Aeronautical Laboratory, Inc., Buffalo, N.Y., Sept. 1970.
2. Standard Details. New Jersey Department of Transportation, Trenton, July 1976.
3. Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances. Transportation Research Circular 191, TRB, National Research Council, Washington, D.C., Feb. 1978.
4. Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances. NCHRP Report 230, TRB, National Research Council, Washington, D.C., March 1983.
5. AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals. FHWA Notice N5040.20. FHWA, U.S. Department of Transportation, July 14, 1976.
6. J.B. Mayer, Jr. and M.E. Bronstad. Full Scale Vehicular Crash Testing of a Modified NJ Breakaway Sign Structure. Southwest Research Institute, San Antonio, Tex., Nov. 1983.

Analysis of Accidents Involving Breakaway-Cable-Terminal End Treatments

JERRY G. PIGMAN, KENNETH R. AGENT and TOM CREASEY

ABSTRACT

This paper includes an analysis of 50 accidents involving breakaway-cable-terminal (BCT) end treatments and 19 accidents involving median-breakaway-cable-terminal (MBCT) end treatments as used in Kentucky. The primary data base consisted of Kentucky accident records for the years 1980-1982; selected accidents were included that occurred before 1980 and after 1982. An attempt was made to document each accident with a police report, photographs, and a maintenance repair form. Results showed that the BCT end treatment performed properly in 60 percent of the accidents; that is, the end treatment performed as it was designed, with the wooden posts breaking away or the guardrail redirecting the vehicle. Only five impacts were known to involve small cars and the BCT performed improperly in four of those accidents. It should be noted that the BCT used in Kentucky is similar to the design tested and evaluated as part of the NCHRP studies and included in the AASHTO barrier guide. The primary difference was that before 1982, most BCTs in Kentucky were installed so that the last 125 ft of rail were placed on a simple curve (4.5 degrees) and there was a 6-ft offset rather than a parabolic flare with a 4-ft offset. However, Kentucky's MBCT design utilizes two BCTs joined together at the end section, and it varies considerably from the design tested as part of the NCHRP studies. The MBCT end treatment performed properly in 50 percent of the accidents. Problems related to stiffness of the end treatment are most apparent when impact angles are shallow. A recommendation was made to remove any existing MBCT designs from gore locations and replace them with crash cushions. A turned-down end treatment design was proposed for consideration at median installations.

The performance of guardrail end treatments has been a subject of concern to highway engineers for many years. A concerted effort was begun in the mid-1960s to evaluate guardrail design and recommend warrants for guardrail use. The work was funded through NCHRP Project 15-1 and a review of current practice was performed by Cornell Aeronautical Laboratory (1). The next study funded by NCHRP was a compilation of recommended practices for locating, designing, and maintaining guardrails and median barriers (2). Results reported from the study were based on a comprehensive literature review, a state-of-the-art survey, and the advice of a selected group of experts. It was noted that ramped end treatments were found to cause test vehicles to launch, roll, and tumble.

The next study in the series under NCHRP Project 15-1 included results of 25 full-scale crash tests and summarized the relative performance of the designs tested (3). Eight full-scale tests were performed on end terminal designs; six involved ramped designs, one was performed on a flared end treatment, and one on a blunt end terminal. With the exception of one test, the vehicles were launched, rolled, and tumbled in the ramp-terminal tests. In the flared-terminal test, the vehicle penetrated the rail and decelerated in an acceptable manner. For the blunt-terminal test, the vehicle sustained major front-end damage, was launched, and landed on top of the rail. It was concluded that all designs tested as part of the research were hazardous and development of a safer end treatment was the highest-priority item for subsequent research.

The fourth in a series of studies as a part of NCHRP Project 15-1 was a synthesis of information on warrants, service requirements, and performance criteria for all traffic-barrier systems (4). Emphasis was placed on the center or "length-of-need" section rather than on the terminal sections.

The last of five documents reporting on research that originated as NCHRP Project 15-1 dealt with guardrail end design and included results of full-scale tests on hydraulic-post guardrail design and concepts for improved end designs (5). Results included in NCHRP Report 118 were 12 new guardrail terminal and transition concepts, one of which was the breakaway cable terminal (BCT). Three full-scale crash tests were performed to evaluate the dynamic performance of the BCT. The BCT concept was shown to be an effective terminal for W-beam guardrail systems and appeared to be a significant improvement over either the turned-down or blunt-nose terminal. It was noted that for end-on impacts, the BCT performed in a manner similar to that of crash cushions. Maximum average vehicle deceleration permissible for crash cushions is 12 *g* and average deceleration values for end-on impacts into the BCT were only 2.5 and 3.4 *g*. Those tests were conducted with 4,100-lb test cars, and it was noted that higher deceleration values should be experienced for smaller test vehicles. Advantages of the flared over the nonflared terminal for end-on impacts were demonstrated in the crash tests. Stabilization of the end nose was achieved by using either steel diaphragms or vermiculite concrete to spread the beam loads over a large frontal area. As a result of the tests conducted and documented in NCHRP Report 129, the BCT was recommended for immediate installation for field evaluation.

The work of the Southwest Research Institute (SWRI) on guardrail end treatments was extended as NCHRP Project 22-2. Included were 25 full-scale crash tests to develop prototype end designs with emphasis on the BCT (6). Three tests of the BCT with subcompact cars were also performed. High rates of deceleration were measured during impacts with the small cars. Results indicated that the BCT neither eliminated nor increased the danger during small-car end-terminal collisions. Modifications to the end treatment were made to include a concrete footing and a drilled hole in the second post. Additional modifications were made to increase the size of the concrete footing, which had failed in one of the earlier tests. Overall results confirmed the recommendation for immediate trial implementation.

Development of the BCT for median barriers followed the research on BCTs for guardrails (7). Test results showed that the median barrier performed acceptably for the steel box-beam median barrier and the blocked-out W-beam median barrier with both steel and wood posts. It was also noted that installation of the BCT for guardrails was encouraged by FHWA as part of the National Experimental and Evaluation Program (Notices HNG-32, December 11, 1972, and HHO-31, May 24, 1973).

Additional research conducted as part of NCHRP Project 22-2 included component testing, analytical simulation, and full-scale crash testing to further develop earlier BCT designs (8). Several modifications were made, including the use of slip-base steel posts, a reduction in the size of wood posts from 8 x 8 in. to 6 x 8 in., and elimination of diaphragms in the nose section. It was noted that more than 12 states had installed BCTs as of March 1976.

An update on development of the BCT was reported by NCHRP in May 1978 (9). Several problems were reported, both in service and during subsequent experimental programs. Those problems included removal of the fractured wood post from the concrete footing, cost of BCT components, and snagging of a subcompact vehicle's underside by steel-post BCTs. Modifications made were such that the BCT was judged to perform satisfactorily for most vehicle impact conditions. It was noted that 30 states had adopted the guardrail BCT as a standard and that there was less widespread use of the median-barrier BCT.

By November 1980 it was reported by NCHRP that nearly 100,000 BCT end treatments had been installed in more than 40 states (10). Problems continued to occur with the removal of broken posts and with installations where the 4-ft flare was not obtained. It was emphasized that lack of the 4-ft flare could result in spearing of vehicles during head-on impacts.

Documentation of field performance of BCT and median-breakaway-cable-terminal (MBCT) end treatments has been relatively scarce since the testing by SWRI. A study by the New Jersey Department of Transportation had the objective of evaluating in-service performance of BCTs (11). A total of 13 vehicular impacts into BCTs was evaluated and results were compared with full-scale crash tests previously conducted by SWRI. The in-service experience was similar to the initial tests by SWRI, and the BCT was recommended for flared-guardrail installations. A significant problem was spearing of small cars during end-on impacts when the end had not been flared. Reinforcement of the unstiffened buffer end on straight guardrail sections was recommended. Replacement of the two 12.5-ft sections with one 25-ft section also was recommended.

The MBCT end treatment as designed and tested by SWRI has had limited use. Installations are known to have been made in New Jersey and North Carolina. New Jersey has installed approximately 40 MBCTs and there has been only one reported accident (E. Dayton, New Jersey Department of Transportation, July 1982, unpublished data). A large automobile struck the device, and it performed as designed. Only one accident has been reported involving a MBCT in North Carolina (M. Bronstad, SWRI, unpublished data). The terminal was impacted end-on by a full-size sedan and performed properly, even though it was damaged extensively.

A recently completed survey by the Transportation Research Program at the University of Kentucky revealed that the BCT was the most common end treatment used; 40 states use this treatment to some degree (12). In 24 states, only the BCT is used for terminating roadside steel-beam guardrails. Some form of the MBCT was used in 16 states.

BCT AND MBCT USE IN KENTUCKY

Kentucky was one of the first states to install BCTs; the first installations were made in 1974. Through 1983 the total number of installations made and included in the Kentucky Department of Highway's summary of unit bid prices was 3,633. The average cost for each was $515. A summary of BCT installations and costs for 1974-1983 is presented in Table 1. The BCT is the current recommended standard in Kentucky for all fills and solid rock cut sections that have an adequate recovery zone behind the guardrail. It should be noted that several BCTs without the parabolic flare have been installed in Kentucky. Before 1982 most BCTs were installed with the last 125 ft of rail placed on a simple curve (4.5 degrees) and an offset of 6 ft. In 1982 Kentucky's standard drawing for BCT installations was revised to reflect a parabolic flare over the last 37.5 ft with a 4-ft offset at the end. A recent installation of a BCT in Kentucky with a 4-ft offset and parabolic flare is shown in Figure 1. Shown in Figure 2 is a BCT installed by using the 4.5-degree simple curve with an offset of about 6 ft. Significant problems can occur if the end is not flared. Only a few accidents were found that involved a BCT without the designed offset. When the BCT end treatment is installed with the designed flare and offset, impacts with the end may result in very acceptable performance, as shown in Figure 3. This BCT was constructed by using the 4.5-degree simple curve as the method to achieve the desired offset.

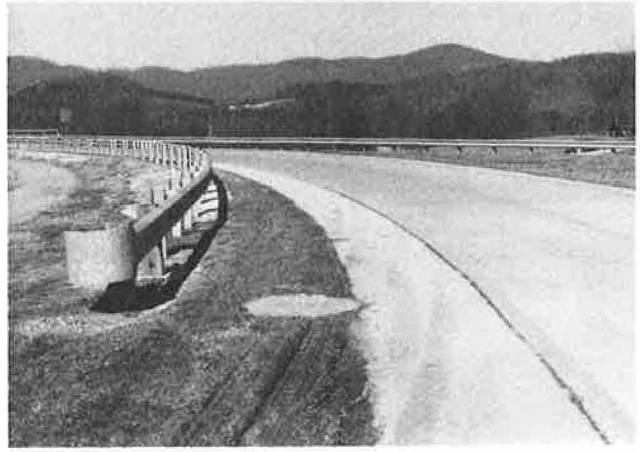

FIGURE 2 BCT installed on 4.5-degree simple curve with offset of 6 ft.

TABLE 1 Summary of BCT and MBCT Installations by Year

	BCT		MBCT	
Year	No.	Avg Unit Price ($)	No.	Avg Unit Price ($)
1974	285	668	2	700
1975	443	617	98	742
1976	421	446	63	590
1977	541	423		
1978	229	444	73	545
1979	350	482	101	574
1980	244	516	10	680
1981	160	519	14	657
1982	498	572	90	636
1983	462	487	122	631
Total	3,633	515[a]	573	627[a]

Note: Numbers and unit prices were tabulated from contracts awarded.

[a]Weighted average.

The MBCT has not been installed in Kentucky as extensively as the BCT. For the period 1974 through 1983, a total of 573 was installed as a part of new construction or reconstruction projects and the average cost was $627 per installation (Table 1). Kentucky's design utilizes two BCTs joined together at the end section as shown in Figure 4. It was noted earlier that head-on impacts into unflared BCTs could result in spearing of the vehicle. Similar problems are associated with head-on impacts into Kentucky's MBCT design (Figure 5). There appears to be little uniformity nationwide in the types of designs used for MBCT end treatments. Only a few states adopted the MBCT for use as it was designed and tested by SWRI. A typical installation using that design is shown in Figure 6. It should be noted that the BCT and MBCT evaluated in this study are the types used in Kentucky. Although the BCT now used in Kentucky is very similar to the design tested, evaluated, and recommended as part of the NCHRP studies (5), the MBCT varies considerably from the MBCT design recommended as part of the NCHRP studies (7,8).

FIGURE 1 BCT end treatment (Kentucky's Type 4).

FIGURE 3 Proper performance of BCT end treatment.

FIGURE 4 MBCT end treatment (Kentucky's Type 6).

FIGURE 5 Spearing of vehicle by MBCT end treatment.

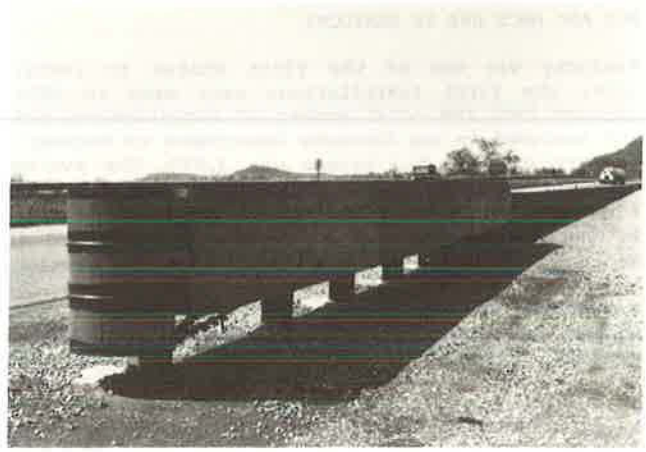

FIGURE 6 MBCT end treatment (similar to design tested by SWRI).

DATA COLLECTION

Data collection for this study involved several phases. Initially, reports of accidents involving all types of safety barriers were collected for 1980. Those barriers included crash cushions, earth mounds, concrete median barriers, and four types of guardrail end treatments: BCT, MBCT, buried (turned down), and blunt. Accident reports were made available through the Accident Surveillance Section of the Division of Traffic, Kentucky Department of Highways. It was decided to search for BCT and MBCT accidents for 1981 and 1982. An inventory of all Kentucky routes having BCT and MBCT installations was used; accident reports pertaining to those routes were reviewed and appropriately selected. Thus a 3-year data base for accidents involving BCT and MBCT end treatments was established.

The next step involved making arrangements with maintenance personnel within the Kentucky Department of Highways so that the study team could be notified when accidents occurred involving BCT or MBCT end treatments. A liaison was appointed for each highway district to supply information concerning guardrail and end-treatment installations and repairs. On-site investigations were made before the guardrail was repaired, and photographs were taken to document the performance and damage of the end treatment. In some instances, photographs of the vehicle were made available through police or other agencies.

Additional accidents involving guardrails were discovered on trips or when accident reports were being searched for other purposes. An effort was made to combine photographs with the accompanying accident reports. However, some accidents involving guardrail ends went unreported. In other cases, the guardrail was repaired before photographs could be taken.

The resulting data base consisted of all known accidents involving BCT and MBCT end treatments since the beginning of those installations. This consisted of a search of accident records for the years 1980, 1981, and 1982 and use of selected accidents before 1980 and after 1982. There was a total of 69 accidents. Time did not permit the investigation of all accidents before 1980 on routes containing BCT and MBCT installations. Correspondence with the district offices eliminated the need to search the records of all accidents occurring after 1982. Information obtained on other types of safety barriers mentioned earlier was used in another phase of the study.

The sample used in the final analysis of data contained verified accidents involving BCT and MBCT end treatments. When possible, each accident was documented with a police report, photographs, repair report, and any other pertinent information. However, not all information could be obtained for every accident.

RESULTS

Data for a total of 69 BCT or MBCT end-treatment accidents were obtained. The majority of accidents (50) involved a BCT. The earliest accident date was May 1976 and the latest was April 1984. Limited repair cost data were available. The average repair cost at eight BCT locations was approximately $700, with a range of about $430 to $920. A wide range of repair costs would be expected because of the difference in damage. The cost to repair one MBCT end treatment was about $890. The repair costs are higher than the original installation costs.

The possible sources of information concerning the accidents included accidents reports, photographs, and repair forms. An accident report was obtained for 51 of the 69 accidents, photographs were obtained for 33 accidents, and a repair form was found for 20 accidents. All three sources of information were found for only six accidents. Both an accident report and photographs were found for 18 accidents. Following is a discussion of the results from the analysis of BCT and MBCT end-treatment accidents.

BCT End-Treatment Accidents

Performance of BCT end treatments was determined for each accident. In addition to end-treatment performance, information concerning vehicle size, impact severity, impact angle, guardrail placement, initial vehicle contact area, vehicle action after impact, and end-treatment damage was analyzed. Subjective judgment was use to determine many of those variables. A detailed description of each accident was included as an appendix in the full report (13) from which this paper was prepared. Sketches were drawn to show the angle of impact when that information was known.

End-treatment performance, when it could be determined, was defined as either proper or improper. Proper performance resulted when the end treatment performed as designed, with the wooden posts breaking away or the guardrail redirecting the vehicle. Of the 50 accidents studied, the BCT end treatment was judged to have performed properly in 30 (60 percent).

Because many of the BCT end treatments were not installed with an offset of 4 ft and a parabolic flare over a distance of 37.5 ft, further analysis was made to document the configuration of the BCT as it was installed. End-treatment configuration was categorized as one of the following:

1. Simple curve: A 4.5-degree simple curve is used to extend the standard section of guardrail to the terminal section. The last 125 ft of guardrail are installed on this 4.5-degree curve to obtain an offset of 6 ft at the end.
2. Parabolic flare: The terminal section is offset 4 ft with a parabolic flare over the last 37.5 ft (type that was tested, evaluated, and recommended as part of NCHRP studies).
3. Straight: The terminal section is placed at the end of a standard section of guardrail with very little or no offset.

Results of categorizing the end-treatment configurations are as follows:

End-Treatment Configuration	No.	Percent
Simple curve	38	76
Parabolic flare	8	16
Straight	4	8
Total	50	

An analysis of the data was made to relate performance to BCT end-treatment configuration (Table 2). It was determined that in 23 of 38 accidents (61 percent) the end treatment performed properly when it was installed on a 4.5-degree simple curve. When the end treatment was installed on a parabolic curve, performance was rated proper in five of eight (63 percent) accidents. For installations that were classified as straight, performance was rated proper in two of four (50 percent) accidents. It is worth noting the specifics of the three accidents involving a BCT end treatment with a parabolic flare that resulted in improper performance:

TABLE 2 Performance Related to BCT End-Treatment Configuration

End-Treatment Configuration	Proper Performance No.	Proper Performance Percent	Improper Performance No.	Improper Performance Percent
Simple curve	23	61	15	39
Parabolic flare	5	63	3	37
Straight	2	50	2	50
Total	30	60	20	40

1. A small car hit the BCT at a moderate angle and overturned;
2. A single-unit truck struck the BCT with its left fender, spun 90 degrees, and overturned; and
3. A large car broke through both wood posts and several metal posts before overturning.

In seven other accidents, the vehicle overturned after impacting the end treatment (six involved a BCT installed on a simple curve and one involved a straight BCT). Only one accident involved spearing of a vehicle. A 1974 Capri went out of control and skidded 210 ft and impacted a BCT installed on a simple curve. Impact was on the driver's door; the vehicle was penetrated by the rail and continued for 20 ft before coming to rest.

Presented in Table 3 is a summary of impact severity cross-tabulated with end-treatment configuration and related to performance. A severe impact was one sufficient to cause heavy or extensive damage to the guardrail, disabling damage to the vehicle, and with injury severity classified as fatal or incapacitating. Nonsevere was classified as slight or moderate damage to the guardrail, functional or nonfunctional damage to the vehicle, and slight or no injury. The data show that proper performance was much higher for nonsevere impacts (73 percent) as compared with severe impacts (55 percent). For end sections installed on a simple curve, there was 55 percent proper performance in severe impacts compared with 86 percent in nonsevere impacts. Even though the sample was small, severe accidents involving the parabolic flare resulted in proper performance in only 57 percent of the accidents (four of seven). As noted previously, in the three cases of improper performance involving a parabolic flare, the vehicle overturned after impacting the end treatment.

Impact angle was cross-tabulated with end-treatment configuration and related to performance in Table 4. A higher percentage of improper performance was noted for impacts at shallow angles (15 degrees or less) than for moderate-to-sharp angles (greater than 16 degrees). At shallow angles, the BCT installed on a simple curve performed properly less

TABLE 3 Impact Severity Related to BCT End-Treatment Performance

Impact Severity	End-Treatment Configuration	Proper Performance No.	Proper Performance Percent	Improper Performance No.	Improper Performance Percent
Severe	Simple curve	17	55	14	45
	Parabolic flare	4	57	3	43
	Straight	1	100	–	–
	Subtotal	22	55	17	45
Nonsevere	Simple curve	6	86	1	14
	Parabolic flare	1	100	–	–
	Straight	1	33	2	67
	Subtotal	8	73	3	27

TABLE 4 Impact Angle Related to BCT End-Treatment Performance

Impact Angle	End-Treatment Configuration	Proper Performance		Improper Performance	
		No.	Percent	No.	Percent
Shallow	Simple curve	11	50	11	50
	Parabolic flare	2	67	1	33
	Straight	–	–	1	100
	Subtotal	13	50	13	50
Moderate-sharp	Simple curve	8	75	4	25
	Parabolic flare	2	50	2	50
	Straight	–	–	–	–
	Subtotal	10	63	6	37

frequently (50 percent) than it did when impacted at moderate-to-sharp angles (75 percent). This could be related to the stiffness of the BCT end section when installed without the parabolic flare, a condition that would be worse for impacts at shallow angles. For impacts into an end treatment installed on a parabolic flare, performance was proper in two of three accidents at shallow angles and two of four at moderate-to-sharp angles.

The results of comparing damage to the various end-treatment configurations with performance are presented in Table 5. End-treatment damage was classified as either slight to moderate or heavy to extensive. Generally, slight-to-moderate damage was deflection of the rail, bending of both posts or the breaking away of one, and/or movement of the concrete footing. Heavy-to-extensive damage was breaking away of both posts and/or breaking of both posts with damage to the rail beyond the second post. When all end-treatment types were combined, performance results were nearly the same for slight-to-moderate and heavy-to-extensive end-treatment damage. For BCT end treatments installed on a simple curve, performance was proper in 7 of 10 accidents (70 percent) when end-treatment damage was slight to moderate and in 11 of 18 accidents (61 percent) when damage was heavy to extensive. Even though only a small sample of accidents was available for end treatments with the parabolic flare, it was found that performance was better for accidents in which end-treatment damage was heavy to extensive (three of four) as compared with slight-to-moderate damage (one of two).

Presented in Table 6 is a summary of performance when vehicle size was cross-tabulated with end-treatment configuration. Five impacts involved small cars and the end treatment performed properly in only one of the collisions. For impacts involving large automobiles, the end treatment performed properly in 14 of 24 accidents (58 percent). For those accidents involving large automobiles, performance

TABLE 5 End-Treatment Damage Related to BCT End-Treatment Performance

End-Treatment Damage	End-Treatment Configuration	Proper Performance		Improper Performance	
		No.	Percent	No.	Percent
Slight-moderate	Simple curve	7	70	3	30
	Parabolic flare	1	50	1	50
	Straight	1	50	1	50
	Subtotal	9	64	5	36
Heavy-extensive	Simple curve	11	61	7	39
	Parabolic flare	3	75	1	25
	Straight	1	50	1	50
	Subtotal	15	63	9	37

TABLE 6 Vehicle Size Related to End-Treatment Performance

Vehicle Size	End-Treatment Configuration	Proper Performance		Improper Performance	
		No.	Percent	No.	Percent
Small automobile	Simple curve	1	25	3	75
	Parabolic flare	–	–	1	100
	Straight	–	–	–	–
	Subtotal	1	20	4	80
Large automobile	Simple curve	11	55	9	45
	Parabolic flare	2	67	1	33
	Straight	1	100	–	–
	Subtotal	14	58	10	42
Truck	Simple curve	3	60	2	40
	Parabolic flare	–	–	1	100
	Straight	–	–	–	–
	Subtotal	3	50	3	50

was proper for 11 of 20 when the BCT included a simple curve and 2 of 3 when the BCT included a parabolic flare. In the six accidents involving trucks, performance was rated proper in three cases. In all three cases of improper performance involving trucks, the vehicle overturned.

It should be noted that vehicle size information was available in sufficient detail to categorize only 35 of the 50 BCT accidents. However, in six other accidents, it was determined that the vehicle was an automobile of unknown size. Performance was rated proper in all six of those accidents; five were at locations where the BCT was a simple curve and one involved a straight BCT.

Data relating the most severe injury in each accident with end-treatment configuration are as follows:

End-Treatment Configuration	No. of Accidents by Severity: Fatal	Injury	Property Damage
Simple curve	5	20	7
Parabolic flare	–	4	1
Straight	–	–	2

There were five fatal accidents and all of these occurred at locations where the BCT had been installed on a simple curve. Of the 24 injury accidents, 8 involved incapacitating injuries and all of these were at locations where the BCT was a simple curve. Injury accidents involving BCTs installed on a parabolic flare resulted in less severe injuries than those involving the simple curve. For accidents in which injury severity was known, 5 of 39 (13 percent) resulted in a fatality. A substantial percentage of accidents (33 percent) resulted in either a fatality or an incapacitating injury. Of the five fatal accidents, one involved spearing of a small car and three involved overturning of the vehicle; in the fifth a car broke one post and then spun counterclockwise 180 degrees.

Improper performance was generally associated with one of the following occurrences: (a) the vehicle hit the end treatment and was stopped when the posts did not break, (b) the vehicle overturned as it hit the end and the post did not break as designed, or (c) a concrete footing moved, which prevented the posts from breaking. There was one instance in which the BCT end treatment (simple curve) speared the vehicle. Other researchers have shown that the BCT has failed to perform properly when impacted head on by small cars. Head-on crash tests performed by SWRI (14) showed that small cars performed satisfactorily in 30-mph tests but not in 60-mph tests. Instances of spearing are usually the result of an impact with an end treatment that has no flare. As will be shown, such a problem may occur when an MBCT end treatment installed in a gore location is impacted.

An analysis of injury severity as compared with end-treatment performance was made. This showed performance to be proper more frequently in accidents where there were no injuries or the injuries were not severe. Injury severity was also compared with end-treatment damage, and it was found that injuries generally were more severe when damage was greater.

MBCT End-Treatment Accidents

Performance was determined for 12 of the accidents involving an MBCT end treatment, with 6 (50 percent) rated as proper performance. Only two of eight severe impacts (25 percent) resulted in proper performance, whereas all four nonsevere impacts were termed proper. Impact angles were classified as either shallow or moderate. For both impact angles, only two of five accidents (40 percent) resulted in proper performance. All accidents (three) in which heavy or extensive guardrail damage resulted and in which performance was also rated resulted in improper performance. Only two accidents in which vehicle size was known involved a small car. Both accidents involved collision with an MBCT placed in a gore and resulted in improper performance in which the end speared the vehicle (Figure 5).

Of 12 accidents in which injury severity was known, 9 (75 percent) resulted in some type of injury and 5 (42 percent) resulted in either a fatality or incapacitating injury. There were two fatal accidents, both the result of spearing when a small vehicle impacted an MBCT in a gore area. The vehicle received disabling damage in 11 of 12 accidents (92 percent). Impact severity was classified as severe in 14 of the 19 accidents (74 percent). Collisions with either small or large automobiles resulted in severe impacts. There were no known accidents involving either a single-unit or combination truck. Six of the 10 accidents (60 percent) in which damage was known resulted in either heavy or extensive guardrail damage.

The MBCT end treatment has been used on medians and at least one gore location. For those accidents in which performance could be rated, both gore accidents were classified as giving improper performance whereas 4 of 10 median-location accidents were classified as resulting in improper performance.

CONCLUSIONS

The analysis of the accidents investigated shows that any accident involving collision with a guardrail end is potentially severe. The BCT end treatment performed properly in most accidents (60 percent); that is, the end treatment performed as designed: the wooden posts broke away or the guardrail redirected the vehicle. This percentage of proper performance occurred even though the BCT was found to have been installed with a parabolic flare in only 8 of the 50 accidents investigated. Most BCT end-treatment configurations evaluated included those installed on a 4.5-degree simple curve with an offset of approximately 6 ft at the end (38 installations) and those installed basically straight with a very small or no offset (4 installations). Only five impacts involved small cars and the BCT end treatment performed properly in only one of these accidents. Improper performance of the BCT was generally related to either failure of the posts and guardrail to break away as designed, causing the vehicle to stop abruptly or overturn, or excessive movement of a concrete footing that prevented the posts from breaking. One accident involved spearing of the vehicle. Performance was not as good when the impact angle was shallow. Poor performance for shallow impact angles involving BCTs and the problem exhibited by MBCT end treatments impacted head on show that a flare is necessary. Any installation of a BCT end treatment without proper flare provides the potential for spearing of a vehicle during a shallow-angle impact.

Evaluation of the performance of Kentucky's BCT end treatment indicates that it may be used where geometrics permit, that is, when a 4-ft flare can be obtained with a 10:1 slope in front and a sufficient recovery area, not exceeding a 3:1 slope, behind. Slopes referred to here are based on general guidelines for BCT design as noted in the survey of other states performed by the Kentucky Transportation Research Program (12) and from the AASHTO barrier guide (15). Where those geometrics are not present, the turned-down end treatment proposed in the previous report should be used (12).

The MBCT end treatment performed properly only 50 percent of the time. The problem appears to be related to the stiffness of the end treatment and is most apparent when the MBCT is used in a gore area where impact angles are shallow. Two fatal accidents occurred when the end treatment speared a small vehicle after a head-on collision in a gore area. If these two accidents involving a MBCT placed in a gore area are excluded, then in 6 of the 10 accidents (60 percent) involving MBCTs in medians, there was proper performance.

The MBCT design as used in Kentucky should be removed from gore locations. The recommended replacement at gore locations would be a crash cushion. Because of the stiffness of the MBCT and the problems associated with impacts at shallow angles, consideration should be given to modification or elimination of Kentucky's MBCT design. It is important that consideration be given to the need for crash testing any new or modified designs for median end treatments before they are used in the field. The importance of evaluating even minor modifications to safety barriers was stressed in NCHRP Report 230 (16).

The question as to the best end treatment that may be used for shoulder and median installations has not been resolved. A continued in-field performance evaluation of the BCT, MBCT, and new turned-down end treatments through in-depth analysis of accidents is warranted. This type of performance evaluation would provide valuable information for future decisions concerning the most crashworthy end treatment to use.

ACKNOWLEDGMENT

The research documented in this paper was cosponsored by the Kentucky Transportation Cabinet and FHWA as part of a research study titled Evaluation of Highway Safety Barriers.

Appreciation is expressed to the following members of the Study Advisory Committee for their guidance in the performance of this research: George Asbury, Grover Ethington, E.B. Drake, C.S. Layson, B.L. Wheat, Bill Netherton, and Bill Bensing.

REFERENCES

1. N.J. Deleys and R.R. McHenry. Highway Guardrails--A Review of Current Practice. NCHRP Report 36. HRB, National Research Council, Washington, D.C., 1967.

2. J.D. Michie and L.R. Calcote. Location, Selection, and Maintenance of Highway Guardrails and Median Barriers. NCHRP Report 54. HRB, National Research Council, Washington, D.C., 1968.
3. J.D. Michie and L.R. Calcote. Guardrail Performance and Design. NCHRP Report 115. TRB, National Research Council, Washington, D.C., 1971.
4. J.D. Michie and M.E. Bronstad. Location, Selection, and Maintenance of Highway Traffic Barriers. NCHRP Report 118. TRB, National Research Council, Washington, D.C., 1971.
5. J.D. Michie and M.E. Bronstad. Guardrail Crash Test Evaluation--New Concepts and End Designs. NCHRP Report 129. TRB, National Research Council, Washington, D.C., 1972.
6. Evaluation of Breakaway Cable Terminals for Guardrails. NCHRP Research Results Digest 43. TRB, National Research Council, Washington, D.C., 1972.
7. Development of a Breakaway Cable Terminal for Median Barrier. NCHRP Research Results Digest 53. TRB, National Research Council, Washington, D.C., 1973.
8. Breakaway Cable Terminals for Guardrails and Median Barriers. NCHRP Research Results Digest 84. TRB, National Research Council, Washington, D.C., March 1976.
9. Modified Breakaway Cable Terminals for Guardrail and Median Barriers. NCHRP Research Results Digest 102. TRB, National Research Council, Washington, D.C., May 1978.
10. A Modified Foundation for Breakaway Cable Terminals. NCHRP Research Results Digest 124. TRB, National Research Council, Washington, D.C., Nov. 1980.
11. R.F. Baker. Breakaway Cable Terminal Evaluation. Report FHWA/NJ-81/001. New Jersey Department of Transportation, Trenton, May 1980.
12. J.G. Pigman and K.R. Agent. Survey of Guardrail End Treatment Usage. Report UKTRP-83-23. Transportation Research Program, University of Kentucky, Lexington, Oct. 1983.
13. J.G. Pigman, K.R. Agent, and T. Creasey. Analysis of Accidents Involving Breakaway-Cable-Terminal End Treatment. Report UKTRP-84-16. Transportation Research Program, University of Kentucky, Lexington, June 1984.
14. C.E. Kimball, Jr., M.E. Bronstad, and L. Meczkowski. Evaluations of Guardrail Breakaway Cable Terminals. Report FHWA-RD-82-57. Southwest Research Institute, San Antonio, Tex., 1982.
15. Guide for Selecting, Locating, and Designing Traffic Barriers. AASHTO, Washington, D.C., 1977.
16. J.D. Michie. Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances. NCHRP Report 230. TRB, National Research Council, Washington, D.C., 1981.

Analysis of Accidents Involving Crash Cushions

JERRY G. PIGMAN, KENNETH R. AGENT, and TOM CREASEY

ABSTRACT

This paper is an analysis of 127 accidents involving crash cushions in Kentucky. The primary data base was for the period 1980-1982, with some additional data before and after this period. An attempt was made to document each accident with a police report, photographs, and a repair form. The largest number of accidents (63) involved a Hi-Dro cell cushion or cluster, followed by 33 accidents involving a Guardrail Energy-Absorbing Terminal (G.R.E.A.T.) crash cushion, 19 with a temporary G.R.E.A.T. system, 10 with sand barrels, and 2 with steel drums. Average repair cost was lowest for the Hi-Dro cell cushion ($392) and highest for the Hi-Dro cell cluster ($2,839). Other repair costs were $1,886 for the G.R.E.A.T. system, $887 for sand-barrel installations, and $1,760 for steel-drum installations. For those accidents in which performance was noted, crash cushions performed properly 85 percent of the time. Instances of improper performance generally involved either rebounding of a vehicle into or across the adjacent roadway or overturning of a vehicle. All the various types performed well. Results from the cost-effectiveness analysis show that crash cushion installations produce a benefit/cost ratio in the range of 1.0-2.0.