

THE EFFECT OF BARRIER TYPE ON INJURY SEVERITY IN MOTORCYCLE TO BARRIER COLLISIONS IN NORTH CAROLINA, TEXAS, AND NEW JERSEY

Allison Daniello

(corresponding author)

Research Engineer
Virginia Tech - Wake Forest University
School of Biomedical Engineering and Sciences
440 ICTAS Building, Stanger Street (MC 0194)
Blacksburg, VA, USA 24061
Phone: (908) 839-6828
Fax: (540) 231-9738
E-Mail: adaniell@vt.edu

Hampton C. Gabler, Ph.D.

Associate Professor and Associate Department Head
Virginia Tech - Wake Forest University
School of Biomedical Engineering and Sciences
445 ICTAS Building, Stanger Street (MC 0194)
Blacksburg, VA, USA 24061
Phone: (540) 231-7190
Fax: (540) 231-9738
Email: gabler@vt.edu

Submission Date: November 15, 2010

Word Count: 4,777

Tables: 6

Figures: 4

Total Word Count Including Tables and Figures: 7,554

ABSTRACT

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 a growing concern about the risk associated with motorcycles colliding with cable barriers, though there is to date no definitive evidence to show 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 2003-2008 in North Carolina, Texas, and New Jersey to determine the effect of barrier type on injury severity in crashes. Barrier types were determined using photographs of the reported crash site. There were 546 W-beam guardrail collisions, 358 concrete barrier collisions and 47 cable barrier collisions observed. 40.1% of people involved in W-beam collisions were fatally or severely injured. Likewise, 40.3% of people involved in cable barrier collisions were fatally or severely injured. The odds of severe injury in w-beam crashes to concrete barrier crashes was 1.164 (95% CI: 0.889 - 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% CI: 1.024-1.966) times greater than the odds of severe injury in concrete barrier collisions, which was found to be significant at the 0.05 level. For both helmeted and un-helmeted riders, there was no significant difference in the odds of severe injury in cable barrier collisions as compared to the odds of severe injury in w-beam guardrail collisions.

INTRODUCTION

Motorcyclists have a much higher fatality risk in collisions with traffic barriers, than do other road users [1]. From 2003-2008, there were 1,604 motorcyclist fatalities from collisions with barriers in the United States, accounting for approximately 5.8% of all motorcyclist fatalities. During the same time period in the U.S., there were 1,723 car fatalities from collisions with barriers, which comprised 1.6% of all car occupant fatalities. In terms of fatalities per registered vehicle, motorcycle riders are dramatically over-represented in number of fatalities resulting from guardrail impacts. In the U.S., 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. For the first time in 2005, 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 barrier provides an example of a very effective barrier system which is threatened by this lack of in-depth crash analyses. Cable barriers have been very effective at protecting motorists from cross-median crashes [2 - 10]. Motorcycle activist groups however perceive cable barrier as a particular threat to motorcyclists referring to this barrier design as ‘cheese cutter’. Both in the U.S. 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 barrier banned. There has been a growing concern about the elevated risk of motorcycle collisions with cable barrier [11]. Several studies have been conducted in the Australia, Europe, and the United States to examine the effects of motorcycle crashes into barriers [2, 10, 12 - 20]. To date, however, there is little evidence to either support or refute the claims that cable barrier is more dangerous than w-beam barrier.

Cable barrier is being installed in Texas at a rapid rate; over \$200 million dollars per year are being spent on high tension cable barrier systems [21]. This makes Texas an ideal candidate for examining motorcycle-cable barrier crashes. Cable barrier has been installed in North Carolina since 1991 [21]. An analysis was conducted regarding motorcycle barrier crashes North Carolina from 2000-2008 [22]. For this study, barrier type was determined based on the police accident report. The study concluded that there were significantly more guardrail crashes than either cable barrier or concrete barrier crashes.

OBJECTIVE

The goal of this study was to determine the influence of barrier design upon serious and fatal injury risk in motorcycle-barrier crashes. A specific objective is to determine whether collisions with cable barriers carry a higher risk than collisions with w-beam guardrail or concrete barrier.

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 Carolina and Texas have installed large amounts of cable barrier – a barrier type which is becoming increasingly popular in the United States. Texas has more cable barrier than any other state in the U.S. Barrier in New Jersey is only comprised of guardrail and concrete barrier. This study examines motorcycle to barrier crashes of all injury severities.

This study is based upon databases of police-reported crashes from each state. Information about North Carolina motorcycle crashes was obtained from the Highway Safety Information System (HSIS). HSIS is a multi-state database that contains information about crashes and roadways. Information about motorcycle-barrier crashes in Texas was obtained from the Texas Crash Record Information System (CRIS). Lastly, information about crashes in New Jersey was obtained from the NJCRASH database. All these databases contain all police reported crashes regardless of injury severity. Crashes from 2003-2008 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 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 barrier type.

North Carolina Crash Locations

The North Carolina HSIS database identified crash locations using the state milepost system. Information about this system was contained in the Linear Referencing System (LRS) shapefile available from the North Carolina Department of Transportation (NCDOT) [23]. The LRS 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 based on the route identification number, which combines the route number and the county. Crash locations were then identified based

55 on the segments. Using the “Path” tool in Google Earth, the appropriate distance from the start or end milepost was measured to the crash location. Crashes reported as containing a collision event with either a guardrail, shoulder barrier, or median barrier were examined. The analysis of North Carolina crashes was limited to Interstates, US Routes, and some state routes. On many state roads, crashes could not be accurately located, and these roads were excluded from the analysis.

Texas Crash Locations

60 The Texas CRIS databases identified crash locations based on latitude and longitude coordinates. These were directly imported into Google Earth for analysis. There were a small percentage of crashes that did not report geographic coordinates. These crashes were excluded from the analysis since they could not be identified. All motorcycle crashes that reported a guardrail, median barrier, guard post, or concrete barrier were examined.

New Jersey Crash Locations

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

Determination of Barrier Type Using Google Earth

70 The barrier type at each crash site was determined using the “Street View” feature of Google Earth. Once the crash was located, the imagery available of the area was used to view the barrier. On several occasions, there was no barrier located at the measured or given crash site. In these cases, roads were scanned for approximately 0.1 miles (0.2 km) upstream and downstream of the crash site. Our 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 there was still no barrier identified near the crash site, the crash was excluded from the analysis. The barrier type at some crash sites was miscoded. Rather than guardrail, for example, inspection of the site photos sometimes showed another object such as a curb or fence. These miscoded cases were also excluded from the study. There were several locations where there were no Street View photographs available. These crashes were also excluded from the analysis since the barrier type could not be confirmed. However, for one mountainous, unusually winding road in North Carolina, there were 35 motorcycle-barrier crashes reported. There was no street view available for this road. Due to the geometry and location, it was assumed that the barrier on this road was W-beam guardrail, and these crashes were included in the analysis.

80 In Texas, it was not specified whether the motorcyclist ran off the road to the left or right. Therefore, to determine the barrier type in cases where there were multiple barriers present, the object struck was used as the first indication. For instance, if there was W-beam guardrail and concrete barrier present and the crash record indicated a collision with concrete barrier, the barrier was recorded as a concrete barrier. The North Carolina data, on the other hand, indicated which side of the road the motorcyclist ran off. 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

90 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 using the KABCO scale. The distribution on injury severity by barrier type was examined for both states, and the total sample. KABCO is a five level crash severity scale used by police. ‘K’ indicates killed. ‘A’ indicates incapacitating injury. ‘B’ indicates moderate injury. ‘C’ indicates complaint of pain. ‘O’ indicates a property-damage-only crash. For this study, severe injury was defined to be crashes in which the most serious injury was either a ‘K’ (killed) or ‘A’ (incapacitating).

95 To directly compare the effect of barrier type on severity, the odds ratio of fatal and severe injury was computed to compare each barrier type. The odds of fatal or severe injury for each barrier was computed using the equation

$$Odds\ of\ Severe\ Injury = \frac{p(Severe\ Injury)}{1-p(Severe\ Injury)} \quad (1)$$

100 The odds ratio (OR) of severe injury was then computed to directly compare each barrier type. Three odds ratios were computed to compare all three barrier types. Each was computed by

$$OR = \frac{\text{Odds of Severe Injury for Barrier A}}{\text{Odds of Severe Injury for Barrier B}} \quad (2)$$

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

110 To compute the confidence interval, first the standard error of the natural log of the OR was computed by

$$SE_{\ln(OR)} = \sqrt{\frac{1}{n_{severe,A}} + \frac{1}{n_{non-severe,A}} + \frac{1}{n_{severe,B}} + \frac{1}{n_{non-severe,B}}} \quad (3)$$

The 95% confidence interval (CI) was then computed as

$$115 \quad CI = \exp(\ln[OR] \pm 1.96 SE) \quad (4)$$

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

$$120 \quad Risk = \frac{\text{Severe Crashes}}{\text{Total Crashes}} \quad (5)$$

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

Comparison of Severity of Crashes by Helmet Usage

125 The effect of helmet usage on injury severity in barrier crashes was next analyzed since many riders were not helmeted at the time of the crash. The riders involved in the crashes analyzed were divided into two groups: helmeted and un-helmeted. 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 un-helmeted riders.

RESULTS

130 There were 2,168 motorcycle-barrier collisions reported to have occurred in the years 2003-2008 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 previously, reasons for exclusion included (1) no barrier present at the crash site, (2) the site could not be accurately determined, or (3) there was no imagery available for the crash site. There were 286 barrier crashes without geographic coordinates in Texas, and 325 crashes where geographic coordinates were not reported in New Jersey. Locations for 113 crashes in North Carolina could not be identified due to the data available. TABLE 1 shows the distribution of barrier types in crashes that were examined in each state.

135

TABLE 1 Crashes Examined by State and Barrier Type

	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
<i>Subtotal</i>	<i>255</i>	<i>172</i>	<i>524</i>	<i>951</i>
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

TABLE 1 (continued) Crashes Examined by State and Barrier Type

Road Functional Class				
Interstate	48	63	209	320
US & 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

140 There were a total of 323 motorcycle-barrier crashes in North Carolina from 2003-2008. The barrier type of 172 of these crashes was identified using Google Earth. These crashes correspond 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

Barrier Type	Injury Severity						Total
	Fatality	Incapacitating Injury	Moderate Injury	Complaint of Pain	Property Damage	Unknown	
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

145 There were 60 riders fatally or severely injured in the barrier crashes examined in North Carolina. There were three people reported to have been involved in a motorcycle-barrier collision whose injury severity was unknown. These riders were excluded from the analyses which follow. The majority of the motorcycle-barrier crashes in North Carolina were collisions with W-beam guardrail. FIGURE 1 compares the injuries sustained by
150 each type of barrier based on the percentage of injuries in each category.

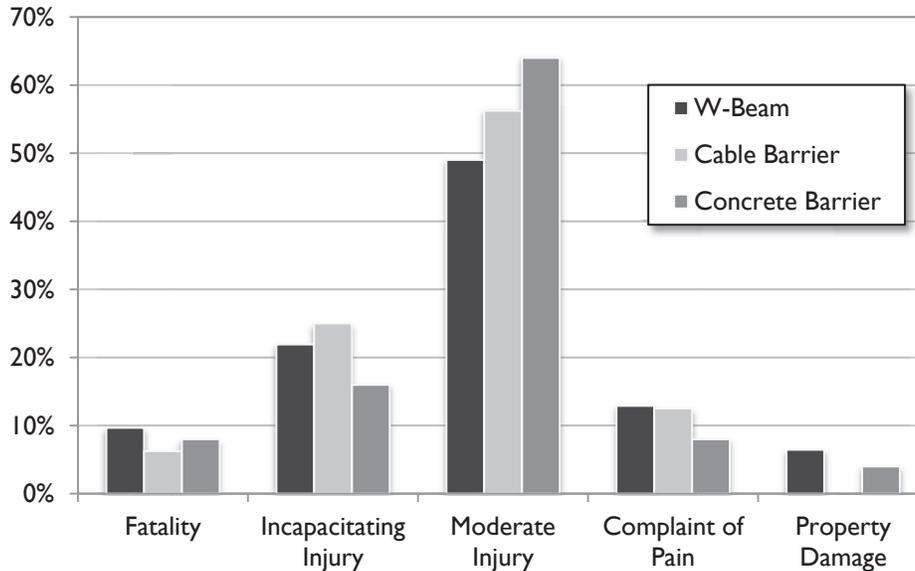


FIGURE 1 Distribution of Injury Severity in North Carolina Motorcycle-Barrier Crashes (2003-2008)

155 The majority of the crashes resulted in moderate injury for all barrier types. There were a higher percentage of concrete barrier crashes resulting in moderate injury than the other barrier types. The percentage of fatalities for each barrier type was approximately equal. However, in absolute terms, there were a larger number of collisions with w-beam guardrail than collisions with cable barrier and concrete barrier.

Texas Barrier Crashes

160 There were 1,268 motorcycle-barrier crashes in Texas, and barrier types were identified for 524 of these crashes. 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.

165 **TABLE 3 Injury Severity by Barrier Type in Texas**

Barrier Type	Injury Severity						Total
	Fatality	Incapacitating Injury	Moderate Injury	Complaint of Pain	Property Damage	Unknown	
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
<i>Total</i>	<i>83</i>	<i>168</i>	<i>194</i>	<i>72</i>	<i>37</i>	<i>26</i>	<i>580</i>

170 As shown in TABLE 3, there were 580 riders and passengers involved in the 524 crashes for which the barrier was identified. There were 83 fatalities and 168 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.

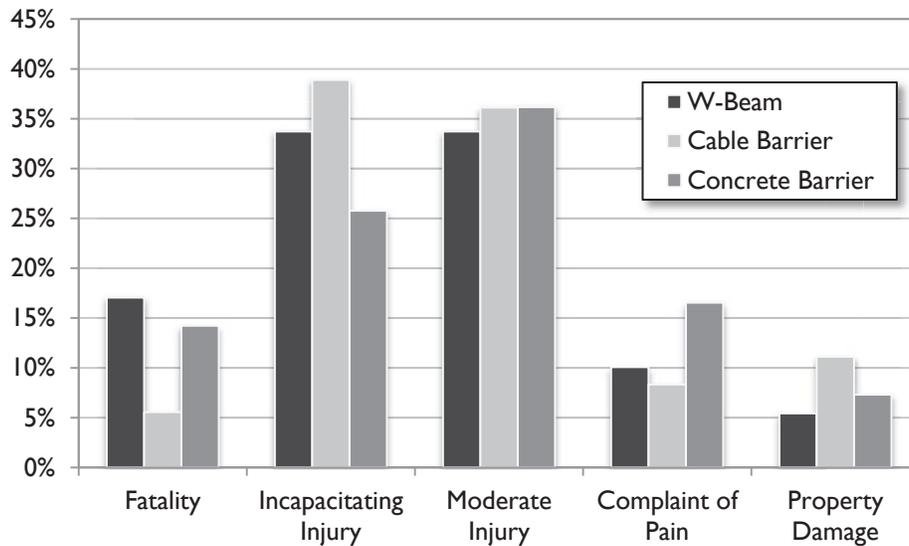


FIGURE 2 Distribution of Injury Severity in Texas Motorcycle-Barrier Crashes (2003-2008)

175 There were a higher percentage of incapacitating injuries for all W-beam guardrail and concrete barrier in Texas as compared to North Carolina. Additionally, there were a higher percentage of fatalities in collisions with W-beam guardrails in Texas as compared to North Carolina. However, though this data set was larger than that for North Carolina, there were still relatively few cable barrier crashes compared to the number of W-beam guardrail and concrete barrier crashes analyzed.

180 **Barrier Crashes in New Jersey**

There were 607 motorcycle-barrier crashes in New Jersey between 2003 and 2008, inclusive. The barrier type of 255 of these crashes was identified using Google Earth. There is no cable barrier installed in New Jersey, thus, the crashes included in this analysis were collisions with either with W-beam guardrail or concrete barrier.

185 **TABLE 4 Injury Severity by Barrier Type in New Jersey**

Barrier Type	Injury Severity						Total
	Fatality	Incapacitating Injury	Moderate Injury	Complaint of Pain	Property Damage	Unknown	
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
<i>Total</i>	<i>44</i>	<i>33</i>	<i>133</i>	<i>40</i>	<i>0</i>	<i>18</i>	<i>268</i>

As shown in TABLE 4, there were 268 riders and passengers involved in the 255 crashes for which the barrier was identified. There were 77 people either fatally or severely injured in these crashes. 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.

190

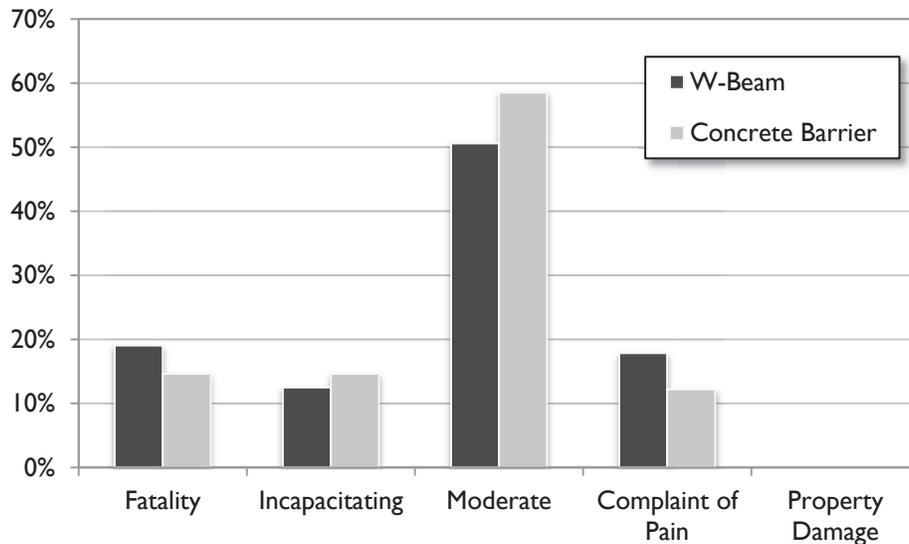


FIGURE 3 Distribution of Injury Severity in New Jersey Motorcycle-Barrier Crashes (2003-2008)

195 There were approximately twice as many W-beam guardrail collisions as there were concrete barrier collisions. The majority of injuries sustained by riders were “moderate” for both w-beam guardrail and concrete barrier. For both barrier types, there were no crashes resulting in no injury. There were a slightly higher percentage of fatal and severe injuries in collisions with W-beam guardrail than in collisions with concrete barrier.

200 Next, the location of the barrier in the context of the barrier type was examined. 92.3% (155) of the motorcycle to w-beam guardrail crashes analyzed occurred in the shoulder, and 7.1 % (12) occurred in the median. The location of one w-beam guardrail crash could not be determined. Contrarily, 85.1% (74) of concrete barrier crashes occurred in the median, and 12.6% (11) occurred in the shoulder. The location of 2 (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.

205 **Analysis of Data Set**

Next, the entire dataset developed was analyzed to determine if barrier type had an effect on injury severity in motorcycle-barrier collisions. There were 1,000 riders involved in the analyzed barrier collisions whose injury severity was known. The injury severity by barrier type of all riders involved in the analyzed crashes is shown in TABLE 5.

210

TABLE 5 Injury Severity by Barrier Type for Combined Data Set

Barrier Type	Injury Severity						Total
	Fatality	Incapacitating Injury	Moderate Injury	Complaint of Pain	Property Damage	Unknown	
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
<i>Total</i>	<i>145</i>	<i>243</i>	<i>428</i>	<i>136</i>	<i>48</i>	<i>47</i>	<i>1,047</i>

As shown for each individual 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.

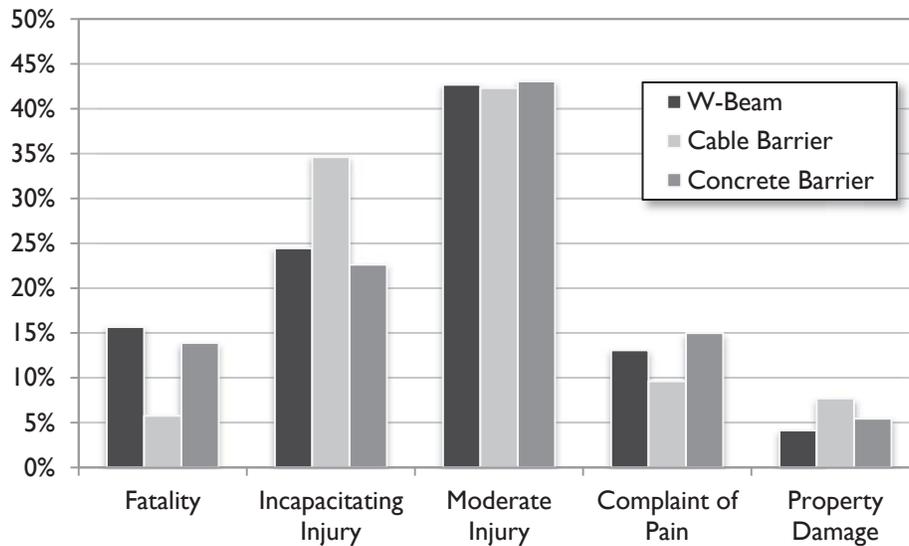


FIGURE 4 Injury Severity by Barrier Type (North Carolina, Texas, and New Jersey, 2003-2008)

For each barrier type, the percentage of moderate injuries was the same. The risk of severe injury in for 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 to the number of W-beam guardrail and concrete barrier collisions, there were a small number of cable barrier crashes examined.

Odds of Severe Injury

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

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

Lastly, the OR of severe injury in crashes with metal barriers to concrete barriers was computed. Metal barriers include both w-beam guardrail and cable barrier. The OR of a severe injury in a collision with a metal barrier as compared to a concrete barrier is 1.165 (95% CI: 0.894 - 1.519). The point estimate shows that the probability of severe injury in a collision with a metal barrier is greater than the probability 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 to concrete barriers.

215

220

225

230

235

240

245

250

Table 6 OR of Severe Injury in Barrier Crashes for Helmeted and Un-helmeted Riders

Barrier Type	OR of Severe Injury (95% CI)	
	Helmeted	Un-helmeted
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)

For un-helmeted riders, it was found that 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. However, this was not found to be statistically significant for comparisons between any barrier types.

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

DISCUSSION

There are several limitations associated with this study. To identify the barrier using Google Earth, several assumptions about the barrier location needed to be made. Many crashes needed to be excluded since the location could not be identified. Additionally, ambiguity in the datasets about the events during the crash also resulted in crashes being excluded. Second, there were a limited number of motorcycle-barrier collisions, which affected the statistical significance of the conclusions drawn from this study. The small number of motorcycle-cable barrier crashes observed over the six year period is anticipated to be due to the low collision rate with this type of barrier, rather than these crashes being excluded from the data analyzed. Additionally, the images available in Google Earth were not clear enough to distinguish between high and low tension cable barrier.

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 guardrail, cable barrier, and concrete barrier. Injury severity patterns in collisions with each barrier type were analyzed. Overall, 40.1% of people involved in motorcycle collisions with w-beam guardrail were fatally or severely injured. Similarly, 40.4% of people involved in a motorcycle collision with cable barrier were 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 motorcycle-W-beam guardrail collision were 1.164 (95% CI: 0.889 - 1.524) times higher than the odds of severe injury in a motorcycle-concrete barrier collision.

The odds of severe injury were considered for riders either wearing or not wearing a helmet. For un-helmeted 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, though this was not found 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 are 1.419 (95% CI: 1.024-1.966) times greater than the odds of severe injury in concrete barrier collisions, which was found to be significant at the 0.05 level. Additionally, 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 un-helmeted 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.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Transportation Research Board for their sponsorship of this research under NCHRP Project 22-26. Our thanks to Justin Litowitz, Ashley Thompson, and Lauren Lemieux, who assisted with the Google Earth analysis.

REFERENCES

- 295 [1] Gabler, H.C., 2007. "The Risk of Fatality in Motorcycle Crashes with Roadside Barriers", In: Proceedings of the Twentieth International Conference on Enhanced Safety of Vehicles, Lyons, France, June, Paper No. 07-0474.
- [2] Grzebieta, R., Jama, H., McIntosh, A., Friswell, R. Favand, J., Attard, M., and Smith, R. Overview of Motorcycle Crash Fatalities Involving Road Safety Barriers. *Journal of the Australasian College of Road Safety*, Vol. 20, No. 4, 2009, pp. 42-52.
- 300 [3] McClanahan, D., Albin, R.B., Milton, J.C., Washington State Cable Median Barrier In-Service Study. Washington State Department of Transportation, 2003.
- [4] Sposito, B., Johnston, S. Three-Cable Median Barrier Final Report. Publication OR-RD-99-03. Oregon Department of Transportation, 1998.
- 305 [5] Hunter, W.W., Stewart, J.R., Eccles, K.A., Huang, H.F., Council, F.M., and Harkey, D.L. Three-Strand Cable Median Barrier in North Carolina: In-Service Evaluation. *Transportation Research Record*, No. 1743, pp. 97-103, 2001.
- [6] Cooner, S.A., Rathod, Y.K. Alberson, D.C., Bligh, R.P., Ranft, S.E., and Sun, D. Performance evaluation of Cable Median Barrier Systems in Texas. Publication FHWA-TX-09-0-5609-1, Federal Highways Administrations, US Department of Transportation, 2009.
- 310 [7] Villwock, N.M., Blond, N., and Tarko, A.P. "Safety Impact of Cable Barriers on Rural Interstates", Proceedings of the 88th Annual Meeting of the Transportation Research Board, Washington, DC, 2009.
- [8] Qin, X., and Wang, M. "High-Tension Median Cable In-Service Performance Evaluation and Cost-Effectiveness Analysis", Proceedings of the 89th Annual Meeting of the Transportation Research Board, Washington, DC, 2010.
- 315 [9] Alberson, D.C., Sheikh, N.M., and Chatham, L.S. Guidelines for the Selection of Cable Barrier Systems – Generic Design vs. High-Tension Design. NCHRP Project 20-7(210) Final Report, National Cooperative Highway Research Program, Washington, D.C., 2007.
- [10] Carlsson, A. Evaluation of 2+1 Roads with Cable Barrier: Final Report. Publication 636A. Swedish National Road and Transport Research Institute, 2009.
- 320 [11] Hammond, P. and Batiste, J.R. Cable Median Barrier: Reassessment and Recommendations Update. Washington State Department of Transportation, 2008.
<http://www.wsdot.wa.gov/Projects/CableBarrier/Report2008.htm>. Accessed July 16, 2010.
- [12] Ouellet, J.V., "Environmental Hazards in Motorcycle Accidents", Proceedings of the 26th Annual Meeting of the American Association for Automotive Medicine, Ottawa, Ontario, Canada , 1982.
- 325 [13] Hurt, H., Ouellet, J.V., and Thom, D., Motorcycle Accident Cause Factors and Identification of Countermeasures, Volume I, DOT Technical Report, Contract No. DOT HS-5-01160, Washington DC, 1981.
- [14] Domham, M. "Crash Barriers and Passive Safety for Motorcyclists", Proceedings of the Stapp Car Crash Conference, SAE Paper No. 870242, 1987.
- 330 [15] Quincy, R., Vulin, D., and Mounier, B., "Motorcycle Impacts with Guardrails", Transportation Research Circular, No. 341, pp. 23-28, 1988.
- [16] Gibson, T. and Benetatos, E., Motorcycles and Crash Barriers, NSW Motorcycle Council Report, 2000.
- 335 [17] Berg, F.A., Rucker, P., Gartner, M., Konig, J., Grzebieta, R., and Zou, R., Motorcycle Impacts into Roadside Barriers – Real Word Accident Studies, Crash Tests, and Simulations Carried Out in Germany and Australia", Proceedings of the Nineteenth International Conference on Enhanced Safety of Vehicles, Washington, DC, 2005.
- [18] Gabler HC, "The Emerging Risk of Fatal Motorcycle Crashes with Guardrails", Proceedings of the 86th Annual Meeting of the Transportation Research Record, Washington, DC, 2007.
- 340 [19] Gabler HC, and Gabauer DJ, "Opportunities for Reduction of Fatalities in Vehicle-Guardrail Collisions", 51st Annual Proceedings of the Association for the Advancement of Automotive Medicine, Melbourne, Australia, 2007.
- [20] Daniello, A. and Gabler, H.C. "Fatality Risk in Single- and Multi- Event Motorcycle Collisions with Roadside Objects in the United States", Proceedings of the International Conference on Safety and Mobility of Vulnerable Road Users: Pedestrians, Motorcyclists, and Bicyclists, Jerusalem, Israel, 2010.
- 345 [21] Cooner, S.A., Rathod, Y.K., Alberson, D.C., Bligh, R.P., Ranft, S.E., and Sun, D. Development of Guidelines for Cable Median Barrier Systems in Texas. Publication FWHA-TX-10-0-50609-2. Federal Highways Administrations, US Department of Transportation, 2009.

- 350 [22] Robinson, B. Motorcycle Guardrail Crashes in North Carolina. Prepared by Safety Evaluation Group,
Traffic Systems Management Section, Transportation Safety and Mobility Division, North Carolina
Department of Transportation, 2008.
- [23] North Carolina Department of Transportation. Linear Referencing System Arcs Shapefile, 2010.
<http://www.ncdot.org/it/gis/default.html>. Accessed July 17, 2010.
- 355 [24] Daniello, A., Powell, B., Schaeffer, N., McClinton, A., Mehta, Y. Swanseen, K., and Hampton, H.C. Initial
site inspection of motorcycle collisions with roadside objects in New Jersey. Proceedings of the Twenty-
First International Conference on Enhanced Safety of Vehicles, Paper No. 09-0450, Stuttgart, Germany,
2009.