TRB PAPER: DESIGN & FULL SCALE TESTING OF AESTHETIC TXDOT TYPE
T224 BRIDGE RAIL FOR MASH TL-5 APPLICATIONS

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ABSTRACT

The purpose of this project was to design and test a new aesthetic concrete post and beam bridge rail for MASH TL-5 applications. The Texas Department of Transportation (TXDOT) Type T224 Bridge Rail developed for this project is a 42-inch high concrete bridge rail for MASH TL-5 applications. The T24 consisted of a concrete post and rail system anchored to the top of a concrete curb. The curb was anchored to an 8 ½-inch thick concrete deck. The concrete curb was 9.0 inches high by 16 ½ inches wide. The concrete posts 12.0 inch high by 5.0 feet wide and were tapered on the sides. These tapers helped with the aesthetic appearance and also improved the crash performance of the rail system. The posts were spaced on 15 feet centers. 12 inch high by 10 feet wide openings were present between the posts. The concrete rail consisted of a single 16 ½-inch wide by 21-inch deep concrete beam. Reinforcement in all the components of the bridge rail were designed and detailed for this project by the author. The bridge rail was designed with a moveable splice joint. This joint will permit longitudinal movement up to 2 inches and still provide transverse resistance between adjacent ends of the barrier system. Full-scale testing was performed on a full-scale test specimen for this project. The T224 successfully met all the performance requirements for MASH TL-5. Details of the design and testing of the T224 for MASH TL-5 Specifications are provided in this paper.
INTRODUCTION

The objective of this research was to design and aesthetic concrete MASH TL-5 bridge rail and evaluate the impact performance of the TXDOT T224 Bridge Rail according to the safety-performance evaluation guidelines included in AASHTO Manual for Assessing Safety Hardware (MASH) for Test Level Five (TL-5) (1). This paper describes the TXDOT T224 Bridge Rail, documents the impact performance of the rail system according to MASH TL-5 evaluation criteria, and presents recommendations regarding implementation.

DESIGN & STRENGTH ANALYSES OF T224 BRIDGE RAIL

A new concrete post and beam bridge rail was designed and detailed for this project. The Texas Department of Transportation (TXDOT) Type T224 Bridge Rail developed for this project is a 42-inch high concrete bridge rail for MASH TL-5 applications. The T224 consisted of a concrete post and rail system anchored to the top of a concrete curb. The curb was anchored to an 8 ½-inch thick concrete deck. The concrete curb was 9.0 inches high by 16 ½ inches wide. The concrete posts 12.0 inch high by 5.0 feet wide and 15 inches thick and were tapered on the sides. These tapers helped with the aesthetic appearance and also improved the crash performance of the rail system. The posts were spaced on 15 feet centers. 12 inch high by 10 feet wide openings were present between the posts. The concrete rail consisted of a single 16 ½-inch wide by 21-inch deep concrete beam. Reinforcement in all the components of the bridge rail were designed and detailed for this project. The bridge rail was designed with a moveable splice joint. This joint permitted longitudinal movement up to 2 inches and still provide transverse resistance between adjacent ends of the barrier system. Details of the T224 Bridge Rail are shown in Figure 1.
FIGURE 1 TXDOT T224 Design Details For Analyses

Strength analyses were performed on the T224 Bridge Rail design as shown in Figures 1 through 6 in accordance with the American Association of State Highways and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Specifications. The nominal bending strength of the rail, based on six No. 6 tension bars was approximately 176 kip feet. Considering the width and thickness of the posts (5.0 feet wide by 15 inches thick) the nominal post bending strength was approximately 174 kip-ft. The total combine resistance of the bridge rail design out at mid-span was calculated to be approximately 131 kips. The resistance of the rail at the open joint was calculated to be approximately 100 kips. A new dowel splice connection was designed and detailed for this project. This new dowel connection consisted of three (3) number 8 (1.0 inch diameter) deformed dowels anchored to one barrier end. These dowels were allowed to move (placed in sleeves) in the adjacent barrier ends. These dowels added additional lateral resistance to the open joint. The calculated lateral resistance contribution of the dowels was approximately 60 kips. As a result the strength of the rail at the open joint considering the added capacity of the anchored/sleeved dowels (3) was approximately 160 kips. This capacity exceed the published capacity of 125 kips at 42 inches height. However, the strength of the rail based on the flexural resistance of the deck at the joint over 2-spans was approximately 124 kips. This 124 kips was the limiting strength of the T224 at the open joint in
the rail and deck. These calculated capacities were used to finalize the design for full-scale
testing for MASH TL-5.

FULL-SCALE TEST INSTALLATION DETAILS

A full-scale test installation was constructed for the TXDOT T224 Bridge Rail Design. The test installation this project consisted of a 160 ft-2 inch long concrete beam on concrete
posts and curb. The concrete bridge rail measured 42 inches in overall height above the bridge
deck, with the bottom of the beam located 21 inches above the bridge deck. The width of the rail
was 16\%2\frac{1}{2} inches, and it was supported on integral posts every 15-ft. with 10-ft. of clear opening
between adjacent posts. The beam and posts were integral with a 9-inch tall steel reinforced
concrete curb. Additionally, the deck, curb, posts, and beam had a 2-inch wide expansion joint
located 65 feet from the upstream end of the installation.

Concrete Rail

The beam was 21 inches tall × 16\%\frac{1}{2} inches wide with the traffic side face flush with the
posts and the curb. The beam was continuous for the length of the installation except for the 2-inch
wide expansion joint. The beam and posts were cast as a monolithic concrete unit atop the curb.

Reinforcing steel in the beam consisted of ten ¾-inch diameter longitudinal reinforcing
bars (#6 rebar); five each on the traffic side and the field side spaced, on approximately 4-inch
vertical centers. Longitudinal bar overlap was 25 inches minimum. These 10 longitudinal bars
were contained within 320 transverse 17-inch × 12\%\frac{1}{2}-inch rectangular reinforcing hoop ‘S’-bars
of \%\frac{1}{8}-inch diameter bars (#5 rebar), longitudinally spaced at 6 inches with 2 inches of concrete
coverage at top and sides. Junctions were wire-tied as necessary.

At the expansion joint, three horizontal 1-inch diameter joint bars (#8 rebar), 60 inches long,
were embedded 29 inches into each adjacent end of the rail. They were located 9\%\frac{1}{4} inches from the
field side face and at vertical depths of 4\%\frac{1}{2}, 10\%\frac{1}{2}, and 16\%\frac{1}{2} inches from the top. The downstream end
of each joint bar was sleeved with 1\%\frac{1}{4}-inch diameter schedule 80 PVC pipe.

Posts, Curb and Deck

The parapet had two configurations of posts: intermediate posts and end posts. The posts
were 5-ft long and spaced 15 feet center-to-center with 10-ft. long windows between the posts.
End posts were located at each end and adjacent to the 2-inch wide expansion joint. The traffic
side of the posts, rail, and curb were flush with one another in a vertical plane.

The posts were 60 inches long × 12 inches tall × 15 inches wide. The exposed ends of the
posts were tapered 7 inches toward the field side over a distance of 14 inches. Intermediate post
reinforcement in the longitudinal direction consisted of one 32-inch long ¾-inch diameter bar (#5
rebar) on the traffic side and two 56-inch long \%\frac{1}{8}-inch diameter bars (#5 rebar) on the field side.
Vertical reinforcement consisted of six VP-1 bars that were 40-inch long, \%\frac{1}{8}-inch diameter (#5
rebar), and equally spaced at 6 inches on the traffic side, and five VP-2 bars that were 40-inch
long, \%\frac{1}{8}-inch diameter (#5 rebar), and equally spaced at 12 inches on the field side. These bars
extended from the top of the bridge deck, through the post, and to within 2 inches of the top of
the beam.
End post reinforcement in the longitudinal direction consisted of one 46-inch long ⅝-inch diameter bar (#5 rebar) on the traffic side and two 56-inch long ½-inch diameter bars (#5 rebar) on the field side. Vertical reinforcement consisted of 12 VP-1 bars that were 40-inch long, ½-inch diameter (#5 rebar), and equally spaced at 4 inches on the traffic side, and 15 VP-2 bars that were 40-inch long, ⅝-inch diameter (#5 rebar), and equally spaced at 4 inches on the field side. These bars extended from the top of the bridge deck, through the post, and to within 2 inches of the top of the beam.

The curb was 16½ inches wide × 9 inches tall. The field side face of the curb was set back 1½ inches from the outer edge of the deck. Curb reinforcement consisted of two longitudinal ⅝-inch diameter bars (#5 rebar) located approximately 6 inches above the bridge deck and transversely located on 10 ⅝-inch centers with 21-inch minimum lap joints. The curb was anchored to the deck with 214 ⅝-inch diameter (#5 rebar) V bars measuring 12½ inches wide × 14¼ inches tall and spaced on 9-inch centers along the length of the curb. The top of the V bars extended 7 inches into the curb above the deck. Engineering details of the T224 Bridge Rail are shown in Figures 2 to 8. For additional information on the T224 design, please refer to Figures 1 to 8. Photographs of the completed installation are shown in Figure 9.
FIGURE 2  T224 Layout and Section Details
#4 longitudinal bars at 12" in new Moment Slab
(Transverse Bars replace top mat U-bars at same spacing.)

2a. Minimum rebar laps are 25" for #6 (Ø3/4") bars, 21" for #5 (Ø5/8") bars, and 17" for #4 (Ø1/2") bars.
2b. Bar spacing may be adjusted ±5/8" to avoid conflict with other bars.
2c. Rebar clearance is 1-1/4" at bottom of Deck and 2-1/2" at top. 2" at all other locations unless otherwise indicated.
2d. L-Tie Bars weld to rebar protruding from existing Moment Slab at 18". Epoxy bars into Moment Slab as needed (not shown here).

FIGURE 3 Deck & Curb Details
FIGURE 4 Deck & Curb Details Side View

3a. Rebar spacing is typical for each side of Expansion Joint. Top Transverse Bars are #5’s alternating single and double at 3-1/2” for 42”, followed by #5’s at 4-1/2” with #4 bars beside alternating #5’s to end of Rail. (Top Deck L-bars will be replaced with straight bars, same size and spacing, in new Moment Slab.)
FIGURE 5 Details at End Post and at Joint
FIGURE 6  Details at Mid-Span Post (Away From Joint)
<table>
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<tr>
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<td>VP-2 Bar</td>
<td>100</td>
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<tr>
<td>Transverse Bar, Top #5</td>
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<td>8</td>
</tr>
<tr>
<td>Post Bar</td>
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<td>4</td>
</tr>
<tr>
<td>Tie Bar</td>
<td>160</td>
</tr>
<tr>
<td>Joint Bar</td>
<td>3</td>
</tr>
<tr>
<td>#5 Moment Slab/Deck Bar</td>
<td>80</td>
</tr>
<tr>
<td>#4 Moment Slab/Deck Bar</td>
<td>40</td>
</tr>
</tbody>
</table>

**FIGURE 7  Rebar Details Deck & Stirrups**

6a. All rebar is grade 60.
FIGURE 8 Rebar Details Deck, Posts and Curb
Material Specifications

The specified minimum unconfined compressive strength of the concrete for the bridge deck, curb, and parapet was 4000 psi TXDOT Class S. The compressive strengths of the six batches of concrete used in the construction measured an average of 3830 psi.

Steel reinforcement was ASTM A615 grade 60 rebar with specified minimum yield strength of 60 ksi. Epoxied connections into our concrete apron were installed with Hilti RE500 epoxy anchoring system according to Hilti instructions.
FULL-SCALE MASH TL-5 CRASH TESTING OF T224 BRIDGE RAIL

Full scale crash testing was performed on the T224 Bridge rail in accordance with MASH TL-5 specifications. The tests performed on the T224 Bridge rail are as follows:

**MASH Test 5-10:** A 2420-lb vehicle impacting the critical impact point (CIP) of the length of need (LON) of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test investigates a barrier’s ability to successfully contain and redirect a small passenger vehicle.

**MASH Test 2-11:** A 5000-lb pickup truck impacting the CIP of the LON of the barrier at a nominal impact speed and angle of 62 mi/h and 25 degrees, respectively. This test investigates a barrier’s ability to successfully contain and redirect light trucks and sport utility vehicles.

**MASH Test 5-12:** An 80000-lb Truck-Tractor Trailer impacting the CIP of the LON of the barrier at a nominal impact speed and angle of 50 mi/h and 15 degrees, respectively. This test investigates a barrier’s ability to successfully contain and redirect light trucks and sport utility vehicles.

MASH Tests 5-10 and 5-11 evaluate a barrier’s ability to successfully contain and redirect passenger vehicles and evaluate occupant risk. **MASH** Test 5-12 evaluates the structural adequacy of the bridge rail. All three tests were performed on the TXDOT T224 Bridge Rail. The target CIP for each test was determined according to the information provided in **MASH** and is summarized in Figure 10.

![Figure 10](image-url)

**FIGURE 10** Target CIP’s for TL-5 Tests on the TXDOT T224 Bridge Rail
MASH Test 5-10 2420-lb Small Car
MASH Test 5-10 was performed on August 08, 2015. Based on the results from the crash test, the T224 Bridge Rail performed acceptably with respect to all the evaluation criteria in MASH Test Level 5-10 Specifications. Photos of the MASH 5-10 small car crash test vehicle and installation before and after the test are provided in Figure 11.

MASH Test 5-11 5000-lb Pickup Truck
MASH Test 5-11 was performed on August 19, 2015. Based on the results from the crash test, the T224 Bridge Rail performed acceptably with respect to all the evaluation criteria in MASH Test Level 5-11 Specifications. Photos of the MASH 5-11 pickup truck crash test vehicle and installation before and after the test are provided in Figure 12.
MASH Test 5-12 80,000-lb Truck Tractor Trailer

MASH Test 5-12 was performed on August 21, 2015. Based on the results from the crash test, the T224 Bridge Rail performed acceptably with respect to all the evaluation criteria in MASH Test Level 5-12 Specifications. Photos of the MASH 5-12 truck tractor trailer crash test vehicle and installation before and after the test are provided in Figure 13.

FIGURE 12 MASH Test 5-11 Before & After Test Photos.
FIGURE 13 MASH Test 5-12 Before & After Test Photos.
Damage to Test Installation for Test 5-12

Figure 13 shows some damage to the TXDOT T224 Bridge Rail. The curb was fractured at its connection with the deck 3.5 feet both upstream and downstream from the joint. The curb was also cracked over a length ranging from 6 feet upstream to 17 feet downstream of the joint. The upper rail was slightly cracked from the joint extending downstream for 18 feet, and two cracks in the rail were noted from the joint extending upstream 12.5 feet (primary crack) and 17 feet 8 inches (secondary crack). The field side of the deck was cracked upstream of post 5. Working width was 38.5 inches from the traffic side of the bridge rail to the farthest extent of the vehicle. Maximum dynamic deflection during the test was approximately 2.1 inches, and maximum permanent deformation as 1.4 inches.

SUMMARY AND CONCLUSIONS

The TXDOT T224 with 15-foot post spacing met all the strength and safety performance criteria of MASH TL-5. The calculated strength of the rail at the open joint over 2-spans was approximately 124 kips. This value was based on the flexural resistance of the deck over the two spans (post in the immediate impact are at the joint). Based on the results from the large truck test, some deck damage was observed in the rail and deck. It appears based on the results, that this calculated strength of 124 kips was exceeded. It is estimated that the impact force from the large TL-5 truck is approximately 150 kips. Based on the results from the crash test, the calculated limiting strength of 124 kips appeared to be a good strength calculation value for this design. The method of analyses used to determine this limiting strength yielded good results. The author of this paper will use the analytical approach to determine this limiting strength for similar calculations in the future. The large truck did impart a force greater than this calculated value based on the slight damage to the bridge rail and deck in the impact region. In addition, the crash results for the small car and pickup truck tests were very good. All the occupant threshold values for the MASH Specification were well within the limits for the small car and pickup truck tests. TXDOT plans to use this bridge rail in the very near future on bridges that need a TL-5 barrier. The T224 Bridge Rail is ready for implementation on TXDOT bridge projects. In addition, the aesthetic openings in the rail make this rail an attractive alternative for MASH TL-5 applications.

REFERENCES


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