TRB PAPER: DESIGN & FULL SCALE TESTING OF TEXAS DEPARTMENT OF TRANSPORTATION TYPE T131RC BRIDGE RAIL

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ABSTRACT
Texas Department of Transportation (TXDOT) currently uses the TXDOT Type T101RC Bridge Rail. The T101RC bridge rail is a steel post and beam bridge rail anchored to the top of a concrete curb. The T101RC has been used extensively on older type bridges in retrofit bridge railing applications. This bridge rail is 27 inches in height and is anchored to the top of concrete curbs of varying heights. The heights of the posts and the number of bridge rail elements vary depending on the height of the concrete curb. The posts are anchored to the curb using four adhesive anchors.

Based on crash testing of similar rail designs of the same height, the TXDOT Type T101RC Bridge Rail would not meet the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH) Test Level 3 (TL-3) criteria. The purpose of this project was to design and crash test a modified design of the TXDOT T101RC Bridge Rail that would meet the strength and safety performance criteria for TL-3 of MASH.

The TXDOT T131RC Bridge Rail design and tested for this project and presented herein met all the strength and safety performance criteria of MASH. This bridge rail is currently being used on new and retrofit applications in Texas. This paper presents the analytical results, details of the design, and full scale crash test results performed on the T131RC bridge rail design.
INTRODUCTION

Texas Department of Transportation (TXDOT) has constructed different types of bridges that have utilize concrete decks and curbs. Larger span bridges often utilize longitudinal steel girders that support the deck with concrete curb. Pan form girders with bridge decks were developed in the late 1940s by TXDOT in anticipation of a need for low cost bridges in rural areas in Texas. The terminology depicts the modular steel forms required for cast-in-place reinforced concrete spans. When assembled, bolted together and supported from bent caps, a metal pan is used to form the concrete and support the weight in flexure without intermediate support. Forms and falsework are combined in a sturdy reusable package. Pan-formed bridges typically have the longitudinal bridge beams cast integrally with the concrete deck. The concrete decks on pan-formed bridges typically range from 6 to 8 inches in thickness and cantilever out from the exterior bridge beams within 2 feet. Concrete curbs of various widths and heights were typically constructed with these decks.

In 1956, a design was introduced for 40-ft spans to be constructed on a skew. In the 1960s, standard drawings were distributed for superstructure and substructure for different combinations or span ranges, roadway widths, and skew angles. Prior to the use of prestressed concrete beams, pan form girders have were the most economical method for constructing a highway bridge over small to moderate streams. Up until 1988, approximately 3750 pan form girder bridges had been constructed on the Texas Highway System. Many of these bridges are still in use at the time of this writing.

TXDOT currently uses a steel post and beam bridge that is anchored to the top of concrete curbs. This bridge rail is called the TXDOT Type T101RC bridge rail. The T101RC is 27 inches in height and can be anchored to the top of concrete curbs of varying heights. The heights of the posts and the number of bridge rail elements vary depending on the height of the concrete curb. The posts are anchored to the curb using four adhesive anchors. Based on crash testing of similar rail designs of the same height, the TXDOT Type T101RC bridge rail does not meet the American Association of State Highway and Transportation Officials (AASHTO) Manual for Assessing Safety Hardware (MASH) (1). The purpose of this portion of the project was to design and crash test a modified design of the TXDOT T101RC bridge rail that would meet the strength and safety performance criteria for Test Level 3 (TL-3) of MASH.

Most bridge railings that were constructed on pan-form bridges or the older longitudinal steel girder bridges with concrete deck and curb do not meet the current crash requirements of MASH (1). Many of these bridges were constructed with curbs of various heights and widths. The railings used on these bridges consisted of a metal post and beam system. These railings were often removed and retrofitted with the TXDOT T101RC bridge rail. The TXDOT T101RC does not meet the current crash performance requirements of MASH. The purpose of this project was to develop a crashworthy replacement for the T101RC bridge rail that meets the current MASH Requirements. This new design, if acceptable with respect to MASH requirements, would be used to replace the T101RC bridge rail. The new design could also be used for new construction. This paper presents the design analyses results, details of the design, and the results from the full-scale crash test performed on the new T131RC bridge rail design.

CURRENT TXDOT TYPE T101RC BRIDGE RAIL DESIGN

The TXDOT TYPE T101RC bridge rail is widely used on bridges in the State of Texas. This bridge rail is typically retrofitted on older bridges constructed with a concrete curb. Many of these bridges were constructed with the steel post and railing system that did not meet the crash
performance criteria prior to MASH. The TXDOT 101RC bridge rail is 27 inches in height with typically two tubular rail elements nested behind a w-beam rail element. The base plate for the T101RC is bent to form the face of the concrete curb. For curbs higher than 12 inches, one tubular rail element is used. The posts are fabricated from W6x20 steel shape. The posts are typically spaced 8 ft-4 inches on centers and anchored to the concrete curb using an adhesive anchoring system. Details of the T101RC bridge rail are shown in Figure 1. The TXDOT T101RC is typically constructed on decks with a thickness of 6.0 inches minimum. Conventional reinforcement in the deck consists of a single layer of reinforcing steel. Reinforcement in the curbs typically consists of vertical “U” shaped stirrups on 10-inch centers or less. Due to the age of these structures, the yield strength of the reinforcing steel is, in many instances, specified to 40 ksi. Longitudinal reinforcement in the curb typically consists of two #4 bars located in the top and within the vertical stirrup reinforcement. Details of the T101RC Bridge Rail are shown in Figure 1. Photos of the T101RC are shown as Figures 2 and 3.

**FIGURE 1 TXDOT T101RC Bridge Rail Details.**
FIGURE 2  Photo of T101RC Installation Traffic Side View.
DESIGN OF NEW T131RC BRIDGE RAIL

Several different design options were considered for the New T131RC Bridge Rail. These designs considered different railing configurations, rail heights, and post anchoring configurations. For this project, a 6-inch thick deck with an 11-inch high by 8-inch wide concrete curb was selected. This concrete deck thickness, curb height and width was considered a “worst case” with respect to strength for a retrofit rail application for a steel post and beam railing system. In addition, for many older bridges in Texas, 40 ksi reinforcing steel was used. For this project 40 ksi reinforcing steel was considered in the design. The amount of steel used in the analyses and design of the new system considered 40 ksi yield strength. Like the T101RC design, the T131RC utilized an adhesive anchoring system to anchor the posts to the concrete curb. For this project, Hilti RE500 Adhesive anchor system was used in the design analyses to anchor the bolts to the concrete curb. Structural strength analyses were performed by the author. Due to crash performance of other steel post and beam railings, a bridge rail height of 36 inches was selected and used in the design for the T131RC Bridge Rail. Due to the strength of the anchor bolt configuration used for the T131RC, the post strength was limited due to the strength of the anchors in the 8 inches wide by 11 inches high curb selected for this project. Strength analyses were performed and the anchors were located to maximize the strength of the post in the concrete curb.

Considering the height of the concrete curb and the overall height of the railing systems, two HSS6x6 tubular rail elements were selected for the T131RC Bridge Rail. The center of the lower rail element was located 21 inches above the deck surface to reduce the interaction (vehicle snagging) with the impacting vehicle with the post. The larger tube size was selected.
for strength and to increase the offset distance from the face of the rail and the post. This offset distance, using the 6-inch square tubes, was 6 inches. Details of the proposed T131RC design are shown in Figures 4 thru 6.

**FIGURE 4** Details of New T131RC Bridge Rail.
FIGURE 5  Details of New T131RC Bridge Rail Traffic Side View.
T131RC POST DETAILS

FIGURE 6 Details of New T131RC Bridge Rail Post.
STRENGTH ANALYSES OF T131RC POST

Strength analyses were performed on the T131RC post design to determine the limiting post strength. The ultimate transverse loads were calculated at the resultant height of the rail elements for several possible failure mode cases. This resultant height was 27 inches for the rail design shown in Figure 4. A list of the different failure modes analyzed for the new T131RC post design is provided as follows:

- **Failure Mode 1**: Ultimate post strength to cause plastic failure of the post
- **Failure Mode 2**: Ultimate post strength to cause rupture of the post welds on the base plate
- **Failure Mode 3**: Ultimate post strength to cause shear failure in the anchor bolts on the front side face of the curb
- **Failure Mode 4**: Ultimate post strength to cause punching shear failure in the curb from shear forces applied to the anchor bolts located in the front side face of the curb

The limiting post strengths for the different possible failure modes were calculated at the rail resultant height of 27 inches. The ultimate calculated strength to cause plastic failure of the post (Failure Mode 1) was approximately 25 kips. The ultimate calculated strength to cause rupture of the post welds (Failure Mode 2) was approximately 23 kips. The ultimate calculated strength to cause shear failure in the anchor bolts on the front face of the curb (Failure Mode 3) was approximately 23 kips. The ultimate calculated strength to cause punching shear failure in the curb from the shear forces applied to the anchor bolts located in the front face of the curb (Failure Mode 4) was approximately 15 kips. Therefore, the limiting post strength of 15 kips calculated in Failure Mode 4 was used to determine the strength of the overall rail design. A figure showing the geometry used to calculate the punching shear failure in the curb is shown as Figure 7.
LRFD STRENGTH ANALYSES OF TXDOT T131RC BRIDGE RAIL

Strength analyses were performed on the proposed TXDOT T131RC Bridge Rail design. The strength analyses were performed in accordance with 2010 American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) 2010 Bridge Design Specifications, Section 13 (2). The following design conditions were considered in the strength of the new T131RC Bridge Rail design:

1.) Limiting post strength of 15 kips to cause to cause punching shear failure in the curb from shear forces applied to the anchor bolts located in the front side face of the curb (Failure Mode 4).
2.) 3600 psi concrete strength in the concrete curb and deck.
3.) Reduced amount of reinforcing steel in the concrete curb and deck to account for 40,000 psi yield strength rebar used in older bridges constructed in the early 1960’s. This reduced yield strength resulted in reducing the bar diameter size by 1/8-inch and using 60,000 ksi yield rebar material on the same spacing.
4.) Two HSS6x6x1/4 tubular rail elements.
5.) W6x15 post size
6.) 36-inch Rail Height
7.) Hilti RE500 Epoxy Anchoring System used to anchor posts to concrete curb
8.) Final Post Spacing: 5 ft-0 inch on centers

Several strength analyses were performed on the T131RC bridge rail design using different post spacing. Using a post spacing of 5 ft-0 inch and the design details and conditions previously listed, the strength of the TXDOT T131RC bridge rail was calculated to be
approximately 76 kips. This strength was based on the resistance of the rail system over 6 post spans. Based on the AASHTO LRFD Specifications, 54 kips of capacity is needed for Test Level 3 impact conditions. The T131RC design as shown in Figures 4 through 6 with posts spaced 5'-0" on centers was constructed for full-scale crash testing.

FULL-SCALE TEST INSTALLATION DETAILS

The TXDOT T131RC Bridge Rail consists of two tubular steel rail elements supported by W6×15 steel posts. The overall length of the test installation was 80 ft-0 inch and consisted of 16 posts spaced on 5 ft-0 inch centers. The total height of the bridge rail is 36 inches above the pavement surface. The steel bridge rail was anchored to an 8-inch wide by 11-inch high cast in place concrete curb. The concrete curb was anchored to a cast-in-place 8-inch thick concrete deck cantilever. The width of the cantilever was 20.75 inches. This width is typical for older bridges utilizing the T101RC bridge rail system.

The TXDOT Type T131RC Bridge Rail tested for this project consisted of two rail elements. Both rail elements were HSS6×6×1/4 A500 Grade C structural tubes. The centerline heights of the rail elements were 21 inches and 33 inches for the lower and top rail elements, respectively. Each rail element was attached to each post using a 5/8-inch diameter A307 button head bolt. The W6×15 posts were welded to 14-inch ×16-inch × 5/8-inch thick baseplates. These baseplates were bent using a 3-inch diameter radius to fit the front and top sides of the concrete curb. These baseplates were fabricated using A572 Grade 50 material. The posts were fabricated from ASTM A992 material. The posts were anchored to the concrete curb using four ¾-inch diameter A193 B7 threaded rods 8½ inches long and anchored 6¾ inches in the concrete curb using the Hilti RE500 anchoring system.

A simulated concrete bridge deck cantilever and curb was constructed immediately adjacent to an existing concrete runway located at the Texas Transportation Institute (TTI) Proving Ground test facility. The total length of the installation was 76 ft-6 inches long. The bridge deck cantilever was 20¾ inches in width and was 6 inches thick. Reinforcement in the deck consisted of a single layer of reinforcing steel placed in the transverse and longitudinal directions. The transverse reinforcement consisted of #4 bars located 10 inches on centers. Longitudinal reinforcement consisted of three #4 bars. Two bars were located immediately beneath the concrete curb with the third bar located approximately 22 inches from the edge of the deck cantilever. Vertical reinforcement in the curb consisted of #3 stirrups located on 10-inch centers. Two longitudinal #3 bars were located within the curb stirrup and at the top corners of the stirrups. All reinforcement used in the concrete deck had minimum specified yield strength of 60 ksi. The concrete deck and curb has a specified concrete strength of 3600 psi. The post base plates were fabricated using A572 Grade 50 material. The posts were fabricated from ASTM A992 material. Details of the full scale test installation are shown in Figures 8 to 11. Photographs of the completed full-scale test installation are shown in Figures 12 and 13. Figure 14 shows photos of the installation just prior to performing full-scale crash test with the MASH pickup truck.
FIGURE 8 Section View T131RC Bridge Rail.
FIGURE 9  T131RC Deck and Curb Details.
FIGURE 10  T131RC Post and Base Plate Details.
FIGURE 11  T131RC Base Plate Details.
FIGURE 12 Photos of T131RC Test Installation.
FIGURE 13 Photos of T131RC Test Installation.
A full-scale crash test was performed on the installation in accordance with MASH Specifications. The test performed on the TXDOT T131RC bridge rail anchored to an 8-inch wide by 11-inch high curb was MASH Test 3-11. The target CIP was determined to be 4.3 ft upstream of a post located near a joint in the bridge rail. The crash test and data analysis procedures were in accordance with guidelines presented in MASH. The crash test was evaluated in accordance with the criteria presented in MASH. MASH Test 3-11 involves a 2270P vehicle weighing 5000 lb ±100 lb and impacting the bridge rail at an impact speed of 62.2 mi/h ±2.5 mi/h and an angle of 25 degrees ±1.5 degrees. The 2007 Dodge Ram 1500 Quad-Cab pickup truck used in the test weighed 4985 lb and the actual impact speed and angle were 63.0 mi/h and 24.7 degrees, respectively. The actual impact point was 5.0 feet upstream of a post near a joint in the bridge rail. Based on the results from the crash test, the TXDOT T131RC bridge rail performed acceptably with respect to all the evaluation criteria in the MASH Test level 3 Specifications. Photographs of the test installation after the full scale crash test was performed are shown in Figure 15. A photograph of the MASH pickup truck after the crash test is shown in Figure 16.
FIGURE 15 Photos of Full-Scale Test Installation After Crash Test.

FIGURE 16 Photo of Pickup Truck After Crash Test.
SUMMARY AND CONCLUSIONS

The TXDOT T131RC Bridge Rail met all the strength and safety performance criteria of MASH. Punching shear concrete failure was observed in several posts after the crash test was performed. This failure mechanism was calculated to be the limiting strength of the post. In addition the punching shear failure mechanism in the curb concrete matched very closely to the mechanism used in the strength analyses. This bridge rail is recommended for implementation on new or retrofit railing applications. This bridge rail is currently used in retrofit and new bridge construction throughout the State of Texas. In addition to the T131RC bridge rail, a transition for the T131RC has also been designed and successfully crash tested with respect to MASH TL-3 Specifications. Both the MASH small car and pickup truck tests were performed on the transition design. Whenever the T131RC bridge rail is being used on new TXDOT projects, this new transition design is being used to transition w-beam guardrail to the new T131RC bridge rail.

REFERENCES


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