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# TECHNICAL MEMORANDUM

**Contract No.:** **T4541-AV**
**Tech Memo No.:** **602181**
**Project Name:** **Small Bridge Barrier/Guide Rail Retrofits (Phase 1)**
**Sponsor:** **Roadside Safety Research Program Pooled Fund Study**

**DATE:** **July 7, 2015**

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## SUMMARY REPORT:

### PROBLEM STATEMENT

Pennsylvania Department of Transportation currently has an extensive inventory of older concrete single span bridges in service. Many of these bridges were constructed in the 1930’s and were used to span over small creeks. These bridges were constructed using concrete post and beam bridge railings with open pickets. These concrete picket railings commonly known as “pigeon hole” barriers are not crashworthy with respect to the current MASH Specifications. Designers face a problem when working on 3R or Pavement Preservation projects where the roadside guide rail is being brought up to current standards. These projects typically do not include any funds for improving the bridge structures. Many of these structures have barriers that are in good structural condition. Typically these bridges with concrete barriers can range from 10 feet to approximately 40 feet long. Typical details of these concrete post and beam railings with concrete pickets are provided in the following figures.

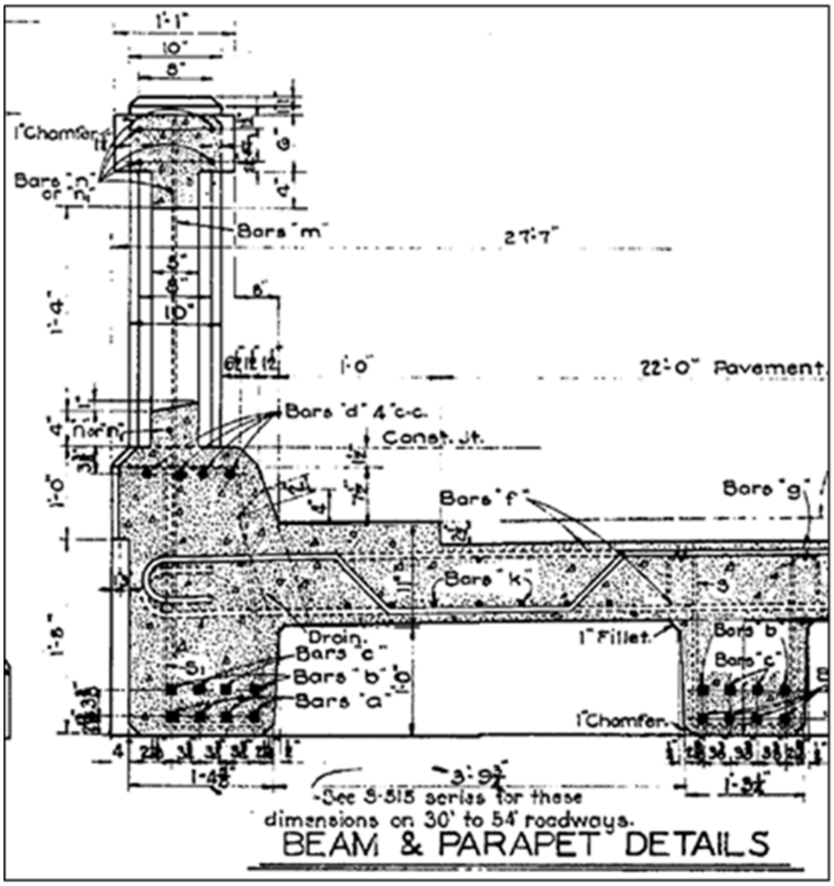


Figure 1 – Cross-Section Details of Concrete Post and Beam Railing with Concrete Pickets

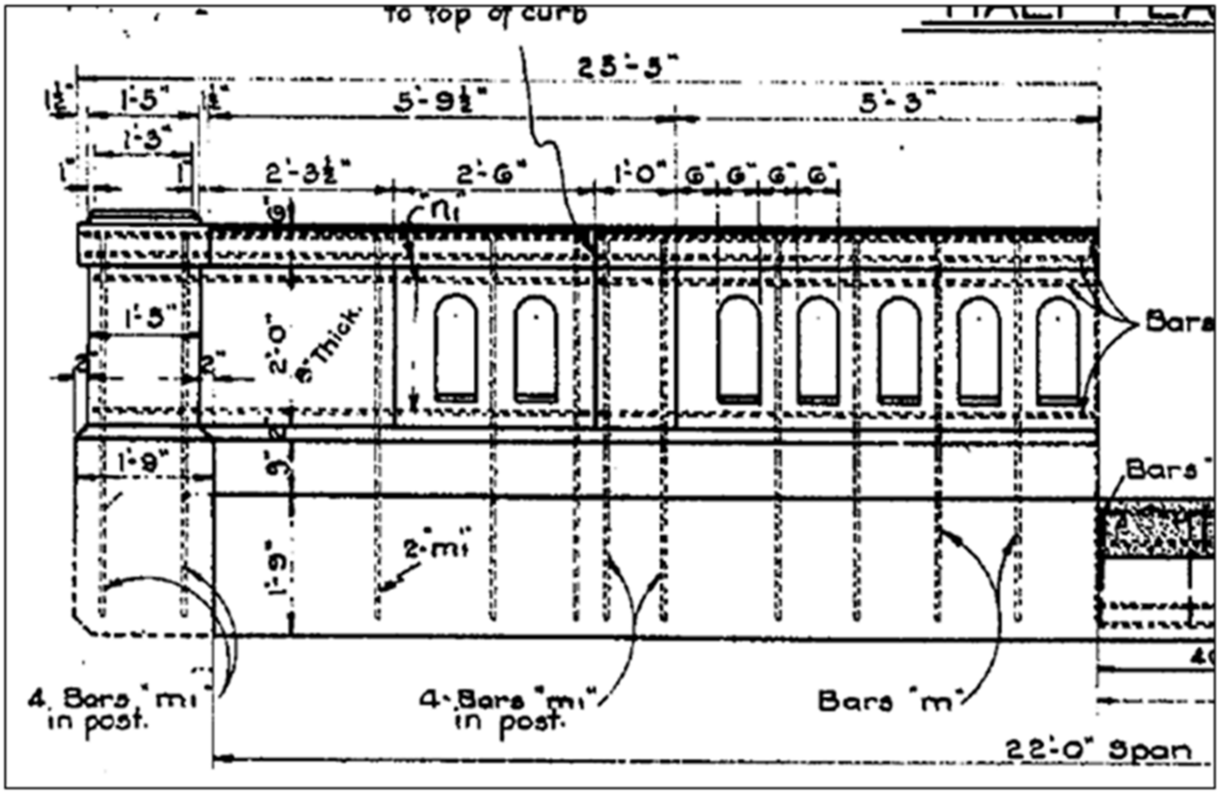


Figure 2 – Elevation View of Concrete Post and Beam Railing with Concrete Pickets

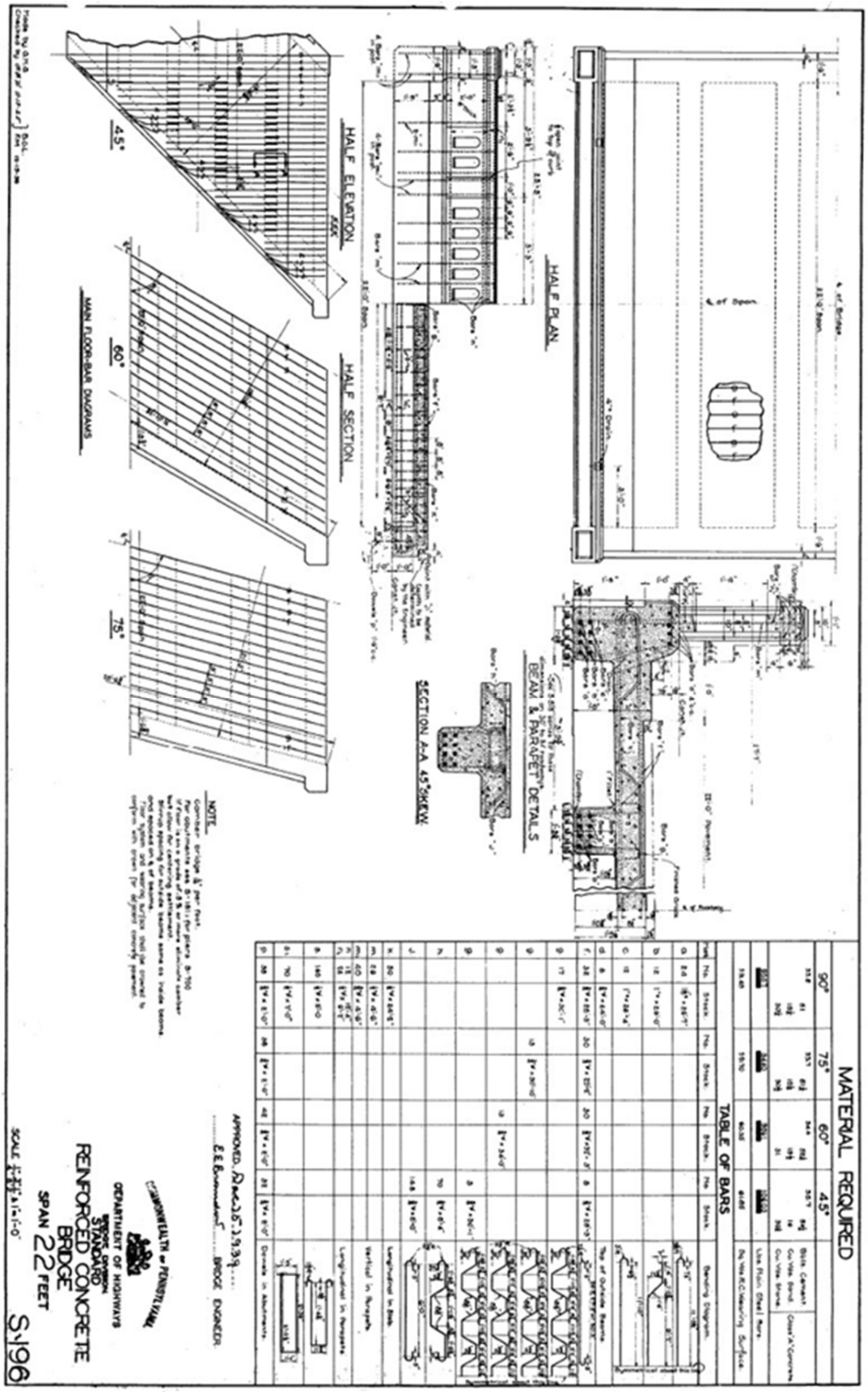

Figure 3 – Typical Details of Concrete Post and Beam Railing with Concrete Pickets

A typical photo of a concrete post and beam bridge railing with concrete pickets is shown in Figure 4.


Figure 4 – Typical Photo of Concrete Post and Beam Railing with Concrete Pickets

A few options are available for making these old bridges crashworthy with respect to MASH. One option that has been used is to span over the structures with nested W-beam rail with no block-outs or attachments to the existing bridge barrier. Containment of a vehicle at TL-3 along with optimum approach guide rail post spacing and placement relative to ends of barrier to eliminate pocketing need evaluated. However, evaluation of the strength of these old bridge railings with respect to MASH TL-3 loading conditions needs to be evaluated. Attaching W-Beam railing to the concrete railing to span over the openings between the pickets without further structural modifications(s) to the concrete railings is desirable. Any additional railing components such as W-Beam railing should add to the overall strength of the railing system.

## BACKGROUND

In August 1990 Texas Department of Transportation (TXDOT) designed and performed full-scale crash testing on the TXDOT Type C411 combination pedestrian and traffic concrete bridge rail with concrete pickets. This bridge rail was constructed of reinforced concrete 42 inches high by 12 inches thick and contains 6 inches wide by 28 inches high openings at 18 inches center-to-center longitudinal spacing [(1)]. This bridge rail was developed for use on urban streets where the speed limit would be 45 mph or less. The rail was crash tested using a 1900 lb. car impacting the bridge rail at a speed and angle of 45 mph and 20 degrees, respectively. The rail was also crash tested using a 4500 lb. sedan impacting the bridge rail at a speed and angle of 45 mph and 25 degrees, respectively. While the crash test variable used were not those recommended by the crash test matrix of NCHRP 230 or the 1989 Guide Specifications for Bridge Railings, the crash test results indicated that the C411 bridge rail was acceptable for use on low speed (45 mph) or less roads.

In early 1997, the TXDOT Type C411 and the T411 (32-inch high version of the C411) were tested in and evaluated in accordance with National Cooperative Highway Research Program (NCHRP) Report 230[(2).] The crash tests performed on the Texas T411 were with a 2043-kg passenger car at 96 km/h and 25 degrees, and another with an 817-kg passenger car at 96 km/h and 20 degrees. The Texas C411 was constructed and tested on a 1.8 m wide sidewalk with a 203 mm high curb. The tests performed were with a 2043-kg passenger car at 72 km/h and 25 degrees, and with a 817-kg passenger car at 72 km/h and 20 degrees.

In September 1997, The Oregon Department of Transportation (ODOT) proposed to further develop the concrete beam and post bridge railing similar to the Texas Type C411 to meet requirements for Test Level four (TL-4) of NCHRP Report 350[(3).] The height of 1.07 m was considered adequate for NCHRP test 4-10; however, concern was expressed about interaction of the 2000-kg and 8000-kg vehicles with the openings in the railing and the posts that protrude above the longitudinal rail element in the proposed design. Full scale crash testing was performed on the C411 with respect to NCHRP Report 350 TL-3. The railing did not meet the crash requirement of Report 350 TL-3. However, strength analyses were performed on the TXDOT Type C411. Analytical strength calculations indicated that the met the strength requirements for NCHRP Report 350 TL-4.

In April 1998, TTI performed full-scale crash testing on the T411 (32 inches high) with respect to NCHRP Report 350 TL-3[(4)]. The Texas Type T411 is an aesthetic bridge rail design that utilizes rail openings similar to the concrete rail shown in Figures 2 through 4. The Texas Type T411 did not meet the requirements of NCHRP Report 350 for TL-3.

In March 1996, TTI completed a project to retrofit a concrete baluster bridge railing similar to the railings described in this report[(5)]. This project entitled “Retrofit W-Beam Bridge Railing” was performed for the Federal Highway Administration Research

Study Number RF 472070. Details of the Retrofit are shown in Figure 5. Photographs of the test installation are shown in Figures 6 to 8. This railing was retrofitted with a blocked W-Beam Rail element.

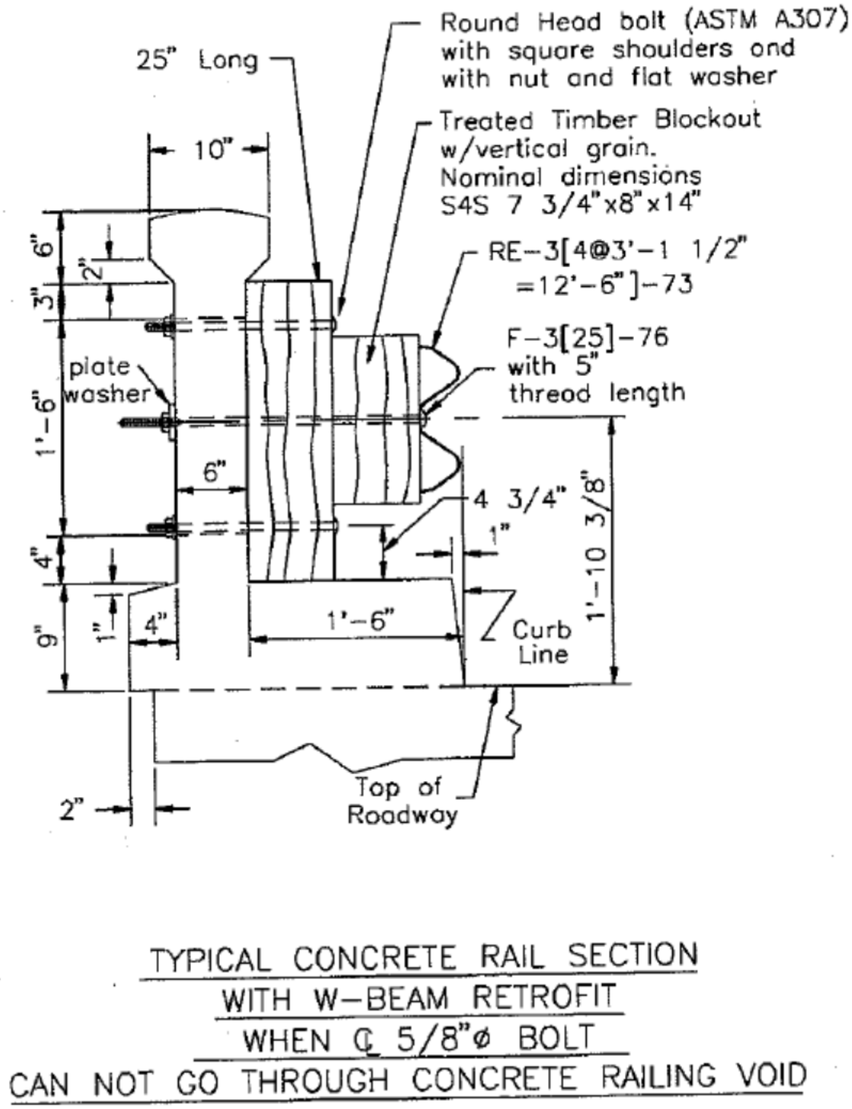


Figure 5 – Details of Concrete Rail Retrofit Project No. 472070

Figure 6 – Photograph of Traffic Side View of Concrete Rail Retrofit Project No. 472070

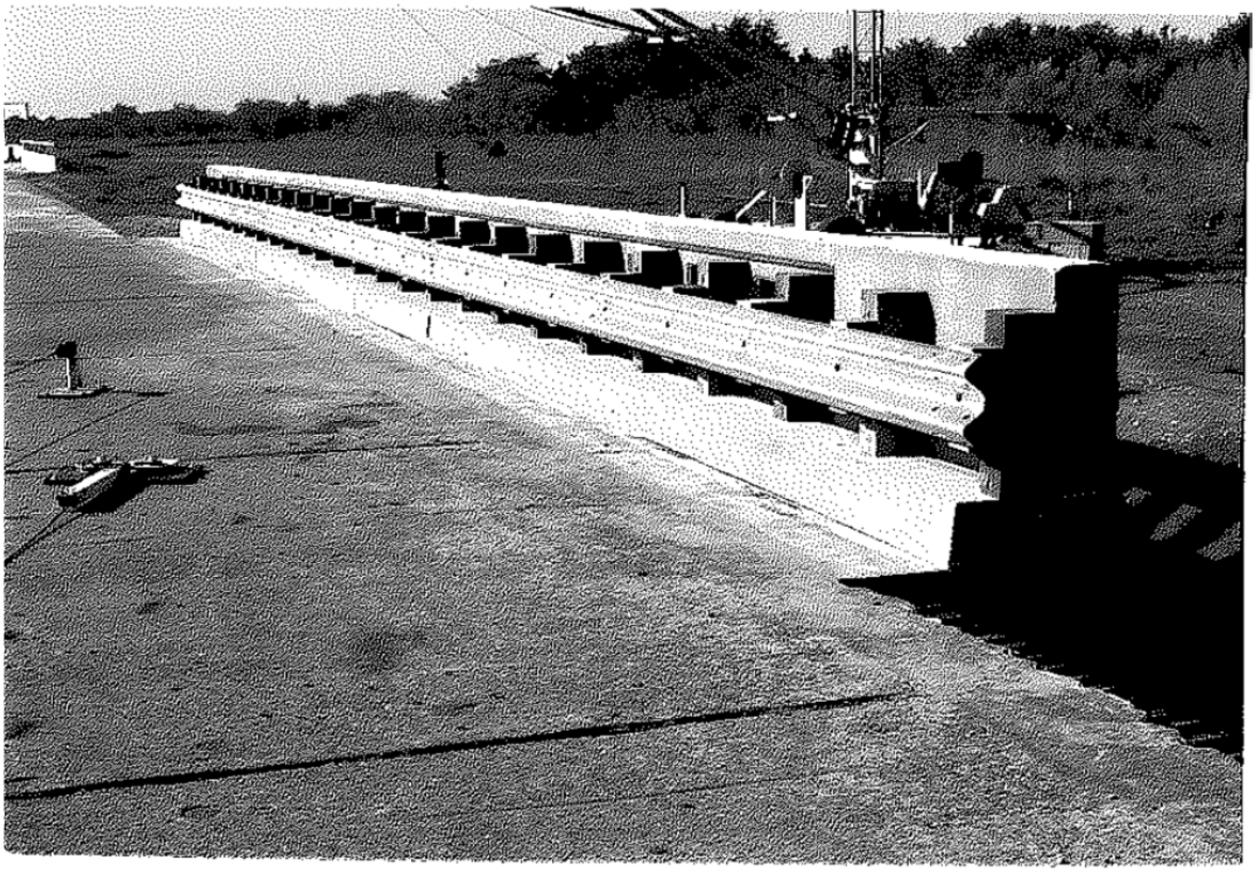

Figure 7 – Photograph of Traffic Side View of Concrete Rail Retrofit Project No. 472070

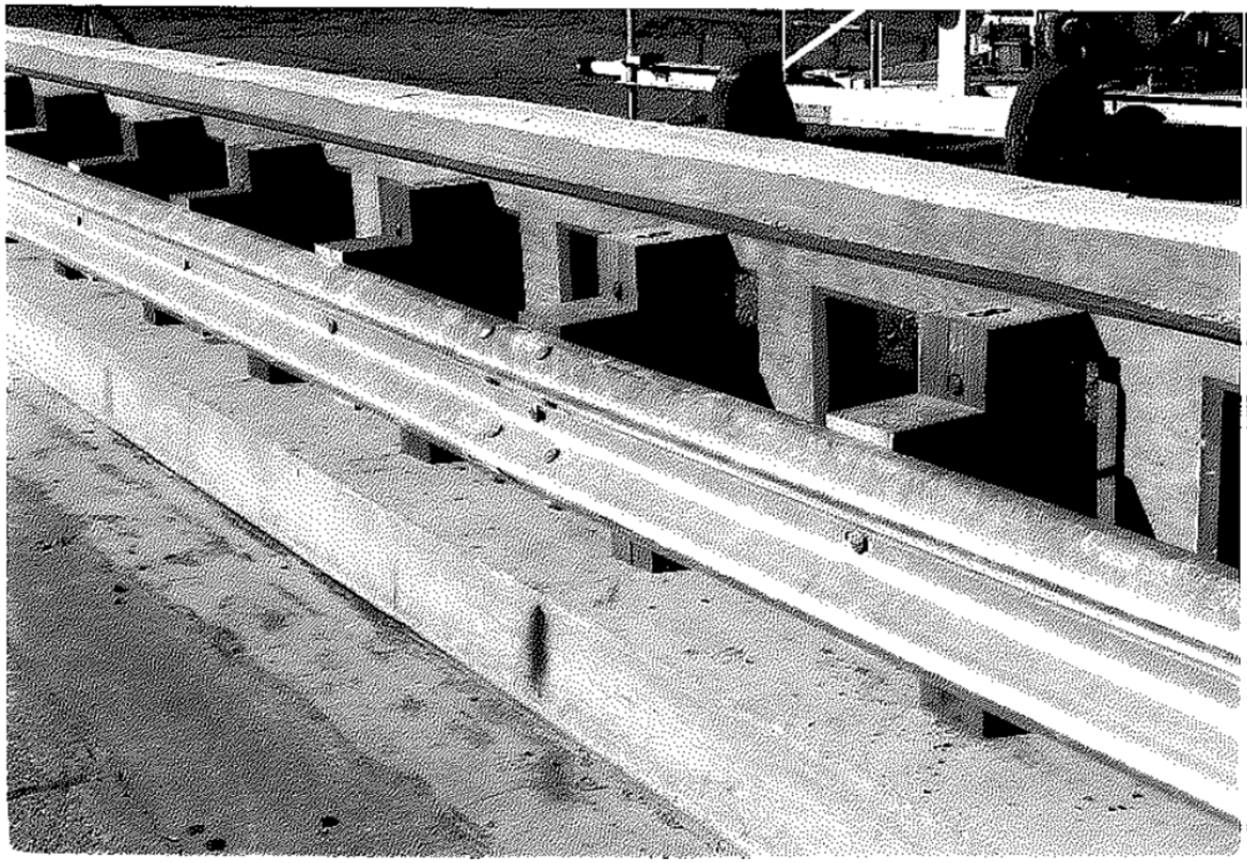

Figure 8 – Photograph of Traffic Side View of Concrete Rail Retrofit Project No. 472070

The W-Beam retrofit for concrete baluster bridge railing met the AASHTO criteria for performance level one for both the small car and pickup truck. The small car test performed using the AASHTO criteria consisted of an 820 kg small car (2 door Yugo) at and impact speed and angle of 80 km/hr. and 20 degrees, respectively. The pickup truck test performed using the AASHTO criteria consisted of a 2452 kg pickup at an impact speed and angle of 80 km/hr. and 20 degrees, respectively.

## OBJECTIVE

The objective of this research was to provide a cost effective crashworthy guide rail retro-fit across older single span bridges that utilize concrete post and beam bridge railings with concrete pickets. A field survey of several structures was performed in October 2013. Several bridge structures at various locations in southern central Pennsylvania were reviewed. The length of spans varied from approximately 15 feet to over a hundred feet. The condition of the structures varied. Overall, most of the structures were in relatively good shape considering age. Most of the structures were constructed in the 1930's.

At this time, this project will be broken into two phases. The first part would be to identify the most common types of concrete post and beam railings used on the older bridge structures. The next objective will be to develop and design suitable retrofit railing(s) for these most common type(s) of structures. This will include development of a retrofit barrier details for full-scale crash testing planned for Phase 2. Phase 2 will involve full-scale crash testing of a selected retrofit design.

The purpose of the study will be to perform engineering strength calculations and develop retrofit details for a few common type of bridge railings surveyed for this project. These retrofit designs will be considered for further analyses and full-scale crash testing for another project. Several retrofit options were considered in the analyses and detailing for the most common types (shapes) of concrete post and beam railing with concrete pickets that are used in the State of Pennsylvania. A photograph showing one option using a bolted W-Beam guardrail is shown in Figures 9 and 10.


Figure 9 – Retrofit Option Using W-Beam Guardrail


Figure 10 – Front View of Retrofit Option Using W-Beam Guardrail

**BENEFITS**

The information compiled from this research will provide details for a retrofit option that meets the strength requirements of Manual for Assessing Safety Hardware (MASH) Test level 3 requirements[6]. These details will be used for Phase 2 of this project. Phase 2 will incorporate full-scale crash testing of the selected retrofit design in accordance with MASH Specifications. The objective of this project (Phases 1 and 2) will be to aid designers in developing final details and plans for guide rail across existing small structures that would be crashworthy and negate any pocketing at the ends of the existing bridge barrier. The resulting details should provide a cost effective retrofit bridge railing option for use on many of the older concrete post and beam bridge railings with concrete pickets used in Pennsylvania. This project (Phase 1) will evaluate the strength of the existing concrete railings systems with the proposed retrofit railing design and consider the crashworthiness of the system(s) selected with the retrofit design using MASH criteria at a TL-3 level. Existing "pigeon hole" bridge barrier will be evaluated as the typical barrier. This barrier is lightly reinforced and assumed to be sound (Sound in the sense that there is no visible concrete damage and deterioration with exposed rebar). We understand, these barriers were used extensively on slab and T-beam bridges built in the 1930's up into the 50's. Many of these structures still exist on rural collectors and local roads.

## PRODUCTS

The objective of this research is to provide a crashworthy retrofit guide rail for use on many of the typical concrete post and beam bridge railings with concrete pickets used in Pennsylvania. The maximum structure span and barrier style/condition will also be determined from this study. The product of this study will be to evaluate the strength(s) of the most common type(s) of concrete post and beam railings with concrete pickets and to determine a suitable and most cost effective retrofit design with respect to MASH TL-3 Specifications. It is assumed this project will be broken into two phases. The first part would be to identify the most common types of concrete post and beam railings used on the older bridge structures. The next objective will be to develop and design suitable retrofit railing(s) for these most common type(s) of structures. This will include development of a retrofit barrier details for full-scale crash testing planned for Phase 2. Phase 2 will involve full-scale crash testing of a selected retrofit design.

### WORK PLAN

#### Task 1 –Perform Review of Existing Concrete Post & Beam Railings with Concrete Pickets Used in Pennsylvania

As part of this project, a review of all available concrete post and beam rails with concrete pickets used in the State of Pennsylvania and select the most common type(s) for retrofit application were performed. A thorough review of the different types of railings was performed for this project. A brief summary of the recent design and testing of similar retrofit rail were discussed in previous section of this report. In summary, past crash testing of similar retrofits on older style bridge railings with opening has not resulted in crashworthy designs meeting the requirements of NCHRP Report 350 or MASH.

#### Task 2 – Retrofit Railing Design, Analyses, and Detailing

For this task, information gathered from the review performed in Task 1 was considered for several different bridge rail options. A field survey of several different bridge railing types was performed in September 2013. Based on the results from this field survey, three different rail types were considered for this project. Retrofit details were developed for each rail type. Analyses results, design details and additional recommendations are provided for each design options as follows. Three types of bridge rails were selected from the field review. The rail designs selected for consisted of:

1.) Concrete Rail with Openings
2.) Concrete Rail without Opening (Solid Concrete parapet)
3.) Combination Concrete Rail with Aluminum Post And Rail

Information on each rail type along with the recommended retrofit fit details for each are provided for each type as follows. Based on the results of this study, further analyses and full-scale testing will be required for each retrofit bridge rail to determine if the proposed designs meet MASH TL-3 requirements.

**Design Option 1 – Concrete Rail with Openings**

Several sites were visited that consisted of small streams with small bridges spanning the streams. The railings on these structures consisted of concrete parapets with openings spaced every 12 inches. Most of the bridges visited consisted of concrete bridge constructed in the early to mid 1930's. The condition of these bridges varied. In some cases, the bridge railings were severely damaged due to vehicular crashes or by road deicing salts and chemicals. Details of this common rail type are shown in the previous figures 1 through 4 and Figures 9 and 10. This bridge type was the most common type visited as part of this study. Details of this concrete bridge rail with opening are shown in Figures 11 and 12.

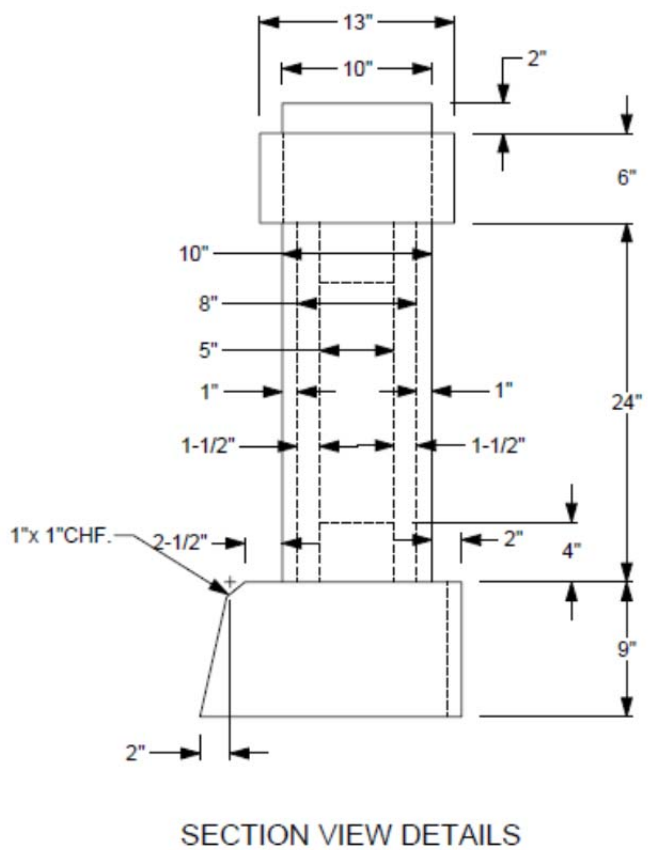


Figure 11 – Concrete Rail with Openings Section Details

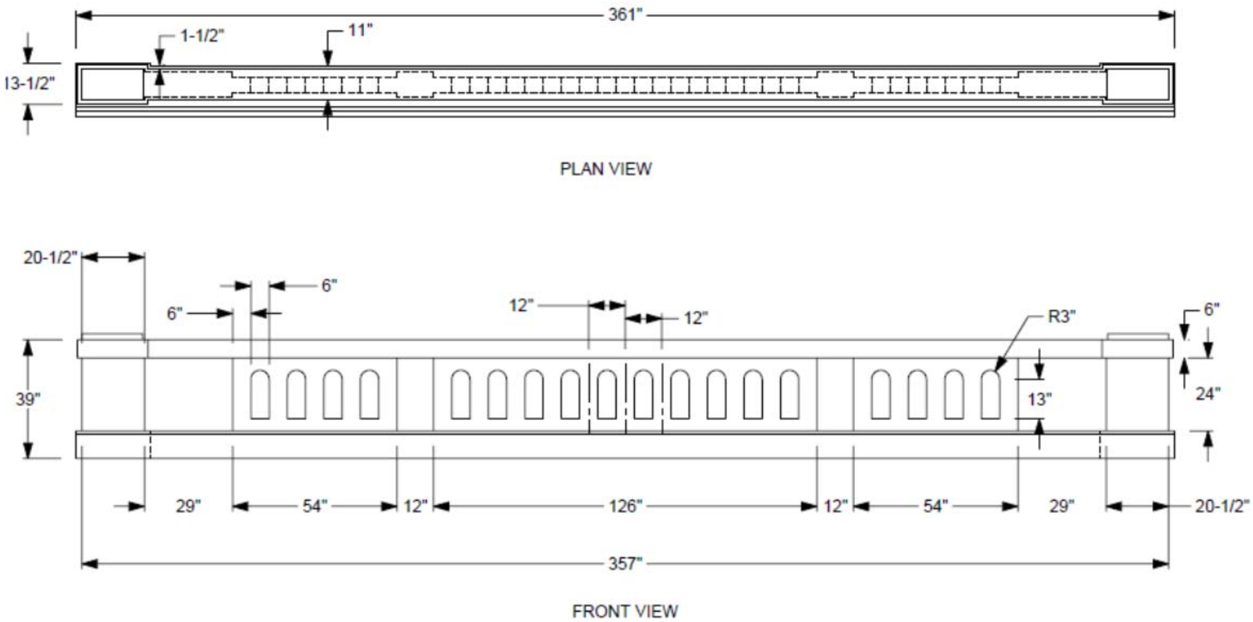


Figure 12 – Concrete Rail with Opening Front and Plan Views

Typically this bridge rail design is 39 inches tall and consists of 6-inch wide by 16 inches tall openings spaced on 12-inch centers. The posts between the openings are 6 inches wide by 5 inches thick. Reinforcement in the post consists of a single No. 4 bar located in the center of the post. A reinforced concrete beam is present on top of the posts. This concrete beam is typically 6 inches high by 10 inches thick. Two No. 4 bars are located in the top beam with approximately 1 ¾ inch of cover on each bar. The concrete bridge rail is constructed on top of a 9-inch high concrete curb. Details of the bridge rail are shown in Appendix A of this report. A strength analysis was performed on this concrete bridge rail in accordance with American Association of State Highways and Transportation Officials (AASHTO) Load and Resistance Factor Design Specifications, Section 13, 2012. The calculated strength of this rail design was approximately 28 kips @ 27 inches height. The strength of this design meets the strength requirements MASH Test Level 2 Requirements. Several retrofit options were considered for this project. Based on the details of the existing design, it is recommended that nested w-beam with a C6x8.2 be used to span across the entire bridge barrier as shown in Figure 12. The W-beam guardrail should be supported on 12-inch centers an attached at the posts by through bolts or by bolting through the openings with other anchoring system that secures the retrofit railing to the parapet. The height of the W-Beam guardrail should be 31 inches. The nested guardrail spanning across the structure should connect to PENNDOT 739 Transitions as shown in the details provided in Appendix A. For the details provided herein, though bolting through the concrete posts are shown. Since the posts are spaced on 12-inch centers, the nested w-beam should be supported every 12 inches by wood blocks that adequately block the nested w-beam out from the concrete openings. Blocking the w-beam on this close spacing is necessary to achieve MASH TL-3 requirements. We recommend further study and/or crash testing to prove this blockout spacing is adequate. For additional information, please refer to the detailed drawings for this retrofit application for concrete railings with openings shown in Appendix A. The engineering calculations performed for this design are provided in Appendix B.

**Design Option 2 – Concrete Rail Without Openings**

Several sites were visited that consisted of small streams with small bridges spanning the streams. The railings on these structures consisted of concrete continuous concrete parapets with a small beam on top of the parapet. Most of the bridges visited consisted of concrete bridge constructed in the early to mid 1930's. The condition of these bridges varied. In some cases, the bridge railings were severely damaged due to vehicular crashes or by road deicing salts and chemicals. Details of this common rail type are shown in the previous Figures 13 and 14. A few photos of this bridge type are shown in Figures 15 and 16.

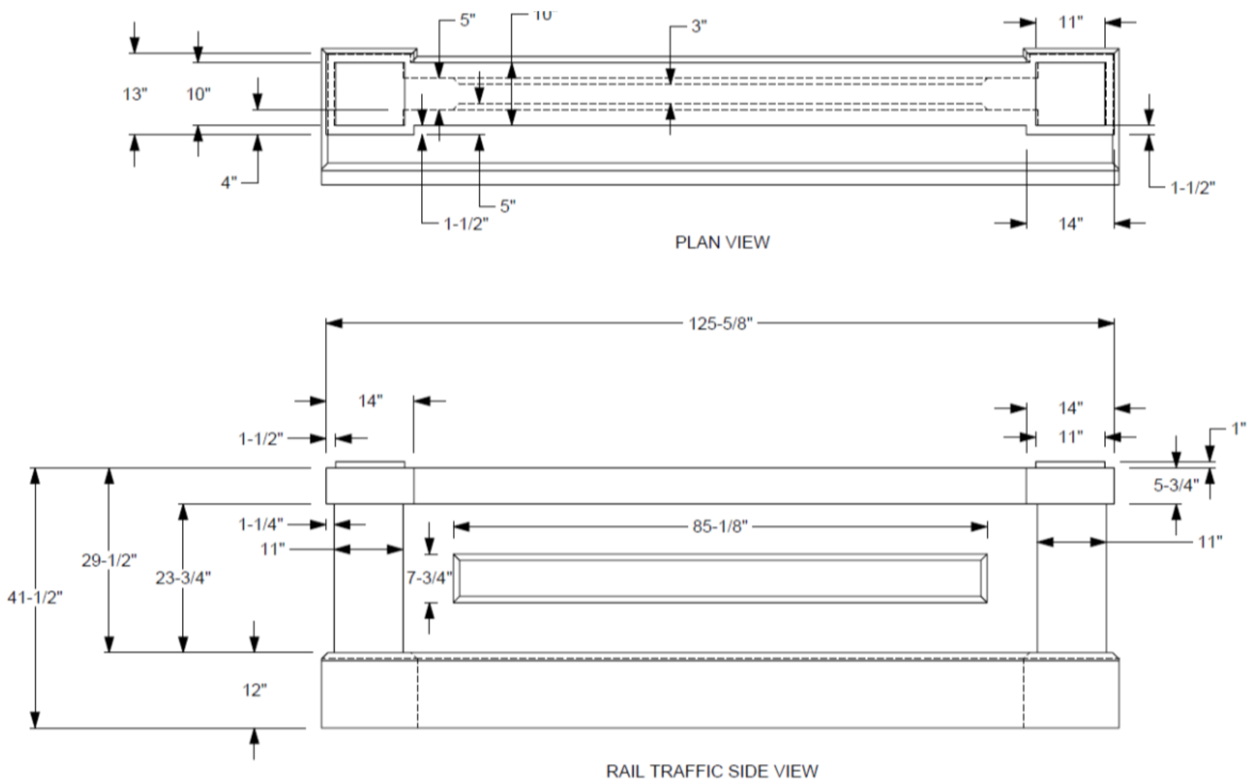


Figure 13 – Concrete Rail without Openings Plan and Elevation Views

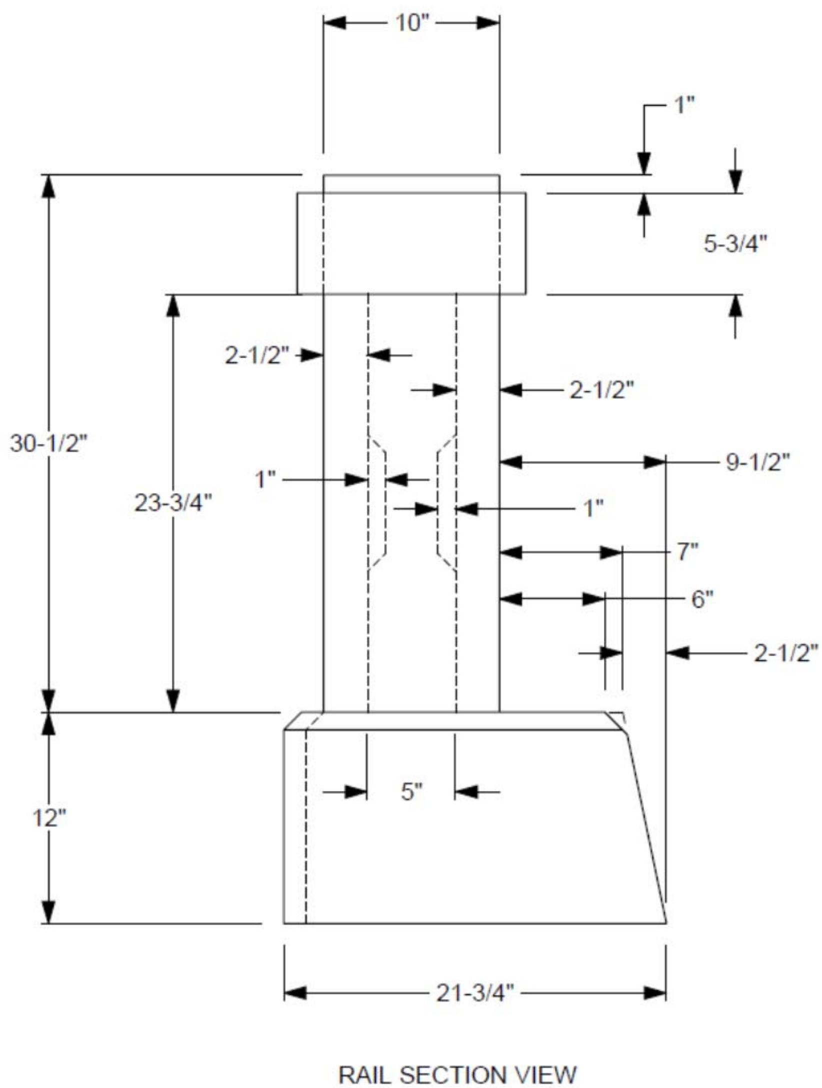


Figure 14 – Concrete Rail without Openings Section Details


Figure 15 – Photo of Typical Concrete Parapet Without Openings


Figure 16 – Photo of Typical Concrete Parapet Without Openings

Typically, this bridge rail design is 42 1/2 inches tall and consists of 5-inch wide concrete wall. This parapet transitions to 3 inches thickness in the center of the parapet. A reinforced concrete beam is present on top of the parapet. This concrete beam is approximately 6 inches high by 13 inches thick (typical). Two No. 4 bars are located in the top beam with approximately 1 ¾ inch of cover on each bar. The concrete bridge rail is constructed on top of a 12-inch high concrete curb. Details of the bridge rail are shown in Appendix A of this report. A strength analysis was not performed on this concrete bridge rail. However, due to the geometry, it is estimated that the strength would be similar to the strength of the concrete parapet with openings. The calculated strength of the rail with the openings was approximately 28 kips @ 27 inches height. The strength of this design is estimated to meet the strength requirements MASH Test Level 2 Requirements. Several retrofit options were considered for this project. Based on the details of the existing design, it is recommended that nested w-beam with a C6x8.2 be used to span across the entire bridge barrier as shown in Figures 17 and 18.

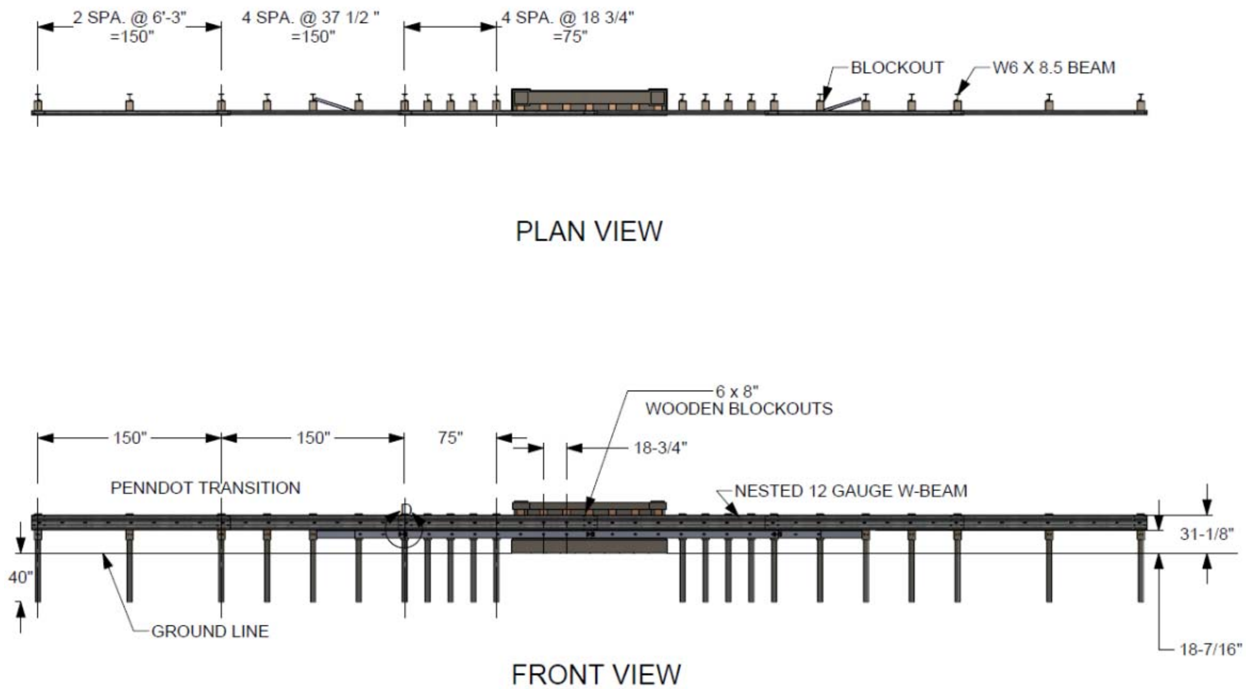


Figure 17 – Details of Concrete Parapet Without Openings

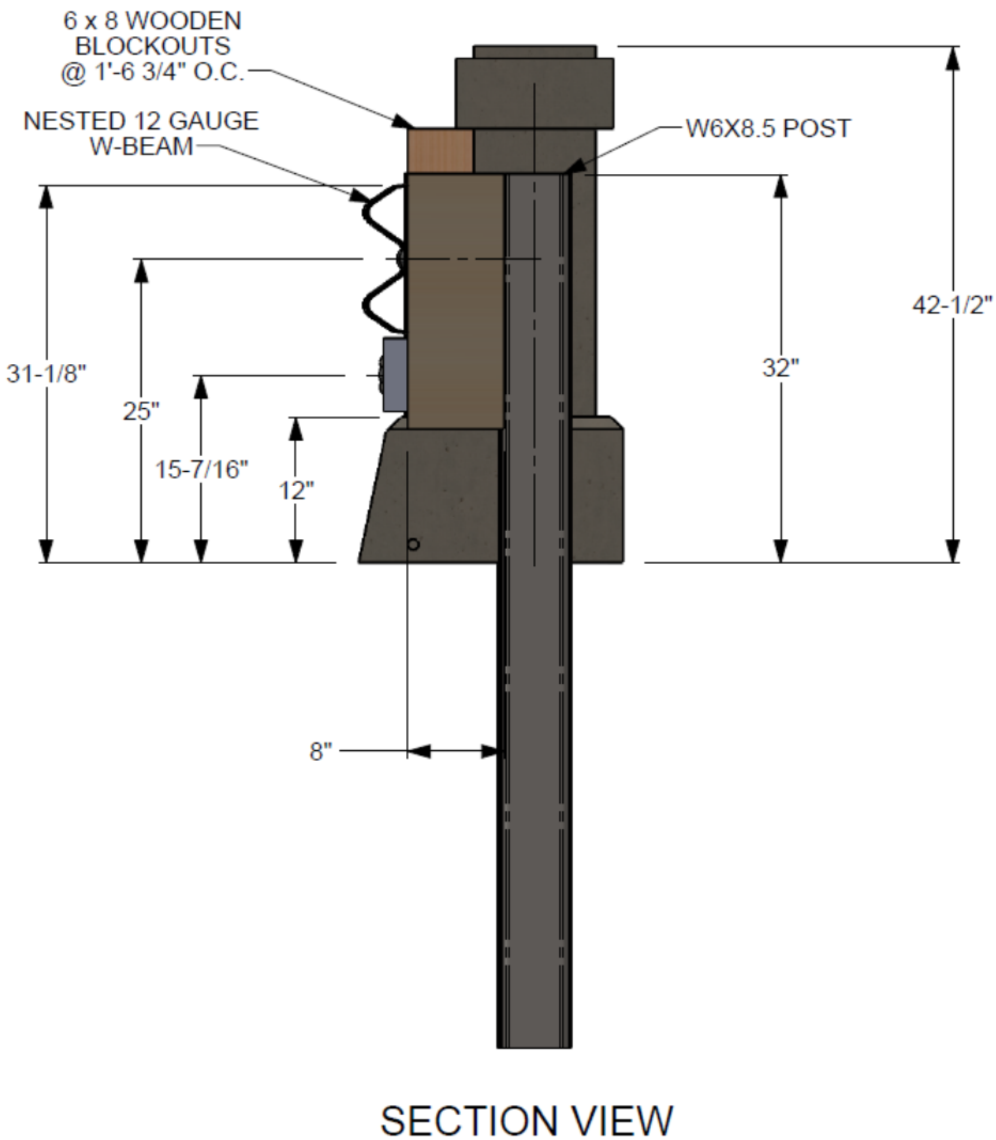


Figure 18 – Details of Concrete Parapet Without Openings Section View

The W-beam guardrail should be supported on 18 3/4-inch centers an attached at the concrete parapet by through bolts. The height of the W-Beam guardrail should be 31 inches. The nested guardrail spanning across the structure should connect to PENNDOT 739 Transitions on each end of the concrete parapet as shown in the details provided in Appendix A. The nested w-beam should be supported every 18 3/4 inches by wood blocks that adequately block the nested w-beam out from the concrete parapet. Blocking the w-beam on this close spacing is necessary to achieve MASH TL-3 requirements. We recommend further study and/or crash testing to prove this blockout spacing is adequate. For additional information, please refer to the detailed drawings for this retrofit application for concrete railings without openings shown in Appendix A.

**Design Option 3 – Combination Concrete Rail with Aluminum Post and Rail**

A few small bridges with bridge railings that consisted of a combination concrete rail and aluminum post and beam rail system. The combination bridge rail usually consisted of a concrete parapet on top of a concrete curb. The aluminum rail system consisted of a cast aluminum post with two aluminum tubular rail elements. This bridge railing system was constructed typically in the 1930's. The condition of these bridges varied. Details of this common rail type are shown in Figures 19 to 21. A few photos of this bridge type are shown in Figures 22 and 23.

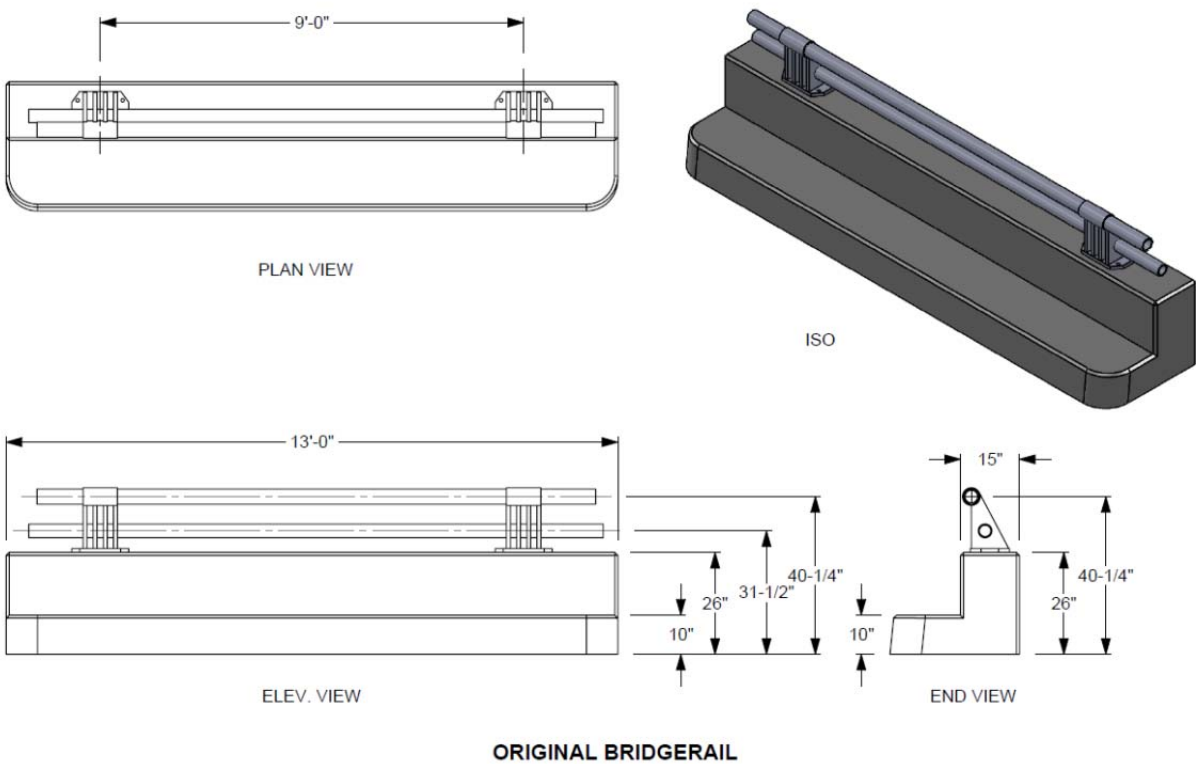


Figure 19 – Details of Combination Concrete Rail with Aluminum Post and Rail

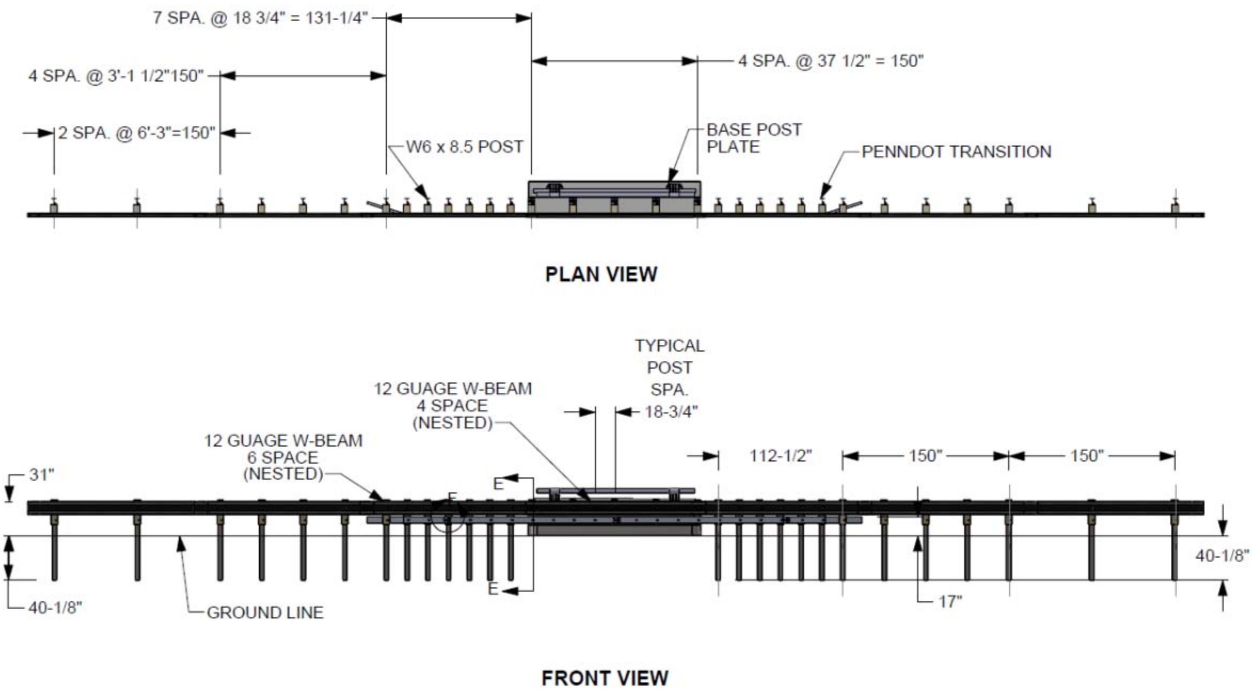


Figure 20 – Details of Combination Concrete Rail with Aluminum Post and Rail

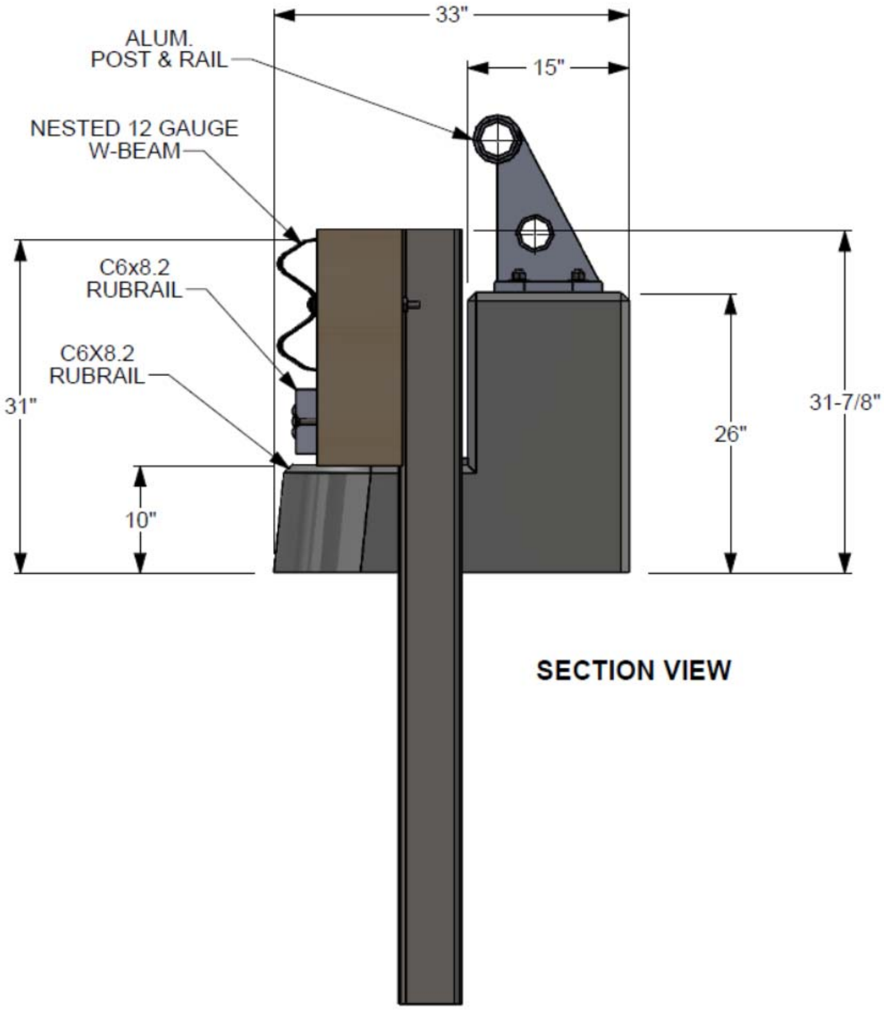


Figure 21 – Section Details of Combination Concrete Rail with Aluminum Post and Rail


Figure 22 – Photo of Combination Concrete Rail with Aluminum Post and Rail


Figure 23 – Photo of Combination Concrete Rail with Aluminum Post and Rail

Typically, this bridge rail is 40 1/4 inches tall and consists of 16-inch tall by 15-inch wide concrete parapet on top of a 10 tall concrete curb. The total height of the concrete parapet is approximately 26 inches. An aluminum post and rail system is anchored on top of the concrete parapet. Information on the reinforcement in the parapet is not known at the time of this writing. Details of the bridge rail are shown in Appendix A of this report. A strength analysis was not performed on this concrete bridge rail. Based on the rail geometry and details, the strength of this design is estimated to meet at least the strength requirements MASH Test Level 2 Requirements. Several retrofit options were considered for this rail type. Based on the details of the existing design, it is recommended that nested w-beam with a C6x8.2 rubrail be used to span across the entire bridge barrier as shown in Figures 19 to 21. The W-beam guardrail should be supported on 18 3/4-inch centers an attached to steel base-plated W6x8.5 posts. These posts should anchor to the existing concrete curb using 10-inch long ¾" diameter galvanized Hilti HAS-E rods. The anchor rods should be embedded a minimum of 8.0 inches into the concrete curb and anchored to the concrete using Hilti RE500 Epoxy Anchoring System. These anchors should be installed as per the manufacturer's recommendations. The height of the nested W-Beam guardrail should be 31 inches. The nested guardrail spanning across the structure should connect to PENNDOT 739 Transitions on each end of the concrete parapet as shown in the details provided in Appendix B. For the details provided herein, though bolting through the concrete parapet are shown in the details provided in Appendix A. The nested w-beam should be supported every 18 3/4 inches by the steel posts with 6-inch by 8-inch wood blocks. Blocking the w-beam on this close spacing is necessary to achieve MASH TL-3 requirements. We recommend further study and/or crash testing to prove that this post and blockout spacing is adequate for MASH TL-3. For additional information, please refer to the detailed drawings for this retrofit application for the combination concrete bridge rail shown in Appendix A.

## IMPLEMENTATION

Based on the results from this project, it is recommended that further analyses and/or full-scale crash testing be performed to prove that the retrofit designs presented herein meet the strength and performance requirements of MASH TL-3.

## REFERENCES


1. Hirsch, T.J., Buth, C.E., Campise, Wanda, "Aesthetically Pleasing Concrete Combination Pedestrian-Traffic Bridge Rail – Texas Type C411", Texas Transportation Institute Research Report 1185-3F, Texas Transportation Institute, August 1990.

2. J.D. Michie, Recommended procedures for the Safety Performance Evaluation of Highway Appurtenances", NCHRP Report 230, Transportation Research Board, Washington, D.C., 1980.

3. Buth, C.E, Menges, Wanda, Butler, Barbara, "Testing and Evaluation of NCHRP Report 350 Test Level Four Concrete Bridge Railing for Crooked River Gorge 18211", Oregon Department of Transportation, Project No. 405890-1, September 1997.

4. Buth, C. Eugene, Bligh Roger P., Menges, Wanda L., "NCHRP Report 350 Test 3-11 of The Texas Type T411 Bridge Rail", Texas Department of Transportation, Report 1804-3, May 1998.

5. Buth, C.E., Menges, Wanda, Butler, Barbara, "Testing and Evaluation of NCHRP350 Test Level Four Concrete Bridge Railing for Crooked River Gorge 18211", Oregon Department of Transportation, Project Number 405890-1, September 1997

# APPENDIX A – DRAWINGS & DETAILS

# APPENDIX B - CALCULATIONS