Injury Outcome in Crashes with Guardrail End Terminals

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Received 16 March 2015, Accepted 22 June 2015

Objective: The goal of this study is to evaluate the crash performance of guardrail end terminals in real-world crashes. Guardrail end terminals are installed at the ends of guardrail systems to prevent the rail from spear ing through the car in an end-on collision. Recently, there has been a great deal of controversy as to the safety of certain widely used end terminal designs, partly because there is surprisingly little real-world crash data for end terminals. Most existing studies of end terminal crashes used data from prior to the mid-1990s. Since then, there have been large improvements to vehicle crashworthiness and seat belt usage rates, as well as new roadside safety hardware compliant with National Cooperative Highway Research Program (NCHRP) Report 350, “Recommended Procedures for the Safety Performance Evaluation of Highway Features.” Additionally, most existing studies of injury in end terminal crashes do not account for factors such as the occurrence of rollover. This analysis uses more recent crash data that represent post-1990s vehicle fleet changes and account for a number of factors that may affect driver injury outcome and rollover occurrence.

Methods: Passenger vehicle crashes coded as involving guardrail end terminals were identified in the set of police-reported crashes in Michigan in 2011 and 2012. End terminal performance was expected to be a function of end terminal system design. State crash databases generally do not identify specific end terminal systems. In this study, the coded crash location was used to obtain photographs of the crash site prior to the crash from Google Street View. These site photographs were manually inspected to identify the particular end terminal system involved in the crash. Multiple logistic regression was used to test for significant differences in the odds of driver injury and rollover between different terminal types while accounting for other factors.

Results: A total of 1,001 end terminal crashes from the 2011–2012 Michigan State crash data were manually inspected to identify the terminal that had been struck. Four hundred fifty-one crashes were found to be suitable for analysis. Serious to fatal driver injury occurred in 3.8% of end terminal crashes, moderate to fatal driver injury occurred in 11.8%, and 72.3% involved property damage only. No significant difference in moderate to fatal driver injury odds was observed between NCHRP 350 compliant end terminals and noncompliant terminals. Car drivers showed odds of moderate to fatal injury 3.6 times greater than LTV drivers in end terminal crashes. Rollover occurrence was not significantly associated with end terminal type.

Conclusions: Car drivers have greater potential for injury in end terminal crashes than light truck/van/sport utility vehicle drivers. End terminal designs compliant with NCHRP 350 did not appear to carry different odds of moderate driver injury than noncompliant end terminals. The findings account for driver seat belt use, rollover occurrence, terminal orientation (leading/trailing), control loss, and the number of impact events. Rollover and nonuse of seat belts carried much larger increases in injury potential than end terminal type. Rollover did not appear to be associated with NCHRP 350 compliance.

Keywords: fixed object, guard-rails, crashworthiness, injury outcome

Introduction

A guardrail is a flexible or semirigid roadside safety barrier designed to intercept and redirect vehicles departing the roadway before they can strike roadside hazards such as trees or buildings. According to the U.S. NASS-CDS, between 1997 and 2008, there were on average about 51,000 police-reported, tow-away crashes with guardrails each year on U.S. roads.

About 13% of those crashes, or about 6,600 per year, involved the ends of the guardrail. The ends of a guardrail are an area of special concern in a crash, because a bare guardrail end can penetrate, or “spear,” into the occupant compartment of a vehicle and strike occupants directly. In practice, guardrail end terminals are installed at the ends of nearly all guardrails to prevent the rail from spearing in an end-on collision. Even so, the 13% of crashes involving guardrail ends still account for about 32% of the total serious injuries and fatalities observed in guardrail crashes (NHTSA 2009).

Recently, there has been a great deal of controversy (Federal Highway Administration 2015; Nadeau 2014) over the safety of certain widely used end terminal designs. Concerns have been raised that some of these systems can penetrate through vehicles, causing amputations and in some cases death of vehicle occupants, despite being designed specifically to prevent this outcome. This controversy exists partly because there
is surprisingly little real-world crash data for end terminals specifically.

Most existing studies of injury in end terminal crashes use data from prior to the mid-1990s (Gattis et al. 1993; Hunter et al. 1993; Ray et al. 2003; Ross et al. 1993; Viner et al. 1994). Substantial changes to the U.S. vehicle fleet have happened in the intervening 20 years. Airbags became mandatory on new vehicles only in 1997–1998. Seat belt use rates have risen since the early 1990s. Crashworthiness of the average fleet vehicle has improved drastically thanks to demanding crash tests performed by the Insurance Institute for Highway Safety and the NHTSA. Roads and roadside hardware have changed as well. In 1995, the national maximum speed limit law was repealed. In late 1998, NCHRP Report 350 (Ross et al. 1993) was adopted by the Federal Highway Administration as the standard for roadside safety appurtenances on the National Highway System.

The adoption of NCHRP 350 is very important, because there is very little data comparing end terminal designs developed subsequent to the adoption of this crash test protocol. End terminals designed to pass the NCHRP 350 crash tests are intended to be more forgiving objects to strike than non-compliant end terminals. Many designs incorporate special energy-absorbing impact heads that dissipate crash energy in a controlled manner by deforming the guardrail. Others prevent spearing by incorporating specially weakened guardrail segments that allow for controlled, predictable buckling of the guardrail. All designs use special posts designed to break away in an impact. In light of these changes, studies based on data from the 1990s or earlier cannot safely be assumed to represent injury potential posed to occupants of the current vehicle fleet.

Research Objective

The goal of this study is to evaluate the crash performance of guardrail end terminals in real world crashes. The specific objectives are to determine the odds of (1) driver injury as a function of guardrail end terminal design and (2) rollover as a function of end terminal design and vehicle type, while accounting for other factors.

Methods

Crashes coded as involving guardrail end terminals in 2011 and 2012 were first selected from the Michigan State crash database. Michigan state data, like most state crash databases, do not precisely identify the type of end terminal struck in a collision. Each crash in this database was, however, geocoded with the crash location. Using the latitude and longitude coded for the crash, each crash location was manually viewed using Google Street View to identify what kind of end terminal was struck. Crashes where the end terminal was successfully identified were used as the final analysis sample. Multiple logistic regression was then used to test for differences in the odds of driver injury between different terminal designs while accounting for other factors such as rollover occurrence and seat belt use.

Preliminary Sample Selection

Potential crashes for this analysis were drawn from the Michigan State UD-10 crash database, sample years 2011 and 2012. This database includes all police-reported crashes in the state of Michigan. Cases in this database are submitted via the UD-10 crash report form, which is filled out by police responding to the crash. Information is collected on the crash location, involved vehicles, vehicle occupants, involved pedestrians, and damaged property. Crashes were selected which met the following criteria:

- Vehicle was either a car or a light truck, van, or sport utility vehicle (LTV).
- Most harmful event (MHE) for the vehicle was coded as an impact with a guardrail end or MHE was coded as a rollover that was directly preceded by impact with a guardrail end.
- Any crashes coded as “backing-up” or “sideswipe” were excluded.
- Latitude and longitude of the crash location were coded.
- Driver was present during the crash.
- Known injury outcome (KABCO) was coded for the driver.

Michigan crash data codes occupant injury level using the KABCO scale. This injury coding scale describes the overall state of an occupant at the scene of the crash and is coded by police. On this scale, “K” denotes a fatality; “A” denotes an incapacitated occupant; “B” denotes an occupant with injuries that are apparent but not incapacitating; “C” denotes an occupant who may be injured but whose (possible) injuries are not apparent; and “O” denotes an uninjured occupant (Gabler et al. 2015).

Michigan crash data coding distinguishes impacts to the guardrail face from impacts to the guardrail end. Even so, there was still some uncertainty as to whether vehicles actually engaged the end of the guardrail or simply struck the guardrail face very near the end. It is likely that at least some crashes coded as striking the guardrail end were in fact impacts to the guardrail face very near the end. However, there are two factors that should mitigate any effects this might have. First, crashes to the guardrail face are frequently sideswipes, and the sample specifically excluded crashes coded as sideswipes. Second, most end terminal systems actually include the first 3 posts in an installation, so impacts to the guardrail face very near the end are still, in fact, impacts to what is commonly considered part of the end terminal.

This analysis examined only drivers and their injuries. Occupants in different seating locations can have different restraints and experience different loads during the same crash. Different vehicle types may also possibly have different occupancy rates (e.g., cars typically have more seats than pickup trucks), which could in turn distort findings if not handled carefully. By examining only drivers, these issues are avoided entirely.

Identification of End Terminals

Crash sites were manually inspected using Google Street View to determine what kind of end terminal was present prior to the crash. Google Street View has recently made street view imagery from previous years available. When imagery...
from multiple dates was available for a crash site, the imagery nearest to the crash date but still preceding it was used for identification of the system. In many cases, imagery was also available subsequent to the crash date as well. This sometimes helped positively identify the end terminal that was involved in the crash, as the replaced terminal was often visibly newer than the rest of the guardrail. As shown in Figure A1 (see online supplement), impacts where the vehicle struck the trailing terminal for the lane of travel or the leading terminal on an oncoming lane were coded as impacts with trailing ends in the analysis sample.

Any crashes for which Street View imagery was not available or was not available prior to the crash date were excluded from the analysis. The latitude and longitude coded as the crash location were occasionally somewhat imprecise or were some distance from the nearest guardrail. In these cases, the written description of the crash location given on the police accident report was also used to help locate the struck end terminal. Even with this approach, it was frequently not possible to identify the crash location with reasonable certainty. Cases where a plausible candidate for the struck end terminal could not be found were excluded from the analysis. In other cases, the crash location was relatively certain but there were multiple end terminals near that location and it was unclear which one had been struck. It was sometimes possible to determine which end terminal had been replaced using postcrash imagery. In others, all possible end terminals were of the same type, so there was no problem identifying the design of the struck terminal. When the contacted terminal could not be identified with certainty, the crash was excluded from the analysis sample.

Appendix A (see online supplement) contains a discussion of different end terminal designs and their distinguishing traits.

Statistical Analysis

All statistical analysis was performed using SAS v9.3 (Cary, North Carolina, USA). The final sample was analyzed using multiple logistic regression (SAS PROC LOGISTIC), in order to test the effects of different variables on driver injury outcome while accounting for one another. Model coefficients in a logistic regression model provide odds ratios for model effects, and the \( P \) values of those model coefficients provide a measure of the statistical significance of that effect within the model being fit. Henceforth, “statistical significance” refers to a 95% confidence level. Variables examined in this analysis included reported driver belt use and rollover occurrence, both of which are known high-risk cofactors, vehicle type (car/LTV), and end terminal type. Regressions were performed using all crashes in the sample and also using subsets of the sample containing crashes on roads of the same access control level, posted speed limit, and road class.

Because state crash data do not oversample crashes with severe outcomes, it can be difficult to obtain large numbers of crashes with severe outcomes. This analysis therefore examined the incidence of crashes including any level of confirmed injury to the driver; that is, crashes were considered to be injury crashes if the driver injury level was coded as K, A, or B. Crashes where the driver sustained a C injury—where injury was possible but not confirmed—were not counted as driver injuries in this study.

Results

A total of 1,001 police-reported guardrail end crashes selected from the 2011–2012 Michigan State crash data were manually inspected to identify the end terminal that had been struck. Table 1 shows a breakdown of both the excluded cases and the final analysis sample on the analysis variables. By definition of the sample, the excluded cases contain primarily unidentified or unknown end terminals, and the analysis sample contains none. The only identified end terminals among the excluded cases were those observed with unrepaired crash damage or those that were incorrectly built prior to the crash or were end terminals for which no precrash imagery was available.

Table 1. Composition of data set (excluded cases and retained cases)

| Entry | Total Analyzed cases | % of Analyzed cases | Total Excluded cases | % of Excluded cases |
|-------|----------------------|---------------------|---------------------|---------------------|
| Driver injury outcome | | | | |
| K     | 3                    | 0.67                | 2                   | 0.36                |
| A     | 14                   | 3.10                | 14                  | 2.55                |
| B     | 36                   | 7.98                | 36                  | 6.55                |
| C     | 72                   | 15.96               | 70                  | 12.73               |
| O     | 326                  | 72.28               | 413                 | 75.09               |
| Unknown | —                  | —                   | 15                  | 2.73                |
| Total | 451                  | 100.00              | 550                 | 100.00              |
| Rollover | | | | |
| Yes   | 43                   | 9.53                | 35                  | 6.36                |
| No    | 408                  | 90.47               | 515                 | 93.64               |
| Total | 451                  | 100.00              | 550                 | 100.00              |
| Driver unbelted | | | | |
| Yes   | 10                   | 2.22                | 14                  | 5.64                |
| No    | 422                  | 93.57               | 505                 | 91.82               |
| Unknown | 19                | 4.21                | 31                  | 2.55                |
| Total | 451                  | 100.00              | 550                 | 100.00              |
| Vehicle type | | | | |
| Car   | 252                  | 55.88               | 298                 | 54.18               |
| LTV   | 199                  | 44.12               | 230                 | 41.82               |
| Unknown | —                  | —                   | 22                  | 4.00                |
| Total | 451                  | 100.00              | 550                 | 100.00              |
| End terminal type | | | | |
| BCT   | 67                   | 14.86               | 6                   | 1.09                |
| End Anchor | 66             | 14.63               | 2                   | 0.36                |
| ET-2000 | 10               | 2.22                | 2                   | 0.36                |
| ET-Plus | 43                | 9.53                | 7                   | 1.27                |
| FLEAT  | 58                   | 12.86               | 7                   | 1.27                |
| MELT   | —                    | —                   | 1                   | 0.18                |
| SKT-350 | 57               | 12.64               | 10                  | 1.82                |
| SRT-350 | 81               | 17.96               | 4                   | 0.73                |
| Spade end/blunt end Concrete–guardrail junction | | | | |
| Other | —                    | —                   | 52                  | 9.46                |
| Unknown | —                  | —                   | 390                 | 70.91               |
| Total | 451                  | 100.00              | 550                 | 100.00              |
| NCHRP-350-compliant end terminal | | | | |
| Compliant | 249            | 55.21               | 34                  | 6.18                |
| Not compliant | 202        | 44.79               | 19                  | 3.45                |
| Neither/unknown | —            | —                   | 497                 | 90.36               |
| Total | 451                  | 100.00              | 550                 | 100.00              |
Table 2. Multiple logistic regression of driver injury outcome on end terminal type, rollover occurrence, vehicle type, belt use, terminal orientation, occurrence of control loss, and number of impacts

| Outcome                     | Model effect          | Odds ratio (for driver injury) | 95% Wald confidence interval | Significant? |
|-----------------------------|-----------------------|-------------------------------|-----------------------------|--------------|
| Driver injured Yes = 48 No = 384 | End terminal NCHRP 350 compliance | 0.821 (noncompliant vs. compliant) | 0.389–1.733 | No          |
|                             | Rollover involvement  | 12.748 (yes vs. no)           | 5.533–29.375               | Yes          |
|                             | Belt use              | 15.144 (unbelted vs. belted)  | 3.140–73.043                | Yes          |
|                             | Terminal orientation  | 0.976 (leading vs. trailing)   | 0.399–2.388                 | No           |
|                             | Vehicle type          | 3.584 (car vs. LTV)           | 1.639–7.874                 | Yes          |
|                             | Crash involved control loss | 1.327 (yes vs. no)           | 0.653–2.696                 | No           |
|                             | Number of impacts     | 1.974 (increases by this factor per additional event) | 0.998–3.904 | Marginal |

*p = Wald's chi-square P value for overall model: <.0001. Model C-statistic: 0.780, n = 432. Nineteen cases were excluded from the regression due to unknown belt use.

Table 1 presents the composition of the data set. A total of 550 crashes were excluded from the analysis, leaving 451 in the final analysis sample. Table A1 (see online supplement) shows the 550 crashes that were excluded with reason for exclusion. The most common reason for excluding crashes was a lack of plausibly struck end terminals in precrash Street View imagery. Other significant reasons for crash exclusion were uncertainty about the crash location, a lack of Street View imagery for the crash site or a lack of Street View imagery prior to the crash date, and miscoded impacts with objects other than guardrail end terminals.

Table 1 shows that there were only 17 serious (K+A) injuries in the entire analysis sample, representing 3.8% of the sampled end terminal crashes. Most drivers in guardrail end terminal collisions were either uninjured (O, 72%) or were not confirmed as injured (C, 16%). Nonincapacitating (B) driver injury occurred in 36 end terminal crashes, making the total number of moderately to seriously injured (K+A+B) drivers 53, or 11.8% of the total sample.

The number of driver injury crashes observed for each individual end terminal system was too small to perform meaningful comparisons between them. For this analysis, end terminals were therefore classified into one of 2 groups: Designs that have successfully met at least test level 2 of the NCHRP Report 350 safety requirements and those that have not. Although the Manual for Assessing Safety Hardware (MASH; American Association of State Highway and Transportation Officials 2009) supplanted NCHRP 350 (Ross et al. 1993) in 2009, the MASH regulations allow the use of all existing end terminal designs that were previously approved under NCHRP 350. In addition, end treatments designed exclusively against MASH are not yet in widespread use on U.S. roadways, so NCHRP 350 is arguably the more relevant guideline.

The regression results in Table 2 show that, when other factors are accounted for, there is no statistically significant difference in the odds of K+A+B driver injury between NCHRP-350-compliant end terminals and noncompliant end terminals. However, odds of K+A+B driver injury for passenger cars were 3.6 times greater than for LTVs, at greater than 95% confidence. This regression accounts for rollover occurrence, nonuse of seat belts, number of impacts, differences between impacts to leading and trailing ends, and differences in impact conditions in control-loss crashes. As expected, both rollover and nonuse of seat belts result in a large and statistically significant increase in driver injury odds. Neither control loss nor terminal orientation (leading/trailing) was observed to have a significant effect on driver injury outcome. Driver injury odds almost doubled for every additional impact event coded for a crash, but the finding was just shy of statistical significance.

Figure 2 shows the proportion of end terminal crashes and injured drivers in passenger cars and LTVs. Cars account for about 56% of end terminal crashes and about 71% of drivers with K+A+B injuries. LTVs account for 44% of crashes and 29% of injured drivers. These proportions reflect the increased driver injury odds displayed by car drivers in Table 2, despite the fact that this plot does not account for any of the cofactors accounted for in Table 2. The regression shown in Table 2 does not account for the area of greatest damage on the crashed vehicle. This factor would be expected to have an effect on driver injury potential. Inclusion of this variable in the regression resulted in a separation of variables, a condition where the cases are perfectly separated into positive and negative outcomes (i.e., injuries and noninjuries) by some combination of the explanatory variable values. This causes the model-fitting process used for multiple logistic regression to fail. The effect of damaged vehicle area was therefore examined separately using contingency table analysis. Table 3 gives the contingency table for driver injury outcome versus vehicle area damaged. Damage to the left (driver) side is associated with driver injury more often than frontal damage (recall that crashes coded as sideswipes were excluded from the sample). Top damage is also more frequently associated with driver injury than frontal damage, but this is to be expected because top damage is indicative of a rollover crash. The “other” category includes rear damage, undercarriage damage, and crashes where the greatest damage involved multiple vehicle surfaces. Disaggregating this analysis by vehicle type resulted in a significant number of table cells with less than 5 observations. Fisher’s exact test found that damaged area was significantly
associated with driver injury outcome for both cars and LTVs separately. However, odds ratios were not computed for cars and LTVs separately due to the small cell counts.

The occurrence of rollover was explicitly accounted for in the analysis. However, it is possible that NCHRP-350-compliant end terminals were more or less associated with rollover than noncompliant end terminals. Table 4 shows a multiple logistic regression of rollover occurrence on end terminal type, vehicle type, terminal orientation relative to direction of travel, and occurrence of control loss. The only factor significantly associated with rollover in the sample was vehicle type. LTVs exhibited higher odds of rollover than did cars. End terminal type, terminal orientation, and control loss showed no significant association with rollover.

### Discussion

In our sample, NCHRP 350 compliance did not appear to have a statistically significant effect on the potential for K+A+B driver injury. End terminals are designed to be as forgiving as possible in crashes, and NCHRP-350-compliant end terminals are designed to be forgiving in extremely severe crashes (American Association of State Highway and Transportation Officials 2009; Ross et al. 1993). However, as Table 1 shows, the sample in this analysis is dominated by minor injuries, and because the sample did not intentionally select for high-severity crashes in any way, it is likely dominated by crashes of only average severity. NCHRP 350 may very well have a protective effect, but given that NCHRP 350 crash testing conditions represent very severe crashes, any protective effect of end terminals designed to this standard will more likely be most evident in higher severity crashes. Subdividing the sample and performing the Table 2 regression for end terminal crashes on roads with the same access control level, road class, or posted speed limit did not qualitatively change this finding.

The regression results in Table 2 clearly show that rollover and nonuse of seat belts are strong predictors of driver injury potential in end terminal crashes.

The observed difference in driver injury odds between passenger cars and LTVs is probably a result of LTVs having higher mass and higher ride height on average. LTVs’ larger masses result in lower delta V’s for a given impact speed, end terminal type, and impact configuration.

Table 3 shows that left-side impacts are more strongly associated with driver injury than frontal impacts, whereas right-side impacts are not associated with any driver injuries in this sample. This suggests that vehicle deformation in proximity to the driver is a key source of driver injury potential in end terminal crashes. Because LTVs have higher ride height and larger dimensions than cars on average, end terminal impacts to the side of an LTV will be lower than on cars, more focused toward the door sill, and further from the driver H-point and torso.

The results of this study were similar to the NCHRP 490 findings for Breakaway Cable Terminal (BCT) and modified eccentric loader terminals (MELTs). NCHRP Report 490 examined injury in crashes with BCTs and MELTs. The study used crash data from North Carolina and Iowa, years 1997–1999. The study found that K+A injury occurred in 5 out of 115, or 4.3%, of crashes with BCT/MELT end terminals (Ray et al. 2003). The analysis presented here found that K+A injury occurred in 3.8% of all end terminal crashes and in 2 out of 67 crashes (3.0%) involving BCTs only (there were no MELTs in this sample). NCHRP Report 490 also reported that 60% of BCT/MELT crashes involved only property damage (i.e., O injury; Ray et al. 2003). In this analysis, O injury accounted for 72% of all end terminal crashes together and 69% of crashes with BCTs only.

Viner et al. (1994) examined crashes involving roadside safety hardware using North Carolina state data from years 1985–1990. The study observed that, for crashes where the most harmful event was an impact with a guardrail end, K+A injury occurred in 19% of car crashes and 13% of LTV crashes. The analysis did not find any statistically significant difference in injury potential between cars and LTVs in guardrail end crashes. In contrast, the analysis presented here found K+A driver injury in 6.0% of car crashes and 1.0% of LTV crashes to guardrail end terminals—substantially less frequent. This analysis also found that K+A+B driver injury was different between cars and LTVs with 95% confidence. This difference could easily be due to lower belt use in the 1980s and the much older vehicles examined by Viner et al., which would have predated current vehicle crash testing requirements. Viner et al. (1994) did not report the composition of end terminal designs represented by their sample but because of the time period presumably all terminals were pre-NCHRP-350 designs.

### Table 3. Contingency table analysis of driver injury outcome and area of greatest vehicle damage

| Driver Injury | K+A+B | C+O | Total |
|---------------|-------|-----|-------|
| Front         | 17    | 238 | 255   |
| Left          | 10    | 34  | 44    |
| Right         | 0     | 32  | 32    |
| Top           | 7     | 11  | 18    |
| Other         | 19    | 83  | 102   |
| Total         | 53    | 398 | 451   |

Odds ratio (left/front): 4.118
Odds ratio (top/front): 8.909
Odds ratio (other/front): 3.205

*Chi-square P value < .0001. Likelihood ratio chi-square P value < .0001. Mantel-Haenszel chi-square P value .0022.

### Table 4. Multiple logistic regression of rollover occurrence on end terminal type, vehicle type, terminal orientation relative to direction of travel (leading/trailing)

| Outcome | Model effect | Odds ratio (for rollover) | 95% Wald confidence interval | Significant? |
|---------|--------------|---------------------------|-----------------------------|--------------|
| Rollover Yes = 43 No = 408 | End terminal NCHRP 350 compliance | 0.761 (noncompliant vs. compliant) | 0.382–1.518 | No |
|          | Vehicle type | 2.074 (LTV vs. car) | 1.087–3.958 | Yes |
|          | Terminal was trailing end | 0.426 (trailing vs. leading) | 0.157–1.154 | No |
|          | Crash involved control loss | 0.920 (yes vs. no) | 0.483–1.750 | No |

*Wald's chi-square P value for overall model: .0575. Model C-statistic: 0.651. n = 451.
K+A driver injury occurred in 3.8% of end terminal crashes, K+A+B driver injury occurred in 11.8%, and 72.3% of end terminal crashes involved property damage only. Car drivers showed odds of K+A+B injury 3.6 times greater than LTV drivers in end terminal crashes. The area of the vehicle damaged in an end terminal crash was also significantly associated with driver injury outcome, with damage to the driver side showing higher injury odds than frontal damage. End terminal designs compliant with NCHRP 350 were not observed to carry significantly different odds of K+A+B driver injury than noncompliant end terminals. The findings account for driver seat belt use, rollover occurrence, terminal orientation (leading/trailing), control loss, and the number of impact events. Rollover and nonuse of seat belts were observed to carry much larger increases in driver injury odds than end terminal type. Rollover occurrence was not significantly associated with end terminal type.

Limitations

Impact conditions—for example, impact speed and angle—are not recorded in the state crash databases. It therefore cannot be determined how the observed crashes compare to NCHRP 350 crash testing conditions. NCHRP 350 crash testing criteria are designed to represent very severe impacts (American Association of State Highway and Transportation Officials 2009; Ross et al. 1993) and the sample should represent a cross section of the full range of impact conditions. It is therefore likely that most of the crashes in this sample were much less severe than the NCHRP 350 crash testing conditions to which 350-compliant end terminals are designed. However, it should be noted that (1) sideswipes—a very low-injury-potential crash mode—were excluded from this sample and (2), the sample is comprised of only those guardrail impacts that were reported to the police. NCHRP Report 490 found that about 90% of all collisions to BCT end terminals are noninjury crashes that are not reported to the police (Ray et al. 2003). This sample contains only police-reported crashes and the NCHRP 350 impact conditions were based on only police-reported crashes as well. Therefore, the sample in this analysis is still likely to represent mostly less severe crash conditions. Many guardrail end terminal crashes may be unreported noninjury crashes (Ray et al. 2003). The absolute percentages of end terminal crashes resulting in driver injury observed in study therefore are probably overestimates of the percentage of driver injury crashes. However, observed differences in driver injury odds between different end terminal types or vehicle types would only be distorted if there were substantial differences in the rate of unreported crashes between them. It should also be noted that this limitation is not unique to guardrail end terminal crashes or to Michigan crash data.

This analysis has found that NCHRP-350-compliant end terminals do not offer a discernable safety advantage over noncompliant end terminals when less severe injuries are considered. There may very well be a difference between the two categories when severe driver injury outcomes are considered, but this sample could not test for such an effect. Additionally, less severe injuries are much more common in guardrail crashes, so the findings of this study still hold relevance. It was also not possible to study differences in driver injury between individual end terminal designs. This is an important and topical question in light of current events. It may be possible to explore this question after collecting a larger sample of crashes.

It is widely accepted that police-reported belt use overestimates actual belt use (Viano and Parenteau 2009). In the future, it would be beneficial to revisit this analysis using crash data with more accurately coded belt use, if such data can be obtained.

Funding

The authors thank the Transportation Research Board for their support of this research under National Cooperative Highway Research Program Project 17-43.

Supplemental Materials

Supplemental data for this article can be accessed on the publisher’s website.

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