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Project Summary Report 9-8132-S
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Project 9-8132: Florida DOT Bridge Rails

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PROJECT SUMMARY REPORT

Evaluation of Florida DOT Transportation Safety Devices

The Florida Department of Transportation (FDOT) identified six transportation safety design issues that could benefit from further research. In conjunction with the Texas Department of Transportation (TxDOT), these were addressed as individual tasks in a pooled fund research project.

What We Did...

The six design issues were identified as follows:

1. FDOT has extensive Jersey-shaped barriers in use on highways today. A number of the designs from previous years have minimal reinforcement, and when the current design procedure is used to evaluate the respective designs, the analysis indicates marginal performance may be anticipated when impacted by an errant vehicle. Therefore, FDOT has elected to full-scale crash test the most critical design currently deployed in the field.

2. The second area of research need is to evaluate one existing variant of the 32-inch Kansas Corral railing to determine compliance status with the *American Association of State Highway and Transportation Officials (AASHTO) Load Resistance Factor Design (LRFD) Bridge Design Specifications* and *National Cooperative Highway Research Program (NCHRP) Report 350*, Test Level 4 (TL-4) criteria. This task is to be accomplished by comparison to existing crash-tested designs and, if warranted, a full-scale crash test to verify acceptable performance.

3. Current design procedures outlined in *AASHTO LRFD Bridge Design Specifications* specify a minimum thickness of the cantilevered portion of the bridge deck based on the strength of the bridge railing. FDOT desires to investigate failure modes of bridge railings and decks when thinner decks are used.

4. FDOT currently uses aluminum directional slip bases for small and medium size sign supports. The bases have not been full-scale tested for proper activation.

5. FDOT has a pending issue that they desire to investigate. Parapet orientation relative to the bridge deck or relative to a horizontal plane requires further evaluation. Sometimes parapets are oriented perpendicular to the deck, or sometimes they are installed plumb with the earth. Investigation of other states and recommendations are desired.

6. FDOT has pending projects that require an aesthetic TL-4 bridge railing. TxDOT has previously tested the F411 bridge rail to Test Level 3 (TL-3) under a previous contract and has approved the testing of the installation under this contract. This task is the full-scale crash test of the F411 to TL-4.

The most direct approach for accomplishing the objectives of Tasks 1, 4, and 6 was through full-scale testing. For Task 1, two full-scale crash tests were performed on the most critical of the three variants of the 32-inch (813 mm) Jersey-shaped railing design used in Florida. *NCHRP Report 350* test 4-12 (single-unit box-van truck at 15 degrees and 49.7 mi/h [80 km/h]) was performed at the mid-length of the barrier (see Figure 1) to evaluate vehicle containment. *NCHRP Report 350* test 4-11 (pickup truck at 25 degrees and 62.2 mi/h [100 km/h]) was performed near the end of the barrier (see Figure 2) to determine the end segment parapet capacity, as well as evaluate vehicle instabilities and rollover potential. Three pendulum tests were performed

to determine proper activation of three uni-directional slip bases for Task 4. Under Task 6, *NCHRP Report 350* test 4-12 was performed on the F411 bridge rail (see Figure 3) to evaluate compliance with *NCHRP Report 350* TL-4 requirements.

Utilizing the guidance of *AASHTO LRFD Bridge Design Specifications* and information from recent testing for comparison purposes, a variant of the Modified Kansas Corral (MKC) bridge rail was evaluated under Task 2.

For Task 3, the guidance of *AASHTO LRFD Bridge Design Specifications* along with static testing was used to investigate the required deck thicknesses associated with safety shapes and, more specifically, the F-shape as adopted by FDOT.

Limited field observation suggests that safety-shaped bridge rail parapets that are cast plumb to the earth may produce a ramping effect on errant vehicles when roadway cross-slopes are high. Under Task 5, the performance of bridge rail parapets with different orientations was comparatively evaluated using finite element analysis. Simulations were performed using LS-DYNA, which is a general-purpose explicit-implicit nonlinear finite element program capable of simulating complex nonlinear dynamic impact problems. It can and has been used to model vehicular collisions with roadside objects.

Figure 1. *NCHRP Report 350* test 4-12 on the 32-inch (813 mm) Jersey-shaped railing design used in Florida.

Figure 2. *NCHRP Report 350* test 4-11 on the 32-inch (813 mm) Jersey-shaped railing design used in Florida.

What We Found...

Task 1. FDOT 32-Inch Jersey-Shaped Railing

With the successful redirection of both the single-unit truck and the pickup, the parapet was deemed acceptable. Since the *AASHTO LRFD Bridge Design Specifications* design method indicated the potential for poor performance in the full-scale crash test, static tests replicating the loads used in the design procedure in *AASHTO LRFD Bridge Design Specifications* were performed to verify actual capacities of the bridge parapet. The damage from the single-unit truck impact at the expansion joint appeared to be limited to surface scarring of the concrete — no visible cracks were identified. The ultimate static load at this location was 45.1 kips (201 kN); predicted was 41.1 kips (183 kN). Therefore, the actual load exceeded the yield line analysis prediction by approximately 10 percent.

Task 2. 32-Inch Kansas Corral Railing

The FDOT variant of the Modified Kansas Corral (FVMKC) is similar to the previously crash-tested Texas T203 (T202 [MOD]) and the California 80SW bridge rail. Offset between the post and beam on the T203 are 4-1/2 inches (114 mm) and 1-1/2 inches (38 mm) on the FVMKC. The post height is 13 inches (330 mm) on both the T203 and the FVMKC. However, portions of the openings on the FVMKC have been reduced by the placement of a 6-inch (152 mm) curb in the openings. Both the California 80SW and the FVMKC are 32 inches (810 mm) tall.

Task 3. Design of Deck Overhang

The results of the static testing clearly indicate that the flexural strength of deck, as designed by FDOT and currently used by FDOT in conjunction with the F-shaped bridge parapet, is appropriate. The flexural strength of the deck is less than the parapet at its base and conflicts with the recommendations found in *AASHTO LRFD Bridge Design Specifications* section A13.4.2.

Task 4. Uni-directional Slip Base Performnce Verification

All three uni-directional slip base supports performed well. The data obtained in the low-speed pendulum tests were used to calculate a predicted change in velocity as a result of a

Figure 3. *NCHRP Report 350* test 4-12 on the TxDOT F411 bridge rail.

theoretical high-speed impact. Based on the results of the pendulum tests and the high-speed extrapolations, the aluminum slip bases and supports used by FDOT and tested under this project are compliant with the performance recommendation outlined in *NCHRP Report 350*.

Task 5. Concrete Parapets with TxDOT T4 Retrofit and Parapet Orientations

Simulation results show that all parapet orientations successfully redirect the impacting vehicle. With increasing roadway cross-slope, the vehicle becomes more unstable due to increased vehicle roll and yaw. Even though the vehicle did not roll over in any of the simulated cases, it should be noted that for a 10 to 1 cross-slope, a 40-degree roll angle was observed. Considering some of the limitations of current suspension models and a potential variation in the center of gravity of vehicles, a roll angle of 40 degrees in simulation would be considered marginal.

Task 6. TL-4 Testing of TxDOT F411 Bridge Rail

The single-unit truck was redirected and remained upright during the collision event. However, upon exiting the installation site, the vehicle rolled 90 degrees. The TxDOT F411 bridge rail performed acceptably for the required criteria in *NCHRP Report 350* test 4-12.

The Researchers Recommend...

Task 1. FDOT 32-Inch Jersy-Shaped Railing

The Florida bridge rail performed acceptably according to the specifications of *NCHRP Report 350* test designations 4-11 and 4-12. *AASHTO LRFD Bridge Design Specifications* uses a 54-kip (240 kN) design load for single-unit trucks. Since the parapet was not structurally damaged in the TL-4 test with the single-unit truck, further research should be undertaken to account for the reduced loads apparently imparted by the impacting single-unit truck.

Task 2. 32-Inch Kansas Corral Railing

The FVMKC is similar to the original Kansas Corral bridge rail. Offset between the post and beams are 1-1/2 inches (38 mm) on the FVMKC and 2 inches (50 mm) on the original Kansas Corral, and the post height is 12 inches (305 mm) on the FDOT variant and 13 inches (330 mm) on the Kansas Corral system. The curb and the shorter opening of the FVMKC will likely produce similar crash test results to the California 80SW bridge rail.

Task 3. Design of Deck Overhang

The results of the static tests clearly indicate that the flexural strength of deck, as designed by FDOT and currently used by FDOT in conjunction with the F-shaped bridge parapet, is appropriate. This research indicates that, for safety-shaped bridge parapets, the design moment capacity of the deck can be less than the design moment capacity at the base of the safety shape. This research is contrary to the statement found in A13.4.2 in *AASHTO LRFD Bridge Design Specifications* that states "...M_s...exceeds M_c of the parapet **at its base**." At end-of-parapet or expansion joints in the bridge, the deck flexural capacity should be increased and designed to minimize potential deck damage in overload conditions.

Task 4. Uni-directional Slip Base Performance Verification

Based on the results of the pendulum tests and the high-speed extrapolations, the aluminum slip bases and supports used by FDOT and tested under this project are compliant with the performance recommendation outlined in *NCHRP Report 350*. These slip bases are uni-directional and, therefore, should only be used where impact angles are not expected to exceed 20 degrees — not used at intersections where perpendicular impacts are expected.

Task 5. Concrete Parapets with TxDOT T4 Retrofit and Parapet Orientations

Using the best available vehicle models and state-of-the-art simulation technology, a high roll angle of 40 degrees was observed for a 10 to 1 cross-slope. Even though this amount of vehicle roll is acceptable in a crash test, given the limitations of current vehicle models, the case should be considered marginal. When cross-slopes approach 10 to 1, parapet orientation should be relative to the deck and not plumb with the earth.

Task 6. TL-4 Testing of TxDOT F411 Bridge Rail

The TxDOT F411 bridge rail performed acceptably for the required criteria *NCHRP Report 350* test 4-12 and may be used where containment of 18,000-lb (8164 kg) single-unit trucks is desired.

For More Details...

The research is documented in the following:

Report 9-8132-1: *Testing and Evaluation of the Florida Jersey Safety Shaped Bridge Rail*
Report 9-8132-2: *Evaluation of the FDOT Variant of the Modified Kansas Corral Bridge Railing*
Report 9-8132-3: *Testing and Evaluation of the Florida F Shape Bridge Rail with Reduced Deck Thickness*
Report 9-8132-5: *Comparative Simulation Evaluation of Bridge Parapet Orientations*
Product 9-8132-P7: *TL-4 Crash Testing of the F411 Bridge Rail*

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