Accident Analysis and Prevention 77 (2015) 105–112

Contents lists available at ScienceDirect

Accident Analysis and Prevention

journal homepage: www.elsevier.com/locate/aap

Influence of horizontally curved roadway section characteristics on motorcycle-to-barrier crash frequency

Douglas J. Gabauer *, Xiaolong Li

Department of Civil and Environmental Engineering, Bucknell University, Lewisburg, PA 17837, USA

ARTICLE INFO

Article history:
Received 19 December 2014
Received in revised form 8 February 2015
Accepted 10 February 2015
Available online 18 February 2015

Keywords:
Motorcycle crash
Longitudinal barriers
Horizontal curves
Roadway characteristics

ABSTRACT

The purpose of this study was to investigate motorcycle-to-barrier crash frequency on horizontally curved roadway sections in Washington State using police-reported crash data linked with roadway data and augmented with barrier presence information. Data included 4915 horizontal curved roadway sections with 252 of these sections experiencing 329 motorcycle-to-barrier crashes between 2002 and 2011. Negative binomial regression was used to predict motorcycle-to-barrier crash frequency using horizontal curvature and other roadway characteristics. Based on the model results, the strongest predictor of crash frequency was found to be curve radius. This supports a motorcycle-to-barrier crash countermeasure placement criterion based, at the very least, on horizontal curve radius. With respect to the existing horizontal curve criterion of 820 feet or less, curves meeting this criterion were found to increase motorcycle-to-barrier crash frequency rate by a factor of 10 compared to curves not meeting this criterion. Other statistically significant predictors were curve length, traffic volume and the location of adjacent curves. Assuming curves of identical radius, the model results suggest that longer curves, those with higher traffic volume, and those that have no adjacent curved sections within 300 feet of either curve end would likely be better candidates for a motorcycle-to-barrier crash countermeasure.

1. Introduction

Motorcycle impacts into traffic barriers, such as w-beam guardrails and concrete barriers, produce particularly severe rider injuries, even when compared to other types of motorcycle crashes (Daniello and Gabler, 2011a). Although not a frequently occurring type of motorcycle crash, they now comprise the largest proportion of guardrail fatalities of any single vehicle type in the US (Gabler, 2007). The majority of the published research to date has focused on determining the characteristics of these crashes as well as the associated rider injury mechanisms and injury consequences (Ouellet, 1982; Bryden and Fortuniewicz, 1986; Koch and Brendicke, 1988; Hell and Lob, 1993; Gibson and Benetatos, 2000; Association of European Motorcycle Manufacturers (ACEM), 2004; Bambach et al., 2012; Daniello and Gabler, 2011b, 2012). In addition, several alternative barrier designs and barrier retrofit devices have been developed to reduce rider injury severity in the event of a motorcycle impact (Koch and Schueler, 1987; Ellmers, 1997; Mulvihill and Corben, 2004; Janssen et al., 2005; Candappa et al., 2005).

While a number of the developed "motorcycle-friendly" barriers have been field-installed, researchers have indicated that these devices are cost effective only at locations predisposed to this crash type (Koch and Schueler, 1987; Domham, 1987). The influence of specific roadway design elements on the incidence of motorcycle-to-barrier crashes, however, is not well understood. As a result, roadway designers have little guidance on where to locate these countermeasures to maximize the effectiveness of each field-installed device. Anecdotal evidence from previous studies indicates motorcycle-to-barrier crashes may occur more frequently on curved roadway sections (Berg et al., 2005; Jama et al., 2011). Although this suggests that curved locations may be good candidates for "motorcycle-friendly" barriers, there is only a single quantitative placement guideline present in published literature (Elliot et al., 2003) with regard to curved sections and none with respect to other roadway geometrics or features. Also, there were no studies found in the available literature specifically investigating how roadway characteristics affect the likelihood that a given roadway section will or will not experience a motorcycle-to-barrier crash.

* Corresponding author. Tel.: +1 570 577 2902; fax: +1 570 577 3415.
E-mail address: doug.gabauer@bucknell.edu (D.J. Gabauer).

http://dx.doi.org/10.1016/j.aap.2015.02.006
0001-4575/

2. Objective

The purpose of this study was to examine the influence of roadway design elements on the frequency of motorcycle-to-barrier crashes occurring on horizontally curved sections. Specific objectives were to (1) compare characteristics of horizontal curve sites with and without motorcycle-to-barrier crashes and (2) develop a statistical model to investigate how curvature and other roadway curve features affect the occurrence of this crash type.

3. Previous research

3.1. Studies specific to motorcycle-to-barrier crashes

Several previous studies specific to motorcycle-to-barrier crashes provided anecdotal insight into roadway characteristics associated with this crash type. At least two studies reported that curved roadway sections experienced a higher proportion of motorcycle-to-barrier crashes. Berg et al. (2005) found that 60 percent of the 57 motorcycle-to-barrier crashes investigated, including various injury severity levels, occurred within curved sections. Examining 77 fatal motorcycle-to-barrier crashes in Australia and New Zealand, Jama et al. (2011) reported that 81 percent involved a horizontal curve with an approximately equal distribution of right and left hand curves. Other studies indicated somewhat differing results regarding curved sections. Based on 8 barrier impact fatalities occurring in New South Wales, Gibson and Benetatos (2000) reported half involved the rider leaving the roadway in a curved section. A previous study by Gabauer (2014) examined police-reported motorcycle-to-barrier crashes occurring in Ohio and Washington State over a 12-year and 10-year period, respectively. Based on the 1511 crashes, 40 percent of motorcycle-to-barrier crashes in Washington State were on curved sections compared to a mere 19 percent of these crashes in Ohio. When compared to all single vehicle motorcycle and all multiple vehicle crashes involving motorcycles, however, motorcycle-to-barrier crashes were found to be overrepresented on curved sections in both states.

Even fewer studies provided curve-specific details beyond a curve/no curve indication. Domham (1987) noted that none of 22 motorcycle-to-barrier crashes in Germany occurred on a horizontal curve with the smallest radius. Based on the reported results of French motorcycle-to-barrier crash study, Elliot et al. (2003) suggested motorcycle-to-barrier countermeasures are appropriate on horizontal curves with radius less than 250 m (820 feet); this was the only quantitative recommendation found in the literature specific to the motorcycle-to-barrier crash mode. The previous study by Gabauer (2014) reported mean horizontal curve radius and mean vertical grade for motorcycle-to-barrier crashes in addition to other roadway characteristics such as mean shoulder width, median width, and annual average daily traffic (AADT). A primary finding with regard to horizontal curvature was that motorcycle-to-barrier crashes were significantly more likely on smaller radius horizontal curves compared to all other single vehicle motorcycle crashes. With respect to the Elliot et al. (2003) recommendation, the author found less than 45 percent of motorcycle-to-barrier crashes occurred on a curved section or within 90 m (300 feet) of either end of a curve meeting the 250 m (820 foot) criterion. Considering only crashes occurring within the curved sections reduced this percentage to less than 25 percent of the total motorcycle-to-barrier crashes in either state. Although the study presented more detailed roadway information for this crash type, barrier presence data was unavailable. This data limitation prevented a distinction between sections with a barrier present but no motorcycle-to-barrier crashes from sections with no barrier present and thus no possibility of a crash of this type. As a result, a full analysis of the effect of roadway characteristics on crash frequency was not possible.

3.2. Relevant general motorcycle crash study results

A number of crash studies not specific to the motorcycle-to-barrier crash mode also provided information related to the influence of roadway alignment on either crash frequency or crash severity, or both. Similar to the studies specific to motorcycle-to-barrier crashes, though, the majority of the results were predominately general in nature, e.g., distinguishing curved sections from tangent sections but no specific curve radius data. The majority of the studies suggested that horizontal curves increased the likelihood (Kim et al., 2002; Association of European Motorcycle Manufacturers (ACEM), 2004; Preusser et al., 1995) and the severity (Savolainen and Mannering, 2007; Kim et al., 2002; Quddus et al., 2002) of either single vehicle motorcycle crashes or all motorcycle crashes. There were two recent crash studies found with more specific alignment data for horizontal curves on rural two-lane highways; one focusing on driver injury severity in all single vehicle crashes (Schneider et al., 2009) and another specific to single vehicle motorcycle crashes (Schneider et al., 2010).

Schneider et al. (2009) used multinomial logit analysis to examine roadway, driver, environmental and vehicle factors affecting horizontal curve crash severity. Data included 10,029 single vehicle crashes in Texas which contained 354 single vehicle motorcycle crashes. Horizontal curves were categorized based on radius with 'small' curves having radii less than 500 feet, 'large' curves having radii greater than 2800 feet, and 'medium' curves having radii between the small and large ranges. Compared to all other vehicle types, fatal and incapacitating motorcycle injuries were found to be approximately 6 times as likely, irrespective of curve category. Non-incapacitating motorcycle rider injuries were also found to be between 73 and 98 percent more likely than for drivers of all other vehicle types negotiating a curved section. Trees were the only fixed object specifically noted as producing higher severity injuries but this finding applied to all vehicle types; results specific only to motorcycle-to-barrier crashes were not reported.

Schneider et al. (2010) used a negative binomial model to investigate roadway geometry effects on single vehicle motorcycle crashes in Ohio. The analysis was based on 225 motorcycle crashes which had occurred on 30,379 rural two-lane highway horizontal curves over a seven year study period. Horizontal curve length, horizontal curve radius, distance beyond either curve end-point, roadway shoulder width, and total segment average daily traffic (ADT) were all found to have a statistically significant effect on motorcycle crash occurrence. Longer, higher speed curves and smaller radius curves were both found to increase motorcycle crash frequency on a given segment. Curves were also found to influence crash risk on adjacent tangent sections for up to 300 feet but with decreasing crash risk as a motorcyclist moved farther from a curved section. A percentage point increase in total ADT was estimated to increase motorcycle crash frequency by 0.43 percent. In addition, roadway sections with shoulders less than 6 feet in width were found to increase motorcycle crash risk by approximately 50 percent. Similar to the previous Schneider et al. (2009) study, motorcycle-to-barrier crashes were not specifically addressed.

4. Methodology

The overall study approach was to investigate motorcycle-to-barrier crash frequency on horizontally curved roadway sections in a single state using police-reported crash data linked with roadway data. The available roadway data was augmented with