TRB PAPER: DESIGN & FULL SCALE TESTING OF TEXAS DEPARTMENT OF TRANSPORTATION TYPE SSTR SINGLE SLOPE CONCRETE BRIDGE RAIL ON THIN PAN-FORMED BRIDGE DECK

By:

William F. Williams, P.E.
Associate Research Engineer
Safety & Structural Systems Division
Texas Transportation Institute
3135 TAMUS
College Station, Texas 77843-3135
Phone: 979-862-2297
Email: w-williams@tamu.edu

John Holt, P.E.
Bridge Standards Engineer
Texas Department of Transportation
Bridge Division
125 East 11th Street
Austin, Texas, FL 78701-2483
Phone: 512-416-2212
Email: john.holt@txdot.gov

Date: August 1, 2012

Word Count: 3,168 words + (15 Figures @ 250 words each) = 6,918 words
Pan-formed girders with bridge decks were developed in the late 1940s resulting from a need for low cost bridges in rural areas in Texas. Modular steel forms are used to construct the deck and bridge beams in a single pour and also serve to support the construction loads during construction. Up until 1988, approximately 3750 pan form girder bridges had been constructed on the Texas Highway System. Many of these bridges utilize a 6-inch thick deck with a narrow deck cantilever. Many of the bridge railings constructed on these bridges do not meet the current MASH crash requirements. The purpose of this project was to develop a crashworthy retrofit bridge rail that could be anchored on a 6-inch thick pan-formed bridge deck. For this project, the TXDOT Type SSTR concrete rail was retrofitted to the 6-inch thick pan-formed bridge deck. The rail is anchored to the concrete deck using bent anchor bolts that anchor (bolt through) to the 6-inch thick concrete deck. The concrete deck was constructed using 3000 psi concrete and a single layer of reinforcement. In addition, instead of conventional reinforcement, welded wire reinforcement was designed and used in the bridge rail. Analyses and details were developed to increase the strength of the barrier system at an open joint in the barrier and deck. The full-scale crash test performed on the retrofit barrier met all the requirements of MASH (1). This paper presents the analytical and full scale crash test results performed on the retrofit bridge rail design.
INTRODUCTION
Pan form girders with bridge decks were developed in the late 1940s by the Texas Department of Transportation (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.

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 been 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.

Most bridge railings that were constructed on pan-form bridges do not meet the current crash requirements of MASH (1). The purpose of this project was to develop a crashworthy concrete bridge rail design that could be retrofitted onto a typical pan-formed bridge utilizing a 6-inch thick concrete deck system. This paper presents the results from the design of the retrofit bridge rail and the results from the full-scale crash test performed on the design.

CURRENT TXDOT TYPE SSTR BRIDGE RAIL DESIGN
The TXDOT TYPE SSTR (Single Slope Traffic Rail) Bridge Rail is widely used on new bridge construction projects in the State of Texas. The SSTR concrete bridge rail is 36 inches high and has a single sloped traffic face. The rail is 7 ½ inches wide at the top and 13 inches wide at the base. Geometric details of the rail are shown in Figure 1. The SSTR bridge rail is typically constructed on decks with a thickness of 8.0 inches minimum. Conventional reinforcement in the traffic rail consists of vertical “V” shaped bars on 6-inch centers. Longitudinal reinforcement in the barrier consists of five #4 bars on each face of the rail (8 bars total). These bars are spaced approximately 8 inches on centers. The SSTR Bridge Rail is typically anchored to an 8-inch thick minimum deck using #4 “U” Bars that extend upwards from the deck into the SSTR Bridge Rail. These “U” Bars are located on 6-inch centers. Typical reinforcing details for the TXDOT Type SSTR Bridge Rail are shown in Figure 2.
FIGURE 1  TXDOT TYPE SSTR Bridge Rail Details.
Several anchoring options were considered for the SSTR retrofit design. The anchoring option selected for this project consisted of drilling through the 6-inch pan-formed deck and bolting through the deck with 1-inch diameter bent anchor bolts with large plate washers beneath the nuts. These bolts would extend upwards into the SSTR bridge rail and serve to anchor the railing to the deck. Structural strength analyses were performed by the author to minimize the size of the bolted anchors and the number of anchors required by maximizing the spacing of the anchors. The ultimate pull-out capacity of the anchors through the deck and the spacing of the anchors were analyzed to minimize the number of anchors required to adequately anchor the barrier for MASH TL-3 impact conditions. The ultimate pullout strength of a single 1-inch diameter bent anchor bolt was calculated to be approximately 34 kips. This pullout capacity was considered in the strength of the retrofit barrier system for this project.

In lieu of conventional reinforcing steel in the barrier, welded wire reinforcement was used in the design of the barrier system. This welded wire reinforcement consisted of smaller diameter reinforcing bars with a higher design yield stress than conventional reinforcing steel.
The design yield stress for the welded wire reinforcement was 75 ksi. The welded wire reinforcement was prefabricated for the SSTR bridge rail by InSteel, Inc., Mount Airy, NC (Houston, Texas Office). The welded wire was fabricated in 30 feet sections to the dimensions of the SSTR bridge rail with adequate concrete on all sides of the barrier when installed. Adequate lap lengths were also provided for all longitudinal reinforcement wire panel sections. All intersection joints between vertical and longitudinal reinforcing bars were welded. These welded joints provide additional strength capacity to the barrier system. Details of the welded wire provided by InSteel, Inc. are shown as Figure 3. Photos of a typical 30-ft section of welded wire reinforcement during fabrication are shown in Figure 4.
FIGURE 3  TXDOT Type SSTR Welded Wire Shop and Fabrication Details.
FIGURE 4 Fabrication of Welded Wire for TXDOT Barrier.
Details of the proposed retrofit bridge rail design using welded wire reinforcement and bent anchor bolts are shown in Figures 5 through 7. Details of the bent anchor bolt used to anchor the barrier to the bridge deck are shown in Figure 8. In addition to the details necessary for strength, two 2-inch diameter PVC conduits were included for electrical wiring. The locations of the electrical conduits were considered in the strength design of the barrier system. The conduit was located at the base of the barrier to optimize the strength of the barrier system. Please refer to Figure 5 & 6 for additional information on the PVC conduit and locations of the conduit. Engineering strength analyses were performed on the proposed barrier design to determine the strength of the barrier system at the mid-span of a barrier segment (between joints without end effects at a joint) and directly at a joint in the barrier system. These calculations were performed in accordance with the American Association of State Highway and Transportation Officials (AASHTO) LRFD Design Specification, Section 13 (2).

FIGURE 5 PROPOSED TXDOT Type SSTR Retrofit Bridge Rail Details.
FIGURE 6 PROPOSED TXDOT Type SSTR Retrofit Bridge Rail Details Cont'd.
FIGURE 7  PROPOSED TXDOT Type SSTR Retrofit Bridge Rail Details Cont’d.
Strength analyses were performed on the proposed TXDOT SSTR retrofit bridge rail design. The strength analyses were performed in accordance with 2004 AASHTO LRFD Bridge Design Specifications, Section 13. The following design conditions were considered in the strength of the retrofit design:

1.) 6-inch thick Deck with single layer of reinforcing steel with design compressive strength of 3000 psi.
2.) Welded wire reinforcement in the barrier.
3.) 1-inch diameter anchor bolts, spaced on 24-inch centers anchoring the barrier to the concrete deck.
4.) Open expansion joint in the barrier and deck.
5.) Two 2-inch diameter electrical conduits located in the center and bottom of the SSTR bridge rail.

Based on these design conditions and the details of the bridge rail as shown in the previous figures, the strength of the TXDOT SSTR retrofit bridge rail was calculated to be approximately 56 kips for mid-span impacts within wall segments (mid-span failure mechanism). The strength of the TXDOT SSTR retrofit bridge rail was calculated to be approximately 37 kips.
at the open join in the barrier section and deck. In accordance with the AASHTO LRFD Specifications, 54 kips of capacity is needed for Test Level 3 impact conditions.

Additional capacity was needed at the open joint in the bridge rail and deck to achieve 54 kips. To increase the strength of the bridge rail at a joint, two dowels were constructed through the open joint in the adjacent ends of the bridge rail. The length of the dowels was approximately 60 inches long. The dowels extended into each end of the bridge rail approximately 30 inches. These dowels were added to improve the lateral strength of the bridge rail at the joint. Number 8 deformed bars were used for the dowels. On one end of the bridge rail, these bars were anchored into the concrete. On the adjacent end, these bars extended through the open joint and into plastic sleeves constructed in the end of the bridge rail. These plastic sleeves permitted longitudinal movement in the barrier and deck at the open joint in the barrier. These dowels were vertically spaced to maximize the lateral strength of the dowels in the barrier. The lateral shear capacity provided by the #8 dowels located in the joint in the bridge rail was calculated to be approximately 25 kips. The lateral shear capacity of the dowels in addition to the lateral capacity of the barrier system at the open joint was calculated to be approximately 65 kips. This overall capacity exceeded the design capacity of 54 kips needed for Test level 3 impact conditions. Figure 9 shows the details of the #8 dowels and the projected concrete shear failure planes analyzed for the dowels.
A full scale test installation was constructed and tested for this project. The TXDOT Type SSTR Single-Slope bridge rail was anchored to the top of a 6-inch thick reinforced concrete deck cantilever. The TXDOT Type SSTR bridge rail was 36 inches in height, 13 inches wide at the base and 7 ½ inches wide at the top. The bridge rail was constructed with a single slope face. The traffic face of the bridge rail was sloped 7 inches over the 36-inch height of the bridge rail. Reinforcement in the bridge rail consisted of pre-fabricated deformed welded wire (WWR) provided by InSteel Wire Products, Mount Airy, North Carolina. The welded wire mesh consisted of 30 ft-0 inch preformed units with all unions of longitudinal and vertical wires welded. TTI received a drawing from InSteel Wire Products, Inc. entitled “SSTR Bridge Rail Texas DOT,” (InSteel Drawing No. 09-DS-99) and dated May 22, 2009. This drawing provided fabrication details for the welded wire reinforcement used in the TXDOT Type SSTR bridge rail tested for this project. Longitudinal reinforcement between the preformed units was lapped.
approximately 12 inches. The specified yield strength of the deformed wire used to fabricate the panels was specified to be 75 ksi steel material.

The TXDOT Type SSTR bridge rail was anchored to the 6-inch thick deck using 1-inch diameter ASTM F1554 Grade 55 galvanized anchor bolts 24 inches in length and spaced on 24-inch centers along the length of the barrier. The bolts were anchored thru the deck in 1¼-inch diameter core drilled holes. The anchor bolts were located approximately 11 inches from the edge of the deck and were fabricated with a 15-degree bend. This bend helped accommodate approximately 15 inches of anchorage embedment within the deformed welded wire reinforcement of the TXDOT Type SSTR bridge rail. The bridge rail was additionally anchored to the deck using #4 dowels spaced on 48-inch centers 4½ inches from the edge of the deck and approximately 4 inches into the deck using the Hilti RE 500 Epoxy anchoring system. The length of these #4 dowels was approximately 16 inches.

A 6-inch thick by 21¼ inches wide deck cantilever was constructed for this project. Reinforcement in the deck cantilever consisted of one layer of steel reinforcement. Transverse reinforcement consisted of #4 bars located on 6.0-inch centers. One longitudinal #4 bar was placed within the deck approximately 1¾ inch from the field side edge of the deck.

The test installation for this project measured approximately 75 ft-¾ inch in length. The installation was constructed with a ¾-inch wide expansion joint in both the TXDOT Type SSTR bridge rail and 6-inch thick deck. This joint in the bridge rail and deck was located approximately 32 ft from the upstream end of the installation. Two #8 deformed bars, approximately 60 inches in length, were used to provide additional lateral strength to the two opposing ends of the bridge rail at the joint. The #8 bars were anchored approximately 31¾ inches within one end of the TXDOT Type SSTR bridge rail at the joint. On the adjacent bridge rail end, these dowels extended through the joint and were placed in sleeved PVC pipe sections. These pipe sections were approximately 32½ inches in length and accommodated movement in the opposing end of the bridge rail. The specified compressive strength of the concrete for the TXDOT Type SSTR bridge rail and the deck were 3600 psi and 3000 psi, respectively. The compressive strengths of the bridge rail and deck on the day the test was performed measured 4360 psi on the upstream end of the parapet (upstream from expansion joint), 3525 psi on the downstream end of the parapet (downstream from expansion joint), and 3450 psi on the deck. Reinforcement in the bridge rail consisted of pre-fabricated deformed welded wire provided by InSteel Wire Products, Mount Airy, North Carolina. Details of the full scale test installation are shown in Figure 10. Photographs of the installation during construction are shown as Figure 11. Photographs of the completed full-scale test installation are shown in Figure 12. Figure 13 shows photos of the installation just prior to performing full-scale crash test with the MASH pickup truck.
FIGURE 10  Full-Scale Test Installation Details.
FIGURE 11  Full-Scale Test Installation During Construction.
FIGURE 12 Photos of the Completed Full-Scale Test Installation.
A full-scale crash test was performed on the TXDOT SSTR retrofit bridge rail anchored to a 6-inch thick pan-formed deck was MASH Test 3-11. The target CIP was determined to be 4.3 ft upstream of 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 2005 Dodge Ram 1500 Quad-Cab pickup truck used in the test weighed 5036 lb and the actual impact speed and angle were 63.8 mi/h and 24.8 degrees, respectively. The actual impact point was 5.2 ft upstream of joint in the bridge rail. Impact severity was calculated at 3881 kip-ft or 5.2 percent above the target value. Based on the results from the crash test, the TXDOT Type SSTR retrofit 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 14. A photograph of the MASH pickup truck after the crash test is shown in Figure 15.
FIGURE 14 Photos of Full-Scale Test Installation After Crash Test.
SUMMARY AND CONCLUSIONS

The objective of this crash test was to determine if the TXDOT Type SSTR bridge rail on pan-formed retrofit bridge deck would perform acceptably according to the guidelines set forth in MASH. The crash test performed was MASH Test 3-11 involving a 2270P vehicle (5000-lb pickup truck) impacting the critical impact point (CIP) of the bridge rail at an impact speed and angle of 62 mi/h and 25 degrees, respectively.

The TXDOT Type SSTR bridge rail retrofitted to the 6.0 inch thick pan-formed bridge deck as tested and described herein performed acceptably for MASH Test 3-11. In addition, the two #8 deformed bars, used in the expansion joint between the barrier ends to provide additional lateral strength to the two opposing ends of the barrier at the joint performed as designed. No significant cracking was observed in the bridge rail or deck after the test. The use of welded wire reinforcement in the barrier saved construction costs and performed well in the test. The retrofit SSTR bridge rail as tested for this project with the #8 expansion dowels in the barrier expansion joints were recommended for implementation on new pan-form bridge upgrade projects with 6-inch minimum deck thickness in the State of Texas.

REFERENCES


ACKNOWLEDGEMENTS

A very special thanks to Mr. John Holt, Bridge Engineer and Project Manager for the Texas Department of Transportation. John’s assistance and valuable input made this a truly great research project.