Performance Evaluation of Breakaway-Cable-Terminal End Treatments

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This report included an analysis of 110 accidents involving breakaway-cable-terminal (BCT) end treatments and 36 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 1980–87, with a few accidents that were identified before 1980. An attempt was made to document each accident with a police report, photographs, and a maintenance repair form. BCT end treatments evaluated included those with the terminal section installed as follows: (1) straight with no offset, (2) flared 6 feet at the end by using a 4.5-degree simple curve over 125 feet, and (3) flared 4 feet with a parabolic curve over the last 37.5 feet. Proper performance was based on a determination of whether the posts broke away as designed and/or the vehicle was redirected after impacting the guardrail. Results indicate that proper performance ranged from 60 percent for end sections with no offset to 69 percent for a "simple curve" offset, and 79 percent for a parabolic flare offset. Only 10 impacts were documented for small cars, and the BCT performed improperly in four of those accidents. Evaluation of the BCT end treatment indicates that it may be used where geometrics permit. Where those geometrics are not present, the turned-down end treatment proposed in a previous report should be used. The MBCT end treatment performed properly in 63 percent of the accidents. Problems related to stiffness of the end treatment were most apparent when impact angles were shallow. A recommendation was made to contour grade gore areas where possible and to install a crash cushion where the need for a barrier could not be eliminated. For MBCT installations at median piers and median width of 20 feet or less, crash cushions were also recommended. A turned-down end-treatment design was proposed for consideration at median piers where the median width was greater than 20 feet.

The performance of guardrail end treatments has been a subject of concern to highway engineers for many years. A concentrated effort was begun in the mid-1960s to evaluate guardrail design and recommend warrants for guardrail usage. The work was funded through the National Cooperative Highway Research Program's (NCHRP) Project 15-1, and a review of current practices was performed by Cornell Aeronautical Laboratory (*1*). A second 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 upon 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 caused test vehicles to launch, roll, and tumble.

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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 involved 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 were hazardous and development of a safer and treatment had the highest priority 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 section of "length of need" section rather than 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*). 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 an effective terminal for W-beam guardrail systems and appeared to be a significant improvement over either the turned-down or the blunt-nose terminal. It was noted that for end-on impacts the BCT performed in a manner similar to 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 g and 3.4 g. The tests were conducted with 4,100-pound test cars, and it was noted that higher deceleration values should be experienced for smaller test vehicles. Advantages of the flared over the non-flared terminal for end-on impacts were demonstrated in the crash tests. Stabilization of the end-nose was achieved by using either steel diaphragms of vermiculite concrete to spread the beam loads over a large frontal area. As a result of tests conducted and documented in NCHRP Report 129, the BCT was recommended for immediate installation for field evaluation.

Southwest Research Institute's (SRI) work 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 breakaway-cable terminal (*6*). Three tests of the BCT using subcompact cars also were 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 that had failed in an earlier test. Overall results confirmed the recommendations for immediate trial implementation.

Development of the breakaway-cable terminal for median barriers followed research on BCTs for guardrails (*7*). Test results indicated the median barrier performed acceptably for the steel box-beam median barrier and the blocked-out W-beam median barrier with both steel and wooden posts. It also was noted that installation of the BCT for guardrails was encouraged by the Federal Highway Administration (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 included the use of slip-base steel posts, a reduction in the size of wooden posts from 8 × 8 inches to 6 × 8 inches, and elimination of use 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, high costs of BCT components, and snagging of a subcompact vehicle's underside by steel-post BCTs. Modifications were made, and 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, with 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 installations where the 4-foot flare was not obtained. It was emphasized that lack of the 4-foot flare could result in spearing of vehicles during head-on impacts.

Documentation of field performance of BCT and median-breakaway-cable-terminal end treatments (MBCT) has been relatively scarce since testing by the SRI. A study by the New Jersey Department of Transportation had the objective of evaluating in-service performance of BCTs (*11*). Thirteen vehicular impacts into BCTs were evaluated, and results were compared with full-scale crash tests previously conducted by SRI. In-service experience was similar to the initial tests by SRI, 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-foot sections with one 25-foot section also was recommended.

The median-breakaway-cable end treatment (MBCT) as designed and tested by SARI has had limited use. Installations are known to have been made in New Jersey and North Carolina. New Jersey has installed approximately 40 of the MBCTs, and there has been only one reported accident (letter of inquiry to E. Dayton, Assistant Chief Engineer of Roadway Design, New Jersey Department of Transportation, July 1982). A large automobile struck the device, and it performed as intended. Only one accident has been reported involving a MBCT in North Carolina (survey questionnaire from M. Bronstad, Southwest Research Institute, Feb. 1984). The terminal was impacted end-on by a full-size sedan and performed properly, even though it was damaged extensively.

A survey completed by the Kentucky Transportation Research Program (KTRP) revealed that the BCT was the most common end treatment used, with 40 states listing use of this treatment to some degree (*12*). In 24 states, only the BCT was used for terminating roadside steel-beam guardrail. Some form of the MBCT was used in 16 states. An investigation of 69 accidents involving BCT and MBCT end treatments was performed by the University of Kentucky, Transportation Research Program, in 1984 (*13*). Results indicated that the BCT performed properly in 60 percent of the accidents, and Kentucky's version of the MBCT performed properly 50 percent of the time.

According to a technical advisory distributed by FHWA in January, 1986, installation of BCTs has continued, with over 130,000 estimated to be in use (*14*). Reported problems with the BCT involving small cars prompted FHWA to perform additional tests on it with 1,800-pound cars. Results were satisfactory at 30 mph but caused vehicle rollover at 60 mph. Efforts to modify the BCT to accommodate 1,800-pound cars resulted in development of the Eccentric Loader BCT as detailed in the FHWA Technical Advisory (*14*).

BCTS AND MBCTS USED IN KENTUCKY

Kentucky was one of the first states to install BCTs in 1974. Through 1986, the total number of installations made and included in the Kentucky Department of Highway's summaries of unit bid prices was 4,308. The weighted average cost for each BCT installation was $509. Summaries of BCT and MBCT installations and costs for 1974–1986 are presented in Table 1. The current recommended standard in Kentucky for all fills and solid rock cut sections having an adequate recovery zone behind the guardrail is the BCT. It should be noted that there are several BCTs installed in Kentucky without the parabolic flare. Before 1982, most BCTs were installed with the last 125 feet of rail placed on a simple curve (4.5 degrees) and an offset of 6 feet. In 1982, Kentucky's Standard Drawing for BCT installations was revised to reflect a parabolic flare over the last 37.5 feet with a 4-foot offset at the end. Significant problems may occur when the end is not flared. When the BCT end treatment is installed with the designed flare and offset, impacts with the end usually result in acceptable performance. It should again be noted that the currently acceptable method of obtaining the 4-foot offset involves the use of a parabolic flare as opposed to the 4.5-degree simple curve.

TABLE 1 SUMMARY OF BCT AND "KENTUCKY" MBCT INSTALLATIONS BY YEAR

	TYPE OF END TREATMENT			
	BCT		KENTUCKY MBCT	
YEAR	NUMBER	AVERAGE UNIT PRICE (DOLLARS)	NUMBER	AVERAGE UNIT PRICE (DOLLARS)
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
1984	180	490	49	622
1985	197	484	39	585
1986	298	464	71	549
TOTALS	4308	509 *	732	617 *

Note: Numbers and unit prices tabulated from contracts awarded.

*Weighted Average

Kentucky's version of the MBCT has not been installed there as extensively as the BCT. For the period 1974 through 1986, a total of 732 were installed as part of new construction or reconstruction projects, and the weighted average cost was $617 per installation (Table 1). Kentucky's design utilizes two BCTs joined together at the end section. 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. 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 SRI. It should be noted that the BCT and MBCT evaluated in this study are the types used in Kentucky. The BCT now used in Kentucky is very similar to the design tested, evaluated, and recommended as part of the NCHRP studies (*5*). However, the MBCT used in Kentucky varies considerably from the MBCT design recommended as part of the NCHRP studies (*7, 8*).

DATA COLLECTION

Data were collected for this study in several phases. Initially, reports of accidents involving all types of safety barriers were collected for the years 1980–1982. The barriers included crash cushions, earth mounds, concrete median barriers, and four types of guardrail end treatments—BCT, MBCT, buried (turned down), and blunt. An inventory of all Kentucky routes having BCT and MBCT installations was used; accident reports pertaining to those routes were reviewed and appropriately selected. The next step was to make arrangements with maintenance personnel within the Kentucky Department of Highways so that the study team would be notified when accidents occurred involving BCT or MBCT treatments. The objective was to notify the study team of such accidents so that on-site investigations could be made before the guardrail was repaired. Photographs were obtained to document the performance and damage to the end treatment. In some instances, photographs of vehicles were provided by police or other agencies.

Additional accidents involving guardrails were discoverd during trips or in the course of searching accident reports for other purposes. An effort was made to combine photographs with appropriate accident reports. However, some accidents involving guardrail ends went unreported. In other cases, the guardrail was repaired before photographs could be obtained.

The initial phase of data collection included a sample of 69 accidents involving BCT and "Kentucky MBCT" end treatments, results of which were reported previously (*13*). Data collection continued after the first research study, and the two data collection efforts have been combined. The result was a total of 146 accidents, with 77 accidents being added during the second period of data collection. Primary data collection included the period 1980 through 1987; however, 10 of the 146 accidents occurred before 1980.

RESULTS

Data for a total of 146 BCT of "Kentucky MBCT" end-treatment accidents were obtained. It should be noted that any reference to an MBCT end treatment in the results is the Kentucky version of the MBCT. The majority of accidents (110) involved a BCT. The earliest accident date was May 1976 and the most recent was May 1987. Limited repair cost data were available. The average repair cost at eight BCT locations was approximately $644, with a range of about $206 to $980. A wide range of repair costs would be expected because of differences in damage. The average cost to repair three MBCT end treatments was about $681. Repair costs were higher than the original installation costs of $509 for BCT's and $617 for MBCT's.

Sources of information concerning accidents included accident reports, photographs, and repair forms. An accident report was obtained for 99 of the 146 accidents, either police photographs or site photographs were obtained for 104 accidents, and a repair form was obtained for 33 accidents. All three types of information were obtained for only 12 accidents.

BCT End Treatment Accidents

Performance of BCT end treatments for each accident were analyzed and summarized. In addition to end treatment performance, information concerning vehicle size, impact severity, impact angle, guardrail placement, end treatment configuration area, vehicle action after impact, and end treatment damage was analyzed. Subjective judgment was used to determine many of the variables.

End treatment performance, when it could be determined, was defined as either proper or improper. Proper performance resulted when the end treatment performed as intended, with the wooden posts breaking away or the guardrail redirecting the vehicle. Impact severity (which involves guardrail damage, vehicle damage, and injury severity) was not used as the criterion for assessing performances. It is possible that the end treatment could perform properly but that severe injuries could occur as a result of other factors such as vehicle size and lack of safety belt usage. Vehicle and guardrail damage may be related more to type and size of vehicle than to end-treatment performance. Therefore, the most consistent criterion to rate performance was selected to be an interpretation of the condition of whether the posts broke away as designed without causing the vehicle to overturn, or proper redirection of the vehicle after impact with the guardrail, or both. Performance was rated for 102 of the 110 BCT accidents.

Because many of the BCT end treatments were not installed with an offset of 4 feet and a parabolic flare over a distance of 37.5 feet, additional analysis was performed 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 feel of guardrail is installed on this 4.5-degree curve to obtain an offset of 6 feet at the end;
2. Parabolic flare—the terminal section is offset 4 feet with a parabolic flare over the last 37.5 feet (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 presented in Table 2. Of 110 accidents, 54 involved BCTs categorized as a simple curve. BCT installations with a parabolic flare totaled 46. Five installations were determined to have very little or not offset, and five configurations were unknown due to lack of data.

An analysis of the data was made to relate performance to

TABLE 2 SUMMARY OF BCT END TREATMENT CONFIGURATIONS

END TREATMENT CONFIGURATION	NUMBER	PERCENT
Simple Curve	54	49.1
Parabolic Flare	46	41.8
Straight	5	4.5
Unknown	5	4.5
Total	110	100.0

TABLE 3 PERFORMANCE RELATED TO BCT END TREATMENT CONFIGURATION

END TREATMENT CONFIGURATION	PROPER PERFORMANCE		IMPROPER PERFORMANCE		UNKNOWN PERFORMANCE
	NUMBER	PERCENT	NUMBER	PERCENT	NUMBER
Simple Curve	35	64.8	16	29.6	3
Parabolic Flare	33	71.7	9	19.6	4
Straight	3	60.0	2	40.0	0
Unknown	3	60.0	1	20.0	1
TOTAL	74	67.3	28	25.5	8

*Percentage include only those accidents where performance was known.

BCT end treatment configuration (Table 3). Where performance was known, it was determined that 35 of 51 (69 percent) performed properly when the end section was installed on a 4.5-degree simple curve. When the end treatment was installed on a parabolic curve, performance was rated proper in 33 of 42 (79 percent) accidents. For installations classified as straight, performance was rated proper in three of five (60 percent) accidents. When all three configurations are combined, performance was rated proper in 73 percent of the accidents.

Presented in Table 4 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, or injury severity classified as fatal or incapacitating, or both. Non-severe was classified as slight or moderate damage to guardrail, functional or non-functional damage to the vehicle, or slight or no injury, or both. The data show proper performance was higher for non-severe impacts (89 percent) than for severe impacts (66 percent). For end sections installed on a simple curve, there was 61 percent proper performance in severe impacts compared with 92 percent in non-severe impacts. Severe accidents involving the parabolic flare resulted in proper performance in 72 percent of the accidents (23 of 32).

Impact angle was cross-tabulated with end treatment configuration and related to performance as shown in Table 5. The percentage of improper performance was higher for impacts at shallow angles (15 degrees or less) than for those at moderate to sharp angles (greater than 16 degrees). At shallow angles, the BCT installed on a simple curve performed properly less frequently (52 percent) than it did when impacted at moderate to sharp angles (82 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 when impacts were at shallow angles. For impacts into an end treatment installed on a parabolic flare, performance was proper in 9 of 14 accidents (64 percent) at shallow angles and 18 of 22 (82 percent) at moderate to sharp angles. This shows that even when the end treatment was installed with the parabolic flare, the BCT performed properly less frequently when impacted at shallow angles than at moderate to sharp angles. In four of the eight fatal accidents involving the BCT, the approaching vehicle ran off the road before reaching the BCT and was attempting to get back onto the road when the impact occurred. This resulted in a very shallow impact angle and spearing of the vehicle. In three of these accidents, the vehicle was sliding sideways at impact, with the impact to the side of the vehicle. The BCT, in either the parabolic flare or simple curve configuration, is too stiff when impacted at a very shallow angle with the side of a vehicle. It was not designed for this type of impact.

Results of comparing damage with performance in the various end treatment configurations are presented in Table 6. End-treatment damage was classified as either slight to moderate or heavy to extensive. Generally, slight to moderate was deflection of the rail, bending both posts or breaking one, and/or movement of the concrete footing. Heavy to extensive was breaking both posts, or breaking both posts with damage to rail beyond the second post, or both. 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 16 of 20 accidents (80 percent) when end treatment damage was slight to moderate and in 14 of 22 accidents (64 percent) when damage was heavy to extensive. For end treatments with the parabolic flare, performance was similar for accidents in which end treatment damage was heavy to extensive (82 percent proper performance) and slight to moderate (81 percent proper performance).

Data were summarized to show a comparison of vehicle size and impact severity. Information concerning the vehicle year, vehicle make, and vehicle style was included. Impact severity was equally severe for all vehicle sizes. Impact was judged to be severe in 72 percent of the accidents (76 of 105) where severity was known. Also, a large majority of vehicles

TABLE 4 IMPACT SEVERITY RELATED TO BCT END TREATMENT PERFORMANCE

		PERFORMANCE				
		PROPER		IMPROPER		UNKNOWN
IMPACT SEVERITY	END TREATMENT CONFIGURATION	NUMBER	PERCENT	NUMBER	PERCENT	NUMBER
Severe	Simple Curve	23	59.0	15	38.5	1
	Parabolic Flare	23	69.7	9	27.3	1
	Straight	2	100.0	0	0.0	0
	Unknown	1	50.0	1	50.0	0
	Subtotal	49	64.5	25	32.9	2
Non-Severe	Simple Curve	11	84.6	1	7.7	1
	Parabolic Flare	9	75.0	0	0.0	3
	Straight	1	33.3	2	66.7	0
	Unknown	2	100.0	0	0.0	0
	Subtotal	23	76.7	3	10.0	4
Unknown	Simple Curve	1	50.0	0	0.0	1
	Parabolic Flare	1	100.0	0	0.0	0
	Straight	0	-	0	-	0
	Unknown	0	0.0	0	0.0	1
	Subtotal	2	50.0	0	0.0	2

***Percentages include only those accidents where performance was known.**

(independent of size) received disabling damage (83 percent). There were eight fatal accidents, of which seven involved a large automobile. More than one-half of the accidents (57 percent) resulted in an injury where the severity of the accident was known. A substantial number of accidents (26 percent) resulted in either a fatality or an incapacitating injury. Vehicle size was related to end treatment damage, with accidents involving small automobiles resulting in less damage. About one-half of the accidents (47 percent) resulted in either heavy or extensive damage to the guardrail. Presented in Table 7 is a summary of performance when vehicle size was cross-tabulated with end treatment configuration. Ten impacts involved small cars, and the end treatment performed properly in four of the collisions. For impacts involving large automobiles, the end treatment performed properly in 33 of 49 accidents (67 percent) when performance was known. For accidents involving large automobiles, performance was proper for 16 of 26 (62 percent) when the BCT was installed as a simple curve and 14 of 20 (70 percent) when the BCT included a parabolic flare. In the seven accidents involving trucks, performance was rated proper in four cases (57 percent). For all three cases of improper performance involving trucks, the vehicle overturned.

Vehicle size information was available in sufficient detail to categorize only 67 of the 110 BCT accidents. In 10 other accidents, it was determined that the vehicle was an automobile of unknown size. Performance was rated in all 10 accidents; 8 were at locations where the BCT was a simple curve, one where it was a parabolic flare, and one where the BCT was straight.

Data relating severity of injury in each accident with end treatment configuration are presented in Table 8. There were eight fatal accidents, and six of those occurred at locations where the BCT had been installed on a simple curve. Of the 42 injury accidents, 11 involved incapacitating injuries and 8 of those were the result of accidents at locations where the

TABLE 5 IMPACT ANGLE RELATED TO BCT END TREATMENT PERFORMANCE

IMPACT ANGLE	END-TREATMENT CONFIGURATION	PERFORMANCE: PROPER NUMBER	PROPER PERCENT*	IMPROPER NUMBER	IMPROPER PERCENT*	UNKNOWN NUMBER
Shallow	Simple Curve	14	51.9	13	48.1	1
	Parabolic Flare	9	64.3	5	35.7	2
	Straight	0	0.0	1	100.0	0
	Unknown	1	50.0	1	50.0	0
	Subtotal	24	54.5	20	45.5	3
Moderate -Sharp	Simple Curve	14	82.4	3	17.6	0
	Parabolic Flare	18	81.8	4	18.2	0
	Straight	0	-	0	-	0
	Unknown	1	100.0	0	0.0	0
	Subtotal	33	82.5	7	17.5	0
Unknown	Simple Curve	7	100.0	0	0.0	2
	Parabolic Flare	6	100.0	0	0.0	2
	Straight	3	75.0	1	25.0	0
	Unknown	1	100.0	0	0.0	1
	Subtotal	17	94.4	1	5.6	5

*** Percentages only include those accidents where performance was known.**

BCT was a simple curve. For accidents in which injury severity was known, 8 of 74 (11 percent) resulted in a fatality. A substantial percentage of accidents (26 percent) resulted in either a fatality or an incapacitating injury. Of the eight fatal accidents, four involved spearing, two involved the vehicle breaking through, one involved overturning of the vehicle, and one involved a car breaking one post and then spinning 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, or (c) a concrete footing moved and prevented the posts from breaking. There were five instances in which the BCT end-treatment speared the vehicle. Three involved a simple curve and two involved a parabolic flare installation. 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 SRI in the study titled "Evaluation of Guardrail BCTs" showed that small cars performed satisfactorily in 30-mph tests but not in 60-mph tests (*14*). Spearing is usually the result of an impact with an end treatment having no flare but may result if a vehicle travels off the road and then the driver attempts to re-enter the road at a very shallow impact angle. Such a problem may occur when impacting an MBCT end-treatment installed in a gore location.

An analysis of injury severity correlated with end treatment performance revealed performance to be proper more frequently in accidents when there were no injuries or injuries were not severe. Injury severity also was correlated with end-treatment damage, and it was noted that injuries generally were more severe when damage was greater.

Kentucky MBCT End Treatment Accidents

Performance was determined for 27 of the 36 accidents involving an MBCT end treatment. For those where performance could be determined, it was rated as proper in 17 (63 percent). Only 5 of 14 severe impacts (36 percent) having performance rated revealed proper performance. In contrast, performance was termed proper in 11 of 12 (92 percent) non-severe impacts.

TABLE 6 END TREATMENT DAMAGE RELATED TO BCT END TREATMENT PERFORMANCE

		PERFORMANCE				
		PROPER		IMPROPER		UNKNOWN
END-TREATMENT DAMAGE	END-TREATMENT CONFIGURATION	NUMBER	PERCENT*	NUMBER	PERCENT*	NUMBER
Slight-	Simple Curve	16	80.0	4	20.0	1
Moderate	Parabolic Flare	17	81.0	4	19.0	3
	Straight	2	66.7	1	33.3	0
	Unknown	0	-	0	-	0
	Subtotal	35	79.5	9	20.5	4
Heavy-	Simple Curve	14	63.6	8	36.4	1
Extensive	Parabolic Flare	14	82.4	3	17.6	1
	Straight	0	0.0	1	100.0	0
	Unknown	1	100.0	0	0.0	0
	Subtotal	29	70.7	12	29.3	2
Unknown	Simple Curve	5	55.6	4	44.4	1
	Parabolic Flare	2	50.0	2	50.0	0
	Straight	1	100.0	0	0.0	0
	Unknown	2	66.7	1	33.3	1
	Subtotal	10	58.8	7	41.2	2

* Percentages only include those accidents where performance was known.

Impact angles were classified as either shallow (or moderate) or sharp. For accidents where impact angles were known, 13 of 23 (57 percent) reflected performance. For accidents in which heavy or extensive guardrail damage resulted and in which performance was also rated, four of seven (57 percent) disclosed improper performance. Only three accidents of known vehicle size involved a small vehicle, and all showed improper performance. Two accidents involved collisions with an MBCT placed in a gore and showed improper performance, with the end spearing the vehicle. The third accident involved a small car impacting the MBCT from the back side and was non-severe.

Of the 36 accidents involving an MBCT, 31 involved an MBCT placed in the median while in five accidents the MBCT was in the gore. Of the 31 accidents in which the MBCT was in the median, 11 involved hitting the end treatment from the rear. None of the three accidents involving an MBCT in the gore reflected proper performance. Performance was rated proper in 68 percent of the accidents involving an MBCT in the median, and proper for 60 percent when the impact was from the front and 80 percent when the impact was from the rear of the MBCT.

Of 20 accidents of known injury severity, 14 (70 percent) resulted in some type of injury and 7 (35 percent) resulted in either a fatality or an incapacitating injury. There were three fatal accidents involving an MBCT. Two fatal accidents were the result of spearing when a small vehicle impacted a MBCT in a gore area, and a third was caused by high-speed impact of a tractor trailer into an MBCT. Vehicles received disabling damage in 14 of 20 accidents (70 percent). Impact severity was classified as severe in 21 of the 34 accidents (62 percent). Collisions involving either small or large automobiles generally resulted in severe impacts. Guardrail damage was either heavy or extensive in 10 of 27 accidents (37 percent).

The MBCT end treatment has been used in medians and at least one gore location. For accidents in which performance could be rated, both gore accidents were classified as not showing proper performance, while 8 of 25 median-location

TABLE 7 VEHICLE SIZE RELATED TO BCT END TREATMENT PERFORMANCE

VEHICLE SIZE	END-TREATMENT CONFIGURATION	PERFORMANCE				
		PROPER		IMPROPER		UNKNOWN
		NUMBER	PERCENT*	NUMBER	PERCENT*	NUMBER
Small Auto	Simple Curve	2	40.0	3	60.0	0
	Parabolic Flare	2	50.0	2	50.0	0
	Straight	0	-	0	-	0
	Unknown	0	0.0	1	100.0	0
	Subtotal	4	40.0	6	60.0	0
Large Auto	Simple Curve	16	61.5	10	38.5	1
	Parabolic Flare	14	70.0	6	30.0	0
	Straight	1	100.0	0	0.0	0
	Unknown	2	100.0	0	0.0	0
	Subtotal	33	67.3	16	32.7	1
Trucks	Simple Curve	3	60.0	2	40.0	0
	Parabolic Flare	1	50.0	1	50.0	0
	Straight	0	-	0	-	0
	Unknown	0	-	0	-	0
	Subtotal	4	57.1	3	42.9	0
Auto-U	Simple Curve	8	100.0	0	0.0	0
	Parabolic Flare	1	100.0	0	0.0	0
	Straight	1	100.0	0	0.0	0
	Unknown	0	-	0	-	0
	Subtotal	10	100.0	0	0.0	0
Unknown	Simple Curve	6	85.7	1	14.3	2
	Parabolic Flare	15	100.0	0	0.0	4
	Straight	1	33.3	2	66.7	0
	Unknown	1	100.0	0	0.0	1
	Subtotal	23	88.5	3	11.5	7

* Percentages include only those accidents where performance was known.

TABLE 8 ACCIDENT SEVERITY RELATED TO BCT END TREATMENT CONFIGURATION

END TREATMENT CONFIGURATION	ACCIDENT SEVERITY			
	FATAL	INJURY	PROPERTY DAMAGE	UNKNOWN
Simple Curve	6	25	11	12
Parabolic Flare	1	17	8	20
Straight	0	0	3	2
Unknown	1	0	2	2

accidents (32 percent) were classified as involving improper performance.

SUMMARY

Analysis revealed that any accident involving collision with a guardrail end is potentially severe. Considering all configurations combined, the BCT end treatment performed properly in most accidents (73 percent); that is, the end treatment performed as it was intended, with the wooden posts breaking away or the guardrail redirecting the vehicle. This percentage of proper performance occurred even though the BCT was determined to have been installed with a parabolic flare in only 46 of the 110 accidents investigated. Results indicate that proper performance ranged from 60 percent for end sections with no offset to 69 percent for end sections with a simple curve offset and 79 percent for ends with a parabolic flare offset. Most MBCT end treatment configurations evaluated were installed on a 4.5-degree simple curve with an offset of approximately 4 to 6 feet at the end (54 installations). A few of the accidents involved a straight BCT with a very small or no offset (5 installations). Only 10 impacts involved small cars, and the BCT end treatment performed properly in 4 of them. Improper performance of the BCT was generally related either to failure of the posts and guardrail to break away as designed, causing the vehicle to stop abruptly or overturn, or to excessive movement of a concrete footing that prevented the posts from breaking. Four accidents involved spearing of the vehicle, and all were shallow-angle impacts with three involving impact with the side of the vehicles. Overall 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 creates a potential to spear a vehicle in a shallow-angle impact.

The Kentucky MBCT end treatment performed properly 63 percent of the time. A problem associated with the MBCT appears to be related to the stiffness of the end treatment. This 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.

RECOMMENDATIONS

Evaluation of the performance of Kentucky's BCT end treatment indicates that it may be used where geometrics permit, that it, when a 4-foot flare can be obtained with a 10:1 slope in advance 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 KTRP (*12*) and the guidance on barriers published by the AASHTO (*15*). Where those geometrics are not present, the turned-down end treatment proposed in the previous report should be used (*12*).

It is recommended that Kentucky's MBCT end treatment design be modified or eliminated because of stiffness of the MBCT and the problems associated with impacts at shallow angles. When MBCT end treatments are installed in gore areas, contour grading should be used where possible, to eliminate the need for a barrier system. When the need for a barrier in a gore area cannot be eliminated, a crash cushion should be installed. When the MBCT is used at median piers, it is recommended that crash cushions be used for median widths of 20 feet or less. For median widths greater than 20 feet, it is recommended that a turned-down median end treatment be used.

The question about which is the best end treatment to use for 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.

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