Upgrading Bridge Rails on Low-Volume Roads in Iowa

(TR-679)

Iowa Highway Research Board
(IHRB Project TR-679)
Iowa Department of Transportation
(InTrans Project 14-508)

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1. INTRODUCTION
   • Goal
   • Research Objectives

2. BACKGROUND
   • Literature
   • Previous Standards (Iowa DOT)

3. DATA
   • Data collection/sampling
   • Statistics

4. ANALYSIS
   • Crash Frequency Model (Negative Binomial Regression)
   • Results

5. CONCLUSION
INTRODUCTION

- **GOAL**
  - Identify significant influencing factors for the Iowa DOT to consider in future updates of its Instructional Memorandum (I.M.) 3.213, which provides guidelines for determining the need for traffic barriers (guardrail and bridge rail) at secondary roadway bridges.

- **RESEARCH OBJECTIVES**
  - Evaluate the practice of upgrading bridge rails on low volume roads.
  - Identify safety problems at bridges on Iowa’s LVRs by conducting a safety impact study.
  - Present bridge and road network characteristics that contribute to more frequent bridge crashes.
BACKGROUND

LITERATURE

- Nation-wide practice
  - FHWA requirement:
    - Bridge/approach guardrails are required for all National Highway and federally funded bridges!
  - AASHTO guidance:
    - Roadside Design Guide—“railing designed to full AASHTO standards may not be necessary/desirable for LVRs”
    - AASHTO LRFD manual—“owner shall develop the warrants for bridge site”

- Other States
  - Kansas: Seitz and Salfrank (2014)—‘not recommended at very low volumes’
  - Minnesota: Gates and Noyce (2005)—‘recommended guardrail at ADT ≥ 400 vpd’
  - Missouri: Dare (1992)—‘roads w/ ADT ≤ 400 at 60mph do not warrant guardrails’
  - Texas: Turner (1984)—‘structures are safer w/ positive relative bridge widths’
BACKGROUND

- LITERATURE
  - Iowa (IHRB TR-592)
    - Crashes more frequent on bridges widths of less than 24 ft. and on bridges with a narrower width compared to the approach roadway width
    - Changes to I.M. 3.213
      - increase the average daily traffic (ADT) exception from 200 vehicles per day (vpd) to 400 vpd
      - add an exception for bridges with widths greater than the approach roadway width
      - no significant changes were made to the detailed bridge rail rating system component
### IM: 3.213A (2013)

<table>
<thead>
<tr>
<th>Crashes</th>
<th>Injuries</th>
<th>Loss (TSIP)</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>None</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>B.</td>
<td>1 PDO</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>C.</td>
<td>1 Personal Injury</td>
<td>1 Major</td>
<td>$332,400</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 Possible</td>
<td>$42,400</td>
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<tr>
<td>D.</td>
<td>1 Fatal</td>
<td>1 Fatality</td>
<td>$332,400</td>
</tr>
<tr>
<td></td>
<td>2 Fatalities</td>
<td></td>
<td>$4,832,400</td>
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<td></td>
<td>2 PDO</td>
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<td>$14,800</td>
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<td></td>
<td>1 PI, 1 PDO</td>
<td>1 Minor</td>
<td>$79,800</td>
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<td></td>
<td></td>
<td>1 Possible</td>
<td>$49,800</td>
</tr>
<tr>
<td>E.</td>
<td>2 Fatal</td>
<td>2 Fatalities</td>
<td>$4,839,800</td>
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<tr>
<td></td>
<td>2 PI</td>
<td>2 Major</td>
<td>$664,800</td>
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<tr>
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<td></td>
<td>2 Possible</td>
<td>$84,800</td>
</tr>
<tr>
<td></td>
<td>3 PDO</td>
<td></td>
<td>$22,200</td>
</tr>
</tbody>
</table>
Bridge crashes:
- crashes within 50 m (164 ft) of inventoried structures in the database
- excluded from consideration were 
  (a) crashes involving collision with an animal, (b) ramp crashes, and 
  (c) crashes indicated as along a structure underpass based on vehicle initial direction of travel.

- **Statewide vs TAC Counties**
- **Paved vs Unpaved Secondary Roads**
ANALYSIS

CRASH FREQUENCY MODEL

- Negative Binomial Regression

\[ \lambda_i = E(y_i) = e^{\beta X_i + \epsilon_i} \quad \text{for} \quad E(y_i) \neq \text{VAR}(y_i) \]

\[ \text{VAR}(y_i) = E(y_i)[1 + \alpha E(y_i)] \]

- where
  - \( E(y_i) = \) the mean accident frequency on a given structure \( i \)
  - \( \beta = \) vector of unknown regression coefficient
  - \( X_i = \) vector of the explanatory variable (AADT, Length, etc...) on \( i \)
  - \( \epsilon_i = \) an error term with \( (1, \alpha^2) \) gamma-distribution
  - \( \alpha = \) over-dispersion parameter > 0

- Overview
  - Introduction
  - Background
  - Data
  - Analysis
  - Conclusion

846 bridge crashes

<table>
<thead>
<tr>
<th>PROPERTY DAMAGE</th>
<th>POSSIBLE/UNKNOWN</th>
</tr>
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<tbody>
<tr>
<td>MINOR</td>
<td>MAJOR</td>
</tr>
<tr>
<td>274</td>
<td>74</td>
</tr>
<tr>
<td>191</td>
<td>74</td>
</tr>
</tbody>
</table>

Paved Road Network: 5312 332 44 11 3 1 1
Unpaved Road Network: 14750 313 16 7 1 0 0
## Analysis

### Negative binomial regression parameter estimates

<table>
<thead>
<tr>
<th>Unpaved Road Network</th>
<th>Explanatory Variable</th>
<th>Coefficient</th>
<th>t-statistic</th>
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</thead>
<tbody>
<tr>
<td>Constant</td>
<td>Constant</td>
<td>-5.14***</td>
<td>-27.84</td>
</tr>
<tr>
<td>Traffic Volume &gt; 50 (vpd)</td>
<td>AADT_50</td>
<td>1.33***</td>
<td>11.45</td>
</tr>
<tr>
<td>Structure Length &gt; 35 (ft.)</td>
<td>LENG_35</td>
<td>0.55***</td>
<td>3.88</td>
</tr>
<tr>
<td>Bridge Width &lt; 20 (ft.)</td>
<td>BRIWID20</td>
<td>0.89***</td>
<td>7.07</td>
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<tr>
<td>Bridge Age &gt; 25 (years)</td>
<td>B_AGE25</td>
<td>0.277**</td>
<td>1.98</td>
</tr>
<tr>
<td>Overdispersion</td>
<td>α</td>
<td>3.96***</td>
<td>4.61</td>
</tr>
<tr>
<td>Number of Observations</td>
<td>N</td>
<td>13898</td>
<td></td>
</tr>
<tr>
<td>Log-likelihood at Zero</td>
<td>LL(0)</td>
<td>-1768.80</td>
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<tr>
<td>Log-likelihood at Convergence</td>
<td>LL(β)</td>
<td>-1524.94</td>
<td></td>
</tr>
<tr>
<td>Goodness of Fit</td>
<td>ρ²</td>
<td>0.137867</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Paved Road Network</th>
<th>Explanatory Variable</th>
<th>Coefficient</th>
<th>t-statistic</th>
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<tr>
<td>Constant</td>
<td>Constant</td>
<td>-3.85***</td>
<td>-22.09</td>
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<tr>
<td>Traffic Volume &gt; 400 (vpd)</td>
<td>AADT_400</td>
<td>0.796***</td>
<td>5.83</td>
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<tr>
<td>Structure Length &gt; 150 (ft.)</td>
<td>LENG_150</td>
<td>0.59***</td>
<td>5.18</td>
</tr>
<tr>
<td>Relative Approach Width &lt; 0 (ft.)</td>
<td>AWID_0_</td>
<td>0.66***</td>
<td>5.19</td>
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<tr>
<td>Bridge Age &gt; 25 (years)</td>
<td>B_AGE25</td>
<td>0.27**</td>
<td>2.14</td>
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<tr>
<td>Overdispersion</td>
<td>α</td>
<td>2.648***</td>
<td>6.10</td>
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<td>Number of Observations</td>
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<td>Log-likelihood at Zero</td>
<td>LL(0)</td>
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<td>Log-likelihood at Convergence</td>
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<td>Goodness of Fit</td>
<td>ρ²</td>
<td>0.191908</td>
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Note: ***, ** ==> Significance at 1% and 5% levels, respectively.
TABLE 1

<table>
<thead>
<tr>
<th>Paved Secondary Roads</th>
<th>Expected Bridge Crash Frequency per 10-year Period</th>
<th>Expected number of years for one crash</th>
<th>No. of Structures “At-risk”</th>
<th>Percent Change in Frequency</th>
<th>TRAFFIC CONDITION</th>
<th>STRUCTURE GEOMETRIC CHARACTERISTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td>Exposed Structures</td>
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<tr>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td>(vpd)</td>
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<tr>
<td>RANK</td>
<td>$E[y_i]$</td>
<td>Years</td>
<td>$n$</td>
<td>%Δ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.218</td>
<td>46</td>
<td>515</td>
<td>-</td>
<td>AADT &gt; 400</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AWID &lt; 0</td>
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<td></td>
<td>LENGTH &gt; 150</td>
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<td></td>
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<td></td>
<td>AGE &gt; 25</td>
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<tr>
<td>2</td>
<td>0.200</td>
<td>50</td>
<td>776</td>
<td>-8.40%</td>
<td>x***</td>
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<tr>
<td>3</td>
<td>0.192</td>
<td>52</td>
<td>693</td>
<td>-12.04%</td>
<td>x***</td>
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<td>4</td>
<td>0.182</td>
<td>55</td>
<td>747</td>
<td>-16.30%</td>
<td>x***</td>
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<td>5</td>
<td>0.168</td>
<td>59</td>
<td>1,109</td>
<td>-22.69%</td>
<td>x***</td>
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<tr>
<td>6</td>
<td>0.167</td>
<td>60</td>
<td>1,168</td>
<td>-23.31%</td>
<td>x***</td>
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<tr>
<td>7</td>
<td>0.164</td>
<td>61</td>
<td>970</td>
<td>-24.58%</td>
<td>x***</td>
<td></td>
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<tr>
<td>8</td>
<td>0.160</td>
<td>63</td>
<td>1,279</td>
<td>-26.65%</td>
<td>x***</td>
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</tr>
<tr>
<td>9</td>
<td>0.152</td>
<td>66</td>
<td>1,754</td>
<td>-30.05%</td>
<td>x***</td>
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<tr>
<td>10</td>
<td>0.146</td>
<td>69</td>
<td>1,606</td>
<td>-33.10%</td>
<td>x***</td>
<td></td>
</tr>
</tbody>
</table>

Note: *** , ** ==> Significance at 1% and 5% levels, respectively.
5,704 structures on the paved network
The study confirmed previous research findings that crashes with bridges on secondary roads are rare, low-severity events. The study did find that crashes are somewhat more frequent on or at bridges possessing certain characteristics:

- Traffic volume greater than 400 vehicles per day (vpd) (paved) or greater than 50 vpd (unpaved)
- Bridge length greater than 150 ft (paved) or greater than 35 ft (unpaved)
- Bridge width narrower than its approach (paved) or narrower than 20 ft (unpaved)
- Bridges older than 25 years (both paved and unpaved).

Although the findings of the study support the appropriate use of bridge rails, it concludes that prescriptive guidelines for bridge rail use on secondary roads may not be necessary, given the limited crash expectancy and lack of differences in crash expectancy among the various combinations of explanatory characteristics.
ACKNOWLEDGEMENTS

- IHRB
- Iowa DOT
  - Nicole Fox, Iowa DOT
  - Chris Poole, Iowa DOT
  - Iowa County Engineers
I.M. No. 3.213 “Traffic Barriers (Guardrail and Bridge Barrier Rails)”

NICOLE FOX, P.E.
DEPUTY DIRECTOR
IOWA DOT, OFFICE OF LOCAL SYSTEMS
Presentation Overview

- **Background**
  - NCHRP, MASH, requirements, FHWA

- **Guardrail**
  - Bridge projects, upgrades, roadway projects

- **Bridge Barrier Rail**
  - Use, new construction, updates
TL-1: A successful test of a 1800 pound car impacting a barrier at 20 degrees, and a 4400 pound pickup truck impacting a barrier at 25 degrees, both at a speed of 31 miles per hour (mph)

TL-2: A successful test of a 1800 pound car impacting a barrier at 20 degrees, and a 4400 pound pickup truck impacting a barrier at 25 degrees, both at a speed of 44 mph

TL-3: A successful test of a 1800 pound car impacting a barrier at 20 degrees, and a 4400 pound pickup truck impacting a barrier at 25 degrees, both at a speed of 62 mph

TL-4: TL-3 car and truck, and a 17,650 pound single-unit truck impacting the barrier at an angle of 15 degrees and a speed of 50 mph

TL-5: TL-3 car and truck, and a 79,400 pound tractor trailer impacting the barrier at an angle of 15 degrees and a speed of 50 mph

TL-6: TL-3 car and truck, and a 79,400 pound tanker trailer impacting the barrier at an angle of 15 degrees and a speed of 50 mph
TL-1: A successful test of a 2420 pound car impacting a barrier at 25 degrees, and a 5000 pound pickup truck impacting a barrier at 25 degrees, both at a speed of 31 miles per hour (mph)

TL-2: A successful test of a 2420 pound car impacting a barrier at 25 degrees, and a 5000 pound pickup truck impacting a barrier at 25 degrees, both at a speed of 44 mph

TL-3: A successful test of a 2420 pound car impacting a barrier at 25 degrees, and a 5000 pound pickup truck impacting a barrier at 25 degrees, both at a speed of 62 mph

TL-4: TL-3 car and truck, and a 22,000 pound single-unit truck impacting the barrier at an angle of 15 degrees and a speed of 56 mph

TL-5: TL-3 car and truck, and a 79,400 pound tractor trailer impacting the barrier at an angle of 15 degrees and a speed of 50 mph

TL-6: TL-3 car and truck, and a 79,400 pound tanker trailer impacting the barrier at an angle of 15 degrees and a speed of 50 mph
Requirements

- On Interstates and NHS -
  - TL-3 for Guardrail & Bridge Rail-required by FHWA
  - Iowa DOT Policy
    - TL-3 Guardrail
    - TL-5 Bridge Rail for Interstates
    - TL-4 Bridge Rail on NHS
      - DOT Standards
      - Open Rail, Barrier Rail

- Off NHS - I.M. 3.213 is the policy for LPA’s
Guardrail: Bridge Projects

- The FHWA will participate in guardrail, including at all 4 corners of a bridge, if desired by the LPA.

- In general, guardrail should, but is not required to, be installed or upgraded under the following circumstances:
  - Farm-to-Market system or on collector streets and roads of a higher classification, guardrail should be installed on all 4 corners; except bridges located within an established speed zone of 35 mph or less.
  - Local roadways, guardrail should be installed on the approach corner in both directions (right side in each direction);
On roadway construction projects on the Farm-to-Market System or on collector streets and roads of a higher classification:

- All 4 corners of bridges within the project limits. Existing W-beam installations that are flared and anchored at both ends may be used as constructed without upgrading to current Iowa DOT standards. Some items to consider when deciding on a guardrail upgrade would include rotten posts, un-anchored ends, or ends that are turned down toward the ground.
Guardrail: Upgrades
Guardrail: Lower Volume Roads

• For roadways with less than 400 vehicles per day, or in established speed zones of 45 mph or less, a shorter length guardrail may be used.

• If ALL of the following conditions exist, the LPA may elect to not install guardrail:
  - Current average daily traffic (ADT) at structure is less than 400 vehicles per day.
  - Structure width (curb-to-curb) is 24 feet or greater, and is wider than the approach roadway width.
  - Structure is on tangent alignment.
Use of Iowa DOT Standard Guardrail

- For a roadway with 400 vehicles per day or higher, the following standards should be used:
  - **LS-630** This guardrail successfully passed a crash test under MASH TL-3 requirements.
  - **BA-250** This guardrail successfully passed a crash test under MASH TL-3 requirements.
For a roadway with less than 400 vehicles per day, the following standards are acceptable:

- **LS-635** This guardrail successfully passed a crash test under the MASH TL-2 requirements.
- **LS-630** This guardrail successfully passed a crash test under MASH TL-3 requirements.
- **BA-250** This guardrail successfully passed a crash test under MASH TL-3 requirements.
FHWA will participate in bridge rail construction or upgrades, if desired by the LPA. In general, bridge barrier rail should, but is not required to, be installed or upgraded under the following circumstances:

- On newly constructed bridges on roadways with **400 vehicles per day or greater**, the bridge barrier rail should be constructed using the Iowa DOT Bridge Standards, which is a **MASH TL-4 design**.

- On roadways with **less than 400 vehicles per day**, Iowa DOT Bridge Standards for bridge barrier rail may be used. However, if the project is not utilizing the Iowa DOT Bridge Standards, a **bridge rail considered to be crashworthy shall be used**, meeting a minimum of TL-1 in NCHRP 350 or MASH.
Upgrade Guardrail when Bridge Barrier Rail needs to be upgraded.

A bridge barrier rail upgrade should be considered if all of the following conditions exist:

- The bridge was designed prior to 1964. According to the Roadside Design Guide 4th Edition 2011, bridge rails designed to AASHTO specifications prior to 1964 may not meet current standards.
- Current average daily traffic (ADT) at structure is 400 vehicles per day or higher.
- Structure width (curb-to-curb) is less than 24 feet, or structure width (curb-to-curb) is narrower than the approach roadway width.
In lieu of bridge rail, consideration may be given to extending the guardrail through the bridge on short bridges or bridges which have no end posts. This may be less costly than constructing an end post and attaching the guardrail as per the Iowa DOT Standard Road Plans. The Iowa DOT has developed a standard for the long span system (BA-211), which will work in some of these cases. The long span system has successfully passed TL-3 under MASH.
Questions?