ 6" Max Spacing
8" Bridge Deck
12"
11"
9"
2'-8"
At Post
PURDUE UNIVERSITY
CONCRETE 5
CROSS-SECTIONS
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
26 OCTOBER 2014
DRAWING 5 OF 35
SHEET 1 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT T221 RAILING



PURDUE UNIVERSITY

CONCRETE 5 PROFILE

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

26 OCTOBER 2014

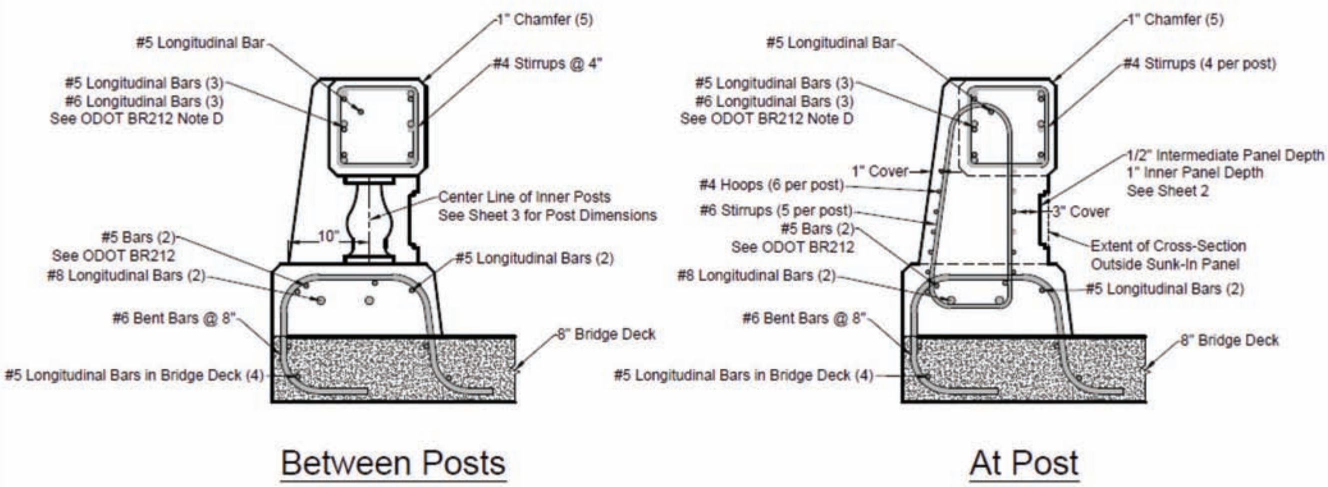
DRAWING 5 OF 35

SHEET 2 OF 2

SCALE: 1/2" = 1'-0"

NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING



PURDUE UNIVERSITY

CONCRETE 7 CROSS-SECTIONS

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

26 OCTOBER 2014

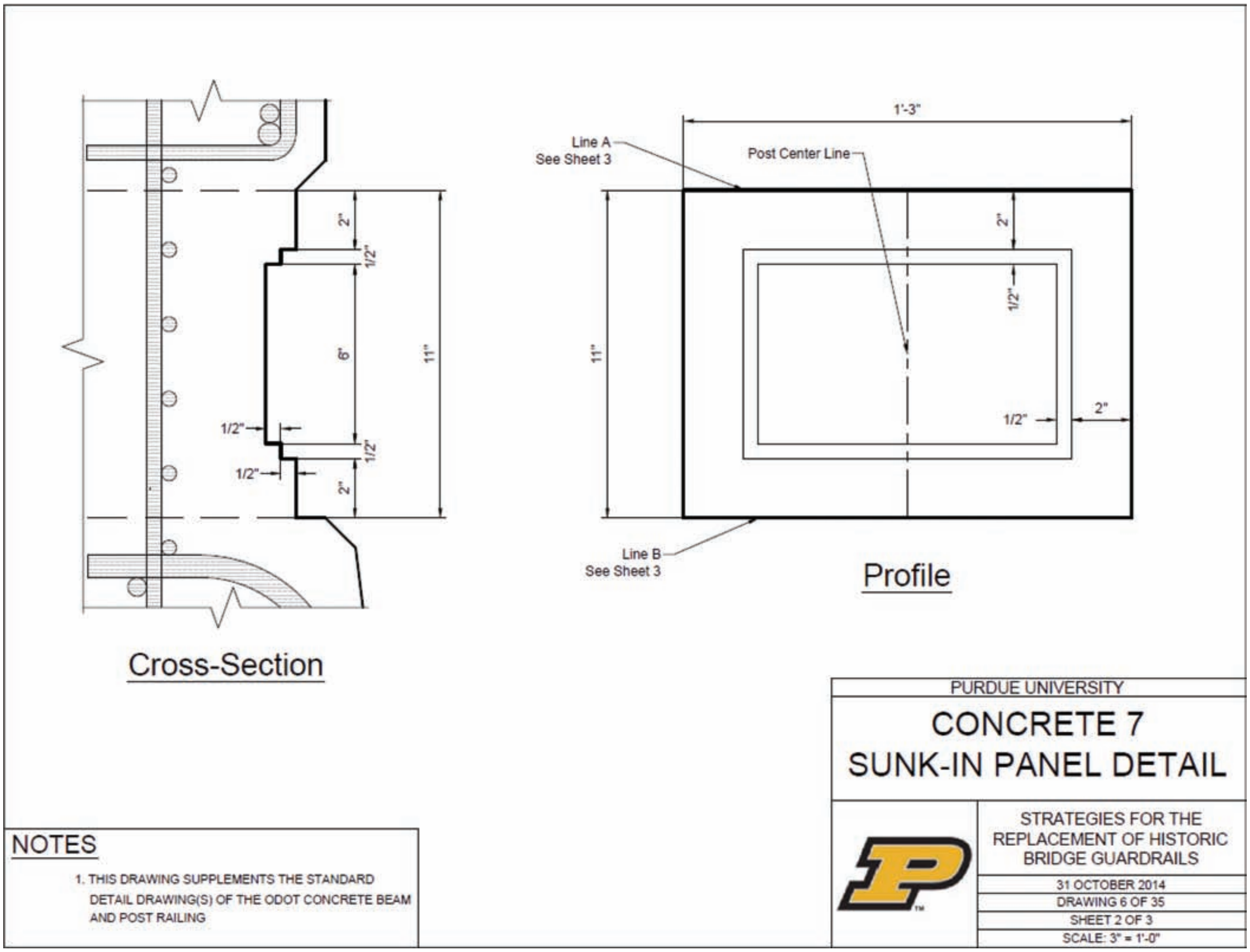
DRAWING 6 OF 35

SHEET 1 OF 3

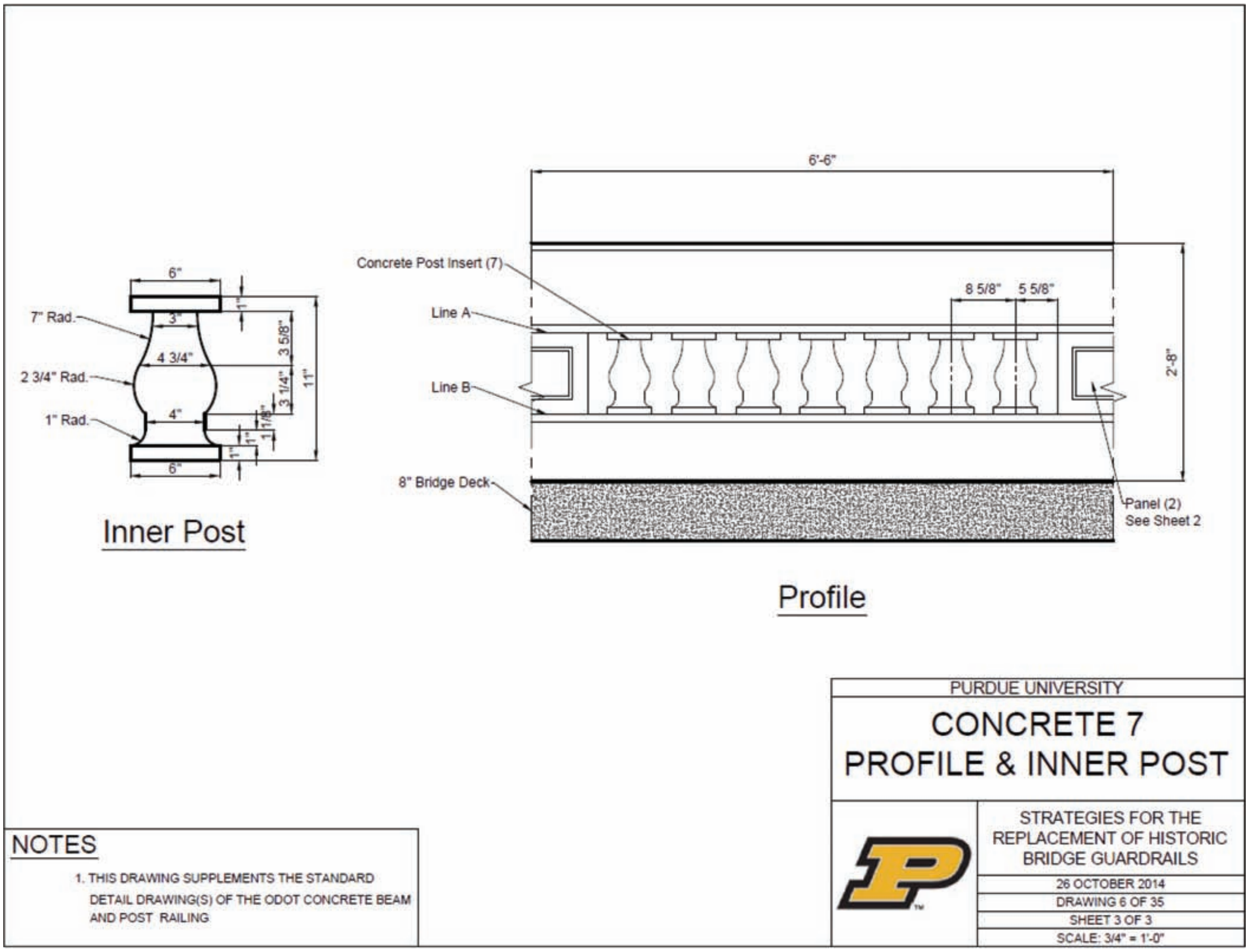
SCALE: 3/4" = 1'-0"

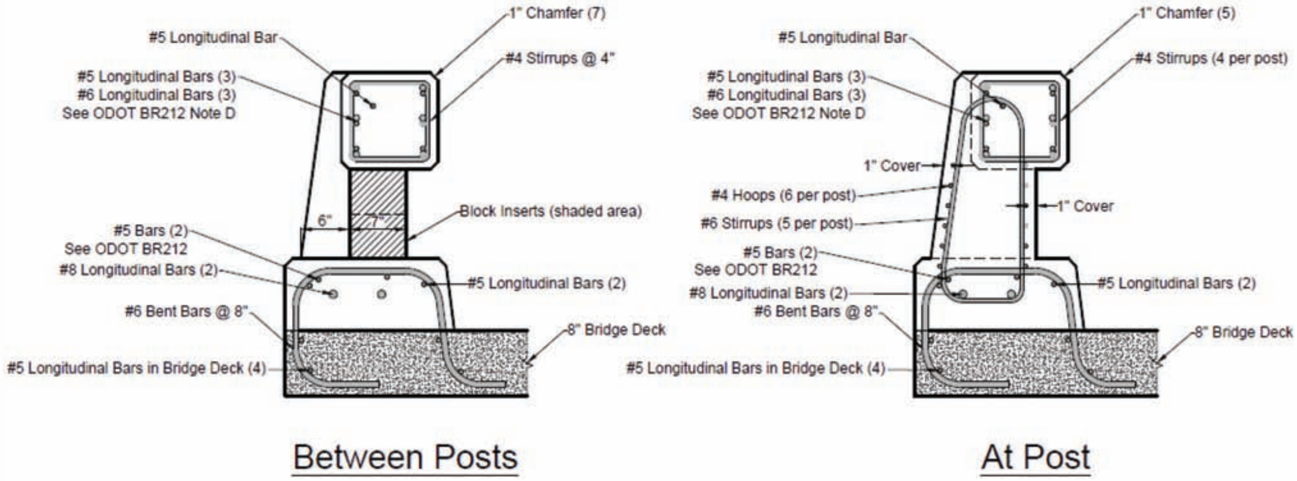
NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING



1'-3"
Line A
See Sheet 3
Post Center Line
2"
1/2"
6"
11"
1/2"
2"
Line B
See Sheet 3
Profile
Cross-Section
PURDUE UNIVERSITY
CONCRETE 7
SUNK-IN PANEL DETAIL
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
31 OCTOBER 2014
DRAWING 6 OF 35
SHEET 2 OF 3
SCALE: 3" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING


6'-6"
Concrete Post Insert (7)
Line A
Line B
8 5/8"
5 5/8"
2'-8"
8" Bridge Deck
Panel (2)
See Sheet 2
Profile
6"
3"
4 3/4"
4"
6"
7" Rad.
2 3/4" Rad.
1" Rad.
1"
3 5/8"
3 1/4"
11"
1 1/8"
1"
1"
Inner Post
PURDUE UNIVERSITY
CONCRETE 7
PROFILE & INNER POST
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
26 OCTOBER 2014
DRAWING 6 OF 35
SHEET 3 OF 3
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM
AND POST RAILING



NOTES

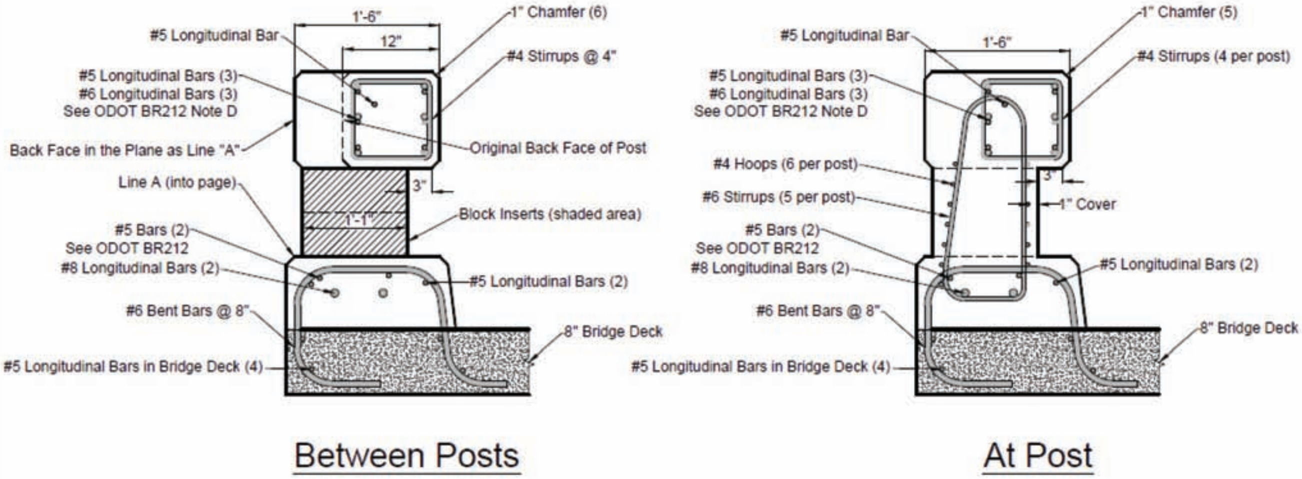
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING

PURDUE UNIVERSITY

CONCRETE 8
CROSS-SECTIONS (1)

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

27 OCTOBER 2014
DRAWING 7 OF 35
SHEET 1 OF 3
SCALE: 3/4" = 1'-0"



PURDUE UNIVERSITY

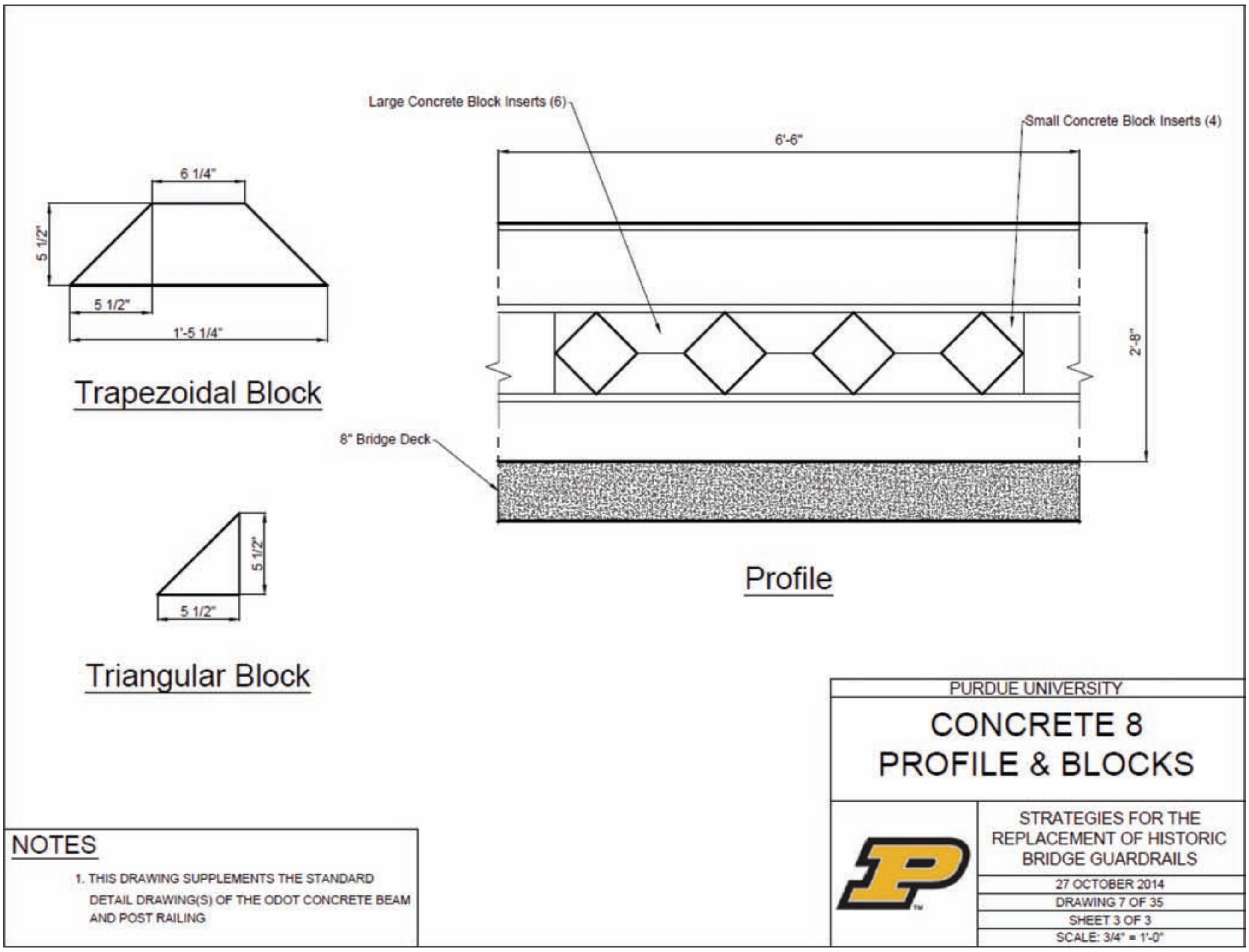
CONCRETE 8
CROSS-SECTIONS (2)

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

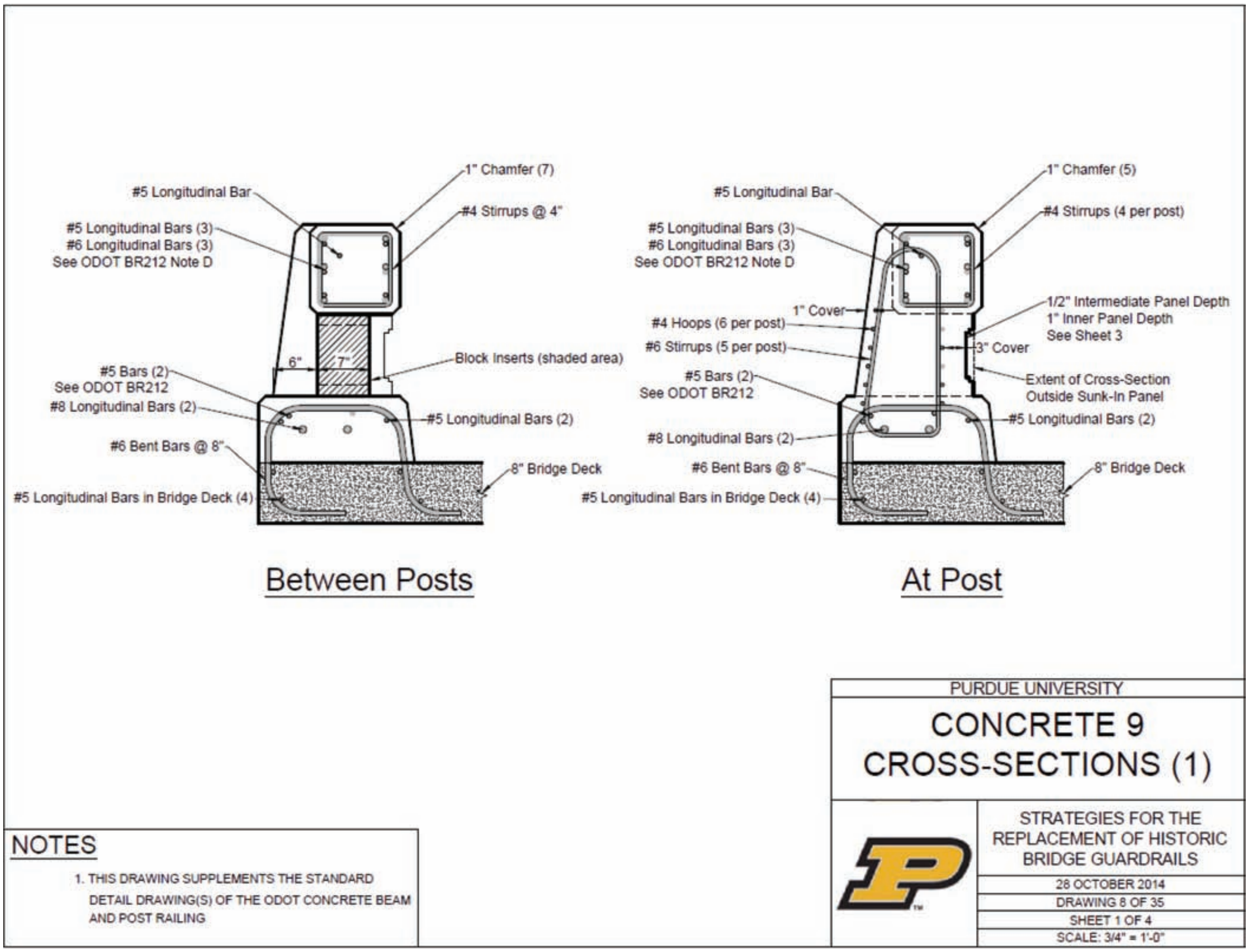
27 OCTOBER 2014
DRAWING 7 OF 35
SHEET 2 OF 3
SCALE: 3/4" = 1'-0"

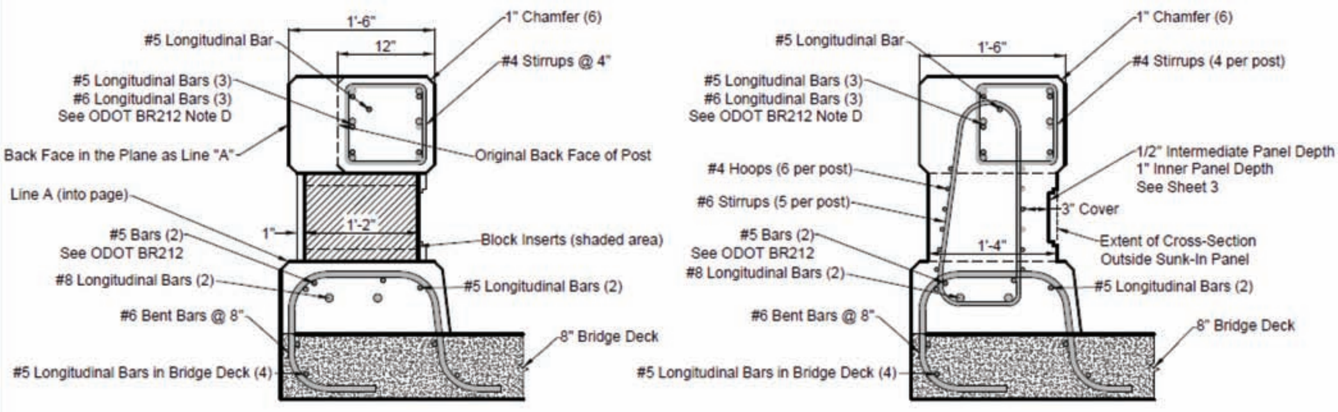
NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE POST AND BEAM RAILING



Large Concrete Block Inserts (6)
Small Concrete Block Inserts (4)
6'-6"
2'-8"
8" Bridge Deck
Profile
6 1/4"
5 1/2"
5 1/2"
1'-5 1/4"
Trapezoidal Block
5 1/2"
5 1/2"
Triangular Block
PURDUE UNIVERSITY
CONCRETE 8
PROFILE & BLOCKS
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
27 OCTOBER 2014
DRAWING 7 OF 35
SHEET 3 OF 3
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING


#5 Longitudinal Bar
1" Chamfer (7)
#4 Stirrups @ 4"
#5 Longitudinal Bars (3)
#6 Longitudinal Bars (3)
See ODOT BR212 Note D
6"
7"
Block Inserts (shaded area)
#5 Bars (2)
See ODOT BR212
#8 Longitudinal Bars (2)
#5 Longitudinal Bars (2)
#6 Bent Bars @ 8"
8" Bridge Deck
#5 Longitudinal Bars in Bridge Deck (4)
Between Posts
#5 Longitudinal Bar
1" Chamfer (5)
#4 Stirrups (4 per post)
#5 Longitudinal Bars (3)
#6 Longitudinal Bars (3)
See ODOT BR212 Note D
1" Cover
1/2" Intermediate Panel Depth
1" Inner Panel Depth
See Sheet 3
#4 Hoops (6 per post)
#6 Stirrups (5 per post)
3" Cover
#5 Bars (2)
See ODOT BR212
Extent of Cross-Section
Outside Sunk-In Panel
#5 Longitudinal Bars (2)
#8 Longitudinal Bars (2)
#6 Bent Bars @ 8"
8" Bridge Deck
#5 Longitudinal Bars in Bridge Deck (4)
At Post
PURDUE UNIVERSITY
CONCRETE 9
CROSS-SECTIONS (1)
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
28 OCTOBER 2014
DRAWING 8 OF 35
SHEET 1 OF 4
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM
AND POST RAILING



Between Posts

At Post

PURDUE UNIVERSITY

CONCRETE 9 CROSS-SECTIONS (2)

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

28 OCTOBER 2014

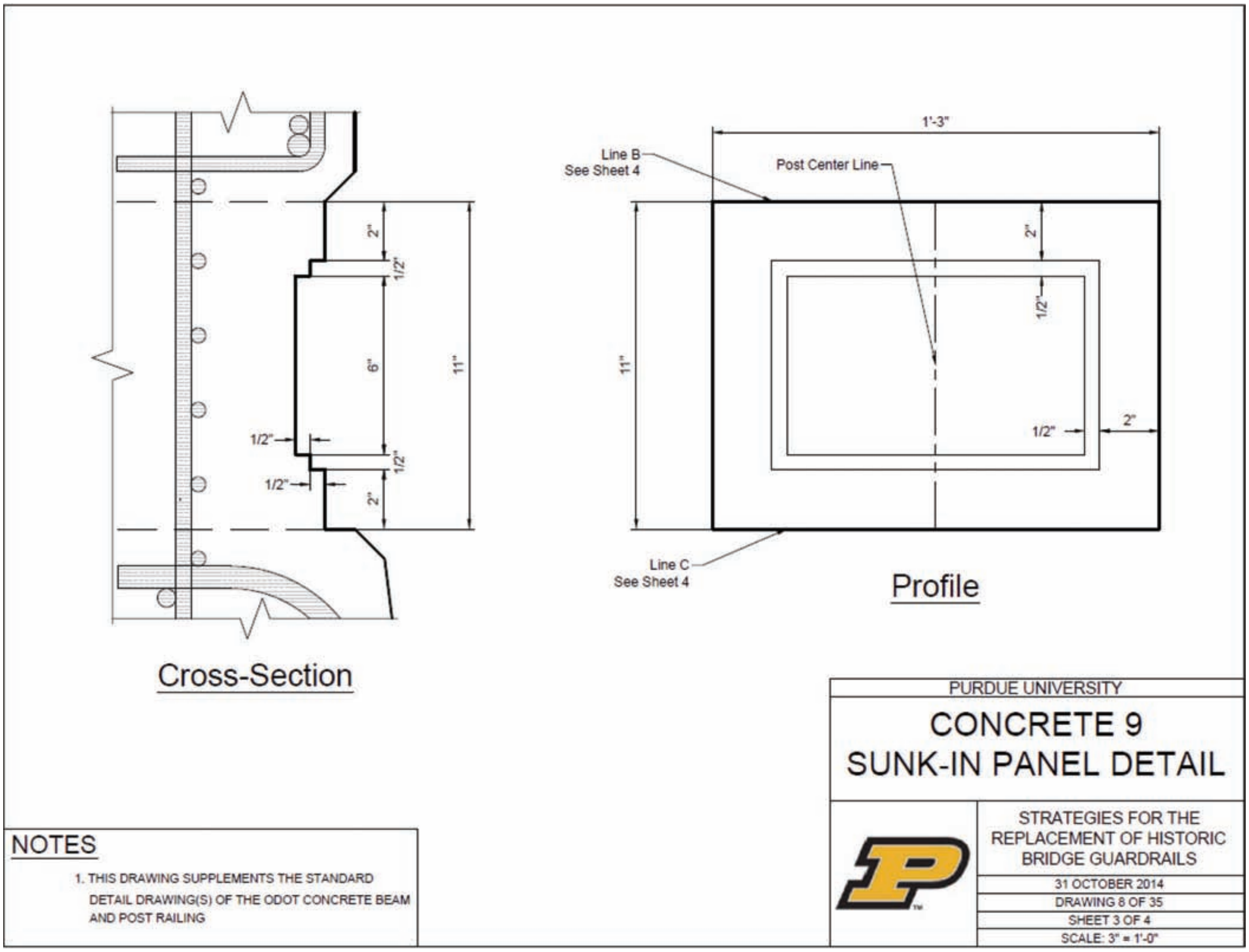
DRAWING 8 OF 35

SHEET 2 OF 4

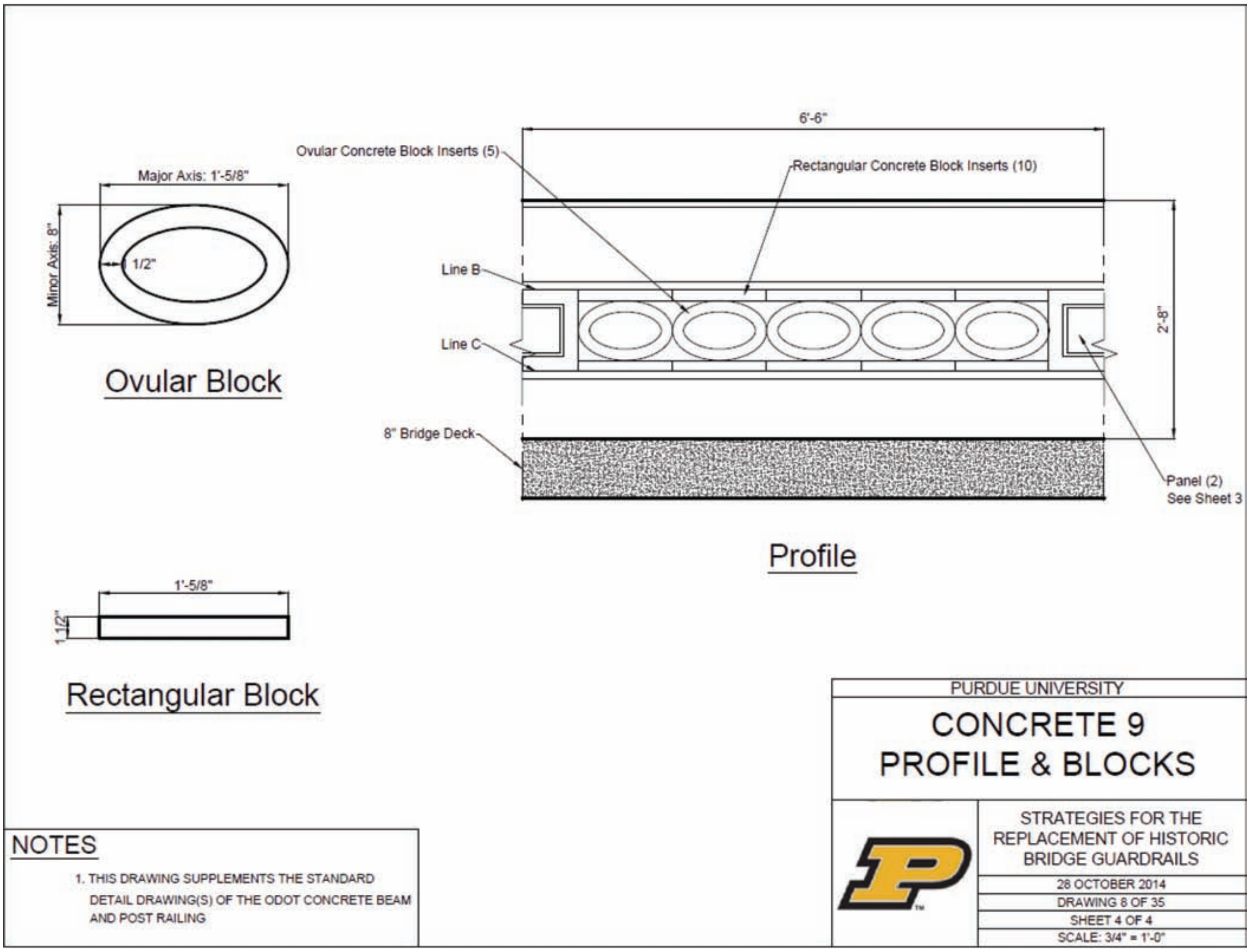
SCALE: 3/4" = 1'-0"

NOTES

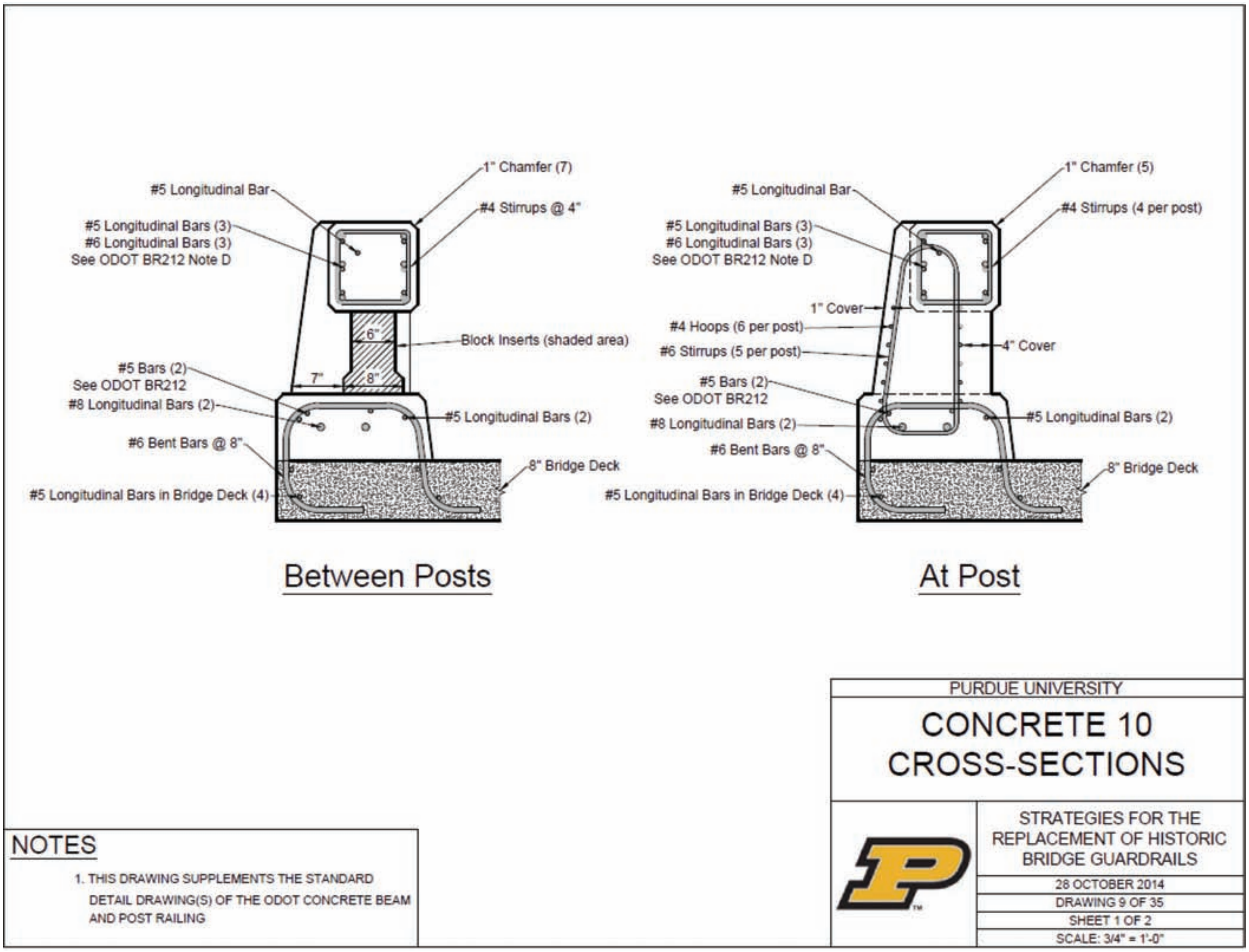
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING

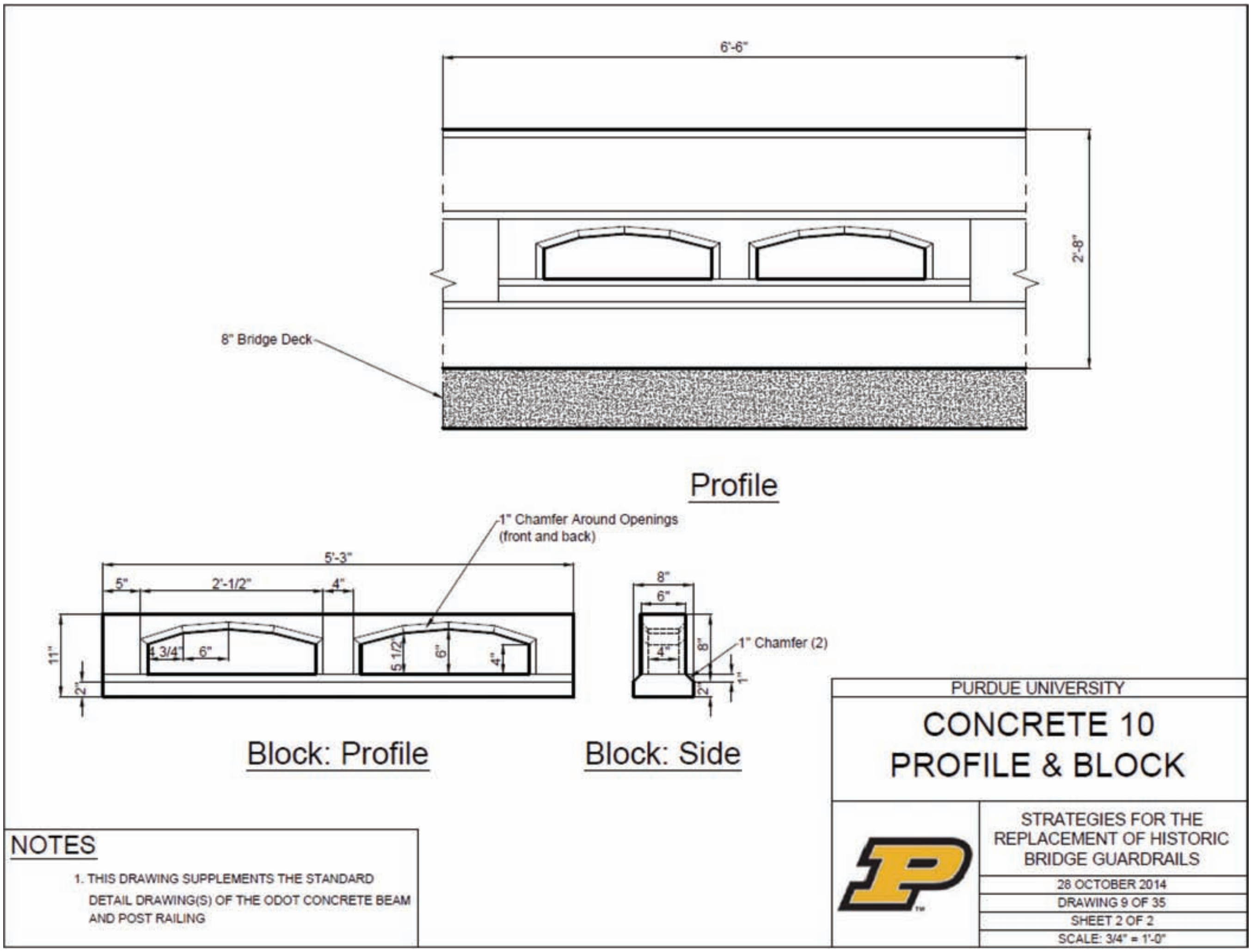


Cross-Section
2"
1/2"
6"
11"
1/2"
1/2"
1/2"
2"
Line B
See Sheet 4
Post Center Line
1'-3"
2"
1/2"
11"
1/2"
2"
Line C
See Sheet 4
Profile
PURDUE UNIVERSITY
CONCRETE 9
SUNK-IN PANEL DETAIL
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
31 OCTOBER 2014
DRAWING 8 OF 35
SHEET 3 OF 4
SCALE: 3" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING

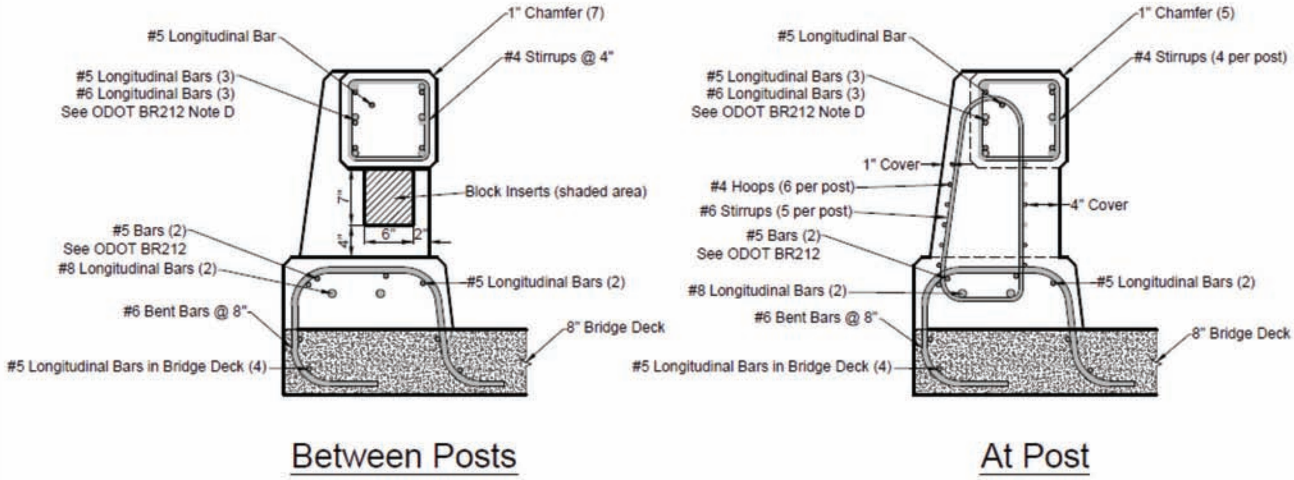


Major Axis: 1'-5/8"
Minor Axis: 8"
1/2"
Ovular Block
1'-5/8"
1 1/2"
Rectangular Block
6'-6"
Ovular Concrete Block Inserts (5)
Rectangular Concrete Block Inserts (10)
Line B
Line C
8" Bridge Deck
2'-8"
Panel (2)
See Sheet 3
Profile
PURDUE UNIVERSITY
CONCRETE 9
PROFILE & BLOCKS
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
28 OCTOBER 2014
DRAWING 8 OF 35
SHEET 4 OF 4
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM
AND POST RAILING


1" Chamfer (7)
#5 Longitudinal Bar
#4 Stirrups @ 4"
#5 Longitudinal Bars (3)
#6 Longitudinal Bars (3)
See ODOT BR212 Note D
6"
Block Inserts (shaded area)
#5 Bars (2)
See ODOT BR212
7"
8"
#8 Longitudinal Bars (2)
#5 Longitudinal Bars (2)
#6 Bent Bars @ 8"
8" Bridge Deck
#5 Longitudinal Bars in Bridge Deck (4)
Between Posts
1" Chamfer (5)
#5 Longitudinal Bar
#4 Stirrups (4 per post)
#5 Longitudinal Bars (3)
#6 Longitudinal Bars (3)
See ODOT BR212 Note D
1" Cover
#4 Hoops (6 per post)
#6 Stirrups (5 per post)
4" Cover
#5 Bars (2)
See ODOT BR212
#8 Longitudinal Bars (2)
#5 Longitudinal Bars (2)
#6 Bent Bars @ 8"
8" Bridge Deck
#5 Longitudinal Bars in Bridge Deck (4)
At Post
PURDUE UNIVERSITY
CONCRETE 10
CROSS-SECTIONS
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
28 OCTOBER 2014
DRAWING 9 OF 35
SHEET 1 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM
AND POST RAILING



6'-6"
2'-8"
8" Bridge Deck
Profile
1" Chamfer Around Openings
(front and back)
5'-3"
5"
2'-1/2"
4"
11"
2"
3/4"
6"
5 1/2"
6"
4"
Block: Profile
8"
6"
4"
8"
1" Chamfer (2)
1"
2"
Block: Side
PURDUE UNIVERSITY
CONCRETE 10
PROFILE & BLOCK
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
28 OCTOBER 2014
DRAWING 9 OF 35
SHEET 2 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM
AND POST RAILING



NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING

PURDUE UNIVERSITY

CONCRETE 11
CROSS-SECTIONS

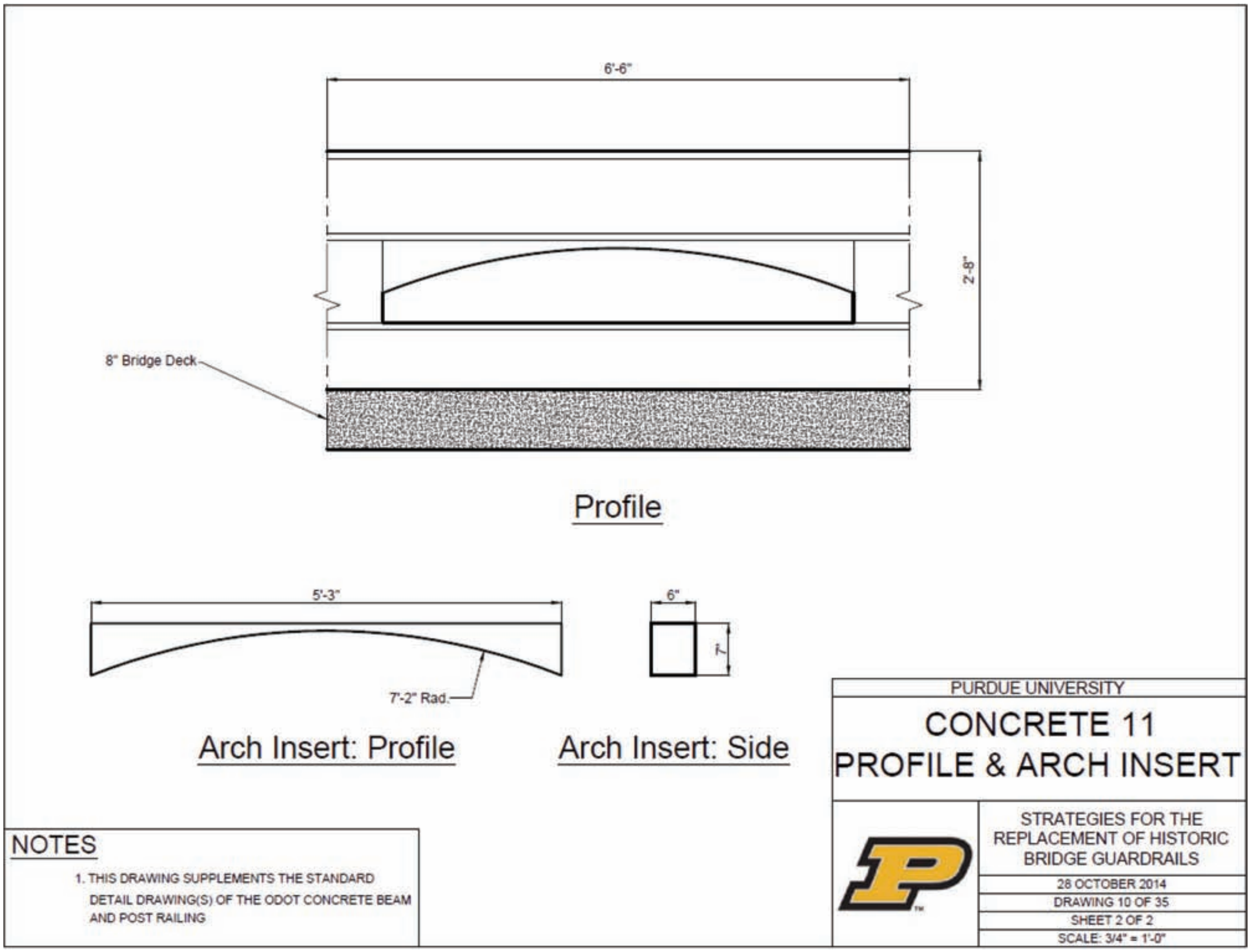
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

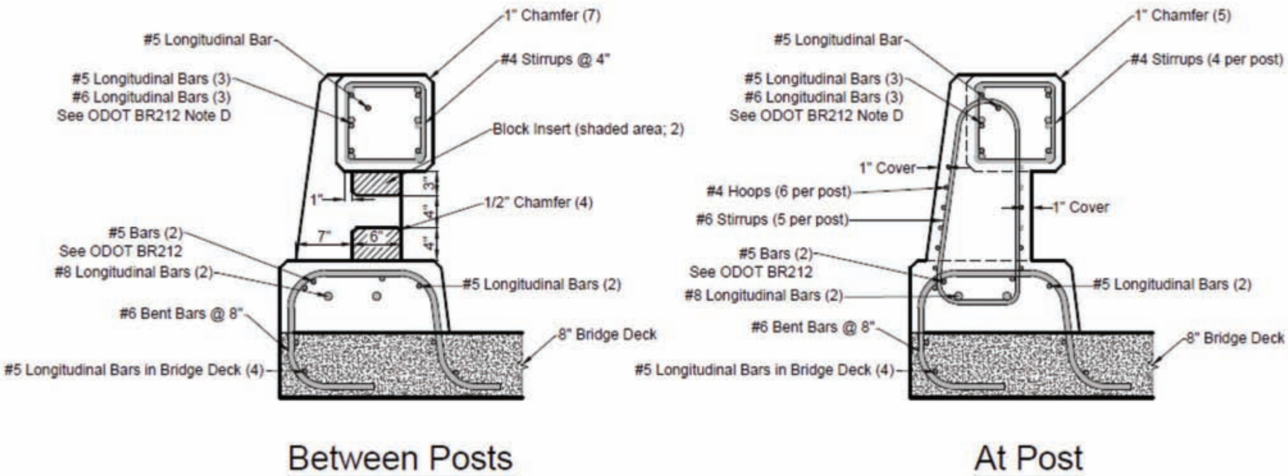
28 OCTOBER 2014

DRAWING 10 OF 35

SHEET 1 OF 2

SCALE: 3/4" = 1'-0"


6'-6"
2'-8"
8" Bridge Deck
Profile
5'-3"
7'-2" Rad.
6"
7"
Arch Insert: Profile
Arch Insert: Side
PURDUE UNIVERSITY
CONCRETE 11
PROFILE & ARCH INSERT
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
28 OCTOBER 2014
DRAWING 10 OF 35
SHEET 2 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING



PURDUE UNIVERSITY

CONCRETE 12 CROSS-SECTIONS

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

30 OCTOBER 2014

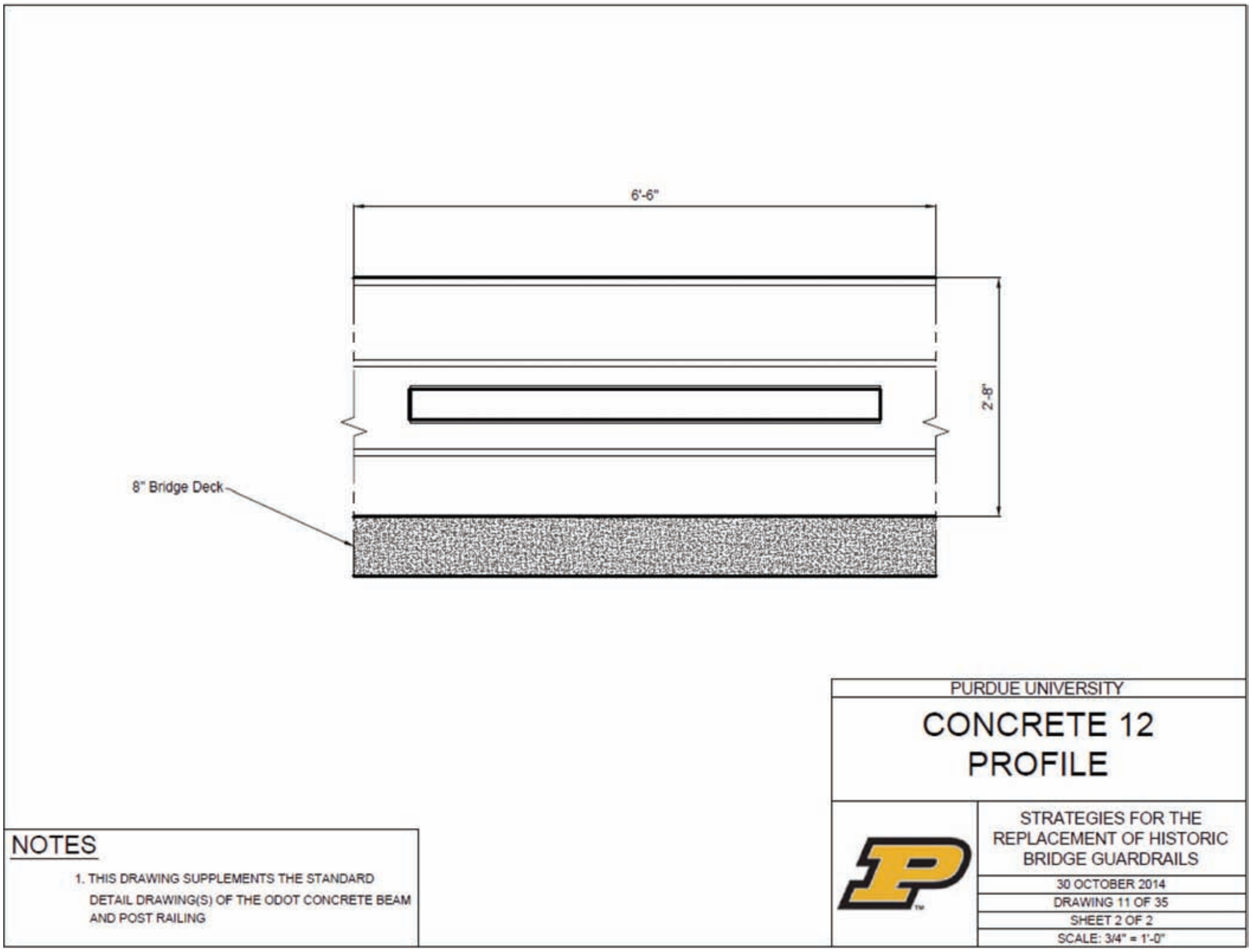
DRAWING 11 OF 35

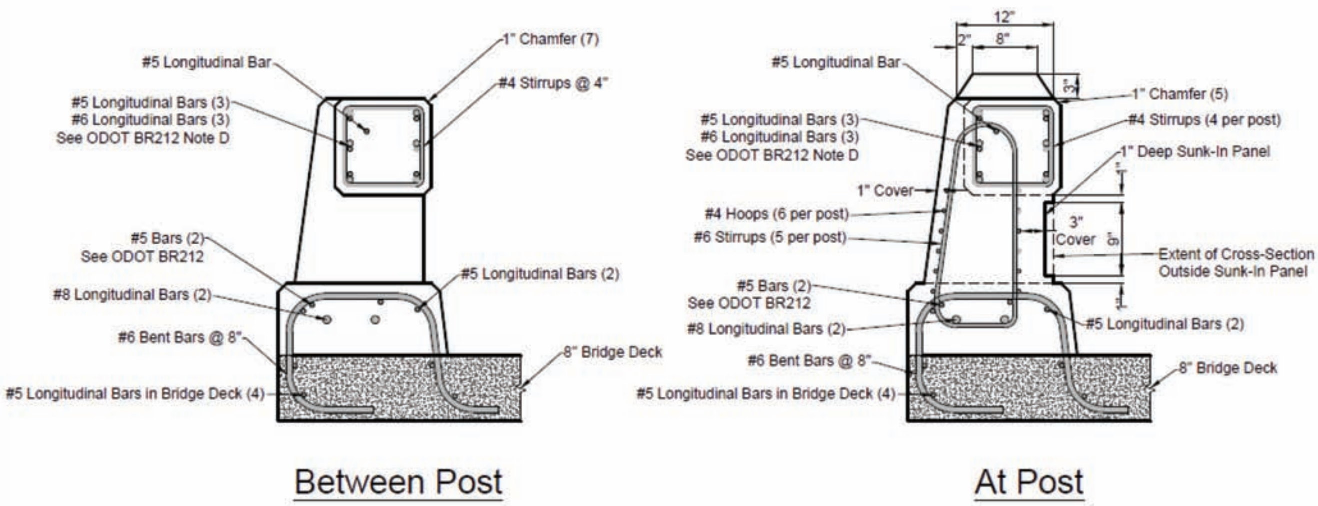
SHEET 1 OF 2

SCALE: 3/4" = 1'-0"

NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING


6'-6"
2'-8"
8" Bridge Deck
PURDUE UNIVERSITY
CONCRETE 12
PROFILE
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
30 OCTOBER 2014
DRAWING 11 OF 35
SHEET 2 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM
AND POST RAILING



PURDUE UNIVERSITY

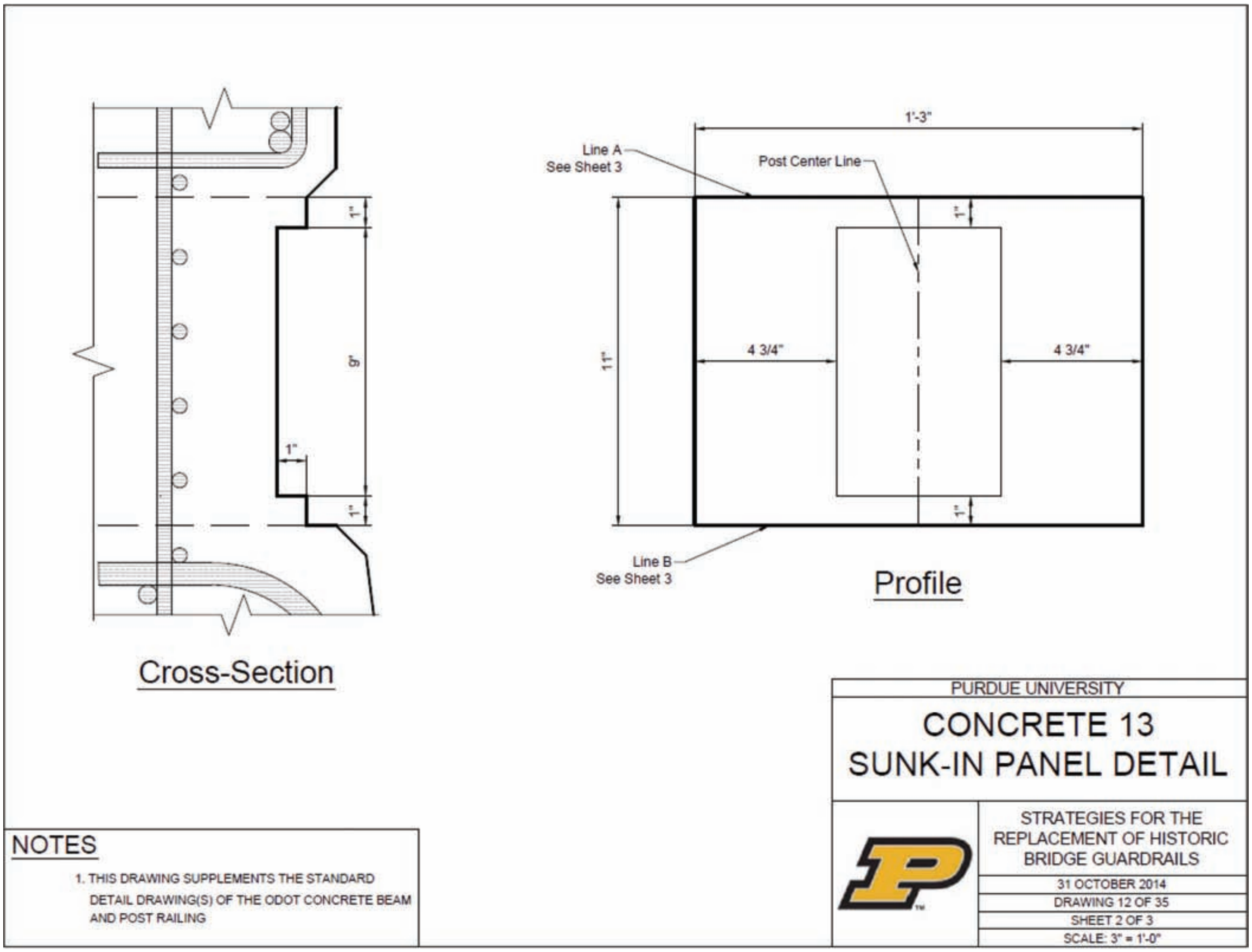
CONCRETE 13 CROSS-SECTIONS

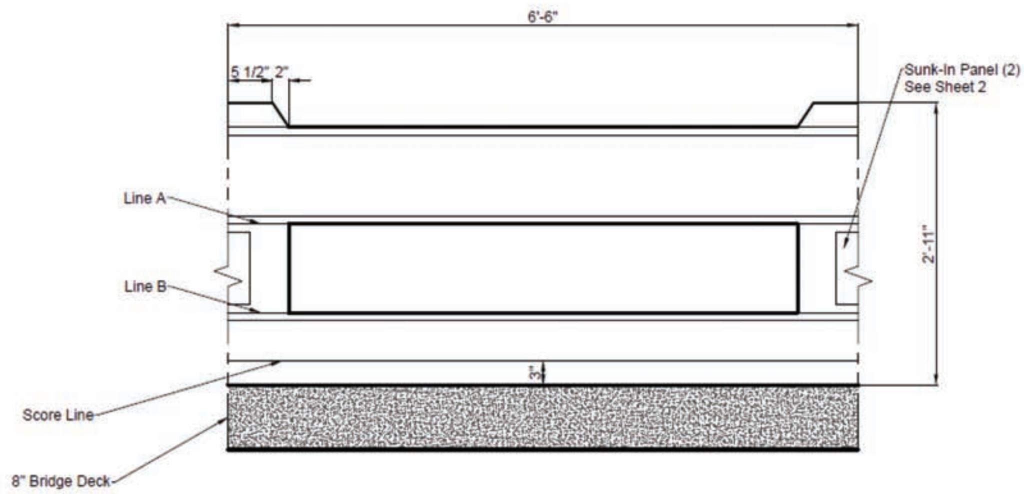
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

28 OCTOBER 2014
DRAWING 12 OF 35
SHEET 1 OF 3
SCALE: 3/4" = 1'-0"

NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING


Cross-Section
1"
9"
1"
1"
Line A
See Sheet 3
1'-3"
Post Center Line
1"
4 3/4"
4 3/4"
11"
1"
Line B
See Sheet 3
Profile
PURDUE UNIVERSITY
CONCRETE 13
SUNK-IN PANEL DETAIL
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
31 OCTOBER 2014
DRAWING 12 OF 35
SHEET 2 OF 3
SCALE: 3" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING



NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING

PURDUE UNIVERSITY

CONCRETE 13 PROFILE

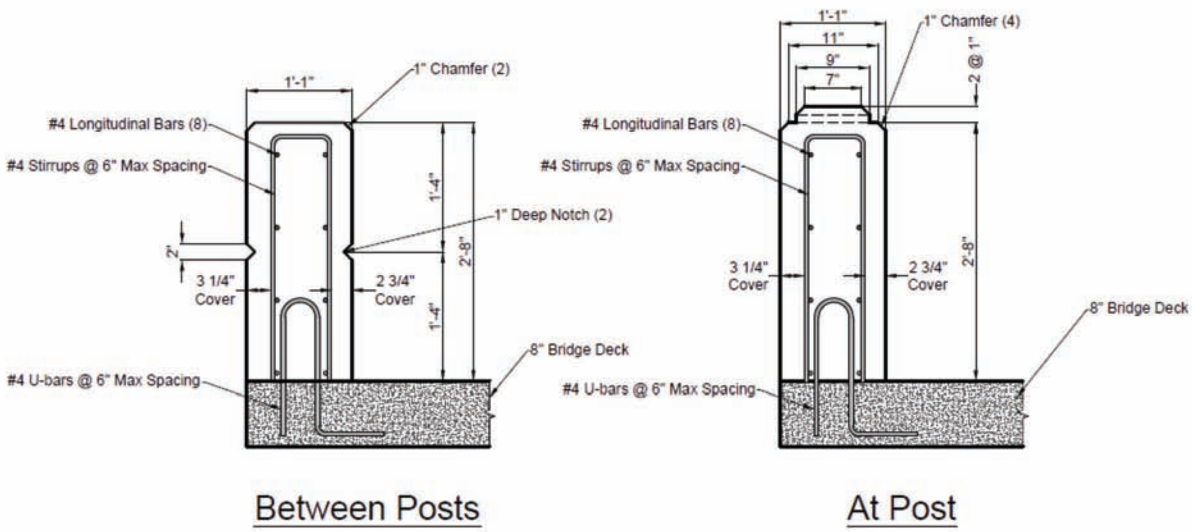
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

28 OCTOBER 2014

DRAWING 12 OF 35

SHEET 3 OF 3

SCALE: 3/4" = 1'-0"



PURDUE UNIVERSITY

CONCRETE 16 CROSS-SECTIONS

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

30 OCTOBER 2014

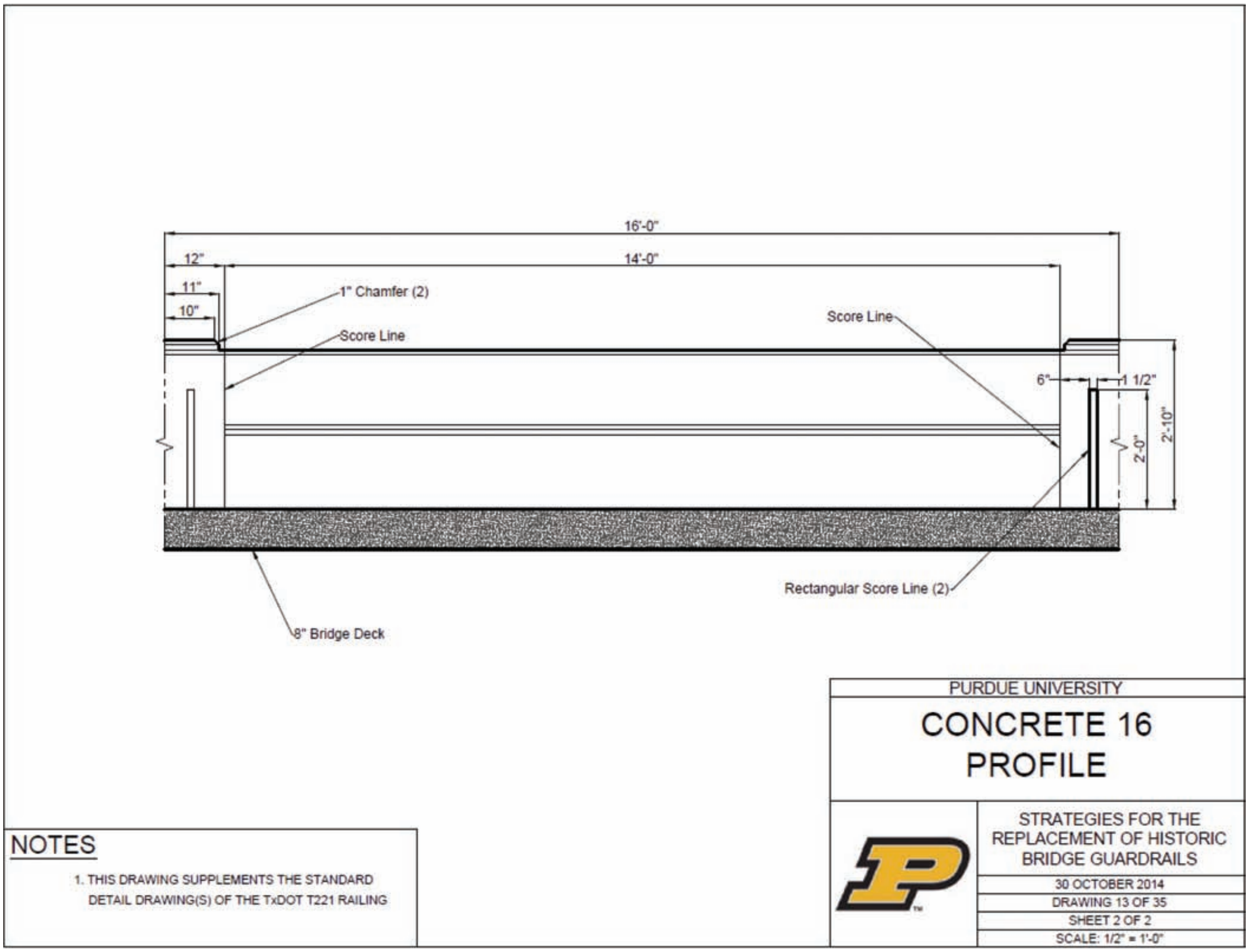
DRAWING 13 OF 35

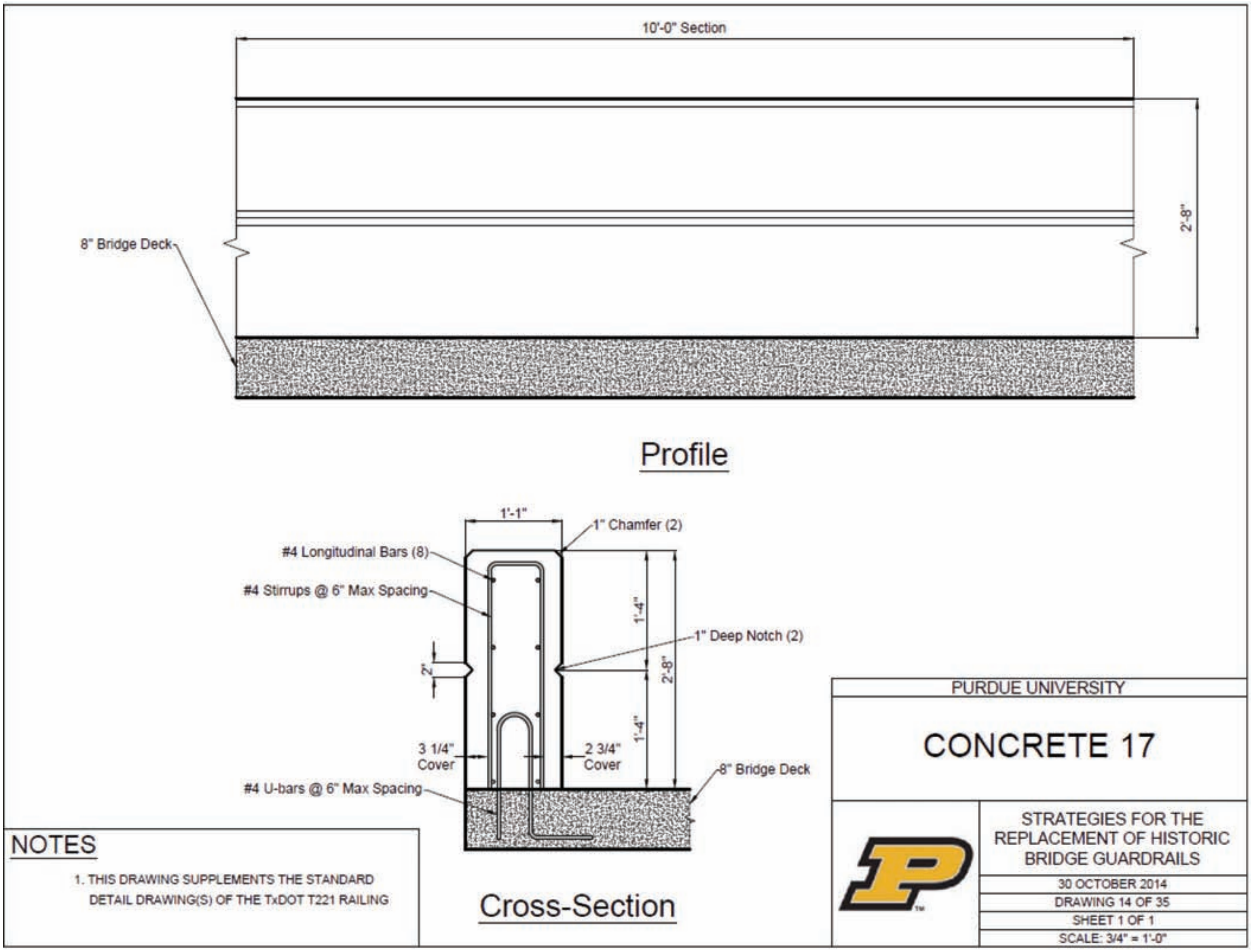
SHEET 1 OF 2

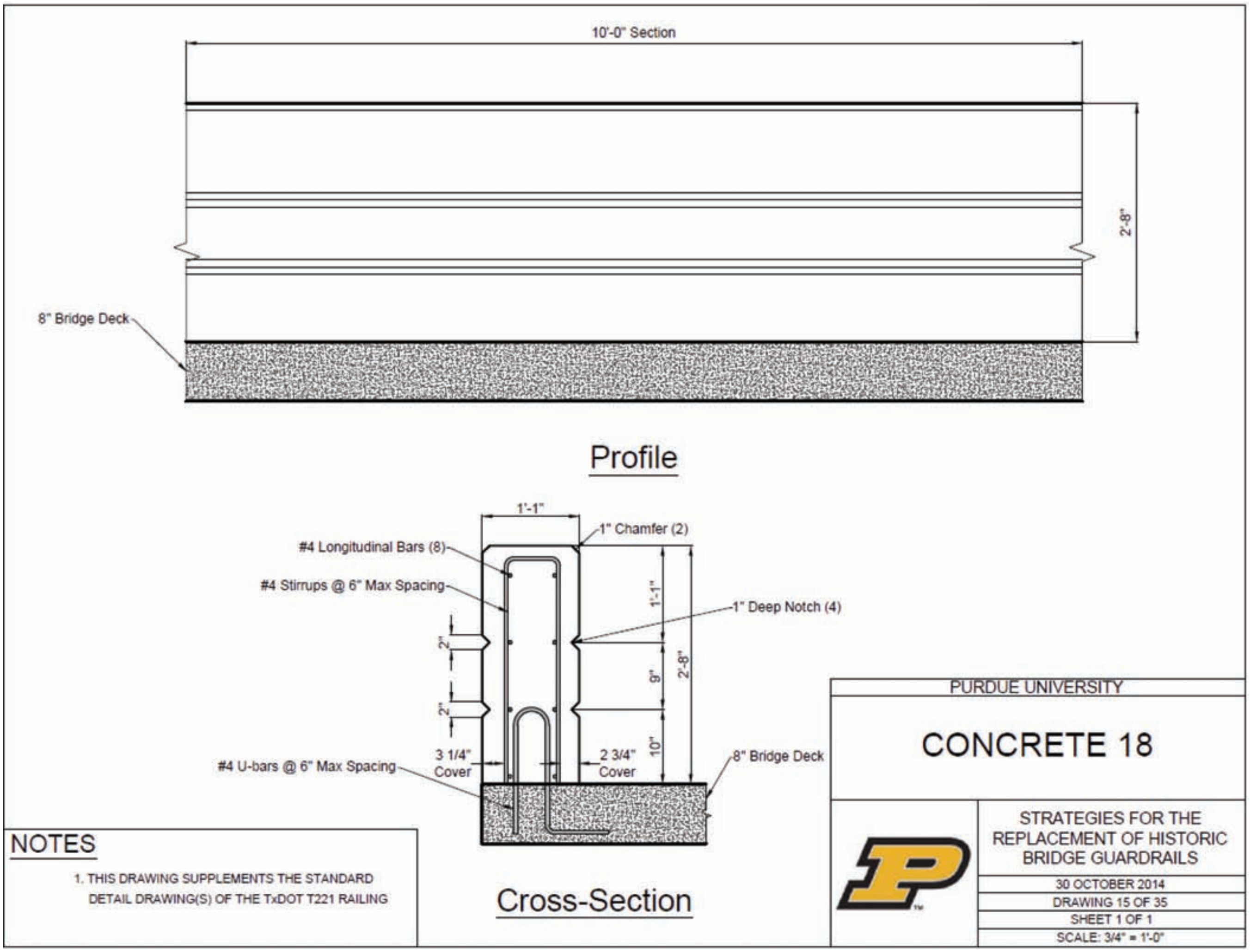
SCALE: 3/4" = 1'-0"

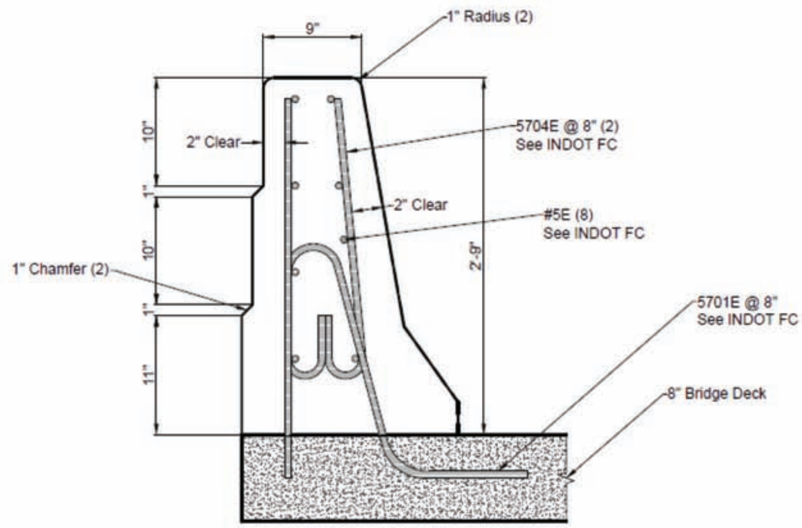
NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING


16'-0"
12"
14'-0"
11"
10"
1" Chamfer (2)
Score Line
Score Line
6"
1 1/2"
2'-0"
2'-10"
Rectangular Score Line (2)
8" Bridge Deck
PURDUE UNIVERSITY
CONCRETE 16
PROFILE
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
30 OCTOBER 2014
DRAWING 13 OF 35
SHEET 2 OF 2
SCALE: 1/2" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT T221 RAILING


10'-0" Section
8" Bridge Deck
2'-8"
Profile
1'-1"
1" Chamfer (2)
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
1'-4"
1" Deep Notch (2)
2"
2'-8"
1'-4"
3 1/4" Cover
2 3/4" Cover
8" Bridge Deck
#4 U-bars @ 6" Max Spacing
Cross-Section
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING
PURDUE UNIVERSITY
CONCRETE 17
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
30 OCTOBER 2014
DRAWING 14 OF 35
SHEET 1 OF 1
SCALE: 3/4" = 1'-0"


10'-0" Section
2'-8"
8" Bridge Deck
Profile
1'-1"
1" Chamfer (2)
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
1" Deep Notch (4)
1'-1"
9"
2'-8"
10"
2"
2"
3 1/4" Cover
2 3/4" Cover
#4 U-bars @ 6" Max Spacing
8" Bridge Deck
Cross-Section
PURDUE UNIVERSITY
CONCRETE 18
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
30 OCTOBER 2014
DRAWING 15 OF 35
SHEET 1 OF 1
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING



PURDUE UNIVERSITY

CONCRETE 19 CROSS-SECTION

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

30 OCTOBER 2014

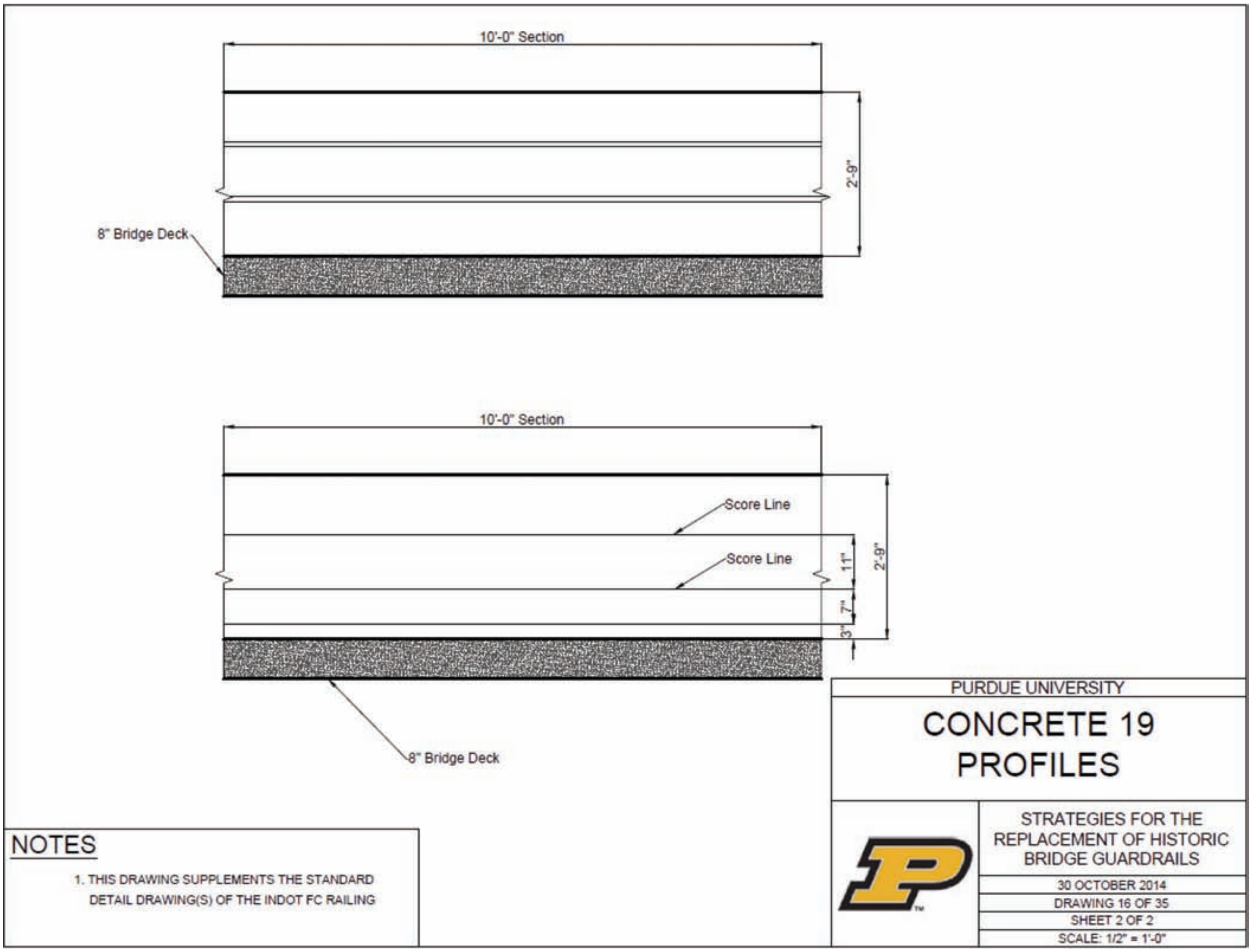
DRAWING 16 OF 35

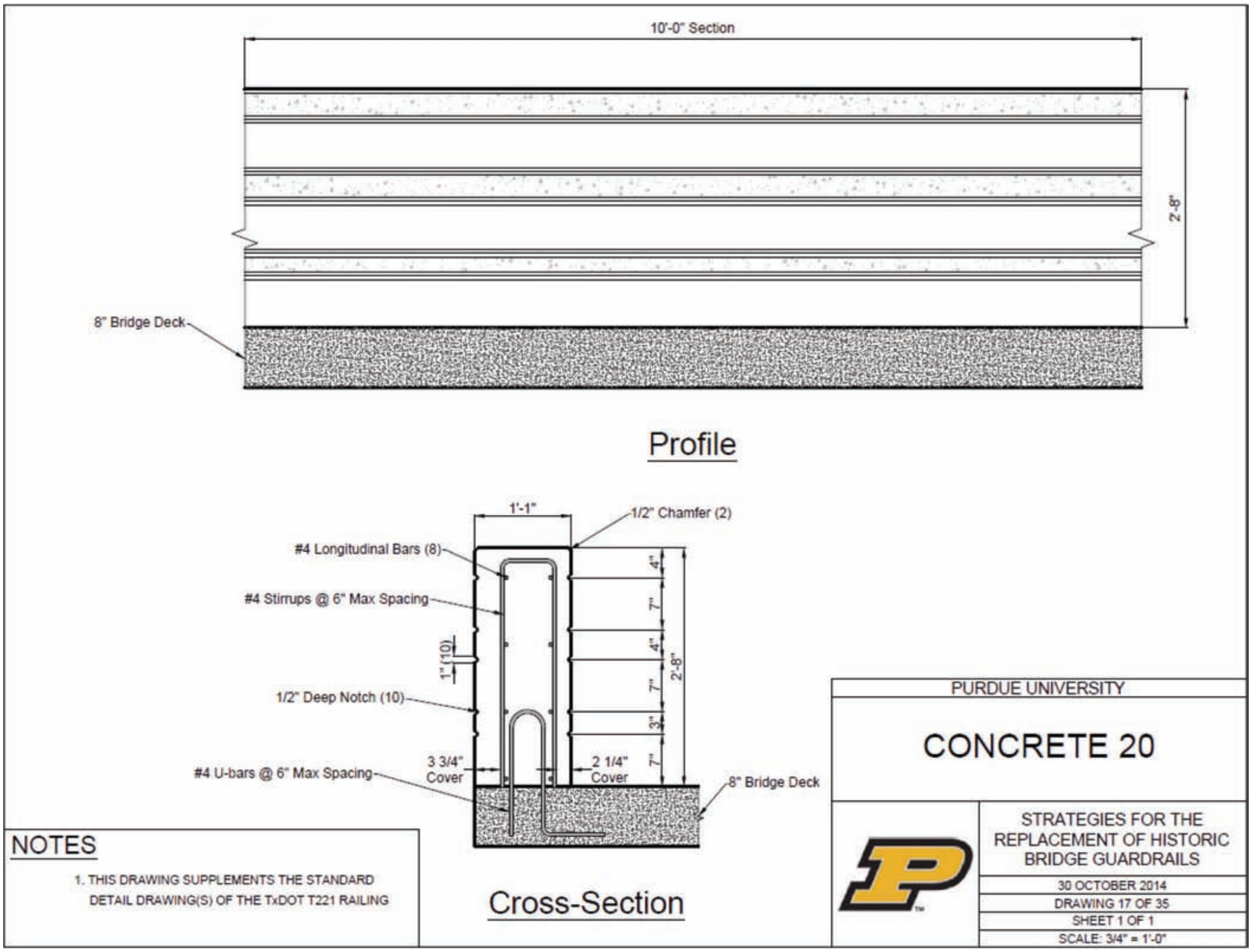
SHEET 1 OF 2

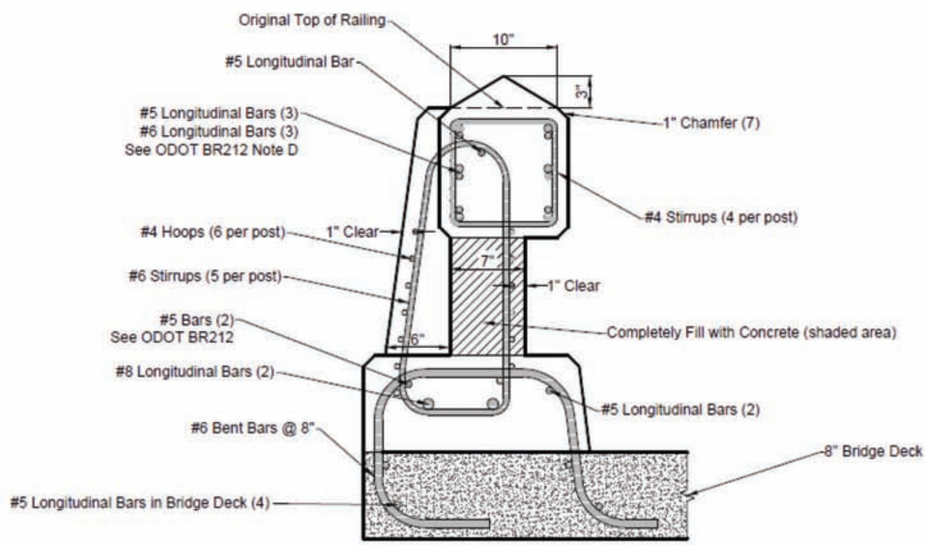
SCALE: 1" = 1'-0"

NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE INDOT FC RAILING


10'-0" Section
2'-9"
8" Bridge Deck
10'-0" Section
Score Line
Score Line
11"
7"
3"
2'-9"
8" Bridge Deck
PURDUE UNIVERSITY
CONCRETE 19
PROFILES
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
30 OCTOBER 2014
DRAWING 16 OF 35
SHEET 2 OF 2
SCALE: 1/2" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE INDOT FC RAILING


10'-0" Section
2'-8"
8" Bridge Deck
Profile
1'-1"
1/2" Chamfer (2)
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
1" (10)
1/2" Deep Notch (10)
#4 U-bars @ 6" Max Spacing
3 3/4" Cover
2 1/4" Cover
4"
7"
4"
7"
3"
7"
2'-8"
8" Bridge Deck
Cross-Section
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING
PURDUE UNIVERSITY
CONCRETE 20
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
30 OCTOBER 2014
DRAWING 17 OF 35
SHEET 1 OF 1
SCALE: 3/4" = 1'-0"



PURDUE UNIVERSITY

CONCRETE 22 CROSS-SECTION

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

30 OCTOBER 2014

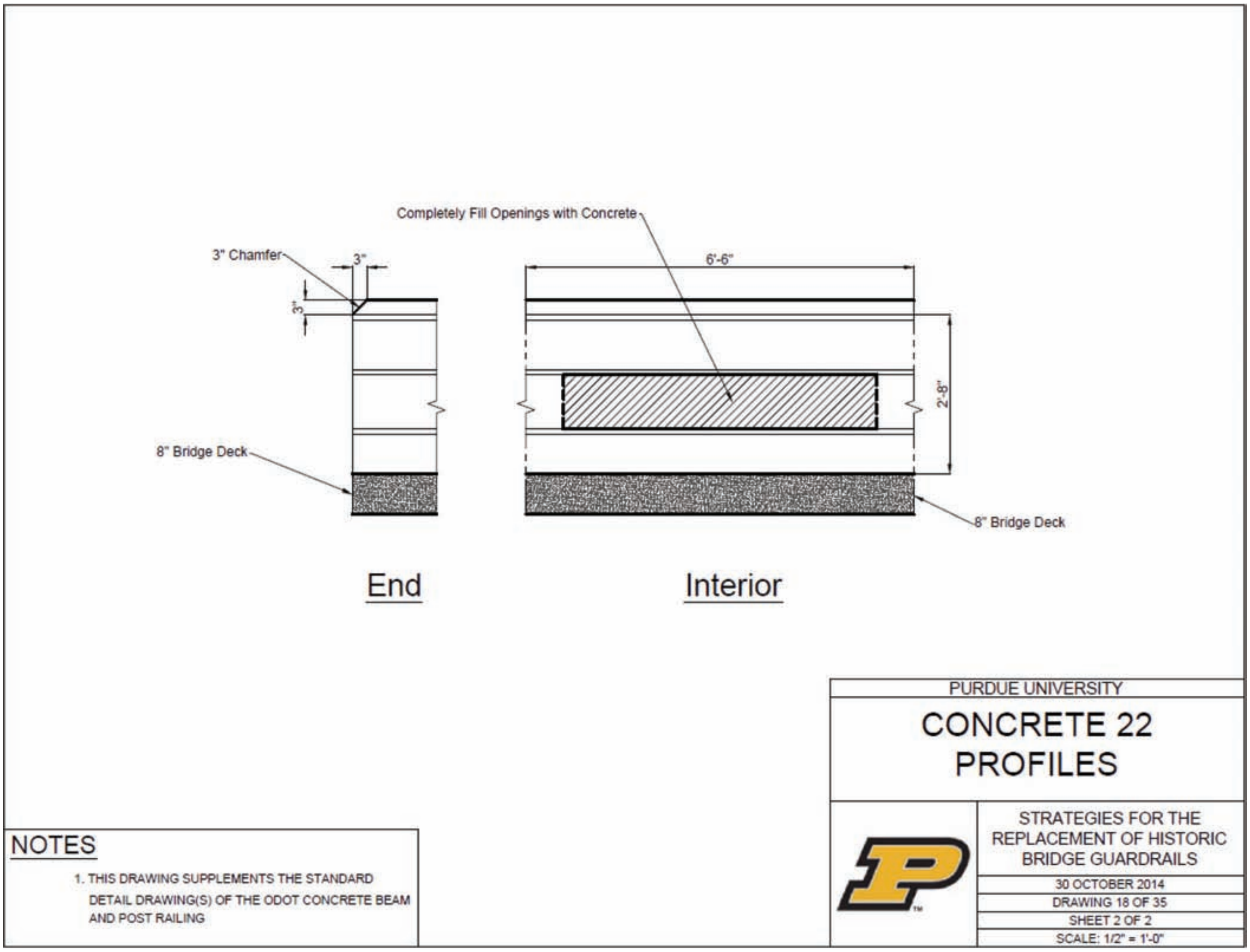
DRAWING 18 OF 35

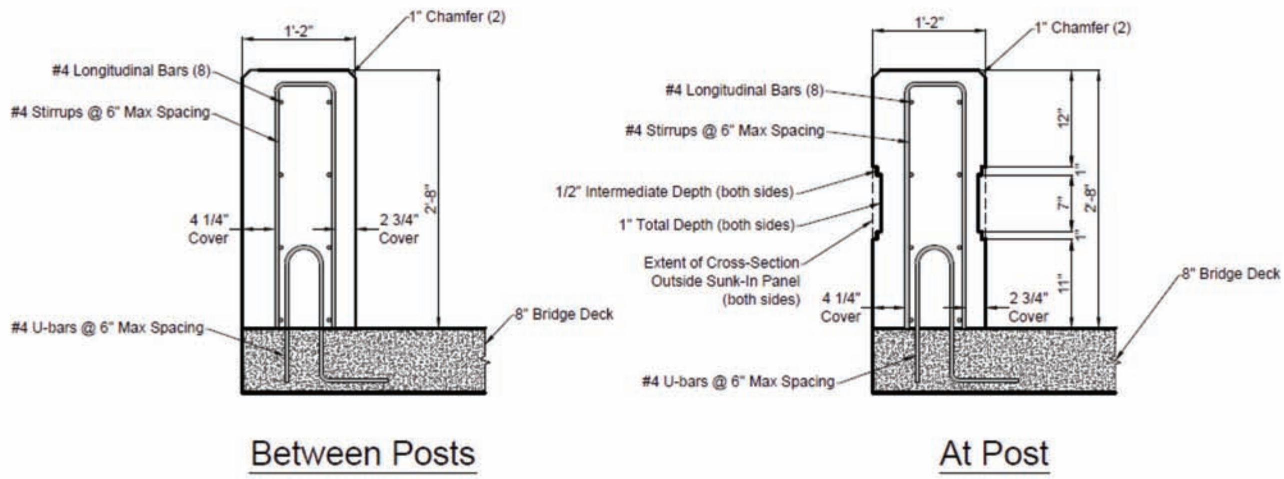
SHEET 1 OF 2

SCALE: 1" = 1'-0"

NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING


Completely Fill Openings with Concrete
3" Chamfer
3"
3"
6'-6"
2'-8"
8" Bridge Deck
8" Bridge Deck
End
Interior
PURDUE UNIVERSITY
CONCRETE 22
PROFILES
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
30 OCTOBER 2014
DRAWING 18 OF 35
SHEET 2 OF 2
SCALE: 1/2" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM
AND POST RAILING



NOTES

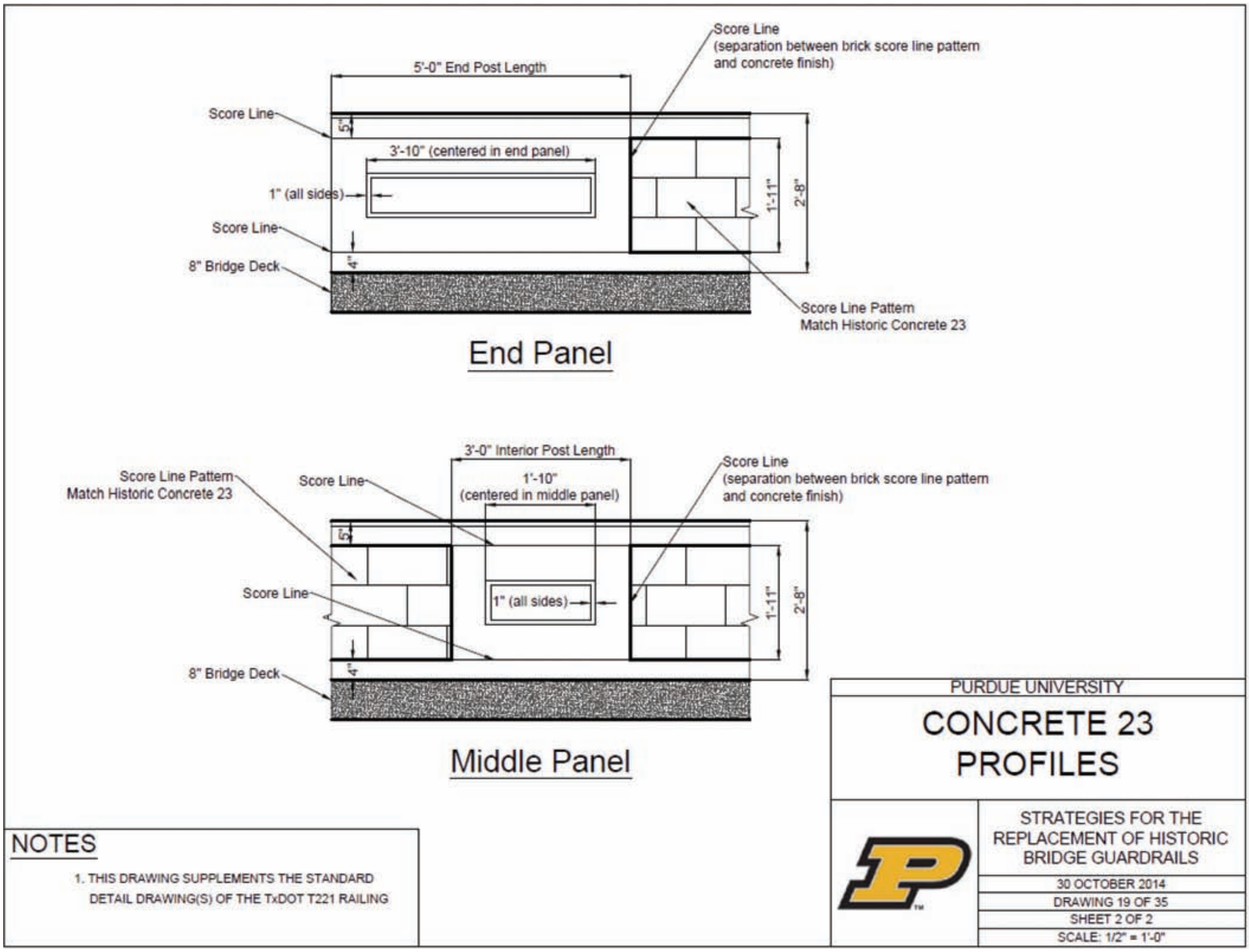
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING

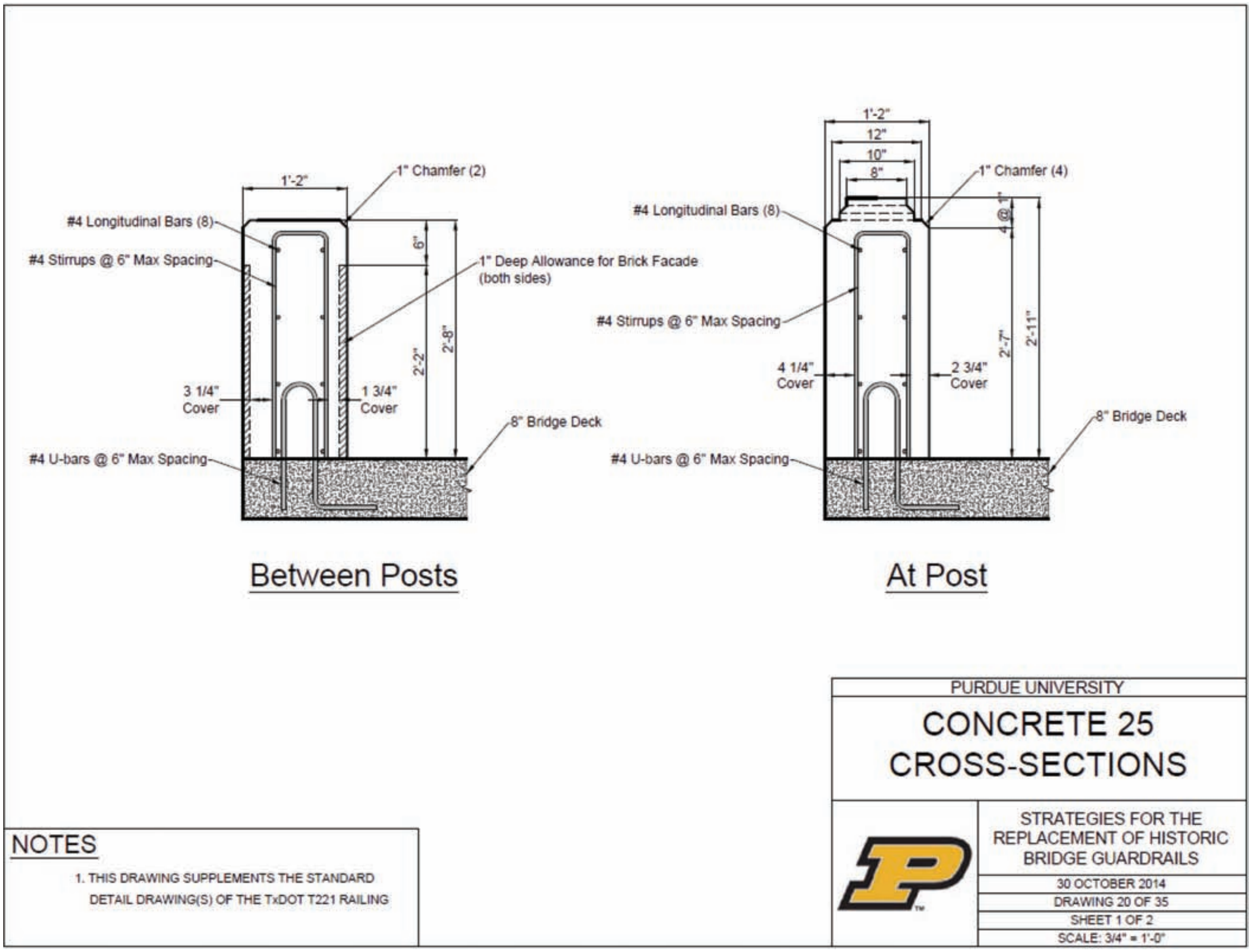
PURDUE UNIVERSITY

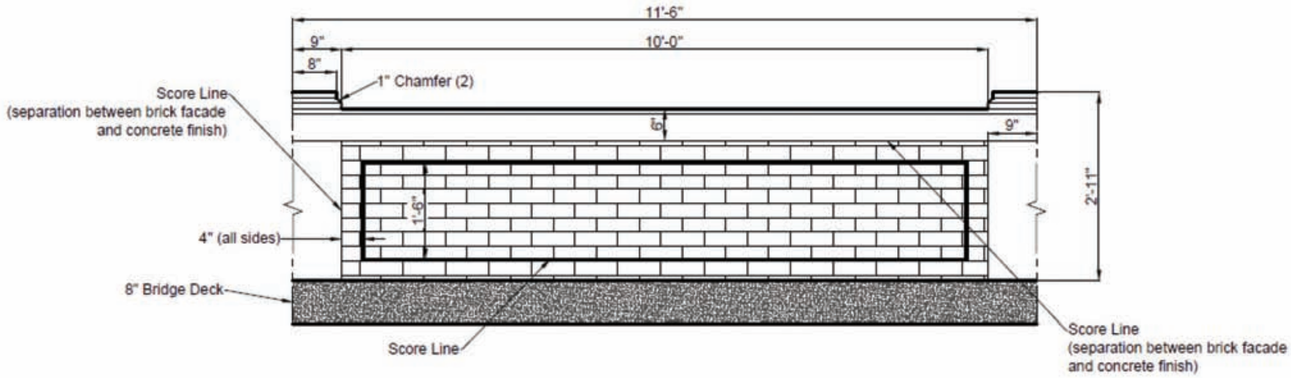
CONCRETE 23
CROSS-SECTIONS

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

30 OCTOBER 2014
DRAWING 19 OF 35
SHEET 1 OF 2
SCALE: 3/4" = 1'-0"


Score Line
(separation between brick score line pattern
and concrete finish)
5'-0" End Post Length
Score Line
5"
3'-10" (centered in end panel)
1" (all sides)
Score Line
8" Bridge Deck
4"
1'-11"
2'-8"
Score Line Pattern
Match Historic Concrete 23
End Panel
3'-0" Interior Post Length
Score Line Pattern
Match Historic Concrete 23
Score Line
1'-10"
(centered in middle panel)
Score Line
(separation between brick score line pattern
and concrete finish)
Score Line
1" (all sides)
8" Bridge Deck
Middle Panel
PURDUE UNIVERSITY
CONCRETE 23
PROFILES
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
30 OCTOBER 2014
DRAWING 19 OF 35
SHEET 2 OF 2
SCALE: 1/2" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT T221 RAILING


1'-2"
1" Chamfer (2)
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
6"
1" Deep Allowance for Brick Facade
(both sides)
2'-2"
2'-8"
3 1/4"
Cover
1 3/4"
Cover
8" Bridge Deck
#4 U-bars @ 6" Max Spacing
Between Posts
1'-2"
12"
10"
8"
1" Chamfer (4)
#4 Longitudinal Bars (8)
4 @ 1"
#4 Stirrups @ 6" Max Spacing
2'-7"
2'-11"
4 1/4"
Cover
2 3/4"
Cover
8" Bridge Deck
#4 U-bars @ 6" Max Spacing
At Post
PURDUE UNIVERSITY
CONCRETE 25
CROSS-SECTIONS
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
30 OCTOBER 2014
DRAWING 20 OF 35
SHEET 1 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT T221 RAILING



PURDUE UNIVERSITY

CONCRETE 25 PROFILE

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

30 OCTOBER 2014

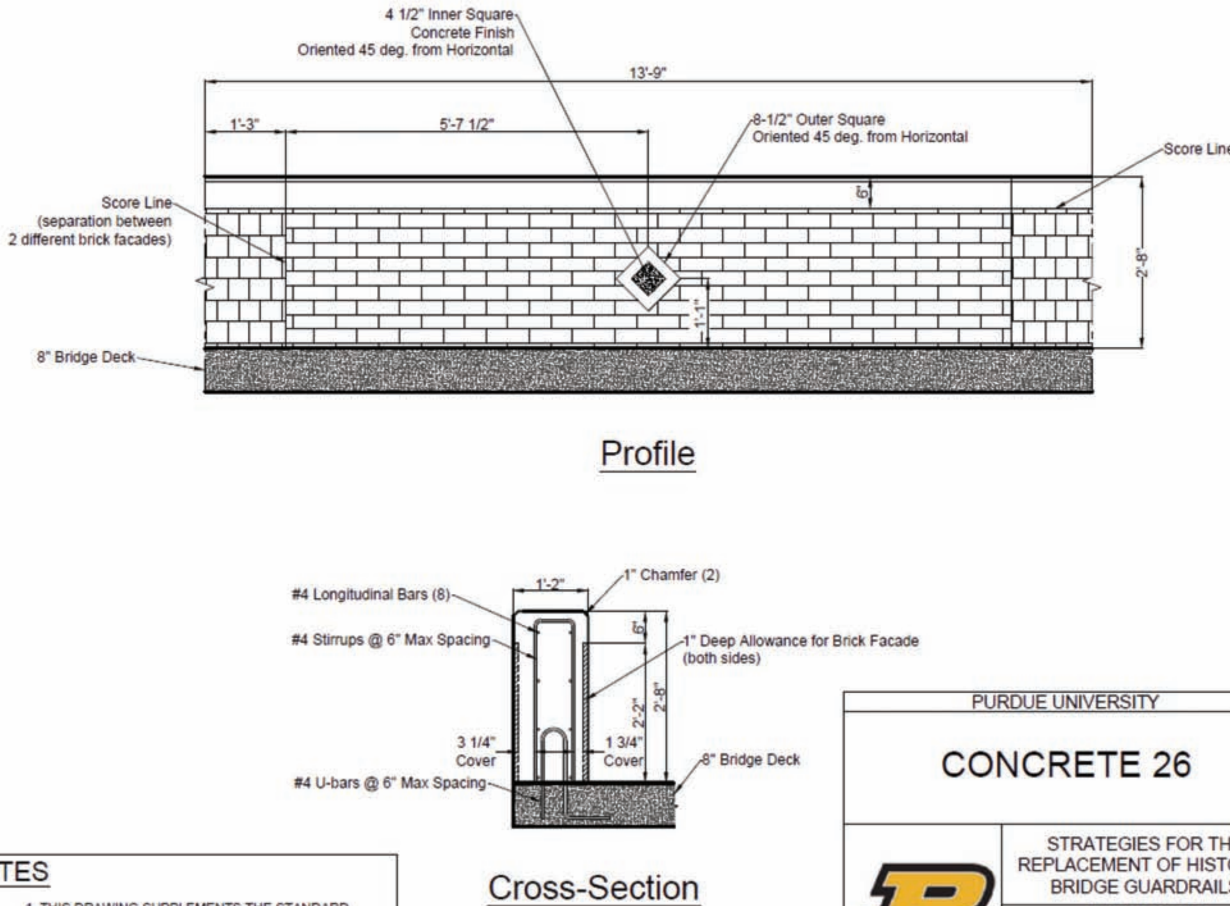
DRAWING 20 OF 35

SHEET 2 OF 2

SCALE: 1/2" = 1'-0"

NOTES

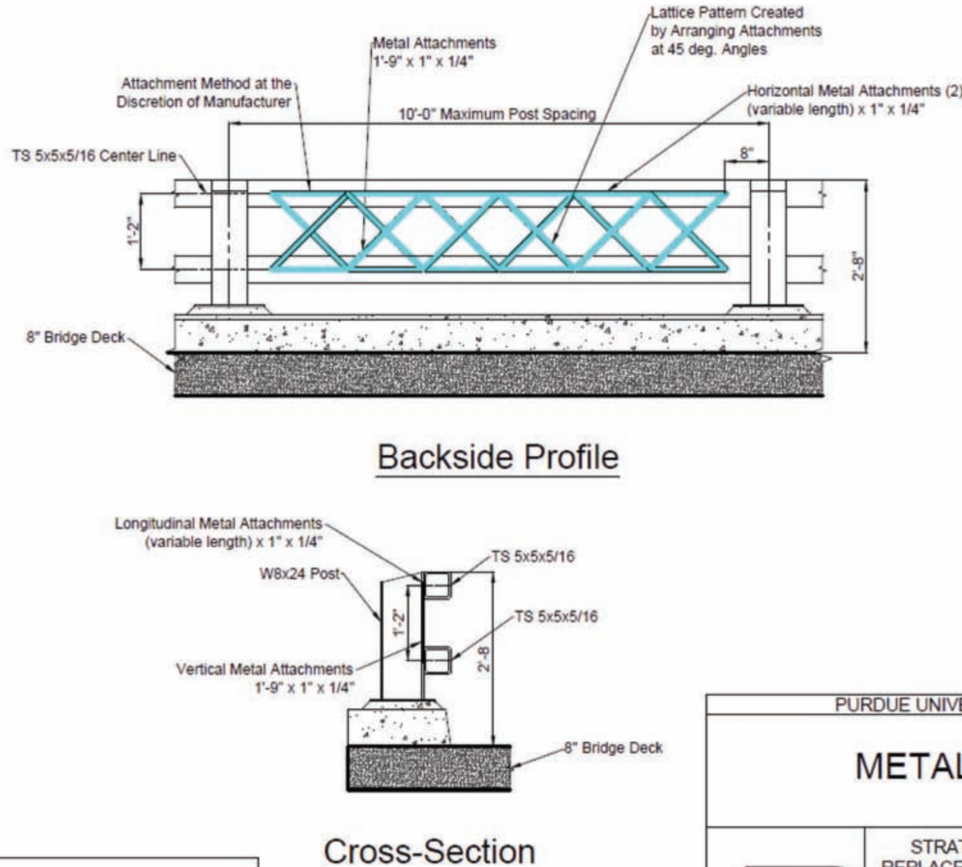
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING



NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING

PURDUE UNIVERSITY	
CONCRETE 26	
	STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
	30 OCTOBER 2014
	DRAWING 21 OF 35
	SHEET 1 OF 1
	SCALE: 1/2" = 1'-0"



PURDUE UNIVERSITY

METAL 6

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

27 OCTOBER 2014

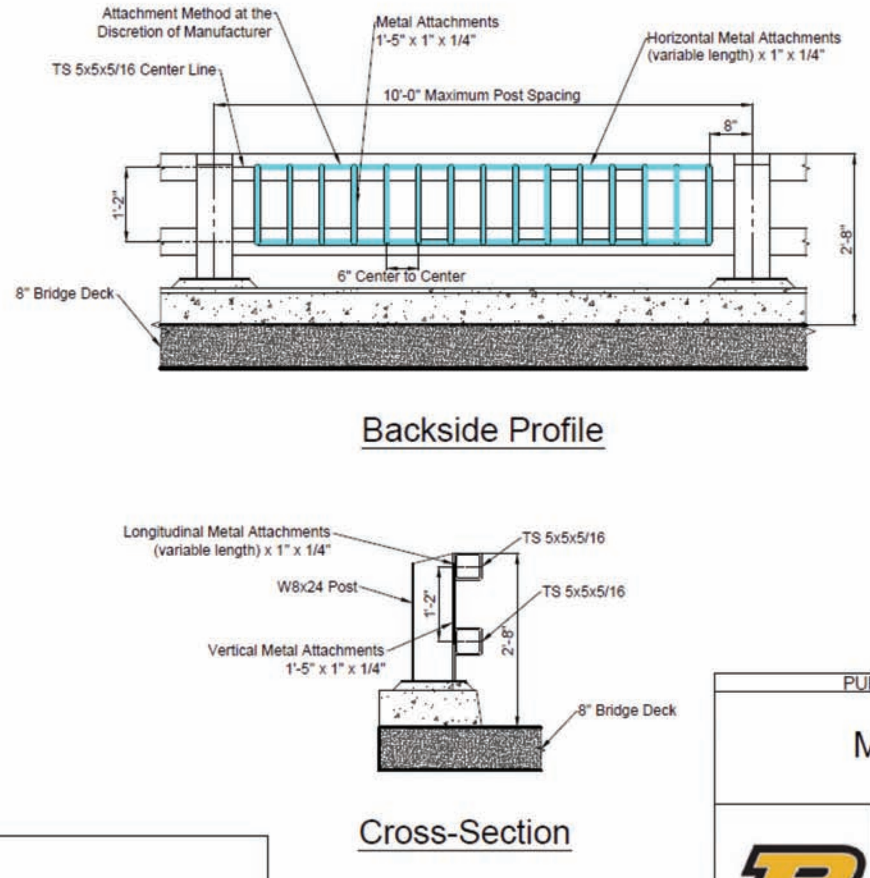
DRAWING 22 OF 35

SHEET 1 OF 1

SCALE: 1/2" = 1'-0"

NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT TWO-TUBE RAILING
2. PAINT METAL ATACHMENTS TO MATCH BRIDGE



NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT TWO-TUBE RAILING
2. PAINT METAL ATTACHMENTS TO MATCH BRIDGE

PURDUE UNIVERSITY

METAL 14

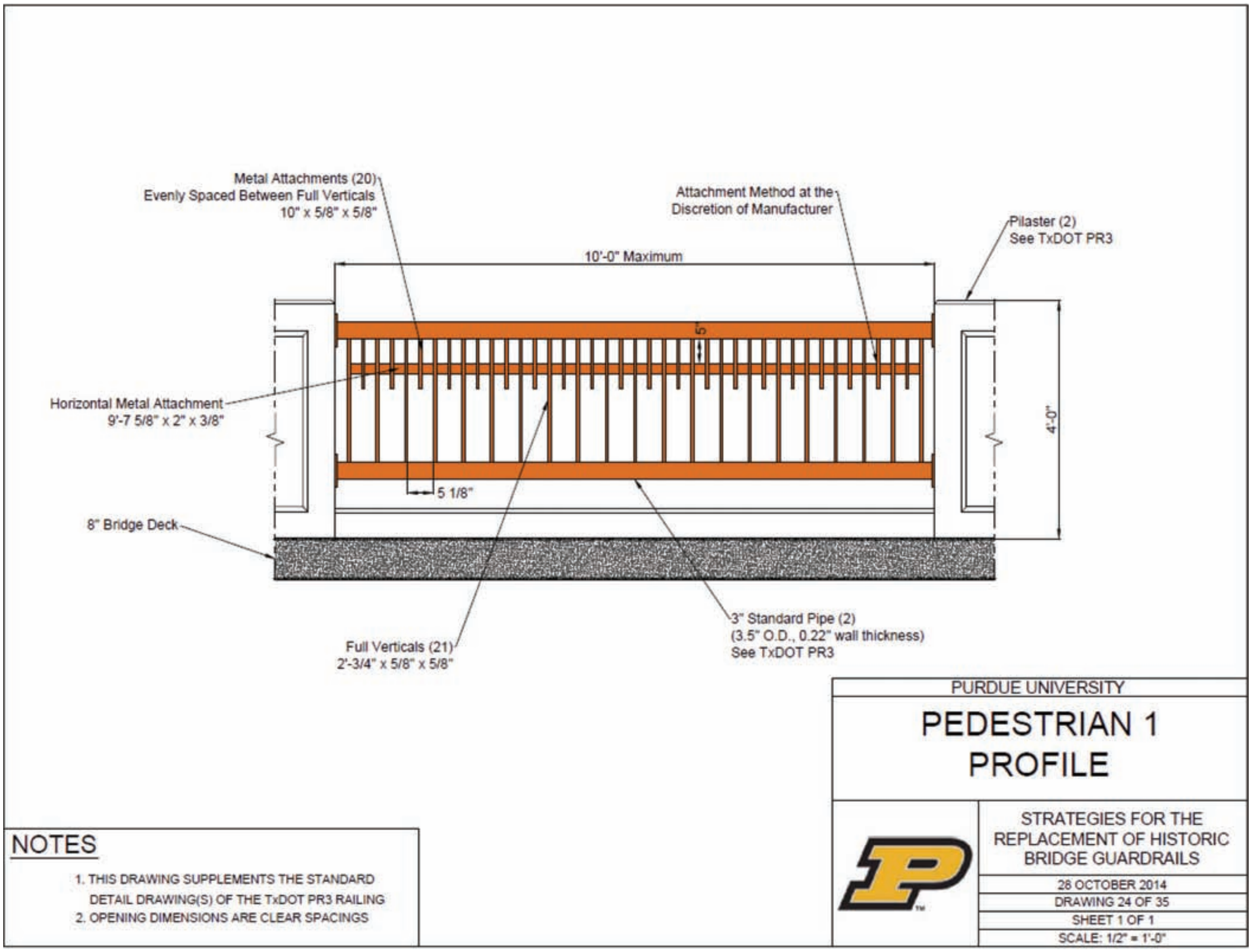
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

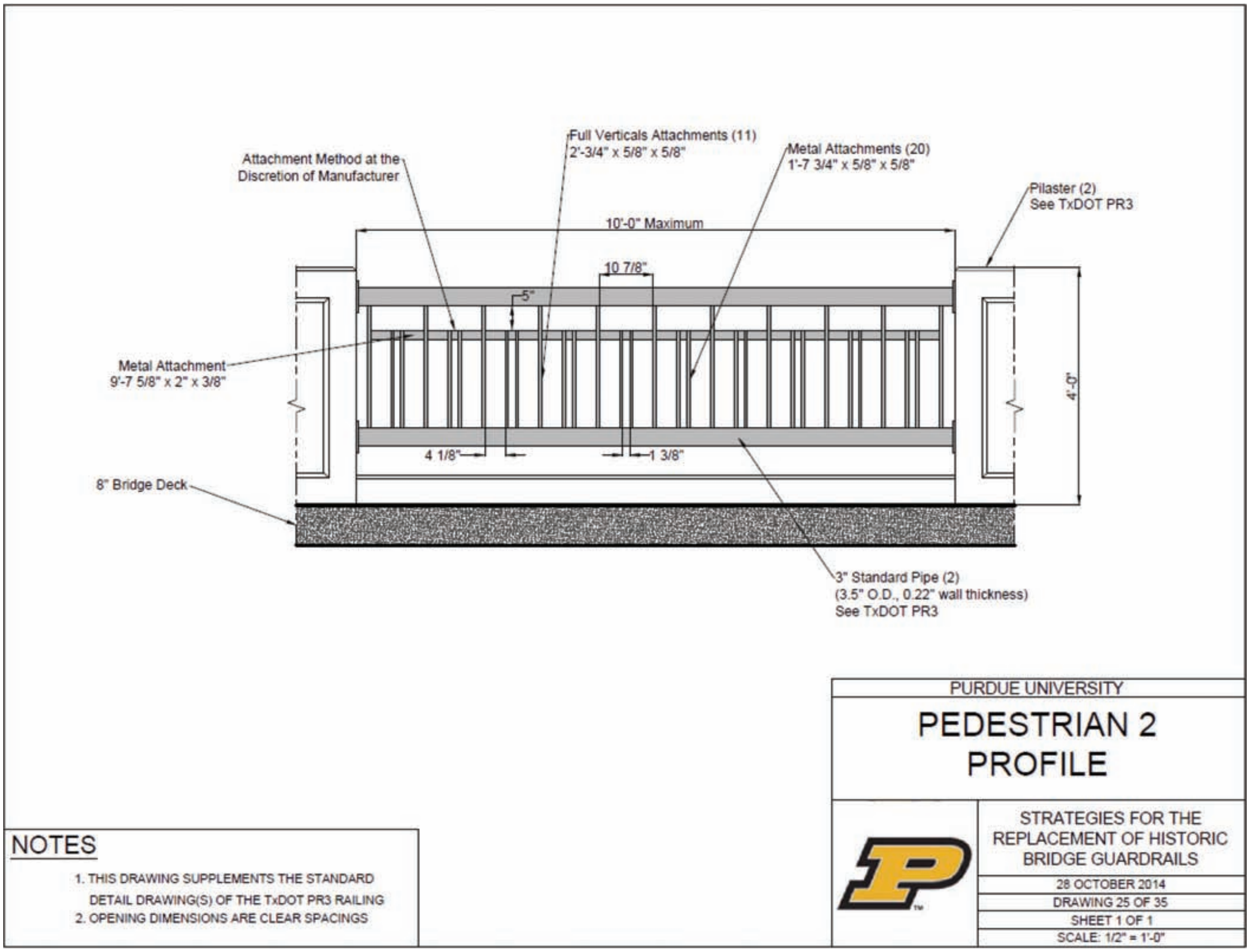
27 OCTOBER 2014

DRAWING 23 OF 35

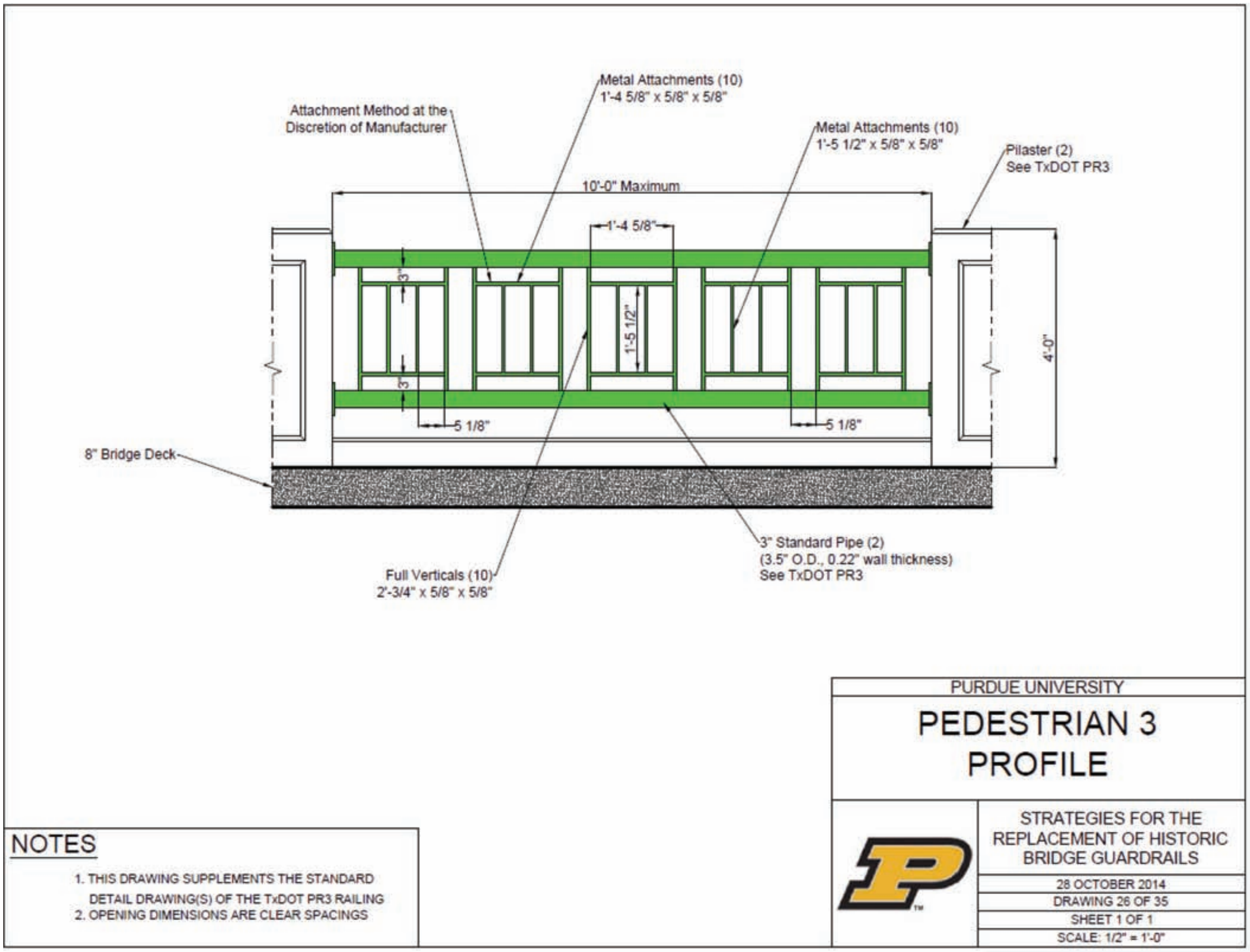
SHEET 1 OF 1

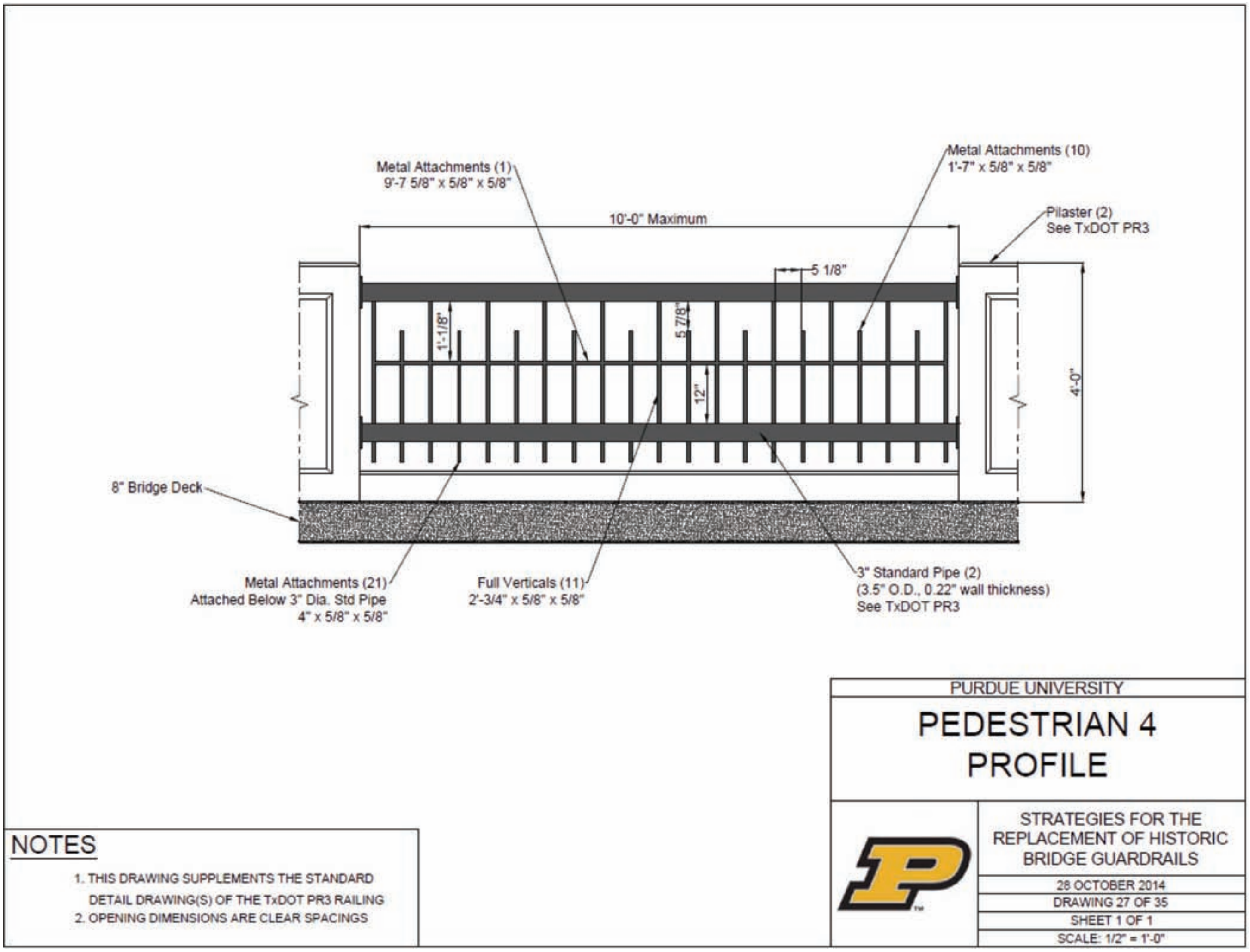
SCALE: 1/2" = 1'-0"

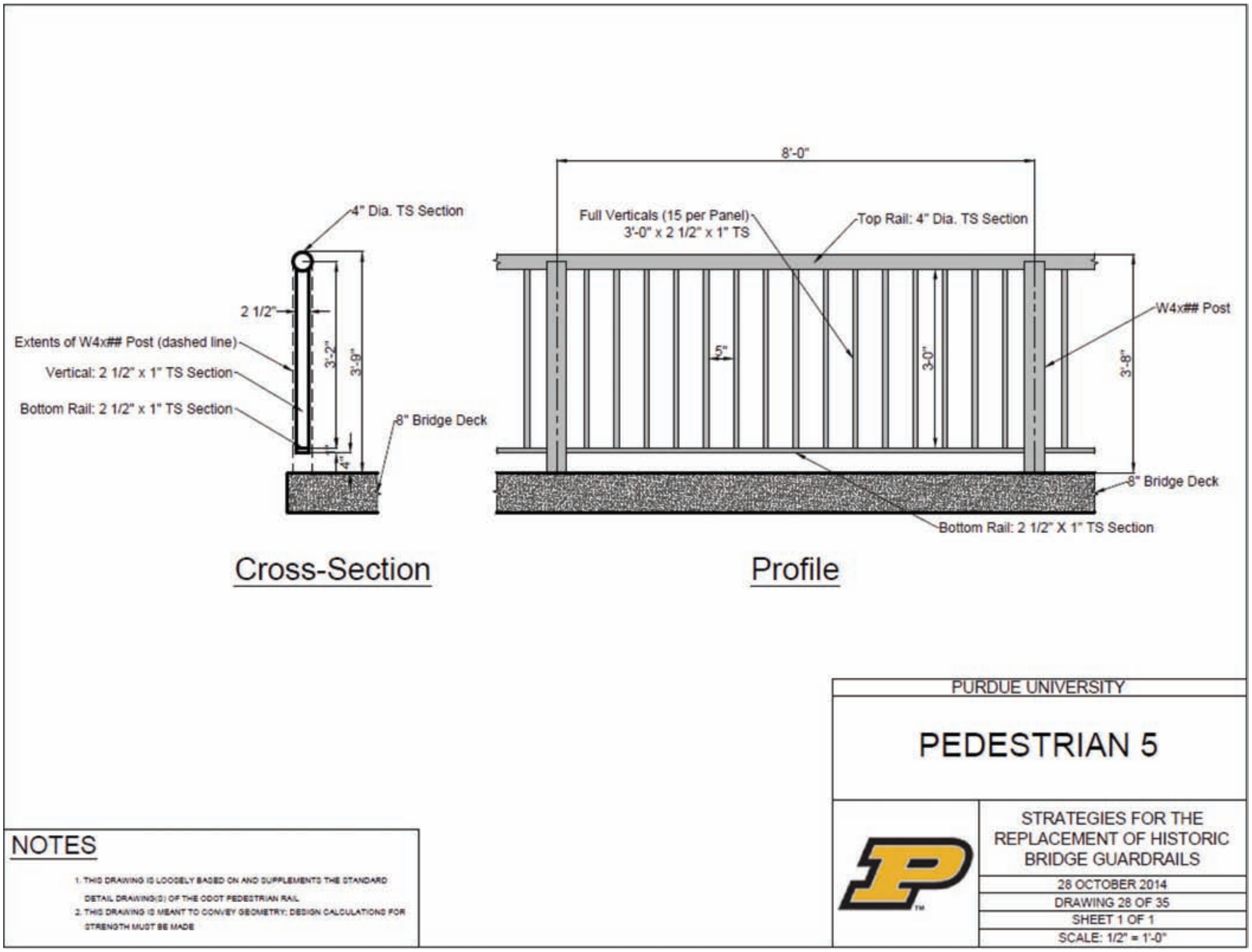

Metal Attachments (20)
Evenly Spaced Between Full Verticals
10" x 5/8" x 5/8"
Attachment Method at the
Discretion of Manufacturer
Pilaster (2)
See TxDOT PR3
10'-0" Maximum
5"
4'-0"
Horizontal Metal Attachment
9'-7 5/8" x 2" x 3/8"
5 1/8"
8" Bridge Deck
3" Standard Pipe (2)
(3.5" O.D., 0.22" wall thickness)
See TxDOT PR3
Full Verticals (21)
2'-3/4" x 5/8" x 5/8"
PURDUE UNIVERSITY
PEDESTRIAN 1
PROFILE
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
28 OCTOBER 2014
DRAWING 24 OF 35
SHEET 1 OF 1
SCALE: 1/2" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT PR3 RAILING
2. OPENING DIMENSIONS ARE CLEAR SPACINGS

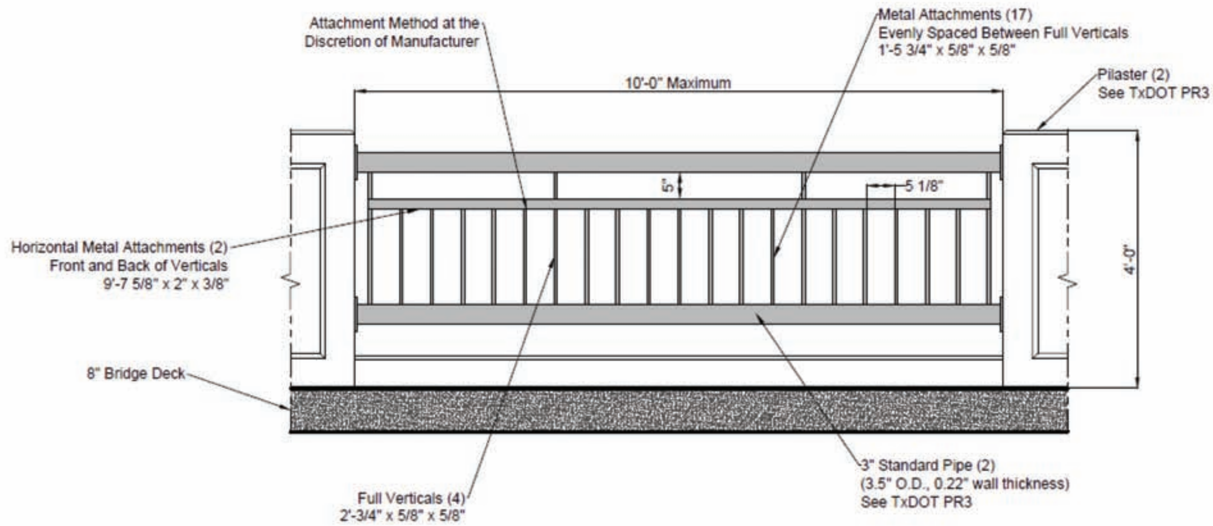


Full Verticals Attachments (11)
2'-3/4" x 5/8" x 5/8"
Attachment Method at the Discretion of Manufacturer
Metal Attachments (20)
1'-7 3/4" x 5/8" x 5/8"
Pilaster (2)
See TxDOT PR3
10'-0" Maximum
10 7/8"
5"
Metal Attachment
9'-7 5/8" x 2" x 3/8"
4'-0"
4 1/8"
1 3/8"
8" Bridge Deck
3" Standard Pipe (2)
(3.5" O.D., 0.22" wall thickness)
See TxDOT PR3
PURDUE UNIVERSITY
PEDESTRIAN 2
PROFILE
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
28 OCTOBER 2014
DRAWING 25 OF 35
SHEET 1 OF 1
SCALE: 1/2" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT PR3 RAILING
2. OPENING DIMENSIONS ARE CLEAR SPACINGS


Metal Attachments (10)
1'-4 5/8" x 5/8" x 5/8"
Attachment Method at the
Discretion of Manufacturer
Metal Attachments (10)
1'-5 1/2" x 5/8" x 5/8"
Pilaster (2)
See TxDOT PR3
10'-0" Maximum
1'-4 5/8"
3"
1'-5 1/2"
4'-0"
3"
5 1/8"
5 1/8"
8" Bridge Deck
3" Standard Pipe (2)
(3.5" O.D., 0.22" wall thickness)
See TxDOT PR3
Full Verticals (10)
2'-3/4" x 5/8" x 5/8"
PURDUE UNIVERSITY
PEDESTRIAN 3
PROFILE
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
28 OCTOBER 2014
DRAWING 26 OF 35
SHEET 1 OF 1
SCALE: 1/2" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT PR3 RAILING
2. OPENING DIMENSIONS ARE CLEAR SPACINGS


Metal Attachments (1)
9'-7 5/8" x 5/8" x 5/8"
Metal Attachments (10)
1'-7" x 5/8" x 5/8"
10'-0" Maximum
Pilaster (2)
See TxDOT PR3
5 1/8"
1'-1/8"
5 7/8"
12"
4'-0"
8" Bridge Deck
Metal Attachments (21)
Attached Below 3" Dia. Std Pipe
4" x 5/8" x 5/8"
Full Verticals (11)
2'-3/4" x 5/8" x 5/8"
3" Standard Pipe (2)
(3.5" O.D., 0.22" wall thickness)
See TxDOT PR3
PURDUE UNIVERSITY
PEDESTRIAN 4
PROFILE
STRATEGIES FOR THE
REPLACEMENT OF HISTORIC
BRIDGE GUARDRAILS
28 OCTOBER 2014
DRAWING 27 OF 35
SHEET 1 OF 1
SCALE: 1/2" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD
DETAIL DRAWING(S) OF THE TxDOT PR3 RAILING
2. OPENING DIMENSIONS ARE CLEAR SPACINGS


8'-0"
4" Dia. TS Section
Full Verticals (15 per Panel)
3'-0" x 2 1/2" x 1" TS
Top Rail: 4" Dia. TS Section
2 1/2"
Extents of W4x## Post (dashed line)
Vertical: 2 1/2" x 1" TS Section
Bottom Rail: 2 1/2" x 1" TS Section
3'-2"
3'-9"
4"
8" Bridge Deck
5"
3'-0"
W4x## Post
3'-8"
8" Bridge Deck
Bottom Rail: 2 1/2" X 1" TS Section
Cross-Section
Profile
PURDUE UNIVERSITY
PEDESTRIAN 5
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
28 OCTOBER 2014
DRAWING 28 OF 35
SHEET 1 OF 1
SCALE: 1/2" = 1'-0"
NOTES
1. THIS DRAWING IS LOOSELY BASED ON AND SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT PEDESTRIAN RAIL
2. THIS DRAWING IS MEANT TO CONVEY GEOMETRY; DESIGN CALCULATIONS FOR STRENGTH MUST BE MADE



PURDUE UNIVERSITY

PEDESTRIAN 6 PROFILE

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

28 OCTOBER 2014

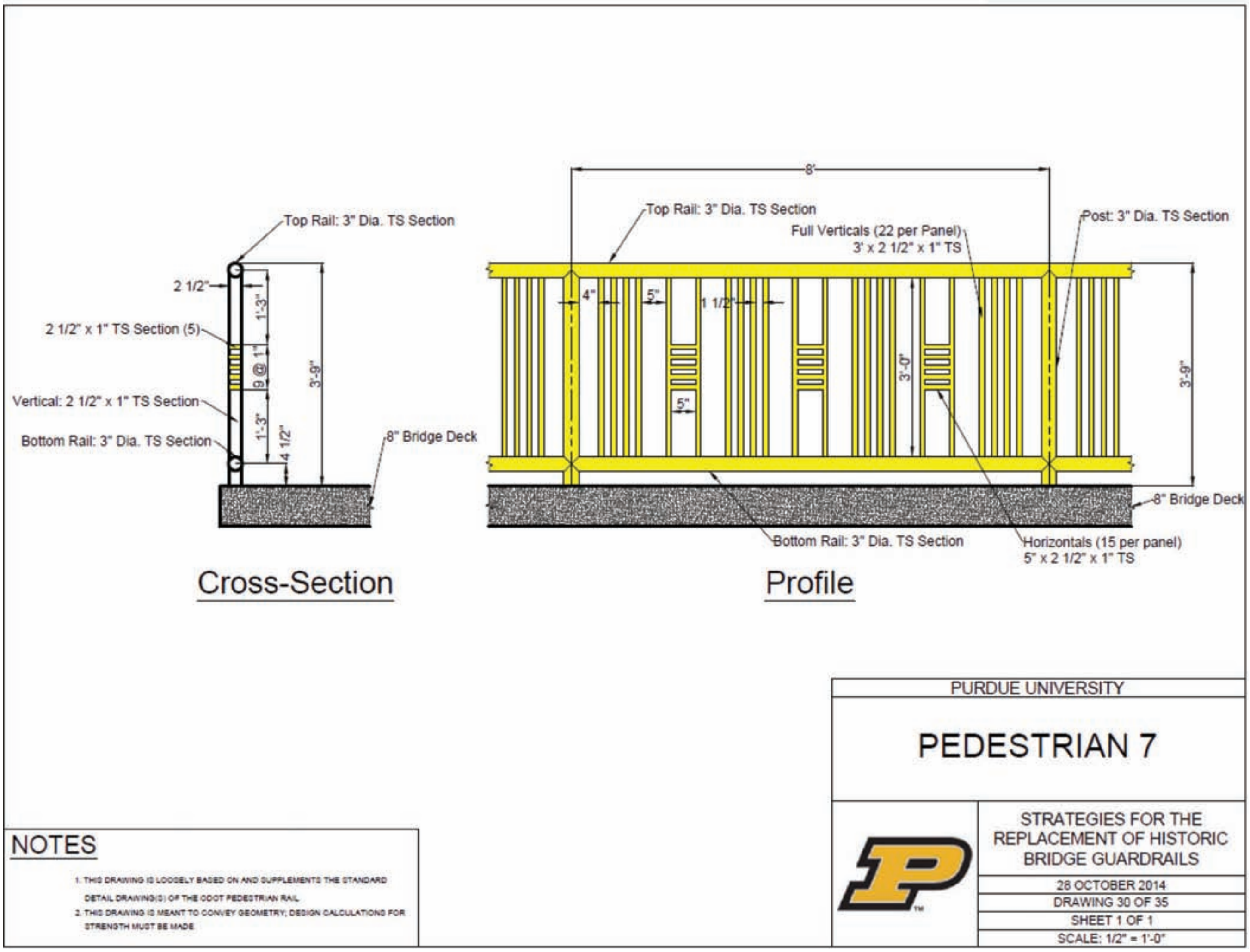
DRAWING 29 OF 35

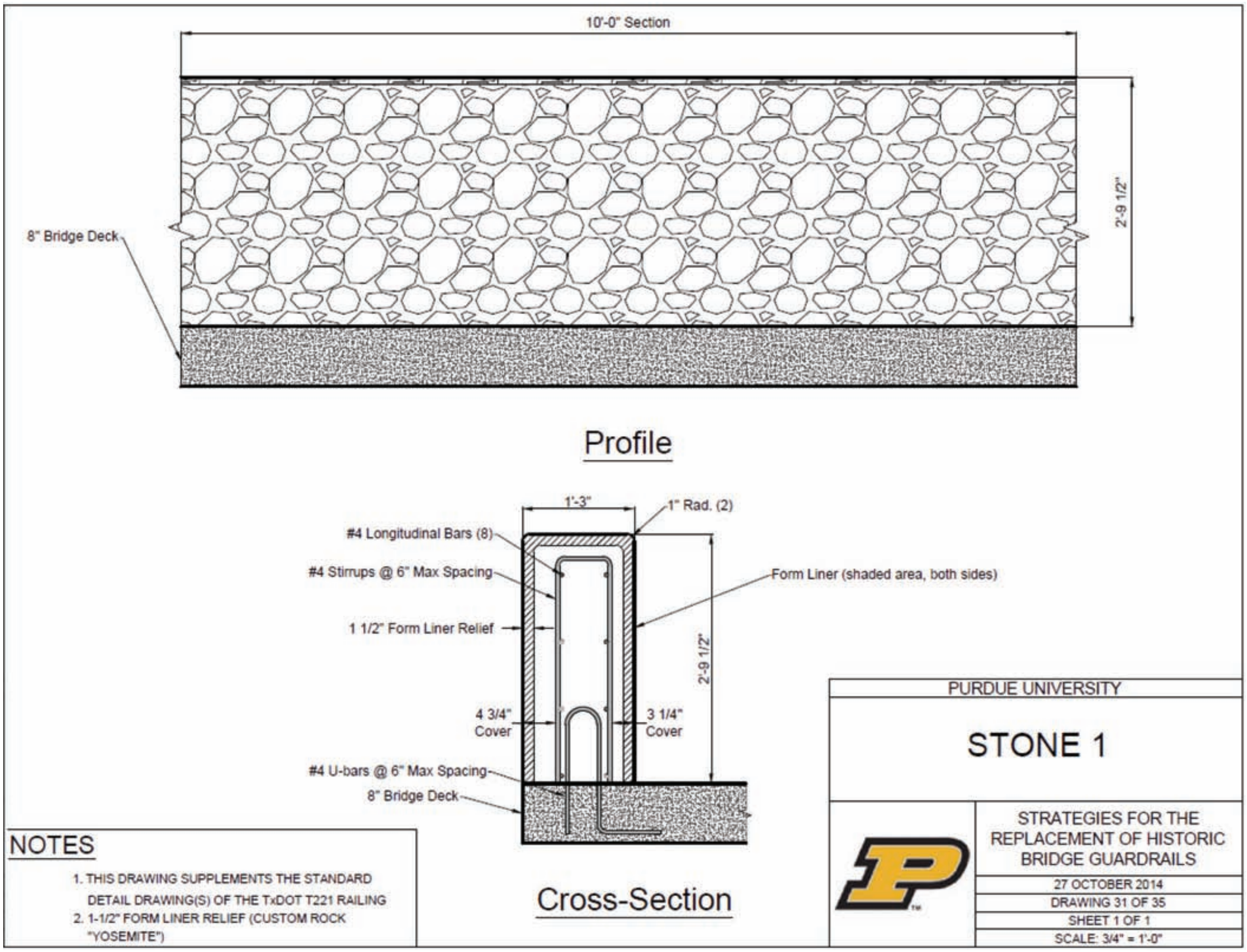
SHEET 1 OF 1

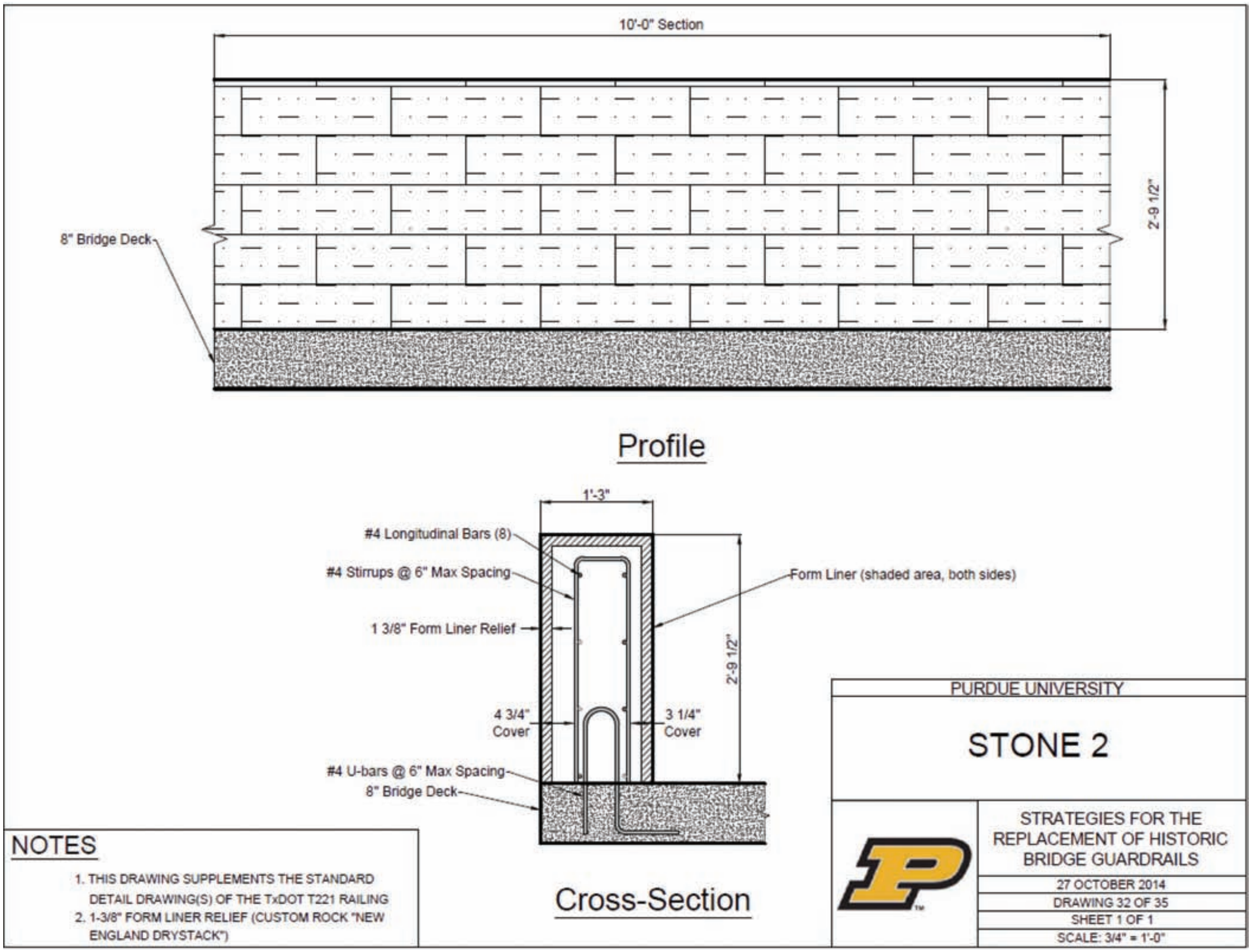
SCALE: 1/2" = 1'-0"

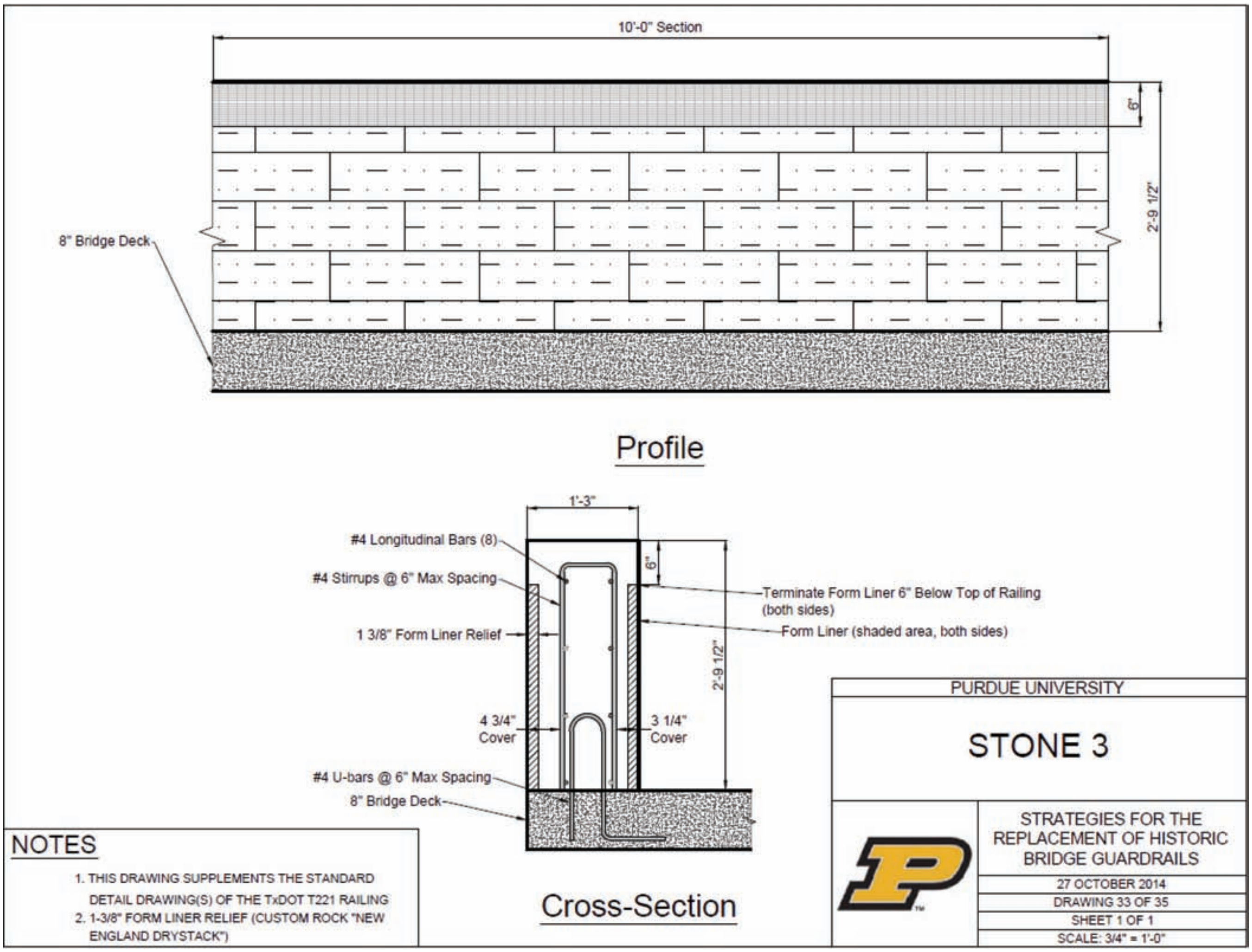
NOTES

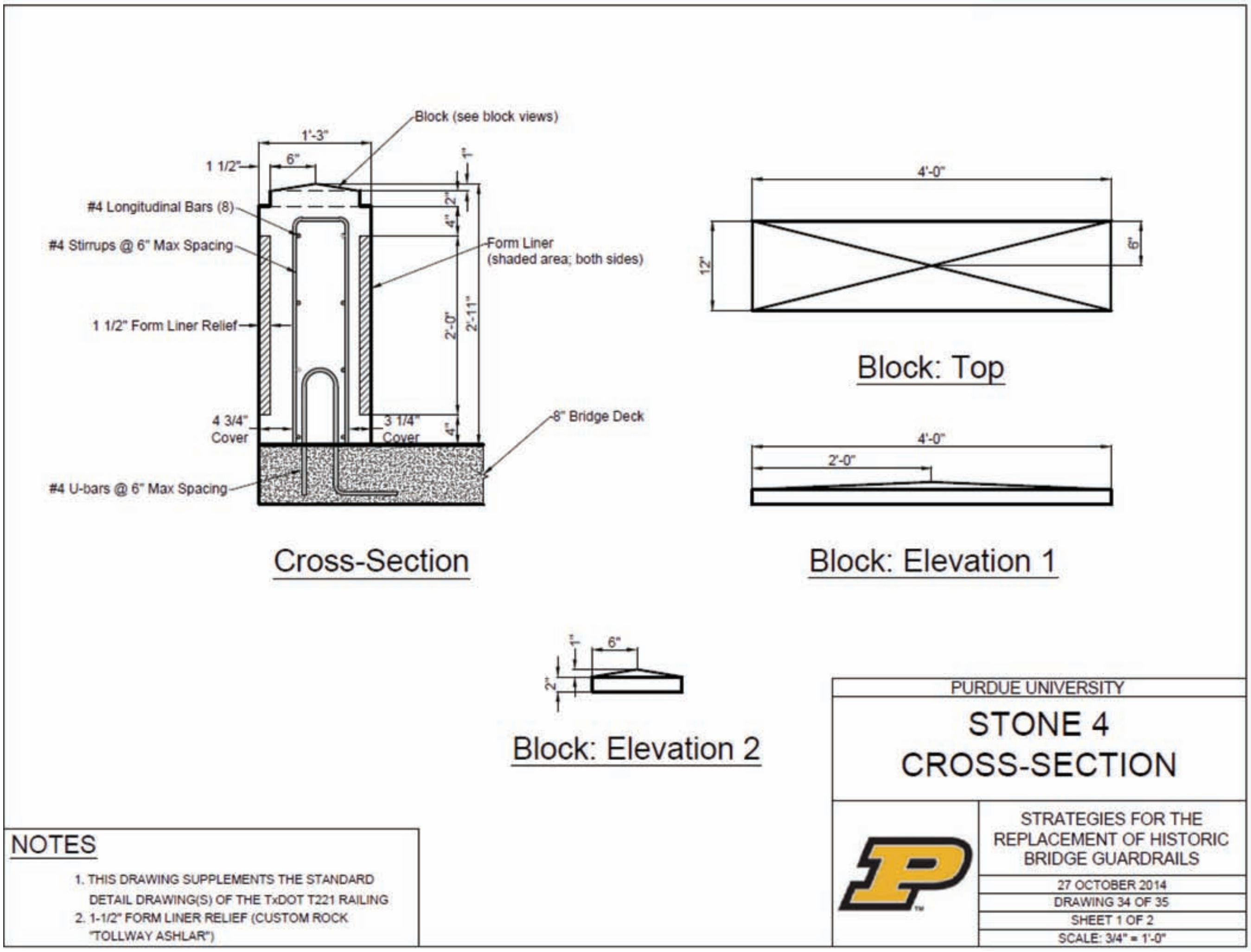
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT PR3 RAILING
2. OPENING DIMENSIONS ARE CLEAR SPACINGS

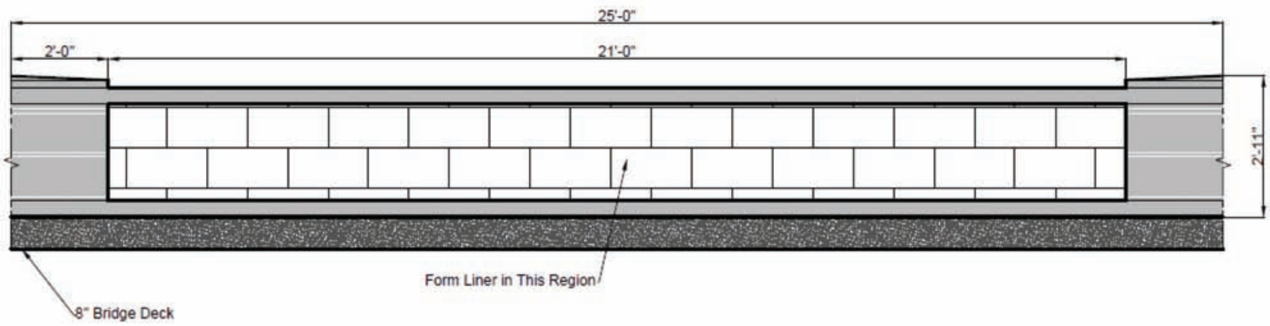

Top Rail: 3" Dia. TS Section
2 1/2"
2 1/2" x 1" TS Section (5)
Vertical: 2 1/2" x 1" TS Section
Bottom Rail: 3" Dia. TS Section
1'-3"
9 @ 1"
1'-3"
4 1/2"
3'-9"
8" Bridge Deck
Cross-Section
8'
Top Rail: 3" Dia. TS Section
Full Verticals (22 per Panel)
3' x 2 1/2" x 1" TS
Post: 3" Dia. TS Section
4"
5"
1 1/2"
5"
3'-0"
3'-9"
8" Bridge Deck
Bottom Rail: 3" Dia. TS Section
Horizontals (15 per panel)
5" x 2 1/2" x 1" TS
Profile
PURDUE UNIVERSITY
PEDESTRIAN 7
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
28 OCTOBER 2014
DRAWING 30 OF 35
SHEET 1 OF 1
SCALE: 1/2" = 1'-0"
NOTES
1. THIS DRAWING IS LOOSELY BASED ON AND SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT PEDESTRIAN RAIL
2. THIS DRAWING IS MEANT TO CONVEY GEOMETRY; DESIGN CALCULATIONS FOR STRENGTH MUST BE MADE


10'-0" Section
2'-9 1/2"
8" Bridge Deck
Profile
1'-3"
1" Rad. (2)
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
Form Liner (shaded area, both sides)
1 1/2" Form Liner Relief
2'-9 1/2"
4 3/4" Cover
3 1/4" Cover
#4 U-bars @ 6" Max Spacing
8" Bridge Deck
Cross-Section
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING
2. 1-1/2" FORM LINER RELIEF (CUSTOM ROCK "YOSEMITE")
PURDUE UNIVERSITY
STONE 1
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
27 OCTOBER 2014
DRAWING 31 OF 35
SHEET 1 OF 1
SCALE: 3/4" = 1'-0"


10'-0" Section
8" Bridge Deck
2'-9 1/2"
Profile
1'-3"
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
1 3/8" Form Liner Relief
Form Liner (shaded area, both sides)
2'-9 1/2"
4 3/4" Cover
3 1/4" Cover
#4 U-bars @ 6" Max Spacing
8" Bridge Deck
Cross-Section
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING
2. 1-3/8" FORM LINER RELIEF (CUSTOM ROCK "NEW ENGLAND DRYSTACK")
PURDUE UNIVERSITY
STONE 2
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
27 OCTOBER 2014
DRAWING 32 OF 35
SHEET 1 OF 1
SCALE: 3/4" = 1'-0"


10'-0" Section
6"
2'-9 1/2"
8" Bridge Deck
Profile
1'-3"
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
1 3/8" Form Liner Relief
Terminate Form Liner 6" Below Top of Railing (both sides)
Form Liner (shaded area, both sides)
6"
2'-9 1/2"
4 3/4" Cover
3 1/4" Cover
#4 U-bars @ 6" Max Spacing
8" Bridge Deck
Cross-Section
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING
2. 1-3/8" FORM LINER RELIEF (CUSTOM ROCK "NEW ENGLAND DRYSTACK")
PURDUE UNIVERSITY
STONE 3
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
27 OCTOBER 2014
DRAWING 33 OF 35
SHEET 1 OF 1
SCALE: 3/4" = 1'-0"


Block (see block views)
1'-3"
1 1/2"
6"
1"
2"
4"
#4 Longitudinal Bars (8)
#4 Stirrups @ 6" Max Spacing
Form Liner
(shaded area; both sides)
1 1/2" Form Liner Relief
2'-0"
2'-11"
4 3/4" Cover
3 1/4" Cover
8" Bridge Deck
#4 U-bars @ 6" Max Spacing
Cross-Section
4'-0"
12"
6"
Block: Top
4'-0"
2'-0"
Block: Elevation 1
1"
6"
2"
Block: Elevation 2
PURDUE UNIVERSITY
STONE 4
CROSS-SECTION
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
27 OCTOBER 2014
DRAWING 34 OF 35
SHEET 1 OF 2
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING
2. 1-1/2" FORM LINER RELIEF (CUSTOM ROCK "TOLLWAY ASHLAR")



PURDUE UNIVERSITY

STONE 4 PROFILE

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

27 OCTOBER 2014

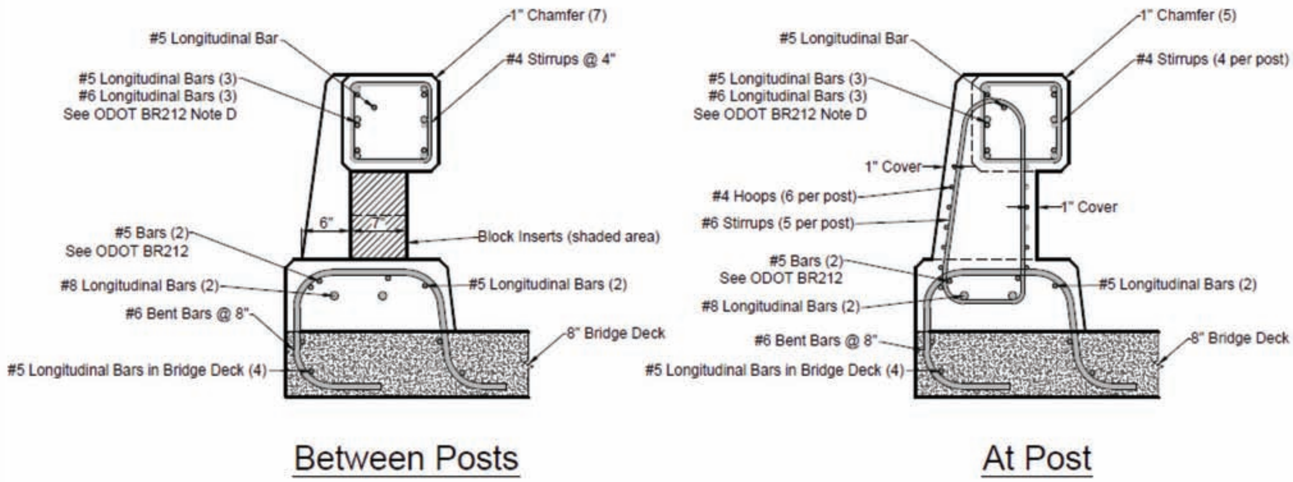
DRAWING 34 OF 35

SHEET 2 OF 2

SCALE: 3/8" = 1'-0"

NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE TxDOT T221 RAILING
2. 1-1/2" FORM LINER RELIEF (CUSTOM ROCK "TOLLWAY ASHLAR")



PURDUE UNIVERSITY

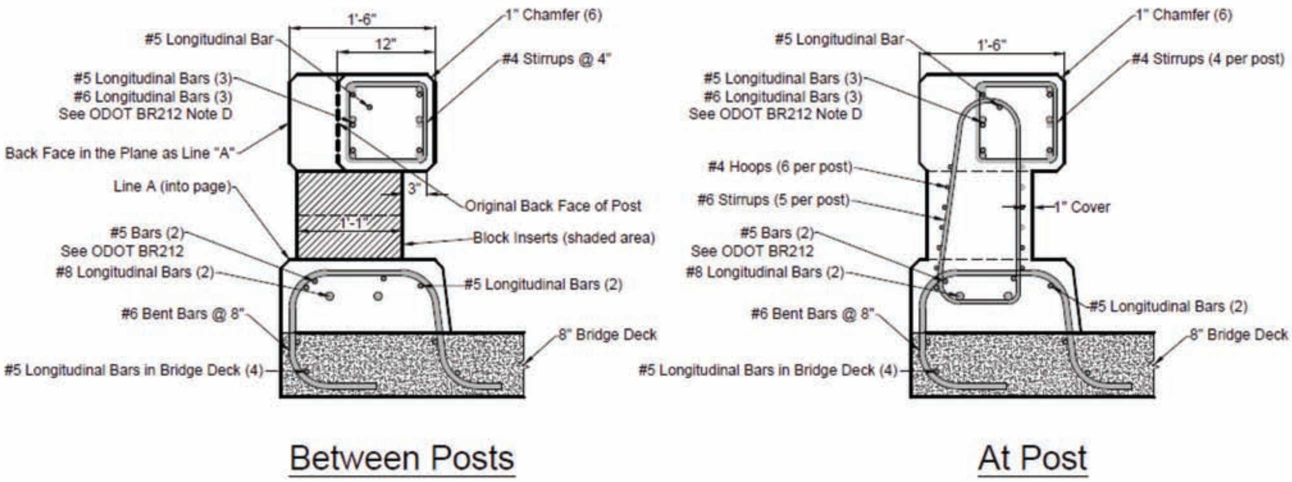
STONE 6
CROSS-SECTIONS (1)

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

27 OCTOBER 2014
DRAWING 35 OF 35
SHEET 1 OF 3
SCALE: 3/4" = 1'-0"

NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING



PURDUE UNIVERSITY

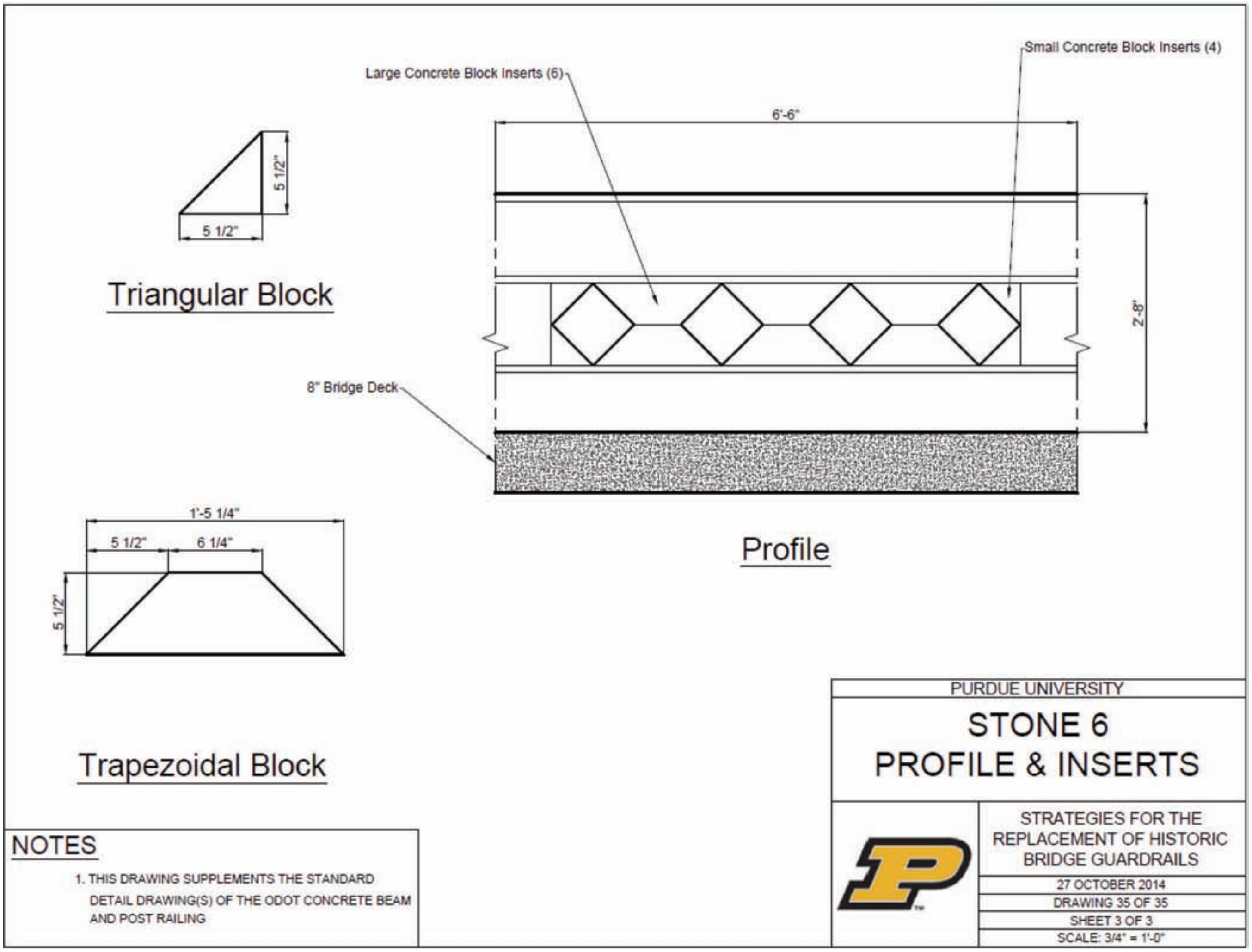
STONE 6
CROSS-SECTIONS (2)

STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS

27 OCTOBER 2014
DRAWING 35 OF 35
SHEET 2 OF 3
SCALE: 3/4" = 1'-0"

NOTES

1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE POST AND BEAM RAILING


Large Concrete Block Inserts (6)
Small Concrete Block Inserts (4)
6'-6"
5 1/2"
5 1/2"
Triangular Block
2'-8"
8" Bridge Deck
1'-5 1/4"
5 1/2"
6 1/4"
5 1/2"
Profile
Trapezoidal Block
PURDUE UNIVERSITY
STONE 6
PROFILE & INSERTS
STRATEGIES FOR THE REPLACEMENT OF HISTORIC BRIDGE GUARDRAILS
27 OCTOBER 2014
DRAWING 35 OF 35
SHEET 3 OF 3
SCALE: 3/4" = 1'-0"
NOTES
1. THIS DRAWING SUPPLEMENTS THE STANDARD DETAIL DRAWING(S) OF THE ODOT CONCRETE BEAM AND POST RAILING

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

About This Report

An open access version of this publication is available online. This can be most easily located using the Digital Object Identifier (doi) listed below. Pre-2011 publications that include color illustrations are available online in color but are printed only in grayscale.

The recommended citation for this publication is:

Frosch, R. J., Kreger, M. E., & Clauss, A. J. (2016). *Guardrails for use on historic bridges: Volume 1—Replacement strategies* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2016/33). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284316360