

Crash Test Evaluation of Eccentric Loader Guardrail Terminals

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ABSTRACT

The test and evaluation of two W-beam guardrail terminal systems are described. The two terminals, though quite similar, are characterized by a 4.0-ft (1.5-m) flare offset and a 1.5-ft (0.5-m) flare offset. Both designs were subjected to the four-test terminal matrix of NCHRP Report 230 with the 1,800-lb minicar and successful results are reported. The basis for the terminal designs is the breakaway cable terminal (BCT) that has been used in this country for more than 10 years. Improvements to the BCT were necessary because of 1,800-lb (800-kg) automobile impact considerations. The improvements include a nose section attached to the beam end to promote beam buckling for end-on impacts. The nose section is enclosed by a length of standard culvert material.

Traffic barrier end treatments have been a troublesome detail since the implementation of these devices. Upright terminals have speared vehicles striking them end-on, and turned-down terminals have launched vehicles into obstacles or multiple rollovers. The guardrail breakaway cable terminal (BCT) was designed and developed in NCHRP projects (1-6) and use of this device has been widespread since the first installation in the mid-1970s. As reported in a recent survey (7) of guardrail end treatments, 40 states specify the W-beam guardrail BCT, and 24 states use a version of the turned-down terminal.

Accident data from the field have indicated some unsatisfactory performance of the guardrail BCT (8-10). Detailed examination of these data indicates that a significant percentage of the guardrail BCTs are being installed without the recommended 4-ft (1.2-m) offset parabolic flare. It is apparent that many of the sites where the guardrail BCT has been installed will not accommodate the full flare. Accordingly, many have been installed straight or offset less than 4 ft (1.2 m). Another installation problem noted was the use of a straight taper instead of the parabolic flare to offset the beam end from the rail tangent line. This tapered section represents essentially the same spearing hazard as the straight BCT.

Recent changes in the testing criteria for terminals, found in NCHRP Report 230 (11), have produced a most demanding test condition for terminals. Test-44 conditions, which call for a 1,800-lb (800-kg) vehicle striking end-on at 60 mph (94 km/hr) with a 15-in. (0.4-m) offset from vehicle centerline to terminal centerline, have resulted in violent reactions of the test vehicle to a properly installed BCT. Results of the test using both wood and steel end posts included violent spinning of the vehicle and either rollover or spearing as reported by Kimball et al. (12).

The FHWA awarded a contract to Southwest Research Institute (SwRI) to produce at least one innovative safe terminal for W-beam guardrails that meets the criteria of NCHRP Report 230 including the 1,800-lb (800-kg) vehicle and, it was hoped, a lower weight vehicle.

The scope of the project included the formulation of design concepts to satisfy the objectives of the contract. On the basis of a critique of these concepts, an uncompleted guardrail concept formulated in a previous FHWA contract at SwRI (13) was selected as a promising solution. This concept used the 4-ft (1.2-m) flare offset geometry of the BCT and was similar in design to the BCT. Another 1.5-ft (0.5-m) flare offset version was also developed.

Development of these terminal designs included detailed design and full-scale crash test evaluations according to the terminal test matrix of NCHRP Report 230 using the 1,800-lb minicar.

TERMINAL DESIGN

General

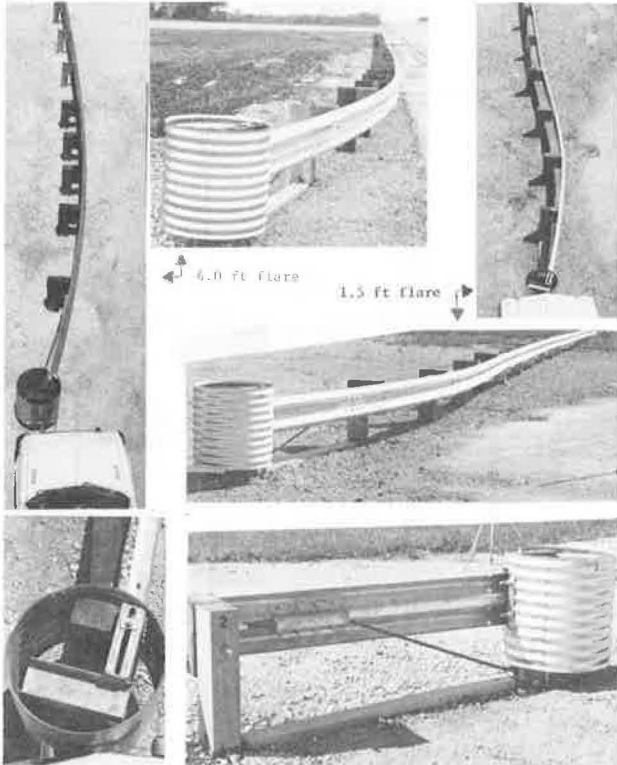
The guardrail BCT provided the basis for a new terminal design called the eccentric loader BCT. The name is derived from a design feature that introduces a bending moment on the beam end through the use of an eccentric connection.

Development of both the 4-ft (1.2-m) and the 1.5-ft (0.5-m) flare offset designs was completed. The initial design and development work was accomplished in another FHWA contract at SwRI and the results of the 4-ft (1.2-m) flare work were also reported in the final report of the project (13). A recent FHWA technical advisory (14) summarizes the work of this project and includes design drawings.

Terminal Description

The eccentric loader design as shown in Figure 1 is similar to a BCT with the nose section removed and replaced with a fabricated structural steel lever surrounded by a vertical section of corrugated steel

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Typical Details

FIGURE 1 Eccentric loader terminal.

pipe. Positive connection of the nose to the end of the W-beam is accomplished by a bolt through the last row of splice holes in the W-beam and long slots in the eccentric loader as shown in Figure 2. The purpose of the bolt is to hold the assembly together after impact; the slot allows longitudinal translation of the end without W-beam resistance. Because the anchor cable provides beam anchorage for the system, no tensile force transfer from the beam to the eccentric loader is necessary or desired.

The eccentric loader has three functions:

- During end-on impacts it transfers the force to the end post, which results in release of the anchor cable before any longitudinal force reaches the W-beam rail element.
- The corrugated steel pipe that encases the W-beam end provides an impenetrable barrier to the end and distributes the resisting force of the W-beam rail element over a large area of the impacting vehicle.
- The off-center attachment of the eccentric loader to the W-beam induces a moment at the W-beam end and thus greatly reduces the buckling strength of the beam.

Further reduction of the beam column strength is accomplished by omission of post-to-rail attachment in the flared area. Position of the beam is maintained by its connection to the eccentric loader; intermediate vertical support for the end beam and anchor cable vertical force component is provided by a shelf angle at the second post.

The first two breakaway posts are installed in steel tube foundations with soil bearing plates as introduced in NCHRP Results Digest 124 (6) and currently used by many states. Because of the additional force transmitted to the anchor cable as a result of

omitting the post-to-rail attachment, a strut is placed between the tube foundations to "couple" the two foundations for maximum resistance in the soil during downstream impacts.

During the development of this design, it was observed that contact with posts beyond the first two breakaway posts during end-on impacts increased the potential for vehicle rollover. To minimize this problem, the next four posts (4-ft flare) and three posts (1.5-ft flare) were replaced by breakaway wood posts with drilled holes at and below grade. These posts, which have been extensively used in other designs, were developed in another FHWA project (15). Because the lateral strength was also reduced by the drilled holes, the post spacing was reduced for the 4-ft (1.2-m) flare design because of the localized increased impact angle of this geometry.

Another feature that differs from the original BCT is the use of a block-out between the second post and beam while maintaining approximately the same post alignment. The increased beam curvature at the end required to clear the block-out further reduces the beam column strength.

FULL-SCALE CRASH TESTS

Crash tests conforming to Tests 45, 40, 41, and 44 from the terminal test matrix of NCHRP Report 230 were conducted and successful results obtained. These tests are summarized in Tables 1 and 2. Results of the successful tests are briefly described.

4-ft (1.2-m) Flare Offset Tests

Test RBCT-13

The terminal was evaluated for 60-mph (95-km/hr), end-on impact with the 1,800-lb (800-kg) vehicle with a 15-in. (0.4-m) offset. This test condition has been particularly troublesome because of the weight and stability of the small automobile.

The test vehicle struck the system as shown in Figure 3 and was redirected behind the barrier as designed. Although there was some intrusion into the right side door, no evidence of spearing or potential spearing was noted. The test values measured were in compliance with the criteria of NCHRP Report 230.

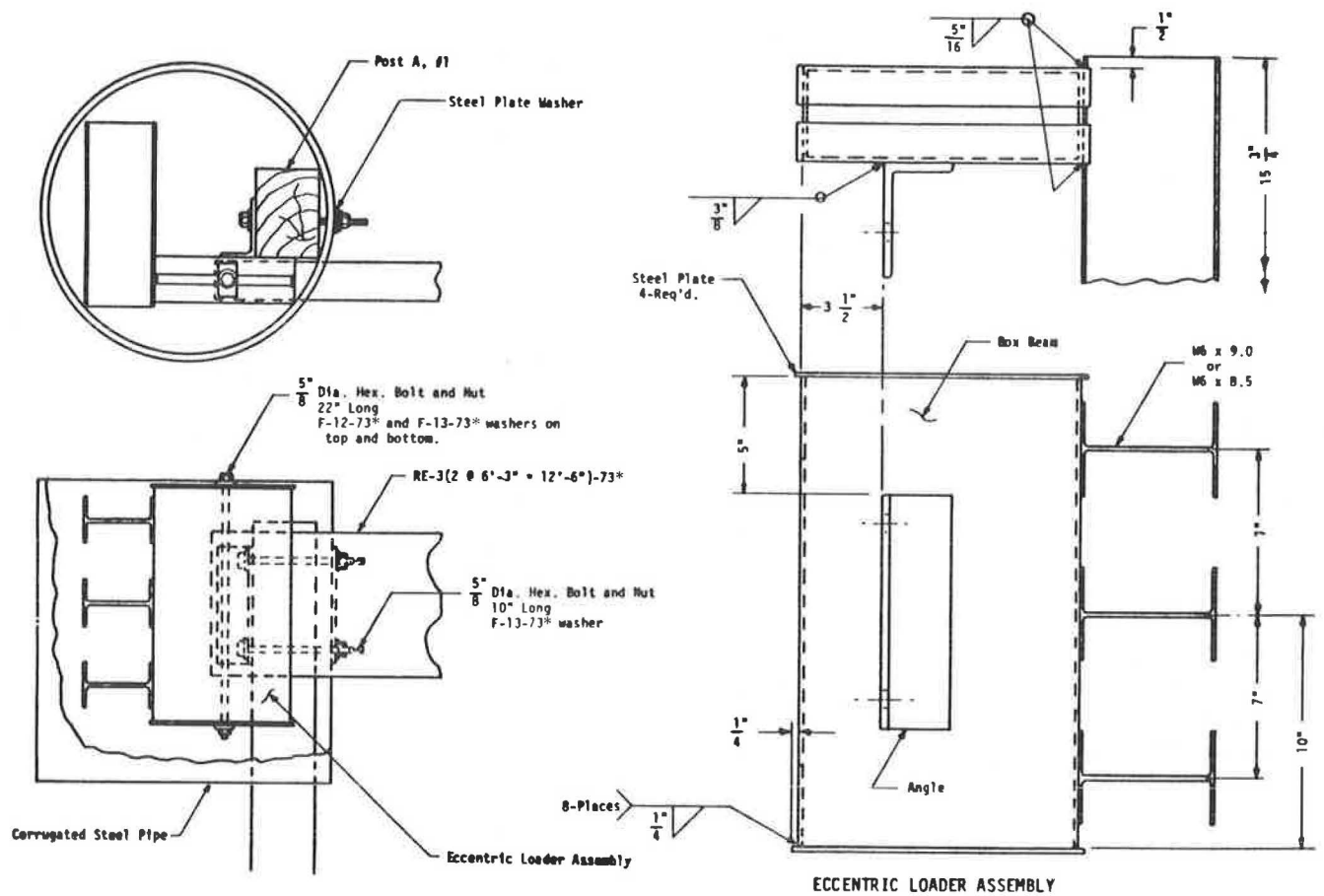
Test RBCT-17

Some difficulty was encountered in achieving the desired results for the length-of-need strength test. Problems attributed to foundation movement at the end post were corrected by adding a strut between the first and second posts. In addition, the slot in the box-beam section of the nose was modified to eliminate loading of the end post by the tension force of the beam, which had caused premature end post failure. Neither of these changes are considered significant for end-on Test RBCT-13 results.

The 4,500-lb (2000-kg) test vehicle struck the terminal downstream of the third post at 58.2 mph (93.6 km/hr) and 24.2 degrees (as measured from the travel way). The vehicle was smoothly redirected as shown in Figure 4 and results indicate compliance with NCHRP Report 230.

Test RBCT-18

This test evaluated the eccentric loader for 60-mph (95-km/hr) end-on performance with the 4,500-lb (2000-kg) vehicle. The vehicle struck the nose and



*See report by AASHTO-AGC-ARTBA-Joint Cooperative Committee, "A Guide to Standardized Barrier Rail Hardware."

FIGURE 2 Eccentric loader.

TABLE 1 Summary of 4-ft Flare Crash Test Results

	Test No.			
	RBCT-13	RBCT-17	RBCT-18	RBCT-19
NCHRP Report 230 test no.	45	40	41	44
Test vehicle	1979 Honda	1978 Plymouth	1978 Plymouth	1978 Honda
Vehicle inertial weight, lb	1,821	4,389	4,423	1,740
Vehicle gross weight, lb	1,986	4,719	4,753	1,905
Impact speed (film), mph	60.5	58.2	59.0	58.9
Impact angle (film), degrees	0.2	24.2	0.6	15.0
Exit angle (film), degrees		14.7		12.6
Maximum 50-msec avg acceleration (accelerometer/film)				
Longitudinal	4.1/6.8	-3.3 film	-2.6/-5.8	-4.8 film
Lateral	5.9/3.4	4.8 film	3.2/4.3	-8.7/-7.4
Occupant risk, NCHRP Report 230 ^a (accelerometer/film)				
ΔV longitudinal, fps (30)	29.1/26.7	16.7 film	16.6/13.5	17.1/-7.6
ΔV lateral, fps (20)	12.4/12.0	11.5 film	-13.2/-10.1	19.2/21.0
Ridedown acceleration, g's (accelerometer)				
Longitudinal (15)	7.4	3.4	11.2	
Lateral (15)	7.5	4.8	13.4	13.7
NCHRP Report 230 evaluation				
Structural adequacy (A,D)	NA	Passed	NA	NA
Occupant risk (E,F,G)	Passed	NA	Passed	Passed
Vehicle trajectory (H,I)	Passed	Passed	Passed	Exit angle 12.6° > 0.6(15°)

Note: multiply lb by 0.454 to obtain kg; multiply ft by 0.305 to obtain m; multiply mph by 1.609 to obtain km/hr; and multiple fps by 0.305 to obtain mps. NA = not applicable.

^aNumbers in parentheses are values recommended in NCHRP Report 230.

TABLE 2 Summary of 1.5-ft Flare Crash Test Results

	Test No.			
	EN-3	EN-5	EN-4	EN-6
NCHRP Report 230 test no.	45	40	41	44
Test vehicle	1979 Honda	1978 Dodge	1978 Dodge	1979 Honda
Vehicle inertial weight, lb	1,815	4,319	4,370	1,785
Vehicle gross weight, lb	1,980	4,649	4,700	1,950
Impact speed (film), mph	59.1	62.9	60.1	58.4
Impact angle (film), degrees	0.5	24.9	0.1	16.4
Exit angle (film), degrees				6.3
Maximum 50-msec avg acceleration (accelerometer/film)				
Longitudinal	-13.8/-8.6	-3.9/-3.0	-5.9/-4.1	-4.4/-3.7
Lateral	4.1/2.9	-7.7/-6.2	2.3/2.1	-8.9/-6.3
Occupant risk, NCHRP Report 230 ^a (accelerometer/film)				
ΔV longitudinal, fps (30)	25.8/27.6	6.5/8.1	9.2/15.3	15.5/13.0
ΔV lateral, fps (20)	4.6/10.6	17.3/14.5	-6.1/-11.5	19.0/20.2
Ridedown acceleration, g's (accelerometer)				
Longitudinal (15)	8.7		7.5	1.2
Lateral (15)	10.4	10.6	5.7	10.5
NCHRP Report 230 evaluation				
Structural adequacy (A,D)	NA	Passed	NA	NA
Occupant risk (E,F,G)	Passed	NA	Passed	Passed
Vehicle trajectory (H,I)	Passed	Passed	Passed	Passed

Note: Multiply lb by 0.454 to obtain kg; multiply ft by 0.305 to obtain m; multiply mph by 1.609 to obtain km/hr; and multiply fps by 0.305 to obtain mps. NA = not applicable.

^aNumbers in parentheses are values recommended in NCHRP Report 230.

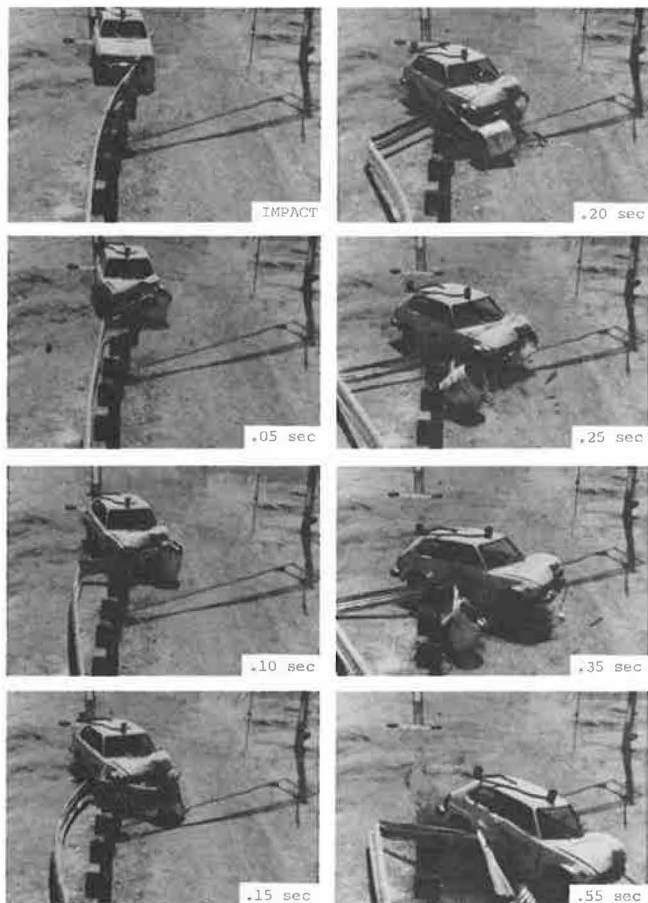


FIGURE 3 Sequential photographs, Test RBCT-13.

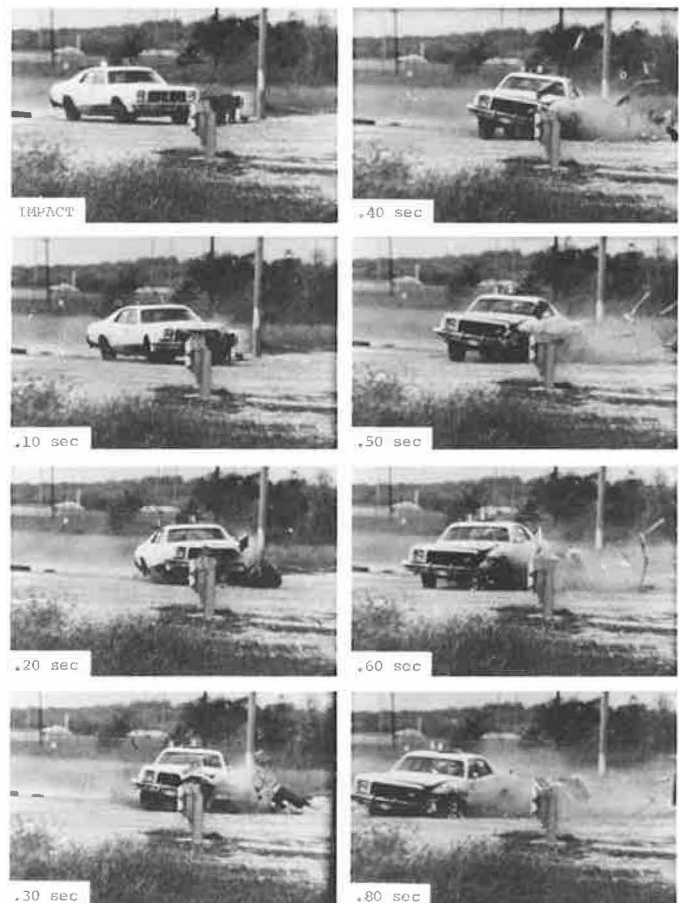


FIGURE 4 Sequential photographs, Test RBCT-17.

was smoothly redirected behind the barrier as shown in Figure 5. Test values indicated compliance with NCHRP Report 230.

Test RBCT-19

This test evaluates a 60-mph (95-km/hr), 15-degree angle impact at a point midway between the nose and length-of-need with a 1,800-lb (800-kg) vehicle. As shown in Figure 6, the vehicle was smoothly redirected. All values of NCHRP Report 230 were met with the exception of the vehicle trajectory requirement of the exit angle not exceeding 60 percent of the impact angle. Although the exit angle at loss of barrier contact exceeded the 60 percent value, the heading angle of the vehicle began to decrease soon after it left the barrier, and the overall vehicle postimpact trajectory is considered excellent.

1.5-ft (0.5-m) Flare Offset Tests

Test EN-3

The terminal was evaluated for the 60-mph (95-km/hr), end-on impact with the 1,800-lb (800-kg) vehicle with a 15-in. (0.4-m) offset. The test vehicle struck the system as shown in Figure 7 and was redirected behind the barrier as designed. Although considerable vehicle roll and pitch were observed during the test, the vehicle remained upright and came to rest 50 ft (15 m) downstream and 18 ft (5 m) behind the initial impact point. Measured test values indicated compliance with the requirements of NCHRP Report 230.

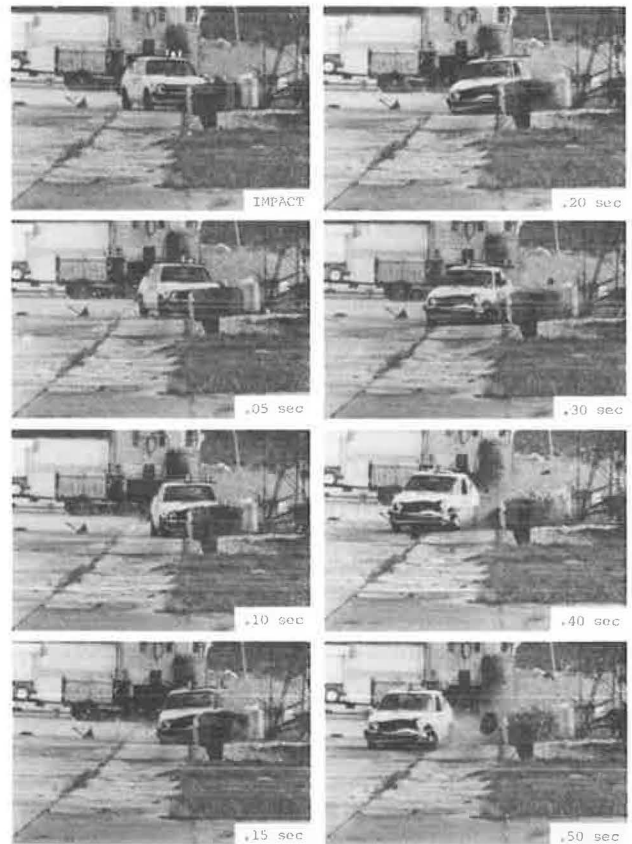


FIGURE 6 Sequential photographs, Test RBCT-19.

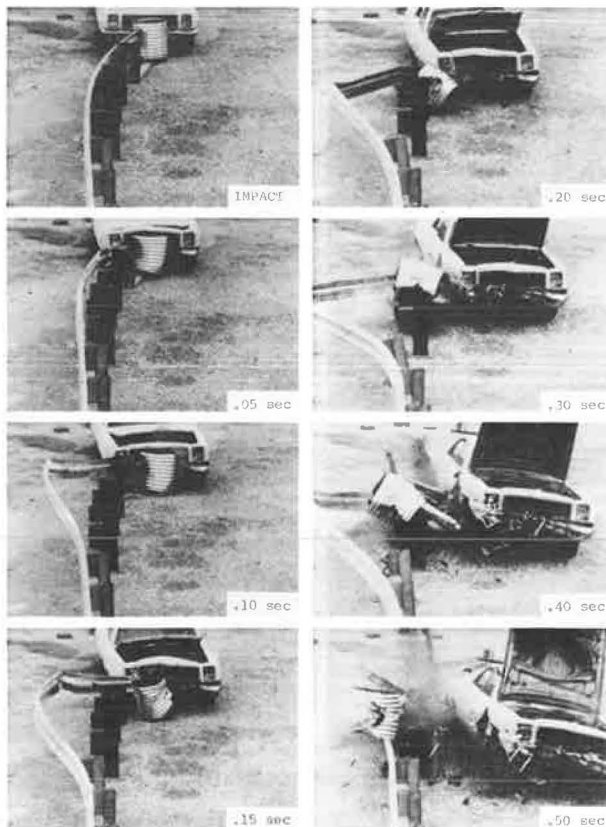


FIGURE 5 Sequential photographs, Test RBCT-18.

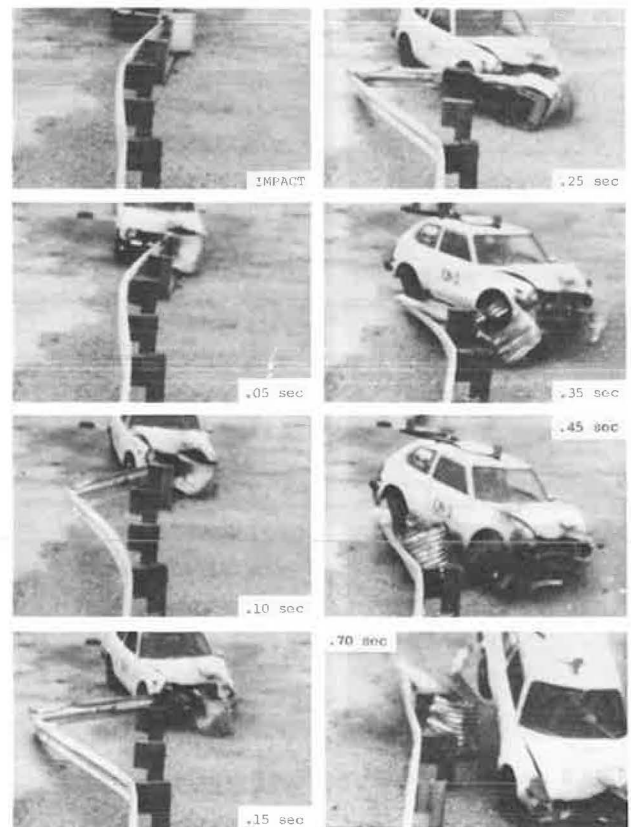


FIGURE 7 Sequential photographs, Test EN-3.

Test EN-4

The purpose of this test was to evaluate the terminal for a center-on impact with the 4,500-lb (1800-kg) vehicle at 60 mph (95 km/hr). As shown in Figure 8, the test vehicle was redirected behind the system although there was considerable vehicle roll. Compliance with the requirements of NCHRP Report 230 was determined.

Test EN-5

This test evaluated the anchor strength of the terminal when struck at the length-of-need by a 4,500-lb (1800-kg) vehicle at 60 mph (95 km/hr) and a 25-degree angle. The test vehicle was smoothly redirected after striking the barrier at the third post as shown in Figure 9. Compliance with the requirements of NCHRP Report 230 was obtained.

Test EN-6

This test was conducted with a 1,800-lb (800-kg) vehicle striking at 60 mph (95 km/hr) and a 15-degree angle with the initial impact point midway between the length-of-need (Post 3) and the end post. As shown in Figure 10, the vehicle was smoothly redirected and the test requirements of NCHRP Report 230 were met.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. On the basis of the results of the test series discussed in this paper, both the 4-ft (1.2-m) and the 1.5-ft (0.5-m) flare offset eccentric loader BCT

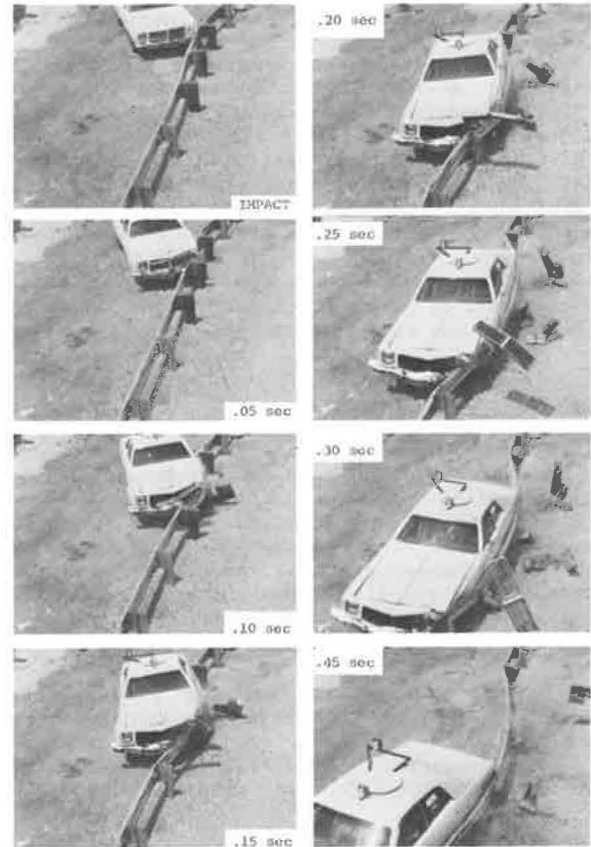


FIGURE 9 Sequential photographs, Test EN-5.

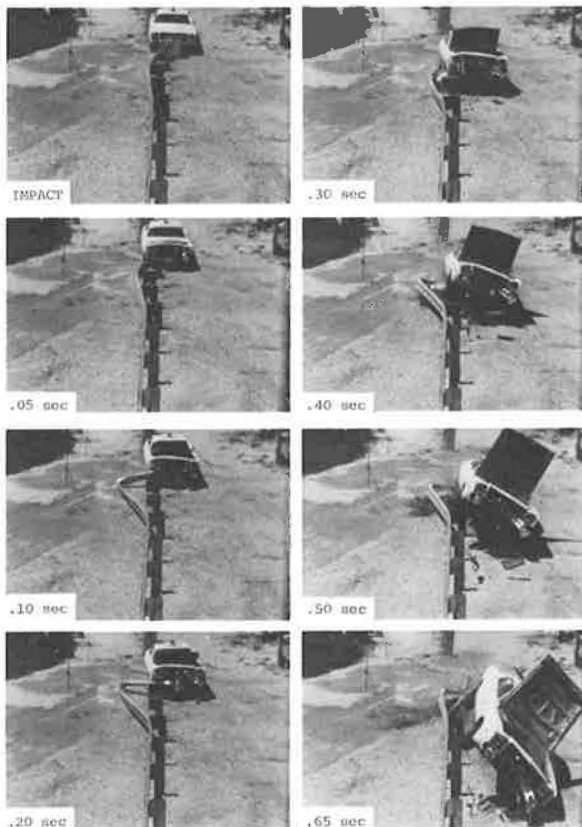


FIGURE 8 Sequential photographs, Test EN-4.

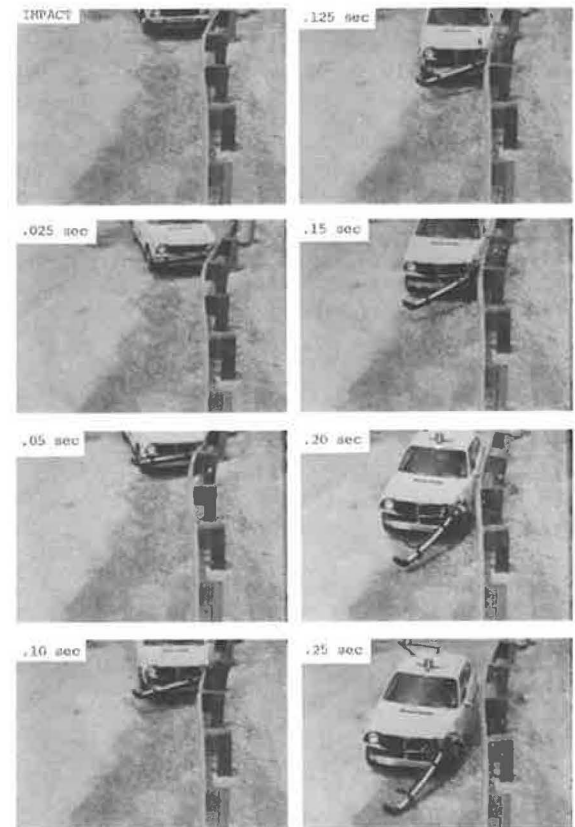


FIGURE 10 Sequential photographs, Test EN-6.

terminal designs satisfy the requirements of NCHRP Report 230.

2. The designs are considered suitable for retrofit or new construction applications.

3. The terminals are considered appropriate for all guardrail systems that are either W-beam systems or have a satisfactory transition to a W-beam system.

4. The 4-ft (1.2-m) flare offset design is considered superior to the 1.5-ft (0.5-m) flare offset design because of the more stable vehicle behavior during end-on impacts.

5. Expected additional costs over the current BCT guardrail terminal for the eccentric loader designs are in the \$300 to \$400 range.

Recommendations

1. The eccentric loader terminals are recommended for immediate implementation as experimental devices. Design drawings are available from FHWA.

2. How changes in the design drawings will affect the performance of the system should be carefully considered. Changes are not recommended unless cost advantages are realized without compromising performance or improved performance is realized.

3. Where space permits, the 4-ft (1.2-m) flare offset design is recommended. The 1.5-ft (0.5-m) flare should be used at sites with limited space; this is preferable to installing the larger flare on the sideslope.

4. Consideration should be given to distance traveled beyond the end during end-on impacts.

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