DEVELOPMENT OF A NEW MEDIAN BARRIER TERMINAL

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Traffic barrier terminals or end treatments have been shown by test and in the field to be more hazardous than the downstream or typical barrier installation. New end treatments are needed to improve the performance of the barriers when they are impacted end-on. Accordingly, new traffic barrier concepts were formulated and two were evaluated by crash tests. A guardrail breakaway cable terminal (BCT) developed previously was subjected to more extensive testing, and modifications were incorporated as indicated by test results. A new median barrier terminal that incorporated breakaway cable features was also developed and evaluated; this terminal is the subject of this paper. Because the purpose of barrier terminals is to provide longitudinal and lateral restraint for downstream impacts without being a hazard for end-on impacts, the test terminals were subjected to both angular and end-on impacts. Impact conditions included both standard (4,000-lbm) and subcompact (2,000-lbm) vehicles, moderate (40-mph) and high-speed (60-mph) velocities, and angles of 0 and 25 deg. Sixteen crash tests were conducted on the median barrier BCT. Crash events were documented by photography and electronic transducers. Results of the tests indicate that these new terminals provide a significant improvement in performance over other currently specified terminals. The median barrier BCT elements that collapse in accordian-like manner when impacted end-on could be used at sites requiring crash cushions (e.g., at elevated gores). The cost is substantial, but the increase in cost over existing terminal designs diminishes as the length of the barrier increases.

•APPROACH ENDS of guardrails and median barriers have long been recognized (8) as formidable roadside obstacles with which traffic must contend. The W-beam in upright terminals has penetrated the passenger compartment in numerous end-on impacts, whereas ramped terminals have caused impacting vehicles to be launched, rolled, and tumbled. A guardrail terminal was developed, evaluated, and then refined in a recent NCHRP program (7). This breakaway cable terminal (BCT) features a horizontally flared end to introduce flexural loading in the end-beam panel for end-on impacts.

The median barrier terminal is exposed to a wider range of vehicle collisions (e.g., being struck from either side) than a typical guardrail terminal; hence, the guardrail BCT is not directly applicable to median barriers. Accordingly, it was deemed desirable to develop a symmetrical median barrier BCT in contrast to the unsymmetrical (i.e., flared) guardrail BCT.

The objective of this research was to develop and evaluate a new median barrier terminal concept by a series of crash tests.

Inasmuch as the dual purposes of traffic barrier terminals are to present minimal hazard for end-on impacts and to anchor the installations for downstream impacts, the terminal concepts were evaluated for both end-on and angular impacts. Both 2,000-lbm (900-kg) and 4,000-lbm (1800-kg) vehicles were used to provide a range of vehicle sizes. Impact conditions included both 40- and 60-mph (64- and 97-km/h) velocities and 0- and 25-deg angles.

TERMINAL DEVELOPMENT

Preliminary Designs

Based on the success of the guardrail BCT, it was concluded that the BCT could be used for the median barrier terminal. Because the horizontal flare in the guardrail BCT is used to reduce longitudinal resistance of the standard W-beam element, another method was needed for the symmetrical (no flare) median barrier end. A design using flat plates in the terminal length to reduce the longitudinal resistance for end-on impacts was formulated. These plates serve as redirection panels for angular impacts within the terminal length. A number of preliminary tests were conducted (Fig. 1) before a finalized configuration was determined. Although a steel post system was tested, most of the preliminary tests were conducted with the blocked-out W-beam median barrier, wood post (5). These early tests were characterized by a relatively smooth deceleration of the vehicle as the flat plates collapsed, followed by launching of the vehicle as it approached the more rigid W-beam elements (Fig. 2).

Finalized Configuration

A major redesign of the median barrier BCT was undertaken with the following primary objectives:

1. Decelerating a 4,000-lbm (1800-kg) vehicle impacting end-on at 60 mph (97 km/hour) to stop in contact with the barrier using a minimum of terminal length (the vehicle must be brought to a stop before contacting the rigid barrier elements; i.e., the terminal must be of sufficient length to stop the vehicle and to keep decelerations within tolerable limits);
2. Redirecting a 4,000-lbm vehicle impacting downstream of the end at 60 mph and at an angle of 25 deg; and
3. Minimizing the terminal length for economic and hazard-exposure conditions.

The finalized BCT configuration as shown in Figures 3 and 13 (Appendix) is characterized by the following features and components: terminal length, beams, posts, nose, and BCT hardware.

Terminal Length—A 24-ft (7.3-m) terminal length was selected based on the loads developed in the preliminary end-on tests and the expression

$$s = \frac{V^2}{2ag} \tag{1}$$

where

s = vehicle stopping distance, ft (m);
V = vehicle impact velocity, fps (m/s);
a = average vehicle deceleration, g; and
g = gravitational constant = 32.2 ft/s^2 (9.8 m/s^2).

If we assume a constant decelerating force of F = 20 kips (89 kN) (based on preliminary tests), the deceleration level for a vehicle of W = 4,000 lb (1800 kg) would be

$$a = \frac{F}{W} = \frac{20}{4} = 5\text{ g} \tag{2}$$

or 10 g for a 2,000-lbm (900-kg) vehicle. From Eq. 1

$$s = \frac{(88\text{ fps})^2}{(2)\,(5\text{ g})\,(32.2\text{ ft/s}^2/\text{g})} = 24\text{ ft}$$

The 10-g level for the 2,000-lbm (900-kg) vehicle is in conformance with current FHWA crash cushion criteria, which specify a maximum of 12 g based on stopping distance (9).

Beams—Launching of the vehicle in preliminary tests was partially attributed to the

Figure 1. Preliminary median barrier terminal test installations.

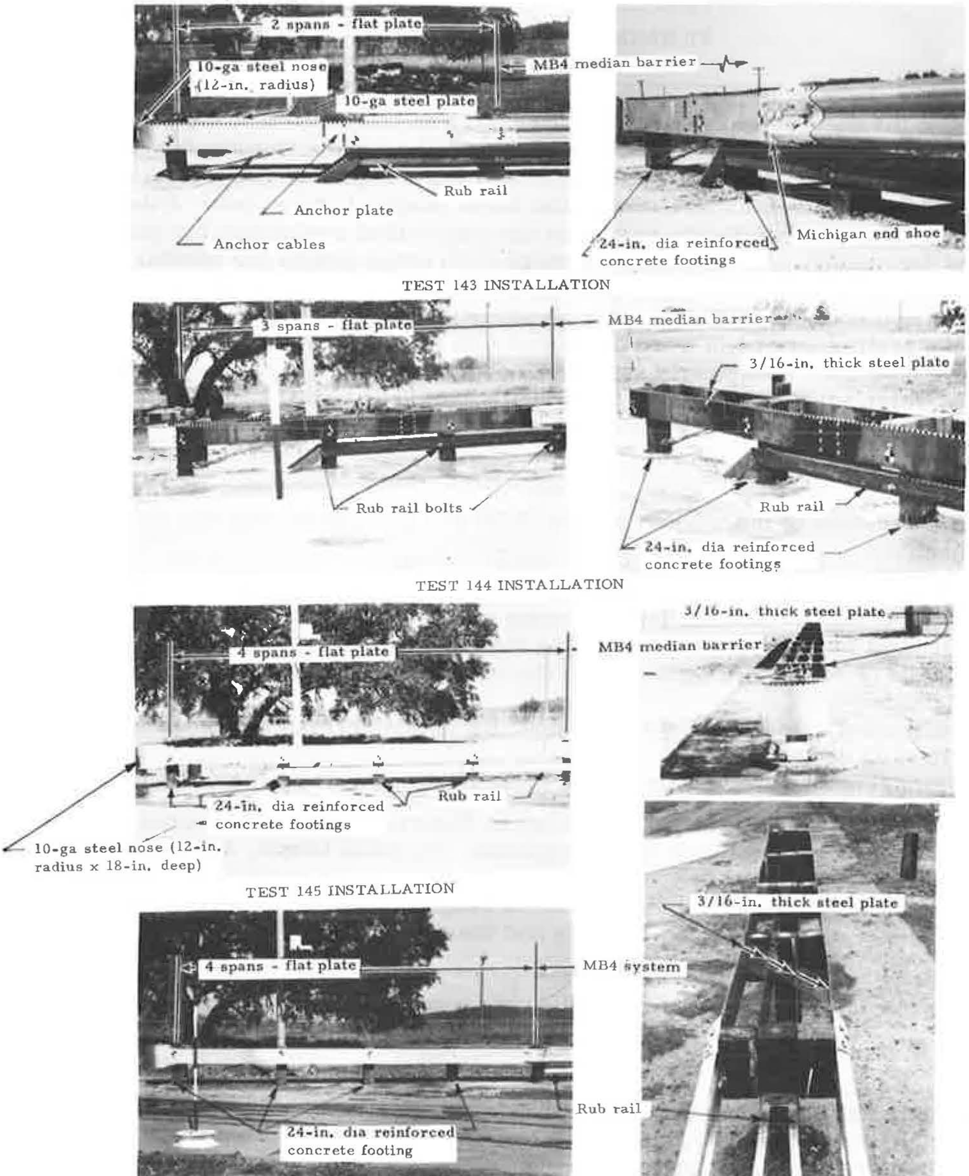
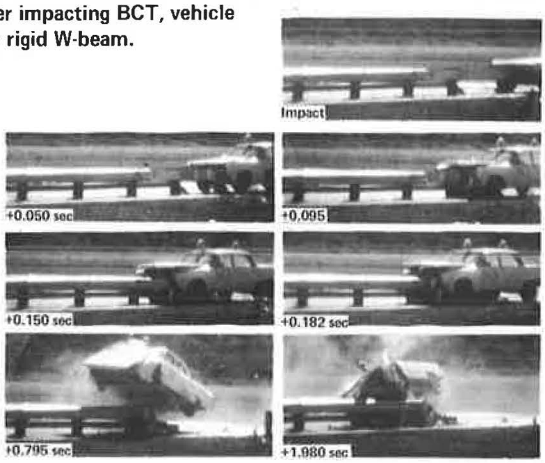


Figure 2. After impacting BCT, vehicle is launched by rigid W-beam.



32-in. (813-mm) height of the terminal. This elevation permitted the vehicle to climb atop the deformed terminal in later stages of a test. This height was modified to 42 in. (1.1 m) for the final terminal design; an outer beam width of 30 in. (0.7 m) was used to prevent vehicle underride for angular impacts. Interior beams 12-in. (0.3-m) wide were placed between the posts and blocks at 42-in. elevation to help minimize launching.

Posts—Both steel and timber posts were used in the final configurations. Because breakaway performance of the terminal posts is essential, steel posts are welded to base plates only on the traffic sides. Both W6 × 8.5 and TS6 × 8 × 0.1875 steel posts were tested in the finalized design configurations. Terminal posts of 6- × 8-in. (150- × 200-mm) timber with a 2³/₈-in. (60-mm) diameter hole bored through the neutral axis were tested in a finalized configuration.

Rigid foundations are considered basic to the breakaway post concept inasmuch as brittle fracture is desirable; posts that lean in soil have launched vehicles. The reinforced concrete footings used in the work provide adequate support for design performance.

Nose—A steel barrel was selected as the terminal nose for the final configuration. Tests of the barrel crash cushion have demonstrated that the front barrels fold over and under the vehicle front forming a mechanical "lock" on the vehicle. This lock is considered desirable because it helps to prevent a vehicle from vaulting over the installation.

BCT Hardware—BCT hardware consisted of anchor plates, anchor cables, and end posts. The steel end post was reinforced locally to increase the anchor load capacity.

TEST PROGRAM

Nine crash tests were conducted on the finalized BCT configuration (Table 1). Test installations included the median barrier BCT installed with the following systems:

1. MB3—box beam median barrier,
2. MB4S—blocked-out W-beam on steel posts, and
3. MB4W—blocked-out W-beam on timber posts.

Terminal posts were of the same material as the system. A design drawing of the BCT installed with the MB4S system is shown in Figure 13. Also shown in the Appendix are photographs of the test series.

End-On Performance

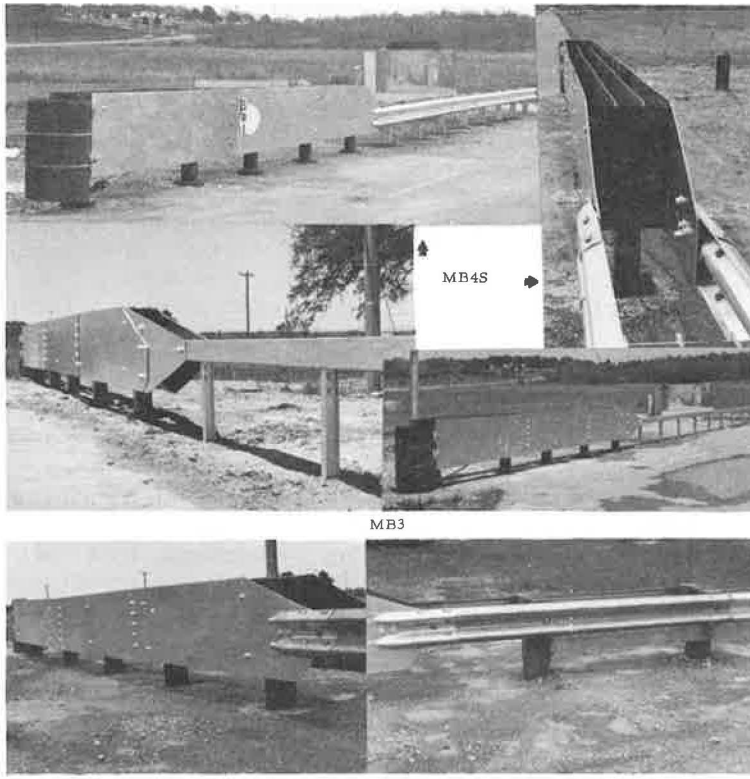
End-on performance of the finalized configuration was demonstrated with both steel and timber terminal posts by using standard-sized and subcompact vehicles. Three terminal post designs were evaluated for end-on performance:

1. W6 × 8.5 post welded to base plate with a $^3/_8$-in. (9.5-mm) fillet weld on the traffic side of the flanges only,
2. TS6 × 6 × 0.1875 box-beam post welded to base plate with a $^3/_8$-in. fillet weld on the traffic side of the flanges only, and
3. Timber posts 6 × 8 in. (150 × 120 mm) with a hole drilled through the neutral axis.

The median barrier BCT with W6 × 8.5 steel posts was impacted end-on with a standard vehicle at 62 mph (100 km/hour) as shown in Figure 4b. The vehicle was decelerated to a stop in contact with the barrier with an effective stopping distance of 30 ft (9 m). A subcompact car impacted an identical installation end-on at 41.5 mph (67 km/hour) and was decelerated to a stop in contact with the barrier as shown in Figure 4a with an effective stopping distance of 13 ft (4 m). The end-on test of the BCT with TS6 × 6 × 0.1875 box-beam posts was conducted with a subcompact vehicle impacting at 62.4 mph (100 km/hour) as shown in Figure 5. The vehicle was decelerated to rest in contact with the barrier with an effective stopping distance of 16 ft (4.9 m).

In test 158, the five terminal posts were 6- × 8-in. (150- × 200-mm) southern pine members embedded in concrete footings; an MB4W system was installed downstream of the terminal. A standard-sized vehicle impacted the barrier end-on at a speed of 64.8 mph (104 km/hour) and was decelerated to rest in contact with the barrier as shown in Figure 6. The effective stopping distance was 22 ft (6.7 m).

Figure 3. BCT installations on three types of median barriers.



MB3

MB4W

Table 1. Summary of finalized median barrier BCT tests.

Barrier System[a]	Terminal Length (ft)	Terminal Post[b]	Terminal Beam Elements (in.)	Terminal Rail Height (in.)	Vehicle Weight (lbm)	Vehicle Speed (mph)	Impact Angle (deg)	Max Average Deceleration[c] (g) Long.	Max Average Deceleration[c] (g) Lat.	Remarks
D, E, F	25	W6 × 8.5 steel	$^3/_{16}$ × 30	42	3,800	63.0	0.5	7.2 (4.4)	1.2	Vehicle smoothly decelerated in contact with barrier (30-ft stopping distance).
D, E, F	25	W6 × 8.5 steel	$^3/_{16}$ × 30	42	2,200	41.5	0.4	5.7 (4.4)	2.4	Vehicle smoothly decelerated in contact with barrier (13-ft stopping distance).
D, E, F	25	W6 × 8.5 steel	$^3/_{16}$ × 30	42	3,900	57.0	27	6.2	2.5	Vehicle impacted rail just upstream of second post; no redirection was evident as vehicle penetrated the system. Local anchorage failure occurred.
D, F, G	25	TS6 × 6 × 0.1875	$^3/_{16}$ × 30	42	4,000	54.5	26.7	7.0	3.3	Vehicle impacted rail 2 ft upstream of second post; little redirection occurred as vehicle penetrated the system. Local anchorage failure occurred.
D, F, G	25	TS6 × 6 × 0.1875	$^3/_{16}$ × 30	42	4,000	61.1	26	7.1	7.6	Vehicle impacted at third post and was smoothly redirected.
D, F, G	25	TS6 × 6 × 0.1875	$^3/_{16}$ × 30	42	2,400	62.4	1.5	13.3 (8.1)	2.7	Vehicle came to rest in contact with barrier with little change in direction (16-ft stopping distance).
D, F, G	25	TS6 × 6 × 0.1875	$^3/_{16}$ × 30	42	3,800	60	25	–	–	Vehicle was redirected although unanchored box beam spans disengaged from posts.
D, F, G	25	TS6 × 6 × 0.1875	$^3/_{16}$ × 30	42	3,900	58	25	8.5	6.4	Vehicle was redirected, noticeable roll away from barrier was evident in redirection. Vehicle impacted rail upstream of third post.
A, C, F	25	6 × 8 timber posts with hole through neutral axis	$^3/_{16}$ × 30	42	3,900	64.8	1.2	11.6 (6.4)	5.0	Vehicle decelerated in contact with barrier; stopping distance 22 ft.

Note: 1 ft = 0.3 m; 1 in. = 25.4 mm; 1 lbm = 0.45 kg; 1 mph = 1.6 km/h.

[a]Barrier systems: A = timber post W beam median barrier, B = rub rail terminated at second post, C = rub rail terminated at sixth post, D = steel post W beam median barrier with no rub rail, E = W6 x 8.5 terminal posts welded to base plate at grade, F = 55-gal drain added to end, interior terminal beams 12 in. wide and placed at top of outside rail elevation, and G = TS6 x 6 x 0.1875 steel posts welded to base plate at grade.

[b]All terminal posts set in 24 in. diameter reinforced concrete footing at 41 in. deep.

[c]Maximum deceleration averaged over 50 msec duration obtained from high-speed cine. Parenthesis indicates deceleration based on stopping distance.

Angular Impact Tests

Crash test evaluation of the finalized median barrier BCT configuration was conducted with standard sedans impacting the barrier upstream of the third terminal post with standard impact conditions [i.e., 4,000-lbm (1800-kg) vehicle, 25 deg, 60 mph (97 km/hour)]. Tests were conducted with the BCT installed with the MB3 and MB4S. The transition from the BCT to the box-beam median barrier was effected as shown in Figure 7. Although significant rolling occurred, which caused the test vehicle to ride up the barrier, the vehicle was redirected (Fig. 8). The BCT-MB4S system installation was impacted upstream of the third post, and the vehicle was then redirected as shown in Figure 9.

CONCLUSIONS

Performance

Performance of this design was demonstrated for terminals constructed with the MB3, MB4S, and MB4W systems. The median barrier BCT behaves as a crash cushion for end-on impacts; i.e., it decelerates the vehicle to a stop in contact with the terminal length. The 25-ft (7.6-m) BCT length appears to be adequate for safely attenuating the energy of a 4,000-lbm vehicle impacting end-on at 60 mph. Although penetration of the system is likely for large-angle impacts near the nose, the terminal is an effective redirection barrier for standard test impacts within the terminal length. The breakaway steel post assembly provides sufficient installation anchorage to redirect vehicles impacting downstream of the third post at standard test conditions. The vehicle deceleration ratings assigned to individual tests correspond closely to those ratings (5) determined for general performance of the length of need.

Economics

The median barrier BCT design is considerably more expensive than many other terminals being used (i.e., $1,263 as compared to $355 for the G4 terminal shown in NCHRP Report 118). (These costs were developed from information obtained from barrier manufacturers.) However, the effect of the additional cost is diminished when the normal length of median barriers is considered. Although a continuous effort was made to keep the design simple and inexpensive, there are features of the median barrier BCT where cost reductions may be appropriate; these are the post and block out, concrete footings, and outer plate thickness.

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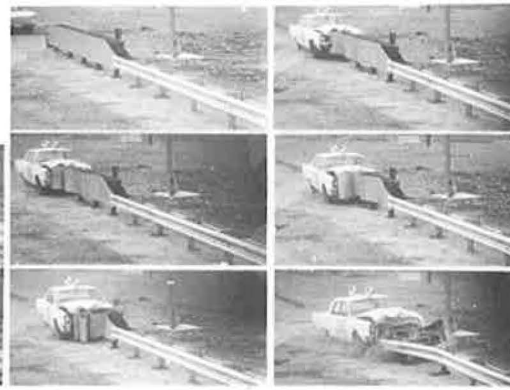
Figure 4. (a) Subcompact and (b) standard-sized vehicles impacting same BCT-barrier configuration.

(b)



(a)

Figure 5. Subcompact car impacting BCT box-beam post configuration.

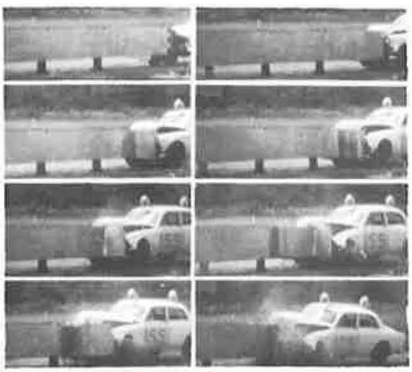


Figure 6. End-on impact of BCT-MB4W configuration.

Figure 7. BCT transition details for MB3 box-beam system.

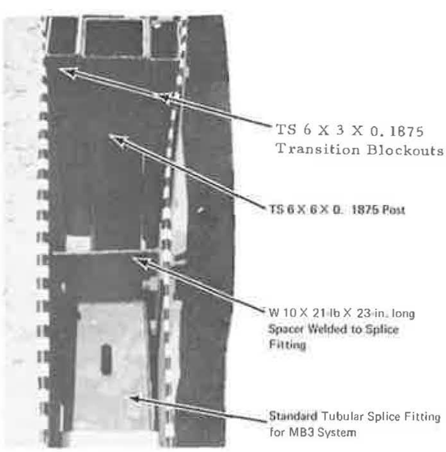


Figure 8. Angle impact of BCT-MB3 configuration.

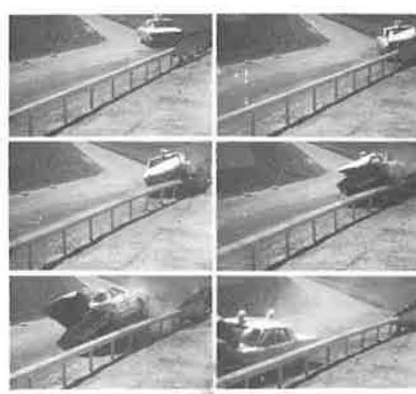


Figure 9. Angle impact of BCT-MB4S configuration.

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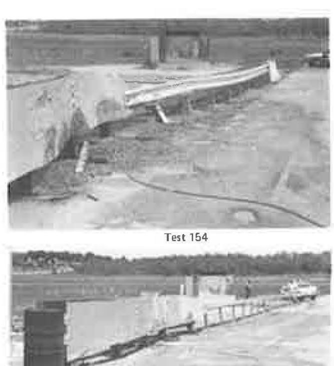
APPENDIX

TEST PHOTOGRAPHS AND INSTALLATION DRAWING

Figure 10. Photographs after end-on tests.

Figure 11. Photographs after angle impacts.



Test 154

Test 157

Figure 12. Vehicle damage.

Figure 13. Median barrier BCT design drawing.