Guardrail–Bridge Rail Transition Evaluations

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This paper addresses the design of transitions between W-beam or thrie-beam approach guardrail and rigid bridge rail parapets or wingwalls. Crash test evaluations of selected current designs and new modified designs were accomplished with 4,500-lb (2000-kg) cars striking at 60 mph (95 km/hr) and a 25-degree angle. Results of these evaluations included the identification of desirable transition characteristics and the evaluation of a large number of designs for both straight and tapered bridge ends. Conclusions and recommendations are offered for satisfactory guardrail–bridge rail transition performance.

Crash tests conducted on selected guardrail–bridge rail transition designs during an FHWA project at Southwest Research Institute are described. The final report of this project *(1)* describes other tasks accomplished regarding guardrail–bridge rail technology.

FULL-SCALE CRASH TESTS

Crash tests conducted in the project included currently utilized systems and modification of these systems. In addition, new designs were conceived and evaluated. The transition systems included the following categories:

- W-beam–wingwall transition
  - Straight wingwall (wingwall parallel to bridge rail or parapet)
  - Tapered wingwall (wingwall end flared away from traffic)
- Thrie-beam–wingwall transition
  - Straight wingwall
  - Tapered wingwall
  - Modified thrie beam [14-in. (35-cm) block-out]

Test procedures and test results are briefly described in this paper. Detailed information on the test installations and results is contained in the final report *(1)*; test results are summarized in Tables 1 and 2.

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Test Procedures

All tests were conducted with a 4,500-lb (2000-kg) car striking at 60 mph (95 km/hr) and a 25-degree angle as specified for transitions in NCHRP Report 230 *(2)*. A restrained 50th-percentile Part 572 dummy was placed in the driver seat and a like unrestrained dummy in the right front passenger position of the car. Dynamic data were recorded from transducers mounted in the dummies and on the vehicle. Extensive film coverage also documented the barrier, vehicle, and dummy behavior.

W-Beam–Wingwall Transition Tests

Wingwall installations evaluated were both straight and tapered (i.e., the wingwall end is flared away from traffic).

Straight Wingwall

The most common transition utilized by the states is a W-beam approach to a straight flat concrete wingwall or parapet. Many of the state designs feature a transition from the flat wingwall to a full safety shape.

Test LA-1 The design tested is shown in Figure 1; it features eight 3-ft 1.5-in. (0.9-m) spaces between posts and wingwall before the typical 6-ft 3-in. (3.8-m) post spacing begins. This is the most common treatment currently being specified by the states. All of the transition posts and blocks were 6 × 8-in. (15 × 20-cm) timber with a Michigan end shoe providing the connection between the wingwall or parapet and the W-beam approach rail.

After striking the transition at the third post from the bridge end at the nominal 60 mph and 25 degrees, the vehicle snagged on the wingwall-parapet end and was abruptly stopped, as shown in Figure 2. Longitudinal and lateral translation of the simulated bridge wingwall or parapet occurred during the test, and the longitudinal displacement was sufficient to cause tensile failure of the beam. Photographs after the test (Figure 1) show the extensive vehicle and barrier-wingwall damage.

Test LA-1M In order to minimize the wheel snagging observed in Test LA-1, a single 12-ft 6-in. (3.8-m) W-beam element was added below the beam as shown in Figure 3; in addition, two more posts were added between the first two spaces at the bridge end. Tapered blocks between the lower beam and the posts were used and the lower beam was field bent about the fifth post from the end as shown in Figure 3.

TABLE 1 SUMMARY OF W-BEAM–WINGWALL TRANSITION TESTS

	Test No.						
	LA-1	LA-1M	T-5	NC-1	NC-1M	NC-2M	T-6
Guardrail	G4(2W)	G4(2W)	G4(2W)	G4(1S)	G4(1S)	G4(1S)	G4(1S)
Test vehicle	1978 Plymouth	1978 Plymouth	1978 Plymouth	1978 Dodge	1978 Dodge	1978 Dodge	1978 Dodge
Gross vehicle weight (lb)	4,635	4,737	4,700	4,642	4,630	4,572	4,655
Impact speed (film) (mph)	62.2	60.6	58.9	60	60.4	59.8	61.7
Impact angle (deg)	25.1	25.3	25.8	25	25.9	25.4	25.6
Impact duration (sec)	.40	.27	.35	.43	.35	.53	.43
Maximum deflection (in.)							
Dynamic	W-beam separated	6.4	10.9	12.6	7.6	29.1	14.1
Permanent	W-beam separated	6	6.0	8.8	4.4	20.0	7.5
Exit angle (deg)							
Film	Did not exit	–5.5	–8.0	Not avail.	–10.7	–16.9	–14.7
Yaw rate transducer	Did not exit	Not avail.	–6.8	–9.5	–7.1	Not avail.	–13.3
Exit speed (mph)							
Film	Did not exit	46.7	40.5	Not avail.	46.1	34.6	40.0
Accelerometer	Did not exit	Not avail.	37.7	34.0	42.9	Not avail.	39.7
Maximum 50-msec avg acceleration (film/accelerometer)							
Longitudinal	–12.9	–7.6/Not avail.	–5.8/–11.1	Not avail./–12.8	–6.5/–9.8	–5.4/–7.1	–6.2/–10.9
Lateral	–6.0	–6.6/Not avail.	6.2/11.9	Not avail./–11.1	–7.7/12.0	–5.5/–5.9	–7.1/–10.0
NCHRP Report 230 evaluation							
Structural adequacy (A,D)	Failed	Passed	Passed	Passed	Passed	Passed	Passed
Occupant risk (E)	Failed	Passed	Passed	Passed	Passed	Passed	Passed
Vehicle trajectory (H,I)	Failed	Passed			Passed		
Exit angle (60% = 15°)	–	–	<15°	<15°	–	>15°	<15°
Δv (15 mph)	–	–	>15 mph	>15 mph	–	>15 mph	–

TABLE 2 SUMMARY OF THRIE BEAM–WINGWALL TRANSITION TESTS

	Test No.			
	T-1	T-7	T-2	T-3
Guardrail	G9(W)	G9(S)	G9(W)	G9(W)
Test vehicle	1978 Plymouth	1978 Dodge	1978 Plymouth	1978 Plymouth
Gross vehicle weight (lb)	4,658	4,675	4,650	4,580
Impact speed (film) (mph)	61.5	58.9	64.0	60.8
Impact angle (deg)	25.2	25.1	25.6	23.8
Impact duration (sec)	.34	.39	.32	.39
Maximum deflection (in.)				
Dynamic	9.4	13.9	14.4	11.3
Permanent	5.6	6.4	9.0	7.9
Exit angle (deg)				
Film	−11.2	−5.7	−9.1	−12.1
Yaw rate transducer	−5.6	−1.4	−2.0	−9.7
Exit speed (mph)				
Film	43.8	40.2	36.8	43.6
Accelerometer	36.8	42.0	35.8	47.4
Maximum 50-msec avg acceleration (film/accelerometer)				
Longitudinal	−5.8/−9.9	−4.5/−5.2	−7.5/−7.9	−5.1/−5.9
Lateral	7.7/16.6	5.9/7.3	−7.4/−13.4	−7.3/−10.4
NCHRP Report 230 Evaluation				
Structural adequacy (A,D)	Passed	Passed	Passed	Passed
Occupant risk (E)	Passed	Passed	Passed	Passed
Vehicle trajectory (H,I)				
Exit angle (60% = 15°)	< 15°	< 15°	< 15°	< 15°
Δv (15 mph)	> 15 mph	> 15 mph	> 15 mph	> 15 mph

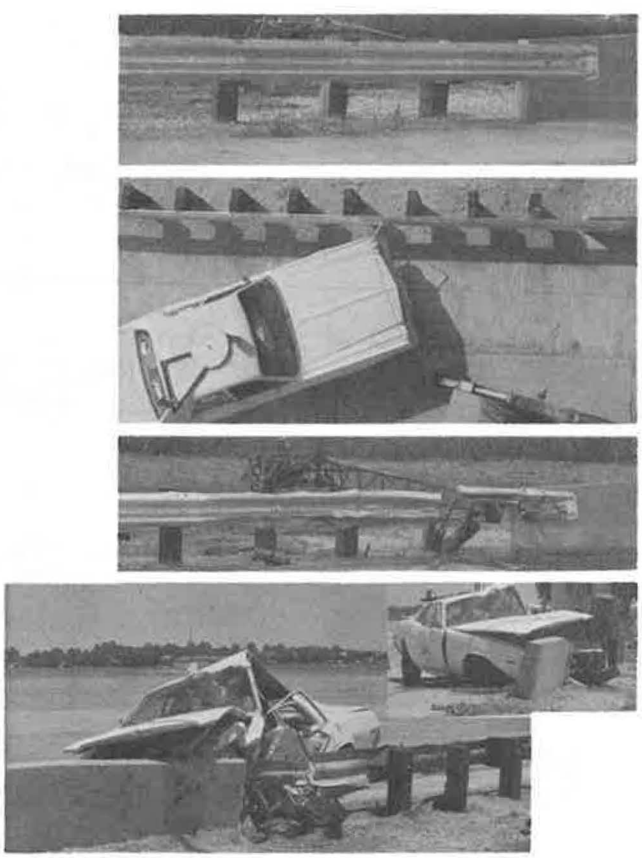

FIGURE 1 Test LA-1.

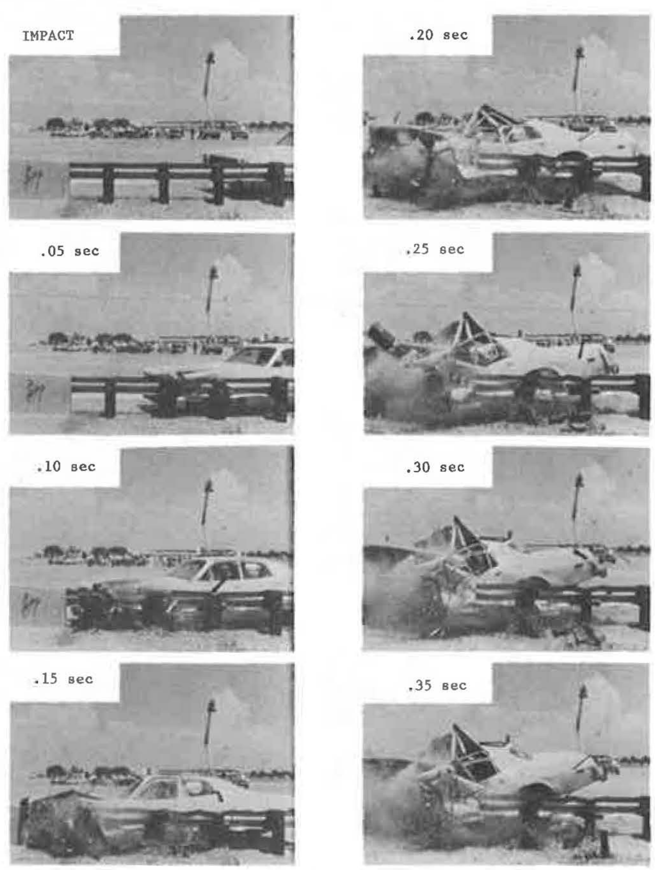

FIGURE 2 Sequential photographs, Test LA-1.

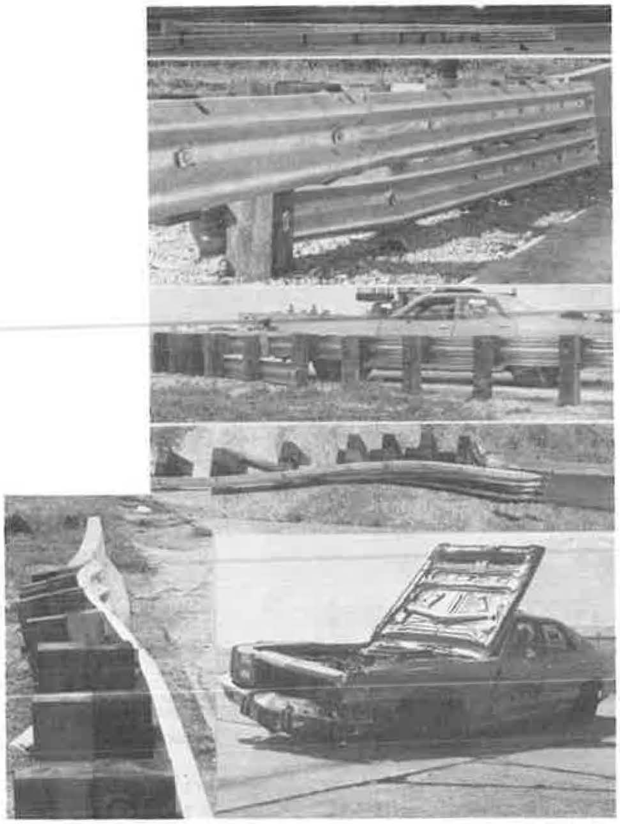

FIGURE 3 Test LA-1M.

FIGURE 5 Before-and-after photographs, Test T-5.

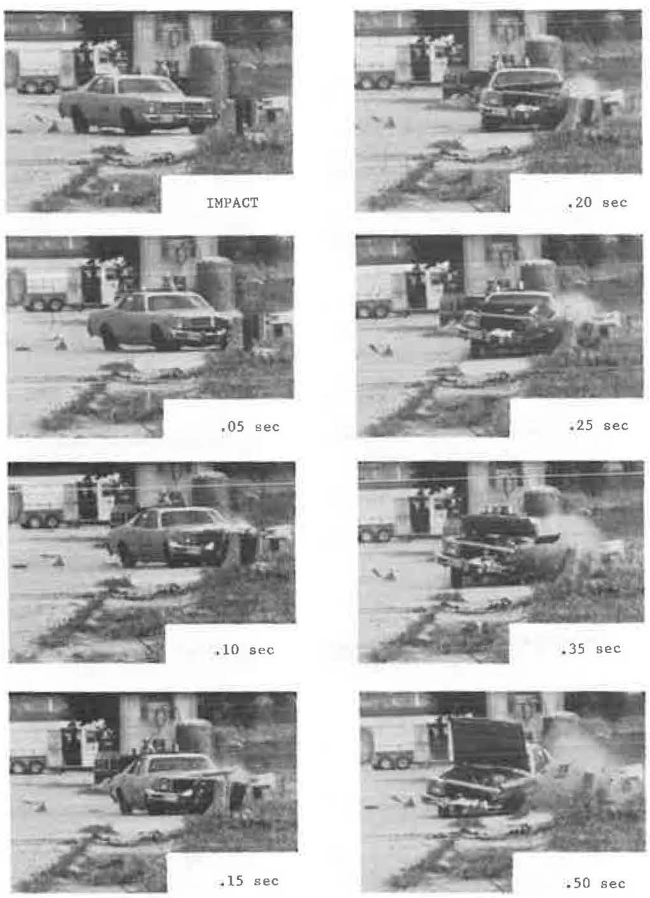

FIGURE 4 Sequential photographs, Test LA-1M.

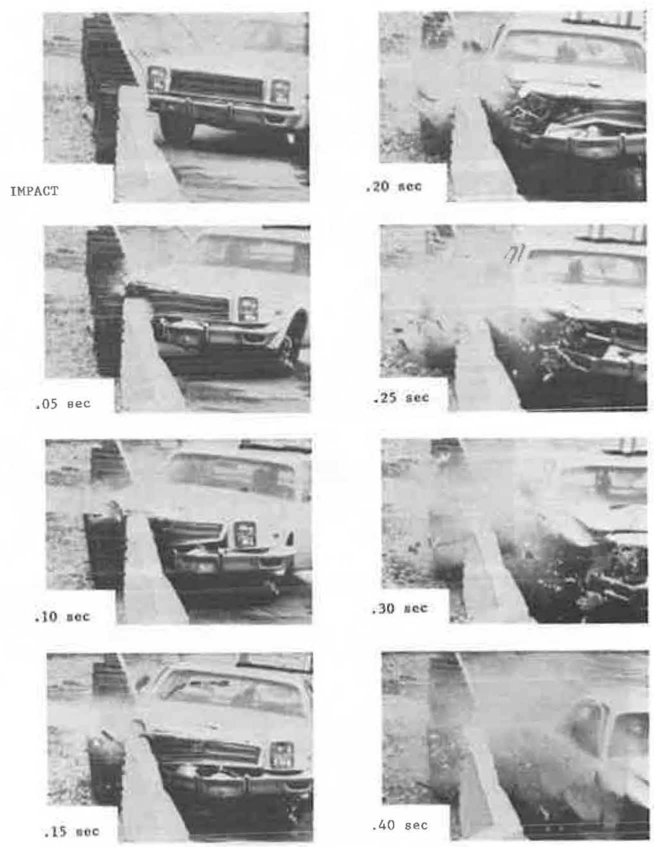

FIGURE 6 Sequential photographs, Test T-5.

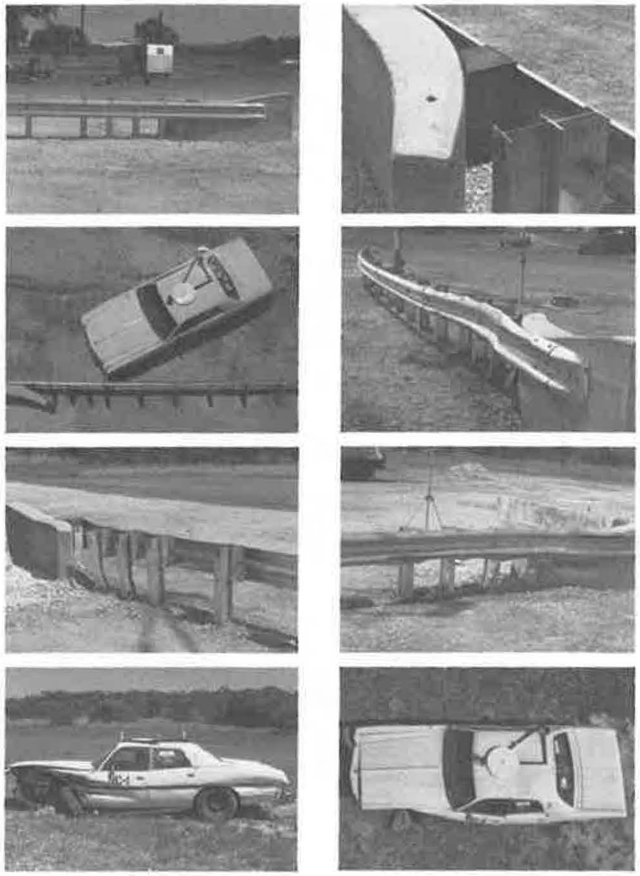

FIGURE 7 Test NC-1.

FIGURE 9 Test NC-1M.

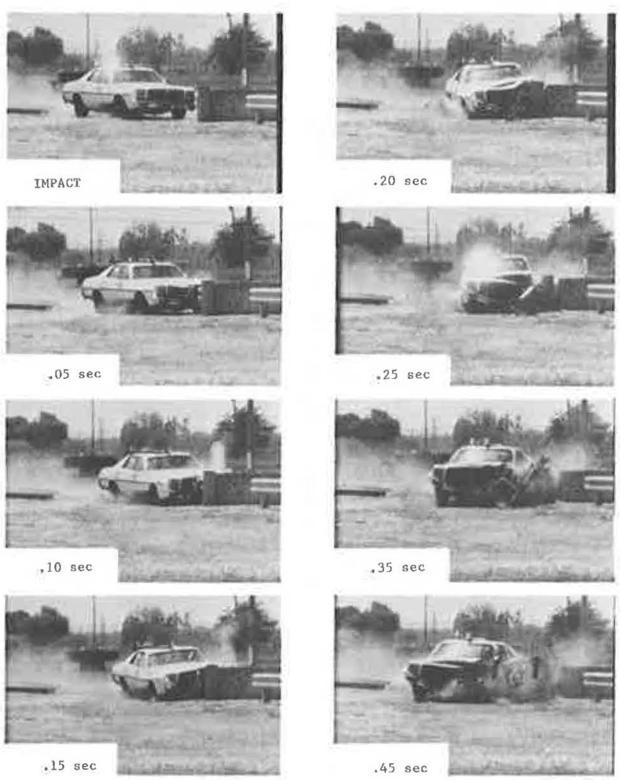

FIGURE 8 Sequential photographs, Test NC-1.

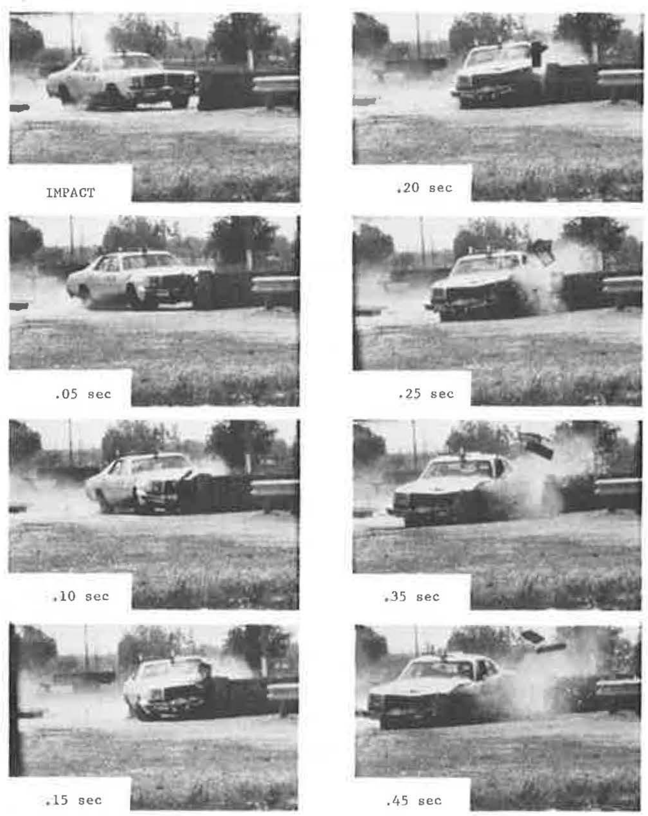

FIGURE 10 Sequential photographs, Test NC-1M.

The test vehicle struck the transition at 60 mph and 25 degrees and was smoothly redirected as shown in Figure 4. There was some rotation of the simulated wingwall or parapet, but no evidence of wheel snagging on the wingwall end. Photographs after the test are shown in Figure 3.

Test T-5 Details for Test T-5 are identical to those for Test LA-1M with the exception of the wingwall or parapet. For this test a much larger concrete mass (see Figure 5) was used to prevent the wingwall rotation observed during Test LA-1M. An additional beam was nested in the first 12.5-ft (3.8-m) upper beam length to minimize local deformations.

As shown in Figure 6, the vehicle struck the transition at 60 mph and a 25-degree angle. The vehicle was smoothly redirected with no evidence of wheel snagging and negligible rotation of the wingwall end. Photographs after the test are shown in Figure 5.

Tapered Wingwall

Included in this test series is an evaluation of the lower beam termination.

Test NC-1 Test NC-1 evaluated the curved wingwall transition, selected as discussed in the previous section. Use of standard steel posts or block-outs with a post spacing of 1 ft 6.75 in. (0.5 m) and the tapered wingwall to prevent snagging resulted in a high rating for this design. Photographs of the test installation are shown in Figure 7.

The test vehicle struck the transition at nominal 60-mph, 25-degree angle conditions and was smoothly redirected as shown in Figure 8. There was considerable evidence of wheel snagging on the last post, which was pushed against the wall. In addition, some snagging occurred because of local deformation of the beam at the wood block between the beam and concrete wall. Photographs after the test are shown in Figure 7.

Test NC-1M Although the vehicle was redirected in Test NC-1, the wheel snagging observed in the test was of some concern. Accordingly, a retrofit design using one 12-ft 6-in. (3.8-m) panel of W-beam for a lower rail was constructed as shown in Figure 9. The lower beam was bolted to all the posts as shown; no attachment of the beam to the wingwall was made, because this was considered unnecessary. The flare or taper screens the lower W-beam end from vehicles striking from opposing directions of traffic.

The test vehicle struck at nominal 60-mph, 25-degree angle conditions and was smoothly redirected as shown in Figure 10. The lower beam element was effective in minimizing wheel snagging. Photographs after test are shown in Figure 9.

Test NC-2M The purpose of Test NC-2M was to evaluate the potential hazard of the lower beam upstream end in the design evaluated in the previous test. For evaluation purposes, the transition was struck three post spans upstream from the beam end, as shown in Figure 11 (note position of vehicle before test).

The vehicle struck the transition at nominal 60-mph, 25-degree impact angle conditions and was smoothly redirected as shown in Figure 12. Photographs after the test are shown in Figure 11.

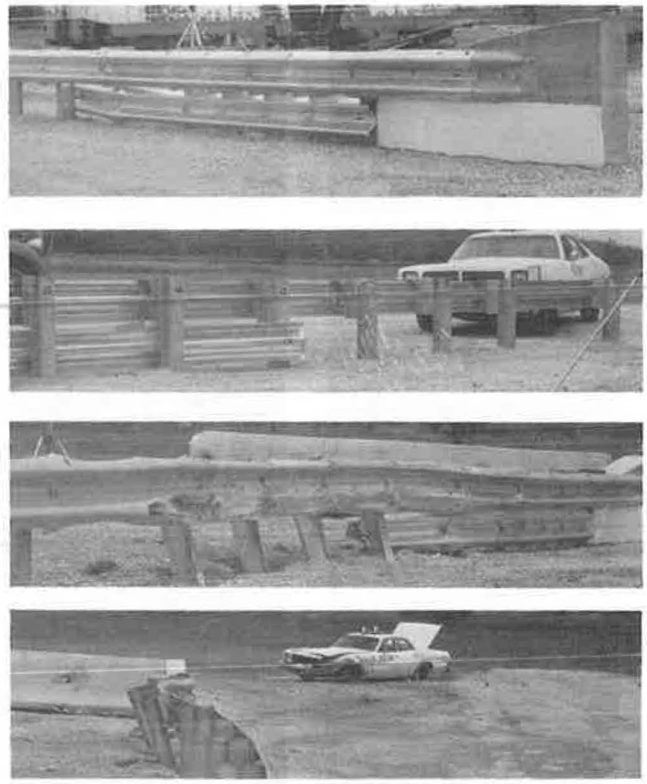

FIGURE 11 Test NC-2M.

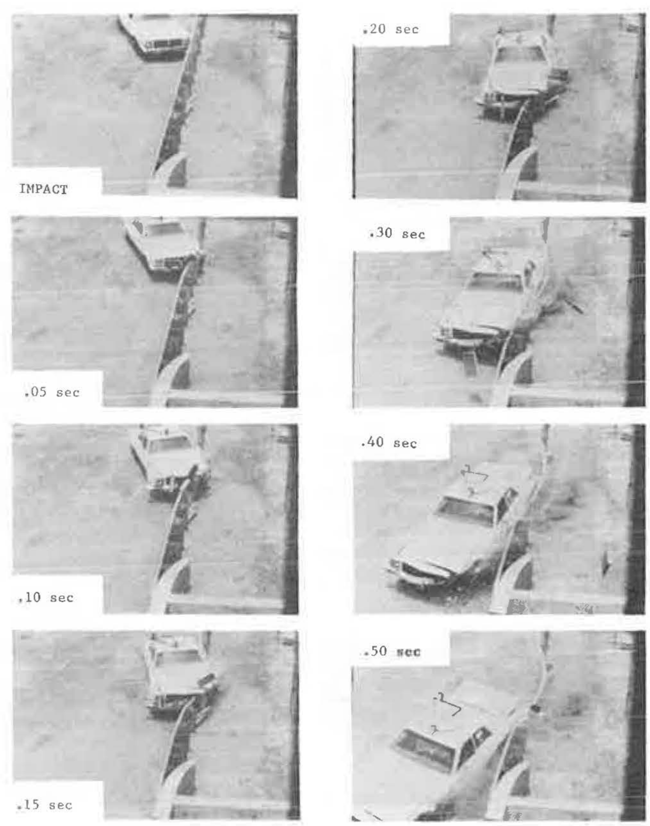

FIGURE 12 Sequential photographs, Test NC-2M.

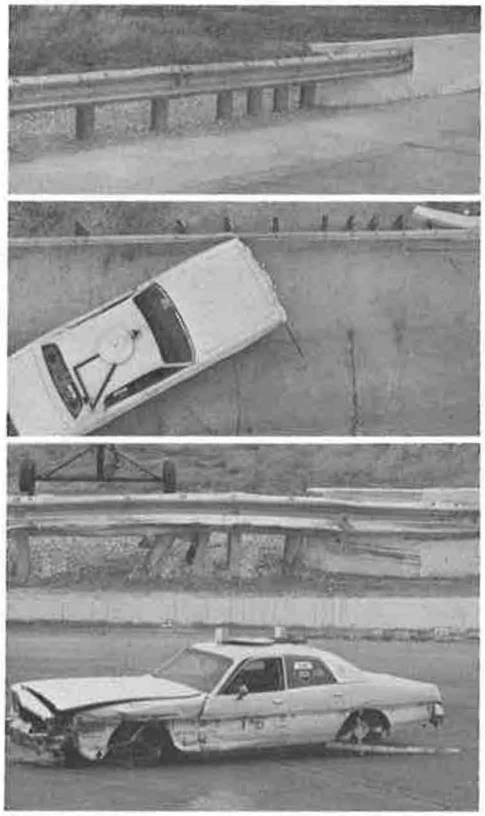

FIGURE 13 Before-and-after photographs, Test T-6.

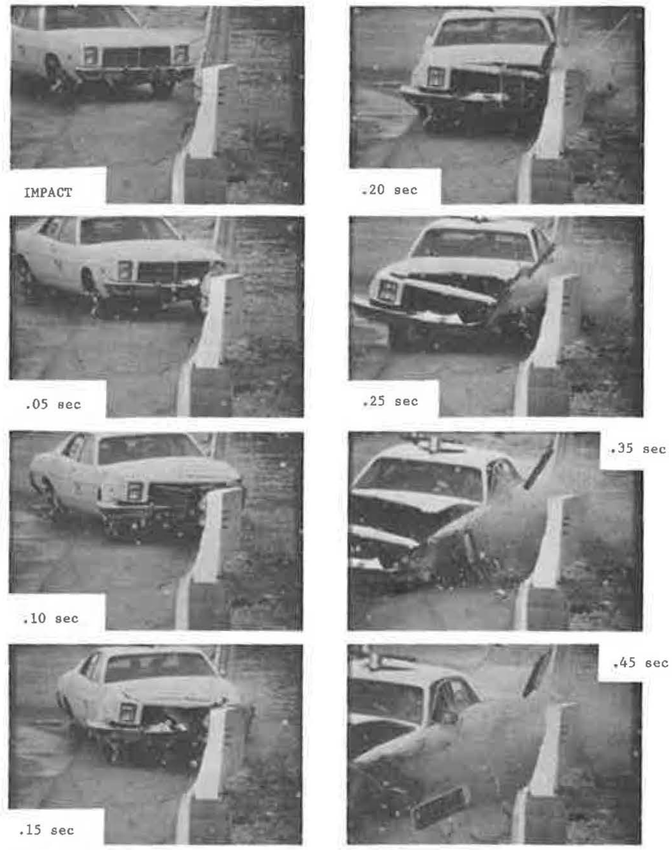

FIGURE 14 Sequential photographs, Test T-6.

Test T-6 The purpose of Test T-6 was to evaluate a straight tapered wingwall; the NC series used a curved wingwall, which is considered to be more expensive to form. In addition, a collapsible pipe section was used as an intermediate block-out, as shown in Figure 13.

The vehicle struck at the nominal test conditions and was smoothly redirected as shown in Figure 14. Figure 13 contains photographs taken after the test.

Thrie-Beam–Wingwall Transitions

Straight Wingwall

Two tests were conducted on straight flat wingwalls that later transition into New Jersey-shaped barriers. One transition design used standard wood posts and the other standard steel posts.

Test T-1 Test T-1 evaluated a G9 (wood post) transition. As shown in Figure 15, there were four 1-ft 6$^{3}/_{4}$-in. (0.5-m) post spacings near the bridge followed by four 3-ft 1$^{1}/_{2}$-in. (1.9-m) spaces before the standard 6-ft 3-in. (3.8-m) spacing was used.

The vehicle impacted the transition at the nominal 60-mph, 25-degree angle conditions and was smoothly redirected as shown in Figure 16. Although no wheel snagging occurred at the wingwall edge, there was some wingwall damage, indicating that additional reinforcement or wall thickness would be required to eliminate such damage. Photographs after test are shown in Figure 15.

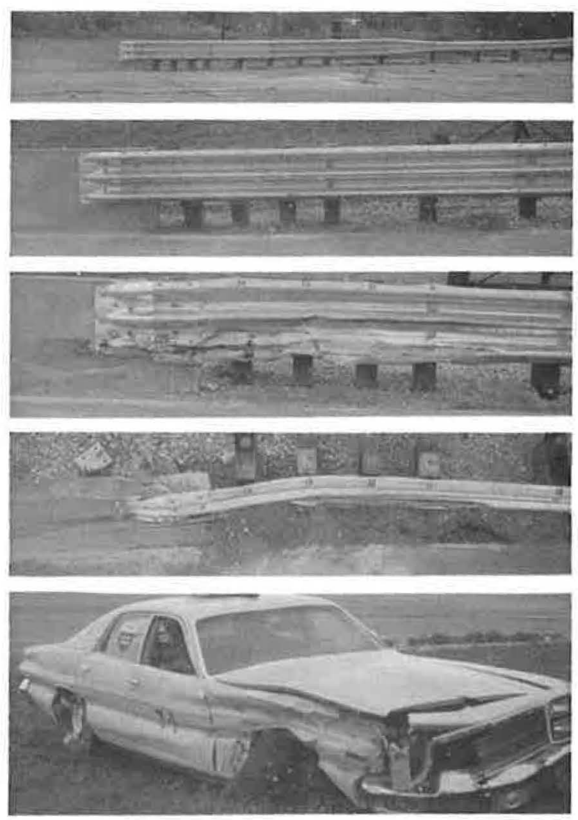

FIGURE 15 Test T-1.

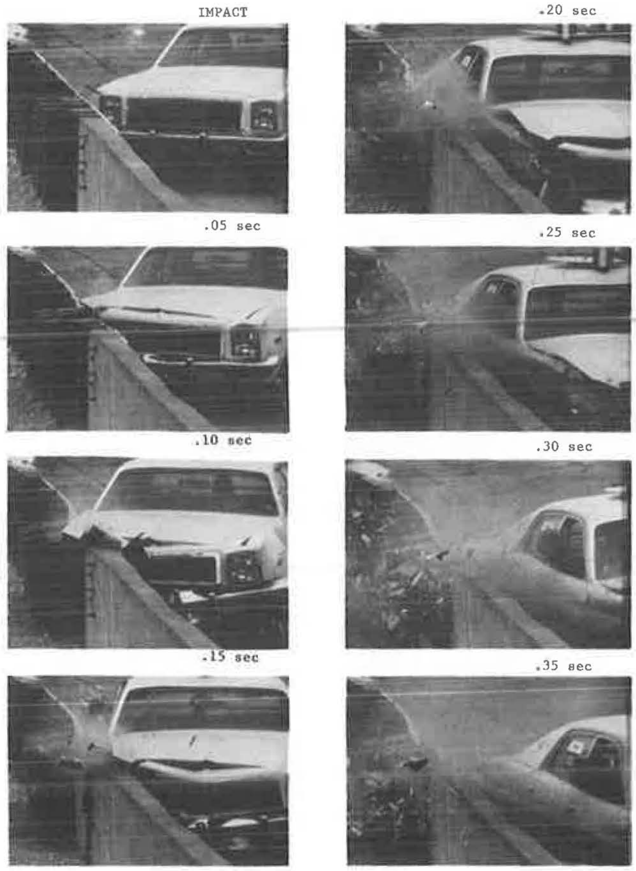

FIGURE 16 Sequential photographs, Test T-1.

FIGURE 17 Before-and-after photographs, Test T-7.

Test T-7 Design details for Test T-7 were similar to those for Test T-1 with the exception of substitution of standard steel posts or blocks for the standard wood posts or blocks, as shown in Figure 17. Also, additional reinforcement was added to the wingwall construction to minimize the damage observed in Test T-1.

The test vehicle was smoothly redirected as shown in Figure 18 with negligible wheel snagging at the wingwall edge. Damage to the wingwall was limited to scraping, as shown in Figure 17.

Tapered Wingwall

Two tests were conducted on a straight tapered wingwall using one spacer between the last guardrail post and the attachment to the parapet. The taper provided a 14.5-in. (0.4-m) offset of the wall end from the wall face.

Test T-2 A wood block-out was used between the last guardrail post and the wall as shown in Figure 19. The vehicle struck the transition and was smoothly redirected as shown in Figure 20. There was some evidence of snagging at the wood block-out because of local beam deformation (Figure 19).

Test T-3 Because the performance of the intermediate wood block was not considered good in the previous test, a steel pipe section was sized to provide a controlled collapsing spacer between the tapered wall and the beam, as shown in Figure 21.

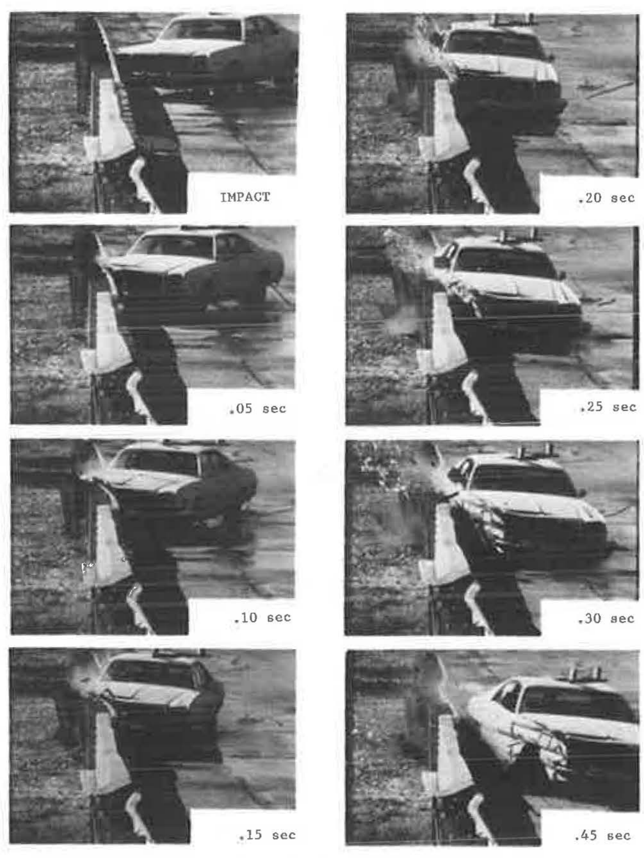

FIGURE 18 Sequential photographs, Test T-7.

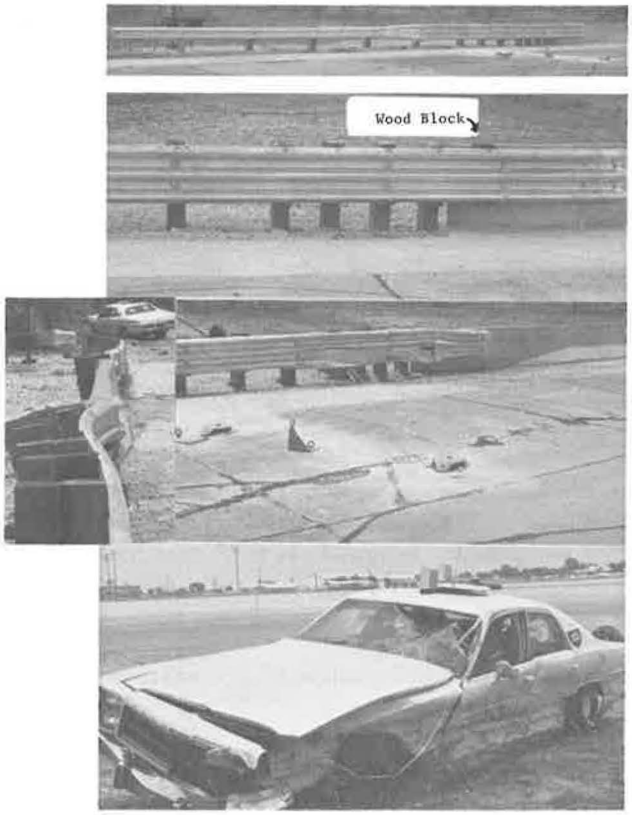

FIGURE 19 Test T-2.

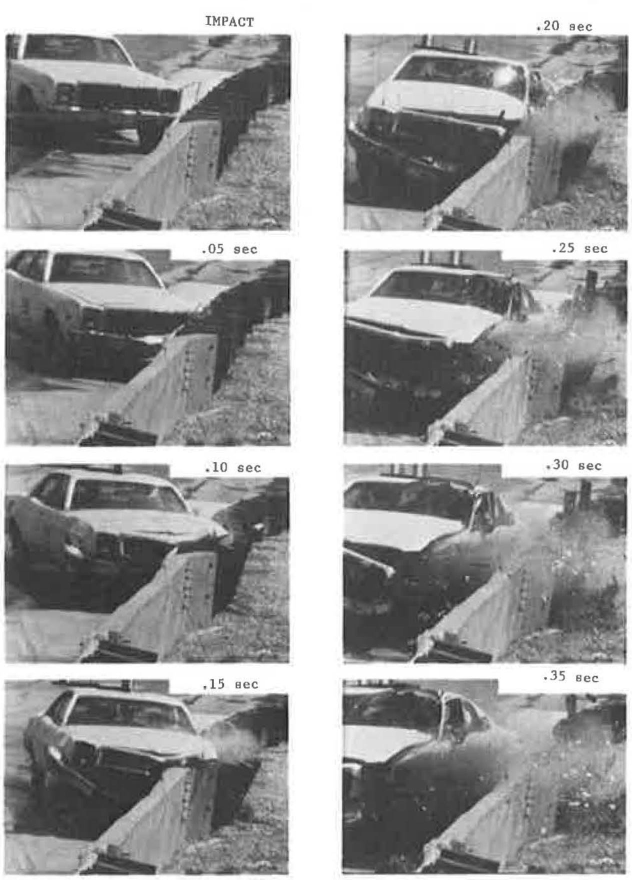

FIGURE 20 Sequential photographs, Test T-2.

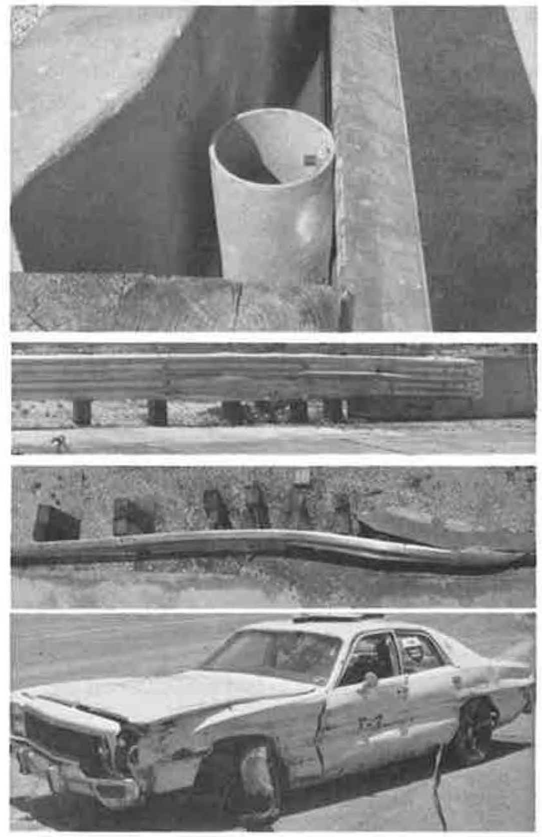

FIGURE 21 Test T-3.

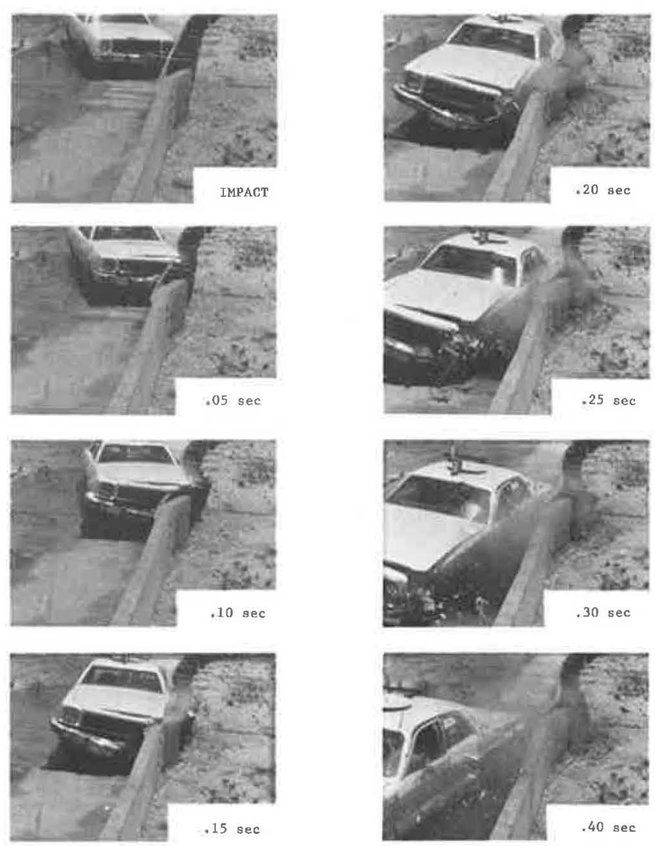

FIGURE 22 Sequential photographs, Test T-3.

The test vehicle was smoothly redirected as shown in Figure 22. There was no evidence of snagging, and some permanent deformation of the pipe spacer occurred. This detail performed as desired. Photographs after the test are shown in Figure 21.

CONCLUSIONS AND RECOMMENDATIONS

In this project a large number of current state guardrail–bridge rail transition designs were evaluated by using an evaluation method developed for the project. Certain of these designs were selected for crash test evaluation and redesign as required. New designs were also formulated for evaluation.

Conclusions

On the basis of the findings of this project, certain desirable characteristics were identified for optimum guardrail–bridge rail transition designs. The characteristics apply to W-beam and thrie-beam systems attached to concrete parapets or wingwalls.

1. Posts: Standard guardrail posts have been shown to be effective with proper spacing. Use of standard posts eliminates the need for stockpiling nonstandard posts. Use of soil plates or concrete footings is also considered to be unnecessarily costly.
2. Transition from safety-shape parapets: It is considered hazardous to mount a W- or thrie-beam on the upper face of a full safety shape. A preferable treatment is to transition from a flat wall to a safety shape.
3. Beam block-outs at parapets or wingwalls: An effective alternative to the lower rub rail adjacent to the bridge is the use of block-outs to minimize wheel snagging on the end. For roadways with two-way traffic, it is necessary to flare or taper the beam back to a flush position with the upper wall face to avoid snagging opposing traffic.
4. Beam attachment: Michigan end shoes for both W- and thrie-beams proved to be effective attachments with 7/8-in. (2.2-cm) diameter bolts through the concrete walls.
5. Post spacing: On the basis of computer simulations verified by crash tests, four spaces at 1 ft 6.75 in. (0.5 m) adjacent to the parapet or wingwall followed by adjacent spaces at 3 ft 1.5 in. (1.0 m) provide an acceptable transition for both W-beam and thrie-beam approach guardrail systems.
6. Parapet-wingwall geometry: For straight parapets or wingwalls, a lower W-beam element is required adjacent to the bridge to prevent wheel snagging on the exposed wall edge for severe impacts. The thrie beam mounted at 31 to 32 in. (0.8 m) does not require a lower beam or rub rail. A tapered wingwall or parapet is an effective means of preventing wheel snagging at the bridge end. Both curved and straight tapered wingwalls were evaluated in this project and the effectiveness of these treatments was demonstrated.
7. Double-beam designs: An effective treatment for the beam element adjacent to the bridge is to double or nest a W- or thrie-beam at this location. For the steel post systems, this eliminates a larger number of 12-in. (0.3-m) backup plates required at each post where a splice does not occur.

Recommendations

Using computer simulation and full-scale crash test evaluations, a number of effective guardrail–bridge rail transition designs were developed in this project. Recommended designs are characterized by the following:

- Standard guardrail posts and blocks with two sets of spacing near the bridge end: 3 ft 1.5 in. and 1 ft 6.75 in. (Use of larger posts near the bridge end was not as effective as reduced spacing of standard posts.)
- One W-beam panel (12 ft 6 in.) as a lower rub rail on straight wingwall or parapets.
- W-beam with single collapsing tube when attached to a tapered wingwall or parapet.
- Thrie beam on both straight and tapered wingwalls.
- Upper W-beam rail and thrie-beam rail panel at the bridge end doubled to reduce local deformations.

Designs using these details, which have been successfully tested for the 4,500-lb car, 60-mph, 25-degree-angle impact, are shown elsewhere *(1)*.

ACKNOWLEDGMENT

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1. *Guardrail–Bridge Rail Transition Designs.* SwRI Project 06-7642. Southwest Research Institute, San Antonio, Tex., in preparation.
2. J. D. Michie. *NCHRP Report 230: Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances.* TRB, National Research Council, Washington, D.C., 1981.

The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the sponsor.