Tennessee Bridge Rail to Guardrail Transition Designs

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Potential problems associated with the impact performance of guardrail to bridge rail transition designs currently used by the Tennessee Department of Transportation were identified through use of computer simulation. To alleviate these deficiencies, three alternative designs were developed for use as a retrofit to their existing transition installations and for new installations. In the first retrofit alternative, the first three 6-ft (1.83-m)-long W6 × 15 posts adjacent to the concrete parapet are replaced with 8-ft (2.44-m)-long W8 × 21 posts. The second design involves the addition of two 6-ft (1.83-m)-long W6 × 15 posts between the first three existing W6 × 15 posts to effectively reduce the post spacing to 1 ft 6.75 in. (0.48 m). The third retrofit design involves the addition of a lower C6 × 8.2 channel rub rail to the existing transition system. All three modified designs were crash tested and found to perform satisfactorily in accordance with the recommended guidelines presented in *NCHRP Report 230.* Since the impact performances of the three systems were essentially the same, the choice of which design to use as a retrofit in the field becomes a consideration of cost and site-specific requirements. Details of these three alternative transition designs and the results of the full-scale crash tests are presented.

A study was undertaken by the Texas Transportation Institute to analyze and evaluate the impact performances of various bridge rail, guardrail, transition, and end treatment designs currently in use by the Tennessee Department of Transportation (TDOT). The results of an evaluation of the existing TDOT guardrail to bridge rail transition design and the effort to design, develop, and crash test various retrofit transition designs are presented here.

TDOT currently uses a steel post design for approach guardrails at bridge ends. The standard steel post system, shown in Figure 1, consists of a 25-ft (7.62-m) section of 10-gage W-beam mounted at a height of 27 in. (68.6 cm) on six W6 × 15 structural steel posts embedded 44 in. (1.12 m) and spaced at a reduced post spacing of 3 ft 1.5 in. (0.95 m). In addition, the first three posts upstream from the end of the concrete bridge parapet have ¼-in. × 8-in. × 24-in. (0.64-cm × 20.3-cm × 61.0-cm) steel soil plates welded 5 in. (12.7 cm) below the ground surface. No W-beam backup plates are specified beyond the first W6 × 15 post in the transition, at which point the post spacing is reduced 3 ft 1.5 in. (0.95 m).

One of the most common parapets to which this transition is attached is shown as Detail A in Figure 1. This design corresponds to TDOT standard drawing K-38-151. The wing post is a vertical concrete wall 27 in. (0.69 m) high and 12 in. (30.5 cm) thick. The end of the wall tapers away from the roadway to a thickness of 3 in. (7.6 cm).

The existing transition design connected to a vertical concrete parapet was evaluated by using the Barrier VII computer simulation program (*1*). The Barrier VII computer simulation model is a two-dimensional simulation program that models vehicular impacts with deformable barriers. The program employs a sophisticated barrier model that is idealized as an assemblage of discrete structural members possessing geometric and material nonlinearities. It has been used successfully to simulate impacts with a variety of flexible barriers, including transitions from flexible to rigid barriers (*2–4*).

The simulation results indicated that this transition design would exhibit undesirable impact performance. Predicted values for maximum dynamic rail deflection and wheel overlap on the end of the flared vertical concrete wing post were 12 in. (30.5 cm) and 4.3 in. (10.9 cm), respectively. With reference to Figure 1, Detail A, it can be seen that the predicted extent of wheel contact projects beyond the back edge of the parapet. Although not confirmed with a full-scale test, contact of this magnitude was considered unacceptable because of the high probability of the wheel assembly hooking or snagging abruptly on the end of the concrete wingpost. Such behavior could lead to severe deceleration of the vehicle or other undesirable results.

In view of the deficiencies identified with the current transition system, it was necessary to investigate alternative designs for potential use by TDOT. In recent years FHWA has issued two technical advisories (TAs) on the subject of guardrail transitions. These TAs provide information on new and retrofit transition systems that have been successfully crash tested (*5,6*). In TA T5040.26 (*5*), several transition designs appropriate for attachment to a vertical parapet with a curved, flared, or tapered end were presented. TA T5040.34 (*6*) presented several additional transition designs appropriate for attachment to concrete safety-shaped bridge parapets.

The parapet commonly used by TDOT possesses some general similarities to the vertical curved-back and vertical flared-back concrete bridge rail ends detailed in TA T5040.26. However, the exposed ends of these parapets are offset 18 in. (45.7 cm) and 16 in. (40.6 cm), respectively, from the traffic face of the rail. As shown in Figure 1, the geometry of the TDOT parapet is much more severe, with the end tapered only 9 in. (22.9 cm) from the face of the rail. For this reason it was concluded that the impact performance of a system consisting of one of the transition designs in the FHWA TAs attached to the TDOT parapet could not be inferred from previous test results and that additional testing was warranted. Furthermore, although TDOT has the option of changing its standard bridge end parapet details and adopting one of the TA designs for new construction applications, it was considered essential that one or more designs be developed and tested for retrofitting the numerous installations that currently exist in the field.

A significant simulation study was undertaken in an effort to identify design modifications that would alleviate the identified deficiencies and improve the impact performance of TDOT's existing transition system. When selecting potential design modifications, several factors were considered including ease of retrofitting

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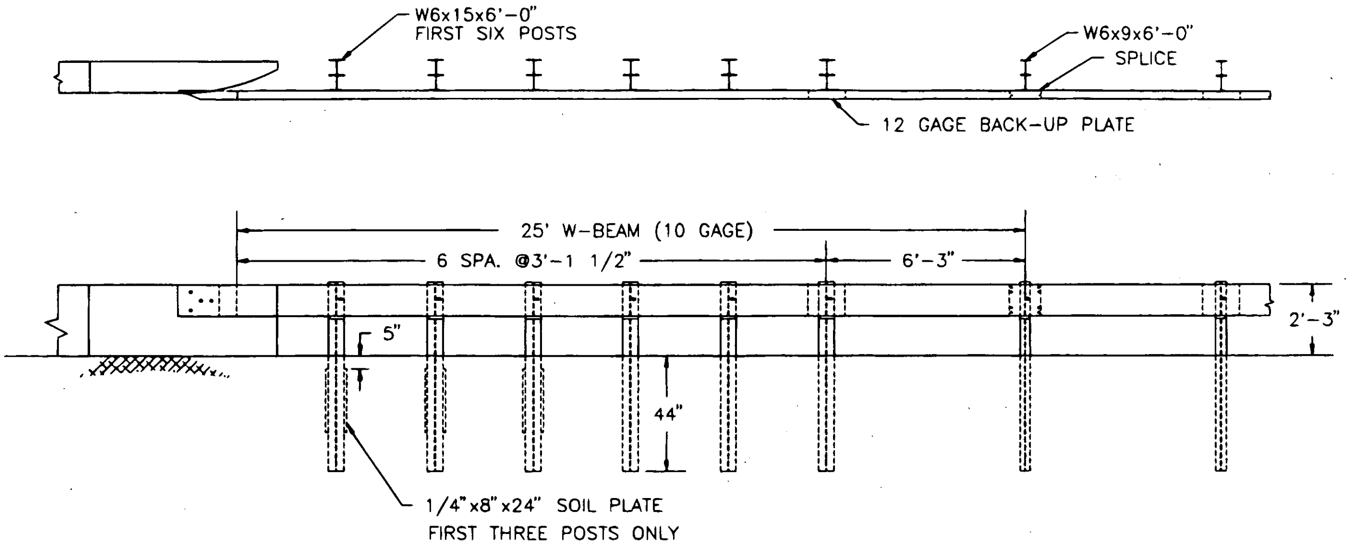


FIGURE 1 Standard TDOT steel post transition to vertical concrete parapet.

existing installations and use of standard hardware items. The objective was to increase lateral barrier stiffness and thereby reduce maximum barrier deflections and wheel snagging on the end of the bridge parapet. The key parameters that were investigated included beam strength, post size, post embedment depth, and post spacing. Although none of the designs contained in the FHWA TAs were directly adopted, many of the design details of these systems were used in developing candidate designs for use with TDOT's vertical concrete parapet.

On the basis of this analysis, three alternative retrofit transition designs were developed for consideration by TDOT. Details of these three retrofit designs are discussed in the following sections.

DESIGN DETAILS

System 1: Larger Post Size and Embedment Depth

In the first retrofit alternative, the first three 6-ft (1.83-m)-long W6 × 15 posts adjacent to the concrete parapet are replaced with 8-ft (2.44-m)-long W8 × 21 posts. These larger posts have an embedment depth of 68 in. (1.73 m), compared with the standard embedment depth of 44 in. (1.12 m). The next three posts upstream in the transition section are the standard 6-ft (1.83-m)-long W6 × 15 structural steel posts with a standard embedment depth of 44 in. (1.12 m) at the existing post spacing of 3 ft 1.5 in. (0.95 m).

The use of the W8 × 21 posts allows greater stiffness to be achieved through increased embedment depths. When the 8-ft (2.44-m)-long W8 × 21 posts were used in lieu of the standard 6-ft (1.83-m)-long W6 × 15 posts, computer simulation indicated a reduction in the amount of wheel overlap on the end of the concrete parapet of 2.5 in. (6.4 cm). Note that soil plates are not used with the W8 × 21 posts since studies have shown that soil plates contribute very little to the post stiffness (*2*).

The rail element consists of a 25-ft (7.62-cm) section of single 12-gage W-beam mounted at a height of 27 in. (68.6 cm). Although the existing standard TDOT transition uses a 10-gage W-beam, TDOT expressed an interest in testing with a 12-gage rail to reduce inventory and eliminate the possibility of construction and maintenance crews installing a rail of improper thickness in the transition. The simulation results indicated and previous testing has shown that a single 12-gage W-beam rail is capable of withstanding the severe dynamic loading that occurs during a transition impact (*7*). However, the use of a single W-beam requires that backup plates be used at all nonsplice post locations. The importance of backup plates in steel post guardrail systems has been demonstrated in full-scale crash testing (*8*).

It should also be noted that a 6-in. (15.24-cm)-inner diameter, 12-in (30.5-cm)-long Schedule 40 pipe is placed between the rail and the flared portion of the concrete parapet. The purpose of this steel pipe is to help minimize deflections and prevent local yielding of the W-beam rail around the end of the parapet by acting as a controlled, collapsible spacer. The spacer tube is connected to the W-beam rail with a single ⅝-in. (1.59-cm) button-head bolt. Other than the use of the spacer pipe, there were no changes to the connection of the W-beam rail to the bridge parapet from the original TDOT design. Details of the System 1 retrofit installation are shown in Figure 2.

System 2: Reduced Post Spacing

The second candidate retrofit transition design incorporates W6 × 15 structural steel posts with two sets of reduced post spacing. Adjacent to the concrete parapet, the post spacing is 1 ft 6.75 in. (0.48 m), which is followed by a post spacing of 3 ft 1.5 in. 0.95 m). In a retrofit situation this alternative would simply involve placing two additional W6 × 15 posts between the first three existing posts. These two additional intermediate posts are not connected to the W-beam but are simply installed with the face of the blockout adjacent to the back side of the rail. The embedment depth for all of the W6 × 15 posts is the standard 44 in. (1.12 m). Note that, although the existing W6 × 15 posts incorporate soil plates, the use of soil plates on these posts and on the additional posts is not required. Previous studies have shown that the addition of soil plates on W6 × 15 posts does little to increase either the stiffness or the maximum capacity of the soil-post system (*2*).

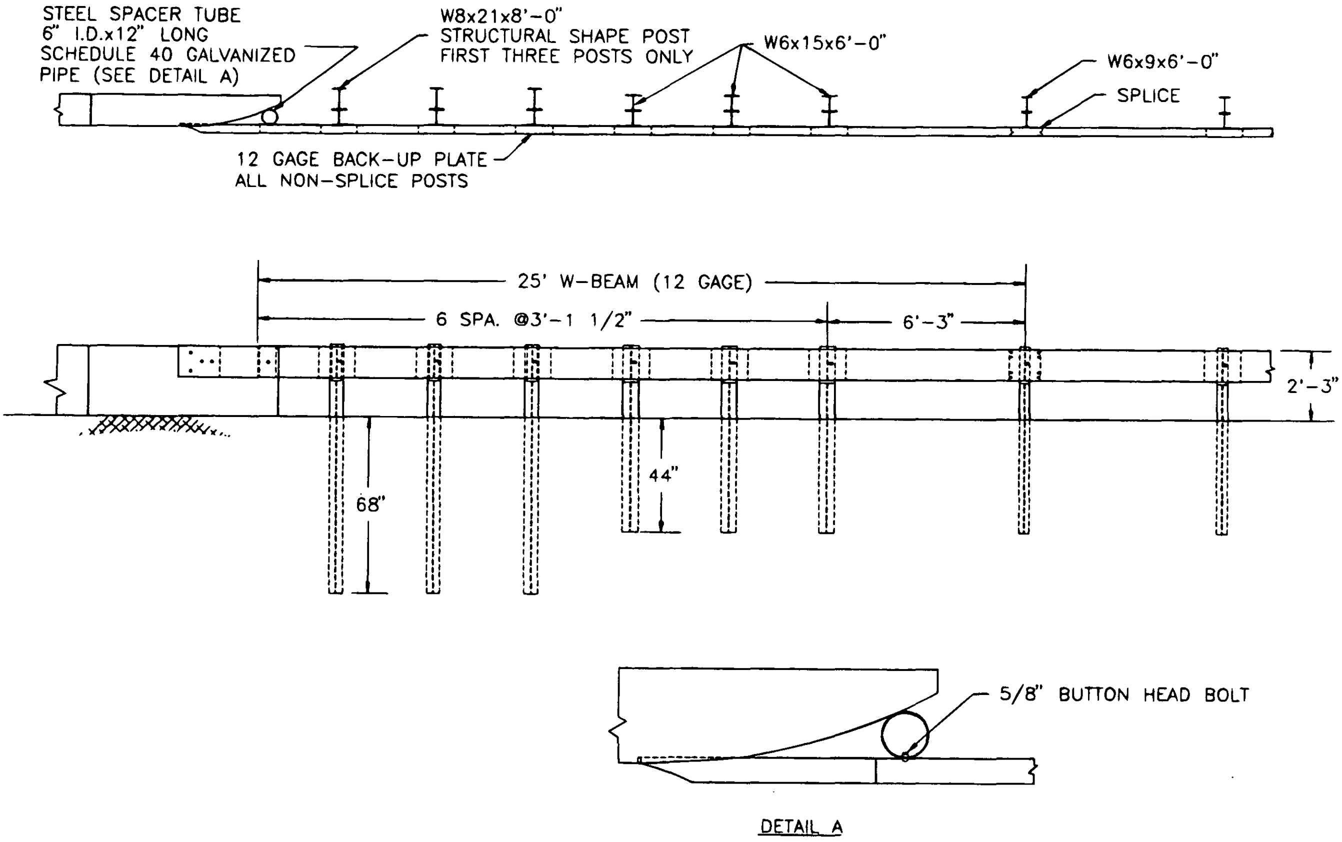


FIGURE 2 Modified steel post transition to vertical concrete parapet—larger post size and embedment depth option.

Based on the crash test results of System 1, a nested 12-gage W-beam rail was incorporated into the design of Transition Systems 2 and 3 to further enhance impact performance. Simulation results indicated that the nested rail would decrease the amount of wheel overlap on the end of the parapet by approximately 0.5 in. (1.27 cm) and, more importantly, would reduce the degree of localized yielding of the rail at the spacer pipe. No backup plates are required in the region of the nested rail.

As with the System 1 design, a 6-in. (15.24-cm)-diameter steel spacer pipe is used between the nested W-beam rail and the flared wall of the concrete parapet. Otherwise, the connection details remain unchanged and the nested W-beam rail is terminated with a standard W-beam terminal connector. Details of the System 2 design are shown in Figure 3.

System 3: Rub Rail

The third alternative transition design uses a C6 × 8.2 steel channel as a lower rub rail element to help mitigate the amount of wheel contact on the end of the concrete parapet. This rub rail is anchored to the concrete parapet and is also connected to the front flanges of the steel guardrail posts. The upstream end of the rub rail is terminated behind the fifth post in the transition to minimize the potential for spearing or wheel snagging during upstream impacts. The posts and post spacing are identical to those of the standard TDOT transition, with W6 × 15 posts embedded 44 in. (1.12 m) and spaced at 3 ft 1.5 in. (0.95 m). Once again, although soil plates will be present in the field on existing installations, their use is not required during repair or new construction applications.

Similar to System 2, this design uses a 25-ft (7.62-m) section of nested 12-gage W-beam rail adjacent to the concrete parapet and a 6-in. (15.24-cm)-diameter spacer pipe between the nested W-beam rail and the flared portion of the concrete parapet. Details of the System 3 retrofit transition installation are shown in Figure 4. Each of these three alternative retrofit designs was crash tested and evaluated, and the results are presented as follows.

CRASH TEST RESULTS

The test installation consisted of a simulated vertical concrete bridge parapet with a 9-in. (22.9-cm) flare away from the roadway. Details of the parapet conform to TDOT standard drawing K-38-151 and are shown in Figure 1. Attached to the vertical parapet is the 25-ft (7.62-m) transition section. The posts in the transition were placed by drilling and backfilling with a standard strong soil as defined in *NCHRP Report 230* (*9*). Upstream from the transition section is a standard G4(1S) guardrail consisting of a 12-gage W-beam mounted at 27 in. (68.6 cm) on W6 × 9 steel posts spaced at 6 ft 3 in. (1.91 m). The total length of the approach guardrail was 75 ft (22.9 m), with the upstream end terminated with a standard breakaway cable terminal end terminal.

Each of the three alternative transition designs was crash tested and evaluated in accordance with the test procedures and the evaluation criteria outlined in *NCHRP Report 230* (*9*). As recommended

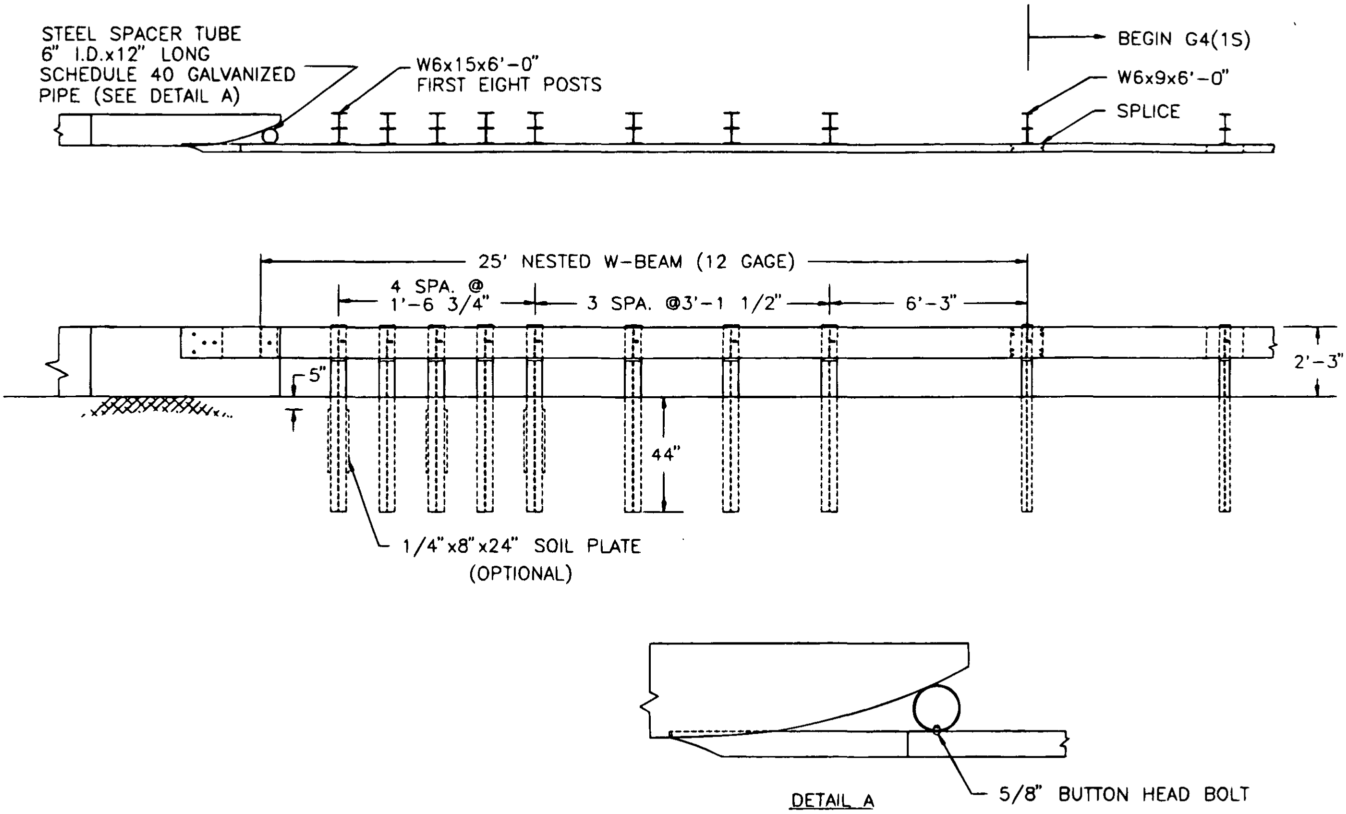


FIGURE 3 Modified steel post transition to vertical concrete parapet—reduced post spacing option.

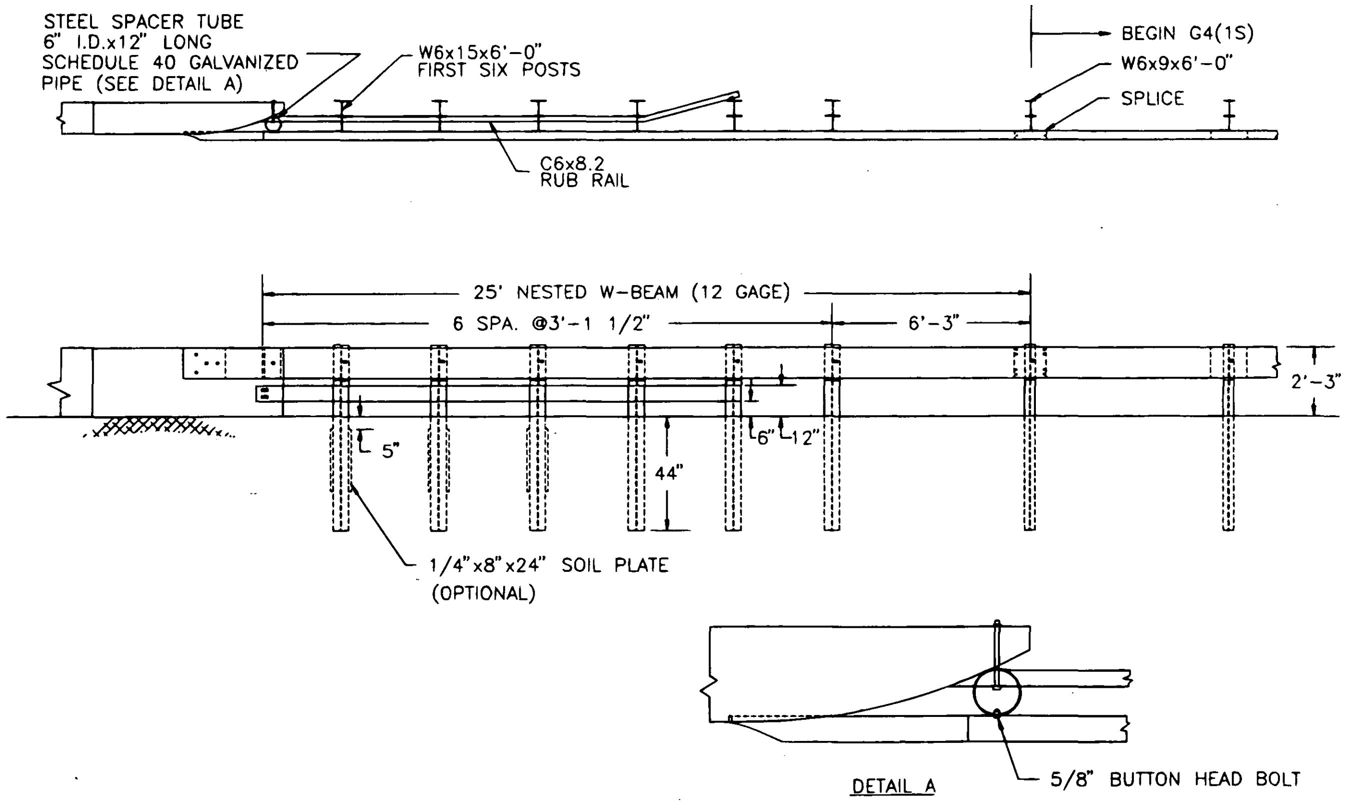


FIGURE 4 Modified steel post transition to vertical concrete parapet—rub rail option.

in *NCHRP Report 230*, each of the three alternative designs was crash tested with a 4,500-lb (2,041-kg) vehicle striking the transition section at a speed of 60 mph (96.6 km/hr) and an angle of 25 degrees. The point of impact for all three transition designs was selected at 6 ft (1.83 m) from the end of the concrete wing post, which was determined to be the critical impact location for these transition systems based on Barrier VII computer simulation results.

System 1: Larger Post Size and Embedment Depth

The System 1 test installation is shown in Figure 5. A 1982 Oldsmobile Ninety-Eight impacted the transition 6.0 ft (1.8 m) upstream from the end of the concrete parapet at 61.4 mph (98.8 km/hr) and at an angle of 25.1 degrees. Although significant wheel contact with the parapet end was observed, the vehicle was successfully redirected. The spacer pipe performed as designed, preventing excessive deflections of the W-beam along the flared portion of the parapet. Although there was some evidence of localized yielding of the W-beam around the spacer pipe, the pipe collapsed in a controlled manner before allowing any significant pocketing or snagging to occur.

As the vehicle redirected, the rocker panel at the base of the A-pillar contacted the flared section of the parapet, causing some buckling and wrinkling of the floor pan beneath the passenger seat and near the transmission housing. The vehicle lost contact with the rail at approximately 0.34 sec after impact, traveling at a speed of 45.3 mph (72.9 km/hr) and at an exit angle of 8.2 degrees.

The damage to both the test installation and the vehicle is shown in Figure 6. The transition and concrete parapet sustained only minor damage. There was residual deformation to the rail in the area of the first three posts, with the maximum permanent rail deformation being 5.0 in. (12.7 cm). The spacer pipe positioned between the W-beam rail and the flared portion of the parapet collapsed approximately 1 in. (2.54 cm).

The damage sustained by the test vehicle was substantial. The maximum crush was 16.0 in. (40.6 cm) at the right front corner of the vehicle. The right front wheel and control arm were bent and pushed rearward 15.3 in. (38.7 cm) because of contact with the end and sloped face of the concrete parapet. The front end of the vehicle was shifted to the left 3.0 in. (7.6 cm). In addition, the subframe was bent, the floor pan was buckled, and the windshield was broken.

In summary, the transition was judged to have met the performance criteria set forth in *NCHRP Report 230* (*9*). The test vehicle

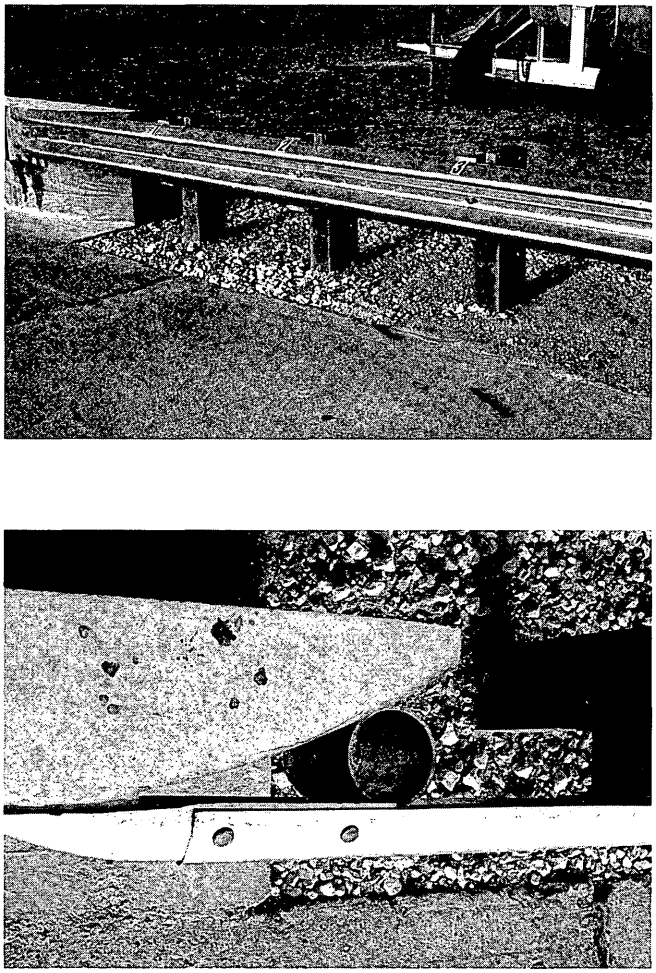


FIGURE 5 Tennessee large post transition before testing of System 1.

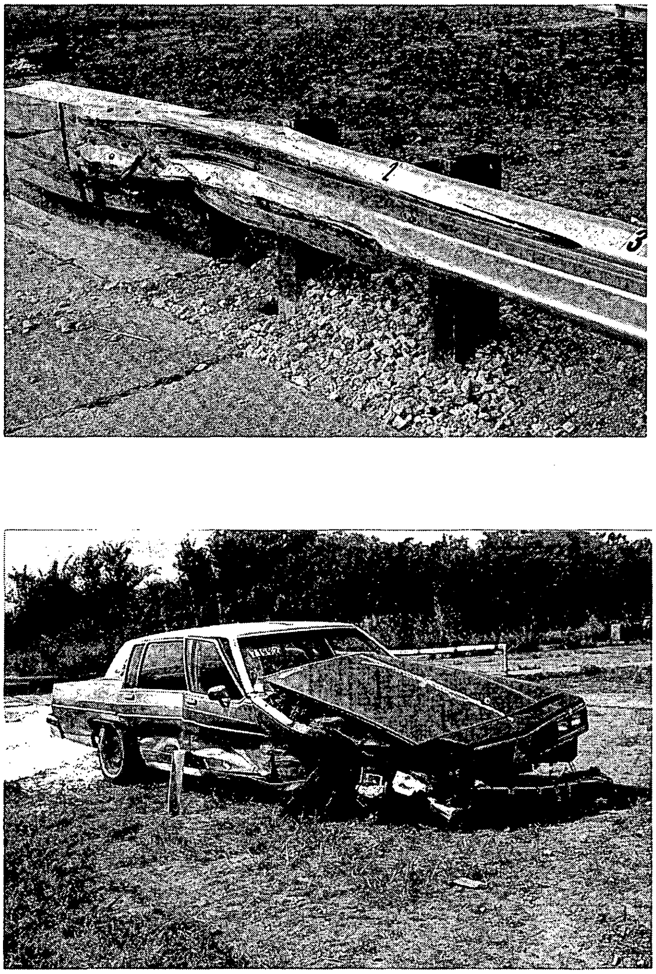


FIGURE 6 Barrier (*top*) and vehicle (*bottom*) damage after testing of System 1.

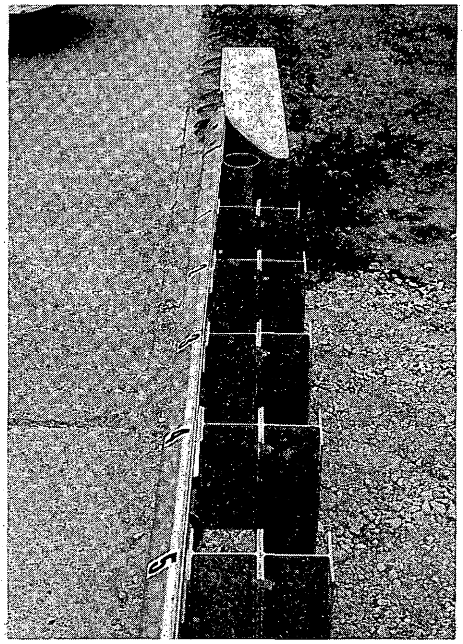
remained upright and stable during the impact period and after leaving the installation, and there was no debris from the vehicle or barrier that might present undue hazard to other traffic. Damage to the transition was relatively minor, with no apparent structural damage to the concrete bridge parapet. Although damage to the test vehicle was severe, there was minimal intrusion into the occupant compartment. Contact of the subframe with the flared wall of the concrete parapet caused the floor pan of the vehicle to buckle. However, this deformation was primarily concentrated under the front passenger's seat and was not judged to pose a significant hazard to the occupant.

System 2: Reduced Post Spacing

The System 2 test installation is shown in Figure 7. In this test a 1980 Oldsmobile Ninety-Eight struck the transition 6.0 ft (1.8 m) upstream from the end of the concrete parapet at 62.0 mph (99.8 km/hr) and at an angle of 24.4 degrees. Shortly after impact, the right front wheel rotated about the spindle assembly, allowing it to fold under the rail and contact the first two guardrail posts upstream from the end of the concrete parapet. As the vehicle progressed along the transition, the right front wheel contacted the end of the parapet and the subframe at the base of the A-pillar contacted the flared face of the parapet. Although this contact was significant, the vehicle remained stable and was successfully redirected. The vehicle lost contact with the rail approximately 0.34 sec after impact, traveling at a speed of 44.3 mph (71.2 km/hr) and at an exit angle of 13.5 degrees.

Figure 8 shows the damage to the barrier and vehicle after the test. Residual deformation of the guardrail occurred in the vicinity of the first six posts. The maximum permanent rail deformation was measured to be 4.0 in. (10.2 cm). Vehicle tire marks were noted on the outside flanges of Posts 1 and 2 and on the end of the concrete bridge parapet. The introduction of additional posts in the wheelpath of the vehicle permitted more wheel snagging to occur, which in turn damaged the wheel and resulted in contact with the end of the parapet. The spacer pipe experienced 2.5 in. (6.53 cm) of permanent deformation and performed as intended.

The test vehicle sustained extensive damage. The maximum recorded crush was 20.0 in. (50.8 cm) at the right front corner of the



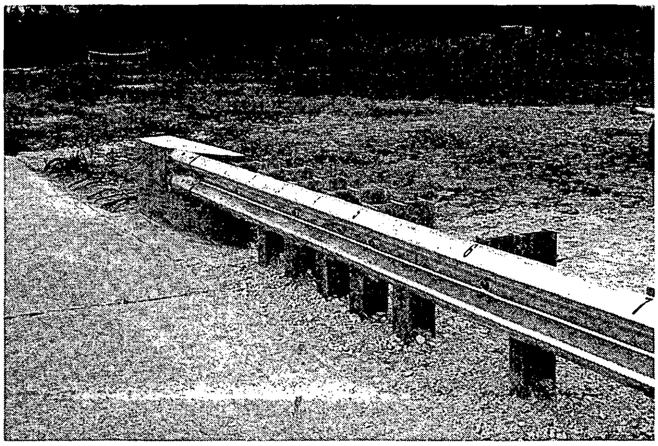


FIGURE 7 Tennessee reduced post spacing transition before testing of System 2.

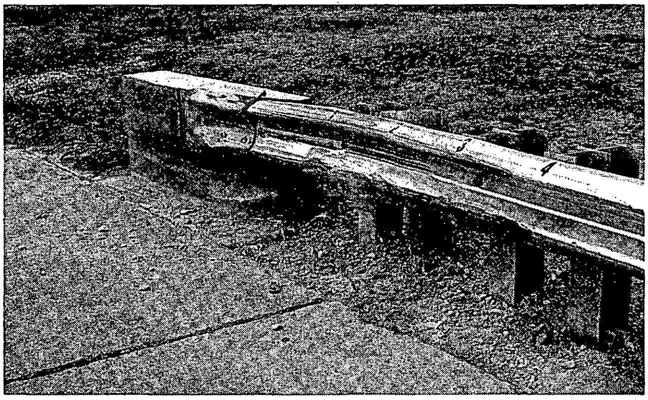


FIGURE 8 Barrier (*top*) and vehicle (*bottom*) damage after testing of System 2.

vehicle. The right front wheel and control arm were bent and pushed rearward a distance of 11.0 in. (27.9 cm). The entire front end of the vehicle was shifted to the left 2.5 in. (6.4 cm). In addition, the right front brake disc was pulled off the spindle, the subframe was bent, and the windshield was broken. Contact of the subframe with the face of the concrete parapet resulted in some minor buckling or wrinkling of the floor pan. The entire right side of the vehicle was dented and scraped by contact with the nested W-beam rail.

In summary, the results of this test were judged to be in compliance with the recommended performance criteria for transitions as presented in *NCHRP Report 230* (*9*). The installation successfully contained and redirected the impacting vehicle. Although not required in the evaluation of a strength test, all occupant risk values were within the maximum acceptable limits set forth in *NCHRP Report 230* for a survivable impact. Damage to the test installation was minor, with no apparent structural damage to the concrete bridge parapet. The test vehicle sustained severe damage, but there was no intrusion into the occupant compartment. There was some buckling of the floor pan under the passenger's seat due to the subframe contacting the side of the concrete parapet. However, this buckling was considered minor in nature and did not constitute a severe hazard for the occupant.

System 3: Rub Rail

The System 3 test installation is shown in Figure 9. A 1984 Cadillac Coupe DeVille struck the transition installation 6.0 ft (1.8 m) upstream of the end of the concrete parapet at 61.0 mph (98.2 km/hr) and at an angle of 24.7 degrees. The rub rail prevented the right front tire from snagging on the end of the concrete bridge parapet, and the vehicle was successfully redirected. However, contact of the subframe and wheel with the flared face of the parapet resulted in some minor buckling of the floor pan on the passenger side of the vehicle and extensive damage to the wheel assembly. The vehicle lost contact with the rail approximately 0.30 sec after impact, traveling at a speed of 44.8 mph (72.1 km/hr) and at an exit angle of 10.5 degrees.

Damage to the transition and vehicle after testing of System 3 is shown in Figure 10. The installation sustained relatively minor damage for an impact of this severity. There was residual deformation to the guardrail in the vicinity of the first three posts. The maximum permanent deformation along the W-beam rail was 4.5 in. (11.4 cm). Maximum permanent deformation to the rub rail was 2.0 in. (5.1 cm). The steel spacer pipe collapsed 1.5 in. (3.81 cm).

Damage to the test vehicle was considerable. The maximum crush was 19.0 in. (48.3 cm) at the right front corner of the vehicle. The right front wheel and control arm were severely bent and pushed rearward 11.0 in. (27.9 cm). The entire front end of the vehicle was shifted to the left 4.5 in. (11.4 cm). In addition, the subframe was bent, the floor pan was buckled, and the windshield was broken.

In summary, the installation successfully contained and redirected the impacting vehicle. Although not required in the evaluation of the strength test, all of the occupant risk criteria were within maximum acceptable values, further indicating that the vehicle was smoothly redirected without experiencing any severe decelerations. Damage to the transition was minor in nature, with no apparent structural damage to the concrete bridge parapet. Damage to the vehicle was severe, but acceptable for an impact of this severity. There was no intrusion into the occupant compartment, and the buckling of the floor pan that occurred did not constitute a severe hazard to the occupants.

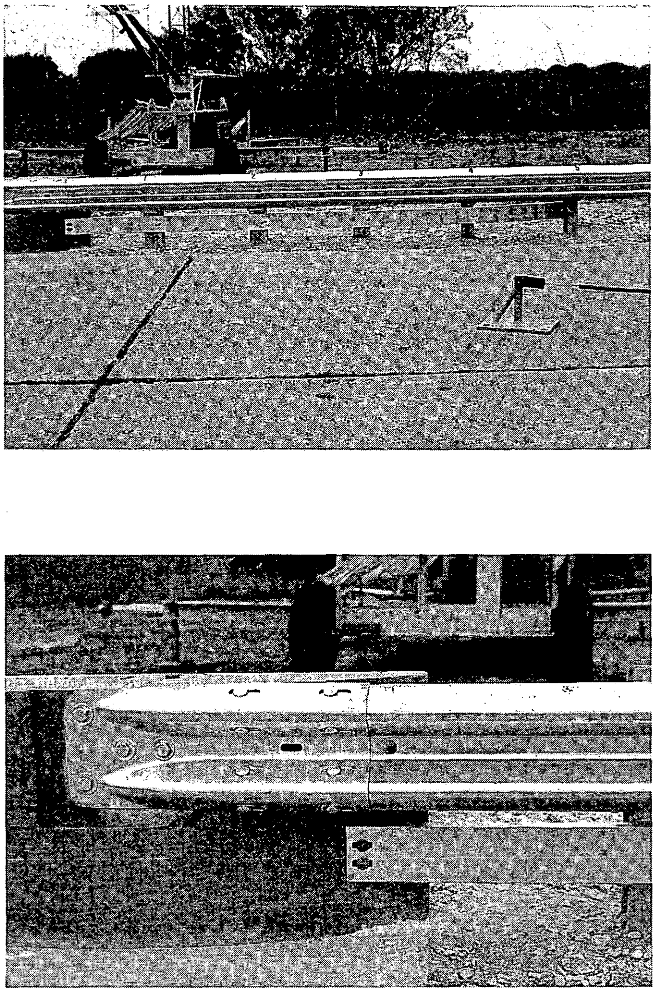


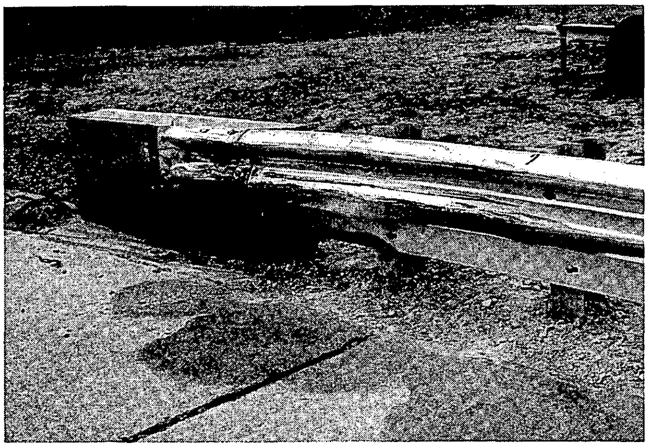
FIGURE 9 Tennessee transition with rub rail before testing of System 3.

CONCLUSIONS AND RECOMMENDATIONS

Simulation results indicated that TDOT's standard guardrail to bridge rail transition design would exhibit undesirable impact performance. Three alternative retrofit transition designs were developed to improve the impact performance of the existing system. Significant details of these systems are as follows:

- System 1: Larger post size and embedment depth. The first three 6-ft (1.83-m)-long W6 × 15 posts in the standard design are replaced with 8-ft (2.44-m)-long W8 × 21 posts.
- System 2: Reduced post spacing. Two 6-ft (1.83-m)-long W6 × 15 steel posts are added between the first three existing W6 × 15 posts to effectively reduce the post spacing adjacent to the parapet from 3 ft 1.5 in. (0.95 m) to 1 ft 6.75 in. (0.48 m).
- System 3: Addition of a lower C6 × 8.2 channel rub rail.

In addition, all three of these retrofit designs use a 6-in. (15.2-cm)-diameter spacer pipe between the W-beam and the flared face of the



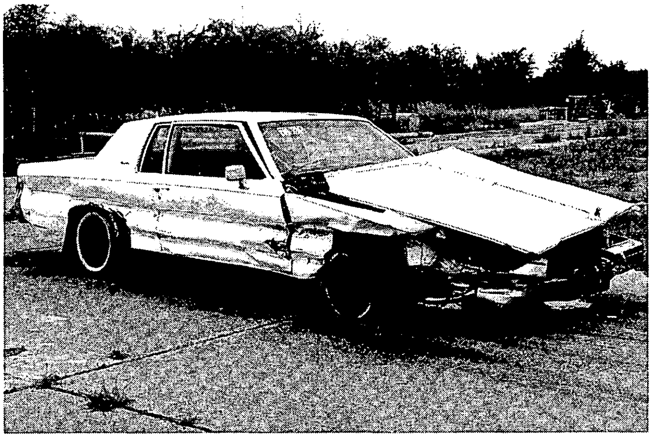


FIGURE 10 Barrier (*top*) and vehicle (*bottom*) damage after testing of System 3.

TABLE 1 Test Results

Description	Test 1 (7199-2)	Test 2 (7199-3)	Test 3 (7199-5)
Test Vehicle	1982 Oldsmobile Ninety-Eight	1980 Oldsmobile Ninety-Eight	1984 Cadillac Coupe DeVille
Test Weight, lb (kg)	4500 (2041)	4500 (2041)	4500 (2041)
Impact Speed, mi/h (km/h)	61.4 (98.8)	62.0 (99.8)	61.0 (98.2)
Impact Angle, deg.	25.1	24.4	24.7
Exit Speed, mi/h (km/h)	45.3 (72.9)	44.3 (71.2)	44.8 (72.1)
Exit Angle, deg.	8.2	13.5	10.5
Velocity Change[a], mi/h (km/h)	16.1 (25.9)	17.7 (28.6)	16.2 (26.1)
Occupant Impact Velocity[b]			
Longitudinal, ft/s (m/s)	18.1 (5.5)	16.5 (5.0)	12.6 (3.8)
Lateral, ft/s (m/s)	-28.3 (8.6)[c]	-21.5 (6.5)[c]	-22.6 (6.9)[c]
Occupant Ridedown Acceleration[b]			
Longitudinal, g	-8.6	-13.1	8.4
Lateral, g	11.5	15.6[d]	16.2[d]
Length of Rail Contact, ft (m)	14.2 (4.3)	14.7 (4.5)	14.2 (4.3)
Maximum Permanent Rail Deflection, in (cm)	5.0 (12.7)	4.0 (10.2)	4.5 (11.4)
Maximum Vehicle Crush, in (cm)	16.0 (40.6)	20.0 (50.8)	19.0 (48.3)

Notes: [a] The velocity change was higher than the recommended value of 15 mi/h (24.1 km/h) in all three tests, but the vehicle was judged not to be a hazard to adjacent traffic lanes.

[b] According to NCHRP Report 230 guidelines, the occupant risk criteria are not applicable for the 4500-lb passenger car crash test.

[c] Greater than recommended value of 20 ft/sec (6.1 m/sec), but less than acceptable limit of 30 ft/sec (9.1 m/sec).

[d] Greater than recommended value of 15g, but less than acceptable limit of 20 g.

concrete parapet to help reduce deflections and to minimize wheel and vehicle contact on the end of the parapet. Also, nested 12-gage W-beam rails were used for Systems 2 and 3 and are recommended for use with all three transition designs.

These three designs were evaluated through a series of full-scale crash tests, the results of which are summarized in Table 1. All three designs were judged to be in compliance with the recommended performance criteria for transitions presented in *NCHRP Report 230* (*9*). These designs provide an acceptable retrofit for the standard TDOT steel post approach guardrail attached to a tapered vertical concrete parapet. Although not required for the evaluation of a strength test, such as those conducted on transitions, occupant risk criteria are presented for information purposes and for comparison of the results with the results obtained from tests of other designs. As shown in Table 1, although some of these values are above the recommended limits, all of the values are below the maximum acceptable limits set forth in *NCHRP Report 230*.

The impact severity of System 1 (larger post size and embedment depth) was found to be slightly greater than those of the other two systems. This difference in performance could likely be attributed to the use of a single W-beam rail for this system, whereas nested W-beam rails were used with the other two systems. It is believed that the performance of System 1 would have been comparable to those of the other two systems had a nested W-beam rail been used.

The additional posts present in System 2 (reduced post spacing) allowed more wheel contact to occur, thereby slightly increasing the impact severity. System 3 (rub rail) prevented the wheels from contacting the end of the parapet and therefore provided slightly better impact performance than those provided by the other two alternative designs.

Since the impact performances of all three systems were essentially the same, the choice of which alternative design to use in the field becomes primarily a consideration of economics and site-specific requirements. The reduced post spacing option (System 2) may be the most economical retrofit design since it does not require any modification to the existing posts in the transition. However, the reduced post spacing severely decreases the clear space between posts, which may pose a problem at sites with bridge end drainage. The other systems retain the existing post spacing of 3 ft 1.5 in. (0.95 m) but require some modifications to the installation. For the large post alternative (System 1) the first three posts are replaced, and the rub rail alternative requires the drilling of holes in the concrete parapet (and in the posts if holes are not already predrilled) to accommodate the channel rub rail.

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