Effect of Barrier Type on Injury Severity in Motorcycle-to-Barrier Collisions in North Carolina, Texas, and New Jersey

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Motorcycle collisions with barriers have been shown to be much more severe than other vehicle collisions with barriers. The impact of barrier type on injury severity for motorcyclists has been greatly debated. There is growing concern about the risk associated with motorcycles colliding with cable barriers, although to date no definitive evidence has shown that cable barriers are indeed more harmful to motorcyclists than other barrier types. This study analyzed 951 motorcycle–barrier crashes involving 1,047 riders from 2003 to 2008 in North Carolina, Texas, and New Jersey to determine the effect of barrier type on injury severity in crashes. Barrier types were determined by using photographs of the reported crash site. There were 546 W-beam guardrail collisions, 358 concrete barrier collisions, and 47 cable barrier collisions observed. Of the people involved in W-beam collisions with known injury severity, 40.1% were fatally or severely injured. Likewise, 40.3% of people involved in cable barrier collisions with known injury severity were fatally or severely injured. The odds of severe injury in W-beam crashes to concrete barrier crashes were 1.164 (95% confidence interval: 0.889 to 1.524) for all riders involved in the barrier crashes analyzed, which was not significant at the 0.05 level. However, if the rider was helmeted, the odds of severe injury in a W-beam guardrail collision were 1.419 (95% confidence interval: 1.024 to 1.966) times as great as the odds of severe injury in concrete barrier collisions, a factor found to be significant at the 0.05 level. For both helmeted and unhelmeted riders, there was no significant difference in the odds of severe injury between the cable barrier collisions and the W-beam guardrail collisions. However, a smaller number of cable barrier collisions than W-beam guardrail collisions were included in the analysis.

Motorcyclists have a much higher fatality risk in collisions with traffic barriers than do other road users (*1*). From 2003 to 2008, 1,604 motorcyclist fatalities occurred from collisions with barriers in the United States, accounting for approximately 5.8% of all motorcyclist fatalities. During the same period in the United States, 1,723 car fatalities occurred from collisions with barriers, which comprised 1.6% of all car occupant fatalities. For fatalities per registered vehicle, motorcycle riders are dramatically overrepresented in the number of fatalities resulting from guardrail impacts. In the United States, motorcycles compose only 3% of the vehicle fleet but account for nearly half of all fatalities resulting from guardrail collisions and 22% of the fatalities from concrete barrier collisions. In 2005, for the first time, motorcycles accounted for more fatalities in metal barrier crashes than any other vehicle type. Beyond these broad categories of metal or concrete barrier, however, little is known about how specific barrier design affects the risk of serious or fatal injury.

Cable barriers provide an example of an extremely effective barrier system that is threatened by this lack of in-depth crash analyses. Cable barriers have been quite effective at protecting motorists from cross-median crashes (*2–10*). Motorcycle activist groups, however, perceive cable barriers as a particular threat to motorcyclists, referring to this barrier design as a "cheese cutter." Both in the United States and overseas, these groups have actively lobbied for a ban on this type of barrier. In Norway, these groups have succeeded in exerting sufficient political pressure to have cable barriers banned. Concern has grown about the elevated risk of motorcycle collisions with cable barriers (*11*). Several studies have been conducted in Australia, Europe, and the United States to examine the effects of motorcycle crashes into barriers (*2*, *10*, *12–20*). To date, however, little evidence either supports or refutes the claims that cable barriers are more dangerous to motorcyclists than W-beam barriers.

Cable barriers are being installed in Texas at a rapid rate; more than $200 million per year has been spent on high-tension cable barrier systems (*21*). This expenditure makes Texas an ideal candidate for an examination of its motorcycle–cable barrier crashes. In addition, cable barriers have been installed in North Carolina since 1991 (*21*). From 2000 to 2008, motorcycle–barrier crashes in North Carolina were analyzed (*22*). For this study, barrier type was determined from police accident reports. The study concluded that significantly more guardrail crashes occurred than either cable barrier or concrete barrier crashes.

OBJECTIVE

The goal of this study was to determine the influence of barrier design on serious- and fatal-injury risk in motorcycle–barrier crashes. A specific objective was to determine whether collisions with cable barriers carried a higher risk than collisions with W-beam guardrails or concrete barriers.

PROCEDURE

An analysis of motorcycle barrier crashes in three states—North Carolina, Texas, and New Jersey—was conducted to determine which type of barrier carries the higher risk for motorcyclists. Both North

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Transportation Research Record: Journal of the Transportation Research Board, No. 2262, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 144–151.
DOI: 10.3141/2262-14

Carolina and Texas have installed large numbers of cable barriers, a barrier type that is becoming increasingly popular in the United States, and Texas has more cable barriers than any other state. Barriers in New Jersey are composed of only guardrails and concrete barriers. This study examines motorcycle–barrier crashes of all injury severities.

This study is based upon databases of police-reported crashes from each of the three states. Information about North Carolina motorcycle crashes was obtained from the Highway Safety Information System, a multistate database that contains information about crashes and roadways. Information about motorcycle–barrier crashes in Texas was obtained from the Texas Crash Record Information System. Finally, information about crashes in New Jersey was obtained from the NJCRASH database. These databases contain all police-reported crashes regardless of injury severity. Crashes from 2003 to 2008 were analyzed in this study.

None of the databases clearly specified which type of barrier was struck by the motorcyclist. To determine barrier type, crash locations were identified in Google Earth. The process for obtaining the location of a crash differed for each state, as described below. Once the crash site was identified, the street view feature of Google Earth was used to determine the barrier type.

Texas Crash Locations

The Texas Crash Record Information System databases identified crash locations on the basis of latitude and longitude coordinates. These were directly imported into Google Earth for analysis. A small percentage of crash reports did not include geographic coordinates. These crashes were excluded from the analysis because they could not be sufficiently identified. All motorcycle crashes that reported a guardrail, median barrier, guard post, or concrete barrier were examined.

North Carolina Crash Locations

The North Carolina Highway Safety Information System database identified crash locations by means of the state milepost system. Information about this system was contained in the Linear Referencing System shapefile available from the North Carolina Department of Transportation (DOT) (*23*). The Linear Referencing System maps each road segment in North Carolina and reports the associated start and end mileposts of the segment. These segments were related to the crash data on the basis of the route identification number, which combines the route number and the county. Crash locations were then identified from these segments. The path tool in Google Earth was used to measure the appropriate distance from the start or end milepost to the crash location. Crashes reported as including a collision event with either a guardrail, shoulder barrier, or median barrier were examined. The analysis of North Carolina crashes was limited to Interstates, U.S. routes, and some state routes. On many state roads, crashes could not be accurately located, and these crashes were excluded from the analysis.

New Jersey Crash Locations

The NJCRASH database reports latitude and longitude coordinates of crash locations. As described for the analysis of the Texas crashes, the latitude and longitude coordinates were put into Google Earth for further analysis. Not all crashes reported latitude and longitude locations, and these crashes were excluded from the analysis because they could not be sufficiently identified. All motorcycle crashes that reported a collision with a guardrail face, guardrail end treatment, and concrete barrier were included in this study; no cable barriers are installed in New Jersey.

Determination of Barrier Type by Using Google Earth

The barrier type at each crash site was determined by using the street view feature of Google Earth. Once the crash was located, the imagery available for the area was used to view the barrier. On several occasions, no barrier was located at the measured or given crash site. In these cases, roads were scanned approximately 0.1 mi (0.2 km) upstream and downstream of the crash site. A previous study, in which motorcycle–barrier crash analyses were conducted, found that the actual crash site is sometimes offset from the reported latitude and longitude coordinates (*24*). If a barrier was still not identified near the crash site, the crash was excluded from the analysis. The barrier type at some crash sites was miscoded in the police report. Rather than guardrail, for example, another object such as a curb or fence sometimes showed in the site photographs. These miscoded cases were also excluded from the study. For several locations, no street view photographs were available. These crashes were also excluded from the analysis because the barrier type could not be confirmed. However, for one mountainous, unusually winding road in North Carolina, 35 motorcycle–barrier crashes were reported, and no street view was available for it. Because of geometry and location, it was assumed that the barrier on this road was a W-beam guardrail, and these crashes were included in the analysis.

The Texas reports did not specify whether the motorcyclist ran off the road to the left or the right. Therefore, to determine the barrier type in cases in which multiple barriers were present, the object struck was used as the first indication. For instance, if a W-beam guardrail and a concrete barrier were present and the crash record indicated a collision with a concrete barrier, the barrier was recorded as a concrete barrier. The North Carolina data, in contrast, indicated whether the motorcyclist ran off the left or the right side of the road. For divided highways, running off the road to the left was assumed to be a median crash.

Comparison of Barrier Types by Severity of Crashes

The reported injury severity was used to determine the different effect that each barrier type had on the severity of the crash. The injury severity was reported in both North Carolina and Texas by means of the KABCO scale, a five-level crash severity scale used by police in which K indicates killed; A, incapacitating injury; B, moderate injury; C, complaint of pain, and O, property-damage-only crash. For this study, a severe injury crash was defined as a crash in which the most serious injury was either a K or an A.

For direct comparison of the effect of barrier type on severity, the odds ratio (OR) of fatal and severe injury was computed for each barrier type by using Equation 1:

$$\text{odds of severe injury} = \frac{p(\text{severe injury})}{1 - p(\text{severe injury})} \tag{1}$$

The OR of severe injury was then computed to directly compare each barrier type. Three ORs were computed to compare all three barrier types. Each was computed by

$$\text{OR} = \frac{\text{odds of severe injury for Barrier A}}{\text{odds of severe injury for Barrier B}} \quad (2)$$

An OR of 1 would indicate that the odds of severe injury for Barrier A are equal to the odds of severe injury for Barrier B. If the OR is greater than 1, then the odds of severe injury in a collision with Barrier A are greater than the odds of severe injury in a collision with Barrier B.

To compute the confidence interval (CI), first the standard error (SE) of the natural log of the OR was computed by

$$\text{SE}_{\ln(\text{OR})} = \sqrt{\frac{1}{n_{\text{severe},A}} + \frac{1}{n_{\text{nonsevere},A}} + \frac{1}{n_{\text{severe},B}} + \frac{1}{n_{\text{nonsevere},B}}} \quad (3)$$

The 95% CI was then computed as

$$\text{CI} = \exp\left(\ln\left[\text{OR}\right] \pm 1.96\ \text{SE}\right) \quad (4)$$

In addition, the risk of severe injury for each barrier type was computed. The risk was defined as

$$\text{risk} = \frac{\text{severe crashes}}{\text{total crashes}} \quad (5)$$

This risk was used to compare directly the hazards of different barriers.

Comparison of Severity of Crashes by Helmet Usage

The effect of helmet usage on injury severity in barrier crashes was analyzed next because many riders were not helmeted at the time of the crash. The riders involved in the analyzed crashes were divided into two groups: helmeted and unhelmeted. The analysis described in the previous section was then conducted for each set of riders to determine the effect of barrier type on injury severity for both helmeted and unhelmeted riders.

RESULTS

From 2003 to 2008, 2,168 motorcycle–barrier collisions were reported in North Carolina, Texas, and New Jersey. Of these crashes, 1,400 were examined in Google Earth, and barriers were identified for 951 crashes. As discussed earlier, reasons for exclusion included (*a*) no barrier was present at the crash site; (*b*) the site could not be accurately determined; and (*c*) no imagery was available for the crash site. There were 286 barrier crashes without geographic coordinates in Texas, and 325 crashes for which geographic coordinates were not reported in New Jersey. Locations for 113 crashes in North Carolina could not be identified because of the inavailability of data. Table 1 shows the distribution of barrier types in crashes examined in each state.

TABLE 1 Crashes Examined by State and Barrier Type

Variable	New Jersey	North Carolina	Texas	Total
Barrier Type				
W-beam guardrail	168	134	244	546
Concrete barrier	87	23	248	358
Cable barrier	0	15	32	47
Subtotal	255	172	524	951
No barrier	21	10	347	378
Indeterminate	1	6	5	12
No imagery available	5	22	32	59
Total	282	210	908	1,400
Road Alignment				
Straight	94	66	346	506
Curved	161	106	172	439
Not reported	0	0	6	6
Total	255	172	524	951
Road Functional Class				
Interstate	48	63	209	320
U.S. & state highway	132	109	187	428
Other	75	0	128	203
Total	255	172	524	951
Helmet Usage				
Helmet	241	192	328	761
No helmet	12	5	190	207
Unknown	15	2	62	79
Total	268	199	580	1,047

North Carolina Barrier Crashes

North Carolina had 323 motorcycle–barrier crashes from 2003 to 2008. The barrier type of 172 of these crashes was identified by using Google Earth. These crashes corresponded to 199 rider and passenger injuries. Table 2 shows the distribution of injury severity by barrier type.

TABLE 2 Injury Severity by Barrier Type in North Carolina

	Injury Severity						
Barrier Type	Fatality	Incapacitating Injury	Moderate Injury	Complaint of Pain	Property Damage	Unknown	Total
W-beam	15	34	76	20	10	2	157
Cable barrier	1	4	9	2	0	0	16
Concrete barrier	2	4	16	2	1	1	26
Total	18	42	101	24	11	3	199

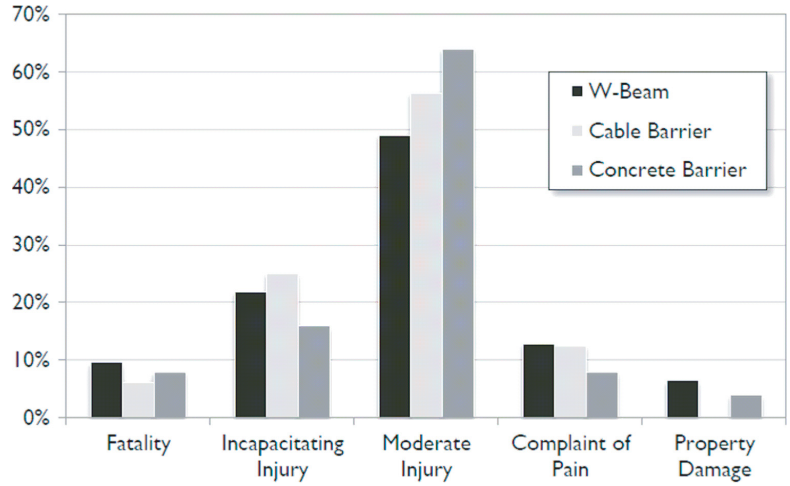

FIGURE 1 Distribution of injury severity in North Carolina motorcycle–barrier crashes, 2003–2008.

Sixty riders were fatally or severely injured in the barrier crashes examined for North Carolina. Three people were reported to have been involved in a motorcycle–barrier collision whose injury severity was unknown. These riders were excluded from the analyses that follow. The majority of the motorcycle–barrier crashes in North Carolina were collisions with W-beam guardrails. Figure 1 compares the injuries sustained by barrier type; the figures are based on the percentage of injuries in each KABCO category.

The majority of the crashes resulted in moderate injury for all barrier types. A higher percentage of concrete barrier crashes resulted in moderate injury than did the other barrier types. The percentage of fatalities for each barrier type was approximately equal. However, in absolute terms, a larger number of collisions occurred with W-beam guardrails than with cable barriers or concrete barriers.

Texas Barrier Crashes

In Texas, 1,268 motorcycle–barrier crashes occurred, and barrier types were identified for 524 of them. The lower percentage of barrier identification may be attributed to two factors. First, no coordinates were given for 286 crashes, so these could not be examined. Second, 151 of the crashes identified as "hit median barrier" did not contain one of the studied barriers in the median. These medians were often raised islands dividing the traffic, with no guardrail, concrete barrier, or cable barrier.

As Table 3 shows, 580 riders and passengers were involved in the 524 crashes for which the barrier was identified. Of these, 83 were fatalities and 168 were incapacitating injuries. The injury severity for 26 riders remained unknown, and these riders were excluded from the analysis. The distribution of injury severity for each barrier type is shown in Figure 2.

A higher percentage of incapacitating injuries for all W-beam guardrail and concrete barrier occurred in Texas than in North Carolina. Furthermore, Texas had a higher percentage of fatalities in collisions with W-beam guardrails than North Carolina. However, although the Texas data set was larger than that for North Carolina, Texas still had relatively few cable barrier crashes compared with the number of W-beam guardrail and concrete barrier crashes analyzed.

Barrier Crashes in New Jersey

Between 2003 and 2008, New Jersey had 607 motorcycle–barrier crashes. The barrier type of 255 of these crashes was identified by means of Google Earth. Because no cable barrier is installed in New Jersey, the crashes included in this analysis were collisions with either W-beam guardrails or concrete barriers.

As Table 4 shows, 268 riders and passengers were involved in the 255 crashes for which the barrier was identified. In these crashes, 77 people were either fatally or severely injured. The injury severity for 18 riders was not known, and these riders were excluded from the analysis. The distribution of injury severity for each barrier type is shown in Figure 3.

W-beam guardrail collisions totaled approximately twice the number as concrete barrier collisions. The majority of injuries sustained

TABLE 3 Injury Severity by Barrier Type in Texas

	Injury Severity						
Barrier Type	Fatality	Incapacitating Injury	Moderate Injury	Complaint of Pain	Property Damage	Unknown	Total
W-beam	44	87	87	26	14	12	270
Cable barrier	2	14	13	3	4	1	37
Concrete barrier	37	67	94	43	19	13	273
Total	83	168	194	72	37	26	580

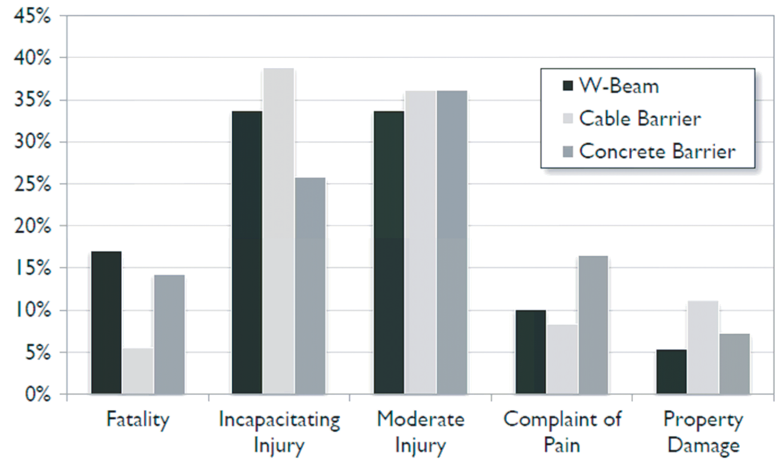

FIGURE 2 Distribution of injury severity in Texas motorcycle–barrier crashes, 2003–2008.

by riders were moderate for both W-beam guardrails and concrete barriers. For both barrier types, all crashes resulted in some injury. A slightly higher percentage of fatal and severe injuries resulted from collisions with W-beam guardrails than with concrete barriers.

Next, the location of the barrier in the context of barrier type was examined. Of W-beam guardrail crashes analyzed, 92.3% (155) occurred in the shoulder and 7.1% (12) in the median. The location of one W-beam guardrail crash could not be determined. In contrast, 85.1% (74) of concrete barrier crashes occurred in the median, and 12.6% (11) occurred in the shoulder. The location of two (2.3%) motorcycle–concrete barrier crashes analyzed could not be determined. These findings are likely a reflection of where the various barrier types are typically used.

Analysis of Data Set

Next, the entire data set was analyzed to determine whether barrier type had an effect on injury severity in motorcycle–barrier collisions. One thousand riders whose injury severity was known were involved in the analyzed barrier collisions. The injury severity by barrier type for all riders involved in the analyzed crashes is shown in Table 5.

As shown for each state, the percentage of each injury severity by barrier type was computed. The distribution of injury severity by barrier type is shown in Figure 4.

For each barrier type, the percentage of moderate injuries was the same. The risk of severe injury in concrete barrier collisions was 0.365. Comparatively, the risk of severe injury in W-beam and cable barrier collisions was 0.401 and 0.404, respectively. Compared with the number of W-beam guardrail and concrete barrier collisions, a small number of cable barrier crashes was examined.

Odds of Severe Injury

The OR of severe injury for all barrier crashes was computed by using Equations 1 and 2. The odds of severe injury in W-beam guardrail collisions were 1.164 times higher (95% CI: 0.889 to 1.524) than the odds of severe injury in concrete barrier collisions. This difference in risk was found not to be statistically significant.

Next, cable barrier collisions were compared with both W-beam guardrail and concrete barrier collisions. The OR of severe injury in a collision with a cable barrier compared with that in one with a concrete barrier was 1.178 (95% CI: 0.651 to 2.132). Likewise, the OR of severe injury in a collision with cable barriers as compared with that with W-beam guardrails is 1.012 (95% CI: 0.567 to 1.804). From these point estimates, it can be determined that the probability of severe injury in a cable barrier crash is greater than that in a collision with a concrete barrier but approximately the same for that with a W-beam guardrail. This result was also found not to be statistically significant.

Last, the OR of severe injury in crashes with metal barriers to crashes with concrete barriers was computed. Metal barriers include both W-beam guardrails and cable barriers. The OR of a severe injury in a collision with a metal barrier compared with one with a concrete barrier was 1.165 (95% CI: 0.894 to 1.519). The point esti-

TABLE 4 Injury Severity by Barrier Type in New Jersey

	Injury Severity						
Barrier Type	Fatality	Incapacitating Injury	Moderate Injury	Complaint of Pain	Property Damage	Unknown	Total
W-beam	32	21	85	30	0	11	179
Cable barrier	0	0	0	0	0	0	0
Concrete barrier	12	12	48	10	0	7	89
Total	44	33	133	40	0	18	268

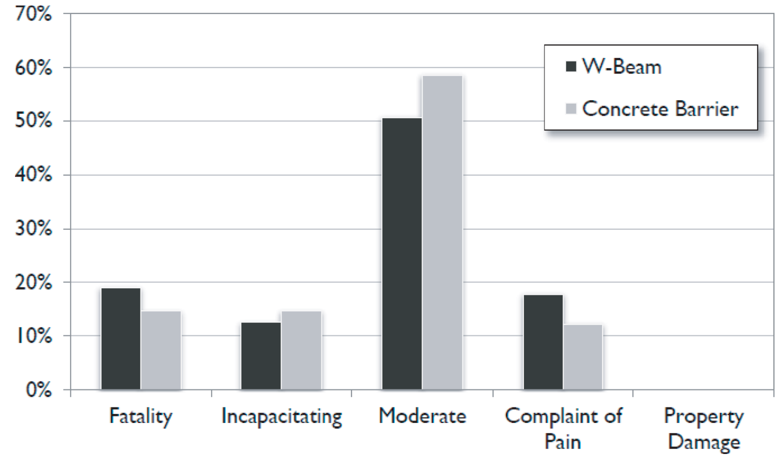

FIGURE 3 Distribution of injury severity in New Jersey motorcycle–barrier crashes, 2003–2008.

mate shows that the probability of severe injury in a collision with a metal barrier is greater than that in a collision with a concrete barrier. However, from these data, it cannot be asserted with confidence that metal barriers were significantly more harmful than concrete barriers.

Effect of Helmet Usage on Injury Severity

The effect of helmet usage on injury severity was next analyzed by comparing the OR of severe injury in barrier collisions for riders with and without a helmet at the time of the crash. OR was computed for comparisons between all barrier types as well as for metal barriers (W-beam and cable) compared with concrete barriers (Table 6).

For unhelmeted riders, the point estimates of the odds of severe injury in metal barrier collisions were less than those of the odds of severe injury in concrete barrier collisions. However, this was found not to be statistically significant for comparisons between any barrier types.

For helmeted riders, the odds of severe injury in metal barrier collisions were 1.404 (95% CI: 1.017 to 1.938) times as high as the odds of severe injury in concrete barrier collisions, which was found to be significant at the 0.05 level. In addition, it was found that, if the rider was helmeted, collisions with W-beam barriers were significantly more likely to result in severe injury than were collisions with concrete barriers. The point estimate of the odds of severe injury in W-beam guardrail collisions was 1.181 (95% CI: 0.557 to 2.508) times as great as the odds of severe injury in cable barrier collisions. From these data, no statistical difference was found in the odds of severe injury between W-beam guardrails and cable barriers.

DISCUSSION OF RESULTS

Several limitations are associated with this study. To identify the barrier by using Google Earth, several assumptions about the barrier location needed to be made. First, many crashes needed to be excluded because the location could not be identified. Furthermore, ambiguity in the data sets about events during a crash also resulted in crashes being excluded. Second, because a limited number of motorcycle–barrier collisions occurred, the statistical significance of the conclusions drawn from this study was affected. The small number of motorcycle–cable barrier crashes observed during the 6-year period was anticipated to be due to the low collision rate with this type of barrier rather than from these crashes being excluded from the data analyzed. In addition, the images available in Google Earth were not sufficiently clear to distinguish between high- and low-tension cable barriers.

CONCLUSIONS

This study has presented an analysis of the injury risk in 951 motorcycle–barrier collisions, involving 1,000 riders, in North Carolina, Texas, and New Jersey. The barriers examined included W-beam guardrails, cable barriers, and concrete barriers. Injury severity patterns in collisions with each barrier type were analyzed. Overall, 40.1% of people involved in motorcycle collisions with W-beam guardrails were fatally or severely injured. Similarly, 40.4% of people involved in a motorcycle collision with a cable barrier were

TABLE 5 Injury Severity by Barrier Type for Combined Data Set

	Injury Severity						
Barrier Type	Fatality	Incapacitating Injury	Moderate Injury	Complaint of Pain	Property Damage	Unknown	Total
W-beam	91	142	248	76	24	25	606
Cable barrier	3	18	22	5	4	1	53
Concrete barrier	51	83	158	55	20	21	388
Total	145	243	428	136	48	47	1,047

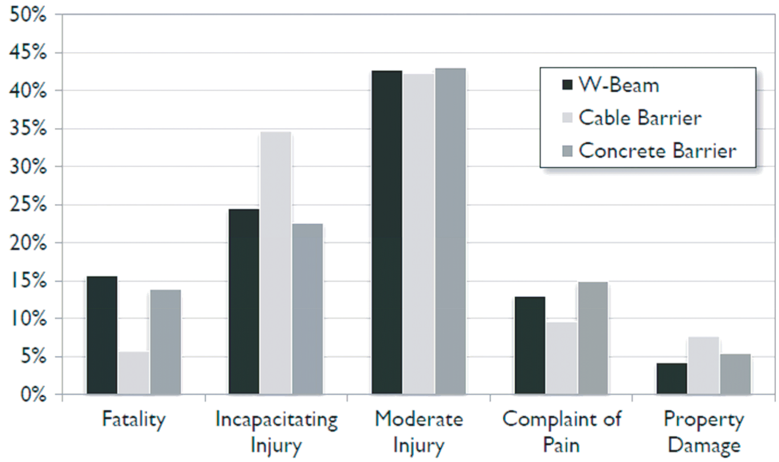

FIGURE 4 Injury severity by barrier type: North Carolina, Texas, and New Jersey, 2003–2008.

fatally or severely injured. A lower percentage (36.5%) of people in motorcycle–concrete barrier collisions were fatally or severely injured. The odds of severe injury in a collision of a motorcycle with a W-beam guardrail were 1.164 (95% CI: 0.889 to 1.524) times as high as the odds of severe injury in a motorcycle–concrete barrier collision.

The odds of severe injury were considered for riders both wearing and not wearing a helmet. For unhelmeted riders, the point estimates of the odds of severe injury in metal barrier collisions were less than the odds of severe injury in concrete barrier collisions, although this was found not to be significant at the 0.05 level. However, if the rider was helmeted, the odds of severe injury in a W-beam guardrail collision were 1.419 (95% CI: 1.024 to 1.966) times as great as the odds of severe injury in concrete barrier collisions. Therefore, for helmeted riders, collisions with guardrails were found to be significantly more likely to cause severe injury than collisions with concrete barriers. Moreover, the odds of severe injury for helmeted riders in collisions with metal barriers were found to be significantly greater than the odds of severe injury in concrete barrier collisions at the 0.05 level. Analyses of both helmeted and unhelmeted riders showed no statistical difference at the 0.05 level in the odds of severe injury between collisions with a cable barrier and collisions with a W-beam guardrail. However, a small number of cable barrier collisions were included in the analysis compared with the number of W-beam guardrail collisions.

TABLE 6 Odds Ratio of Severe Injury in Barrier Crashes for Helmeted and Unhelmeted Riders

	OR of Severe Injury (95% CI)	
Barrier Type	Helmeted	Unhelmeted
W-beam–concrete barrier	1.419 (1.024–1.966)	0.705 (0.397–1.252)
Cable barrier–concrete barrier	1.202 (0.553–2.613)	0.905 (0.301–2.718)
Cable barrier–W-beam	0.847 (0.399–1.799)	1.283 (0.434–3.796)
Metal barrier–concrete barrier	1.404 (1.017–1.938)	0.728 (0.417–1.271)

ACKNOWLEDGMENTS

The authors gratefully acknowledge the Transportation Research Board for its sponsorship of this research under NCHRP Project 22-26, Factors Related to Serious Injury and Fatal Motorcycle Crashes with Traffic Barriers. The authors thank the Federal Highway Administration, Texas Department of Transportation, and the New Jersey Department of Transportation for the use of their data. Thanks also go to Justin Litowitz, Ashley Thompson, and Lauren Lemieux, who assisted with the Google Earth analysis.

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The Roadside Safety Design Committee peer-reviewed this paper.