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IN-SERVICE PERFORMANCE EVALUATION OF THE BCT AND MELT GUARDRAIL TERMINALS IN IOWA AND NORTH CAROLINA

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ABSTRACT

Developing safe and effective guardrail terminals has been a high priority for roadside safety researchers for several decades. Numerous full-scale crash tests have been performed and many types of new terminals have been developed. This paper presents results for an in-service performance evaluation of two popular guardrail terminals, the breakaway cable terminal and the modified eccentric loader breakaway cable terminal. The data was collected in portions of Iowa and North Carolina during a 24-month data collection effort in 1997 to 1999. The collision performance was measured in terms of collision characteristics, occupant injury and barrier damage.

KEYWORD

Roadside safety, in-service performance evaluation, guardrail terminals.

INTRODUCTION

The breakaway cable terminal (BCT) is one of the most widely used guardrail terminals in the United States.*(1)* Although current Federal Highway Administration (FHWA) policy excludes the use of the BCT for new construction, there are still hundreds of thousands of these terminals in place on the National Highway System (NHS).*(2)* Many states adopted the modified eccentric loader breakaway cable terminal (MELT) as an alternative to the BCT when the FHWA policy regarding the BCT was changed in 1994.*(2)* While the MELT was only widely installed between 1994 and 1998, there are many thousands of installations in service throughout the United States. More recently the FHWA has made both the BCT and the MELT obsolete for new construction by adopting a policy of requiring all guardrail terminals to have been successfully crash tested according to the recommendations of National Cooperative Highway Research Program Report 350 (Report 350).*(3)(4)(5)* Though they are being replaced by guardrail terminals that have passed the recommended Report 350 crash tests, both the BCT and MELT will continue to be important guardrail terminal systems for the next several decades because of the large number of devices already installed on the NHS. It is important to gain a better understanding of the performance of these guardrail terminals so that good decisions can be made about when or if these devices should be replaced.

The purpose of this paper is to examine the in-service performance of the BCT and the MELT in portions of two States, Iowa and North Carolina. All collisions involving the BCT and the MELT were investigated in a four county area of Iowa and a three county area in North Carolina. The data collection began on 1 July 1997 and continued until 30 June 1999. There were approximately 600 BCT and 50 MELT guardrail terminals on state-maintained roads in the Iowa data collection area and a similar number in the North Carolina data collection area.

The data collection teams were notified about collisions from police and highway maintenance agencies in their respective data collection areas. Information from the police accident reports and maintenance cost-recovery reports were collected for each case where available. In addition to these official sources of information, the collision sites were visited and the damage to the guardrail terminal was measured and documented with photographs. The following sections will address the performance of the BCT and MELT guardrail terminals with respect to collision characteristics, occupant injury and barrier damage.

COLLISION CHARACTERISTICS

Data from a total of 102 BCT collisions and 42 MELT collisions was collected in the two study areas during the 24-month data collection period. Impact scenarios were determined based on physical evidence observed at the scene like skid marks on the pavement, ruts in the soil and scraps on the guardrail. When the collision was reported to the police, the officer's sketch of the impact was also useful in determining the collision scenario. There are three types of end-on impact scenarios and three types of redirectional scenarios illustrated in Figure 1. At least 60 percent of the police-reported collisions on the 11.43-m long MELT and BCT terminals involved a vehicle striking the end of the guardrail (e.g., near post one). The remaining 40 percent of collisions involved striking the guardrail at or downstream of post number two. Both the BCT and the MELT use a 1220-mm first-post offset, so the ends of such guardrail terminals appear to be struck more often than portions of the terminal at or downstream of post two. This demonstrates the importance of developing terminals with good end-on impact performance.

The data summarized in Figure 1 can also be used to assess the field relevance of the recommended full-scale crash tests in Report 350.*(3)* Four of the ten tests (40 percent) recommended for gating guardrail terminals in Report 350 involve end-on impacts with a variety of vehicle types and impact conditions (e.g., Tests 30 through 33).*(3)* Although the collisions that are represented in Figure 1 involve many different types of vehicles and impact conditions, they represent the same types of scenarios that are addressed by tests 30 through 33 in Report 350. Since approximately 50 percent of the real-world impacts involve end-on collisions, it is appropriate that at least four of the ten recommended tests also involve end-on collisions.

Side impact collisions, collisions where the vehicle slides essentially broadside into the end of the guardrail terminal, account for approximately 10 percent of the real-world BCT and MELT impacts, yet there are no recommended tests in Report 350 that explore the performance of guardrail terminals in this impact scenario. The data in Figure 1 indicate that the side impact performance of guardrail terminals should not be ignored, since such impacts account for approximately one of every ten collisions with a guardrail terminal and one of every six collisions with the end of a guardrail terminal.

Mid-section impacts were classified as those that occurred at or downstream of post two on the BCT and MELT. Of the ten recommended crash tests for gating terminals, six (60 percent) address various aspects of the redirectional performance although only about 40 percent of the real-world collisions occurred downstream of post two.*(3)* There were only three reverse direction collisions in the real-world data, although the probable reason is that the data were dominated by interstate collisions where such events would be unusual. There were three collisions that struck a MELT in North Carolina from behind. This was due to the fact that North Carolina installs BCT and MELT terminals in the median where they can be exposed to such collisions. Figure 1 indicates that the recommendations in Report 350 are, in general, relevant to the way guardrail terminals are struck in the field, although there appears to be more attention than is warranted to the redirectional performance and not enough attention to the end-on side impact performance of guardrail terminals.

The type of vehicle involved in the collision could only be determined in the 115 collisions that were reported to the police. More than 80 percent of the police-reported BCT and MELT cases in North Carolina and 50 percent of the BCT and MELT cases in Iowa involved collisions by passenger cars as shown in Table 1. The primary difference between the North Carolina and Iowa data collection areas is the percentage of tractor trailer trucks. The Iowa data collection area is bisected by a major east-west cross-country truck route (Interstate 80) which results in a relatively high proportion of truck collisions (e.g., almost 30 percent). Pickup trucks were involved in approximately 10 percent of cases in both areas, three sport utility vehicle (SUV) cases were observed, and there was only one case involving a van. The proportion of pickup, SUV and van vehicles is lower than might be expected given recent indications of the popularity of these types of vehicles.*(6)* Possible reasons for the relatively small proportion of pickup trucks, sport utilities and vans may be regional (e.g., both data collection areas are in “college towns”), or they may reflect the fact that the vehicle population is dominated by older vehicles.

The events that preceded, followed and resulted from the guardrail terminal impact in the 115 police-reported cases are shown in Table 2. The errant vehicle interacted with no other vehicles or objects prior to striking the guardrail terminal in approximately 90 percent of the cases in both States for both types of terminals, except for the MELT in Iowa, where there were too few cases for a significant estimate. The errant vehicle interacted with another vehicle in the traffic stream in eight percent of the cases and with a tree, pole or other roadside object in the remainder of the cases. In general it appears that most guardrail terminal collisions are the first impact in the sequence of collision events.

The result of the impact with the guardrail terminal is shown in the middle portion of Table 2. The vehicle was either redirected or gated in about half the collisions (e.g., between 46 and 74 percent), and the vehicle stopped while still in contact with the terminal in most of the rest. There were three cases where the vehicle snagged and spun out, two cases where it penetrated the rail, and four cases where it overrode the barrier. The result of the collision was acceptable in 106 of the 115 collisions (91 percent). The collision with the barrier was the last event in nearly 90 percent of the cases as shown in the bottom portion of Table 2. There were three cases where the vehicle subsequently struck a tree after being redirected, four cases where it struck another roadside object, one case where it struck another vehicle, and three cases where the subsequent event could not be determined. The differences between the distributions for the BCT and the MELT collisions in the two States are not statistically significant at the 90 percent confidence level. The data in Table 2 indicate that guardrail terminal impacts are generally single-vehicle single-event collisions that result in an acceptable vehicle response (i.e, the terminal is not penetrated or overridden).

The proportion of police-reported collisions and maintenance-only reported collisions is very different in Iowa and North Carolina as shown in Table 3. The reason for this is that State DOT workers perform repairs to guardrails in Iowa and are therefore notified by the police whenever a barrier is struck. In North Carolina, repair and maintenance are generally contracted out such that DOT is not notified unless the damage itself poses a hazard to traffic. The actual number of unreported collisions, of course, is probably much higher than either estimate indicates.

A 35.8 km portion of an interstate in the Iowa data collection area was closely monitored during the first 12 months of data collection. This control segment contained 24 BCT guardrail terminals and experienced average daily traffic (ADT) volumes of about 32,000 vehicles per day.   In addition to collecting information about all collisions reported to the police or maintenance agencies, the data collection team surveyed every BCT installation (there were no MELT installations on this segment) on the 35.8-km long control segment approximately once every month in order to record any minor damage to guardrail terminals. Such damage generally consisted of paint scraps and black marks from tires (e.g., very minor damage) as well as dents in the guardrail, collapsed end sections, or slightly bent posts (e.g., minor damage).

There was evidence of at least 69 guardrail terminal collision events on the 24 BCTs in the control segment as shown in Table 4. Of these 69 presumed collision events, only four (six percent) were reported to the police and three (four percent) were reported only to the DOT maintenance garage. The data in Table 4 suggest that 90 percent of the collisions with guardrail terminals in the State of Iowa are not reported to the police or DOT.   Presumably, if no one was injured and the vehicle was still operable after the collision, the driver left the scene without a police report being filed or maintenance personnel being notified. These collisions represent guardrail and guardrail terminal successes, since they shielded an errant vehicle from some more hazardous roadside feature without causing occupant injuries or serious property damage.

Where both inventory and collision information are available, it is possible to calculate expected average collision rates based on the number of vehicles passing guardrail terminal installations.   The Iowa control section was inventoried and the locations of guardrail terminals were recorded. There were 24 BCT terminals on this segment of interstate highway, and the ADT was approximately 32,000 vehicle/day. The ADT was determined at each guardrail terminal location based on Iowa DOT traffic volume data for the year 1996 and then adjusted to a 1997 basis by multiplying by a traffic growth rate of 2 percent.*(7)* An estimate of the number of vehicles passing BCT sites can be obtained by multiplying the number of BCTs at each location by the one-way ADT at that location.   Nearly 140 million vehicles pass BCT installations each year in this 35.8-km section of interstate highway as shown in Table 5.

As shown in Table 4, there was evidence of 69 collision events, seven of which were reported to either the police or maintenance agencies. Using these data, the collision rates shown in Table 5 can be calculated. One collision event (e.g., reported and unreported) occurred for every two million vehicles that passed a BCT terminal. As shown earlier in Table 4, 90 percent of these can be expected to be minor collisions that result in little property damage and no occupant injury. Collisions serious enough to be reported to the police will occur on average once for every 34 million vehicles passing the BCT installations. This analysis, of course, is based on the average occurrence of guardrail terminal collisions. Some sites will experience higher or lower rates because of traffic conditions or site characteristics at that specific location. For example, a BCT located on an approach to a narrow bridge on a high-volume high-speed highway might experience a higher rate than a BCT shielding a fixed hazard on a lightly traveled rural road. In any case, Tables 4 and 5 demonstrate that collisions with guardrail terminals are rare events, and those serious enough to report to the police are exceptionally rare.

OCCUPANT INJURY

The most important measure of roadside hardware performance is the amount of human trauma resulting from roadside hardware impacts. The reason for installing the hardware in the first place is to minimize the risk to vehicle occupants by shielding them from even more serious collisions with more hazardous roadside objects like poles, trees and steep side slopes. The severity of injuries to the vehicle occupants were assessed using the occupant injury codes listed on the police report (e.g., the KABCO scale). Each case was assigned the code for its most severe injury. Since the occupant injury information comes from the police report, the information was limited to the 115 police-reported collisions.

Of the 115 police-reported collisions of the BCT and the MELT, there was one fatality and four severe injuries (e.g., A level). During the 24-month data collection effort in Iowa, as shown in Table 6, 75 percent of the police-reported BCT collisions and 50 percent of the MELT collisions (e.g., one of two) involved only property damage. In North Carolina, over 60 percent of the police-reported collisions involving the BCT and over 50 percent involving the MELT resulted in only property damage. While the sample sizes shown in Table 6 are modest, they show that the majority of BCT and MELT impacts (e.g., approximately 75 percent) result in property-damage-only collisions.

The 90 th percentile precision ranges of the error rates were calculated where possible and are shown in Table 6 (the range cannot be calculated for a category if there were no observations in that category). For example, the probability that the true proportion of property-damage-only BCT collisions in Iowa is 75 percent ±15 percent (e.g., between 60 and 90) is at least 0.90 (e.g., 90 percent confidence). The proportion of property-damage-only BCT collisions in North Carolina is 66 percent ± 10 percent (e.g., between 56 and 76 percent) at the 90 percent confidence level. While the range of the estimates is relatively wide (e.g., 10 percent for North Carolina and 15 percent for Iowa), the estimates for both data collection areas overlap, indicating that the data are consistent with each other. The ranges for BCT performance in Iowa and North Carolina overlap at all severity levels where a range could be calculated, indicating that there is no statistical difference between the performance of the BCT in the two states. There is also no statistical difference between the performance of the MELT and BCT in North Carolina (there are not enough MELT cases in Iowa to calculate appropriate statistics). Additional data will reduce the size of the ranges shown in Table 6 and increase the confidence in the precision of the estimates. The data in Table 6 do indicate, however, that if there is a difference between the occupant injury rates of the MELT and the BCT, it is likely to be relatively small.

The level of occupant injury can also be cross-tabulated with the impact scenario, shown in Table 7, to gain insight into the most hazardous collision scenarios. In general, both end-on and mid-section impacts with both BCT and MELT guardrail terminals resulted in about the same proportion of property-damage-only collisions. Two of the five severe injury collisions involved a side impact with a BCT, and of the ten side impacts with BCT terminals, four (e.g., 40 percent) resulted in occupant injuries. Side impact collisions are the most serious impact scenario in terms of causing occupant injuries.

The aggregate level of occupant injury is summarized at the end of Table 7 for all BCT and MELT collisions in both data collection areas. Severe and fatal injury (e.g., A+K) collisions occurred in 5 percent of the police-reported BCT collisions, minor and moderate occupant injury (e.g., B+C) occurred in 27 percent of the police-reported BCT collisions and property damage only resulted in the remaining 68 percent of BCT collisions. Similarly, 4 percent of the police-reported MELT collisions involved severe or fatal injuries, 31 percent involved minor or moderate injuries and 64 percent involved only property damage. In general, then, both BCT and MELT collisions result in severe and fatal occupant injuries in approximately 5 percent of the police-reported collisions. Some level of occupant injury occurs in about 35 percent of police-reported collisions. As noted above, since police-reported collisions represent only six percent of all collisions, it would appear that occupants are injured in about 2 percent of all collision events (i.e., reported and unreported).

TERMINAL DAMAGE

The amount and type of damage that a guardrail terminal experiences can provide information about typical performance problems and the amount of resources required to repair the barrier. The damage characteristics of the BCT and MELT collisions in Iowa and North Carolina are shown in Tables 8 and 9.

The damaged length of the guardrail is an estimate of the contact length between the vehicle and the barrier. The damage length was measured even if it extended beyond the end of the guardrail terminal (e.g., 11.43 m) and included parts of the downstream guardrail or transition. Damaged lengths varied from a minimum of 0.2 m to a maximum of 19 m. The maximum values were recorded in cases where tractor trailer trucks completely destroyed the guardrail terminal and transition in a bridge approach. Typical damaged lengths were longer in Iowa than in North Carolina. This may be due to the higher proportion of heavy truck collisions in Iowa (see Table 1). In North Carolina, where the vehicle population was dominated by passenger cars, the mean damaged length was 4.4 m for the BCT and 5.0 m for the MELT.

The number of posts broken or bent over is another indication of the length of barrier damage. The number of posts indicated in Table 8 include only the posts that are part of the guardrail terminal itself. In Iowa, where timber posts are used, posts may be either broken off or displaced in the soil. In North Carolina, where steel wide flange posts are used, the post is usually twisted and bent to the ground or displaced in the soil. The values shown in Table 8 are for posts that were either broken or bent sufficiently to require replacement. It was not uncommon to observe minor collisions that did not bend or break any posts. Conversely, sometimes as many as seven of the posts required replacement.

As described earlier, guardrail terminal collisions can be categorized into end-on and mid-section collisions. End-on collisions are defined somewhat differently in this section since different performance will be observed depending on whether the first post breaks or not. The guardrail deflections and foundation performance for BCT and MELT terminals that were struck end-on are summarized in Table 9. The nose of the BCT and MELT sometimes came to rest as far as 14 m downstream of its original impact location. Similarly, the nose sometimes came to rest more than 9 m from the edge of the roadway. The data in Table 9 show that the area behind the guardrail terminal should be kept free of hazardous objects since if the nose of the terminal came to rest in this area it is probable that the vehicle also traversed this area.

Iowa uses a concrete foundation for the first two breakaway posts in the BCT, whereas North Carolina uses a steel foundation tube for its BCT. The MELT in both states uses a steel foundation tube. In an end-on impact the foundation must provide sufficient support to allow the breakaway post to fail. If the foundation support is inadequate the breakaway post may not fail or may fail too late. As shown in Table 9, only one of the concrete foundations used in the BCT in Iowa was observed to have moved during an end-on collision. On the other hand, 12 of the 37 (32 percent) end-on collisions involving the steel foundation tube (e.g., used in all the MELTs and the North Carolina BCTs) moved. Often when there was movement, it was extreme, causing the foundation to be pulled completely up out of the soil. The very high foundation movement values for the North Carolina BCT and MELT cases may indicate that the breakaway post sometimes failed late and allowed the vehicle to push the foundation out of the ground. In at least one North Carolina case, the foundation tube was pulled completely out of the ground without fracturing the wood post. Another possible explanation might be that the vehicle was snagging on the top of the foundation and pulling it out of the soil. Neither explanation involves satisfactory performance, and since this foundation design is widely used in other types of guardrail terminals, this issue should be investigated further.

When the first post does not break, the guardrail terminal should redirect the vehicle. Post three has normally been considered the beginning of the length of need in crash test evaluations of the BCT and MELT. The beginning of the length of need is the point where the terminal behaves like a standard section of guardrail and redirects errant vehicles. The lateral static deflection at the rail height in this case should be similar to the deflection of a strong post

W-beam guardrail. Table 10 shows the damage characteristics of impacts that occurred downstream of post two where the first post did not break. The maximum static rail height deflection was 820 mm for the MELT and 700 mm for the BCT.

The foundation must transmit all the guardrail loading from a redirectional impact into the ground. Excessive foundation movement indicates that more load is being transmitted to the foundation than the soil can distribute. If the foundation moves too much, the impacting vehicle may pocket into the guardrail rather than being redirected. Table 10 shows that some foundation movement was observed in three of the 27 redirectional impacts, indicating that most of the concrete and steel tube foundations were providing adequate soil support for typical real-world collisions.

The guardrail bolt should pull through the guardrail slot if the post is broken away or experiences large rotations. The purpose of this feature is to prevent the guardrail from being pulled to the ground when a post rotates in the soil. As shown in Table 11, the majority of cases did not result in the guardrail bolt pulling through the slot or failing. This is probably because the majority of collisions were relatively minor and did not involve large displacements of the post.

Tearing of the guardrail was not an unusual occurrence in the 144 real-world BCT and MELT collisions. Guardrail tearing was noted whenever any evidence of tearing was observed, such as when a tear initiated in a splice bolt hole. There was some evidence of tearing in 21 of the cases, as shown in Table 11; one MELT case in North Carolina resulted in a complete rupture of the guardrail. The proportion of collisions where tearing was observed was higher in Iowa, perhaps because of the higher proportion of heavy truck impacts (see Table 1). Even under typical in-service impact conditions, Table 11 indicates that at least one tear in the guardrail splice occurs in one in ten cases and perhaps in as many as three in ten cases.

In summary, the BCT and MELT terminals experienced similar types of damage. While the overall performance of the terminals was adequate, there were some potential problems that should be further investigated. For reasons that are not yet clear, the steel-tube foundation was pulled up out of the ground in a number of cases in North Carolina. There was also evidence of guardrail tearing in a number of cases that suggests that the guardrail splice may be close to its capacity even in typical field impact situations. The final resting position of the terminal nose reinforces the importance of keeping the entire area behind the 11.43-m long terminal clear of fixed objects, since the terminal nose and vehicle often travel long distances behind the barrier.

CONCLUSIONS

The previous sections have described a preliminary analysis of the data collected in an in-service performance evaluation of the BCT and MELT guardrail terminals in Iowa and North Carolina. The data indicate that roughly 60 percent of impacts involved striking the end of a 1220-mm offset guardrail terminal and the remaining 40 percent involved striking at or downstream of post two. The recommended Report 350 crash tests appear to be relevant to the way vehicles strike guardrail terminals in the field, but some tested scenarios like reverse direction collisions were rarely observed in the field whereas important real-world scenarios like side impacts are unaddressed by Report 350. Passenger cars dominated the in-service collision data, and there were significant differences between the two data collection areas with respect to the percentage of large trucks involved in terminal collisions. On average, a police-reported BCT collision occurred in the Iowa area once for every 23 million vehicles that passed the site.

Over 60 percent of the police-reported MELT and BCT collisions resulted in only property damage. Five of the 115 police-reported collisions involved severe occupant injuries; one of these cases involved a side impact with a poorly installed guardrail terminal, and the one fatality involved an end-on impact by a motorcycle. Within the limits of the data collected to date, there was no statistically significant difference between the performance of the BCT in Iowa and North Carolina and there was no difference between the performance of the BCT and MELT. Some potential problems with steel-tube foundations were observed, and the unexpectedly large number of cases with some evidence of guardrail tearing may indicate that standard 12-gauge guardrail splice is performing at its limit in the field.

The foregoing sections have indicated that the BCT and MELT terminals are performing reasonably well in Iowa and North Carolina. These analyses, however, are limited by a modest number of cases and the conclusions may require revision as more data is collected. It should also be noted that both Iowa and North Carolina have many years of experience in using these terminals and the proportion of properly installed terminals was very high. A state with a larger number of poorly installed and maintained BCT and MELT terminals cannot expect to replicate these results, since poorly installed systems have been shown to result in unsatisfactory performance. *(8)(9)(10)*

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Table 1. Vehicle types involved in 115 police-reported BCT and MELT collisions.

	Iowa				North Carolina					
Scenario	BCT		MELT		BCT		MELT		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Passenger car	12	50	1	50	51	82	23	85	87	76
Pickup truck	3	13	0	0	6	10	2	7	11	10
Sport utility vehicle	2	8	0	0	0	0	1	4	3	3
Van	0	0	0	0	1	2	0	0	1	1
Bus	0	0	0	0	1	2	0	0	1	1
Tractor-trailer truck	7	29	1	50	3	5	1	4	12	10
Total	24	100	2	100	62	100	27	100	115	100

Table 2. Events in 115 police-reported BCT and MELT collisions.

	Iowa				North Carolina					
Scenario	BCT		MELT		BCT		MELT		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Events prior to impact										
None	21	88	1	50	56	90	26	96	104	90
Tree or pole	0	0	0	0	1	2	0	0	1	1
Other vehicle	2	8	1	50	5	8	1	4	9	8
Other roadside object	1	4	0	0	0	0	0	0	1	1
Unknown	0	0	0	0	0	0	0	0	0	0
Total	24	100	2	100	62	100	27	100	115	100
Result of impact										
Redirected/Gated	11	46	0	0	35	56	20	74	66	57
Stopped in Contact	8	33	1	50	24	39	6	22	39	34
Snagged/spun out	2	8	0	0	1	2	0	0	3	3
Override	3	13	0	0	1	2	0	0	4	3
Penetrated	0	0	1	50	0	0	1	4	2	2
Unknown	0	0	0	0	1	2	0	0	0	0
Total	24	100	2	100	62	100	27	100	115	100
Events following impact										
None	21	88	0	0	54	87	26	96	101	88
Tree or pole	0	0	0	0	3	5	0	0	3	3
Other vehicle	0	0	0	0	1	2	0	0	1	1
Other roadside object	2	8	2	100	1	2	0	0	5	4
Unknown	1	4	0	0	3	5	1	4	5	3
Total	24	100	2	100	62	100	27	100	115	100

Table 3. Reported and unreported BCT and MELT collisions.

Collision Type	Iowa				North Carolina			
	BCT		MELT		BCT		MELT	
	No.	%	No.	%	No.	%	No.	%
Police-reported	24	65	2	14	62	95	27	96
Maintenance-reported	13	35	12	86	3	5	1	4
Total	37	100	14	100	65	100	28	100

Table 4. Reported and unreported guardrail and guardrail terminal collisions on a 35.8-km segment of an interstate in Johnson County, Iowa from 1 July 1997 to 30 June 1998.

Collision Type	No.	%
Unreported Events		
Very minor damage	39	57
Minor damage	23	33
Reported Events		
Maintenance only	3	4
Police and maintenance	4	6
Police only	0	0
Total	69	100

Table 5. Collision rates for BCT and MELT terminals in a four-county area in Iowa.

Characteristics	Iowa control section[¶]
No. of terminals	24
Million vehicles passing per year	136
Collision events in one year	
All collisions	69
All reported collisions[§]	7
Police-reported	4
Millions of vehicles passing for one collision	
All collisions	2
All reported collisions	19
Police-reported	34

§ Reported collisions are those that are reported to either a police agency or a maintenance agency.

¶ The Iowa control section is a 35.8-km long segment of the east-bound alignment of an Interstate in Johnson County, Iowa with a one-way ADT of approximately 16,000 vehicles/day.

Table 6. Occupant injury severity in 115 police-reported BCT and MELT collisions.

Scenario	Iowa				North Carolina					
	BCT		MELT		BCT		MELT		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Severe or Fatal (A+K)	1	4±7	0	0	3	5±5	1	4±6	5	4±3
Moderate Injury (B+C)	5	21±14	1	50±58	18	29±9	12	44±16	36	31±7
Property damage only	18	75±15	1	50±58	41	66±10	14	52±16	74	64±7
Total	24	100	2	100	62	100	27	100	115	100

Table 7. Occupant injury severity and impact scenario in 115 police-reported BCT and MELT collisions.

Scenario	A+K		B+C		PDO		Total
	No	%	No	%	No.	%	No.
Iowa BCT Collisions							
End-on impacts							
Redirected behind	0	0	1	17	5	83	6
Redirected in front	0	0	0	0	4	100	4
Side impact	1	50	0	0	1	50	2
Mid-section impacts							
Redirected	0	0	1	20	4	80	5
Reverse direction	0	0	0	0	0	0	0
Hit from behind	0	0	0	0	0	0	0
All end-on impacts	1	8	1	8	10	83	12
All mid-section impacts	0	0	1	20	4	80	5
Unknown impacts	0	0	3	43	4	57	7
All impacts	1	4	5	21	18	75	24
Iowa MELT Collisions							
Mid-section impacts							
Penetrated	0	0	0	0	1	100	1
All mid-section impacts	0	0	0	0	1	100	1
Unknown impacts	0	0	1	100	0	0	1
All impacts	0	0	1	50	1	50	2
North Carolina BCT Collisions							
End-on impacts							
Redirected behind	2	18	3	27	6	55	11
Redirected in front	0	0	7	30	16	70	23
Side impact	1	14	2	29	4	57	7
Mid-section impacts							
Redirected	0	0	4	31	9	69	13
Reverse direction	0	0	1	33	2	67	3
Hit from behind	0	0	0	0	1	100	1
All end-on impacts	3	7	12	29	26	63	41
All mid-section impacts	0	0	5	29	12	71	17
Unknown impacts	0	0	1	25	3	75	4
All impacts	3	5	18	29	41	66	62
North Carolina MELT Collisions							
End-on impacts							
Redirected behind	0	0	0	0	4	100	4
Redirected in front	1	9	5	45	5	45	11
Side impact	0	0	0	0	1	100	1
Mid-section impacts							
Redirected	0	0	1	25	3	75	4
Reverse direction	0	0	0	0	0	0	0
Hit from behind	0	0	1	50	1	50	2
All end-on impacts	1	6	5	31	10	63	16
All mid-section impacts	0	0	2	33	4	67	6
Unknown impacts	0	0	5	100	0	0	5
All impacts	1	4	12	44	14	52	27

Table 7 (continued). Occupant injury severity and impact scenario in 115 police-reported BCT and MELT collisions.

Scenario	A+K		B+C		PDO		Total
	No	%	No	%	No.	%	No.
All Collisions							
All BCT impacts	4	5	23	27	59	68	86
All MELT impacts	1	3	13	45	15	52	29
All impacts	5	4	36	31	74	64	115

Table 8. Typical damage length and number of posts broken or bent in 144 BCT and MELT collisions.

	Iowa		North Carolina	
	BCT	MELT	BCT	MELT
Damaged Length				
No.	27	13	59	22
Missing	10	1	6	6
Mean (m)	6.2	8.2	4.4	5.0
Minimum (m)	0.2	1.6	0.2	0.9
Maximum (m)	19.0	19.0	11.0	10.0
Number of posts broken				
No.	31	13	61	24
Missing	6	1	4	4
Mean	1.6	1.7	1.6	2.2
Minimum	0	0	0	0
Maximum	5	5	7	7

Table 9. Typical damage in 54 BCT and MELT collisions where the first post failed.

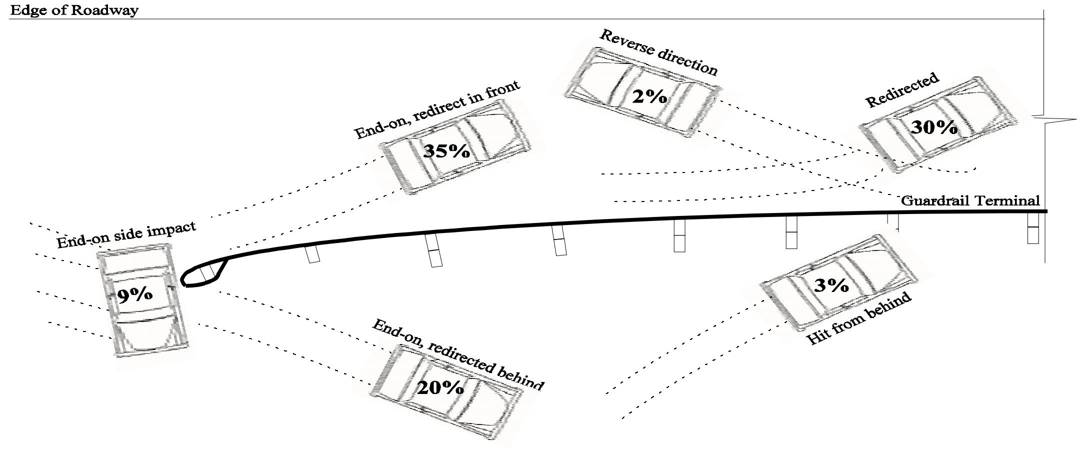
	Iowa		North Carolina	
	BCT	MELT	BCT	MELT
Final position of the nose				
Downstream				
No.	17	1	22	14
Mean (m)	2.8	4.1	1.9	3.8
Minimum (m)	0	4.1	0	0
Maximum (m)	11.0	4.1	5.8	14.2
Perpendicular to roadway				
No.	17	1	22	14
Mean (m)	4.9	1.6	4.6	3.3
Minimum (m)	0	1.6	0	0
Maximum (m)	9.7	1.6	8.9	6.0
Foundation Movement				
First post movement				
No Movement	17	1	14	10
Some movement	0	0	8	4
Mean (mm)	-	-	548	790
Minimum (mm)	-	-	10	40
Maximum (mm)	-	-	2940	2940
Second post movement				
No Movement	16	1	18	10
Some movement	1	0	4	4
Mean	60	-	600	553
Minimum	60	-	20	30
Maximum	60	-	1900	2120

Table 10. Typical damage in 27 BCT and MELT collisions where the first post did not break and the impact was downstream of post two.

	Iowa		North Carolina	
	BCT	MELT	BCT	MELT
Maximum lateral deflection				
No.	5	5	15	2
Mean (m)	201	283	277	410
Minimum (m)	0	45	0	0
Maximum (m)	660	680	700	820
Foundation Movement				
First post movement				
No Movement	4	5	14	1
Some movement	1	0	1	1
Second post movement				
No Movement	5	5	15	1
Some movement	0	0	0	1

Table 11. Component failures in 144 BCT and MELT collisions.

	Iowa				North Carolina					
Failed component	BCT		MELT		BCT		MELT		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Guardrail bolt performance										
Pulled through or failed	5	14	0	0	21	32	3	11	29	20
No failure	32	86	14	100	44	68	25	89	115	80
Total	37	100	14	100	65	100	28	100	144	100
Guardrail performance										
Tearing observed	9	24	2	14	7	11	3	11	21	15
No tearing	28	76	12	86	58	89	25	89	123	85
Total	37	100	14	100	65	100	28	100	144	100



Scenario	Iowa				North Carolina					
	BCT		MELT		BCT		MELT		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
End-on impacts										
Redirected behind	11	37	0	0	11	18	4	18	26	20
Redirected in front	9	30	1	8	23	38	11	47	44	35
Side impact	2	7	0	0	8	13	1	4	11	9
All end-on	22	74	1	8	42	69	16	69	81	64
Mid-section impacts										
Penetrated	0	0	1	8	0	0	0	0	1	1
Redirected	8	26	11	84	15	24	4	18	38	30
Reverse direction	0	0	0	0	3	5	0	0	3	2
Hit from behind	0	0	0	0	1	2	3	13	4	3
All mid-section	8	26	12	92	19	31	7	31	46	36
All collisions	30	100	13	100	61	100	23	100	127	100
Unknown or missing	7		1		4		5		17	
Total	37		14		65		28		144	

Figure 1. Impact scenario in 144 BCT and MELT collisions.